National Aeronautics and Space Administration

Non-nuclear Deep Space Exploration Using Ultralight Radiation Hard Photovoltaics

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Program: FY21 R&TD Topics **Strategic Focus Area: Power generation**

Project Objective:

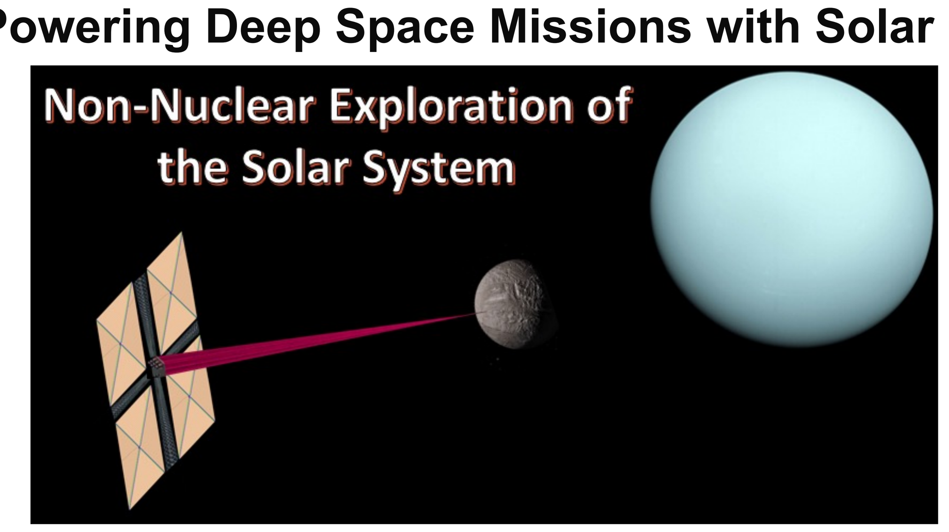
Perovskite solar cells (PSCs) show promise for deep space applications due to their radiation hard, light weight, and low cost characteristics. The aim of this project is to characterize and analyze various types of PSCs to determine their performance and lifetime for potential deep space mission requirements. To do this, we take low intensity, low temperature (LILT) current-voltage (I-V) measurements and external quantum efficiency (EQE) measurements to obtain the performance of the PSCs across a variety of conditions. Then, the PSCs undergo low energy proton radiation and the I-V and EQE measurements are re-taken to determine the effects of radiation mimicking the environment of space. Based on these results, we aim to identify where PSCs can be utilized or which aspects of PSCs need to be improved.

Benefits to NASA and JPL (or significance of results):

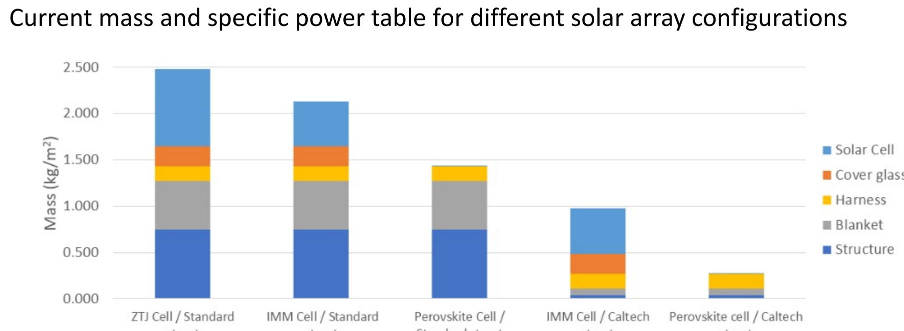
This work benefits deep space exploration because research into perovskite solar cells (PSCs) will enable ultralight photovoltaic power systems with a much higher specific power (W/kg). PSCs can deliver the same amount of power while accounting for a smaller fraction of the weight of a space mission, which leaves room for more mission critical components. While perovskite degradation remains a core problem, current results look to be promising:

- Device efficiency exceeding 24% in optimal conditions of 5.5 AU and -50℃ for Caelux solar cell
- Device efficiencies exceeding 20% all the way from 1 AU to 30 AU for Caelux solar cells at peak temperature, although device performance suffers at extreme lower temperatures (-140℃ and -170℃)
- No cell degradation occurs after cells are subjected to LILT conditions, confirmed by identical 28℃ measurements taken before and after LILT conditions
- Certain cells experience degradation at lower light intensities, but this is not universally experienced by all cells
- External quantum efficiency (EQE) exceeding 80% for ANU solar cell

