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The A. D. Wright Lab

spectroscopy · light-matter interactions · solar cells

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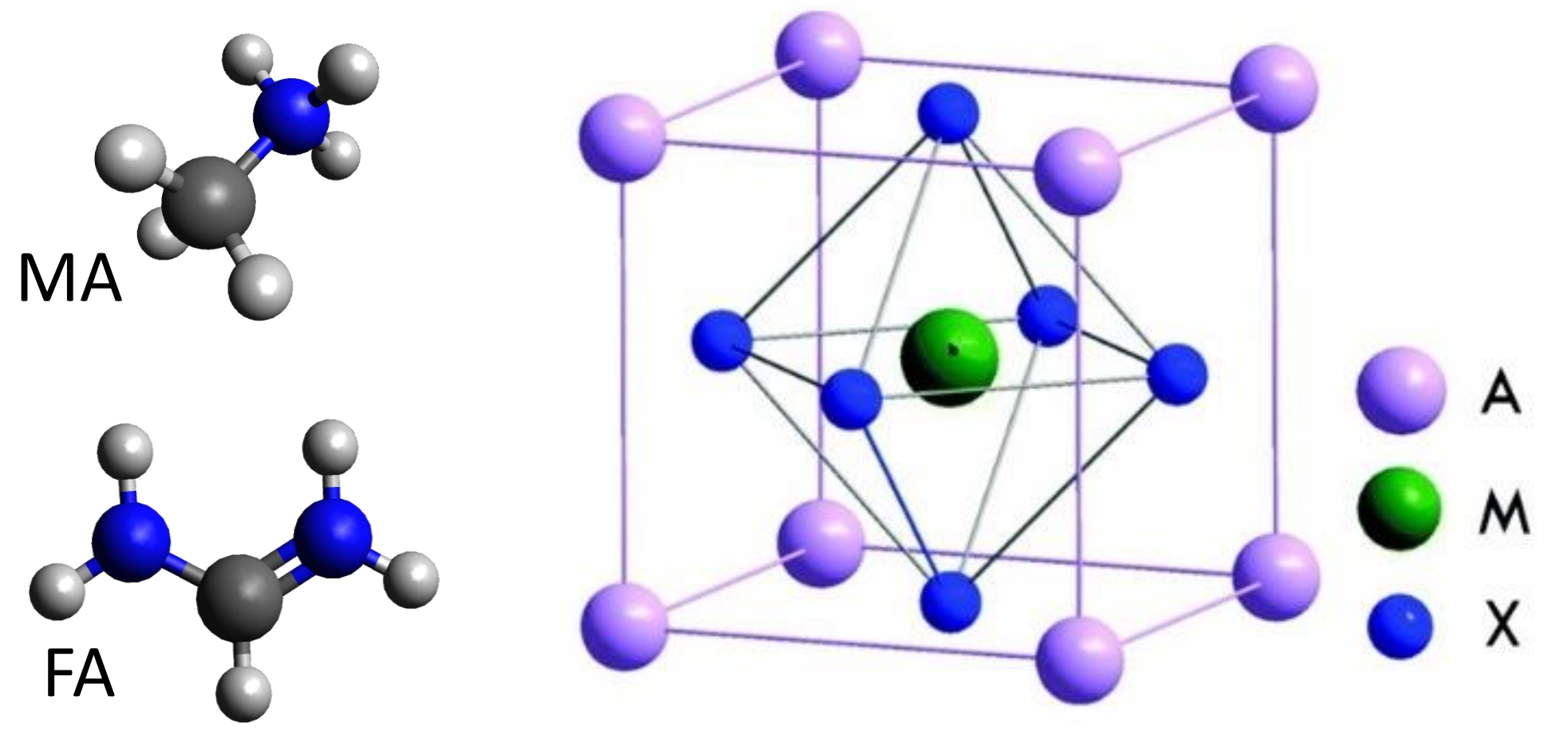
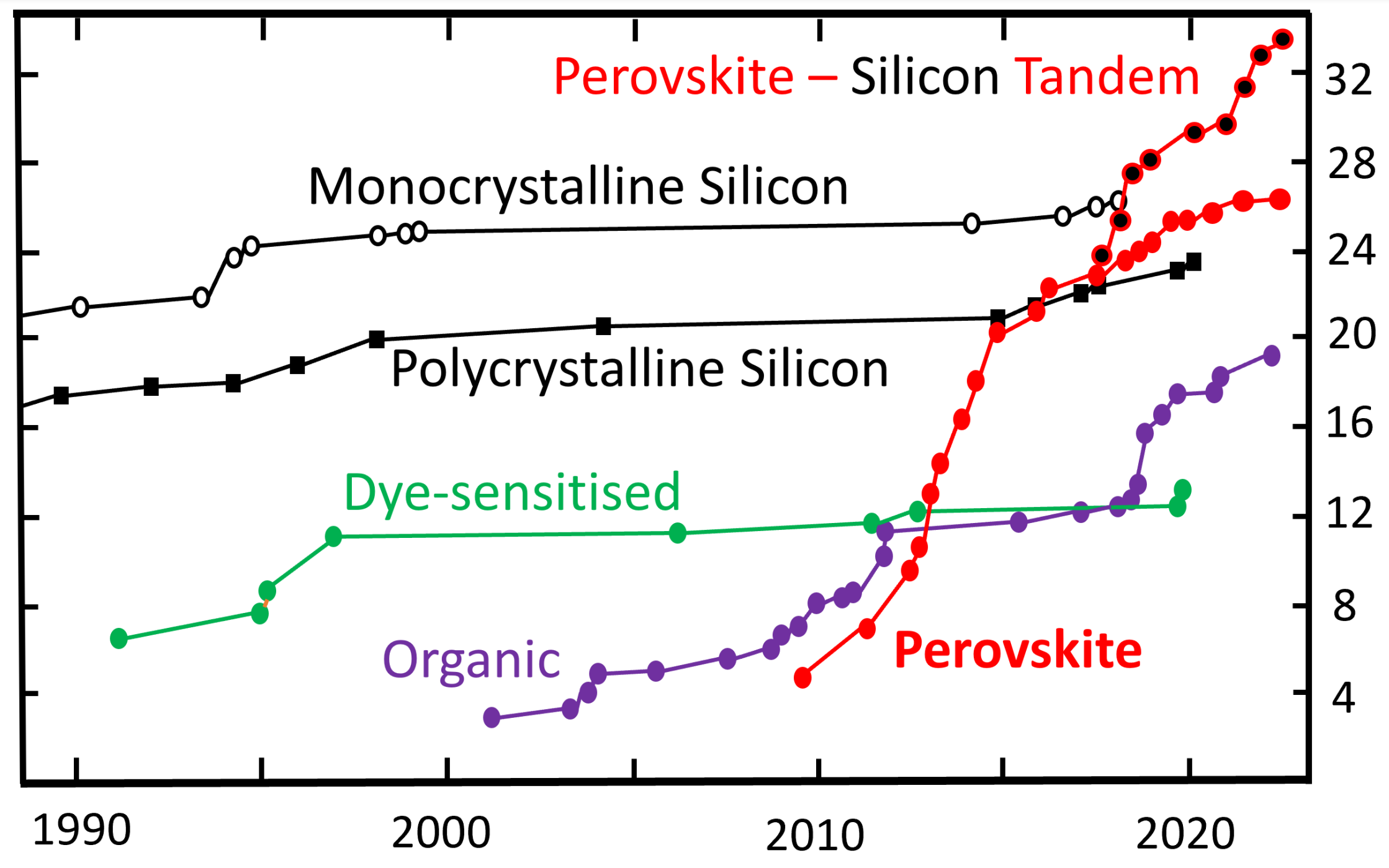
Perovskite Solar Cells

