



International Space Station Lithium-Ion Battery Status

NASA Aerospace Battery Workshop

November 19, 2019

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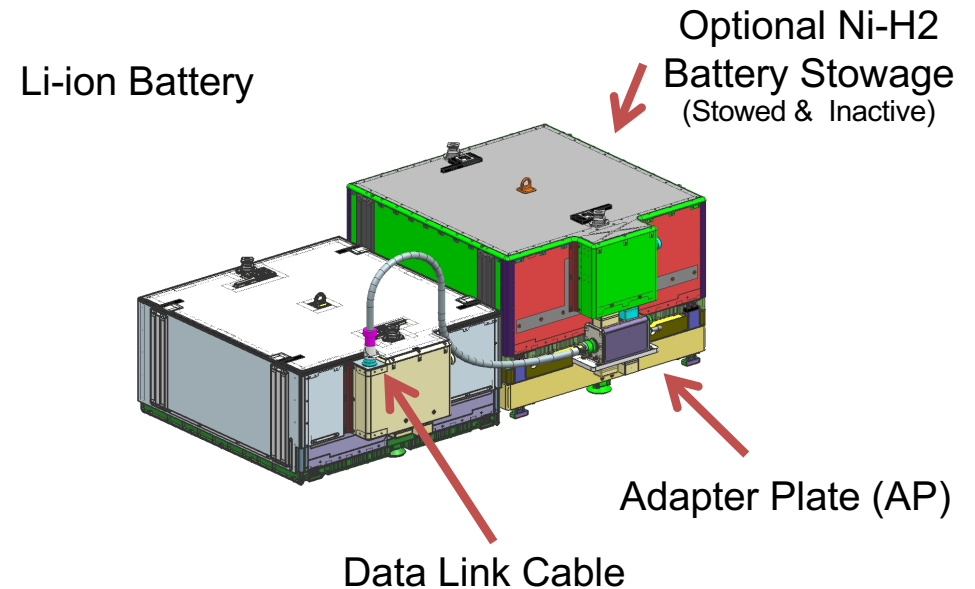
Tim North, The Boeing Company

Sonia Balcer, Aerojet Rocketdyne



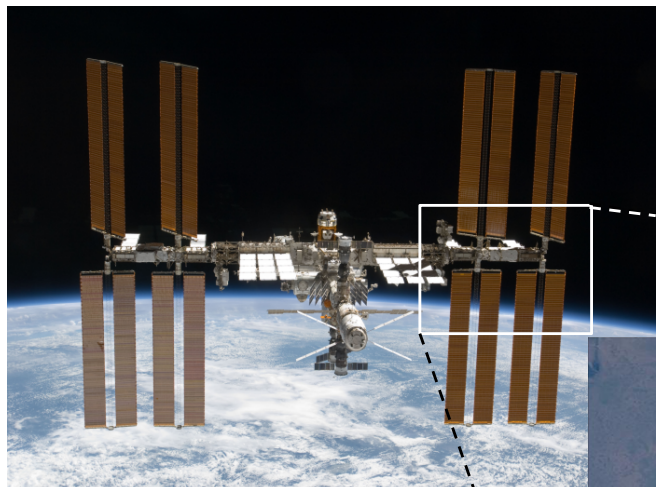
ISS Li-Ion Battery - Outline

- Configuration of Existing ISS Electric Power System
- ISS Upgrade to Li-Ion
- Launch History
- Battery Charge Control & On-Orbit Cycling Data
- Typical Capacity Test Battery
- Cell Life Test Data
- On-Orbit Operations
- Forward Work





ISS Configuration - Battery Locations

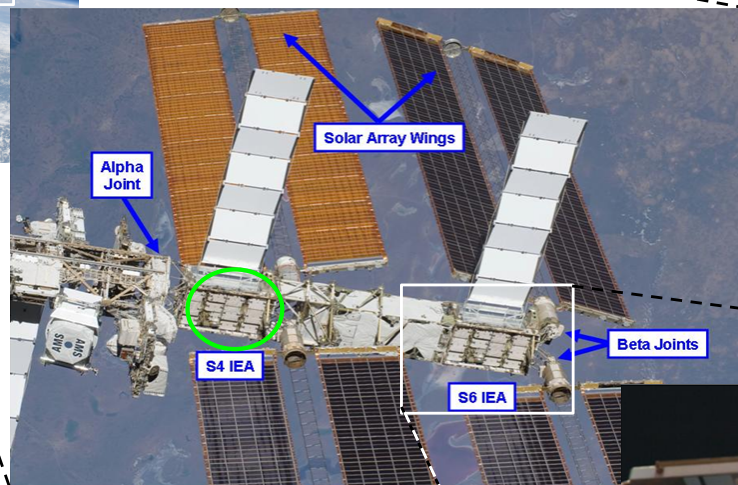


Batteries are located in the 4 Integrated Equipment Assemblies (IEAs)

2 Power Channels per IEA

8 Power Channels total

1 Li-Ion and 1 Adapter Plate replace 2 Ni-H₂

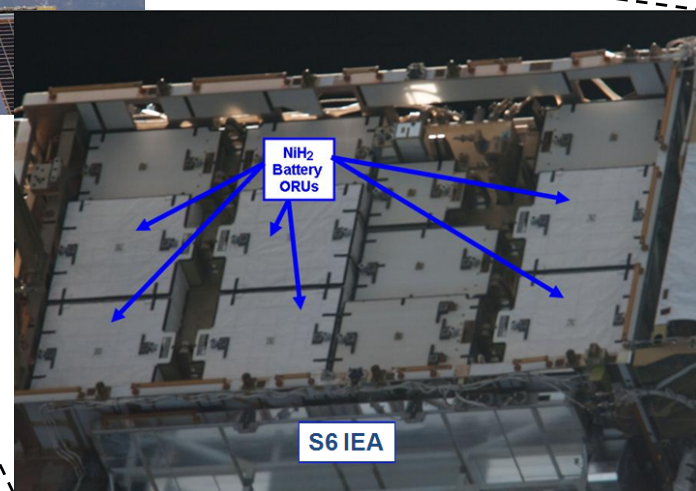


Initial Configuration:

