



# International Space Station Lithium-Ion Battery Start-Up

Space Power Workshop

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# ISS Li-Ion Battery - Outline

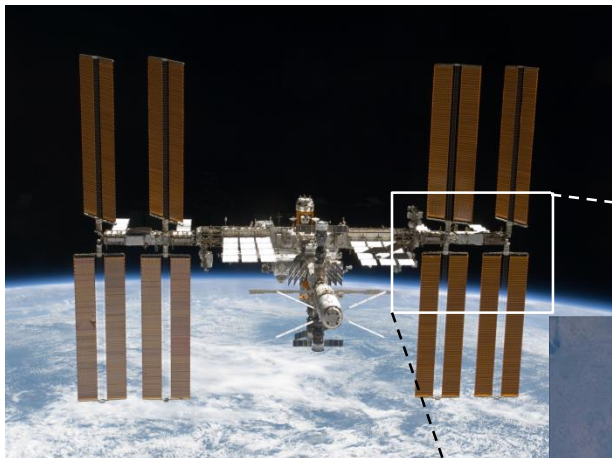
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- Configuration of Existing ISS Electric Power System
- Final Flight Adapter Plate and Battery Design
- Launch and Installation
- Battery Charge Control and LEO Cycle Test Data
- On-Orbit cycling data
- Cell and ORU Life Test





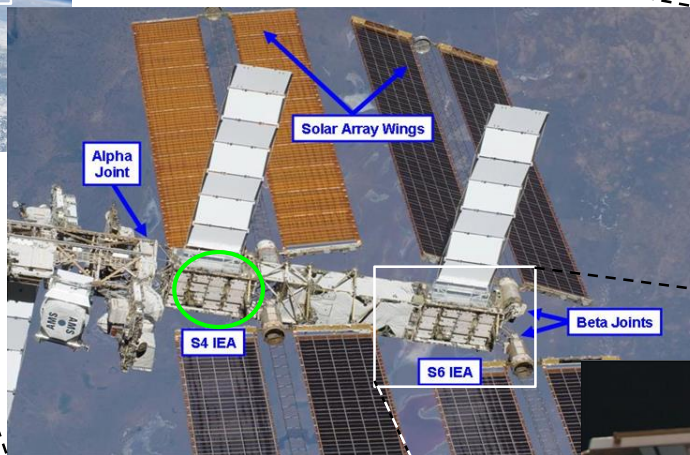
# ISS Configuration - Battery Locations



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

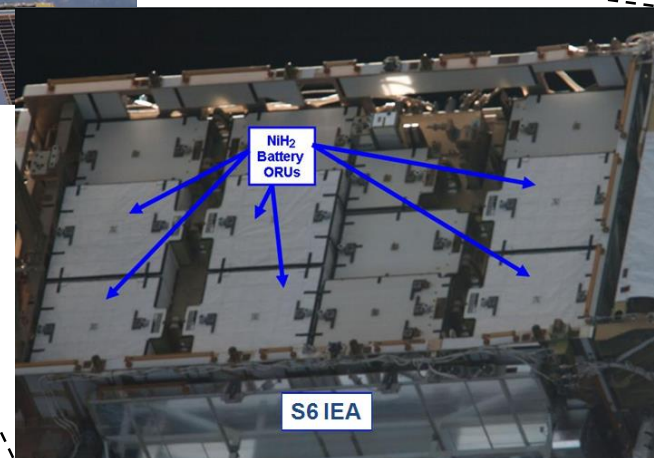
2 Power Channels per IEA

8 Power Channels total



6 Ni-H<sub>2</sub> ORUs per channel – 48 total

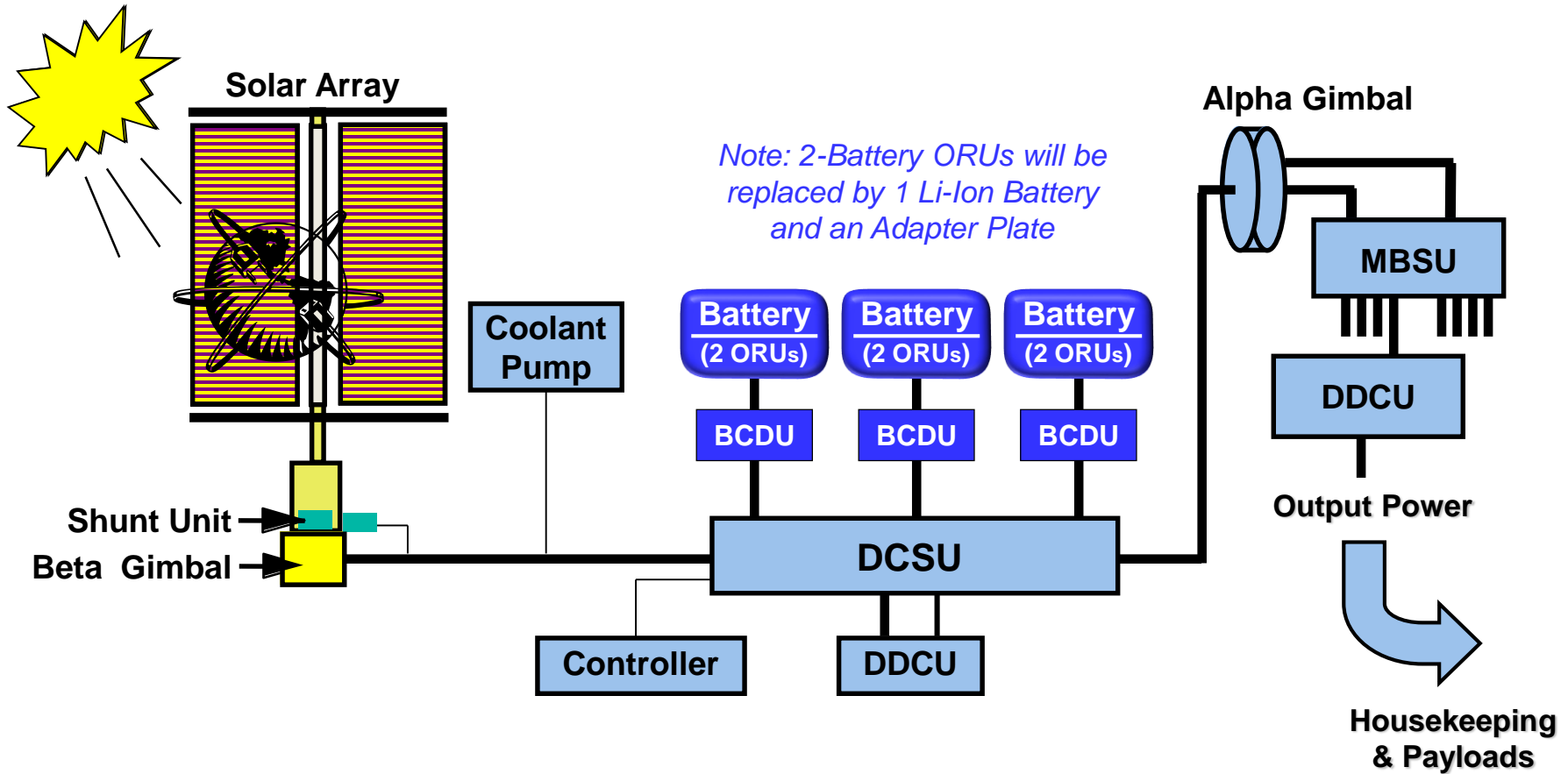
1 Li-Ion and 1 Adapter Plate to replace  
2 Ni-H<sub>2</sub> – 24 total Li-Ion batteries





