MAI TAI

Mitigating Arc Inception via Transformational Array Instrumentation

Jeremiah Sims, Meghan Bush, Timothy Peshek

NASA GRC, Photovoltaics and Electrochemical Systems Branch

Space Power Workshop

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Outline

- Overview of MAI TAI
- Introduction to Spacecraft Charging and Arcing
- Introduction to Mitigation
- Active Mitigation- Primary Arc Detector
- Active Mitigation- Secondary Arc Quencher
- Adaptive Mitigation

Goal: enable **resilient**, **high voltage**, **high power density** solar arrays

MAI TAI

- FY24 Early Career Initiative (ECI) Award
- Funded by NASA’s Space Technology Mission Directorate (STMD)
- **Research and Development**

TRL 4 → TRL 6

Team

Early Career

- **Meghan Bush** – Principal Investigator
- **Jeremiah Sims** – Co-Investigator
- **Dr. Kristina Vailonis** – Thin Films
- **Brooke Weborg** – Data Analysis, Machine Learning
- **Darcy DeAngelis** – Safety and Mission Assurance
- **Natalie Weckesser** – Operations Research Analyst
- **Alexis Arroyo** – Electrical Engineering Support
- **Hana Winchester** – Data Science Summer Intern

Senior Staff & Mentors

- **Dr. Boris Vayner** – Spacecraft Charging Expert
- **Dr. Timothy J. Peshek** – Space Photovoltaics
- **Dr. Kristen John** – Lunar Dust Impacts

