

Enzyme-Like Polyene Cyclizations Catalyzed by Dynamic, Self-Assembled, Supramolecular Fluoro Alcohol-Amine Clusters

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— SUPPLEMENTARY INFORMATION —

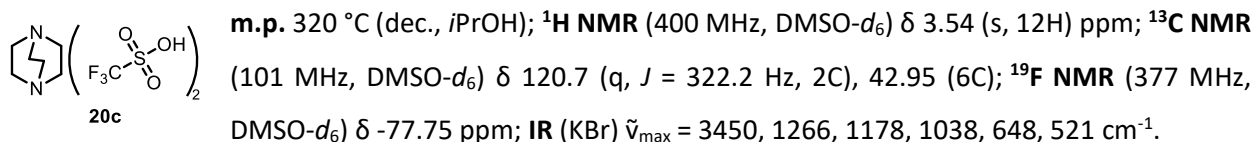
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1. General Information

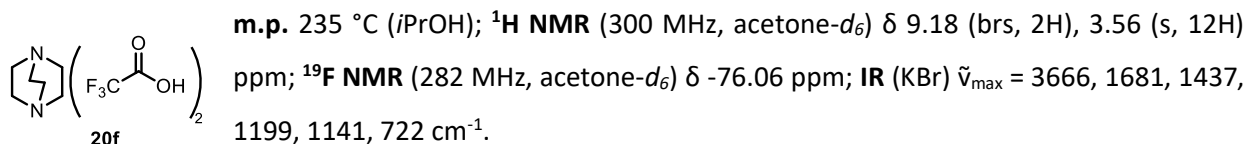
All solvents used in reactions were p.A. grade. Solvents for chromatography were technical grade and distilled before use. Anhydrous dichloromethane, diethyl ether, and THF were obtained from a MBraun MB-SPS 800 solvent purification system. Other dry solvents were obtained from Fluka and Acros in the highest purity available and used without further purification. 1,1,1,3,3,3-hexafluoroisopropanol (HFIP) and nonafluoro-*tert*-butanol (PFTB) was purchased from Fluorochem with a purity >99%. Reagents were purchased at the highest commercial quality and used without further purification. Yields refer to chromatographically and spectroscopically (^1H NMR) homogeneous material unless otherwise stated. Reactions were monitored by thin layer chromatography (TLC) carried out on Merck silica gel aluminium plates with Fan -254 indicator using UV light as the visualizing agent (UV), basic potassium permanganate solution (KMnO_4), ceric ammonium molybdate (CAM), and heat as developing agents, or by GC-FID or GC-MS where applicable. Silica gel Merck 60 (particle size 40 – 60 μm) was used for flash column chromatography. Solvent mixtures are understood as volume/volume. NMR spectra were recorded on Bruker AV300, Bruker AV400, Bruker AV500, or Bruker AV500-cryo spectrometers. The spectra were calibrated using residual undeuterated solvent as an internal reference (CDCl_3 @ 7.26 ppm, CDCl_3 @ 77.16 ppm ^{13}C NMR). The following abbreviations (or combinations thereof) were used to explain the multiplicities: s = singlet, d = doublet, dd = doublet of doublets, t = triplet, dt = doublet of triplets, q = quartet, quint = quintet (with 1:2:3:2:1 intensity), hept = heptet, m = multiplet, br = broad. In addition, the following abbreviations were used: EtOAc = ethyl acetate, MeCN = acetonitrile, DCM = dichloromethane, DCE = 1,2-dichloroethane, TFE = 1,1,1-trifluoroethanol, HFIP = 1,1,1,3,3,3-hexafluoro-2-propanol, PFTB = nonafluoro-*tert*-butanol, TLC = thin layer chromatography, rt = room temperature, sat = saturated. Melting points were measured on a Büchi 510 and are not calibrated. IR spectra were recorded on a JASCO FT-IR-4100 (ATR) and are reported in terms of frequency of absorption (cm^{-1}). Mass spectra were conducted on a Finnigan MAT SSQ 7000 (MS-EI, 70 eV; CI, 100 eV), or a Thermo Scientific LTQ-FT ultra and ThermoFisher Scientific LTQ Orbitrap XL spectrometer (ESI HRMS). Diastereomeric ratios (d.r.) were determined using GC-FID or GC-MS. The following method was used for GC separation: 60 $^{\circ}\text{C}$ 3 min, 15 $^{\circ}\text{C}/\text{min}$ $\rightarrow$ 250 $^{\circ}\text{C}$, 250 $^{\circ}\text{C}$ 5 min.

2. Preparation of DABCO(TfOH)₂ (20c) and DABCO(TFA)₂ (20f)

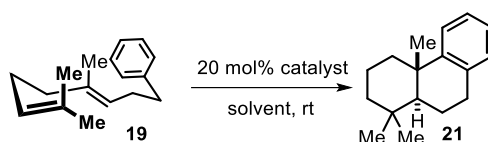
2.00 g DABCO (**53**, 17.8 mmol, 1.0 eq) were dissolved in 40 mL abs. CH₂Cl₂. At 0 °C, 3.31 mL trifluoromethanesulfonic acid (5.61 mL, 37.4 mmol, 2.1 eq) was added dropwise. The mixture was allowed to stir for 30 min at rt and then the volatiles were removed under reduced pressure. The crude product was twice triturated with abs. isopropanol and dried under a high vacuum to give 6.06 g **20c** (14.7 mmol, 83%) as a colorless solid.



500 mg DABCO (**53**, 4.45 mmol, 1.0 eq) were dissolved in 15 mL dry CH₂Cl₂. At 0 °C, and 825 μL trifluoromethanesulfonic acid (1.40 g, 9.35 mmol, 2.1 eq) was added dropwise. The mixture was allowed to stir for 30 min at rt and then the volatiles were removed under reduced pressure. The crude product was twice triturated with abs. isopropanol and dried under a high vacuum to give 1.34 g DABCO(TFA)₂ (**20f**, 14.7 mmol, 88%) as colorless solid.



3. Optimization of Reaction Conditions



22.8 mg Homogeranyl benzene (**19**, 100 μ mol, 1.0 eq) and 20 mol% catalyst (20.0 μ mol) were mixed in 1.00 mL solvent and the reaction was monitored via GC-FID.

Supplementary Table 1. Proton-induced cyclization of **19**.

entry	solvent	catalyst	time	conversion	yield 21 ^a	d.r. ^a
1	HFIP	-	1 d	> 95%	61%	> 95:5
2	HFIP ^b	-	7 d	< 5%	-	-
3	HFIP ^b	mor-HCl (20a)	1 d	> 95%	72%	> 95:5
4	HFIP ^b	mor-HBr	5 h	> 95%	69%	> 95:5
5	HFIP ^b	mor-TosOH	1 d	12%	8%	-
6	HFIP ^b	mor-H ₂ SO ₄	1 d	> 95%	65%	> 95:5
7	HFIP ^b	mor-AcOH	20 d	< 1%	-	-
8	HFIP ^b	py-HCl	1 d	> 95%	66%	> 95:5
9	HFIP ^b	py-HBr (20b)	13 h	> 95%	71%	> 95:5
10	HFIP ^b	py-HI	15 h	> 95%	63%	> 95:5
11	HFIP ^b	py-TfOH	3 h	> 95%	63%	> 95:5
12	HFIP ^b	py-3-SO ₃ H	1 h	> 95%	61%	> 95:5
13	HFIP ^b	py-HPF ₆	12 h	> 95%	57%	> 95:5
14	HFIP ^b	py-HClO ₄	1 h	> 95%	67%	> 95:5
15	HFIP ^b	py-SO ₃	1 h	> 95%	64%	> 95:5

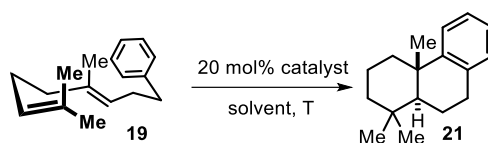
^aDetermined by GC-FID from the crude reaction mixture using an internal standard. ^bHFIP was distilled from a 3 Å/4 Å molecular sieve and 250 mg KOH/100 mL HFIP. mor = morpholine, py = pyridine, TosOH = *p*-toluolsulphonic acid, AcOH = acetic acid, TfOH = triflic acid

Supplementary Table 2. Screening of organic and inorganic acids.

entry	solvent	catalyst	time	conversion	yield 21 ^a	d.r. ^a
1	HFIP ^b	TosOH·H ₂ O	15 min	> 95%	62%	> 95:5
2	HFIP ^b	H ₂ SO ₄	15 min	> 95%	59%	> 95:5
3	HFIP ^b	TFA	15 min	> 95%	56%	> 95:5
4	HFIP ^b	CF ₃ SO ₂ NH ₂	1 d	93%	59%	> 95:5
5	HFIP ^b	C ₆ F ₅ OH	14 d	> 95%	61%	> 95:5
6	PFTB	AcOH	2 d	> 95%	71%	> 95:5
7	PFTB*	H ₂ SO ₄	30 min	> 95%	84%	> 95:5
8	PFTB	TFA	2 h	> 95%	63%	> 95:5

^aDetermined by GC-FID from the crude reaction mixture using an internal standard.

^bHFIP was distilled from 3 Å/4 Å molecular sieve and 250 mg KOH/100 mL HFIP. *ca. 15% of substrate **19** was converted by protonation of the internal alkene moiety leading to regioisomeric carbon cycles that could not be removed from **21**. TosOH = *p*-toluolsulphonic acid, AcOH = acetic acid, TfOH = triflic acid, TFA = trifluoro acetic acid.

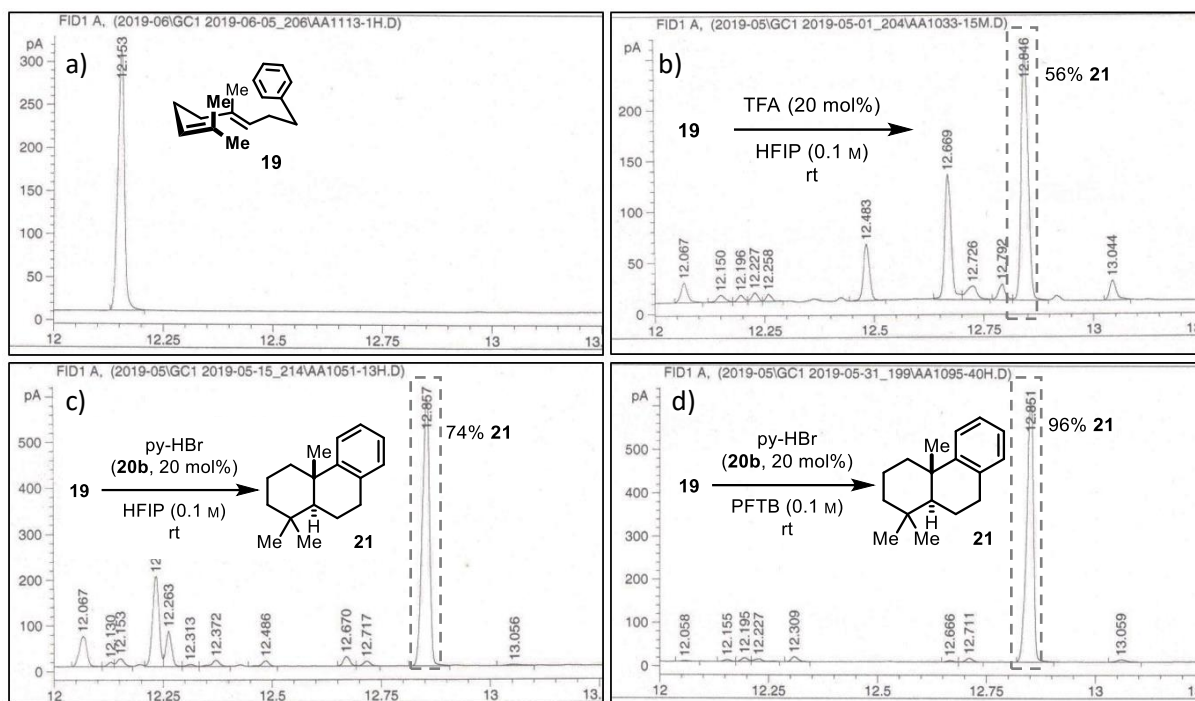


22.8 mg Homogeranyl benzene (**19**, 100 μmol , 1.0 eq) and 20 mol% catalyst (20.0 μmol) were mixed in 1.00 mL solvent and the reaction was monitored via GC-FID.

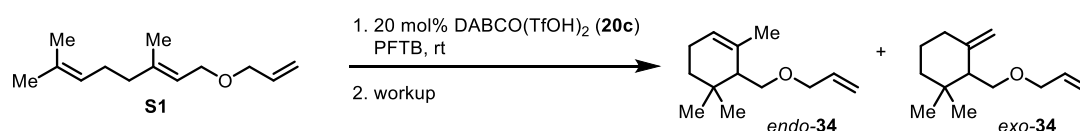
Supplementary Table 3. Screening of different solvents for the cyclization of **19**.

entry	solvent	catalyst	time	conversion	yield 21 ^a	d.r. ^a
1	HFIP	-	1 d	> 95%	61%	> 95:5
2	HFIP ^b	-	7 d	< 5%	-	-
3	HFIP ^b	py-HBr (20b)	13 h	> 95%	71%	> 95:5
4	HFIP (65 °C) ^b	py-HBr (20b)	1 h	> 95%	74%	> 95:5
5	Et ₂ O	py-HBr (20b)	5 d	< 1%	-	-
6	<i>i</i> PrNO ₂	py-HBr (20b)	5 d	< 1%	-	-
7		py-HBr (20b)	5 d	44%	28%	-
8	CH ₂ Cl ₂	py-HBr (20b)	5 d	< 1%	-	-
9	<i>i</i> PrOH	py-HBr (20b)	5 d	< 1%	-	-
10	TFE	py-HBr (20b)	5 d	75%	5%	-
11		py-HBr (20b)	5 d	2%	-	-
12	PFTB	py-HBr (20b)	24 h	> 99%	96%	> 95:5
13	PFTB/HFIP (1:9)	py-HBr (20b)	2 h	> 99%	71%	> 95:5
14	PFTB	py-HBr (20b)	20 h	> 99%	96%	> 95:5
15	PFTB	DABCO(TfOH) ₂ (20c)	1 h	> 99%	96% (94%)	> 95:5

^aDetermined by GC-FID from the crude reaction mixture using an internal standard. Isolated yields are in parentheses. ^bHFIP was distilled from a 3 Å/4 Å molecular sieve and 250 mg KOH/100 mL HFIP. py = pyridine, DABCO = 1,4-diazabicyclo[2.2.2]octane, TfOH = triflic acid



Supplementary Figure 1. GC traces of a) **19**, and conversion of **19** using b) TFA in HFIP (Table S2, entry 3); c) **20b** in HFIP (Table S3, entry 3); d) **20b** in PFTB (optimized conditions; Table S3, entry 15).



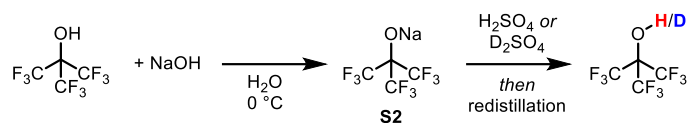
19.5 mg allyl geraniol allyl ether (**S1**, 100 μ mol, 1.0 eq) and 8.20 mg DABCO(TfOH)₂ (**20c**, 20.0 μ mol, 20 mol%) were stirred in 1.00 mL PFTB at rt. After completion, the reaction mixture was evenly distributed into 5 vials and treated as described below. The crude mixtures were then diluted with 10 mL CH₂Cl₂, filtered (entries 2-3 and 5), partitioned between water (10 mL) and CH₂Cl₂ (15 mL), and extracted twice with CH₂Cl₂. The combined organic layers were washed with brine, dried over MgSO₄, filtered and the solvent was removed under reduced pressure. The ratio of *endo*:*exo* **34** was determined by GC-FID

Supplementary Table 4. Different workup procedures and their effect on the regioselectivity of the deprotonation.

entry	workup	<i>endo</i> - 34 : <i>exo</i> - 34
1	standard conditions (chapter 5.2)	> 99:1
2	addition of the crude mixture to 2.00 g solid KOH pellets	> 99:1
3	addition of the crude mixture to basic aluminium oxide	> 99:1
4	addition of the crude mixture to 2.00 mL neat NEt ₃	> 99:1
5	addition of the crude mixture to 2.00 g solid <i>t</i> BuOK	> 99:1

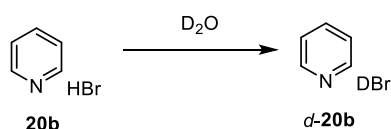
4. Mechanistic Studies

4.1 Preparation of PFTB-OD and Pyridine-DBr (*d*-20b)



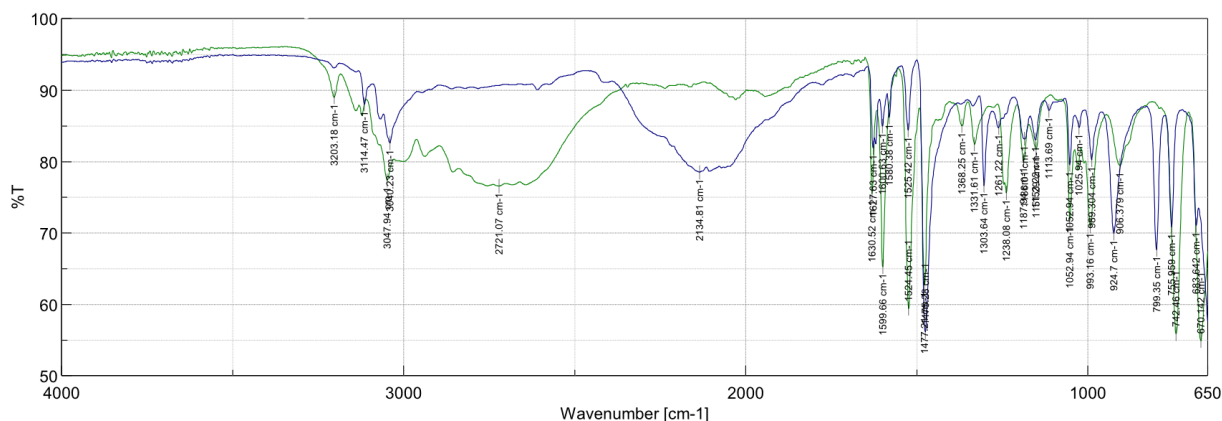
11.2 g PFTB (47.6 mmol, 1.25 eq) was carefully added to 15.0 mL of an aq. solution of 1.52 g NaOH (38.1 mmol, 1.0 eq) at 0 °C. Upon complete dissolution, the volatiles were removed under high vacuum, 500 μL PFTB was added, and the mixture stirred for 1 minute followed by removing the volatiles again under high vacuum. 9.31 g (24.0 mmol, 63%) PFTB sodium salt **S2** was obtained as a colorless powder.

2.50 g PFTB sodium salt (**S2**, 9.69 mmol, 1.0 eq) was slowly added to 1.50 mL of either concentrated H_2SO_4 or D_2SO_4 (1.86 g, 29.1 mmol, 3.0 eq) at rt. Reduced pressure was applied via a neoprene tubing leading to a -78 °C cooled flask collecting the volatile solvent. Redistillation from rt to -78 °C afforded 1.2 mL of PFTB-OH and 1.1 mL PFTB-OD, respectively. These solvents were used in the experiments determining the kinetic isotope effect (KIE, see chapter 4.2, SI).



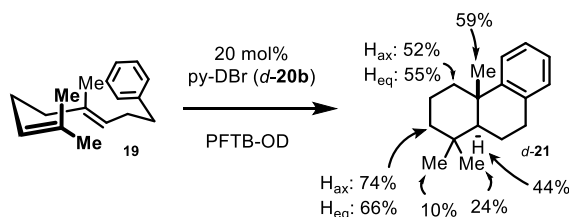
500 mg Pyridinium bromide (**20b**, 313 μmol) was dissolved in 2.00 mL of D_2O , stirred for 1 minute and the solvent was removed under reduced pressure upon gentle heating. This procedure was repeated 5 times to afford 502 mg pyridine deuterobromide (*d*-**20b**, 312 μmol , 99%) as a colorless solid.

