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# Synthesis, Chiroptical Properties, and Solid-State Structure Determination of Two New Chiral Dipyrrin Difluoroboryl Chelates

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***Abstract:*** Two new types of optically active BODIPY fluorophores bearing chiral phenyl substituents either at the *meso*-position or at both external α-positions have been synthesized. Their chiroptical properties are strongly dependent both on the position of the chiral group and on the protonation of the chromophore. The solid-state structures of one of the difluoroboryl chelates bearing the chiral phenyl substituent at the *meso*-position (**9a**) as well as of the corresponding ligand (**8a**) and its perchlorate have been determined by X-ray diffraction analysis. These are, to the best of our knowledge, the first crystal structures of a dipyrrin free base and of a dipyrrin salt which have been obtained by X-ray diffraction analysis. Hence, for the first time, the helical structure of a protonated dipyrrin chromophore has been proved experimentally.

Because of their photochemical stability and exceptional spectral properties, particularly their high absorption coefficients ($\epsilon_{max} \approx 7 \times 10^4$ to $10^5$ L mol$^{-1}$ cm$^{-1}$ at $\lambda_{max} \geq 500$ up to 630 nm[1]) and high quantum yields of emission ($\Phi > 0.5$),[2−12] dipyrrin difluoroboryl chelates (4,4-difluoro-4-bora-3a,4a-diaza-*s*-indacenes), which are marketed under the trade name BODIPY,[13] have multiple applications in chemistry and biology. Thus, they have been used as fluorescent probes for proton[1,14−18] and metal ions detection,[19,20] as well as for DNA sequencing[21−23] and for the study of dynamics, structure, and function of biological systems such as monosaccharides,[24] lipid membranes,[5,25−27] and proteins.[5,27,28] Moreover, BODIPY chromophores are used in chromatography,[29] as dopants in liquid crystals,[30] as laser dyes,[31−37] and as constitutive elements in optoelectronic devices.[7,14,38−49] Recently, the chiroptical properties of chiral

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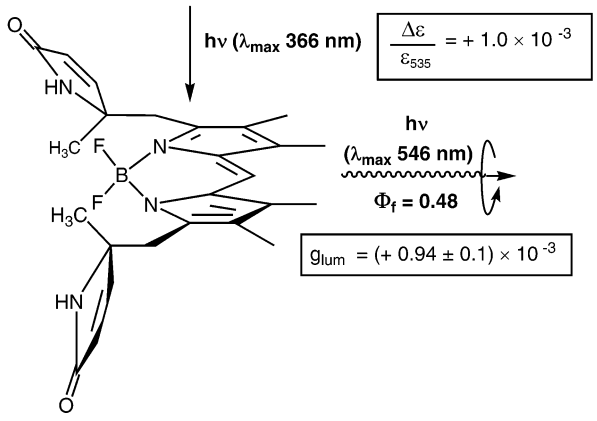


***Figure 1.*** Both light absorption and fluorescence emission of urobilinoid $BF_3$ complexes are strongly circular polarized.

BODIPY fluorophores[46] and their use in enantiomeric discrimination[50] have been reported.

Within the scope of our work on the optical activity of urobilins (a class of bile pigments, which possess the dipyrrin chromophore), some chiral difluoroboron complexes were synthesized which display an extremely high circular polarization of both light absorption and photoluminescence (Figure 1).[51] The latter property could be of particular interest for the analysis of enantiomeric mixtures as it enables the characterization of a particular chromophore not only by the wavelength of emitted light but also by the sign of its Cotton effect. Moreover, chiral fluorophores emitting circular polarized light have practical use within different sensor systems[52] and in light-emitting diodes (LED)[53] as well.

In fact, the high optical dissymmetry of the dipyrrin chromophore which has been observed in urobilin difluoroboryl complexes is surprising because the chromophore in such metal chelates is planar, as it was proved in our own work by X-ray diffraction analysis. A possible explanation for this phenomenon could be that the origin of the circular polarization of these compounds is a "chiral perturbation" of the inherently achiral boron complexing dipyrrin chromophore rather than an inherent dissymmetric chromophore, as suggested by Moscowitz et al. more than 40 years ago.[54] In agreement with this hypothesis are the high rotational strength ($\Delta\epsilon_{max} \approx 100$) of the (achiral) protobiliverdin IX$\gamma$ chromophore, which occurs in the cabbage butterfly (*Pieris brassicae* L.) bound to an apoprotein,[55] as well as the high optical activity ($[\alpha]^{20}_D = -2370°$) of the planar chiral metacycloprodigiosin (a metabolite of *Streptomyces longisporus ruber*), in alkaline solution.[56]

In view of a better understanding of the chiroptical properties of "chirally perturbed" dipyrrin chromophores, a systematic study of a series of structurally more simple derivatives than the urobilins would be suitable. Thus, the present work deals with such a study of dipyrrin difluoroboryl chelates, in which the symmetry-breaking moiety is a phenyl ring bearing a chiral substituent at the *ortho* position. As a chiral substituent on the phenyl ring, which is attached either at the *meso*-C-atom (compounds **9a** and **9b**) or at both α-positions of the dipyrrin chromophore (compound **15**), the (trifluoromethyl)methoxymethyl group was chosen because of its firmly established dissymmetrizing effect.[57]

## Experimental Results

**BODIPY Fluorophores with a Chiral Substituent at the *meso*-Position.** The synthesis of the dipyrrin difluoroboryl chelates **9a** and **9b** was carried out following the conventional route by condensation of ethyl[58,59] or benzyl[60] 3,4-dimethylpyrrole-2-carboxylate with 2-(2,2,2-trifluoro-1-methoxyethyl) benzaldehyde (**6**) to yield dipyrrylmethanes **7a** and **7b**, respectively (cf. ref 61), which were subsequently oxidized with 3,5-dichloro-2,6-dicyano-*p*-benzoquinone (DDQ) to the corresponding dipyrrin derivatives **8a** and **8b**, respectively, a procedure which has been reported to be particularly suitable for the synthesis of 5-aryldipyrrins.[62] Subsequent chelation of **8a**/**b** with boron trifluoride etherate[63] afforded the desired fluorophores **9a**/**b** (cf. Scheme 1).

Optically active **6** was synthesized in six conventional steps starting with the known[65] ethylene acetal of *o*-bromobenzaldehyde. Resolution of racemic 2-[2-(2,2,2-trifluoro-1-hydroxyethyl)phenyl]dioxolane (**3**) was carried out by fractional crystallization of the corresponding ester of (−)-ω-camphanic acid according to the procedure reported by Jurczak et al. for the resolution of 2,2,2-trifluoro-1-phenylethanol.[66] The thus obtained pure diastereomer (+)-**4** (ee: >98% as determined by $^1$H NMR spectroscopy) yielded, on recrystallization from diethyl ether, crystals in a suitable quality for X-ray diffraction analysis, which enabled one to establish the relative configuration of all asymmetric C-atoms present in the molecule (cf. Figure 2). Because the absolute configuration of (−)-ω-camphanic acid

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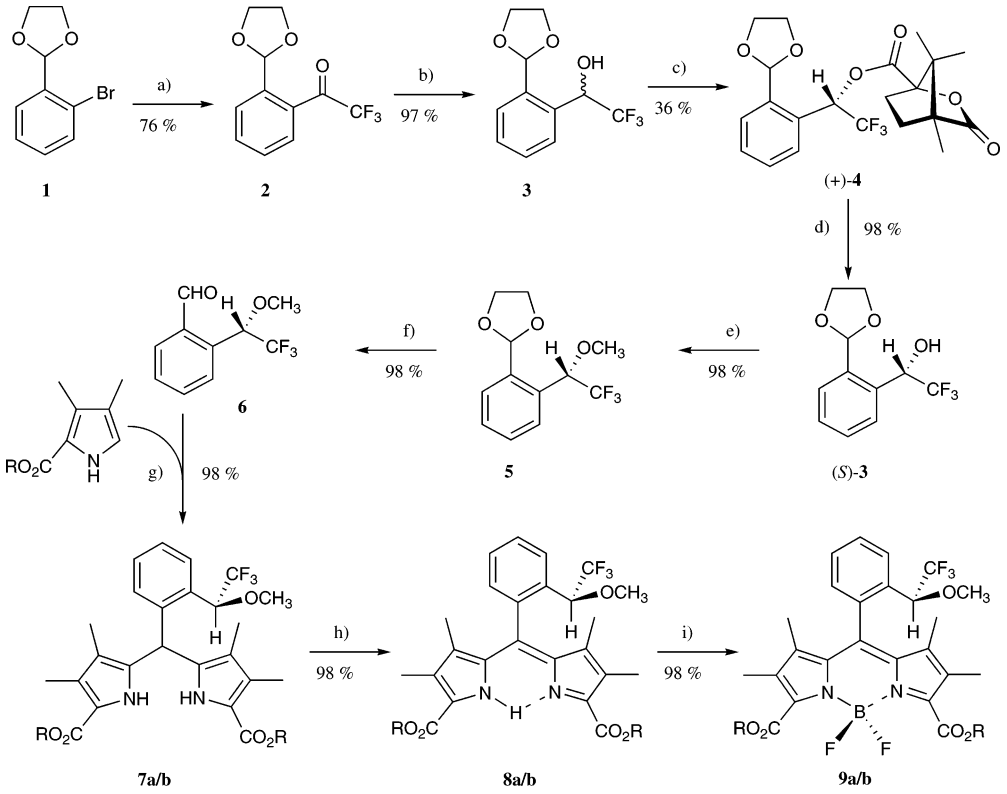
***Scheme 1*** [a]




**a**: R = $C_2H_5$; **b**: R = $CH_2$-$C_6H_5$

[a] (a) $C_4H_9Li$ in THF, then $F_3C-CO_2C_2H_5$ (cf. ref 64); (b) $NaBH_4$ in $H_3COH$; (c) (−)-camphanic acid chloride in pyridine, then fractional crystallization; (d) NaOH in methanol; (e) $AgO_2/ICH_3$; (f) HCl in THF; (g) $BF_3{\cdot}O(C_2H_5)_2$ in $CH_2Cl_2$; (h) DDQ in $CH_2Cl_2$; (i) $BF_3{\cdot}O(C_2H_5)_2$/diisopropylamine in $CH_2Cl_2$.

