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Copper(II)- and Palladium(II)-Catalyzed Enantioselective Claisen Rearrangement of Allyloxy- and Propargyloxy-Indoles to Quaternary Oxindoles and Spirocyclic Lactones

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Abstract

In this paper, a strategy to obtain highly enantioselective catalysts for the Claisen rearrangement of allyloxy- and propargyloxy-indoles is outlined. Ultimately, copper BOX and palladium BINAP or PHOX catalysts were discovered as superior in catalyzing Claisen rearrangements of allyloxy- or propargyloxy-substituted indoles to generate oxindoles bearing allyl- or allenyl-substituted quaternary centers. This method proved to be tolerant of a broad range of functional groups. Tandem reactions of the silyl-allene products provide rapid access to a variety of spirocyclic oxindoles in one operation.

INTRODUCTION

The oxindole framework bearing a C3-quaternary stereocenter is a privileged heterocyclic motif, which is present in a large number of biologically active natural products.¹ Many of these natural products, including physostigmine,² flustramine B,³ pseudophrynaminol,⁴ and mollenine,⁵ contain an allyl chain at the C3-position (Figure 1). This chain could easily be installed in an asymmetric fashion utilizing Claisen rearrangement methodology. Notably, syntheses have not been described for mollenine and notamides,⁶ novel alkaloids derived from marine sources, which incorporate this motif.

The oxindole moiety is also a popular fragment for drug discovery, and several reports describe its incorporation into compounds with potent biological activity (Figure 1).^{7–9} The apparent clinical significance of the spirocyclic quaternary center at the C3 position of oxindoles¹⁰ has led to a demand for efficient methods for their enantioselective synthesis.¹¹

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Supporting Information

Characterization data including ¹H and ¹³C NMR spectra. X-ray crystallographic information for select compounds. This material is available free of charge via the Internet at <http://pubs.acs.org>.

The topology of this moiety allows functionalization of all four faces of a tetrahedron centered on the spirocyclic center, creating an ideal environment for structural diversity.

To facilitate the synthesis of natural products and related analogues for biological evaluation and structure-activity relationships, catalytic asymmetric syntheses of oxindoles with a quaternary center have been of intense interest (Figure 2).^{1e,2,11,12} For example, Overman generated such oxindoles via an asymmetric Heck reaction with very good enantioselectivity.¹³ Later, Fu developed an enantioselective intramolecular acyl transfer of benzofurans and indoles, which requires an unusual carbonate.¹⁴ Recognizing that oxindoles can be enolized readily, Trost developed an asymmetric π -allylation to yield oxindole variants.¹⁵ For most of these methods, several steps are needed to prepare the precursors. Moreover, in all cases, *N*-masked indoles are used. Also, not all substituent combinations are available at the quaternary center. For example, ester/allyl combinations, which map onto many natural products, are not available in high enantioselectivity. By exploiting sigmatropic rearrangements we theorized that a number of structures could be achieved that would be difficult or impossible to obtain via other routes including ester/allyl combinations, generation of two adjacent quaternary centers, and formation of allenes from the propargyl alcohols.

The Claisen rearrangement of allyl vinyl ethers is a [$\pi^2s + \sigma^2s + \pi^2s$] sigmatropic isomerization process. This transformation is a key entry to generate the γ,δ -unsaturated carbonyl moiety.¹⁶ In spite of the utility of these compounds, the development of asymmetric catalysts has proven difficult for this transformation.^{17,18} As we have previously reported, we identified palladium complexes that effect the asymmetric catalytic Meerwein-Eschenmoser Claisen^{18a} or Saucy-Marbet Claisen^{18b} rearrangements to produce a range of oxindoles bearing a quaternary stereocenter. In this paper, we provide a complete account of our development of allyloxy or propargyloxy indoles as precursors for the generation of oxindoles and spirocyclic variants bearing a tetrasubstituted stereocenter using palladium systems.

RESULTS AND DISCUSSION

We employed allyl or propargyl substituted indoles **3** or **4**, which were obtained from indole **1** and allylic or propargyl alcohols **2** (Scheme 1).^{18,19} Though a few of these substrates were found to rearrange spontaneously at low temperatures (rt – 40 °C), care in the isolation provided indole substrates that could be stored up to a year at –20 °C.

1. Monodentate Indoles

The first substrates that were investigated bore a nitrile at the C3-position (Scheme 2) with the aim of identifying a catalyst that would activate the substrate via interaction with the ethereal oxygen. The nitrile served as an electron-withdrawing group that would decelerate the Claisen rearrangement and allow isolation of **3a** and **3b** in pure form.²⁰ The substituents at C2' are known to affect the rate of the rearrangement, so both allyloxy and methallyloxy groups were incorporated. Evaluation of C3-nitrile substituents with representative Brønsted and Lewis acids revealed that these catalysts did not facilitate the Claisen rearrangement.

2. Bidentate Indoles

2.1. Allyloxy Indoles—Due to the lack of success with the monodentate substrate, an ester group was added to the C3-position. It was envisioned that either a Brønsted acid (BA) or Lewis acid (LA) could coordinate to both the sp^3 oxygen of the allyl chain, as well as the sp^2 oxygen of a carbonyl substituent (Scheme 3), and that this double activation would accelerate the reaction.

Brønsted Acid Catalyst Survey: Brønsted acid catalysts were screened first (Scheme 4). Bisamidinium catalyst **C1**²¹ gave complete conversion and 16% enantiomeric excess while 80% conversion and racemic product were observed with sulfonamide **C2**. Urea **C3** also gave 80% conversion, with 6% enantiomeric excess. The low selectivity issue arises due to the competing background reaction, with 60% conversion being observed without catalyst over the same time frame.

Lewis Acid Catalyst Survey: Lewis acid catalysts, which have a much broader reactivity range, were investigated next. In order to diminish the background reaction and allow a gauge of the inherent selectivity of the catalysts, initial screens were conducted with stoichiometric bisoxazoline copper complexes (Scheme 5).²² The substitution on the oxazoline portion of the ligand, as well as the counterion on the copper, both dramatically affected the enantioselectivity. When copper triflate was used with the *tert*-butyl bisoxazoline ligand **L1**, only 34% ee was achieved. However, with the less-coordinating hexafluoroantimonate counterion, the selectivity increased to 58% ee. This trend was consistent regardless of the ligand used, with the hexafluoroantimonate copper complexes always giving higher enantioselectivity. Apparently, substrate binding to the Lewis acidic copper is weak; either the catalyzed reaction is quicker with the more Lewis acidic species resulting in higher enantioselectivity due to less competing thermal background reaction or the more tightly bound complex brings the asymmetric environment of the ligand into closer proximity of the reacting partners amplifying the intrinsic asymmetric induction. Overall, the selectivity could be improved up to 81% ee with Cu(SbF₆)₂ and the indanol bisoxazoline **L4**.

For further optimization, a variety of solvents were evaluated (Table 1). It was necessary to use distilled solvents as trace HCl could catalyze the rearrangement.²³ Dichloromethane allowed complete conversion to product **5c** with 81% ee (entry 1). 1,2-Dichloroethane gave comparable results, however when chloroform or toluene was used, both the selectivity and the conversion were lower (entries 2–4). Interestingly, THF gave no conversion to product either with (entry 6) or without catalyst (entry 5). Since THF appears to inhibit the background reaction that occurs in CH₂Cl₂ at room temperature, it was thought that a small amount of THF might inhibit the background reaction while allowing the enantioselective rearrangement to proceed. Unfortunately, any amount of THF resulted in no conversion to product (entry 7). Lastly, acetonitrile caused decomposition of the starting material (entry 8).

With the copper complexes, the steric environment around the coordinating carbonyl proved to be an important factor to control the selectivity. Larger ester groups led to lower selectivity (Scheme 6) with the ethyl and benzyl esters **5d** and **5e** resulting in 79% ee and 73% ee, respectively. The isopropyl ester **5f** decreased the selectivity further to 65% ee. The large substrate **5g**, with a *tert*-butyl ester, provided only 42% ee. Conversely, the small methyl ester **5c** gave the best result with 81% ee.

It was hypothesized that replacing the methyl ester with a methyl ketone **3h** might improve the selectivity (Scheme 7) as smaller esters afforded better enantioselectivities (Scheme 6). Unfortunately, rearranged product **5h** was not stable. The methyl ketone was cleaved, presumably via a facile retro-Claisen condensation of the more electrophilic ketone, affording only product **6**. In principle, this route to mono-substituted oxindoles such as **6** could be subject to asymmetric induction using a chiral protonation catalyst. However, this exchange of methyl ketone for an allyl was not investigated further.

Installation of an amide at the 3-position of the indole provided another possible substrate (Scheme 8). In an analogous fashion to the ester series, the C3-amide was generated by

reaction with *N*-chlorosuccinimide and allyl alcohol. Disappointingly, copper(II) was unable to promote the rearrangement with high enantioselectivity. It appears that allylic strain (see Scheme 8) destabilizes coordination mode **7**, which is necessary for good asymmetry transfer from the catalyst to the product.

To further optimize the rearrangement of the ester substrates, a range of loadings of the copper species were investigated (Table 2). When 200 mol% loading was used, there was no improvement in enantioselectivity (entries 1–2). When the loading was lowered to 50 mol%, almost complete conversion was observed with only a small loss in enantioselectivity. Decreasing the loading to 25 mol% lowered conversion (78%) and selectivity (76% ee) indicating that thermal rearrangement was intervening during the relatively slow turnover.

Due to poor turnover with substoichiometric copper (II), additional metals were examined for superior turnover (Table 3). The bisoxazoline metal complexes were screened as stoichiometric promoters for the rearrangement with the goal of selectively stabilizing the starting material complex **3c** and destabilizing the product-metal adduct **5c**. Copper provided the highest enantioselectivities and complete conversion. Both nickel and zinc resulted in lower conversion to product, as well as lower selectivity. Interestingly, when zinc was employed, the opposite enantiomer of the product was formed, which is consistent with a change from square planar to tetrahedral coordination geometry.²⁴ Encouragingly, the palladium adduct exhibited reactivity at the same level as the copper adduct, along with moderate levels of selectivity (73% ee).

Palladium Catalysts: Attention turned to the palladium complexes because palladium can accommodate a wider array of ligands (diamines, aminophosphines, and diphosphines) offering more opportunity for catalyst optimization. A number of diphosphine ligands were screened (Scheme 9), building on the promising 73% ee with [Pd(*S,S*)-Ind-box](SbF₆)₂. BINAP (**L5**) gave a promising 45% ee and exceedingly fast reactions (complete conversion to product in just five minutes at room temperature). Lowering the temperature only slowed the rate of conversion to product and did not increase the selectivity. More sterically encumbered ligands such as tol-BINAP (**L6**) and xylyl-BINAP (**L7**) were used without any appreciable change in the enantioselectivity. DifluoroPhos (**L8**), which has a smaller bite angle than that of BINAP, increased the selectivity to 56% ee.²⁵ Finally, BIPHEP (**L9**) gave moderate selectivity.

Changing the palladium counterion did little to affect the enantioselectivity. In the case of triflate or acetate, the product formed very slowly (Scheme 10). Presumably, strongly coordinating counterions inhibit the coordination of the substrate.²⁶

Lowering the loading to 20 mol% showed no drop in selectivity and complete conversion to product was observed in 10 minutes at room temperature (Table 4). Decreasing the loading further to 5 mol% provided **5g** with the same enantioselectivity at 82% ee, and did not substantially reduce the rate.

Two proposed transition states (Figure 3), which are in accord with those computed²⁷ for the copper catalyzed reactions of substrates containing a similar coordination array,^{17a–b} illustrate the *C*₂-symmetric BINAP-derived catalyst coordinating to the indole starting material **3j** (the BINAP backbone is removed for clarity).²⁸ In **TS2**, there are steric interactions between the ester and the pseudoequatorial phenyl group, as well as between the allyl group and the pseudoequatorial phenyl group on the other phosphorus center. These interactions suggest that increasing the steric bulk of the ester might further destabilize **TS2** and increase the enantioselectivity.

In order to test this theory, a series of esters were screened using the palladium-BINAP catalyst (Scheme 11). Notably, the selectivity was improved when the steric bulk of the C3-ester increased, as the isopropyl and *tert*-butyl esters (**5f** and **5g**) of the methylallyl derivative furnished the product in 63% ee and 85% ee, respectively, relative to the 48% ee of the methyl ester (**5c**). Similar results were seen with both the isopropyl and benzyl esters (**5l** and **5m**) in the allyl series. Decreasing the steric bulk at R¹ on the allyl group also improved the selectivity, in accordance with the above hypothesis. While the ethallyl derivative **5k** afforded only 35% ee, the allyl derivative **5j** provided a much higher 71% ee. The *tert*-butyl ester with allyl substitution **5i** gave the best selectivity with 89% ee. Moreover, the turnover problems observed with copper catalysts were not seen with the palladium catalysts.

To understand how the catalyst conveys asymmetry in the reaction, it was necessary to determine the absolute configuration of the quaternary stereocenter that is formed during the course of the reaction. In an effort to obtain an X-ray crystal structure, attempts were made to synthesize a hydrazone derivative of the oxindole product over two steps by sulfonylation of the *tert*-butyl ester **5i** and condensation with 2,4-dinitrophenylhydrazine (2,4-DNPH) (Scheme 12). The transesterified methyl ester **5'i** was observed, rather than the expected hydrazone. An X-ray crystal structure was obtained showing that **5'i** was the (*S*)-configuration. All other structures were assigned by analogy from this result.

Although the goal of establishing a Meerwein-Eschenmoser Claisen rearrangement with high enantioselectivity using substoichiometric catalyst loadings had been achieved, the substrate scope of this reaction was limited. High enantioselectivity was only observed when unsubstituted allyl alcohol was used, with the exception of compound **5g** (Scheme 11). New ligands were investigated to further optimize the reaction with the aim of expanding the substrate scope. The phosphinooxazoline (PHOX) ligands were screened because they combine the scaffolds of both the diphosphine ligands and the bisoxazoline ligands (Scheme 13). Only moderate enantioselectivities were observed with the phenyl- and benzyl-phosphinooxazoline ligands (**L10**, **L11**). Indanol ligand **L12**, as well as the isopropyl ligand **L13**, provided the product **5c** in good selectivity. The *tert*-butyl-phosphinooxazoline ligand **L14** generated the highest selectivity (89% ee).

tert-Butyl-phosphinooxazoline ligand afforded high selectivities over a range of substrates (Scheme 14). While methyl ester with allyl alcohol **5j** afforded the product in 83% ee, methyl allyl alcohol **5c** and ethyl allyl alcohol **5k** provided 89% and 92% ee, respectively. The enantioselectivity (91% ee) and yield (95%) improved when the reaction was performed on a 1 mmol scale. Contrary to results with the BINAP ligand, the use of the *tert*-butyl ester **5g** lowered both enantioselectivity and yield. Interestingly, the smaller methyl ester provided high enantioselectivity regardless of the electronics of the aromatic ring (**5n–5p**).

Mechanism: Since copper(II), zinc(II), nickel(II), and palladium(II) complexes all promote the Meerwein-Eschenmoser Claisen, a Lewis acid activation pathway seemed plausible.²⁸ With the same ligand, the selectivity copper(II) and palladium(II) was virtually identical (Table 3, entries 1 and 5), which is consistent with the square planar coordination environments of these Lewis acids. As would be expected with a large change in coordination environment, zinc(II), which forms tetrahedral complexes, was much less selective (Table 3, entry 3). The major difference between copper(II) and palladium(II) lies in the turnover, which is ascribed to the larger size and weaker O-coordinating ability of the palladium. To determine if reduced palladium(0) was forming and causing to a π -allyl cation pathway, a deuterium atom was installed on the allyl group of the indole starting material **3q** (Scheme 15). This substrate was subjected to the reaction conditions and only

the [3,3'] rearranged product **5q** was observed by ^1H NMR, resulting in 80% isolated yield and 92% ee.

A further study of the mechanism of the formation of allyloxindole from the indole precursor was undertaken, utilizing two different substrates with unique substitution on the allyl and indole fragments (Scheme 16). If discrete π -allyl species were forming, four products arising from both allyl fragments combining with both indole fragments should be observed. There is also literature precedent for alkene activation with palladium(II) catalysts.²⁹ However, these cases do not possess an alternate strong coordination site for the palladium as shown in Scheme 3. If reaction via alkene coordination was occurring, substrates lacking the ester coordination group should also be viable, which is not the case (Scheme 2 and reference ^{29b}). Finally, the Lewis acid activation²⁸ models explain the sense and trends in the stereochemical induction (see Figure 3 and discussion above). Overall, the evidence supports the concerted Meerwein-Eschenmoser Claisen rearrangement illustrated in Figure 3.

In summary, the palladium-catalyzed enantioselective Meerwein-Eschenmoser Claisen rearrangement is a useful tool to give access to oxindole products bearing an allyl-substituted quaternary stereocenter. While the BINAP (**L5**) provided higher selectivities with large esters and small allyl alcohols, *tert*-butyl-phosphinooxazoline (**L14**) afforded the best selectivity with the smaller C3-methyl ester and the larger allyl alcohols (Scheme 17). The rearrangement has proven to be general, as substrates with either electron-withdrawing or electron-donating groups on the indole framework work well. In addition, catalyst loadings as low as 5 mol% can be used. The absolute configurations of the products were established through crystal structures (see Supporting Information) and are in accord with the proposed stereochemical models.

2.2. Propargyloxy indoles—With the goal of expanding this methodology from allyl ethers to propargyl ethers, we investigated the Saucy-Marbet rearrangement. Very few catalytic asymmetric methods of forming allenes exist,³⁰ as most transformations to allenes commence with enantioenriched precursors.³¹ Notably, enantioenriched allenes have many potential applications.³² In asymmetric catalysis, the transformations of propargyl vinyl ethers to provide β -substituted allenyl carbonyls remains highly challenging, as evidenced by the fact that no catalytic asymmetric Saucy-Marbet Claisen rearrangements were reported prior to our effort.^{18,33} Examination of simple models revealed that the alkyne sp centers significantly perturb the sigmatropic rearrangement transition state. In addition, cylindrically symmetric alkyne gives no opportunity for facial discrimination. Based on the success of palladium catalysts for the transformation of allyloxy indoles to allyl oxindoles, a stereochemical model of the Pd(*t*-BuPHOX) catalyst with the propargyl substituted indoles was proposed (Figure 4). This model suggested that the ester group, which most likely coordinates to the palladium metal, could interact with larger alkyne terminal substituents suppressing the pathways to one of the enantiomers.

Palladium catalyst survey: In line with this hypothesis, increasing the size of the terminal alkyne substituents did result in enhanced selectivity with the Pd(*t*-BuPHOX) catalyst (Table 5, entries 1–5). In particular, very high levels of enantioselectivity (96–98% ee) were observed with alkynes having *ortho*-substituted aryl groups at R^2 . In addition, the reactivity of these compounds with the catalyst was significantly higher. For example, complete conversion to product was observed in 8 h at -15°C with just 5 mol% catalyst loading (entries 5–9). Other alkynes with large groups, such as TMS, *tert*-butyl and *N*-methyliminodiacetic acid (MIDA) boronates provided lower selectivity (entries 10–12).

In an effort to improve the enantioselection of non-aryl alkynes, alternative ligands were evaluated. Trends similar to Pd(*t*-BuPHOX) catalyst (i.e. better selectivity for large substituents) were also observed with BINAP-derived complexes (Table 6). Methyl ester with propargyl alcohol **4d** afforded 4% ee (entry 2) while *tert*-butyl-substituted propargyl alcohol **4k** provided 76% ee (entry 3). Among a series of biaryl diphosphine ligands, DifluoroPHOS proved the most effective, providing *tert*-butyl-substituted allene **8k** with 90% yield and 86% ee (entry 4). Most surprising was the poor selectivity of the TMS-substituted alkyne (entry 6). A significant improvement with a return to BINAP (44% vs 77% ee, entries 6–7) suggested that trace fluoride from the DifluoroPHOS interferes with the rearrangement. While elevated temperature (rt vs 0 °C) allowed for good conversion of TBS substrates (entry 9), it also led to lower selectivity, which limited the utility of this system for large silyl-substituted terminal alkynes. However, this problem could be solved by modifying the reaction solvent. A screen of CH₂Cl₂, C₆H₅CF₃, THF, toluene, C₆H₅Cl and several mixtures thereof revealed that a toluene-C₆H₅Cl mixture afforded good conversion and enantioselectivity (89% ee, entry 10) with the TBS substrate.

Gratifyingly, the Pd-(*R*)-BINAP complex afforded high selectivities with a range of TES- or TBS-substrates (Table 7). Both electron-withdrawing and electron-donating groups were tolerated on the indole framework. However, lower catalyst loadings translated into unacceptably long reaction times and lower enantioselectivity. To maintain the enantioselectivity for a 5 mol% catalyst reaction, we discovered that degassing of solvents was critical (Table 7, entry 4). To increase the rate of this reaction, a similar diphosphine ligand bearing an electron-withdrawing group was theorized to result in a more Lewis-acidic and reactive catalyst. BIPHEP (**L9**, entry 5) was indeed better in terms of reaction time but worse than BINAP (**L5**, entry 4) in terms of enantioselectivity. The (*R*)-configuration of the products was established through crystal structure (see Supporting Information).

