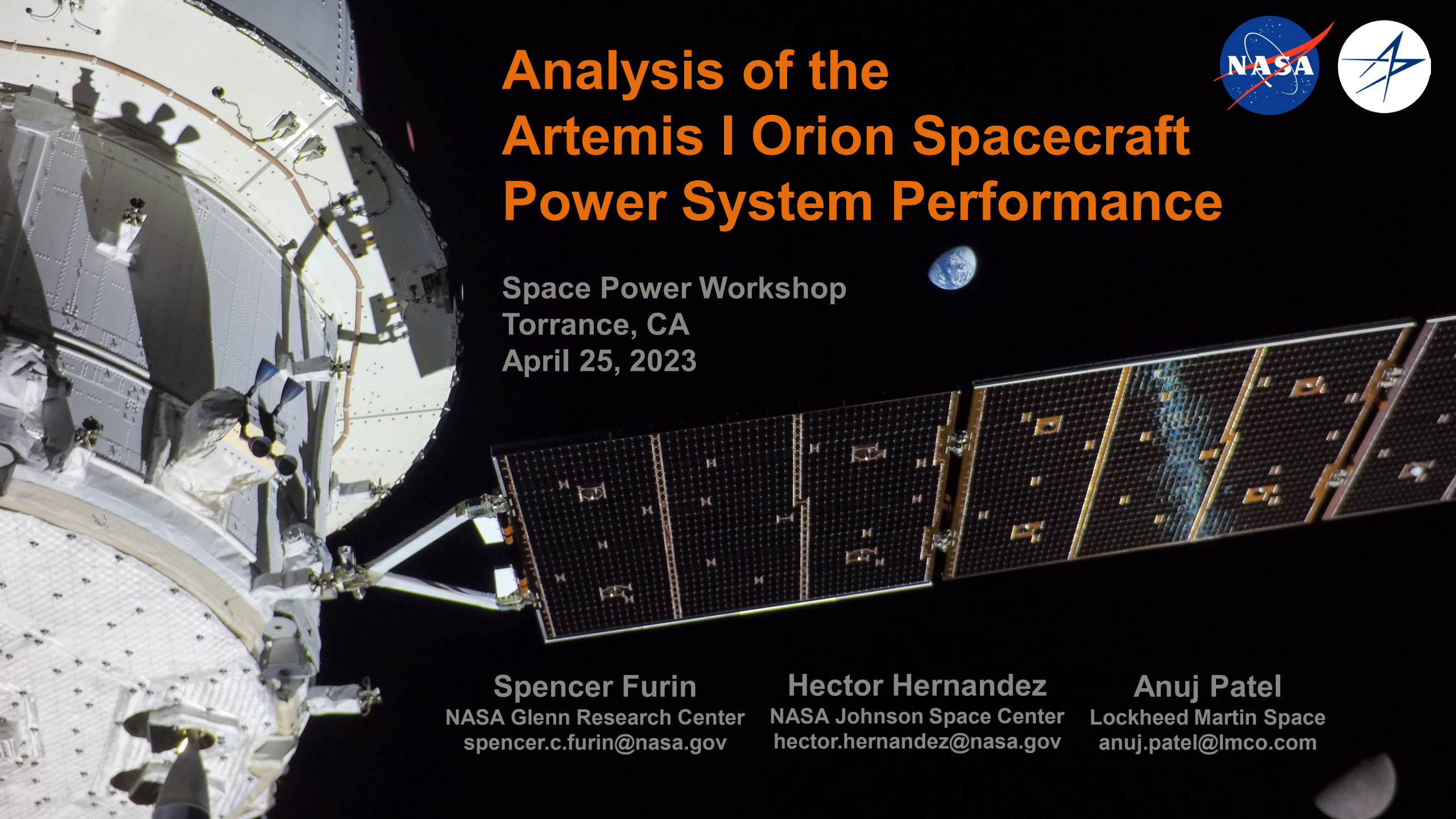
Analysis of the Artemis I Orion Spacecraft Power System Performance



Space Power Workshop
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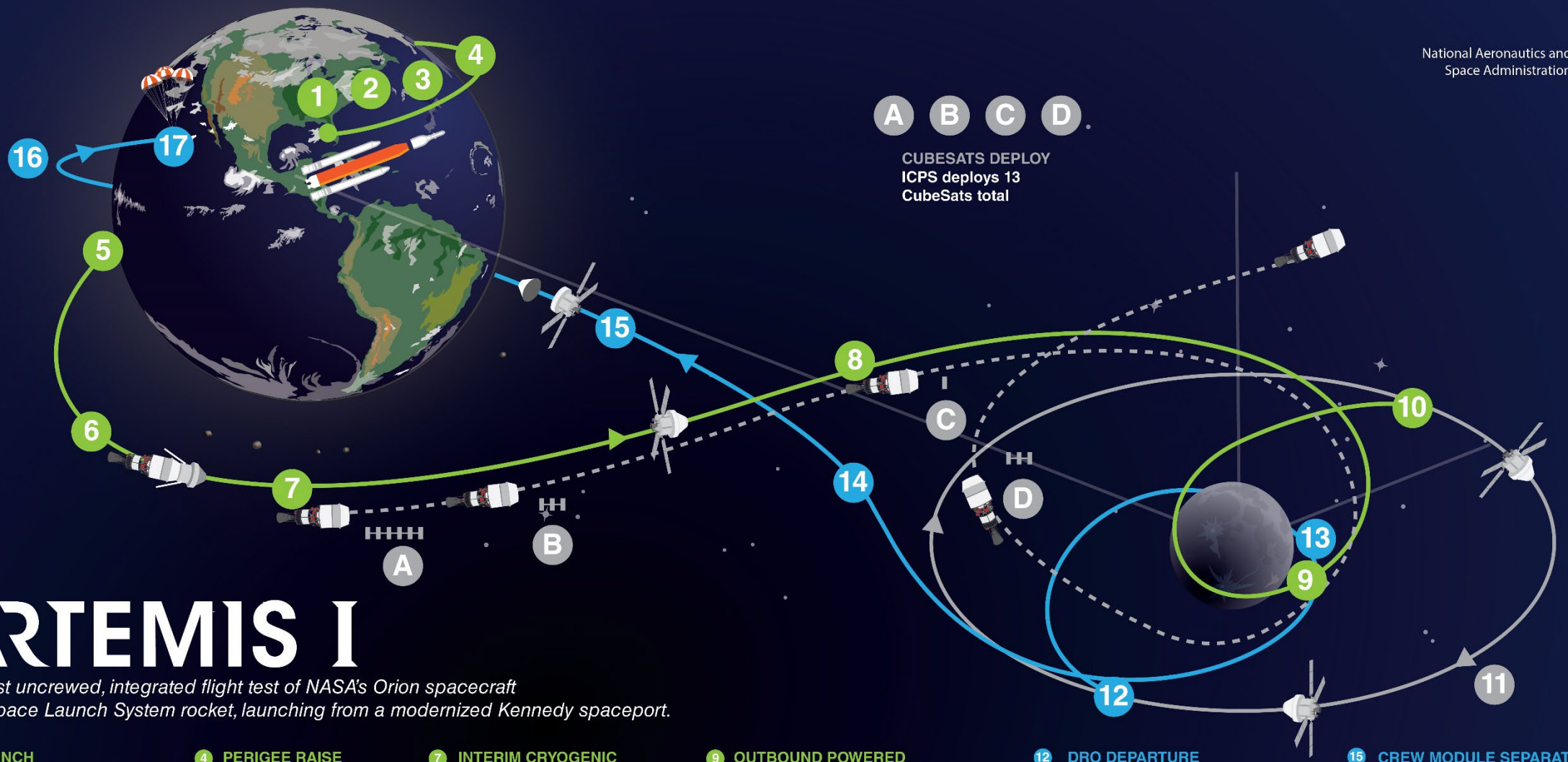
Spencer Furin
NASA Glenn Research Center
spencer.c.furin@nasa.gov

