Proton Irradiation Tolerance of Wide and Narrow Band Gap Mixed Organic-Inorganic Halide Perovskites: Implications for Power Generation in Space

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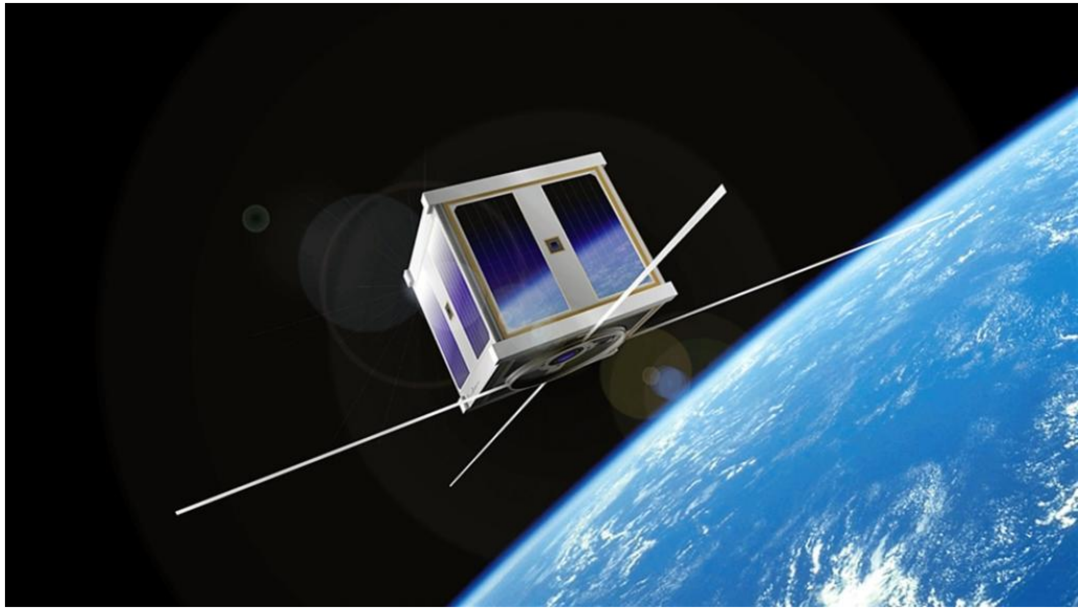
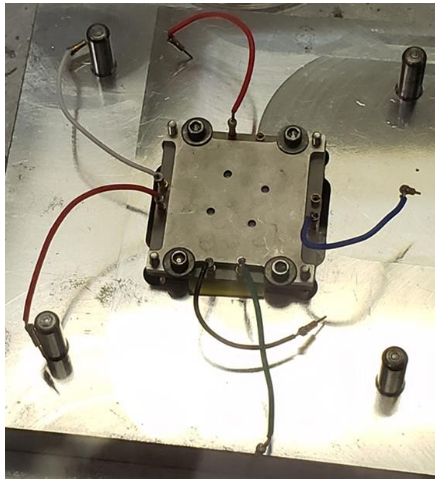
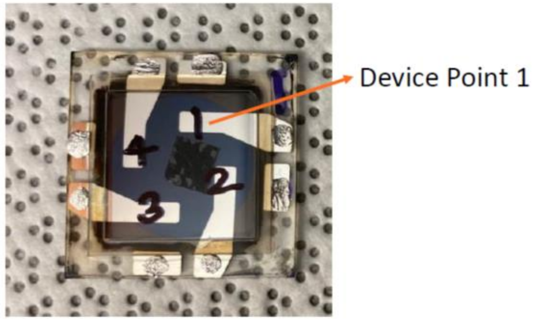
Outline

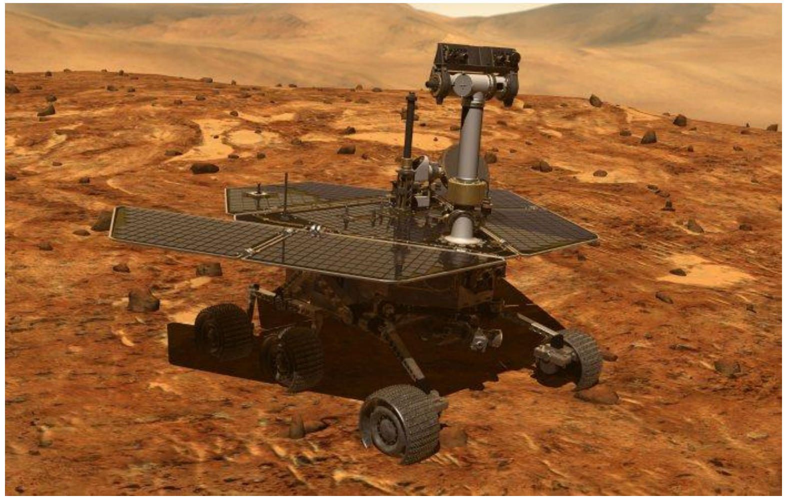
- Motivation
- Hybrid Organic-Inorganic Perovskites
- Temperature Dependent Device Characterization
- Proton Irradiated Solar Cells
- Conclusions and Acknowledgments







Narrow gap perovskite solar cell



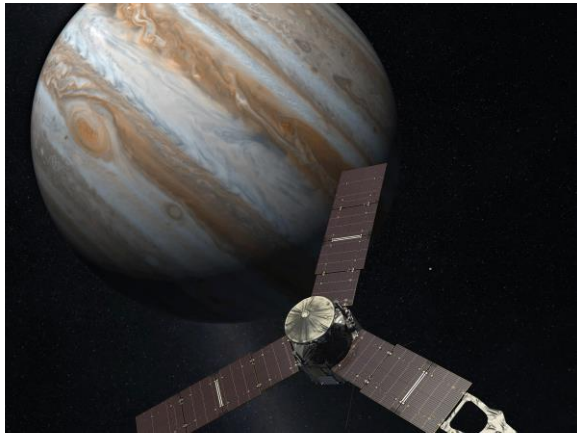
Motivation

Requirements for space applications:

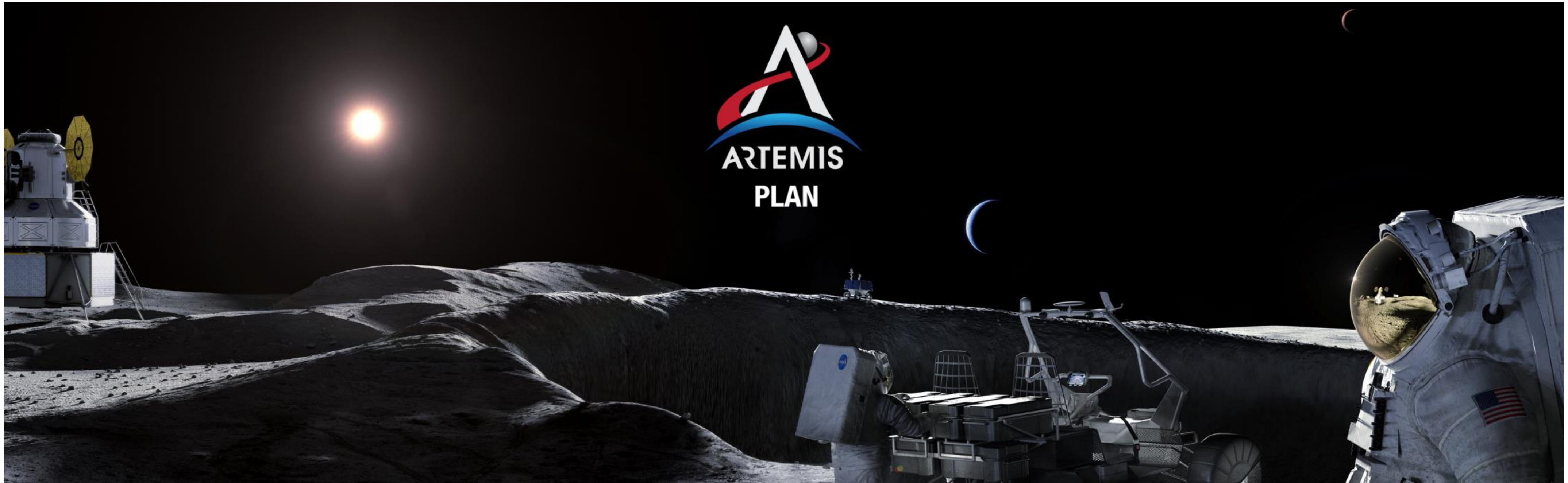
- High specific power (W/kg)
- Withstand extreme temperature fluctuations and vacuum
- Tolerate high energy particles (mainly electrons and protons)

