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Samantha Green 3/22/13

Synthesis of Highly Functionalized Pyrroles Using a Dirhodium Catalyst

by

Samantha Green

Dr. Huw M.L. Davies
Advisor

Department of Chemistry

Dr. Huw M.L. Davies

Advisor

Dr. Jose Soria

Committee Member

Dr. Judy Raggi Moore

Committee Member

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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
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Abstract

Synthesis of Highly Functionalized Pyrroles Using a Dirhodium Catalyst

By Samantha Green

Pyrroles are common structural motifs in natural compounds, which, in recent years, have called for an increased demand of new methods for their synthesis. The conversion of furan to highly functionalized pyrroles was investigated using a dirhodium catalyst. It was found that in the presence of an *N*-sulfonyltriazoles, a formal [3+2] cycloaddition occurred to produced bicyclic hemiaminals which ring opened, resulting in pyrrole product. This study focused primarily on expanding the scope of this reaction in terms of variation of the *N*-sulfonyl protecting group and substituents on the triazole compound. In comparison to other synthetic methods, this synthesis utilizes mild reaction conditions and inexpensive, shelf-stable starting materials.

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Thank you to Brendan Parr, the graduate student who has been my mentored over the past two years and who helped me greatly on this project. Thank you for all of the advice, your patience, and always being willing to answer my plethora of questions.

Finally, thank you to the entire Davies' lab group for answering any additional questions I had and for your kindness.

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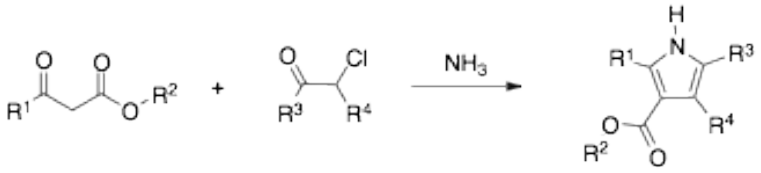
Pyrroles: Background and Recent Synthetic Approaches

Heterocycles are widely seen in natural products and pharmaceutical drugs. Specifically, pyrrole, a five membered aromatic heterocycle with nitrogen, is seen as a building block for physiological products, such as heme and vitamin B12.[1] Additionally, pyrroles have become key components of pharmaceutical drugs, especially in the field of antifungal agents.[2] Other recent pharmaceutical advances have been in the fields of antioxidants with tetraarylpyrroles, antivirals with respect to HIV binding inhibition, and antibacterials through the development of BM 212 to treat TB.[345] Interestingly, several natural marine products, such as lamellarin O, are pyrrole derivatives that are currently under investigation for their use as antitumor agents to reverse multi-drug resistance.[6]

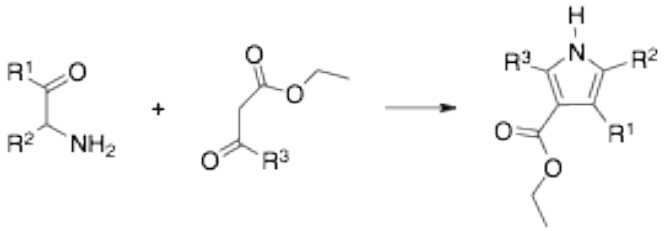
Because of their prevalence in natural products, the synthesis of pyrroles has long been explored. As long ago as the late 1800s, various classical methods for the synthesis of pyrroles and their derivatives were established (**eq. 1-3**).[7], [8], [9]. With the wide occurrence of pyrroles in pharmaceutical and natural products, there has been a desire to develop streamlined and selective methods for the synthesis of pyrroles.

---

[1] Narayan, R.; Frohlich, R.; Wurthwein, E-U. *J. Org. Chem.* **2012**, *77*: 1868-1879.
[2] Kathiravan, M. K.; Salake, A. B.; Chothe, A. S.; Dudhe, P.B.; Watode, R. P.; Mukta, M. S.; Gadhwe, S. *Bioorg. Med. Chem.* **2012**, *20*: 5678-5698.
[3] Lehuédé, J.; Fauconneau, B.; Barrier, L.; Ourakow, M.; Piriou, A.; Vierfond, J-M. *Eur. J. Med. Chem.* **1999**, *34*: 991-996.
[4] Teixeira, C.; Barbault, F.; Rebehmed, J.; Liu, K.; Xie, L.; Lu, H.; Jiang, S.; Fan, B.; Maurel, F. *Bioorg. Med. Chem.* **2008**. *16*: 3039-3048.
[5] Biava, M.; Porretta, G.C.; Deidda, D.; Pompei, R.; Tafi, A.; Manetti, F. *Bioorg. Med. Chem.* **2004**, *12*: 1453-1458.
[6] Boger, D.L.; Boyce, C.W.; Labroli, M.A.; Sehon, C.A.; Jin, Q. *J. Am. Chem. Soc.* **1999**, *121*: 54-62.
[7] Hantzsch. A. *Ber. Dtsch. Chem. Ges.* **1890**. *23*: 1474-1483
[8] Knorr, L. *Ber. Dtsch. Chem. Ges.* **1884**, *17*: 1635-1642.
[9] Paal. C. *Ber. Dtsch. Chem. Ges.* **1885**. *18*: 367-371.



(1)



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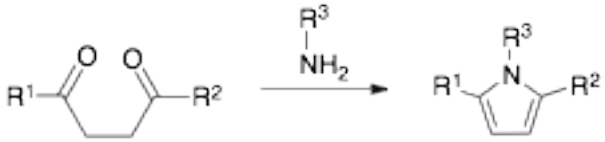


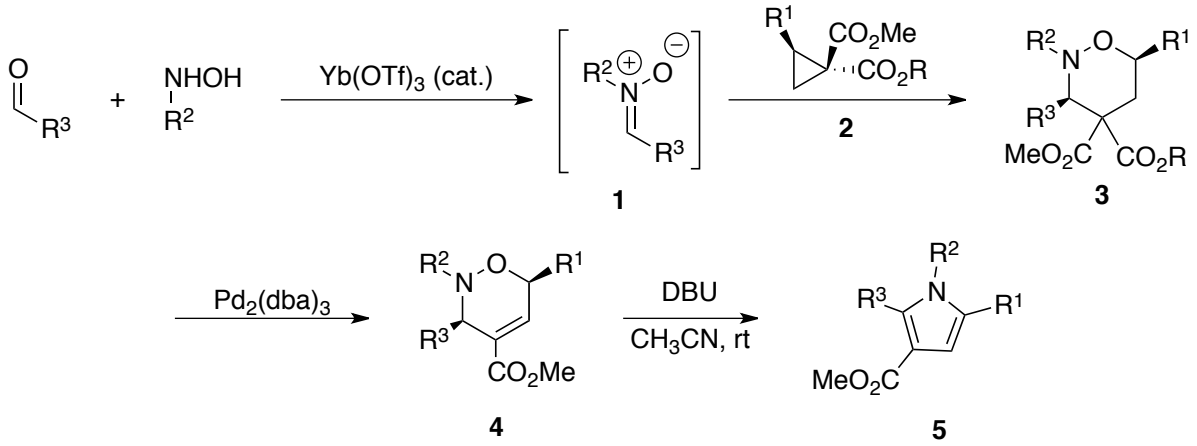
(3)

The older synthesis models are still being improved; however, each has its own limitations. The Hantzsch synthesis **(eq 1)** requires alkyl substitution at C-3 and no substituents at C-4, greatly limiting the scope of the reaction. Additionally, this synthesis only sees moderate yields. The Knorr synthesis **(eq 2)** requires an α-amino-ketone as starting material; however, these compounds have a strong propensity to self-condense. The α-amino-ketone must be prepared *in situ* from the starting oxime. Finally, the Paal-Knorr synthesis **(eq. 3)** requires harsh reaction conditions such as prolonged heating in acid. Additionally, the reaction requires the presence of a Lewis acid or protic solution for pyrrole formation and has a scope limited to the availability of 1,4-diketones.

In more recent years, metal-catalyzed approaches for the synthesis of pyrroles have become popular. A one-pot synthesis of pyrroles was serendipitously found from transformations with dihydro-1,2-oxazines. The Kerr group originally intended on generating dihydro-1,2-oxazines **4** to better understand their reactivity. Nitrone **1** was reacted with a

cyclopropanediester **2**, resulting in a tetrahydro-1,2-oxazine **3** which could subsequently be dehydrocarbonylated to give dihydro-1,2-oxazines **4**. Surprisingly, under basic conditions, these decomposed to substituted pyrroles **5** within 5 minutes. Subsequent investigation found that base addition to the initial starting mixture provided a one-pot synthesis of pyrrole **5** in moderate to high yield (**Scheme 1**).[10] This pyrrole formation, however, is contingent upon first forming the starting material which must first be synthesized rather than easily purchased and requires upwards of 24 hours to synthesize.

Scheme 1. Pd catalyzed pyrrole formation

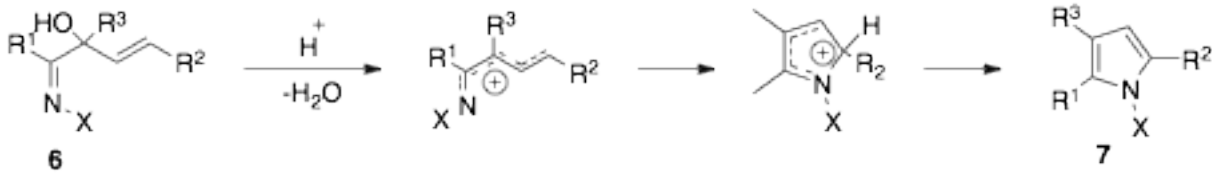


Pyrrole formation can also be achieved by a 4π-electrocyclization of 1-azapentadienyl cations. 1-Azapenta-1,4-diene-3-ols **6** were synthesized via a lithiation reaction between 1-azapenta-1,4-diene-3-one and methyllithium. These substrates **6** were then observed to undergo multiple 4π-electrocyclizations in the presence of an acid and ultimately the formation of pyrroles **7**. Several of the 4π-electrocyclizations were found to be quite limited in scope; however, the authors found **Scheme 2** to be rather extensive in versatility.[11] The authors discovered triflic acid was required to enable the cyclization to the pyrrole **7** while no weaker

[10] Humenny, W. J.; Kyriacou, P.; Sapeta, K.; Karadoelian, A.; Kerr, M. A. *Angew. Chem., Int. Ed.* **2012**. *51:* 11088-11091.
[11] Narayan, R.; Fröhlich, R.; Würthwein, E-U. *J. Org. Chem*. **2012**. *77*:1868-1877.

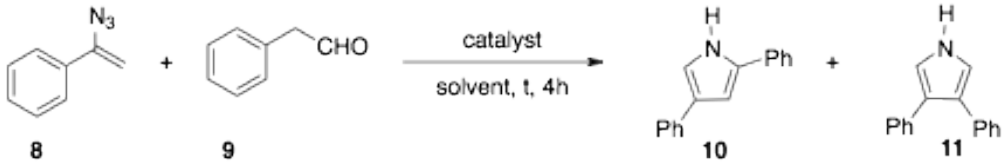
acids catalyzed the formation. While the scope of this reaction is rather broad, the harsh conditions necessary to produce the starting material can be considered a limitation to this synthesis.

Scheme 2. 4π-electrocyclization synthesis of pyrroles



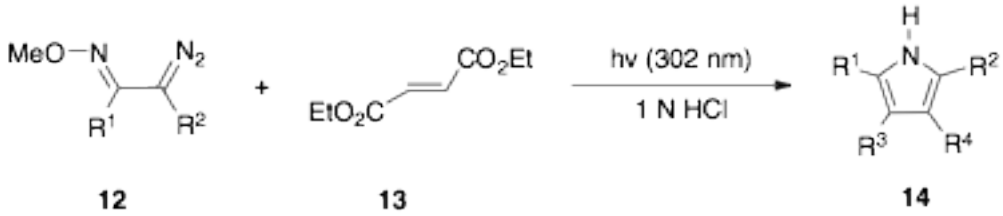
Using nickel and copper catalysis, 3,4- **(10)** and 2,4-diaryl **(11)** substituted pyrroles were synthesized using α−azidostyrene **8** and phenylacetaldehyde **9**. Previously, there was difficulty in synthesizing a 3,4-disubstituted pyrrole **10** because addition was prone at the α position. In the presence of a nickel catalyst, only the 3,4-disubstituted pyrrole **10** was observed. Conversely, they found that using a copper catalyst resulted in 2,4-diaryl substitution **11** as the sole product (**eq 4**).[12] The difference in regioisomers can be explained by the electronic difference between Ni and Cu. Ni(II) is quite stable and essentially acts similarly to a proton. Cu(II) on the other hand is very reactive and wants to reduce to Cu(I). To do this, it undergoes a radical process with the *α* carbon, leading to 2,4-diaryl substitution. The overall variability for this reaction is quite limited. Most of the substrates for the copper-catalyzed reaction require a phenyl ring in either the 2 or 4 position with a substituted phenyl ring in the other position. Similarly, the substrates for the nickel-catalyzed reaction have somewhat more variety; however, they are still quite limited. Finally, both reactions require 5 mol % of catalyst, which, if scaled up for large manufacturing, would prove to be rather costly.

[12] Chen, F.; Shen, T.; Cui, Y.; Jiao, N. *Org. Lett*. **2012**, *14*:4926-4929.



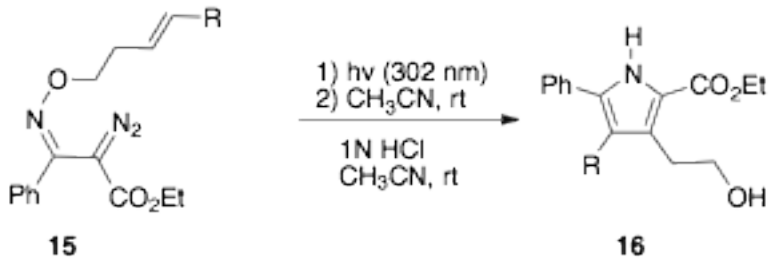
(4)

Another recent approach for the synthesis of pyrroles investigated the use of α-diazo oxime ethers **12**. Under photochemical conditions, the reaction of **12** with diethyl fumarate **13** produced the pyrrole **14** (**eq 5**).[13]



(5)

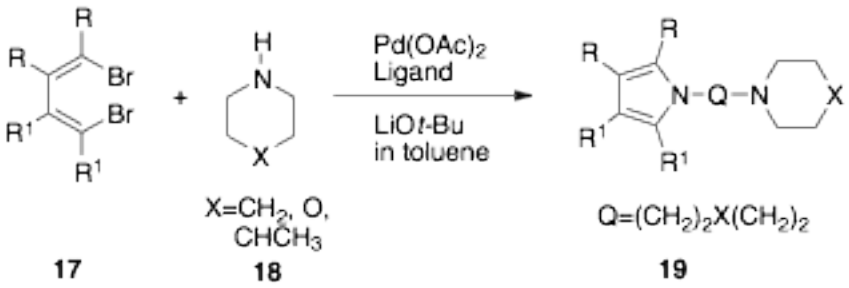
The authors also observed intramolecular pyrrole synthesis **16** beginning with α-diazo oxime ethers **15** in the presence of UV-light (**eq. 6**). Unfortunately, yields were not as high the intermolecular reaction.



(6)

Another paper found that use of a palladium catalyst could result in pyrrole **19** formation and catalyze C(sp^3)-N bond cleavage in secondary amines.[14] Geng found that rather bulky cyclopentadiene ligands provided the highest yields for formation. The Pd-catalyzed coupling substrates were highly substituted dibromides **17** and cyclic amines **18** (**eq. 7**).

[13] Qi. X.; Xu, X.; Park, C-M. *Chem. Commun.* **2012**. *48*: 3996-3998
[14] Geng, W.; Zhang, W-X.; Hao, W.; Xi, Z. *J. Am. Chem. Soc.* **2012**. *134*: 20230-20233.



