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Light-Enabled Radical 1,4-Aryl Migration Via a Phospho-Smiles Rearrangement

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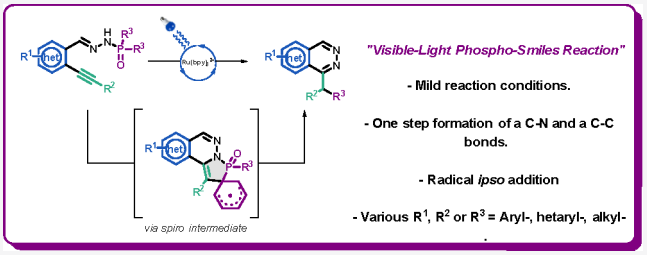
ABSTRACT: Rearrangement reactions in organic chemistry are attractive strategies to build efficiently complex scaffolds, in just one step, from simple starting materials. Among them, aryl migrations are certainly one of the most useful and straightforward rearrangement for building attractive carbon−carbon bonds. Of note, anionic aryl migration reactions have been largely described compared to their radical counterparts. Recently, visible-light catalysis has proven its efficiency to generate such radical rearrangements due to the concomitant loss of a particle (often CO_2 or SO_2), which is the driving-force of the reaction. Here, we disclose a Smiles-type rearrangement, triggered by a phosphorus-containing unit (arylphosphoramidate), therefore called "phospho-Smiles" rearrangement, allowing a Csp^2-Csp^2 bond formation thanks to a 1,4-aryl migration reaction. In addition, combining this approach with a radical hydroamination/amination reaction produces an amination/phospho-Smiles cascade particularly attractive, for instance, to investigate the synthesis of the phthalazine core, a scarcely described scaffold of interest for medicinal chemistry projects.



INTRODUCTION

Creation of useful complex structures using a minimum number of steps remains a big challenge for organic chemists.[1] This strategy promotes the exploration of the molecular diversity. Indeed, in such a tactic, rearrangements implying an aryl migration from an easily accessible starting material represents one ideal way to gain access to more complex and diversified structures.[2] One of the most useful and studied migration reaction is certainly the Smiles rearrangement.[3] This reaction, described by Smiles and co-workers almost a century ago, allows the migration of an aromatic ring linked to a sulfone function to an ortho hydroxide group.[4] This work has been further extended from hydroxide to carbanion units by Truce and co-workers,[5] followed by other teams,[6] expanding therefore the scope to the formation of Csp^3-Csp^2 and Csp^2-Csp^2 bonds. Such approaches shed light on a new retrosynthetic pathway in order to build complex scaffolds, especially biaryls.[7] This rearrangement takes place through an *ipso*-attack of the anion to an activated ring system bearing a strong electron withdrawing function. The generated Meisenheimer complex is then opened with a concomitant SO_2 extrusion (See mechanistic proposal for details). Dramatic improvements of this rearrangement have also been possible with the development of radical versions. Indeed, Speckamp,[8] Motherwell[9] and others have greatly improved the application field of such method. Radical aryl migrations are now often used to build complex scaffolds. However, the required conditions to generate a radical species remain often harsh and thus limit the expandability of such strategy. To circumvent this drawback, visible-light catalysis[10] recently appeared to be the ideal initiation process to generate many useful radicals, and this concept has been used in several radical aryl migration reactions.[11] Similarly to the ionic Smiles rearrangement, SO_2 or CO_2 moieties are often lost during these processes (Scheme 1a,b).

In order to find new methods to generate a radical species, such as *N*-centered radicals, we recently gained interest in phosphoramidates[12] and speculated about their reactivity in migratory processes. We conceptually wondered if an arylphosphoramidate group could transfer one of its substituents through a Smiles-type rearrangement, via a carbon−phosphorus bond cleavage with the phosphorus-containing functional group being extruded, as for SO_2 or CO_2 (Scheme 1c). To the best of our knowledge, this concept will represent the first example of a phospho-Smiles rearrangement under photoredox conditions.[13] Phosphoramidates, unknown for such rearrangements, represent thus a new functional group in Smiles-type rearrangement to efficiently build Csp^2-Csp^2 bonds. It is indeed important to find new

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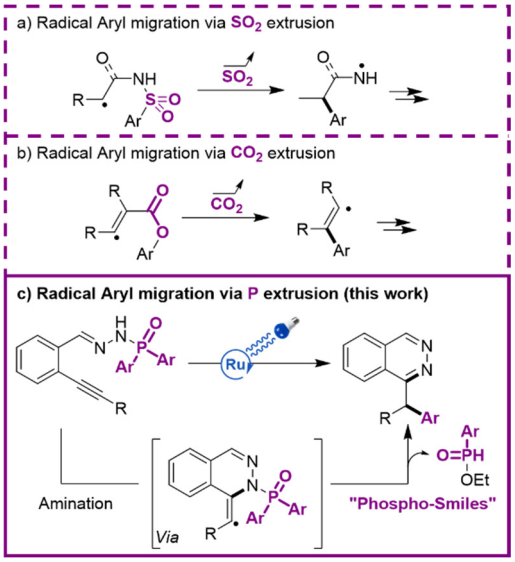
Scheme 1. Aryl Migrations Principle with SO_2 and CO_2 Extrusions and our work on the P extrusion



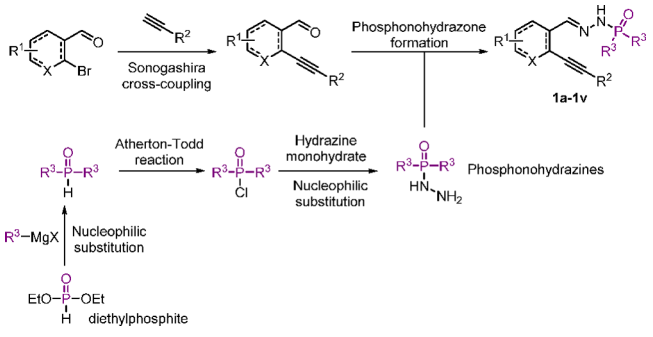
functionalities compatible with known rearrangements to expand their applicability.

RESULTS AND DISCUSSION

To test our idea, we recently disclosed that *N*-centered radicals can be generated with phosphoramidates using photoredox conditions and subsequently be engaged in a radical intramolecular hydroamination reaction.[12] We wondered if this hydroamination product could be further engaged in a radical phospho-Smiles rearrangement to reach 1-benzhydrylphthalazines. This new cascade would imply the formation of one C−N and one C−C bond followed by a N−P bond cleavage in one step. It is important to note that the majority of radical intermediates generated in Smiles rearrangement leads to amidyl radicals at the end.[11a] Thereby, new substrates are highly requested to explore the chemical accessibility using this strategy.

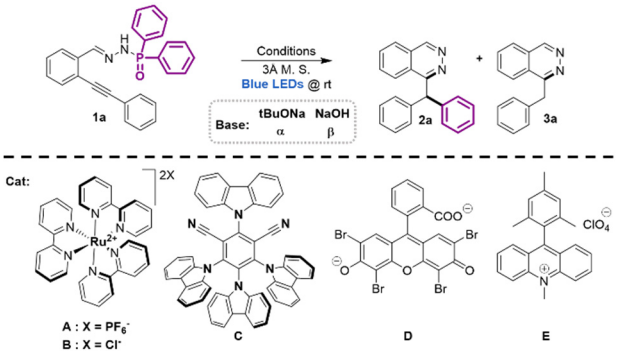
Formation of the starting material starts with a Sonogashira cross-coupling reaction to affords 2-(arylethynyl)benzaldehyde substrates (see the SI and Scheme 2). Then, the phosphonohydrazones are obtained by the condensation of the phosphonohydrazines with the Sonogashira cross-coupling product. The synthesis of differently substituted phosphonohydrazine derivatives was easily accomplished via the nucleophilic substitution of the ethoxy chains of diethylphosphite by the selected Grignard reagent.[14] Then, an Atherton-Todd reaction[15] followed by a nucleophilic substitution with hydrazine afforded the desired phosphonohydrazine compounds **1a**−**v**.

Scheme 2. Starting Materials Synthesis



To test the phospho-Smiles potential, we started our investigation on model substrate **1a**, with no functional group on the aldehyde part nor on the hydrazine one. Based on previous work from our lab,[12,16] we were delighted to find that our proposed phospho-Smiles reaction did occur on **1a** providing the desired product **2a** in an encouraging 16% yield (entry 1, Table 1). However, **2a** was obtained concomitantly to

Table 1. Optimization of the Reaction Conditions



entry	cat	base	solvent (M)	2a[a]	3a[a]
1	A	α (3 equiv)	MeOH (0.3 M)	16%	15%
2	A	α (3 equiv)	EtOH (0.3 M)	15%	27%
3	B	α (3 equiv)	EtOH (0.3 M)	18%	39%
4	C[b]	α (3 equiv)	EtOH (0.3 M)	0%	traces
5	D[b]	α (3 equiv)	EtOH (0.3 M)	0%	traces
6	E[b]	α (3 equiv)	EtOH (0.3 M)	0%	traces
7	B	β (3 equiv)	EtOH (0.3 M)	21%	31%
8	B	β (1.5 equiv)	EtOH (0.3 M)	21%	39%
9	B	β (1.5 equiv)	EtOH (0.0187 M)	45%	25%
10	B	β (1.5 equiv)	propanol (0.0187 M)	36%	62%
11	B	β (1.5 equiv)	EtOH/DMSO 15:1 (0.0187 M)	46%	traces
12	A	β (1.5 equiv)	EtOH/MeCN 15:1 (0.0187 M)	58%	traces
13[c]	A	β (1.5 equiv)	EtOH/MeCN 3:1 (0.0187 M)	65%	traces
14[d]	A	β (1.5 equiv)	EtOH/MeCN 3:1 (0.0187 M)	0%	0%
15[e]	A	/	EtOH/MeCN 3:1 (0.0187 M)	0%	0%
16[f]		β (1.5 equiv)	EtOH/MeCN 3:1 (0.0187 M)	0%	0%

[a]Isolated yields. [b]5 mol % of photocatalyst. [c]Standard conditions: reactions were performed with **1a** (0.15 mmol), photocatalyst (2.5 mol %), and base (1.5 equiv) in a mixture of 6 mL of EtOH and 2 mL of MeCN and the presence of 3 Å molecular sieves. The reaction was irradiated with blue LED for 12 h. [d]Reaction performed without light. [e]Reaction performed without base. [f]Reaction performed without photocatalyst.

the formation of the hydroamination product **3a** (i.e., without the Smiles rearrangement) in 15% yield. Therefore, formation of the 1-benzylphthalazine **3a** is in competition with the access to the desired product **2a**. Thus, the optimization of the reaction conditions was not only focused on increasing the yield of the phospho-Smiles product but also on decreasing the formation of the hydroamination side product **3a**. Additionally, product **2a** was successfully crystallized and its structure

