Applications of Small High-Altitude Balloons: Is it time for flown perovskite solar simulator standards?

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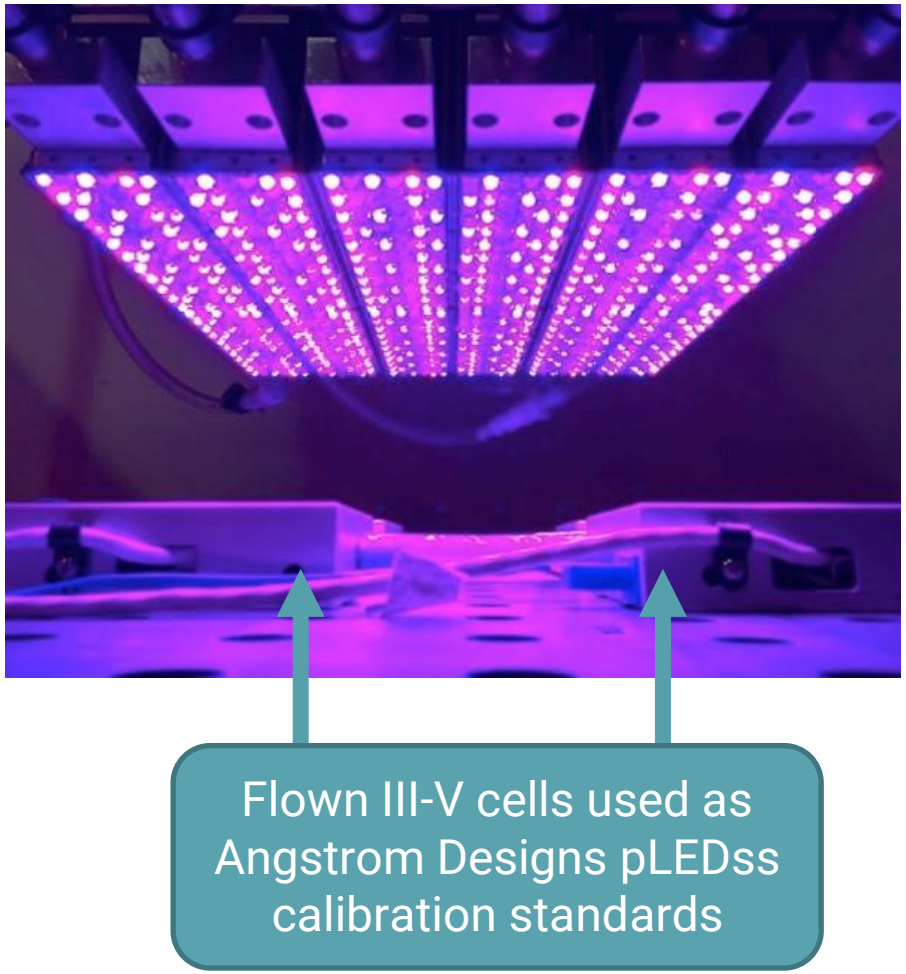
ÅNGSTROM DESIGNS