(7)

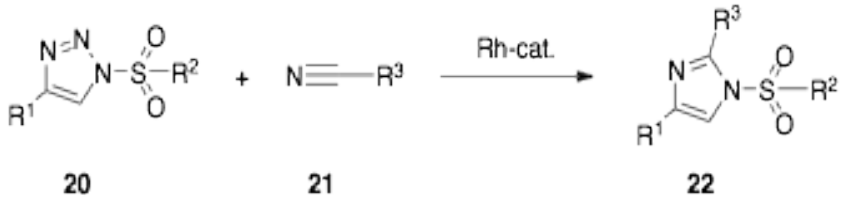
The reaction was also found to be successful when acyclic dialkylamines were used in place of cyclic amines; however, a slight reduction in yield was observed. When unsymmetrical dialkylamines were employed, selective C-N cleavage occurred between the weaker bond (i.e. lower bond energy); however, in the case of Et(Pr)NH where bond strength is more similar between the two substituents, a mixture of pyrrole products was observed. Limitations to this reaction extend to the synthesis of the appropriate ligands for the Pd-catalyzed reaction.

Introduction to Triazoles and Carbenoid Chemistry

Previous work in the Davies lab has focused on Rhodium-catalyzed reactions of donor/acceptor carbenes using diazo compounds.[15] Recently, Fokin and Gevorgyan have demonstrated the wide variability of rhodium catalyzed *N*-sulfonyl-1,2,3-triazole reactions.[16] Similar to diazo compounds, triazole compounds can produce reactive rhodium-carbenoid species because the triazole exists in an equilibrium state with the diazo in solution. Most triazole compounds have been found to be shelf stable and can be readily synthesized. Fokin found that a Rhodium-catalyzed reaction between variously substituted *N*-sulfonyl triazoles **20** and nitriles **21** afforded various imidizoles **22** (**eq. 8**). This reaction was found to successfully occur because the triazole compound afforded some diazo compound in solution, which subsequently reacted with

[15] Li, Z.; Davies, H.M.L. *J. Am. Chem. Soc.* **2010**, *132*: 396-401.
[16] Horneff, T.; Chuprakov, S.; Chernyak, N.; Gevorgyan, V.; Fokin, V. *J. Am. Chem. Soc.* **2008**, *130*: 14972-14974.

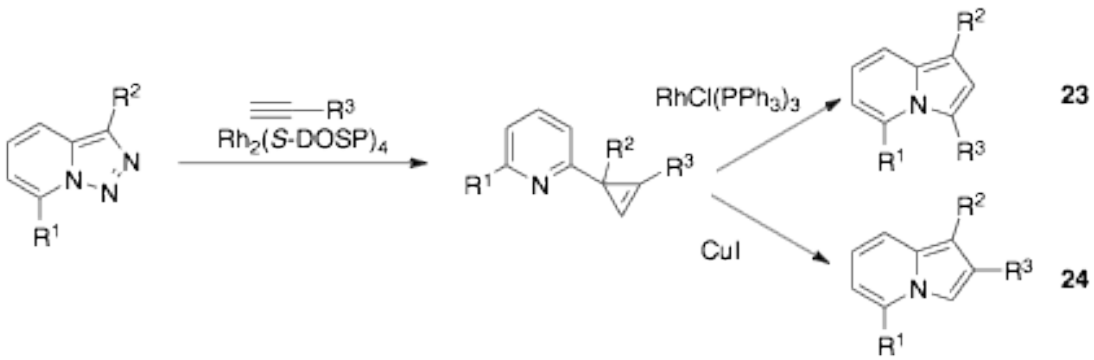
the Rhodium, providing the Rhodium carbenoid. Catalyst screening found that $Rh_2(Oct)_4$ and $Rh_2(S\text{-DOSP})_4$ provided equally high yields.



(8)

Research by Gevorgyan found that 3-iminocyclopropenes could be formed from the anticipated cyclopropanation reaction between a Rhodium-catalyzed triazole cycloaddition with an alkyne. Subsequent transformations provided the final indolizine product. It was found that a copper(I) catalyst induced 3,4-disubstituted indolizine **23** formation while a rhodium(I) catalyst induced 1,3-disubstituted indolizine **24** formation (**Scheme 3**).[17] Interestingly, when Rh(II) was used to induce indolizine formation, **24** resulted in low yields. The difference in regioismer formation can be attributed to the difference in overlap between the metal catalyst and the cyclopropene.

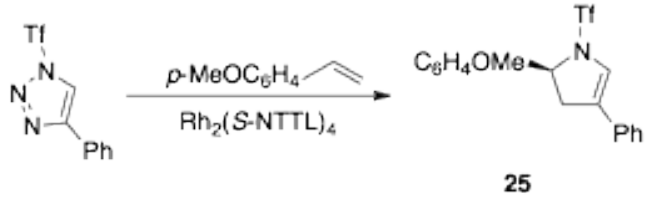
Scheme 3. Copper and Rhodium catalyzed formation of disubstituted indolizines



Previous research by Davies has shown donor/acceptor Rhodium-carbenes normally undergo cyclopropanation in high yield. Additional research by Fokin demonstrated that while *N*-sulfonyltriazoles could undergo cyclopropanation, they could also produce dihydropyrroles **25**

[17] Chuprakov, S.; Gevorgyan, V. *Org. Lett.* **2007**, *22*:4463-4466.

in high yield using *p*-methoxystyrene as the rhodium carbene substrate (**eq. 9)**.[18] It was found that no dihydropyrrole formation occurred in electron-neutral or electron-deficient styrenes.



25 (9)

Further experiments have demonstrated the versatility of triazoles and their ability to undergo rhodium catalyzed C-H insertion and rearrangements.[19,20] *N*-sulfonyltriazole stability and similarity in reactivity makes them a suitable substitute for previously used diazo compounds. Furthermore, the formation of the metal carbenoid from a triazole compound results in a nitrogen atom still present on the carbenoid, which can subsequently be incorporated into various final structures. This is not a possibility when starting with a diazo compound.

Rhodium-Catalyzed Furan reactivity

Fokin's research successfully shows the possibility of *p*-methoxystyrene as an electron rich system capable of trapping the rhodium carbene. This prompted us to investigate the ability of electron rich heterocycles to perform similar chemistry. Davies previously investigated the use of heterocycles in rhodium catalyzed donor acceptor reactions using diazo compounds.[21] It was found that double cyclopropanation was the major product **26** when a furan was used as the carbene trap (**eq 10**). Interestingly, the enantiomer formed was dependent upon the location of initial attack. When 2,5-dimethylfuran was used in place of furan, attack was blocked at the C-2 position and thus proceeded through attack at the C3 position resulting in the opposite

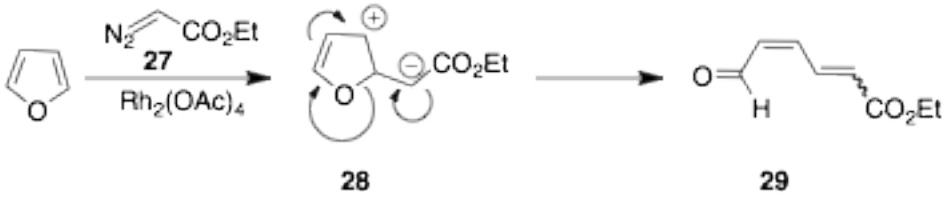
[18] Grimster, N.; Zhang, L.; Fokin, V. *J. Am. Chem. Soc.* **2010**, *132:* 2510-2511.
[19] Chuprakov, S.; Hwang, F.W.; Gevorgyan, V. *Angew. Chem., Int. Ed.* **2007**, *46*:4757-4759.
[20] Alford, J.S; Daives, H.M.L *Org. Lett*. **2012**, *14*: 6020-6023.
[21] Hedley, S.J.; Ventura, D. L.; Dominiak, P.M.; Nygren, C.L.: Davies, H.M.L. *J. Org. Chem*. **2006**, *71*:5349-5356.

enantiomer. This result was found despite the same chiral catalyst used to generate both double cyclopropanation reactions. Futhermore, this paper demonstrated the propensity for multiple cyclopropanations with furan.

(10)

Davies also found that the reaction with acceptor substituted carbenoids resulted in dienes. This ring-opened product **29** is proposed to be generated through a zwitterionic intermediate **28** after electrophilic addition of the carbenoid **27** to the C-2 position (**Scheme 4)**. Interestingly, ring opening was not found with donor acceptor substituted carbenoids. However, an electron-donating substitution on the furan results in solely ring opening product via zwitterionic transformation.

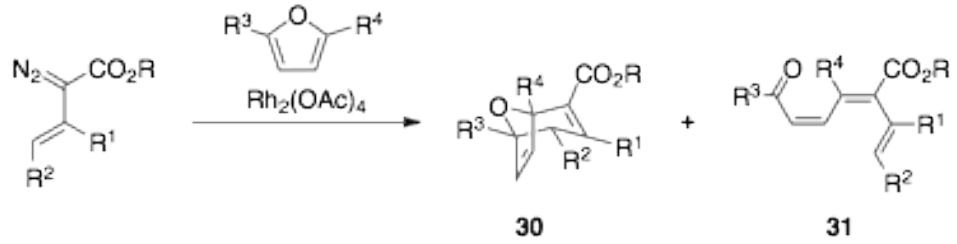
Scheme 4. Ring-opened diene product through zwitterionic intermediate



In the presence of vinylcarbenoids, [4 + 3] cycloadditions have been observed with furans affording, 8-oxabicyclo[3.2.1]octadienes followed by Cope rearrangement **30**[22,23]. This reaction is thought to proceed first through an addition at the C-3 position followed by formation of a cyclopropanation intermediate **32** and subsequent ring closure **30** (**Scheme 5**). The competing byproduct for this reaction is the ring opened triene **31** formed when addition at the C-2 position

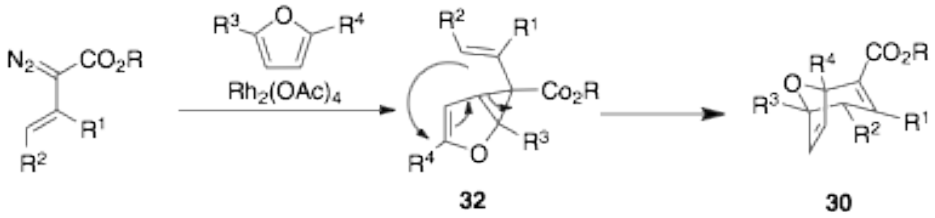
[22] Davies, H.M.L.; Clark, D.M.; Alligood, D.B.; Eiband, G.R. *Tetrahedron*. **1987**, *43*: 4265-4270.
[23] Davies, H.M.L.; Clark, D.M.; Smith, T.K. *Tetrahedron Lett.* **1985**, *26*:5659-5662.

is more prone than addition at C3. The major product formation was largely dependent upon the substituents on the furan. It was seen that electron-donating substituents on the furan led to ring opening over the oxabicycle, whereas 2,5-dimethyl furan exclusive resulted in the oxabicycle cope rearrangement (**eq 11**).



(11)

Scheme 5. Mechanism of 8-oxabicyclo[3.2.1]octadiene formation



Metal-Catalyzed Reactions

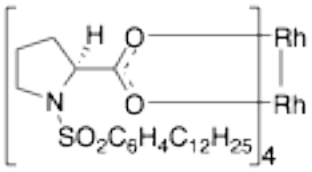
The result of metal-catalyzed reactions is strongly dependent upon the type of transition metal used. Dirhodium complexes have been found to be successful at C-H insertion. This success is contributed to the dirhodium bridge within a "lantern" structure. It is believed that only one of the two rhodium centers actually acts as the carbene binding site while the second rhodium is an electron-sink that increases the electrophilicity of the carbene and helps in the final cleavage of the rhodium-carbene bond.[24]

Dirhodium carboxylates have been found to be rather successful in donor/acceptor carbene chemistry, readily decomposing diazo compounds. Additionally, they serve successfully as chiral catalysts. The development of chiral catalysts has led to vast improvements in C-H

[24] Davies, H.M.L.; Beckwith, R.E.J. *Chem. Rev.* **2003**, *103*:2861-2903.

insertion, allowing for the enantioselective induction of achiral starting materials. One such chiral catalyst is $Rh_2(DOSP)_4$, which Fokin found to produce the highest yields in his *N*-sulfonyltriazole chemistry (**Figure 1)**.

Figure 1. Structure of Rh_2(*S*-DOSP)$_4$

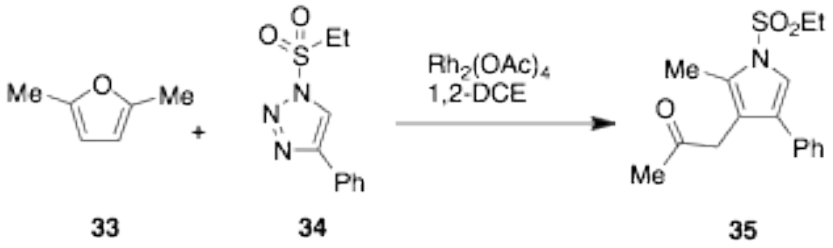


Discovery of a New Approach to Pyrroles

Brendan Parr, a graduate student in the Davies group, was exploring whether *N*-sulfonyltriazoles would undergo reactions that were otherwise impossible with donor/acceptor diazo derived carbenes. During the course of these studies, he found that the rhodium(II) catalyzed reaction 2,5-dimethyl furan **33** with ethanesulfonyltriazole **34** unexpectedly resulted in pyrrole formation **35** (**eq 12**) rather than undergoing the anticipated cyclopropanation reaction.[25] The reaction was first investigated using $Rh_2(OAc)_4$ to catalyze the reaction between ethanesulfonyltriazole and 2,5-dimethylfuran resulting in a 41 percent pyrrole yield. Because the reaction proceeded smoothly using inexpensive starting materials, moderate reaction conditions, and had a promising yield, Brendan pursued further investigation. After further optimization, he found that the yield was dependent upon the catalyst and solvent. The reaction was first investigated using only achiral rhodium catalysts, with $Rh_2(OOct)_4$ giving the highest yield. However, only moderate yields were observed (**Table 1**). It was found that 1,2-dichloroethane was the optimum solvent for the pyrrole reaction. These preliminary studies suggested that a

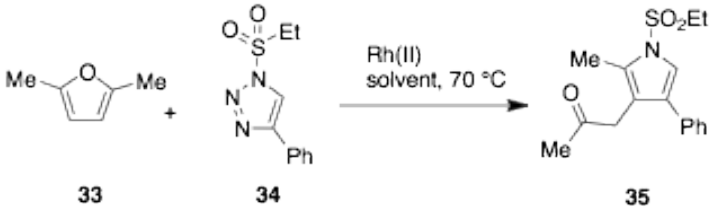
[25] Parr, B. T.; Green, S.A.; Davies, H.M.L. *J. Am. Chem. Soc.* **2013**, *133:*4716-4718.

novel approach for the synthesis of pyrroles could be possible by reacting furan and traizoles. The aim of my project was to further optimize the reaction as well as to determine the scope and limitations of the process.



33 34 35 (12)

Table 1. Catalyst and Solvent Screening



33 34 35

Entry	Rh(II)-cat.	Solvent	Yield[a]
1	$Rh_2(OAc)_4$	1,2-DCE	41
2	$Rh_2(esp)_2$	1,2-DCE	35
3	$Rh_2(OOct)_4$	1,2-DCE	56
4	$Rh_2(OPiv)_4$	1,2-DCE	31
5	$Rh_2(TFA)_4$	1,2-DCE	0[b]
6	$Rh_2(pfb)_4$	1,2-DCE	0[b]
7	$Rh_2(OOct)_4$	PhCH3	42
8	$Rh_2(OOct)_4$	CHCl3	29

[a]Isolated yields. [b]*N*-sulfonyltriazole recovered

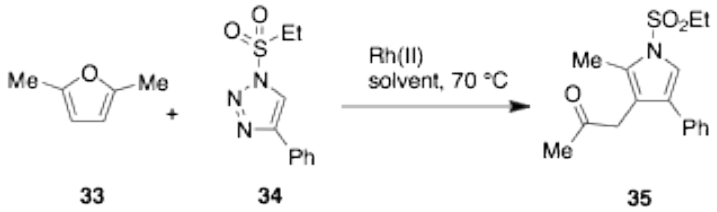
Results and Discussion

Brendan Parr's preliminary results showed that pyrrole synthesis was possible from furans and triazoles; however, low yields were observed and the scope was limited to one substrate. To expand the scope of the reaction, substituent groups on the triazole and sulfonyl were altered, in hopes that this would increase the yield. Furthermore, various furan compounds were explored to determine the extent of the pyrrole synthesis.

