

Cyclic Hypervalent Iodine Reagents for Azidation: Safer Reagents and Photoredox-Catalyzed Ring Expansion

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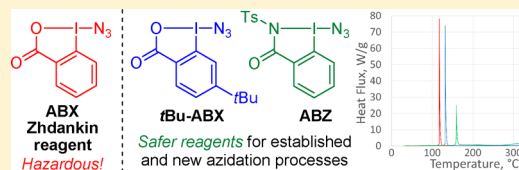
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Supporting Information

ABSTRACT: Azides are building blocks of increasing importance in synthetic chemistry, chemical biology, and materials science. Azidobenziodoxolone (ABX, Zhdankin reagent) is a valuable azide source, but its safety profile has not been thoroughly established. Herein, we report a safety study of ABX, which shows its hazardous nature. We introduce two derivatives, *t*Bu-ABX and ABZ (azidobenziodazolon), with a better safety profile, and use them in established photoredox- and metal-mediated azidations, and in a new ring-expansion of silylated cyclobutanols to give azidated cyclopentanones.

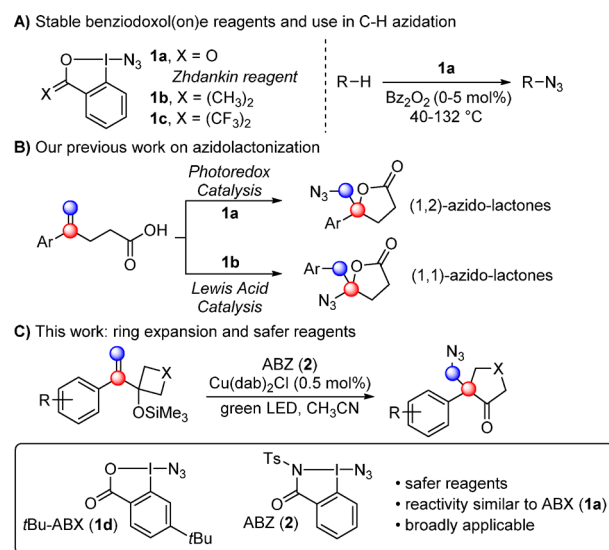


Organic azides are versatile building blocks in synthetic chemistry, chemical biology, and materials science.¹ Therefore, the development of a new synthetic methodology to access them is an important field of research.² In this context, azide-containing hypervalent iodine(III) reagents³ derived from iodobenzene have been known for a long time as sources of electrophilic azides or azido radicals.⁴ Nevertheless, these reagents are highly unstable at room temperature and need to be generated in situ.

In 1994, an important progress was realized by Zhdankin and co-workers,⁵ shortly followed by Kita and co-workers,⁶ with the isolation of the first cyclic hypervalent iodine reagents being stable up to 100 °C: the azidobenziodoxol(ones) (ABX) **1a–1c** (Scheme 1A). Zhdankin demonstrated the functionalization of C–H bonds with azidobenziodoxolone **1a** (Zhdankin reagent) under mild thermal activation with or without dibenzoyl peroxide as the initiator.^{5c} Surprisingly, this result did not attract the attention it should have, and it was only in 2013 that our group, as well as Gade and co-workers, reported the excellent properties of ABX reagents as a source of electrophilic azides, whereas Studer and co-workers reported reductive conditions to generate azido radicals from **1a**.⁷ Since then, the Zhdankin reagent **1a** has established itself as an excellent azide source, either under thermal,^{5c,8} photoredox,⁹ or metal-mediated activation.¹⁰

In 2017, our group reported the divergent reactivity of the Zhdankin reagent (**1a**) and azidobenziodoxole **1b** in the azidolactonization of alkenes (Scheme 1B).¹¹ Whereas **1a** was ideally suited for 1,2-azidation under photoredox conditions, Lewis acid activation of **1b** led to 1,1-azidolactonization via an 1,2-aryl shift. On the basis of these results, we wondered if we could also develop an azidative ring-expansion of alkene-substituted

Scheme 1. Cyclic Hypervalent Iodine Reagents as Azide Sources



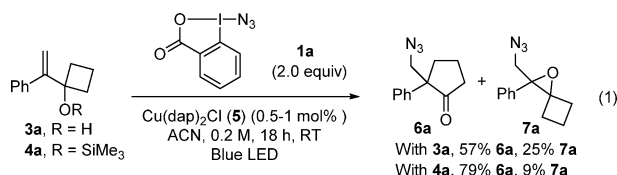
cyclobutanol derivatives via reaction with azido radicals (Scheme 1C). Such ring expansions are usually initiated by the addition of electrophilic¹² or organometallic¹³ intermediates onto the olefin. More recently, the addition of a radical followed by oxidation and an 1,2-shift under photoredox conditions has emerged as a very efficient approach for ring

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expansion,¹⁴ but it has never been reported for the synthesis of organic azides.¹⁵ Preliminary results with the Zhdankin reagent (**1a**) using a copper photoredox catalyst were highly promising, but a spontaneous explosion of a pure sample of **1a** in our laboratory made us aware of serious safety hazards.

Herein, we report safety studies of the Zhdankin reagent (**1a**), which highlighted a very high shock and friction sensitivity.¹⁶ The stability of two higher weight derivatives (*t*Bu-ABX (**1c**) and ABZ (azidobenziodazolone **2**), Scheme 1C) was investigated, showing an enhanced safety profile. ABZ (**2**), in particular, was well suited for the generation of azido radicals under mild photoredox conditions, allowing us to develop the desired ring expansion in high yield and with a broad scope. Finally, we demonstrate that either *t*Bu-ABX (**1d**) or ABZ (**2**) can be used as alternatives to the Zhdankin reagent in a broad range of transformations involving thermal, photoredox, or metal-mediated activation.

On the basis of our photocatalyzed azidolactonisation work,¹¹ we started our investigations on the tandem azidation-ring expansion by reacting 1-(1-phenylvinyl)cyclobutanol (**3a**) with ABX (**1a**) (2.0 equiv) as an azide precursor in acetonitrile in the presence of Cu(dap)₂Cl (**5**)¹⁷ (0.5–1 mol %) under blue LED irradiation (eq 1). The expected product **6a** was obtained in



57% yield as a mixture with 25% of 1,2-azido-epoxyde **7a**. To avoid this oxyazidation process, the silyl-protected precursor **4a** was used, and the ring-expansion product **6a** could be obtained in an improved 79% yield.

However, during further optimization studies, a freshly prepared batch of ABX reagent (**1a**) (500 mg) spontaneously exploded when the researcher was handling the reagent with a spatula in a glass flask, causing multiple serious cuts and burns.¹⁸ We therefore decided to stop experimentation with reagent **1a** until its safety profile had been further evaluated. In addition, we synthesized the azidobenziodoxolone reagents *t*Bu-ABX (**1d**) and ABZ (**2**) with higher molecular weight, hoping that the lower proportional azide content would diminish their explosion potential (Scheme 1C). Both reagents **1d** and **2** are easily accessible on gram scale from 4-*tert*-butyl toluene (3.4 g in 5 steps and 31% overall yield) and 2-iodobenzoic acid (5.4 g in 4 steps and 30% overall yield), respectively.

The stability of the compounds was then determined by differential scanning calorimetry (DSC, Figure 1 and Table 1).¹⁹ According to Stoessel,²⁰ thermal risk is the combination of the severity (expressed by the average heat release) and the likelihood of occurrence (defined as TD₂₄ corresponding to the temperature at which the time to the maximum rate of the decomposition reaction is 24 h). Mage et al.²¹ defined a 3 × 3 risk matrix using both the released energy and the TD₂₄. Compounds with severity higher than 400 kJ/kg and TD₂₄ below 150 °C are classified in the most hazardous category. The DSC results (see Table 1) revealed a heat release of 1770 kJ/kg for the Zhdankin reagent (**1a**), 1440 kJ/kg for *t*Bu-ABX (**1d**), and 965 kJ/kg (first peak, with a second peak of 380 kJ/kg) for ABZ (**2**). Onset temperatures were higher for **1d** and **2**. Estimated values²² for TD₂₄ are 45 °C for the Zhdankin

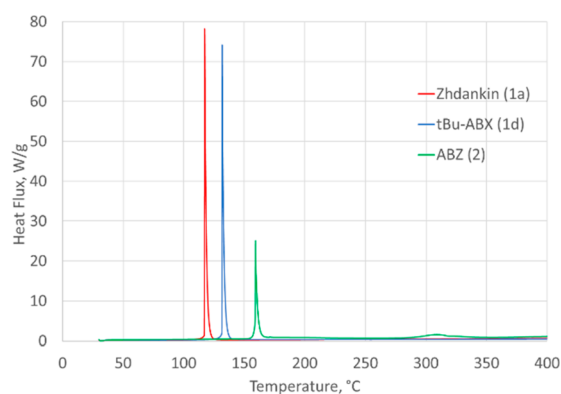


Figure 1. DSC thermograms for the three studied reagents.

reagent (**1a**), 52 °C for *t*Bu-ABX (**1d**), and 88 °C for ABZ (**2**). Therefore, all three compounds have a high severity and likelihood of occurrence, with the Zhdankin reagent having the highest thermal potential hazard.

Another safety parameter for these compounds is related to impact sensitivity. A Fallhammer test showed limiting energies of 1, 2, and 5 J for reagents **1a**, **1d**, and **2** (Table 1). As a comparison, the energy released by the fall of a flask on the floor can be estimated to 3.4 J and of a spatula in a flask to 0.1 J.²³ Both scenarios are hazardous for the Zhdankin reagent (**1a**), even if the lower limit for impact could not be determined experimentally. In addition, all three reagents were sensitive to a friction load of 360 N on a porcelain plate. The results for ABZ (**2**) and *t*Bu-ABX (**1d**) were, however, most probably false positives as they showed no friction sensitivity on Alox plates.

In light of the preliminary safety studies, ABZ (**2**) is the most stable reagent to use as an azide source.

Motivated by the better safety profiles of *t*Bu-ABX (**1d**) and, especially, ABZ (**2**), we then investigated the use of these reagents in the ring expansion reaction. The best results were obtained with ABZ (**2**), and the desired product **6a** was obtained in 90% yield after a short optimization (Scheme 2).²⁴ This is an important result, demonstrating that Zhdankin and ABZ reagents **1a** and **2** have similar efficiency in the generation of azido radicals under photoredox conditions. The scope of the transformation was broad, and *para*-substituted styrenes with alkyl-, phenyl-, as well as methoxy-, and chlorine- groups gave the desired cyclopentanones **6a–6g** in excellent yields. Cyclopentanones **6h–j** and **6k** with either a *meta* or an *ortho* substituent on the arene ring were also obtained in very good yields. *Meta*, *para*-disubstituted derivatives **6l–6n** were as well isolated in very good yields. 1-Naphthyl substituted **6o** was isolated in 95% yield, whereas the more hindered 2-naphthyl derivative **6p** was obtained in 79% yield. Interestingly, oxetanes were suitable substrates for the ring expansion reaction, and 3-furanone **6q** was obtained in 58% yield. However, the corresponding Boc-protected azetidine did not react. Styrenes with 1,2-disubstituted olefins were also not suitable substrates, and the secondary azide **6s** was not obtained. A surprising result was observed when the *para*-CF₃-substituted styrene **4t** was subjected to the optimized reaction conditions: epoxide **7t** was isolated as the only product. Azides are versatile functional groups, and the obtained products were readily converted into useful structural motives, such as triazoles, protected amines, or isothiocyanates.

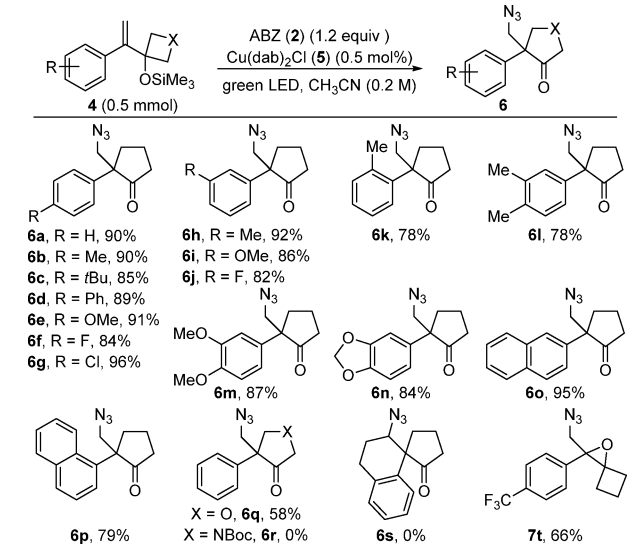
When considering the better safety profile of ABZ (**2**) and to a lesser extend *t*Bu-ABX (**1d**), we decided to investigate their

Table 1. Safety Test Results

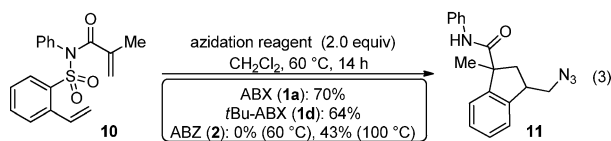
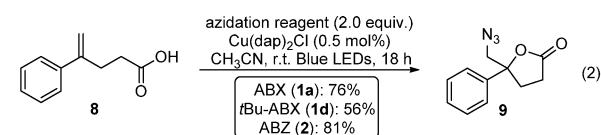
test	data	units	1a	1d	2
DSC	decomposition energy	kJ/kg	1770	1440	965 ^b , 380 ^c
	T_{onset}	°C	90	98–110 ^a	143 ^b , 268 ^c
	T_{peak}	°C	127	139	159 ^b , 308 ^c
impact	limiting energy	J	<1	2	5
friction	friction load 360 N porcelain plate		positive	positive	positive
	friction load 360 N alox plate		positive	negative	negative

^aLarge variation in onset temperature between two measurements. ^bFirst peak. ^cSecond peak.

Scheme 2. Scope of the Ring Expansion Reaction

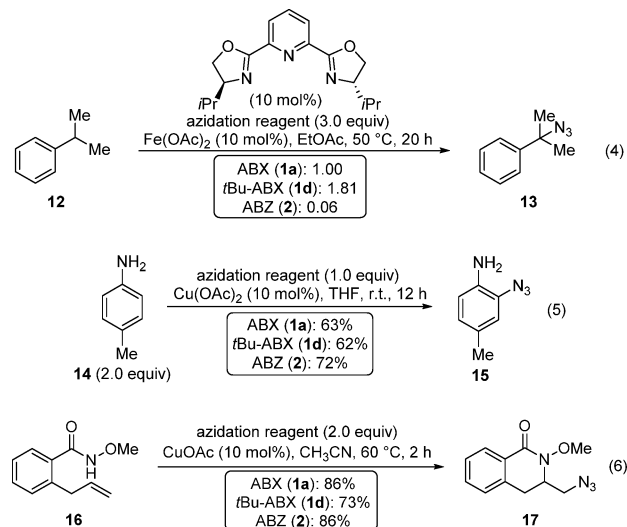


use in other transformations recently discovered using ABX (1a). First, we examined the azidolactonisation previously reported in our group (eq 2).¹¹ The reaction of alkene 8 gave 76% yield



of azidolactone 9 with ABX (1a), 56% with *t*Bu-ABX (1d), and 81% with ABZ (2). This result definitively confirmed that ABZ (2) is an excellent and safer substitute of ABX (1a) for the generation of azide radicals under photoredox conditions. Another azidative cyclization, but using thermal activation, was then investigated (eq 2). The cyclization of 10 to give azide 11 has been reported in 70% yield with ABX (1a) by the Nevado group.^{8c} *t*Bu-ABX (1d) gave 64% yield of 11, but ABZ did not show any reactivity at 60 °C. However, by heating at 100 °C, 11 could be obtained in 43% yield with ABZ (2). This is in good accordance with the higher thermal stability of ABZ (2), requiring higher temperature for activation.

Next, metal-catalyzed azidation processes were examined, starting with the iron-catalyzed sp^3 C–H azidation reported by Hartwig and co-workers (eq 4).^{10c} The representative reaction selected was the azidation of cumene (12). Compared to



ABX (1a) set at 1.00, relative yields of 1.81 and 0.06 were obtained for *t*Bu-ABX (1d) and ABZ (2), respectively, by GC-MS.²⁵ This result may be due to the relative solubility of the reagents in ethyl acetate: ABZ (2) was nearly insoluble, while *t*Bu-ABX (1d) was more soluble than ABX (1a). As a next example, we examined the copper-catalyzed sp^2 C–H bond azidation of anilines reported by Hao and co-workers (eq 5).^{10b} Azide 15 was obtained in 63, 62, or 72% yields²⁶ using reagents 1a, 1d, or 2, respectively, from *p*-toluidine (14). Finally, the copper-catalyzed aminoazidation of olefins developed by Wang and co-workers was examined on alkene 16 (eq 6).^{10h} Again, no significant difference of reactivity between the reagents was observed, and the use of ABZ (2) should be favored.

In summary, we have reported the first in-depth safety studies of the hypervalent iodine azidation reagents ABX (Zhdankin reagent, 1a), *t*Bu-ABX (1d), and ABZ (2), showing the better profile of the latest in particular. ABZ (2) was as efficient as the Zhdankin reagent (1a) in a new photoredox-mediated ring expansion process as well as in established radical- or metal-mediated transformations. When considering the growing importance of hypervalent iodine reagents for azide transfer in synthetic chemistry, we are convinced that our work will be highly useful for researchers to continue to exploit their amazing reactivity in safer settings.

EXPERIMENTAL SECTION

General Methods. All reactions were carried out in oven- or flame-dried glassware under a nitrogen atmosphere, unless stated otherwise. For quantitative flash chromatography, distilled technical grade solvents were used. THF, Et₂O, CH₃CN, and CH₂Cl₂ were dried by passage over activated alumina under a nitrogen atmosphere (H₂O content < 7 ppm, Karl Fischer titration). NEt₃ was dried by distillation over CaH₂ under a nitrogen atmosphere. All chemicals were purchased and used as received, unless stated otherwise.

Chromatographic purification was performed as flash chromatography using Macherey–Nagel silica 40–63, 60 Å, using the solvents indicated as the eluent with 0.1–0.5 bar pressure. TLC was performed on Merck silica gel 60 F254 TLC aluminum plates and visualized with UV-light, permanganate, CAM, or *p*-anisaldehyde stains. ^1H NMR spectra were recorded at room temperature on a Bruker DPX-400 400 MHz spectrometer in chloroform-*d* or d_6 -DMSO; all signals are reported in ppm with the internal chloroform signal at 7.26 ppm or the internal d_6 -DMSO signal at 2.50 ppm as the standard. The data are being reported as (s = singlet, d = doublet, t = triplet, q = quadruplet, qi = quintet, m = multiplet or unresolved, br = broad signal, integration, coupling constant(s) in Hz, interpretation). ^{13}C NMR spectra were recorded with ^1H -decoupling on a Bruker DPX-400 101 MHz spectrometer in chloroform-*d* or d_6 -DMSO; all signals are reported in ppm with the internal chloroform signal at 77.00 ppm or the internal DMSO signal at 39.51 ppm as the standard. Infrared spectra were recorded on a JASCO FT-IR B4100 spectrophotometer with an ATR PRO4100-S and a ZnSe prism and are reported as cm^{-1} (w = weak, m = medium, s = strong). High-resolution mass spectrometric measurements were performed by the mass spectrometry service of ISIC at the EPFL on a MICROMASS (ESI): Q-TOF Ultima API. Melting points were measured on a Büchi B-540 melting point apparatus and were not corrected. Reactions were performed in test tubes (1.0–0 mL), which were held using a rack for test tubes placed at the center of a crystallization flask. On this flask, were attached the LEDs (LED ribbon cable with open ends, Barthelme Y51516414 182405 24 V 502 cm blue 1 pc(s), and LED ribbon cable with open ends, Barthelme Y51515213 182007 12 V 502 cm green 1 pc(s), both purchased directly on www.conrad.ch/fr). The distance between the LEDs and the test tubes was approximately 3–4 cm. Long irradiation for more than 2 h resulted in the temperature increasing up to 34 °C. 3GC-MS analysis was performed on a TSQ 8000 EVO coupled with TRACE 1300 through a Sebron ZB-5 ms column. The injection volume was 1 μL at 250 °C, and the gradient started at 50 °C for 3 min, then 15 °C/min up to 300 °C, and finally 300 °C for 10 min. Reactions under microwave irradiation were performed using a Biotage Initiator reactor in a sealed vial using external temperature control.

Synthesis of ABX (1a). Caution: For safety reasons, the reaction was carried out behind an antiblast shield. Following a reported procedure,^{7b} 2-iodobenzoic acid (**18**) (13.6 g, 54.8 mmol, 1.0 equiv) and NaIO_4 (17 g, 81 mmol, 1.0 equiv) were suspended in aq. AcOH (30% v/v, 83 mL). The mixture was stirred at reflux (120 °C) for 4 h. Past this time, ice-cold water (80 mL) was added under stirring, and the mixture was allowed to cool down to room temperature, while being protected from light with aluminum foil. It was then filtered, and the solid was washed with ice-cold water (3 $\times$ 70 mL) and cold acetone (3 $\times$ 70 mL). The resulting colorless solid (HO-BX, 13.4 g, 50.6 mmol, 92% yield) was allowed to dry in the air overnight and then directly used in the next step. ^1H NMR (400 MHz, d_6 -DMSO, δ): 8.02 (dd, J = 7.7, 1.4 Hz, 1H), 7.97 (m, 1H), 7.85 (dd, J = 8.2, 0.7 Hz, 1H), 7.71 (td, J = 7.6, 1.2 Hz, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, d_6 -DMSO, δ): 167.7, 134.5, 131.5, 131.1, 130.4, 126.3, 120.4 ppm. The signals of the NMR spectra were in accordance with the data reported in the literature.^{7b}

Caution: For safety reasons, the reaction was carried out behind an antiblast shield. Following a reported procedure,^{7b} HO-BX (5.70 g, 21.6 mmol) was suspended in acetic anhydride (20 mL). The suspension was stirred to reflux (140 °C), until it converted into a clear solution. Heating was then stopped, and the solution was allowed to cool down to room temperature over a period of 1.5 h, resulting in the precipitation of a crystalline, colorless solid. Crystallization was continued at –18 °C overnight. The solid was collected by filtration and washed with several portions of pentane. Pure AcO-BX (5.50 g, 18.0 mmol, 83% yield) was dried in the air overnight and directly used as such. ^1H NMR (400 MHz, CDCl_3 , δ): 8.25 (dd, J = 7.6, 1.4 Hz, 1H), 8.00 (dd, J = 8.3, 0.5 Hz, 1H), 7.92 (dt, J = 7.0, 1.7 Hz, 1H), 7.71 (td, J = 7.6, 0.9 Hz, 1H), 2.25 (s, 3H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.^{7b}

Caution: For safety reasons, the reaction was carried out behind an antiblast shield. However, this procedure led to occasional detonations, one of which with severe injuries (see [Supporting Information](#)). Following a reported procedure,^{7b} AcO-BX (1.00 g, 3.28 mmol, 1.00 equiv, synthesized in our laboratory) was stirred in dry DCM (3 mL), and then TMSN_3 (0.66 mL, 4.9 mmol, 1.5 equiv, 94% from Alfa Aesar, catalogue number L00173-22) was cautiously added. A catalytic amount of TMSOTf (3 μL , 0.02 mmol, 0.005 equiv, Fluorochem, catalogue number S20400-250g) was added last to the mixture, which was then stirred at room temperature for 30 min. The solvent was then removed under reduced pressure at room temperature, and the residue was dried under high vacuum for 1 h to give a yellow solid, which was washed with pentane (2 $\times$ 10 mL), cold acetone (2 $\times$ 5 mL), and pentane (2 $\times$ 10 mL) and dried 1 h under a high vacuum. ABX (**1a**) (0.711 g, 2.46 mmol, 75% yield) was obtained as a pale yellow solid.

