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Facile deprotection of F-BODIPYs using methylboronic acid†

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4,4-Difluoro-4-bora-3*a*,4*a*-diaza-*s*-indacenes (F-BODIPYs) are deprotected through removal of the –BF_2 moiety upon treatment with methylboronic acid. The tolerance of various substitution patterns about the dipyrrinato core is demonstrated *via* the deprotection of thirteen F-BODIPYs and an F-aza-BODIPY. Work-up with aq. HBr affords the desired dipyrin HBr salt in quantitative yield without need for purification.

Introduction

The dipyrrinato framework is a useful ligand for complexation to metals, the most common featuring first-row transition metals and boron.[1–4] The photophysical characteristics of –BF_2 complexes of dipyrrins, known widely as 4,4-difluoro-4-bora-3*a*,4*a*-diaza-*s*-indacenes (F-BODIPYs), have enabled applications across many of the chemical sciences.[5–8] For example, F-BODIPYs have been used as dyes to label proteins,[9] DNA[10] and functional materials.[11] Furthermore, the potential of F-BODIPYs for use in photo-assisted rechargeable batteries has been investigated.[12] Recently, efforts have focused on substituting the boron centre of BODIPYs with alkyl, alkynyl and chloro substituents in order to tune spectroscopic properties and thus potentially extend the performance of these conjugated chemical species.[13–25]

Parallel to the photophysical and spectroscopic advances that have involved BODIPYs, dipyrrins have emerged as capable of providing a useful structural framework for incorporation into catalysts,[26–29] supramolecular assembles,[30,31] and polypyrroles with desirable biological activity.[32–35] As such, there is a desire to substitute, functionalise and manipulate dipyrrins, en route to accessing the dipyrrinato ligand. Given the broad range of strategies by which to functionalise F-BODIPYs, as well as the facile manner by which to purify them using chromatography, the use of the –BF_2 moiety has emerged as a useful approach to the protection of dipyrrins.[36–44] Reported methods for the removal of the –BF_2 moiety from F-BODIPYs, *i.e.* deprotection to yield the parent dipyrrin, have involved the use of alkoxides and strong Brønstead and Lewis acids. Herein, we report using methylboronic acid to deprotect thirteen F-BODIPYs and an F-aza-BODIPY to generate the corresponding dipyrrins and aza-dipyrrin in quantitative yield.

Results and discussion

Upon treating an F-BODIPY with methyl boronic acid, with anticipation that an appended boronic ester would be hydrolysed,[45] a dipyrrin was isolated as a result of removal of the –BF_2 unit. Cognisant that these conditions represent a mild alternative to existing methods for the deprotection of F-BODIPYs, and in light of the fact that the volatility of methylboronic acid renders work-up facile, we investigated the scope of the reaction conditions. Treatment of 4,4-difluoro-8-phenyl-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1a**) with 5 equiv. methylboronic acid at room temperature (Table 1) gave clean conversion, after 24 hours, to provide the corresponding dipyrrin **2a** in quantitative yield (entry 1). The incorporation of alkyl groups about the pyrrolic units was well tolerated, as was a methyl substituent in the meso-position (entries 2 and 3, respectively). Work-up using aqueous HBr provided the corresponding dipyrrin salts which are known to be more stable and more crystalline than their HX counterparts, an observation of significant value when storing *meso*-unsubstituted dipyrrins.[4] Using these reaction conditions provided the *meso*-unsubstituted dipyrrin salts **2d** and **2e** in quantitative yield (entries 4 and 5, respectively). The preparation of the HBr salt of **2d** was equally successful on a one-gram scale (entry 4). Furthermore, the corresponding free-base was isolated in quantitative yield, again on a one-gram scale, upon implementation of a basic work-up procedure. The removal of the –BF_2 unit using methylboronic acid was effective for F-BODIPYs bearing unsubstituted positions about the pyrrolic core (entry 6), as well as for unsymmetrical variants (entry 7).

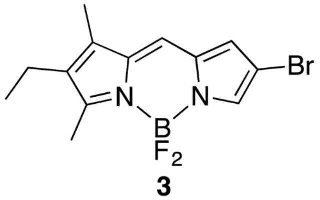

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Fig. 1 Bromo-substituted F-BODIPY.