NASA GRC Team

M. Bush

J. Sims

K. Vailonis

B. Weborg

D. DeAngelis

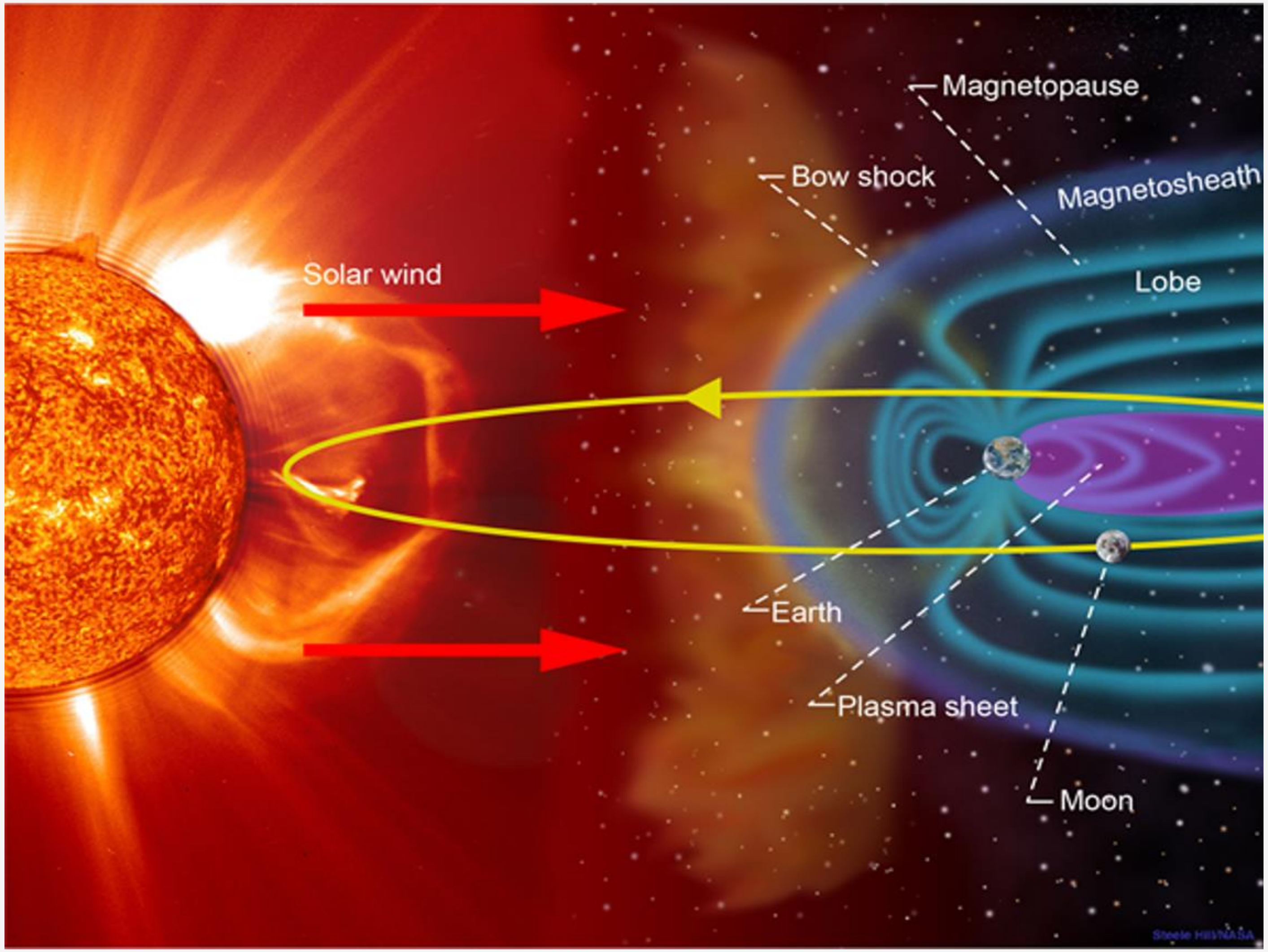
N. Weckesser

A. Arroyo

B. Vayner

T. J. Peshek

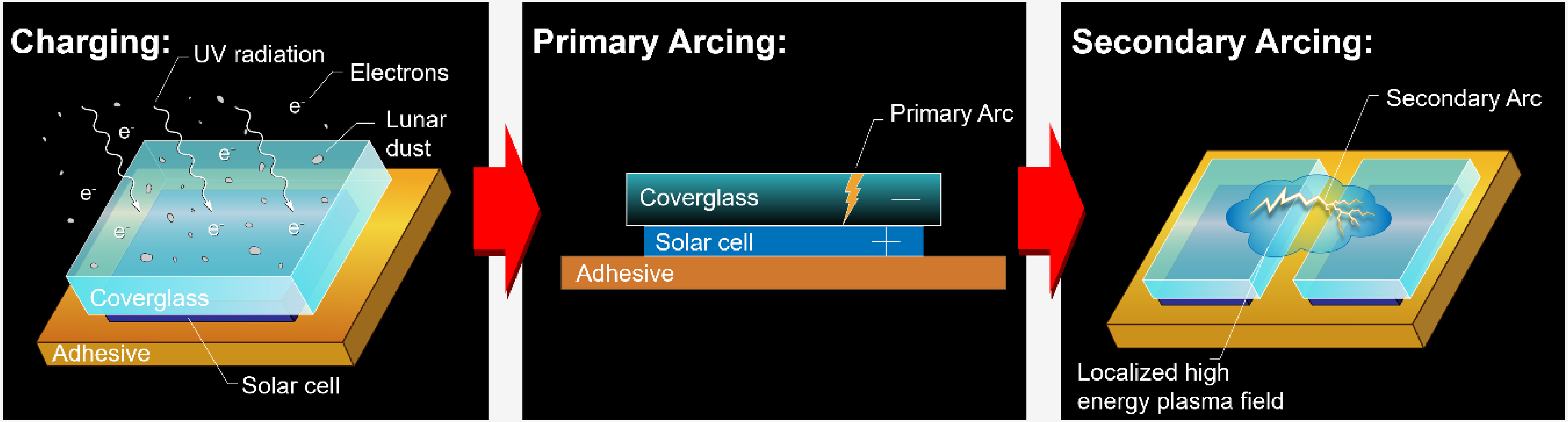
Spacecraft Charging



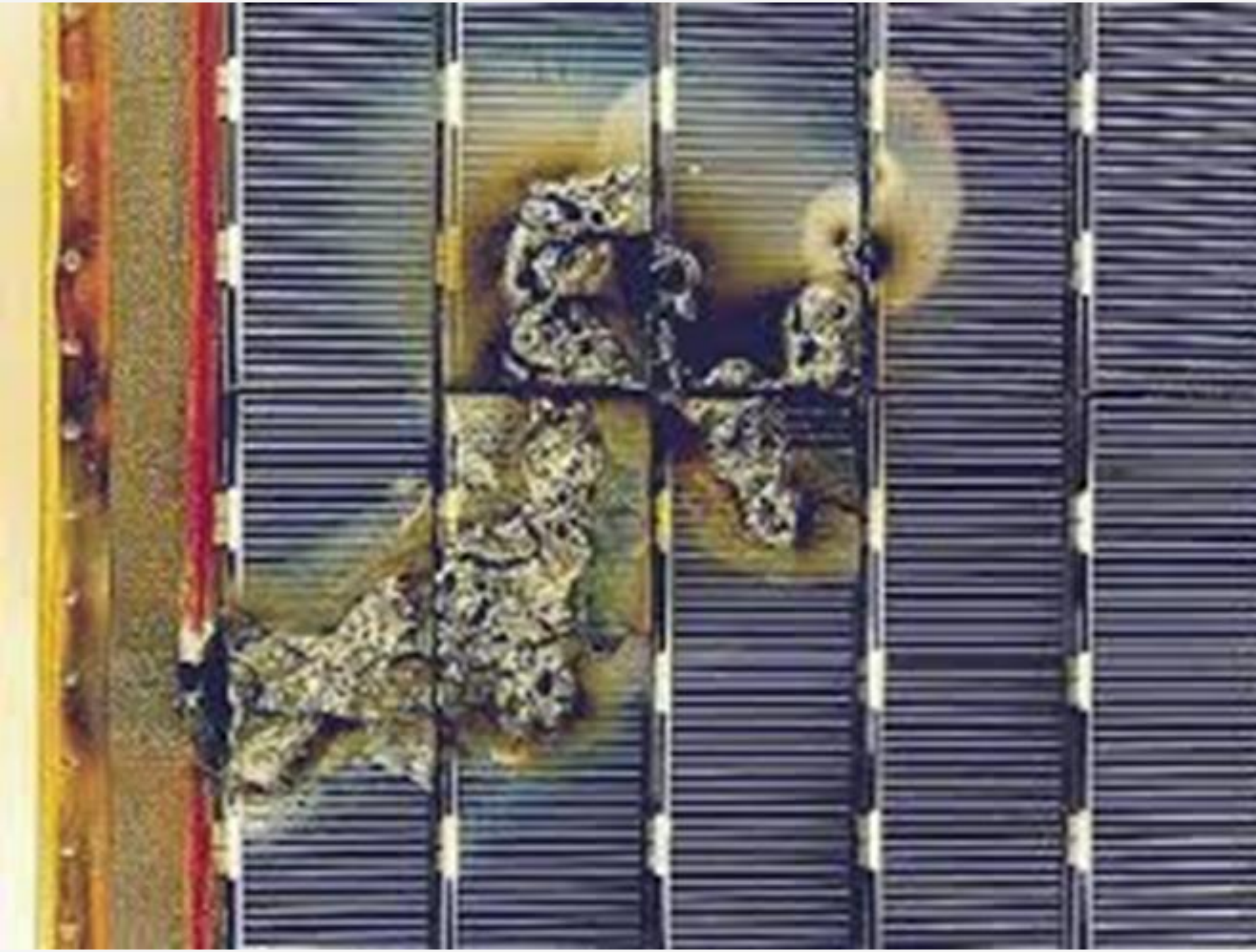
- Charging regimes on the lunar surface vary wildly throughout the lunar cycle