Hector Hernandez
NASA Johnson Space Center
hector.hernandez@nasa.gov

Anuj Patel
Lockheed Martin Space
anuj.patel@lmco.com

National Aeronautics and Space Administration



CUBESATS DEPLOY
ICPS deploys 13 CubeSats total

ARTEMIS I

The first uncrewed, integrated flight test of NASA's Orion spacecraft and Space Launch System rocket, launching from a modernized Kennedy spaceport.

1 **LAUNCH**
SLS and Orion lift off from pad 39B at Kennedy Space Center.

2 **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**

3 **CORE STAGE MAIN ENGINE CUT OFF**
With separation.

4 **PERIGEE RAISE MANEUVER**

5 **EARTH ORBIT**
Systems check with solar panel adjustments.

6 **TRANS LUNAR INJECTION (TLI) BURN**
Maneuver lasts for approximately 20 minutes.

7 **INTERIM CRYOGENIC PROPULSION STAGE (ICPS) SEPARATION AND DISPOSAL**
The ICPS has committed Orion to TLI.

8 **OUTBOUND TRAJECTORY CORRECTION (OTC) BURNS**
As necessary adjust trajectory for lunar flyby to Distant Retrograde Orbit (DRO).

9 **OUTBOUND POWERED FLYBY (OPF)**
60 nmi from the Moon; targets DRO insertion.

10 **LUNAR ORBIT INSERTION**
Enter Distant Retrograde Orbit for next 6-23 days.

11 **DISTANT RETROGRADE ORBIT**
Perform half or one and a half revolutions in the 12 day orbit period 38,000 nmi from the surface of the Moon.

12 **DRO DEPARTURE**
Leave DRO and start return to Earth.

13 **RETURN POWER FLY-BY (RPF)**
RPF burn prep and return coast to Earth initiated.

14 **RETURN TRANSIT**
Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time 5-11 days.

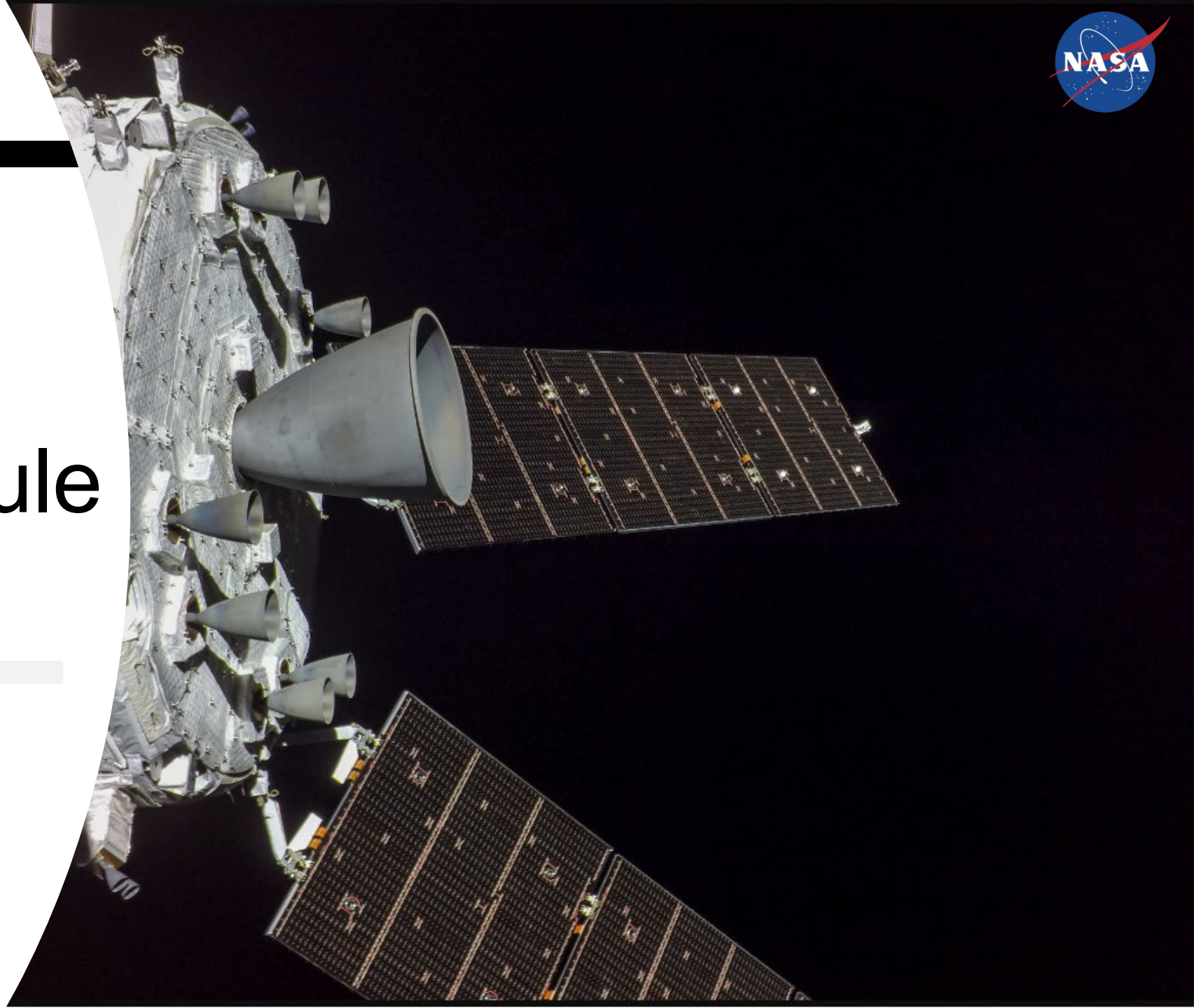
15 **CREW MODULE SEPARATION FROM SERVICE MODULE**

