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Trifluoromethylallylation of Heterocyclic C−H Bonds with Allylic Carbonates under Rhodium Catalysis

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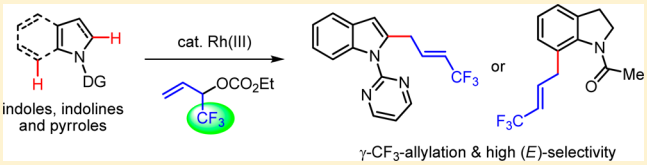
Supporting Information

ABSTRACT: The rhodium(III)-catalyzed γ-trifluoromethylallylation of various heterocyclic C−H bonds with CF_3-substituted allylic carbonates is described. These reactions provide direct access to linear CF_3-containing allyl frameworks with complete *trans*-selectivity via C−H bond activation followed by a formal S_N-type reaction pathway.

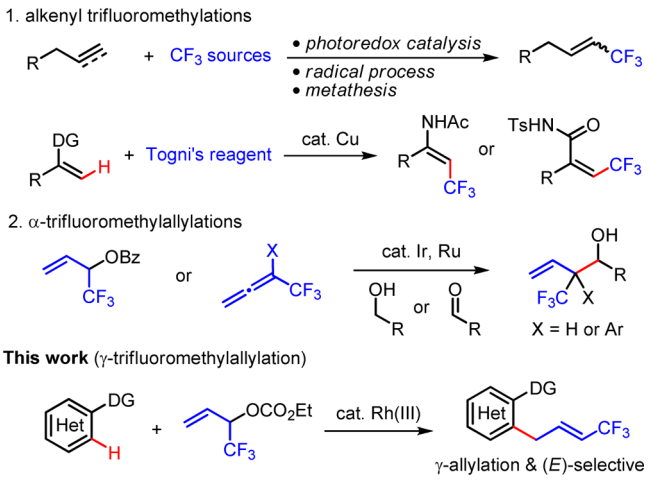


INTRODUCTION

With considerable progress in medicinal chemistry, the incorporation of fluorine or fluoroalkyl groups in pharmaceuticals and biologically active molecules has gained increasing attention in the past decades.[1] In particular, the trifluoromethyl group is prevalent in pharmaceuticals, agrochemicals, and functional materials. Due to their unique characteristics, such as high electronegativity, hydrophobicity, metabolic stability, bioavailability, and binding affinity, trifluoromethyl groups in organic molecules can bring beneficial effects to pharmacokinetic properties.[2] Therefore, the structural modification using a trifluoromethyl group has progressively evolved as an important area in the quest for new active candidates. In this regard, substantial efforts have been made to the exploration of new synthetic methods for the introduction of the trifluoromethyl functionality into a series of useful substrates.[3] Among them, the transition-metal-mediated or -catalyzed trifluoromethylation reactions have proven to be extremely appealing in view of their regioselectivity, functional compatibility, and reaction efficiency.[4]

The past decade witnessed the rapid development of transition-metal-catalyzed C−H functionalization as a powerful tool in organic and medicinal chemistry.[5] Recently, the directing-group-assisted trifluoromethylation of aromatic C−H bonds using various electrophilic and nucleophilic CF_3 sources has been disclosed.[6] In addition, photoredox catalysis and the radical process also provided facile access to the formation of aromatic $C(sp^2)-CF_3$ bonds.[7] In contrast to aromatic C−H trifluoromethylation, olefinic and alkynyl trifluoromethylations have been less explored. For instance, Cho and co-workers demonstrated the trifluoromethylation of alkynes and alkenes under photoredox catalysis and the radical process to afford alkenyl-CF_3 products (Scheme 1).[8] Loh et al. described the Cu-catalyzed olefinic trifluoromethylation of acrylamides and enamides with Togni's reagent.[9] Additionally, an olefin metathesis reaction using Grubbs catalysts was also employed for the formation of alkenyl-CF_3 products.[10]

Scheme 1. Alkenyl Trifluoromethylations and Trifluoromethylallylations



With the development of catalytic C−H bond functionalization, direct C−H allylations have been performed using various metal catalysts. In this area, allylic halides, acetates, carbonates, phosphonates, allenes, and vinyl oxiranes have been used as allyl sources.[11] However, CF_3-containing allyl substrates have rarely been explored in the C−H allylation strategy. Krische and co-workers described beautiful examples of iridium- and ruthenium-catalyzed carbonyl α-trifluoromethylallylations of alcohols and aldehydes using α-trifluoromethyl allyl benzoate and trifluoromethyl allenes.[12]

To this end, we envisioned that readily available CF_3-containing allylic carbonates could provide easy access to γ-trifluoromethylallyl frameworks. In continuation of our recent

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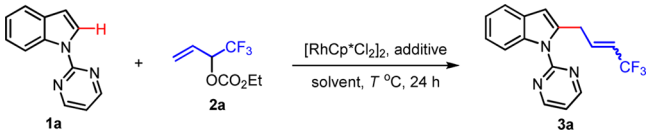
studies on C−H allylation reactions,[13] we herein present the first directing-group-assisted Rh(III)-catalyzed γ-trifluoromethylallylation of various heterocyclic C−H bonds with α-trifluoromethyl allyl carbonate.

RESULTS AND DISCUSSION

Our study was initiated by subjecting the coupling of 1-(pyrimidin-2-yl)-1*H*-indole **1a** and α-trifluoromethyl allyl carbonate **2a** under rhodium catalysis (Table 1). To our delight, the reaction of **1a** and **2a** in the presence of 2.5 mol % of $[RhCp^*Cl_2]_2$ and 10 mol % of $AgSbF_6$ in *tert*-amyl alcohol (*t*-AmOH) at 80 °C afforded the desired product **3a** in 80% yield, albeit in a low level of *E*/*Z*-selectivity (Table 1, entry 1). After additives and solvents were further screened, THF solvent was found to be relatively effective in both chemical yield and diastereoselectivity (Table 1, entries 2−8). Interestingly, loading of $Cu(OAc)_2$ at 100 °C resulted in an increase of diastereomeric ratio (6:1), providing **3a** in 80% yield (Table 1, entry 9). Surprisingly, remarkable improvement of *E*-selectivity was observed by increasing reaction temperature to 120 °C (Table 1, entry 10). However, further increasing of reaction temperature to 160 °C was found to give a decreased yield and *E*-selectivity (Table 1, entry 11). Further study revealed that 50 mol % of $Cu(OAc)_2$ was found to be an optimal amount for this reaction (Table 1, entries 12 and 13). Other additives and catalysts were also less effective under otherwise identical conditions (Table 1, entries 14−17). Finally, increasing the amount of **2a** provided the desired product **3a** in comparable yield and *E*-selectivity (Table 1, entry 18).

Table 1. Selected Optimization of Reaction Conditions[a]