Caution: For safety reasons, the reaction was carried out behind an antiblast shield. Following a modified reported procedure,^{7b} AcO-BX (306 mg, 1.00 mmol, 1.0 equiv) was dissolved in dry DCM (2 mL). TMS-azide (0.21 mL, 1.5 mmol, 1.5 equiv) was cautiously added by syringe dropwise at 0 °C, leading to the conversion of the initial colorless mixture to a yellowish suspension. One drop of TMS-triflate (ca. 0.90 μL , 5.0 mmol, 5 mol %) was finally added, and the mixture was stirred at 0 °C for 30 min. The solids were then filtered under low pressure suction in two portions (for safety reasons), washed with pentane, and dried in the air for 15 min. ABX (**1a**) (0.246 g, 0.853 mmol, 85% yield) was obtained as a pale yellow solid. ^1H NMR (400 MHz, CDCl_3 , δ): 8.19 (dd, J = 7.5, 1.4 Hz, 1H), 7.95 (dd, J = 8.4, 1.3 Hz, 1H), 7.91 (ddd, J = 8.4, 7.0, 1.4 Hz, 1H), 7.70 (ddd, J = 7.8, 6.8, 1.2 Hz, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 ; CD_3CN ; 10:1, δ): 166.2, 134.8, 131.8, 130.4, 125.4, 116.6, 115.4 ppm.

Synthesis of tBuABX (1d). Following a reported procedure,²⁷ iodine (11.42 g, 45.00 mmol, 0.50 equiv) was dissolved in TFA (90 mL; some iodine remained undissolved) to give a violet solution. Under stirring, this mixture was treated with aq. HCl (37% w/w; 1.1 mL, 13 mmol, 0.15 equiv) and aq. NaNO_2 (40% w/w; 0.776 g, 4.50 mmol, 0.05 equiv), which resulted in the rapid darkening of the solution to red-brown-black. (1.0 mmol). 4-*tert*-Butyltoluene (**19**) (15.5 mL, 90.0 mmol, 1.0 equiv) was finally added. Using a balloon, oxygen was bubbled through the mixture. Stirring was then continued under oxygen for 4 h, after which the reaction was quenched by the addition of saturated sodium thiosulfate (200 mL) and sat. aq. NaHCO_3 (200 mL). The mixture was partitioned between dichloromethane (400 mL) and deionized water (400 mL). The organic layer was collected, dried over MgSO_4 , filtered, and concentrated under vacuum to provide a red-brown crude oil. The latter was purified by flash chromatography (silica; pentane) to give 4-(*tert*-butyl)-2-iodo-1-methylbenzene (**20**) (24.6 g, 90.0 mmol, quantitative yield) as a bright yellow oil. ^1H NMR (400 MHz, CDCl_3 , δ): 7.80 (d, J = 2.0 Hz, 1H), 7.27 (q, J = 2.4, 1.9 Hz, 1H), 7.16 (d, J = 7.7 Hz, 1H), 2.39 (s, 3H), 1.29 (s, 9H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.²⁸

Following a slightly modified reported procedure,²⁹ 4-(*tert*-butyl)-2-iodo-1-methylbenzene (**20**) (15.0 g, 54.7 mmol, 1.0 equiv) was dissolved in a mixture of water (175 mL) and pyridine (220 mL). Potassium permanganate (34.6 g, 219 mmol, 4.0 equiv) was added to the mixture, followed by tetrabutylammonium iodide (0.303 g, 0.821 mmol, 15 mol %). The violet suspension was refluxed under vigorous stirring for 3 days. It was then allowed to cool down to room temperature, and the solids were filtered off through a plug of Celite, which was then washed with aq. NaOH (2.0 M; 300 mL). Most of the pyridine was removed from the filtrate by evaporation under reduced pressure. The aqueous residue was washed with diethyl ether (3 $\times$ 200 mL), and it was then acidified until pH < 2 by careful addition of aq. HCl (37% v/v). The aqueous layer was extracted with DCM (3 $\times$ 200 mL), and the combined organic extracts were dried over MgSO_4 , filtered, and concentrated under vacuum to furnish the desired product as a pale yellow solid. The latter was recrystallized from hexane and chloroform (30 mL + 8 mL) to furnish highly pure 4-(*tert*-butyl)-2-iodobenzoic acid (**21**) (8.10 g, 26.6 mmol, 48%) as a

sticky, pale yellow crystalline solid. ^1H NMR (400 MHz, CDCl_3 , δ): 11.81 (br s, 1H), 8.05 (d, J = 1.9 Hz, 1H), 7.99 (d, J = 8.3 Hz, 1H), 7.46 (dd, J = 8.3, 2.0 Hz, 1H), 1.33 (s, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 171.4, 157.6, 139.3, 132.0, 130.0, 125.2, 95.2, 34.8, 30.9 ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.²⁹

Caution: For safety reasons, the reaction was carried out behind an antibrast shield. Following a slightly modified reported procedure,²⁹ 4-(*tert*-butyl)-2-iodobenzoic acid (**21**) (7.70 g, 25.3 mmol, 1.0 equiv) and NaIO_4 (5.42 g, 25.3 mmol, 1.0 equiv) were suspended in a 7:3 mixture of water (34.4 mL) and AcOH (14.7 mL). The mixture was stirred at 110 °C for 4 h (behind a safety shield). Full dissolution of the solids was observed a few minutes after reaching the reflux temperature, to give a clear, pale yellow solution. Stirring was continued while protecting the mixture from light with aluminum foil. Ice-cold water (35 mL) was added under stirring, which resulted in the immediate precipitation of a colorless solid. The mixture was allowed to cool down to room temperature, while being protected from light with aluminum foil. It was then filtered, and the solid was washed with ice-cold water (3 $\times$ 30 mL) and cold acetone (3 $\times$ 30 mL). The resulting colorless solid ($\text{HO}(\text{tBu})\text{BX}$ (**7.15** g, 22.3 mmol, 88%)) was dried in the air overnight and then directly used in the next step.

Caution: For safety reasons, the reaction was carried out behind an antibrast shield. The solid obtained from the previous step (7.07 g, 22.1 mmol) was suspended in acetic anhydride (20 mL). The suspension was heated to reflux (140 °C) while being stirred. The complete dissolution of the solid was observed when the temperature was ca. 125 °C: at this point, the suspension converted into an off-white, clear solution. After the temperature reached 140 °C, stirring was continued for 2 h. During this time, the solution became yellow. Heating was then stopped, and the solution was allowed to cool down to room temperature, with incipient precipitation of a colorless crystalline solid. The flask was then cooled to -18 °C for 3 h. $\text{AcO}(\text{tBu})\text{BX}$ (**22**) (6.80 g, 18.8 mmol, 85% yield; 75% over 2 steps, starting from 4-(*tert*-butyl)-2-iodobenzoic acid (**21**)) was then collected by filtration and washed with several portions of pentane. ^1H NMR (400 MHz, CDCl_3 , δ): 8.15 (d, J = 8.0 Hz, 1H), 7.95 (d, J = 1.5 Hz, 1H), 7.71 (dd, J = 8.0, 1.6 Hz, 1H), 2.27 (s, 3H), 1.41 (s, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 176.2, 168.3, 161.0, 132.8, 128.9, 126.2, 125.6, 119.0, 36.2, 31.1, 20.3 ppm. The signals of the NMR spectra were in accordance with the data reported in the literature.²⁹

Caution: For safety reasons, the reaction was carried out behind an antibrast shield. Following a slightly modified reported procedure, $\text{AcO}(\text{tBu})\text{BX}$ (**22**) (4.09 g, 11.3 mmol, 1.0 equiv) was dissolved in DCM (dry; 11.3 mL) to provide a clear, pale yellow solution. The latter was cooled to 0 °C (ice-water bath), and TMS-azide (2.3 mL, 16 mmol, 1.4 equiv) was added via syringe. Finally, TMS-triflate (0.10 mL, 0.56 mmol, 5 mol %) was added at 0 °C. Immediately, the reaction mixture turned bright yellow. After 2–3 min, a pale yellow solid precipitated. Stirring was continued at 0 °C for 45 min. The cooling bath was removed, and hexane (dry; 50 mL) was added under stirring. The mixture was cooled to -20 °C for 30 min. Finally, the supernatant liquid was removed by suction filtration to provide tBuABX (**1d**) (3.41 g, 9.88 mmol, 87%) as a pale yellow solid, which was washed with several portions of pentane and allowed to dry in the air. ^1H NMR (400 MHz, CDCl_3 , δ): 8.20 (d, J = 8.0 Hz, 1H), 7.93 (d, J = 1.5 Hz, 1H), 7.77 (dd, J = 8.0, 1.5 Hz, 1H), 1.44 (s, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 167.3, 161.4, 133.1, 129.3, 126.7, 122.9, 118.3, 36.3, 31.1 ppm. HRMS (ESI): $[\text{M} + \text{H}]^+$ calcd. for $\text{C}_{11}\text{H}_{13}\text{IN}_3\text{O}_2^+$, 346.0047; found, 346.0042. IR (film): 2968 (w), 2056 (s), 1661 (m), 1651 (m), 1595 (w), 1549 (w), 1390 (w), 1280 (m), 1232 (m), 1156 (w), 1137 (w), 859 (w) cm^{-1} .

Synthesis of ABZ (2). SOCl_2 (3.53 mL, 48.4 mmol, 1.2 equiv) followed by DMF (0.20 mL, 2.6 mmol, 0.06 equiv) were added dropwise to a solution of 2-iodobenzoic acid (**18**) (10.0 g, 40.3 mmol, 1 equiv) in CH_2Cl_2 (200 mL, 0.2 M), and the resulting mixture was stirred for 3 h at room temperature. Thereafter, the solvent was evaporated, the residue was dissolved in toluene (32 mL), and then the mixture was added to a solution of 4-toluenesulfonamide (6.90 g,

40.3 mmol, 1.00 equiv), triethylamine (14.0 mL, 101 mmol, 2.50 equiv), and DMAP (0.250 g, 2.02 mmol, 0.05 equiv) in EtOAc (80 mL). The mixture was heated for 1 h to 60 °C, then cooled to room temperature, and quenched with 1 M HCl (50 mL). The mixture was extracted with EtOAc (3 $\times$ 50 mL), and the combined organic extracts were washed with brine and dried over MgSO_4 . The drying agent was filtered off, and the solvent was evaporated. The residue was purified by column chromatography (silica, CH_2Cl_2) affording 2-iodo-N-tosylbenzamide (**23**) (15.8 g, 39.5 mmol, 98%) as a colorless oil. R_f (silica, CH_2Cl_2): 0.5. ^1H NMR (400 MHz, CDCl_3 , δ): 8.78 (s, 1H), 8.01 (d, J = 8.4 Hz, 2H), 7.80 (dd, J = 8.0, 1.0 Hz, 1H), 7.43–7.31 (m, 4H), 7.10 (ddd, J = 8.0, 7.2, 2.0 Hz, 1H), 2.44 (s, 3H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 165.6, 145.3, 140.2, 138.4, 134.9, 132.4, 129.5, 128.8, 128.7, 128.3, 91.6, 21.7 ppm. HRMS (ESI): $[\text{M} + \text{H}]^+$ calcd. for $\text{C}_{14}\text{H}_{13}\text{INO}_3\text{S}^+$, 401.9655; found, 401.9653. IR (film): 3222 (w), 2257 (w), 1702 (m), 1598 (w), 1431 (m), 1346 (m), 1237 (w), 1167 (s), 1083 (s), 1016 (m), 911 (m), 888 (m), 834 (m) cm^{-1} .

Caution: For safety reasons, the reaction was carried out behind an antibrast shield. mCPBA (77% pure; 8.85 g, 39.6 mmol, 1.00 equiv) was added to a solution of **23** (15.8 g, 39.5 mmol, 1.00 equiv) and Ac_2O (160 mL, 1.68 mol, 42.4 equiv) in AcOH (158 mL, 0.10 M), and the resulting mixture was heated for 48 h to 80 °C. Thereafter, the mixture was cooled to room temperature, and diethyl ether (150 mL) was added. Compound **24** (7.13 g, 15.5 mmol, 39%) crystallized at 0 °C from the solution and was collected by filtration. mp 161 °C (decomposition). ^1H NMR (400 MHz, d_6 -DMSO, δ): 8.02–7.95 (m, 2H), 7.95–7.89 (m, 2H), 7.86 (dd, J = 8.8, 0.9 Hz, 1H), 7.80–7.71 (m, 1H), 7.44 (d, J = 8.1 Hz, 2H), 2.38 (s, 3H), 2.26 (s, 3H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, d_6 -DMSO, δ): 174.1, 162.4, 144.5, 136.8, 136.0, 132.3, 131.4, 131.2, 129.7, 128.8, 127.9, 118.0, 21.1, 20.2 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{16}\text{H}_{14}\text{INNaO}_5\text{S}^+$, 481.9530; found, 481.9537. IR (film): 3062 (w), 1673 (m), 1585 (w), 1440 (w), 1334 (m), 1267 (s), 1149 (s), 1085 (m), 1009 (w), 908 (m), 845 (s) cm^{-1} .

Caution: For safety reasons, the reaction was carried out behind an antibrast shield. TMSOTf (14 μL , 0.080 mmol, 0.005 equiv) was added dropwise to a suspension of **24** (7.13 g, 15.5 mmol, 1 equiv) and TMSN_3 (3.0 mL, 23 mmol, 1.5 equiv) in CH_2Cl_2 (31 mL) at 0 °C. The resulting mixture was stirred for 30 min at 0 °C, and thereafter, the formed solid was filtered, washed with CH_2Cl_2 followed by pentane, and dried in vacuo, affording ABZ (**2**) (5.38 g, 12.2 mmol, 78%) as a pale yellow solid. mp 166 °C (decomposition). ^1H NMR (400 MHz, d_6 -DMSO, δ): 8.17 (dd, J = 8.3, 0.9 Hz, 1H), 8.03–7.93 (m, 2H), 7.93–7.87 (m, 2H), 7.75 (td, J = 7.4, 0.9 Hz, 1H), 7.46–7.37 (m, 2H), 2.38 (s, 3H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, d_6 -DMSO, δ): 162.6, 144.0, 136.7, 136.3, 132.5, 131.2, 131.2, 129.5, 128.5, 127.8, 118.2, 21.1 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{14}\text{H}_{11}\text{IN}_4\text{NaO}_3\text{S}^+$, 464.9489; found, 464.9487. IR (film): 2052 (m), 1671 (m), 1437 (w), 1286 (s), 1266 (m), 1212 (m), 1147 (s), 1084 (m), 900 (s), 849 (m) cm^{-1} .

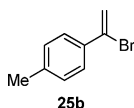
Synthesis of 1-(1-Bromovinyl)-arenes. (1-Bromovinyl)benzene (**25a**) was commercially available and used as such without further purifications. All of the other compounds were synthesized as described below.

General Method A. Bromine (1.25 equiv) was added to a cold solution of triphenyl phosphite (1.1 equiv) in CH_2Cl_2 (0.3 M) at -60 °C. Then, a solution of triethylamine (1.35 equiv) and the acetophenone (1.0 equiv) in CH_2Cl_2 (1 M) was added dropwise to the pale orange solution, and the reaction mixture was thereafter stirred for 18 h, while warming to room temperature. Then, the mixture was heated to reflux for another 2 h. The reaction was quenched with sat. aq. $\text{Na}_2\text{S}_2\text{O}_3$ (50 mL) and extracted with CH_2Cl_2 (3 $\times$ 30 mL). The combined organic extracts were washed with brine (150 mL) and dried over sodium sulfate, the drying agent was filtered off, and the solvent was evaporated. The residue was purified by column chromatography (silica, pentane:EtOAc 1:0 to 95:5) affording the desired 1-(1-bromovinyl)-arene **25**, which, due to low stability, was used immediately in the next step.

General Method B. Bromine (1.2 equiv) was added dropwise to a solution of the styrene (1.0 equiv) in CH_2Cl_2 (20 mL) over 5 min

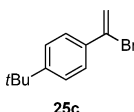
at 0 °C. Thereafter, the reaction mixture was stirred for 15 min at 0 °C and then quenched with sat. aq. Na₂S₂O₃. The mixture was extracted with CH₂Cl₂ (3 × 30 mL), and the combined organic extracts were washed with brine and dried over Na₂SO₄. The drying agent was filtered off, and the solvent was evaporated. The residue was dissolved in THF/CH₃OH 1:1 (0.5 M), K₂CO₃ (2.0 equiv) was added, and the mixture was stirred for 3 h at room temperature. Thereafter, the solvent was evaporated, and the residue was suspended in water (50 mL) and then extracted with pentane (3 × 50 mL). The combined organic extracts were washed with brine (150 mL) and dried over Na₂SO₄. The drying agent was filtered off, and the solvent was evaporated. The residue was purified by column chromatography (silica, pentane), affording the desired 1-(1-bromovinyl)-arene **25**, which, due to low stability, was used immediately in the next step.

1-(1-Bromovinyl)-4-methylbenzene (25b).



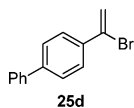
Compound **25b** was prepared according to the general method A, starting with 1-(*p*-tolyl)ethanone (1.1 mL, 9.3 mmol, 1.0 equiv), Br₂ (0.60 mL, 12 mmol, 1.2 equiv), triphenyl phosphite (2.7 mL, 10 mmol, 1.1 equiv), and Et₃N (1.7 mL, 13 mmol, 1.35 equiv). The title compound **25b** was obtained as a colorless liquid (1.2 g, 6.1 mmol, 65% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.60–7.44 (m, 2H), 7.24–7.07 (m, 2H), 6.10 (s, 1H), 5.75 (s, 1H₂), 2.38 (s, 3H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.³⁰

1-(1-Bromovinyl)-4-(*tert*-butyl)benzene (25c).



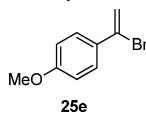
Compound **25c** was prepared according to the general method B, starting with 1-(*tert*-butyl)-4-vinylbenzene (1.9 mL, 10 mmol, 1.0 equiv), Br₂ (0.60 mL, 12 mmol, 1.2 equiv), and K₂CO₃ (2.8 g, 20 mmol, 2.0 equiv). The title compound **25c** was obtained as a colorless liquid (2.0 g, 8.4 mmol, 84% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.58–7.49 (m, 2H), 7.42–7.34 (m, 2H), 6.10 (d, *J* = 2.0 Hz, 1H), 5.74 (d, *J* = 2.0 Hz, 1H), 1.33 (s, 9H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.³¹

4-(1-Bromovinyl)-1,1'-biphenyl (25d).



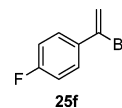
Compound **25d** was prepared according to the general method A, starting with 1-([1,1'-biphenyl]-4-yl)ethanone (2.1 g, 11 mmol, 1.0 equiv), Br₂ (0.62 mL, 12 mmol, 1.2 equiv), triphenyl phosphite (3.1 mL, 12 mmol, 1.10 equiv), and Et₃N (2.0 mL, 14 mmol, 1.35 equiv). The title compound **25d** was obtained as a colorless oil (1.6 g, 6.2 mmol, 58% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.70–7.65 (m, 2H), 7.63–7.56 (m, 4H), 7.50–7.42 (m, 2H), 7.40–7.33 (m, 1H), 6.18 (d, *J* = 2.0 Hz, 1H), 5.81 (d, *J* = 2.0 Hz, 1H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.³²

1-(1-Bromovinyl)-4-methoxybenzene (25e).



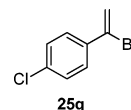
Compound **25e** was prepared according to general method A, starting with 1-(4-methoxyphenyl)ethanone (1.4 g, 9.3 mmol, 1.0 equiv), Br₂ (0.62 mL, 12 mmol, 1.25 equiv), triphenyl phosphite (2.7 mL, 10 mmol, 1.1 equiv), and Et₃N (1.8 mL, 13 mmol, 1.35 equiv). The title compound **25e** was obtained as a colorless oil (1.5 g, 7.0 mmol, 76% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.64–7.51 (m, 2H), 6.90–6.76 (m, 2H), 6.02 (d, *J* = 2.0 Hz, 1H), 5.68 (d, *J* = 2.0 Hz, 1H), 3.83 (s, 3H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.³³

1-(1-Bromovinyl)-4-fluorobenzene (25f).



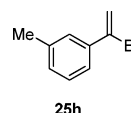
Compound **25f** was prepared according to general method B, starting with 1-fluoro-4-vinylbenzene (1.2 mL, 10 mmol, 1.0 equiv), Br₂ (0.62 mL, 12 mmol, 1.2 equiv), and K₂CO₃ (2.8 g, 20 mmol, 2.0 equiv). The title compound **25f** was obtained as a colorless liquid (1.6 g, 8.0 mmol, 80% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.61–7.53 (m, 2H), 7.12–6.97 (m, 2H), 6.06 (d, *J* = 2.1 Hz, 1H), 5.76 (d, *J* = 2.1 Hz, 1H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.³⁴

1-(1-Bromovinyl)-4-chlorobenzene (25g).



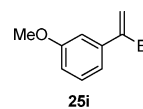
Compound **25g** was prepared according to general method B, starting with 1-chloro-4-vinylbenzene (1.3 mL, 10 mmol, 1.0 equiv), Br₂ (0.62 mL, 12 mmol, 1.2 equiv), and K₂CO₃ (2.8 g, 20 mmol, 2.0 equiv). The title compound **25g** was obtained as a colorless liquid (1.0 g, 4.6 mmol, 46% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.59–7.48 (m, 2H), 7.36–7.29 (m, 2H), 6.11 (d, *J* = 2.2 Hz, 1H), 5.79 (d, *J* = 2.2 Hz, 1H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.³⁴

1-(1-Bromovinyl)-3-methylbenzene (25h).



