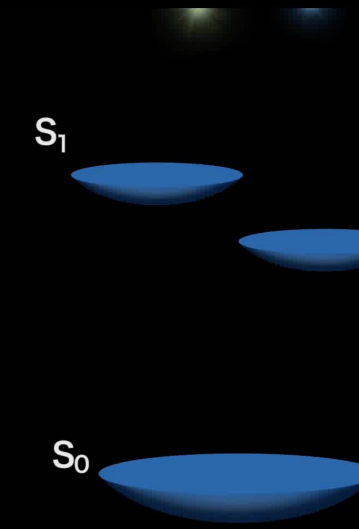
DOE WS@2022

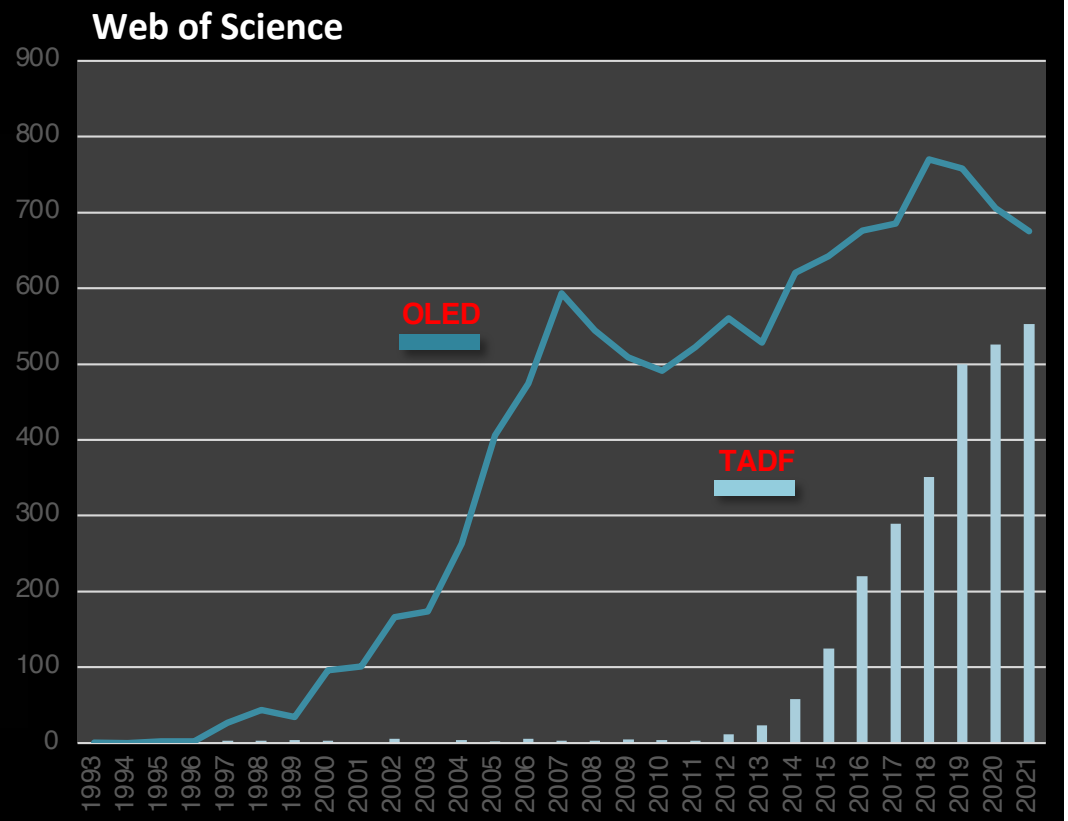
Blue Hyperfluorescence OLEDs aimed for high efficiency and stability

Center for Organic Photonics and Electronics Research (OPERA), Kyushu University

Chin-Yiu Chan, Yi-Ting Lee, Youichi Tsuchiya, Masaki Tanaka, Hajime Nakanotani and Chihaya Adachi

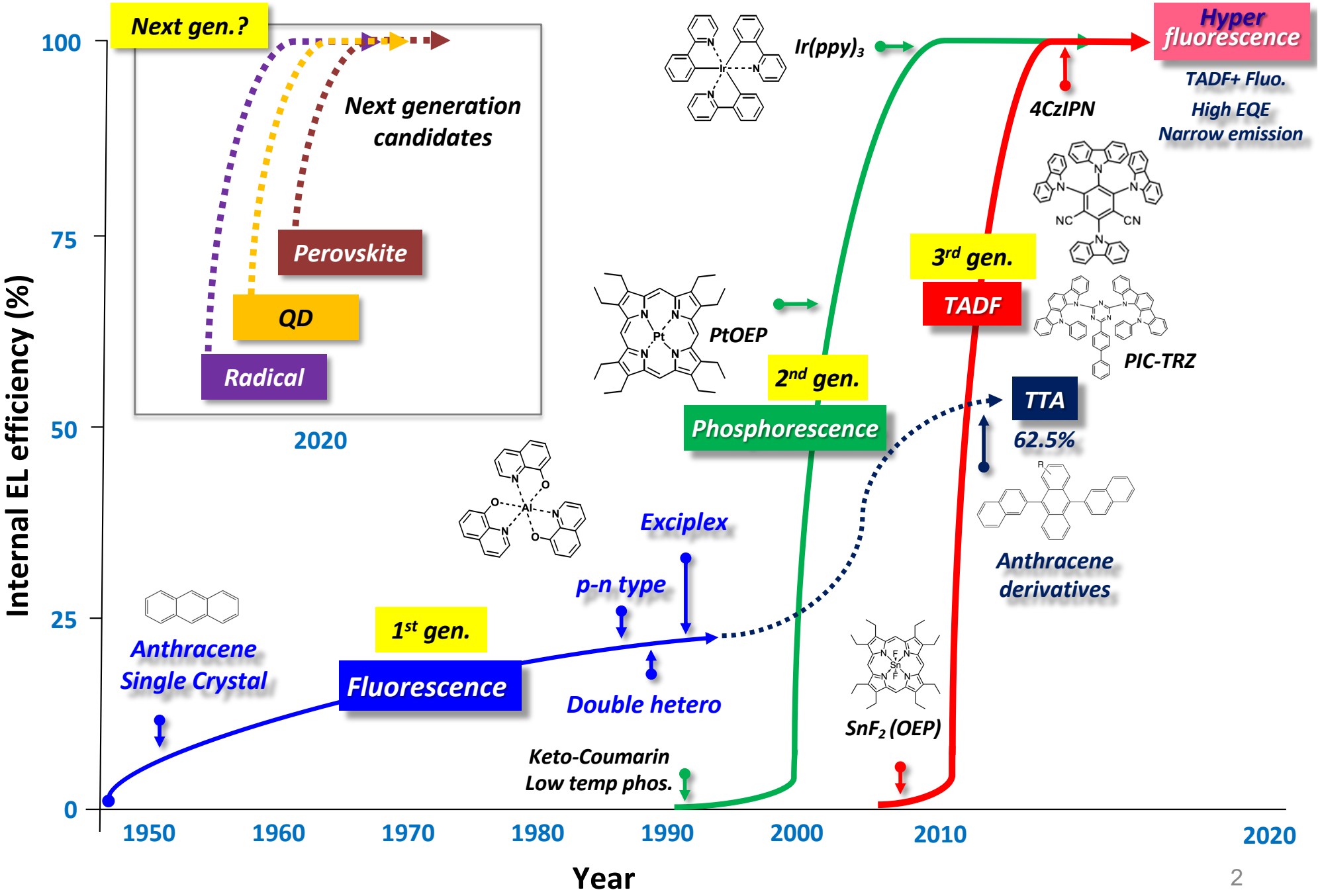


Conventional fluorescence and phosphorescence processes

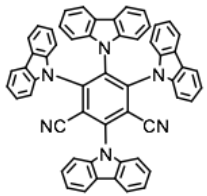


1) *Importance of short triplet lifetime in OLED emitters*
2) *Blue hyperfluorescence OLEDs with advanced materials combination*

Progress of molecular emitters in OLEDs



Acceleration of RISC



4CzIPN

$$k_{RISC} = A \exp\left(-\frac{\Delta E_{ST}}{k_B T}\right) \qquad A \approx \frac{\langle \phi_i | H_{SO} | \phi_f \rangle}{\Delta E_{ST}} \qquad H_{SO} = \xi \cdot S \cdot L$$

A is related with spin orbital coupling (H_{SOC})

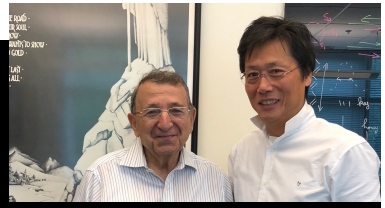
ξ : spin-orbit coupling constant (Heavy atom effect)

L : orbital angular momentum

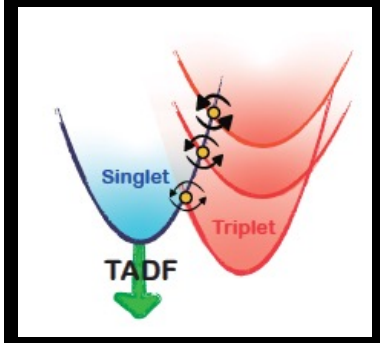
S : spin angular momentum

El-Sayed rule: *Formulated by Prof. Mostafa A. El-Sayed in 1960s*

Chemical Reviews **66** (2): 199–241.



