Regiocontrolled Routes to Substituted Pyridines via Directed Cycloaddition Reactions

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Abstract

New strategies have been investigated for the synthesis of highly substituted pyridine rings *via* inverse electron demand aza-Diels-Alder reactions of 1,2,4-triazines with alkynes.

The synthesis of pyridines via cycloaddition/retro-cycloaddition strategies has largely focused on the use of enamine dienophiles as alkyne surrogates, as alkynes themselves only participate in [4+2] cycloadditions with triazines under very harsh conditions. Moreover, such processes usually provide the products in low yields and regioselectivities. To tackle these drawbacks, we were interested in a directed cycloaddition concept where 1,2,4-triazines were reacted with alkynyltrifluoroborate salts in the presence of a Lewis acid to form pyridines possessing a boron moiety offering further synthetic opportunities. The generated Lewis acidic alkynes, containing a "BF_2" moiety, were then used in conjunction with triazines equipped with a Lewis base (such as a pyridine or an amide). Coordination of the two partners lowered the overall energy needed for the cycloaddition to take place and the corresponding pyridines were obtained within 10 minutes at 40 °C with complete regiocontrol.

Organoboranes are a widely employed fluorophore family because of their excellent optical properties and their conveniently variable emission wavelength. The tetravalent boron found in the borylated bipyridines products (BOBIPYs) formed *via* our previously developed methodology prompted us to investigate their optical properties. These proved to comprise a new family of fluorophores showing blue to green fluorescence with quantum yields up to 41%. A series of compounds was synthesized and interrogated *via* DFT calculations and photophysical measurements.

Streptonigrin, an antitumor and antibiotic agent, has drawn considerable attention from synthetic organic chemists because of its challenging structure, containing a highly substituted pyridine core. To date, only two groups achieved its total synthesis, and two more reached a formal synthesis. We established a succinct formal synthesis of streptonigrin, establishing the practical advantages of our cycloaddition methodology.

This thesis is dedicated to the memory of my dear friend from the ENSCM Diane de Girval.

Cette thèse est dédiée à la mémoire de mon amie et camarade de l'ENSCM Diane de Girval.

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Similarly, thanks to Peakdale, discovering industrial research was quite an experience and it taught me a lot for my future.

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all for the best, look at us now! Two pesadilla doctors … I'm glad you survived everytime I tried to kill you in the lab, the stairs, during football, squash or even golf. Thanks for being there to complain about everything with me and remember not to let chemistry influence your mood! Thanks for supporting my own bipolarity, but I guess that's why you're my best foreign friend! Fes me cas Victoriaaaaaa …

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"I am among those who think that science has great beauty. A scientist in his laboratory is not only a technician: he is also a child placed before natural phenomena which impress him like a fairy tale."

Marie Curie

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Abbreviations

Ac	Acetyl
AIN	isopentyl nitrite
aq	aqueous
Ar	Aryl
Bn	Benzyl
Boc	*tert*-Butoxycarbonyl
BOBIPY	borylated bipyridines
BODIPY	boron-dipyrromethene
BINOL	1,1'-bi-2,2'-naphthol
br	broad
^{n}Bu	*normal*-Butyl
^{t}Bu	*tert*-Butyl
°C	degrees celsius
calcd	calculated
CAN	ceric ammonium nitrate
cat	catalytic
C.I.	chemical ionisation
cod	1,5-cyclooctadiene
Cp	cyclopentadienyl
CuMeSal	copper (I) methylsalicylate
δ	chemical shift
o-DCB	*ortho*-dichlorobenzene
DCM	dichloromethane
DEA	diethylaniline
dec.	decomposition
DFT	Density functional theory
DG	directing group
DIPEA	*N*,*N*-diisopropylethylamine
DMF	dimethylformamide
DMSO	dimethyl sulfoxide
dppf	1,1’-bis(diphenylphosphino)ferrocene
E^{+}	electrophile

ε	molar extinction coefficient
E.I.	electron ionisation
eq/equiv	equivalent
Et	ethyl
eV	electronvolt
FAB	fast atom bombardment
FTIR	Fourier transform infrared
GC	gas chromatography
Het	Heteroaryl
h	hour, Planck constant
HeLa	human cervix carcinoma
HOMO	highest occupied molecular orbital
hr	hour
HRMS	high resolution mass spectrum
Hz	Hertz
J	coupling constant
L	litre
λ	wavelength
LHMDS	Lithium bis(trimethylsilyl)amide
LUMO	lowest unoccupied molecular orbital
m	milli, medium (FTIR), multiplet (NMR)
M	molar or metal
mCPBA	*meta*-chloroperoxybenzoic acid
Me	Methyl
Mes	Mesityl
MeSal	methylsalicylate
min	minutes
mol	mole
M.p.	melting point
MS	mass spectrometry
MW	microwave
ν	frequency
NBS	*N*-bromosuccinimide
NMR	nuclear magnetic resonance

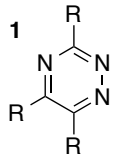
Nu	nucleophile
o	ortho
o/n	overnight
ORTEP	Oak Ridge Thermal Ellipsoid Plot
pdt	product
Ph	Phenyl
Pin	pinacolato
PLQY	photoluminescence quantum yield
ppm	parts per million
^{i}Pr	Isopropyl
py	pyridine
Pyr	Pyridyl
RSM	recovered starting material
RT or rt	room temperature
RuPhos	2-Dicyclohexylphosphino-2',6'-diisopropoxybiphenyl
s	singlet (NMR), strong (FTIR)
S_n	level of excited state
sat.	saturated
SM	starting material
S_NAr	nucleophilic aromatic substitution
t	triplet
TBABr	tetra-*n*-butylammonium bromide
TBAF	tetra-*n*-butylammonium fluoride
TBATB	tetra-*n*-butylammonium tribromide
Tf	Trifluoromethanesulfonyl
THF	tetrahydrofurane
TLC	thin layer chromatography
TMS	trimethylsilyl
TOF	time of flight
Tol	toluene
t_R	retention time
Ts	*para*-toluenesulfonyl (Tosyl)
UV	ultraviolet
w	weak

W	watt
X	halogen

Chapter I. Synthesis and use of 1,2,4-triazines

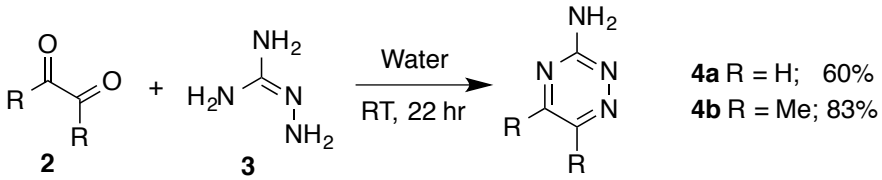
1,2,4-Triazines are an important class of molecules as they are found in many bioactive compounds, used as pharmaceuticals or agrochemicals, and they have also found applications as ligands for metal ions. On the other hand, from a synthetic chemistry viewpoint, they are also useful intermediates for the synthesis of substituted pyridines through cycloaddition and release of N_2.

1,2,4-Triazines **1**, also known as *as*-triazines, are aromatic molecules composed of a 6-membered ring with 3 carbon atoms and 3 nitrogen atoms placed in positions 1, 2 and 4.



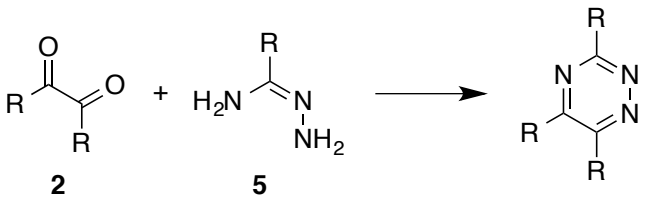
Scheme I-1: General structure of a 1,2,4-triazine

Erikson reported the first synthesis[1] of 1,2,4-triazine in 1952 by cyclisation of glyoxal **2a** (R = H) and biacetyl **2b** (R = Me) with aminoguanidine bicarbonate **3**. Under these conditions, he obtained 3-amino-1,2,4-triazine **4a** and 3-amino-5,6-dimethyl-1,2,4-triazine **4b** in 60% and 83% yield respectively.



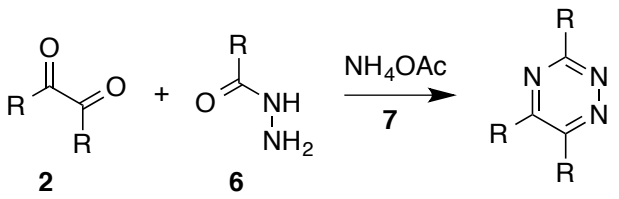
Scheme I-2: Synthesis of triazines 4a,b by Erickson

The 4+2 atom combination of amidrazone **5** with 1,2-dicarbonyl **2** has become the most commonly used technique as it utilises readily available starting materials and generally delivers reliable results.



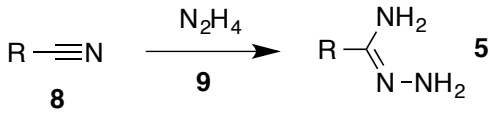
Scheme I-3: 4+2 atom combination

Historically, a 2+3+1 atom combination has also been successfully used. For example, reacting ammonium acetate **7**, a 1,2-dicarbonyl **2** with an acyl hydrazine derivative **6** results in cyclisation to the triazine product. The acyl hydrazine introduces the substituent at C3 of the product while ammonium acetate brings the final nitrogen N4 required for 6-membered ring formation.



Scheme I-4: 2+3+1 atom combination

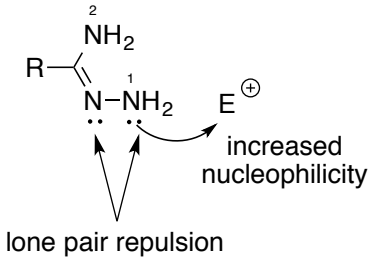
Focusing on the 4+2 atom combination, two challenges can be anticipated. First, the availability of the starting materials could be an issue. Indeed, amidrazones **5** are generally found to decompose on storage under ambient conditions.[2] Nevertheless, they are quite often easily obtained from nitriles **8** by reacting with hydrazine **9**.[3]



Scheme I-5: Synthesis of amidrazones

In addition, relatively few 1,2-dicarbonyl compounds **2** are commercially available. As this substrate dictates the type of substitution that will be obtained in the product, the following section will discuss approaches to these compounds.

One of the biggest challenges in the formation of 1,2,4-triazines is the attainment of good regioselectivity during the cyclisation reaction. The reactivity of both reagents needs to be ascertained to ensure complete regiocontrol. Specifically, amidrazones require a more nucleophilic amine than the other, and dicarbonyls demand a more electrophilic site. With respect to the amidrazone partner **5**, the regioselectivity is controlled by the alpha effect (Scheme I-6). Specifically, lone pair repulsion between the adjacent nitrogen atoms serves to increase nucleophilicity on amine 1 as compared to amine 2. This effect promotes regioselective electrophile addition at this more nucleophilic heteroatom.



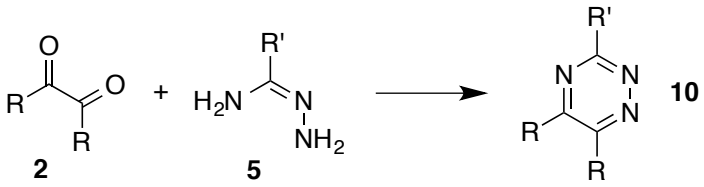
Scheme I-6: Alpha effect on amidrazone

The regiocontrol thus entirely depends on the choice of the 1,2-dicarbonyl **2** used. As discussed in the following sections, this choice can enable the formation of 5,6-disubstituted or mono-substituted (5 or 6) *as*-triazines. This chapter will focus on the strategies employed to obtain triazines with specific substitution patterns, rather than listing reactions that are commonly employed.

1. Synthesis of triazines by condensation reactions

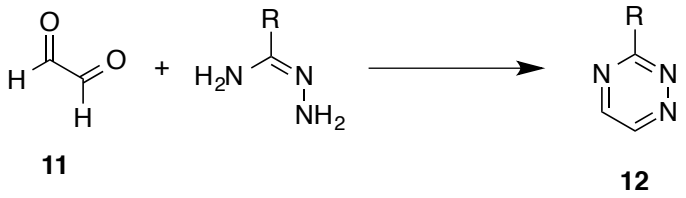
In the simplest case, when a symmetrical diketone is used, there is no problem of regioselectivity and the reaction can proceed smoothly.

Triazines **10**, bearing the same group at C5 and C6, can be synthesised by condensing amidrazones **5** with 1,2-diketones **2**. The latter can be made from the corresponding disubstituted alkynes by oxidation of the π-system.[4]



Scheme I-7: Synthesis of 5,6-disubstituted-1,2,4-triazines

As this reaction is the most widely used technique for triazine synthesis, many examples can be found in the literature. For example, as shown in Scheme I-8, triazine **12** can be obtained from glyoxal **11**. The main issue with glyoxal is that it can only be found as a monomer in aqueous solution. When the amidrazone partner is soluble and stable in water, the reaction can then proceed effectively. On the other hand, when the amidrazone is unstable or insoluble in water, yields are directly impacted.[5] One solution to this issue is to isolate the monomeric glyoxal from the corresponding trimer and react it under anhydrous conditions. This option is not ideal however as the isolation process requires highly toxic chemicals, but it gives good results.[6-9]



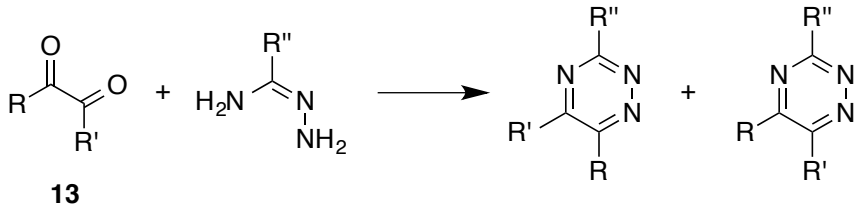
Scheme I-8: Synthesis of 3-substituted-1,2,4-triazines

In all other cases, there is no issue related to the use of diketones to perform a condensation on the amidrazone chosen. Thus, a large variety of triazines substituted by the same moiety have been synthesised in the literature in overall good yields. Examples include ketones bearing a methyl,[10-11] an ester,[12-14] a phenyl,[15] a pyridine[15-18] or a furan.[19] Recently, microwave technology has been applied and considerably reduced the reaction time.[20] It is also important to note that the 3+2+1 atom combination has also been successfully employed with symmetrical diketones.[21-22]

The use of symmetrical 1,2-diketones thus provides 5,6-unsubstituted, 5,6-dialkyl, 5,6-diester or 5,6-diaryl-1,2,4-triazines within a reliable strategy. The methods have generally

improved with respect to efficiency over the years and the procedures have been adapted to take advantage of new technologies.

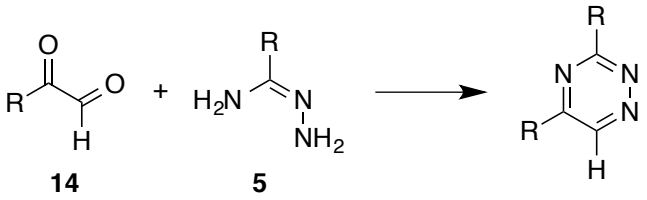
The use of asymmetric 1,2-diketones **13** raises an important challenge relating to the regioselectivity of triazine formation. Several instances have been reported where unsymmetrical 1,2-dicarbonyl substrates have been used, but unsurprisingly, they resulted in the formation of a mixture of regioisomers.[23-25]



Scheme I-9: Synthesis of 5,6-disubstituted-1,2,4-triazines

The difficulties arising from selectively cyclising unsymmetrical diketones coupled with the inherent inefficiency of generating mixtures has prompted researchers to search for new and more general routes to triazines bearing different moities at C5 and C6.

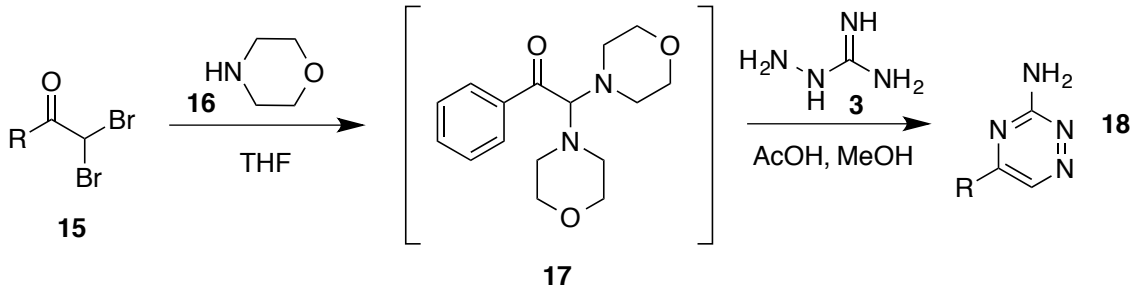
A particularly effective method to obtain those is through the condensation of amidrazones **5** with ketoaldehydes **14**. The ketoaldehydes are readily prepared by oxidation of the corresponding methyl ketones.[26] With regard to the condensation step, the ketoaldehyde enables the control of the regioselectivity of the reaction because the aldehyde is more reactive than the ketone. Thus, the combination of aldehyde reactivity and the enhanced amine nucleophilicity of the hydrazine amine controls the regiodetermining addition step very efficiently.[27-37]



Scheme I-10: Synthesis of 5-substituted-1,2,4-triazines

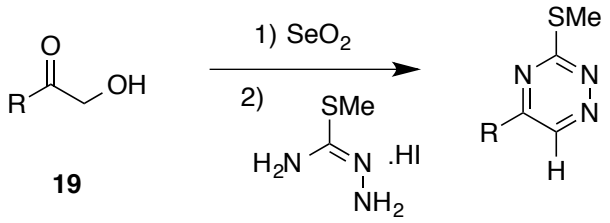
Limanto *et al.* introduced the use of α,α-dibromoketones **15** as ketoaldehyde equivalents. They showed that these could be reacted with morpholine **16** and form

intermediate **17**, which can then be condensed in a one-pot fashion on aminoguanidine **3** to obtain regioselectively 5-substituted-3-amino-1,2,4-triazines **18**.[38]



Scheme I-11: Synthesis of 5-substituted-3-amino-1,2,4-triazines

More recently, it has been demonstrated that the cyclization of 1,2,4-triazines can take place in a one-pot process with concomitant oxidation of α-hydroxyketone **19** in the presence of selenium dioxide.[39]

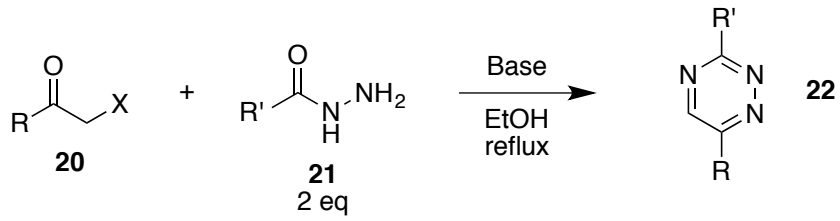


Scheme I-12: Synthesis of 5-substituted-3-methylthio-1,2,4-triazines

The employment of ketoaldehydes and their equivalents offers a reasonably general solution to the regioselective synthesis of unsymmetrical 1,2,4-triazines. However, this solution enforces the presence of a proton at C6. In order to generate alternative products, different routes have been devised.

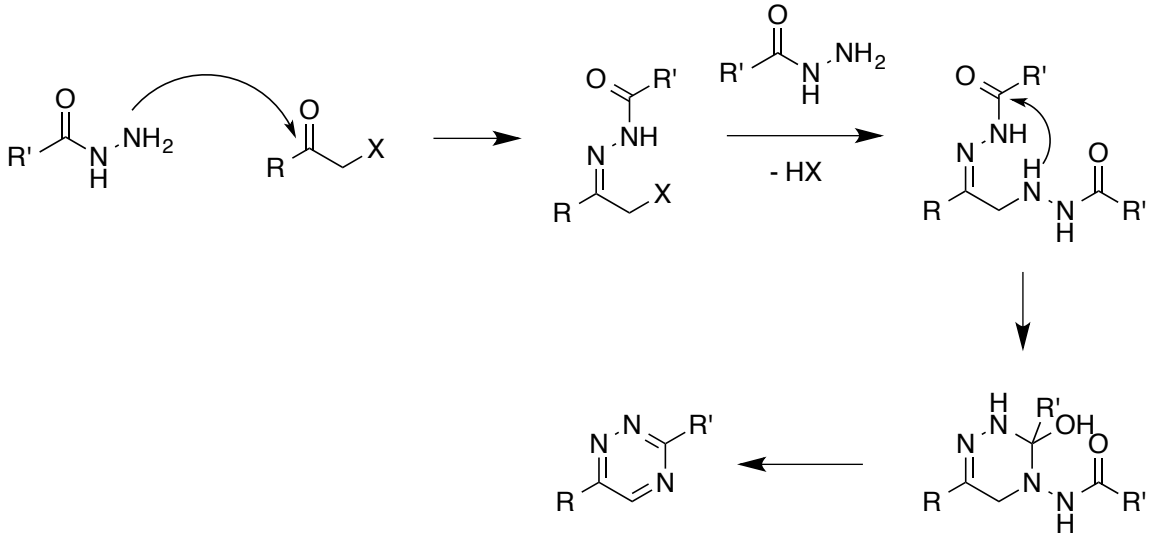
2. Synthesis of 6-substituted-1,2,4-triazines

The first unsymmetrical 1,2,4-triazines reported were substituted at the C6 position, and not at C5. These 6-substituted-1,2,4-triazines **22**[40] were generated by mixing two equivalents of acyl hydrazide **21** with one equivalent of halomethylketone **20**. An extended scope (61 examples) of this technique was reported a few years later by the same team.[41] A combination of substituted aromatic and heteroaromatic groups were used as substituents, giving yields from 31% to 85%.



Scheme I-13: Synthesis of 6-substituted-1,2,4-triazines

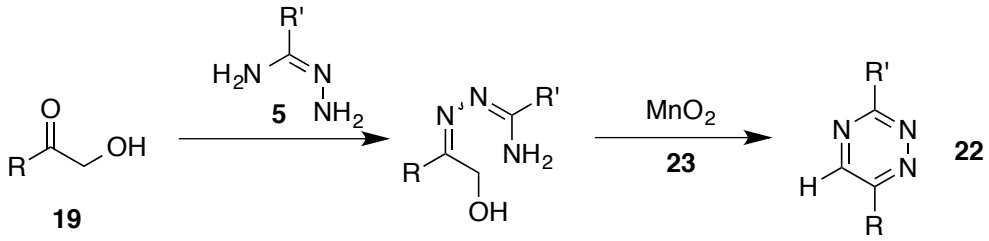
Mechanistically, it is proposed that the first equivalent of the hydrazide reacts at the carbonyl of the halomethylketone (Scheme I-14). The second equivalent of acyl hydrazide displaces the halide of the intermediate. Subsequent cyclisation and aromatisation drives the reaction forward by removal of H_2O and an amide to obtain the final product. The disadvantage of this procedure therefore is that it relies on two equivalents of acyl hydrazide substrate.



Scheme I-14: Mechanism of acyl hydrazide condensation reaction

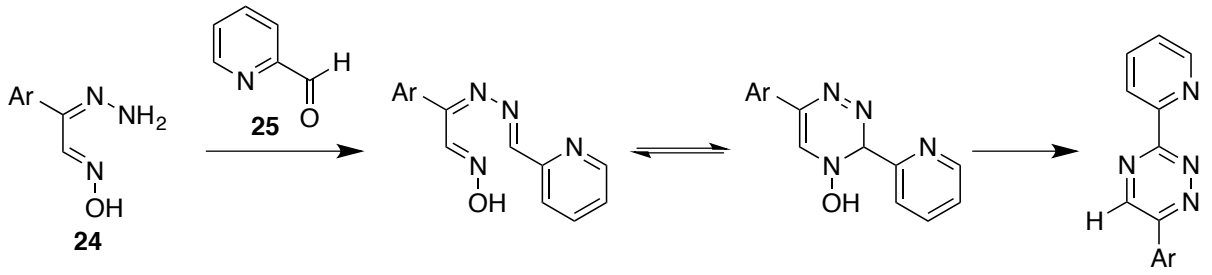
The concept of employing a one-pot oxidation-condensation of an α-hydroxyketone inspired Laphookhieo *et al.* to adapt these conditions to regioselectively form 6-substituted-1,2,4-triazines.[42] Indeed, mixing first the reagents leads to condensation of the amidrazone **5** on the carbonyl of the α-hydroxyketone **19**, positioning the substituent in the 6 position. Adding then the oxidising reagent **23** transforms the alcohol into an aldehyde, which subsequently undergoes cyclisation with the remaining free amine of the amidrazone to form

the final 6-substituted-1,2,4-triazine **22**. With this method, aromatic and heteroaromatic substituents were screened and gave yields between 51% and 73%.[43-44]



Scheme I-15: One-pot synthesis of 6-substituted-1,2,4-triazines

Finally, Kozhevnikov *et al.* reported that hydrazones **24** underwent condensation with pyridinecarboxaldehyde **25** in ethanol to obtain a triazine hydrate after cyclization. Heating this intermediate in acetic acid promoted aromatisation of the product.[45-47] Yields between 56% and 88% were obtained, but the authors noted that this dehydration step was only possible if a 2-pyridinyl group was placed at the 3 position.



Scheme I-16: Synthesis of 6-substituted-3-(2-pyridyl)-1,2,4-triazines

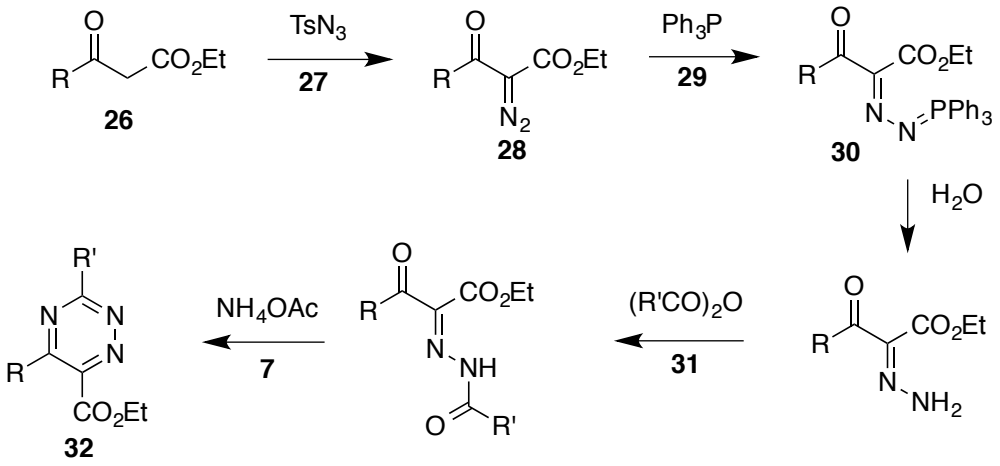
Thus, 6-substituted-1,2,4-triazines were obtained selectively with good to very good yields. Some limitations were however encountered, especially with regard to the scope of available substituents at C3.

3. Synthesis of alkyl 1,2,4-triazine-6-carboxylates

As seen previously, the best way to prepare triazines bearing different substituents at the 5- and 6-positions is to react an amidrazone with a dicarbonyl substrate where the two electrophilic positions have distinct reactivity. Except ketoaldehydes, the only other dicarbonyl compounds that fit these characteristics, and that have been used successfully, are

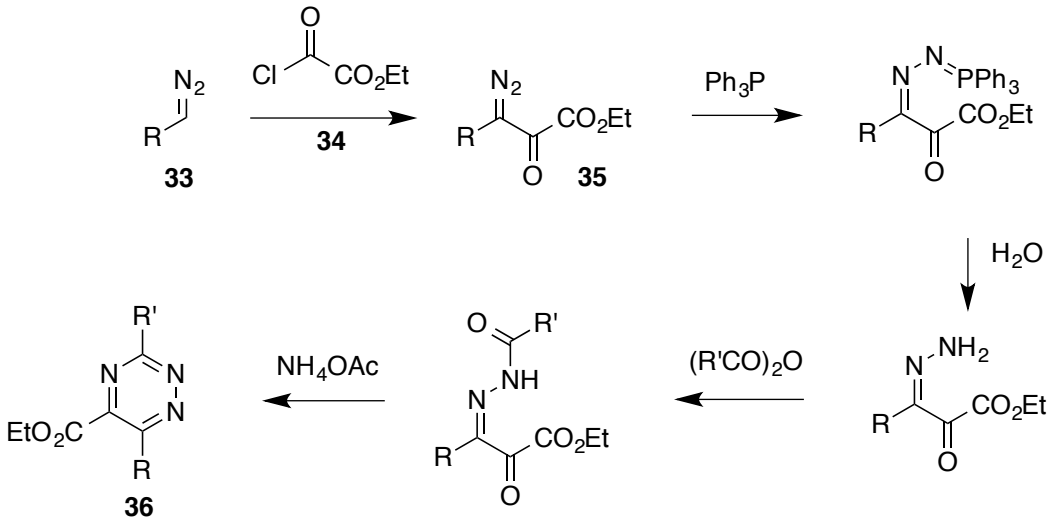
ester-substituted diketones. Indeed, these substrates have a tricarbonyl array that makes the central ketone more reactive because of its strong electrophilicity.

Ohsumi and Neunhoeffer devised an interesting variant of this approach by preparing a diazo compound flanked by a ketone and an ester.[48] The *β*-ketoester **26** was reacted with *p*-toluenesulfonyl azide **27** to give the diazo compound **28**. Subsequent treatment with triphenylphosphine **29** gave the corresponding phosphazine **30**. Hydrolysis followed by acylation with the corresponding anhydride **31** and heating with ammonium acetate **7** gave the alkyl 1,2,4-triazine-6-carboxylate **32**. Alkyl and aryl substituents were screened and gave product yields between 48% and 83%.



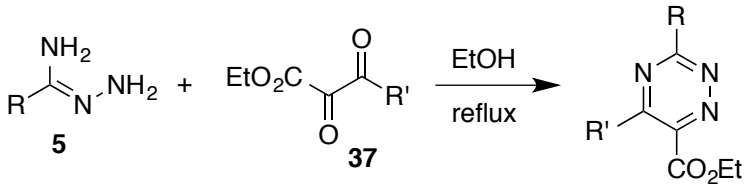
Scheme I-17: Synthesis of alkyl 1,2,4-triazine-6-carboxylates

In a subsequent report, alkyl 1,2,4-triazine-5-carboxylates were obtained by a modification of the original process.[49] Starting from diazo alkanes **33** and reacting with ethyl (chloroformyl)formate **34**, the authors were able to generate the corresponding diazodicarbonyl **35**. Subsequent elaboration of those compounds via the same route gave alkyl 1,2,4-triazine-5-carboxylates **36** in yields varying from 36% to 55%.



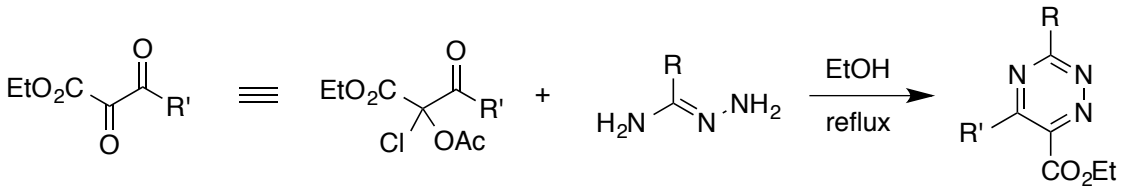
Scheme I-18: Synthesis of alkyl 1,2,4-triazine-5-carboxylates

Stanforth *et al.* have made significant progress towards the regioselective synthesis of triazines using 1,2,3-tricarbonyl substrates. They showed that while mixtures of regioisomers were obtained by reacting tricarbonyls **37** with amidrazone **5** in ethanol at reflux, selectivities could be modulated by increasing the steric bulk of the ketone substituent.[50-53]



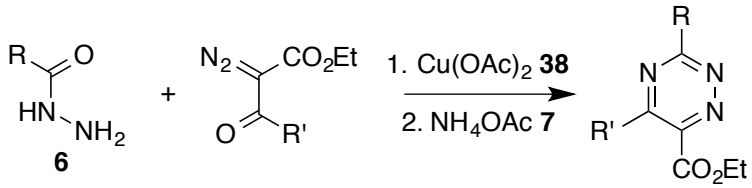
Scheme I-19: Synthesis of alkyl 1,2,4-triazine-6-carboxylates

In an effort to further improve reaction regioselectivity, a new equivalent of the tricarbonyl was developed by the same team.[54-56] Employing *gem*-chloroacetates as tricarbonyl surrogates, triazines were synthesized in yields from 53% to 98% and as single regioisomers. A range of substrates worked well but those bearing less bulky substituents on the chloroacetates gave lower yields.



Scheme I-20: Synthesis of alkyl 1,2,4-triazine-6-carboxylate

Finally, Moody *et al.* have also exploited 2-diazo-1,3-dicarbonyl substrates in triazine synthesis.[57-58] Formation of a metal carbenoid using copper acetate **38** allowed an N-H insertion reaction of hydrazide **6** to take place. The final N-atom was provided by ammonium acetate **7**. Yields between 28% and 58% were reached, most of them with a methyl group in the 5-position although it was also possible to include a 5- CF_3 substituent.

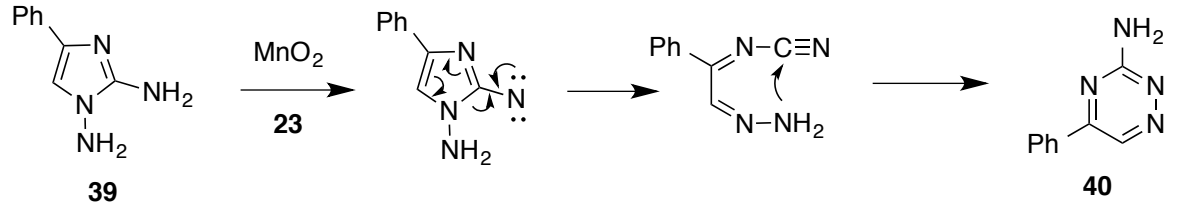


Scheme I-21: Synthesis of alkyl 1,2,4-triazine-6-carboxylate

Thus, alkyl 1,2,4-triazine-6-carboxylates can be obtained selectively and in good yield when 1,2,3-tricarbonyl substrates and their equivalents are used. Notably, this approach allows useful flexibility as to the nature of the substituent incorporated at C-5.

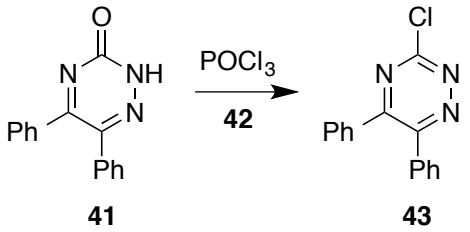
4. Synthesis of 1,2,4-triazines from a pre-formed ring

A final strategy that is commonly employed to synthesize 1,2,4-triazines starts from a pre-formed ring. These transformations typically involve ring expansion or aromatisation processes. With regard to ring expansion, Anselme *et al.* described the oxidation of 1,2-diaminoimidazole **39** with manganese dioxide **23** to give 3-amino-1,2,4-triazine **40** in 22% yield.[59] In 1978,[60] the same team expanded the scope (with respect to aryl groups in the 5-position), and obtained improved yields. The proposed mechanism involves the oxidation of the amine, followed by ring opening and cyclization to the 6 membered ring before aromatisation.



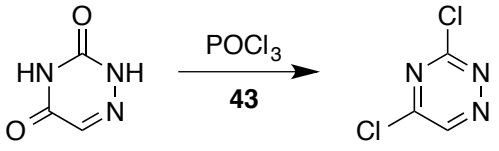
Scheme I-22: Synthesis of triazine from aminoimidazole

Another useful method to obtain 1,2,4-triazines is to conduct a chlorination of a triazinone. This method has the potential to introduce a range of new functionality to the product depending on the reagent used. For example, Laakso *et al.* reacted 3-hydroxy-5,6-diphenyl-1,2,4-triazine **41** with phosphorus oxychloride **42** to give 3-chloro-5,6-diphenyl-1,2,4-triazine **43** in 99% yield.[21]



Scheme I-23: Synthesis of 3-chloro-5,6-diphenyl-1,2,4-triazine

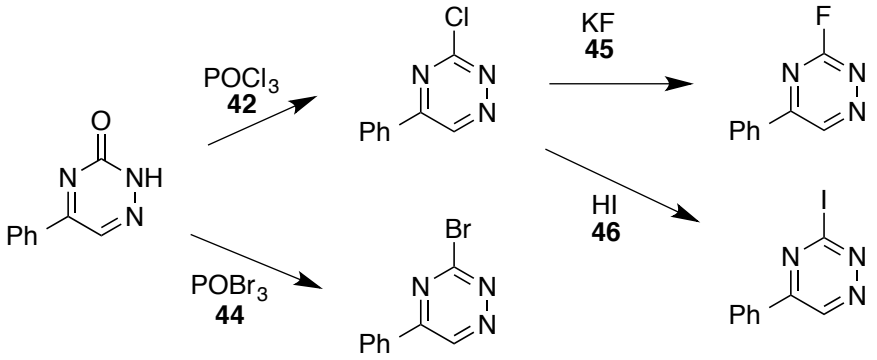
Grundmann *et al.* obtained a dichlorinated triazine using phosphorus oxychloride **42** at reflux, but only in 10% yield.[61] They then used this product to further functionalise the triazine with amines or thiols by substitution reactions of the chlorides. Other teams showed that other chlorination reagents can be used, such as oxalyl chloride $(COCl)_2$ or phosphorus pentachloride (PCl_5).[62-64]



Scheme I-24: Synthesis of a dichlorinated triazine

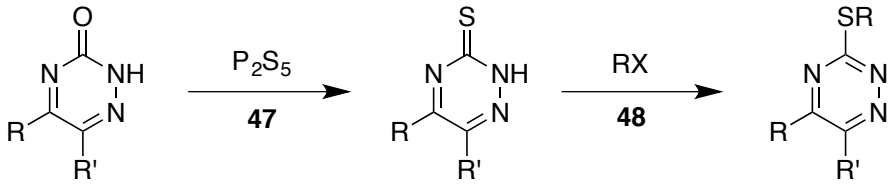
In 1980, Rykowski and Van der Plas showed that any halide could be incorporated into the C-3 position using this strategy.[65] The chloride can be obtained by reaction of

phosphorus oxychloride **42** in 45% yield, the bromide by reaction of phosphoryl bromide **44** in 53% yield, and the iodo- and fluoro-compounds are formed from the 3-chloro-triazine when reacted with potassium fluoride **45** (25% yield) and hydriodic acid **46** (14% yield) respectively.



Scheme I-25: Synthesis of halo-triazines

Finally, triazinones can be employed in the synthesis of triazines bearing a sulfide group. In all the examples compiled so far,[66-68] phosphorus pentasulfide **47** was used to create the corresponding thione triazine in good yields (53% to 89%), which upon submission to alkyl halides **48** gave the aromatic triazine substituted by the corresponding sulfides in excellent yields (83% to 96%).

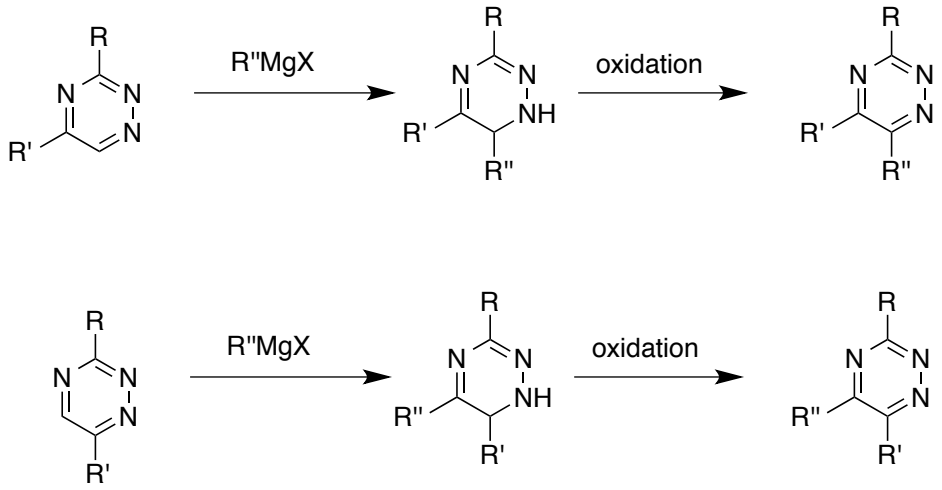


Scheme I-26: Synthesis of alkylthio-1,2,4-triazines

The main advantage of this last technique is the possibility of functionalisation on specific position of the 1,2,4-triazine. Unfortunately, the starting materials are not always easy to make and can be challenging to handle as they often show poor solubility. The halo-triazines are also reported to be quite unstable, even when stored under inert atmosphere conditions. Nevertheless, 1,2,4-triazines, once formed, can undergo further functionalisation, and also show useful synthetic properties, particularly for the synthesis of substituted pyridines.

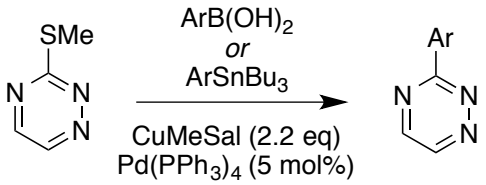
5. Functionalisation of 1,2,4-triazines

As described earlier in section I.2, triazines bearing different substituents at positions 5 and 6 are not easy to access using ring forming techniques. Alphonse *et al.* developed a two-step procedure that addresses this limitation (Scheme I-27).[69] Grignard reagents were found to add to either the 3,5- or 3,6-disubstituted 1,2,4-triazines, at the unsubstituted position. A subsequent oxidation step gave the rearomatised product. Addition at C5 proceeded in high yield whereas addition at C-6 was much less efficient. Nonetheless, the oxidation step proceeded in quantitative yield in all cases.



Scheme I-27: Addition to the ring

In the same paper, coupling at C-3 was also achieved, starting from the methylthio triazine and using copper(I) methylsalicylate (Scheme I-28). Suzuki and Stille coupling were accomplished, enabling heteroaromatic and aromatic substituents to be directly incorporated.



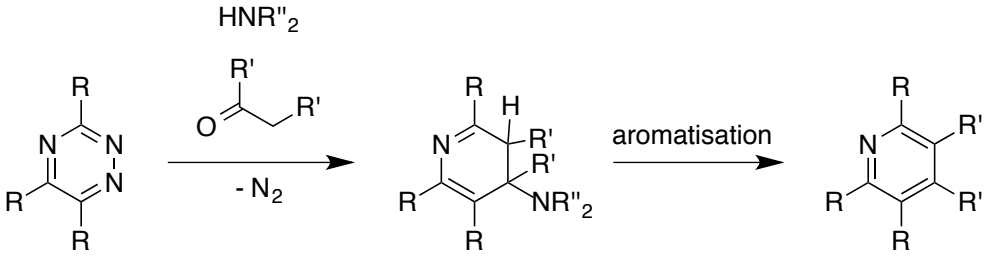
Scheme I-28: Coupling at the 3-position

With all those procedures in hand, full functionalisation of 1,2,4-triazines can be achieved. This is of particular interest as the main synthetic use of those triazines is in the

synthesis of pyridines by merged cycloaddition/retrocycloadditions (see below). Accordingly, the development of efficient and flexible methods for triazine synthesis will enhance the range of pyridines available by cycloaddition methods.

6. Applications

Pyridines are obtained from 1,2,4-triazines via inverse electron demand Diels-Alder reactions (also called aza-Diels-Alder reactions). Reaction with an alkene followed by an aromatisation step, or directly by employing an alkyne, affords substituted pyridines. Boger published an extensive review on this subject in 1983.[70] More recently, including new results enabling a one pot procedure for the reaction of triazines with dienophiles (Scheme I-29), Foster and Willis gave an update on the progress of these reactions.[71]



Scheme I-29: Inverse electron demand Diels-Alder reaction

Aza-Diels-Alder reactions of 1,2,4-triazines with alkynes, on the other hand, have not been much studied so far and are found to be poorly efficient, requiring harsh conditions and long reaction times. Finding solutions to these limitations is the aim of the upcoming project.

In addition to their use as substrates in cycloadditions, 1,2,4-triazines are also useful compounds in their own right, and find diverse applications in a range of sectors. For example, given their high nitrogen content, they are commonly used as ligands for complexing to metal cations. Some recent examples show that they bind to iron[72] and lanthanides[73] to enable measurements of cation concentrations in those cases.

Their second main use relies in therapeutic chemistry. For example, they prevent HIV infection[74] when bound to platinum, or interact with DNA[75] when cobalt is involved. Finally, they have also found applications as agrochemicals.[76]

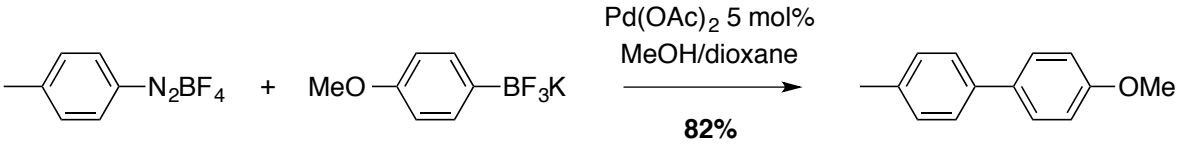
7. Conclusion and outlook

There remain a very large number of challenges associated with the synthesis of 1,2,4-triazines, many of these compounds are generated in poor yields and with limited substitution patterns. However, 1,2,4-triazines are valuable compounds with a diverse array of applications. The following study is focused, in a first part, on the development of mild conditions to achieve the cycloaddition of alkynes and triazines. In a second part, the photophysical properties of the products generated *via* this new methodology are discussed. Finally, the application of this cycloaddition to the synthesis of streptonigrin, a natural product that displays both antibiotic and anticancer activity, will highlight the value of this technique in target synthesis.

Chapter II. Directed cycloaddition reactions

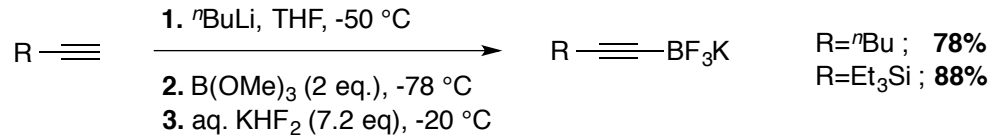
1. Alkynyltrifluoroborate salts

Organotrifluoroborate salts are well known compounds and have been used in a range of reactions such as iodinations,[77] Petasis-type Mannich reactions[78] or cross-coupling reactions, where they are a valuable alternative to boronic acids which can be difficult to handle and characterise. Potassium salts, which were first discovered by Chambers *et al.* in 1960,[79] are the most common as they show extremely good stability, both as solids or in solution, and have proven to undergo successful cross-coupling reactions (Scheme II-1).[80]



Scheme II-1: Organotrifluoroborate salts in cross-coupling reactions

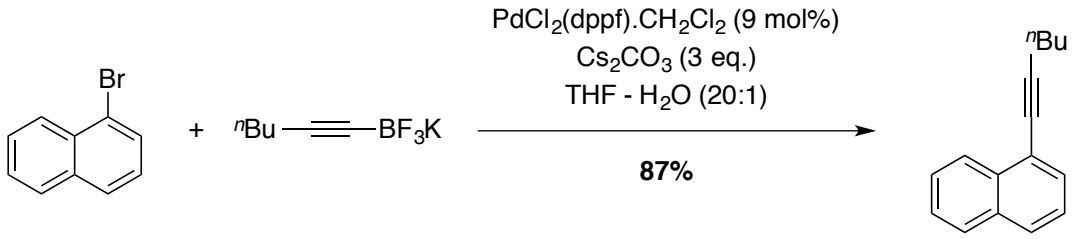
Surprisingly, the first synthesis of alkynyltrifluoroborate salts was only achieved in 1999 by Genêt and coworkers.[80] Following their optimized procedure to obtain potassium organotrifluoroborates, which consists of treating the corresponding boronic acid with potassium hydrogen difluoride (KHF_2), they obtained potassium alkynyltrifluoroborates in a one pot procedure (Scheme II-2). Starting from the terminal alkyne, deprotonation followed by borylation gave access to the corresponding alkynylboronic ester ate complex, which was then converted to the desired product with KHF_2.



Scheme II-2: Route to potassium alkynyltrifluoroborates

With those new substrates in hand, they next studied their use in cross-coupling reactions. Unfortunately, the optimum conditions for the coupling of usual potassium organotrifluoroborate with aryl diazonium salts did not proceed as expected because of side-reactions such as electron transfer to the arene diazonium salt. To circumvent this issue,

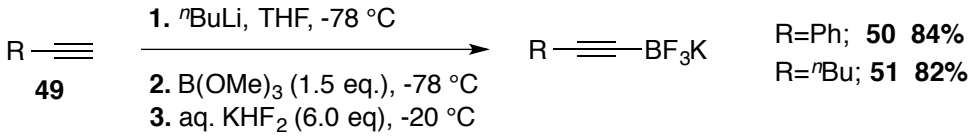
Molander *et al.* proposed in 2002[81] to change the coupling partner from aryldiazonium salts to aryl halides. In the course of their work, they established a wider scope of potassium alkynyltrifluoroborate substrates, as well as proving their potential to undergo efficient Suzuki-Miyaura cross-coupling reactions (Scheme II-3).



Scheme II-3: Potassium alkynyltrifluoroborate in cross-coupling reactions

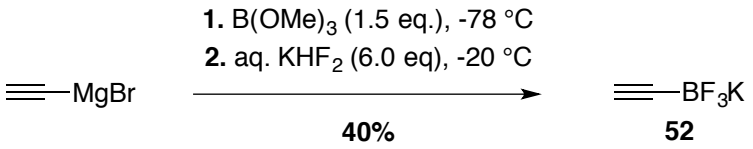
This work from Molander represented a good starting point for our project as it offered a solid route to a variety of potassium alkynyltrifluoroborates, which were key starting materials in the chemistry studied.

Following the procedure described by Molander, a series of potassium alkynyltrifluoroborates were synthesised (Scheme II-4). The commercially available terminal alkynes **49** were first treated with *n*-butyllithium at -78 °C for 1 hour to achieve full deprotonation. Addition of 1.5 equivalents of trimethyl borate at -78 °C and stirring at that temperature for 1 hour followed by one hour at -20 °C enabled the borylation to take place. Final treatment with potassium hydrogen difluoride for 1 hour at -20 °C and 1 hour at room temperature afforded the trifluoroborate salts **50** and **51** in very good yields.



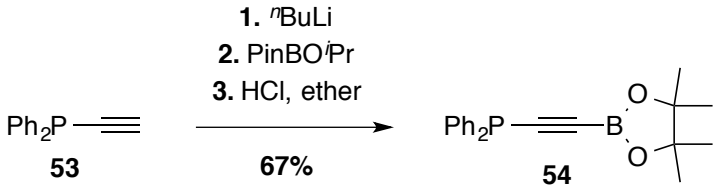
Scheme II-4: Synthesis of potassium alkynyltrifluoroborates

To obtain potassium ethynyltrifluoroborate **52** (R = H), ethynylmagnesium bromide was used, as it is a commercially available source of acetylide starting material. In the event, this procedure gave potassium ethynyltrifluoroborate in acceptable yield (Scheme II-5).



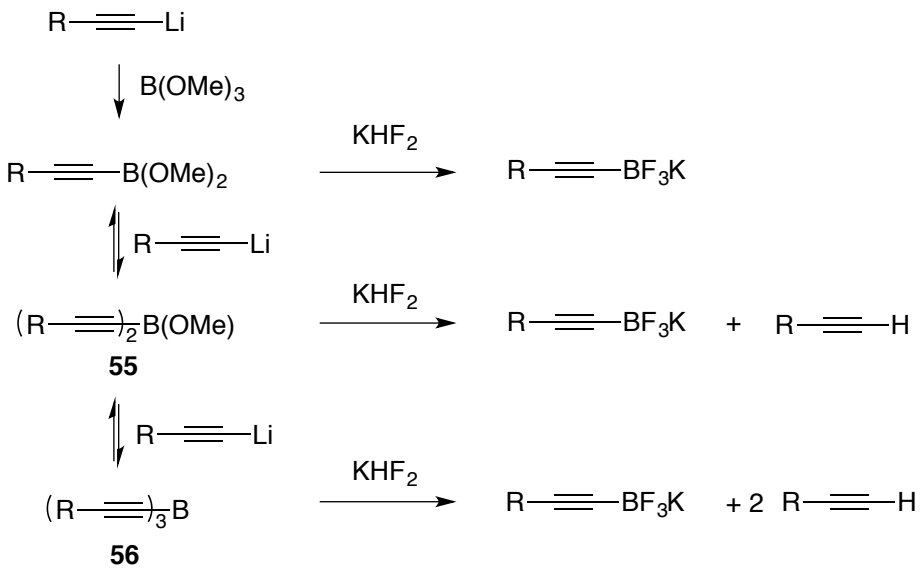
Scheme II-5: Synthesis of potassium ethynyltrifluoroborate

Finally, in an effort to incorporate novel functional groups on potassium alkynyltrifluoroborates, part of our work focused on the synthesis of phosphine-substituted alkynyltrifluoroborate salts. Previous work in our team established that the synthesis of alkynylboronate **54** could be successfully achieved from ethynyldiphenylphosphine **53** following a similar procedure to the one used for alkynyltrifluoroborate salts (Scheme II-6).[82]



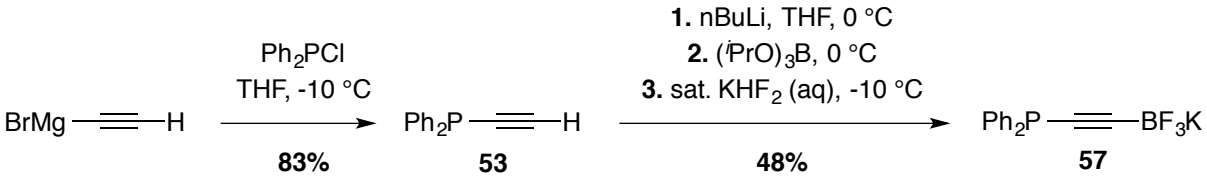
Scheme II-6: Synthesis of a phosphine-substituted alkynylborate

Unfortunately, this product proved highly sensitive to protodeboronation induced by exposure to air and moisture. As potassium alkynyltrifluoroborates previously studied showed higher stability than their corresponding alkynylborates, the synthesis of the corresponding trifluoroborate salt was pursued. Starting from ethynylmagnesium bromide, reaction with chlorodiphenylphosphine yielded diphenylethynylphosphine **53** in 83% yield. With this intermediate in hand, the usual procedure previously described was attempted. Unfortunately, no product was isolated and mostly starting material was recovered. The hypothesis at this point was that the small methoxy groups around the boron did not permit any control on the borylation step. Formation of over alkynylated boron intermediates **55** and **56**,[83] would have an adverse impact on the yield of the reaction and might explain why no product could be isolated (Scheme II-7).



Scheme II-7: Side reaction proposed with trimethyl borate

Trimethyl borate was thus replaced by triisopropyl borate to enhance the steric hindrance around the boron and the temperature was raised to 0 °C to promote the first substitution by an alkyne. Gratifyingly, the use of this reagent at this temperature afforded **57** in 48% yield (Scheme II-8). It is noteworthy that the usually very convenient purification of potassium alkynyltrifluoroborates, consisting in a recrystallisation from ether, was not efficient for this substrate as it proved soluble at room temperature in this solvent. The best purification method found consisted of flash column chromatography on silica gel, an unusual purification method for a salt.

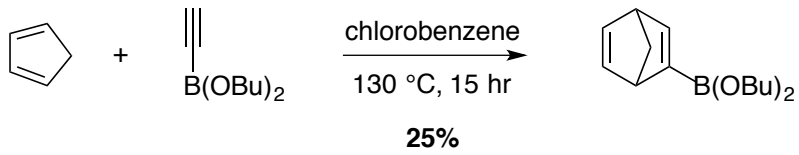


Scheme II-8: Synthesis of potassium ((diphenylphosphino)ethynyl)-trifluoroborate 57

With those alkynyltrifluoroborate salts in hand, we moved on to further research on another application of alkynes in organic synthesis: cycloaddition reactions.

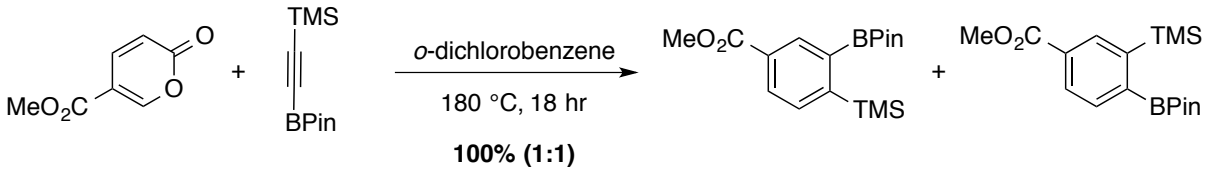
2. Background Directed Cycloadditions

Alkynylboronates were used in cycloaddition reactions for the first time in 1963 when Matteson disclosed their use in Diels-Alder reactions with reactive dienes.[84] Later, their reactivity with tetrazines in inverse-electron demand Diels-Alder was established by Seitz.[85] Those compounds are of particular interest because they show good stability, as stated before, but also because they provide products equipped with a versatile substituent enabling various transformations to take place at the carbon-boron position. Unfortunately, the activating effect of the boronic ester functionality on the alkyne is quite moderate, which limits the scope of compatible reaction partners. Moreover, even very reactive substrates require harsh conditions (high temperatures and long reaction time), and this represents the major drawback of this chemistry. Fortunately, the use of transition-metal-catalysts has improved these kinds of reactions (Scheme II-9), an extensive review published in 2005 discusses progress in this area.[86]



Scheme II-9: Alkynylboronates in cycloaddition reactions

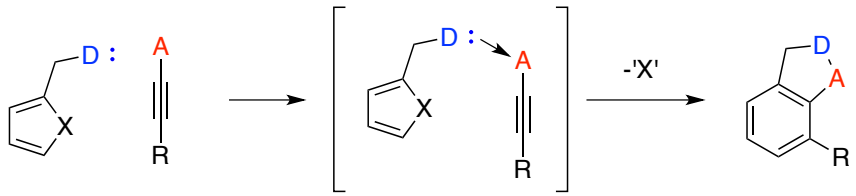
The second issue with cycloadditions of alkynylboronates (as with many other alkynes) lies in their (lack of) regioselectivity (Scheme II-10). Even with improved conditions, this selectivity remains a problem and only steric hindrance seems to have some effect with specific examples.[87]



Scheme II-10: Regioselectivity issue in cycloadditions with alkynylboronates

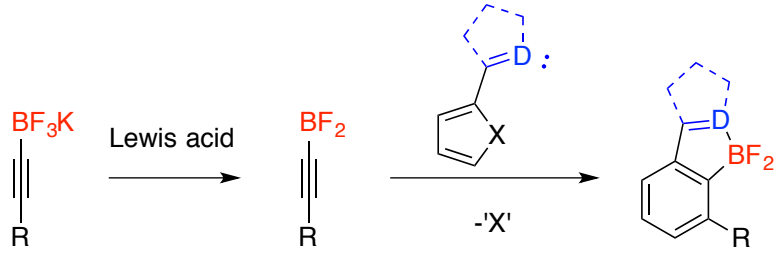
To address these flaws, a strategy has been developed in our laboratory based on the pre-association of a Lewis pair, which would enable the reactions to take place under milder

conditions. The presence of a Lewis acid acceptor on the alkyne, associated to a Lewis basic donor substituent on the diene, would promote an interaction between those two partners (Scheme II-11). The resulting complex formed would greatly lower the energy required for the reaction to proceed and thus the cycloaddition would proceed under relatively mild conditions. Moreover, this technique completely controls the regioselectivity of the cycloaddition, as the complexation event fixes the position of the alkyne, with the Lewis acid group ending up adjacent to the Lewis base.



Scheme II-11: Concept of directed cycloaddition

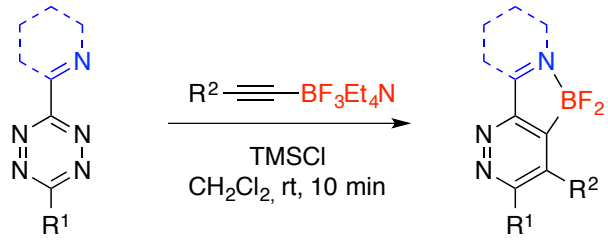
The boron atom of the alkynyltrifluoroborate salt represents a perfect opportunity to act as a Lewis acid acceptor, and to this end, the addition of a fluorophilic reagent forms a reactive alkynyldifluoroborane in situ, with the 'BF_2' moiety able to associate with the Lewis base attached to the diene (Scheme II-12).



Scheme II-12: Application of directed cycloaddition to alkynyltrifluoroborate salts

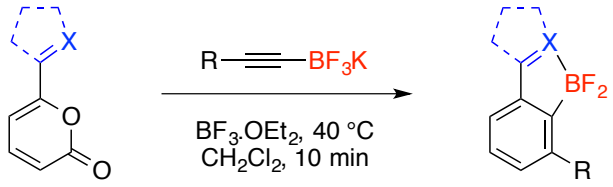
Several examples applying this strategy have been studied by our team in the past, showing its versatility in multiple cycloaddition reactions, thus facilitating the synthesis of aromatics and heteroaromatics. The first substrates that showed great results for this technique were tetrazines (Scheme II-13).[88] An extensive scope of pyridazines bearing a boron substituent were generated from cycloadditions requiring only a few minutes at room temperature, in excellent yields. Playing the role of Lewis bases, pyrazole and pyridine rings showed great efficiency in directing the cycloaddition via the lone pair of the nitrogen. The

active Lewis acid on the alkyne was formed from either potassium or tetraethylammonium alkynyltrifluoroborates, as both salts were found to be viable. Great results were thus obtained with tetrazines, but those are considered as highly activated dienes, less reactive substrates were then studied to try to establish the versatility of this chemistry.



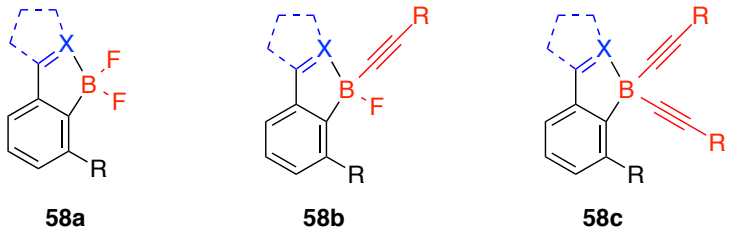
Scheme II-13: Directed cycloaddition with tetrazines

To this end, 2-pyrones represented an interesting class of substrates, as they usually require very harsh reaction conditions and show poor regioselectivity (Scheme II-10). The synthesis of 2-pyrones with directing groups at C-6 was carried out and their participation in directed cycloadditions was tested (Scheme II-14).[89] In the event, substituted pyridines, azole heterocycles and amides were successfully used with good to very good yields. In this case, boron trifluoride diethyl etherate ($BF_3.OEt_2$) was found to be the most efficient fluorophile to activate the alkyne. A large scope of polysubstituted benzene rings was thus achieved, all reactions being completed within minutes and at only 40 °C.



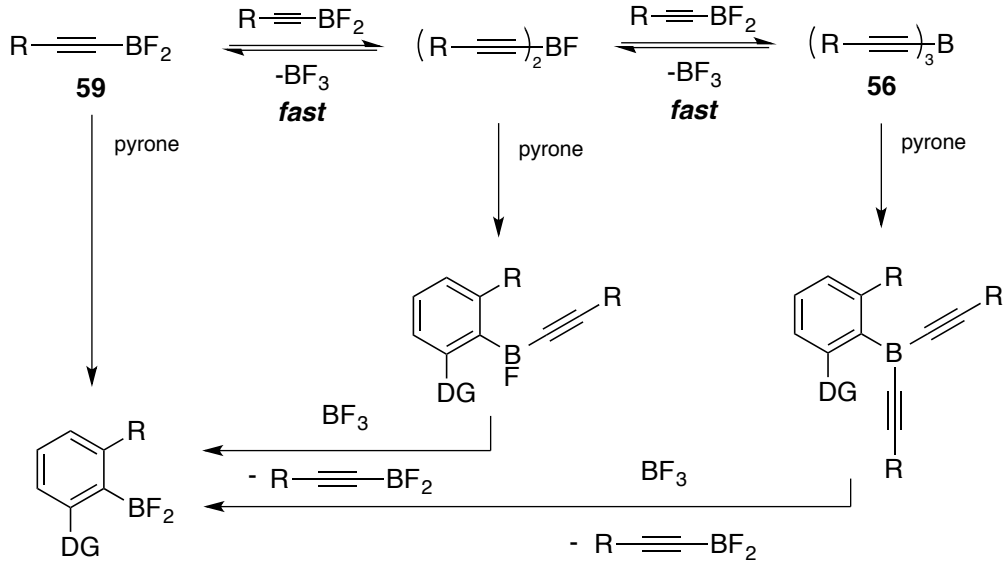
Scheme II-14: Directed cycloaddition with 2-pyrones

Interestingly, the cycloaddition of 2-pyrones unexpectedly generated two side products **58b** and **58c**, bearing different substitution on the boron (Scheme II-15).



Scheme II-15: Side-products in cycloaddition with 2-pyrones

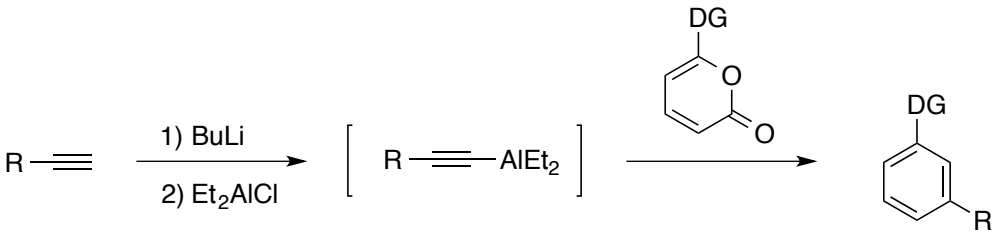
Density functional theory (DFT) studies were conducted to further study this mechanism.[90] Conclusions indicated that upon addition of the Lewis acid, the alkynyltrifluoroborate salt disproportionates from the initially formed difluoroborane **59**, to the trialkynylborane **56**, which was found to be the more stable of those intermediates (Scheme II- 16). At that point, cycloaddition proceeds and products bearing two alkynes on the boron are obtained. A final disproportionation affords the difluoroborane product. The side products observed earlier on thus arise from the rapidity of this last disproportionation; if the reaction is quenched before complete equilibration, they can be observed. Moreover, this last study showed that if alternative Lewis acids were used, alternative halides could substitute the boron on the product. Thus, the use of BBr_3 and BCl_3 afforded the dibromoborane and dichloroborane products, respectively.



Scheme II-16: Mechanistic scheme for the directed cycloaddition

Finally, alternative Lewis acid containing alkynes have been employed in reactions of 2-pyrones.[91] In a similar way to the alkynylboranes, alkynylaluminium reagents were generated in situ from the corresponding terminal alkynes (Scheme II-17). Specifically, after deprotonation of the alkyne, diethylaluminium chloride was added to generate the alkynylaluminium reagent. The pyrone was then introduced, and, once the cycloaddition was complete, the reaction was quenched with water to substitute the aluminium substituent with a proton. Once again, a very large scope of directing groups was successfully implemented, including amides and heteroaromatic rings. It was also discovered that if an alternative

electrophile was introduced directly after the cycloaddition, different substitutions of the final benzene ring could be obtained. Although this alternative source of Lewis acid has not been studied yet on other dienes, it embodies promising outlook for directed cycloadditions.

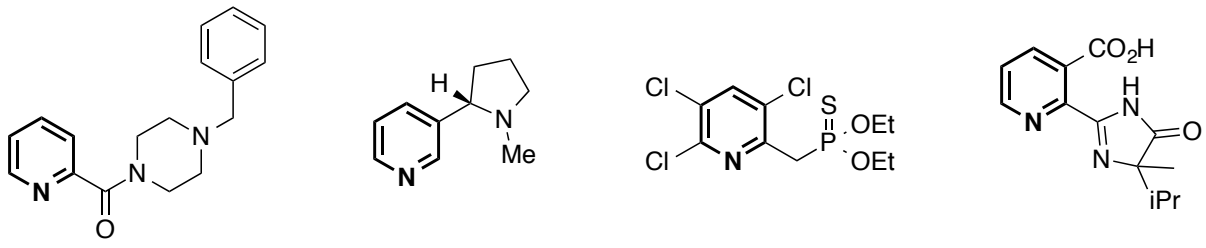


Scheme II-17: Directed cycloaddition with alkynylaluminium

Overall, the directed cycloaddition offers a new, efficient, regiocontrolled and mild way to obtain benzene and pyridazine rings. To widen the scope of this methodology to include pyridine rings, it was decided to investigate even less reactive heteroaromatic dienes: 1,2,4-triazines.

3. Previous work done in the group

Pyridines are a key class of heteroaromatic molecules and they appear in many bioactive compounds used for medicinal and agrochemistry, but also in numerous natural products (Scheme II-18).[92]



piberaline
pharmaceutical
(antidepressant)

nicotine
natural product

chloropyrifos-ethyl
agrochemical
(insecticide)

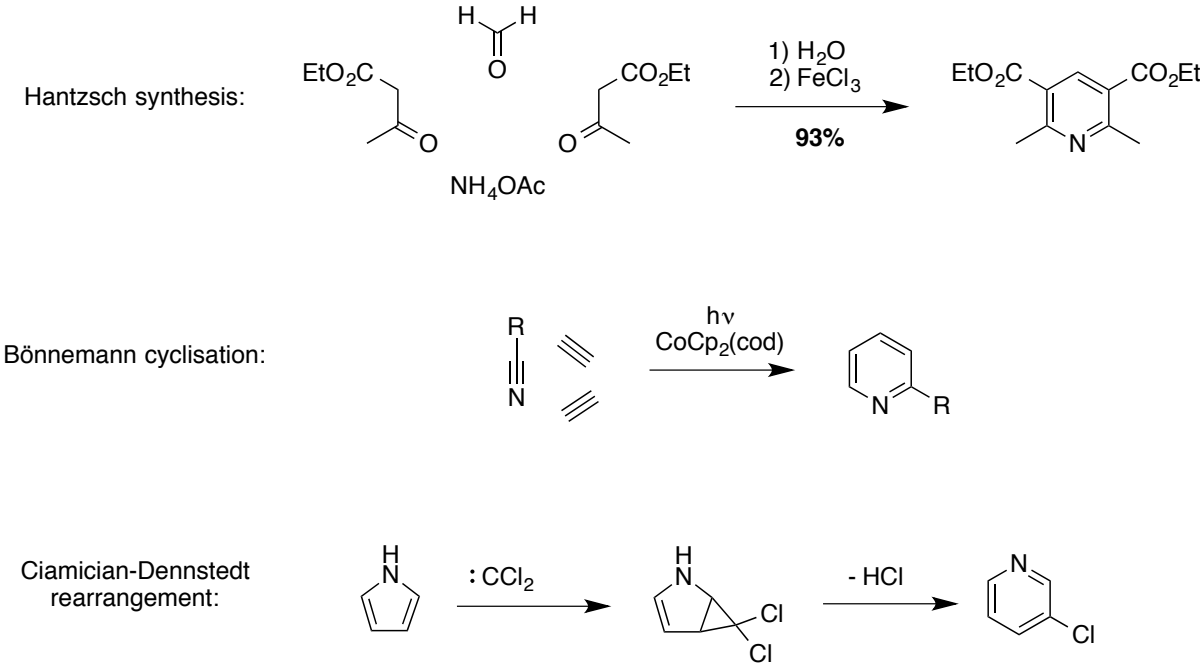
imizapyr
agrochemical
(herbicide)

Scheme II-18: Examples of pyridine rings in important compounds

From a synthetic viewpoint, the electron withdrawing effect of the nitrogen atom in the pyridine ring makes electrophilic substitution processes difficult to proceed, as exemplified by the following examples (Scheme II-19).[92]

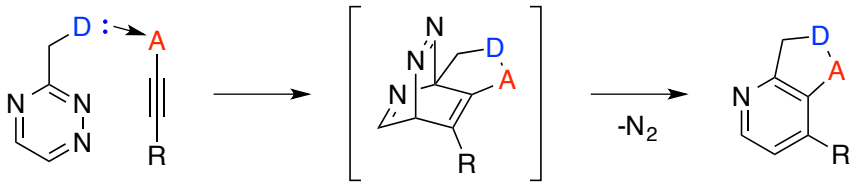
Scheme II-19: Electrophilic substitution on pyridine rings

Pyridine functionalisation thus often depends on the presence of a halide substituent, or related group, enabling substitution or cross-coupling reactions to proceed. For these reasons, alternative strategies comprising ring formation have been commonly employed in the formation of pyridines. These approaches allow substituents to be incorporated without having to resort to performing transformations on the heteroaromatic ring (Scheme II-20).[93-95]



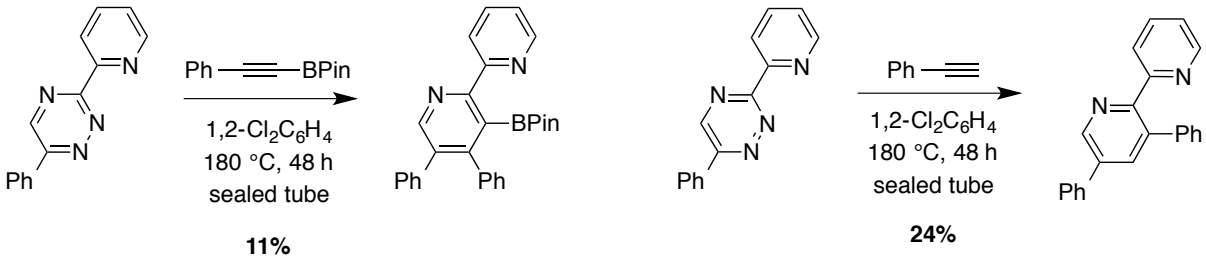
Scheme II-20: Classical approaches to pyridine rings

The following work focuses on the application of directed cycloadditions as a ring forming approach to pyridines, specifically via the inverse electron demand aza-Diels–Alder reaction of 1,2,4-triazines and alkynes (Scheme II-21).



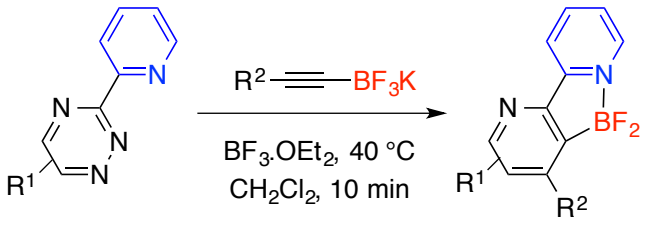
Scheme II-21: Directed inverse electron demand aza-Diels-Alder reaction

Previous work[96-97] focused on establishing the reactivity of non-activated triazines with alkynes. Thus, a triazine equipped with a directing group was successively reacted with an alkyne and an alkynylboronate. The results indicated that very harsh conditions were required (180 °C for 48 hours) leading to poor yields (Scheme II-22); there was therefore significant room for improvement.

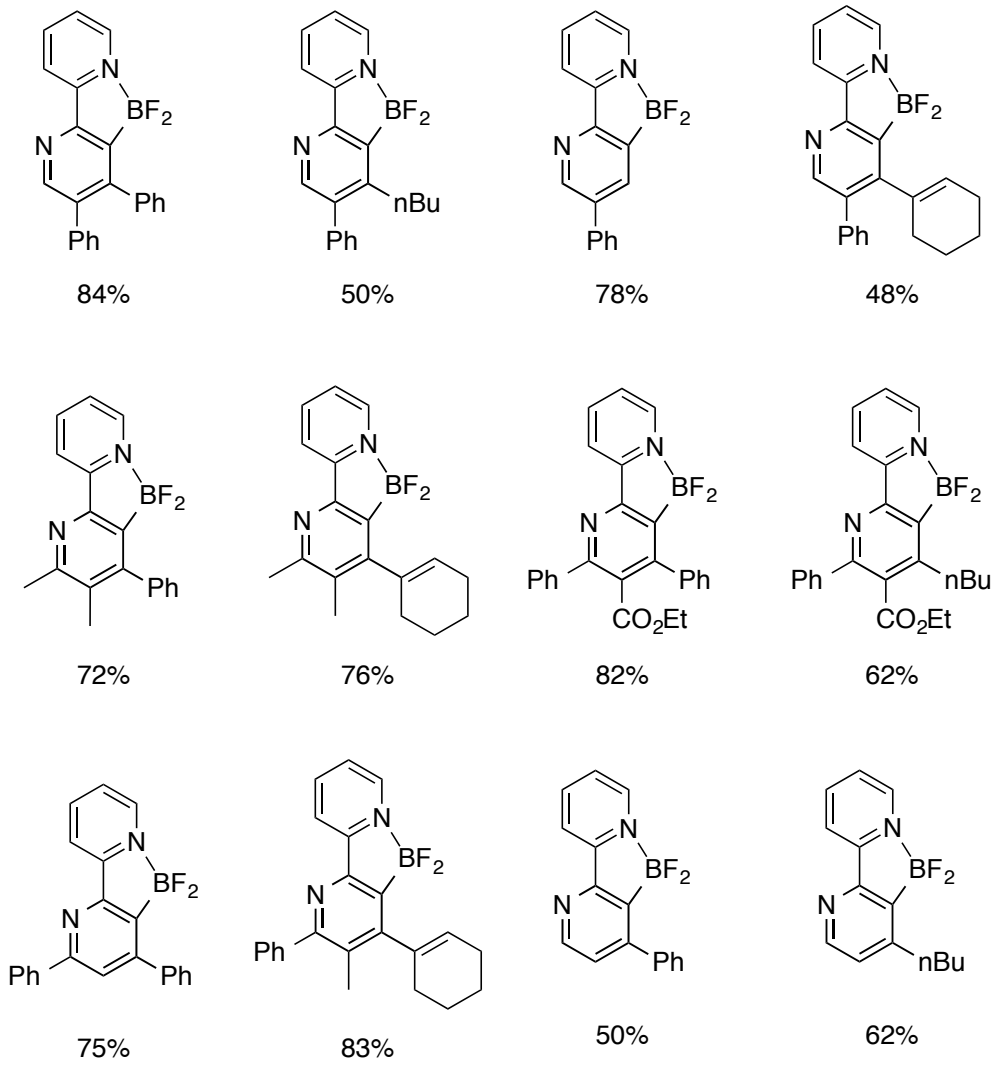


Scheme II-22: Triazine cycloaddition of alkynes

The same substrate was then employed to optimise the directed cycloaddition with potassium (phenylethynyl)trifluoroborate. After screening the reaction temperature and Lewis acid promoters, the best conditions consisted of using 3 equivalents of alkyne and 3 equivalents of $BF_3.OEt_2$ at 40 °C in dichloromethane for 10 minutes (Scheme II-23). Continuing with a pyridine ring as directing group, a large scope of substituted pyridines was obtained by varying both the substituents on the triazine and the substituent on the alkyne (Scheme II-23).