Perovskites adaptable to flexible architecture

- Low packing volume, lightweight, high specific power
- Composed of Earth abundant elements
- Low energy processing requirements

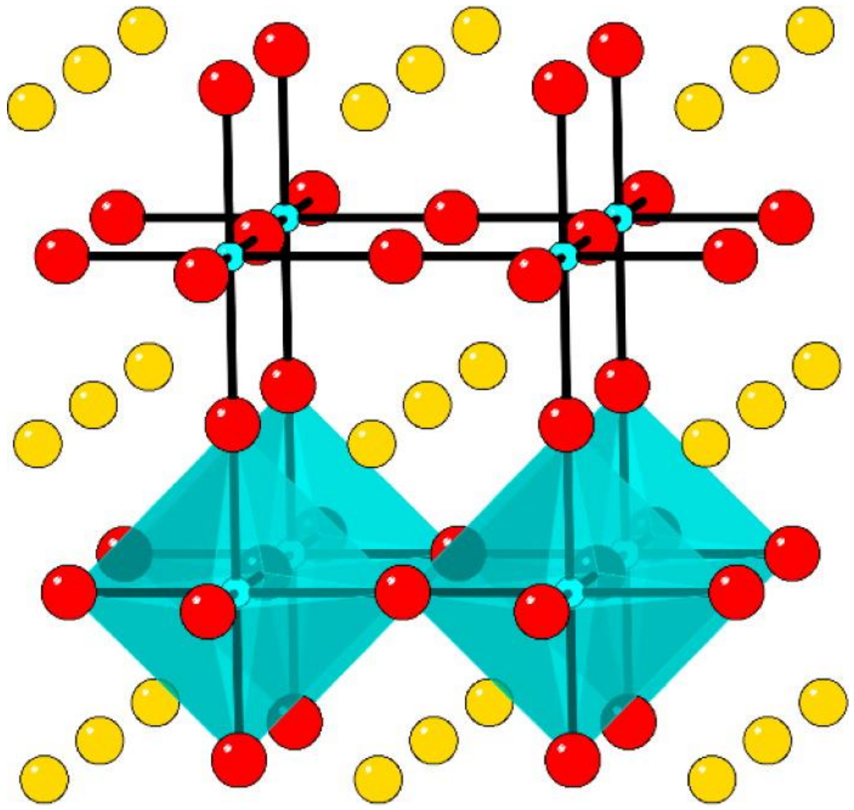


Juno and Artemis: www.nasa.gov



Hybrid Organic-Inorganic Perovskites

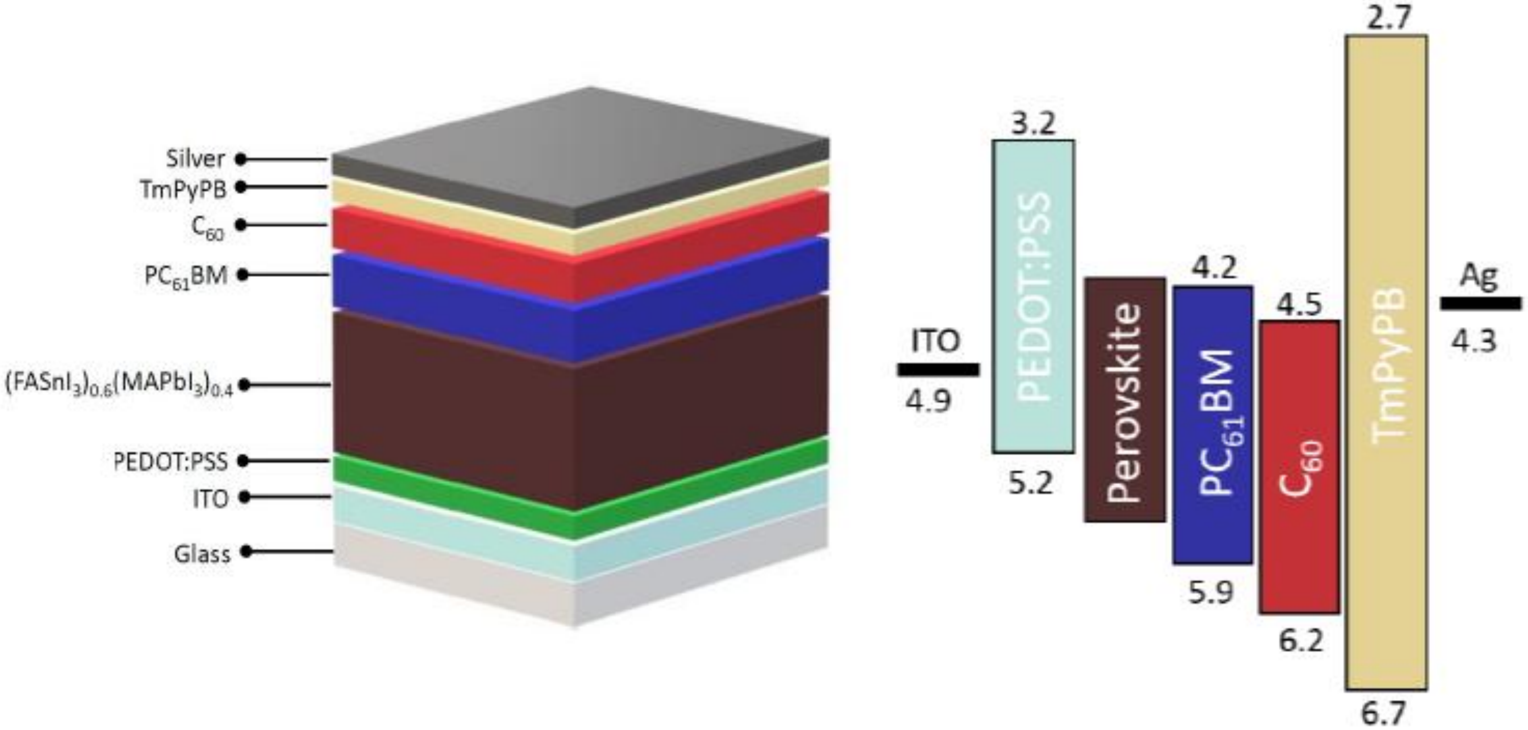
- ABX_3 composition
- A=methylammonium, formamidinium, or Cs
- B=Pb or Sn
- X=I, Br, or Cl
- Solution processable
- Tunable band gap
- 23% power conversion efficiency with polycrystalline thin film solar cells