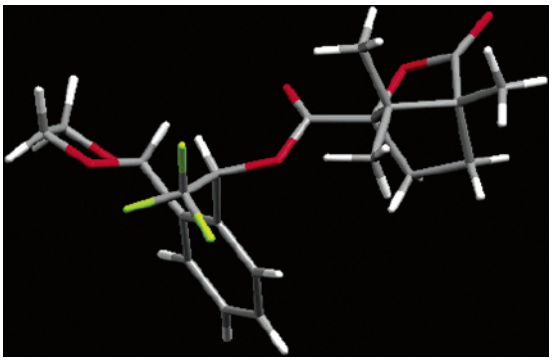


***Figure 2.*** Molecular structure of (+)-2-[2-(2,2,2-trifluoro-1-hydroxyethyl)-phenyl] dioxolane camphanoate (**(+)-4**) as obtained from X-ray diffraction analysis.

has been unequivocally determined to be 1*S*,4*R*,[67] the (*S*)-configuration must be assigned to the chiral phenyl substituent in the dextrorotatory ester **4**. Alkaline hydrolysis of the latter yielded optically active dioxolane (*S*)-**3**, which was transformed into the corresponding methyl ether **5** to avoid intramolecular nucleophilic addition of the hydroxy group to the aldehyde group after deprotection of the latter. On tratement with acid, **5** was transformed into the desired *o*-[(2,2,2-trifluoro-1-methoxy)ethyl] benzaldehyde (**6**). Like the corresponding methyl ether of (*S*)-2,2,2-trifluoro-1-phenylethanol,[68] the (*S*)-enantiomer of **6** is dextrorotatory ($[\alpha]^{20}_D = +128.8°$).

**BODIPY Fluorophores with Chiral Substituents at the α-Positions.** Although a straightforward synthesis of 1,5,9-triaryldipyrrins as ligands for BODIPY dyes has been reported recently,[6] a synthesis using aldehyde **6**, as a starting material, seemed to be more appropriate for our purpose because its absolute configuration had been unequivocally established as described above. Thus, optically active **6** was reacted with the Grignard derivative of 2-(2-bromoethyl)-1,3-dioxolane according to the procedure given in ref 69 to yield carbinol **10**, as a mixture of epimers, which, on oxidation, was transformed into a single enantiomer of ketone **11**. Deprotection of the aldehyde group of **11** and subsequent reaction with ammonium acetate according to the conditions of Paal-Knorr's synthesis of pyrroles (cf. ref 70) yielded the α-arylpyrrole **12**, which on reaction with bezaldehyde was transformed into dipyrrylmethane **13**. As before, the latter was subsequently oxidized with DDQ to the corresponding dipyrrin derivative **14**, which was reacted with boron trifluoride etherate to yield the desired $BF_2$ complex **15** (cf. Scheme 2).

## Discussion

The magnitude of the Cotton effect in the optically active dipyrrin difluoroboryl chelates **9a** and **9b** described in the present work is considerably lower than that in the case of the urobilin derivatives previously decribed[51] (cf. Figures 3 and 4).

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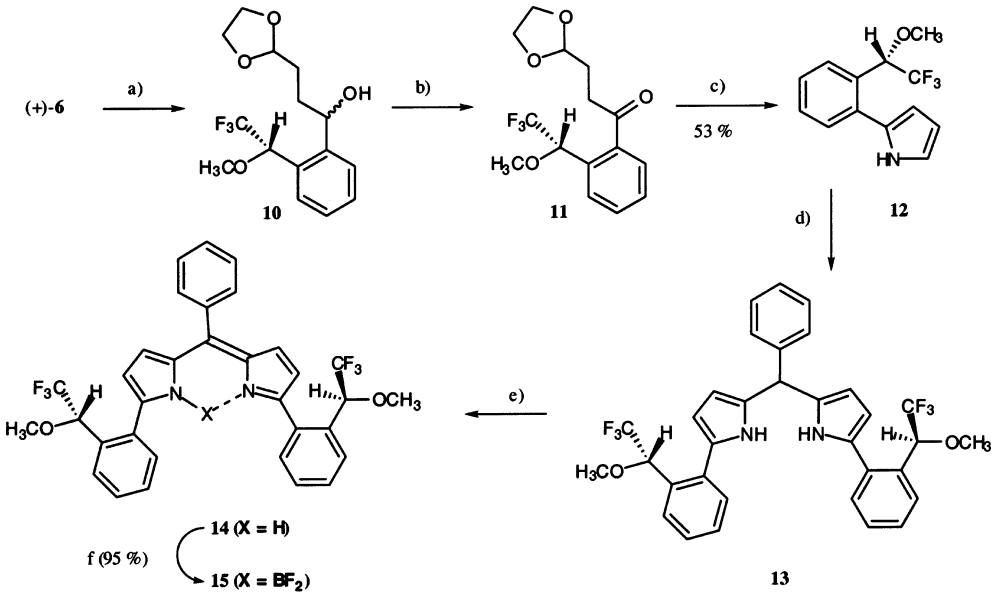
***Scheme 2*** [a]




[a] (a) 1,3-Dioxolan-1-yl-$(CH_2)_2BrMg$ in THF; (b) PCC in $CH_2Cl_2$; (c) $AcONH_4$ in AcOH; (d) $C_6H_5CHO$ in $CH_2Cl_2$; (e) DDQ in $CH_2Cl_2$; (f) $BF_3{\cdot}O(C2H_5)_2$/$Et_3N$ in $CH_2Cl_2$.

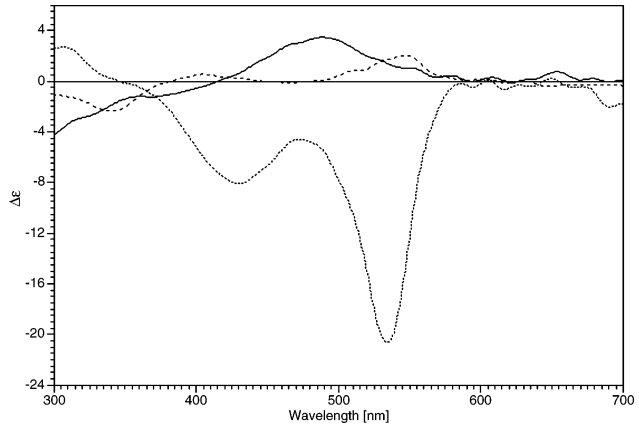



***Figure 3.*** CD spectra of **8a** (—), its conjugated acid (· · ·), and the corresponding difluoroboryl chelate **9a** (- - -), all in $CH_2Cl_2$.

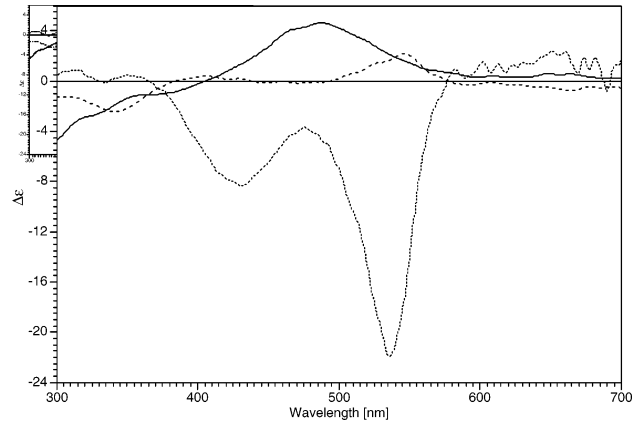



***Figure 4.*** CD spectra of **8b** (—), its conjugated acid (· · ·), and the corresponding difluoroboryl chelate **9b** (- - -), all in $CH_2Cl_2$.