Compound **25h** was prepared according to general method B, starting with 1-methyl-3-vinylbenzene (1.3 mL, 10 mmol, 1.0 equiv), Br₂ (0.62 mL, 12 mmol, 1.2 equiv), and K₂CO₃ (2.8 g, 20 mmol, 2.0 equiv). The title compound **25h** was obtained as a colorless liquid (1.0 g, 5.1 mmol, 51% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.42–7.38 (m, 2H), 7.27–7.20 (m, 1H), 7.18–7.14 (m, 1H), 6.11 (d, *J* = 2.0 Hz, 1H), 5.77 (d, *J* = 2.0 Hz, 1H), 2.38 (s, 3H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.³⁰

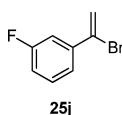
1-(1-Bromovinyl)-3-methoxybenzene (25i).



Compound **25i** was prepared according to general method A, starting with 1-(3-methoxyphenyl)ethanone (1.3 mL, 9.3 mmol, 1.0 equiv), Br₂ (0.62 mL, 12 mmol, 1.25 equiv), triphenyl phosphite (2.7 mL, 10 mmol, 1.1 equiv), and Et₃N (1.8 mL,

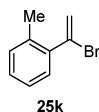
13 mmol, 1.35 equiv). The title compound **25i** was obtained as a colorless oil (0.50 g, 2.3 mmol, 25% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.32–7.26 (m, 1H), 7.20 (m, 1H), 7.16 (m, 1H), 6.95–6.89 (m, 1H), 6.15 (d, $J = 2.0$ Hz, 1H), 5.80 (d, $J = 2.0$ Hz, 1H), 3.86 (s, 3H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.³⁵

1-(1-Bromovinyl)-3-fluorobenzene (**25j**).



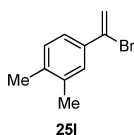
Compound **25j** was prepared according to general method B, starting with 1-fluoro-3-vinylbenzene (1.2 mL, 10 mmol, 1.0 equiv), Br_2 (0.62 mL, 12 mmol, 1.2 equiv), and K_2CO_3 (2.8 g, 20 mmol, 2.0 equiv). The title compound **25j** was obtained as a colorless liquid (1.6 g, 7.9 mmol, 79% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.42–7.04 (m, 3H), 7.03 (m, 1H), 6.15 (d, $J = 2.1$ Hz, 1H), 5.82 (d, $J = 2.2$ Hz, 1H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.³⁰

1-(1-Bromovinyl)-2-methylbenzene (**25k**).



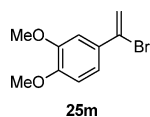
Compound **25k** was prepared according to general method A, starting with 1-(*o*-tolyl)ethanone (1.3 mL, 10 mmol, 1.0 equiv), Br_2 (64 μL , 13 mmol, 1.25 equiv), triphenyl phosphite (2.9 mL, 11 mmol, 1.1 equiv), and Et_3N (1.9 mL, 13 mmol, 1.35 equiv). The title compound **25k** was obtained as a colorless oil (1.2 g, 6.2 mmol, 62% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.34–7.16 (m, 4H), 5.92 (d, $J = 1.5$ Hz, 1H), 5.77 (d, $J = 1.6$ Hz, 1H), 2.44 (s, 3H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.³⁶

4-(1-Bromovinyl)-1,2-dimethylbenzene (**25l**).



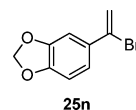
Compound **25l** was prepared according to general method A, starting with 1-(3,4-dimethylphenyl)ethanone (1.5 mL, 10 mmol, 1.0 equiv), Br_2 (64 μL , 13 mmol, 1.25 equiv), triphenyl phosphite (2.9 mL, 11 mmol, 1.1 equiv), and Et_3N (1.9 mL, 14 mmol, 1.35 equiv). The title compound **25l** was obtained as a colorless oil (1.3 g, 6.0 mmol, 60% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.39 (s, 1H), 7.35 (d, $J = 8.0$ Hz, 1H), 7.13 (d, $J = 8.0$ Hz, 1H), 6.16–6.03 (m, 1H), 5.81–5.69 (m, 1H), 2.31 (s, 3H), 2.30 (s, 3H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 137.9, 136.4, 136.1, 131.2, 129.5, 128.4, 124.7, 116.6, 19.8, 19.5 ppm. HRMS (ESI): $[\text{M}^+]$ calcd. for $\text{C}_{10}\text{H}_{11}\text{Br}$, 211.0117; found, 211.0117. IR (film): 2970 (w), 2921 (w), 1681 (w), 1605 (m), 1499 (w), 1449 (w), 1384 (w), 1241 (m), 1215 (w), 1126 (w), 1065 (m), 880 (s), 821 (s), 729 (m) cm^{-1} .

4-(1-Bromovinyl)-1,2-dimethoxybenzene (**25m**).



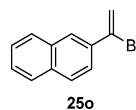
Compound **25m** was prepared according to general method A, starting with 1-(3,4-dimethoxyphenyl)ethanone (1.7 g, 9.3 mmol, 1.0 equiv), Br_2 (0.62 mL, 12 mmol, 1.25 equiv), triphenyl phosphite (2.7 mL, 10 mmol, 1.1 equiv), and Et_3N (1.8 mL, 13 mmol, 1.35 equiv). The title compound **25m** was obtained as a colorless oil (0.60 g, 2.5 mmol, 27% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.17 (dd, $J = 8.4$, 2.3 Hz, 1H), 7.10 (d, $J = 2.2$ Hz, 1H), 6.82 (d, $J = 8.4$ Hz, 1H), 6.02 (d, $J = 2.0$ Hz, 1H), 5.69 (d, $J = 2.0$ Hz, 1H), 3.91 (s, 3H), 3.89 (s, 3H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.³⁷

5-(1-Bromovinyl)benzo[d][1,3]dioxole (**25n**).



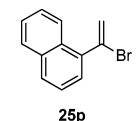
Compound **25n** was prepared according to general method A, starting with 1-(benzo[d][1,3]dioxol-5-yl)ethanone (1.5 g, 9.3 mmol, 1.0 equiv), Br_2 (0.62 mL, 12 mmol, 1.25 equiv), triphenyl phosphite (2.7 mL, 10 mmol, 1.1 equiv), and Et_3N (1.8 mL, 13 mmol, 1.35 equiv). The title compound **25n** was obtained as a colorless oil (1.5 g, 6.6 mmol, 71% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.11 (dd, $J = 8.1$, 1.9 Hz, 1H), 7.07 (d, $J = 1.9$ Hz, 1H), 6.77 (d, $J = 8.1$ Hz, 1H), 5.99 (m, 3H), 5.67 (d, $J = 2.0$ Hz, 1H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.³⁸

2-(1-Bromovinyl)naphthalene (**25o**).



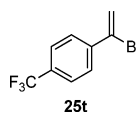
Compound **25o** was prepared according to the general method A, starting with 1-(naphthalen-2-yl)ethanone (1.6 g, 9.3 mmol, 1.0 equiv), Br_2 (0.62 mL, 12 mmol, 1.25 equiv), triphenyl phosphite (2.7 mL, 10 mmol, 1.1 equiv), and Et_3N (1.8 mL, 13 mmol, 1.35 equiv). The title compound **25o** was obtained as a colorless oil (1.0 g, 4.3 mmol, 46% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 8.09 (d, $J = 1.8$ Hz, 1H), 7.90–7.78 (m, 3H), 7.69 (dd, $J = 8.7$, 1.9 Hz, 1H), 7.56–7.43 (m, 2H), 6.27 (d, $J = 2.1$ Hz, 1H), 5.88 (d, $J = 2.1$ Hz, 1H). The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.³⁶

1-(1-Bromovinyl)naphthalene (**25p**).



Compound **25p** was prepared according to general method B, starting with 1-vinylnaphthalene (1.95 g, 12.7 mmol, 1.0 equiv), Br_2 (78 μL , 15 mmol, 1.20 equiv), and K_2CO_3 (3.49 g, 25.3 mmol, 2.0 equiv). The title compound **25p** was obtained as a colorless liquid (2.48 g, 10.6 mmol, 84% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 8.23 (dq, $J = 8.5$, 0.9 Hz, 1H), 7.93–7.77 (m, 2H), 7.65–7.39 (m, 4H), 6.10 (d, $J = 1.5$ Hz, 1H), 5.97 (d, $J = 1.5$ Hz, 1H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.³⁹

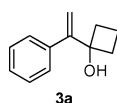
1-(1-Bromovinyl)-4-(trifluoromethyl)benzene (**25t**).



Compound **25t** was prepared according to general method B, starting with 4-(trifluoromethyl)-styrene (3.4 g, 20 mmol, 1.0 equiv), Br₂ (1.3 mL, 24 mmol, 1.2 equiv), and K₂CO₃ (5.5 g, 40 mmol, 2.0 equiv). The title compound **25t** was obtained as a colorless liquid (2.2 g, 8.7 mmol, 43% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.77–7.68 (m, 2H), 7.61 (d, *J* = 8.2 Hz, 2H), 6.21 (d, *J* = 2.2 Hz, 1H), 5.90 (d, *J* = 2.2 Hz, 1H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃; the multiplet peak corresponding to the CF₃ was not resolved, δ): 141.9, 131.4, 131.0 (q, *J* = 32.7 Hz), 127.6, 125.3 (q, *J* = 3.9 Hz), 122.5, 119.7 ppm. HRMS (ESI): [*M*⁺] calcd for C₉H₆BrF₃, 249.9599; found, 249.9541. IR (film): 1612 (w), 1408 (w), 1327 (s), 1218 (w), 1170 (m), 1130 (s), 1075 (m), 1016 (w), 898 (w), 847 (m) cm⁻¹.

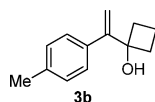
Synthesis of 1-(1-(Arene)vinyl)cyclobutanols. *General Method C.* One crystal of iodine and 1,2-dibromoethane (0.4 equiv) were added to a suspension of magnesium (4.0 equiv) in THF (0.2 m). Thereafter, a solution of (1-bromovinyl)arene (1.3 equiv) in THF (1 M) was added dropwise, and the reaction mixture was stirred for 1 h at 60 °C. Then, the corresponding cyclobutanone (1.0 equiv) was added dropwise, and stirring was continued at 60 °C for 5 h. After being cooled to room temperature, the reaction was quenched with water and extracted with ethyl acetate (3 × 40 mL). The combined organic extracts were washed with water (50 mL) and brine (50 M) and then dried over Na₂SO₄, the drying agent was filtered off, and the solvent was evaporated. The residue was purified by column chromatography (silica; pentane:EtOAc 100:0 to 95:5 to 80:20 to 70:30), affording the title compound **3**.

1-(1-Phenylvinyl)cyclobutanols (**3a**).



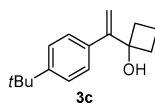
Compound **3a** was prepared according to general method C using magnesium (0.40 g, 16 mmol, 4.0 equiv), 1,2-dibromoethane (0.14 mL, 1.6 mmol, 0.4 equiv), (1-bromovinyl)benzene (0.70 mL, 5.2 mmol, 1.3 equiv, 90% purity), and cyclobutanone (0.30 mL, 4.0 mmol, 1.0 equiv). The title compound **3a** was obtained as a colorless oil (0.65 g, 3.7 mmol, 93% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.52–7.45 (m, 2H), 7.38–7.27 (m, 3H), 5.38 (s, 1H), 5.36 (d, *J* = 0.9 Hz, 1H), 2.54–2.42 (m, 2H), 2.25 (m, 2H), 1.99 (m, 2H), 1.63 (m, 1H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.^{13c}

1-(1-(*p*-Tolyl)vinyl)cyclobutanol (**3b**).



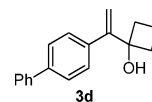
Compound **3b** was prepared according to general method C using magnesium (0.30 g, 13 mmol, 4.0 equiv), 1,2-dibromoethane (0.10 mL, 1.3 mmol, 0.4 equiv), 1-(1-bromovinyl)-4-methylbenzene (**25b**, 1.0 g, 4.1 mmol, 1.3 equiv), and cyclobutanone (0.25 mL, 3.4 mmol, 1.0 equiv). The title compound **3b** was obtained as a colorless oil (0.48 g, 2.5 mmol, 75% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.44–7.38 (m, 2H), 7.16 (d, *J* = 7.9 Hz, 2H), 5.34 (m, 2H), 2.53–2.43 (m, 2H), 2.37 (s, 3H), 2.26 (m, 3H), 2.01 (m, 1H), 1.64 (m, 1H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.^{13c}

1-(1-(4-(*tert*-Butyl)phenyl)vinyl)cyclobutanols (**3c**).



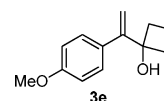
Compound **3c** was prepared according to general method C using magnesium (0.30 g, 13 mmol, 4.0 equiv), 1,2-dibromoethane (0.10 mL, 1.3 mmol, 0.4 equiv), 1-(1-bromovinyl)-4-(*tert*-butyl)benzene (**25c**, 1.0 g, 4.2 mmol, 1.3 equiv), and cyclobutanone (0.26 mL, 3.4 mmol, 1.00 equiv). The title compound **3c** was obtained as a colorless oil (0.46 g, 2.0 mmol, 53% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.44–7.40 (m, 2H), 7.37–7.34 (m, 2H), 5.37 (d, *J* = 0.9 Hz, 1H), 5.34 (d, *J* = 1.0 Hz, 1H), 2.50 (m, 2H), 2.27 (m, 2H), 1.98 (m, 2H), 1.64 (m, 1H), 1.32 (s, 9H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.^{13c}

1-(1-([1,1'-Biphenyl]-4-yl)vinyl)cyclobutanols (**3d**).



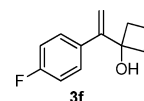
Compound **3d** was prepared according to general method C using magnesium (0.25 g, 11 mmol, 4.00 equiv), 1,2-dibromoethane (0.10 mL, 1.1 mmol, 0.4 equiv), 4-(1-bromovinyl)-1,1'-biphenyl (**25d**, 0.85 g, 3.3 mmol, 1.3 equiv), and cyclobutanone (0.21 mL, 2.7 mmol, 1.0 equiv). The title compound **3d** was obtained as a colorless oil (0.56 g, 2.7 mmol, 53% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.64–7.53 (m, 5H), 7.45 (m, 2H), 7.35 (m, 1H), 5.45 (d, *J* = 0.8 Hz, 1H), 5.41 (d, *J* = 0.8 Hz, 1H), 2.52 (m, 2H), 2.29 (m, 2H), 2.02 (m, 2H), 1.67 (m, 1H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.^{14a}

1-(1-(4-Methoxyphenyl)vinyl)cyclobutanols (**3e**).



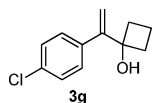
Compound **3e** was prepared according to general method C using magnesium (0.380 g, 15.6 mmol, 4.00 equiv), 1,2-dibromoethane (0.13 mL, 1.6 mmol, 0.40 equiv), 1-(1-bromovinyl)-4-methoxybenzene (**25e**, 1.0 g, 4.7 mmol, 1.3 equiv), and cyclobutanone (0.29 mL, 3.9 mmol, 1.00 equiv). The title compound **3e** was obtained as a colorless oil (0.560 g, 2.74 mmol, 70% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.44 (m, 2H), 6.86 (m, 2H), 5.31 (d, *J* = 0.9 Hz, 1H), 5.30 (d, *J* = 0.9 Hz, 1H), 3.81 (s, 3H), 2.47 (m, 2H), 2.25 (m, 2H), 1.98 (m, 2H), 1.63 (m, 1H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.^{14a}

1-(1-(4-Fluorophenyl)vinyl)cyclobutanols (**3f**).

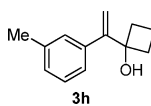


Compound **3f** was prepared according to general method C using magnesium (0.40 g, 16 mmol, 4.0 equiv), 1,2-dibromoethane (0.20 mL, 2.6 mmol, 0.4 equiv), 1-(1-bromovinyl)-4-fluorobenzene (**25f**, 1.6 g, 8.0 mmol, 1.3 equiv), and cyclobutanone (0.50 mL, 6.6 mmol, 1.0 equiv). The title compound **3f** was obtained as a colorless oil (0.95 g, 4.9 mmol, 74% yield). ¹H NMR (400 MHz, CDCl₃, δ): 7.52–7.41 (m, 2H), 7.13–6.91 (m, 2H), 5.36 (d, *J* = 0.8 Hz, 1H), 5.32 (d, *J* = 0.7 Hz, 1H), 2.44 (m, 2H), 2.22 (m, 2H), 1.99 (m, 1H), 1.90 (m, 1H), 1.62 (m, 1H) ppm. The signals of the ¹H NMR spectra were in accordance with the data reported in the literature.^{13c}

1-(1-(4-Chlorophenyl)vinyl)cyclobutanols (3g).

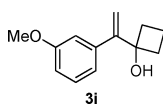


Compound **3g** was prepared according to general method C using magnesium (0.30 g, 12 mmol, 4.0 equiv), 1,2-dibromoethane (0.11 mL, 1.3 mmol, 0.4 equiv), 1-(1-bromovinyl)-4-chlorobenzene (**25g**, 0.83 g, 3.8 mmol, 1.3 equiv), and cyclobutanone (0.24 mL, 3.2 mmol, 1.0 equiv). The title compound **3g** was obtained as a colorless oil (0.42 g, 2.0 mmol, 64% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.46–7.39 (m, 2H), 7.31–7.27 (m, 2H), 5.38 (s, 1H), 5.36 (d, $J = 0.7$ Hz, 1H), 2.44 (m, 2H), 2.22 (m, 2H), 1.99 (m, 1H), 1.86 (brs, 1H), 1.62 (m, 1H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.^{13c}

1-(1-(*m*-Tolyl)vinyl)cyclobutanol (3h).

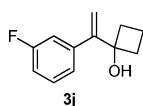
Compound **3h** was prepared according to general method C using magnesium (0.410 g, 16.9 mmol, 4.00 equiv), 1,2-dibromoethane (0.14 mL, 1.7 mmol, 0.40 equiv), 1-(1-bromovinyl)-3-methylbenzene (**25h**, 1.0 g, 5.1 mmol, 1.3 equiv), and cyclobutanone (0.32 mL, 4.23 mmol, 1.0 equiv). The title compound **3h** was obtained as a colorless oil (0.680 g, 3.61 mmol, 85% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.27 (m, 2H), 7.22 (td, $J = 7.3, 1.3$ Hz, 1H), 7.12 (m, 1H), 5.36 (d, $J = 0.9$ Hz, 1H), 5.34 (d, $J = 0.9$ Hz, 1H), 2.48 (m, 2H), 2.36 (s, 3H), 2.25 (m, 2H), 1.99 (m, 2H), 1.63 (m, 1H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.^{13c}

1-(1-(3-Methoxyphenyl)vinyl)cyclobutanol (3i).



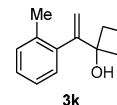
Compound **3i** was prepared according to the general method C using magnesium (0.140 g, 5.63 mmol, 4.00 equiv), 1,2-dibromoethane (50 μL , 0.60 mmol, 0.40 equiv), 1-(1-bromovinyl)-3-methoxybenzene (**25i**, 0.36 g, 1.67 mmol, 1.3 equiv), and cyclobutanone (0.11 mL, 1.4 mmol, 1.0 equiv). The title compound **3i** was obtained as a colorless oil (0.15 g, 0.73 mmol, 52% yield). R_f (silica, pentane:EtOAc 4:1): 0.4. ^1H NMR (400 MHz, CDCl_3 , δ): 7.27 (t, $J = 8.0$ Hz, 1H), 7.14–7.03 (m, 2H), 6.87 (ddd, $J = 8.2, 2.6, 1.0$ Hz, 1H), 5.39 (d, $J = 2.3$ Hz, 1H), 3.83 (s, 3H), 2.56–2.44 (m, 2H), 2.35 (t, $J = 3.8$ Hz, 1H), 2.33–2.20 (m, 2H), 2.09–1.91 (m, 1H), 1.65 (dt, $J = 11.0, 8.8, 6.8$ Hz, 1H). The ^1H NMR data correspond to the reported values.^{12f}

1-(1-(3-Fluorophenyl)vinyl)cyclobutanols (3j).



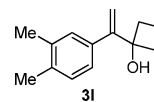
Compound **3j** was prepared according to general method C using magnesium (0.400 g, 16.5 mmol, 4.00 equiv), 1,2-dibromoethane (0.23 mL, 2.7 mmol, 0.40 equiv), 1-(1-bromovinyl)-3-fluorobenzene (**25j**, 1.6 g, 8.0 mmol, 1.3 equiv), and cyclobutanone (0.50 mL, 6.6 mmol, 1.0 equiv). The title

compound **3j** was obtained as a colorless oil (0.670 g, 3.49 mmol, 52% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.31–7.12 (m, 3H), 6.95 (m, 1H), 5.37 (s, 1H), 5.36 (s, 1H), 2.42 (m, 2H), 2.20 (m, 2H), 1.97 (m, 1H), 1.92 (brs, 1H), 1.59 (m, 1H) ppm. The ^1H NMR data correspond to the reported values, with a systematic shift of 0.15 ppm.^{13c}

1-(1-(*o*-Tolyl)vinyl)cyclobutanol (3k).

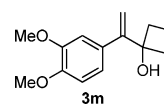
A solution of *t*BuLi (6.18 mL, 12.4 mmol, 2 m in hexane, 2 equiv) was added at -78°C to a solution of **25k** (1.22 g, 6.19 mmol, 1 equiv) in THF (25 mL, 0.25 m), and the resulting mixture was stirred for 1.5 h at -78°C . Thereafter, cyclobutanone (0.59 mL, 8.1 mmol, 1.3 equiv) was added dropwise, and stirring was continued for 1 h at -78°C . Then, the reaction was quenched with water (30 mL), warmed to room temperature, and extracted with Et_2O (3 $\times$ 30 mL). The combined organic extracts were washed with brine (20 mL) and dried over MgSO_4 . The drying agent was filtered off, and the solvent was evaporated. The residue was purified by column chromatography (silica, pentane:EtOAc 1:0 to 10:1) affording 336 mg (1.79 mmol, 29%) of the title compound **3k** as a colorless oil. ^1H NMR (400 MHz, CDCl_3 , δ): 7.57–6.90 (m, 4H), 5.53 (t, $J = 1.5$ Hz, 1H), 4.99 (t, $J = 1.6$ Hz, 1H), 2.52–2.36 (m, 2H), 2.28 (s, 3H), 2.17–2.02 (m, 2H), 2.02–1.76 (m, 2H), 1.66–1.45 (m, 1H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.^{13c}

1-(1-(3,4-Dimethylphenyl)vinyl)cyclobutanols (3l).