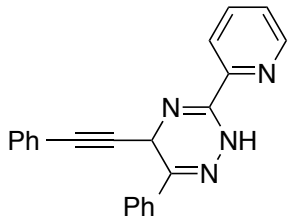


Scheme II-23: Pyridine-directed cycloaddition with 1,2,4-triazines



Scheme II-24: Scope of poly-substituted pyridines

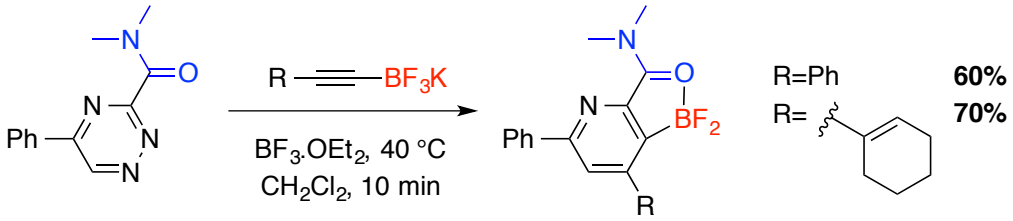
Good to very good yields were obtained, except when unsubstituted triazines were used, which provided the corresponding products in only modest yields. The reason behind those lower yields was found to be the formation of a side product **60** when the triazine ring was less substituted (Scheme II-25). In these cases, direct acetylide addition at the heteroaromatic ring was observed leading to a minor side product during the optimisation.



60

Scheme II-25: Side-product formed from direct acetylide addition

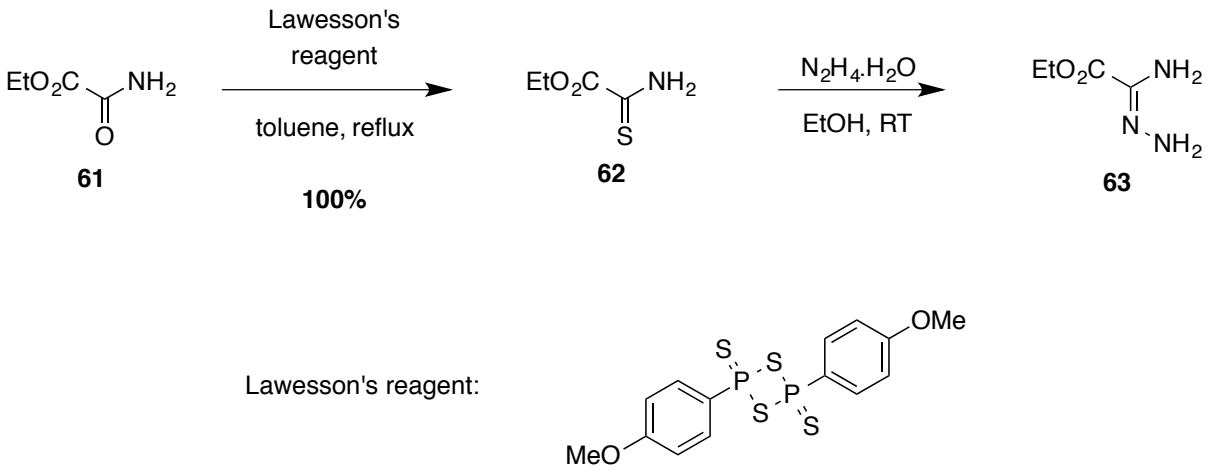
In an effort to discover alternative directing groups, triazines substituted by an amide were investigated. Amide groups indeed present much more versatility towards further transformations than pyridine rings. Dimethylamides were first synthesised and gave good yields and promising results (Scheme II-26).[96-97]



Scheme II-26: Dimethylamide-directed cycloaddition with 1,2,4-triazines

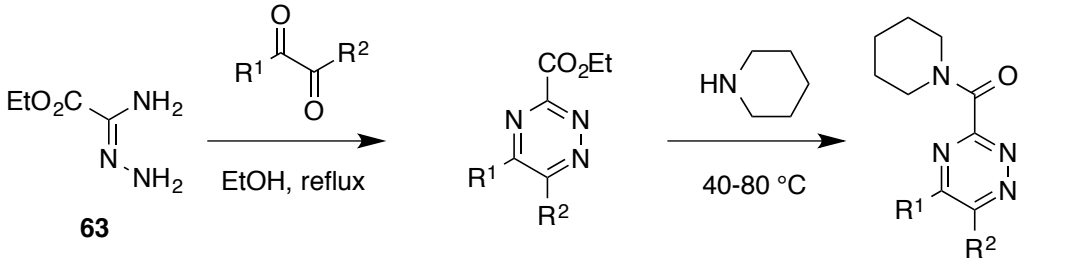
4. Further study and limitations

The very first step of the project thus consisted of increasing the scope of pyridines obtained when amides were used as a directing group. We thus set out to synthesise the corresponding triazines (Scheme II-27). Starting from ethyl oxamate **61**, reaction with Lawesson's reagent in refluxing toluene for 1 hour afforded ethyl thiooxamate **62** quantitatively. A second step with hydrazine in ethanol at room temperature overnight gave the amidrazone **63**, which proved to be very unstable and degraded rapidly.[2] This compound was used immediately in the next step to minimise degradation losses.



Scheme II-27: Route to amidrazone 63

Condensation of this amidrazone was accomplished with three different reagents to obtain triazines **64-66**, enabling the study of the influence of substituents (Scheme II-28). In the first case, amidrazone **63** was treated with benzil and formed triazine **64** in 84% yield. Phenylglyoxal monohydrate was then employed in refluxing ethanol, but the poor stability of the starting material to water resulted in 41% of triazine **65**. The condensation reaction with glyoxal proved to be even less efficient (Table II-1). Using 1,4-dioxane-2,3-diol only gave traces of product (entry 1 and 2). Despite the fact that monomeric glyoxal can only be found in aqueous solution, we then focused on the use of this reagent. When water and ethanol were used as solvents, no product was observed as they probably degraded the starting material very quickly (entry 3 and 4). Changing to boiling methanol finally afforded 28% of product (entry 5) and a similar yield of 26% was obtained in methanol at room temperature (entry 6). This final set of conditions were judged to afford sufficient material and thus used subsequently. Finally, amidation was achieved by heating the corresponding esters obtained with piperidine and afforded triazines **67-69** equipped with an amide directing group in 24%, 90% and 87% yield respectively.



R^1=R^2=Ph; **64 84%** R^1=R^2=Ph; **67 24%**
R^1=Ph; R^2=H; **65 41%** R^1=Ph; R^2=H; **68 90%**
R^1=R^2=H; **66 28%** R^1=R^2=H; **69 87%**

Scheme II-28: Synthesis of amide-substituted 1,2,4-triazines

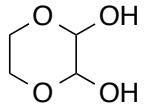
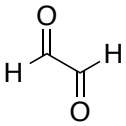
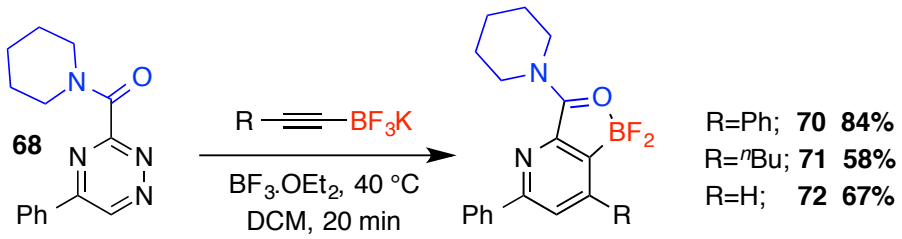
Entry	Glyoxal eq	Solvent	Temperature	Time	Outcome
1		THF, EtOH	-78 °C to RT	24 h	Traces
2		MeOH	RT to reflux	3 h	5%
3	 aqueous	H_2O	RT	overnight	0%
4		EtOH	RT	36 h	0%
5		MeOH	RT to reflux	3 h	28%
6		MeOH	RT	30 min	26%

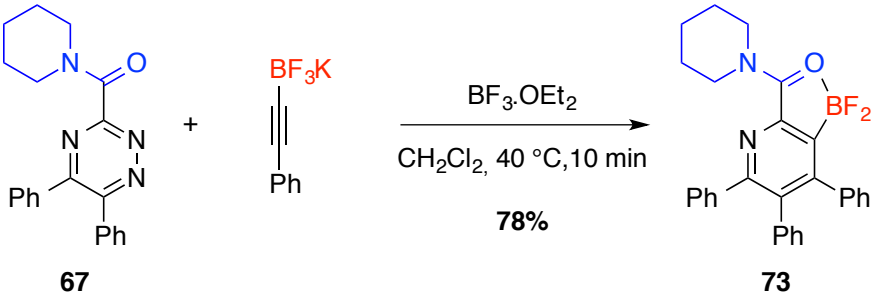
Table II-1: Optimisation for the synthesis of 66

With these new substrates in hand, their cycloaddition with different potassium alkynyltrifluoroborates was studied (Scheme II-29). Three of the previously synthesised alkynes were first used with **68** and, despite stability issues on silica during the purification, the use of florisil (for **71**) or trituration (for **70** and **72**) afforded the corresponding products with good to very good yields.



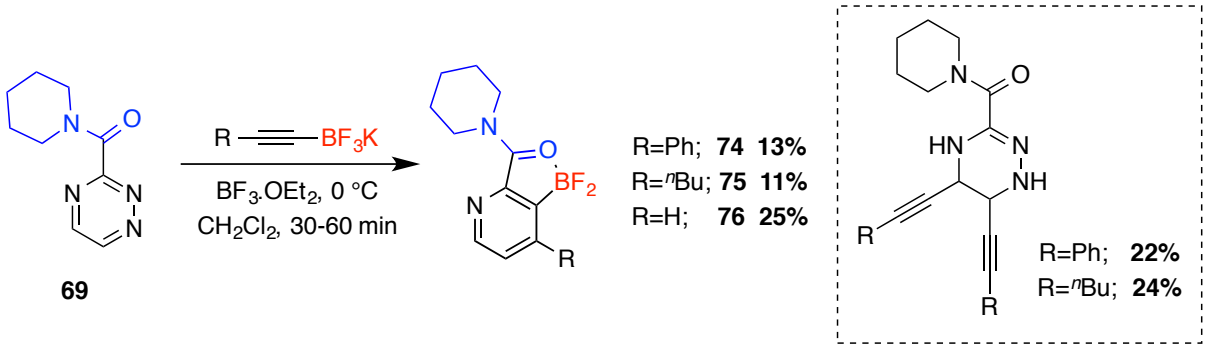
Scheme II-29: Amide-directed cycloaddition with 1,2,4-triazine

Similarly, triazine **67** gave a good yield of pyridine **73** upon cycloaddition with potassium phenylethynyltrifluoroborate (Scheme II-30), confirming that triazines with one or two substituents are suitable substrates for our methodology.



Scheme II-30: Cycloaddition with triazine 73

Unsubstituted triazine **69** proved less efficient. As observed before when some positions of the triazine were unsubstituted, a side product resulting from the addition of the alkyne to the ring was formed (Scheme II-31). In this case, with both C5 and C6 positions unsubstituted, double addition was observed, which had a major adverse impact on the yield of the cycloaddition product.



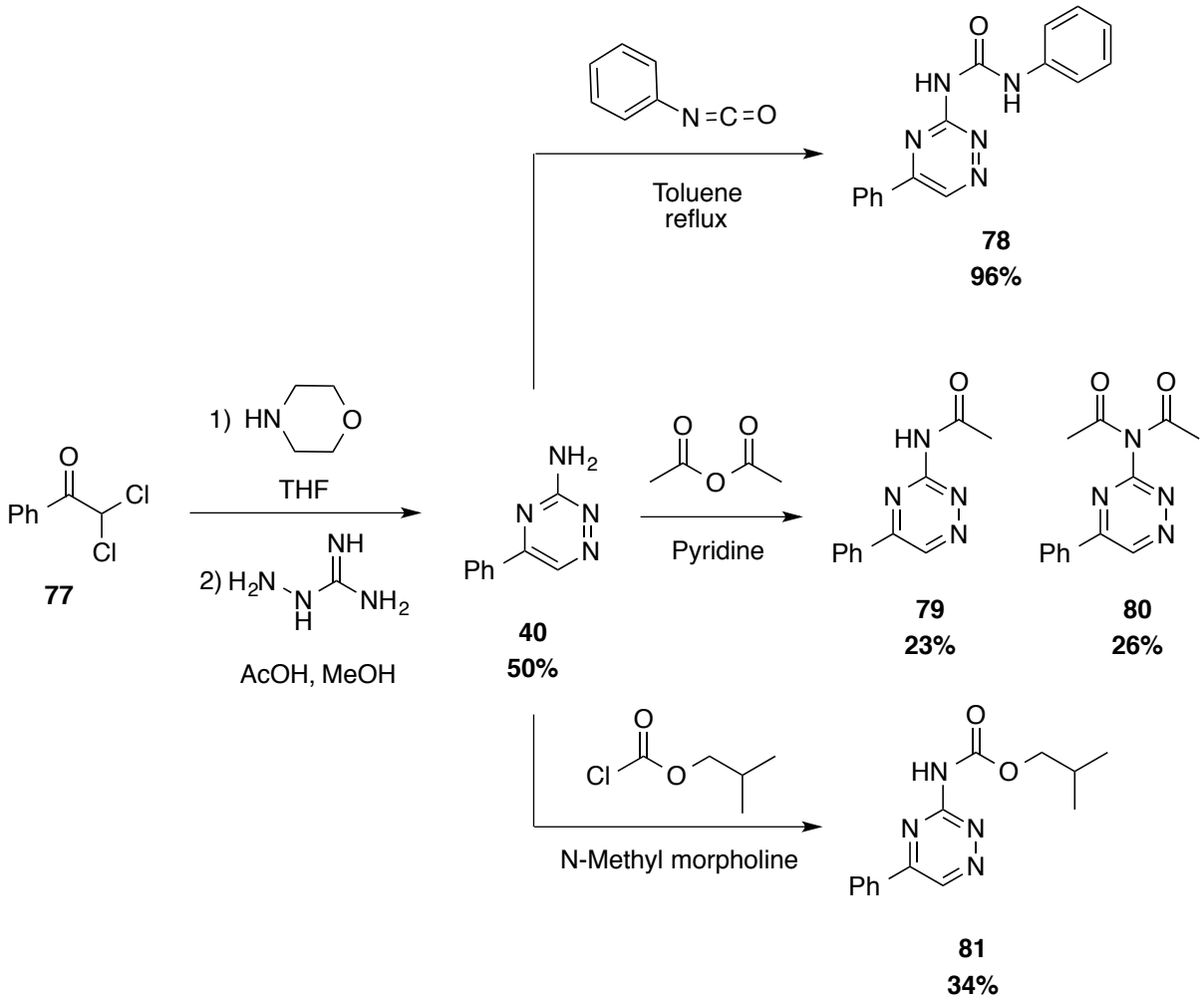
Scheme II-31: Amide-directed cycloaddition with monosubstituted 1,2,4-triazine

From those results, one major limitation to this chemistry seems to be the requirement for substitution at C5 and/or C6 of the triazine. As our main goal was originally to perform a ring synthesis to obtain highly-substituted pyridines, this was viewed as a minor issue. Indeed, to obtain less substituted pyridines, it might therefore be appropriate to return to the original strategy of functionalisation through aromatic substitution.

5. Study of alternative directing groups

Interestingly, all examples of directed alkynylborane cycloaddition reported within the group maintained coordination between the boron and the directing group via a 5-membered ring. In an effort to expand the scope of Lewis bases available, alternative directing groups requiring the formation of 6-membered ring intermediates were next investigated. In order to perform this study, we decided to prepare 3-aminotriazines that would allow a range of carbonyl based fragments to be prepared and tested for cycloadditions (Scheme II-32).

The synthesis of the 3-amino-triazine was achieved by reacting dichloroacetophenone **77** with two equivalents of morpholine in THF,[38] and then with aminoguanidine bicarbonate in acetic acid and methanol to yield 50% of **40**. This intermediate could be used to generate a series of amide and related groups capable of directing the cycloaddition. Triazine **78** was synthesised by reacting phenyl isocyanate in refluxing toluene to form a urea-like substituent in 96% yield. Triazines **79** and **80** were produced from mono and di-acylation with acetic anhydride in 23% and 26% yields, respectively. Those compounds were found to be poorly soluble in common cycloaddition solvents, and so a final triazine **81** was designed with a greasy chain on the amide to improve its solubility. It was obtained in 34% yield from isobutyl chloroformate and *N*-methyl morpholine.

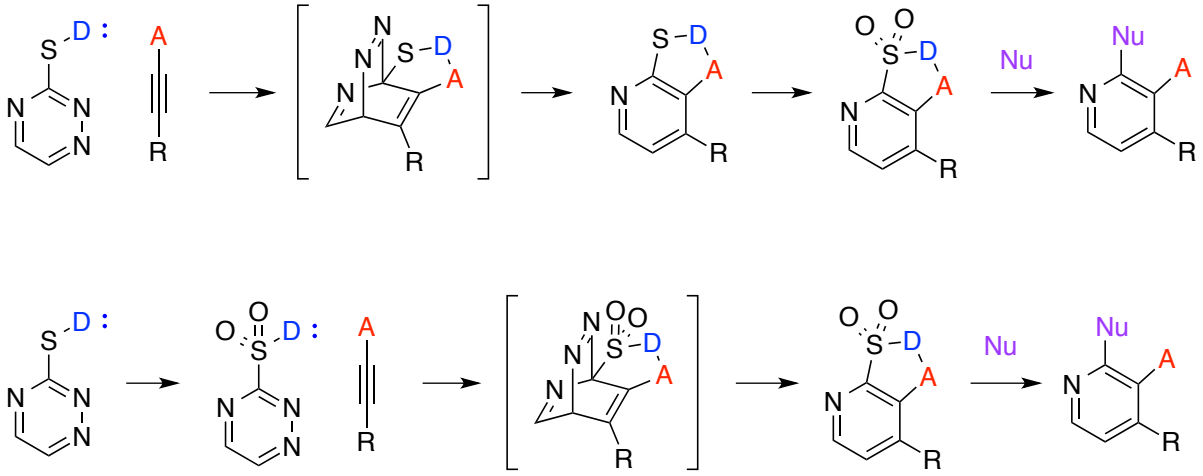


Scheme II-32: Synthesis of triazines bearing alternative directing groups

Despite our efforts, none of the substrates **78-81** underwent cycloaddition with in situ generated alkynylboranes. Several hypotheses were formulated to explain these results. In some cases, solubility was an issue but even switching to more soluble substrates such as **81** did not improve the results. The suitability of the directing groups for this process can also be questioned, it might be that they are not suitable Lewis bases or that the aminotriazine group deactivates the diene towards cycloaddition. Finally, it is also conceivable that cycloaddition cannot proceed via a 6-membered tether, although this does seem rather unlikely. Nevertheless, not discouraged by those results, we then set out to explore yet another alternative directing group forming this kind of intermediate.

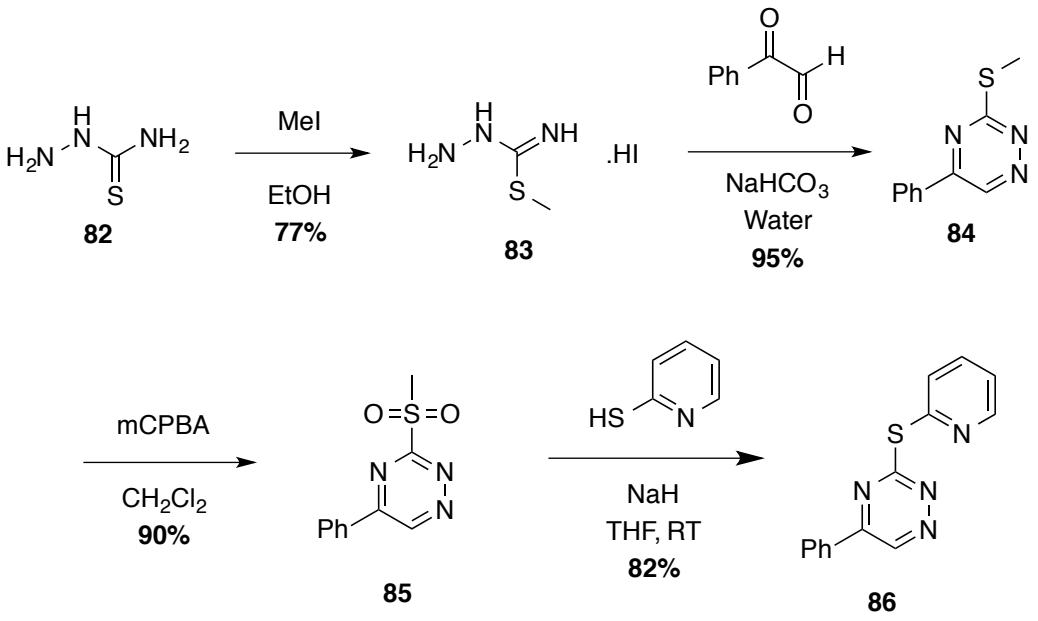
The idea was to design a directing group that could be removed later on by substitution. This ‘traceless’ directing group would address one of the major drawbacks of

this chemistry. To this end, a pyridine ring Lewis base was employed, as it proved successful to direct the cycloaddition, but a sulfur atom was positioned between this ring and the triazine. Thus, pre- or post-cycloaddition oxidation would provide a sulfone group that could function as a leaving group in a substitution reaction (Scheme II-33).



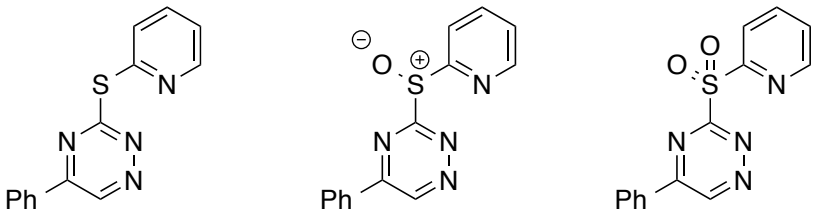
Scheme II-33: Concept of traceless directing group for cycloaddition

Following a literature procedure,[28] the sequence to synthesise these triazines began with methylation of thiosemicarbazide **82** with iodomethane in ethanol, which proceeded smoothly to give compound **83** in 77% yield (Scheme II-34). Cyclisation with phenyl glyoxal was very efficient and afforded triazine **84** in 95% yield, and the following oxidation with mCPBA provided triazine **85** equipped with a very good leaving group at C3 in 90% yield. Indeed, the leaving group ability of the sulfone was evidenced by triazine hydrolysis with traces of water. However, substitution with 2-mercaptopyridine in anhydrous conditions formed triazine **86** in 82% yield, separating by a sulfur atom the triazine core and the directing group.



Scheme II-34: Synthesis of the initial substrate for a cleavable directing group strategy

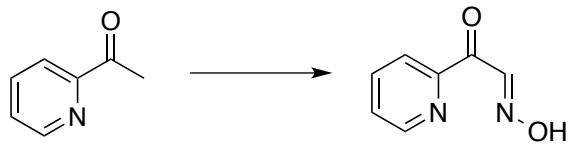
From this point, several opportunities were offered. Either submit triazine **86** to cycloaddition or perform first the oxidation. We initially opted for the cycloaddition with alkynyltrifluoroborate **50**, but unfortunately only starting material was returned, suggesting that triazine **86** is more electron-rich than the previous triazines, because of the adjacent sulfur atom, thus disfavouring the inverse electron demand Diels-Alder. We then moved on to the oxidation, hoping that the sulfoxide or the sulfone would improve the reactivity of the substrate. But this time, and as suggested by the poor stability of triazine **85**, none of the oxidised products could be isolated cleanly, and they also proved to be highly unstable. The low stability of these substrates suggested that they would not survive the cycloaddition reaction conditions, and so these were not further pursued.



Scheme II-35: Triazines equipped with unsuccessful or unstable directing groups

6. Alternative position of the directing group

Studies to-date had focused entirely on triazines bearing directing groups at C3. However, C6 also appeared to be a suitable position for a directing group, as it is also next to the two adjacent nitrogen atoms. To explore this possibility, triazine **91** was synthesised to assess if a pyridine ring could direct the cycloaddition from C6. The route started with the nitrosation of 2-acetylpyridine **87** to obtain **88**, but despite numerous conditions screened (Table II-2), the yield never exceeded 18%.

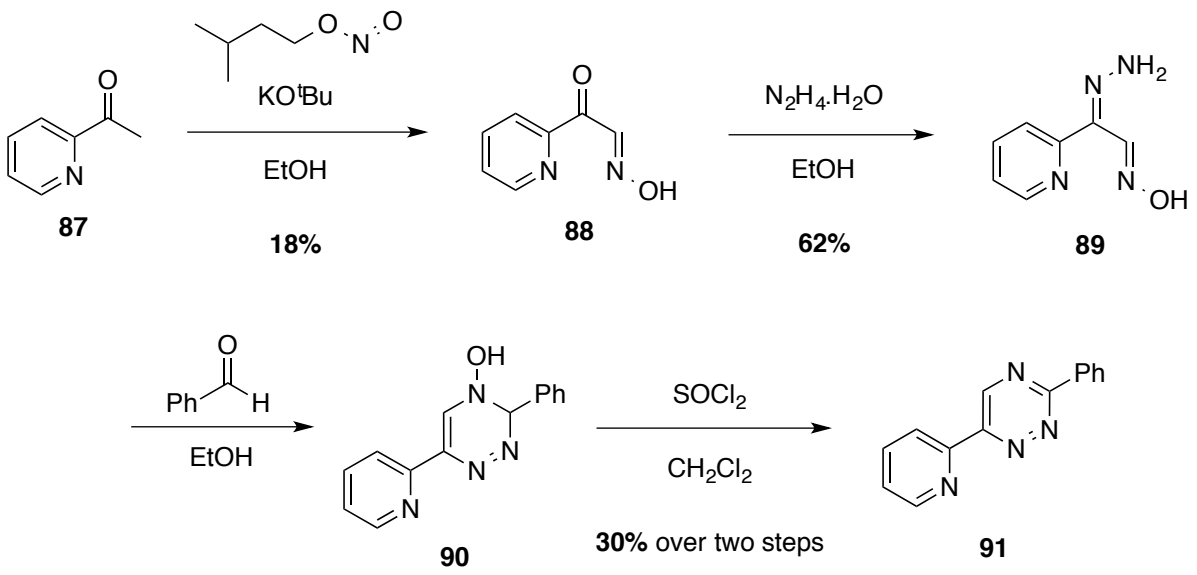


87 **88**

Entry	Source of "N-OH"	Base/Acid	Solvent	T (°C)	Outcome
1	AIN	KO^tBu	Toluene	-10	18%
2	AIN	Me_3SiCl	DCM	-10	More than 80% RSM
3	AIN	NaH	THF	-10	
4	$NaNO_2$	HCl	H_2O/EtOH	RT	
5	Isopropyl nitrite	NaH	THF	-10	
6	Isopropyl nitrite	Et_2NH	MeOH	RT	
7	Isopropyl nitrite	KH	THF	-30	
8	Isopropyl nitrite	LHMDS	THF	-78	
9	Isopropyl nitrite	NaOEt	EtOH	0	17%

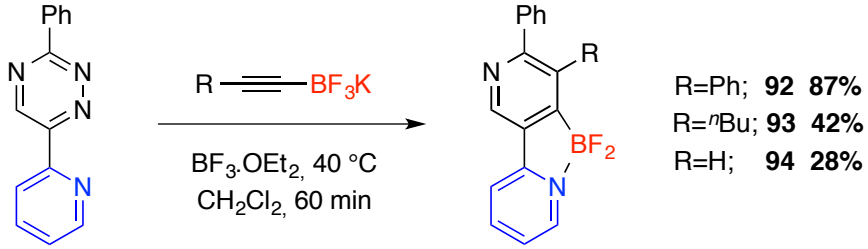
Table II-2: Screening of conditions for the nitrosation of 87

Hydrazine was used in the second step to condense on the carbonyl and form **89** in 62% yield (Scheme II-36). Cyclisation was then achieved with benzaldehyde in ethanol to obtain **90**, which was subsequently treated with thionyl chloride to promote elimination and aromatisation thereby generating **91** in 30% yield over two steps.



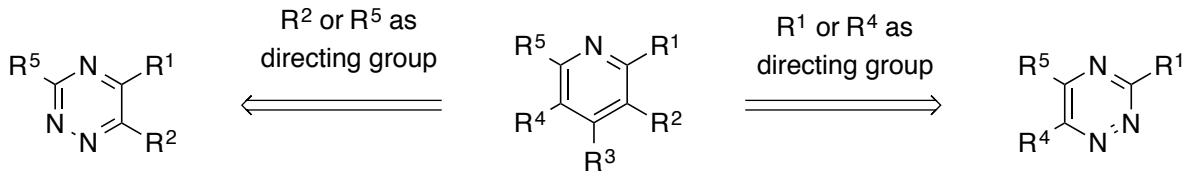
Scheme II-36: Synthesis of triazine equipped with a directing group on C6

With our new substrate in hand, cycloaddition was performed and, despite longer reaction times being required, the pyridine was generated in very good yield when R=Ph, **92** (Scheme II-37). Alternative R groups gave modest results for **93** and **94** as shown below.



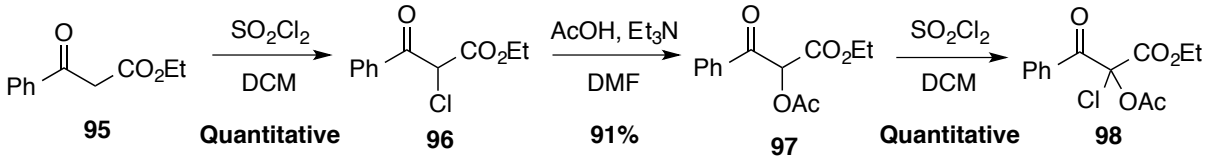
Scheme II-37: Cycloadditions with pyridine as directing group at C6

This result proved to be of great interest, as it significantly improved the scope of substitution patterns available by this method. Specifically, every position but the one opposite to the nitrogen preserved in the product could be considered as potential position for a directing group (Scheme II-38).



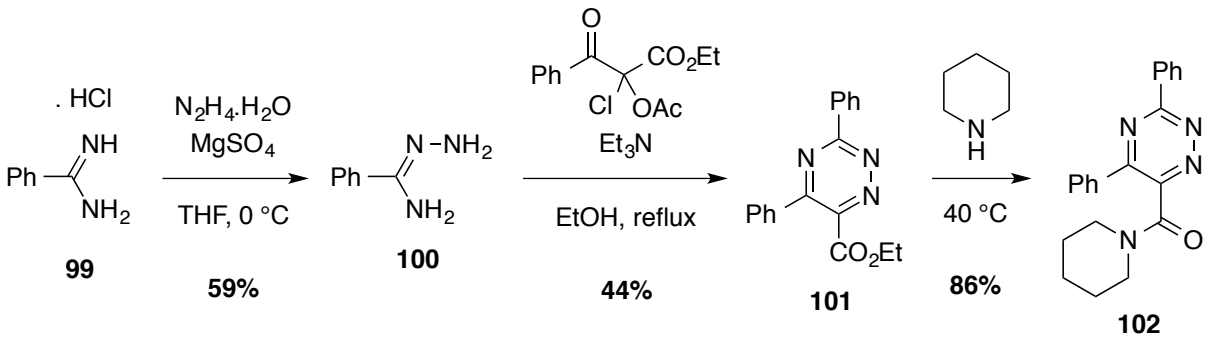
Scheme II-38: New retrosynthesis possibilities for pyridine rings

To further study the scope of cycloadditions of triazines bearing a directing group at C6, a triazine equipped with an amide as directing group was next prepared. As seen previously for the synthesis of triazines substituted by a carboxylate at C6,[56] a 1,2,3-tricarbonyl equivalent **98** must be formed. This was done in very good yield via chlorination of **95** to **96**, substitution with acetic acid to **97** and second chlorination to **98** (Scheme II-39).



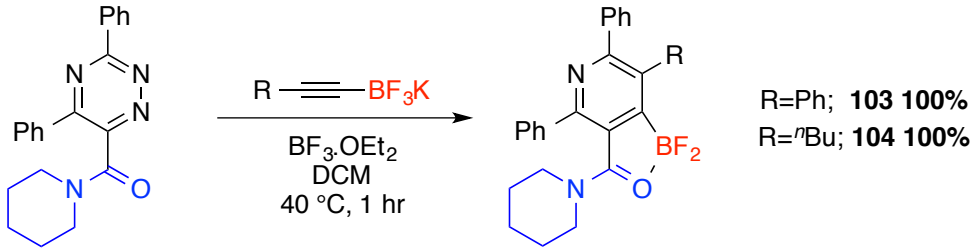
Scheme II-39: Synthesis of dicarbonyl for triazine with a carboxylate at C6

Meanwhile, benzamidrazone **100** was formed from benzamidine hydrochloride **99** in THF, but once again, the instability of the amidrazone proved problematic. To minimise its degradation, magnesium sulfate was used to dehydrate the mixture and afforded 59% of the product (Scheme II-40). Subsequent cyclisation in ethanol afforded **101** substituted at C6 by an ester as the major product in 44% yield,[56] the low yield was probably because of partial instability of the starting amidrazone in those conditions. Amidation of the ester in hot piperidine finished this sequence and provided our new cycloaddition substrate **102** in 86% yield.



Scheme II-40: Synthesis of triazine with an amide as directing group at C6

With our new substrate in hand, cycloaddition was then performed. Quite surprisingly, results were excellent as **103** (R=Ph) and **104** (R=^{n}Bu) were obtained in quantitative yield (Scheme II-41).



Scheme II-41: Cycloaddition with amide directing group on C6

From these preliminary results, a general trend can be noted. Indeed, it appears that cycloaddition efficiency depends more on the nature of the triazine ring, rather than the position of the directing group. As shown in Figure II-1, isomeric triazines offer similar yields of cycloadducts:

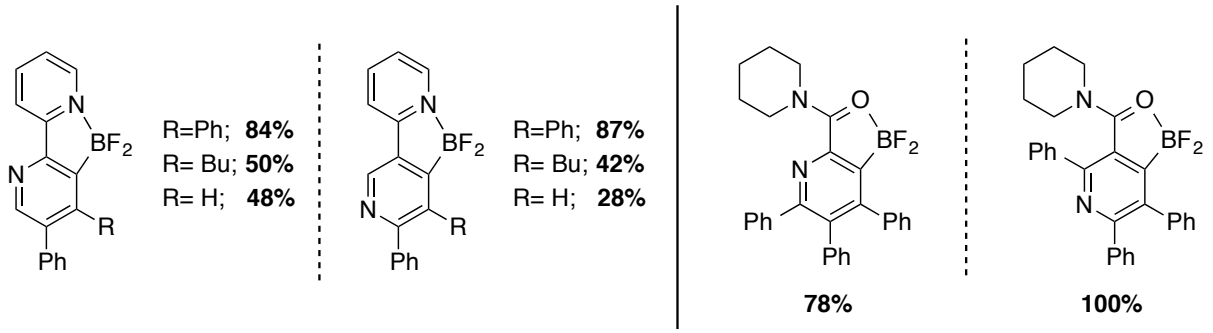
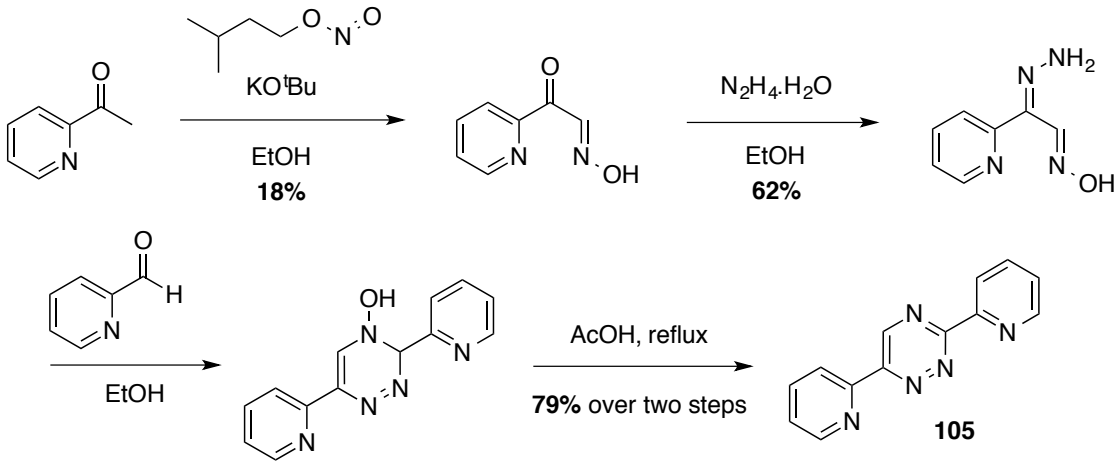


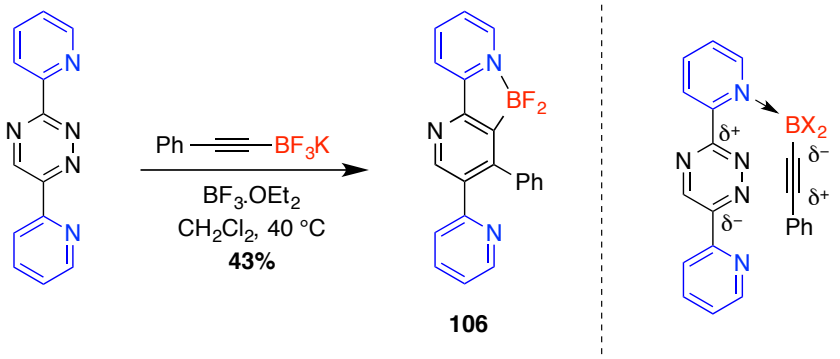
Figure II-1: Direct comparison of a DG on C3 vs C6

The final question we wished to answer related to the cycloaddition of a triazine bearing a directing group at both C3 and C6. Specifically, would one regioisomer be formed selectively? To this end, a route described in the literature[47] was followed to obtain triazine **105**, substituted by a pyridine on C3 and C6 (Scheme II-42). Instead of using benzaldehyde for the cyclisation step, we used 2-pyridinecarboxaldehyde and the aromatisation step was performed in refluxing acetic acid to afford the product in 79% yield over two steps.



Scheme II-42: Synthesis of bis-pyridine triazine

Cycloaddition revealed that the pyridine at C3 was exclusively directing the reaction and led to **106** (Scheme II-43), as less than 5% of the other regioisomer was present in the mixture as judged by LC-MS analysis. The regioselectivity of the product was confirmed by X-ray analysis (Figure II-2). We believe that this selectivity is due to the higher electron deficiency of C3 compared to C6, in line with previous reports of cycloadditions of triazines with enamines.[70] The polarisation of the alkyne thus dictates the regioselectivity of the cycloaddition.



Scheme II-43: Cycloaddition of triazine with two competitive directing groups

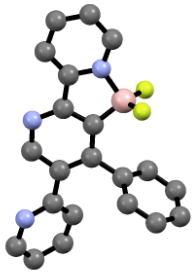


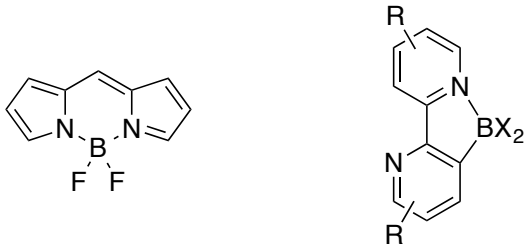
Figure II-2: X-ray crystal structure of 106

To summarise, the strategy to direct cycloaddition reactions using a Lewis pair has been applied with great results to 1,2,4-triazines, affording boron-substituted pyridines with complete regiocontrol and under very mild conditions. Two positions can be occupied by the directing group, C3 or C6.

These results indicate that, as well as being an efficient way to obtain functionalised pyridines, this directed cycloaddition concept shows great versatility and can be adapted to different types of pyridine targets.

Chapter III. BOBIPYs: a new family of fluorophores

Recently, fluorescent dyes have been extensively investigated, and they have found numerous applications in biological imaging[98] and materials sciences,[99] and as chemosensors,[100] laser dyes,[101] fluorescent switches[102] or in photodynamic therapy.[103-104] Organoboron molecules are a notorious class of fluorescent compounds, and boron-dipyrromethenes (BODIPYs, Scheme III-1) are a popular sub-class because of their excellent photophysical properties, with high quantum yields and strong stability to physiological conditions.[105] Besides, minimal structural changes enable systematical fine-tuning of their emission wavelength.[106] Nevertheless, despite the various results reached in this field, there is still a large interest in the discovery of new dye families that offer short synthesis routes, facile structure modifications and good optical properties.[107-109]



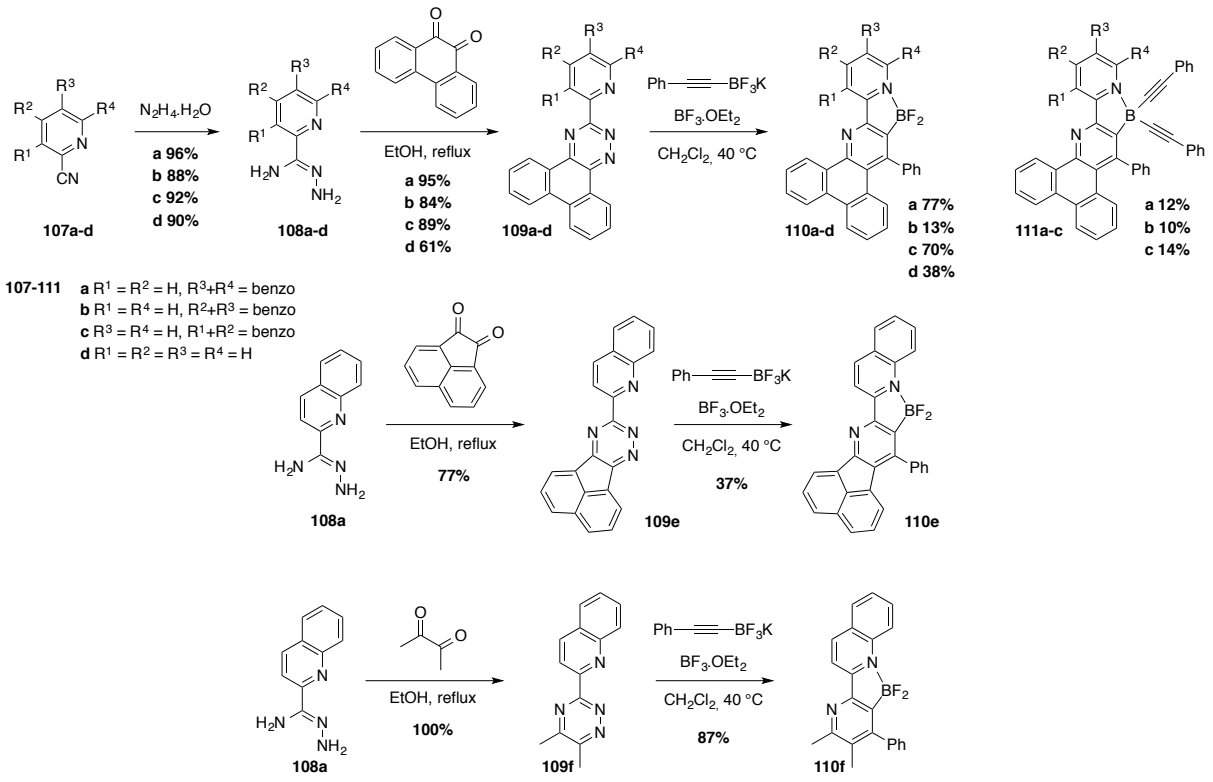
BODIPY BOBIPY

Figure III-1: Structure of BODIPYs and BOBIPYs.

We were intrigued to find that our own organoboron molecules formed by the cycloaddition methodology described in the previous chapter exhibited strong fluorescence. In fact, although many dyes contain the difluoroboryl group,[110] these are generally coordinated to two heteroatoms. Four-coordinate organoboron compounds based on *N,C* chelates are arising as an alternative pattern of fluorescent molecules,[111-115] although only a few reports on analogues possessing the BF_2 moiety have been reported.[116-117] As our cycloaddition chemistry forms N,C chelated difluoroboranes, namely borylated bipyridines (BOBIPYs), with the opportunity to vary substituents along the synthesis, we decided to study this novel pattern of fluorescent molecules, the influence of the substituents and the origin on their photophysical properties

1. Synthesis of BOBIPYs

Aiming for a fluorophore with powerful photophysical properties, we decided to synthesise a target with an extended aromatic system. Accordingly, nitrile **107a** and hydrazine formed amidrazone **108a**, which, upon condensation with 9,10-phenanthrenequinone, afforded triazine **109a** (Scheme III-1). Finally, directed cycloaddition with potassium phenylethynyltrifluoroborate **50** afforded a first BOBIPY **110a** in good yield over the three steps. To study the influence of the extent of the conjugation of the aromatic system, BOBIPYs **110d**, **110e** and **110f** were also prepared in modest to good yields. Besides, different isomeric structures of the Lewis basic donor were investigated and BOBIPYs **110b,c** were synthesized in acceptable overall yield. As discussed in chapter II, the directed cycloadditions are known to produce side-products bearing a dialkynylborane unit. Consequently, three BOBIPYs **111a-c** were isolated that each contained alkynylboranes and the measurement of their photophysical properties enabled the study of the influence of the boron substituent.



Scheme III-1: Synthesis of BOBIPYs 110 and 111.

A simple reaction scheme therefore led to a set of nine pyridyl boranes with diversity at all keypoints of the fluorophore framework. X-ray analysis was collected for three representative examples with variations at those key points (Figure III-2).

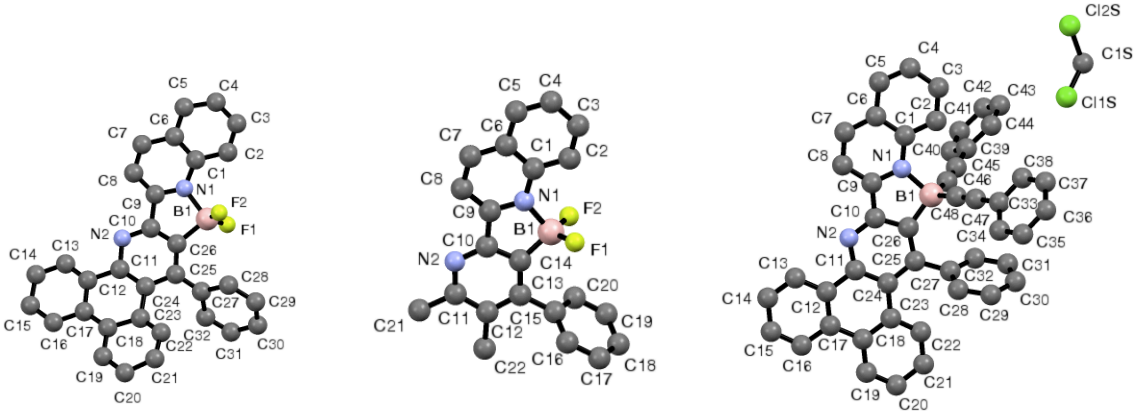


Figure III-2: Xray crystal structure of BOBIPY 110a (left), 110f (middle) and 111a (right).

2. Photophysical Properties of BOBIPYs and DFT calculations

Table III-1 compiles the photophysical properties of the new compounds synthesised.[118] Excitation spectra were measured by monitoring the peak emission of the respective compounds and emission spectra were obtained by excitation at 365 nm for each sample. The emission colour in dichloromethane solution varied from 420 to 473 nm, because of the high diversity of the structures. The absorption spectra differed greatly with each substitution pattern and both Stokes shifts and photoluminescent quantum yields (PLQY) covered a broad range. All together, the new BOBIPYs showed promising properties with PLQY values up to 41% and emission colours ranging from blue to green with ideal Stokes shifts. In addition, they also showed solid-state luminescence, as exemplified for **110a**, **110d** and **110e**. They respectively emitted in the solid state at 490 nm, 450 nm and 504 nm, with PLQY values of 0.24, 0.20 and 0.19. As expected, those values differed from solution measurements, but interestingly, the trends also varied. The overlap between absorption and emission spectra in solution suggests that complex, intermolecular energy transfer processes occur in the solid state, where the chromophores are close to each other.

Compound	λ_{abs} (nm)	ε ($M^{-1}.cm^{-1}$)	λ_{em} (nm)	Stokes shift (nm)	PLQY Φ
110a	388	22921	473	85	0.33
110b	377	20497	452	75	0.08
110c	392	13358	467	75	0.23
110d	373	17901	424	51	0.12
110e	421	40587	465	44	0.41
110f	376	15396	423	47	0.13
111a	400	25245	456	56	0.13
111b	381	29729	420	39	0.11
111c	408	17218	453	45	0.11

Table III-1: Basic spectroscopic data of fluorophores 110a-f and 111a-c in dichloromethane.

To discuss the impact of the molecular structure of the BOBIPYs on the photophysical properties, we split the molecule in three key moieties (Figure III-3), and have designated these the northern ring (I), the borane (II) and the southern ring (III). As stressed before, the synthetic route provides step by step modifications of both the northern and southern rings, while the substitution of the boron group results from the cycloaddition step.

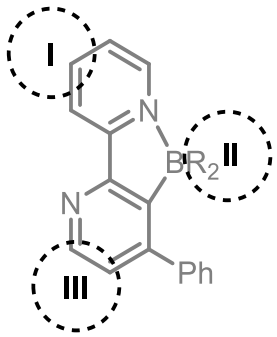


Figure III-3: Three easily modifiable positions in the general skeleton of the BOBIPYs.

Variation of the northern ring (I) and borane (II) on photophysics properties: Comparing compounds **110a-d** and **111a-c** respectively provides a direct conclusion of the

impact of the substitution pattern of the northern ring on photophysical properties. Similarly, comparing each pair **110a/111a** to **110c/111c** informs on the effect of varying the nature of the boron substitution pattern from B-F to B-(phenylacetylide) (Figure III-4). Figures 4a and 4b show the absorption and emission spectra for these seven compounds.

The qualitative shape of the spectra is dictated by the ring systems: **110b, 110d** and **111b** are different compared to the other compounds. Their PLQY is considerably lower, the absorption spectra are more structured and the low-energy bands associated with the HOMO-LUMO transition are blue-shifted compared to **110a/110c** and **111a/111c**, while the π- π* transitions around 260 nm are not. The emission spectra are also blue shifted, suggesting that the bandgap of **110b, 110d** and **111b** is larger.

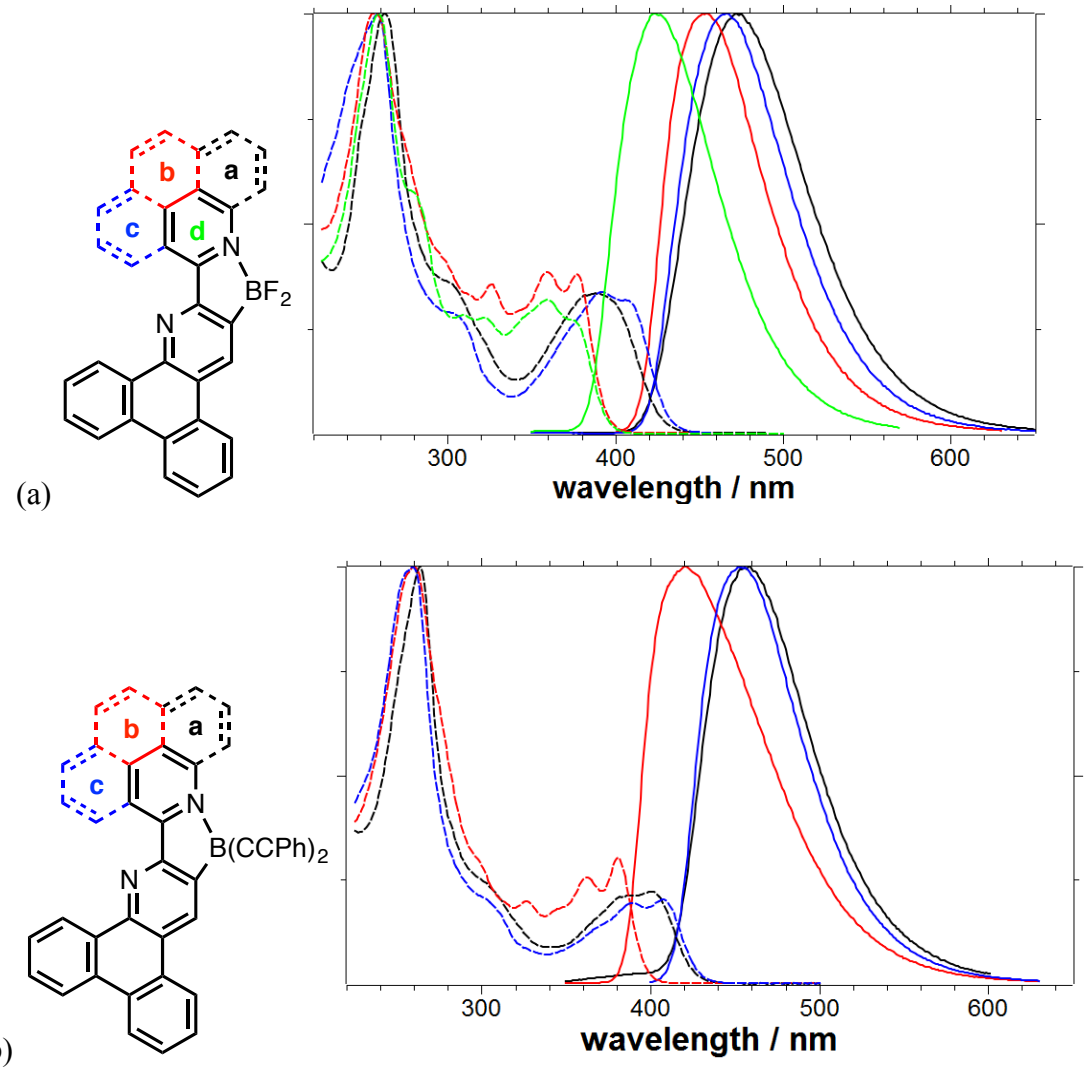


Figure III-4: Normalized absorption (left) and emission spectra (right) of compounds 110a-d (a) and 111a-c (b) in CH_2Cl_2. The colour of the ring systems indicates the colour of the respective spectra in (a) and (b).

The substituents attached on the boron do not seem to affect the absorption spectra too much – the spectra are almost superimposable, which shows that photoexcitation initially leads to similar excited states. This suggests that the BR_2 units don't host the HOMO or the LUMO. On the other hand, the emission spectra are significantly different. **110a/111a** and **110c/111c** have similar energies, while emissive energies for **110b/111b** are slightly higher, showing that the main trends seem to be dependent on the relative orientation of the quinoline/isoquinoline rings. For the BF_2-compounds, the emission is red shifted, the PLQY is much higher and the Stokes shifts are larger. This suggests that the B-substituents affect the excited molecules, either by opening up additional quenching pathways (e.g. by vibronic quenching) or by steric or electronic effects.

Multiple transitions of similar energy and relative extinction can be observed in every absorption spectra. The emission spectra show one broad emission in each case, while the Stokes shifts are fairly large. This is characteristic of a certain charge-transfer of the emissive transition. Analysis of the photophysical properties of **110a-d** and **111a-c** suggests that either the HOMO or the LUMO is likely to be localized on the quinoline/isoquinoline moiety, but the BR_2 units seem to have an indirect effect on the photophysical properties, caused by steric or electronic effects. A strong charge-transfer character is likely.

Variation of the southern ring (III) on photophysics properties: To study the effect of the southern ring on photophysical properties, we measured absorption and emission spectra of compounds **110a**, **110e** and **110f** (Figure III-5), PLQYs are collected in Table III-1.

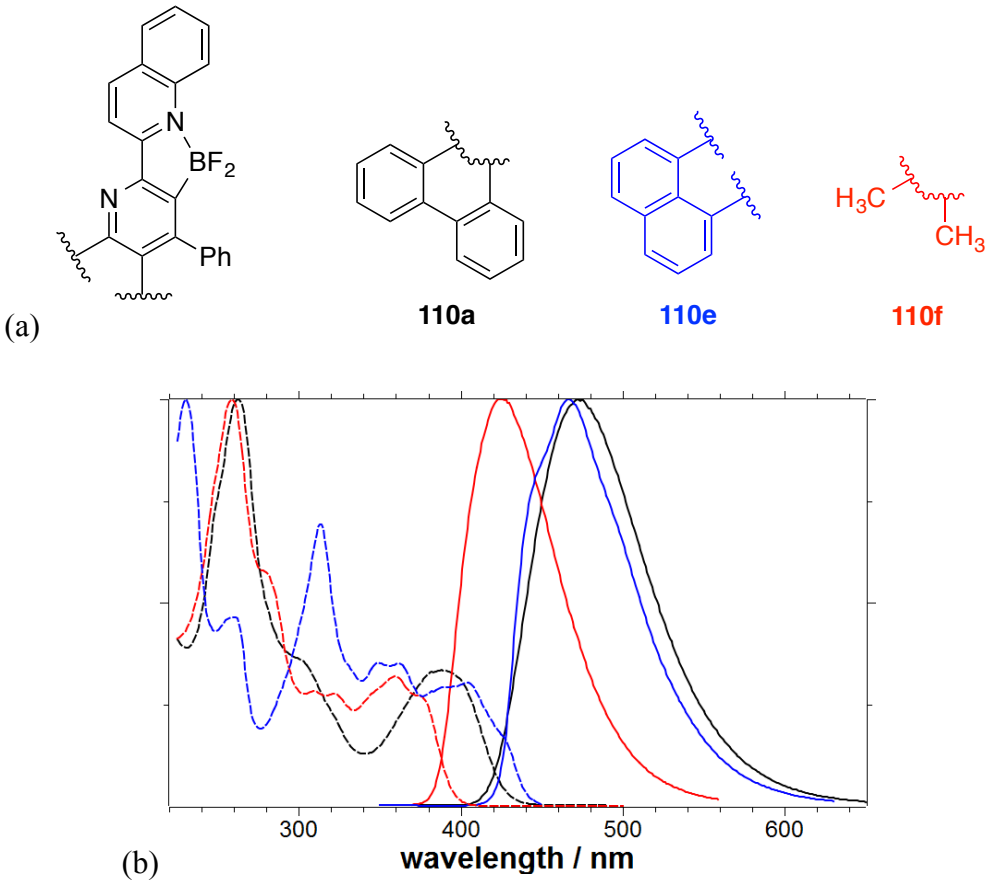
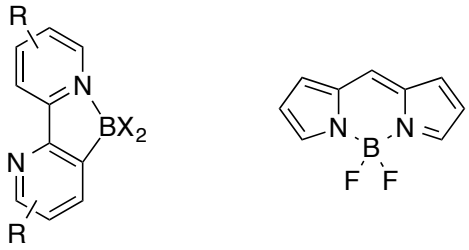


Figure III-5: Normalized absorption (left) and emission spectra (right) of compounds 110a, 110e and 110f in CH_2Cl_2. The colour of the depicted subunits in (a) indicates the colour of the respective spectra in (b).

Both emission and absorption spectra in Figure III-5 show that modification of (III) has a strong impact on the frontier orbitals and the electronic states, as they are all essentially unique. For **110f**, a rather localized π-system is present, which yields relatively high emission energy in both absorption and emission spectra, although the PLQY is rather low (13%, Table III-1), showing the importance of the aromatic system on this property. The strong qualitative difference in the absorption spectra suggests that the electronic state of **110e** and **110f** differ greatly. For **110e**, both emission and absorption spectra are unique in this study: the emission shows a slightly structured profile, and the absorption spectra shows an additional high energy band around 320 nm. Additionally, the relative extinction coefficient of the low energy bands around 420 nm is double that observed for all other compounds in the study (see Table III-1). These results point towards a more localized transition for this compound, especially

compared to reference compound **110a**. In summary, variation of position III allows for an even stronger manipulation of the optoelectronic properties than positions I and II.

DFT calculations. Overview of structural and electronic properties: Surprised by the significant difference between the photophysical properties of those structurally similar compounds, DFT calculations were carried out in an effort to study the origin of those differencies and the origin of the fluorescence of those molecules.[118] BOBIPYs **110a-f** and **111a-c**, together with a BF_2-containing BODIPY analog **112** (Figure III-6), were optimized using the B3LYP functional[119] combined with the 6-31G(d) basis set[120] as implemented in Gaussian 09 program package.[121] The level of theory B3LYP/6-31G(d) was selected based on the fact that it was previously successfully applied to calculate similar systems.[122]



BOBIPY **110a-f**, **111a-c** BODIPY **112**

Figure III-6: General structure of BOBIPYs (110a-f, 111a-c) and BODIPY 112 used for comparison of optical properties.

Molecular orbital plots and orbital energies for fluorophores **110a-f**, **111a-c** and BODIPY **112** were calculated and selected orbitals are presented in Figure III-7. Similar to BODIPY **112**, the HOMO to LUMO excitation is dominant in most of the BOBIPYs. Two other excitations (HOMO-2 to LUMO and HOMO to LUMO+1) are important in some cases, and this observation will be discussed later. Generally, the LUMO is mainly localized on the heterocycle used as directing group, whereas the HOMO spreads over almost the whole molecule, except for the boron moiety (Figure III-7). The group originating from the alkyne does not contribute to the LUMO and slightly contributes to the HOMO of these molecules, probably because it offers less electronic coupling, as its conformation would be out of the plane.

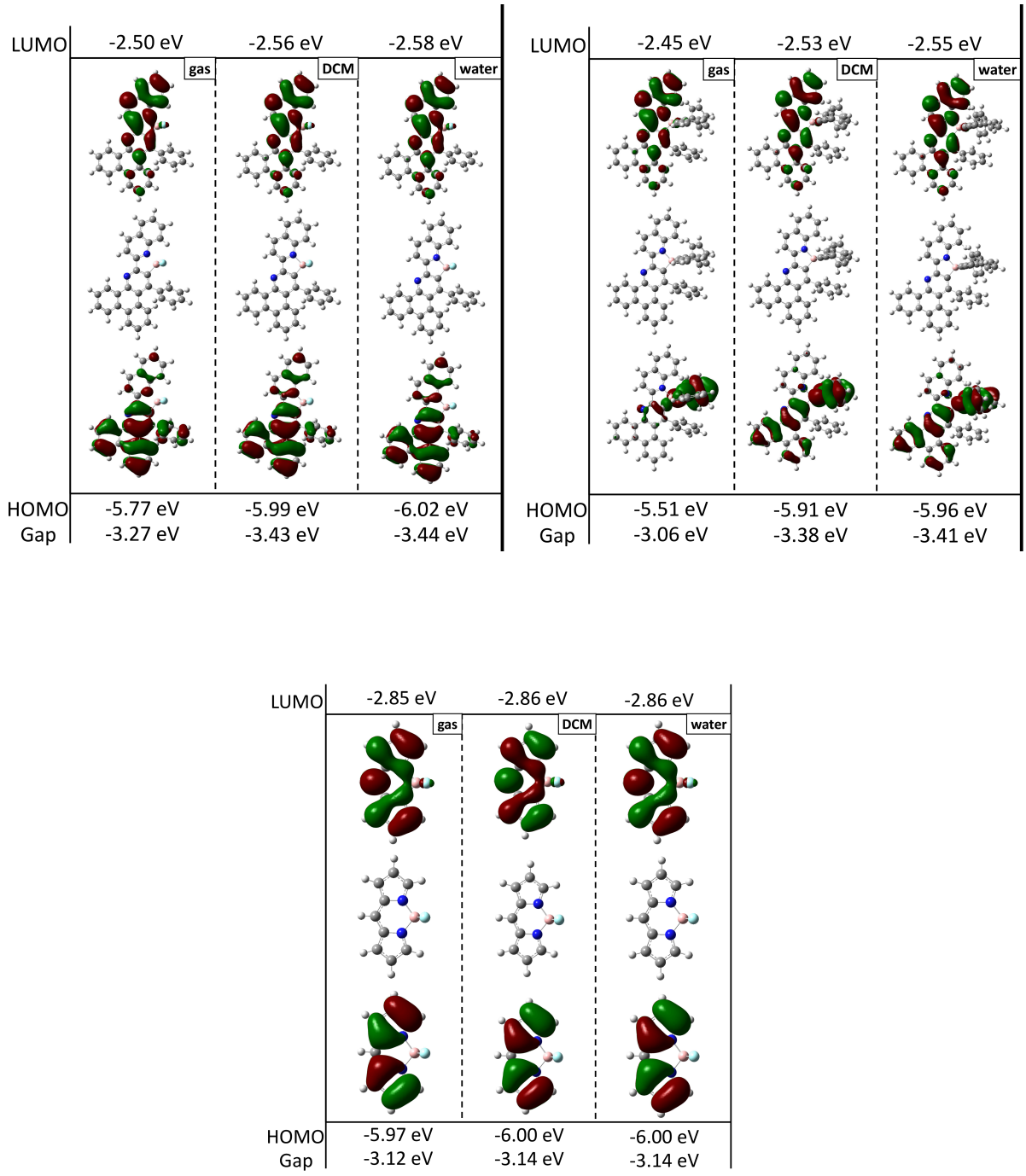


Figure III-7: Molecular orbital plots and orbital energies of 110a, 111a and BODIPY 112 along their optimised structures (middle row) in gas phase and in solvents.

DFT analysis of variation of the northern ring (I) and borane (II): The main differences arising from the different structures of the northern part (I) are explained by the electronic transition with the strongest oscillation strength for each molecule. **110a** and **110c** show similar behaviours and their maximum absorption wavelengths are assigned to the $S_0 \rightarrow S_1$ electronic transition. On the other hand, the excitation wavelength of **110b** is assigned to the $S_0 \rightarrow S_2$ electronic transition from HOMO to LUMO+1, which explains why it has a lower value, and the phenanthrene moiety does not contribute at all to the LUMO, which could be one of the reasons why this compound has a lower quantum yield. Finally, **110d** has a bigger HOMO-LUMO gap, explaining the lower value of its absorption wavelength. For **111a-c**, the electronic transition with the strongest oscillator strength is $S_0 \rightarrow S_3$ from HOMO-2 to LUMO and HOMO to LUMO+1 for **111a/111c** and **111b**, respectively, explaining their even lower absorption properties.

Overall therefore, these observations are in agreement with the photophysical measurements, as they show that the boron substituents affect the photophysical properties of the molecules (different electronic transitions), but the position of the quinoline/isoquinoline rings plays a more important role.

DFT analysis of variation of the southern ring (III): The HOMO of **110f** is less delocalised because of its structure, which lowers its energy and thus results in the largest HOMO-LUMO gap within the whole set of BOBIPYs. The highest quantum yield (0.41) was found in the case of **110e**. The whole structure (except the phenyl group) is here arranged in one plane and helps the delocalization, while in **110a** there is a slight twist between the isoquinoline and the phenanthrene moiety (Figure III-8), which results in a less electronically coupled system and a smaller quantum yield than in **110e**.

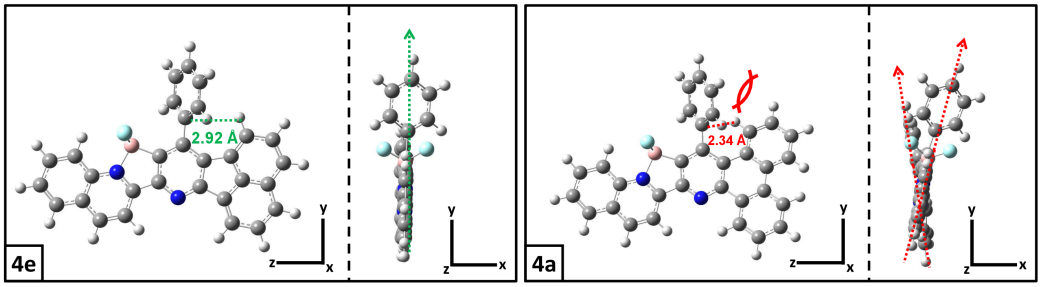


Figure III-8: Structural differences between the optimized 110e and 110a in dichloromethane.

3. Application to biological imaging

Based on best photophysical properties and chemical accessibility, we chose to use BOBIPY **110a** to study the suitability of this new fluorophore family for cell uptake and imaging studies. Indeed, its PLQY in solution is in the order of 35% and the emission colour is in the green region of the optical spectrum. Its broad absorption band, which is well above 400 nm, should allow the use of blue light rather than UV light sources for excitation, which is mandatory to perform fluorescence microscopy experiments without risking photo-damage. Besides, its rather high Stokes shift permits a good distinction between the emitted and excitation lights, as well as distinction of the fluorophore from auto-fluorescence of biological tissue.

To maximise its attractiveness for biological applications, shifting of absorption and emission wavelengths towards the yellow or red region would be highly interesting. Preliminary strategies can be deduced from the conclusion of the previous DFT studies: since the HOMO is mainly localised on the southern heterocycle unit (III), addition of electron-donating groups would increase the energy of the HOMO, thus decreasing the bandgap and increasing the corresponding wavelengths. Similarly, since the LUMO is mainly localised on the northern ring (I), addition of electron-withdrawing groups would decrease the energy of the LUMO and have a similar effect on the photophysical properties (Figure III-9). Interestingly, the phenyl ring arising from the alkyne is not a significant part of either the HOMO or the LUMO, and can be used to add further functionality, such as solubilising groups or transporters, which can be used to facilitate uptake in living cells.

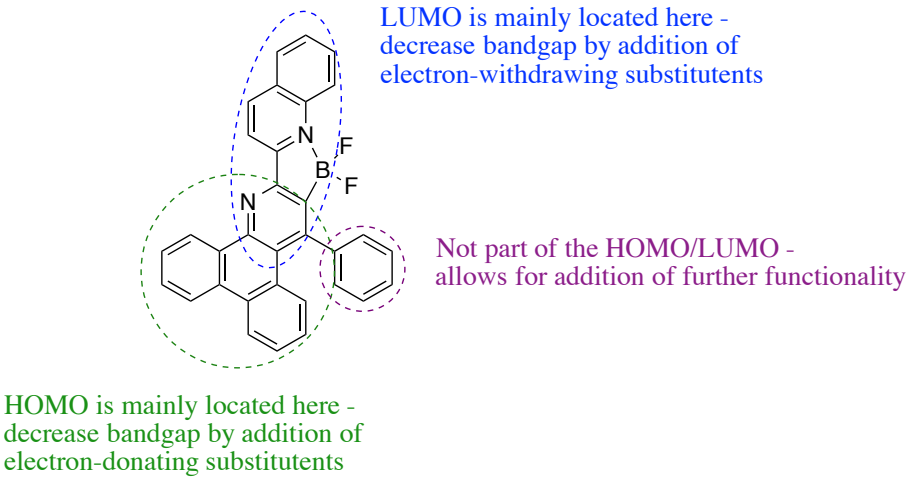
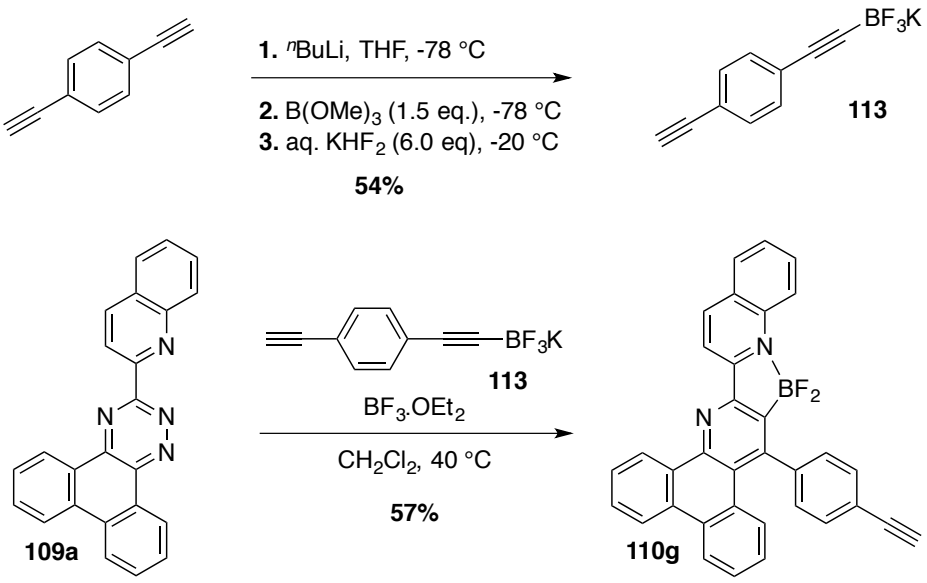


Figure III-9: Modification of the fluorophore 110a allows for further colour tuning or the addition of more functionalities.

To exemplify the power of our dyes for biological imaging, we adapted the synthesis of BOBIPY **110a** to bear a free alkyne moiety on the part of the molecule not involved in the photophysical properties. This free alkyne offers the opportunity to attach any fragment of interest to the fluorophore *via* a 'click' reaction. Alkyne **113** was thus prepared and its cycloaddition with triazine **109a** afforded fluorophore **110g**, equipped with a free alkyne (Scheme III-2).



Scheme III-2: Synthesis of 110g.

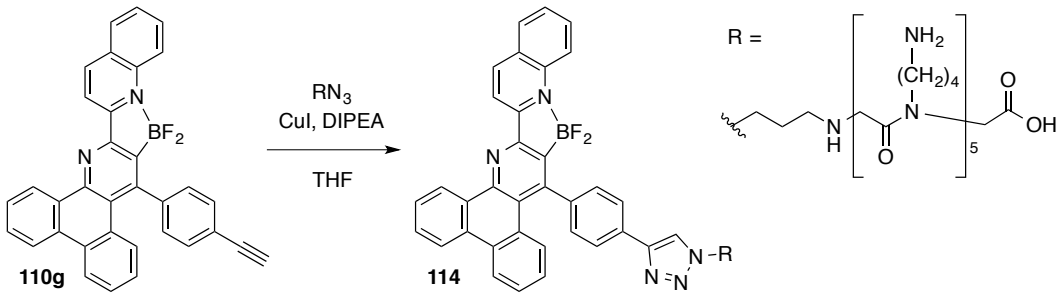
As expected, the properties of **110a** and **110g** are very similar and this confirmed the possibility to incorporate functionality without influencing the compound photophysics. Their

emission wavelengths are identical (473 nm) and the high PLQY is maintained even after addition of the conjugated alkyne group (Table III-2). This characteristic proved highly interesting, as the addition of conjugated groups can lead to significant differences for different emissive compounds.[123]

Compound	λ_{abs} (nm)	ε ($M^{-1}.cm^{-1}$)	λ_{em} (nm)	Stokes shift (nm)	PLQY **Φ**
110a	388	22921	473	85	0.33
110g	389	22252	473	84	0.31

Table III-2: Photophysical properties of 110g compared to 110a in dichloromethane.

The utility of **110g** was demonstrated via coupling to a peptoid bearing an azide side chain on solid phase in a sub-monomer approach using copper iodide and *N*,*N*-diisopropylethylamine (DIPEA).[118] This peptoid is a hexameric compound with five aminobutyl- and one azidopropyl-side chain and was designed to enhance the water-solubility of the final compound (Scheme III-3). Peptoid **114** was characterized in aqueous solution, preventing any direct comparison with the parent fluorophore (spectra obtained in dichloromethane, see Table III-1), but measurements revealed that **114** emits around 510 nm in water, in the green region, and maintains high PLQY values. The red shift compared to the DCM-measurements of **110a** and **110g** was attributed to a more polar environment, which affects the emission by stabilization of the charge transfer transitions.



Scheme III-3: Synthesis of peptoid 114.

To examine the cell compatibly, human cervix carcinoma (HeLa) cells were treated with peptoid **114** for 24 hours and subsequently imaged with a confocal fluorescence microscope.[118] The results confirmed the accumulation of the compound in endosomal vesicles, indicating an endocytotic uptake (Figure III-10). With this method, the intracellular location of **114** could be detected and this demonstrates the potential of BOBIPYs for biological imaging.

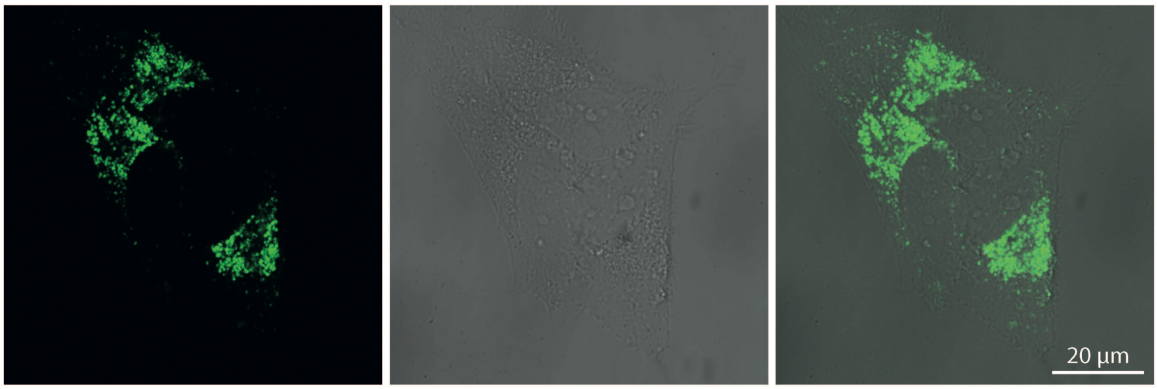
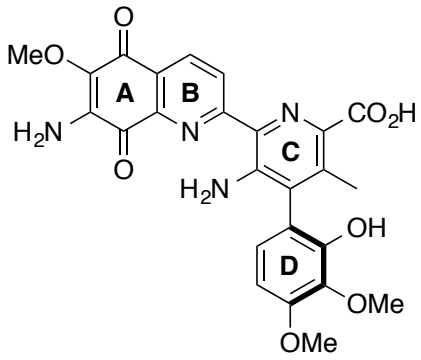


Figure III-10: Fluorescent confocal microscopy of 114 in HeLa cells. Left: Emission bandwidth set to 487-543 nm; Middle: Brightfield; Right: Merge.

The directed cycloaddition methodology discussed in Chapter II thus proves to be an efficient method to rapidly obtain powerful fluorophores. But it also proves to be of great interest as key step in the total synthesis of compounds possessing a fully substituted pyridine as core ring, as we will see in the next chapter.