# ISS Configuration - EPS Schematic

## Electrical Power Channel – 1 of 8

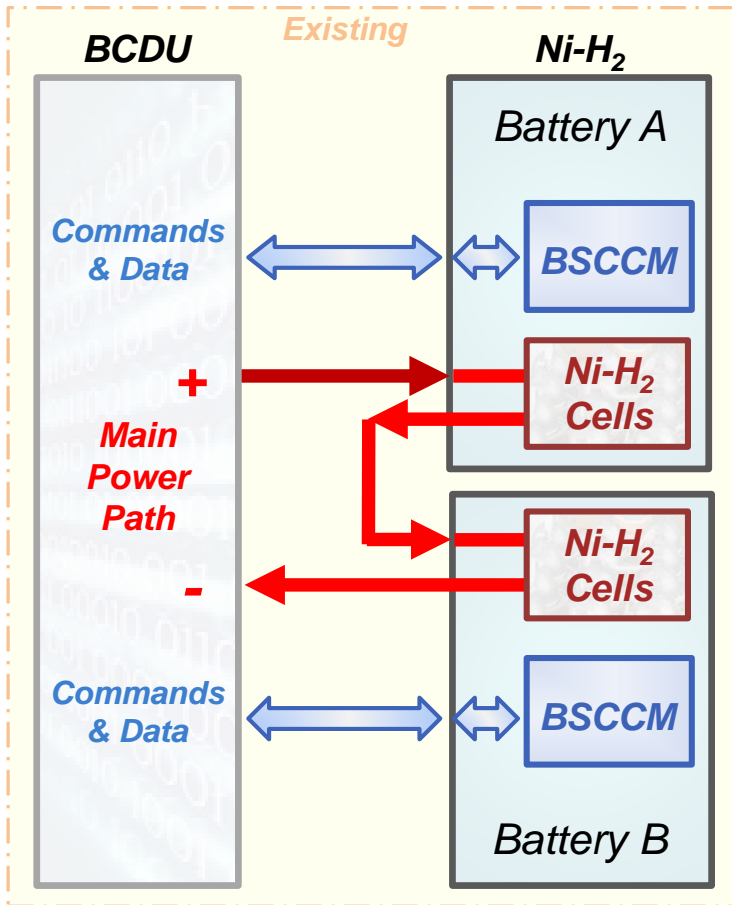


EPS:: Electric Power System  
BCDU: Battery Charge / Discharge Unit  
DCSU: DC Switching Unit  
DDCU: DC-to-DC Converter Unit  
MBSU: Main Bus Switching Units

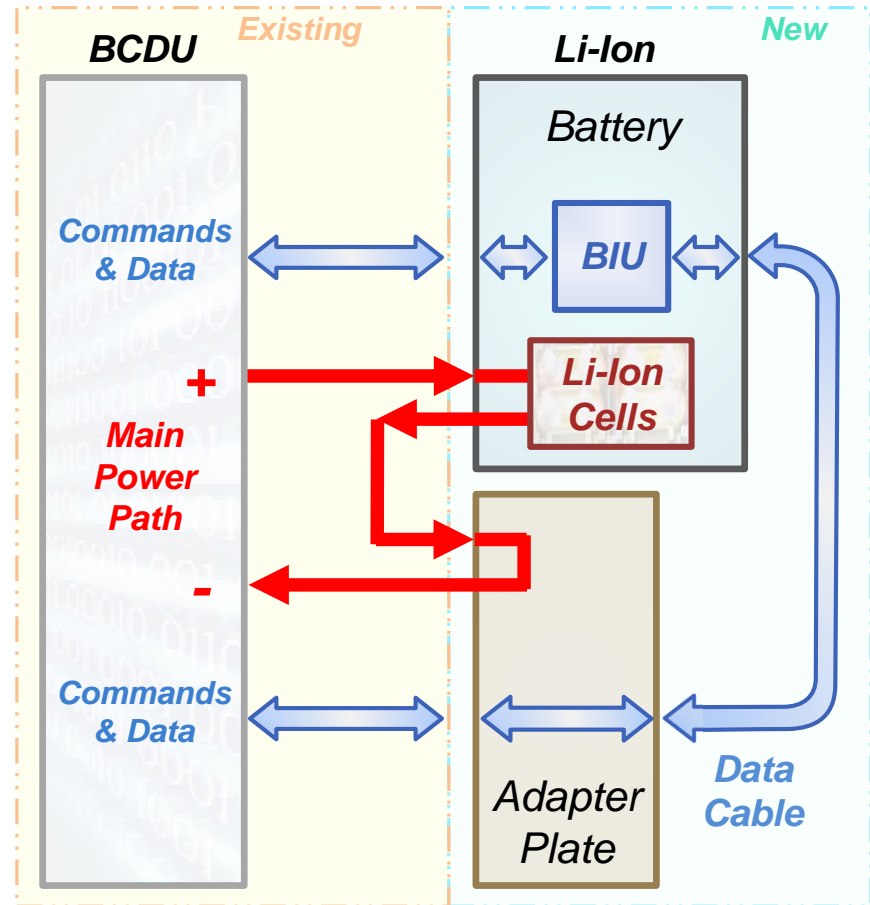


# ISS Upgrade to Li-Ion

**Ni-H<sub>2</sub>**  
(76 cells in series)



**Li-Ion**  
(30 cells in series)



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

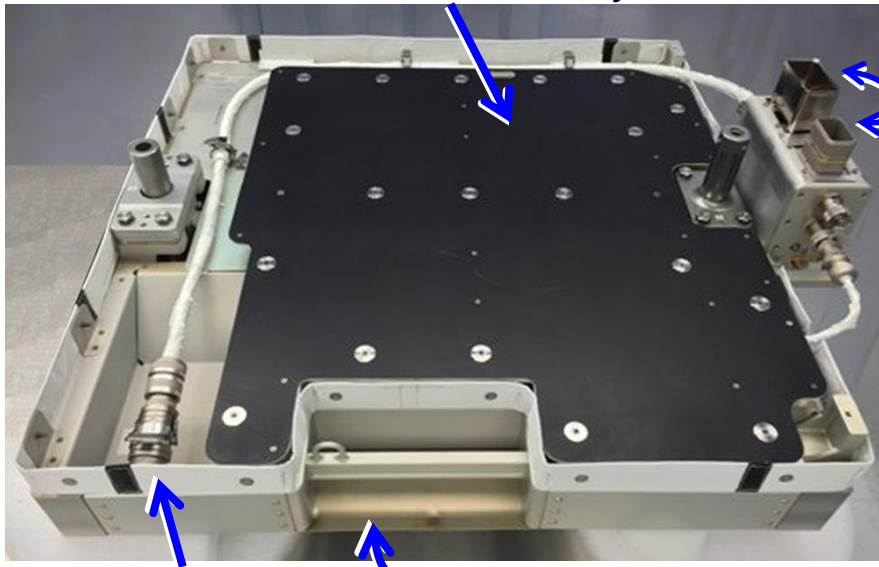


# ISS Li-Ion Orbital Replacement Units

(Direct drop in replacement for Ni-H<sub>2</sub>)



Heater Matt  
Heater Plate Assembly

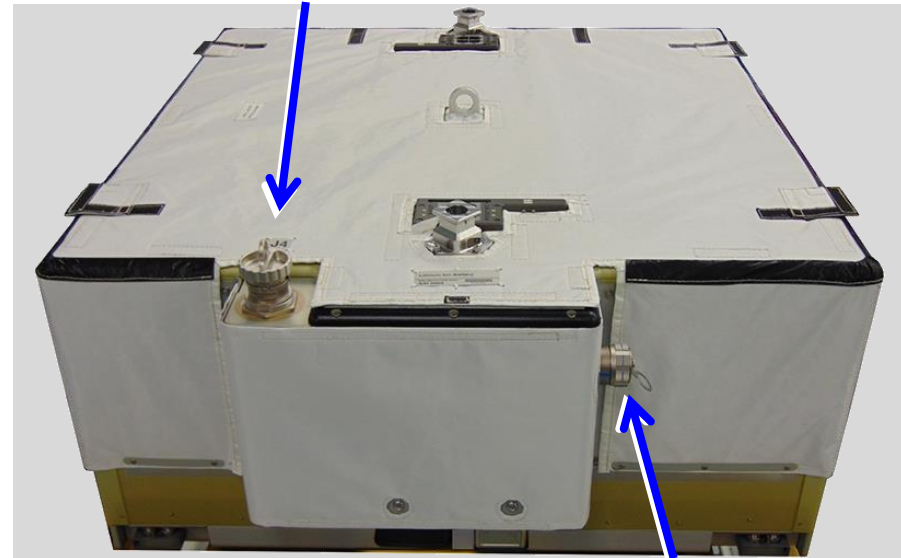


P4 Connector  
(stowed for launch)

