Potential of High-Stability Perovskite Solar Cells for Low-Intensity-Low-Temperature (LILT) Outer Planetary Space Missions

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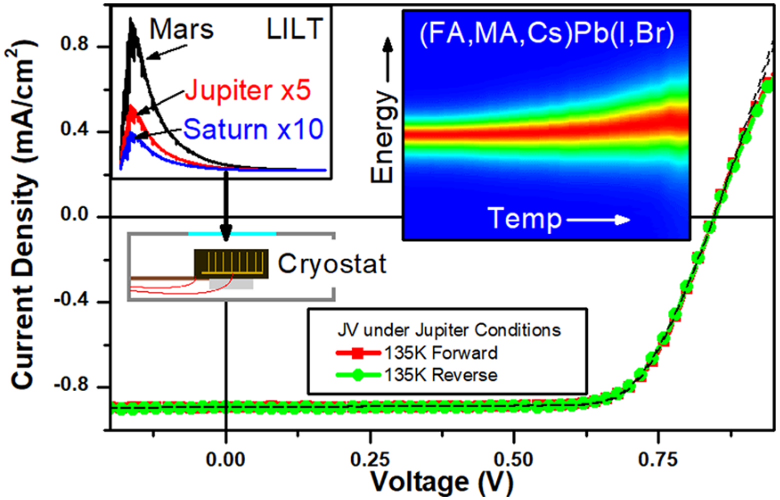

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C. R. Brown, G. E. Eperon, V. R. Whiteside, and I. R. Sellers, "Potential of High-Stability Perovskite Solar Cells for Low-Intensity–Low-Temperature (LILT) Outer Planetary Space Missions," ACS Applied Energy Materials, vol. 2, no. 1, pp. 814-821, 2019/01/28 2019.

Outline

- Perovskite Solar Cells
  - Our Motivation
- Experimental Results
  - Photoluminescence Spectroscopy (PL)
  - 1 Sun Current Density-Voltage (J-V)
  - Low-Intensity-Low-Temperature(LILT) Current Density-Voltage(J-V)
- Discussion
  - Barrier to Current Flow
  - Further Evidence of a Barrier
- Conclusion

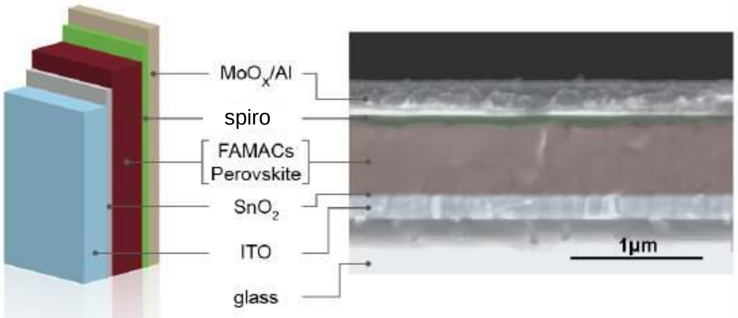
Perovskite Solar Cells – For Space Application

JUNO - www.nasa.gov

BioSentinel - www.nasa.gov

- Higher power requirements for ambitious outer planet exploration
- Outer planets
  - Low temperature
  - Low intensity
  - Possibility of intense radiation

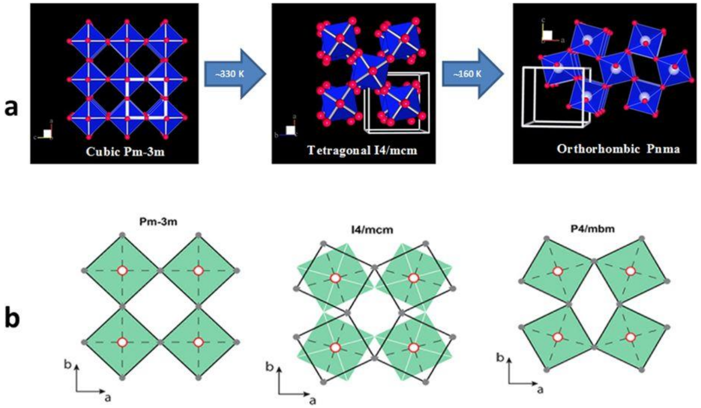
- Perovskite solar cells could be an option, based on ease of manufacture, performance, and radiation tolerance



