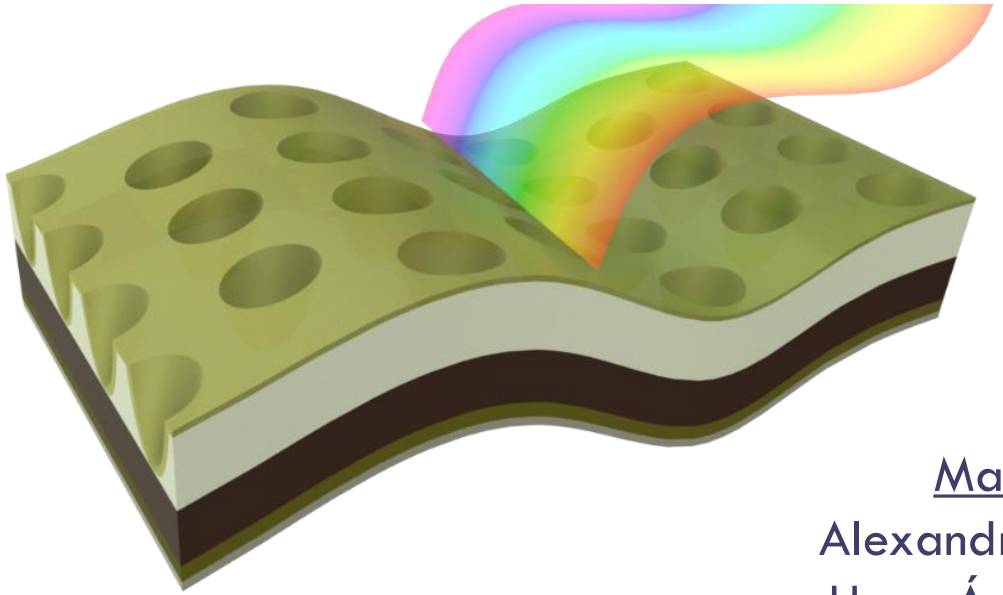
PHOTONIC-ENHANCED PEROVSKITE SOLAR CELLS: NEW AVENUES FOR EFFICIENCY AND STABILITY IMPROVEMENT



Manuel J. Mendes, Sirazul Haque, Miguel Alexandre, Manuel Chapa, Olalla S.-Sobrado, Hugo Águas, Elvira Fortunato, Rodrigo Martins

E-MRS Spring 2019
Symposium B

i3N/CENIMAT, Department of Materials Science, Faculty of Science and Technology, Universidade NOVA de Lisboa and CEMOP/UNINOVA, Campus de Caparica, 2829-516 Caparica, Portugal.

Objectives for Thin-film Photovoltaics

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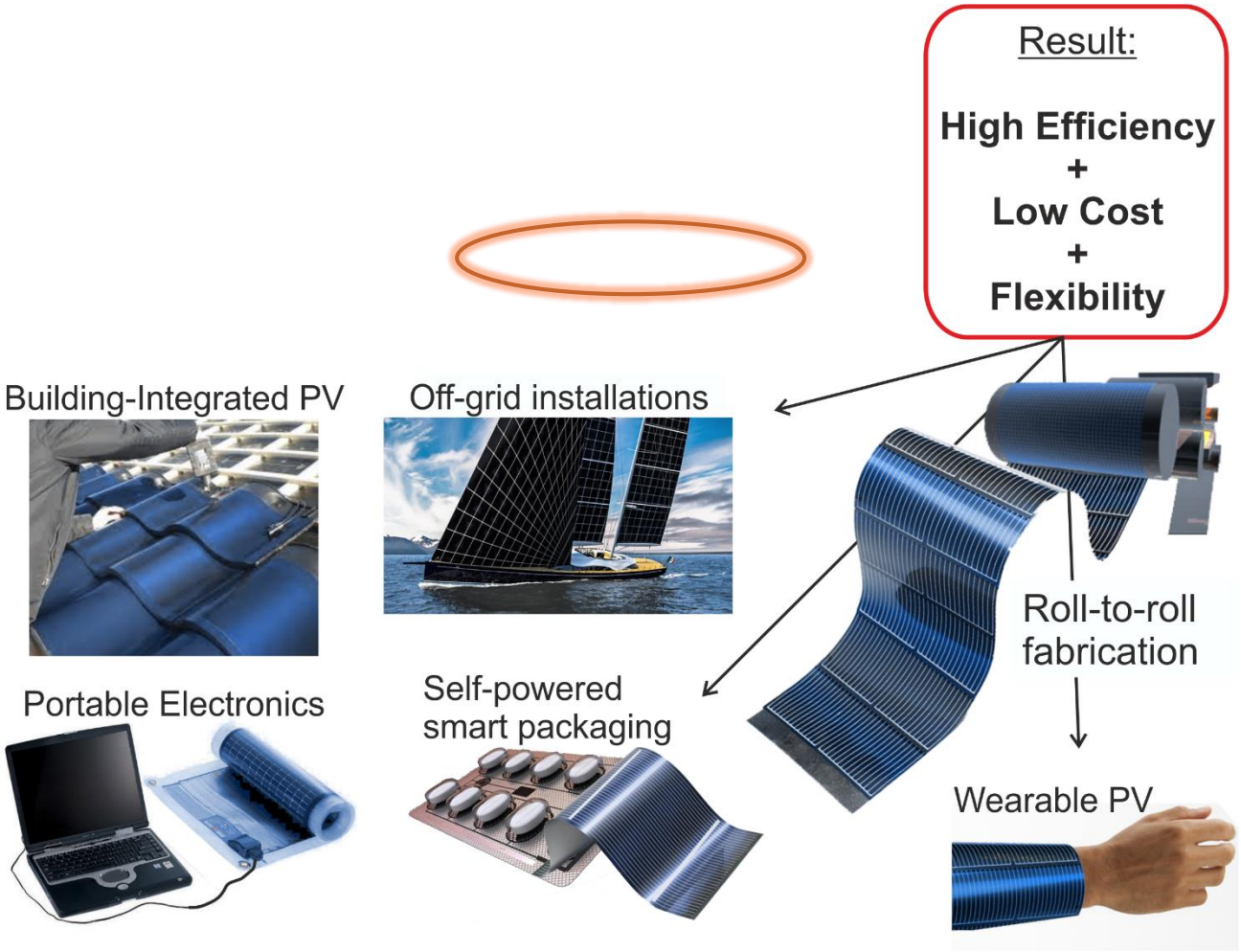

- ✓ **Lower material costs** – thicknesses on the order of **µm**
- ✓ **No epitaxial constraints** - infinite material possibilities
- ✓ **Flexibility** – fabrication in roll-to-roll processes and easier implementation in a broad-range of consumer-oriented applications

Photonic-enhanced Perovskite Solar Cells (PSC)

