Supporting Information

Buchwald-Hartwig Aminated Pyrene-Heterocycles with Host-Guest-Enhanced NIR Phosphorescence: DFT-Guided Design Toward Breast Cancer Imaging Probes

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1 General procedure for the synthesis of target compounds

^{1}H and ^{13}C NMR both were recorded on a Bruker 400 spectrometer. ^{1}H NMR data are reported as follows: chemical shift in ppm (δ), multiplicity (s = singlet, d = doublet, t = triplet, m = multiplet, dd = doublet of doublets, dq = doublet of quarter, dt = doublet of triplet, qd = quarter of doublet, qt= quarter of triplet, td = triplet of doublet, tq = triplet of quarter), coupling constant (Hz), relative intensity. ^{13}C NMR data are reported as follows: chemical shift in ppm (δ).

1.1 Synthesis of Se-pyrene

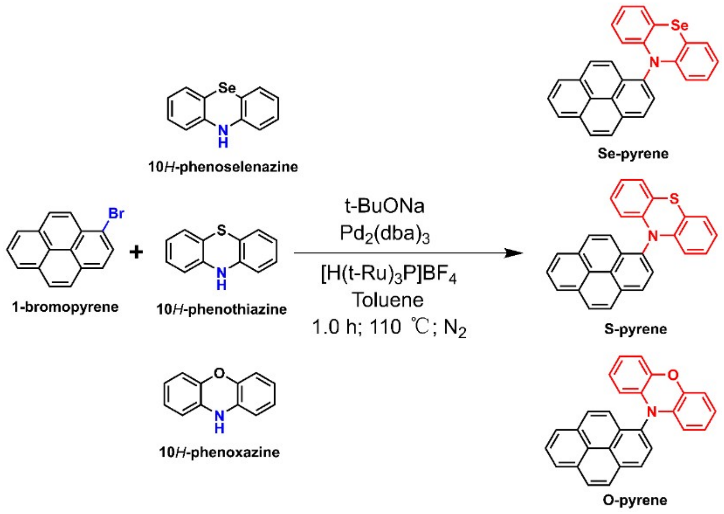
Under nitrogen protection, 1-bromopyrene (422.0 mg, 1.5 mmol), 10*H*-phenoselenazine (553.9 mg, 2.25 mmol), $NaHCO_3$ (378.0 mg, 4.5 mmol), and tetrakis (triphenylphosphine) palladium (174.0 mg, 0.15 mmol) were dissolved in 1,4-dioxane and water (5:1, 2.5 ml:0.5 ml). The reaction was carried out using a fully automated microwave synthesizer at 120 °C for 1.0 h. When the reaction was complete, the reaction was detected using thin layer chromatography, the reaction mixture was cooled to room temperature, extracted with ethyl acetate, dried over Na_2SO_4, and finally the crude product was obtained by distillation of the organic phase under reduced pressure. The product was purified by silica gel column chromatography and eluted with gradient of ethyl acetate/hexane (0-20%) to obtain the brown solid product Se-pyrene. ^{1}H NMR (400 MHz, CDCl3) δ 8.30 (d, J = 8.0 Hz, 1H), 8.25 (d, J = 9.2 Hz, 1H), 8.18 (d, J = 7.6 Hz, 1H), 8.14 – 8.05 (m, 4H), 8.02 – 7.93 (m, 2H), 7.19 (d, J = 1.6 Hz, 1H), 7.17 (d, J = 1.6 Hz, 1H), 6.73 (td, J = 7.4, 1.2 Hz, 2H), 6.69 – 6.62 (m, 2H), 6.12 (dd, J = 8.3, 1.2 Hz, 2H). ^{13}C NMR (100 MHz, CDCl3) δ 144.51 (s), 135.27 (s), 131.85 – 130.90 (m), 130.17 (s), 129.35 (t, J = 31.3 Hz), 128.34 (s), 127.21 (d, J = 16.6 Hz), 126.17 (dd, J = 48.8, 21.8 Hz), 124.75 (s), 123.03 (d, J = 7.7 Hz), 117.46 (s), 115.47 (s).