Compound **3l** was prepared according to general method C using magnesium (0.450 g, 18.4 mmol, 4.00 equiv), 1,2-dibromoethane (0.16 mL, 1.8 mmol, 0.400 equiv), 4-(1-bromovinyl)-1,2-dimethylbenzene (**25l**, 1.26 g, 5.97 mmol, 1.30 equiv), and cyclobutanone (0.34 mL, 4.6 mmol, 1.0 equiv). The title compound **3l** was obtained as a yellow oil (0.590 g, 2.91 mmol, 63% yield). R_f (silica, pentane): 0.5. ^1H NMR (400 MHz, CDCl_3 , δ): 7.27–7.23 (m, 1H), 7.23–7.18 (m, 1H), 7.09 (d, $J = 7.8$ Hz, 1H), 5.40–5.17 (m, 2H), 2.58–2.42 (m, 2H), 2.34–2.18 (m, 8H), 2.11–1.86 (m, 2H), 1.72–1.55 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 152.3, 136.5, 136.3, 136.0, 129.4, 128.8, 125.0, 112.0, 78.1, 35.7, 19.9, 19.4, 13.4 ppm. HRMS (ESI): $[\text{M}^+]$ calcd for $\text{C}_{14}\text{H}_{18}\text{O}$, 202.1352; found, 202.1354. IR (film): 3398 (m), 2986 (m), 2940 (s), 2871 (w), 1624 (w), 1503 (m), 1451 (m), 1383 (w), 1250 (m), 1225 (w), 1153 (m), 1111 (m), 1078 (w), 1022 (w), 908 (s), 826 (s) cm^{-1} .

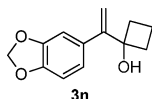
1-(1-(3,4-Dimethoxyphenyl)vinyl)cyclobutanol (3m).



Compound **3m** was prepared according to general method C using magnesium (0.190 g, 7.95 mmol, 4.00 equiv), 1,2-dibromoethane (70 μL , 0.79 mmol, 0.40 equiv), 4-(1-bromovinyl)-1,2-dimethoxybenzene (**25m**, 0.580 g, 2.39 mmol, 1.30 equiv), and cyclobutanone (0.15 mL, 2.0 mmol, 1.00 equiv).

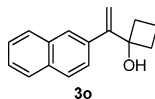
The title compound **3m** was obtained as a colorless oil (0.20 g, 0.85 mmol, 62% yield). R_f (silica, pentane:EtOAc 4:1): 0.2. ^1H NMR (400 MHz, CDCl_3 , δ): 7.02 (m, 2H), 6.78 (d, J = 8.1 Hz, 1H), 5.28 (d, J = 0.9 Hz, 1H), 5.26 (d, J = 0.9 Hz, 1H), 3.84 (s, 6H), 2.43 (m, 2H), 2.35–2.16 (m, 3H), 1.95 (m, 1H), 1.59 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 151.8, 148.5, 148.4, 131.7, 119.9, 111.7, 110.9, 110.7, 78.2, 55.8, 35.6, 13.4 ppm. One alkyl signal was not resolved. HRMS (ESI): $[\text{M} + \text{H}]^+$ calcd. for $\text{C}_{14}\text{H}_{19}\text{O}_3^+$, 235.1329; found, 235.1329. IR (film): 3484 (w), 2986 (w), 2937 (w), 2912 (w), 2835 (w), 2361 (w), 2342 (w), 2254 (w), 1514 (s), 1254 (s), 1143 (s), 1027 (s), 909 (s) cm^{-1} .

1-(1-(Benzo[d][1,3]dioxol-5-yl)vinyl)cyclobutanol (**3n**).



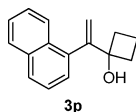
Compound **3n** was prepared according to general method C using magnesium (0.530 g, 22.0 mmol, 4.00 equiv), 1,2-dibromoethane (0.19 mL, 2.0 mmol, 0.40 equiv), 5-(1-bromovinyl)benzo[d][1,3]dioxole (**25n**, 1.5 g, 6.6 mmol, 1.3 equiv), and cyclobutanone (0.41 mL, 5.5 mmol, 1.00 equiv). The title compound **3n** was obtained as a colorless oil (0.560 g, 2.57 mmol, 47% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.01 (d, J = 1.8 Hz, 1H), 6.97 (dd, J = 8.1, 1.7 Hz, 1H), 6.77 (dt, J = 8.1, 0.9 Hz, 1H), 5.95 (m, 2H, OCH_2O), 5.29 (m, 2H), 2.45 (m, 2H), 2.22 (m, 2H), 1.97 (m, 2H), 1.61 (m, 1H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.^{14a}

1-(1-(Naphthalen-2-yl)vinyl)cyclobutanol (**3o**).



Compound **3o** was prepared according to general method C using magnesium (0.35 g, 14.3 mmol, 4.00 equiv), 1,2-dibromoethane (0.12 mL, 1.4 mmol, 0.40 equiv), 2-(1-bromovinyl)naphthalene (**25o**, 1.0 g, 4.3 mmol, 1.3 equiv), and cyclobutanone (0.27 mL, 3.6 mmol, 1.0 equiv). The title compound **3o** was obtained as a colorless oil (0.50 g, 2.2 mmol, 62% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.96 (m, 1H), 7.87–7.76 (m, 3H), 7.63 (dd, J = 8.5, 1.8 Hz, 1H), 7.47 (m, 2H), 5.50 (d, J = 0.8 Hz, 1H), 5.48 (d, J = 0.8 Hz, 1H), 2.53 (m, 2H), 2.31 (m, 2H), 2.02 (m, 2H), 1.67 (m, 1H) ppm. ^1H NMR data correspond to the reported values, apart from the peak at δ = 1.67 ppm, which corresponds better to the attributed ^1H nuclei than the signal in the reference article.^{14a}

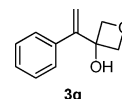
1-(1-(Naphthalen-1-yl)vinyl)cyclobutanol (**3p**).



Compound **3p** was prepared according to general method C using magnesium (796 mg, 32.7 mmol, 4.00 equiv), 1,2-dibromoethane (0.28 mL, 3.3 mmol, 0.40 equiv), **25p** (2.48 g, 10.6 mmol, 1.3 equiv), and cyclobutanone (0.60 mL, 8.2 mmol, 1.0 equiv). The title compound **3p** was obtained as a colorless oil (1.01 g, 4.48 mmol, 55% yield). R_f (silica, pentane:EtOAc 10:1): 0.5. ^1H NMR (400 MHz, CDCl_3 , δ): 8.09–8.02 (m, 1H), 7.89–7.84 (m, 1H), 7.84–7.78 (m, 1H),

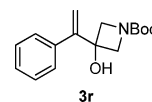
7.53–7.42 (m, 3H), 7.40 (dt, J = 7.0, 1.0 Hz, 1H), 5.78 (d, J = 1.4 Hz, 1H), 5.19 (d, J = 1.4 Hz, 1H), 2.54–2.37 (m, 2H), 2.21–2.04 (m, 2H), 2.04–1.85 (m, 2H), 1.68–1.50 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 151.1, 137.9, 133.6, 132.5, 128.1, 127.6, 126.3, 126.1, 125.9, 125.7, 124.9, 115.2, 78.5, 35.3, 13.5 ppm. HRMS (ESI): $[\text{M}]^+$ calcd for $\text{C}_{16}\text{H}_{16}\text{O}$, 224.1196; found, 224.1201. IR (film): 3390 (w), 3043 (w), 2985 (w), 2946 (w), 1591 (w), 1506 (w), 1462 (w), 1249 (w), 1156 (w), 1122 (w), 913 (m), 804 (m), 779 (s) cm^{-1} .

3-(1-Phenylvinyl)oxetan-3-ol (**3q**).



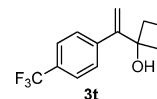
Compound **3q** was prepared according to general method C using magnesium (0.400 g, 16.4 mmol, 4.00 equiv), 1,2-dibromoethane (0.14 mL, 1.6 mmol, 0.40 equiv), (1-bromovinyl)benzene (0.71 mL, 4.9 mmol, 1.3 equiv, 90% purity), and oxetan-3-one (0.29 mL, 4.1 mmol, 1.0 equiv). The title compound **3q** was obtained as a colorless oil (0.41 g, 2.3 mmol, 57% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.42–7.29 (m, 5H), 5.59 (s, 1H), 5.41 (s, 1H), 4.93 (dd, J = 6.9, 0.9 Hz, 2H), 4.80 (dd, J = 6.9, 0.9 Hz, 2H), 2.57 (s, 1H) ppm. The ^1H NMR data correspond to the reported values, with a systematic shift of 0.15 ppm.^{13c}

tert-Butyl 3-Hydroxy-3-(1-phenylvinyl)azetidine-1-carboxylate (**3r**).



Compound **3r** was prepared according to general method C using magnesium (227 mg, 9.35 mmol, 4.00 equiv), 1,2-dibromoethane (0.08 mL, 0.09 mmol, 0.40 equiv), (1-bromovinyl)benzene (0.40 mL, 2.8 mmol, 1.2 equiv), and tert-butyl 3-oxoazetidine-1-carboxylate (0.40 g, 2.3 mmol, 1.00 equiv). The title compound **3r** was obtained as a colorless solid (95% pure; 0.46 g, 1.7 mmol, 71% yield). mp 95–110 °C. ^1H NMR (400 MHz, CDCl_3 , δ): 7.45–7.38 (m, 2H), 7.38–7.28 (m, 3H), 5.50 (s, 1H), 5.39 (s, 1H), 4.20 (d, J = 9.3, 2H), 4.03 (dd, J = 9.3, 1.1, 2H), 1.41 (s, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 156.4, 149.5, 137.7, 128.5, 128.0, 126.9, 114.8, 79.7, 72.5, 69.9, 61.9, 28.3 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd for $\text{C}_{16}\text{H}_{21}\text{NNaO}_3^+$, 298.1414; found, 298.1413.

1-(1-(4-(Trifluoromethyl)phenyl)vinyl)cyclobutanol (**3t**).

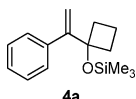


Compound **3t** was prepared according to general method C using magnesium (843 mg, 34.7 mmol, 4.00 equiv), 1,2-dibromoethane (0.30 mL, 3.5 mmol, 0.40 equiv), **25t** (2.83 g, 11.3 mmol, 1.30 equiv), and cyclobutanone (0.64 mL, 8.7 mmol, 1.00 equiv). The title compound **3t** was obtained as a colorless oil (1.01 g, 4.16 mmol, 48% yield). R_f (silica, pentane:EtOAc 10:1): 0.5. ^1H NMR (400 MHz, CDCl_3 , δ): 7.72–7.44 (m, 4H), 5.46 (s, 1H), 5.42 (s, 1H), 2.49–2.39 (m, 2H), 2.29–2.18 (m, 2H), 2.08–1.94 (m, 2H), 1.70–1.55 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 151.4, 142.8, 129.4 (q, J = 32.4 Hz), 127.9, 125.0 (q, J = 3.7 Hz), 124.2 (q, J = 271.4 Hz), 114.5, 77.9, 35.6, 13.3 ppm. HRMS (ESI): $[\text{M}]^+$ calcd for $\text{C}_{13}\text{H}_{13}\text{F}_3\text{O}$, 242.0913; found, 242.0917.

IR (film): 3381 (w), 2991 (w), 2953 (w), 1619 (w), 1573 (w), 1407 (w), 1326 (s), 1251 (w), 1166 (m), 1122 (s), 1067 (m), 1018 (m), 912 (m), 850 (m) cm^{-1} .

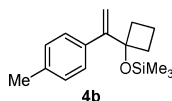
Synthesis of 1-(1-(Arene)vinyl)cyclobutoxy)trimethylsilanes. General Procedure D. TMSCl (1.2 equiv) was added dropwise to a solution of 1-(arene)vinylcyclobutanol **3** (1.0 equiv) and triethylamine (1.5 equiv) in DCM (0.2 M) at 0 °C. The reaction mixture was stirred until full conversion on TLC, then it was quenched with sat. aq. NH_4Cl (10 mL), and extracted with CH_2Cl_2 (3 $\times$ 30 mL). The combined organic extracts were washed with brine and dried over MgSO_4 , the drying agent was filtered off, and the solvent was evaporated. Purification of the residue by column chromatography (silica, pentane:EtOAc 1:0 to 97:3) afforded the title product **4**.

Trimethyl(1-(1-phenylvinyl)cyclobutoxy)silane (4a).



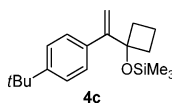
Compound **4a** was prepared according to general method D using 1-(1-phenylvinyl)cyclobutanol (**3a**, 1.58 g, 9.07 mmol, 1.00 equiv), Et_3N (0.90 mL, 13 mmol, 1.5 equiv), and TMSCl (1.4 mL, 11 mmol, 1.3 equiv). The title compound **4a** was obtained as a colorless oil (2.0 g, 8.1 mmol, 90% yield). R_f (silica, pentane): 0.6. ^1H NMR (400 MHz, CDCl_3 , δ): 7.53 (m, 2H), 7.29 (m, 3H), 5.46 (d, J = 0.8 Hz, 1H), 5.40 (d, J = 0.8 Hz, 1H), 2.45 (m, 2H), 2.33 (m, 2H), 1.83 (m, 1H), 1.55 (m, 1H), 0.01 (s, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 151.8, 139.7, 128.1, 127.8, 127.2, 112.3, 79.0, 37.3, 13.7, 1.7 ppm. HRMS (ESI): $[\text{M}^+]$ calcd. for $\text{C}_{15}\text{H}_{22}\text{OSi}$, 246.1434; found, 246.1431. IR (film): 2988 (w), 2956 (w), 2901 (w), 2895 (w), 2254 (w), 1252 (w), 1126 (w), 992 (w), 906 (s), 841 (m) cm^{-1} .

Trimethyl(1-(1-(*p*-tolyl)vinyl)cyclobutoxy)silane (4b).



Compound **4b** was prepared according to general method D using 1-(1-(*p*-tolyl)vinyl)cyclobutanol (**3b**, 0.45 g, 2.4 mmol, 1.0 equiv), Et_3N (0.50 mL, 3.6 mmol, 1.5 equiv), and TMSCl (0.37 mL, 2.9 mmol, 1.3 equiv). The title compound **4b** was obtained as a colorless oil (0.56 g, 2.1 mmol, 90% yield). R_f (silica, pentane): 0.8. ^1H NMR (400 MHz, CDCl_3 , δ): 7.44 (dd, J = 8.2, 2.1 Hz, 2H), 7.11 (m, 2H), 5.44 (s, 1H), 5.35 (s, 1H), 2.48–2.39 (m, 2H), 2.37–2.21 (m, 5H), 1.83 (m, 1H), 1.53 (m, 1H), 0.00 (m, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 151.6, 136.9, 136.6, 128.5, 128.0, 111.7, 79.1, 37.2, 21.3, 13.7, 1.8 ppm. HRMS (ESI): $[\text{M}^+]$ calcd. for $\text{C}_{16}\text{H}_{24}\text{OSi}$, 260.1591; found, 260.1591. IR (film): 2989 (w), 2988 (w), 2970 (w), 2958 (w), 2946 (w), 2917 (w), 2365 (m), 2358 (m), 2343 (m), 2335 (m), 2328 (m), 2254 (w), 1510 (w), 1265 (s), 1253 (m), 1161 (m), 1125 (m), 1118 (m), 1086 (w), 991 (m), 886 (m), 876 (m), 863 (w), 856 (m), 845 (s), 837 (m), 828 (m), cm^{-1} .

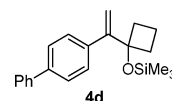
1-(1-(4-(*tert*-Butyl)phenyl)vinyl)cyclobutoxy)trimethylsilane (4c).



Compound **4c** was prepared according to general method D using 1-(1-(4-(*tert*-butyl)phenyl)vinyl)cyclobutanol (**3c**, 0.45 g, 2.0 mmol, 1.0 equiv), Et_3N (0.40 mL, 2.9 mmol, 1.5 equiv), and TMSCl (0.30 mL, 2.3 mmol, 1.3 equiv). The title compound

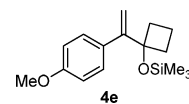
4c was obtained as a pale yellow oil (0.47 g, 1.6 mmol, 90% yield). R_f (silica, pentane): 0.8. ^1H NMR (400 MHz, CDCl_3 , δ): 7.46 (m, 2H), 7.32 (m, 2H), 5.44 (d, J = 1.0 Hz, 1H), 5.35 (d, J = 0.9 Hz, 1H), 2.44 (m, 2H), 2.31 (m, 2H), 1.82 (m, 1H), 1.53 (m, 1H), 1.33 (s, 9H), 0.00 (s, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 151.7, 150.2, 136.8, 127.9, 124.8, 111.8, 79.2, 37.35, 34.7, 31.6, 13.8, 1.9 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{19}\text{H}_{30}\text{NaOSi}^+$, 325.1958; found, 325.1952. IR (film): 3091 (w), 3049 (w), 3034 (w), 2987 (w), 2959 (m), 2958 (m), 2903 (w), 2871 (w), 2360 (m), 1671 (w), 1512 (w), 1511 (w), 1364 (w), 1251 (s), 1163 (m), 1125 (m), 1115 (m), 1018 (m), 992 (m), 928 (m), 913 (m), 899 (w), 881 (m), 865 (m), 841 (s) cm^{-1} .

1-(1-([1,1'-Biphenyl]-4-yl)vinyl)cyclobutoxy)trimethylsilane (4d).



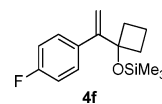
Compound **4d** was prepared according to general method D using 1-(1-([1,1'-biphenyl]-4-yl)vinyl)cyclobutanol (**3d**, 0.48 g, 1.9 mmol, 1.0 equiv), Et_3N (0.40 mL, 2.9 mmol, 1.5 equiv), and TMSCl (0.30 mL, 2.3 mmol, 1.3 equiv). The title compound **4d** was obtained as a white solid (0.500 g, 1.55 mmol, 81% yield). R_f (silica, pentane): 0.8. mp 54 °C. ^1H NMR (400 MHz, CDCl_3 , δ): 7.63 (m, 4H), 7.56 (m, 2H), 7.45 (m, 2H), 7.36 (m, 1H), 5.55 (d, J = 0.8 Hz, 1H), 5.43 (d, J = 0.8 Hz, 1H), 2.49 (m, 2H), 2.37 (m, 2H), 1.86 (m, 1H), 1.59 (m, 1H), 0.04 (s, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 151.4, 141.0, 139.9, 138.5, 128.9, 128.5, 127.3, 127.1, 126.5, 112.3, 79.1, 37.3, 13.7, 1.8 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{21}\text{H}_{26}\text{NaOSi}^+$, 345.1645; found, 345.1639. IR (film): 3096 (w), 3090 (w), 3080 (w), 3063 (w), 3050 (w), 3032 (w), 2988 (w), 2988 (w), 2955 (w), 2917 (w), 2901 (w), 2900 (w), 2895 (w), 2874 (w), 2330 (w), 2253 (w), 1489 (w), 1251 (m), 1161 (w), 1125 (w), 1089 (w), 990 (m), 906 (s), 842 (m) cm^{-1} .

1-(1-(4-Methoxyphenyl)vinyl)cyclobutoxy)trimethylsilane (4e).



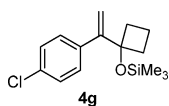
Compound **4e** was prepared according to general method D using 1-(1-(4-methoxyphenyl)vinyl)cyclobutanol (**3e**, 0.50 g, 2.5 mmol, 1.0 equiv), Et_3N (0.51 mL, 3.7 mmol, 1.5 equiv), and TMSCl (0.370 mL, 2.93 mmol, 1.30 equiv). The title compound **4e** was obtained as a colorless oil (0.55 g, 2.0 mmol, 81% yield). R_f (silica, pentane): 0.7. ^1H NMR (400 MHz, CDCl_3 , δ): 7.49 (m, 2H), 6.83 (m, 2H), 5.40 (s, 1H), 5.30 (d, J = 0.8 Hz, 1H), 3.81 (s, 3H), 2.43 (m, 2H), 2.31 (m, 2H), 1.82 (m, 1H), 1.53 (m, 1H), 0.00 (d, J = 1.1 Hz, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 159.0, 151.0, 132.0, 129.2, 113.2, 111.0, 79.2, 55.4, 37.3, 13.8, 1.8 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{16}\text{H}_{24}\text{NaO}_2\text{Si}^+$, 299.1438; found, 299.1435. IR (film): 3097 (w), 2988 (w), 2955 (w), 2903 (w), 2837 (w), 2254 (w), 1609 (w), 1511 (m), 1250 (m), 1182 (m), 1161 (m), 1124 (m), 991 (m), 912 (s), 908 (s), 838 (m) cm^{-1} .

1-(1-(4-Fluorophenyl)vinyl)cyclobutoxy)trimethylsilane (4f).



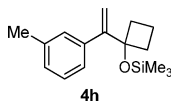
Compound **4f** was prepared according to general method D using 1-(1-(4-fluorophenyl)vinyl)cyclobutanol (**3f**, 0.50 g, 2.6 mmol, 1.0 equiv), Et₃N (0.54 mL, 3.9 mmol, 1.5 equiv), and TMSCl (0.40 mL, 3.1 mmol, 1.3 equiv). The title compound **4f** was obtained as a colorless oil (0.64 g, 2.4 mmol, 90% yield). *R_f* (silica, pentane): 0.6. ¹H NMR (400 MHz, CDCl₃, δ): 7.51 (m, 2H), 6.98 (m, 2H), 5.41 (d, *J* = 0.7 Hz, 1H), 5.37 (s, 1H), 2.41 (m, 2H, CH₂), 2.32 (m, 2H), 1.98 (m, 1H), 1.53 (m, 1H), 0.01 (m, 9H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 162.3 (d, *J* = 246.0 Hz), 150.8, 135.5 (d, *J* = 3.4 Hz), 129.7 (d, *J* = 7.7 Hz), 114.6 (d, *J* = 21.0 Hz), 112.1, 79.0, 37.2, 13.7, 1.7 ppm. ¹⁹F{¹H} NMR (376 MHz, CDCl₃, δ): −115.74 ppm. HRMS (ESI): [*M*⁺] calcd. for C₁₅H₂₁FOSi, 264.1340; found, 264.1339. IR (film): 4014 (s), 3154 (w), 3142 (w), 3122 (w), 2988 (w), 2966 (w), 2956 (w), 2901 (w), 2254 (w), 1604 (w), 1509 (w), 1251 (w), 1162 (w), 990 (w), 906 (m), 841 (m) cm^{−1}.

(1-(1-(4-Chlorophenyl)vinyl)cyclobutoxy)trimethylsilane (4g).