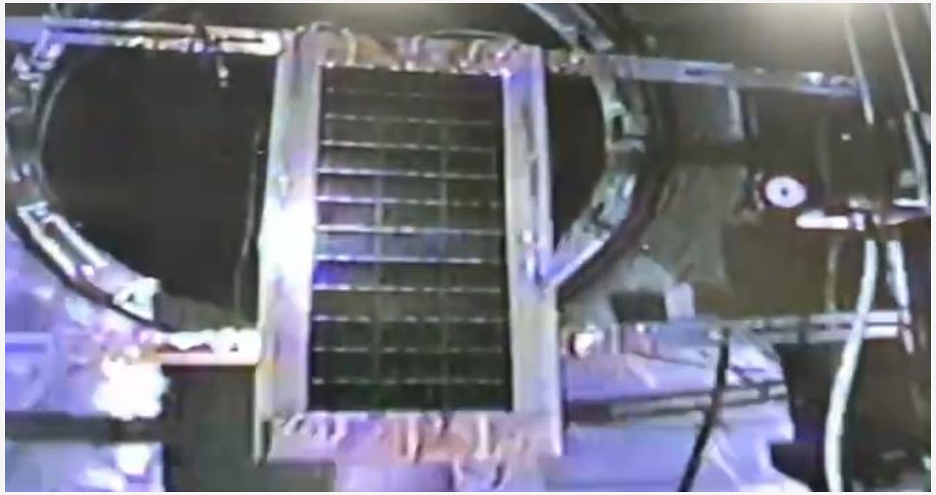
- Passive mitigation techniques **design for worst-case scenario**

