AMOLF physics of functional complex matter

Towards efficient and stable perovskite/silicon tandem solar cells

Bruno Ehrler

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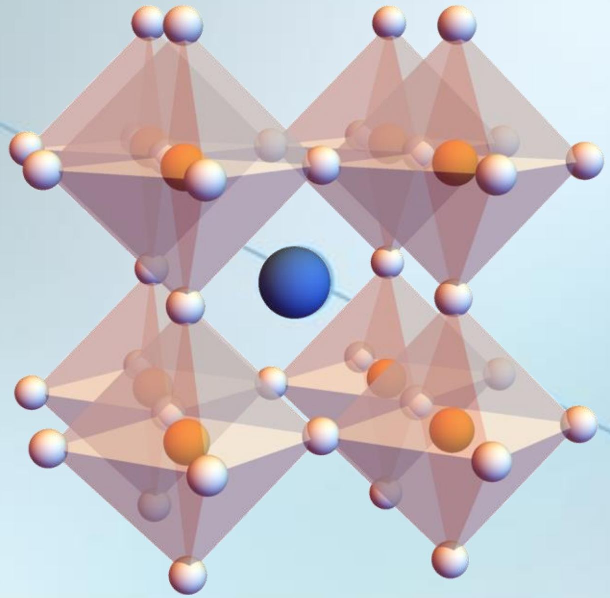

Acknowledgements

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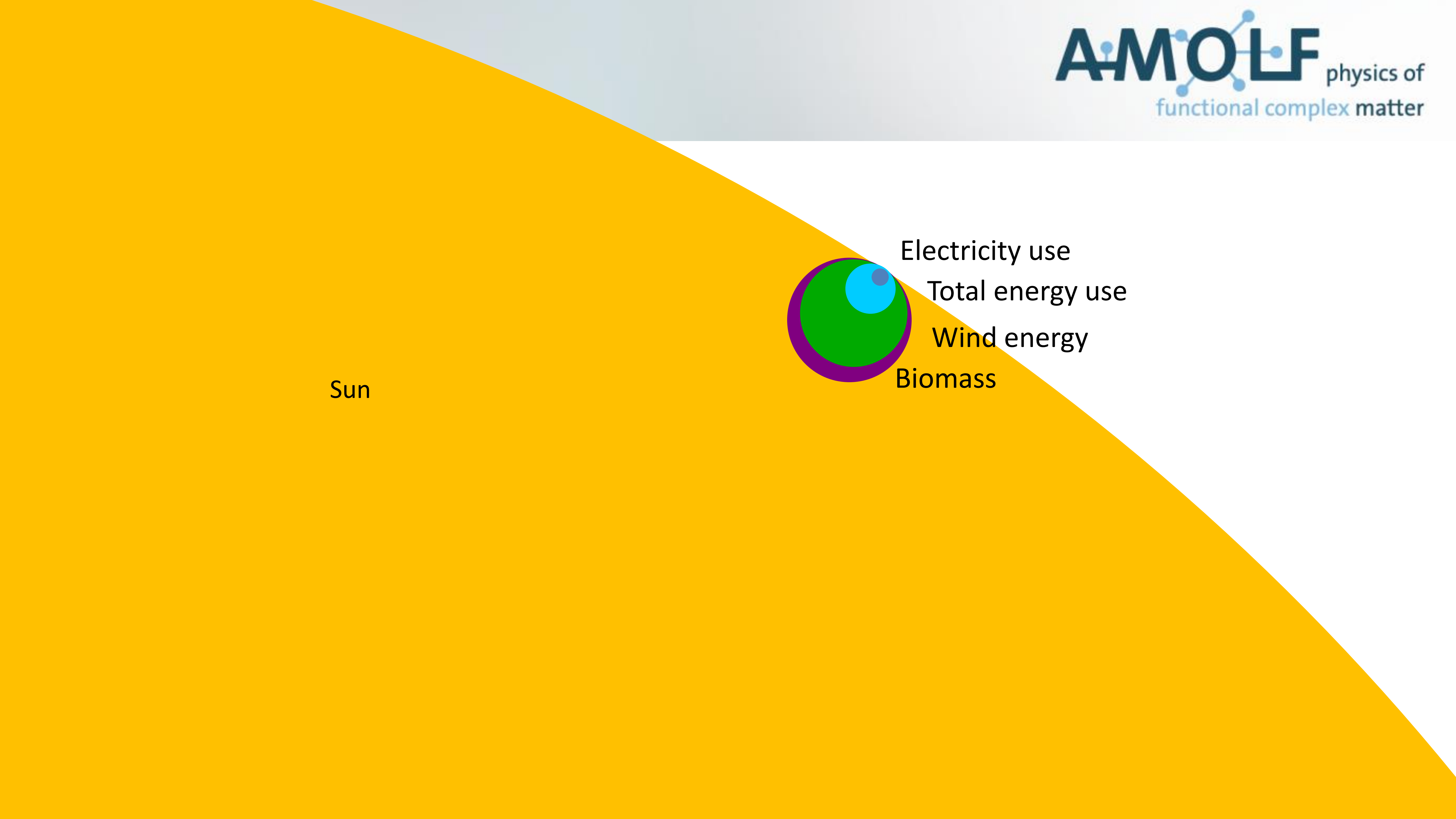
Michael Saliba

University of Konstanz

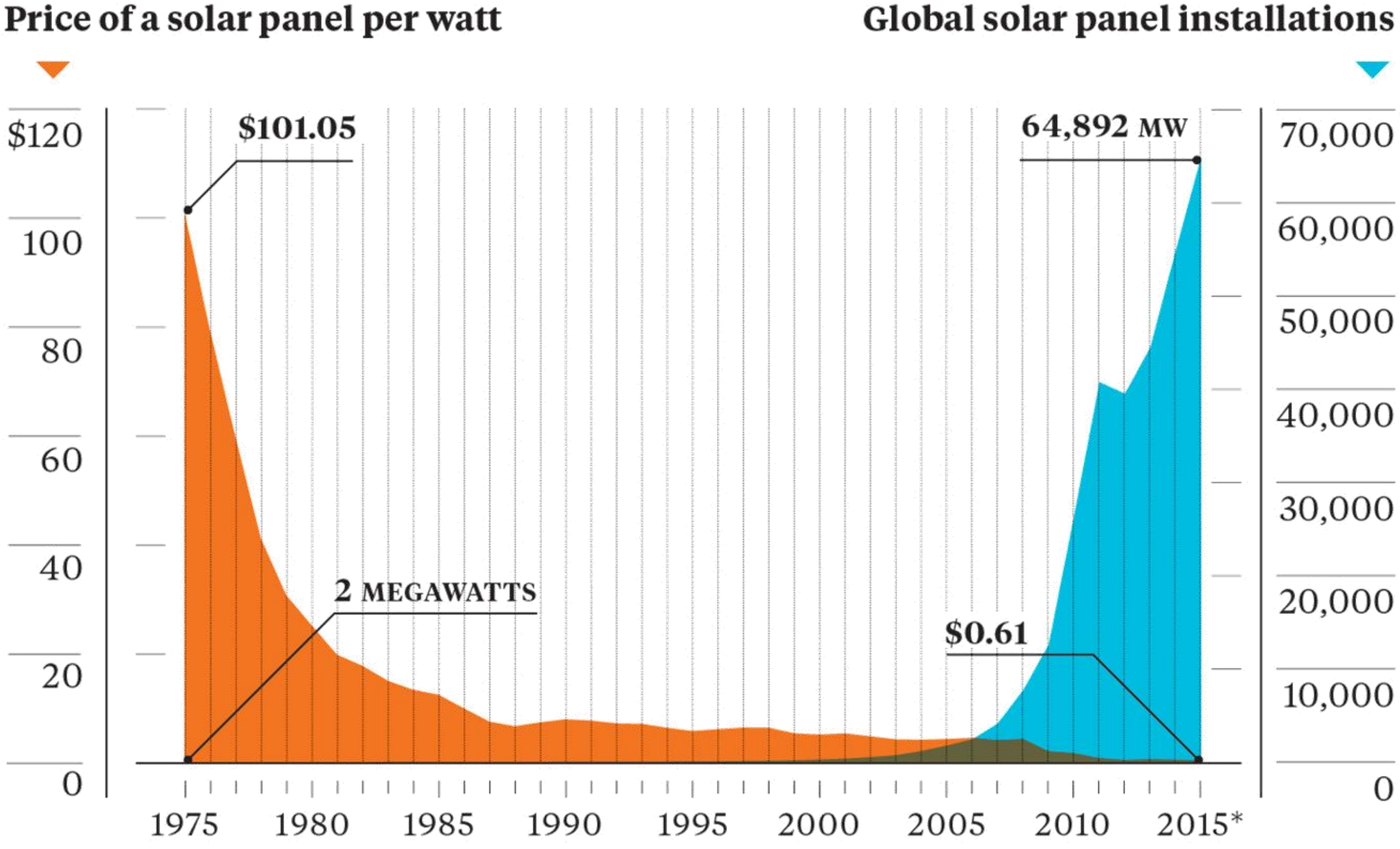
Irfan Haider
Azhar Fakharuddin
Lukas Schmidt-Mende

AMOLF physics of functional complex matter


Electricity use
Total energy use
Wind energy
Biomass
Sun

Solar on Fire

As prices have dropped, installations have skyrocketed.

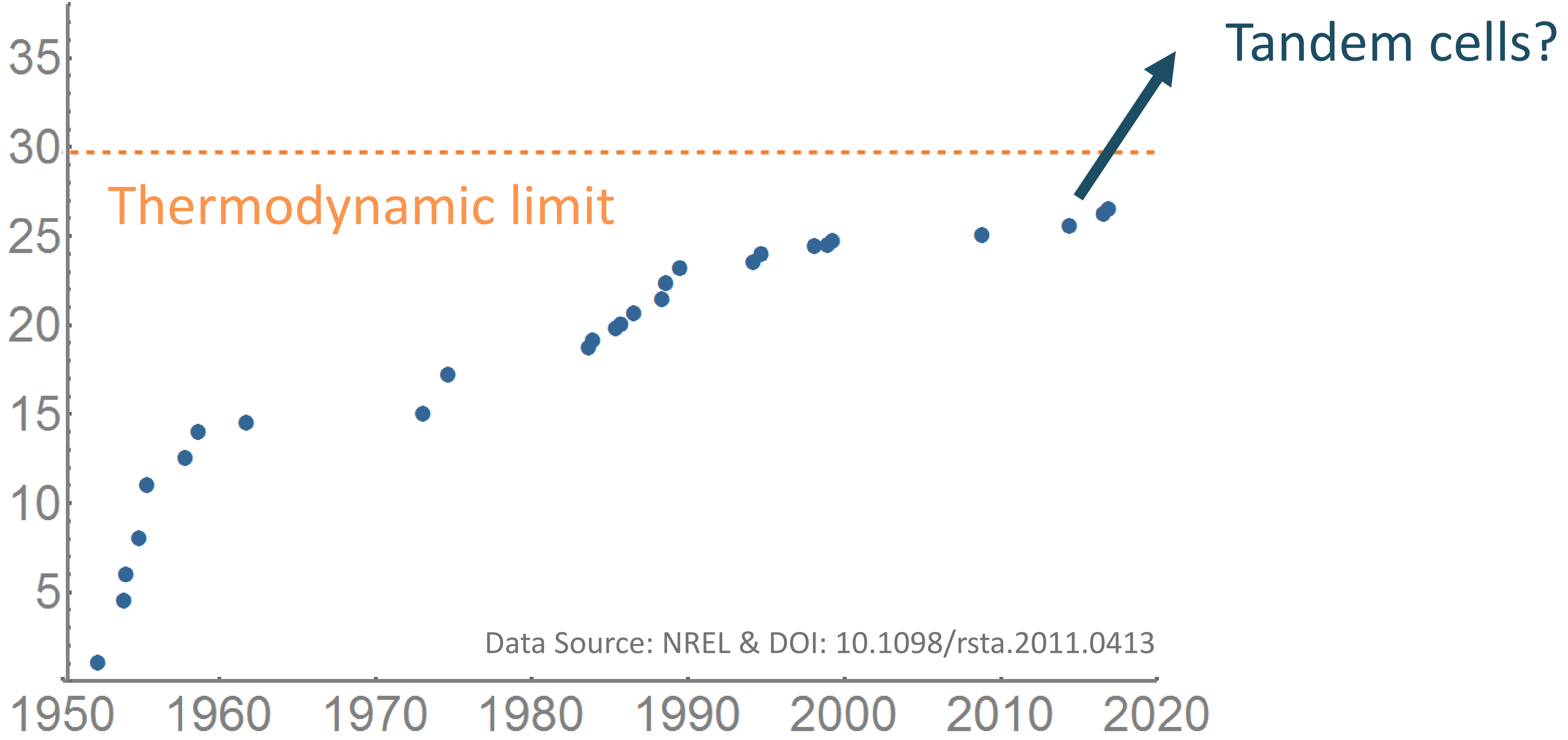


*Estimate. Sources: Bloomberg, Earth Policy Institute, www.earth-policy.org

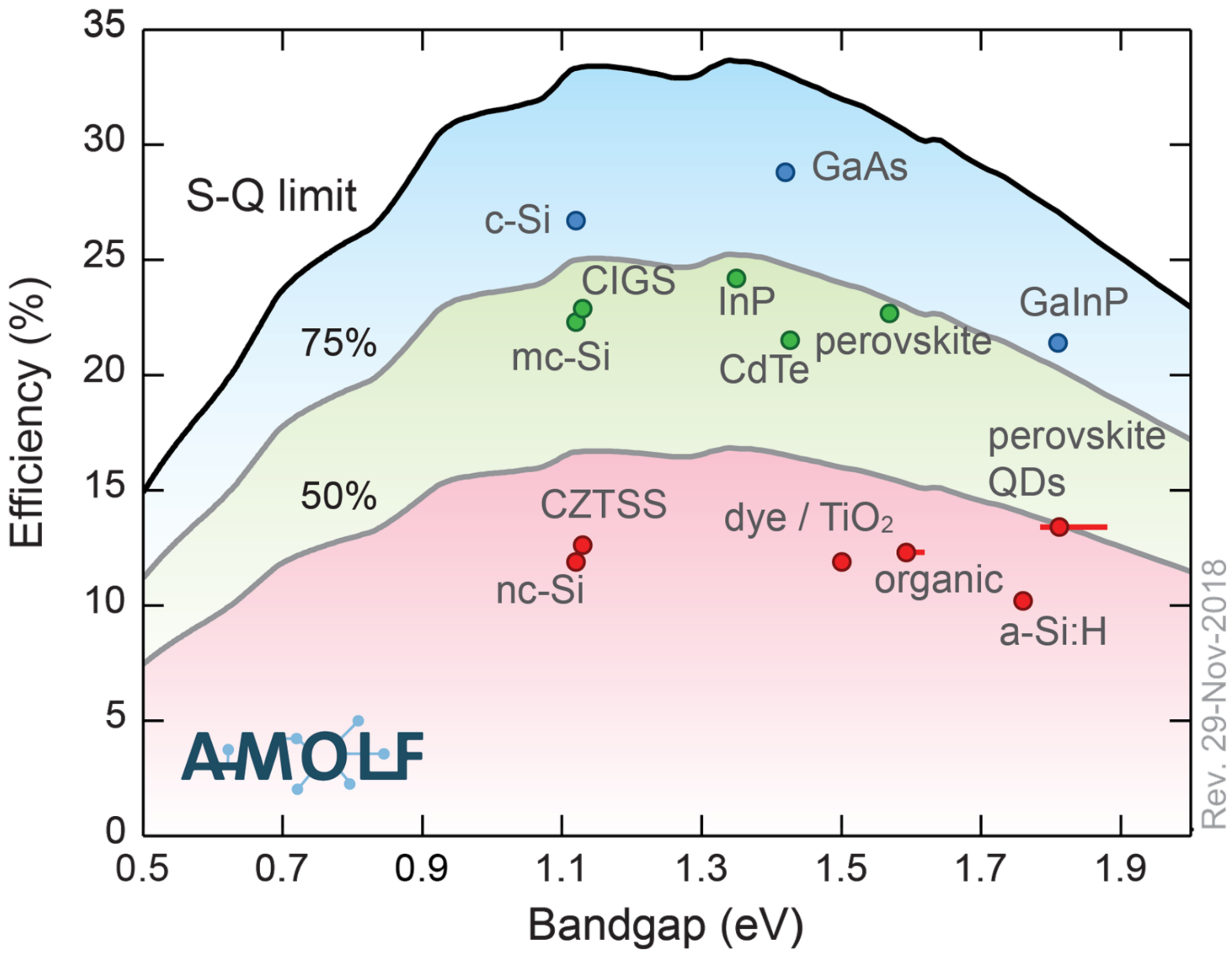
Solar park auction Mexico 2017: 0.0177 $/kWh!