IR (neat) $\tilde{\nu}_{\text{max}}$ = 2135, 1477, 1304, 1188, 1151, 1053, 989, 925, 799, 756, 684 cm^{-1} . The spectroscopic data are in accordance with those reported in the literature.¹

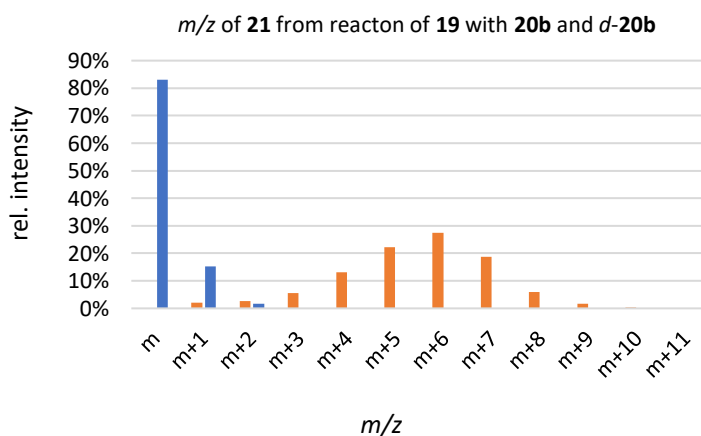


Supplementary Figure 2. Overlaid IR spectra (neat) of **20b** (green) and *d*-**20b** (blue).

4.2 Reaction of Homogeranyl Benzene **19** using Catalyst *d*-**20b** in Deuterated PTFB

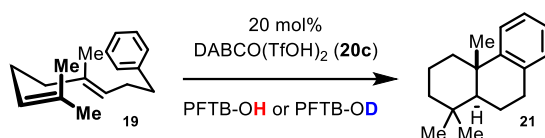


22.8 mg Homogeranyl benzene (**19**, 100 μmol, 1.0 eq) and 3.20 mg pyridine deuterobromide (*d*-**20b**, 20.0 μmol, 20 mol%) were mixed in 1.00 mL PFTB-OD and stirred at rt. The conversion from **19** to *d*-**21** was monitored by GC-MS. Percentages in *d*-**21** refer to the degree of deuteration. All unlabeled sites show <5% D incorporation.

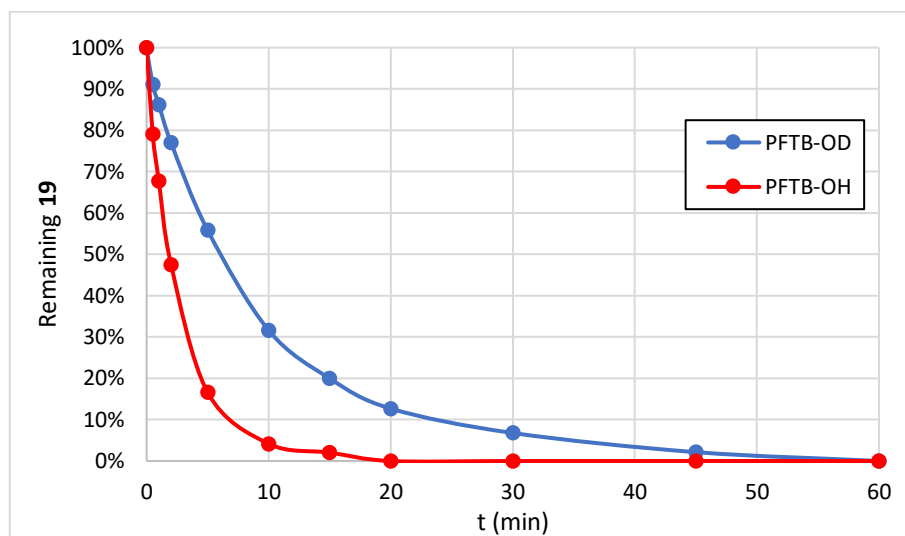


Supplementary Figure 3. Mass distribution of **21** (blue) obtained from converting **19** using unlabelled **20b** in PFTB and *d*-**21** (red) obtained from converting **19** using deuterated *d*-**20b** in PFTB-OD (m refers to the mass of the undeuterated product **21** (*m/z* = 228)).

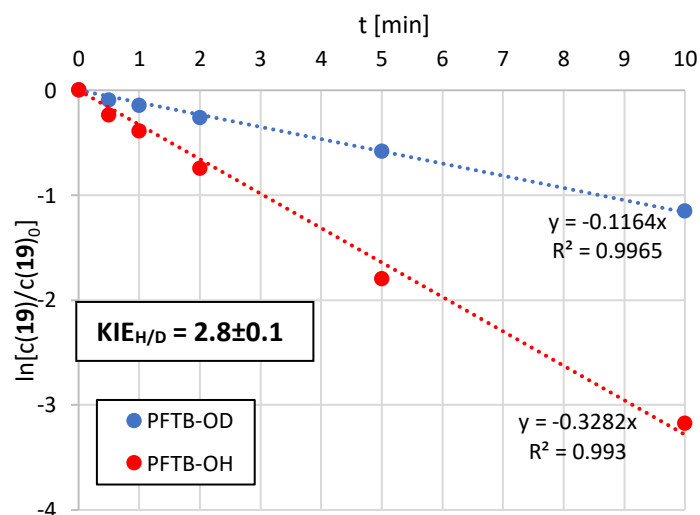
4.3. Kinetic Isotope Effect (KIE) Determination



22.8 mg Homogeranyl benzene (**19**, 100 μmol , 1.0 eq) and 8.20 mg DABCO(TfOH)₂ (**20c**, 20.0 μmol , 20 mol%) were mixed in 1.0 mL PFTB-OH and PFTB-OD prepared above, respectively, and the reaction monitored via GC-FID.

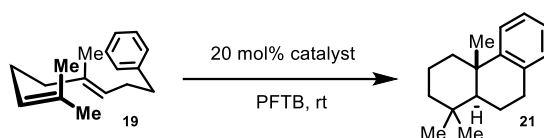


Supplementary Figure 4. Consumption of starting material **19** in PFTB-OH (red) or PFTB-OD (blue) in the presence of 20 mol% **20c**.

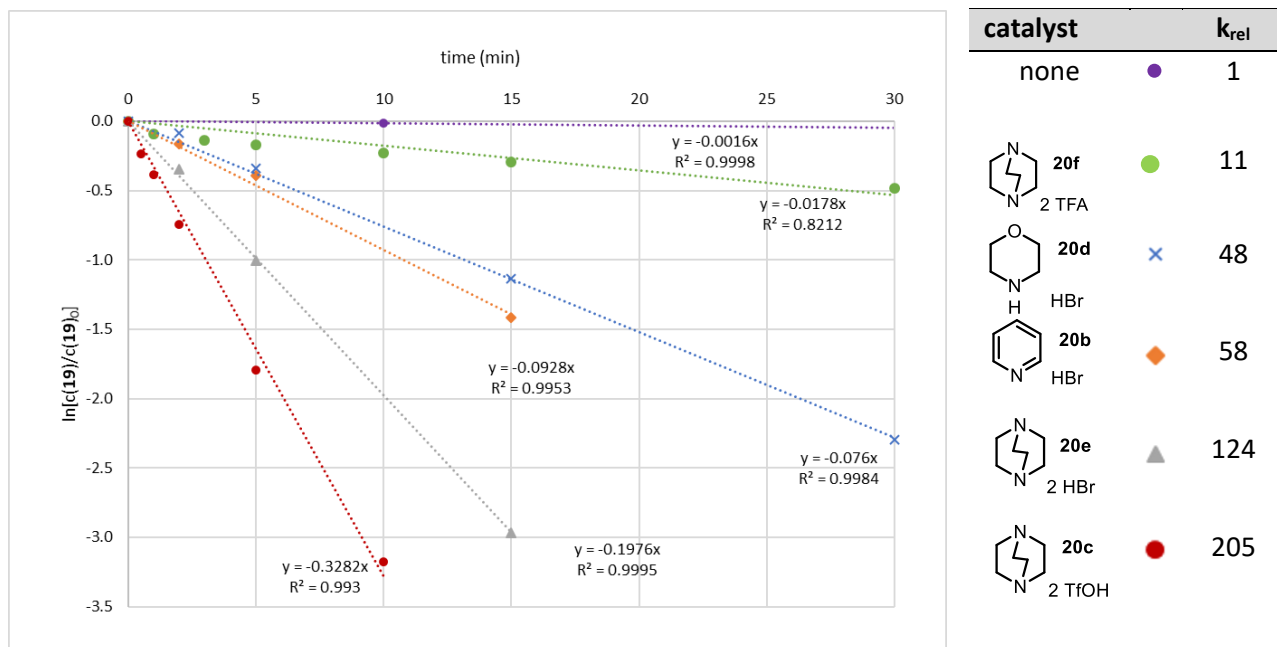


Supplementary Figure 5. Slopes for the consumption of **19** within the first 10 min. The $\text{KIE}_{\text{H/D}}$ value of 2.8 ± 0.1 for PFTB-OH (red) and PFTB-OD (blue) was determined.

4.4. Determination of the Reaction Rate depending on the Catalysts



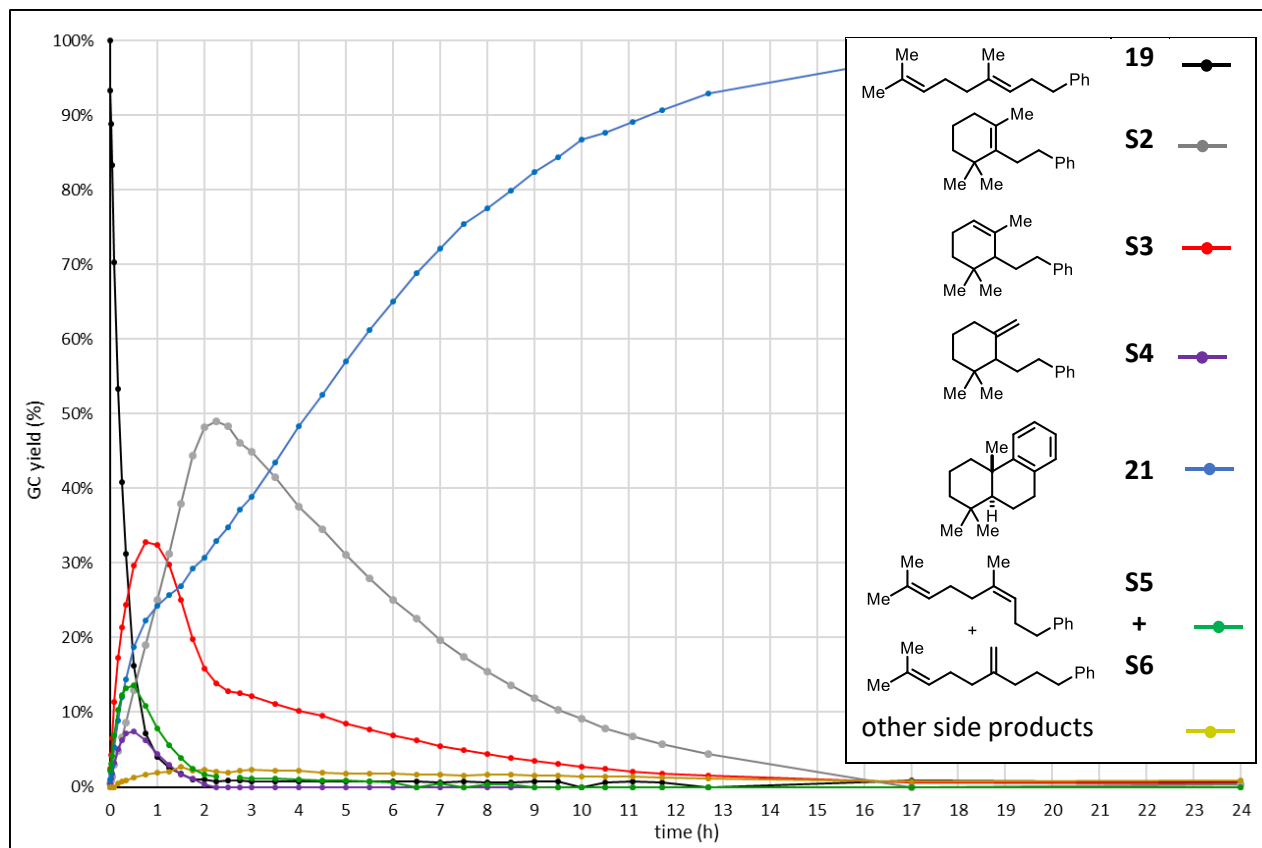
22.8 mg Homogeranyl benzene (**19**, 100 μmol , 1.0 eq) and 20 mol% catalyst (20.0 μmol) were mixed in 1.0 mL PFTB, and the reaction was monitored via GC-FID.



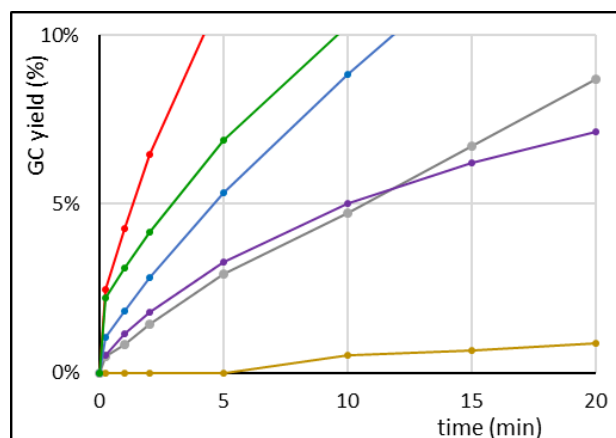
Supplementary Figure 6. Slopes for the consumption of **19** (k_{rel}) over time using the different amine and pyridinium salts **20b-20f**.

4.5. Time-Dependent Conversion of Homogeranyl Benzene (**19**) and Homoneryl Benzene (**52a**)

45.6 mg Homogeranyl benzene (**19**, 200 μ mol, 1.0 eq) and 6.40 mg py-HBr (**20b**, 40.0 μ mol, 20 mol%) were mixed in 2.0 mL PFTB and the reaction was monitored via GC-FID.

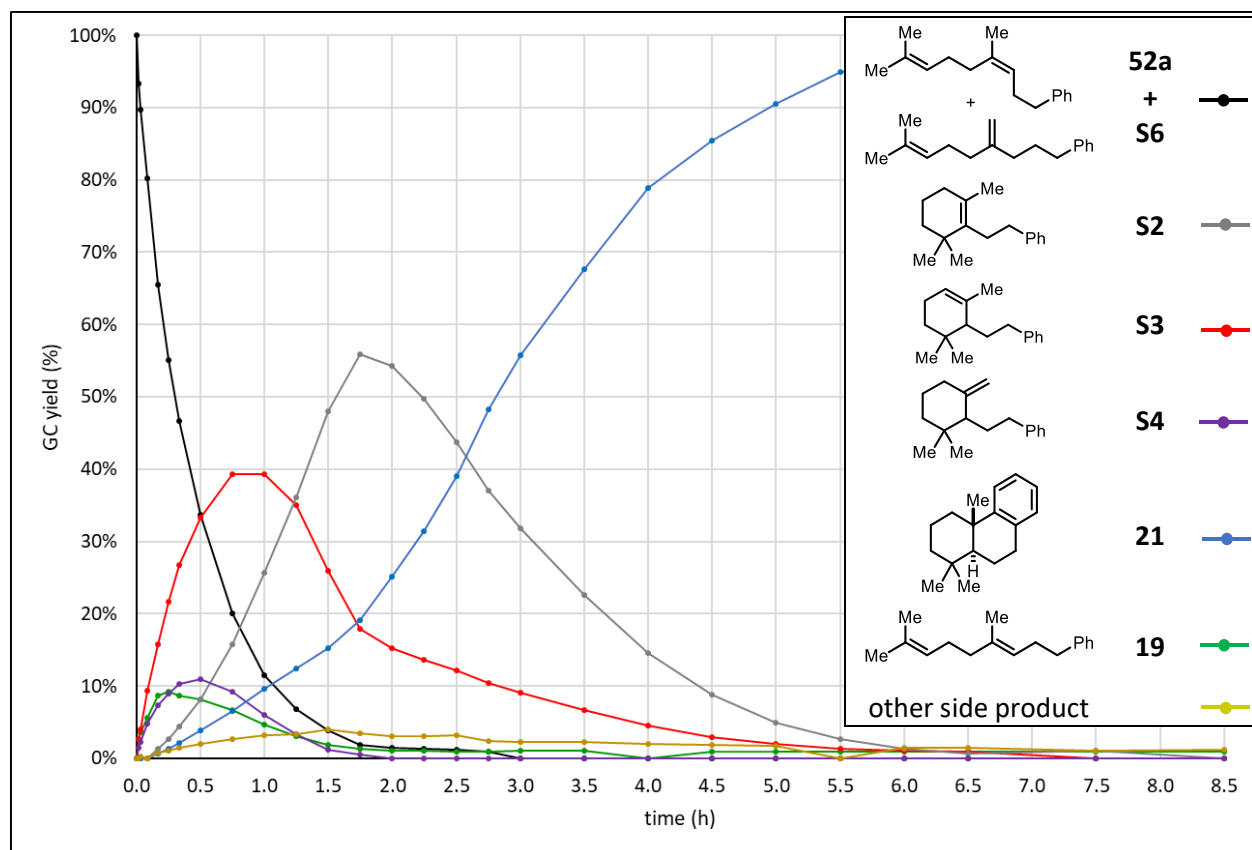


Supplementary Figure 7. Reaction kinetics for the conversion of **19** to **21** using py-HBr (**20b**) in PTFB.

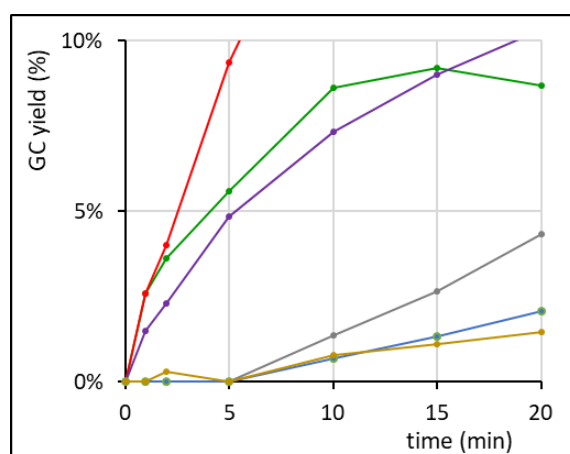


Supplementary Figure 8. Enlarged graphs of the first 20 minutes. The completely cyclized product **21** (blue line) is formed within seconds directly from homogeranyl benzene (**19**).

45.6 mg Homoneryl benzene (**52a**, 200 μ mol, 1.0 eq) and 6.40 mg py-HBr (**20b**, 40.0 μ mol, 20 mol%) were mixed in 2.0 mL PTFB and the reaction was monitored via GC-FID.



