International Space Station Lithium-Ion Battery Status

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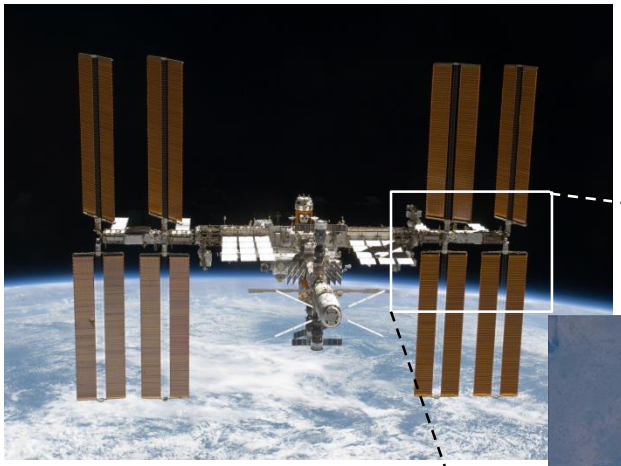
ISS Li-Ion Battery - Outline

- Configuration of Existing ISS Electric Power System
- Launch and Docking
- Battery Charge Control and LEO Cycle Test Data
- On-Orbit Cycling Data
- Cell and ORU Life Test

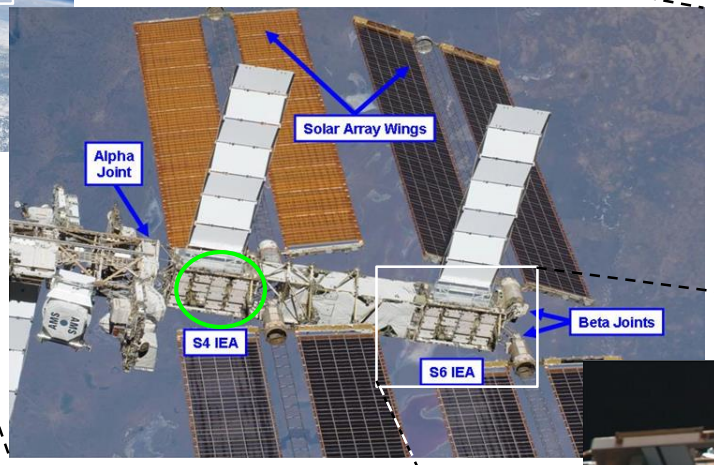
ISS Configuration - Battery Locations



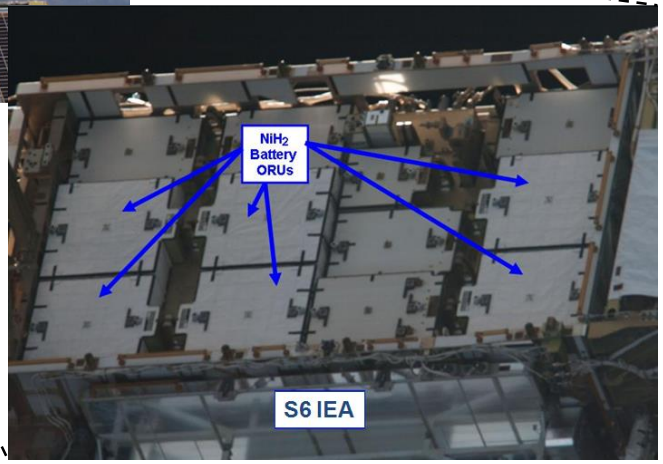
Batteries are located in the 4 Integrated Equipment Assemblies (IEAs)

2 Power Channels per IEA

8 Power Channels total



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



2017/2018 Configuration:

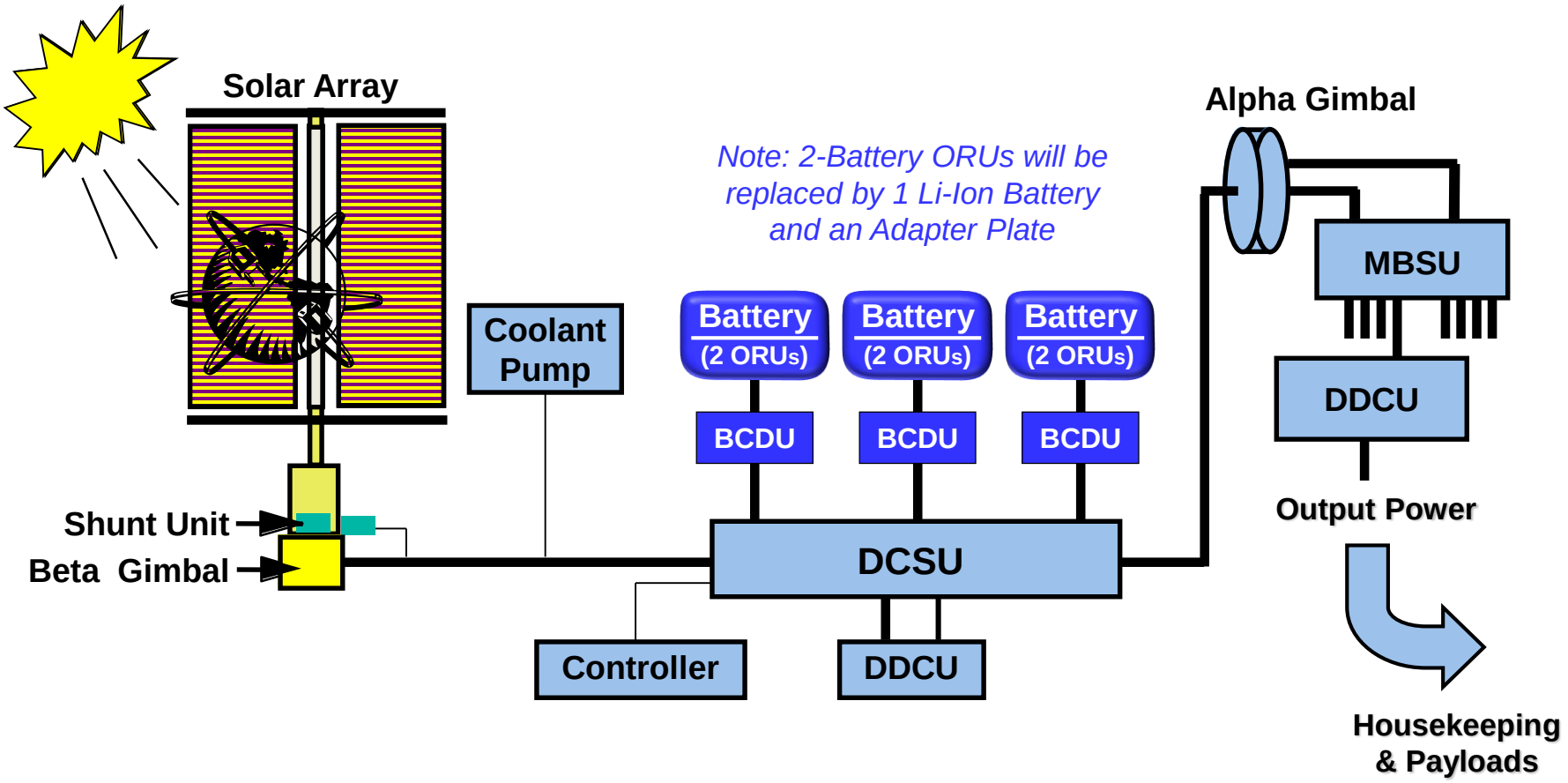
- 6 Ni-H_2 ORUs per 6 channels – 36 total
- 3 Li-Ion ORUs per 2 channels – 6 total

Final Configuration:

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

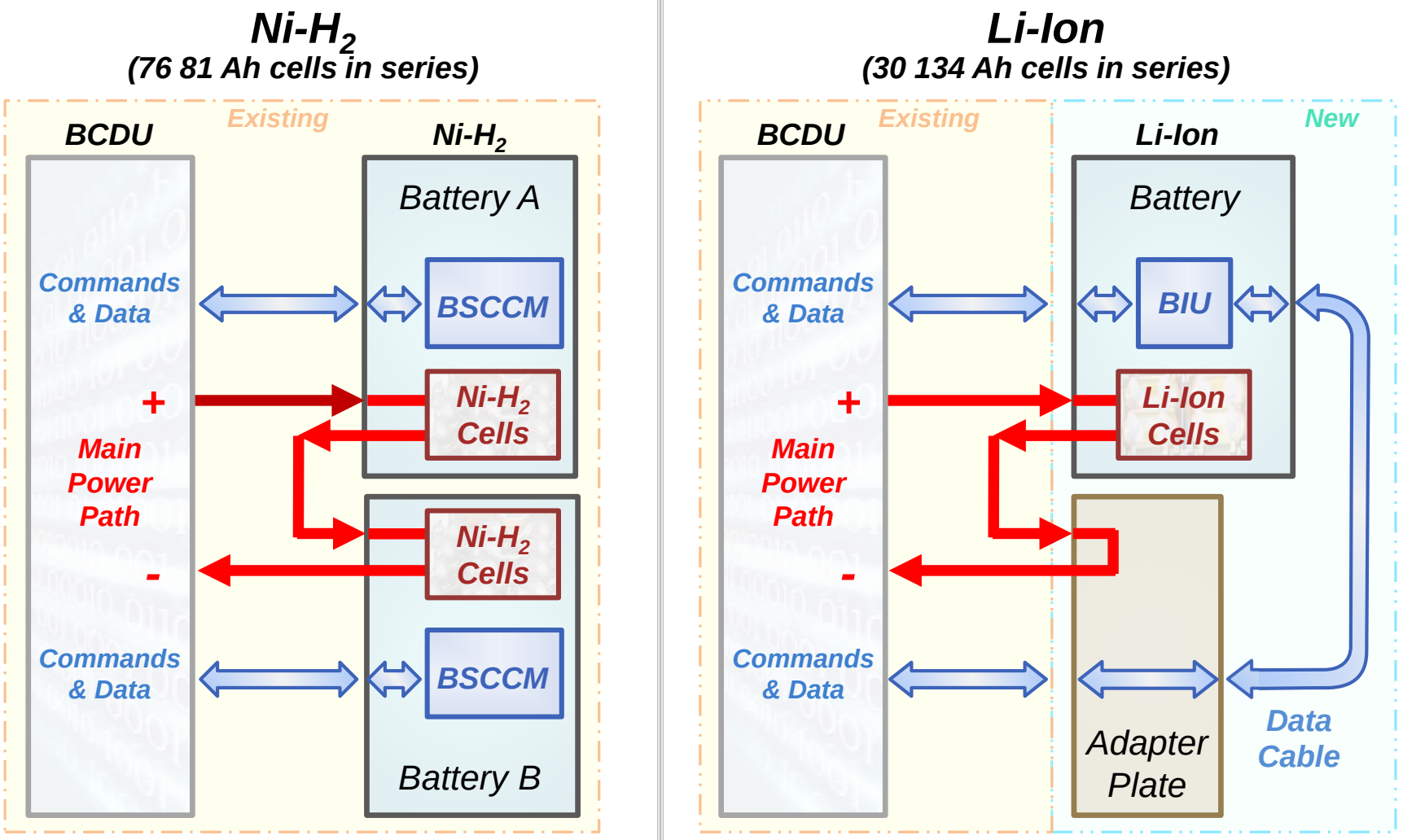
ISS Configuration - EPS Schematic

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

Launch Integration

- Adapter Plates Integrated at Tomioka, Japan: March 2018
- Batteries Integrated and charged to 4.1V at Tonegashima, Japan: April 2018

