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Anthracene Cycloadducts as Highly Selective Chiral Auxiliaries

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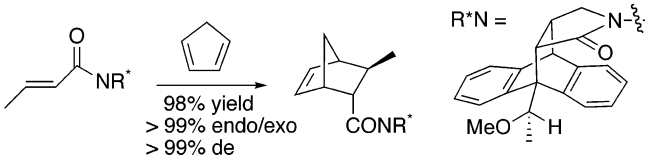


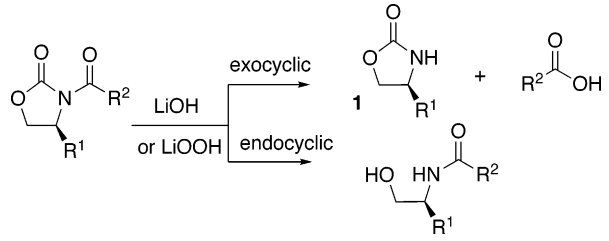
A new chiral auxiliary was designed and easily prepared from a Diels−Alder cycloadduct of an enantiomerically pure anthracene with maleimide. Excellent diastereoselectivities in Diels−Alder reactions, conjugate additions, and aldol reactions employing these auxiliaries are now reported.

Chiral auxiliaries have found wide applications in a variety of chirality transfer reactions with some of the best known auxiliaries belonging to the Evans class of oxazolidinones.[1] In the past two decades, these auxiliaries (**1)** have proven to be among the best for controlling stereoselectivity in Diels−Alder, aldol, and many other reactions. Subsequent to Evans' initial reports, many related auxiliaries have been synthesized and investigated,[2] and the search for universally applicable chiral auxiliaries has continued, as exemplified by the nice contribution from the Boeckman group with their camphor-derived auxiliary.[3]

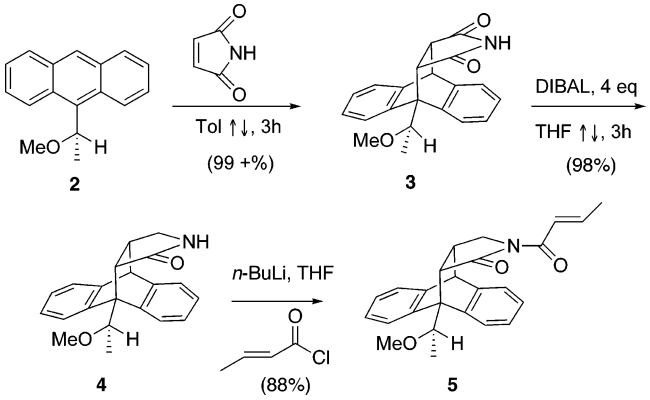
"Cleavability" of the auxiliaries can be an issue in chiral auxiliary methodology (Scheme 1). While LiOOH is frequently applied to remove Evans' type auxiliaries, greatly favoring regioselective cleavage of the exocyclic carbonyl group, unwanted endo cleavage has been observed with some sterically congested acyl imides.[4]

Previously, we reported highly diastereoselective cycloadditions between enantiomerically pure anthracenes bearing C9 stereogenic groups with maleimides (Scheme 2).[5] We also demonstrated that the imide carbonyl remote to the original

SCHEME 1. Nucleophilic Cleavage of the Oxazolidinones



SCHEME 2. Synthesis of Auxiliary 4



stereogenic substituent of the anthracene can be selectively manipulated by simple procedures, such as reductions and Grignard additions. The simple preparation of the crystalline lactam **4** from readily obtainable chiral anthracene **2**[6] makes it a candidate as a facially restrictive chiral auxiliary. The recent work of Suárez[7] on the use of a levoglucosenone-anthracene cycloadduct, which also produces a facially restrictive chiral auxiliary for Diels−Alder chemistry, has led us to report our work on **4**.