B. Saparov, D.B. Mitzi, *Chem. Rev.*, 2016, 116, 7, 4558-4596

Y. Yang, *et al.*, Nature Photonics, **10** (2015) 53

Device Structure and Energy Band Diagram



1.24 eV

- >13% PCE (AM1.5)
- 3:2 $FASnI_3$:$MAPbI_3$ absorber layer
  FA=Formamidinium
  MA=Methylammonium
  - SnF_2 antisolvent additive
- Organic-based electron and hole transport layers
- TmPyPB small molecule interfacial layer[1]

<u>Developed by Do Young Kim's group at OSU Tulsa</u>

[1]M. Li, et. al., RSC Advances, 7 (2017) 31158-31163

Current Density-Voltage Curves JV

$$Fill\ Factor\ (FF) = \frac{Vmax * Jmax}{Voc\ * Jsc}$$

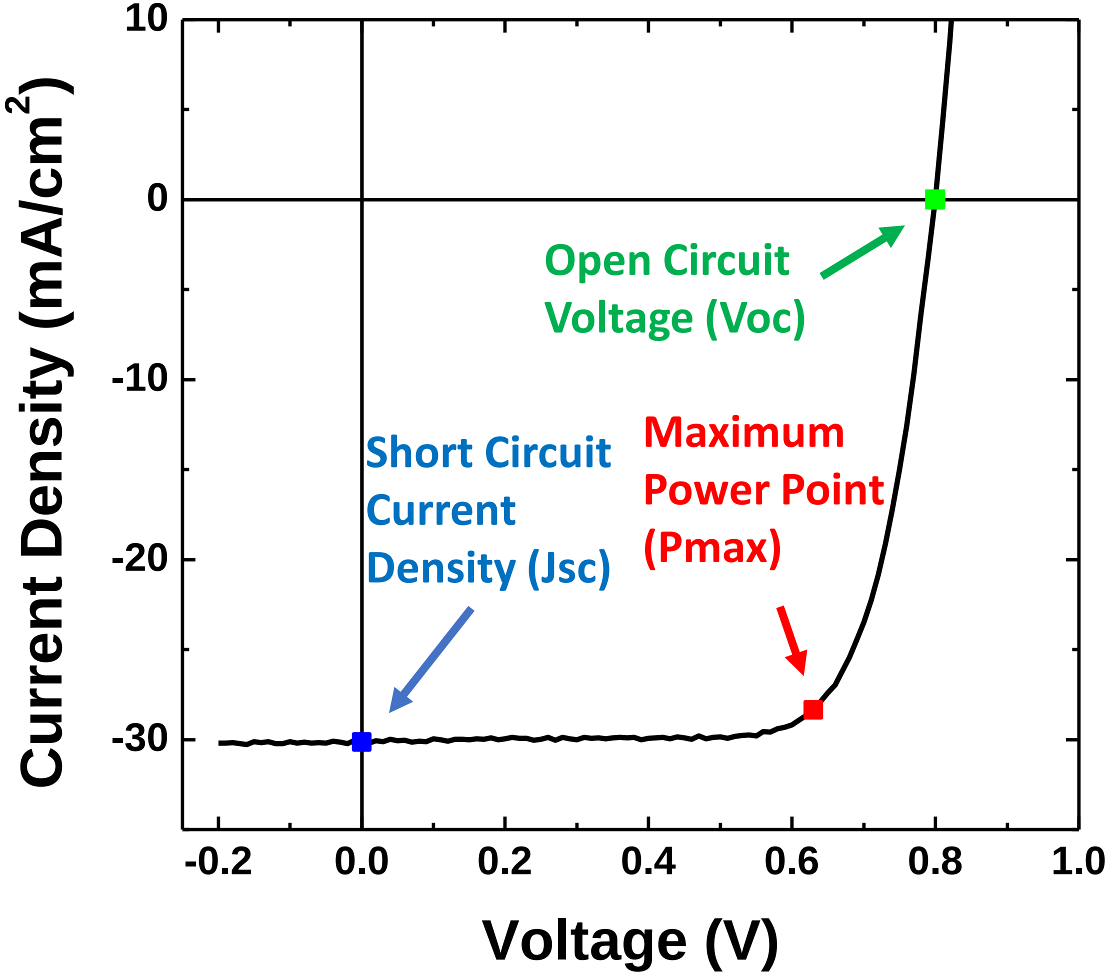
Power Conversion Efficiency (PCE) in %

$$= \frac{Vmax * Jmax}{Pin} * 100$$

$$= \frac{Jsc * Voc * FF}{Pin} * 100$$

Spectrum is typically:

- AM1.5 (terrestrial)
- AM0 (outside atmosphere)

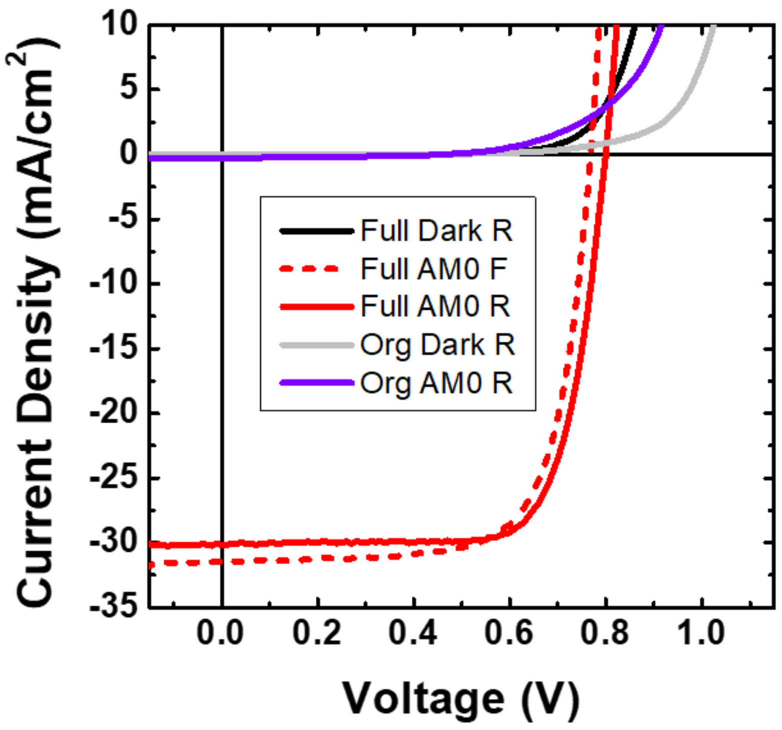


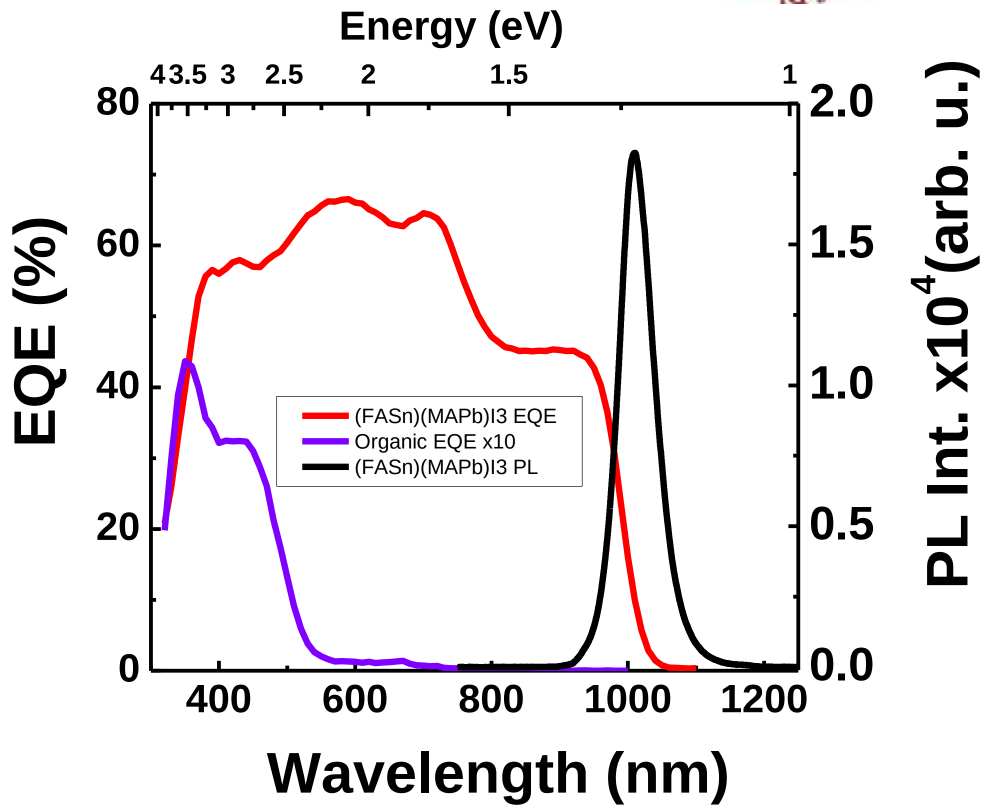
JV, External Quantum Efficiency, Photoluminescence

