SUPPORTING INFORMATION

A convergent formal [4+2] cycloaddition of 1,6-diynes and benzyl

azides: construction of spiro-polyheterocycles

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General Information

All reactions were carried out in oven-dried glassware. Solvents were dried by the standard methods. Flash column chromatography was performed using silica gel (300-400 mesh). Analytical thin-layer chromatography was performed using glass plates pre-coated with 200-300 mesh silica gel impregnated with a fluorescent indicator (254 nm). ¹H NMR and ¹³C NMR spectra were recorded in CDCl₃ on a 400 MHz spectrometer; chemical shifts were reported in ppm with the solvent signal as reference, and coupling constants (*J*) were given in Hertz. The peak information was described as: br = broad, s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, comp = composite. High-resolution mass spectra (HRMS) were recorded on a commercial apparatus (ESI or CI Source).

General Procedure for the Preparation of 1,6-Diynes 1.¹⁻⁴



<u>Synthesis of S-3</u>:¹ To a 50-mL oven-dried flask containing a magnetic stirring bar, S-1 (2.1 g, 10 mmol), propargyl alcohol S-2 (11 mmol, 1.1 equiv.), PPh₃ (3.934g, 1.5 equiv.), dry THF (30 mL), and DIAD (3.033g, 1.5 equiv.) were added in sequence at 0 ^oC. The reaction mixture was stirred at room temperature for 4-5 hours. Upon completion (monitored by TLC), the solvent was evaporated in *vacuo*. The residue was purified by column chromatography on silica gel (Hexanes : EtOAc = 20:1) to give the products S-3 as white solid in > 80% yields.



<u>Synthesis of 1a-1h</u>² To a 50-mL oven-dried flask containing a magnetic stirring bar,

aryl iodides **S-4** (2.2 mmol, 1.1 equiv.), $PdCl_2(PPh_3)_2$ (28.0 mg, 0.02 equiv.), CuI (3.8 mg, 0.01 equiv.), compound **S-3** (2.0 mmol), diisopropyl amine (4.0 mL), and THF (20 mL) were added in sequence under argon atmosphere at room temperature. The reaction mixture was stirred for 5-6 hours under these conditions. Then the reaction mixture was filtered through a short pad of Celite and the solid was washed with EtOAc (20.0 mL). The combined organic phase was concentrated under reduced pressure, and the residue was purified by column chromatography on silica gel (Hexanes : EtOAc = 10:1) to afford pure proudcts **1** in >80% yields.



Synthesis of 1*j*, **1***k*:³ To a 50-mL oven-dried flask containing a magnetic stirring bar, compound **S-5** (5.0 mmol) in THF (25 mL) was added NaH (500 mg, 60% suspension in mineral oil, 2.5 equiv.) slowly and the reaction mixture was stirred for 30 min at 0 °C. Then propargyl bromine **S-6** (2.145 g, 11.0 mmol, 2.2 equiv.) was added drop wise, and the reaction mixture was stirred for 4 hours at room temperature. Then H₂O (10 mL) was added to quench the reaction, and the aqueous layer was extracted with ether (3×10 mL), the combined organic layers was washed with brine and dried over anhydrous Na₂SO₄. The solvent was evaporated in vacuo after filtration, and the residue was purified by column chromatography on silica gel (Hexanes : EtOAc = 15:1) to afford compound **1***j*, **1***k* in > 85% yields.



<u>Synthesis of 11</u>:⁴ To a 50-mL oven-dried flask containing a magnetic stirring bar, acetylacetone (200.1 mg, 2.0 mmol), Cs_2CO_3 (1.952 g, 6.0 mmol, 3.0 equiv.), and

acetone (25 mL) were added in sequence at room temperature, and the reaction mixture was stirred for 30 min under these conditions. Then propargyl bromine **S-6** (1.164 g, 6.0 mmol, 3.0 equiv.) was added drop wise, and the reaction mixture was stirred for 4 hours at room temperature. Then H₂O (10 mL) were added to quench the reaction, and the aqueous layer was extracted with ether (3×10 mL), the combined organic layers was washed with brine and dried over anhydrous Na₂SO₄, The solvent was evaporated in vacuo after filtration, and the residue was purified by column chromatography on silica gel (Hexanes : EtOAc = 15:1) to afford compound **11** in 75% yield.

General Procedure for the Preparation of Azides 2.⁵



<u>Synthesis of 2</u>:⁵ To a 50-mL oven-dried flask containing a magnetic stirring bar, and bromides S-7 (3.0 mmol) in mixed solvent (acetone/H₂O = 4 : 1, 15.0 mL), was added NaN₃ (292.5 mg, 4.5 mmol, 1.5 equiv.) at room temperature, and the reaction mixture was stirred overnight under these conditions. Then the reaction mixture was diluted with dichloromethane (20 mL) and washed with saturated aqueous NaCl (20 mL). The organic phase was dried over Na₂SO₄ and the solvent was evaporated in *vacuo* after filtration. The residue was purified by column chromatography on silica gel (Hexanes : EtOAc = 50:1) to afford pure products **2** in > 90% yields.



4-Methyl-*N*,*N*-**bis(3-phenylprop-2-ynyl)benzenesulfonamide** (1a).⁶ Yellow solid, mp = 80.5-83.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ, ppm) 7.78 – 7.76 (d, 2H), 7.29 – 7.18 (comp, 12H), 4.42 (s, 4H), 2.29 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ, ppm) 143.9, 135.3, 131.7, 129.6, 128.5, 128.2, 128.0, 112.2, 85.8, 81.7, 37.5, 21.4; HRMS

(TOF MS CI⁺) calculated for $C_{25}H_{22}NO_2S[M+H]^+$: 400.1366, found 400.1369.



N-(3-(4-Methoxyphenyl)prop-2-ynyl)-4-methyl-*N*-(3-phenylprop-2-ynyl)benzenes ulfonamide (1b). Yellow solid, mp = 76.5-78.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.77 (d, *J* = 8.2 Hz, 2H), 7.31 – 7.10 (comp, 9H), 6.76 (d, *J* = 8.8 Hz, 2H), 4.43 (s, 2H), 4.42 (s, 2H), 3.75 (s, 3H), 2.28 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 159.7, 143.8, 135.3, 133.1, 131.6, 129.6, 128.5, 128.1, 127.9, 122.2, 114.2, 113.8, 85.73, 85.72, 81.71, 80.2, 55.2, 37.6, 37.4, 21.4; HRMS (TOF MS CI⁺) calculated for C₂₆H₂₄NO₃S [M+H]⁺: 430.1471, found 430.1478.



N,N-Bis(3-(4-fluorophenyl)prop-2-ynyl)-4-methylbenzenesulfonamide (1c). Yellow solid, mp = 93.5-95.5 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.82 (d, *J* = 8.1 Hz, 2H), 7.32 – 7.17 (comp, 6H), 6.97 (t, *J* = 8.6 Hz, 4H), 4.45 (s, 4H), 2.34 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 162.6 (d, *J* = 250.0 Hz), 143.9, 135.4, 133.6 (d, *J* = 8.4 Hz), 129.6, 128.0, 118.3 (d, *J* = 3.5 Hz), 115.5 (d, *J* = 22.1 Hz), 84.8, 81.5, 37.5, 21.4; ¹⁹F NMR (376 MHz, CDCl₃) (δ , ppm) -110.28; HRMS (TOF MS CI⁺) calculated for C₂₅H₂₀F₂NO₂S [M+H]⁺: 436.1177, found 436.1182.



N,N-Bis(3-(4-chlorophenyl)prop-2-ynyl)-4-methylbenzenesulfonamide (1d). Yellow solid, mp = 142.5-145.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.79 (d, *J* = 8.3 Hz, 2H), 7.28 – 7.20 (comp, 6H), 7.19 – 7.07 (comp, 4H), 4.43 (s, 4H), 2.33 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 144.0, 135.5, 134.7, 133.0, 129.7, 128.6, 128.1, 120.7, 84.8, 82.8, 37.6, 21.5; HRMS (TOF MS Cl⁺) calculated for C₂₅H₂₀Cl₂NO₂S [M+H]⁺: 468.0586, found 468.0588.