Chapter IV. Synthesis of streptonigrin

Streptonigrin was first isolated in 1959 by Rao and Cullen from *Streptomyces flocculus*.[124] Since then, this antitumour antibiotic has drawn considerable attention from both synthetic organic chemists, attracted by its challenging structure, and biochemists, interested in its broad-spectrum anticancer activity. Its molecular framework was established by Rao, Biemann and Cullen through a series of spectroscopic and chemical degradation studies,[125] and later confirmed via X-ray crystallography by Chiu and Lipscomb.[126] The cytotoxic mode of action, discovered from truncated analogues,[127] is believed to be free radical-mediated DNA strand cleavage resulting from reductive activation by a metal ion and oxygen.[128] The essential moieties of the structure responsible for this activity include the two pyridyl nitrogens in rings B and C, the C-ring carboxylic acid and the 7-aminoquinoline-5,8-dione AB-ring system. Finally, circular dichroism studies established the absolute stereochemistry about the configurationally stable C-D ring axis to be (*M*), which is responsible for the observed optical activity of the natural product (Scheme IV-1).[129]



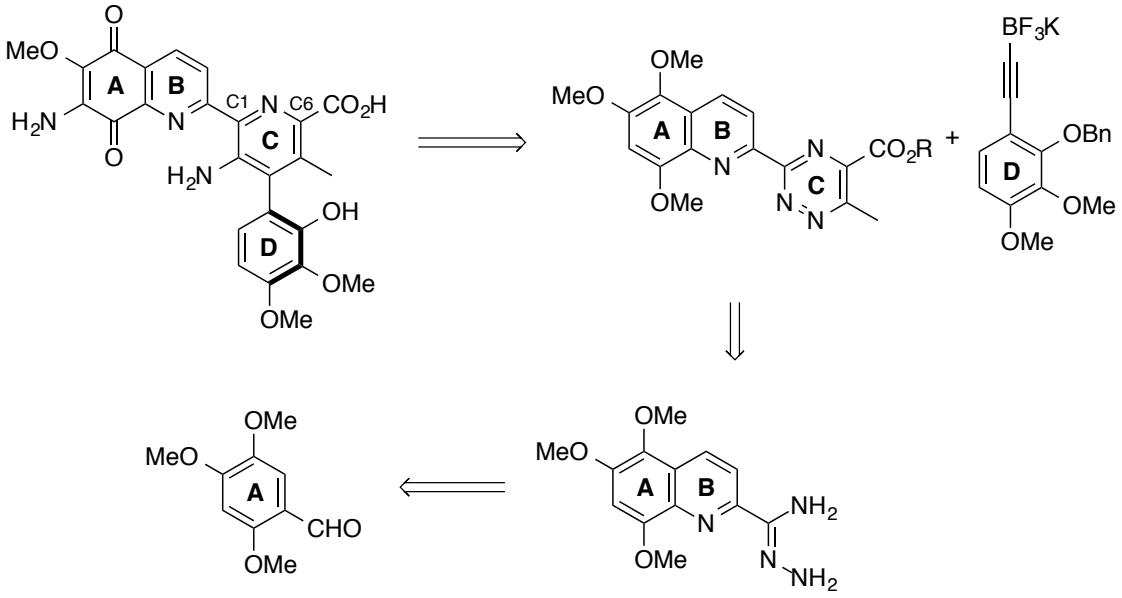
Scheme IV-1: Structure of streptonigrin

In the 1970s, streptonigrin proved extremely efficient in the treatment of cancer and reached phase II clinical trials. However, side effects caused by high levels of toxicity led to cessation of those trials.[130] Investigating the synthesis of analogues thus became of high interest to attempt to reduce those side effects, but studies reporting the direct modification of the metabolite have been scarce as isolation from the fermentation of *Streptomyces* species affords only 13 mg per 1 L of culture filtrates.[131] A robust route to the original compound was thus a first requirement to obtain analogues. To date, only two groups achieved its total

synthesis, and two groups achieved two formal syntheses where the routes stopped after reaching known intermediates. Weinreb *et al.* first used a 34-step route in 1980 but obtained considerably less than 1% overall yield. In this strategy, the construction of the key pyridine C-ring was achieved via an imino Diels-Alder reaction.[132-133] The following year, Kende developed a shorter route consisting of 27 steps by using a regioselective condensation of a β-ketoenamine with methyl acetoacetate, stopping 5 steps short of the target.[134] Later, Boger and coworkers' strategy through an inverse-electron-demand Diels-Alder reaction of a heterocyclic azadiene diminished the number of steps to only 17, the last seven were not realised because the advanced intermediate intercepted that reported in Weinreb's route. However this approach was still inefficient, proceeding in less than 1% overall yield.[135] In 2004, an extensive review on the progresses made towards the chemistry of streptonigrin was published by Bringmann, Reichert and Kane.[136] More recently, Donohoe *et al.* applied their strategy of synthesis of heteroaromatics via ring closing metathesis to its synthesis, along with modern cross-coupling techniques, in two different routes affording streptonigrin in 14 linear steps and 11% overall yield.[137-138]

We envisaged that a triazine cycloaddition route to streptonigrin, similar to Boger's strategy, represented an ideal opportunity to highlight the advantages brought by our directed cycloaddition method, as it would solve the regioselectivity issues they experienced and thus should greatly improve the overall yield. To this end, a retrosynthetic strategy was designed, forming the pyridine C-ring from a triazine by cycloaddition (Scheme IV-2). Several choices concerning the directing group were possible: the carboxylic acid on C6 could derive from an amide that would, as demonstrated in the previous chapters, direct the cycloaddition; or the quinoline system on C1 could also be used as pyridine rings are very effective directing groups. In the event, we chose the latter option as it offered a potentially simple synthesis of the required 1,2,4-triazine.

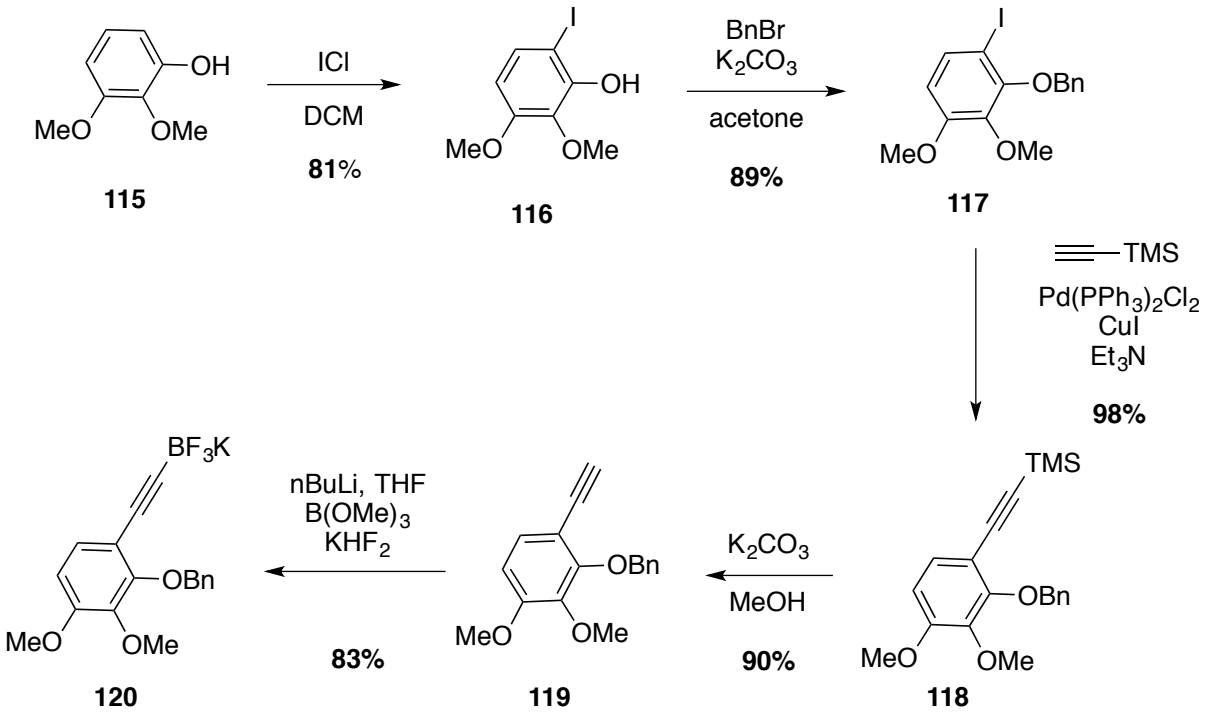
The D-ring would thus be introduced as an alkyne and incorporated during the cycloaddition. The C-ring would be formed by cyclisation of an amidrazone bearing the quinoline fragment.



Scheme IV-2: Retrosynthesis strategy to streptonigrin

1. Synthesis of the alkyne bearing D-ring

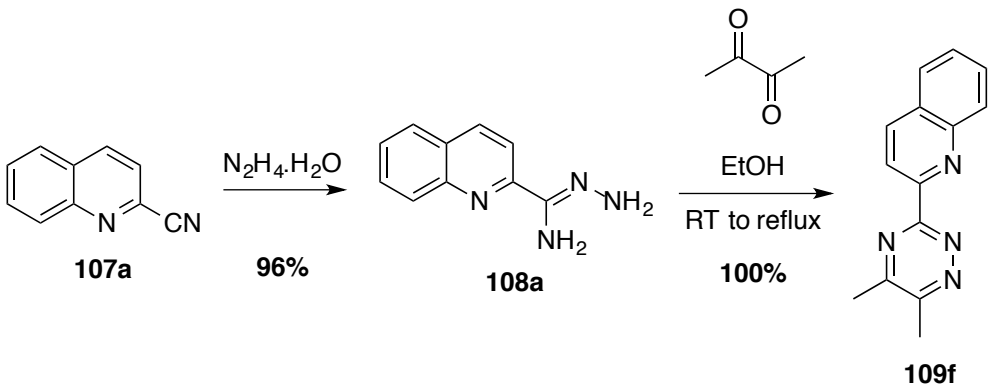
We began our synthesis by targeting the potassium alkynyltrifluoroborate required to introduce ring D. Following the route described in Chapter II, the corresponding terminal alkyne was synthesised and then transformed to the salt (Scheme IV-3). Starting from 2,3-dimethoxyphenol **115**, iodination with iodine monochloride was selectively achieved in 81% yield, followed by protection of the phenol with benzyl bromide and potassium carbonate to give **117** in 89% yield. Sonogashira coupling with ethynyltrimethylsilane then afforded **118** in 98% yield, and subsequent deprotection of the TMS group was achieved in 90% yield. From there, the usual strategy of lithiation, borylation and final treatment with KHF_2 provided the desired potassium alkynyltrifluoroborate **120** in 83% yield.



Scheme IV-3: Route to potassium alkynyltrifluoroborate 120

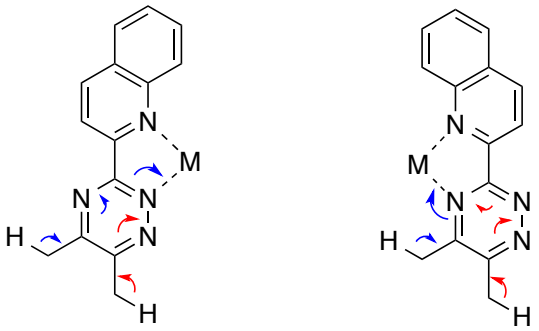
2. Preliminary studies towards the cycloaddition product

To first assess if the key cycloaddition step of our strategy would be a success, we decided to test the chemistry using a simple non-substituted quinoline ring. To this end, amidrazone **108a** was obtained in 96% yield upon addition of hydrazine to commercially available cyanoquinoline **107a**, as depicted in the previous Chapter.



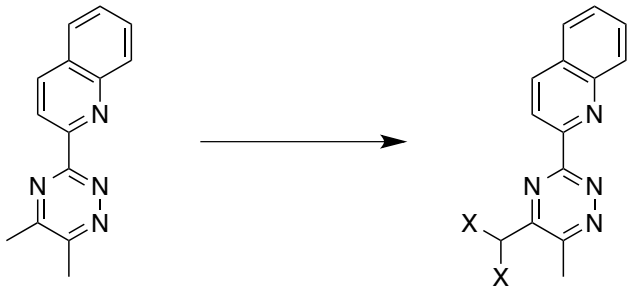
Scheme IV-4: First strategy towards a suitable triazine ring

Our original strategy consisted of the synthesis of **109f**, as cyclisation with symmetric diketones can be accomplished without regioselectivity issue, and this was indeed achieved in quantitative yield. The next step required the selective functionalisation of the methyl at C5. Initial studies investigating radical bromination with NBS and 2,2'-azobis(2-methylpropionitrile) (AIBN) under light irradiation only returned starting material (entry 1, Table IV-1). An alternative strategy relied on the use of a metal to complex the quinoline and the triazine ring, which was expected to selectively favour the deprotonation of the methyl at C5 (Scheme IV-5).



Scheme IV-5: Selective metal promoted deprotonation concept

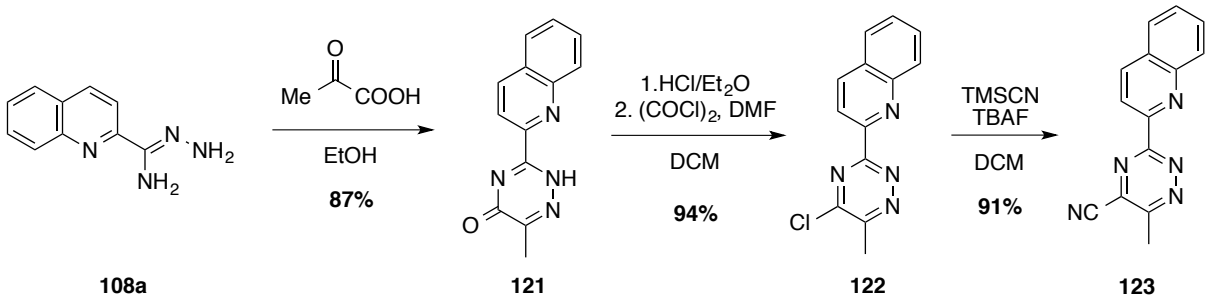
The use of zinc salts was first investigated, but deprotonation with ^{n}BuLi in the presence of $ZnCl_2$ followed by quenching with D_2O only returned starting material (entry 2). Our attention then turned to lithium cation, as it would be introduced with the base. Initial studies aimed to assess the reaction time needed to achieve full deprotonation by adding 2.1 equivalents of ^{n}BuLi and monitoring the level of deuterium incorporation by LCMS analysis after addition of D_2O. After 15 minutes, only starting material was returned (entry 3), but after 30 minutes, a 1:1 mixture of starting material and product bearing two atoms of deuterium was observed (entry 4). After one hour of reaction, full conversion into dideuterated product was achieved (entry 5). With the conditions of the first part of the reaction in hand, we then studied the addition of alternative electrophiles, as deuterium quenching studies did not give any indication regarding the regioselectivity of the deprotonation. The use of iodomethane satisfyingly led to a triazine bearing an isopropyl group, but in a poor 9% yield (entry 6). Unfortunately, the use of alternative electrophiles did not improve the reaction (iodine, bromine or diphenyl disulfide), with degradation and loss of material observed during purification.



Entry	"M" source	Reagent	X	Time	Outcome
1		NBS/AIBN	Br	Up to 5 h	RSM
2	$ZnCl_2$	D_2O	D	1 h	RSM
3	^{n}BuLi	D_2O	D	15 min	RSM
4	^{n}BuLi	D_2O	D	30 min	1:1 mixture
5	^{n}BuLi	D_2O	D	1 h	Full conversion
6	^{n}BuLi	MeI	Me	1 h + 1 h	9%

Table IV-1: Selective functionalisation of the C5 methyl

An alternative strategy was thus designed to obtain different substituents on C5 and C6 of the triazine. Following Neunhoeffer's work,[139] this could be achieved in 4 steps from the cyanoquinoline to install a cyanide moiety at C5 (Scheme IV-6). Cyclisation with pyruvic acid first gave triazinone **121** in 87% yield and subsequent chlorination, after much optimisation (Table IV-2), was successfully achieved. These studies highlighted that protonation of the quinoline ring was necessary to efficiently perform the chlorination, affording **122** in 94% yield upon treatment with oxalyl chloride and catalytic DMF. The following cyanation also required optimisation, but finally afforded triazine **123** in 91% yield when a combination of trimethylsilyl cyanide and tetrabutylammonium fluoride were employed (Table IV-3).



108a **121** **122** **123**

Scheme IV-6: Route to simplified ABC-ring system

Entry	Reagent	Solvent	Temperature (°C)	Time	Outcome
1	$POCl_3$ + DEA	Toluene	RT	2 h	19% + SM
2	$SOCl_2$	DCM	80	2 h	RSM
3	$(COCl)_2$	DCM	RT	o/n	degrad
4	HCl then $(COCl)_2$, DMF	DCM (0.1 M)	RT	20 min	54%
5	HCl then $(COCl)_2$, DMF	DCM (0.02 M)	RT	20 min	**94%**

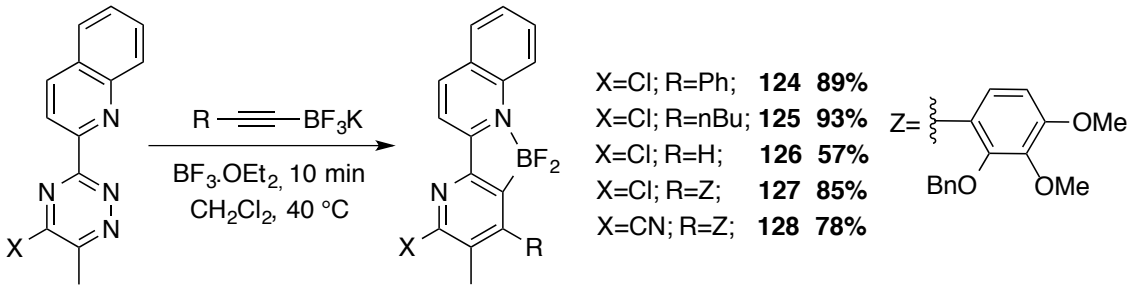
Table IV-2: Chlorination optimisation

Entry	Reagent	Eq	Solvent	Time	Outcome
1	KCN		MeOH	24 h	MeO substitution
2	KCN	1.1	DMF	1 h	Mixture + degrad
3	NaCN + TBABr	2.0	DCM	o/n	1:2 (Pdt:SM)
4	TMSCN + TBAF	1.5	DCM	1 hr	1:0.2 (57% isolated)
5	TMSCN + TBAF	2.5	DCM	5 min	**91%**

Table IV-3: Cyanation optimisation

At this stage of our study, the intermediates formed were suitable to investigate the cycloaddition step. Pleasingly, triazines **122** and **123** both demonstrated excellent reactivity with a range of trifluoroborate salts, delivering the corresponding pyridines in high yields (Scheme IV-7). Cycloaddition of triazine **122** with alkyne **120** was of special interest,

enabling the formation of the core structure of streptonigrin in 85% yield after only 4 steps. Furthermore, the presence of the chloride substituent at C5 of **127** offered many possibilities regarding alternative functionalisation and the synthesis of analogues. Nevertheless, as we ultimately required an acid at the 2-position of the newly formed ring, we pleasingly discovered that the cycloaddition of triazine **123** bearing the cyanide function with trifluoroborate **120** formed the corresponding pyridine in 78% yield, and this structure was confirmed by X-ray crystallography (Figure IV-1).



Scheme IV-7: Key directed cycloadditions towards streptonigrin

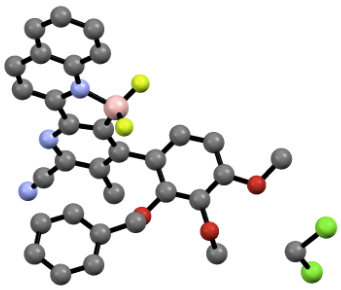


Figure IV-1: X-ray analysis of pyridine 128

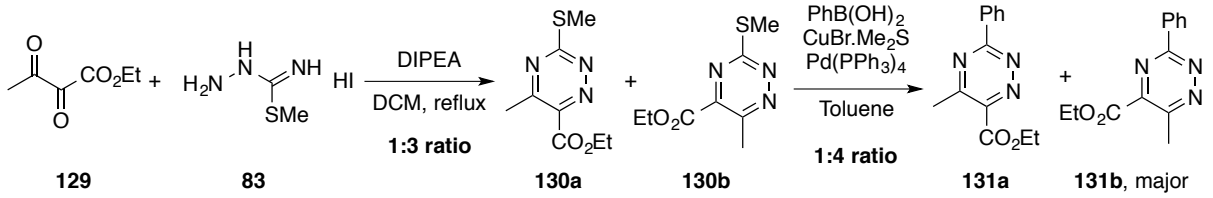
At this stage of our studies, the transformation of the carbon-boron bond to a carbon-nitrogen bond was investigated, as the hydrolysis of the cyanide moiety was planned at a later stage. Unfortunately, despite multiple attempts with different conditions, incorporation of azides, alcohols, halides or protected amines only returned starting material (Table IV-4). Only Suzuki cross-coupling formed traces of product, but mainly returned protodeborylated material. The same observation was made when variation of the boronate moiety was attempted.

Entry	X	Reagent	Solvent	Temperature	Outcome
1	N_3	NaN_3, $Cu(OAc)_2$	MeOH/THF	55 °C	RSM
2	OH	H_2O_2, Na_2CO_3	EtOH	RT	RSM
3	OH	Oxone	EtOAc	RT	RSM
4	Br	TBATB	THF/H_2O	RT	RSM
5	Br	NBS	DCM	RT	RSM
6	Cl	$CuCl_2$	MeCN	50 °C	RSM
7	NHTMS	$TMSN_3$	DCM	RT	RSM
8	NHBn	BnN_3, $SiCl_4$	DCM	RT	RSM
9	pTol	I-pTol, $Pd(OAc)_2$, Ruphos, Na_2CO_3	DME/H_2O	Reflux	14% + protodeboronation
10	B(tartrate)	(L)-tartrate, NaOH	THF	Reflux	protodeboronation
11	BPin	Pinacol, base	THF	Reflux	RSM
12	BF_3K	KHF_2	MeOH	70 °C	RSM
13	$B(OH)_2$	NaOH	THF	Reflux	protodeboronation

Table IV-4: Difluoroborane modification

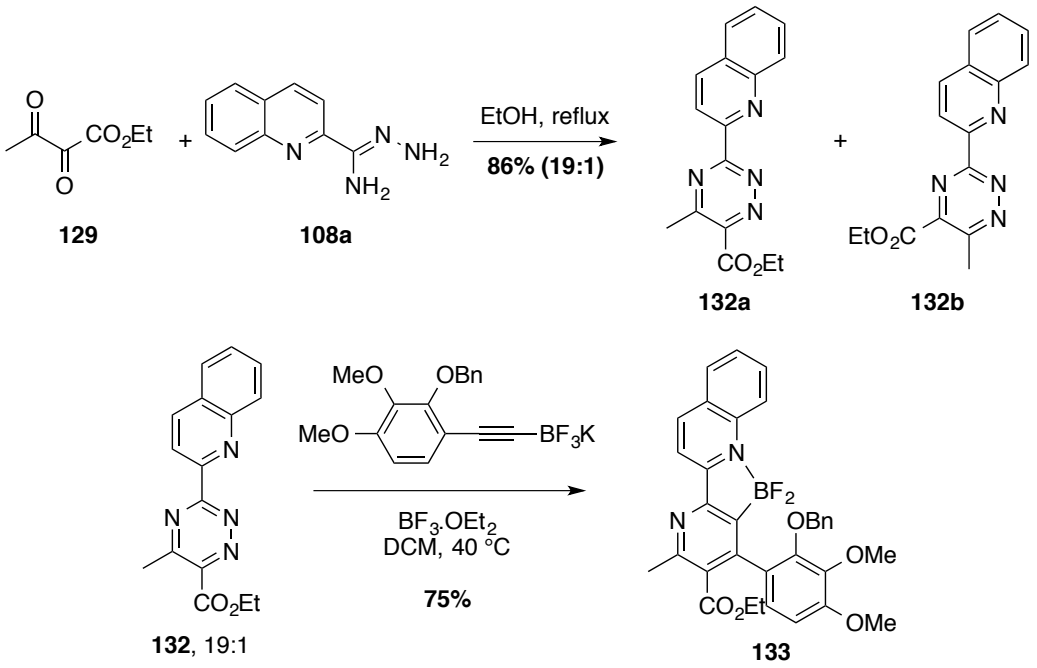
Facing those difficulties on a substrate that was obtained in 5 steps, we decided to investigate the condensation of amidrazones with commercially available tricarbonyl **129**, which could deliver the properly substituted triazines in 2 steps. We were mindful of the fact (and as explained in Chapter I) that mixtures of regioisomers are often observed when unsymmetrical diketones are used. Therefore, to first test this route, we decided to synthesise triazines **130** substituted with a SMe group, which can give access to triazines **131** via Suzuki coupling. As triazines **131** are known compounds, this would thus enable us to determine

which regioisomer was major. Notably, as those reactions were performed solely for regioselectivity studies, no extensive analytical measurements were performed, as all conclusions could be drawn from ^{1}H NMR spectra. Upon reaction, triazines **130** were formed in 58% yield in a 3:1 ratio and triazines **131** in 50% yield in a 4:1 ratio (Scheme IV-8). The major product formed was found to match the literature data for isomer **131b** (the methyl singlet coming at δ 2.98 ppm)[49] and the minor product matched the data of isomer **131a** (δ 2.89 ppm).[48] These studies indicated that the major product obtained in this case was the desired regioisomer, with the ester incorporated at C5 of the triazine.



Scheme IV-8: Regioselectivity studies using tricarbonyls

Convinced that this strategy was the most efficient, we then set out to study this strategy using quinoline amidrazone **108a** and tricarbonyl **129** (Scheme IV-9). Interestingly, this condensation formed **132** in 86% yield in a 19:1 ratio, proving to be even more efficient than in our preliminary studies. The subsequent cycloaddition with **120** gave the corresponding pyridine **133** in 75% yield with no traces of the minor regioisomer. But at this point, X-ray analysis disappointingly proved that the undesired regioisomer was in fact obtained for this substrate (Figure IV-2).



Scheme IV-9: Synthesis of the first properly substituted C-ring

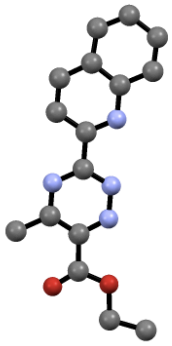
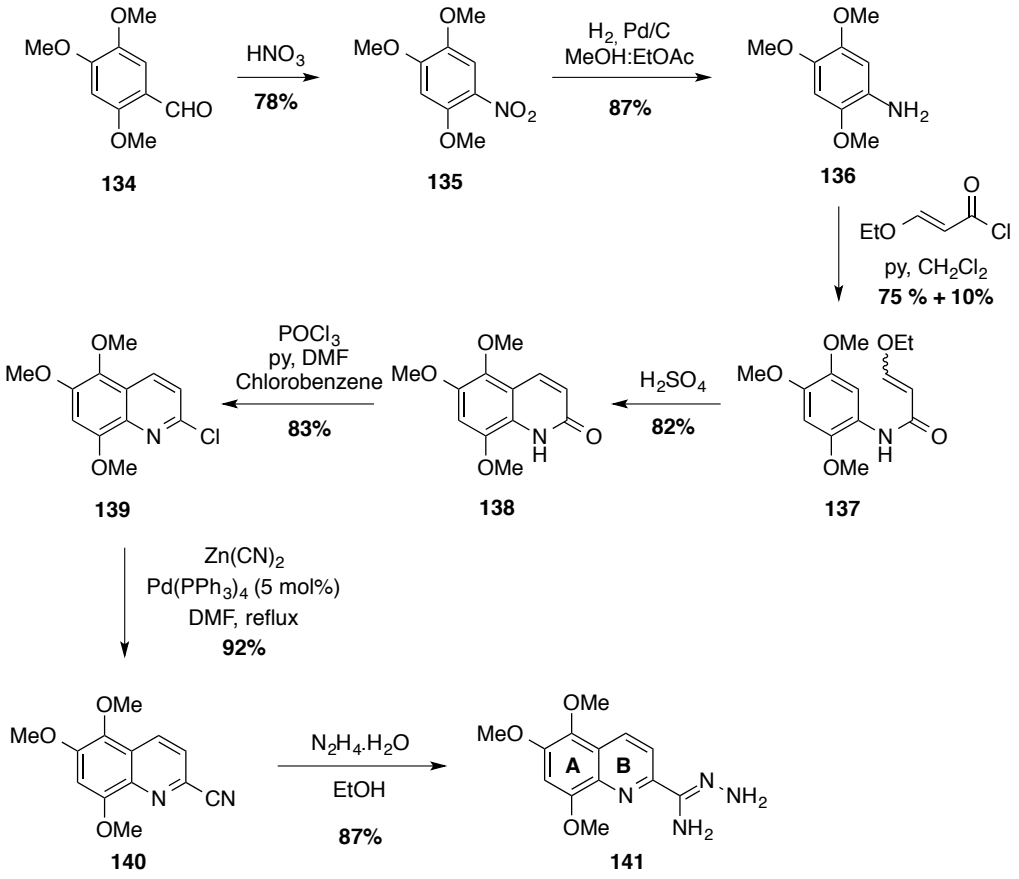


Figure IV-2: X-ray analysis of undesired regioisomer of triazine 132

3. Formation of the AB-system and subsequent cycloaddition attempts

In the intervening time between generating cycloadduct **133** and confirming its regiochemistry by X-ray crystallography, we decided to carry out preliminary studies on the cycloaddition reaction using a quinolone fragment that could ultimately be transformed into the streptonigrin AB-ring. We initially decided to adapt Donohoe's route to our cycloaddition

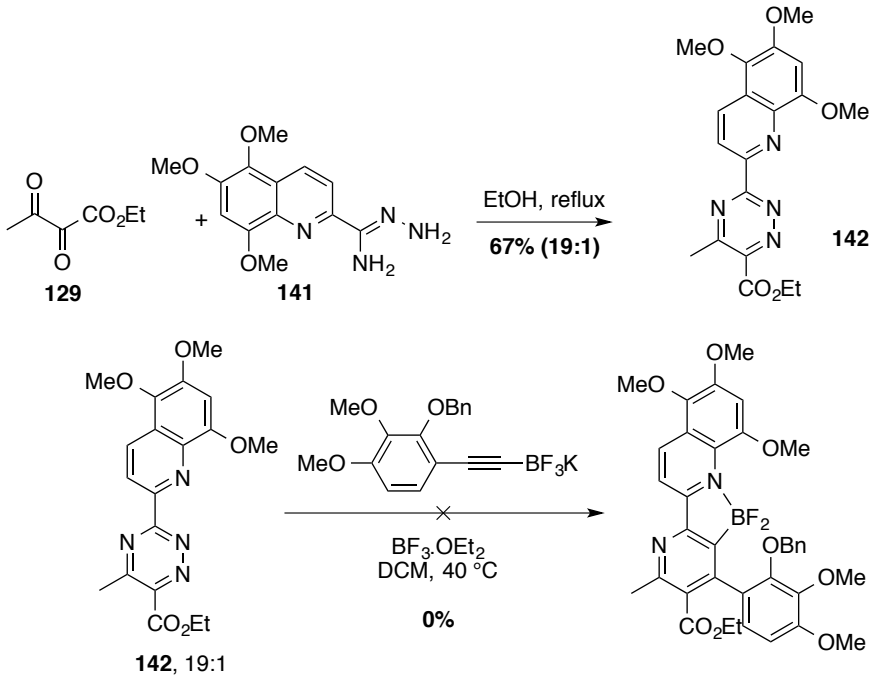
chemistry,[137] and the process is outlined in Scheme IV.10. Starting from 2,4,5-trimethoxybenzaldehyde **134**, the corresponding nitro compound **135** was formed with nitric acid in 78% yield. Reduction using hydrogen and catalytic Pd/C afforded aniline **136** in 87% yield, which upon reaction with (*E*)-3-ethoxyacryloyl chloride provided aryl amide **137** in a separable 9:1 ratio of E/Z product with an overall yield of 85%. The AB ring system was obtained by cyclisation in sulfuric acid, generating **138** in 82% yield, and chlorination was effected with phosphorus oxychloride to obtain chloroquinoline **139** in 83% yield. Diverging here from Donohoe's route, where he chose to introduce a stannane moiety, we aimed to incorporate a cyanide group to substitute the chloride of **139**. Coupling of zinc cyanide led to **140** in 92% yield, which afforded the first key intermediate: amidrazone **141** in 87% yield, substituted with the protected quinoline ring.



Scheme IV-10: Route to AB-ring system

From there, the strategy was to follow the developed route previously described in Scheme IV-9. Accordingly, using tricarbonyl **129**, triazine **142** was formed in 67% yield in a 19:1 ratio of regioisomers (Scheme IV-11). Once again, X-ray crystallography later on

confirmed that the undesired regioisomer was the major product of this cyclisation (Figure IV-3). Moreover, we had a further surprise when we noted that the subsequent cycloaddition did not proceed, and mainly returned starting material untouched.



Scheme IV-11: Unsuccessful cycloaddition towards Donohoe's intermediate

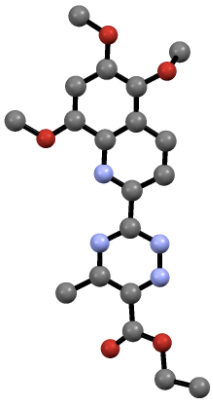
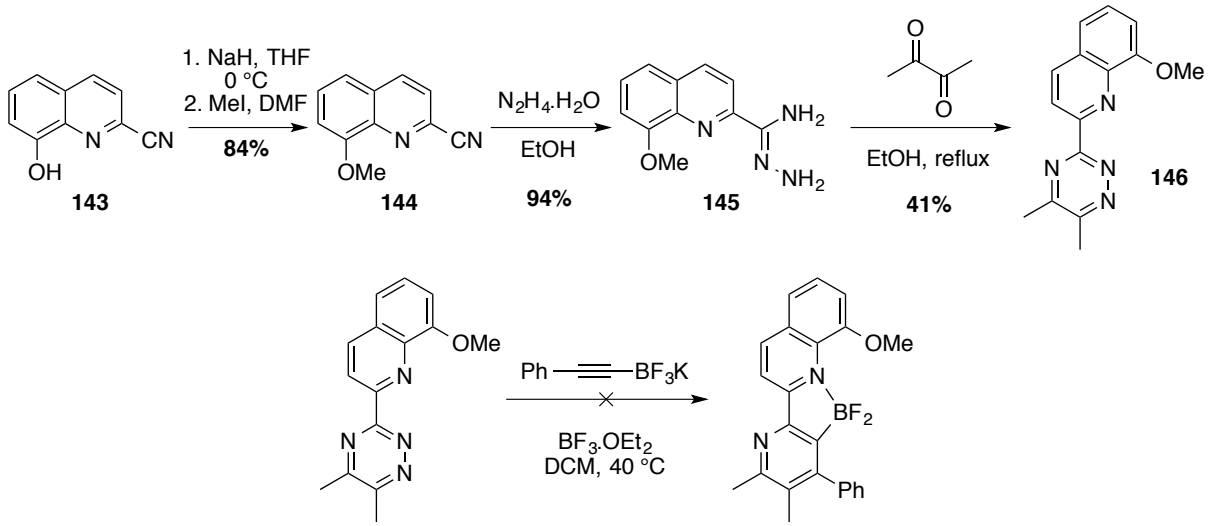


Figure IV-3: X-ray analysis of undesired regioisomer of triazine 142

Puzzled by this observation, we decided to investigate the effect of a substituent on the C8 position of the quinoline directing group, envisaging that its presence could hinder the key borane-Lewis base interaction, thus preventing any cycloaddition. Accordingly, we synthesised triazine **146** in three steps from the commercially available 8-hydroxyquinoline-2-

carbonitrile **143** (Scheme IV-12). Protection of the alcohol with sodium hydride and iodomethane yielded quinoline **144** in 84% yield, which, upon treatment with hydrazine hydrate, gave amidrazone **145** in 94% yield. Final cyclisation with butanedione yielded the desired triazine **146** in 41% yield. Confirming our hypothesis, the subsequent cycloaddition step with potassium phenylethynyltrifluoroborate under our standard conditions also returned starting material back. This result indicates that a C8 substituent on the quinoline directing group has an inhibitory effect on the cycloaddition process.

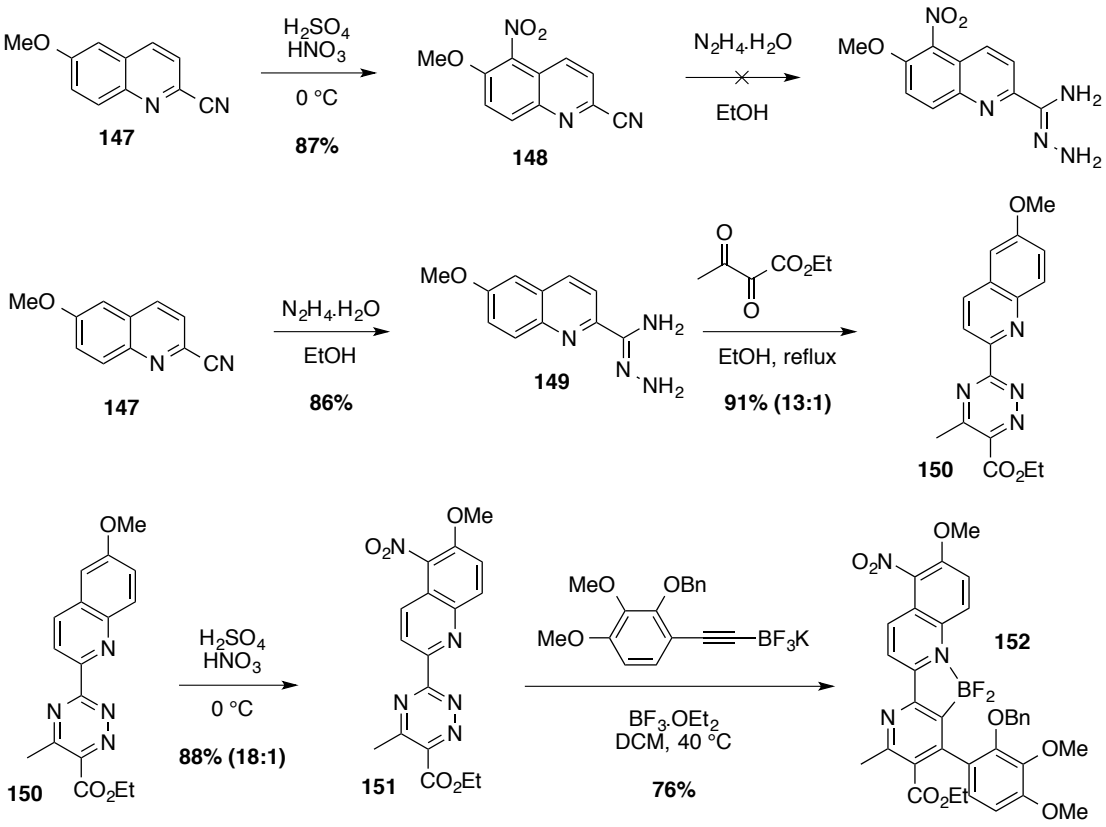


Scheme IV-12: Influence of a C8-substituent on the directing group

4. New strategy towards the cycloaddition step and subsequent amination

Inspired by Kende and Boger's work,[134-135] where they form the framework of streptonigrin *via* a 6-methoxy-5-nitroquinoline group, we decided to use this approach to prevent the presence of a C8 substituent on the quinoline during the cycloaddition (Scheme IV-13). Following Boger's procedure, we first attempted the nitration of commercially available 6-methoxyquinoline-2-carbonitrile **147** with sulfuric and nitric acid. The corresponding nitro-quinoline **148** was obtained in 87% yield, but the amidrazone formation from this substrate proved difficult and returned a complex mixture of compounds, possibly because of partial reduction of the nitro group with hydrazine. We thus decided to form amidrazone **149** directly from **147**, which was satisfyingly achieved in 86% yield. We next

used the cyclisation procedure with tricarbonyl **129** to form triazine **150** in 91% in a 13:1 ratio. We were then able to perform the selective nitration with the same conditions that Boger used previously in 88% yield to form triazine **151** in an 18:1 ratio. Gratifyingly, the cycloaddition with this triazine and alkyne **120** formed **152** in 75% yield, in only one regioisomer. Once again, X-ray crystallographic analysis of this compound proved the wrong regioisomer was synthesised (Figure IV-4).



Scheme IV-13: Route towards precursor 152

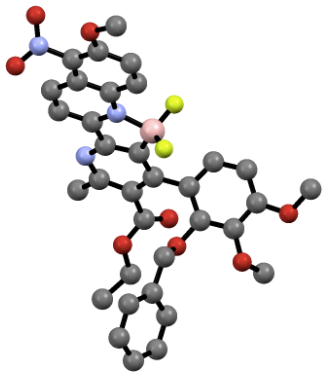
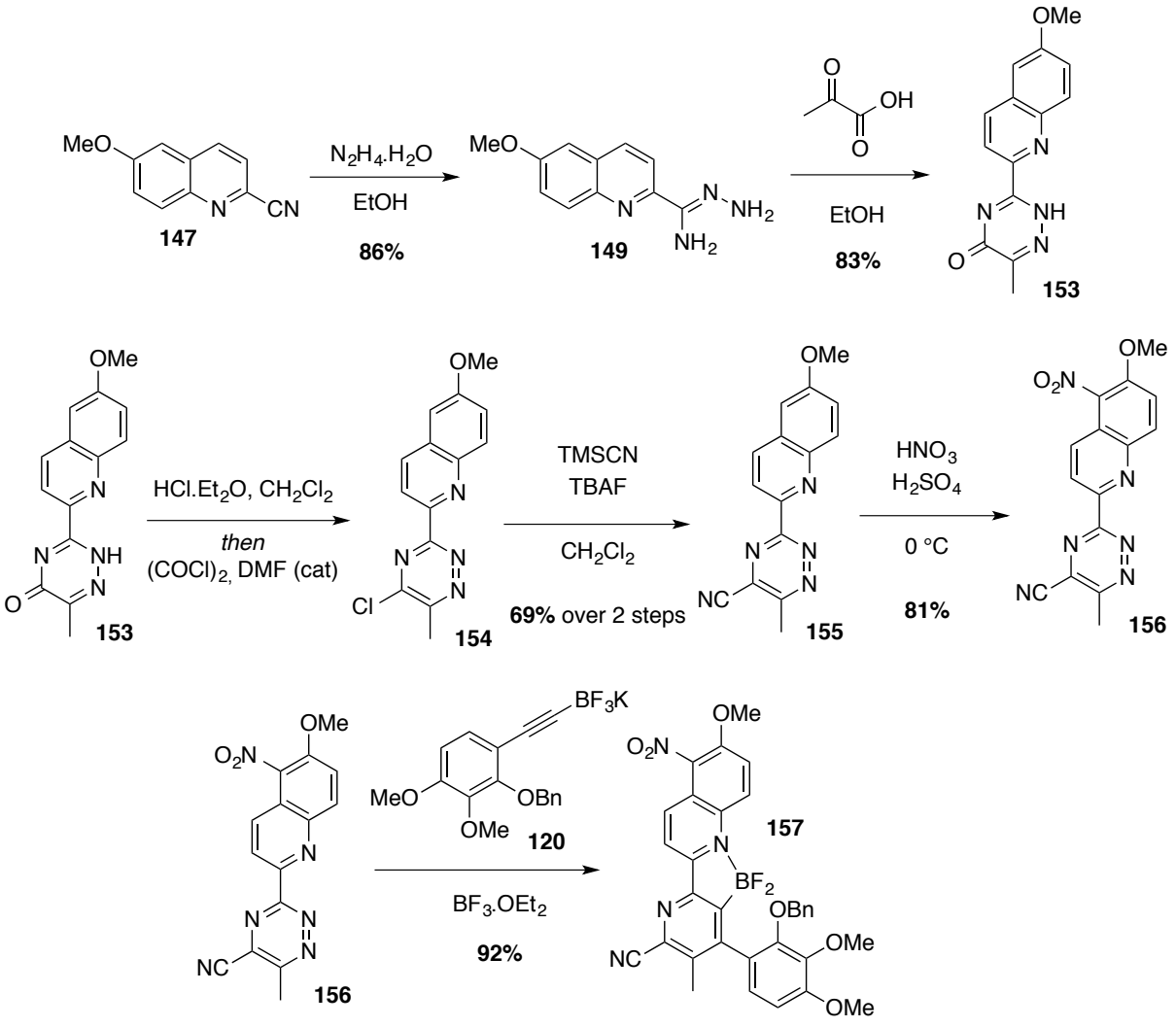


Figure IV-4: X-ray analysis of wrong regioisomer of 152

Having demonstrated that triazine formation with quinolone based amidrazones and tricarbonyl **129** consistently delivered the undesired regioisomer, we changed tack. We thus restarted this last route using the previously optimised conditions for the synthesis of a triazine bearing a cyano group at C5 and a methyl at C6. Amidrazone **149** previously described was thus cyclised with pyruvic acid to form triazinone **153** in 83% yield (Scheme IV-14). Chlorination with oxalyl chloride and DMF formed **154**, and subsequent cyanation with TMSCN and TBAF provided triazine **156** in 69% over two steps. Nitration of this substrate with sulfuric acid and nitric acid formed the desired triazine **156** in 81% yield. Cycloaddition with alkyne **120** finally provided pyridine **157**, with the required substitution pattern around the pyridine ring, and a properly substituted quinoline ring in 92% yield, as confirmed by X-ray crystallography (Figure IV-5).



Scheme IV-14: Route towards pyridine 157

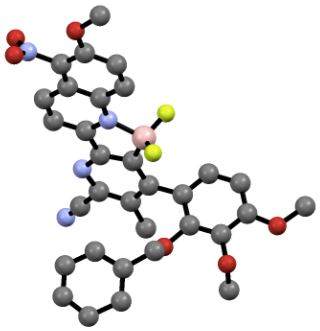
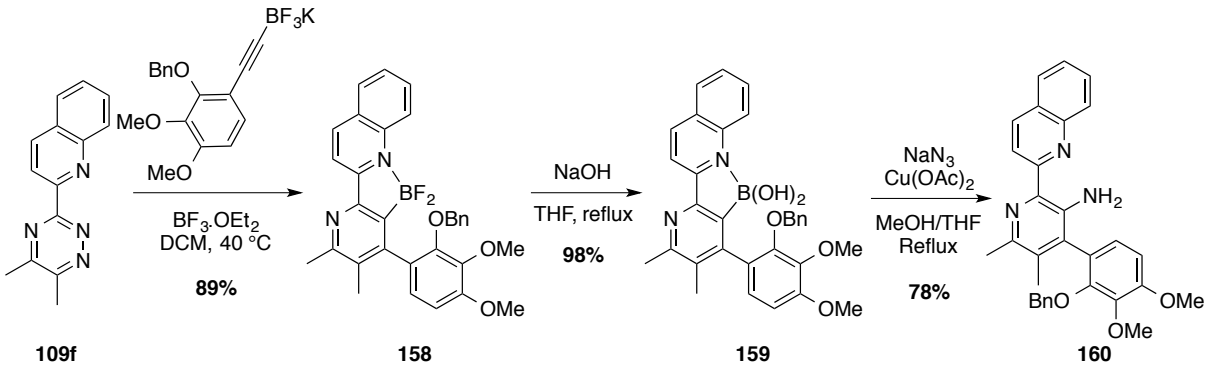


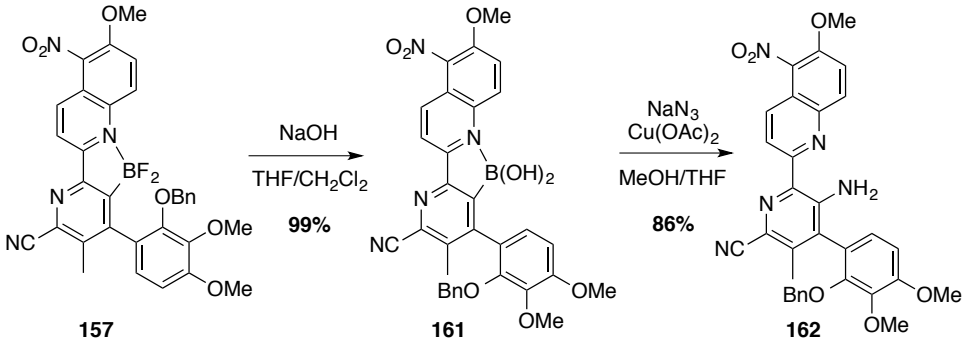
Figure IV-5: X-ray analysis of 157

The next step consisted of the amination of the pyridine ring, which had raised a lot of problems previously. To study this step in depth, we synthesised a simpler system that would serve as a model for our target compound. Starting from readily available triazine **109f** (described earlier), we performed the cycloaddition with alkyne **120** to form the corresponding pyridine **158** in 89% yield. Facing the lack of reactivity of the BF_2 moiety observed earlier, we decided to look for conditions that would provide the boronic acid that we envisaged could be more prone to conversion into the corresponding amine. Boronic acid **159** was thus formed in 98% yield in the presence of sodium hydroxide in refluxing THF. Inspired by a combination of papers where the amination of similar systems was achieved with copper acetate and sodium azide,[89, 140] we successfully developed a one pot reaction where the boronic acid is first transformed into the azide and subsequently modified *in situ* to the amine by copper. The conditions were modified to enhance the solubility of our compound, namely with a mixture of methanol and THF, and the use of stoichiometric quantities of copper acetate and 1.5 equivalent of sodium azide afforded amine **160** in 78% yield (Scheme IV-15).



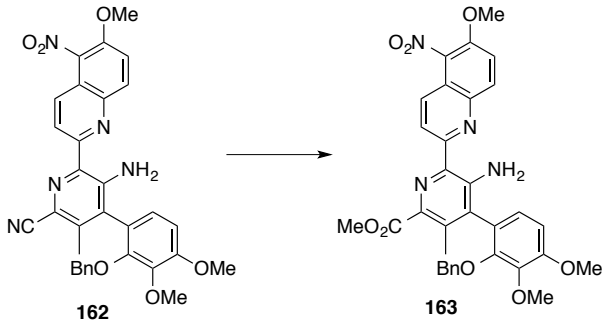
Scheme IV-15: Amination optimisation on a model compound

With optimised conditions in hand, we next employed them on pyridine **157**. To minimise the risks of protodeboronation observed previously when the cyano substituent was present, we designed a set of conditions to form boronic acid **161** at room temperature: treating **157** with a sodium hydroxide aqueous solution in a mixture of DCM and THF overnight gave the desired product in 99% yield (Scheme IV-16). This solvent system enabled both reagents to be soluble in the same phase and react. Using the optimised conditions of the amination, amine **162** was successfully formed in 86% yield.



Scheme IV-16: Amination on target compound

Finally, the end of the formal synthesis consists in the hydrolysis of the cyano group into the methyl ester **163**, previously reported by Boger, and this step is currently under investigation.

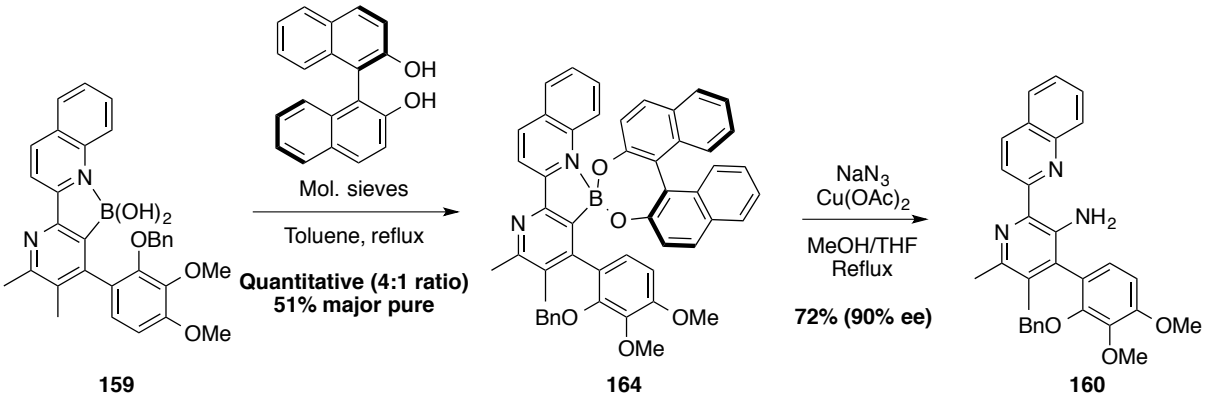


Scheme IV-17: Final steps towards known intermediate 163

Altogether, this route shows the benefits of using our directed cycloaddition in total synthesis with better performances than the previous route reported by Boger. One step away from the formal synthesis of streptonigrin, the strategy consists of 13 steps with two convergent routes of 5 and and 8 steps respectively, and with a 37% overall yield (when Boger's formal synthesis consists in 10 steps with a 5% overall yield).

5. Controlling axial chirality

With the boron centre installed in **157**, we envisaged the possibility of controlling the axial chirality of the molecule *via* the installation of a chiral ligand at boron, which could favour one atropoisomer over the other. In our preliminary studies, we investigated this possibility on model compound **159**. The installation of the ligand was accomplished from the boronic acid by heating in the presence of a chiral diol for 1 hour in the presence of molecular sieves. The use of different tartrate esters was inconclusive, but (*R*)-BINOL gave a 4:1 ratio of the two diastereoisomers in quantitative yield. Their separation proved rather difficult but the major isomer **164** was isolated in 51% yield. The high conversion and diastereoselectivity were indicative of a dynamic resolution of the racemic substrates. Moreover, when this boronic ester was subjected to the conditions developed for the amidation of the corresponding boronic acid, amine **160** was obtained in 72% yield in 90% ee.



159 **164** **160**

Scheme IV-18: Axial chirality controlled via BINOL ligand

This result offered the prospect for one of the most selective enantiocontrolled syntheses of streptonigrin, as the best selectivity obtained to-date was obtained by Donohoe but was only of 42% ee.[138] A range of ligands is planned to be screened to try to improve the ratio of diastereoisomers formed to try to minimise the need for their separation when used with the target compound, and could thus enable the stereoselective formation of amine **163**.

Besides enantiocontrol, this new proposed route offers extended possibilities for the synthesis of analogues as the convergent strategy can access alternative substitutions at many different points of the route.

Conclusions and outlook

Potassium alkynyltrifluoroborates have been showed to be excellent reaction partners for 1,2,4-triazines in directed cycloadditions. Two families of directing groups have proven successful: pyridine rings and amides, both forming a 5-membered intermediate around the newly formed carbon boron bond. Two positions available for the directing group have also been identified; incorporation of these groups at the C3 and C6 positions of triazines offer similar good results but show limitations when C5 is unsubstituted. This new methodology offers high versatility in the synthesis of highly substituted pyridines.

The fluorescent properties of the products from directed cycloadditions bearing a BF_2-moiety have been studied and showed excellent photophysical features. DFT studies allowed for a mapping of the structure to identify where functionalities could be incorporated. This led to the addition of a linker moiety that was further clicked onto a peptoid which enabled its tracking in cells. Further work will focus on the incorporation of electron-withdrawing and electron-donating groups to induce a push-pull system that would shift the absorption and emission spectra of BOBIPYs towards the infrared region, increasing their applicability in biological systems.

Finally, this new strategy for pyridine formation has been applied to the synthesis of streptonigrin, an antitumor antibiotic composed of a fully substituted pyridine ring as core structure. An efficient route stopping one step from the formal synthesis has been developed in an excellent overall yield and in a reduced number of steps. Promising results have been gathered to control the enantioselectivity of the synthesis and further work will focus on the optimisation and application of this methodology.

This work was supported by the FP7 Marie Curie Actions of the European Commission via the ITN ECHONET Network (MCITN-2012-316379).

Chapter V. Experimental

1. General procedures

All reactions were conducted in oven or flame-dried glassware under an inert atmosphere of dry nitrogen or argon. Flash chromatography was performed on silica gel (Fluorochem Davisil silica gel 43-60) or on Florisil (BDH Florisil 60-100 mesh). The solvent system used was a gradient of petroleum ether (40-60), increasing in polarity to ethyl acetate, unless otherwise stated. Thin layer chromatography (TLC) was performed on aluminium backed plates pre-coated with silica (0.2 mm, Merck DC-alufolien Kieselgel 60 F_{254}) which were developed using standard visualizing agents: Ultraviolet light or potassium permanganate.

^{1}H NMR spectra were recorded on a BRUKER DRX 250 (250 MHz), BRUKER Avance 300 (300 MHz), a BRUKER Avance 400 (400 MHz), BRUKER Avance III HD 400 (400 MHz) or a BRUKER Avance DRX 500 (500 MHz) device as solutions at room temperature. Chemical shifts are expressed in parts per million (ppm, δ), downfield from tetramethylsilane (TMS) and referenced to chloroform (δ 7.26 ppm) as internal standards. All coupling constants are absolute values and J values are expressed in Hertz (Hz). The spectra were analyzed according to first order and the descriptions of signals include: s = singlet, d = doublet, dd = doublet of doublets, t = triplet, q = quartet, m = multiplet.

^{13}C NMR spectra were recorded on a BRUKER DRX 250 (62.9 MHz), BRUKER Avance 300 (75.5 MHz), a BRUKER Avance 400 (100.6 MHz) or a BRUKER Avance DRX 500 (125.8 MHz) device as solutions at room temperature. Chemical shifts are expressed in parts per million (ppm, δ), downfield from tetramethylsilane (TMS) and referenced to $CDCl_3$ (δ 77.0 ppm) as internal standards. It has to be highlighted that in the spectra of boron containing compounds the carbon atom directly *alpha* to boron is often too broad to be detected.

^{11}B NMR spectra were recorded on a BRUKER Avance III HD 400 (128.4 MHz) or a BRUKER DRX-500 (160.5 MHz) device as solutions at room temperature. Chemical shifts are reported in ppm with H_3BO_3 as an internal standard (H_3BO_3: δ 19.6 ppm).

^{19}F NMR spectra were recorded on a BRUKER Avance 400 (376 .5 MHz), a BRUKER Avance III HD 400 (376.5 MHz) or a BRUKER Avance DRX 500 (470.6 MHz)

device as solutions at room temperature. Chemical shifts are reported in ppm with $CFCF_3$ as an external standard ($CFCF_3$: δ 0.0 ppm).

^{31}P NMR spectra were recorded on a Bruker AMX-400 (162.0 MHz). Chemical shifts are reported in ppm with H_3PO_4 as an external standard (H_3PO_4: δ 0.0 ppm). Data are reported as follows: chemical shift, multiplicity if coupling with ^{13}C (d = doublet, coupling constant (*J*) in Hz.

Infrared (FTIR) spectra were recorded on a Perkin Elmer Paragon 100 FTIR spectrophotometer or FT-IR Bruker IFS 88, ν_{max} in cm^{-1}. Bands are characterized as broad (br), strong (s), medium (m) and weak (w). Samples were recorded as thin films using sodium chloride plates.

Low resolution mass spectra were recorded on Micromass Autospec, operating in E.I., C.I. or FAB mode; or a Perkin-Elmer Turbomass Benchtop GC-MS operating in either E.I. or C.I mode. High-resolution mass spectroscopy (HRMS) recorded for accurate mass analysis, were performed on either a MicroMass LCT operating in Electrospray mode (TOF ES^+) or a MicroMass Prospec operating in either FAB (FAB^+), EI (EI^+) or CI (CI^+) mode.

Melting points were performed on recrystallised solids and recorded on a Gallenkamp melting point apparatus and are uncorrected.

Optical rotation values were recorded on a Perkin Elmer 241 automatic polarimeter at 589 nm (Na-D line) with a path length of 1 dm, and are given in 10^{-1} deg cm^{-2} g^{-1} with concentrations (*c*) quoted in g 100 mL^{-1}.

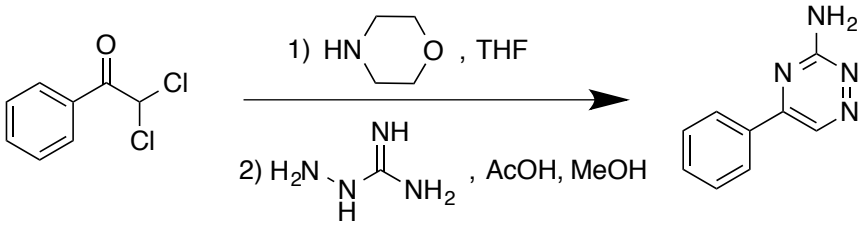
Solvents and reagents were used either as received from commercial suppliers or, when necessary, purified using standard laboratory techniques according to methods published in "Purification of Laboratory Chemicals" by Perrin, Armarego, and Perrin (Pergamon Press, 1966) or dried over alumina using a Grubbs Solvent Drying System (manufactured by Innovative Technology). In an individual solvent line, the untreated solvent is contained within a lined metal reservoir and, using nitrogen as pressure, forced through a pair of metal columns each containing either activated alumina or molecular sieves. The dried solvent is then dispensed to a suitable collection vessel under vacuum via a Schlenk line system. Water content of the solvents is routinely monitored by Karl Fisher titration.

General procedure for $BF_3.OEt_2$-promoted cycloadditions

To a solution of triazine and alkynyltrifluoroborate salt (3.0 eq) in refluxing DCM was added dropwise $BF_3.OEt_2$ (3.0 eq). The reaction was stirred for 10 minutes. Water and brine were added and the mixture was extracted with DCM. The organics were dried over $MgSO_4$, filtered and the solvent evaporated.

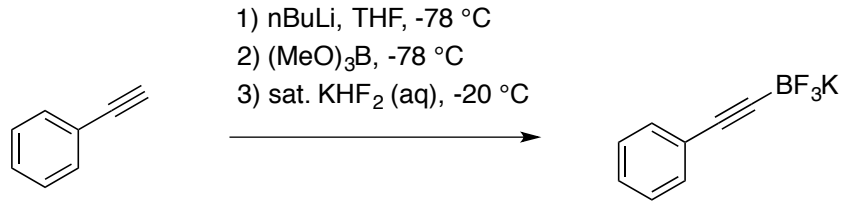
2. Experimental procedures

5-Phenyl-3-amino-1,2,4-triazine 40[38]



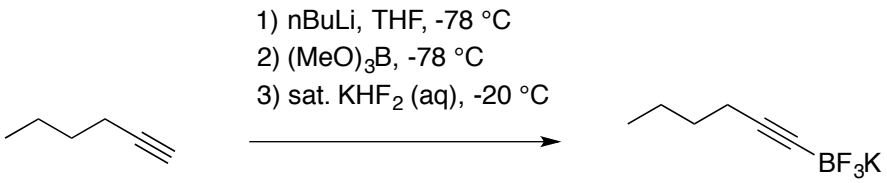
To a solution of 2,2-dichloroacetophenone (7.05 mL, 50.0 mmol, 1.0 eq) in anhydrous THF (50 mL) under N_2 was added neat morpholine (18.10 mL, 210.0 mmol, 4.2 eq) at RT. The resulting solution was slowly heated to 68 °C over 1 hour and left to stir at that temperature for 69 hours. After cooling to RT, the suspension was filtered through a fritted funnel and the wet cake was washed with THF (50 mL). The combined filtrate was concentrated to give the intermediate product. To a solution of the intermediate product in MeOH (75 mL) under N_2 was added solid aminoguanidine bicarbonate (6.69 g, 50.0 mmol, 1.0 eq), followed by slow addition of neat AcOH (8.6 mL, 150 mmol, 3.0 eq) over 10 min at RT. The resulting solution was stirred at RT for 2 hrs, at which time CO_2 evolution ceased, and then slowly heated to reflux and stirred for 25 hrs. After cooling to RT, the resulting suspension was concentrated to about half its volume, cooled to 0 °C, stirred for 1 hr, filtered through a fritted funnel and washed with cold MeOH/H_2O (4/1). The collected solid was dried in vacuo to afford the product as a brown solid (4.27 g, 50% yield). **M.p.** 224-228 °C (lit. 232-235 °C dec). **^{1}H NMR** (250 MHz, d^6-DMSO): δ 7.26 (2H, br, NH_2), 7.56-7.59 (3H, m, CH), 8.19 (2H, dd, *J* = 8.0 Hz, 1.5, CH), 9.23 (1H, s, CH). **^{13}C NMR** (101 MHz, d^6-DMSO): δ 127.7, 129.5, 132.3, 134.4, 137.5, 155.3, 163.5.

Potassium phenylethynyltrifluoroborate 50[81]



To a solution of phenylacetylene (1.00 g, 10.0 mmol, 1.0 eq) in THF (25 mL) under N_2 at -78 °C was added a 1.6 M solution of *n*-butyllithium in hexane (6.25 mL, 10.0 mmol, 1.0 eq). After 1 hour, trimethyl borate (1.56 g, 15.0 mmol, 1.5 eq) was added and the reaction stirred at -78 °C for 1 hour. The reaction was allowed to warm to -20 °C and stirred for 1 hour before a saturated aqueous solution of KHF_2 (4.7 g, 60 mmol, 6.0 equiv) in distilled water was added. After 1 hour, the reaction was allowed to warm to room temperature and stirred for a further hour. The reaction mixture was concentrated and thoroughly dried under reduced pressure. The crude products were washed with cold acetone (2 x 50 mL) and the residue was removed by filtration. The acetone fractions were combined and the solvent evaporated to afford potassium phenylethynyltrifluoroborate (1.75 g, 84%) as a white solid. **M.p.** 240 °C dec (lit. 238 °C dec). **^{1}H NMR** (250 MHz, d^6-DMSO): δ 7.30-7.32 (5H, m, Ar). **^{13}C NMR** (101 MHz, d^6-DMSO): δ 89.8, 126.0, 127.2, 128.7, 131.4. **^{19}F NMR** (235.1 MHz, $CDCl_3$): δ -131.7. **^{11}B NMR** (128.4 MHz, d^6-DMSO): δ -1.5.

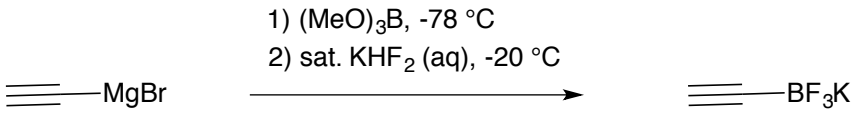
Potassium (1-hexyn-1-yl)trifluoroborate 51[81]



To a solution of hex-1-yne (1.0 g, 12.17 mmol, 1.0 eq) in THF (25 mL) under N_2 at -78 °C was added a 2.4 M solution of *n*-butyllithium in hexane (5.5 mL, 12.17 mmol, 1.0 eq). After 1 hour, trimethyl borate (2.0 mL, 18.26 mmol, 1.5 eq) was added and the reaction stirred at -78 °C for 1 hour. The reaction was allowed to warm to -20 °C and stirred for 1 hour before a saturated aqueous solution of KHF_2 (5.71g, 73.05 mmol, 6.0 eq) in distilled water (25 mL) was added. After 1 hour, the reaction was allowed to warm to room temperature and stirred for a further hour. The reaction mixture was concentrated and thoroughly dried under

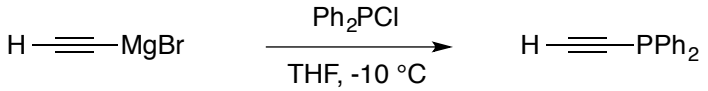
reduced pressure. The crude products were washed with cold acetone (2 x 50 mL) and the residue was removed by filtration. The acetone fractions were combined and the solvent evaporated to afford pure potassium (1-hexyn-1-yl)trifluoroborate (1.87 g, 82%) as a white solid. **M.p.** 256 °C dec (lit. 256 °C dec). **^{1}H NMR** (250 MHz, d^{6}-DMSO): δ 0.82-0.88 (3H, m, CH_3), 1.31-1.35 (4H, m, CH_2), 1.97-1.98 (2H, m, CH_2). **^{13}C NMR** (101 MHz, d^{6}-DMSO): δ 14.0, 19.0, 21.8, 31.5, 89.1. **^{19}F NMR** (235.1 MHz, $CDCl_3$): δ -130.9. **^{11}B NMR** (128.4 MHz, d^{6}-DMSO): δ -1.8.

Potassium ethynyltrifluoroborate 52[81]



Trimethyl borate (3.35 mL, 30.0 mmol, 1.5 eq) was added to a solution of ethynylmagnesium bromide in THF (0.5 M) (40.0 mL, 20.0 mmol, 1.0 eq) at -78 °C under N_2. The solution was stirred for 1 hour at this temperature, and then warmed up to -20 °C for 1 hour. To the resultant white suspension, a solution of KHF_2 (6.25 g, 80.0 mmol, 4.0 eq) in distilled water (25 mL) was added at -20 °C and the solution was stirred at this temperatue for 1 hour, and a further hour at RT. The reaction mixture was concentrated and thoroughly dried under reduced pressure.The crude product was dissolved in hot acetone (2 x 50 mL) and the residue was removed by filtration. The filtrate was concentrated to afford potassium ethynyltrifluoroborate (1.07 g, 40%) as a pale brown solid. **M.p.** 211-212 °C dec (lit. 211-212 °C dec). **^{1}H NMR** (250 MHz, d^{6}-DMSO): δ 1.89 (1H, br, C-H). **^{13}C NMR** (101 MHz, d^{6}-DMSO): δ 79.0. **^{19}F NMR** (235.1 MHz, $CDCl_3$): δ -132.2. **^{11}B NMR** (128.4 MHz, d^{6}-DMSO): δ -2.3.

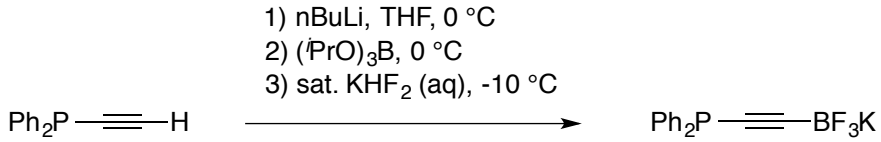
Diphenylethynylphosphine 53[141]



To a 0.5 M solution of ethynylmagnesium bromide in THF (100.0 mL, 50.0 mmol, 1.0 eq) under N_2 at -10 °C was added dropwise a solution of chlorodiphenylphosphine (9.0 mL, 48 mmol, 1.0 eq) in THF (75 mL). The resulting mixture was stirred for 1 hour at room

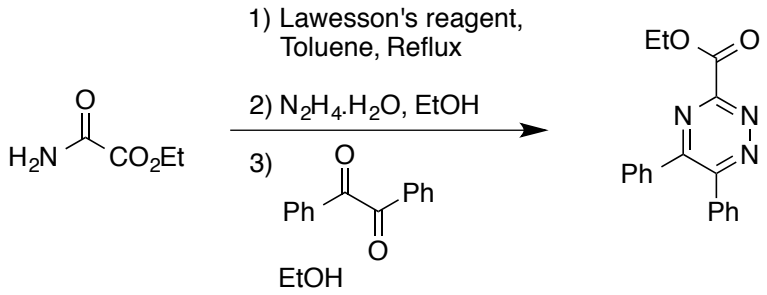
temperature and then quenched with an aqueous solution of acetic acid (2%, 50 mL) and solid $NaHCO_3$. The organic layer was separated, and the aqueous layer washed with petrol. The organic extracts were combined, dried over $MgSO_4$, filtered and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/petrol : 1/50) to give diphenylethynylphosphine (8.41 g, 83%) as a light brown solid. **M.p** 33-35 °C (lit. 35 °C). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 3.25 (1H, s, CH), 7.26-7.37 (6H, m, Ar), 7.61-7.66 (4H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 81.9 (d, *J* = 12.0), 96.1 (d, *J* = 2.0), 128.7 (d, *J* = 7.5), 129.2, 132.6 (d, *J* = 21.0), 135.3 (d, *J* = 6.0). **^{31}P NMR** (162.0 MHz, $CDCl_3$) δ -34.1.

Potassium ((diphenylphosphino)ethynyl)trifluoroborate 57[82, 96]



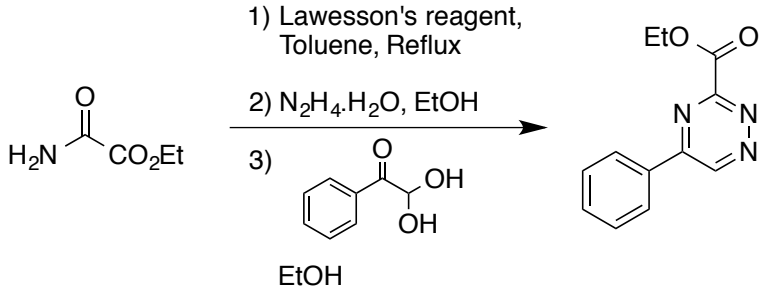
To a solution of ethynyldiphenylphosphine (1.0 g, 4.76 mmol, 1.0 eq) in dry THF (20 mL) under argon at 0 °C was added a 2.5 M solution of *n*-butyllithium in hexane (1.90 mL, 4.76 mmol, 1.0 eq). After 30 minutes, triisopropyl borate (1.65 mL, 7.14 mmol, 1.5 eq) was added and the reaction mixture stirred at this temperature for 1 hour, then a saturated aqueous solution of KHF_2 (2.23 g, 28.56 mmol, 6.0 eq) was added at -10°C. After 1 hour the reaction was allowed to warm to room temperature and stirred for a further hour. The organic phase was separated, dried over $MgSO_4$, filtered and concentrated in vacuo. The residue was purified by flash chromatography on silica gel (ethyl acetate/petrol : 4/6) to give potassium ((diphenylphosphino)ethynyl)-trifluoroborate (717 mg, 48%) as a light brown solid. **M.p** 80-82 °C (dec.) (lit. 80-82°C (dec.)). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.15-7.18 (2H, m, Ar-H), 7.24-7.28 (4H, m, Ar-H), 7.57-7.61 (4H, m, Ar-H). **^{13}C NMR** (62.9 MHz, $CDCl_3$): δ 128.7 (d, *J* = 7.5 Hz), 129.0, 130.7 (d, *J* = 11.5 Hz), 132.5 (d, *J* = 20.5 Hz), 136.2 (d, *J* = 6.5 Hz). **^{31}P NMR** (101.1 MHz, $CDCl_3$) δ -34.7. **^{19}F NMR** (376.5 MHz, $CDCl_3$) δ -136.4.

Ethyl 5-phenyl-1,2,4-triazine-3-carboxylate 64



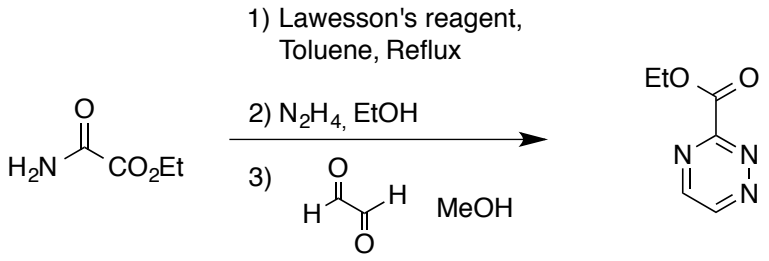
To a solution of ethyl oxamate (2.00 g, 17.1 mmol, 1.0 eq) in dry toluene (50 mL) at RT under argon was added Lawesson's reagent (3.45 g, 8.54 mmol, 0.5 eq). The solution was heated to 80 °C and stirred at that temperature for 1 hour. The mixture was then evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel (gradient; starting with dichloromethane, ending with ethyl acetate) to afford the intermediate as a yellow solid. The solid was dissolved in ethanol (50 mL) under argon. Hydrazine hydrate (0.83 mL, 17.1 mmol, 1.0 eq) was then added in small portions and the resulting mixture was stirred at RT overnight. After evaporation of the solvent, the residue was dissolved in ethanol (50 mL) under argon, this intermediate is unstable under air. Benzil (3.59 g, 17.1 mmol, 1.0 eq) was added and the mixture was heated to 80 °C. After 2 hours of stirring at that temperature, the solvent was evaporated under reduced pressure and the residue was redissolved in DCM, washed with water and brine, dried over $MgSO_4$ and filtered. The organic layers were evaporated and the residue was purified by flash chromatography on silica gel (petrol/EtOAc 9:1 then 8 :2) to afford the product as an orange oil (4.40 g, 84%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.47 (3H, t, *J* = 7.0 Hz, CH_3), 4.57 (2H, q, *J* = 7.0 Hz, CH_2), 7.31-7.37 (4H, m, Ar), 7.39-7.42 (2H, m, Ar), 7.57-7.62 (4H, m, Ar). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 14.2, 63.0, 128.7 (x2), 129.6, 130.0, 130.2, 130.3, 131.3, 134.6, 154.6, 156.4, 158.1, 162.7. **FTIR**: 2936 (w), 1738 (s), 1531 (m), 1445 (s), 1371 (m), 1272 (s), 1181 (s), 1005 (m), 767 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{18}H_{16}N_3O_2$: 306.1237, found 306.1238.

Ethyl 5-phenyl-1,2,4-triazine-3-carboxylate 65



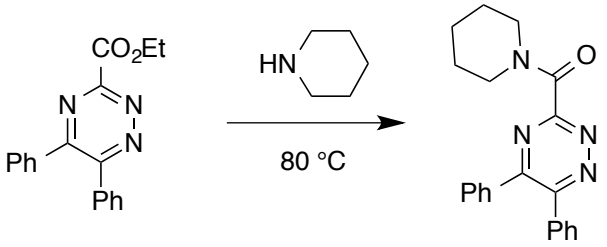
To a solution of ethyl oxamate (2.00 g, 17.08 mmol, 1.0 eq) in dry toluene (50.0 mL) at RT under argon was added Lawesson's reagent (3.45 g, 8.54 mmol, 0.5 eq). The solution was heated to 80 °C and stirred at that temperature for 1 hour. The mixture was then evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel (gradient; starting with dichloromethane, ending with ethyl acetate) to afford the intermediate as a yellow solid. The solid was dissolved in ethanol (50.0 mL) under argon. Hydrazine hydrate (0.83 mL, 17.08 mmol, 1.0 eq) was then added in small portions and the resulting mixture was stirred at RT overnight. After evaporation of the solvent, the residue was dissolved in ethanol (50.0 mL) under argon (this intermediate is unstable in air). Phenyl glyoxal monohydrate (2.29 g, 17.08 mmol, 1.0 eq) was added and the mixture heated to 80 °C. After 2 hours of stirring at that temperature, the solvent was evaporated under reduced pressure and the residue was redissolved in EtOAc, washed with water and brine, dried over $MgSO_4$ and filtered. The organic layers were evaporated and the residue was purified by flash chromatography on silica gel (petrol/EtOAc 9:1) to afford the product as a yellow solid (1.59 g, 41%) **M.p.** 80-82 °C (lit.[34] 83-84 °C). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.51 (3H, t, J = 7.0 Hz, CH_3), 4.61 (2H, q, J = 7.0 Hz, CH_2), 7.57-7.67 (3H, m, Ar), 8.26-8.28 (2H, m, Ar), 9.80 (1H, s, Ar). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 14.2, 63.2, 128.1, 129.6, 132.4, 133.3, 147.0, 156.2, 156.9, 162.8.