Mechanism: A further study of the mechanism of the formation of allene **8** from **4** was undertaken by utilizing two different substrates, each containing unique propargyl and indole fragments, in one reaction (Scheme 18). As was the case for the allyloxy substrates (see Scheme 16 above), no crossover was observed in the reaction and the products arising from a [3,3']-sigmatropic rearrangement were isolated in high isolated yield and enantioselectivity. This result ruled out a stepwise ionic mechanism and confirmed a concerted Saucy-Marbet Claisen rearrangement to generate the enantioenriched allenes.

Parallel Microscale Screening: The main drawback with the palladium catalysts remained the long reaction times. In an attempt to resolve this issue, a number of different metals were complexed with BINAP and examined (Table 8). Although 100 mol% catalyst was used, the reactions with Ag, Cu, Pt were very slow and resulted in decomposition (entries 1–3). Among metal complexes, Ni catalyst gave highest selectivity, but poor turnover (entry 4–5). On the other hand, the reaction with Au(III) proceeded at a much faster rate but with modest selectivity (entry 6).³⁵

Encouraged with the reactivity of the gold (III) catalyst (Table 9, entries 1 and 3), we undertook a parallel microscale screen with resources that became available at this point in the project. Using 1-mL vials with 100 μ L reaction volumes at a 0.1M concentration, 192 chiral mono- and bi-dentate phosphine ligands were screened in 96-well plates. A control experiment on larger scale showed that the AgCl formed during the generation of the gold catalyst did not affect the enantioselectivity; this result was crucial as it is very difficult to remove the AgCl precipitate at the microscale level. However, we were disappointed with the poor selectivity of substrates (R^2 = TBS, 0–67% ee) seen with either Au(III) or Au(I) catalysts. Use of a larger silyl group (TIPS, Table 9, entry 4) or smaller groups (TMS and Me, entries 6–8) did not result in retention of the selectivity. Unfortunately, the

enantioselectivity could not be improved using different solvents (entry 3) or counter-anions (entry 5). As a result, we determined that the palladium (II) catalyst is the most efficient catalyst for the Saucy-Marbet Claisen rearrangement, providing both sufficient reactivity and high enantioselectivity.

2.3. Spirocyclization with Propargyloxy Indoles—Higher temperatures (40 °C vs rt) were required when the optimized conditions using catalytic palladium were applied to the larger TIPS substrates. Under these conditions, an entirely different product, spirocyclic lactone **9s** was observed as the major product (eq 1). Only a few examples of the racemic, saturated versions of these spirooxindoles have been reported.^{7,36} Because of the broad utility of tandem reactions and the interesting structures of the spirocyclic lactones, further study of this tandem cyclization was undertaken.

(eq 1)

To determine the cause of the cyclization, the allene was investigated as a potential intermediate (Figure 5). Notably, the cyclization is not catalyzed by Brønsted acid and the Pd catalyst is necessary to generate the spiro lactone from the allene (Figure 5). Specially, TIPS-substituted **8s** (89% ee) was isolated at lower temperature and then resubjected to the reaction conditions, resulting in full conversion to **9s** (90% ee). Hypothesizing that the spirocyclic compounds **9** arose from hydration of allenes **8** and subsequent Lewis acid induced cyclization, β -silyl ketone **10** was generated (see below). Upon subsection of this ketone to the palladium catalyst, the spirocyclic lactone **9o** was obtained as the sole product.

We also observed that non-silyl substrates reluctantly formed the spiro lactone. The mechanism most consistent with all the data is the formation of allene **8** followed by hydration and a palladium-catalyzed cyclization to generate lactone **9** (Scheme 19). A key component of this mechanism is carbocation intermediate **11**, which is stabilized via the β -silyl effect,³⁷ and explains why non-silyl substrates cyclize slowly.

In order to selectively generate the allene **8** at elevated temperature (vs spirocyclic lactone **9**), efforts were directed at removing trace water and acid from the reaction mixtures (Table 10). Water absorbents such as 3 or 4 Å MS, MgO, and MgSO₄ were used, which stopped the cyclization process to some extent (entries 1–4). It was exciting to find that the use of 2,4,6-tri-*tert*-butylpyridine or (TMEDA)Zn(SbF₆)₂ prevented the cyclization entirely (entries 5 and 7).

In line with the proposed mechanism (Scheme 19), addition of water shifted the reaction outcome entirely to the spiro lactone **9**. A range of substrates was readily transformed to the corresponding spirooxindole lactones (Table 11). Substrates with different esters or indole substituents were well tolerated, providing the lactone in good yields and enantioselectivities. Reactions on a larger scale also proceeded well (Table 11, entry 1).

The allenyl products were found to be useful in a number of transformations (Scheme 20). Hydration of the allene **8o** with Hg(O₂CCF₃)₂ provided α -silyl ketone **10**. This ketone could

easily undergo Brook rearrangement to form silyl enol ether **12** or cyclization to form lactone **9o**. The silyl group on **8n** was effectively removed by TBAF to provide the simplest congener **8c**, a compound that was not directly accessible with good selectivity via the Saucy-Marbet Claisen rearrangement (see Table 5, entry 3).

Conclusion—In this paper, highly enantioselective catalytic processes are described for the Meerwein-Eschenmoser and Saucy-Marbet Claisen rearrangements using BINAP or *t*-BuPHOX palladium catalysts to construct a range of oxindoles bearing an allyl- or allenyl-substituted quaternary center. Mechanistic evidence firmly established the intermediacy of a [3,3']-sigmatropic rearrangement vs ionic or stepwise processes. Indole substrates with functional groups at different positions can be utilized, which allow for further functionalization of the resultant oxindole products. Tandem reactions of silyl-allene indoles provide rapid access to a variety of spirocyclic oxindoles in one operation. In summary, a wide range of structurally rich chiral oxindoles is readily accessible via the catalytic transformations described herein.

EXPERIMENTAL SECTION

General Information

Unless otherwise noted, all non-aqueous reactions were carried out under an atmosphere of dry N₂ in dried glassware. When necessary, solvents and reagents were dried prior to use. THF was distilled from sodium benzophenone ketyl. CH₃CN, CH₂Cl₂, TMEDA, and toluene were distilled from CaH₂. The alcohols³⁸ and some indole precursors^{17,18,19,39} were prepared following the literature protocols.

When necessary, the column was pre-washed with 1% Et₃N in the eluent system. Enantiomeric excesses were determined using analytical high performance liquid chromatography (HPLC) or supercritical fluid chromatography (SFC) with UV detection at 254 nm, using analytical OD, AS AD, IA, OJ-H columns (0.46 cm × 25 cm). Chemical shifts are reported in ppm from tetramethylsilane (0 ppm) or from the solvent resonance (CDCl₃ 7.26 ppm, THF-*d*₈ 3.58 ppm, acetone-*d*₆ 2.05 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, br = broad, m = multiplet), coupling constants, and number of protons. Mass spectra were obtained from a TOF mass spectrometer with an ionization mode of either CI or ES. Optical rotations are reported as follows [α]_D²³ (c g/mL × 100, solvent).

Representative Procedure (A) for Installation of an Allyl Alcohol to Indole Substrates

Methyl 2-(2-methylallyloxy)-1H-indole-3-carboxylate (3c): To a flame-dried round-bottom flask was added methyl indole-3-carboxylate (3.0 g, 17.13 mmol). CH₂Cl₂ (15 mL) was added and upon cooling to 0 °C, distilled 1,4-dimethylpiperazine (1.29 mL, 9.60 mmol) and recrystallized *N*-chlorosuccinimide (2.52 g, 19.02 mmol) were added. The resulting solution was stirred at 0 °C for 2 h. In a separate flame-dried round bottom flask, methallyl alcohol (2.9 mL, 34.26 mmol) and trichloroacetic acid (0.67 g, 4.11 mmol) were dissolved in CH₂Cl₂ (15 mL). The solution was cooled to 0 °C, and transferred via cannula to the indole solution. This mixture was stirred for 2 h at 0 °C, at which time the reaction mixture was concentrated under vacuum. It was then loaded onto a base-washed SiO₂ column (1% Et₃N, 24% EtOAc, 75% Hexanes) and eluted with 25% EtOAc/Hexanes to afford **3c** (2.5 g) in 60% yield as a white solid; mp 92–94 °C; ¹H NMR (500 MHz, CDCl₃) δ 8.63 (bs, 1H), 8.03 (d, *J* = 7.7 Hz, 1H), 7.23–7.14 (m, 3H), 5.18 (s, 1H), 5.05 (s, 1H), 4.81 (s, 2H), 3.93 (s, 3H), 1.86 (s, 3H); ¹³C NMR (90 MHz, THF-*d*₈) δ 164.5, 156.9, 141.4, 131.0, 127.2, 121.5,

121.4, 121.1, 113.1, 110.6, 89.9, 76.8, 49.9, 19.0; IR (film) 3231, 2949, 1660, 1552, 1475 cm^{-1} ; HRMS (ES) m/z = 268.0949 calcd for $\text{C}_{14}\text{H}_{15}\text{NO}_3\text{Na}$ $[\text{MNa}]^+$, found 268.0957.

2-(allyloxy)-1H-indole-3-carbonitrile (3a): Following the general procedure, compound **3a** was obtained in 38% yield. Due to the difficulty in separating compound **3a** from the indole-3-nitrile, the isolated yield was calculated from the mixture of compound **3a** and indole-3-nitrile. As the consequence, compound **3a** was only assessed by ^1H NMR experiment and mass spectrum. ^1H NMR (500 MHz, CDCl_3) δ 8.53 (bs, 1H), 7.55-7.53 (m, 1H), 7.26-7.14 (m, 3H), 5.54 (dd, J = 1.2, 17.2 Hz, 1H), 5.40 (dd, J = 1.1, 10.5 Hz, 1H), 5.10 (dt, J = 1.3, 5.5 Hz, 2H); HRMS (CI) m/z = 199.0871 calcd for $\text{C}_{12}\text{H}_{11}\text{N}_2\text{O}$ $[\text{MH}]^+$, found 199.0878.

2-(2-methylallyloxy)-1H-indole-3-carbonitrile (3b): Following the general procedure (A) **3b** (0.056 g, 0.26 mmol) was obtained in 38% yield as a white solid: mp 104–106 °C ^1H NMR (500 MHz, CDCl_3) δ 8.05 (bs, 1H), 7.58 (d, J = 3.7 Hz, 1H), 7.24-7.18 (m, 3H), 5.20 (s, 1H), 5.10 (s, 1H), 5.03 (s, 2H), 1.89 (s, 3H); ^{13}C NMR (90 MHz, THF-d_8) δ 157.0, 139.7, 130.1, 127.3, 121.7, 121.1, 117.4, 114.8, 113.1, 110.5, 107.7, 75.0, 18.3; IR (film) 3223, 3173, 2926, 2212, 1563, 1471 cm^{-1} ; HRMS (CI) m/z = 213.1028 calcd for $\text{C}_{13}\text{H}_{13}\text{N}_2\text{O}$ $[\text{MH}]^+$, found 213.0994.

Ethyl 2-(2-methylallyloxy)-1H-indole-3-carboxylate (3d): Following the general procedure (A) **3d** (0.06 g, 0.23 mmol) was obtained in 47% yield as beige solid: mp 90–91 °C ^1H NMR (500 MHz, CDCl_3) δ 9.16 (bs, 1H), 8.06 (d, J = 7.8 Hz, 1H), 7.24-7.12 (m, 3H), 5.15 (s, 1H), 5.00 (s, 1H), 4.77 (s, 1H), 4.43 (q, J = 7.1 Hz, 2H), 1.81 (s, 3H), 1.47 (t, J = 7.1 Hz, 3H); ^{13}C NMR (90 MHz, THF-d_8) δ 164.0, 156.8, 141.4, 131.0, 127.3, 121.4, 121.3, 121.2, 113.0, 110.5, 90.2, 76.9, 58.9, 19.1, 14.7; IR (film) 3231, 2980, 1660, 1552, 1471 cm^{-1} ; HRMS (CI) m/z = 260.1287 calcd for $\text{C}_{15}\text{H}_{18}\text{NO}_3$ $[\text{MH}]^+$, found 260.1299.

Benzyl 2-(2-methylallyloxy)-1H-indole-3-carboxylate (3e): Following the general procedure (A) **3e** (0.073 g, 0.23 mmol) was obtained in 45% yield as a brown oil: ^1H NMR (500 MHz, CDCl_3) δ 8.30 (bs, 1H), 7.51 (d, J = 7.3 Hz, 1H), 7.40-7.31 (m, 4H), 7.23-7.14 (m, 4H), 5.41 (s, 2H), 5.15 (s, 1H), 5.05 (s, 1H), 4.81 (s, 2H), 1.85 (s, 3H); ^{13}C NMR (90 MHz, THF-d_8) δ 163.9, 157.1, 141.2, 138.4, 131.1, 128.6, 128.3, 127.9, 127.3, 121.6, 121.4, 121.1, 113.2, 109.9, 89.7, 76.7, 64.9, 19.1; IR (film) 3250, 2926, 1660, 1552, 1475, 1455 cm^{-1} ; HRMS (ES) m/z = 344.1263 calcd for $\text{C}_{20}\text{H}_{19}\text{NO}_3\text{Na}$ $[\text{MNa}]^+$ found 344.1270.

Isopropyl 2-(2-methylallyloxy)-1H-indole-3-carboxylate (3f): Following general procedure (A) **3f** (0.191 g, 0.70 mmol) was obtained in 55% yield as a white solid: mp 88–90 °C ^1H NMR (500 MHz, CDCl_3) δ 8.36 (bs, 1H), 8.06 (d, J = 8.0 Hz, 1H), 7.25-7.12 (m, 3H), 5.31-5.28 (m, 1H), 5.19 (s, 1H), 5.06 (s, 1H), 4.83 (s, 2H), 1.88 (s, 3H), 1.43 (d, J = 6.2 Hz, 6H); ^{13}C NMR (90 MHz, THF-d_8) δ 163.7, 156.8, 141.4, 130.9, 127.4, 121.4, 121.3, 121.2, 113.0, 110.5, 90.5, 76.8, 65.9, 22.2, 19.1; IR (film) 3227, 2980, 2937, 1656, 1552, 1471, 1374 cm^{-1} ; HRMS (ES) m/z = 296.1263 calcd for $\text{C}_{16}\text{H}_{19}\text{NO}_3\text{Na}$ $[\text{MNa}]^+$, found 296.1268.

tert-Butyl 2-(2-methylallyloxy)-1H-indole-3-carboxylate (3g): Following the general procedure (A) **3g** (0.12 g, 0.418 mmol) was obtained in 34% yield as a pale yellow solid: mp 105–107 °C; ^1H NMR (500 MHz, CDCl_3) δ 8.20 (bs, 1H), 7.96 (d, J = 8.7 Hz, 1H), 7.15-7.08 (m, 3H), 5.13 (s, 1H), 5.01 (s, 1H), 4.77 (s, 2H), 1.82 (s, 3H), 1.60 (s, 9H); ^{13}C NMR (90 MHz, THF-d_8) δ 163.8, 156.6, 141.0, 129.9, 127.4, 121.2 (2), 121.1, 113.1, 110.4, 91.6, 78.6, 76.8, 28.6, 19.1; IR (film) 3237, 2976, 1656, 1552, 1459, 1366 cm^{-1} ; HRMS (ES) m/z = 310.1419 calcd for $\text{C}_{17}\text{H}_{21}\text{NO}_3\text{Na}$ $[\text{MNa}]^+$, found 310.1411.

Methyl 2-(2-methylenebutoxy)-1H-indole-3-carboxylate (3k): Following the general procedure (A) **3k** (0.257 g, 0.99 mmol) was obtained in 43% yield as a yellow oil: ^1H NMR (300 MHz, CDCl_3) δ 8.30 (bs, 1H), 8.04 (d, $J = 7.4$ Hz, 1H), 7.26–7.15 (m, 3H), 5.23 (s, 1H), 5.09 (s, 1H), 4.89 (s, 2H), 3.93 (s, 3H), 2.23 (q, $J = 7.0$ Hz, 2H), 1.13 (t, $J = 7.4$ Hz, 3H); ^{13}C NMR (90 MHz, THF-d_8) δ 165.1, 157.5, 147.4, 131.5, 127.7, 122.0, 121.9, 121.6, 111.8, 111.1, 90.4, 76.4, 50.4, 26.6, 12.5; IR (film) 3229, 2966, 2881, 1668, 1552, 1468, 1352, 1267 cm^{-1} ; HRMS (ES, negative ion) $m/z = 258.1130$ calcd for $\text{C}_{15}\text{H}_{16}\text{NO}_3$ $[\text{M-H}]^-$, found 258.1123.

Methyl 2-(1-deutero-2-methylenebutoxy)-1H-indole-3-carboxylate (3q): Following the general procedure (A) **3q** (0.036 g, 0.14 mmol) was obtained in 17% yield as a yellow resin: ^1H NMR (300 MHz, CDCl_3) δ 8.22 (bs, 1H), 8.04 (d, $J = 7.2$ Hz, 1H), 7.26–7.16 (m, 3H), 5.23 (t, $J = 1.1$ Hz, 1H), 5.09 (s, 1H), 4.86 (s, 1H), 3.91 (s, 3H), 2.23 (q, $J = 7.4$ Hz, 2H), 1.27 (t, $J = 7.1$ Hz, 3H); ^{13}C NMR (90 MHz, THF-d_8) δ 164.5, 157.0, 147.0, 131.1, 127.3, 121.5, 121.4, 121.2, 111.5, 110.6, 90.0, 75.8 (t, $J = 22.3$ Hz), 49.9, 26.2, 12.3; IR (film) 3229, 3090, 2935, 2881, 1668, 1552, 1468, 1328, 1244 cm^{-1} ; HRMS (ES) $m/z = 283.1169$ calcd for $\text{C}_{15}\text{H}_{16}\text{DNO}_3\text{Na}$ $[\text{MNa}]^+$, found 283.1165.

2-(allyloxy)-N,N-dimethyl-1H-indole-3-carboxamide (7): Following the general procedure (A), compound **7** (0.145 g, 0.59 mmol) was obtained in 59% yield as a beige solid: mp $^{\circ}\text{C}$; ^1H NMR (500 MHz, CDCl_3) δ 8.85 (bs, 1H), 7.46 (d, $J = 7.5$ Hz, 1H), 7.15 (d, $J = 8.0$ Hz, 1H), 7.07 (m, 2H), 5.94 (m, 1H), 5.32 (d, $J = 17.0$ Hz, 1H), 5.24 (d, $J = 10.5$ Hz, 1H), 4.65 (d, $J = 5.5$ Hz, 2H), 3.11 (s, 6H); ^{13}C NMR (125 MHz, CDCl_3) δ 167.2, 150.2, 132.5, 129.9, 126.3, 120.9, 120.7, 119.0, 118.6, 110.3, 91.2, 73.1, 38.6; IR (film) 3460, 3182, 3066, 2943, 2765, 1776, 1707, 1591, 1514, 1468, 1429, 1352, 1182 cm^{-1} ; HRMS (ES) $m/z = 245.1290$ calcd for $\text{C}_{14}\text{H}_{17}\text{N}_2\text{O}_2$ $[\text{MH}]^+$, found 245.1285.

Representative Procedure (B) for Installation of an Allyl Alcohol to Indole Substrates

Methyl 2-(allyloxy)-1H-indole-3-carboxylate (3j): To a flame-dried round-bottom flask was added methyl indole-3-carboxylate (0.30 g, 1.71 mmol). After dissolving in CH_2Cl_2 (4 mL) and cooling to 0°C , 1,4-diazobicyclo[2.2.0]octane (DABCO) (0.108 g, 0.96 mmol) was added followed by recrystallized *N*-chlorosuccinimide (0.253 g, 1.90 mmol) were added. The resultant solution was stirred at 0°C for 30 min, followed by addition of allyl alcohol (0.23 mL, 3.42 mmol) and methanesulfonic acid (0.016 mL, 0.24 mmol). This mixture was stirred for 30 min at 0°C , at which time the reaction mixture was concentrated under vacuum and chromatographed on a base-washed SiO_2 column (1% Et_3N , 24% EtOAc , 75% Hexanes) using 25% EtOAc /Hexanes as the eluent to afford **3j** (0.224 g, 0.97 mmol) in 57% yield as an off-white oil: mp $80\text{--}82^{\circ}\text{C}$; ^1H NMR (300 MHz, CDCl_3) δ 8.21 (bs, 1H), 8.05 (m, 1H), 7.22–7.18 (m, 3H), 6.13–6.05 (m, 1H), 5.49 (d, $J = 17.2$ Hz, 1H), 5.36 (d, $J = 10.4$ Hz, 1H), 4.95 (d, $J = 5.7$ Hz, 2H), 3.94 (s, 3H); ^{13}C NMR (90 MHz, THF-d_8) δ 164.7, 157.0, 133.7, 131.0, 127.3, 121.6, 121.5, 121.2, 117.8, 110.7, 90.3, 74.4, 50.0; IR (film) 3229, 2997, 2950, 1668, 1552, 1468, 1328, 1251, 1213 cm^{-1} ; HRMS (ES) $m/z = 254.0799$ calcd for $\text{C}_{13}\text{H}_{13}\text{NO}_3\text{Na}$ $[\text{MNa}]^+$, found 254.0797.

tert-Butyl 2-(allyloxy)-1H-indole-3-carboxylate (3i): Following the general procedure (A) **3i** (0.53 g, 1.94 mmol) was obtained in 77% yield as a white solid: mp $124\text{--}126^{\circ}\text{C}$; ^1H NMR (300 MHz, CDCl_3) δ 8.36 (bs, 1H), 8.01 (d, $J = 7.0$ Hz, 1H), 7.25–7.13 (m, 3H), 6.15–6.02 (m, 1H), 5.46 (dd, $J = 17.2, 1.4$ Hz, 1H), 5.33 (dd, $J = 10.4, 1.2$ Hz, 1H), 4.92 (m, 2H), 1.66 (s, 9H); ^{13}C NMR (90 MHz, THF-d_8) δ 163.9, 156.7, 134.0, 130.9, 127.4, 121.4 (2), 121.3, 117.7, 110.6, 92.1, 81.6, 74.6, 28.6; IR (film) 3229, 2981, 2881, 1661, 1552,

1468, 1367, 1251, 1174, 1097 cm^{-1} ; HRMS (ES) $m/z = 274.1443$ calcd for $\text{C}_{16}\text{H}_{20}\text{NO}_3$ $[\text{MH}]^+$, found 274.1435.