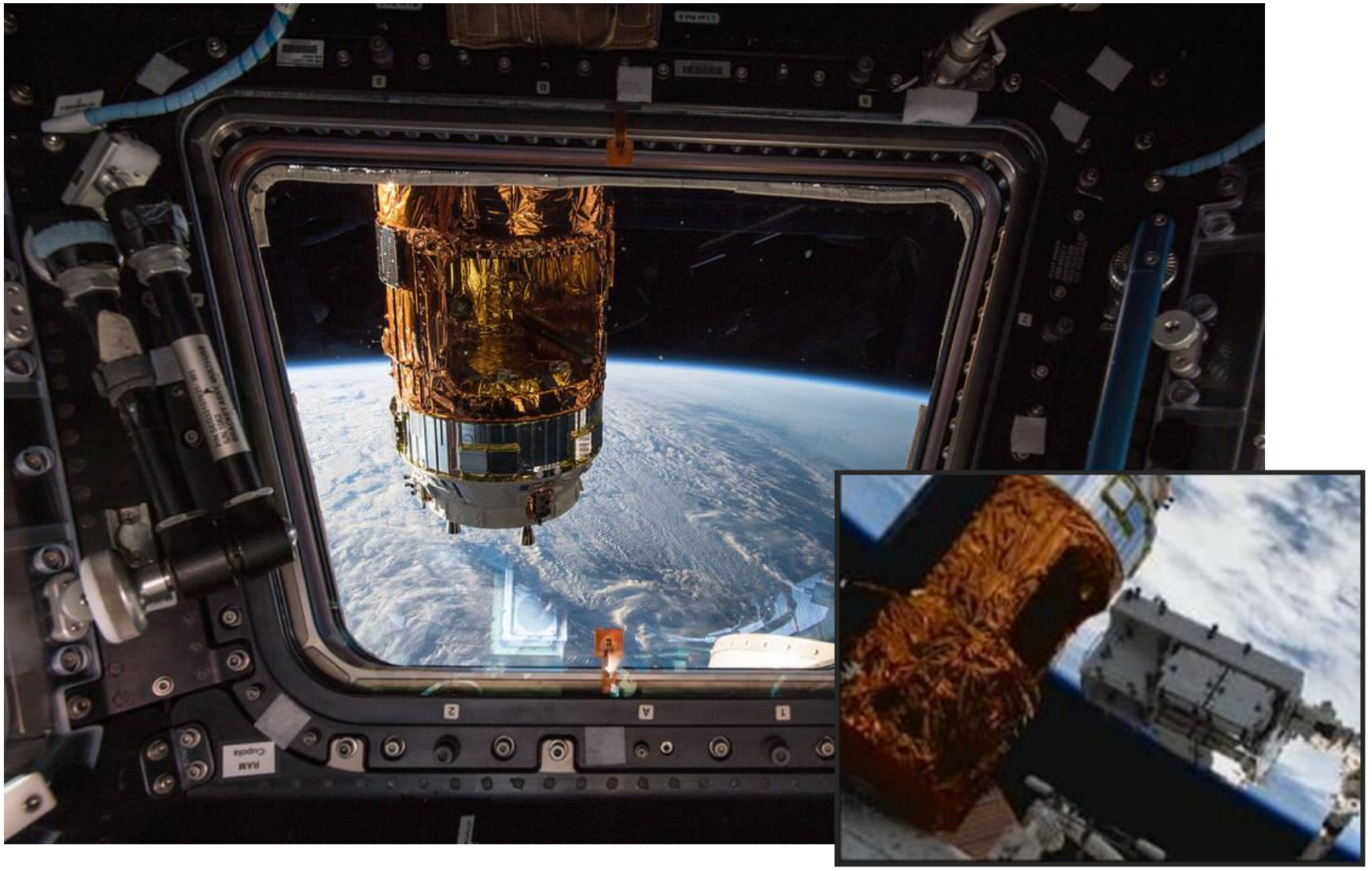
Launch

- HTV7 Launched from Tanegashima, Japan on September 22, 2018

Docking of HTV7 to ISS

- HTV7 Capture
  September 27, 2018

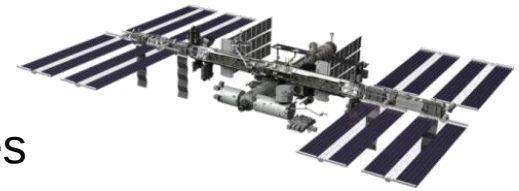
HTV7 - EP Removed



Li-Ion Battery Installation

- Installation of P4 2A and 4A Batteries was planned for October 2018
- After the emergency landing of the Russian Soyuz on October 11, 2018, all Extravehicular and Robotic installation of batteries was postponed
- Installation likely pushing to 2019

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 ~10,500 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