Ethyl 1,2,4-triazine-3-carboxylate 66



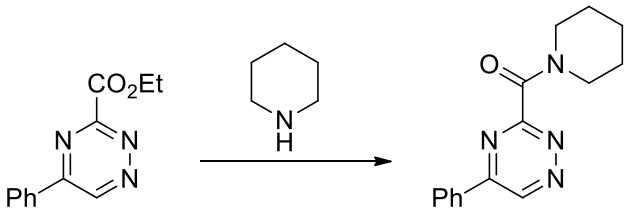
To a solution of ethyl oxamate (88 mg, 0.75 mmol, 1.0 eq) in dry toluene (2.0 mL) at RT under argon was added Lawesson's reagent (154 mg, 0.38 mmol, 0.5 eq). The solution was heated to 80 °C and stirred at that temperature for 1 hour. The mixture was then evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel (gradient; starting with dichloromethane, ending with ethyl acetate) to afford the intermediate as a yellow solid. This compound was dissolved in ethanol (5.0 mL) under argon. Hydrazine (1.0 M in THF) (0.75 mL, 0.75 mmol, 1.0 eq) was then added dropwise and the resulting mixture was stirred at RT for 1 hour. After evaporation of the solvent, the residue was dissolved in methanol (11.0 mL) under argon. Aquous glyoxal (0.13 mL, 1.13 mmol, 1.5 eq) was added and the mixture stirred for 30 min at RT. The solution was evaporated under reduced pressure and the residue was dissolved in DCM, washed with water and brine, dried over $MgSO_4$ and filtered. The organic layers were evaporated and the residue was purified by flash chromatography on silica gel (DCM/EtOAc 8:2) to afford the product as a yellow solid (32 mg, 26%) **M.p.** 64-66 °C (lit.[5] 72-74 °C). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.48 (3H, t, J = 7.0 Hz, CH_3), 4.59 (2H, q, J = 7.0 Hz, CH_2), 8.84 (1H, d, J = 2.5 Hz, Ar), 9.43 (1H, d, J = 2.5 Hz, Ar). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 14.2, 63.4, 149.3, 150.6, 157.2, 162.2.

(5,6-Diphenyl-1,2,4-triazin-3-yl)(piperidin-1-yl)methanone 67



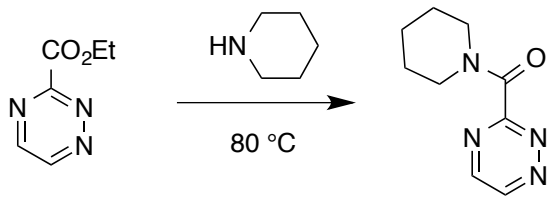
Ethyl 5-phenyl-1,2,4-triazine-3-carboxylate (106 mg, 0.35 mmol, 1.0 eq) was dissolved in piperidine (0.65 mL) and the mixture was heated to 80 °C overnight. Evaporation of the solvent followed by chromatographic purification over silica gel (gradient; starting with petrol, ending with ethyl acetate) afforded (5,6-diphenyl-1,2,4-triazin-3-yl)(piperidin-1-yl)methanone as a yellow solid. (29 mg, 24%). **M.p.** 206-208 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.67-1.75 (6H, m, CH_2), 3.45 (2H, t, *J* = 5.0 Hz, CH_2), 3.83 (2H, t, *J* = 5.0 Hz, CH_2), 7.31-7.46 (6H, m, Ar), 7.57-7.63 (4H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 24.6, 25.5, 26.5, 43.2, 48.5, 128.7, 128.9 (x2), 129.6, 130.1, 131.3, 135.0, 135.2, 156.7, 157.3, 159.4, 163.7. **FTIR**: 2943 (w), 1635 (s), 1477 (m), 1442 (m), 1369 (s), 1276 (m), 1205 (m), 1012 (m), 853 (m), 751 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{21}H_{21}N_4O$ 345.1710, found 345.1717.

(5-Phenyl-1,2,4-triazin-3-yl)(piperidin-1-yl)methanone 68



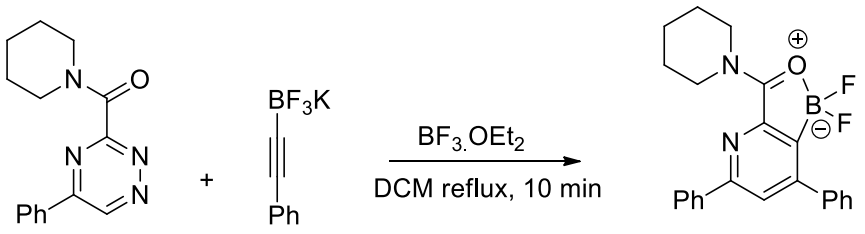
Ethyl 5-phenyl-1,2,4-triazine-3-carboxylate (619 mg, 2.70 mmol) was dissolved in piperidine (5.0 mL) and the mixture was heated at 40 °C for 2 hours. Evaporation of the solvent followed by chromatographic purification over silica gel (gradient; starting with petroleum ether, ending with ethyl acetate) afforded (5-phenyl-1,2,4-triazin-3-yl)(piperidin-1-yl)methanone as a dark solid. (608 mg, 84%). **M.p** 88-90 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.62-1.64 (2H, m, CH_2), 1.71-1.75 (4H, m, CH_2), 3.30-3.32 (2H, m, CH_2), 3.80-3.83 (2H, m, CH_2), 7.54-7.62 (3H, m, Ar), 8.20-8.23 (2H, m, Ar), 9.69 (1H, s, Ar-H). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 24.4, 25.4, 26.3, 43.0, 48.2, 127.9, 129.5, 132.7, 133.1, 145.7, 155.9, 161.8, 163.5. **FTIR**: 3483 (w), 2940 (m), 2858 (w), 1646 (s), 1544 (s), 1481 (s), 1441 (w), 1320 (w), 1222 (m), 1135 (w), 1011 (w) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{15}H_{17}N_4O$ 269.1402, found 269.1401.

(1,2,4-Triazin-3-yl)(piperidin-1-yl)methanone 69



Ethyl 1,2,4-triazine-3-carboxylate (400 mg, 2.61 mmol) was dissolved in piperidine (4.0 mL) and the mixture was heated at 80 ^{o}C for 3 hours. Evaporation of the solvent followed by chromatographic purification over silica gel (gradient; starting with dichloromethane, ending with ethyl acetate) afforded (1,2,4-triazin-3-yl)(piperidin-1-yl)methanone as a yellow oil. (295 mg, 87%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.61-1.62 (2H, m, CH_2), 1.71-1.73 (4H, m, CH_2), 3.26-3.29 (2H, m, CH_2), 3.78-3.81 (2H, m, CH_2), 8.73 (1H, d, *J* = 2.5, Ar), 9.29 (1H, d, *J* = 2.5, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 24.4, 25.3, 26.3, 43.1, 48.2, 149.3, 149.4, 162.5, 163.0. **FTIR**: 2497 (w), 2939 (m), 2858 (m), 1646 (s), 1448 (m), 1395 (m), 1345 (m), 1298(m), 1209 (m), 1132 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_9H_{13}N_4O$ 193.1089, found 193.1080.

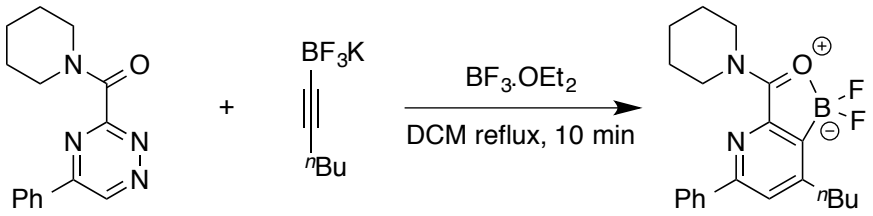
(3-(Difluoroboryl)-4,6-diphenylpyridin-2-yl)(piperidin-1-yl)methanone 70



Following the general procedure, a solution of (5-phenyl-1,2,4-triazin-3-yl)(piperidin-1-yl)methanone (50 mg, 0.19 mmol) and potassium (phenylethynyl)trifluoroborate (116 mg, 0.56 mmol) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.07 mL, 0.56 mmol). Trituration in DCM/petroleum ether afforded (3-(difluoroboryl)-4,6-diphenylpyridin-2-yl)(piperidin-1-yl)methanone (62 mg, 84%) as a brown solid. **M.p** 166-168 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.85-1.93 (6H, m, CH_2), 4.03-4.05 (2H, m, CH_2), 5.20-5.22 (2H, m, CH_2), 7.46-7.55 (6H, m, Ar), 7.93-7.99 (4H, m, Ar), 8.01 (1H, s, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 23.8, 26.1, 26.6, 48.0, 48.9, 122.8, 127.0, 128.4, 129.0 (x2), 129.1, 129.6, 138.6, 138.8, 153.2, 153.6, 158.0, 168.3. **^{19}F NMR** (235.1 MHz, $CDCl_3$): δ -149.2. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 7.6. **FTIR**: 3033 (w), 2940 (m), 2866 (w), 1642 (s), 1586 (m), 1575 (m), 1444 (m), 1250 (m),

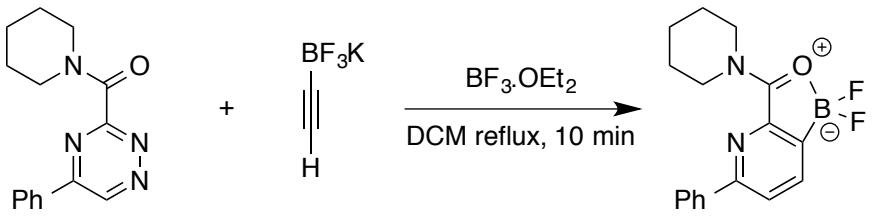
1177 (m), 1110 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{23}H_{22}{}^{11}BN_2OF_2$: 391.1793, found 391.1783.

(3-(Difluoroboryl)-4-butyl-6-phenylpyridin-2-yl)(piperidin-1-yl)methanone 71



Following the general procedure, a solution of (5-phenyl-1,2,4-triazin-3-yl)(piperidin-1-yl)methanone (50 mg, 0.19 mmol) and potassium (hex-1-ynyl)trifluoroborate (105 mg, 0.56 mmol) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.07 mL, 0.56 mmol). Chromatographic purification over florisil (gradient; starting with petroleum ether, ending with ethyl acetate) afforded (3-(difluoroboryl)-4-butyl-6-phenylpyridin-2-yl)(piperidin-1-yl)methanone (41 mg, 58%) as a white solid. **M.p** 112-114 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 0.94-0.98 (3H, m, CH_3), 1.14-1.47 (2H, m, CH_2), 1.70-1.78 (2H, m, CH_2), 1.82-1.89 (6H, m, CH_2), 2.86-2.90 (2H, m, CH_2), 3.98-4.01 (2H, m, CH_2), 5.15-5.17 (2H, m, CH_2), 7.43-7.52 (3H, m, Ar), 7.66 (1H, s, Ar), 7.91-7.93 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 14.0, 22.6, 23.8, 26.1, 26.5, 32.5, 34.9, 47.8, 48.8, 123.8, 126.9, 128.9, 129.3, 138.9, 152.3, 156.6, 157.7, 168.5. **^{19}F NMR** (235.1 MHz, $CDCl_3$): δ -152.9. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 7.4. **FTIR**: 3034 (w), 2929 (m), 2862 (w), 1644 (s), 1589 (m), 1444 (m), 1265 (w), 1174 (m), 1107 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{21}H_{26}{}^{11}BN_2OF_2$: 371.2106, found 371.2090.

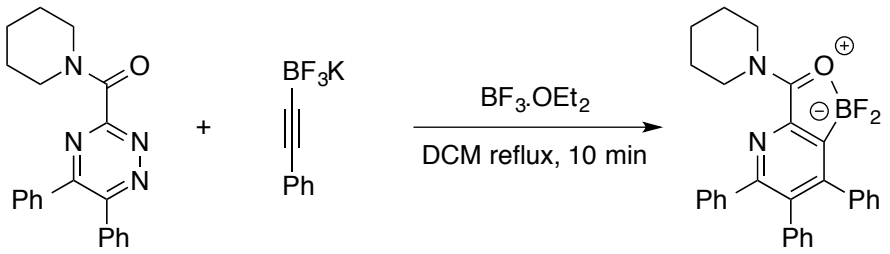
(3-(Difluoroboryl)-6-phenylpyridin-2-yl)(piperidin-1-yl)methanone 72



Following the general procedure, a solution of (5-phenyl-1,2,4-triazin-3-yl)(piperidin-1-yl)methanone (50 mg, 0.19 mmol) and potassium ethynyltrifluoroborate (74 mg, 0.56 mmol) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.07 mL, 0.56 mmol). Trituration in

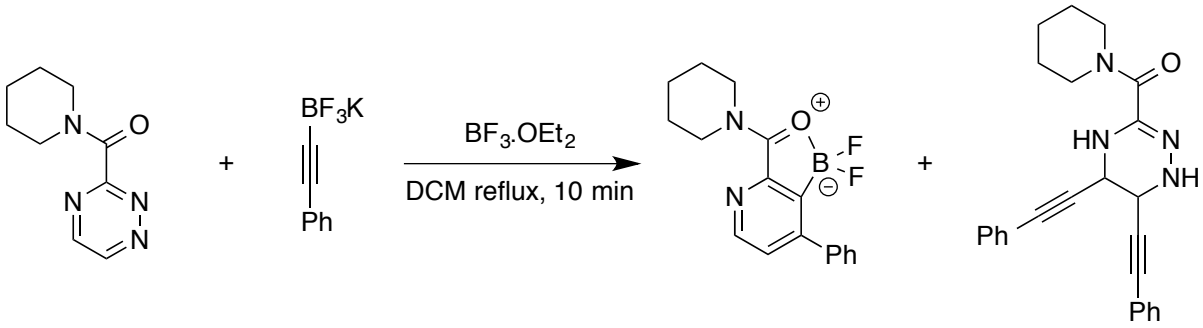
DCM/petroleum ether afforded (3-(difluoroboryl)-6-phenylpyridin-2-yl)(piperidin-1-yl)methanone (40 mg, 67%) as a white solid. **M.p** 214-216 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.85-1.90 (6H, m, CH_2), 3.99-4.01 (2H, m, CH_2), 5.13-5.16 (2H, m, CH_2), 7.46-7.52 (3H, m, Ar), 7.86 (1H, d, *J* = 8.0 Hz, Ar), 7.91-7.94 (2H, m, Ar), 8.15 (1H, d, *J* = 8.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 23.7, 26.0, 26.5, 47.8, 48.8, 124.1, 126.9, 129.0, 129.6, 138.5, 139.2, 152.6, 157.4, 168.2. **^{19}F NMR** (235.1 MHz, $CDCl_3$): δ -154.0. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 7.1. **FTIR**: 3426 (w), 3027 (w), 2951 (w), 2862 (w), 1646 (s), 1584 (m), 1442 (m), 1353 (m), 1271 (m), 1216 (m), 1121 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{17}H_{18}{}^{11}BN_2OF_2$: 315.1480, found 315.1482.

(3-(Difluoroboranyl)-4,5,6-triphenylpyridin-2-yl)(piperidin-1-yl)methanone 73



Following the general procedure, a solution of (5,6-diphenyl-1,2,4-triazin-3-yl)(piperidin-1-yl)methanone (50 mg, 0.15 mmol, 1.0 eq) and potassium phenylethynyltrifluoroborate (91 mg, 0.44 mmol, 3.0 eq) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.05 mL, 0.44 mmol, 3.0 eq). Chromatographic purification over silica (gradient; starting with petrol, ending with ethyl acetate) afforded (3-(difluoroboranyl)-4,5,6-triphenylpyridin-2-yl)(piperidin-1-yl)methanone (53 mg, 78%) as a white solid. **M.p.** 246-248 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.94-1.99 (6H, m, CH_2), 4.14 (2H, t, *J* = 5.0 Hz, CH_2), 5.23 (t, *J* = 5.0 Hz, CH_2), 6.98 (2H, dd, *J* = 8.0, 1.5 Hz, Ar), 7.15-7.21 (3H, m, Ar), 7.33-7.39 (10H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 23.9, 26.3, 26.7, 47.9, 48.9, 127.0, 127.5 (x2), 127.7, 127.8 (x2), 129.7, 130.0, 131.3, 137.7, 138.2, 138.3, 140.5, 151.2, 153.4, 158.8, 168.1. **^{19}F NMR** (376.6 MHz, $CDCl_3$): δ -150.22. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 7.3. **FTIR**: 2941 (w), 1643 (s), 1551 (m), 1425 (s), 1288 (m), 1128 (s), 1008 (s), 895 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{29}H_{26}{}^{11}BN_2F_2O$: 467.2101, found 467.2110.

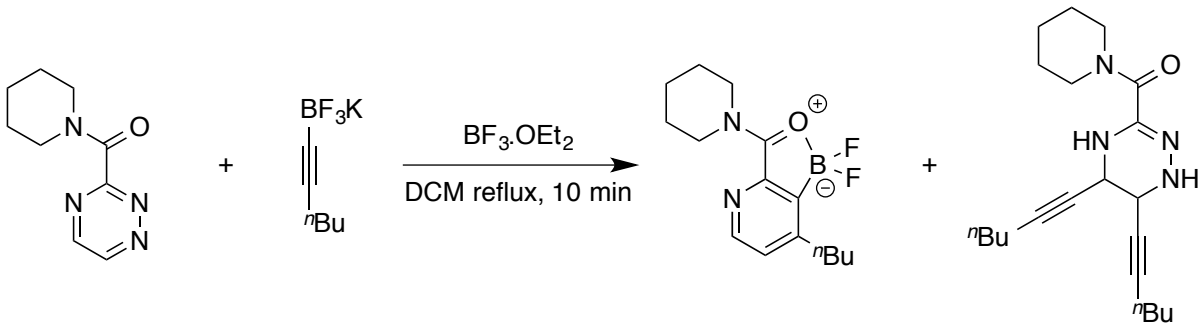
(3-(Difluoroboryl)-4-phenylpyridin-2-yl)(piperidin-1-yl)methanone 74



Following the general procedure, a solution of (1,2,4-triazin-3-yl)(piperidin-1-yl)methanone (20 mg, 0.15 mmol) and potassium (phenylethynyl)trifluoroborate (96 mg, 0.46 mmol) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.06 mL, 0.46 mmol). Chromatographic purification over florisil (gradient; starting with dichloromethane, ending with ethyl acetate) afforded (3-(difluoroboryl)-4-phenylpyridin-2-yl)(piperidin-1-yl)methanone (6 mg, 13%) as a white solid. **M.p** 168-170 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.84-1.87 (6H, m, CH_2), 3.99-4.02 (2H, m, CH_2), 5.05-5.08 (2H, m, CH_2), 7.44-7.56 (4H, m, Ar), 7.88-7.90 (2H, m, Ar), 8.62-8.63 (1H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 23.8, 26.1, 26.5, 47.8, 48.8, 125.7, 128.4, 128.9, 129.1, 138.5, 149.6, 152.8, 153.0, 168.2. **^{19}F NMR** (235.1 MHz, $CDCl_3$): δ -149.3. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 7.5. **FTIR**: 3033 (w), 2923 (m), 2851 (w), 1645 (s), 1573 (m), 1419 (m), 1306 (m), 1194 (w), 1111 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{17}H_{18}{}^{11}BN_2OF_2$: 315.1480, found 315.1488.

Alkyne addition side product was isolated as a brown oil (13 mg, 22%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.63-1.67 (6H, m, CH_2), 3.62-3.65 (2H, m, CH_2), 3.91 (1H, d, J = 7.0 Hz, CH), 3.97-4.03 (2H, m, CH_2), 4.71 (1H, d, J = 7.0 Hz, CH), 5.35 (1H, br, NH), 5.59 (1H, br, NH), 7.33-7.35 (6H, m, Ar), 7.47-7.49 (4H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 24.6, 25.7, 26.7, 44.5, 47.2, 48.3, 50.0, 84.6, 84.9, 85.4, 86.0, 122.1, 122.2, 128.2, 128.3, 128.6, 128.7, 131.9, 132.1, 140.3, 161.4. **FTIR**: 3292 (w), 2937 (w), 2895 (w), 1617 (s), 1490 (m), 1443 (m), 1281 (w), 1026 (w), 757 (w), 691 (w) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{25}H_{25}N_4O$: 397.2028, found 397.2039.

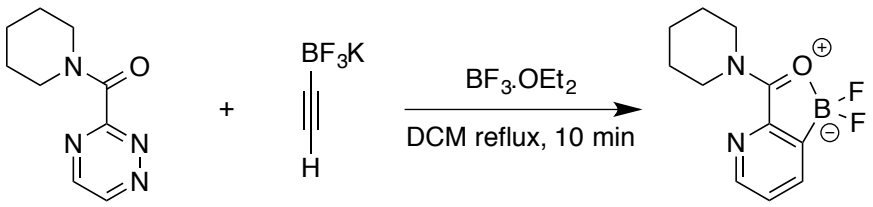
(3-(Difluoroboryl)-4-butylpyridin-2-yl)(piperidin-1-yl)methanone 75



Following the general procedure, a solution of (1,2,4-triazin-3-yl)(piperidin-1-yl)methanone (20 mg, 0.15 mmol) and potassium (hex-1-ynyl)trifluoroborate (87 mg, 0.46 mmol) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.06 mL, 0.46 mmol). Chromatographic purification over florisil (gradient; starting with dichloromethane, ending with ethyl acetate) afforded (3-(difluoroboryl)-4-butylpyridin-2-yl)(piperidin-1-yl)methanone (5 mg, 11%) as a colourless oil. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 0.92-0.95 (3H, m, CH_3), 1.36-1.42 (2H, m, CH_2), 1.66-1.70 (2H, m, CH_2), 1.82-1.83 (6H, m, CH_2), 2.79-2.83 (2H, m, CH_2), 3.95-3.98 (2H, m, CH_2), 5.00-5.03 (2H, m, CH_2), 7.20 (1H, d, *J* = 5.0 Hz, Ar), 8.45 (1H, d, *J* = 5.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 13.9, 22.4, 23.7, 26.0, 26.4, 32.3, 34.5, 47.6, 48.6, 126.7, 149.2, 152.1, 155.8, 168.4. **^{19}F NMR** (235.1 MHz, $CDCl_3$): δ -153.2. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 6.1. **FTIR**: 3033 (w), 2929 (m), 2860 (m), 1643 (s), 1581 (m), 1419 (m), 1302 (m), 1187 (w), 1107 (m), 1009 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{15}H_{22}{}^{11}BN_2OF_2$: 295.1793, found 295.1791.

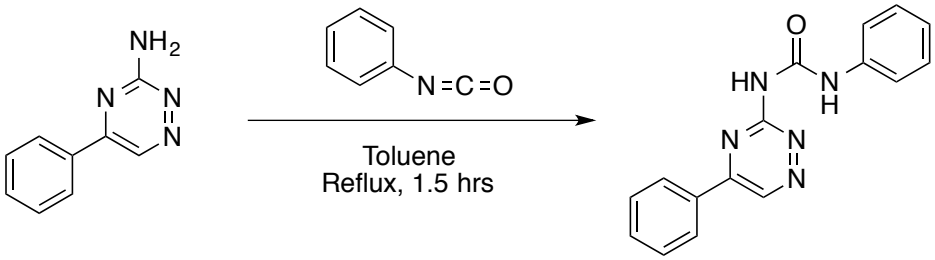
Side product was isolated as a brown oil (13 mg, 24%) and tentatively assigned on the basis of ^{1}H NMR spectroscopy and HRMS. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 0.89-0.92 (6H, m, CH_3), 1.40-1.64 (14H, m, CH_2), 2.20-2.22 (4H, m, CH_2), 3.41-3.43 (1H, m, CH), 3.57 (2H, m, CH_2), 3.89-3.93 (2H, m, CH_2), 4.23-4.26 (1H, m, CH), 5.11 (1H, br, NH), 5.26 (1H, br, NH). **HRMS**: (ESI) [MH^+] calcd for $C_{21}H_{33}N_4O$: 357.2654, found 357.2646.

(3-(Difluoroboryl)-pyridin-2-yl)(piperidin-1-yl)methanone 76



Following the general procedure, a solution of (1,2,4-triazin-3-yl)(piperidin-1-yl)methanone (20 mg, 0.15 mmol) and potassium ethynyltrifluoroborate (61 mg, 0.46 mmol) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.06 mL, 0.46 mmol). Trituration in DCM/petroleum ether afforded (3-(difluoroboryl)-pyridin-2-yl)(piperidin-1-yl)methanone (9 mg, 25%) as a yellow oil. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.83-1.85 (6H, m, CH_2), 3.96-3.99 (2H, m, CH_2), 5.00-5.02 (2H, m, CH_2), 7.41 (1H, dd, *J* = 5.0, 7.5 Hz, Ar), 8.09 (1H, dd, *J* = 1.5, 7.5 Hz, Ar), 8,58 (1H, dd, *J* = 1.5, 5.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 23.7, 26.0, 26.5, 47.6, 48.7, 127.1, 138.3, 149.2, 152.5, 168.1. **^{19}F NMR** (235.1 MHz, $CDCl_3$): δ -154.2. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 7.3. **FTIR**: 3444 (m), 2928 (w), 2858 (w), 1646 (s), 1567 (w), 1419 (m), 1303 (m), 1265 (m), 1120 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{11}H_{14}{}^{11}BN_2OF_2$: 239.1167, found 239.1177.

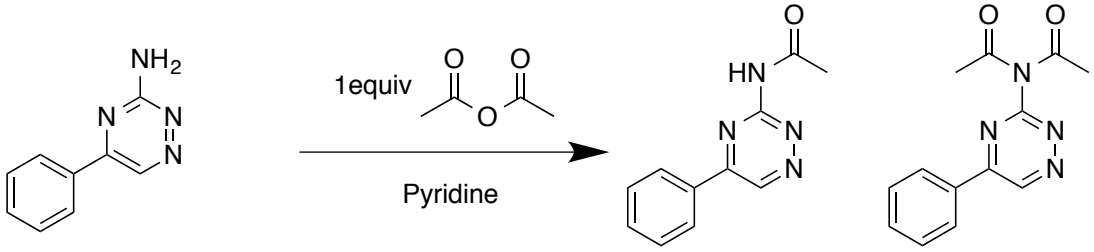
1-Phenyl-3-(5-phenyl-1,2,4-triazin-3-yl)urea 78



To a suspension of 5-phenyl-3-amino-1,2,4-triazine (0.172 g, 1.0 mmol, 1.0 eq) in toluene (5 mL) was added neat phenyl-isocyanate (0.11 mL, 1.1 mmol, 1.1 eq) at RT. The resulting solution was heated to reflux for 1.5 hrs. After cooling to RT, the suspension was evaporated under vacuum. The residue was then dissolved in 100 mL of hot EtOH and filtered through a fritted funnel to afford the product as a white solid (235 mg, 0.81 mmol, 81%). **M.p.** 240-242 °C. **^{1}H NMR** (250 MHz, d^6-DMSO): δ 7.07-7.12 (1H, m, C-H), 7.34-7.40 (2H, m, C-H), 7.57-7.68 (5H, m, C-H), 8.31-8.35 (2H, m, C-H), 9.76 (1H, s, C-H), 10.60 (1H, br, N-H), 10.96 (1H, br, N-H). **FTIR:** 3099 (w), 2959 (w), 2842 (w), 1694 (s), 1591 (m), 1507

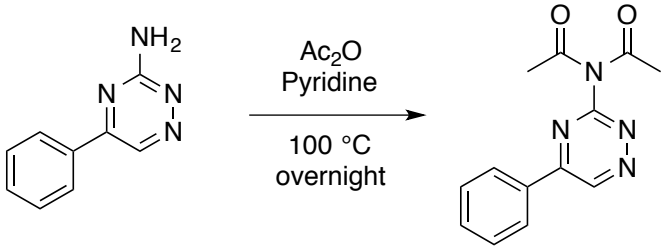
(s), 1447 (s), 1374 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calculated for $C_{16}H_{14}N_5O$: 292.1198, found: 292.1194. The poor solubility of the product prevented analysis by ^{13}C NMR spectroscopy.

_N_-(5-phenyl-1,2,4-triazin-3-yl)acetamide 79



To a solution of 5-phenyl-3-amino-1,2,4-triazine (0.172 g, 1.0 mmol, 1.0 eq) dissolved in pyridine (3 mL) at 100 °C was added acetic anhydride (0.1 mL, 1.0 mmol, 1.0 eq). The resulting solution was stirred at 100 °C overnight. After cooling to RT, the mixture was evaporated under vacuum. The residue was purified by flash chromatography on silica gel (petrol/EtOAc 1:1) to afford *N*-(5-phenyl-1,2,4-triazin-3-yl)acetamide as a yellow solid (50 mg, 0.23 mmol, 23%). **M.p.** 174-176 °C. **^{1}H NMR** (250 MHz, $CDCl_3$): δ 2.69 (3H, s, C-H), 7.60-7.63 (3H, m, C-H), 8.16-8.20 (2H, m, C-H), 8.32 (1H, br, N-H), 9.46 (1H, s, C-H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 25.6, 127.8, 129.2, 129.5, 132.9, 133.1, 141.9, 156.3, 158.2. **FTIR:** 3210 (w), 3047 (w), 1715 (m), 1524 (s), 1434 (m), 1236 (m), 1079 (w) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{11}H_{11}N_4O$: 215.0933, found: 215.0926. *N*-acetyl-*N*-(5-phenyl-1,2,4-triazin-3-yl)acetamide was also obtained as a yellow solid (66 mg, 0.26 mmol, 26%).

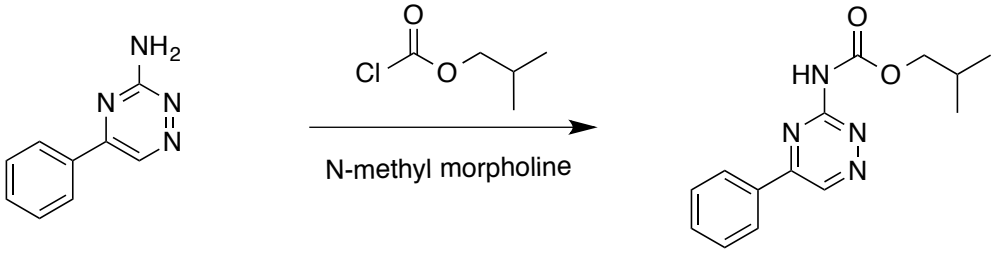
_N_-acetyl-_N_-(5-phenyl-1,2,4-triazin-3-yl)acetamide 80



To a solution of 5-phenyl-3-amino-1,2,4-triazine (0.172 g, 1.0 mmol, 1.0 eq) dissolved in pyridine (3 mL) at 100 °C was added acetic anhydride (3 mL). The resulting solution was stirred at 100 °C overnight. After cooling to RT, the mixture was evaporated under vacuum. The residue was purified by flash chromatography on silica gel (petrol/EtOAc 1:1) to afford

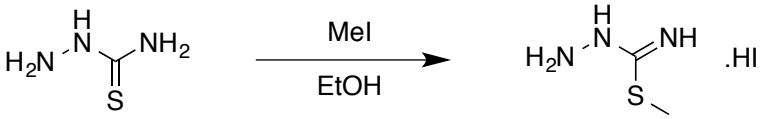
the product as a yellow solid (161 mg, 0.75 mmol, 75%). **M.p.** 112-114 °C. **^{1}H NMR** (250 MHz, $CDCl_3$): δ 2.40 (6H, s, C-H), 7.61-7.65 (3H, m, C-H), 8.20-8.24 (2H, m, C-H), 9.74 (1H, s, C-H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 26.4, 128.1, 129.7, 132.1, 133.6, 145.2, 158.1, 161.1, 171.8. **FTIR:** 3263 (w), 3065 (w), 1728 (s), 1600 (w), 1547 (m), 1503 (m), 1447 (w), 1369 (s), 1314 (m), 1288 (m), 1234 (s), 1042 (w) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{13}H_{13}N_4O_2$: 257.1039, found: 257.1028.

Isobutyl (5-phenyl-1,2,4-triazin-3-yl)carbamate 81



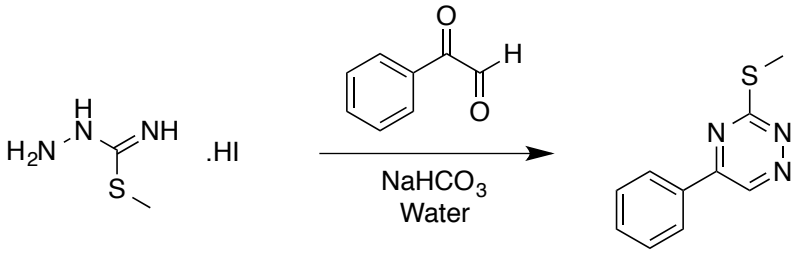
To a suspension of 5-phenyl-3-amino-1,2,4-triazine (0.172 g, 1.00 mmol, 1.0 eq) in DCM (10 mL) at 0 °C under N_2 was added isobutyl chloroformate (0.15 mL, 1.15 mmol, 1.2 eq) and *N*-methyl morpholine (0.17 mL, 1.50 mmol, 1.5 eq). The resulting solution was stirred at 0 °C for 3 hours. The mixture was quenched with dilute HCl (1 M, 6 mL), and then extracted with DCM (2 x 10 mL) and washed with water (2 x 6 mL) and brine (6 mL). After drying over $MgSO_4$ and filtration, the solution was evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel (petrol/EtOAc 1:1) to afford the product as a yellow solid (93.7 mg, 0.34 mmol, 34%). **M.p.** 110-112 °C. **^{1}H NMR** (250 MHz, $CDCl_3$): δ 1.01-1.02 (6H, d, J = 6.5 Hz, C-H), 2.05-2.08 (1H, m, C-H), 4.08-4.10 (2H, d, J = 6.5 Hz, C-H), 7.54-7.61 (3H, m, C-H), 8.22-8.24 (2H, m, C-H), 8.43 (1H, br, N-H), 9.44 (1H, s, C-H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 19.0, 27.9, 72.2, 127.9, 129.4, 132.8, 133.1, 141.7, 151.5, 156.4, 158.6. **FTIR:** 3217 (w), 2961 (m), 1757 (m), 1566 (m), 1519 (s), 1314 (m), 1216 (s), 1090 (m), 769 (m) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{14}H_{17}N_4O_2$: 273.1352, found: 273.1365.

S-methylthiosemicarbazide hydrogen iodide 83[142]



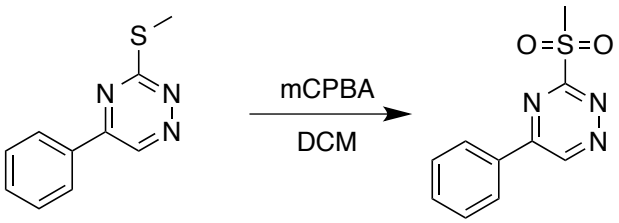
A solution of hydrazinecarbothioamide (10.0 g, 109.7 mmol, 1.0 eq) in ethanol (100 mL) was heated to 60 °C and methyliodide (6.83 mL, 109.7 mmol, 1.0 eq) was added. After stirring for 30 min, the resulting suspension was filtered to give a white solid (19.8 g, 84.8 mmol, 77%). **M.p.** 132 °C (lit. 137-139 °C). **^{1}H NMR** (400 MHz, d^{6}-DMSO): δ 2.57 (3H, s, C-H), 5.19 (2H, br, N-H), 9.14 (2H, br, N-H), 10.57 (1H, br).**^{13}C NMR** (101 MHz, $CDCl_3$): δ 13.0, 167.9.

3-(Methylthio)-5-phenyl-1,2,4-triazine 84[28]



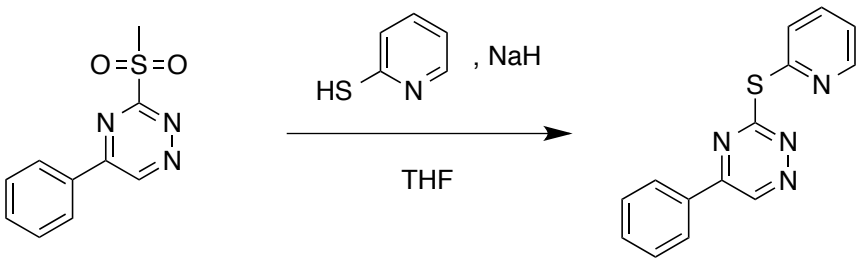
A solution of phenylglyoxal (0.78 g, 5.16 mmol, 1.2 eq) and $NaHCO_3$ (0.40 g, 4.73 mmol, 1.1 eq) in water (10 mL) at 0 °C was added to a solution of *S*-methylthiosemicarbazide hydrogen iodide (1.00 g, 4.30 mmol, 1.0 eq) dissolved in water (6 mL) at 0 °C. After stirring for 5 hours at 0 °C, the mixture was extracted with DCM (2 x 50 mL). The organic layers were combined and washed with brine (10 mL), dried over $MgSO_4$, filtered and evaporated under reduced pressure. The product was collected as a yellow solid (0.83 g, 4.08 mmol, 95%). **M.p.** 90-92 °C (lit. 99-100.5 °C). **^{1}H NMR** (250 MHz, $CDCl_3$): δ 2.74 (3H, s, C-H), 7.55-7.60 (3H, m, C-H), 8.15-8.18 (2H, m, C-H), 9.38 (1H, s, C-H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 13.9, 127.7, 129.4, 132.7, 133.2, 142.0, 154.6, 173.8.

3-Methylsulfonyl-5-phenyl-1,2,4-triazine 85[30]



To a solution of 3-(methylthio)-5-phenyl-1,2,4-triazine (5.82 g, 28.61 mmol, 1.0 eq) in dry DCM (150 mL) at 0 °C was added m-chloroperbenzoic acid (15.47 g, 69.02 mmol, 2.4 eq) as a solid in small portions over the course of a few minutes. After stirring for 3 hours at RT, the solution was evaporated under reduced pressure. The resulting solid was suspended in boiling ether and the undissolved solid was collected by filtration and washed with ether to afford the product as a pale yellow solid (6.06 g, 25.75 mmol, 90%). **M.p.** 134-136 °C (lit. 146-148 °C). **^{1}H NMR** (250 MHz, $CDCl_3$): δ 3.56 (3H, s, C-H), 7.62-7.71 (3H, m, C-H), 8.29-8.33 (2H, m, C-H), 9.86 (1H, s, C-H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 39.7, 128.4, 129.8, 131.4, 134.3, 147.9, 157.6, 166.8.

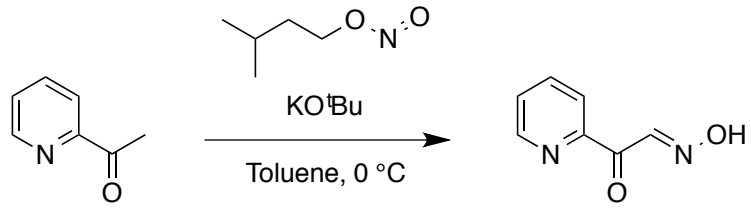
5-Phenyl-3-(2-pyridylthio)-1,2,4-triazine 86



To a solution of 2-mercaptopyridine (300 mg, 2.70 mmol, 1.3 eq) in dry THF (20.0 mL) at 0 °C under N_2 was added sodium hydride (140 mg, 3.40 mmol, 1.6 eq). The solution was stirred at RT for 1 hour. 3-Methylsulfonyl-5-phenyl-1,2,4-triazine (500 mg, 2.10 mmol, 1.0 eq) was then added and the mixture was stirred at RT for 3 hours. The mixture was quenched with MeOH and the solvent was evaporated under reduced pressure. The residue was redissolved in DCM and washed with water and brine. After drying over $MgSO_4$ and filtration, the solution was evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel (DCM/EtOAc 9:1) to afford the product as a yellow solid (460 mg, 1.73 mmol, 82%). **M.p.** 116-117 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.35-7.38 (1H, m, C-H), 7.48-7.52 (2H, m, C-H), 7.55-7.59 (1H, m, C-H), 7.78-7.82 (1H, m, C-H), 7.85-7.87

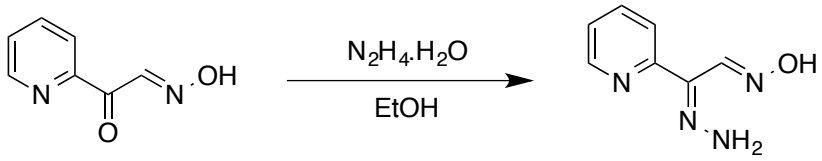
(1H, m, C-H), 7.99-8.02 (2H, m, C-H), 8.68-8.69 (1H, m, C-H), 9.41 (1H, s, C-H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 123.5, 127.7, 128.5, 129.4, 130.1, 132.8, 137.4, 142.7, 150.6, 152.3, 155.1, 173.1. **FTIR:** 3048 (w), 2923 (w), 2856 (w), 1573 (m), 1534 (s), 1496 (s), 1420 (m), 1318 (m), 1241 (s), 1117 (m) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{14}H_{11}N_4S$: 267.0704, found: 267.0707.

2-Oxo-2-(pyridin-2-yl)acetaldehyde oxime 88



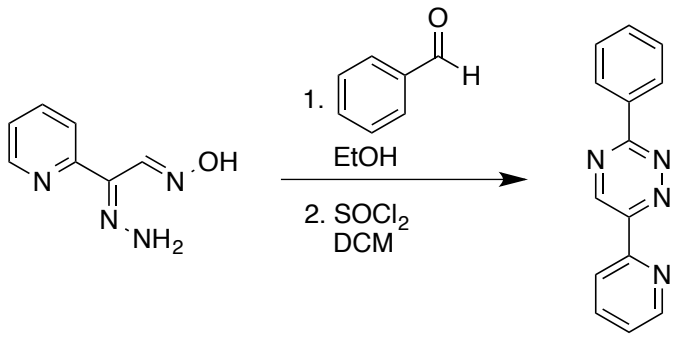
To a solution of 2-acetylpyridine (5.00 mL, 44.5 mmol, 1.0 eq) in anhydrous toluene (220 mL) at -10 °C under argon was added potassium *tert*-butoxide (12.5 g, 111.5 mmol, 2.5 eq). The solution was stirred at -10 °C for 15 min. Isopentyl nitrite (7.10 mL, 53.5 mmol, 1.2 eq) was then added dropwise and the mixture was stirred at -10 °C for 30 min. The mixture was quenched with iced water (200 mL) and acetic acid (22.5 mL), extracted with AcOEt and washed with brine. After drying over $MgSO_4$ and filtration, the solution was evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel (petrol/EtOAc 8:2 then DCM/AcOEt 8:2) to afford the product as a pink solid (1.23 g, 8.2 mmol, 18%). **M.p.** 110-112 °C. **^{1}H NMR** (400 MHz, d^6-DMSO): δ 7.67-7.71 (1H, m, Ar), 8.00-8.07 (2H, m, Ar), 8.75-8.76 (2H, m, Ar and OH), 12.81 (1H, s, CH).**^{13}C NMR** (101 MHz, d^6-DMSO): δ 123.3, 128.3, 138.2, 145.7, 149.8, 153.6, 186.9. **FTIR:** 3262 (m), 2924 (m), 2685 (m), 1663 (s), 1584 (m), 1454 (s), 1318 (m), 1253 (w) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_7H_7N_2O_2$: 151.0508, found: 151.0511.

2-Hydrazono-2-(pyridin-2-yl)acetaldehyde oxime 89[47]



To a solution of 2-oxo-2-(pyridin-2-yl)acetaldehyde oxime (500 mg, 3.33 mmol, 1.0 eq) in ethanol (3.0 mL) was added dropwise hydazine hydrate (0.32 mL, 6.66 mmol, 2.0 eq). The solution was stirred at RT overnight. Water was added and the resulting precipitate was filtered and dried to afford the product as a pale yellow solid (341 mg, 2.08 mmol, 62%). **M.p.** 152-154 °C. **^{1}H NMR** (400 MHz, d^{6}-DMSO): δ 7.18-7.21 (1H, m, Ar), 7.69-7.74 (1H, m, Ar), 7.80-7.82 (1H, m, Ar), 8.44-8.45 (1H, m, Ar), 8.78 (1H, s, OH), 9.45 (2H, br, NH_2), 11.48 (1H, s, CH).**^{13}C NMR** (101 MHz, d^{6}-DMSO): δ 118.6, 121.9, 129.5, 136.9, 145.3, 148.6, 156.1. **FTIR:** 3369 (w), 3161 (w), 1594 (w), 1425 (m), 1213 (w), 894 (m), 778 (s), 690 (w) cm^{-1}. **HRMS**: (ES^{+}) [MH^{+}] calcd for $C_7H_9N_4O$: 165.0776, found: 165.0775.

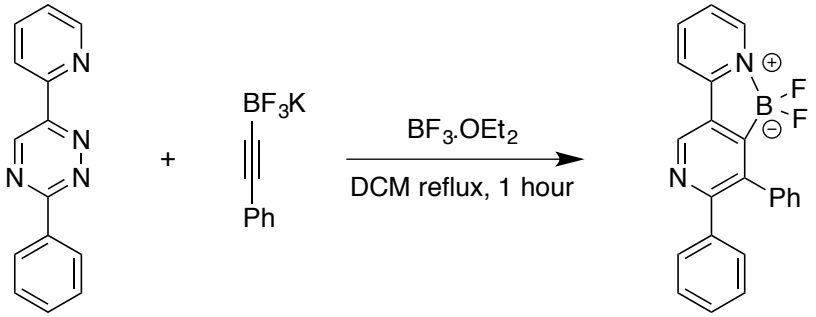
3-Phenyl-6-(2-pyridyl)-1,2,4-triazine 91



To a solution of 2-hydrazono-2-(pyridin-2-yl)acetaldehyde oxime (261 mg, 1.59 mmol, 1.0 eq) in ethanol (7.0 mL) was added benzaldehyde (0.16 mL, 1.59 mmol, 1.0 eq). The solution was stirred at RT overnight. The resulting mixture was evaporated under reduced pressure. The solid was then dissolved in dry dichloromethane (7.0 mL) and thionyl chloride (0.12 mL, 1.59 mmol) was added at 0 °C. The mixture was stirred at RT for 1.5 hours. The solution was neutralized with $NaHCO_3$, extracted with DCM and washed with water and brine. After drying over $MgSO_4$ and filtration, the solution was evaporated under reduced pressure and the residue was purified by flash chromatography over silica gel (gradient; starting with petroleum ether, ending with ethyl acetate) to afford 3-phenyl-6-(2-pyridyl)-1,2,4-triazine as a yellow solid (110 mg, 30%). **M.p** 162-164 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.42-7.46 (1H, m, Ar), 7.56-7.58 (3H, m, Ar), 7.90-7.94 (1H, m, Ar), 8.60-8.63 (2H, m, Ar), 8.65-8.67 (1H, m, Ar), 8.75-8.77 (1H, m, Ar), 9.69 (1H, s, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 121.5, 125.2, 128.4, 129.0, 131.9, 134.7, 137.4, 148.0, 149.7, 151.7, 154.1,

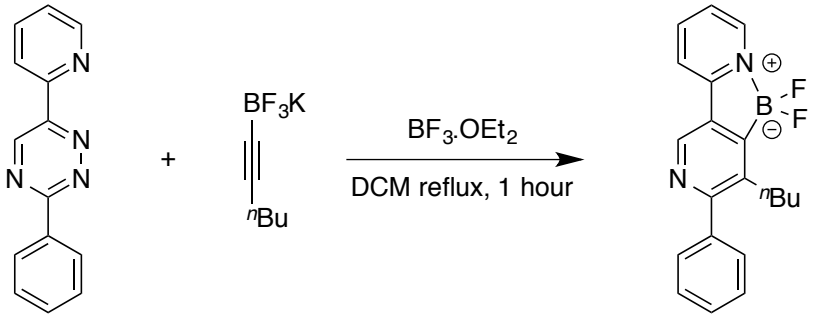
163.5. **FTIR**: 3062 (w), 1587 (m), 1404 (s), 1086 (w), 787 (w), 690 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_9H_{13}N_4O$: 193.1089 found 193.1080.

4-(Difluoroboryl)-2,3-diphenyl-5,2'-bipyridine 92



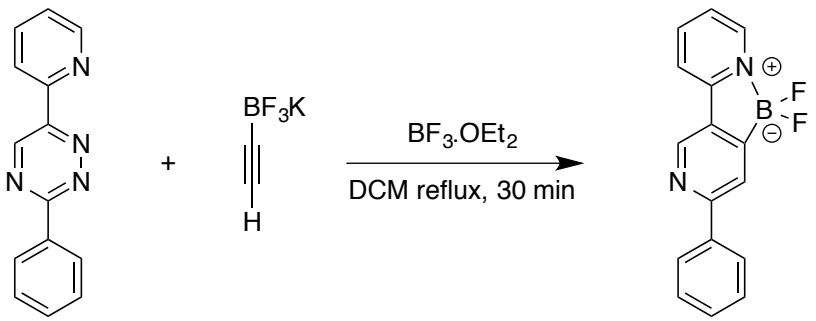
Following the general procedure, a solution of 3-phenyl-6-(2-pyridyl)-1,2,4-triazine (20 mg, 0.09 mmol) and potassium (phenylethynyl)trifluoroborate (53 mg, 0.26 mmol) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.03 mL, 0.26 mmol) for 1 hour. Chromatographic purification over silica gel (gradient; starting with dichloromethane, ending with ethyl acetate) afforded 4-(difluoroboryl)-2,3-diphenyl-5,2'-bipyridine (26 mg, 87%) as a colourless solid. **M.p** 222-224 °C. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.23-7.25 (3H, m, Ar), 7.27-7.31 (3H, m, Ar), 7.36-7.40 (4H, m, Ar), 7.55-7.57 (1H, m, Ar), 8.08 (1H, d, *J* = 8.0 Hz, Ar), 8.18-8.21 (1H, m, Ar), 8.54-8.55 (1H, d, *J* = 5.5 Hz, Ar), 9.08 (1H, s, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): δ 118.5, 124.1, 127.1, 127.8, 127.9, 128.0, 130.0, 130.1, 131.6, 139.0, 139.1, 140.3, 141.4, 142.2, 143.8, 153.8, 160.2. **^{19}F NMR** (376.5 MHz, $CDCl_3$): δ -155.7. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 7.6. **FTIR**: 3057 (w), 2924 (w), 1625 (s), 1575 (m), 1486 (s), 1386 (s), 1160 (m), 1099 (s), 1017 (m), 767 (s), 733 (s), 700 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{22}H_{16}{}^{11}BF_2N_2$: 357.1375, found 357.1379.

3-Butyl-4-(difluoroboryl)-2-phenyl-5,2'-bipyridine 93



Following the general procedure, a solution of 3-phenyl-6-(2-pyridyl)-1,2,4-triazine (20 mg, 0.09 mmol) and potassium (hex-1-ynyl)trifluoroborate (48 mg, 0.26 mmol) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.03 mL, 0.26 mmol) for 1 hour. Chromatographic purification over silica gel (gradient; starting with dichloromethane, ending with ethyl acetate) afforded 3-butyl-4-(difluoroboryl)-2-phenyl-5,2'-bipyridine (13 mg, 42%) as a colourless solid. **M.p** 99-101 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 0.77-0.81 (3H, m, CH_3), 1.24-1.29 (2H, m, CH_2), 1.52-1.56 (2H, m, CH_2), 2.83-2.87 (2H, m, CH_2), 7.41-7.52 (5H, m, Ar), 7.58-7.60 (1H, m, Ar), 8.04-8.06 (1H, m, Ar), 8.18-8.22 (1H, m, Ar), 8.59-8.61 (1H, m, Ar), 8.92 (1H, s, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 13.7, 22.8, 31.7, 33.3, 118.6, 124.0, 128.1, 128.2, 128.7, 131.7, 139.7, 140.0, 140.7, 142.1, 143.9, 154.2, 161.9. **^{19}F NMR** (376.5 MHz, $CDCl_3$): δ -158.7. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 7.7. **FTIR**: 2957 (m), 1624 (s), 1487 (s), 1387 (m), 1325 (w), 1188 (m), 1098 (m), 1018 (m), 778 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{20}H_{20}{}^{10}BF_2N_2$: 336.1724, found 336.1720.

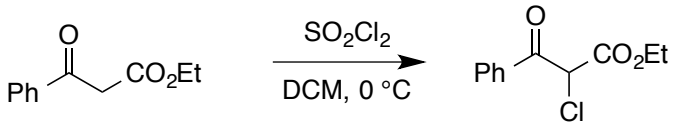
4-(Difluoroboryl)-2-phenyl-5,2'-bipyridine 94



Following the general procedure, a solution of 3-phenyl-6-(2-pyridyl)-1,2,4-triazine (20 mg, 0.09 mmol) and potassium ethynyltrifluoroborate (34 mg, 0.26 mmol) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.03 mL, 0.26 mmol) for 30 min. Chromatographic

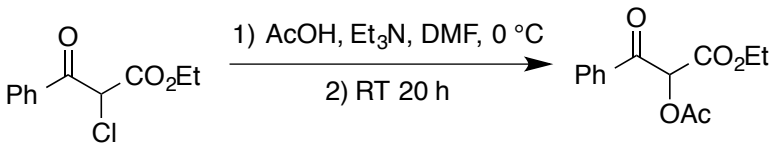
purification over silica gel (gradient; starting with dichloromethane, ending with ethyl acetate) afforded 4-(difluoroboryl)-2-phenyl-5,2'-bipyridine (7 mg, 28%) as a colourless solid. **M.p** 184-186 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.44-7.51 (3H, m, Ar), 7.55-7.59 (1H, m, Ar), 8.04-8.10 (4H, m, Ar), 8.13-8.22 (1H, m, Ar), 8.59-8.61 (1H, m, Ar), 9.09 (1H, s, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 118.5, 122.0, 123.9, 127.4, 128.8, 129.6, 131.6, 139.1, 142.3, 142.9, 143.9, 154.1, 159.8. **^{19}F NMR** (376.5 MHz, $CDCl_3$): δ -160.0. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 7.7. **FTIR**: 3407 (w), 1625 (s), 1486 (m), 1448 (s), 1373 (m), 1168 (s), 1098 (m), 1018 (m), 773 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{16}H_{13}{}^{11}BO_2N_2$: 277.1143, found 277.1155.

Ethyl 2-chloro-3-oxo-3-phenylpropanoate 96[56]



To a stirred solution of ethyl benzoylacetate (4.50 mL, 26.0 mmol, 1.0 eq) in dry CH_2Cl_2 (50.0 mL) at 0 °C under N_2 was slowly added sulfuryl chloride (2.07 mL, 28.6 mmol, 1.1 eq). After stirring for one hour at room temperature, the solution was washed with a saturated solution of sodium carbonate. The organic layer was separated, dried over $MgSO_4$ and evaporated to give ethyl 2-chloro-3-oxo-3-phenylpropanoate as a colourless oil (5.99 g, 100%). The crude material was used in the next step without further purification. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.25 (3H, t, J = 7.0 Hz, CH_3), 4.30 (2H, q, J = 7.0 Hz, CH_2), 5.61 (1H, s, CHCl), 7.49-7.53 (2H, m, Ar), 7.62-7.66 (1H, m, Ar), 7.99-8.02 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 13.9, 58.0, 63.2, 128.7, 128.9, 129.3, 134.4, 165.3, 188.2.

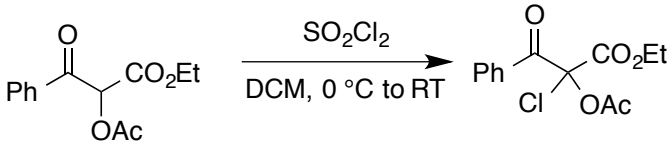
Ethyl 2-acetoxy-3-oxo-3-phenylpropanoate 97[56]



To a stirred solution of glacial acetic acid (13.4 mL, 234 mmol, 9.0 eq) in DMF (70 mL) at 0 °C was added slowly Et_3N (18.1 mL, 130 mmol, 5.0 eq). After warming to room temperature, ethyl 2-chloro-3-oxo-3-phenylpropanoate (5.89 g, 26 mmol, 1.0 eq) was added.

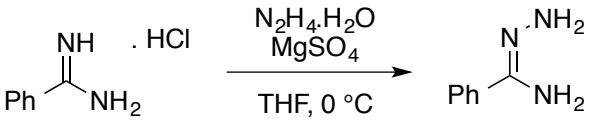
The solution was allowed to stir for 20 hours at room temperature. The solution was washed with water and an aqueous solution of LiCl (5%), and extracted with DCM. The organic layer was separated, dried over $MgSO_4$ and evaporated to give ethyl 2-acetoxy-3-oxo-3-phenylpropanoate as a colourless oil (5.94 g, 91%). The crude material was used in the next step without further purification. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.22 (3H, t, *J* = 7.0 Hz, CH_3), 2.23 (3H, s, CH_3), 4.26 (2H, q, *J* = 7.0 Hz, CH_2), 6.33 (1H, s, CHOAc), 7.48-7.52 (2H, m, Ar), 7.61-7.65 (1H, m, Ar), 7.99-8.02 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 13.9, 20.5, 62.5, 74.5, 128.8, 129.2, 134.2 (x2), 165.1, 169.5, 189.7.

Ethyl 2-acetoxy-2-chloro-3-oxo-3-phenylpropanoate 98[56]



To a stirred solution of 2-acetoxy-3-oxo-3-phenylpropanoate (5.94 g, 24 mmol, 1.0 eq) in DCM (60 mL) at 0 °C was added dropwise SO_2Cl_2 (9.6 mL, 119 mmol, 5.0 eq). The reaction was allowed to warm to room temperature and stirred for 48 hours. The solution was then washed with a saturated solution of sodium carbonate. The organic layer was separated, dried over $MgSO_4$ and evaporated to give ethyl 2-acetoxy-2-chloro-3-oxo-3-phenylpropanoate as a colourless oil (7.11 g, 100%). The crude material was used in the next step without further purification. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.29 (3H, t, *J* = 7.0 Hz, CH_3), 2.20 (3H, s, CH_3), 4.30 (2H, q, *J* = 7.0 Hz, CH_2), 7.46-7.50 (2H, m, Ar), 7.60-7.62 (1H, m, Ar), 8.08-8.11 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 13.8, 21.0, 64.0, 64.7, 128.6, 130.1, 134.1, 134.2, 163.5, 167.3, 185.5.

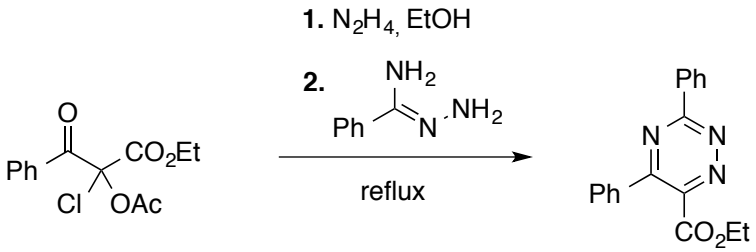
Benzamidrazone 100



To a stirred suspension of hydrazine hydrate (3.10 mL, 64 mmol, 2.0 eq) and magnesium sulfate (2.0 g, 16 mmol, 0.5 eq) in dry THF (65 mL) at 0 °C under argon was added benzamidine hydrochloride (5.0 g, 32 mmol, 1.0 eq). The reaction was stirred for 4

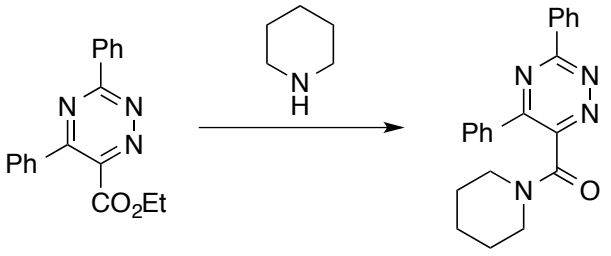
hours at 0 °C. After addition of water, the solution was extracted with ethyl acetate and washed with brine. The organic layer was separated, dried over $MgSO_4$ and evaporated to give benzamidrazone as a white solid (3.35 g, 77%). **M.p** 72-74 °C (lit.[3] 75-76 °C). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 4.15 (2H, br, NH_2), 4.66 (2H, br, NH_2), 7.36-7.38 (3H, m, Ar), 7.62-7.64 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 125.5, 128.5, 129.4, 134.7, 151.4.

Ethyl 3,5-diphenyl-1,2,4-triazine-6-carboxylate 101[56]



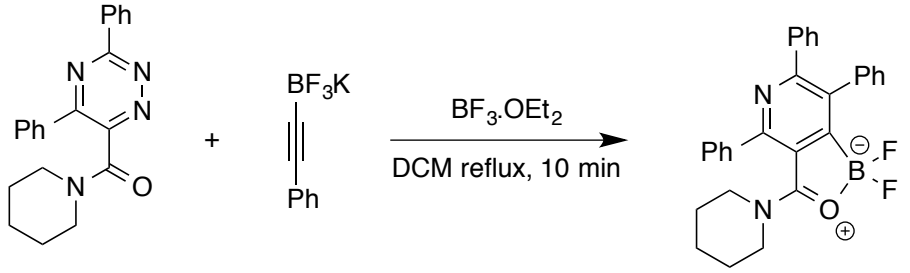
To a stirred solution of ethyl 2-acetoxy-2-chloro-3-oxo-3-phenylpropanoate (100 mg, 0.35 mmol, 1.0 eq) in ethanol (3.5 mL) under N_2 was added hydrazine (0.35 mL, 0.35 mmol, 1.0 eq) and the reaction was stirred for 1 hour at RT. The solution was then evaporated and dissolved in ethanol (3.5 mL). Benzamidrazone (48 mg, 0.35 mmol, 1.0 eq) was added and the solution was stirred for 2 hours at reflux. After evaporation of the solvent, the residue was dissolved in DCM and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel (DCM/petrol 4:6) to afford ethyl 3,5-diphenyl-1,2,4-triazine-6-carboxylate (47 mg, 44%) as a yellow oil. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.31 (3H, t, J = 7.0 Hz, CH_3), 4.44 (2H, q, J = 7.0 Hz, CH_2), 7.55-7.61 (6H, m, Ar), 7.86-7.88 (2H, m, Ar), 8.66-8.68 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 13.9, 62.7, 128.9 (x 3), 129.0, 131.7, 132.3, 134.2, 134.6, 149.2, 156.0, 163.1, 165.3.

(3,5-Diphenyl-1,2,4-triazin-6-yl)(piperidin-1-yl)methanone 102



Ethyl 3,5-diphenyl-1,2,4-triazine-6-carboxylate (350 mg, 1.15 mmol) was dissolved in piperidine (1.70 mL) and the mixture heated at 80 ^{o}C for 3 hours. Evaporation of the solvent followed by chromatographic purification over silica gel (gradient; starting with dichloromethane, ending with ethyl acetate) afforded (3,5-diphenyl-1,2,4-triazin-6-yl)(piperidin-1-yl)methanone as a yellow solid. (252 mg, 64%). **M.p** 140-142 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.26-1.27 (2H, m, CH_2), 1.59-1.62 (4H, m, CH_2), 3.14-3.17 (2H, m, CH_2), 3.76-3.79 (2H, m, CH_2), 7.55-7.58 (6H, m, Ar), 8.05-8.07 (2H, m, Ar), 8.64-8.66 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 24.3, 25.2, 25.7, 42.9, 48.0, 128.5, 128.9, 129.1 (x 2), 132.0 (x 2), 134.2, 134.5, 152.2, 154.4, 163.0, 164.6. **FTIR**: 3059 (w), 2940 (m), 2857 (w), 1641 (s), 1507 (s), 1390 (m), 1275 (m), 996 (w), 750 (w) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{21}H_{21}N_4O$ 345.1715, found 345.1731.

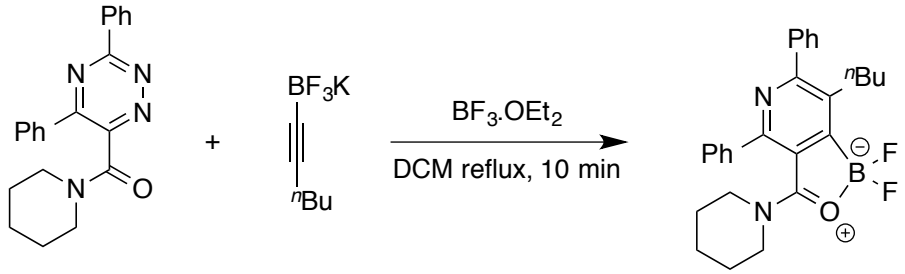
(4-(Difluoroboryl)-2,5,6-triphenylpyridin-3-yl)(piperidin-1-yl)methanone 103



Following the general procedure, a solution of (3,5-diphenyl-1,2,4-triazin-6-yl)(piperidin-1-yl)methanone (100 mg, 0.29 mmol) and potassium (phenylethynyl)-trifluoroborate (181 mg, 0.87 mmol) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.11 mL, 0.87 mmol). Extraction with DCM afforded the product in quantitative yield. Recrystallisation in DCM/petroleum ether afforded (4-(difluoroboryl)-1,4,5-triphenylpyridin-3-yl)(piperidin-1-yl)methanone (101 mg, 75%) as a white solid. **M.p** 125-127 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.22-1.26 (2H, m, CH_2), 1.54-1.57 (2H, m, CH_2), 1.75-1.77 (2H, m, CH_2), 3.08 (2H, m, CH_2), 3.86-3.89 (2H, m, CH_2), 7.24-7.34 (5H, m, Ar), 7.46-7.54 (6H, m, Ar), 7.59-7.61 (2H, m, Ar), 7.74-7.76 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 23.1, 25.2, 25.7, 48.1, 51.1, 127.2, 127.9, 128.1, 128.3, 128.7, 128.9, 129.4, 129.9, 130.4, 130.6, 131.5, 132.1, 138.4, 139.1, 140.1, 153.1, 159.0. **^{19}F NMR** (235.1 MHz, $CDCl_3$): δ -146.7. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 7.7. **FTIR**: 3058 (w), 2939 (m), 2858 (w), 1613 (s), 1447 (m), 1395 (m),

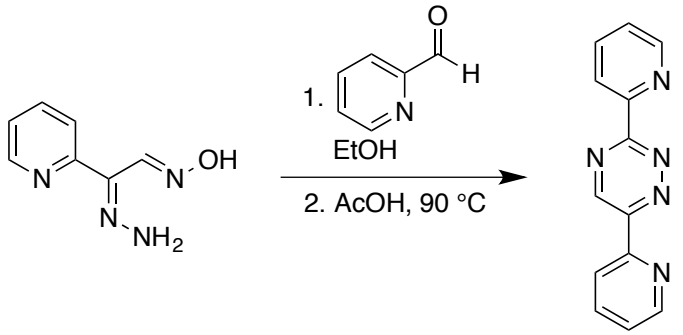
1267 (m), 1135 (m), 1027 (m), 757 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{29}H_{26}{}^{11}BN_2OF_2$: 467.2106, found 467.2119.

(5-Butyl-4-(difluoroboryl)-2,6-diphenylpyridin-3-yl)(piperidin-1-yl)methanone 104



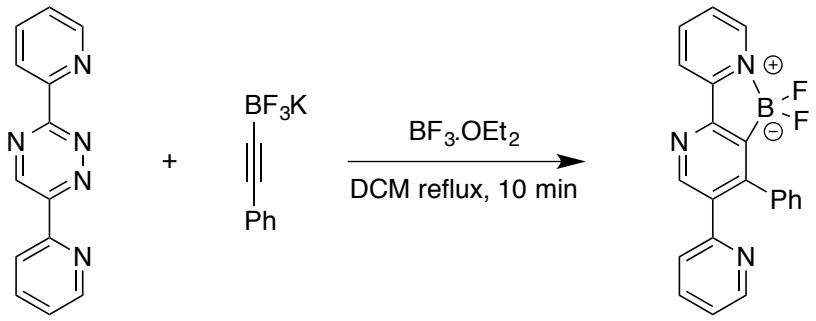
Following the general procedure, a solution of (3,5-diphenyl-1,2,4-triazin-6-yl)(piperidin-1-yl)methanone (100 mg, 0.29 mmol) and potassium (hex-1-ynyl)trifluoroborate (164 mg, 0.87 mmol) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.11 mL, 0.87 mmol). Extraction with DCM afforded the product in quantitative yield. Recrystallisation in DCM/petroleum ether afforded (4-(difluoroboryl)-1,4,5-triphenylpyridin-3-yl)(piperidin-1-yl)methanone (92 mg, 71%) as a white solid. **M.p.** 94-96 °C. **^{1}H NMR** (500 MHz, d^6-DMSO): δ 0.62 (3H, t, J = 7.0 Hz, CH_3), 0.71-0.77 (1H, m, CH_2), 0.87-0.89 (1H, m, CH_2), 1.04-1.11 (2H, m, CH_2), 1.29-1.47 (6H, m, CH_2), 2.75-2.80 (1H, m, CH_2), 2.93-3.00 (4H, m, CH_2), 3.51-3.54 (1H, m, CH_2), 7.49-7.68 (10H, m, Ar). **^{13}C NMR** (125.8 MHz, d^6-DMSO): δ 13.7, 22.9, 24.3, 24.8, 25.0, 30.5, 32.8, 41.6, 47.2, 128.2, 128.7, 130.0, 130.2, 130.6, 131.9, 133.2, 138.5, 143.9, 144.3, 150.0, 166.2, 169.0. **^{19}F NMR** (376.5 MHz, d^6-DMSO): δ -134.8. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 7.3. **FTIR**: 2935 (m), 2859 (m), 1615 (s), 1447 (m), 1365 (w), 1273 (w), 1107 (w), 1072 (m), 1028 (m), 967 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{27}H_{30}{}^{11}BN_2OF_2$: 447.2419, found 447.2413.

3,6-Bis(2-pyridyl)-1,2,4-triazine 105[47]



To a solution of 2-hydrazono-2-(pyridin-2-yl)acetaldehyde oxime (100 mg, 0.61 mmol, 1.0 eq) in ethanol (3.0 mL) was added 2-pyridinecarboxaldehyde (0.06 mL, 0.61 mmol, 1.0 eq). The solution was stirred at RT overnight. The resulting precipitate was filtered, washed with ethanol and dried. The solid was then dissolved in acetic acid (2.0 mL) and the solution stirred for 1 hour at 90 °C. The mixture was diluted with water, extracted with DCM and washed with brine. After drying over $MgSO_4$ and filtration, the solution was evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel (DCM/EtOAc 6:4) to afford the product as a yellow solid (113 mg, 0.48 mmol, 79%). **M.p.** 142-144 °C (lit. 155-157 °C). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.64-7.68 (2H, m, Ar), 8.07-8.14 (2H, m, Ar), 8.53-8.62 (2H, m, Ar), 8.85-8.87 (2H, m, Ar), 9.72 (1H, s, Ar).**^{13}C NMR** (101 MHz, $CDCl_3$): δ 122.1, 124.5, 126.4, 138.0, 138.5, 148.6, 149.1, 150.5, 150.7, 151.4, 152.8, 155.1, 162.8. **FTIR:** 3389 (m), 1678 (w), 1587 (m), 1404 (s), 1045 (w) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{13}H_{10}N_5$: 236.0936, found: 236.0943.

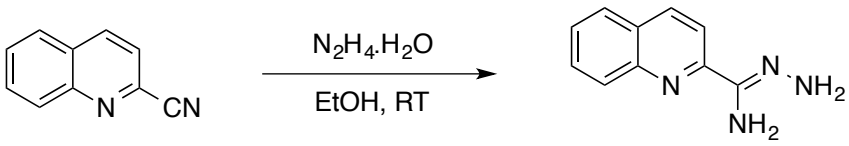
3'-(Difluoroboryl)-4'-phenyl-2,2':5',2''-terpyridine 106



Following the general procedure, a solution of 3,6-bis(2-pyridyl)-1,2,4-triazine (50 mg, 0.21 mmol) and potassium (phenylethynyl)trifluoroborate (133 mg, 0.64 mmol) in DCM

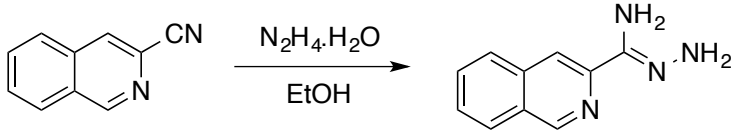
(2.0 mL) was treated with $BF_3.OEt_2$ (0.08 mL, 0.64 mmol). Chromatographic purification over silica gel (gradient; starting with dichloromethane, ending with ethyl acetate) afforded 3'-(difluoroboryl)-4'-phenyl-2,2':5',2''-terpyridine (31 mg, 41%) as a colourless solid. **M.p** 196-198 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 6.90-6.93 (1H, m, Ar), 7.14-7.17 (1H, m, Ar), 7.29-7.30 (3H, m, Ar), 7.37-7.44 (3H, m, Ar), 7.61-7.64 (1H, m, Ar), 8.22-8.27 (1H, m, Ar), 8.39-8.41 (1H, m, Ar), 8.56-8.57 (1H, m, Ar), 8.67-8.69 (1H, m, Ar), 8.91 (1H, s, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 119.3, 122.0, 125.2, 125.9, 127.9, 128.2, 129.6, 135.5, 137.1, 138.3, 141.4, 144.2, 149.8, 151.6, 152.4, 154.8, 155.2, 156.7. **^{19}F NMR** (235.1 MHz, $CDCl_3$): δ -156.4. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 7.7. **FTIR**: 3642 (w), 3059 (m), 2924 (m), 2227 (w), 1627 (s), 1588 (m), 1490 (s), 1439 (s), 1290 (m), 1135 (s), 1014 (s), 790 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{21}H_{15}{}^{11}BN_3F_2$: 358.1327, found 358.1333.

2-Quinolylamidrazone 108a[15]



To a stirred suspension of quinoline-2-carbonitrile (500 mg, 3.24 mmol, 1.0 eq) in a minimum of ethanol under N_2 was added hydrazine hydrate (0.32 mL, 6.49 mmol, 2.0 eq) and the reaction was stirred overnight at RT. The precipitate was filtered and washed with diethyl ether to afford 2-quinolylamidrazone (579 mg, 96%) as a yellow solid. **M.p** 188-190 °C (lit. 191-192 °C). **^{1}H NMR** (400 MHz, d^6-DMSO): δ 5.65 (2H, br, NH_2), 5.91 (2H, br, NH_2), 7.54-7.58 (1H, m, Ar), 7.72-7.76 (1H, m, Ar), 7.92-7.94 (1H, m, Ar), 7.99-8.01 (1H, m, Ar), 8.07-8.10 (1H, m, Ar), 8.23-8.25 (1H, m, Ar). **^{13}C NMR** (100.6 MHz, d^6-DMSO): δ 117.5, 126.3, 127.4, 127.7, 128.5, 129.6, 135.6, 142.9, 146.2, 151.6.

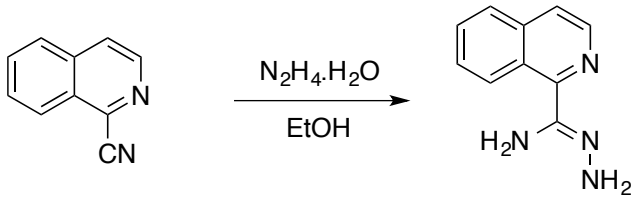
Isoquinoline-3-carbohydrazonamide 108b



To a stirred solution of isoquinoline-3-carbonitrile (100 mg, 0.65 mmol, 1.0 eq) in ethanol (0.10 mL) was added hydrazine monohydrate (0.31 mL, 6.49 mmol, 10.0 eq). The

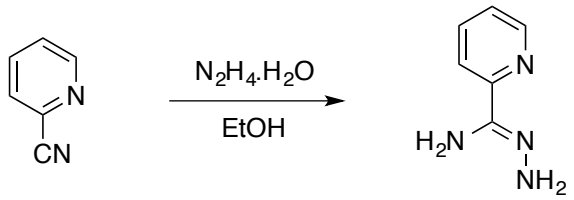
mixture was stirred for 4 days at RT. The solution was extracted with dichloromethane and washed with water and brine. The organic layer was dried over Na_2SO_4, filtered and evaporated to dryness to give isoquinoline-3-carbohydrazonamide (106 mg, 88%) as a yellow solid. **M.p.** 119-121 °C (lit.[143] 122-123 °C). **^{1}H NMR** (250 MHz, $CDCl_3$): δ 4.05 (2H, br, NH_2), 5.48 (2H, br, NH_2), 7.56-7.72 (2H, m, Ar), 7.85-7.89 (1H, m, Ar), 7.95-7.99 (1H, m, Ar), 8.40 (1H, m, Ar), 9.17-9.18 (1H, m, Ar). **^{13}C NMR** (62.9 MHz, $CDCl_3$): δ 116.4, 127.5, 127.6, 128.8, 130.6, 136.3, 144.9, 149.6, 150.9, 151.0. **FTIR:** 3428 (w), 3288 (m), 1654 (m), 1618 (s), 1383 (m), 1270 (m), 891 (s), 743 (s), 467 (m) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{10}H_{10}N_4$: 186.0900, found: 186.0901.

Isoquinoline-1-carbohydrazonamide 108c



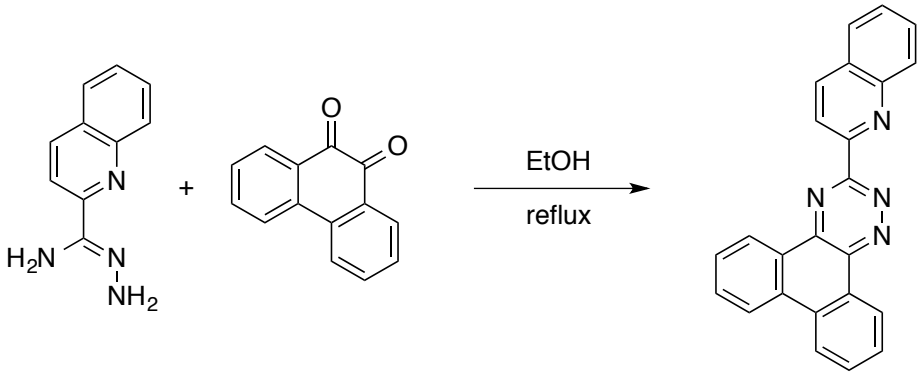
To a stirred solution of isoquinoline-1-carbonitrile (200 mg, 1.30 mmol, 1.0 eq) in methanol (2.0 mL) was added hydrazine monohydrate (0.63 mL, 12.97 mmol, 10.0 eq). The mixture was stirred for 4 days at RT. The solution was extracted with dichloromethane and washed with water and brine. The organic layer was dried over Na_2SO_4, filtered and evaporated to dryness to give isoquinoline-1-carbohydrazonamide (222 mg, 92%) as a yellow solid. **M.p.** 68-70 °C (lit.[144] 88-89 °C). **^{1}H NMR** (250 MHz, $CDCl_3$): δ 4.75 (2H, br, NH_2), 5.44 (2H, br, NH_2), 7.54-7.65 (3H, m, Ar), 7.71-7.73 (1H, m, Ar), 8.39-8.41 (1H, m, Ar), 9.38-9.42 (1H, m, Ar). **^{13}C NMR** (75.5 MHz, $CDCl_3$): δ 121.9, 126.2, 127.8, 128.7, 129.9, 137.1, 139.9, 141.0, 149.9, 150.2. **FTIR:** 3426 (w), 3307 (m), 1682 (m), 1499 (s), 1294 (m), 1137 (m), 1058 (w), 896 (m), 823 (s), 745 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{10}H_{10}N_4$: 186.0900, found: 186.0899.

