International Space Station Lithium-Ion Battery Status

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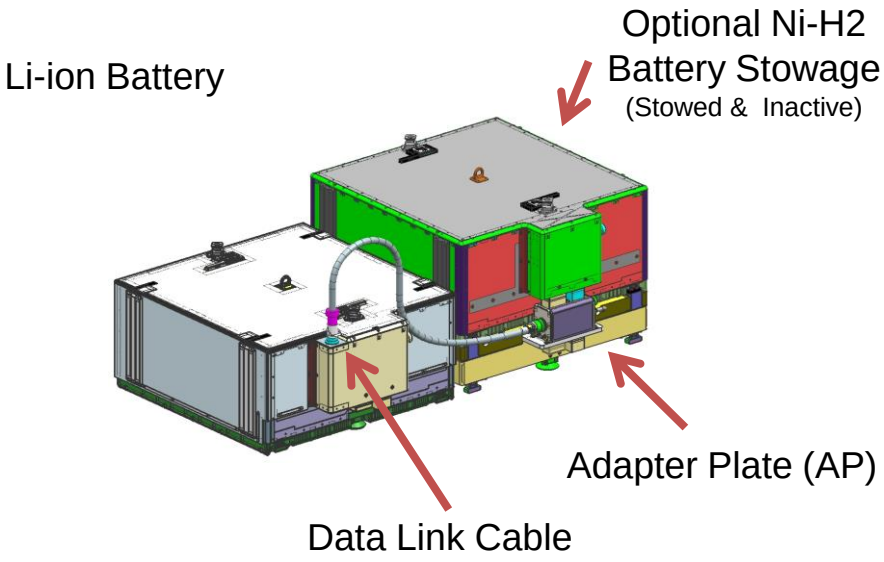
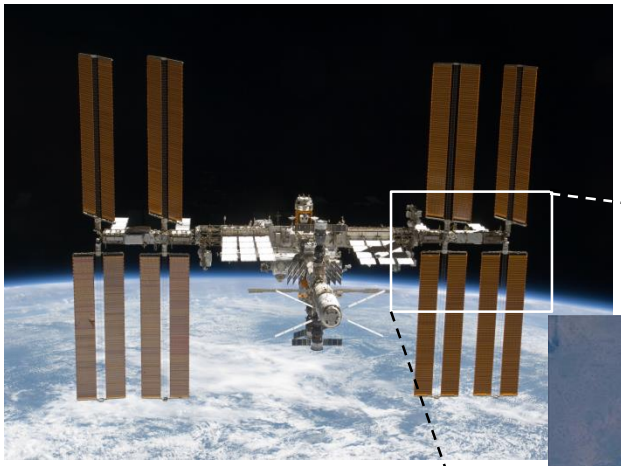
ISS Li-Ion Battery - Outline

- 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



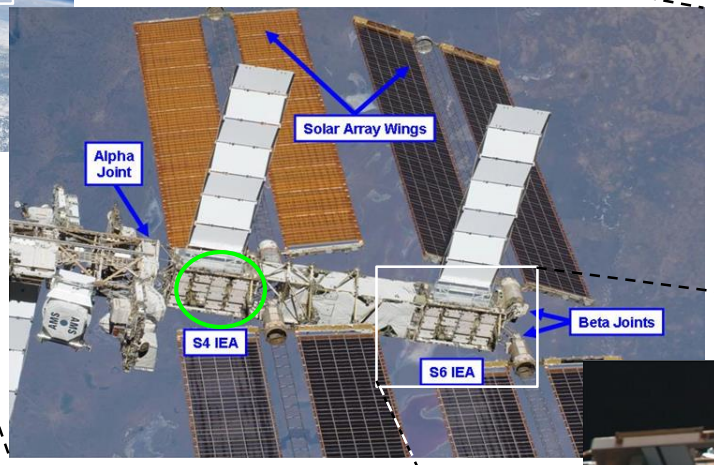
ISS Configuration - Battery Locations



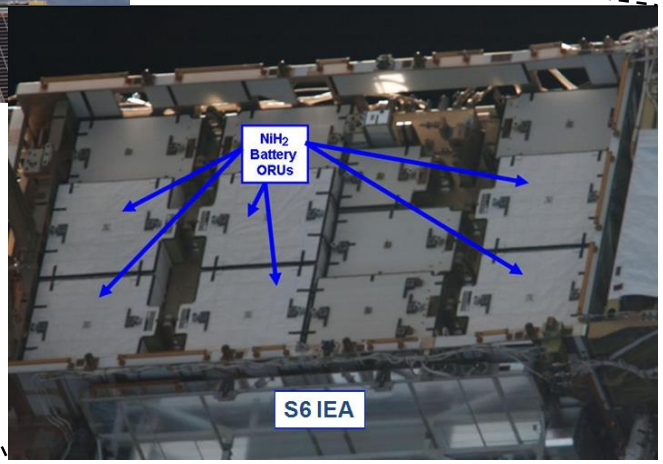
Batteries are located in the 4 Integrated Equipment Assemblies (IEAs)