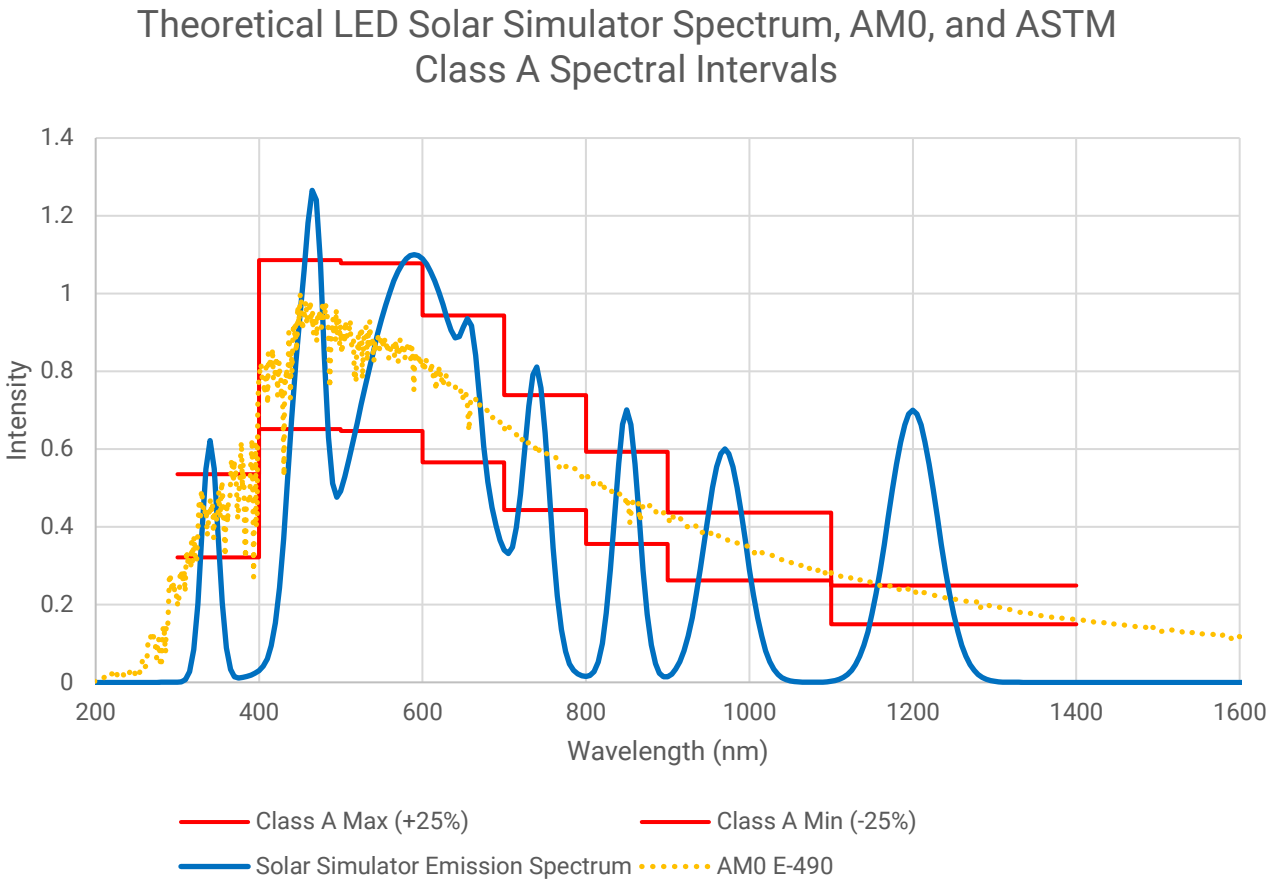
Why Fly Perovskites on Balloons?

- Researchers have made significant advancements in perovskite solar cell feasibility
- Multi-junction perovskites are being developed for space
- Perovskites need calibrated light IV measurements and flight heritage to transition from research to marketability
- Recent developments in stability and encapsulation show that perovskites can be used as balloon flown solar simulator calibration standards



What is a class A spectrally matched AM0 Solar Simulator?

- ASTM E927-10 defines class A AM0 spectral match by the integration of solar simulator irradiance across 8 bins to **+/- 25%**
- AIAA S-111 and S-112 standards carve out the spectral requirement for multi-junction cells and replace it with current matching sub-junctions to balloon flown standards within +/- 1% (except Ge bottom junctions at +30% -1%)
- Measuring current match on reference isotypes verify that accurate cell performance measurements can be made
- LED solar simulator spectral intensity can be tuned against flown isotypes such that sub-junction currents match AM0. Angstrom Designs holds a patent on this process.



Flown calibration standards become even more important when testing multi-junction perovskites!

Perovskite Solar Cells As Standards

- Perovskite solar cell performance degrades with humidity
- Stability has improved dramatically in recent years. With proper encapsulation, a perovskite could be stable enough to meet AIAA requirements for calibration standards
- As PSCs degrade, EQE shape is maintained