Isopropyl 2-(allyloxy)-1H-indole-3-carboxylate (3l): Following the general procedure (B) **3l** (0.15 g, 0.59 mmol) was obtained in 80% yield as an off-white oil: ^1H NMR (300 MHz, CDCl_3) δ 8.22 (bs, 1H), 8.05 (d, $J = 7.0$ Hz, 1H), 7.25–7.19 (m, 3H), 6.18–6.05 (m, 1H), 5.49 (ddd, $J = 1.4, 2.9, 17.2$ Hz, 1H), 5.36 (ddd, 1.4, 2.9, 10.4 Hz, 1H), 5.35 (septet, $J = 6.3$ Hz, 1H), 4.96 (ddd, $J = 1.3, 2.7, 5.7$ Hz, 2H); 1.42 (d, $J = 6.3$ Hz, 6H); ^{13}C NMR (90 MHz, THF-d_8) δ 163.9, 156.9, 133.8, 131.5, 127.4, 121.5 (2), 121.3, 117.7, 110.7, 90.9, 74.4, 66.2, 22.3; IR (film) 3229, 2981, 2935, 1738, 1661, 1552, 1468, 1375, 1244, 1097 cm^{-1} ; HRMS (ES) $m/z = 260.1287$ calcd for $\text{C}_{15}\text{H}_{18}\text{NO}_3$ $[\text{MH}]^+$, found 260.1281.

Benzyl 2-(allyloxy)-1H-indole-3-carboxylate (3m): Following the general procedure (B) **3m** (0.121 g, 0.39 mmol) was obtained in 66% yield as a yellow oil: ^1H NMR (360 MHz, THF-d_8) δ 10.87 (bs, 1H), 8.07 (m, 1H), 7.53 (d, $J = 7.3$ Hz, 2H), 7.37–7.20 (m, 4H), 7.11–7.06 (m, 2H), 6.14–6.04 (m, 1H), 5.45 (dd, $J = 1.6, 17.2$ Hz, 1H), 5.39 (s, 2H), 5.24 (dd, $J = 1.3, 10.5$ Hz), 4.92 (m, 2H); ^{13}C NMR (90 MHz, THF-d_8) δ 164.1, 157.2, 138.4, 133.5, 131.2, 128.7, 128.2, 128.0, 127.3, 121.7, 121.6, 121.2, 118.0, 110.8, 90.1, 74.2, 64.9; IR (film) 3229, 3090, 3035, 2950, 2881, 1661, 1552, 1460, 1352, 1259, 1213 cm^{-1} ; HRMS (ES) $m/z = 308.1287$ calcd for $\text{C}_{19}\text{H}_{18}\text{NO}_3$ $[\text{MH}]^+$, found 308.1285.

Methyl 2-(2-methylallyloxy)-5-methoxy-1H-indole-3-carboxylate (3n): Following the general procedure (B) **3n** (0.03 g, 0.11 mmol) was obtained in 22% yield as an off-white oil: ^1H NMR (300 MHz, CDCl_3) δ 8.44 (bs, 1H), 7.59 (m, 1H), 7.10 (d, $J = 8.6$ Hz, 1H), 6.78 (d, $J = 8.6$ Hz, 1H), 5.19 (s, 1H), 5.06 (s, 1H), 4.79 (s, 2H), 3.90 (s, 3H), 3.83 (s, 3H), 1.89 (s, 3H); ^{13}C NMR (90 MHz, THF-d_8) δ 164.6, 157.1, 156.3, 141.5, 128.2, 125.6, 113.1, 111.2, 110.1, 104.2, 90.2, 76.8, 55.4, 49.9, 19.1; IR (film) 3244, 2950, 1668, 1591, 1552, 1468, 1352, 1274, 1205 cm^{-1} ; HRMS (ES) $m/z = 298.1055$ calcd for $\text{C}_{15}\text{H}_{17}\text{NO}_4\text{Na}$ $[\text{MNa}]^+$, found 298.1066.

Methyl 2-(2-methylallyloxy)-5-bromo-1H-indole-3-carboxylate (3o): Following the general procedure (B) **3o** (0.07 g, 0.22 mmol) was obtained in 55% yield as an off-white oil: ^1H NMR (300 MHz, CDCl_3) δ 8.23 (bs, 1H), 8.17 (d, $J = 2.0$ Hz, 1H), 7.26 (m, 1H), 7.09 (d, $J = 8.5$ Hz, 1H), 5.20 (s, 1H), 5.10 (s, 1H), 4.85 (s, 2H), 3.93 (s, 3H), 1.90 (s, 3H); ^{13}C NMR (90 MHz, THF-d_8) δ 164.2, 157.6, 141.1, 134.6, 129.1, 124.3, 123.5, 115.1, 113.4, 112.4, 89.7, 76.8, 50.7, 19.1; IR (film) 3221, 2950, 1668, 1552, 1483, 1352, 1251, 1213 cm^{-1} ; HRMS (ES) $m/z = 346.0055$ calcd for $\text{C}_{14}\text{H}_{14}\text{BrNO}_3\text{Na}$ $[\text{MNa}]^+$, found 346.0045.

Methyl 2-(2-methylallyloxy)-7-methoxy-1H-indole-3-carboxylate (3p): Following general procedure (B), **3p** (0.086 g, 0.31 mmol) was obtained in 43% yield as a white resin: ^1H NMR (500 MHz, CDCl_3) δ 8.45 (bs, 1H), 7.63 (d, $J = 8.1$ Hz, 1H), 7.13 (t, $J = 8.0$ Hz, 1H), 6.66 (d, $J = 7.9$ Hz, 1H), 5.21 (s, 1H), 5.08 (s, 1H), 4.83 (s, 2H), 3.94 (s, 3H), 3.90 (s, 3H), 1.90 (s, 3H); ^{13}C NMR (90 MHz, THF-d_8) δ 164.0, 156.0, 145.4, 141.1, 127.5, 121.9, 121.3, 113.5, 112.6, 101.9, 90.5, 77.0, 54.6, 49.3, 18.6; IR (film) 3221, 1950, 2842, 1668, 1552, 1475, 1367, 1282, 1220 cm^{-1} ; HRMS (ES) $m/z = 298.1055$ calcd for $\text{C}_{15}\text{H}_{17}\text{NO}_4\text{Na}$ $[\text{MNa}]^+$, found 298.1057.

Representative Procedure for Installation of a Propargyl Alcohol to Indole Substrates

Methyl 2-((4,4-dimethylpent-2-yn-1-yl)oxy)-1H-indole-3-carboxylate (4k): To a solution of methyl indole-3-carboxylate (200 mg, 1.14 mmol) in CH_2Cl_2 (10 mL) cooled to 0 $^\circ\text{C}$,

1,4-dimethylpiperazine (0.085 mL, 0.64 mmol) was added and followed by recrystallized *N*-chlorosuccinimide (167 mg, 1.26 mmol). The resultant solution was stirred at 0 °C for 3 h. A solution of the propargyl alcohol (127 mg, 1.14 mmol) and trichloroacetic acid (45 mg, 0.27 mmol) in CH₂Cl₂ (1 mL) at 0 °C was transferred via cannula to the indole solution. This mixture was stirred for 12 h at 0 °C, at which time the reaction mixture was concentrated and chromatographed on a base-washed SiO₂ column using 15% ethyl ether/hexane to afford **4k** (131 mg, 0.456 mmol) in 40% yield as a white resin: ¹H NMR (360 MHz, CDCl₃) δ 8.55 (bs, 1H), 8.05 (d, *J* = 7.9 Hz, 1H), 7.26-7.16 (m, 3H), 5.03 (s, 2H), 3.92 (s, 3H), 1.19 (s, 9H); ¹³C NMR (90 MHz, CDCl₃) δ 165.1, 155.8, 129.8, 126.1, 122.33, 122.3, 121.31, 110.5, 99.3, 91.4, 73.1, 62.0, 51.1, 30.8, 27.8; IR (film) 3236, 2974, 2873, 2248, 1668, 1552, 1468, 1352, 1267, 1205, 1104 cm⁻¹; HRMS (ES) *m/z* = 308.1263 calcd for C₁₇H₁₉NO₃Na [MNa]⁺, found 308.1259.

***tert*-Butyl 2-(prop-2-yn-1-yloxy)-1*H*-indole-3-carboxylate (4a):** Following the general procedure, compound **4a** was obtained as a white solid in 30% yield: ¹H NMR (500 MHz, CDCl₃) δ 8.55 (bs, 1H), 8.03 (d, *J* = 7.0 Hz, 1H), 7.30-7.17 (m, 3H), 5.07 (d, *J* = 2.5 Hz, 2H), 2.58 (t, *J* = 2.5 Hz, 1H), 1.66 (s, 9H); ¹³C NMR (125 MHz, CDCl₃) δ 164.1, 155.1, 129.7, 126.0, 122.4, 122.2, 121.5, 110.8, 93.5, 80.5, 78.3, 77.4, 61.7, 28.8; IR (film) 3283, 2974, 2124, 1653, 1552, 1468, 1367, 1328, 167, 1213, 1174, 1097 cm⁻¹; HRMS (ES) *m/z* = 294.1106 calcd for C₁₆H₁₇NO₃Na [MNa]⁺, found 294.1104.

***tert*-Butyl 2-(but-2-yn-1-yloxy)-1*H*-indole-3-carboxylate (4b):** Following the general procedure, compound **4b** was obtained as a white solid in 44% yield: ¹H NMR (500 MHz, CDCl₃) δ 8.45 (bs, 1H), 8.02 (d, *J* = 8.0 Hz, 1H), 7.26-7.15 (m, 3H), 5.02 (q, *J* = 2.4 Hz, 2H), 1.86 (t, *J* = 2.4 Hz, 3H), 1.65 (s, 9H); ¹³C NMR (125 MHz, CDCl₃) δ 164.2, 155.6, 129.7, 126.2, 122.1, 121.4, 110.6, 100.2, 92.9, 86.2, 80.2, 73.8, 62.0, 28.9, 3.9; IR (film) 3221, 2974, 2927, 2240, 1661, 1552, 1468, 1352, 1213, 1174, 1097 cm⁻¹; HRMS (ES) *m/z* = 308.1263 calcd for C₁₇H₁₉NO₃Na [MNa]⁺, found 308.1266.

Methyl 2-(prop-2-yn-1-yloxy)-1*H*-indole-3-carboxylate (4c): Following the general procedure, compound **4c** was obtained as a white resin in 45% yield: ¹H NMR (500 MHz, CDCl₃) δ 8.31 (bs, 1H), 8.05 (d, *J* = 7.0 Hz, 1H), 7.30-7.19 (m, 3H), 5.13 (d, *J* = 2.5 Hz, 2H), 3.93 (s, 3H), 2.62 (t, *J* = 2.5 Hz, 1H); ¹³C NMR (125 MHz, CDCl₃) δ 165.2, 155.4, 129.8, 125.9, 122.6, 122.4, 121.3, 110.9, 91.7, 78.0, 77.6, 61.7, 51.23; IR (film) 3283, 2950, 2132, 1676, 1552, 1468, 1344, 1267, 1205, 1104 cm⁻¹. HRMS (ES) *m/z* = 252.0637 calcd for C₁₃H₁₁NO₃Na [MNa]⁺, found 252.0634.

Methyl 2-(but-2-yn-1-yloxy)-1*H*-indole-3-carboxylate (4d): Following the general procedure, compound **4d** was obtained as a white resin in 47% yield: ¹H NMR (500 MHz, CDCl₃) δ 8.37 (bs, 1H), 8.05 (d, *J* = 8.0 Hz, 1H), 7.26-7.15 (m, 3H), 5.04 (q, *J* = 2.5 Hz, 2H), 3.92 (s, 3H), 1.87 (t, *J* = 2.4 Hz, 5H); ¹³C NMR (125 MHz, THF-*d*₈) δ 163.5, 155.3, 129.9, 126.0, 120.7, 120.5, 120.3, 109.8, 90.0, 83.5, 73.3, 60.9, 49.0, 1.8; IR (film) 3229, 2950, 2240, 1668, 1552, 1468, 1344, 1267, 1213, 1097 cm⁻¹; HRMS (ES) *m/z* = 244.0974 calcd for C₁₄H₁₄NO₃ [MH]⁺, found 244.0963.

Methyl 2-((3-phenylprop-2-yn-1-yl)oxy)-1*H*-indole-3-carboxylate (4e): Following the general procedure, compound **4e** was obtained as a colorless oil in 28% yield: ¹H NMR (500 MHz, CDCl₃) δ 9.02 (bs, 1H), 8.07 (d, *J* = 8.0 Hz, 1H), 7.36-7.19 (m, 8H), 5.29 (s, 2H), 3.95 (s, 1H); ¹³C NMR (125 MHz, CDCl₃) δ 165.4, 155.7, 132.0, 129.9, 129.2, 128.6, 126.0, 122.4, 122.3, 121.9, 121.3, 110.9, 91.5, 89.3, 83.1, 62.4, 51.2; IR (film) 3233, 2950, 2235, 1670, 1550, 1468, 1345, 1205, 1103, 1018 cm⁻¹; HRMS (ES) *m/z* = 328.0950 calcd for C₁₉H₁₅NO₃Na [MNa]⁺, found 328.0948.

Methyl 2-((3-(*o*-tolyl)prop-2-yn-1-yl)oxy)-1*H*-indole-3-carboxylate (4f): Following the general procedure, compound **4f** was obtained as a colorless oil in 31% yield: ^1H NMR (500 MHz, CDCl_3) δ 8.77 (bs, 1H), 8.07 (d, J = 8.0 Hz, 1H), 7.33 (d, J = 7.5 Hz, 1H), 7.27-7.14 (m, 5H), 7.10 (t, J = 6.5 Hz, 1H), 5.36 (s, 2H), 3.94 (s, 3H), 2.27 (s, 3H); ^{13}C NMR (125 MHz, CDCl_3) δ 165.3, 155.7, 140.7, 132.4, 129.8, 129.7, 129.3, 126.0, 125.8, 122.5, 122.3, 121.6, 121.3, 110.7, 91.7, 88.3, 86.8, 62.4, 51.2, 20.7; IR (film) 3227, 2949, 2221, 1671, 1551, 1472, 1343, 1210, 1101, 1010 cm^{-1} ; HRMS (ES) m/z = 320.1287 calcd for $\text{C}_{20}\text{H}_{18}\text{NO}_3$ $[\text{MH}]^+$, found 320.1281.

Methyl 2-((3-(2-bromophenyl)prop-2-yn-1-yl)oxy)-1*H*-indole-3-carboxylate (4g):

Following the general procedure, compound **4g** was obtained as a colorless resin in 15% yield: ^1H NMR (500 MHz, CDCl_3) δ 9.09 (bs, 1H), 8.05 (d, J = 7.5 Hz, 1H), 7.54 (d, J = 8.0 Hz, 1H), 7.38 (d, J = 7.7 Hz, 1H), 7.28-7.16 (m, 5H), 5.31 (s, 2H), 3.94 (s, 3H); ^{13}C NMR (125 MHz, CDCl_3) δ 165.3, 155.6, 133.9, 132.6, 130.5, 130.0, 127.4, 125.9, 125.7, 123.9, 122.4, 122.3, 121.3, 110.8, 91.5, 87.9, 87.6, 61.9, 51.2; IR (film) 3253, 2954, 2233, 1671, 1550, 1466, 1344, 1204, 1104, 1017 cm^{-1} ; HRMS (ES) m/z = 406.0055 calcd for $\text{C}_{19}\text{H}_{14}\text{NO}_3\text{NaBr}$ $[\text{MNa}]^+$, found 406.0051.

Methyl 2-((3-(naphthalen-1-yl)prop-2-yn-1-yl)oxy)-1*H*-indole-3-carboxylate (4h):

Following the general procedure, compound **4h** was obtained as a colorless resin in 17% yield: ^1H NMR (500 MHz, CDCl_3) δ 8.48 (bs, 1H), 8.10 (d, J = 7.5 Hz, 1H), 7.92 (d, J = 8.4 Hz, 1H), 7.82 (t, J = 8.5 Hz, 1H), 7.61 (d, J = 7.2 Hz, 1H), 7.46 (t, J = 7.0 Hz, 1H), 7.39 (t, J = 7.3 Hz, 1H), 7.29-7.19 (m, 5H), 5.51 (s, 2H), 3.96 (s, 3H); ^{13}C NMR (125 MHz, CDCl_3) δ 165.4, 155.6, 133.3, 133.2, 130.9, 129.9, 129.7, 128.4, 127.2, 126.7, 126.1, 125.9, 125.2, 122.5, 122.3, 121.4, 119.5, 110.9, 92.0, 87.9, 87.5, 62.6, 51.2; IR (film) 3245, 3061, 2225, 1671, 1549, 1466, 1333, 1205, 1102 cm^{-1} ; HRMS (ES) m/z = 378.1106 calcd for $\text{C}_{23}\text{H}_{17}\text{NO}_3\text{Na}$ $[\text{MNa}]^+$, found 378.1106.

Methyl 2-((3-(2-methoxyphenyl)prop-2-yn-1-yl)oxy)-1*H*-indole-3-carboxylate (4i):

Following the general procedure, compound **4i** was obtained in 15% yield. Due to the difficulty in separating compound **4i** from the methylindole-3-carboxylate and the instability of this material at ambient temperature, the isolated yield was calculated from the mixture of compound **4i** and methylindole-3-carboxylate (1.4:1). As the consequence, compound **4i** was only assessed by ^1H NMR experiment and mass spectrum. ^1H NMR (500 MHz, $\text{THF}-d_8$) δ 7.99-7.97 (m, 1H), 7.25 (d, J = 7.5 Hz, 1H), 7.21-7.05 (m, 4H), 6.90 (d, J = 7.8 Hz, 1H), 6.81 (t, J = 8.3 Hz, 1H), 5.36 (s, 2H), 3.82 (s, 3H), 3.68 (s, 3H); HRMS (ES) m/z = 358.1055 calcd for $\text{C}_{20}\text{H}_{17}\text{NO}_4\text{Na}$ $[\text{MNa}]^+$, found 358.1055.

Methyl 2-((3-(trimethylsilyl)prop-2-yn-1-yl)oxy)-1*H*-indole-3-carboxylate (4j):

Following the general procedure, compound **4j** was obtained as a white resin in 26% yield: ^1H NMR (360 MHz, CDCl_3) δ 8.48 (bs, 1H), 8.05 (d, J = 8.0 Hz, 1H), 7.27-7.17 (m, 3H), 5.06 (s, 2H), 3.93 (s, 3H), 0.16 (s, 9H); ^{13}C NMR (90 MHz, CDCl_3) δ 165.0, 155.3, 129.7, 126.0, 122.6, 122.4, 121.5, 110.6, 99.5, 95.7, 91.8, 62.5, 51.2, -0.2; IR (film) 3236, 2958, 2186, 1668, 1552, 1468, 1344, 1251, 1205, 1104, 1035 cm^{-1} ; HRMS (ES) m/z = 324.1032 calcd for $\text{C}_{16}\text{H}_{19}\text{NO}_3\text{NaSi}$ $[\text{MNa}]^+$, found 324.1041.