2 Power Channels per IEA

8 Power Channels total



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



Initial Configuration:

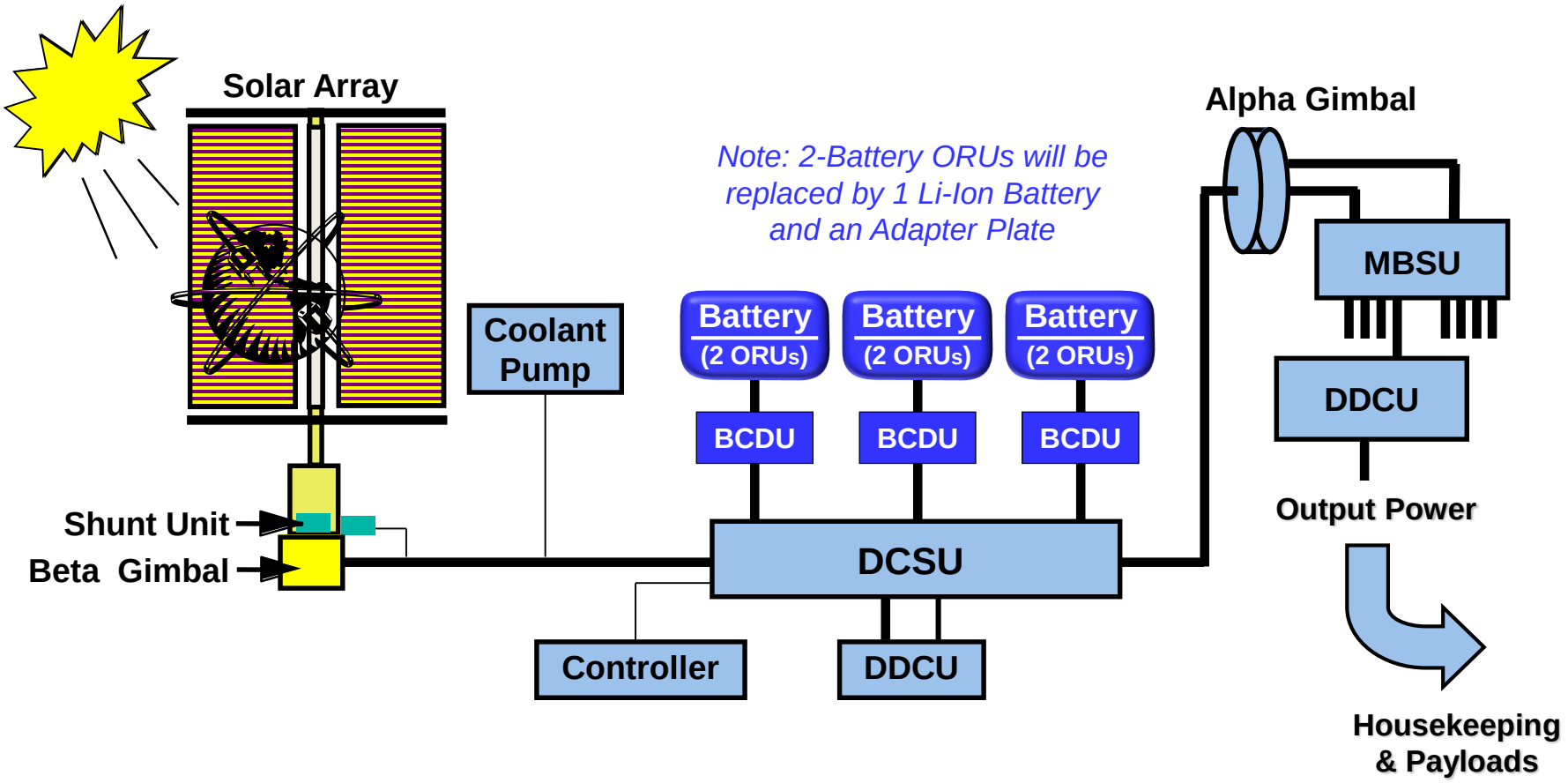
- 6 Ni-H_2 ORUs per 8 channels – 48 total

Final Configuration:

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

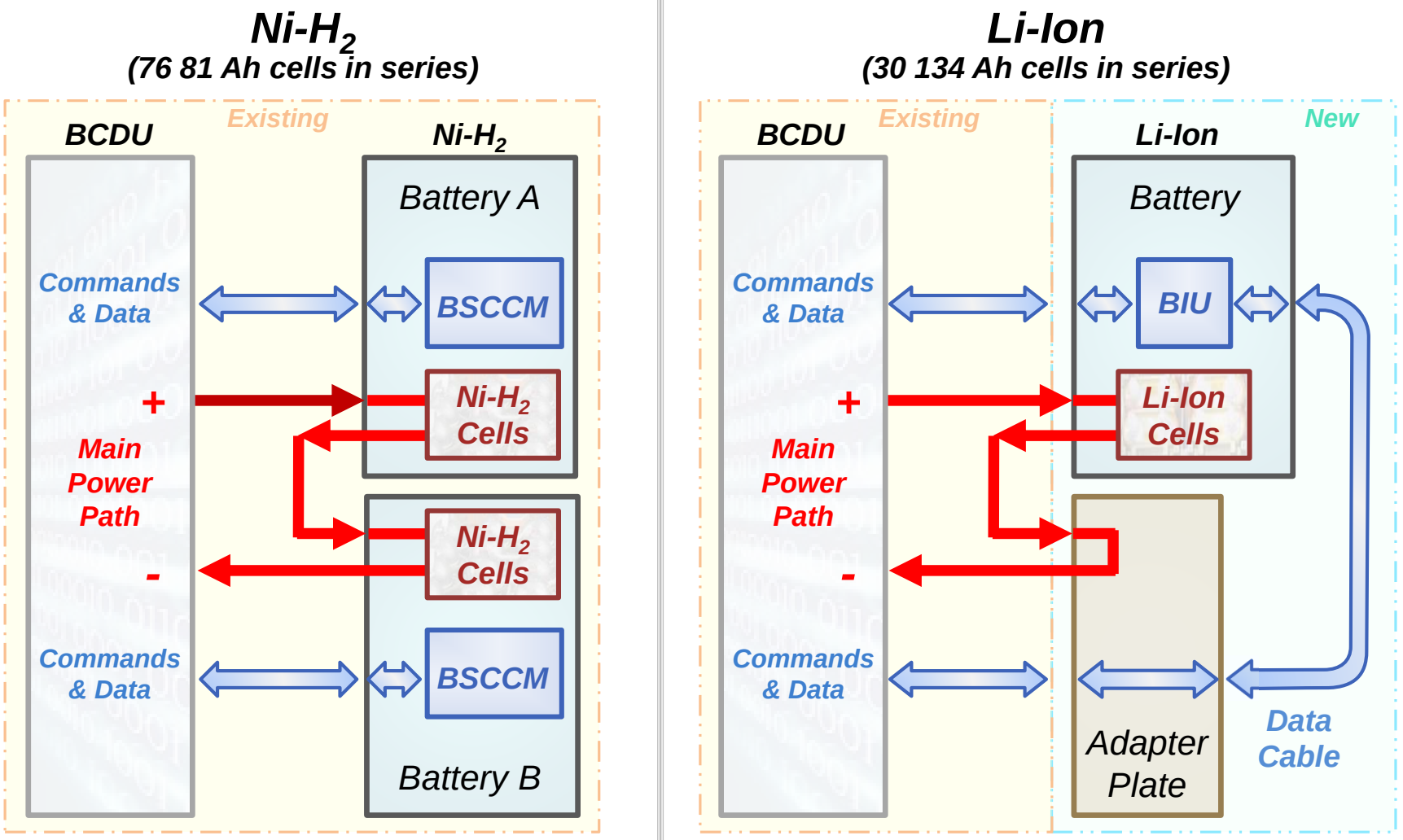
ISS Configuration - EPS Schematic

Electrical Power Channel – 1 of 8



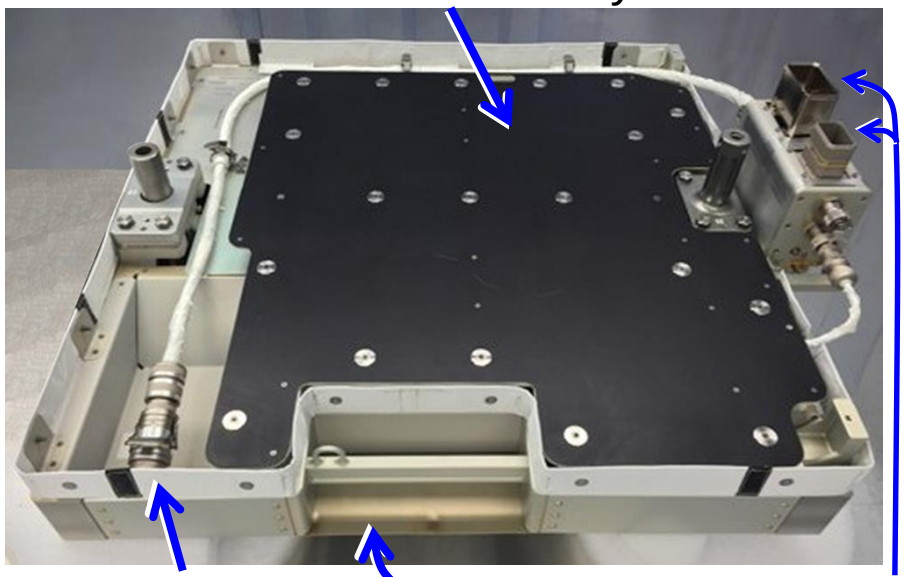
EPS:: Electric Power System
BCDU: Battery Charge / Discharge Unit
DCSU: DC Switching Unit
DDCU: DC-to-DC Converter Unit
MBSU: Main Bus Switching Units