Mostafa



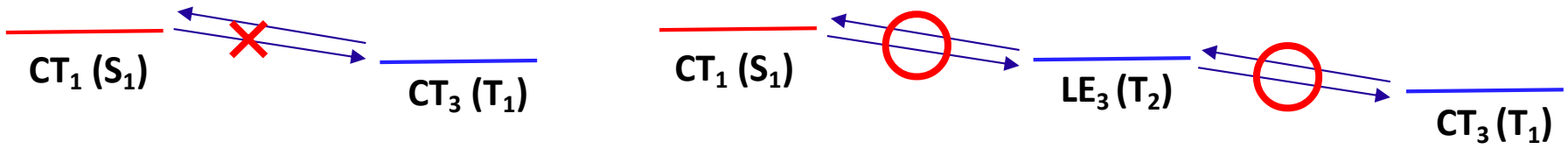
$$^1CT \not\leftrightarrow {}^3CT \qquad \langle \psi_{1CT} | H_{SOC} | \psi_{3CT} \rangle = 0$$

$$^1CT \leftrightarrow {}^3LE \qquad \langle \psi_{1CT} | H_{SOC} | \psi_{3LE} \rangle \neq 0$$

Second order vibronic coupling between LE and CT states

$$k_{RISC} = \frac{2}{\hbar} \left| \frac{\langle \psi_{1CT} | H_{SOC} | \psi_{3LE} \rangle \langle \psi_{3LE} | H_{vib} | \psi_{3CT} \rangle}{E_{3CT} - E_{3LE}} \right|^2 \delta(E_{1CT} - E_{3LE})$$

M. K. Etherington et al., *Nat. Commun.*, **7**, 13680 (2016)



Quantum Chemical Cal.: Excited-state engineering for efficient TADF

Georgia Tech

Prof. Xiankai Chen

(now, City U of HK)

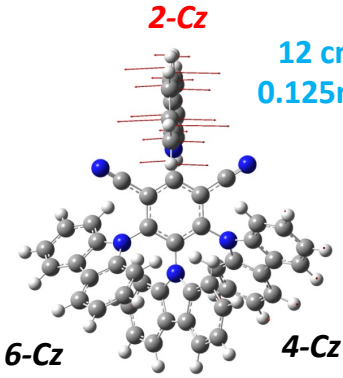
Article | Published: 02 September 2019

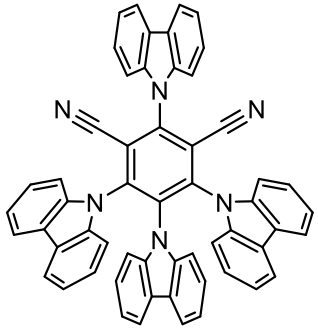
Critical role of intermediate electronic states for spin-flip processes in charge-transfer-type organic molecules with multiple donors and acceptors

Hiroki Noda, Xian-Kai Chen, Hajime Nakanotani ✉, Takuya Hosokai, Momoka Miyajima, Naoto Notsuka, Yuuki Kashima, Jean-Luc Brédas ✉ & Chihaya Adachi ✉

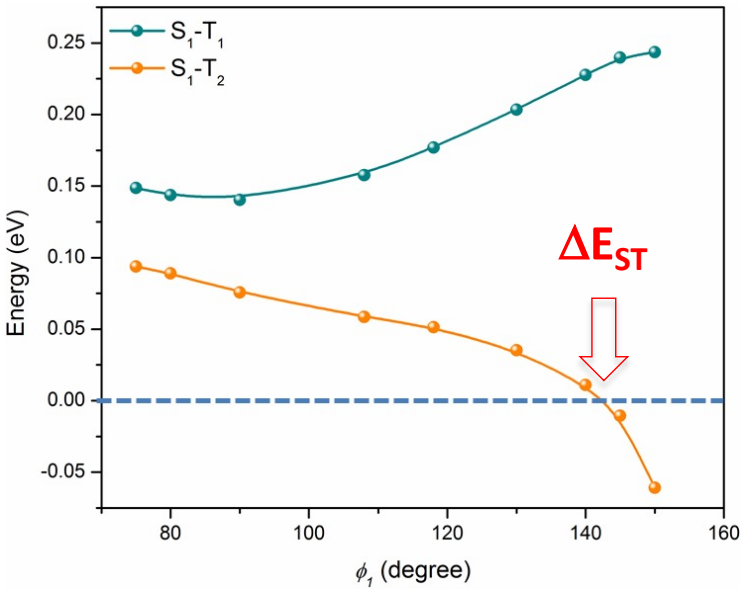
Nature Materials **18**, 1084–1090(2019) | Cite this article

9110 Accesses | **35** Citations | **15** Altmetric | Metrics

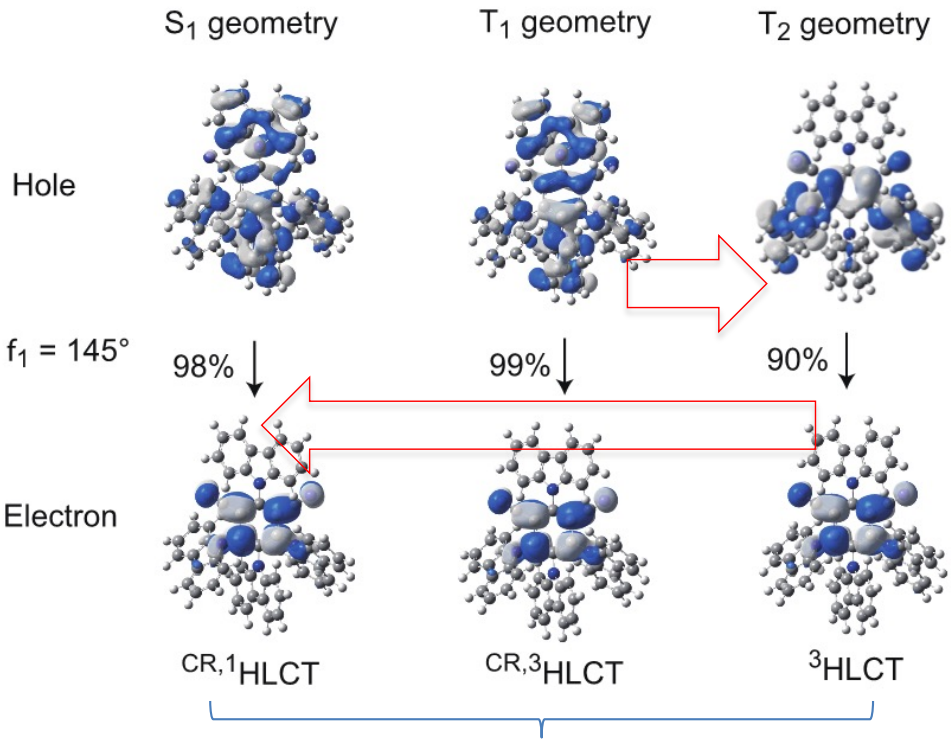




4CzIPN



SOC: 0.06 cm^{-1} S_1-T_1 (^{CR,1}HLCT-^{3}HLCT)



SOC: 0.51 cm^{-1}

S_1-T_2 (^{CR,1}HLCT-^{3}HLCT)

Spin selection rule

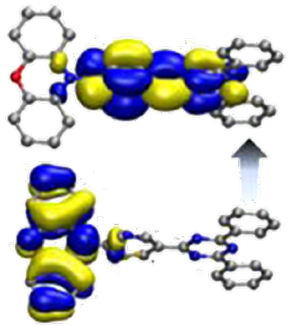
$^1CT \not\leftrightarrow {}^3CT$ $\quad \langle \psi_{1CT} | H_{SOC} | \psi_{3CT} \rangle = 0$

M. A. El-Sayed, et al., *J. Chem. Phys.*, **36**, 573 (1962).

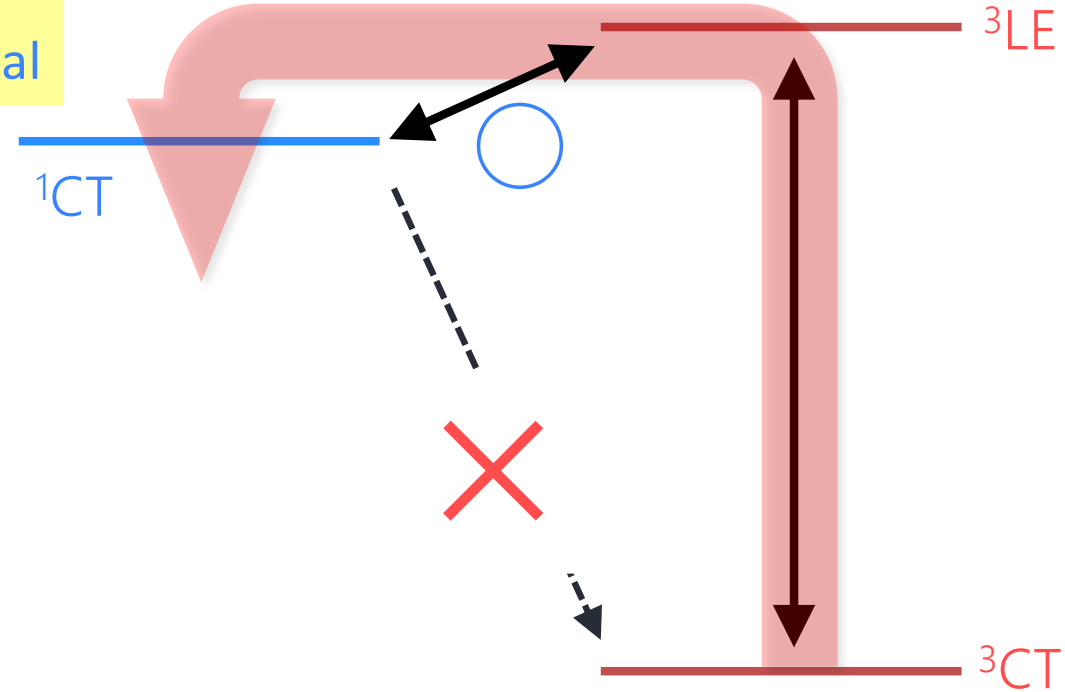
$^1CT \leftrightarrow {}^3LE$ $\quad \langle \psi_{1CT} | H_{SOC} | \psi_{3LE} \rangle \neq 0$

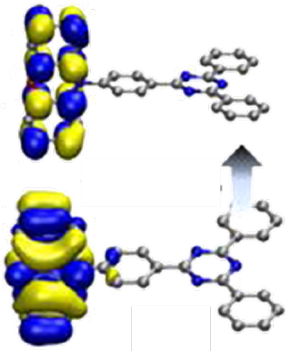
B. T. Lim, et al., *Chem. Phys. Lett.*, **79**, 22 (1981).