16 **ENTRY INTERFACE (EI)**
Enter Earth's atmosphere.

17 **SPLASHDOWN**
Pacific Ocean landing within view of the U.S. Navy recovery ship.

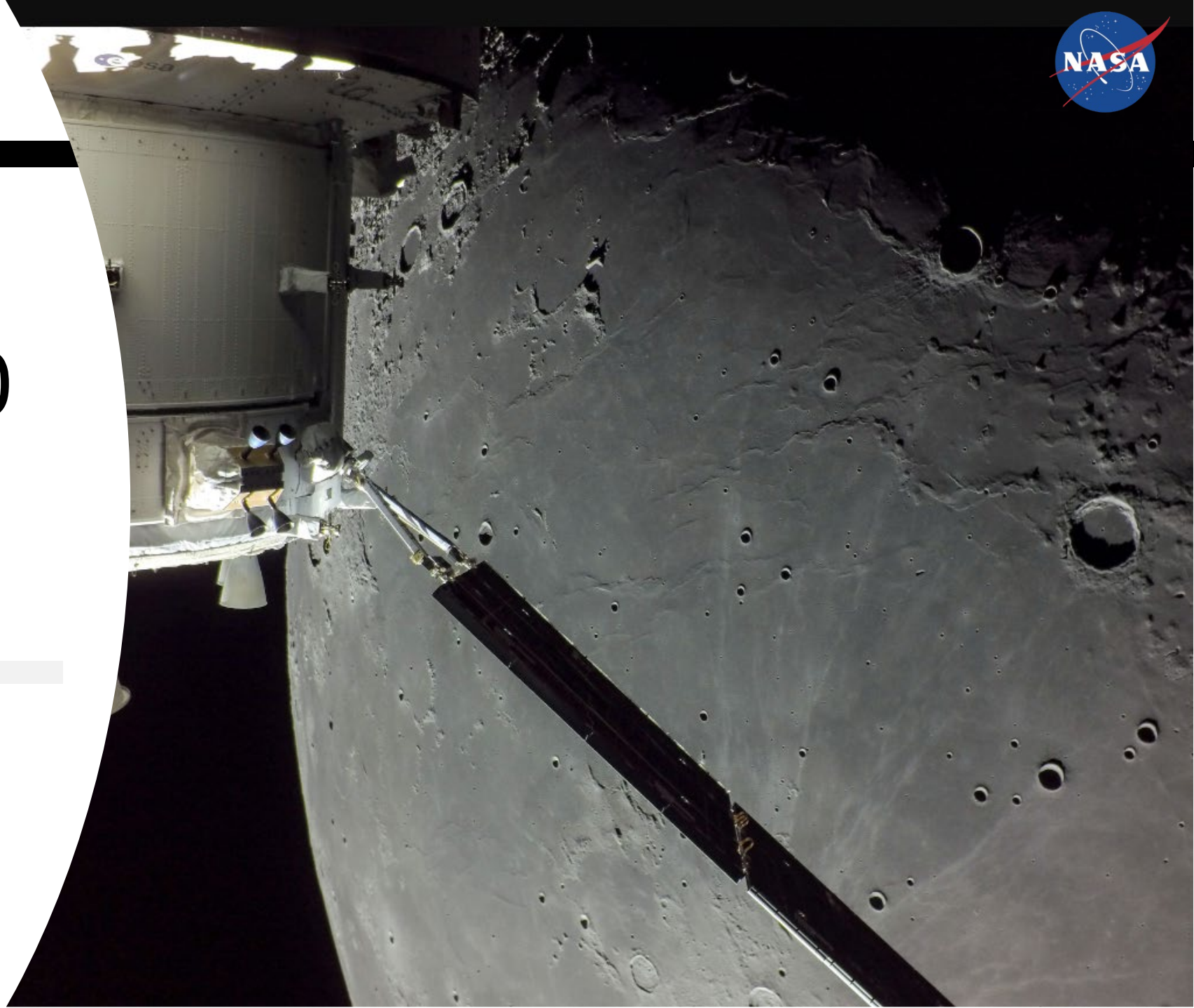
Flight Day 1 Post-Solar Array Deployment