8-(3-((3-(Methoxycarbonyl)-1*H*-indol-2-yl)oxy)prop-1-yn-1-yl)-4-methyl-2,6-dioxohexahydro-[1,3,2]oxazaborolo[2,3-*b*][1,3,2]oxazaborol-4-ium-8-uide (4l):

Following the general procedure, to a solution of methyl indole-3-carboxylate (61 mg, 0.35 mmol) in CH_2Cl_2 (2 mL) cooled to 0 $^\circ\text{C}$, 1,4-dimethylpiperazine (0.026 mL, 0.20 mmol) was added, followed by recrystallized *N*-chlorosuccinimide (58 mg, 0.44 mmol). The resultant solution was stirred at 0 $^\circ\text{C}$ for 3 h. A solution of the propargyl alcohol (30 mg,

0.14 mmol) and trichloroacetic acid (14 mg, 0.08 mmol) in THF (0.5 mL) at 0 °C was transferred via cannula to the indole solution. This mixture was stirred for 12 h at 0 °C, at which time the reaction mixture was concentrated and chromatographed on a base-washed SiO₂ column using 80% ethyl acetate/hexane to afford **4l** (46 mg, 0.12 mmol) in 90% yield as a white resin; ¹H NMR (500 MHz, acetone-*d*₆) δ 7.99–7.97 (m, 1H), 7.33–7.91 (m, 1H), 7.16–7.11 (m, 2H), 5.21 (s, 2H), 4.21 (d, *J* = 17.0 Hz, 2H), 3.94 (d, *J* = 17.0 Hz, 2H), 3.84 (s, 3H), 2.94 (s, 3H); ¹³C NMR (125 MHz, acetone-*d*₆) δ 168.4, 165.1, 156.3, 131.2, 127.1, 122.7, 122.4, 121.6, 111.8, 91.7, 62.27, 62.25, 50.8, 48.2. The ¹³C NMR signals for two alkynyl carbons were not seen in accord with prior reports;⁴⁰ IR (film) 3222, 2945, 2200, 1773, 1694, 1562, 1469, 1350, 1271, 1113, 1034 cm⁻¹; HRMS (ES) *m/z* = 407.1027 calcd for C₁₈H₁₇BN₂O₇Na [MNa]⁺, found 407.1033.

Methyl 2-((3-(*tert*-butyldimethylsilyl)prop-2-yn-1-yl)oxy)-1*H*-indole-3-carboxylate

(4m): Following the general procedure, compound **4m** was obtained as a white solid in 43% yield: mp 128–129 °C; ¹H NMR (500 MHz, CDCl₃) δ 8.83 (bs, 1H), 8.06 (d, *J* = 7.5 Hz, 1H), 7.26–7.17 (m, 3H), 5.07 (s, 2H), 3.94 (s, 3H), 0.86 (s, 9H), 0.08 (s, 6H); ¹³C NMR (125 MHz, CDCl₃) δ 165.2, 155.5, 129.8, 125.9, 122.4, 122.3, 121.3, 110.7, 100.0, 94.1, 91.6, 62.1, 51.2, 26.1, 16.5, –4.7; IR (film) 3190, 2958, 2858, 2186, 1661, 1552, 1468, 1259, 1097, 1027 cm⁻¹; HRMS (ES) *m/z* = 344.1682 calcd for C₁₉H₂₆NO₃Si [MH]⁺, found 344.1690.

Ethyl 2-((3-(*tert*-butyldimethylsilyl)prop-2-yn-1-yl)oxy)-7-methoxy-1*H*-indole-3-carboxylate

(4n): Following the general procedure, compound **4n** was obtained as a white solid in 50% yield: mp 98–99 °C; ¹H NMR (500 MHz, CDCl₃) δ 8.94 (bs, 1H), 8.06 (d, *J* = 7.5 Hz, 1H), 7.26–7.16 (m, 3H), 5.07 (s, 2H), 3.94 (s, 3H), 0.93 (t, *J* = 8 Hz, 9H), 0.58 (q, *J* = 8.0 Hz, 6H); ¹³C NMR (125 MHz, CDCl₃) δ 165.3, 155.6, 129.9, 125.9, 122.4, 122.3, 121.2, 110.7, 100.4, 93.3, 91.5, 62.1, 51.4, 7.46, 4.21; IR (film) 3259, 2958, 2881, 2186, 1668, 1552, 1468, 1205, 1104, 1012 cm⁻¹; HRMS (ES) *m/z* = 344.1682 calcd for C₁₉H₂₆NO₃Si [MH]⁺, found 344.1699.

Ethyl 2-((3-(*tert*-butyldimethylsilyl)prop-2-yn-1-yl)oxy)-7-methyl-1*H*-indole-3-carboxylate

(4o): Following the general procedure, compound **4o** was obtained as a white solid in 31% yield: mp 117–118 °C; ¹H NMR (500 MHz, CDCl₃) δ 8.55 (bs, 1H), 7.90 (d, *J* = 8.0 Hz, 1H), 7.15 (dd, *J* = 8.0, 7.0 Hz, 1H), 7.00 (d, *J* = 7.0 Hz, 1H), 5.08 (s, 2H), 4.40 (q, *J* = 7 Hz, 2H), 2.41 (s, 3H), 1.45 (t, *J* = 7 Hz, 3H), 0.87 (s, 9H), 0.09 (s, 6H); ¹³C NMR (125 MHz, CDCl₃) δ 164.8, 155.4, 129.2, 125.6, 123.2, 122.4, 119.7, 119.2, 100.3, 93.7, 92.5, 62.4, 59.8, 26.1, 16.5 (2C), 14.8, –4.8; IR (film) 3229, 2958, 2858, 2186, 1668, 1552, 1468, 1274, 1213, 1097 cm⁻¹; HRMS (ES) *m/z* = 370.1838 calcd for C₂₁H₂₈NO₄Si [M-H]⁻, found 370.1855.

Ethyl 2-((3-(*tert*-butyldimethylsilyl)prop-2-yn-1-yl)oxy)-5-methoxy-1*H*-indole-3-carboxylate

(4p): Following the general procedure, compound **4p** was obtained as a white solid in 39% yield: mp 145–146 °C; ¹H NMR (500 MHz, CDCl₃) δ 8.37 (bs, 1H), 7.60 (d, *J* = 2.0 Hz, 1H), 7.10 (d, *J* = 9.0 Hz, 1H), 6.82 (dd, *J* = 2.0, 9.0 Hz, 1H), 5.05 (s, 2H), 4.39 (q, *J* = 7.0 Hz, 2H), 3.87 (s, 3H), 1.44 (t, *J* = 7.0 Hz, 3H), 0.87 (s, 9H), 0.08 (s, 6H); ¹³C NMR (125 MHz, CDCl₃) δ 164.7, 156.0, 155.5, 126.9, 124.3, 111.8, 111.4, 104.2, 100.2, 94.0, 92.2, 62.4, 59.8, 55.9, 26.1, 16.6, 14.8, –4.7; IR (film) 3213, 2935, 2858, 2186, 1653, 1468, 1352, 1205, 1166, 1104, 1043 cm⁻¹; HRMS (ES) *m/z* = 388.1944 calcd for C₂₁H₃₀NO₄Si [MH]⁺, found 388.1934.

Ethyl 2-((3-(*tert*-butyldimethylsilyl)prop-2-yn-1-yl)oxy)-7-methoxy-1*H*-indole-3-carboxylate

(4q): Following the general procedure, compound **4q** was obtained as a white

solid in 16% yield: mp 107–108 °C; ^1H NMR (500 MHz, CDCl_3) δ 8.79 (bs, 1H), 7.62 (d, J = 8.0 Hz, 1H), 7.12 (dd, J = 8.0, 8.0 Hz, 1H), 6.65 (d, J = 8.0 Hz, 1H), 5.03 (s, 2H), 4.37 (q, J = 7.5 Hz, 2H), 3.90 (s, 3H), 1.41 (t, J = 7.5 Hz, 3H), 0.86 (s, 9H), 0.08 (s, 6H); ^{13}C NMR (125 MHz, CDCl_3) δ 164.8, 154.9, 145.4, 127.1, 122.6, 119.8, 114.0, 102.8, 100.2, 94.2, 92.5, 62.1, 59.8, 55.5, 26.1, 16.5, 14.8, –4.8; IR (film) 3244, 2935, 2858, 2186, 1676, 1552, 1468, 1282, 1027 cm^{-1} ; HRMS (ES) m/z = 386.1788 calcd for $\text{C}_{21}\text{H}_{28}\text{NO}_4\text{Si}$ $[\text{M}-\text{H}]^-$, found 386.1796.

Ethyl 5-bromo-2-((3-(*tert*-butyldimethylsilyl)prop-2-yn-1-yl)oxy)-1*H*-indole-3-

carboxylate (4r): Following the general procedure, compound **4r** was obtained as a light gray solid in 28% yield: mp 155–156 °C; ^1H NMR (500 MHz, CDCl_3) δ 8.72 (bs, 1H), 8.15 (d, J = 2.0 Hz, 1H), 7.25 (dd, J = 8.5, 2.0 Hz, 1H), 7.07 (d, J = 8.5 Hz, 1H), 5.05 (s, 2H), 4.37 (q, J = 7.0 Hz, 2H), 1.42 (t, J = 7 Hz, 3H), 0.82 (s, 9H), 0.04 (s, 6H); ^{13}C NMR (125 MHz, CDCl_3) δ 164.4, 155.9, 128.4, 127.7, 125.3, 124.1, 115.7, 112.1, 99.7, 94.4, 91.8, 62.2, 60.1, 26.1, 16.5, 14.8, –4.8; IR (film) 3221, 2958, 2858, 2186, 1668, 1552, 1475, 1328, 1251, 1205, 1104, 1027 cm^{-1} ; HRMS (ES) m/z = 458.0763 calcd for $\text{C}_{20}\text{H}_{26}\text{BrNO}_3\text{SiNa}$ $[\text{MNa}]^+$, found 458.0781.

Methyl 2-((3-(triisopropylsilyl)prop-2-yn-1-yl)oxy)-1*H*-indole-3-carboxylate (4s):

Following the general procedure, compound **4s** was obtained as a white solid in 59% yield: mp 92–93 °C; ^1H NMR (500 MHz, CDCl_3) δ 9.56 (bs, 1H), 8.09 (d, J = 8.0 Hz, 1H), 7.27–7.17 (m, 3H), 5.12 (s, 2H), 3.97 (s, 3H), 1.12–0.88 (m, 21H); ^{13}C NMR (125 MHz, CDCl_3) δ 165.6, 155.6, 130.1, 125.9, 122.12, 122.07, 121.0, 110.8, 100.8, 91.9, 91.2, 61.6, 51.1, 18.5, 11.1; IR (film) 3259, 2950, 2866, 2178, 1668, 1552, 1460, 1344, 1274, 1205, 1104, 1020 cm^{-1} ; HRMS (ES) m/z = 386.2151 calcd for $\text{C}_{22}\text{H}_{32}\text{NO}_3\text{Si}$ $[\text{MH}]^+$, found 386.2137.

Ethyl 2-((3-(triisopropylsilyl)prop-2-yn-1-yl)oxy)-1*H*-indole-3-carboxylate (4t):

Following the general procedure, compound **4t** was obtained as a white solid in 40% yield: mp 93–94 °C; ^1H NMR (500 MHz, CDCl_3) δ 9.03 (bs, 1H), 8.05 (d, J = 7.5 Hz, 1H), 7.24–7.17 (m, 3H), 5.11 (s, 2H), 4.41 (q, J = 7 Hz, 2H), 1.45 (t, J = 7 Hz, 3H), 1.09–0.86 (m, 21H); ^{13}C NMR (125 MHz, CDCl_3) δ 164.9, 155.5, 129.9, 125.9, 122.2, 122.1, 121.2, 110.6, 101.1, 92.0, 91.7, 61.9, 59.8, 18.6, 14.7, 11.1; IR (film) 3244, 2943, 2866, 2178, 1668, 1552, 1460, 1375, 1274, 1205, 1097, 1020 cm^{-1} ; HRMS (ES) m/z = 422.2127 calcd for $\text{C}_{23}\text{H}_{33}\text{NO}_3\text{SiNa}$ $[\text{MNa}]^+$, found 422.2125.

2,2,2-Trifluoroethyl 2-((3-(triisopropylsilyl)prop-2-yn-1-yl)oxy)-1*H*-indole-3-

carboxylate (4u): Following the general procedure, compound **4u** was obtained as a white solid in 26% yield: mp 97–98 °C; ^1H NMR (500 MHz, CDCl_3) δ 8.90 (bs, 1H), 8.00 (d, J = 8.0 Hz, 1H), 7.29–7.21 (m, 3H), 5.08 (s, 2H), 4.73 (q, J = 8.5 Hz, 2H), 1.06–0.98 (m, 21H); ^{13}C NMR (125 MHz, CDCl_3) δ 162.7, 156.6, 129.9, 125.5, 123.8 (q, J = 275.1 Hz, 1C), 122.9, 122.8, 121.2, 110.7, 100.6, 93.1, 90.1, 61.8, 59.9 (q, J = 35 Hz, 1C), 18.6, 11.2; IR (film) 3267, 2950, 2873, 2178, 1684, 1552, 1460, 1282, 1166, 1104, 1022 cm^{-1} ; HRMS (ES) m/z = 476.1845 calcd for $\text{C}_{23}\text{H}_{30}\text{F}_3\text{NO}_3\text{SiNa}$ $[\text{MNa}]^+$, found 476.1849.

Benzyl 2-((3-(triisopropylsilyl)prop-2-yn-1-yl)oxy)-1*H*-indole-3-carboxylate (4v):

Following the general procedure, compound **4v** was obtained as a white resin in 16% yield: ^1H NMR (500 MHz, CDCl_3) δ 8.60 (bs, 1H), 8.03 (d, J = 7.9 Hz, 1H), 7.49 (d, J = 7.2 Hz, 2H), 7.40–7.31 (m, 3H), 7.21–7.15 (m, 3H), 5.40 (s, 2H), 5.09 (s, 2H), 1.05–0.95 (m, 21H); ^{13}C NMR (125 MHz, CDCl_3) δ 164.4, 155.7, 137.0, 129.7, 128.7, 128.2, 128.1, 125.9, 122.4, 122.3, 121.5, 110.5, 101.2, 92.4, 91.7, 65.6, 62.1, 18.6, 11.2; IR (film) 3259, 2946, 2865, 2173, 1670, 1550, 1461, 1343, 1203, 1090, 1021 cm^{-1} ; HRMS (ES) m/z = 484.2284 calcd for $\text{C}_{28}\text{H}_{35}\text{NO}_3\text{NaSi}$ $[\text{MNa}]^+$, found 484.2292.

Ethyl 7-methyl-2-((3-(triisopropylsilyl)prop-2-yn-1-yl)oxy)-1H-indole-3-carboxylate

(4w): Following the general procedure, compound **4w** was obtained as a white solid in 18% yield: mp 104–105 °C; ^1H NMR (300 MHz, CDCl_3) δ 8.40 (bs, 1H), 7.89 (d, J = 7.8 Hz, 1H), 7.13 (dd, J = 7.8, 5.5 Hz, 1H), 6.99 (d, J = 7.5 Hz, 1H), 5.14 (s, 2H), 4.39 (q, J = 7.2 Hz, 2H), 2.42 (s, 3H), 1.44 (t, J = 7.2 Hz, 3H), 1.08–0.93 (m, 21H); ^{13}C NMR (75 MHz, CDCl_3) δ 164.8, 155.3, 129.1, 125.7, 123.2, 122.4, 119.6, 119.2, 101.4, 92.7, 91.8, 62.4, 59.8, 18.7, 16.5, 14.8, 11.4; IR (film) 3229, 2943, 2866, 2178, 1668, 1552, 1468, 1313, 1274, 1213, 1097, 1020 cm^{-1} ; HRMS (ES) m/z = 436.2284 calcd for $\text{C}_{24}\text{H}_{35}\text{NO}_3\text{SiNa}$ $[\text{MNa}]^+$, found 436.2271.

Ethyl 5-methoxy-2-((3-(triisopropylsilyl)prop-2-yn-1-yl)oxy)-1H-indole-3-carboxylate

(4x): Following the general procedure, compound **4x** was obtained as a white solid in 12% yield: mp 109–111 °C; ^1H NMR (500 MHz, CDCl_3) δ 8.48 (bs, 1H), 7.59 (d, J = 2.5 Hz, 1H), 7.08 (d, J = 8.5 Hz, 1H), 6.81 (dd, J = 8.5, 2.5 Hz, 1H), 5.08 (s, 2H), 4.39 (q, J = 7.5 Hz, 2H), 3.87 (s, 3H), 1.44 (t, J = 7.5 Hz, 3H), 1.08–0.97 (m, 21H); ^{13}C NMR (125 MHz, CDCl_3) δ 164.7, 155.9, 155.6, 127.0, 124.4, 111.7, 111.3, 104.2, 101.3, 92.2, 92.1, 62.1, 59.8, 55.9, 18.7, 14.8, 11.1; IR (film) 3205, 2943, 2866, 2178, 1653, 1483, 1352, 1282, 1205, 1166, 1035 cm^{-1} ; HRMS (ES) m/z = 452.2233 calcd for $\text{C}_{24}\text{H}_{35}\text{NO}_4\text{SiNa}$ $[\text{MNa}]^+$, found 452.2234.

Ethyl 7-methoxy-2-((3-(triisopropylsilyl)prop-2-yn-1-yl)oxy)-1H-indole-3-carboxylate

(4y): Following the general procedure, compound **4y** was obtained as a colorless oil in 31% yield: ^1H NMR (500 MHz, CDCl_3) δ 8.81 (bs, 1H), 7.63 (d, J = 8.5 Hz, 1H), 7.13 (dd, J = 8.5, 8.0 Hz, 1H), 6.65 (d, J = 8.0 Hz, 1H), 5.09 (s, 2H), 4.39 (q, J = 7.0 Hz, 2H), 3.91 (s, 3H), 1.43 (t, J = 7.0 Hz, 3H), 1.10–0.94 (m, 21H); ^{13}C NMR (125 MHz, CDCl_3) δ 164.5, 154.6, 145.1, 126.9, 122.3, 119.5, 113.7, 102.5, 100.9, 92.2, 92.0, 61.8, 59.5, 55.1, 18.8, 14.5, 10.9; IR (film) 3244, 2943, 2866, 2178, 1676, 1552, 1468, 1367, 1282, 1213, 1097, 1020 cm^{-1} ; HRMS (ES) m/z = 452.2233 calcd for $\text{C}_{24}\text{H}_{35}\text{NO}_4\text{SiNa}$ $[\text{MNa}]^+$, found 452.2234.

Ethyl 5-bromo-2-((3-(triisopropylsilyl)prop-2-yn-1-yl)oxy)-1H-indole-3-carboxylate

(4z): Following the general procedure, compound **4z** was obtained as a light gray solid in 28% yield: mp 119–120 °C; ^1H NMR (500 MHz, CDCl_3) δ 8.91 (bs, 1H), 8.16 (d, J = 2.0 Hz, 1H), 7.26 (dd, J = 8.5, 2.0 Hz, 1H), 7.07 (d, J = 8.5 Hz, 1H), 5.10 (s, 2H), 4.40 (q, J = 7.0 Hz, 2H), 1.44 (t, J = 7 Hz, 3H), 1.07–0.93 (m, 21H); ^{13}C NMR (125 MHz, CDCl_3) δ 164.4, 155.9, 128.4, 127.7, 125.2, 124.0, 115.7, 112.1, 100.7, 92.6, 91.7, 61.9, 60.1, 18.6, 14.7, 11.2; IR (film) 3229, 2943, 2866, 2178, 1668, 1552, 1468, 1328, 1251, 1205, 1097, 1027 cm^{-1} ; HRMS (ES) m/z = 500.1233 calcd for $\text{C}_{23}\text{H}_{32}\text{BrNO}_3\text{SiNa}$ $[\text{MNa}]^+$, found 500.1226.

General Procedure for the Racemic Claisen Rearrangement

3-Allyl-2-oxoindoline-3-carbonitrile (5a): To a solution of **3a** (0.015 g, 0.081 mmol) in CH_2Cl_2 (0.50 mL) was added SiO_2 (0.02 g, 0.32 mmol). The resulting solution was allowed to stir at room temperature until the starting material was consumed (2 days). The reaction mixture was filtered to remove the SiO_2 and then concentrated under vacuum to afford the rearranged product **5a** (0.014 g, 0.075 mmol) as a white resin in 93% yield. ^1H NMR (500 MHz, CDCl_3) δ 8.70 (bs, 1H), 7.41–7.35 (m, 2H), 7.17 (t, J = 7.7 Hz, 1H), 7.00 (d, J = 7.8 Hz, 1H), 5.77–5.69 (m, 1H), 5.24 (d, J = 10.5 Hz, 1H), 5.21 (d, J = 17.2 Hz, 1H), 3.04 (dd, J = 6.4, 13.6 Hz, 1H), 2.82 (dd, J = 8.1, 13.5 Hz, 1H); ^{13}C NMR (125 MHz, CDCl_3) δ 172.2, 140.0, 130.4, 128.8, 125.3, 124.7, 123.7, 122.2, 116.4, 110.9, 46.9, 41.1, 22.7; IR (film) 3262, 2922, 2247, 1725, 1621, 1475 cm^{-1} ; HRMS (CI): m/z = 199.0871 calcd for

$C_{12}H_{10}N_2O$ $[MH]^+$, found 199.0866; CSP HPLC (Chiralpak AD, 1.0 mL/min, 95:5 hexanes:*i*-PrOH): $t_R(\text{ent-1}) = 15.5$ min, $t_R(\text{ent-2}) = 18.3$ min.