Powering Deep Space Missions with Solar Cells



Current mass and specific power table for different solar array configurations



AU/ Specific Power (W/kg)	ZTJ cell/ Standard Struct	IMM cell/ Standard Struct	Perovskite cell/ Standard Struct	IMM cell/ Caltech Struct	Perovskite (ideal) cell/ Caltech Struct	ANU PSC/ Caltech Struct (pre-rad)	ANU PSC/ Caltech Struct (post-rad)	CA PSC/ Caltech Struct (pre-rad)	CA PSC/ Caltech Struct (post-rad)
1 (Earth)	162	205	179	447	928	506	412	775	6
5.5 (Jupiter)	5.37	6.78	5.93	14.79	30.67	15.75	6.06	9.07	0.13
19.2 (Uranus)	0.44	0.56	0.49	1.21	2.52	1.24	0.41	1.06	0.01

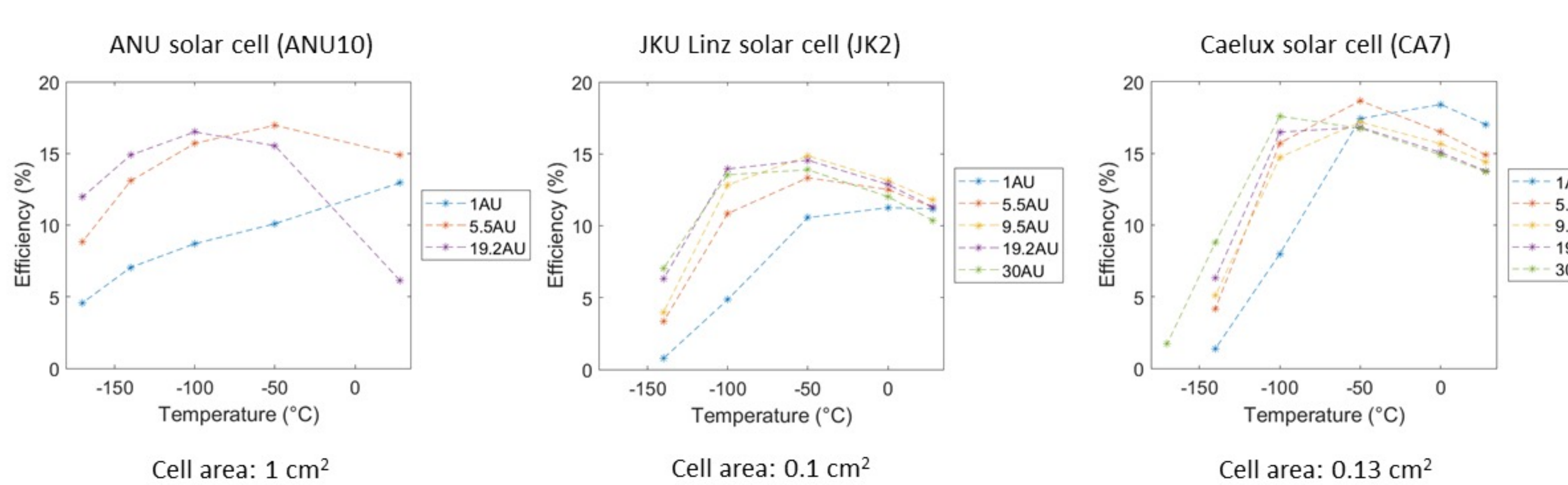


Figure 1. Solar cell efficiency with respect to temperature for three different cell types (ANU, Caelux, JKU Linz) and various different light intensities (based on AU). The Caelux cell reaches the highest cell efficiency with a peak exceeding 24% at -50℃ and 5.5 AU. In general, the relationship between efficiency and temperature is not monotonic, with the peak in efficiency occurring usually around 0℃, -50℃, or -100℃. The efficiency remains relatively high for most of the temperature and light intensity range, but efficiency drops drastically at extreme lower temperatures of -140℃ and -170℃.