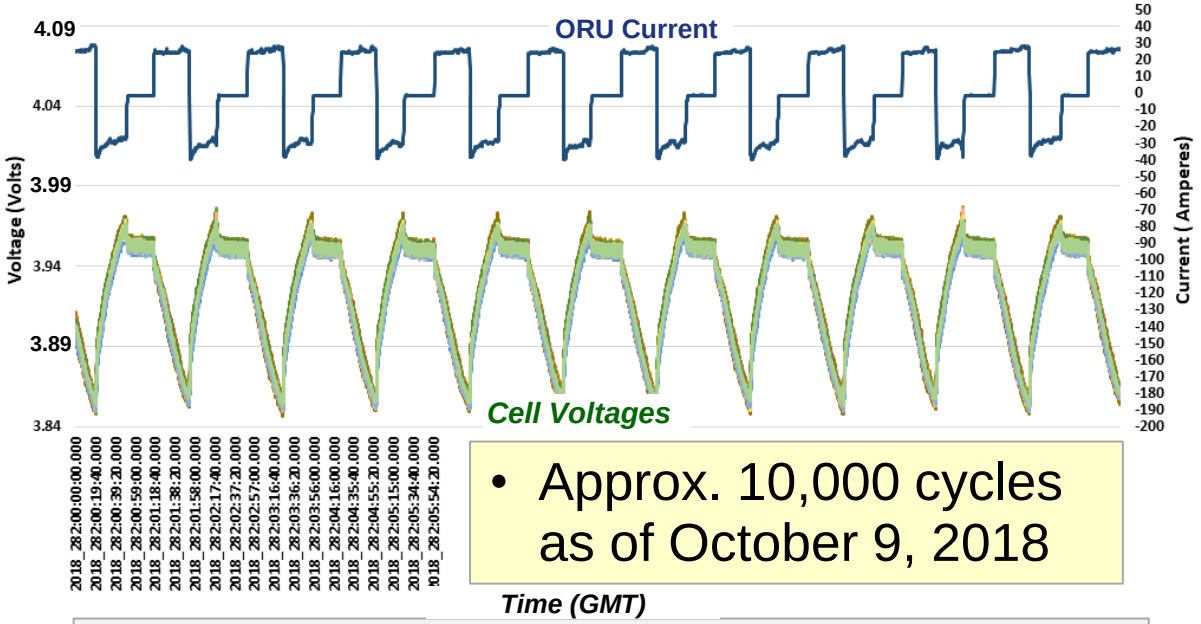
Battery Location	Start Up Capacity (Ahr), Jan. 2017	Annual Capacity (Ahr), Feb. 2018
1A1	113.1	111.0
1A2	109.7	107.5
1A3	111.6	109.8
3A1	108.7	107.4
3A2	110.0	108.2
3A3	110.4	109.1

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

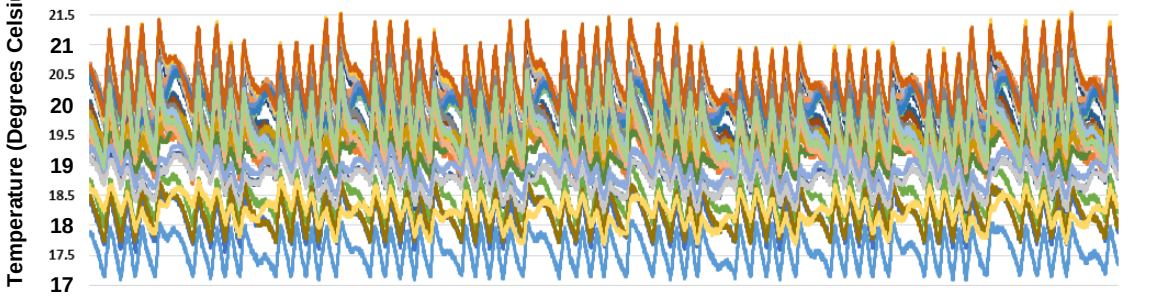
Charge Current Profile		
	Highest of the Cell Terminal Voltages	**Charge Current**
Point 1	EOCV + 19mV	55
Point 2	EOCV + 19mV	49
Point 3	EOCV + 18mV	44
Point 4	EOCV + 17mV	39
Point 5	EOCV + 16mV	36
Point 6	EOCV + 15mV	33
Point 7	EOCV + 14mV	30
Point 8	EOCV + 13mV	26
Point 9	EOCV + 12mV	22
Point 10	EOCV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