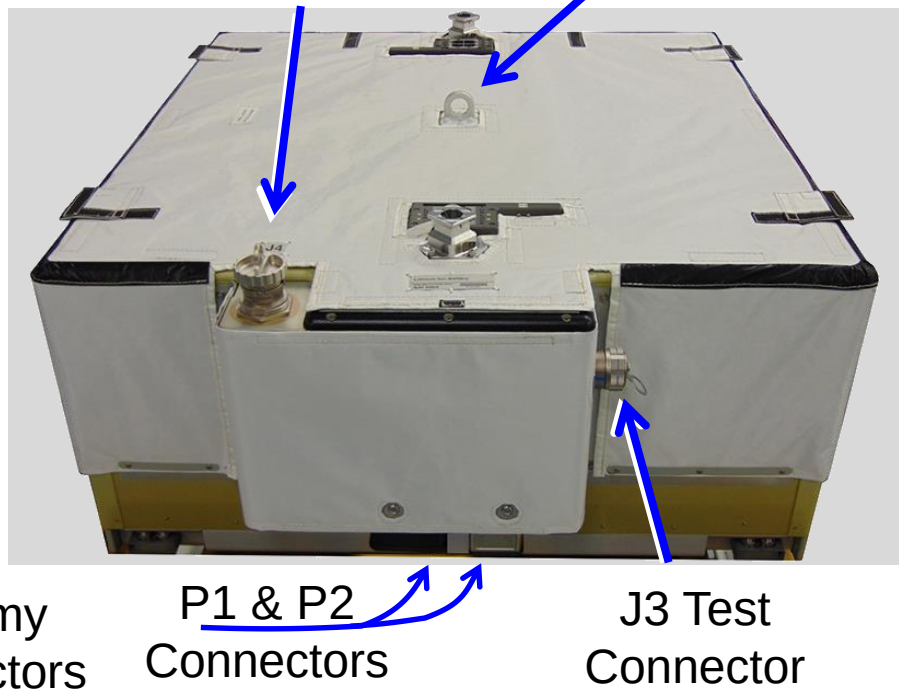
ISS Upgrade to Li-Ion



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

ISS Li-Ion Orbital Replacement Units





Adapter Plate ORU

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

Li-ion Battery ORU

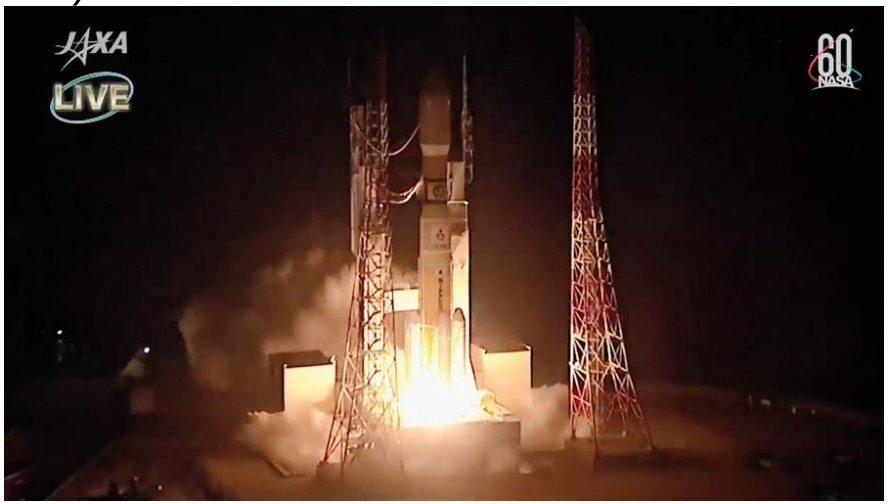
Dimensions (LxWxH): ~ 41” x 37” x 21”
Spec Weight: 435 Lbs