Flight Day 1 Service Module Inspection

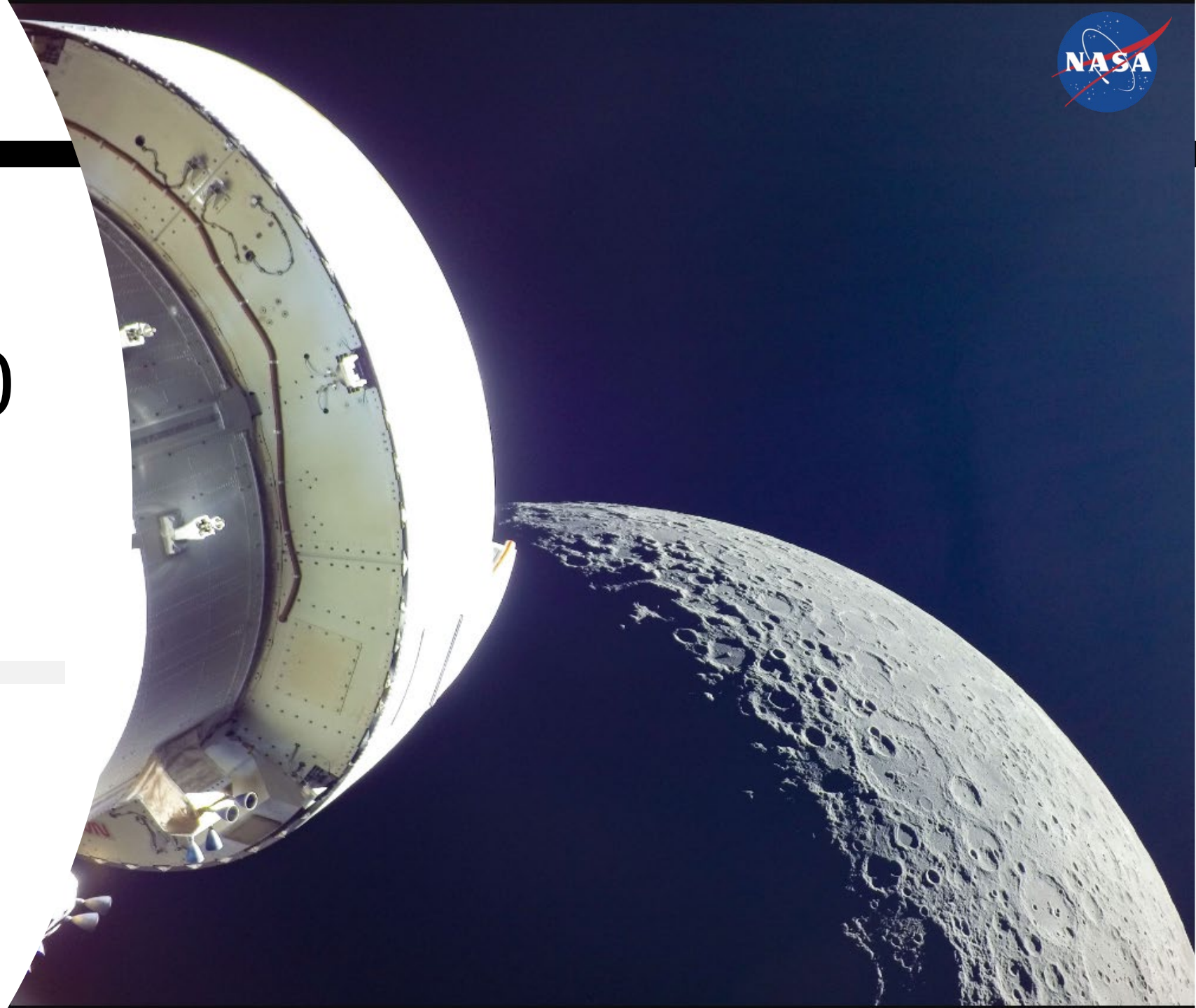


Flight Day 13 Orion Selfie

Flight Day 20
Pre-
Lunar Flyby



Flight Day 20
Post-
Lunar Flyby



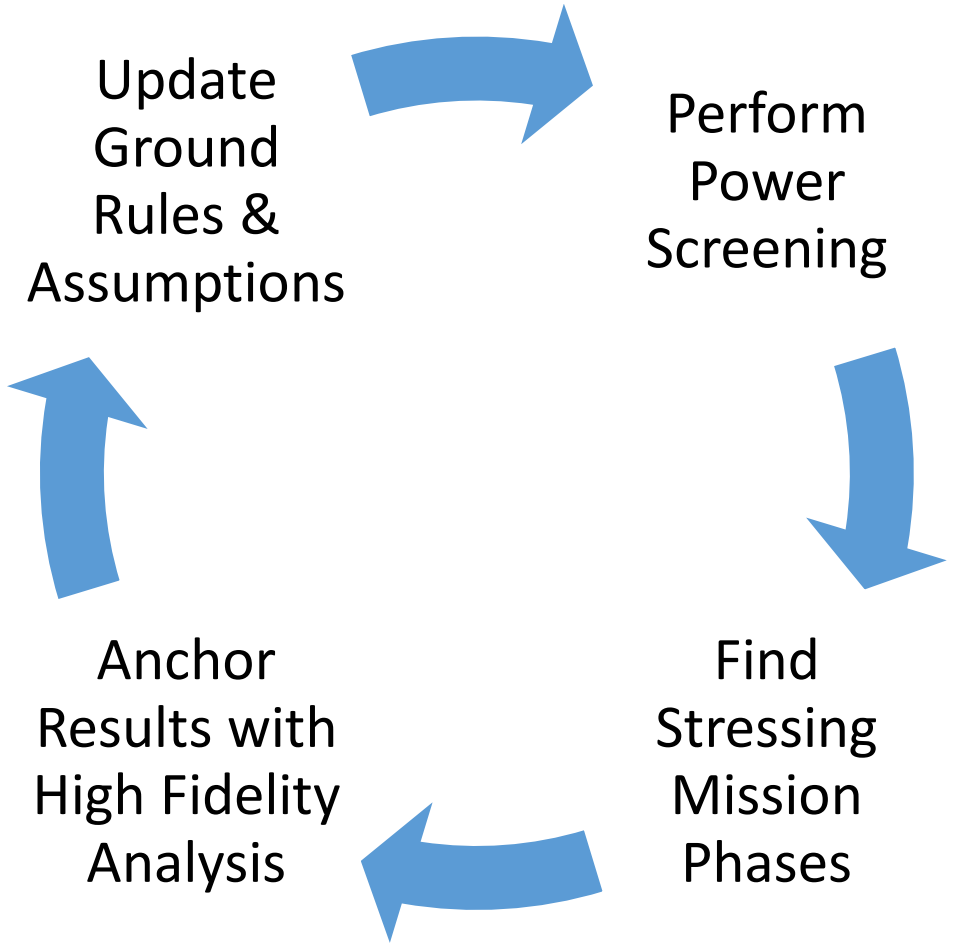
Analysis Tools

- **High fidelity**
  - Spacecraft Power Capability (SPoC), Lockheed Martin
  - System Power Analysis for Capability Evaluation (SPACE), NASA GRC
  - Used for verification of requirements and validation of mission plans
  - Detailed inputs and assumptions, modelling a particular case (slow to setup)
  - Choosing a conservative and bounding case can be challenging
- **Screening**
  - Power screening tool, Lockheed Martin
  - Simpler, conservative assumptions (fast to setup and run)
  - Quickly assess thousands of possible trajectories

