High Altitude Flight Results using Selenium, A PV Measurement Ecosystem

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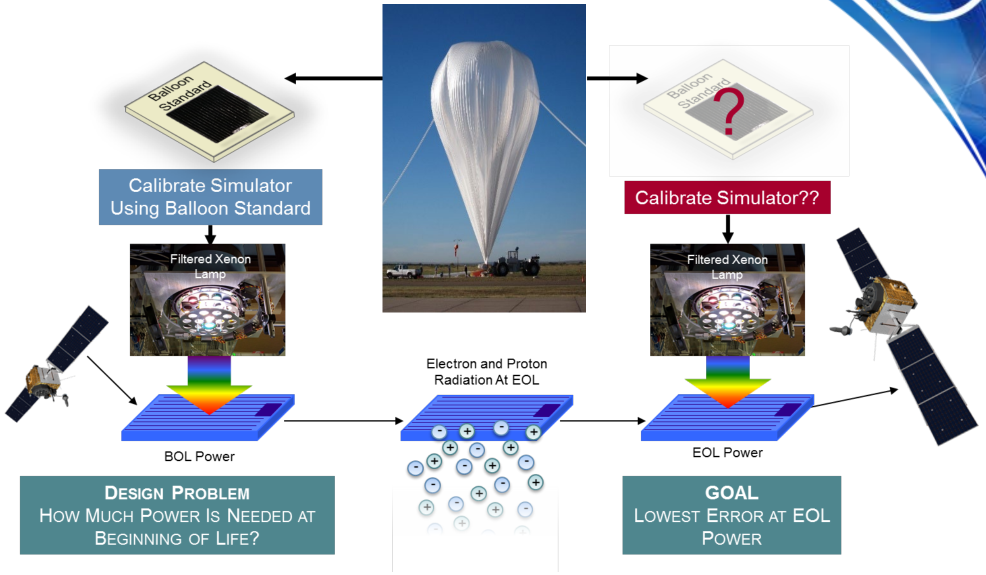
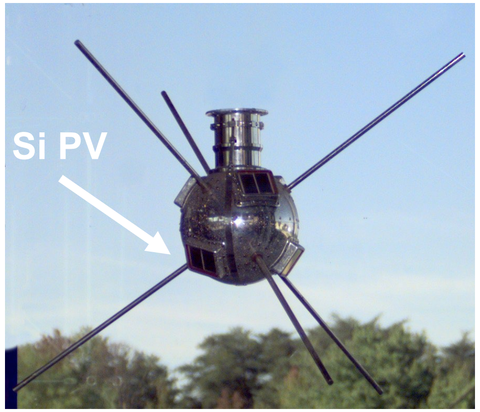
Background

- Critical capability
  - *High altitude measurements of solar cells have been carried out on a yearly basis since 1962, 4 years after the launch of the first US solar power satellite Vanguard 1 on March 17, 1958*



- Accurate Prediction of On-Orbit Power
  - *Duplicating the AM0 solar spectrum both spatially over an area and in intensity has yet to be achieved*
    - Supercontinuum lasers can match the solar spectrum, but lack UV and the area for larger devices



Vanguard-1

http://nssdc.gsfc.nasa.gov/image/spacecraft/vanguard1.jpg

- Solution
  - *Obtaining short circuit current of solar cells near AM0 and using those calibrated solar cells to calibrate ground based solar simulators*

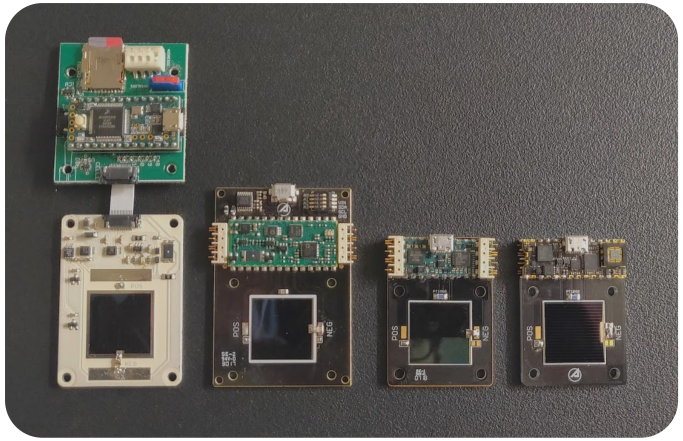
Challenges

- Cost
  - *Flying large balloons is expensive*
- Schedule
  - *Limited flight opportunities*
  - *Casolba – Scheduled to fly 8/2022, last flight was in 2017*
  - *Data processing takes months*
- Increases barrier to entry into Space PV market
  - *High altitude solar cell samples are treated like rare, irreplaceable artifacts*
  - *Was once a way to evaluate and test space PV tech*

New Space Approach

- Smaller, lighter, faster, cheaper
  - *Miniaturize electronics, balloon, payload,*