Chiral Catalyst

Exploration was done to see if the use of a chiral catalyst provided better yields than the achiral catalyst. Various chiral catalysts were screened using 1,2-DCE as the solvent and it was found that Rh_2(*S*-DOSP)$_4$ provided the highest yields (77%). Interestingly, Rh_2(*S*-NTTL)$_4$ gave amongst the lowest yields for all catalysts, while Rh_2(*S*-PTAD)$_4$ gave relatively the same yield as Rh_2(OOct)$_4$ (**Table 2**). Previous research with triazoles did not see a difference in yields between the uses of chiral versus achiral catalysts. Folkin observed both Rh_2(*S*-DOSP)$_4$ and Rh_2(OOct)$_4$ gave the same moderate yields. Because the product is achiral, the use of a chiral catalyst was not considered upon first optimization. It was not until after several other methods to increase yields failed that trying a different catalyst was considered.

Table 2. Exploration of chiral catalysts.



33 34 35

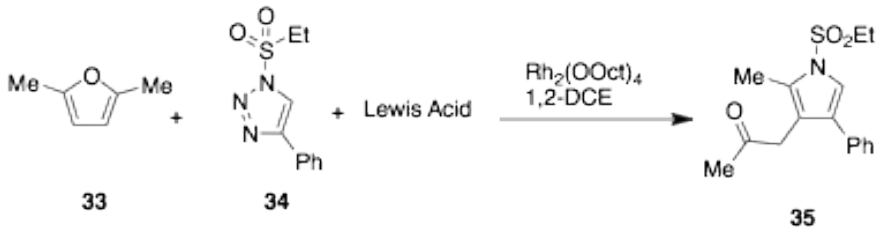
Entry	Rh(II)-cat.	Solvent	Yield[a]
9	Rh_2(*S*-DOSP)$_4$	1,2-DCE	77
10	Rh_2(*S*-NTTL)$_2$	1,2-DCE	41
11	Rh_2(*S*-PTAD)$_4$	1,2-DCE	55

[a]Isolated yields. [b]*N*-sulfonyltriazole recovered

Exploration of Lewis Acids

In attempt to increase pyrrole formation, the use of a lewis acid was investigated. An oven dried pressure tube was charged with 1 mol% Rh catalyst, 0.5 mmol triazole, 1.5 mmol furan, and 2.5 mL 1,2-dichloroethane before being capped, shaken and sealed. The pressure tube was then placed into an oil bath and allowed to stir for 4-8 hours at 70°C. The reaction was then removed from the heat and 1 mol % lewis acid was added. The reaction was then allowed to stir at ambient temperature for 4 hours. The reaction was quenched with water and subjected to a standard an aqueous workup to yield the crude product, which was purified by flash chromatography (SiO_2, Hexane/EtOAc). The summary of results can be seen in **Table 3**.

Table 3: Lewis Acid Screening



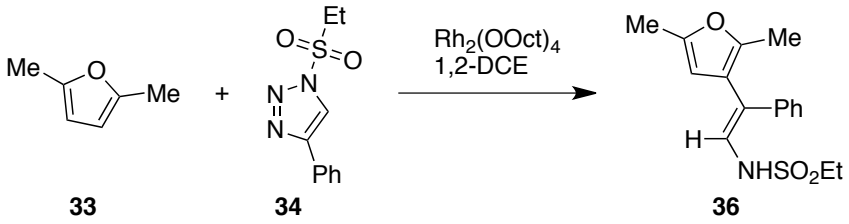
33 34 35

entry	Lewis Acid	Yield (%)
12	None	50
13	BF_3 OEt_2	40
14	$Sc(OTf)_3$	48
15	$SnCl_2$	56
16	$TiCl_4$	0[a]
17	$AlCl_3$	37
18	$ZnCl_2$	44
19	$SnCl_4$	44
20	GaOTf	57
21	$HfCl_4$	23

[a]No product observed by TLC analysis

We knew that the major byproduct from the pyrrole reaction was the enamine **36** (**eq 13**). We knew that in solution, the enamine was able to tautomerize to the imine, which could subsequently attack the furan ring to produce a hemiaminal. We hoped that the presence of the Lewis acid would provide an acid environment to facilitate the closure to the hemiaminal structure. Analysis of the crude reaction mixtures via ^{1}H NMR spectroscopy of the Lewis acid addition initially seemed promising, as there was reduced evidence of enamine byproduct **36** formation. However, after final purification it was found that in most cases, pyrrole yield

decreased and the enamine was completely decomposed. Strong Lewis acids (**entry 16**) were found to eliminate the enamine byproduct as well as the pyrrole product entirely. Two of the Lewis acids (**entries 15 and 20**) were found to increase the yield of the pyrrole; however, the increase in yield was not significant enough to pursue further exploration.



33 **34** **36** (13)

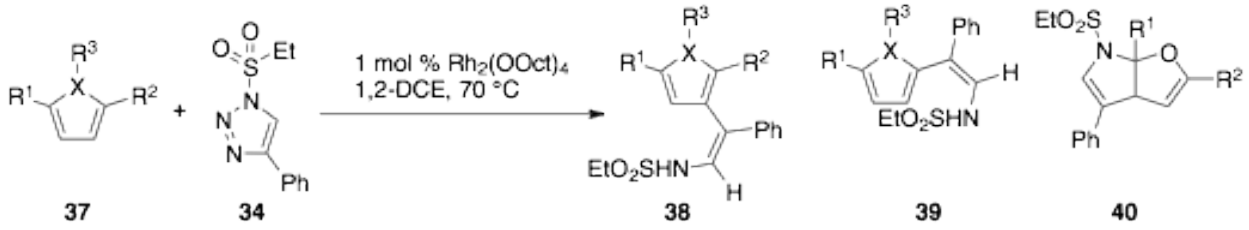
Heterocycle Scope Exploration

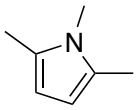
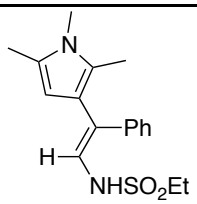
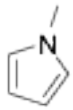
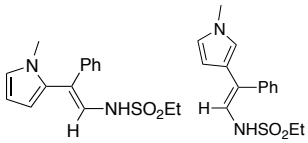
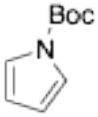
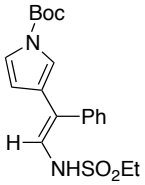
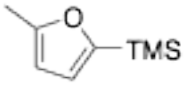
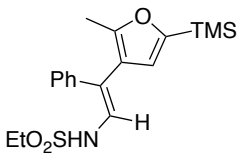
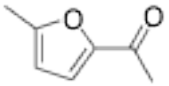
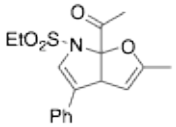
A portion of my project explored whether the reaction conditions could be applied to other heterocycles and result in pyrrole formation. The results can be found in **Table 4**. It was found that pyrrole rings exclusively formed enamine product and thus a lack of ring opening. Interestingly, while the pyrrole product formation produced highest yields in 1,2-DCE, the enamine formation was most prevalent in chloroform.

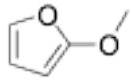
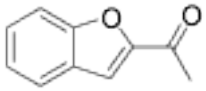
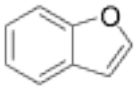
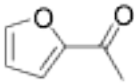
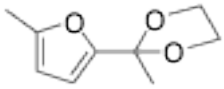
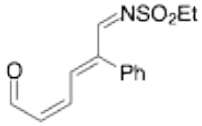
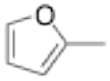
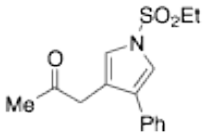
Various furans were tested to evaluate the significance of substituent location and electron-richness of the system. Furan did not result in pyrrole formation instead forming the anticipated ring-opened dienal product, as was observed previously by Davies exploration of furan with donor acceptor diazo compounds. This product was not stable upon isolation and the only evidence of the formation was observed via NMR analysis. The 2-methyfuran produced pyrrole product in moderate yield (41%), whereas other singly substituted furans **37f** and **37k** were found to result in no reaction. Interestingly, 2,3-dimethylfuran **37h** resulted in enamine **38h** and **38h** rather than pyrrole formation as well. Altering the electron richness of the system, greatly impacted the resulting formation. When the electron richness of the system was increased

(**entry 37f**), a complex mixture of the anticipated ring opened product resulted. When the electron richness of the system was reduced (**entries 37g-j**), no reaction was observed. This substrate scope determined that 2,5 substitution was favorable for pyrrole formation and the reaction was highly sensitive to the degree of electron-richness of the starting material.

Table 4: Heterocycle and substrate exploration



Entry	Heterocycle[a]	Product	Yield (%)
a			-
b			42, 17[c]
c			88
d			53
e			-

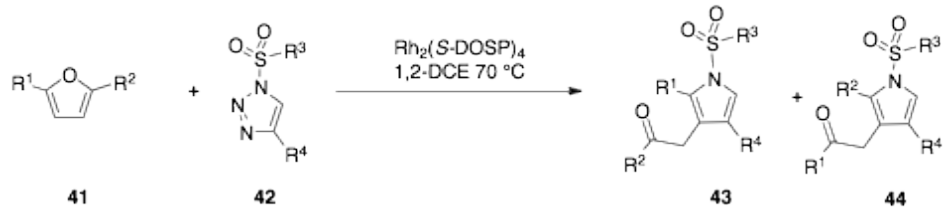
Entry	Heterocycle[a]	Product	Yield (%)
f		Complex mixture	-
g		no reaction[b]	-
h		no reaction[b]	-
i		no reaction[b]	-
j		no reaction[b]	-
k			-
l			41

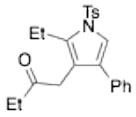
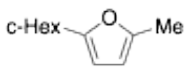
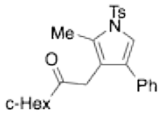
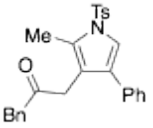
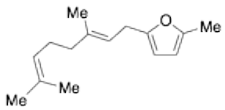
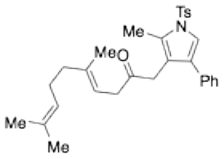
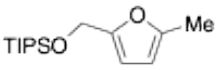
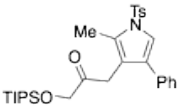
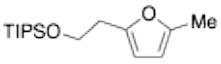
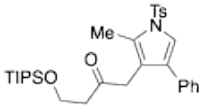
[a]**37**a-c,e-i, k-l commercially available. **37**d and j were made according to literature procedure.[b]only starting material observed via TLC analysis and crude ^{1}H NMR analysis. [c]determined by crude NMR analysis

Furan Scope Exploration

My exploration of various heterocyles and their substitution suggested that a 2,5-disubstituted furan ring was favorable to facilitate pyrrole formation. With this information, Brendan sought to investigate the substrate scope of 2,5-disubstituted furans. Various disubstituted furans were prepared and were shown to give high yields of the corresponding pyrrole (**Table 5**). He found that a 99 percent yield was obtainable when 2,5-diethyl furan **41a** was used as the starting material. The asymmetric substituted furans provided a mixture of **43** and **44**, usually favoring the formation of **43**. The notable exception to this trend is **41e,** which selectively favored formation of **43**. This selectivity can be attributed to the perfect blend of steric and electronic interactions that favors the formation of **43** over **44**.

Table 5. 2,5-disubstituted Furan scope



Entry	Furan	Product	Yield %	Ratio
a			99	-
b			67[a]	2:1
c			71[a]	3:1
d			65[a]	2:1
e			83	>10:1
f			89[a]	2:1

[a]Combined yield of two regioisomers 43 and 44.

Synthesis of Triazole Compounds

Preparation of the *N*-sulfonyltriazole **42** compounds was made from established procedure.[26] The triazoles can easily be synthesized from a starting alkyne **45** and *N*-azidesulfonyl **46**. Most alkynes and *N*-azidesulfonyl compounds were known compounds and purchased. The procedure is scalable, enabling the synthesis of gram quantities of material (eq 14).

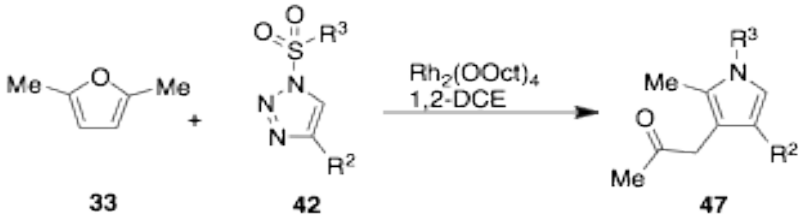
(14)

Exploration of Substrates

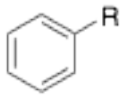
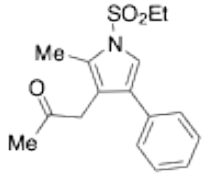
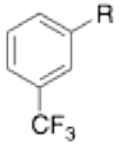
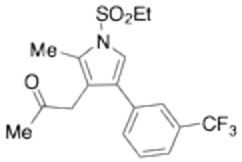
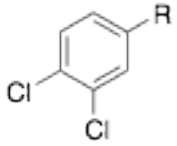
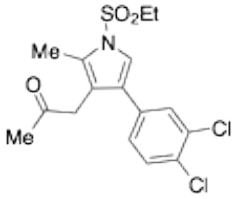
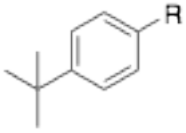
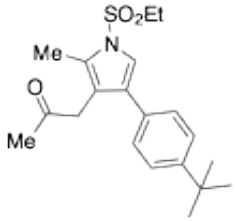
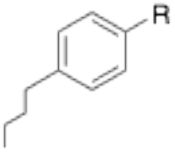
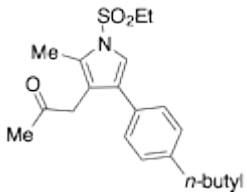
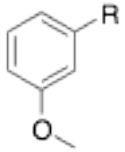
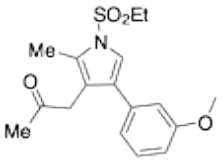
With the established conditions using the achiral catalyst, the expansion of the triazole scope was investigated. We first sought to investigate the variation of substrates at the C-4 position on the aryl substituent on the triazole. For the triazole optimization, the triazoles were synthesized according to **equation 14** with *N*-ethanesulfonyl as the *N*-sulfonyl protecting group (R^1). We anticipated that substitution at the *ortho* position **42l** would result in steric hindrance and thus reduced yields **47l**. We found steric effects to have no significant effect on yield. *Ortho* versus para substituted trifluoromethyl were explored **42b** and **42h**. Again, only a slight difference in yield was seen between the two compounds **47b** and **47h**. Furthermore, the reaction was unaffected by electron withdrawing or donating substituents **42b** and **42f**. A summary of the ethanesulfonyltriazole scope can be seen in **Table 5**.