EVA  
Hand Hold

P1 & P2  
Connectors

J4  
Connector



J3 Test  
Connector

## Adapter Plate ORU

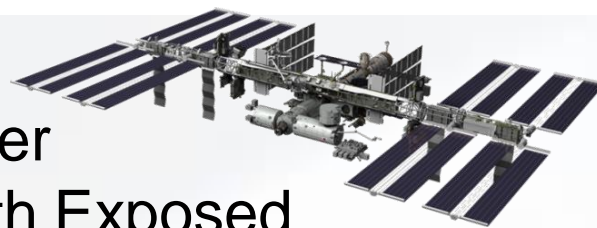
Dimensions (LxWxH): ~ 41" x 36" x 15"  
Spec Weight: 85 Lbs

## Li-Ion Battery ORU

Dimensions (LxWxH): ~ 41" x 37" x 21"  
Spec Weight: 435 Lbs



# ISS Li-Ion Flight Battery Status



- 6 Flight Li-Ion Adapter Plates integrated with Exposed Pallet in Japan, Tomioka: April 2016
- 6 Flight Li-Ion Batteries integrated with Exposed Pallet in Japan, Tanegashima: May 2016
- Final charge to 4.1V: May-June 2016
- Launch on HTV6: December 9, 2016
  - Each IEA will have 3 Li-Ion ORUs and 3 Adapter Plate ORUs
- Installation and start-up on ISS:
  - S4 3A channel – Jan. 6, 2017
  - S4 1A channel, Jan. 13, 2017

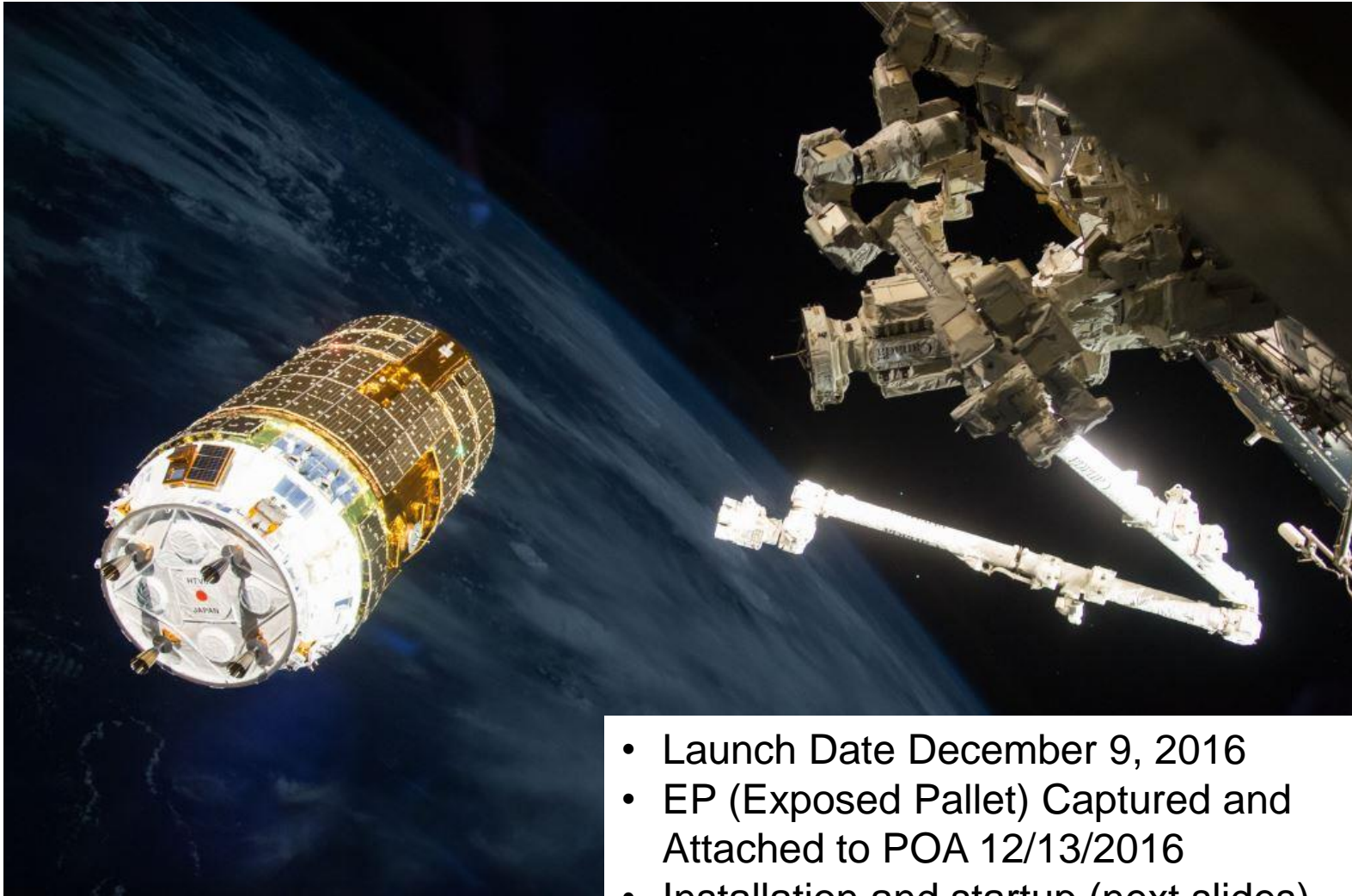


*HTV Berthing with Exposed Pallet*

*HTV2  
March 10, 2011*



# Docking of HTV6 to ISS



- Launch Date December 9, 2016
- EP (Exposed Pallet) Captured and Attached to POA 12/13/2016
- Installation and startup (next slides)

*HTV Approach to ISS*





# Removal of Exposed Pallet with Li-Ion ORUs

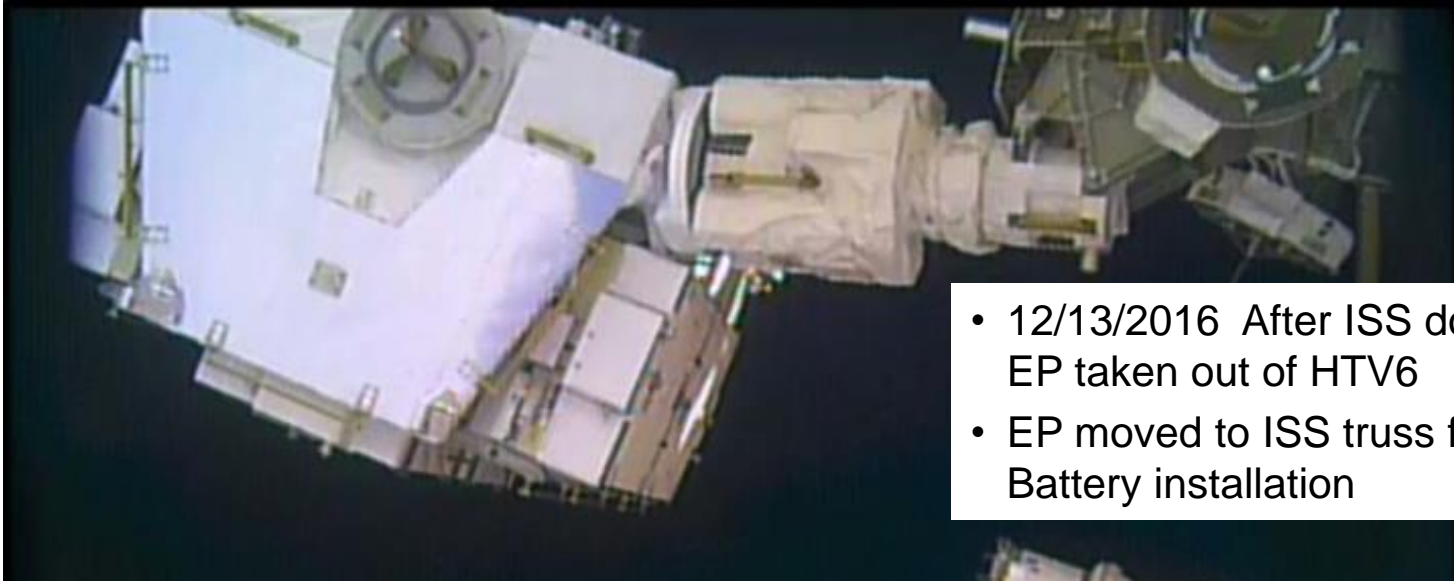
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- 12/13/2016 After docking, robotic removal of EP with Li-Ion ORUs