Acylation of **4** produces a Lewis acid chelation site to lock an α,β-unsaturated carbonyl moiety (acrylate, crotonate etc) above a rigidly positioned aryl ring, providing the desired facial selectivity. Initial studies focused on cycloadditions of crotonylated auxiliary **5**, readily prepared following Evans' acylation procedure (88%),[8] with cyclopentadiene (Table 1).

Extensive screening of Lewis acids demonstrated that the reaction could be promoted by several catalysts with high endo/exo selectivities (Table 1). The rates and selectivities were dependent upon the Lewis acid; $SnCl_4$ (entries 1 and 2), $TiCl_4$ (entry 3), Et_2AlCl (entry 4), Me_2AlCl (entry 5), and $BF_3{\cdot}OEt_2$ all gave very high catalytic activities (100% conversion in 3 h or less at −100 °C), but $SnCl_4$ showed much better diastereoselectivity favoring *endo*-I cycloadduct **6a** (entries 1 and 2). The best selectivity was achieved with $ZrCl_4$, though the reaction was sluggish at −78 °C. With $ZrCl_4$ (10 mol %) at −50 °C, an endo/exo diastereoselectivity of >200:1 with an *endo*-I/*endo*-II diastereoselectivity of 75:1 was obtained in 6 h. The selectivity was slightly lower when Me_2AlCl or Et_2AlCl were used. Other

(1) Reviews: (a) Ager, D. J.; Prakash, I.; Schaad, D. R. *Aldrichim. Acta* **1997**, *30*, 3. (b) Evans, D. A.; Shaw, J. T. *Actual. Chim.* **2003**, 35.

(2) Recent reviews: (a) Gnas, Y.; Glorius, F. *Synthesis* **2006**, 1899. (b) Evans, D. A.; Helmchen, G.; Ruping, M.; Wolfgang, J. In *Asymmetric Synthesis*: *The Essentials*, Christmann, M., Bräse, S., Eds.; Wiley-VCH: Weinheim, Germany, 2007; p 3.

(3) Boeckman, R. K., Jr.; Shao, P.; Wrobleski, S. T.; Boehmler, D. J.; Heintzelman, G. R.; Barbosa, A. J. *J. Am. Chem. Soc.* **2006**, *128*, 10572 and references therein.

(4) Evans, D. A.; Britton, T. C.; Ellman, J. A. *Tetrahedron Lett.* **1987**, *28*, 6141.

(5) (a) Burgess, K. L.; Corbett, M. S.; Eugenio, P.; Lajkiewicz; N. J.; Liu, X.; Sanyal, A.; Yan, W.; Yuan, Q.; Snyder, J. K. *Bioorg. Med. Chem.* **2005**, *13*, 5299. For related work, see: (b) Bawa, R. A.; Jones, S. *Tetrahedron* **2004**, *60*, 2765 and references therein.

(6) (a) Reiners, I.; Martens, J. *Tetrahedron: Asymmetry* **1997**, *8*, 27. (b) Sanyal, A.; Snyder, J. K. *Org. Lett.* **2000**, *2*, 2527.

(7) Sarotti, A. M.; Spanevello, R. A.; Suárez, A. G. *Org. Lett.* **2006**, *8*, 1487.

(8) Evans, D. A.; Chapman, K. T.; Bisaha, J. *J. Am. Chem. Soc.* **1988**, *110*, 1238.

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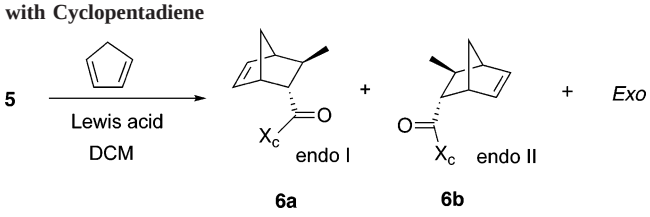
TABLE 1. Lewis Acid-Catalyzed Cycloadditions of Crotonate 5 with Cyclopentadiene