(Pyridine-2-yl)amidrazone 108d[145]



To a stirred solution of 2-cyanopyridine (5.5 g, 48 mmol, 1.0 eq) in a minimum amount of ethanol was added hydrazine monohydrate (3.63 mL, 75 mmol, 1.5 eq). The mixture was stirred overnight at RT. The precipitate was filtered and washed with diethyl ether to afford (pyridine-2-yl)amidrazone (5.9 g, 90%) as a yellow solid. **M.p.** 94-95 °C (lit. 96-98 °C). **^{1}H NMR** (250 MHz, $CDCl_3$): δ 4.60 (2H, br, NH_2), 5.39 (2H, br, NH_2), 7.25-7.30 (1H, m, Ar), 7.70 (1H, td, *J* = 8.0, 2.0 Hz, Ar), 8.02 (1H, dt, *J* = 8.0, 1.0 Hz, Ar), 8.52 (1H, dt, *J* = 5.0, 1.0 Hz, Ar). **^{13}C NMR** (75.5 MHz, $CDCl_3$): δ 119.9, 123.9, 136.5, 148.1, 148.8, 151.0.

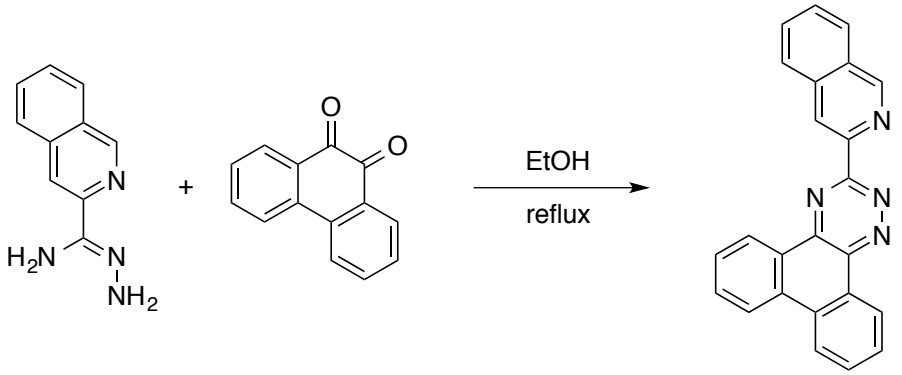
3-(Quinolin-2-yl)phenanthro[9,10-*e*][1,2,4]triazine 109a



To a stirred suspension of 2-quinolylamidrazone (50 mg, 0.27 mmol, 1.0 eq) in ethanol (1.0 mL) was added phenanthrene-9,10-dione (56 mg, 0.27 mmol, 1.0 eq). The mixture was stirred overnight at reflux and then cooled to RT. The mixture was evaporated and recrystalisation with dichloromethane and cyclohexane afforded 3-(quinolin-2-yl)phenanthro[9,10-*e*][1,2,4]triazine (92 mg, 95%) as a yellow solid. **M.p.** 257-259 °C. **^{1}H NMR** (250 MHz, $CDCl_3$): δ 7.62-7.71 (1H, m, Ar), 7.77-8.00 (6H, m, Ar), 8.42-8.53 (2H, m, Ar), 8.62 (2H, d, *J* = 8.5 Hz, Ar), 8.97 (1H, d, *J* = 8.5 Hz, Ar), 9.50-9.61 (2H, m, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): δ 121.2, 123.2, 123.3, 125.6, 127.4, 127.7 (x2), 128.0 (x2), 128.3, 128.9, 129.0, 130.2, 131.1, 131.3, 131.7, 132.8, 134.2, 137.4, 143.5, 145.8, 148.7,

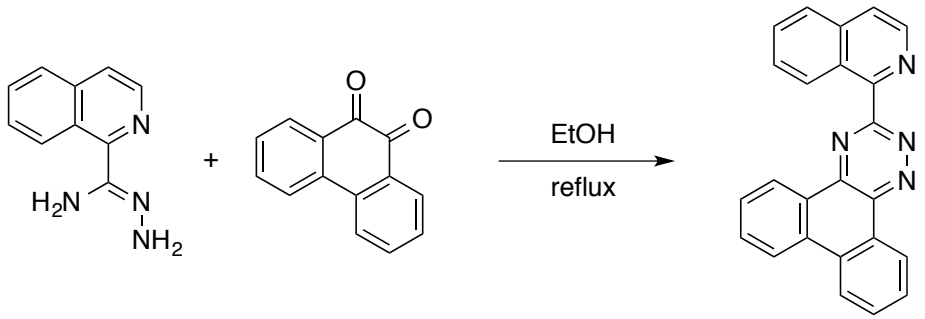
153.7. **FTIR:** 3053 (w), 1596 (w), 1367 (s), 1078 (m), 826 (w), 767 (s), 725 (s), 542 (m) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{24}H_{14}N_4$: 358.1213, found: 358.1214.

3-(Isoquinolin-3-yl)phenanthro[9,10-*e*][1,2,4]triazine 109b



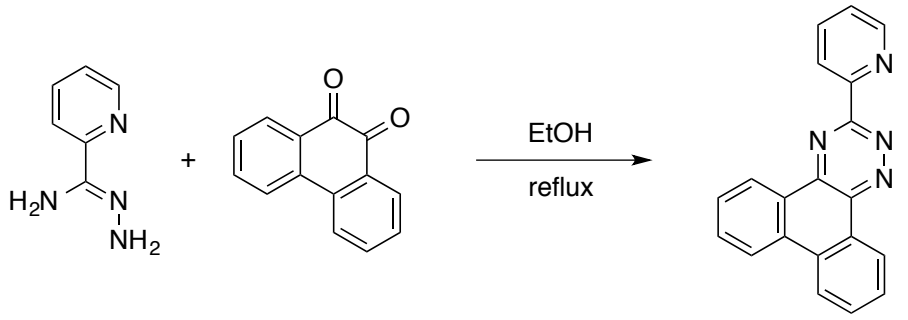
To a stirred solution of isoquinoline-3-carbohydrazonamide (106 mg, 0.57 mmol, 1.0 eq) in ethanol (2.0 mL) was added phenanthrene-9,10-dione (119 mg, 0.57 mmol, 1.0 eq). The mixture was stirred overnight at reflux and then cooled to RT. After evaporation, the residue was purified by flash chromatography on silica gel (ethyl acetate/dichloromethane : 1/9 then 8/2) to give 3-(isoquinolin-3-yl)phenanthro[9,10-*e*][1,2,4]triazine (172 mg, 84%) as a yellow solid. **M.p.** 243-245 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.55-9.59 (3H, m, Ar), 9.34 (1H, s, Ar), 8.60-8.63 (2H, m, Ar), 8.09-8.13 (2H, m, Ar), 7.79-7.94 (5H, m, Ar), 7.74 (1H, ddd, *J* = 8.0, 7.0, 1.0 Hz, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): δ 122.4, 123.2 (x2), 125.3, 127.4, 127.8, 127.9, 128.1 (x2), 128.3, 128.8, 129.0, 129.6, 131.1, 131.1, 131.5, 132.6, 134.1, 136.4, 143.4, 145.4, 147.5, 153.5. **FTIR:** 3045 (w), 1605 (w), 1503 (w), 1367 (s), 1271 (w), 1074 (m), 946 (w), 760 (m), 722 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{24}H_{14}N_4$: 358.1213, found: 358.1212.

3-(Isoquinolin-1-yl)phenanthro[9,10-*e*][1,2,4]triazine 109c



To a stirred solution of isoquinoline-1-carbohydrazonamide (93 mg, 0.50 mmol, 1.0 eq) in ethanol (2.0 mL) was added phenanthrene-9,10-dione (104 mg, 0.50 mmol, 1.0 eq). The mixture was stirred overnight at reflux and then cooled to RT. The mixture was evaporated and recrystalisation with dichloromethane and cyclohexane afforded 3-(isoquinolin-1-yl)phenanthro[9,10-*e*][1,2,4]triazine (159 mg, 89%) as a yellow solid. **M.p.** 219-221 °C. **^{1}H NMR** (300 MHz, $CDCl_3$): δ 7.66-7.89 (7H, m, Ar), 7.97 (1H, d, *J* = 8.0 Hz, Ar), 8.54 (2H, d, *J* = 8.0 Hz, Ar), 8.63 (1H, d, *J* = 8.5 Hz, Ar), 8.87 (1H, d, *J* = 5.5 Hz, Ar), 9.31 (1H, d, *J* = 8.0 Hz, Ar), 9.53 (1H, d, *J* = 7.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 122.6, 123.1, 124.0, 125.4, 127.2, 127.3, 127.4, 127.8, 128.3, 128.4, 128.8, 129.6, 130.5, 131.3, 131.6, 132.7, 134.0, 136.0, 137.3, 142.6, 143.2, 145.2, 154.6. **FTIR:** 3045 (w), 1606 (w), 1503 (w), 1365 (m), 1039 (w), 761 (m), 720 (s), 542 (m) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{24}H_{14}N_4$: 358.1213, found: 358.1211.

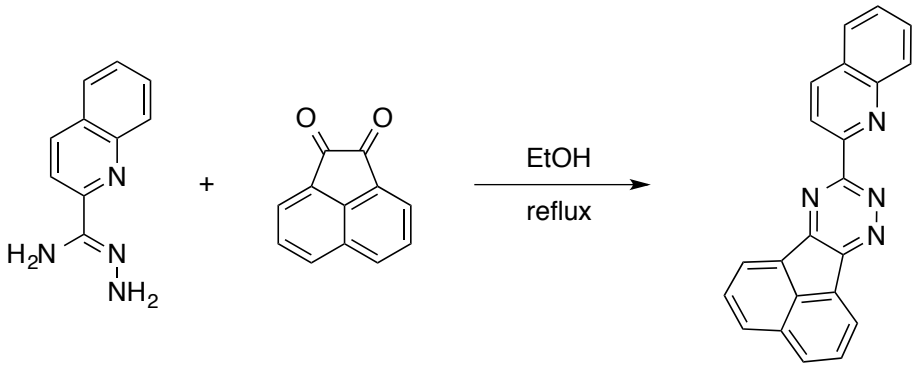
3-(Pyridin-2-yl)phenanthro[9,10-*e*][1,2,4]triazine 109d



To a stirred solution of 2-picolinamidrazone (812 mg, 5.96 mmol, 1.0 eq) in ethanol (80.0 mL) was added phenanthrene-9,10-dione (1242 mg, 5.96 mmol, 1.0 eq). The mixture was stirred overnight at reflux and then cooled to RT. The precipitate was filtered and washed with ethanol to give 3-(pyridin-2-yl)phenanthro[9,10-*e*][1,2,4]triazine (1.12 g, 61%) as a

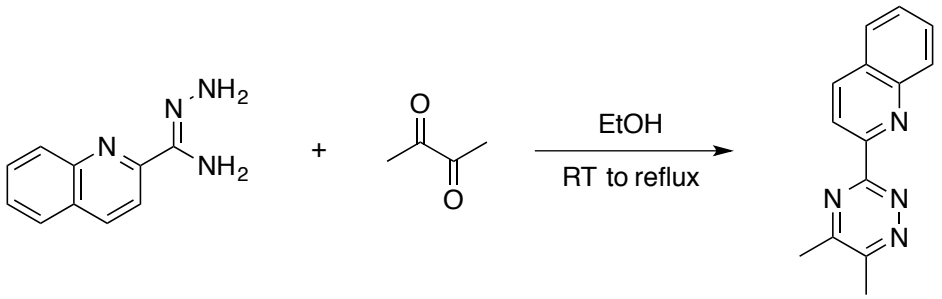
yellow solid. **M.p.** 201-203 °C. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.75-7.91 (5H, m, Ar), 8.11 (2H, t, *J* = 9.0 Hz, Ar), 8.61-8.59 (2H, m, Ar), 9.33 (1H, s, Ar), 9.56-9.54 (2H, m, Ar), 9.59 (1H, s, Ar). **^{13}C NMR** (62.9 MHz, $CDCl_3$): δ 123.1, 124.4, 125.3, 127.2, 127.6, 127.9, 128.2, 128.7, 131.1, 131.4, 132.6, 133.9, 137.2, 143.2, 145.6, 150.7, 153.9, 160.7. **FTIR:** 3051 (w), 1605 (w), 1506 (w), 1402 (m), 1367 (s), 1271 (w), 1067 (w), 990 (w), 757 (s), 543 (m) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{20}H_{12}N_4$: 308.1056, found: 308.1055.

9-(Quinolin-2-yl)acenaphtho[1,2-*e*][1,2,4]triazine 109e



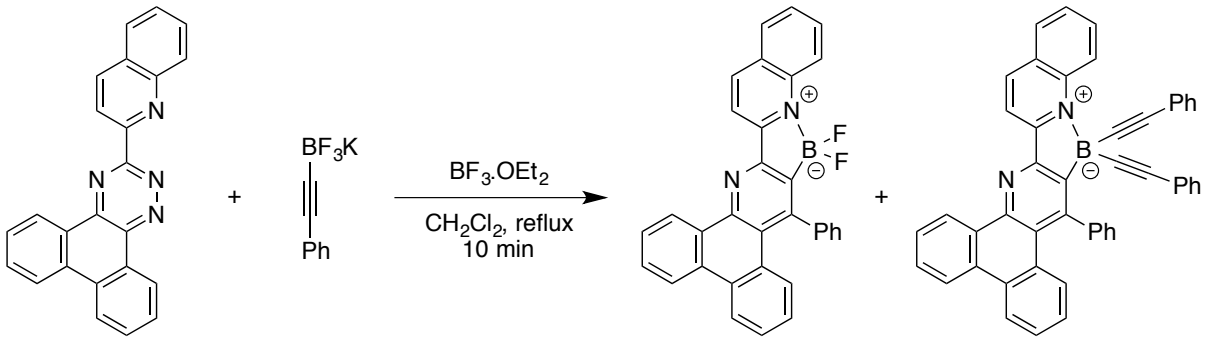
To a stirred solution of 2-quinolylamidrazone (167 mg, 0.90 mmol, 1.0 eq) in ethanol (3.5 mL) was added acenaphthylene-1,2-dione (163 mg, 0.90 mmol, 1.0 eq). The mixture was stirred overnight at reflux and then cooled to RT and evaporated. The residue was purified by flash chromatography on silica gel (ethyl acetate/cyclohexane : 1/2) to give 9-(quinolin-2-yl)acenaphtho[1,2-*e*][1,2,4]triazine (229 mg, 77%) as a yellow solid. **M.p.** 227-229 °C. **^{1}H NMR** (250 MHz, $CDCl_3$): δ 7.51-7.57 (1H, m, Ar), 7.69-7.83 (4H, m, Ar), 8.02-8.12 (2H, m, Ar), 8.29 (1H, d, *J* = 8.0 Hz, Ar), 8.37-8.44 (2H, m, Ar), 8.59 (1H, d, *J* = 6.5 Hz, Ar), 8.79 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (62.9 MHz, $CDCl_3$): δ 121.3, 124.1, 126.4, 127.6, 128.8, 129.6, 130.6, 130.8, 132.4, 134.5, 137.2, 148.4, 153.7, 155.9, 158.1, 160.8. **FTIR:** 3048 (w), 1594 (w), 1432 (m), 1384 (w), 1329 (m), 1207 (w), 1164 (m), 1028 (m), 821 (m), 768 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{22}H_{12}N_4$: 332.1056, found: 332.1057.

5,6-Dimethyl-3-(2-quinolyl)-1,2,4-triazine 109f



To a stirred suspension of 2-quinolylamidrazone (1.00 g, 5.40 mmol, 1.0 eq) in ethanol (10.0 mL) was added 2,3-butanedione (0.47 mL, 5.40 mmol, 1.0 eq) and the reaction was stirred for 3 hours at reflux. After cooling down, the resulting precipitate was filtered to afford 5,6-dimethyl-3-(2-quinolyl)-1,2,4-triazine (1.28 g, 100%) as a yellow solid. **M.p** 184-186 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 2.71 (3H, s, CH_3), 2.77 (3H, s, CH_3), 7.56-7.60 (1H, m, Ar), 7.73-7.76 (1H, m, Ar), 7.86-7.88 (1H, m, Ar), 8.32-8.34 (2H, m, Ar), 8.69-8.71 (1H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 19.7, 22.2, 120.7, 127.5, 127.7, 128.8, 129.8, 130.8, 137.2, 148.3, 153.1, 157.2, 159.7, 161.6. **FTIR**: 1595 (w), 1527 (m), 1429 (m), 1394 (s), 1366 (m), 1162 (m), 988 (w), 853 (s), 788 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{14}H_{13}N_4$: 237.1140, found 237.1149.

3-(Difluoroboranyl)-4-phenyl-2-(quinolin-2-yl)dibenzo[*f*,*h*]quinoline 110a and 3-(bis(phenylethynyl)boranyl)-4-phenyl-2-(quinolin-2-yl)dibenzo[*f*,*h*]quinoline 111a

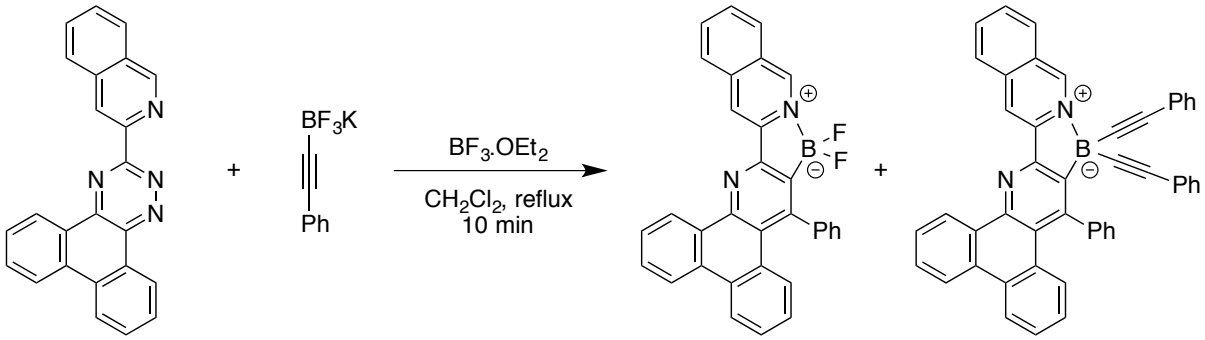


Following the general procedure, a suspension of 3-(quinolin-2-yl)phenanthro[9,10-*e*][1,2,4]triazine (50 mg, 0.14 mmol) and potassium phenylethynyltrifluoroborate (87 mg, 0.42 mmol) in DCM (1.0 mL) was treated with $BF_3.OEt_2$ (0.05 mL, 0.42 mmol). Chromatographic purification over silica (gradient; starting with cyclohexane, ending with dichloromethane) afforded 3-(difluoroboranyl)-4-phenyl-2-(quinolin-2-

yl)dibenzo[*f*,*h*]quinoline (52 mg, 77%) as a light yellow solid. **M.p** 353-355 °C. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.11 (1H, t, *J* = 7.5 Hz, Ar), 7.49-7.57 (4H, m, Ar), 7.64 (2H, d, *J* = 7.0 Hz, Ar), 7.69 (1H, t, *J* = 7.5 Hz, Ar), 7.77 (2H, dd, *J* = 6.0, 3.5 Hz, Ar), 7.83 (1H, d, *J* = 8.5 Hz, Ar), 7.91 (1H, t, *J* = 7.5 Hz, Ar), 8.00 (1H, d, *J* = 8.0 Hz, Ar), 8.58 (2H, d, *J* = 7.5 Hz, Ar), 8.66 (1H, d, *J* = 8.5 Hz, Ar), 8.69 (1H, d, *J* = 8.5 Hz, Ar), 8.75 (1H, d, *J* = 8.5 Hz, Ar), 9.52-9.54 (1H, m, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): δ 116.2, 122.5, 123.3, 123.3, 125.7, 125.9, 126.0, 127.6, 127.7, 128.1, 128.4, 128.7, 129.0, 129.1, 129.3, 129.5, 129.6, 130.7, 131.2, 131.6, 131.9, 133.5, 140.3, 142.4, 144.4, 149.2, 151.7, 153.5. **^{19}F NMR** (470.6 MHz, $CDCl_3$): δ -151.4. **^{11}B NMR** (160.5 MHz, $CDCl_3$): δ 9.3. **FTIR**: 3051 (w), 1595 (w), 1521 (m), 1439 (w), 1098 (s), 999 (m), 917 (w), 823 (m), 724 (s), 619 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{32}H_{19}{}^{11}BN_2F_2$: 480.1604, found 480.1607.

3-(bis(phenylethynyl)boranyl)-4-phenyl-2-(quinolin-2-yl)dibenzo[*f*,*h*]quinoline was isolated as side product (11 mg, 12%) as a white solid. **M.p** 347-349 °C. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.13-7.19 (11H, m, Ar), 7.47-7.57 (4H, m, Ar), 7.71-7.76 (3H, m, Ar), 7.91 (2H, d, *J* = 7.5 Hz, Ar), 7.96-8.05 (3H, m, Ar), 8.59 (2H, dd, *J* = 8.5, 4.5 Hz, Ar), 8.68 (1H, d, *J* = 8.5 Hz, Ar), 8.84 (1H, d, *J* = 8.5 Hz, Ar), 9.33 (1H, d, *J* = 9.0 Hz, Ar), 9.59 (1H, dd, *J* = 6.0, 3.5 Hz, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): 97.7, 117.0, 122.5, 123.3, 124.8, 125.5, 125.6, 125.9, 126.3, 127.0, 127.5 (x2), 127.6, 127.9, 128.1, 128.8, 128.9, 129.0, 129.6, 129.8, 130.0, 131.0, 131.5, 131.6, 131.7, 132.4, 141.0, 142.7, 143.2 (x2), 148.5, 151.3, 153.3. **^{11}B NMR** (160.5 MHz, $CDCl_3$): δ -9.1. **FTIR**: 3623 (w), 2879 (m), 2503 (w), 2159 (s), 2031 (s), 1342 (m), 1100 (s), 962 (m), 842 (s), 753 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{48}H_{30}{}^{11}BN_2$: 645.2505, found 645.2499.

3-(Difluoroboranyl)-2-(isoquinolin-3-yl)-4-phenyldibenzo[*f*,*h*]quinoline 110b and 3-(Bis(phenylethynyl)boranyl)-2-(isoquinolin-3-yl)-4-phenyldibenzo[*f*,*h*]quinoline 111b

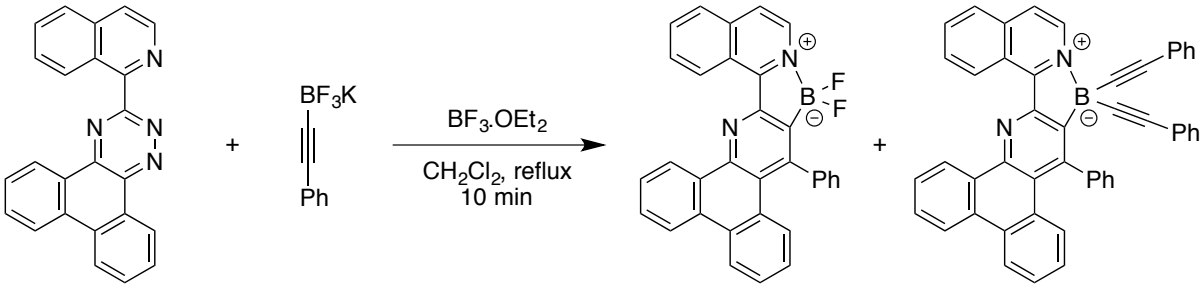


Following the general procedure, a suspension of 3-(isoquinolin-3-yl)phenanthro[9,10-*e*][1,2,4]triazine (50 mg, 0.14 mmol) and potassium phenylethynyltrifluoroborate (87 mg, 0.42 mmol) in DCM (1.0 mL) was treated with $BF_3.OEt_2$ (0.05 mL, 0.42 mmol). Chromatographic purification over silica (gradient; starting with cyclohexane, ending with dichloromethane) afforded 3-(difluoroboranyl)-2-(isoquinolin-3-yl)-4-phenyldibenzo[*f*,*h*]quinoline (12 mg, 13%) as a yellow solid. **M.p** 364-366 °C. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.10 (1H, t, *J* = 7.5 Hz, Ar), 7.47-7.54 (4H, m, Ar), 7.62 (2H, d, *J* = 7.0 Hz, Ar), 7.79 (4H, dd, *J* = 11.5, 5.5 Hz, Ar), 8.00 (1H, t, *J* = 7.5 Hz, Ar), 8.18-8.20 (2H, m, Ar), 8.57-8.61 (2H, m, Ar), 8.95 (1H, s, Ar), 9.28 (1H, s, Ar), 9.59-9.61 (1H, m, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): δ 116.5, 122.6, 123.3, 125.2, 125.6, 126.0, 127.4, 127.5, 128.0, 128.2, 128.3, 129.0, 129.1, 129.2, 129.6, 129.7, 130.1, 130.5, 131.3, 131.4 (x2), 132.0, 135.0, 139.5, 142.5, 145.8, 147.4, 149.5. **^{19}F NMR** (470.6 MHz, $CDCl_3$): δ -152.2. **^{11}B NMR** (160.5 MHz, $CDCl_3$): δ 8.3. **FTIR**: 3049 (w), 2921 (w), 1639 (w), 1444 (w), 1283 (w), 1087 (m), 995 (m), 868 (m), 723 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{32}H_{19}{}^{11}BN_2F_2$: 480.1604, found 480.1602.

3-(Bis(phenylethynyl)boranyl)-2-(isoquinolin-3-yl)-4-phenyldibenzo[*f*,*h*]quinoline was isolated as side product (7 mg, 10%) as a white solid. **M.p** 374-376 °C. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.10-7.13 (1H, m, Ar), 7.15-7.19 (6H, m, Ar), 7.29 (4H, dd, *J* = 7.5, 2.0 Hz, Ar), 7.46-7.55 (5H, m, Ar), 7.74-7.80 (3H, m, Ar), 7.85 (2H, d, *J* = 7.0 Hz, Ar), 7.91 (1H, d, *J* = 8.5 Hz, Ar), 7.96 (1H, d, *J* = 8.0 Hz, Ar), 8.10 (1H, d, *J* = 8.5 Hz, Ar), 8.58-8.59 (2H, m, Ar), 9.00 (1H, s, Ar), 9.60-9.63 (2H, m, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): 96.7, 116.9, 122.5, 123.2, 125.5, 125.6, 126.0, 127.0, 127.1, 127.4, 127.5, 127.9 (x2), 128.4, 128.8, 128.9, 129.0, 129.6, 129.9, 130.0, 130.6, 131.3, 131.6, 131.7 (x2), 134.2, 138.6, 142.9, 148.2, 148.3,

148.4, 149.6, 151.6. **^{11}B NMR** (160.5 MHz, $CDCl_3$): δ -8.4. **FTIR**: 3199 (m), 2974 (w), 2103 (w), 1691 (s), 1621 (s), 1407 (s), 1243 (s), 1151 (s), 1010 (m), 847 (s), 762 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{48}H_{30}{}^{11}BN_2$: 645.2497, found 645.2494.

3-(Difluoroboranyl)-2-(isoquinolin-1-yl)-4-phenyldibenzo[*f*,*h*]quinoline 110c and 3-(Bis(phenylethynyl)boranyl)-4-phenyl-2-(pyridin-2-yl)dibenzo[*f*,*h*]quinoline 111c

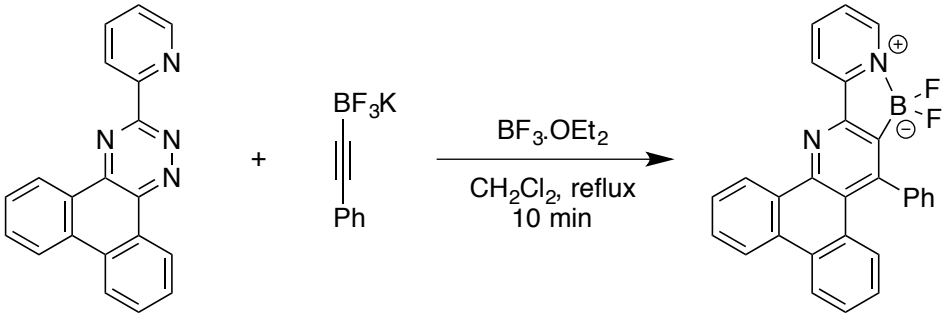


Following the general procedure, a suspension of 3-(isoquinolin-1-yl)phenanthro[9,10-*e*][1,2,4]triazine (50 mg, 0.14 mmol) and potassium phenylethynyltrifluoroborate (87 mg, 0.42 mmol) in DCM (1.0 mL) was treated with $BF_3.OEt_2$ (0.05 mL, 0.42 mmol). Chromatographic purification over silica (gradient; starting with cyclohexane, ending with dichloromethane) afforded 3-(difluoroboranyl)-2-(isoquinolin-1-yl)-4-phenyldibenzo[*f*,*h*]quinoline (47 mg, 70%) as a yellow solid. **M.p** 322-324 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.12 (1H, td, *J* = 7.5, 1.0 Hz, Ar), 7.48-7.55 (4H, m, Ar), 7.62 (2H, d, *J* = 7.0 Hz, Ar), 7.97-7.87 (3H, m, Ar), 7.98 (1H, d, *J* = 6.0 Hz, Ar), 8.04 (2H, d, *J* = 3.5 Hz, Ar), 8.10 (1H, dt, *J* = 8.5, 4.0 Hz, Ar), 8.44 (1H, d, *J* = 6.0 Hz, Ar), 8.59-8.64 (2H, m, Ar), 9.43 (1H, dd, *J* = 8.0, 1.5 Hz, Ar), 10.77 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): δ 122.8, 123.3, 124.2, 125.4, 125.5, 125.8 (x2), 127.5, 127.8 (x2), 128.0, 129.0, 129.1, 129.2, 129.4, 130.0, 130.6, 130.7, 131.4, 131.6, 132.1, 132.4, 134.4, 139.9, 142.3, 143.1, 149.1, 151.5. **^{19}F NMR** (376.5 MHz, $CDCl_3$): δ -158.9. **^{11}B NMR** (160.5 MHz, $CDCl_3$): δ 7.8. **FTIR**: 3047 (w), 1547 (m), 1440 (m), 1359 (w), 1283 (w), 1098 (s), 1002 (m), 830 (s), 701 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{32}H_{19}{}^{11}BN_2F_2$: 480.1604, found 480.1606.

3-(Bis(phenylethynyl)boranyl)-4-phenyl-2-(pyridin-2-yl)dibenzo[*f*,*h*]quinoline was isolated as side product (13 mg, 14%) as a white solid. **M.p** 349-351 °C. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.11-7.19 (7H, m, Ar), 7.24 (3H, d, *J* = 1.5 Hz, Ar), 7.48 (1H, t, *J* = 7.5 Hz, Ar), 7.51-7.55 (3H, m, Ar), 7.77-7.80 (1H, m, Ar), 7.82-7.87 (3H, m, Ar), 7.98 (2H, dd, *J* = 7.5, 4.0 Hz, Ar), 8.02 (2H, t, *J* = 7.5 Hz, Ar), 8.09 (1H, ddd, *J* = 8.5, 6.5, 2.0 Hz, Ar), 8.61 (2H, t,

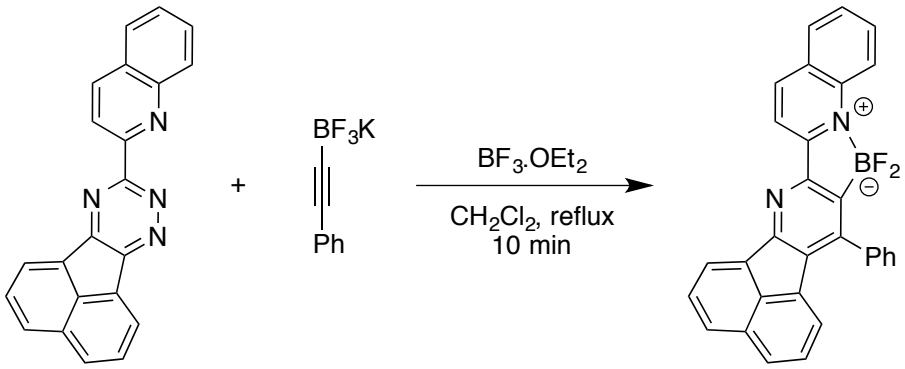
J = 7.5 Hz, Ar), 8.84 (1H, d, *J* = 6.5 Hz, Ar), 9.48 (1H, d, *J* = 8.0 Hz, Ar), 10.85 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): 96.5, 122.7, 123.2, 123.5, 125.5 (x2), 125.7, 125.8, 126.0, 127.0, 127.3, 127.6, 127.7, 127.9, 128.8 (x2), 129.0, 129.5, 129.7, 130.0, 130.2, 130.9, 131.6 (x2), 131.7, 131.9, 133.9, 135.4, 138.7, 142.6, 148.3, 151.1, 155.2. **^{11}B NMR** (160.5 MHz, $CDCl_3$): δ -9.1. **FTIR**: 2920 (m), 2850 (w), 1486 (m), 1398 (m), 1226 (w), 1159 (w), 945 (m), 824 (m), 755 (s), 690 (s) cm^{-1}. **HRMS**: (ESI) [MNa^+] calcd for $C_{48}H_{29}{}^{11}BN_2Na$: 667.2321, found 667.2353.

3-(Difluoroboranyl)-4-phenyl-2-(pyridin-2-yl)dibenzo[*f*,*h*]quinoline 110d



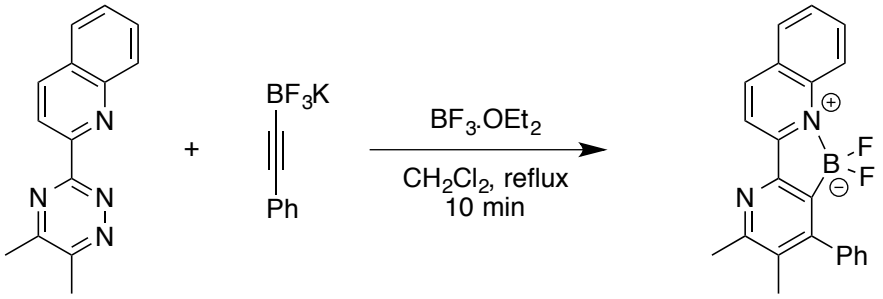
Following the general procedure, a suspension of 3-(pyridin-2-yl)phenanthro[9,10-*e*][1,2,4]triazine (100 mg, 0.32 mmol) and potassium phenylethynyltrifluoroborate (202 mg, 0.97 mmol) in DCM (3.0 mL) was treated with $BF_3.OEt_2$ (0.12 mL, 0.97 mmol). Chromatographic purification over silica (gradient; starting with cyclohexane, ending with dichloromethane) afforded 3-(difluoroboranyl)-4-phenyl-2-(pyridin-2-yl)dibenzo[*f*,*h*]quinoline (53 mg, 38%) as a white solid. **M.p** 291-293 °C. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.08-7.11 (1H, m, Ar), 7.47-7.53 (4H, m, Ar), 7.58 (2H, d, *J* = 7.0 Hz, Ar), 7.63-7.66 (1H, m, Ar), 7.74-7.80 (3H, m, Ar), 8.28 (1H, td, *J* = 7.5, 1.0 Hz, Ar), 8.56-8.59 (3H, m, Ar), 8.63 (1H, d, *J* = 8.0 Hz, Ar), 9.49 (1H, dd, *J* = 7.5, 1.5 Hz, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): δ 119.7, 122.5, 123.3, 125.3, 125.6, 125.7, 125.9, 127.5, 127.6, 128.0, 128.9, 129.1, 129.3, 129.4, 130.6, 131.2, 131.4, 131.9, 141.4, 142.3, 144.0, 149.2, 152.1, 153.3. **^{19}F NMR** (376.5 MHz, $CDCl_3$): δ -155.6. **^{11}B NMR** (160.5 MHz, $CDCl_3$): δ 8.1. **FTIR**: 1662 (w), 1479 (m), 1312 (w), 1126 (m), 1081 (s), 996 (m), 751 (s), 719 (s), 622 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{28}H_{17}{}^{11}BN_2F_2$: 430.1447, found 430.1445.

9-(Difluoroboranyl)-10-phenyl-8-(quinolin-2-yl)acenaphtho[1,2-*b*]pyridine 110e



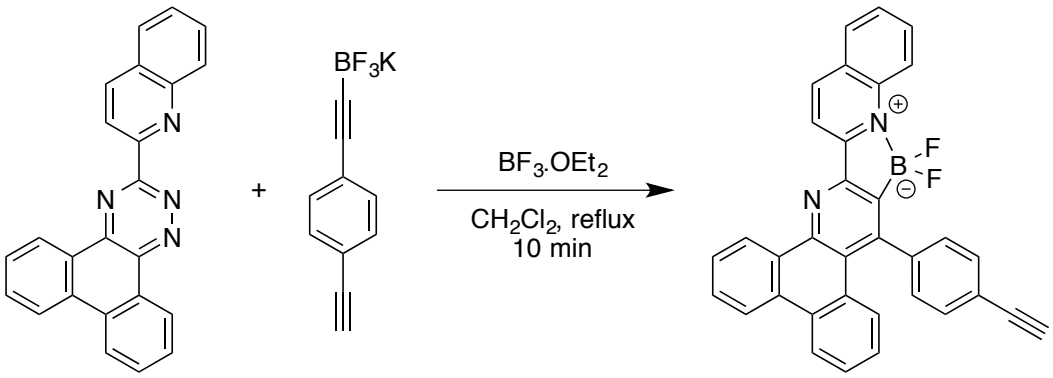
Following the general procedure, a suspension of 9-(quinolin-2-yl)acenaphtho[1,2-*e*][1,2,4]triazine (100 mg, 0.30 mmol) and potassium phenylethynyltrifluoroborate (188 mg, 0.90 mmol) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.11 mL, 0.90 mmol). Chromatographic purification over silica (gradient; starting with cyclohexane, ending with dichloromethane) afforded 9-(difluoroboranyl)-10-phenyl-8-(quinolin-2-yl)acenaphtho[1,2-*b*]pyridine (50 mg, 37%) as a yellow solid. **M.p** 359-361 °C. **^{1}H NMR** (300 MHz, $CDCl_3$): δ 7.42-7.50 (2H, m, Ar), 7.58-7.71 (4H, m, Ar), 7.77-7.93 (5H, m, Ar), 8.00 (2H, d, *J* = 8.0 Hz, Ar), 8.43 (1H, d, *J* = 7.0 Hz, Ar), 8.60 (1H, d, *J* = 9.0 Hz, Ar), 8.68 (2H, m, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): δ 116.1, 122.0, 123.0, 124.8, 128.0, 128.1, 128.2, 128.3, 128.7 (x2), 129.0, 129.1, 129.3, 129.8, 131.6, 133.1, 133.5, 133.8, 133.9, 135.0, 138.2, 140.3, 144.4, 148.5, 154.1, 157.1. **^{19}F NMR** (470.6 MHz, $CDCl_3$): δ -153.5. **^{11}B NMR** (160.5 MHz, $CDCl_3$): δ 9.0. **FTIR**: 3054 (w), 1593 (w), 1521 (w), 1424 (w), 1265 (w), 1138 (m), 1078 (m), 845 (w), 763 (s), 698 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{30}H_{17}{}^{11}BN_2F_2$: 454.1447, found 454.1446.

2-(3-(Difluoroboranyl)-5,6-dimethyl-4-phenylpyridin-2-yl)quinoline 110f



Following the general procedure, a solution of 2-(5,6-dimethyl-1,2,4-triazin-3-yl)quinoline (100 mg, 0.42 mmol) and potassium phenylethynyltrifluoroborate (264 mg, 1.27 mmol) in DCM (4.0 mL) was treated with $BF_3.OEt_2$ (0.16 mL, 1.27 mmol). Chromatographic purification over silica (gradient; starting with cyclohexane, ending with ethyl acetate) afforded 2-(3-(difluoroboranyl)-5,6-dimethyl-4-phenylpyridin-2-yl)quinoline (131 mg, 87%) as a white solid. **M.p** 248-250 °C. **^{1}H NMR** (300 MHz, $CDCl_3$): δ 2.25 (3H, s, CH_3), 2.67 (3H, s, CH_3), 7.40-7.55 (5H, m, Ar), 7.59-7.69 (1H, m, Ar), 7.81-7.90 (1H, m, Ar), 7.95 (1H, d, *J* = 8.0 Hz, Ar), 8.39-8.47 (1H, m, Ar), 8.49-8.64 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 17.0, 23.8, 115.6, 123.0, 127.8, 127.9, 128.2, 128.7, 129.1, 129.2, 132.8, 133.3, 139.3, 140.2, 144.3, 152.3, 152.8, 157.1. **^{19}F NMR** (376.5 MHz, $CDCl_3$): δ -158.7. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 8.8. **FTIR**: 1588 (w), 1523 (m), 1382 (w), 1264 (m), 1085 (s), 951 (m), 752 (s), 702 (s), 592 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{22}H_{17}{}^{11}BN_2F_2$: 358.1447, found 358.1450.

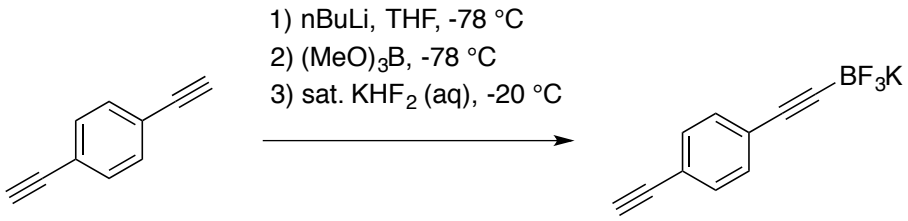
3-(Difluoroboranyl)-4-(4-ethynylphenyl)-2-(quinolin-2-yl)dibenzo[*f*,*h*]quinoline 110g



Following the general procedure, a suspension of 3-(quinolin-2-yl)phenanthro[9,10-*e*][1,2,4]triazine (50 mg, 0.14 mmol) and potassium ((4-ethynylphenyl)ethynyl)trifluoroborate

(97 mg, 0.42 mmol) in DCM (1.0 mL) was treated with $BF_3.OEt_2$ (0.05 mL, 0.42 mmol). Chromatographic purification over silica (gradient; starting with cyclohexane, ending with dichloromethane) afforded 3-(difluoroboranyl)-4-(4-ethynylphenyl)-2-(quinolin-2-yl)dibenzo[*f*,*h*]quinoline (40 mg, 57%) as a yellow solid. **M.p** 345 °C dec. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 3.18 (1H, s, CH), 7.13-7.17 (1H, m, Ar), 7.52-7.57 (1H, m, Ar), 7.61-7.63 (2H, m, Ar), 7.65-7.69 (2H, m, Ar), 7.72-7.81 (4H, m, Ar), 7.93-7.97 (1H, m, Ar), 8.05-8.07 (1H, m, Ar), 8.61-8.59 (2H, m, Ar), 8.67-8.65 (1H, m, Ar), 8.81-8.74 (2H, m, Ar), 9.56-9.54 (1H, m, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): δ 77.7, 77.9, 116.2, 122.6, 123.3, 123.4, 125.8, 125.9 (x2), 127.7 (x2), 127.9, 128.5, 128.8, 129.1, 129.2, 129.4, 129.7, 130.7, 131.1, 131.6, 131.9, 133.0, 133.6, 140.3, 143.0, 144.6, 149.4, 151.4, 153.6. **^{19}F NMR** (376.5 MHz, $CDCl_3$): δ -151.3. **^{11}B NMR** (160.5 MHz, $CDCl_3$): δ 9.4. **FTIR**: 3301 (w), 2921 (w), 2109 (w), 1594 (w), 1522 (w), 1096 (m), 918 (m), 841 (m), 722 (s), 617 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{34}H_{20}{}^{11}BN_2F_2$: 505.1682, found 505.1680.

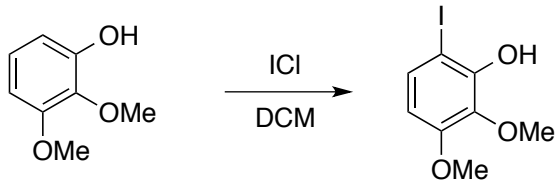
Potassium ((4-ethynylphenyl)ethynyl)trifluoroborate 113



To a solution of 1,4-diethynylbenzene (500 mg, 3.96 mmol, 1.0 eq) in THF (15 mL) under N_2 at -78 °C was added a 2.27 M solution of *n*-butyllithium in hexane (1.74 mL, 3.96 mmol, 1.0 eq). After 1 hour, trimethyl borate (0.66 mL, 5.94 mmol, 1.5 eq) was added and the reaction stirred at -78 °C for 1 hour. The reaction was allowed to warm to -20 °C and stirred for 1 hour before a saturated aqueous solution of KHF_2 (1856 mg, 23.76 mmol, 6.0 equiv) in distilled water was added. After 1 hour, the reaction was allowed to warm to room temperature and stirred for a further hour. The reaction mixture was concentrated and thoroughly dried under reduced pressure. The crude products were washed with hot acetone (2 x 50 mL) and the residue was removed by filtration. The acetone fractions were combined and the solvent evaporated. Trituration using acetone and diethyl ether afforded potassium ((4-ethynylphenyl)ethynyl)trifluoroborate (498 mg, 54%) as a white solid. **M.p.** 213-215 °C dec. **^{1}H NMR** (300 MHz, d^6-DMSO): δ 4.24 (1H, s, CH), 7.28 (2H, d, *J* = 8.0 Hz, Ar), 7.37

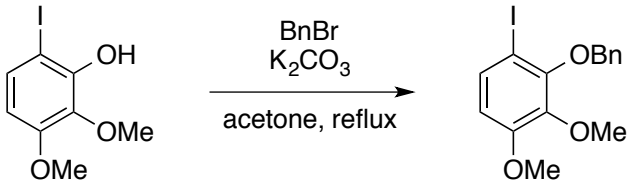
(2H, d, J = 8.0 Hz, Ar). **^{13}C NMR** (75.5 MHz, d^6-DMSO): δ 82.2, 83.8, 120.3, 126.5, 131.6, 132.1. **^{19}F NMR** (376.5 MHz, d^6-DMSO): δ -131.8. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 1.6. **FTIR**: 3277 (w), 2186 (w), 1499 (w), 1230 (w), 953 (s), 836 (s), 627 (m), 555 (m), 464 (m) cm^{-1}. **HRMS**: (ESI) [MH$^+$] calcd for $C_{10}H_5{}^{11}BF_3$: 192.0478, found 192.0481.

6-Iodo-2,3-dimethoxyphenol 116



To a stirred solution of 2,3-dimethoxyphenol (1.30 mL, 10.00 mmol, 1.0 eq) in dichloromethane (10.0 mL) at room temperature was added dropwise a solution of iodine monochloride (0.50 mL, 10.00 mmol, 1.0 eq) in dichloromethane (40.0 mL). The mixture was stirred overnight at RT, washed with water, $Na_2S_2O_3$ and brine, dried over $MgSO_4$, filtered and evaporated to dryness. The residue was purified by flash chromatography on silica gel (dichloromethane/petrol 1:1) to give 6-iodo-2,3-dimethoxyphenol (1.90 g, 68%) as a colourless solid. The structure has been confirmed by HMBC analysis. **M.p.** 50-52 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 3.84 (3H, s, CH_3), 3.90 (3H, s, CH_3), 6.20 (1H, s, OH), 6.33 (1H, d, J = 9.0 Hz, Ar), 7.34 (1H, d, J = 9.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 56.1, 61.1, 71.6, 106.5, 132.7, 135.6, 149.3, 156.9. **FTIR:** 3401 (m), 2937 (w), 2833 (w), 1583 (m), 1452 (s), 1292 (s), 1201 (s), 1090 (s), 987 (s), 778 (s) cm^{-1}. **HRMS**: (ES$^+$) [MH$^+$] calcd for $C_8H_{10}O_3I$: 280.9675, found: 280.9679.

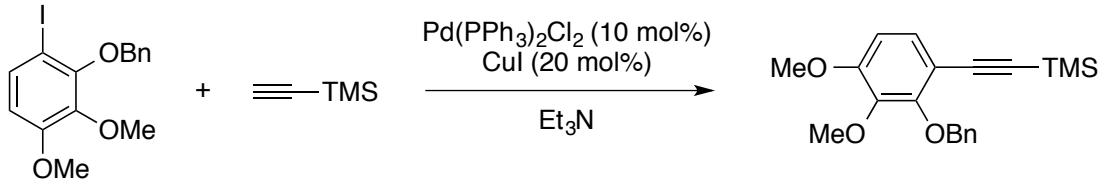
2-Benzyloxy-1-iodo-2,3-dimethoxybenzene 117



To a stirred solution of 6-iodo-2,3-dimethoxyphenol (900 mg, 3.21 mmol, 1.0 eq) in acetone (30.0 mL) was added benzyl bromide (0.42 mL, 3.53 mmol, 1.1 eq) and potassium carbonate (666 mg, 4.82 mmol, 1.5 eq). The mixture was stirred for 4 hours at reflux and then

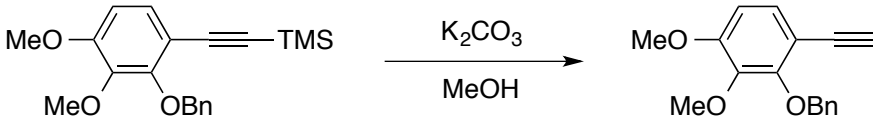
cooled to RT. The solvent was evaporated, the residue redissolved in dichloromethane and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/petrol : 5/95) to give 2-(benzyloxy)-1-iodo-2,3-dimethoxybenzene (1.057 g, 89%) as a colorless solid. **M.p.** 71-73 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 3.87 (3H, s, CH_3), 3.89 (3H, s, CH_3), 5.06 (2H, s, CH_2), 6.53 (1H, d, J = 9.0 Hz, Ar), 7.34-7.46 (4H, m, Ar), 7.59-7.62 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 56.3, 61.1, 75.2, 81.9, 110.1, 128.2, 128.4, 128.7, 132.8, 137.0, 143.1, 152.3, 154.5. **FTIR:** 2933 (w), 1571 (m), 1475 (s), 1418 (s), 1289 (s), 1217 (s), 1087 (s), 996 (s), 740 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{15}H_{16}O_3I$: 371.0144, found: 371.0159.

(2-Benzyloxy-2,3-dimethoxyphenylethynyl)trimethylsilane 118



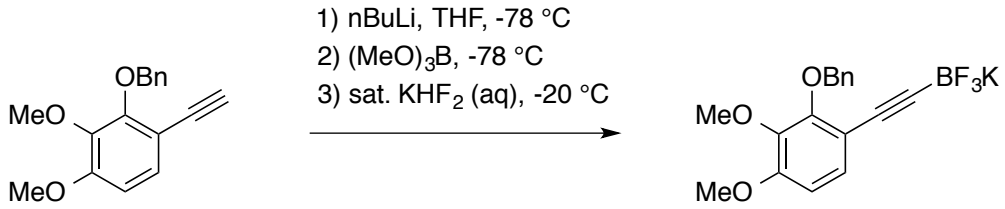
A suspension of 2-(benzyloxy)-1-iodo-2,3-dimethoxybenzene (1.28 g, 3.46 mmol, 1.0 eq), bis(triphenylphosphine)palladium(II) dichloride (246 mg, 0.35 mmol, 0.1 eq) and copper(I) iodide (131 mg, 0.69 mmol, 0.2 eq) in triethylamine (13.0 mL) under N_2 was stirred for 15 min at RT. Ethynyltrimethylsilane (2.44 mL, 17.29 mmol, 5.0 eq) was then added and the mixture stirred at RT overnight. Two more equivalents of ethynyltrimethylsilane were added and the mixture stirred for a further 2 hours. The mixture was filtered, extracted in dichloromethane and washed with water, aqueous HCl and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/petrol : 5/95) to give (2-benzyloxy-2,3-dimethoxyphenylethynyl)trimethylsilane (1.15 g, 98%) as a yellow oil. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 0.24 (9H, s, CH_3), 3.86 (3H, s, CH_3), 3.87 (3H, s, CH_3), 5.17 (2H, s, CH_2), 6.62 (1H, d, J = 9.0 Hz, Ar), 7.18 (1H, d, J = 9.0 Hz, Ar), 7.31-7.40 (3H, m, Ar), 7.57-7.59 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 0.1, 56.1, 61.1, 75.4, 97.0, 101.3, 107.4, 110.9, 128.0, 128.3 (x 2), 128.6, 137.6, 142.4, 154.1, 154.6. **FTIR:** 2959 (m), 2151 (m), 1592 (m), 1492 (s), 1427 (m), 1295 (s), 1100 (s), 1047 (m), 843 (s), 758 (m) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{20}H_{25}O_3Si$: 341.1573, found: 341.1581.

2-Benzyloxy-1-ethynyl-2,3-dimethoxybenzene 119



A suspension of (2-benzyloxy-2,3-dimethoxyphenylethynyl)trimethylsilane (3.41 g, 10.02 mmol, 1.0 eq) and potassium carbonate (3.60 g, 21.05 mmol, 2.1 eq) in methanol (35.0 mL) was stirred overnight at RT. After evaporation of the solvent, the residue was dissolved in dichloromethane and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/petrol : 1/9) to give 2-benzyloxy-1-ethynyl-2,3-dimethoxybenzene (2.41 g, 90%) as a colorless solid. **M.p.** 69-71 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 3.21 (1H, s, CH), 3.87 (3H, s, CH_3), 3.88 (3H, s, CH_3), 5.17 (2H, s, CH_2), 6.64 (1H, d, *J* = 9.0 Hz, Ar), 7.19 (1H, d, *J* = 9.0 Hz, Ar), 7.33-7.40 (3H, m, Ar), 7.55-7.57 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 56.1, 61.1, 75.6, 80.0 (x 2), 107.5, 109.8, 128.0, 128.3, 128.5, 128.7, 137.3, 142.5, 154.3, 154.8. **FTIR:** 3283 (m), 2939 (m), 2104 (m), 1594 (m), 1491 (s), 1453 (m), 1294 (s), 1098 (s), 1037 (m), 804 (m) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{17}H_{17}O_3$: 269.1178, found: 269.1174.

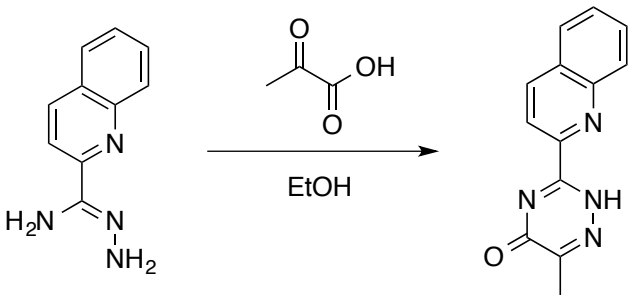
Potassium ((2-(benzyloxy)-3,4-dimethoxyphenyl)ethynyl)trifluoroborate 120



To a solution of 2-benzyloxy-1-ethynyl-2,3-dimethoxybenzene (2.00 g, 7.45 mmol, 1.0 eq) in THF (15 mL) under argon at -78 °C was added a 2.27 M solution of *n*-butyllithium in hexane (3.28 mL, 7.45 mmol, 1.0 eq). After 1 hour, trimethyl borate (1.25 mL, 11.18 mmol, 1.5 eq) was added and the reaction stirred at -78 °C for 1 hour. The reaction was allowed to warm to -20 °C and stirred for 1 hour before a saturated aqueous solution of KHF_2 (3.49 g, 44.72 mmol, 6.0 equiv) in distilled water was added. After 1 hour, the reaction was allowed to warm to room temperature and stirred for a further hour. The reaction mixture was

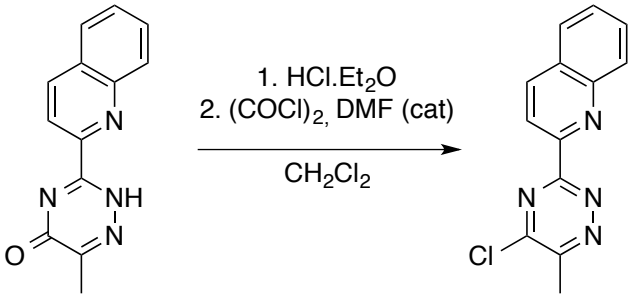
concentrated and thoroughly dried under reduced pressure. The crude products were washed with cold acetone (2 x 50 mL) and the residue was removed by filtration. The acetone fractions were combined and the solvent evaporated. The residue was dissolved in a minimum of hot acetone and, after addition of diethyl ether, filtration afforded potassium ((2-(benzyloxy)-3,4-dimethoxyphenyl)ethynyl)trifluoroborate (2.32 g, 6.21 mmol, 83%) as a white solid. **M.p.** 210-212 °C dec. **^{1}H NMR** (400 MHz, d^{6}-DMSO): δ 3.70 (3H, s, CH_3), 3.78 (3H, s, CH_3), 5.07 (2H, s, CH_2), 6.73 (1H, d, *J* = 8.5 Hz, CH), 7.01 (1H, d, *J* = 8.5 Hz, CH), 7.32-7.38 (3H, m, Ar), 7.61-7.63 (2H, m, Ar). **^{13}C NMR** (101 MHz, d^{6}-DMSO): δ 55.8, 60.5, 74.3, 85.2, 108.0, 112.9, 127.4, 127.8, 128.1, 128.6, 137.5, 141.9, 152.6, 152.9. **^{19}F NMR** (376.6 MHz, d^{6}-DMSO): δ -131.7. **^{11}B NMR** (128.4 MHz, d^{6}-DMSO): δ 1.3. **FTIR**: 2942 (w), 2183 (w), 1594 (w), 1490 (m), 1295 (m), 1051 (s), 970 (s), 748 (m) cm^{-1}. **HRMS**: (ESI) [M^{-}] calcd for $C_{17}H_{15}{}^{11}BF_3O_3$: 335.1072, found 335.1060.

5-Hydroxy-6-methyl-3-(2-quinolyl)-1,2,4-triazine 121



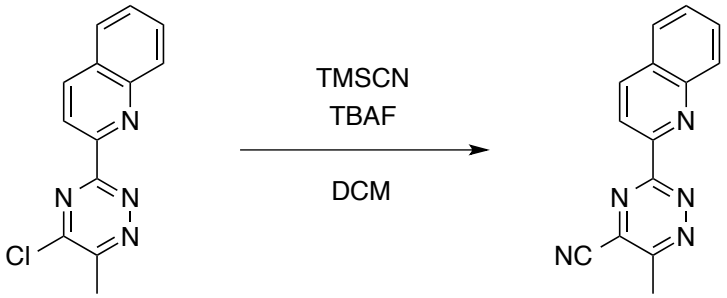
To a stirred suspension of 2-quinolylamidrazone (3.50 g, 18.90 mmol, 1.0 eq) in ethanol (70.0 mL) was added pyruvic acid (1.31 mL, 18.90 mmol, 1.0 eq). The mixture was stirred overnight at room temperature and for 4 hours at reflux. The mixture was allowed to cool and the resulting precipitate was filtered to afford 5-hydroxy-6-methyl-3-(2-quinolyl)-1,2,4-triazine (3.91 g, 87%) as a yellow solid. **M.p** 248-250 °C dec. **^{1}H NMR** (400 MHz, d^{6}-DMSO): δ 2.27 (3H, s, CH_3), 7.75-7.79 (1H, m, Ar), 7.90-7.94 (1H, m, Ar), 8.12-8.14 (1H, m, Ar), 8.20-8.22 (1H, m, Ar), 8.33-8.36 (1H, m, Ar), 8.63-8.65 (1H, m, Ar), 14.21 (1H, br, NH). **^{13}C NMR** (100.6 MHz, d^{6}-DMSO): δ 17.8, 119.3, 128.7, 129.1, 129.4, 129.7, 131.3, 138.7, 147.0, 148.8, 153.3, 156.0, 163.6. **FTIR**: 3310 (w), 1640 (m), 1476 (s), 1341 (m), 1212 (m), 841 (s), 750 (s) cm^{-1}. **HRMS**: (ESI) [MH^{+}] calcd for $C_{13}H_{11}N_4O$: 239.0933, found 239.0942.

5-Chloro-6-methyl-3-(2-quinolyl)-1,2,4-triazine 122



To a solution of 5-hydroxy-6-methyl-3-(2-quinolyl)-1,2,4-triazine (1.895 g, 7.95 mmol, 1.0 eq) in dichloromethane (400 mL) was added 7.95 mL of a 1.0 M solution of HCl in Et_2O. The mixture was stirred for 10 min when oxalyl chloride (0.82 mL, 9.54 mmol, 1.2 eq) and a catalytic amount of DMF were added. The mixture was stirred for 30 min at room temperature and washed with $NaHCO_3$ and brine. The organic layer was extracted with dichloromethane, dried over $MgSO_4$, filtered and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/dichloromethane : 1/9) to give 5-chloro-6-methyl-3-(2-quinolyl)-1,2,4-triazine (1.910 g, 94%) as a white solid. **M.p.** 136 °C (dec). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 2.89 (3H, s, CH_3), 7.59-7.63 (1H, m, Ar), 7.75-7.80 (1H, m, Ar), 7.86-7.89 (1H, m, Ar), 8.34-8.38 (2H, m, Ar), 8.63-8.65 (1H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 20.0, 120.6, 127.6, 128.2, 128.9, 130.1, 130.8, 137.4, 148.3, 151.4, 157.6, 158.6, 161.8. **FTIR**: 3059 (w), 1594 (w), 1487 (m), 1397 (s), 1112 (m), 896 (m), 840 (m), 786 (m) cm^{-1}. **HRMS** calcd for $C_{13}H_{10}N_4{}^{35}Cl$: 257.0594. Found: 257.0594.

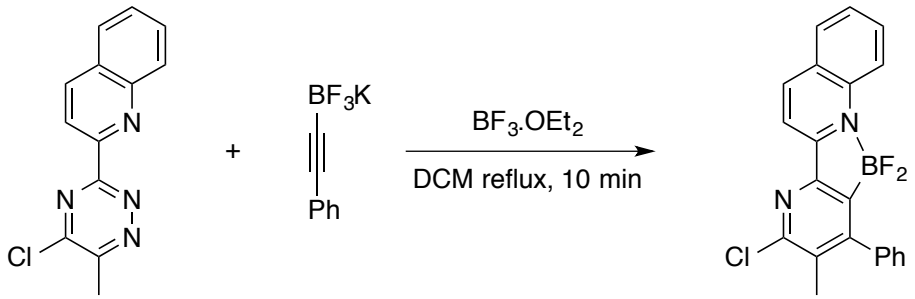
6-Methyl-3-(2-quinolyl)-1,2,4-triazine-5-carbonitrile 123



To a solution of 5-chloro-6-methyl-3-(2-quinolyl)-1,2,4-triazine (1.55 g, 6.02 mmol, 1.0 eq) and trimethylsilyl cyanide (1.88 mL, 15.06 mmol, 2.5 eq) in dichloromethane (60 mL) under N_2 at RT was added 15 mL of a 1.0 M tetrabutylammonium fluoride solution in THF (15.06 mmol, 2.5 eq). The resulting solution was stirred at RT for 5 minutes. The mixture was

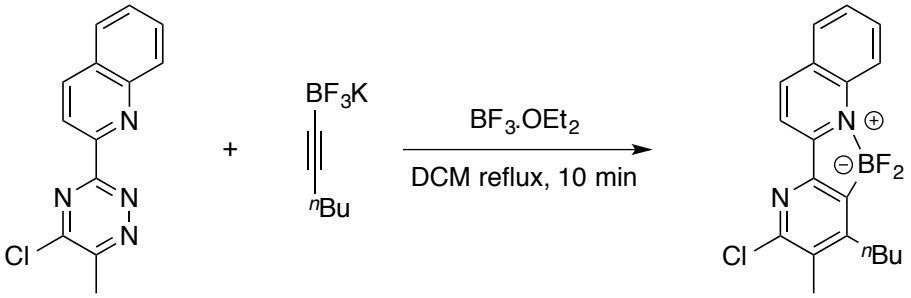
dissolved in DCM and washed with water and brine. The organic fractions were combined, dried over $MgSO_4$, filtered and evaporated under vacuum. The residue was purified by flash chromatography on silica gel (dichloromethane/EtOAc 39:1) to afford 6-methyl-3-(2-quinolyl)-1,2,4-triazine-5-carbonitrile as an orange solid (1.36 g, 5.49 mmol, 91%). **M.p.** 155-157 °C dec. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 3.06 (3H, s, CH_3), 7.64-7.68 (1H, m, Ar), 7.70-7.84 (1H, m, Ar), 7.90-7.93 (1H, m, Ar), 8.36-8.42 (2H, m, Ar), 8.66-8.68 (1H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 19.5, 113.5, 120.5, 127.6, 128.6, 129.0, 130.5, 130.8, 135.8, 137.7, 148.4, 150.9, 158.2, 161.6. **FTIR:** 2922 (w), 1502 (m), 1394 (m), 1100 (m), 1050 (m), 854 (s), 787 (s), 751 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{14}H_{10}N_5$: 248.0936, found: 248.0941.

2-Chloro-5-(difluoroboryl)-3-methyl-4-phenyl-6-(2-quinolyl)-pyridine 124



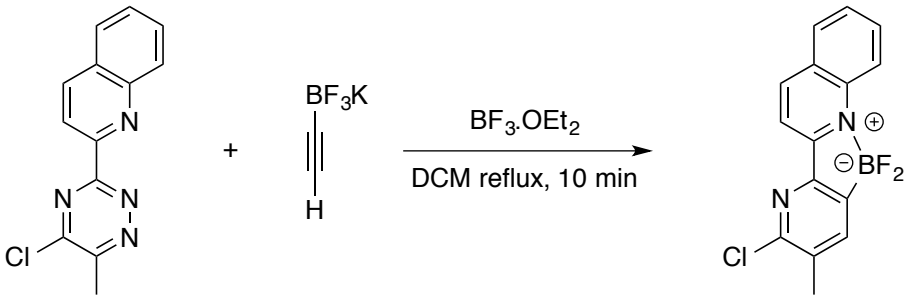
Following the general procedure, a solution of 5-chloro-6-methyl-3-(2-quinolyl)-1,2,4-triazine (100 mg, 0.39 mmol, 1.0 eq) and potassium (phenylethynyl)trifluoroborate (243 mg, 1.17 mmol, 3.0 eq) in DCM (4.0 mL) was treated with $BF_3.OEt_2$ (0.14 mL, 1.17 mmol, 3.0 eq). Chromatographic purification over silica (gradient; starting with petrol, ending with dichloromethane) afforded 2-chloro-5-(difluoroboryl)-3-methyl-4-phenyl-6-(2-quinolyl)-pyridine (132 mg, 89%) as a white solid. **M.p** 272-274 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 2.38 (3H, s, CH_3), 7.44-7.55 (5H, m, Ar), 7.66-7.70 (1H, m, Ar), 7.87-7.91 (1H, m, Ar), 7.97-7.99 (1H, m, Ar), 8.40-8.42 (1H, m, Ar), 8.52-8.54 (1H, m, Ar), 8.63-8.65 (1H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 18.0, 115.5, 122.9, 128.2 (x2), 128.3, 128.6, 128.8, 129.3, 133.4, 133.5, 138.3, 140.1, 144.6, 153.8, 155.3, 155.5. **^{19}F NMR** (376.5 MHz, $CDCl_3$): δ -153.5. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 8.5. **FTIR**: 3060 (w), 1543 (m), 1181 (m), 1098 (s), 1057 (s), 842 (m), 743 (m), 726 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{21}H_{15}{}^{11}BN_2{}^{35}ClF_2$: 379.0985, found 379.1000.

4-Butyl-2-chloro-5-(difluoroboryl)-3-methyl-6-(2-quinolyl)-pyridine 125



Following the general procedure, a solution of 5-chloro-6-methyl-3-(2-quinolyl)-1,2,4-triazine (100 mg, 0.39 mmol, 1.0 eq) and potassium (hex-1-ynyl)trifluoroborate (220 mg, 1.17 mmol, 3.0 eq) in DCM (4.0 mL) was treated with $BF_3.OEt_2$ (0.14 mL, 1.17 mmol, 3.0 eq). Chromatographic purification over silica (gradient; starting with petrol, ending with dichloromethane) afforded 4-butyl-2-chloro-5-(difluoroboryl)-3-methyl-6-(2-quinolyl)-pyridine (134 mg, 96%) as a white solid. **M.p.** 208-210 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.00 (3H, t, *J* = 7.0 Hz, CH_3), 1.48-1.57 (2H, m, CH_2), 1.62-1.71 (2H, m, CH_2), 2.45 (3H, s, CH_3), 2.93 (2H, t, *J* = 8.0 Hz, CH_2), 7.64-7.68 (1H, m, Ar), 7.91-7.95 (2H, m, Ar), 8.29-8.31 (1H, m, Ar), 8.58-8.61 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 13.9, 15.9, 23.1, 32.2, 33.2, 115.4, 122.8, 128.1, 128.6, 129.2, 133.5, 133.7, 140.1, 144.5, 152.6, 153.4, 155.6, 156.7. **^{19}F NMR** (376.5 MHz, $CDCl_3$): δ -155.8. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 8.8. **FTIR**: 2955 (m), 2873 (w), 1600 (m), 1549 (m), 1296 (m), 1087 (s), 1049 (s), 934 (m), 843 (s), 753 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{19}H_{19}{}^{11}BN_2{}^{35}ClF_2$: 359.1298, found 359.1301.

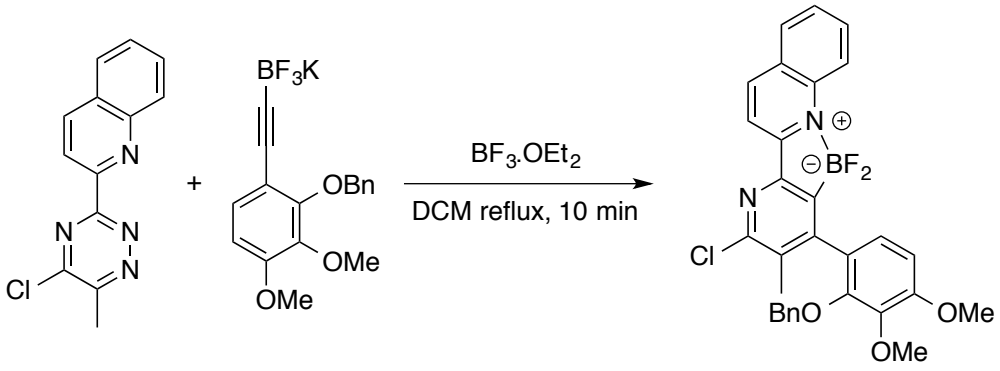
2-Chloro-5-(difluoroboryl)-3-methyl-6-(2-quinolyl)-pyridine 126



Following the general procedure, a solution of 5-chloro-6-methyl-3-(2-quinolyl)-1,2,4-triazine (100 mg, 0.39 mmol, 1.0 eq) and potassium ethynyltrifluoroborate (154 mg, 1.17 mmol, 3.0 eq) in DCM (4.0 mL) was treated with $BF_3.OEt_2$ (0.14 mL, 1.17 mmol, 3.0 eq). Chromatographic purification over silica (gradient; starting with petrol, ending with

dichloromethane) afforded 2-chloro-5-(difluoroboryl)-3-methyl-6-(2-quinolyl)-pyridine (74 mg, 63%) as a white solid. **M.p.** 240-242 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 2.49 (3H, s, CH_3), 7.69-7.73 (1H, m, Ar), 7.94-8.01 (3H, m, Ar), 8.36-8.38 (1H, m, Ar), 8.60-8.66 (2H, m, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 20.3, 115.4, 122.9, 128.3, 128.7, 129.3, 133.7, 135.7, 140.2, 141.4, 144.8, 152.6, 153.8, 155.2. **^{19}F NMR** (376.5 MHz, $CDCl_3$): δ -156.7. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 8.5. **FTIR**: 1598 (m), 1523 (m), 1415 (w), 1318 (m), 1055 (s), 841 (s), 771 (s), 724 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{15}H_{13}{}^{11}BN_2{}^{35}ClO_2$: 299.0759, found 299.0753.

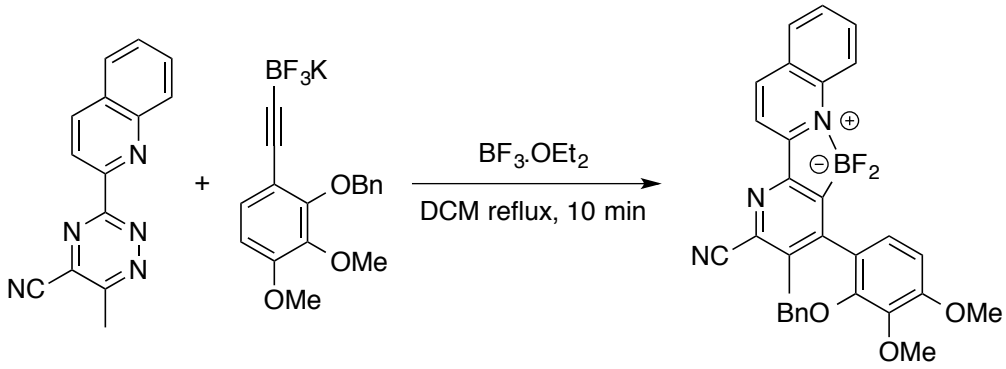
2-(4-(2-(Benzyloxy)-3,4-dimethoxyphenyl)-6-chloro-3-(difluoroboranyl)-5-methylpyridin-2-yl)quinoline 127



Following the general procedure, a solution of 5-chloro-6-methyl-3-(2-quinolyl)-1,2,4-triazine (36 mg, 0.14 mmol, 1.0 eq) and potassium ((2-(benzyloxy)-3,4-dimethoxyphenyl)ethynyl)trifluoroborate (157 mg, 0.42 mmol, 3.0 eq) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.05 mL, 0.42 mmol, 3.0 eq). Chromatographic purification over silica (gradient; starting with petrol, ending with ethyl acetate) afforded 2-(4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-6-chloro-3-(difluoroboranyl)-5-methylpyridin-2-yl)quinoline (65 mg, 85%) as a white solid. **M.p.** 232-234 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 2.29 (3H, s, CH_3), 3.92 (3H, s, CH_3), 3.96 (3H, s, CH_3), 4.55 (1H, d, *J* = 11.0 Hz, CH), 4.95 (1H, d, *J* = 11.0 Hz, CH), 6.90 (1H, d, *J* = 8.5 Hz, Ar), 7.00 (2H, t, *J* = 3.5 Hz, Ar), 7.15-7.22 (4H, m, Ar), 7.69 (1H, t, *J* = 7.5 Hz, Ar), 7.90 (1H, t, *J* = 7.5 Hz, Ar), 7.99 (1H, d, *J* = 8.0 Hz, Ar), 8.42 (1H, d, *J* = 8.5 Hz, Ar), 8.54 (1H, d, *J* = 8.5 Hz, Ar), 8.66 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 18.0, 56.1, 61.4, 75.7, 107.8, 115.6, 122.9, 124.7, 125.9, 127.7 (x2), 128.2, 128.4, 128.8, 129.4, 133.7, 135.8, 137.7, 140.2, 142.7, 144.8, 150.2, 152.3, 152.7, 153.2, 154.1, 155.5. **^{19}F NMR** (376.6 MHz, $CDCl_3$): δ -150.2 (d, *J* = 96.5 Hz), -157.5 (d, *J* = 96.5

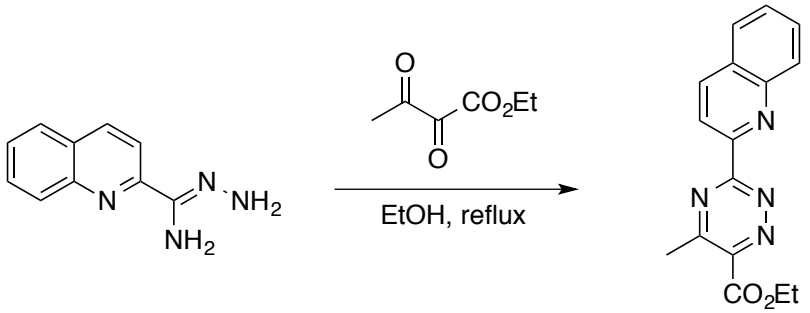
Hz). **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 8.7. **FTIR**: 2940 (w), 1596 (w), 1273 (w), 1067 (m), 986 (w), 753 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{30}H_{25}{}^{11}BN_2{}^{35}ClF_2O_3$: 545.1615, found 545.1600.