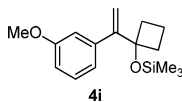
Compound **4g** was prepared according to general method D using 1-(1-(4-chlorophenyl)vinyl)cyclobutanol (**3g**, 0.40 g, 1.9 mmol, 1.0 equiv), Et₃N (0.40 mL, 2.9 mmol, 1.5 equiv), and TMSCl (0.30 mL, 2.3 mmol, 1.3 equiv). The title compound **4g** was obtained as a colorless oil (0.43 g, 1.5 mmol, 80% yield). *R_f* (silica, pentane): 0.7. ¹H NMR (400 MHz, CDCl₃, δ): 7.48 (m, 2H), 7.26 (m, 2H), 5.45 (d, *J* = 0.6 Hz, 1H), 5.39 (d, *J* = 0.6 Hz, 1H), 2.45–2.21 (m, 4H), 1.82 (m, 1H), 1.53 (m, 1H), 0.00 (s, 9H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 150.7, 137.9, 133.1, 129.4, 128.0, 112.7, 78.8, 37.1, 13.7, 1.8 ppm. HRMS (ESI): [*M*⁺] calcd. for C₁₅H₂₁ClOSi, 280.1045; found, 280.1045. IR (film): 3098 (w), 2988 (w), 2956 (w), 2902 (w), 2901 (w), 2894 (w), 2254 (w), 1491 (m), 1252 (m), 1161 (m), 1125 (m), 1096 (m), 1015 (m), 991 (m), 905 (s), 860 (m), 839 (m) cm^{−1}.

Trimethyl(1-(1-(*m*-tolyl)vinyl)cyclobutoxy)silane (4h).



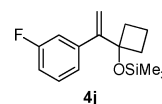
Compound **4h** was prepared according to the general method D using 1-(1-(*m*-tolyl)vinyl)cyclobutanol (**3h**, 0.68 g, 3.6 mmol, 1.0 equiv), Et₃N (0.75 mL, 5.4 mmol, 1.5 equiv), and TMSCl (0.55 mL, 4.3 mmol, 1.3 equiv). The title compound **4h** was obtained as a colorless oil (0.76 g, 2.9 mmol, 81% yield). *R_f* (silica, pentane): 0.8. ¹H NMR (400 MHz, CDCl₃, δ): 7.35 (m, 2H), 7.19 (m, 1H), 7.08 (m, 1H), 5.42 (m, 1H), 5.37 (m, 1H), 2.43 (m, 2H), 2.34 (m, 5H), 1.81 (m, 1H), 1.53 (m, 1H), 0.01 (m, 9H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 152.0, 139.7, 137.2, 128.8, 128.0, 127.7, 125.3, 112.3, 79.0, 37.2, 21.7, 13.7, 1.8 ppm. HRMS (ESI): [*M* + Na]⁺ calcd. for C₁₆H₂₄NaOSi⁺, 283.1489; found, 283.1485. IR (film): 3095 (w), 3092 (w), 3041 (w), 3034 (w), 3026 (w), 2988 (w), 2954 (w), 2953 (w), 2901 (w), 2874 (w), 1250 (s), 1158 (m), 1124 (m), 991 (s), 913 (m), 840 (s) cm^{−1}.

(1-(1-(3-Methoxyphenyl)vinyl)cyclobutoxy)trimethylsilane (4i).



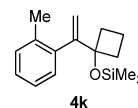
Compound **4i** was prepared according to general method D using 1-(1-(3-methoxyphenyl)vinyl)cyclobutanol (**3i**, 0.15 g, 0.73 mmol, 1.0 equiv), Et₃N (0.15 mL, 1.1 mmol, 1.5 equiv), and TMSCl (0.11 mL, 0.88 mmol, 1.3 equiv). The title compound **4i** was obtained as a colorless oil (0.15 g, 0.54 mmol, 74% yield). *R_f* (silica, pentane): 0.6. ¹H NMR (400 MHz, CDCl₃, δ): 7.22 (m, 1H), 7.13 (m, 2H), 6.82 (ddd, *J* = 8.1, 2.6, 1.1 Hz, 1H), 5.46 (d, *J* = 0.9 Hz, 1H), 5.39 (d, *J* = 0.8 Hz, 1H), 3.81 (s, 3H), 2.43 (m, 2H), 2.31 (m, 2H), 1.82 (m, 1H), 1.54 (m, 1H), 0.04 (s, 9H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃; one C(sp²) signal was not resolved, δ): 159.2, 151.8, 141.3, 128.8, 120.8, 114.0, 112.8, 79.1, 55.4, 37.2, 13.8, 1.9 ppm. HRMS (ESI): [*M*⁺] calcd. for C₁₆H₂₄O₂Si, 276.1540; found, 276.1541. IR (film): 3080 (w), 2988 (w), 2955 (w), 2920 (w), 2905 (w), 2896 (w), 2875 (w), 2832 (w), 1598 (m), 1578 (m), 1489 (m), 1287 (m), 1251 (s), 1158 (m), 1125 (m), 992 (s), 915 (m), 914 (m), 841 (s) cm^{−1}.

(1-(1-(3-Fluorophenyl)vinyl)cyclobutoxy)trimethylsilane (4j).

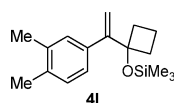


Compound **4j** was prepared according to general method D using 1-(1-(3-fluorophenyl)vinyl)cyclobutanol (**3j**, 0.67 g, 3.5 mmol, 1.0 equiv), Et₃N (0.73 mL, 5.2 mmol, 1.5 equiv), and TMSCl (0.53 mL, 4.2 mmol, 1.3 equiv). The title compound **4j** was obtained as a colorless oil (0.74 g, 2.8 mmol, 80% yield). *R_f* (silica, pentane): 0.7. ¹H NMR (400 MHz, CDCl₃, δ): 7.31 (m, 3H), 6.99 (td, *J* = 8.3, 2.6, 1.2 Hz, 1H), 5.52 (d, *J* = 0.6 Hz, 1H), 5.46 (s, 1H), 2.52–2.23 (m, 4H), 1.87 (m, 1H), 1.58 (m, 1H), 0.05 (s, 9H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 162.5 (d, *J* = 243.9 Hz), 150.8 (d, *J* = 2.2 Hz), 141.9 (d, *J* = 7.7 Hz), 129.2 (d, *J* = 8.3 Hz), 123.7 (d, *J* = 2.8 Hz), 115.0 (d, *J* = 22.3 Hz), 114.0 (d, *J* = 21.1 Hz), 113.2, 78.8, 37.1, 13.6, 1.7 ppm. HRMS (ESI): [*M*⁺] calcd. for C₁₅H₂₁FOSi, 264.1340; found, 264.1339. IR (film): 3091 (w), 2988 (w), 2956 (w), 2916 (w), 2901 (w), 2875 (w), 2874 (w), 2360 (m), 2342 (m), 1614 (w), 1580 (m), 1488 (m), 1251 (s), 1155 (m), 1121 (m), 990 (s), 917 (s), 840 (s) cm^{−1}.

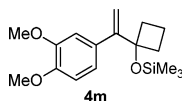
Trimethyl(1-(1-(*o*-tolyl)vinyl)cyclobutoxy)silane (4k).



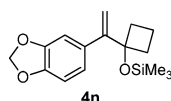
Compound **4k** was prepared according to the general method D using **3k** (0.340 g, 1.79 mmol, 1.00 equiv), Et₃N (0.37 mL, 2.7 mmol, 1.5 equiv), and TMSCl (0.27 mL, 2.1 mmol, 1.3 equiv). The title compound **4k** was obtained as a colorless oil (317 mg, 2.68 mmol, 68% yield). *R_f* (silica, pentane:EtOAc 99:1): 0.8. ¹H NMR (400 MHz, CDCl₃, δ): 7.25–7.09 (m, 4H), 5.55 (d, *J* = 1.6 Hz, 1H), 4.98 (d, *J* = 1.6 Hz, 1H), 2.46–2.35 (m, 2H), 2.31 (s, 3H), 2.28–2.18 (m, 2H), 1.84–1.71 (m, 1H), 1.53–1.38 (m, 1H), 0.10 (s, 9H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 151.7, 140.6, 136.2, 129.8, 129.5, 126.7, 124.7, 113.6, 79.5, 36.1, 20.5, 13.6, 1.9 ppm. HRMS (ESI): [*M*⁺] calcd. for C₁₆H₂₄OSi, 260.1596; found, 260.1586. IR (film): 2987 (m), 2958 (m), 1489 (w), 1381 (w), 1250 (s), 1167 (w), 1079 (w), 995 (m), 926 (m), 841 (s), 760 (m), 732 (m) cm^{−1}.

(1-(1-(3,4-Dimethylphenyl)vinyl)cyclobutoxy)trimethylsilane (4l).

Compound **4l** was prepared according to the general method D using 1-(3-phenylprop-1-en-2-yl)cyclobutanol (**3l**, 0.680 g, 3.61 mmol, 1.00 equiv), Et₃N (0.75 mL, 5.4 mmol, 1.5 equiv), and TMSCl (0.55 mL, 4.3 mmol, 1.3 equiv). The title compound **4l** was obtained as a colorless oil (0.610 g, 2.34 mmol, 65% yield). *R_f* (silica, pentane:EtOAc 99:1): 0.9. ¹H NMR (400 MHz, CDCl₃, δ): 7.32 (d, *J* = 2.0 Hz, 1H), 7.29 (dd, *J* = 7.8, 2.0 Hz, 1H), 7.07 (d, *J* = 7.8 Hz, 1H), 5.42 (d, *J* = 1.0 Hz, 1H), 5.34 (d, *J* = 1.0 Hz, 1H), 2.49–2.38 (m, 2H), 2.36–2.29 (m, 2H), 2.28 (s, 3H), 2.27 (s, 3H), 1.90–1.76 (m, 1H), 1.64–1.44 (m, 1H), 0.04 (s, 9H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 151.6, 137.0, 135.6, 135.4, 129.1, 128.9, 125.5, 111.6, 79.0, 37.0, 19.9, 14.3, 13.6, 1.7 ppm. HRMS (ESI): [*M*⁺] calcd for C₁₇H₂₆OSi, 274.1747; found, 274.1751. IR (film): 2969 (m), 2901 (m), 2361 (w), 1505 (w), 1451 (w), 1407 (w), 1250 (s), 1118 (m), 991 (m), 839 (s), 753 (m) cm⁻¹.

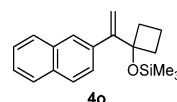
(1-(1-(3,4-Dimethoxyphenyl)vinyl)cyclobutoxy)trimethylsilane (4m).

Compound **4m** was prepared according to general method D using 1-(1-(3,4-dimethoxyphenyl)vinyl)cyclobutanol (**3m**, 0.20 g, 0.85 mmol, 1.0 equiv), Et₃N (0.18 mL, 1.3 mmol, 1.5 equiv), and TMSCl (0.13 mL, 1.0 mmol, 1.3 equiv). The title compound **4m** was obtained as a colorless oil (0.13 g, 0.42 mmol, 50% yield). *R_f* (silica, pentane): 0.4. ¹H NMR (400 MHz, CDCl₃, δ): 7.17 (d, *J* = 2.1 Hz, 1H), 7.11 (dd, *J* = 8.4, 2.1 Hz, 1H), 6.80 (d, *J* = 8.4 Hz, 1H), 5.42 (d, *J* = 0.8 Hz, 1H), 5.31 (d, *J* = 0.8 Hz, 1H), 3.88 (s, 3H), 3.88 (s, 3H), 2.40 (m, 2H), 2.29 (m, 2H), 1.82 (m, 1H), 1.52 (m, 1H), 0.02 (s, 9H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 151.0, 148.4, 148.1, 132.3, 120.5, 111.6, 111.3, 110.5, 79.2, 55.9, 37.1, 13.7, 1.8 ppm. One aliphatic signal was not resolved. HRMS (ESI): [*M*⁺] calcd for C₁₇H₂₆O₃Si, 306.1646; found, 306.1645. IR (film): 2988 (w), 2988 (w), 2955 (w), 2907 (w), 2873 (w), 2835 (w), 2255 (w), 1516 (s), 1272 (m), 1259 (s), 1250 (s), 1144 (m), 1123 (m), 1122 (m), 1029 (m), 992 (m), 991 (m), 912 (s), 842 (s) cm⁻¹.

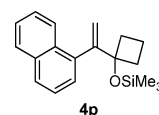
(1-(1-(Benzo[d][1,3]dioxol-5-yl)vinyl)cyclobutoxy)-trimethylsilane (4n).

Compound **4n** was prepared according to general method D using 1-(1-(benzo[d][1,3]dioxol-5-yl)vinyl)cyclobutanol (**3n**, 0.55 g, 2.5 mmol, 1.0 equiv), Et₃N (0.53 mL, 3.8 mmol, 1.5 equiv), and TMSCl (0.39 mL, 3.0 mmol, 1.3 equiv). The title compound **4n** was obtained as a colorless oil (0.610 g, 2.10 mmol, 83% yield). *R_f* (silica, pentane): 0.4. ¹H NMR (400 MHz, CDCl₃, δ): 7.07 (d, *J* = 1.8 Hz, 1H), 7.03 (dd, *J* = 8.1, 1.8 Hz, 1H), 6.75 (d, *J* = 8.1 Hz, 1H), 5.94 (s, 2H), 5.37 (d, *J* = 0.7 Hz, 1H), 5.31 (d, *J* = 0.7 Hz, 1H), 2.40 (m, 2H), 2.29 (m, 2H), 1.81 (m, 1H), 1.51 (m, 1H), 0.02 (s, 9H) ppm.

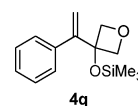
¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 151.2, 147.1, 146.8, 133.7, 121.7, 111.7, 108.6, 107.7, 101.0, 79.0, 37.2, 13.7, 1.8 ppm. HRMS (ESI): [*M*⁺] calcd. for C₁₆H₂₂O₃Si 290.1333; found, 290.1334. IR (film): 3097 (w), 3090 (w), 3081 (w), 3080 (w), 3068 (w), 2988 (w), 2954 (w), 2893 (w), 2774 (w), 2332 (w), 1506 (m), 1490 (s), 1437 (m), 1250 (s), 1239 (s), 1121 (s), 1043 (s), 991 (s), 941 (m), 915 (m), 854 (s), 842 (s), 818 (m) cm⁻¹.

Trimethyl(1-(1-(naphthalen-2-yl)vinyl)cyclobutoxy)silane (4o).

Compound **4o** was prepared according to general method D using 1-(1-(naphthalen-2-yl)vinyl)cyclobutanol (**3o**, 0.50 g, 2.2 mmol, 1.0 equiv), Et₃N (0.47 mL, 3.3 mmol, 1.5 equiv), and TMSCl (0.34 mL, 2.7 mmol, 1.3 equiv). The title compound **4o** was obtained as a colorless oil (0.43 g, 1.4 mmol, 65% yield). *R_f* (silica, pentane): 0.8. ¹H NMR (400 MHz, CDCl₃, δ): 8.03 (s, 1H), 7.84 (m, 2H), 7.78 (d, *J* = 8.6 Hz, 1H), 7.70 (dd, *J* = 8.7, 1.6 Hz, 1H), 7.50–7.42 (m, 2H), 5.62 (d, *J* = 0.9 Hz, 1H), 5.50 (s, 1H), 2.51 (m, 2H), 2.40 (m, 2H), 1.87 (m, 1H), 1.57 (m, 1H), 0.03 (s, 9H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 151.7, 137.0, 133.3, 132.7, 128.4, 127.5, 127.1, 127.0, 126.4, 125.9, 125.8, 112.9, 79.1, 37.3, 13.7, 1.8 ppm. HRMS (ESI): [*M*⁺] calcd. for C₁₉H₂₄OSi, 296.1591; found, 296.1594. IR (film): 3058 (w), 2988 (w), 2954 (w), 2898 (w), 2873 (w), 1250 (s), 1119 (m), 990 (s), 912 (s), 893 (m), 840 (s), 821 (m) cm⁻¹.

Trimethyl(1-(1-(naphthalen-1-yl)vinyl)cyclobutoxy)silane (4p).

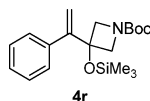
Compound **4p** was prepared according to the general method D using **3p** (1.00 g, 4.46 mmol, 1.00 equiv), Et₃N (0.93 mL, 6.7 mmol, 1.5 equiv), and TMSCl (0.67 mL, 5.3 mmol, 1.3 equiv). The title compound **4p** was obtained as a colorless oil (1.10 g, 3.71 mmol, 83% yield). *R_f* (silica, pentane:EtOAc 99:1): 0.6. ¹H NMR (400 MHz, CDCl₃, δ): 8.15–8.06 (m, 1H), 7.90–7.82 (m, 1H), 7.82–7.76 (m, 1H), 7.51–7.41 (m, 4H), 5.80 (d, *J* = 1.6 Hz, 1H), 5.19 (d, *J* = 1.7 Hz, 1H), 2.58–2.41 (m, 2H), 2.34–2.19 (m, 2H), 1.82–1.70 (m, 1H), 1.52–1.37 (m, 1H), 0.07 (s, 9H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 150.3, 138.7, 133.5, 132.9, 128.0, 127.2, 126.8, 126.5, 125.4, 125.4, 124.7, 115.2, 79.4, 36.1, 13.5, 1.9 ppm. HRMS (ESI): [*M*⁺] calcd for C₁₆H₂₁F₃OSi, 314.1308; found, 314.1314. IR (film): 2991 (w), 2954 (w), 1250 (m), 1162 (w), 1135 (w), 1115 (w), 992 (m), 908 (m), 839 (s), 778 (s), 732 (s) cm⁻¹.

Trimethyl((3-(1-phenylvinyl)oxetan-3-yl)oxy)silane (4q).

Compound **4q** was prepared according to the general procedure, 3-(1-phenylvinyl)oxetan-3-ol (**3q**, 0.400 g, 2.27 mmol, 1.00 equiv), Et₃N (0.48 mL, 3.4 mmol, 1.5 equiv), and TMSCl (0.35 mL, 2.8 mmol, 1.3 equiv). The title compound **4q** was obtained as a pale yellow oil (0.440 g, 1.77 mmol, 78% yield).

R_f (silica, pentane): 0.7. ^1H NMR (400 MHz, CDCl_3 , δ): 7.42 (m, 2H), 7.31 (m, 3H), 5.69 (s, 1H), 5.46 (s, 1H), 4.84 (s, 4H), 0.04 (s, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 149.52, 137.8, 128.3, 128.0, 127.2, 114.2, 84.0, 78.1, 1.5 ppm. HRMS (ESI): $[\text{M}^+]$ calcd. for $\text{C}_{14}\text{H}_{20}\text{O}_2\text{Si}$, 248.1227; found, 248.1224. IR (film): 3058 (w), 2958 (w), 2875 (w), 2251 (w), 1253 (m), 1153 (m), 991 (s), 908 (s), 843 (s) cm^{-1} .

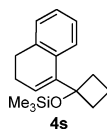
tert-Butyl 3-(1-Phenylvinyl)-3-((trimethylsilyl)oxy)azetidine-1-carboxylate (4r).



Compound **4r** was prepared according to the general method D using **3r** (0.44 g, 1.6 mmol, 1.00 equiv), Et_3N (0.33 mL, 2.4 mmol, 1.50 equiv), and TMSCl (0.24 mL, 1.9 mmol, 1.2 equiv). The title compound **4r** was obtained as a colorless oil (0.410 g, 1.18 mmol, 74% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.45 (dd, J = 8.2, 1.5 Hz, 2H), 7.36–7.27 (m, 3H), 5.61 (s, 1H), 5.41 (s, 1H), 4.18 (s, 2H), 4.06 (dd, J = 9.0, 0.9 Hz, 2H), 1.42 (s, 9H), 0.04 (s, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 156.3, 149.4, 137.8, 128.2, 127.8, 127.1, 114.2, 79.5, 73.8, 63.5, 62.0, 28.3, 1.3 ppm. HRMS (ESI): $[\text{M} + \text{H}]^+$ calcd for $\text{C}_{19}\text{H}_{30}\text{NO}_3\text{Si}^+$, 348.1989; found, 348.1989.

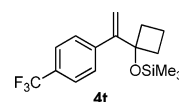
(1-(3,4-Dihydronaphthalen-1-yl)cyclobutoxy)trimethylsilane (4s). Following a reported procedure,⁴⁰ Br_2 (0.60 mL, 12 mmol, 1.25 equiv) was added dropwise to a solution of triphenyl phosphite (2.7 mL, 10 mmol, 1.1 equiv) in anhydrous dichloromethane (31.1 mL) maintained at -60°C under Ar. A solution of Et_3N (1.7 mL, 13 mmol, 1.35 equiv) and 3,4-dihydronaphthalen-1(2H)-one (**26**) (1.2 mL, 9.3 mmol, 1.0 equiv) in DCM (5 mL) was then added, and the resulting mixture was stirred for 18 h, while allowing it to warm to room temperature, and then heated to reflux for another 2 h. The reaction was quenched with saturated aqueous $\text{Na}_2\text{S}_2\text{O}_3$ (50 mL). The organic layer was separated, and the aqueous layer was extracted with dichloromethane (3×30 mL). The organic layers were combined, dried over anhydrous Na_2SO_4 , filtered, and concentrated under reduced pressure. The residue was purified by column chromatography (silica, pentane) to give the 4-bromo-1,2-dihydronaphthalene (**25s**) (1.3 g, 6.2 mmol, 67%) as a colorless oil. ^1H NMR (400 MHz, CDCl_3 , δ): 7.57 (dd, J = 7.6, 1.4, 1H), 7.24 (m, 2H), 7.12 (dd, J = 7.2, 1.4, 1H), 6.46 (t, J = 4.8, 1H), 2.86 (t, J = 8.1, 2H), 2.43–2.34 (m, 2H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.⁴⁰

Following a reported procedure,⁴¹ $t\text{BuLi}$ (2.0 M in heptanes; 4.6 mL, 9.2 mmol, 2.0 equiv) was added dropwise to a solution of 4-bromo-1,2-dihydronaphthalene (**25s**) (0.96 g, 4.6 mmol) in anhydrous THF (20 mL) at -78°C , over a period of 3 min. The resultant colorless solution was stirred at -78°C for 0.5 h. Cyclobutanone (0.38 mL, 5.1 mmol, 1.1 equiv) was then added, and the resulting mixture was stirred at -78°C for 0.5 h. It was then allowed to slowly warm to room temperature. Water was added to quench the reaction, and the aqueous layer was extracted with EtOAc . The combined organic layers were dried over anhydrous Na_2SO_4 , filtered, and concentrated under reduced pressure. The crude residue was then purified by flash chromatography (silica, pentane: EtOAc 100:0 to 95:5 to 85:15) to give pure 1-(3,4-dihydronaphthalen-1-yl)cyclobutanone (**3s**) (0.750 g, 3.74 mmol, 81%) as a colorless solid. ^1H NMR (400 MHz, CDCl_3 , δ): 7.51 (d, J = 7.3, 1H), 7.23–7.10 (m, 3H), 6.20 (t, J = 4.6, 1H), 2.75 (t, J = 8.0, 2H), 2.61–2.47 (m, 2H), 2.40–2.26 (m, 4H), 2.08–1.88 (m, 1H), 1.60 (dt, J = 11.0, 8.8, 7.5, 1H), 0.93 (s, 1H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.⁴¹



Compound **4s** was prepared according to the general method D using **3s** (0.750 g, 3.74 mmol, 1.0 equiv), Et_3N (0.78 mL, 5.6 mmol, 1.5 equiv), and TMSCl (0.57 mL, 4.5 mmol, 1.2 equiv). The title compound **4s** was obtained as a colorless oil (810 mg, 2.97 mmol, 79% yield). ^1H NMR (400 MHz, CDCl_3 , δ): 7.57 (dt, J = 6.1, 1.8, 1H), 7.20–7.06 (m, 3H), 6.18 (t, J = 4.6, 1H), 2.79–2.68 (m, 2H), 2.54–2.41 (m, 2H), 2.40–2.25 (m, 4H), 1.88–1.73 (m, 1H), 1.56–1.40 (m, 1H), -0.08 (s, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 139.2, 137.1, 132.8, 127.3, 126.6, 126.3, 125.6, 124.4, 77.8, 37.0, 28.2, 23.3, 14.0, 1.5 ppm. HRMS (ESI): $[\text{M}^+]$ calcd for $\text{C}_{17}\text{H}_{24}\text{OSi}$, 272.1591; found, 272.1589.