entry[a]	Lewis acid (equiv)	*T* (°C)	time (h)	endo/exo[b]	*endo*-I/*endo*-II[b]
1	$SnCl_4$ (1.1)	−100	0.25	97/1	32/1
2	$SnCl_4$ (0.2)	−100	7	82/1	28/1
3	$TiCl_4$ (1.1)	−100	0.25	125/1	2.4/1
4	Et_2AlCl (1.4)	−100	0.25	83/1	13.2/1
5	Me_2AlCl (1.4)	−100	0.25	90/1	12/1
6	$BF_3{\cdot}OEt_2$ (1.4)	−100	3	50/1	17/1
7	$ZrCl_4$ (1.4)	−32	0.5	66/1	52/1
8	$ZrCl_4$ (0.1)	−32	2	101/1	40/1
9	$ZrCl_4$ (0.1)	−50	6	>200/1	75/1
10	$AlCl_3$ (1.4)	−32	12	32/1	31/1

[a] All reactions were run in CH_2Cl_2, 0.1 M **5**, 5 equiv of cyclopentadiene; all gave 100% conversion by H NMR. [b] Endo/exo and *endo*-I/*endo*-II ratios from HPLC ((R,R)-Whelk-O, 1% IPA/hexanes). Authentic exo adducts were prepared by separate means for structure confirmation.[9]

catalysts such as $Cu(OTf)_2$, $Mg(OTf)_2$, $Zn(OTf)_2$, TMSI, and $Ti(O^iPr)_4$ gave lower reactivity and/or lower selectivity.

The stereochemical assignment of **6a** was established by cleaving the auxiliary exclusively at the exocyclic imide carbonyl with LiOH and comparison of the optical rotation of the resultant carboxylic acid with the literature value.[10] Suprisingly, this assignment indicated that the crotonyl bond was aligned in the s-trans orientation during the cycloaddition,[11] assuming dicarbonyl chelation of the Lewis acid, which is strongly supported by the requirement of 1.4 equiv of the aluminum catalysts to maximally accelerate the reaction and to achieve the optimal diastereoselectivity.[8] Given the variation of the *endo*-I/*endo*-II ratios with the catalyst, introduction of a group "R" on the γ-position of the lactam was considered with the hope of enforcing the chelation pathway, particularly with aluminum catalysts (Figure 1).

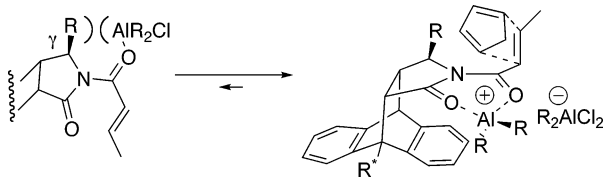
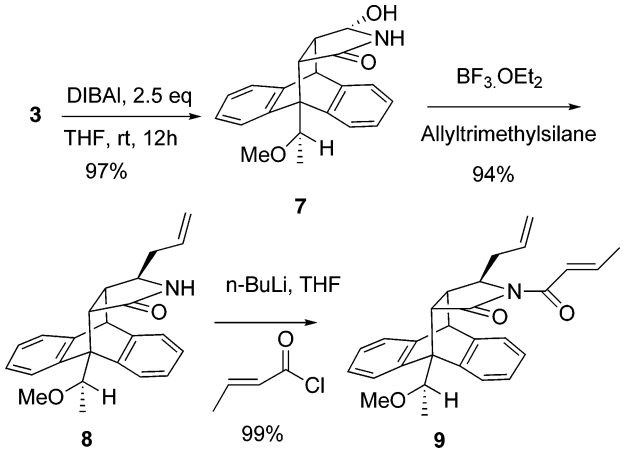


FIGURE 1. Proposed transition state to improve diastereofacial selectivity with aluminum catalysts.