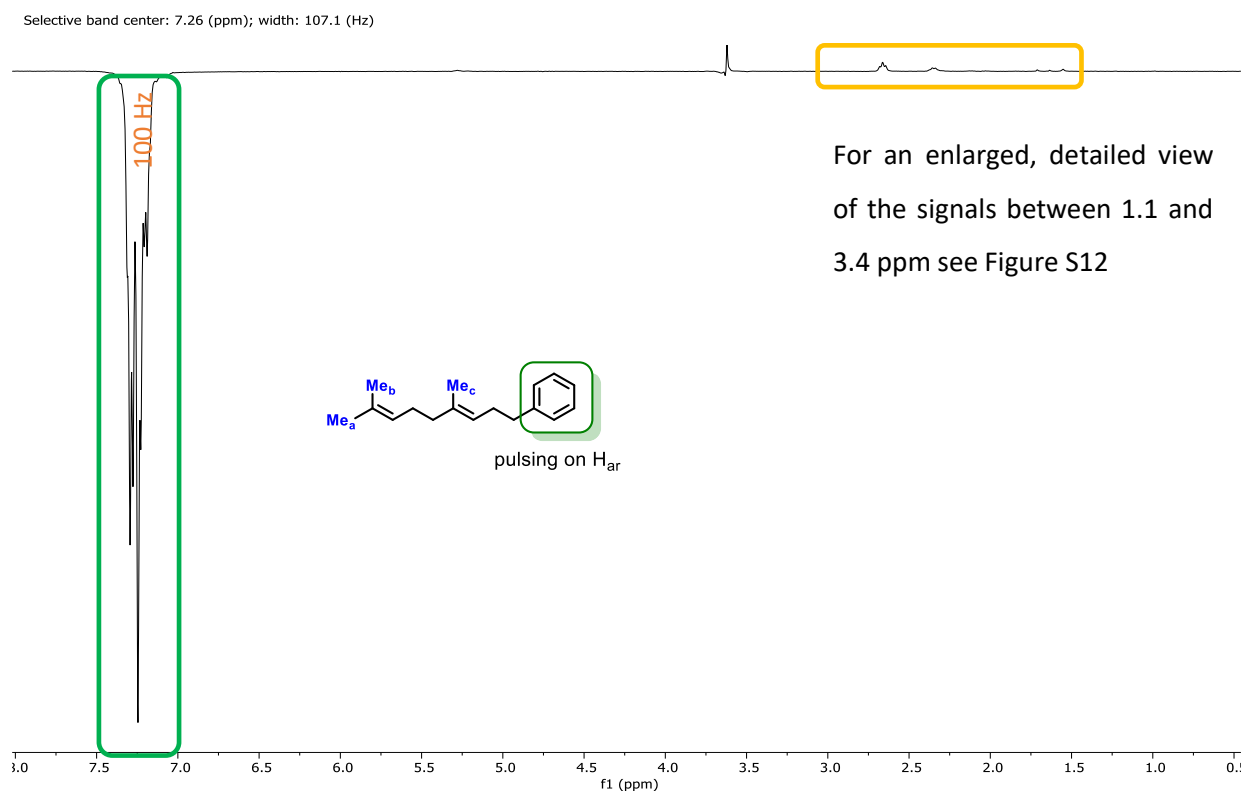
Supplementary Figure 9. Reaction kinetics for the conversion of homoneryl benzene (**52a**) to **21** using py-HBr (**20b**) in PTFB.



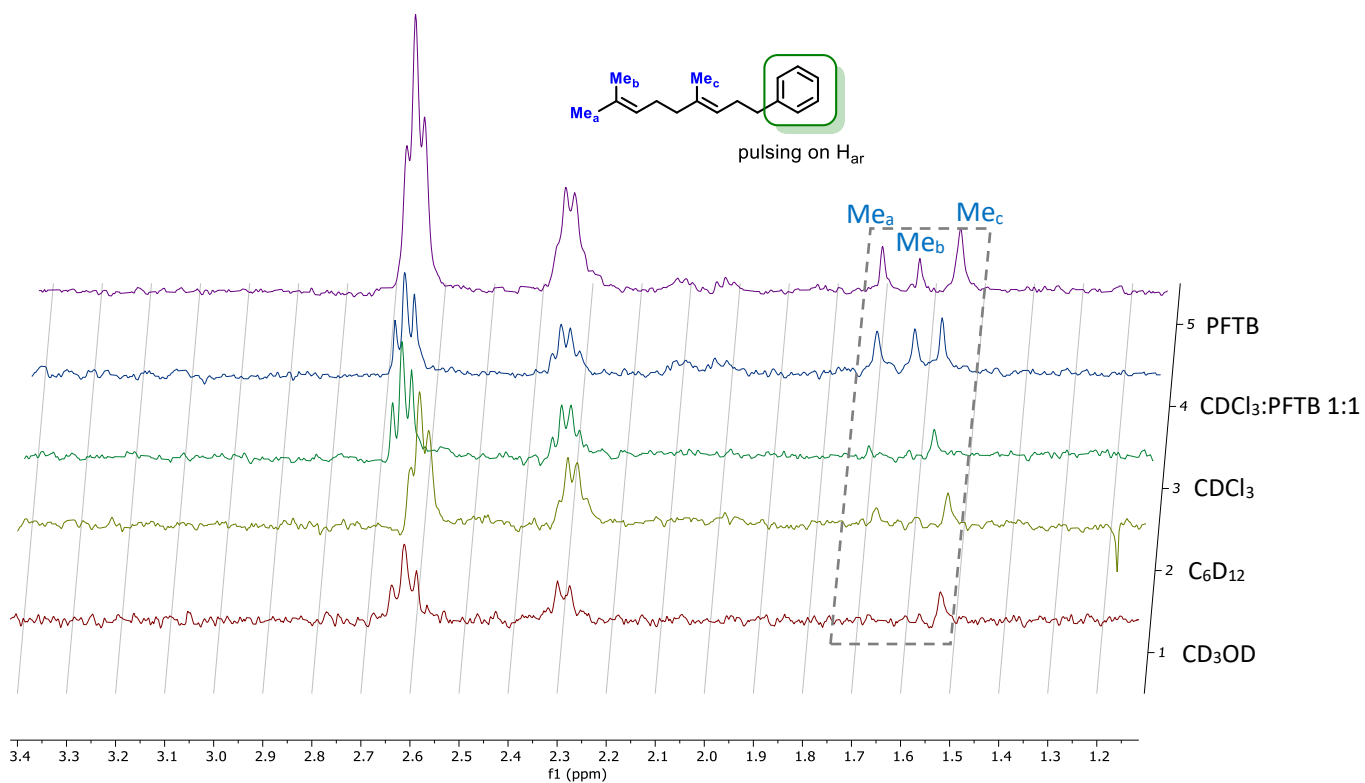
Supplementary Figure 10. Enlarged graphs of the first 20 minutes. Homoneryl benzene (**52a**, black) is converted to geranyl benzene **19** (green) followed by cyclization to the *trans*-decalin product **21** (blue).

4.6. 1D-¹H-NOESY Investigations on the Folding of Homogeranylbenezene (**19**) in Different Solvents

12.5 mg homogeranyl benzene (**19**, 55.0 μmol) was dissolved in 0.55 mL (0.1 M) of the respective solvent and directly subjected to 1D-¹H-NOESY measurements. The aromatic protons of **19** were selectively excited with 100 ± 10 Hz. On the NMR timescale, interactions of the aromatic Hs with Me_a and Me_b in **19** were only observed in PFTB or CDCl₃:PFTB (1:1).²



Supplementary Figure 11. 1D-¹H-NOESY with **19** in PFTB. Positive signals show interactions of the protons through space.



Supplementary Figure 12. Enlarged excerpts (1.1 – 3.4 ppm) from the 1D- ^1H -NOESY spectra of 0.1 M **19** in 1) CD_3OD (red), 2) C_6D_{12} (yellow), 3) CDCl_3 (green), 4) $\text{CDCl}_3/\text{PFTB}$ 1:1 (blue), 5) PFTB (purple).

Significant interactions of Me_a and Me_b and the aryl protons in **19** are only observed in samples containing PFTB. This hints at a more rigid, coiled conformation of **19** triggered by the fluorinated alcohol solvent.

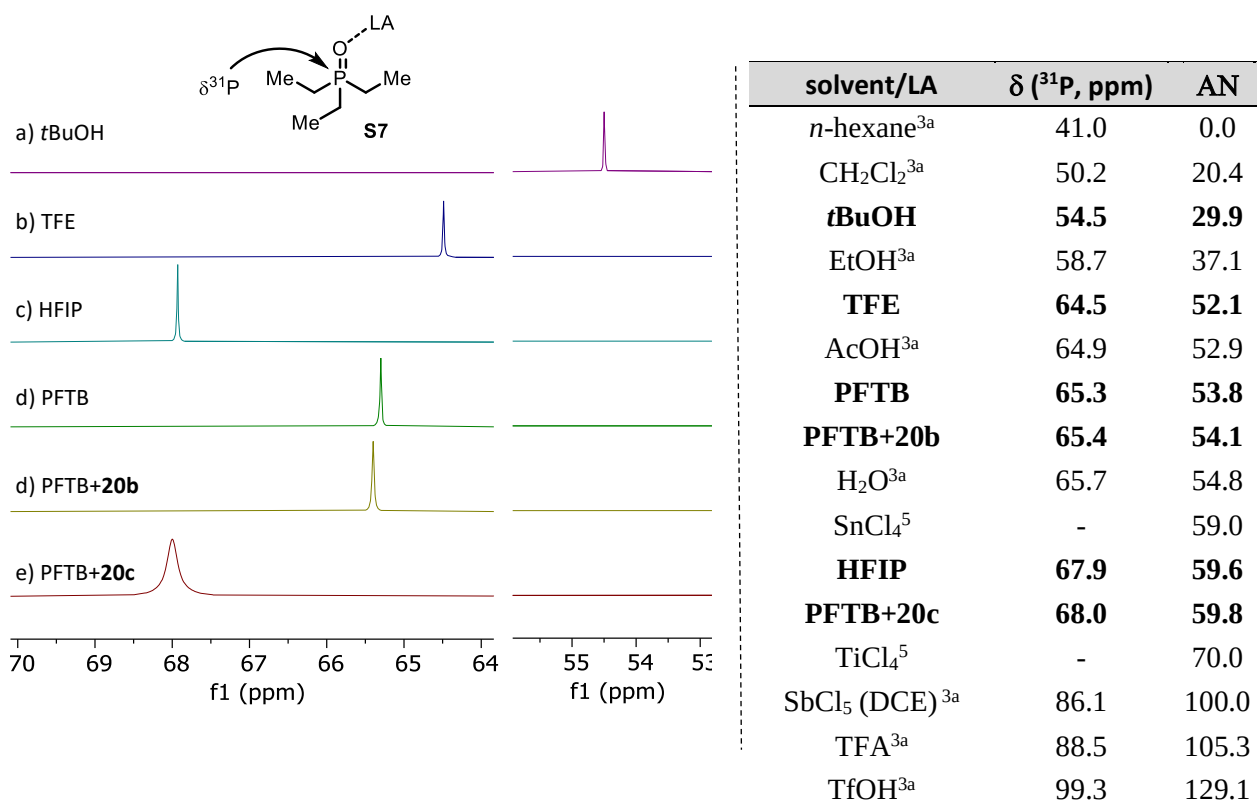
4.7. Comparison of the Lewis Acidities of *t*BuOH, TFE, HFIP, PTFB, PTFB + **20b**, and PTFB + **20c** using the Gutmann-Beckett Method

Gutmann-Beckett experiments were conducted according to the procedure reported in the literature.³ 7.40 mg Et₃PO (**S7**, 55.0 μmol) were dissolved in 0.55 mL (0.1 M) of the corresponding solvent, and, where applicable, 11.0 μmol salt was added to the solution. A ³¹P-NMR spectrum of each sample was immediately recorded. Shifts are in relation to (MeO)₃PO (2.0 M in CDCl₃, δ = 2.2 ppm; internal reference).

4

The acceptor number (AN) was calculated according to equation 1 with the AN of Et₃PO (**S7**) in *n*-hexane set to zero and the AN of a 1:1 complex of Et₃PO (**S7**) and SbCl₅ in DCE to 100.⁵

$$AN = (\delta_{\text{sample}} - 41.0) \times \left(\frac{100}{86.14 - 41.0} \right) \quad (1)$$



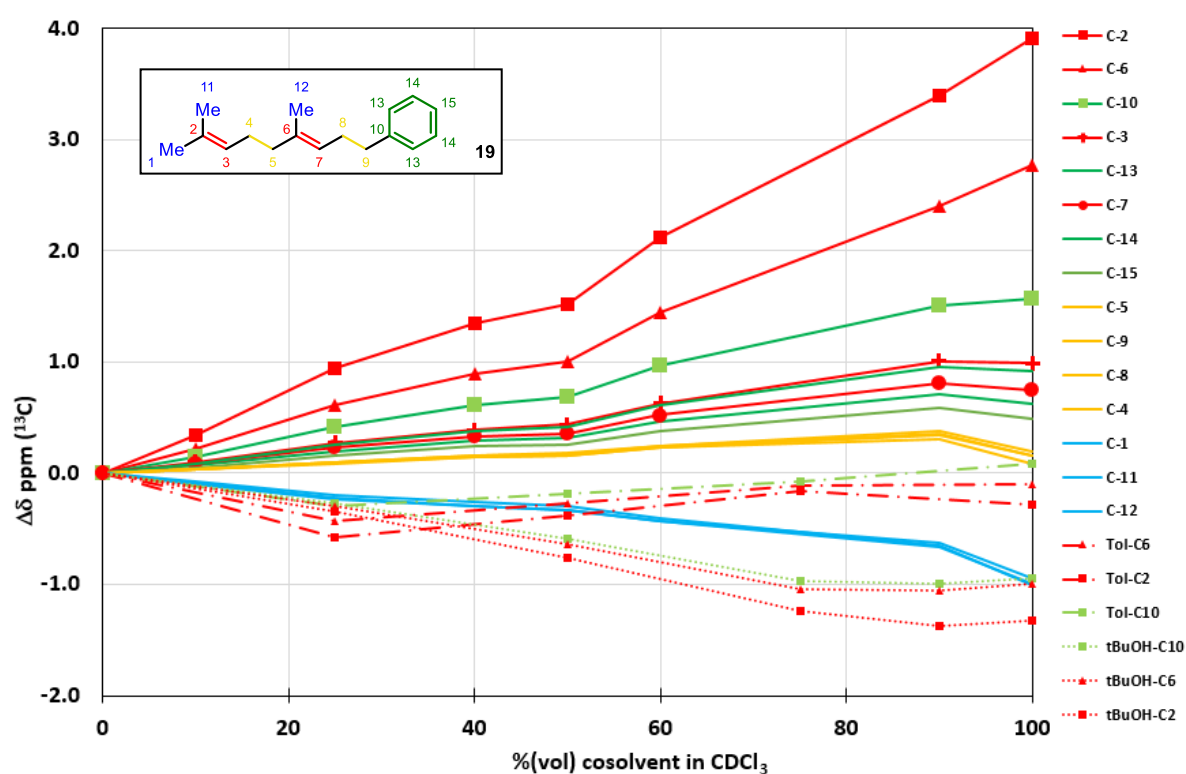
Supplementary Figure 13. ³¹P-NMR spectra of 0.1M Et₃PO in different solvents and solvent-solute (0.02M) mixtures (left) and AN values of different Lewis acids (right). The higher the AN the stronger the Lewis acidity.

The addition of *N*-containing salts to the Lewis acidic *F*-alcohol PTFB shifted the ³¹P-NMR signal of **S7** downfield due to the non-covalent interactions of the Lewis basic **S7** and the Lewis acidic *F*-alcohol-salt

containing environment. The addition of DABCO(TfOH)₂ (**20c**) to PTFB resulted in a more significant downfield shift (ca. 3 ppm) of the ³¹P-NMR signal and thus to an increase in the Lewis acidity of the fluorinated environment. In addition, the signal was broadened, hinting at a dynamic interaction of the PTFB-**20c** mixture and **S7**.

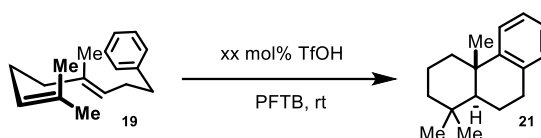
4.8. NMR Investigations on Non-Covalent Interactions of Homogeranyl Benzene (**19**) and Different Solvents

12.6 mg **19** (55.0 μmol) were dissolved in 550 μL (0.1 M) of the corresponding solvent or solvent:CDCl₃ mixture. A ¹³C-NMR spectrum of each sample was recorded.



Supplementary Figure 14. ¹³C-NMR titration curves of homogeranyl benzene (**19**) in different solvents. In the case of the experiments conducted in *t*BuOH/CDCl₃ (dotted lines) or toluene/CDCl₃ (dashed lines) only the curves for C2, C6 and C10 are shown for clarity.

4.9 Transformation of Homogeranyl Benzene (**19**) using Trifilic Acid (TfOH) as Catalyst



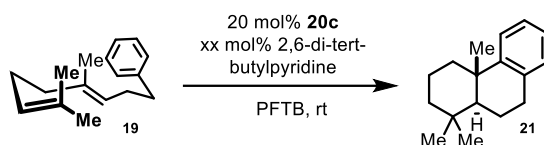
22.8 mg Homogeranyl benzene (**19**, 100 μmol , 1.0 eq) and 20 mol% catalyst (20.0 μmol) were mixed in 1.0 mL PFTB, and the reaction was monitored via GC-FID.

Supplementary Table 5. Cyclization of **19** using different loadings of TfOH catalyst.

entry	TfOH [mol%]	time	conversion	yield 21 ^a	d.r. ^a
1	0.1 ^b	24 h	46%	31%	> 95:5
2	1.0	8 h	> 99%	68%	> 95:5
3	5.0	4 h	> 99%	71%	> 95:5

^aDetermined by GC-FID from the crude reaction mixture using an internal standard. ^bno further conversion was observed after 24h. HFIP was distilled from a 3 Å/4 Å molecular sieve and 250 mg KOH/100 mL HFIP.

4.10 Transformation of Homogeranyl Benzene (**19**) performed in the presence of 2,6-di-*tert*-butylpyridine



22.8 mg Homogeranyl benzene (**19**, 100 μmol , 1.0 eq) and 20 mol% catalyst (20.0 μmol) were mixed in a solution of varying amount of 2,6-di-*tert*-butylpyridine in 1.0 mL PFTB, and the reaction was monitored via GC-FID.

Supplementary Table 6. Cyclization of **19** with 2,6-di-*tert*-butylpyridine as additive.

entry	2,6-di- <i>tert</i> -butylpyridine [mol%]	time	conversion	yield 21 ^a	d.r. ^a
1	5.0	1.5 h	> 99%	95%	> 95:5
2	10	12 h	> 99%	93%	> 95:5
3	20	24 h	-	n.d.	n.d.
4	50	24 h	-	n.d.	n.d.
5	100	24 h	-	n.d.	n.d.

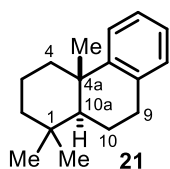
^aDetermined by GC-FID from the crude reaction mixture using an internal standard. HFIP was distilled from a 3 Å/4 Å molecular sieve and 250 mg KOH/100 mL HFIP.

5. General Procedure for the Cyclization of Linear Polyenes

The corresponding linear polyene substrate was dissolved in 0.1 M PFTB at rt in a 4 mL screw cap vial with a magnetic stir bar. 20 mol% of DABCO(TfOH)₂ (**20c**) was added and the mixture was stirred until completion (determined by GC or TLC). Then, 2 mL CHCl₃ was added to terminate the reaction and the solvent was removed under reduced pressure. The crude mixture was then directly purified by column chromatography on silica gel to obtain the corresponding product.

6. Physical and Spectroscopic Data of Compounds 21 – 51

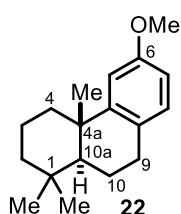
1,1,4a-Trimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene (21), prepared from homogeranyl benzene (**19**, 22.8 mg, 100 μ mol); colorless oil (21.4 mg, 93.8 μ mol, 94%, d.r. > 95:5); prepared from homoneryl benzene (**52a**, 22.8 mg, 100 μ mol); colorless oil (20.5 mg, 89.9 μ mol, 90%, d.r. > 95:5).