4-(2-(Benzyloxy)-3,4-dimethoxyphenyl)-5-(difluoroboranyl)-3-methyl-6-(quinolin-2-yl)picolinonitrile 128



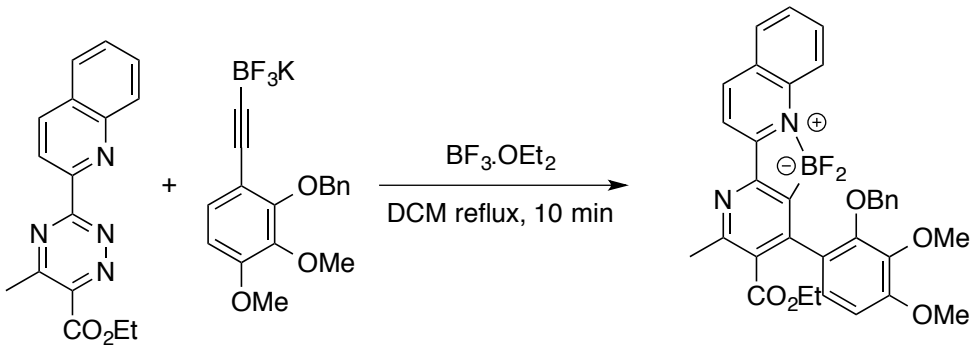
Following the general procedure, a solution of 6-methyl-3-(quinolin-2-yl)-1,2,4-triazine-5-carbonitrile (51 mg, 0.21 mmol, 1.0 eq) and potassium ((2-(benzyloxy)-3,4-dimethoxyphenyl)ethynyl)trifluoroborate (232 mg, 0.62 mmol, 3.0 eq) in DCM (2.0 mL) was treated with $BF_3.OEt_2$ (0.08 mL, 0.62 mmol, 3.0 eq). Chromatographic purification over silica (gradient; starting with petrol, ending with dichloromethane) afforded 4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-5-(difluoroboranyl)-3-methyl-6-(quinolin-2-yl)picolinonitrile (88 mg, 78%) as a white solid. **M.p.** 243-245 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 2.45 (3H, s, CH_3), 3.94 (3H, s, CH_3), 3.97 (3H, s, CH_3), 4.53 (1H, d, *J* = 11.0 Hz, CH), 5.01 (1H, d, *J* = 11.0 Hz, CH), 6.93 (3H, m, Ar), 7.13-7.19 (4H, m, Ar), 7.74 (1H, t, *J* = 7.5 Hz, Ar), 7.94 (1H, t, *J* = 7.5 Hz, Ar), 8.04 (1H, d, *J* = 8.0 Hz, Ar), 8.48 (1H, d, *J* = 8.5 Hz, Ar), 8.57 (1H, d, *J* = 8.5 Hz, Ar), 8.73 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 17.4, 56.1, 61.4, 75.9, 108.0, 115.7, 117.1, 123.0, 124.6 (x2), 127.6, 127.8, 128.2, 128.8, 128.9, 129.8, 133.9, 134.3, 137.5, 140.1, 141.6, 142.7, 145.1, 150.2, 151.5, 154.4, 154.5, 154.9. **^{19}F NMR** (376.6 MHz, $CDCl_3$): δ -148.9 (d, *J* = 102.5 Hz), -156.5 (d, *J* = 102.5 Hz). **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 8.5. **FTIR**: 2940 (w), 2159 (m), 1595 (m), 1494 (m), 1296 (m), 1095 (s), 948 (m), 764 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{31}H_{25}{}^{11}BN_3F_2O_3$: 536.1957, found 536.1957.

Ethyl 5-methyl-3-(quinolin-2-yl)-1,2,4-triazine-6-carboxylate 132



To a solution of quinoline-2-carbohydrazonamide (100 mg, 0.54 mmol, 1.0 eq) in ethanol (3.0 mL) was added ethyl 2,3-dioxobutanoate (175 mg, 0.54 mmol, 1.0 eq). The mixture was stirred 3 hours at reflux and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/dichloromethane : 5/95) to give ethyl 5-methyl-3-(quinolin-2-yl)-1,2,4-triazine-6-carboxylate as a mixture of regioisomers in a 19:1 ratio (136 mg, 86%), and as a yellow solid. **M.p.** 86-88 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.48 (3H, t, *J* = 7.0 Hz, CH_3), 2.98 (3H, s, CH_3), 4.55 (2H, q, *J* = 7.0 Hz, CH_2), 7.60-7.64 (1H, m, Ar), 7.78 (1H, ddd, *J* = 8.5, 7.0, 1.5 Hz, Ar), 7.89 (1H, d, *J* = 8.5 Hz, Ar), 8.35-8.39 (2H, m, Ar), 8.76 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 14.3, 23.4, 63.0, 121.3, 127.7, 128.5, 129.1, 130.3, 130.9, 137.6, 148.4, 149.7, 151.9, 161.2, 162.6, 164.0. **FTIR:** 3022 (w), 1717 (s), 1513 (m), 1369 (w), 1267 (s), 1152 (s), 1112 (m), 811 (m), 771 (m) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{16}H_{15}N_4O_2$: 295.1190, found: 295.1189.

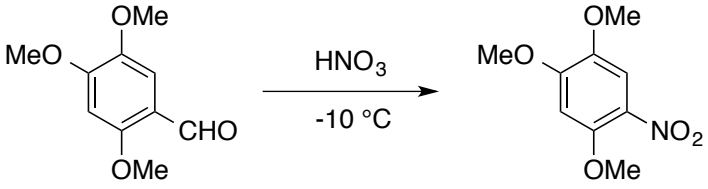
Ethyl 4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-5-(difluoroboranyl)-2-methyl-6-(quinolin-2-yl)nicotinate 133



Following the general procedure, a solution of ethyl 5-methyl-3-(quinolin-2-yl)-1,2,4-triazine-6-carboxylate (105 mg, 0.36 mmol, 1.0 eq) and potassium ((2-(benzyloxy)-3,4-

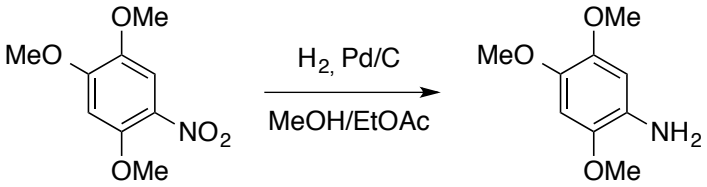
dimethoxyphenyl)ethynyl)trifluoroborate (400 mg, 1.07 mmol, 3.0 eq) in DCM (5.0 mL) was treated with $BF_3.OEt_2$ (0.13 mL, 1.07 mmol, 3.0 eq). Chromatographic purification over silica (gradient; starting with dichloromethane, ending with ethyl acetate) afforded ethyl 4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-5-(difluoroboranyl)-2-methyl-6-(quinolin-2-yl)nicotinate (157 mg, 75%) as a pale yellow solid. **M.p.** 175-177 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.03 (3H, t, *J* = 7.0 Hz, CH_3), 2.74 (3H, s, CH_3), 3.87 (3H, s, CH_3), 3.94 (3H, s, CH_3), 4.07-4.18 (2H, m, CH_2), 4.62 (1H, d, *J* = 11.5 Hz, CH), 4.90 (1H, d, *J* = 11.5 Hz, CH), 6.89 (1H, d, *J* = 8.5 Hz, Ar), 7.07-7.16 (5H, m, Ar), 7.36 (1H, dd, *J* = 8.5, 1.5 Hz, Ar), 7.63-7.67 (1H, m, Ar), 7.88 (1H, ddd, *J* = 8.5, 7.0, 1.5 Hz, Ar), 7.94 (1H, d, *J* = 8.0 Hz, Ar), 8.42 (1H, d, *J* = 8.5 Hz, Ar), 8.57 (1H, d, *J* = 8.5 Hz, Ar), 8.60 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 13.8, 23.9, 56.0, 61.1, 75.5, 107.6, 115.8, 123.0, 125.1 (x2), 126.1, 127.3, 127.8, 127.9, 128.4, 128.8, 129.5, 131.4, 133.5, 137.8, 140.1, 142.3, 144.7, 148.9, 150.0, 153.9, 155.6, 155.8, 157.3, 168.3. **^{19}F NMR** (376.6 MHz, $CDCl_3$): δ -148.5 (d, *J* = 107.0 Hz), -156.9 (d, *J* = 107.0 Hz). **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 8.6. **FTIR**: 1727 (w), 1596 (w), 1497 (w), 1425 (w), 1296 (w), 1243 (w), 1093 (s), 991 (w), 736 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{33}H_{30}{}^{11}BN_2F_2O_5$: 583.2216, found 583.2221.

1,2,4-Trimethoxy-5-nitrobenzene 135[137]



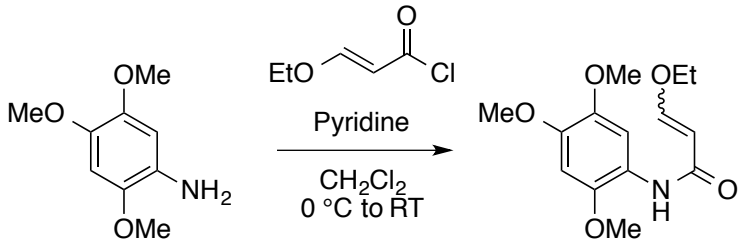
To a stirred solution of 28% aq. nitric acid (60 mL) at -10 °C was added portionwise 2,4,5-trimethoxybenzaldehyde (3.00 g, 15.3 mmol, 1.0 eq). The mixture was stirred for 3 hours at -10 °C and then allowed to warm to RT. The mixture was extracted with dichloromethane and washed with a saturated $NaHCO_3$ solution and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness to give 1,2,4-trimethoxy-5-nitrobenzene (2.53 g, 78%) as a yellow solid. **M.p.** 127-128 °C (lit. 123-124 °C). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 3.89 (3H, s, CH_3), 3.97 (3H, s, CH_3), 3.98 (3H, s, CH_3), 6.55 (1H, s, Ar), 7.57 (1H, s, Ar). **^{13}C NMR** (76 MHz, $CDCl_3$): δ 56.6 (x2), 57.3, 97.6, 109.1, 131.0, 142.5, 150.5, 154.9.

2,4,5-Trimethoxyaniline 136[137]



A stirred suspension of 1,2,4-trimethoxy-5-nitrobenzene (2.42 g, 11.35 mmol, 1.0 eq) and 5% Pd/C (0.50 g) in methanol :EtOAc (9 :1, 100 mL) was stirred overnight at RT under a H_2 atmosphere. The mixture was filtered through Celite, eluting with methanol and evaporated to dryness. The crude product was purified by column chromatography (EtOAc:heptane, 1:1) to give 2,4,5-trimethoxyaniline (1.81 g, 87%) as a white solid. **M.p.** 93-94 °C (lit. 89-90 °C). **^{1}H NMR** (300 MHz, $CDCl_3$): δ 3.55 (2H, s, NH_2), 3.79 (3H, s, CH_3), 3.81 (3H, s, CH_3), 3.82 (3H, s, CH_3), 6.39 (1H, s, Ar), 6.53 (1H, s, Ar). **^{13}C NMR** (76 MHz, $CDCl_3$): δ 56.6, 56.7, 57.4, 100.2, 101.9, 129.7, 140.9, 141.5, 143.9.

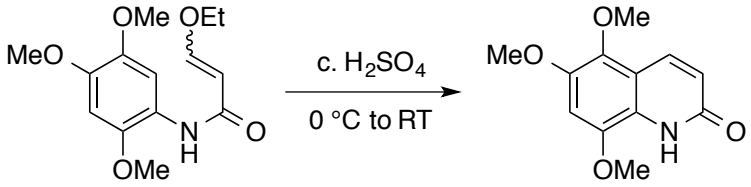
3-Ethoxy-*N*-(2,4,5-trimethoxyphenyl)acrylamide 137[137]



To a stirred solution of 2,4,5-trimethoxyaniline (1.38 g, 7.53 mmol, 1.0 eq) and pyridine (1.83 mL, 22.6 mmol, 3.0 eq) in dichloromethane (90 mL) was added dropwise a solution of 3-ethoxyacryloyl chloride (1.27 g, 9.42 mmol, 1.25 eq) in dichloromethane (5 mL) at 0 °C. The mixture was stirred at RT for 4 hours and the solvent evaporated. The residue was extracted with ethyl acetate and washed with a 1 M HCl solution, a sat. $NaHCO_3$ solution and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness and the crude product was purified by column chromatography (EtOAc:heptane, 1:1 to 4 :1) to give (E)-3-ethoxy-*N*-(2,4,5-trimethoxyphenyl)acrylamide (1.58 g, 75%) as a white solid and (Z)-3-ethoxy-*N*-(2,4,5-trimethoxyphenyl)acrylamide (0.22 g, 10%) as a white solid. (E)-3-Ethoxy-*N*-(2,4,5-trimethoxyphenyl)acrylamide: **M.p.** 91-92 °C (lit. 91 °C). **^{1}H NMR** (300 MHz, $CDCl_3$): δ 1.34 (3H, t, J = 7.0 Hz, CH_3), 3.84 (3H, s, CH_3), 3.86 (3H, s, CH_3), 3.87

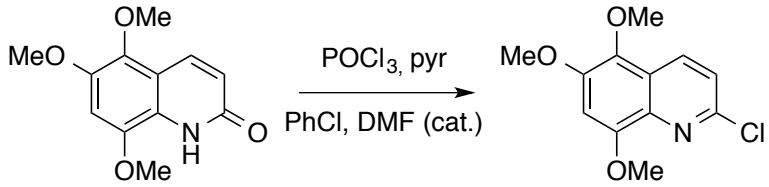
(3H, s, CH_3), 3.92 (2H, q, *J* = 7.0 Hz, CH_2), 5.39 (1H, d, *J* = 12.0 Hz, CH), 6.54 (1H, s, Ar), 7.51 (1H, br, NH), 7.62 (1H, d, *J* = 12.0 Hz, CH), 8.20 (1H, br, Ar). **^{13}C NMR** (76 MHz, $CDCl_3$): δ 14.5, 56.3, 56.4 (x2), 67.0, 97.4, 99.3, 105.3, 121.3, 141.9, 142.7, 144.5, 160.4, 164.8. (Z)-3-Ethoxy-*N*-(2,4,5-trimethoxyphenyl)acrylamide: **M.p.** 112-113 °C (lit. 112-113 °C). **^{1}H NMR** (300 MHz, $CDCl_3$): δ 1.43 (3H, t, *J* = 7.0 Hz, CH_3), 3.83 (3H, s, CH_3), 3.84 (3H, s, CH_3), 3.85 (3H, s, CH_3), 4.11 (2H, q, *J* = 7.0 Hz, CH_2), 4.93 (1H, d, *J* = 7.0 Hz, CH), 6.50 (1H, d, *J* = 7.0 Hz, CH), 6.53 (1H, s, Ar), 8.29 (1H, s, Ar), 9.42 (1H, s, NH). **^{13}C NMR** (76 MHz, $CDCl_3$): δ 15.3, 56.4, 56.6, 56.7, 70.9, 97.8, 103.7, 105.3, 122.0, 141.8, 142.9, 144.3, 152.9, 163.6.

5,6,8-Trimethoxyquinolin-2(1H)-one 138[137]



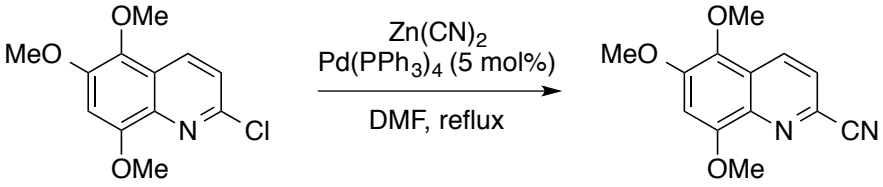
To a stirred solution of conc. sulfuric acid (12 mL) at 0 °C was dissolved 3-ethoxy-*N*-(2,4,5-trimethoxyphenyl)acrylamide (1.75 g, 6.22 mmol, 1.0 eq) and the mixture was stirred 2 hours at RT. Iced water (20 mL) was slowly added and the mixture stirred one more hour at RT. The mixture was extracted with dichloromethane and washed with a sat. $NaHCO_3$ solution and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness and the crude product was purified by column chromatography (EtOAc) to give 5,6,8-trimethoxyquinolin-2(1H)-one (1.20 g, 82%) as a white solid. **M.p.** 171-172 °C (lit. 171-173 °C). **^{1}H NMR** (300 MHz, $CDCl_3$): δ 3.85 (3H, s, CH_3), 3.88 (3H, s, CH_3), 3.91 (3H, s, CH_3), 6.62 (1H, d, *J* = 10.0 Hz, Ar), 6.69 (1H, s, Ar), 7.97 (1H, d, *J* = 10.0 Hz, Ar), 9.24 (1H, br, NH). **^{13}C NMR** (76 MHz, $CDCl_3$): δ 56.4, 57.5, 61.7, 100.4, 115.0, 122.7, 123.1, 135.0, 138.3, 141.6, 146.3, 161.7.

2-Chloro-5,6,8-trimethoxyquinoline 139[137]



To a stirred solution of 5,6,8-trimethoxyquinolin-2(1H)-one (1.19 g, 5.06 mmol, 1.0 eq), pyridine (0.14 mL, 1.69 mmol, 0.3 eq) and DMF (0.02 mL) in chlorobenzene (50 mL) at RT was added phosphorous oxychloride (2.83 mL, 30.35 mmol, 6.0 eq) and the mixture was heated at reflux for 3 hours. After cooling to RT, the reaction was quenched by slow addition to a vigorously stirred water bath. The mixture was extracted with EtOAc and washed with a sat. $NaHCO_3$ solution and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness and the crude product was purified by column chromatography (EtOAc:heptane, 6 :1) to give 2-chloro-5,6,8-trimethoxyquinoline (1.06 g, 83%) as a white solid. **M.p.** 147-148 °C (lit. 146-147 °C). **^{1}H NMR** (300 MHz, $CDCl_3$): δ 3.89 (3H, s, CH_3), 3.99 (3H, s, CH_3), 4.02 (3H, s, CH_3), 6.85 (1H, s, Ar), 7.34 (1H, d, J = 9.0 Hz, Ar), 8.30 (1H, d, J = 9.0 Hz, Ar). **^{13}C NMR** (76 MHz, $CDCl_3$): δ 56.3, 57.1, 61.6, 99.4, 123.1, 123.3, 133.2, 134.6, 135.5, 148.0, 149.0, 151.7.

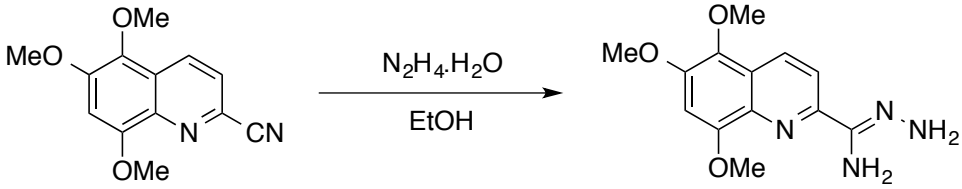
5,6,8-Trimethoxyquinoline-2-carbonitrile 140



To a solution of 2-chloro-5,6,8-trimethoxyquinoline (50 mg, 0.20 mmol, 1.0 eq) in dry DMF (2.0 mL) under argon was added zinc cyanide (35 mg, 0.30 mmol, 1.5 eq) and palladium tetrakis(triphenylphosphine)palladium (11 mg, 0.01 mmol, 0.05 eq). The mixture was stirred overnight at reflux in a sealed tube. The mixture was extracted with dichloromethane and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/dichloromethane : 1/9) to give 5,6,8-trimethoxyquinoline-2-carbonitrile (45 mg, 92%) as a yellow solid. **M.p.** 168-170 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 3.87 (3H, s, CH_3), 4.03 (3H, s, CH_3), 4.06 (3H, s, CH_3), 6.90 (1H, s, Ar), 7.61 (1H, d, J =

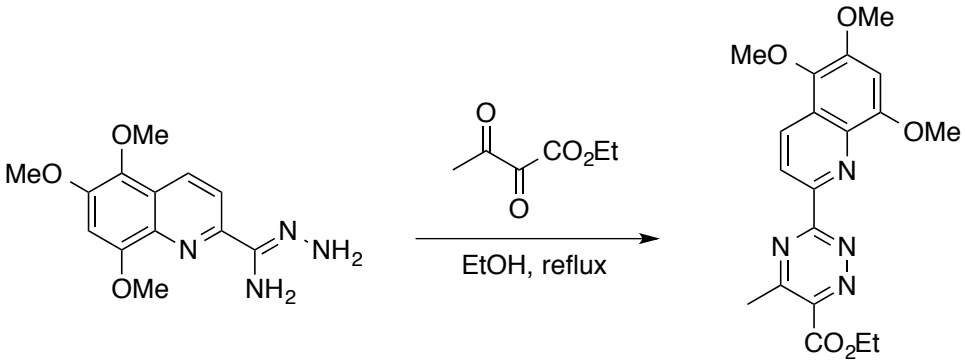
8.5 Hz, Ar), 8.43 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 56.5, 56.9, 61.5, 99.2, 117.9, 124.1, 125.2, 129.8, 131.1, 134.7, 135.3, 151.2, 152.9. **FTIR:** 2845 (w), 2518 (w), 2228 (m), 2028 (m), 1603 (m), 1449 (s), 1349 (s), 1205 (s), 1109 (s), 1053 (s), 996 (s), 832 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{13}H_{13}N_2O_3$: 245.0921, found: 245.0922.

5,6,8-Trimethoxyquinoline-2-carbohydrazonamide 141



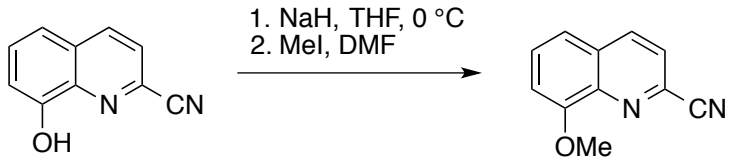
To a stirred suspension of 5,6,8-trimethoxyquinoline-2-carbonitrile (504 mg, 2.06 mmol, 1.0 eq) in a minimum of ethanol was added hydrazine hydrate (10 mL, 206 mmol, 100 eq). The mixture was stirred overnight, extracted with dichloromethane and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness to afford 5,6,8-trimethoxyquinoline-2-carbohydrazonamide (498 mg, 87%) as a yellow solid. **M.p.** 156-158 °C. **^{1}H NMR** (400 MHz, d^6-DMSO): δ 3.81 (3H, s, CH_3), 3.98 (3H, s, CH_3), 4.02 (3H, s, CH_3), 5.52 (2H, s, NH_2), 5.78 (2H, s, NH_2), 7.10 (1H, s, Ar), 8.04 (1H, d, *J* = 9.0 Hz, Ar), 8.23 (1H, d, *J* = 9.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, d^6-DMSO): δ 56.2, 56.8, 61.0, 99.6, 118.0, 123.2, 129.1, 132.9, 134.7, 143.3, 148.2, 148.5, 152.0. **FTIR**: 2360 (w), 1972 (m), 1612 (w), 1484 (m), 1347 (m), 1229 (m), 1099 (s), 1051 (m), 997 (m), 843 (m), 725 (w) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{13}H_{17}N_4O_3$: 277.1295, found 277.1294.

Ethyl 5-methyl-3-(5,6,8-trimethoxyquinolin-2-yl)-1,2,4-triazine-6-carboxylate 142



To a solution of 5,6,8-trimethoxyquinoline-2-carbohydrazonamide (20 mg, 0.07 mmol, 1.0 eq) in ethanol (1.0 mL) was added ethyl 2,3-dioxobutanoate (12 mg, 0.07 mmol, 1.0 eq). The mixture was stirred for 3 hours at reflux and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/dichloromethane : 3/5) to give ethyl 5-methyl-3-(5,6,8-trimethoxyquinolin-2-yl)-1,2,4-triazine-6-carboxylate (as a 19:1 mixture of regioisomers) (18 mg, 67%) as a yellow solid. **M.p.** 160-162 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.48 (3H, t, *J* = 7.0 Hz, CH_3), 2.97 (3H, s, CH_3), 3.95 (3H, s, CH_3), 4.06 (3H, s, CH_3), 4.09 (3H, s, CH_3), 4.54 (2H, q, *J* = 7.0 Hz, CH_2), 6.87 (1H, s, Ar), 8.60 (1H, d, *J* = 9.0 Hz, Ar), 8.81 (1H, d, *J* = 9.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 14.3, 23.4, 56.2, 57.0, 61.6, 62.9, 98.2, 122.0, 125.6, 131.3, 135.1, 135.8, 148.6, 149.4, 150.6, 153.7, 161.4, 162.6, 164.1. **FTIR:** 3030 (w), 1719 (m), 1605 (w), 1459 (m), 1353 (m), 1249 (s), 1104 (s), 1049 (s), 992 (s), 814 (m) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{19}H_{21}N_4O_5$: 385.1506, found: 385.1505.

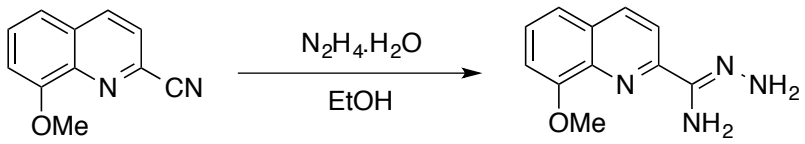
8-Methoxyquinoline-2-carbonitrile 144



To a solution of 8-hydroxyquinoline-2-carbonitrile (200 mg, 1.18 mmol, 1.0 eq) in dry THF (12.0 mL) at 0 °C under N_2 was added sodium hydride (94 mg, 2.35 mmol, 2.0 eq) and the mixture was stirred 30 min at 0 °C. Iodomethane (0.15 mL, 2.35 mL, 2.0 eq) and DMF (2.0 mL) were then added and the mixture was stirred overnight at RT. The mixture was extracted with dichloromethane and washed with $NaHCO_3$, water and brine. The organic layer

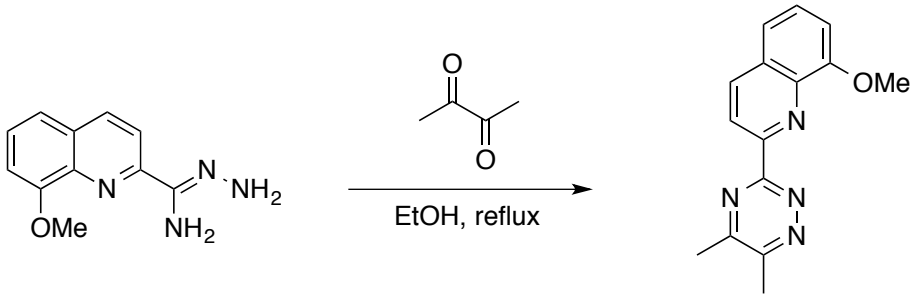
was dried over $MgSO_4$, filtered and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/petrol : 1/1) to give 8-methoxyquinoline-2-carbonitrile (182 mg, 84%) as a white solid. **M.p.** 188-190 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 4.11 (3H, s, CH_3), 7.16 (1H, d, *J* = 8.0 Hz, Ar), 7.45 (1H, d, *J* = 8.0 Hz, Ar), 7.63 (1H, t, *J* = 8.0 Hz, Ar), 7.72 (1H, d, *J* = 8.5 Hz, Ar), 8.27 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 56.5, 109.3, 117.7, 119.5, 124.3, 130.0, 130.2, 132.4, 137.4, 140.5, 155.6. **FTIR:** 3029 (w), 2939 (w), 2234 (w), 1614 (w), 1555 (w), 1461 (s), 1380 (m), 1320 (s), 1213 (m), 1106 (s), 996 (m), 839 (s), 760 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{11}H_9N_2O$: 185.0709, found: 185.0711.

8-Methoxyquinoline-2-carbohydrazonamide 145



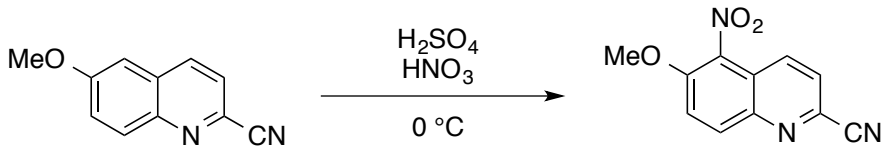
To a stirred suspension of 8-methoxyquinoline-2-carbonitrile (182 mg, 0.99 mmol, 1.0 eq) in a minimum of ethanol was added hydrazine hydrate (1.20 mL, 24.7 mmol, 25 eq). The mixture was stirred overnight and then extracted with dichloromethane and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness to afford 8-methoxyquinoline-2-carbohydrazonamide (202 mg, 94%) as a yellow solid. **M.p.** 110-112 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 3.98 (3H, s, CH_3), 4.83 (2H, s, NH_2), 5.61 (2H, s, NH_2), 6.95-6.97 (1H, m, Ar), 7.28 (1H, dd, *J* = 8.0, 1.0 Hz, Ar), 7.35 (1H, t, *J* = 8.0 Hz, 1H), 8.00 (1H, d, *J* = 8.5 Hz, Ar), 8.13 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 55.9, 108.2, 118.1, 119.4, 126.8, 129.3, 136.0, 138.4, 148.5, 149.7, 155.1. **FTIR**: 3385 (w), 3309 (m), 2924 (w), 1606 (m), 1455 (s), 1385 (m), 1257 (s), 1098 (s), 990 (m), 825 (s), 743 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{11}H_{13}N_4O$: 217.1084, found 217.1087.

2-(5,6-Dimethyl-1,2,4-triazin-3-yl)-8-methoxyquinoline 146



To a solution of 8-methoxyquinoline-2-carbohydrazonamide (90 mg, 0.42 mmol, 1.0 eq) in ethanol (4.0 mL) was added 2,3-butanedione (0.04 mL, 0.42 mmol, 1.0 eq). The mixture was stirred overnight at reflux, cooled and filtered to give 2-(5,6-dimethyl-1,2,4-triazin-3-yl)-8-methoxyquinoline (46 mg, 41%) as a yellow solid. **M.p.** 126-128 °C (dec.). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 2.68 (3H, s, CH_3), 2.73 (3H, s, CH_3), 4.05 (3H, s, CH_3), 7.03 (1H, d, *J* = 8.0 Hz, Ar), 7.40 (1H, d, *J* = 8.0 Hz, 1H), 7.48 (1H, t, *J* = 8.0 Hz, Ar), 8.29 (1H, d, *J* = 8.5 Hz, Ar), 8.72 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 19.7, 22.1, 55.8, 107.8, 119.1, 121.2, 128.2, 129.8, 137.2, 140.2, 151.7, 155.9, 157.0, 160.0, 161.6. **FTIR:** 2923 (w), 1679 (w), 1566 (w), 1460 (m), 1362 (s), 1323 (s), 1261 (s), 1095 (s), 978 (m), 860 (m), 766 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{15}H_{15}N_4O$: 267.1240, found: 267.1246.

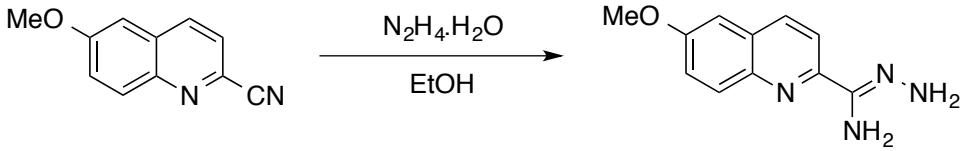
6-Methoxy-5-nitroquinoline-2-carbonitrile 148[135]



To a stirred solution of 6-methoxyquinoline-2-carbonitrile (50 mg, 0.27 mmol, 1.0 eq) in sulfuric acid (0.3 mL) at 0 °C was added nitric acid (0.05 mL). The mixture was stirred 10 min at 0 °C and then neutralised with NaOH (2M). The mixture was extracted with dichloromethane and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness to afford 6-methoxy-5-nitroquinoline-2-carbonitrile (54 mg, 87%) as a yellow solid. **M.p.** 165-167 °C (lit. 158-160 °C). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 4.14 (3H, s, CH_3), 7.73 (1H, d, *J* = 9.5 Hz, Ar), 7.79 (1H, d, *J* = 9.0 Hz, Ar), 8.21 (1H, d, *J* =

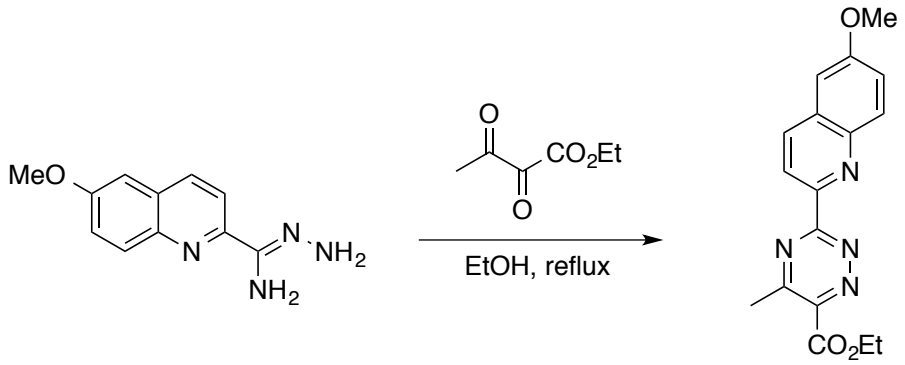
9.0 Hz, Ar), 8.34 (1H, d, *J* = 9.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 57.6, 117.0, 118.3, 121.6, 122.2, 125.8, 131.0, 132.9, 135.0, 142.2, 151.6.

6-Methoxyquinoline-2-carbohydrazonamide 149



To a stirred suspension of 6-methoxyquinoline-2-carbonitrile (300 mg, 1.63 mmol, 1.0 eq) in a minimum of ethanol was added hydrazine hydrate (7.90 mL, 163 mmol, 100 eq). The mixture was stirred overnight, filtered and washed with diethyl ether to afford 6-methoxyquinoline-2-carbohydrazonamide (303 mg, 86%) as a yellow solid. **M.p.** 219-221 °C (dec.). **^{1}H NMR** (400 MHz, d^6-DMSO): δ 3.89 (3H, s, CH_3), 5.42 (2H, s, NH_2), 5.83 (2H, s, NH_2), 7.34-7.39 (2H, m, Ar), 7.90 (1H, d, *J* = 9.0 Hz, Ar), 8.02 (1H, d, *J* = 8.5 Hz, Ar), 8.14 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, d^6-DMSO): δ 55.5, 106.0, 117.8, 121.6, 128.6, 130.0, 134.6, 142.0, 143.2, 149.5, 157.2. **FTIR**: 3220 (w), 1635 (w), 1501 (w), 1390 (w), 1230 (m), 1164 (m), 1023 (m), 909 (m), 850 (s), 821 (s) cm^{-1}. **HRMS**: (ESI) [MH$^+$] calcd for $C_{11}H_{13}N_4O$: 217.1084, found 217.1087.

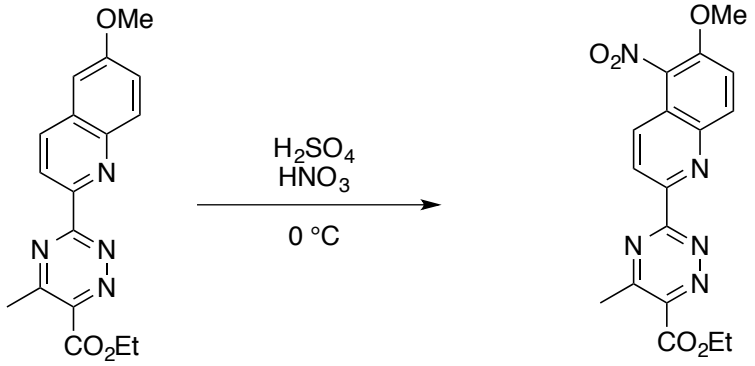
Ethyl 3-(6-methoxyquinolin-2-yl)-5-methyl-1,2,4-triazine-6-carboxylate 150



To a solution of 6-methoxyquinoline-2-carbohydrazonamide (50 mg, 0.23 mmol, 1.0 eq) in ethanol (2.5 mL) was added ethyl 2,3-dioxobutanoate (37 mg, 0.23 mmol, 1.0 eq). The mixture was stirred 3 hours at reflux and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/dichloromethane : 3/7) to give ethyl 3-(6-

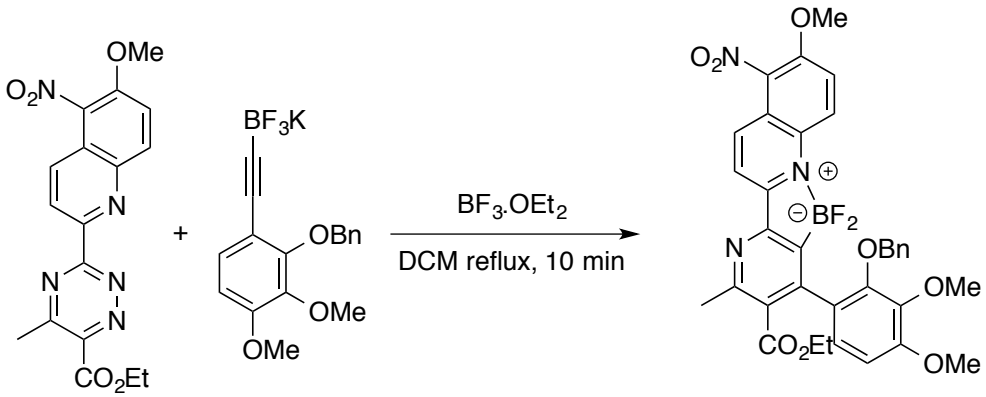
methoxyquinolin-2-yl)-5-methyl-1,2,4-triazine-6-carboxylate in a 13:1 ratio (68 mg, 91%) as a yellow solid. **M.p.** 159-161 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.47 (3H, t, *J* = 7.0 Hz, CH_3), 2.97 (3H, s, CH_3), 3.94 (3H, s, CH_3), 4.54 (2H, q, *J* = 7.0 Hz, CH_2), 7.11 (1H, d, *J* = 3.0 Hz, Ar), 7.41 (1H, dd, *J* = 9.0, 3.0 Hz, Ar), 8.23 (1H, d, *J* = 3.0 Hz, Ar), 8.25 (1H, d, *J* = 3.0 Hz, Ar), 8.74 (1H, d, *J* = 9.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 14.3, 23.4, 55.7, 62.9, 104.9, 121.8, 123.3, 130.5, 132.5, 136.0, 144.7, 149.5, 159.4, 161.1, 162.7, 164.1. **FTIR:** 2161 (m), 1716 (w), 1619 (w), 1481 (w), 1369 (w), 1225 (s), 1110 (m), 833 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{17}H_{17}N_4O_3$: 325.1295, found: 325.1299.

Ethyl 3-(6-methoxy-5-nitroquinolin-2-yl)-5-methyl-1,2,4-triazine-6-carboxylate 151



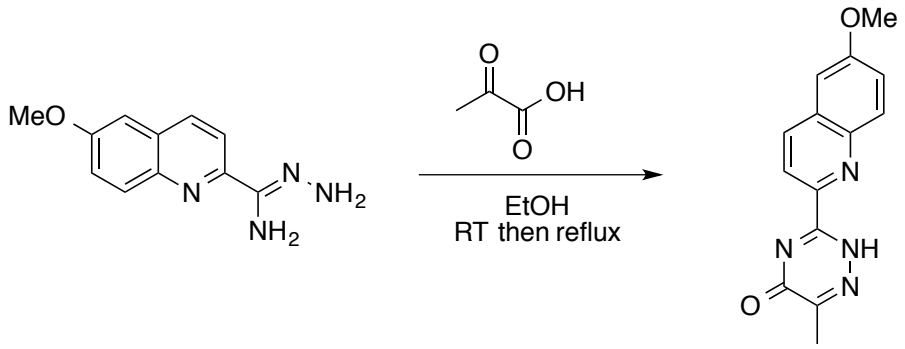
To a stirred solution of ethyl 3-(6-methoxyquinolin-2-yl)-6-methyl-1,2,4-triazine-5-carboxylate (375 mg, 1.16 mmol, 1.0 eq) in sulfuric acid (1.31 mL) at 0 °C was added nitric acid (0.19 mL). The mixture was stirred 30 min at 0 °C and then neutralised with NaOH (2 M). The mixture was extracted with dichloromethane and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness to afford ethyl 3-(6-methoxy-5-nitroquinolin-2-yl)-5-methyl-1,2,4-triazine-6-carboxylate as an 18:1 mixture of regioisomers (377 mg, 88%), and as a yellow solid. **M.p.** 148-150 °C (dec.). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.50 (3H, t, *J* = 7.0 Hz, CH_3), 2.99 (3H, s, CH_3), 4.12 (3H, s, CH_3), 4.57 (2H, q, *J* = 7.0 Hz, CH_2), 7.68 (1H, d, *J* = 9.5 Hz, Ar), 8.31 (1H, d, *J* = 9.0 Hz, Ar), 8.55 (1H, d, *J* = 9.5 Hz, Ar), 8.90 (1H, d, *J* = 9.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 14.3, 23.4, 57.4, 63.1, 117.1, 122.4, 123.9, 130.8, 134.6, 135.7, 142.5, 150.0, 150.8, 151.4, 161.3, 161.9, 163.9. **FTIR:** 1716 (m), 1615 (w), 1516 (s), 1331 (w), 1261 (s), 1114 (s), 1067 (s), 1002 (m), 849 (s), 817 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{17}H_{16}N_5O_5$: 370.1146, found: 370.1147.

Ethyl 4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-5-(difluoroboranyl)-6-(6-methoxy-5-nitroquinolin-2-yl)-2-methylnicotinate 152



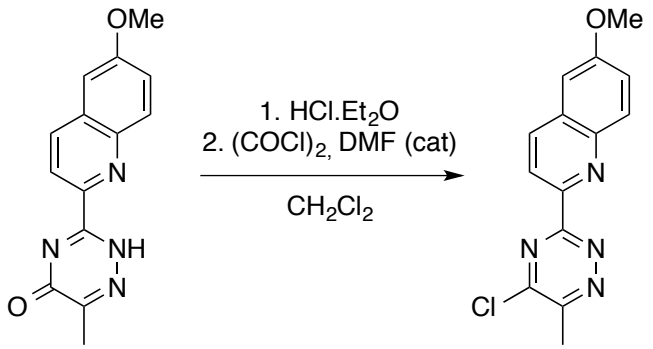
Following the general procedure, a solution of ethyl 3-(6-methoxy-5-nitroquinolin-2-yl)-5-methyl-1,2,4-triazine-6-carboxylate (300 mg, 0.81 mmol, 1.0 eq) and potassium ((2-(benzyloxy)-3,4-dimethoxyphenyl)ethynyl)trifluoroborate (912 mg, 2.44 mmol, 3.0 eq) in DCM (8.0 mL) was treated with $BF_3.OEt_2$ (0.30 mL, 2.44 mmol, 3.0 eq). Chromatographic purification over silica (gradient; starting with dichloromethane, ending with ethyl acetate) afforded ethyl 4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-5-(difluoroboranyl)-6-(6-methoxy-5-nitroquinolin-2-yl)-2-methylnicotinate (407 mg, 76%) as a pale yellow solid. **M.p.** 188-190 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.02 (3H, t, *J* = 7.0 Hz, CH_3), 2.74 (3H, s, CH_3), 3.86 (3H, s, OCH_3), 3.94 (3H, s, OCH_3), 4.06-4.17 (5H, m, OCH_3, OCH_2), 4.59 (1H, d, *J* = 11.5 Hz, CH), 4.89 (1H, d, *J* = 11.5 Hz, CH), 6.87 (1H, d, *J* = 8.5 Hz, Ar), 7.06-7.14 (5H, m, Ar), 7.29 (d, *J* = 8.5 Hz, 1H), 7.75 (1H, d, *J* = 9.5 Hz, Ar), 8.55 (1H, d, *J* = 9.0 Hz, Ar), 8.59 (1H, d, *J* = 9.0 Hz, Ar), 8.73 (1H, d, *J* = 9.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 13.8, 23.9, 56.1, 57.7, 61.2 (x2), 75.5, 107.6, 118.8, 120.2, 122.9, 124.9, 125.9, 127.4, 127.6, 127.8, 128.0, 131.8, 134.1, 135.1, 137.5, 137.7, 142.4, 149.0, 150.0, 150.5, 154.0, 154.8, 155.2, 157.7, 168.1. **^{19}F NMR** (376.6 MHz, $CDCl_3$): δ -147.0 (d, *J* = 104.5 Hz), -155.1 (d, *J* = 104.5 Hz). **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 9.1. **FTIR**: 3013 (w), 1725 (m), 1596 (w), 1533 (m), 1498 (m), 1279 (m), 1147 (m), 1090 (s), 799 (m), 737 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{34}H_{31}{}^{11}BN_3F_2O_8$: 659.2167, found 659.2181.

3-(6-Methoxyquinolin-2-yl)-6-methyl-1,2,4-triazin-5(2*H*)-one 153



To a suspension of 6-methoxyquinoline-2-carbohydrazonamide (1.14 g, 5.26 mmol, 1.0 eq) in EtOH (20 mL) was added pyruvic acid (0.37 mL, 5.26 mmol, 1.0 eq) and the mixture was stirred overnight at RT and for 4 hours at reflux. Filtration and washing with Et_2O afforded 3-(6-methoxyquinolin-2-yl)-6-methyl-1,2,4-triazin-5(2*H*)-one (1.17 g, 83%) as a white solid. **M.p.** 263-265 °C. **^{1}H NMR** (400 MHz, d^6-DMSO): δ 2.25 (3H, s, CH_3), 3.94 (3H, s, OCH_3), 7.50 (1H, s, Ar), 7.54 (1H, d, *J* = 9.0 Hz, Ar), 8.08 (1H, d, *J* = 9.0 Hz, Ar), 8.28 (1H, d, *J* = 8.0 Hz, Ar), 8.48 (1H, d, *J* = 8.0 Hz, Ar), 14.03 (1H, br, NH). **^{13}C NMR** (125.8 MHz, d^6-DMSO, 75 °C): δ 16.5, 55.4, 105.7, 118.6, 122.9, 130.2, 130.4, 136.1, 142.3, 145.3, 152.9, 154.9, 158.6. Weak spectrum due to low solubility. **FTIR:** 3293 (w), 1652 (s), 1535 (m), 1477 (s), 1383 (m), 1232 (s), 1024 (s), 868 (s), 822 (s), 732 (s) cm^{-1}. **HRMS**: (ES$^+$) [MH$^+$] calcd for $C_{14}H_{13}N_4O_2$: 269.1033, found: 269.1039.

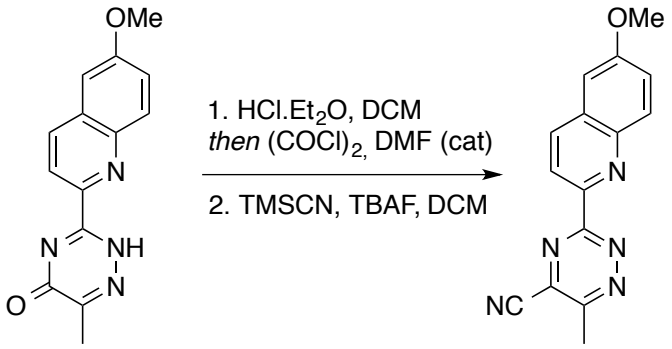
2-(5-Chloro-6-methyl-1,2,4-triazin-3-yl)-6-methoxyquinoline 154



To a suspension of 3-(6-methoxyquinolin-2-yl)-6-methyl-1,2,4-triazin-5(2*H*)-one (100 mg, 0.37 mmol, 1.0 eq) in dichloromethane (40 mL) was added 0.19 mL of a 2.0 M solution of HCl in Et_2O. The mixture was stirred for 10 min when oxalyl chloride (0.04 mL, 0.45 mmol, 1.2 eq) and a catalytic amount of DMF were added. The mixture was stirred for 30 min

at room temperature and washed with $NaHCO_3$ and brine. The organic layer was extracted with dichloromethane, dried over $MgSO_4$, filtered and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/dichloromethane : 3/7) to give 2-(5-chloro-6-methyl-1,2,4-triazin-3-yl)-6-methoxyquinoline (77 mg, 73%) as a white solid. **M.p.** 152-154 °C (dec). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 2.90 (3H, s, CH_3), 3.97 (3H, s, OCH_3), 7.13 (1H, d, *J* = 3.0 Hz, Ar), 7.44 (1H, dd, *J* = 9.0, 3.0 Hz, 1H), 8.25 (2H, app. t, *J* = 9.0 Hz, Ar), 8.63 (1H, d, *J* = 9.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 20.1, 55.8, 105.0, 121.2, 123.3, 130.5, 132.5, 136.0, 144.7, 149.0, 157.4, 158.7, 159.3, 162.1. **FTIR**: 3005 (w), 1619 (w), 1478 (m), 1399 (m), 1227 (m), 1111 (m), 1028 (m), 869 (s), 830 (s), 787 (m) cm^{-1}. **HRMS** calcd for $C_{14}H_{12}N_4{}^{35}Cl$: 287.0694. Found: 287.0699.

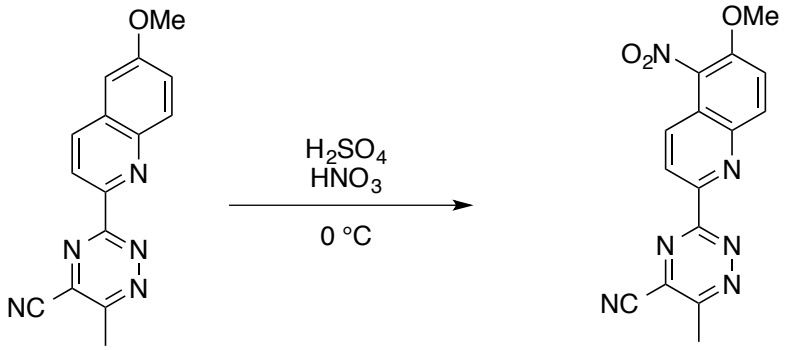
3-(6-methoxyquinolin-2-yl)-6-methyl-1,2,4-triazine-5-carbonitrile 155



To a suspension of 3-(6-methoxyquinolin-2-yl)-6-methyl-1,2,4-triazin-5(2*H*)-one (1.00 g, 3.73 mmol, 1.0 eq) in dichloromethane (350 mL) was added 1.86 mL of a 2.0 M solution of HCl in Et_2O. The mixture was stirred for 10 min when oxalyl chloride (0..38 mL, 4.47 mmol, 1.2 eq) and a catalytic amount of DMF were added. The mixture was stirred for 30 min at room temperature and washed with $NaHCO_3$ and brine. The organic layer was extracted with dichloromethane, dried over $MgSO_4$, filtered and evaporated to dryness. The residue was dissolved in dry dichloromethane (40 mL) under N_2 at RT and trimethylsilyl cyanide (1.17 mL, 9.33 mmol, 2.5 eq) and 9.33 mL of a 1.0 M tetrabutylammonium fluoride solution in THF (9.33 mmol, 2.5 eq) were added. The resulting solution was stirred at RT for 5 minutes. The mixture was dissolved in DCM and washed with water and brine. The organic fractions were combined, dried over $MgSO_4$, filtered and evaporated under vacuum. The residue was purified by flash chromatography on silica gel (dichloromethane/EtOAc 95:5) to afford 3-(6-methoxyquinolin-2-yl)-6-methyl-1,2,4-triazine-5-carbonitrile as an orange solid

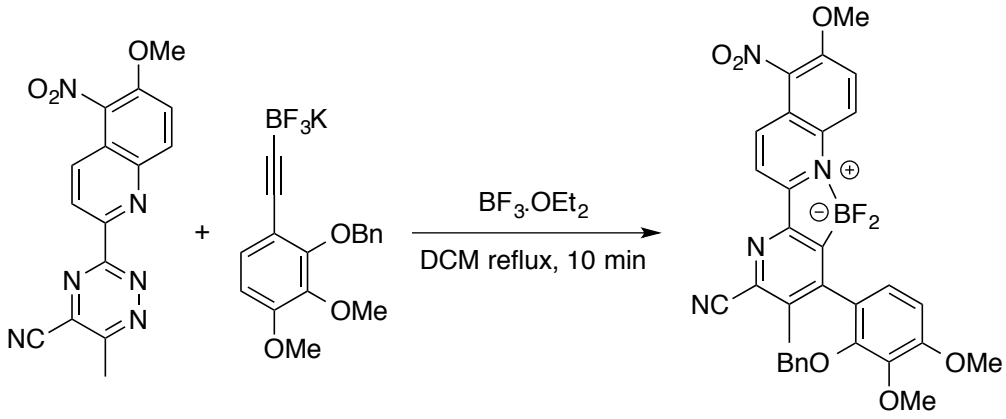
(711 mg, 69%). **M.p.** 167-169 °C dec. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 3.05 (3H, s, CH_3), 3.98 (3H, s, OCH_3), 7.14 (1H, d, *J* = 3.0 Hz, Ar), 7.46 (1H, dd, *J* = 9.0, 3.0 Hz, Ar), 8.25 (1H, d, *J* = 4.5 Hz, Ar), 8.27 (1H, d, *J* = 4.5 Hz, Ar), 8.63 (1H, d, *J* = 9.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 19.6, 55.8, 105.0, 113.7, 121.1, 123.7, 130.7, 132.4, 135.8, 136.3, 144.7, 148.5, 158.0, 159.6, 161.9. **FTIR:** 2999 (w), 2008 (w), 1615 (m), 1481 (m), 1380 (m), 1223 (s), 1163 (s), 1092 (m), 1022 (s), 874 (m), 832 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{15}H_{12}N_5O$: 278.1036, found: 278.1041.

3-(6-methoxy-5-nitroquinolin-2-yl)-6-methyl-1,2,4-triazine-5-carbonitrile 156



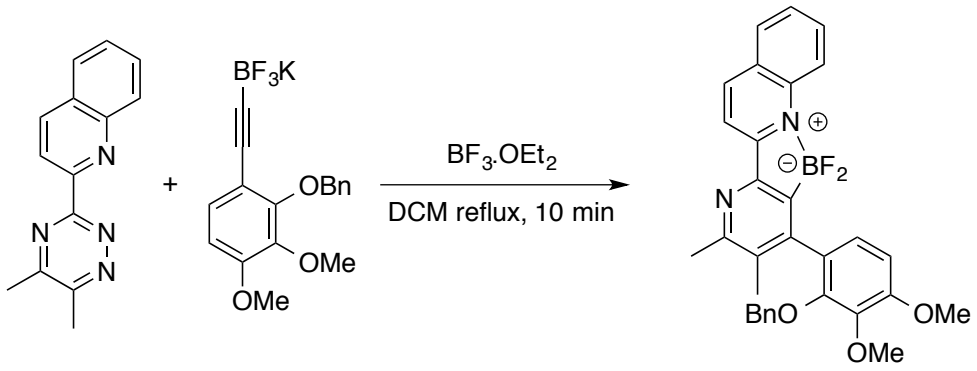
To a stirred solution of 3-(6-methoxyquinolin-2-yl)-6-methyl-1,2,4-triazine-5-carbonitrile (607 mg, 2.19 mmol, 1.0 eq) in sulfuric acid (2.48 mL) at 0 °C was added nitric acid (0.36 mL). The mixture was stirred 30 min at 0 °C and then neutralised with NaOH (2 M). The mixture was extracted with dichloromethane and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness to afford 3-(6-methoxy-5-nitroquinolin-2-yl)-6-methyl-1,2,4-triazine-5-carbonitrile (570 mg, 81%) as a yellow solid. **M.p.** 170-172 °C (dec.). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 3.09 (3H, s, CH_3), 4.14 (3H, s, OCH_3), 7.70 (1H, d, *J* = 9.5 Hz, Ar), 8.31 (1H, dd, *J* = 9.0, 0.5 Hz, Ar), 8.55 (1H, dd, *J* = 9.5, 0.5 Hz, Ar), 8.78 (1H, d, *J* = 9.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 19.7, 57.4, 113.5, 117.4, 122.4, 123.2, 131.1, 134.6, 135.6, 135.9, 142.5, 150.3, 150.9, 158.7, 161.0. **FTIR:** 2996 (w), 2159 (w), 1627 (w), 1524 (s), 1338 (m), 1270 (s), 1117 (m), 1077 (s), 797 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{15}H_{12}N_6O_3$: 323.0887, found: 323.0893.

4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-5-(difluoroboranyl)-6-(6-methoxy-5-nitroquinolin-2-yl)-3-methylpicolinonitrile 157



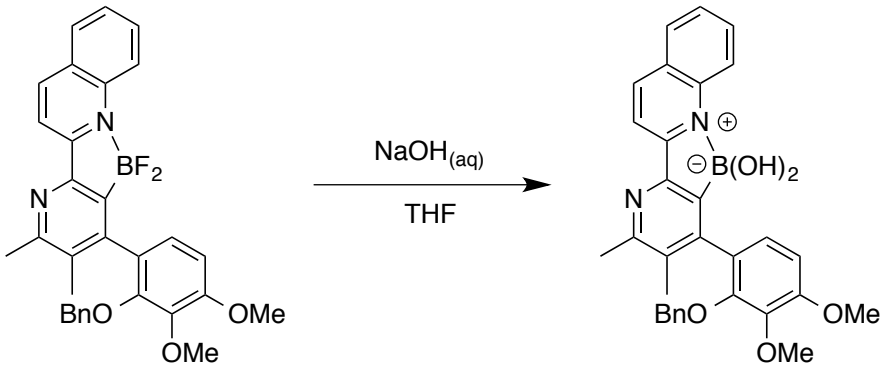
Following the general procedure, a solution of 3-(6-methoxy-5-nitroquinolin-2-yl)-6-methyl-1,2,4-triazine-5-carbonitrile (535 mg, 1.66 mmol, 1.0 eq) and potassium ((2-(benzyloxy)-3,4-dimethoxyphenyl)ethynyl)trifluoroborate (1.86 g, 4.98 mmol, 3.0 eq) in DCM (17.0 mL) was treated with $BF_3.OEt_2$ (0.61 mL, 4.98 mmol, 3.0 eq). Chromatographic purification over silica (ethyl acetate/petrol : 1/4 then ethyl acetate/dichloromethane 1/99) afforded 4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-5-(difluoroboranyl)-6-(6-methoxy-5-nitroquinolin-2-yl)-3-methylpicolinonitrile (932 mg, 92%) as a pale yellow solid. **M.p.** 258-260 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 2.44 (3H, s, CH_3), 3.94 (3H, s, OCH_3), 3.97 (3H, s, OCH_3), 4.13 (3H, s, OCH_3), 4.51 (1H, d, *J* = 11.5 Hz, CH), 5.02 (1H, d, *J* = 11.5 Hz, CH), 6.90 (1H, d, *J* = 8.5 Hz, Ar), 6.93-6.95 (2H, m, Ar), 7.10-7.13 (4H, m, Ar), 7.77 (1H, d, *J* = 9.5 Hz, Ar), 8.55 (1H, d, *J* = 9.0 Hz, Ar), 8.57 (1H, d, *J* = 9.0 Hz, Ar), 8.67 (1H, d, *J* = 9.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 17.5, 56.1, 57.7, 61.4, 75.9, 108.0, 116.9, 118.6, 120.5, 123.0, 124.3, 124.4, 127.4, 127.5, 127.8, 128.2, 133.8, 134.5, 135.0, 137.4, 137.9, 142.0, 142.7, 150.2, 150.7, 151.7, 153.6, 154.0, 154.6. **^{19}F NMR** (376.6 MHz, $CDCl_3$): δ -147.1 (d, *J* = 104.5 Hz), -154.6 (d, *J* = 104.5 Hz). **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 8.6. **FTIR**: 1598 (w), 1529 (m), 1344 (w), 1273 (m), 1126 (m), 1093 (s), 833 (m), 752 (m) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{32}H_{26}{}^{11}BN_4F_2O_6$: 611.1908, found 611.1930.

2-(4-(2-(Benzyloxy)-3,4-dimethoxyphenyl)-3-(difluoroboranyl)-5,6-dimethylpyridin-2-yl)quinoline 158



Following the general procedure, a solution of 2-(5,6-dimethyl-1,2,4-triazin-3-yl)quinoline (200 mg, 0.85 mmol, 1.0 eq) and potassium ((2-(benzyloxy)-3,4-dimethoxyphenyl)ethynyl)trifluoroborate (950 mg, 2.54 mmol, 3.0 eq) in DCM (10.0 mL) was treated with $BF_3.OEt_2$ (0.31 mL, 2.54 mmol, 3.0 eq). Chromatographic purification over silica (gradient; starting with petrol, ending with ethyl acetate) afforded 2-(4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-3-(difluoroboranyl)-5,6-dimethylpyridin-2-yl)quinoline (398 mg, 89%) as a white solid. **M.p.** 217-219 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 2.16 (3H, s, CH_3), 2.63 (3H, s, CH_3), 3.92 (3H, s, CH_3), 3.96 (3H, s, CH_3), 4.54 (1H, d, *J* = 11.0 Hz, CH), 4.90 (1H, d, *J* = 11.0 Hz, CH), 6.90 (1H, d, *J* = 8.5 Hz, Ar), 6.96 (2H, dd, *J* = 7.0, 3.0 Hz, Ar), 7.15 (3H, m, Ar), 7.23 (1H, dd, *J* = 8.5, 1.5 Hz, Ar), 7.64 (1H, t, *J* = 8.0 Hz, Ar), 7.86 (1H, ddd, *J* = 8.5, 7.0, 1.5 Hz, Ar), 7.95 (1H, d, *J* = 8.0 Hz, Ar), 8.44 (1H, d, *J* = 8.5 Hz, Ar), 8.55 (1H, d, *J* = 8.5 Hz, Ar), 8.60 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 16.9, 23.7, 56.1, 61.4, 75.6, 107.8, 115.6, 122.8, 124.9, 126.8, 127.5, 127.8, 127.9, 128.1, 128.7, 129.1, 133.3, 135.1, 138.0, 140.2, 142.6, 144.3, 149.3, 150.3, 152.3, 153.7, 157.3, 158.3. **^{19}F NMR** (376.6 MHz, $CDCl_3$): δ -150.6 (d, *J* = 103.0 Hz), -157.9 (d, *J* = 103.0 Hz). **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 8.8. **FTIR**: 2941 (w), 1597 (m), 1495 (m), 1272 (m), 1085 (s), 952 (m), 752 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{31}H_{28}{}^{11}BN_2F_2O_3$: 525.2156, found 525.2165.

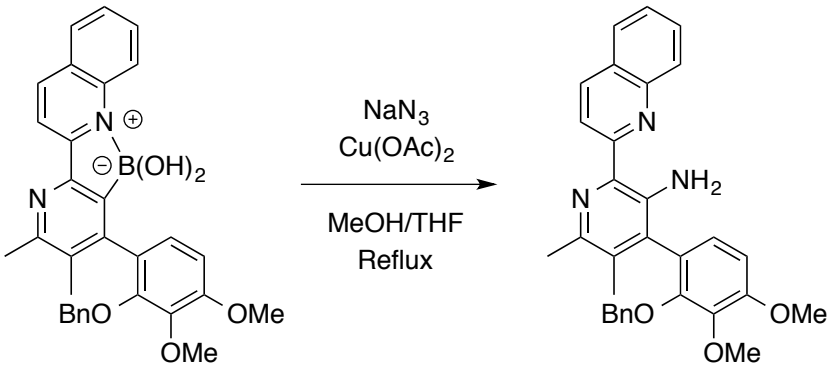
(4-(2-(Benzyloxy)-3,4-dimethoxyphenyl)-5,6-dimethyl-2-(quinolin-2-yl)pyridin-3-yl)boronic acid 159



To a stirred suspension of 2-(4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-3-(difluoroboranyl)-5,6-dimethylpyridin-2-yl)quinoline (200 mg, 0.38 mmol, 1.0 eq) in tetrahydrofuran (20 mL) was added 3.80 mL of a sodium hydroxide solution (1 M). The mixture was stirred overnight at reflux and then cooled to RT. The solution was extracted with dichloromethane and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness to afford (4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-5,6-dimethyl-2-(quinolin-2-yl)pyridin-3-yl)boronic acid (193 mg, 98%) as a white solid. **M.p.** 158-160 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.90 (3H, s, CH_3), 2.55 (3H, s, CH_3), 3.95 (3H, s, CH_3), 3.99 (3H, s, CH_3), 4.78 (1H, d, *J* = 11.5 Hz, CH), 4.92 (d, *J* = 11.5 Hz, CH), 6.82-6.87 (3H, m, Ar), 6.96 (1H, d, *J* = 8.5 Hz, Ar), 7.03-7.09 (3H, m, Ar), 7.56-7.60 (1H, m, Ar), 7.81 (1H, ddd, *J* = 8.5, 7.0, 1.5 Hz, Ar), 7.91 (1H, d, *J* = 8.0 Hz, Ar), 8.41 (1H, d, *J* = 8.5 Hz, Ar), 8.47 (1H, d, *J* = 8.5 Hz, Ar), 8.79 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 16.6, 23.7, 56.2, 61.4, 75.3, 107.9, 115.6, 124.0, 124.5, 127.1, 127.3, 127.8, 128.1 (x2), 128.4, 129.2, 132.3, 133.3, 137.2, 140.9, 142.1, 142.9, 148.1, 149.3, 151.7, 153.4, 155.5, 157.4. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 10.5. **FTIR**: 3627 (w), 2940 (s), 2519 (m), 2159 (s), 2032 (s), 1599 (w), 1496 (m), 1089 (s), 750 (s) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{31}H_{30}{}^{11}BN_2O_5$: 321.2242, found 321.2246.

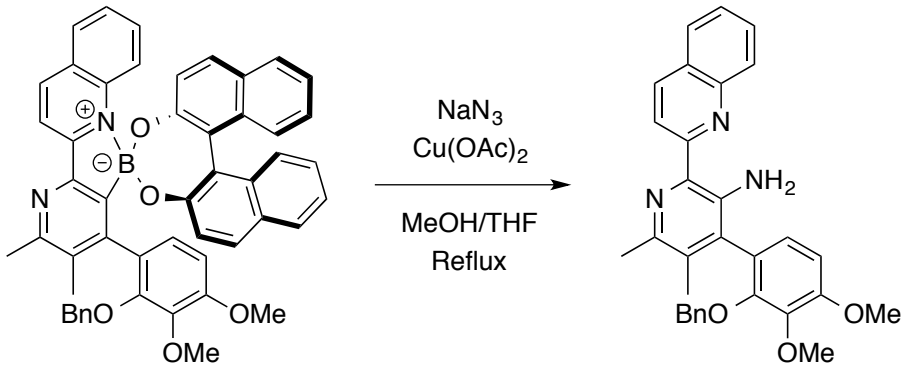
2'-(Benzyloxy)-3',4'-dimethoxy-5,6-dimethyl-3-(quinolin-2-yl)-[1,1'-biphenyl]-2-amine

160



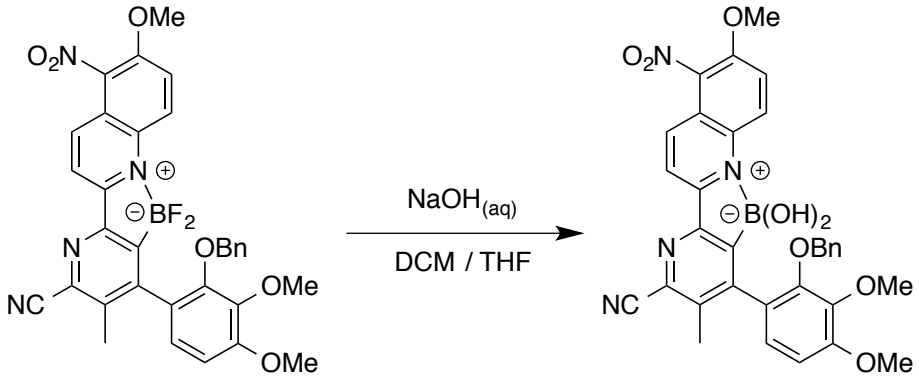
To a solution of (2'-(benzyloxy)-3',4'-dimethoxy-5,6-dimethyl-3-(quinolin-2-yl)-[1,1'-biphenyl]-2-yl)boronic acid (50 mg, 0.10 mmol, 1.0 eq) in a methanol/THF mixture (1:1, 2.0 mL) was added sodium azide (9 mg, 1.14 mmol, 1.5 eq) and copper acetate (17 mg, 0.10 mmol, 1.0 eq) and the mixture was stirred overnight at 70 °C. The mixture was extracted with ethyl acetate and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/dichloromethane : 1/9) to give 2'-(benzyloxy)-3',4'-dimethoxy-5,6-dimethyl-3-(quinolin-2-yl)-[1,1'-biphenyl]-2-amine (37 mg, 78%) as a yellow solid. **M.p.** 200-202 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 1.94 (3H, s, CH_3), 2.54 (3H, s, CH_3), 3.96 (6H, s, 2x OCH_3), 4.89 (1H, d, *J* = 11.0 Hz, CH), 4.91 (1H, d, *J* = 11.0 Hz, CH), 6.62 (2H, s, NH_2), 6.85 (1H, d, *J* = 8.5 Hz, Ar), 6.90 (1H, d, *J* = 8.5 Hz, Ar), 7.02 (2H, dd, *J* = 7.0, 2.0 Hz, Ar), 7.12-7.13 (3H, m, Ar), 7.46-7.50 (1H, m, Ar), 7.65 (1H, td, *J* = 7.5, 1.5 Hz, Ar), 7.79-7.81 (1H, m, Ar), 7.96 (1H, d, *J* = 8.5 Hz, Ar), 8.21 (1H, d, *J* = 9.0 Hz, Ar), 8.87 (1H, d, *J* = 9.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 17.0, 23.1, 56.2, 61.3, 75.3, 108.5, 120.7, 123.2, 125.2, 126.0, 126.9, 127.6, 127.8, 128.2, 128.3, 128.8, 129.2, 132.5, 132.8, 133.4, 135.8, 137.5, 141.7, 143.5, 144.7, 146.5, 150.8, 153.9, 160.1. **FTIR:** 3420 (w), 2924 (w), 1590(m), 1491 (m), 1421 (s), 1291 (m), 1212 (m), 1092 (s), 978 (m), 843 (s), 753 (s), 702 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{31}H_{30}N_3O_3$: 492.2282, found: 492.2290.

2'-(Benzyloxy)-3',4'-dimethoxy-5,6-dimethyl-3-(quinolin-2-yl)-[1,1'-biphenyl]-2-amine 160



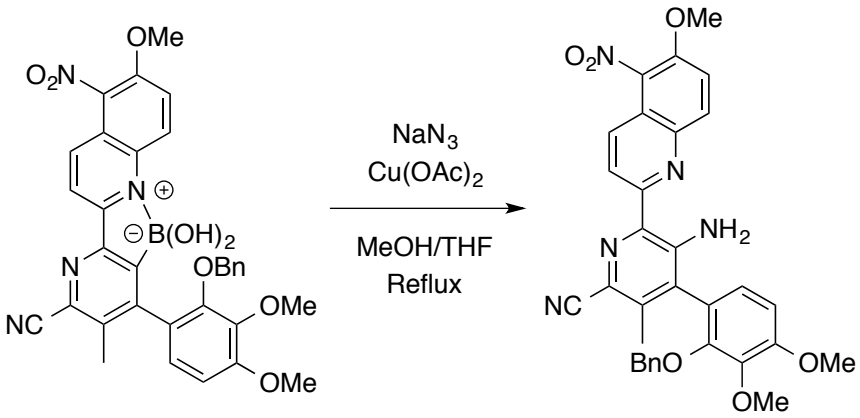
To a solution of (11b*S*)-10'-(2-(benzyloxy)-3,4-dimethoxyphenyl)-8',9'-dimethyl-4λ^4,12'λ^4-spiro[dinaphtho[2,1-*d*:1',2'-*f*][1,3,2]dioxaborepine-4,11'-pyrido[3',2':3,4][1,2]azaborolo[1,5-*a*]quinoline] (50 mg, 0.07 mmol, 1.0 eq) in a methanol/THF mixture (1:1, 2.0 mL) was added sodium azide (6 mg, 0.10 mmol, 1.5 eq) and copper acetate (12 mg, 0.07 mmol, 1.0 eq) and the mixture was stirred overnight at 70 °C. The mixture was extracted with ethyl acetate and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness. The residue was purified by flash chromatography on silica gel (ethyl acetate/dichloromethane : 1/9) to give 2'-(benzyloxy)-3',4'-dimethoxy-5,6-dimethyl-3-(quinolin-2-yl)-[1,1'-biphenyl]-2-amine (23 mg, 72%) as a yellow solid. Spectroscopic data as described above. **HPLC**: (Cellulose-2, hexane:^{i}PrOH 95:5, flow rate 1.0 mL/min, λ = 225 nm, 22 °C) t_R (major) = 14.590, t_R (minor) = 12.840, er = 95:5.

(4-(2-(Benzyloxy)-3,4-dimethoxyphenyl)-6-cyano-2-(6-methoxy-5-nitroquinolin-2-yl)-5-methylpyridin-3-yl)boronic acid 161



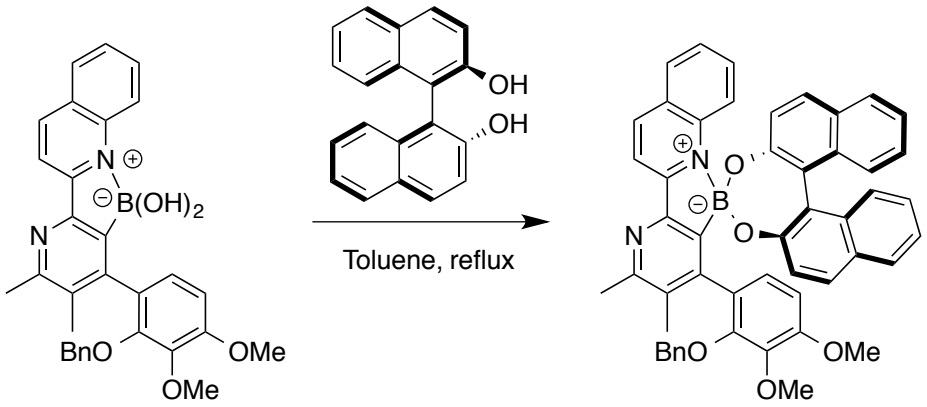
To a stirred solution of 4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-5-(difluoroboranyl)-6-(6-methoxy-5-nitroquinolin-2-yl)-3-methylpicolinonitrile (849 mg, 1.39 mmol, 1.0 eq) in a mixture of dichloromethane and tetrahydrofuran (1:2, 35 mL) was added 14 mL of a sodium hydroxide solution (1 M). The mixture was stirred overnight at RT. The solution was extracted with dichloromethane and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness to afford (4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-6-cyano-2-(6-methoxy-5-nitroquinolin-2-yl)-5-methylpyridin-3-yl)boronic acid (840 mg, 99%) as a white solid. **M.p.** 185-187 °C. **^{1}H NMR** (500 MHz, $CDCl_3$): δ 2.08 (3H, s, CH_3), 3.96 (3H, s, OCH_3), 4.00 (3H, s, OCH_3), 4.11 (3H, s, OCH_3), 4.91 (1H, d, *J* = 12.0 Hz, CH), 5.02 (1H, d, *J* = 12.0 Hz, CH), 6.82-6.83 (3H, m, Ar), 6.88-6.90 (1H, m, Ar), 7.05-7.08 (2H, m, Ar), 7.11-7.14 (1H, m, Ar), 7.68 (1H, d, *J* = 9.5 Hz, Ar), 8.44 (1H, d, *J* = 9.0 Hz, Ar), 8.53 (1H, d, *J* = 9.0 Hz, Ar), 8.93 (1H, d, *J* = 9.5 Hz, Ar). **^{13}C NMR** (125.8 MHz, $CDCl_3$): δ 17.3, 56.2, 57.6, 61.3, 75.6, 108.2, 117.1, 118.8, 119.2, 123.0, 124.1, 124.6, 128.4 (x3), 129.2, 134.0, 135.1, 135.5, 136.8, 140.1, 143.0, 147.7, 148.7, 150.1, 150.3, 152.4, 153.5, 154.3. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 13.9. **FTIR**: 2159 (m), 1976 (m), 1597 (w), 1530 (m), 1496 (m), 1354 (m), 1274 (s), 1093 (s), 1003 (m), 827 (w), 758 (w) cm^{-1}. **HRMS**: (ESI) [MH^+] calcd for $C_{32}H_{28}{}^{11}BN_4O_8$: 607.1995, found 607.2014.

5-Amino-4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-6-(6-methoxy-5-nitroquinolin-2-yl)-3-methylpicolinonitrile 162



To a solution of (4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-6-cyano-2-(6-methoxy-5-nitroquinolin-2-yl)-5-methylpyridin-3-yl)boronic acid (100 mg, 0.16 mmol, 1.0 eq) in a methanol/THF mixture (1:1, 2.0 mL) was added sodium azide (16 mg, 0.25 mmol, 1.5 eq) and copper acetate (30 mg, 0.16 mmol, 1.0 eq) and the mixture was stirred one hour at 70 °C. The mixture was extracted with ethyl acetate and washed with water and brine. The organic layer was dried over $MgSO_4$, filtered and evaporated to dryness to give 5-amino-4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-6-(6-methoxy-5-nitroquinolin-2-yl)-3-methylpicolinonitrile (82 mg, 86%) as a black solid. **M.p.** 230-232 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 2.12 (3H, s, CH_3), 3.99 (6H, app. s, OCH_3), 4.08 (3H, s, OCH_3), 4.94 (1H, d, *J* = 11.5 Hz, CH), 5.00 (1H, d, *J* = 11.5 Hz, CH), 6.89 (2H, br, NH_2), 6.98-7.19 (7H, m, Ar), 7.53 (1H, d, *J* = 9.0 Hz, Ar), 8.08 (1H, d, *J* = 9.0 Hz, Ar), 8.15 (1H, d, *J* = 9.0 Hz, Ar), 8.90 (1H, d, *J* = 9.0 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 17.3, 56.3, 57.3, 61.2, 75.5, 108.8, 116.2, 118.2, 120.3, 120.4, 120.8, 123.2, 124.7, 128.0, 128.1, 128.3, 129.4, 132.1, 133.0, 134.2, 135.1, 137.0, 139.0, 140.1, 143.6, 145.9, 149.4, 150.4, 154.7, 157.4. **FTIR:** 3450 (w), 2929 (w), 2527 (w), 2218 (w), 2014 (w), 1583 (m), 1524 (s), 1450 (m), 1357 (m), 1266 (s), 1076 (s), 999 (m), 822 (m) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{32}H_{28}N_5O_6$: 578.2034, found: 578.2040.

2-(4-(2-(Benzyloxy)-3,4-dimethoxyphenyl)-3-((*S*)-dinaphtho[2,1-*d*:1',2'-*f*][1,3,2]dioxaborepin-4-yl)-5,6-dimethylpyridin-2-yl)quinoline 164



To a solution of (4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-5,6-dimethyl-2-(quinolin-2-yl)pyridin-3-yl)boronic acid (100 mg, 0.19 mmol, 1.0 eq) in toluene (2.0 mL) was added (R)-BINOL (55 mg, 0.19 mmol, 1.0 eq) in the presence of molecular sieves. The mixture was stirred 1 hour at reflux. The mixture was cooled and evaporated to dryness to afford the product as a mixture of diastereoisomers in a 4:1 ratio (155 mg, quantitative yield). The residue was purified by flash chromatography on silica gel (ethyl acetate/dichloromethane : 45/55) to give the product (74 mg, 51%) as a yellow solid. **M.p.** 269-271 °C. **^{1}H NMR** (400 MHz, $CDCl_3$): δ 2.07 (3H, s, CH_3), 2.61 (3H, s, CH_3), 3.18 (3H, s, CH_3), 3.96 (3H, s, CH_3), 4.75 (1H, d, *J* = 10.5 Hz, CH), 5.15 (1H, d, *J* = 10.5 Hz, CH), 5.22 (1H, d, *J* = 8.5 Hz, Ar), 6.30 (1H, ddd, *J* = 8.5, 7.0, 1.5 Hz, Ar), 6.59 (1H, d, *J* = 8.5 Hz, Ar), 6.79 (1H, d, *J* = 8.5 Hz, Ar), 7.09-7.13 (3H, m, Ar), 7.16-7.25 (5H, m, Ar), 7.31-7.40 (6H, m, Ar), 7.48 (1H, d, *J* = 8.5 Hz, Ar), 7.65 (1H, d, *J* = 9.0 Hz, Ar), 7.75 (2H, d, *J* = 8.0 Hz, Ar), 7.87 (1H, d, *J* = 8.0 Hz, Ar), 8.53 (1H, d, *J* = 8.5 Hz, Ar), 8.61 (1H, d, *J* = 8.5 Hz, Ar). **^{13}C NMR** (100.6 MHz, $CDCl_3$): δ 17.5, 23.8, 55.3, 61.3, 75.5, 106.3, 115.8, 118.0, 120.7, 122.9, 123.0, 123.1, 123.2, 123.3, 123.5, 124.9, 125.4, 126.1, 126.5, 126.7, 127.1, 127.2, 127.7 (x2), 128.0, 128.2, 128.3, 129.0, 129.1, 129.2, 129.9, 130.5, 130.9, 133.6, 133.8, 135.8, 138.0, 141.5, 141.6, 143.7, 148.4, 149.8, 152.3, 153.0, 155.1, 155.6, 158.0, 158.2. **^{11}B NMR** (128.4 MHz, $CDCl_3$): δ 10.2. **FTIR:** 2928 (w), 1593 (m), 1497 (m), 1371 (m), 1269 (s), 1095 (s), 956 (s), 748 (s) cm^{-1}. **HRMS**: (ES^+) [MH^+] calcd for $C_{51}H_{40}N_2O_5$: 771.3030, found: 771.3055. The conformation of the major diastereoisomer has not been identified yet.