As expected, the X-ray diffraction analysis of the boron chelate **9b** confirms that the corresponding dipyrrin chromophore is planar (cf. Figure 5). Therefore, the "chiral perturbation" introduced by the asymmetric substituent on the phenyl ring at

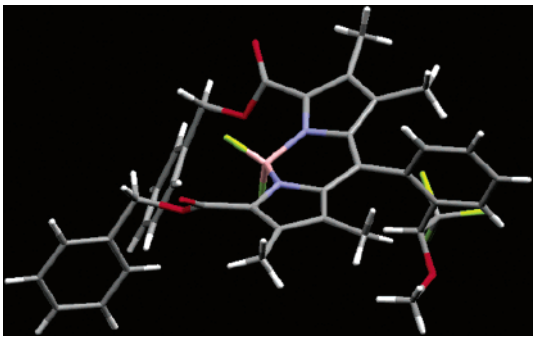


***Figure 5.*** Molecular structure of **9a** as obtained from X-ray diffraction analysis.

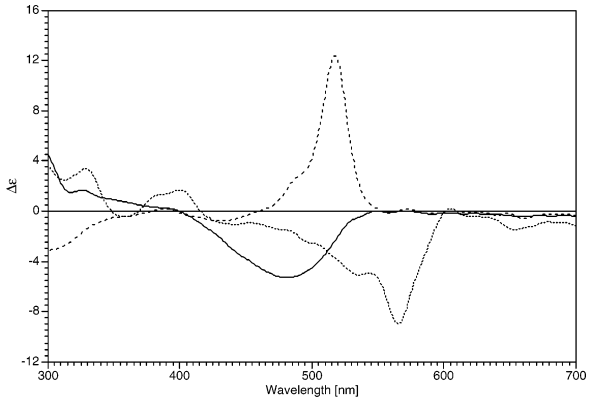



***Figure 6.*** CD spectra of **14** (—), its conjugated acid (· · ·), and the corresponding difluoroboryl chelate **15** (- - -), all in $CH_2Cl_2$.

the *meso* (C5)-position seems to be less important than that of the asymmetric centers C4 and C16 in urobilin derivatives. On the other hand, difluoroboryl complex **15** (Figure 6), in which the perturbing chiral centers are located — like in the urobilins — at the ends of the chromophore, displays a Cotton effect of a magnitude comparable to that of the difluoroboryl chelate of mesourobilin IIIα-8,12-despropionic acid, although its specific rotation ($[\alpha]^{20}_D = +720°$ vs $-2940°$) is less spectacular.

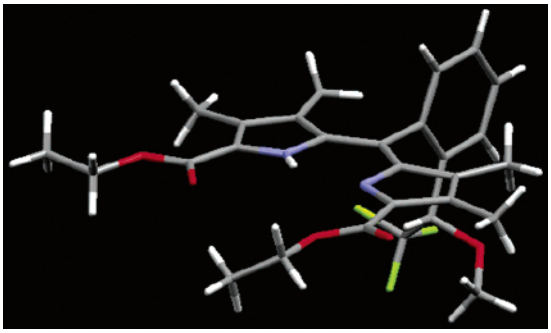


***Figure 7.*** Molecular structure of **8a** as obtained from X-ray diffraction analysis.

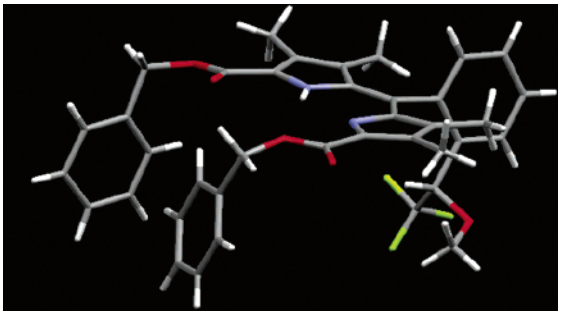


***Figure 8.*** Molecular structure of **8b** as obtained from X-ray diffraction analysis.

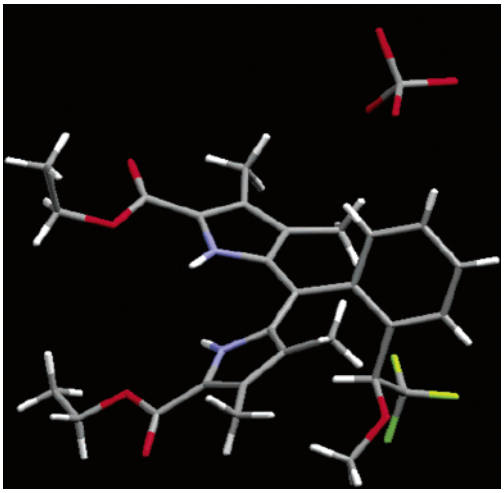


***Figure 9.*** Molecular structure of **8a** perchlorate as obtained from X-ray diffraction analysis.

Also, the corresponding ligands (**8a**/**b** and **14**) display weak Cotton effects (cf. Figures 3, 4, and 6, respectively). According to the X-ray diffraction analysis of **8a** and **8b** (cf. Figures 7 and 8, respectively), their molecules are essentially planar in the solid state. In acidic solution, however, the protonated dipyrrin chromophores of **8a** and **8b** show strong Cotton effects, which are of sign opposite to those of the corresponding free bases and difluoroboryl chelates (cf. Figures 3 and 4). The highest specific rotation ($[\alpha]^{20}_D = -4892°$) was found for compound **8a**; it corresponds to the values measured in the urobilin series for *N*-protonated species. As revealed by X-ray diffraction analysis, the conjugated acid of **8a** is, at least in the solid state, markedly twisted clockwise (cf. Figure 9), so that evidently the high rotational strength of the inherent dissymmetric chromophore, which is actually opposite to that of (*P*)-helicene, is superimposed to that of the chiral substituent on the *meso*-position of the dipyrrin molecule. This is in agreement with Moscowitz's interpretation of the optical activity of urobilinoids. It is noteworthy, however, that in the case of compound **14** both the free base and its conjugated acid display CD curves of the same sign, whereas the corresponding difluoroboryl chelate shows an opposite Cotton effect.

Unfortunately, in the urobilin series neither the structure of the free bases nor that of their corresponding conjugated acids has been proven, until now, by X-ray diffraction analysis, so that a comparison with the results obtained in the present work relies on the assumption that the structures of their chromophores in basic and acidic medium, respectively, resemble those of more simple substituted dipyrrins. As a matter of fact, the structures depicted in Figures 7−9 are, to the best of our knowledge, the first crystal structures of dipyrrin free bases (**9a**/**b**) and of a dipyrrin salt (Figure 9), which have been obtained by X-ray diffraction analysis.

From the present work, it must be concluded that both a "chiral perturbation" of an inherently planar dipyrrin chromophore and a twisting deformation of the latter may give rise to high optical activity of the corresponding derivatives. However, to understand the relationship between the structural and optical dissymmetry of this class of compounds, a larger number of compounds of unequivocally determined structure is necessary. Therefore, the syntheses of further dipyrrin difluoroboryl chelates analogous to **9a**/**b** and **14** bearing more efficient chiral substituents on the phenyl rings are currently in progress.

## Experimental Section

**Materials.** Solvents for chemical reactions and chromatography were generally dried and distilled prior to use. All air- and water-sensitive reactions were carried out under Ar. Reactions were monitored by thin-layer chromatography (TLC) on Merck silica gel 60 $F_{254}$ (0.2 mm) precoated aluminum foils. Column chromatography (CC) and flash chromatography (FC) were done on silica gel 60 (0.063−0.200 mm, 700−230 mesh) and silica gel 60 (0.040−0.063 mm, 230−400 mesh), respectively, from E. Merck AG. Dimethylformamide (DMF), trifluoroacetic acid (TFA), tetrahydrofuran (THF), 2,3-dichloro-5,6-dicyano-*p*-benzoquinone (DDQ), and other reagents were purchased from Fluka Chemie AG (CH-9471 Buchs, Switzerland).

**Instruments.** Melting points (mp) were determined with a hot stage apparatus (Thermovar, C. Reichert AG, Vienna) equipped with a digital thermometer. UV/vis spectra were recorded in $CH_2Cl_2$ on a Hewlett-Packard 8452A diode-array or a Perkin-Elmer Lambda 40 spectrometer; $\lambda_{max}$ (log $\epsilon$) in nm. Specific optical rotations ($[\alpha]^{20}_D$) were measured on a Perkin-Elmer 241-MC polarimeter, and CD spectra were measured in a CD spectropolarimeter Jasco J-715. Wavelengths ($\lambda$) and band amplitudes ($\Delta\epsilon_{max}$) are quoted in nm and L mol$^{-1}$ cm$^{-1}$, respectively. Quantum yields of fluorescence ($\Phi$) were measured, relative to rhodamine 6G ($\Phi = 0.88$ in ethanol), as standard, on a Perkin-Elmer MPF-4 fluorescence spectrophotometer. NMR (in $CDCl_3$): Bruker Avance DRX 500 ($^1$H, 500.13 MHz; $^{13}$C, 125.76 MHz); $^1$H and $^{13}$C chemical shifts ($\delta$) are given in ppm relative to $Me_4Si$ as internal standard, *J* values in Hz. Assignments are based on homonuclear COSY-45, $^1$H{$^1$H} NOE difference correlations, and/or chemical shifts. $^{13}$C signal multiplicities were determined by attached proton test (APT) experiments. Mass spectra: EI-MS (electron ionization, 70 eV) and ESI-MS (electrospray ionization, positive mode) were measured on HP 5988 A and Bruker 4.7T BioAPEX II instruments, respectively. Combustion analyses were carried out by Ilse Beetz, Microanalytical Laboratory, Kronach (Germany).