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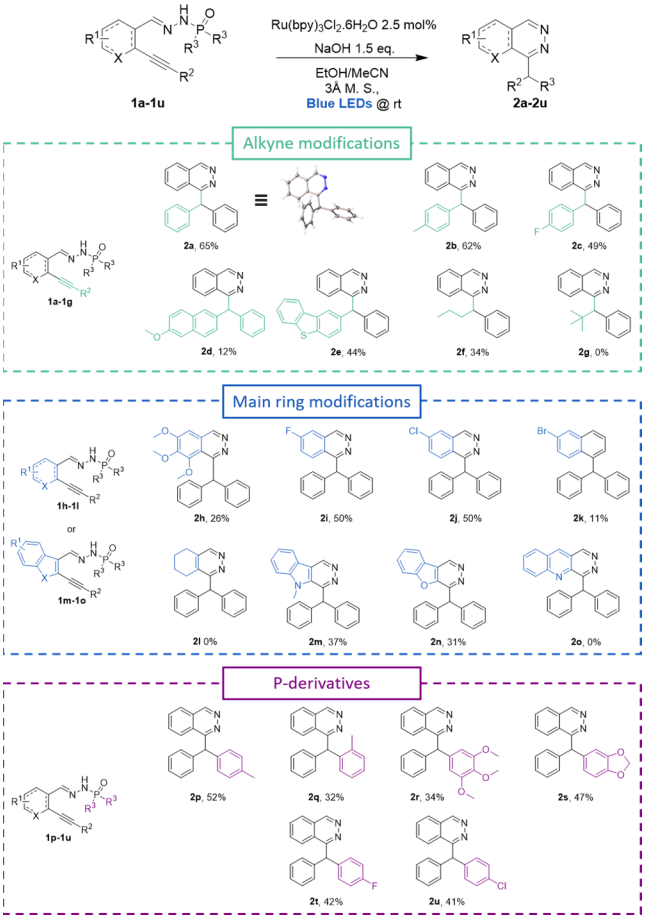
established by XRD. These data confirmed that the phosphorus moiety was effectively cleaved in the process after a successful Smiles-type rearrangement. Thereafter, modifying the solvent to EtOH led to a similar 15% yield for **2a** but we observed a higher conversion of the starting material in this solvent, although this was in favor of compound **3a** (27%, entry 2, Table 1). The better solubility of the starting material in EtOH compared to MeOH guided us to keep EtOH for the next optimization steps. We then modified the nature of the photocatalyst, having in mind that the first step of the reaction is the oxidation of the anionic phosphoramidyl intermediate. We thus focused our attention on photocatalysts able to perform a reductive quenching (i.e., capable of oxidizing the *N*-anion derivative, see cyclic voltammetry in S.I.). We were pleased to obtain **2a** with an 18% yield when using $Ru(bpy)_3Cl_2.6H_2O$ (entry 3, Table 1), however accompanied by the formation of the side product **3a** in a higher 39% yield. Regrettably, organic photocatalysts such as 4CzIPN, eosin Y and Mes-Acr$^+$$ClO_4^-$ only led to traces of the undesired hydroamination product **3a** (entries 4−6, Table 1). Thus, $Ru(bpy)_3Cl_2{\cdot}6H_2O$ was selected as the best photocatalyst for the optimization of the reaction conditions. We then investigated the effect of several bases as the next factor (see the SI). Among these bases, sodium hydroxide proved to be the best candidate, we found that it led to a slight yield increase (**2a**, 21%) both with 3 and 1.5 equiv (entries 7−8, Table 1). Nevertheless, the formation of the undesired product **3a** was still observed in both cases. Then, the modulation of the solvent and the concentration of the reaction medium were investigated. Interestingly, a strong dilution (16-fold) of the reaction medium, from 0.3 to 0.01875 M, resulted in a switch in the reaction outcome. Indeed, **2a** was formed in an encouraging 45% yield whereas the undesired product **3a** was obtained in a 25% yield (entry 9, Table 1). Propan-1-ol (0.01875 M) led to the inverse reactivity switch with the undesired product **3a** formed in a 62% yield and 36% for **2a** (entry 10, Table 1). Therefore, we decided to avoid alcohol solvent with a chain longer than two carbons since it appeared to promote instead the formation of the hydroamination product **3a**. Finally, the lack of selectivity in products formation was circumvented with mixture of solvents. Indeed, a mixture of EtOH and DMSO (15:1, 0.01875 M) gave the desired product **2a** in a 46% yield while only traces of the undesired product **3a** were observed (entry 11, Table 1). Further optimization of the solvent mixture increased the final isolated yield of **2a** to 58% with a 15:1 mixture of EtOH and MeCN (0.01875 M, entry 12, Table 1). This dramatical impact of the dilution on the yield of the reaction can be easily explained. We propose that the alkene radical intermediate (**IV**, see Scheme 5) can follow two possible pathways (further detailed in Scheme 5). First, as expected, the *ipso* addition can occur in an intramolecular fashion leading to the desired product **2a**. However, this critical step may follow an alternative pathway, where a back-electron transfer of the photocatalyst to the alkene radical may furnish the corresponding anionic species which is rapidly protonated, leading to the hydroamination product **3a**. Dilution is thus promoting the intramolecular reaction compared to the intermolecular protonation.

Finally, changing the ratio between EtOH and MeCN from 15:1 to 3:1 led to the formation of 65% of the desired product **2a** while only traces of the undesired **3a** were obtained (entry 13, Table 1). Other solvent mixtures were tested giving also **2a** as the major product; despite our extensive efforts we were not able to further increase the reaction yield while maintaining the same 2.5 mol % catalytic loading (see SI for all details). We also performed control experiments without light, base and photocatalyst (entries 14−16 respectively, Table 1), and we could not observe any formation of product **2a** under these conditions, confirming the photoinduced nature of the reaction. Therefore, the best selected reaction conditions were: starting material (0.15 mmol), $Ru(bpy)_3Cl_2{\cdot}6H_2O$ (2.5 mol %) and NaOH (1.5 equiv) in a mixture of 6 mL of EtOH and 2 mL of MeCN, irradiated with blue LED for 12 h, at room temperature, to provide the desired model product **2a** in 65% yield.

With these best conditions in hand, we then focused our attention on the scope of the reaction by modifying the substitution pattern on the alkynyl part, on the main ring and on the phosphorus atom (Table 2). Starting with modified

Table 2. Scope of the Reaction



alkynes, an electron-donating group such as a *p*-tolyl derivative gave the final corresponding phthalazine **2b** in a good 62% yield. Electron-withdrawing group, such as a *p*-fluorine, was also well tolerated and led to **2c** in a slightly decreased 49% yield. A bulky 2-methoxy-substituted naphthalene derivative resulted in a huge yield drop to 12% for the desired product **2d** while another sterically hindered dibenzothiophene derivative allowed the formation of the final product **2e** in a medium 44% yield. Steric hindrance is not the only important parameter in the observed drop yield. Indeed, more interestingly the reaction was also compatible with alkyl substituted alkynes

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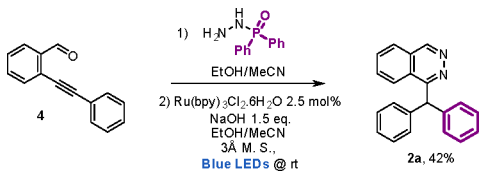
such as a propyl chain in an encouraging 34% yield for the expected product **2f**. On the other hand, a bulky *tert*-butyl substituted alkyne blocked the formation of the desired product **2g**.

We then changed the substitution on the main ring and witnessed that electron-rich groups, such as trimethoxy substitutions, were detrimental for the reaction with a yield of 26% for the desired product **2h**. Electron-withdrawing substitutions such as halogen atoms led to a medium 50% yield in the case of **2i** with a fluoro-substitution and **2j** for a chloro-substitution. It is surprising to note an important yield drop to 11% when a bromo-substitution is present on the same position in the product **2k**. In this specific case, we also observed an in situ debromination reaction leading finally to product **2a** in 25% yield. Heterocyclic rings in the starting materials were also compatible, successfully giving several products such as **2m** an indolo- fused pyridazine or **2n** a benzofuran-fused pyridazine, synthesized in fair 37% and 31% yields, respectively. On the contrary, the quinoline-pyridazine derivative **2o** was not obtained as well as an alkyl-substituted pyridazine **2l**.

Next, we changed the nature of the migratory group by modifying the substitution (R^3) on the phosphorus atom. We were pleased to note that a wide variety of substituted aryl groups could migrate such as electron-rich *p*-tolyl, *o*-tolyl, 3,4,5-trimethoxybenzene, and methylene dioxy substitutions in 52%, 32%, 34%, and 47% yield, respectively, for products **2p**, **2q**, **2r**, and **2s**. It is interesting to note that the *o*-tolyl substitution on product **2q** led to a slight decrease of the yield while not being totally detrimental for the migration. The *para*-halogen substitution led to medium yields such as 42% for the *p*-fluoro substitution **2t** and 41% yield for the *p*-chloro substitution **2u**.

Our methodology appeared to be also compatible in a sequential one-pot two-steps synthesis for the desired benzhydrylphthalazine **2a**, although in a lower 42% yield (versus 65%). In this case, starting from the aldehyde derivative **4** (Scheme 3), the first step consisted in the

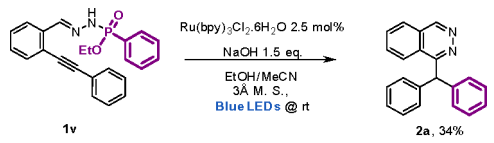
Scheme 3. One-Pot Two-Steps Synthesis of Benzhydrylphthalazine 2a



formation of the hydrazone moiety by mixing the phosphonohydrazine and the aldehyde **4**. After total conversion to the corresponding phosphonohydrazone (followed by TLC), the reaction was then subjected to our optimized reaction conditions without isolation of this intermediate. Using such strategy, it is still possible to reach the desired product **2a** but in a lower 42% yield than in a sequential fashion. It is important to note that, a gram-scale experiment did not provide any product, using a different apparatus (see the SI).

Finally, we wanted to investigate if the unsymmetrical phosphonohydrazone **1v**, bearing one aryl ring and one ethoxy chain, could be used to efficiently form the desired product **2a** (Scheme 4). This alternative compound **1v** could promote a more atom-economical variation of our optimized reaction

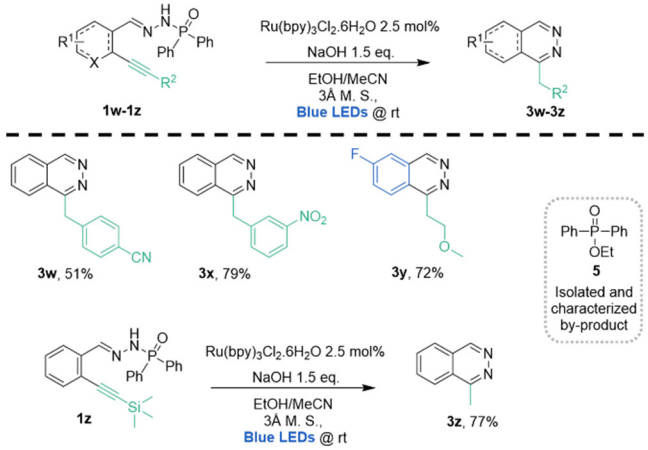
Scheme 4. Unsymmetrical Phosphonohydrazone Engaged in Photoredox Catalysis



conditions. We were pleased to observe the formation of the desired product **2a**, but the isolated yield was two times lower (34% versus 65%). This diminished yield can be attributed to the 50% less probability of a favorable alignment between the migrating aromatic ring and the carbon-centered radical, leading to an efficient radical aryl migration.