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Appendix

X-ray crystal structures of compounds **106**, **110a**, **110f**, **111a**, **128**, **132**, **142**, **152** and **157** are provided below.

X-ray crystal structure data for 3'-(difluoroboryl)-4'-phenyl-2,2':5',2''-terpyridine 106

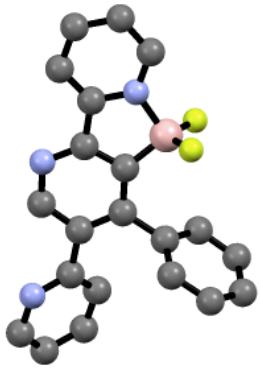

Table 1. Crystal data and structure refinement for sb165a_0m_a.

Identification code	sb165a_0m_a	
Empirical formula	C21 H14 B F2 N3	
Formula weight	357.16	
Temperature	99(2) K	
Wavelength	0.71073 Å	
Crystal system	Monoclinic	
Space group	$P2_1/c$	
Unit cell dimensions	a = 10.1420(7) Å	a= 90°.
	b = 14.5184(9) Å	b= 90.697(4)°.
	c = 11.5315(7) Å	g = 90°.
Volume	1697.84(19) $Å^3$	
Z	4	
Density (calculated)	1.397 Mg/m^3	
Absorption coefficient	0.099 mm^{-1}	
F(000)	736	

Crystal size	0.500 x 0.210 x 0.210 mm^3
Theta range for data collection	2.008 to 27.494°.
Index ranges	-13<=h<=13, -18<=k<=18, -14<=l<=14
Reflections collected	19317
Independent reflections	3887 [R(int) = 0.0918]
Completeness to theta = 25.242°	100.0 %
Absorption correction	None
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	3887 / 0 / 244
Goodness-of-fit on F^2	1.039
Final R indices [I>2sigma(I)]	R1 = 0.0504, wR2 = 0.1156
R indices (all data)	R1 = 0.0853, wR2 = 0.1330
Extinction coefficient	n/a
Largest diff. peak and hole	0.280 and -0.288 $e.Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters (Å^{2}x 10^3) for sb165a_0m_a. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
B(1)	890(2)	6929(1)	6228(2)	21(1)
F(1)	-242(1)	7333(1)	5767(1)	29(1)
F(2)	1214(1)	7335(1)	7288(1)	27(1)
N(1)	548(1)	5845(1)	6487(1)	20(1)
N(2)	3262(1)	5404(1)	4631(1)	20(1)
N(3)	6057(2)	7088(1)	3184(1)	27(1)
C(1)	-420(2)	5501(1)	7145(2)	23(1)
C(2)	-588(2)	4561(1)	7258(2)	24(1)
C(3)	277(2)	3974(1)	6697(2)	23(1)
C(4)	1291(2)	4333(1)	6042(2)	22(1)
C(5)	1392(2)	5277(1)	5939(2)	18(1)
C(6)	2326(2)	5820(1)	5256(2)	18(1)
C(7)	2105(2)	6762(1)	5368(2)	18(1)
C(8)	2964(2)	7354(1)	4787(2)	17(1)
C(9)	3939(2)	6949(1)	4089(2)	18(1)
C(10)	4032(2)	5989(1)	4049(2)	20(1)
C(11)	4852(2)	7461(1)	3319(2)	19(1)
C(12)	4434(2)	8227(1)	2688(2)	21(1)
C(13)	5267(2)	8603(1)	1874(2)	24(1)
C(14)	6500(2)	8215(1)	1720(2)	28(1)
C(15)	6848(2)	7467(1)	2389(2)	31(1)
C(16)	2895(2)	8370(1)	5007(2)	19(1)
C(17)	3911(2)	8787(1)	5641(2)	25(1)
C(18)	3871(2)	9721(1)	5878(2)	30(1)
C(19)	2843(2)	10254(1)	5456(2)	32(1)
C(20)	1829(2)	9847(1)	4822(2)	30(1)
C(21)	1841(2)	8906(1)	4621(2)	25(1)

Table 3. Bond lengths [Å] and angles [°] for sb165a_0m_a.

B(1)-F(1)	1.390(2)
B(1)-F(2)	1.393(2)
B(1)-C(7)	1.609(3)
B(1)-N(1)	1.639(3)
N(1)-C(1)	1.344(2)
N(1)-C(5)	1.351(2)
N(2)-C(10)	1.339(2)
N(2)-C(6)	1.343(2)
N(3)-C(15)	1.344(2)
N(3)-C(11)	1.348(2)
C(1)-C(2)	1.382(2)
C(1)-H(1)	0.9500
C(2)-C(3)	1.389(2)
C(2)-H(2)	0.9500
C(3)-C(4)	1.386(2)
C(3)-H(3)	0.9500
C(4)-C(5)	1.379(2)
C(4)-H(4)	0.9500
C(5)-C(6)	1.469(2)
C(6)-C(7)	1.392(2)
C(7)-C(8)	1.400(2)
C(8)-C(9)	1.410(2)
C(8)-C(16)	1.499(2)
C(9)-C(10)	1.399(2)
C(9)-C(11)	1.489(2)
C(10)-H(10)	0.9500
C(11)-C(12)	1.393(2)
C(12)-C(13)	1.382(2)
C(12)-H(12)	0.9500
C(13)-C(14)	1.385(3)
C(13)-H(13)	0.9500
C(14)-C(15)	1.374(3)
C(14)-H(14)	0.9500
C(15)-H(15)	0.9500
C(16)-C(21)	1.390(3)

C(16)-C(17)	1.395(2)
C(17)-C(18)	1.384(3)
C(17)-H(17)	0.9500
C(18)-C(19)	1.382(3)
C(18)-H(18)	0.9500
C(19)-C(20)	1.387(3)
C(19)-H(19)	0.9500
C(20)-C(21)	1.386(3)
C(20)-H(20)	0.9500
C(21)-H(21)	0.9500

F(1)-B(1)-F(2)	109.96(16)
F(1)-B(1)-C(7)	117.60(16)
F(2)-B(1)-C(7)	115.44(16)
F(1)-B(1)-N(1)	107.41(15)
F(2)-B(1)-N(1)	107.19(15)
C(7)-B(1)-N(1)	97.70(13)
C(1)-N(1)-C(5)	120.50(15)
C(1)-N(1)-B(1)	128.14(15)
C(5)-N(1)-B(1)	111.36(14)
C(10)-N(2)-C(6)	113.82(15)
C(15)-N(3)-C(11)	117.62(16)
N(1)-C(1)-C(2)	120.87(17)
N(1)-C(1)-H(1)	119.6
C(2)-C(1)-H(1)	119.6
C(1)-C(2)-C(3)	118.80(17)
C(1)-C(2)-H(2)	120.6
C(3)-C(2)-H(2)	120.6
C(4)-C(3)-C(2)	120.08(17)
C(4)-C(3)-H(3)	120.0
C(2)-C(3)-H(3)	120.0
C(5)-C(4)-C(3)	118.47(16)
C(5)-C(4)-H(4)	120.8
C(3)-C(4)-H(4)	120.8
N(1)-C(5)-C(4)	121.25(16)
N(1)-C(5)-C(6)	109.79(15)
C(4)-C(5)-C(6)	128.94(16)

N(2)-C(6)-C(7)	127.43(16)
N(2)-C(6)-C(5)	120.71(15)
C(7)-C(6)-C(5)	111.86(15)
C(6)-C(7)-C(8)	117.11(16)
C(6)-C(7)-B(1)	109.26(15)
C(8)-C(7)-B(1)	133.57(15)
C(7)-C(8)-C(9)	117.58(15)
C(7)-C(8)-C(16)	119.44(15)
C(9)-C(8)-C(16)	122.75(15)
C(10)-C(9)-C(8)	118.82(16)
C(10)-C(9)-C(11)	115.80(16)
C(8)-C(9)-C(11)	125.28(16)
N(2)-C(10)-C(9)	125.14(17)
N(2)-C(10)-H(10)	117.4
C(9)-C(10)-H(10)	117.4
N(3)-C(11)-C(12)	122.07(16)
N(3)-C(11)-C(9)	116.07(15)
C(12)-C(11)-C(9)	121.55(16)
C(13)-C(12)-C(11)	119.05(17)
C(13)-C(12)-H(12)	120.5
C(11)-C(12)-H(12)	120.5
C(12)-C(13)-C(14)	119.13(18)
C(12)-C(13)-H(13)	120.4
C(14)-C(13)-H(13)	120.4
C(15)-C(14)-C(13)	118.38(18)
C(15)-C(14)-H(14)	120.8
C(13)-C(14)-H(14)	120.8
N(3)-C(15)-C(14)	123.72(18)
N(3)-C(15)-H(15)	118.1
C(14)-C(15)-H(15)	118.1
C(21)-C(16)-C(17)	119.01(17)
C(21)-C(16)-C(8)	122.30(16)
C(17)-C(16)-C(8)	118.68(16)
C(18)-C(17)-C(16)	120.35(18)
C(18)-C(17)-H(17)	119.8
C(16)-C(17)-H(17)	119.8
C(19)-C(18)-C(17)	120.23(19)

C(19)-C(18)-H(18)	119.9
C(17)-C(18)-H(18)	119.9
C(18)-C(19)-C(20)	119.88(18)
C(18)-C(19)-H(19)	120.1
C(20)-C(19)-H(19)	120.1
C(21)-C(20)-C(19)	120.00(19)
C(21)-C(20)-H(20)	120.0
C(19)-C(20)-H(20)	120.0
C(20)-C(21)-C(16)	120.45(18)
C(20)-C(21)-H(21)	119.8
C(16)-C(21)-H(21)	119.8

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for sb165a_0m_a. The anisotropic displacement factor exponent takes the form: $-2\pi^2[h^2 a^{*2} U^{11} + ... + 2 h k a^* b^* U^{12}]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
B(1)	23(1)	19(1)	20(1)	-1(1)	3(1)	0(1)
F(1)	25(1)	29(1)	32(1)	5(1)	4(1)	6(1)
F(2)	34(1)	25(1)	21(1)	-5(1)	6(1)	1(1)
N(1)	20(1)	22(1)	16(1)	0(1)	3(1)	-1(1)
N(2)	23(1)	20(1)	17(1)	0(1)	4(1)	1(1)
N(3)	24(1)	31(1)	27(1)	7(1)	4(1)	1(1)
C(1)	20(1)	30(1)	19(1)	0(1)	5(1)	1(1)
C(2)	24(1)	30(1)	19(1)	5(1)	3(1)	-4(1)
C(3)	26(1)	23(1)	21(1)	4(1)	1(1)	-3(1)
C(4)	26(1)	20(1)	20(1)	-1(1)	5(1)	1(1)
C(5)	19(1)	21(1)	16(1)	-1(1)	1(1)	0(1)
C(6)	20(1)	21(1)	14(1)	-1(1)	2(1)	0(1)
C(7)	22(1)	17(1)	15(1)	-2(1)	-1(1)	1(1)
C(8)	19(1)	18(1)	13(1)	1(1)	-2(1)	1(1)
C(9)	20(1)	22(1)	14(1)	1(1)	-1(1)	0(1)
C(10)	22(1)	22(1)	16(1)	0(1)	4(1)	1(1)
C(11)	23(1)	20(1)	14(1)	0(1)	0(1)	-2(1)
C(12)	23(1)	22(1)	17(1)	-2(1)	0(1)	0(1)
C(13)	33(1)	21(1)	17(1)	1(1)	-2(1)	-5(1)
C(14)	28(1)	35(1)	21(1)	5(1)	4(1)	-10(1)
C(15)	21(1)	41(1)	32(1)	9(1)	9(1)	0(1)
C(16)	26(1)	17(1)	14(1)	1(1)	5(1)	-1(1)
C(17)	28(1)	25(1)	23(1)	1(1)	2(1)	-4(1)
C(18)	36(1)	28(1)	26(1)	-6(1)	7(1)	-9(1)
C(19)	45(1)	22(1)	30(1)	-4(1)	18(1)	-2(1)
C(20)	36(1)	24(1)	29(1)	4(1)	8(1)	7(1)
C(21)	27(1)	25(1)	22(1)	-1(1)	3(1)	1(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters (Å^{2}x 10^3) for sb165a_0m_a.

	x	y	z	U(eq)
H(1)	-995	5909	7537	28
H(2)	-1284	4320	7712	29
H(3)	174	3326	6763	28
H(4)	1903	3938	5671	26
H(10)	4693	5731	3571	24
H(12)	3589	8488	2814	25
H(13)	4997	9120	1426	28
H(14)	7091	8459	1166	33
H(15)	7695	7204	2282	37
H(17)	4634	8427	5913	30
H(18)	4552	9996	6331	36
H(19)	2832	10898	5600	39
H(20)	1126	10214	4525	36
H(21)	1125	8625	4218	30

X-ray crystal structure data for 3-(difluoroboranyl)-4-phenyl-2-(quinolin-2-yl)dibenzo[*f*,*h*]quinoline 110a

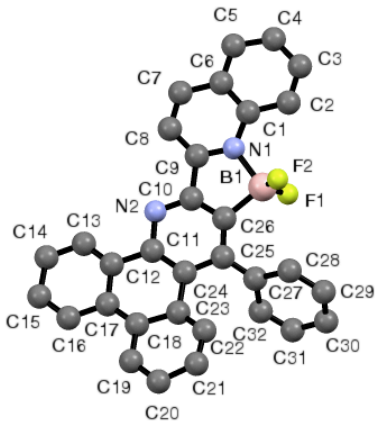

Table 1. Crystal data and structure refinement for OHJ310.

Identification code	shelx	
Empirical formula	C32 H19 B F2 N2	
Formula weight	480.30	
Temperature	150(2) K	
Wavelength	1.54178 Å	
Crystal system	Monoclinic	
Space group	$P2_1/c$	
Unit cell dimensions	a = 12.910(4) Å	a= 90°.
	b = 26.974(6) Å	b= 106.671(17)°.
	c = 8.0032(18) Å	g = 90°.
Volume	2669.9(12) $Å^3$	
Z	4	
Density (calculated)	1.195 Mg/m^3	
Absorption coefficient	0.640 mm^{-1}	
F(000)	992	
Crystal size	0.320 x 0.120 x 0.120 mm^3	
Theta range for data collection	3.277 to 66.791°.	
Index ranges	-14<=h<=14, -32<=k<=31, -9<=l<=8	
Reflections collected	11561	
Independent reflections	4259 [R(int) = 0.3165]	
Completeness to theta = 66.500°	89.9 %	
Absorption correction	Semi-empirical from equivalents	

Max. and min. transmission	0.93 and 0.87
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	4259 / 300 / 334
Goodness-of-fit on F^2	1.326
Final R indices [I>2sigma(I)]	R1 = 0.1938, wR2 = 0.4706
R indices (all data)	R1 = 0.2903, wR2 = 0.5115
Extinction coefficient	n/a
Largest diff. peak and hole	0.438 and -0.428 e.$Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters (Å^{2}x 10^3) for OHJ310. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
B(1)	2948(16)	10002(4)	1540(20)	77(5)
F(1)	2425(6)	9919(2)	2745(9)	71(2)
F(2)	2505(6)	10330(2)	339(8)	66(2)
N(1)	4248(9)	10202(3)	2559(12)	58(3)
N(2)	5142(8)	9155(2)	781(11)	52(2)
C(1)	4477(11)	10624(3)	3563(16)	62(2)
C(2)	3679(12)	10926(3)	4054(15)	65(2)
C(3)	3972(12)	11336(4)	5017(16)	66(2)
C(4)	5027(12)	11442(4)	5726(16)	66(2)
C(5)	5877(12)	11162(3)	5402(16)	64(2)
C(6)	5575(12)	10750(3)	4306(16)	64(2)
C(7)	6384(12)	10439(3)	3852(16)	63(2)
C(8)	6065(11)	10043(3)	2823(15)	60(2)
C(9)	5010(11)	9925(3)	2268(15)	58(2)
C(10)	4473(11)	9488(3)	1127(15)	59(2)
C(11)	4596(11)	8772(3)	-312(16)	62(2)
C(12)	5365(12)	8402(3)	-668(17)	64(1)
C(13)	6394(12)	8408(4)	104(17)	68(2)
C(14)	7088(12)	8059(3)	-241(17)	69(2)
C(15)	6629(12)	7664(3)	-1430(17)	68(2)
C(16)	5559(12)	7656(3)	-2214(17)	65(2)
C(17)	4833(12)	8011(3)	-1823(16)	64(2)
C(18)	3751(12)	8033(3)	-2722(16)	65(2)
C(19)	3256(12)	7704(3)	-4142(16)	68(2)
C(20)	2221(12)	7713(4)	-5044(17)	70(2)
C(21)	1575(13)	8109(4)	-4620(17)	71(2)
C(22)	1968(12)	8413(3)	-3264(16)	67(2)
C(23)	2950(12)	8379(3)	-2318(16)	64(1)
C(24)	3471(11)	8754(3)	-903(16)	61(1)

C(25)	2839(11)	9086(3)	-176(16)	63(1)
C(26)	3386(11)	9479(3)	719(16)	60(2)
C(27)	1775(12)	9019(3)	-296(17)	68(2)
C(28)	944(12)	9399(4)	-973(18)	70(2)
C(29)	-127(12)	9329(4)	-946(18)	74(2)
C(30)	-441(13)	8896(4)	-281(18)	78(2)
C(31)	334(13)	8531(4)	204(18)	78(2)
C(32)	1342(13)	8575(4)	265(18)	74(2)

Table 3. Bond lengths [Å] and angles [°] for OHJ310.

B(1)-F(1)	1.341(16)
B(1)-F(2)	1.313(17)
B(1)-N(1)	1.73(2)
B(1)-C(26)	1.720(16)
N(1)-C(9)	1.308(14)
N(1)-C(1)	1.375(13)
N(2)-C(10)	1.328(13)
N(2)-C(11)	1.406(14)
C(1)-C(6)	1.412(19)
C(1)-C(2)	1.454(15)
C(2)-C(3)	1.339(15)
C(2)-H(2)	0.9500
C(3)-C(4)	1.347(19)
C(3)-H(3)	0.9500
C(4)-C(5)	1.417(17)
C(4)-H(4)	0.9500
C(5)-C(6)	1.400(15)
C(5)-H(5)	0.9500
C(6)-C(7)	1.463(16)
C(7)-C(8)	1.340(15)
C(7)-H(7)	0.9500
C(8)-C(9)	1.345(18)
C(8)-H(8)	0.9500
C(9)-C(10)	1.529(16)
C(10)-C(26)	1.347(17)
C(11)-C(24)	1.393(18)
C(11)-C(12)	1.492(15)
C(12)-C(13)	1.295(19)
C(12)-C(17)	1.440(17)
C(13)-C(14)	1.380(15)
C(13)-H(13)	0.9500
C(14)-C(15)	1.438(16)
C(14)-H(14)	0.9500
C(15)-C(16)	1.343(19)
C(15)-H(15)	0.9500

C(16)-C(17)	1.438(16)
C(16)-H(16)	0.9500
C(17)-C(18)	1.376(19)
C(18)-C(19)	1.440(17)
C(18)-C(23)	1.496(16)
C(19)-C(20)	1.325(19)
C(19)-H(19)	0.9500
C(20)-C(21)	1.455(17)
C(20)-H(20)	0.9500
C(21)-C(22)	1.338(17)
C(21)-H(21)	0.9500
C(22)-C(23)	1.280(18)
C(22)-H(22)	0.9500
C(23)-C(24)	1.524(17)
C(24)-C(25)	1.441(14)
C(25)-C(26)	1.358(16)
C(25)-C(27)	1.361(18)
C(27)-C(32)	1.447(14)
C(27)-C(28)	1.469(18)
C(28)-C(29)	1.402(18)
C(28)-H(28)	0.9500
C(29)-C(30)	1.390(15)
C(29)-H(29)	0.9500
C(30)-C(31)	1.379(18)
C(30)-H(30)	0.9500
C(31)-C(32)	1.294(18)
C(31)-H(31)	0.9500
C(32)-H(32)	0.9500

F(1)-B(1)-F(2)	115.8(14)
F(1)-B(1)-N(1)	109.6(12)
F(2)-B(1)-N(1)	107.1(9)
F(1)-B(1)-C(26)	115.3(9)
F(2)-B(1)-C(26)	113.1(11)
N(1)-B(1)-C(26)	93.1(11)
C(9)-N(1)-C(1)	122.0(11)
C(9)-N(1)-B(1)	114.6(9)

C(1)-N(1)-B(1)	123.4(9)
C(10)-N(2)-C(11)	112.7(10)
N(1)-C(1)-C(6)	117.8(10)
N(1)-C(1)-C(2)	124.8(12)
C(6)-C(1)-C(2)	117.1(11)
C(3)-C(2)-C(1)	120.8(13)
C(3)-C(2)-H(2)	119.6
C(1)-C(2)-H(2)	119.6
C(2)-C(3)-C(4)	120.2(12)
C(2)-C(3)-H(3)	119.9
C(4)-C(3)-H(3)	119.9
C(3)-C(4)-C(5)	123.5(11)
C(3)-C(4)-H(4)	118.3
C(5)-C(4)-H(4)	118.2
C(4)-C(5)-C(6)	116.6(13)
C(4)-C(5)-H(5)	121.7
C(6)-C(5)-H(5)	121.7
C(1)-C(6)-C(5)	121.3(11)
C(1)-C(6)-C(7)	117.4(10)
C(5)-C(6)-C(7)	121.3(13)
C(8)-C(7)-C(6)	119.5(13)
C(8)-C(7)-H(7)	120.2
C(6)-C(7)-H(7)	120.2
C(9)-C(8)-C(7)	119.8(11)
C(9)-C(8)-H(8)	120.1
C(7)-C(8)-H(8)	120.1
C(8)-C(9)-N(1)	123.2(10)
C(8)-C(9)-C(10)	128.5(10)
N(1)-C(9)-C(10)	108.2(11)
N(2)-C(10)-C(26)	129.3(11)
N(2)-C(10)-C(9)	115.7(11)
C(26)-C(10)-C(9)	114.8(9)
N(2)-C(11)-C(24)	121.6(9)
N(2)-C(11)-C(12)	111.6(11)
C(24)-C(11)-C(12)	126.7(10)
C(13)-C(12)-C(17)	123.4(10)
C(13)-C(12)-C(11)	123.3(11)

C(17)-C(12)-C(11)	113.0(12)
C(12)-C(13)-C(14)	122.2(12)
C(12)-C(13)-H(13)	118.9
C(14)-C(13)-H(13)	118.9
C(13)-C(14)-C(15)	118.0(14)
C(13)-C(14)-H(14)	121.0
C(15)-C(14)-H(14)	121.0
C(16)-C(15)-C(14)	119.7(11)
C(16)-C(15)-H(15)	120.2
C(14)-C(15)-H(15)	120.2
C(15)-C(16)-C(17)	122.3(12)
C(15)-C(16)-H(16)	118.8
C(17)-C(16)-H(16)	118.8
C(18)-C(17)-C(16)	122.8(11)
C(18)-C(17)-C(12)	122.0(10)
C(16)-C(17)-C(12)	114.0(13)
C(17)-C(18)-C(19)	122.7(10)
C(17)-C(18)-C(23)	125.1(11)
C(19)-C(18)-C(23)	112.2(12)
C(20)-C(19)-C(18)	124.7(12)
C(20)-C(19)-H(19)	117.7
C(18)-C(19)-H(19)	117.7
C(19)-C(20)-C(21)	116.3(12)
C(19)-C(20)-H(20)	121.8
C(21)-C(20)-H(20)	121.8
C(22)-C(21)-C(20)	122.0(14)
C(22)-C(21)-H(21)	119.0
C(20)-C(21)-H(21)	119.0
C(23)-C(22)-C(21)	121.2(12)
C(23)-C(22)-H(22)	119.4
C(21)-C(22)-H(22)	119.4
C(22)-C(23)-C(18)	123.1(12)
C(22)-C(23)-C(24)	122.9(10)
C(18)-C(23)-C(24)	112.9(12)
C(11)-C(24)-C(25)	119.8(11)
C(11)-C(24)-C(23)	118.0(9)
C(25)-C(24)-C(23)	122.1(12)

C(26)-C(25)-C(27)	120.1(10)
C(26)-C(25)-C(24)	115.4(12)
C(27)-C(25)-C(24)	124.5(11)
C(10)-C(26)-C(25)	119.3(10)
C(10)-C(26)-B(1)	109.1(11)
C(25)-C(26)-B(1)	131.5(13)
C(25)-C(27)-C(32)	124.0(12)
C(25)-C(27)-C(28)	123.3(9)
C(32)-C(27)-C(28)	112.6(12)
C(29)-C(28)-C(27)	121.3(10)
C(29)-C(28)-H(28)	119.3
C(27)-C(28)-H(28)	119.3
C(28)-C(29)-C(30)	121.1(12)
C(28)-C(29)-H(29)	119.5
C(30)-C(29)-H(29)	119.5
C(29)-C(30)-C(31)	116.1(13)
C(29)-C(30)-H(30)	121.9
C(31)-C(30)-H(30)	121.9
C(32)-C(31)-C(30)	125.8(11)
C(32)-C(31)-H(31)	117.1
C(30)-C(31)-H(31)	117.1
C(31)-C(32)-C(27)	122.6(12)
C(31)-C(32)-H(32)	118.7
C(27)-C(32)-H(32)	118.7

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for OHJ310. The anisotropic displacement factor exponent takes the form: $-2\pi^2[h^2 a^{*2} U^{11} + ... + 2 h k a^* b^* U^{12}]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
B(1)	115(16)	43(6)	80(10)	-19(7)	38(11)	-18(8)
F(1)	100(6)	54(3)	72(4)	14(3)	45(4)	11(3)
F(2)	97(6)	39(3)	62(4)	23(3)	20(4)	16(3)
N(1)	93(8)	37(4)	53(5)	2(4)	35(5)	3(4)
N(2)	77(7)	34(3)	48(5)	4(3)	26(5)	-2(4)
C(1)	86(4)	44(3)	62(3)	9(2)	32(3)	3(3)
C(2)	87(4)	46(3)	66(3)	7(3)	29(3)	5(3)
C(3)	88(4)	46(3)	67(3)	6(3)	30(3)	6(3)
C(4)	90(4)	46(3)	68(3)	7(3)	30(3)	3(3)
C(5)	88(4)	46(2)	65(3)	8(2)	32(3)	1(3)
C(6)	88(4)	45(2)	65(3)	8(2)	32(3)	1(2)
C(7)	87(4)	45(2)	65(3)	12(2)	34(3)	0(2)
C(8)	83(3)	44(2)	65(3)	11(2)	38(3)	0(3)
C(9)	81(3)	44(2)	64(3)	13(2)	45(3)	-1(3)
C(10)	82(3)	44(2)	65(3)	12(2)	44(3)	2(3)
C(11)	86(3)	41(2)	70(3)	3(2)	41(3)	0(2)
C(12)	88(3)	41(2)	73(3)	1(2)	40(2)	1(2)
C(13)	89(3)	44(3)	77(3)	1(2)	37(3)	2(3)
C(14)	90(3)	44(3)	79(3)	-1(3)	35(3)	2(3)
C(15)	91(3)	42(3)	78(3)	0(3)	35(3)	3(3)
C(16)	91(3)	40(2)	74(3)	0(2)	37(3)	0(3)
C(17)	89(3)	40(2)	73(3)	2(2)	38(2)	0(2)
C(18)	91(3)	41(2)	70(3)	3(2)	36(2)	-1(2)
C(19)	94(4)	44(2)	70(3)	2(2)	33(3)	-1(3)
C(20)	96(4)	47(3)	71(3)	2(3)	31(3)	0(3)
C(21)	97(4)	49(3)	72(3)	3(3)	29(3)	1(3)
C(22)	93(3)	44(3)	69(3)	4(2)	33(3)	0(3)
C(23)	90(3)	41(2)	70(3)	6(2)	37(2)	-1(2)
C(24)	86(3)	40(2)	69(3)	7(2)	40(2)	1(2)
C(25)	85(3)	44(2)	71(3)	8(2)	40(2)	4(2)

C(26)	82(3)	43(2)	68(3)	9(2)	44(3)	4(2)
C(27)	86(3)	47(2)	80(3)	8(2)	37(3)	5(2)
C(28)	89(3)	48(3)	82(4)	9(3)	35(3)	6(3)
C(29)	88(4)	52(3)	88(4)	10(3)	33(3)	6(3)
C(30)	90(4)	55(3)	93(4)	11(3)	32(3)	2(3)
C(31)	89(4)	54(3)	94(4)	13(3)	33(3)	1(3)
C(32)	89(4)	50(3)	87(4)	12(3)	35(3)	1(3)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters (Å^{2}x 10^{-3}) for OHJ310.

	x	y	z	U(eq)
H(2)	2939	10831	3687	78
H(3)	3435	11552	5201	79
H(4)	5210	11719	6485	80
H(5)	6614	11249	5902	77
H(7)	7131	10518	4283	76
H(8)	6582	9846	2488	72
H(13)	6681	8661	934	81
H(14)	7846	8080	292	82
H(15)	7080	7411	-1660	82
H(16)	5273	7406	-3056	78
H(19)	3704	7463	-4455	81
H(20)	1917	7474	-5919	84
H(21)	852	8154	-5327	86
H(22)	1510	8657	-2998	80
H(28)	1136	9698	-1437	84
H(29)	-647	9581	-1390	89
H(30)	-1148	8855	-166	94
H(31)	107	8218	521	93
H(32)	1817	8306	696	88

X-ray crystal structure data for 2-(3-(difluoroboranyl)-5,6-dimethyl-4-phenylpyridin-2-yl)quinoline 110f

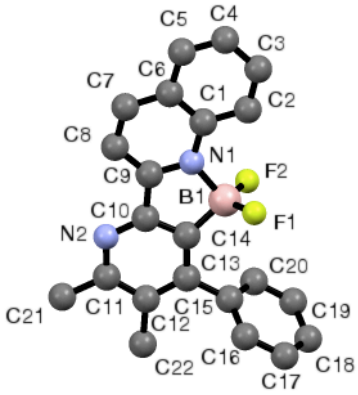

Table 1. Crystal data and structure refinement for OHJ302_0m_a.

Identification code	OHJ302_0m_a	
Empirical formula	C22 H17 B F2 N2	
Formula weight	358.18	
Temperature	100(2) K	
Wavelength	1.54178 Å	
Crystal system	Triclinic	
Space group	P-1	
Unit cell dimensions	a = 6.9846(3) Å	a= 110.893(2)°.
	b = 10.4119(5) Å	b= 94.149(2)°.
	c = 12.9983(6) Å	g = 100.118(2)°.
Volume	859.97(7) $Å^3$	
Z	2	
Density (calculated)	1.383 Mg/m^3	
Absorption coefficient	0.784 mm^{-1}	
F(000)	372	
Crystal size	0.180 x 0.120 x 0.110 mm^3	
Theta range for data collection	4.726 to 66.712°.	
Index ranges	-8<=h<=8, -11<=k<=12, -15<=l<=14	
Reflections collected	9977	
Independent reflections	2994 [R(int) = 0.0384]	
Completeness to theta = 66.500°	98.4 %	

Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.83 and 0.58
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	2994 / 0 / 246
Goodness-of-fit on F^2	1.091
Final R indices [I>2sigma(I)]	R1 = 0.0398, wR2 = 0.1028
R indices (all data)	R1 = 0.0545, wR2 = 0.1272
Extinction coefficient	n/a
Largest diff. peak and hole	0.249 and -0.272 e.$Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3)
for OHJ302_0m_a. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
B(1)	2709(3)	5490(2)	3167(2)	17(1)
F(1)	4422(2)	6301(1)	3059(1)	21(1)
F(2)	1086(2)	5862(1)	2763(1)	21(1)
N(1)	2655(2)	5837(2)	4510(1)	16(1)
N(2)	2327(2)	2152(2)	3740(1)	18(1)
C(1)	2686(3)	7107(2)	5336(2)	18(1)
C(2)	2838(3)	8338(2)	5098(2)	23(1)
C(3)	2837(3)	9590(2)	5935(2)	28(1)
C(4)	2703(3)	9672(2)	7036(2)	29(1)
C(5)	2575(3)	8495(2)	7279(2)	25(1)
C(6)	2555(3)	7175(2)	6438(2)	20(1)
C(7)	2386(3)	5917(2)	6640(2)	21(1)
C(8)	2339(3)	4666(2)	5798(2)	19(1)
C(9)	2492(2)	4663(2)	4729(2)	16(1)
C(10)	2470(2)	3440(2)	3714(2)	16(1)
C(11)	2313(3)	1121(2)	2762(2)	19(1)
C(12)	2499(3)	1353(2)	1762(2)	19(1)
C(13)	2637(2)	2726(2)	1778(2)	16(1)
C(14)	2603(2)	3816(2)	2791(2)	16(1)
C(15)	2778(3)	3026(2)	740(2)	18(1)
C(16)	4439(3)	2916(2)	206(2)	21(1)
C(17)	4524(3)	3190(2)	-764(2)	24(1)
C(18)	2948(3)	3547(2)	-1216(2)	25(1)
C(19)	1293(3)	3664(2)	-696(2)	24(1)
C(20)	1218(3)	3420(2)	289(2)	20(1)
C(21)	2054(3)	-338(2)	2779(2)	25(1)
C(22)	2486(3)	111(2)	712(2)	23(1)

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Table 3. Bond lengths [Å] and angles [°] for OHJ302_0m_a.

B(1)-F(1)	1.384(2)
B(1)-F(2)	1.386(2)
B(1)-C(14)	1.620(3)
B(1)-N(1)	1.657(2)
N(1)-C(9)	1.339(2)
N(1)-C(1)	1.370(2)
N(2)-C(11)	1.338(3)
N(2)-C(10)	1.340(2)
C(1)-C(2)	1.411(3)
C(1)-C(6)	1.419(3)
C(2)-C(3)	1.369(3)
C(2)-H(2)	0.9500
C(3)-C(4)	1.414(3)
C(3)-H(3)	0.9500
C(4)-C(5)	1.360(3)
C(4)-H(4)	0.9500
C(5)-C(6)	1.416(3)
C(5)-H(5)	0.9500
C(6)-C(7)	1.412(3)
C(7)-C(8)	1.363(3)
C(7)-H(7)	0.9500
C(8)-C(9)	1.400(3)
C(8)-H(8)	0.9500
C(9)-C(10)	1.468(3)
C(10)-C(14)	1.392(3)
C(11)-C(12)	1.416(3)
C(11)-C(21)	1.507(3)
C(12)-C(13)	1.408(3)
C(12)-C(22)	1.506(3)
C(13)-C(14)	1.403(3)
C(13)-C(15)	1.496(3)
C(15)-C(20)	1.391(3)
C(15)-C(16)	1.395(3)
C(16)-C(17)	1.391(3)
C(16)-H(16)	0.9500

C(17)-C(18)	1.379(3)
C(17)-H(17)	0.9500
C(18)-C(19)	1.383(3)
C(18)-H(18)	0.9500
C(19)-C(20)	1.394(3)
C(19)-H(19)	0.9500
C(20)-H(20)	0.9500
C(21)-H(21A)	0.9800
C(21)-H(21B)	0.9800
C(21)-H(21C)	0.9800
C(22)-H(22A)	0.9800
C(22)-H(22B)	0.9800
C(22)-H(22C)	0.9800

F(1)-B(1)-F(2)	110.05(15)
F(1)-B(1)-C(14)	116.84(16)
F(2)-B(1)-C(14)	115.82(15)
F(1)-B(1)-N(1)	108.12(15)
F(2)-B(1)-N(1)	107.51(14)
C(14)-B(1)-N(1)	97.04(13)
C(9)-N(1)-C(1)	120.85(16)
C(9)-N(1)-B(1)	111.11(15)
C(1)-N(1)-B(1)	127.99(15)
C(11)-N(2)-C(10)	115.50(16)
N(1)-C(1)-C(2)	120.56(17)
N(1)-C(1)-C(6)	119.32(16)
C(2)-C(1)-C(6)	120.12(17)
C(3)-C(2)-C(1)	119.37(19)
C(3)-C(2)-H(2)	120.3
C(1)-C(2)-H(2)	120.3
C(2)-C(3)-C(4)	121.10(19)
C(2)-C(3)-H(3)	119.4
C(4)-C(3)-H(3)	119.4
C(5)-C(4)-C(3)	120.10(19)
C(5)-C(4)-H(4)	120.0
C(3)-C(4)-H(4)	120.0
C(4)-C(5)-C(6)	120.81(19)

C(4)-C(5)-H(5)	119.6
C(6)-C(5)-H(5)	119.6
C(7)-C(6)-C(5)	123.13(18)
C(7)-C(6)-C(1)	118.36(17)
C(5)-C(6)-C(1)	118.50(18)
C(8)-C(7)-C(6)	120.94(17)
C(8)-C(7)-H(7)	119.5
C(6)-C(7)-H(7)	119.5
C(7)-C(8)-C(9)	118.28(17)
C(7)-C(8)-H(8)	120.9
C(9)-C(8)-H(8)	120.9
N(1)-C(9)-C(8)	122.24(17)
N(1)-C(9)-C(10)	110.75(16)
C(8)-C(9)-C(10)	127.00(16)
N(2)-C(10)-C(14)	127.41(17)
N(2)-C(10)-C(9)	120.96(16)
C(14)-C(10)-C(9)	111.63(15)
N(2)-C(11)-C(12)	123.31(16)
N(2)-C(11)-C(21)	115.61(17)
C(12)-C(11)-C(21)	121.08(17)
C(13)-C(12)-C(11)	118.90(17)
C(13)-C(12)-C(22)	122.49(17)
C(11)-C(12)-C(22)	118.59(16)
C(14)-C(13)-C(12)	118.56(17)
C(14)-C(13)-C(15)	120.23(16)
C(12)-C(13)-C(15)	121.20(16)
C(10)-C(14)-C(13)	116.27(16)
C(10)-C(14)-B(1)	109.43(16)
C(13)-C(14)-B(1)	134.30(16)
C(20)-C(15)-C(16)	118.91(17)
C(20)-C(15)-C(13)	119.47(16)
C(16)-C(15)-C(13)	121.62(17)
C(17)-C(16)-C(15)	120.39(18)
C(17)-C(16)-H(16)	119.8
C(15)-C(16)-H(16)	119.8
C(18)-C(17)-C(16)	120.08(18)
C(18)-C(17)-H(17)	120.0

C(16)-C(17)-H(17)	120.0
C(17)-C(18)-C(19)	120.24(18)
C(17)-C(18)-H(18)	119.9
C(19)-C(18)-H(18)	119.9
C(18)-C(19)-C(20)	119.87(18)
C(18)-C(19)-H(19)	120.1
C(20)-C(19)-H(19)	120.1
C(15)-C(20)-C(19)	120.48(18)
C(15)-C(20)-H(20)	119.8
C(19)-C(20)-H(20)	119.8
C(11)-C(21)-H(21A)	109.5
C(11)-C(21)-H(21B)	109.5
H(21A)-C(21)-H(21B)	109.5
C(11)-C(21)-H(21C)	109.5
H(21A)-C(21)-H(21C)	109.5
H(21B)-C(21)-H(21C)	109.5
C(12)-C(22)-H(22A)	109.5
C(12)-C(22)-H(22B)	109.5
H(22A)-C(22)-H(22B)	109.5
C(12)-C(22)-H(22C)	109.5
H(22A)-C(22)-H(22C)	109.5
H(22B)-C(22)-H(22C)	109.5

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for OHJ302_0m_a. The anisotropic
displacement factor exponent takes the form: $-2\pi^2[h^2 a^{*2} U^{11} + ... + 2 h k a^* b^* U^{12}]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
B(1)	21(1)	18(1)	12(1)	6(1)	2(1)	4(1)
F(1)	23(1)	20(1)	22(1)	9(1)	7(1)	3(1)
F(2)	24(1)	22(1)	19(1)	8(1)	1(1)	8(1)
N(1)	13(1)	17(1)	16(1)	5(1)	1(1)	3(1)
N(2)	15(1)	18(1)	21(1)	8(1)	0(1)	4(1)
C(1)	14(1)	19(1)	18(1)	3(1)	1(1)	3(1)
C(2)	24(1)	22(1)	23(1)	8(1)	2(1)	6(1)
C(3)	26(1)	19(1)	33(1)	4(1)	1(1)	6(1)
C(4)	21(1)	24(1)	29(1)	-4(1)	0(1)	6(1)
C(5)	17(1)	30(1)	19(1)	0(1)	1(1)	5(1)
C(6)	12(1)	27(1)	18(1)	5(1)	0(1)	3(1)
C(7)	16(1)	29(1)	15(1)	8(1)	1(1)	3(1)
C(8)	15(1)	24(1)	19(1)	10(1)	1(1)	3(1)
C(9)	11(1)	20(1)	19(1)	9(1)	1(1)	3(1)
C(10)	13(1)	18(1)	17(1)	8(1)	1(1)	4(1)
C(11)	14(1)	19(1)	24(1)	8(1)	0(1)	4(1)
C(12)	14(1)	18(1)	23(1)	7(1)	1(1)	4(1)
C(13)	12(1)	18(1)	18(1)	6(1)	0(1)	3(1)
C(14)	13(1)	19(1)	17(1)	7(1)	1(1)	4(1)
C(15)	23(1)	11(1)	14(1)	1(1)	2(1)	1(1)
C(16)	22(1)	17(1)	20(1)	3(1)	2(1)	4(1)
C(17)	29(1)	19(1)	19(1)	2(1)	11(1)	1(1)
C(18)	41(1)	15(1)	16(1)	5(1)	6(1)	1(1)
C(19)	32(1)	17(1)	20(1)	5(1)	-1(1)	6(1)
C(20)	23(1)	17(1)	18(1)	5(1)	4(1)	4(1)
C(21)	28(1)	20(1)	30(1)	10(1)	3(1)	6(1)
C(22)	28(1)	19(1)	23(1)	6(1)	4(1)	6(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters (Å^{2}x 10^{-3}) for OHJ302_0m_a.

	x	y	z	U(eq)
H(2)	2940	8298	4362	28
H(3)	2929	10418	5774	33
H(4)	2702	10550	7606	34
H(5)	2498	8561	8022	29
H(7)	2303	5943	7373	25
H(8)	2206	3818	5933	23
H(16)	5518	2652	506	25
H(17)	5670	3132	-1116	29
H(18)	2999	3713	-1887	30
H(19)	208	3909	-1009	29
H(20)	94	3524	656	24
H(21A)	1880	-299	3530	38
H(21B)	3221	-713	2566	38
H(21C)	893	-952	2252	38
H(22A)	2437	404	75	35
H(22B)	1330	-634	607	35
H(22C)	3681	-244	772	35

Table 6. Hydrogen bonds for OHJ302_0m_a [Å and °].

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
C(2)-H(2)...F(1)	0.95	2.60	3.160(2)	118.0

Symmetry transformations used to generate equivalent atoms:

X-ray crystal structure data for 3-(bis(phenylethynyl)boranyl)-4-phenyl-2-(quinolin-2-yl)dibenzo[*f*,*h*]quinoline 111a

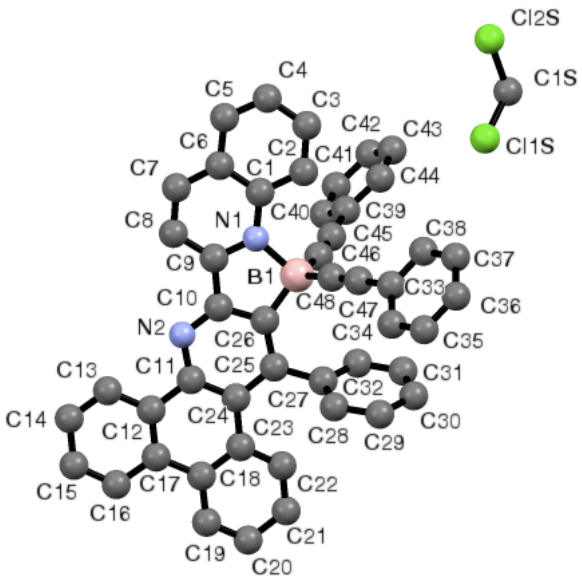

Table 1. Crystal data and structure refinement for ohj322_0m_a.

Identification code	ohj322_0m_a	
Empirical formula	C49 H31 B Cl2 N2	
Formula weight	729.47	
Temperature	150(2) K	
Wavelength	1.54178 Å	
Crystal system	Monoclinic	
Space group	$P2_1/c$	
Unit cell dimensions	a = 10.9044(4) Å	a= 90°.
	b = 30.1211(10) Å	b= 106.416(2)°.
	c = 11.5250(4) Å	g = 90°.
Volume	3631.1(2) $Å^3$	
Z	4	
Density (calculated)	1.334 Mg/m^3	
Absorption coefficient	1.905 mm^{-1}	
F(000)	1512	
Crystal size	0.210 x 0.100 x 0.100 mm^3	
Theta range for data collection	2.934 to 59.027°.	
Index ranges	-12<=h<=12, -33<=k<=32, -12<=l<=12	

Reflections collected	45883
Independent reflections	5208 [R(int) = 0.2448]
Completeness to theta = 59.027°	99.8 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.89 and 0.65
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	5208 / 0 / 487
Goodness-of-fit on F^2	1.024
Final R indices [I>2sigma(I)]	R1 = 0.0758, wR2 = 0.1501
R indices (all data)	R1 = 0.1909, wR2 = 0.2045
Extinction coefficient	n/a
Largest diff. peak and hole	0.597 and -0.581 e.$Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3)
for ohj322_0m_a. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
B(1)	5376(6)	4024(2)	6158(6)	25(2)
N(1)	4281(4)	4312(1)	5180(4)	25(1)
N(2)	4822(4)	5116(1)	7528(4)	26(1)
C(1)	3619(5)	4191(2)	4025(5)	25(1)
C(2)	3878(5)	3785(2)	3540(5)	33(2)
C(3)	3163(5)	3663(2)	2417(5)	36(2)
C(4)	2182(5)	3938(2)	1734(5)	39(2)
C(5)	1925(5)	4337(2)	2171(5)	38(2)
C(6)	2632(5)	4474(2)	3347(5)	28(1)
C(7)	2401(5)	4880(2)	3873(5)	32(2)
C(8)	3067(5)	4988(2)	5022(5)	27(1)
C(9)	4007(5)	4694(2)	5664(5)	25(1)
C(10)	4833(5)	4746(2)	6897(5)	23(1)
C(11)	5651(5)	5128(2)	8646(5)	26(1)
C(12)	5643(5)	5537(2)	9325(5)	26(1)
C(13)	4780(5)	5874(2)	8797(5)	33(2)
C(14)	4786(5)	6272(2)	9388(6)	38(2)
C(15)	5639(6)	6336(2)	10513(6)	43(2)
C(16)	6474(6)	6006(2)	11054(6)	39(2)
C(17)	6493(5)	5594(2)	10469(5)	30(2)
C(18)	7326(5)	5228(2)	11039(5)	28(1)
C(19)	8071(5)	5257(2)	12244(5)	37(2)
C(20)	8781(5)	4905(2)	12834(5)	40(2)
C(21)	8737(5)	4502(2)	12218(5)	38(2)
C(22)	8029(5)	4468(2)	11036(5)	34(2)
C(23)	7330(5)	4827(2)	10390(5)	29(1)
C(24)	6544(5)	4784(2)	9129(5)	24(1)
C(25)	6604(5)	4414(2)	8358(5)	25(1)
C(26)	5666(5)	4383(2)	7251(5)	22(1)

C(27)	7658(5)	4080(2)	8573(5)	26(1)
C(28)	8876(5)	4224(2)	8638(5)	35(2)
C(29)	9831(6)	3919(2)	8650(5)	42(2)
C(30)	9557(6)	3474(2)	8605(5)	46(2)
C(31)	8359(6)	3328(2)	8578(5)	41(2)
C(32)	7396(5)	3630(2)	8560(5)	34(2)
C(33)	8566(5)	3751(2)	4886(5)	29(1)
C(34)	9705(5)	3970(2)	5395(5)	35(2)
C(35)	10784(5)	3869(2)	5046(5)	43(2)
C(36)	10735(6)	3552(2)	4183(6)	47(2)
C(37)	9606(7)	3337(2)	3668(7)	61(2)
C(38)	8526(6)	3437(2)	4002(6)	54(2)
C(39)	3041(5)	2929(2)	6344(5)	28(1)
C(40)	2170(6)	2935(2)	7011(6)	51(2)
C(41)	1268(6)	2601(2)	6888(6)	59(2)
C(42)	1216(6)	2259(2)	6092(6)	43(2)
C(43)	2092(6)	2247(2)	5439(5)	44(2)
C(44)	2993(5)	2578(2)	5567(5)	38(2)
C(45)	3927(5)	3286(2)	6399(5)	28(1)
C(46)	4626(5)	3593(2)	6374(5)	25(1)
C(47)	7453(5)	3849(2)	5288(5)	30(2)
C(48)	6537(5)	3924(2)	5635(5)	28(2)
C(1S)	6606(7)	2270(2)	557(6)	80(2)
Cl(1S)	7531(2)	2692(1)	1275(2)	107(1)
Cl(2S)	5741(2)	2386(1)	-948(2)	74(1)

Table 3. Bond lengths [Å] and angles [°] for ohj322_0m_a.

B(1)-C(48)	1.577(8)
B(1)-C(46)	1.591(8)
B(1)-C(26)	1.621(8)
B(1)-N(1)	1.641(7)
N(1)-C(9)	1.347(6)
N(1)-C(1)	1.372(6)
N(2)-C(10)	1.333(6)
N(2)-C(11)	1.349(6)
C(1)-C(2)	1.407(7)
C(1)-C(6)	1.421(7)
C(2)-C(3)	1.359(7)
C(2)-H(2)	0.9500
C(3)-C(4)	1.405(7)
C(3)-H(3)	0.9500
C(4)-C(5)	1.363(7)
C(4)-H(4)	0.9500
C(5)-C(6)	1.418(7)
C(5)-H(5)	0.9500
C(6)-C(7)	1.420(7)
C(7)-C(8)	1.358(7)
C(7)-H(7)	0.9500
C(8)-C(9)	1.400(7)
C(8)-H(8)	0.9500
C(9)-C(10)	1.459(7)
C(10)-C(26)	1.407(6)
C(11)-C(24)	1.423(7)
C(11)-C(12)	1.460(7)
C(12)-C(17)	1.392(7)
C(12)-C(13)	1.402(7)
C(13)-C(14)	1.378(7)
C(13)-H(13)	0.9500
C(14)-C(15)	1.379(7)
C(14)-H(14)	0.9500
C(15)-C(16)	1.373(7)
C(15)-H(15)	0.9500

C(16)-C(17)	1.416(7)
C(16)-H(16)	0.9500
C(17)-C(18)	1.462(7)
C(18)-C(19)	1.400(7)
C(18)-C(23)	1.422(7)
C(19)-C(20)	1.373(7)
C(19)-H(19)	0.9500
C(20)-C(21)	1.401(7)
C(20)-H(20)	0.9500
C(21)-C(22)	1.366(7)
C(21)-H(21)	0.9500
C(22)-C(23)	1.408(7)
C(22)-H(22)	0.9500
C(23)-C(24)	1.468(7)
C(24)-C(25)	1.438(7)
C(25)-C(26)	1.395(7)
C(25)-C(27)	1.495(7)
C(27)-C(28)	1.379(7)
C(27)-C(32)	1.384(7)
C(28)-C(29)	1.384(7)
C(28)-H(28)	0.9500
C(29)-C(30)	1.370(8)
C(29)-H(29)	0.9500
C(30)-C(31)	1.371(7)
C(30)-H(30)	0.9500
C(31)-C(32)	1.387(7)
C(31)-H(31)	0.9500
C(32)-H(32)	0.9500
C(33)-C(38)	1.380(7)
C(33)-C(34)	1.382(7)
C(33)-C(47)	1.447(8)
C(34)-C(35)	1.380(7)
C(34)-H(34)	0.9500
C(35)-C(36)	1.371(8)
C(35)-H(35)	0.9500
C(36)-C(37)	1.368(8)
C(36)-H(36)	0.9500

C(37)-C(38)	1.372(8)
C(37)-H(37)	0.9500
C(38)-H(38)	0.9500
C(39)-C(44)	1.378(7)
C(39)-C(40)	1.381(7)
C(39)-C(45)	1.437(7)
C(40)-C(41)	1.385(7)
C(40)-H(40)	0.9500
C(41)-C(42)	1.370(8)
C(41)-H(41)	0.9500
C(42)-C(43)	1.374(7)
C(42)-H(42)	0.9500
C(43)-C(44)	1.378(7)
C(43)-H(43)	0.9500
C(44)-H(44)	0.9500
C(45)-C(46)	1.202(7)
C(47)-C(48)	1.198(7)
C(1S)-Cl(1S)	1.687(6)
C(1S)-Cl(2S)	1.759(7)
C(1S)-H(1S1)	0.9900
C(1S)-H(1S2)	0.9900

C(48)-B(1)-C(46)	114.1(5)
C(48)-B(1)-C(26)	115.0(4)
C(46)-B(1)-C(26)	114.7(5)
C(48)-B(1)-N(1)	110.2(4)
C(46)-B(1)-N(1)	103.5(4)
C(26)-B(1)-N(1)	97.2(4)
C(9)-N(1)-C(1)	120.8(4)
C(9)-N(1)-B(1)	111.7(4)
C(1)-N(1)-B(1)	127.3(5)
C(10)-N(2)-C(11)	115.9(5)
N(1)-C(1)-C(2)	120.5(5)
N(1)-C(1)-C(6)	118.9(5)
C(2)-C(1)-C(6)	120.5(5)
C(3)-C(2)-C(1)	119.2(5)
C(3)-C(2)-H(2)	120.4

C(1)-C(2)-H(2)	120.4
C(2)-C(3)-C(4)	121.0(6)
C(2)-C(3)-H(3)	119.5
C(4)-C(3)-H(3)	119.5
C(5)-C(4)-C(3)	121.2(6)
C(5)-C(4)-H(4)	119.4
C(3)-C(4)-H(4)	119.4
C(4)-C(5)-C(6)	119.7(5)
C(4)-C(5)-H(5)	120.2
C(6)-C(5)-H(5)	120.2
C(5)-C(6)-C(7)	122.9(5)
C(5)-C(6)-C(1)	118.4(5)
C(7)-C(6)-C(1)	118.7(5)
C(8)-C(7)-C(6)	120.9(5)
C(8)-C(7)-H(7)	119.6
C(6)-C(7)-H(7)	119.6
C(7)-C(8)-C(9)	118.2(5)
C(7)-C(8)-H(8)	120.9
C(9)-C(8)-H(8)	120.9
N(1)-C(9)-C(8)	122.5(5)
N(1)-C(9)-C(10)	110.3(5)
C(8)-C(9)-C(10)	127.2(5)
N(2)-C(10)-C(26)	126.6(5)
N(2)-C(10)-C(9)	121.6(5)
C(26)-C(10)-C(9)	111.6(5)
N(2)-C(11)-C(24)	123.7(5)
N(2)-C(11)-C(12)	115.5(5)
C(24)-C(11)-C(12)	120.7(5)
C(17)-C(12)-C(13)	120.4(5)
C(17)-C(12)-C(11)	120.6(5)
C(13)-C(12)-C(11)	118.9(5)
C(14)-C(13)-C(12)	120.5(6)
C(14)-C(13)-H(13)	119.7
C(12)-C(13)-H(13)	119.7
C(13)-C(14)-C(15)	119.6(6)
C(13)-C(14)-H(14)	120.2
C(15)-C(14)-H(14)	120.2

C(16)-C(15)-C(14)	120.7(6)
C(16)-C(15)-H(15)	119.6
C(14)-C(15)-H(15)	119.6
C(15)-C(16)-C(17)	121.0(6)
C(15)-C(16)-H(16)	119.5
C(17)-C(16)-H(16)	119.5
C(12)-C(17)-C(16)	117.7(5)
C(12)-C(17)-C(18)	119.6(5)
C(16)-C(17)-C(18)	122.6(5)
C(19)-C(18)-C(23)	119.2(5)
C(19)-C(18)-C(17)	120.7(5)
C(23)-C(18)-C(17)	119.9(5)
C(20)-C(19)-C(18)	122.0(6)
C(20)-C(19)-H(19)	119.0
C(18)-C(19)-H(19)	119.0
C(19)-C(20)-C(21)	118.9(6)
C(19)-C(20)-H(20)	120.5
C(21)-C(20)-H(20)	120.5
C(22)-C(21)-C(20)	120.0(6)
C(22)-C(21)-H(21)	120.0
C(20)-C(21)-H(21)	120.0
C(21)-C(22)-C(23)	122.6(6)
C(21)-C(22)-H(22)	118.7
C(23)-C(22)-H(22)	118.7
C(22)-C(23)-C(18)	117.1(5)
C(22)-C(23)-C(24)	122.3(5)
C(18)-C(23)-C(24)	120.5(5)
C(11)-C(24)-C(25)	117.9(5)
C(11)-C(24)-C(23)	117.8(5)
C(25)-C(24)-C(23)	124.3(5)
C(26)-C(25)-C(24)	118.0(5)
C(26)-C(25)-C(27)	115.8(5)
C(24)-C(25)-C(27)	125.9(5)
C(25)-C(26)-C(10)	117.3(5)
C(25)-C(26)-B(1)	133.4(5)
C(10)-C(26)-B(1)	109.0(5)
C(28)-C(27)-C(32)	120.0(5)

C(28)-C(27)-C(25)	118.9(5)
C(32)-C(27)-C(25)	120.7(5)
C(27)-C(28)-C(29)	120.2(6)
C(27)-C(28)-H(28)	119.9
C(29)-C(28)-H(28)	119.9
C(30)-C(29)-C(28)	119.5(6)
C(30)-C(29)-H(29)	120.3
C(28)-C(29)-H(29)	120.3
C(29)-C(30)-C(31)	120.8(6)
C(29)-C(30)-H(30)	119.6
C(31)-C(30)-H(30)	119.6
C(30)-C(31)-C(32)	120.1(6)
C(30)-C(31)-H(31)	120.0
C(32)-C(31)-H(31)	120.0
C(27)-C(32)-C(31)	119.4(5)
C(27)-C(32)-H(32)	120.3
C(31)-C(32)-H(32)	120.3
C(38)-C(33)-C(34)	118.5(5)
C(38)-C(33)-C(47)	121.4(5)
C(34)-C(33)-C(47)	120.1(5)
C(35)-C(34)-C(33)	120.6(6)
C(35)-C(34)-H(34)	119.7
C(33)-C(34)-H(34)	119.7
C(36)-C(35)-C(34)	120.2(6)
C(36)-C(35)-H(35)	119.9
C(34)-C(35)-H(35)	119.9
C(37)-C(36)-C(35)	119.3(6)
C(37)-C(36)-H(36)	120.3
C(35)-C(36)-H(36)	120.3
C(36)-C(37)-C(38)	120.8(6)
C(36)-C(37)-H(37)	119.6
C(38)-C(37)-H(37)	119.6
C(37)-C(38)-C(33)	120.5(6)
C(37)-C(38)-H(38)	119.8
C(33)-C(38)-H(38)	119.8
C(44)-C(39)-C(40)	117.8(5)
C(44)-C(39)-C(45)	120.4(5)

C(40)-C(39)-C(45)	121.7(5)
C(39)-C(40)-C(41)	120.9(6)
C(39)-C(40)-H(40)	119.5
C(41)-C(40)-H(40)	119.5
C(42)-C(41)-C(40)	120.5(6)
C(42)-C(41)-H(41)	119.7
C(40)-C(41)-H(41)	119.7
C(41)-C(42)-C(43)	118.9(6)
C(41)-C(42)-H(42)	120.5
C(43)-C(42)-H(42)	120.5
C(42)-C(43)-C(44)	120.5(6)
C(42)-C(43)-H(43)	119.8
C(44)-C(43)-H(43)	119.8
C(43)-C(44)-C(39)	121.3(6)
C(43)-C(44)-H(44)	119.3
C(39)-C(44)-H(44)	119.3
C(46)-C(45)-C(39)	176.0(6)
C(45)-C(46)-B(1)	170.9(5)
C(48)-C(47)-C(33)	178.9(6)
C(47)-C(48)-B(1)	177.2(6)
Cl(1S)-C(1S)-Cl(2S)	114.4(4)
Cl(1S)-C(1S)-H(1S1)	108.7
Cl(2S)-C(1S)-H(1S1)	108.7
Cl(1S)-C(1S)-H(1S2)	108.7
Cl(2S)-C(1S)-H(1S2)	108.7
H(1S1)-C(1S)-H(1S2)	107.6

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for ohj322_0m_a. The anisotropic
displacement factor exponent takes the form: $-2p^2[\ h^2\ a^{*2}U^{11} + ... + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
B(1)	17(4)	28(4)	29(4)	5(3)	2(3)	7(3)
N(1)	14(2)	34(3)	27(3)	5(2)	5(2)	-4(2)
N(2)	21(3)	28(3)	32(3)	0(2)	10(2)	0(2)
C(1)	15(3)	39(4)	21(4)	7(3)	4(3)	-6(3)
C(2)	29(4)	39(4)	31(4)	-2(3)	10(3)	-4(3)
C(3)	27(4)	47(4)	32(4)	-5(3)	5(3)	-5(3)
C(4)	33(4)	58(5)	29(4)	1(3)	12(3)	-18(3)
C(5)	22(3)	57(5)	31(4)	12(3)	3(3)	-6(3)
C(6)	21(3)	37(4)	28(4)	9(3)	11(3)	-4(3)
C(7)	20(3)	38(4)	38(4)	14(3)	10(3)	2(3)
C(8)	17(3)	32(4)	31(4)	5(3)	8(3)	5(3)
C(9)	24(3)	28(4)	26(4)	1(3)	11(3)	-2(3)
C(10)	21(3)	22(4)	28(4)	4(3)	10(3)	-3(3)
C(11)	20(3)	30(4)	29(4)	3(3)	12(3)	-4(3)
C(12)	17(3)	30(4)	36(4)	-2(3)	15(3)	-4(3)
C(13)	32(4)	33(4)	38(4)	-2(3)	16(3)	-8(3)
C(14)	39(4)	27(4)	54(5)	1(3)	25(4)	3(3)
C(15)	45(4)	33(4)	56(5)	-12(3)	22(4)	-9(3)
C(16)	39(4)	39(4)	43(4)	-11(3)	18(3)	-11(3)
C(17)	23(3)	30(4)	39(4)	-2(3)	13(3)	-12(3)
C(18)	17(3)	40(4)	29(4)	-10(3)	9(3)	-12(3)
C(19)	26(4)	49(4)	37(4)	-7(3)	11(3)	-11(3)
C(20)	22(4)	67(5)	31(4)	-6(4)	7(3)	-11(3)
C(21)	26(4)	57(5)	34(4)	5(3)	10(3)	-2(3)
C(22)	24(3)	47(4)	31(4)	-2(3)	8(3)	-4(3)
C(23)	18(3)	41(4)	29(4)	-1(3)	10(3)	-9(3)
C(24)	17(3)	30(4)	25(3)	1(3)	6(3)	-10(3)
C(25)	21(3)	27(4)	28(4)	3(3)	10(3)	-1(3)
C(26)	15(3)	23(3)	31(4)	3(3)	11(3)	-2(3)

C(27)	16(3)	30(4)	29(4)	4(3)	3(3)	1(3)
C(28)	22(3)	40(4)	40(4)	7(3)	3(3)	4(3)
C(29)	29(4)	65(5)	32(4)	14(3)	8(3)	3(4)
C(30)	33(4)	71(6)	34(4)	8(3)	9(3)	22(4)
C(31)	45(4)	36(4)	37(4)	3(3)	5(3)	8(3)
C(32)	24(3)	36(4)	39(4)	2(3)	5(3)	4(3)
C(33)	20(3)	33(4)	38(4)	1(3)	11(3)	0(3)
C(34)	30(4)	49(4)	29(4)	-4(3)	11(3)	-6(3)
C(35)	20(4)	66(5)	41(4)	4(4)	8(3)	-7(3)
C(36)	37(4)	47(5)	67(5)	10(4)	29(4)	7(4)
C(37)	61(5)	49(5)	87(6)	-33(4)	42(5)	-13(4)
C(38)	34(4)	55(5)	80(6)	-32(4)	29(4)	-15(3)
C(39)	25(3)	25(4)	32(4)	-2(3)	5(3)	-4(3)
C(40)	52(4)	47(5)	64(5)	-19(4)	31(4)	-20(4)
C(41)	58(5)	62(5)	72(5)	-25(4)	43(4)	-30(4)
C(42)	39(4)	36(4)	51(5)	-4(3)	10(4)	-15(3)
C(43)	39(4)	48(4)	46(4)	-13(3)	16(4)	-10(3)
C(44)	34(4)	44(4)	42(4)	-7(3)	21(3)	-14(3)
C(45)	19(3)	35(4)	29(4)	-4(3)	5(3)	4(3)
C(46)	24(3)	26(4)	24(3)	-3(3)	4(3)	5(3)
C(47)	26(3)	21(4)	41(4)	4(3)	8(3)	2(3)
C(48)	21(3)	26(4)	35(4)	-2(3)	2(3)	-1(3)
C(1S)	84(6)	57(5)	83(6)	8(4)	-3(5)	-23(4)
Cl(1S)	118(2)	67(2)	113(2)	4(1)	-3(2)	-14(1)
Cl(2S)	67(1)	83(2)	76(2)	0(1)	24(1)	1(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters (Å^{2}x 10^3) for ohj322_0m_a.

	x	y	z	U(eq)
H(2)	4545	3598	3991	39
H(3)	3330	3388	2088	43
H(4)	1690	3844	955	47
H(5)	1274	4523	1689	45
H(7)	1771	5078	3415	38
H(8)	2899	5257	5380	32
H(13)	4188	5829	8025	40
H(14)	4206	6501	9023	45
H(15)	5649	6612	10917	52
H(16)	7047	6055	11834	47
H(19)	8085	5528	12668	45
H(20)	9295	4935	13647	48
H(21)	9198	4252	12621	46
H(22)	8009	4192	10634	41
H(28)	9062	4532	8675	42
H(29)	10669	4017	8690	50
H(30)	10205	3265	8592	55
H(31)	8189	3018	8571	49
H(32)	6564	3530	8539	40
H(34)	9746	4192	5991	43
H(35)	11563	4021	5406	51
H(36)	11477	3481	3944	56
H(37)	9569	3116	3072	74
H(38)	7745	3290	3622	65
H(40)	2190	3171	7563	62
H(41)	680	2610	7360	71
H(42)	583	2034	5993	51
H(43)	2077	2008	4896	52
H(44)	3593	2563	5109	46

H(1S1)	5994	2190	1015	96
H(1S2)	7156	2008	562	96

X-ray crystal structure data for 4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-5-(difluoroboranyl)-3-methyl-6-(quinolin-2-yl)picolinonitrile 128

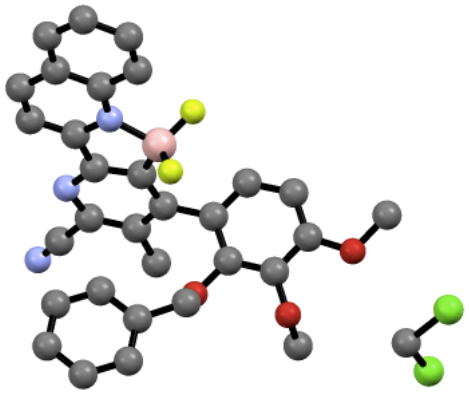

Table 1. Crystal data and structure refinement for OHJ301_0m_a.

Identification code	OHJ301_0m_a	
Empirical formula	C32 H26 B Cl2 F2 N3 O3	
Formula weight	620.27	
Temperature	100(2) K	
Wavelength	1.54178 Å	
Crystal system	Monoclinic	
Space group	C2/c	
Unit cell dimensions	a = 35.8163(17) Å	a= 90°.
	b = 11.1019(5) Å	b= 112.663(3)°.
	c = 15.9945(7) Å	g = 90°.
Volume	5868.8(5) $Å^3$	
Z	8	
Density (calculated)	1.404 Mg/m^3	
Absorption coefficient	2.432 mm^{-1}	
F(000)	2560	
Crystal size	0.180 x 0.110 x 0.020 mm^3	
Theta range for data collection	2.674 to 66.852°.	
Index ranges	-42<=h<=42, -13<=k<=13, -19<=l<=18	
Reflections collected	45929	
Independent reflections	5154 [R(int) = 0.1521]	
Completeness to theta = 66.500°	99.4 %	

Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.97 and 0.72
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	5154 / 0 / 391
Goodness-of-fit on F^2	1.011
Final R indices [I>2sigma(I)]	R1 = 0.0629, wR2 = 0.1225
R indices (all data)	R1 = 0.1480, wR2 = 0.1543
Extinction coefficient	n/a
Largest diff. peak and hole	0.441 and -0.530 e.$Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3)
for OHJ301_0m_a. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
B(1)	6934(1)	4373(4)	5429(3)	27(1)
O(1)	5748(1)	2670(2)	3384(2)	26(1)
O(2)	5163(1)	2411(2)	4118(2)	32(1)
O(3)	5371(1)	1755(2)	5845(2)	34(1)
N(1)	7329(1)	4984(3)	5302(2)	24(1)
N(2)	7149(1)	2748(3)	3597(2)	25(1)
N(3)	6882(1)	520(3)	2027(2)	42(1)
F(1)	7042(1)	4065(2)	6328(1)	33(1)
F(2)	6630(1)	5238(2)	5174(1)	32(1)
C(1)	7552(1)	5951(3)	5760(2)	26(1)
C(2)	7471(1)	6503(3)	6468(3)	32(1)
C(3)	7707(1)	7439(4)	6936(3)	37(1)
C(4)	8025(1)	7874(4)	6704(3)	42(1)
C(5)	8105(1)	7369(4)	6012(3)	40(1)
C(6)	7870(1)	6381(3)	5519(3)	30(1)
C(7)	7940(1)	5815(4)	4805(3)	32(1)
C(8)	7711(1)	4851(3)	4370(3)	28(1)
C(9)	7408(1)	4447(3)	4636(2)	23(1)
C(10)	7129(1)	3417(3)	4274(2)	24(1)
C(11)	6870(1)	1859(3)	3346(2)	26(1)
C(12)	6584(1)	1607(3)	3714(2)	25(1)
C(13)	6578(1)	2368(3)	4417(2)	23(1)
C(14)	6860(1)	3294(3)	4708(2)	21(1)
C(15)	6268(1)	2202(3)	4815(2)	24(1)
C(16)	6377(1)	1906(3)	5721(2)	26(1)
C(17)	6090(1)	1744(3)	6092(3)	28(1)
C(18)	5682(1)	1882(3)	5559(3)	27(1)
C(19)	5566(1)	2199(3)	4643(3)	24(1)

C(20)	5857(1)	2351(3)	4286(2)	24(1)
C(21)	5651(2)	3924(4)	3213(3)	72(2)
C(22)	5736(1)	4346(4)	2415(3)	35(1)
C(23)	6125(1)	4289(4)	2428(3)	38(1)
C(24)	6215(1)	4709(4)	1722(3)	35(1)
C(25)	5913(1)	5210(3)	980(3)	31(1)
C(26)	5525(1)	5279(4)	948(3)	34(1)
C(27)	5435(1)	4839(4)	1661(3)	37(1)
C(28)	4947(1)	1346(4)	3693(3)	43(1)
C(29)	5482(1)	1667(4)	6808(3)	42(1)
C(30)	6883(1)	1117(4)	2597(3)	28(1)
C(31)	6290(1)	587(3)	3345(3)	32(1)
C(1S)	4388(1)	2430(4)	5036(3)	49(1)
Cl(1)	4150(1)	1045(1)	4779(1)	93(1)
Cl(2)	4401(1)	3009(1)	6075(1)	65(1)

Table 3. Bond lengths [Å] and angles [°] for OHJ301_0m_a.