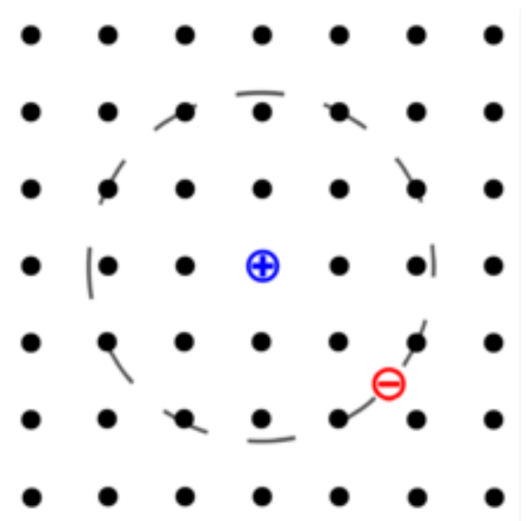
Solar cells based on metal halide perovskite (MHP) semiconductors have rapidly advanced in efficiency over the past decade. MHPs have the stoichiometry AMX_3, where A = MA/FA/Cs, M = Pb/Sn, X = I/Br.

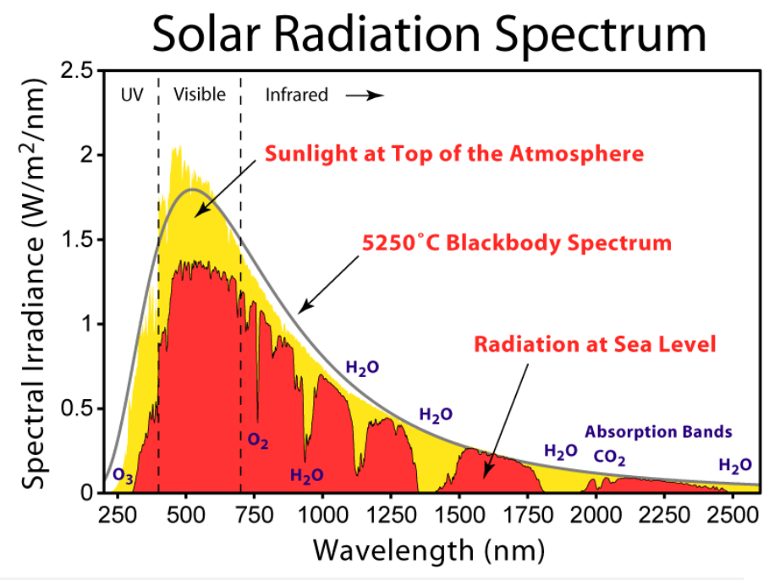




Why are perovskites such good solar cell materials?

- Good at absorbing light in the visible spectrum
- Low exciton binding energies
- Long charge-carrier diffusion lengths

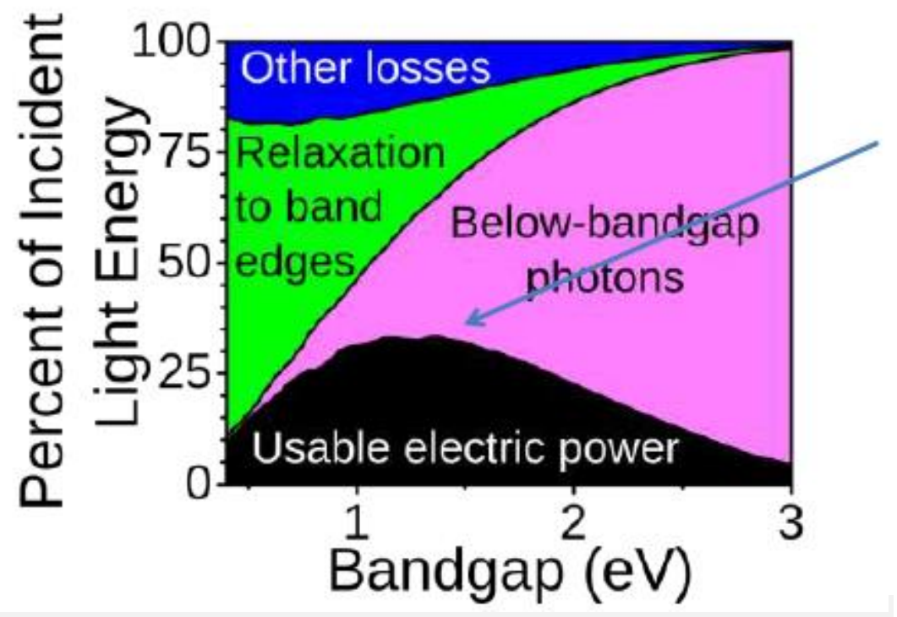


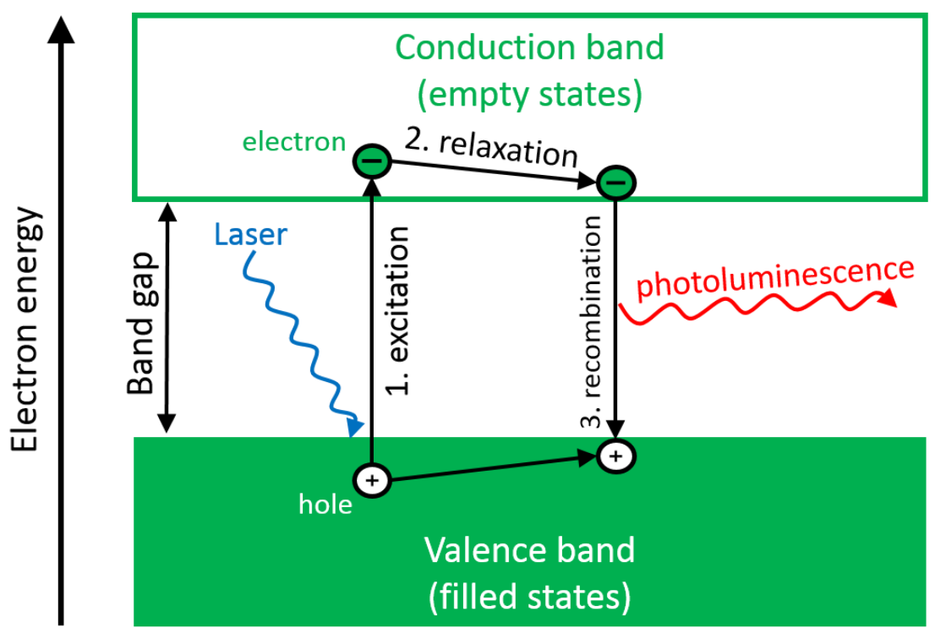


- Can be solution processed
  - Roll-to-roll printing
- Cheap, abundant materials
- Simple fabrication process
- Tune properties by varying composition

Solar cell efficiency

Shockley-Queisser limit ~ 33% for single band gap absorber, no solar concentration.