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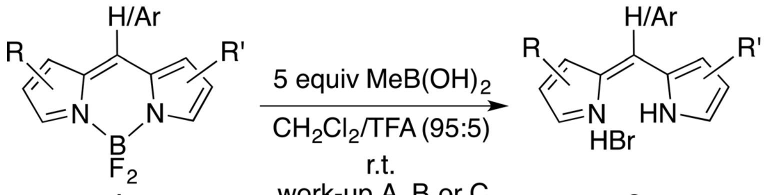
Given the previously documented sternutatory properties of the free base of **2f**,[39] an alternative work-up procedure was implemented so as to ensure successful formation of the corresponding HBr salt. Dipyrrin **2g** was also isolated in quantitative yield upon treatment of 4,4-difluoro-1,3-dimethyl-2-ethyl-6-pinacolatoboron-8-*H*-4-bora-3*a*,4*a*-diaza-*s*-indacene with 5 equiv. methylboronic acid, thereby effecting both deborylation (of the BPin moiety) as well as removal of the –BF$_2$ unit. The new method for the deprotection of F-BODIPYs proceeded in the presence of bromo-substituents, as exemplified by the isolation of quantitative yields of the dipyrrins **2h** and **2i** (entries 8 and 9). Similarly, the dipyrrin **2j** was isolated in quantitative yield upon

Table 1 Substrate scope for the deprotection of F-BODIPYs using methylboronic acid



1 **2**

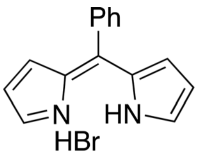
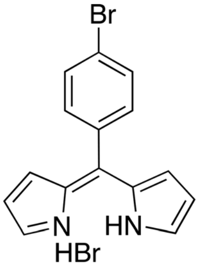
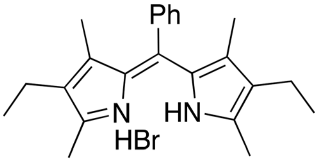
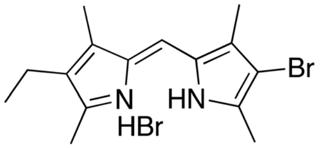
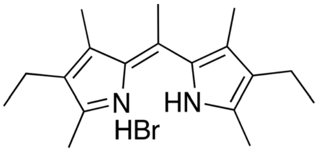
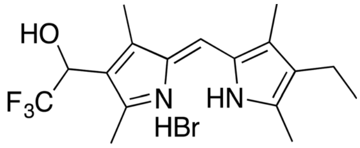
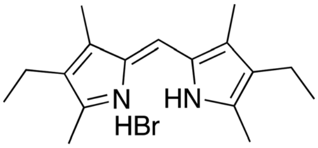
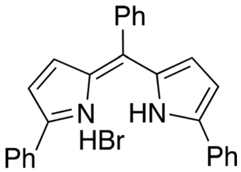
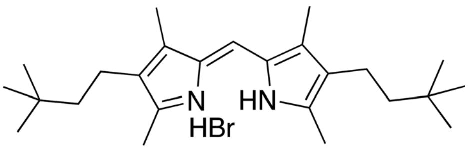
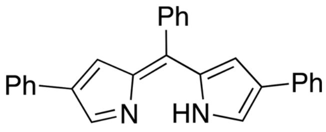
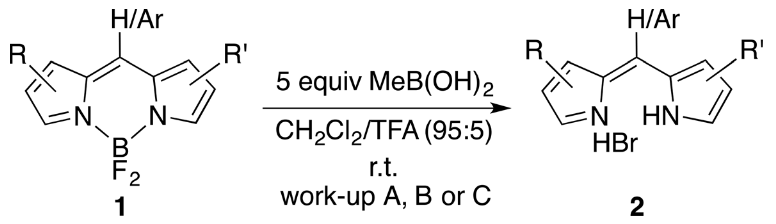
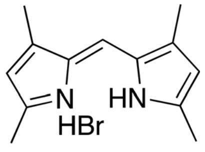
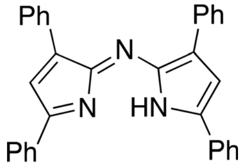
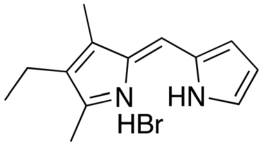
Entry	Product dipyrrin salt yield (%)	Entry	Product dipyrrin salt yield (%)
1	 **2a**, >99%^{a}	8	 **2h**, >99%^{a}
2	 **2b**, >99%^{a}	9	 **2i**, >99%^{b}
3	 **2c**, >99%^{a}	10	 **2j**, >99%^{b}
4	 **2d**, >99%^{a,d,e}	11	 **2k**, >99%^{a}
5	 **2e**, >99%^{a}	12	 **2l**, >99%^{c}

Table 1 (*Contd.*)



Entry	Product dipyrrin salt yield (%)	Entry	Product dipyrrin salt yield (%)
6	 **2f**, >99%^{b,f}	13	 **2m**, >99%^{c}
7	 **2g**, >99%^{a,f}		

[a] Work-up A involved quenching with 2 M aq. HBr. [b] Work-up B involved quenching with 1 M aq. HBr. [c] Work-up C involved quenching with sat. aq. $NaHCO_3$. [d] Work-up involved quenching with 2 M aq. HBr performed on a gram scale. [e] Work-up quenching with sat. aq. $NaHCO_3$ performed on a gram scale. [f] Using work-up A, dipyrrin **2g** was prepared upon treatment of 4,4-difluoro-1,3-dimethyl-2-ethyl-6-pinacolatoboron-8-*H*-4-bora-3*a*,4*a*-diaza-*s*-indacene with 5 equiv. methylboronic thereby effecting both deborylation (of the BPin moiety) in addition to removal of the –BF_2 unit.