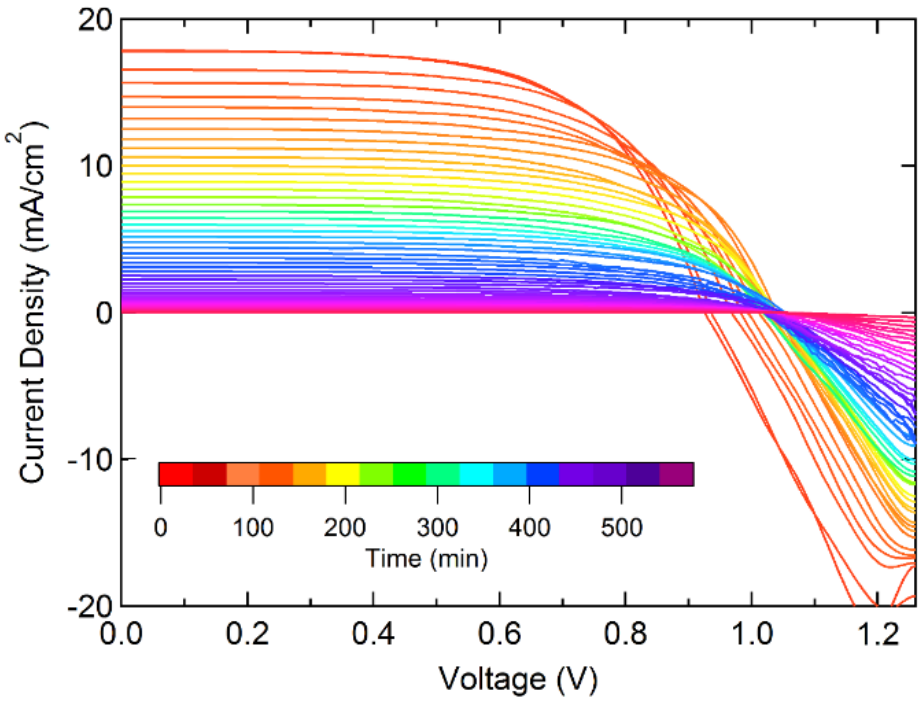


Figure S8. *J-V* curves of a perovskite device aging under a moist N_2 flow of 80 % RH. The time intervals are 12 min. The initial improvement in V_{OC} can be attributed to the fact that the device was stored in a nitrogen-filled glove box prior to first measurements, which removed the oxygen-induced doping from the spiro-OMeTAD. Exposure to air