Challenges – Analyze the Mission Space

- **Rapidly analyze years' worth of launch opportunities (17,000+ trajectories)**
- **Sun, Earth and Moon phasing throughout the year causes eclipses to move relative to major mission events**
  - Could not use generic mission timeline analysis across the mission space
  - Mission duration variability (28-42 days) caused additional complexity
- **Ensure Orion survives with potential power faults, such as:**
  - 1 Battery Failure
  - 1 Solar Array Wing Failure
- **Provide mission ops situational awareness for potentially power stressing situations**
  - Deconflict events such as correction burns or out of attitude maneuvers (that reduce power generation)

Reducing Fidelity, Increasing Speed

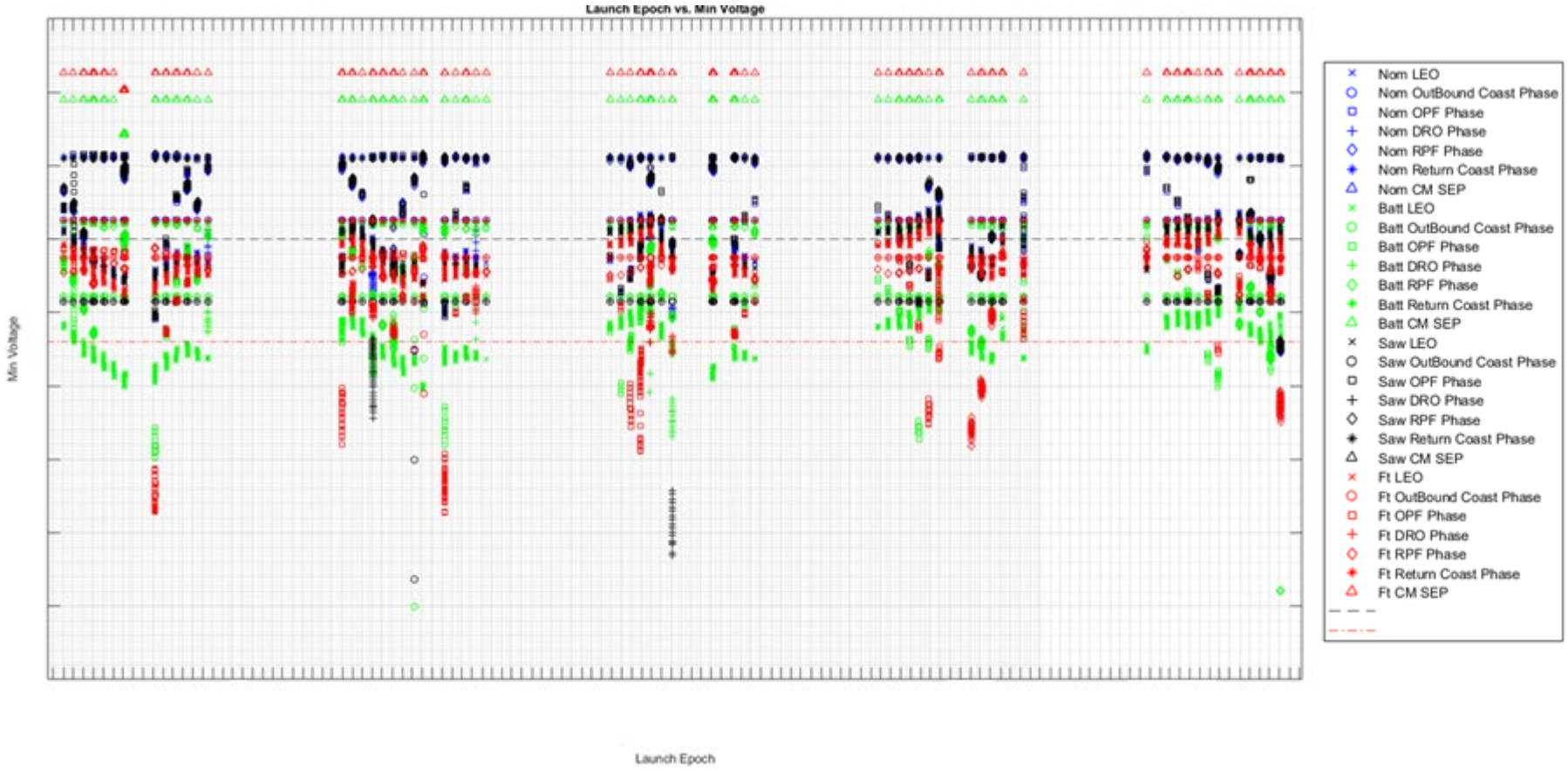


- **Create a new analysis tool that would leverage existing trajectory data, assume conservative CONOPS, and simple charging and discharging models to speed up the analysis**
  - Charging and Discharging assumptions are based in high fidelity SIMULINK Integrated battery model (SPOC)
- **High Fidelity analysis takes ~20 hours to run an End-to-End power analysis**
- **New Power Screening Tool can scan over 17,000 trajectories in less than 2hrs**
- **Ensure the Power Screening tool is more conservative such that the results are bounding**