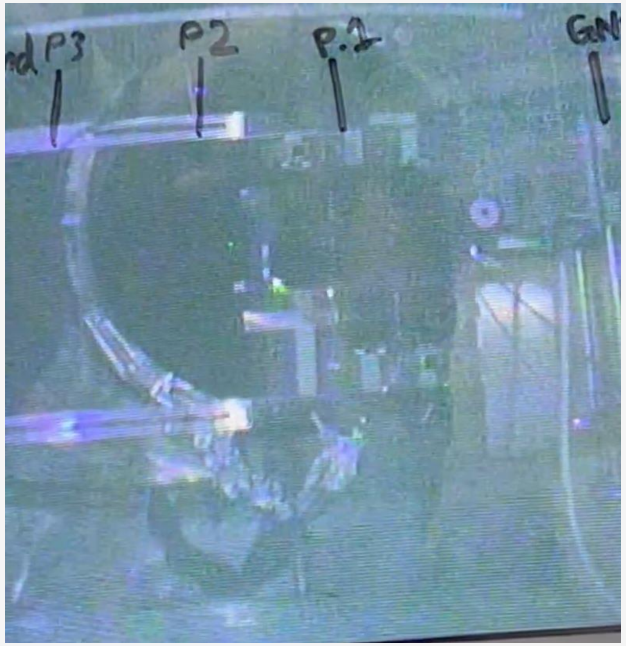
Spacecraft Charging



Secondary Arcing



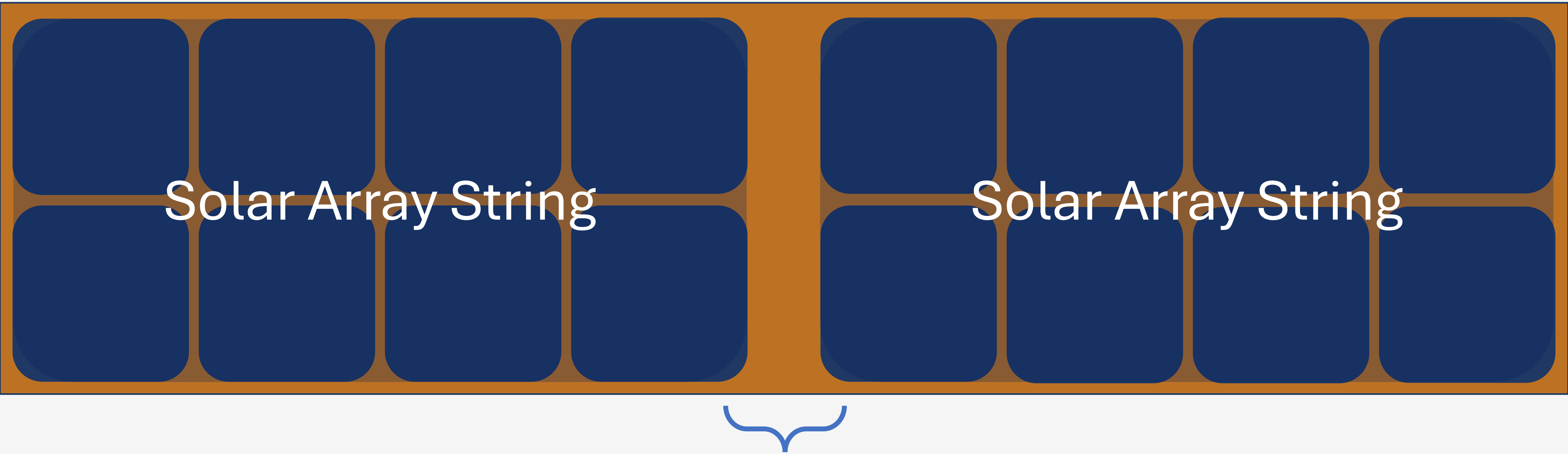




slow motion

real time

Current State of Practice



Distance between strings: **above a cell-dependent threshold**

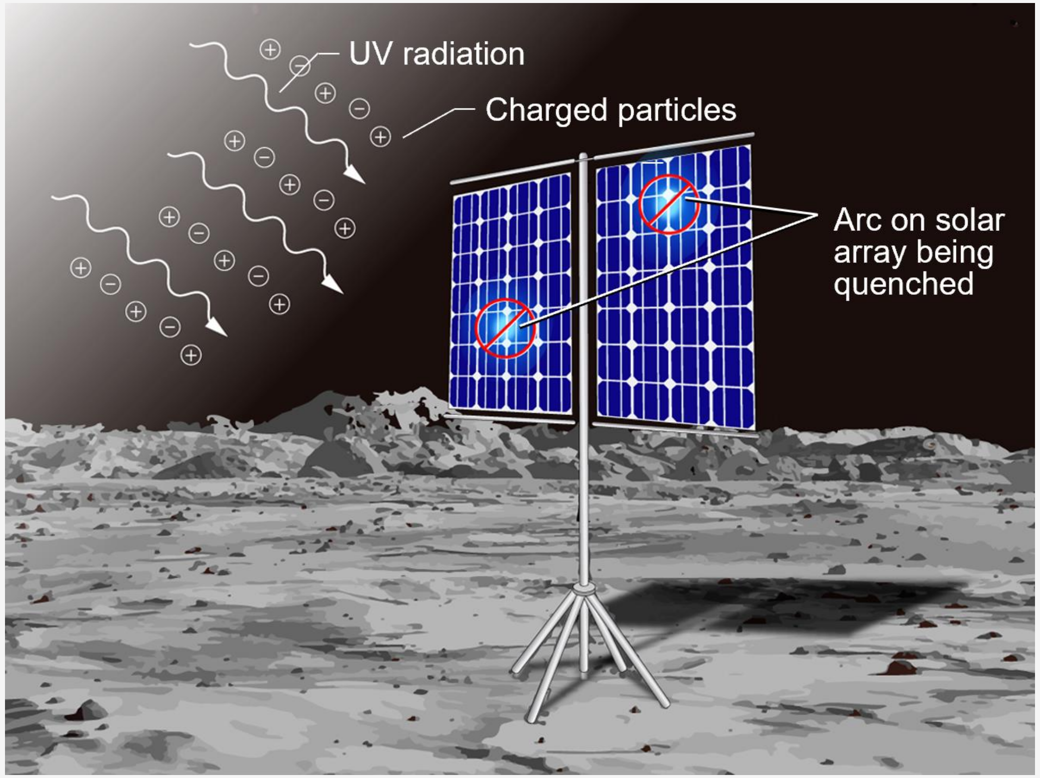
Cell-to-cell voltage: **< 40V**

Does not account for *next-generation solar cells* (larger/higher voltage, thin film) and *lunar environment*

Capabilities under Development

Passive:

- Aimed at thin film solar cells (susceptible to primary arcing)
- Develop and test architecture to prevent primary arcs



Active:

- Improve upon secondary arcing protections
- Novel high-speed circuitry that detects and quenches secondary arcs

Adaptive:

- Protect solar arrays in variable charging environments while maximizing power
- Develop dataset and ML/AI algorithm for controlling circuitry in lunar environmental extremes