1.2 Synthesis of S-pyrene:

Under nitrogen protection, 1-bromopyrene (422.0 mg, 1.5 mmol), 10*H*-phenothiazine (448.4 mg, 2.25 mmol), $NaHCO_3$ (378.0 mg, 4.5 mmol), and tetrakis (triphenylphosphine) palladium (174.0 mg, 0.15 mmol) were dissolved in 1,4-dioxane and water (5:1, 2.5 ml:0.5 ml). The reaction was carried out using a fully automated microwave synthesizer at 120 °C for 1.0 h. When the reaction was complete, the reaction was detected using thin layer chromatography, the reaction mixture was cooled to room temperature, extracted with ethyl acetate, dried over Na_2SO_4, and the crude product was obtained by distillation of the organic phase under reduced pressure. The product was purified by silica gel column chromatography and eluted with gradient of ethyl acetate/hexane (0-20%) to obtain the brown solid product S-pyrene. ^{1}H NMR (400 MHz, CDCl3) δ 8.32 (d, J = 8.0 Hz, 1H), 8.25 – 8.07 (m, 5H), 8.05 – 7.96 (m, 3H), 6.99 (dd, J = 7.6, 1.5 Hz, 2H), 6.70 (td, J = 7.5, 1.1 Hz, 2H), 6.63 – 6.56 (m, 2H), 5.88 (dd, J = 8.3, 1.0 Hz, 2H). ^{13}C NMR (100 MHz, CDCl3) δ 144.16 (s), 134.11 (s), 129.14 (d, J = 14.1 Hz), 128.38 (s), 127.03 (d, J = 18.0 Hz), 126.73 – 126.29 (m), 125.83 (d, J = 4.5 Hz), 122.78 (s), 122.44 (s), 119.66 (s), 115.98 (s), 77.29 (d, J = 11.5 Hz), 77.03 (s), 76.71 (s).

1.3 Synthesis of O-pyrene

Under nitrogen protection, 1-bromopyrene (422.0 mg, 1.5 mmol), 10*H*-phenoxazine (412.2 mg, 2.25 mmol), $NaHCO_3$ (378.0 mg, 4.5 mmol), and tetrakis (triphenylphosphine) palladium (174.0 mg, 0.15 mmol) were dissolved in 1,4-dioxane and water (5:1, 2.5 ml:0.5 ml). The reaction was carried out using a fully automated microwave synthesizer at 120 °C for 1.0 h. When the reaction was complete, the reaction was detected using thin layer chromatography, the reaction mixture was cooled to room temperature, extracted with ethyl acetate, dried over Na_2SO_4, and the crude product was obtained by distillation of the organic phase under reduced pressure. The product was purified by silica gel column chromatography and eluted with gradient of ethyl acetate/hexane (0-20%) to obtain the brown solid product O-pyrene. ^{1}H NMR (400 MHz, CDCl3) δ 8.30 (dd, J = 7.9, 5.1 Hz, 1H), 8.23 – 8.06 (m, 5H), 8.04 – 7.92 (m, 3H), 6.71 (dd, J = 7.9, 1.3 Hz, 2H), 6.57 (s, 2H), 6.39 (dd, J = 11.1, 4.3 Hz, 2H), 5.59 (d, J = 7.9 Hz, 1H). ^{13}C NMR (100 MHz, CDCl3) δ 144.02 (s), 134.63 (s), 132.13 – 131.17 (m), 129.09 (s), 128.40 (s), 127.10 (s), 126.85 (s), 126.51 (s), 125.83 (d, J = 7.6 Hz), 123.40 (s), 122.40 (s), 121.39 (s), 115.46 (s), 113.61 (s), 77.34 (s), 77.03 (s), 76.71 (s).



Scheme S1. The synthetic route of the Se-pyrene, S-pyrene and O-pyrene compounds.