treatment of the corresponding F-BODIPY with methylboronic acid, thereby demonstrating tolerance of the hydroxy and trifluoromethyl functionalities within these electron-poor constructs. Further demonstration of the ability of methylboronic acid to deprotect F-BODIPYs bearing aryl substituents involved isolation of the two triphenyl-substituted dipyrrins **2k** and **2l** in quantitative yields (entries 11 and 12, respectively), with **2l** being isolated as its free-base on account of the rather poor solubility of the corresponding HBr salt. Expanding the scope further, an aza-F-BODIPY *i.e.* a bridging nitrogen between the two pyrrolic sub-units, was successfully deprotected to provide the aza-dipyrrin **2m** in quantitative yield (entry 13).

Attempts to reduce the equivalencies of the Lewis acid were briefly explored, resulting in the observation that **2d** could be generated in quantitative yield upon treatment of the corresponding F-BODIPY with just 1 equiv. methylboronic acid. However, this achievement did not extend to the deprotection of F-BODIPYs appended with *meso*-aryl substituents. Despite the successful deprotection of thirteen F-BODIPYs and one F-aza-BODIPY using 5 equiv. methylboronic acid, the bromo-substituted F-BODIPY **3** (Fig. 1) reacted sluggishly to result in decomposition. Equally unsuccessful were attempts to use methylboronic acid to remove the –BF_2 unit from F-BODIPYs bearing carboxylate- or azido- functionality around the dipyrrolic core.

Conclusion

In conclusion, we have developed a high yielding and mild method for the deprotection of F-BODIPYs through the use of volatile methylboronic acid using 5% TFA and CH_2Cl_2 as solvent. The reaction is performed at room temperature, tolerates substrates bearing a range of substituents around the F-BODIPY framework, and requires only a facile work-up procedure in order to isolate quantitative yields of the dipyrrin as either an HBr salt or a free-base.

Experimental section

General information

Reactions involving air-sensitive reagents and dry solvents were performed using glassware that had been oven-dried (150 °C) or flame-dried prior to use. NMR spectra were recorded using a 500 MHz spectrometer. ^{1}H chemical shifts are reported in ppm relative to tetramethylsilane using the solvent residual as an internal standard ($\delta = 7.26$ for $CDCl_3$; 5.32 for CD_2Cl_2; 2.05 for acetone-d_6; 2.50 for DMSO-d_6) ^{13}C NMR chemical shifts are reported in ppm using the residual solvent as an internal standard ($\delta = 77.2$ for $CDCl_3$; 53.8 for CD_2Cl_2; 29.8 for acetone-d_6; 39.5 for DMSO-d_6). Signals in NMR spectra are described as singlet (s), doublet (d), triplet (t), quartet (q), multiplet (m), broad (br.), apparent (app.) or a combination of these, referring to the observed spin–spin coupling pattern. Spin–spin coupling constants are reported in hertz (Hz), and are uncorrected. Mass spectrometry was performed using a TOF spectrometer operating in ESI$^+$ or APCI mode, as indicated. Flash chromatography was performed using forced air flow of the indicated solvent system using silica gel 60 as solid support. Reactions were monitored by thin layer chromatography (TLC) on silica gel 60-covered aluminium sheets. TLC plates were developed under UV-light and/or with an acidic ethanolic anisaldehyde solution, vanillin or a $KMnO_4$-solution upon heating. All reagents were purchased from commercial suppliers and used without further purification unless otherwise stated. F-BODIPYs **1a**,[1] **1b**,[2] **1c**,[3] **1d**,[4] **1f**,[5] **1g**,[6] **2h**,[1] **2j**[7] and **2k**[8] were prepared according to literature procedures, as was F-aza-BODIPY **1m**.[9]

(*Z*)-4-Bromo-2-((4-ethyl-3,5-dimethyl-2*H*-pyrrol-2-ylidene)methyl)-1*H*-pyrrole hydrobromide