$(FA_{0.79}MA_{0.16}Cs_{0.05})_{0.97}Pb(I_{0.84}Br_{0.16})_{2.97}$

Credit: Joseph M. Luther, NREL

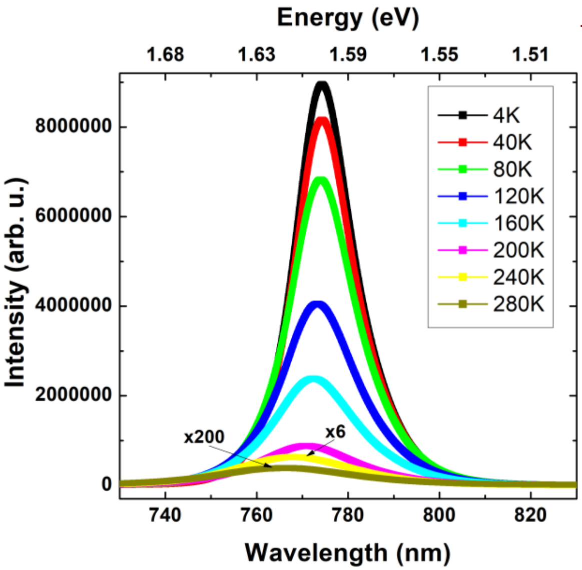
J. A. Christians et al., Nature Energy 3 (1), 68 (2018).

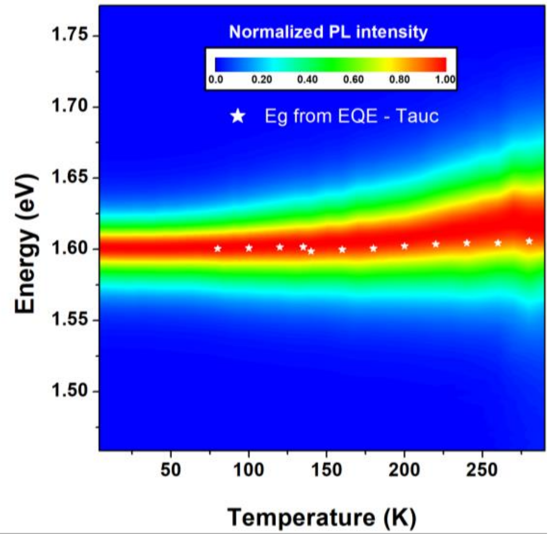


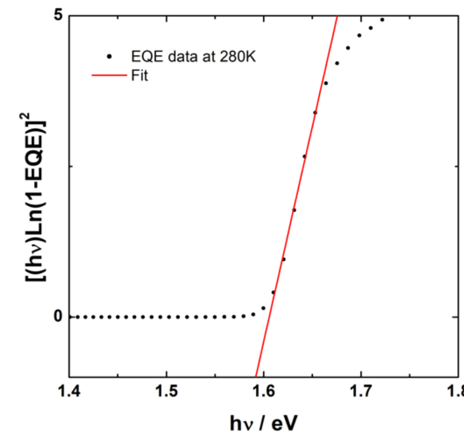
P. S. Whitfield et al., Scientific Reports, Article vol. 6, p. 35685, 10/21/online 2016.

- Stability under space conditions should be studied
  - Radiation tolerance
  - Moisture ingress
  - Ion migration
  - <u>Phase stability at low temperature</u>
  - <u>Effect of Low-Intensity-Low-Temperature</u>