- 6 Ni-H₂ ORUs per 8 channels – 48 total

Final Configuration:

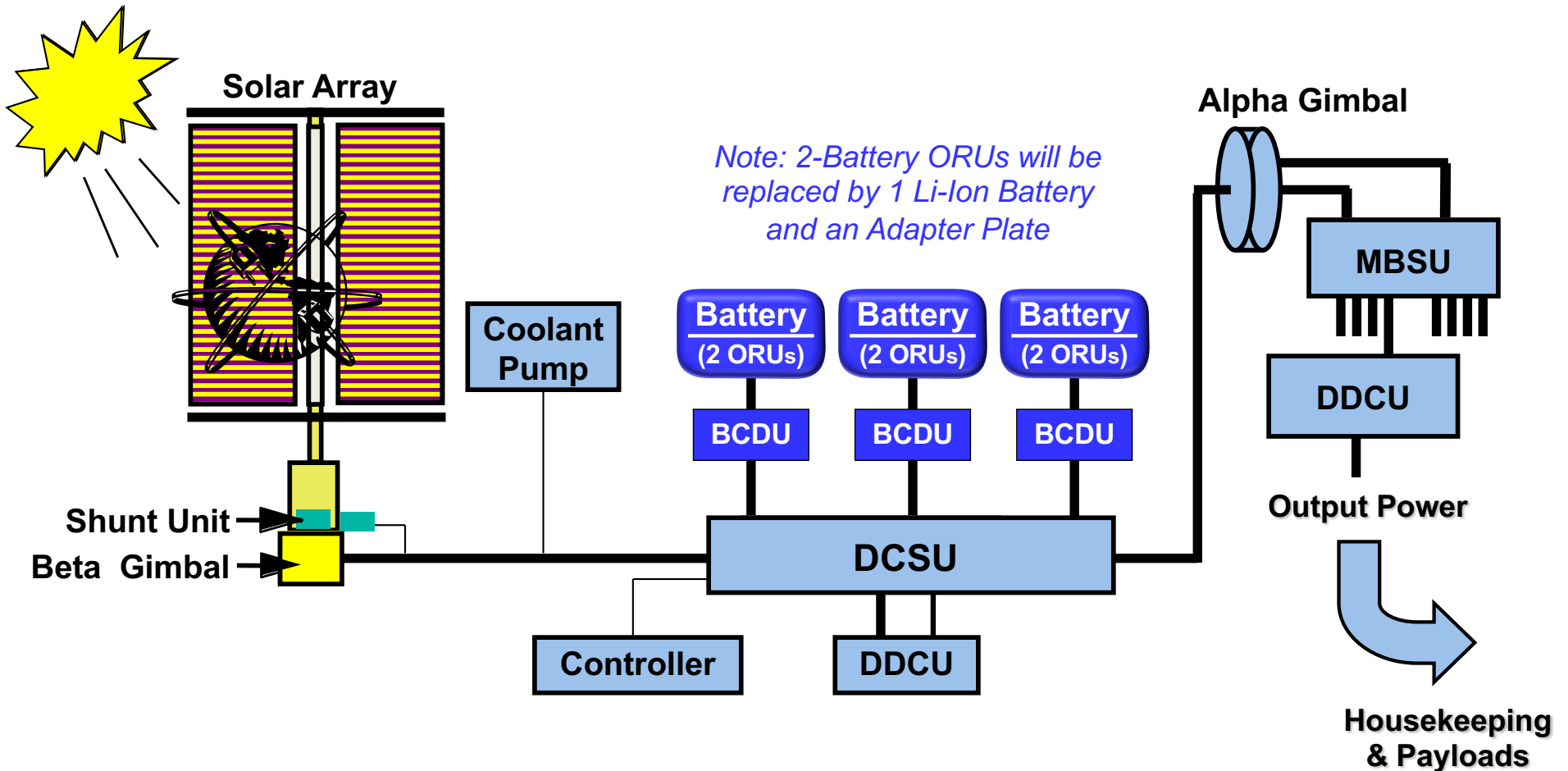
- 3 Li-Ion ORUs per 8 channels – 24 total