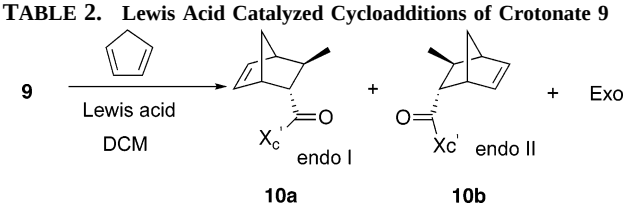
Reduction of cycloadduct **3** to the hemiaminal followed by allylation[5a,12] gave γ-allyl lactam **8**, also crystalline, as a single diastereomer (94%, two steps). Crotylation as before gave **9**, ready for the Diels−Alder chemistry (Scheme 3).

SCHEME 3. Synthesis of Auxiliary 8



As hoped, significantly higher selectivity was achieved with **8** employing aluminum catalysts, though with cycloadducts still arising from the s-trans conformation (Table 2). With Me_2AlCl, only one endo diastereomer, *endo*-I, was detected. Surprisingly, $BF_3{\cdot}OEt_2$ also provided very high selectivity, giving the same stereoisomer as the chelating Lewis acids. Interestingly, $ZrCl_4$ proved to be less selective than in the previous case with auxiliary **4**. One possible reason for this reduced selectivity with $ZrCl_4$ might be that the allyl group in **9** renders formation of the bipyramidal complexation of Zr (IV) too hindered, leading to increased population of the *s*-cis enamide conformation and, hence, producing slightly greater amounts of the *endo*-II adduct.

TABLE 2. Lewis Acid Catalyzed Cycloadditions of Crotonate 9



entry[a]	Lewis acid (equiv)	*T* (°C)	time (h)	yield[b] (%)	*e*ndo/exo[c]	*endo*-I/*endo*-II[c]
1	$SnCl_4$ (0.2)	−100	7	99	no exo	70/1
2	Et_2AlCl (1.4)	−100	0.25	96	107/1	210/1
3	Me_2AlCl (1.4)	−100	0.25	98	160/1	>300/1
4	$BF_3{\cdot}OEt_2$ (1.4)	−100	5.5	97	73/1	100/1
5	$ZrCl_4$ (0.1)	−32	2	98	66/1	25/1

[a] All reactions were run in CH_2Cl_2, 0.1 M with 5 equiv of cyclopentadiene. [b] Isolated yields. [c] *Endo*/*exo* and *endo*-I/*endo*-II ratios from HPLC ((R,R)-Whelk-O, 1% IPA/hexanes).

The application of these auxiliaries to other dienes and dienophiles also succeeded with excellent yields and diastereoselectivities (Table 3). Structure assignments followed basic hydrolyses[8] to remove the auxiliary, affording known compounds.[9] With less reactive dienophiles such as 2,3-dimethyl-1,3-butadiene and isoprene, auxiliary **4** was applied since the allyl group in **8** dramatically slowed the reaction. The more reactive catalyst $TiCl_4$ was needed to propel these reactions to completion. All cycloadducts could be rationalized as resulting from top-face approach to the dienophile in the s-trans conformation as depicted in Figure 1.

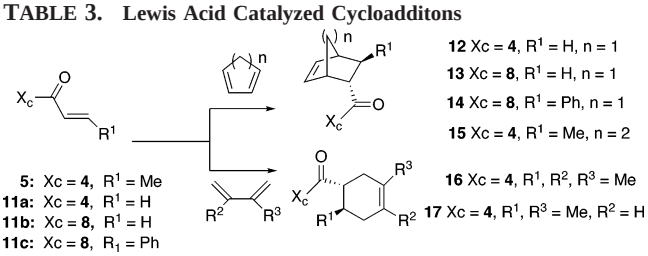
(9) See the Supporting Information.

(10) (a) Kouklovsky, C.; Pouilhes, A.; Langlois, Y. *J. Am. Chem. Soc.* **1990**, *112*, 6672. (b) Berson, J. A.; Hammons, J. H.; McRowe, A. W.; Bergman, R. G.; Remanick, A.; Houston, P. J. *J. Am. Chem. Soc.* **1967**, *89*, 2590.