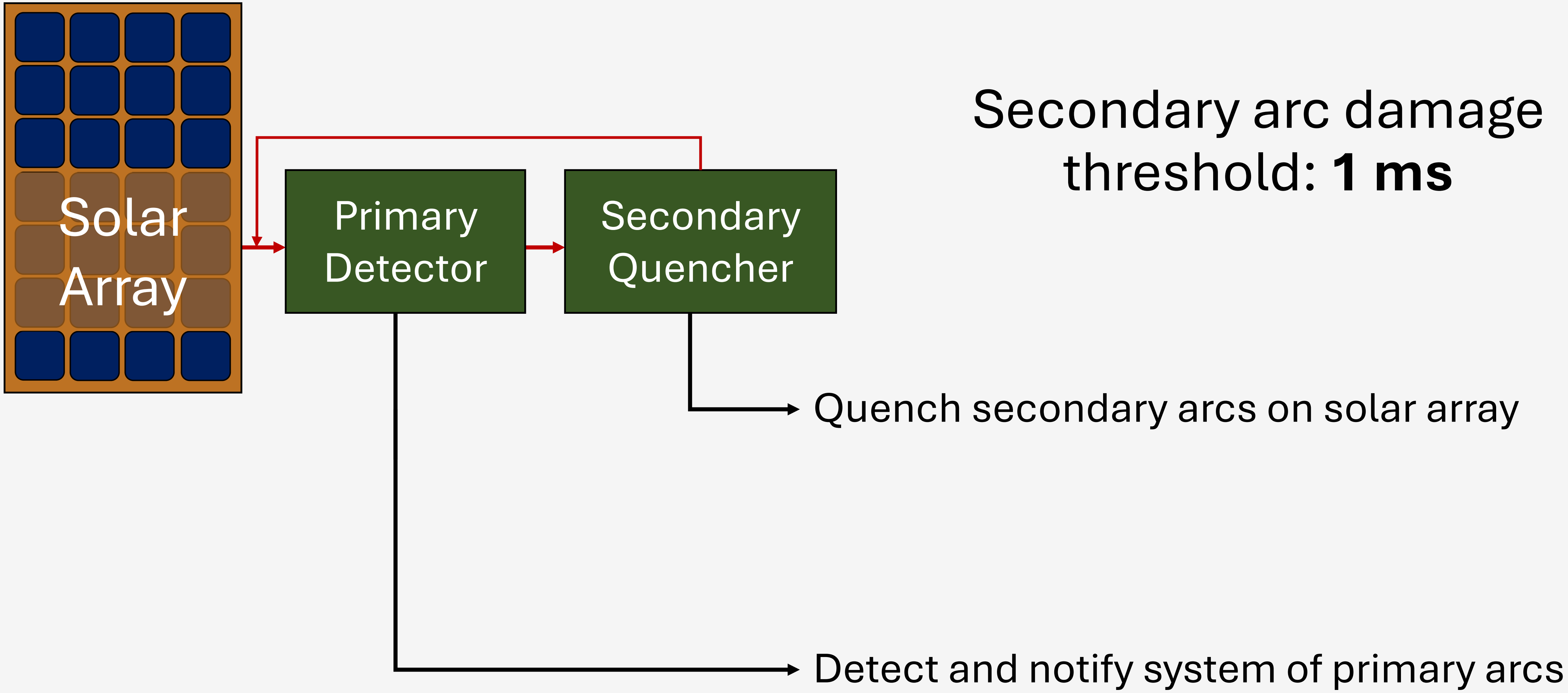
Benefits

- **High Voltage Operations**: bypassing current best practices allows for higher bus voltages, **lowering conductor mass** and **increasing power output**

- **Enable next-generation solar cells**: prepare novel solar cells to **survive the harsh lunar surface charging environment**

- **Boost reliability and resiliency of solar arrays**: lower risk of arcing damage **increases array lifetimes**

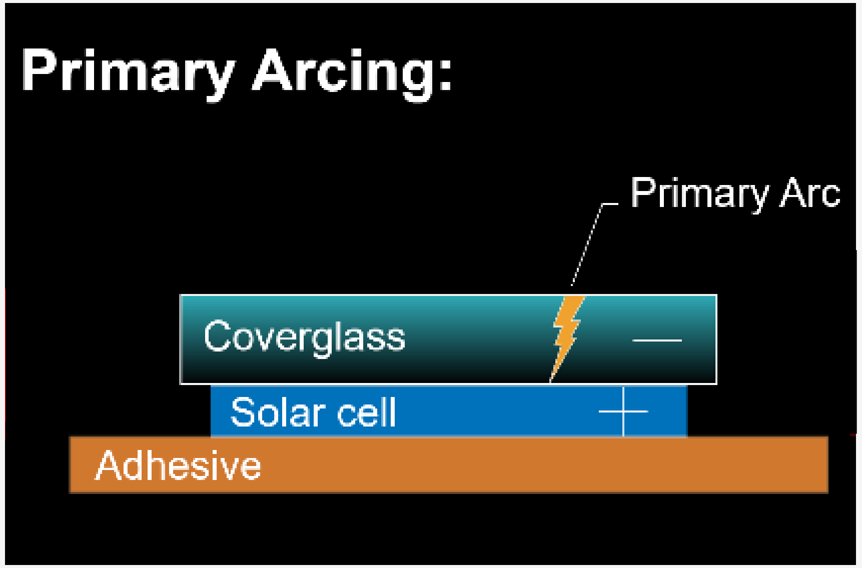
Active Arc Mitigation



Secondary arc damage threshold: **1 ms**

Primary Arc Detector

- Monitors the solar array current without interfering or impacting power
- Detects a primary arc event and notifies the system
- Key qualities: fast, accurate
- **Crucial for ML/AI integration and variable environment sensing**