ISS Configuration - EPS Schematic

Electrical Power Channel – 1 of 8

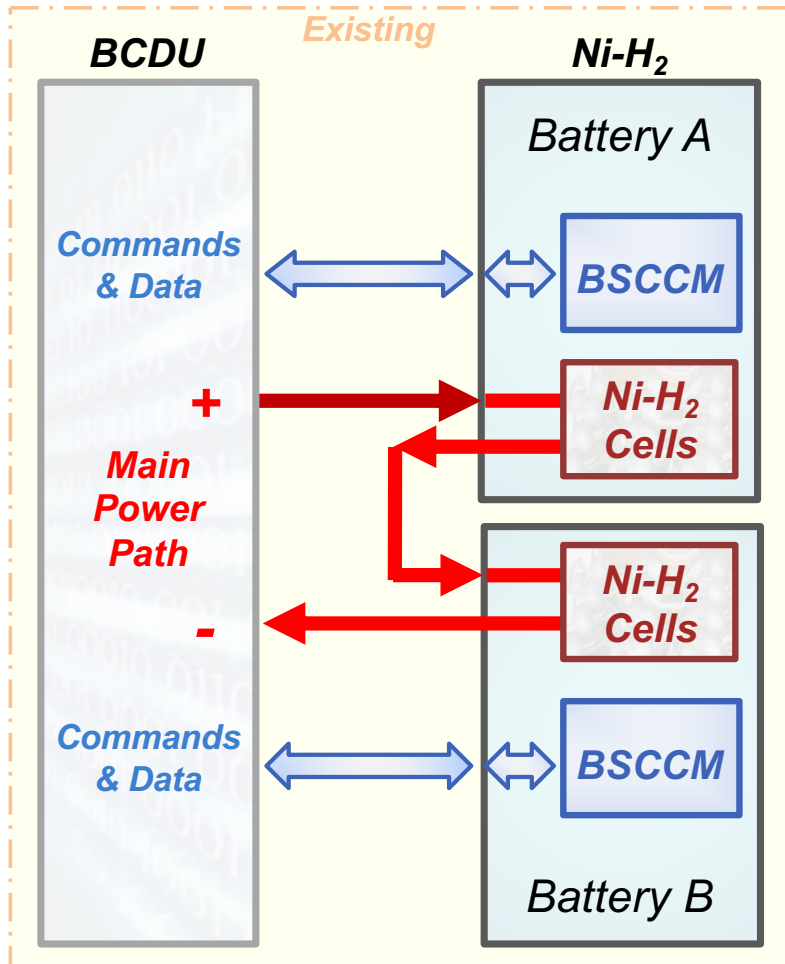


EPS: Electric Power System
BCDU: Battery Charge / Discharge Unit
DCSU: DC Switching Unit
DDCU: DC-to-DC Converter Unit
MBSU: Main Bus Switching Units

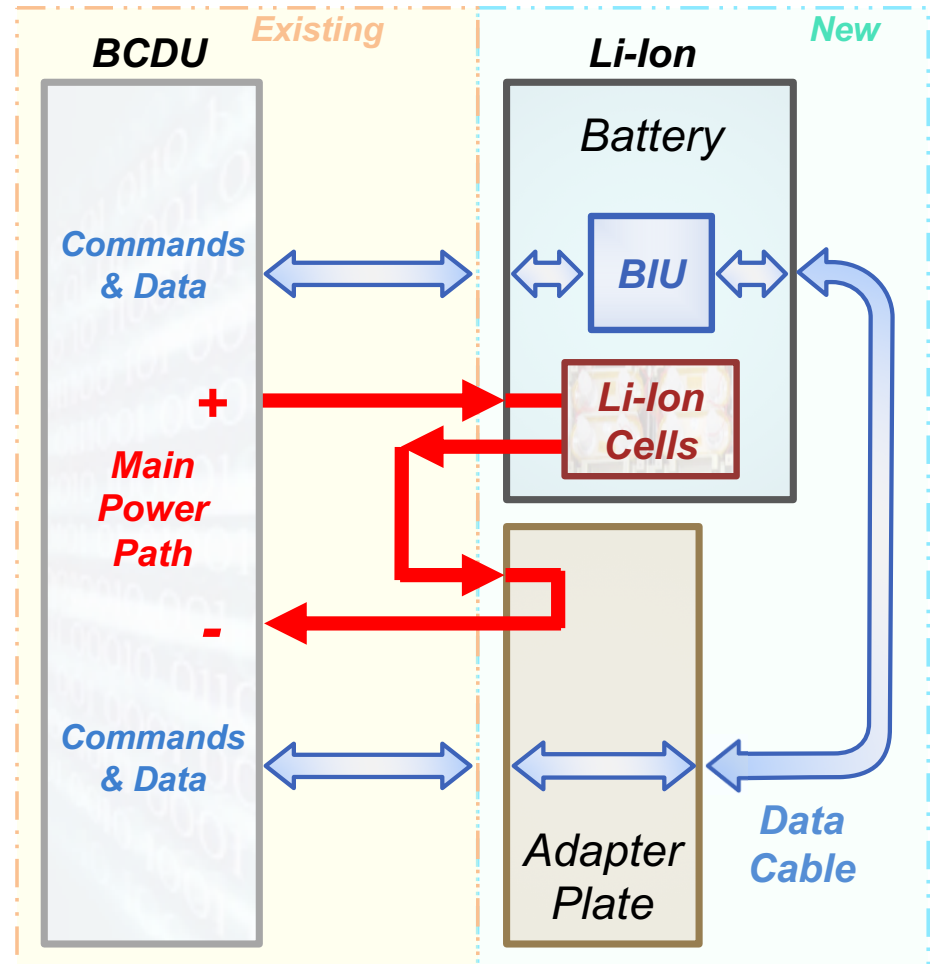


ISS Upgrade to Li-Ion

Ni-H₂
(76 81 Ah cells in series)



Li-Ion
(30 134 Ah cells in series)



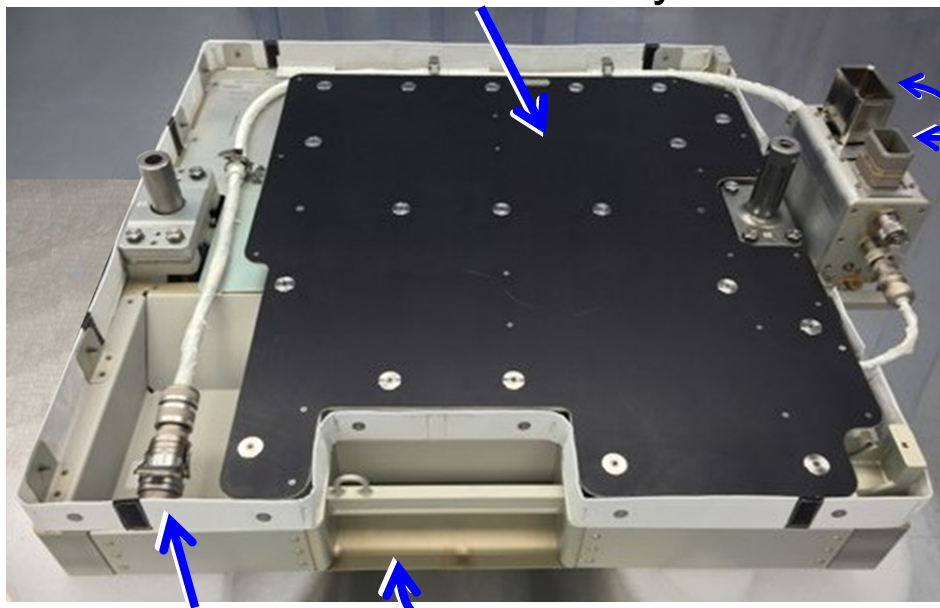
BCDU: Battery Charge / Discharge Unit
 BIU: Battery Interface Unit
 BSCCM: Battery Signal Conditioning and Control Module