TLC: R_f = 0.60 (silica gel, *n*-hexane) [CAM]; **¹H NMR** (400 MHz, CDCl₃) δ 7.29 – 7.26 (m, 1H), 7.16 – 7.02 (m, 3H), 3.00 – 2.81 (m, 2H), 2.30 (bd, J = 12.9, Hz, 1H), 1.93 – 1.86 (m, 1H), 1.80 – 1.68 (m, 2H), 1.66 – 1.60 (m, 1H), 1.52 – 1.47 (m, 1H), 1.46 – 1.32 (m, 2H), 1.25 (dd, J = 13.5, 4.2 Hz, 1H), 1.20 (s, 3H), 0.97 (s, 3H), 0.95 (s, 3H) ppm; **¹³C NMR** (101 MHz, CDCl₃) δ 150.3, 135.4, 129.1, 125.7, 125.3, 124.5, 50.44, 41.84, 38.95, 37.95, 33.62, 33.45, 30.54, 25.01, 21.79, 19.45, 19.17 ppm.

The spectroscopic data are in accordance with those reported in the literature.⁶

6-Methoxy-1,1,4a-trimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthrene (22), prepared from (*E*)-1-(4,8-dimethylnona-3,7-dien-1-yl)-4-methoxybenzene (34.2 mg, 132 μ mol); colorless oil (30.0 mg, 116 μ mol, 88%, d.r. > 95:5).

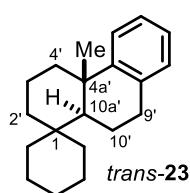


TLC: R_f = 0.43 (silica gel, *n*-hexane/EtOAc; 95:5) [CAM]; **¹H NMR** (300 MHz, CDCl₃) δ 6.96 (d, J = 8.4, 1H), 6.82 (d, J = 2.8 Hz, 1H), 6.67 (dd, J = 8.4, 2.7 Hz, 1H), 3.78 (s, 3H), 2.94 – 2.84 (m, 1H), 2.85 – 2.75 (m, 1H), 2.30 – 2.19 (m, 1H), 1.93 – 1.82 (m, 1H), 1.81 – 1.71 (m, 2H), 1.71 – 1.58 (m, 1H), 1.53 – 1.40 (m, 2H), 1.33 (dd, J = 12.3, 2.4 Hz, 1H), 1.28 – 1.21 (m, 1H), 1.20 (d, J = 0.8 Hz, 3H), 0.96 (s, 3H), 0.94 (s, 3H) ppm; **¹³C NMR** (75 MHz, CDCl₃) δ 157.8, 151.6, 130.0, 127.6, 110.9, 110.3, 55.40, 50.47, 41.83, 38.99, 38.17, 33.64, 33.46, 29.71, 24.89, 21.81, 19.47, 19.30 ppm.

The NMR spectra contain ca. 9% of 4,4'-dimethoxybibenzyl, a side product generated during starting material synthesis and which could not be separated at either of the following steps. The yield of **22** was corrected accordingly.

The spectroscopic data are in accordance with those reported in the literature.⁷

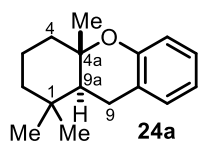
4a'-Methyl-3',4',4a',9',10',10a'-hexahydro-2'H-spiro[cyclohexane-1,1'-phenanthrene] (23), prepared from (*E*)-(7-cyclohexylidene-4-methylhept-3-en-1-yl)benzene (35.2 mg, 131 μ mol); colorless oil (32.0 mg, 119 μ mol, 91%, d.r. = 91:9).



TLC: R_f = 0.78 (silica gel, *n*-hexane) [CAM]; *trans isomer*: **¹H NMR** (300 MHz, CDCl₃) δ 7.30 – 7.23 (m, 1H), 7.17 – 7.08 (m, 1H), 7.08 – 6.99 (m, 2H), 3.01 – 2.75 (m, 2H), 2.29 (td, J = 12.0, 11.4, 5.3 Hz, 2H), 2.03 – 1.94 (m, 1H), 1.85 – 1.73 (m, 2H), 1.72 – 1.59 (m, 4H), 1.50 (m, 4H), 1.33 – 1.24 (m, 2H), 1.21 (s, 3H), 0.98 – 0.73 (m, 4H) ppm; **¹³C NMR** (76 MHz, CDCl₃) δ 150.7, 135.4, 129.1, 125.7, 125.3, 124.5, 51.42, 39.41, 39.20, 38.27, 36.45, 33.62, 31.15, 28.12, 26.72, 26.24, 21.96, 21.92, 18.75, 18.70 ppm; **IR** (KBr) $\tilde{\nu}_{\max}$ = 2935, 1683, 1449, 1217, 1044, 759 cm⁻¹; **HRMS** (EI) calcd. for C₂₀H₂₈ [M]⁺ 268.2184, found 268.2194.

Characteristic signals for the *cis isomer*: **¹H NMR** (300 MHz, CDCl₃) δ 6.88 (t, J = 4.5 Hz, 1H), 2.69 (dt, J = 7.0, 3.1 Hz, 1H), 2.56 (t, J = 7.5 Hz, 1H), 1.12 (s, 3H) ppm; **¹³C NMR** (76 MHz, CDCl₃) δ 128.5, 128.4, 45.13, 36.29, 35.46, 31.74, 27.25, 22.80, 13.32 ppm.

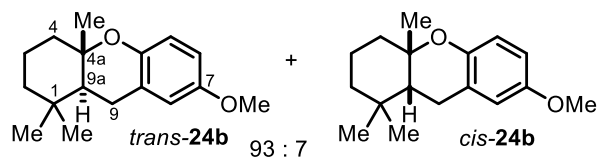
1,1,4a-Trimethyl-2,3,4,4a,9,9a-hexahydro-1H-xanthene (24a), prepared from (*E*)-2-(3,7-dimethylocta-2,6-dien-1-yl)phenol (39.1 mg, 170 μ mol); colorless solid (25.0 mg, 109 μ mol, 64%, d.r. > 95:5).



TLC: R_f = 0.19 (silica gel, *n*-hexane) [CAM]; **¹H NMR** (500 MHz, CDCl₃) δ 7.11 – 7.03 (m, 2H), 6.82 (t, J = 7.3 Hz, 1H), 6.76 (d, J = 8.0 Hz, 1H), 2.71 (dd, J = 16.3, 5.0 Hz, 1H), 2.61 (dd, J = 16.4, 13.1 Hz, 1H), 2.00 – 1.94 (m, 1H), 1.71 (dd, J = 13.2, 5.1 Hz, 1H), 1.69 – 1.63 (m, 1H), 1.61 (d, J = 4.2 Hz, 1H), 1.55 (dt, J = 11.7, 3.0 Hz, 1H), 1.52 – 1.46 (m, 1H), 1.37 – 1.29 (m, 1H), 1.22 (s, 3H), 1.01 (s, 3H), 0.91 (s, 3H) ppm; **¹³C NMR** (75 MHz, CDCl₃) δ 153.4, 129.8, 127.3, 122.8, 119.8, 117.2, 77.36, 48.25, 41.68, 40.17, 33.54, 32.25, 23.41, 20.83, 20.00, 19.95 ppm.

The spectroscopic data are in accordance with those reported in the literature.⁸

7-Methoxy-1,1,4a-trimethyl-2,3,4,4a,9,9a-hexahydro-1H-xanthene (24b), prepared from (*E*)-2-(3,7-dimethylocta-2,6-dien-1-yl)-4-methoxyphenol (28.1 mg, 108 μ mol); colorless oil (24.0 mg, 92.2 μ mol, 85%, d.r. = 93:7).



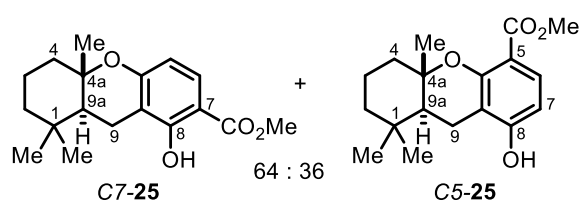
TLC: R_f = 0.61 (silica gel, *n*-hexane/EtOAc; 90:10) [CAM]; *trans isomer*: $^1\text{H NMR}$ (300 MHz, CDCl_3) δ 6.71 – 6.64 (m, 2H), 6.64 – 6.61 (m, 1H), 3.75 (s, 3H), 2.69 (dd, J = 16.5, 5.5 Hz, 1H), 2.58 (dd, J = 16.5, 12.7

Hz, 1H), 1.99 – 1.91 (m, 1H), 1.70 (dd, J = 12.6, 5.5 Hz, 1H), 1.64 – 1.55 (m, 2H), 1.54 – 1.45 (m, 1H), 1.41 – 1.26 (m, 2H), 1.20 (s, 3H), 1.00 (s, 3H), 0.90 (s, 3H) ppm; $^{13}\text{C NMR}$ (75 MHz, CDCl_3) δ 153.1, 147.4, 123.3, 117.6, 114.4, 113.3, 77.00, 55.84, 48.27, 41.68, 40.13, 33.49, 32.23, 23.78, 20.78, 19.94, 19.84 ppm.

Characteristic signals for the cis isomer: $^1\text{H NMR}$ (300 MHz, CDCl_3) δ 3.01 (dd, J = 17.6, 8.1 Hz, 1H), 1.18 (s, 3H), 0.96 (s, 3H), 0.67 (s, 3H) ppm.

The spectroscopic data are in accordance with those reported in the literature.⁸

Methyl-8-hydroxy-1,1,4a-trimethyl-2,3,4,4a,9,9a-hexahydro-1H-xanthene-7-carboxylate (25), prepared from methyl (*E*)-3-(3,7-dimethylocta-2,6-dien-1-yl)-2,4-dihydroxybenzoate (23.6 mg, 77.5 μ mol); colorless oil (20.1 mg, 66.0 μ mol, 85%, d.r. > 95:5, 64:36 mixture of inseparable regioisomers).



TLC: R_f = 0.35-0.42 (silica gel, *n*-hexane/EtOAc; 95:5) [CAM].

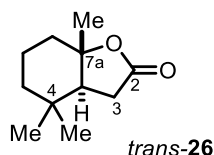
C7-isomer: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 11.28 (s, 1H), 7.60 – 7.53 (m, 1H), 6.31 (d, J = 8.8 Hz, 1H), 3.90 (s, 3H), 2.81 (dd, J = 16.9, 4.8 Hz, 1H), 2.32 (ddd, J = 16.9, 13.3, 0.9 Hz, 1H), 2.01 – 1.94 (m, 1H), 1.75 – 1.54 (m, 4H), 1.52 – 1.39 (m, 2H), 1.38 – 1.27 (m, 2H), 1.22 (s, 3H), 1.04 (s, 3H), 0.94 (s, 3H) ppm.

C5-isomer: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 10.60 (s, 1H), 7.62 – 7.52 (m, 1H), 6.31 (d, J = 8.8 Hz, 1H), 3.89 (s, 3H), 2.73 – 2.60 (m, 1H), 2.52 (ddd, J = 15.9, 13.3, 1.3 Hz, 1H), 2.01 – 1.94 (m, 1H), 1.71 – 1.55 (m, 4H), 1.53 – 1.39 (m, 2H), 1.34 – 1.29 (m, 2H), 1.22 (s, 3H), 0.99 (s, 3H), 0.89 (s, 3H) ppm.

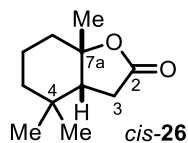
Mixture of *C7*-**25** and *C5*-**25**: $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 171.0, 170.4, 161.4, 161.1, 160.0, 159.4, 131.2, 128.3, 124.0, 114.7, 110.4, 109.1, 105.1, 104.2, 104.0, 78.70, 78.48, 51.86, 51.84, 48.09, 47.39, 41.49, 41.34, 39.78, 39.74, 33.56, 33.48, 32.11, 32.02, 22.42, 20.68, 20.62, 20.06, 19.76, 19.72, 17.56 ppm; **IR**

(KBr) $\tilde{\nu}_{\max}$ = 2951, 2866, 1667, 1492, 1439, 1346, 1264, 1164, 987, 758 cm^{-1} ; **HRMS** (ESI+) calcd. for $\text{C}_{18}\text{H}_{25}\text{O}_4^+ [\text{M}+\text{H}]^+$ 305.1747, found 305.1726.

(±)-Tetrahydroactinidiolide (26), prepared from (*E*)-4,8-dimethylnona-3,7-dienoic acid (32.3 mg, 177 μmol); colorless wax (31.6 mg, 174 μmol , 98%; d.r. = 76:24) separable mixture of diastereomers



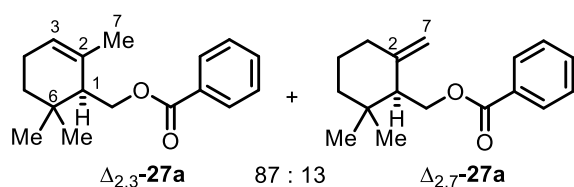
trans-isomer: 24.0 mg, 132 μmol , 74%; **TLC**: R_f = 0.45 (silica gel, *n*-hexane/EtOAc; 50:50) [CAM]; **^1H NMR** (300 MHz, CDCl_3) δ 2.42 (dd, J = 16.3, 14.6 Hz, 1H), 2.29 (ddd, J = 16.3, 6.8, 0.6 Hz, 1H), 2.03 – 1.94 (m, 2H), 1.83 – 1.72 (m, 1H), 1.69 – 1.49 (m, 3H), 1.34 (d, J = 0.7 Hz, 3H), 1.32 – 1.21 (m, 1H), 0.96 (s, 3H), 0.93 (s, 3H) ppm; **^{13}C NMR** (75 MHz, CDCl_3) δ 176.6, 86.63, 55.73, 40.24, 37.34, 32.86, 32.40, 29.35, 20.86, 20.61, 19.95 ppm.



cis-isomer: 7.6 mg, 41.7 μmol , 24%; **TLC**: R_f = 0.33 (silica gel, *n*-hexane/EtOAc; 50:50) [CAM]; **^1H NMR** (500 MHz, CDCl_3) δ 2.51 (dd, J = 17.3, 12.7 Hz, 1H), 2.43 (dd, J = 17.4, 8.2 Hz, 1H), 2.06 (dd, J = 12.8, 8.2 Hz, 1H), 1.89 – 1.83 (m, 1H), 1.64 – 1.59 (m, 2H), 1.53 (s, 3H), 1.51 – 1.35 (m, 2H), 1.33 – 1.27 (m, 1H), 1.05 (s, 3H), 0.91 (s, 3H) ppm; **^{13}C NMR** (126 MHz, CDCl_3) δ 175.9, 86.25, 52.09, 34.85, 33.70, 33.41, 32.34, 30.28, 28.55, 27.08, 19.10 ppm.

The spectroscopic data for the *trans*⁹ and *cis*¹⁰ isomer of **26** are in accordance with those reported in the literature.

(2,6,6-Trimethylcyclohex-2-en-1-yl)methyl benzoate (27a), prepared from geraniol benzoate (32.3 mg, 125 μmol); colorless oil (27.4 mg, 106 μmol , 85%; 87:13 mixture of inseparable regioisomers).

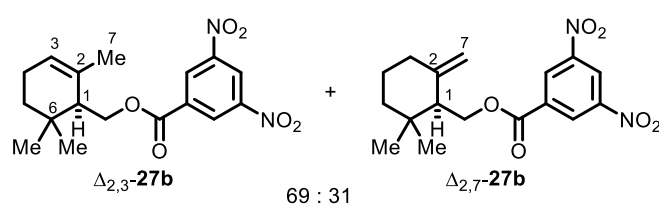


TLC: R_f = 0.50 (silica gel, *n*-hexane/EtOAc; 95:5) [KMnO_4]; $\Delta_{2,3}$ -**27a**: **^1H NMR** (300 MHz, CDCl_3) δ 8.05 – 8.00 (m, 2H), 7.58 – 7.52 (m, 1H), 7.48 – 7.40 (m, 2H), 5.50 (s, 1H), 4.38 (d, J = 4.6 Hz, 2H), 2.06 – 1.99 (m, 2H), 1.95 (q, J = 3.9, 1H), 1.80 (d, J = 1.9 Hz, 3H), 1.64 – 1.49 (m, 1H), 1.26 (dtd, J = 13.2, 5.0, 1.2 Hz, 1H), 1.03 (s, 3H), 0.97 (s, 3H) ppm; **^{13}C NMR** (75 MHz, CDCl_3) δ 166.7, 132.9, 132.3, 130.7, 129.7, 128.5, 123.5, 64.69, 49.16, 32.32, 31.95, 27.57, 27.40, 23.11, 23.06 ppm;

Characteristic signals for $\Delta_{2,7}$ -**27a**: **^1H NMR** (300 MHz, CDCl_3) δ 4.85 (s, 1H), 4.71 (s, 1H), 4.54 (dd, J = 11.1, 4.9 Hz, 1H), 4.11 (d, J = 2.4 Hz, 1H), 2.33 (dd, J = 9.4, 4.9 Hz, 1H), 0.95 (s, 3H); **^{13}C NMR** (75 MHz, CDCl_3) δ 132.9, 129.7, 128.4, 110.2, 63.51, 52.47, 37.91, 34.51, 33.47, 28.90, 25.50, 24.00 ppm;

Mixture of $\Delta_{2,3}$ -**27a** and $\Delta_{2,7}$ -**27a**: IR (film) $\tilde{\nu}_{\max}$ = 1718, 1451, 1275, 1114, 712 cm^{-1} ; HRMS (EI) calcd. for $\text{C}_{17}\text{H}_{22}\text{O}_2^+ [\text{M}]^+$ 258.1620, found 258.1629.

(2,6,6-Trimethylcyclohex-2-en-1-yl)methyl 3',5'-dinitrobenzoate (27b), prepared from (*E*)-3,7-dimethylocta-2,6-dien-1-yl 3',5'-dinitrobenzoate (38.3 mg, 110 μmol); yellow oil (29.5 mg, 84.6 μmol , 77% as a 69:31 mixture of inseparable regioisomers) or prepared from (*Z*)-3,7-dimethylocta-2,6-dien-1-yl 3',5'-dinitrobenzoate (50.3 mg, 144 μmol); yellow oil (40.6 mg, 117 μmol , 81%; 68:32 mixture of inseparable regioisomers).



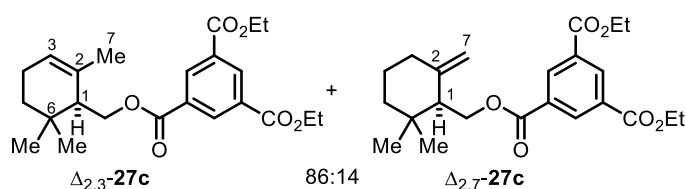
TLC: R_f = 0.84 (silica gel, *n*-hexane/EtOAc; 80:20) [UV]; $\Delta_{2,3}$ -**27b**: $^1\text{H NMR}$ (500 MHz, CDCl_3) δ 9.23 (t, J = 2.1 Hz, 1H), 9.13 (d, J = 2.1 Hz, 2H), 5.56 (s, 1H), 4.53 (dd, J = 11.7, 5.7 Hz, 1H), 4.48

(dd, J = 11.7, 3.1 Hz, 1H), 2.09 – 2.05 (m, 2H), 1.97 (br s, 1H), 1.79 (q, J = 1.9 Hz, 3H), 1.60 – 1.49 (m, 1H), 1.31 (dt, J = 13.8, 4.6 Hz, 1H), 1.04 (s, 3H), 0.98 (s, 3H) ppm; $^{13}\text{C NMR}$ (126 MHz, CDCl_3) δ 162.6, 148.8, 134.3, 131.3, 129.5, 124.2, 122.4, 66.35, 49.02, 32.09, 31.98, 27.71, 27.38, 23.08, 22.97 ppm.