Interestingly, some starting materials did not lead to the expected products (Table 3). Indeed, when using stronger

Table 3. Scope of the Reaction without Aryl Migration



electron-withdrawing groups on the alkynyl part, such as a *p*-nitrile or a *m*-nitro substitution, no aryl migrations were observed and only hydroamination products **3w** and **3x** were isolated in a 51% and 79% yield, respectively. The absence of Smiles rearrangement implies that the back-electron transfer in these cases is certainly faster than the *ipso* addition (see Scheme 5). The alkene radical intermediate is certainly destabilized by an electron withdrawing group strengthening its electrophilic character, thus the radical is more prone to be reduced and protonated or quenched by a hydrogen atom transfer.

We observed the same reactivity using starting materials **1y** and **1z** bearing respectively a methyl propargyl ether and a TMS acetylene unit. In these cases, only hydroamination products were obtained in good yields, respectively 72% and 77%, certainly due to a destabilized radical intermediate. Interestingly, the trimethylsilyl substitution led to the formation of 1-methylphthalazine **3z** (77% yield), the in situ cleavage of the trimethylsilyl part being certainly promoted by the basic ethanolic reaction medium. In order to have some clues on the mechanism, we performed cyclic voltammetry experiments in order to determine the oxidation potential of several starting materials in a basic medium. We found that the oxidation potentials are in the range of +0.5 and +0.54 V vs SCE. These potentials are in a compatible range toward $Ru(bpy)_3Cl_2$ indicating a plausible radical mechanism. Based on literature reports and on our own experiments, we believe

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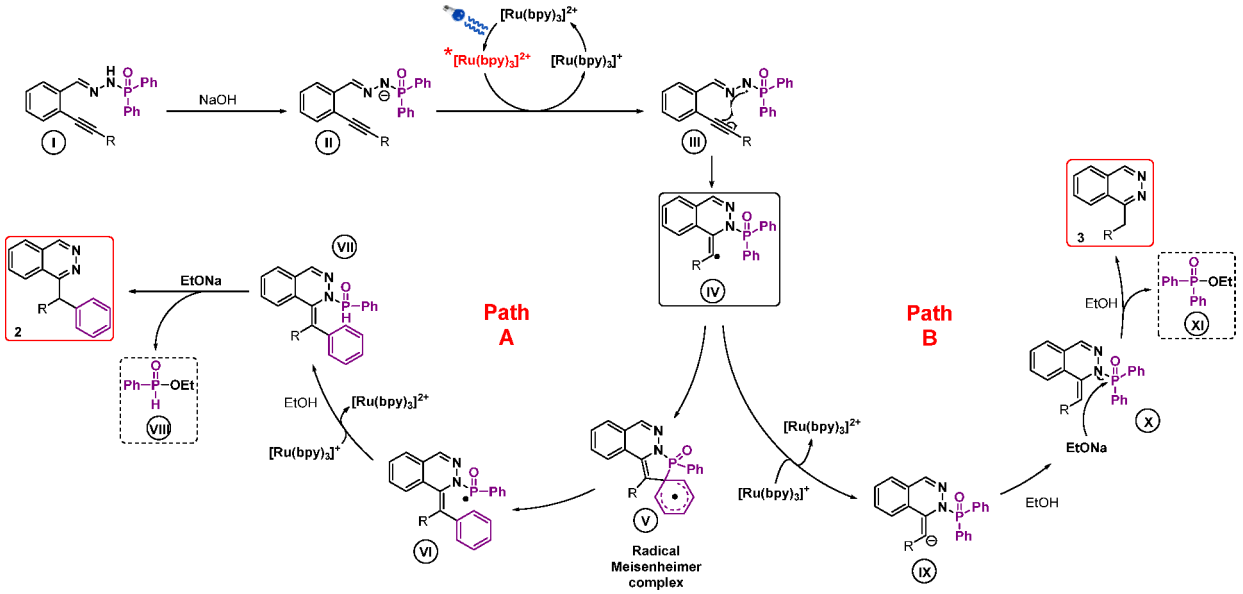
Scheme 5. Proposed Mechanism



that the reaction mechanism starts by the deprotonation of the phosphonohydrazone **I** by the base (Scheme 5). Then, the anionic intermediate **II** can be oxidized by the excited $[Ru(bpy)_3^{2+}]^*$ photocatalyst, yielding the nitrogen-centered radical **III** which is subsequently engaged in an intramolecular addition onto the alkyne in a 6-*exo*-dig-fashion giving the carbon-centered radical **IV**. The latter is a key intermediate since it can give rise to two products. Indeed, in path A (see Scheme 5), the key intermediate **IV** can undergo an *ipso* addition on one aromatic ring of the phosphorus group leading to the spiro intermediate **V**. Then, rearomatization of the ring may lead to the P-centered radical **VI**. Reduction of this radical to the corresponding anionic species and protonation by the solvent releasing intermediate **VII** can close the catalytic cycle. Finally, ethanolysis yields the desired phospho-Smiles product **2** concomitantly with the loss of **VIII** (identified, see the SI). Another pathway is also possible to explain the formation of hydroamination products **3** (path B, Table 3). Intermediate **IV** can indeed undergo a back-electron transfer from the photocatalyst leading to the alkenyl anion **IX**. Protonation of **IX** by the solvent and ethanolysis of the intermediate **X** then furnish the hydroamination side product **3**, while liberating the phosphorus-based byproduct **XI** (characterized, see the SI).[13b]

In conclusion, we report herein the first example of a Smiles rearrangement using a phosphorus-containing junction under photoredox catalysis. We demonstrated that phosphonohydrazones were able to be converted to the corresponding *N*-centered radicals and then be engaged in a so-called phospho-Smiles rearrangement. Although radical aryl migrations have been reported for decades, under various operational conditions and on many types of substrates, examples using phosphorus atoms remain anecdotic. This first report of a 1,4-aryl migration using phosphonohydrazone moieties under smooth photoredox conditions will certainly expand the utilization of such cascade reactions. Development of an enantioselective version of this rearrangement is currently under investigation in our laboratory since the P-containing function allows for the first time the introduction of a chirogenic center.

EXPERIMENTAL SECTION

General Information. ^{1}H NMR, ^{13}C{1H} NMR, ^{31}P NMR, and ^{19}F NMR spectra were recorded on Bruker Avance 300, 400, or 600 MHz spectrometers in $CDCl_3$, DMSO-d_6 or acetone-d_6 solution with internal solvent signal as reference. NMR data are reported as follows: chemical shift (ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, quint = quintet, dd = doublet of doublets, ddd = doublet of doublet of doublets, td = triplet of doublets, qd = quartet of doublets, m = multiplet, br. s. = broad singlet), and coupling constants (Hz) and number of protons (for ^{1}H NMR). All mass spectra were recorded on a Bruker QTOF maXis II instrument. All reactions were monitored by thin-layer chromatography using Merck silica gel plates 60 F254. Visualization was accomplished with short wavelength UV light (254 and 365 nm) and/or staining with appropriate stains (anisaldehyde, *ortho*-phosphomolybdic acid). Standard flash chromatography was performed using silica gel of particle size 40−63 μm. All photocatalytic reactions were performed with 455 nm LEDs (Cree XLamp XT-E Royal Blue LEDs (λ = 455 nm (±5 nm), 12 V, 1.5 A). The sample was irradiated with a LED through the vial's plane bottom side and cooled from the side using custom-made aluminum cooling blocks connected to a thermostat. Photocatalysts were purchased from Aldrich, TCI, and used without any further purification or synthesized as reported in literature. All other commercially available reagents and solvents were used without further purification.

General Procedure Synthesis of Phosphonohydrazones and Characterizations. To an oven-dried sealable glass vial was added A (aldehyde or ketone derivative; 1 equiv), phosphonohydrazine (1.1 equiv), and MeOH (0.8 M). The vials were sealed with 20 mm crimp caps with silicone/PTFE septum and stirred overnight at 20 °C. After completion of the reaction checked by TLC, the reaction medium was filtered using a Büchner funnel if precipitation of the phosphonohydrazone occurred. The product was dried under vacuum, characterized, and used without any further purification. If precipitation did not occur, the crude mixture was concentrated and purification of the residue by silica gel column chromatography eluting with a cyclohexane/ethyl acetate mixture gave the desired product.

Compound ***1a.*** P,P-diphenyl-*N*′-(2-(phenylethynyl)benzylidene)-phosphinic hydrazide: Yield: 85% (9.73 mmol, 4092 mg). Consistent with literature.[12]

Compound ***1b.*** P,P-diphenyl-*N*′-(2-(*p*-tolylethynyl)benzylidene)-phosphinic hydrazide: Yield: 93% (1.14 mmol, 496 mg). R_f = 0.45 (cyclohexane/EA, 3:7). Aspect: White solid. ^{1}H NMR (400 MHz, chloroform-*d*) δ 8.51 (s, 1H), 7.94 (dd, *J* = 12.4, 7.3 Hz, 4H), 7.76 (d,

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J = 7.7 Hz, 1H), 7.56−7.40 (m, 9H), 7.30−7.18 (m, 2H), 7.13 (d, J = 7.8 Hz, 2H), 2.37 (s, 3H). $^{13}C\{^1H\}$ NMR (101 MHz, chloroform-d) δ 144.2 (d, J = 16.5 Hz), 138.8, 135.3, 132.5 (d, J = 10.0 Hz), 132.4, 132.3 (d, J = 1.5 Hz), 131.7, 130.9 (d, J = 128.8 Hz), 129.3, 128.9, 128.6 (d, J = 13.1 Hz), 128.3, 125.3, 122.7, 119.9, 95.1, 86.0, 21.7. ^{31}P NMR (162 MHz, chloroform-d) δ 24.31.HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{28}H_{24}N_2OP$ 435.1621; Found 435.1622.

Compound **1c**. N'-(2-((4-Fluorophenyl)ethynyl)benzylidene)-P,P-diphenylphosphinic hydrazide: Yield: quant. (0.69 mmol, 302 mg), R_f = 0.5 (cyclohexane/EA, 3:7). Aspect: White solid. ^1H NMR (400 MHz, chloroform-d) δ 8.49 (s, 1H), 7.94−7.87 (m, 5H), 7.75 (d, J = 7.3 Hz, 1H), 7.58−7.50 (m, 4H), 7.47−7.42 (m, 5H), 7.26−7.19 (m, 2H), 6.99 (td, J = 8.7, 1.9 Hz, 2H). $^{13}C\{^1H\}$ NMR (101 MHz, chloroform-d) δ 162.8 (d, J = 250.1 Hz), 144.1 (d, J = 16.9 Hz), 135.5, 133.8 (d, J = 8.4 Hz), 132.5, 132.5 (d, J = 10.0 Hz), 132.4, 130.9 (d, J = 133.5 Hz), 129.0, 128.7, 128.6, 125.3, 122.4, 119.1 (d, J = 3.5 Hz), 115.8 (d, J = 22.1 Hz), 93.8, 86.3. ^{31}P NMR (162 MHz, chloroform-d) δ 24.79. ^{19}F NMR (376 MHz, chloroform-d) δ −110.41 to −110.54 (m). HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{27}H_{20}FN_2OP$ 439.1370; Found 439.1368.