New installations 2018 >95 GW_p

Si Solar Cell Efficiency Close to Limit

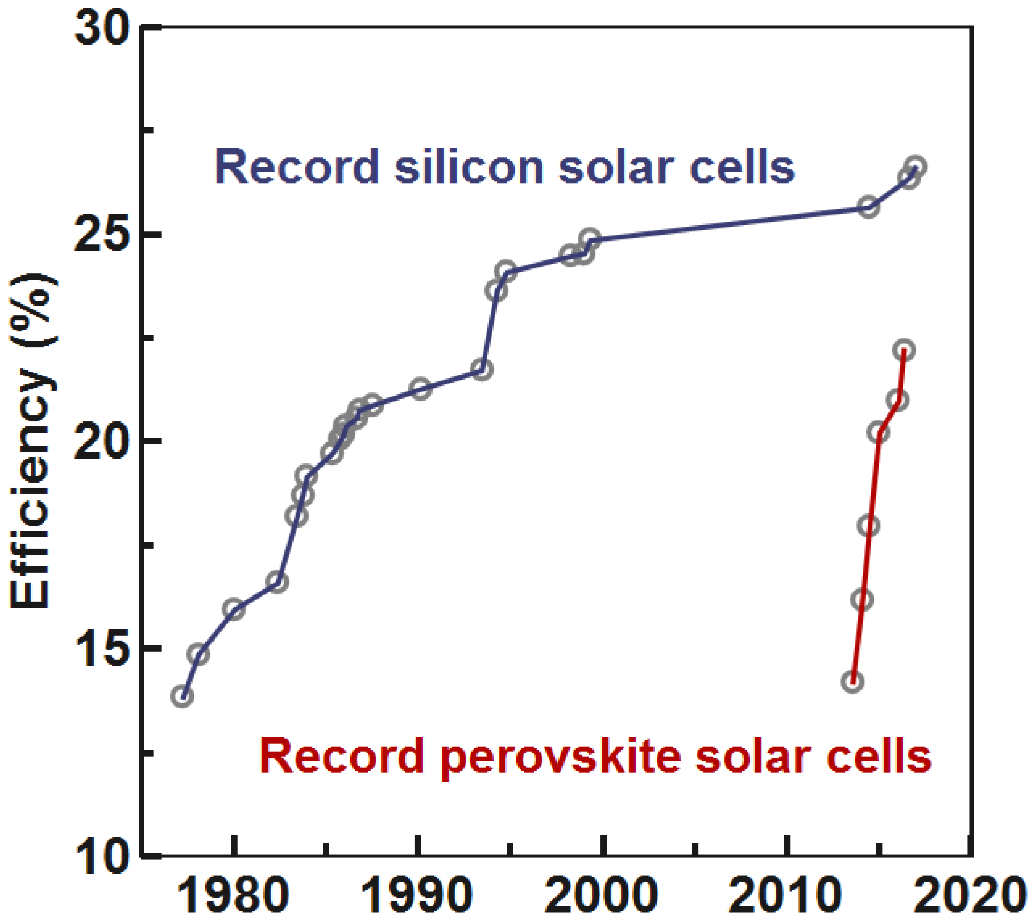


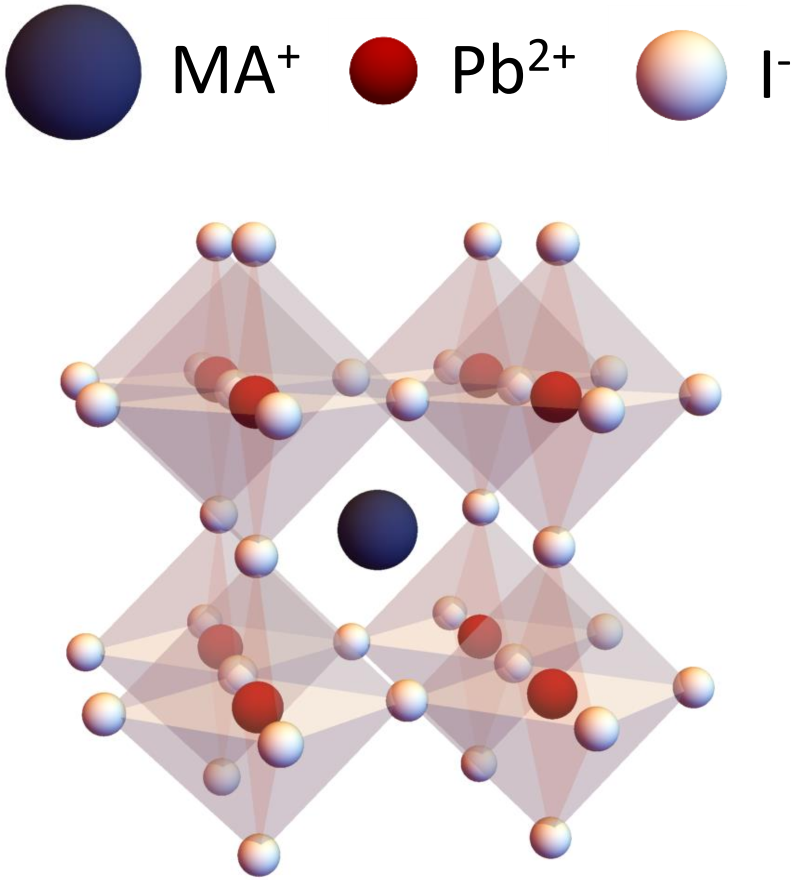
Si Solar Cell Efficiency Close to Limit



A. Polman, M. Knight, E. C. Garnett, B. Ehrler, W. Sinke Science 352, aa4424 (2016)

The rise of perovskites

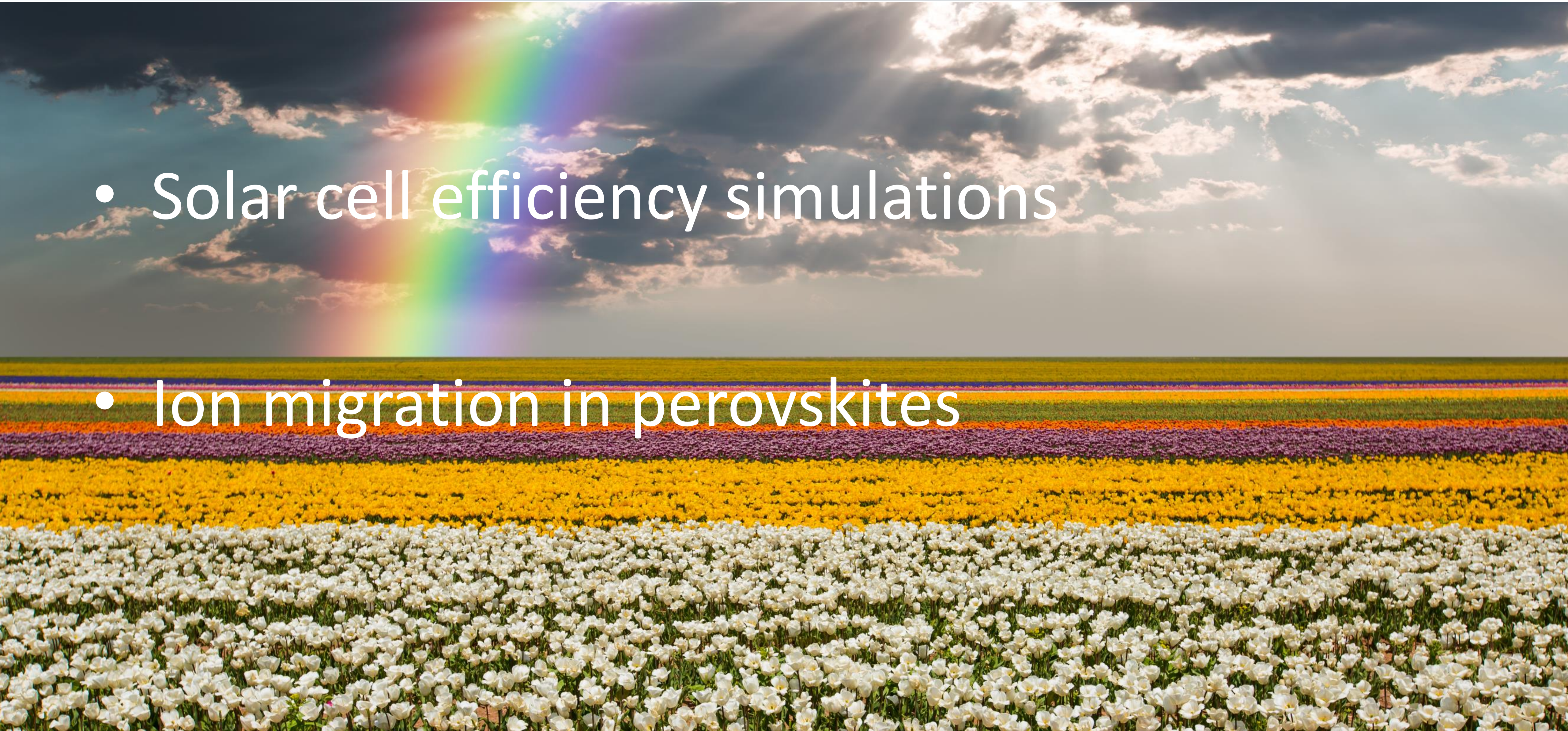




NREL efficiency chart

Towards efficient and stable perovskite/silicon tandem solar cells

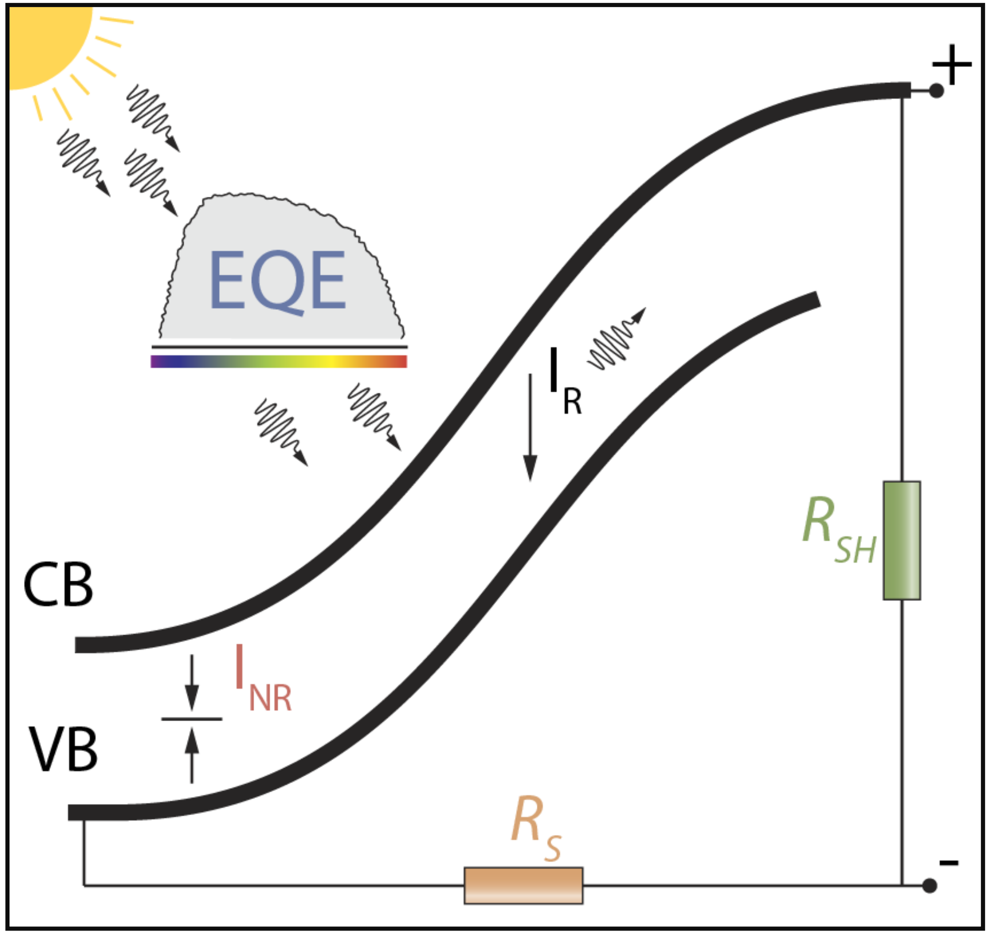
AMOLF physics of functional complex matter



- Solar cell efficiency simulations
- Ion migration in perovskites

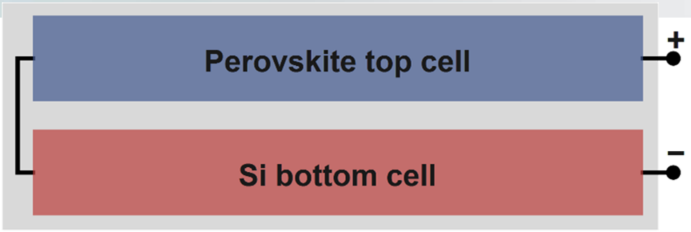
Realistic solar cell model

- How good can perovskite/silicon solar cells be?
- How much of an advantage do they have under real-life conditions?
- Model predicts performance under real-life conditions