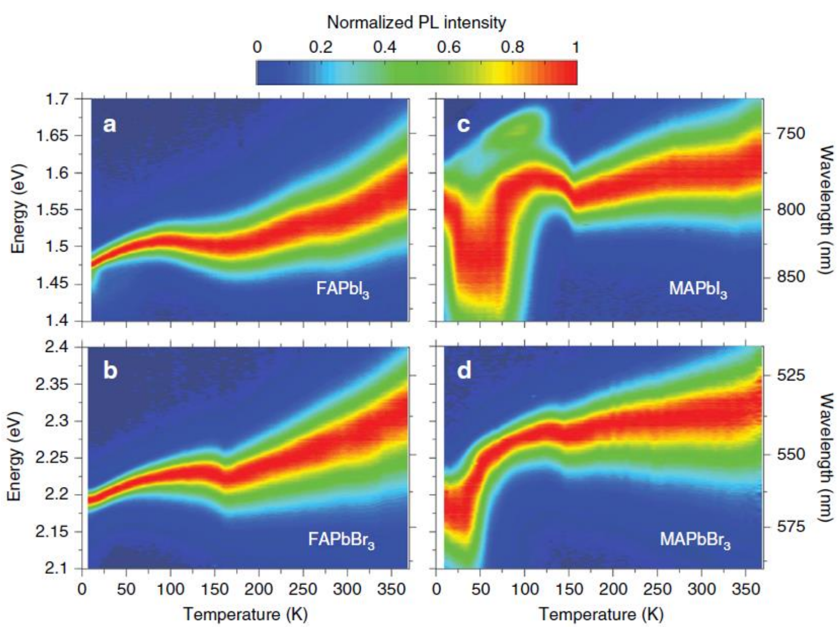
Experimental Results - PL







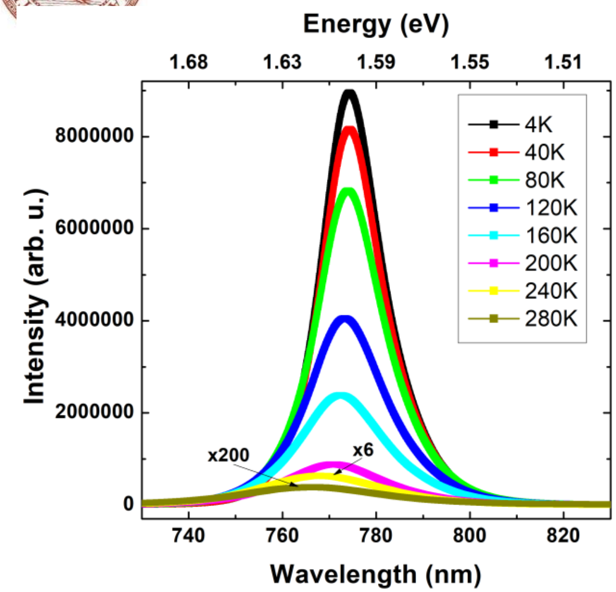
C. R. Brown *et al*, ACS Applied Energy Materials, vol. 2, no. 1, pp. 814-821, 2019/01/28 2019.



A. D. Wright et al., Nature Communications, Article vol. 7, p. 11755, 05/26/online 2016.

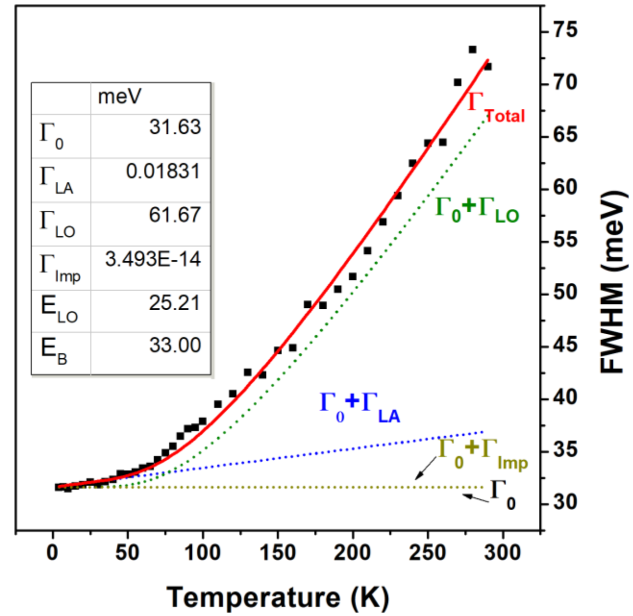
- Temperature dependent photoluminescence spectroscopy (PL) is used to probe the stability of the FAMACs based Perovskite SC
- No clear evidence of a phase change is seen in the PL

Experimental Results – PL Linewidth



C. R. Brown *et al*, ACS Applied Energy Materials, vol. 2, no. 1, pp. 814-821, 2019/01/28 2019.

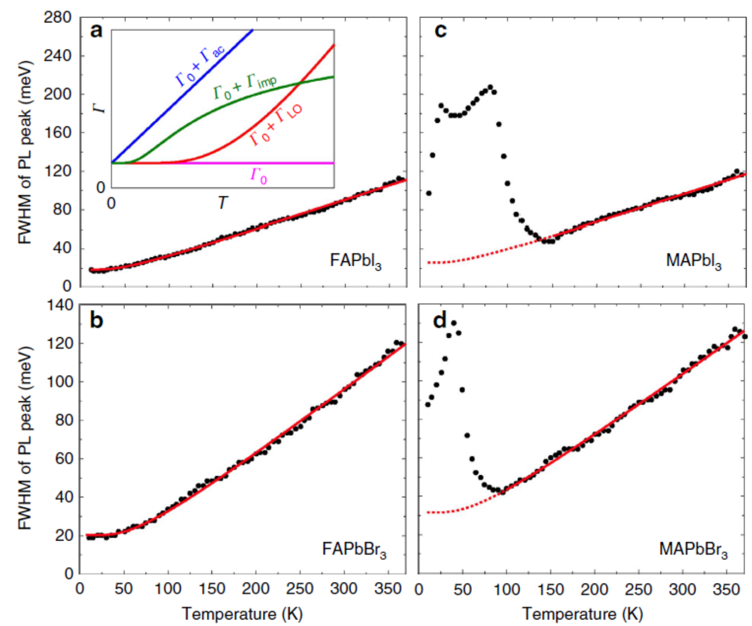
H. Esmaielpour et al., Progress in Photovoltaics: Research and Applications, vol. 25, no. 9, pp. 782-790, 2017.