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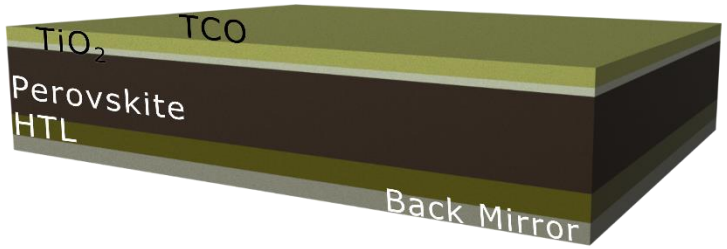
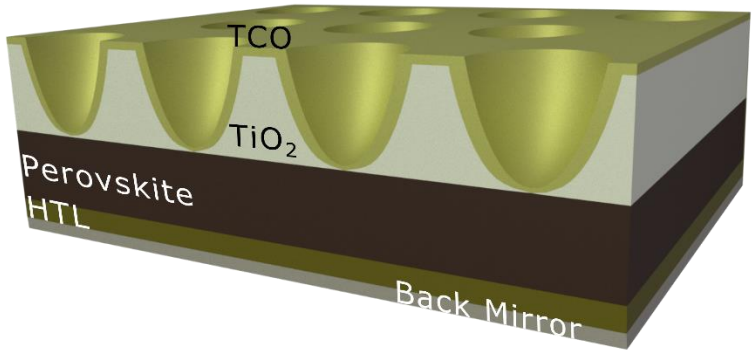
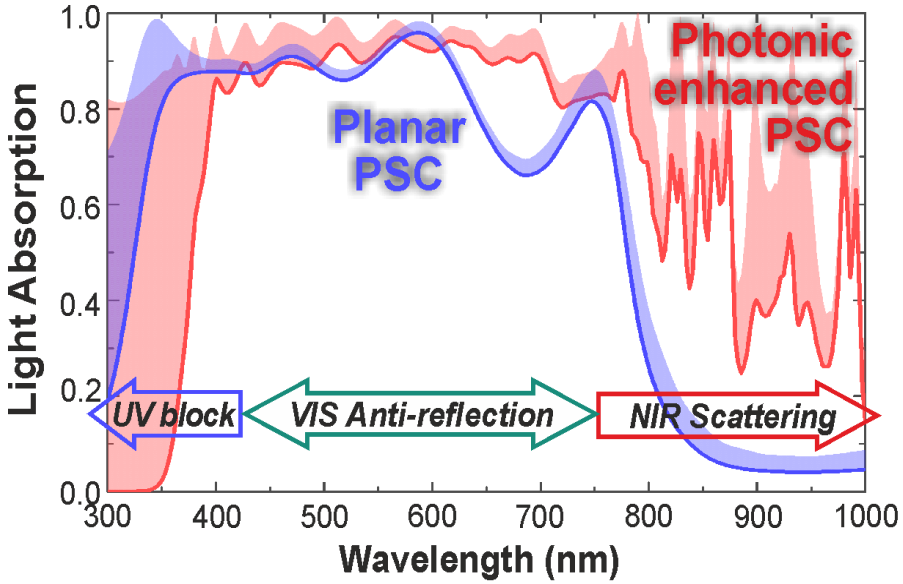
Planar PSC

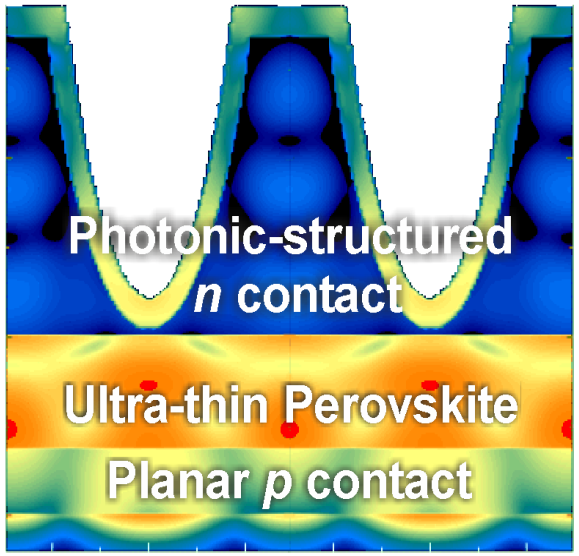
(Reference)



PSC with Light Trapping







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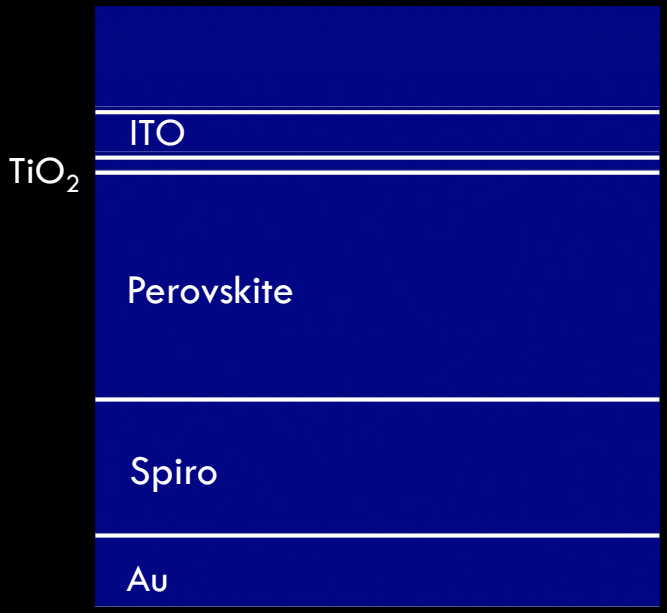

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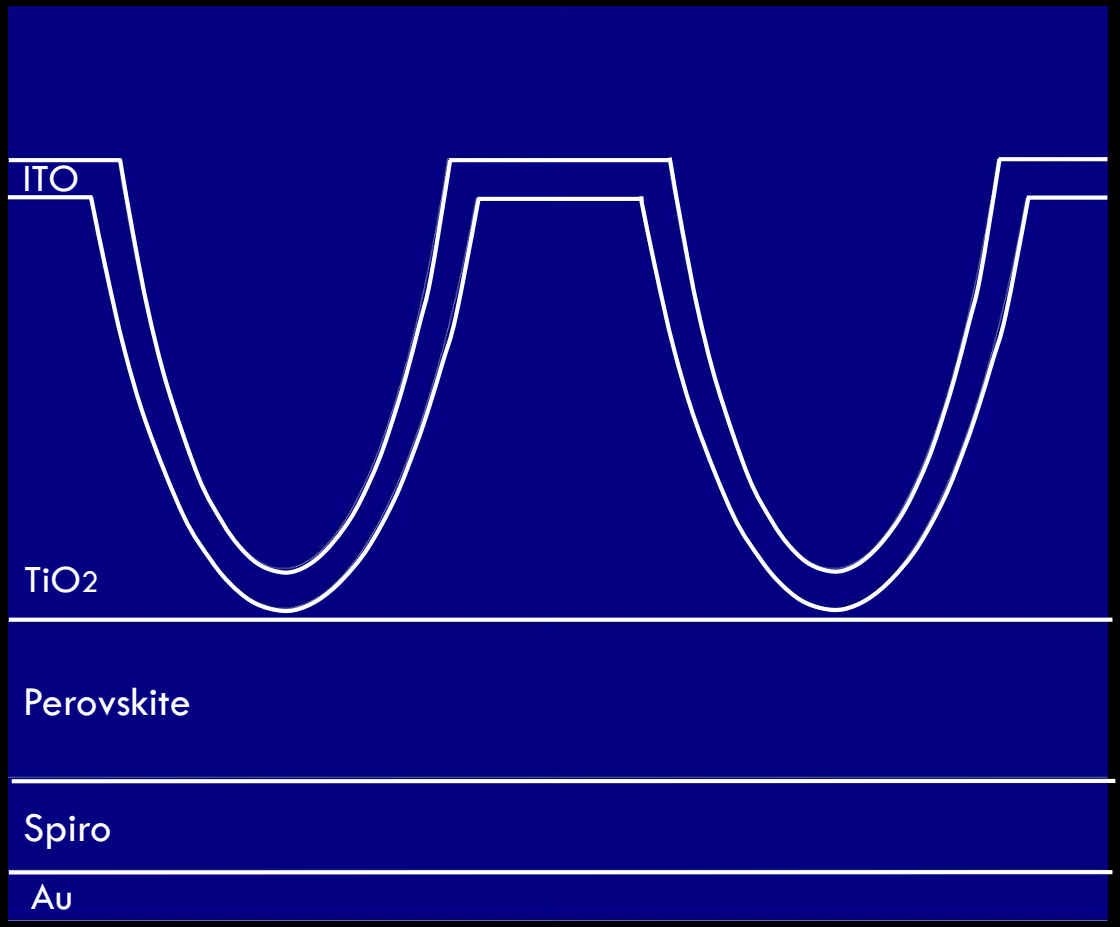