at the beginning of the experiment reintroduced doping and helped to initially improve the performance of the device.

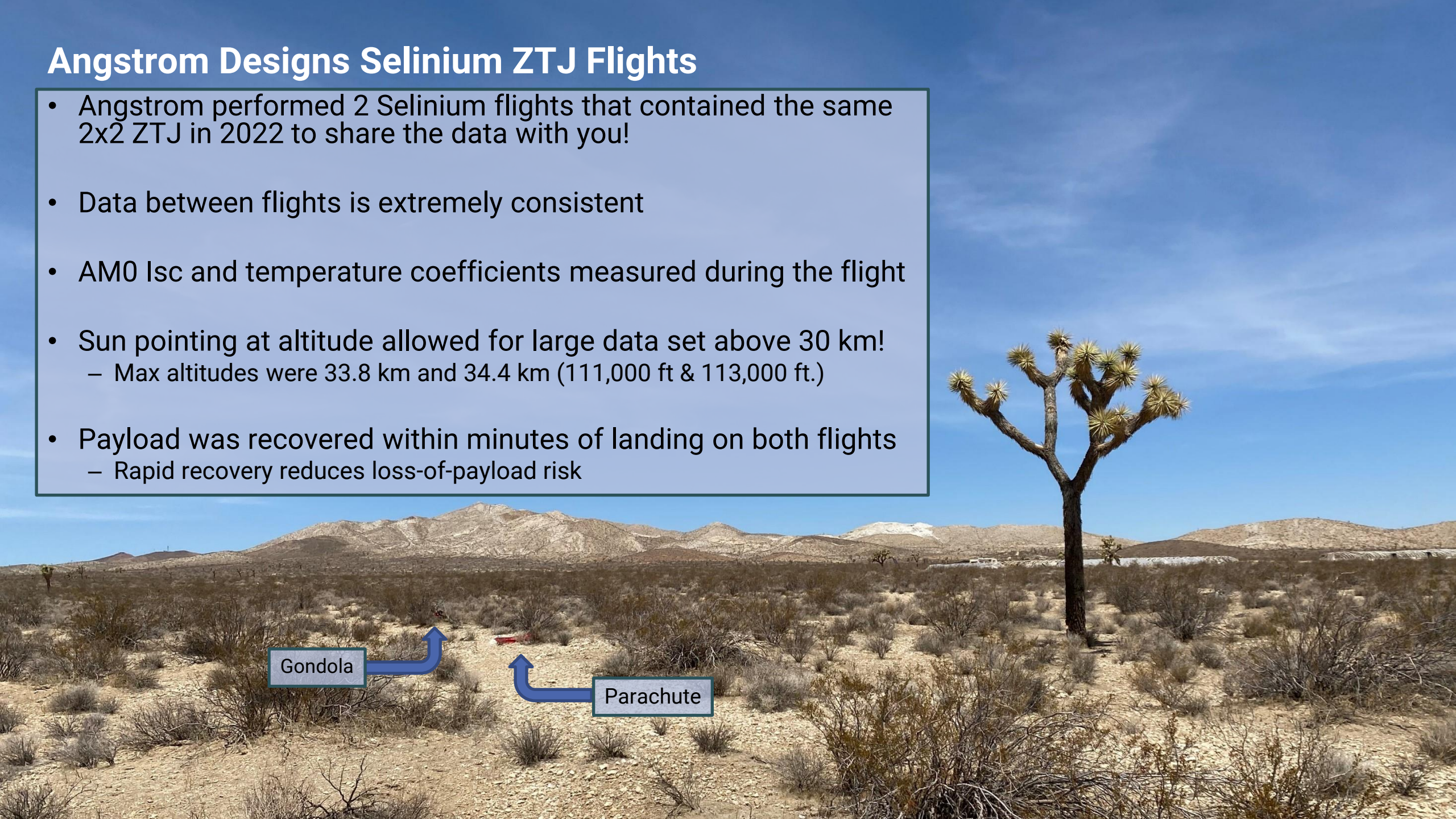
Figure included with permission:
Song, Zhaoning, et al. "Perovskite Solar Cell Stability in Humid Air: Partially Reversible Phase Transitions in the PbI2-CH3NH3I-H2O System." Advanced Energy Materials, vol. 6, no. 15, 2016, 1600846.