Following a modified literature procedure,[10] to a round-bottom flask was added 3-ethyl-2,4-dimethyl-pyrrole (1.73 g, 14.1 mmol) and 4-bromo-pyrrole-2-carbaldehyde (2.44 g, 14.1 mmol). The pyrroles were dissolved in THF : MeOH (1 : 1; 85 mL), and the resulting solution was purged with nitrogen before 48% aq. HBr (3.2 mL, 28 mmol) was added drop-wise to the solution. The reaction mixture was stirred at 70 °C for 2 hours, monitoring by TLC analysis until complete consumption of starting material was observed. The reaction mixture was then poured into diethyl ether (100 mL) to induce precipitation. The resulting solid was collected by suction filtration, and dried to afford the title compound as a brown solid (3.60 g, 71%). ^{1}H NMR (500 MHz; $CDCl_3$) δ (ppm): 13.67 (s, 1H), 13.42 (s, 1H), 7.49 (s, 1H), 7.13 (s, 1H), 7.04 (s, 1H), 2.75 (s, 3H), 2.45 (q, $J = 7.6$ Hz, 2H), 2.30 (s, 3H), 1.09 (t, $J = 7.6$ Hz, 3H); ^{13}C NMR (125 MHz; $CDCl_3$) δ (ppm): 164.9, 146.4, 135.6, 134.7, 130.7, 130.7, 130.3, 127.0, 101.8, 17.4, 14.1, 13.8, 10.4; HRMS-ESI (*m*/*z*): $[M + H]^+$ calcd for $C_{13}H_{16}BN_2$, 279.0491; found, 279.0497.

4,4-Difluoro-1,3-dimethyl-2-ethyl-6-bromo-8-*H*-4-bora-3*a*,4*a*-diaza-*s*-indacene

Following a literature procedure,[4] to a solution of (*Z*)-4-bromo-2-((4-ethyl-3,5-dimethyl-2*H*-pyrrol-2-ylidene)methyl)-1*H*-pyrrole hydrobromide (3.60 g, 10.0 mmol) in CH_2Cl_2 (180 mL) under air with stirring at room temperature, was added NEt_3 (8.4 mL, 60 mmol) and the resulting solution stirred for 10 minutes. Anhydrous $BF_3 \cdot OEt_2$ (11 mL, 90 mmol) was then added and the reaction mixture was sealed with a septum and stirred for 1 hour. The septum was then removed, and another aliquot of NEt_3 (8.4 mL, 60 mmol) was added. The vessel was resealed and stirred for 10 minutes, after which the septum was again removed and another aliquot of anhydrous $BF_3 \cdot OEt_2$ (11.1 mL, 90 mmol) was added. The resulting solution was sealed again and stirred for another 1 hour. The reaction mixture was concentrated *in vacuo* to yield the crude product, which was dissolved in ether (60 mL). The resulting solution washed with 1 M aq. hydrochloric acid (4× 50 mL) and 5 M aq. hydrochloric acid (1× 50 mL). The organic fraction was dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude material was purified *via* column chromatography on silica (hexanes/CH_2Cl_2; 1 : 1) to afford the title compound as a red solid (2.30 g, 62%). ^{1}H NMR (500 MHz; $CDCl_3$) δ (ppm): 7.44 (s, 1H), 7.02 (s, 1H), 6.77 (s, 1H), 2.58 (s, 3H), 2.41 (q, $J = 7.6$ Hz, 2H), 2.19 (s, 3H), 1.09 (t, $J = 7.6$ Hz, 3H); ^{13}C NMR (125 MHz; $CDCl_3$) δ (ppm): 166.2, 142.3, 137.2, 136.1, 136.0, 131.8, 124.4, 122.6, 102.7, 17.4, 14.2, 13.7, 9.7; ^{11}B NMR (160 MHz; $CDCl_3$) δ (ppm): 0.3 (t, $J = 31$ Hz); ^{19}F NMR (470 MHz; $CDCl_3$) δ (ppm): −146.1 (q, $J = 31$ Hz); HRMS-APCI (*m*/*z*): $[M + H]^+$ calcd for $C_{13}H_{15}BBrF_2N_2$, 327.0474; found, 327.0478.

4,4-Difluoro-1,3-dimethyl-2-ethyl-6-pinacolatoboron-8-*H*-4-bora-3*a*,4*a*-diaza-*s*-indacene