3-(2-Methylallyl)-2-oxoindoline-3-carbonitrile (5b): Following the general procedure, **5b** (0.011 g, 0.052 mmol) was obtained as a white resin in 73% yield. 1H NMR (500 MHz, $CDCl_3$) δ 8.41 (bs, 1H), 7.34-7.25 (m, 2H), 7.09 (t, $J = 7.6$ Hz, 1H), 6.91 (d, $J = 7.8$ Hz, 1H), 4.86 (t, $J = 1.5$ Hz, 1H), 4.68 (s, 1H), 2.92 (d, $J = 13.5$ Hz, 1H), 2.79 (d, $J = 13.5$ Hz, 1H), 1.61 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.0, 140.6, 137.6, 130.2, 125.0, 123.2, 117.9, 117.2, 110.7, 64.4, 46.6, 44.0, 23.4; IR (film) 3250, 2926, 2856, 2227, 1729, 1621, 1475 cm^{-1} ; HRMS (CI): $m/z = 213.1028$ calcd for $C_{13}H_{13}N_2O$ $[MH]^+$, found 213.1041; CSP HPLC (Chiralpak AD, 1.0 mL/min, 95:5 hexanes:*i*-PrOH): $t_R(\text{ent-1}) = 13.9$ min, $t_R(\text{ent-2}) = 16.1$ min.

3-(2-Methylallyl)indolin-2-one (6): Following the general procedure, compound **6** was obtained as a white resin: 1H NMR (500 MHz, $CDCl_3$) δ 8.12 (bs, 1H), 7.23 (m, 2H), 7.00 (dt, $J = 0.5, 7.5$ Hz, 1H), 6.89 (d, $J = 8.0$ Hz, 1H), 4.91 (s, 1H), 4.79 (s, 1H), 3.60 (dd, $J = 4.5, 9.5$ Hz, 1H), 2.83 (dd, $J = 4.0, 14.5$ Hz, 1H), 2.41 (dd, $J = 10.0, 14.0$ Hz, 1H), 1.83 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 179.7, 141.8, 141.1, 129.5, 127.9, 124.9, 122.1, 113.6, 109.5, 43.9, 38.9, 22.2; IR (film) 3213, 3082, 2935, 1707, 1622, 1468, 1336, 1228 cm^{-1} ; HRMS (ES) $m/z = 210.0895$ calcd for $C_{12}H_{13}NONa$ $[MNa]^+$, found 210.0879.

Typical Experimental Procedure for the Asymmetric Meerwein-Eschenmoser Claisen Rearrangement

(S)-Methyl 3-(2-methylallyl)-2-oxoindoline-3-carboxylate (5c): To a solution of Pd(*t*-BuPHOX) Cl_2 (0.004 g, 0.008 mmol) in CH_2Cl_2 (0.5 mL) was added, via cannula, a solution of AgSbF₆ (0.005 g, 0.014 mmol) in CH_2Cl_2 (0.50 mL). The resulting solution was stirred in the absence of light for 3 h, and filtered through a PTFE filter to remove the precipitated AgCl. The resulting clear yellow solution was cooled to 0 °C, followed by addition of **3c** (0.009 g, 0.038 mmol) in CH_2Cl_2 (1.0 mL) via cannula. The reaction mixture was stirred at 0 °C until the starting material was completely consumed, as determined by TLC. Filtration through a plug of SiO₂ (5 mm $\times$ 2 cm) with 25% EtOAc/Hexanes and concentration of the solution under vacuum **5c** (0.008 g, 0.033 mmol) in 89% yield as a white resin: $[\alpha]_D^{23} +79.25$ (*c* 0.40, 89% ee, CH_2Cl_2); 1H NMR (500 MHz, $CDCl_3$) δ 8.84 (bs, 1H), 7.27-7.26 (m, 2H), 7.05 (t, $J = 7.9$ Hz, 1H), 6.94 (d, $J = 7.7$ Hz, 1H), 4.65 (s, 1H), 4.63 (s, 1H), 3.69 (s, 3H), 3.06 (s, 2H), 1.41 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 176.1, 169.6, 141.3, 139.4, 129.1, 128.3, 124.4, 122.6, 115.7, 110.1, 59.9, 53.1, 41.2, 23.6; IR (film) 3250, 2953, 1741, 1702, 1621, 1475 cm^{-1} ; HRMS (CI) $m/z = 246.1130$ calcd for $C_{14}H_{16}NO_3$ $[MH]^+$, found 246.1136; CSP HPLC (Chiralpak OD, 1.0 mL/min, 96.5:3.5 hexanes:*i*-PrOH): $t_R(R) = 16.5$ min, $t_R(S) = 20.3$ min.

(R)-Ethyl 3-(2-methylallyl)-2-oxoindoline-3-carboxylate (5d): Following the general procedure, using Cu(Ind-BOX **L7**)(SbF₆)₂ catalyst, compound **5d** was obtained as a white resin in 100% yield: $[\alpha]_D^{23} -48.44$ (*c* 0.45, 79% ee, CH_2Cl_2); 1H NMR (500 MHz, $CDCl_3$) δ 7.93 (bs, 1H), 7.28-7.19 (m, 2H), 7.05 (t, $J = 7.6$ Hz, 1H), 6.89 (d, $J = 7.7$ Hz, 1H), 4.67 (d, $J = 16.6$ Hz, 2H), 4.17 (m, 2H), 3.07 (d, $J = 16.8$ Hz, 1H), 3.03 (d, $J = 16.8$ Hz, 1H), 1.42 (s, 3H), 1.18 (t, $J = 7.0$ Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 175.6, 169.1, 141.2, 139.6, 129.0, 128.5, 124.4, 122.6, 115.6, 109.8, 62.1, 59.9, 41.0, 23.7, 11.9; IR (film) 3250, 2980, 2922, 2853, 1718, 1621, 1475 cm^{-1} ; HRMS (ES) $m/z = 282.1106$ calcd for $C_{15}H_{17}NO_3Na$ $[MNa]^+$, found 282.1115; CSP HPLC (Chiralpak OD, 1.0 mL/min, 96.5:3.5 hexanes:*i*-PrOH): $t_R(R) = 13.0$ min, $t_R(S) = 20.0$ min.

(R)-Benzyl 3-(2-methylallyl)-2-oxoindoline-3-carboxylate (5e): Following the general procedure, using Cu(Ind-BOX **L7**)(SbF₆)₂ catalyst, compound **5e** was obtained as a pale yellow resin in 73% yield: $[\alpha]_D^{23}$ -22.00 (*c* 0.55, 73% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 8.25 (bs, 1H), 7.25-7.13 (m, 7H), 7.02 (t, *J* = 7.6 Hz, 1H), 6.88 (d, *J* = 7.8 Hz, 1H), 5.12 (s, 2H), 4.66 (s, 1H), 4.62 (s, 1H), 3.07 (d, *J* = 19.5 Hz, 1H), 3.03 (d, *J* = 19.5 Hz, 1H), 1.41 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 175.6, 168.9, 141.3, 139.4, 135.3, 129.1, 128.4, 128.2, 128.1, 127.4, 124.4, 122.6, 115.7, 110.0, 67.3, 60.0, 40.9, 23.7; IR (film) 3242, 2926, 2856, 1718, 1621, 1471 cm⁻¹; HRMS (ES) *m/z* = 344.1263 calcd for C₂₀H₁₉NO₃Na [MNa]⁺, found 344.1264; CSP HPLC (Chiralpak OD, 1.0 mL/min, 96.5:3.5 hexanes: *i*-PrOH): t_R(*R*) = 17.8 min, t_R(*S*) = 27.8 min.

(R)-Isopropyl 3-(2-methylallyl)-2-oxoindoline-3-carboxylate (5f): Following the general procedure, using Cu(Ind-BOX **L7**)(SbF₆)₂ catalyst, compound **5f** was obtained as white resin in 100% yield: $[\alpha]_D^{23}$ -22.00 (*c* 0.2, 65% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 8.22 (bs, 1H), 7.25-7.21 (m, 2H), 7.03 (t, *J* = 7.6 Hz, 1H), 6.88 (d, *J* = 8.0 Hz, 1H), 5.02-4.97 (m, 1H), 4.65 (s, 1H), 4.62 (s, 1H), 3.04 (d, *J* = 18.5 Hz, 1H), 3.01 (d, *J* = 18.5 Hz, 1H), 1.41 (s, 3H), 1.21 (d, *J* = 6.2 Hz, 6H); ¹³C NMR (125 MHz, CDCl₃) δ 175.6, 168.5, 141.2, 139.7, 128.9, 128.6, 124.2, 122.5, 115.5, 109.7, 69.7, 60.1, 40.9, 23.7, 21.4, 21.3; IR (film) 3250, 2984, 1733, 1621, 1475 cm⁻¹; HRMS (ES) *m/z* = 296.1263 calcd for C₁₆H₁₉NO₃Na [MNa]⁺, found 296.1264; CSP HPLC (Chiralpak OD, 1.0 mL/min, 96.5:3.5 hexanes: *i*-PrOH): t_R(*R*) = 7.7 min, t_R(*S*) = 11.8 min.

(S)-tert-Butyl 3-(2-methylallyl)-2-oxoindoline-3-carboxylate (5g): Following the general procedure, using Pd(BINAP)(SbF₆)₂ catalyst, compound **5g** was obtained as a white resin in 100% yield: $[\alpha]_D^{23}$ +66.89 (*c* 0.90, 85% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 9.09 (bs, 1H), 7.23 (m, 2H), 7.02 (t, *J* = 7.6 Hz, 1H), 6.90 (d, *J* = 7.7 Hz, 1H), 4.61 (s, 2H), 3.04 (d, *J* = 13.9 Hz, 1H), 2.97 (d, *J* = 13.9 Hz, 1H), 1.38 (s, 3H), 1.36 (s, 9H); ¹³C NMR (125 MHz, CDCl₃) 175.6, 167.9, 141.1, 139.9, 129.0, 128.8, 124.1, 122.4, 115.3, 109.6, 82.5, 60.7, 40.8, 27.7, 23.7; IR (film) 3262, 2980, 2930, 1733, 1621, 1475 cm⁻¹; HRMS (ES) *m/z* = 310.1419 calcd for C₁₇H₂₁NO₃Na [MNa]⁺, found 310.1416; CSP HPLC (Chiralpak OD, 1.0 mL/min, 96.5:3.5 hexanes: *i*-PrOH): t_R(*R*) = 6.1 min, t_R(*S*) = 9.2 min.

(S)-tert-Butyl 3-allyl-2-oxoindoline-3-carboxylate (5i): Following the general procedure, using Pd(BINAP)(SbF₆)₂ catalyst, compound **5i** was obtained as a white resin in 60% yield: $[\alpha]_D^{23}$ +106.5 (*c* 0.30, 89% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 8.95 (bs, 1H), 7.26-7.23 (m, 2H), 7.05 (t, *J* = 7.6 Hz, 1H), 6.89 (d, *J* = 7.8 Hz, 1H), 5.50 (m, 1H), 5.06 (d, *J* = 17.0 Hz, 1H), 4.94 (d, *J* = 10.1 Hz, 1H), 2.98-2.90 (m, 2H), 1.31 (s, 9H); ¹³C NMR (125 MHz, CDCl₃) δ 175.9, 167.7, 141.2, 131.2, 128.8, 128.7, 123.7, 122.6, 119.5, 109.7, 82.5, 60.5, 38.2, 27.7; IR (film) 3252, 3090, 2981, 2927, 1722, 1622, 1475, 1251, 1159 cm⁻¹; HRMS (CI) *m/z* = 274.1443 calcd for C₁₆H₂₀NO₃ [MH]⁺, found 274.1459; CSP HPLC (Chiralpak OD, 1.0 mL/min, 96.5:3.5 hexanes: *i*-PrOH): t_R(*R*) = 7.2 min, t_R(*S*) = 8.8 min.

(S)-Methyl 3-allyl-2-oxoindoline-3-carboxylate (5j): Following the general procedure, compound **5j** was obtained as a white resin in 100% yield: $[\alpha]_D^{23}$ +51.30 (*c* 0.50, 83% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 8.20 (bs, 1H), 7.28-7.25 (m, 2H), 7.07 (t, *J* = 7.6 Hz, 1H), 6.92 (d, *J* = 7.9 Hz, 1H), 5.49-5.41 (m, 1H), 5.08 (dd, *J* = 1.2, 17.0 Hz, 1H), 4.97 (d, *J* = 10.1 Hz, 1H), 3.71 (s, 3H), 3.04 (dd, *J* = 6.7, 13.8 Hz, 1H), 2.97 (dd, *J* = 7.9, 13.8 Hz, 1H); ¹³C NMR (125 MHz, CDCl₃) δ 175.6, 169.3, 141.1, 130.8, 129.1, 128.0, 124.0, 122.8, 120.0, 110.0, 59.6, 53.1, 38.4; IR (film) 3252, 3090, 2958, 2858, 1715, 1622, 1475, 1437, 1336, 1236 cm⁻¹; HRMS (ES) *m/z* = 254.0793 calcd for C₁₃H₁₃NO₃Na [MNa]⁺, found

254.0791; CSP HPLC (Chiralpak AD, 1.0 mL/min, 95.5 hexanes:*i*-PrOH): $t_R(S)$ = 18.4 min, $t_R(R)$ = 20.6 min.

(S)-Methyl 3-(2-methylenebutyl)-2-oxoindoline-3-carboxylate (5k): Following the general procedure, compound **5k** was obtained as a white resin in 82% yield: $[\alpha]_D^{23}$ +59.00 (*c* 0.45, 92% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 8.12 (bs, 1H), 7.28-7.23 (m, 2H), 7.05 (t, *J* = 7.5 Hz, 1H), 6.88 (d, *J* = 7.7 Hz, 1H), 4.66 (t, *J* = 1.4 Hz, 1H), 4.64 (s, 1H), 3.69 (s, 3H), 3.08 (d, *J* = 16.7 Hz, 1H), 3.05 (d, *J* = 16.8 Hz, 1H), 1.68 (q, *J* = 7.4 Hz, 2H), 0.84 (t, *J* = 7.4 Hz, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 176.0, 169.7, 145.0, 141.3, 129.1, 128.3, 124.4, 122.6, 113.2, 110.0, 60.0, 53.1, 39.5, 29.7, 12.3; IR (film) 3275, 2927, 2858, 1715, 1622, 1444, 1236 cm⁻¹; HRMS (CI) *m/z* = 260.1287 calcd for C₁₅H₁₈NO₃ [MH]⁺, found 260.1287; CSP HPLC (Chiralpak OD, 1.0 mL/min, 96.5:3.5 hexanes:*i*-PrOH): $t_R(R)$ = 13.6 min, $t_R(S)$ = 15.8 min.

(S)-Isopropyl 3-allyl-2-oxoindoline-3-carboxylate (5l): Following the general procedure, using Pd(BINAP)(SbF₆)₂ catalyst, compound **5l** was obtained as white resin in 91% yield: $[\alpha]_D^{23}$ +44.20 (*c* 0.50, 74% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 8.04 (bs, 1H), 7.25-7.23 (m, 2H), 7.05 (t, *J* = 7.6 Hz, 1H), 6.90 (d, *J* = 7.8 Hz, 1H), 5.50-5.41 (m, 1H), 5.07 (d, *J* = 17.0 Hz, 1H), 5.02 (m, 1H), 5.00 (d, *J* = 10.1 Hz, 1H), 3.01 (dd, *J* = 6.7, 13.8 Hz, 1H), 2.95 (dd, *J* = 7.8, 13.8, 1H), 1.23 (d, *J* = 6.3 Hz, 3H), 1.13 (d, *J* = 6.3 Hz, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 175.5, 168.3, 141.1, 131.0, 128.9, 128.4, 123.9, 122.7, 119.8, 109.8, 69.7, 59.8, 38.3, 21.5, 21.3; IR (film) 3252, 3090, 2981, 2927, 2858, 1722, 1622, 1468, 1236 cm⁻¹; HRMS (ES) *m/z* = 282.1106 calcd for C₁₅H₁₇NO₃Na [MNa]⁺, found 282.1091; CSP HPLC (Chiralpak OD, 1.0 mL/min, 96.5:3.5 hexanes:*i*-PrOH): $t_R(R)$ = 11.8 min, $t_R(S)$ = 14.9 min.

(S)-Benzyl 3-allyl-2-oxoindoline-3-carboxylate (5m): Following the general procedure, using Pd(BINAP)(SbF₆)₂ catalyst, compound **5m** was obtained as a white resin in 74% yield: $[\alpha]_D^{23}$ +51.38 (*c* 0.40, 72% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 8.28 (bs, 1H), 7.28-7.22 (m, 5H), 7.17-7.16 (m, 2H), 7.05 (td, *J* = 7.5, 0.9 Hz, 1H), 6.90 (d, *J* = 7.8 Hz, 1H), 5.50-5.41 (m, 1H), 5.16 (d, *J* = 15.5 Hz, 1H), 5.14 (d, *J* = 15.6 Hz, 1H), 5.08 (dd, *J* = 1.4, 16.9 Hz, 1H), 4.96 (dd, *J* = 1.7, 10.1 Hz, 1H), 3.05 (dd, *J* = 6.7, 13.9 Hz, 1H), 2.99 (dd, *J* = 7.9, 13.9 Hz, 1H); ¹³C NMR (125 MHz, CDCl₃) δ 175.3, 168.6, 141.2, 135.3, 130.8, 129.1, 128.4, 128.1, 128.0, 127.4, 124.0, 122.7, 120.0, 110.0, 67.3, 59.7, 38.2; IR (film) 3259, 3066, 2927, 1715, 1622, 1468, 1336 cm⁻¹; HRMS (ES) *m/z* = 308.1263 calcd for C₁₉H₁₈NO₃ [MH]⁺, found 308.1273; CSP HPLC (Chiralpak OD, 1.0 mL/min, 96.5:3.5 hexanes:*i*-PrOH): $t_R(R)$ = 20.7 min, $t_R(S)$ = 29.7 min.

(S)-Methyl 5-methoxy-3-(2-methylallyl)-2-oxoindoline-3-carboxylate (5n): Following the general procedure, compound **5n** was obtained as a white resin in 60% yield: $[\alpha]_D^{23}$ +40.83 (*c* 0.30, 91% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 7.55 (bs, 1H), 6.88 (s, 1H), 6.80 (m, 2H), 4.70 (s, 1H), 4.65 (s, 1H), 3.79 (s, 3H), 3.70 (s, 3H), 3.05 (d, *J* = 19.5 Hz, 1H), 3.02 (d, *J* = 19.4 Hz, 1H), 1.42 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 175.6, 169.6, 155.9, 139.4, 134.5, 129.5, 115.7, 113.9, 111.3, 110.3, 60.2, 55.8, 53.2, 41.2, 23.7; IR (film) 3259, 2927, 2858, 1715, 1607, 1491, 1444, 1236 cm⁻¹; HRMS (ES) *m/z* = 276.1236 calcd for C₁₅H₁₈NO₄ [MH]⁺, found 276.1248; CSP HPLC (Chiralpak OD, 1.0 mL/min, 96.5:3.5 hexanes:*i*-PrOH): $t_R(R)$ = 20.7 min, $t_R(S)$ = 23.8 min.

(S)-Methyl 5-bromo-3-(2-methylallyl)-2-oxoindoline-3-carboxylate (5o): Following the general procedure, compound **5o** was obtained as a white resin in 82% yield: $[\alpha]_D^{23}$ +38.67 (*c* 0.45, 87% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 8.34 (bs, 1H), 7.40 (m, 2H), 6.80 (d,

$J = 8.7$ Hz, 1H), 4.70 (s, 1H), 4.63 (s, 1H), 3.72 (s, 3H), 3.05 (d, $J = 19.8$ Hz, 1H), 3.02 (d, $J = 19.8$ Hz, 1H), 1.46 (s, 3H); ^{13}C NMR (125 MHz, CDCl_3) δ 175.3, 168.9, 140.2, 139.0, 132.0, 130.2, 127.7, 116.1, 115.2, 111.4, 59.9, 53.4, 41.2, 23.7; IR (film) 3252, 2958, 2858, 1738, 1614, 1475, 1228 cm^{-1} ; HRMS (ES) $m/z = 324.0235$ calcd for $\text{C}_{14}\text{H}_{15}\text{BrNO}_3$ $[\text{MH}]^+$, found 324.0240; CSP HPLC (Chiralpak AS, 1.0 mL/min, 92.5:7.5 hexanes:*i*-PrOH): $t_R(R) = 15.1$ min, $t_R(S) = 25.5$ min.