Different
molecular orbital

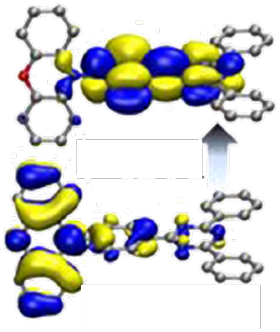


CT state





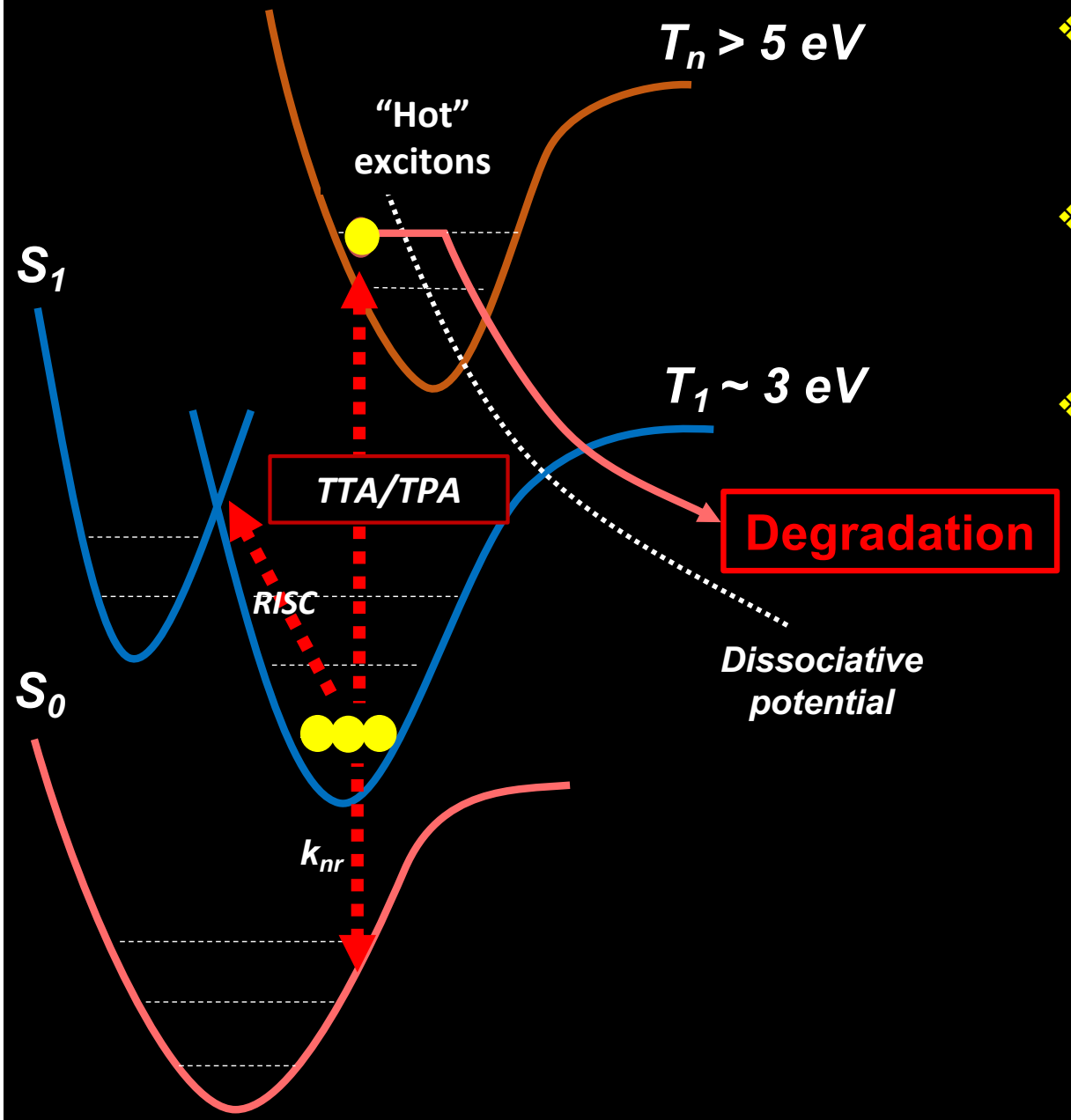
LE state



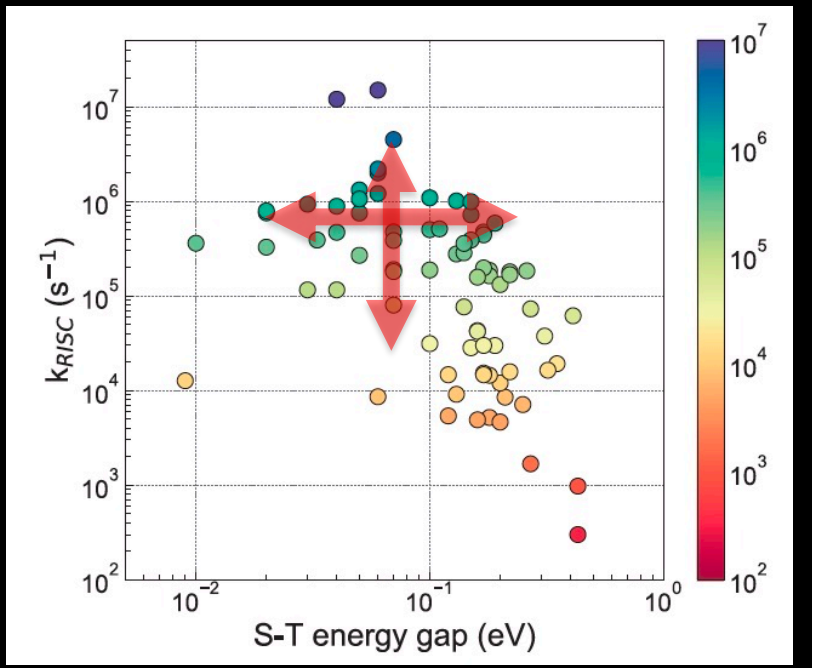
CT state

P. K. Samanta., et al., *J. Am. Chem. Soc.*, **139**, 4042 (2017)

OLED device lifetime -Degradation via triplet states-



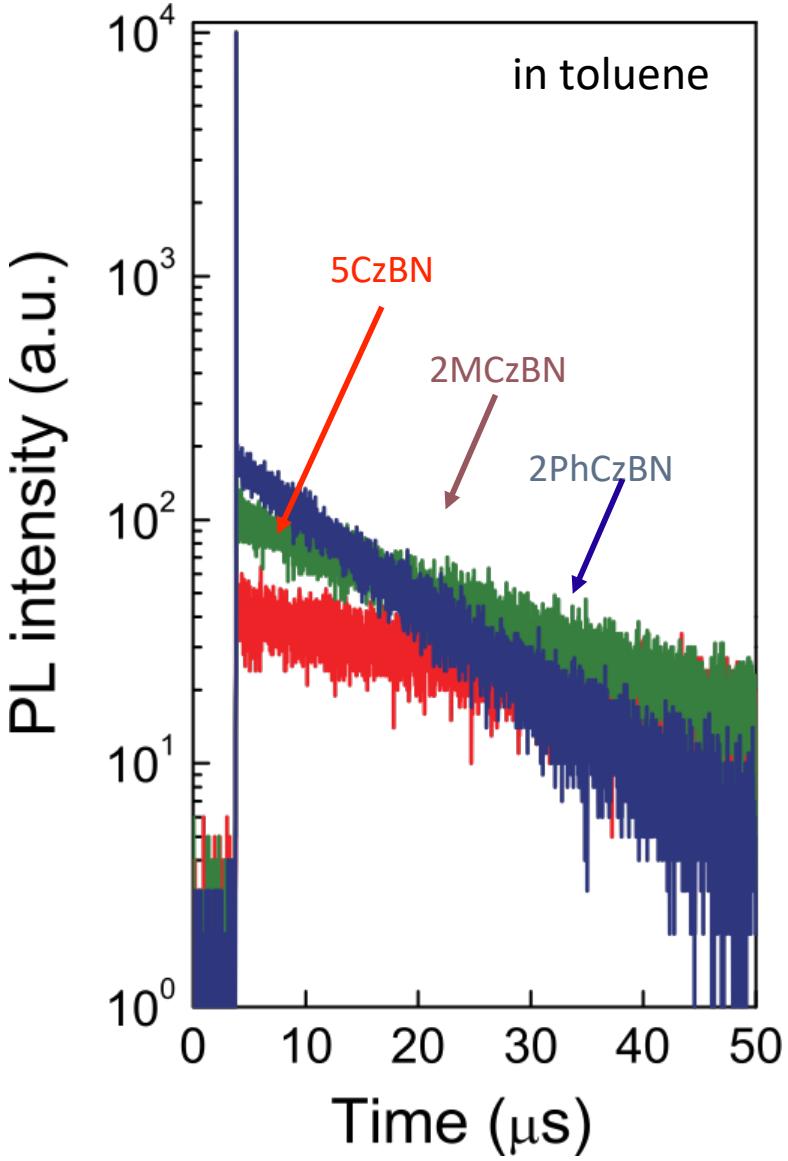
- *Long-live triplet exciton*
  - *μs to ms order*
  - *Exciton annihilation*
- *High triplet energy*
  - *T_1~3 eV (for blue)*
  - *T_n>5 eV (for blue)*
- *Chemical bond dissociation*
  - *C-N: ~3.5 eV*



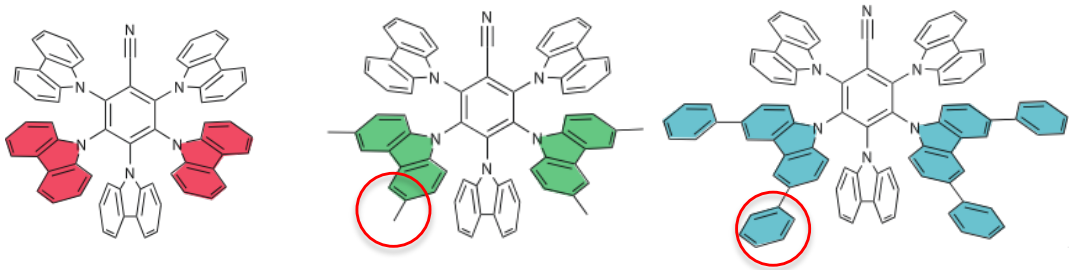
Chem. Lett. (2021)