Compound **1d**. N'-(2-((6-Methoxynaphthalen-2-yl)ethynyl)-benzylidene)-P,P-diphenylphosphinic hydrazide :Yield: 59% (0.49 mmol, 246 mg). R_f = 0.41 (cyclohexane/EA, 3:7). Aspect: Yellow solid. ^1H NMR (300 MHz, chloroform-d) δ 8.49 (s, 1H), 8.00−7.87 (m, 5H), 7.79 (d, J = 7.4 Hz, 1H), 7.68 (dd, J = 8.7, 2.7 Hz, 2H), 7.56−7.43 (m, 8H), 7.31−7.18 (m, 3H), 7.17−7.08 (m, 2H), 3.93 (s, 3H). $^{13}C\{^1H\}$ NMR (75 MHz, chloroform-d) δ 158.6, 144.1 (d, J = 15.8 Hz), 135.1, 134.4, 132.5 (d, J = 9.9 Hz), 132.4 (d, J = 1.2 Hz), 132.4, 131.4, 131.1 (d, J = 129.8 Hz), 129.5, 129.1, 129.0, 129.0, 128.7 (d, J = 13.1 Hz), 128.5, 127.1, 125.5, 122.6, 119.7, 117.8, 105.9, 95.4, 86.2, 55.5.^{31}P NMR (121 MHz, chloroform-d) δ 23.48. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{32}H_{26}N_2O_2P$ 501.1726; Found 501.1729.

Compound **1e**. N'-(2-(Dibenzo[b,d]thiophen-2-ylethynyl)-benzylidene)-P,P-diphenylphosphinic hydrazide: Yield: 96% (0.86 mmol, 454 mg). R_f = 0.7 (cyclohexane/EA, 3:7). Aspect: Beige solid.^1H NMR (300 MHz, chloroform-d) δ 8.58 (s, 1H), 8.34 (s, 1H), 8.15 (d, J = 7.3 Hz, 1H), 7.96−7.86 (m, 5H), 7.83 (d, J = 7.6 Hz, 1H), 7.78−7.71 (m, 2H), 7.62 (d, J = 8.2 Hz, 1H), 7.53−7.36 (m, 9H), 7.29−7.15 (m, 2H). $^{13}C\{^1H\}$ NMR (75 MHz, chloroform-d) δ 144.0 (d, J = 16.0 Hz), 139.8, 139.7, 135.8, 135.4, 135.0, 132.5 (d, J = 9.9 Hz), 132.4, 132.3 (d, J = 2.8 Hz), 131.2 (d, J = 129.6 Hz), 129.9, 129.0, 128.6 (d, J = 13.0 Hz), 128.5, 127.3, 125.4, 124.9, 124.8, 122.9, 122,9, 122.4, 122.1, 119.0, 95.0, 86.6. ^{31}P NMR (121 MHz, chloroform-d) δ 23.95. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{33}H_{24}N_2OPS$ 527.1341; Found 527.1337.

Compound **1f**. N'-(2-(Pent-1-yn-1-yl)benzylidene)-P,P-diphenylphosphinic hydrazide: Yield: 52% (0.68 mmol, 264 mg). R_f = 0.45 (cyclohexane/EA, 3:7). Aspect: White solid. ^1H NMR (400 MHz, chloroform-d) δ 8.33 (s, 1H), 7.93 (dd, J = 12.0, 7.7 Hz, 4H), 7.71 (d, J = 7.6 Hz, 1H), 7.54 (t, J = 6.6 Hz, 2H), 7.51−7.44 (m, 4H), 7.35 (d, J = 7.4 Hz, 1H), 7.18 (dd, J = 17.5, 8.2 Hz, 3H), 2.39 (t, J = 7.0 Hz, 2H), 1.63 (h, J = 7.1 Hz, 2H), 1.03 (t, J = 7.3 Hz, 3H). $^{13}C\{^1H\}$ NMR (101 MHz, chloroform-d) δ 144.3 (d, J = 16.0 Hz), 135.0, 132.5 (d, J = 9.9 Hz), 132.5, 132.3 (d, J = 3.0 Hz), 131.3 (d, J = 129.6 Hz), 129.0, 128.6 (d, J = 13.0 Hz), 127.8, 125.3, 123.4, 96.1, 78.0, 22.3, 21.7, 13.8. ^{31}P NMR (162 MHz, chloroform-d) δ 23.41. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{24}H_{24}N_2OP$ 387.1621; Found 387.1621.

Compound **1g**. N'-(2-(3,3-Dimethylbut-1-yn-1-yl)benzylidene)-P,P-diphenylphosphinic hydrazide: Yield: 70% (1.42 mmol, 569 mg). R_f = 0.5 (cyclohexane/EA, 3:7). Aspect: White solid. ^1H NMR (300 MHz, chloroform-d) δ 8.35 (d, J = 16.4 Hz, 1H), 7.96−7.86 (m, 4H), 7.73−7.66 (m, 1H), 7.58−7.40 (m, 7H), 7.35−7.30 (m, 1H), 7.16 (m, 2H), 1.31 (s, 9H). $^{13}C\{^1H\}$ NMR (75 MHz, chloroform-d) δ 144.0 (d, J = 16.4 Hz), 135.1, 132.4 (d, J = 10.0 Hz), 132.4, 132.2 (d, J = 2.9 Hz), 129.7 (d, J = 123.7 Hz), 128.8, 128.5 (d, J = 13.0 Hz), 127.7, 125.0, 123.2, 104.2, 76.3, 31.1, 28.3. ^{31}P NMR (121 MHz, chloroform-d) δ 24.51. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{25}H_{26}N_2OP$ 401.1777; Found 401.1771.

Compound **1h**. P,P-Diphenyl-N'-(3,4,5-trimethoxy-2-(phenylethynyl)benzylidene)phosphinic hydrazide: Yield: 96% (1.3 mmol, 663 mg). R_f = 0.34 (cyclohexane/EA, 3:7). Aspect: White solid. ^1H NMR (300 MHz, chloroform-d) δ 8.56 (d, J = 19.1 Hz, 1H), 8.48 (s, 1H), 7.85 (dd, J = 12.2, 7.9 Hz, 4H), 7.60−7.52 (m, 2H), 7.46 (t, J = 7.3 Hz, 2H), 7.36 (dt, J = 10.0, 4.9 Hz, 4H), 7.24 (d, J = 6.0 Hz, 2H), 6.96 (s, 1H), 3.95 (s, 3H), 3.83 (s, 3H), 3.64 (s, 3H).$^{13}C\{^1H\}$ NMR (101 MHz, chloroform-d) δ 154.2, 153.7, 143.6 (d, J = 16.6 Hz), 142.9, 132.4 (d, J = 9.8 Hz), 132.0 (d, J = 1.5 Hz), 132.0, 131.5, 131.1 d, J = 129.7 Hz), 128.4 (d, J = 13.0 Hz), 128.4, 128.2, 123.4, 110.5, 103.3, 97.4, 82.7, 61.3, 61.1, 55.7. ^{31}P NMR (121 MHz, chloroform-d) δ 24.13. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{30}H_{27}N_2O_4P$ 511.1781; Found 511.1771.

Compound **1i**. N'-(5-Fluoro-2-(phenylethynyl)benzylidene)-P,P-diphenylphosphinic hydrazide: Yield: 87% (1.55 mmol, 679 mg). R_f = 0.42 (cyclohexane/EA, 3:7). Aspect: White solid. ^1H NMR (300 MHz, Chloroform-d) δ 8.44 (s, 1H), 8.17 (s, 1H), 7.89 (dd, J = 12.4, 8.1 Hz, 4H), 7.54 (dd, J = 15.3, 7.2 Hz, 4H), 7.48−7.36 (m, 6H), 7.30 (d, J = 5.3 Hz, 3H), 6.94 (td, J = 8.4, 2.7 Hz, 1H).$^{13}C\{^1H\}$ NMR (75 MHz, chloroform-d) δ 162.4 (d, J = 249.2 Hz), 143.4 (d, J = 15.2 Hz), 137.9 (d, J = 8.6 Hz), 134.3 (d, J = 8.4 Hz), 132.6 (d, J = 2.9 Hz), 132.5 (d, J = 10.1 Hz), 131.9, 130.0 (d, J = 133.2 Hz), 128.7 (d, J = 13.2 Hz), 128.7, 128.5, 122.9, 118.7 (d, J = 3.1 Hz), 116.6 (d, J = 23.0 Hz), 111.6 (d, J = 23.7 Hz), 94.6 (d, J = 1.5 Hz), 85.6.^{31}P NMR (121 MHz, chloroform-d) δ 24.71. ^{19}F NMR (282 MHz, chloroform-d) δ −110.31. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{27}H_{20}FN_2OP$ 439.1370; Found 439.1369.

Compound **1j**. N'-(5-Chloro-2-(phenylethynyl)benzylidene)-P,P-diphenylphosphinic hydrazide. Yield: 91% (1.13 mmol, 516 mg). R_f = 0.61 (cyclohexane/EA, 3:7). Aspect: White solid. ^1H NMR (300 MHz, chloroform-d) δ 8.43 (s, 1H), 8.05 (d, J = 18.6 Hz, 1H), 7.88 (dd, J = 12.3, 7.2 Hz, 4H), 7.69 (d, J = 1.7 Hz, 1H), 7.53 (t, J = 6.4 Hz, 4H), 7.44 (td, J = 7.4, 3.3 Hz, 4H), 7.38 (d, J = 8.4 Hz, 1H), 7.30 (d, J = 7.0 Hz, 3H), 7.18 (dd, J = 8.3, 2.0 Hz, 1H).$^{13}C\{^1H\}$ NMR (75 MHz, chloroform-d) δ 142.7 (d, J = 16.3 Hz), 136.9, 134.7, 133.5, 132.4 (d, J = 9.9 Hz), 132.4 (d, J = 2.8 Hz), 131.8, 131.0 (d, J = 129.4 Hz), 129.1, 128.9, 128.7 (d, J = 13.2 Hz), 128.6, 125.1, 122.7, 120.8, 95.6, 85.6.^{31}P NMR (121 MHz, chloroform-d) δ 24.34. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{27}H_{21}ClN_2OP$ 455.1075; Found 455.1071.

Compound **1k**. N'-(5-Bromo-2-(phenylethynyl)benzylidene)-P,P-diphenylphosphinic hydrazide. Yield: 74% (0.94 mmol, 468 mg). R_f = 0.45 (cyclohexane/EA, 3:7). Aspect: White solid.^1H NMR (300 MHz, chloroform-d) δ 8.39 (s, 1H), 7.93−7.80 (m, 6H), 7.57−7.51 (m, 4H), 7.48−7.42 (m, 4H), 7.37−7.28 (m, 5H). $^{13}C\{^1H\}$ NMR (75 MHz, chloroform-d) δ 142.6 (d, J = 16.1 Hz), 137.0, 133.7, 132.5 (d, J = 2.8 Hz), 132.5 (d, J = 9.9 Hz), 132.0, 131.8, 130.9 (d, J = 129.5 Hz), 128.9, 128.7 (d, J = 13.0 Hz), 128.6, 128.1, 123.0, 122.7, 121.2, 95.8, 85.7. ^{31}P NMR (121 MHz, chloroform-d) δ 24.08. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{27}H_{21}BrN_2OP$ 499.0569; Found 499.0565.

Compound **1l**. P,P-Diphenyl-N'-((2-(phenylethynyl)cyclohex-1-en-1-yl)methylene)phosphinic hydrazide. Yield: 57% (0.82 mmol, 349 mg). R_f = 0.49 (cyclohexane/EA, 3:7). Aspect: Beige solid. ^1H NMR (300 MHz, chloroform-d) δ 8.20 (s, 1H), 7.88 (dd, J = 12.4, 7.5 Hz, 4H), 7.47 (m, 9H), 7.32−7.28 (m, 2H), 6.99 (d, J = 18.9 Hz, 1H), 2.30 (d, J = 32.1 Hz, 4H), 1.60 (s, 4H).$^{13}C\{^1H\}$ NMR (75 MHz, chloroform-d) δ 146.9 (d, J = 15.6 Hz), 139.6, 132.5 (d, J = 9.9 Hz), 131.5, 131.3 (d, J = 129.6 Hz), 129.0, 128.8, 128.5 (d, J = 13.0 Hz), 128.5, 123.9, 123.3, 95.6, 88.3, 31.2, 24.4, 22.4, 21.7. ^{31}P NMR (121 MHz, chloroform-d) δ 23.02. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{27}H_{26}N_2OP$ 425.1777; Found 425.1770.

