International Space Station Lithium-Ion Battery Start-Up and Cycling

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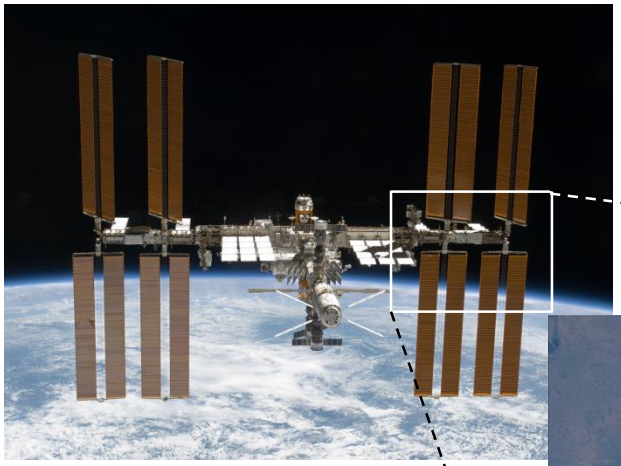
ISS Li-Ion Battery - Outline

- Configuration of Existing ISS Electric Power System
- Final Flight Adapter Plate and Battery Design
- Launch and Installation
- Battery Charge Control and LEO Cycle Test Data
- On-Orbit cycling data
- Cell and ORU Life Test

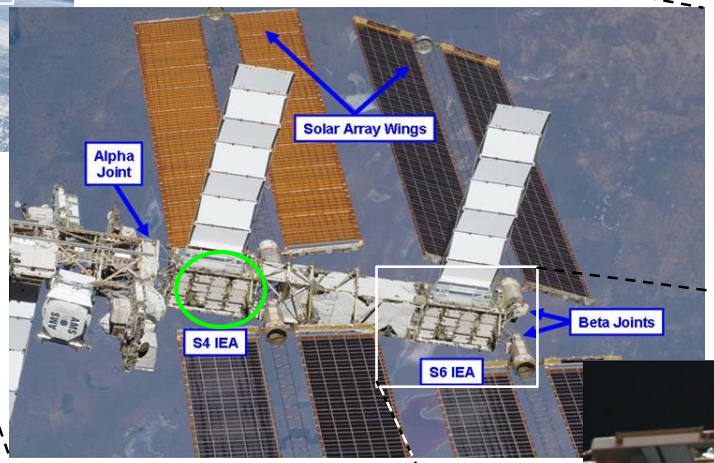
ISS Configuration - Battery Locations



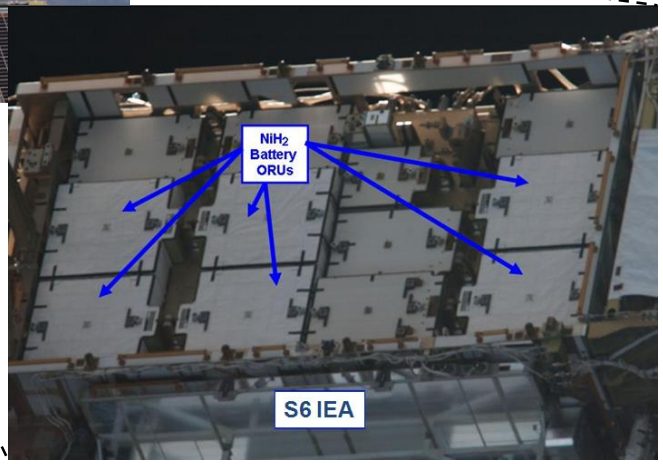
Batteries are located in the 4 Integrated Equipment Assemblies (IEAs)

2 Power Channels per IEA

8 Power Channels total



1 Li-Ion and 1 Adapter Plate replace 2 Ni-H_2



2017 Configuration:

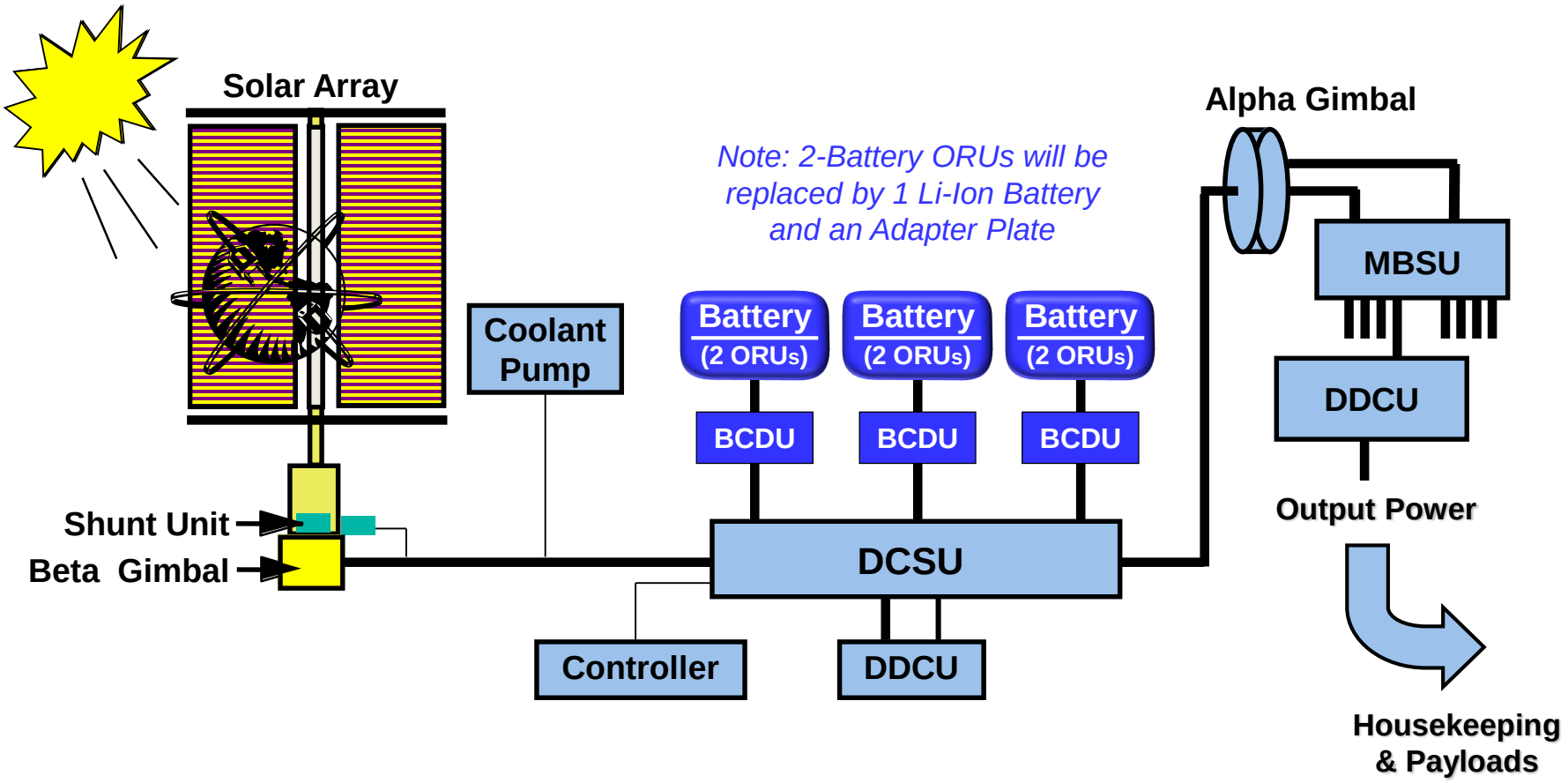
- 6 Ni-H_2 ORUs per 6 channels – 36 total
- 3 Li-Ion ORUs per 2 channels – 6 total