FY20/21 Results:

- Obtained selected cells from The Australian National University (ANU), Caelux, and The Johannes Kepler University Linz (JKU Linz) to be tested
- Completed pre-radiation LILT IV measurements and EQE measurements
  - LILT IV measurements taken at solar intensities of 1 AU, 5.5 AU, 9.5 AU, 19.2 AU, 30 AU and temperatures of 28℃, 0℃, -50℃, -100℃, -140℃, and -170℃ for Caelux and JKU Linz cells
  - LILT IV measurements taken at solar intensities of 1 AU, 5.5 AU, 19.2 AU and temperatures of 28℃, 0℃, -50℃, -100℃, -140℃, and -170℃ for ANU cells
  - EQE measurements taken on one selected ANU cell
- Completed low energy proton radiation at 30 keV and 75 keV for 6, 12, 18, and 24 hour periods at Boeing Radiation Effects Laboratory in Seattle, Washington
- Currently in the process of obtaining post-radiation LILT IV and EQE measurements to compare with pre-radiation measurements

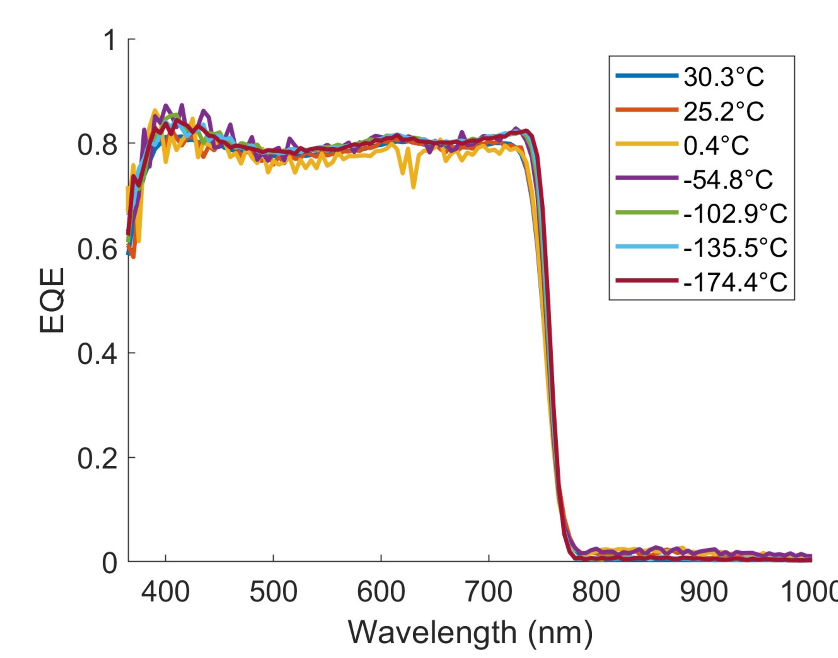


Figure 2. External quantum efficiency (EQE) measurements of ANU solar cell at various temperatures. The changing temperature causes very slight changes in the curve around the bandgap.