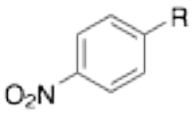
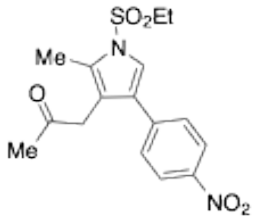
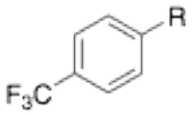
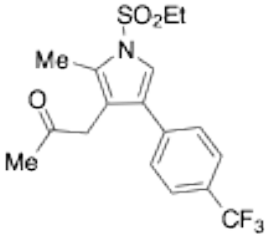
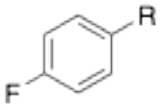
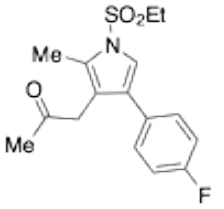
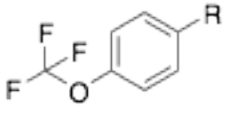
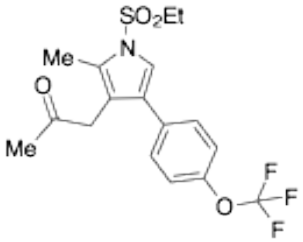
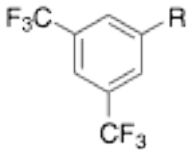
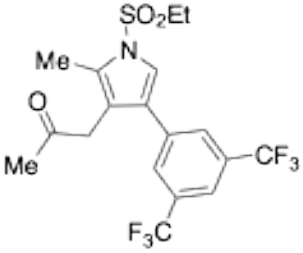
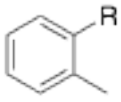
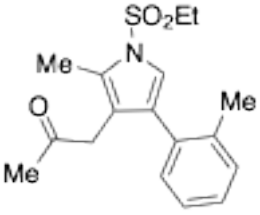
[26] Raushel, J.; Fokin, V.V. *Org. Lett.* **2012**, *12*, 4952.

Table 6: Ethanesulfonyltriazole Substrate scope



33 42 47

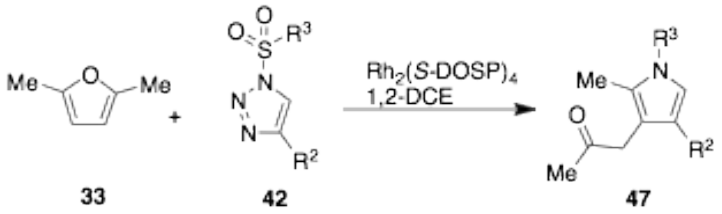
Entry	Triazole	Product	Yield (%)
a			50
b			76
c			62
d			74
e			48
f			48

g			42
h			47
i			60
j			54
k			68
l			35

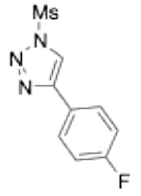
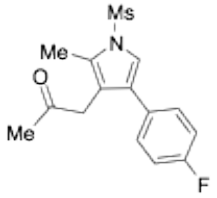
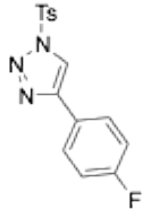
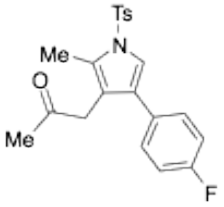
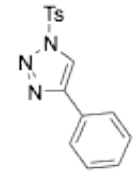
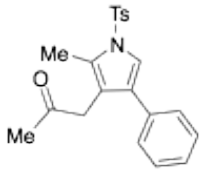
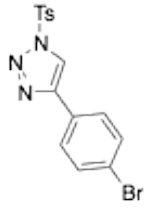
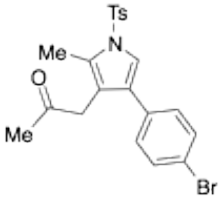
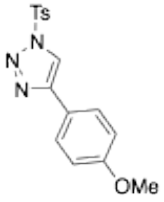
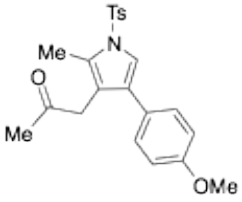
Further exploration of triazole substrate

When varying the aryl substitution seemed to have little impact on yield, we decided to vary the *N*-sulfonyl protecting group; however, we did not anticipate this would have a significant impact on yield. To our surprise, varying the *N*-sulfonyl protecting group was found to have a profound impact on yield. When switching the ethanesulfonyl moiety with a tosyl moiety, high yields were observed (73-98%). **Table 6** summarizes the results from the substrate scope. Similar to the ethanesulfonyl triazole, there was little variation in yield as a result of substitution on the aryl ring. As a result, the scope with this triazole is less extensive and, similarly, neither electronic nor steric effects from changing substitution on the aryl ring were seen to be a factor in the reaction yields.

Table 7: Triazole substrate scope



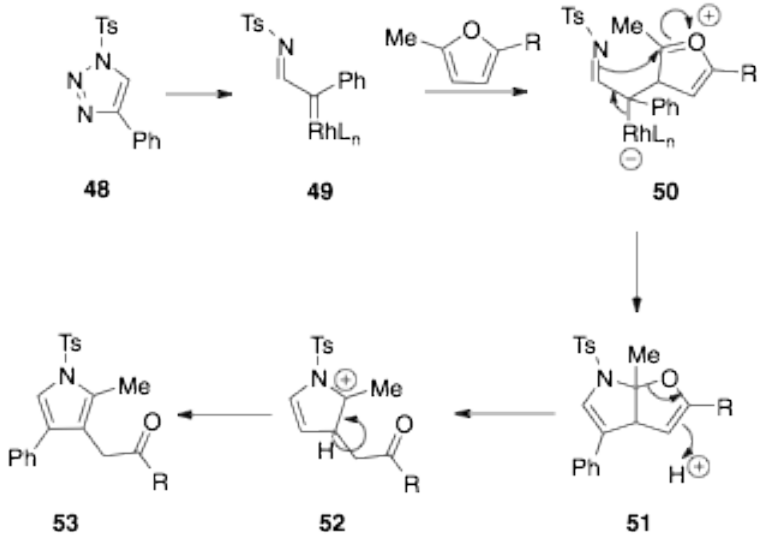
33 42 47

Entry	Substrate	Product	Yield
m			81%
n			98%
o			84%
p			73%
q			91%

Discussion

The proposed mechanism for this reaction can be seen in **Scheme 6**. When the triazole **48** is heated in the presence of the dirhodium catalyst, the triazole ring opens at C-3 to form the diazo compound. Rhodium interaction with the diazo compound subsequently releases N_2, resulting in the imino carbene-intermediate **49**. Electrophilic addition of the rhodium carbene to the furan at the C3, followed by reductive elimination of the rhodium and concomitant imine attack, furnishes **50** which closes to the hemiaminal **51**. Mildly acidic conditions promote ring opening to generate **52**. This aromatizes to the more stable configuration of the pyrrole **53**, yielding the final product.

Scheme 6. Proposed mechanism for pyrrole formation

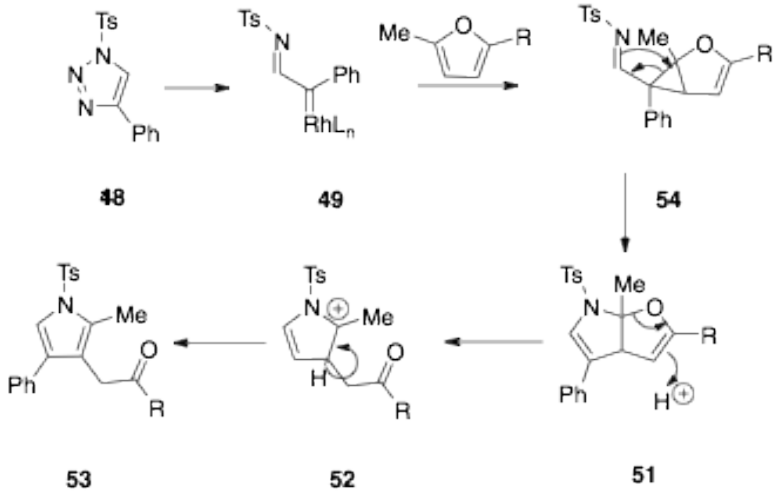


With this proposed mechanism, several theories result to explain the failures of some of the substrate. Electronically favorable reactivity would suggest attack at the C-2 position. However, the above scheme mandates attack at C-3 to allow for closure to the hemiaminal **51**. This explains why the dienal product resulted from the reaction with furan or other reactions lacking blockage at the C-2 or C-5 position. In the reaction with 2-methylfuran, the pyrrole was seen in moderate yield, suggesting that blocking the C2-position alone resulted in some pyrrole

formation; however, blocking both the C-2 and C-5 position was necessary for complete pyrrole formation.

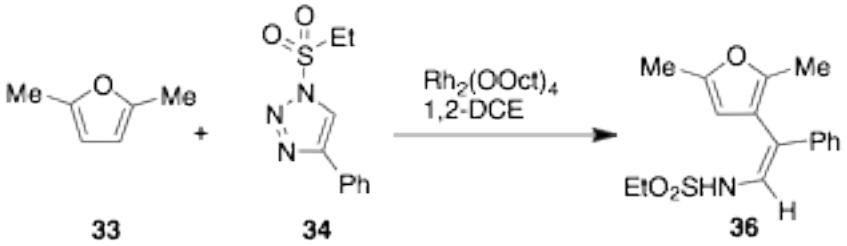
A proposed, but less likely mechanism, is a cyclopropanation followed by vinyl addition as seen in **Scheme7**.

Scheme 7. Proposed cyclopropanation mechanism for pyrrole formation



This is a less likely mechanism for several reasons. Firstly, as discussed in the introduction (**eq. 11**), a similar reaction is known to occur via a [4+3] cycloaddtion, beginning with a cyclopropanation and resulting in an oxabicyclic product. We would have anticipated seeing evidence of this bicyclic product as a byproduct of the reaction if the reaction proceeded via a cyclopropanation; however, there is no such product in the crude NMR analysis. Additionally, as discussed in the introduction, cyclopropanation reactions are common when 2,5-dimethyl furan is used as starting material (**eq 10**). It can be seen in this reaction that there is a propensity for further cyclopropanations once the aromaticity of the furan has been lost. There is no evidence of the doubly cyclopropanated furan ring in the crude NMRs as a byproduct. The lack of both byproducts suggests that scheme 6 is the more likely mechanism.

The main byproduct of the pyrrole reaction was consistently the enamine **36** formation (eq 13).



33 **34** **36** (13)

We anticipated that the addition of a Lewis acid would facilitate hemiaminal formation after enamine tautomerization to the imine. Instead, we only saw the decomposition of the enamine **36** product and some decomposition of the pyrrole. The only method for elimination of the enamine byproduct **36** was by altering the *N*-sulfonyl protecting group and changing catalysts. Comparing the nature of the sulfonamide, there is not a substantial difference between the ethanesulfonyl and tosyl moieties; however, the difference between the two groups is enough to result in a substantial increase in yields by diminishing the likelihood for the enamine byproduct to form. An increase in the nucleophilicity of the imine bond allows for a greater propensity for hemiaminal formation. Being an aryl group, the tosyl moiety has the ability to participate in resonance and thus donate electron density toward the nitrogen and increase the nucleophilicity. On the contrary, ethanesulfonyl cannot participate in resonance, making it plausible to explain the difference in reactivity. The fact that aryl substitution had little impact on yields was found to be a beneficial result for future use of this reaction. Because moderate to high yields were observed regardless of aryl substitution, a wide range of products can be formed, implying that the versatility of this pyrrole is great for future use in total synthesis reactions.

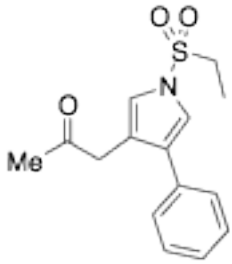
The exploration of substrate scope on the furans showed that electron-withdrawing groups at the C5-position either failed or gave primarily enamine product. The methyl group at the C5-position is necessary to stabilize the resulting carbocation after the furan ring opening. An electron-withdrawing group, not being able to stabilize a carbocation, would make the ring opening considerably more difficult. When an electron-donating group was used, the electron-richness of the system was too great and the opened diene product was observed. On the contrary, when the electron-richness of the system was decreased too much, such as with benzofuran, no reaction was observed. Overall, the highest yielding furan substrate was found to be the 2,5-diethylfuran **41a**, while moderate to high yields were found for various 2,5-disubstituted furans.

Brendan found that substitution at the C-2 position required either a methyl or ethyl substituent; however, variance at the C-5 position could be rather extensive. With asymmetric substitution, a mixture of regioisomers was observed, the exception being **41e**, which resulted in high regioselectivity **43e**. Speculation proposed for the high regioselectivity is the steric crowding and electronic deactivation by the (triisopropyl)siloxymethyl group prevented formation of two isomers.

Finally, we are able to speculate why Rh_2(*S*-DOSP)$_4$ was more effective than $Rh_2(OOct)_4$. Theoretically, there is no reason to use a chiral catalyst since neither the starting material nor the product has a chiral center. Therefore, the symmetry of the Rh_2(*S*-DOSP)$_4$ versus the symmetry of the $Rh_2(OOct)_4$ should not be a factor here. Rather, the ligands on a catalyst affect the reactivity of the resulting carbene with electron withdrawing ligands creating highly reactive carbene intermediates. The ligands on Rh_2(*S*-DOSP)$_4$ must result in a carbene with reactivity more likely to undergo pyrrole production than enamine formation.

Conclusion

A novel synthesis of a pyrrole ring was found to result from furan and N-sulfonyltriazole catalyzed by a dirhodium catalyst. The reaction was found to occur at highest yields using a tosyl substituted triazole compound. Meanwhile, the variance of substrate on the phenyl ring of the triazole had little effect on yield. The main byproduct of the reaction was found to be the enamine formation. It was found that this product could be eliminated using variously substituted 2,5-disubstituted furans, a tosyltriazole, and Rh_2(*S*-DOSP)$_4$. The success of the reaction was highly contingent upon the substitution at the C-2 position. Electron withdrawing groups present at the C-2 position often resulted in minimal conversion. The mechanism is believed to occur via a formal [3+2] cycloaddition between the overlap of the rhodium carbene and the C2-C3 pi bond of the furan with concomitant imine attack. This is followed by hemiaminal formation and ring opening. Upon final rearomatization, the pyrrole product is formed. This synthesis requires very mild reaction conditions in comparison to other methods for pyrrole synthesis. While other synthesis methods require prolonged heating, this reaction proceeds at 70°C in 4 to 6 hours. Furthermore, substituted furans are common and inexpensively purchased or made. Similarly, the triazoles can be easily synthesized as well from inexpensive starting materials. Both compounds are shelf stable and relatively safe to work with. The material of this thesis has been compiled into a paper written by Brendan Parr and was accepted for publication on March 11th, 2013 in the *Journal of American Chemical Society*.



1-(1-(ethylsulfonyl)-4-phenyl-1H-pyrrol-3-yl)propan-2-one (38l)

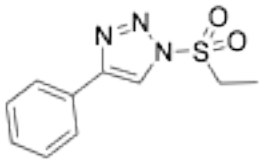
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42a** (134 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (7.8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **37l** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 24 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a pale yellow oil (43 mg, 41%).

^{1}H NMR (400 MHz, CDCl3): δ 7.52–7.45 (m, 2H), 7.37 (dd, *J* = 4.7, 2.7 Hz, 2H), 7.34 (s, 1H), 7.28–7.23 (m, 1H), 6.46 (d, *J* = 1.9 Hz, 1H), 4.03 (s, 2H), 3.37 (q, *J* = 7.4 Hz, 2H), 2.27 (s, 3H), 1.36 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 205.8, 133.4, 129.1, 129.0, 127.2, 127.2, 125.7, 118.8, 114.4, 49.8, 42.7, 29.8, 8.2.

FTIR (neat): ν_{max}/cm^{-1} 3135, 3029, 2983, 2942, 1718, 1608, 1528, 1452, 1358, 1142.

HRMS (p-APCI): *m/z* 291.0921 [(M+H)+ requires 291.0921].