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



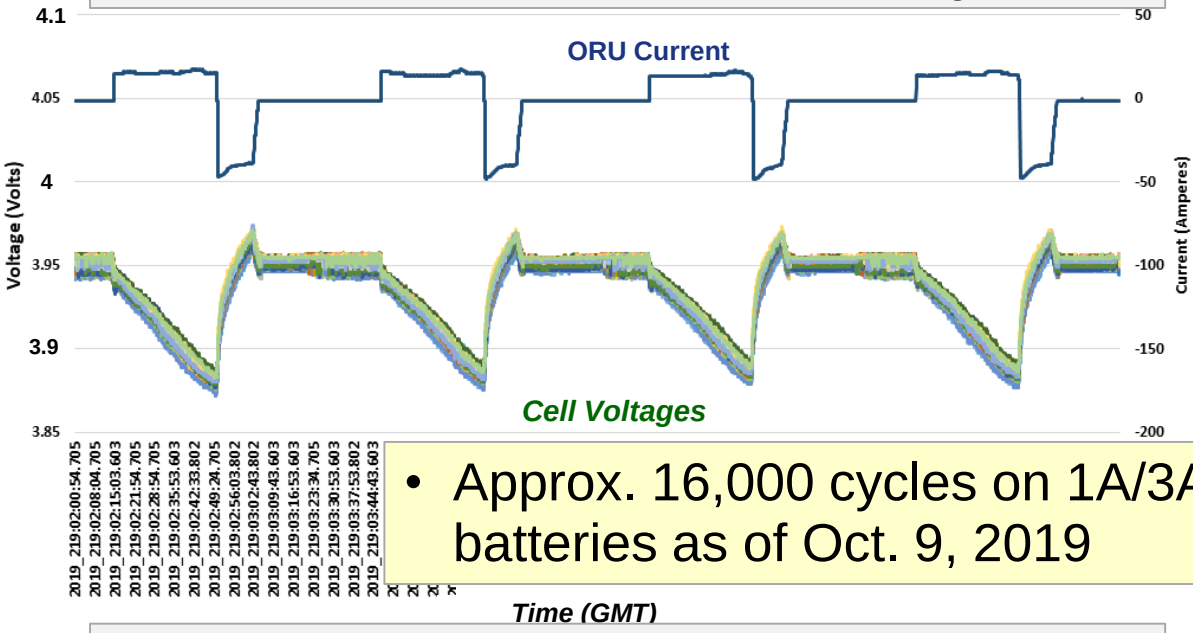
- Launch on HTV8: September 24, 2019
  - Installation and start-up on ISS:
    P6 2B channel – Oct. 18, 2019
    P6 4B channel – TBD

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

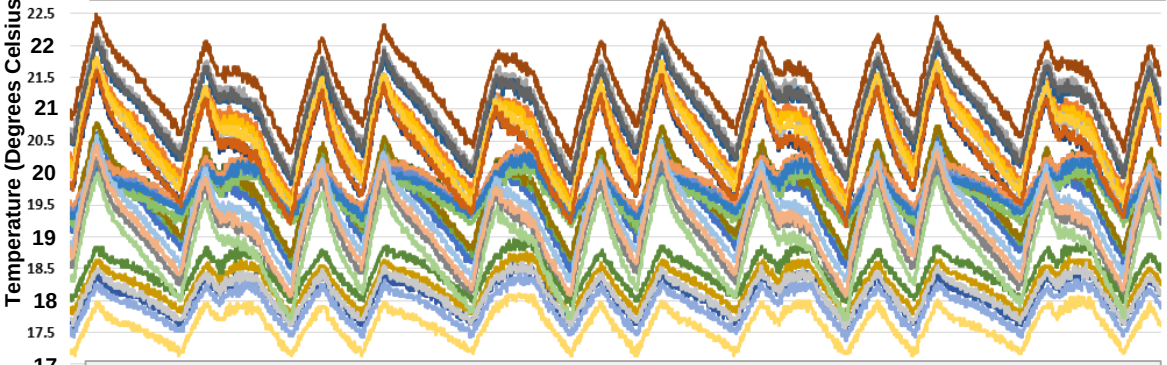
Charge Current Profile		
	Highest of the Cell Terminal Voltages	**Charge Current**
Point 1	EOCV + 19mV	55
Point 2	EOCV + 19mV	49
Point 3	EOCV + 18mV	44
Point 4	EOCV + 17mV	39
Point 5	EOCV + 16mV	36
Point 6	EOCV + 15mV	33
Point 7	EOCV + 14mV	30
Point 8	EOCV + 13mV	26
Point 9	EOCV + 12mV	22
Point 10	EOCV + 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