(S)-Methyl 7-methoxy-3-(2-methylallyl)-2-oxoindoline-3-carboxylate (5p): Following the general procedure, compound **5p** was obtained as a white resin in 95% yield: $[\alpha]_D^{23} +82.78$ (c 0.450, 85% ee, CH_2Cl_2); ^1H NMR (500 MHz, CDCl_3) δ 8.65 (bs, 1H), 7.01 (t, $J = 8.0$ Hz, 1H), 6.89 (d, $J = 7.5$ Hz, 1H), 6.84 (d, $J = 8.1$ Hz, 1H), 4.67 (s, 1H), 4.64 (s, 1H), 3.88 (s, 3H), 3.69 (s, 3H), 3.04 (m, 2H), 1.43 (s, 3H); ^{13}C NMR (125 MHz, CDCl_3) δ 174.7, 169.6, 143.8, 139.5, 130.1, 128.9, 123.1, 116.6, 115.6, 111.3, 60.5, 55.6, 53.1, 41.0, 23.7; IR (film) 3229, 3090, 2958, 2850, 1715, 1622, 1498, 1228 cm^{-1} ; HRMS (ES) $m/z = 298.1055$ calcd for $\text{C}_{15}\text{H}_{17}\text{NO}_4\text{Na}$ $[\text{MNa}]^+$, found 298.1057; CSP HPLC (Chiralpak AS, 1.0 mL/min, 96.5:3.5 hexanes:*i*-PrOH): $t_R(R) = 21.3$ min, $t_R(S) = 27.0$ min.

(S)-Methyl 3-(2-(deuteromethylene)butyl)-2-oxoindoline-3-carboxylate (5q): Following the general procedure, compound **5q** was obtained as a white resin in 80% yield: $[\alpha]_D^{23} +43.13$ (c 0.40, 92% ee, CH_2Cl_2); ^1H NMR (500 MHz, CDCl_3) δ 8.04 (bs, 1H), 7.32–7.24 (m, 2H), 7.05 (t, $J = 7.6$ Hz, 1H), 6.88 (d, $J = 7.6$ Hz, 1H), 4.63 (s, 0.5 H, *Z*-deutero), 4.62 (s, 0.5 H, *E*-deutero), 3.70 (s, 3H), 3.07 (d, $J = 16.3$ Hz, 1H), 3.04 (d, $J = 16.2$ Hz, 1H), 1.68 (q, $J = 7.3$ Hz, 2H), 0.84 (t, $J = 7.4$ Hz, 3H); ^{13}C NMR (125 MHz, CDCl_3) δ 175.8, 169.9, 145.1, 141.4, 129.3, 128.6, 124.7, 122.8, 113.1 (t, $J_{\text{CD}} = 23.6$ Hz), 110.1, 60.2, 53.4, 39.7, 29.9, 12.5; IR (film) 3252, 3090, 2981, 2935, 1715, 1622, 1475, 1375, 1251, 1159 cm^{-1} ; HRMS (ES) $m/z = 283.1169$ calcd for $\text{C}_{15}\text{H}_{16}\text{DNO}_3\text{Na}$ $[\text{MNa}]^+$, found 283.1173; CSP HPLC (Chiralpak OD, 1.0 mL/min, 96.5:3.5 hexanes:*i*-PrOH): $t_R(R) = 13.6$ min, $t_R(S) = 15.8$ min.

General Procedure for Preparing Catalysts

Pd[(R)-BINAP](SbF₆)₂: To a flask of Pd[(R)-BINAP]Cl₂ (4 mg, 0.005 mmol) in CH_2Cl_2 (0.5 mL) was added a solution of AgSbF₆ (3.3 mg, 0.0095 mmol) in CH_2Cl_2 (0.5 mL). The resulting solution was stirred in the absence of light for 3 h, and filtered through a PTFE filter to remove the precipitated AgCl. The resulting clear yellow solution was concentrated to afford Pd[(R)-BINAP](SbF₆)₂ as a yellow solid in 100% yield.

Pd[(S)-*t*-BuPHOX](SbF₆)₂: To a flask of Pd[(S)-*t*-BuPHOX]Cl₂ (2.8 mg, 0.005 mmol) in CH_2Cl_2 (0.5 mL) was added a solution of AgSbF₆ (3.3 mg, 0.0095 mmol) in CH_2Cl_2 (0.5 mL). The resulting solution was stirred in the absence of light for 3 h, and filtered through a PTFE filter to remove the precipitated AgCl. The resulting clear yellow solution was concentrated to afford Pd[(S)-*t*-BuPHOX](SbF₆)₂ as a light yellow solid in 100% yield.

Typical Procedure for the Asymmetric Saucy-Marbet Claisen Rearrangement

(R)-Ethyl 3-(1-(tert-butyldimethylsilyl)propa-1,2-dien-1-yl)-5-methoxy-2-oxoindoline-3-carboxylate (8p): To a solution of the Pd[(R)-BINAP](SbF₆)₂ complex (12 mg, 0.01 mmol, 20 mol%) in $\text{C}_6\text{H}_5\text{Cl}$ (1 mL) was added a solution of **4p** (19.4 mg, 0.05 mmol) in toluene (1 mL) at ambient temperature. The resulting solution was stirred in the absence of light at room temperature until the starting material was completely consumed, as determined by TLC. Filtration through a plug of SiO₂ (5 mm × 2 cm) with ethyl ether, concentration of the solution and purification by column chromatography using 50% ethyl ether/hexane afforded **8p** as a white resin in 82% yield: mp 136–137 °C; $[\alpha]_D^{23} +158.18$ (c 0.17, 93% ee,

CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 7.92 (bs, 1H), 6.89 (d, *J* = 2.0 Hz, 1H), 6.79–6.74 (m, 2H), 4.60 (d, *J* = 11.5 Hz, 1H), 4.41 (d, *J* = 11.5 Hz, 1H), 4.22 (qd, *J* = 7.5, 11.0 Hz, 1H), 4.13 (qd, *J* = 7.5, 11.0 Hz, 1H), 3.78 (s, 3H), 1.23 (t, *J* = 7.5 Hz, 3H), 0.92 (s, 9H), 0.12 (s, 3H), 0.10 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 212.5, 174.8, 168.8, 155.7, 134.3, 129.7, 114.5, 113.2, 110.2, 100.2, 93.6, 74.1, 62.4, 56.1, 27.6, 19.4, 14.2, –4.0, –4.2; IR (film) 3252, 2958, 2858, 1931, 1746, 1622, 1468, 1259, 1089, 1027 cm^{–1}; HRMS (ES) *m/z* = 386.1788 calcd for C₂₁H₂₈NO₄Si [M–H][–], found 386.1776; CSP HPLC (Chiralpak IA, 1 mL/min, 95:5 hexanes: *i*-PrOH) *t*_R(1) = 14.0 min, *t*_R(2) = 21.6 min.

(*S*)-tert-Butyl 2-oxo-3-(propa-1,2-dien-1-yl)indoline-3-carboxylate (8a): Following the general procedure, using Pd(*t*-BuPHOX)(SbF₆)₂ catalyst and CH₂Cl₂ as the solvent, compound **8a** was obtained as a white solid in 100% yield: mp 140–141 °C; ¹H NMR (500 MHz, CDCl₃) δ 8.78 (bs, 1H), 7.31–7.24 (m, 2H) 7.04 (t, *J* = 7.5 Hz, 1H), 6.94 (d, *J* = 8.0 Hz, 1H), 5.79 (t, *J* = 6.5 Hz, 1H) 4.87 (dd, 11.5, 6.5 Hz, 1H), 4.77 (dd, 11.5, 6.5 Hz, 1H), 1.38 (s, 9H); ¹³C NMR (125 MHz, CDCl₃) δ 208.5, 175.3, 167.1, 141.3, 129.2, 128.5, 125.0, 122.7, 110.3, 89.2, 83.3, 79.3, 60.2, 27.9; IR (film) 3221, 2927, 2858, 1962, 1668, 1738, 1622, 1468, 1259, 1159 cm^{–1}; HRMS (ES) *m/z* = 294.1106 calcd for C₁₆H₁₇NO₃Na [MNa]⁺, found 294.1100; CSP HPLC (Chiralpak AS, 1.0 mL/min, 90:10 hexanes: *i*-PrOH) *t*_R(1) = 18.3 min, *t*_R(2) = 26.8 min.

(*S*)-tert-Butyl 3-(buta-2,3-dien-2-yl)-2-oxoindoline-3-carboxylate (8b): Following the general procedure, using Pd(*t*-BuPHOX)(SbF₆)₂ catalyst and CH₂Cl₂ as the solvent at 0 °C, compound **8b** was obtained as a white solid in 100% yield: mp 119–120 °C; ¹H NMR (500 MHz, CDCl₃) δ 9.01 (bs, 1H), 7.31 (d, *J* = 7.5 Hz, 1H), 7.24 (td, *J* = 7.5, 1.0 Hz, 1H), 7.03 (td, *J* = 7.5, 1.0 Hz, 1H), 6.86 (d, *J* = 7.5 Hz, 1H), 4.77 (dq, *J* = 10.5, 3.0 Hz, 1H), 4.59 (dq, *J* = 10.5, 3.0 Hz, 1H), 1.90 (t, *J* = 3 Hz, 3H), 1.42 (s, 9H); ¹³C NMR (125 MHz, CDCl₃) δ 207.8, 175.3, 166.9, 141.3, 129.2, 128.0, 125.9, 122.4, 110.2, 97.6, 83.1, 77.8, 63.2, 27.9, 15.6; IR (film) 3213, 2927, 2858, 1962, 1738, 1622, 1475, 1259 cm^{–1}; HRMS (ES) *m/z* = 308.1263 calcd for C₁₇H₁₉NO₃Na [MNa]⁺, found 308.1263; CSP HPLC (Chiralpak AS, 1.0 mL/min, 96.5:3.5 hexanes: *i*-PrOH) *t*_R(1) = 17.6 min, *t*_R(2) = 21.9 min.

(*S*)-Methyl 2-oxo-3-(propa-1,2-dien-1-yl)indoline-3-carboxylate (8c): Following the general procedure, using Pd[(*S*)-*t*-BuPHOX](SbF₆)₂ catalyst and CH₂Cl₂ as the solvent at 0 °C, compound **8c** was obtained as a white solid in 100% yield: mp 128–129 °C; [*α*]_D²³ +2.85 (c 0.175, 14% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 8.82 (bs, 1H), 7.30–7.26 (m, 2H) 7.06 (td, *J* = 7.5, 1.0 Hz, 1H), 6.95 (d, *J* = 7.5, 1H), 5.82 (t, *J* = 6.5 Hz, 1H), 4.91 (dd, *J* = 11.5, 6.5 Hz, 1H), 4.79 (dd, *J* = 11.5, 6.5 Hz, 1H), 3.73 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 208.5, 174.9, 168.8, 141.1, 129.5, 127.8, 125.4, 122.9, 110.5, 83.1, 79.7, 59.2, 53.7; IR (film) 3252, 2935, 2889, 1962, 1746, 1475, 1244, 1189 cm^{–1}; HRMS (ES) *m/z* = 230.0817 calcd for C₁₃H₁₂NO₃ [MH]⁺, found 230.0818; CSP HPLC (Chiralpak AD, 0.75 mL/min, 92.5:7.5 hexanes: *i*-PrOH) *t*_R(1) = 20.5 min, *t*_R(2) = 22.5 min.

(*S*)-Methyl 3-(buta-2,3-dien-2-yl)-2-oxoindoline-3-carboxylate (8d): Following the general procedure, using Pd[(*S*)-*t*-BuPHOX](SbF₆)₂ catalyst and CH₂Cl₂ as the solvent at 0 °C, compound **8d** was obtained as a white solid in 100% yield: [*α*]_D²³ +26.67 (c 0.075, 45% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 7.66 (bs, 1H), 7.33 (d, *J* = 7.5 Hz, 1H), 7.26 (td, *J* = 7.5, 1.5 Hz, 1H), 7.05 (td, *J* = 7.5, 1.0 Hz, 1H), 6.87 (d, *J* = 7.5 Hz, 1H), 4.80 (dq, *J* = 11.0, 3.0 Hz, 1H), 4.64 (dd, *J* = 11.5, 3.0 Hz, 1H), 3.75 (s, 3H), 1.89 (t, *J* = 3.0 Hz, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 207.9, 173.9, 168.5, 140.8, 129.5, 127.6, 126.4, 122.8, 109.9, 97.5, 78.1, 62.4, 53.5, 15.5; IR (film) 3252, 3066, 2935, 2858, 1962, 1738, 1622, 1475, 1437, 1236, 1189 cm^{–1}; HRMS (ES) *m/z* = 244.0974 calcd for C₁₄H₁₄NO₃ [MH]⁺, found

244.0962; CSP HPLC (Chiralpak AD, 1.0 mL/min, 96.5:3.5 hexanes: *i*-PrOH) $t_R(1) = 23.7$ min, $t_R(2) = 26.7$ min.

(S)-Methyl 2-oxo-3-(1-phenylpropa-1,2-dien-1-yl)indoline-3-carboxylate (8e): Following the general procedure, the reaction with 5 mol% Pd[(*S*)-*t*-BuPHOX](SbF₆)₂ catalyst and CH₂Cl₂ as the solvent was conducted at -78 °C and slowly warmed to -15 °C. Compound **8e** was obtained as a white solid in 96% yield: mp 149–150 °C; $[\alpha]_D^{23} +98.57$ (c 0.14, 78% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 9.21 (bs, 1H), 7.42–7.39 (m, 2H), 7.36 (d, *J* = 7.5, Hz, 1H), 7.26–7.17 (m, 4H), 7.02 (td, *J* = 7.6, 1.0 Hz, 1H), 6.87 (d, *J* = 7.8 Hz, 1H), 5.11 (d, *J* = 12.5 Hz, 1H), 5.02 (d, *J* = 12.5 Hz, 1H), 3.69 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 210.0, 175.0, 168.6, 141.2, 133.9, 129.6, 128.4, 127.96, 127.91, 127.5, 126.3, 122.9, 110.5, 104.9, 80.3, 62.8, 53.5; IR (film) 3283, 3073, 2934, 1941, 1740, 1612, 1477, 1236, 1029 cm⁻¹; HRMS (ES) *m/z* = 328.0950 calcd for C₁₉H₁₅NO₃Na [MNa]⁺, found 328.0944; CSP HPLC (Chiralpak IA, 1.0 mL/min, 90:10 hexanes: *i*-PrOH) $t_R(1) = 16.47$ min, $t_R(2) = 26.69$ min.

(S)-Methyl 2-oxo-3-(1-(*o*-tolyl)propa-1,2-dien-1-yl)indoline-3-carboxylate (8f): Following the general procedure, the reaction with 5 mol% Pd[(*S*)-*t*-BuPHOX](SbF₆)₂ catalyst and CH₂Cl₂ as the solvent was conducted at -78 °C and slowly warmed to -15 °C. Compound **8f** was obtained as a white solid in 95% yield: mp 140–141 °C; $[\alpha]_D^{23} +58.50$ (c 0.4, 98% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 8.70 (bs, 1H), 7.22–7.18 (m, 3H), 7.10–7.09 (m, 2H), 7.03–7.00 (m, 1H), 6.95 (t, *J* = 7.5, Hz, 1H), 6.85 (d, *J* = 7.7 Hz, 1H), 4.98 (d, *J* = 12.0 Hz, 1H), 4.95 (d, *J* = 12.0 Hz, 1H), 3.71 (s, 3H), 2.20 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 208.5, 174.4, 168.3, 141.1, 137.7, 133.5, 130.4, 129.5, 128.7, 127.9, 127.5, 126.4, 125.8, 122.7, 110.2, 101.2, 78.4, 63.6, 53.4, 20.2; IR (film) 3268, 2954, 1949, 1742, 1613, 1477, 1235, 1106 cm⁻¹; HRMS (ES) *m/z* = 342.1106 calcd for C₂₀H₁₇NO₃Na [MNa]⁺, found 342.1105; CSP HPLC (Chiralpak IA, 1.0 mL/min, 90:10 hexanes: *i*-PrOH) $t_R(1) = 10.65$ min, $t_R(2) = 14.33$ min.

(S)-Methyl 3-(1-(2-bromophenyl)propa-1,2-dien-1-yl)-2-oxoindoline-3-carboxylate (8g): Following the general procedure, the reaction with 5 mol% Pd[(*S*)-*t*-BuPHOX](SbF₆)₂ catalyst and CH₂Cl₂ as the solvent was conducted at -78 °C and slowly warmed to -15 °C. Compound **8g** was obtained as a white resin in 93% yield: $[\alpha]_D^{23} +44.44$ (c 0.315, 96% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 9.10 (bs, 1H), 7.55 (dd, *J* = 7.7, 1.6 Hz, 1H), 7.48 (dd, *J* = 8.0, 1.2 Hz, 1H), 7.26–7.14 (m, 3H), 7.06 (td, *J* = 7.5, 1.7 Hz, 1H), 6.94 (t, *J* = 7.7 Hz, 1H), 6.86 (d, *J* = 7.5 Hz, 1H), 5.07 (d, *J* = 12.0 Hz, 1H), 5.02 (d, *J* = 12.0 Hz, 1H), 3.68 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 209.4, 174.7, 168.4, 141.4, 135.2, 132.9, 130.6, 129.6, 129.4, 127.4, 127.1, 126.5, 125.9, 122.6, 110.3, 101.9, 79.8, 62.5, 53.4; IR (film) 3272, 3062, 2954, 1951, 1742, 1614, 1474, 1235, 1029 cm⁻¹; HRMS (ES) *m/z* = 406.0055 calcd for C₁₉H₁₄NO₃NaBr [MNa]⁺, found 406.0052; CSP HPLC (Chiralpak IA, 1.0 mL/min, 90:10 hexanes: *i*-PrOH) $t_R(1) = 15.07$ min, $t_R(2) = 19.92$ min.

(S)-Methyl 3-(1-(naphthalen-1-yl)propa-1,2-dien-1-yl)-2-oxoindoline-3-carboxylate (8h): Following the general procedure, the reaction with 5 mol% Pd[(*S*)-*t*-BuPHOX](SbF₆)₂ catalyst and CH₂Cl₂ as the solvent was conducted at -78 °C and slowly warmed to -15 °C. Compound **8h** was obtained as a white solid in 95% yield: decomposed at 197 °C; $[\alpha]_D^{23} +59.22$ (c 0.07, 98% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 8.84 (bs, 1H), 8.11 (d, *J* = 8.2 Hz, 1H), 7.75 (d, *J* = 7.5 Hz, 1H), 7.69 (d, *J* = 8.2 Hz, 1H), 7.44–7.37 (m, 3H), 7.30–7.20 (m, 2H), 7.11 (td, *J* = 7.7, 1.2 Hz, 1H), 6.83 (td, *J* = 7.7, 1.0 Hz, 1H), 6.71 (d, *J* = 7.7 Hz, 1H), 5.07 (d, *J* = 12.0 Hz, 1H), 5.04 (d, *J* = 12.0 Hz, 1H), 3.69 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 209.4, 174.6, 168.4, 141.1, 133.8, 132.4, 131.7, 129.5, 128.5, 128.3, 127.3, 126.6,

126.4, 126.1, 125.87, 125.86, 125.2, 122.6, 110.3, 100.1, 78.7, 63.9, 53.5; IR (film) 3262, 3061, 2934, 1950, 1740, 1613, 1474, 1235, 1029 cm^{-1} ; HRMS (ES) $m/z = 378.1106$ calcd for $\text{C}_{23}\text{H}_{17}\text{NO}_3\text{Na}$ $[\text{MNa}]^+$, found 378.1109; CSP HPLC (Chiralpak IA, 1.0 mL/min, 90:10 hexanes: *i*-PrOH) $t_R(1) = 14.3$ min, $t_R(2) = 17.9$ min.

(S)-Methyl 3-(1-(2-methoxyphenyl)propa-1,2-dien-1-yl)-2-oxoindoline-3-carboxylate (8i):

Following the general procedure, the reaction of a mixture of compound **4i** and methylindole-3-carboxylate (1.4:1) with 5 mol% $\text{Pd}[(S)\text{-}t\text{-BuPHOX}](\text{SbF}_6)_2$ catalyst and CH_2Cl_2 as the solvent was conducted at -78°C and slowly warmed to -15°C . Compound **8i** was obtained as a colorless resin in 90% yield: $[\alpha]_D^{23} +14.25$ (c 0.035, 98% ee, CH_2Cl_2); ^1H NMR (500 MHz, CDCl_3) δ 7.91 (bs, 1H), 7.32 (dd, $J = 7.5, 1.7$ Hz, 1H), 7.17–7.11 (m, 2H), 6.97 (d, $J = 7.8$ Hz, 1H), 6.87 (t, $J = 7.5$ Hz, 1H), 6.81–6.76 (m, 2H), 6.55 (d, $J = 8.2$ Hz, 1H), 5.15 (d, $J = 11.5$ Hz, 1H), 5.12 (d, $J = 12.0$ Hz, 1H), 3.73 (s, 3H), 3.41 (s, 3H); ^{13}C NMR (125 MHz, CDCl_3) δ 210.7, 174.6, 169.0, 156.7, 141.2, 131.2, 129.4, 129.0, 127.4, 126.5, 124.0, 122.0, 120.6, 110.3, 109.2, 100.4, 78.4, 62.6, 54.7, 53.5; IR (film) 3226, 2924, 2857, 1940, 1745, 1617, 1472, 1227, 1024 cm^{-1} ; HRMS (ES) $m/z = 358.1055$ calcd for $\text{C}_{20}\text{H}_{17}\text{NO}_4\text{Na}$ $[\text{MNa}]^+$, found 358.1063; CSP HPLC (Chiralpak IA, 1.0 mL/min, 90:10 hexanes: *i*-PrOH) $t_R(1) = 22.93$ min, $t_R(2) = 28.84$ min.