Final Configuration:

- 3 Li-Ion ORUs per 8 channels – 24 total

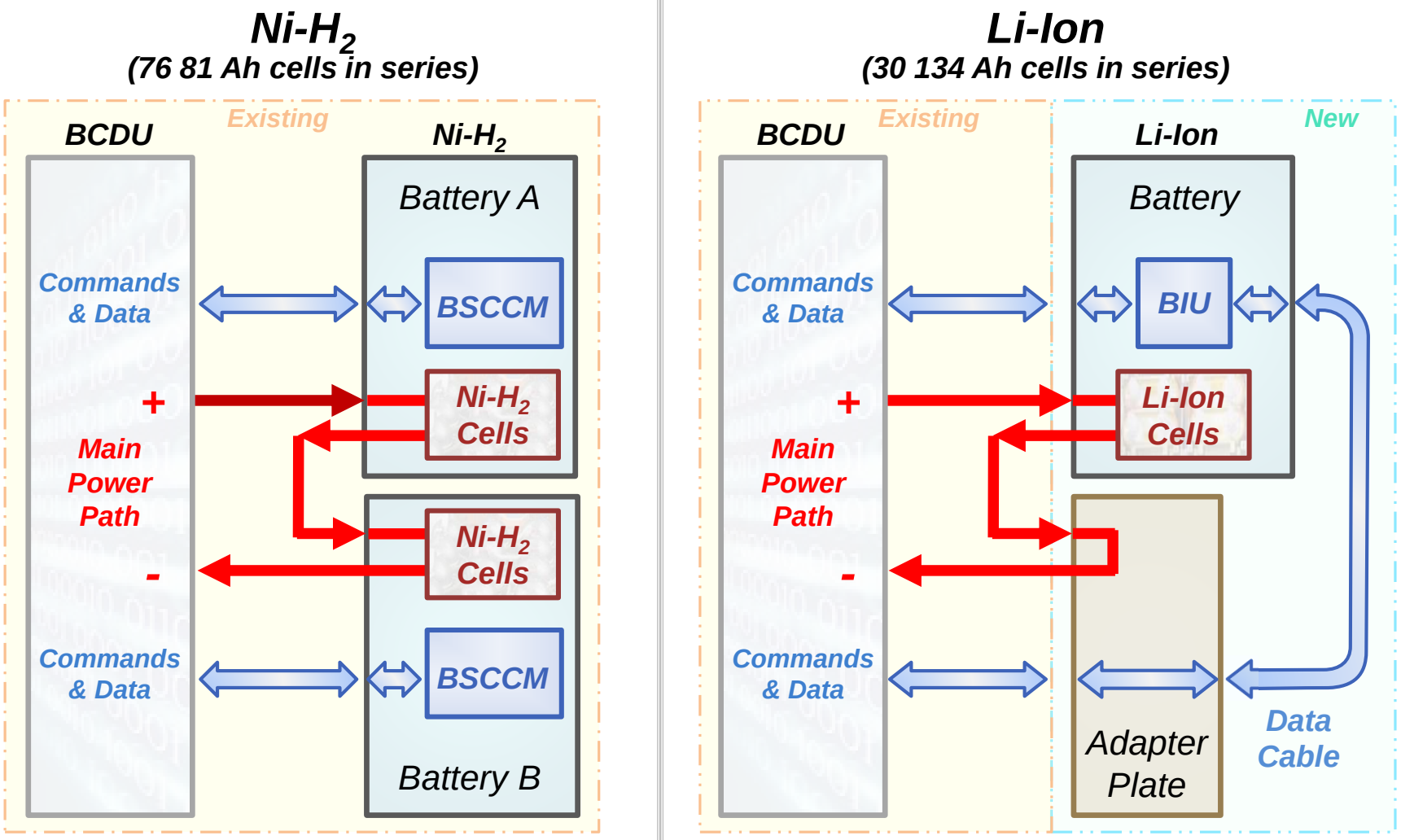
ISS Configuration - EPS Schematic

Electrical Power Channel – 1 of 8



EPS:: Electric Power System
BCDU: Battery Charge / Discharge Unit
DCSU: DC Switching Unit
DDCU: DC-to-DC Converter Unit
MBSU: Main Bus Switching Units

ISS Upgrade to Li-Ion



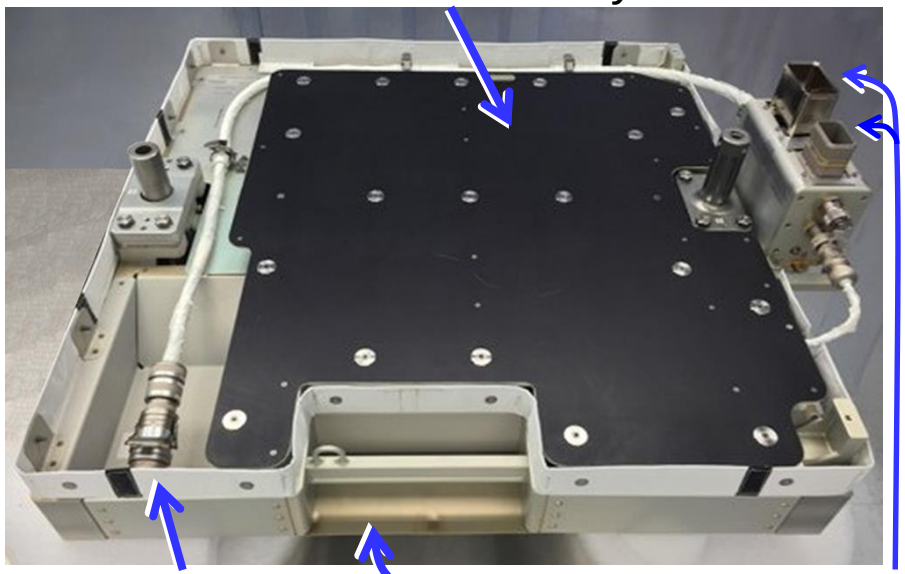
BCDU: Battery Charge / Discharge Unit
BIU: Battery Interface Unit
BSCCM: Battery Signal Conditioning and Control Module

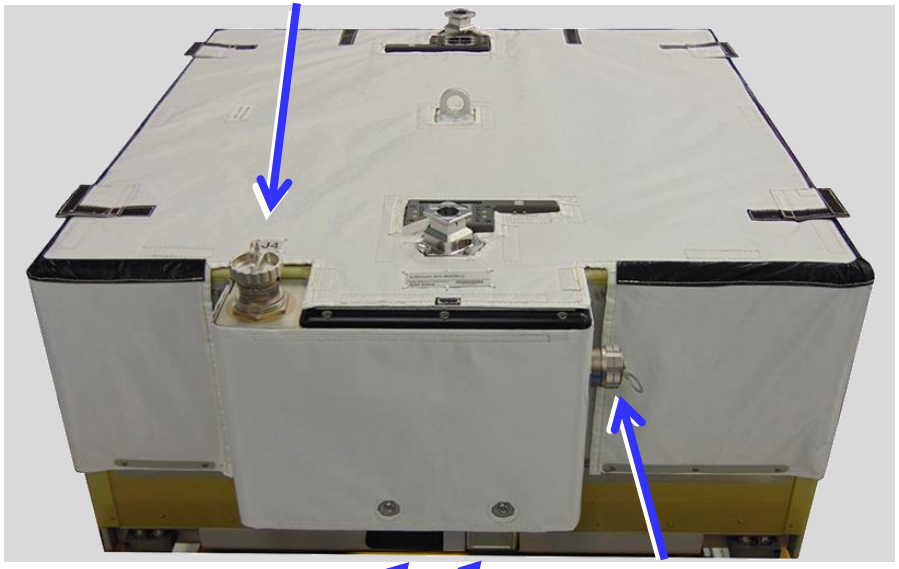
ISS Li-Ion Orbital Replacement Units

(Direct drop in replacement for Ni-H_2)