# Moving the Li-Ion ORUs



- 12/13/2016 After ISS docking, EP taken out of HTV6
- EP moved to ISS truss for Battery installation





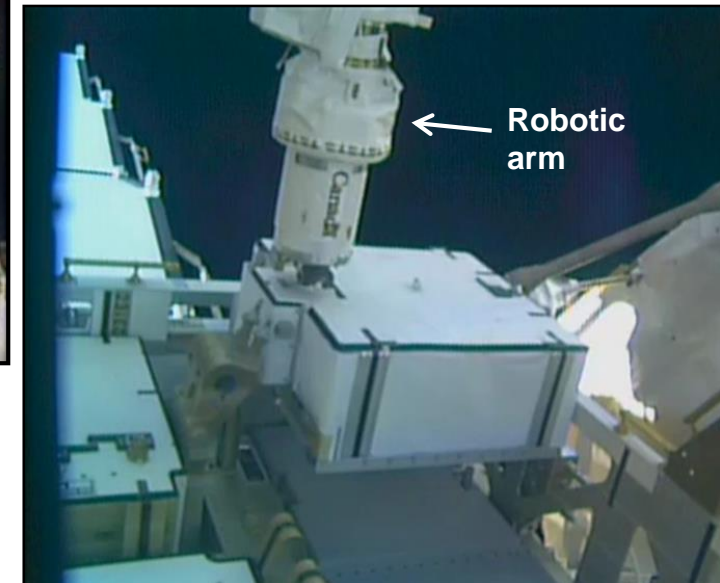
# Robotic Installation of Li-Ion Battery ORU



Li-Ion  
Battery  
ORU

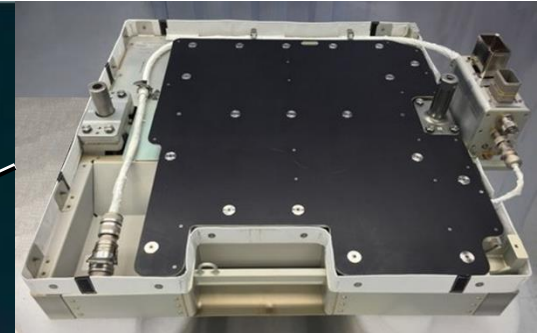
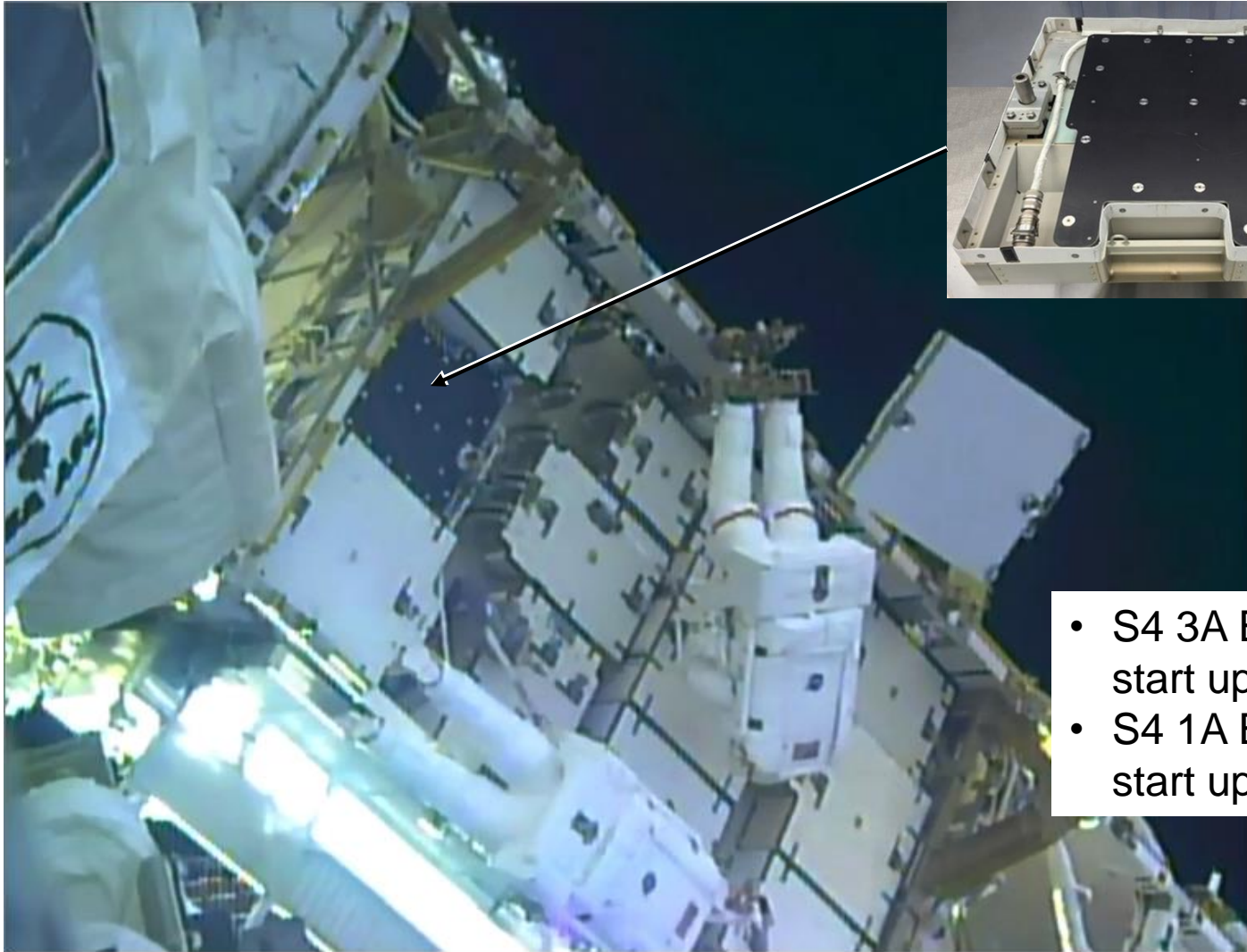
Robotic Arm  
(Dextre)

- **S4 3A Batteries**
  - Robotically installed 12/31–1/2/2017
  - EVA and start up 1/6/2017
- **S4 1A Batteries**
  - Robotically installed 1/8–1/12/2017
  - EVA and start up 1/13/2017