AM0 (outside atmosphere)
Voc: 0.77 V
Jsc: 31.4 mA/cm²
FF: 71 %
PCE: 12.8 %

Absorption onset and Photoluminescence well matched = 1.24 eV

Organic layers low absorption and photocurrent





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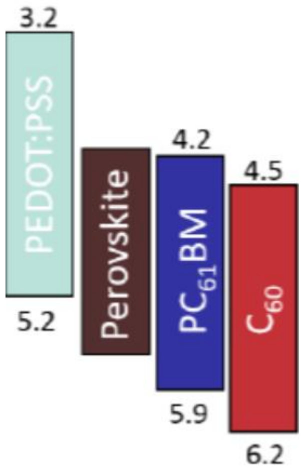
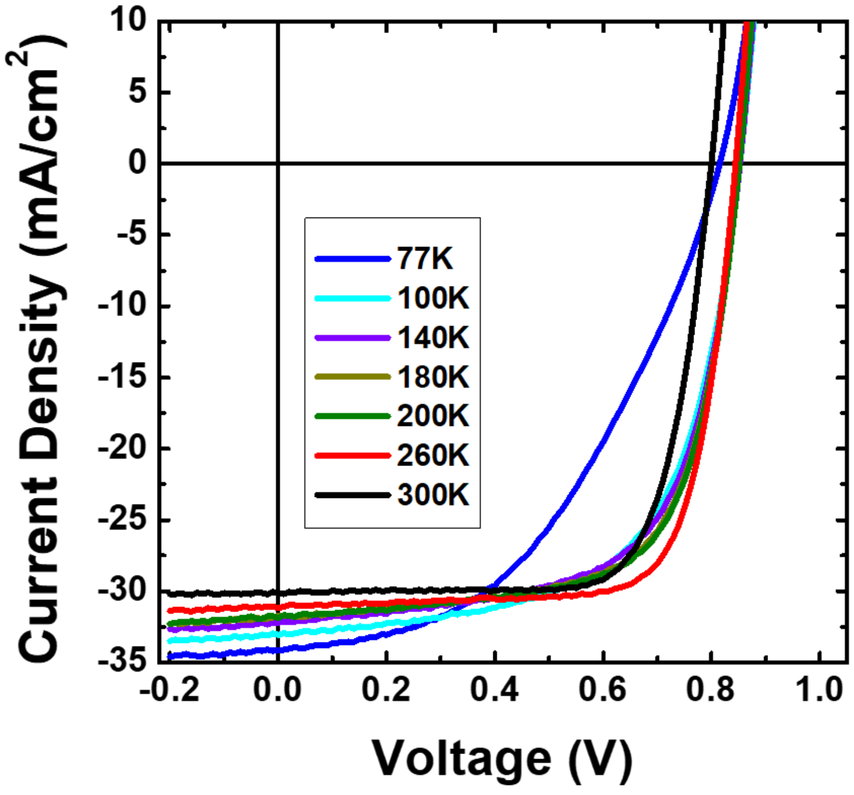
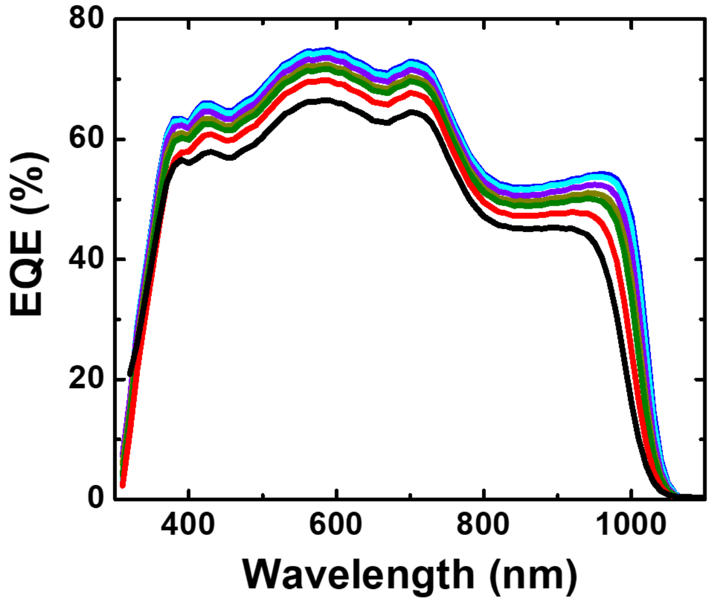
Temperature Dependence

Reduced temperatures increase in Voc and Jsc

- Increased collection efficiency throughout absorber
- Decrease in band gap
- Parasitic barrier to carriers (also decrease in dark current)
- Probable phase transition <100 K







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Proton Irradiation

Solar Winds
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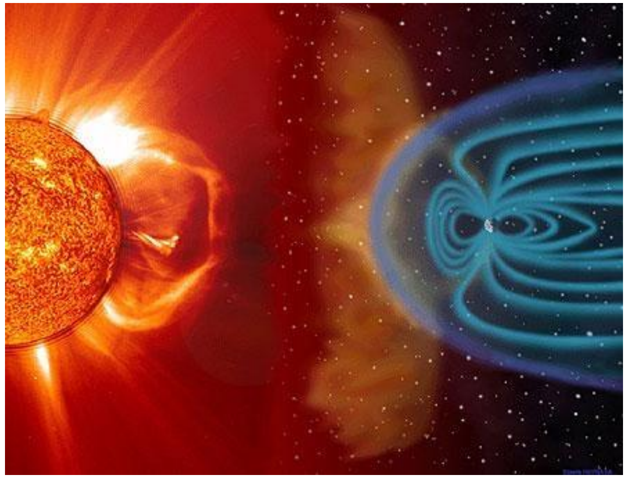
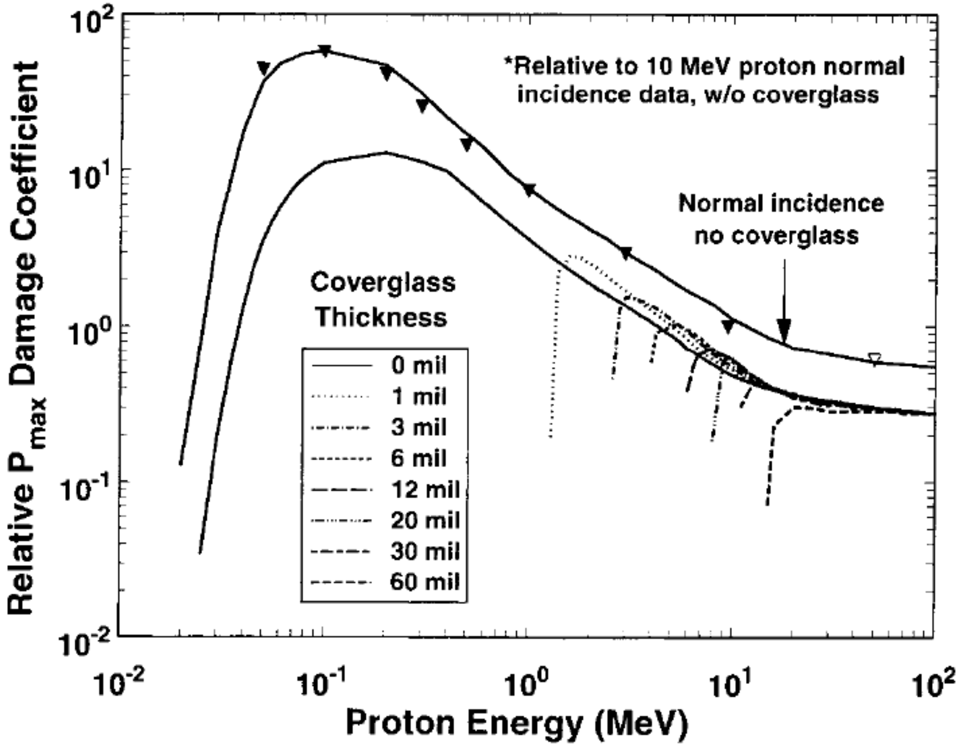