Compound **1m**. N'-((1-Methyl-2-(phenylethynyl)-1H-indol-3-yl)-methylene)-P,P-diphenylphosphinic hydrazide. Yield: 92% (1.24 mmol, 585 mg). R_f = 0.38 (cyclohexane/EA, 3:7). Aspect: Yellow solid. ^1H NMR (300 MHz, chloroform-d) δ 8.39 (d, J = 1.6 Hz, 1H), 8.16 (d, J = 14.1 Hz, 1H), 8.01−7.89 (m, 4H), 7.60 (dd, J = 6.5, 3.0 Hz, 3H), 7.53−7.45 (m, 2H), 7.42−7.32 (m, 7H), 7.19 (t, J = 7.1 Hz, 1H), 7.07 (d, J = 8.2 Hz, 1H), 6.89 (t, J = 7.1 Hz, 1H), 3.55 (s, 3H). $^{13}C\{^1H\}$ NMR (75 MHz, chloroform-d) δ 142.1 (d, J = 17.2 Hz), 137.4, 132.6 (d, J = 9.6 Hz), 131.9 (d, J = 2.6 Hz), 131.6, 131.5 (d, J =

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130.9 Hz), 128.9, 128.6, 128.4 (d, J = 12.8 Hz), 124.1, 123.9, 123.7, 123.3, 122.5, 121.0, 116.4, 108.6, 99.8, 79.2, 30.6. ^{31}P NMR (121 MHz, chloroform-d) δ 24.37. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{30}H_{24}N_3OP$ 474.1730; Found 474.1727.

Compound ***1n***. P,P-Diphenyl-N'-((2-(phenylethynyl)benzofuran-3-yl)methylene)phosphinic hydrazide. Yield: 71% (0.89 mmol, 408 mg). R_f = 0.31 (cyclohexane/EA, 3:7). Aspect: Yellow solid.^{1}H NMR (300 MHz, chloroform-d) δ 8.88 (s, 1H), 8.35 (s, 1H), 7.92 (dd, J = 12.1, 7.5 Hz, 4H), 7.69−7.57 (m, 2H), 7.50 (t, J = 7.2 Hz, 2H), 7.45−7.29 (m, 8H), 7.24 (s, 2H), 7.06−6.88 (m, 1H). ^{13}C{^{1}H} NMR (75 MHz, chloroform-d) δ 154.5, 139.5 (d, J = 18.1 Hz), 138.9, 132.5 (d, J = 9.7 Hz), 132.2 (d, J = 2.6 Hz), 131.8, 130.5 (d, J = 133.8 Hz), 129.4, 128.7, 128.7, 128.5, 126.2, 124.4, 123.5 (d, J = 16.3 Hz), 121.8, 121.4, 110.6, 99.9, 78.4. ^{31}P NMR (121 MHz, chloroform-d) δ 24.98. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{29}H_{21}N_2O_2P$ 461.1413; Found 461.1409.

Compound ***1o***. P,P-Diphenyl-N'-((2-(phenylethynyl)quinolin-3-yl)methylene)phosphinic hydrazide. Yield: 76% (0.76 mmol, 241 mg). R_f = 0.48 (cyclohexane/EA, 3:7). Aspect: White solid. ^{1}H NMR (400 MHz, Chloroform-d) δ 8.73 (d, J = 20.6 Hz, 1H), 8.70 (s, 1H), 8.40 (s, 1H), 7.98 (d, J = 8.4 Hz, 1H), 7.95−7.86 (m, 4H), 7.69 (dd, J = 8.3, 1.3 Hz, 2H), 7.65−7.57 (m, 2H), 7.50 (ddd, J = 7.6, 6.4, 1.4 Hz, 2H), 7.42 (qd, J = 8.2, 7.3, 2.2 Hz, 5H), 7.36−7.31 (m, 1H), 7.29−7.24 (m, 2H).^{13}C{^{1}H} NMR (101 MHz, chloroform-d) δ 147.6, 142.1 (d, J = 16.9 Hz), 141.6, 132.6, 132.5, 132.5 (d, J = 9.9 Hz), 132.3 (d, J = 2.7 Hz), 131.0 (d, J = 130.1 Hz), 130.7, 129.5, 128.8, 128.6 (d, J = 13.0 Hz), 128.5, 128.5, 128.3, 127.6, 127.1, 121.8, 94.9, 86.4. ^{31}P NMR (162 MHz, chloroform-d) δ 24.1. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{30}H_{23}N_3OP$ 472.1573; Found 472.1572.

Compound ***1p***. N'-(2-(Phenylethynyl)benzylidene)-P,P-di-*p*-tolylphosphinic hydrazide. Yield: 58% (1.41 mmol, 634 mg). R_f = 0.43 (cyclohexane/EA, 3:7). Aspect: White solid. ^{1}H NMR (400 MHz, chloroform-d) δ 8.48 (s, 1H), 7.78 (m, 6H), 7.55 (dd, J = 7.2, 2.0 Hz, 2H), 7.46 (d, J = 7.2 Hz, 1H), 7.29 (d, J = 6.1 Hz, 3H), 7.27−7.17 (m, 6H), 2.37 (s, 6H).^{13}C{^{1}H} NMR (101 MHz, chloroform-d) δ 143.5 (d, J = 16.3 Hz), 142.6 (d, J = 2.8 Hz), 135.6, 132.4 (d, J = 10.3 Hz), 132.3, 131.7, 129.3 (d, J = 13.4 Hz), 128.8, 128.6, 128.5, 128.5, 128.2 (d, J = 131.8 Hz), 125.3, 123.0, 122.3, 94.7, 86.7, 21.7. ^{31}P NMR (162 MHz, chloroform-d) δ 24.5. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{29}H_{25}N_2OP$ 449.1777; Found 449.1772.

Compound ***1q***. N'-(2-(Phenylethynyl)benzylidene)-P,P-di-o-tolylphosphinic hydrazide. Yield: 83% (2 mmol, 899 mg). R_f = 0.63 (cyclohexane/EA, 3:7). Aspect: White solid.^{1}H NMR (400 MHz, chloroform-d) δ 8.58 (s, 1H), 8.45 (d, J = 20.4 Hz, 1H), 7.78−7.65 (m, 3H), 7.60−7.54 (m, 2H), 7.48 (dd, J = 7.6, 1.5 Hz, 1H), 7.40 (tt, J = 7.5, 1.5 Hz, 2H), 7.23 (dddd, J = 18.9, 11.5, 9.7, 4.3 Hz, 9H), 2.50 (d, J = 1.3 Hz, 6H). ^{13}C{^{1}H} NMR (101 MHz, chloroform-d) δ 142.7 (d, J = 9.9 Hz), 142.6 (d, J = 16.6 Hz), 135.9, 133.5 (d, J = 11.3 Hz), 132.4, 132.2 (d, J = 2.7 Hz), 131.8, 131.6 (d, J = 12.0 Hz), 130.2 (d, J = 124.4 Hz), 128.6, 128.5, 128.5, 128.4, 125.6 (d, J = 13.2 Hz), 125.1, 123.0, 122.3, 94.8, 86.7, 21.8 (d, J = 4.1 Hz). ^{31}P NMR (121 MHz, chloroform-d) δ 29.60. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{29}H_{25}N_2OP$ 449.1777; Found 449.1774.

Compound ***1r***. N'-(2-(Phenylethynyl)benzylidene)-P,P-bis(3,4,5-trimethoxyphenyl)phosphinic hydrazide. Yield: 73% (0.44 mmol, 267 mg). R_f = 0.13 (cyclohexane/EA, 3:7). Aspect: Yellow solid. ^{1}H NMR (300 MHz, chloroform-d) δ 8.65 (s, 1H), 8.49 (d, J = 16.5 Hz, 1H), 7.83 (d, J = 6.3 Hz, 1H), 7.61−7.43 (m, 3H), 7.30−7.04 (m, 9H), 3.86 (s, 6H), 3.75 (s, 12H). ^{13}C{^{1}H} NMR (75 MHz, chloroform-d) δ 153.2 (d, J = 18.8 Hz), 144.1 (d, J = 16.3 Hz), 141.3, 135.4, 132.4, 131.6, 129.0, 128.5 (d, J = 12.3 Hz), 128.4, 125.7 (d, J = 131.5 Hz), 124.8, 122.8, 122.3, 109.3, 109.2, 94.9, 86.5, 60.9, 56.3. ^{31}P NMR (121 MHz, chloroform-d) δ 25.69. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{33}H_{34}N_2O_7P$ 601.2098; Found 601.2083.

Compound ***1s***. P,P-Bis(benzo[d][1,3]dioxol-5-yl)-N'-(2-(phenylethynyl)benzylidene)phosphinic hydrazide. Yield: 67% (0.79 mmol, 400 mg). R_f = 0.57 (cyclohexane/EA, 3:7). Aspect: White solid. ^{1}H NMR (300 MHz, chloroform-d) δ 8.42 (s, 1H), 7.90−7.72 (m, 1H), 7.61−7.53 (m, 2H), 7.49 (d, J = 8.5 Hz, 2H), 7.45 (d, J = 8.1 Hz, 1H), 7.39−7.23 (m, 8H), 6.88 (dd, J = 7.9, 2.3 Hz, 2H), 6.00 (d, J = 3.4 Hz, 4H). ^{13}C{^{1}H} NMR (75 MHz, chloroform-d) δ 150.9 (d, J = 3.0 Hz), 147.8 (d, J = 19.7 Hz), 143.9 (d, J = 16.8 Hz), 135.6, 132.2, 131.7, 128.7, 128.5, 128.4, 128,4, 127.9 (d, J = 10.9 Hz), 125.1, 124.5 (d, J = 135.3 Hz), 123.0, 122.2, 111.7 (d, J = 12.6 Hz), 108.6 (d, J = 16.3 Hz), 101.6, 94.7, 86.7. ^{31}P NMR (121 MHz, chloroform-d) δ 24.53. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{29}H_{22}N_2O_5P$ 509.1261; Found 509.1264.

Compound ***1t***. P,P-Bis(4-fluorophenyl)-N'-(2-(phenylethynyl)-benzylidene)phosphinic hydrazide. Yield: 67% (1 mmol, 460 mg). R_f = 0.53 (cyclohexane/EA, 3:7). Aspect: Beige solid. ^{1}H NMR (400 MHz, chloroform-d) δ 8.44 (s, 1H), 7.86 (dddd, J = 11.3, 8.4, 5.1, 2.3 Hz, 4H), 7.70 (dd, J = 7.7, 1.7 Hz, 1H), 7.61 (d, J = 18.3 Hz, 1H), 7.54−7.49 (m, 2H), 7.46 (dd, J = 7.6, 1.6 Hz, 1H), 7.34−7.26 (m, 3H), 7.26−7.20 (m, 2H), 7.11 (td, J = 8.8, 2.5 Hz, 4H). ^{13}C{^{1}H} NMR (101 MHz, chloroform-d) δ 165.5 (dd, J = 254.0, 3.4 Hz), 144.5 (d, J = 16.4 Hz), 135.1, 135.0 (dd, J = 11.3, 8.9 Hz), 132.5, 131.7, 129.3, 128.8, 128.6, 128.6, 127.0 (dd, J = 134.0, 3.4 Hz), 125.3, 122.9, 122.6, 116.1 (dd, J = 21.5, 14.2 Hz), 94.9, 86.5. ^{31}P NMR (162 MHz, chloroform-d) δ 22.39. ^{19}F NMR (376 MHz, Chloroform-d) δ −105.97. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{27}H_{20}F_2N_2OP$ 457.1276; Found 457.1271.