Heater Matt
Heater Plate Assembly

J4
Connector





P4 Connector
(stowed for launch)

EVA
Hand Hold

P1 & P2
Connectors

J3 Test
Connector

Adapter Plate ORU

Dimensions (LxWxH):	~ 41” x 36” x 15”
Actual Weight:	~ 75 Lbs

EOCV: End Of Charge Voltage

Li-Ion Battery ORU

Dimensions (LxWxH):	~ 41” x 37” x 21”
Actual Weight:	~ 428 Lbs
Capacity: 144 Ah to 4.1V EOCV	

Launch Integration

Credit: JAXA/SpaceFlightNow

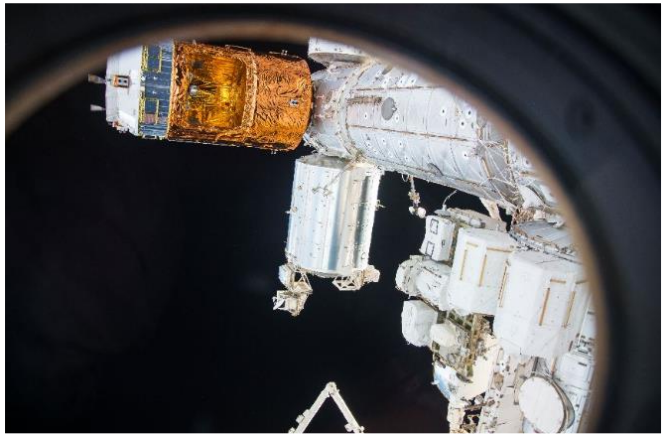
Credit: JAXA

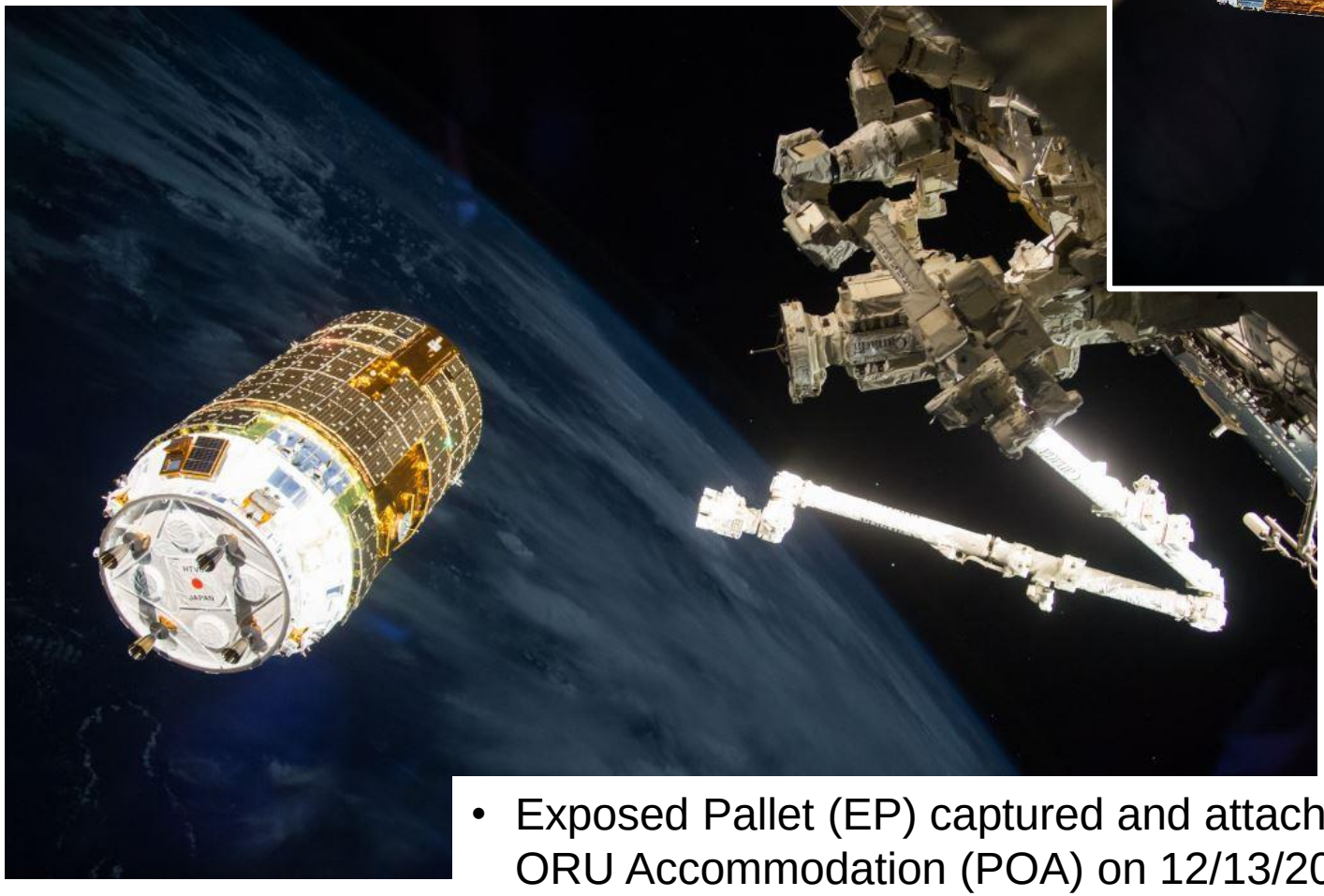
- Adapter Plates Integrated at Tomioka, Japan: April-May 2016
- Batteries Integrated and charged to 4.1V at Tonegashima, Japan: May- June 2016