A 4 mL screw-top vial was charged with 4,4-difluoro-1,3-dimethyl-2-ethyl-6-bromo-8-*H*-4-bora-3*a*,4*a*-diaza-*s*-indacene (163 mg, 0.5 mmol), $Pd_2(dba)_3$ (5 mg, 5 μmol), XPhos (9 mg, 20 μmol), bis(-pinacolato)diboron (380 mg, 1.50 mmol) and oven dried KOAc (147 mg, 1.50 mmol). The vial was capped with a septum and then evacuated and backfilled with N_2 (this sequence was carried out two times). 1,4-Dioxane (3 mL) was added *via* syringe through the septum. Under a flow of nitrogen, the septum was replaced with a screw cap. The reaction mixture was stirred at 110 °C in a preheated aluminium block until consumption of the F-BODIPY starting material was complete, as judged by TLC analysis (approximately 20 minutes). The reaction mixture was allowed to cool to room temperature and then filtered through a thin pad of Celite, eluting with CH_2Cl_2. The crude material was purified *via* rapid chromatography on silica (hexanes : EtOAc; 8 : 2), with minimal residence time ensured in order to minimise decomposition over the solid phase. The product was crystallised from hexanes to give the title compound as a bench- and air-stable brown solid (113 mg, 60%). ^{1}H NMR (500 MHz; $CDCl_3$) δ (ppm): 7.96 (s, 1H), 7.22 (s, 1H), 7.17 (s, 1H), 2.61 (s, 3H), 2.45 (q, $J = 7.6$ Hz, 2H), 2.24 (s, 3H), 1.36 (s, 12H), 1.12 (t, $J = 7.6$ Hz, 3H); ^{13}C NMR (125 MHz; $CDCl_3$) δ (ppm): 164.2, 145.2, 141.4, 136.9, 135.5, 133.5, 131.8, 123.6, 83.5, 25.0, 17.5, 14.3, 13.5, 9.7, 1× Ar C signal missing; ^{11}B NMR (160 MHz; $CDCl_3$) δ (ppm): 30.4 (br. s) 0.6 (t, $J = 32$ Hz); ^{19}F NMR (470 MHz; $CDCl_3$) δ (ppm): −146.0 (q, $J = 31$ Hz); HRMS-APCI (*m*/*z*): $[M + H]^+$ calcd for $C_{19}H_{27}B_2F_2N_2O_2$, 375.2221; found, 375.2234.

4,4-Difluoro-1,3,5,7-tetramethyl-2-ethyl-6-bromo-8-*H*-4-bora-3*a*,4*a*-diaza-*s*-indacene (1i)

To a 100 mL round-bottom flask, charged with a magnetic stirrer bar, was added 4,4-difluoro-1,3,5,7-tetramethyl-2-ethyl-8-*H*-4-bora-3*a*,4*a*-diaza-*s*-indacene[11] (730 mg, 2.64 mmol) and CH_2Cl_2 (37 mL). To the solution was added *N*-bromosuccinimide (469 mg, 2.64 mmol). The reaction mixture was stirred at room temperature for 1 hour, then quenched with H_2O (30 mL) and extracted with CH_2Cl_2 (3× 50 mL). The combined organic fractions were dried over Na_2SO_4, filtered and concentrated *in vacuo*. The crude material was purified *via* column chromatography on silica (hexanes/CH_2Cl_2; 8 : 2) to afford the title compound as a red solid (906 mg, 97%). ^{1}H NMR (500 MHz; $CDCl_3$) δ (ppm): 6.98 (s, 1H), 2.53 (s, 3H), 2.52 (s, 3H), 2.39 (q, $J = 7.6$ Hz, 2H), 2.19 (s, 3H), 2.17 (s, 3H), 1.07 (t, $J = 7.6$ Hz, 3H); ^{13}C

NMR (125 MHz; $CDCl_3$) δ (ppm): 159.5, 150.8, 139.3, 136.3, 134.1, 133.7, 130.6, 119.5, 107.6, 17.4, 14.5, 13.3, 13.1, 11.0, 9.6; ^{11}B NMR (160 MHz; $CDCl_3$) δ (ppm): 0.7 (t, J = 33 Hz); ^{19}F NMR (470 MHz; $CDCl_3$) δ (ppm): −146.4 (q, J = 33 Hz); HRMS-APCI (*m*/*z*): $[M + H]^+$ calcd for $C_{15}H_{19}BBrF_2N_2$, 355.0787; found, 355.0781.

General procedure (GP) for the deprotection of F-BODIPYs using $MeB(OH)_2$

A 4 mL screw-top vial was charged with F-BODIPY (0.2 mmol) and $MeB(OH)_2$ (1.0 mmol). To this was added CH_2Cl_2 (1.90 mL) and trifluoroacetic acid (0.10 mL). The vial was capped with a screw cap and the mixture was stirred until F-BODIPY had been completely consumed as judged by analysis using TLC (typically stirred for 24 hours).

Work-up A. The reaction mixture was transferred to a separatory funnel using CH_2Cl_2, quenched with 2 M aq. hydrobromic acid (40 mL) and the aqueous phase then extracted with CH_2Cl_2 (3× 40 mL). The combined organic extracts were dried over Na_2SO_4 and volatiles were then removed *in vacuo* to afford the dipyrrin HBr salt.

Work-up B. The reaction mixture was transferred into a 100 mL round-bottomed flask using CH_2Cl_2 and all volatiles removed *in vacuo*. To the 100 mL round-bottomed flask was added 1 M aq. hydrobromic acid (40 mL) which was then removed under reduced pressure, followed by the addition of CH_2Cl_2. After filtration of the resulting mixture, volatiles were removed *in vacuo* to afford the dipyrrin HBr salt.

Work-up C. The reaction mixture was transferred to a separatory funnel using CH_2Cl_2 and to the resulting solution was added sat. aq. $NaHCO_3$ (40 mL). The mixture was extracted with CH_2Cl_2 (3× 40 mL), the combined organic extracts dried over Na_2SO_4 and volatiles removed *in vacuo* to afford the dipyrrin as a free base.