ISS Li-Ion Orbital Replacement Units



Heater Mat
Heater Plate Assembly



P4 Connector
(stowed for launch)

EVA
Hand Hold &
Tether

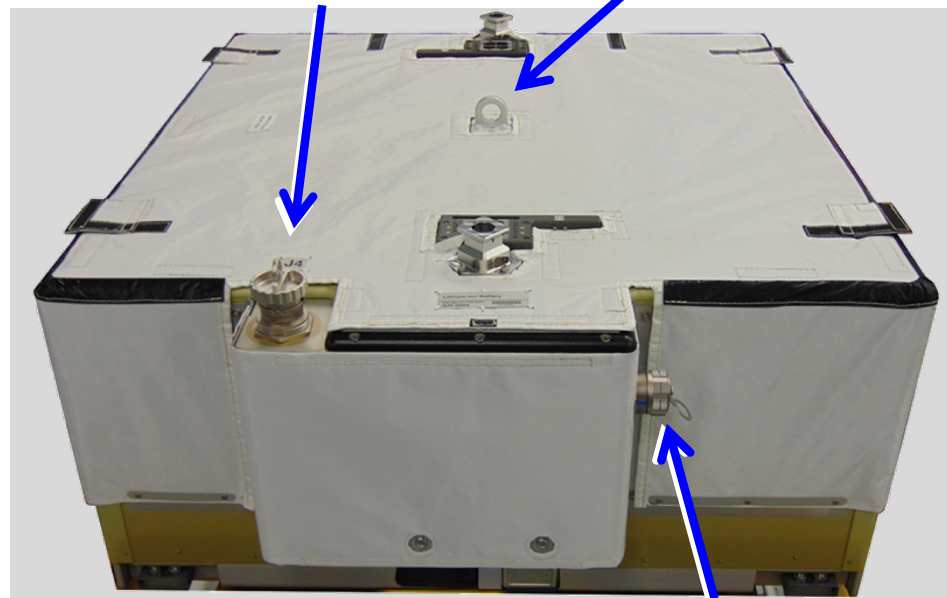
Dummy
Connectors

Adapter Plate ORU

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

J4
Connector

EVA
Tether



P1 & P2
Connectors

J3 Test
Connector

Li-ion Battery ORU

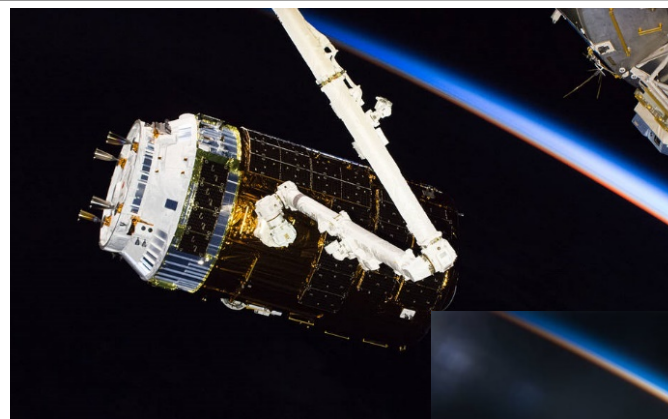
Dimensions (LxWxH): ~ 41" x 37" x 21"
Spec Weight: 435 Lbs



Launch History

- Launch on HTV6: December 9, 2016

- Installation and start-up on ISS:
S4 3A channel – Jan. 6, 2017
S4 1A channel, Jan. 13, 2017



- Launch on HTV7: September 22, 2018

BCDU failure blew the fuse in one of the new Li-Ion batteries

- One IEA Mixed Configuration operating with 2 Li-Ion and 1 pair of NiH2 ORUs since April 27, 2019
- Spare for 4A3 launching on SpX-19 (Dec. 2019)
- Installation and start-up on ISS:
P4 4A channel – March 22, 2019
P4 2A channel – March 29, 2019



- Launch on HTV8: September 24, 2019

- Installation and start-up on ISS:
P6 2B channel – Oct. 18, 2019
P6 4B channel – TBD