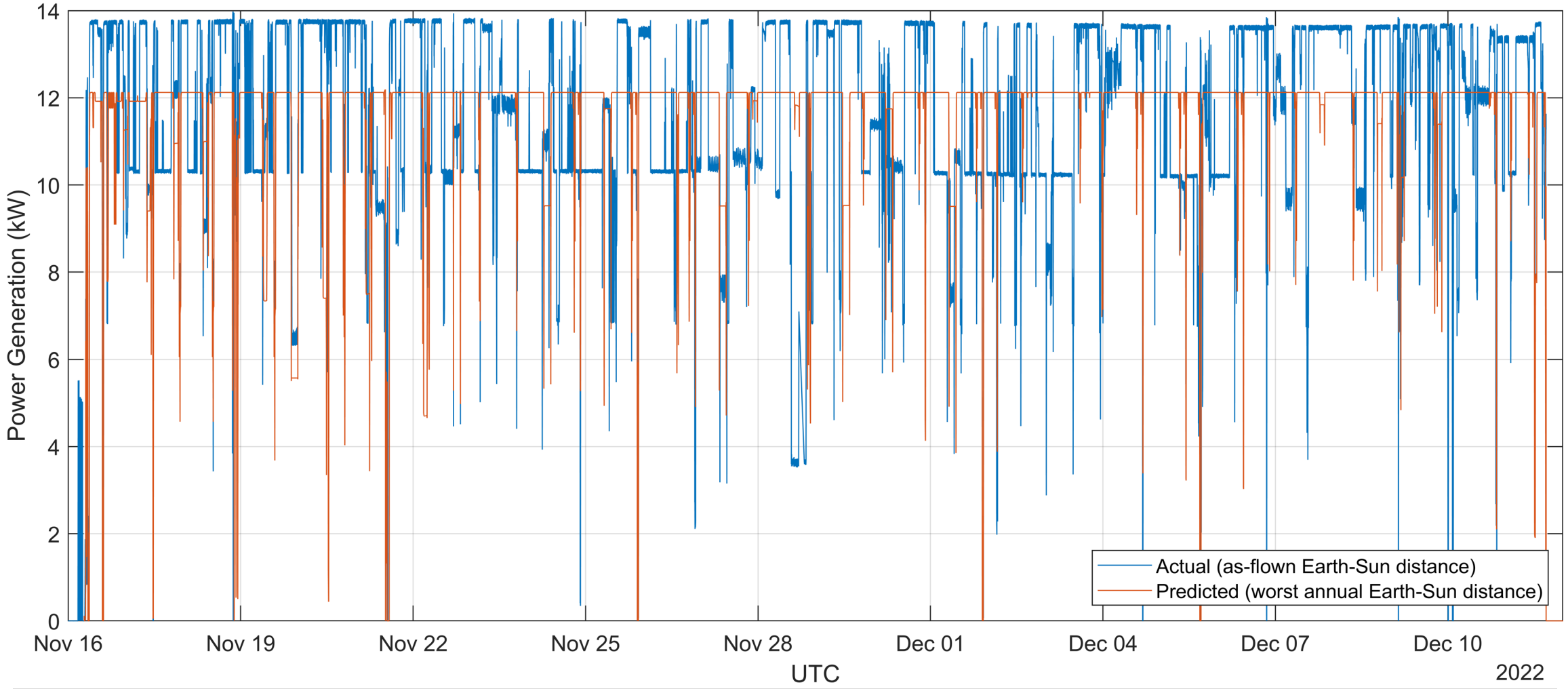
Continuous integration led to quick analysis turnaround

Go/No-Go Recommendations

- Launch window cutouts based on minimum voltage for a given epoch
- Provide situational awareness to mission ops to schedule power downs prior to stressing situations