Nominal On-orbit Current and Cell Voltages



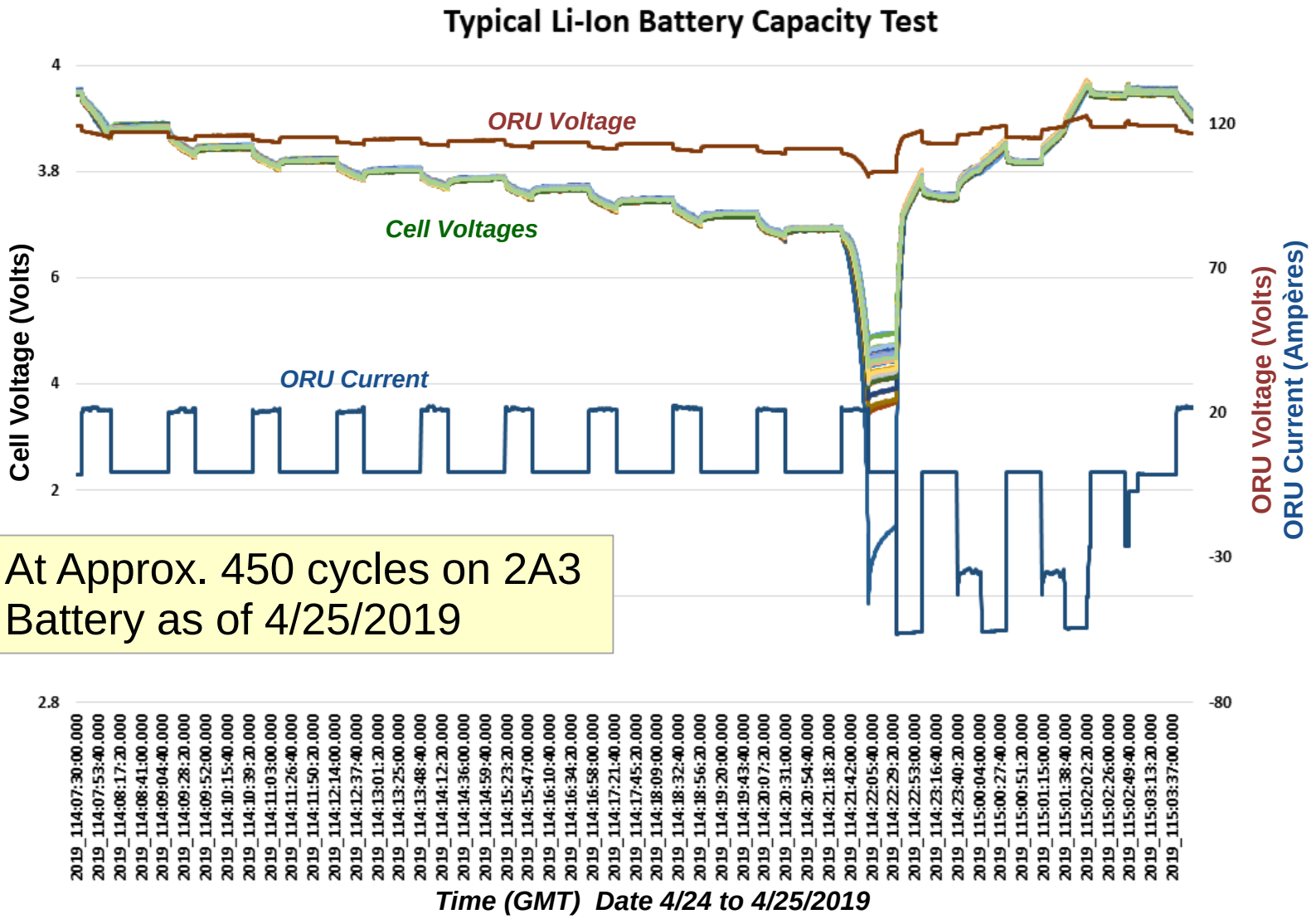
- Approx. 16,000 cycles on 1A/3A batteries as of Oct. 9, 2019