1-(ethylsulfonyl)-4-phenyl-1H-1,2,3-triazole (42a)

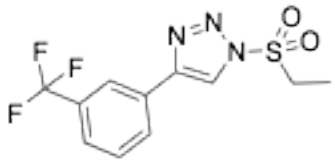
To an oven dried 100 mL round bottom flask equipped with stir vane, phenylacetylene (1.02 g,10.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 45 mL). The flask was charged with CuTC (190 mg, 1.0 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Ethanesulfonyl azide (1.35 g, 10.0 mmol, 1.0 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 12 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 4:1) and recrystallized (hexanes/EtOAc, 10:1) to afford the title compound as a white solid (2.041 g, 86% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.31 (s, 1H), 7.90–7.87 (m, 1H), 7.87–7.85 (m, 1H), 7.51–7.44 (m, 2H), 7.44–7.38 (m, 1H), 3.71 (q, *J* = 7.4 Hz, 2H), 1.40 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 147.5, 129.4, 129.3, 128.8, 126.3, 120.0, 50.3, 7.9.

FTIR (neat): ν_{max}/cm^{-1} 2979, 2940, 1484,1450, 1373, 1168.

HRMS (p-APCI): *m/z* 146.0713 [(M-SO2Et+H)+ requires 146.0713].



1-(ethylsulfonyl)-4-(3-(trifluoromethyl)phenyl)-1H-1,2,3-triazole (42b)

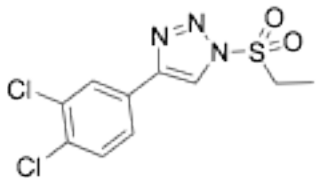
To an oven dried 100 mL round bottom flask equipped with stir vane, 3-ethynyl-α,α,α-trifluorotoluene (825 mg, 5.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (95 mg, 0.50 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Ethanesulfonyl azide (745 mg, 5.5 mmol, 1.1 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 12 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 3:1) and recrystallized (hexanes/EtOAc, 10:1) to afford the title compound as a white solid (941 g, 62% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.39 (s, 1H), 8.14 (s, 1H), 8.08 (d, *J* = 7.7 Hz, 1H), 7.68 (d, *J* = 7.7 Hz, 1H), 7.62 (t, *J* = 7.7 Hz, 1H), 3.74 (q, *J* = 7.4 Hz, 2H), 1.43 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 146.2, 129.9, 129.8, 129.5, 126.1, 123.2, 120.6, 50.4, 8.0.

FTIR (neat): ν_{max}/cm^{-1} 3148, 1456, 1379, 1354.

HRMS (p-APCI): *m/z* 306.0518 [(M+H)+ requires 306.0519].

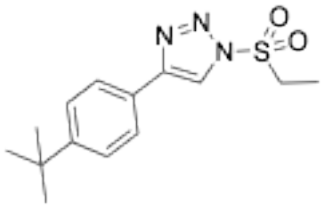


1-(ethylsulfonyl)-4-(3,4-(dichloro)phenyl)-1*H*-1,2,3-triazole (42c)

To an oven dried 100 mL round bottom flask equipped with stir vane, 4-ethynyl-1,2-dichlorotoluene (855 mg, 5.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (95 mg, 0.50 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Ethanesulfonyl azide (745 mg, 5.5 mmol, 1.1 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 12 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 3:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (1.03 g, 67% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.31 (s, 1H), 7.99 (d, *J* = 1 Hz, 1H), 7.70 (dd, *J* = 4 Hz, 1H), 7.55 (d, 6Hz, 1H), 3.83 (s, 3H), 3.72 (q, *J* = 12Hz, 2H), 1.42 (t, *J* = 12 Hz, 3H).

*Compound partially characterized



4-(4-(tert-butyl)phenyl)-1-(ethylsulfonyl)-1H-1,2,3-triazole (42d)

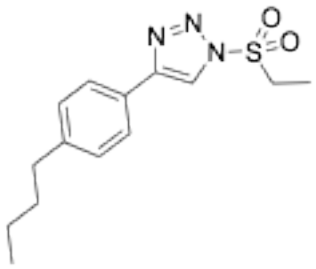
To an oven dried 100 mL round bottom flask equipped with stir vane, 4-*tert*-butylphenylacetylene (824 mg, 5.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (95 mg, 0.50 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Ethanesulfonyl azide (745 mg, 5.5 mmol, 1.1 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 12 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 3:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (996 g, 68% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.27 (s, 1H), 7.81 (d, J = 8.2 Hz, 2H), 7.50 (d, J = 8.2 Hz, 2H), 3.71 (q, J = 7.4 Hz, 2H), 1.39 (t, J = 7.4 Hz, 3H), 1.36 (s, 9H).

^{13}C NMR (100 MHz, CDCl3): δ 152.8, 147.5, 126.2, 126.1, 126.0, 119.2, 50.3, 35.0, 31.4, 8.0.

FTIR (neat): ν_{max}/cm^{-1} 3147, 2962, 2869, 1495, 1456, 1376.

HRMS (p-APCI): m/z 294.1270 [(M+H)+ requires 294.1271].



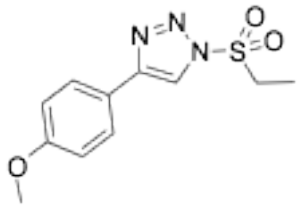
4-(4-(*n*-butyl)phenyl)-1-(ethylsulfonyl)-1H-1,2,3-triazole (42e) 02-121

To an oven dried 100 mL round bottom flask equipped with stir vane, 4-*n*-butylphenylacetylene (833 mg, 5.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (95 mg, 0.50 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Ethanesulfonyl azide (745 mg, 5.5 mmol, 1.1 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 12 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 3:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (1.3386 g, 91% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.24 (s, 1H), 7.78 (d, J = 8 Hz, 2H), 7.25 (d, J = 8 Hz, 2H), 3.75 (q, J = 7.4 Hz, 2H), 2.65 (t, J = 7.4 Hz, 2H), 1.62 (m, 3H), 1.38 (m, 5H), 0.94 (t, *J* = 7.4Hz, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 147.8, 144.2, 129.6, 126.1, 126.0, 119.9, 50.4, 36.0, 34.0, 22.8, 14.4, 8.6.

FTIR (neat): ν_{max}/cm^{-1} 3143, 2955, 2929, 2857, 1497, 1375.



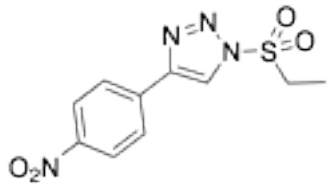
4-(4-(*n*-butyl)phenyl)-1-(ethylsulfonyl)-1H-1,2,3-triazole (42f)

To an oven dried 100 mL round bottom flask equipped with stir vane, 4-methoxyphenylacetylene (1.377 g, 10.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 45 mL). The flask was charged with CuTC (190 mg, 1.0 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Ethanesulfonyl azide (1.35 g, 10 mmol, 1.0 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 12 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 3:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (1.977 g, 86% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.26 (s, 1H), 7.48 (s, 1H), 7.40 (m, 2H), 6.69 (d, J = 8.2Hz, 1H), 3.96 (s, 3H), 3.70 (q, *J* = 7.4 Hz, 2H), 1.40 (t, *J* = 7.4 Hz, 3H).

FTIR (neat): ν_{max}/cm^{-1} 3143, 2943, 2837, 1608, 1586, 1436.

*Partially characterized compound

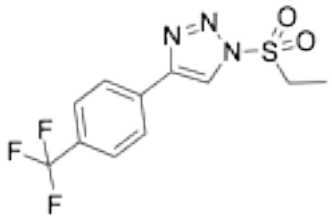


1-(ethylsulfonyl)-4-(4-nitrophenyl)-1*H*-1,2,3-triazole (42g)

To an oven dried 100 mL round bottom flask equipped with stir vane, 4-nitrophenylacetylene (806 mg, 5.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (95 mg, 0.50 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Ethanesulfonyl azide (745 mg, 5.5 mmol, 1.1 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 12 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 3:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (156.8 mg, 11% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.42 (s, 1H), 8.38 (d, *J* = 8Hz, 2H), 8.08 (d, *J* = 8Hz, 2H), 3.78 (q, *J* = 7.4Hz, 2H), 1.40 (t, *J* = 7.4Hz, 3H).

*Partially characterized compound



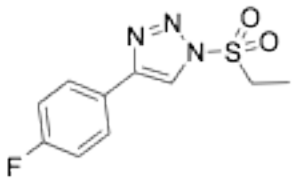
1-(ethylsulfonyl)-4-(4-(trifluoromethyl)phenyl)-1H-1,2,3-triazole (42h)

To an oven dried 100 mL round bottom flask equipped with stir vane, 4-nitrophenylacetylene (563 mg, 3.3 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (95 mg, 0.50 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Ethanesulfonyl azide (446 mg, 3.3 mmol, 1.0 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 24 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 3:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (551.6 mg, 55% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.38 (s, 1H), 8.02 (d, *J* = 8Hz, 2H), 7.78 (d, *J* = 8Hz, 2H), 7.24 (s, 1H), 3.74 (q, *J* = 7.4 Hz, 2H), 1.40 (t, *J* = 7.4 Hz, 3H).

FTIR (neat): ν_{max}/cm^{-1} 3152, 2982, 1624, 1378, 1330, 1313.

*Partially characterized compound



1-(ethylsulfonyl)-4-(4-fluorophenyl)-1H-1,2,3-triazole (42i)

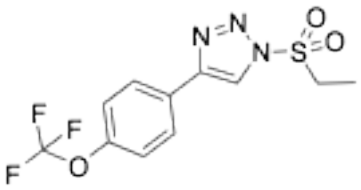
To an oven dried 100 mL round bottom flask equipped with stir vane, 1-ethynyl-4-fluorobenzene (563 mg, 3.3 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (95 mg, 0.50 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Ethanesulfonyl azide (446 mg, 3.3 mmol, 1.0 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 24 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 3:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (551.6 mg, 55% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.27 (s, 1H), 7.91–7.81 (m, 2H), 7.23–7.12 (m, 2H), 3.72 (q, *J* = 7.4 Hz, 2H), 1.41 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 128.3, 128.2, 119.7, 116.5, 116.3, 50.3, 8.0.

FTIR (neat): ν_{max}/cm^{-1} 3134, 2981, 2948, 1608, 1560, 1495.

HRMS (p-APCI): *m/z* 256.0551 [(M+H)+ requires 256.0551].



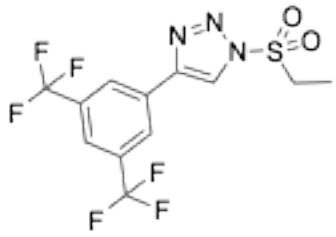
1-(ethylsulfonyl)-4-(4-trifluoromethoxyphenyl)-1H-1,2,3-triazole (42j)

To an oven dried 100 mL round bottom flask equipped with stir vane, 4-ethynyl-α,α,α-trifluoromethoxytoluene (956 mg, 5.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (95 mg, 0.50 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Ethanesulfonyl azide (745 mg, 5.5 mmol, 1.1 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 12 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 3:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (1.03 g, 64% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.34 (s, 1H), 7.90 (d, *J* = 8 Hz, 2H), 7.36 (d, *J* = 8 Hz, 2H), 3.78 (q, *J* = 7.4 Hz, 2H), 1.40 (t, *J* = 7.4 Hz, 3H).

FTIR (neat): ν_{max}/cm^{-1} 3139, 2990, 1561, 1495, 1376, 1210.

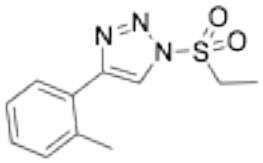
*Partially characterized compound



4-(3,5-bis(trifluoromethyl)phenyl)-1-(ethylsulfonyl)-1*H*-1,2,3-triazole (42k)

To an oven dried 100 mL round bottom flask equipped with stir vane, 4-ethynyl-α,α,α-3,5-bistrifluoromethoxytoluene (995 mg, 4.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (76 mg, 0.40 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Ethanesulfonyl azide (541 mg, 4.0 mmol, 1.0 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 12 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 3:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (983 mg, 66% yield).

FTIR (neat): ν_{max}/cm^{-1} 3150, 1379, 1356, 1311, 1171.

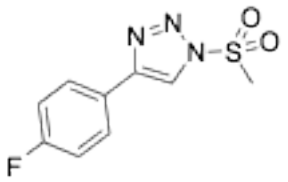


1-(ethylsulfonyl)-4-(*o*-tolyl)-1*H*-1,2,3-triazole (42l)

To an oven dried 100 mL round bottom flask equipped with stir vane, 2-methylphenylacetylene (581 mg, 5.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (95 mg, 0.50 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Ethanesulfonyl azide (745 mg, 5.5 mmol, 1.1 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 12 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 3:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (936 mg, 74% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.18 (s, 1H), 7.80 (d, *J* = 12Hz, 2H), 7.30 (m, *J* = 12Hz, 2H), 3.70 (q, *J* = 7.4 Hz, 2H), 2.43 (s, 3H), 1.40 (t, *J* = 7.4 Hz, 3H).

FTIR (neat): ν_{max}/cm^{-1} 3150, 1379, 1356, 1311, 1171.



4-(4-fluorophenyl)-1-(methylsulfonyl)-1H-1,2,3-triazole (42m)

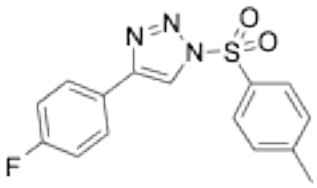
To an oven dried 100 mL round bottom flask equipped with stir vane, 1-ethynyl-4-fluorobenzene (605 mg, 5.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (95 mg, 0.50 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Methanesulfonyl azide (667 mg, 5.5 mmol, 1.1 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 12 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 2:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (1.04 g, 86% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.28 (s, 1H), 7.88–7.83 (m, 2H), 7.20–7.14 (m, 2H), 3.58 (s, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 128.3, 128.2, 118.8, 116.6, 116.3, 42.9.

FTIR (neat): ν_{max}/cm^{-1} 3147, 3034, 3020, 2936, 1904, 1610, 1563, 1496.

HRMS (p-APCI): *m/z* 242.0394 [(M+H)+ requires 242.0394].



4-(4-fluorophenyl)-1-tosyl-1H-1,2,3-triazole (42n)

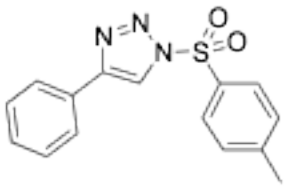
To an oven dried 100 mL round bottom flask equipped with stir vane, 1-ethynyl-4-fluorobenzene (605 mg, 5.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (95 mg, 0.50 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Toluenesulfonyl azide (1.08 g, 5.5 mmol, 1.1 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 8 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 4:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (1.39 g, 88% yield).

^{1}H NMR (400 MHz, CDCl3): δ 8.30 (s, 1H), 8.02 (d, *J* = 8.2 Hz, 2H), 7.83–7.78 (m, 2H), 7.39 (d, *J* = 8.2 Hz, 2H), 7.17–7.04 (m, 2H), 2.44 (s, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 163.3 (d, *J* = 248 Hz), 147.7, 146.6, 133.1, 130.7, 128.9, 128.1 (d, *J* = 8 Hz), 125.3 (d, *J* = 3 Hz), 118.9, 116.2 (d, *J* = 22 Hz), 22.0.

FTIR (neat): ν_{max}/cm^{-1} 3152, 1902, 1611, 1593, 1563, 1495, 1394.

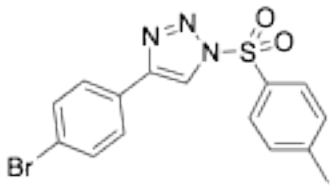
HRMS (p-APCI): *m/z* 318.0706 [(M+H)+ requires 318.0707].



4-phenyl-1-tosyl-1H-1,2,3-triazole (42o)

To an oven dried 250 mL round bottom flask equipped with stir vane, phenylacetylene (2.04 g, 20.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 90 mL). The flask was charged with CuTC (380 mg, 2.0 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Toluenesulfonyl azide (3.944 g, 20.0 mmol, 1.0 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 8 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 4:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (5.33 g, 89% yield).