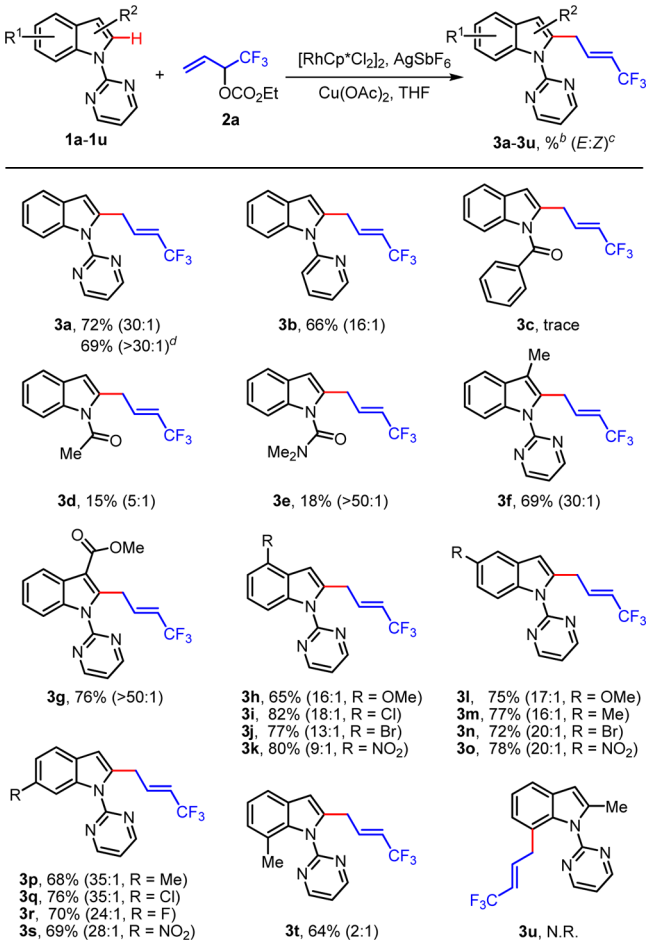


entry	additive (mol %)	solvent	*T* (°C)	yield (%)[b,c]
1	$AgSbF_6$ (10)	*t*-AmOH	80	80 (1:1)
2	$AgNTf_2$ (10)	*t*-AmOH	80	57 (1:1)
3	$AgBF_4$ (10)	*t*-AmOH	80	64 (1:1)
4		*t*-AmOH	80	NR
5	$AgSbF_6$ (10)	*o*-xylene	80	70 (1:1)
6	$AgSbF_6$ (10)	DCE	80	27 (1:1)
7	$AgSbF_6$ (10)	TFE	80	57 (1:1)
8	$AgSbF_6$ (10)	THF	80	76 (3:1)
9	$AgSbF_6$ (10), $Cu(OAc)_2$ (50)	THF	100	80 (6:1)
10	**$AgSbF_6$ (10), $Cu(OAc)_2$ (50)**	**THF**	**120**	**72 (30:1)**
11	$AgSbF_6$ (10), $Cu(OAc)_2$ (50)	THF	160	57 (20:1)
12	$AgSbF_6$ (10), $Cu(OAc)_2$ (100)	THF	120	72 (17:1)
13	$AgSbF_6$ (10), $Cu(OAc)_2$ (30)	THF	120	66 (18:1)
14	$AgSbF_6$ (10), AcOH (100)	THF	120	34 (15:1)
15	$AgSbF_6$ (10), AgOAc (50)	THF	120	24 (10:1)
16[d]	$AgSbF_6$ (10), $Cu(OAc)_2$ (50)	THF	120	trace
17[e]	$AgSbF_6$ (10), $Cu(OAc)_2$ (50)	THF	120	trace
18[f]	$AgSbF_6$ (10), $Cu(OAc)_2$ (50)	THF	120	68 (30:1)

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (0.4 mmol), $[RhCp^*Cl_2]_2$ (2.5 mol %), additive (quantity noted), solvent (1 mL) under air at indicated temperature for 24 h in pressure tubes. [b]Isolated yield by flash column chromatography. [c]Parentheses show *E*/*Z* isomeric ratio. [d]$[Ru(p\text{-cymene})Cl_2]_2$ (2.5 mol %) was used as a catalyst. [e]$[CoCp^*(CO)I_2]$ (5 mol %) was used as a catalyst. [f]**2a** (0.6 mmol, 3 equiv) was used.

To explore the substrate scope and limitations of the γ-trifluoromethylallylation reaction, various directing groups on indole were screened to couple with **2a**, as shown in Table 2.

Table 2. Scope of Indoles[a]



[a]Reaction conditions: **1a**−**1u** (0.2 mmol), **2a** (0.4 mmol), $[RhCp^*Cl_2]_2$ (2.5 mol %), $AgSbF_6$ (10 mol %), $Cu(OAc)_2$ (50 mol %), THF (1 mL) under air at 120 °C for 24 h in pressure tubes. [b]Isolated yield by flash column chromatography. [c]Parentheses show *E*/*Z* isomeric ratio. [d]Scale-up experiment (2 mmol scale).

Indole **1b**, containing a 2-pyridinyl directing group, provided the desired product **3b** in 66% yield and a 16:1 *E*/*Z* ratio. However, other directing groups such as benzoyl, acetyl, and carbamoyl were unreactive or less reactive for this coupling reaction. Notably, this reaction was found to be highly tolerable, with C3-substituted indoles **1f** and **1g** furnishing the desired products **3f** and **3g** in good yields with high *E*-selectivity. With either electron-rich or electron-deficient groups at the C4-, C5-, and C6-positions of indoles, α-trifluoromethyl allyl carbonate **2a** was efficiently coupled to give the corresponding CF_3-allylation products **3h**−**3s**. It should be mentioned that this transformation showed good tolerance toward halogen and nitro groups. It is quite interesting that C7-substituted indole **1t** also underwent the C−H γ-allylation reaction to afford **3t** in 64% yield, albeit in a low isomeric ratio. However, no formation of allylation product **3u** was observed in the case of C2-substituted indole. To show the practicality of this transformation, we successfully scaled the reaction to 2 mmol and obtained 0.41 g of **3a** in 69% isolated yield.

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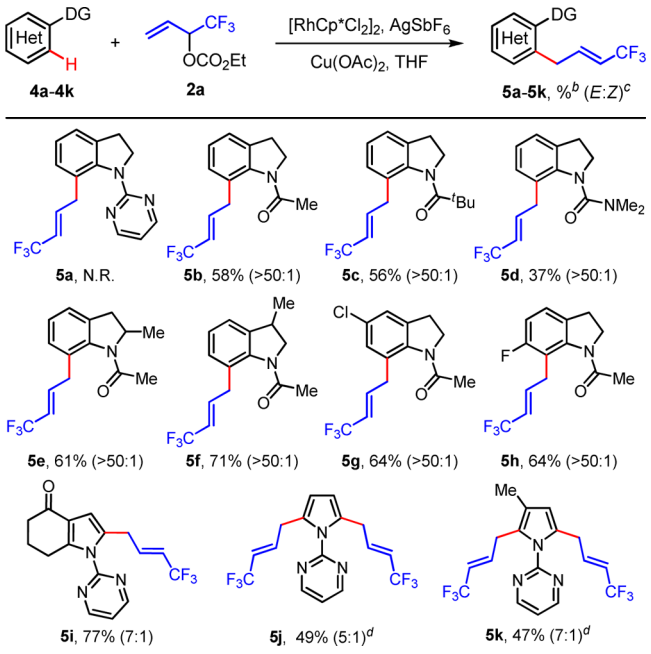
To further evaluate the scope of this process, the coupling of other heterocycles, such as indolines and pyrroles **4a**−**4k** with **2a**, was screened under the optimal reaction conditions (Table 3). Interestingly, a pyrimidinyl directing group on indoline did not deliver our desired C7-allylated product **5a**. Gratifyingly, other carbonyl directing groups such acetyl, pivaloyl, and *N*,*N*-dimethylcarbamoyl participated in the cross-coupling reaction to yield the corresponding products **5b**−**5d** with excellent *E*-selectivity. It should be noted that the C2-allylation of indoles was observed by assistance of a pyrimidinyl directing group, whereas the C7-allylation of indolines occurred by using a carbonyl directing group. No reactivity was observed in the C7-allylation of C2-substituted indole **1u** containing a pyrimidinyl directing group. Thus, we believe that directing groups of indoles and indolines play a crucial role in the site-selective allylation reaction. Further screening of solvents such as DME (1,1-dimethoxyethane) and 1,4-dioxane with **4b** resulted in the formation of **5b** in trace amounts and 48% yield. Thus, we screened other substituted indolines **4e**−**4h** with an acetyl directing group in THF. All cases provided the desired products in moderate to good yields with high diastereoselectivity (>50:1). In some cases with indolines, we observed olefin migrated compounds in less than 10% yield along with recovered starting materials. Further investigation on the γ-trifluoromethylallylation reaction of pyrroles **4i**−**4k** was conducted. A pyrimidinyl directing group on 2,3-disubstituted pyrrole **4i** was found to give the desired coupling product **5i** in good yield (77%). Pyrrole **4j** and C3-substituted pyrrole **4k** also participated in this catalytic reaction, furnishing bisalkylated products **5j** and **5k** in low yields (20−30%) under the standard reaction conditions, and no monoalkylated products were detected. Thus, we increased the amount of α-trifluoromethyl allyl carbonate **2a** under otherwise indentical reaction conditions, and bisallylated products **5j** and **5k** were formed in 49 and 47% yields, respectively.

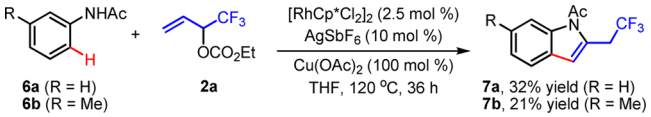
Table 3. Scope of Indolines and Pyrroles[a]



[a]Reaction conditions: **4a**−**4k** (0.2 mmol), **2a** (0.4 mmol), $[RhCp^*Cl_2]_2$ (2.5 mol %), $AgSbF_6$ (10 mol %), $Cu(OAc)_2$ (50 mol %), THF (1 mL) under air at 120 °C for 24 h in pressure tubes. [b]Isolated yield by flash column chromatography. [c]Parentheses show *E*/*Z* isomeric ratio. [d]**2a** (0.8 mmol, 4 equiv) was used.

Based on previous reports of tandem rhodium-catalyzed allylation and annulation of acetanilides with allyl acetates,[14] we envisioned that α-trifluoromethyl allyl carbonate **2a** can be used for the formation of CF_3-containing indoles (Scheme 2).

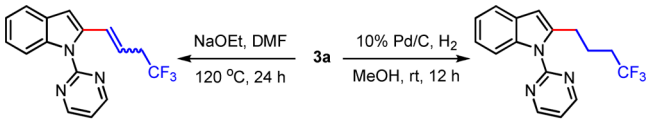
Scheme 2. Synthesis of CF_3-Containing Indoles



Acetanilides **6a** and **6b** were employed under the slightly modified reaction conditions with **2a** to furnish the corresponding indole products **7a** and **7b**, albeit in low yields. Further optimization of the reaction conditions is underway.