4-Methyl-*N***,***N***-bis(3***-p***-tolylprop-2-ynyl)benzenesulfonamide (1e).** Yellow solid, mp = 110.5-113.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.8 (d, *J* = 8.2 Hz, 2H), 7.25 (d, *J* = 8.1 Hz, 2H), 7.12 (d, *J* = 8.1 Hz, 4H), 7.07 (d, *J* = 8.0 Hz, 4H), 4.45 (s, 4H), 2.33 (s, 9H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 143.8, 138.7, 135.5, 131.6, 129.6, 129.0, 128.0, 119.2, 85.9, 81.0, 37.5, 21.49, 21.47; HRMS (TOF MS CI⁺) calculated for C₂₇H₂₆NO₂S [M+H]⁺: 428.1679, found 428.1686.



N,N-Bis(3-(4-methoxyphenyl)prop-2-ynyl)-4-methylbenzenesulfonamide (1g). Yellow oil; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.78 (d, *J* = 8.3 Hz, 2H), 7.23 (d, *J* = 7.9 Hz, 2H), 7.14 (d, *J* = 8.9 Hz, 4H), 6.77 (d, *J* = 8.9 Hz, 4H), 4.42 (s, 4H), 3.76 (s, 6H), 2.31 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 159.7, 143.7, 135.4, 133.1, 129.5, 127.9, 114.2, 113.8, 85.6, 80.2, 55.2, 37.5, 21.4; HRMS (TOF MS CI⁺) calculated for C₂₇H₂₆NO₄S [M+H]⁺: 460.1577, found 460.1591.



4-Methyl-*N*,*N***-bis(3-***m***-tolylprop-2-ynyl)benzenesulfonamide (1h).** Yellow solid, mp = 89.0-91.5 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.84 (d, *J* = 8.3 Hz, 2H), 7.27 (d, *J* = 8.0 Hz, 2H), 7.15 (comp, 4H), 7.06 (d, *J* = 7.2 Hz, 4H), 4.48 (s, 4H), 2.34 (s, 3H), 2.30 (s, 6H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 143.7, 137.8, 135.4, 132.2, 129.6, 129.4, 128.7, 128.1, 128.0, 122.0, 86.0, 81.3, 37.6, 21.4, 21.1; HRMS (TOF MS CI⁺) calculated for C₂₇H₂₆NO₂S [M+H]⁺: 428.1679, found 428.1688.



3,3'-Oxybis(prop-1-yne-3,1-diyl)dibenzene (1i).⁶ Yellow oil; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.59 – 7.46 (comp, 4H), 7.40 – 7.31 (comp, 6H), 4.58 (s, 4H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 131.8, 128.6, 128.3, 122.5, 86.9, 84.5, 84.5, 57.4; HRMS (TOF MS CI⁺) calculated for C₁₈H₁₅O [M+H]⁺: 247.1117, found 247.1124.



Diethyl 2,2-bis(3-phenylprop-2-ynyl)malonate (1j). White solid, mp = 55.5-58.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.41 (comp, 4H), 7.29 (comp, 6H), 4.29 (q, J = 7.1 Hz, 4H), 3.30 (d, J = 1.1 Hz, 4H), 1.31 (d, J = 7.1 Hz, 6H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 169.0, 131.8, 128.3, 128.1, 123.2, 84.2, 83.8, 62.0, 57.2, 23.8, 14.2; HRMS (TOF MS CI⁺) calculated for C₂₅H₂₅O₃ [M+H]⁺: 389.1747, found 389.1762.



Ethyl 2-benzoyl-5-phenyl-2-(3-phenylprop-2-ynyl)pent-4-ynoate (1k).⁶ White solid, mp = 105.5-107.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.98 – 7.91 (m, 2H), 7.60 – 7.54 (m, 1H), 7.46 (m, 2H), 7.43 – 7.36 (comp, 4H), 7.33 – 7.27 (comp, 6H), 4.30 (q, *J* = 7.1 Hz, 2H), 3.50 (q, *J* = 17.5 Hz, 4H), 1.22 (t, *J* = 7.1 Hz, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 194.2, 170.7, 135.7, 133.0, 131.7, 128.7, 128.3, 128.2, 128.1, 123.1, 84.4, 84.1, 62.2, 60.8, 24.8, 14.0; HRMS (TOF MS CI⁺) calculated for C₂₉H₂₅O₃ [M+H]⁺: 421.1798, found 421.1805.



3,3-Bis(3-phenylprop-2-ynyl)pentane-2,4-dione (11).⁶ White solid, mp = 84.0-86.5 °C; ¹H NMR (400 MHz, CDCl₃) (δ, ppm) 7.37 (comp, 4H), 7.29 – 7.21 (comp, 6H),

3.29 (s, 4H), 2.23 (s, 6H).; ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 202.7, 131.5, 128.1, 128.1, 122.7, 84.3, 84.1, 70.3, 26.3, 22.1; HRMS (TOF MS CI⁺) calculated for C₂₃H₂₁O₂ [M+H]⁺: 329.1536, found 329.1548.



(Azidomethyl)benzene (2a).⁷ Colorless liquid; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.53 – 7.29 (comp, 5H), 4.36 (s, 2H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 135.4, 128.8, 128.3, 128.2, 54.7; HRMS (TOF MS ESI⁺) calculated for C₇H₈N₃ [M+H]⁺: 134.0713, found 134.0710.



1-(Azidomethyl)-4-fluorobenzene (2m).⁷ Colorless liquid; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.39 – 7.26 (m, 2H), 7.14 – 7.02 (m, 2H), 4.31 (s, 2H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 162.7 (d, *J* = 246.9 Hz), 131.3 (d, *J* = 3.2 Hz), 130.0 (d, *J* = 8.3 Hz), 115.8 (d, *J* = 21.6 Hz), 54.0; ¹⁹F NMR (376 MHz, CDCl₃) (δ , ppm) -113.57; HRMS (TOF MS ESI⁺) calculated for C₇H₇FN₃ [M+H]⁺: 152.0619, found 152.0618.



1-(Azidomethyl)-4-chlorobenzene (2n).⁷ Colorless liquid; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.38 (d, J = 8.4 Hz, 2H), 7.28 (d, J = 8.4 Hz, 2H), 4.34 (s, 2H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 134.1, 133.9, 129.5, 129.0, 54.0; HRMS (TOF MS CI⁺) calculated for C₇H₇ClN₃ [M+H]⁺: 168.0323, found 168.0334.



1-(Azidomethyl)-4-bromobenzene (20).⁷ Colorless liquid; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.51 (d, J = 8.4 Hz, 2H), 7.19 (d, J = 8.5 Hz, 2H), 4.29 (s, 2H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 134.4, 131.9, 129.8, 122.3, 54.0; HRMS (TOF MS CI⁺) calculated for C₇H₇BrN₃ [M+H]⁺: 211.9818, found 211.9834.



1-(Azidomethyl)-4-methylbenzene (2p).⁷ Colorless liquid; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.25 – 7.17 (comp, 4H), 4.30 (s, 2H), 2.38 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 138.3, 132.4, 129.6, 128.4, 54.7, 27.04; HRMS (TOF MS CI⁺) calculated for C₈H₁₀N₃ [M+H]⁺: 148.0869, found 148.0866.



1-(Azidomethyl)-4-ethylbenzene (2q). Colorless liquid; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.42 – 7.29 (comp, 4H), 4.39 (s, 2H), 2.81 (q, *J* = 7.6 Hz, 2H), 1.41 (t, *J* = 7.6 Hz, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 144.2, 132.6, 128.2, 128.2, 54.4, 28.5, 15.4; HRMS (TOF MS CI⁺) calculated for C₉H₁₂N₃ [M+H]⁺: 162.1026, found 162.1030.