$$\Gamma(T) = \Gamma_0 + \Gamma_{ac} + \Gamma_{LO} + \Gamma_{imp}$$
$$= \Gamma_0 + \gamma_{ac} T + \gamma_{LO} N_{LO}(T) + \gamma_{imp} e^{-E_b/k_B T}$$

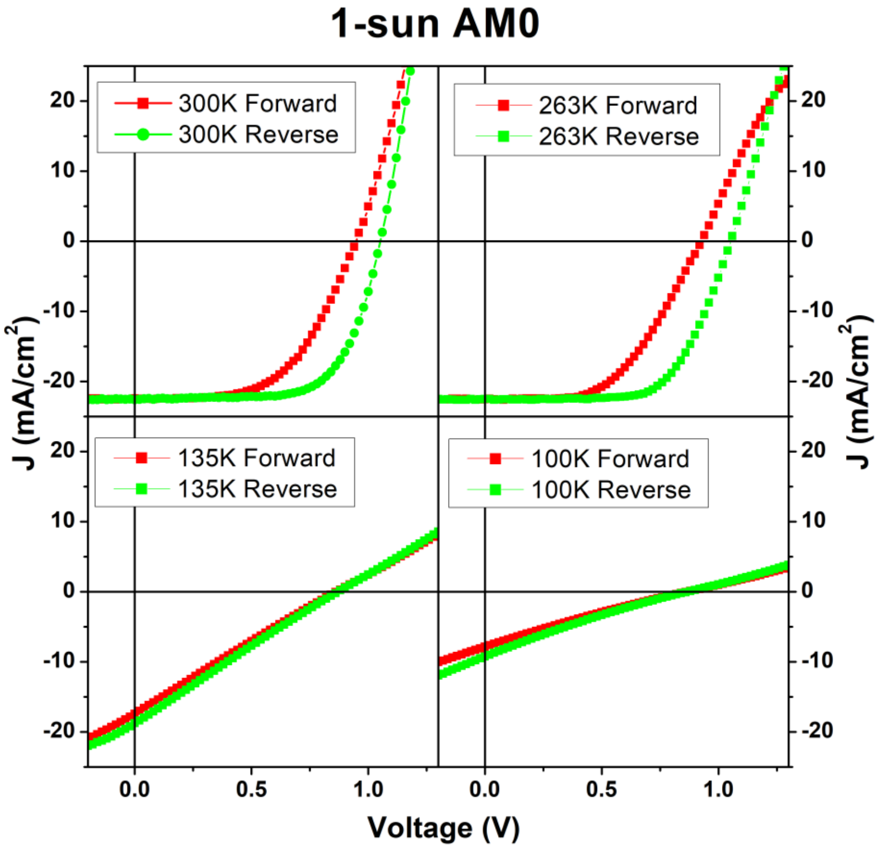
- Temperature dependent FWHM of the PL is fitted to determine relative contributions of different broadening parameters

- Strong LO phonon contribution is expected, as these material systems are strongly polar