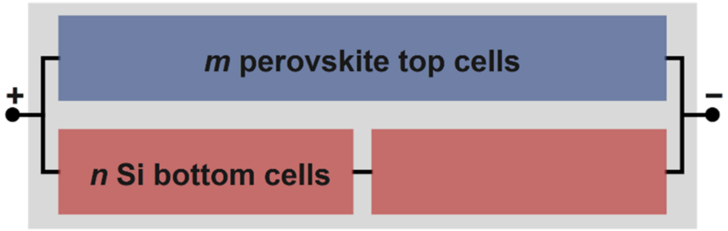


Three different connection schemes

Series tandem – current matching

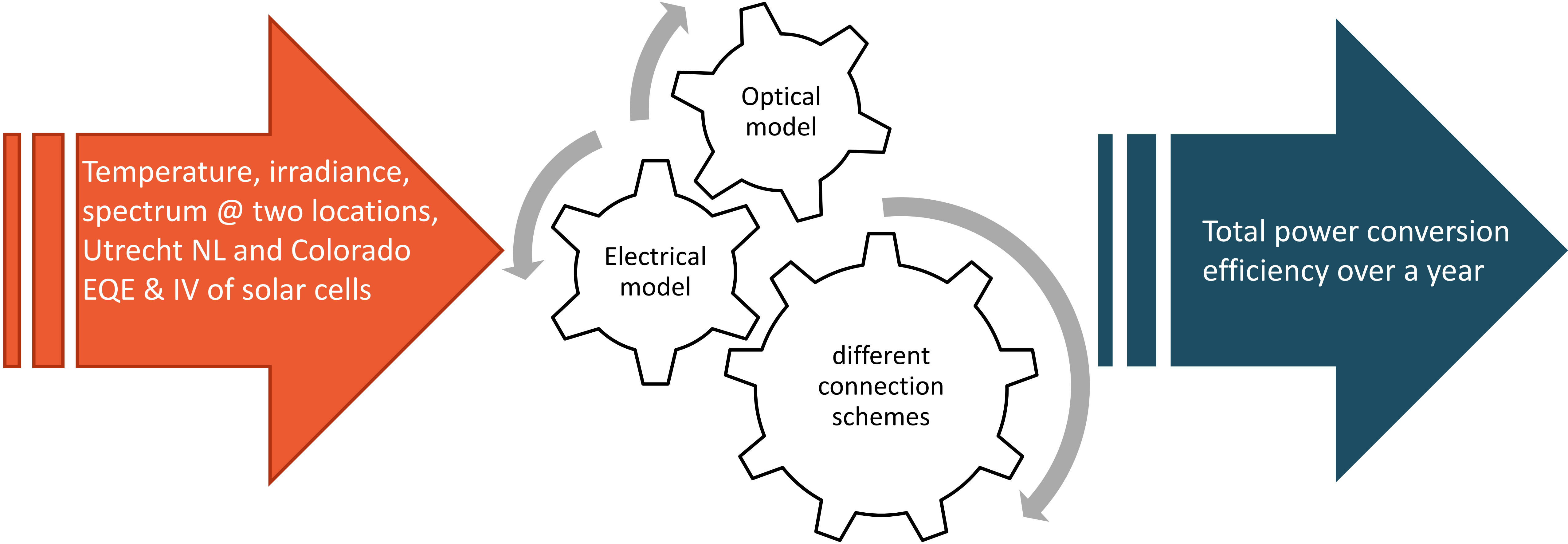


Module tandem – voltage matching

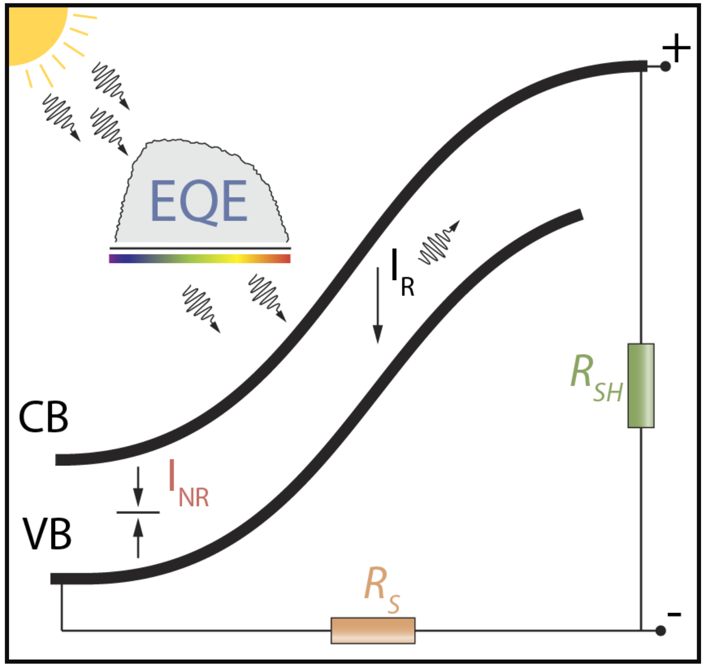


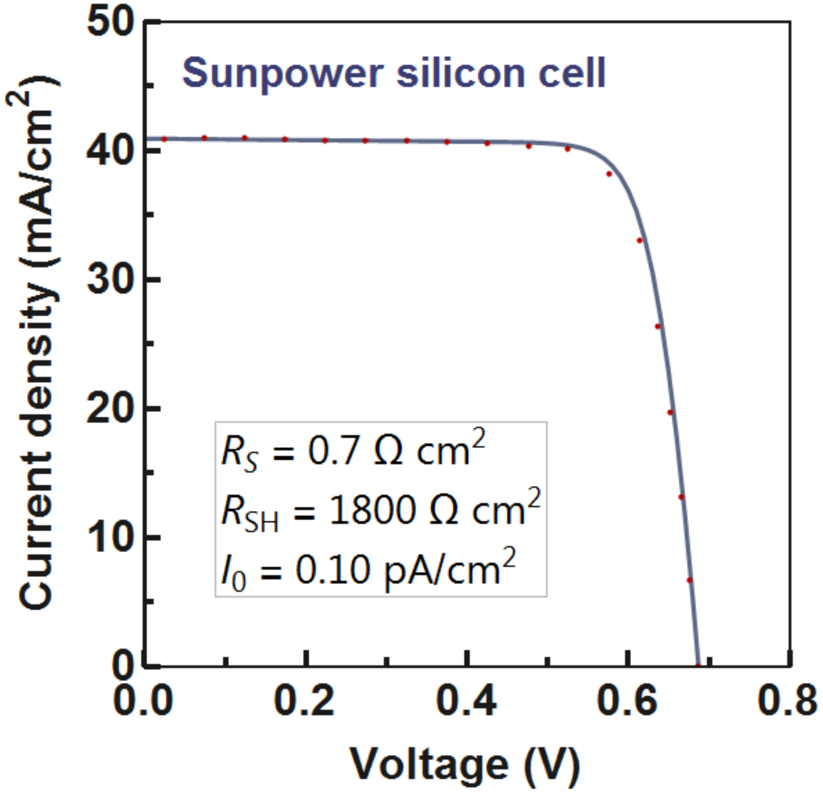
Four-terminal tandem – electrically independent

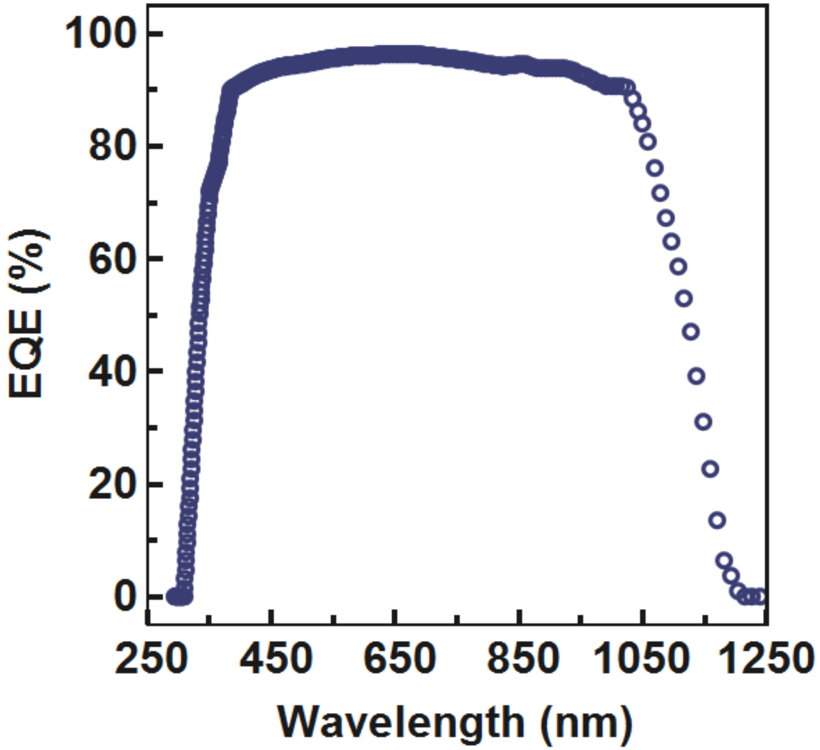
Realistic solar cell model



Sunpower solar cell model

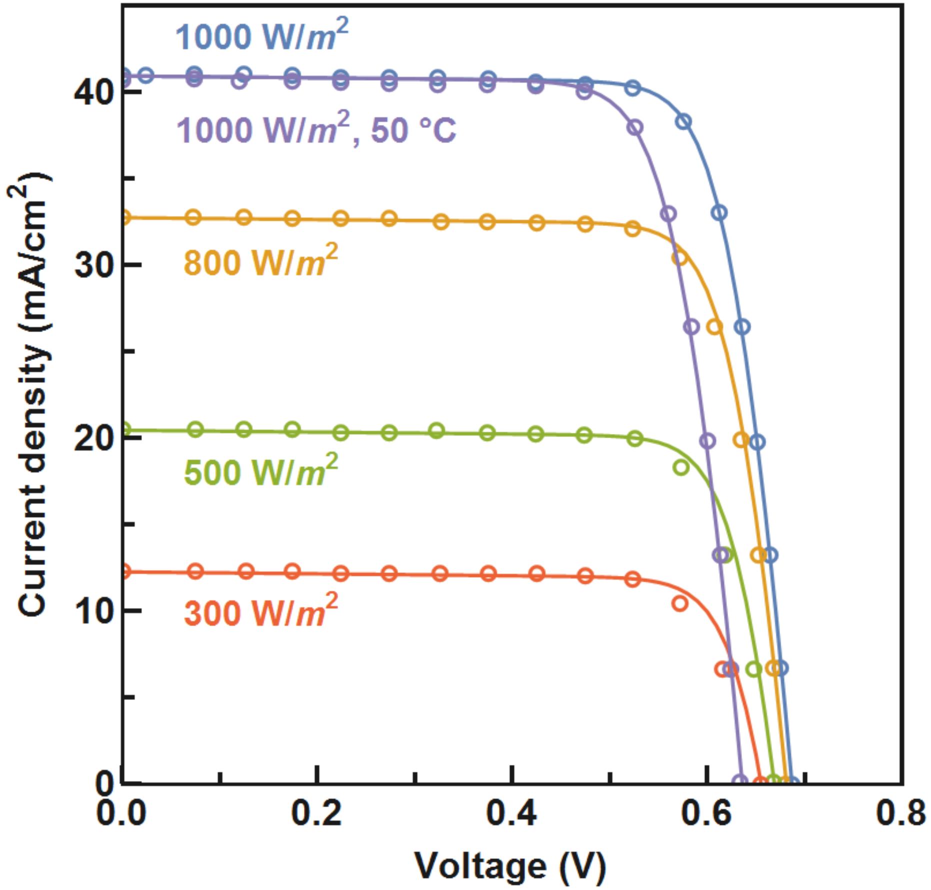


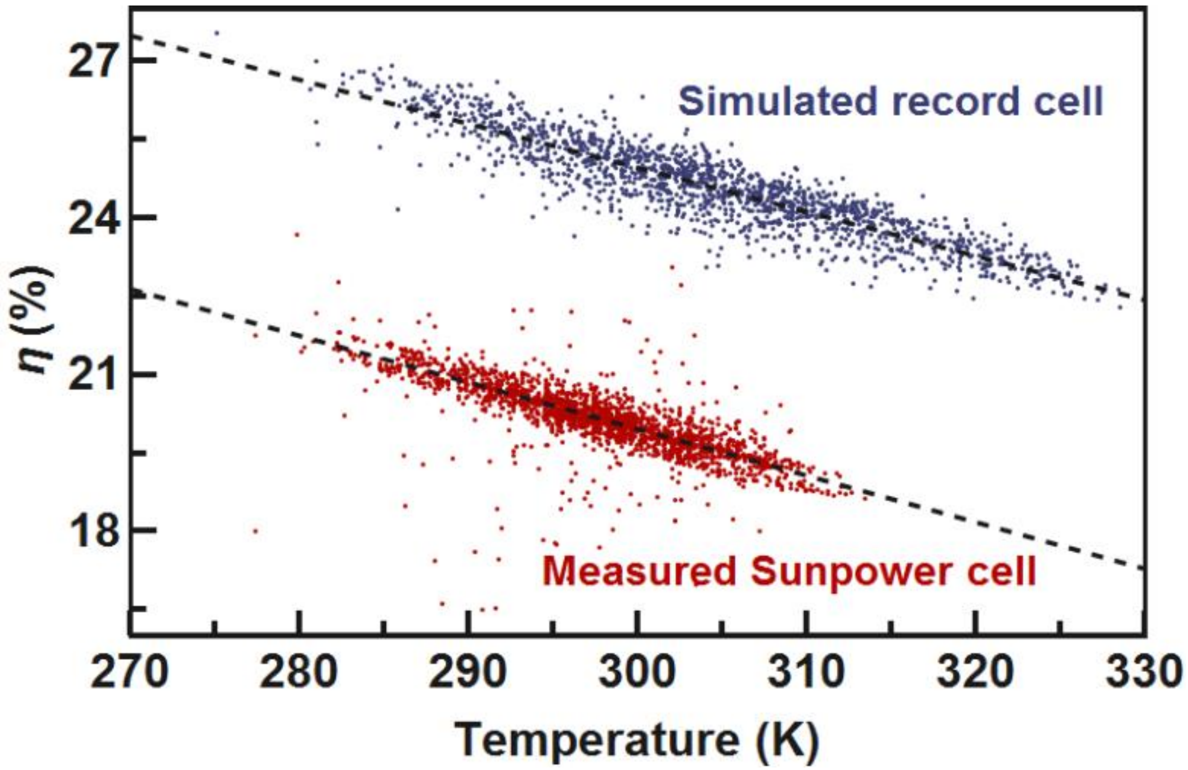




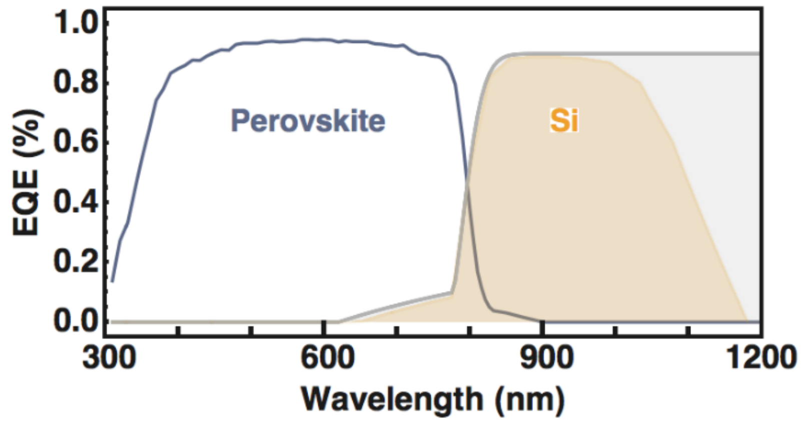
SunPower C60® mono-crystalline silicon solar