1-(Azidomethyl)-4-methoxybenzene (2r). Colorless liquid; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.28 (d, J = 8.6 Hz, 2H), 6.95 (d, J = 8.6 Hz, 2H), 4.30 (s, 2H), 3.85 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 159.7, 129.8, 127.5, 114.3, 55.4, 54.5; HRMS (TOF MS CI⁺) calculated for C₈H₁₀N₃O [M+H]⁺: 164.0818, found 164.0828.



1-(Azidomethyl)-4-nitrobenzene (2s).⁷ Yellow liquid; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 8.23 (d, *J* = 7.2 Hz, 2H), 7.49 (d, *J* = 8.6 Hz, 2H), 4.50 (s, 2H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 147.8, 142.8, 128.7, 124.1, 53.8; HRMS (TOF MS CI⁺) calculated for C₇H₇N₄O₂ [M+H]⁺: 179.0564, found 179.0567.

N₃

1-(Azidomethyl)naphthalene (2t). Colorless liquid; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 8.14 (d, *J* = 8.3 Hz, 1H), 8.04 – 7.91 (m, 2H), 7.73 – 7.61 (m, 2H), 7.58 – 7.49 (m, 2H), 4.78 (s, 2H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 133.8, 131.2, 130.9, 129.3, 128.7, 127.1, 126.6, 126.1, 125.1, 123.4, 52.7; HRMS (TOF MS CI⁺) calculated for C₁₁H₁₀N₃ [M+H]⁺: 184.0869, found 184.0872.



1-(Azidomethyl)-2-methylbenzene (2u). Colorless liquid; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.31 – 7.22 (comp, 4H), 4.37 (s, 2H), 2.39 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 136.9, 133.5, 130.8, 129.4, 128.7, 126.3, 53.1, 19.1; HRMS (TOF MS CI⁺) calculated for C₈H₁₀N₃ [M+H]⁺: 148.0869, found 148.0864.

1-(Azidomethyl)-3-methylbenzene (2v). Colorless liquid; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.31 (m, 1H), 7.17 (t, *J* = 11.9 Hz, 3H), 4.32 (s, 2H), 2.41 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 138.7, 135.4, 129.1, 129.0, 128.8, 125.4, 54.9, 21.4; HRMS (TOF MS CI⁺) calculated for C₈H₁₀N₃ [M+H]⁺: 148.0869, found 148.0867.

General Procedure for the Convergent [4+2] Cycloaddition.

To a 10-mL oven-dried vial with a magnetic stirring bar, 1,6-diynes compounds **1** (0.2 mmol), PPh₃AuNTf₂ (7.4 mg, 5.0 mol%), and anhydrous DCE (1.0 mL) were added in sequence under atmosphere of argon, and the reaction mixture was stirred at 60 °C for 5 hours. When the reaction was completed (monitored by TLC), azides **2** (0.4 mmol, 2.0 equiv.) in anhydrous DCE (1.0 mL), and TfOH (36 μ L, 2.0 equiv.) in anhydrous DCE (0.5 mL), were added in sequence to the solution under atmosphere

of argon, and the reaction mixture was stirred at room temperature overnight. When the reaction was completed (monitored by TLC), the crude reaction mixture was quenched with saturated aqueous sodium bicarbonate (10.0 mL) and extracted with EtOAc (15.0 mL). The combined organic layer was washed with brine and dried over anhydrous Na₂SO₄. The solvent was evaporated in *vacuo* after filtration. The residue was purified by flash column chromatography on silica gel (Hexanes : EtOAc = 5:1 to 3:1) to give the pure products **3** in high yields.

Procedure for the Synthesis of 3c and 3d: To a 10-mL oven-dried vial with a magnetic stirring bar, 1,6-diynes compounds 1c or 1d (0.5 mmol), PPh₃AuNTf₂ (18.5 mg, 5.0 mol%), and anhydrous DCE (1.0 mL) were added in sequence under atmosphere of argon, and the reaction mixture was stirred at 60 °C for 5 hours. When the reaction was completed (monitored by TLC), azides 2a (53.2 mg, 0.2 mmol,) in anhydrous DCE (1.0 mL), TfOH (18 μ L, 0.2 mmol) in anhydrous DCE (0.5 mL), were added in sequence under atmosphere of argon, and the reaction mixture was stirred at room temperature overnight. When the reaction was completed (monitored by TLC), the crude reaction mixture was quenched with saturated aqueous sodium bicarbonate (10.0 mL) and extracted with EtOAc (15.0 mL). The combined organic layer was washed with brine and dried over anhydrous Na₂SO₄. The solvent was evaporated in *vacuo* after filtration. The residue was purified by flash column chromatography on silica gel (Hexanes : EtOAc = 5:1 to 3:1) to give the pure products **3c** and **3d** in 76% and 75% yields, respectively.



6-Phenyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][2,7]naphthyridine (3a). 82.6 mg, 82% yield. White solid, mp = 110.5-113.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ, ppm) 7.56 (d, *J* = 4.4 Hz, 6H), 7.51 – 7.45 (m, 1H), 7.39 – 7.35 (m, 2H), 7.25 – 7.13 (comp, 4H), 6.99 – 6.92 (m, 1H), 6.55 (d, *J* = 7.5 Hz, 1H), 6.49 (d, *J* = 7.5

Hz, 1H), 6.41 (t, J = 7.3 Hz, 1H), 4.76 (d, J = 12.3 Hz, 1H), 4.11 – 4.07 (m, 2H), 3.82 – 3.78 (m, 1H), 3.37 – 3.33 (m, 1H), 3.18 (d, J = 12.3 Hz, 1H), 2.80 (t, J = 12.0 Hz, 1H), 2.38 (s, 3H), 1.89 – 1.81 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 153.9, 143.5, 143.0, 142.4, 141.3, 140.5, 134.7, 133.5, 129.8, 129.3, 128.9, 128.2, 128.0, 127.5, 127.0, 126.9, 125.9, 124.9, 121.3, 117.8, 117.1, 114.6, 54.1, 46.8, 42.5, 41.9, 38.4, 21.6; HRMS (TOF MS ESI⁺) calculated for C₃₂H₂₈N₂NaO₂S [M+Na]⁺: 527.1764, found 527.1770.



6-(4-Methoxyphenyl)-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][2,7]na phthyridine (3b). 74.8 mg, 70% yield. White solid, mp = 103.5-105.5 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.55 (d, *J* = 8.3 Hz, 2H), 7.50 – 7.44 (m, 2H), 7.38 – 7.33 (m, 1H), 7.25 – 7.16 (comp, 4H), 7.16 – 7.03 (comp, 3H), 6.98 – 6.90 (m, 1H), 6.54 (d, *J* = 7.9 Hz, 1H), 6.48 – 6.44 (m, 1H), 6.40 (t, *J* = 6.9 Hz, 1H), 4.76 – 4.72 (m, 1H), 4.10 – 4.06 (m, 1H), 3.91 (s, 3H), 3.82 – 3.58 (m, 2H), 3.37 – 3.33 (m, 1H), 3.13 (d, *J* = 12.2 Hz, 1H), 2.77 (t, *J* = 12.0 Hz, 1H), 2.37 (s, 3H), 1.86 – 1.81 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) 159.5, 153.9, 143.5, 142.9, 142.7, 140.7, 140.1, 134.8, 130.5, 129.8, 128.0, 127.6, 127.02, 127.01, 125.9, 125.8, 124.9, 121.3, 118.0, 117.4, 114.8, 114.4, 55.5, 54.0, 46.9, 42.6, 42.0, 38.4, 21.6; HRMS (TOF MS ESI⁺) calculated for C₃₃H₃₀N₂NaO₃S [M+Na]⁺: 557.1869, found 557.1860.