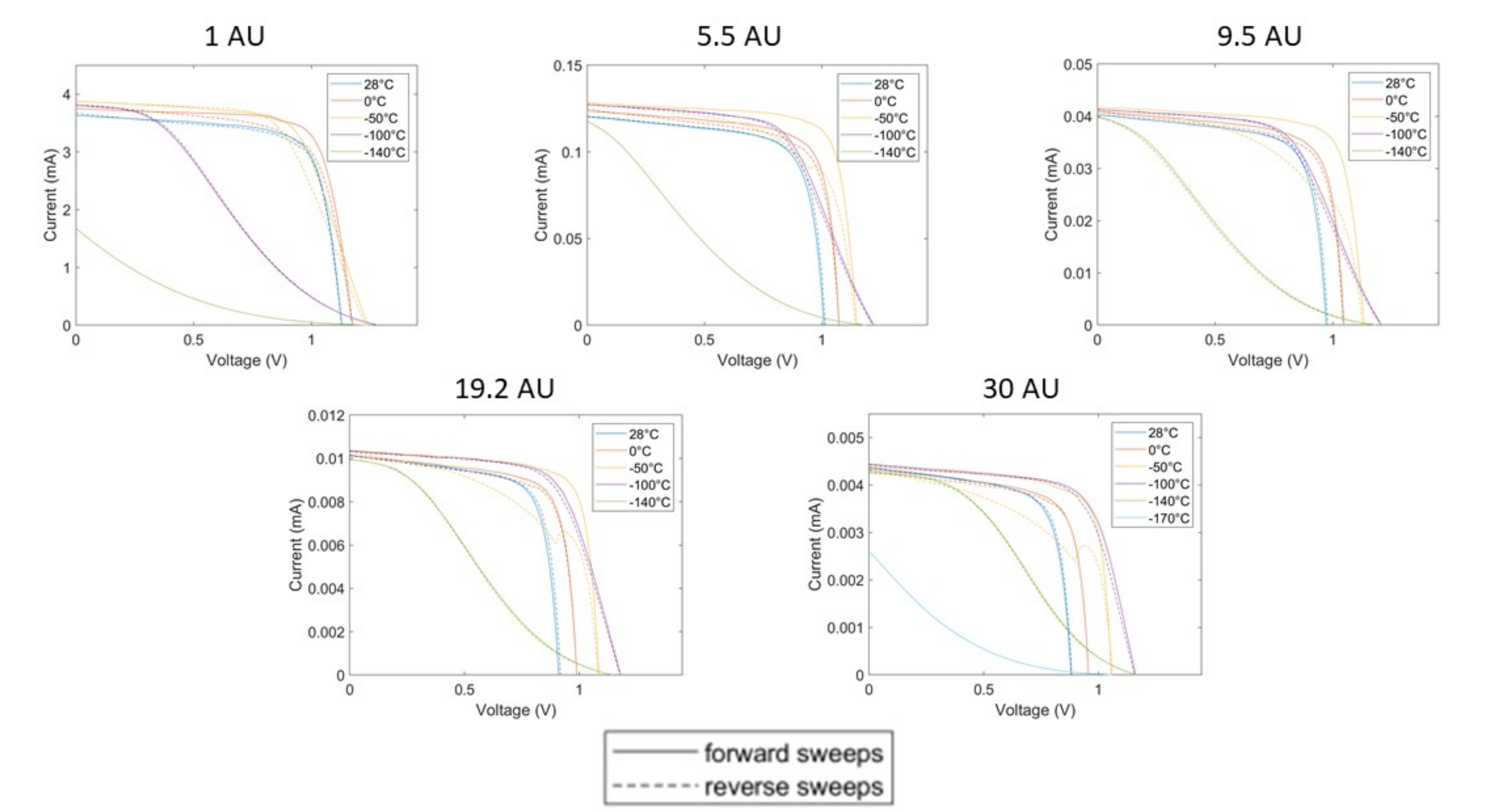
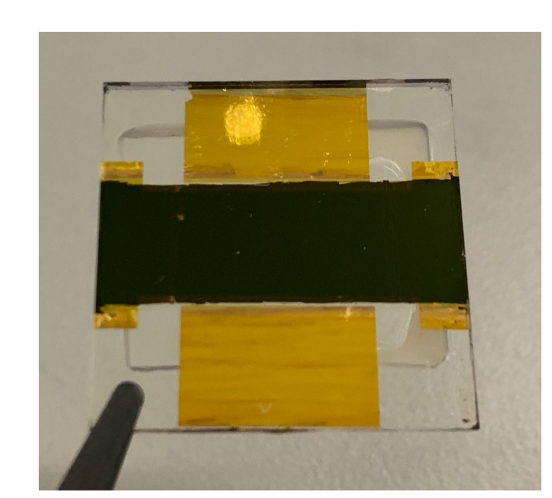


Figure 3. Caelux solar cell (CA7) current-voltage (I-V) curve measurements taken under low temperature, low intensity (LILT) conditions. The temperatures that were tested are 28℃, 0℃, -50℃, -100℃, -140℃, and -170℃ (only at 30 AU). The light intensities that were tested are based on astronomical units (AU) denoting the distance from the sun. This corresponds to the solar intensity at Earth (1 AU), Jupiter (5.5 AU), Saturn (9.5 AU), Uranus (19.2 AU), and Neptune (30 AU). As shown, the cell performs well across all light intensities, but starts to degrade at the extreme lower temperatures of -140℃ and -170℃.

Material	Thickness
Glass	2.2 mm
FTO 90:10 wt% ~SnO_2:SnF_2	500-550 nm
NiOx (~20 nm) – x~1	~20 nm
PTAA (<5 nm) - $[C_6H_4N(C_6H_2(CH_3)_3)C_6H_4]n$	<5 nm
Perovskite $Cs_{0.05}FA_{0.9}MA_{0.05}PbI_{2.74}Br_{0.26}$	~500 nm
PCBM - $C_{72}H_{14}O_2$	~80 nm
BCP - $C_{26}H_{20}N_2$	~5 nm
Gold	~100 nm

Composition of the perovskite solar cells



Photograph of the perovskite solar cell from the Australia National University (ANU).

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