Generating Flown Calibration Standards

	Mountaintop	Fixed Wing Aircraft	Large Balloons	Small Balloons
Cost	✓	✗	⚠	✓
Accessibility	✓	✗	⚠	✓
Flight Simplicity	✓	✗	✗	✓
Result Accuracy	✗	⚠	✓	✓

Angstrom Designs Selinium ZTJ Flights

- Angstrom performed 2 Selinium flights that contained the same 2x2 ZTJ in 2022 to share the data with you!
- Data between flights is extremely consistent
- AM0 Isc and temperature coefficients measured during the flight
- Sun pointing at altitude allowed for large data set above 30 km!
  - Max altitudes were 33.8 km and 34.4 km (111,000 ft & 113,000 ft.)
- Payload was recovered within minutes of landing on both flights
  - Rapid recovery reduces loss-of-payload risk

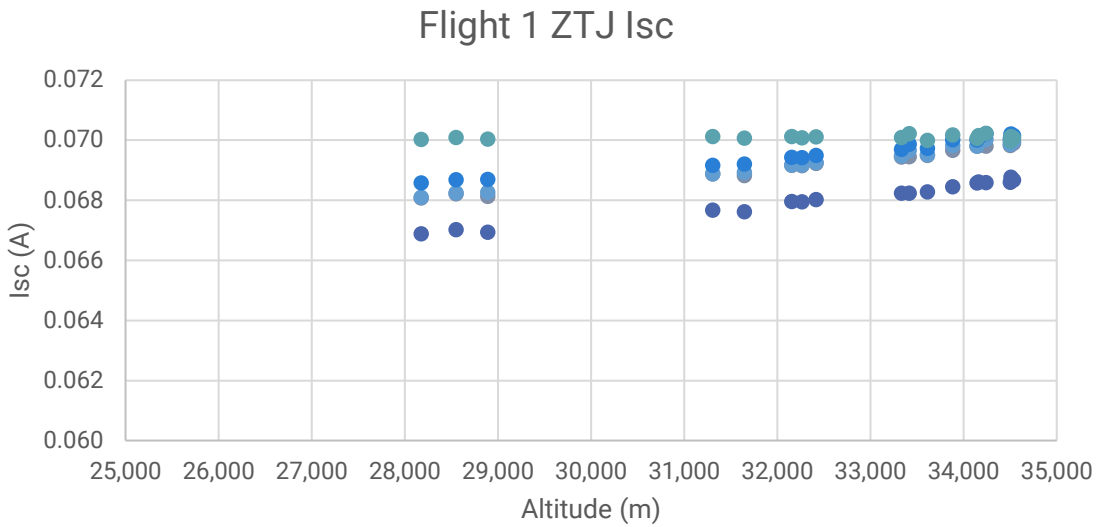


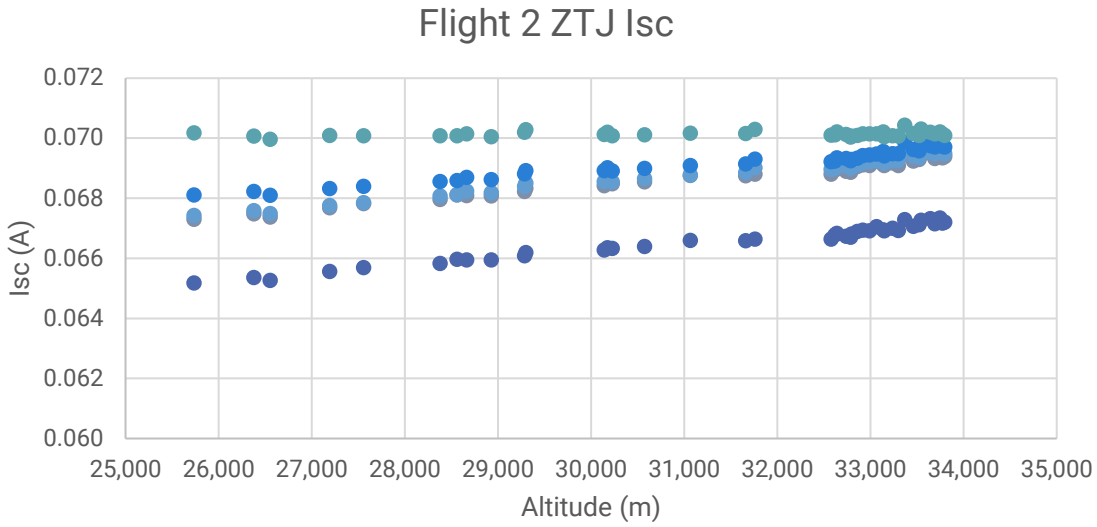
ZTJ Flight Results: Short-Circuit Current

Deviation between flight results was only 0.07%!

Metric	Flight 1	Flight 2
AM0 Isc (mA)	70.104	70.149
Difference from Datasheet	+0.72%	+0.78%
Difference from Measured QE	-0.87%	-0.81%

Isc corrected to 28C
Expected Isc from:
Datasheet = 69.6 mA
Measured QE = 70.72 mA