Launch

- HTV6 Launched from Tanegashima, Japan on December 9, 2016

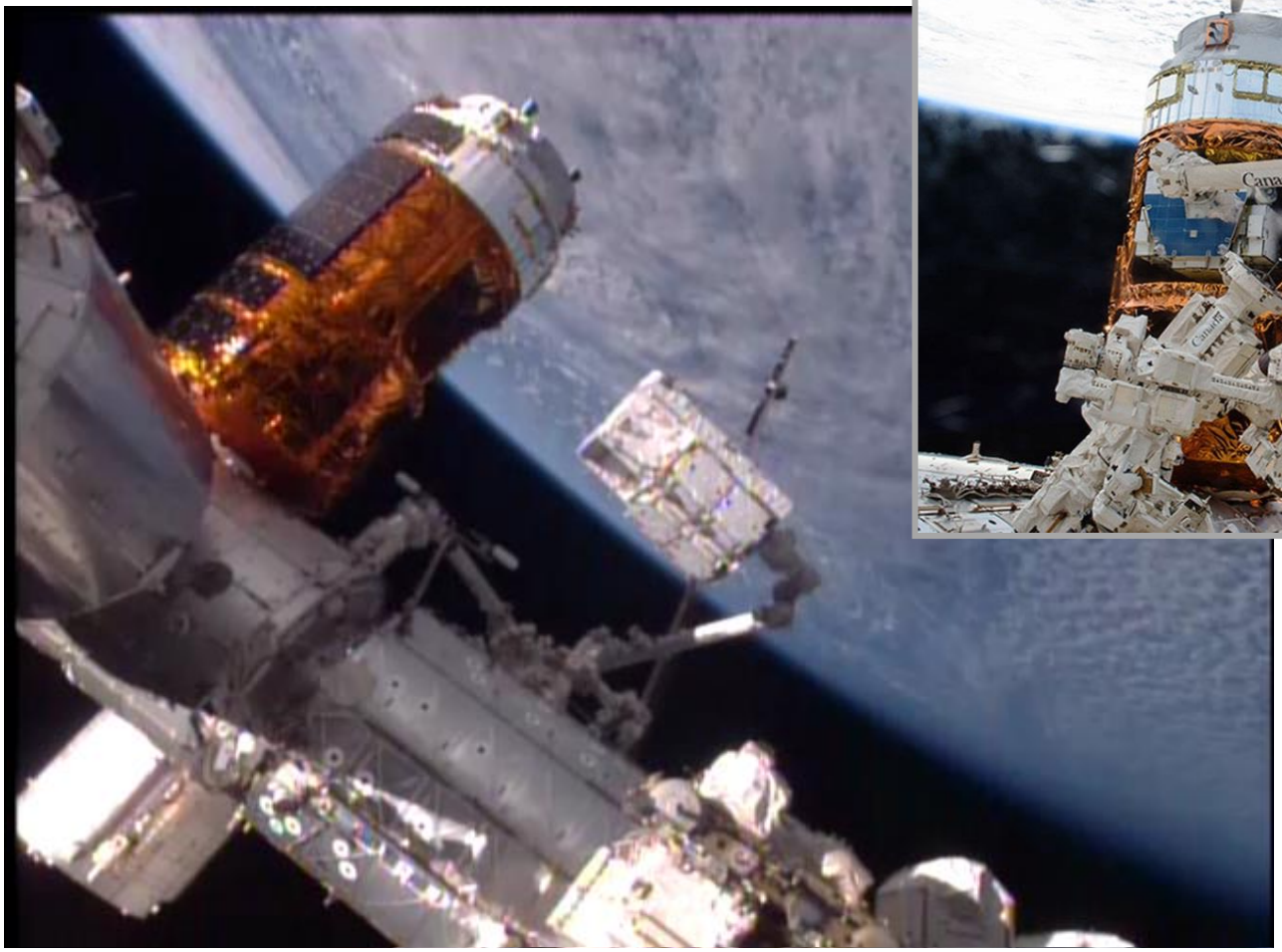
Docking of HTV6 to ISS





- Exposed Pallet (EP) captured and attached to Payload ORU Accommodation (POA) on 12/13/2016

Removal of Exposed Pallet with Li-Ion ORUs



- 12/13/2016 robotic removal of EP with Li-Ion ORUs

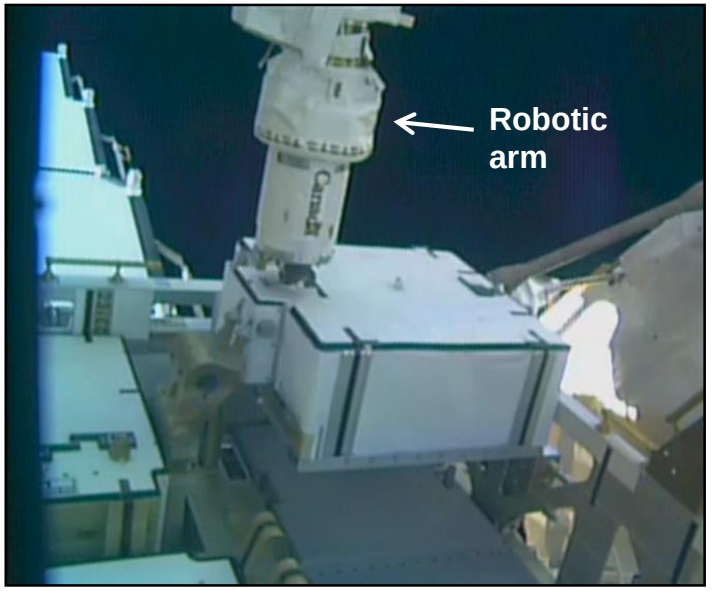
Positioning the EP with Li-Ion ORUs

- 12/13/2016 EP moved to ISS truss for Battery installation

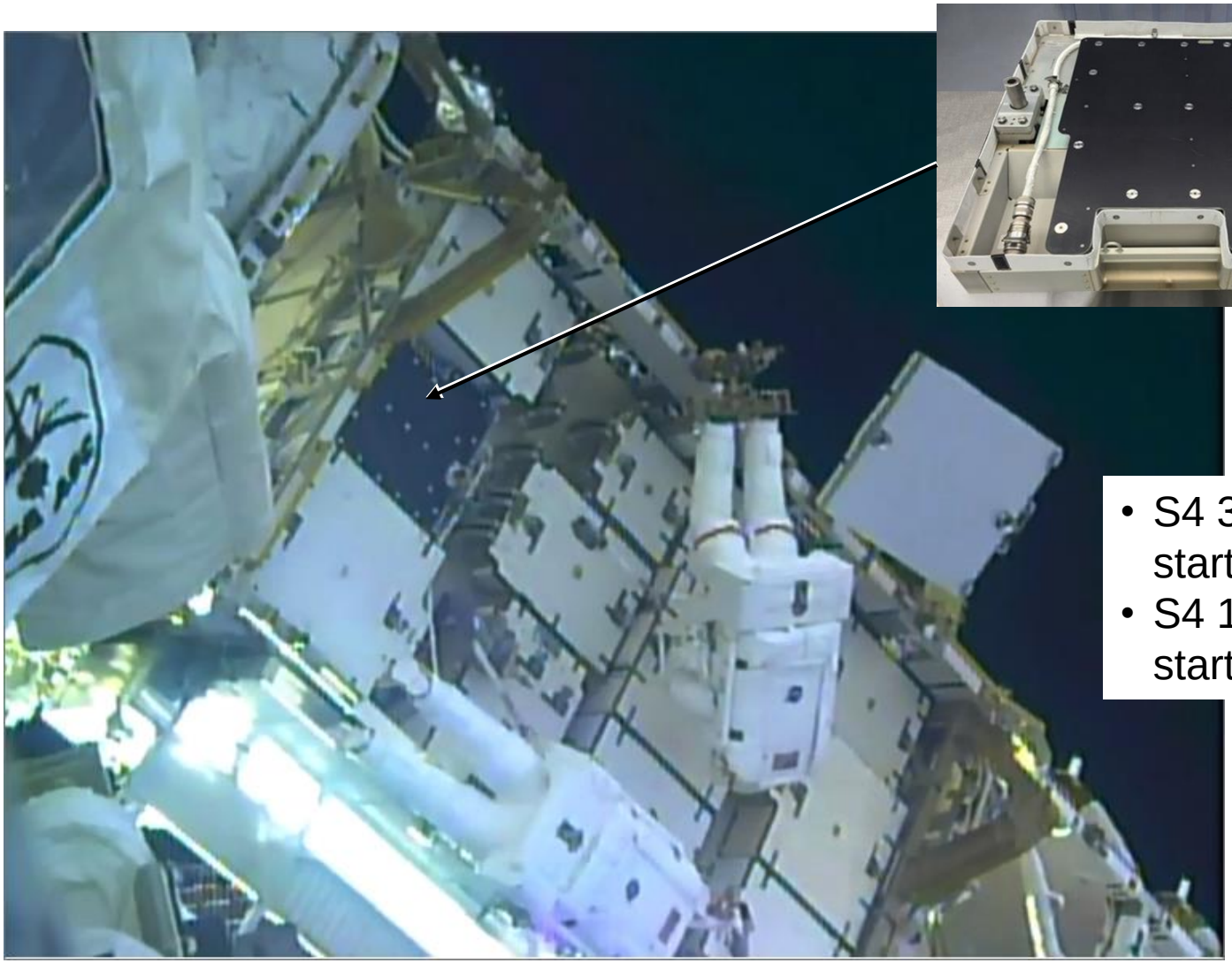
Dextre

Robotic Installation of Li-Ion Battery ORUs

- **S4 3A Batteries**
  - Robotically installed 12/31–1/2/2017
- **S4 1A Batteries**
  - Robotically installed 1/8–1/12/2017