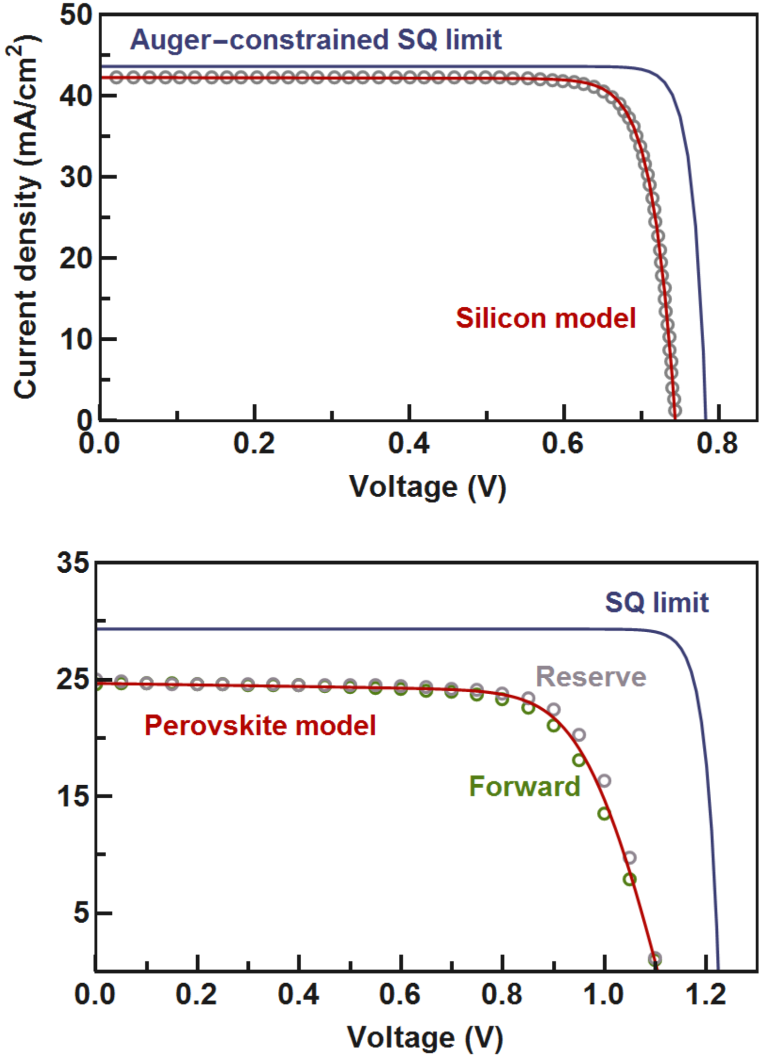
Sunpower solar cell model



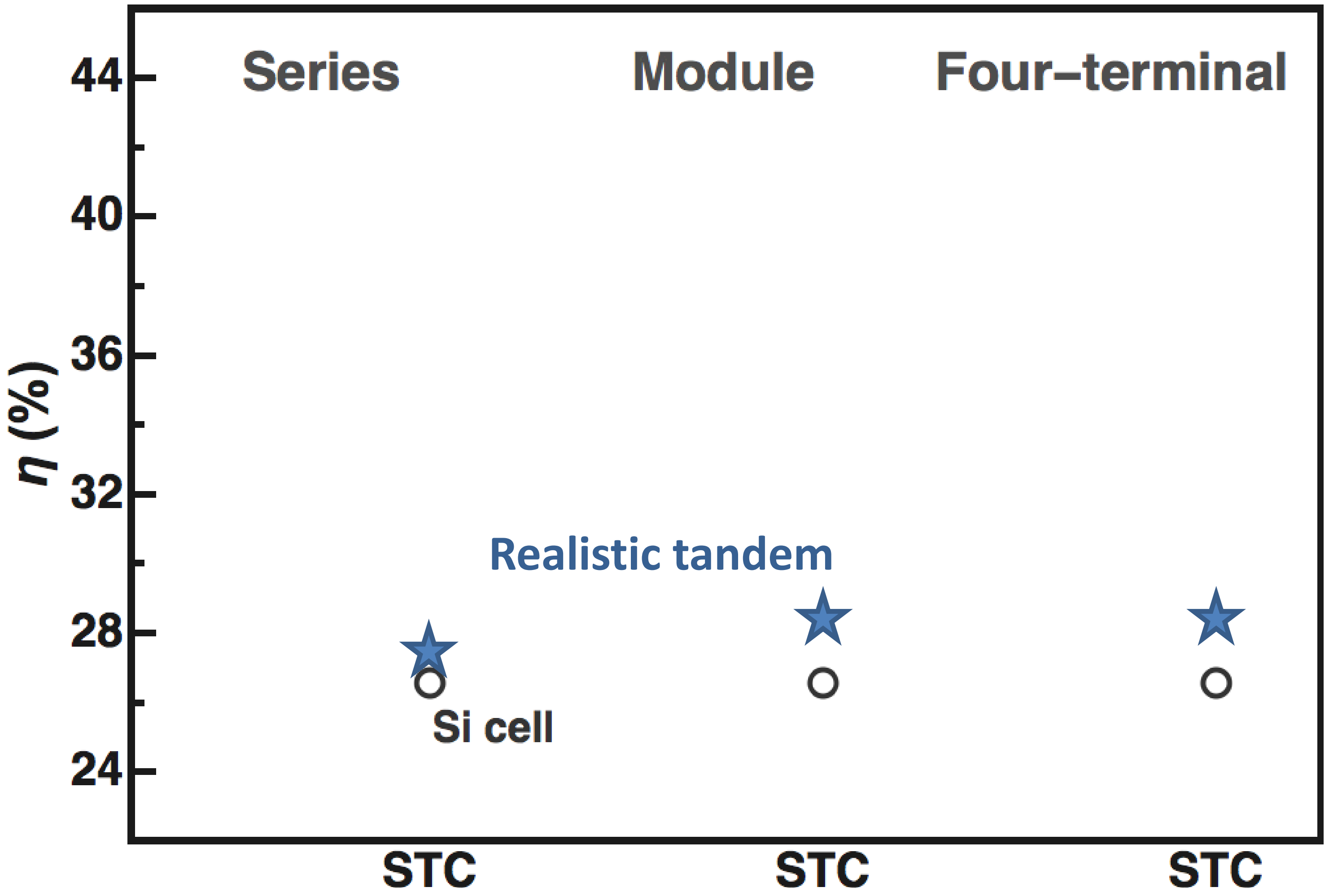


Perovskite/Silicon tandem





Realistic tandem solar cell model



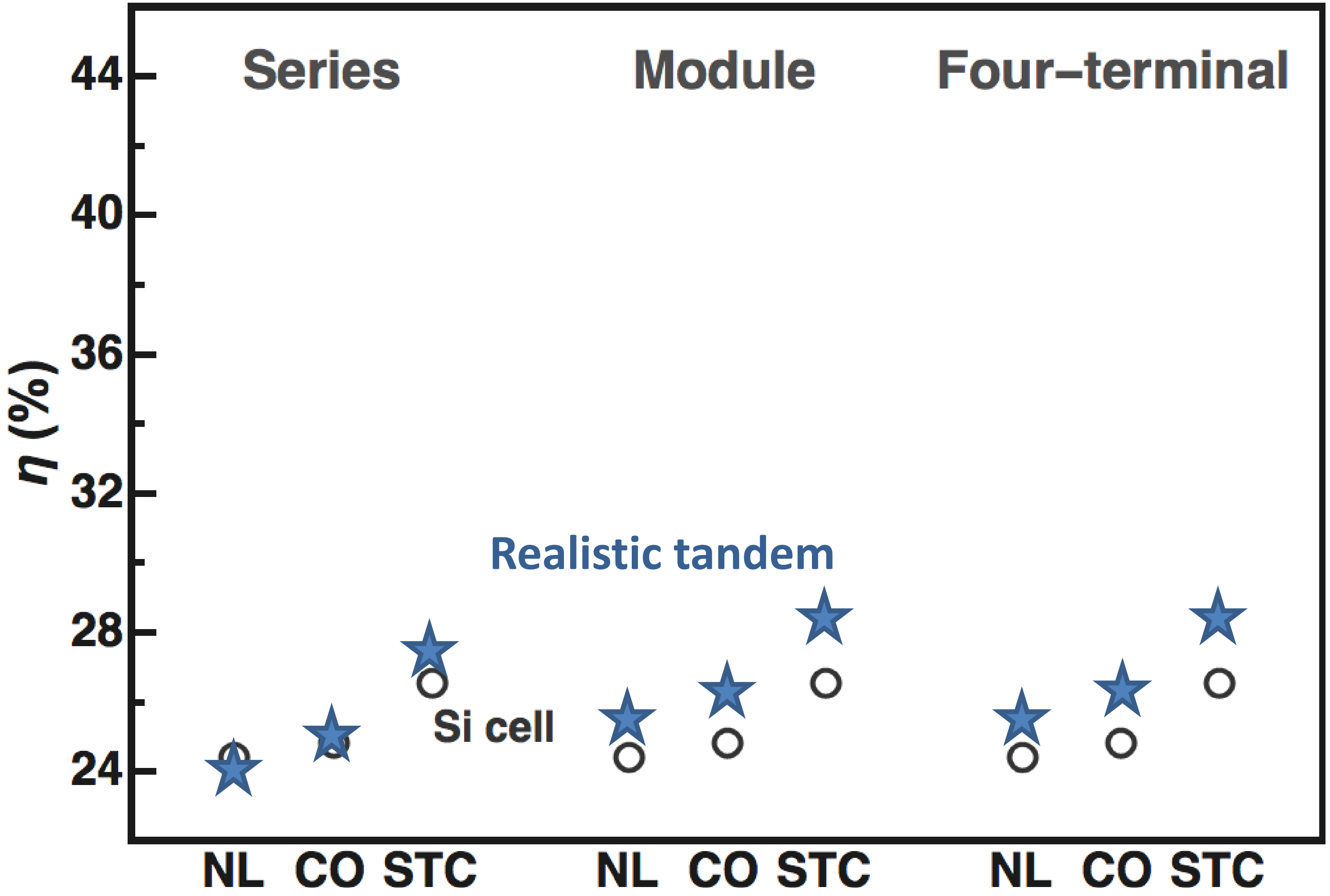
Utrecht, The Netherlands

- narrow annual temperature range
- high precipitation
- hours sunshine 1475 per year

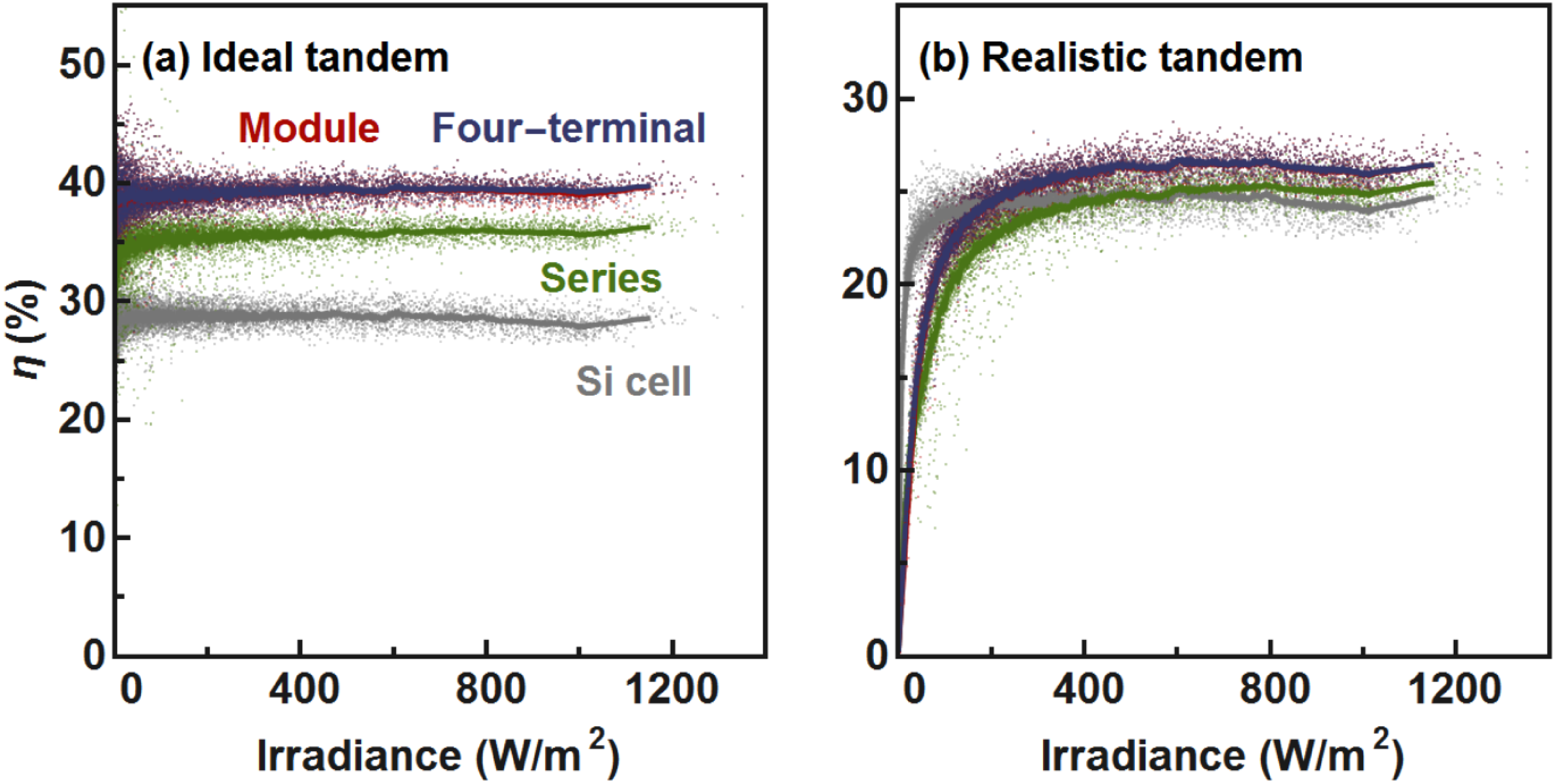
Denver, Colorado (US)

- broad annual temperature range
- low precipitation
- hours of sunshine 3107 per year

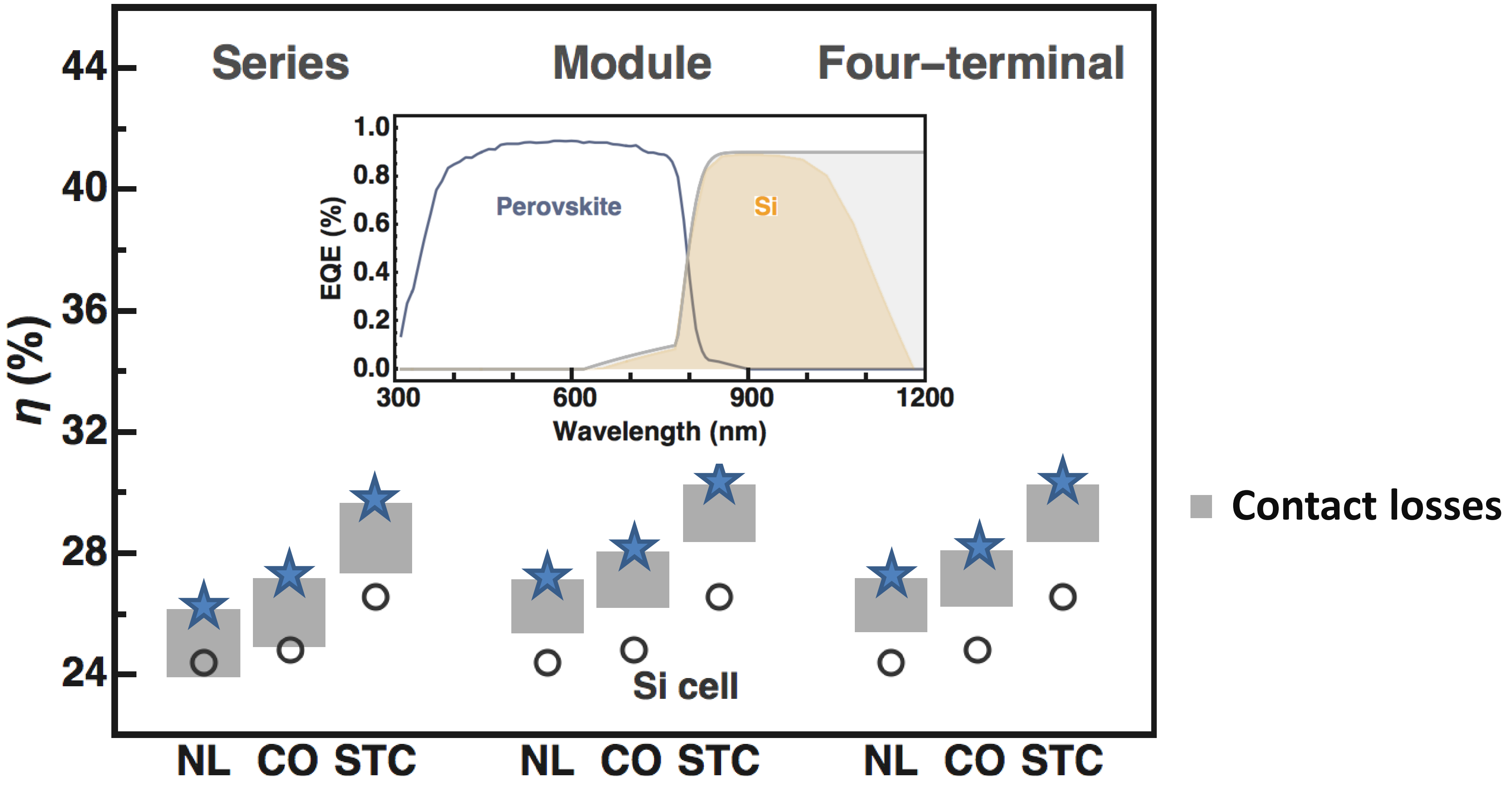
Realistic tandem solar cell model



Low Irradiance is a problem!