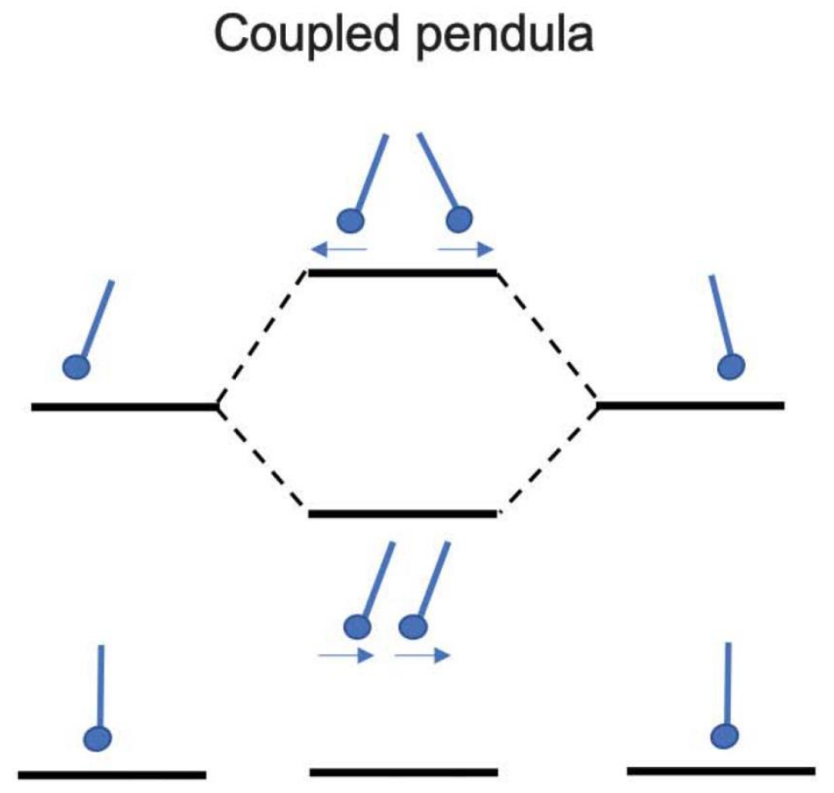


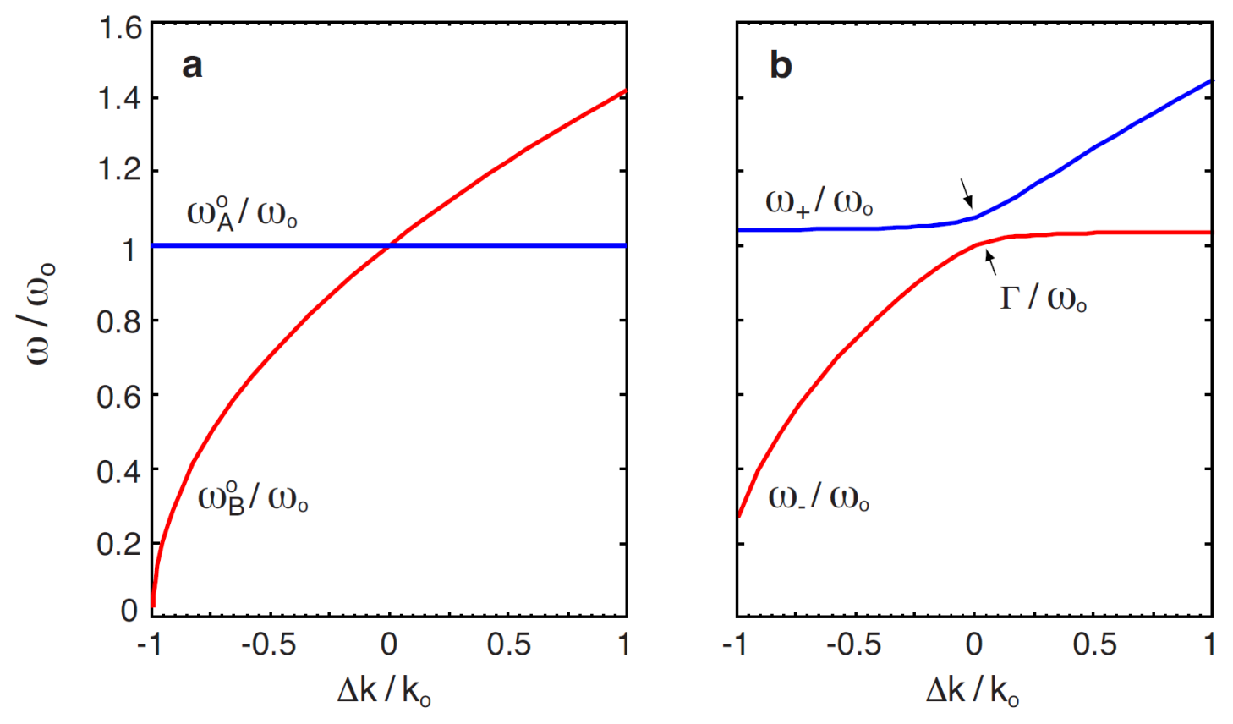
Losses

- Photons not absorbed
- Excess energy of absorbed photons
- Black body radiation
- Radiative recombination

Polaritonic Effects

Huygens (1665): coupled oscillators can generate new modes of motion by exchange of energy.