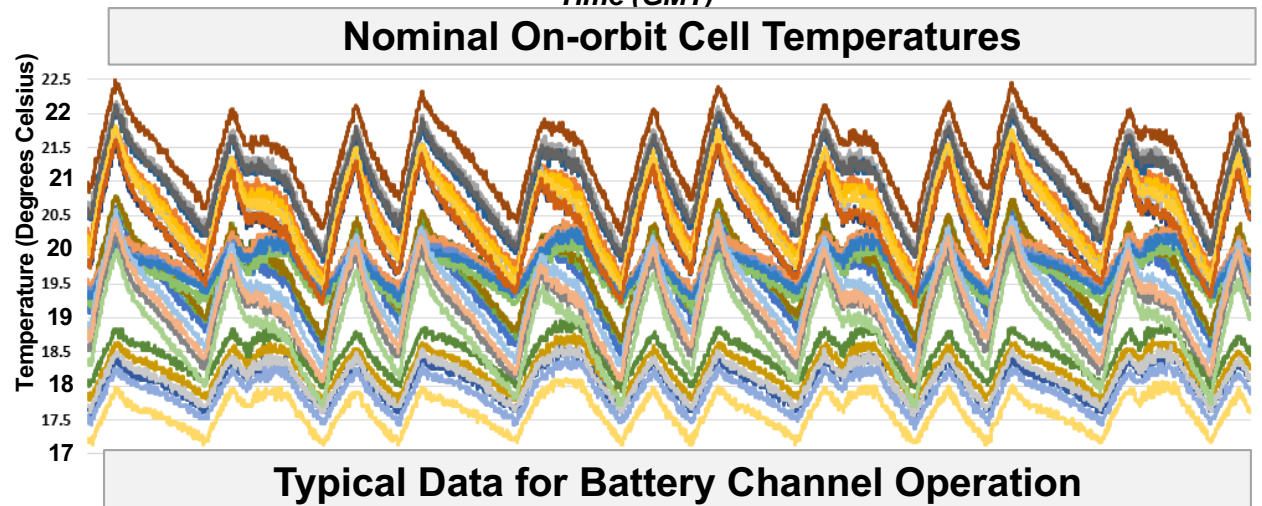
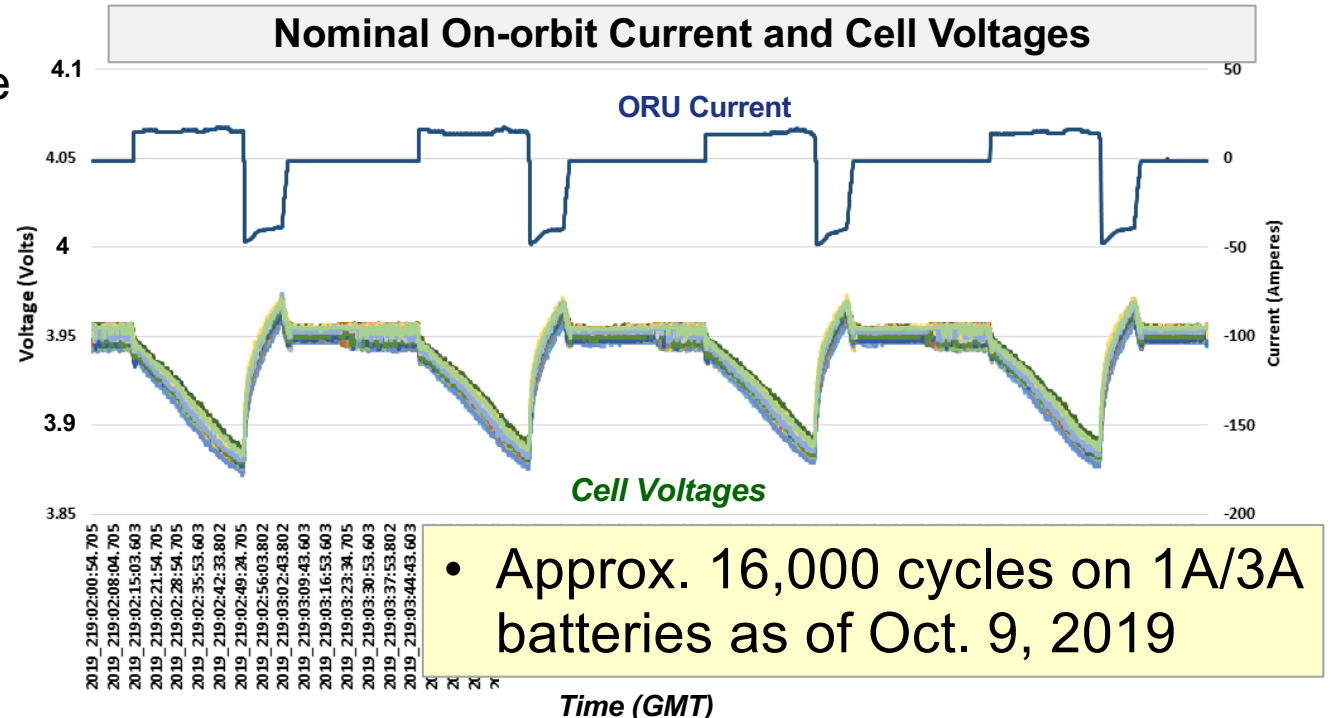