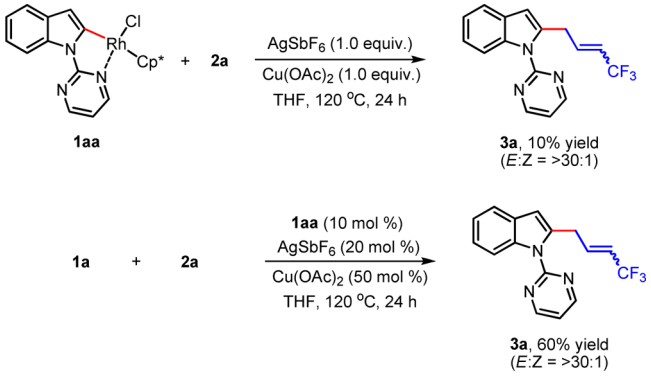
To show the synthetic transformation of γ-CF_3-allylated products, the olefin migration of **3a** was first subjected under basic conditions to afford the corresponding product **8a** in 52% yield with an *E*/*Z* ratio of 10:1 (Scheme 3). In addition, hydrogenation of the olefin moiety was carried out under the standard reaction conditions to provide **8b** in 56% yield. However, we were not able to find suitable conditions for the deprotection of a pyrimidyl directing group to afford free NH-indole.

Scheme 3. Olefin Migration and Reduction of Coupling Product 3a



Based on previous literature,[15] a cyclometalated Rh(III) complex **1aa** was synthesized by treatment of 1-(pyrimidin-2-yl)-1*H*-indole **1a** with $[RhCp^*Cl_2]_2$. The stoichiometric reaction using Rh(III) complex **1aa** gave a lower yield (Scheme 4). However, the reaction using **1aa** as a catalyst was found to be almost efficient under the standard reaction conditions because 2-pyrimidinyl indole **1a** might act as a proton source and help to release the product from the rhodium complex.[16]

Scheme 4. Mechanistic Investigation Using a Rhodacycle Intermediate



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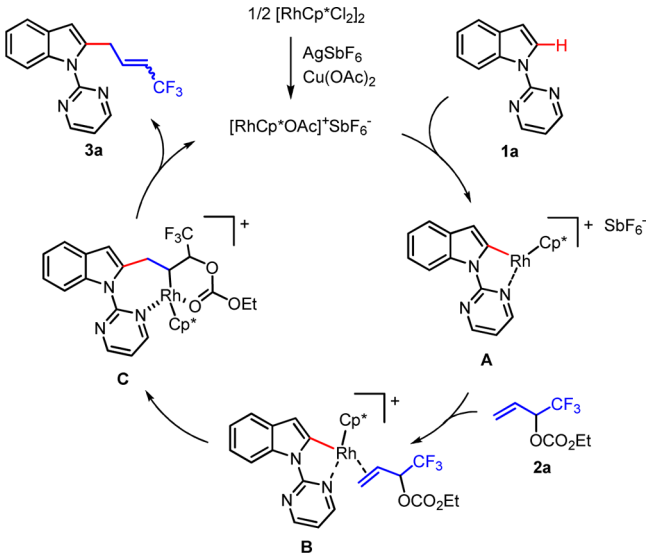
A plausible reaction mechanism is outlined in Scheme 5. Coordination of a pyrimidyl group to the cationic Rh(III)

Scheme 5. Plausible Reaction Mechanism



catalyst and subsequent C−H cleavage delivers a rhodacyle intermediate **A**. Coordination and subsequent migratory insertion of allylic carbonate **2a** into the Rh−C bond affords a seven-membered Rh(III) intermediate **C**. Further, β-oxygen elimination provides allylation product **3a** and regenerates a Rh(III) catalyst. Alternatively, coordination of **2a** to the cyclorhodated species **A** followed by nucleophilic substitution cannot be ruled out in the catalytic cycle to afford **3a**.[17]

CONCLUSION

In conclusion, we described the rhodium(III)-catalyzed direct C−H trifluoromethylallylation reaction of various heterocycles such as indoles, indolines, and pyrroles with α-trifluoromethyl allyl carbonate to afford biologically important γ-CF_3-allylated heterocycles. Further synthetic transformations revealed that this protocol can be readily applied to the formation of CF_3-containing indoles. The ongoing research seeks to expand the scope to the catalytic trifluoromethylallylation reaction of sp^3 C−H bonds.

EXPERIMENTAL SECTION

General Procedure and Characterization Data for the Synthesis of 2a. To an oven-dried flask charged with H_2SO_4 (8 mL) and P_2O_5 (1.2 g) was added dropwise trifluoroacetaldehyde hydrate (3 mL, 36 mmol, 1 equiv) by syringe at 100 °C. Trifluoroacetaldehyde gas was trapped in THF (20 mL) by using a dry ice/acetone bath. Further, vinyl magnesium bromide (42 mL, 42 mmol, 1.16 equiv, 1.0 M solution in THF) was added dropwise to flask charged with trifluoroacetaldehyde solution. The resulting mixture was stirred for 30 min at 0 °C under N_2 atmoshphere. After being stirred for 0.5 h, the reaction mixture was allowed to stir for 5 h at room temperature and was quenched with saturated aq NH_4Cl (8 mL) at 0 °C. The quenched solution was filtered by Et_2O (30 mL), and the organic layer was separated. Et_3N (10 mL, 72 mmol, 1 equiv) was added dropwise to the organic layer at room temperature with the addition of ethyl chloroformate (5.2 mL, 54 mmol, 1.5 equiv) at 0 °C. The reaction mixture was allowed to stir for 24 h at room temperature. After completion of the reaction, the mixture was diluted with saturated $NaHCO_3$ (4 mL). The combined layer was extracted with ether, dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by flash column chromatography (*n*-hexanes/EtOAc = 9:1) to afford **2a** (3.42 g, 17.26 mmol) in 48% yield.

*Ethyl 1,1,1-Trifluorobut-3-en-2-yl Carbonate (**2a**):* 3.42 g (48%); colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.89−5.80 (m, 1H), 5.62 (d, J = 17.0 Hz, 1H), 5.54 (d, J = 10.5 Hz, 1H), 5.49−5.42 (m, 1H), 4.25 (q, J = 7.1 Hz, 2H), 1.32 (t, J = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.8, 126.8 (q, J_{C-F} = 1.3 Hz), 124.0, 122.9 (q, J_{C-F} = 278.7 Hz), 74.6 (q, J_{C-F} = 33.5 Hz), 65.4, 14.2; IR (KBr) ν 2923, 1715, 1432, 1362, 1221, 1092, 1006, 905, 757 cm^{-1}; HRMS (quadrupole, EI) calcd for $C_7H_9F_3O_3$ $[M]^+$ 198.0504, found 198.0508.

Typical Procedure and Characterization Data for the Synthesis of 3a−3u. To an oven-dried sealed tube charged with 1-(pyrimidin-2-yl)-1*H*-indole (**1a**) (39.0 mg, 0.2 mmol, 100 mol %), $[RhCp^*Cl_2]_2$ (3.1 mg, 0.005 mmol, 2.5 mol %), $AgSbF_6$ (6.9 mg, 0.02 mmol, 10 mol %), and $Cu(OAc)_2$ (18.2 mg, 0.1 mmol, 50 mol %) in THF (1 mL) was added ethyl 1,1,1-trifluorobut-3-en-2-yl carbonate (**2a**) (79.3 mg, 0.4 mmol, 120 mol %) under air. The reaction mixture was allowed to stir at 120 °C for 24 h and cooled to room temperature. The reaction mixture was diluted with EtOAc (3 mL) and concentrated in vacuo. The residue was purified by flash column chromatography (*n*-hexanes/EtOAc = 10:1) to afford **3a** (43.5 mg) in 72% yield.

*(E)-1-(Pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3a**):* 43.5 mg (72%); *E*:*Z* ratio = 30:1; light brown solid; mp = 50.3−51.9 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.76 (d, J = 4.8 Hz, 2H), 8.36 (d, J = 8.2 Hz, 1H), 7.57 (d, J = 7.6 Hz, 1H), 7.29 (t, J = 7.2 Hz, 1H), 7.23 (t, J = 7.7 Hz, 1H), 7.14 (t, J = 4.7 Hz, 1H), 6.64−6.57 (m, 1H), 6.52 (s, 1H), 5.62 (dtt, J = 15.7, 6.4, 1.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.3, 158.1, 138.1 (q, J_{C-F} = 6.4 Hz), 137.1, 136.9, 129.1, 123.4, 123.1 (q, J_{C-F} = 267.9 Hz), 122.3, 120.2, 120.0 (q, J_{C-F} = 33.2 Hz), 117.4, 114.5, 107.8, 32.1; IR (KBr) ν 3407, 1680, 1562, 1454, 1427, 1348, 1324, 1287, 1118, 1064, 977, 805, 747 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{16}H_{13}F_3N_3$ $[M + H]^+$ 304.1062, found 304.1057.