J. Lee, S. R. Forrest, et al.,
Nat. Commun. **2017**, 8, 15566.

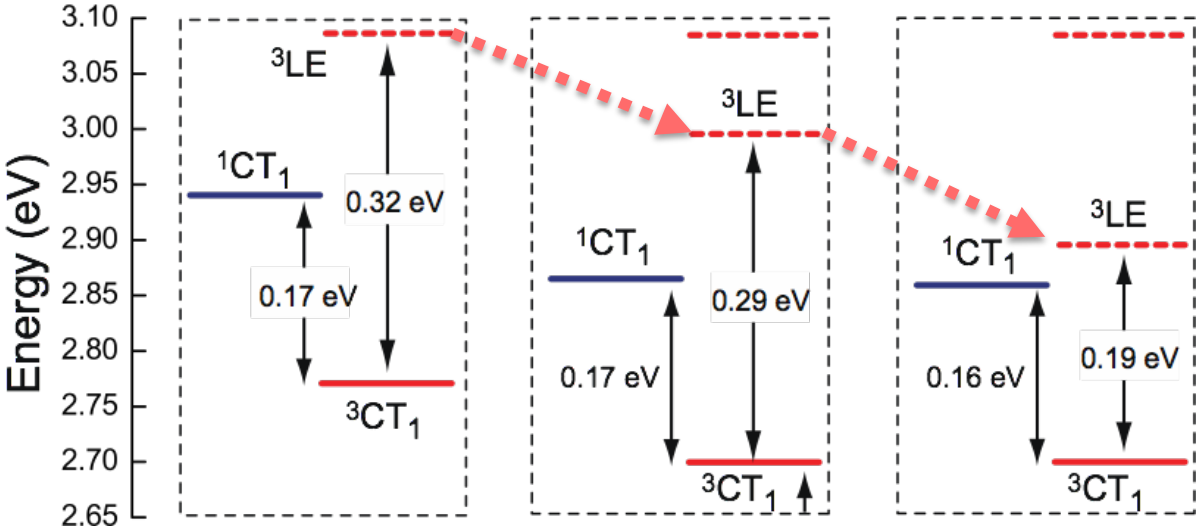
Excited-state engineering for efficient TADF



5CzBN

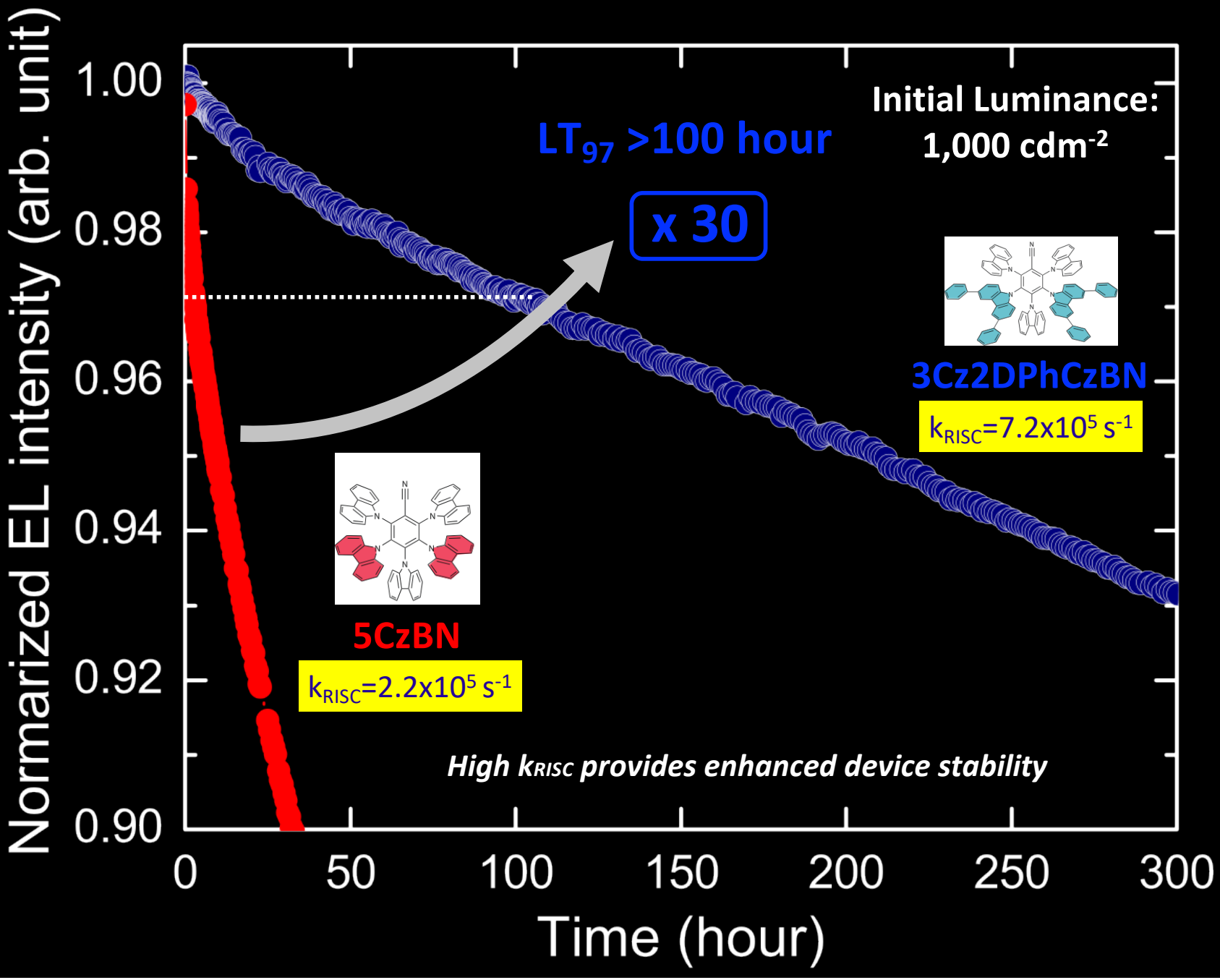


75% 85% 85%



k_{RISC} $2.2\times10^5\ s^{-1}$ < $4.4\times10^5\ s^{-1}$ < **$7.2\times10^5\ s^{-1}$**

Prolonged OLED device lifetime with



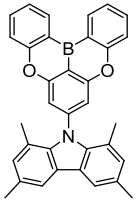
Recent advanced TADF emitters

$k_{ISC} > k_{RISC} > k_r$

TMCz-BO

$k_r > k_{ISC} > k_{RISC}$

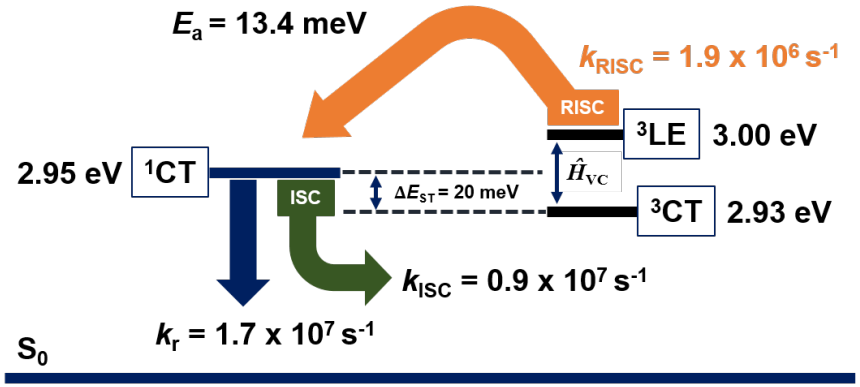
JU Kim et al., Nature Comm. 11, 1765 (2020)



(a) TMCz-BO τ_d = 750 ns

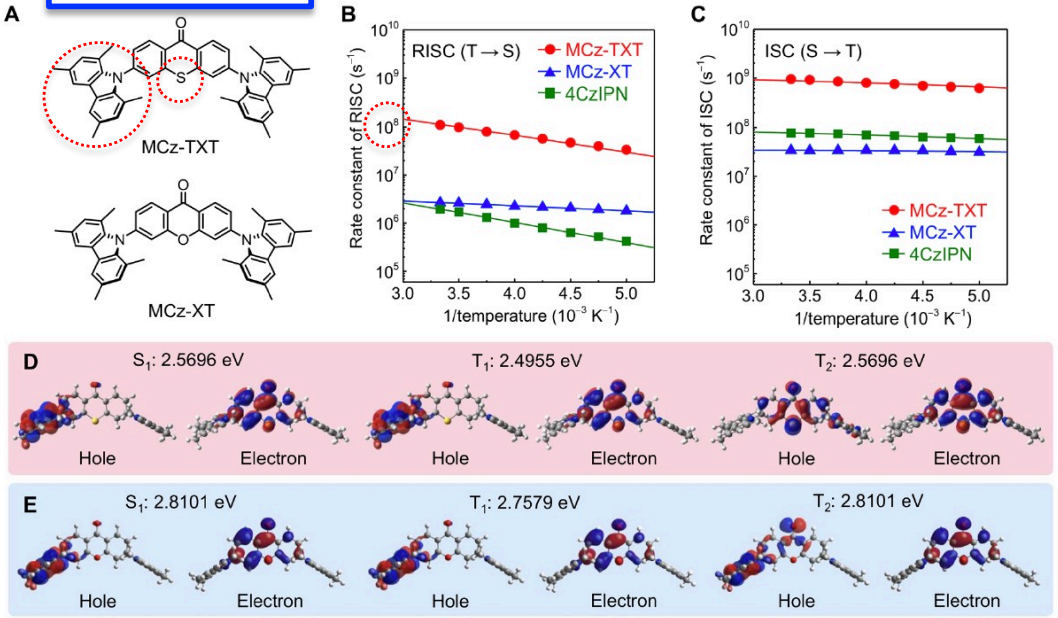
$\langle^1CT|\hat{H}_{soc}|^3LE\rangle$ = 0.124 cm^{-1}