ISS Li-Ion Charge Control and Cycling

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

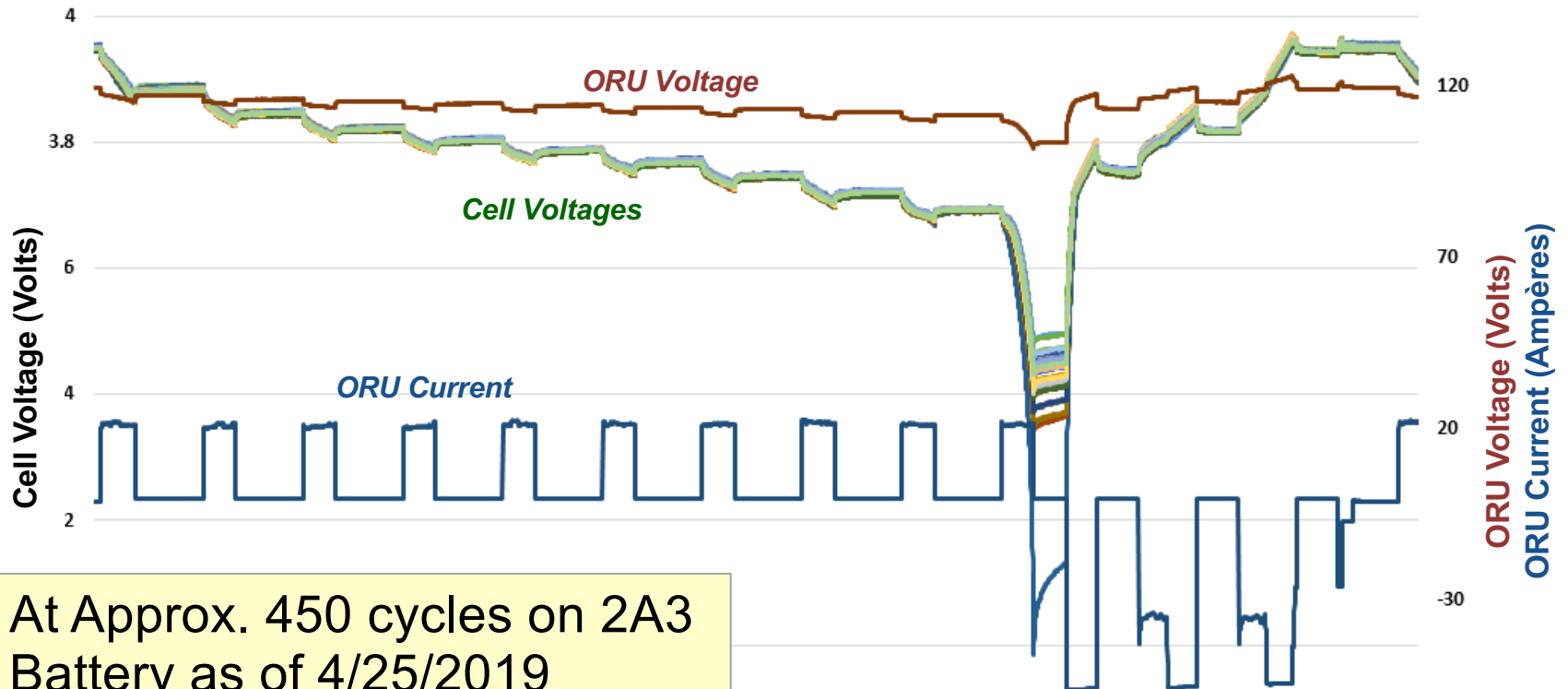
| Charge Current Profile | | |
|------------------------|---------------------------------------|----------------|
| | Highest of the Cell Terminal Voltages | Charge Current |
| Point 1 | EOCV + 19mV | 55 |
| Point 2 | EOCV + 19mV | 49 |
| Point 3 | EOCV + 18mV | 44 |
| Point 4 | EOCV + 17mV | 39 |
| 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 |



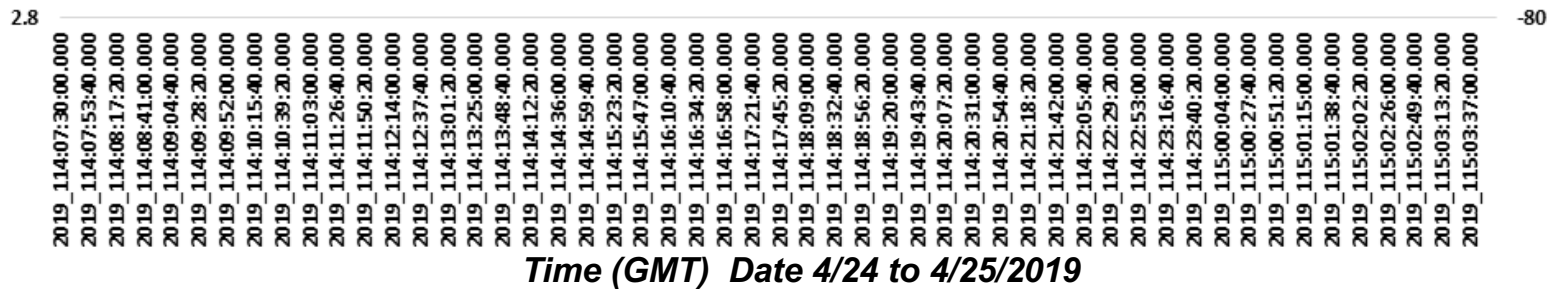


ISS Li-Ion Start-up Capacity Test

Typical Li-Ion Battery Capacity Test



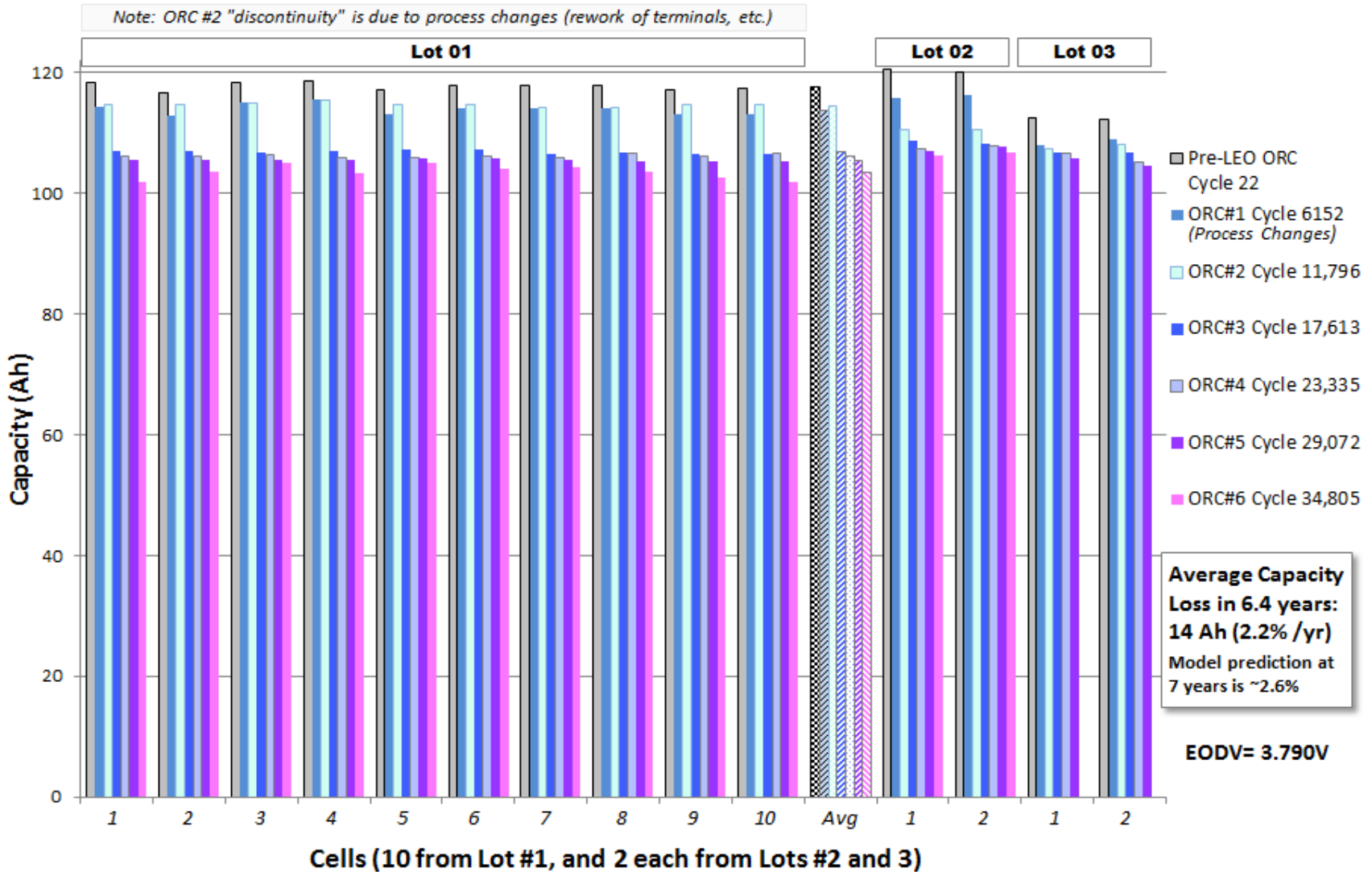
- At Approx. 450 cycles on 2A3 Battery as of 4/25/2019