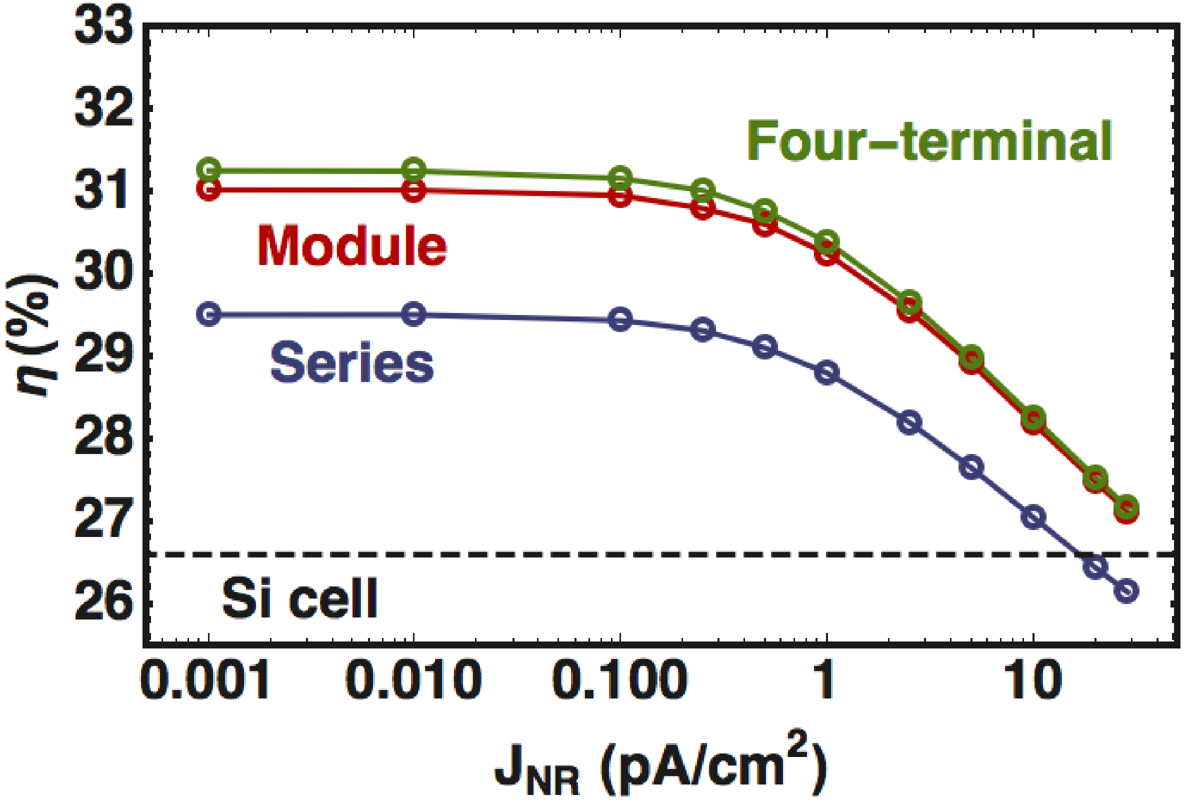


Realistic tandem solar cell model

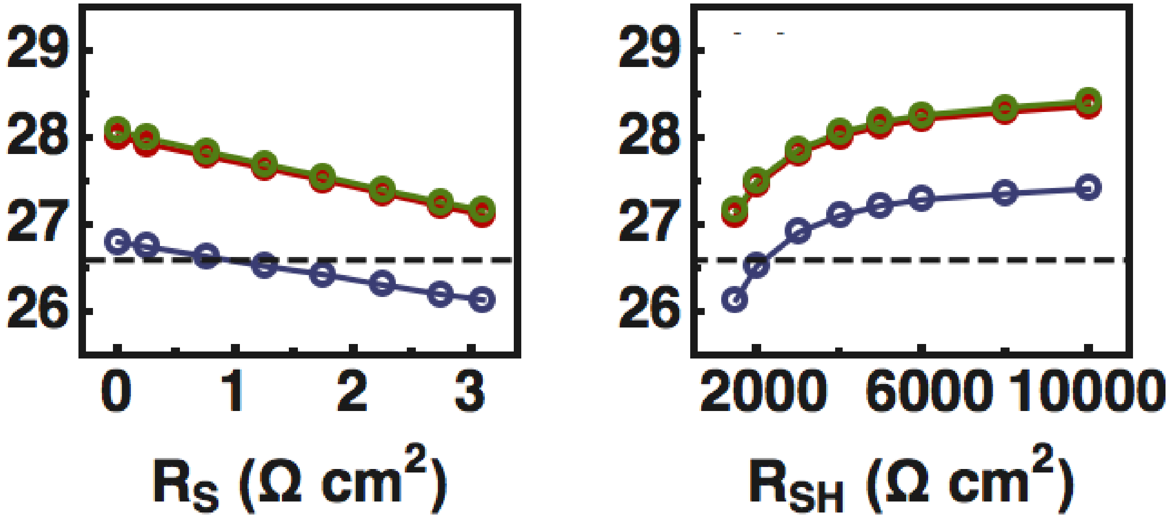


Realistic tandem solar cell model

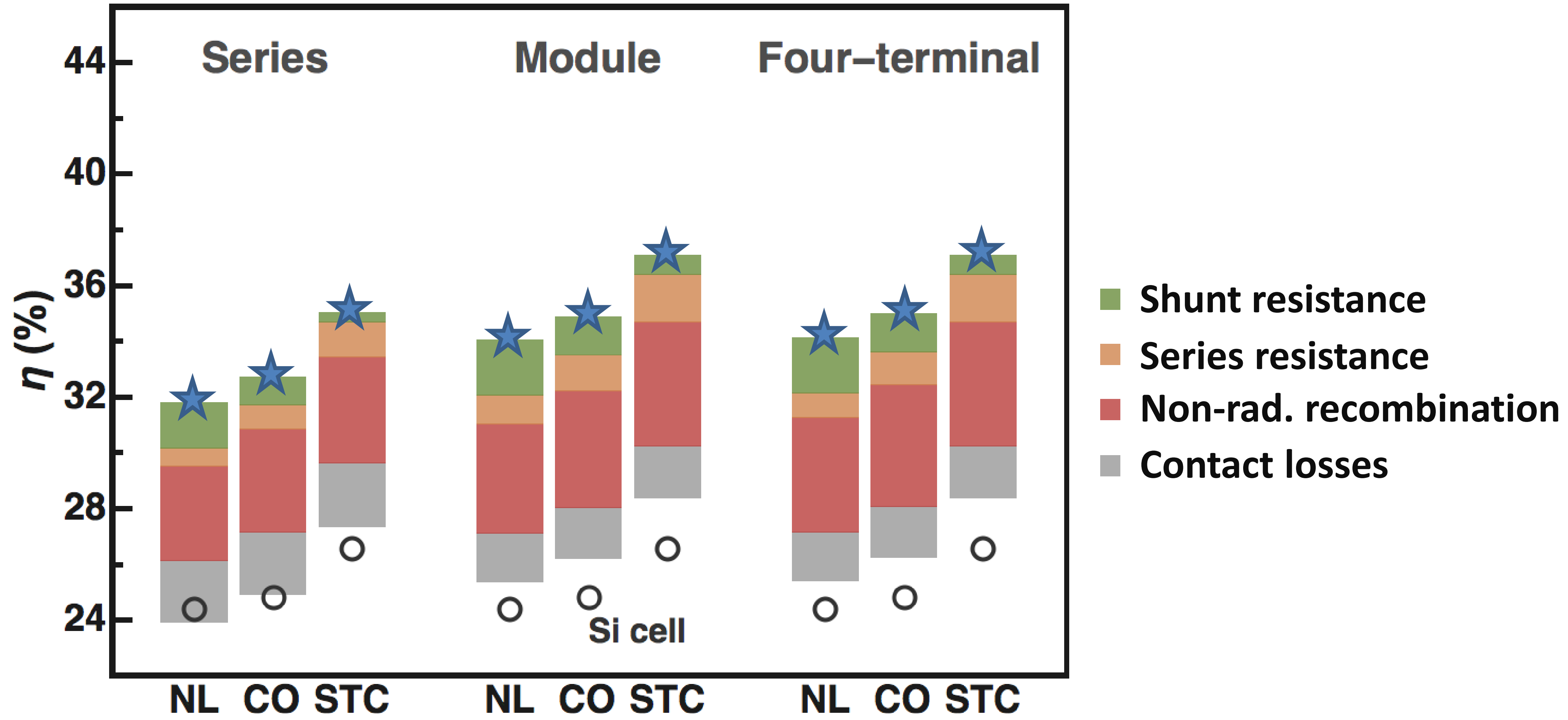
Non-radiative recombination



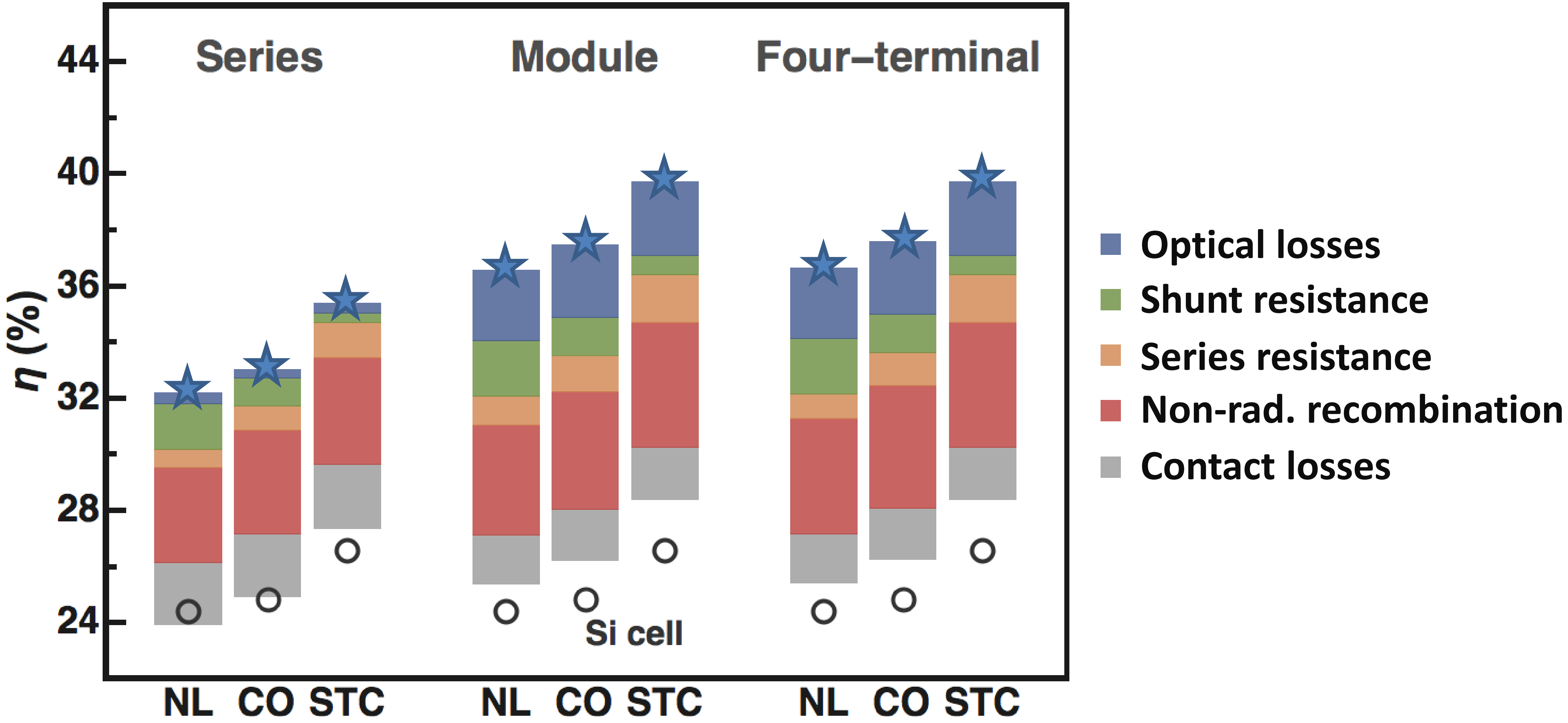
Parasitic resistances



Realistic tandem solar cell model

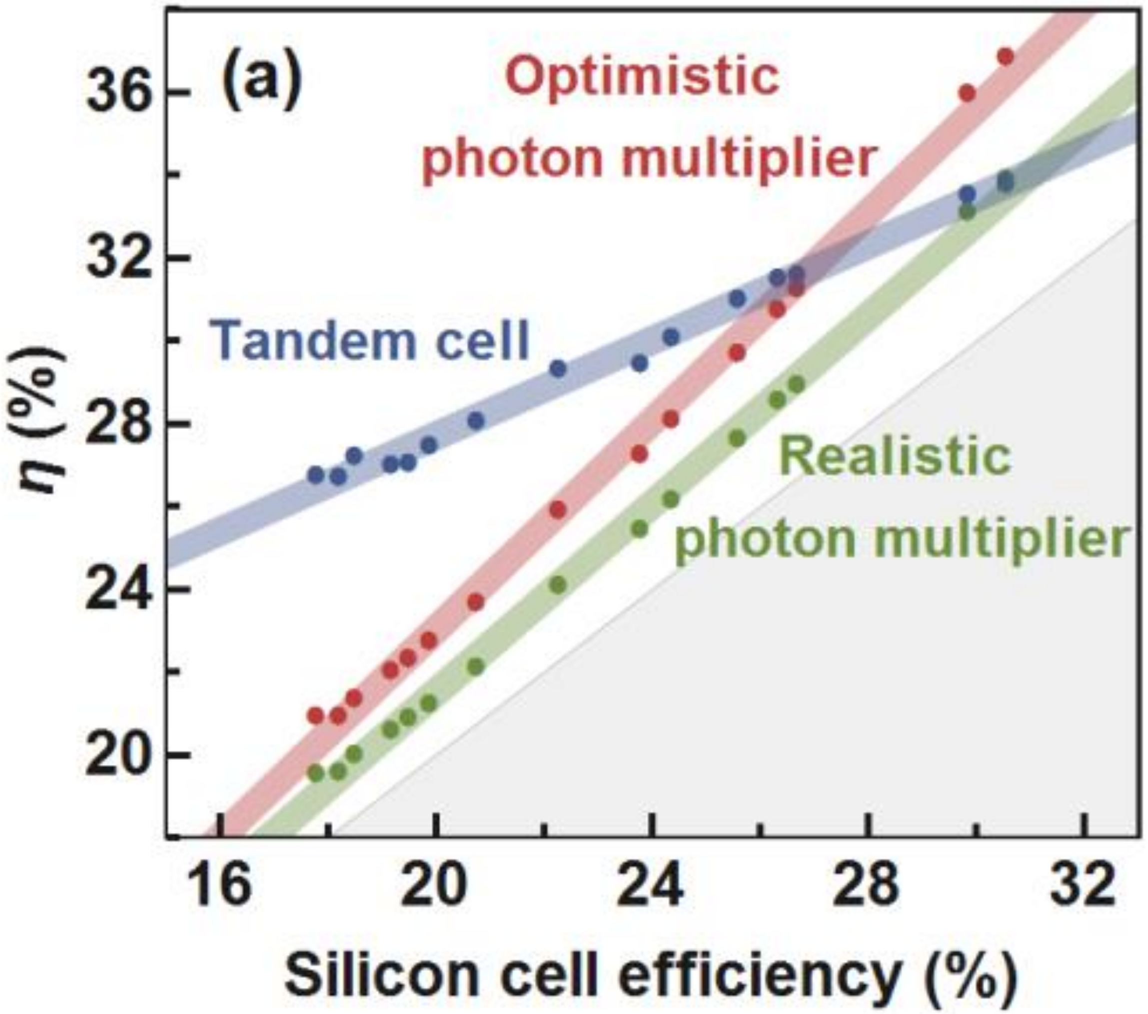


Realistic tandem solar cell model



Realistic tandem solar cell model

- A bad silicon cell is improved most



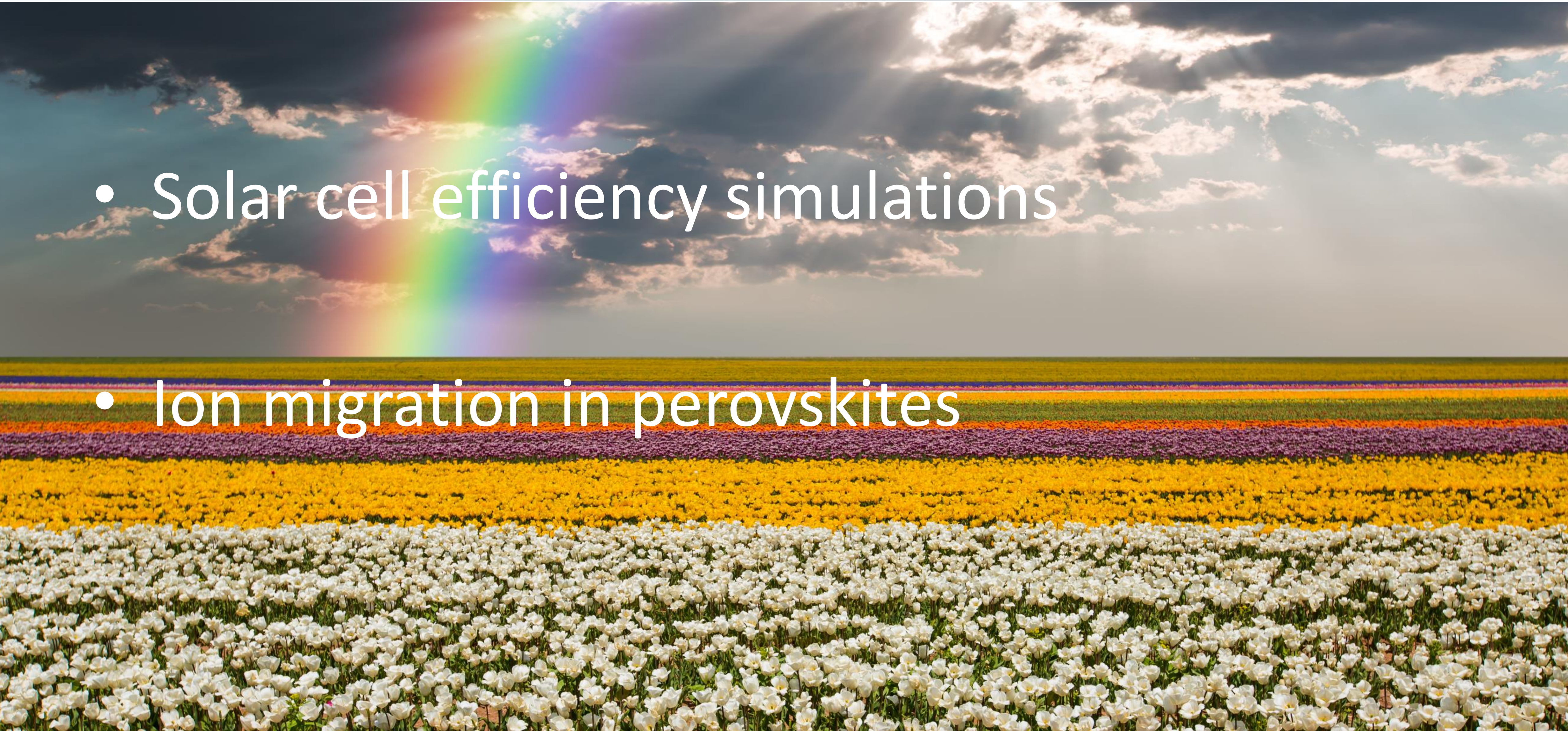
Conclusion I: Solar cell model

- Tandem solar cells
  - Sensitive to environmental conditions
  - Device parameters of perovskite cells are not good enough yet
  - Tandem cells make most sense for a bad Si base cell

Moritz Futscher et al., ACS Energ. Lett. 1, 2016
Mortiz Futscher et al., ACS Energ. Lett. 2, 2017
Moritz Futscher et al., ACS Energ. Lett. 3, 2018

Towards efficient and stable perovskite/silicon tandem solar cells

AMOLF physics of functional complex matter



- Solar cell efficiency simulations

- Ion migration in perovskites

Ion migration important for...