A. D. Wright et al., Nature Communications, Article vol. 7, p. 11755, 05/26/online 2016.

Experimental Results – 1 Sun JV



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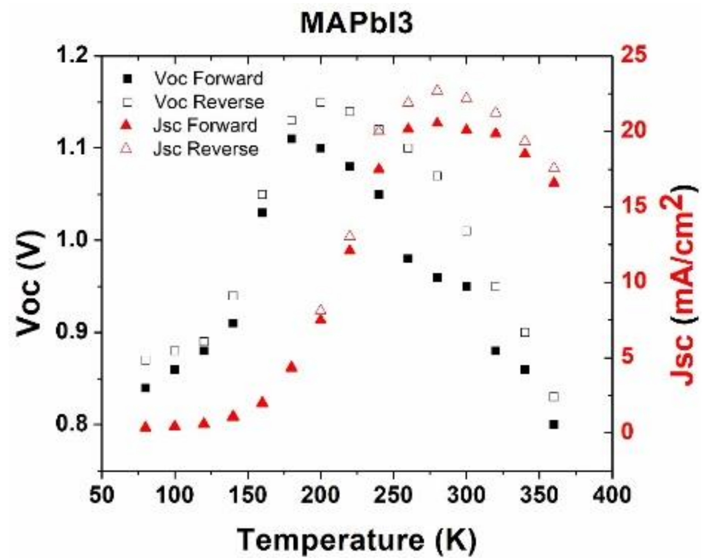
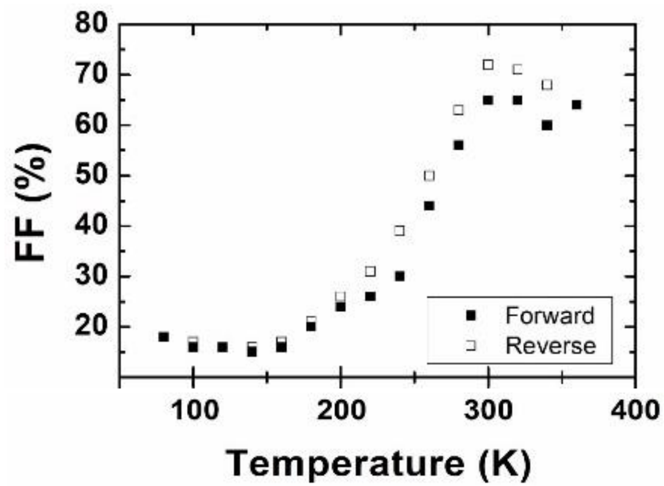




- Hysteresis in the JV characteristic is observed – degradation during transit

- Low Temp performance is poor, but consistent with the literature

H. Zhang et al., "Photovoltaic behaviour of lead methylammonium triiodide perovskite solar cells down to 80 K," Journal of Materials Chemistry A, 10.1039/C5TA02206A vol. 3, no. 22, pp. 11762-11767, 2015.

Experimental Results – LILT JV

TABLE 1: THE SOLAR INTENSITY AT JUPITER AND SATURN, AND THE EQUILIBRIUM FLAT-PLATE TEMPERATURE OF A SOLAR ARRAY

Conditions	Distance (AU)	I (suns)	I (W/m^2)	T_{eq} (K)	T_{eq} (°C)
Jupiter					
Aphelion	5.458	0.03357	46.0	133	-139
Perihelion	4.950	0.04081	55.8	140	-133
Saturn					
Aphelion	10.12	0.0098	13.4	98	-175
Perihelion	9.048	0.0122	16.7	103	-161

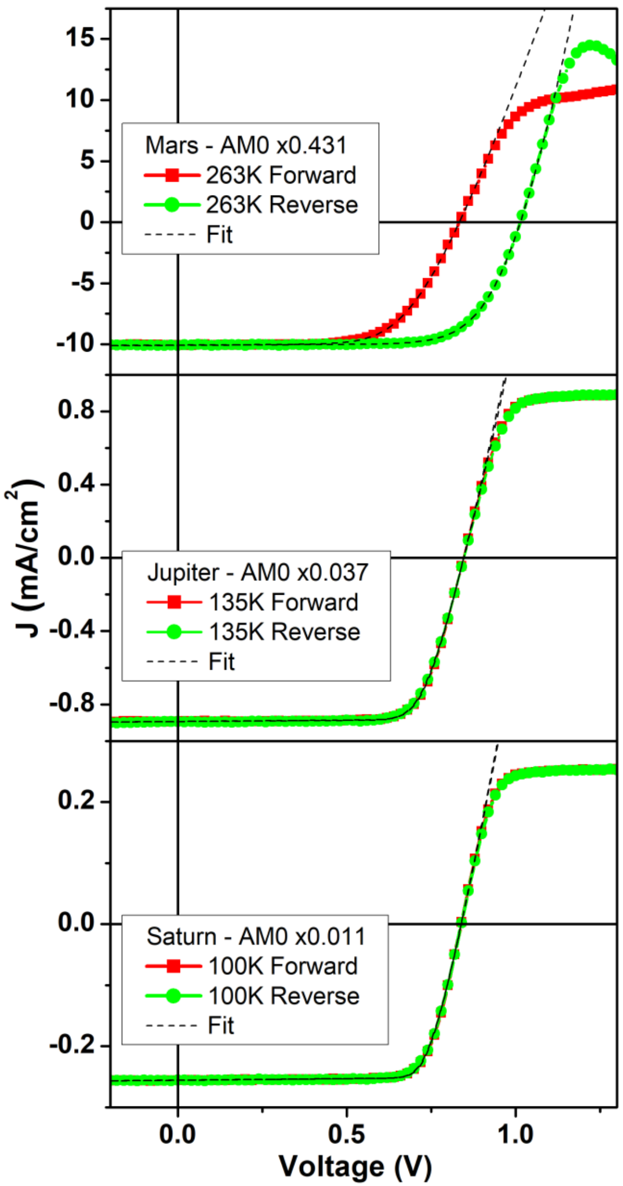
Temperatures calculated for absorptivity 0.92; front and back side thermal emissivity of 0.85, and cell efficiency of 25%.