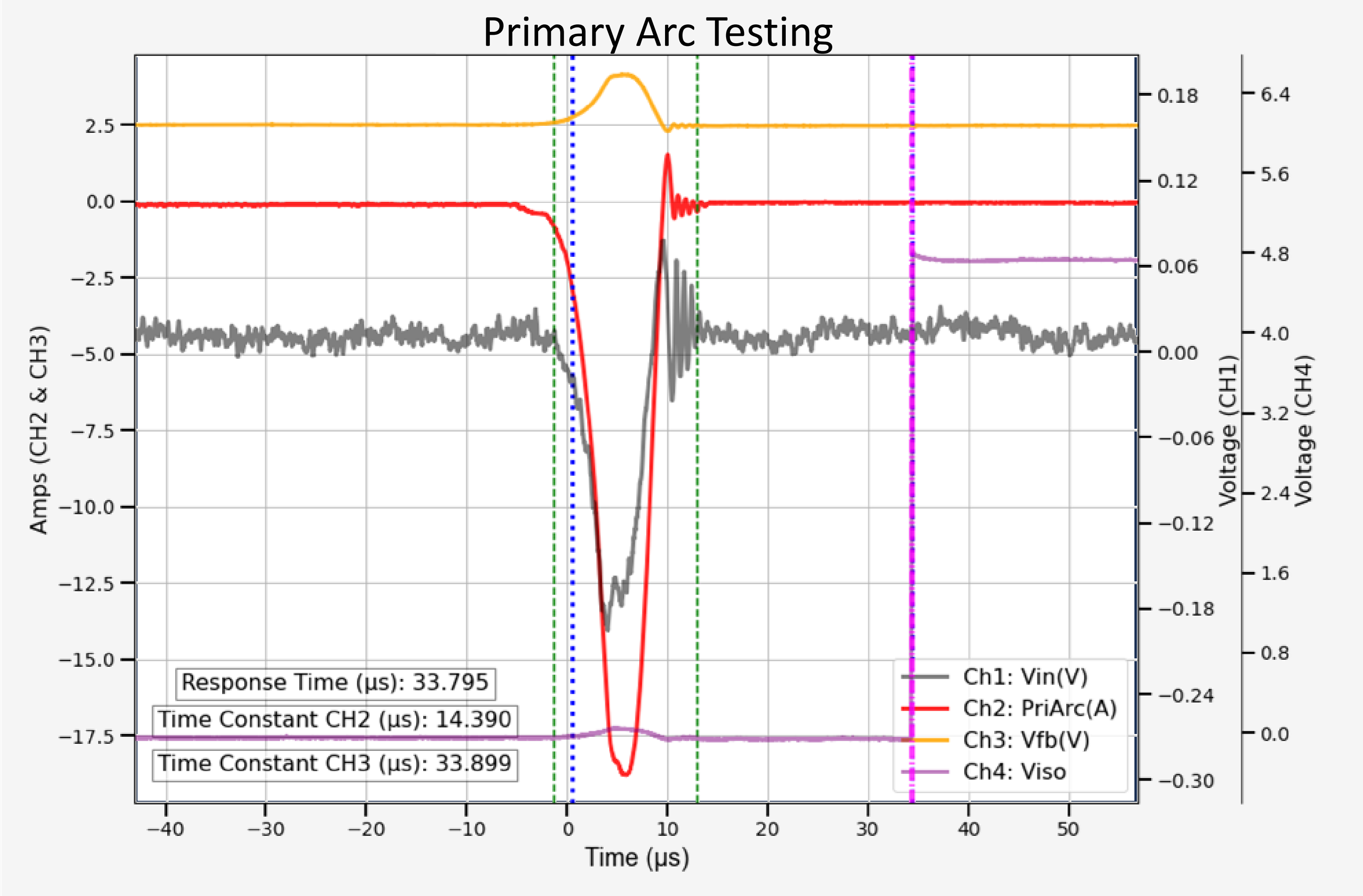


environmental sensors monitoring array → primary arc → detector **measures** and **confirms** arc event → arc event notification → **Primary Arc Detected**

Primary Arc Detector

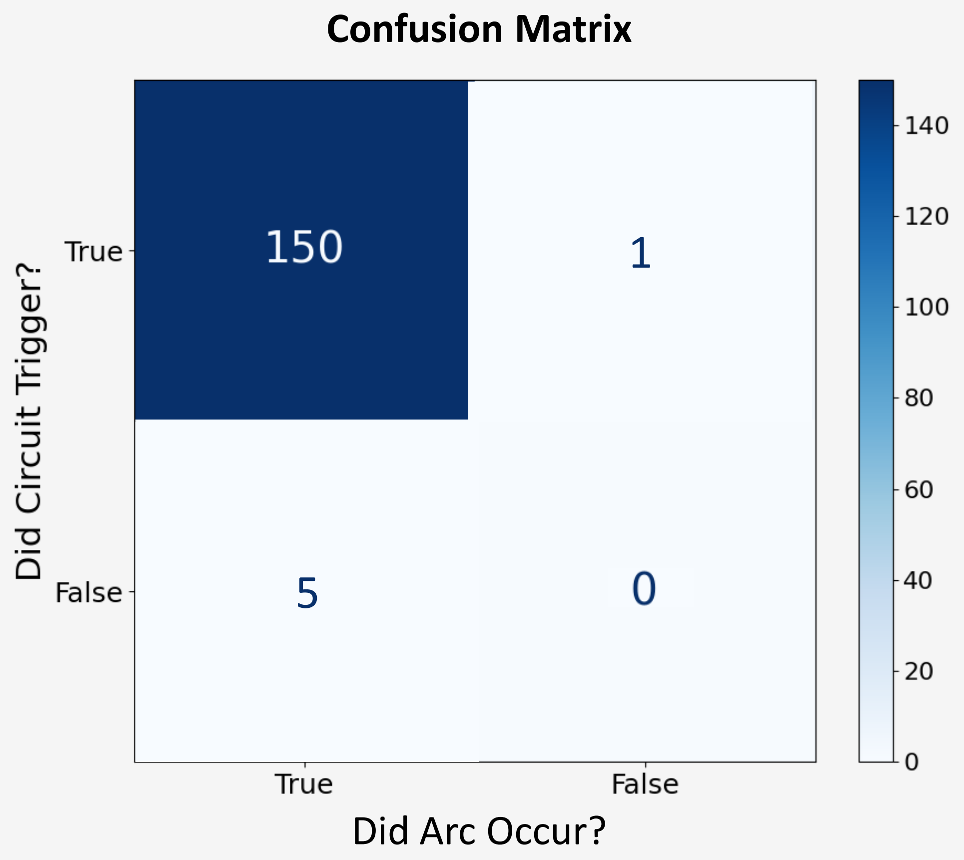
- Series of programmable analog bandpass filters for arc signal filtering

- Performance:
  - Average response time**: 25 μs**



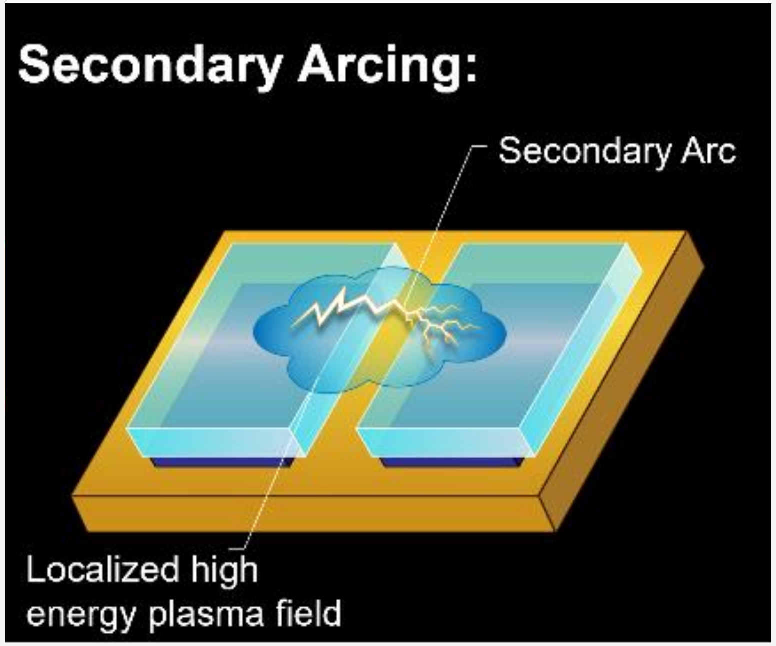
Primary Arc Detector

- 156 Arcs detected with active circuitry
- Utilizing a Stochastic Hill Climbing ML algorithm
- Algorithm took ~10-12 arc events to establish arc rate and lock in bandpass filter selection
- 96% detection accuracy over data set of 156 Arcs