Compound ***1u***. P,P-Bis(4-chlorophenyl)-N'-(2-(phenylethynyl)-benzylidene)phosphinic hydrazide. Yield: 80% (0.54 mmol, 266 mg). R_f = 0.15 (cyclohexane/EA, 3:7). Aspect: White solid. ^{1}H NMR (400 MHz, chloroform-d) δ 8.59 (d, J = 17.9 Hz, 1H), 8.58 (s, 1H), 7.75 (dd, J = 11.9, 8.4 Hz, 4H), 7.67 (d, J = 7.5 Hz, 1H), 7.58−7.51 (m, 2H), 7.49−7.43 (m, 1H), 7.36 (dd, J = 8.4, 2.5 Hz, 4H), 7.32−7.16 (m, 5H). ^{13}C{^{1}H} NMR (101 MHz, chloroform-d) δ 144.8 (d, J = 17.1 Hz), 139.0 (d, J = 3.5 Hz), 135.2, 133.7 (d, J = 10.8 Hz), 132.4, 131.7, 129.6 (d, J = 131.9 Hz), 129.1, 129.0 (d, J = 13.7 Hz), 128.7, 128.6, 128.5, 125.1, 123.0, 122.5, 94.9, 86.6. ^{31}P NMR (162 MHz, chloroform-d) δ 23.41. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{27}H_{20}Cl_2N_2OP$ 489.0685; Found 489.0686.

Compound ***1v***. Ethyl (E)-phenyl(2-(2-(phenylethynyl)-benzylidene)hydrazineyl)phosphinate. Yield: 44% (0.51 mmol, 200 mg). R_f = 0.51 (cyclohexane/EA, 3:7). Aspect: Beige solid. ^{1}H NMR (300 MHz, chloroform-d) δ 8.48 (s, 1H), 8.28 (d, J = 23.7 Hz, 1H), 8.03−7.90 (m, 3H), 7.63−7.55 (m, 2H), 7.51 (dd, J = 6.8, 1.8 Hz, 2H), 7.47−7.39 (m, 2H), 7.36−7.27 (m, 5H), 4.34−4.19 (m, 2H), 1.39 (t, J = 7.1 Hz, 3H). ^{13}C{^{1}H} NMR (75 MHz, chloroform-d) δ 143.1 (d, J = 17.5 Hz), 135.6, 132.4, 132.2 (d, J = 3.0 Hz), 131.8 (d, J = 9.7 Hz), 131.8, 131.0, 128.9, 128.7, 128.6, 128.5, 128.4 (d, J = 14.9 Hz), 124.9, 123.0, 122.5, 95.1, 86.5, 61.5 (d, J = 6.6 Hz), 16.5 (d, J = 6.6 Hz). ^{31}P NMR (162 MHz, chloroform-d) δ 17.89. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{23}H_{22}N_2O_2P$ 389.1413; Found 389.1413.

Compound ***1w***. N'-(2-((4-Cyanophenyl)ethynyl)benzylidene)-P,P-diphenylphosphinic hydrazide. Yield: 76% (0.89 mmol, 395 mg). R_f = 0.29 (cyclohexane/EA, 3:7). Aspect: Beige solid. ^{1}H NMR (300 MHz, chloroform-d) δ 8.68 (d, J = 18.4 Hz, 1H), 8.58 (s, 1H), 7.90−7.81 (m, 4H), 7.77−7.71 (m, 1H), 7.63 (d, J = 8.3 Hz, 2H), 7.56−7.49 (m, 2H), 7.43 (m, 7H), 7.28−7.21 (m, 2H). ^{13}C{^{1}H} NMR (75 MHz, Chloroform-d) δ 143.5 (d, J = 16.7 Hz), 136.1, 132.4, 132.4, 132.4 (d, J = 2.7 Hz), 132.3, 132.2 (d, J = 12.1 Hz), 131.2 (d, J = 128.6 Hz), 129.3, 128.9, 128.5, 127.9, 125.2, 121.2, 118.6, 111.6, 93.1, 91.0. ^{31}P NMR (121 MHz, chloroform-d) δ 25.59. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{28}H_{21}N_3OP$ 446.1417; Found 446.1416.

Compound ***1x***. N'-(2-((3-Nitrophenyl)ethynyl)benzylidene)-P,P-diphenylphosphinic hydrazide. Yield: 85% (0.88 mmol, 409 mg). R_f = 0.77 (EA). Aspect: Beige solid. ^{1}H NMR (300 MHz, chloroform-d) δ 8.53 (s, 1H), 8.33 (s, 1H), 8.22 (d, J = 18.8 Hz, 1H), 8.12 (d, J = 8.3 Hz, 1H), 7.88 (dd, J = 12.4, 6.9 Hz, 5H), 7.80−7.72 (m, 1H), 7.56−7.36 (m, 8H), 7.30−7.21 (m, 2H). ^{13}C{^{1}H} NMR (75 MHz, chloroform-d) δ 148.1, 143.5 (d, J = 16.3 Hz), 137.7, 135.9, 132.6, 132.4 (d, J = 9.9 Hz), 132.3, 131.1 (d, J = 129.4 Hz), 129.5, 129.3, 129.0, 128.6 (d, J = 13.0 Hz), 126.3, 125.4, 124.8, 123.2, 121.2, 92.1, 89.2. ^{31}P NMR (121 MHz, chloroform-d) δ 24.41. HR-MS (ESI) m/z: $[M + H]^+$ Calcd for $C_{27}H_{21}FN_3O_3P$ 466.1315; Found 466.1310.

Compound ***1y***. N'-(5-Fluoro-2-(3-methoxyprop-1-yn-1-yl)-benzylidene)-P,P-diphenylphosphinic hydrazide. Yield: 91% (1.9

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mmol, 771 mg). R_f = 0.32 (cyclohexane/EA, 3:7). Aspect: Beige solid. ^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.58 (d, *J* = 19.4 Hz, 1H), 8.38 (s, 1H), 7.93−7.79 (m, 4H), 7.55−7.47 (m, 2H), 7.42 (td, *J* = 7.8, 3.2 Hz, 4H), 7.35−7.27 (m, 2H), 6.84 (td, *J* = 8.3, 2.7 Hz, 1H), 4.24 (s, 2H), 3.35 (s, 3H). ^{13}C{^{1}H} NMR (101 MHz, chloroform-*d*) δ 162.5 (d, *J* = 249.3 Hz), 142.9 (dd, *J* = 16.8, 2.6 Hz), 138.3 (d, *J* = 8.6 Hz), 134.4 (d, *J* = 8.5 Hz), 132.4 (d, *J* = 9.9 Hz), 132.3 (d, *J* = 2.8 Hz), 131.0 (d, *J* = 130.2 Hz), 128.6 (d, *J* = 13.0 Hz), 117.6 (d, *J* = 3.1 Hz), 116.2 (d, *J* = 23.0 Hz), 111.5 (d, *J* = 23.8 Hz), 89.9 (d, *J* = 1.6 Hz), 82.8, 60.4, 57.9. ^{31}P NMR (162 MHz, chloroform-*d*) δ 23.90. ^{19}F NMR (376 MHz, chloroform-*d*) δ −110.05. HR-MS (ESI) *m*/*z*: [M + H]$^+$ Calcd for $C_{23}H_{21}FN_2O_2P$ 407.1319; Found 407.1318.

Compound ***1z***. P,P-Diphenyl-*N*′-(2-((trimethylsilyl)ethynyl)-benzylidene)phosphinic hydrazide. Yield: 44% (1.16 mmol, 485 mg). R_f = 0.36 (cyclohexane/EA, 3:7). Aspect: Beige solid. ^{1}H NMR (300 MHz, chloroform-*d*) δ 8.36 (s, 1H), 7.91 (dd, *J* = 12.3, 7.0 Hz, 4H), 7.78 (d, *J* = 18.3 Hz, 1H), 7.73−7.67 (m, 1H), 7.46 (ddt, *J* = 15.7, 12.3, 7.4 Hz, 7H), 7.24−7.14 (m, 2H), 0.24 (s, 9H). ^{13}C{^{1}H} NMR (75 MHz, chloroform-*d*) δ 143.5 (d, *J* = 16.5 Hz), 135.6, 132.8, 132.4 (d, *J* = 9.9 Hz), 132.2 (d, *J* = 2.8 Hz), 131.3 (d, *J* = 129.2 Hz), 128.8, 128.66, 128.5 (d, *J* = 13.0 Hz), 125.1, 122.2, 102.1, 100.1, 0.1. ^{31}P NMR (121 MHz, chloroform-*d*) δ 24.42. HR-MS (ESI) *m*/*z*: [M + H]$^+$ Calcd for $C_{24}H_{26}N_2OPSi$ 417.1547; Found 417.1547.

General Procedure for the Synthesis of Phthalazines and Characterizations. To an oven-dried sealable glass vial was added phosphonohydrazone (0.150 mmol, 1 equiv), sodium hydroxide (0.225 mmol, 1.5 equiv), tris(2,2′-bipyridyl)dichlororuthenium(II) hexahydrate (0.00375 mmol, 2.5 mol %), and a mixture of EtOH (6 mL) and MeCN (2 mL). The vials were sealed with 20 mm crimp caps with silicone/PTFE septum and stirred 12 h under visible-light irradiation (Blue LED, 18 W). After completion of the reaction checked by TLC, the resulting suspension was filtered through a pad of Celite eluting with ethyl acetate. The crude filtrate was concentrated and purification of the residue by silica gel column chromatography eluting with a cyclohexane/ethyl acetate mixture gave the desired product.