G. A. Landis and J. Fincannon, "Study of power options for Jupiter and outer planet missions," *2015 IEEE 42nd Photovoltaic Specialist Conference (PVSC)*, New Orleans, LA, 2015, pp. 1-5.

LILT spectrum

D. A. Scheiman and D. B. Snyder, "Low intensity low temperature (LILT) measurements of state-of-the-art triple junction solar cells for space missions," in 2008 33rd IEEE Photovoltaic Specialists Conference, 2008, pp. 1-6.

- Under Low-Intensity-Low-Temperature (LILT) conditions, performance comparable to room temperature is recovered
- At forward bias, evidence of a barrier to current flow is observed, which does limit operating voltage



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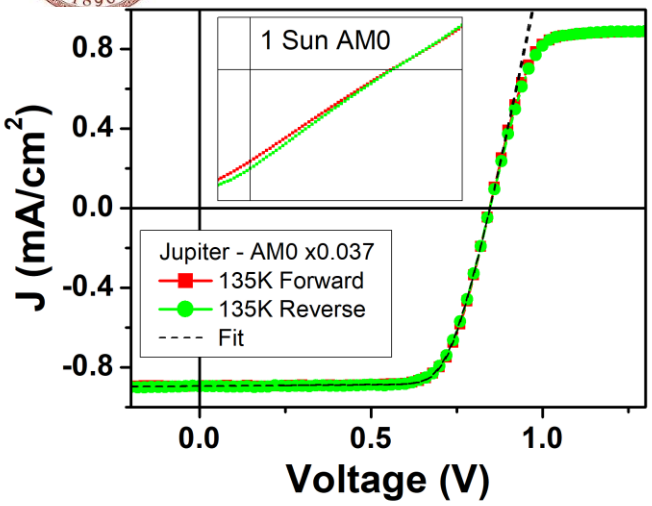
Barrier to Current Flow