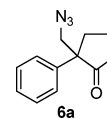
Trimethyl(1-(1-(4-(trifluoromethyl)phenyl)vinyl)cyclobutoxy)silane (4t).



Compound **4t** was prepared according to the general method D using **3t** (1.00 g, 4.13 mmol, 1.00 equiv), Et_3N (0.86 mL, 6.2 mmol, 1.5 equiv), and TMSCl (0.62 mL, 5.0 mmol, 1.3 equiv). The title compound **4t** was obtained as a colorless oil (956 mg, 3.04 mmol, 74% yield). R_f (silica, pentane: EtOAc 99:1): 0.6. ^1H NMR (400 MHz, CDCl_3 , δ): 7.68–7.62 (m, 2H), 7.55 (d, J = 8.3 Hz, 2H), 5.52 (s, 1H), 5.48 (s, 1H), 2.41 (dddd, J = 10.8, 8.4, 4.2, 1.9 Hz, 2H), 2.37–2.28 (m, 2H), 1.92–1.72 (m, 1H), 1.54 (dt, J = 10.9, 8.7 Hz, 1H), 0.00 (s, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 150.78, 143.1, 129.1 (q, J = 32.4 Hz), 128.2, 124.6 (d, J = 3.9 Hz), 124.3 (q, J = 101.5 Hz), 113.7, 78.56, 36.9, 13.5, 1.6 ppm. $^{19}\text{F}\{^1\text{H}\}$ NMR (376 MHz, CDCl_3 , δ): -62.49 ppm. HRMS (ESI): $[\text{M}]^+$ calcd for $\text{C}_{16}\text{H}_{21}\text{F}_3\text{OSi}$, 314.1308; found, 314.1314. IR (film): 2987 (s), 2901 (m), 1619 (w), 1407 (m), 1326 (s), 1252 (s), 1165 (m), 1123 (s), 1068 (s), 991 (m), 840 (s), 754 (w) cm^{-1} .

Ring Expansion Reactions. General Procedure E. Freshly dried CH_3CN (2.5 mL, 0.20 M) was added to a mixture of (1-(1-(arene)vinyl)cyclobutoxy) trimethylsilane **4** (0.5 mmol, 1 equiv), **2** (0.27 mg, 0.60 mmol, 1.2 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (2.2 mg, 2.5 μmol , 5 mol %), and the mixture was degassed (three pump and freeze cycles) and stirred for 16 h at room temperature, while being irradiated with green LEDs. Thereafter, the mixture was filtered through a plug of Celite and concentrated. The residue was purified by column chromatography (silica, pentane: EtOAc 30:1), affording the title compounds **6**.

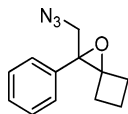
2-(Azidomethyl)-2-phenylcyclopentanone (6a).



Compound **6a** was prepared according to general method E using **4a** (246 mg, 1.00 mmol, 1.0 equiv), **2** (531 mg, 1.20 mmol, 1.2 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (4.4 mg, 5.0 μmol , 0.5 mol %) in CH_3CN (5.0 mL, 0.2 M). The title compound **6a** was obtained as a colorless oil (193 mg, 0.897 mmol, 90%). R_f 0.7 (silica, pentane: EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.37 (m, 4H), 7.30 (m, 1H), 3.72 (d, J = 12.2 Hz, 1H), 3.49 (d, J = 12.2 Hz, 1H), 2.60 (m, 1H), 2.41–2.19 (m, 3H), 2.00 (m, 1H), 1.78 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 217.5, 136.9, 129.0, 127.8, 126.8, 57.9, 57.8, 37.5, 31.7, 18.5 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{12}\text{H}_{13}\text{N}_3\text{NaO}^+$, 238.0951; found, 238.0953. IR (film): 2967 (w), 2925 (w), 2917 (w), 2890 (w), 2104 (s), 1738 (s), 1497 (w), 1448 (w), 1301 (w),

1300 (w), 1288 (w), 1253 (w), 1160 (w) cm^{-1} . NMR data correspond to the reported values.³⁷

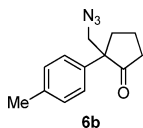
Characterization of 2-(Azidomethyl)-2-phenyl-1-oxaspiro[2.3]-hexane (7a).



7a

R_f 0.45 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.41–7.29 (m, 5H), 3.87 (d, J = 13.3 Hz, 1H), 3.48 (d, J = 13.3 Hz, 1H), 2.67–2.55 (m, 1H), 2.53–2.44 (m, 1H), 2.32 (m, 1H), 1.98–1.82 (m, 2H), 1.78–1.68 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 136.2, 128.5, 128.1, 126.6, 69.7, 65.5, 54.7, 29.6, 29.3, 12.9 ppm. HRMS (ESI): $[\text{M}+\text{H}-\text{N}_2]^+$ calcd. for $\text{C}_{12}\text{H}_{14}\text{NO}^+$, 188.1070; found, 188.1071. IR (film): 2987 (s), 2972 (s), 2902 (m), 2105 (m), 1408 (m), 1329 (s), 1251 (w), 1168 (m), 1127 (m), 1067 (s), 894 (w), 846 (w) cm^{-1} .

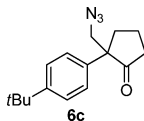
2-(Azidomethyl)-2-(*p*-tolyl)cyclopentanone (6b).



6b

Compound **6b** was prepared according to general method E using **4b** (130 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (2.2 mg, 2.5 μmol , 0.50 mol %) in CH_3CN (2.5 mL, 0.20 m). The title compound **6b** was obtained as a colorless oil (103 mg, 0.449 mmol, 90%). R_f 0.7 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.28 (d, J = 8.2 Hz, 2H, ArH), 7.18 (d, J = 8.2 Hz, 2H, ArH), 3.72 (d, J = 12.2 Hz, 1H, $\text{CH}_2\text{-N}_3$), 3.47 (d, J = 12.2 Hz, 1H, $\text{CH}_2\text{-N}_3$), 2.60 (m, 1H, CH_2), 2.42–2.16 (m, 6H, CH_3 and CH_2), 2.04–1.92 (m, 1H, CH_2), 1.79 (m, 1H, CH_2) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 217.5, 137.5, 133.6, 129.6, 126.6, 57.8, 57.4, 37.3, 31.6, 20.9, 18.4 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{13}\text{H}_{15}\text{N}_3\text{NaO}^+$, 252.1107; found, 252.1114. IR (film): 2968 (w), 2924 (w), 2886 (w), 2101 (s), 1737 (s), 1515 (w), 1456 (w), 1299 (w), 1279 (w), 1163 (w), 1022 (w), 908 (w), 817 (w) cm^{-1} .

2-(Azidomethyl)-2-(4-(*tert*-butyl)phenyl)cyclopentanone (6c).

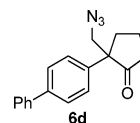


6c

Compound **6c** was prepared according to general method E using **4c** (151 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (2.2 mg, 2.5 μmol , 0.5 mol %) in CH_3CN (2.5 mL, 0.2 m). The title compound **6c** was obtained as a colorless oil (115 mg, 0.424 mmol, 85%). R_f 0.7 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.39–7.34 (m, 2H), 7.32–7.27 (m, 2H), 3.74 (d, J = 12.3 Hz, 1H), 3.46 (d, J = 12.3 Hz, 1H), 2.64–2.56 (m, 1H), 2.40–2.18 (m, 3H), 2.07–1.92 (m, 1H), 1.87–1.72 (m, 1H), 1.30 (s, 9H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 217.5, 150.6, 133.6, 126.3, 125.8, 57.7, 57.3, 37.4, 34.3, 31.5, 31.2, 18.4 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{16}\text{H}_{21}\text{N}_3\text{NaO}^+$, 294.1577; found, 294.1584. IR (film): 2964 (m), 2907 (w), 2870 (w), 2597 (w), 2104 (s), 1739 (m),

1510 (w), 1464 (w), 1405 (w), 1365 (w), 1272 (w), 1160 (w), 1018 (w), 836 (w) cm^{-1} .

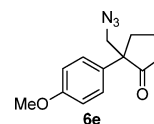
2-([1,1'-Biphenyl]-4-yl)-2-(azidomethyl)cyclopentanone (6d).



6d

Compound **6d** was prepared according to general method E using **4d** (161 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (2.2 mg, 2.5 μmol , 0.5 mol %) in CH_3CN (2.5 mL, 0.2 m). The title compound **6d** was obtained as a colorless oil (130 mg, 0.446 mmol, 89%). R_f 0.7 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.63–7.55 (m, 4H), 7.51–7.42 (m, 4H), 7.40–7.33 (m, 1H), 3.78 (d, J = 12.2 Hz, 1H), 3.53 (d, J = 12.3 Hz, 1H), 2.73–2.59 (m, 1H), 2.45–2.22 (m, 3H), 2.10–1.98 (m, 1H₂), 1.93–1.76 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 217.3, 140.5, 140.1, 135.7, 128.7, 127.5, 127.4, 127.1, 126.9, 57.7, 57.4, 37.4, 31.6, 18.4 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{18}\text{H}_{17}\text{N}_3\text{NaO}^+$, 314.1264; found, 314.1266. IR (film): 3033 (w), 2973 (w), 2881 (w), 2103 (s), 1737 (s), 1601 (w), 1523 (w), 1489 (w), 1406 (w), 1301 (w), 1271 (w), 1159 (w), 1009 (w), 842 (w) cm^{-1} .

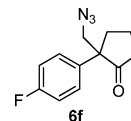
2-(Azidomethyl)-2-(4-methoxyphenyl)cyclopentanone (6e).



6e

Compound **6e** was prepared according to general method E using **4e** (138 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (2.2 mg, 2.5 μmol , 0.5 mol %) in CH_3CN (2.5 mL, 0.2 m). The title compound **6e** was obtained as a colorless oil (112 mg, 0.457 mmol, 91%). R_f 0.5 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.35–7.19 (m, 2H), 6.95–6.79 (m, 2H), 3.77 (s, 3H), 3.67 (d, J = 12.3 Hz, 1H), 3.43 (d, J = 12.2 Hz, 1H), 2.56 (m, 1H), 2.40–2.13 (m, 3H), 2.03–1.88 (m, 1H), 1.86–1.67 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 217.4, 159.0, 128.3, 127.8, 114.2, 57.7, 56.9, 55.1, 37.2, 31.5, 18.3 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{13}\text{H}_{15}\text{N}_3\text{NaO}_2^+$, 268.1056; found, 268.1055. IR (film): 2961 (w), 2838 (w), 2101 (s), 1734 (s), 1609 (w), 1512 (s), 1464 (w), 1253 (s), 1187 (m), 1034 (m), 905 (m), 832 (m) cm^{-1} .

2-(Azidomethyl)-2-(4-fluorophenyl)cyclopentanone (6f).

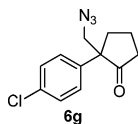


6f

Compound **6f** was prepared according to general method E using **4f** (132 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (2.2 mg, 2.5 μmol , 0.5 mol %) in CH_3CN (2.5 mL, 0.2 m). The title compound **6f** was obtained as a colorless oil (98 mg, 0.42 mmol, 84%). R_f 0.7 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.49–7.28 (m, 2H), 7.11–6.93 (m, 2H), 3.66 (d, J = 12.3 Hz, 1H), 3.45 (d, J = 12.3 Hz, 1H), 2.56 (m, 1H), 2.46–2.16 (m, 3H), 2.13–1.89 (m, 1H), 1.76 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 217.2, 162.16 (d, J = 247.4 Hz), 132.48 (d, J = 3.3 Hz), 128.50 (d, J = 8.1 Hz), 115.75 (d, J = 21.3 Hz),

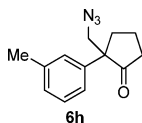
57.8, 57.0, 37.4, 31.8, 18.4 ppm. $^{19}\text{F}\{^1\text{H}\}$ NMR (376 MHz, CDCl_3): δ = -114.44 (tt, J = 8.2, 5.2 Hz) ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{12}\text{H}_{12}\text{FN}_3\text{NaO}^+$, 256.0857; found, 256.0857. IR (film): 2977 (w), 2255 (w), 2105 (s), 1737 (m), 1605 (w), 1510 (m), 1405 (w), 1284 (w), 1239 (m), 1167 (w), 1110 (w), 1016 (w), 908 (s), 837 (w) cm^{-1} .

2-(Azidomethyl)-2-(4-chlorophenyl)cyclopentanone (6g).



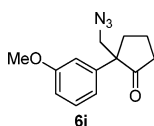
Compound **6g** was prepared according to general method E using **4g** (140 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (2.2 mg, 2.5 μmol , 0.5 mol %) in CH_3CN (2.5 mL, 0.2 m). The title compound **6g** was obtained as a colorless oil (120 mg, 0.481 mmol, 96%). R_f 0.7 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.35–7.28 (m, 4H), 3.66 (d, J = 12.3 Hz, 1H), 3.44 (d, J = 12.3 Hz, 1H), 2.59–2.49 (m, 1H), 2.39–2.18 (m, 3H), 2.04–1.93 (m, 1H), 1.82–1.67 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 216.9, 135.3, 133.7, 128.9, 128.1, 57.6, 57.0, 37.4, 31.6, 18.4 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{12}\text{H}_{12}\text{ClN}_3\text{NaO}^+$, 272.0561; found, 272.0563. IR (film): 2971 (w), 2885 (w), 2105 (s), 1739 (m), 1494 (m), 1404 (w), 1276 (w), 1159 (w), 1097 (w), 1014 (m), 832 (w) cm^{-1} .

2-(Azidomethyl)-2-(*m*-tolyl)cyclopentanone (6h).



Compound **6h** was prepared according to general method E using **4h** (130 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (2.2 mg, 2.5 μmol , 0.5 mol %) in CH_3CN (2.5 mL, 0.2 m). The title compound **6h** was obtained as a colorless oil (105 mg, 0.458 mmol, 92%). R_f 0.7 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.27–7.21 (m, 1H, ArH), 7.20–7.15 (m, 2H, ArH), 7.10 (d, J = 7.5 Hz, 1H, ArH), 3.72 (d, J = 12.3 Hz, 1H, $\text{CH}_2\text{-N}_3$), 3.47 (d, J = 12.3 Hz, 1H, $\text{CH}_2\text{-N}_3$), 2.60 (m, 1H, CH_2), 2.44–2.17 (m, 6H, CH_3 , CH_2), 1.99 (m, 1H, CH_2), 1.86–1.69 (m, 1H, CH_2) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 217.4, 138.5, 136.7, 128.7, 128.4, 127.3, 123.5, 57.7, 57.6, 37.3, 31.6, 21.4, 18.3 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{13}\text{H}_{15}\text{N}_3\text{NaO}^+$, 252.1107; found, 252.1111. IR (film): 3458 (w), 3027 (w), 2968 (w), 2886 (w), 2253 (w), 2101 (s), 1736 (s), 1605 (w), 1456 (w), 1300 (w), 1272 (w), 1158 (w), 909 (m) cm^{-1} .

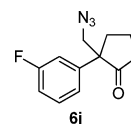
2-(Azidomethyl)-2-(3-methoxyphenyl)cyclopentanone (6i).



Compound **6i** was prepared according to general method E using **4i** (138 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (2.2 mg, 2.5 μmol , 0.5 mol %) in CH_3CN (2.5 mL, 0.2 m). The title compound **6i** was obtained as a colorless oil (105 mg, 0.428 mmol, 86%). R_f 0.6 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.27 (t, J = 8.0 Hz, 1H), 6.95 (ddd, J = 8.0, 2.2,

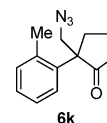
0.9 Hz, 1H), 6.92 (t, J = 2.2 Hz, 1H), 6.83 (ddd, J = 8.0, 2.2, 0.9 Hz, 1H), 3.80 (s, 3H), 3.71 (d, J = 12.2 Hz, 1H), 3.48 (d, J = 12.2 Hz, 1H), 2.64–2.52 (m, 1H), 2.41–2.16 (m, 3H), 2.07–1.93 (m, 1H), 1.87–1.71 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 217.3, 159.9, 138.4, 129.9, 118.9, 113.0, 112.7, 57.7, 55.2, 37.4, 31.7, 18.4 ppm. HRMS (ESI): $[\text{M}^+]$ calcd for $\text{C}_{13}\text{H}_{15}\text{NO}_2$, 217.1097; found, 217.1101 (loss of N_2). IR (film): 2968 (w), 2837 (w), 2102 (s), 1736 (s), 1599 (m), 1582 (m), 1490 (m), 1435 (w), 1292 (m), 1263 (m), 1242 (m), 1157 (w), 1053 (m), 883 (w), 781 (w) cm^{-1} .

2-(Azidomethyl)-2-(3-fluorophenyl)cyclopentanone (6j).



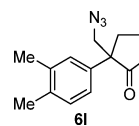
Compound **6j** was prepared according to general method E using **4j** (132 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (2.2 mg, 2.5 μmol , 0.5 mol %) in CH_3CN (2.5 mL, 0.2 m). The title compound **6j** was obtained as a colorless oil (96 mg, 0.41 mmol, 82%). R_f 0.6 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.33 (td, J = 8.0, 6.1 Hz, 1H), 7.17 (dt, J = 8.0, 1.2 Hz, 1H), 7.12 (dt, J = 10.5, 2.2 Hz, 1H), 7.03–6.95 (m, 1H), 3.69 (d, J = 12.3 Hz, 1H), 3.48 (d, J = 12.3 Hz, 1H), 2.62–2.52 (m, 1H), 2.43–2.23 (m, 3H), 2.09–1.96 (m, 1H), 1.87–1.70 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 216.9, 163.0 (d, J = 246.8 Hz), 139.5 (d, J = 7.0 Hz), 130.4 (d, J = 8.3 Hz), 122.4 (d, J = 2.9 Hz), 114.8 (d, J = 21.1 Hz), 114.0 (d, J = 22.6 Hz), 57.7, 57.5 (d, J = 1.7 Hz), 37.5, 31.8, 18.5 ppm. ^{19}F NMR (376 MHz, CDCl_3 , δ): -111.5 (ddd, J = 10.7, 7.7, 6.1 Hz) ppm. HRMS (ESI): $[\text{M} + \text{H}]^+$ calcd. for $\text{C}_{12}\text{H}_{13}\text{FNO}^+$, 206.0976; found, 206.0973 (loss of N_2). IR (film): 2972 (w), 2105 (s), 1738 (m), 1614 (w), 1588 (w), 1490 (w), 1439 (w), 1274 (w), 1161 (w), 875 (w), 789 (w) cm^{-1} .

2-(Azidomethyl)-2-(*o*-tolyl)cyclopentanone (6k).



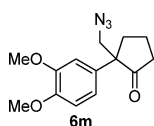
Compound **6k** was prepared according to general method E using **4k** (0.13 g, 0.50 mmol, 1 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (2.2 mg, 2.5 μmol , 0.5 mol %) in CH_3CN (2.5 mL, 0.2 m). The title compound **6k** was obtained as a colorless oil (89 mg, 0.39 mmol, 78%). R_f 0.7 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.21–7.04 (m, 4H), 3.82 (d, J = 12.3 Hz, 1H), 3.77 (d, J = 12.4 Hz, 1H), 2.58–2.43 (m, 2H), 2.41 (s, 3H), 2.40–2.25 (m, 2H), 2.03–1.90 (m, 1H), 1.87–1.73 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 219.1, 136.9, 136.0, 133.1, 127.5, 127.5, 126.1, 58.3, 55.1, 37.8, 32.9, 21.8, 18.7 ppm. HRMS (ESI): $[\text{M} + \text{H}]^+$ calcd for $\text{C}_{13}\text{H}_{16}\text{NO}^+$, 202.1226; found, 202.1228 (loss of N_2). IR (film): 2970 (w), 2102 (s), 1737 (m), 1490 (w), 1453 (w), 1279 (w), 1163 (w), 1039 (w), 909 (m), 760 (m), 726 (s) cm^{-1} .

2-(Azidomethyl)-2-(3,4-dimethylphenyl)cyclopentanone (6l).



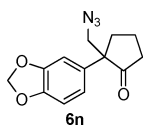
Compound **6l** was prepared according to general method E using **4l** (0.13 g, 0.50 mmol, 1 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and Cu(dap)₂Cl (2.2 mg, 2.5 μmol, 0.5 mol %) in CH₃CN (2.5 mL, 0.2 m). The title compound **6l** was obtained as a colorless oil (89 mg, 0.39 mmol, 78%). *R_f* 0.7 (silica, pentane:EtOAc 10:1). ¹H NMR (400 MHz, CDCl₃, δ): 7.20–6.94 (m, 3H), 3.72 (d, *J* = 12.3 Hz, 1H), 3.46 (d, *J* = 12.3 Hz, 1H), 2.70–2.54 (m, 1H), 2.46–2.16 (m, 9H), 2.06–1.91 (m, 1H), 1.84–1.72 (m, 1H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 217.6, 137.2, 136.2, 134.0, 130.1, 127.8, 123.9, 57.8, 57.4, 37.3, 31.5, 19.9, 19.3, 18.4 ppm. HRMS (ESI): [M + H]⁺ calcd. for C₁₄H₁₈NO⁺, 216.1383; found, 216.1381 (loss of N₂). IR (film): 2972 (w), 2101 (s), 1736 (m), 1506 (w), 1455 (w), 1296 (w), 1159 (w), 910 (m), 732 (s) cm⁻¹.