$\langle^1CT|\hat{H}_{soc}|^3CT\rangle$ = 0.001 cm^{-1}



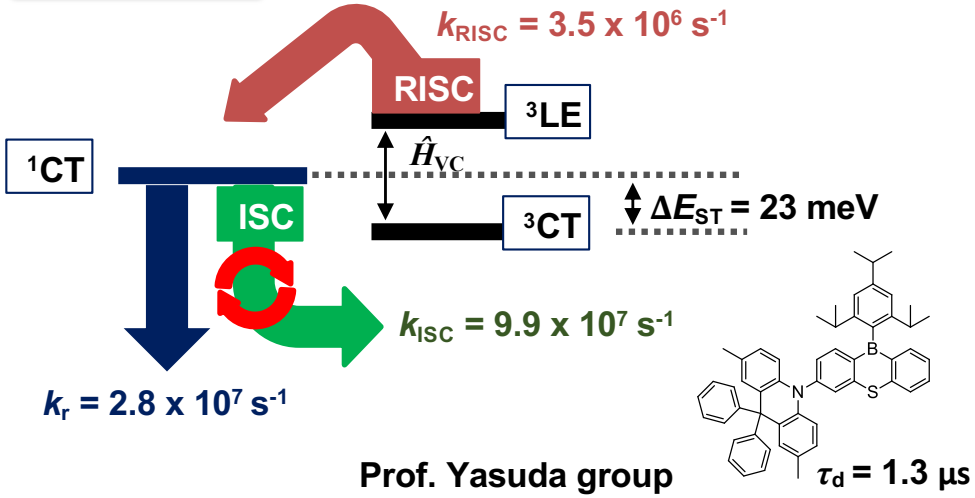
MCz-TXT

N. Aizawa, et al., *Sci. Adv. 7, eabe5769 (2021)*



MPAc-BS

$k_{ISC} > k_r > k_{RISC}$



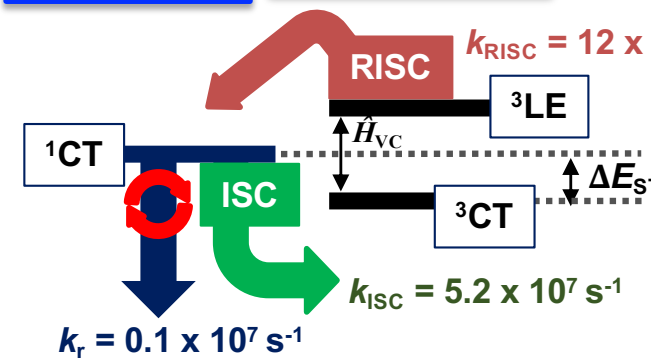
τ_d = 1.3 µs

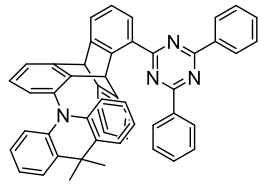
Prof. Yasuda group

I. S. Park et al., *Adv. Funct. Mater.*, **2018**, *28*, 1802031.

TpAT-tFFO

$k_{ISC} > k_{RISC} > k_r$





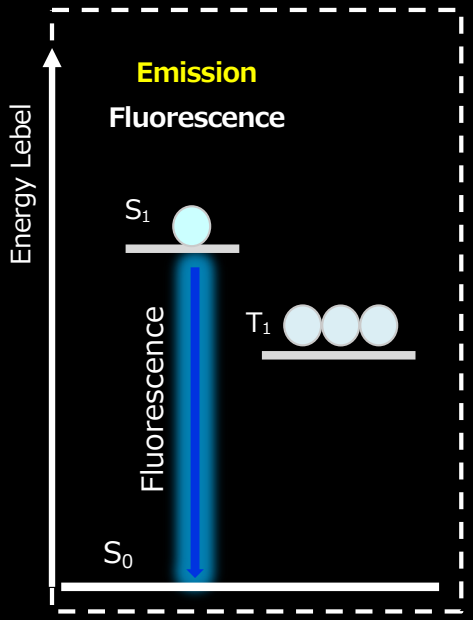
τ_d = 4.1 µs

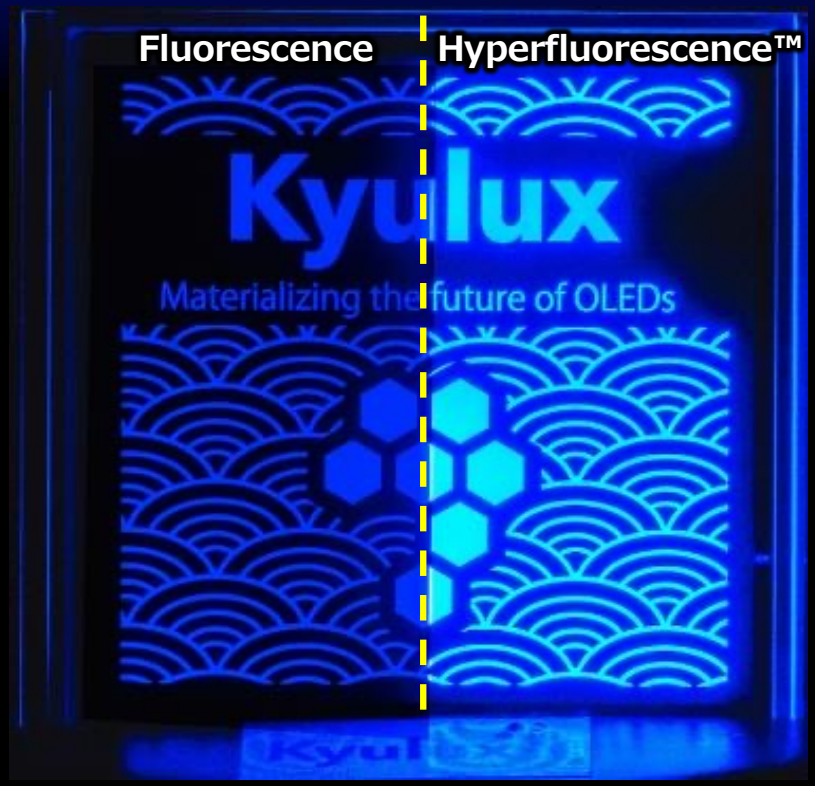
Prof. Kaji group

Y. Wada et al., *ChemRxiv*, **2019**, DOI:10.26434/chemrxiv.9745289.

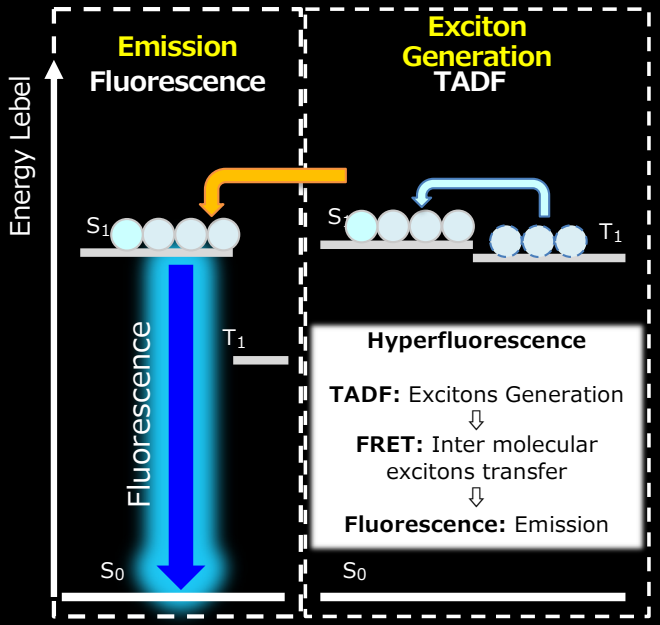
Advanced Blue Hyperfluorescence OLED

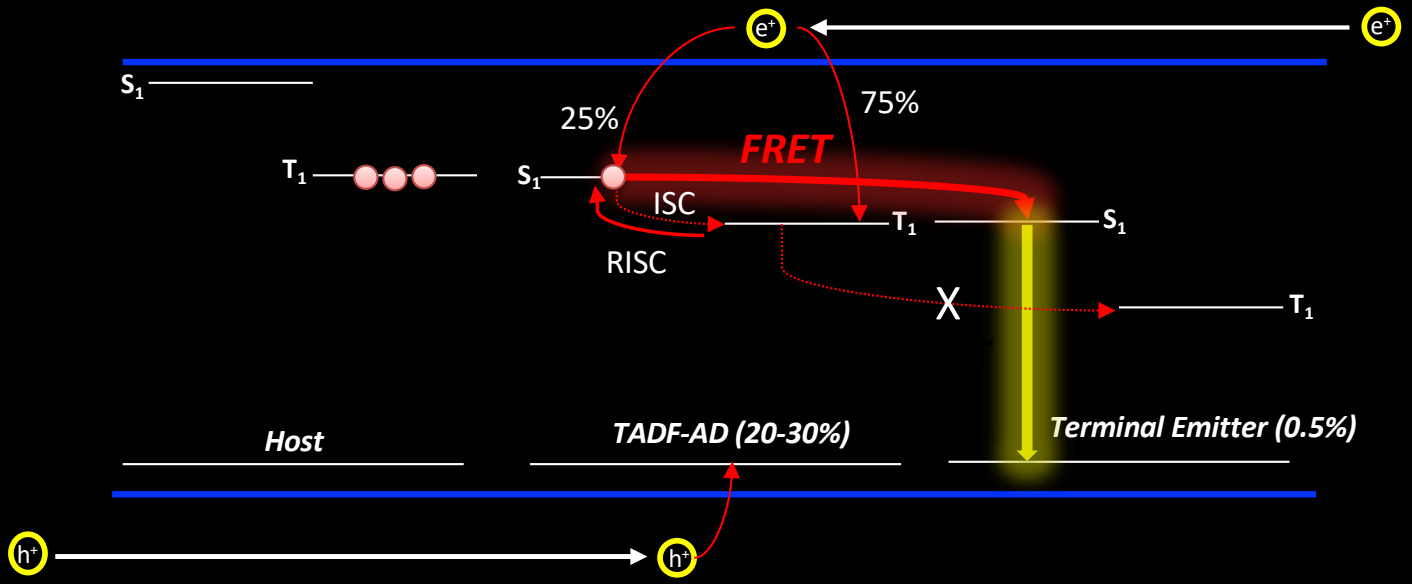
Fluorescence
Low efficiency:
IQE_{MAX}=25%