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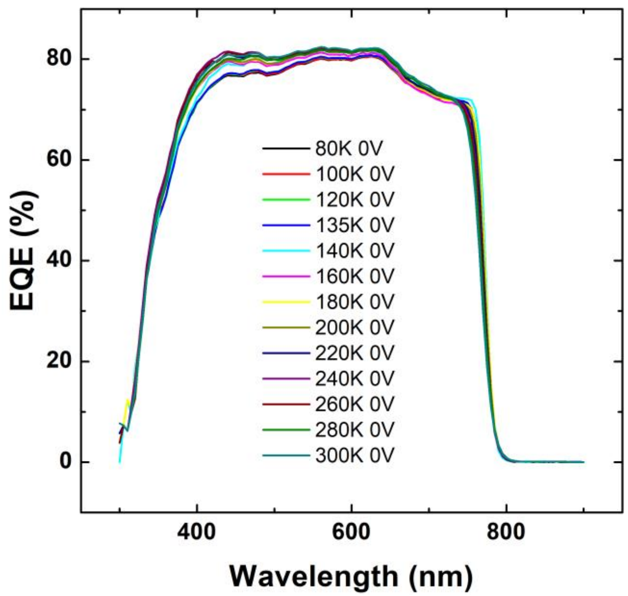
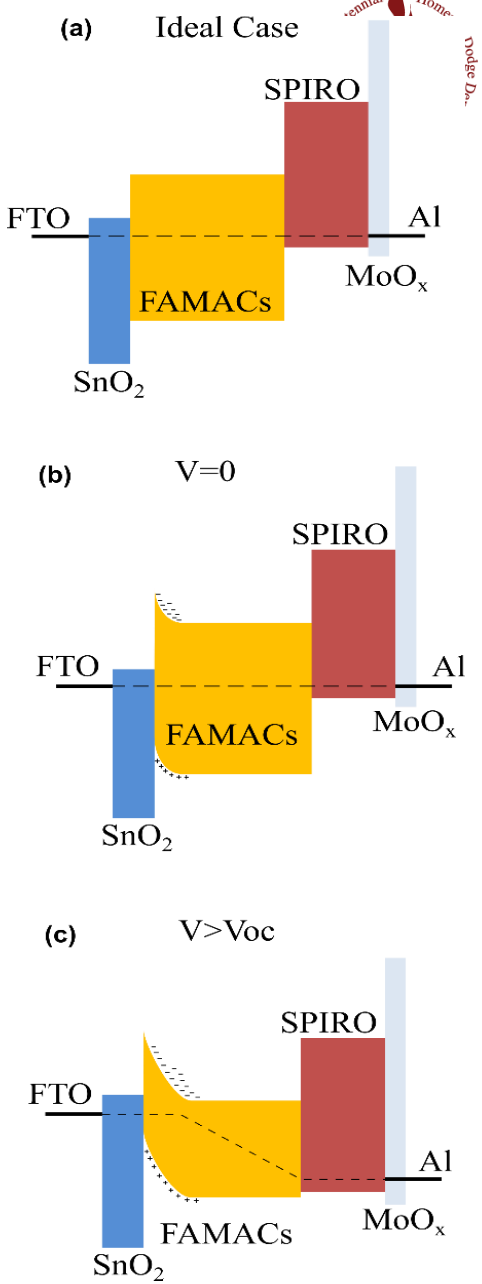
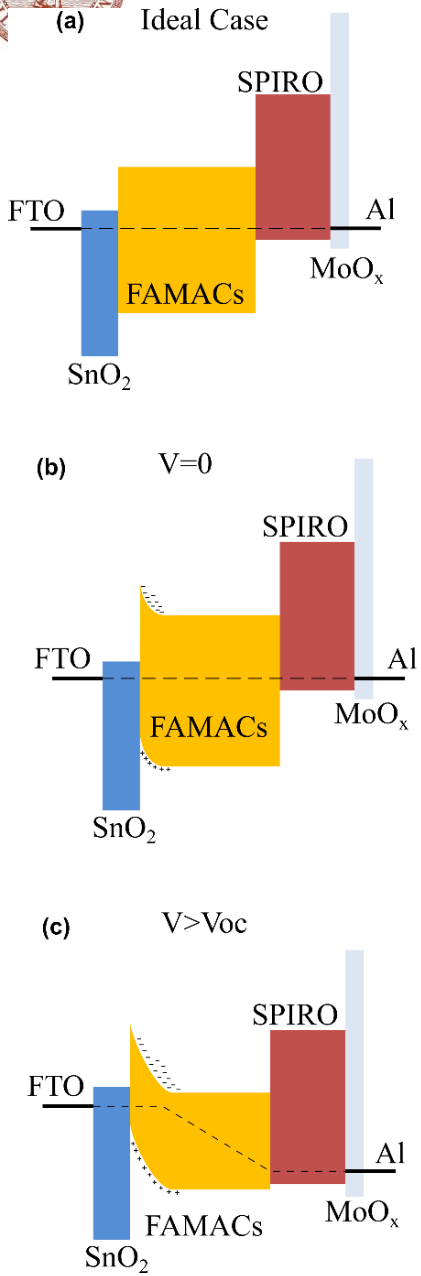
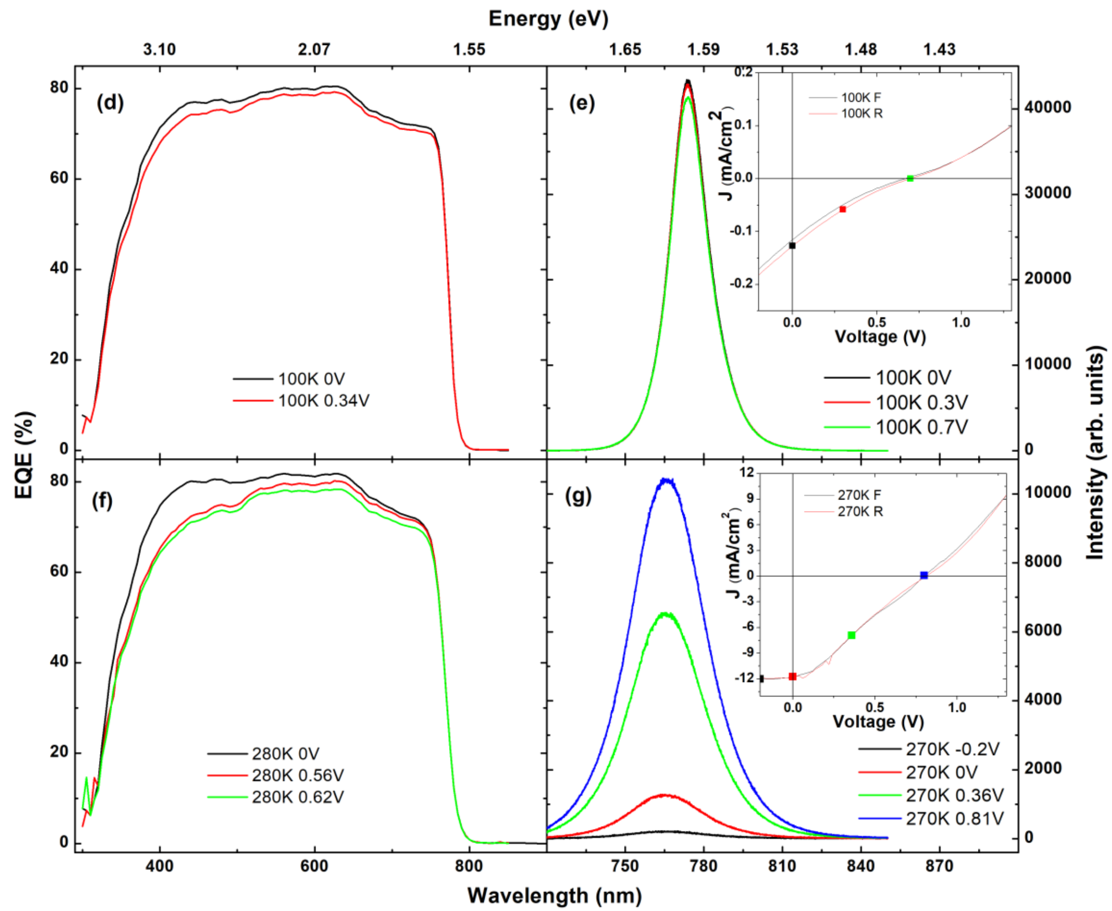