(*Z*)-2-(Phenyl(2*H*-pyrrol-2-ylidene)methyl)-1*H*-pyrrole hydrobromide (2a)

Following the GP and work-up A, using 4,4-difluoro-8-phenyl-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1a**),[6] provided the title compound as a brown solid (60 mg, >99%). ^1H NMR (500 MHz; $CDCl_3$) δ (ppm): 13.43 (br. s, 2H), 8.09 (br. s, 2H), 7.64 (s, 1H), 7.51–7.45 (m, 4H), 6.81 (s, 2H), 6.63 (s, 2H); ^{13}C NMR (125 MHz; $CDCl_3$) δ (ppm): 149.9, 143.9, 136.7, 133.9, 132.1, 131.6, 131.3, 128.2, 117.5; HRMS-ESI (*m*/*z*): $[M + H]^+$ calcd for $C_{15}H_{13}N_2$, 221.1073; found, 221.1073.

(*Z*)-3-Ethyl-5-((4-ethyl-3,5-dimethyl-2*H*-pyrrol-2-ylidene)(phenyl)methyl)-2,4-dimethyl-1*H*-pyrrole hydrobromide (2b)

Following the GP and work-up A, using 4,4-difluoro-1,3,5,7-tetramethyl-2,6-diethyl-8-phenyl-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1b**),[2] provided the title compound as a red solid (82 mg, > 99%).^1H NMR (500 MHz; $CDCl_3$) δ (ppm): 11.01 (br. s, 2H), 7.59 (t, J = 7.3 Hz, 1H), 7.48 (t, J = 7.3 Hz, 2H), 7.30 (d, J = 7.4 Hz, 2H), 2.70 (br. s, 6H), 2.41–2.35 (m, 4H), 1.36 (br. s, 6H), 1.06–1.03 (m, 6H); ^{13}C NMR (125 MHz; $CDCl_3$) δ (ppm): 152.4, 144.2, 140.1, 137.1, 133.7, 131.8, 128.7, 129.0, 17.5, 14.5, 13.7, 12.3, 1× aryl signal missing; HRMS-ESI (*m*/*z*): $[M + H]^+$ calcd for $C_{23}H_{29}N_2$, 333.2325; found, 333.2323.

(*Z*)-3-Ethyl-5-(1-(4-ethyl-3,5-dimethyl-2*H*-pyrrol-2-ylidene)ethyl)-2,4-dimethyl-1*H*-pyrrole hydrobromide (2c)

Following the GP and work-up A, using 4,4-difluoro-1,3,5,7,8-pentamethyl-2,6-diethyl-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1c**),[3] provided the title compound as a brown solid (70 mg, > 99%). ^1H NMR (500 MHz; $CDCl_3$) δ (ppm): 11.82 (br. s, 2H), 2.87 (s, 3H), 2.54 (s, 6H), 2.39 (q, J = 7.4 Hz, 4H), 2.05 (s, 6H), 1.05 (t, J = 7.4 Hz, 6H); ^{13}C NMR (125 MHz; $CDCl_3$) δ (ppm): 149.2, 146.7, 137.1, 132.2, 131.5, 25.0, 17.6, 14.5, 12.7, 12.4. Data correspond to literature values.[12]

(*Z*)-3-Ethyl-5-((4-ethyl-3,5-dimethyl-2*H*-pyrrol-2-ylidene)methyl)-2,4-dimethyl-1*H*-pyrrole hydrobromide (2d)

Following the GP and work-up A, using 4,4-difluoro-1,3,5,7-tetramethyl-2,6-diethyl-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1d**),[4] provided the title compound as a brown solid (67 mg, > 99%). ^1H NMR (500 MHz; $CDCl_3$) δ (ppm): 12.87 (br. s, 2H), 7.01 (s, 1H), 2.64 (s, 6H), 2.40 (q, J = 7.6 Hz, 4H), 2.25 (s, 6H), 1.05 (t, J = 7.6 Hz, 6H); ^{13}C NMR (125 MHz; $CDCl_3$) δ (ppm): 153.7, 141.3, 130.6, 126.1, 118.7, 17.3, 14.5, 12.8, 10.1. Data correspond to literature values.[13]

(*Z*)-3-(3,3-Dimethylbutyl)-5-((4-(3,3-dimethylbutyl)-3,5-dimethyl-2*H*-pyrrol-2-ylidene)methyl)-2,4-dimethyl-1*H*-pyrrole hydrobromide (2e)

Following the GP and work-up A, using, 4-difluoro-1,3,5,7-tetramethyl-2,6-(3,3-dimethylbutyl)-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1e**), provided the title compound as a red solid (90 mg, > 99%). ^1H NMR (500 MHz; CD_2Cl_2) δ (ppm): 12.92 (br. s, 2H), 7.06 (s, 1H), 2.59 (s, 6H), 2.36–2.33 (m, 4H), 2.27 (s, 6H), 1.28–1.25 (m, 4H), 0.97 (s, 18H); ^{13}C NMR (125 MHz; CD_2Cl_2) δ (ppm): 153.4, 141.5, 129.5, 126.0, 118.7, 44.0, 30.3, 28.8, 19.1, 12.5, 10.3; HRMS-ESI (*m*/*z*): $[M + H]^+$ calcd for $C_{25}H_{41}N_2$, 369.3264; found, 369.3278.