8-Fluoro-6-(4-fluorophenyl)-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][**2,7]naphthyridine (3c).** 82.1 mg, 76% yield. White solid, mp = 111.5-113.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ, ppm) 7.52 (comp, 4H), 7.28 – 7.14 (comp, 5H), 7.02 – 6.92 (m, 2H), 6.85 – 6.81 (m, 1H), 6.54 (d, J = 7.9 Hz, 1H), 6.46 – 6.37 (m, 2H), 4.70 – 4.66 (m, 1H), 4.24 – 4.07 (m, 1H), 4.04 – 4.00 (m, 1H), 3.84 – 3.74 (m, 1H), 3.41 – 3.76 (m, 1H), 3.12 (d, J = 12.3 Hz, 1H), 2.76 (t, J = 12.1 Hz, 1H), 2.38 (s, 3H), 1.87 – 18.1 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 162.7 (d, J = 247.8 Hz), 162.6 (d, J = 244.2 Hz), 149.4 (d, J = 2.4 Hz), 144.3 (d, J = 8.6 Hz), 143.9, 143.7, 142.9, 138.7 (d, J = 3.0 Hz), 134.5, 130.9 (d, J = 8.1 Hz), 129.9, 128.9 (d, J = 3.4 Hz), 128.2, 127.5, 126.7, 125.7 (d, J = 9.1 Hz), 117.9, 116.5, 116.1 (d, J = 21.5 Hz), 114.8, 112.6 (d, J = 22.8 Hz), 108.3 (d, J = 23.8 Hz), 53.7, 46.7, 42.5, 41.8, 38.8, 21.6; ¹⁹F NMR (376 MHz, CDCl₃) (δ , ppm) -112.90, -115.39; HRMS (TOF MS ESI⁺) calculated for C₃₂H₂6F₂N₂NaO₂S [M+Na]⁺: 563.1575, found 563.1572.



8-Chloro-6-(4-chlorophenyl)-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*] [**2,7**]naphthyridine (3d). 85.8 mg, 75% yield. White solid, mp = 86.0-88.5 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.54 – 7.44 (comp, 4H), 7.45 (d, *J* = 8.4 Hz, 2H), 7.26 (d, *J* = 1.5 Hz, 1H), 7.21 (d, *J* = 8.1 Hz, 2H), 7.16 – 7.10 (m, 2H), 6.99 – 6.92 (m, 1H), 6.54 (d, *J* = 8.1 Hz, 1H), 6.41 (d, *J* = 4.0 Hz, 2H), 4.65 – 4.62 (m, 1H), 4.08 (s, 1H), 4.08 – 3.99 (m, 1H), 3.83 – 3.73 (m, 1H), 3.39 – 3.35 (m, 1H), 3.10 (d, *J* = 12.3 Hz, 1H), 2.76 (t, *J* = 12.1 Hz, 1H), 2.38 (s, 3H), 1.85 – 1.81(m, 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 152.1, 143.9, 143.9, 143.8, 142.9, 138.5, 134.49, 134.47, 133.3, 131.3, 130.6, 129.9, 129.4, 128.4, 127.6, 126.7, 126.0, 125.8, 121.3, 118.0, 116.1, 114.9, 54.1, 46.7, 42.4, 41.8, 38.7, 21.7; HRMS (TOF MS ESI⁺) calculated for C₃₂H₂₇Cl₂N₂O₂S [M+H]⁺: 573.1165, found 573.1162.



8-Methyl-6-p-tolyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][2,7]napht hyridine (3e). 86.2 mg, 81% yield. White solid, mp = 93.5-95.5 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.55 (d, *J* = 8.3 Hz, 2H), 7.44 (d, *J* = 8.0 Hz, 2H), 7.37 (d, *J* = 7.9 Hz, 2H), 7.19 (d, *J* = 8.6 Hz, 3H), 7.12 (d, *J* = 7.6 Hz, 1H), 6.99 – 6.90 (m, 2H), 6.55 – 6.51 (m, 1H), 6.5.0 – 6.46 (m, 1H), 6.44 – 6.37 (m, 1H), 4.77 – 4.73(m, 1H), 4.09 – 4.05 (m, 2H), 3.80 – 3.76 (m, 1H), 3.36 – 3.32(m, 1H), 3.14 (d, *J* = 12.2 Hz, 1H), 2.77 (t, *J* = 12.0 Hz, 1H), 2.48 (s, 3H), 2.37 (s, 3H), 2.32 (s, 3H), 1.83 – 1.79 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 151.3, 143.4, 142.9, 142.7, 141.3, 140.4, 137.9, 136.8, 134.8, 130.6, 129.8, 129.6, 129.2, 127.9, 127.5, 126.9, 126.6, 124.5, 122.0, 117.9, 117.5, 114.6, 53.7, 46.9, 42.6, 41.9, 38.5, 21.6, 21.5; HRMS (TOF MS ESI⁺) calculated for C₃₄H₃₂N₂NaO₂S [M+Na]⁺: 555.2077, found 555.2074.



8,12-Dimethyl-6-p-tolyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][2,7] **naphthyridine (3f).** 85.2 mg, 78% yield. White solid, mp = 101.5-103.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.72 – 7.30 (comp, 6H), 7.17 – 7.13(comp, 4H), 6.95 (d, *J* = 7.3 Hz, 1H), 6.74 (d, *J* = 7.1 Hz, 1H), 6.45 (d, *J* = 8.0 Hz, 1H), 6.24 (s, 1H), 4.73 (d, *J* = 12.3 Hz, 1H), 4.04 (d, *J* = 12.3 Hz, 1H), 3.92 (s, 1H), 3.76 (d, *J* = 11.5 Hz, 1H), 3.31 (d, *J* = 12.0 Hz, 1H), 3.13 (d, *J* = 12.1 Hz, 1H), 2.77 (t, *J* = 12.0 Hz, 1H), 2.48 (s, 3H), 2.38 (s, 3H), 2.32 (s, 3H), 1.97 (s, 3H), 1.79 – 1.75(m 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 151.4, 143.4, 142.8, 141.5, 140.6, 140.2, 137.9, 136.7, 134.9, 130.7, 120.0 Hz, 130.7,

129.8, 129.6, 129.3, 128.8, 127.6, 127.1, 126.9, 126.6, 124.6, 122.0, 117.5, 114.7, 53.8, 46.9, 42.6, 42.0, 38.9, 21.64, 21.56, 20.6; HRMS (TOF MS ESI^+) calculated for $C_{35}H_{34}N_2NaO_2S$ [M+Na]⁺: 569.2233, found 569.2231.



8-Methoxy-6-(4-methoxyphenyl)-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1, 2-*e*][2,7]naphthyridine (3g). 93.7 mg, 83% yield. White solid, mp = 108.0-110.5 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.55 (d, *J* = 8.3 Hz, 2H), 7.51 – 7.43 (m, 2H), 7.19 (d, *J* = 8.0 Hz, 2H), 7.12 – 7.08(comp, 3H), 6.97 – 6.87 (m, 2H), 6.69 – 6.65 (m, 1H), 6.53 (d, *J* = 7.6 Hz, 1H), 6.49 – 6.45 (m, 1H), 6.44 – 6.37 (m, 1H), 4.76 – 4.72 (m, 1H), 4.06 – 4.02 (m, 2H), 3.91 (s, 3H), 3.80 – 3.75 (m, 1H), 3.75 (s, 3H), 3.36 – 3.32 (m, 1H), 3.12 (d, *J* = 12.3 Hz, 1H), 2.75 (t, *J* = 12.1 Hz, 1H), 2.37 (s, 3H), 1.82 – 1.79 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 159.5, 159.3, 146.5, 144.2, 143.5, 142.8, 142.1, 139.9, 134.7, 130.5, 129.8, 127.9, 127.6, 126.9, 125.7, 125.3, 118.0, 117.8, 114.7, 114.4, 111.3, 107.2, 55.6, 55.5, 53.3, 46.9, 42.6, 42.0, 38.8, 21.6; HRMS (TOF MS ESI⁺) calculated for C₃₄H₃₂N₂NaO₂S [M+Na]⁺: 587.1975, found 587.1973.