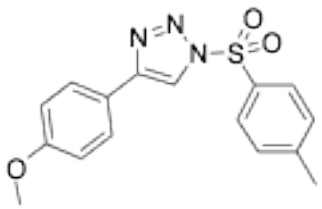
*Known compound.



4-(4-bromophenyl)-1-tosyl-1H-1,2,3-triazole (42p)

To an oven dried 100 mL round bottom flask equipped with stir vane, 1-ethynyl-4-bromobenzene (542 mg, 3.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (57 mg, 0.30 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Toluenesulfonyl azide (592 mg, 3.0 mmol, 1.0 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 8 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 4:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (851 mg, 75% yield).

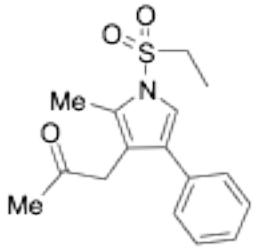
*Known compound



4-(4-methoxyphenyl)-1-tosyl-1H-1,2,3-triazole (42q)

To an oven dried 100 mL round bottom flask equipped with stir vane, 1-ethynyl-4-methoxybenzene (661 mg, 5.0 mmol, 1.0 equiv) was added and diluted in toluene (anhydrous, 20 mL). The flask was charged with CuTC (95 mg, 0.50 mmol, 0.10 equiv) and allowed to stir at room temperature for 1-3 minutes. Toluenesulfonyl azide (1.08 g, 5.5 mmol, 1.1 equiv) was diluted in toluene (anhydrous, 5.0 mL) and added dropwise via syringe pump to the suspension over 5 minutes. The reaction was stirred for 8 h at ambient temperature. After concentration of the filtrate, the residue was purified by flash chromatography (hexanes/EtOAc, 4:1) and recrystallized (hexane/EtOAc, 10:1) to afford the title compound as a white solid (1.03 g, 79% yield).

*Known compound



1-(1-(ethylsulfonyl)-2-methyl-4-phenyl-1H-pyrrol-3-yl)propan-2-one (47a)

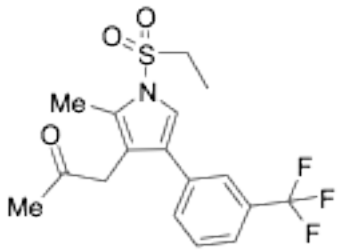
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42a** (120 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005 mol, 0.01 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 4 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a pale yellow oil (117 mg, 76%).

^{1}H NMR (400 MHz, CDCl3): δ 7.39–7.35 (m, 4H), 7.31–7.27 (m, 1H), 7.15 (s, 1H), 4.00 (s, 2H), 3.28 (q, *J* = 7.4 Hz, 2H), 2.26 (s, 3H), 2.02 (s, 3H), 1.30 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 206.1, 134.2, 128.7, 128.4, 127.2, 124.7, 122.6, 119.7, 49.8, 40.4, 29.8, 10.7, 8.2.

FTIR (neat): ν_{max}/cm^{-1} 2926, 1717, 1621, 1534, 1449, 1355.

HRMS (p-APCI): *m/z* 306.1162 [(M+H)+ requires 306.1158].



1-(1-(ethylsulfonyl)-2-methyl-4-(3-(trifluoromethyl)phenyl)-1H-pyrrol-3-yl)propan-2-one (47b)

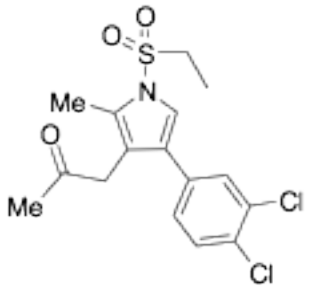
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42b** (153 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005 mol, 0.01 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 3 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 3:1) to afford the title compound as a colorless oil (142 mg, 76%).

^{1}H NMR (400 MHz, CDCl3): δ 7.62 (s, 1H), 7.57–7.47 (m, 3H), 7.21 (d, *J* = 1.1 Hz, 1H), 4.02 (s, 2H), 3.38–3.25 (m, 3H), 2.28 (d, *J* = 1.5 Hz, 3H), 2.02 (s, 4H), 1.33 (td, *J* = 7.4, 1.5 Hz, 4H),

^{13}C NMR (100 MHz, CDCl3): δ 205.6, 134.8, 131.4, 130.8 (q, *J* = 32 Hz), 128.9, 127.0, 125.0, 124.8 (m), 124.0 (q, *J* = 271 Hz), 123.5 (m), 121.9, 119.9, 49.7, 40.1, 29.5, 10.2, 7.9.

FTIR (neat): ν_{max}/cm^{-1} 2927, 1720, 1616, 1534, 1456.

HRMS (p-APCI): *m/z* 374.1032 [(M+H)+ requires 374.1032].



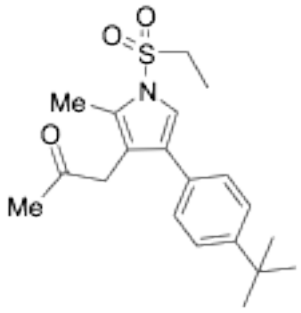
1-(1-(ethylsulfonyl)-2-methyl-4-(3,4-(dichloro)phenyl)-1H-pyrrol-3-yl)propan-2-one (47c)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42c** (153 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (7.8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 6 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a colorless oil (117 mg, 62%).

^{1}H NMR (400 MHz, CDCl3): δ 7.43 (d, J = 1.1 Hz, 2H), 7.18-7.23 (m, 1H), 4.02 (s, 2H), 3.38–3.25 (m, 3H), 3.34 (q, 3H), 2.28 (s, 3H), 2.04 (s, 3H), 2.54 (t, J = 7.4Hz, 3H)

FTIR (neat): ν_{max}/cm^{-1} 2927, 1720, 1600, 405, 1355.

*Partially characterized



1-(4-(4-(tert-butyl)phenyl)-1-(ethylsulfonyl)-2-methyl-1H-pyrrol-3-yl)propan-2-one (47d)

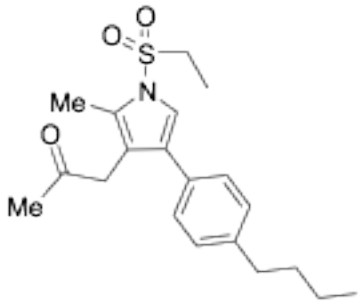
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42d** (147 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (7.8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 8 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a colorless, amorphous solid (133 mg, 74%).

^{1}H NMR (400 MHz, CDCl3): δ 7.41 (d, *J* = 8.3 Hz, 2H), 7.32 (d, J = 8.1 Hz, 2H), 7.15 (s, 1H), 4.01 (s, 2H), 3.28 (q, *J* = 7.4 Hz, 2H), 2.27 (s, 3H), 2.04 (s, 3H), 1.34 (s, 9H), 1.33–1.28 (m, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 205.8, 149.8, 131.0, 128.2, 127.8, 125.4, 124.4, 122.5, 119.3, 49.5, 40.2, 34.4, 31.3, 29.5, 10.4, 7.9.

FTIR (neat): ν_{max}/cm^{-1} 2961, 1721, 1541, 1457, 1354.

HRMS (p-NSI): *m/z* 362.1785 [(M+H)+ requires 362.1784].



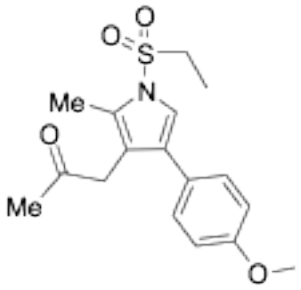
1-(4-(4-(*n*-butyl)phenyl)-1-(ethylsulfonyl)-2-methyl-1H-pyrrol-3-yl)propan-2-one (47e)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42e** (146 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (7.8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a colorless, amorphous solid (181 mg, 50%).

^{1}H NMR (400 MHz, CDCl3): δ 7.38-7.42 (m, 2H), 7.06-1.14 (m, 2H), 4.02 (s, 2H), 4.01 (s, 2H), 3.30 (q, *J* = 7.4 Hz, 2H), 2.25 (s, 3H), 2.04 (s, 3H), 1.34 (s, 9H), 1.38 (t, *J* = 7.4Hz, 3H).

FTIR (neat): ν_{max}/cm^{-1} 2943, 1721, 1600, 1538, 1496, 1354.

*Partially characterized compound

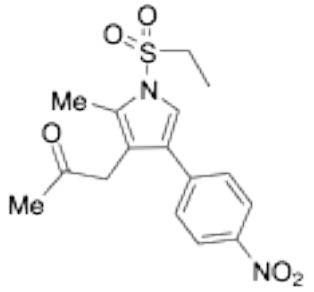


1-(4-(4-methoxyphenyl)-2-methyl-1-tosyl-1*H*-pyrrol-3-yl)propan-2-one (47f)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42f** (134 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (7.8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 24 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a colorless, amorphous solid (95.4 mg, 57%).

^{1}H NMR (400 MHz, CDCl3): δ 8.26 (s, 1H), 7.20-7.30 (m, 2H), 6.80-6.94 (m, 2H), 4.02 (s, 2H), 3.80 (s, 3H), 3.28 (q, *J* = 7.4 Hz, 2H), 2.27 (s, 3H), 2.04 (s, 3H), 1.33–1.28 (m, 3H).

*Partially characterized compound



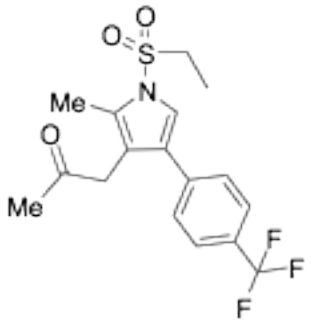
1-(4-(4-nitrophenyl)-1-(ethylsulfonyl)-2-methyl-1H-pyrrol-3-yl)propan-2-one (47g)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42g** (141 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (7.8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 24 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a colorless, amorphous solid (73 mg, 42%).

^{1}H NMR (400 MHz, CDCl3): δ 8.22 (d, *J* = 8.3 Hz, 2H), 7.56 (d, J = 8.1 Hz, 2H), 7.24 (s, 1H), 4.04 (s, 2H), 3.28 (q, *J* = 7.4 Hz, 2H), 2.27 (s, 3H), 2.04 (s, 3H), 1.38 (t, *J* = 7.4, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 205.8, 146.8, 141.6, 129.0, 126.4, 126.0, 124.1, 122.0, 121.2, 50.0, 40.2, 30.1, 11.6, 8.0.

FTIR (neat): ν_{max}/cm^{-1} 3135, 2928, 1717, 1597, 1512, 1336.



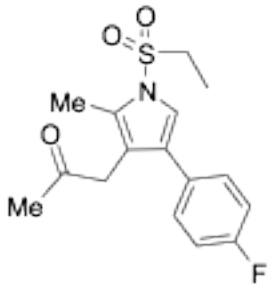
1-(4-(4-(trifluoro)phenyl)-1-(ethylsulfonyl)-2-methyl-1H-pyrrol-3-yl)propan-2-one (47h)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42h** (153 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (7.8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 3:1) to afford the title compound as a colorless, amorphous solid (88 mg, 47%).

^{1}H NMR (400 MHz, CDCl3): δ 7.64 (d, *J* = 8.3 Hz, 2H), 7.46 (d, J = 8.1 Hz, 2H), 7.20 (s, 1H), 4.06 (s, 2H), 3.38 (q, *J* = 7.4 Hz, 2H), 2.30 (s, 3H), 2.04 (s, 3H), 1.38 (t, *J* = 7.4, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 205.8, 138.0, 128.2, 127.2, 126.0, 123.2, 122.2, 49.8, 40.0, 29.8, 11.3, 7.9.

FTIR (neat): ν_{max}/cm^{-1} 2930, 1720, 1618, 1356, 1323, 11163.



1-(1-(ethylsulfonyl)-4-(4-fluorophenyl)-2-methyl-1H-pyrrol-3-yl)propan-2-one (47i)

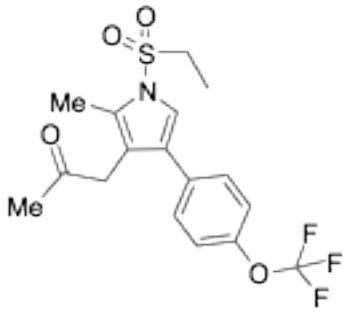
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42i** (128 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (7.8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a colorless, amorphous solid (98 mg, 60%).

^{1}H NMR (400 MHz, CDCl3): δ 7.34–7.27 (m, 2H), 7.10 (s, 1H), 7.09–7.01 (m, 2H), 3.99 (s, 2H), 3.28 (q, *J* = 7.4 Hz, 2H), 2.26 (s, 3H), 1.98 (s, 3H), 1.30 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 206.0, 162.2 (d, *J* = 244 Hz), 130.2, 130.0 (d, *J* = 8 Hz), 127.6, 124.8, 122.4, 119.6, 115.6 (d, *J* = 22 Hz), 49.8, 40.4, 29.8, 10.5, 8.2.

FTIR (neat): ν_{max}/cm^{-1} 2926, 1721, 1600, 1538, 1496, 1354.

HRMS (p-NSI): *m/z* 324.1064 [(M+H)+ requires 324.1064.

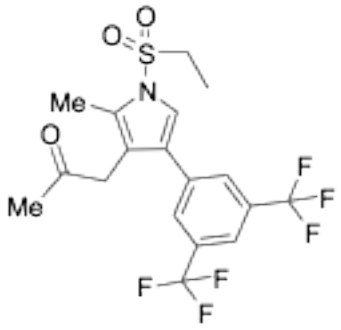


1-(1-(ethylsulfonyl)-4-(4-(trifluoromethoxy)phenyl)-2-methyl-1H-pyrrol-3-yl)propan-2-one (47j)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42j** (161 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (7.8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a pale yellow oil (195 mg, 54 %).

^{1}H NMR (400 MHz, CDCl3): δ 7.80 (s, 4H), 7.28 (s, 1H), 4.04 (s, 2H), 3.38 (q, *J* = 7.4 Hz, 2H), 2.32 (s, 3H), 2.04 (s, 3H), 1.38(t, *J* = 7.4 Hz, 3H).

*Partially characterized



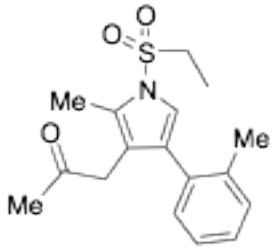
1-(1-(ethylsulfonyl)-4-(3,4-(bistrifluoro)phenyl)-2-methyl-1H-pyrrol-3-yl)propan-2-one (47k)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42k** (187 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (7.8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a colorless, amorphous solid (150 mg, 68%).

^{1}H NMR (400 MHz, CDCl3): δ 7.40 (d, J = 8 Hz, 2H), 7.22 (m, 1H), 7.08 (s, 1H), 4.04 (s, 2H), 3.30 (q, J = 7.4 Hz, 2H), 2.28 (s, 3H), 2.02 (s, 3H), 1.38 (t, J = 7.4 Hz, 3H).

FTIR (neat): ν_{max}/cm^{-1} 2946, 1721, 1539, 1356, 1254.

*Partially characterized compound



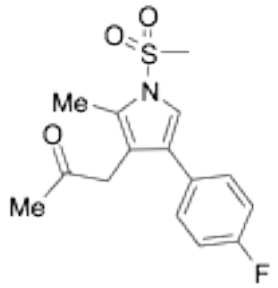
1-(1-(ethylsulfonyl)-4-(2-methylphenyl)-2-methyl-1H-pyrrol-3-yl)propan-2-one (47l)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42l** (128 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (7.8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 8 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a pale yellow oil (64 mg, 40%).

^{1}H NMR (400 MHz, CDCl3): δ 7.08-7.28 (m, 4H), 6.99 (s, 1H), 4.01 (s, 2H), 3.32 (q, J = 7.4 Hz, 2H), 2.28 (s, 3H), 2.20 (s, 3H), 1.80 (s, 3H), 1.36 (t, J = 7.4 Hz, 3H).