1.4 ^{1}H NMR (400 MHz, CDCl$_3$) Spectrum of Se-pyrene

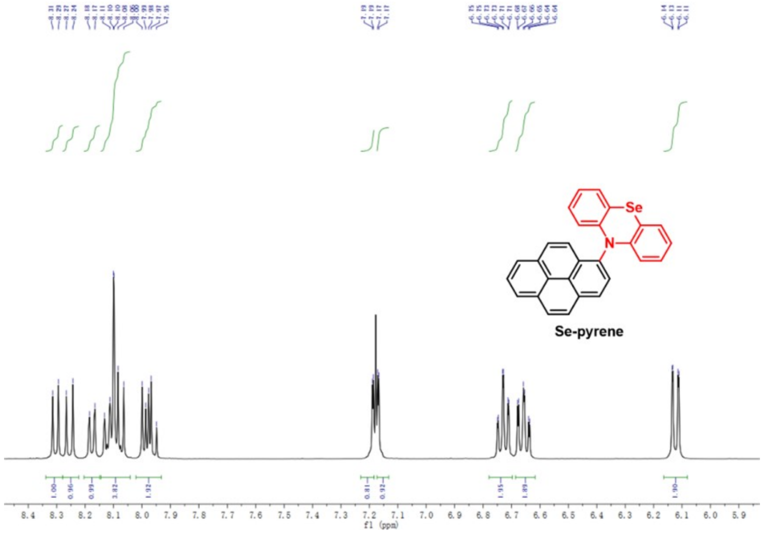


Figure S1. ^{1}H NMR spectrum of Se-pyrene (in CDCl$_3$).

1.5 ^{1}H NMR (400 MHz, CDCl$_3$) Spectrum of S-pyrene

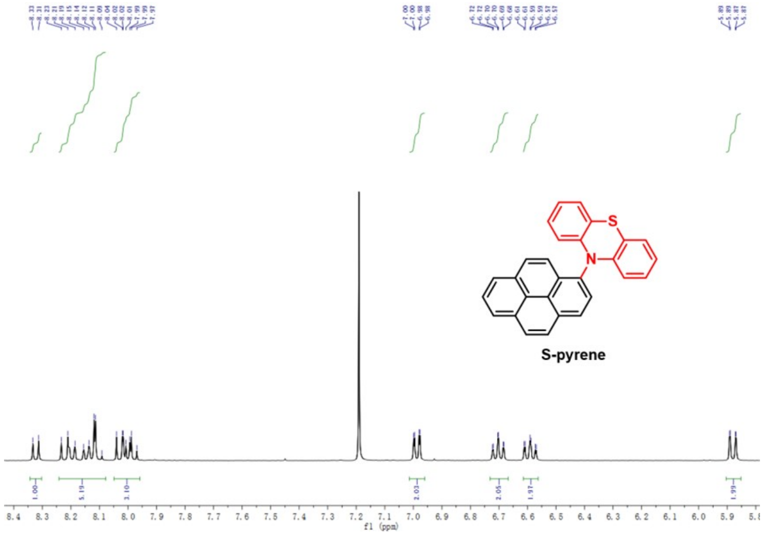


Figure S2. ^{1}H NMR spectrum of S-pyrene (in CDCl$_3$).

1.6 ^{1}H NMR (400 MHz, $CDCl_3$) Spectrum of O-pyrene

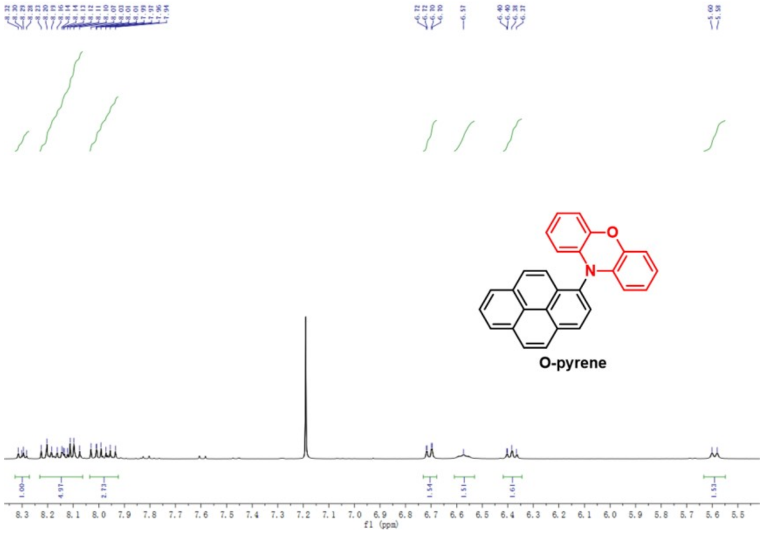


Figure S3. ^{1}H NMR spectrum of S-pyrene (in $CDCl_3$).