Hyperfluorescence
High efficiency: IQE_{MAX}=100%





Hyperfluorescence™: The Optimum Solution for OLED Display

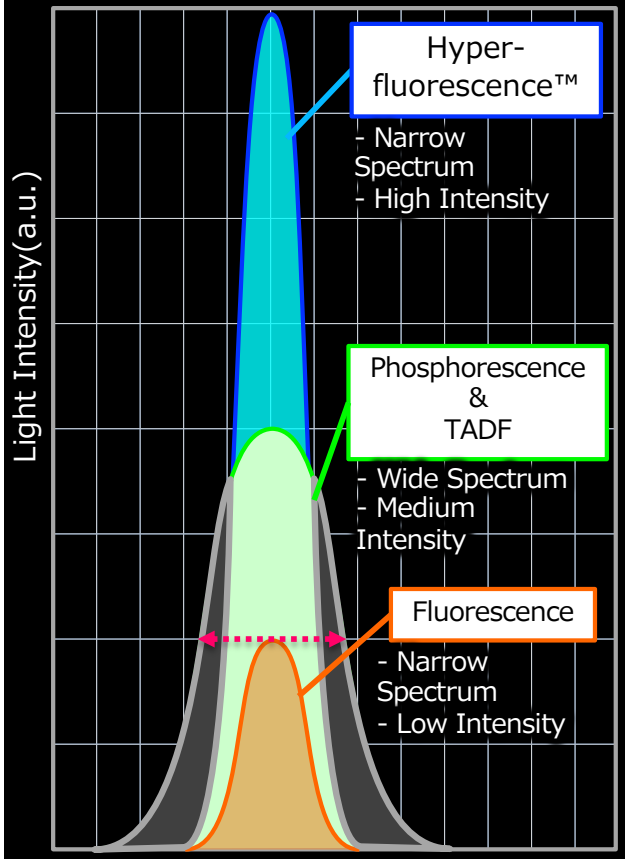
Nat. Commun., **5**, 5016, 2014

H. Nakanotani et al.

M. Baldo et al., Nature 403, 750 (2000) Phos. sensitizing fluo.

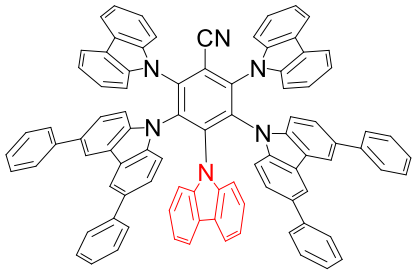
L. Duan et al., Adv. Mat., 26, 5050 (2014) TADF sensitizing fluo.

Spectra Comparison



Emission Technology	R	G	B	Efficiency	Cost	Color Purity	
Fluorescence (1Gen)	–	–	O	Low	$	high	
Phosphorescence (2Gen)	O	O	–	High	$$$	Low	
TADF (3Gen)	O	O	–	High	$	Low	
Hyper-fluorescence™ (4Gen)	O	O	O	High	$	High	

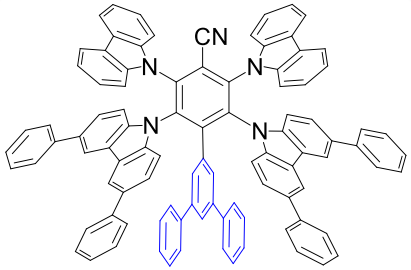
Advanced Performance of Hyperfluorescence Blue OLED



3Cz2DPhCzBN

λ_{EL} = **495 nm**

Most advanced TADF

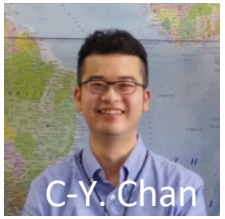


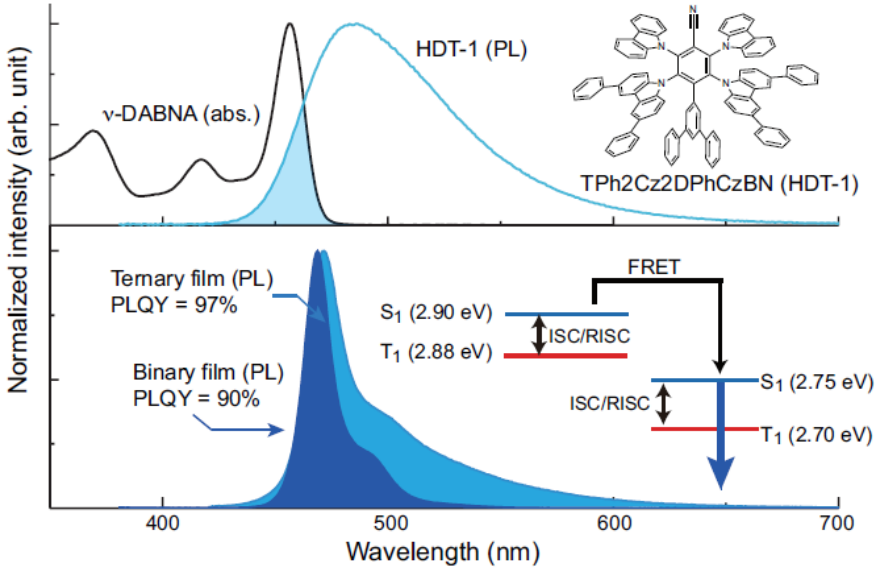
HDT-1

λ_{EL} = **486 nm**

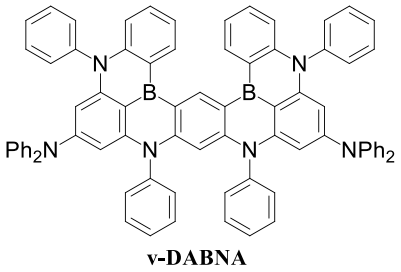
$k_{RISC} \sim 9.2 \times 10^5\ s^{-1}$

C-Y. Chan et al.,
Nat. Photonics, 2021
DOI: https://doi.org/10.1038/s41566-020-00745-z





- Bulky terphenyl substituent prevents molecular aggregation, while maintains a fast k_{RISC} and a high PLQY

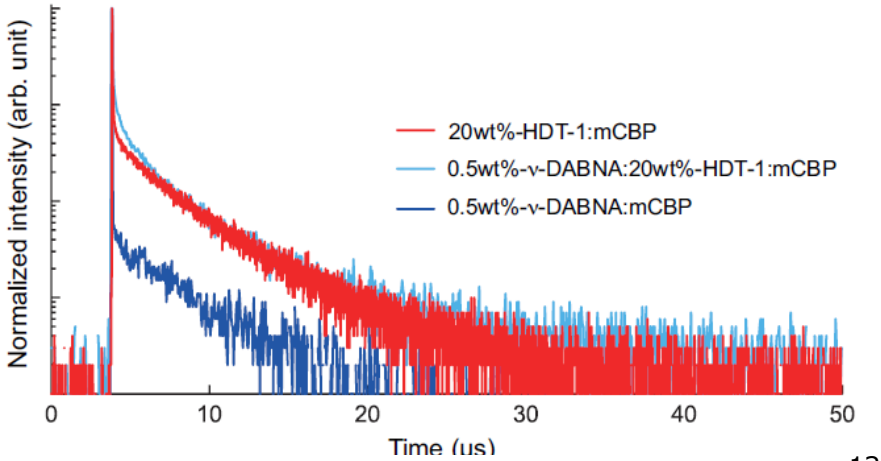


ν-DABNA

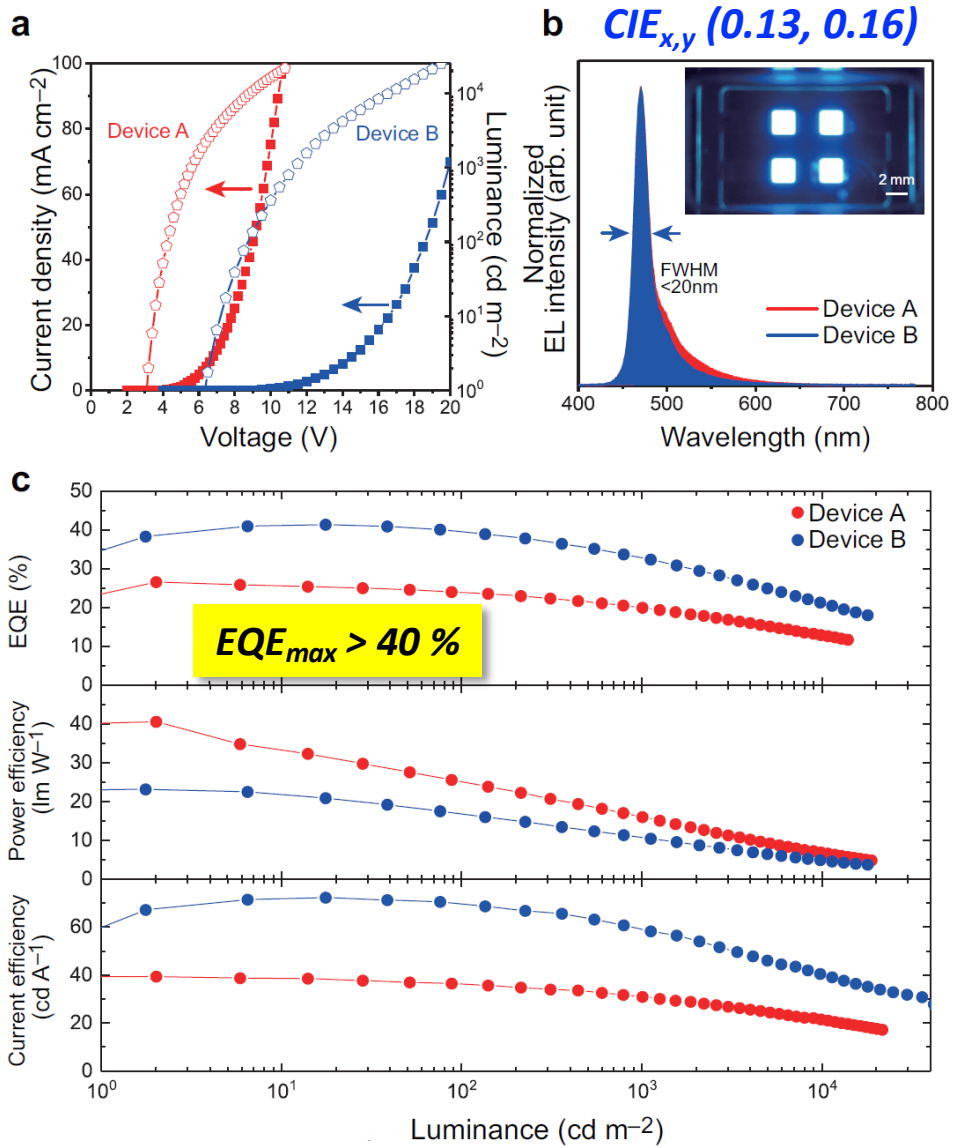
Terminal Emitter

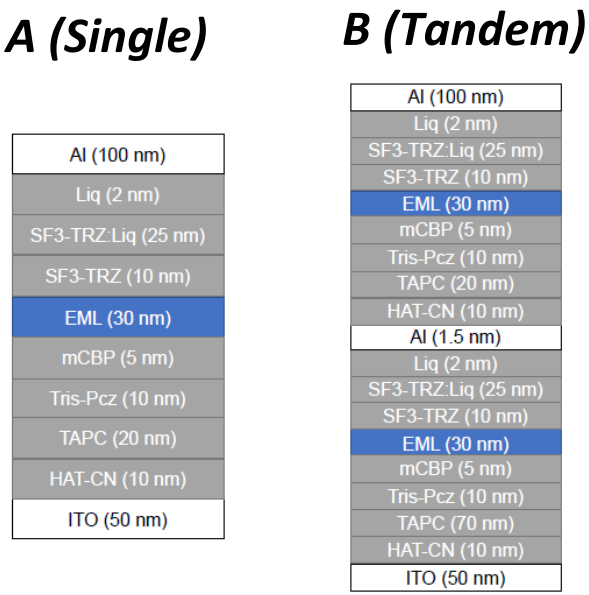
T. Hatakeyama and coworkers,
Nat. Photonics **2019**, *13*, 678.