# EVA Adapter Plate Installation

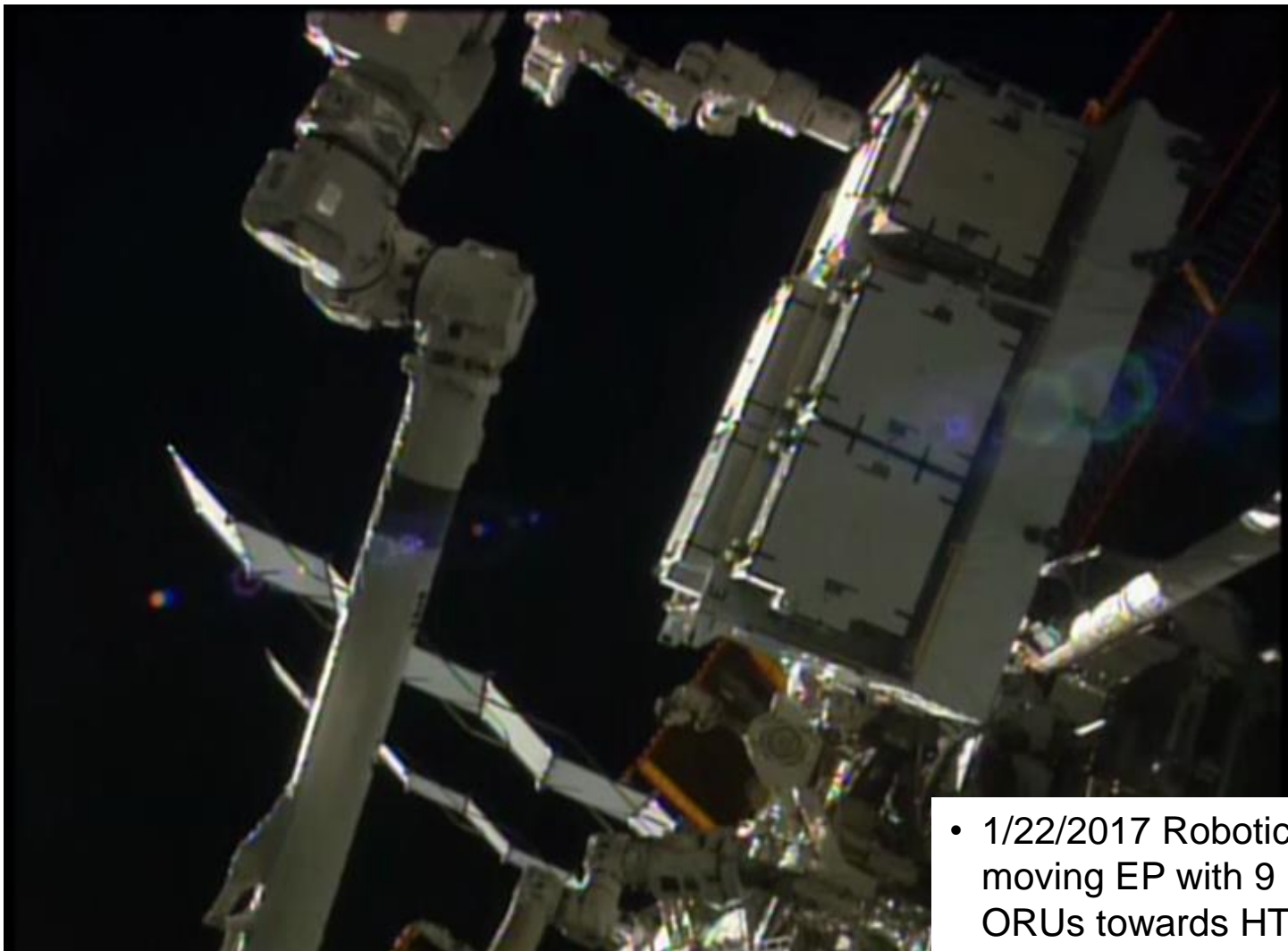


- S4 3A EVA and start up 1/6/2017
- S4 1A EVA and start up 1/13/2017



# Robotic Disposal of Exposed Pallet with 9 Ni-H<sub>2</sub> ORUs

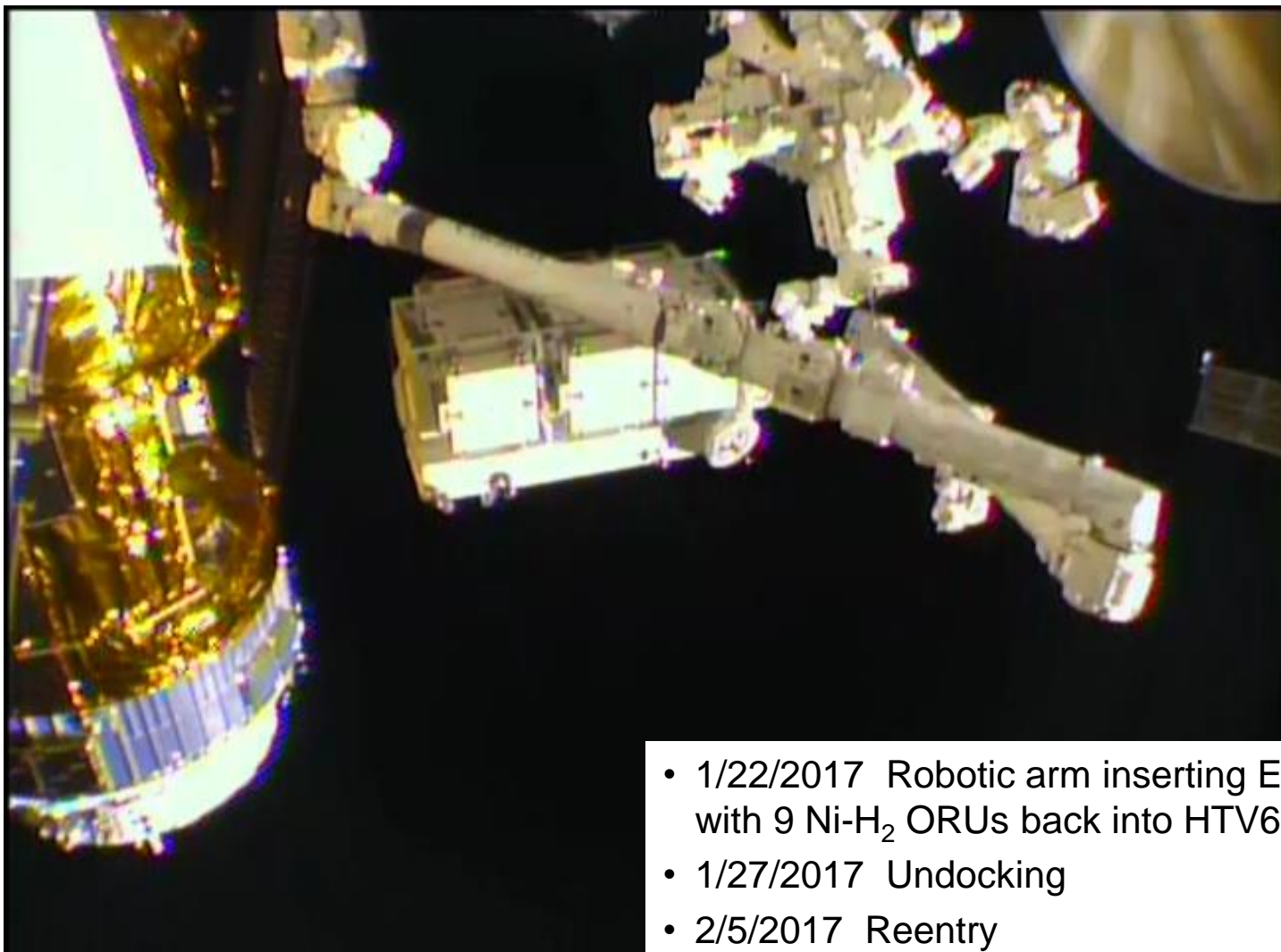
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- 1/22/2017 Robotic arm moving EP with 9 Ni-H<sub>2</sub> ORUs towards HTV6