Life Test Program

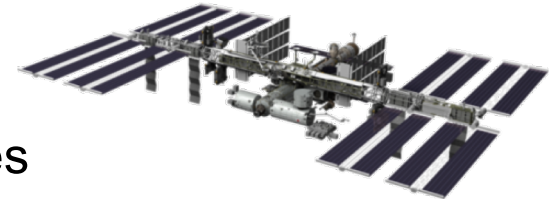
ORC Capacity Data for Life Test of LSE134 Cells at Crane





S4 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 ~16,000 LEO cycles
 - Batteries being operated at EOCV of 3.95V
 - Cell EODVs within ~10 mV
 - Cell temperatures within 5 degrees C
 - Initial and Annual On-Orbit Capacity tests performed
 - Results in line with GS Yuasa model

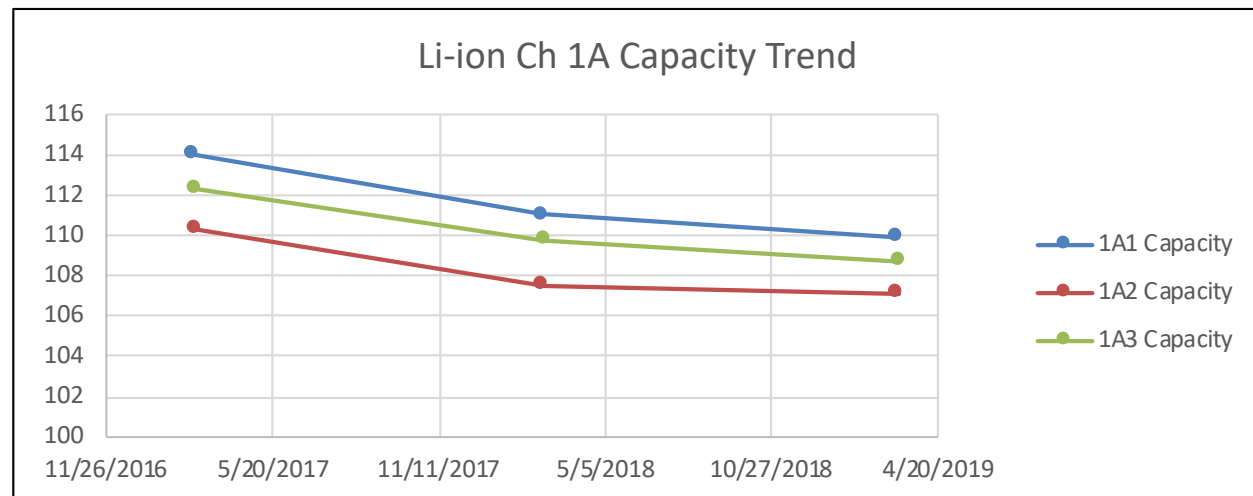
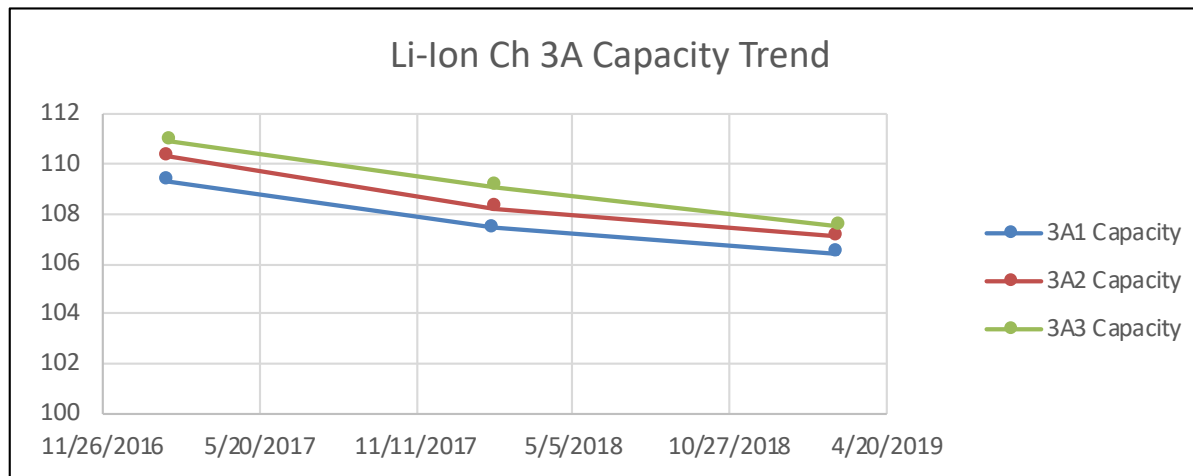