*(E)-1-(Pyridin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3b**):* 40.1 mg (66%); *E*:*Z* ratio =16:1; brown sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.64 (d, J = 4.7 Hz, 1H), 7.89 (t, J = 7.8 Hz, 1H), 7.62−7.60 (m, 1H), 7.47 (d, J = 7.9 Hz, 1H), 7.38−7.32 (m, 2H), 7.20−7.15 (m, 2H), 6.51 (s, 1H), 6.46−6.38 (m, 1H), 5.51−5.42 (m, 1H), 3.82−3.80 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 151.2, 149.8, 138.6, 137.4, 137.0 (q, J_{C-F} = 6.4 Hz), 136.4, 128.4, 122.9 (q, J_{C-F} = 267.5 Hz), 122.5, 122.4, 121.2, 120.9, 120.2 (q, J_{C-F} = 33.2 Hz), 120.5, 110.3, 104.3, 30.1; IR (KBr) ν 3056, 2931, 1680, 1587, 1470, 1455, 1437, 1342, 1323, 1286, 1189, 1120, 1050, 976, 781, 746 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{17}H_{14}F_3N_2$ $[M + H]^+$ 303.1109, found 303.1109.

*(E)-1-(2-(4,4,4-Trifluorobut-2-enyl)-1H-indol-1-yl)ethanone (**3d**):* 8.0 mg (15%); *E*:*Z* ratio =5:1; red sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.70 (d, J = 7.6 Hz, 1H), 7.52 (d, J = 7.2 Hz, 1H), 7.32−7.23 (m, 2H), 6.67−6.58 (m, 1H), 6.45 (s, 1H), 5.68 (dtt, J = 15.7, 6.4, 1.5 Hz, 1H), 3.92−3.91 (m, 2H), 2.80 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.4, 137.5 (q, J_{C-F} = 6.4 Hz), 136.1, 129.9, 124.3, 123.4, 123.2 (q, J_{C-F} = 266.1 Hz), 121.1, 120.3 (q, J_{C-F} = 33.2 Hz), 114.5, 110.2, 32.8, 27.7; IR (KBr) ν 2923, 1703, 1569, 1459, 1376, 1316, 1299, 1211, 1184, 1120, 1065, 989, 812, 748 cm^{-1}; HRMS (quadrupole, EI) calcd for $C_{14}H_{12}F_3NO$ $[M]^+$ 267.0871, found 267.0872.

*(E)-N,N-Dimethyl-2-(4,4,4-trifluorobut-2-enyl)-1H-indole-1-carboxamide (**3e**):* 10.4 mg (18%); *E*:*Z* ratio = >50:1; yellow sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55 (d, J = 7.7 Hz, 1H), 7.25−7.13 (m, 3H), 6.52−6.43 (m, 1H), 6.43 (s, 1H), 5.68 (dtt, J = 15.6, 6.3, 1.5 Hz, 1H), 3.77 (s, 2H), 3.01 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.1, 136.9 (q, J_{C-F} = 6.4 Hz), 136.0, 135.9, 128.3, 123.3, 123.2, 122.9 (q, J_{C-F} = 267.9 Hz), 121.6, 120.9, 120.8 (q, J_{C-F} = 33.1 Hz), 111.2, 105.5, 37.9, 29.7; IR (KBr) ν 3052, 2926, 1682, 1558, 1454, 1390, 1300, 1285, 1264, 1196, 1116, 1062, 978, 845, 796, 743 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{15}H_{16}F_3N_2O$ $[M + H]^+$ 297.1215, found 297.1212.

*(E)-3-Methyl-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3f**):* 43.7 mg (69%); *E*:*Z* ratio = 30:1; light yellow solid; mp =

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75.2−77.6 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.74 (d, J = 4.7 Hz, 2H), 8.36 (d, J = 8.2 Hz, 1H), 7.55 (d, J = 7.0 Hz, 1H), 7.32−7.24 (m, 2H), 7.11 (t, J = 4.8 Hz, 1H), 6.60−6.53 (m, 1H), 5.62 (dtt, J = 15.7, 6.4, 1.7 Hz, 1H), 4.09−4.07 (m, 2H), 2.31 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.2, 158.1, 138.5 (q, J_{C-F} = 6.7 Hz), 136.3, 131.6, 130.2, 123.6, 123.3 (q, J_{C-F} = 267.4 Hz), 121.9, 118.8 (q, J_{C-F} = 33.3 Hz), 118.4, 117.0, 115.1, 114.3, 28.8, 8.9; IR (KBr) ν 3046, 2921, 1677, 1561, 1455, 1427, 1336, 1287, 1192, 1113, 977, 804, 746 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{17}H_{15}F_3N_3$ $[M + H]^+$ 318.1218, found 318.1216.

*(E)-Methyl 1-(Pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole-3-carboxylate (**3g**):* 54.8 mg (76%); *E*:*Z* ratio = 50:1; light yellow solid; mp = 86.0−87.8 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.87 (d, J = 4.8 Hz, 2H), 8.21−8.18 (m, 1H), 7.98−7.94 (m, 1H), 7.35−7.29 (m, 3H), 6.56−6.49 (m, 1H), 5.52 (dtt, J = 15.8, 6.4, 1.5 Hz, 1H), 4.49−4.47 (m, 2H), 3.99 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.5, 158.8, 157.1, 143.7, 137.2 (q, J_{C-F} = 6.6 Hz), 136.2, 126.8, 124.3, 123.5, 123.0 (q, J_{C-F} = 268.0 Hz), 121.9, 119.7 (q, J_{C-F} = 33.2 Hz), 119.3, 113.1, 109.3, 51.4, 28.7; IR (KBr) ν 3051, 2951, 1701, 1566, 1547, 1455, 1418, 1336, 1288, 1246, 1194, 1120, 1051, 979, 809, 751 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{18}H_{15}F_3N_3O_2$ $[M + H]^+$ 362.1116, found 362.1111.

*(E)-4-Methoxy-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3h**):* 44.0 mg (66%); *E*:*Z* ratio = 16:1; light brown solid; mp = 70.0−71.3 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.87 (d, J = 4.7 Hz, 2H), 7.94 (d, J = 8.4 Hz, 1H), 7.20 (t, J = 8.0 Hz, 1H), 7.14 (t, J = 4.8 Hz, 1H), 6.67−6.56 (m, 3H), 5.52 (dtt, J = 15.7, 6.3, 1.4 Hz, 1H), 4.06−4.05 (m, 2H), 3.97 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.3, 158.2, 152.6, 138.4, 138.1 (q, J_{C-F} = 6.3 Hz), 135.4, 124.1, 123.1 (q, J_{C-F} = 268.1 Hz), 119.9 (q, J_{C-F} = 33.0 Hz), 119.4, 117.4, 107.7, 104.5, 102.4, 55.5, 32.0; IR (KBr) ν 3043, 2939, 2838, 1680, 1564, 1495, 1437, 1423, 1354, 1327, 1270, 1248, 1182, 1110, 988, 806, 769, 732 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{17}H_{15}F_3N_3O$ $[M + H]^+$ 334.1167, found 334.1165.

*(E)-4-Chloro-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3i**):* 55.2 mg (82%); *E*:*Z* ratio = 18:1; brown solid; mp = 74.9−75.7 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.78 (d, J = 4.8 Hz, 2H), 8.23 (d, J = 7.8 Hz, 1H), 7.22−7.16 (m, 3H), 6.63 (s, 1H), 6.61−6.55 (m, 1H), 5.60 (dtt, J = 15.6, 6.4, 1.4 Hz, 1H), 4.09−4.07 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.5, 158.4, 157.9, 137.8, 137.6 (q, J_{C-F} = 6.6 Hz), 127.8, 125.4, 123.9, 123.1 (q, J_{C-F} = 267.7 Hz), 122.0, 120.2 (q, J_{C-F} = 33.2 Hz), 117.8, 113.2, 105.8, 32.0; IR (KBr) ν 3046, 1681, 1560, 1490, 1325, 1282, 1175, 1119, 979, 809, 770, 730 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{16}H_{12}ClF_3N_3$ $[M + H]^+$ 338.0672, found 338.0668.