(11) (a) Oelichmann, H.-J.; Bougeard, D.; Schrader, B. *Angew. Chem.* **1982**, 648. (b) Chamberlin, A. R.; Reich, S. H. *J. Am. Chem. Soc.* **1985**, *107*, 1440.

(12) Burgess, K. L.; Lajkiewicz, N. J.; Sanyal, A.; Yan, W.; Snyder, J. K. *Org. Lett.* **2005**, *7*, 31.

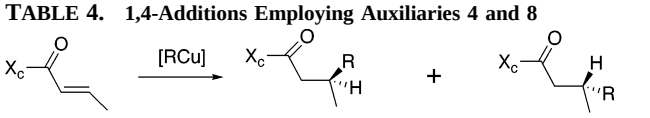
TABLE 3. Lewis Acid Catalyzed Cycloadditons



entry/Xc	R^1	dienophile	conditions[a]	yield[b] (%)	product de[c] (%)
1/**4**	H	cyclopentadiene	**A**, 0.25 h	95	**12**, 93
2/**8**	H	cyclopentadiene	**A**, 0.25 h	96	**13**, >96
3/**8**	Ph	cyclopentadiene	**A**, 2 h	94	**14**, >96
4/**4**	Me	1,3-cyclohexadiene	**B**, 10 h	87[d]	**15**, >96
5/**4**	Me	2,3-dimethyl-1,3-butadiene	**B**, 12 h	90	**16**, >96
6/**4**	Me	isoprene	**B**, 8 h	85	**17**, >96

[a] Conditions A: 0.1 M in CH_2Cl_2, 1.4 equiv Me_2AlCl, −100 °C. Conditions B: 0.1 M in CH_2Cl_2, 1 equiv of $TiCl_4$, entries 5 and 6 at −32 °C, 4 at −5 °C. [b] Isolated yield. [c] de determined by NMR. [d] 10% exo product isolated.

TABLE 4. 1,4-Additions Employing Auxiliaries 4 and 8



entry/Xc	R	conditions[a]	yield[b] (%)	product, de[c] (%)
1/**4**	Bu	**A**	85	**18**, >96%
2/**8**	Bu	**B**	80	**19**, 15:1
3/**4**	Ph	**A**	81	**20**, >96%
4/**8**	Ph	**B**	80	**21**, 8:1

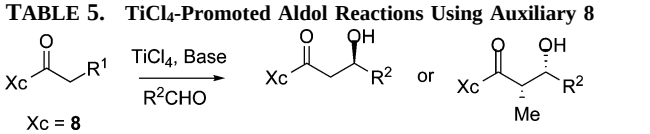
[a] Conditions A: 2.0 equiv of CuI·0.75Me_2S in THF, 1.8 equiv of RLi, −32 °C, 30 min; 1.5 equiv of TMSI, −100 °C; substrate added in THF, −100 °C. Conditions B: 2.0 equiv of CuI·0.75Me_2S in Et_2O, 1.8 equiv of RLi, −32 °C, 30 min; substrate added in Et_2O, −78 °C. [b] Isolated yields. [c] de determined by H NMR.

Other applications of these auxiliaries were also examined, beginning with 1,4-additions.[13] Excellent yields and good to excellent diastereoselectivities were observed (Table 4).

Either *R*- and *S*-adducts could be generated selectively depending upon conditions. Under chelation conditions, Li^+ chelates with the two carbonyl groups of **9**, and the cuprate reagent adds from the top face of the crotonate, aligned in the s-cis orientation. Under the nonchelation conditions, TMSI was applied as a catalyst with **4**, which provided the opposite diastereomer. The absolute configurations were established by cleavage of the auxiliary and comparison of optical rotation of the resultant carboxylic acids with literature values.[9]