**X-ray diffraction analyses** were carried out, except for compound **(+)-4**, at 153(2) K on a Stoe Image Plate Diffraction System[71] equipped with a two-circle goniometer using Mo Kα ($\lambda = 0.71073$ Å) graphite-monochromated radiation. Intensity data for **(+)-4** were collected at room temperature (293 K) on a Stoe AED2 four-circle diffractometer using Cu Kα graphite-monochromated radiation ($\lambda = 1.54186$ Å). The structures were solved by direct methods using the program SHELXS-97.[72] H-atoms were included in calculated positions and treated as riding atoms using SHELXL default parameters. H-atoms bound to N were located from difference Fourier maps and refined isotropically. $F^2$ refinements and all further calculations were carried out using SHELXL-97.[73] The non-H atoms were refined anisotropically, using weighted full-matrix least-squares on $F^2$.

**Crystal Data for (+)-4.** $C_{21}H_{23}F_3O_6$, $M = 428.39$, colorless plates (0.53 × 0.38 × 0.13 mm). Crystal cell parameters were determined from ±ω values of 26 reflections and their equivalents in the range 10.60° < Θ < 23.15°: orthorhombic, *P* 21 21 21, $a = 6.3446(5)$ Å, $b = 11.1480(8)$ Å, $c = 28.869(2)$ Å, $V = 2041.9(3)$ Å$^3$, $Z = 4$; density (calc.) = 1.394 g cm$^{-3}$; of 4035 measured reflections, 2852 were independent and 2714 were observed with $I > 2\sigma(I)$. R1 = 0.0378, wR2 = 0.1001 for 364 parameters.

**Crystal Data for 8a.** $C_{28}H_{31}F_3N_2O_5$, $M = 532.55$, red rods (0.30 × 0.20 × 0.20 mm). Crystal cell parameters were determined from ±ω values of 8000 reflections and their equivalents in the range 2.04° < Θ < 25.96°: monoclinic, *C*2, $a = 24.694(2)$ Å, $b = 12.3509(7)$ Å, $c = 18.4241(14)$ Å, $\beta = 111.657(9)°$, $V = 5222.6(7)$ Å$^3$, $Z = 8$; density (calc.) = 1.355 g cm$^{-3}$; of 20 771 measured reflections, 9161 were independent and 6915 were observed with $I > 2\sigma(I)$. R1 = 0.0345, wR2 = 0.0709 for 693 parameters. In the crystal, there are two independent molecules per asymmetric unit which stack head-to-tail and are almost parallel to each other with a separation of ca. 3.46(1) Å.

**Crystal Data for 8a Perchlorate.** $C_{28}H_{32}F_3N_2O_5$, $ClO_4$, $M = 633.01$, red rods (0.50 × 0.07 × 0.07 mm). Crystal cell parameters were determined from ±ω values of 6667 reflections and their equivalents in the range 1.59° < Θ < 24.95°: monoclinic, *P* 2$_1$, $a = 9.7201(14)$ Å, $b = 11.7883(12)$ Å, $c = 12.7055(19)$ Å, $\alpha = \gamma = 90°$, $\beta = 91.197(12)°$, $V = 1455.5(3)$ Å$^3$, $Z = 2$; density (calc.) = 1.444 g cm$^{-3}$; of 10 183 measured reflections, 4619 were independent and 3155 were observed with $I > 2\sigma(I)$. R1 = 0.0485, wR2 = 0.0855 for 397 parameters.

**Crystal Data for 8b.** $C_{38}H_{35}F_3N_2O_5$, $M = 656.68$, red blocks (0.35 × 0.25 × 0.15 mm). Crystal cell parameters were determined from ±ω values of 3227 reflections and their equivalents in the range 2.17° < Θ < 25.98°: triclinic, *P*1, $a = 11.2174(13)$ Å, $b = 12.3780(14)$ Å, $c = 12.8428(14)$ Å, $\alpha = 74.290(13)°$, $\beta = 72.683(13)°$, $\gamma = 84.530(14)°$, $V = 1638.6(3)$ Å$^3$, $Z = 2$; density (calc.) = 1.331 g cm$^{-3}$; of 13 057 measured reflections, 10 792 were independent and 2775 were observed with $I > 2\sigma(I)$. R1 = 0.0459, wR2 = 0.0767 for 865 parameters.

**Crystal Data for 9b.** $C_{38}H_{34}BF_5N_2O_5$, $M = 704.48$, red blocks (0.30 × 0.25 × 0.25 mm). Crystal cell parameters were determined from ±ω values of 8000 reflections and their equivalents in the range 1.91° < Θ < 25.93°: triclinic, *P*-1 (No. 2), $a = 12.5290(8)$ Å, $b = 14.5853(10)$ Å, $c = 20.0347(14)$ Å, $\alpha = 77.050(8)°$, $\beta = 81.031(8)°$, $\gamma = 73.014(8)°$, $V = 3396.3(4)$ Å$^3$, $Z = 4$; density (calc.) = 1.378 g cm$^{-3}$; of 26 913 measured reflections, 12 336 were independent and 4725 were observed with $I > 2\sigma(I)$. R1 = 0.0794, wR2 = 0.1865 for 945 parameters.

**1-[2-(1,3-Dioxolan-2-yl)phenyl]-2,2,2-trifluoro-1-ethanone (2).** A solution of **1**[65] (4.6 g, 20 mmol) in dry THF (100 mL) was cooled to −78 °C under Ar, and 14 mL of 1.6 M *n*-buthyllithium in hexane was added dropwise. A white precipitate separated during the addition. After being stirred for 15 min at about −70 °C, the mixture was transferred to an addition funnel and added dropwise to a cooled (−78 °C) solution of ethyl trifluoracetate (3.13 g, 22 mmol) in 50 mL of dry THF. The mixture was then allowed to warm to room temperature, diluted with water, and extracted with $CH_2Cl_2$. The organic layer was dried ($Na_2SO_4$), and the solvent was removed in a rotary evaporator to yield 4.05 g (82%) of crude product which was purified by CC (hexane/AcOEt 5:1): 3.76 g (76%) of colorless liquid **2**. $^1$H NMR: 7.66, 7.59, 7.51, 7.48 (4 m, 4H), 6.22 (s, CH), 3.99 (m, $CH_2$), 3.88 (m, $CH_2$). $^{13}$C NMR: 185.3 (q, $J_{C,F} = 36$, C=O), 138.6 (arom. C-(2)), 130.9 (arom. C-(1)), 131.6, 128.5, 127.0, 126.9 (4 arom. CH), 115.6 (q, $J_{C,F} = 291$, $CF_3$), 100.8 (CH), 64.3 (2 $CH_2$). EI-MS: 247 (54, M + 1), 246 (5, $M^+$), 203 (100), 186 (59), 182 (41), 177 (12), 155 (37), 151 (14), 149 (8), 133 (85), 105 (44), 77 (48). ESI-MS (exact mass): 247.0572 ([M + H]$^+$, calc. for $C_{11}H_{10}F_3O_3^+$: 247.0576).

**1-[2-(1,3-Dioxolan-2-yl)phenyl]-2,2,2-trifluoro-1-ethanol (3).** A solution of **2** (3.5 g, 14.2 mmol) in dry MeOH (50 mL) was cooled to 10 °C, and $NaBH_4$ (0.53 g, 14 mmol) was added portionwise over 10 min. The mixture was stirred for 1 h at room temperature, poured into water (500 mL), and extracted with $Et_2O$. The combined organic layer was washed (brine), dried over $MgSO_4$, and evaporated: 3.44 g (97%) of colorless highly viscous oil *rac*-**3**. $^1$H NMR: 7.67−7.60 (m, 2 arom. H), 7.47−7.39 (m, 2 arom. H), 6.02 (s, CH), 5.57 (dq, $J = 4.8, 6.9$, CH), 4.19−4.01 (m, 4H, $CH_2CH_2$), 3.32 (d, $J = 4.8$, OH). $^{13}$C NMR: 135.8 (arom. C-(2)), 133.2 (arom. C-(1)), 129.6, 129.3, 128.1, 126.8 (4 arom. CH), 124.5 (q, $J_{C,F} = 282$, $CF_3$), 101.8 (CH), 68.8 (q, *J*C,F = 32, *C*HCF$_3$), 65.2, 65.1 (2 $CH_2$). EI-MS: 248 (2, $M^+$), 247 (12, M − 1), 230 (42), 203 (4), 167 (6), 155 (8), 149 (26), 133 (11), 105 (16), 73 (100). ESI-MS (exact mass): 271.0554 ([M + Na]$^+$, calc. for $C_{11}H_{11}F_3O_3Na^+$: 271.0553).