Optimized photonic-structured TiO_2 on Perovskites

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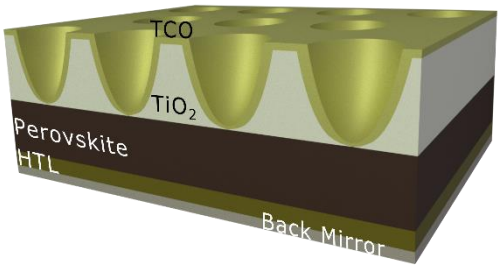
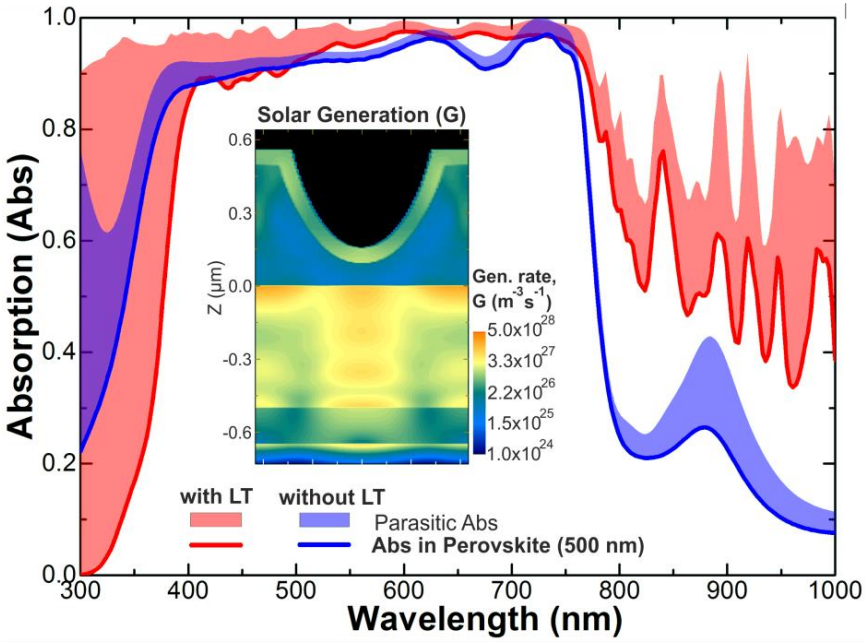
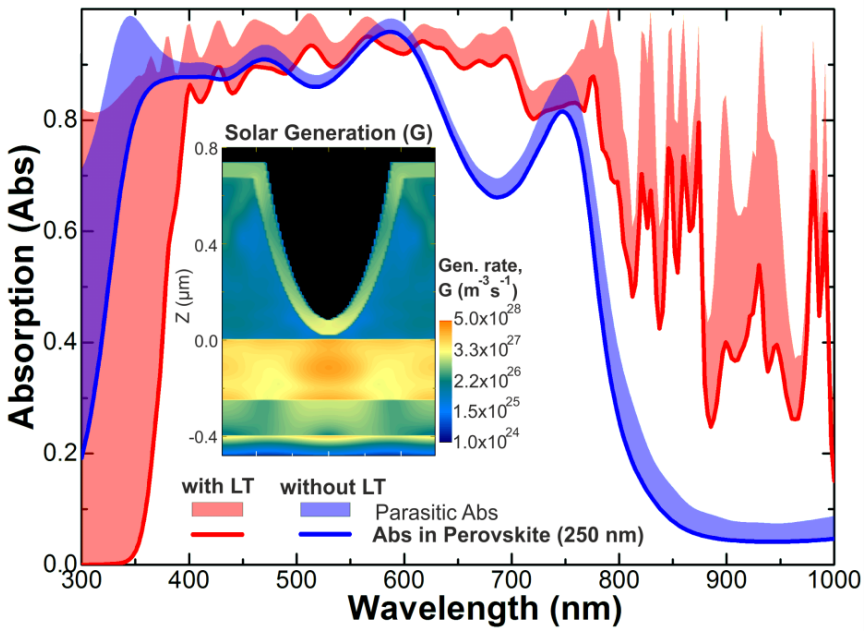
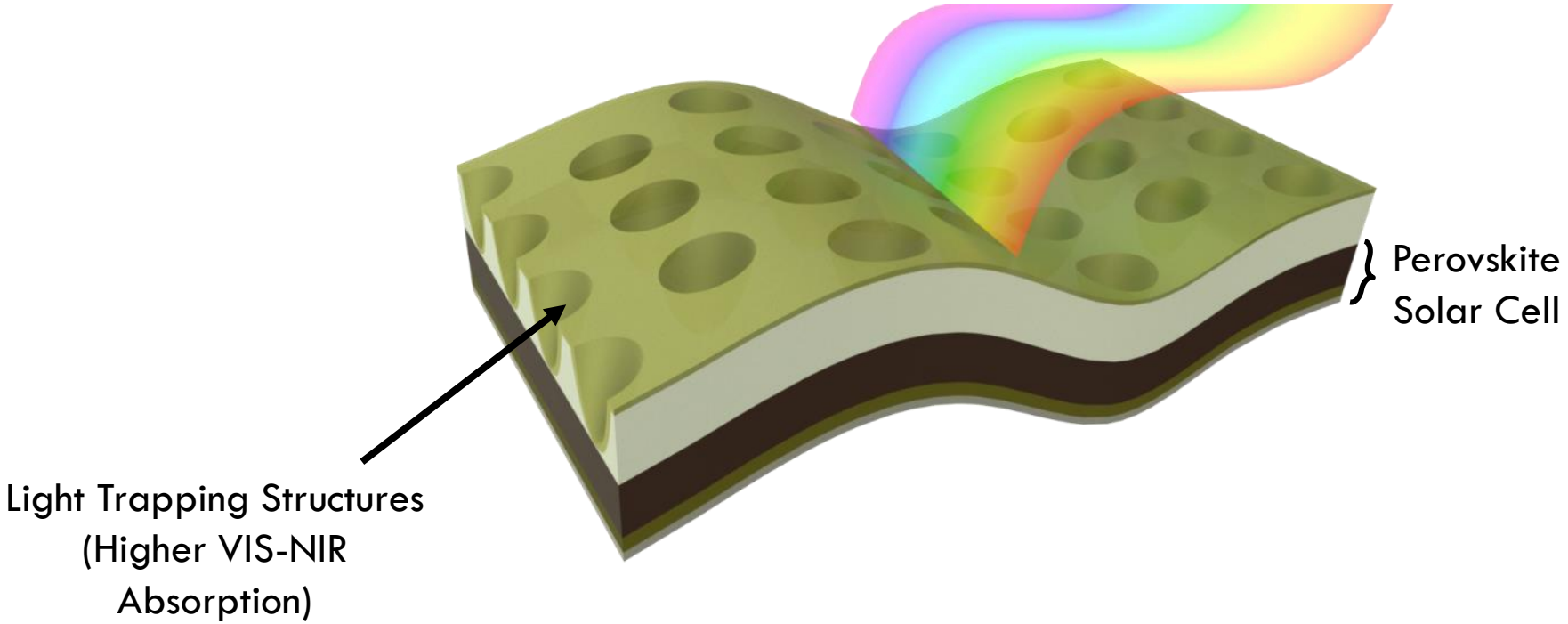