Auxiliary **8** was also useful in Evans' *syn*-aldol reaction (Table 5).[14] Excellent yields and selectivities were achieved for the reactions of propionate **23** when $TiCl_4$ (4 equiv) and TMEDA (4 equiv) were applied at −40 °C, followed by aldehyde addition at −78 °C. Even for the problematic acetate aldol reaction,[15] only a single isomer was observed by NMR

TABLE 5. $TiCl_4$-Promoted Aldol Reactions Using Auxiliary 8



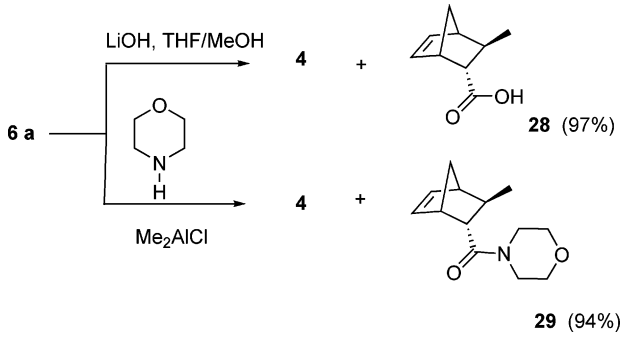
22: R^1 = H **24**: R^2 = Ph **26**: R^2 = Ph

23: R^1 = Me **25**: R^2 = isopropyl **27**: R^1 = Me, R^2 = *i*-Pr

entry	conditions[a]	R^1	R^2	yield[b] (%)	product, de[c] (%)
1	**A**	H	Ph	90	**24**, >96
2	**A**	H	isopropyl	88	**25**, >96
3	**B**	Me	Ph	91	**26**, >96
4	**B**	Me	isopropyl	93	**27**, >96

[a] Conditions A: 0.1 M in CH_2Cl_2, 2 equiv of $TiCl_4$, −40 °C, 5 min, then 2 equiv of DIPEA, −40 °C, 2 h; 1.5 equiv of RCHO, −100 °C, 5 h. Conditions B: 0.1 M in CH_2Cl_2, 2 equiv of $TiCl_4$ −40 °C, 5 min, then 4 equiv of TMEDA, −40 °C, 1 h; 1.5 equiv of RCHO, −100 °C to rt. [b] Isolated yields. [c] de determined by H NMR.

SCHEME 4. Examples of Auxiliary Cleavage



when $TiCl_4$ (2 equiv) and DIPEA (4 equiv) were applied. The configurations of **24**−**27** were confirmed by reductive cleavage of the auxiliary ($LiAlH_4$) and comparison with authentic diols.[9]

The auxiliary can also be easily cleaved and recovered under different conditions (Scheme 4). Quantitative basic hydrolysis of **6a** using Evans' conditions,[8] for example, gave **28** with 100% recovered auxiliary, while Weinreb-type amidation yielded **29**, also with completely recovered auxiliary, a procedure that should be applicable to adduct diversification.

In conclusion, new, facially restrictive chiral auxiliaries **4** and **8** were designed and synthesized in good yields, and on multigram scales. The rigid diastereofacial structures exert excellent stereocontrol in Diels−Alder reactions, and have also proven successful in the limited number of conjugate additions and aldol reactions examined to date. Further applications of these auxiliaries to other reactions are under investigation.

Experimental Section

General Procedure A: Acylation of Auxiliaries 4 and 8. To a solution of **4** or **8** in anhydrous THF (0.25 M) at −78 °C was added *n*-BuLi (1.1 equiv, 2.5 M in hexanes) with stirring. After 1 h, freshly distilled acid chloride (1.3 equiv) was added, and the reaction mixture was allowed to warm to rt with stirring for 4 h, and then the reaction was quenched with saturated aqueous ammonium chloride. The mixture was extracted with EtOAc, and then the combined organic layers were washed with brine, dried

(13) For a recent report of similar 1,4-additions with Evans' auxiliary, see: Dambacher, J.; Anness, R.; Pollock, P.; Bergdahl, M. *Tetrahedron* **200**4, *60*, 2097.