1.7 ^{13}C NMR (100 MHz, $CDCl_3$) Spectrum of Se-pyrene

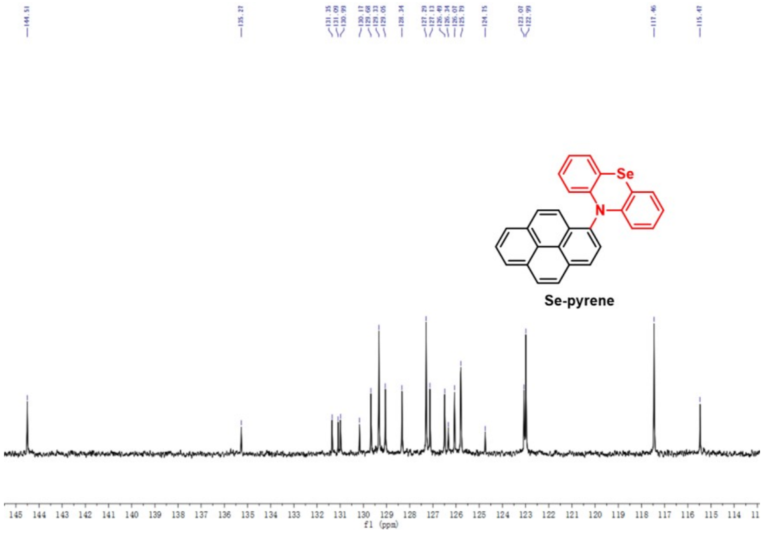


Figure S4. ^{13}C NMR spectrum of Se-pyrene (in $CDCl_3$).

1.8 ^{13}C NMR (100 MHz, $CDCl_3$) Spectrum of S-pyrene

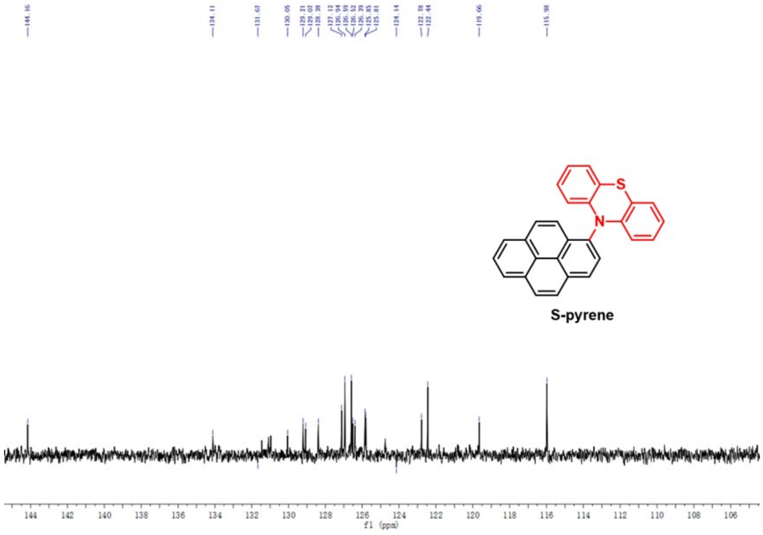


Figure S5. ^{13}C NMR spectrum of S-pyrene (in $CDCl_3$).