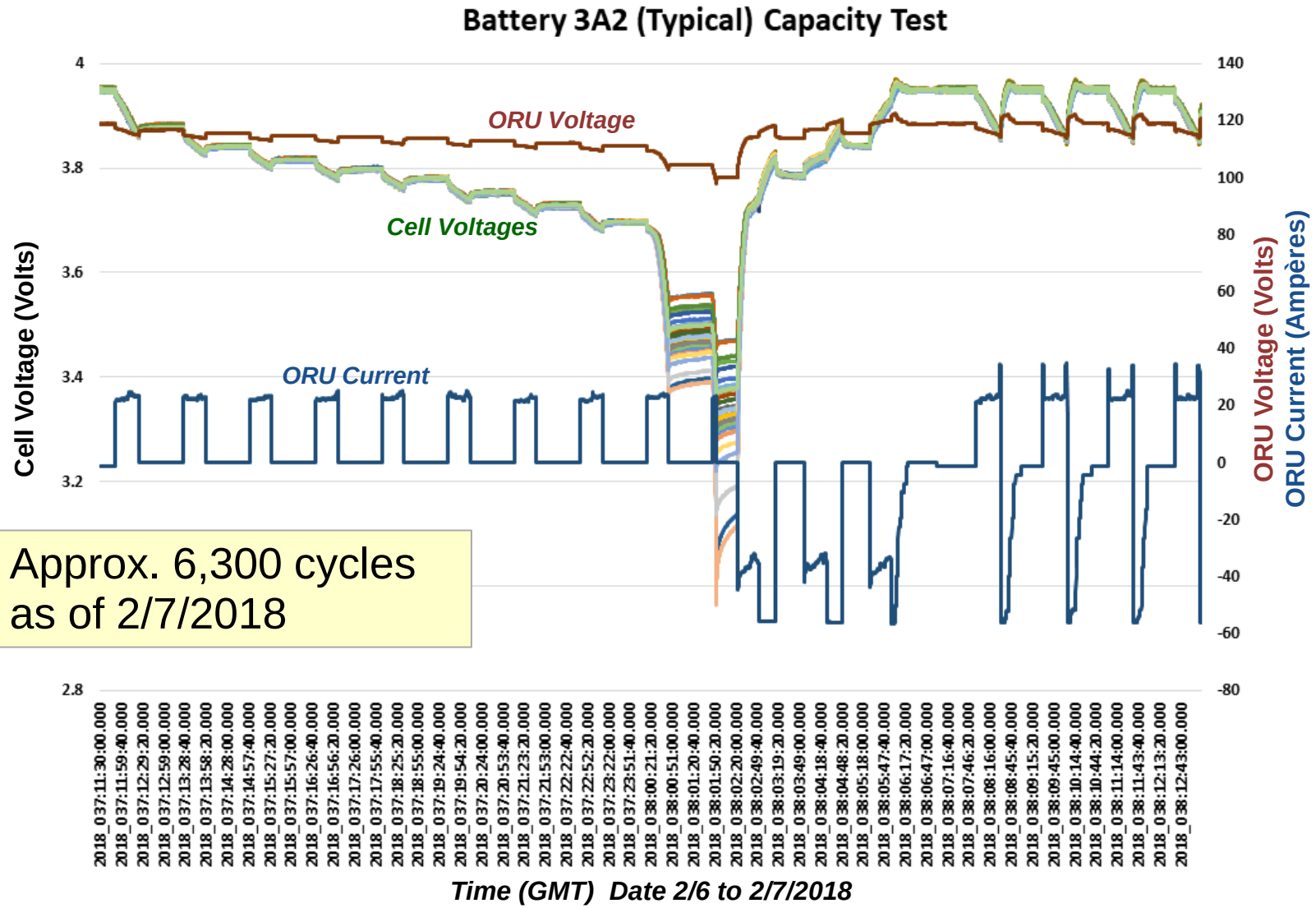
- Approx. 10,000 cycles as of October 9, 2018