(R)-Methyl 2-oxo-3-(1-(trimethylsilyl)propa-1,2-dien-1-yl)indoline-3-carboxylate (8j):

Following the general procedure, using 100 mol% $\text{Pd}[(R)\text{-BINAP}](\text{SbF}_6)_2$ and CH_2Cl_2 as the solvent at 0°C , compound **8j** was obtained as a white solid in 90% yield: $[\alpha]_D^{23} +48.33$ (c 0.06, 77% ee, CH_2Cl_2); ^1H NMR (500 MHz, CDCl_3) δ 7.99 (bs, 1H), 7.31 (ddd, $J = 7.5, 1.0, 0.5$ Hz, 1H), 7.26 (td, $J = 7.5, 1.0$ Hz, 1H), 7.05 (td, $J = 7.5, 1.0$ Hz, 1H), 6.87 (ddd, $J = 7.5, 1.0, 0.5$ Hz, 1H), 4.61 (d, $J = 11.5$ Hz, 1H), 4.45 (d, $J = 11.5$ Hz, 1H), 3.72 (s, 3H), 0.11 (s, 9H); ^{13}C NMR (125 MHz, CDCl_3) δ 211.3, 174.9, 169.2, 140.7, 129.5, 128.3, 126.6, 122.6, 109.9, 95.4, 73.3, 61.7, 53.3, -0.1 ; IR (film) 3275, 2958, 2858, 1931, 1746, 1622, 1475, 1244 cm^{-1} ; HRMS (ES) $m/z = 324.1032$ calcd for $\text{C}_{16}\text{H}_{19}\text{NO}_3\text{NaSi}$ $[\text{MNa}]^+$, found 324.1021; CSP HPLC (Chiralpak AD, 0.75 mL/min, 92.5:7.5 hexanes: *i*-PrOH) $t_R(1) = 12.6$ min, $t_R(2) = 19.4$ min.

(S)-Methyl 3-(4,4-dimethylpenta-1,2-dien-3-yl)-2-oxoindoline-3-carboxylate (8k):

Following the general procedure, using $\text{Pd}(\text{difluoroPHOX})(\text{SbF}_6)_2$ catalyst and CH_2Cl_2 as the solvent at 0°C , compound **8k** was obtained as a white solid in 100% yield: $[\alpha]_D^{23} +51.20$ (c 0.08, 86% ee, CH_2Cl_2); ^1H NMR (500 MHz, CDCl_3) δ 7.58 (bs, 1H), 7.46 (d, $J = 7.5$ Hz, 1H), 7.27 (td, $J = 7.5, 1.0$ Hz, 1H), 7.05 (td, $J = 7.5, 1.0$ Hz, 1H), 6.84 (d, $J = 7.5$ Hz, 1H), 4.94 (d, $J = 11.0$ Hz, 1H), 4.81 (d, $J = 11.0$ Hz, 1H), 3.71 (s, 3H), 1.06 (s, 9H); ^{13}C NMR (125 MHz, CDCl_3) δ 209.7, 174.6, 168.8, 140.5, 129.5, 128.1, 128.0, 122.6, 110.7, 109.8, 79.3, 63.8, 53.5, 34.8, 31.1; IR (film) 3252, 2958, 1946, 1746, 1622, 1475, 1228 cm^{-1} ; HRMS (ES) $m/z = 308.1263$ for $\text{C}_{17}\text{H}_{19}\text{NO}_3\text{Na}$ $[\text{MNa}]^+$, found 308.1255; CSP HPLC (Chiralpak AD, 0.75 mL/min, 92.5:7.5 hexanes: *i*-PrOH) $t_R(1) = 15.4$ min, $t_R(2) = 24.3$ min.

(S)-Methyl 3-(1-(6-methyl-4,8-dioxo-1,3,6,2-dioxazaborocan-2-yl)propa-1,2-dien-1-yl)-2-oxoindoline-3-carboxylate (8l):

Following the general procedure, the reaction with 20 mol% $\text{Pd}[(S)\text{-}t\text{-BuPHOX}](\text{SbF}_6)_2$ catalyst and $\text{MeCN}:\text{C}_6\text{H}_5\text{Cl}:\text{CH}_2\text{Cl}_2$ (1:5:5) as the solvent was conducted at 45°C for 2 days. Compound **8l** was obtained as a white solid in 60% yield: decomposed at 164°C , $[\alpha]_D^{23} +5.73$ (c 0.035, 70% ee, MeCN); ^1H NMR (500 MHz, acetone- d_6) δ 9.59 (bs, 1H), 7.35 (d, $J = 7.5$ Hz, 1H), 7.23 (t, $J = 7.5$ Hz, 1H), 7.02 (t, $J = 7.5$ Hz, 1H), 6.92 (d, $J = 7.5$ Hz, 1H), 4.68 (d, $J = 12.0$ Hz, 1H), 4.53 (d, $J = 12.0$ Hz, 1H), 4.30 (d, $J = 17.5$ Hz, 1H), 4.21 (s, 2H), 4.07 (d, $J = 17.5$ Hz, 1H), 3.66 (s, 3H), 3.13 (s, 3H); ^{13}C NMR (125 MHz, acetone- d_6) δ 212.4, 174.6, 169.4, 168.3, 167.7, 141.9, 129.3, 128.9,

125.9, 122.0, 109.7, 109.6, 74.5, 63.8, 63.7, 61.4, 52.3, 48.3; IR (film) 3208, 2960, 1944, 1743, 1617, 1464, 1244, 1042 cm^{-1} ; HRMS (ES) m/z = 407.1027 calcd for $\text{C}_{18}\text{H}_{17}\text{N}_2\text{O}_7\text{NaB} [\text{MNa}]^+$, found 407.1060; CSP SFC (Chiralpak IA, gradient 20–35% MeOH in CO_2 , 2–4 mL/min, 12MPa) $t_R(1)$ = 7.94 min, $t_R(2)$ = 8.24 min.

(R)-Methyl 2-oxo-3-(1-(triethylsilyl)propa-1,2-dien-1-yl)indoline-3-carboxylate (8n):

Following the general procedure, compound **8n** was obtained as a white solid in 78% yield:

$[\alpha]_D^{23} +81.00$ (c 0.05, 90% ee, CH_2Cl_2); ^1H NMR (500 MHz, CDCl_3) δ 9.12 (bs, 1H), 7.34 (dd, J = 7.5, 0.5 Hz, 1H), 7.25 (td, J = 8.0, 1.5 Hz, 1H), 7.03 (td, J = 7.5, 1.0 Hz, 1H), 6.90 (d, J = 8.0 Hz, 1H), 4.61 (d, J = 11.5 Hz, 1H), 4.44 (d, J = 11.5 Hz, 1H), 3.72 (s, 3H), 0.89 (t, J = 8.0 Hz, 9H), 0.67–0.54 (m, 6H); ^{13}C NMR (125 MHz, CDCl_3) δ 212.0, 175.8, 169.2, 141.1, 129.4, 128.4, 126.5, 122.5, 110.2, 92.2, 72.9, 62.0, 53.2, 7.5, 4.1; IR (film) 3259, 2958, 2881, 1931, 1738, 1622, 1468, 1328, 1236, 1104 cm^{-1} ; HRMS (ES) m/z = 342.1525 calcd for $\text{C}_{19}\text{H}_{24}\text{NO}_3\text{Si} [\text{M-H}]^-$, found 342.1537; CSP HPLC (Chiralpak IA, 1 mL/min, 95:5 hexanes: *i*-PrOH) $t_R(1)$ = 14.6 min, $t_R(2)$ = 18.4 min.

(R)-Methyl 3-(1-(tert-butyldimethylsilyl)propa-1,2-dien-1-yl)-2-oxoindoline-3-carboxylate (8m):

Following the general procedure, compound **8m** was obtained as a white solid in 90% yield: mp 132–133 $^\circ\text{C}$; $[\alpha]_D^{23} +128.57$ (c 0.07, 89% ee, CH_2Cl_2); ^1H NMR (500 MHz, CDCl_3) δ 7.87 (bs, 1H), 7.28 (d, J = 7.5 Hz, 1H), 7.22 (td, J = 7.5, 1.0 Hz, 1H), 7.01 (td, J = 7.5, 1.0 Hz, 1H), 6.83 (d, J = 7.5 Hz, 1H), 4.56 (d, J = 11.5 Hz, 1H), 4.39 (d, J = 11.5 Hz, 1H), 3.69 (s, 3H), 0.89 (s, 9H), 0.09 (s, 3H), 0.06 (s, 3H); ^{13}C NMR (125 MHz, CDCl_3) δ 212.6, 174.6, 169.3, 140.8, 129.4, 128.5, 126.8, 122.6, 109.7, 93.8, 74.0, 62.3, 53.2, 27.6, 19.4, –4.15, –4.18; IR (film) 3252, 2958, 2858, 1931, 1746, 1622, 1468, 1259, 1089, 1027 cm^{-1} ; HRMS (ES) m/z = 366.1501 calcd for $\text{C}_{19}\text{H}_{25}\text{NO}_3\text{SiNa} [\text{MNa}]^+$, found 366.1494; CSP HPLC (Chiralpak IA, 1 mL/min, 95:5 hexanes: *i*-PrOH) $t_R(1)$ = 6.1 min, $t_R(2)$ = 11.0 min.

(R)-Ethyl 3-(1-(tert-butyldimethylsilyl)propa-1,2-dien-1-yl)-7-methyl-2-oxoindoline-3-carboxylate (8o):

Following the general procedure using 5 mol% $\text{Pd}[(R)\text{-BINAP}](\text{SbF}_6)_2$ as the catalyst, compound **8o** was obtained as a white solid in 76% yield: mp 135–136 $^\circ\text{C}$; $[\alpha]_D^{23} +137.43$ (c 0.35, 90% ee, CH_2Cl_2); ^1H NMR (300 MHz, CDCl_3) δ 9.82 (bs, 1H), 7.09 (d, J = 7.5 Hz, 1H), 7.05 (d, J = 7.5 Hz, 1H), 6.93 (dd, J = 7.5, 7.5 Hz, 1H), 4.55 (d, J = 11.5 Hz, 1H), 4.36 (d, J = 11.5 Hz, 1H), 4.23 (qd, J = 7.0, 11.0 Hz, 1H), 4.11 (qd, J = 7.0, 11.0 Hz, 1H), 2.31 (s, 3H), 1.22 (t, J = 7.0 Hz, 3H), 0.94 (s, 9H), 0.17 (s, 3H), 0.14 (s, 3H); ^{13}C NMR (75 MHz, CDCl_3) δ 212.3, 176.4, 169.2, 140.2, 130.6, 128.2, 123.6, 122.2, 119.7, 93.6, 74.0, 62.8, 62.2, 27.7, 19.4, 16.7, 14.2, –4.0, –4.1; IR (film) 3198, 2935, 2858, 1931, 1715, 1630, 1468, 1228, 1050 cm^{-1} ; HRMS (ES) m/z = 370.1838 calcd for $\text{C}_{21}\text{H}_{28}\text{NO}_3\text{Si} [\text{M-H}]^-$, found 370.1825; CSP HPLC (Chiralpak IA, 1 mL/min, 95:5 hexanes: *i*-PrOH) $t_R(1)$ = 12.3 min, $t_R(2)$ = 13.8 min.

(R)-Ethyl 3-(1-(tert-butyldimethylsilyl)propa-1,2-dien-1-yl)-7-methoxy-2-oxoindoline-3-carboxylate (8q):

Following the general procedure, compound **8q** was obtained as a white solid in 91% yield: $[\alpha]_D^{23} +172.80$ (c 0.13, 93% ee, CH_2Cl_2); ^1H NMR (500 MHz, CDCl_3) δ 7.68 (bs, 1H), 6.98 (dd, J = 7.5, 7.5 Hz, 1H), 6.90 (d, J = 7.5 Hz, 1H), 6.81 (d, J = 7.5 Hz, 1H), 4.55 (d, J = 12.0 Hz, 1H), 4.37 (d, J = 12.0 Hz, 1H), 4.20 (qd, J = 7.0, 11.0 Hz, 1H), 4.10 (qd, J = 7.0, 11.0 Hz, 1H), 3.86 (s, 3H), 1.22 (t, J = 7.0 Hz, 3H), 0.92 (s, 9H), 0.14 (s, 3H), 0.11 (s, 3H); ^{13}C NMR (125 MHz, CDCl_3) δ 212.4, 174.0, 168.9, 143.8, 129.9, 129.2, 122.7, 118.7, 111.5, 100.2, 93.5, 73.9, 62.3, 55.9, 27.6, 19.4, 14.2, –4.1, –4.2; IR (film) 3205, 2935, 2858, 1931, 1722, 1630, 1498, 1282, 1236, 1043 cm^{-1} ; HRMS (ES) m/z =

388.1944 calcd for $C_{21}H_{30}NO_4Si$ $[MH]^+$, found 388.1954; CSP HPLC (Chiralpak IA, 1 mL/min, 95:5 hexanes: *i*-PrOH) $t_R(1) = 11.5$ min, $t_R(2) = 25.2$ min.

(R)-Ethyl 5-bromo-3-(1-(tert-butyldimethylsilyl)propa-1,2-dien-1-yl)-2-oxoindoline-3-carboxylate (8r): Following the general procedure, compound **8r** was obtained as a white solid in 85% yield: mp 133–134 °C; $[\alpha]_D^{23} +130.43$ (c 0.12, 90% ee, CH_2Cl_2); 1H NMR (500 MHz, $CDCl_3$) δ 9.14 (bs, 1H), 7.40 (d, $J = 2.0$ Hz, 1H), 7.36 (dd, $J = 8.5, 2.0$ Hz, 1H) 6.77 (d, $J = 8.5$ Hz, 1H), 4.63 (d, $J = 12.0$ Hz, 1H), 4.43 (d, $J = 12.0$ Hz, 1H), 4.23 (qd, $J = 7.0, 10.5$ Hz, 1H), 4.15 (qd, $J = 7.0, 10.5$ Hz, 1H), 1.25 (t, $J = 7.0$ Hz, 3H), 0.91 (s, 9H), 0.12 (s, 3H), 0.10 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 212.4, 175.4, 168.3, 140.1, 132.2, 130.4, 129.5, 115.0, 111.6, 93.3, 74.5, 62.7, 62.5, 27.5, 19.3, 14.2, -4.1, -4.2; IR (film) 3275, 2935, 2858, 1931, 1738, 1614, 1475, 1298, 1236, 1043 cm^{-1} ; HRMS (ES) $m/z = 458.0756$ calcd for $C_{20}H_{26}BrNO_3SiNa$ $[MNa]^+$, found 458.0779; CSP HPLC (Chiralpak IA, 1 mL/min, 95:5 hexanes: *i*-PrOH) $t_R(1) = 9.2$ min, $t_R(2) = 22.3$ min.

(R)-4-(tert-Butyldimethylsilyl)-5-methyl-2H-spiro[furan-3,3'-indoline]-2,2'-dione (9m): Following the general procedure, the reaction mixture was stirred at ambient temperature using $C_6H_5Cl:C_6H_5CH_3$ (1:1) as the solvent until the starting material was completely consumed, as determined by TLC (in 84 h). Then, 5 mol% H_2O was added and the mixture was stirred at 40 °C for 36 h. Filtration through a plug of SiO_2 (5 mm $\times$ 2 cm) with ethyl ether, concentration of the solution and purification by column chromatography using 50% ethyl ether/hexane afforded **9m** as a white resin in 95% yield: $[\alpha]_D^{23} +21.66$ (c 0.06, 86% ee, CH_2Cl_2); 1H NMR (500 MHz, $CDCl_3$) δ 8.27 (bs, 1H), 7.31-7.26(m, 1H), 7.06-6.93(m, 2H), 6.92(d, $J = 7.5$ Hz, 1H), 2.27 (s, 3H), 0.82(s, 9H), -0.07(s, 3H), -0.18(s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 174.3, 173.6 163.2, 141.7, 130.2, 127.7, 124.8, 123.4, 110.8, 110.4, 66.5, 27.2, 18.2, 16.4, -4.92, -4.96; IR (film) 3251, 2955, 2870, 1797, 1718, 1624, 1473, 1167, 995 cm^{-1} ; HRMS (ES) $m/z = 352.1345$ calcd for $C_{18}H_{23}NO_3SiNa$ $[MNa]^+$, found 352.1337; CSP HPLC (Chiralpak IA, 1 mL/min, 90:10 hexanes: *i*-PrOH) $t_R(1) = 6.3$ min, $t_R(2) = 10.0$ min.

(R)-5-Methyl-4-(triisopropylsilyl)-2H-spiro[furan-3,3'-indoline]-2,2'-dione (9s): Following the general procedure using 5 mol% H_2O and C_6H_5Cl as the solvent at 40 °C, compound **9s** was obtained as a white solid in 78% yield: mp 202–203 °C; $[\alpha]_D^{23} +112.00$ (c 0.025, 92% ee, CH_2Cl_2); 1H NMR (500 MHz, $CDCl_3$) δ 8.93 (bs, 1H), 7.27 (dd, $J = 8.0, 1.0$ Hz, 1H), 7.07 (d, $J = 7.5$ Hz, 1H), 7.03 (dd, $J = 7.5, 1.0$ Hz, 1H), 6.92 (d, $J = 8.0$ Hz, 1H), 2.28 (s, 3H), 1.03-1.01 (m, 12H), 0.89-0.87 (m, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 174.4, 174.1, 163.0, 142.0, 130.3, 127.9, 124.8, 123.3, 110.9, 109.3, 67.6, 19.2, 18.9, 16.6, 12.5; IR (film) 3236, 2950, 2873, 1800, 1715, 1622, 1468, 1220, 1166 cm^{-1} ; HRMS (ES) $m/z = 370.1839$ calcd for $C_{21}H_{28}NO_3Si$ $[M-H]^-$, found 370.1807; CSP HPLC (Chiralpak IA, 1 mL/min, 98:2 hexanes: *i*-PrOH) $t_R(1) = 15.3$ min, $t_R(2) = 39.0$ min.

(R)-5,7'-Dimethyl-4-(triisopropylsilyl)-2H-spiro[furan-3,3'-indoline]-2,2'-dione (9w): Following the general procedure using 5 mol% H_2O and $C_6H_5Cl:C_6H_5CH_3$ (1:1) as the solvent at 40 °C, compound **9w** was obtained as a white solid in 93% yield: mp 239–240 °C; $[\alpha]_D^{23} +73.53$ (c 0.34, 96% ee, CH_2Cl_2); 1H NMR (500 MHz, $CDCl_3$) δ 8.37 (bs, 1H), 7.09 (d, $J = 7.5$ Hz, 1H), 6.95 (dd, $J = 7.5, 7.5$ Hz, 1H), 6.90 (d, $J = 7.5$ Hz, 1H), 2.27 (s, 6H), 1.05-0.99 (m, 12H), 0.91-0.86 (m, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 174.4, 173.6 162.9, 140.5, 131.5, 127.5, 123.3, 122.2, 120.1, 109.3, 66.9, 19.2, 18.9, 16.68, 16.65, 12.6; IR (film) 3198, 2950, 2873, 1800, 1715, 1622, 1468, 1220, 1159, 1027 cm^{-1} ; HRMS (ES) $m/z = 384.1995$ calcd for $C_{22}H_{30}NO_3Si$ $[M-H]^-$, found 384.1985; CSP HPLC (Chiralpak IA, 1 mL/min, 95:5 hexanes: *i*-PrOH) $t_R(1) = 8.9$ min, $t_R(2) = 13.4$ min.

(R)-5'-Methoxy-5-methyl-4-(triisopropylsilyl)-2H-spiro[furan-3,3'-indoline]-2,2'-dione (9x): Following the general procedure using 5 mol% H₂O and CH₂Cl₂ as the solvent at 40 °C, compound **9x** was obtained as a white solid in 81% yield: mp 147–148 °C; $[\alpha]_D^{23} +60.00$ (c 0.05, 91% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 7.68 (bs, 1H), 6.83 (d, *J* = 1.5 Hz, 2H), 6.67 (s, 1H), 3.74 (s, 3H), 2.28 (s, 3H), 1.08–1.00 (m, 12H), 0.94–0.89 (m, 9H); ¹³C NMR (125 MHz, CDCl₃) δ 174.3, 172.9, 163.2, 156.4, 134.9, 128.9, 115.6, 111.4, 111.2, 109.3, 66.9, 56.0, 19.2, 18.9, 16.7, 12.6; IR (film) 3252, 2950, 2873, 1800, 1715, 1622, 1491, 1298, 1205, 1159, 1081, 1027 cm⁻¹; HRMS (ES) *m/z* = 424.1920 calcd for C₂₂H₃₁NO₄SiNa [MNa]⁺, found 424.1910; CSP HPLC (Chiralpak IA, 1 mL/min, 95:5 hexanes: *i*-PrOH) t_R(1) = 11.0 min, t_R(2) = 27.0 min.