# Robotic Disposal of Exposed Pallet with 9 Ni-H<sub>2</sub> ORUs

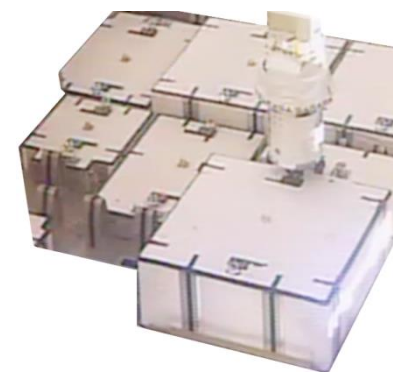
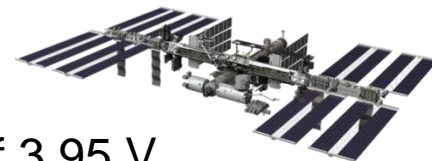


- 1/22/2017 Robotic arm inserting EP with 9 Ni-H<sub>2</sub> ORUs back into HTV6
- 1/27/2017 Undocking
- 2/5/2017 Reentry



# Li-Ion Battery Status

- Starting January 13, 2017, S4 Channels 3A and 1A are being operated using only Li-Ion Batteries
  - Batteries are performing well – capacity tests at EOCV of 3.95 V
    - 3A: 109.3, 110.3, 110.9 Ah (see page 18)
    - 1A: 114.0, 110.3, 112.3 Ah
  - Minor operational observations / forward work
    - Battery Charge Discharge Unit advisory message – upper Voltage Limit of 122 V exceeded (Limit to be updated to 124 V)
    - Occasional switchovers of redundant heaters (A to B, B to A) (Persistence time to be updated)
    - State of Charge calculation to be updated to increase accuracy
    - Adjustments to Charge Profile to be evaluated
- 17 of 27 Li-Ion batteries have been built and delivered
  - 6 on orbit, 11 in cold storage at KSC
- 16 of 25 Adapter Plates have been built and delivered
  - 6 on orbit, 10 in storage at KSC
- Future Launches
  - Next Lithium-Ion Battery launch on HTV7, NET Feb. 2018
  - Subsequent launches on HTV8- 2019, HTV9- 2020



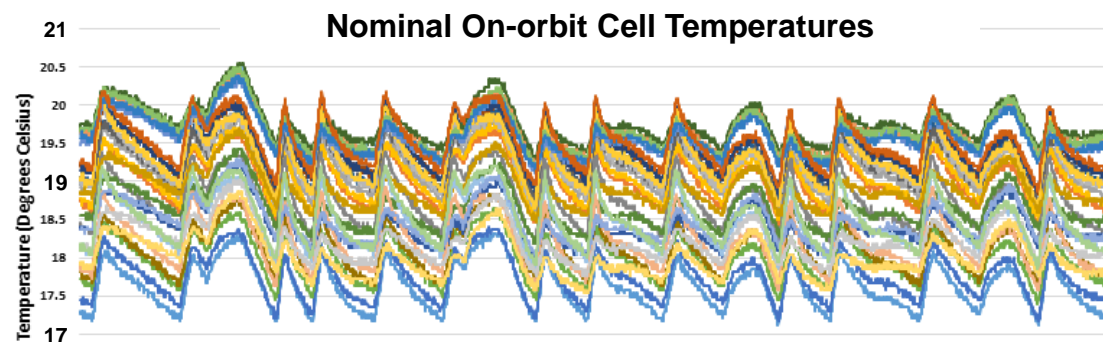
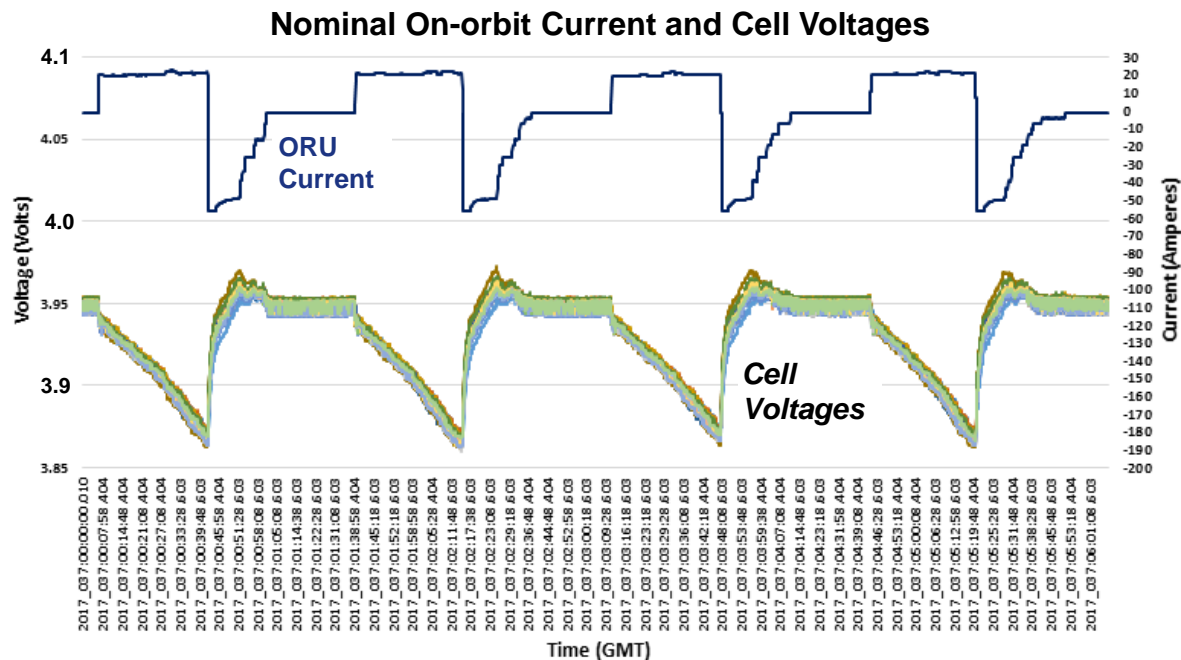