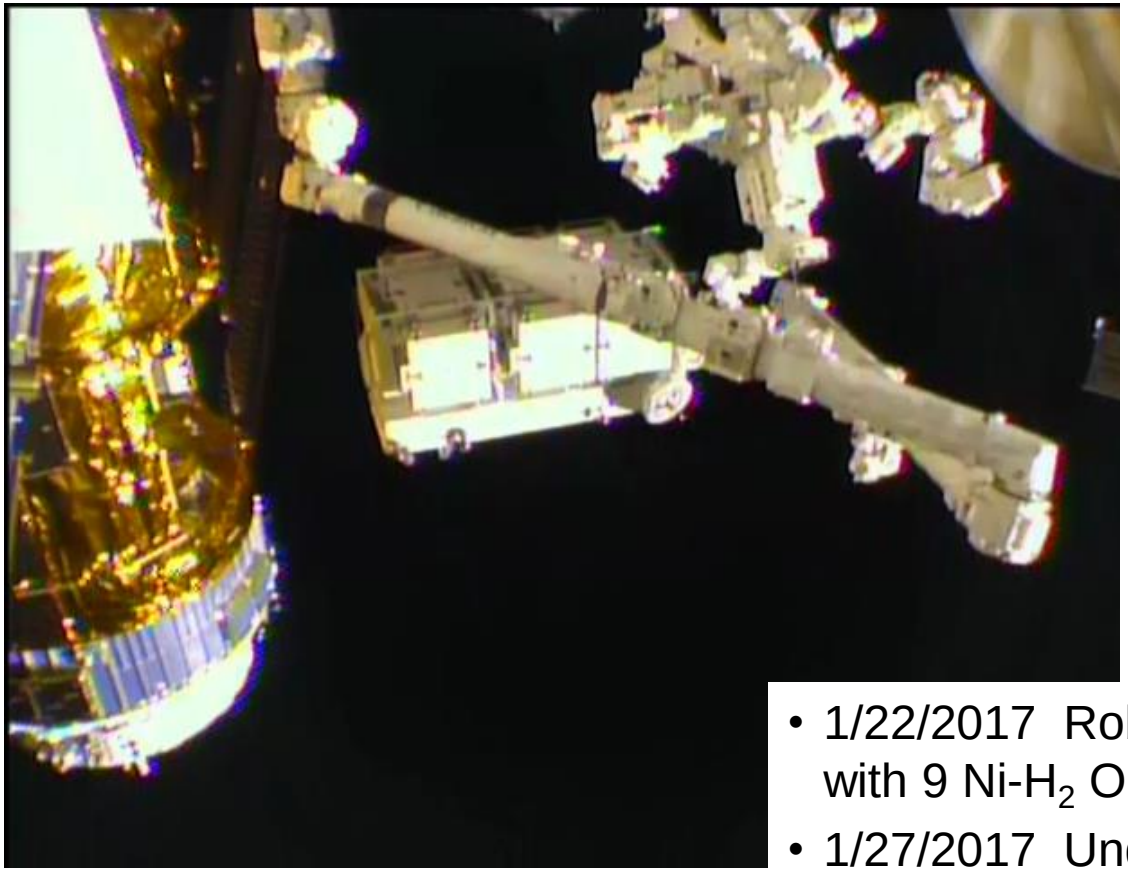


EVA Adapter Plate Installation



- S4 3A EVA and start up 1/6/2017
- S4 1A EVA and start up 1/13/2017

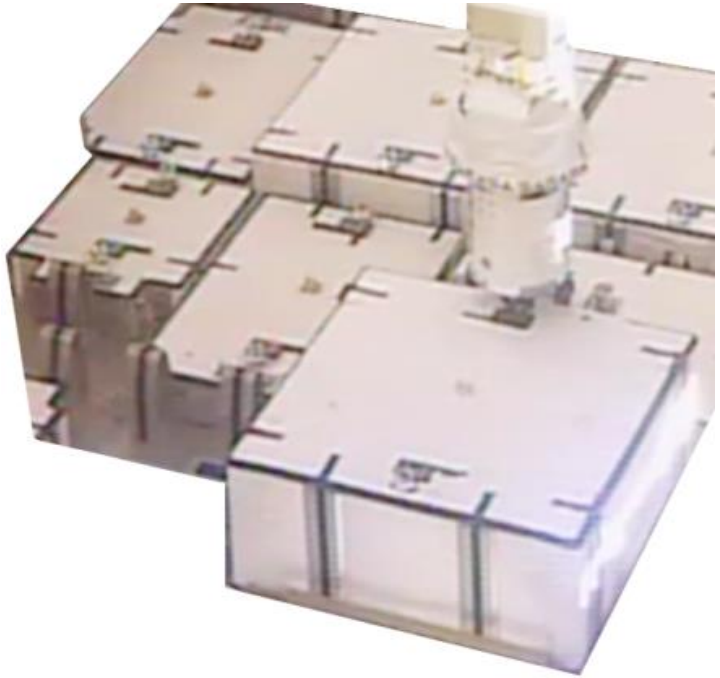
Robotic Disposal of Exposed Pallet with 9 Ni-H_2 ORUs



- 1/22/2017 Robotic arm inserting EP with 9 Ni-H_2 ORUs back into HTV6
- 1/27/2017 Undocking
- 2/5/2017 Reentry

Li-Ion Battery Orbit Operations

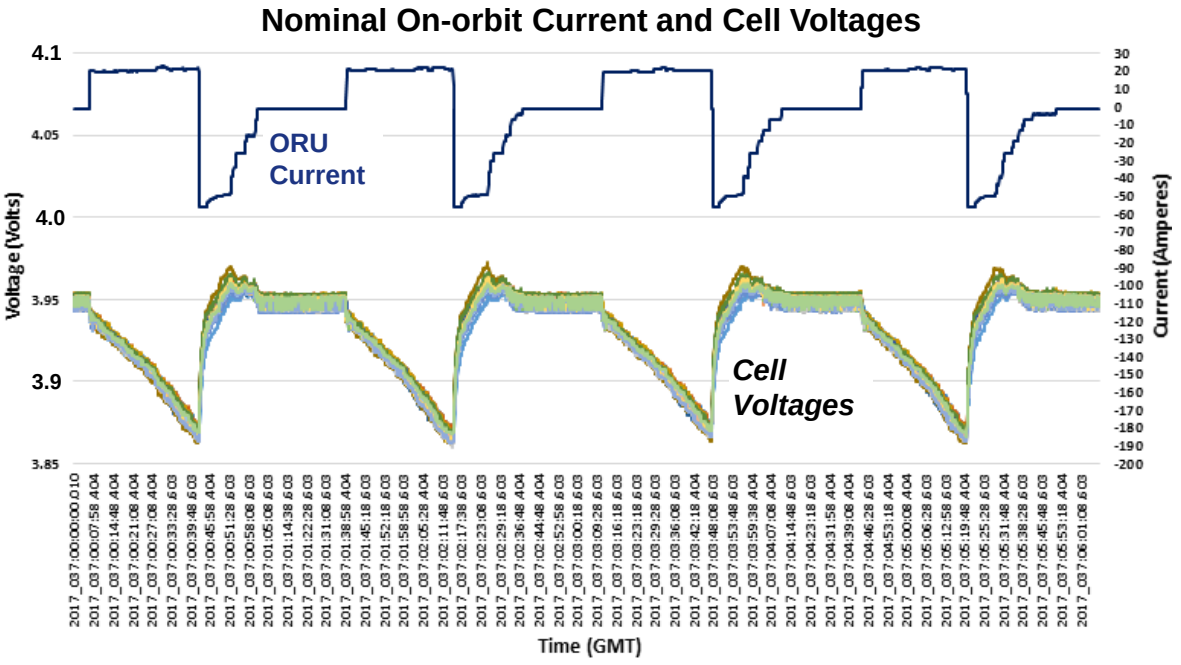
- Starting January 13, 2017, S4 Channels 3A and 1A are being operated using only Li-Ion Batteries
  - Batteries are performing well after approximately 4,800 LEO cycles
    - Batteries being operated at EOCV of 3.95V
    - Cell EODVs within ~10 mV
    - Cell temperatures within 5 degrees C
  - Initial On-Orbit Capacity tests performed
    - Discharge using ISS loads, no charge during insolation
    - 3A: average capacity 110.2 Ah, performed 2/7-10/17
    - 1A: average capacity 112.0 Ah, performed 2/27-3/5/17
    - Slightly higher than predicted start-up capacity of 109 and 110 Ah