(*Z*)-2-((3,5-Dimethyl-2*H*-pyrrol-2-ylidene)methyl)-3,5-dimethyl-1*H*-pyrrole hydrobromide (2f)

Following the GP and work-up B, using 4,4-difluoro-1,3,5,7-tetramethyl-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1f**),[2] provided the title compound as a red solid (56 mg, > 99%). ^1H NMR (500 MHz; $CDCl_3$) δ (ppm): 13.06 (br. s, 2H), 7.07 (s, 1H), 6.14 (s, 2H), 2.66 (s, 6H), 2.34 (s, 6H); ^{13}C NMR (125 MHz; $CDCl_3$) δ (ppm): 155.6, 146.1, 126.8, 120.1, 117.6, 14.6, 12.3. Data correspond to literature values.[14] Caution: the free-base of **2f** has been reported to exhibit sternutatory properties.[7]

(*Z*)-2-((4-Ethyl-3,5-dimethyl-2*H*-pyrrol-2-ylidene)methyl)-1*H*-pyrrole hydrobromide (2g)

Following the GP and work-up A, using 4,4-difluoro-1,3-dimethyl-2-ethyl-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1g**),[15] provided the title compound as a red solid (56 mg, > 99%). ^1H NMR (500

MHz; CDCl$_3$) δ (ppm): 13.50 (br. s, 1H), 13.31 (br. s, 1H), 7.65 (s, 1H), 7.21 (s, 1H), 7.09 (s, 1H), 6.47 (s, 1H), 2.73 (s, 3H), 2.43 (q, J = 7.5 Hz, 2H), 2.29 (s, 3H), 1.08 (t, J = 7.5 Hz, 3H); ^{13}C NMR (125 MHz; CDCl$_3$) δ (ppm): 162.0, 145.4, 137.6, 133.6, 132.1, 129.3, 127.3, 124.8, 114.6, 17.3, 14.2, 13.6, 10.3. Data correspond to literature values.[10]

Alternatively, following the GP and work-up A using 4,4-difluoro-1,3-dimethyl-2-ethyl-6-pinacolatoboron-8-*H*-4-bora-3*a*,4*a*-diaza-*s*-indacene provided the title compound as a red solid (56 mg, > 99%). Data as above.

(*Z*)-2-((4-Bromophenyl)(2*H*-pyrrol-2-ylidene)methyl)-1*H*-pyrrole hydrobromide (2h)

Following the GP and work-up A, using 4,4-difluoro-8-(phenyl(4-bromo))-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1h**),[7] provided the title compound as a red solid (76 mg, > 99%).^{1}H NMR (500 MHz; CDCl$_3$) δ (ppm): 13.48 (br. s, 2H), 8.10 (br. s, 2H), 7.66 (d, J = 6.3 Hz, 2H), 7.29 (br. s, 2H), 6.81 (br. s, 2H), 6.65 (s, 2H); ^{13}C NMR (125 MHz; CDCl$_3$) δ (ppm): 148.2, 144.4, 136.3, 135.3, 133.5, 131.6, 131.0, 126.6, 117.8.

(*Z*)-3-Bromo-5-((4-ethyl-3,5-dimethyl-2*H*-pyrrol-2-ylidene)methyl)-2,4-dimethyl-1*H*-pyrrole hydrobromide (2i)

Following the GP and work-up B, using 4,4-difluoro-1,3,5,7-tetramethyl-2-ethyl-6-bromo-8-*H*-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1i**), provided the title compound as a red solid (78 mg, > 99%). ^{1}H NMR (500 MHz; CDCl$_3$) δ (ppm): 13.20 (br. s, 2H), 7.08 (s, 1H), 2.67 (s, 3H), 2.64 (s, 3H), 2.42 (q, J = 7.6 Hz, 2H), 2.32 (s, 3H), 2.29 (s, 3H), 1.07 (t, J = 7.6 Hz, 3H); ^{13}C NMR (125 MHz; CDCl$_3$) δ 158.2, 150.3, 143.7, 141.1, 132.3, 127.4, 124.8, 119.8, 106.6, 17.4, 14.3, 13.4, 13.2, 11.9, 10.3; HRMS-ESI (*m*/*z*): $[M + H]^+$ calcd for C$_{15}$H$_{20}$BrN$_2$, 307.0804; found, 307.0803.