Characteristic signals of $\Delta_{2,7}$ -**27b**: $^1\text{H NMR}$ (500 MHz, CDCl_3) δ 9.21 (t, J = 2.2 Hz, 1H), 9.12 (d, J = 2.2 Hz, 2H), 4.87 (s, 1H), 4.69 (s, 1H), 4.61 (d, J = 0.9 Hz, 1H), 4.60 (s, 1H), 2.39 (t, J = 7.6 Hz, 1H), 2.25 – 2.18 (m, 1H), 2.13 (dt, J = 13.5, 5.3 Hz, 1H), 1.64 – 1.59 (m, 2H), 1.45 – 1.34 (m, 2H), 1.04 (s, 3H), 0.97 (s, 3H) ppm; $^{13}\text{C NMR}$ (126 MHz, CDCl_3) δ 162.6, 148.8, 146.8, 134.3, 129.6, 122.4, 110.8, 65.17, 52.46, 37.33, 34.49, 32.86, 28.70, 25.93, 23.34 ppm.

Mixture of $\Delta_{2,3}$ -**27b** and $\Delta_{2,7}$ -**27b**: IR (neat) $\tilde{\nu}_{\max}$ = 2959, 2924, 1733, 1629, 1548, 1458, 1344, 1261, 1165, 1075, 800 cm^{-1} ; HRMS (EI) calcd. for $\text{C}_{17}\text{H}_{20}\text{N}_2\text{O}_6^+ [\text{M}]^+$ 348.1316, found 348.1318.

1',3-Diethyl 5-((2,6,6-trimethylcyclohex-2-en-1-yl)methyl) benzene-1',3',5'-tricarboxylate (27c), prepared from (*E*)-1-(3,7-dimethylocta-2,6-dien-1-yl) 3',5'-diethyl benzene-1',3',5'-tricarboxylate (28.1 mg, 69.9 μmol); colorless oil (20.4 mg, 50.7 μmol , 73%; 86:14 mixture of inseparable regioisomers).



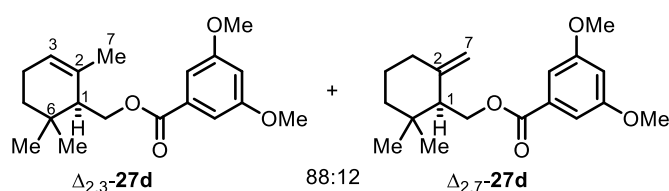
TLC: R_f = 0.24 (silica gel, *n*-hexane/EtOAc; 95:5) [CAM]; $\Delta_{2,3}$ -**27c**: $^1\text{H NMR}$ (300 MHz, CDCl_3) δ 8.89 – 8.81 (m, 1H), 8.84 – 8.81 (m, 2H), 5.53 (s, 1H), 4.47 – 4.38 (m, 6H), 2.07 –

2.01 (m, 2H), 1.95 (t, $J = 4.0$ Hz, 1H), 1.79 (q, $J = 1.6$ Hz, 3H), 1.65 – 1.54 (m, 1H), 1.43 (t, $J = 7.2$ Hz, 6H), 1.31 – 1.24 (m, 1H), 1.04 (s, 3H), 0.97 (s, 3H) ppm; $^{13}\text{C NMR}$ (75 MHz, CDCl_3) δ 165.2, 165.2, 134.61, 134.57, 131.9, 131.7, 131.6, 123.8, 65.20, 61.82, 49.12, 32.22, 31.98, 27.59, 27.54, 23.11, 23.05, 14.43 ppm.

Characteristic signals of $\Delta_{2,7}$ -**27c**: $^1\text{H NMR}$ (300 MHz, CDCl_3) δ 8.89 – 8.81 (m, 1H), 8.84 – 8.81 (m, 2H), 4.86 (s, 1H), 4.71 (s, 1H), 4.54 – 4.49 (m, 2H) 2.37 (dd, $J = 8.1, 6.5$ Hz, 1H), 2.28 – 2.14 (m, 1H), 1.04 (s, 3H), 0.96 (s, 3H) ppm.

Mixture of $\Delta_{2,3}$ -**27c** and $\Delta_{2,7}$ -**27c**: IR (KBr) $\tilde{\nu}_{\text{max}} = 2964, 1728, 1241, 1026, 741 \text{ cm}^{-1}$; HRMS (ESI $^+$) calcd. for $\text{C}_{23}\text{H}_{30}\text{NaO}_6^+ [\text{M}+\text{Na}]^+$ 425.1935, found 425.1903.

(2,6,6-Trimethylcyclohex-2-en-1-yl)methyl 3',5'-dimethoxybenzoate (27d), prepared from (*E*)-3,7-dimethylocta-2,6-dien-1-yl 3',5'-dimethoxybenzoate (41.0 mg, 129 μmol); colorless oil (33.2 mg, 104 μmol , 81%; 88:12 mixture of inseparable regioisomers).



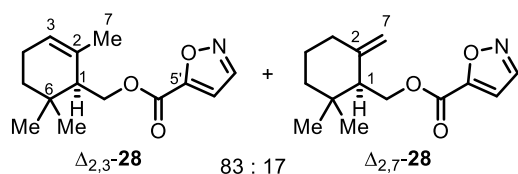
TLC: $R_f = 0.36$ (silica gel, n-n-hexane/EtOAc; 95:5) [CAM]; $\Delta_{2,3}$ -**27d**: $^1\text{H NMR}$ (300 MHz, CDCl_3) δ 7.18 (d, $J = 2.4$ Hz, 2H), 6.64 (t, $J = 2.4$ Hz, 1H), 5.50 (s, 1H), 4.36 (d, $J = 4.6$ Hz, 2H),

3.82 (s, 6H), 2.06 – 1.98 (m, 2H), 1.92 (t, $J = 4.7$ Hz, 1H), 1.79 (q, $J = 1.4$ Hz, 3H), 1.57 (dt, $J = 16.2, 6.5$ Hz, 1H), 1.30 – 1.20 (m, 1H), 1.03 (s, 3H), 0.96 (s, 3H) ppm; $^{13}\text{C NMR}$ (75 MHz, CDCl_3) δ 166.4, 160.8, 132.6, 132.2, 123.5, 107.3, 105.7, 64.79, 55.64, 49.14, 32.27, 31.94, 27.55, 27.46, 23.09 ppm.

Characteristic signals for $\Delta_{2,7}$ -**27d**: $^1\text{H NMR}$ (300 MHz, CDCl_3) δ 7.17 (d, $J = 2.4$ Hz, 2H), 6.63 (t, $J = 2.4$ Hz, 1H), 4.85 (br s, 1H), 4.70 (dt, $J = 1.9, 0.9$ Hz, 1H), 4.51 (dd, $J = 11.1, 5.1$ Hz, 1H), 4.42 (dd, $J = 11.0, 9.4$ Hz, 1H), 3.81 (s, 6H), 2.32 (dd, $J = 9.6, 5.3$ Hz, 1H), 2.27 – 2.07 (m, 2H), 1.40 – 1.30 (m, 2H), 1.03 (s, 3H), 0.94 (s, 3H) ppm; $^{13}\text{C NMR}$ (75 MHz, CDCl_3) δ 160.7, 147.3, 110.2, 107.3, 105.7, 63.68, 52.49, 37.74, 34.46, 33.31, 28.84, 25.68, 23.50 ppm; further signals could not be identified due to overlapped with the signals of the major isomer.

Mixture of $\Delta_{2,3}$ -**27d** and $\Delta_{2,7}$ -**27d**: IR (KBr) $\tilde{\nu}_{\text{max}} = 1718, 1598, 1463, 1302, 1206, 1157, 1050, 767 \text{ cm}^{-1}$; HRMS (ESI $^+$) calcd. for $\text{C}_{19}\text{H}_{26}\text{NaO}_4^+ [\text{M}+\text{Na}]^+$ 341.1723, found 341.1723.

(2,6,6-Trimethylcyclohex-2-en-1-yl)methyl isoxazole-5-carboxylate (28), prepared from geranyl isoxazole-5-carboxylate (39.9 mg, 160 μmol); colorless oil (39.7 mg, 159 μmol , 99%; 83:17 mixture of inseparable regioisomers).



TLC: R_f = 0.35 (silica gel, *n*-hexane/EtOAc; 95:5); $\Delta_{2,3}$ -**28**: ^1H

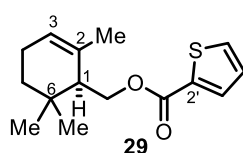
NMR (300 MHz, CDCl_3) δ 8.36 (d, J = 1.8 Hz, 1H), 6.91 (d, J = 1.8 Hz, 1H), 5.53 – 5.46 (m, 1H), 4.47 (dd, J = 11.6, 5.8 Hz, 1H), 4.36 (dd, J = 11.7, 3.5 Hz, 1H), 2.03 – 1.96 (m, 2H), 1.93

– 1.88 (m, 1H), 1.77 (q, J = 1.7 Hz, 3H), 1.58 – 1.49 (m, 1H), 1.30 – 1.20 (m, 1H), 1.00 (s, 3H), 0.94 (s, 3H) ppm; ^{13}C **NMR** (75 MHz, CDCl_3) δ 160.3, 156.7, 150.7, 131.5, 124.1, 108.7, 65.88, 48.96, 31.99, 31.89, 27.39, 27.37, 23.05, 22.97 ppm.

Characteristic signals of $\Delta_{2,7}$ -**28**: ^1H **NMR** (300 MHz, CDCl_3) δ 8.34 (d, J = 1.8 Hz, 1H), 6.89 (d, J = 1.8 Hz, 1H), 4.82 (d, J = 1.6 Hz, 1H), 4.64 (br s, 1H), 4.54 (d, J = 3.3 Hz, 1H), 4.52 (d, J = 0.7 Hz, 1H), 2.31 (dd, J = 8.6, 5.9 Hz, 1H), 1.01 (s, 3H), 0.92 (s, 3H); ^{13}C **NMR** (75 MHz, CDCl_3) δ 160.2, 158.3, 150.9, 146.5, 110.6, 109.7, 64.78, 52.28, 37.69, 34.47, 33.20, 28.76, 25.54, 23.36 ppm; further signals could not be identified due to overlapped with the signals of the major isomer.

Mixture of $\Delta_{2,3}$ -**28** and $\Delta_{2,7}$ -**28**: **IR** (neat) $\tilde{\nu}_{\text{max}}$ = 2962, 1736, 1280, 1204, 1143, 769 cm^{-1} ; **HRMS** (ESI+) calcd. for $\text{C}_{14}\text{H}_{19}\text{NNaO}_3^+$ $[\text{M}+\text{Na}]^+$ 272.1257, found 272.1255.

(2,6,6-Trimethylcyclohex-2-en-1-yl)methyl thiophene-2'-carboxylate (29), prepared from geranyl thiophene-2-carboxylate (34.6 mg, 131 μmol); slightly yellow oil (31.6 mg, 120 μmol , 91%; single regioisomer).

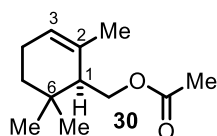


TLC: R_f = 0.60 (silica gel, *n*-hexane/EtOAc; 95:5); ^1H **NMR** (400 MHz, CDCl_3) δ 7.78

(dd, J = 3.7, 1.3 Hz, 1H), 7.54 (dd, J = 5.0, 1.3 Hz, 1H), 7.09 (dd, J = 5.0, 3.7 Hz, 1H), 5.49 (br, 1H), 4.37 (dd, J = 11.6, 5.6 Hz, 1H), 4.32 (dd, J = 11.6, 3.6 Hz, 1H), 2.01 (br, 2H), 1.90 (t, J = 4.5 Hz, 1H), 1.78 (q, J = 1.9 Hz, 3H), 1.70 – 1.50 (m, 2H), 1.29 – 1.17

(m, 1H), 1.02 (s, 3H), 0.95 (s, 3H) ppm; ^{13}C **NMR** (101 MHz, CDCl_3) δ 162.3, 134.4, 133.3, 132.3, 132.1, 127.9, 123.6, 64.81, 49.11, 32.22, 31.91, 27.55, 27.44, 23.12, 23.06 ppm; **IR** (neat) $\tilde{\nu}_{\text{max}}$ = 2963, 1710, 1419, 1258, 1096, 751, 718 cm^{-1} ; **HRMS** (ESI+) calcd. for $\text{C}_{15}\text{H}_{20}\text{NaO}_2\text{S}^+$ $[\text{M}+\text{Na}]^+$ 287.1076, found 287.1072.

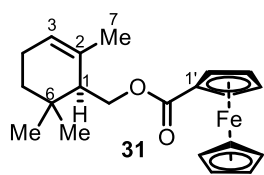
($\pm$)-Cyclogeranylacetat (30), prepared from geranyl acetate (18.9 mg, 96.3 μmol); clear oil (16.6 mg, 84.6 μmol , 88%; single regioisomer).



TLC: R_f = 0.51 (silica gel, *n*-hexane/EtOAc; 95:5) [CAM]; **$^1\text{H NMR}$** (300 MHz, CDCl_3) δ 5.44 (br, 1H), 4.16 (dd, J = 11.7, 5.8 Hz, 1H), 4.05 (dd, J = 11.7, 3.7 Hz, 1H), 2.02 (s, 3H), 1.99 – 1.93 (m, 2H), 1.83 – 1.74 (m, 1H), 1.72 (q, J = 1.9 Hz, 3H), 1.46 (dt, J = 13.3, 8.1 Hz, 1H), 1.23 – 1.17 (m, 1H), 0.93 (s, 3H), 0.90 (s, 3H) ppm; **$^{13}\text{C NMR}$** (75 MHz, CDCl_3) δ 171.3, 132.4, 123.3, 64.44, 48.90, 32.14, 31.87, 27.46, 27.13, 23.08, 23.01, 21.26 ppm.

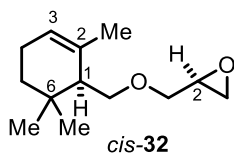
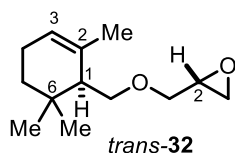
The spectroscopic data are in accordance with those reported in the literature.¹¹

(2,6,6-Trimethylcyclohex-2-en-1-yl)methyl ferrocene-1'-carboxylate (31), prepared from geranyl ferrocene-1'-carboxylate (25.1 mg, 68.5 μmol); deep orange oil (17.8 mg, 48.6 μmol , 71%; single regioisomer).



TLC: R_f = 0.53 (silica gel, *n*-hexane/EtOAc, 90:10); **$^1\text{H NMR}$** (400 MHz, CDCl_3) δ 5.52 (s, 1H), 4.77 (dt, J = 3.4, 1.8 Hz, 2H), 4.38 (t, J = 2.0 Hz, 2H), 4.31 (dd, J = 11.7, 5.4 Hz, 1H), 4.23 (dd, J = 11.7, 3.3 Hz, 1H), 4.19 (s, 5H), 2.08 – 2.03 (m, 2H), 1.86 (s, 1H), 1.80 (q, J = 1.9 Hz, 3H), 1.63 (dt, J = 13.3, 8.3 Hz, 1H), 1.27 (dt, J = 12.5, 4.3 Hz, 1H), 1.06 (s, 3H), 0.97 (s, 3H) ppm; **$^{13}\text{C NMR}$** (101 MHz, CDCl_3) δ 171.9, 132.3, 123.4, 71.77, 71.29, 71.27, 70.24, 70.18, 69.82, 63.84, 49.22, 32.50, 31.96, 27.73, 27.55, 23.15, 23.11 ppm; **IR** (neat) $\tilde{\nu}_{\text{max}}$ = 2958, 1711, 1460, 1380, 1273, 1135, 821 cm^{-1} ; **Anal.** calcd. for $\text{C}_{21}\text{H}_{26}\text{FeO}_2$: C: 68.9, H: 7.16, Fe: 15.3; found: C: 68.9, H: 7.44, Fe: 15.6.

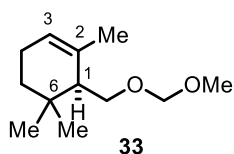
2-(((2,6,6-Trimethylcyclohex-2-en-1-yl)methoxy)methyl)oxirane (32), prepared from 2-geranyl methyloxirane ether (29.9 mg, 142 μmol); colorless oil (20.0 mg, 95.1 μmol , 67%; d.r = 50:50; single regioisomer).



TLC: R_f = 0.29 (silica gel, *n*-hexane/EtOAc, 90:10); mixture of diastereoisomers: **$^1\text{H NMR}$** (400 MHz, CDCl_3) δ 5.42 (tt, J = 3.5, 1.5 Hz, 2H), 3.68 (dd, J = 11.6, 3.1 Hz, 1H), 3.67 (dd, J = 11.6, 3.1 Hz, 1H), 3.57 (dd, J = 10.0, 5.5 Hz, 1H), 3.53 – 3.46 (m, 2H), 3.42 (dd, J = 10.0, 3.4 Hz, 1H), 3.37 (dd, J = 11.6, 3.0, 1H), 3.36 (dd, J = 11.6, 3.2 Hz, 1H), 3.17 – 3.11 (m, 2H), 2.78 (ddd, J = 5.1, 4.1, 1.7 Hz, 2H), 2.60 (ddd, J = 5.2, 4.3, 2.7 Hz, 2H), 1.96 (br, 4H), 1.74 (q, J = 1.9 Hz, 6H), 1.47 (dtd, J = 13.2, 8.1, 2.3 Hz, 2H), 1.18 (dt, J = 13.1, 4.6 Hz, 2H), 1.02 – 0.96 (m, 2H), 0.95 (d, J = 1.1 Hz, 6H), 0.90 (s, 6H) ppm; **$^{13}\text{C NMR}$** (101 MHz, CDCl_3) δ 133.5, 122.6, 71.98, 71.93, 71.68, 71.46, 51.05, 50.07, 44.51, 44.45, 32.54, 31.87, 27.61, 27.20, 27.14, 23.26, 23.12 ppm; some signals of the two

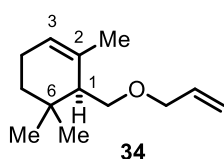
diastereomers overlap; **IR** (KBr) $\tilde{\nu}_{\max}$ = 2923, 1716, 1455, 1109, 759 cm^{-1} ; **HRMS** (EI) calcd. for $\text{C}_{13}\text{H}_{22}\text{O}_2^+$ $[\text{M}]^+$ 210.1614, found 210.1633.

1'-((Methoxymethoxy)methyl)-2,6,6-trimethylcyclohex-2-ene (33), prepared from geranyl methoxymethyl ether (18.9 mg, 95.3 μmol); colorless oil (10.6 mg, 53.5 μmol , 56%, single regioisomer).



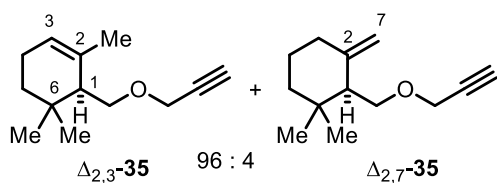
TLC: R_f = 0.53 (silica gel, *n*-hexane/EtOAc; 95:5); **^1H NMR** (500 MHz, CDCl_3) δ 5.44 (s, 1H), 4.61 (d, J = 6.6 Hz, 1H), 4.58 (d, J = 6.6 Hz, 1H), 3.59 (dd, J = 10.2, 5.2 Hz, 1H), 3.53 (dd, J = 10.3, 3.4 Hz, 1H), 3.37 (s, 3H), 1.97 (br, 2H), 1.74 (q, J = 1.9 Hz, 3H), 1.73 – 1.68 (m, 1H), 1.56 – 1.45 (m, 1H), 1.18 (dtd, J = 13.3, 5.0, 1.2 Hz, 1H), 0.97 (s, 3H), 0.91 (s, 3H) ppm; **^{13}C NMR** (126 MHz, CDCl_3) δ 133.4, 122.6, 96.74, 68.08, 55.53, 49.96, 32.59, 31.89, 27.70, 27.20, 23.16, 23.10 ppm; **IR** (KBr) $\tilde{\nu}_{\max}$ = 2927, 1715, 1457, 1378, 1037, 756 cm^{-1} ; **HRMS** (EI) calcd. for $\text{C}_{12}\text{H}_{22}\text{O}_2^+$ $[\text{M}]^+$ 198.1614, found 198.1626.