2-(Azidomethyl)-2-(3,4-dimethoxyphenyl)cyclopentanone (6m).



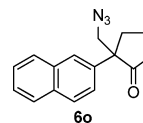
Compound **6m** was prepared according to general method E using **4m** (153 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.2 equiv), and Cu(dap)₂Cl (2.2 mg, 2.5 μmol, 0.5 mol %) in CH₃CN (2.5 mL, 0.2 m). The title compound **6m** was obtained as a colorless oil (120 mg, 0.436 mmol, 87%). *R_f* 0.2 (silica, pentane:EtOAc 10:1). ¹H NMR (400 MHz, CDCl₃, δ): 7.01–6.78 (m, 3H), 3.88 (s, 3H), 3.87 (s, 3H), 3.70 (d, *J* = 12.2 Hz, 1H), 3.46 (d, *J* = 12.2 Hz, 1H), 2.63–2.53 (m, 1H), 2.41–2.20 (m, 3H), 2.06–1.94 (m, 1H), 1.87–1.73 (m, 1H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 217.5, 149.2, 148.7, 128.8, 119.1, 111.2, 110.0, 58.0, 57.3, 56.0, 55.8, 37.4, 31.7, 18.5 ppm. HRMS (ESI): [M + Na]⁺ calcd for C₁₄H₁₇N₃NaO₃⁺, 298.1162; found, 298.1170. IR (film): 2971 (s), 2902 (s), 2104 (m), 1735 (w), 1519 (m), 1465 (w), 1409 (m), 1259 (s), 1151 (w), 1066 (s), 1040 (s), 872 (w), 742 (w) cm⁻¹.

2-(Azidomethyl)-2-(benzo[d][1,3]dioxol-5-yl)cyclopentanone (6n).



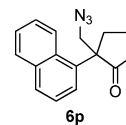
Compound **6n** was prepared according to general method E using **4n** (145 mg, 0.500 mmol, 1.00 equiv), **2** (0.26 g, 0.60 mmol, 1.2 equiv), and Cu(dap)₂Cl (2.2 mg, 2.5 μmol, 0.5 mol %) in CH₃CN (2.5 mL, 0.2 m). The title compound **6n** was obtained as a colorless oil (109 mg, 0.420 mmol, 84%). *R_f* 0.4 (silica, pentane:EtOAc 10:1). ¹H NMR (400 MHz, CDCl₃, δ): 6.88 (d, *J* = 1.9 Hz, 1H), 6.81 (dd, *J* = 8.2, 1.9 Hz, 1H), 6.75 (d, *J* = 8.2 Hz, 1H), 5.92 (q, *J* = 1.4 Hz, 2H), 3.63 (d, *J* = 12.3 Hz, 1H), 3.41 (d, *J* = 12.3 Hz, 1H), 2.50 (m, 1H), 2.33 (m, 1H), 2.27–2.16 (m, 2H), 2.05–1.90 (m, 1H), 1.76 (m, 1H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 217.1, 148.2, 147.0, 130.2, 120.1, 108.3, 107.1, 101.2, 57.8, 57.2, 37.2, 31.8, 18.3 ppm. HRMS (ESI): [M + Na]⁺ calcd. for C₁₃H₁₃N₃NaO₃⁺, 282.0849; found, 282.0849. IR (film): 3454 (w), 2972 (w), 2890 (w), 2780 (w), 2102 (s), 1734 (s), 1611 (w), 1505 (s), 1488 (s), 1437 (m), 1297 (w), 1237 (s), 1157 (w), 1115 (w), 1039 (s), 911 (s) cm⁻¹.

2-(Azidomethyl)-2-(naphthalen-2-yl)cyclopentanone (6o).



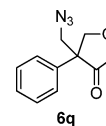
Compound **6o** was prepared according to general method E using **4o** (148 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and Cu(dap)₂Cl (2.2 mg, 2.5 μmol, 0.5 mol %) in CH₃CN (2.5 mL, 0.2 m). The title compound **6o** was obtained as a colorless oil (126 mg, 0.475 mmol, 95%). *R_f* 0.6 (silica, pentane:EtOAc 10:1). ¹H NMR (400 MHz, CDCl₃, δ): 7.92–7.77 (m, 4H), 7.62–7.45 (m, 3H), 3.83 (d, *J* = 12.3 Hz, 1H), 3.58 (d, *J* = 12.3 Hz, 1H), 2.82–2.67 (m, 1H), 2.47–2.24 (m, 3H), 2.09–1.96 (m, 1H), 1.88–1.73 (m, 1H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃; 1 aromatic signal was not resolved, δ): 217.3, 134.0, 133.1, 132.5, 128.8, 128.0, 127.4, 126.3, 126.0, 124.1, 57.8, 57.6, 37.4, 31.7, 18.4 ppm. HRMS (ESI): [M + Na]⁺ calcd. for C₁₆H₁₅N₃NaO⁺, 288.1107; found, 288.1118. IR (film): 3061 (w), 2972 (w), 2105 (s), 1738 (m), 1598 (w), 1507 (w), 1437 (w), 1343 (w), 1301 (w), 1275 (w), 1160 (w), 1036 (w), 968 (w), 863 (w), 821 (w) cm⁻¹.

2-(Azidomethyl)-2-(naphthalen-1-yl)cyclopentanone (6p).



Compound **6p** was prepared according to general method E using **4p** (0.15 g, 0.50 mmol, 1 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and Cu(dap)₂Cl (2.2 mg, 2.5 μmol, 0.5 mol %) in CH₃CN (2.5 mL, 0.2 m). The title compound **6p** was obtained as a colorless oil (105 mg, 0.396 mmol, 79%). *R_f* 0.7 (silica, pentane:EtOAc 10:1). ¹H NMR (400 MHz, CDCl₃, δ): 8.16–8.09 (m, 1H), 7.89 (dd, *J* = 7.9, 1.7 Hz, 1H), 7.79 (dt, *J* = 8.2, 1.1 Hz, 1H), 7.59–7.46 (m, 2H), 7.35 (dd, *J* = 8.2, 7.4 Hz, 1H), 7.22 (dd, *J* = 7.4, 1.1 Hz, 1H), 4.21 (d, *J* = 12.5 Hz, 1H), 4.00 (d, *J* = 12.5 Hz, 1H), 2.89 (dddd, *J* = 13.0, 7.2, 3.9, 1.5 Hz, 1H), 2.66 (ddd, *J* = 13.0, 9.5, 7.2 Hz, 1H), 2.56 (dddd, *J* = 18.8, 9.5, 4.8, 1.5 Hz, 1H), 2.38 (dt, *J* = 18.8, 8.6 Hz, 1H), 2.08–1.92 (m), 1.82–1.68 (m, 1H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃, δ): 219.3, 135.3, 134.3, 130.5, 129.9, 129.1, 125.8, 125.7, 125.4, 125.0, 125.0, 58.7, 55.4, 37.6, 33.0, 18.9 ppm. HRMS (ESI): [M]⁺ calcd. for C₁₆H₁₅NO, 237.1148; found, 237.1156 (loss of N₂). IR (film): 2972 (m), 2902 (m), 2100 (s), 1737 (s), 1599 (w), 1510 (w), 1448 (w), 1398 (w), 1297 (w), 1252 (w), 1164 (w), 1077 (m), 1052 (m), 910 (w), 803 (m), 776 (s), 733 (m) cm⁻¹.

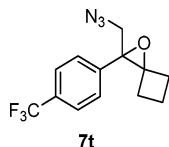
4-(Azidomethyl)-4-phenyldihydrofuran-3(2H)-one (6q).



Compound **6q** was prepared according to general method E using **4q** (157 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and Cu(dap)₂Cl (2.2 mg, 2.5 μmol, 0.5 mol %) in CH₃CN (2.5 mL, 0.2 m). The title compound **6q** was obtained as a colorless oil (82 mg, 0.29 mmol, 58%). *R_f* 0.6 (silica, pentane:EtOAc 10:1). ¹H NMR (400 MHz, CDCl₃; 3:1 mixture of keto/enol tautomers, δ): 7.47–7.28 (m, 5H),

5.07 (s, 1H), 4.77 (d, J = 8.4 Hz, 1H), 4.72 (d, J = 10.0 Hz, 1H), 4.47 (d, J = 10.0 Hz, 1H), 4.43 (d, J = 8.4 Hz, 1H), 4.11 (d, J = 17.3 Hz, 1H), 4.03 (d, J = 17.4 Hz, 1H), 3.92 (d, J = 13.9 Hz, 1H), 3.84 (d, J = 12.5 Hz, 1H), 3.69 (d, J = 12.5 Hz, 1H), 3.61 (d, J = 13.9 Hz, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , keto, δ): 212.8, 135.4, 129.2, 128.3, 126.6, 74.1, 71.1, 68.1, 54.9 ppm. HRMS (ESI): $[\text{M} + \text{H}]^+$ calcd. for $\text{C}_{11}\text{H}_{12}\text{NO}_2^+$, 190.0863; found, 190.0863 (loss of N_2). IR (film): 2968 (w), 2879 (w), 2105 (s), 1760 (m), 1499 (w), 1448 (w), 1299 (w), 1190 (w), 1067 (w), 967 (w), 930 (w), 764 (w) cm^{-1} .

2-(Azidomethyl)-2-(4-(trifluoromethyl)phenyl)-1-oxaspiro[2.3]hexane (7t).



Compound **7t** was prepared according to general method E using **4t** (124 mg, 0.500 mmol, 1.00 equiv), **2** (265 mg, 0.600 mmol, 1.20 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (2.2 mg, 2.5 μmol , 0.50 mol %) in CH_3CN (2.5 mL, 0.20 m). The title compound **7t** was obtained as a colorless oil (72 mg, 0.33 mmol, 66%). R_f 0.5 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.64 (d, J = 8.2 Hz, 2H), 7.46 (d, J = 8.2 Hz, 2H), 3.89 (d, J = 13.4 Hz, 1H), 3.51 (d, J = 13.4 Hz, 1H), 2.72–2.57 (m, 1H), 2.57–2.44 (m, 1H), 2.42–2.26 (m, 1H), 2.01–1.88 (m, 1H), 1.87–1.68 (m, 2H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 140.2, 130.1 (q, J = 32.5 Hz), 126.8, 125.4 (q, J = 3.8 Hz), 124.0 (q, J = 272.9 Hz), 69.8, 65.0, 54.1, 29.4, 29.0, 12.7 ppm. ^{19}F NMR (376 MHz, CDCl_3 , δ): –62.6 (s) ppm. HRMS (ESI): $[\text{M} + \text{H}]^+$ calcd. for $\text{C}_{13}\text{H}_{13}\text{F}_3\text{NO}^+$, 256.0944; found, 256.0945 (loss of N_2). IR (film): 2987 (s), 2972 (s), 2902 (m), 2105 (m), 1408 (m), 1329 (s), 1251 (w), 1168 (m), 1127 (m), 1067 (s), 894 (w), 846 (w) cm^{-1} .

Product Functionalization. 2-Phenyl-2-((4-phenyl-1H-1,2,3-triazol-1-yl)methyl)cyclopentanone (27). Triethylamine (0.10 mL, 0.70 mmol, 2 equiv) followed by phenylacetylene (77 μL , 0.70 mmol, 2 equiv) were added to a solution of **6a** (75 mg, 0.35 mmol, 1 equiv) and CuI (6 mg, 0.04 mmol, 10 mol %) in THF (1.7 mL, 0.2 m) at room temperature, and the resulting mixture was stirred for 16 h at room temperature. Thereafter, the mixture was concentrated, and the residue was purified by column chromatography (silica, pentane:EtOAc 20:1 to 10:1), affording 102 mg (0.321 mmol, 92%) of the title compound **27** as a colorless oil. R_f 0.3 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.61–7.55 (m, 2H), 7.29–7.10 (m, 9H), 4.60 (d, J = 14.1 Hz, 1H), 4.49 (d, J = 14.1 Hz, 1H), 2.55–2.44 (m, 1H), 2.25–2.13 (m, 1H), 1.99 (dt, J = 19.5, 9.2 Hz, 1H), 1.91–1.82 (m, 1H), 1.72–1.63 (m, 1H), 1.62–1.49 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 217.2, 147.3, 135.7, 130.3, 129.1, 128.6, 128.1, 128.0, 126.6, 125.5, 120.7, 58.6, 56.0, 37.0, 31.4, 17.9 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{20}\text{H}_{19}\text{N}_3\text{NaO}^+$, 340.1420; found, 340.1420. IR (film): 3147 (w), 3066 (w), 2977 (w), 2944 (w), 2888 (w), 2250 (w), 1734 (w), 1464 (w), 1356 (w), 1231 (w), 1158 (w), 1077 (w), 1048 (w), 907 (s), 766 (m), 728 (s) cm^{-1} .

Benzyl ((2-oxo-1-phenylcyclopentyl)methyl)carbamate (28). A mixture of **6a** (75 mg, 0.35 mmol, 1 equiv) and Pd/C (7 mg, 10% w/w, 10% Pd) in methanol (1.7 mL, 0.2 m) was purged with hydrogen and then stirred for 16 h under a hydrogen atmosphere. Thereafter, the mixture was filtered through a plug of Celite and concentrated. The crude amine was dissolved in CH_2Cl_2 (0.7 mL, 0.5 m), then NEt_3 (0.10 mL, 0.70 mmol, 2 equiv) followed by CbzCl (75 μL , 0.52 mmol, 1.5 equiv) were added, and stirring was continued for 3 h at room temperature. Then, the reaction was quenched with

water (5 mL) and extracted with CH_2Cl_2 (3 $\times$ 10 mL). The combined organic extracts were washed with brine and dried over MgSO_4 . The drying agent was filtered off, and the solvent was evaporated. The residue was purified by column chromatography (silica, pentane:EtOAc 10:1) affording 74 mg (0.23 mmol, 66%) of the title compound **28** as a colorless oil. R_f 0.5 (silica, pentane:EtOAc 10:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.25–7.14 (m, 10H), 4.94 (s, 2H), 3.49 (dd, J = 14.0, 6.7 Hz, 1H), 3.40 (dd, J = 14.0, 6.7 Hz, 1H), 2.46–2.36 (m, 1H), 2.30–1.99 (m, 3H), 1.90–1.79 (m, 1H), 1.74–1.60 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 219.5, 156.5, 137.6, 136.3, 128.8, 128.4, 128.0, 127.9, 127.4, 126.7, 66.6, 58.3, 47.0, 37.7, 32.5, 18.3 ppm. HRMS (ESI): $[\text{M} + \text{Na}]^+$ calcd. for $\text{C}_{20}\text{H}_{21}\text{NNaO}_3^+$, 346.1414; found, 346.1420. IR (film): 3440 (w), 3350 (w), 3029 (w), 2965 (w), 2886 (w), 2250 (w), 1721 (s), 1509 (m), 1456 (w), 1404 (w), 1232 (s), 1137 (w), 1010 (w), 911 (m), 733 (s) cm^{-1} .

2-(Isothiocyatomethyl)-2-phenylcyclopentanone (29). Triphenylphosphine (0.11 g, 0.42 mmol, 1.2 equiv) was added at room temperature to a solution of **6a** (75 mg, 0.35 mmol, 1 equiv) and CS_2 (0.30 mL, 5.0 mmol, 14 equiv) in THF (0.7 mL, 0.5 m), and the resulting mixture was stirred for 3 h at room temperature. Thereafter, the mixture was concentrated, and the residue was purified by column chromatography (silica, pentane:EtOAc 50:1) affording 58 mg (0.25 mmol, 72%) of the title compound **29** as a colorless oil. R_f 0.3 (silica, pentane:EtOAc 20:1). ^1H NMR (400 MHz, CDCl_3 , δ): 7.49–7.28 (m, 5H), 3.85 (d, J = 14.2 Hz, 1H), 3.70 (d, J = 14.2 Hz, 1H), 2.84–2.67 (m, 1H), 2.45–2.20 (m, 3H), 2.09–1.98 (m, 1H), 1.88–1.73 (m, 1H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 215.9, 135.4, 131.9, 129.1, 128.1, 126.6, 57.8, 51.6, 37.0, 31.9, 18.3 ppm. HRMS (ESI): $[\text{M} + \text{H}]^+$ calcd. for $\text{C}_{13}\text{H}_{14}\text{NOS}^+$, 232.0791; found, 232.0801. IR (film): 2972 (s), 2901 (s), 2188 (m), 2084 (s), 1736 (s), 1599 (w), 1497 (w), 1447 (m), 1404 (m), 1339 (m), 1158 (m), 1067 (s), 880 (w), 759 (m) cm^{-1} .

Established Azidation Reactions Performed with tBuABX (1d) and ABZ (2). **4-Phenylpent-4-enoic Acid (8).** Following a reported procedure,¹¹ a solution of tBuOK (4.91 g, 43.8 mmol, 2.6 equiv) in dry THF (0.5 M) was added under nitrogen to bromo(methyl)triphenylphosphorane (7.82 g, 21.9 mmol, 1.3 equiv) in portions at 0 °C. The mixture was stirred at 0 °C for 30 min, and a solution of 4-oxo-4-phenylbutanoic acid (**30**) (3.00 g, 16.8 mmol, 1.0 equiv) in dry THF (1 M) was added dropwise. The reaction was stirred at 0 °C for 1 h and at room temperature overnight. The solvent was removed in vacuo, and the residue was diluted with DCM and aqueous NaOH (1 M). The aqueous layer was separated, washed with DCM, and acidified to pH 1 with concentrated HCl (35%). DCM was added, and the organic compound was extracted twice with DCM. The organic layer was washed with water, dried over MgSO_4 , and concentrated in vacuo. The crude product was purified by flash column chromatography (SiO_2 , DCM/MeOH: 100/0 then 95/5 and 90/10) to give 4-phenylpent-4-enoic acid (**8**) (2.38 g, 13.5 mmol, 80%). R_f (silica, DCM/MeOH 9/1) 0.70. ^1H NMR (400 MHz, CDCl_3 , δ): 11.60 (bs, 1 H), 7.46–7.27 (m, 5 H), 5.35 (s, 2 H), 2.87 (t, J = 7.8 Hz, 2 H), 2.56 (dd, J = 8.9, 6.7 Hz, 2 H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.¹¹

N-Phenyl-N-((2-vinylphenyl)sulfonyl)methacrylamide (10). Following a reported procedure,⁴² 2-bromobenzene-1-sulfonyl chloride (**31**) (1.34 g, 5.24 mmol, 1.0 equiv) was dissolved in DMF (52 mL). The resulting colorless solution was cooled to 0 °C (ice–water bath), and aniline (**32**) (1.9 mL, 21 mmol, 4.0 equiv) was added dropwise via syringe. The cooling bath was removed, and the mixture was stirred at room temperature for 1.5 h. During this time, it became pale yellow. The reaction was then quenched by the addition of water (50 mL). The aqueous layer was extracted with EtOAc (4 $\times$ 50 mL). The organic extracts were washed with aq. HCl (3 $\times$ 30 mL) and twice with brine, dried over MgSO_4 , filtered, and concentrated under vacuum. The resulting yellow, crude oil was submitted to flash column chromatography (SiO_2 ; pentane/EtOAc in pentane 19/1 to 6/4) to provide 2-bromo-N-phenylbenzenesulfonamide (**33**) (0.819 g, 2.62 mmol, 50%) as a pale yellow, crystalline solid. R_f (silica, pentane/EtOAc 4/1) 0.39. ^1H NMR

(400 MHz, CDCl_3 , δ): 8.02 (m, 1H), 7.70 (m, 1H), 7.36 (m, 2H), 7.25–7.18 (m, 2H), 7.18–7.06 (m, 4H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.⁴³

Following a reported procedure,⁴⁴ a 25 mL round-bottom test tube was charged with 2-bromo-*N*-phenylbenzenesulfonamide (**33**) (0.600 g, 1.92 mmol, 1.0 equiv), $\text{PdCl}_2(\text{PPh}_3)_2$ (67 mg, 0.096 mmol, 5 mol %), potassium (vinyl)trifluoroborate (0.283 g, 2.11 mmol, 1.1 equiv), and cesium carbonate (1.88 g, 5.77 mmol, 3.0 equiv). The tube was sealed, evacuated, and backfilled with nitrogen (3 times). A 9:1 mixture of THF and water (degassed; 9.0 mL) was then added via syringe. The resulting mixture was then heated at 85–90 °C under stirring, turning from a clear, pale brown solution into a dark brown suspension. After 16 h, the mixture was allowed to cool down to room temperature, and it was diluted with water (15 mL). The aqueous layer was then extracted with diethyl ether (3 $\times$ 20 mL). The combined organic extracts were washed with brine, dried over MgSO_4 , filtered, and concentrated under vacuum to furnish an orange crude oil. The latter was submitted to column chromatography (silica; pentane/EtOAc in pentane 19:1 to 6:4) to provide pure *N*-phenyl-2-vinylbenzenesulfonamide (**34**) (0.425 g, 1.64 mmol, 85%) as a pale yellow solid. R_f (pentane:EtOAc, 4:1) 0.4. ^1H NMR (400 MHz, CDCl_3 , δ): 7.89 (dd, J = 7.9, 1.3 Hz, 1H), 7.61 (dd, J = 17.3, 11.0 Hz, 1H), 7.56–7.45 (m, 2H), 7.30 (td, J = 7.6, 1.6 Hz, 1H), 7.17 (t, J = 7.8 Hz, 2H), 7.06 (m, 1H), 7.00–6.94 (m, 2H, ArH), 6.52 (br s, 1H), 5.70 (dd, J = 17.3, 1.3 Hz, 1H), 5.56 (dd, J = 11.0, 1.3 Hz, 1H) ppm.