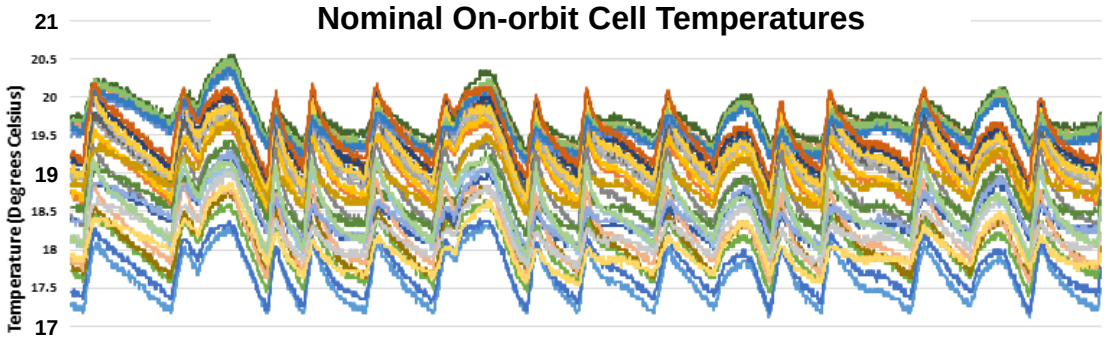


ISS Li-Ion Charge Control and Cycling

- Li-Ion charge current profile is based on cell voltages
- Cell bypass/balancing at EOCV every orbit
- EOCV ground command-able

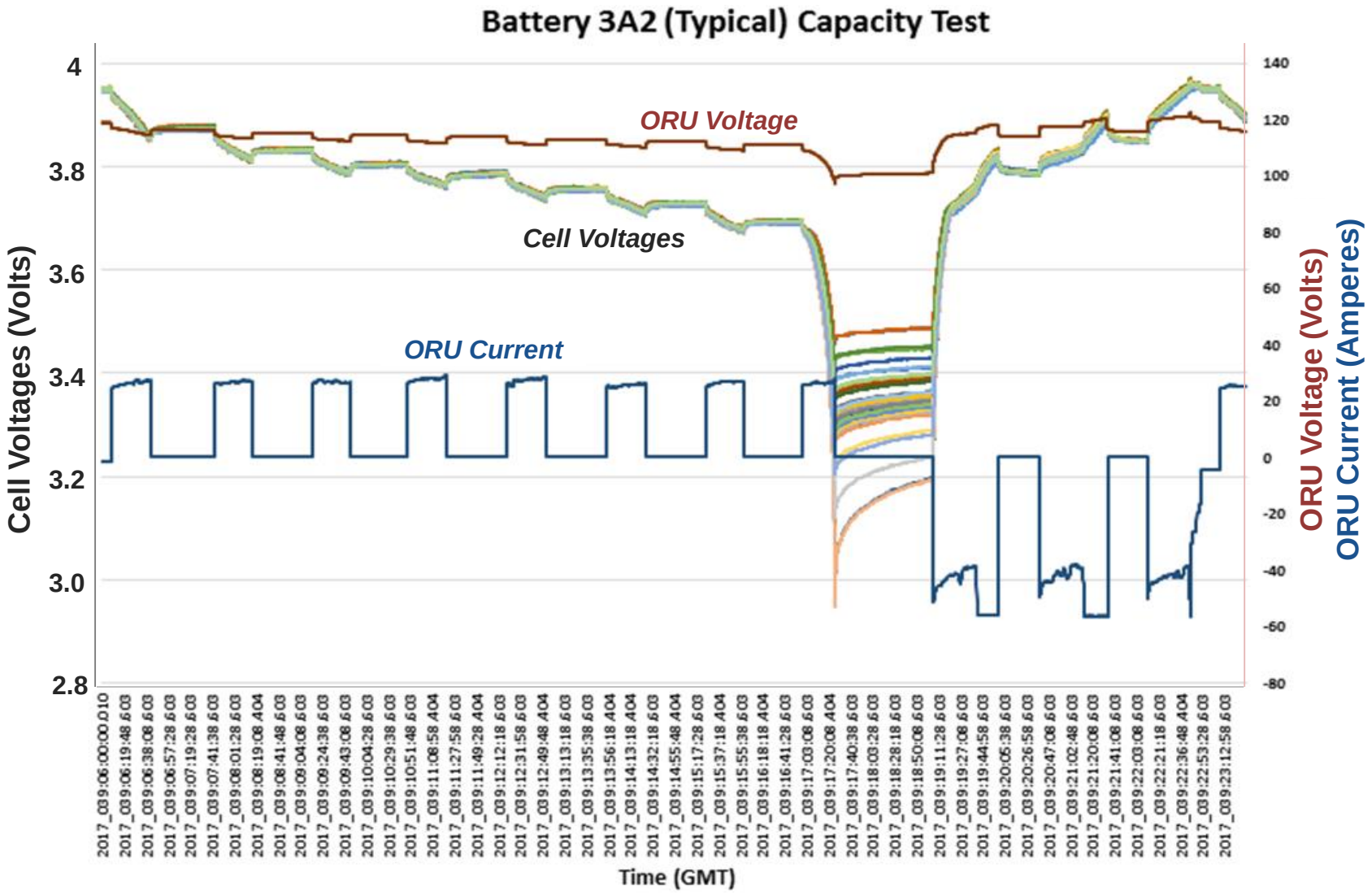
Charge Current Profile		
	Highest of the Cell Terminal Voltages	**Charge Current**
Point 1	EOCV + 19mV	55
Point 2	EOCV + 19mV	49
Point 3	EOCV + 18mV	44
Point 4	EOCV + 17mV	39
Point 5	EOCV + 16mV	36
Point 6	EOCV + 15mV	33
Point 7	EOCV + 14mV	30
Point 8	EOCV + 13mV	26
Point 9	EOCV + 12mV	22
Point 10	EOCV + 11mV	19
Point 11	EOCV + 10mV	16
Point 12	EOCV + 9mV	13
Point 13	EOCV + 8mV	10
Point 14	EOCV + 7mV	7
Point 15	EOCV + 6mV	4
Point 16	not applicable	1