1-((Allyloxy)methyl)-2,6,6-trimethylcyclohex-2-ene (34), prepared from geranyl allyl ether (17.5 mg, 90.1 μmol); colorless oil (17.5 mg, 90.1 μmol , quant., single regioisomer).



TLC: R_f = 0.58 (silica gel, *n*-hexane); **^1H NMR** (500 MHz, CDCl_3) δ 5.91 (ddt, J = 17.2, 10.8, 5.5 Hz, 1H), 5.42 (dt, J = 3.9, 2.2 Hz, 1H), 5.26 (dq, J = 17.2, 1.8 Hz, 1H), 5.16 (dq, J = 10.4, 1.5 Hz, 1H), 3.94 (dd, J = 5.5, 1.5 Hz, 2H), 3.47 (dd, J = 9.9, 5.5 Hz, 1H), 3.38 (dd, J = 10.0, 3.6 Hz, 1H), 1.96 (tdt, J = 7.0, 3.8, 2.0 Hz, 2H), 1.74 (d, J = 2.0 Hz, 3H), 1.70 – 1.62 (m, 1H), 1.49 (dt, J = 13.1, 8.1 Hz, 1H), 1.17 (dt, J = 13.2, 4.7 Hz, 1H), 0.95 (s, 3H), 0.90 (s, 3H) ppm; **^{13}C NMR** (75 MHz, CDCl_3) δ 135.3, 133.8, 122.4, 116.7, 71.94, 70.79, 50.10, 32.56, 31.89, 27.63, 27.18, 23.29, 23.14 ppm; **IR** (neat) $\tilde{\nu}_{\max}$ = 2959, 2925, 1453, 1383, 1102, 921 cm^{-1} ; **HRMS** (EI) calcd. for $\text{C}_{13}\text{H}_{22}\text{O}^+$ $[\text{M}]^+$ 194.1665, found 194.1664.

2,6,6-Trimethyl-1-((prop-2'-yn-1'-yloxy)methyl)cyclohex-2-ene (35), prepared from geranyl propargyl ether (20.5 mg, 107 μ mol); colorless oil (20.3 mg, 106 μ mol, 99%, 94:6 mixture of inseparable regioisomers).



TLC: R_f = 0.63 (silica gel, *n*-hexane/EtOAc; 95:5); $\Delta_{2,3}$ -**35**: ^1H

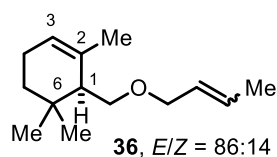
NMR (400 MHz, CDCl_3) δ 5.44 (s, 1H), 4.11 (d, J = 2.4 Hz, 2H), 3.58 (dd, J = 9.8, 5.3 Hz, 1H), 3.50 (dd, J = 9.8, 3.2 Hz, 1H), 2.40 (t, J = 2.4 Hz, 1H), 1.97 (br, 2H), 1.74 (q, J = 1.9 Hz, 3H), 1.54 –

1.44 (m, 2H), 1.18 (dtd, J = 13.0, 5.0, 1.2 Hz, 1H), 0.96 (s, 3H), 0.90 (s, 3H) ppm; ^{13}C **NMR** (75 MHz, CDCl_3) δ 133.4, 122.7, 80.19, 74.23, 70.29, 58.08, 49.94, 32.70, 31.96, 27.69, 27.12, 23.14, 23.10 ppm.

Characteristic signals for $\Delta_{2,7}$ -**35**: ^1H **NMR** (400 MHz, CDCl_3) δ 4.85 (dq, J = 1.9, 1.0 Hz, 1H), 4.69 (br s, 1H), 0.99 (s, 3H), 0.84 (s, 3H) ppm.

Mixture of $\Delta_{2,3}$ -**35** and $\Delta_{2,7}$ -**35**: **IR** (neat) $\tilde{\nu}_{\text{max}}$ = 2956, 2914, 1452, 1364, 1096, 663 cm^{-1} ; **HRMS** (EI) calcd. for $\text{C}_{13}\text{H}_{20}\text{O}^+ [\text{M}]^+$ 192.1509, found 192.1511.

1-((But-2'-en-1'-yloxy)methyl)-2,6,6-trimethylcyclohex-2-ene (36), prepared from geranyl but-2-en ether (31.5 mg, 151 μ mol, *E/Z* = 87:13); colorless oil (31.5 mg, 151 μ mol, *quant.*, 86:14 inseparable mixture of (*E/Z*)-isomers).



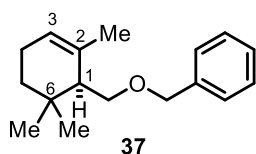
TLC: R_f = 0.38 (silica gel, *n*-hexane/EtOAc; 95:5); *E*-isomer: ^1H **NMR** (300 MHz, CDCl_3) δ 5.77 – 5.63 (m, 1H), 5.63 – 5.51 (m, 1H), 5.40 (br, 1H), 3.88 – 3.84 (m, 2H), 3.43 (dd, J = 10.0, 5.6 Hz, 1H), 3.34 (dd, J = 10.0, 3.6 Hz, 1H), 1.96 (br, 2H), 1.74 – 1.69 (m, 6H), 1.58 – 1.42 (m, 1H), 1.21 – 1.11 (m, 1H), 1.08 – 0.99 (m, 1H),

0.94 (s, 3H), 0.90 (s, 3H) ppm; ^{13}C **NMR** (75 MHz, CDCl_3) δ 133.9, 129.0, 128.1, 122.2, 71.61, 70.58, 50.11, 32.56, 31.90, 27.60, 27.15, 23.29, 23.15, 17.91 ppm.

Characteristic signal of the *Z*-isomer: ^1H **NMR** (300 MHz, CDCl_3) δ 4.00 (dt, J = 6.2, 1.0 Hz, 2H) ppm; ^{13}C **NMR** (75 MHz, CDCl_3) δ 127.5, 70.72, 66.18 ppm.

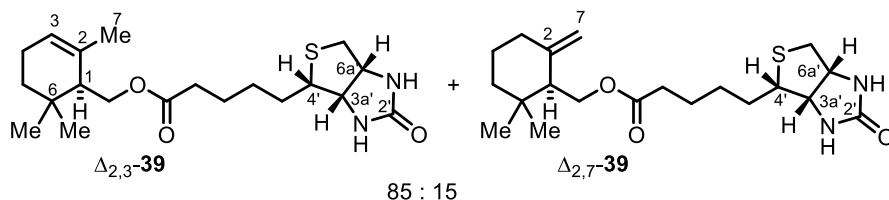
Mixture of *E*- and *Z*-**36**: **IR** (neat) $\tilde{\nu}_{\text{max}}$ = 2957, 1452, 1365, 1102, 966 cm^{-1} ; **HRMS** (EI) calcd. for $\text{C}_{14}\text{H}_{24}\text{O}^+ [\text{M}]^+$ 208.1822, found 208.1811.

(((2,6,6-Trimethylcyclohex-2-en-1-yl)methoxy)methyl)benzene (37), prepared from geranyl benzyl ether (35.2 mg, 144 μ mol); colorless oil (35.2 mg, 144 μ mol, *quant.*, single regioisomer).



TLC: R_f = 0.33 (silica gel, *n*-hexane/EtOAc; 95:5); **^1H NMR** (300 MHz, CDCl_3) δ 7.41 – 7.25 (m, 5H), 5.43 (dt, J = 3.6, 2.0 Hz, 1H), 4.48 (s, 2H), 3.52 (dd, J = 9.9, 5.4 Hz, 1H), 3.44 (dd, J = 9.9, 3.5 Hz, 1H), 1.97 (br, 2H), 1.74 (q, J = 1.9 Hz, 3H), 1.64 – 1.53 (m, 1H), 1.53 – 1.43 (dt, J = 13.1, 7.4 Hz, 1H), 1.19 (dtd, J = 13.2, 5.4, 1.5 Hz, 1H), 0.97 (s, 3H), 0.91 (s, 3H) ppm; **^{13}C NMR** (75 MHz, CDCl_3) δ 138.9, 133.7, 128.4, 127.7, 127.5, 122.4, 73.10, 70.93, 50.17, 32.58, 31.93, 27.63, 27.23, 23.28, 23.15 ppm; **IR** (neat) $\tilde{\nu}_{\text{max}}$ = 2955, 2868, 1454, 1363, 1101, 733, 697 cm^{-1} ; **HRMS** (EI) calcd. for $\text{C}_{17}\text{H}_{24}\text{O}^+$ $[M]^+$ 244.1822, found 244.1815.

(2,6,6-trimethylcyclohex-2-en-1-yl)methyl 5'-((3a'S,4'S,6a'R)-2'-oxohexahydro-1'H-thieno[3',4'-d]imidazol-4'-yl)pentanoate (39), prepared from geranyl biotinate (39.4 mg, 104 μ mol); colorless semisolid (28.1 mg, 73.8 μ mol, 71%, d.r. = 50:50 (epimers); 85:15 mixture of inseparable regioisomers).



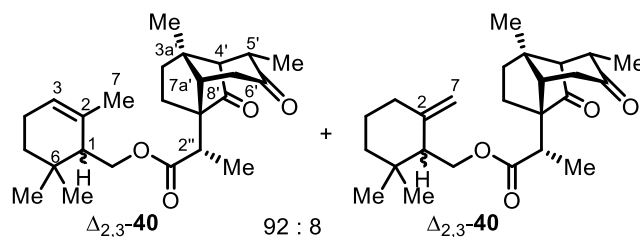
TLC: R_f = 0.36 (silica gel, EtOAc/MeOH; 90:10); diastereomeric mixture of $\Delta_{2,3}$ -**39**: **^1H NMR** (400 MHz, CDCl_3) δ 5.67 (s, 1H), 5.44

(s, 1H), 5.36 (s, 1H), 4.51 (dd, J = 7.8, 5.0 Hz, 1H), 4.31 (dd, J = 7.0, 5.3 Hz, 1H), 4.17 (m, 1H), 4.05 (dd, J = 11.7, 3.5 Hz, 1H), 3.15 (br, 1H), 2.91 (dd, J = 12.9, 5.0 Hz, 1H), 2.74 (d, J = 12.8 Hz, 1H), 2.31 (t, J = 7.5 Hz, 2H), 1.97 (br, 2H), 1.79 – 1.76 (m, 1H), 1.72 (q, J = 1.9 Hz, 3H), 1.70 – 1.59 (m, 4H), 1.48 – 1.40 (m, 3H), 1.19 (dt, J = 12.9, 4.9 Hz, 1H), 0.93 (s, 3H), 0.91 (s, 3H) ppm; **^{13}C NMR** (101 MHz, CDCl_3) δ 173.7, 163.7, 132.33, 132.31, 123.38, 123.36, 64.27, 64.24, 62.12, 60.30, 55.55, 48.97, 40.70, 34.28, 32.19, 31.89, 28.56, 28.51, 27.51, 27.28, 27.26, 24.87, 23.12, 23.04 ppm.

Characteristic signal of $\Delta_{2,7}$ -**39**: **^1H NMR** (400 MHz, CDCl_3) δ 4.81 (s, 1H), 4.58 (d, J = 2.0 Hz, 1H), 4.25 – 4.21 (m, 1H), 2.15 (dt, J = 8.9, 4.8 Hz, 2H), 0.98 (s, 3H), 0.86 (s, 3H) ppm.

Mixture of $\Delta_{2,3}$ -**39** and $\Delta_{2,7}$ -**39**: **IR** (neat) $\tilde{\nu}_{\text{max}}$ = 3215, 2921, 1733, 1698, 1472, 1168, 731 cm^{-1} ; **HRMS** (ESI+) calcd. for $\text{C}_{20}\text{H}_{33}\text{N}_2\text{O}_3\text{S}^+$ $[M+H]^+$ 381.2206, found 381.2210.

(2,6,6-Trimethylcyclohex-2-en-1-yl)methyl 2''-(3a',5'-dimethyl-6',8'-dioxooctahydro-1'H-1',4'-methanoinden-1'-yl)propanoate (40), prepared from geranyl santonate (41.4 mg, 103 μ mol); colorless oil (27.3 mg, 68.0 μ mol, 66%, 92:8 mixture of inseparable regioisomers, d.r = 55:45 [*C1*-epimer]).



Major *C1*-epimer of the $\Delta_{2,3}$ -isomer: **TLC**: R_f = 0.26 (silica gel, *n*-hexane/EtOAc; 80:20); **^1H NMR** (400 MHz, CDCl_3) δ 5.45 (s, 1H), 4.23 (dd, J = 11.8, 5.7 Hz, 1H), 3.96 (dd, J = 11.7, 2.9 Hz, 1H), 2.78 (q, J = 7.2 Hz, 1H), 2.67 (dd, J = 7.1, 3.9 Hz, 1H),

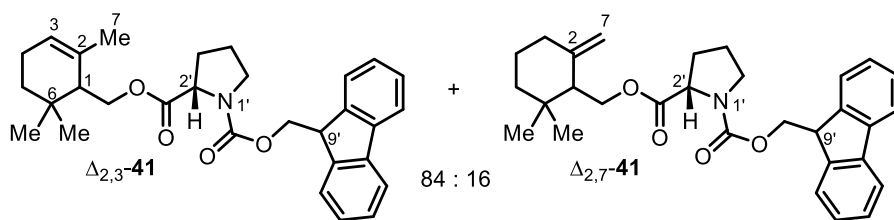
2.63 (dd, J = 18.1, 2.3 Hz, 1H), 2.48 (dd, J = 18.1, 4.9 Hz, 1H), 2.18 (td, J = 12.4, 5.6 Hz, 1H), 2.08 (t, J = 3.6 Hz, 1H), 2.02 (br, 1H), 1.97 (bt, 2H), 1.71 (q, J = 1.9 Hz, 3H), 1.62 (dd, J = 9.4, 5.7 Hz, 1H), 1.55 – 1.43 (m, 2H), 1.33 (s, 3H), 1.32 (d, J = 7.2 Hz, 3H), 1.15 (d, J = 6.7 Hz, 3H), 0.94 (s, 3H), 0.91 (s, 3H) ppm; **^{13}C NMR** (101 MHz, CDCl_3) δ 216.3, 209.5, 174.4, 132.1, 123.6, 64.19, 63.09, 61.34, 51.62, 49.04, 44.76, 44.22, 38.03, 37.83, 33.46, 32.10, 31.89, 27.58, 27.47, 26.42, 23.07, 23.03, 16.79, 13.59, 12.67 ppm.

Characteristic signals of the major *C1*-epimer of the $\Delta_{2,7}$ -isomer: **^1H NMR** (400 MHz, CDCl_3) δ 4.82 (s, 1H), 4.59 (s, 1H), 4.32 – 4.24 (m, 1H), 4.10 (dd, J = 8.6, 4.3 Hz, 1H), 0.98 (s, 3H), 0.85 (s, 3H) ppm.

Mixture of $\Delta_{2,3}$ -**40** and $\Delta_{2,7}$ -**40** major *C1*-epimer: **IR** (neat) $\tilde{\nu}_{\text{max}}$ = 2931, 2875, 1727, 1713, 1458, 1382, 1324, 1259, 1162, 1123, 1103, 1068, 1021, 921, 846, 801 cm^{-1} ; **HRMS** (ESI+) calcd. for $\text{C}_{25}\text{H}_{37}\text{O}_4^+$ [$\text{M}+\text{H}$] $^+$ 401.2686, found 401.2688;

Minor *C1*-epimer of the $\Delta_{2,3}$ -isomer: **TLC**: R_f = 0.23 (silica gel, *n*-hexane/EtOAc; 80:20); **^1H NMR** (400 MHz, CDCl_3) δ 5.47 (s, 1H), 4.13 (dd, J = 11.8, 5.1 Hz, 1H), 4.08 (dd, J = 11.8, 3.4 Hz, 1H), 2.77 (q, J = 7.1 Hz, 1H), 2.69 – 2.56 (m, 2H), 2.45 (dd, J = 18.2, 4.9 Hz, 1H), 2.18 (td, J = 12.3, 5.4 Hz, 1H), 2.07 (t, J = 3.6 Hz, 1H), 2.05 – 1.94 (m, 3H), 1.71 (q, J = 1.9 Hz, 3H), 1.65 – 1.58 (m, 1H), 1.56 – 1.45 (m, 3H), 1.34 (d, J = 7.1 Hz, 3H), 1.33 (s, 3H), 1.32 – 1.28 (m, 2H), 1.14 (d, J = 6.8 Hz, 3H), 0.94 (s, 3H), 0.91 (s, 3H) ppm; **^{13}C NMR** (101 MHz, CDCl_3) δ 216.2, 209.5, 174.6, 132.0, 123.8, 64.34, 63.06, 61.39, 51.78, 48.94, 44.70, 44.27, 38.02, 37.61, 33.46, 32.38, 31.89, 27.63, 27.41, 26.21, 23.00, 22.96, 16.77, 13.61, 12.63 ppm; **IR** (neat) $\tilde{\nu}_{\text{max}}$ = 2937, 1728, 1458, 1382, 1323, 1256, 1160, 1105, 1058, 1022, 846, 800 cm^{-1} ; **HRMS** (ESI+) calcd. for $\text{C}_{25}\text{H}_{37}\text{O}_4^+$ [$\text{M}+\text{H}$] $^+$ 401.2686, found 401.2689.

1-((9'*H*-Fluoren-9'-yl)methyl) 2-((2,6,6-trimethylcyclohex-2-en-1-yl)methyl) (2*S*)-pyrrolidine-1',2'-dicarboxylate (41), prepared from *N*-Fmoc-L-proline geranyl ester (70.6 mg, 149 μ mol); colorless oil (41.5 mg, 87.6 μ mol, 59%, 84:16 mixture of inseparable regioisomers, d.r. = 52:48 [*C1*-epimers]).



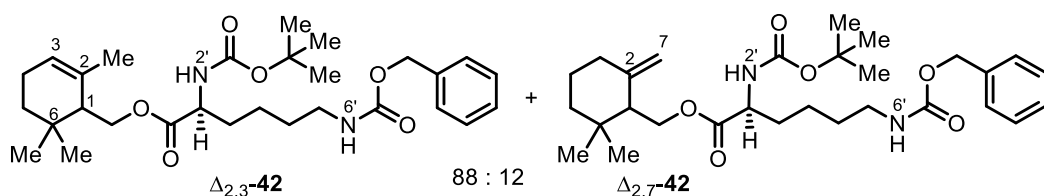
TLC: R_f = 0.38 (silica gel, *n*-hexane/EtOAc; 80:20); Major *C1*-epimer of $\Delta_{2,3}$ -**41**: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 7.76 (dd, J = 7.5,

4.9 Hz, 2H), 7.65 – 7.52 (m, 2H), 7.40 (td, J = 7.5, 3.3 Hz, 2H), 7.31 (tdd, J = 7.5, 2.6, 1.2 Hz, 2H), 5.43 (br s, 1H), 4.45 – 4.23 (m, 4H), 4.23 – 4.01 (m, 2H), 3.65 (br, 1H), 3.54 (br, 1H), 2.34 – 2.12 (m, 1H), 2.12 – 1.85 (m, 5H), 1.72 (d, J = 1.8 Hz, 1H), 1.66 (q, J = 2.0 Hz, 1H), 1.64 – 1.58 (m, 1H), 1.58 – 1.37 (m, 1H), 1.17 (dtd, J = 13.0, 9.6, 8.8, 6.6 Hz, 1H), 1.00 – 0.81 (m, 7H) ppm; $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 172.8, 172.7, 172.6, 155.0, 154.5, 144.3, 144.1, 143.9, 141.4, 132.2, 132.1, 131.8, 131.7, 127.8, 127.2, 127.2, 125.4, 125.3, 125.2, 123.7, 123.7, 123.5, 120.1, 67.89, 67.81, 67.59, 64.96, 64.68, 59.65, 59.59, 59.28, 49.03, 48.96, 48.91, 47.41, 47.15, 46.62, 32.35, 32.22, 31.86, 31.25, 31.19, 30.00, 29.93, 27.61, 27.50, 27.37, 27.29, 27.18, 27.06, 24.52, 23.58, 23.51, 23.03, 22.99 ppm.