Combined in 79% yield, 84.1 mg (3h : 3h' = 1.3 : 1). White solid, mp = 115.5-120.5 °C; composite NMR signals of **3h** (two diasteroisomers) and **3h**' ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.56 – 6.94 (comp, 28.15H), 6.56 – 6.40 (comp, 6.84H), 4.76 (d, J =

12.2 Hz, 1H), 4.41 – 4.34 (comp, 1.32H), 4.12 – 4.00 (comp, 4.67H), 3.82 – 3.71 (comp, 2.36H), 3.36 – 3.34 (comp, 2.27H), 3.13 (d, J = 12.2 Hz, 1H), 3.05 – 2.98 (comp, 1.36H), 2.80 – 2.74 (comp, 2.38H), 2.50 (s, 3H), 2.47 (s, 1.89H), 2.45 (s, 2.08H), 2.38 – 2.37 (comp, 6.85H), 2.30 (s, 3H), 1.97 (s, 1.87H), 1.95 (s, 2.02H), 1.89 – 1.79 (comp, 2.31H). ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 154.4, 154.3, 154.2, 143.4, 143.0, 142.4, 142.24, 142.21, 140.4, 140.10, 140.05, 140.0, 139.9, 138.6, 138.3, 137.7, 136.2, 136.1, 135.6, 134.8, 134.6, 133.6, 132.5, 130.3, 130.2, 130.00, 129.97, 129.9, 129.8, 129.7, 128.9, 128.8, 128.6, 128.5, 128.0, 127.94, 127.91, 127.7, 127.6, 127.5, 127.0, 126.9, 126.7, 126.5, 126.3, 125.7, 125.7, 122.7, 121.0, 117.8, 117.74, 117.72, 117.4, 117.3, 114.58, 114.55, 53.9, 53.3, 47.0, 46.91, 46.85, 42.6, 42.5, 42.4, 41.9, 41.8, 38.73, 38.68, 38.4, 21.68, 21.67, 21.65, 21.6, 20.34, 20.25. HRMS (TOF MS ESI⁺) calculated for C₃₄H₃₂N₂NaO₂S [M+Na]⁺: 555.2077, found 555.2079.



6-Phenyl-1,2,2a,3-tetrahydro-5*H***-indeno[1',2':4,5]pyrano[3,4-***c***]quinoline (3i). 52.7 mg, 75% yield. White solid, mp = 85.5-88.0 °C; ¹H NMR (400 MHz, CDCl₃) 7.55 – 7.51 (comp, 4H), 7.49 – 7.42 (m, 2H), 7.36 – 7.27 (m, 2H), 7.21 – 7.17 (m, 1H), 7.07 – 7.00 (m, 1H), 6.64 – 6.58 (m, 2H), 6.54 – 6.48 (m, 1H), 4.70 (d, J = 12.0 Hz, 1H), 4.10 – 4.06 (m, 3H), 3.81 – 3.77 (m, 1H), 3.63 (t, J = 11.5 Hz, 1H), 3.34 – 3.30 (m, 1H), 1.94 – 1.89 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) (\delta, ppm) 154.6, 144.4, 143.2, 142.6, 139.5, 134.0, 129.4, 128.8, 128.0, 127.3, 126.8, 125.8, 124.9, 121.2, 118.0, 117.8, 114.7, 67.6, 62.8, 53.8, 41.3, 40.8; HRMS (TOF MS ESI⁺) calculated for C₂₅H₂₂NO [M+H]⁺: 352.1696, found 352.1703.**



Diethyl 6-Phenyl-1,2,2a,3-tetrahydroindeno[2,1-*l*]phenanthridine-4,4(5*H*)dicarboxylate (3j). 72.0 mg, 73% yield. White solid, mp = 81.5-83.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.50 (d, J = 4.2 Hz, 4H), 7.42 – 7.38 (m, 1H), 7.29 – 7.24 (m, 2H), 7.19 (t, J = 7.4 Hz, 1H), 7.10 (t, J = 7.4 Hz, 1H), 7.00 (t, J = 7.5 Hz, 1H), 6.64 – 6.55 (m, 2H), 6.50 (t, J = 7.4 Hz, 1H), 4.15 – 4.02 (m, 4H), 4.00 – 3.92 (m, 1H), 3.55 – 3.44 (m, 2H), 3.30 (d, J = 12.1 Hz, 1H), 2.73 (d, J = 13.6 Hz, 1H), 2.30 – 2.26 (m, 1H), 2.07 (d, J = 12.6 Hz, 1H), 1.96 (t, J = 12.9 Hz, 1H), 1.16 (t, J = 7.1 Hz, 3H), 0.81 (t, J = 7.1 Hz, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 171.4, 170.4, 154.9, 145.5, 143.1, 142.8, 140.1, 134.6, 129.3, 128.6, 127.9, 127.5, 127.2, 126.6, 125.2, 124.9, 120.4, 118.8, 117.9, 114.5, 61.6, 61.2, 57.7, 55.2, 43.7, 35.9, 33.6, 28.8, 14.1, 13.5; HRMS (TOF MS ESI⁺) calculated for C₃₂H₃₁NNaO₄ [M+Na]⁺: 516.2145, found 516.2129.



Ethyl 4-benzoyl-6-phenyl-1,2,2a,3,4,5-hexahydroindeno[2,1-*l*]phenanthridine-4carboxylate (3k). Combined in 73% yield, 76.6 mg. (dr = 2 : 1). White solid, mp = 96.5-99.0 °C; One isomer: ¹H NMR (400 MHz, CDCl₃) (δ, ppm) 7.88 – 6.48 (comp, 18H), 4.22 - 4.08 (m, 3H), 3.76 - 3.72 (m, 1H), 3.43 - 3.39 (m, 1H), 3.08 (d, J =14.0 Hz, 1H), 2.56 - 2.47 (m, 2H), 2.10 (t, J = 12.9 Hz, 1H), 1.10 (t, J = 7.1 Hz, 3H). The other isomer: 7.88 - 6.48 (comp, 18H), 4.20 - 4.08 (m, 1H), 3.86 - 3.78 (m, 1H), 3.54 - 3.50 (m, 1H), 3.49 - 3.43 (m, 1H), 3.34 - 3.31 (m, 1H), 3.03 (d, J = 13.8 Hz, 1H), 2.27 - 2.20 (m, 2H), 1.98 (t, J = 12.9 Hz, 1H), 0.61 (t, J = 7.1 Hz, 3H). 13 C NMR (100 MHz, CDCl₃) composite signals of the two isomers (δ , ppm) 196.6, 196.5, 173.2, 172.4, 155.1, 154.9, 146.1, 144.8, 143.1, 142.99, 142.97, 142.9, 140.3, 140.1, 136.0, 135.2, 134.6, 133.9, 132.8, 132.6, 129.3, 129.0, 128.7, 128.64, 128.56, 128.5, 128.24, 128.22, 127.9, 127.51, 127.45, 127.2, 127.0, 126.64, 126.57, 125.2, 125.1, 124.9, 124.8, 120.44, 120.37, 119.1, 118.9, 118.13, 118.07, 114.8, 114.6, 62.1, 61.9, 61.3, 61.0, 55.3, 55.0, 43.79, 43.77, 36.1, 35.2, 35.1, 34.7, 29.8, 29.6, 13.9, 13.2. HRMS (TOF MS ESI⁺) calculated for $C_{36}H_{31}NNaO_3$ [M+Na]⁺: 548.2196, found 548.2203.