1.9 ^{13}C NMR (100 MHz, CDCl$_3$) Spectrum of O-pyrene

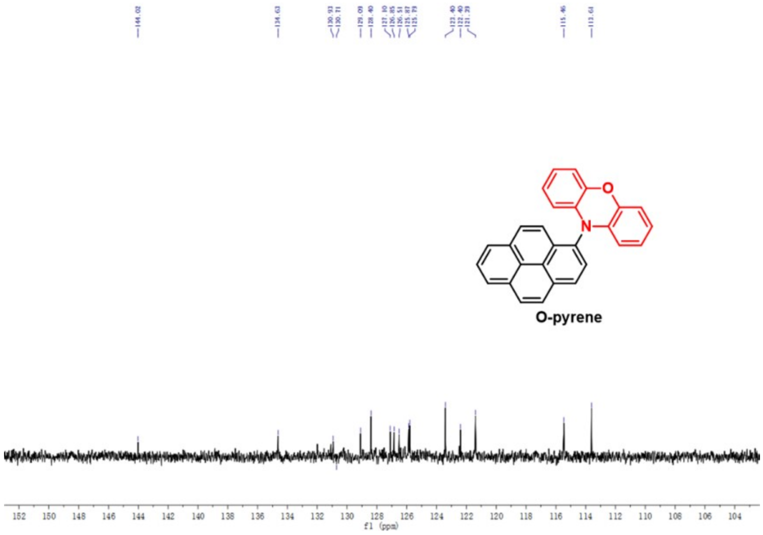


Figure S6. ^{13}C NMR spectrum of O-pyrene (in CDCl$_3$).

2 Theoretical calculation

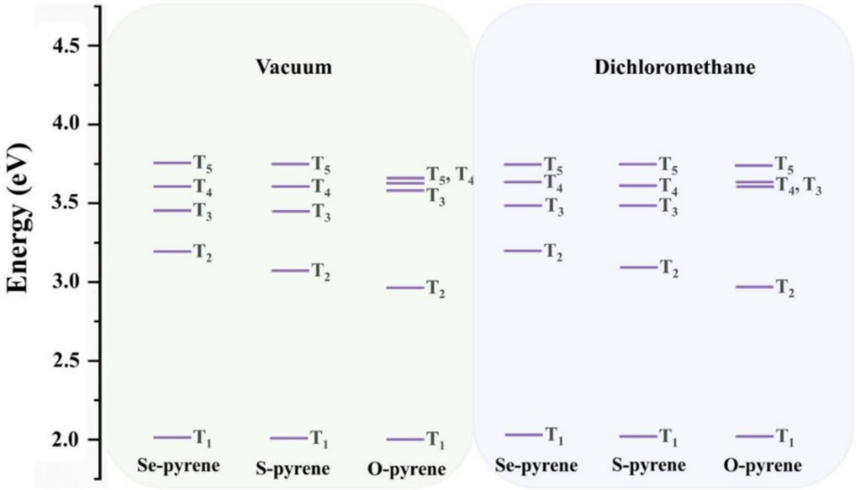


Figure S7. Diagrams of the TD-DFT calculated energy levels

Table S1. The S_n and T_n excitation energy (n = 1, 2, 3, 4, 5) in ev of compound **Se-pyrene** calculated at the TD-ωB97X-D3/6-31G (d, p) level, where the smallest S_n and T_n energies are underlined.

State	**S_0 geometry**	**S_1 geometry**	**T_1 geometry**
S_1	3.986	**3.235**	3.347
S_2	4.014	**3.601**	3.606
S_3	4.033	**3.731**	3.734
S_4	4.219	**3.882**	4.093
S_5	4.648	**4.210**	4.320
T_1	2.017	1.577	**0.836**
T_2	3.185	**2.580**	3.149
T_3	3.461	3.277	**3.163**
T_4	3.623	**3.352**	3.469
T_5	3.758	**3.422**	3.487

Table S2. The S_n and T_n excitation energy (n = 1, 2, 3, 4, 5) in ev of compound S-pyrene calculated at the TD-ωB97X-D3/6-31G (d, p) level, where the smallest S_n and T_n energies are underlined.

State	**S_0 geometry**	**S_1 geometry**	**T_1 geometry**
S_1	3.910	3.181	**3.163**
S_2	4.013	3.497	**3.479**
S_3	4.033	3.733	**3.684**
S_4	4.151	3.883	**3.856**
S_5	4.593	4.201	**4.191**
T_1	2.011	1.577	**1.496**
T_2	3.075	2.469	**2.463**
T_3	3.457	3.231	**3.206**
T_4	3.620	3.320	**3.317**
T_5	3.756	3.421	**3.385**

Table S3. The S_n and T_n excitation energy (n = 1, 2, 3, 4, 5) in ev of compound O-pyrene calculated at the TD-ωB97X-D3/6-31G (d, p) level, where the smallest S_n and T_n energies are underlined.