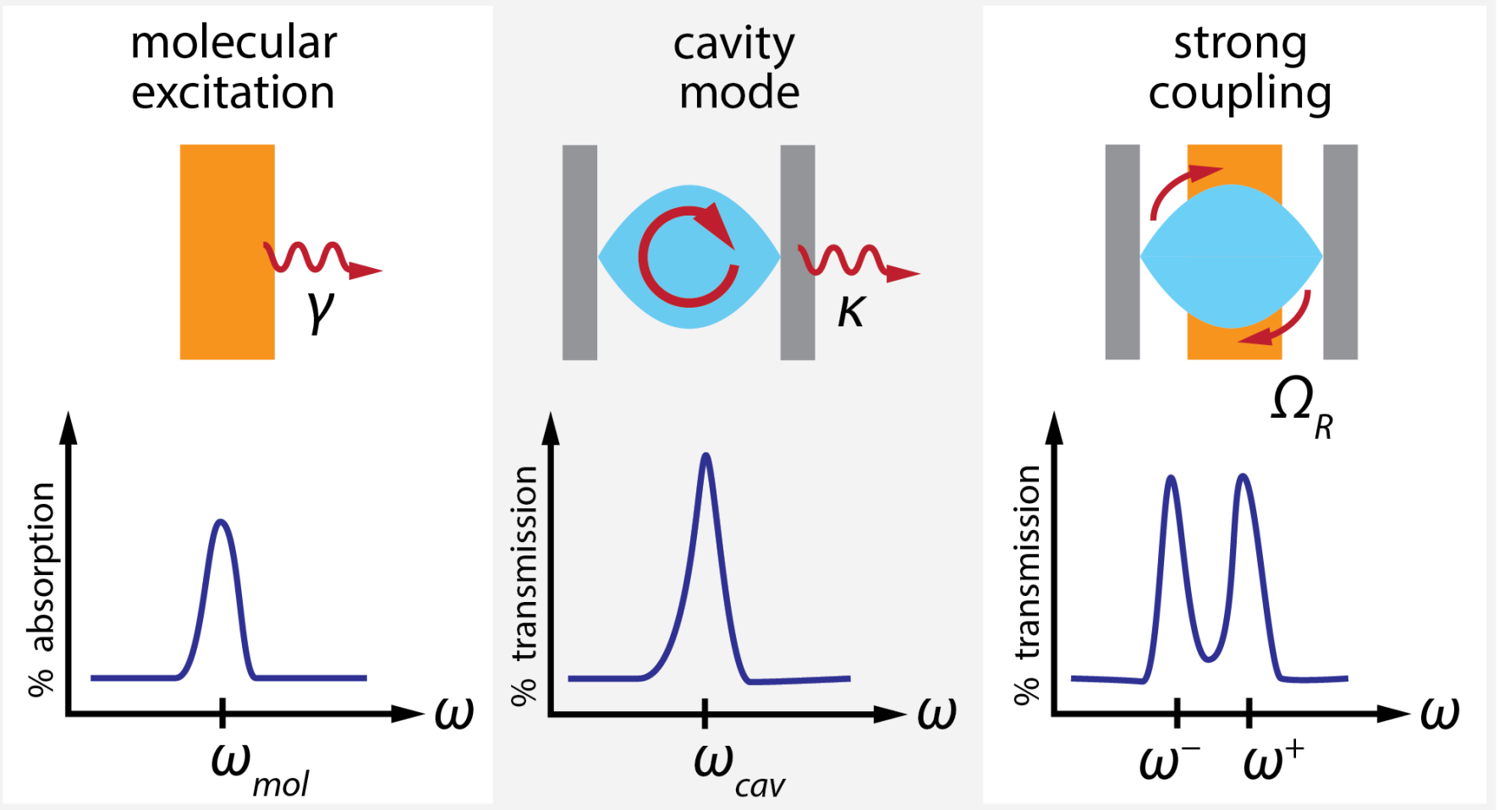


Strong coupling regime:

- Rate of energy exchange > rate of loss
- Doublet structure in energy spectrum
- Splitting scales linearly with coupling strength

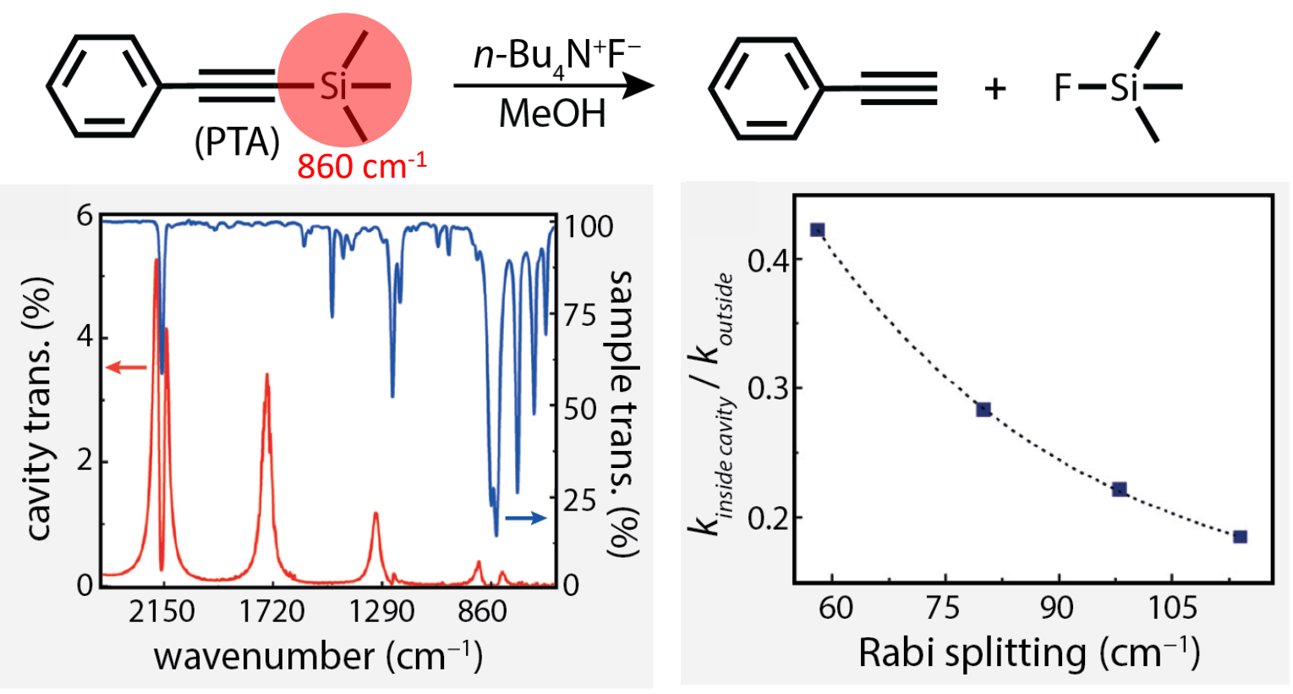
Polaritons arise from strong coupling between an **optical cavity mode** and a transition of a material placed within it.

$$\hbar\Omega_R = 2\mu_{ij}\sqrt{\frac{N}{V}}\sqrt{\frac{\hbar\omega}{2\varepsilon_0}}\sqrt{n+1}$$