Compound ***2a***. 1-Benzhydrylphthalazine: Yield: 65% (0.097 mmol, 28.8 mg). R_f = 0.65 (cyclohexane/EA, 3:7). Aspect: White solid. ^{1}H NMR (400 MHz, chloroform-*d*) δ 9.47 (s, 1H), 8.17 (d, *J* = 7.5 Hz, 2H), 8.01−7.94 (m, 1H), 7.89−7.78 (m, 3H), 7.33 (d, *J* = 6.7 Hz, 11H), 7.28−7.23 (m, 2H), 6.44 (s, 1H). ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 160.7, 150.6, 141.6, 132.7, 132.0, 129.6, 128.6, 127.3, 127.1, 126.9, 126.0, 124.3, 54.3. HR-MS (ESI) *m*/*z*: [M + Na]$^+$ Calcd for $C_{21}H_{16}N_2Na$ 319.1211; Found 319.1212. Consistent with literature.[16]

Compound ***2b***. 1-(Phenyl(p-tolyl)methyl)phthalazine. Yield: 62% (0.093 mmol, 28.9 mg). R_f = 0.69 (cyclohexane/EA, 3:7). Aspect: Yellow solid. ^{1}H NMR (300 MHz, chloroform-*d*) δ 9.48 (s, 1H), 8.15 (d, *J* = 8.9 Hz, 1H), 8.01−7.90 (m, 1H), 7.87−7.78 (m, 2H), 7.30 (d, *J* = 4.2 Hz, 4H), 7.20 (d, *J* = 7.9 Hz, 3H), 7.11 (d, *J* = 7.9 Hz, 2H), 6.38 (s, 1H), 2.30 (s, 3H). ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$) δ 160.8, 150.6, 141.8, 138.6, 136.5, 132.7, 131.9, 129.6, 129.5, 129.3, 128.6, 127.2, 127.0, 126.8, 125.9, 124.3, 53.9, 21.2. HR-MS (ESI) *m*/*z*: [M + Na]$^+$ Calcd for $C_{22}H_{18}N_2Na$ 333.1368; Found 333.1365. Consistent with literature.[16]

Compound ***2c***. 1-((4-Fluorophenyl)(phenyl)methyl)phthalazine. Yield: 49% (0.073 mmol, 22.9 mg). R_f = 0.71 (cyclohexane/EA, 3:7). Aspect: Yellow solid. ^{1}H NMR (300 MHz, acetone-d_6) δ 9.54 (s, 1H), 8.42−8.33 (m, 1H), 8.22−8.10 (m, 1H), 8.01−7.88 (m, 2H), 7.47−7.35 (m, 4H), 7.30 (t, *J* = 7.3 Hz, 2H), 7.22 (t, *J* = 7.1 Hz, 1H), 7.14−7.00 (m, 2H), 6.69 (s, 1H). ^{13}C{^{1}H} NMR (75 MHz, acetone-d_6) δ 162.5 (d, *J* = 224.9 Hz), 160.8, 151.3, 143.2, 139.3 (d, *J* = 3.2 Hz), 133.6, 133.0, 132.3 (d, *J* = 8.0 Hz), 130.3, 129.2, 128.1, 127.7, 127.5, 126.2, 124.9, 115.6 (d, *J* = 21.4 Hz), 53.0.^{19}F NMR (282 MHz, acetone-d_6) δ −118.08 to −118.24 (m). HR-MS (ESI) *m*/*z*: [M + H]$^+$ Calcd for $C_{21}H_{16}N_2F$ 315.1298; Found 315.1292. Consistent with literature.[16]

Compound ***2d***. 1-((6-methoxynaphthalen-2-yl)(phenyl)methyl)-phthalazine. Yield: 12% (0.019 mmol, 7 mg). R_f = 0.61 (cyclohexane/EA, 3:7). Aspect: Amorphous solid. ^{1}H NMR (400 MHz, chloroform-*d*) δ 9.45 (s, 1H), 8.18 (d, *J* = 8.1 Hz, 1H), 7.97−7.93 (m, 1H), 7.86−7.77 (m, 2H), 7.68 (d, *J* = 8.5 Hz, 1H), 7.59 (d, *J* = 7.5 Hz, 2H), 7.47 (dd, *J* = 8.5, 1.5 Hz, 1H), 7.37−7.24 (m, 5H), 7.09 (d, *J* = 7.7 Hz, 2H), 6.53 (s, 1H), 3.89 (s, 3H). ^{13}C{^{1}H} NMR (101 MHz, chloroform-*d*) δ 160.8, 157.8, 150.7, 141.7, 136.9, 133.6, 132.7, 132.0, 129.8, 129.6, 129.0, 128.6, 128.6, 127.9, 127.3, 127.2, 127.1, 126.9, 126.0, 124.4, 118.9, 105.8, 55.4, 54.3. HR-MS (ESI) *m*/*z*: [M + H]$^+$ Calcd for $C_{26}H_{21}N_2O$ 377.1648; Found 377.1649.

Compound ***2e***. 1-(Dibenzo[b,d]thiophen-2-yl(phenyl)methyl)-phthalazine. Yield: 44% (0.067 mmol, 26.5 mg). R_f = 0.64 (cyclohexane/EA, 3:7). Aspect: Yellow oil. ^{1}H NMR (300 MHz, chloroform-*d*) δ 9.47 (s, 1H), 8.19 (d, *J* = 7.0 Hz, 1H), 8.08 (s, 1H), 8.04−7.94 (m, 2H), 7.90−7.75 (m, 4H), 7.49−7.25 (m, 8H), 6.60 (s, 1H). ^{13}C{^{1}H} NMR (75 MHz, chloroform-*d*) δ 160.7, 150.8, 141.7, 139.9, 138.2, 138.1, 135.9, 135.5, 132.8, 132.1, 129.7, 128.7, 128.7, 127.3, 127.1, 127.1, 126.8, 125.9, 124.4, 124.3, 123.0, 122.9, 122.5, 121.8, 54.3. HR-MS (ESI) *m*/*z*: [M + H]$^+$ Calcd for $C_{27}H_{19}N_2S$ 403.1263; Found 403.1267.

Compound ***2f***. 1-(1-Phenylbutyl)phthalazine. Yield: 34% (0.051 mmol, 13.4 mg). R_f = 0.47 (cyclohexane/EA, 5:5). Aspect: Yellow solid. ^{1}H NMR (400 MHz, chloroform-*d*) δ 9.42 (s, 1H), 8.23−8.08 (m, 1H), 7.90 (d, *J* = 4.1 Hz, 1H), 7.84−7.77 (m, 2H), 7.43 (d, *J* = 7.5 Hz, 2H), 7.25 (q, *J* = 7.8, 5.6 Hz, 2H), 7.15 (t, *J* = 7.5 Hz, 1H), 4.82 (t, *J* = 7.5 Hz, 1H), 2.60 (dq, *J* = 14.0, 6.9 Hz, 1H), 2.30 (tt, *J* = 13.6, 7.2 Hz, 1H), 1.48−1.31 (m, 2H), 0.96 (t, *J* = 7.4 Hz, 3H). ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 160.7, 150.1, 143.3, 132.5, 131.8, 128.7, 128.3, 127.2, 126.9, 126.7, 126.0, 124.0, 48.2, 37.8, 21.4, 14.3. HR-MS (ESI) *m*/*z*: [M + H]$^+$ Calcd for $C_{18}H_{19}N_2$ 263.1543; Found 263.1546. Consistent with literature.[16]

Compound ***2h***. 1-Benzhydryl-6,7,8-trimethoxyphthalazine. Yield: 26% (0.039 mmol, 15.1 mg). R_f = 0.5 (EA). Aspect: Yellow solid. ^{1}H NMR (300 MHz, acetone-d_6) δ 9.28 (s, 1H), 7.90−7.78 (m, 1H), 7.63−7.47 (m, 2H), 7.42 (s, 1H), 7.27 (s, 2H), 7.25 (s, 3H), 7.22−7.14 (m, 2H), 7.04 (s, 1H), 4.06 (s, 3H), 3.93 (s, 3H), 3.78 (s, 3H). ^{13}C{^{1}H} NMR (101 MHz, acetone-d_6) δ 149.3, 132.6, 132.6, 132.2, 132.1, 131.9, 130.5, 129.3, 129.1, 128.5, 126.6, 103.2, 61.9, 61.0, 56.5, 55.5. HR-MS (ESI) *m*/*z*: [M + Na]$^+$ Calcd for $C_{24}H_{22}N_2O_3Na$ 409.1528; Found 409.1517. Consistent with literature.[16]

Compound ***2i***. 1-Benzhydryl-6-fluorophthalazine. Yield: 50% (0.075 mmol, 23.6 mg). R_f = 0.78 (cyclohexane/EA, 3:7). Aspect: Yellow solid. ^{1}H NMR (400 MHz, acetone-d_6) δ 9.56 (s, 1H), 8.51 (dd, *J* = 9.2, 5.1 Hz, 1H), 7.89 (dd, *J* = 8.5, 2.5 Hz, 1H), 7.77 (td, *J* = 9.0, 2.6 Hz, 1H), 7.37 (d, *J* = 7.6 Hz, 4H), 7.30 (t, *J* = 7.5 Hz, 4H), 7.22 (t, *J* = 7.2 Hz, 2H), 6.66 (s, 1H). ^{13}C{^{1}H} NMR (101 MHz, acetone-d_6) δ 164.4 (d, *J* = 253.3 Hz), 160.8 (d, *J* = 1.8 Hz), 151.0 (d, *J* = 4.4 Hz), 143.1, 130.5, 129.7 (d, *J* = 9.8 Hz), 129.1, 129.0, 127.4, 123.6 (d, *J* = 1.6 Hz), 123.2 (d, *J* = 24.9 Hz), 111.7 (d, *J* = 21.3 Hz), 54.1. ^{19}F NMR (376 MHz, acetone-d_6) δ −106.10. HR-MS (ESI) *m*/*z*: [M + H]$^+$ Calcd for $C_{21}H_{16}N_2F$ 315.1298; Found 315.1301. Consistent with literature.[16]

Compound ***2j***. 1-Benzhydryl-6-chlorophthalazine. Yield: 50% (0.075 mmol, 24.7 mg). R_f = 0.76 (cyclohexane/EA, 3:7). Aspect: White solid. ^{1}H NMR (400 MHz, chloroform-*d*) δ 9.35 (s, 1H), 8.04 (d, *J* = 8.9 Hz, 1H), 7.89 (s, 1H), 7.70 (dd, *J* = 8.9, 1.9 Hz, 1H), 7.31−7.16 (m, 10H), 6.33 (s, 1H). ^{13}C{^{1}H} NMR (101 MHz, chloroform-*d*) δ 160.5, 149.7, 141.2, 138.1, 133.6, 129.6, 128.7, 127.9, 127.1, 126.4, 126.2, 124.2, 54.5. HR-MS (ESI) *m*/*z*: [M + H]$^+$ Calcd for $C_{21}H_{16}ClN_2$ 331.0997; Found 331.0993. Consistent with literature.[16]

Compound ***2k***. 1-Benzhydryl-6-bromophthalazine. Yield: 11% (0.016 mmol, 6 mg). R_f = 0.69 (cyclohexane/EA, 4:6). Aspect: Amorphous solid. ^{1}H NMR (400 MHz, chloroform-*d*) δ 9.38 (s, 1H), 8.11 (d, *J* = 1.7 Hz, 1H), 7.98 (d, *J* = 8.9 Hz, 1H), 7.87 (dd, *J* = 8.9, 2.0 Hz, 1H), 7.37−7.34 (m, 2H), 7.31−7.29 (m, 3H), 7.29−7.27 (m, 5H), 6.35 (s, 1H). ^{13}C{^{1}H} NMR (101 MHz, chloroform-*d*) δ 160.7, 149.5, 141.4, 141.2, 136.3, 129.6, 128.7, 128.2, 127.1, 126.5, 126.4, 124.5, 54.5. HR-MS (ESI) *m*/*z*: [M + H]$^+$ Calcd for $C_{21}H_{16}BrN_2$ 375.0491; Found 375.0489.

Compound ***2m***. 4-Benzhydryl-5-methyl-5H-pyridazino[4,5-*b*]-indole. Yield: 37% (0.056 mmol, 19.4 mg). R_f = 0.71 (cyclohexane/

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EA, 3:7). Aspect: Beige solid. ^{1}H NMR (400 MHz, chloroform-*d*) δ 9.74 (s, 1H), 8.20 (d, J = 7.8 Hz, 1H), 7.67 (t, J = 7.6 Hz, 1H), 7.51 (d, J = 8.5 Hz, 1H), 7.44 (t, J = 7.5 Hz, 1H), 7.29 (m, 4H), 7.25 (m, 6H), 6.53 (s, 1H), 4.05 (s, 3H). ^{13}C{^{1}H} NMR (101 MHz, chloroform-*d*) δ 149.8, 142.3, 141.8, 141.6, 135.9, 129.9, 129.4, 128.7, 127.1, 122.2, 121.6, 120.3, 119.8, 110.5, 54.4, 32.9. HR-MS (ESI) m/z: [M + H]$^+$ Calcd for $C_{24}H_{19}N_3$ 350.1652; Found 350.1651.