(*Z*)-1-(2-((4-Ethyl-3,5-dimethyl-1*H*-pyrrol-2-yl)methylene)-3,5-dimethyl-2*H*-pyrrol-4-yl)-2,2,2-trifluoroethanol hydrobromide (2j)

Following the GP and work-up B, using 4,4-difluoro-1,3,5,7-tetramethyl-2-trifluoroethanol-6-ethyl-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1j**),[7] provided the title compound as a red solid (81 mg, > 99%). ^{1}H NMR (500 MHz; acetone-d$_6$) δ (ppm): 13.75 (br. s, 1H), 13.53 (br. s, 1H), 7.44 (s, 1H), 5.86 (d, J = 5.0 Hz, 1H), 5.39–5.33 (m, 1H), 2.72 (s, 3H), 2.69 (s, 3H), 2.51 (q, J = 7.5 Hz, 2H), 2.46 (s, 3H), 2.39 (s, 3H), 1.11 (t, J = 7.5 Hz, 3H); ^{13}C NMR (125 MHz; acetone-d$_6$) δ (ppm): 158.5, 152.5, 145.0, 144.0, 132.8, 128.1, 126.4 (q, J = 281 Hz), 125.9, 121.4, 110.8, 66.8 (q, J = 33 Hz), 17.6, 14.5, 13.3, 12.8, 10.6, 10.1; ^{19}F NMR (470 MHz; acetone-d$_6$) δ (ppm): −78.4 (d, J = 7.6 Hz). Data correspond to literature values.[16]

(*Z*)-2-Phenyl-5-(phenyl(5-phenyl-2*H*-pyrrol-2-ylidene)methyl)-1*H*-pyrrole hydrobromide (2k)

Following the GP and work-up C, using 4,4-difluoro-2,5,8-triphenyl-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1k**),[8] provided the title compound as a red solid (90 mg, > 99%). ^{1}H NMR (500 MHz; acetone-d$_6$) δ (ppm): 13.05 (br. s, 2H), 8.36–8.29 (m, 4H), 7.74 (t, J = 7.2 Hz, 1H), 7.62 (t, J = 7.6 Hz, 2H), 7.57 (d, J = 7.4 Hz, 2H), 7.53–7.50 (m, 6H), 7.33 (s, 2H), 7.20–6.90 (m, 2H); ^{13}C NMR (125 MHz; acetone-d$_6$) δ (ppm): 154.6, 147.2, 137.8, 135.8, 135.1, 134.8, 133.5, 131.7, 130.0, 129.8, 129.5, 129.2, 117.9; HRMS-ESI (*m*/*z*): $[M + H]^+$ calcd for C$_{27}$H$_{21}$N$_2$, 373.1699; found, 373.1702.

(*Z*)-4-Phenyl-2-(phenyl(4-phenyl-2*H*-pyrrol-2-ylidene)methyl)-1*H*-pyrrole (2l)

Following the GP and work-up C, using 4,4-difluoro-3,6,8-triphenyl-4-bora-3*a*,4*a*-diaza-*s*-indacene (**1l**), provided the title compound as a dark blue solid (74 mg, >99%). ^{1}H NMR (500 MHz; DMSO-d$_6$) δ (ppm): 8.28 (s, 2H), 7.62–7.57 (m, 9H), 7.36–7.33 (m, 4H), 7.23–7.20 (m, 2H), 6.76 (s, 2H); HRMS-ESI (*m*/*z*): $[M + H]^+$ calcd for C$_{27}$H$_{21}$N$_2$, 373.1699; found, 373.1699. The title compound was insufficiently soluble to enable the acquisition of ^{13}C NMR data.

(*Z*)-*N*-(3,5-Diphenyl-2*H*-pyrrol-2-ylidene)-3,5-diphenyl-1*H*-pyrrol-2-amine (2m)

Following the GP and work-up C, using 4,4-difluoro-1,3,5,7-tetraphenyl-4-bora-3*a*,4*a*,8-triaza-*s*-indacene (**1m**),[9] provided the title compound as a dark blue solid (90 mg, >99%). ^{1}H NMR (500 MHz; CDCl$_3$) δ (ppm): 8.07 (d, J = 7.3 Hz, 4H), 7.96 (d, J = 7.4 Hz, 4H), 7.54 (t, J = 7.5 Hz, 4H), 7.48 (d, J = 7.4 Hz, 2H), 7.43 (t, J = 7.5 Hz, 4H), 7.36 (t, J = 7.3 Hz, 2H), 7.21 (s, 2H); ^{13}C NMR (125 MHz; CDCl$_3$) δ (ppm): 155.3, 149.8, 142.8, 133.9, 132.4, 130.2, 129.3, 129.2, 128.4, 128.2, 126.7, 115.1. Data correspond to literature values.[17]

Conflicts of interest

The authors declare no competing financial interest.

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