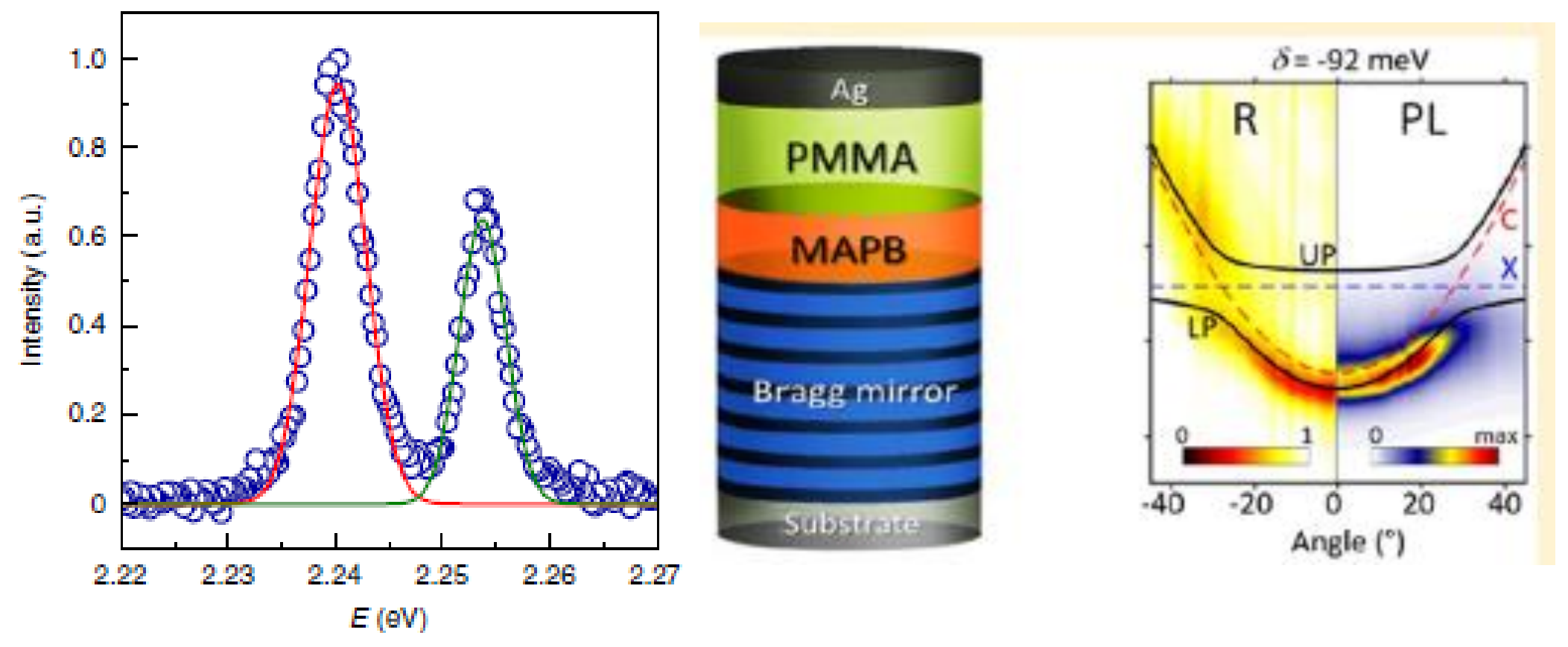
The **optical cavity** consists of two precisely spaced mirrors facing each other, acting like a trap for light, which can sustain only certain frequencies of radiation due to interference effects.

Strong light-matter coupling has been observed to **alter chemical reaction rates**, allowing for **cavity catalysis.**



Thomas *et al.* Angewandte Chemie Int. Ed., **55**, 11462 (2016)

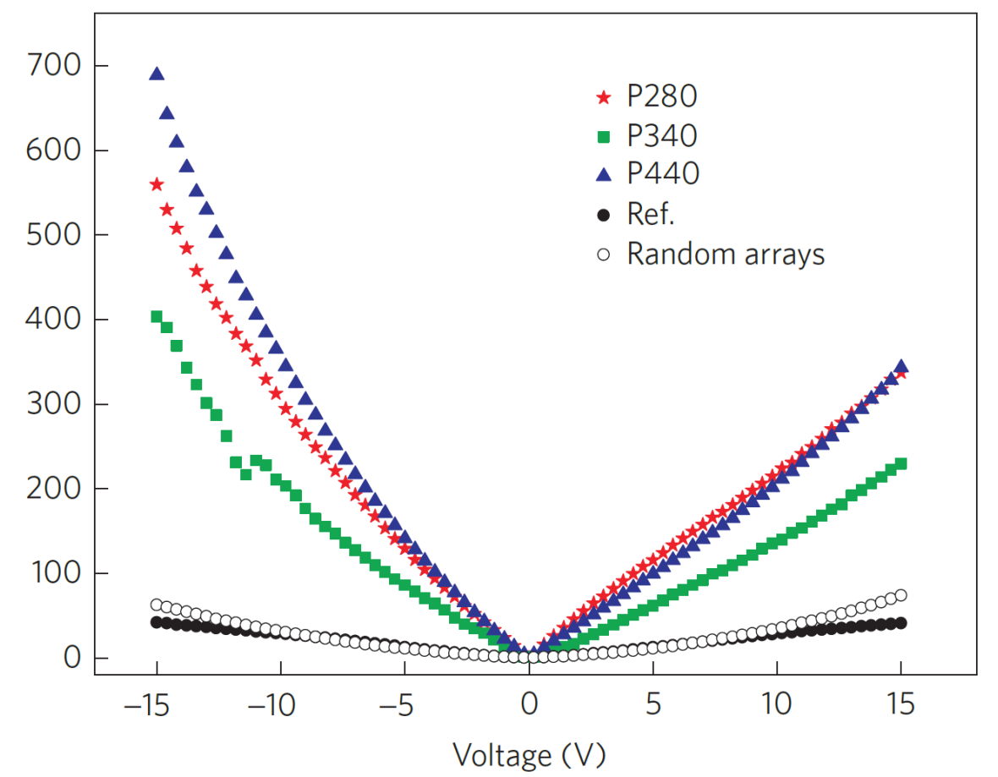
R. Su *et al., Nat. Phys*. (2020) **16,** 301
P. Bouteyre *et al., ACS Photonics (*2019) **6**, 1804



Polariton formation has been observed in atoms, molecules and semiconductors – **including metal halide perovskites**!