- Selenium AMU software to make using the device user friendly



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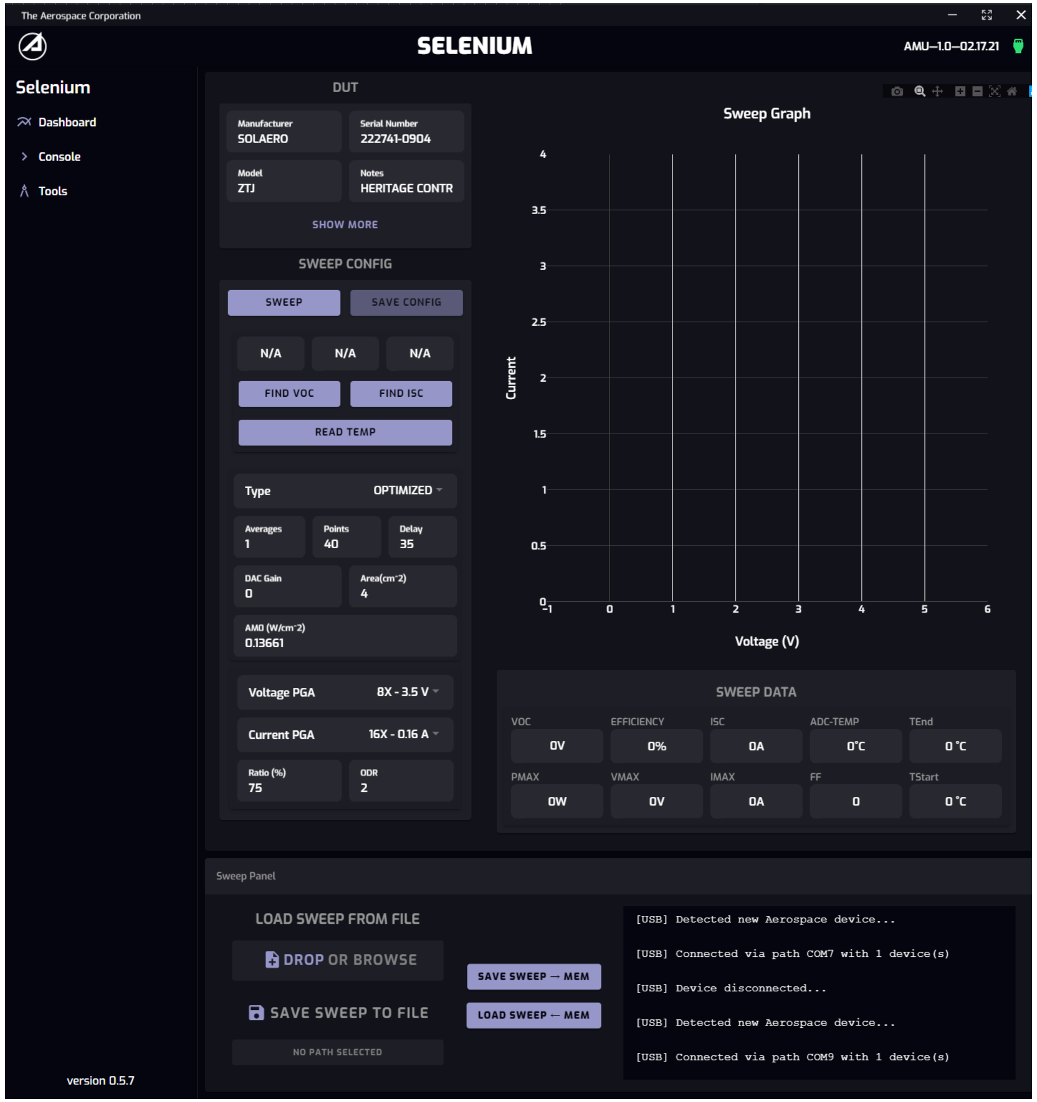
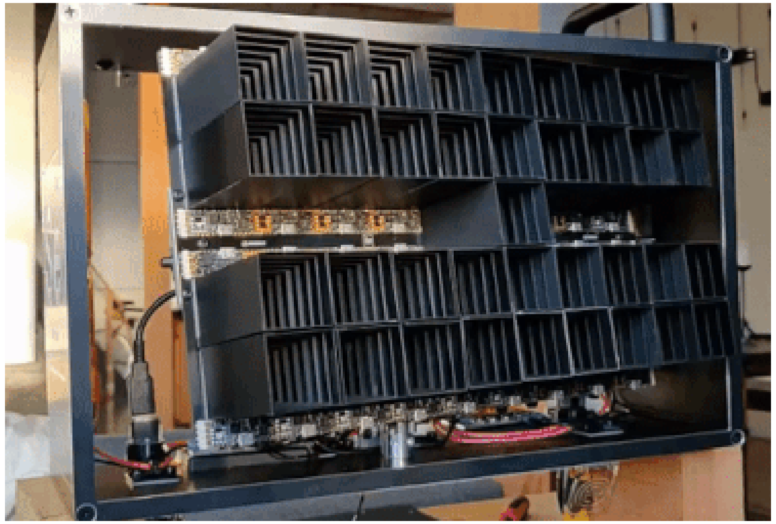


Selenium 34 and Eyas



- Develop two Payloads
  - *Calibrated sun sensor*
  - *GPS*
  - *IMU*
  - *Pressure*
  - *Microspectrometers (190-800nm)*
- Only difference between payloads is the size and weight

- Selenium 34
  - *34 AMU carriers*
  - *fine pitch and yaw tracking to complement JPL balloon tracking*
- Eyas
  - *12 AMU platform*
  - *Low SWAP*
    - <500g