- Ejected from sun as solar winds
- Trapped in the magnetosphere (Van Allen Belt)
- Europa very high due to Io's volcanic activity
- Non elastic nuclear scattering vs electronic ionization (nuclei recoil and displacement)
- 3 years GEO ≈ 10^{12} H^{+}/cm^{2} accumulated fluence

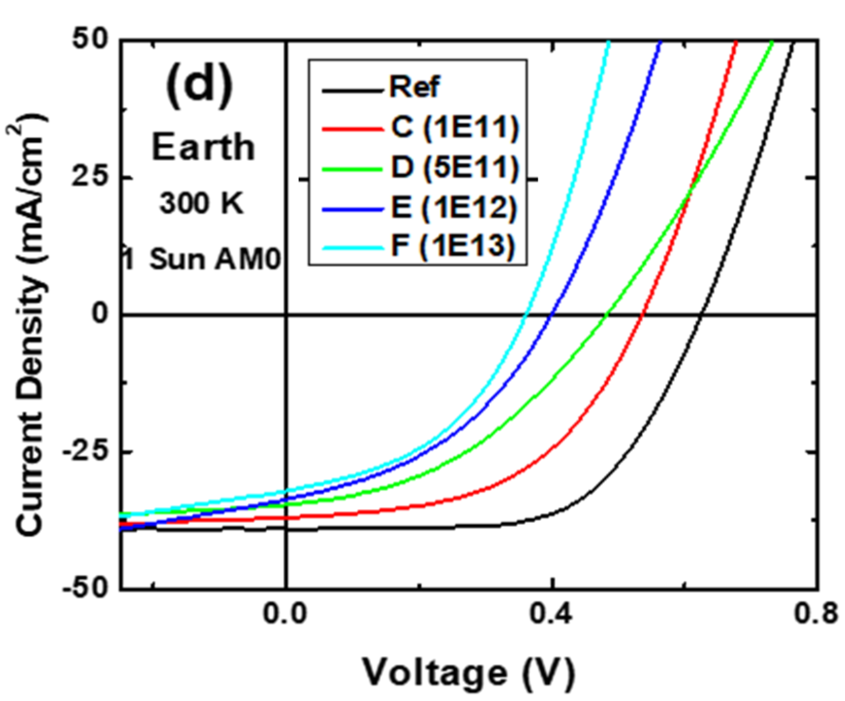
Messenger, S., *et al*, Modeling solar cell degradation in space: A comparison of the NRL displacement damage dose and the JPL equivalent fluence approaches. *Progress in Photovoltaics: Research and Applications* **2001**, 9 (2), 103-121.

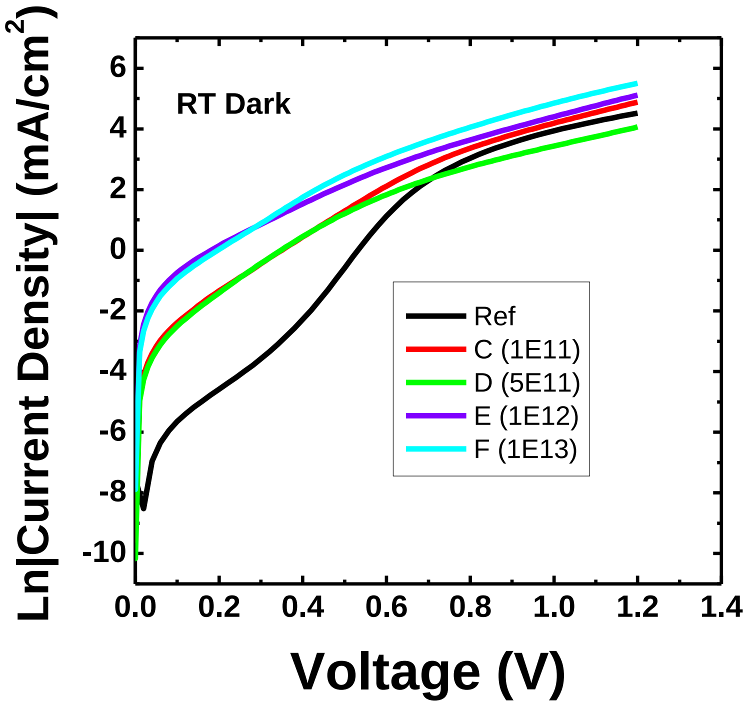
Polycrystalline Thin Film Photovoltaics

- Thin absorber = less interaction length
- Diffusion lengths already lower

Proton Irradiation: $Cu(In,Ga)Se_2$

- Competing thin-film technology
- Unencapsulated flexible CIGS solar cells
- 1.5 MeV proton energy
- Radiation hard compared to III-V based technologies





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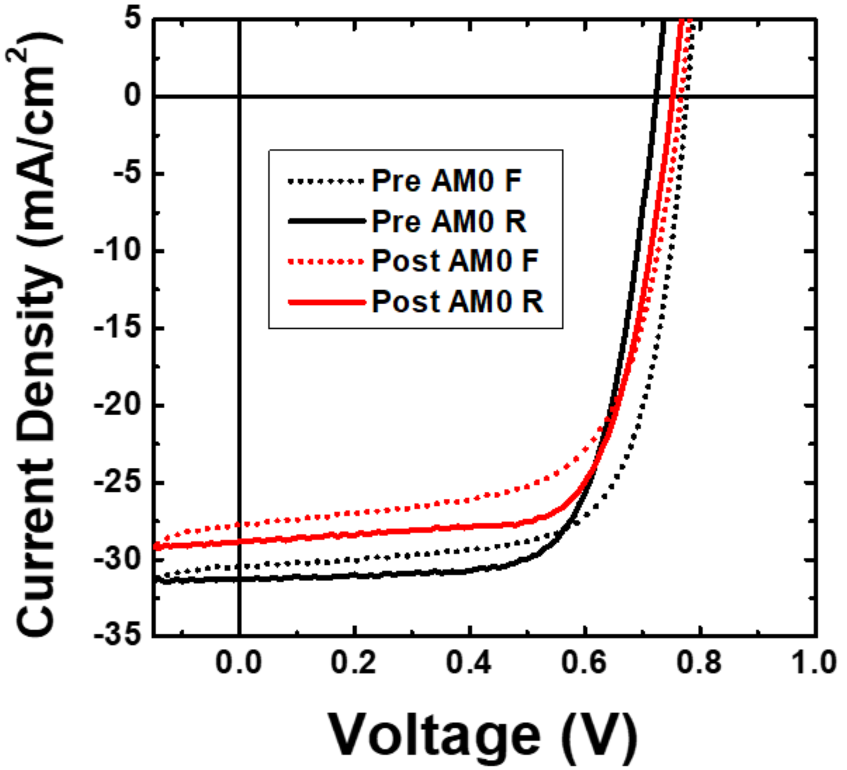
Afshari, H.; Durant, B. K.; Brown, C. R.; Hossain, K.; Poplavskyy, D.; Rout, B.; Sellers, I. R., "The role of metastability and concentration on the performance of CIGS solar cells under Low-Intensity-Low-Temperature conditions." *Solar Energy Materials and Solar Cells* ***2020***, 212, 110571.