1,1'-(6-Phenyl-1,2,2a,3,4,5-hexahydroindeno[2,1-/]phenanthridine-4,4-diyl)dietha none (31). 66.7 mg, 77% yield. White solid, mp = 85.0-86.5 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.56 – 7.47 (comp, 4H), 7.44 – 7.40 (m, 1H), 7.30 (d, J = 7.4 Hz, 1H), 7.25 – 7.17 (m, 2H), 7.12 – 7.08 (m, 1H), 7.04 – 6.97 (m, 1H), 6.64 – 6.54 (m, 2H), 6.53 – 6.46 (m, 1H), 4.15 – 4.11 (m, 2H), 3.57 – 3.53 (m, 1H), 3.36 – 3.32 (m, 1H), 2.66 (d, J = 14.3 Hz, 1H), 2.46 – 2.42 (m 1H), 1.99 (s, 3H), 1.86 – 1.82 (m, 1H), 1.75 (t, J = 12.7 Hz, 1H), 1.54 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 206.4, 205.6, 154.6, 145.8, 143.0, 142.5, 139.7, 134.4, 134.2, 129.4, 129.0, 128.0, 127.0, 126.7, 125.3, 125.0, 120.4, 118.7, 117.9, 114.5, 71.7, 55.2, 43.9, 35.4, 32.2, 27.7, 26.5, 26.2; HRMS (TOF MS ESI⁺) calculated for C₃₀H₂₈NO₂ [M+H]⁺: 434.2115, found 434.2110.



12-Fluoro-6-phenyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][2,7]nap hthyridine (3m). 81.5 mg, 78% yield. White solid, mp = 144.5-146.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.63 – 7.51 (comp, 6H), 7.49 – 7.44 (m, 1H), 7.38 (d, *J* = 7.5 Hz, 1H), 7.26 – 7.13 (comp, 5H), 6.69 – 6.65 (m, 1H), 6.50 – 6.46 (m, 1H), 6.22 – 6.18 (m, 1H), 4.74 (d, *J* = 12.3 Hz, 1H), 4.12 – 3.94 (m, 2H), 3.81 – 3.77 (m, 1H), 3.34 (d, *J* = 12.2 Hz, 1H), 3.10 (d, *J* = 12.3 Hz, 1H), 2.73 (t, *J* = 12.0 Hz, 1H), 2.38 (s, 3H), 1.87 – 1.83 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 155.8 (d, *J* = 234.8 Hz), 153.4, 143.6, 142.4, 140.9 (d, *J* = 13.4 Hz), 139.3, 134.4, 133.3, 129.8, 129.3, 129.0, 128.3, 127.6, 127.3, 126.1, 124.8, 121.5, 118.2 (d, *J* = 6.4 Hz), 115.5 (d, *J* = 7.5 Hz), 115.3, 115.1, 112.7 (d, *J* = 22.4 Hz), 54.1, 46.8, 42.6, 41.9, 38.1, 21.6; ¹⁹F NMR (376 MHz, CDCl₃) (δ , ppm) -127.23; HRMS (TOF MS ESI⁺) calculated for C₃₂H₂₇FN₂NaO₂S [M+Na]⁺: 545.1669, found 545.1672.



12-Chloro-6-phenyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][2,7]nap hthyridine (3n). 82.9 mg, 77% yield. White solid, mp = 123.5-125.5 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.58 – 7.53 (comp, 6H), 7.50 – 7.44 (m, 1H), 7.38 (d, *J* = 7.5 Hz, 1H), 7.24 (d, *J* = 1.3 Hz, 1H), 7.22 (d, *J* = 8.7 Hz, 3H), 7.19 – 7.13 (m, 1H), 6.90 – 6.86 (m, 1H), 6.47 (d, *J* = 8.6 Hz, 1H), 6.42 (d, *J* = 2.4 Hz, 1H), 4.76 – 4.72 (m, 1H), 4.13 (s, 1H), 4.07 – 4.03 (m, 1H), 3.80 – 3.76 (m, 1H), 3.35 (d, *J* = 12.4 Hz, 1H), 3.11 (d, *J* = 12.3 Hz, 1H), 2.69 (t, *J* = 12.0 Hz, 1H), 2.39 (s, 3H), 1.90 – 1.78 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 153.2, 143.6, 142.3, 141.6, 141.0, 140.5, 134.4, 133.2, 129.9, 129.3, 129.0, 128.3, 128.1, 127.6, 127.3, 126.4, 126.1, 124.8, 122.0, 121.5, 118.6, 115.8, 54.0, 46.8, 42.6, 41.8, 38.1, 21.7; HRMS (TOF MS ESI⁺) calculated for C₃₂H₂₈ClN₂O₂S [M+H]⁺: 539.1555, found 539.1549.



12-Bromo-6-phenyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][2,7]nap hthyridine (**3o**). 92.0 mg, 79% yield. White solid, mp = 116.5-119.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.66 – 7.51 (comp, 6H), 7.49 – 7.45 (m, 1H), 7.38 (d, *J* = 7.5 Hz, 1H), 7.28 (d, *J* = 1.3 Hz, 1H), 7.25 – 7.13 (comp, 4H), 7.03 – 6.99 (m, 1H), 6.54 (d, *J* = 2.2 Hz, 1H), 6.43 (d, *J* = 8.6 Hz, 1H), 4.74 (d, *J* = 12.3 Hz, 1H), 4.15 (d, *J* = 10.5 Hz, 1H), 4.06 – 4.02 (m, 1H), 3.81 – 3.75 (m, 1H), 3.34 (d, *J* = 12.3 Hz, 1H), 3.11 (d, *J* = 12.3 Hz, 1H), 2.68 (t, *J* = 12.0 Hz, 1H), 2.39 (s, 3H), 1.86 – 1.82 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 153.2, 143.7, 142.3, 142.1, 141.0, 140.5, 134.4, 133.2, 130.9, 129.9, 129.3, 129.2, 129.0, 128.3, 127.6, 127.3, 126.1, 124.8, 121.5, 119.1, 116.3, 109.0, 54.0, 46.8, 42.5, 41.7, 38.1, 21.7; HRMS (TOF MS ESI⁺) calculated for C₃₂H₂₈BrN₂O₂S [M+H]⁺: 583.1049, found 583.1049.



12-Methyl-6-phenyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]**indeno**[**1,2**-*e*][**2,7**]**nap hthyridine (3p).** 83.9 mg, 81% yield. White solid, mp = 104.5-107.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.62 – 7.53 (comp, 6H), 7.50 – 7.46 (m, 1H), 7.40 (d, *J* = 7.4 Hz, 1H), 7.26 (t, *J* = 7.4 Hz, 2H), 7.23 – 7.14 (comp, 3H), 6.79 – 6.74 (m, 1H), 6.48 (d, *J* = 8.1 Hz, 1H), 6.27 (d, *J* = 1.4 Hz, 1H), 4.80 – 4.76 (m, 1H), 4.08 (d, *J* = 9.8 Hz, 1H), 3.98 (s, 1H), 3.83 – 3.79 (m, 1H), 3.33 (d, *J* = 12.2 Hz, 1H), 3.19 (d, *J* = 12.2 Hz, 1H), 2.83 (t, *J* = 12.0 Hz, 1H), 2.38 (s, 3H), 2.00 (s, 3H), 1.86 – 1.78 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 154.0, 143.4, 142.4, 141.6, 140.7, 140.2, 134.8, 133.6, 129.9, 129.8, 129.3, 129.0, 128.9, 128.1, 127.6, 126.9, 126.8, 125.9, 124.9, 121.2, 117.0, 114.8, 54.2, 46.8, 42.6, 41.9, 38.7, 21.6, 20.5; HRMS (TOF MS ESI⁺) calculated for C₃₃H₃₁N₂O₂S [M+H]⁺: 519.2101, found 519.2100.