Following a reported procedure,⁴⁵ in a 50 mL two-neck, round-bottom flask, *N*-phenyl-2-vinylbenzenesulfonamide (**34**) (0.420 g, 1.62 mmol, 1.0 equiv) was dissolved in DCM (dry; 8.1 mL), and the resulting solution was cooled to 0 °C (ice–water bath). Triethylamine (0.68 mL, 4.9 mmol, 3.0 equiv) and methacryloyl chloride (0.34 mL, 3.2 mmol, 2.0 equiv) were added by syringe in this order. The cooling bath was removed, and the mixture was stirred at room temperature for 20 h. The reaction was then quenched with sat. aq. NaHCO_3 (10 mL). The aqueous layer was extracted with DCM (4 $\times$ 15 mL), and the combined organic extracts were washed with brine, dried over MgSO_4 , filtered, and concentrated under vacuum. The resulting pale orange crude oil was submitted to column chromatography (SiO_2 ; pentane:EtOAc in pentane 19:1 to 6:4) to afford pure *N*-phenyl-*N*-(2-vinylphenyl)sulfonylmethacrylamide (**10**) (0.454 g, 1.39 mmol, 86%) as a pale yellow solid. R_f (silica, pentane:EtOAc, 4:1) 0.45. ^1H NMR (400 MHz, CDCl_3 , δ): 8.18 (dd, J = 8.1, 1.2 Hz, 1H), 7.64–7.57 (m, 2H), 7.45 (ddd, J = 8.7, 6.7, 2.3 Hz, 1H), 7.42–7.32 (m, 3H), 7.29 (dd, J = 7.7, 2.0 Hz, 2H), 5.65 (dd, J = 17.3, 1.2 Hz, 1H), 5.31 (dd, J = 10.9, 1.2 Hz, 1H), 5.31–5.29 (m, 1H), 5.21 (d, J = 1.9 Hz, 1H), 1.66 (t, J = 1.3 Hz, 3H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 170.9, 139.3, 138.0, 136.1, 136.0, 134.0, 133.9, 132.0, 130.5, 129.4, 129.2, 127.9, 127.6, 123.7, 118.5, 19.2 ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.^{3c}

2-Allyl-*N*-methoxybenzamide (16). Following a reported procedure,⁴⁶ methyl 2-iodobenzoate (**35**) (1.21 g, 4.62 mmol, 1.0 equiv), palladium tetrakis (0.294 g, 0.254 mmol, 5.5 mol %), and allyltributylstannane (1.7 mL, 5.5 mmol, 1.2 equiv) were dissolved in DMF (dry; 5.1 mL). The mixture was submitted to microwave irradiation in a sealed reaction vessel at 120 °C (temperature was monitored using an external surface sensor) for 10 min, turning from yellow to dark brown. The suspension was filtered through a pad of Celite, which was then washed with several portions of EtOAc (overall, 30 mL). The filtrate was washed with aq. HCl (1.0 M; 30 mL), water, and brine, and it was dried over MgSO_4 , filtered, and concentrated under vacuum. The resulting dark brown crude product was submitted to column chromatography (silica; pentane:DCM 92:8 to 60:40) to furnish pure methyl 2-allylbenzoate (**36**) (0.650 g, 3.69 mmol, 80%) as a pale yellow oil. R_f (silica, pentane:DCM 4:1) 0.59. ^1H NMR (400 MHz, CDCl_3 , δ): 7.88 (dd, J = 8.3, 1.5 Hz, 1H), 7.44 (td, J = 7.5, 1.5 Hz, 1H), 7.27 (m, 2H), 6.01 (ddt, J = 16.8, 10.3, 6.4 Hz, 1H), 5.04 (dt, J = 4.3, 1.7 Hz, 1H), 5.01 (m, 1H), 3.89 (s, 3H), 3.76 (dt, J = 6.4, 1.6 Hz, 2H) ppm. The signals of the

^1H NMR spectra were in accordance with the data reported in the literature.⁴⁶

Following a reported procedure,⁴⁷ methyl 2-allylbenzoate (**36**) (0.650 g, 3.69 mmol, 1.0 equiv) was dissolved in a mixture of THF (12.3 mL), MeOH (3.1 mL), and water (3.1 mL). LiOH (0.883 g, 36.9 mmol, 10 equiv) was added, and the resulting suspension was vigorously stirred overnight at room temperature. After 16 h, the mixture was diluted with water (30 mL), and most of the volatile solvents were removed by evaporation under reduced pressure. The aqueous residue was washed with diethyl ether (3 $\times$ 20 mL) and acidified by cautious addition of conc. HCl (32% v/v) until pH < 3. It was then extracted with DCM (3 $\times$ 30 mL). The combined organic extracts were dried over MgSO_4 , filtered, and concentrated under vacuum to afford 2-allylbenzoic acid (**37**) (0.500 g, 3.08 mmol, 83%) as a colorless solid, which did not require any further purification. ^1H NMR (400 MHz, d_6 -DMSO; the signal corresponding to the CO_2H was not resolved, δ): 7.80 (dd, J = 7.7, 1.5 Hz, 1H), 7.48 (td, J = 7.5, 1.5 Hz, 1H), 7.35–7.26 (m, 2H), 5.96 (ddt, J = 18.5, 9.4, 6.5 Hz, 1H), 5.01 (dd, J = 3.7, 1.8 Hz, 1H), 4.97 (d, J = 1.6 Hz, 1H), 3.71 (d, J = 6.6 Hz, 2H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 173.6, 142.8, 137.3, 133.1, 131.7, 131.1, 128.2, 126.3, 115.7, 38.6. The signals of the NMR spectra were in accordance with the data reported in the literature.¹¹

Following a reported procedure,^{10h} a 50 mL round-bottom test tube was charged 2-allylbenzoic acid (**37**) (0.400 g, 2.47 mmol, 1.0 equiv) and DCM (dry; 12.3 mL). *O*-Methylhydroxylamine hydrochloride (0.309 g, 3.70 mmol, 1.5 equiv), DMAP (0.603 g, 4.93 mmol, 2.0 equiv), and EDCI (0.946 g, 4.93 mmol, 2.0 equiv) were added to provide a pale yellow-pink solution, which was stirred at room temperature for 20 h. The organic solution was then treated with aq. HCl (1.0 M; 15 mL). The aqueous layer was extracted with DCM (3 $\times$ 15 mL). The combined organic extracts were washed with brine, dried over MgSO_4 , filtered, and concentrated under vacuum to furnish a pale yellow crude solid. The latter was submitted to column chromatography (SiO_2 ; pentane:EtOAc 50:50 to 30:70) to afford pure 2-allyl-*N*-methoxybenzamide (**16**) (0.380 g, 2.00 mmol, 81%) as a colorless solid. R_f (silica, pentane:EtOAc 5:4) 0.37. ^1H NMR (400 MHz, CDCl_3 , δ): 8.42 (br s, 1H), 7.37–7.29 (m, 2H), 7.30–7.22 (m, 2H), 6.00 (ddt, J = 16.6, 10.1, 6.3 Hz, 1H), 5.09 (dd, J = 10.2, 1.6 Hz, 1H), 5.02 (dd, J = 17.1, 1.8 Hz, 1H), 3.88 (s, 3H), 3.57 (d, J = 6.3 Hz, 2H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.⁴⁸

Cu(I)-Catalyzed Intramolecular Oxidation of Alkenes: Synthesis of 5-(Azidomethyl)-5-phenyldihydrofuran-2(3H)-one (9). *Experiment with ABX (General Method F).* Following a slightly modified procedure,¹¹ distilled dry acetonitrile (preliminarily purged with Ar for 5 min; 1.0 mL) was added in a flame-dried 4 mL round bottom test tube containing 4-phenylpent-4-enoic acid (**8**) (35.0 mg, 0.200 mmol, 1.0 equiv), ABX (**1a**) (116 mg, 0.400 mmol, 2.0 equiv), and $\text{Cu}(\text{dap})_2\text{Cl}$ (0.90 mg, 1.0 μmol , 0.50 mol %). The resulting solution was irradiated with blue light LEDs under stirring at room temperature for 18 h. The reaction mixture was then concentrated, diluted with Et_2O (10 mL), filtered through a plug of Celite, and again concentrated under reduced pressure. The residue was submitted to flash column chromatography (SiO_2 , previously deactivated with Et_3N ; pentane:EtOAc 90:10 to 80:20) to afford pure 5-(azidomethyl)-5-phenyldihydrofuran-2(3H)-one (**9**) (33.0 mg, 0.152 mmol, 76%) as a yellow solid. R_f (silica, pentane:EtOAc 8:2) 0.45. ^1H NMR (400 MHz, CDCl_3 , δ): 7.44–7.32 (m, 5 H), 3.68 (d, J = 13.2 Hz, 1 H), 3.53 (d, J = 13.2 Hz, 1 H), 2.81–2.64 (m, 2 H), 2.57–2.38 (m, 2 H) ppm. The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.¹¹

Experiment with tBuABX (1d). The reaction was performed following the general method F, starting from the same amounts of 4-phenylpent-4-enoic acid (**8**) and $\text{Cu}(\text{dap})_2\text{Cl}$, but using *t*BuABX (**1d**) (138 mg, 0.400 mmol, 2.0 equiv) instead of ABX (**1a**). 5-(Azidomethyl)-5-phenyldihydrofuran-2(3H)-one (**9**) was obtained in 56% yield (24.0 mg, 0.112 mmol).²⁶

Experiment with ABZ (2). The reaction was performed following the general method F, starting from the same amounts of

4-phenylpent-4-enoic acid (**8**) and $\text{Cu}(\text{dap})_2\text{Cl}$, but using ABZ (**2**) (177 mg, 0.400 mmol, 2.0 equiv) instead of ABX (**1a**). 5-(Azidomethyl)-5-phenyldihydrofuran-2(3H)-one (**9**) was obtained in 81% (35.0 mg, 0.162 mmol).²⁶

Generation of Functionalized Indanes through a Complex Radical Cascade Reaction: Synthesis of 3-(Azidomethyl)-1-methyl-N-phenyl-2,3-dihydro-1H-indene-1-carboxamide (11**).** *Experiment with tBuABX (**1d**).* Following a reported procedure,^{8c} a 25 mL round-bottom test tube was charged with N-phenyl-N-((2-vinylphenyl)sulfonyl)methacrylamide (**10**) (98 mg, 0.30 mmol, 1.0 equiv) and tBuABX (**1d**) (0.207 g, 0.600 mmol, 2.0 equiv). The tube was sealed, evacuated, and backfilled with nitrogen three times. DCM (dry and freshly degassed by the freeze–pump–thaw method; 6.0 mL) was then added via syringe. The mixture was stirred at room temperature for 10 s, resulting in the immediate dissolution of the solids, and then heated at 60 °C overnight (14 h). The mixture was then concentrated under vacuum in the presence of silica gel. The crude product, adsorbed on silica gel, was then submitted to column chromatography (SiO_2 ; pentane:EtOAc 19:1 to 9:1) to afford a mixture of the desired product with *tert*-butyl iodobenzoic acid. To remove the latter, this mixture was diluted with DCM (10 mL) and washed twice with aq. K_2CO_3 (2.0 M; 15 mL). The aqueous layer was extracted with DCM (3 $\times$ 15 mL), and the organic extracts were dried over MgSO_4 , filtered, and concentrated under reduced pressure. 3-(Azidomethyl)-1-methyl-N-phenyl-2,3-dihydro-1H-indene-1-carboxamide (**11**) was finally obtained as a pale yellow viscous oil (mixture of diastereoisomers, dr 9:1; 65 mg, 0.19 mmol, 64%). ^1H NMR (400 MHz, CDCl_3 , δ): 7.45–7.37 (m, 4H), 7.38–7.31 (m, 2H), 7.25 (dd, J = 8.6, 7.2 Hz, 2H), 7.07 (ddt, J = 8.6, 7.1, 1.2 Hz, 1H), 6.99 (br s, 1H), 3.70–3.59 (m, 2H), 3.51 (dq, J = 9.3, 6.4 Hz, 1H), 3.00 (dd, J = 13.1, 7.3 Hz, 1H), 1.87 (dd, J = 13.1, 9.5 Hz, 1H), 1.73 (s, 3H) ppm. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3 , δ): 174.1, 145.8, 144.6, 137.6, 129.0, 128.8, 128.6, 124.8, 124.5, 123.8, 119.8, 55.6, 54.9, 44.7, 42.6, 25.1 ppm. The signals of the ^1H and ^{13}C NMR spectra were in accordance with the data reported in the literature.^{8c}

*Experiment with ABZ (**2**).* Following a modified version of a reported procedure,^{8c} a 25 mL round-bottom test tube was charged with N-phenyl-N-((2-vinylphenyl)sulfonyl)methacrylamide (**10**) (98 mg, 0.30 mmol, 1.0 equiv) and ABZ (**2**) (0.265 g, 0.600 mmol, 2.0 equiv). The vial was sealed, evacuated, and backfilled with nitrogen three times. DCE (dry and freshly degassed by the freeze–pump–thaw method; 6.0 mL) was then added via syringe. The mixture was heated at 100 °C under stirring overnight (14 h). The initially green-yellow solution became dark brown, remaining clear all the time. The mixture was allowed to cool down to room temperature, silica gel was added, and the volatiles were removed under reduced pressure with adsorption of the crude product on the silica gel itself. Column chromatography (SiO_2 ; pentane:EtOAc 39:1 to 19:1) afforded 3-(azidomethyl)-1-methyl-N-phenyl-2,3-dihydro-1H-indene-1-carboxamide (**11**) (0.0399 g, 0.130 mmol, 43%) as a pale yellow oil.

Metal-Catalyzed Azidation of Tertiary C–H bonds: Synthesis of (2-Azidopropan-2-yl)benzene (13**).** *Experiment with ABX (General Method G).* Following a slightly modified procedure,^{10c} a flame-dried 4 mL round bottomed test tube was charged with $\text{Fe}(\text{OAc})_2$ (3.4 mg, 0.020 mmol, 10 mol %) and 2,6-bis((*S*)-4-isopropyl-4,5-dihydrooxazol-2-yl)pyridine (6.0 mg, 0.020, 10 mol %) (this operation was performed inside a nitrogen-filled glovebox). EtOAc (1.0 mL) was added, and the resulting reaction mixture was stirred at room temperature for 40 min, during which time the color changed from a colorless solution to blue. Cumene (**12**) (30 μL , 0.20 mmol, 1.0 equiv) was added, followed by ABX (**1a**) (0.17 g, 0.60 mmol, 3.0 equiv). The vial was sealed with a cap containing a PTFE septum and then stirred at 50 °C for 22 h. The reaction was monitored by GC-MS to compare the consumption of cumene and the formation of (2-azidopropan-2-yl)benzene (**13**), using dodecane as an internal standard (Figure S1). The area of the peak of the product was measured and normalized using the area of the dodecane peak as an internal standard (not shown on the spectra below for more clarity). Then, a ratio was done between the area of the peaks with **1a**, **1d**, or **2** as the reagent using **1a** as the reference (ratio of 1.00).

*Experiment with tBuABX (**1d**).* The reaction was performed following the general method G, starting from the same amounts of cumene (**12**), $\text{Fe}(\text{OAc})_2$, and 2,6-bis((*S*)-4-isopropyl-4,5-dihydrooxazol-2-yl)pyridine, but using tBuABX (**1d**) (207 mg, 0.600 mmol, 3.0 equiv) instead of ABX (**1a**). The reaction was monitored by GC-MS (the chromatogram showing the reaction progress after 22 h is shown in Figure S2).

*Experiment with ABZ (**2**).* The reaction was performed following the general method G, starting from the same amounts of cumene (**12**), $\text{Fe}(\text{OAc})_2$, and 2,6-bis((*S*)-4-isopropyl-4,5-dihydrooxazol-2-yl)pyridine, but using ABZ (**2**) (265 mg, 0.600 mmol, 3.0 equiv) instead of ABX (**1a**). The reaction was monitored by GC-MS (the chromatogram showing the reaction progress after 22 h is shown in Figure S3).

Cu(II)-Catalyzed Azidation of Anilines: Synthesis of 2-Azido-4-methylaniline (15**).** *Experiment with ABX (**1a**) (General Method H).* Following a slightly modified procedure,^{10b} a 10 mL round bottomed test tube was charged with ABX (**1a**) (116 mg, 0.400 mmol, 1.0 equiv), $\text{Cu}(\text{OAc})_2$ (15 mg, 0.080 mmol, 10 mol %), and THF (2.7 mL) under air. *p*-Toluidine (**14**) (86 mg, 0.80 mmol, 2.0 equiv) was then added, and the resulting dark mixture was stirred at room temperature under air for 12 h. The solution was then diluted with ethyl acetate (27 mL), washed with saturated aqueous NaHCO_3 , and the two layers were separated. The organic layer was then dried over MgSO_4 , filtered, and concentrated in vacuo to afford a brown crude oil (^1H NMR yield with CH_2Br_2 (20 μL , 0.28 mmol) as internal standard: 63%). The latter was adsorbed on silica gel and submitted to chromatography (silica; petroleum ether:EtOAc 100:0 to 95:5) to afford pure 2-azido-4-methylaniline (**15**) as a brown oil (14 mg, 0.10 mmol, 24% yield; the volatility of the compound accounts for the low isolated yield). R_f (silica, pentane:EtOAc 8:2) 0.45. ^1H NMR (400 MHz, CDCl_3 , δ): 6.84 (d, J = 1.9 Hz, 1H), 6.76 (dd, J = 8.1, 1.9 Hz, 1H), 6.61 (d, J = 8.0 Hz, 1H), 3.67 (s, 2H), 2.27 (s, 3H). The signals of the ^1H NMR spectra were in accordance with the data reported in the literature.^{10b}

*Experiment with tBuABX (**1d**).* The reaction was performed following the general method H, starting from the same amounts of *p*-toluidine (**14**) and $\text{Cu}(\text{OAc})_2$, but using tBuABX (**1d**) (138 mg, 0.400 mmol, 1.0 equiv) instead of ABX (**1a**). 2-Azido-4-methylaniline (**15**) was generated in 62% yield (based on ^1H NMR and using CH_2Br_2 (20 μL , 0.28 mmol) as an internal standard). Upon column chromatography, it was isolated as a brown oil (15 mg, 0.10 mmol, 25% yield; the volatility of the compound accounts for the low isolated yield).

*Experiment with ABZ (**2**).* The reaction was performed following the general method H, starting from the same amounts of *p*-toluidine (**14**) and $\text{Cu}(\text{OAc})_2$, but using ABZ (**2**) (177 mg, 0.400 mmol, 1.0 equiv) instead of ABX (**1a**). 2-Azido-4-methylaniline (**15**) was generated in 72% yield (based on ^1H NMR and using CH_2Br_2 (20 μL , 0.28 mmol) as an internal standard). Upon column chromatography, it was isolated as a brown oil (16 mg, 0.10 mmol, 26% yield; the volatility of the compound accounts for the low isolated yield).

Cu(I)-Catalyzed Intramolecular Alkene Aminoazidation: Synthesis of 3-(Azidomethyl)-2-methoxy-3,4-dihydroisquinolin-1(2H)-one (17**).** *Experiment with tBuABX (**1d**) (General Method I).* Following a reported procedure,^{10h} a 25 mL round-bottom test tube was charged with 2-allyl-N-methoxybenzamide (**16**) (57 mg, 0.30 mmol, 1.0 equiv), tBuABX (**1d**) (0.124 g, 0.360 mmol, 1.2 equiv), and $\text{Cu}(\text{OAc})_2$ (3.7 mg, 0.030 mmol, 10 mol %). The vessel was sealed, evacuated, and backfilled with nitrogen (3 times). Acetonitrile (dry and degassed by purging it with Ar for 15 min; 3.0 mL) was added via syringe, giving initially a pale blue suspension. The latter was heated at 60 °C under stirring for 2 h. After 5 min at this temperature, the suspension had turned into a clear blue-green solution; a precipitate was formed after 1.5 h. After 2 h, TLC analysis (pentane:EtOAc 3:1) showed the complete consumption of the starting material. The reaction mixture was poured into sat. aq. NaHCO_3 (15 mL), and the aqueous layer was extracted with EtOAc (3 $\times$ 15 mL). The combined organic extracts were washed with brine, dried over MgSO_4 , filtered, and concentrated under vacuum to afford a pale yellow crude solid.

The latter was submitted to column chromatography (SiO₂; pentane:EtOAc 94:4 to 50:50) to afford 3-(azidomethyl)-2-methoxy-3,4-dihydroisoquinolin-1(2H)-one (**17**) (95% pure; 0.054 g, 0.23 mmol, 73% yield) as a colorless oil. ¹H NMR (400 MHz, CDCl₃, δ): 8.12 (dd, *J* = 7.8, 1.4 Hz, 1H), 7.48 (td, *J* = 7.5, 1.5 Hz, 1H), 7.37 (tt, *J* = 7.7, 1.1 Hz, 1H), 7.22 (dd, *J* = 7.4, 1.3 Hz, 1H), 4.07 (ddt, *J* = 8.5, 5.9, 3.8 Hz, 1H), 3.93 (s, 3H), 3.67 (ddd, *J* = 12.2, 3.6, 0.8 Hz, 1H), 3.48–3.31 (m, 2H), 3.18 (dd, *J* = 16.5, 4.0 Hz, 1H) ppm. ¹³C{¹H} NMR (101 MHz, CDCl₃; one aromatic signal was not resolved, δ): 163.2, 134.8, 132.8, 128.2, 128.0, 127.5, 63.1, 57.9, 50.5, 31.4 ppm. The signals of the ¹H and ¹³C NMR spectra were in accordance with the data reported in the literature.^{10h} In the ¹H NMR spectrum, all peaks were shifted +0.17 ppm with respect to the ones in the literature.

Experiment with ABZ (2). The reaction was performed following the general method I, starting from the same amounts of 2-allyl-N-methoxybenzamide (**16**) and CuOAc, but using ABZ (**2**) (159 mg, 0.360 mmol, 2.0 equiv) instead of tBuABX (**1d**). The crude product was purified by column chromatography (SiO₂; pentane:EtOAc 94:4 to 50:50), followed by preparative TLC (SiO₂, 20 × 20 sq. cm; hexane:EtOAc 50:50), to afford 3-(azidomethyl)-2-methoxy-3,4-dihydroisoquinolin-1(2H)-one (**17**) (0.060 g, 0.26 mmol, 86% yield) as a colorless oil.

METHODS FOR SAFETY STUDIES

The stability of the compounds was determined by DSC. A few milligrams of samples were sealed in gold plated pressure resistant crucibles. The crucibles were heated in an oven from 30 to 400 °C at a rate of 4 °C/min. The *T*_{onset} (temperature at which an exothermic signal is detected), the decomposition energy, and the peak temperature were recorded and compared. The provided data are the mean of the two measurements.

The sensitivity to friction and impact as well as the energy of decomposition measured by DSC were determined for the Zhdankin reactive (**1a**) as well as for tBu-ABX (**1d**) and ABZ (**2**).

The sensitivity to impact or shock (Fallhammer test) consists of subjecting 40 μL of substance to different drop-weight impacts. The impact energy is varied by the selection of drop height and weight. A drop weight of 1 kg was used for this study. The test is positive if at least one positive result (detonation, fume, fire, or sparks) in a series of six measurements is obtained. Here a microphone was used for the detection. The limiting impact energy is the lowest energy at which there is still a positive result. The tests were performed with 1 J steps.

The sensitivity to friction was measured with a BAM friction apparatus. A porcelain plate with 10 μL of test substance was moved by an electric motor against a stationary porcelain peg. The load corresponded to a friction force of 360 N. The test was then repeated on AlOx (aluminum oxide) plates, as many false positives were measured with porcelain plates.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.8b02068.

Reactions schemes for the synthesis of starting materials and reagents, reaction optimization details, accident report, and chromatogram and NMR spectra of new compounds or reported compounds synthesized using modified methods (PDF)

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Notes

The authors declare no competing financial interest.

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