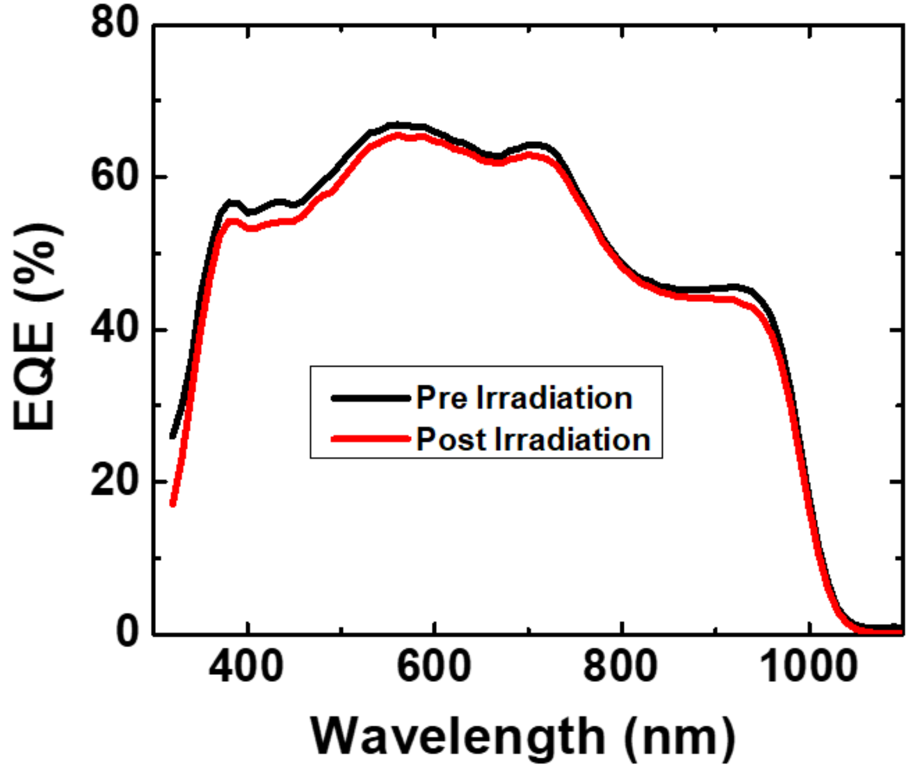
Proton Irradiation: $(FASn)_{0.6}(MAPb)_{0.6}I_3$

3.7 MeV H^+
(100 µm coverglass back encapsulation)

1E11 H^+/cm^2 fluence

- Remarkably tolerant compared to CIGS
- Halide displacements less detrimental





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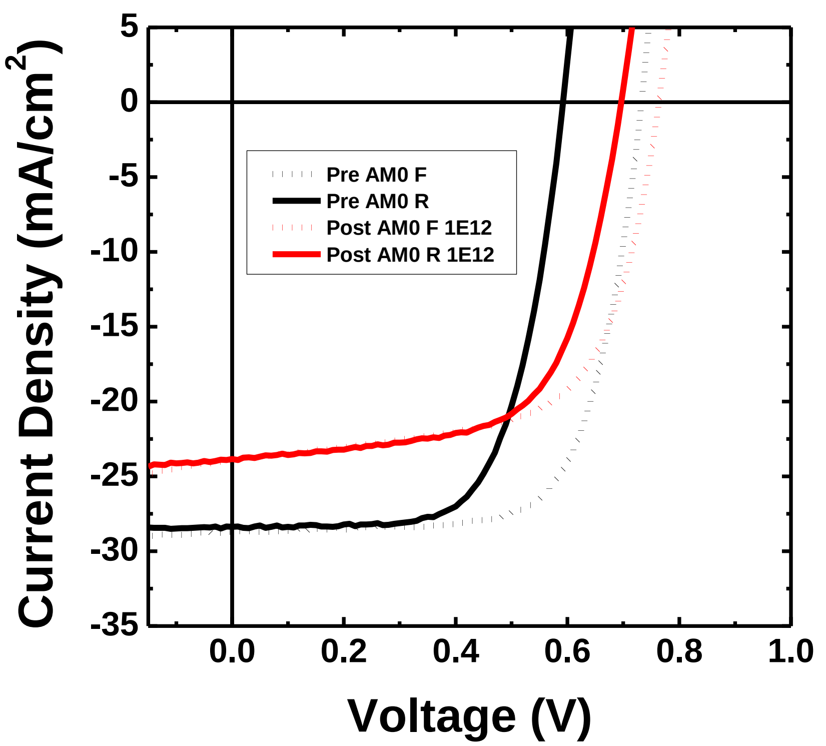
Proton Irradiation: $(FASn)_{0.6}(MAPb)_{0.6}I_3$

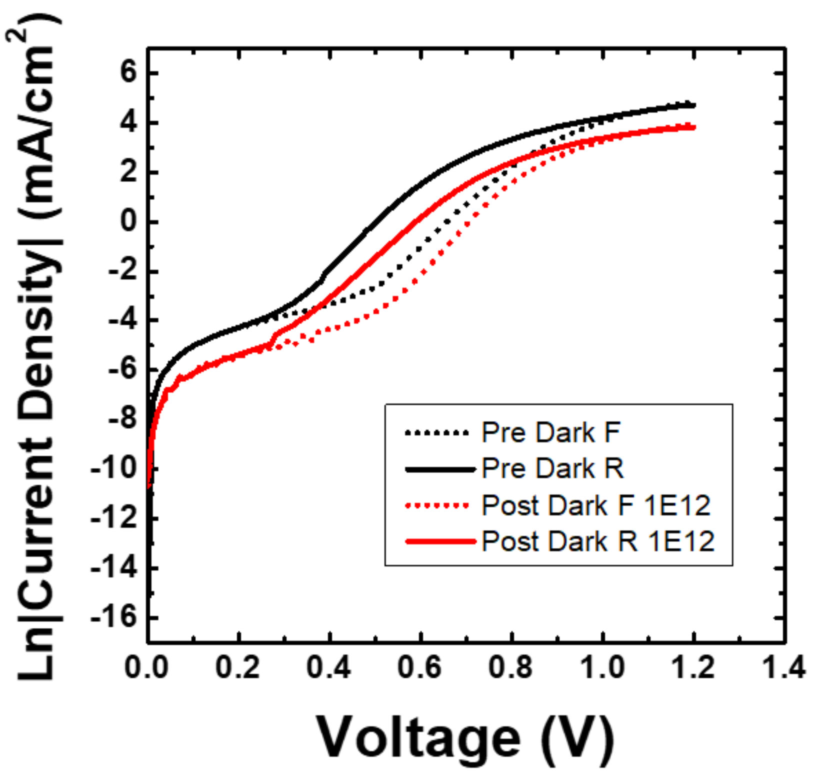
3.7 MeV H^+
(100 µm coverglass back encapsulation)