Light Trapping Structure	**500 nm** Perovskite absorber *(Conventional)*	**250 nm** Perovskite absorber *(Higher Flexibility)*
	J_{PH} (mA/cm²)	J_{PH} (mA/cm²)
Planar ARC (Reference)	25.95	22.64
TiO_2 Voids array on ETL	31.30	28.62





- How to make better use of energy in UV portion of sunlight?



Optimum Luminescent Down-Shifting Properties for High Efficiency and Stable Perovskite Solar Cells.
M. Alexandre et. al., **ACS App. Energy Mat.** (2019)

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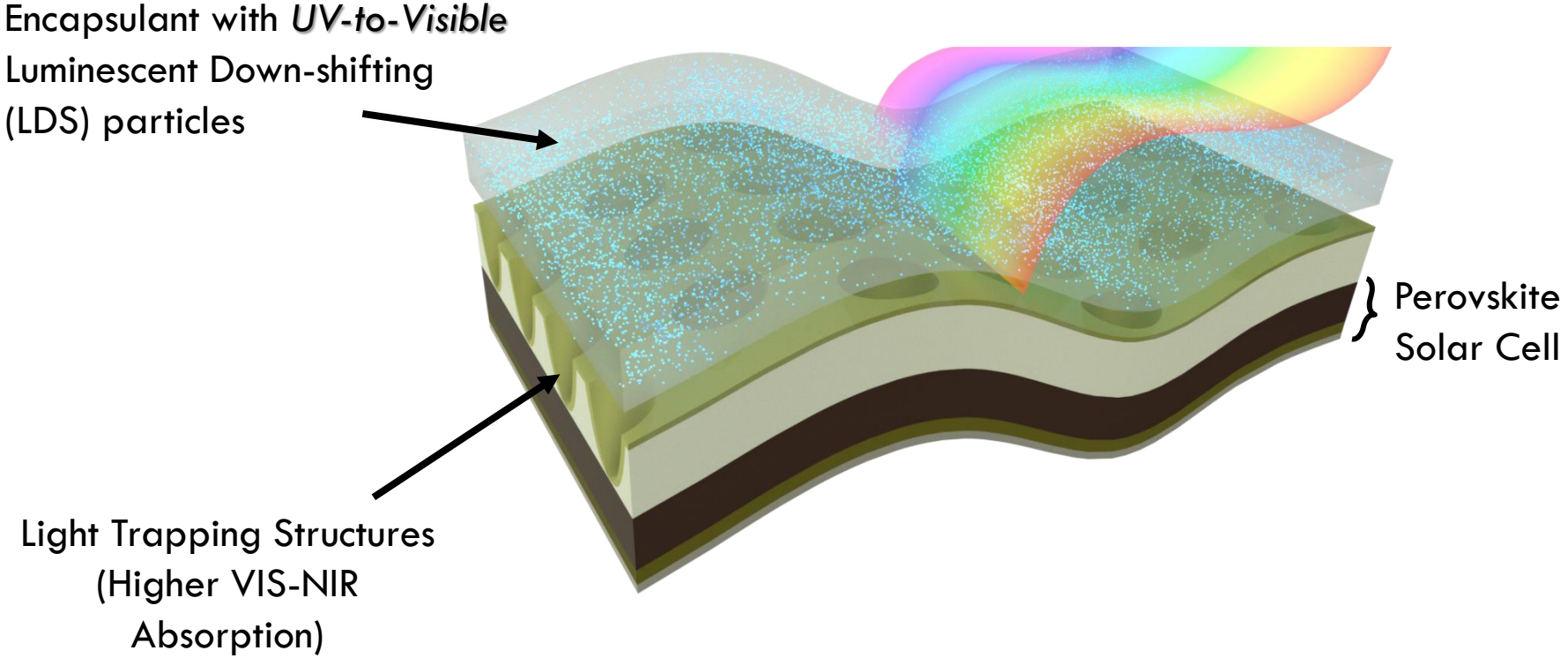

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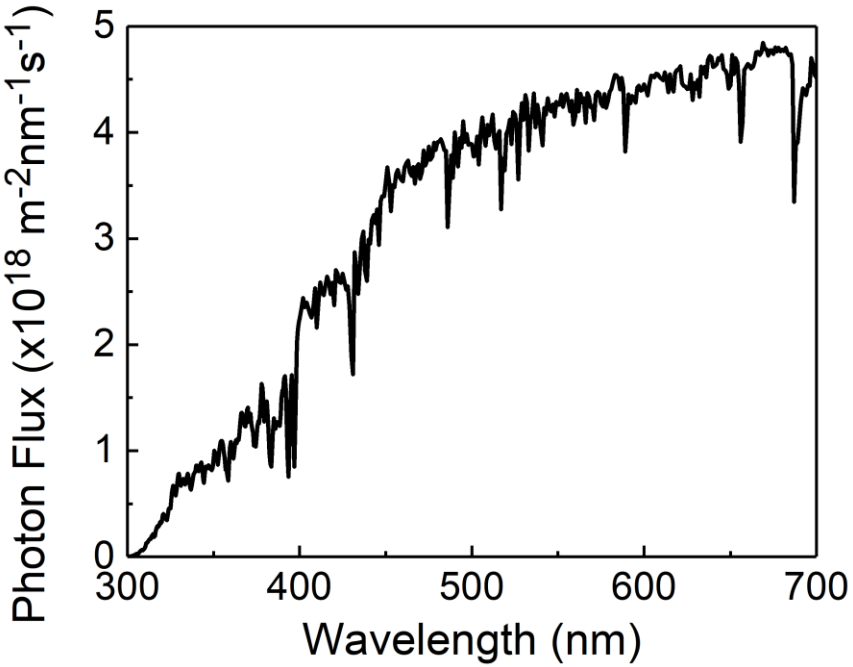
Down-Shifting (DS) analytical model

Manuel J. Mendes (mj.mendes@fct.unl.pt) – CENIMAT-UNINOVA FCT-UNL, Caparica, Portugal