Impact of Selenium

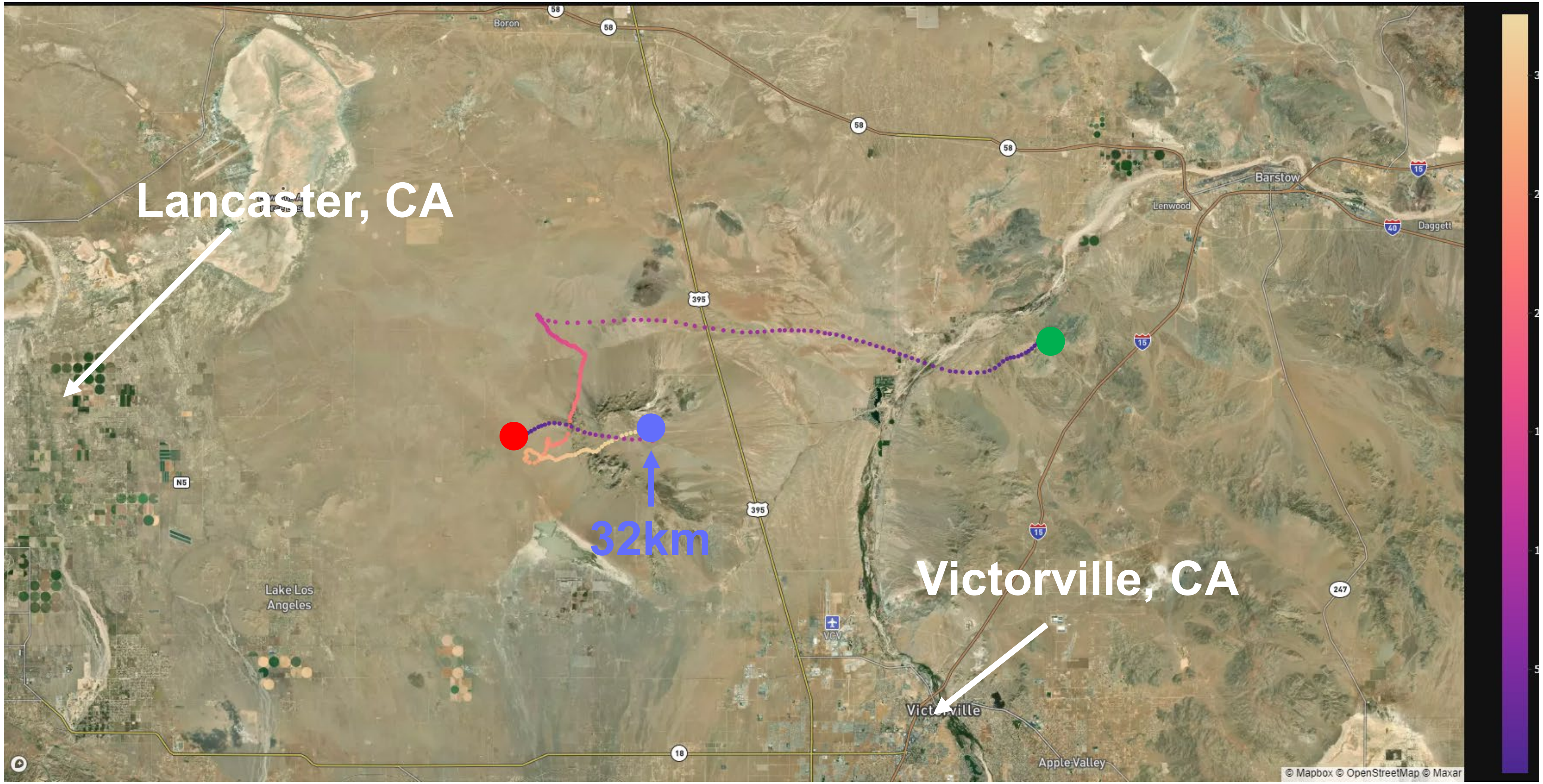
- **Over 12 flights from 2019 to 2021**
  - *13 different PV technologies flown*
  - *Over 150 cells flown*

- **AMU**
  - *Space Based Characterization*
    - NASA LISA-T
    - NASA Solar Cruiser
    - Aerocube X
    - Caltech, UO, Nebraska, Rhodes
  - *High Altitude Measurements*
    - BlackSky AM0
    - Angstrom Designs
    - JPL
    - SolAero, mPower, Nasa Glenn, NREL

- **Selenium 34 and Eyas**
  - *2 Govt. Programs*
    - Provided mission specific radiation testing and AM0 measurements
    - Cells were flown -> irradiated -> flown again

- **Selenium AMU and Data**
  - *Distributed to contractors and universities*
    - Selenium Aerospace Git
  - *NRL Baffle Calculator*