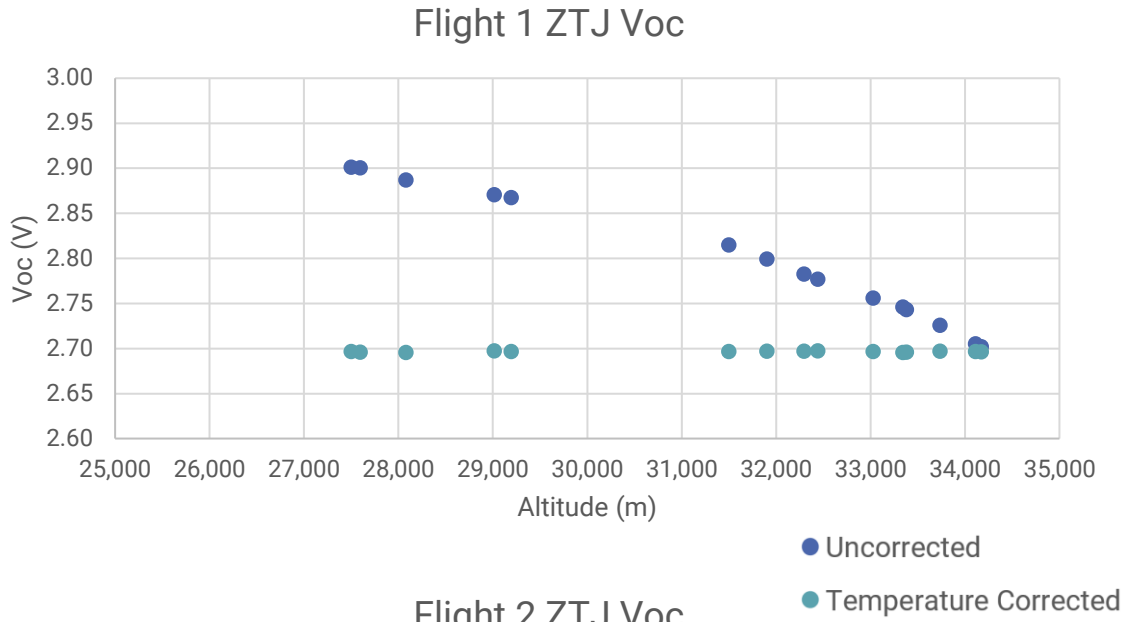


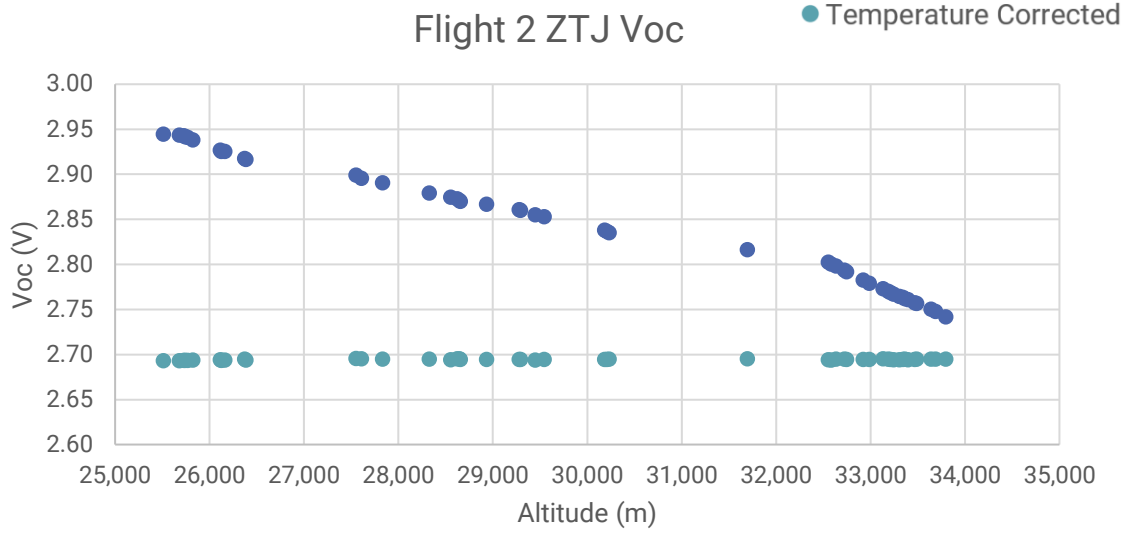
ZTJ Flight Results: Open-Circuit Voltage

Metric	Flight 1	Flight 2
AM0 Voc (V)	2.694	2.695
Difference from Datasheet	-1.17%	-1.14%

Voc corrected to 28C
Voc from datasheet: 2.726 V

Deviation between flight results was only 0.03%!





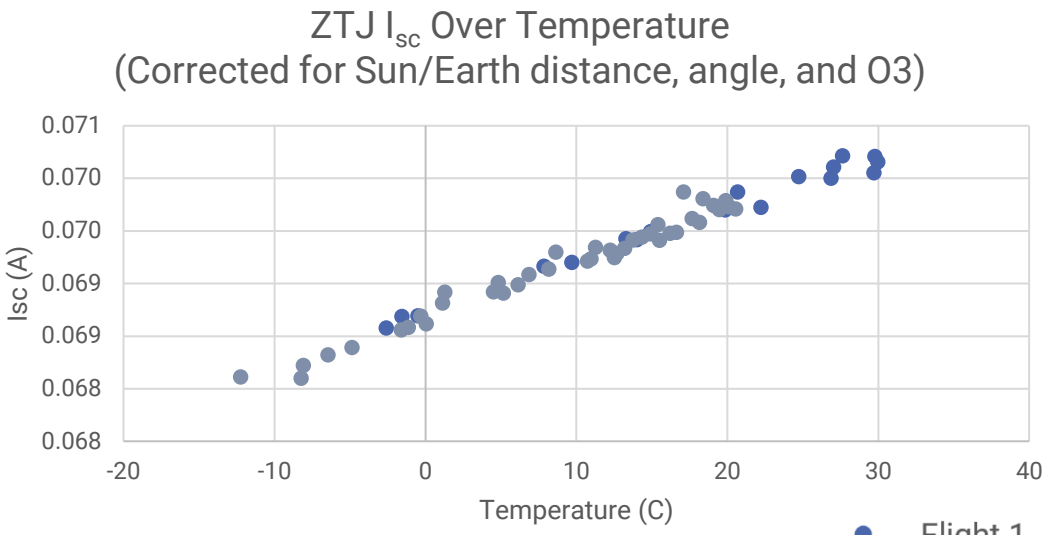
ZTJ Flight Results: Temperature Coefficients