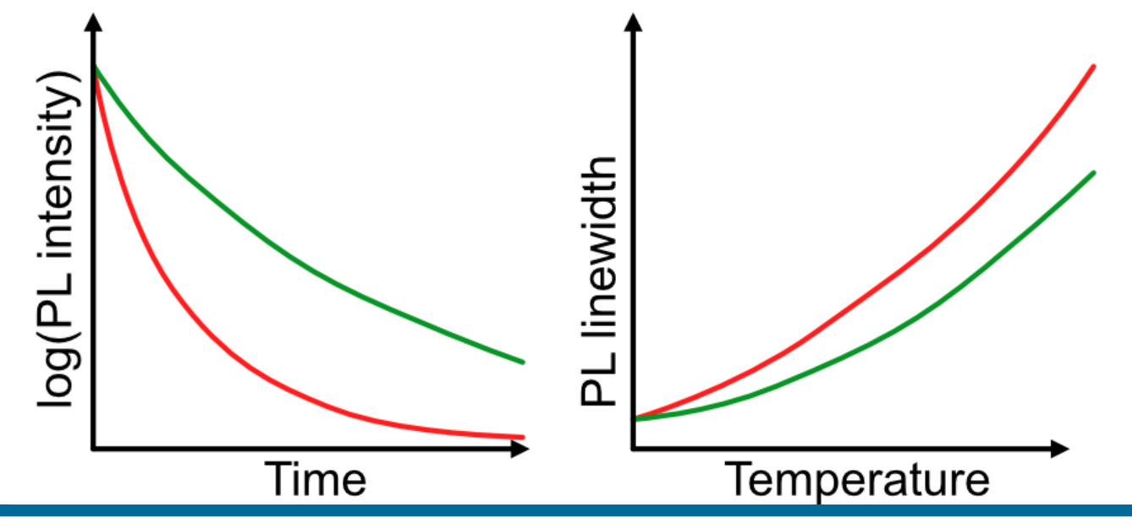
Polaritonic enhancement of metal halide perovskite photovoltaic performance

Polaritonic effects allow us to **influence energetics without changing structure**, and have been used to **enhance charge transport in organic semiconductors.**