AM1.5G Photon Flux

$$J_{ph} = \int A(\omega) AM_{1.5G} d\omega$$

Change to include DS effect

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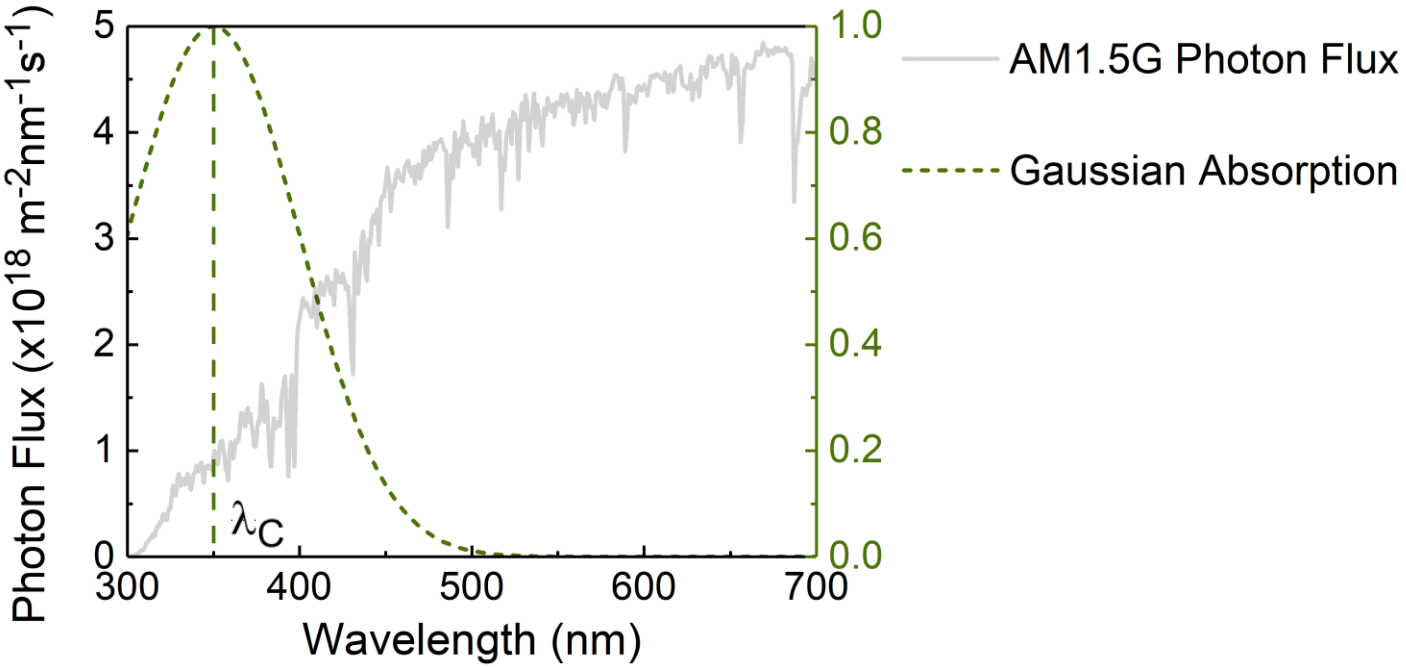

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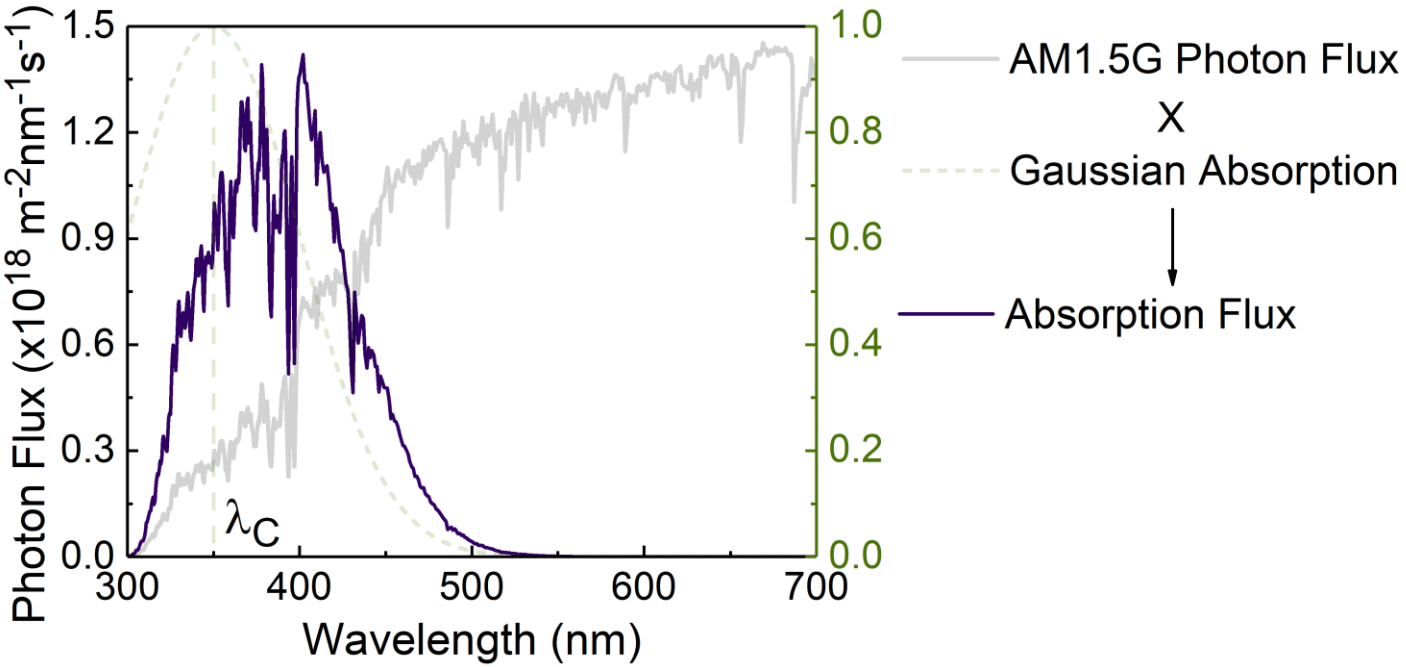

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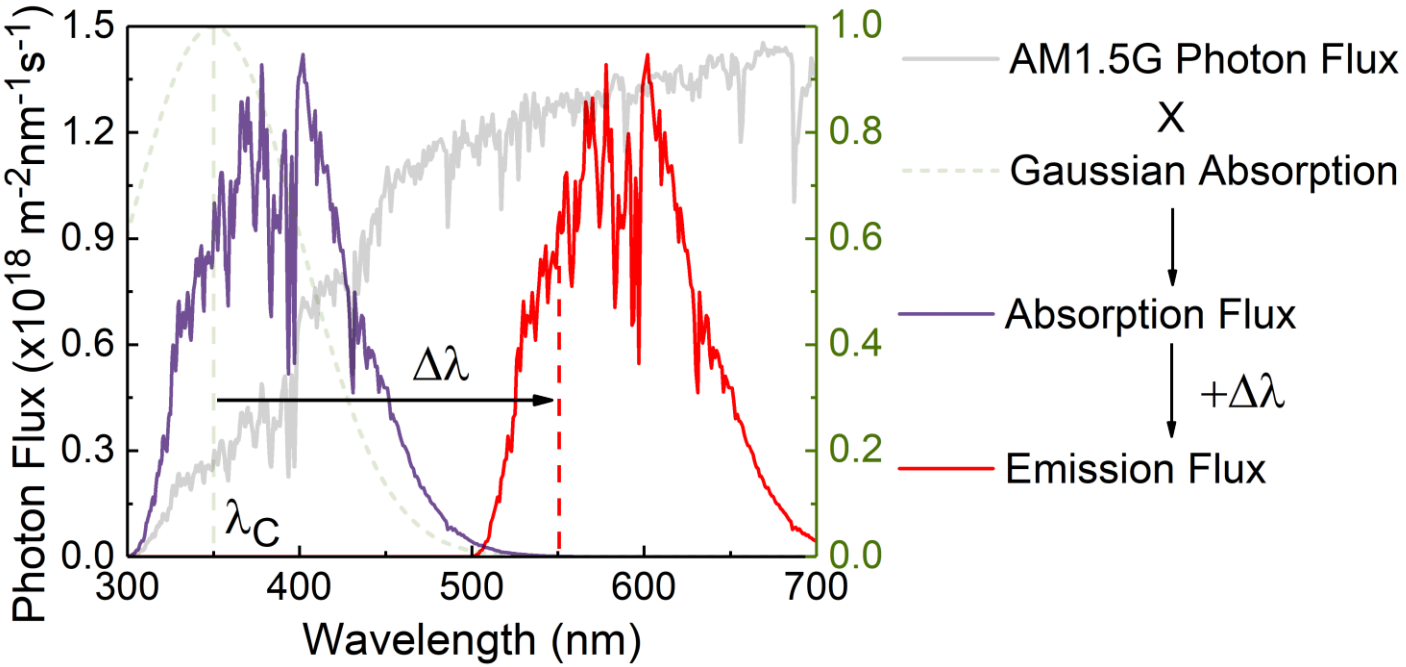
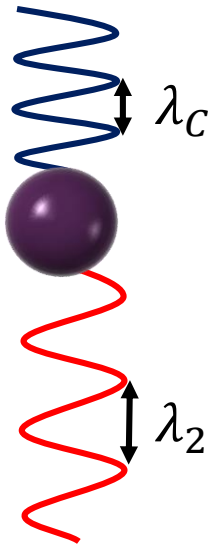