FTIR (neat): ν_{max}/cm^{-1} 2946, 1721, 1539, 1356, 1254.

*Partially characterized compound



1-(4-(4-fluorophenyl)-2-methyl-1-(methylsulfonyl)-1H-pyrrol-3-yl)propan-2-one (47m)

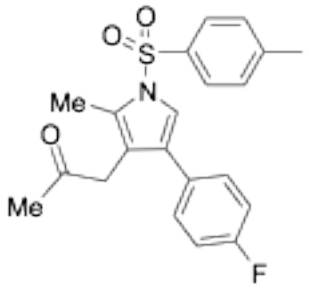
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42m** (128 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005 mol, 0.01 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 2 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a pale yellow oil (123 mg, 80%).

^{1}H NMR (400 MHz, CDCl3): δ 7.35–7.30 (m, 2H), 7.14 (s, 1H), 7.10–7.04 (m, 2H), 4.02 (s, 2H), 3.16 (s, 3H), 2.29 (s, 3H), 2.00 (s, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 206.0, 162.1 (d, *J* = 245 Hz), 130.0 (d, *J* = 3 Hz), 129.9 (d, *J* = 8 Hz), 128.4, 125.0, 122.2, 118.6, 115.5 (d, *J* = 21 Hz), 42.1, 40.3, 29.7, 10.4.

FTIR (neat): ν_{max}/cm^{-1} 2927, 1719, 1601, 1539, 1497, 1354.

HRMS (p-APCI): *m/z* 310.0907 [(M+H)+ requires 310.0908].



1-(4-(4-fluorophenyl)-2-methyl-1-tosyl-1H-pyrrol-3-yl)propan-2-one (47n)

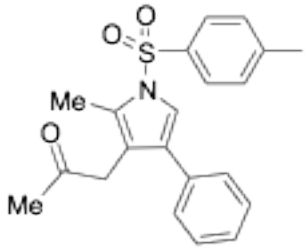
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42n** (120 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005 mol, 0.01 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 6 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as an amorphous pale yellow solid (187 mg, 97%).

^{1}H NMR (400 MHz, CDCl3): δ 7.67 (d, *J* = 8.4 Hz, 2H), 7.38–7.26 (m, 5H), 7.17–7.00 (m, 2H), 3.86 (s, 2H), 2.40 (s, 3H), 2.18 (s, 3H), 1.95 (s, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 204.5, 162.1 (d, *J* = 245 Hz), 145.3, 136.2, 130.2, 130.2, 129.9 (d, *J* = 8 Hz), 128.1, 127.0, 124.7, 122.8, 119.2, 115.5 (d, *J* = 21 Hz), 40.3, 29.4, 21.8, 10.5.

FTIR (neat): ν_{max}/cm^{-1} 2924, 1726, 1597, 1537, 1495, 1357.

HRMS (p-APCI): *m/z* 386.1221 [(M+H)+ requires 386.1221].



1-(2-methyl-4-phenyl-1-tosyl-1H-pyrrol-3-yl)propan-2-one (47o)

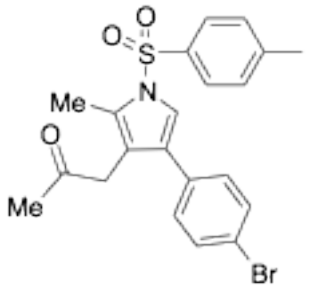
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42o** (150 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005 mol, 0.01 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 2 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a colorless oil (156 mg, 85%).

^{1}H NMR (400 MHz, CDCl3): δ 7.71–7.63 (m, 2H), 7.41–7.36 (m, 4H), 7.34 (s, 1H), 7.32–7.28 (m, 3H), 3.85 (s, 2H), 2.40 (s, 3H), 2.17 (s, 3H), 1.99 (s, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 204.8, 145.2, 136.3, 134.2, 130.2, 129.1, 128.7, 128.4, 127.2, 127.0, 124.7, 123.0, 119.5, 40.4, 29.4, 21.9, 10.7.

FTIR (neat): ν_{max}/cm^{-1} 2924, 1720, 1596, 1534, 1448, 1358.

HRMS (p-APCI): *m/z* 368.1316 [(M+H)+ requires 368.1315].



1-(4-(4-bromophenyl)-2-methyl-1-tosyl-1H-pyrrol-3-yl)propan-2-one (47p)

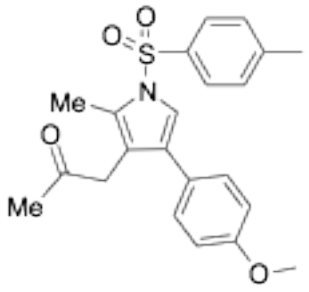
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42p** (190 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005 mol, 0.01 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 2 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as an amorphous, pale yellow solid (158 mg, 71%).

^{1}H NMR (400 MHz, CDCl3): δ 7.67 (d, *J* = 8.0 Hz, 2H), 7.51–7.47 (m, 2H), 7.33 (s, 1H), 7.30 (d, *J* = 8.0 Hz, 2H), 7.25–7.21 (m, 2H), 3.85 (s, 2H), 2.40 (s, 3H), 2.18 (s, 3H), 1.95 (s, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 204.6, 145.4, 136.1, 133.1, 131.8, 130.3, 129.9, 127.9, 127.0, 124.9, 122.6, 121.1, 119.4, 40.3, 29.4, 21.8, 10.6.

FTIR (neat): ν_{max}/cm^{-1} 2955, 2924, 1720, 1596, 1532.

HRMS (p-APCI): *m/z* 446.0424 [(M+H)+ requires 446.0420].



1-(4-(4-methoxyphenyl)-2-methyl-1-tosyl-1H-pyrrol-3-yl)propan-2-one (47q)

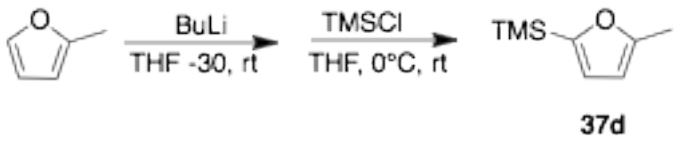
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42q** (165 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005 mol, 0.01 equiv) before being backfilled with argon three times. **33** was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 10 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as an amorphous, colorless solid (181 mg, 91%).

^{1}H NMR (400 MHz, CDCl3): δ 7.67 (d, *J* = 12 Hz, 7.30–7.26 (m, 5H), 6.93 (d, *J* = 12 Hz, 2H), 3.84 (s, 2H), 3.83 (s, 3H), 2.40 (s, 3H), 2.17 (s, 3H), 1.96 (s, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 204.9, 158.9, 145.2, 136.4, 130.2, 129.5, 128.8, 127.0, 126.6, 124.6, 123.1, 119.0, 114.1, 55.5, 40.5, 29.4, 21.9, 10.7.

FTIR (neat): ν_{max}/cm^{-1} 2925, 1720, 1614, 1596, 1539, 1497.

HRMS (p-APCI): *m/z* 398.1418 [(M+H)+ requires 398.1421].



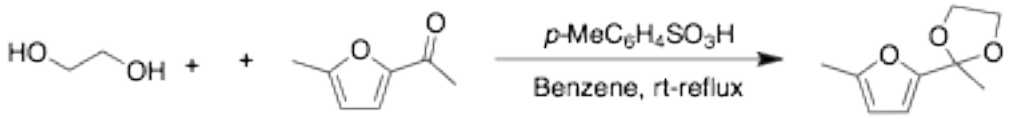
37d

trimethyl(5-methylfuran-2-yl)silane (37d)

An oven dried 250 mL round bottom flask equipped with stir vane was charged with 2-methylfuran (9.05 mL, 100 mmol, 1.0 equiv) and diluted in THF (75 mL). The flask was cooled to -30°C before the BuLi (7.6872 g, 120 mmol, 1.2 equiv) was added dropwise via syringe pump to the reaction solution. The mixture stirred for 5 minutes before being brought to ambient temperature and stirred for an additional 40 minutes. The reaction was cooled to 0°C and the TMSCl (15.2 mL, 120 mmol, 1.2 equiv) was added dropwise via syringe pump. The reaction was brought to ambient temperature and stirred for 1.5 h. The reaction was quenched with water (50 mL) and washed with brine (3 x 50 mL), dried over $MgSO_4$, and concentrated *in vacuo*. The concentrated product was distilled for purification to yield the titled product (9.6892 g, 63%).

^{1}H NMR (400 MHz, CDCl3): δ 6.54 (d, *J* = 4 Hz, 1H), 5.98 (d, J = 1Hz, 1H), 2.35 (s, 3H), 3.84 (s, 2H), 0.7 (s, 9H).

*partially characterized compound



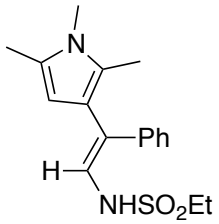
37j

2-methyl-2-(5-methylfuran-2-yl)-1,3-dioxolane (37j)

A 500 mL oven dried round bottom flask equipped with stir vane, reflux condenser, and Dean-Stark trap were assembled. The flask was charged with 2-acetyl-5-methyl furan, and ethylene glycol, and diluted with anhydrous benzene (25 mL). The flask was then charged with p-toluenesulfonic acid and brought to reflux. The reaction refluxed for 3 h. Reaction was brought to ambient temperature and diluted with benzene (50 mL). The reaction was then washed with aqueous NaOH (0.5 M, 100 mL) and brine (50 mL), dried over $MgSO_4$ and concentrated *in vacuo* to yield the titled compound as a colorless oil (6.481 g, 39%).

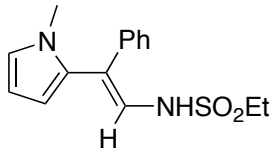
^{1}H NMR (400 MHz, CDCl3): δ 6.20 (d, *J* = 1 Hz, 1H), 5.90 (d, J = 1Hz, 1H), 4.05 (t, 4H), 2.25 (s, 3H), 1.76 (s, 3H).

*partially characterized compound



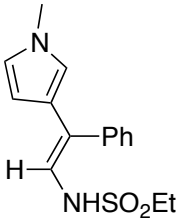
(*Z*)-*N*-(2-phenyl-2-(1,2,5-trimethyl-1*H*-pyrrol-3-yl)vinyl)ethanesulfonamide (38a)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42a** (237 mg, 1.0 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (4 mg, 0.005 mol, 0.005 equiv) before being backfilled with argon three times. **37a** (0.27 mL, 2.0 mmol, 2.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. Crude ^{1}H NMR analysis identified titled compound as the main product and was not purified.



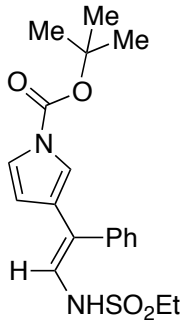
(*Z*)-*N*-(2-(1-methyl-1*H*-pyrrol-2-yl)-2-phenylvinyl)ethanesulfonamide (39b)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42a** (118 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **37b** (0.18 mL, 1.0 mmol, 2.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*.



(*Z*)-*N*-(2-(1-methyl-1*H*-pyrrol-3-yl)-2-phenylvinyl)ethanesulfonamide (38b)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42a** (118 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **37b** (0.18 mL, 1.0 mmol, 2.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. Crude ^{1}H NMR analysis determined that the major products were the title compounds and ratio analysis was used to approximate yields for each (42% and 17% respectively).

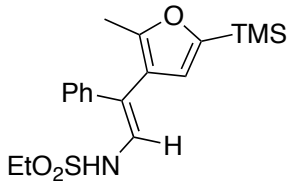


(*Z*)-*tert*-butyl 3-(2-(ethylsulfonamido)-1-phenylvinyl)-1*H*-pyrrole-1-carboxylate (38c)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42b** (153 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **37c** (176 mg, 1.0 mmol, 2.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a pale yellow oil (165 mg, 88%).

^{1}H NMR (400 MHz, CDCl3): δ 7.40-7.45 (m, 5H), 6.93 (d, *J* = 8 Hz, 1H), 6.78 (d, *J* = 8 Hz, 1H) 6.40 (s, 1H), 6.20 (s, 2H), 3.22 (q, *J* = 7.4 Hz, 2H), 1.60 (s, 9H), 1.40-1.45 (m, 3H).

*Partially characterized compound

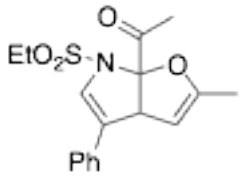


(*Z*)-*N*-(2-(5-methyl-2-(trimethylsilyl)furan-3-yl)-2-phenylvinyl)ethanesulfonamide (38d)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42b** (153 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(OOct)_4$ (8 mg, 0.010 mol, 0.02 equiv) before being backfilled with argon three times. **37d** (154 mg, 1.0 mmol, 2.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 4:1) to afford the title compound as a pale yellow oil (113 mg, 53%).

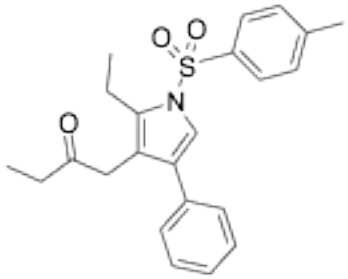
^{1}H NMR (400 MHz, CDCl3): δ 7.28 (q, *J* = 7.4 Hz, 2H), 7.21 (d, *J* = 8Hz, 2H), 6.80 (d, *J* = 8 Hz, 1H), 6.40 (s, 1H), 6.25 (d, *J* = 8Hz, 1H), 3.16 (q, *J* = 7.4Hz, 2H), 2.18 (s, 3H), 1.40 (t, *J* = 8Hz, 3H).

*Partially characterized compound



1-(6-(ethylsulfonyl)-2-methyl-4-phenyl-6,6a-dihydro-3a*H*-furo[2,3-*b*]pyrrol-6a-yl)ethanone (40e)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42a** (118 mg, 0.50 mmol, 1.0 equiv), and $Rh_2(PTTL)_4$ (6 mg, 0.005 mol, 0.01 equiv) before being backfilled with argon three times. **37e** (0.12 mL, 1.0 mmol, 2.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. Titled compound identified by crude ^{1}H NMR but was not stable upon purification.



1-(2-ethyl-4-phenyl-1-tosyl-1H-pyrrol-3-yl)butan-2-one (43a)

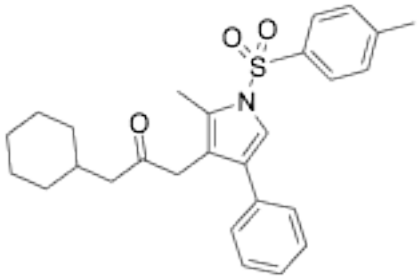
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42o** (150 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005mol, 0.01 equiv) before being backfilled with argon three times. **41a** (186 mg, 1.5 mmol, 3.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 4 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 5:1) to afford the title compound as a pale yellow oil (196 mg, 99%).

^{1}H NMR (400 MHz, CDCl3): δ 7.63 (d, *J* = 8.4 Hz, 2H), 7.39–7.33 (m, 4H), 7.33–7.25 (m, 3H), 7.24 (s, 1H), 3.81 (s, 2H), 2.49 (q, *J* = 7.3 Hz, 2H), 2.44–2.33 (m, 5H), 1.03 (q, *J* = 7.3 Hz, 3H), 0.90 (q, *J* = 7.5 Hz, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 207.4, 145.1, 136.4, 134.5, 130.2, 129.3, 128.7, 128.7, 128.4, 127.2, 127.0, 124.4, 119.9, 39.3, 35.2, 21.8, 18.0, 15.2, 7.8.

FTIR (neat): ν_{max}/cm^{-1} 3137, 3059, 2971, 2935, 2875, 1722, 1596, 1362.