Characteristic signals for $\Delta_{2,7}$ -**41**: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 4.81 (dd, J = 12.4, 7.4 Hz, 1H), 4.65 – 4.54 (m, 1H) ppm.

Mixture of $\Delta_{2,3}$ -**41** and $\Delta_{2,7}$ -**41**: IR (KBr) $\tilde{\nu}_{\text{max}}$ = 2957, 1740, 1704, 1451, 1419, 1350, 1176, 758 cm^{-1} ; HRMS (ESI+) calcd. for $\text{C}_{30}\text{H}_{36}\text{NO}_4^+$ $[\text{M}+\text{H}]^+$ 474.2639, found 474.2639.

(2,6,6-Trimethylcyclohex-2-en-1-yl)methyl N6'-((benzyloxy)carbonyl)-N2'-(tert-butoxycarbonyl)-L-lysinate (42), prepared from *N2'*-Boc-*N6'*-Cbz-L-lysine geranyl ester (30.6 mg, 59.2 μmol); colorless semisolid (23.6 mg, 45.6 μmol , 77%, 88:12 mixture of inseparable regioisomers; d.r. = 50:50 [*C1*-epimers]).



TLC: R_f = 0.18 (silica gel, *n*-hexane/EtOAc; 80:20); $\Delta_{2,3}$ -**42**: ^1H

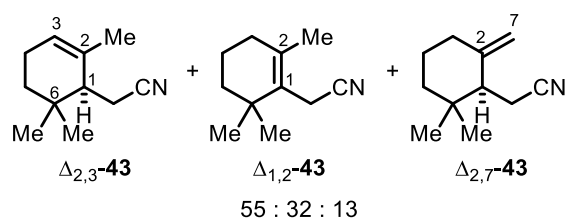
NMR (400 MHz, CDCl_3) δ 7.38 – 7.29 (m, 4H), 7.33 – 7.29 (m, 1H), 5.46 (s, 1H), 5.09 (s, 2H), 5.08 – 5.00 (m, 1H), 4.81 (br s, 1H), 4.29 (dd, J = 17.8, 8.5 Hz, 1H), 4.23 (dd, J = 11.7, 5.7 Hz, 1H), 4.11 (ddd, J = 11.4, 7.5, 3.2 Hz, 1H), 3.18 (d, J = 7.4 Hz, 2H), 2.18 – 2.01 (m, 1H), 1.97 (br, 2H), 1.78 (br, 2H), 1.71 (dd, J = 3.6, 1.8 Hz, 3H), 1.68 – 1.47 (m, 3H), 1.43 (s, 9H), 1.39 – 1.28 (m, 2H), 1.20 (dt, J = 13.7, 4.7 Hz, 1H), 0.93 (d, J = 2.6 Hz, 3H), 0.91 (s, 3H) ppm; $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 173.6, 156.4, 154.7, 136.6, 131.8, 131.7, 128.5, 128.14, 128.09, 123.6, 123.5, 79.89, 66.65, 65.02, 64.79, 53.26, 48.88, 48.82, 40.73, 32.37, 32.06, 31.99,

31.74, 29.40, 28.33, 27.36, 27.29, 27.19, 22.91, 22.88, 22.84, 22.37 ppm further signals could not be identified due to overlapped with the signals of the major isomer.

Characteristic signals of $\Delta_{2,3}$ -**42**: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 4.65 (s, 1H), 4.63 (s, 1H), 4.58 (s, 1H), 4.56 (s, 1H) ppm.

Mixture of $\Delta_{2,3}$ -**42** and $\Delta_{2,7}$ -**42**: IR (neat) $\tilde{\nu}_{\text{max}}$ = 3342, 2932, 1712, 1524, 1250, 1168, 1023, 698 cm^{-1} ; HRMS (ESI+) calcd. for $\text{C}_{29}\text{H}_{44}\text{N}_2\text{O}_6\text{Na}^+ [\text{M}+\text{Na}]^+$ 539.3091, found 539.3102.

2-(2,6,6-Trimethylcyclohex-2-en-1-yl)acetonitrile (43), prepared from geranyl nitrile (37.0 mg, 227 μmol); yellow oil (33.3 mg, 204 μmol , 90%, 55:32:13 mixture of regioisomers).



TLC: R_f = 0.33 (silica gel, *n*-hexane/EtOAc; 95:5) [CAM];

$\Delta_{2,3}$ -**43**: $^1\text{H NMR}$ (500 MHz, CDCl_3) δ 5.50 (t, J = 3.3 Hz, 1H), 2.45 (dd, J = 17.3, 6.3 Hz, 1H), 2.37 (dd, J = 17.4, 4.6 Hz, 1H), 2.01 (br, 2H), 1.75 (q, J = 1.9 Hz, 3H), 1.62 – 1.50 (m, 2H), 1.26 – 1.19 (m, 1H), 1.01 (s, 3H), 0.93 (s, 3H)

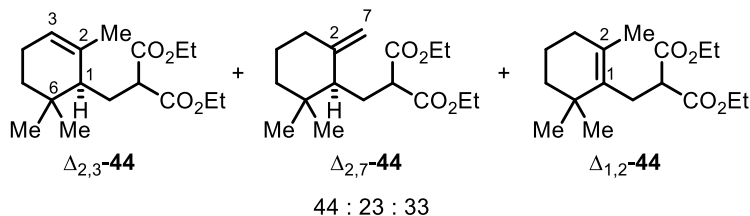
ppm; $^{13}\text{C NMR}$ (75 MHz, CDCl_3) δ 132.4, 124.0, 120.2, 46.28, 32.36, 31.08, 27.82, 27.37, 27.01, 22.77, 17.78 ppm.

Characteristic signals for $\Delta_{1,2}$ -**43**: $^1\text{H NMR}$ (500 MHz, CDCl_3) δ 2.98 (s, 2H), 1.98 (t, J = 6.3 Hz, 2H), 1.70 (s, 3H), 1.04 (s, 6H) ppm further signals could not be identified due to overlapped with the signals of the other isomer.

Characteristic signals of $\Delta_{2,7}$ -**43**: $^1\text{H NMR}$ (500 MHz, CDCl_3) δ 4.95 (s, 1H), 4.74 (s, 1H), 2.55 (dd, J = 16.7, 4.3 Hz, 1H), 2.09 (dd, J = 7.8, 5.4 Hz, 1H), 0.99 (s, 3H), 0.80 (s, 3H) ppm further signals could not be identified due to overlapped with the signals of the other isomer.

The spectroscopic data are in accordance with those reported in the literature.¹²

Diethyl 2-((2,6,6-trimethylcyclohex-2-en-1-yl)methyl)malonate (44), prepared from diethyl 2-geranyl malonate (44.2 mg, 149 μmol); colorless oil (38.0 mg, 128 μmol , 86%, 44:23:33 mixture of inseparable regioisomers);



TLC: R_f = 0.32 (silica gel, *n*-hexane/EtOAc; 90:10); Characteristic signals of $\Delta_{2,3}$ -44: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 5.30 (s, 1H), 4.23 – 4.13 (m, 4H), 3.47 (t, J = 7.0 Hz, 1H), 2.04 – 1.89

(m, 4H), 1.68 (q, J = 1.7 Hz, 3H), 1.30 – 1.23 (m, 6H), 1.13 (dt, J = 13.6, 4.4 Hz, 1H), 0.93 (s, 3H), 0.87 (s, 3H) ppm further signals could not be identified due to overlapped with the signals of the other isomers.

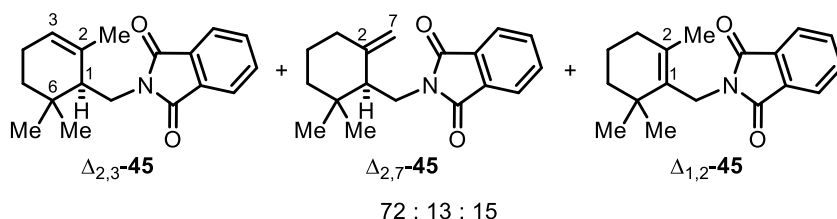
Characteristic signals of $\Delta_{2,7}$ -44: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 4.76 (s, 1H), 4.49 (s, 1H), 3.27 (dd, J = 11.2, 3.4 Hz, 1H), 2.12 (ddd, J = 14.1, 11.2, 3.1 Hz, 1H), 1.71 (dd, J = 12.2, 3.1 Hz, 1H), 0.86 (s, 3H), 0.82 (s, 3H) ppm further signals could not be identified due to overlapped with the signals of the other isomers.

Characteristic signals of $\Delta_{1,2}$ -44: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 2.67 (d, J = 7.0 Hz, 2H), 1.50 (s, 3H), 0.92 (s, 6H) ppm further signals could not be identified due to overlapped with the signals of the other isomers.

Mixture of $\Delta_{2,3}$ -44, $\Delta_{2,7}$ -44, and $\Delta_{1,2}$ -44: $^{13}\text{C NMR}$ (75 MHz, CDCl_3) δ 170.3, 170.0, 169.9, 169.7, 148.1, 135.9, 134.1, 130.6, 121.2, 110.6, 110.1, 61.45, 61.42, 61.23, 52.89, 52.77, 51.66, 50.55, 46.80, 40.25, 34.94, 33.16, 32.91, 30.96, 30.35, 28.80, 28.40, 27.53, 27.30, 27.24, 26.21, 23.60, 23.48, 23.13, 20.58, 19.42, 14.29, 14.26, 14.23, 14.19 ppm further signals could not be identified due to overlapped with the signals of the isomers.

The spectroscopic data are in accordance with those reported in the literature.¹³

2-((2,6,6-Trimethylcyclohex-2-en-1-yl)methyl)isoindolinedione (45), prepared from *N*-geranyl phthalimide (18.5 mg, 65.4 μmol); colorless oil (13.4 mg, 47.3 μmol , 72%, 72:13:15 mixture of inseparable regioisomers).



TLC: R_f = 0.37 (silica gel, *n*-hexane/EtOAc; 90:10); $\Delta_{2,3}$ -45: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 7.83 (dd, J = 5.4, 3.1 Hz, 2H), 7.70 (dd, J = 5.5, 3.0 Hz, 2H),

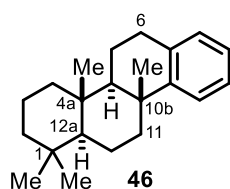
5.41 (s, 1H), 3.82 (dd, J = 14.0, 7.0 Hz, 1H), 3.54 (dd, J = 14.0, 5.9 Hz, 1H), 2.25 (t, J = 6.5 Hz, 1H), 2.10 – 1.96 (m, 2H), 1.72 (q, J = 1.9 Hz, 3H), 1.65 – 1.55 (m, 1H); 1.26 – 1.17 (m, 1H), 0.96 (s, 3H), 0.89 (s, 3H) ppm; $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 168.8, 134.0, 132.3, 123.3, 123.2, 122.8, 47.29, 40.21, 32.21, 30.40, 27.31, 26.96, 23.77, 23.20 ppm.

Characteristic signals of $\Delta_{2,7}$ -**45**: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 4.59 (t, $J = 2.2$ Hz, 1H), 4.41 (t, $J = 2.0$ Hz, 1H), 4.00 (dd, $J = 13.4, 12.2$ Hz, 1H), 3.69 (dd, $J = 13.4, 4.6$ Hz, 1H) ppm further signals could not be identified due to overlapped with the signals of the other isomers.

Characteristic signals of $\Delta_{1,2}$ -**45**: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 4.39 (s, 2H), 1.81 (s, 3H), 1.04 (s, 3H) ppm further signals could not be identified due to overlapped with the signals of the other isomers.

Mixture of $\Delta_{2,3}$ -**45**, $\Delta_{2,7}$ -**45**, and $\Delta_{1,2}$ -**45**: IR (neat) $\tilde{\nu}_{\text{max}} = 2916, 1771, 1713, 1436, 1398, 1353, 717 \text{ cm}^{-1}$; HRMS (ESI+) calcd. for $\text{C}_{18}\text{H}_{22}\text{NO}_2^+$ $[\text{M}+\text{H}]^+$ 284.1645, found 284.1646.

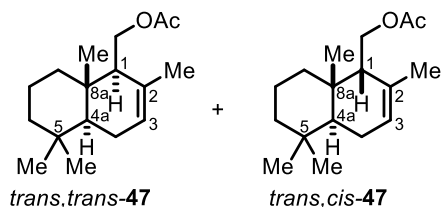
1,1,4a,10b-tetramethyl-1,2,3,4,4a,4b,5,6,10b,11,12,12a-dodecahydrochrysene (46), prepared from (*E,E*)-homofarnesyl benzene (35.2 mg, 119 μmol); colorless oil (24.3 mg, 82.1 μmol , 69%, d.r. > 95:5).



TLC: $R_f = 0.56$ (silica gel, *n*-hexane); $^1\text{H NMR}$ (500 MHz, CDCl_3) δ 7.25 (d, $J = 7.5$ Hz, 1H), 7.12 (t, $J = 7.5$ Hz, 1H), 7.08 – 7.01 (m, 2H), 2.93 (ddd, $J = 17.2, 6.6, 1.8$ Hz, 1H), 2.86 – 2.78 (m, 1H), 2.39 (dd, $J = 9.5, 3.2$ Hz, 1H), 1.85–1.76 (m, 2H), 1.73 – 1.62 (m, 3H), 1.53 – 1.35 (m, 6H), 1.30 – 1.25 (m, 2H), 1.20 (s, 3H), 0.93 (s, 3H), 0.87 (s, 3H), 0.86 (s, 3H); $^{13}\text{C NMR}$ (126 MHz, CDCl_3) δ 150.6, 135.3, 128.9, 125.8, 125.2, 124.7, 56.40, 55.30, 42.20, 40.71, 39.95, 38.29, 37.80, 33.48, 33.44, 31.02, 26.31, 21.60, 19.27, 18.76, 18.09, 16.44 ppm.

The spectroscopic data are in accordance with those reported in the literature.¹³

(±)-Drimenol acetate (47), prepared from (*E,E*)-farnesyl acetate (39.4 mg, 149 μmol); colorless oil (25.9 mg, 98.0 μmol , 66%, d.r. = 65:35 [*C1*-epimer]).



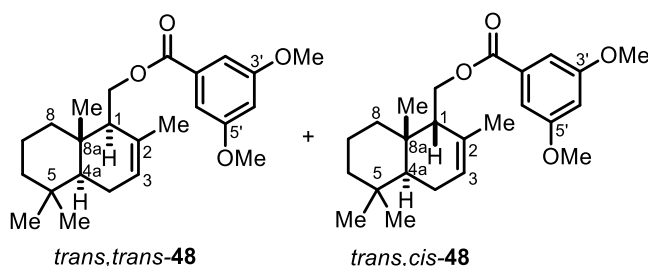
TLC: $R_f = 0.61$ (silica gel, *n*-hexane/EtOAc; 90:10); major diastereoisomer *trans,trans*-**47**: $^1\text{H NMR}$ (300 MHz, CDCl_3) δ 5.52 – 5.42 (m, 1H), 4.24 (dd, $J = 11.6, 3.3$ Hz, 1H), 4.08 (dd, $J = 11.7, 6.4$ Hz, 1H), 2.03 (s, 3H), 2.05 – 1.82 (m, 4H), 1.67 (dt, $J = 2.5, 1.4$ Hz, 3H), 1.54 – 1.37 (m, 3H), 1.24 – 1.08 (m, 3H), 0.89 (s, 3H), 0.86 (s, 3H), 0.81 (s, 3H) ppm.

Characteristic signals of the minor diastereoisomer *trans,cis*-**47**: $^1\text{H NMR}$ (300 MHz, CDCl_3) δ 5.44 (br s, 1H) ppm further signals could not be identified due to overlapped with the signals of the major isomers.

Mixture of *trans,trans*-**47** and *trans,cis*-**47**: ^{13}C NMR (101 MHz, CDCl_3) δ 171.3, 132.7, 123.8, 63.36, 53.52, 50.01, 42.23, 39.70, 36.10, 33.45, 33.11, 23.75, 22.08, 21.85, 21.40, 18.87, 14.62 ppm.

The spectroscopic data are in accordance with those reported in the literature.¹⁴

(2,5,5,8a-Tetramethyl-1,4,4a,5,6,7,8,8a-octahydronaphthalen-1-yl)methyl 3',5'-dimethoxybenzoate (48), prepared from (*E,E*)-farnesyl 3,5-dimethoxybenzoate (48.2 mg, 125 μmol); colorless oil (29.7 mg, 76.8 μmol , 62%, d.r = 65:35 [*C1*-epimer]).



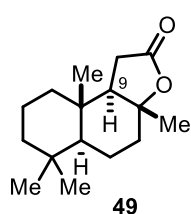
TLC: R_f = 0.61 (silica gel, *n*-hexane/EtOAc; 90:10); major diastereoisomer *trans,trans*-**48**: ^1H NMR (400 MHz, CDCl_3) δ 7.17 (d, J = 2.3 Hz, 2H), 6.64 (t, J = 2.4 Hz, 1H), 5.56 – 5.53 (m, 1H), 4.55 (dd, J = 11.7, 3.4 Hz, 1H), 4.30 (dd, J = 11.7, 6.0 Hz, 1H), 3.82 (s, 6H), 2.18 (br s, 1H), 2.08 –

1.86 (m, 2H), 1.74 (s, 3H), 1.64 – 1.53 (m, 2H), 1.52 – 1.38 (m, 3H), 1.25 (q, J = 5.1 Hz, 1H), 1.17 (dd, J = 12.9, 3.9 Hz, 1H), 0.90 (s, 6H), 0.88 (s, 3H) ppm; ^{13}C NMR (75 MHz, CDCl_3) δ 166.5, 160.8, 132.6, 132.5, 124.1, 107.3, 105.7, 63.85, 55.68, 53.77, 50.04, 42.23, 39.83, 36.21, 33.48, 33.13, 23.80, 22.12, 22.05, 18.90, 14.87 ppm.

Characteristic signals of the minor diastereoisomer *trans,cis*-**48**: ^1H NMR (400 MHz, CDCl_3) δ 5.48 (t, J = 7.4 Hz, 1H), 1.00 (s, 3H) ppm further signals could not be identified due to overlapped with the signals of the major isomers.

Mixture of *trans,trans*-**48** and *trans,cis*-**48**: IR (KBr) $\tilde{\nu}_{\text{max}}$ = 2926, 1716, 1598, 1459, 1303, 1230, 1157, 1052, 759 cm^{-1} ; HRMS (ESI+) calcd. for $\text{C}_{24}\text{H}_{35}\text{O}_4^+$ [$\text{M}+\text{H}$] $^+$ 387.2530, found 387.2537.

($\pm$)-sclareolide (49), prepared from (*E,E*)-homofarnesoic acid (31.0 mg, 124 μmol); colorless solid (17.7 mg, 70.7 μmol , 57%); 9-*epi*-sclareolide (minor diastereomer) could not be separated from further side products.

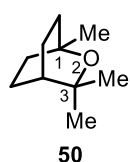


($\pm$)-49: TLC: R_f = 0.44 (silica gel, *n*-hexane/EtOAc; 80:20) [KMnO_4]; ^1H NMR (300 MHz, CDCl_3) δ 2.41 (dd, J = 16.2, 14.7 Hz, 1H), 2.23 (ddd, J = 16.2, 6.5, 0.6 Hz, 1H), 2.08 (dt, J = 11.8, 3.3 Hz, 1H), 1.97 (dd, J = 14.7, 6.5 Hz, 1H), 1.88 (ddt, J = 14.0, 4.2, 2.9 Hz, 1H), 1.75 – 1.62 (m, 2H), 1.51 – 1.35 (m, 4H), 1.33 (d, J = 1.0 Hz, 3H), 1.19 (td, J = 13.6, 4.3

Hz, 1H), 1.04 (ddd, $J = 13.8, 10.3, 3.3$ Hz, 2H), 0.91 (s, 3H), 0.89 (s, 3H), 0.84 (s, 3H) ppm; ^{13}C NMR (75 MHz, CDCl_3) δ 177.0, 86.52, 59.28, 56.82, 42.33, 39.67, 38.88, 36.22, 33.32, 33.28, 28.87, 21.72, 21.07, 20.71, 18.24, 15.22 ppm.