DOI: 10.1039/C4MH00238E (Communication) *Mater. Horiz.*, 2015, 2, 315-322

Charge selective contacts, mobile ions and anomalous hysteresis in organic–inorganic perovskite solar cells†

Ye Zhang‡ [ab], Mingzhen Liu‡ [a], Giles E. Eperon [a], Tomas C. Leijtens [ac], David McMeekin [a], Michael Saliba [a], Wei Zhang [a], Michele de Bastiani [c], Annamaria Petrozza [c], Laura M. Herz [a], Michael B. Johnston *[a], Hong Lin *[b] and Henry J. Snaith *[a]

Evidence for ion migration in hybrid perovskite solar cells with minimal hysteresis

Philip Calado, Andrew M. Telford, Daniel Bryant, Xiaoe Li, Jenny Nelson, Brian C. O'Regan & Piers R.F. Barnes

Nature Communications 7, Article number: 13831 (2016) | Download Citation

Defect migration in methylammonium lead iodide and its role in perovskite solar cell operation

Check for updates

Jon M. Azpiroz,[ab] Edoardo Mosconi,*[a] Juan Bisquert[cd] and Filippo De Angelis*[a]

Migration of cations induces reversible performance losses over day/night cycling in perovskite solar cells

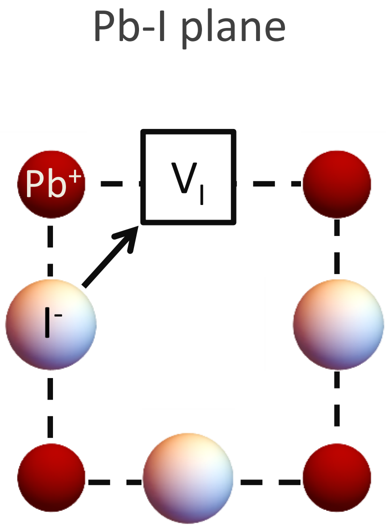
Check for updates

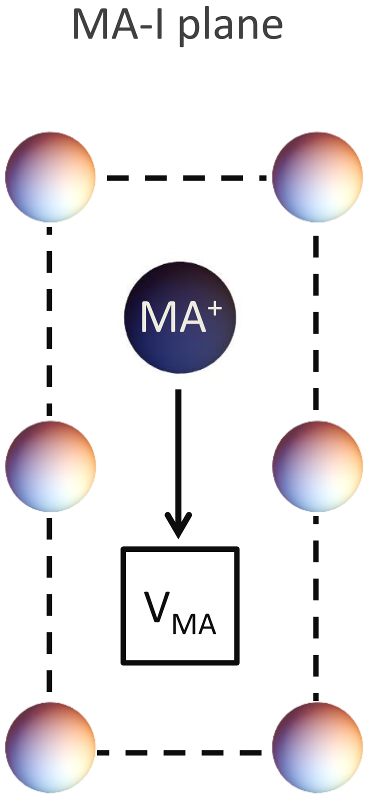
Konrad Domanski,[a] Bart Roose,[b] Taisuke Matsui,[c] Michael Saliba,[a] Silver-Hamill Turren-Cruz,[d] Juan-Pablo Correa-Baena,[d] Cristina Roldan Carmona,[e] Giles Richardson,[f] Jamie M. Foster,[g] Filippo De Angelis,[hi] James M. Ball,[j] Annamaria Petrozza,[j] Nicolas Mine,[k] Mohammad K. Nazeeruddin,[e] Wolfgang Tress,[a] Michael Grätzel,[a] Ullrich Steiner,[b] Anders Hagfeldt[d] and Antonio Abate*[ab]

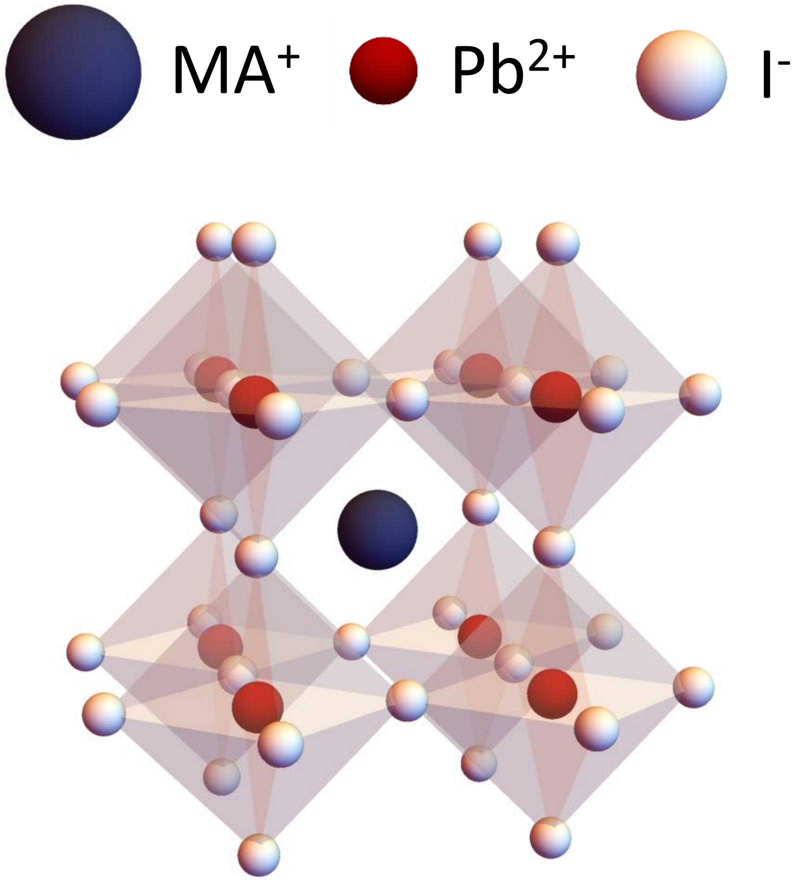
Impact of Capacitive Effect and Ion Migration on the Hysteretic Behavior of Perovskite Solar Cells

Bo Chen*†, Mengjin Yang‡, Xiaojia Zheng†, Congcong Wu†, Wenle Li§, Yongke Yan†, Juan Bisquert*∥⊥, Germà Garcia-Belmonte∥, Kai Zhu*‡, and Shashank Priya†