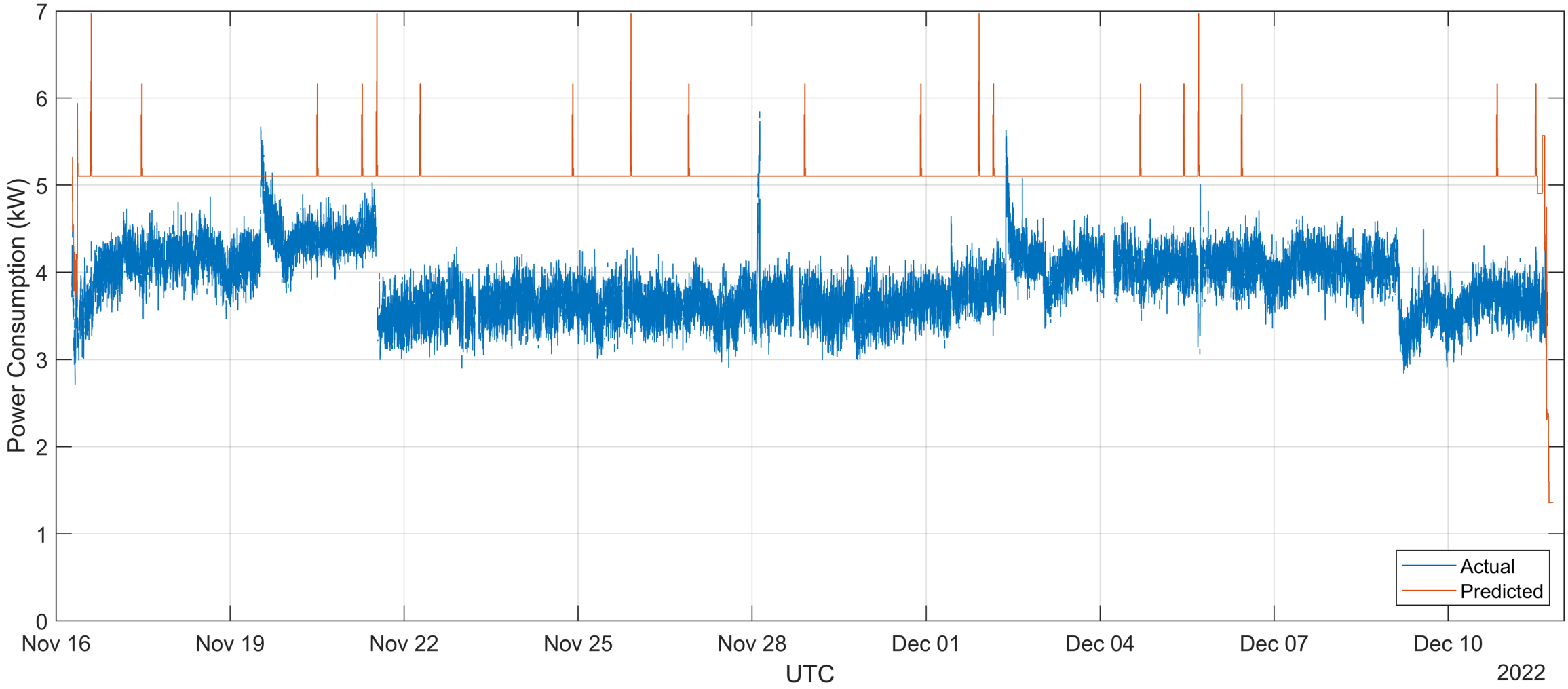


Power Generation



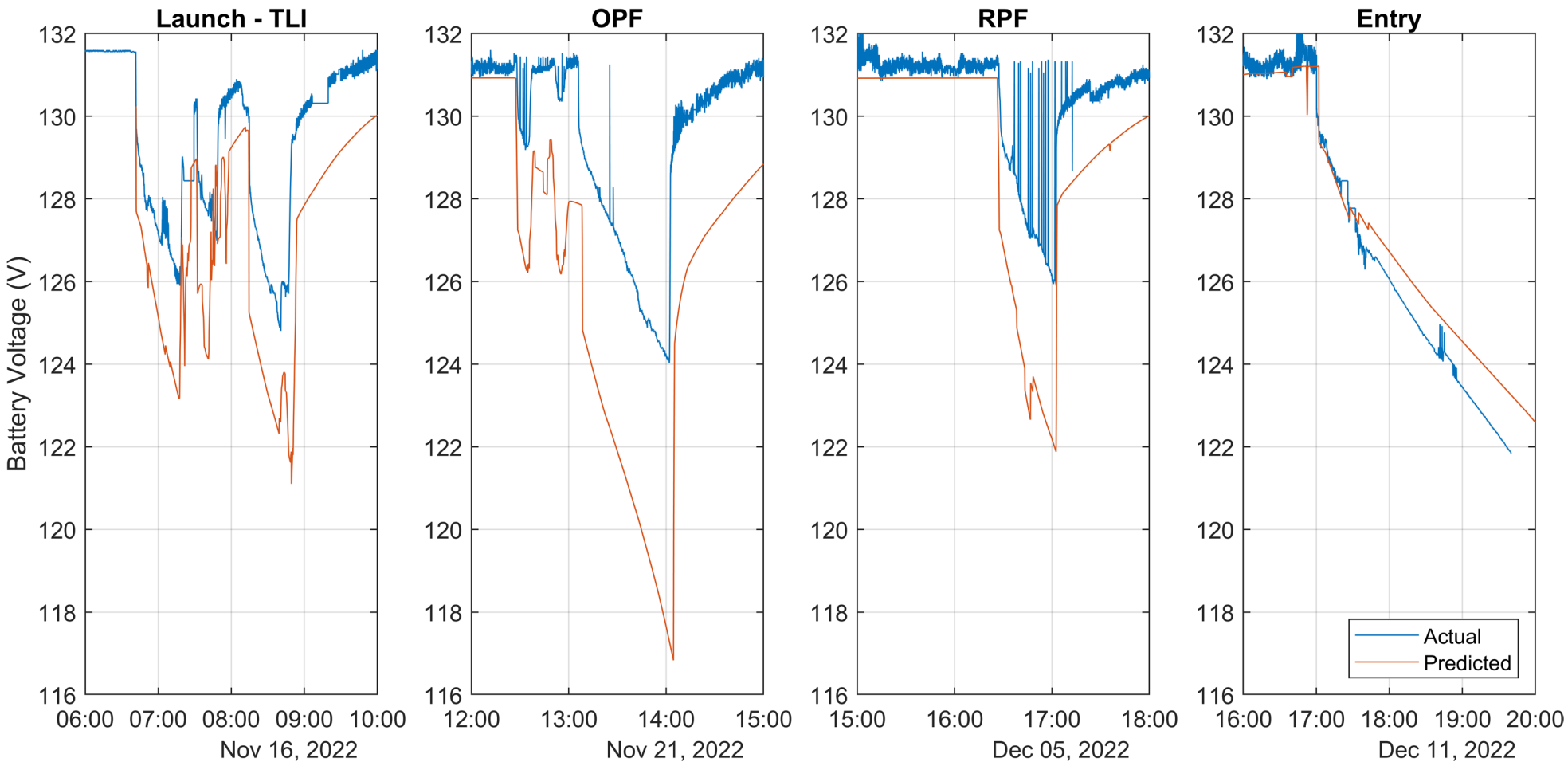
Significant additional power generation primarily due to higher solar flux in Nov/Dec
Model predictions were within ~3% after correcting for as-flown flux