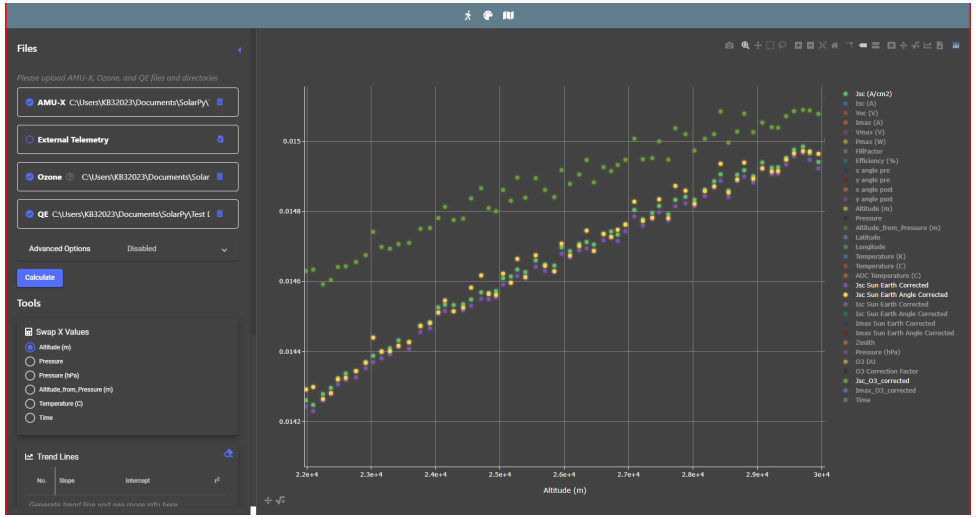
Flight Operation

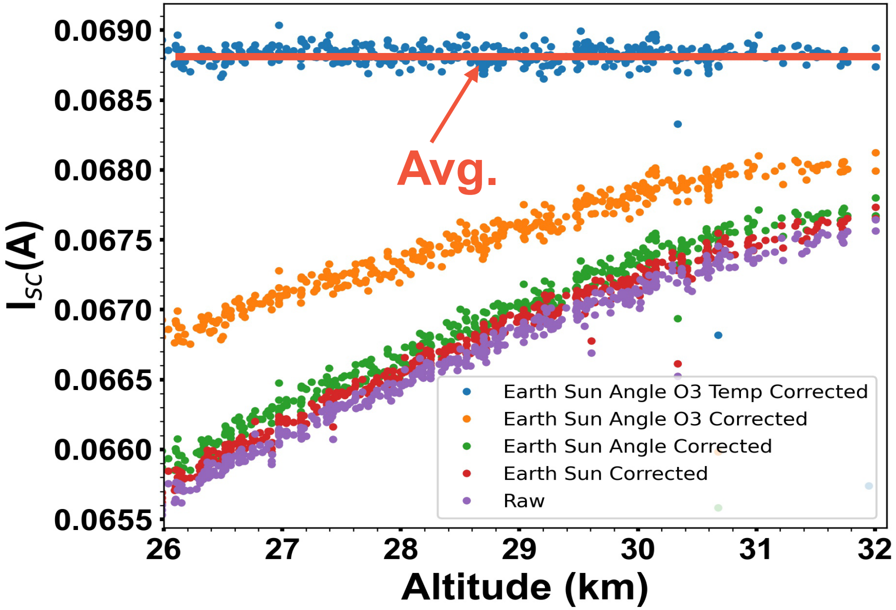


Data Analysis and Corrections

- Selenium Data Software allows us to do all the corrections immediately after flight

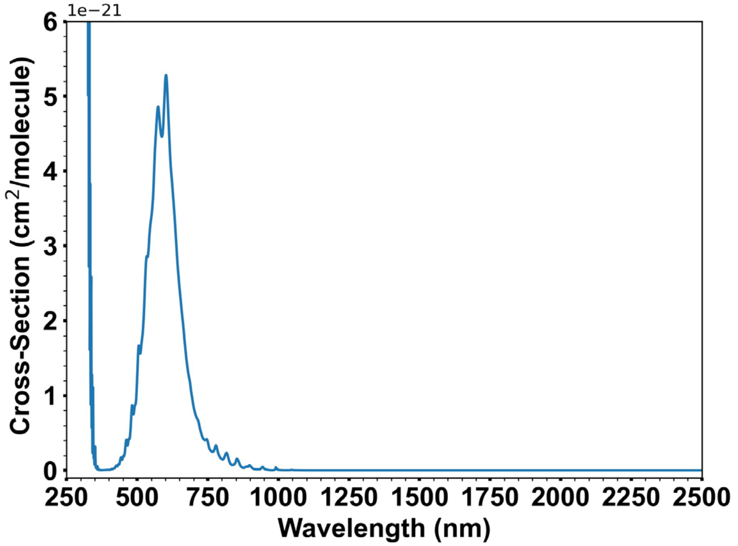
- Step 1: Correct for sun-earth distance
  - *Solar intensity varies ±3%*
  - *We used the NREL Solar Position Algorithm (NREL SPA) as it is one of the most accurate solar position calculators*
- Step 2: Angle Correction
  - *Our sun sensor is calibrated using a 5 axis stage that is laser aligned to set the zero offset. Angle measurements are taken every 0.1 degrees from ±10 degrees and fit to a polynomial*
  - *The angle for the calibrated sun sensor is used to correct for current lost using the cosine law*
- Step 3: Correcting for Ozone
  - *Next Slide*
- Step 4: Obtain Temperature Coeffecients
  - *Using the temperature data from the RTDs on the cell holders we can determine the temperature coefficients of the solar cells after correcting for Steps 1-3*
- Step 5: Correct data to 28 °C