**(1*S*)-1-[2-(1,3-Dioxolan-2-yl)phenyl]-2,2,2-trifluoroethyl 4,7,7-trimethyl-3-oxo-2-oxabicyclo[2.2.1]heptane-1-carboxylate (4).** To a solution of *rac*-**3** (3.4 g, 13.7 mmol) in dry pyridine (30 mL) was added (−)-camphanic acid chloride (3.4 g, 15.7 mmol) at 5 °C. The mixture was stirred overnight at room temperature, then diluted with water (100 mL), and finally extracted with $CH_2Cl_2$. The combined extract was washed with water, dried over $MgSO_4$, and evaporated. The residue of crude ester (5.7 g, 97%) was dissolved in ether (100 mL), and the solution was cooled overnight at −15 °C. The resulting crystalline fraction was recrystallized twice from an *n*-hexane/ether mixture: 2.2 g of pure (*S*)-**4**. Crystals suitable for X-ray analysis were grown from a solution of $Et_2O$ by slow evaporation. Mp 136−137 °C. $[\alpha]^{20}_D$ = +8.5° ($c = 3.45$, $CH_2Cl_2$). ee: >98% (determined by $^1$H NMR). $^1$H NMR: 7.63 (m, 2 arom. H), 7.46 (m, 1 arom. H), 7.43 (m, 1 arom. H), 7.03 (q, $J = 6.6$, CH), 6.09 (s, CH), 4.23−4.03 (m, 4H, $CH_2CH_2$), 2.43 (m, 1H), 2.05 (m, 1H), 1.95 (m, 1H), 1.70 (m, 1H), 1.12 (s, $CH_3$), 1.09 (s, $CH_3$), 0.91 (s, $CH_3$). $^{13}$C NMR: 178.0 (C=O), 165.8 (C=O), 137.4 (arom. C-(2)), 129.5 (arom. C-(1)), 130.5, 129.8, 128.9, 127.7 (4 arom. CH), 123.6 (q, $J_{C,F} = 282$, $CF_3$), 102.2 (CH), 91.01 (C(1′)), 68.5 (q, $J_{C,F} = 34$, *C*HCF$_3$), 65.6, 65.5 (2 $CH_2$), 55.2, 55.0 (C(4′), C(7′)), 31.0, 29.3 (C(5′), C(6′)), 17.0, 16.8 (2 $H_3$C−C(7′), 10.0 ($H_3$C−C(4′)). ESI-MS (exact mass): 451.1339 ([M + Na]$^+$, calc. for $C_{21}H_{23}F_3O_6Na^+$: 451.1339).

**(1*S*)-1-[2-(1,3-Dioxolan-2-yl)phenyl]-2,2,2-trifluoro-1-ethanol ((*S*)-3).** To a solution of **4** (2.1 g, 4.9 mmol) in MeOH (5 mL) was added 10% aqueous NaOH solution (25 mL). The mixture was refluxed for 2 h, then diluted with water (100 mL), and extracted with $Et_2O$. The combined extract was washed (brine), dried over $MgSO_4$, and evaporated: 1.16 g (95%) of colorless highly viscous oil (*S*)-**3**. $[\alpha]^{20}_D$ = +33.1° ($c = 3.75$, $CH_2Cl_2$). ee: >98% (determined by $^1$H NMR in *R*(−)-1-(9-anthryl)-2,2,2-trifluoroethanol as chiral additive).

**2-{2-[(1*S*)-2,2,2-Trifluoro-1-methoxyethyl]phenyl}-1,3-dioxolane (5).** To a solution of (*S*)-**3** (1.1 g, 4.4 mmol) in $CH_3I$ (8 mL) was added silver oxide (2.1 g). The mixture was refluxed for 3 h, then diluted with $Et_2O$ (50 mL), and filtered. The solid was extracted with three 20-mL portions of $Et_2O$. The combined organic solutions were

(71) *IPDS* Software 2000, Stoe & Cie. GmbH, Darmstadt, Germany.
(72) Sheldrick, G. M. *Acta Crystallogr*. **1990**, *A46*, 467−473.
(73) Sheldrick, G. M. *SHELXL-97*; Universität Göttingen, Germany.

evaporated, and the yellow residue was distilled in a Kugelrohr apparatus (120 °C, 0.05 mbar): 1.05 g (90%) of colorless liquid. (*S*)-**5**. $[\alpha]^{20}_D = +84.6°$ ($c = 4.61$, $CH_2Cl_2$). $^1$H NMR: 7.67−7.59 (m, 2 arom. H), 7.48−7.38 (m, 2 arom. H), 6.00 (s, CH); 5.26 (q, $J = 6.6$, CH), 4.20−4.00 (m, 4H, $CH_2CH_2$), 3.38 (s, $OCH_3$). $^{13}$C NMR: 137.5 (arom. C-(2)), 131.8 (arom. C-(1)), 129.8, 129.7, 128.7, 126.8 (4 arom. CH), 124.4 (q, $J_{C,F} = 282$, $CF_3$), 101.9 (CH), 76.6 (q, $J_{C,F} = 31$, *C*HCF$_3$), 65.6, 65.4 (2 $CH_2$), 58.1 ($CH_3$). EI-MS: 262 (4, $M^+$), 261 (15, M − 1), 247 (7), 230 (100), 217 (13), 203 (23), 193 (8), 187 (23), 167 (12), 155 (19), 149 (28), 133 (40), 121 (23), 119 (19), 109 (26), 105 (16), 91 (26), 73 (66), 45 (69). ESI-MS (exact mass): 285.0708 ($[M + Na]^+$, calc. for $C_{12}H_{13}F_3O_3Na^+$: 285.0709).

**2-[(1*S*)-2,2,2-Trifluoro-1-methoxyethyl]benzaldehyde (6).** To a solution of (*S*)-**5** (1.0 g, 3.8 mmol) in THF/$H_2O$ (2:1) (25 mL) were added five drops of concentrated HCl (35%). The mixture was stirred overnight at room temperature, then diluted with water (300 mL), and finally extracted with $Et_2O$. The combined extract was washed with 10% $NaHCO_3$ solution and brine, dried ($MgSO_4$), and evaporated: 0.80 g (96%) of colorless liquid. (*S*)-**6**. $[\alpha]^{20}_D = +128.8°$ ($c = 6.46$, $CH_2Cl_2$). $^1$H NMR: 10.1 (s, CHO), 7.87, 7.81, 7.68, 7.63 (4 m, 4 arom. H), 6.00 (q, $J = 6.4$, CH), 3.46 (s, $OCH_3$). $^{13}$C NMR: 193.4 (*C*HO), 135.0 (arom. C-(2)), 134.6 (arom. C-(1)), 134.9, 134.2, 130.0, 129.5 (4 arom. CH), 124.1 (q, $J_{C,F} = 282$, $CF_3$), 76.0 (q, $J_{C,F} = 31$, *C*HCF$_3$), 59.0 ($OCH_3$). EI-MS: 218 (4, $M^+$), 203 (55), 198 (100), 186 (73), 183 (53), 158 (58), 155 (76), 149 (25), 138 (22), 133 (96), 127 (73), 119 (57), 109 (62), 105 (54), 91 (71), 89 (40), 77 (63), 69 (26), 63 (42), 51 (60). ESI-MS (exact mass): 241.0446 ($[M + Na]^+$, calc. for $C_{10}H_9F_3O_2Na^+$: 241.0447).

**Diethyl (*S*)-5-{2-[2,2,2-Trifluoro-1-methoxyethyl)phenyl]-5,11-dihydro-2,3,7,8-tetramethyl-10*H*-dipyrrin-1,9-dicarboxylate (7a).** Freshly distilled $BF_3$·$OEt_2$ (100 $\mu$L, 0.8 mmol) was added under Ar to a mixture of 420 mg (1.92 mmol) of (*S*)-**6** and 700 mg (4.18 mmol) of ethyl 3,4-dimethylpyrrol-2-carboxylate[58] in dry $CH_2Cl_2$ (5 mL). The solution was stirred for 12 h at room temperature, diluted with $CH_2Cl_2$ (200 mL), washed with aqueous 10% $NaHCO_3$ solution and water, dried ($MgSO_4$), and evaporated. The residue was purified by FC ($CH_2Cl_2$): 925 mg (90%) of (*S*)-**7a**. $[\alpha]^{20}_D = -170.0°$ ($c = 1.00$, $CH_2Cl_2$). $^1$H NMR: 8.18 (s, NH), 8.01 (s, NH), 7.61 (d, $J = 7.6$, 1H, arom. H), 7.38 (td, $J = 7.5$, 1.4, 1 arom. H), 7.34 (td, $J = 7.5$, 1.4, 1H, arom. H), 6.84 (dd, $J = 7.8$, 1.4, 1H, arom. H), 5.69 (s, CH), 4.58 (q, $J = 6.4$, CH), 4.33−4.16 (m, 2 × $CH_2$), 2.84 (s, $OCH_3$), 2.27, 2.26, 1.86, 1.72 (4s, 4 × $CH_3$), 1.34, 1.30 (2t, $J = 7.1$, 2 × $CH_3$). $^{13}$C NMR: 162.35, 162.00 (2 CO), 139.21, 131.65, 130.95, 130.38, 128.29, 128.20, 119.15, 118.92, 118.70, 118.48 (10 arom. C), 130.67, 129.29, 128.82, 128.69 (4 arom. CH), 124.44 (q, $J_{C,F} = 282$, $CF_3$), 76.82 (q, $J_{C,F} = 31$, *C*HCF$_3$), 60.54, 60.43 (2 × $CH_2$), 58.00 ($OCH_3$), 37.86 (CH), 15.01, 14.91, 11.19, 11.07, 9.03, 8.87 (6 × $CH_3$). ESI-MS (exact mass): 535.2417 ($[M + H]^+$, calc. for $C_{28}H_{34}F_3N_2O_5^+$: 535.2414).