*(E)-4-Bromo-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3j**):* 59.1 mg (77%); *E*:*Z* ratio = 13:1; yellow solid; mp = 80.0−82.6 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.77 (d, J = 4.8 Hz, 2H), 8.28 (d, J = 8.3 Hz, 1H), 7.37 (d, J = 7.6 Hz, 1H), 7.18 (t, J = 4.8 Hz, 1H), 7.12 (t, J = 8.0 Hz, 1H), 6.62−6.55 (m, 2H), 5.61 (dtt, J = 15.7, 6.2, 1.6 Hz, 1H), 4.08−4.07 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.4, 157.9, 137.8, 137.6 (q, J_{C-F} = 6.4 Hz), 137.4, 129.6, 125.1, 124.3, 123.0 (q, J_{C-F} = 267.9 Hz), 120.2 (q, J_{C-F} = 33.3 Hz), 117.8, 114.0, 113.6, 107.5, 32.0; IR (KBr) ν 3046, 1680, 1575, 1528, 1428, 1324, 1282, 1172, 1118, 978, 808, 768 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{16}H_{12}BrF_3N_3$ $[M + H]^+$ 382.0167, found 382.0170.

*(E)-4-Nitro-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3k**):* 55.5 mg (80%); *E*:*Z* ratio = 9:1; dark yellow solid; mp = 142.4−144.5 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.84 (d, J = 4.8 Hz, 2H), 8.60 (d, J = 8.3 Hz, 1H), 8.16 (d, J = 8.1 Hz, 1H), 7.32−7.28 (m, 3H), 6.60−6.53 (m, 1H), 5.60 (dtt, J = 15.7, 6.3, 1.5 Hz, 1H), 4.12−4.11 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.6, 157.4, 141.7, 139.8, 138.9, 137.0 (q, J_{C-F} = 6.5 Hz), 123.5, 122.9 (q, J_{C-F} = 267.8 Hz), 122.4, 120.9, 120.6 (q, J_{C-F} = 33.4 Hz), 119.4, 118.6, 107.0, 31.9; IR (KBr) ν 2360, 1680, 1577, 1511, 1438, 1423, 1331, 1282, 1251, 1120, 980, 800, 738 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{16}H_{12}F_3N_4O_2$ $[M + H]^+$ 349.0912, found 349.0906.

*(E)-5-Methoxy-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3l**):* 59.7 mg (75%); *E*:*Z* ratio = 17:1; dark yellow solid; mp = 73.4−74.8 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.72 (d, J = 4.8 Hz, 2H), 8.32 (d, J = 9.0 Hz, 1H), 7.10 (t, J = 4.8 Hz, 1H), 7.02 (d, J = 2.5 Hz, 1H), 6.90 (dd, J = 9.1, 2.6 Hz, 1H), 6.64−6.57 (m, 1H), 6.43 (s, 1H), 5.62 (dtt, J = 15.7, 6.4, 1.5 Hz, 1H), 4.09−4.07 (m, 2H), 3.87 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.2, 158.1, 155.7, 138.2 (q, J_{C-F} = 6.4 Hz), 137.6, 132.0, 129.9, 123.1 (q, J_{C-F} = 267.4 Hz), 119.9 (q, J_{C-F} = 33.2 Hz), 117.0, 115.8, 112.3, 107.8, 102.4, 55.8, 32.4; IR (KBr) ν 2950, 2820, 2341, 1680, 1576, 1476, 1428, 1328, 1206, 1174, 1118, 1034, 976, 803, 775 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{17}H_{15}F_3N_3O$ $[M + H]^+$ 334.1167, found 334.1162.

*(E)-5-Methyl-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3m**):* 48.8 mg (77%); *E*:*Z* ratio = 16:1; yellow solid; mp = 67.2−71.2 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.74 (d, J = 4.8 Hz, 2H), 8.27 (d, J = 8.5 Hz, 1H), 7.35 (s, 1H), 7.12−7.09 (m, 2H), 6.64−6.57 (m, 1H), 6.43 (s, 1H), 5.61 (dtt, J = 15.7, 6.4, 1.5 Hz, 1H), 4.09−4.08 (m, 2H), 2.46 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.3, 158.2, 138.2 (q, J_{C-F} = 6.6 Hz), 137.0, 135.4, 131.7, 129.4, 124.8, 123.2 (q, J_{C-F} = 267.6 Hz), 120.2, 119.8 (q, J_{C-F} = 33.3 Hz), 117.0, 114.4, 107.6, 32.3, 21.5; IR (KBr) ν 3043, 2921, 2857, 1680, 1575, 1560, 1425, 1325, 1270, 1179, 1116, 1064, 976, 803, 740 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{17}H_{15}F_3N_3$ $[M + H]^+$ 318.1218, found 318.1213.

*(E)-5-Bromo-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3n**):* 54.8 mg (72%); *E*:*Z* ratio = 20:1; light brown solid; mp = 54.6−57.3 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.75 (d, J = 4.8 Hz, 2H), 8.24 (d, J = 8.9 Hz, 1H), 7.66 (s, 1H), 7.33 (dd, J = 8.8, 2.0 Hz, 1H), 7.16 (t, J = 4.8 Hz, 1H), 6.60−6.53 (m, 1H), 6.42 (s, 1H), 5.61 (dtt, J = 15.7, 6.4, 1.5 Hz, 1H), 4.07−4.06 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.3, 157.9, 138.4, 137.8 (q, J_{C-F} = 6.6 Hz), 135.8, 130.8, 126.1, 123.0 (q, J_{C-F} = 267.8 Hz), 122.7, 120.2 (q, J_{C-F} = 33.3 Hz), 117.6, 116.2, 115.4, 106.9, 32.1; IR (KBr) ν 2923, 2359, 1681, 1575, 1561, 1426, 1323, 1279, 1188, 1120, 1060, 977, 803, 748 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{16}H_{12}BrF_3N_3$ $[M + H]^+$ 382.0167, found 382.0165.

*(E)-5-Nitro-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3o**):* 54.3 mg (78%); *E*:*Z* ratio = 20:1; yellow solid; mp = 146.3−147.9 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.83 (d, J = 4.8 Hz, 2H), 8.43 (s, 1H), 8.33 (d, J = 9.2 Hz, 1H), 8.09 (dd, J = 9.2, 2.3 Hz, 1H), 7.29 (t, J = 4.8 Hz, 1H), 6.60 (s, 1H), 6.59−6.52 (m, 1H), 5.62 (dtt, J = 15.7, 6.2, 1.5 Hz, 1H), 4.08−4.07 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.6, 157.4, 143.3, 140.5, 140.1, 137.1 (q, J_{C-F} = 6.7 Hz), 122.9 (q, J_{C-F} = 267.5 Hz), 120.7 (q, J_{C-F} = 33.4 Hz), 118.7, 118.6, 116.6, 114.6, 108.2, 31.9; IR (KBr) ν 3094, 2924, 1677, 1570, 1514, 1449, 1410, 1336, 1293, 1266, 1180, 1117, 1075, 1050, 978, 889, 813, 795, 750 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{16}H_{12}F_3N_4O_2$ $[M + H]^+$ 349.0912, found 349.0906.

*(E)-6-Methyl-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3p**):* 43.0 mg (68%); *E*:*Z* ratio = 35:1; yellow solid; mp = 61.0−62.2 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.77 (d, J = 4.8 Hz, 2H), 8.15 (s, 1H), 7.44 (d, J = 7.9 Hz, 1H), 7.14 (t, J = 4.8 Hz, 1H), 7.06 (d, J = 7.9 Hz, 1H), 6.62−6.54 (m, 1H), 6.46 (s, 1H), 5.63−5.54 (m, 1H), 4.05 (br s, 2H), 2.50 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.3, 158.2, 138.2 (q, J_{C-F} = 6.5 Hz), 137.5, 136.2, 133.3, 126.9, 123.8, 123.2 (q, J_{C-F} = 267.5 Hz), 119.9, 119.8 (q, J_{C-F} = 33.2 Hz), 117.3, 114.4, 107.7, 32.1, 22.2; IR (KBr) ν 3043, 2920, 2359, 1679, 1563, 1487, 1426, 1322, 1286, 1189, 1116, 978, 815 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{17}H_{15}F_3N_3$ $[M + H]^+$ 318.1218, found 318.1218.

*(E)-6-Chloro-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3q**):* 51.4 mg (76%); *E*:*Z* ratio = 35:1; yellow solid; mp = 74.9−76.3 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.76 (d, J = 4.8 Hz, 2H), 8.42 (s, 1H), 7.44 (d, J = 8.3 Hz, 1H), 7.19 (dd, J = 8.3, 1.8 Hz, 1H), 7.16 (t, J = 4.8 Hz, 1H), 6.61−6.55 (m, 1H), 6.46 (s, 1H), 5.61 (dtt, J = 15.7, 6.3, 1.5 Hz, 1H), 4.07−4.06 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.4, 157.9, 137.8 (q, J_{C-F} = 6.0 Hz), 137.4, 129.2, 127.6, 123.1 (q, J_{C-F} = 267.5 Hz), 122.8, 120.8, 120.1 (q, J_{C-F} = 33.4 Hz), 117.6, 114.9, 107.5, 32.1; IR (KBr) ν 2924, 2853, 1681, 1574, 1561, 1425, 1346, 1321, 1296, 1187, 1118, 1064, 977, 820, 738 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{16}H_{12}ClF_3N_3$ $[M + H]^+$ 338.0672, found 338.0666.