Compound ***2n***. 4-Benzhydrylbenzofuro[2,3-*d*]pyridazine. Yield: 31% (0.046 mmol, 15.5 mg). R_f = 0.77 (cyclohexane/EA, 3:7). Aspect: Beige solid. ^{1}H NMR (400 MHz, chloroform-*d*) δ 9.79 (s, 1H), 8.08 (d, J = 7.8 Hz, 1H), 7.67 (d, J = 6.8 Hz, 2H), 7.49 (dd, J = 20.3, 7.0 Hz, 5H), 7.32 (t, J = 7.5 Hz, 4H), 7.28−7.22 (m, 2H), 6.39 (s, 1H). ^{13}C{^{1}H} NMR (101 MHz, chloroform-*d*) δ 156.2, 152.8, 152.3, 144.2, 140.7, 131.0, 129.5, 128.6, 127.1, 125.0, 122.9, 122.5, 120.1, 113.1, 52.8. HR-MS (ESI) m/z: [M + H]$^+$ Calcd for $C_{23}H_{16}N_2O$ 337.1335; Found 337.1334.

Compound ***2p***. 1-(Phenyl(*p*-tolyl)methyl)phthalazine. Yield: 52% (0.078 mmol, 24.2 mg). R_f = 0.69 (cyclohexane/EA, 3:7). Aspect: Yellow solid. ^{1}H NMR (300 MHz, chloroform-*d*) δ 9.48 (s, 1H), 8.15 (d, J = 8.9 Hz, 1H), 8.01−7.90 (m, 1H), 7.87−7.78 (m, 2H), 7.30 (d, J = 4.2 Hz, 4H), 7.20 (d, J = 7.9 Hz, 3H), 7.11 (d, J = 7.9 Hz, 2H), 6.38 (s, 1H), 2.30 (s, 3H). ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$) δ 160.8, 150.6, 141.8, 138.6, 136.5, 132.7, 131.9, 129.6, 129.5, 129.3, 128.6, 127.2, 127.0, 126.8, 125.9, 124.3, 53.9, 21.2. HR-MS (ESI) m/z: [M + Na]$^+$ Calcd for $C_{22}H_{18}N_2Na$ 333.1368; Found 333.1365. Consistent with literature.[16]

Compound ***2q***. 1-(Phenyl(*o*-tolyl)methyl)phthalazine. Yield: 32% (0.048 mmol, 14,8 mg). R_f = 0.88 (cyclohexane/EA, 3:7). Aspect: Amorphous solid. ^{1}H NMR (300 MHz, acetone-d_6) δ 9.53 (s, 1H), 8.26−8.11 (m, 2H), 7.99−7.87 (m, 2H), 7.31 (d, J = 4.3 Hz, 4H), 7.26−7.19 (m, 2H), 7.10 (dt, J = 23.2, 7.2 Hz, 2H), 6.87 (d, J = 7.5 Hz, 1H), 6.71 (s, 1H), 2.27 (s, 3H). ^{13}C{^{1}H} NMR (75 MHz, acetone-d_6) δ 161.3, 151.3, 142.0, 141.9, 136.9, 133.6, 133.0, 131.3, 131.0, 130.1, 129.0, 128.1, 127.7, 127.5, 127.4, 126.6, 126.3, 124.9, 51.3, 20.1. HR-MS (ESI) m/z: [M + H]$^+$ Calcd for $C_{22}H_{18}N_2$ 311.1543; Found 311.1543.

Compound ***2r***. 1-(Phenyl(3,4,5-trimethoxyphenyl)methyl)-phthalazine. Yield: 34% (0.045 mmol, 17.5 mg). R_f = 0.76 (EA). Aspect: Yellow solid. ^{1}H NMR (400 MHz, chloroform-*d*) δ 9.49 (s, 1H), 8.17 (d, J = 8.7 Hz, 1H), 7.99 (dd, J = 5.8, 3.0 Hz, 1H), 7.92−7.81 (m, 2H), 7.30 (d, J = 4.2 Hz, 4H), 7.25−7.20 (m, 1H), 6.53 (s, 2H), 6.34 (s, 1H). ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$) δ 160.7, 153.3, 150.7, 141.5, 137.1, 136.9, 132.8, 132.1, 129.5, 128.6, 128.3, 127.3, 127.0, 125.9, 124.2, 106.9, 60.9, 56.2, 54.3. HR-MS (ESI) m/z: [M + H]$^+$ Calcd for $C_{24}H_{23}N_2O_3$ 387.1703; Found 387.1703. Consistent with literature.[16]

Compound ***2s***. 1-(Benzo[d][1,3]dioxol-5-yl(phenyl)methyl)-phthalazine. Yield: 47% (0.071 mmol, 24 mg). R_f = 0.52 (cyclohexane/EA, 3:7). Aspect: Yellow oil. ^{1}H NMR (400 MHz, chloroform-*d*) δ 9.42 (s, 1H), 8.14−8.06 (m, 1H), 7.96−7.89 (m, 1H), 7.86−7.75 (m, 2H), 7.28−7.23 (m, 4H), 7.20 (q, J = 4.5 Hz, 1H), 6.81 (d, J = 1.6 Hz, 1H), 6.73−6.68 (m, 2H), 6.29 (s, 1H), 5.88 (d, J = 3.3 Hz, 2H).^{13}C{^{1}H} NMR (101 MHz, chloroform-*d*) δ 150.7, 147.9, 146.6, 141.7, 135.5, 132.8, 132.0, 129.5, 128.7, 127.3, 127.0, 127.0, 125.9, 124.3, 122.7, 122.7, 110.4, 108.2, 101.1, 53.9. HR-MS (ESI) m/z: [M + H]$^+$ Calcd for $C_{22}H_{17}N_2O_2$ 341.1285; Found 341.1288.

Compound ***2t***. 1-((4-Fluorophenyl)(phenyl)methyl)phthalazine. Yield: 42% (0.063 mmol, 19.8 mg). R_f = 0.66 (cyclohexane/EA, 3:7). Aspect: Yellow solid. ^{1}H NMR (400 MHz, chloroform-*d*) δ 9.42 (s, 1H), 8.14−8.04 (m, 1H), 7.99−7.88 (m, 1H), 7.81 (tt, J = 7.2, 5.5 Hz, 2H), 7.29−7.18 (m, 7H), 6.96 (t, J = 8.7 Hz, 2H), 6.35 (s, 1H). ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$) δ 161.8 (d, J = 245.5 Hz), 160.5, 150.7, 141.5, 137.3 (d, J = 3.2 Hz), 132.8, 132.1, 131.3, 131.2, 129.4, 128.8, 127.3, 127.1, 125.8, 124.1, 115.4 (d, J = 21.2 Hz), 53.4. ^{19}F NMR (376 MHz, chloroform-*d*) δ −116.26. HR-MS (ESI) m/z: [M + H]$^+$ Calcd for $C_{21}H_{16}FN_2$ 315.1292; Found 315.1294. Consistent with literature.[16]

Compound ***2u***. 1-((4-Chlorophenyl)(phenyl)methyl)phthalazine. Yield: 41% (0.061 mmol, 20.3 mg). R_f = 0.56 (cyclohexane/EA, 3:7). Aspect: Yellow solid. ^{1}H NMR (400 MHz, chloroform-*d*) δ 9.45 (s, 1H), 8.10 (d, J = 7.8 Hz, 1H), 7.96 (d, J = 7.6 Hz, 1H), 7.85 (p, J = 7.1 Hz, 2H), 7.28 (t, J = 8.8 Hz, 9H), 6.36 (s, 1H). ^{13}C{^{1}H} NMR (101 MHz, chloroform-*d*) δ 160.3, 150.8, 141.2, 140.2, 132.9, 132.8, 132.1, 131.1, 129.5, 128.8, 128.7, 127.4, 127.2, 127.1, 125.9, 124.1, 53.6. HR-MS (ESI) m/z: [M + H]$^+$ Calcd for $C_{21}H_{16}ClN_2$ 331.0997; Found 331.0994.

Compound ***3a***. 1-Benzylphthalazine. Yield: 58% (0.174 mmol, 38.3 mg). Consistent with literature.[12]

Compound ***3w***. 4-(Phthalazin-1-ylmethyl)benzonitrile. Yield: 51% (0.076 mmol, 18.7 mg). Consistent with literature.[12]

Compound ***3x***. 1-(3-Nitrobenzyl)phthalazine. Yield: 79% (0.12 mmol, 31.5 mg). R_f = 0.49 (EA). Aspect: Amorphous solid. ^{1}H NMR (300 MHz, chloroform-*d*) δ 9.49 (d, J = 1.0 Hz, 1H), 8.22 (t, J = 2.1 Hz, 1H), 8.11−7.95 (m, 3H), 7.94−7.84 (m, 2H), 7.68 (ddd, J = 7.7, 1.9, 1.0 Hz, 1H), 7.44 (t, J = 7.9 Hz, 1H), 4.84 (s, 2H). ^{13}C{^{1}H} NMR (75 MHz, chloroform-*d*) δ 157.9, 151.3, 148.5, 140.2, 135.2, 133.1, 132.6, 129.8, 127.4, 127.1, 125.7, 124.0, 123.7, 122.1, 39.4. HR-MS (ESI) m/z: [M + H]$^+$ Calcd for $C_{15}H_{12}N_3O_2$ 266.0924; Found 266.0923.

Compound ***3y***. 6-Fluoro-1-(2-methoxyethyl)phthalazine. Yield: 72% (0.11 mmol, 22.2 mg). R_f = 0.18 (cyclohexane/EA, 3:7). Aspect: Amorphous solid. ^{1}H NMR (300 MHz, chloroform-*d*) δ 9.40 (s, 1H), 8.25 (dd, J = 9.1, 5.0 Hz, 1H), 7.65 (td, J = 8.8, 2.5 Hz, 1H), 7.55 (dd, J = 8.0, 2.4 Hz, 1H), 3.97 (t, J = 6.7 Hz, 2H), 3.61 (t, J = 6.7 Hz, 2H), 3.35 (s, 3H). ^{13}C{^{1}H} NMR (101 MHz, chloroform-*d*) δ 164.0 (d, J = 256.6 Hz), 158.1, 150.3, 128.8, 128.3 (d, J = 9.0 Hz), 123.6, 122.6 (d, J = 24.6 Hz), 110.7 (d, J = 21.0 Hz), 71.6, 59.0, 33.5. ^{19}F NMR (282 MHz, Methanol-d_4) δ −103.16. HR-MS (ESI) m/z: [M + H]$^+$ Calcd for $C_{11}H_{12}FN_2O$ 207.0928; Found 207.0931.

Compound ***3z***. 1-Methylphthalazine. Yield: 77% (0.12 mmol, 16.6 mg). Consistent with literature.[12]

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.joc.0c02540.

Full spectroscopic data for all new compounds (PDF)

Accession Codes

CCDC 2030922 and 2031023 contain the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

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The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

Notes

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