Perovskites are ionic semiconductors

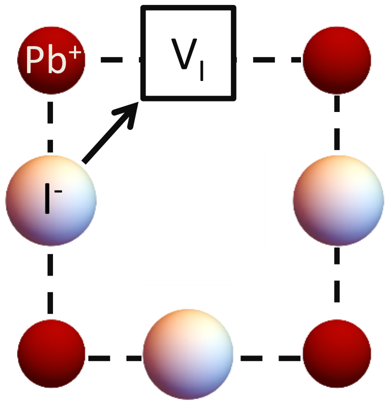




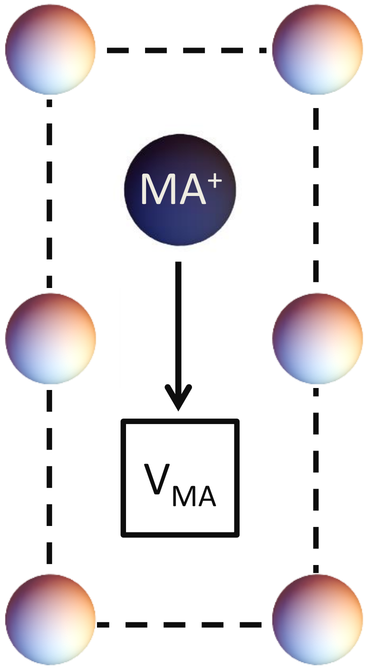


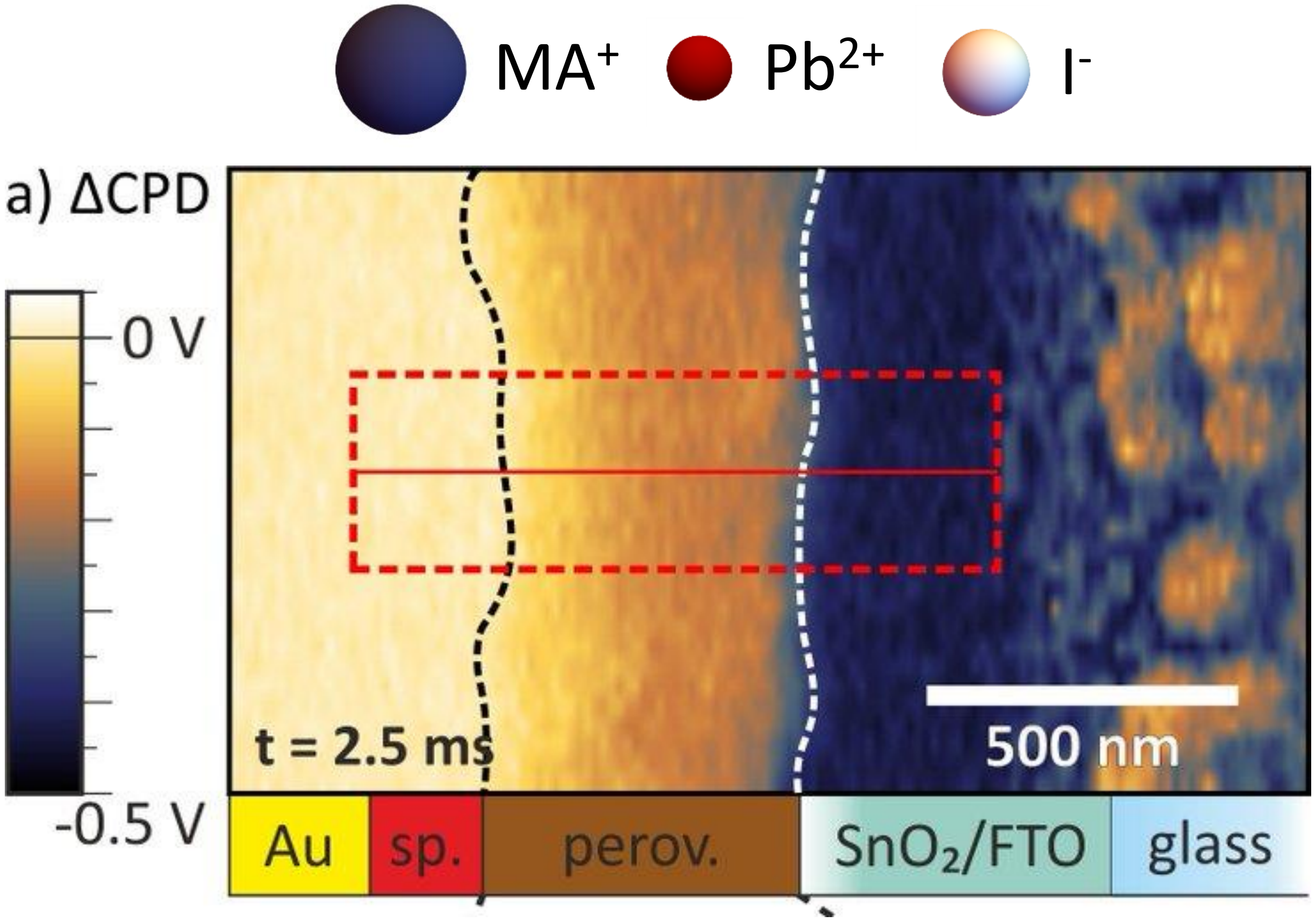
Ion migration in $MAPbI_3$

Pb-I plane



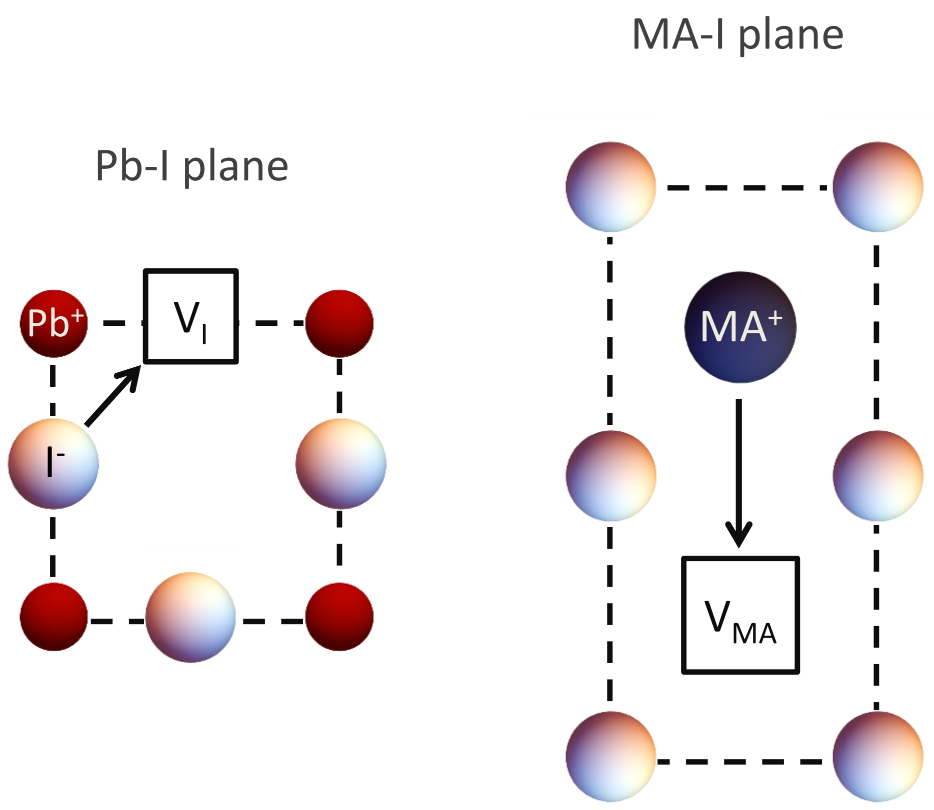
MA-I plane

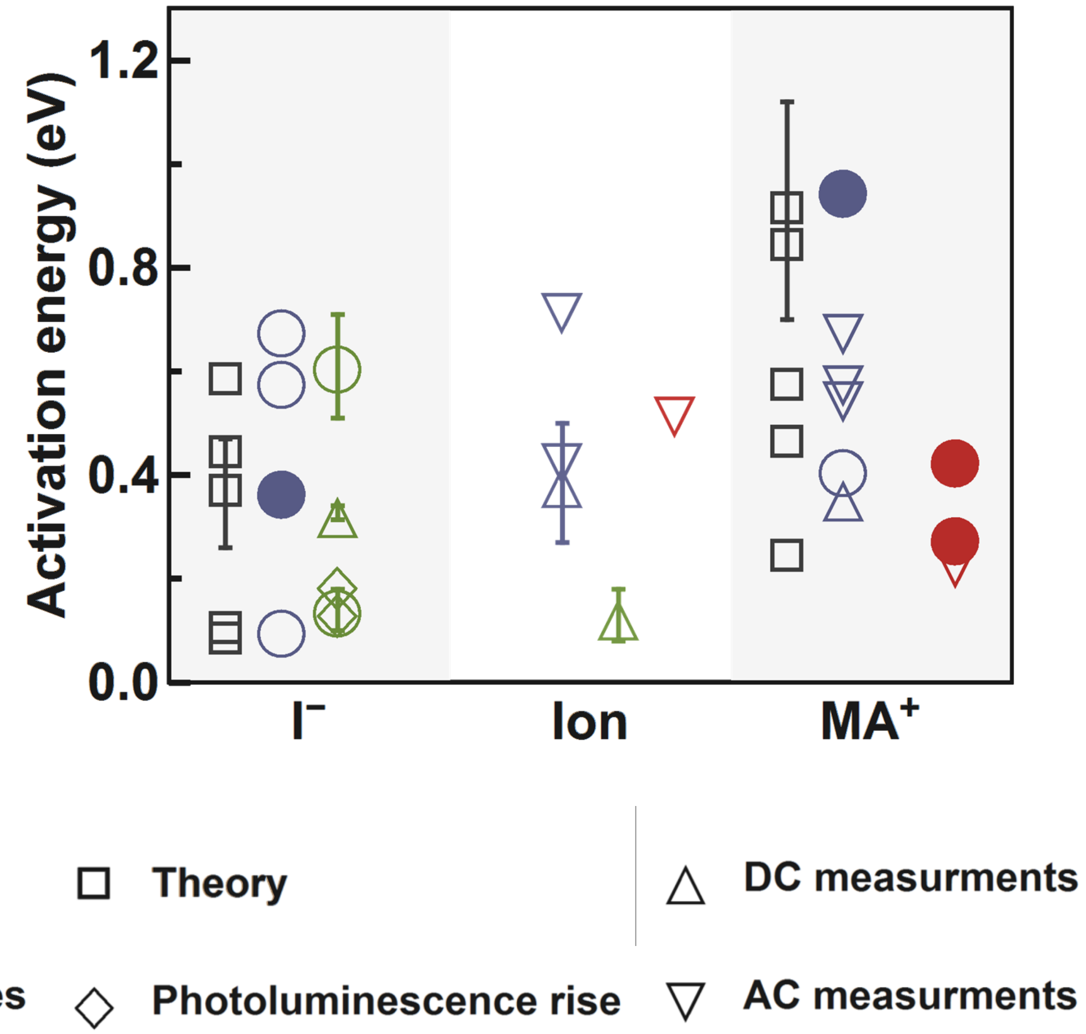




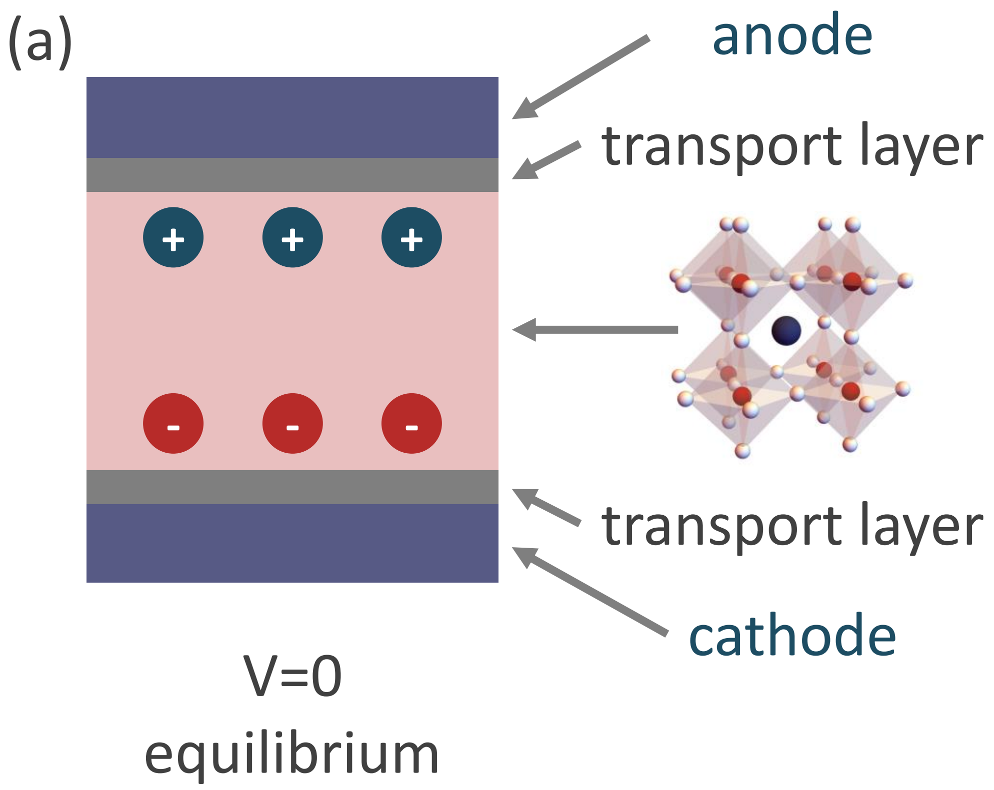
Stefan A.L. Weber et al., ***Energy Environ. Sci.***, 2018,**11**, 2404-2413

Ion migration in $MAPbI_3$



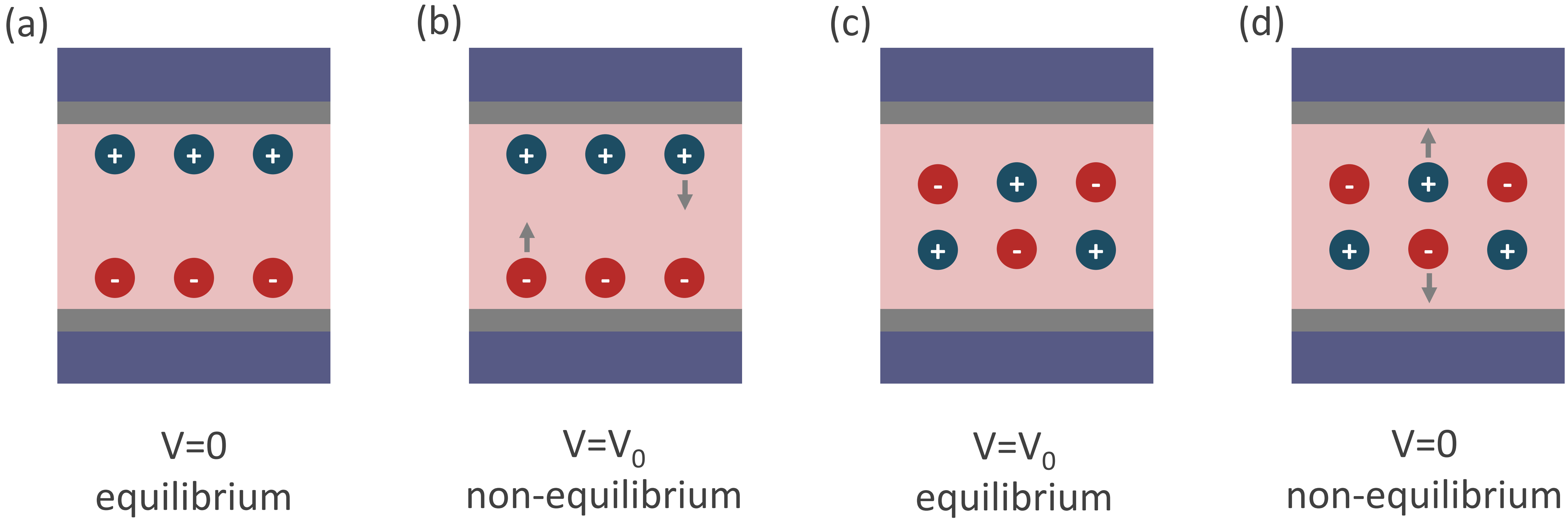


Effect of an external electric field on ion migration



Effect of an external electric field on ion migration

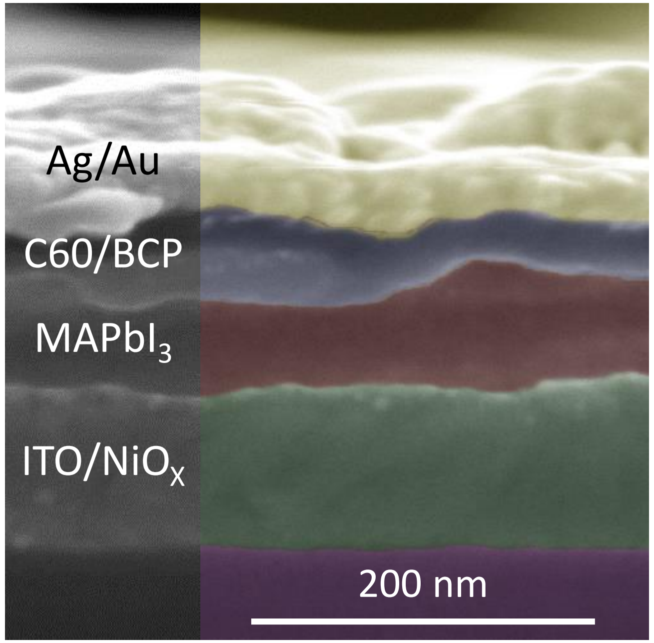
AMOLF physics of functional complex matter



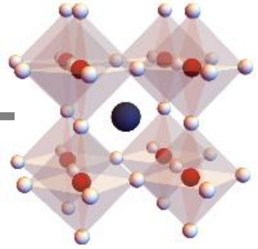
Going from (d) to (a): mobile ions drift towards the interfaces to screen the built-in electric field.