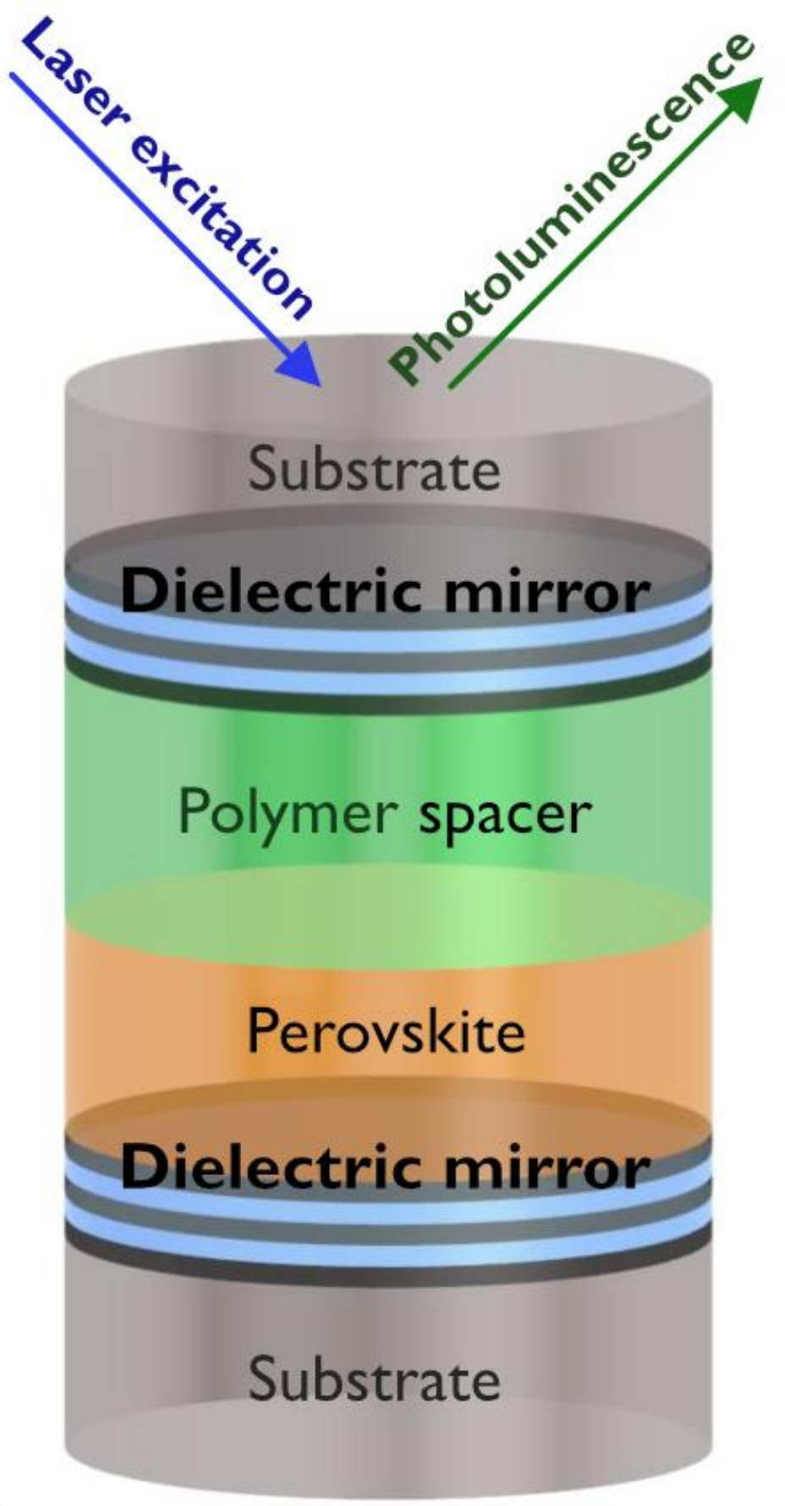


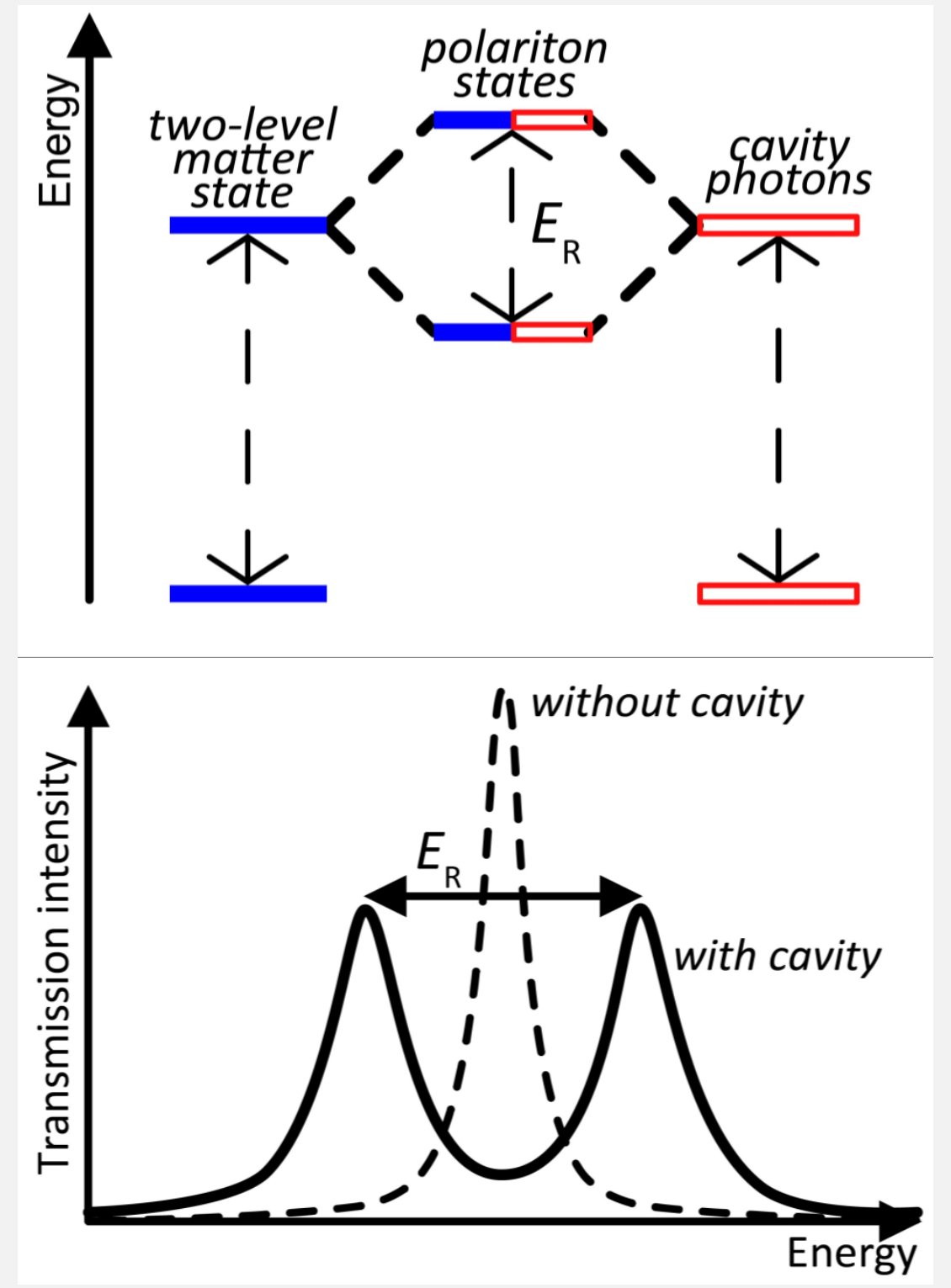
E. Orgiu *et al., Nat. Mater.* (2015) **14,** 1123

Polaritonic lasing has been observed in metal halide perovskites, i.e. the lasing threshold was lowered by coupling between excitons and the cavity electromagnetic field. Could **material properties affecting solar cell performance also be improved**, e.g. charge-carrier lifetime or electron-phonon coupling?

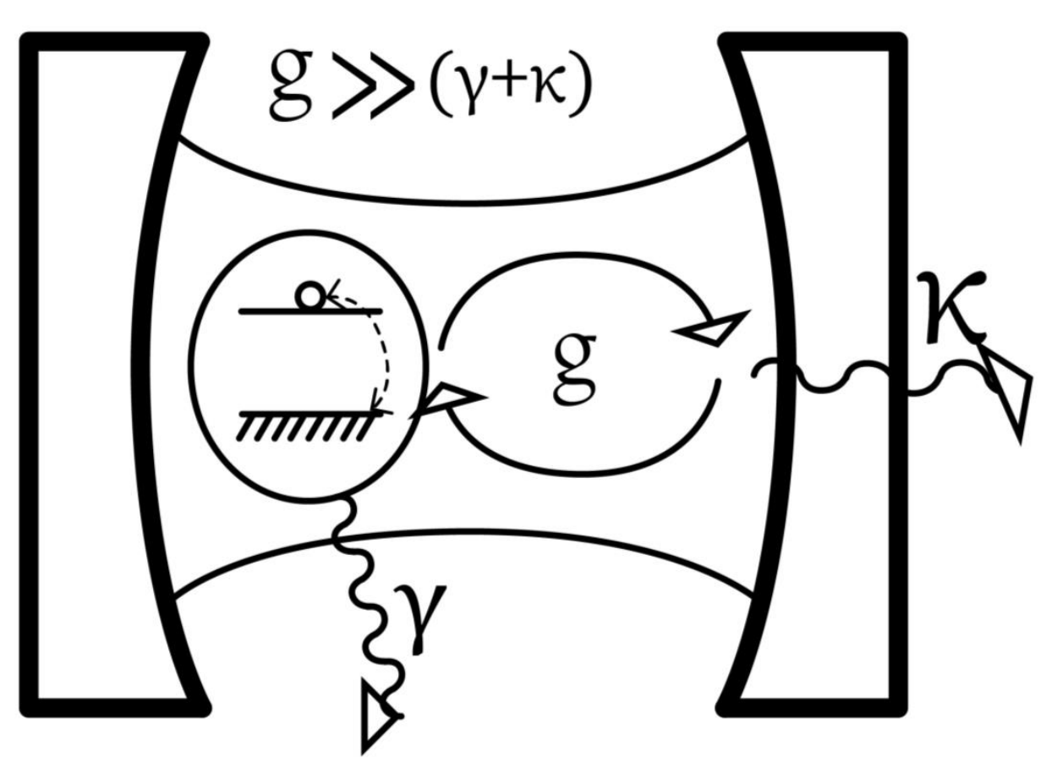


We will carry out **optical spectroscopy** on MHP thin films sandwiched between dielectric mirrors, acting as an **optical cavity**.