Secondary Arc Quencher

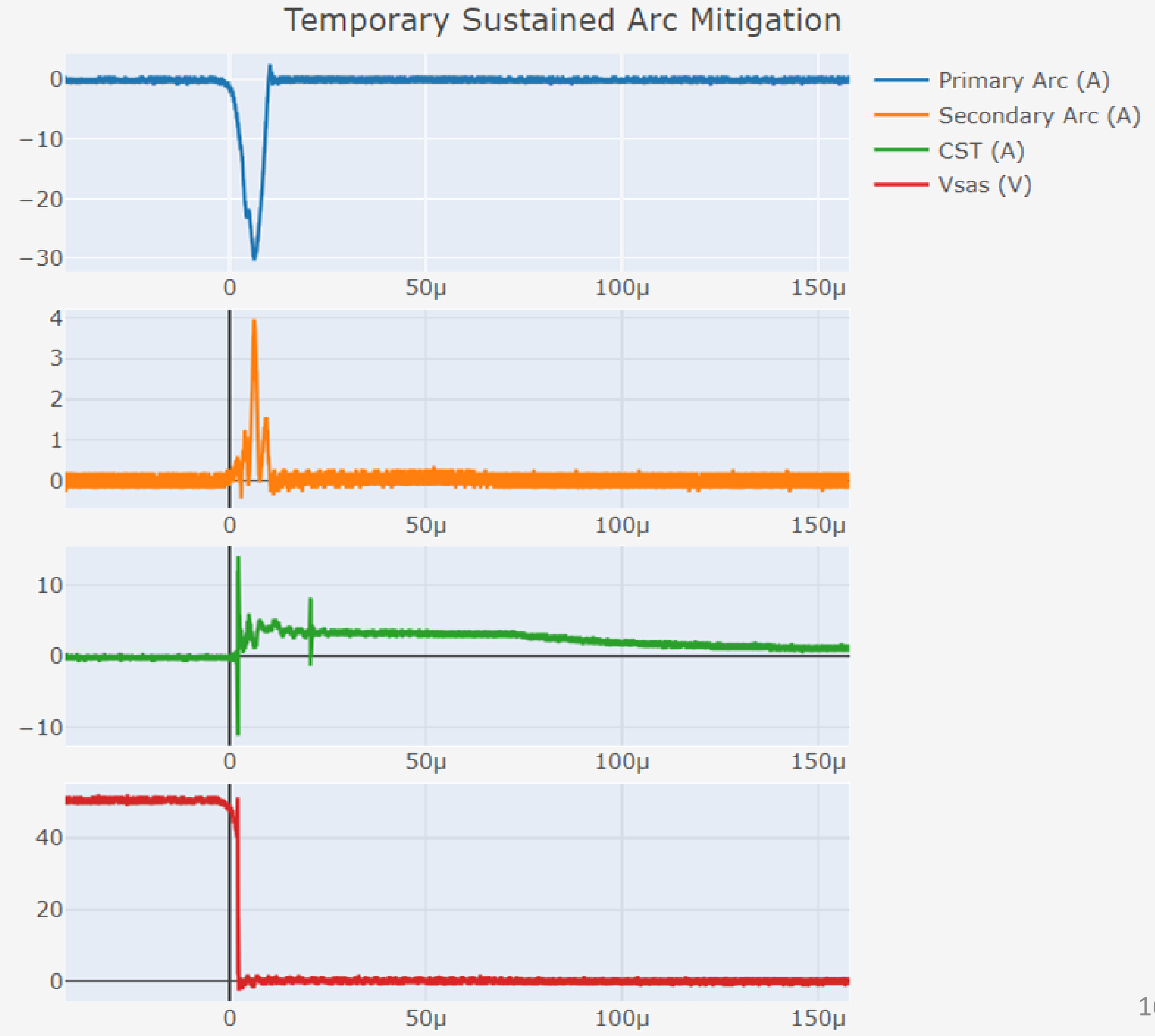
- Reroutes and absorbs the current generated during a secondary arc
- Key qualities: fast, robust
- **Crucial for mitigating damage via secondary arcs**



secondary arc current → quencher **redirects** and **dissipates** current → solar cells shorted → **Secondary Arc Quenched**