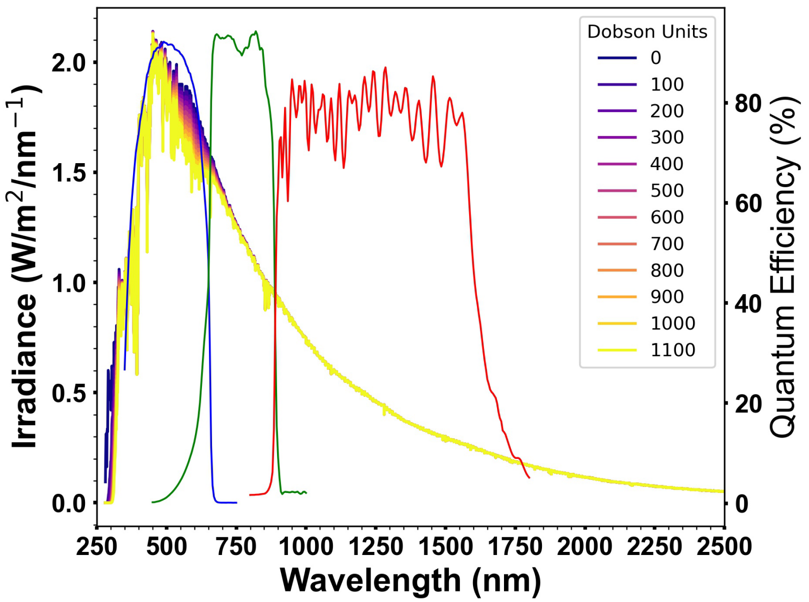




Ozone Correction

- Step 3: Ozone Correction
  - *Ozone is not found in space and is found as one of the final layers in the Earth's atmosphere*
  - *Ozone absorbs light in a region of the solar cell that can introduce an error when extrapolating to space conditions*
  - *We need to correct for ozone to get a true AM0 measurement.*
  - *By convolving the ozone absorption cross section spectrum, AM0 Spectrum, and measured ozone concentration we can correct for ozone absorption*