| Battery Location | Start Up Capacity (Ahr), Jan. 2017 | Annual Capacity (Ahr), Feb. 2018 | Annual Capacity (Ahr), Feb. 2019 |
|------------------|------------------------------------|----------------------------------|----------------------------------|
| 1A1 | 113.1 | 111.0 | 109.9 |
| 1A2 | 109.7 | 107.5 | 107.1 |
| 1A3 | 111.6 | 109.8 | 108.7 |
| 3A1 | 108.7 | 107.4 | 106.4 |
| 3A2 | 110.0 | 108.2 | 107.1 |
| 3A3 | 110.4 | 109.1 | 107.5 |



S4 Performance

S4 Capacity Data has been trending well within the expected range of capacity loss based on battery life performance test data and model predictions.





P4 Li-Ion Battery Operations

- Starting March 22, 2019, P4 Channels 4A operating in Mixed Configuration and Channel 2A operating with only Li-Ion Batteries
 - These Batteries have been performing after ~3,400 LEO cycles
 - Li-Ion Batteries being operated at EOCV of 3.95V
 - Cell EODVs within ~10 mV
 - Cell temperatures within 5 degrees C
 - NiH₂ Battery being operated nominally
 - Cell temperatures within 0 to 20 degrees C



| Battery Location | Start Up Capacity (Ahr), April 2019 |
|------------------|-------------------------------------|
| 2A1 | 109.6 |
| 2A2 | 110.5 |
| 2A3 | 105.4 |
| 4A1 | N/A |
| 4A2 | N/A |
| 4A3* | 56.8 |



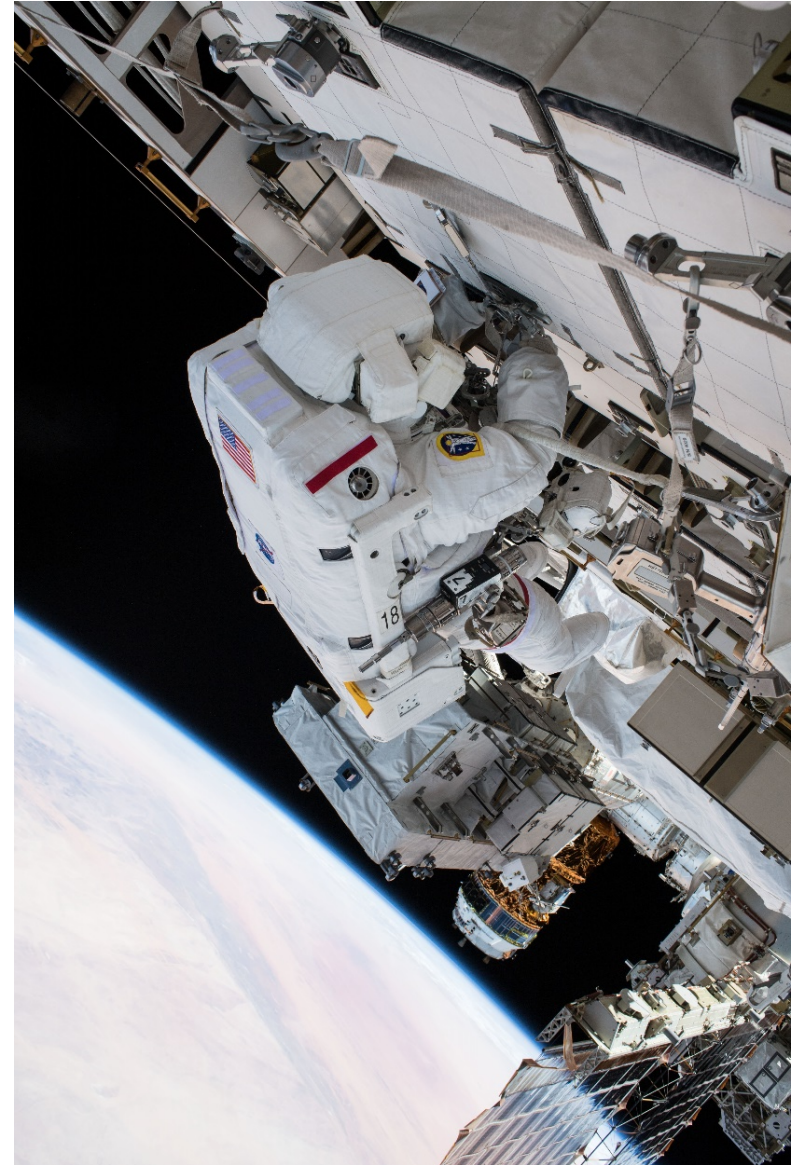
*4A3 is NiH₂ Battery Pair

Performing quarterly capacity test to closely monitor the performance



P6 Install in Work

- Starting October 18, 2019, P6 Channels 2B began operating with only Li-Ion Batteries
- P6 Channel 4B battery upgrades are TBD.





In Closing

- The first set of six ISS Li-ion Batteries continues to operate, meeting or exceeding expectations
- 5 out of 8 channels have been upgraded and are operating with Li-Ion
- The final set of six ISS Li-Ion Batteries is planned to launch on HTV-9 May 2020
- Questions?