The spectroscopic data are in accordance with those reported in the literature.¹⁵

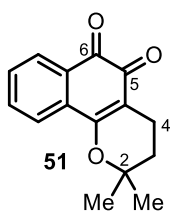
1,3,3-Trimethyl-2-oxabicyclo[2.2.2]octane (50), prepared from (-)- α -terpineol (17.6 mg, 114 μmol); colorless liquid (13.5 mg, 87.5 μmol , 77%; d.r. $\geq 95:5$).



TLC: $R_f = 0.63$ (silica gel, n -hexane/EtOAc; 95:5); ^1H NMR (400 MHz, CDCl_3) δ 2.01 (tdd, $J = 9.1, 3.8, 1.2$ Hz, 2H), 1.73 – 1.57 (m, 2H), 1.56 – 1.43 (m, 4H), 1.39 (tq, $J = 3.4, 1.2$ Hz, 1H), 1.23 (s, 6H), 1.04 (s, 3H) ppm; ^{13}C NMR (101 MHz, CDCl_3) δ 73.76, 69.92, 33.06, 31.63, 29.02, 27.71, 22.95 ppm.

The spectroscopic data are in accordance with those reported in the literature.¹⁶

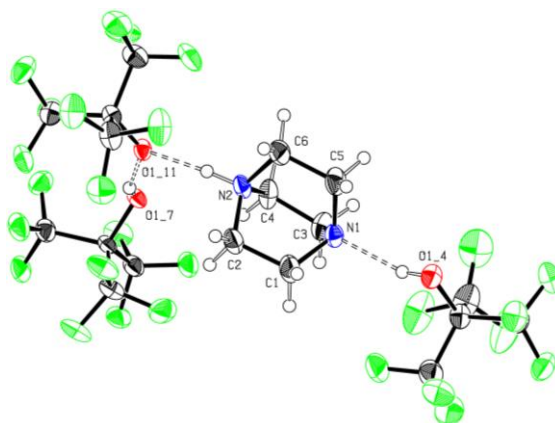
2,2-Dimethyl-3,4-dihydro-2H-benzo[h]chromene-5,6-dione (51), prepared from lapachol (31.0 mg, 128 μmol); orange crystals (27.0 mg, 111 μmol , 87%).



TLC: $R_f = 0.20$ (silica gel, n -hexane/EtOAc; 80:20); ^1H NMR (400 MHz, CDCl_3) δ 8.04 (dd, $J = 7.6, 1.2$ Hz, 1H), 7.80 (dd, $J = 7.9, 1.2$ Hz, 1H), 7.63 (td, $J = 7.6, 1.4$ Hz, 1H), 7.49 (td, $J = 7.5, 1.2$ Hz, 1H), 2.56 (t, $J = 6.7$ Hz, 2H), 1.85 (t, $J = 6.7$ Hz, 2H), 1.46 (s, 6H) ppm; ^{13}C NMR (101 MHz, CDCl_3) δ 180.0, 178.7, 162.2, 134.9, 132.8, 130.8, 130.3, 128.7, 124.2, 112.9, 79.40, 31.74, 26.89 (2C), 16.29 ppm.

The spectroscopic data are in accordance with those reported in the literature.¹⁷

7. X-ray Crystal Analysis of DABCO-PFTB 54 (CCDC 2205029/ArnAn8)



Supplementary Figure 15. X-ray crystal structure of DABCO-(PFTB)₂ salt (**54**). Ortez drawing with 50% ellipsoids shown.

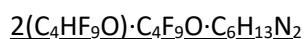
A suitable crystal of compound **54** was grown by slow diffusion of a mixture of DABCO in excess PFTB. A colorless fragment-like specimen of C₇₂H₆₀F₁₀₈N₈O₁₂, approximate dimensions 0.252 mm x 0.276 mm x 0.295 mm, was used for the X-ray crystallographic analysis.

Data were collected on a Bruker D8 Venture single crystal x-ray diffractometer equipped with a CMOS detector (Bruker Photon-100), a TXS rotating anode with MoK α radiation ($\lambda = 0.71073 \text{ \AA}$) and a Helios optic using the APEX3 software package.¹⁸ Measurements were performed on single crystals coated with perfluorinated ether. The crystals were fixed on top of a kapton micro sampler and frozen under a stream of cold nitrogen. A matrix scan was used to determine the initial lattice parameters. Reflections were corrected for Lorentz and polarisation effects, scan speed, and background using SAINT.¹⁹ Absorption correction, including odd and even ordered spherical harmonics was performed using SADABS.¹⁹ Space group assignments were based upon systematic absences, E statistics, and successful refinement of the structures. The structure was solved using SHELXT with the aid of successive difference Fourier maps and was refined as a perfect inversion twin against all data using SHELXL in conjunction with SHELXLE.²⁰ Hydrogen atoms (except on heteroatoms) were calculated in ideal positions as follows: Methyl hydrogen atoms were refined as part of rigid rotating groups with a C–H distance of 0.98 $\text{\AA}$ and $U_{\text{iso}}(\text{H}) = 1.5 \cdot U_{\text{eq}}(\text{C})$. Non-methyl H atoms were placed in calculated positions and refined using a riding model with methylene, aromatic, and other C–H distances of 0.99 $\text{\AA}$, 0.95 $\text{\AA}$, and 1.00 $\text{\AA}$, respectively, all with $U_{\text{iso}}(\text{H}) = 1.2 \cdot U_{\text{eq}}(\text{C})$. H atoms bound to heteroatoms were refined freely, if possible, and with appropriate restraints otherwise. Non-hydrogen atoms were refined with anisotropic displacement parameters. Full-matrix least-squares refinements were carried out by minimizing $\sum w(F_o^2 - F_c^2)^2$ with the SHELXL weighting scheme.³ Neutral atom scattering factors for all atoms and anomalous dispersion corrections for the non-hydrogen atoms were taken from *International Tables for Crystallography*.²¹ Disordered PFTB molecules were refined using a split layer refinement and appropriate geometries and restraints provided by DSR.²² Images of

the crystal structures were generated with PLATON.²³ CCDC 2205029 contains the supplementary crystallographic data for this paper. These data are provided free of charge by The Cambridge Crystallographic Data Centre.

Diffraction operator C. Jandl
 scanspeed 1-10 s per frame
 dx 100 mm
 5876 frames measured in 19 data sets
 phi-scans with $\Delta\phi = 0.5$
 omega-scans with $\Delta\omega = 0.5$
 shutterless mode

7.1 Crystal data



$M_r = 820.32$

$D_x = 1.962 \text{ Mg m}^{-3}$

Monoclinic, Cc

Melting point: ? K

Hall symbol: C -2yc

Mo K α radiation, $\lambda = 0.71073 \text{ \AA}$

$a = 51.072 (5) \text{ \AA}$

Cell parameters from 9763 reflections

$b = 10.0761 (11) \text{ \AA}$

$\theta = 2.7\text{--}26.9^\circ$

$c = 22.372 (3) \text{ \AA}$

$\mu = 0.25 \text{ mm}^{-1}$

$\beta = 105.274 (4)^\circ$

$T = 103 \text{ K}$

$V = 11106 (2) \text{ \AA}^3$

Fragment, colorless

$Z = 16$

$0.30 \times 0.28 \times 0.25 \text{ mm}$

$F(000) = 6464$

7.2 Data Collection

Bruker Photon CMOS
 diffractometer

20316 independent reflections

Radiation source: TXS rotating anode 19605 reflections with $I > 2\sigma(I)$

Helios optic monochromator

$R_{\text{int}} = 0.037$

Detector resolution: 16 pixels mm^{-1}

$\theta_{\text{max}} = 25.4^\circ$, $\theta_{\text{min}} = 2.1^\circ$

phi- and ω -rotation scans

$h = -61 \text{ } 61$

Absorption correction: multi-scan
SADABS 2016/2, Bruker

$k = -12 \text{ } 12$

$T_{\min} = \underline{0.695}$, $T_{\max} = \underline{0.745}$

$l = \underline{-26} \quad \underline{26}$

188659 measured reflections

7.3 Refinement

Refinement on F^2

Least-squares matrix: full

$R[F^2 > 2\sigma(F^2)] = \underline{0.033}$

$wR(F^2) = \underline{0.089}$

$S = \underline{1.01}$

20316 reflections

2217 parameters

28488 restraints

0 constraints

Primary atom site location: iterative

Secondary atom site location: difference Fourier map

Hydrogen site location: mixed

H atoms treated by a mixture of independent and constrained refinement

$W = 1/[\Sigma^2(FO2) + (0.0563P)^2 + 8.9206P]$ WHERE $P = (FO2 + 2FC2)/3$

$(\Delta/\sigma)_{\max} = \underline{0.001}$

$\Delta\rho_{\max} = \underline{0.42} \text{ e } \text{\AA}^{-3}$

$\Delta\rho_{\min} = \underline{-0.30} \text{ e } \text{\AA}^{-3}$

Extinction correction: none

Extinction coefficient: -

Absolute structure: Flack⁹

Absolute structure parameter: 0.5 (4)

8. Simulation Details

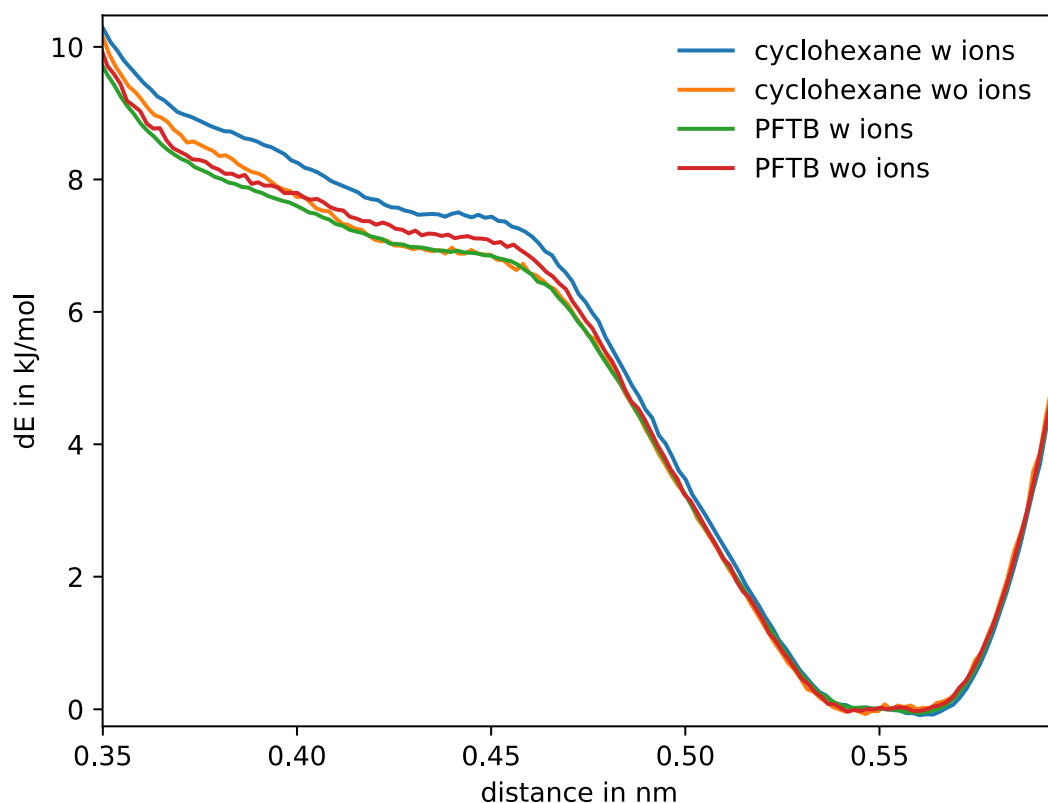
MD investigations were performed with the GROMACS simulation package²⁴ (versions ranging from 2018-2020) with the GAFF²⁵ force field with a timestep of 2 fs and the Verlet scheme. The corresponding point charges were obtained from the wfx-files with Multiwfn 3.6²⁶ after geometry optimization at B3LYP 6-311G** level with ORCA (versions 4.1.2 and 4.2.1)²⁷ employing a RESP-fitting procedure for equivalence of hydrogen CH3 and CH2. One must note that no equivalence criteria were defined for CF3 Groups. The charges on cyclohexane were averaged to obtain equivalent positions. For the bromide, the parameters in literature²⁸ were used. (Likewise for the control simulation containing sodium cations.)

Two boxes used for umbrella sampling contained 300 solvent molecules (either cyclohexane or PFTB), 10 py-H cations, 10 bromide anions, and one homogeranyl benzene molecule (**19**). Two other boxes were prepared with the same numbers but without the ionic species.

They were equilibrated for at least 10ns at the reference temperature of 300K with the velocity-rescaling thermostat ($\tau_T = 1$ ps) and a reference-pressure of 1 bar given the Parrinello-Rahman barostat ($\tau_p = 2$ ps, compressibility = 4.5×10^{-5} /bar). Coulomb interactions were treated by PME. The VdW modifier was chosen as 'Potential-Shift-Verlet'.

For the umbrella windows, a force constant of 1000 kJ/mol/nm² was chosen. The coordinate determined was the distance between the carbon atoms, which are involved in the bond formation. This allows for the determination of the free energy difference between the different solvent cases in the presence and without the presence of the number of ions mentioned above. This corresponds to the amount of stabilization of the folded to the unfolded state of **19**. Every 50th frame was written to file. From this, the PMF was obtained with the program gmx wham once equilibration was reached. The number of umbrella windows (4-12) was adjusted so that all histograms yielded sufficient overlap and equilibration could be assumed.

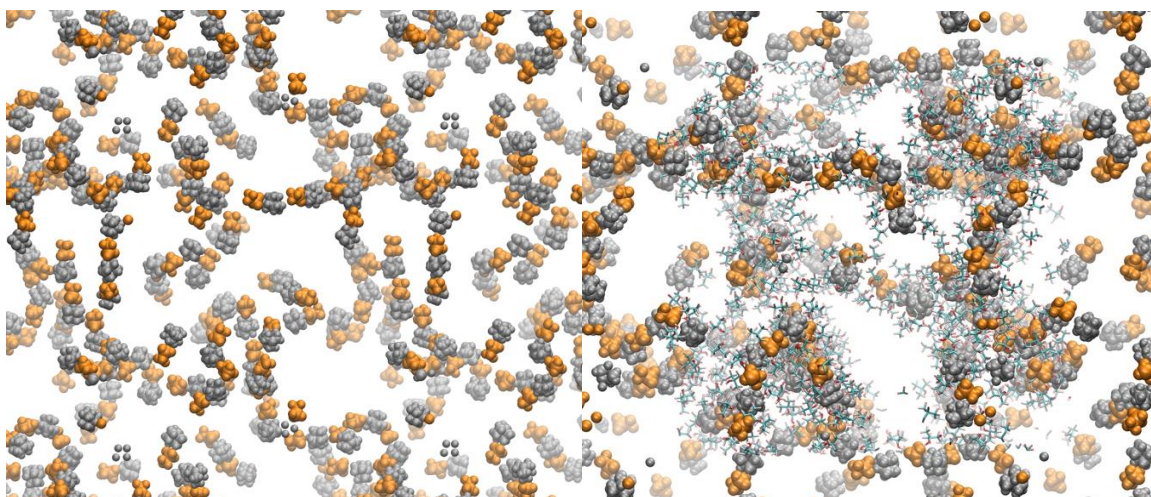
Every umbrella window was simulated at least for 30ns. In the case where ions were present in the solvent PTFB, the windows were sampled up to 200ns (of which at least the first 20 were discarded in addition to the regular equilibration period) because equilibration needed to take the slow formation of the supramolecular structures into account.



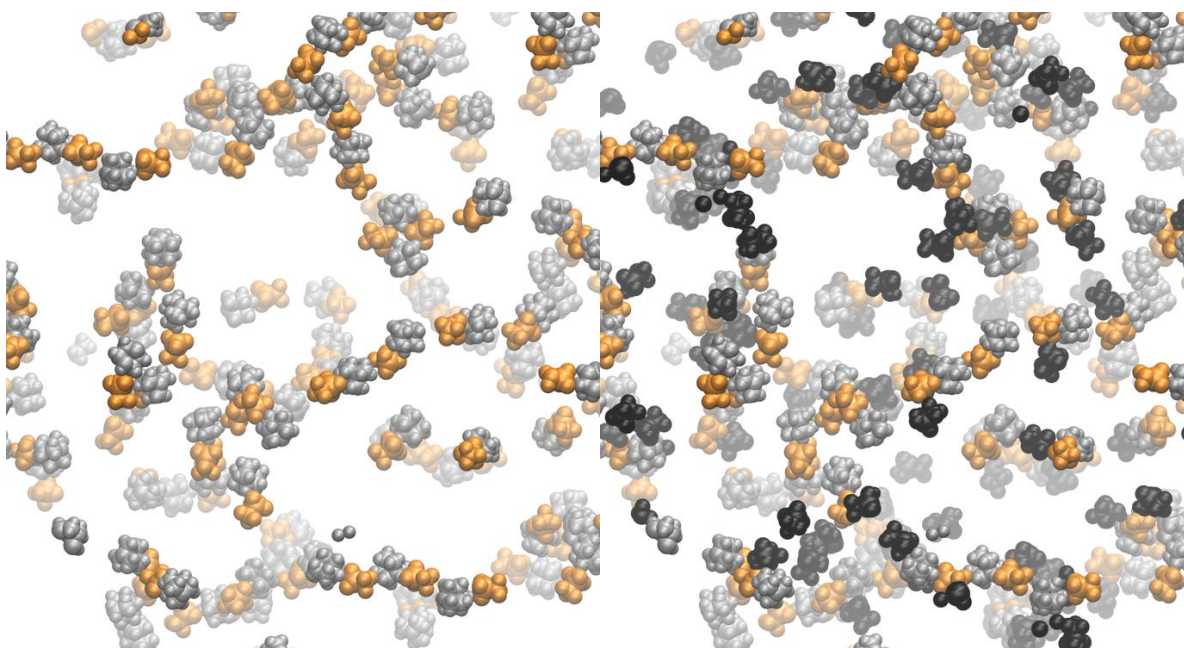
Supplementary Figure 16. PMF of the C-C distance for the reacting carbon atoms in homogeranyl benzene (**19**) in PFTB as opposed to cyclohexane at conditions described above.

To compare the ionic aggregates of catalysts **20b** and **20c** in PTBF we simulated DABCO- H^+ , TfOH, TfO^- as those are expected to play the main role in the experiments. The forcefields were obtained employing the same procedure as described above and the simulations run with conditions as before except no umbrella sampling was employed for the conformational stability of homogeranyl benzene (**19**) in solution. The system size employed was set to 8 times the previous size (2400 solvent molecules, 80 anions and cations) for efficiency (Figure S9).

Additionally, a second system was simulated where 172 of the solvent were replaced by 80 TfOH (1:1 to TfO^-) molecules and keeping the DABCO concentration roughly identical (Figure S10). Both DABCO bistriflate systems showed the familiar extended ionic aggregates as previously observed for the pyridinium-HBr system.



Supplementary Figure 17. Snapshot of the $\text{DABCOH}^+/\text{TfO}^-$ simulation – PFTB shown on the right-hand side revealing a preferential OH orientation towards the aggregates.



Supplementary Figure 18. Snapshot of the $\text{DABCOH}^+/\text{TfO}^-/\text{TfOH}$ simulation – TfOH displayed in black on the right-hand side.

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