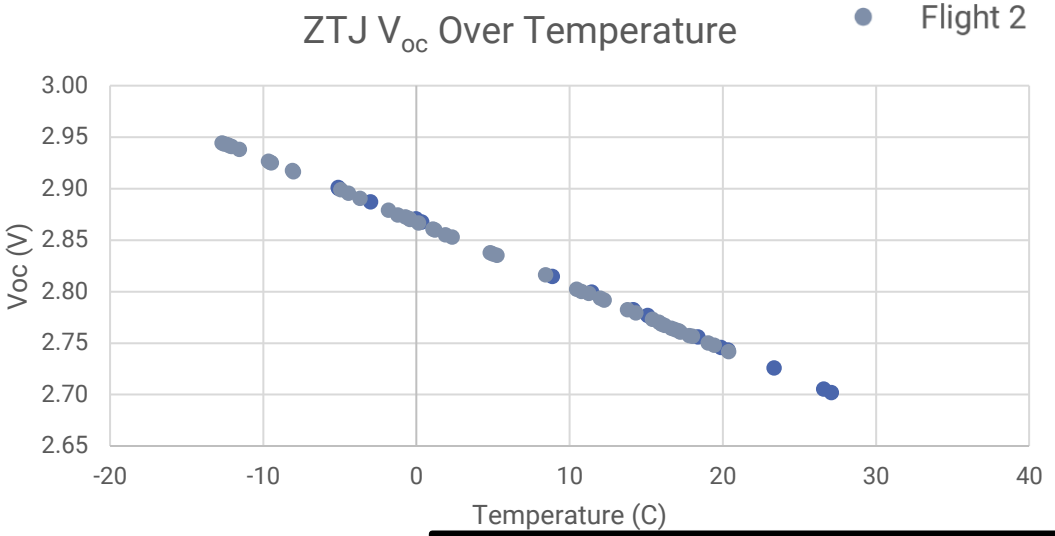
- Cells typically experience temperature shift from -20°C to +30°C at altitude
- Large balloons rise too slowly to measure temperature coefficients

Metric	Flight 1	Flight 2
J_{sc} Temp Co (μA/cm²/°C)	11.8	12.8
J_{sc} Temp Co Difference From Datasheet	0.85%	9.4%
V_{oc} Temp Co (mV/°C)	-6.18	-6.17
V_{oc} Temp Co Difference From Datasheet	1.9%	2.1%

Datasheet J_{sc} Temp Co: 11.7 (μA/cm²/°C)
Datasheet V_{oc} Temp Co: -6.3 (mV/°C)

9% is good!
Isc Temp Co is such a sensitive measurement that the difference in temp co 11.8 and 12.8 only result in an Isc difference of 0.1%.





Gathered TempCos Too

Other Reasons to Fly

- Accurately measure performance at AM0
- Measure temperature coefficients
- Directly compare multiple technologies or iterations during the flight
  - Test as you fly
- Establish flight heritage to advance TRL

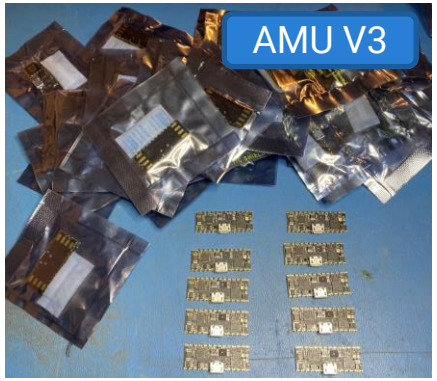
Angstrom Designs flight team during launch.

Angstrom Designs
Small High-Altitude Balloon Capabilities

- Flexible gondola can accommodate various payload form factors
  - 2x2s, 4x8s, 8x8s, 7x15s, 15x15s
  - NSCAP Holders or AMU Holders
  - Selinium
  - Custom payloads