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*(E)-6-Fluoro-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3r**):* 45.2 mg (70%); *E*:*Z* ratio = 24:1; yellow solid; mp = 55.8−59.8 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.76 (d, J = 4.8 Hz, 2H), 8.16 (dd, J = 11.0, 2.3 Hz, 1H), 7.45 (dd, J = 8.5, 5.5 Hz, 1H), 7.16 (t, J = 4.8 Hz, 1H), 6.98 (t, J = 9.0 Hz, 1H), 6.62−6.55 (m, 1H), 6.46 (s, 1H), 5.61 (dtt, J = 15.7, 6.3, 1.6 Hz, 1H), 4.08−4.06 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.5 (d, J_{C-F} = 236.0 Hz), 158.3, 158.0, 138.1 (q, J_{C-F} = 6.6 Hz), 137.4 (q, J_{C-F} = 3.0 Hz), 137.2 (q, J_{C-F} = 12.8 Hz), 125.5, 123.2 (q, J_{C-F} = 267.5 Hz), 120.6 (d, J_{C-F} = 9.8 Hz), 120.0 (q, J_{C-F} = 33.3 Hz), 117.5, 110.6 (d, J_{C-F} = 24.2 Hz), 107.6, 102.1 (d, J_{C-F} = 28.8 Hz), 32.2; IR (KBr) ν 2924, 2856, 2359, 1680, 1572, 1482, 1427, 1352, 1322, 1286, 1204, 1191, 1118, 979, 851, 814, 732 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{16}H_{12}F_4N_3$ $[M + H]^+$ 322.0967, found 322.0961.

*(E)-6-Nitro-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H -indole (**3s**):* 47.9 mg (69%); *E*:*Z* ratio = 28:1; dark yellow solid; mp = 144.3−145.5 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.27 (s, 1H), 8.84 (d, J = 4.8 Hz, 2H), 8.10 (dd, J = 8.6, 2.1 Hz, 1H), 7.57 (d, J = 8.6 Hz, 1H), 7.28 (t, J = 4.8 Hz, 1H), 6.62−6.55 (m, 2H), 5.66 (dtt, J = 15.7, 6.3, 1.5 Hz, 1H), 4.13−4.12 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.7, 157.5, 144.3, 143.1, 136.9 (q, J_{C-F} = 6.5 Hz), 135.8, 133.9, 122.9 (q, J_{C-F} = 267.5 Hz), 120.9 (q, J_{C-F} = 33.4 Hz), 120.0, 118.4, 117.8, 111.7, 107.6, 32.3; IR (KBr) ν 3127, 2932, 2359, 1682, 1566, 1509, 1469, 1435, 1331, 1295, 1274, 1208, 1109, 1071, 984, 828, 730 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{16}H_{12}F_3N_4O_2$ $[M + H]^+$ 349.0912, found 349.0907.

*(E)-7-Methyl-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1H-indole (**3t**):* 40.9 mg (64%); *E*:*Z* ratio = 2:1; brown sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) (*E* isomer) δ 8.83 (d, J = 4.8 Hz, 2H), 7.47−7.44 (m, 1H), 7.33−7.28 (m, 1H), 7.13−7.08 (m, 1H), 7.02−6.98 (m, 1H), 6.49 (s, 1H), 6.40−6.32 (m, 1H), 5.42−5.33 (m, 1H); 3.71−3.70 (m, 2H), 1.99 (s, 3H); (*Z* isomer) δ 8.85 (d, J = 4.8 Hz, 2H), 7.47−7.44 (m, 1H), 7.33−7.28 (m, 1H), 7.13−7.08 (m, 1H), 7.02−6.98 (m, 1H), 6.48 (s, 1H), 6.17 (dt, J = 18.9, 7.3 Hz, 1H), 5.64−5.55 (m, 1H), 3.78−3.76 (m, 2H), 1.97 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) (*E* isomer) δ 158.6, 158.5, 137.1 (q, J_{C-F} = 6.4 Hz), 138.1, 136.8, 129.4, 125.9, 122.8 (q, J_{C-F} = 267.6 Hz), 122.2, 121.8, 120.1 (q, J_{C-F} = 33.1 Hz), 119.4, 118.4, 105.5, 30.1, 20.3; (*Z* isomer) δ 158.6, 158.5, 139.2 (q, J_{C-F} = 5.1 Hz), 138.1, 136.8, 129.5, 125.6, 123.2 (q, J_{C-F} = 270.1 Hz), 122.1, 121.7, 119.5, 118.7 (q, J_{C-F} = 33.5 Hz), 118.4, 118.4, 104.6, 27.1, 20.3; IR (KBr) ν 3046, 2930, 1680, 1562, 1459, 1421, 1328, 1284, 1269, 1121, 976, 815, 798, 743 cm^{-1}; HRMS (quadrupole, EI) calcd for $C_{17}H_{14}F_3N_3$ $[M]^+$ 317.1140, found 317.1139.

Typical Procedure and Characterization Data for the Synthesis of 5b−5k. To an oven-dried sealed tube charged with 1-(indolin-1-yl)ethanone (**4b**) (32.2 mg, 0.2 mmol, 100 mol %), $[RhCp^*Cl_2]_2$ (3.1 mg, 0.005 mmol, 2.5 mol %), $AgSbF_6$ (6.9 mg, 0.02 mmol, 10 mol %), and $Cu(OAc)_2$ (18.2 mg, 0.1 mmol, 50 mol %) in THF (1 mL) was added ethyl 1,1,1-trifluorobut-3-en-2-yl carbonate (**2a**) (79.3 mg, 0.4 mmol, 120 mol %) under air. The reaction mixture was allowed to stir at 120 °C for 24 h and cooled to room temperature. The reaction mixture was diluted with EtOAc (3 mL) and concentrated in vacuo. The residue was purified by flash column chromatography (*n*-hexanes/EtOAc 2:1) to afford **5b** (31.2 mg) in 58% yield.

*(E)-1-(7-(4,4,4-Trifluorobut-2-enyl)indolin-1-yl)ethanone (**5b**):* 31.2 mg (58%); *E*:*Z* ratio = >50:1; dark brown sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.13 (d, J = 7.2 Hz, 1H), 7.07 (t, J = 7.5 Hz, 1H), 7.99 (d, J = 7.5 Hz, 1H), 6.45−6.38 (m, 1H), 5.64−5.58 (m, 1H), 4.05 (t, J = 7.5 Hz, 2H), 3.59 (br s, 2H), 3.05 (t, J = 7.5 Hz, 2H), 2.26 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.6, 141.1, 138.8 (q, J_{C-F} = 6.5 Hz), 135.1, 129.4, 128.4, 125.7, 123.3 (q, J_{C-F} = 267.5 Hz), 123.2, 119.3 (q, J_{C-F} = 33.1 Hz), 51.3, 36.7, 30.1, 23.9; IR (KBr) ν 2908, 2842, 2360, 2342, 2296, 1665, 1592, 1450, 1386, 1337, 1283, 1269, 1186, 1111, 1056, 985, 920, 859, 777, 756 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{14}H_{15}F_3NO$ $[M + H]^+$ 270.1106, found 270.1107.

*(E)-2,2-Dimethyl-1-(7-(4,4,4-trifluorobut-2-enyl)indolin-1-yl)-propan-1-one (**5c**):* 34.8 mg (56%); *E*:*Z* ratio = >50:1; light yellow sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.15 (d, J = 7.2 Hz, 1H), 7.07 (t, J = 7.5 Hz, 1H), 7.99 (d, J = 7.6 Hz, 1H), 6.45−6.37 (m, 1H), 5.63−5.54 (m, 1H), 4.12 (t, J = 7.4 Hz, 2H), 3.48−3.47 (m, 2H), 3.04 (t, J = 7.3 Hz, 2H), 1.37 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 178.2, 143.1, 138.8 (q, J_{C-F} = 6.5 Hz), 134.9, 129.1, 128.9, 125.5, 124.6 (q, J_{C-F} = 266.1 Hz), 123.1, 119.4 (q, J_{C-F} = 33.0 Hz), 51.4, 36.7, 40.1, 36.4, 31.7, 28.6; IR (KBr) ν 2965, 2854, 1649, 1593, 1477, 1449, 1401, 1351, 1323, 1285, 1269, 1221, 1178, 1119, 985, 906, 757 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{17}H_{21}F_3NO$ $[M + H]^+$ 312.1575, found 312.1575.