HRMS (p-APCI): *m/z* 396.1631 [(M+H)+ requires 396.1628]



1-cyclohexyl-3-(2-methyl-4-phenyl-1-tosyl-1H-pyrrol-3-yl)propan-2-one (43b)

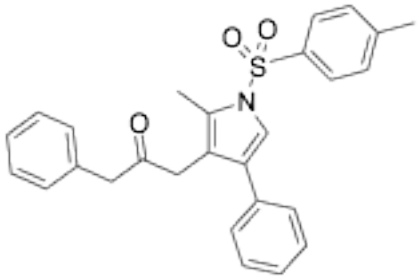
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42o** (150 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005mol, 0.01 equiv) before being backfilled with argon three times. **41b** (267 mg, 1.5 mmol, 3.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 4 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 8:1) to afford the title compound as a pale yellow oil (101 mg, 45%).

^{1}H NMR (400 MHz, CDCl3): δ 7.66 (d, *J* = 8.2 Hz, 2H), 7.41–7.35 (m, 4H), 7.35–7.25 (m, 4H), 3.82 (s, 2H), 2.40 (s, 3H), 2.30 (d, *J* = 6.7 Hz, 2H), 1.97 (s, 3H), 1.83–1.80 (m, 1H), 1.68–1.65 (m, 5H), 1.35–1.20 (m, 2H), 1.20–1.06 (m, 1H), 0.98–0.81 (m, 2H).

^{13}C NMR (100 MHz, CDCl3): δ 206.1, 145.1, 136.5, 134.3, 130.2, 129.1, 128.7, 128.4, 127.1, 127.0, 124.7, 123.0, 119.5, 49.5, 40.4, 33.6, 33.4, 26.4, 26.3, 21.9, 10.8.

FTIR (neat): ν_{max}/cm^{-1} 2921, 2850, 1718, 1597, 1534, 1448.

HRMS (p-APCI): *m/z* 450.2096 [(M+H)+ requires 450.2097].



1-(2-methyl-4-phenyl-1-tosyl-1H-pyrrol-3-yl)-3-phenylpropan-2-one (43c)

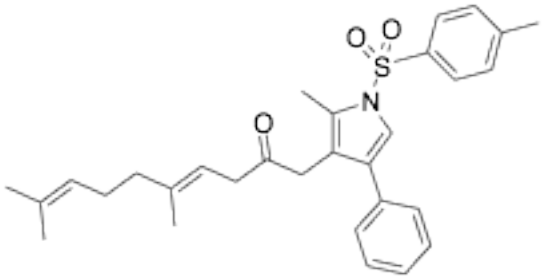
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42o** (150 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005mol, 0.01 equiv) before being backfilled with argon three times. **41c** (258 mg, 1.5 mmol, 3.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 6:1) to afford the title compound as a pale yellow, amorphous solid (120 mg, 54%).

^{1}H NMR (400 MHz, CDCl3): δ 7.62–7.60 (m, 2H), 7.40–7.24 (m, 11H), 7.21–7.19 (m, 2H), 3.85 (s, 2H), 3.77 (s, 2H), 2.39 (s, 3H), 1.81 (s, 3H), 1.56 (s, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 204.1, 145.2, 136.3, 134.2, 134.2, 130.2, 129.8, 129.2, 128.8, 128.7, 128.4, 127.2, 127.2, 127.0, 124.3, 123.4, 119.5, 49.3, 39.2, 21.9, 10.6.

FTIR (neat): ν_{max}/cm^{-1} 3029, 2923, 1724, 1597, 1495, 1362.

HRMS (p-APCI): *m/z* 444.1625 [(M+H)+ requires 444.1628].



(E)-5,9-dimethyl-1-(2-methyl-4-phenyl-1-tosyl-1H-pyrrol-3-yl)deca-4,8-dien-2-one (43d)

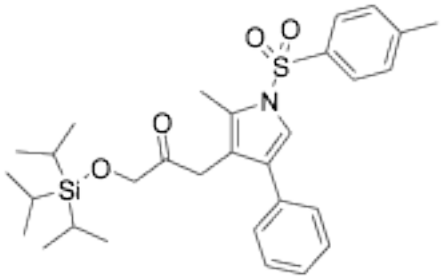
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42o** (150 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005mol, 0.01 equiv) before being backfilled with argon three times. **41d** (327 mg, 1.5 mmol, 3.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 10:1) to afford the title compound as a pale yellow, amorphous solid (107 mg, 44%).

^{1}H NMR (400 MHz, CDCl3): δ 7.65–7.63 (m, 2H), 7.38–7.24 (m, 7H), 5.34–5.26 (m, 1H), 5.12– 5.04 (m, 1H), 3.85 (s, 2H), 3.17 (d, *J* = 6.9 Hz, 2H), 2.38 (s, 3H), 2.10–2.03 (m, 4H), 1.94 (s, 3H), 1.65 (s, 3H), 1.60 (s, 3H), 1.58 (s, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 205.1, 145.1, 139.8, 136.4, 134.3, 131.9, 130.2, 129.1, 128.7, 128.4, 127.1, 127.0, 124.7, 124.2, 123.0, 119.5, 115.7, 41.9, 39.9, 39.2, 26.7, 25.9, 219, 17.9, 16.7, 10.7.

FTIR (neat): ν_{max}/cm^{-1} 3057, 3029, 2964, 2921, 2855, 1722, 1597, 1534, 1447, 1363, 1173, 1098.

HRMS (p-NSI): *m/z* 490.2412 [(M+H)+ requires 490.2410].



1-(2-methyl-4-phenyl-1-tosyl-1H-pyrrol-3-yl)-3-((triisopropylsilyl)oxy)propan-2-one (43e)

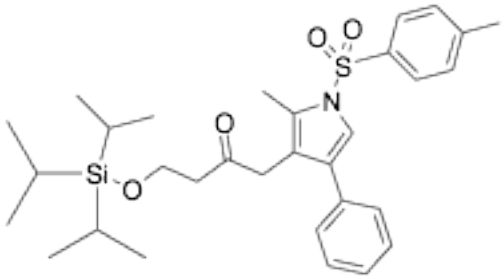
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42o** (150 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005mol, 0.01 equiv) before being backfilled with argon three times. **41e** (403 mg, 1.5 mmol, 3.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 6 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 12:1) to afford the title compound as a pale yellow, amorphous solid (225 mg, 83%).

^{1}H NMR (400 MHz, CDCl3): δ 7.70–7.64 (m, 2H), 7.38–7.35 (m, 4H), 7.34–7.23 (m, 4H), 4.38 (s, 2H), 4.10 (s, 2H), 2.40 (s, 3H), 1.97 (s, 3H), 1.28–1.03 (m, 21H).

^{13}C NMR (100 MHz, CDCl3): δ 206.9, 145.0, 136.5, 134.4, 130.1, 129.2, 128.6, 128.4, 127.0, 124.1, 123.2, 119.5, 69.8, 35.9, 21.9, 18.2, 12.1, 10.7.

FTIR (neat): ν_{max}/cm^{-1} 2943, 2865, 1733, 1597, 1535, 1462, 1365.

HRMS (p-APCI): *m/z* 540.2598 [(M+H)+ requires 540.2598].



1-(2-methyl-4-phenyl-1-tosyl-1H-pyrrol-3-yl)-4-((triisopropylsilyl)oxy)butan-2-one (43f)

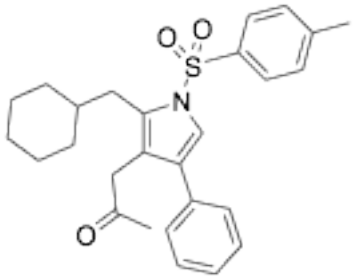
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42o** (150 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005mol, 0.01 equiv) before being backfilled with argon three times. **41e** (424 mg, 1.5 mmol, 3.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 15:1) to afford the title compound as a pale yellow, amorphous solid (135 mg, 48%).

^{1}H NMR (400 MHz, CDCl3): δ 7.65 (d, *J* = 8.4 Hz, 2H), 7.38–7.34 (m, 4H), 7.32–7.23 (m, 4H), 3.97 (t, *J* = 6.3 Hz, 2H), 3.90 (s, 2H), 2.69 (t, *J* = 6.3 Hz, 2H), 2.38 (s, 3H), 1.96 (s, 3H), 1.15–0.97 (m, 21H).

^{13}C NMR (100 MHz, CDCl3): δ 205.4, 145.1, 136.5, 134.3, 130.2, 129.1, 128.7, 128.4, 127.1, 127.0, 124.6, 123.1, 119.4, 59.3, 45.3, 40.6, 21.9, 18.2, 12.1, 10.7.

FTIR (neat): ν_{max}/cm^{-1} 3030, 2942, 2890, 2865, 1721, 1597, 1534, 1462, 1363, 1174, 1105.

HRMS (p-APCI): *m/z* 554.2761 [(M+H)+ requires 554.2755].



1-(2-(cyclohexylmethyl)-4-phenyl-1-tosyl-1H-pyrrol-3-yl)propan-2-one (44b)

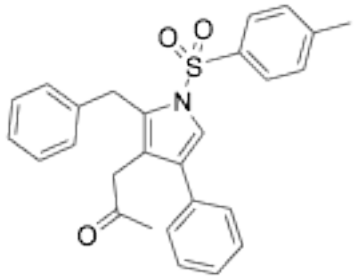
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42o** (150 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005mol, 0.01 equiv) before being backfilled with argon three times. **41b** (267 mg, 1.5 mmol, 3.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 4 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 8:1) to afford the title compound as a pale yellow oil (50 mg, 22%).

^{1}H NMR (400 MHz, CDCl3): δ 7.64 (d, *J* = 8.2 Hz, 2H), 7.40–7.24 (m, 8H), 3.83 (s, 2H), 2.40 (s, 3H), 2.29 (d, *J* = 7.2 Hz, 2H), 2.20 (s, 3H), 1.52–1.50 (m, 3H), 1.43–1.40 (m, 2H), 1.10–1.04 (m, 1H), 1.00–0.90 (m, 3H), 0.68–0.59 (m, 2H).

^{13}C NMR (100 MHz, CDCl3): δ 204.8, 145.2, 136.3, 134.2, 130.2, 129.1, 128.7, 128.4, 127.2, 127.0, 124.7, 123.0, 119.5, 53.7, 40.4, 29.4, 21.9, 10.7.

FTIR (neat): ν_{max}/cm^{-1} 2922, 2850, 1722, 1597, 1532, 1448.

HRMS (p-APCI): *m/z* 450.2098 [(M+H)+ requires 450.2097].



1-(2-benzyl-4-phenyl-1-tosyl-1H-pyrrol-3-yl)propan-2-one (44c)

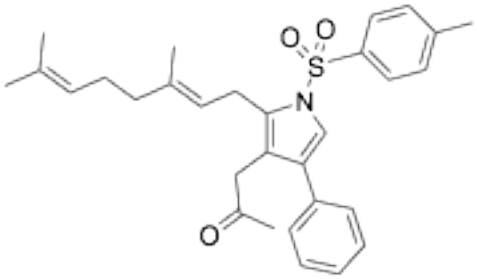
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42o** (150 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005mol, 0.01 equiv) before being backfilled with argon three times. **41c** (258 mg, 1.5 mmol, 3.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 6:1) to afford the title compound as a pale yellow, amorphous solid (41 mg, 18%).

^{1}H NMR (400 MHz, CDCl3): δ 7.72–7.65 (m, 2H), 7.37 (s, 1H), 7.35–7.09 (m, 10H), 6.96–6.94 (m, 2H), 3.79 (s, 2H), 3.76 (s, 2H), 2.43 (s, 3H), 2.05 (s, 3H), 1.57 (s, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 204.5, 145.4, 139.9, 136.3, 133.9, 130.2, 129.7, 128.7, 128.6, 128.6, 128.2, 127.3, 127.1, 126.4, 126.3, 125.3, 120.1, 40.5, 30.2, 29.5, 21.9.

FTIR (neat): ν_{max}/cm^{-1} 3028, 2920, 1722, 1597, 1494, 1452, 1363.

HRMS (p-APCI): *m/z* 444.1625 [(M+H)+ requires 444.1628].



(E)-1-(2-(3,7-dimethylocta-2,6-dien-1-yl)-4-phenyl-1-tosyl-1H-pyrrol-3-yl)propan-2-one (44d)

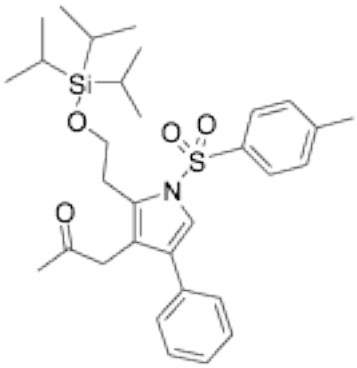
An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42o** (150 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005mol, 0.01 equiv) before being backfilled with argon three times. **41d** (327 mg, 1.5 mmol, 3.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 10:1) to afford the title compound as a pale yellow, amorphous solid (53 mg, 21%).

^{1}H NMR (400 MHz, CDCl3): δ 7.68 (d, *J* = 8.3 Hz, 2H), 7.38–7.26 (m, 2H), 5.02–4.96 (m, 2H), 3.83 (s, 2H), 3.09 (d, *J* = 6.4 Hz, 2H), 2.41 (s, 3H), 2.06 (s, 3H), 1.98–1.94 (m, 2H), 1.92–1.86 (m, 2H), 1.64 (s, 3H), 1.56 (s, 3H), 1.54 (s, 3H).

^{13}C NMR (100 MHz, CDCl3): δ 204.9, 145.2, 136.4, 136.0, 134.2, 131.7, 130.2, 129.1, 128.7, 128.6, 127.1, 126.8, 125.2, 124.3, 122.7, 119.5, 40.4, 39.7, 29.4, 26.7, 25.9, 23.8, 21.9, 17.9, 16.3.

FTIR (neat): ν_{max}/cm^{-1} 3034, 2963, 2855, 1720, 1597, 1447, 1364, 1173, 1098.

HRMS (p-APCI): *m/z* 490.2411 [(M+H)+ requires 490.2410].



1-(4-phenyl-1-tosyl-2-(2-((triisopropylsilyl)oxy)ethyl)-1H-pyrrol-3-yl)propan-2-one (44f)

An oven dried 35 mL pressure tube equipped with stir vane and rubber septum, was charged with **42o** (150 mg, 0.50 mmol, 1.0 equiv), and Rh_2(*S*-DOSP)$_4$ (9 mg, 0.005mol, 0.01 equiv) before being backfilled with argon three times. **41e** (424 mg, 1.5 mmol, 3.0 equiv) was diluted in 1,2-dichloroethane (anhydrous, 2.5 mL) and added to the pressure tube. The reaction vessel was sealed with a teflon screwcap and placed in a preheated oil bath (70 °C). The reaction was stirred at 70 °C for 12 h. The reaction mixture was removed from the heat and concentrated *in vacuo*. The product was isolated by flash chromatography (hexanes/EtOAc, 15:1) to afford the title compound as a pale yellow, amorphous solid (107 mg, 39%).

^{1}H NMR (400 MHz, CDCl3): δ 7.68 (d, *J* = 8.4 Hz, 2H), 7.38–7.35 (m, 4H), 7.32–7.25 (m, 4H), 3.93 (s, 2H), 3.52 (t, *J* = 7.1 Hz, 2H), 2.66 (t, *J* = 7.1 Hz, 2H), 2.41 (s, 3H), 2.21 (s, 3H), 0.92–0.84 (m, 21H).

^{13}C NMR (100 MHz, CDCl3): δ 204.9, 145.2, 136.4, 134.3, 130.2, 129.0, 128.7, 128.7, 127.3, 127.2, 125.9, 124.2, 119.8, 63.3, 40.6, 29.6, 28.4, 21.9, 18.1, 12.0.

FTIR (neat): ν_{max}/cm^{-1} 3060, 2942, 2891, 2865, 1723, 1597, 1532, 1463, 1366, 1103.

HRMS (p-APCI): *m/z* 554.2760 [(M+H)+ requires 554.2755].