B(1)-F(1)	1.381(5)
B(1)-F(2)	1.390(5)
B(1)-C(14)	1.612(6)
B(1)-N(1)	1.653(5)
O(1)-C(20)	1.389(4)
O(1)-C(21)	1.435(5)
O(2)-C(19)	1.381(4)
O(2)-C(28)	1.433(5)
O(3)-C(18)	1.367(4)
O(3)-C(29)	1.438(4)
N(1)-C(9)	1.342(4)
N(1)-C(1)	1.370(5)
N(2)-C(10)	1.338(4)
N(2)-C(11)	1.351(5)
N(3)-C(30)	1.126(5)
C(1)-C(2)	1.414(5)
C(1)-C(6)	1.417(5)
C(2)-C(3)	1.368(5)
C(2)-H(2)	0.9500
C(3)-C(4)	1.411(6)
C(3)-H(3)	0.9500
C(4)-C(5)	1.365(6)
C(4)-H(4)	0.9500
C(5)-C(6)	1.422(5)
C(5)-H(5)	0.9500
C(6)-C(7)	1.408(5)
C(7)-C(8)	1.365(5)
C(7)-H(7)	0.9500
C(8)-C(9)	1.383(5)
C(8)-H(8)	0.9500
C(9)-C(10)	1.484(5)
C(10)-C(14)	1.393(5)
C(11)-C(12)	1.393(5)
C(11)-C(30)	1.469(5)
C(12)-C(13)	1.413(5)

C(12)-C(31)	1.504(5)
C(13)-C(14)	1.390(5)
C(13)-C(15)	1.490(5)
C(15)-C(16)	1.388(5)
C(15)-C(20)	1.396(5)
C(16)-C(17)	1.382(5)
C(16)-H(16)	0.9500
C(17)-C(18)	1.386(5)
C(17)-H(17)	0.9500
C(18)-C(19)	1.406(5)
C(19)-C(20)	1.378(5)
C(21)-C(22)	1.499(5)
C(21)-H(21A)	0.9900
C(21)-H(21B)	0.9900
C(22)-C(27)	1.383(5)
C(22)-C(23)	1.387(5)
C(23)-C(24)	1.369(5)
C(23)-H(23)	0.9500
C(24)-C(25)	1.377(5)
C(24)-H(24)	0.9500
C(25)-C(26)	1.374(5)
C(25)-H(25)	0.9500
C(26)-C(27)	1.388(5)
C(26)-H(26)	0.9500
C(27)-H(27)	0.9500
C(28)-H(28A)	0.9800
C(28)-H(28B)	0.9800
C(28)-H(28C)	0.9800
C(29)-H(29A)	0.9800
C(29)-H(29B)	0.9800
C(29)-H(29C)	0.9800
C(31)-H(31A)	0.9800
C(31)-H(31B)	0.9800
C(31)-H(31C)	0.9800
C(1S)-Cl(1)	1.729(4)
C(1S)-Cl(2)	1.768(5)
C(1S)-H(1S1)	0.9900

C(1S)-H(1S2)	0.9900
F(1)-B(1)-F(2)	110.5(3)
F(1)-B(1)-C(14)	117.6(3)
F(2)-B(1)-C(14)	114.2(3)
F(1)-B(1)-N(1)	108.7(3)
F(2)-B(1)-N(1)	107.0(3)
C(14)-B(1)-N(1)	97.4(3)
C(20)-O(1)-C(21)	113.3(3)
C(19)-O(2)-C(28)	113.2(3)
C(18)-O(3)-C(29)	116.0(3)
C(9)-N(1)-C(1)	121.0(3)
C(9)-N(1)-B(1)	111.6(3)
C(1)-N(1)-B(1)	127.3(3)
C(10)-N(2)-C(11)	112.4(3)
N(1)-C(1)-C(2)	120.7(4)
N(1)-C(1)-C(6)	118.8(3)
C(2)-C(1)-C(6)	120.5(4)
C(3)-C(2)-C(1)	119.4(4)
C(3)-C(2)-H(2)	120.3
C(1)-C(2)-H(2)	120.3
C(2)-C(3)-C(4)	120.6(4)
C(2)-C(3)-H(3)	119.7
C(4)-C(3)-H(3)	119.7
C(5)-C(4)-C(3)	121.0(4)
C(5)-C(4)-H(4)	119.5
C(3)-C(4)-H(4)	119.5
C(4)-C(5)-C(6)	120.2(4)
C(4)-C(5)-H(5)	119.9
C(6)-C(5)-H(5)	119.9
C(7)-C(6)-C(1)	118.8(4)
C(7)-C(6)-C(5)	122.9(4)
C(1)-C(6)-C(5)	118.3(4)
C(8)-C(7)-C(6)	120.2(4)
C(8)-C(7)-H(7)	119.9
C(6)-C(7)-H(7)	119.9
C(7)-C(8)-C(9)	119.1(4)

C(7)-C(8)-H(8)	120.5
C(9)-C(8)-H(8)	120.5
N(1)-C(9)-C(8)	122.0(4)
N(1)-C(9)-C(10)	109.6(3)
C(8)-C(9)-C(10)	128.4(3)
N(2)-C(10)-C(14)	127.8(4)
N(2)-C(10)-C(9)	120.3(3)
C(14)-C(10)-C(9)	111.9(3)
N(2)-C(11)-C(12)	127.0(3)
N(2)-C(11)-C(30)	113.6(3)
C(12)-C(11)-C(30)	119.4(4)
C(11)-C(12)-C(13)	117.1(4)
C(11)-C(12)-C(31)	120.3(3)
C(13)-C(12)-C(31)	122.6(3)
C(14)-C(13)-C(12)	118.5(3)
C(14)-C(13)-C(15)	120.9(3)
C(12)-C(13)-C(15)	120.6(3)
C(13)-C(14)-C(10)	117.2(3)
C(13)-C(14)-B(1)	133.4(3)
C(10)-C(14)-B(1)	109.3(3)
C(16)-C(15)-C(20)	117.8(3)
C(16)-C(15)-C(13)	121.4(4)
C(20)-C(15)-C(13)	120.8(3)
C(17)-C(16)-C(15)	121.6(4)
C(17)-C(16)-H(16)	119.2
C(15)-C(16)-H(16)	119.2
C(16)-C(17)-C(18)	120.2(4)
C(16)-C(17)-H(17)	119.9
C(18)-C(17)-H(17)	119.9
O(3)-C(18)-C(17)	125.8(3)
O(3)-C(18)-C(19)	115.0(4)
C(17)-C(18)-C(19)	119.2(4)
C(20)-C(19)-O(2)	120.5(3)
C(20)-C(19)-C(18)	119.6(4)
O(2)-C(19)-C(18)	119.8(3)
C(19)-C(20)-O(1)	120.4(3)
C(19)-C(20)-C(15)	121.6(3)

O(1)-C(20)-C(15)	117.9(3)
O(1)-C(21)-C(22)	110.5(4)
O(1)-C(21)-H(21A)	109.6
C(22)-C(21)-H(21A)	109.6
O(1)-C(21)-H(21B)	109.6
C(22)-C(21)-H(21B)	109.6
H(21A)-C(21)-H(21B)	108.1
C(27)-C(22)-C(23)	118.2(4)
C(27)-C(22)-C(21)	121.3(4)
C(23)-C(22)-C(21)	120.5(4)
C(24)-C(23)-C(22)	121.7(4)
C(24)-C(23)-H(23)	119.2
C(22)-C(23)-H(23)	119.2
C(23)-C(24)-C(25)	119.5(4)
C(23)-C(24)-H(24)	120.2
C(25)-C(24)-H(24)	120.2
C(26)-C(25)-C(24)	120.1(4)
C(26)-C(25)-H(25)	119.9
C(24)-C(25)-H(25)	119.9
C(25)-C(26)-C(27)	120.1(4)
C(25)-C(26)-H(26)	120.0
C(27)-C(26)-H(26)	120.0
C(22)-C(27)-C(26)	120.4(4)
C(22)-C(27)-H(27)	119.8
C(26)-C(27)-H(27)	119.8
O(2)-C(28)-H(28A)	109.5
O(2)-C(28)-H(28B)	109.5
H(28A)-C(28)-H(28B)	109.5
O(2)-C(28)-H(28C)	109.5
H(28A)-C(28)-H(28C)	109.5
H(28B)-C(28)-H(28C)	109.5
O(3)-C(29)-H(29A)	109.5
O(3)-C(29)-H(29B)	109.5
H(29A)-C(29)-H(29B)	109.5
O(3)-C(29)-H(29C)	109.5
H(29A)-C(29)-H(29C)	109.5
H(29B)-C(29)-H(29C)	109.5

N(3)-C(30)-C(11)	177.4(5)
C(12)-C(31)-H(31A)	109.5
C(12)-C(31)-H(31B)	109.5
H(31A)-C(31)-H(31B)	109.5
C(12)-C(31)-H(31C)	109.5
H(31A)-C(31)-H(31C)	109.5
H(31B)-C(31)-H(31C)	109.5
Cl(1)-C(1S)-Cl(2)	112.2(3)
Cl(1)-C(1S)-H(1S1)	109.2
Cl(2)-C(1S)-H(1S1)	109.2
Cl(1)-C(1S)-H(1S2)	109.2
Cl(2)-C(1S)-H(1S2)	109.2
H(1S1)-C(1S)-H(1S2)	107.9

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for OHJ301_0m_a. The anisotropic
displacement factor exponent takes the form: $-2p^2[\ h^2\ a^{*2}U^{11} + ... + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
B(1)	30(3)	24(3)	27(3)	1(2)	11(2)	0(2)
O(1)	28(2)	22(2)	29(2)	5(1)	12(1)	3(1)
O(2)	26(2)	28(2)	39(2)	5(1)	11(1)	1(1)
O(3)	33(2)	40(2)	37(2)	8(1)	20(1)	0(1)
N(1)	26(2)	18(2)	28(2)	3(2)	8(2)	-1(2)
N(2)	27(2)	22(2)	27(2)	-1(2)	10(2)	1(2)
N(3)	39(2)	42(2)	47(2)	-6(2)	19(2)	-1(2)
F(1)	45(2)	27(1)	28(1)	-1(1)	14(1)	-5(1)
F(2)	35(1)	23(1)	41(1)	-4(1)	17(1)	4(1)
C(1)	25(2)	14(2)	32(2)	4(2)	4(2)	1(2)
C(2)	39(3)	21(2)	34(2)	0(2)	11(2)	0(2)
C(3)	41(3)	24(2)	39(2)	-3(2)	7(2)	-1(2)
C(4)	43(3)	20(3)	47(3)	-5(2)	1(2)	-3(2)
C(5)	34(3)	24(3)	52(3)	8(2)	5(2)	-5(2)
C(6)	27(2)	22(2)	35(2)	4(2)	5(2)	1(2)
C(7)	25(2)	30(3)	38(2)	9(2)	10(2)	-2(2)
C(8)	28(2)	24(2)	33(2)	2(2)	14(2)	1(2)
C(9)	25(2)	19(2)	29(2)	3(2)	14(2)	1(2)
C(10)	26(2)	16(2)	26(2)	5(2)	6(2)	3(2)
C(11)	27(2)	22(2)	26(2)	-2(2)	7(2)	7(2)
C(12)	24(2)	20(2)	30(2)	2(2)	9(2)	3(2)
C(13)	24(2)	18(2)	24(2)	3(2)	6(2)	4(2)
C(14)	22(2)	17(2)	23(2)	4(2)	6(2)	3(2)
C(15)	27(2)	17(2)	31(2)	-1(2)	16(2)	-2(2)
C(16)	26(2)	22(2)	29(2)	1(2)	10(2)	2(2)
C(17)	36(3)	18(2)	30(2)	1(2)	12(2)	3(2)
C(18)	33(3)	19(2)	37(2)	2(2)	21(2)	0(2)
C(19)	25(2)	17(2)	32(2)	2(2)	11(2)	1(2)
C(20)	32(2)	15(2)	25(2)	2(2)	11(2)	0(2)

C(21)	117(5)	53(4)	82(4)	44(3)	78(4)	51(3)
C(22)	51(3)	25(2)	38(2)	7(2)	26(2)	10(2)
C(23)	42(3)	37(3)	33(2)	7(2)	13(2)	12(2)
C(24)	31(3)	31(3)	42(3)	6(2)	14(2)	3(2)
C(25)	40(3)	20(2)	34(2)	3(2)	16(2)	-4(2)
C(26)	36(3)	29(3)	32(2)	7(2)	7(2)	-1(2)
C(27)	33(3)	27(3)	55(3)	10(2)	22(2)	3(2)
C(28)	39(3)	47(3)	38(3)	-3(2)	10(2)	-12(2)
C(29)	43(3)	55(3)	35(2)	14(2)	22(2)	7(2)
C(30)	24(2)	26(2)	39(2)	0(2)	15(2)	2(2)
C(31)	32(2)	24(2)	39(2)	-8(2)	13(2)	-4(2)
C(1S)	54(3)	36(3)	55(3)	-1(2)	19(3)	-11(3)
Cl(1)	117(1)	48(1)	145(2)	-33(1)	86(1)	-38(1)
Cl(2)	80(1)	59(1)	59(1)	-2(1)	31(1)	10(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters (Å^{2}x 10^{-3}) for OHJ301_0m_a.

	x	y	z	U(eq)
H(2)	7253	6226	6618	39
H(3)	7657	7800	7421	44
H(4)	8186	8528	7034	50
H(5)	8318	7678	5860	48
H(7)	8147	6105	4625	38
H(8)	7759	4463	3891	33
H(16)	6655	1813	6096	31
H(17)	6172	1537	6714	34
H(21A)	5813	4400	3755	86
H(21B)	5361	4051	3094	86
H(23)	6335	3950	2940	45
H(24)	6483	4656	1744	42
H(25)	5974	5507	490	37
H(26)	5318	5629	437	41
H(27)	5165	4876	1632	45
H(28A)	5084	962	3338	64
H(28B)	4671	1563	3292	64
H(28C)	4938	786	4158	64
H(29A)	5625	905	7027	63
H(29B)	5239	1693	6945	63
H(29C)	5660	2341	7108	63
H(31A)	6053	873	2829	48
H(31B)	6203	288	3819	48
H(31C)	6421	-66	3147	48
H(1S1)	4245	3006	4544	59
H(1S2)	4669	2347	5067	59

X-ray crystal structure data for ethyl 5-methyl-3-(quinolin-2-yl)-1,2,4-triazine-6-carboxylate 132

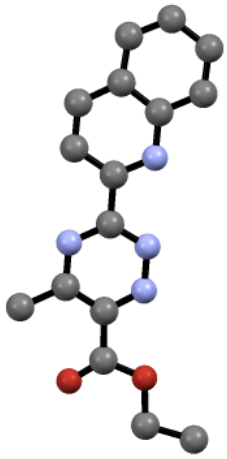

Table 1. Crystal data and structure refinement for OHJ348_0m.

Identification code	OHJ348_0m	
Empirical formula	C16 H14 N4 O2	
Formula weight	294.31	
Temperature	100(2) K	
Wavelength	1.54178 Å	
Crystal system	Triclinic	
Space group	P-1	
Unit cell dimensions	a = 7.6077(4) Å	a= 90.810(3)°.
	b = 8.2893(4) Å	b= 96.215(3)°.
	c = 11.5651(6) Å	g = 107.385(2)°.
Volume	691.08(6) $Å^3$	
Z	2	
Density (calculated)	1.414 Mg/m^3	
Absorption coefficient	0.795 mm^{-1}	
F(000)	308	
Crystal size	0.300 x 0.300 x 0.300 mm^3	
Theta range for data collection	3.849 to 66.889°.	
Index ranges	-9<=h<=9, -9<=k<=9, -13<=l<=13	
Reflections collected	11274	
Independent reflections	2413 [R(int) = 0.0943]	

Completeness to theta = 66.889°	98.6 %
Absorption correction	None
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	2413 / 0 / 201
Goodness-of-fit on F^2	1.021
Final R indices [I>2sigma(I)]	R1 = 0.0664, wR2 = 0.1719
R indices (all data)	R1 = 0.0883, wR2 = 0.1906
Extinction coefficient	n/a
Largest diff. peak and hole	0.389 and -0.447 e.$Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3)
for OHJ348_0m. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
N(1)	5104(3)	823(2)	1807(2)	24(1)
N(2)	4154(3)	1275(2)	899(2)	24(1)
N(3)	6991(3)	2803(2)	192(2)	22(1)
N(4)	2258(3)	2040(2)	-1033(2)	21(1)
O(1)	9508(2)	1449(2)	3341(2)	33(1)
O(2)	6728(2)	-392(2)	3536(1)	24(1)
C(1)	6956(3)	1328(3)	1918(2)	21(1)
C(2)	7943(3)	2326(3)	1078(2)	21(1)
C(3)	5130(3)	2255(3)	134(2)	20(1)
C(4)	4065(3)	2818(3)	-849(2)	19(1)
C(5)	4995(3)	4162(3)	-1517(2)	23(1)
C(6)	3984(3)	4722(3)	-2369(2)	24(1)
C(7)	2044(3)	3977(3)	-2583(2)	22(1)
C(8)	1236(3)	2604(3)	-1886(2)	19(1)
C(9)	-708(3)	1800(3)	-2070(2)	23(1)
C(10)	-1797(3)	2360(3)	-2880(2)	26(1)
C(11)	-995(4)	3743(3)	-3556(2)	28(1)
C(12)	871(3)	4514(3)	-3413(2)	26(1)
C(13)	10013(3)	2896(3)	1112(2)	28(1)
C(14)	7891(3)	815(3)	3000(2)	22(1)
C(15)	7563(3)	-891(3)	4612(2)	26(1)
C(16)	6051(4)	-2176(3)	5144(2)	33(1)

Table 3. Bond lengths [Å] and angles [°] for OHJ348_0m.

N(1)-N(2)	1.332(3)
N(1)-C(1)	1.336(3)
N(2)-C(3)	1.340(3)
N(3)-C(2)	1.323(3)
N(3)-C(3)	1.345(3)
N(4)-C(4)	1.324(3)
N(4)-C(8)	1.364(3)
O(1)-C(14)	1.203(3)
O(2)-C(14)	1.333(3)
O(2)-C(15)	1.456(3)
C(1)-C(2)	1.415(3)
C(1)-C(14)	1.502(3)
C(2)-C(13)	1.498(3)
C(3)-C(4)	1.486(3)
C(4)-C(5)	1.418(3)
C(5)-C(6)	1.356(3)
C(5)-H(5)	0.9500
C(6)-C(7)	1.412(3)
C(6)-H(6)	0.9500
C(7)-C(12)	1.407(3)
C(7)-C(8)	1.428(3)
C(8)-C(9)	1.420(3)
C(9)-C(10)	1.361(3)
C(9)-H(9)	0.9500
C(10)-C(11)	1.417(4)
C(10)-H(10)	0.9500
C(11)-C(12)	1.362(3)
C(11)-H(11)	0.9500
C(12)-H(12)	0.9500
C(13)-H(13A)	0.9800
C(13)-H(13B)	0.9800
C(13)-H(13C)	0.9800
C(15)-C(16)	1.509(3)
C(15)-H(15A)	0.9900
C(15)-H(15B)	0.9900

C(16)-H(16A)	0.9800
C(16)-H(16B)	0.9800
C(16)-H(16C)	0.9800

N(2)-N(1)-C(1)	119.9(2)
N(1)-N(2)-C(3)	117.4(2)
C(2)-N(3)-C(3)	117.3(2)
C(4)-N(4)-C(8)	118.0(2)
C(14)-O(2)-C(15)	114.41(18)
N(1)-C(1)-C(2)	121.2(2)
N(1)-C(1)-C(14)	115.6(2)
C(2)-C(1)-C(14)	123.1(2)
N(3)-C(2)-C(1)	118.5(2)
N(3)-C(2)-C(13)	116.8(2)
C(1)-C(2)-C(13)	124.7(2)
N(2)-C(3)-N(3)	125.6(2)
N(2)-C(3)-C(4)	117.2(2)
N(3)-C(3)-C(4)	117.2(2)
N(4)-C(4)-C(5)	123.4(2)
N(4)-C(4)-C(3)	117.0(2)
C(5)-C(4)-C(3)	119.6(2)
C(6)-C(5)-C(4)	118.7(2)
C(6)-C(5)-H(5)	120.6
C(4)-C(5)-H(5)	120.6
C(5)-C(6)-C(7)	120.4(2)
C(5)-C(6)-H(6)	119.8
C(7)-C(6)-H(6)	119.8
C(12)-C(7)-C(6)	124.6(2)
C(12)-C(7)-C(8)	118.6(2)
C(6)-C(7)-C(8)	116.8(2)
N(4)-C(8)-C(9)	118.3(2)
N(4)-C(8)-C(7)	122.5(2)
C(9)-C(8)-C(7)	119.2(2)
C(10)-C(9)-C(8)	120.5(2)
C(10)-C(9)-H(9)	119.8
C(8)-C(9)-H(9)	119.8
C(9)-C(10)-C(11)	120.2(2)

C(9)-C(10)-H(10)	119.9
C(11)-C(10)-H(10)	119.9
C(12)-C(11)-C(10)	120.5(2)
C(12)-C(11)-H(11)	119.7
C(10)-C(11)-H(11)	119.7
C(11)-C(12)-C(7)	121.0(2)
C(11)-C(12)-H(12)	119.5
C(7)-C(12)-H(12)	119.5
C(2)-C(13)-H(13A)	109.5
C(2)-C(13)-H(13B)	109.5
H(13A)-C(13)-H(13B)	109.5
C(2)-C(13)-H(13C)	109.5
H(13A)-C(13)-H(13C)	109.5
H(13B)-C(13)-H(13C)	109.5
O(1)-C(14)-O(2)	124.4(2)
O(1)-C(14)-C(1)	123.1(2)
O(2)-C(14)-C(1)	112.54(19)
O(2)-C(15)-C(16)	107.76(19)
O(2)-C(15)-H(15A)	110.2
C(16)-C(15)-H(15A)	110.2
O(2)-C(15)-H(15B)	110.2
C(16)-C(15)-H(15B)	110.2
H(15A)-C(15)-H(15B)	108.5
C(15)-C(16)-H(16A)	109.5
C(15)-C(16)-H(16B)	109.5
H(16A)-C(16)-H(16B)	109.5
C(15)-C(16)-H(16C)	109.5
H(16A)-C(16)-H(16C)	109.5
H(16B)-C(16)-H(16C)	109.5

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for OHJ348_0m. The anisotropic displacement factor exponent takes the form: $-2p^2[\ h^2\ a^{*2}U^{11} + ... + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
N(1)	17(1)	15(1)	36(1)	3(1)	-1(1)	1(1)
N(2)	17(1)	15(1)	36(1)	7(1)	2(1)	1(1)
N(3)	17(1)	15(1)	32(1)	0(1)	4(1)	2(1)
N(4)	18(1)	11(1)	32(1)	-1(1)	4(1)	1(1)
O(1)	20(1)	24(1)	46(1)	8(1)	-5(1)	-2(1)
O(2)	20(1)	19(1)	32(1)	6(1)	2(1)	3(1)
C(1)	18(1)	10(1)	33(1)	-1(1)	4(1)	1(1)
C(2)	17(1)	13(1)	32(1)	-3(1)	1(1)	3(1)
C(3)	20(1)	9(1)	31(1)	-2(1)	6(1)	0(1)
C(4)	15(1)	10(1)	31(1)	0(1)	6(1)	0(1)
C(5)	19(1)	12(1)	34(1)	-1(1)	7(1)	-2(1)
C(6)	24(1)	11(1)	32(1)	2(1)	8(1)	-1(1)
C(7)	25(1)	12(1)	29(1)	-2(1)	7(1)	3(1)
C(8)	17(1)	13(1)	27(1)	-1(1)	5(1)	3(1)
C(9)	19(1)	14(1)	33(1)	1(1)	4(1)	1(1)
C(10)	20(1)	22(1)	34(1)	-2(1)	2(1)	4(1)
C(11)	31(2)	23(1)	32(1)	1(1)	1(1)	12(1)
C(12)	30(2)	15(1)	32(1)	5(1)	5(1)	4(1)
C(13)	16(1)	29(1)	37(1)	6(1)	6(1)	1(1)
C(14)	14(1)	11(1)	38(1)	-2(1)	2(1)	1(1)
C(15)	20(1)	22(1)	32(1)	2(1)	-1(1)	4(1)
C(16)	28(2)	30(2)	38(2)	11(1)	2(1)	4(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters (Å^{2}x 10^3) for OHJ348_0m.

	x	y	z	U(eq)
H(5)	6301	4660	-1371	27
H(6)	4586	5622	-2825	28
H(9)	-1253	865	-1625	27
H(10)	-3098	1821	-2993	31
H(11)	-1765	4136	-4113	34
H(12)	1389	5429	-3881	31
H(13A)	10448	1909	1008	42
H(13B)	10573	3482	1865	42
H(13C)	10371	3667	485	42
H(15A)	8126	108	5156	31
H(15B)	8546	-1389	4446	31
H(16A)	5092	-1666	5311	49
H(16B)	6578	-2539	5869	49
H(16C)	5501	-3157	4598	49

X-ray crystal structure data for ethyl 5-methyl-3-(5,6,8-trimethoxyquinolin-2-yl)-1,2,4-triazine-6-carboxylate 142

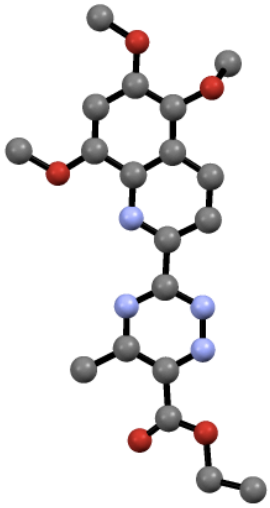

Table 1. Crystal data and structure refinement for ojh340_0m.

Identification code	ojh340_0m	
Empirical formula	C19 H20 N4 O5	
Formula weight	384.39	
Temperature	100(2) K	
Wavelength	1.54178 Å	
Crystal system	Triclinic	
Space group	P-1	
Unit cell dimensions	a = 7.4974(3) Å	a= 83.956(3)°.
	b = 7.7808(3) Å	b= 89.055(3)°.
	c = 15.4339(7) Å	g = 80.491(3)°.
Volume	883.04(6) $Å^3$	
Z	2	
Density (calculated)	1.446 Mg/m^3	
Absorption coefficient	0.891 mm^{-1}	
F(000)	404	
Crystal size	0.130 x 0.070 x 0.020 mm^3	
Theta range for data collection	5.765 to 66.631°.	
Index ranges	-8<=h<=8, -9<=k<=9, -18<=l<=18	
Reflections collected	11571	
Independent reflections	3081 [R(int) = 0.0390]	

Completeness to theta = 66.631°	98.8 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.7528 and 0.6836
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	3081 / 0 / 258
Goodness-of-fit on F^2	1.021
Final R indices [I>2sigma(I)]	R1 = 0.0441, wR2 = 0.1026
R indices (all data)	R1 = 0.0634, wR2 = 0.1121
Extinction coefficient	n/a
Largest diff. peak and hole	0.199 and -0.232 e.$Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3)
for ojh340_0m. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
O(1)	2108(2)	9978(2)	3040(1)	22(1)
O(2)	5194(2)	9910(2)	2053(1)	24(1)
O(3)	8644(2)	6468(2)	4444(1)	23(1)
O(4)	5616(2)	2934(3)	9777(1)	49(1)
O(5)	2627(2)	3262(2)	9563(1)	27(1)
N(1)	5667(2)	6702(2)	5448(1)	19(1)
N(2)	2810(2)	6075(2)	7299(1)	24(1)
N(3)	5946(2)	4991(2)	7118(1)	22(1)
N(4)	2830(2)	5241(2)	8098(1)	25(1)
C(1)	7105(2)	7406(2)	4081(1)	19(1)
C(2)	7002(2)	8219(2)	3246(1)	20(1)
C(3)	5339(3)	9141(2)	2894(1)	20(1)
C(4)	3788(2)	9237(2)	3388(1)	19(1)
C(5)	3879(2)	8476(2)	4261(1)	19(1)
C(6)	5532(2)	7517(2)	4623(1)	18(1)
C(7)	4198(2)	6829(2)	5932(1)	20(1)
C(8)	2505(2)	7805(2)	5644(1)	22(1)
C(9)	2358(2)	8610(2)	4817(1)	21(1)
C(10)	4341(2)	5902(2)	6834(1)	20(1)
C(11)	5996(3)	4221(2)	7927(1)	23(1)
C(12)	4382(3)	4331(2)	8416(1)	22(1)
C(13)	4300(3)	3440(3)	9327(1)	27(1)
C(14)	2469(3)	2307(3)	10418(1)	32(1)
C(15)	511(3)	2228(3)	10569(2)	40(1)
C(16)	7798(3)	3264(3)	8261(1)	32(1)
C(17)	10146(2)	6070(3)	3864(1)	22(1)
C(18)	6842(3)	10240(3)	1629(1)	25(1)
C(19)	1825(3)	11865(2)	2933(1)	25(1)

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Table 3. Bond lengths [Å] and angles [°] for ojh340_0m.

O(1)-C(4)	1.387(2)
O(1)-C(19)	1.441(2)
O(2)-C(3)	1.368(2)
O(2)-C(18)	1.437(2)
O(3)-C(1)	1.354(2)
O(3)-C(17)	1.441(2)
O(4)-C(13)	1.203(2)
O(5)-C(13)	1.325(2)
O(5)-C(14)	1.457(2)
N(1)-C(7)	1.317(2)
N(1)-C(6)	1.359(2)
N(2)-N(4)	1.331(2)
N(2)-C(10)	1.339(2)
N(3)-C(11)	1.326(2)
N(3)-C(10)	1.347(2)
N(4)-C(12)	1.330(2)
C(1)-C(2)	1.373(3)
C(1)-C(6)	1.430(3)
C(2)-C(3)	1.418(2)
C(2)-H(2)	0.9500
C(3)-C(4)	1.376(3)
C(4)-C(5)	1.413(3)
C(5)-C(9)	1.412(3)
C(5)-C(6)	1.426(2)
C(7)-C(8)	1.420(2)
C(7)-C(10)	1.496(3)
C(8)-C(9)	1.359(3)
C(8)-H(8)	0.9975
C(9)-H(9)	0.9500
C(11)-C(12)	1.411(3)
C(11)-C(16)	1.502(3)
C(12)-C(13)	1.506(3)
C(14)-C(15)	1.492(3)
C(14)-H(14A)	0.9900
C(14)-H(14B)	0.9900

C(15)-H(15A)	0.9800
C(15)-H(15B)	0.9800
C(15)-H(15C)	0.9800
C(16)-H(16A)	0.9800
C(16)-H(16B)	0.9800
C(16)-H(16C)	0.9800
C(17)-H(17A)	0.9800
C(17)-H(17B)	0.9800
C(17)-H(17C)	0.9800
C(18)-H(18A)	0.9800
C(18)-H(18B)	0.9800
C(18)-H(18C)	0.9800
C(19)-H(19A)	0.9800
C(19)-H(19B)	0.9800
C(19)-H(19C)	0.9800

C(4)-O(1)-C(19)	113.23(14)
C(3)-O(2)-C(18)	116.77(14)
C(1)-O(3)-C(17)	116.59(14)
C(13)-O(5)-C(14)	114.90(15)
C(7)-N(1)-C(6)	117.86(15)
N(4)-N(2)-C(10)	118.44(16)
C(11)-N(3)-C(10)	116.54(17)
C(12)-N(4)-N(2)	118.86(16)
O(3)-C(1)-C(2)	123.72(17)
O(3)-C(1)-C(6)	116.06(16)
C(2)-C(1)-C(6)	120.23(16)
C(1)-C(2)-C(3)	121.08(17)
C(1)-C(2)-H(2)	119.5
C(3)-C(2)-H(2)	119.5
O(2)-C(3)-C(4)	117.65(16)
O(2)-C(3)-C(2)	122.02(17)
C(4)-C(3)-C(2)	120.30(17)
C(3)-C(4)-O(1)	121.92(16)
C(3)-C(4)-C(5)	119.54(16)
O(1)-C(4)-C(5)	118.44(16)
C(4)-C(5)-C(9)	122.33(16)

C(4)-C(5)-C(6)	120.92(17)
C(9)-C(5)-C(6)	116.75(17)
N(1)-C(6)-C(5)	123.00(17)
N(1)-C(6)-C(1)	119.16(16)
C(5)-C(6)-C(1)	117.83(16)
N(1)-C(7)-C(8)	123.41(17)
N(1)-C(7)-C(10)	117.81(16)
C(8)-C(7)-C(10)	118.78(17)
C(9)-C(8)-C(7)	118.94(18)
C(9)-C(8)-H(8)	121.7
C(7)-C(8)-H(8)	119.3
C(8)-C(9)-C(5)	119.96(17)
C(8)-C(9)-H(9)	120.0
C(5)-C(9)-H(9)	120.0
N(2)-C(10)-N(3)	125.33(17)
N(2)-C(10)-C(7)	115.39(16)
N(3)-C(10)-C(7)	119.28(17)
N(3)-C(11)-C(12)	118.95(17)
N(3)-C(11)-C(16)	116.84(17)
C(12)-C(11)-C(16)	124.21(17)
N(4)-C(12)-C(11)	121.76(17)
N(4)-C(12)-C(13)	115.73(17)
C(11)-C(12)-C(13)	122.51(17)
O(4)-C(13)-O(5)	124.60(19)
O(4)-C(13)-C(12)	123.22(19)
O(5)-C(13)-C(12)	112.17(17)
O(5)-C(14)-C(15)	107.40(17)
O(5)-C(14)-H(14A)	110.2
C(15)-C(14)-H(14A)	110.2
O(5)-C(14)-H(14B)	110.2
C(15)-C(14)-H(14B)	110.2
H(14A)-C(14)-H(14B)	108.5
C(14)-C(15)-H(15A)	109.5
C(14)-C(15)-H(15B)	109.5
H(15A)-C(15)-H(15B)	109.5
C(14)-C(15)-H(15C)	109.5
H(15A)-C(15)-H(15C)	109.5

H(15B)-C(15)-H(15C)	109.5
C(11)-C(16)-H(16A)	109.5
C(11)-C(16)-H(16B)	109.5
H(16A)-C(16)-H(16B)	109.5
C(11)-C(16)-H(16C)	109.5
H(16A)-C(16)-H(16C)	109.5
H(16B)-C(16)-H(16C)	109.5
O(3)-C(17)-H(17A)	109.5
O(3)-C(17)-H(17B)	109.5
H(17A)-C(17)-H(17B)	109.5
O(3)-C(17)-H(17C)	109.5
H(17A)-C(17)-H(17C)	109.5
H(17B)-C(17)-H(17C)	109.5
O(2)-C(18)-H(18A)	109.5
O(2)-C(18)-H(18B)	109.5
H(18A)-C(18)-H(18B)	109.5
O(2)-C(18)-H(18C)	109.5
H(18A)-C(18)-H(18C)	109.5
H(18B)-C(18)-H(18C)	109.5
O(1)-C(19)-H(19A)	109.5
O(1)-C(19)-H(19B)	109.5
H(19A)-C(19)-H(19B)	109.5
O(1)-C(19)-H(19C)	109.5
H(19A)-C(19)-H(19C)	109.5
H(19B)-C(19)-H(19C)	109.5

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for ojh340_0m. The anisotropic displacement factor exponent takes the form: $-2\pi^2[\ h^2\ a^{*2}U^{11} + ... + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
O(1)	16(1)	22(1)	24(1)	3(1)	-3(1)	0(1)
O(2)	19(1)	32(1)	19(1)	7(1)	1(1)	0(1)
O(3)	15(1)	29(1)	21(1)	4(1)	1(1)	4(1)
O(4)	29(1)	82(1)	29(1)	23(1)	-6(1)	-6(1)
O(5)	26(1)	34(1)	19(1)	5(1)	2(1)	-5(1)
N(1)	17(1)	20(1)	19(1)	-1(1)	0(1)	-4(1)
N(2)	22(1)	29(1)	18(1)	2(1)	0(1)	-2(1)
N(3)	22(1)	21(1)	21(1)	1(1)	-1(1)	-2(1)
N(4)	25(1)	31(1)	19(1)	1(1)	1(1)	-2(1)
C(1)	16(1)	17(1)	23(1)	0(1)	-1(1)	-1(1)
C(2)	15(1)	21(1)	22(1)	0(1)	2(1)	0(1)
C(3)	22(1)	20(1)	18(1)	1(1)	-1(1)	-3(1)
C(4)	16(1)	18(1)	21(1)	0(1)	-3(1)	1(1)
C(5)	18(1)	17(1)	22(1)	-3(1)	0(1)	-2(1)
C(6)	20(1)	17(1)	18(1)	0(1)	-1(1)	-3(1)
C(7)	21(1)	21(1)	18(1)	-1(1)	-1(1)	-3(1)
C(8)	18(1)	25(1)	23(1)	-2(1)	3(1)	-1(1)
C(9)	17(1)	23(1)	22(1)	0(1)	-2(1)	0(1)
C(10)	20(1)	19(1)	21(1)	-2(1)	0(1)	-4(1)
C(11)	25(1)	21(1)	22(1)	0(1)	-2(1)	-4(1)
C(12)	24(1)	22(1)	21(1)	-1(1)	-1(1)	-5(1)
C(13)	27(1)	30(1)	24(1)	1(1)	2(1)	-4(1)
C(14)	34(1)	40(1)	21(1)	6(1)	2(1)	-7(1)
C(15)	37(1)	52(2)	31(1)	6(1)	6(1)	-13(1)
C(16)	24(1)	41(1)	24(1)	8(1)	1(1)	2(1)
C(17)	16(1)	25(1)	23(1)	1(1)	3(1)	0(1)
C(18)	23(1)	29(1)	21(1)	5(1)	3(1)	-2(1)
C(19)	21(1)	23(1)	28(1)	2(1)	-2(1)	2(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters (Å^{2}x 10^3) for ojh340_0m.

	x	y	z	U(eq)
H(2)	8063	8162	2897	23
H(8)	1450	7869	6049	27
H(9)	1232	9262	4612	25
H(14A)	2940	2917	10874	39
H(14B)	3172	1109	10436	39
H(15A)	-163	3419	10573	60
H(15B)	362	1554	11131	60
H(15C)	50	1660	10102	60
H(16A)	7781	2000	8327	47
H(16B)	8044	3642	8827	47
H(16C)	8746	3525	7847	47
H(17A)	9771	5470	3388	33
H(17B)	11144	5310	4186	33
H(17C)	10546	7160	3624	33
H(18A)	7543	10791	2018	38
H(18B)	6555	11022	1092	38
H(18C)	7553	9130	1487	38
H(19A)	2035	12300	3490	37
H(19B)	581	12312	2740	37
H(19C)	2669	12267	2495	37

Table 6. Hydrogen bonds for ojh340_0m [Å and °].

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
C(19)-H(19C)...N(3)#1	0.98	2.65	3.176(3)	114.1
C(19)-H(19C)...O(2)	0.98	2.55	3.097(2)	115.4
C(19)-H(19B)...N(2)#2	0.98	2.64	3.585(2)	161.8
C(19)-H(19A)...N(1)#1	0.98	2.66	3.530(3)	148.3
C(18)-H(18C)...O(5)#3	0.98	2.61	3.411(3)	138.6
C(18)-H(18B)...O(4)#4	0.98	2.43	3.405(2)	175.8
C(17)-H(17B)...N(1)#5	0.98	2.67	3.609(2)	161.5
C(17)-H(17B)...O(3)#5	0.98	2.39	3.152(2)	133.8
C(17)-H(17B)...O(3)#5	0.98	2.39	3.152(2)	133.8
C(17)-H(17B)...N(1)#5	0.98	2.67	3.609(2)	161.5
C(18)-H(18B)...O(4)#4	0.98	2.43	3.405(2)	175.8
C(18)-H(18C)...O(5)#3	0.98	2.61	3.411(3)	138.6
C(19)-H(19A)...N(1)#1	0.98	2.66	3.530(3)	148.3
C(19)-H(19B)...N(2)#2	0.98	2.64	3.585(2)	161.8
C(19)-H(19C)...O(2)	0.98	2.55	3.097(2)	115.4
C(19)-H(19C)...N(3)#1	0.98	2.65	3.176(3)	114.1
C(17)-H(17B)...O(3)#5	0.98	2.39	3.152(2)	133.8
C(17)-H(17B)...N(1)#5	0.98	2.67	3.609(2)	161.5
C(18)-H(18B)...O(4)#4	0.98	2.43	3.405(2)	175.8
C(18)-H(18C)...O(5)#3	0.98	2.61	3.411(3)	138.6
C(19)-H(19A)...N(1)#1	0.98	2.66	3.530(3)	148.3
C(19)-H(19B)...N(2)#2	0.98	2.64	3.585(2)	161.8
C(19)-H(19C)...O(2)	0.98	2.55	3.097(2)	115.4
C(19)-H(19C)...N(3)#1	0.98	2.65	3.176(3)	114.1

Symmetry transformations used to generate equivalent atoms:
#1 -x+1,-y+2,-z+1 #2 -x,-y+2,-z+1 #3 -x+1,-y+1,-z+1
#4 x,y+1,z-1 #5 -x+2,-y+1,-z+1

X-ray crystal structure data for ethyl 4-(2-(benzyloxy)-3,4-dimethoxyphenyl)-5-(difluoroboranyl)-6-(6-methoxy-5-nitroquinolin-2-yl)-2-methylnicotinate 152

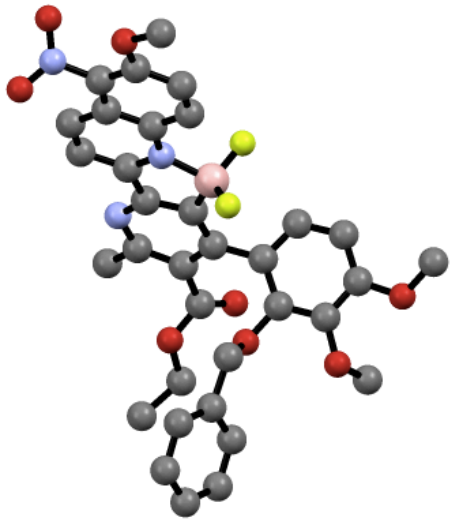

Table 1. Crystal data and structure refinement for ohj349p21c.

Identification code	ohj349p21c	
Empirical formula	C34 H30 B F2 N3 O8	
Formula weight	657.42	
Temperature	100(2) K	
Wavelength	1.54178 Å	
Crystal system	Monoclinic	
Space group	$P2_1/c$	
Unit cell dimensions	a = 17.6410(17) Å	a= 90°.
	b = 11.2310(11) Å	b= 101.295(7)°.
	c = 15.6262(15) Å	g = 90°.
Volume	3036.0(5) $Å^3$	
Z	4	
Density (calculated)	1.438 Mg/m^3	
Absorption coefficient	0.931 mm^{-1}	
F(000)	1368	
Crystal size	0.300 x 0.150 x 0.040 mm^3	
Theta range for data collection	2.554 to 67.164°.	
Index ranges	-20<=h<=21, -13<=k<=13, -18<=l<=18	

Reflections collected	41038
Independent reflections	5404 [R(int) = 0.5029]
Completeness to theta = 67.164°	99.4 %
Absorption correction	None
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	5404 / 0 / 439
Goodness-of-fit on F^2	1.009
Final R indices [I>2sigma(I)]	R1 = 0.1012, wR2 = 0.1731
R indices (all data)	R1 = 0.2609, wR2 = 0.2395
Extinction coefficient	n/a
Largest diff. peak and hole	0.364 and -0.403 e.$Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3)
for ohj349p21c. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
B(1)	5241(5)	6265(9)	8199(5)	26(2)
F(1)	5123(2)	7295(4)	7692(2)	29(1)
F(2)	4795(2)	5336(4)	7765(2)	28(1)
N(1)	4893(3)	6508(6)	9089(4)	24(2)
N(2)	6785(3)	5682(6)	10174(4)	26(2)
N(3)	2993(4)	7692(6)	10829(4)	30(2)
O(1)	8405(3)	4707(5)	8227(3)	31(1)
O(2)	8760(3)	6165(5)	9202(3)	27(1)
O(3)	7805(3)	7107(5)	5792(3)	30(1)
O(4)	6631(3)	6017(5)	4700(3)	29(1)
O(5)	1980(3)	8083(5)	9336(3)	29(1)
O(6)	2407(3)	7198(5)	10971(3)	33(2)
O(7)	3405(3)	8347(5)	11349(3)	35(2)
O(8)	7891(3)	7083(5)	7539(3)	27(1)
C(1)	3609(4)	7043(7)	8385(5)	29(2)
C(2)	2882(4)	7442(7)	8420(5)	26(2)
C(3)	2676(4)	7666(7)	9238(5)	27(2)
C(5)	3990(4)	7073(7)	9979(4)	23(2)
C(6)	4157(4)	6878(7)	9145(5)	26(2)
C(7)	4565(4)	6878(7)	10726(4)	25(2)
C(9)	5432(4)	6319(7)	9798(4)	19(2)
C(10)	6175(4)	5961(7)	9559(4)	20(2)
C(11)	6118(4)	5962(7)	8658(4)	22(2)
C(12)	6797(5)	5767(7)	8353(5)	28(2)
C(13)	7472(4)	5580(7)	8987(5)	26(2)
C(14)	7434(4)	5493(7)	9876(5)	25(2)
C(15)	6776(4)	5796(7)	7393(4)	20(2)
C(20)	6189(4)	5189(7)	6827(5)	26(2)
C(19)	6123(4)	5236(7)	5933(4)	27(2)

C(18)	6651(4)	5875(7)	5572(4)	25(2)
C(17)	7266(4)	6449(7)	6110(5)	26(2)
C(16)	7302(4)	6450(7)	7004(5)	24(2)
C(33)	8116(4)	5096(7)	10557(4)	31(2)
C(30)	8242(5)	5428(8)	8739(5)	29(2)
C(31)	9545(4)	6124(7)	9039(5)	30(2)
C(32)	10015(4)	7014(7)	9646(5)	38(2)
C(28)	8305(5)	6424(8)	5374(6)	45(3)
C(29)	5914(4)	5723(7)	4126(5)	34(2)
C(8)	5283(4)	6507(7)	10645(4)	21(2)
C(34)	1436(4)	8417(8)	8551(5)	41(2)
C(4)	3220(4)	7464(7)	9982(4)	22(2)
C(21)	7662(4)	8296(7)	7631(5)	28(2)
C(27)	9043(4)	8815(7)	7543(4)	27(2)
C(22)	8370(4)	9086(7)	7839(5)	27(2)
C(26)	9646(4)	9631(8)	7685(5)	37(2)
C(25)	9592(5)	10708(8)	8099(5)	40(2)
C(24)	8927(5)	10964(8)	8396(6)	46(3)
C(23)	8322(5)	10143(8)	8263(5)	35(2)

Table 3. Bond lengths [Å] and angles [°] for ohj349p21c.

B(1)-F(1)	1.395(10)
B(1)-F(2)	1.399(9)
B(1)-C(11)	1.611(11)
B(1)-N(1)	1.650(9)
N(1)-C(9)	1.328(8)
N(1)-C(6)	1.383(9)
N(2)-C(10)	1.333(8)
N(2)-C(14)	1.334(8)
N(3)-O(7)	1.224(7)
N(3)-O(6)	1.231(7)
N(3)-C(4)	1.477(8)
O(1)-C(30)	1.212(8)
O(2)-C(30)	1.335(9)
O(2)-C(31)	1.456(7)
O(3)-C(17)	1.372(8)
O(3)-C(28)	1.421(8)
O(4)-C(18)	1.366(8)
O(4)-C(29)	1.438(8)
O(5)-C(3)	1.350(8)
O(5)-C(34)	1.450(8)
O(8)-C(16)	1.394(8)
O(8)-C(21)	1.436(8)
C(1)-C(2)	1.371(9)
C(1)-C(6)	1.388(9)
C(1)-H(1)	0.9500
C(2)-C(3)	1.417(9)
C(2)-H(2)	0.9500
C(3)-C(4)	1.375(9)
C(5)-C(7)	1.406(9)
C(5)-C(6)	1.408(9)
C(5)-C(4)	1.429(9)
C(7)-C(8)	1.363(9)
C(7)-H(7)	0.9500
C(9)-C(8)	1.415(9)
C(9)-C(10)	1.486(9)

C(10)-C(11)	1.392(9)
C(11)-C(12)	1.389(9)
C(12)-C(13)	1.408(10)
C(12)-C(15)	1.494(9)
C(13)-C(14)	1.408(9)
C(13)-C(30)	1.493(10)
C(14)-C(33)	1.509(9)
C(15)-C(20)	1.400(9)
C(15)-C(16)	1.411(9)
C(20)-C(19)	1.380(9)
C(20)-H(20)	0.9500
C(19)-C(18)	1.382(9)
C(19)-H(19)	0.9500
C(18)-C(17)	1.393(10)
C(17)-C(16)	1.386(9)
C(33)-H(33A)	0.9800
C(33)-H(33B)	0.9800
C(33)-H(33C)	0.9800
C(31)-C(32)	1.510(10)
C(31)-H(31A)	0.9900
C(31)-H(31B)	0.9900
C(32)-H(32A)	0.9800
C(32)-H(32B)	0.9800
C(32)-H(32C)	0.9800
C(28)-H(28A)	0.9800
C(28)-H(28B)	0.9800
C(28)-H(28C)	0.9800
C(29)-H(29A)	0.9800
C(29)-H(29B)	0.9800
C(29)-H(29C)	0.9800
C(8)-H(8)	0.9500
C(34)-H(34A)	0.9800
C(34)-H(34B)	0.9800
C(34)-H(34C)	0.9800
C(21)-C(22)	1.514(9)
C(21)-H(21A)	0.9900
C(21)-H(21B)	0.9900

C(27)-C(26)	1.387(10)
C(27)-C(22)	1.390(9)
C(27)-H(27)	0.9500
C(22)-C(23)	1.370(10)
C(26)-C(25)	1.383(11)
C(26)-H(26)	0.9500
C(25)-C(24)	1.374(10)
C(25)-H(25)	0.9500
C(24)-C(23)	1.395(10)
C(24)-H(24)	0.9500
C(23)-H(23)	0.9500

F(1)-B(1)-F(2)	109.7(6)
F(1)-B(1)-C(11)	116.9(7)
F(2)-B(1)-C(11)	117.2(7)
F(1)-B(1)-N(1)	107.6(7)
F(2)-B(1)-N(1)	105.5(6)
C(11)-B(1)-N(1)	98.2(6)
C(9)-N(1)-C(6)	121.6(6)
C(9)-N(1)-B(1)	110.7(6)
C(6)-N(1)-B(1)	127.7(6)
C(10)-N(2)-C(14)	114.4(6)
O(7)-N(3)-O(6)	124.2(6)
O(7)-N(3)-C(4)	117.9(6)
O(6)-N(3)-C(4)	117.8(6)
C(30)-O(2)-C(31)	117.3(6)
C(17)-O(3)-C(28)	114.4(6)
C(18)-O(4)-C(29)	116.3(6)
C(3)-O(5)-C(34)	117.4(6)
C(16)-O(8)-C(21)	110.7(6)
C(2)-C(1)-C(6)	120.6(7)
C(2)-C(1)-H(1)	119.7
C(6)-C(1)-H(1)	119.7
C(1)-C(2)-C(3)	120.1(7)
C(1)-C(2)-H(2)	120.0
C(3)-C(2)-H(2)	120.0
O(5)-C(3)-C(4)	117.4(6)

O(5)-C(3)-C(2)	124.3(7)
C(4)-C(3)-C(2)	118.3(7)
C(7)-C(5)-C(6)	119.8(7)
C(7)-C(5)-C(4)	125.2(6)
C(6)-C(5)-C(4)	115.0(7)
N(1)-C(6)-C(1)	119.4(6)
N(1)-C(6)-C(5)	118.3(7)
C(1)-C(6)-C(5)	122.3(7)
C(8)-C(7)-C(5)	120.2(7)
C(8)-C(7)-H(7)	119.9
C(5)-C(7)-H(7)	119.9
N(1)-C(9)-C(8)	121.5(7)
N(1)-C(9)-C(10)	110.9(6)
C(8)-C(9)-C(10)	127.6(7)
N(2)-C(10)-C(11)	128.1(7)
N(2)-C(10)-C(9)	120.6(6)
C(11)-C(10)-C(9)	111.2(7)
C(12)-C(11)-C(10)	116.8(7)
C(12)-C(11)-B(1)	134.3(7)
C(10)-C(11)-B(1)	108.8(6)
C(11)-C(12)-C(13)	116.7(7)
C(11)-C(12)-C(15)	119.2(7)
C(13)-C(12)-C(15)	124.0(7)
C(12)-C(13)-C(14)	120.4(7)
C(12)-C(13)-C(30)	121.5(7)
C(14)-C(13)-C(30)	118.0(7)
N(2)-C(14)-C(13)	122.9(7)
N(2)-C(14)-C(33)	114.9(7)
C(13)-C(14)-C(33)	122.0(7)
C(20)-C(15)-C(16)	116.7(7)
C(20)-C(15)-C(12)	119.5(7)
C(16)-C(15)-C(12)	123.7(7)
C(19)-C(20)-C(15)	121.7(7)
C(19)-C(20)-H(20)	119.1
C(15)-C(20)-H(20)	119.1
C(20)-C(19)-C(18)	120.2(7)
C(20)-C(19)-H(19)	119.9

C(18)-C(19)-H(19)	119.9
O(4)-C(18)-C(19)	125.4(7)
O(4)-C(18)-C(17)	114.5(7)
C(19)-C(18)-C(17)	120.1(7)
O(3)-C(17)-C(16)	117.8(7)
O(3)-C(17)-C(18)	122.9(7)
C(16)-C(17)-C(18)	119.1(7)
C(17)-C(16)-O(8)	119.1(7)
C(17)-C(16)-C(15)	121.9(7)
O(8)-C(16)-C(15)	118.9(6)
C(14)-C(33)-H(33A)	109.5
C(14)-C(33)-H(33B)	109.5
H(33A)-C(33)-H(33B)	109.5
C(14)-C(33)-H(33C)	109.5
H(33A)-C(33)-H(33C)	109.5
H(33B)-C(33)-H(33C)	109.5
O(1)-C(30)-O(2)	123.1(7)
O(1)-C(30)-C(13)	126.3(8)
O(2)-C(30)-C(13)	110.5(6)
O(2)-C(31)-C(32)	107.1(6)
O(2)-C(31)-H(31A)	110.3
C(32)-C(31)-H(31A)	110.3
O(2)-C(31)-H(31B)	110.3
C(32)-C(31)-H(31B)	110.3
H(31A)-C(31)-H(31B)	108.6
C(31)-C(32)-H(32A)	109.5
C(31)-C(32)-H(32B)	109.5
H(32A)-C(32)-H(32B)	109.5
C(31)-C(32)-H(32C)	109.5
H(32A)-C(32)-H(32C)	109.5
H(32B)-C(32)-H(32C)	109.5
O(3)-C(28)-H(28A)	109.5
O(3)-C(28)-H(28B)	109.5
H(28A)-C(28)-H(28B)	109.5
O(3)-C(28)-H(28C)	109.5
H(28A)-C(28)-H(28C)	109.5
H(28B)-C(28)-H(28C)	109.5

O(4)-C(29)-H(29A)	109.5
O(4)-C(29)-H(29B)	109.5
H(29A)-C(29)-H(29B)	109.5
O(4)-C(29)-H(29C)	109.5
H(29A)-C(29)-H(29C)	109.5
H(29B)-C(29)-H(29C)	109.5
C(7)-C(8)-C(9)	118.6(7)
C(7)-C(8)-H(8)	120.7
C(9)-C(8)-H(8)	120.7
O(5)-C(34)-H(34A)	109.5
O(5)-C(34)-H(34B)	109.5
H(34A)-C(34)-H(34B)	109.5
O(5)-C(34)-H(34C)	109.5
H(34A)-C(34)-H(34C)	109.5
H(34B)-C(34)-H(34C)	109.5
C(3)-C(4)-C(5)	123.6(6)
C(3)-C(4)-N(3)	117.6(7)
C(5)-C(4)-N(3)	118.8(6)
O(8)-C(21)-C(22)	109.9(6)
O(8)-C(21)-H(21A)	109.7
C(22)-C(21)-H(21A)	109.7
O(8)-C(21)-H(21B)	109.7
C(22)-C(21)-H(21B)	109.7
H(21A)-C(21)-H(21B)	108.2
C(26)-C(27)-C(22)	118.7(8)
C(26)-C(27)-H(27)	120.6
C(22)-C(27)-H(27)	120.6
C(23)-C(22)-C(27)	119.2(8)
C(23)-C(22)-C(21)	119.0(7)
C(27)-C(22)-C(21)	121.6(7)
C(25)-C(26)-C(27)	122.1(8)
C(25)-C(26)-H(26)	119.0
C(27)-C(26)-H(26)	119.0
C(24)-C(25)-C(26)	118.8(8)
C(24)-C(25)-H(25)	120.6
C(26)-C(25)-H(25)	120.6
C(25)-C(24)-C(23)	119.4(9)

C(25)-C(24)-H(24)	120.3
C(23)-C(24)-H(24)	120.3
C(22)-C(23)-C(24)	121.8(8)
C(22)-C(23)-H(23)	119.1
C(24)-C(23)-H(23)	119.1

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for ohj349p21c. The anisotropic displacement factor exponent takes the form: $-2\pi^2[h^2 a^{*2} U^{11} + ... + 2 h k a^* b^* U^{12}]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
B(1)	36(6)	28(6)	15(5)	1(4)	8(4)	-6(5)
F(1)	33(3)	37(3)	17(2)	6(2)	4(2)	1(2)
F(2)	29(3)	36(3)	20(2)	-3(2)	7(2)	-8(2)
N(1)	27(4)	23(4)	20(4)	-1(3)	5(3)	-5(3)
N(2)	27(4)	34(5)	16(3)	2(3)	4(3)	1(3)
N(3)	26(4)	40(5)	23(4)	4(4)	8(3)	-1(4)
O(1)	40(4)	27(4)	26(3)	-5(3)	11(3)	2(3)
O(2)	13(3)	40(4)	28(3)	-1(3)	3(2)	4(3)
O(3)	30(3)	37(4)	28(3)	3(3)	18(3)	-6(3)
O(4)	34(3)	47(4)	7(3)	0(3)	4(2)	-3(3)
O(5)	23(3)	43(4)	23(3)	5(3)	8(2)	4(3)
O(6)	38(4)	33(4)	31(3)	-3(3)	14(3)	-3(3)
O(7)	40(4)	45(4)	21(3)	-5(3)	6(3)	-4(3)
O(8)	31(3)	22(3)	28(3)	-3(3)	7(2)	-4(3)
C(1)	30(5)	43(6)	18(4)	5(4)	13(4)	-6(4)
C(2)	25(5)	36(6)	18(4)	-1(4)	4(3)	-9(4)
C(3)	23(5)	41(6)	18(4)	-4(4)	8(4)	-11(4)
C(5)	26(5)	32(5)	13(4)	3(4)	7(3)	-4(4)
C(6)	36(5)	29(5)	11(4)	-1(4)	4(3)	-1(4)
C(7)	38(5)	24(5)	13(4)	1(3)	7(4)	-11(4)
C(9)	20(4)	23(5)	15(4)	6(3)	4(3)	1(4)
C(10)	24(5)	23(5)	16(4)	0(4)	12(3)	-2(4)
C(11)	29(5)	25(5)	12(4)	2(3)	7(3)	-5(4)
C(12)	40(5)	26(5)	18(4)	-8(4)	10(4)	-9(4)
C(13)	34(5)	30(5)	15(4)	-2(4)	9(4)	0(4)
C(14)	23(5)	24(5)	26(4)	-1(4)	3(4)	1(4)
C(15)	14(4)	30(5)	17(4)	-1(4)	4(3)	5(3)
C(20)	21(5)	31(5)	27(4)	-9(4)	6(4)	-6(4)
C(19)	31(5)	36(6)	14(4)	3(4)	1(4)	-5(4)
C(18)	33(5)	29(5)	13(4)	-6(4)	5(3)	-6(4)

C(17)	35(5)	20(5)	30(5)	-4(4)	27(4)	1(4)
C(16)	26(5)	25(5)	23(4)	-5(4)	8(4)	0(4)
C(33)	32(5)	37(6)	22(4)	-7(4)	5(4)	-3(4)
C(30)	42(6)	31(6)	16(4)	-4(4)	12(4)	0(4)
C(31)	24(5)	32(6)	40(5)	0(4)	19(4)	4(4)
C(32)	29(5)	31(6)	55(6)	-3(5)	15(4)	4(4)
C(28)	44(6)	41(6)	60(6)	6(5)	34(5)	8(5)
C(29)	39(6)	37(6)	25(5)	-3(4)	4(4)	0(4)
C(8)	27(5)	26(5)	11(4)	2(4)	4(3)	-2(4)
C(34)	23(5)	69(7)	30(5)	13(5)	-1(4)	6(5)
C(4)	33(5)	25(5)	11(4)	2(3)	12(3)	-10(4)
C(21)	29(5)	18(5)	39(5)	-4(4)	9(4)	-3(4)
C(27)	27(5)	31(6)	21(4)	7(4)	-1(4)	-2(4)
C(22)	32(5)	23(5)	28(5)	2(4)	13(4)	-1(4)
C(26)	22(5)	50(7)	38(5)	21(5)	2(4)	-2(5)
C(25)	32(6)	34(6)	51(6)	-2(5)	3(4)	-19(4)
C(24)	43(6)	39(7)	54(6)	-9(5)	4(5)	-16(5)
C(23)	33(5)	36(6)	40(5)	-3(5)	16(4)	-2(4)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters (Å^{2}x 10^{-3}) for ohj349p21c.

	x	y	z	U(eq)
H(1)	3740	6878	7836	35
H(2)	2515	7569	7896	32
H(7)	4452	7004	11289	30
H(20)	5827	4732	7066	31
H(19)	5712	4827	5565	33
H(33A)	8476	5763	10707	46
H(33B)	8380	4437	10326	46
H(33C)	7936	4831	11080	46
H(31A)	9547	6332	8424	36
H(31B)	9763	5314	9154	36
H(32A)	9792	7810	9527	56
H(32B)	10549	7015	9552	56
H(32C)	10011	6795	10252	56
H(28A)	8705	6051	5816	68
H(28B)	8548	6945	5003	68
H(28C)	8006	5805	5015	68
H(29A)	5824	4864	4147	51
H(29B)	5939	5957	3529	51
H(29C)	5489	6149	4313	51
H(8)	5675	6378	11147	25
H(34A)	1675	9008	8226	62
H(34B)	972	8758	8711	62
H(34C)	1295	7711	8187	62
H(21A)	7365	8353	8105	34
H(21B)	7324	8566	7083	34
H(27)	9090	8086	7250	32
H(26)	10110	9443	7492	44
H(25)	10008	11260	8176	48
H(24)	8880	11693	8689	55

H(23)	7864	10321	8473	42

X-ray crystal structure data for 4-(2-(Benzyloxy)-3,4-dimethoxyphenyl)-5-(difluoroboranyl)-6-(6-methoxy-5-nitroquinolin-2-yl)-3-methylpicolinonitrile 157

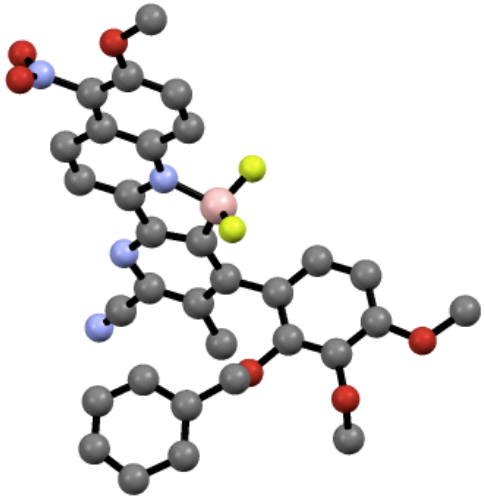

Table 1. Crystal data and structure refinement for ojh355_0m.

Identification code	ojh355_0m	
Empirical formula	C32 H25 B F2 N4 O6	
Formula weight	610.37	
Temperature	100(2) K	
Wavelength	1.54178 Å	
Crystal system	Triclinic	
Space group	P-1	
Unit cell dimensions	a = 7.2043(2) Å	a= 84.7792(18)°.
	b = 8.3817(3) Å	b= 87.3209(18)°.
	c = 24.3148(8) Å	g = 82.206(2)°.
Volume	1447.75(8) $Å^3$	
Z	2	
Density (calculated)	1.400 Mg/m^3	
Absorption coefficient	0.891 mm^{-1}	
F(000)	632	
Crystal size	0.200 x 0.200 x 0.050 mm^3	
Theta range for data collection	3.653 to 67.045°.	
Index ranges	-8<=h<=8, -9<=k<=9, -28<=l<=28	

Reflections collected	36899
Independent reflections	5099 [R(int) = 0.0920]
Completeness to theta = 67.045°	98.8 %
Absorption correction	None
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	5099 / 66 / 429
Goodness-of-fit on F^2	1.027
Final R indices [I>2sigma(I)]	R1 = 0.0748, wR2 = 0.1762
R indices (all data)	R1 = 0.1308, wR2 = 0.2046
Extinction coefficient	n/a
Largest diff. peak and hole	0.625 and -0.282 e.$Å^{-3}$

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3)
for ojh355_0m. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
B(1)	5792(7)	10178(6)	2906(2)	65(1)
F(1)	7131(3)	10317(3)	2488(1)	68(1)
F(2)	5123(3)	11682(3)	3089(1)	77(1)
N(1)	6828(5)	9048(4)	3432(1)	68(1)
N(2)	3308(6)	6546(5)	3282(2)	80(1)
N(3)	-245(6)	4474(5)	3046(2)	99(1)
N(4)	11500(6)	7311(6)	4821(2)	95(1)
O(1)	3525(3)	10860(3)	458(1)	61(1)
O(2)	2026(3)	13879(3)	625(1)	67(1)
O(3)	3697(3)	8445(3)	1318(1)	56(1)
O(4)	13084(5)	10029(5)	4514(1)	101(1)
O(5)	13121(7)	6735(8)	4776(2)	108(2)
O(6)	10455(7)	7012(7)	5219(2)	99(2)
O(5')	11914(19)	7699(17)	5264(3)	107(2)
O(6')	12180(20)	6011(11)	4660(5)	104(2)
C(1)	9241(6)	10694(6)	3546(2)	74(1)
C(2)	10810(6)	10946(6)	3809(2)	78(1)
C(3)	11574(7)	9836(7)	4232(2)	83(1)
C(4)	10732(7)	8482(7)	4376(2)	81(1)
C(5)	9099(7)	8143(6)	4125(2)	78(1)
C(6)	8378(6)	9302(6)	3697(2)	72(1)
C(7)	5976(6)	7750(6)	3571(2)	73(1)
C(8)	6650(8)	6574(6)	3983(2)	85(1)
C(9)	8200(8)	6758(6)	4258(2)	85(1)
C(10)	4377(6)	7741(6)	3214(2)	73(1)
C(11)	4224(6)	9050(5)	2817(2)	65(1)
C(12)	2881(6)	9115(5)	2418(2)	67(1)
C(13)	1705(6)	7867(5)	2465(2)	70(1)
C(14)	1984(7)	6687(5)	2901(2)	75(1)

C(15)	2690(5)	10409(4)	1963(2)	61(1)
C(16)	2085(5)	12007(5)	2053(2)	68(1)
C(17)	1862(5)	13194(5)	1620(2)	68(1)
C(18)	2255(5)	12830(4)	1084(2)	57(1)
C(19)	2961(5)	11233(4)	987(2)	56(1)
C(20)	3127(4)	10049(4)	1419(2)	55(1)
C(21)	5657(5)	8063(5)	1193(3)	91(2)
C(22)	6123(5)	6282(5)	1219(2)	69(1)
C(23)	6346(5)	5418(5)	1723(2)	78(1)
C(24)	6779(6)	3790(6)	1786(3)	90(1)
C(25)	6986(6)	2995(6)	1347(3)	89(1)
C(26)	6753(5)	3677(5)	825(2)	82(1)
C(27)	6289(5)	5453(5)	754(2)	78(1)
C(28)	234(6)	7840(5)	2054(2)	83(1)
C(29)	743(7)	5431(6)	2980(2)	85(1)
C(30)	2102(6)	10268(5)	184(2)	71(1)
C(31)	1260(5)	15527(4)	689(2)	74(1)
C(32)	13850(8)	11521(8)	4422(2)	105(2)

Table 3. Bond lengths [Å] and angles [°] for ojh355_0m.

B(1)-F(1)	1.377(5)
B(1)-F(2)	1.392(5)
B(1)-C(11)	1.602(6)
B(1)-N(1)	1.664(6)
N(1)-C(7)	1.330(5)
N(1)-C(6)	1.366(5)
N(2)-C(10)	1.338(5)
N(2)-C(14)	1.347(6)
N(3)-C(29)	1.138(5)
N(4)-O(5)	1.206(4)
N(4)-O(5')	1.214(5)
N(4)-O(6')	1.223(5)
N(4)-O(6)	1.225(4)
N(4)-C(4)	1.470(6)
O(1)-C(19)	1.380(5)
O(1)-C(30)	1.416(4)
O(2)-C(18)	1.359(5)
O(2)-C(31)	1.436(4)
O(3)-C(20)	1.392(4)
O(3)-C(21)	1.429(4)
O(4)-C(3)	1.347(5)
O(4)-C(32)	1.429(6)
C(1)-C(2)	1.374(6)
C(1)-C(6)	1.407(6)
C(1)-H(1)	0.9500
C(2)-C(3)	1.403(7)
C(2)-H(2)	0.9500
C(3)-C(4)	1.369(7)
C(4)-C(5)	1.423(6)
C(5)-C(9)	1.411(6)
C(5)-C(6)	1.422(6)
C(7)-C(8)	1.395(6)
C(7)-C(10)	1.476(6)
C(8)-C(9)	1.362(7)
C(8)-H(8)	0.9500

C(9)-H(9)	0.9500
C(10)-C(11)	1.390(6)
C(11)-C(12)	1.394(6)
C(12)-C(13)	1.426(5)
C(12)-C(15)	1.474(6)
C(13)-C(14)	1.384(6)
C(13)-C(28)	1.494(6)
C(14)-C(29)	1.465(6)
C(15)-C(16)	1.384(5)
C(15)-C(20)	1.395(6)
C(16)-C(17)	1.381(6)
C(16)-H(16)	0.9500
C(17)-C(18)	1.373(6)
C(17)-H(17)	0.9500
C(18)-C(19)	1.402(5)
C(19)-C(20)	1.376(6)
C(21)-C(22)	1.481(5)
C(21)-H(21A)	0.9900
C(21)-H(21B)	0.9900
C(22)-C(23)	1.369(6)
C(22)-C(27)	1.373(6)
C(23)-C(24)	1.354(6)
C(23)-H(23)	0.9500
C(24)-C(25)	1.302(7)
C(24)-H(24)	0.9500
C(25)-C(26)	1.352(7)
C(25)-H(25)	0.9500
C(26)-C(27)	1.477(6)
C(26)-H(26)	0.9500
C(27)-H(27)	0.9500
C(28)-H(28A)	0.9800
C(28)-H(28B)	0.9800
C(28)-H(28C)	0.9800
C(30)-H(30A)	0.9800
C(30)-H(30B)	0.9800
C(30)-H(30C)	0.9800
C(31)-H(31A)	0.9800

C(31)-H(31B)	0.9800
C(31)-H(31C)	0.9800
C(32)-H(32A)	0.9800
C(32)-H(32B)	0.9800
C(32)-H(32C)	0.9800

F(1)-B(1)-F(2)	110.9(4)
F(1)-B(1)-C(11)	116.7(3)
F(2)-B(1)-C(11)	115.4(4)
F(1)-B(1)-N(1)	107.3(3)
F(2)-B(1)-N(1)	107.5(3)
C(11)-B(1)-N(1)	97.3(3)
C(7)-N(1)-C(6)	121.1(4)
C(7)-N(1)-B(1)	111.0(4)
C(6)-N(1)-B(1)	127.8(4)
C(10)-N(2)-C(14)	112.6(4)
O(5')-N(4)-O(6')	120.3(11)
O(5)-N(4)-O(6)	124.5(5)
O(5)-N(4)-C(4)	117.9(4)
O(5')-N(4)-C(4)	123.1(8)
O(6')-N(4)-C(4)	113.4(7)
O(6)-N(4)-C(4)	117.5(5)
C(19)-O(1)-C(30)	112.2(3)
C(18)-O(2)-C(31)	118.6(3)
C(20)-O(3)-C(21)	114.7(3)
C(3)-O(4)-C(32)	118.8(4)
C(2)-C(1)-C(6)	120.2(5)
C(2)-C(1)-H(1)	119.9
C(6)-C(1)-H(1)	119.9
C(1)-C(2)-C(3)	121.0(5)
C(1)-C(2)-H(2)	119.5
C(3)-C(2)-H(2)	119.5
O(4)-C(3)-C(4)	117.6(5)
O(4)-C(3)-C(2)	124.0(5)
C(4)-C(3)-C(2)	118.5(5)
C(3)-C(4)-C(5)	123.7(5)
C(3)-C(4)-N(4)	119.4(5)

C(5)-C(4)-N(4)	116.9(5)
C(9)-C(5)-C(6)	118.9(5)
C(9)-C(5)-C(4)	125.3(5)
C(6)-C(5)-C(4)	115.7(4)
N(1)-C(6)-C(1)	120.0(4)
N(1)-C(6)-C(5)	119.1(4)
C(1)-C(6)-C(5)	120.9(4)
N(1)-C(7)-C(8)	121.6(4)
N(1)-C(7)-C(10)	110.4(4)
C(8)-C(7)-C(10)	127.9(4)
C(9)-C(8)-C(7)	119.8(5)
C(9)-C(8)-H(8)	120.1
C(7)-C(8)-H(8)	120.1
C(8)-C(9)-C(5)	119.4(5)
C(8)-C(9)-H(9)	120.3
C(5)-C(9)-H(9)	120.3
N(2)-C(10)-C(11)	127.6(4)
N(2)-C(10)-C(7)	120.8(4)
C(11)-C(10)-C(7)	111.6(4)
C(10)-C(11)-C(12)	117.8(4)
C(10)-C(11)-B(1)	109.5(4)
C(12)-C(11)-B(1)	132.5(4)
C(11)-C(12)-C(13)	117.2(4)
C(11)-C(12)-C(15)	121.5(4)
C(13)-C(12)-C(15)	121.3(4)
C(14)-C(13)-C(12)	117.8(4)
C(14)-C(13)-C(28)	121.5(4)
C(12)-C(13)-C(28)	120.7(5)
N(2)-C(14)-C(13)	126.9(4)
N(2)-C(14)-C(29)	113.7(5)
C(13)-C(14)-C(29)	119.4(5)
C(16)-C(15)-C(20)	117.5(4)
C(16)-C(15)-C(12)	122.3(4)
C(20)-C(15)-C(12)	120.2(3)
C(17)-C(16)-C(15)	121.4(4)
C(17)-C(16)-H(16)	119.3
C(15)-C(16)-H(16)	119.3

C(18)-C(17)-C(16)	120.9(4)
C(18)-C(17)-H(17)	119.5
C(16)-C(17)-H(17)	119.5
O(2)-C(18)-C(17)	126.2(3)
O(2)-C(18)-C(19)	115.3(4)
C(17)-C(18)-C(19)	118.5(4)
C(20)-C(19)-O(1)	120.1(3)
C(20)-C(19)-C(18)	120.1(4)
O(1)-C(19)-C(18)	119.7(4)
C(19)-C(20)-O(3)	120.1(4)
C(19)-C(20)-C(15)	121.4(3)
O(3)-C(20)-C(15)	118.5(4)
O(3)-C(21)-C(22)	108.5(3)
O(3)-C(21)-H(21A)	110.0
C(22)-C(21)-H(21A)	110.0
O(3)-C(21)-H(21B)	110.0
C(22)-C(21)-H(21B)	110.0
H(21A)-C(21)-H(21B)	108.4
C(23)-C(22)-C(27)	118.4(4)
C(23)-C(22)-C(21)	119.4(5)
C(27)-C(22)-C(21)	122.2(5)
C(24)-C(23)-C(22)	123.6(5)
C(24)-C(23)-H(23)	118.2
C(22)-C(23)-H(23)	118.2
C(25)-C(24)-C(23)	118.6(6)
C(25)-C(24)-H(24)	120.7
C(23)-C(24)-H(24)	120.7
C(24)-C(25)-C(26)	124.5(5)
C(24)-C(25)-H(25)	117.7
C(26)-C(25)-H(25)	117.7
C(25)-C(26)-C(27)	117.0(5)
C(25)-C(26)-H(26)	121.5
C(27)-C(26)-H(26)	121.5
C(22)-C(27)-C(26)	117.9(5)
C(22)-C(27)-H(27)	121.0
C(26)-C(27)-H(27)	121.0
C(13)-C(28)-H(28A)	109.5

C(13)-C(28)-H(28B)	109.5
H(28A)-C(28)-H(28B)	109.5
C(13)-C(28)-H(28C)	109.5
H(28A)-C(28)-H(28C)	109.5
H(28B)-C(28)-H(28C)	109.5
N(3)-C(29)-C(14)	178.8(5)
O(1)-C(30)-H(30A)	109.5
O(1)-C(30)-H(30B)	109.5
H(30A)-C(30)-H(30B)	109.5
O(1)-C(30)-H(30C)	109.5
H(30A)-C(30)-H(30C)	109.5
H(30B)-C(30)-H(30C)	109.5
O(2)-C(31)-H(31A)	109.5
O(2)-C(31)-H(31B)	109.5
H(31A)-C(31)-H(31B)	109.5
O(2)-C(31)-H(31C)	109.5
H(31A)-C(31)-H(31C)	109.5
H(31B)-C(31)-H(31C)	109.5
O(4)-C(32)-H(32A)	109.5
O(4)-C(32)-H(32B)	109.5
H(32A)-C(32)-H(32B)	109.5
O(4)-C(32)-H(32C)	109.5
H(32A)-C(32)-H(32C)	109.5
H(32B)-C(32)-H(32C)	109.5

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for ojh355_0m. The anisotropic displacement factor exponent takes the form: $-2\pi^2[h^2 a^{*2} U^{11} + ... + 2 h k a^* b^* U^{12}]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
B(1)	64(3)	75(3)	60(3)	-19(3)	6(2)	-19(3)
F(1)	64(1)	82(2)	60(1)	-8(1)	2(1)	-17(1)
F(2)	72(2)	81(2)	82(2)	-25(1)	2(1)	-20(1)
N(1)	70(2)	81(2)	57(2)	-9(2)	6(2)	-21(2)
N(2)	81(3)	88(3)	79(3)	-24(2)	20(2)	-34(2)
N(3)	106(3)	91(3)	110(3)	-35(2)	32(3)	-51(3)
N(4)	101(4)	125(4)	62(3)	-7(3)	10(3)	-26(3)
O(1)	46(1)	49(1)	92(2)	-22(1)	-13(1)	-4(1)
O(2)	43(1)	40(1)	119(2)	-17(2)	-20(2)	0(1)
O(3)	37(1)	40(1)	94(2)	-19(1)	-9(1)	-2(1)
O(4)	94(2)	152(3)	64(2)	-1(2)	-17(2)	-40(2)
O(5)	87(3)	176(4)	59(3)	9(3)	-5(3)	-19(3)
O(6)	101(3)	155(4)	42(2)	0(2)	10(2)	-26(3)
O(5')	99(5)	169(5)	51(4)	5(4)	3(4)	-25(4)
O(6')	94(5)	166(5)	50(4)	15(4)	3(4)	-21(4)
C(1)	73(3)	96(3)	56(3)	-10(2)	4(2)	-24(3)
C(2)	77(3)	112(4)	51(3)	-3(3)	1(2)	-34(3)
C(3)	78(3)	125(4)	51(3)	-9(3)	4(2)	-32(3)
C(4)	84(3)	117(4)	41(2)	3(3)	-1(2)	-16(3)
C(5)	85(3)	107(4)	44(2)	-5(3)	7(2)	-21(3)
C(6)	70(3)	96(3)	53(3)	-11(2)	8(2)	-25(3)
C(7)	78(3)	80(3)	63(3)	-9(3)	13(2)	-21(3)
C(8)	102(4)	92(3)	62(3)	-3(3)	18(3)	-33(3)
C(9)	102(4)	104(4)	53(3)	-9(3)	14(3)	-34(3)
C(10)	77(3)	82(3)	65(3)	-19(3)	13(2)	-26(3)
C(11)	61(3)	67(3)	70(3)	-16(2)	11(2)	-15(2)
C(12)	56(2)	60(3)	86(3)	-22(2)	9(2)	-8(2)
C(13)	53(2)	64(3)	97(3)	-30(3)	12(2)	-14(2)
C(14)	74(3)	69(3)	88(3)	-25(3)	20(3)	-27(2)
C(15)	43(2)	49(2)	93(3)	-23(2)	-3(2)	-8(2)

C(16)	49(2)	63(3)	97(3)	-33(3)	-1(2)	-6(2)
C(17)	42(2)	48(2)	119(4)	-34(3)	-9(2)	2(2)
C(18)	31(2)	43(2)	101(3)	-23(2)	-10(2)	-2(2)
C(19)	34(2)	46(2)	91(3)	-23(2)	-10(2)	-8(2)
C(20)	32(2)	40(2)	96(3)	-22(2)	-9(2)	-6(2)
C(21)	41(2)	44(2)	186(5)	-11(3)	17(3)	3(2)
C(22)	34(2)	54(2)	121(3)	-17(2)	-12(2)	-6(1)
C(23)	46(2)	61(2)	131(3)	-10(2)	-15(2)	-17(2)
C(24)	52(2)	73(2)	145(3)	-2(2)	-19(2)	-12(2)
C(25)	47(2)	70(2)	150(3)	-14(2)	-13(2)	-8(2)
C(26)	41(2)	78(2)	135(3)	-36(2)	-10(2)	-16(2)
C(27)	35(2)	76(2)	125(3)	-20(2)	-14(2)	-8(2)
C(28)	55(2)	67(3)	133(4)	-30(3)	-2(3)	-16(2)
C(29)	90(3)	79(3)	91(4)	-32(3)	28(3)	-29(3)
C(30)	66(3)	56(2)	94(3)	-12(2)	-24(2)	-10(2)
C(31)	41(2)	33(2)	149(4)	-24(2)	-18(2)	1(2)
C(32)	99(4)	173(6)	55(3)	-4(3)	-12(3)	-56(4)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters (Å^{2}x 10^{-3}) for ojh355_0m.

	x	y	z	U(eq)
H(1)	8737	11461	3262	88
H(2)	11386	11886	3702	94
H(8)	6029	5648	4071	101
H(9)	8671	5960	4538	102
H(16)	1817	12292	2420	82
H(17)	1431	14278	1694	82
H(21A)	6392	8507	1463	110
H(21B)	5970	8546	819	110
H(23)	6189	5992	2045	94
H(24)	6928	3240	2144	108
H(25)	7323	1857	1397	106
H(26)	6883	3042	518	98
H(27)	6112	6004	397	93
H(28A)	812	7374	1722	124
H(28B)	-361	8945	1956	124
H(28C)	-713	7182	2215	124
H(30A)	1673	9352	411	106
H(30B)	2600	9915	-173	106
H(30C)	1046	11127	125	106
H(31A)	77	15554	906	110
H(31B)	1031	16102	324	110
H(31C)	2149	16050	880	110
H(32A)	14365	11637	4043	158
H(32B)	14848	11528	4682	158
H(32C)	12861	12421	4480	158

Table 6. Hydrogen bonds for ojh355_0m [Å and °].

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
C(1)-H(1)...F(1)	0.95	2.58	3.112(5)	115.9
C(1)-H(1)...F(2)	0.95	2.64	3.193(5)	117.9
C(21)-H(21B)...O(1)	0.99	2.56	3.093(5)	113.8
C(32)-H(32A)...F(2)#1	0.98	2.36	3.323(5)	169.3
C(32)-H(32B)...O(4)#2	0.98	2.65	3.522(6)	148.2
C(32)-H(32B)...O(5')#2	0.98	2.52	3.343(13)	141.9
C(32)-H(32C)...O(6)#3	0.98	2.46	3.287(8)	141.5

Symmetry transformations used to generate equivalent atoms:
#1 x+1,y,z #2 -x+3,-y+2,-z+1 #3 -x+2,-y+2,-z+1