(R)-7'-Methoxy-5-methyl-4-(triisopropylsilyl)-2H-spiro[furan-3,3'-indoline]-2,2'-dione (9y): Following the general procedure using 5 mol% H₂O and C₆H₅Cl as the solvent at 40 °C, compound **9y** was obtained as a white solid in 90% yield: mp 237–238 °C; $[\alpha]_D^{23} +64.00$ (c 0.4, 92% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 7.60 (bs, 1H), 7.00 (dd, *J* = 8.0, 7.5 Hz, 1H), 6.86 (d, *J* = 8.0 Hz, 1H), 6.71 (d, *J* = 7.5 Hz, 1H), 3.88 (s, 3H), 2.26 (s, 3H), 1.05–0.99 (m, 12H), 0.91–0.87 (m, 9H); ¹³C NMR (125 MHz, CDCl₃) δ 174.2, 172.2, 163.0, 144.4, 130.7, 128.5, 123.9, 116.9, 112.4, 109.1, 67.0, 56.0, 19.2, 18.9, 16.7, 12.6; IR (film) 3198, 2950, 2873, 1800, 1715, 1630, 1498, 1460, 1290, 1159, 1066, 1004 cm⁻¹; HRMS (ES) *m/z* = 400.1944 calcd for C₂₂H₃₀NO₄Si [M-H]⁻, found 400.1935; CSP HPLC (Chiralpak IA, 1 mL/min, 95:5 hexanes: *i*-PrOH) t_R(1) = 19.5 min, t_R(2) = 22.9 min.

(R)-5'-Bromo-5-methyl-4-(triisopropylsilyl)-2H-spiro[furan-3,3'-indoline]-2,2'-dione (9z): Following the general procedure using 10 mol% H₂O and C₆H₅Cl:C₆H₅CH₃ (1:1) at 40 °C, compound **9z** was obtained as a white solid in 82% yield: mp 180–181 °C; $[\alpha]_D^{23} +70.66$ (c 0.15, 92% ee, CH₂Cl₂); ¹H NMR (500 MHz, CDCl₃) δ 8.80 (bs, 1H), 7.41 (dd, *J* = 8.0, 2.0 Hz, 1H), 7.20 (d, *J* = 2.0 Hz, 1H), 6.81 (d, *J* = 8.0 Hz, 1H), 2.28 (s, 3H), 1.03 (d, *J* = 6.0 Hz, 9H), 1.00 (qq, *J* = 6.0, 7.0 Hz, 3H), 0.90 (d, *J* = 7.0 Hz, 9H); ¹³C NMR (125 MHz, CDCl₃) δ 173.7, 173.5, 163.7, 140.9, 133.1, 129.8, 128.2, 115.8, 112.3, 108.9, 66.5, 19.1, 18.9, 16.7, 12.5; IR (film) 3252, 2950, 2873, 1800, 1722, 1622, 1475, 1383, 1228, 1166 cm⁻¹; HRMS (ES) *m/z* = 448.0944 calcd for C₂₁H₂₇BrNO₃Si [M-H]⁻, found 448.0936; CSP HPLC (Chiralpak IA, 1 mL/min, 95:5 hexanes: *i*-PrOH) t_R(1) = 8.1 min, t_R(2) = 21.7 min.

Ethyl 3-(1-(tert-butyldimethylsilyl)-2-oxopropyl)-7-methyl-2-oxoindoline-3-carboxylate (10): To a flask of **8o** (35 mg, 0.1 mmol) and (CF₃CO₂)₂Hg (40 mg, 0.1 mmol) was added AcOH (0.5 mL) and H₂O (0.3 mL). The reaction solution was stirred at room temperature. After 45 min, the mixture was cooled to 0 °C, diluted with ethyl acetate and quenched with saturated aq. Na₂S₂O₃. The mixture was stirred for 30 min at room temperature. The aqueous layer was extracted with EtOAc and the combined organic extracts were washed with saturated aq. NaHCO₃, dried (MgSO₄), filtered and concentrated. The residue was purified by flash column chromatography (40% ethyl acetate/hexane) to afford **10** as a white solid in 72% yield: ¹H NMR (300 MHz, CDCl₃) δ 9.24 (bs, 1H), 7.09 (d, *J* = 7.5 Hz, 1H), 7.06 (d, *J* = 7.8 Hz, 1H), 6.94 (dd, *J* = 7.5, 7.8 Hz, 1H), 4.12 (qd, *J* = 10.5, 7.0 Hz, 1H), 4.10 (qd, *J* = 10.5, 7.0 Hz, 1H), 3.58 (s, 1H), 2.37 (s, 3H), 2.29 (s, 3H), 1.14 (t, *J* = 7.0 Hz, 3H), 0.82 (s, 9H), 0.06 (s, 3H), -0.26 (s, 3H); ¹³C NMR (75 MHz, CDCl₃) δ 207.7, 177.4, 170.2, 140.0, 131.1, 128.5, 122.8, 121.7, 119.7, 62.7, 60.8, 49.7, 31.3, 27.2, 18.2, 16.5, 14.0, -5.0, -5.5; IR (film) 3213, 2966, 2866, 1737, 1715, 1661, 1468, 1259, 1213, 1027 cm⁻¹; HRMS (ES) *m/z* = 390.2101 calcd for C₂₁H₃₃NO₄Si [MH]⁺, found 390.2109.

Ethyl 3-(2-((*tert*-butyldimethylsilyl)oxy)prop-1-en-1-yl)-7-methyl-2-oxoindoline-3-carboxylate (12**):** To a flask of **10** (10 mg, 0.026 mmol) in toluene (1 mL) was added 4 Å MS (30 mg). The mixture was stirred for 12 h at 45 °C and filtered through a plug of Celite. The solution was concentrated *in vacuo* to afford **12** as a white solid in 93% yield: $[\alpha]_D^{23} +176.57$ (c 0.175, 89% ee, CH₂Cl₂), ¹H NMR (500 MHz, CDCl₃) δ 8.50 (bs, 1H), 7.07 (d, *J* = 7.5 Hz, 1H), 7.05 (d, *J* = 8.0 Hz, 1H), 6.94 (dd, *J* = 7.5, 8.0 Hz, 1H), 5.25 (s, 1H), 4.17 (qd, *J* = 10.5, 7.0 Hz, 1H), 4.13 (qd, *J* = 10.5, 7.0 Hz, 1H), 2.28 (s, 3H), 1.47 (s, 3H), 1.17 (t, *J* = 7.0 Hz, 3H), 0.91 (s, 9H), 0.18 (s, 3H), 0.17 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 176.6, 169.5, 154.9, 139.8, 130.8, 130.4, 123.2, 121.8, 119.4, 105.1, 62.4, 59.8, 25.8, 19.7, 18.2, 16.7, 14.1, -4.2, -4.3; IR (film) 3229, 2927, 2858, 1746, 1715, 1661, 1460, 1383, 1228, 1089, 1043 cm⁻¹; HRMS (ES) *m/z* = 388.1944 calcd for C₂₁H₃₀NO₄Si [M-H]⁻, found 388.1941; CSP HPLC (Chiralpak IA, 0.75 mL/min, 92.5:7.5 hexanes: *i*-PrOH) *t*_R(1) = 7.9 min, *t*_R(2) = 9.6 min.

***N*-Camphorsulfonyl derivative of **5i** (**5'i**):** To a solution of 60% NaH in oil (0.003 g, 0.13 mmol) in THF (2 mL) at 0 °C was added **5i** (0.018 g, 0.07 mmol). After stirring 5 min, camphorsulfonyl chloride (0.0180 g, 0.07 mmol) was added and the mixture was warmed to rt. After 2 h, H₂O was added, and the aqueous layer was extracted with CH₂Cl₂, dried over Na₂SO₄, and concentrated under vacuum to give the camphorsulfonyl derivative in 47% yield as a white solid (0.015 g, 0.03 mmol) which was used without further purification.

The camphorsulfonyl derivative (0.015 g, 0.03 mmol) was treated with a solution of 2,4-dinitrophenylhydrazine (0.26 mL, 0.12 M) in 1:1 H₂SO₄/MeOH. The resulting solution was allowed to stir for 10 min, then cooled to 0 °C, where upon formation of crystals were observed after 24 h. Instead of obtaining the expected hydrazone, the transesterified methyl ester product was observed. The configuration obtained from the crystal structure was used to establish the absolute stereochemistry of **5i**. The remaining compounds were assigned by analogy.

Cyclization of **10 to form **9o**:** To a solution of **10** (21 mg, 0.053 mmol) in THF was added a solution of LDA in THF (0.065 mmol). The reaction mixture was stirred for 4 h at 0 °C and quenched with saturated aq. NH₄Cl. The aqueous layer was extracted with diethyl ether and the combined organic extracts were dried (MgSO₄), filtered and concentrated. The residue was purified by flash column chromatography (15% ethyl acetate/hexane) to afford **9o** as a white solid in 81% yield.

Protodesilylation of **8n to form **8c**:** To a solution of **8n** (10 mg, 0.029 mmol) in CH₂Cl₂ was added a solution of TBAF in THF (0.073 mmol). The reaction mixture was stirred for 24 h at room temperature and quenched with saturated aq. NH₄Cl. The aqueous layer was extracted with diethyl ether and the combined organic extracts were dried (MgSO₄), filtered and concentrated. The residue was purified by flash column chromatography (20% ethyl acetate/hexane) to afford **8c** as a white solid in 100% yield.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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a. Natural Products **b. Therapeutic Agents**

Figure 1.
Natural Products and Pharmaceutical Agents Incorporating an Oxindole

a. Overman's Asymmetric Heck Reaction **b. Fu's Enantioselective Rearrangement** **c. Trost's Asymmetric Allylation**

Figure 2.
Catalytic Asymmetric Synthesis of Oxindoles Bearing a C3 Quaternary Stereocenter

Figure 3.
Stereochemical Model of the Pd-BINAP Catalyzed Rearrangement

Figure 4.
Proposed Transition States with the *t*-BuPHOX Pd Catalyst

Conditions**Results**AgSbF₆, CH₂Cl₂, 2 d

No reaction

CF₃CO₂H 25 mol%,
CH₂Cl₂ 2 d

No reaction

Pd(BINAP)(SbF₆)₂ 20 mol%,
CH₂Cl₂, 3 d

100% conv

Figure 5.
Formation of the Spirocyclic Lactone

R^1 = carboxylate, acetyl, nitrile, amide

R^2 = H, Me, *t*-Bu, MIDA, Ar, TMS, TES, TBS, TIPS

R^3 = H, Me, Et

R^4 = H, 5-OMe, 7-OMe, 5-Br, 7-Me

Scheme 1.
 Synthesis of Indole Series

Scheme 2.
Claisen Rearrangement of 3-Nitrile Indole

Scheme 3.
Coordination of Catalyst to a Bidentate Substrate

1% ee (*S*)
80% conv

6% ee (*R*)
80% conv

* Conversion measured by TLC

Scheme 4.
Brønsted Acid Screening

X = OTf 34% ee, 18 h
X = SbF₆ 58% ee, 4 h

X = OTf 10% ee, 35 min
X = SbF₆ 54% ee, 5 h

X = OTf 37% ee, 50 min
X = SbF₆ 67% ee, 4 h

X = OTf 35% ee, 3 h
 X = BF₄ 52% ee, 30 min
X = SbF₆ 81% ee, 35 min

* Conversion measured by TLC

Scheme 5.
 Copper Complex Counterion and Ligand Screening

* Conversion measured by TLC

Scheme 6.
Substrate Scope with Copper Indanol Bisoxazoline

Scheme 7.
Effect of Methyl Ketone at C3 Position

* Conversion measured by TLC

Scheme 8.
Use of C3-Amide Derivative

L5 BINAP

45% ee, rt, 5 min
48% ee, 0 °C, 50 min
50% ee, -20 °C, 18 h

L6 tol-BINAP

Ar = 4-MeC₆H₄
50% ee, 0 °C, 20 min

L7 xyl-BINAP

Ar = 3,5-Me₂-C₆H₃
47% ee, 0 °C, 20 min

L8 DifluoroPhos

56% ee, 0 °C, 75 min

L9 BIPHEP

42% ee, 0 °C, 65 min

* Conversion measured by TLC

Scheme 9.
 Initial Screening of Diphosphine Palladium Complexes

X	ee (%)
SbF_6	89
BF_4	90
ClO_4	86
OTf	84 ^b
OAc	NA ^c

(a) Conversion measured by TLC

(b) 60% conversion

(c) 10% conversion

Scheme 10.
Effect of Pd Counterion on Enantioselectivity

* Conversion measured by TLC

Scheme 11.
Substrate Scope with Palladium-BINAP Catalyst

Scheme 12.
Crystal Structure of the Derivatized Oxindole

* Conversion measured by TLC

Scheme 13.
Substrate Screening with PHOX Pd Catalysts

^aParanthetic results are from a larger scale (1 mmol) reaction.

Scheme 14.
Substrate Scope with *t*-BuPHOX Pd Catalyst

Scheme 15.
[3,3'] vs [1',3] rearrangement

Scheme 16.
Crossover Mechanism Experiment

Scheme 17.
Comparison of t-BuPHOX Ligand with BINAP Ligand

Scheme 18.
Mechanism Study

Scheme 19.
Proposal Mechanism for the Formation of Spirocyclic Lactones

Scheme 20.
Transformations of Allenyl Compounds

Table 1

Copper Catalyst Solvent Screening

Entry	Solvent	R	Conv ^a (%)	t	ee (%)
1	CH_2Cl_2	Indanol	100	35 min	81
2	$\text{Cl}(\text{CH}_2)_2\text{Cl}$	Indanol	100	35 min	78
3	CHCl_3	Indanol	60	4 h	69
4	PhCH_3	Indanol	80	5 h	70
5 ^b	THF	--	SM	18 h	NA
6	THF	<i>t</i> -Bu	SM	18 h	NA
7	2:1 $\text{CH}_2\text{Cl}_2/\text{THF}$	Ph	SM	18 h	NA
8	MeCN	<i>t</i> -Bu	Decomp.	18 h	NA

^(a) Conversion measured by TLC^(b) No catalyst was used.

Table 2

Catalyst Loading with Copper Indanol Complex

Entr	Cat. Loading	T	Conv ^a (%)	t	ee (%)
1	200 mol%	10 °C	100	10 min	82
2	100 mol%	10 °C	90	5 h	80
3	100 mol%	rt	100	35 min	81
4	50 mol%	rt	93	2 h	77
5	25 mol%	rt	78	2.5 h	76

^a) Conversion measured by NMR

Table 3

Metal Screening

Entry	M	Conv ^a (%)	t	ee (%)
1	CuCl ₂	100	35 min	81
2	CuBr ₂	100	75 min	80
3	ZnCl ₂	30	2 h	24 ^b
4	NiBr ₂	50	2 h	47
5	PdCl ₂	100	1 h	73

(^a) Conversion measured by TLC

(^b) Opposite enantiomer

Table 4

Effect of Pd Catalyst Loading on Enantioselectivity

Entry	Mol%	T	t (min)	ee (%)
1	100	0 °C	10	84
2	20	rt	10	82
3	20	0 °C	80	85
4	5	rt	80	82

Conversion measured by TLC.

Table 5

Substrate Scope with Palladium *t*-BuPHOX

Entry	4	R ¹	R ²	mol% cat	T (°C)	t	Yield (%)	ee (%)
1	a	<i>i</i> -Bu	H	20	0	10 min	100 ^a	0
2	b	<i>i</i> -Bu	Me	20	0	15 min	100 ^a	4
3	c	Me	H	20	0	10 min	100 ^a	14
4	d	Me	Me	20	0	15 min	100 ^a	45
5	e	Me	Ph	5	-15	8 h	96	78
6	f	Me	<i>o</i> -MePh	5	-15	8 h	95	98
7	g	Me	<i>o</i> -BrPh	5	-15	8 h	93	96
8	h	Me	1-Nap	5	-15	8 h	95	98
9	i	Me	<i>o</i> -MeOPh	5	-15	8 h	90	98
10	j	Me	TMS	20	0	90 min	15	14
11	k	Me	<i>i</i> -Bu	20	0	2 d	100 ^a	45
12 ^b	l	Me	MIDA-B	20	45	2 d	60	70

^(a) Conversion (%) measured by TLC.^(b) MIDA boronate, see reference 34. Solvent: 1:5:5 MeCN:C₆H₅Cl:CH₂Cl₂.

Table 6

Diphosphine Ligand Screening in the Saucy-Marbet Rearrangement

Entry	L	4	R ²	Mol% cat.	t	Yield (%)	ee (%)
1	L5	c	H	20	10 min	100	8
2	L5	d	Me	20	30 min	100	4
3	L5	k	<i>i</i> -Bu	20	2 d	40	76
4	L8	k	<i>i</i> -Bu	100	10 h	90	86
5	L15	k	<i>i</i> -Bu	100	10 h	90	83
6	L8	j	TMS	100	10 h	95	44
7	L5	j	TMS	100	4 h	90	77
8	L5	j	TMS	20	4 d	100	60
9	L5	m	TBS	100	14 h	100	78 ^a
10	L5	m	TBS	20	5 d	90	89 ^b

^(a) room temperature;^(b) Reaction condition: 1:1 C₆H₅Cl:C₆H₅CH₃ at rt.

Table 7

Substrate Scope in the Saucy-Marbet Rearrangement

Entry	4	R ¹	R ²	R ³	t	Yield (%)	ee (%)
1	n	Me	TES	H	6 d	78	90
2	m	Me	TBS	H	5 d	90	89
3	o	Et	TBS	7-Me	5 d	87	90
4	o	Et	TBS	7-Me	10 d	76	90 ^a
5	o	Et	TBS	7-Me	6 d	65	86 ^{a,b}
6	p	Et	TBS	5-OMe	5 d	82	93
7	q	Et	TBS	7-OMe	6 d	91	93
8	r	Et	TBS	5-Br	6 d	85	90

^(a) 5 mol% L*Pd(SbF₆)₂;^(b) BIPHEP **L9** was used

Table 8

Metal Screening

Entry	M	R ²	Cat. mol %	t	Yield (%)	ee (%)
1	Ag(I)	<i>i</i> -Bu	100	4 d	0	NA
2	Cu(II)	<i>i</i> -Bu	100	4 d	0	NA
3	Pt(II)	<i>i</i> -Bu	100	2 d	decomp.	NA
4	Ni(II)	<i>i</i> -Bu	100	4 d	30	87
5	Ni(II)	TIPS	100	4 d	90	66 ^a
6	Au(III)	TBS	20	2 h	100	60 ^b

(^a) Temperature: $45\text{ }^\circ\text{C}$.

(^b) R³ = 5-MeO. Reaction conditions: Au(III) catalyst, $\text{C}_6\text{H}_5\text{Cl}$, $0\text{ }^\circ\text{C}$

Table 9

Gold Catalyst Optimization

Entry	n	X	R ¹	R ²	R ³	T (°C)	t	Conv (%)	ee (%)
1	3	SbF ₆ ⁻	Me	TBS	5-MeO	rt	2 h	100	60
2	1	SbF ₆ ⁻	Me	TBS	5-MeO	rt	3 h	100	47
3	3	SbF ₆ ⁻	Me	TBS	5-MeO	0	6 h	100	60 ^a
4	3	SbF ₆ ⁻	Me	TIPS	H	rt	18 h	100	36
5	3	BF ₄ ⁻	Me	TIPS	H	rt	14 h	50	10
6	3	SbF ₆ ⁻	i-Pr	TMS	H	0	1 h	100	6
7	3	SbF ₆ ⁻	Me	Me	H	0	30 min	100	3
8	1	SbF ₆ ⁻	Me	Me	H	0	30 min	100	7

^(a) Solvent: C₆H₅Cl

Table 10

Additives Screening

Entry	Additives	Yield (%)	8s : 9s
1	1 equiv MgO	65	1 : 0.8
2	1 equiv MgSO_4	85	1 : 4.4
3	MS 3 Å or 4 Å	0 – 5	NA
4	NaHCO_3	100	1 : 2.2
5 ^a	10 mol% tri- <i>tert</i> -butylpyridine	80 (10 d)	1 : 0 (82% ee)
6	10 mol%	50 (10 d)	NA
7 ^a	10 mol% $\text{Zn}(\text{TMEDA})(\text{SbF}_6)_2$	55	1 : 0 (94% ee)

(^a) 30 mol% palladium catalyst

Table 11

Tandem Rearrangement-Cyclization

Entry	4	R ¹	R ²	R ³	t (d)	Solvent ^a	Yield (%)	ee (%)
1	s	Me	TIPS	H	4.5	C	78 ^b	90
2	t	Et	TIPS	H	4	C	95	90
3	u	CH ₂ CF ₃	TIPS	H	4	C	90	87
4	v	Bn	TIPS	H	4	C	95	92
5	w	Et	TIPS	7-Me	6	B	93	96
6	x	Et	TIPS	5-OMe	5	A	81	91
7	y	Et	TIPS	7-OMe	6	C	90	92
8	z	Et	TIPS	5-Br	6	B	82	92
9 ^c	m	Me	TBS	H	5	B	95	86

^(a) Solvents: A) CH₂Cl₂, B) 1:1 C₆H₅Cl:C₆H₅CH₃, C) C₆H₅Cl.

^(b) Performed with 0.5 mmol substrate.

^(c) Reaction conducted at rt.