State	**S_0 geometry**	**S_1 geometry**	**T_1 geometry**
S_1	3.710	3.181	**3.172**
S_2	4.012	**3.497**	3.683
S_3	4.037	**3.733**	3.786
S_4	4.134	3.883	**3.857**
S_5	4.489	**4.201**	4.263
T_1	2.007	1.577	**1.490**
T_2	2.968	**2.469**	2.671
T_3	3.616	3.231	**3.172**
T_4	3.620	**3.320**	3.379
T_5	3.659	**3.421**	3.538

Table S4. The S_n and T_n excitation energy (n = 1, 2, 3, 4, 5) in ev of compound Se-pyrene calculated at the TD-ωB97X-D3/6-31G (d, p) level (PCM: dichloromethane), where the smallest S_n and T_n energies are underlined.

State	**S_0 geometry**	**S_1 geometry**	**T_1 geometry**
S_1	3.935	3.256	**3.205**
S_2	4.014	**3.667**	3.731
S_3	4.054	3.803	**3.757**
S_4	4.310	**3.859**	4.125
S_5	4.634	**4.297**	4.301
T_1	2.029	1.411	**0.865**
T_2	3.203	**2.811**	3.172
T_3	3.486	3.303	**3.172**
T_4	3.630	**3.387**	3.486
T_5	3.746	**3.478**	3.495

Table S5. The S_n and T_n excitation energy (n = 1, 2, 3, 4, 5) in ev of compound S-pyrene calculated at the TD-ωB97X-D3/6-31G (d, p) level (PCM: dichloromethane), where the smallest S_n and T_n energies are underlined.

State	**S_0 geometry**	**S_1 geometry**	**T_1 geometry**
$\mathbf{S_1}$	3.933	**3.201**	3.322
$\mathbf{S_2}$	3.994	3.574	**3.508**
$\mathbf{S_3}$	4.014	3.752	**3.559**
$\mathbf{S_4}$	4.239	**3.819**	3.845
$\mathbf{S_5}$	4.576	4.238	**4.151**
$\mathbf{T_1}$	2.024	**1.428**	1.493
$\mathbf{T_2}$	3.094	2.643	**2.469**
$\mathbf{T_3}$	3.482	**3.249**	3.330
$\mathbf{T_4}$	3.629	**3.384**	3.386
$\mathbf{T_5}$	3.746	3.420	**3.403**

Table S6. The S_n and T_n excitation energy (n = 1, 2, 3, 4, 5) in ev of compound O-pyrene calculated at the TD-ωB97X-D3/6-31G (d, p) level (PCM: dichloromethane), where the smallest S_n and T_n energies are underlined.

State	**S_0 geometry**	**S_1 geometry**	**T_1 geometry**
$\mathbf{S_1}$	3.862	**3.102**	3.186
$\mathbf{S_2}$	3.934	3.740	**3.652**
$\mathbf{S_3}$	4.015	3.838	**3.731**
$\mathbf{S_4}$	4.117	3.885	**3.820**
$\mathbf{S_5}$	4.487	4.304	**4.211**
$\mathbf{T_1}$	2.019	**1.421**	1.482
$\mathbf{T_2}$	2.972	2.810	**2.620**
$\mathbf{T_3}$	3.630	**3.153**	3.171
$\mathbf{T_4}$	3.632	**3.377**	3.381
$\mathbf{T_5}$	3.735	**3.498**	3.505

Table S7. Absolute value of SOCMEs (cm^{-1}) calculated at TD-ωB97X-D3/def2-TZVP(-f) level of theory of compound **Se-pyrene (PCM: dichloromethane).**