12-Ethyl-6-phenyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][2,7]napht hyridine (3q). 80.9 mg, 76% yield. White solid, mp = 104.5-106.5 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.63 – 7.53 (comp, 6H), 7.51 – 7.46 (m, 1H), 7.40 (d, *J* = 7.5 Hz, 1H), 7.29 – 7.24 (m, 2H), 7.23 – 7.12 (comp, 3H), 6.83 – 6.79 (m, 1H), 6.51 (d, *J* = 8.2 Hz, 1H), 6.29 (s, 1H), 4.77 (d, *J* = 12.3 Hz, 1H), 4.10 –4.06 (m, 1H), 3.99 (s, 1H), 3.82 – 3.78 (m, 1H), 3.33 (d, *J* = 11.1 Hz, 1H), 3.20 (d, *J* = 12.3 Hz, 1H), 2.84 (t, *J* = 12.0 Hz, 1H), 2.38 (s, 3H), 2.33 – 2.28 (m, 2H), 1.85 – 1.79 (m, 1H), 1.00 (t, *J* = 7.6 Hz, 3H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 154.0, 143.4, 142.4, 141.6, 140.9, 140.2, 134.8, 133.6, 133.4, 129.8, 129.3, 128.9, 128.1, 127.6, 127.5, 126.9, 125.9, 124.9, 121.2, 116.9, 114.7, 54.3, 46.8, 42.5, 41.9, 38.7, 27.8, 21.6, 15.7; HRMS (TOF MS ESI⁺) calculated for C₃₄H₃₃N₂O₂S [M+H]⁺: 533.2257, found 533.2250.



12-Methoxy-6-phenyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][2,7]na phthyridine (3r). 86.5 mg, 81% yield. White solid, mp = 122.5-125.0 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.58 – 7.52 (comp, 6H), 7.49 – 7.43 (m, 1H), 7.37 (d, *J* = 7.5 Hz, 1H), 7.27 – 7.23 (m, 2H), 7.23 – 7.19 (m, 2H), 7.18 – 7.13 (m, 1H), 6.61 – 6.57 (m, 1H), 6.51 (d, *J* = 8.7 Hz, 1H), 6.07 (d, *J* = 2.8 Hz, 1H), 4.76 – 4.72 (m, 1H), 4.09 – 4.05 (m, 1H), 3.90 – 3.86 (m, 1H), 3.82 – 3.78 (m, 1H), 3.53 (s, 3H), 3.34 – 3.30 (m, 1H), 3.14 (d, *J* = 12.2 Hz, 1H), 2.79 (t, *J* = 12.0 Hz, 1H), 2.38 (s, 3H), 1.87 – 1.80 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 153.7, 152.1, 143.5, 142.4, 141.3, 140.6, 137.2, 134.6, 133.5, 129.8, 129.3, 128.9, 128.2, 127.6, 127.1, 125.9, 124.9, 121.3, 118.4, 115.8, 114.1, 112.0, 55.6, 54.4, 46.9, 42.6, 42.1, 38.6, 21.6; HRMS (TOF MS ESI⁺) calculated for C₃₃H₃₁N₂O₃S [M+H]⁺: 535.2050, found 535.2045.



12-Nitro-6-phenyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][2,7]napht hyridine (3s). 69.2 mg, 63% yield. White solid, mp = 117.5-119.5 °C; ¹H NMR (400 MHz, DMSO-*d*) (δ , ppm) 8.32 – 8.28 (m, 1H), 7.89 – 7.76 (m, 2H), 7.59 (comp, 7H), 7.38 – 7.17 (comp, 6H), 6.68 (d, *J* = 9.2 Hz, 1H), 4.66 (d, *J* = 12.8 Hz, 1H), 3.88 (d, *J* = 13.7 Hz, 1H), 3.78 (d, *J* = 11.8 Hz, 1H), 3.58 (d, *J* = 13.5 Hz, 1H), 3.10 (d, *J* = 12.8 Hz, 1H), 2.32 (s, 3H), 2.24 (t, *J* = 12.2 Hz, 1H), 1.77 – 1.71 (m, 1H); ¹³C NMR (100 MHz, DMSO-*d*) (δ , ppm) 152.7, 150.0, 143.7, 141.2, 140.4, 139.7, 135.8, 133.3, 132.4, 130.0, 129.1, 128.9, 128.6, 127.5, 127.4, 126.5, 124.9, 124.4, 122.9, 121.1, 115.1, 113.4, 79.2, 53.0, 46.2, 42.2, 36.2, 21.0; HRMS (TOF MS ESI⁺) calculated for C₃₂H₂₇N₃NaO₄S [M+Na]⁺: 572.1614, found 572.1609.



11-Phenyl-13-tosyl-12,13,14,14a,15,16-hexahydroindeno[**1,2-***e***]naphtho**[**1,2-***c***][2,7**] **naphthyridine (3t).** 88.7 mg, 80% yield. White solid, mp = 98.5-100.5 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.76 (d, J = 8.2 Hz, 1H), 7.68 – 7.64 (m, 1H), 7.61 – 7.39 (comp, 10H), 7.25 – 7.18 (m, 2H), 7.16 – 7.11 (comp, 3H), 6.94 (d, J = 8.5 Hz, 1H), 6.56 (d, J = 8.5 Hz, 1H), 4.81 – 4.74 (m, 2H), 4.26 – 4.22 (m, 1H), 3.85 – 3.81 (m, 1H), 3.62 – 3.58 (m, 1H), 3.04 (d, J = 12.1 Hz, 1H), 2.76 (t, J = 12.0 Hz, 1H), 2.31 (s, 3H), 1.98 – 1.92 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 143.6, 142.7, 141.4, 141.0, 134.4, 134.3, 134.2, 133.7, 133.4, 132.1, 129.9, 129.4, 129.0, 128.8, 128.7, 128.3, 127.64, 127.59, 127.4, 126.2, 126.0, 125.2, 124.9, 123.4, 121.5, 120.2, 54.2, 46.8, 42.8, 42.2, 38.1, 21.6; HRMS (TOF MS ESI⁺) calculated for C₃₆H₃₁F₃N₂O₂S [M+Na]⁺: 555.2101, found 555.2104.



14-Methyl-6-phenyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]**indeno**[**1,2**-*e*][**2,7**]**nap hthyridine (3u).** 77.7 mg, 75% yield. White solid, mp = 216.0-218.5 °C; ¹H NMR (400 MHz, CDCl₃) (δ , ppm) 7.58 – 7.50 (comp, 6H), 7.49 – 7.42 (m, 1H), 7.39 – 7.34 (m, 1H), 7.26 – 7.10 (comp, 5H), 6.89 – 6.85 (m, 1H), 6.42 – 6.32 (m, 2H), 4.75 – 4.71 (m, 1H), 4.16 – 4.12 (m, 1H), 3.94 (s, 1H), 3.81 – 3.77 (m, 1H), 3.49 – 3.45 (m, 1H), 3.18 (d, *J* = 12.3 Hz, 1H), 2.79 (t, *J* = 12.1 Hz, 1H), 2.37 (s, 3H), 2.14 (s, 3H), 1.88 – 1.79 (m, 1H); ¹³C NMR (100 MHz, CDCl₃) (δ , ppm) 154.1, 143.4, 142.4, 141.7, 141.1, 140.3, 135.0, 133.6, 129.8, 129.3, 129.1, 128.9, 128.1, 127.6, 127.0, 125.9, 124.9, 124.8, 121.5, 121.3, 117.1, 116.5, 54.3, 46.7, 42.5, 42.1, 38.3, 21.6, 17.6; HRMS (TOF MS ESI⁺) calculated for C₃₃H₃₁N₂O₂S [M+H]⁺: 519.2101, found 519.2094.



11-Methyl-6-phenyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][2,7]nap hthyridine (3v). ¹H NMR (400 MHz, CDCl₃) (δ, ppm) 7.62 – 6.28 (comp, 16H), 4.79 – 4.74 (m, 1H), 4.11 – 4.09 (m, 1H), 3.95 – 3.91 (m, 1H), 3.84 – 3.75 (m, 1H), 3.28 – 3.25 (d, *J* = 12.0 Hz, 1H), 3.03 (d, *J* = 11.6 Hz, 1H), 2.90 (t, *J* = 11.9 Hz, 1H), 2.38 (s, 3H), 1.59 (s, 3H), 1.50 – 1.43 (m, 1H).