1E12 H^+/cm^2 fluence

Long-term and thermal stability issues remain

- Must tolerate vacuum
- Sn/Pb phase segregation
- Sn oxidation





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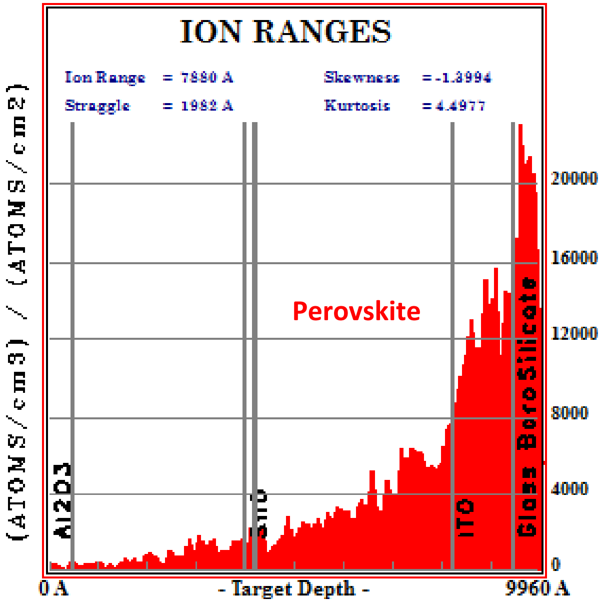
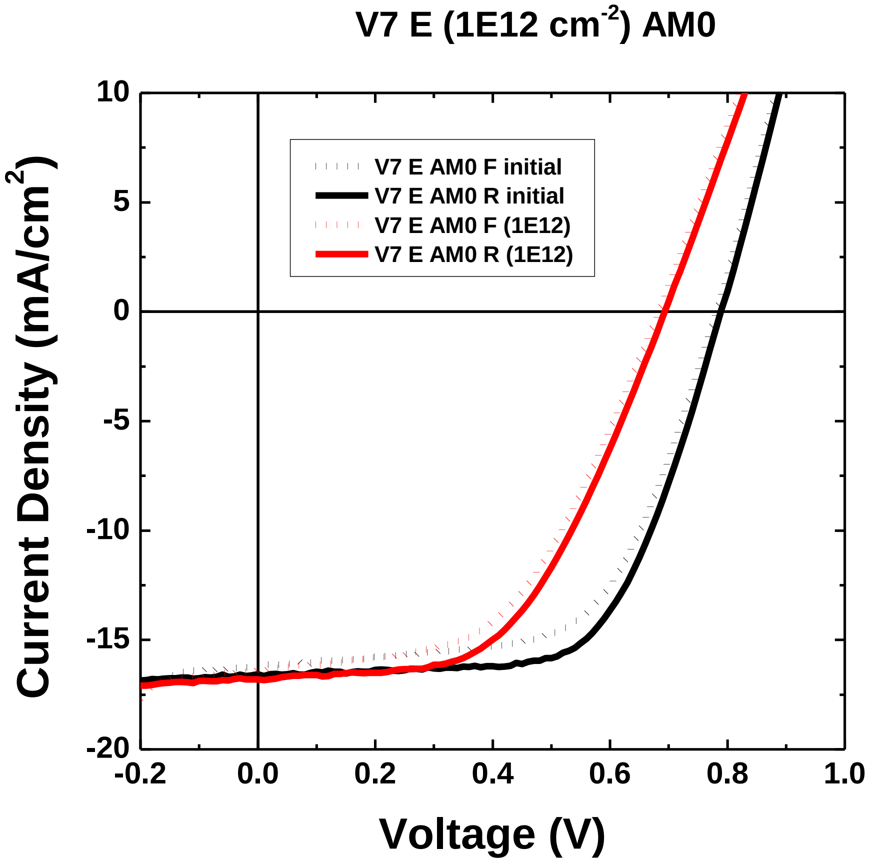
Proton Irradiation: $FA_{0.8}Cs_{0.2}PbI_{2.4}Br_{0.6}$