**Dibenzyl (*S*)-5-{2-[2,2,2-trifluoro-1-methoxyethyl)phenyl]-5,11-dihydro-2,3,7,8-tetramethyl-10*H*-dipyrrin-1,9-dicarboxylate (7b)** was synthesized by the same procedure as described for **7a** starting with 240 mg (1.1 mmol) of (*S*)-**6** and 520 mg (2.26 mmol) of benzyl 3,4-dimethylpyrrol-2-carboxylate.[59] After the mixture was stirred for 7 h at room temperature, the yield of pure **7b** amounted to 435 mg (60%). $[\alpha]^{20}_D = -150.9°$ ($c = 3.20$, $CH_2Cl_2$). $^1$H NMR: 8.17 (s, NH), 7.99 (s, NH), 7.60 (d, $J = 7.7$, 1 arom. H), 7.44−7.27 (m, 12 arom. H), 6.83 (d, $J = 7.8$, 1 arom. H), 5.68 (s, CH), 5.28, 5.27 (2d, $J = 12.6$, $CH_2$), 5.28, 5.19 (2d, $J = 12.6$, $CH_2$), 4.56 (q, $J = 6.4$, CH), 2.81 (s, $OCH_3$), 2.27, 2.26, 1.84, 1.70 (4s, 4 $CH_3$). $^{13}$C NMR: 161.5, 161.2 (2 × CO), 138.5, 136.5, 136.2, 131.1, 130.8, 118.2, 118.3, 118.2, 117.9 (9 arom. C), 130.2, 128.9, 128.6, 128.5, 128.4, 128.2, 128.1, 128.0, 127.9, 127.8 (10 arom. CH), 123.9 (q, $J_{C,F} = 282$, $CF_3$), 76.4 (q, $J_{C,F} = 31$, *C*HCF$_3$), 65.8, 65.7 (2 $CH_2$), 57.5 ($OCH_3$), 37.5 (CH), 10.8, 10.7, 8.6, 8.4 (4 $CH_3$). ESI-MS (exact mass): 659.2724 ($[M + H]^+$, calc. for $C_{38}H_{38}F_3N_2O_5^+$: 659.2727).

**Diethyl (*S*)-5-{2-[2,2,2-Trifluoro-1-methoxyethyl)phenyl]-2,3,7,8-tetramethyl-10*H*-dipyrrin-1,9-dicarboxylate (8a).** To a solution of **7a** (900 mg, 1.68 mmol) in benzene (10 mL) was added DDQ (386 mg, 1.7 mmol) in $CH_2Cl_2$ (20 mL). The mixture was stirred for 3 h at room temperature. The reaction mixture was evaporated to dryness, and the residue was purified by FC (*n*-hexane/AcOEt, 4:1) to yield 655 mg (73%) of **8a**, as a dark-red solid, which was recrystallized from *n*-hexane. Mp 139.5−141.5 °C. Crystals suitable for X-ray analysis were grown from a solution of *n*-hexane by slow evaporation of the solvent. UV/vis ($CH_2Cl_2$): 470 (4.35). UV/vis ($CH_2Cl_2$ + HCl): 399 (4.08), 534 (4.80). CD ($3.92 \times 10^{-5}$ M, $CH_2Cl_2$): 489 (+3.4). CD ($1.96 \times 10^{-5}$ M, $CH_2Cl_2$ + HCl): 534 (−21). $[\alpha]^{20}_D = +471°$ ($c = 1.79 \times 10^{-2}$, $CH_2Cl_2$). $[\alpha]^{20}_D = -4892°$ ($c = 1.79 \times 10^{-3}$, $CH_2Cl_2$ + HCl). $^1$H NMR: 13.29 (br. s, NH), 7.75 (br. d, $J = 8.0$, 1 arom. H), 7.57 (td, $J = 7.6$, 1.5, 1 arom. H), 7.50 (td, $J = 7.6$, 1.4, 1 arom. H), 7.31 (ddd, $J = 7.8$, 1.4, 0.5, 1 arom. H), 4.52 (q, $J = 6.6$, CH), 4.42 (q, $J = 7.1$, 2 $CH_2$), 3.24 (s, $OCH_3$), 2.15 (d, $J = 0.5$, $CH_3$), 2.12 (d, $J = 0.5$, $CH_3$), 1.46, 1.45 (2t, $J = 7.1$, 2 $CH_3$), 1.20, 1.21 (2s, 2 $CH_3$). $^{13}$C NMR: 163.04, 162.69 (2 CO), 146.30, 141.86, 141.75, 140.94, 139.55, 138.56, 137.31, 136.86, 133.234, 13214, 131.10, (11 quarternary C), 130.34, 130.10, 129.94, 129.47 (4 arom. CH), 125.06 (q, $J_{C,F} = 285$, $CF_3$), 78.15 (q, $J_{C,F} = 31$, *C*HCF$_3$), 61.39, 61.31 (2 $CH_2$), 60.70 ($OCH_3$), 14.87, 14.86, 12.30, 11.44, 10.86, 10.72 (6 $CH_3$). ESI-MS (exact mass): 533.2261 ($[M + H]^+$, calc. for $C_{28}H_{32}F_3N_2O_5^+$: 533.2258). A sample (25 mg) of **8a**, dissolved in $CH_2Cl_2$ (50 mL), was transformed into the corresponding perchlorate by shaking the solution with 15% aqueous $HClO_4$. The organic layer was dried over $Na_2SO_4$, and the residue obtained after evaporation of the solvent was dissolved in 1 mL of $CH_2Cl_2$, pentane was added (5 mL), and the solution was cooled overnight at 0−5 °C. Crystals suitable for X-ray analysis were obtained by recrystallization from $CH_2Cl_2$/*n*-pentane. Mp 207−210 °C (dec). Anal. Calcd for $C_{28}H_{32}ClF_3N_2O_9$ (633.01): C, 53.12; H, 5.10; N, 4.43. Found: C, 53.30; H, 5.03; N, 4.42.

**Dibenzyl (*S*)-5-{2-[2,2,2-trifluoro-1-methoxyethyl)phenyl]-2,3,7,8-tetramethyl-10*H*-dipyrrin-1,9-dicarboxylate (8b)** was synthesized by the same procedure as described for **8a** starting with 350 mg (0.53 mmol) of **7b**. After purification by FC ($CH_2Cl_2$), 235 mg (67%) of **8b** was obtained, as a dark-red solid, which was recrystallized from $CHCl_3$/*n*-hexane. Mp 140−141 °C. UV/vis ($CH_2Cl_2$): 472 (4.32). UV/vis ($CH_2Cl_2$ + HCl): 402 (4.09), 536 (4.81). CD ($5.74 \times 10^{-5}$ M, $CH_2Cl_2$): 488 (+4.6). CD ($1.28 \times 10^{-5}$ M, $CH_2Cl_2$ + HCl): 535 (−22). $[\alpha]^{20}_D = +520°$ ($c = 4.22 \times 10^{-3}$, $CH_2Cl_2$). $[\alpha]^{20}_D = -4330°$ ($c = 5.75 \times 10^{-3}$, $CH_2Cl_2$ + HCl). $^1$H NMR: 13.37 (s, NH), 7.75 (br. d, $J = 7.9$, 1 arom. H), 7.57 (td, $J = 7.5$, 1.4, 1 arom. H), 7.50 (td, $J = 7.5$, 1.3, 1 arom. H), 7.46 (m, 4 arom. H), 7.38−7.28 (m, 7 arom. H), 5.33, 5.27 (2d, $J = 12.6$, $CH_2$), 5.32, 5.26 (2d, $J = 12.6$, $CH_2$), 4.51 (q, $J = 6.5$, CH), 3.24 (s, $OCH_3$), 2.14, 2.12, 1.20, 1.19 (4s, 4 $CH_3$). $^{13}$C NMR: 162.34, 161.96 (2 × CO), 145.74, 141.69, 141.37, 140.15, 139.10, 138.28, 136.78, 136.36, 136.13, 136.11, 132.77, 131.88, 130.83 (13 quarternary C), 129.90, 129.65, 129.50, 129.01 (4 arom. CH), 128.53 (2 arom. CH), 128.52 (2 arom. CH), 128.08 (2 arom. CH), 128.05 (2 arom. CH), 128.00 (2 arom. CH), 124.58 (q, $J_{C,F} = 285$, $CF_3$), 77.69 (q, $J_{C,F} = 31$, *C*HCF$_3$), 66.31, 66.24 (2 $CH_2$), 60.25 ($OCH_3$), 11.83, 10.97, 10.46, 10.32 (4 $CH_3$). ESI-MS (exact mass): 657.2573 ($[M + H]^+$, calc. for $C_{38}H_{36}F_3N_2O_5^+$: 657.2570).