*(E)-N,N-Dimethyl-7-(4,4,4-trifluorobut-2-enyl)indoline-1-carboxamide (**5d**):* 22.1 mg (37%); *E*:*Z* ratio = >50:1; colorless sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.10 (d, J = 6.6 Hz, 1H), 7.00−6.94 (m, 2H), 6.46−6.37 (m, 1H), 5.67−5.58 (m, 1H), 3.90 (t, J = 8.0 Hz, 2H), 3.48−3.46 (m, 2H), 3.09 (t, J = 8.0 Hz, 2H), 2.97 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 161.0, 143.8, 138.8 (q, J_{C-F} = 6.5 Hz), 134.1, 128.9, 126.8, 124.0, 123.4 (q, J_{C-F} = 267.6 Hz), 123.3, 119.4 (q, J_{C-F} = 32.9 Hz), 52.9, 37.8, 35.8, 30.6; IR (KBr) ν 2923, 2832, 1652, 1454, 1379, 1269, 1167, 1108, 1057, 983, 918, 858, 765, 751 cm^{-1}; HRMS (quadrupole, EI) calcd for $C_{15}H_{17}F_3N_2O$ $[M]^+$ 298.1293, found 298.1295.

*(E)-1-(2-Methyl-7-(4,4,4-trifluorobut-2-enyl)indolin-1-yl)ethanone (**5e**):* 34.5 mg (61%); *E*:*Z* ratio = >50:1; light yellow solid; mp = 56.2−58.4 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.13 (d, J = 7.2 Hz, 1H), 7.08 (t, J = 7.4 Hz, 1H), 7.02 (d, J = 7.4 Hz, 1H), 6.37−6.28 (m, 1H), 5.56 (dtt, J = 15.6, 6.4, 1.4 Hz, 1H), 4.54−4.47 (m, 1H), 3.88−3.82 (m, 1H), 3.44−3.39 (m, 2H), 2.51 (d, J = 15.4 Hz, 1H), 2.25 (s, 3H), 1.21 (d, J = 6.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.1, 139.7, 138.7 (q, J_{C-F} = 6.5 Hz), 134.0, 129.7, 129.1, 125.8, 123.8, 123.3 (q, J_{C-F} = 267.3 Hz), 119.2 (q, J_{C-F} = 33.0 Hz), 58.2, 37.0, 36.9, 23.1, 20.6; IR (KBr) ν 2961, 2925, 2853, 1661, 1592, 1480, 1447, 1386, 1339, 1298, 1271, 1112, 1053, 992, 920, 855, 765 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{15}H_{17}F_3NO$ $[M + H]^+$ 284.1262, found 284.1262.

*(E)-1-(3-Methyl-7-(4,4,4-trifluorobut-2-enyl)indolin-1-yl)ethanone (**5f**):* 40.5 mg (71%); *E*:*Z* ratio = >50:1; yellow sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.13−7.08 (m, 2H), 7.03−7.00 (m, 1H), 6.48−6.39 (m, 1H), 5.61 (dtt, J = 15.6, 6.4, 1.5 Hz, 1H), 4.19 (t, J = 7.9 Hz, 1H), 3.65−3.53 (m, 3H), 3.41−3.32 (m, 1H), 2.26 (s, 3H), 1.29 (d, J = 6.8 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.7, 140.9, 140.3, 138.8 (q, J_{C-F} = 6.5 Hz), 129.4, 128.4, 125.9, 123.3 (q, J_{C-F} = 267.3 Hz), 121.9, 119.3 (q, J_{C-F} = 32.8 Hz), 58.9, 36.6, 36.5, 23.9, 18.1; IR (KBr) 2964, 2931, 2874, 1666, 1592, 1445, 1386, 1340, 1270, 1178, 1112, 1057, 979, 943, 854, 754 cm^{-1}; HRMS (quadrupole, EI) calcd for $C_{15}H_{16}F_3NO$ $[M]^+$ 283.1184, found 283.1181.

*(E)-1-(5-Chloro-7-(4,4,4-trifluorobut-2-enyl)indolin-1-yl)ethanone (**5g**):* 38.6 mg (64%); *E*:*Z* ratio = >50:1; yellow solid; mp = 59.8−61.3 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.11 (s, 1H), 6.98 (s, 1H), 6.42−6.33 (m, 1H), 5.62 (dtt, J = 15.6, 6.4, 1.5 Hz, 1H), 4.06 (t, J = 7.6 Hz, 2H), 3.57−3.54 (m, 2H), 3.04 (t, J = 7.6 Hz, 2H), 2.25 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.7, 140.0, 137.9 (q, J_{C-F} = 6.5 Hz), 137.0, 130.8, 129.9, 129.2, 123.4, 123.2 (q, J_{C-F} = 270.5 Hz), 119.9 (q, J_{C-F} = 32.8 Hz), 51.4, 36.5, 29.9, 23.8; IR (KBr) 2922, 2853, 2322, 1667, 1593, 1456, 1427, 1380, 1335, 1267, 1233, 1186, 1111, 1056, 975, 921, 863, 812, 742 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{14}H_{14}ClF_3NO$ $[M + H]^+$ 304.0716, found 304.0717.

*(E)-1-(6-Fluoro-7-(4,4,4-trifluorobut-2-enyl)indolin-1-yl)ethanone (**5h**):* 36.5 mg (64%); *E*:*Z* ratio = >50:1; light yellow sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.08−7.05 (m, 1H), 6.84−6.80 (m, 1H), 6.45−6.36 (m, 1H), 5.60−5.51 (m, 1H), 4.07 (t, J = 7.6 Hz, 2H), 3.64−3.63 (m, 2H), 3.01 (t, J = 7.5 Hz, 2H), 2.25 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.8, 161.2 (d, J_{C-F} = 241.3 Hz), 142.7 (d, J_{C-F} = 7.0 Hz), 137.8 (q, J_{C-F} = 6.3 Hz), 130.4 (d, J_{C-F} = 2.5 Hz), 123.6, 123.5, 123.3 (q, J_{C-F} = 267.2 Hz), 119.1 (q, J_{C-F} = 33.0 Hz), 116.9 (d, J_{C-F} = 19.2 Hz), 112.0 (d, J_{C-F} = 24.7 Hz), 52.0, 29.4, 29.1 (d, J_{C-F} = 4.6 Hz), 23.9; IR (KBr) ν 2923, 2854, 1668, 1613, 1494, 1475, 1436, 1387, 1321, 1275, 1233, 1114, 1055, 1030, 986, 917, 866, 808, 721 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{14}H_{14}F_4NO$ $[M + H]^+$ 288.1012, found 288.1012.

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*(E)-1-(Pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-6,7-dihydro-1H-indol-4(5H)-one (**5i**):* 49.8 mg (77%); *E*:*Z* ratio = 7:1; yellow solid; mp = 94.9−97.8 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.78 (d, J = 4.8 Hz, 2H), 7.29 (t, J = 4.8 Hz, 1H), 6.45 (s, 1H), 6.39−6.32 (m, 1H), 5.44 (dtt, J = 15.7, 6.3, 1.5 Hz, 1H), 3.73−3.72 (m, 2H), 2.99 (t, J = 6.1 Hz, 2H), 2.49 (t, J = 5.9 Hz, 2H), 2.13−2.08 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 195.0, 158.7, 156.8, 146.0, 137.6 (q, J_{C-F} = 6.5 Hz), 131.4, 122.9 (q, J_{C-F} = 267.9 Hz), 121.8, 119.9 (q, J_{C-F} = 33.3 Hz), 119.4, 107.3, 37.9, 30.4, 24.7, 24.0; IR (KBr) ν 2946, 1662, 1561, 1531, 1459, 1421, 1274, 1170, 1118, 1062, 977, 829, 741 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{16}H_{15}F_3N_3O$ $[M + H]^+$ 322.1167, found 322.1164.

*2-(2,5-Bis((E)-4,4,4-Trifluorobut-2-enyl)-1H-pyrrol-1-yl)pyrimidine (**5j**):* 35.4 mg (49%); *E*:*Z* ratio = 5:1; brown sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.74 (d, J = 7.2 Hz, 2H), 7.21 (t, J = 4.8 Hz, 1H), 6.39−6.33 (m, 2H), 6.03 (s, 2H), 5.43−5.35 (m, 2H), 3.84−3.82 (m, 1H), 3.71 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.6, 158.7, 138.3 (q, J_{C-F} = 6.4 Hz), 130.4, 123.1 (q, J_{C-F} = 267.5 Hz), 119.4 (q, J_{C-F} = 33.2 Hz), 118.8, 110.2, 30.6; IR (KBr) ν 3047, 2910, 2359, 1680, 1561, 1518, 1428, 1331, 1289, 1271, 1182, 1112, 1050, 974, 860, 816, 773 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{16}H_{14}F_6N_3$ $[M + H]^+$ 362.1092, found 362.1093.