(14) Crimmins, M. T.; King, B. W.; Tabet, E. A.; Chaudhary, K. *J. Org. Chem.* **2001**, *66*, 894.

(15) (a) Crimmins, M. T.; Shamszad, M. *Org. Lett.* **2007**, *9*, 149. For a recent review: (b) Kimball, D. B.; Silks, L. A., III. *Curr. Org. Chem.* **2006**, *10*, 1975.

over sodium sulfate, and filtered. The solvent was removed in vacuo and the residue was purified by flash chromatography on silica gel.

General Procedure B: Lewis Acid Promoted Diels−Alder Reactions Using Auxiliaries 4 and 8. To a solution of dienophile **5** or **11** in anhydrous CH_2Cl_2 (0.1 M) at the desired temperature was added the appropriate amount of Lewis acid (see Tables 1−3). After the mixture was stirred for 5 min, freshly distilled diene (5 equiv) was added, and the reaction mixture was stirred at the same temperature until TLC showed no starting material remained. The reaction was quenched with 1 N HCl and then extracted with CH_2Cl_2. The combined organic layers were washed with brine, dried over Na_2SO_4, and filtered, and then the solvent was removed in vacuo. The residue was loaded onto a short silica plug (∼2 cm) in a disposable pipet and then eluted first with hexanes to remove excess diene and then with EtOAc to recover the cycloadduct mixture. The diastereoselectivities were determined by 400 MHz ^{1}H NMR on this mixture. Diastereomeric excesses of cycloadducts **6** and **10** were also determined by HPLC analysis (Tables 1 and 2). Further purification by flash chromatography gave the main cycloadduct, if necessary (see the Supporting Information).

General Procedure C: Conjugate Addition to 5. To a slurry of CuI·0.75 Me_2S (2.0 equiv) in THF was added the organolithium reagent (1.8 equiv) at −32 °C. After being stirred for 30 min, the mixture was cooled to −100 °C, followed by the dropwise addition of TMSI (1.5 equiv) via syringe with stirring. After 10 min, the crotonate solution (**5**, 0.1 M in THF) was added dropwise via syringe, and the reaction mixture was stirred at the same temperature for 6 h. The reaction was quenched with saturated aqueous ammonium chloride, and then the solution was extracted with EtOAc. The combined organic layers were washed with brine, dried over Na_2SO_4, and filtered, and the solvent was removed in vacuo. The diastereoselectivities were determined by 400 MHz ^{1}H NMR on this crude mixture. Further purification by flash chromatography gave the main adduct (**18**, **20**, see the Supporting Information).

General Procedure D: Conjugate Addition to 9. To a slurry of CuI·0.75 Me_2S (2.0 equiv) in Et_2O was added the organolithium reagent (1.8 equiv) at −32 °C. After being stirred for 30 min, the mixture was cooled to −78 °C followed by the dropwise addition of the crotonate solution (**9**, 0.1 M in Et_2O) via syringe, and the reaction mixture was allowed to stir at the same temperature for 6 h. The reaction was quenched with saturated aqueous ammonium chloride, and then the solution was extracted with EtOAc. The combined organic layers were washed with brine, dried over Na_2SO_4, and filtered, and the solvent was removed in vacuo. The diastereoselectivities were determined by 400 MHz ^{1}H NMR on this crude mixture. Further purification by flash chromatography gave the main adduct (**19**, **21**, see the Supporting Information).

General Procedure E: Aldol Reactions of 22. To a solution of acetate **22** in anhydrous CH_2Cl_2 (0.1 M) at −40 °C was added $TiCl_4$ (1 M in CH_2Cl_2, 2.0 equiv). After being stirred for 5 min, freshly distilled DIPEA (2 equiv) was added. The reaction mixture was stirred at the same temperature for 2 h and then cooled to −100 °C, followed by the addition of freshly distilled RCHO (1.5 equiv) dropwise via syringe. After being stirred for 5 h, the reaction was quenched with 1 N HCl at −100 °C and then allowed to warm to rt. The mixture was extracted with CH_2Cl_2, the combined organic layers were washed with brine, dried over Na_2SO_4, and filtered, and the solvent was removed in vacuo. The residue was loaded onto a short Celite plug (∼2 cm) in a disposable pipet and then eluted with CH_2Cl_2 to afford the aldol adduct mixture. The diastereoselectivities were determined by 400 MHz ^{1}H NMR on this mixture. Further purification by flash chromatography gave the main adduct (**24**, **25**, see the Supporting Information).