$$\lambda_2 - \lambda_C = \Delta\lambda$$



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Example of Down-shifted incidence spectrum

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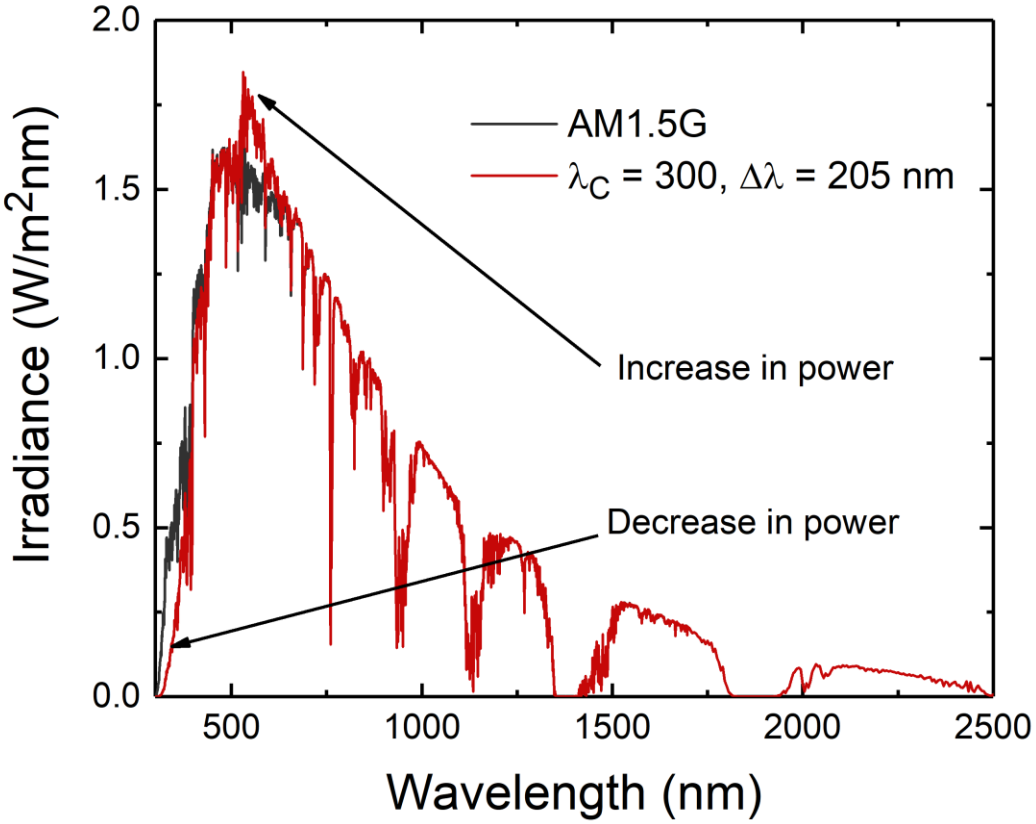

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Optimal Down-shifting for PSCs

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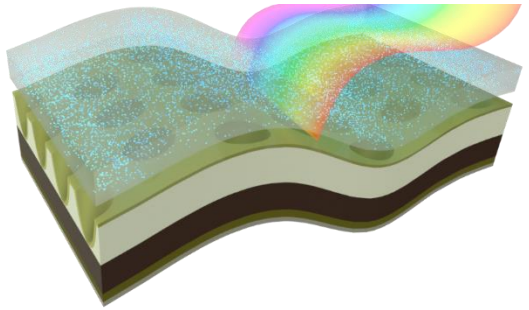
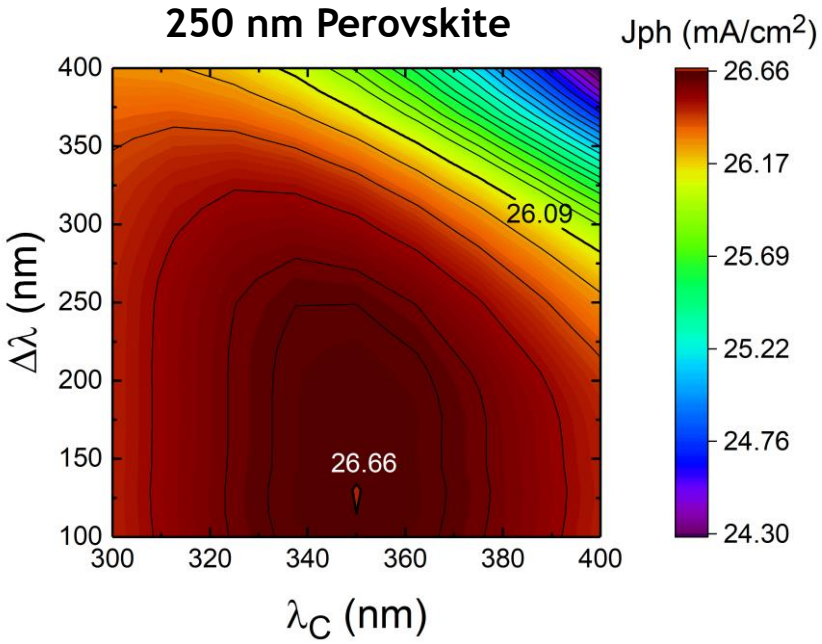
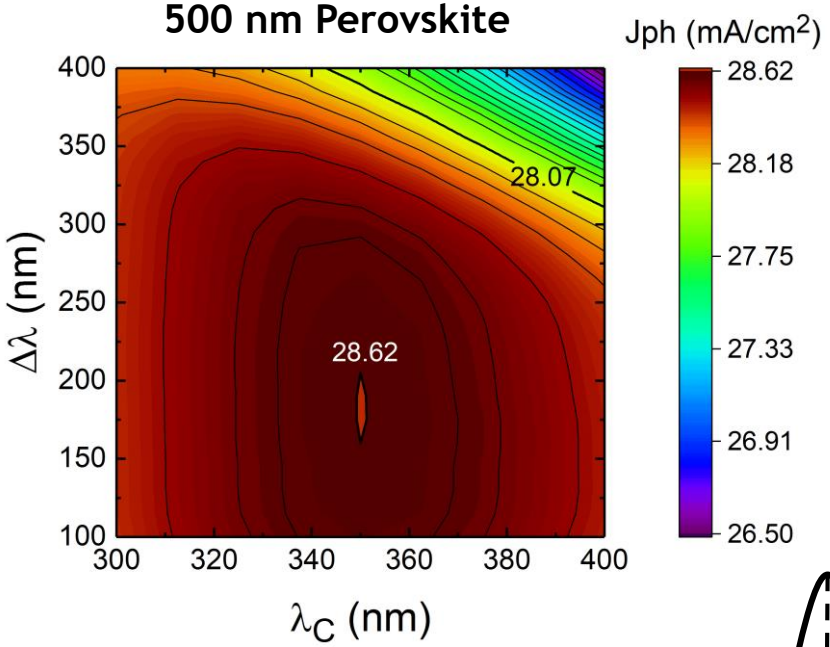