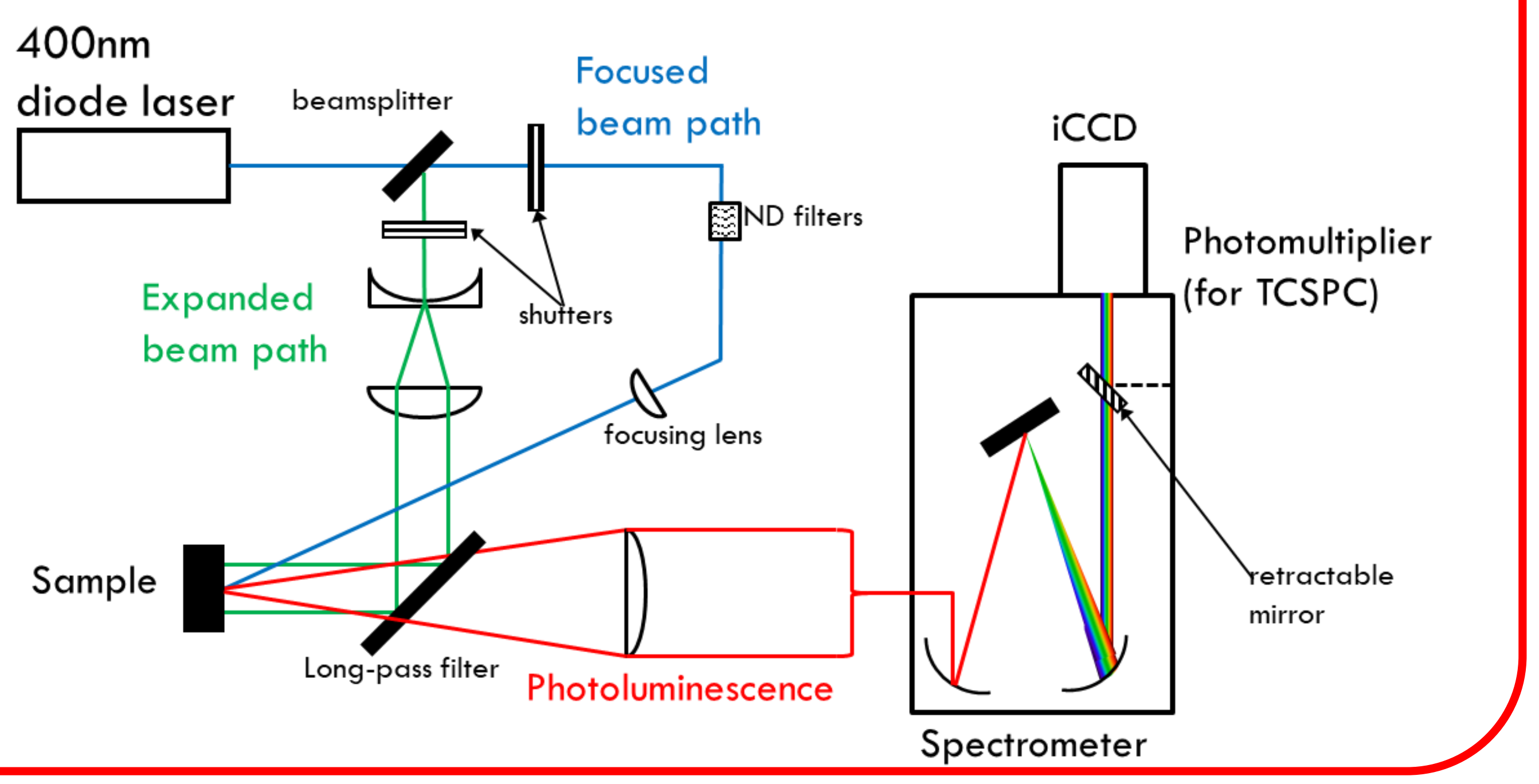




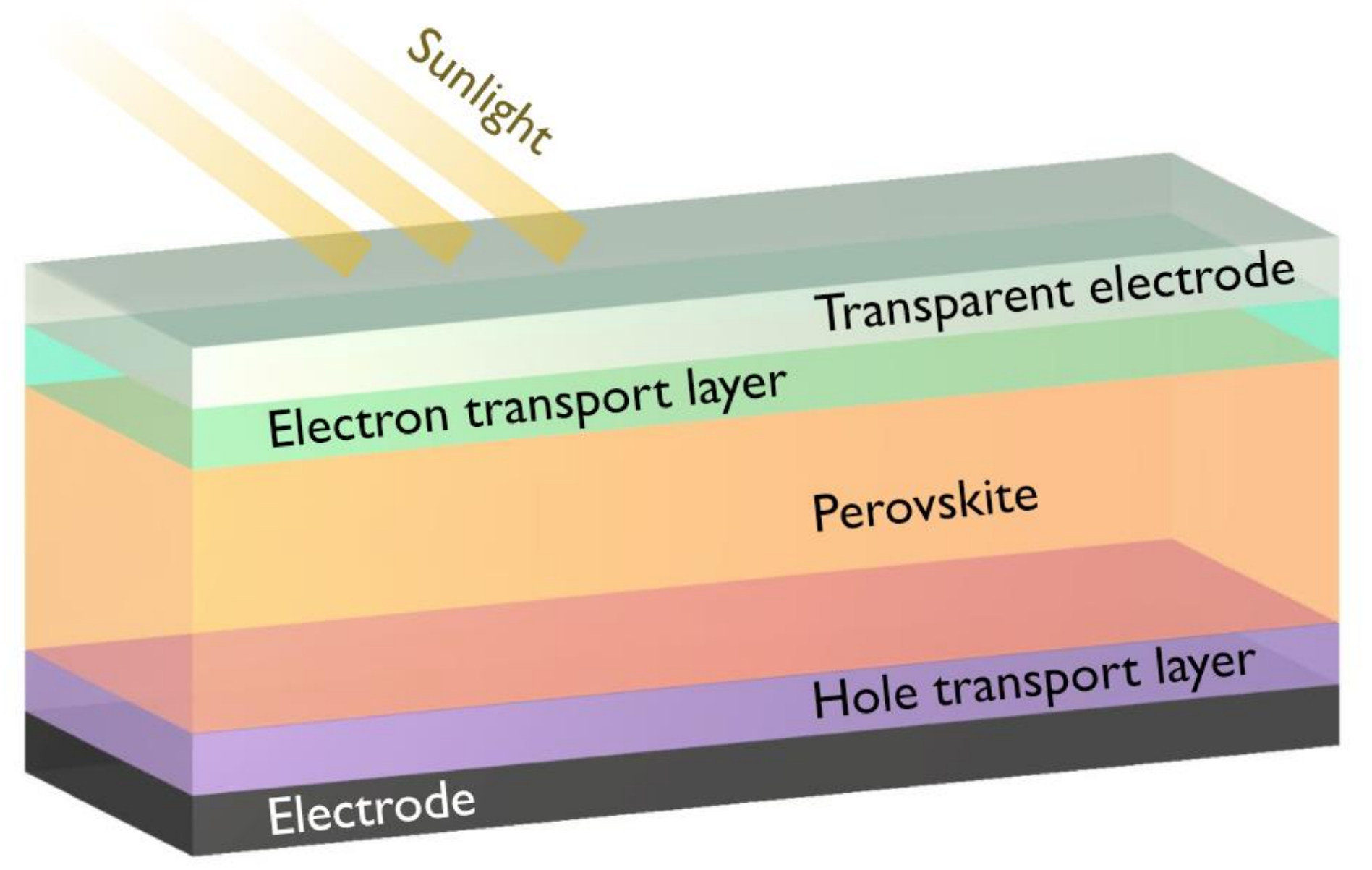
After demonstrating the formation of polaritons, we will investigate whether the **charge-carrier dynamics** and **electronic energies** are affected, by examining the **photoluminescence transients and spectra** of the perovskite thin films.



We will **develop quantitative models** to account for changes to the charge-carrier dynamics, and use these models to **propose strategies for enhancing perovskite solar cell performance** using polaritonic effects.



Existing perovskite solar cell devices have a **layered structure**. Microcavities could be incorporated into this structure as layers above and below the perovskite later.



Target outcomes:

- **Rational control** of MHP material properties and solar cell efficiency using optical cavities
- Incorporation into general optoelectronic devices, e.g. LEDs, transistors
- Better understanding of **fundamental physics!**