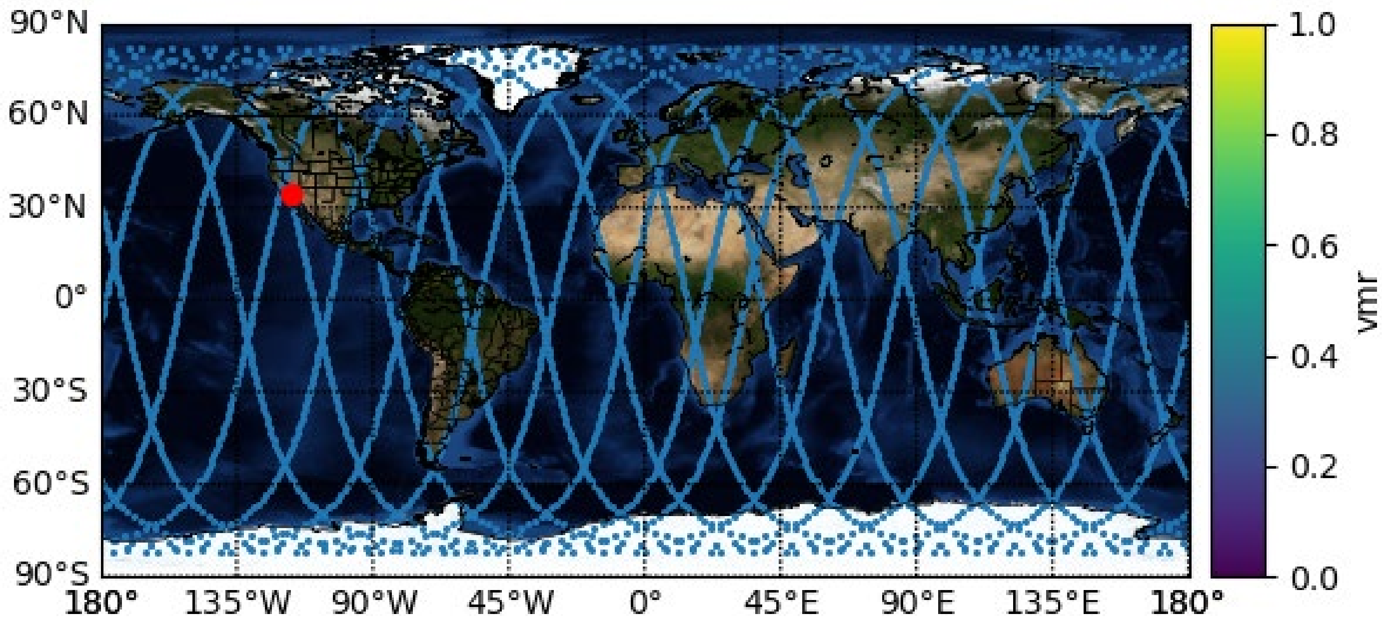


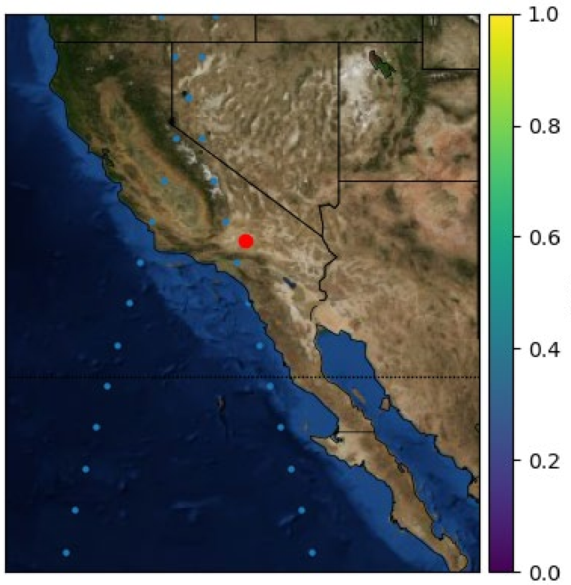


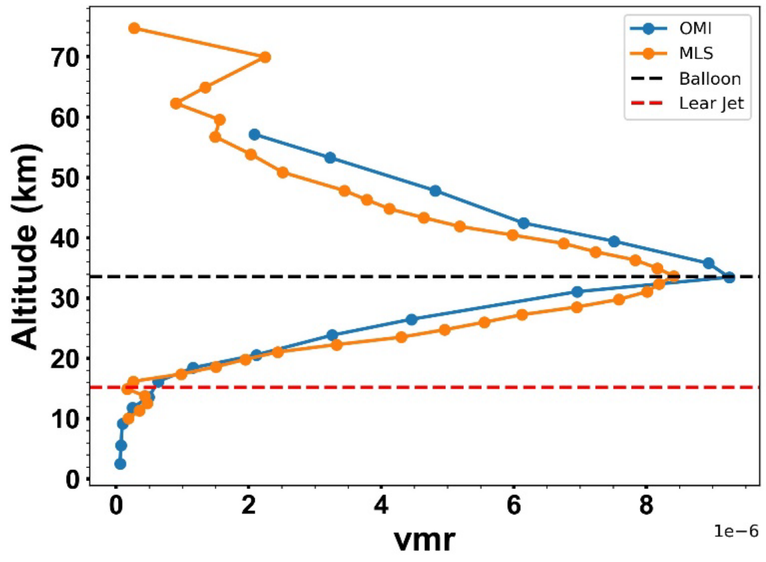
Ozone Correction

Step 3 cont

- Solar zenith angle and altitude(pressure) affect the about of ozone that is absorbed before the solar cell.
- In order to correct for this we use data from the Microwave Limb Sounder (MLS) and the Ozone Monitoring instrument on the Aura Satellite. The MLS provides the most accurate ozone measurements from a satellite from 15-50km, where as the OMI is more accurate below the troposphere
- Using the Level 2 dataset we can get the ozone profile for a specific latitude and longitude on a given day
- Our correction technique follows the ozone correction technique as applied by NASA Glenn and NRL, with the addition that we use the L2 profile data when available