- $\lambda_C + \Delta\lambda$ sum ~ 500 nm → J_{ph} increase 2% *(max with all UV ~4%)*
- J_{ph} reduction ~ 7% for unoptimized $\lambda_C + \Delta\lambda$





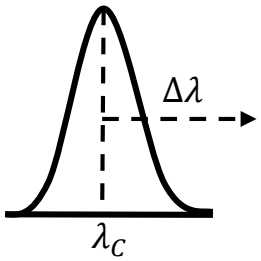


Photo-Generation Profiles and UV absorption

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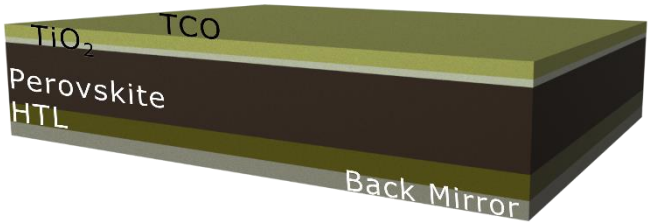
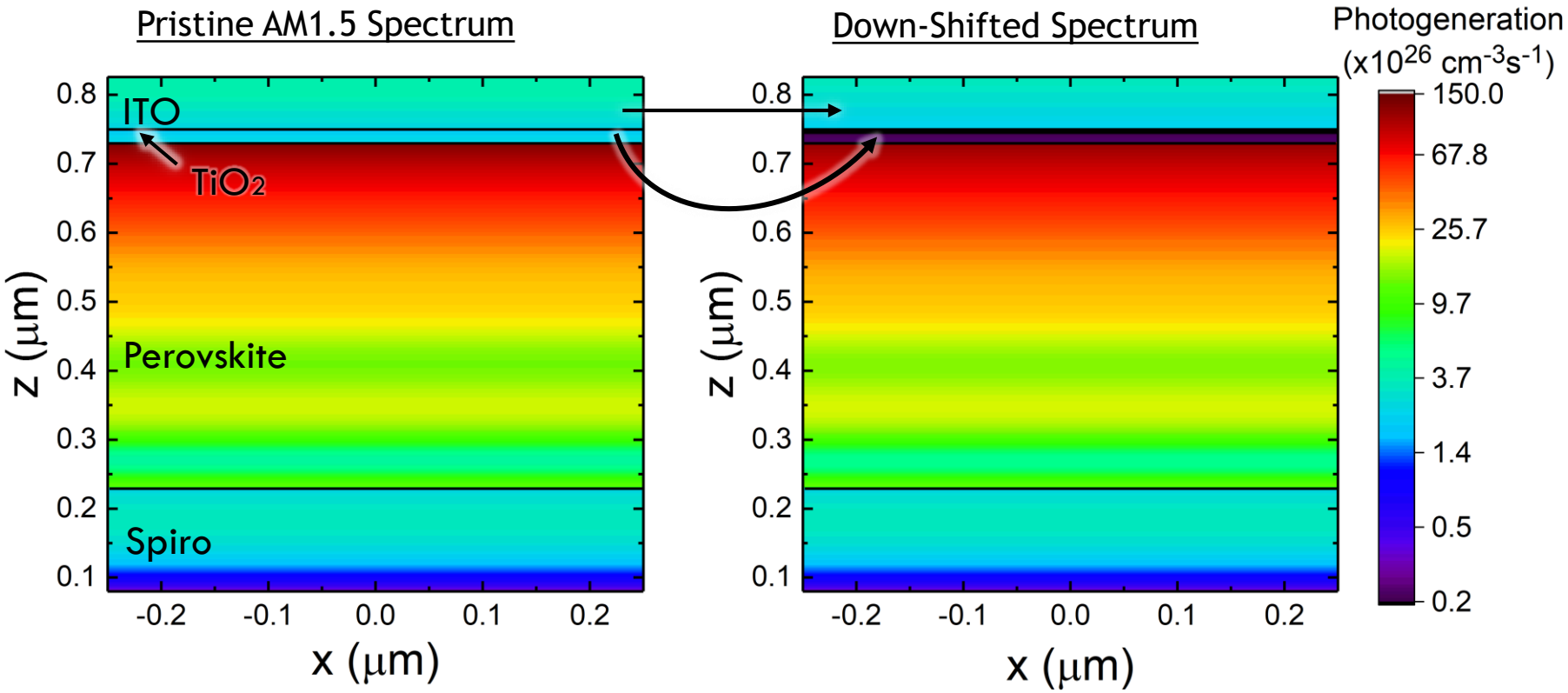
- Lower (by 10x) photogeneration in TiO_2
- **Photocurrent from UV (300-400 nm) reduces >80%**
- Increase in Perovskite bulk absorption





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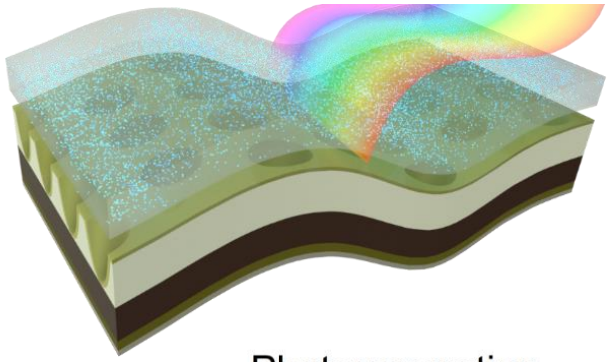