Nominal On-orbit Cell Temperatures



Typical Data for Battery Channel Operation

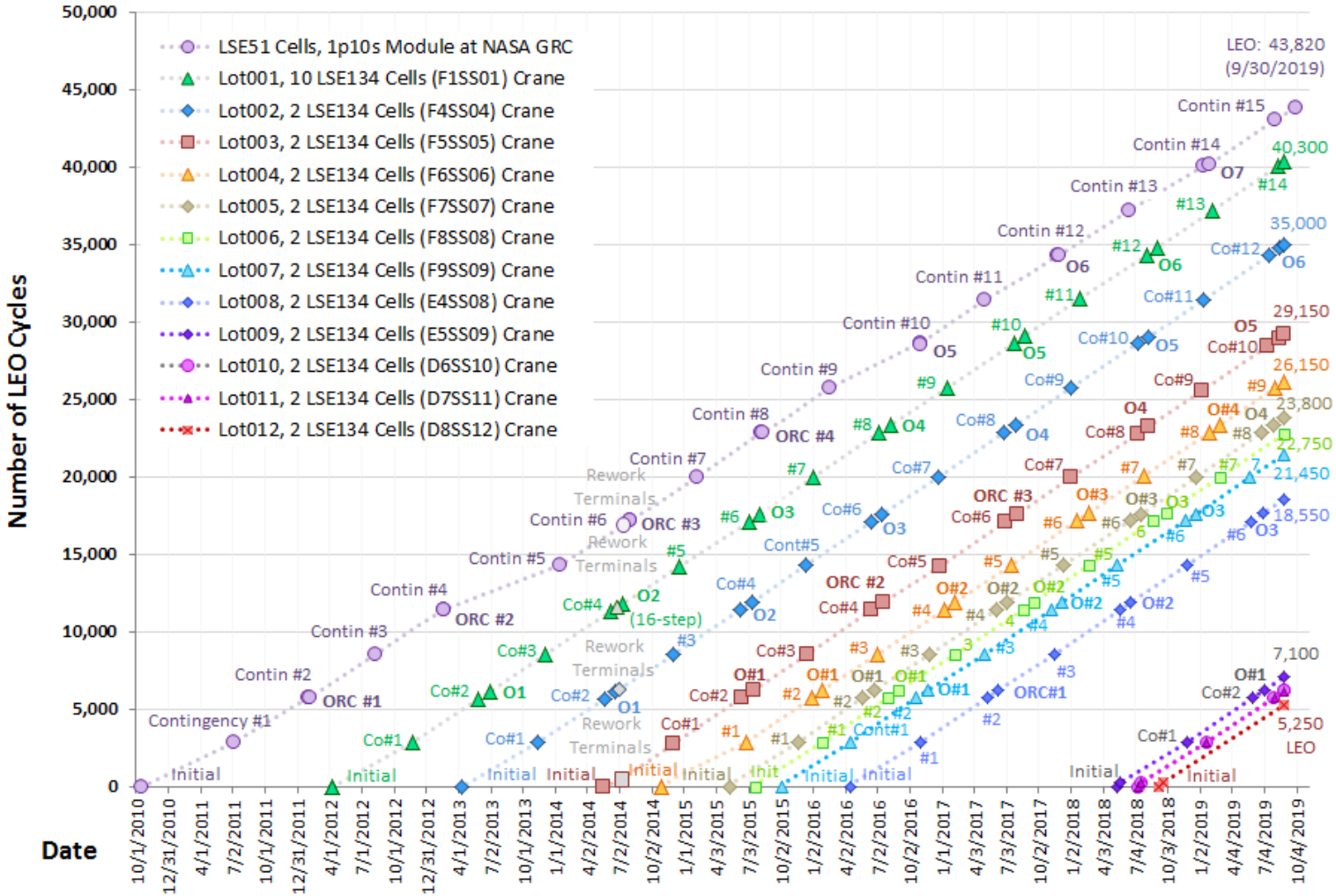
ISS Li-Ion Start-up Capacity Test



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

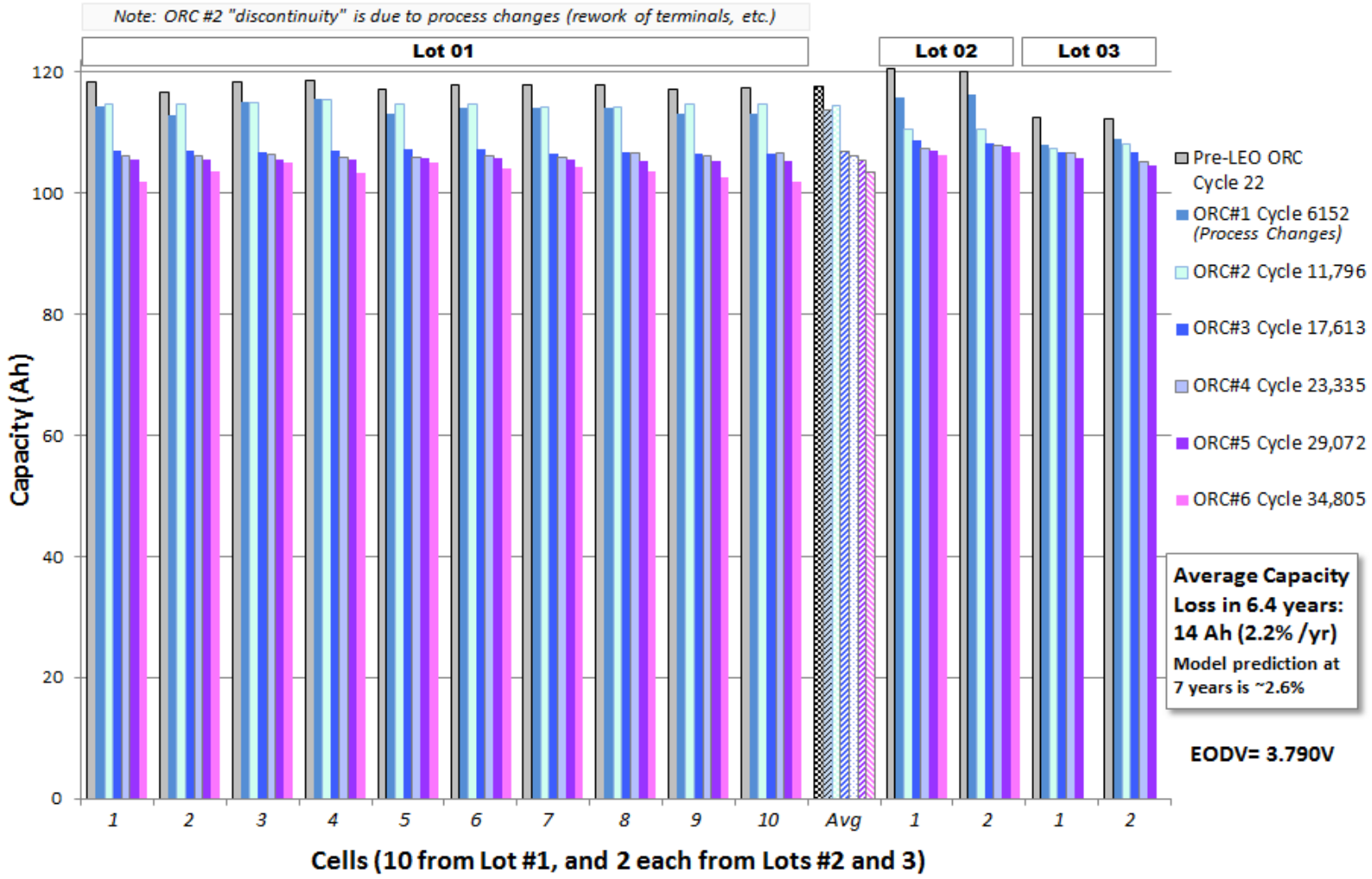
Life Test Program

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

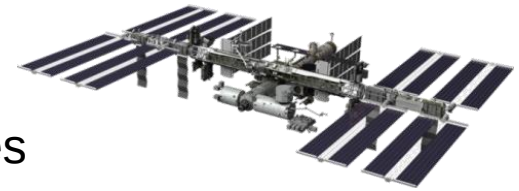


Life Test Program

ORC Capacity Data for Life Test of LSE134 Cells at Crane



S4 Li-Ion Battery Orbit Operations

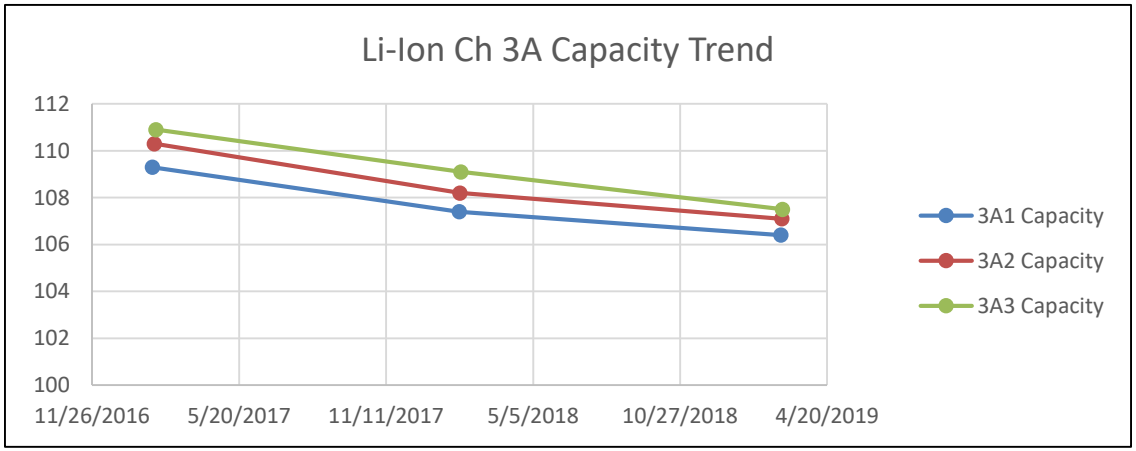