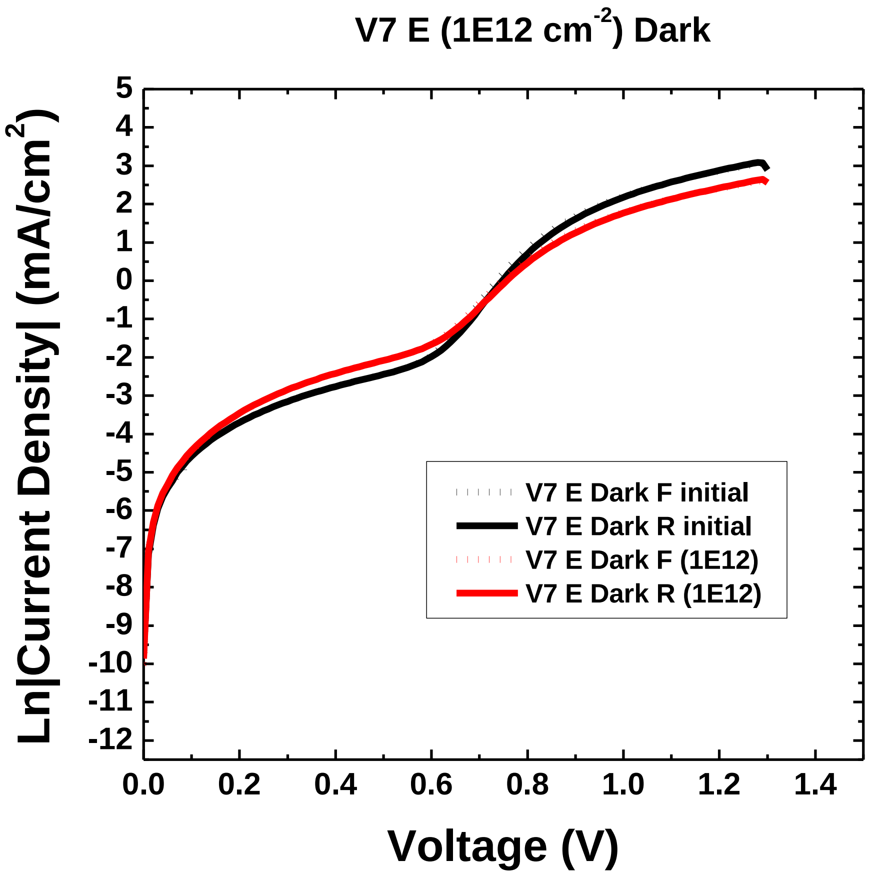
1.7 eV Eg

- 50 keV H^+ (10's nm encapsulation)
- 1E12 H^+/cm^2 fluence



Stopping and Range of Ions in Matter: 80 keV





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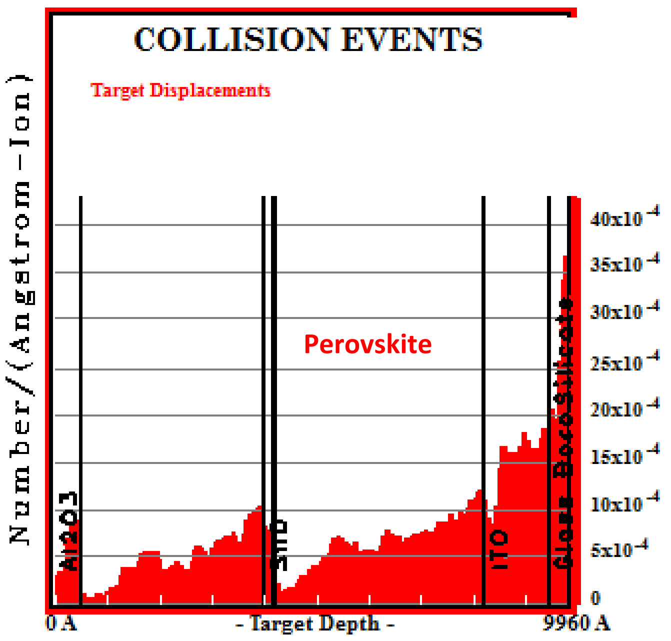
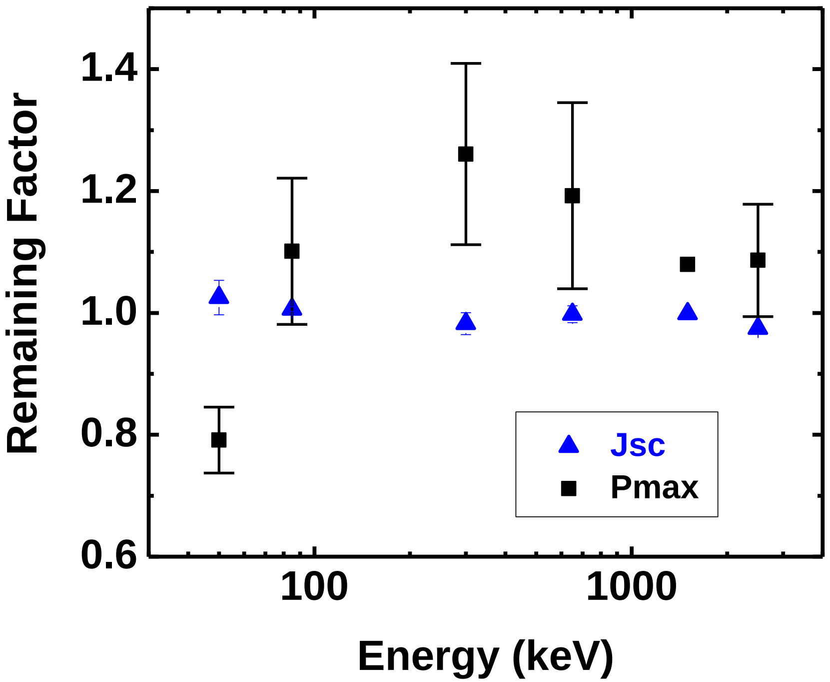
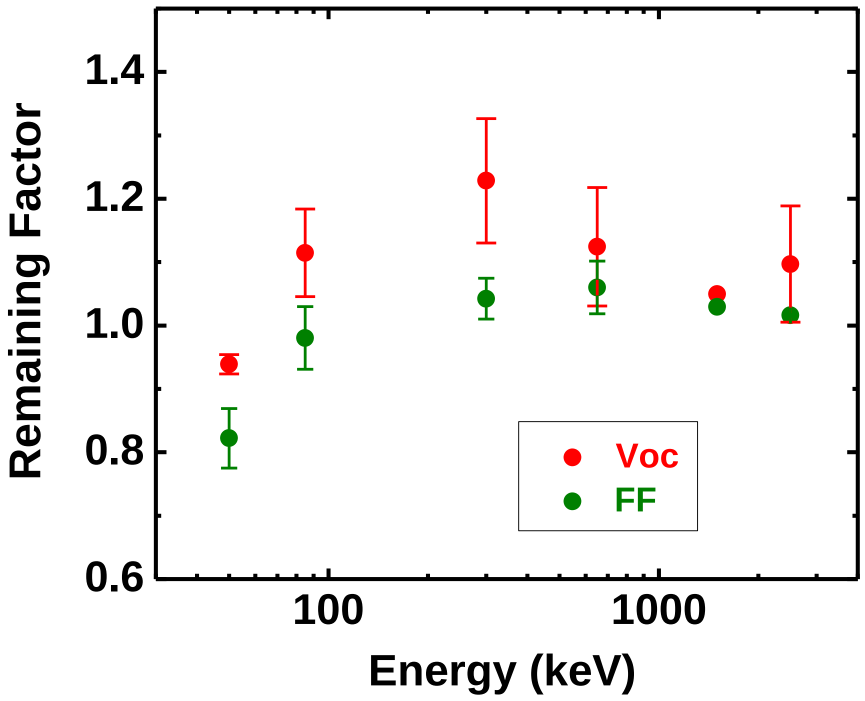
Proton Irradiation: $FA_{0.8}Cs_{0.2}PbI_{2.4}Br_{0.6}$

- >50 keV deeper, can result in heating/ionization

$$Remaining\ Factor = \frac{Final\ Value}{Initial\ Value}$$







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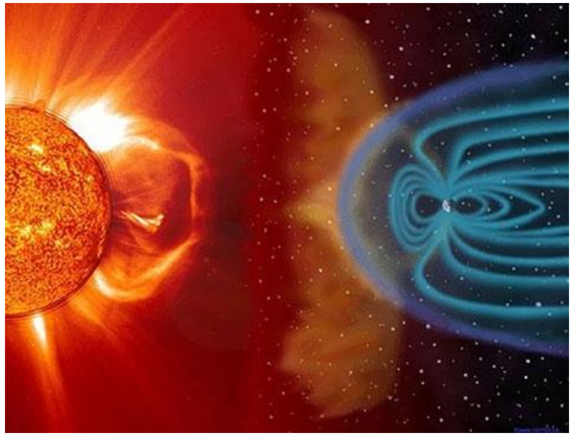
Conclusions

- Remarkable tolerance for *both* wide and narrow band gap perovskite based solar cells compared to other technologies
- All Perovskite tandem devices could be attractive candidates for high energy particle environments
- Prohibitive effects of low temperatures, thermal cycling and vacuum still need continued research efforts



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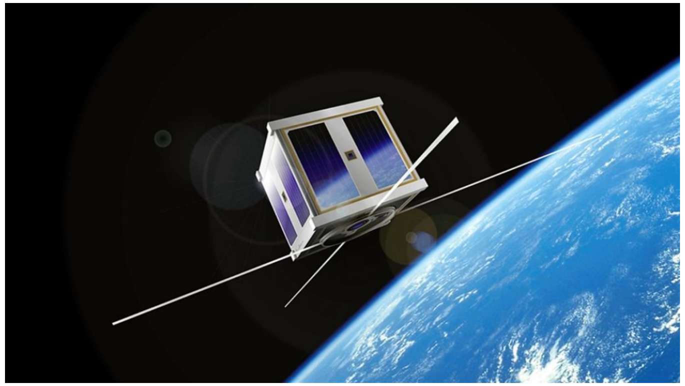

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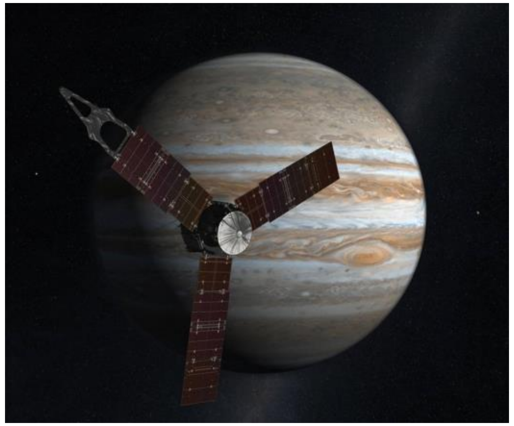

Juno: www.nasa.gov

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