# ISS Li-Ion Charge Control and Cycling



- 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



*Data for Battery Channel 3A after ~30 days operation*

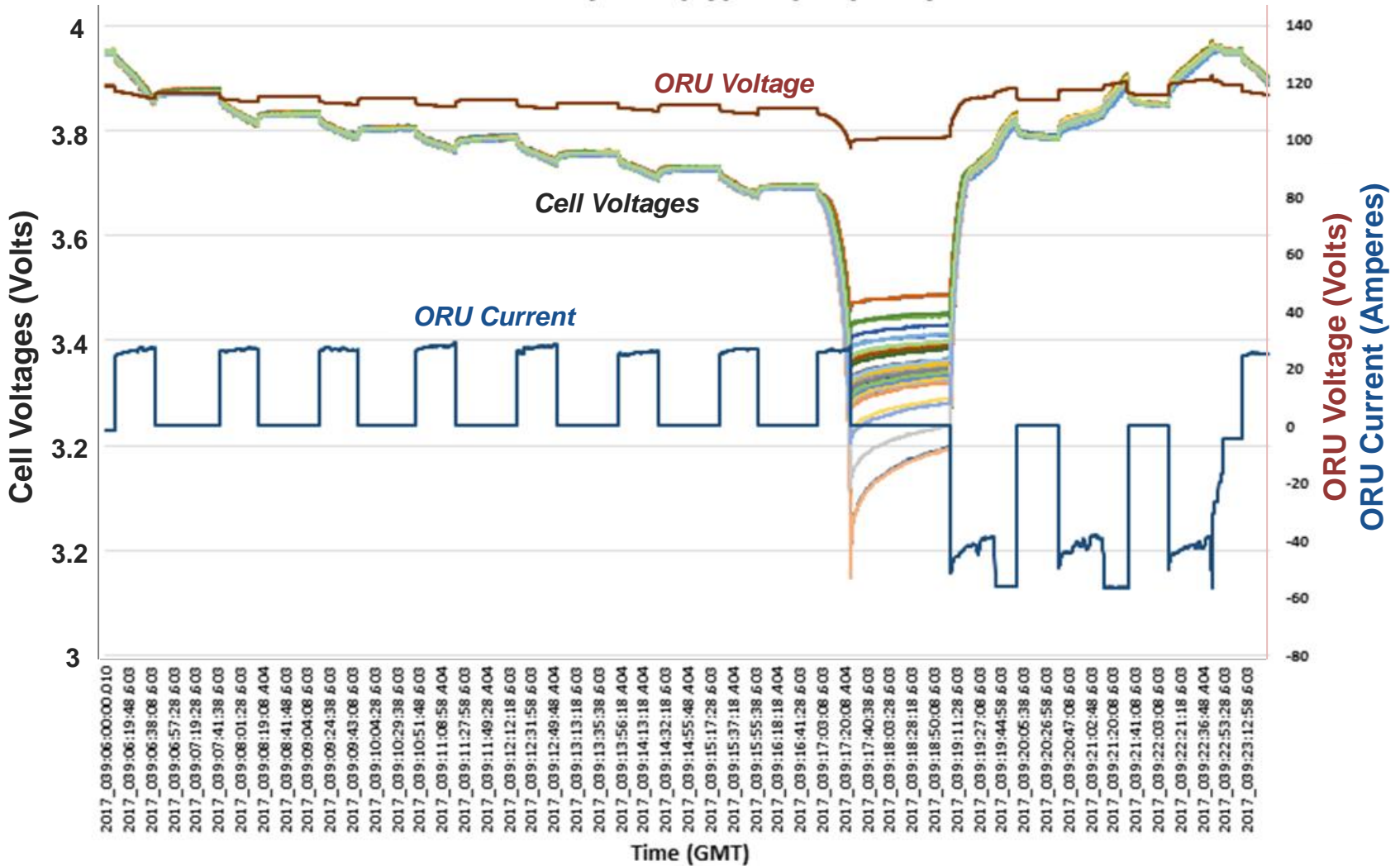




# ISS Li-Ion Charge Control and Cycling



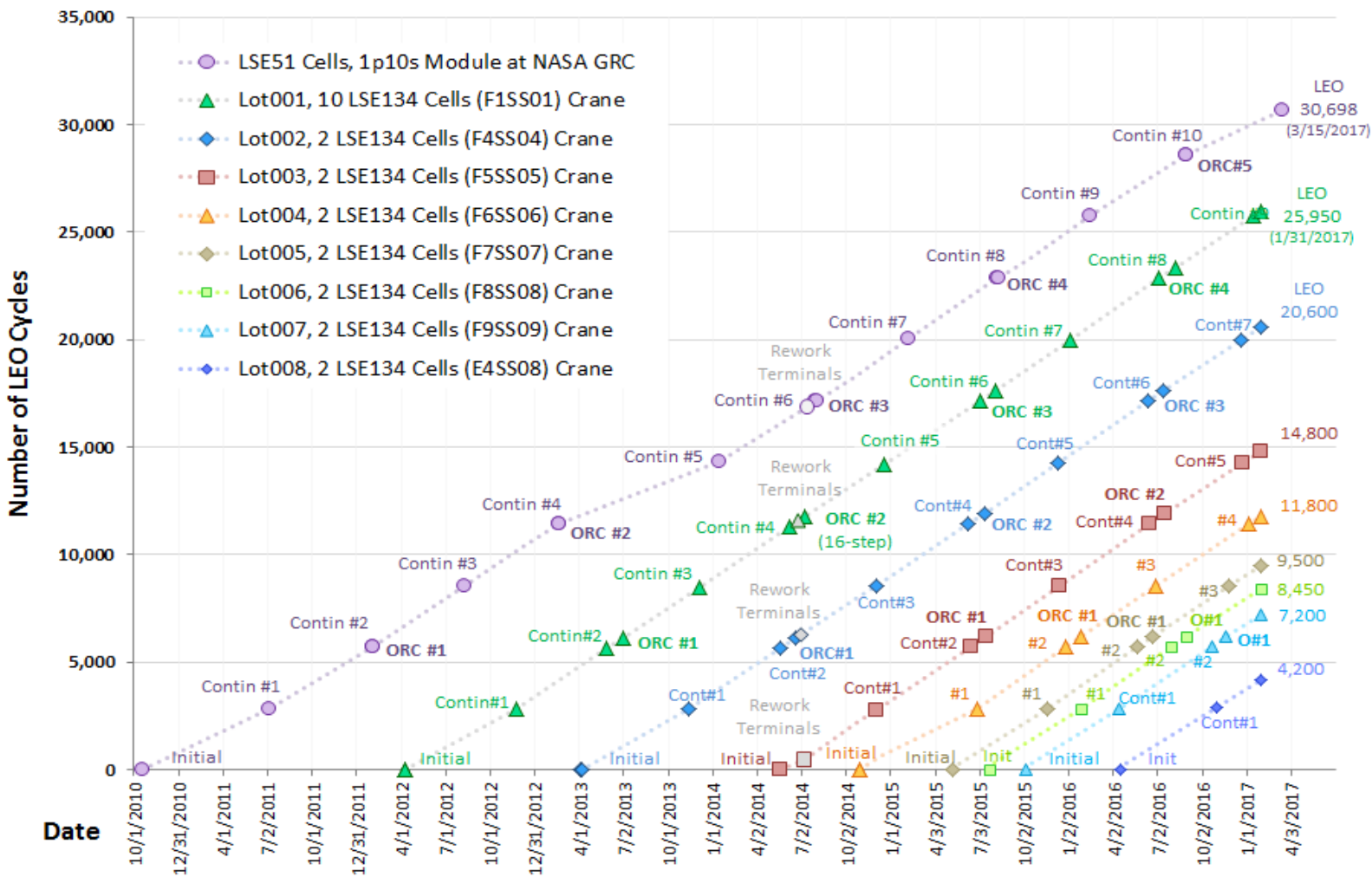
### Battery 3A2 (Typical) Capacity Test





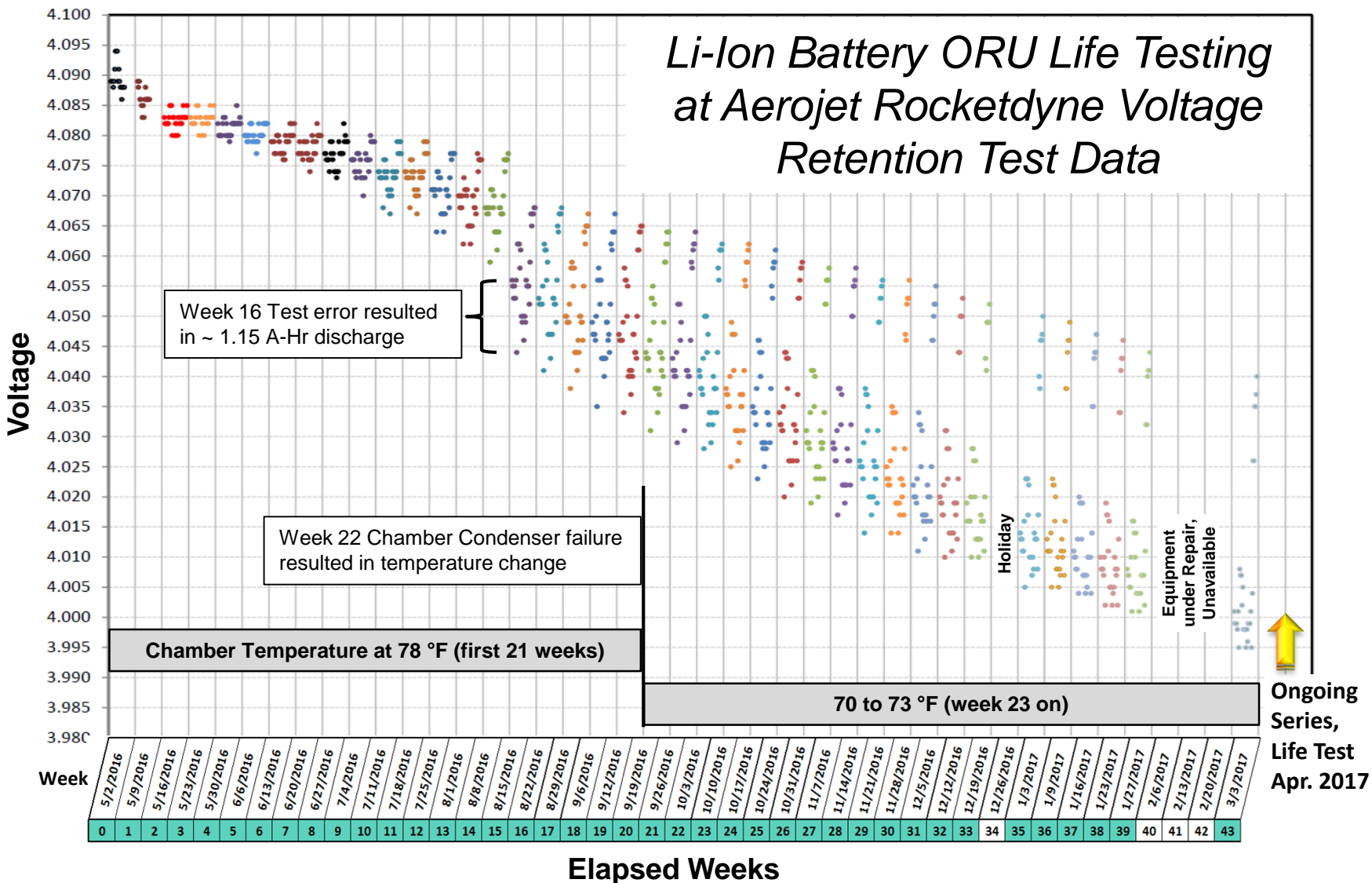
# Life Test Program

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





# Life Test Program

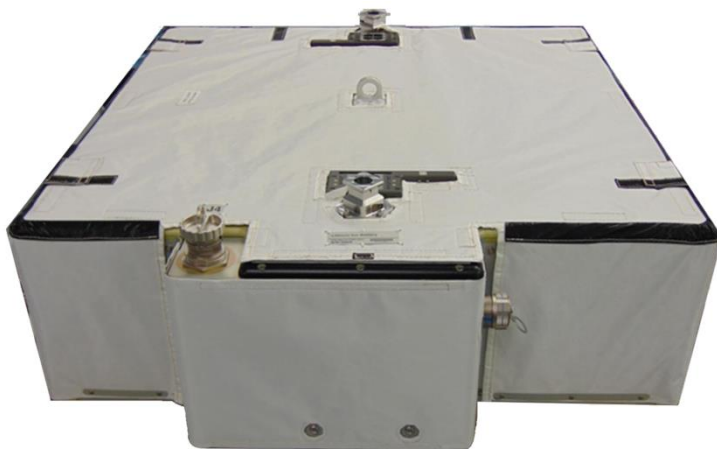




# ISS Li-Ion Battery Future Plans

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- Data analysis for NESC (NASA Engineering & Safety Center) Thermal runaway propagation test performed October 2016 at the White Sands Test Facility
- Launch of remaining Li-Ion Batteries and Adapter Plates in 2018, 2019, 2020 to provide a full complement on ISS