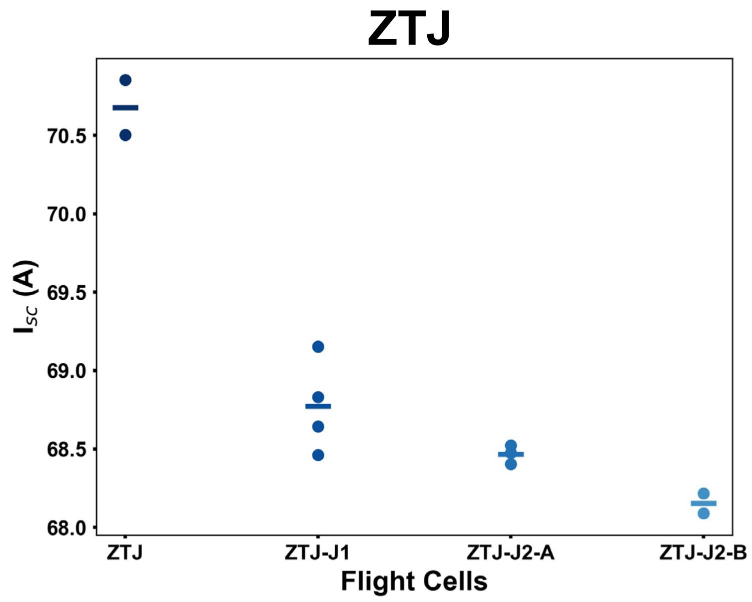


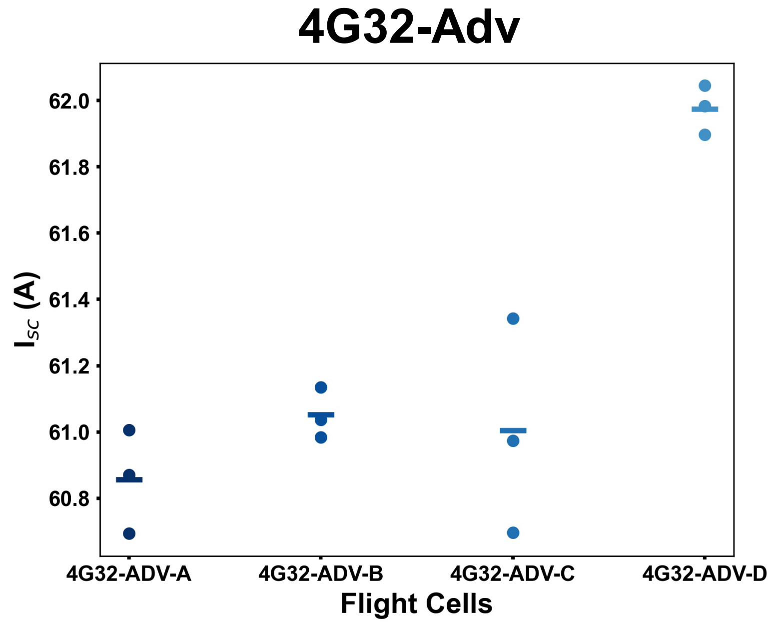


Flight History

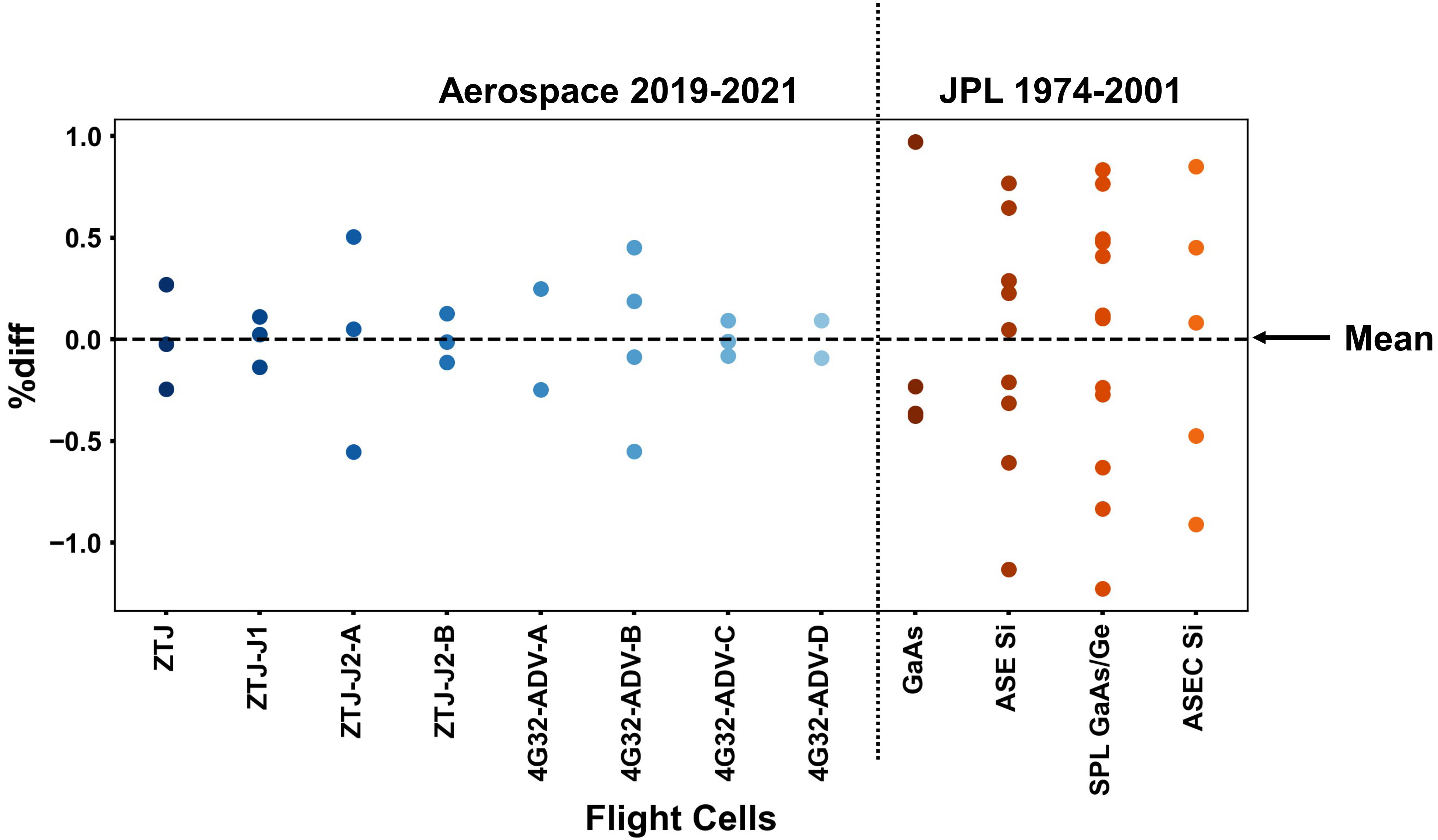
Flight Results

- Success!
  - *Data presented represents cells used as controls and thus have multiple flights on them*
  - *Data represents 2 flight from 2019 and 6 flights from 10/2020 to 12/21*
  - *Plots represent only data of cells that had multiple flights*
- LIV data take every 30 secs
- I_{sc} and V_{oc} data taken every 2 sec
- Obtained data on isotypes as well as full stack devices
- ZTJ-J1 isotype had a total of 4 flights
- Lines represent the average
- Dots represent the I_{sc} as averaged from the corrected flight data
  - *Each dot represents the average of 200-500 data points*
  - *Sigma of the error was ± 100uA/50uA depending on the gain setting*
  - *Sigma within error of AMU*





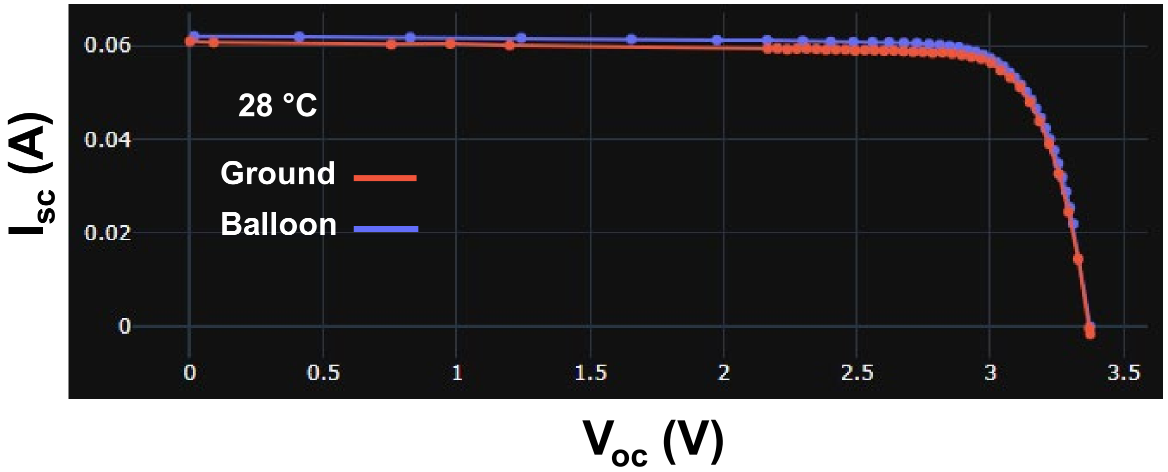
Comparing Aero Flights to JPL Flights of Yesteryear