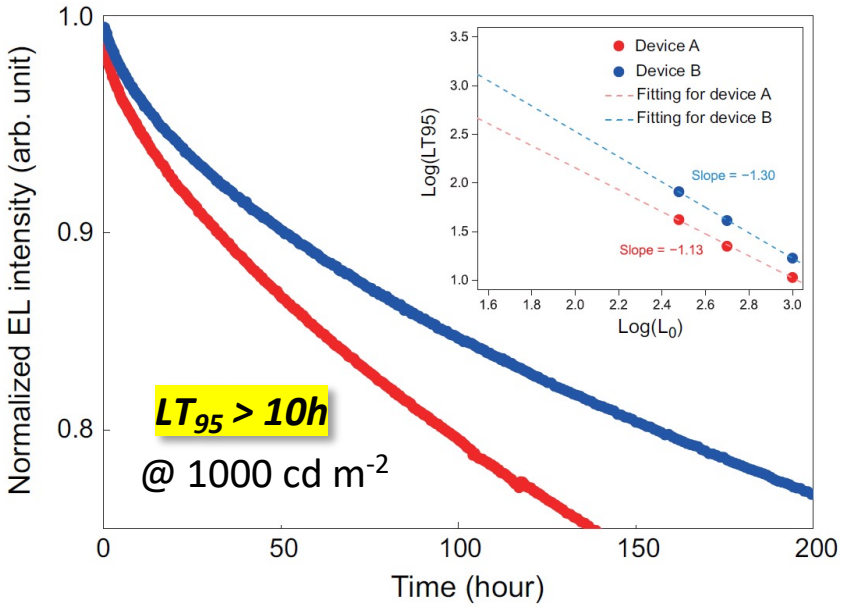
- Sky-blue emission of HDT-1 ensures singlet-excited state energy transfer to the terminal dopant, hence improving color purity.



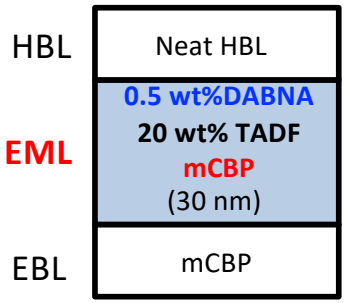
Hyperfluorescence Blue OLED: Tandem for brighter luminance

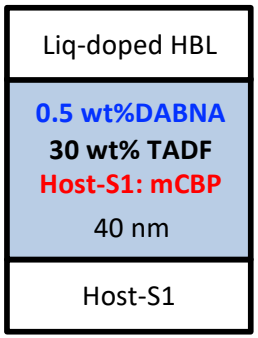






Hyperfluorescence Blue OLED: Lifetime enhancement by mixed host

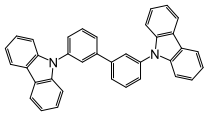




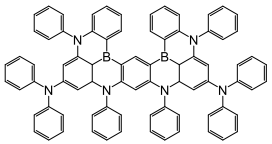
Single host mCBP

Mixed host Host-S1 : mCBP

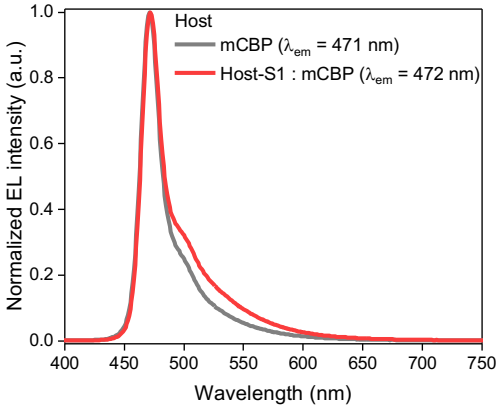
Host-S1
- Cz-based
- Slight shallow HOMO
- High hole-transport