➤ *First six batteries (2 power channels) operating successfully on orbit*



# In Closing

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- Questions?



# Backup Materials

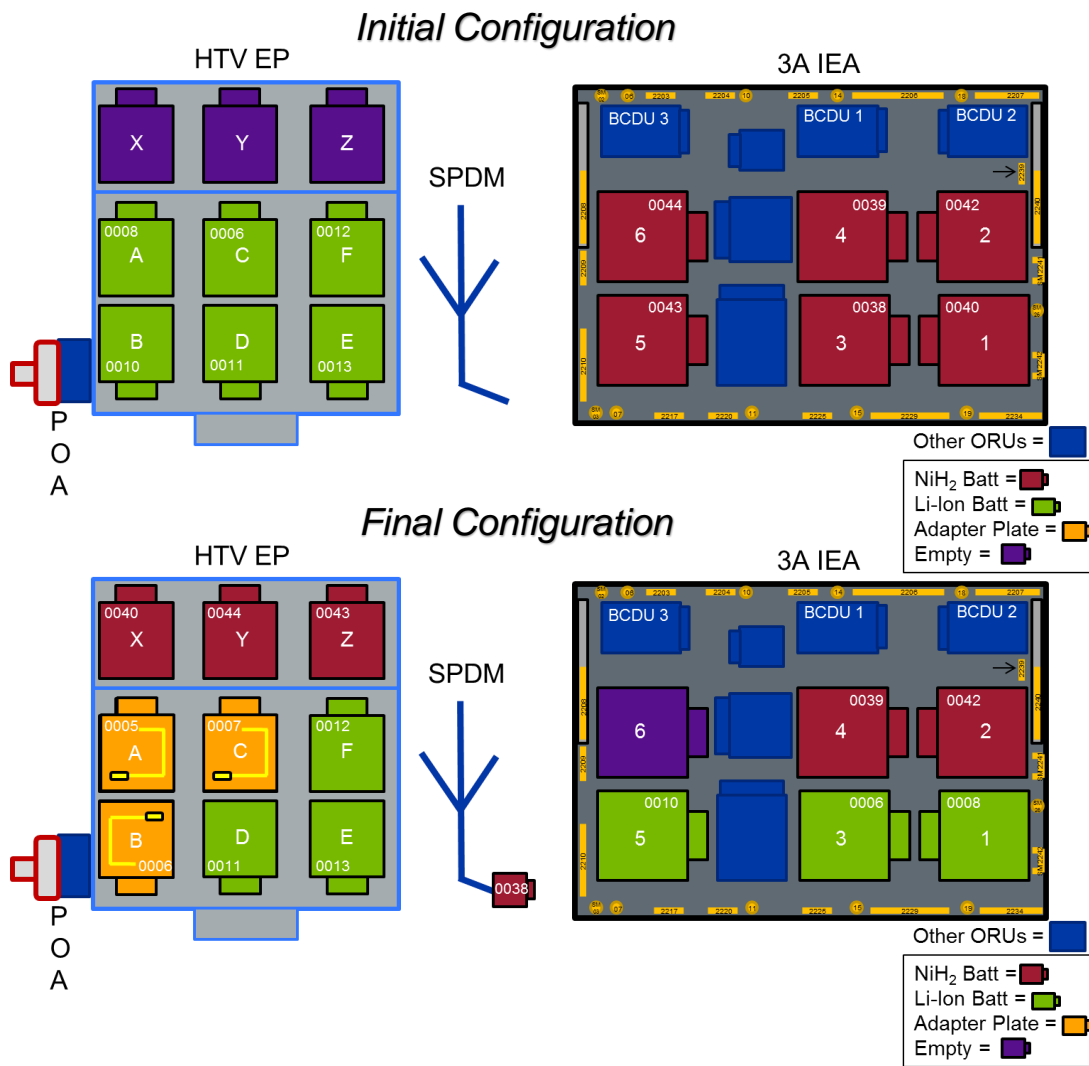
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- Installation Robotic and EVA sequence



# Robotic Operations

3A Robotic: (12/31/2016 – 1/3/2017)	
1A Robotic: (1/8/2017 – 1/12/2017)	
Shift	Operation
1A	Ni-H <sub>2</sub> : 5 > Z
1B	Ni-H <sub>2</sub> : 6 > Y
2A	Li-Ion: B > 5
2B	Ni-H <sub>2</sub> : 1 > X
3A	Li-Ion: A > 1
3B	Ni-H <sub>2</sub> : 3 > EOTP
4A	Li-Ion: C > 3
4B	ROST: 1/5





# EVA Operations

**3A EVA:**  
(1/6/2017 & 1/13/2017)  
**1A EVA:**  
(1/13/2017)

Adapter Plate  
A > 6

Ni-H<sub>2</sub>  
4 > AP 6

Adapter Plate  
B > 4

Ni-H<sub>2</sub>  
2 > AP 4

Adapter Plate  
C > 2

Release  
1A IEA H1 Slot 2