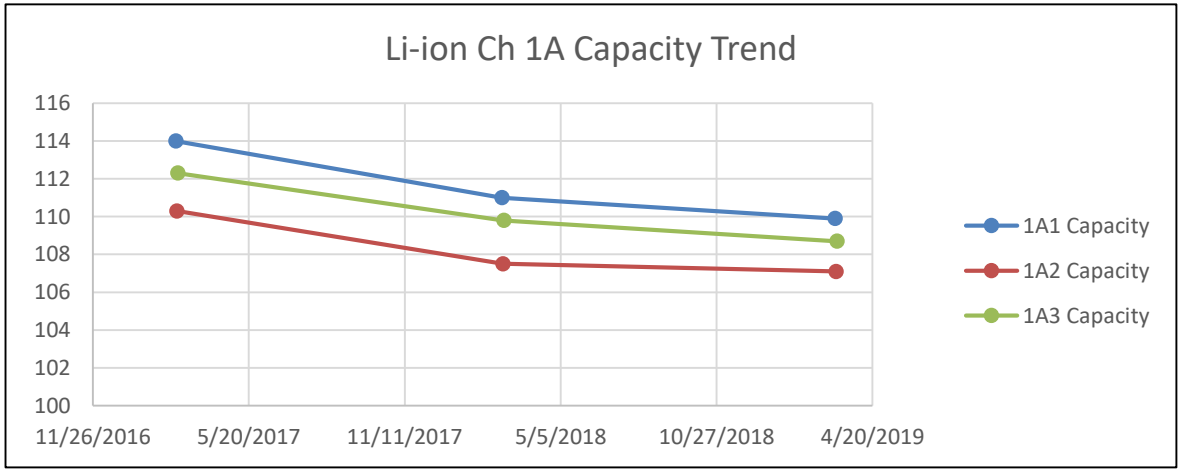
- Starting January 13, 2017, S4 Channels 3A and 1A are being operated using only Li-Ion Batteries
  - Batteries are performing well after ~16,000 LEO cycles
    - Batteries being operated at EOCV of 3.95V
    - Cell EODVs within ~10 mV
    - Cell temperatures within 5 degrees C
  - Initial and Annual 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
    - NiH_2 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 NiH_2 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?