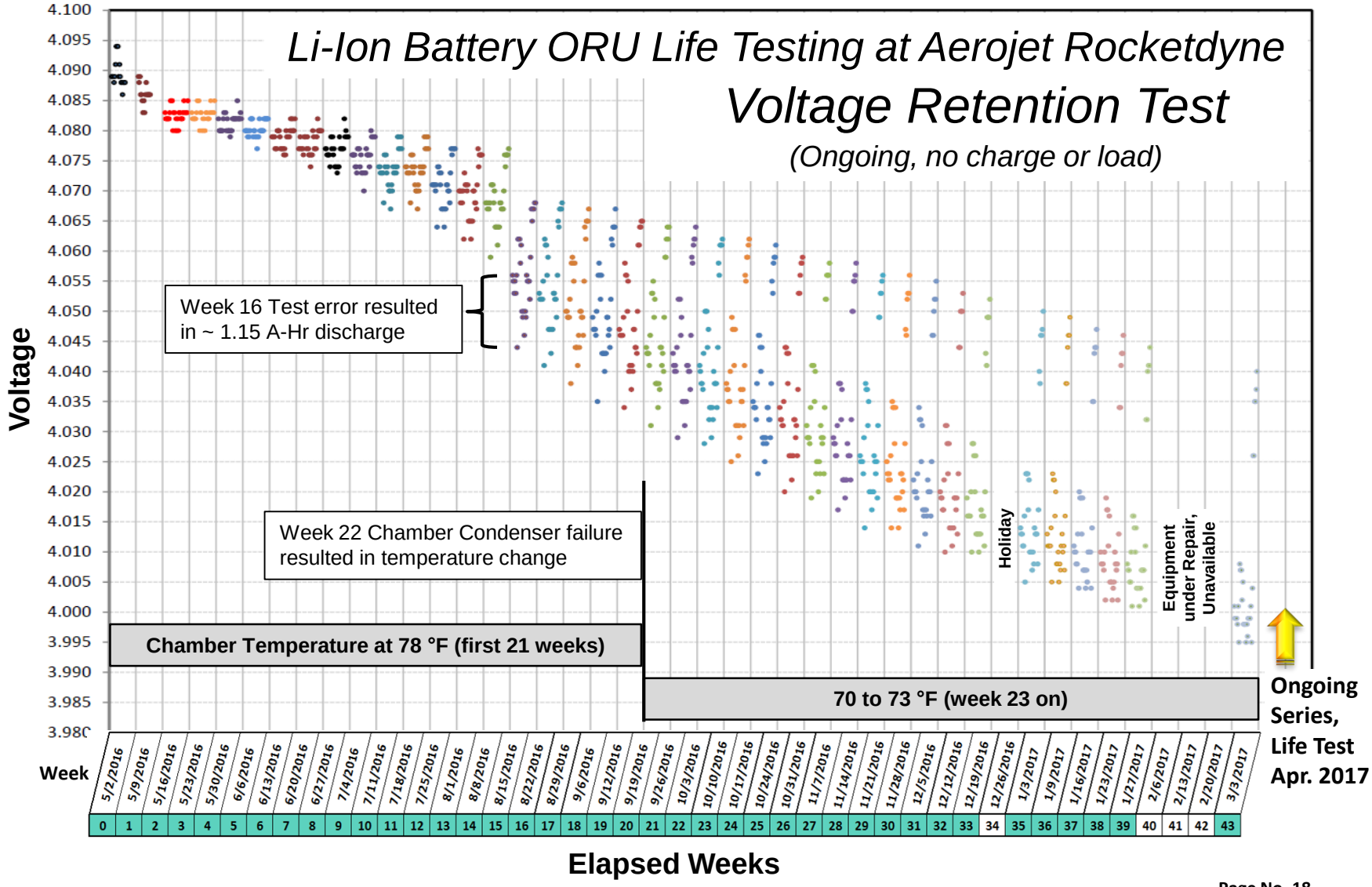


Typical Data for Battery Channel operation

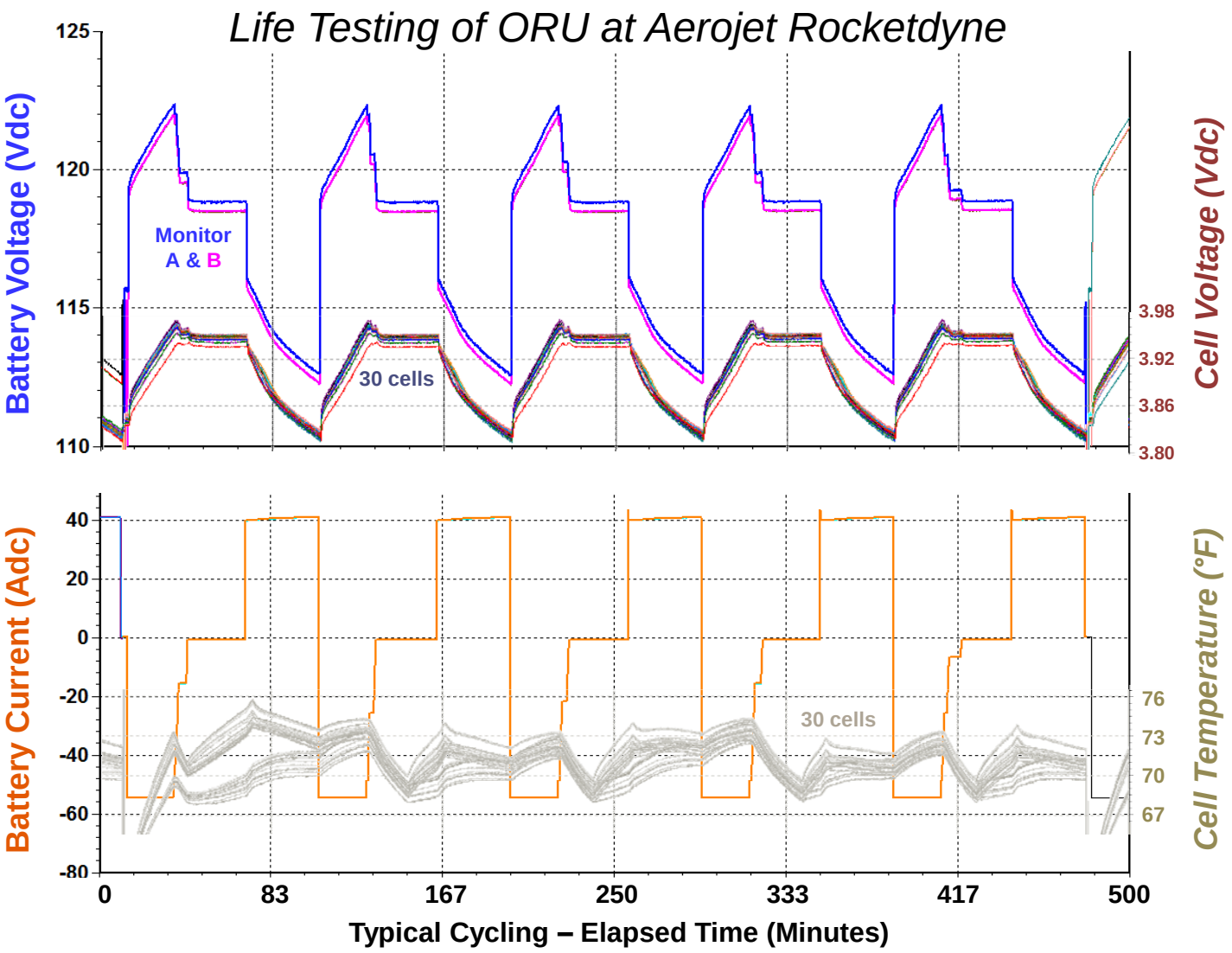
ISS Li-Ion Capacity Test



ORU Life Test Program

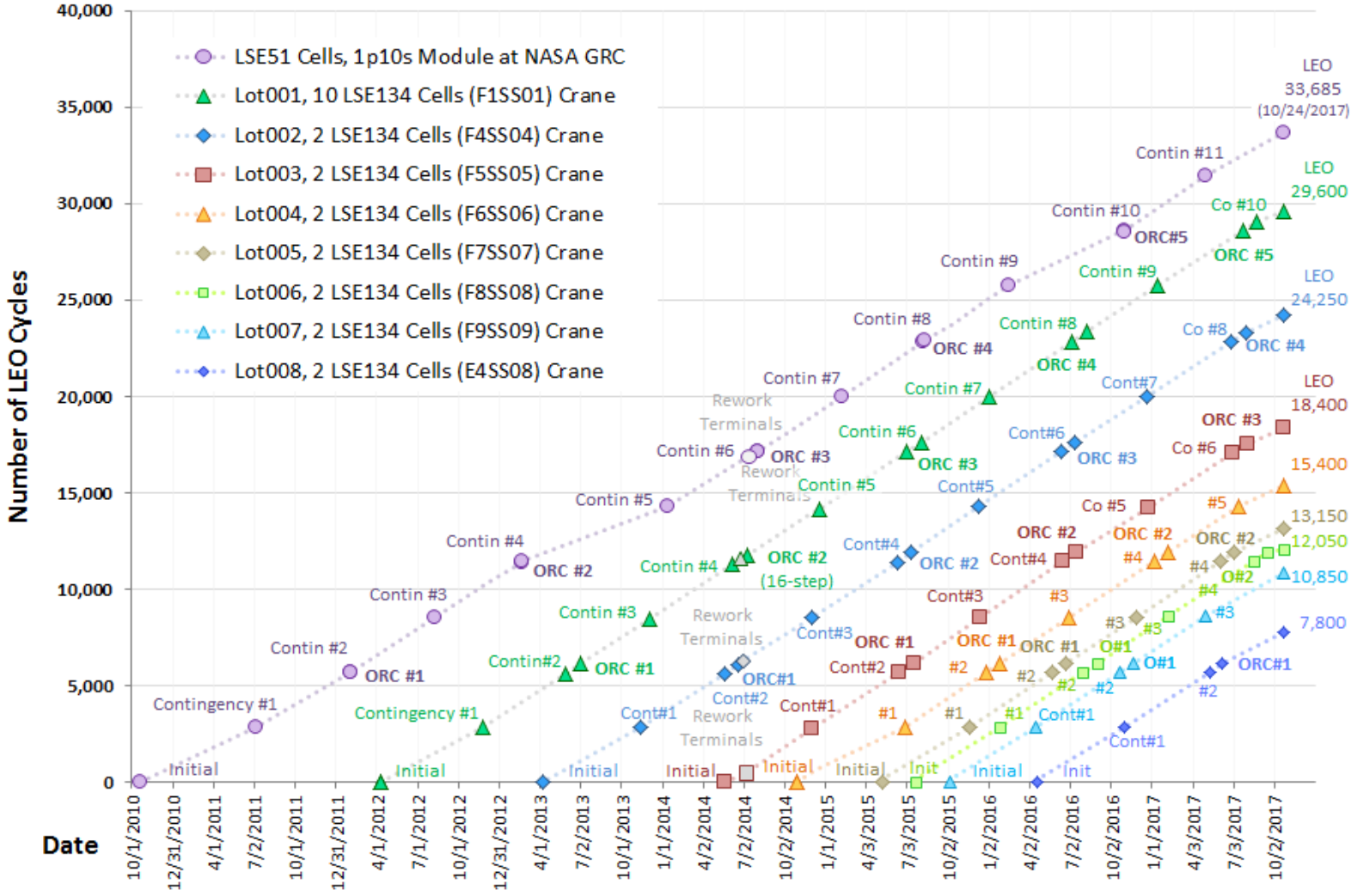


Life Test Program



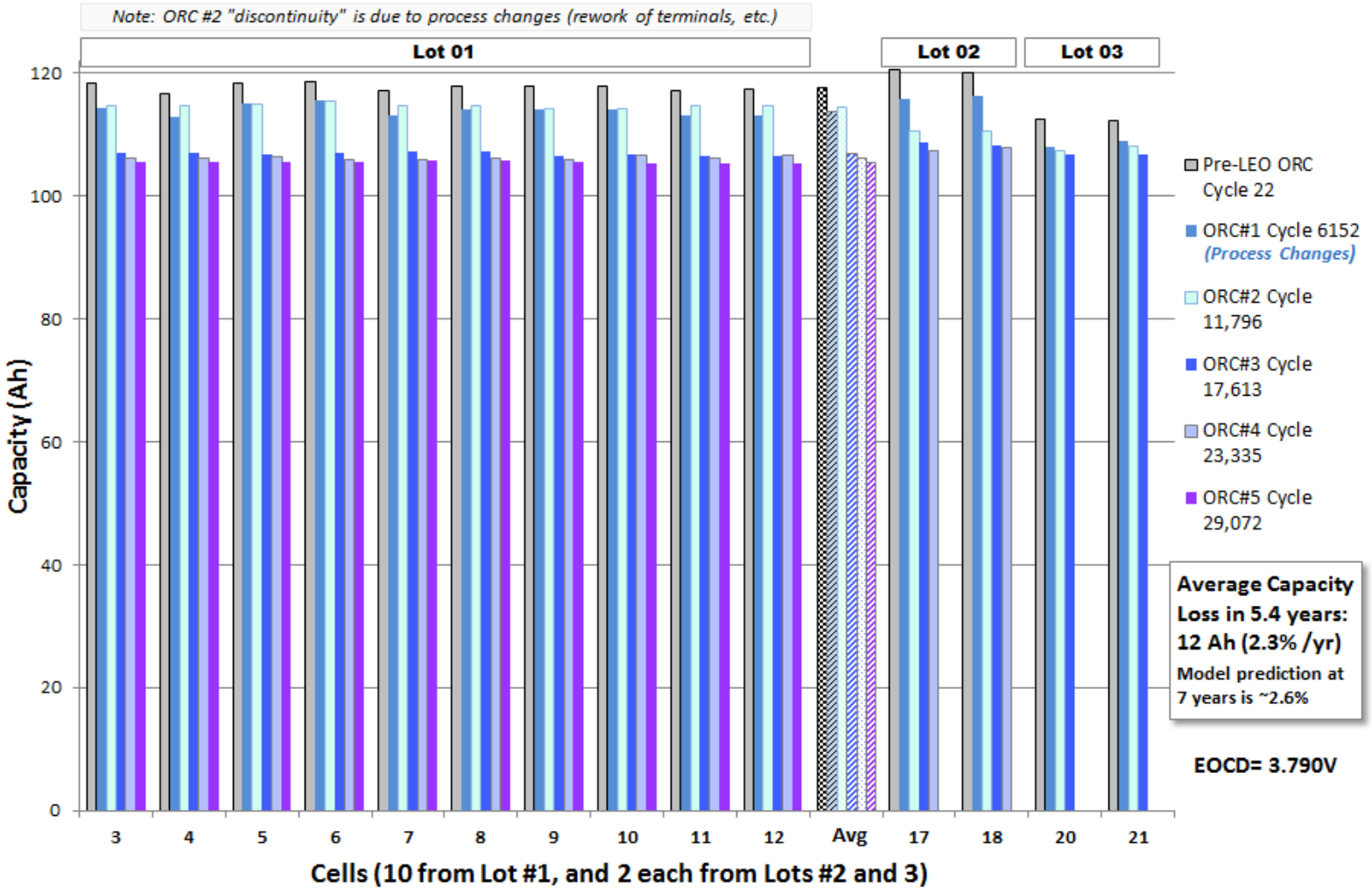
Life Test Program

- Cell Life Testing performed at Crane Lab and NASA-GRC



Life Test Program

ORC Capacity Data for Life Test of LSE134 Cells at Crane



ISS Li-Ion Battery Forward Work

- Ground
  - Deliver final 5 (of 27 total) Li-Ion batteries for storage and launch
  - Launch 6 Li-Ion Batteries and Adapter Plates in each of 2018, 2019, and 2020

- On-orbit
  - Update State of Charge calculation to increase accuracy
  - Evaluate optimization of charge profile
  - Deploy full complement of 24 Li-Ion batteries on ISS

In Closing

- Questions?