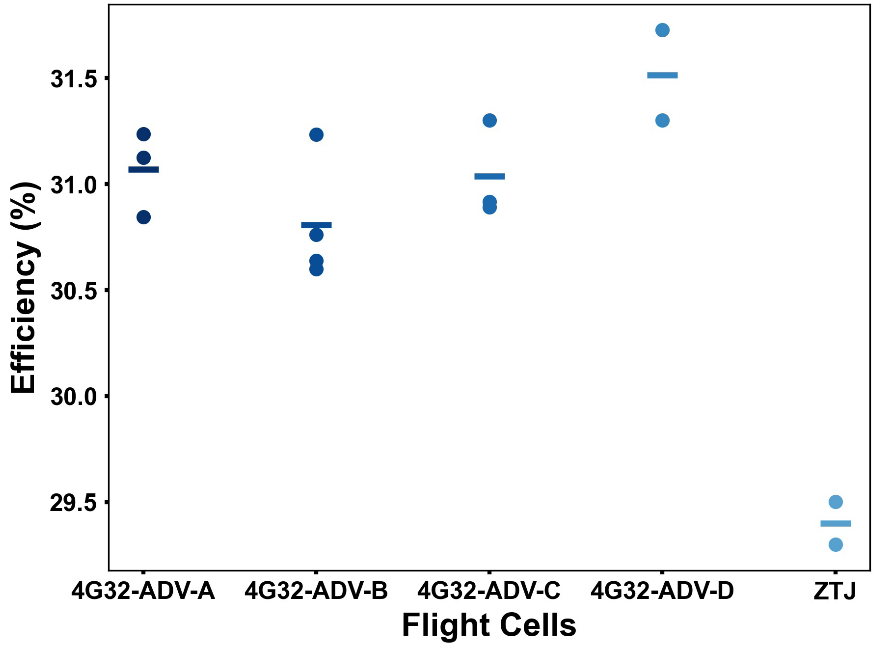


Variability of flight data is similar or better than JPL flights

Current Voltage Data

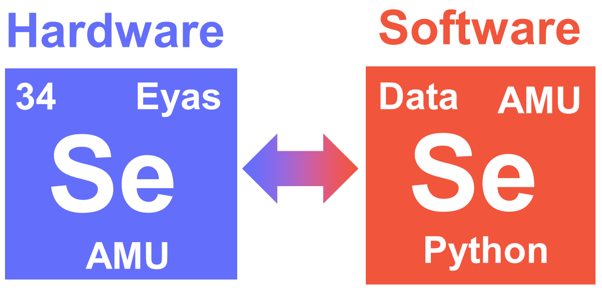
- Using the LIV data take every 30 secs we are able to get I_{max} and V_{max}
  - *Allows us to get P_{max} and Efficiency (E490 2019 1366.1 W/m²)*
- On our last flight we obtained IV curves at 28 °C
- IV curve could be corrected and stored on the device
- Ground Based IV was measured using Radiocal, an Aerospace developed synthetic calibration method

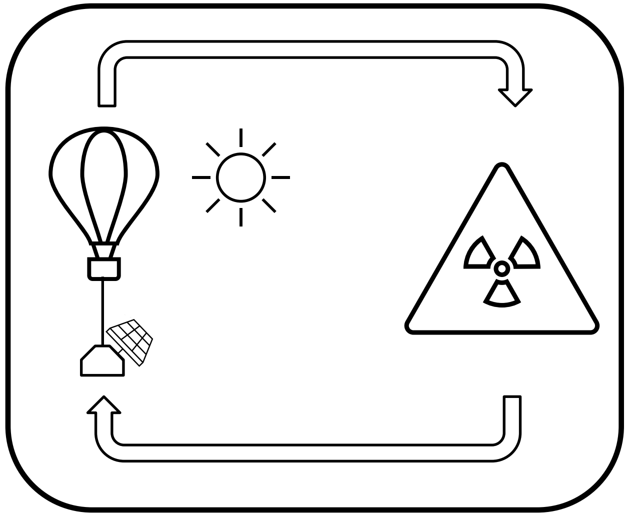




The Future

- Selenium Ecosystem allows for on demand near space measurements of solar cell
- Use balloons as solar simulators
- EOL Cal Standards
- Metrology on Cal standards
- Get mission specific power by flying cells irradiated to mission fluences
- Digitally tune and calibrate solar simulator
- Verify new solar simulator calibration methods





Thanks

- SolAero and Spectrolab
- NASA Flight Opportunity
- The Aerospace Corporation Technical Investment Program