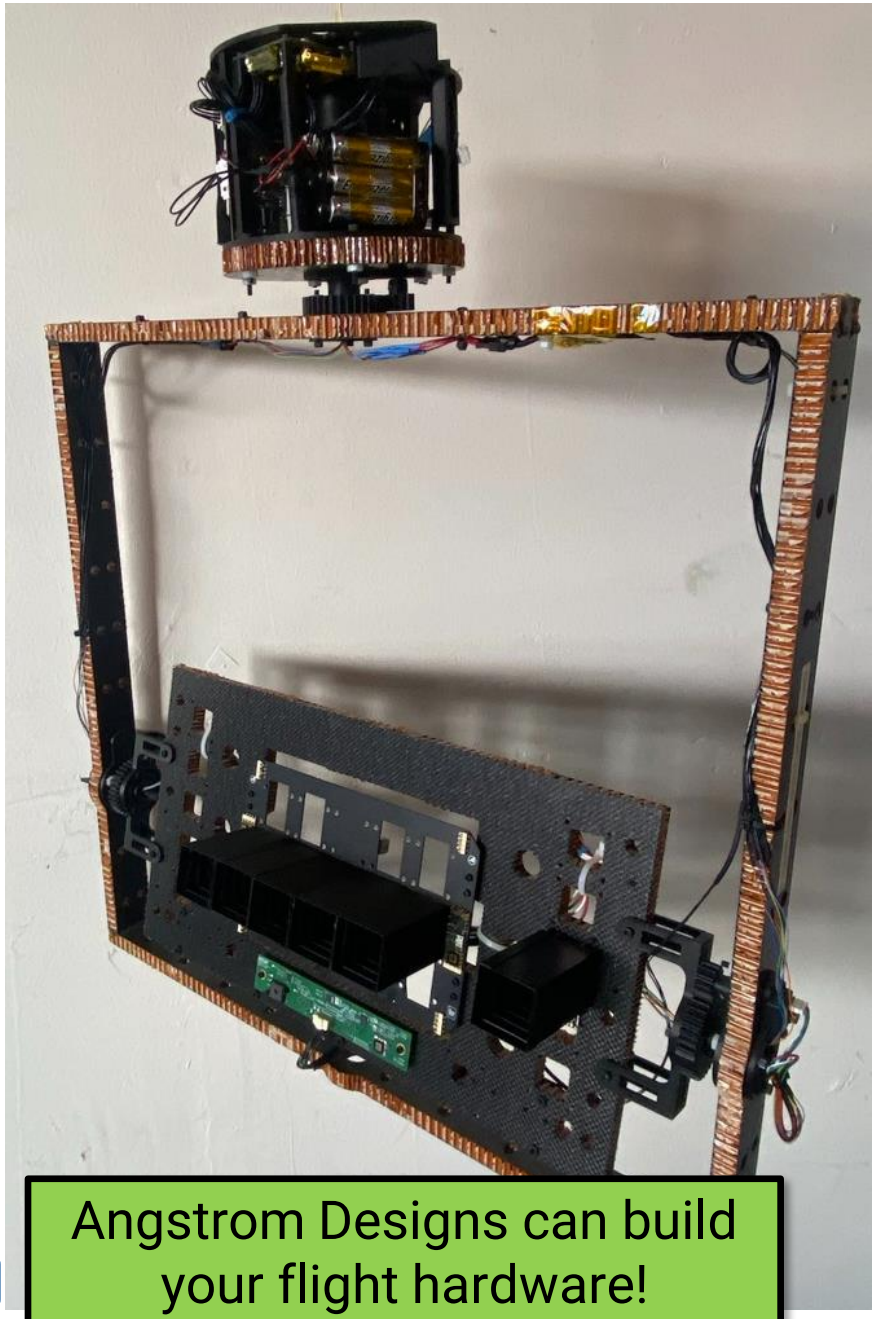
- Flight prices range from $2850 to $7100 per cell depending on quote specifics


2x2 Baffle


AMU V3


2x2 AMU Holders

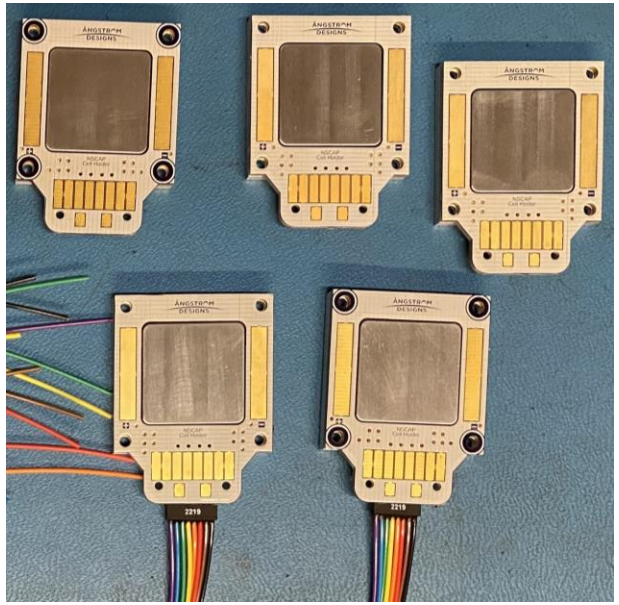

2x2 NSCAP Holders



Angstrom Designs can build your flight hardware!

Concluding Thoughts and Acknowledgements

- Perovskites ready to start building flight heritage and are stable enough to act as solar simulator calibration standards
- Angstrom Designs is looking to offer existing III-V solar cell flight capabilities in partnership with perovskite researchers
- Thanks to SMC, AFRL, Aerospace (Colin Mann and Don Walker), Ahmad Kirmani (RIT), Zhaoning Song (UToledo), and many others for their contributions



We want to hear from you!

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