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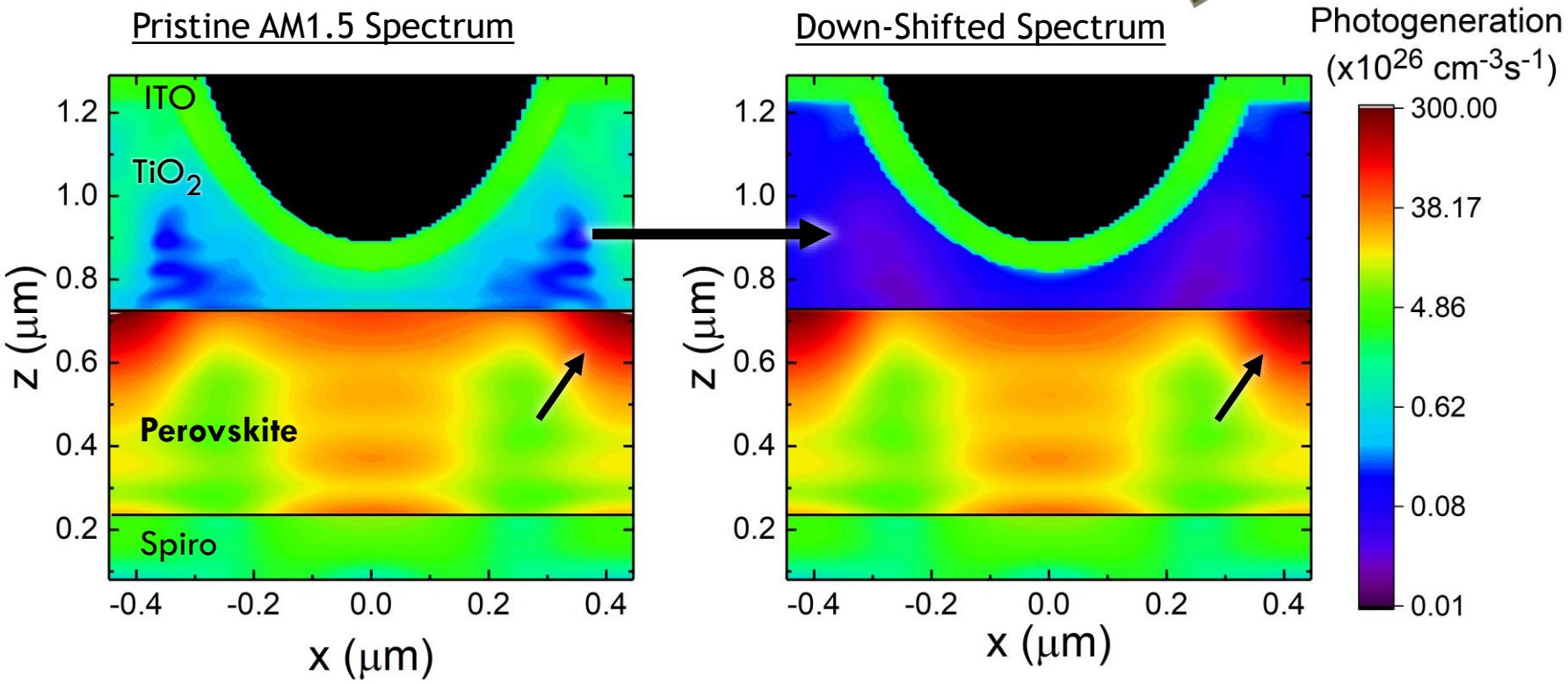

Main Conclusions

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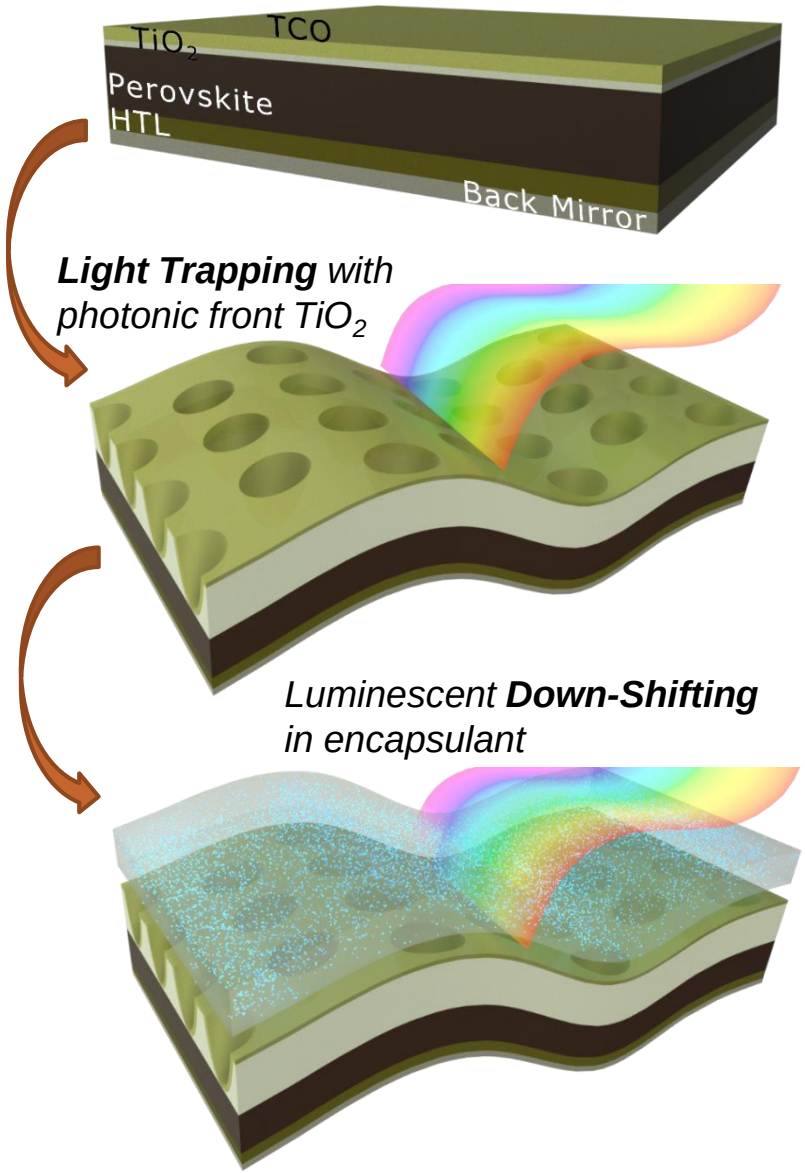
Photonic front structures allow reducing Perovskite thickness while boosting efficiency, but there is still room for improvement

Photocurrent (J_{PH}) of PSCs	500 nm Perovskite	250 nm Perovskite
	J_{PH} (mA/cm^2)	J_{PH} (mA/cm^2)
Planar ARC (Reference)	25.95	22.64
with Light Trapping	31.30	28.62
Enhancement	***20.6%***	***26.4%***

Lambertian light trapping (Ray optics limit)		
Max. Enhancement	*25.2%*	*30.6%*

+ Luminescent Down-shifting *(UV→Vis)*:

- Slight (2%) J_{ph} increase (of 0.6 mA/cm^2) due to low UV photocurrent (max 1.4 mA/cm^2)
- Tremendous reduction in UV penetration in TiO_2 (by 10x) and in Perovskite (80-86%)



Thank You !

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- **APOLO** - Smart Designed Full Printed Flexible Robust Efficient Organic Halide Perovskite Solar Cells *(H2020-LCE-2017-RES-RIA, Grant No. 763989)*

FEDER funds, through COMPETE 2020, and national funds, through FCT-MEC, under POCI-01-0145-FEDER-007688 (UID/CTM/50025) and the projects:

- **ALTALUZ –** *High Efficient Thin-film Tandem Solar Cells via Combined Materials and NanoPhotonic Light Trapping (PTDC/CTM-ENE/5125/2014)*
- **SuperSolar –** *Superior Efficiency and Flexibility with Quantum Nano-structured Perovskite Solar Cells enhanced by Light Management (PTDC/NAN-OPT/28430/2017)*
- **TACIT -** *Tandem Solar Cells Improved Optically (PTDC/NAN-OPT/28837/2017)*
- **LocalEnergy –** *Local Resources for Multifunctional Tetrahedrite-based Energy-Harvesting Applications (PTDC/EAM-PEC/29905/2017)*

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