General Procedure F: Aldol Reactions of 23. To a solution of propionate **23** in anhydrous CH_2Cl_2 (0.1 M) at −40 °C was added $TiCl_4$ (1 M in CH_2Cl_2, 2.0 equiv). After the mixture was stirred for 5 min, freshly distilled TMEDA (4 equiv) was added. After the mixture was stirred at the same temperature for 1 h, the reaction was cooled to −100 °C, followed by the dropwise addition of freshly distilled RCHO (1.5 equiv) via syringe. After being stirred for 2 h, the reaction mixture was allowed to slowly warm to rt over 4 h and then quenched with saturated aqueous ammonium chloride. The mixture was extracted with CH_2Cl_2. The combined organic layers were washed with brine, dried over Na_2SO_4, and filtered, and the solvent was removed in vacuo. The residue was loaded onto a short Celite plug (∼2 cm) in a disposable pipet and then eluted with CH_2Cl_2 to afford the aldol adduct mixture. The diastereoselectivities were determined by 400 MHz ^{1}H NMR on this mixture. Further purification by flash chromatography gave the main adduct (**26**, **27**, see the Supporting Information).

Auxiliary Cleavage via Weinreb-Type Amidation. To a stirred solution of cycloadduct **6a** (129 mg, 0.284 mmol, 1.0 equiv) in THF (2.8 mL) was added Me_2AlCl (0.68 mL, 1 M in hexanes, 2.4 equiv) at −78 °C. After 30 min, morpholine (68 μL, 0.68 mmol, 2.4 equiv) was added, and the reaction mixture was allowed to slowly warm to rt and stirred for 3 h. The reaction was quenched with saturated aqueous ammonium chloride (2 mL), and the resultant slurry was extracted with CH_2Cl_2 (3 × 10 mL). The combined organic layers were dried over Na_2SO_4 and filtered, and solvent was removed in vacuo to afford crude **29** and **4**. Purification by flash chromatography gave pure **29** (hexanes/EtOAc, 1:1, R_f 0.31, 59 mg, 94% yield) as a colorless oil: $[\alpha]^{25}_D$ −101.7 (*c* 0.6, $CHCl_3$); IR (NaCl) 1639 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.06 (d, J = 7.2 Hz, 3H), 1.38 (ddd, J = 8.4, 2.0, 1.4 Hz, 1H), 1.54 (br d, J = 8.4 Hz, 1H), 2.11 (qdd, J = 7.2, 4.6, 1.6 Hz, 1H), 2.40 (dd, J = 4.6, 3.6 Hz, 1H), 2.44 (br s, 1H), 2.88 (br s, 1H), 3.40−3.70 (overlap, 8H), 5.79 (dd, J = 5.6, 2.8 Hz, 1H), 6.29 (dd, J = 5.6, 3.0 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 47.4, 57.0, 60.4, 62.7, 63.05, 63.08, 64.6, 64.8, 75.2 (2C), 113.6, 118.4, 138.4; HRMS (ESI) *m*/*z* 222.1487 ([M + 1]$^+$, 19%), calcd for $C_{13}H_{20}NO_2$ 222.1494. Auxiliary **4** was also recovered (94 mg, 0.284 mmol, 100%).

Supporting Information Available: General information, experimental procedures, characterization data, and copies of ^{1}H and ^{13}C NMR spectra of all products. This material is available free of charge via the Internet at http://pubs.acs.org.

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