Transition type	**S_0 geometry**	**S_1 geometry**	**T_1 geometry**
$\left|\langle T_1 \middle| H_{SOC} \middle| S_0\rangle\right|$	0.000	0.558	0.000
$\left|\langle T_2 \middle| H_{SOC} \middle| S_0\rangle\right|$	147.4	78.79	0.950
$\left|\langle T_3 \middle| H_{SOC} \middle| S_0\rangle\right|$	10.14	43.74	146.8
$\left|\langle T_4 \middle| H_{SOC} \middle| S_0\rangle\right|$	0.930	35.71	3.170
$\left|\langle T_5 \middle| H_{SOC} \middle| S_0\rangle\right|$	0.150	30.60	11.39
$\left|\langle T_1 \middle| H_{SOC} \middle| S_1\rangle\right|$	0.000	1.262	0.000
$\left|\langle T_2 \middle| H_{SOC} \middle| S_1\rangle\right|$	0.282	1.882	0.050
$\left|\langle T_3 \middle| H_{SOC} \middle| S_1\rangle\right|$	0.010	1.185	0.253
$\left|\langle T_4 \middle| H_{SOC} \middle| S_1\rangle\right|$	0.050	0.703	0.070
$\left|\langle T_5 \middle| H_{SOC} \middle| S_1\rangle\right|$	0.070	2.717	0.140

Table S8. Absolute value of SOCMEs (cm^{-1}) calculated at TD-ωB97X-D3/def2-TZVP(-f) level of theory of compound **S-pyrene (PCM: dichloromethane).**

Transition type	**S_0 geometry**	**S_1 geometry**	**T_1 geometry**
$\lvert\langle T_1 \vert H_{SOC} \vert S_0\rangle\rvert$	0.020	0.244	0.010
$\lvert\langle T_2 \vert H_{SOC} \vert S_0\rangle\rvert$	24.99	9.282	2.417
$\lvert\langle T_3 \vert H_{SOC} \vert S_0\rangle\rvert$	2.930	4.177	0.421
$\lvert\langle T_4 \vert H_{SOC} \vert S_0\rangle\rvert$	0.210	1.668	0.073
$\lvert\langle T_5 \vert H_{SOC} \vert S_0\rangle\rvert$	0.040	6.741	1.306
$\lvert\langle T_1 \vert H_{SOC} \vert S_1\rangle\rvert$	0.000	0.238	0.262
$\lvert\langle T_2 \vert H_{SOC} \vert S_1\rangle\rvert$	0.108	0.591	0.400
$\lvert\langle T_3 \vert H_{SOC} \vert S_1\rangle\rvert$	0.030	0.325	0.322
$\lvert\langle T_4 \vert H_{SOC} \vert S_1\rangle\rvert$	0.040	0.102	0.112
$\lvert\langle T_5 \vert H_{SOC} \vert S_1\rangle\rvert$	0.070	0.410	0.580

Table S9. Absolute value of SOCMEs (cm^{-1}) calculated at TD-ωB97X-D3/def2-TZVP(-f) level of theory of compound **O-pyrene (PCM: dichloromethane).**

Transition type	**S_0 geometry**	**S_1 geometry**	**T_1 geometry**
$\lvert\langle T_1 \vert H_{SOC} \vert S_0\rangle\rvert$	0.010	0.287	0.108
$\lvert\langle T_2 \vert H_{SOC} \vert S_0\rangle\rvert$	0.323	0.737	0.720
$\lvert\langle T_3 \vert H_{SOC} \vert S_0\rangle\rvert$	0.240	1.236	1.292
$\lvert\langle T_4 \vert H_{SOC} \vert S_0\rangle\rvert$	0.420	0.297	0.249
$\lvert\langle T_5 \vert H_{SOC} \vert S_0\rangle\rvert$	0.290	0.721	0.580
$\lvert\langle T_1 \vert H_{SOC} \vert S_1\rangle\rvert$	0.772	0.601	0.625
$\lvert\langle T_2 \vert H_{SOC} \vert S_1\rangle\rvert$	0.850	0.786	0.776
$\lvert\langle T_3 \vert H_{SOC} \vert S_1\rangle\rvert$	0.271	0.299	0.271
$\lvert\langle T_4 \vert H_{SOC} \vert S_1\rangle\rvert$	0.455	0.191	0.108
$\lvert\langle T_5 \vert H_{SOC} \vert S_1\rangle\rvert$	0.242	0.457	0.457