**Diethyl (*S*)-8-[2-(2,2,2-Trifluoro-1-methoxyethyl)phenyl]-1,2,6,7-tetramethyl-4,4-difluoro-4-bora-3a,4a-diaza-*s*-indacene-3,5-dicarboxylate (9a).** A solution of **8a** (53.3 mg, 0.10 mmol) in dry $CH_2Cl_2$ (5 mL) was cooled under Ar to 0 °C before 0.2 mL of *N*,*N*-diisopropylethylamine was added. After 2 min of stirring, freshly distilled $BF_3$·$OEt_2$ (1 mL) was added dropwise, during 2 min. After 20 min, the same portions of *N*,*N*-diisopropylethylamine and $BF_3$·$OEt_2$ were added likewise, and, thereafter, the pink-red strongly fluorescent mixture was stirred for 30 min at 0 °C before it was diluted with $CH_2Cl_2$ (80 mL), washed with $H_2O$ (2 × 50 mL), dried ($MgSO_4$), and evaporated. The residue was purified by two successive FC (AcOEt/

hexane 1:1), to yield 44 mg (77%) of the $BF_2$ chelate of **9a**, as a dark-red solid, which was recrystallized from *n*-hexane. Mp 143−145 °C. UV/vis ($CH_2Cl_2$): 425 (3.99), 538 (4.62). Emission spectrum ($CH_2Cl_2$): $\lambda_{max}$ (exc.) 366; $\lambda_{max}$ (em) 567. $\Phi = 0.93$. CD ($4.1 \times 10^{-5}$ M, $CH_2Cl_2$): 546 (+2.0). $[\alpha]^{20}_D = +350°$ ($c = 1.1 \times 10^{-5}$, $CH_2Cl_2$). $^1$H NMR: 7.81 (br. d, $J = 7.9$, 1 arom. H), 7.63 (td, $J = 7.6$, 1.4, 1 arom. H), 7.56 (td, $J = 7.5$, 1.3, 1 arom. H), 7.244 (ddd, $J = 7.7$, 1.5, 0.5, 1 arom. H), 4.53 (q, $J = 6.5$, CH), 4.53−4.41 (m, 2 $CH_2$), 3.34 (s, $OCH_3$), 2.006 (d, $J = 0.4$, $CH_3$), 1.986 (d, $J = 0.4$, $CH_3$), 1.452, 1.448 (2t, $J = 7.1$, 2 $CH_3$), 1.30, 1.29 (2s, 2 $CH_3$). $^{13}$C NMR: 162.59 (2 CO), 147.12, 145.62, 145.57, 143.53, 141.90, 134.84, 133.84, 132.95, 132.65, 130.32, 130.12 (11 quarternary C), 130.98, 130.79, 129.79, 128.70 (4 arom. CH), 124.90 (q, $J_{C,F} = 285$, $CF_3$), 78.37 (q, $J_{C,F} = 31$, *C*HCF$_3$), 62.65, 62.55 (2 $CH_2$), 61.01 ($CH_3$), 14.48 (2 $CH_3$), 12.63, 12.05, 10.04, 9.95 (4 $CH_3$). ESI-MS (exact mass): 603.2066 ([M + Na]$^+$, calc. for $C_{28}H_{30}{}^{11}BF_5N_2O_5Na^+$: 603.2060).

**Dibenzyl (*S*)-8-[2-(2,2,2-trifluoro-1-methoxyethyl)phenyl]-1,2,6,7-tetramethyl-4,4-difluoro-4-bora-3a,4a-diaza-*s*-indacene-3,5-dicarboxylate (9b)** was synthesized by the same procedure as described for **9a** starting with 90 mg (0.137 mmol) of **8b**. After purification by two successive FC (AcOEt/hexane 4:5), 58.9 mg (61%) of **9b** was obtained as a dark-red solid, which was recrystallized from $CHCl_3$/*n*-hexane. Mp 127−128.5 °C. UV/vis ($CH_2Cl_2$): 424 (3.96), 540 (4.58). Emission spectrum ($CH_2Cl_2$): $\lambda_{max}$ (exc.) 366; $\lambda_{max}$ (em) 571. $\Phi = 0.86$. CD ($6.00 \times 10^{-5}$ M, $CH_2Cl_2$): 543 (+2.05). $[\alpha]^{20}_D = +327°$ ($c = 1.2 \times 10^{-2}$ M, $CH_2Cl_2$). $^1$H NMR: 7.80 (br. d, $J = 7.9$, 1 arom. H), 7.62 (td, $J = 7.6$, 1.4, 1 arom. H), 7.56 (td, $J = 7.5$, 1.3, 1 arom. H), 7.51 (m, 4 arom. H), 7.38−7.28 (m, 6 arom. H), 7.23 (ddd, $J = 7.7$, 1.5, 0.5, 1 arom. H), 5.451, 5.418 (2d, $J = 12.35$, $CH_2$), 5.447, 5.436 (2d, $J = 12.26$, $CH_2$), 4.50 (q, $J = 6.4$, CH), 3.32 (s, $OCH_3$), 1.96 (d, $J = 0.5$, $CH_3$), 1.94 (d, $J = 0.5$, $CH_3$), 1.29, 1.28 (2s, 2 $CH_3$). $^{13}$C NMR: 161.89 (2 × CO), 146.28, 145.31, 144.70, 143.15, 141.50, 135.20, 135.09, 134.22, 133.49, 132.62, 132.13, 130.05, 129.82 (13 quat. C), 130.51, 130.30, 129.32 (3 arom. CH), 128.70 (4 arom. CH), 128.50 (2 arom. CH), 128.49 (2 arom. CH), 128.35, 128.32, 128.13 (3 arom. CH), 124.38 (q, $J_{C,F} = 285$, $CF_3$), 77.86 (q, $J_{C,F} = 31$, *C*HCF$_3$), 67.97, 67.86 (2 $CH_2$), 60.53 ($OCH_3$), 12.12, 11.53, 9.64, 9.54 (4 $CH_3$). ESI-MS (exact mass): 727.2371 ([M + Na]$^+$, calc. for $C_{38}H_{34}{}^{11}BF_5N_2O_5Na^+$: 727.2373).

**(*S*)-3-(1,3-Dioxolan-2-yl)-1-[2-(2,2,2-trifluoro-1-methoxyethyl)-phenyl]propan-1-one (11).** A solution of 605.8 mg (3.35 mmol) of 2-(2-bromoethyl)-1,3-dioxolane (Fluka Chemie GmbH) in dry THF (15 mL) was added dropwise during 2 h to 78.5 mg of Mg turnings under Ar atmosphere at 28 °C. Thereafter, stirring was continued for 1 h at the same temperature and the thus obtained Grignard reagent solution was added dropwise during 20 min under stirring to an ice-cooled solution of aldehyde **6** (603.4 mg, 2.77 mmol) in 8 mL of THF. Thereon, stirring was continued for 2 h at 0 °C and then for 1 h at room temperature. Finally, a saturated aqueous solution of ammonium chloride (15 mL) was added, the organic layer was separated, and the aqueous layer was extracted with ethyl ether (3 × 50 mL). The combined organic layers were washed with 100 mL of brine, dried over $MgSO_4$, and the solvent was evaporated under reduced pressure. By CC of the residue on silica gel using ethyl acetate:hexane (1:3) as eluant, 29.3 mg of unreacted aldehyde **6** was retrieved, and a colorless oil (732.6 mg, 87%) was obtained, consisting of a mixture of two epimeric alkohols, which were transformed, without further purification, into ketone **11**.