Effect of ion migration

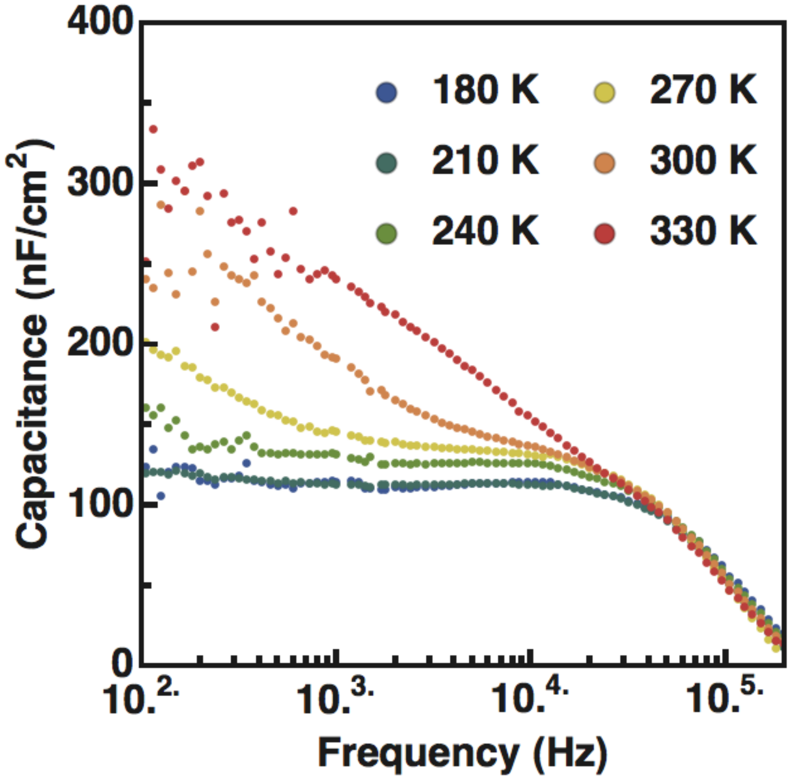
Inverted perovskite structure



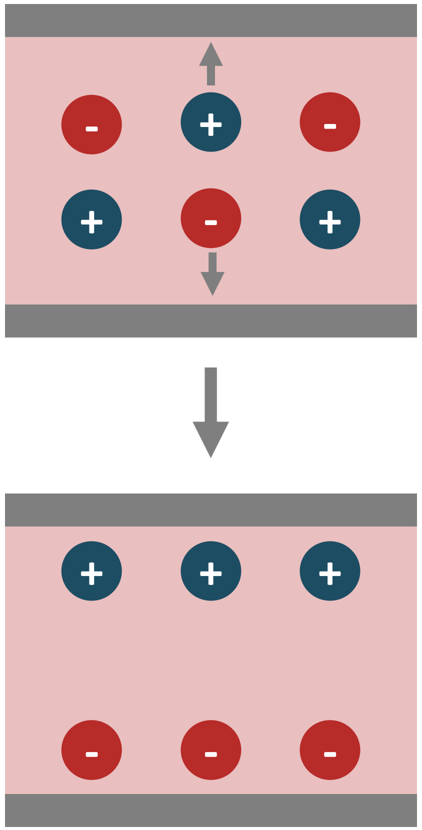
anode

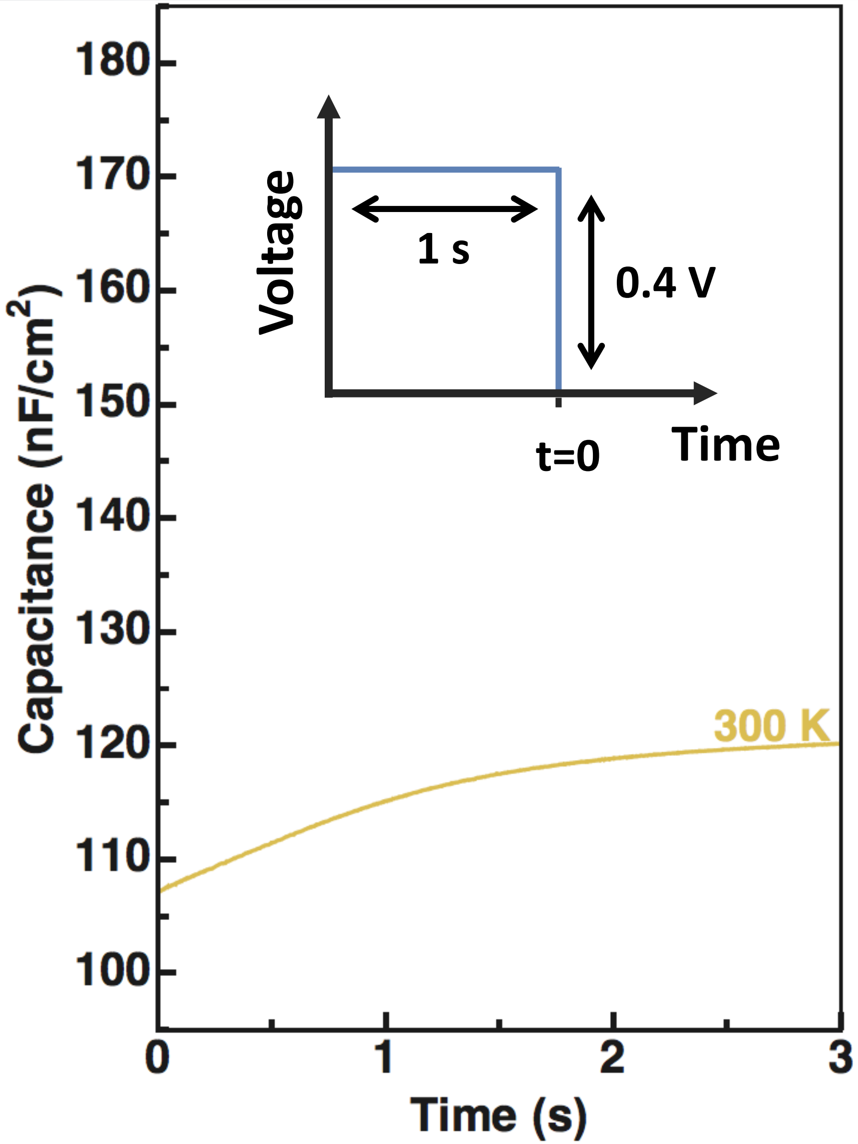


cathode

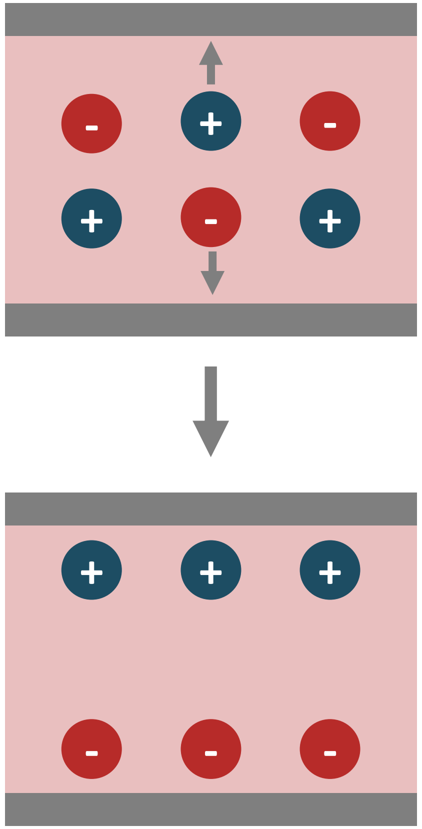


Quantifying ion migration





Quantifying ion migration

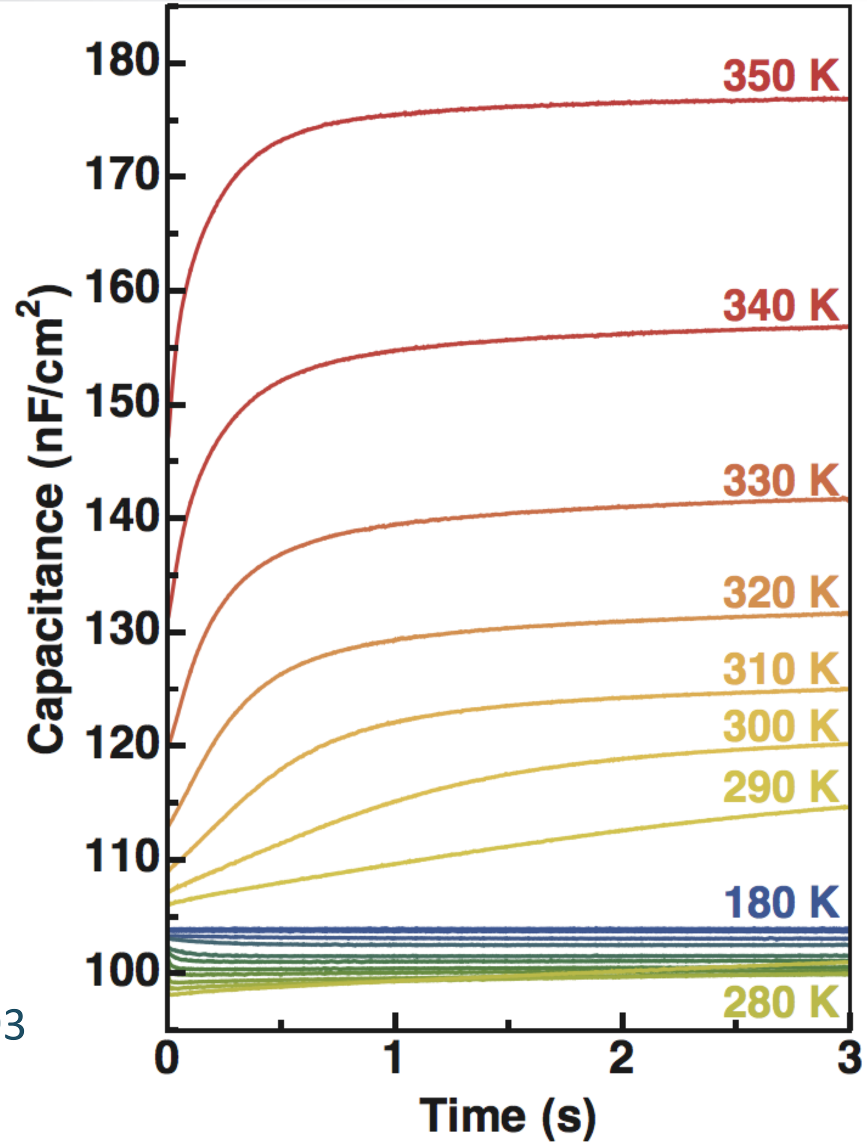


Transcient ion-drift

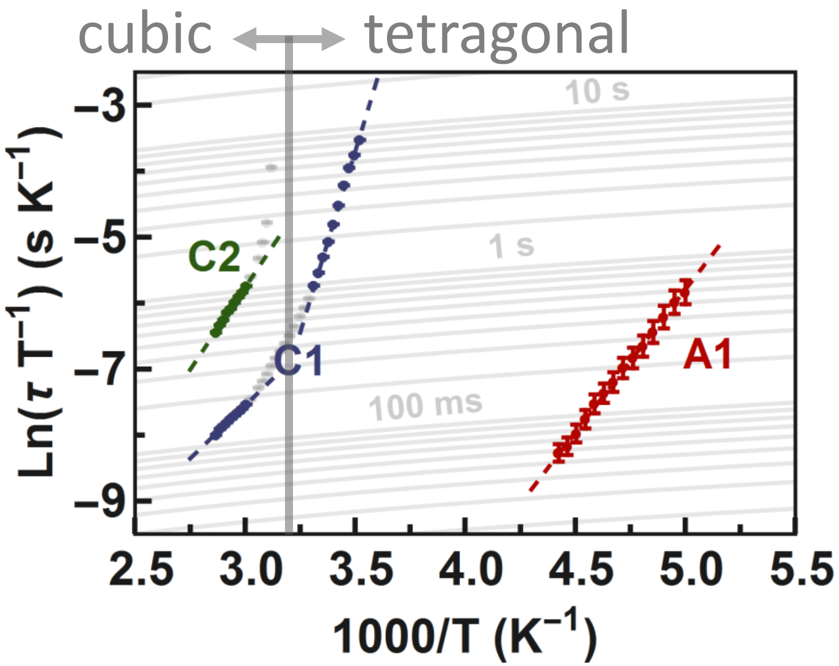
$$C(t) = \Delta C(\boldsymbol{N_{ion}})\left[1 - \exp\left(-\frac{t}{\tau}\right)\right]$$

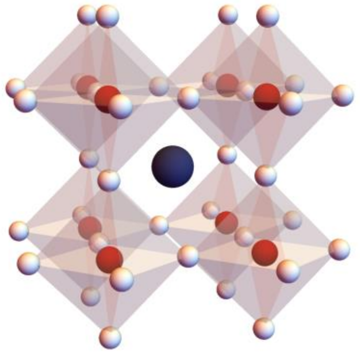
$$\tau = \frac{k_B T \epsilon}{q^2 \boldsymbol{D_0} N_A} \exp\left(\frac{\boldsymbol{E_A}}{k_B T}\right)$$

Thomas Heiser *et al.* Applied Physics A 57, 325, 1993

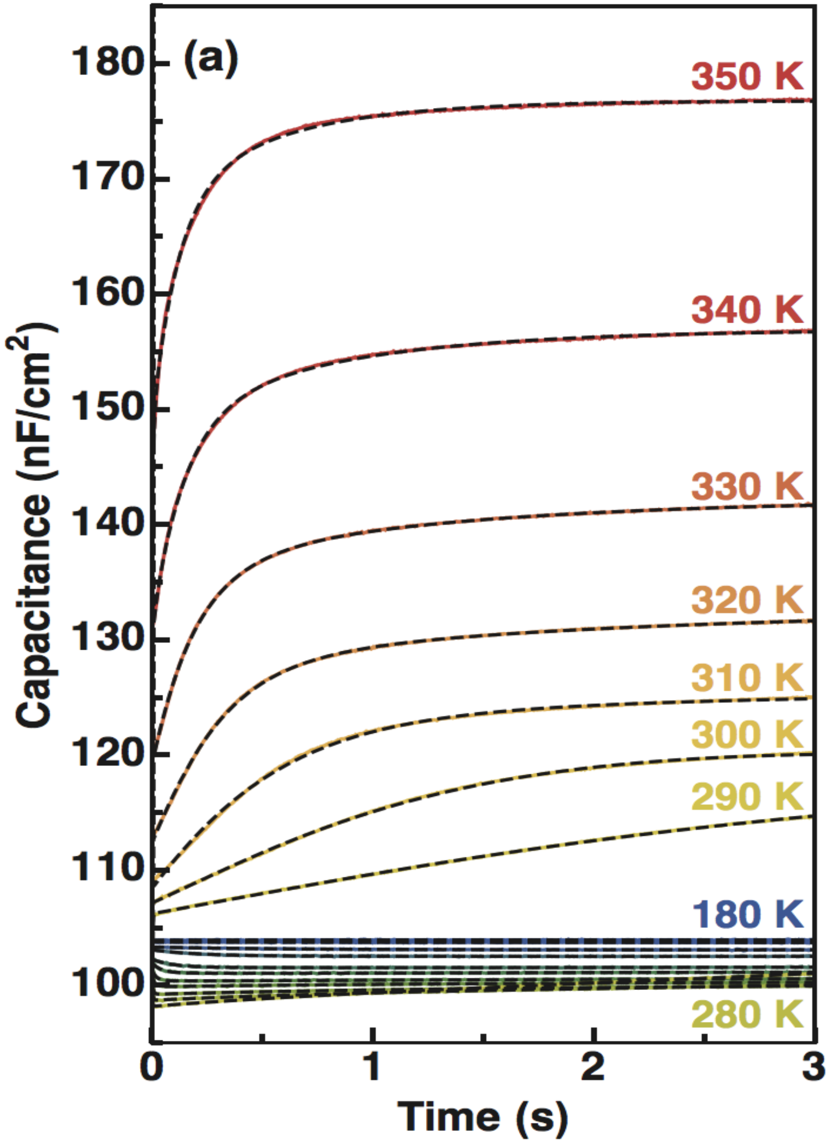


Mobile ion species in $MAPbI_3$

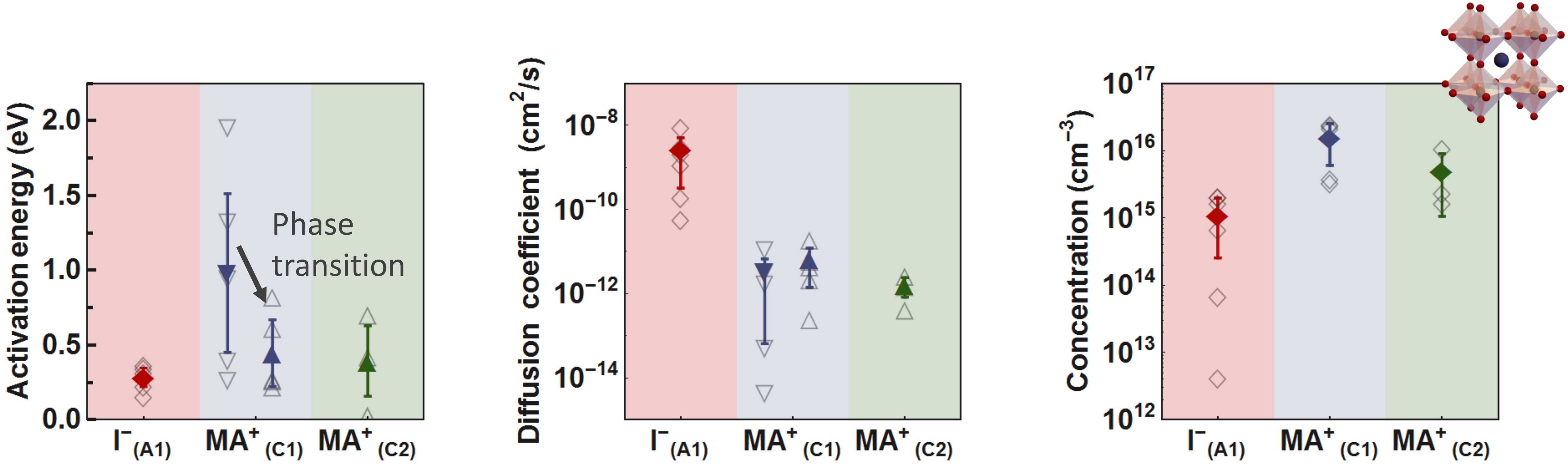




	A1	C1	C2
Migrating ion species	I^-	MA^+	MA^+



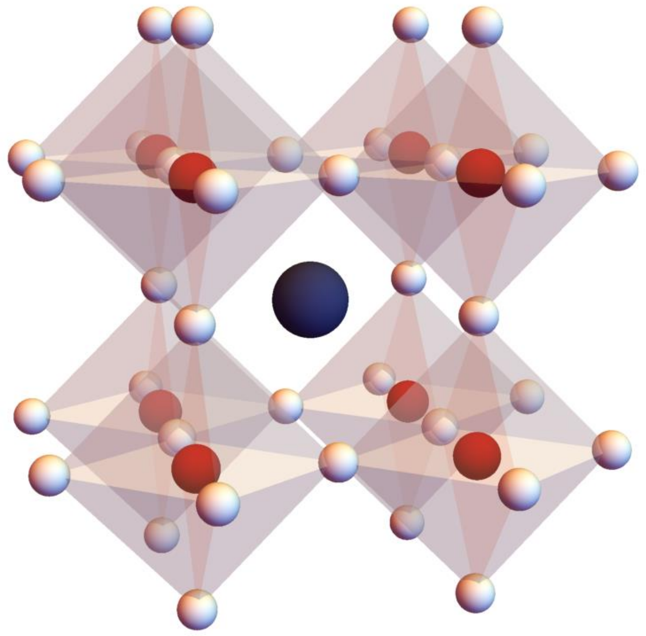
Quantifying ion migration in $MAPbI_3$



Solar cells fabricated at AMOLF and at the University of Konstanz with power conversion efficiencies ranging from 1 to 12%.

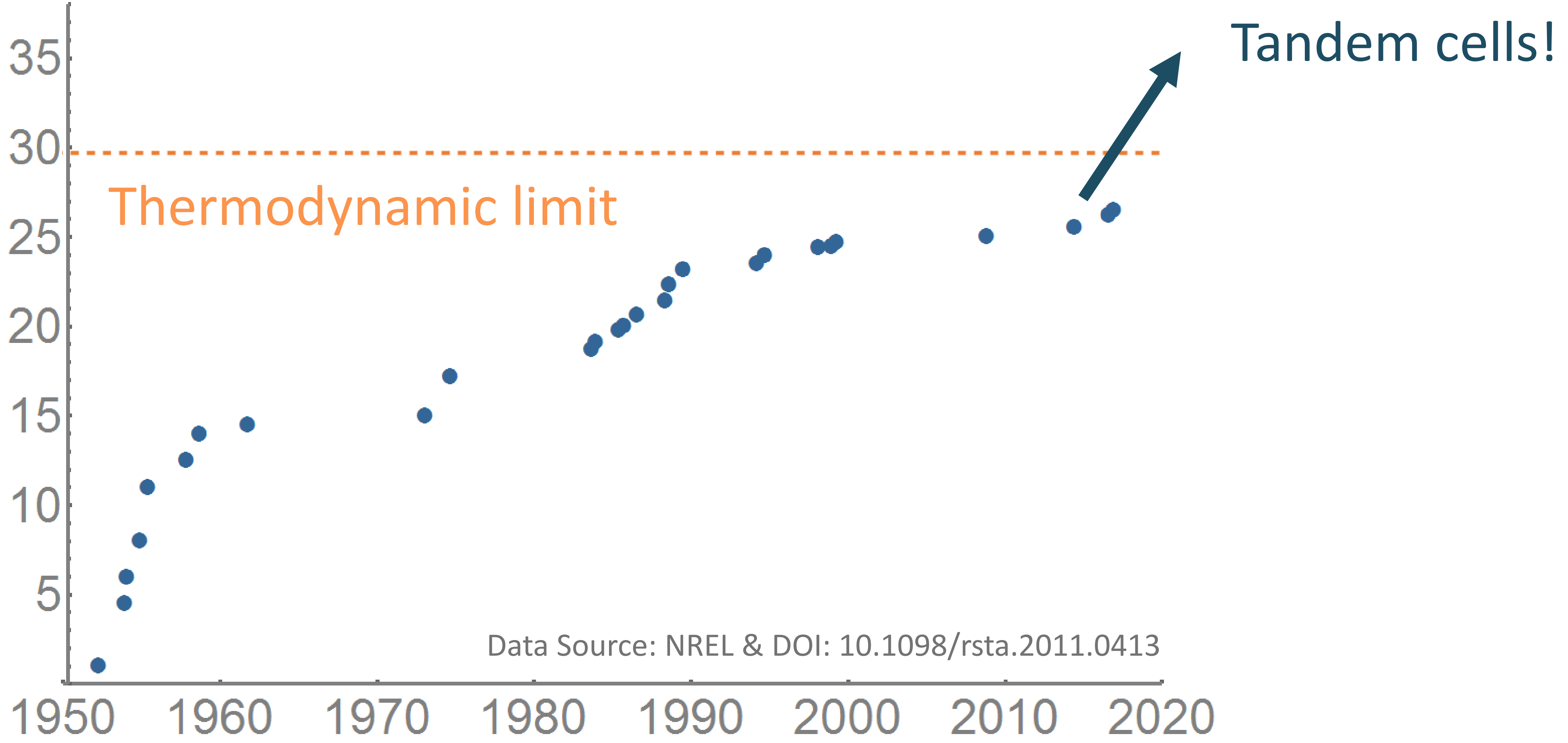
Conclusion I → $MAPbI_3$

- Both MA^+ and I^- are migrating but on completely different timescales.
- The migration of MA^+ ions is the major factor influencing the hysteresis in MAPI solar cells
- I^- migration reproducible, MA^+ migration depends heavily on fabrication, degradation



Si Solar Cell Efficiency Close to Limit

physics of functional complex matter



Towards efficient and stable perovskite/silicon tandem solar cells

- Solar cell efficiency simulations
  - Need for better materials – less NR recombination
- Ion migration in perovskites
  - Less migration = more stable
  - Material development can suppress ion migration

Acknowledgements

Netherlands Organisation for Scientific Research

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