13-Methyl-6-phenyl-4-tosyl-1,2,2a,3,4,5-hexahydrobenzo[*c*]indeno[1,2-*e*][2,7]nap hthyridine (3v'). ¹H NMR (400 MHz, CDCl₃) (δ, ppm) 7.62 – 6.28 (comp, 16H), 4.79 – 4.74 (m, 1H), 4.09 – 4.06 (m, 1H), 4.04 – 4.00 (m, 1H), 3.84 – 3.75 (m, 1H), 3.34 (d, *J* = 12.0 Hz, 1H), 3.20 (d, *J* = 12.3 Hz, 1H), 2.84 (t, *J* = 11.9 Hz, 1H), 2.37 (s, 3H), 2.16 (s, 3H), 1.87 – 1.79 (m, 1H).

Combined in 72% yield, 74.6 mg (3v : 3v' = 2 : 1). Yellow solid, mp = 210.5-215.5 °C; ¹³C NMR (100 MHz, CDCl₃) composite signals of the two isomers (δ , ppm) 154.0, 151.2, 144.2, 143.7, 143.5, 143.4, 143.2, 142.9, 142.3, 141.5, 140.3, 138.9, 138.6, 137.8, 135.0, 134.4, 133.9, 133.6, 129.81, 129.79, 129.3, 129.0, 128.9, 128.1, 128.0, 127.6, 127.54, 127.50, 127.1, 126.9, 126.8, 125.9, 125.8, 125.3, 124.8, 121.2, 121.0, 119.0, 115.7, 115.1, 114.2, 113.2, 55.5, 53.9, 46.83, 46.77, 42.49, 42.46, 42.2, 42.1, 41.9, 38.5, 21.61, 21.60, 21.3, 20.0.; HRMS (TOF MS ESI⁺) calculated for C₃₃H₃₁N₂O₂S [M+H]⁺: 519.2101, found 519.2065.

1D-NOE NMR Analysis:



Fig. S1 Proton NMR spectra of mixture of 4b and 4b'.







Fig. S3 Proton NMR spectra of mixture of 4h and 4h'.







Fig. S6 NOE NMR spectra of 3v and 3v'.

Control Experiment:



To a 10-mL oven-dried vial with a magnetic stirring bar, compound **4a** (80.0 mg, 0.2 mmol) in DCE (1.0 mL), azide **2a** (53.2 mg, 0.4 mmol, 2.0 equiv.) in anhydrous DCE (1.0 mL) and TfOH (36 μ L, 2.0 equiv.) in anhydrous DCE (0.5 mL) were added in sequence to the solution under atmosphere of argon, and the reaction mixture was stirred at room temperature overnight. When the reaction was completed (monitored by TLC), the crude reaction mixture was quenched with saturated sodium bicarbonate (NaHCO₃) and extracted with EtOAc, the combined organic layer was washed with brine and dried over anhydrous Na₂SO₄. The solvent was evaporated in *vacuo* after filtration, and the residue was purified by flash column chromatography on silica gel (Hexanes : EtOAc = 5:1 to 3:1) to give the pure product **3a** in 93% yield (93.8 mg).

Proton NMR Observation:

To a 10-mL oven-dried vial with a magnetic stirring bar, 1,6-diynes compounds **1b** (85.9 mg, 0.2 mmol), PPh₃AuNTf₂ (7.4 mg, 5.0 mol %), and anhydrous DCE (1.0 mL) were added in sequence under atmosphere of argon, and the reaction mixture was stirred at 60 °C for 5 hours. When the reaction was completed (monitored by TLC), the solvent was evaporated in *vacuo* and the residues was subjected to proton NMR analysis in CDCl₃ (Fig. S7, up spectrum, **4b**/**4b'** = 6:1). Then TfOH (18 μ L, 1.0 eq) was added to the above NMR tube. The reaction mixture was keeping in 30 °C for 5 hours and the subjected to proton NMR analysis (Fig. S7, bottom spectrum, **4b**/**4b'** = 10:1).



Fig. S7 Proton NMR spectra of reaction mixture after treating 4b and 4b' with TfOH.

To a 10-mL oven-dried vial with a magnetic stirring bar, 1,6-diynes compounds **1b** (85.9 mg, 0.2 mmol), PPh₃AuNTf₂ (7.4 mg, 5.0 mol %), and anhydrous DCE (1.0 mL) were added in sequence under atmosphere of argon, and the reaction mixture was stirred at 60 °C for 5 hours. When the reaction was completed (monitored by TLC), azides **2** (0.4 mmol, 2.0 equiv.) in anhydrous DCE (1.0 mL), and TfOH (36 μ L, 2.0 equiv.) in anhydrous DCE (0.5 mL), were added in sequence to the solution under atmosphere of argon, and the reaction mixture was stirred at room temperature overnight. When the reaction was completed (monitored by TLC), the crude reaction mixture was quenched with saturated aqueous sodium bicarbonate (10.0 mL) and extracted with EtOAc (15.0 mL). The combined organic layer was washed with brine and dried over anhydrous Na₂SO₄. The solvent was evaporated in *vacuo* after filtration. The residue was subjected to proton NMR analysis in CDCl₃ (Fig. S8, middle spectrum), and only product **3b** was detected.



Fig. S8 Proton NMR spectra of crude reaction mixtures with 1b.

General Procedure for Scale up:



To a 50-mL oven-dried round-bottom flask with a magnetic stirring bar, 1,6-diynes compounds **1a** (0.998 g, 2.5 mmol), PPh₃AuNTf₂ (92.4 mg, 5.0 mol%), and anhydrous DCE (15.0 mL) were added in sequence under atmosphere of argon, and the reaction mixture was stirred at 60 °C for 5 hours. When the reaction was completed (monitored by TLC), azides **2d** (1.06 g, 5.0 mmol, 2.0 equiv.) in anhydrous DCE (5.0 mL), and TfOH (0.45 mL, 2.0 equiv.) in anhydrous DCE (2.0 mL), were added in sequence under atmosphere of argon, and the reaction mixture was stirred at room temperature overnight. When the reaction was completed (monitored by TLC), the crude reaction mixture was quenched with saturated aqueous sodium bicarbonate

(50.0 mL) and extracted with EtOAc (50.0 mL). The combined organic layer was washed with brine and dried over anhydrous Na_2SO_4 . The solvent was evaporated in *vacuo* after filtration. The residue was purified by flash column chromatography on silica gel (Hexanes : EtOAc = 5:1 to 3:1) to give the 1.049 g pure product **30** (72% yield).

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Nov10-2017-f400-bm-273
























0 -10 -30 -50 -70 -90 -110 -130 -150 -170 -190 -210 -230 -250 -270 -290 f1 (ppm)





90 80 f1 (ppm)





























Nov29-2017-f400-bm-497





























0 -10 -30 -50 -70 -90 -110 -130 -150 -170 -190 -210 -230 -250 -270 -290 f1 (ppm)














S74





S76

Crystallographic Data for Compound 3n

		e o o o o o o o o o o o o o o o o o o o	
Bond precision:	C-C = 0.0049 A	Wavelength=0.71073	
Cell:	a=17.6414(12) alpha=90	b=17.5960(12) beta=103.004(2)	c=17.5732(11) gamma=90
Temperature:	120 K		
Volume Space group	Calculated Reported 5315.1(6) 5315.1(6) C 2/c C 1 2/c 1		
Moiety formula Sum formula Mr	C32 H27 C1 N2 O2 C32 H27 C1 N2 O2 C32 H27 C1 N2 O2 539.07	-C 290 S C32 H2 S C32 H2 539.06	27 C1 N2 O2 S 27 C1 N2 O2 S 27 C1 N2 O2 S
Dx,g cm-3 Z Mu (mm-1) F000	1.347 8 0.256 2256 0	1.347 8 0.256 2256	1
F000' h,k,lmax Nref	2258.99 22,22,22 6096	22,22, 6080	22
Tmin, Tmax Tmin'	0.940,0.975	0.662,	0.746
Correction meth AbsCorr = MULTI	nod= # Reported T -SCAN	Limits: Tmin=0.6	62 Tmax=0.746
Data completeness= 0.997		Theta(max) = 27.482	
R(reflections) = 0.0565(3449)		wR2(reflections) = 0.1840(6080)	
S = 1.108 Npar= 344			

S77