Thus, the mixture was dissolved in 15 mL of dry $CH_2Cl_2$ and the solution was added dropwise to a suspension of pyridinium chlorochromate (986 mg, 4.57 mmol), sodium acetate (376 mg, 4.58 mmol), and pyridine (362 mg, 4.58 mmol) in 15 mL of dry $CH_2Cl_2$ under Ar atmosphere. The mixture was stirred for 90 min at room temperature before a saturated aqueous solution of $NaHCO_3$ was added until no more $CO_2$ was evolved. The heterogeneous mixture was filtered, and the solid residue was washed on the filter with $CH_2Cl_2$ (40 mL). The organic phase was separated from the filtrate, dried ($MgSO_4$), and the solvent was removed under reduced pressure. The residue was purified by CC on silica gel using ethyl acetate:hexane (1:3) as eluant, to yield 646.2 mg (89%) of **11** as a colorless oil. $R_f = 0.37$ (silica gel, ethyl acetate:*n*-hexane 1:2); $[\alpha]^{20}_D = 85.4°$ ($c = 11$ mg/cm$^3$ in $CH_2Cl_2$). $^1$H NMR: $\delta$ 2.13 (m, 2H, C$H_2$), 2.95 (ddd, $J = 17.8$, 8.2, 6.3 Hz, 1H), 3.17 (ddd, $J = 17.8$, 8.2, 6.6 Hz, 1H), 3.46 (s, 3H, C$H_3$), 3.92 (m, 4H, 2 × C$H_2$O), 4.99 (t, $J = 4.2$ Hz, 1H), 5.72 (q, $J = 6.6$ Hz, 1H), 7.47 (dt, $J = 7.7$, 1.3 Hz, 1H), 7.57 (dt, $J = 7.5$, 1.4 Hz, 1H), 7.74 (dd, $J = 7.8$, 1.4 Hz, 1H), 7.79 (d, $J = 7.9$ Hz, 1H). $^{13}$C NMR (125.77 MHz, $CDCl_3$): $\delta$ 27.8, 35.3, 58.6, 65.0, 75.4 (q, $^3J_{C-F} = 30.7$ Hz), 103.2, 124.0 (q, $^1J_{C-F} = 282.6$ Hz), 128.4, 128.8, 129.0, 131.7, 132.3, 139.0, 203.4. ESI-MS (exact mass): 341.0974 (M + Na$^+$), calcd for $C_{15}H_{17}F_3O_4Na$: 341.0971. Anal. Calcd for $C_{15}H_{17}F_3O_4$: C, 56.60; H, 5.38. Found: C, 56,65; H, 5.36.

**(*S*)-2-[2-(2,2,2-Trifluoro-1-methoxyethyl)phenyl]-1*H*-pyrrole (12).** A mixture of **11** (231.7 mg, 0.73 mmol) and ammonium acetate (1.18 g, 15.29 mmol) in 30 mL of acetic acid was refluxed under Ar atmosphere until no more ketone was detectable by TLC (12−16 h). Thereafter, the mixture was cooled to room temperature, poured into ice-water (200 mL), neutralized with solid $NaHCO_3$, and extracted with $CH_2Cl_2$ (3 × 50 mL). The combined organic layers were washed with water (50 mL), dried ($MgSO_4$), and after removal of the solvent the residue was purified by CC on silica gel using diethyl ether:hexane (1:10) as eluant to yield 129.2 mg (70%) of **12** as a yellowish oil which was crystallized from pentane at ca. −100 °C to give 111.4 mg (60%) of slightly yellow needles. Mp 51.2−52.3 °C. $R_f = 0.35$ (diethyl ether: hexane (1:3) on silica gel). $[\alpha]^{20}_D = 138.6°$ ($c = 6.53$ mg/cm$^3$ in $CH_2Cl_2$). $^1$H NMR: $\delta$ 3.25 (s, 3H, C$H_3$), 4.97 (q, $J = 6.6$ Hz, 1H), 6.27 (m, 1H), 6.33 (m, 1H), 6.92 (m, 1H), 7.42 (m, *H-arom*, 3H), 7.68 (m, *H-arom*, 1H), 8.33 (br. s, N*H*, 1H). $^{13}$C NMR: $\delta$ 57.5, 77.4 (q, $^3J_{C-F} = 27.4$ Hz), 109.5, 109.7, 119.0, 124.3 (q, $^1J_{C-F} = 282.2$ Hz), 128.0, 128.3, 129.2, 129.3, 129.8, 130.8, 135.2. ESI-MS (exact mass): 256.0947 (M + H$^+$), calcd for $C_{13}H_{13}F_3NO$: 256.0943. Anal. Calcd for $C_{13}H_{12}F_3NO$: C, 61.17; H, 4.74; N, 5.49. Found: C, 61.23; H, 4.70; N, 5.48.

**(*S,S*)-1,9-Bis-[2-(2,2,2-trifluoro-1-methoxyethyl)phenyl]-5-phenyl-10*H*-dipyrrin (14).** Benzaldehyde (47 mg, 0.45 mmol) and **12** (84 mg, 0.33 mmol) were dissolved in 30 mL of $CH_2Cl_2$, and the solution was degassed by bubbling Ar for 30 min. Two drops of TFA were added, and the solution was stirred for 16 h at room temperature under Ar atmosphere. Thereafter, DDQ (30 mg, 0.13 mmol) was added, and stirring was continued for 2 h at room temperature. The reaction mixture was diluted with 100 mL of $CH_2Cl_2$, washed with saturated aqueous $NaHCO_3$ solution and water, and dried over $MgSO_4$. The residue obtained after evaporation of the solvent under reduced pressure was purified by CC on silica gel using ethyl acetate/*n*-hexane (1:10), containing 0.5% triethylamine, as eluant to yield 68 mg (70%) of **14** as orange crystals. Mp 143−144 °C. $R_f = 0.47$ (ethyl acetate/*n*-hexane (1:3) on silica gel). UV/vis ($c = 1.15 \times 10^{-5}$ M in $CH_2Cl_2$): 476 (4.56). UV/vis ($c = 2.01 \times 10^{-5}$ M in $CH_2Cl_2$ saturated with HCl): 393 (4.10), 562 (5.00). CD ($3.69 \times 10^{-5}$ M, $CH_2Cl_2$): 482 (−5.3). CD ($1.48 \times 10^{-5}$ M, $CH_2Cl_2$ + HCl): 566 (−9.0). $[\alpha]^{20}_D = -391°$ ($c = 2.2 \times 10^{-2}$, $CH_2Cl_2$). $^1$H NMR: 12.58 (br. s, NH), 7.72−7.67 (m, 2 arom. H), 7.63−7.58 (m, 2 arom. H), 7.56−7.41 (m, 9 arom. H), 6.72 (d, $J = 4.3$, 2 CH), 6.55 (d, $J = 4.1$, 2 CH), 5.42 (q, $J = 6.4$, 2 CH), 3.12 (s, 2 $OCH_3$). $^{13}$C NMR: 154.67, 142.68, 142.25, 137.95, 136.20, 131.95 (C), 131.79, 130.92, 130.70, 130.14, 129.97, 129.91, 129.26, 128.62, 120.39 (CH), 124.93 (q, $J_{C,F} = 282$, $CF_3$), 77.47 (q, $J_{C,F} = 31$, *C*HCF$_3$), 58.29 ($OCH_3$). ESI-MS (exact mass): 597.1945 ([M + H]$^+$, calc. for $C_{33}H_{27}F_6N_2O_2^+$: 597.1971).

**(*S,S*)-3,5-Bis-[2-(2,2,2-trifluoro-1-methoxyethyl)phenyl]-5-phenyl-8-phenyl-4,4-difluoro-4-bora-3a,4a-diaza-*s*-indacene (15).** To a solution of **13** (30 mg, $5 \times 10^{-5}$ mol) in 10 mL of 1,2-dichloroethane were subsequently added triethylamine (0.2 mL, 1.44 mmol) and boron trifluoride etherate (0.2 mL, 1.58 mmol); the resulting mixture was stirred for 10 min at 25 °C, and then heated under reflux for 30 min. The

fluorescent reaction mixture was filtered through basic alumina, and the residue obtained after evaporation of the solvent was purified by CC on silica gel using ethyl acetate/*n*-hexane (1:6) as eluant. Pure **15** (31 mg, 95%) was obtained by crystallization from ethyl acetate/*n*-hexane (1:5) as orange crystals. Mp: 292−294 °C. $R_f = 0.43$ (ethyl acetate/*n*-hexane (1:3) on silica gel); $[\alpha]^{20}_D = +720°$ ($c = 2.8 \times 10^{-2}$ in $CH_2Cl_2$). UV/vis ($CH_2Cl_2$): 353 (4.29), 520 (4.87). CD ($2.89 \times 10^{-5}$ M in $CH_2Cl_2$): 518 (+12.4). Emission spectrum ($CH_2Cl_2$): $\lambda_{max}$ (exc.) 520; $\lambda_{max}$ (em.) 555. $\Phi = 0.39$. $^1$H NMR: 7.73−7.67 (m, 2 arom. H), 7.66−7.54 (m, 5 arom. H), 7.49−7.27 (m, 6 arom. H), 6.96 (br. d, $J =$ 4.0, 2H), 6.44 (br. s, 2H), 4.64 (br. s, 2H), 3.32 (br. s, 2 $OCH_3$). $^{13}$C NMR: 156.84, 147.05, 135.99, 134.42, 134.21, 132.49 (C), 131.11, 131.08, 129.99, 128.85, 127.98 (CH), 124.50 (q, $J_{C,F} = 282$, $CF_3$), 78.12 (q, $J_{C,F} = 30$, $CHCF_3$), 58.38 ($OCH_3$). ESI-MS (exact mass): 667.1775 ($[M + Na]^+$, calc. for $C_{33}H_{25}{}^{11}BF_8N_2O_2Na^+$: 667.1774).

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**Supporting Information Available:** Experimental spectra (PDF) and crystallographic details (CIF). This material is available free of charge via the Internet at http://pubs.acs.org. Full tables of atomic parameters and bond lengths and angles from the X-ray diffraction analyses may be obtained from the Cambridge Crystallographic Data Centre, U.K.

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