*2-(3-Methyl-2,5-bis((E)-4,4,4-trifluorobut-2-enyl)-1H-pyrrol-1-yl)-pyrimidine (**5k**):* 35.4 mg (37%); *E*:*Z* ratio = 7:1; yellow sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.64 (d, J = 4.8 Hz, 2H), 7.10 (t, J = 4.8 Hz, 1H), 6.33−6.20 (m, 2H), 5.85 (s, 1H), 5.33 (dtt, J = 15.8, 6.4, 1.7 Hz, 1H), 5.20 (dtt, J = 15.8, 6.5, 1.4 Hz, 1H), 3.73−3.58 (m, 4H), 1.96 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.6, 158.5, 138.7 (q, J_{C-F} = 6.2 Hz), 138.4 (q, J_{C-F} = 6.4 Hz), 129.3, 125.7, 124.6 (q, J_{C-F} = 269.1 Hz), 124.6 (q, J_{C-F} = 269.1 Hz), 124.4 (q, J_{C-F} = 267.6 Hz), 119.4 (q, J_{C-F} = 33.3 Hz), 119.1, 118.6 (q, J_{C-F} = 33.0 Hz), 118.5, 112.8, 30.5, 27.8, 11.2; IR (KBr) ν 3045, 2923, 2855, 1679, 1563, 1428, 1334, 1286, 1184, 1108, 1050, 973, 882, 808, 744 cm^{-1}; HRMS (quadrupole, EI) calcd for $C_{17}H_{15}F_6N_3$ $[M]^+$ 375.1170, found 375.1170.

General Procedure and Characterization Data for the Synthesis of 7a and 7b. To an oven-dried sealed tube charged with *N*-phenylacetamide (**6a**) (27.0 mg, 0.2 mmol, 100 mol %), $[RhCp^*Cl_2]_2$ (3.1 mg, 0.005 mmol, 2.5 mol %), $AgSbF_6$ (6.9 mg, 0.02 mmol, 10 mol %), and $Cu(OAc)_2$ (36.3 mg, 0.2 mmol, 100 mol %) in THF (1 mL) was added ethyl 1,1,1-trifluorobut-3-en-2-yl carbonate (**2a**) (79.3 mg, 0.4 mmol, 120 mol %) under air. The reaction mixture was allowed to stir at 120 °C for 36 h and cooled to room temperature. The reaction mixture was diluted with EtOAc (3 mL) and concentrated in vacuo. The residue was purified by flash column chromatography (*n*-hexanes/EtOAc 12:1) to afford **7a** (15.6 mg) in 32% yield.

*1-(2-(2,2,2-Trifluoroethyl)-1H-indol-1-yl)ethanone (**7a**):* 15.6 mg (32%); yellow sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (d, J = 8.2 Hz, 1H), 7.57 (d, J = 7.4 Hz, 1H), 7.33 (t, J = 7.2 Hz, 1H), 7.29−7.25 (m, 1H), 6.71 (s, 1H), 4.13−4.05 (m, 2H), 2.83 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.8, 136.0, 130.8 (q, J_{C-F} = 3.3 Hz), 125.5 (q, J_{C-F} = 274.9 Hz), 124.8, 123.1, 121.6, 114.3, 112.6, 34.7 (q, J_{C-F} = 30.8 Hz), 27.8; IR (KBr) ν 2929, 2861, 2359, 1761, 1709, 1571, 1459, 1436, 1401, 1367, 1295, 1277, 1254, 1211, 1138, 1082, 1034, 989, 906, 813, 742 cm^{-1}; HRMS (quadrupole, EI) calcd for $C_{12}H_{10}F_3NO$ $[M]^+$ 241.0714, found 241.0715.

*1-(6-Methyl-2-(2,2,2-trifluoroethyl)-1H-indol-1-yl)ethanone (**7b**):* 10.5 mg (21%); yellow sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 (d, J = 8.2 Hz, 2H), 7.10 (d, J = 7.7 Hz, 1H), 6.65 (s, 1H), 4.10−4.02 (q, J = 9.9 Hz, 2H), 2.81 (s, 3H), 2.50 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.9, 136.5, 134.7, 130.1 (q, J_{C-F} = 2.9 Hz), 127.3, 125.5 (q, J_{C-F} = 275.7 Hz), 124.8, 121.1, 114.7, 112.5, 34.7 (q, J_{C-F} = 30.9 Hz), 27.9, 22.4; IR (KBr) ν 2927, 2863, 2361, 1707, 1486, 1401, 1372, 1312, 1277, 1256, 1219, 1145, 1081, 950, 906, 823, 730 cm^{-1}; HRMS (quadrupole, EI) calcd for $C_{13}H_{12}F_3NO$ $[M]^+$ 255.0871, found 255.0874.

General Procedure and Characterization Data for the Olefin Migration Product 8a. An oven-dried sealed tube was charged with (*E*)-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1*H*-indole (**3a**) (60.7 mg, 0.2 mmol, 100 mol %), NaOEt (28.7 mg, 0.4 mmol, 200 mol %), and DMF (1 mL) under N_2 atmosphere. The reaction mixture was allowed to stir at 120 °C for 24 h and cooled to room temperature. The reaction mixture was diluted with EtOAc (3 mL) and concentrated in vacuo. The residue was purified by flash column chromatography (*n*-hexanes/EtOAc = 10:1) to afford **8a** (31.3 mg) in 52% yield.

*(E)-1-(Pyrimidin-2-yl)-2-(4,4,4-trifluorobut-1-enyl)-1H-indole (**8a**):* 31.3 mg (52%); *E*:*Z* ratio = 10:1; light yellow sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.80 (d, J = 4.8 Hz, 2H), 8.31 (d, J = 7.8 Hz, 1H), 7.57 (d, J = 7.8 Hz, 1H), 7.30−7.16 (m, 4H), 6.89 (s, 1H), 6.12 (dt, J = 15.7, 7.2 Hz, 1H), 3.09−2.98 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.4, 158.3, 137.4, 137.3, 129.3, 129.1, 126.1 (q, J_{C-F} = 275.3 Hz), 123.9, 122.6, 120.7, 118.2 (q, J_{C-F} = 3.5 Hz), 117.4, 114.4, 106.4, 37.9 (q, J_{C-F} = 29.7 Hz); IR (KBr) ν 3047, 2926, 2840, 2357, 1573, 1562, 1451, 1420, 1347, 1249, 1211, 1132, 1107, 1041, 958, 845, 808, 746 cm^{-1}; HRMS (quadrupole, EI) calcd for $C_{16}H_{12}F_3N_3$ $[M]^+$ 303.0983, found 303.0979.

General Procedure and Characterization Data for the Reduction Product 8b. An oven-dried sealed tube was charged with (*E*)-1-(pyrimidin-2-yl)-2-(4,4,4-trifluorobut-2-enyl)-1*H*-indole (**3a**) (60.7 mg, 0.2 mmol, 100 mol %), 10% Pd/C (21.0 mg, 0.02 mmol, 10 mol %), and MeOH (1 mL) under a H_2 balloon. The reaction mixture was allowed to stir at room temperature for 12 h. The reaction mixture was diluted with EtOAc (3 mL) and concentrated in vacuo. The residue was purified by flash column chromatography (*n*-hexanes/EtOAc = 10:1) to afford **8b** (34.1 mg) in 56% yield.

*Ethyl 7-(Butylcarbamoyl)-2-methyl-1-(pyridin-2-yl)-1H-indole-3-carboxylate (**8b**):* 34.1 mg (56%); yellow solid; mp = 49.8−50.3 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.79 (d, J = 4.8 Hz, 2H), 8.31 (d, J = 8.2 Hz, 1H), 7.54 (d, J = 8.2 Hz, 1H), 7.27−7.15 (m, 3H), 6.49 (s, 1H), 3.26 (t, J = 7.6 Hz, 2H), 2.24−2.12 (m, 2H), 2.12−1.93 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.4, 158.3, 140.4, 137.2, 129.4, 127.4 (q, J_{C-F} = 275.3 Hz), 123.1, 122.2, 120.0, 117.3, 114.3, 106.6, 33.5 (q, J_{C-F} = 275.3 Hz), 28.7, 21.7 (q, J_{C-F} = 275.3 Hz); IR (KBr) ν 3726, 3624, 3048, 2946, 2360, 1796, 1563, 1423, 1349, 1314, 1250, 1205, 1131, 1010, 990, 804, 747 cm^{-1}; HRMS (Orbitrap, ESI) calcd for $C_{16}H_{15}F_3N_3$ $[M + H]^+$ 306.1218, found 306.1220.

*Rhodacycle **1aa**:*[15] 350.6 mg (60%); orange solid; mp = >300 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.67−8.63 (m, 2H), 8.42 (d, J = 8.0 Hz, 1H), 7.42 (d, J = 8.0 Hz, 1H), 7.14 (t, J = 8.4 Hz, 1H), 7.06 (t, J = 8.4 Hz, 1H), 6.93 (t, J = 5.2 Hz, 1H), 6.63 (s, 1H), 1.73 (s, 15H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.7, 163.4, 159.6, 159.3, 158.7, 136.4, 135.0, 122.4, 120.4, 118.0, 114.3, 113.4, 110.7, 96.6, 96.5, 9.4; HRMS (quadrupole, EI) calcd for $C_{22}H_{23}ClN_3Rh$ $[M]^+$ 467.0636, found 467.0634.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b00721.

Spectroscopic data for all products (PDF)

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Notes

The authors declare no competing financial interest.

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