Load Demand



Lower than expected loads driven by heater usage

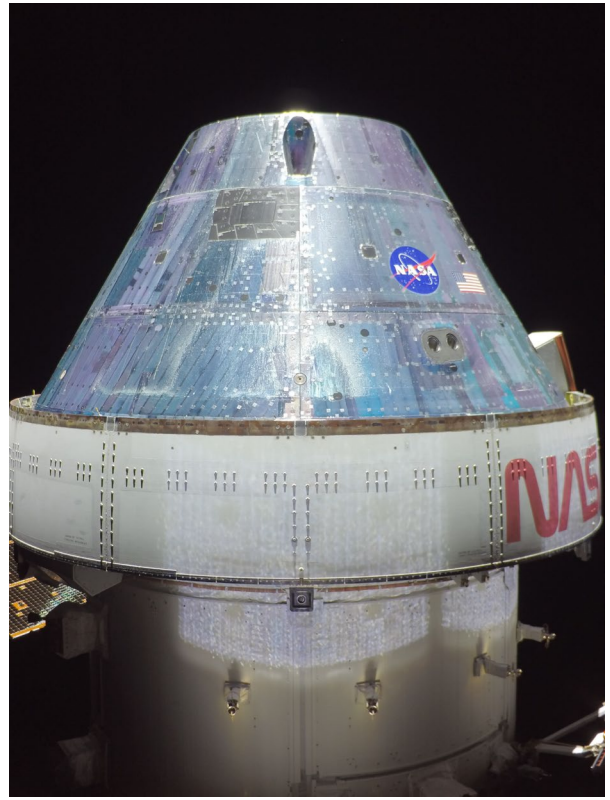
Battery Voltage



Battery performance benefited from low overall load demand

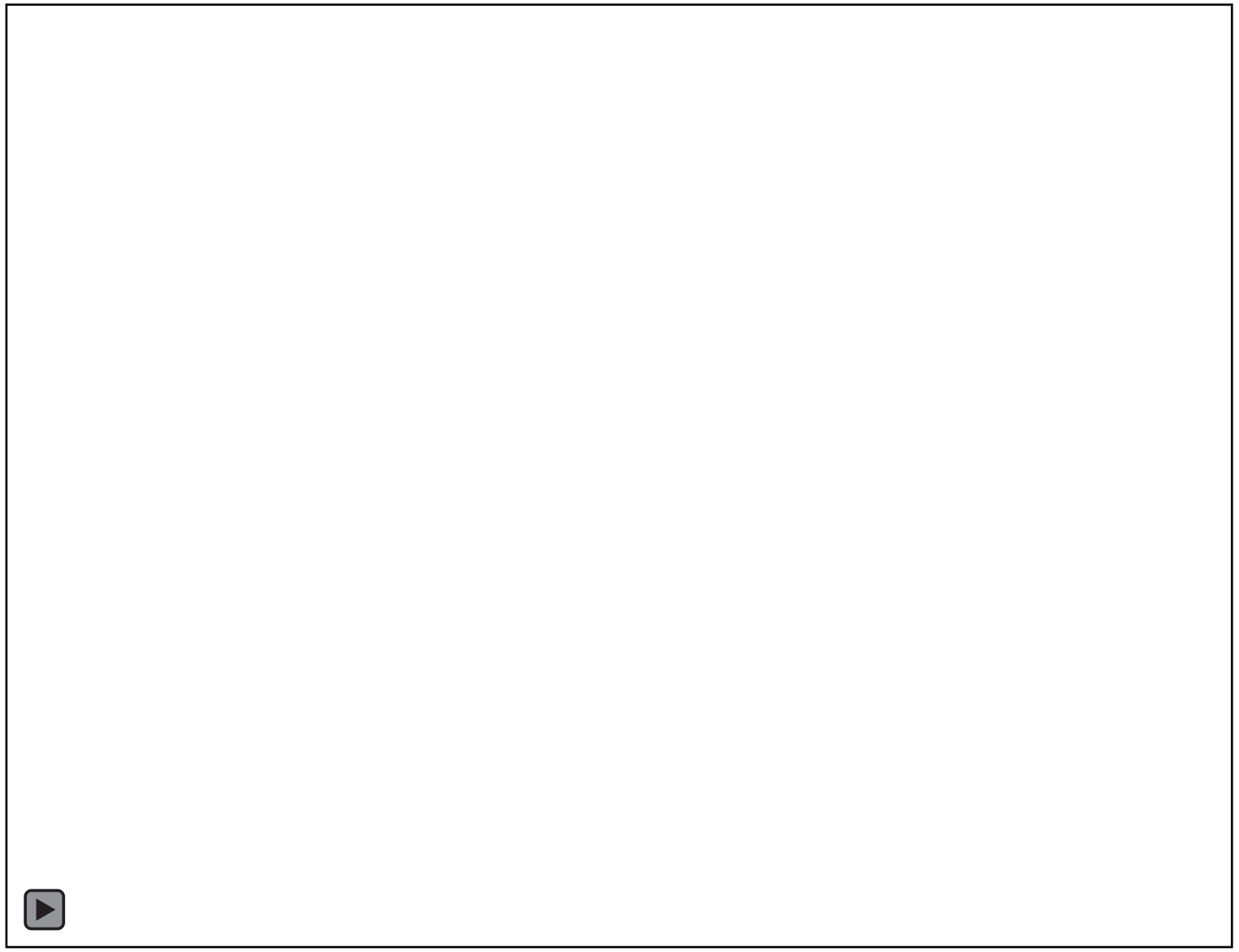
Anomalies and Interesting Observations

- **PCDU LCL Uncommanded Opening Anomaly**
  - Uncommanded opening of latching current limiter (LCL) on Power Conditioning and Distribution Unit (PCDU) end of umbilical
  - Occurred 22 times on 4 different LCLs (one at a time, always Umbilical 1)
  - One similar event involving multiple 120V load LCLs
  - One similar event involving 28V DC-DC converter internal to the PCDU
  - Never observed in ground testing at the component, subsystem, or vehicle level
  - Root cause undetermined, investigation still ongoing
- **Glint from crew module backshell**
  - Planned to measure during external survey
  - Observed localized current increases from increased flux



Anomalies and Interesting Observations

- **Solar array photoluminescence**
  - Partially shadowed string of solar cells
  - III-V cell photoluminescence occurs in visible spectrum
  - Happened to occur while filming upper stage separation



Questions?

Spencer Furin

Hector Hernandez

Anuj Patel

Acronym Definitions

- **CM** – Crew Module
- **CONOPS** – Concept of Operations
- **DC** – Direct Current
- **DRO** – Distant Retrograde Orbit
- **EI** – Entry Interface
- **GRC** – Glenn Research Center
- **ICPS** – Interim Cryogenic Propulsion Stage
- **LCL** – Latching Current Limiter
- **LEO** – Low Earth Orbit
- **NASA** – National Aeronautics and Space Administration
- **OPF** – Outbound Powered Flyby
- **OTC** – Outbound Trajectory Correction
- **PCDU** – Power Conditioning and Distribution Unit
- **RPF** – Return Powered Flyby
- **RTC** – Return Trajectory Correction
- **SLS** – Space Launch System
- **SPACE** – System Power Analysis for Capability Evaluation
- **SPoC** – Spacecraft Power Capability
- **TLI** – Trans-Lunar Injection