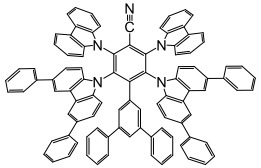


mCBP host

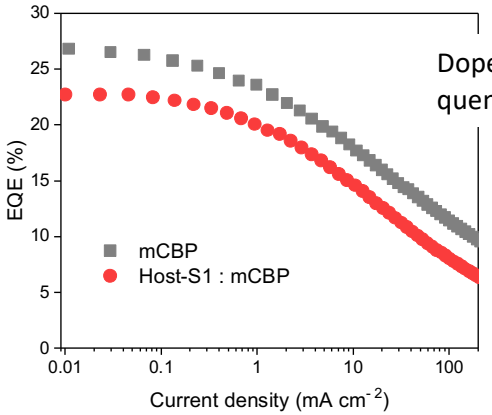


ν-DABNA pure blue terminal emitter

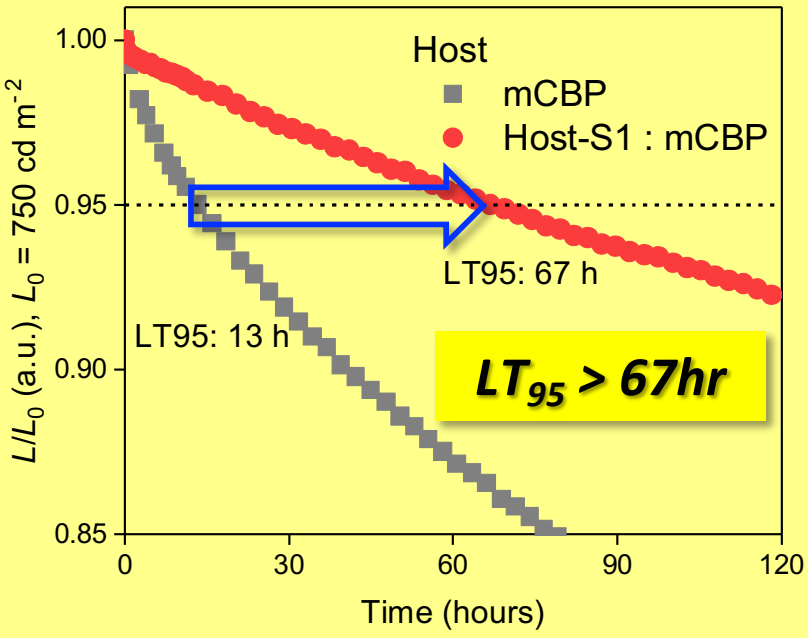


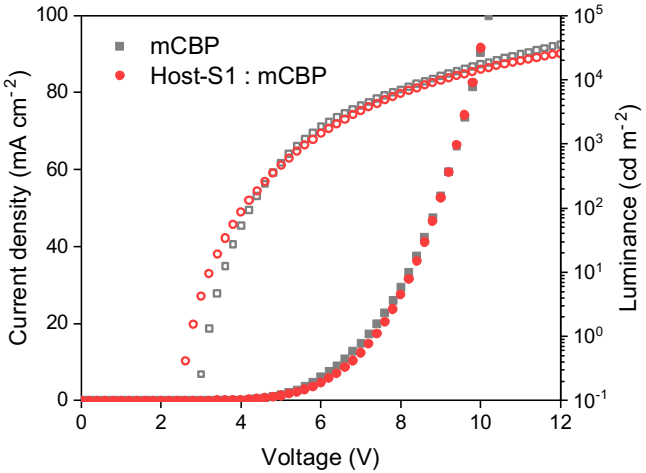


Sky-blue TADF Assistant dopant

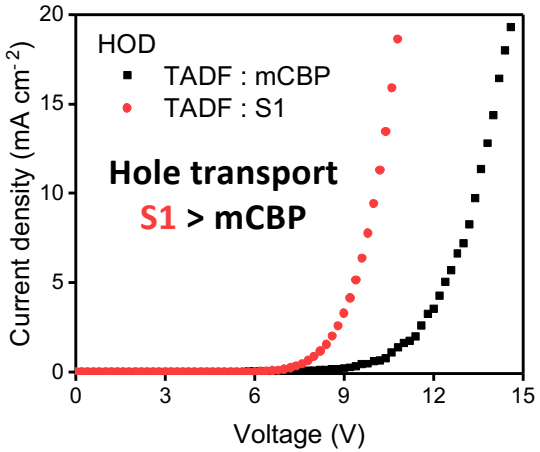


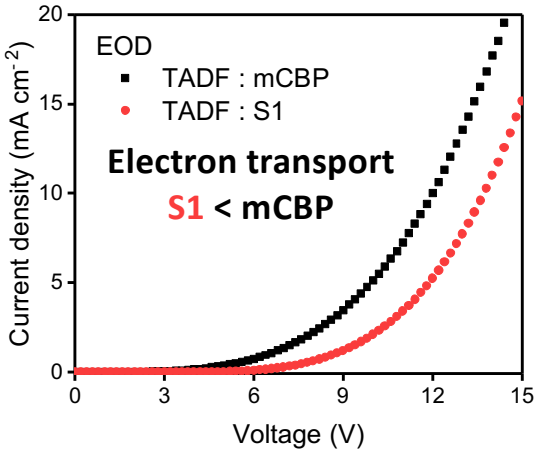
Doped-Liq slightly quenched exciton





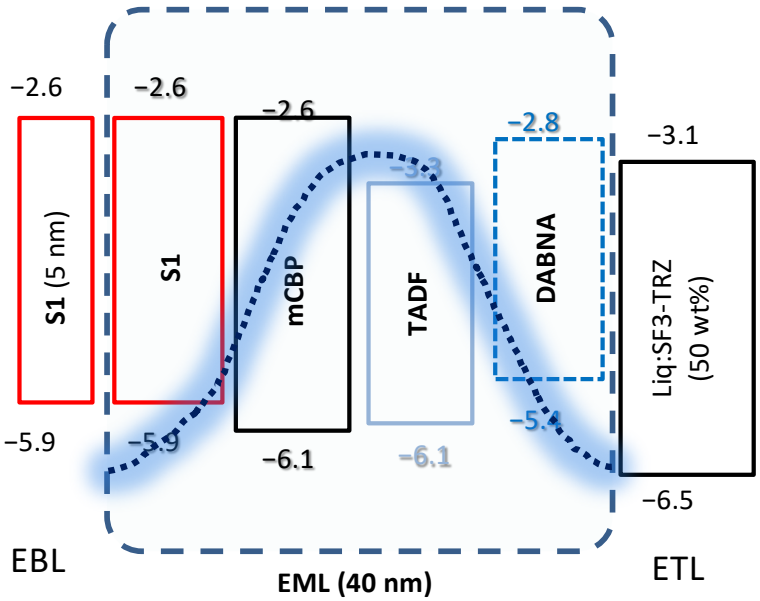
Hyperfluorescence Blue OLED: Lifetime enhancement with mixed host

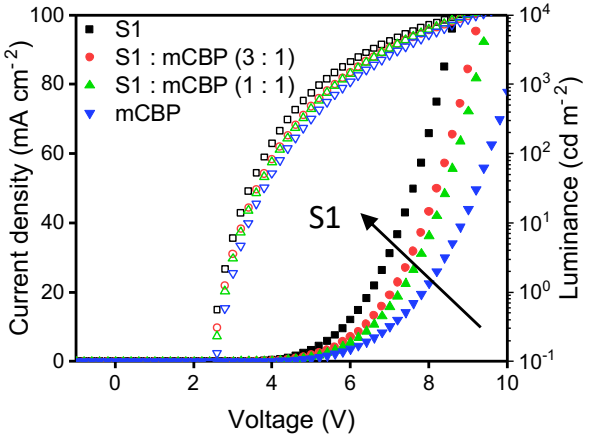


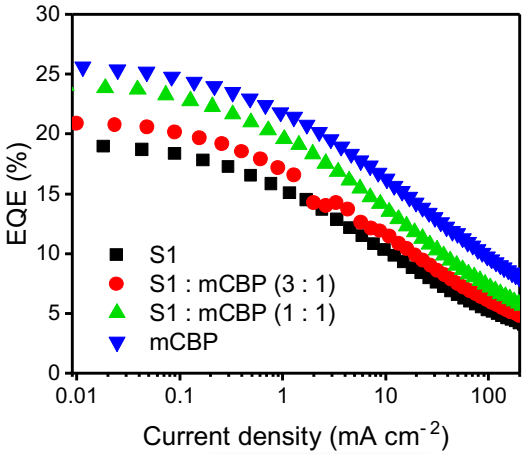


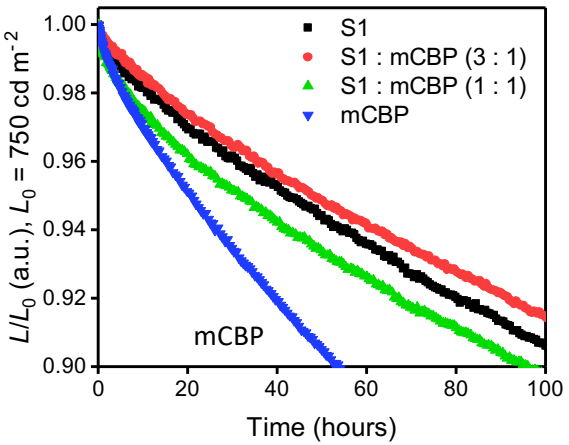
Host-**S1**

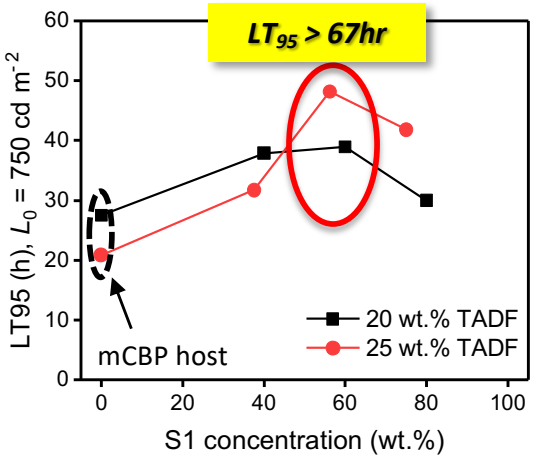
- Cz backbone
- Shallow HOMO
- T_1~2.8 eV











Latest achievements: Red, Green and Blue

Kyulux

SID Display Week 2021 Symposium

Color		λ_{peak} (nm)	FWHM (nm)	CIE xy	Efficiency (cd/A)	LT95@1000nit (hours)
Red	BE	617	43	0.65, 0.35	32	>37,000
	TE	618	23	0.68, 0.32		
Green	BE	522	34	0.24, 0.70	81	> 20,000
	TE	523	17	0.14, 0.79		
Blue	BE	471	21	0.12, 0.13	43	280
	TE	469	16	0.12, 0.06		

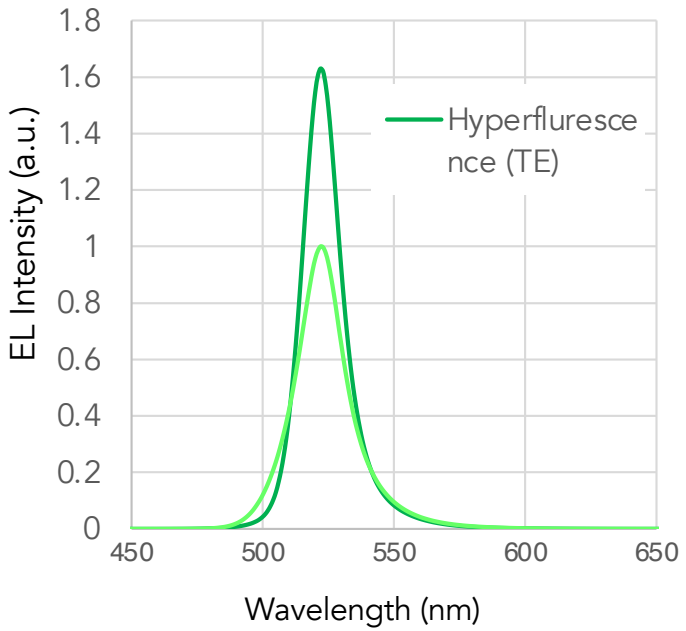
Advantages of Green Hyperfluorescence™

OLEDs WORLD SUMMIT

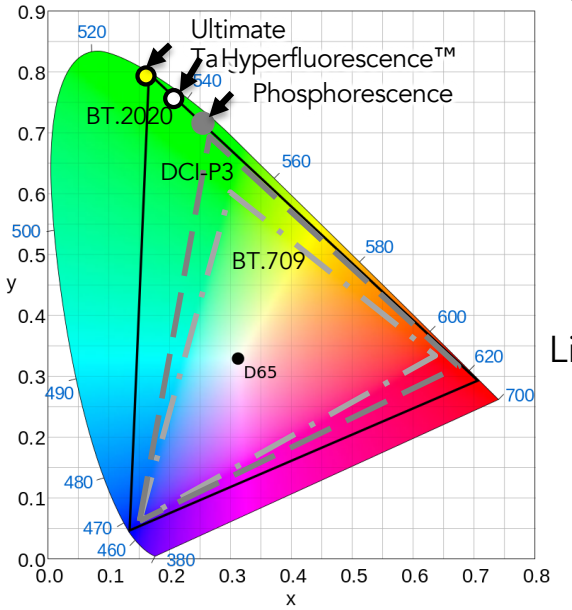
Kyulux

- Top-emitting green Hyperfluorescence™ (HF) device has achieved better chromaticity, higher current efficiency, and longer lifetime than phosphorescence.
- The current target specs in efficiency, lifetime and driving voltage have been achieved.
- Chromaticity of the HF reaches 95% of the ultimate target. The target shall be achieved by using optimized green fluorescence dopants designed by Kyulux before soon.
- HF is able to satisfy the major requirements of the next-generation display. (BT.2020)

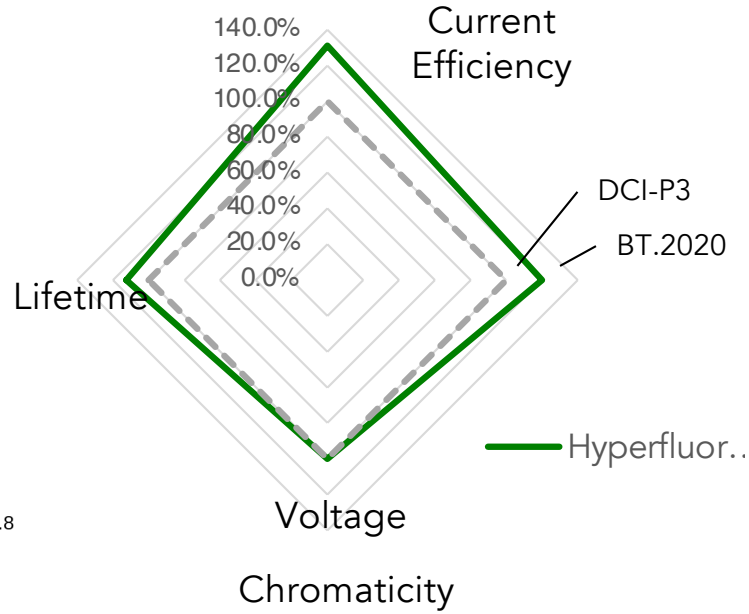
Emission Spectrum of Device



Chromaticity Coordinate



Hyperfluorescence™ Performance



Acknowledgments

TADF works

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