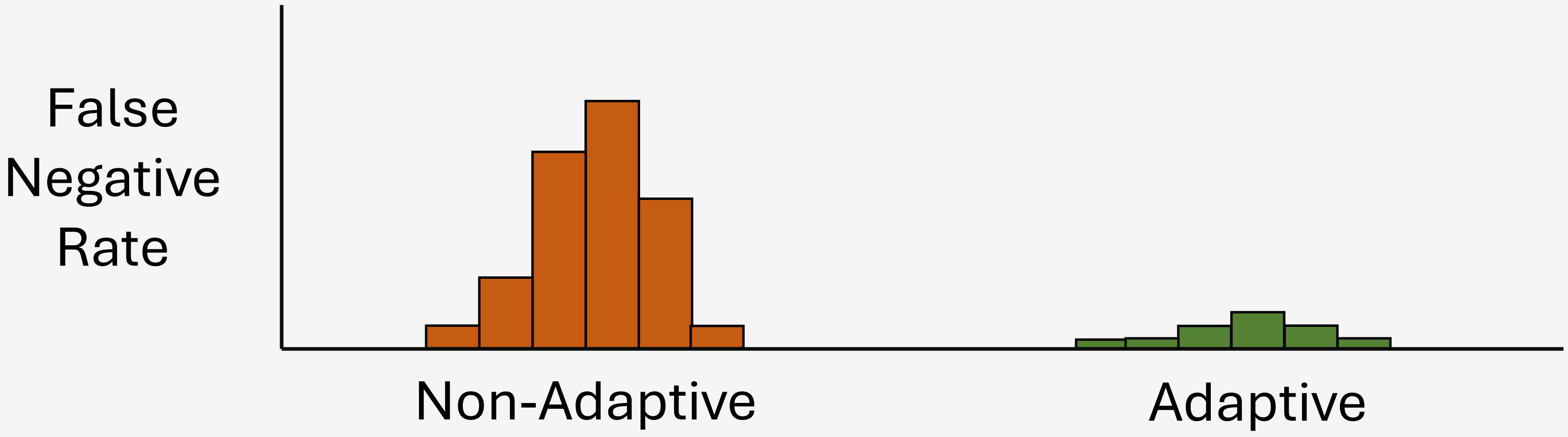
Secondary Arc Quencher

- Solar array voltage is shorted to 0 V
- Performance:
  - Average response time: **4.6 μs**
  - Average quench time: **~17 μs**



Adaptive Mitigation

- Rely on the **primary arc detection circuitry**; use arc rate to determine the environmental hazard level
- Exploring incorporating different environmental sensor to help inform design
- Acquire large dataset via ground testing in the PIF to train ML models
- **Target: solar array operations as a function of local charging environment to maximize power output throughout the lunar cycle**



Forward Work

- Investigate arcing behavior in **charged dust environment**
- Further development and testing of **thin film solar cells**
- Further **validation** of the active arc mitigation circuitry
- **Machine learning algorithm** development and testing

Conclusion

MAI TAI aims to enable **resilient**, **high voltage**, **high power density** solar array installations on the lunar surface through novel arcing mitigation technology development.

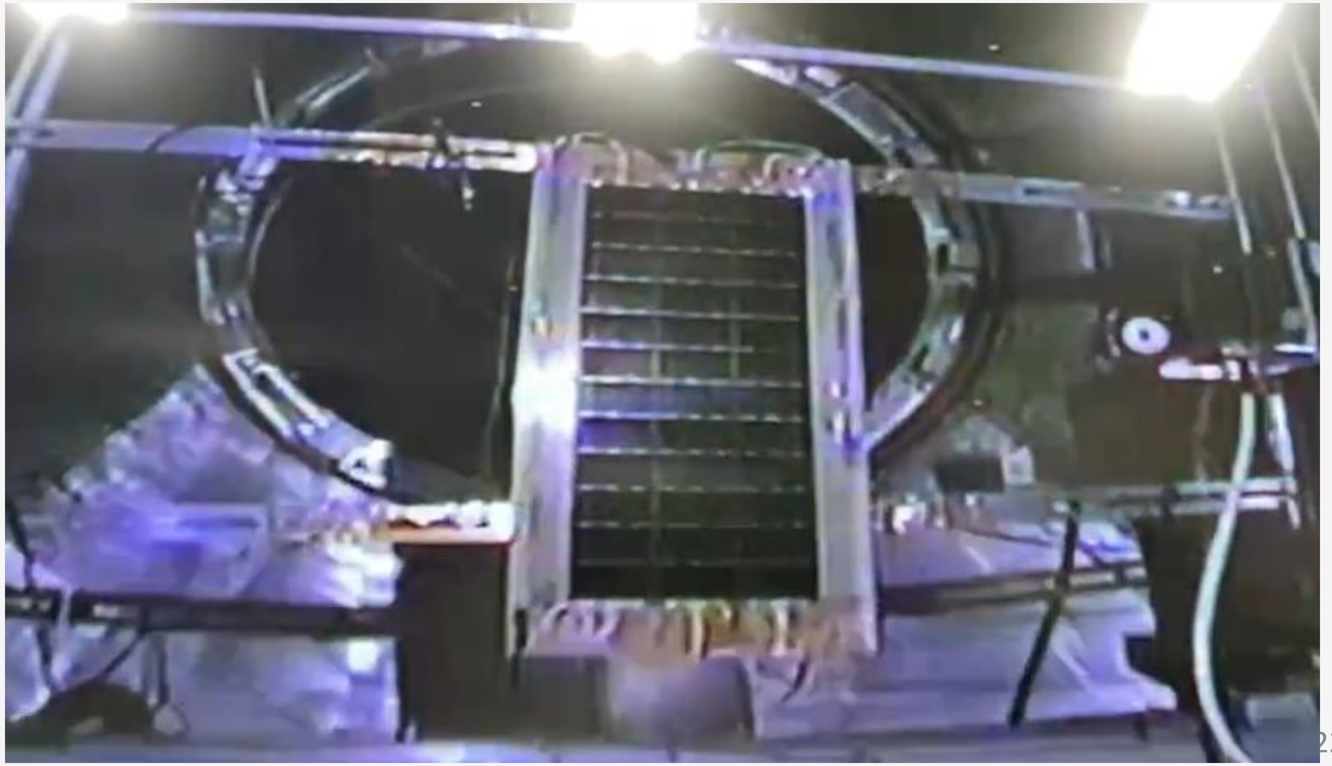
Lunar Dust

- Impact of Lunar Simulant on Space Solar Cell Performance
- Thursday, May 1
- Energy Generation III – Reliability and Characterization

Backup Slides

Test Facilities: VF-20

- Spacecraft charging investigations
- Simulate LEO and GEO conditions for ESD testing



Passive Mitigation

Transparent Conductive Oxides (TCOs) dissipate built-up charge on the surface of solar cells *without* significant absorption of incoming light.

Characterization Plan: Analyze thin film coatings before and after exposure experiments to understand their performance in extreme environments.

PVD interior

Physical Vapor Deposition (PVD) System