- Evidence of a barrier
  - current saturation at forward bias under LILT conditions
  - increased resistance under 1 sun low temperature conditions
- Barrier mediated by thermionic emission
- photocurrent generated at LILT conditions or by EQE is less than the thermionic emission rate
- Current greater than that rate is impeded, introducing large resistance



Barrier to Current Flow – Further evidence





C. R. Brown *et al*, ACS Applied Energy Materials, vol. 2, no. 1, pp. 814-821, 2019/01/28 2019.

- Reduction in the blue region of the EQE under forward bias is consistent with a barrier
- This barrier also serves to increase radiative recombination, by inhibiting carrier separation

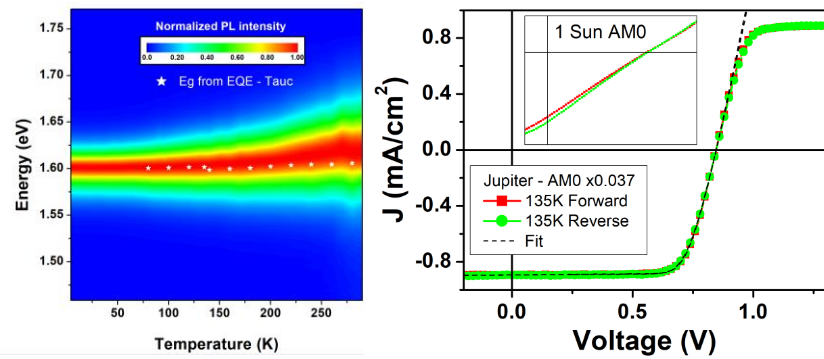
Conclusion

- Stability of the FAMACs based perovskite absorbed supported by PL

- Hysteresis in the JV data is observed, indicating degradation. Under low temperature, the mechanism responsible appears to be frozen out.

- Evidence of a barrier is observed, but performance is recovered under LILT operating conditions, though operating voltage is limited

- LILT performance of these devices is promising, and suggests they may be useful for low cost outer planetary CubeSat missions



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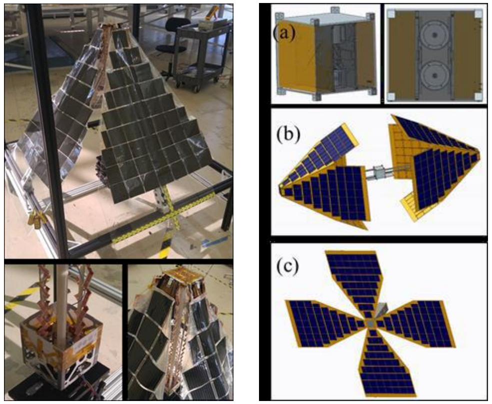

Les Johnson, John A. Carr, and Darren Boyd, presented at the 68th International Astronautical Congress, Adelaide, Australia, 2017

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G. E. Eperon - Marie Skłodowska-Curie Grant Agreement 699935.

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