Nominal On-orbit Cell Temperatures



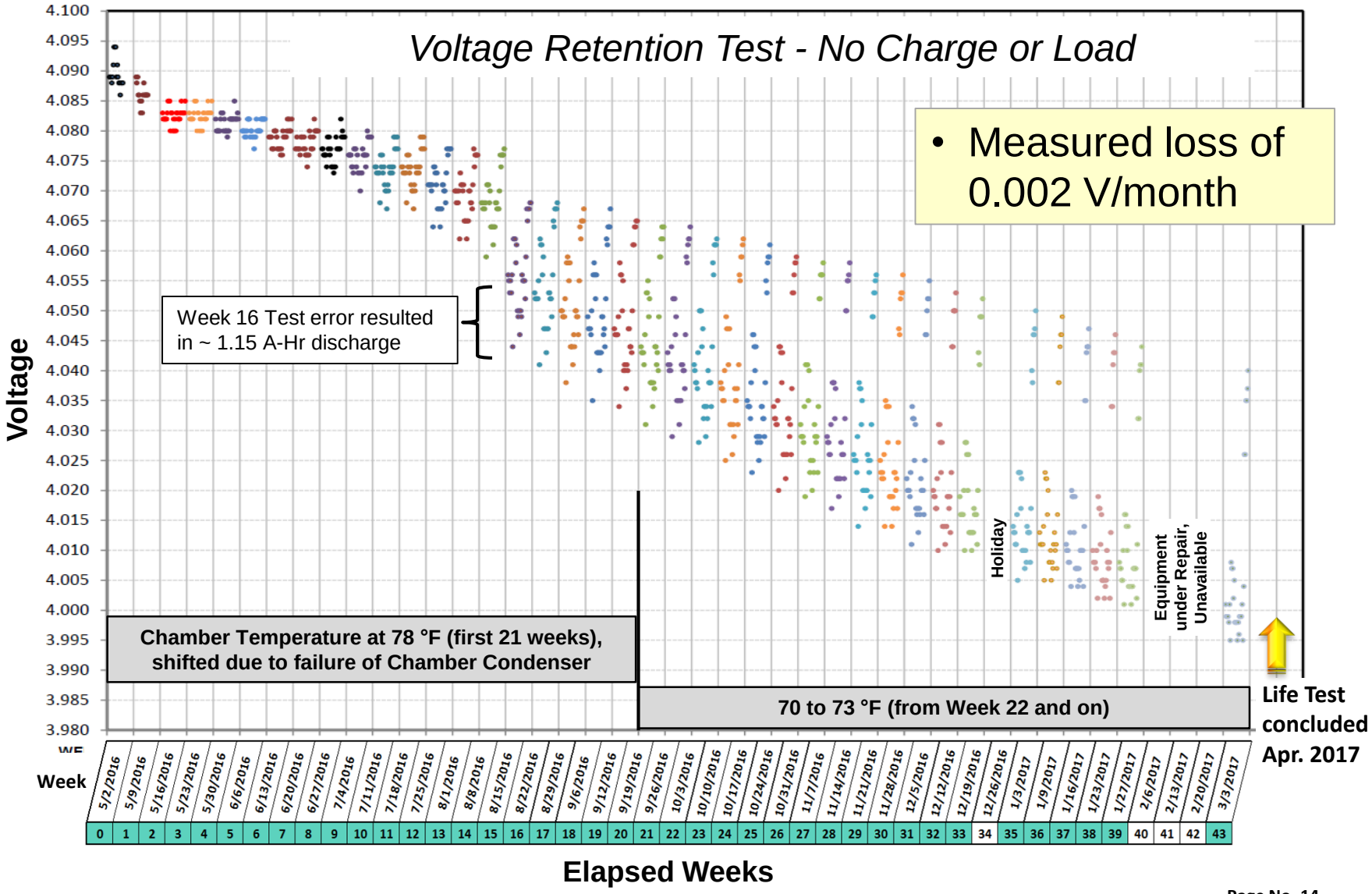
Typical Data for Battery Channel Operation

ISS Li-Ion Annual Capacity Test

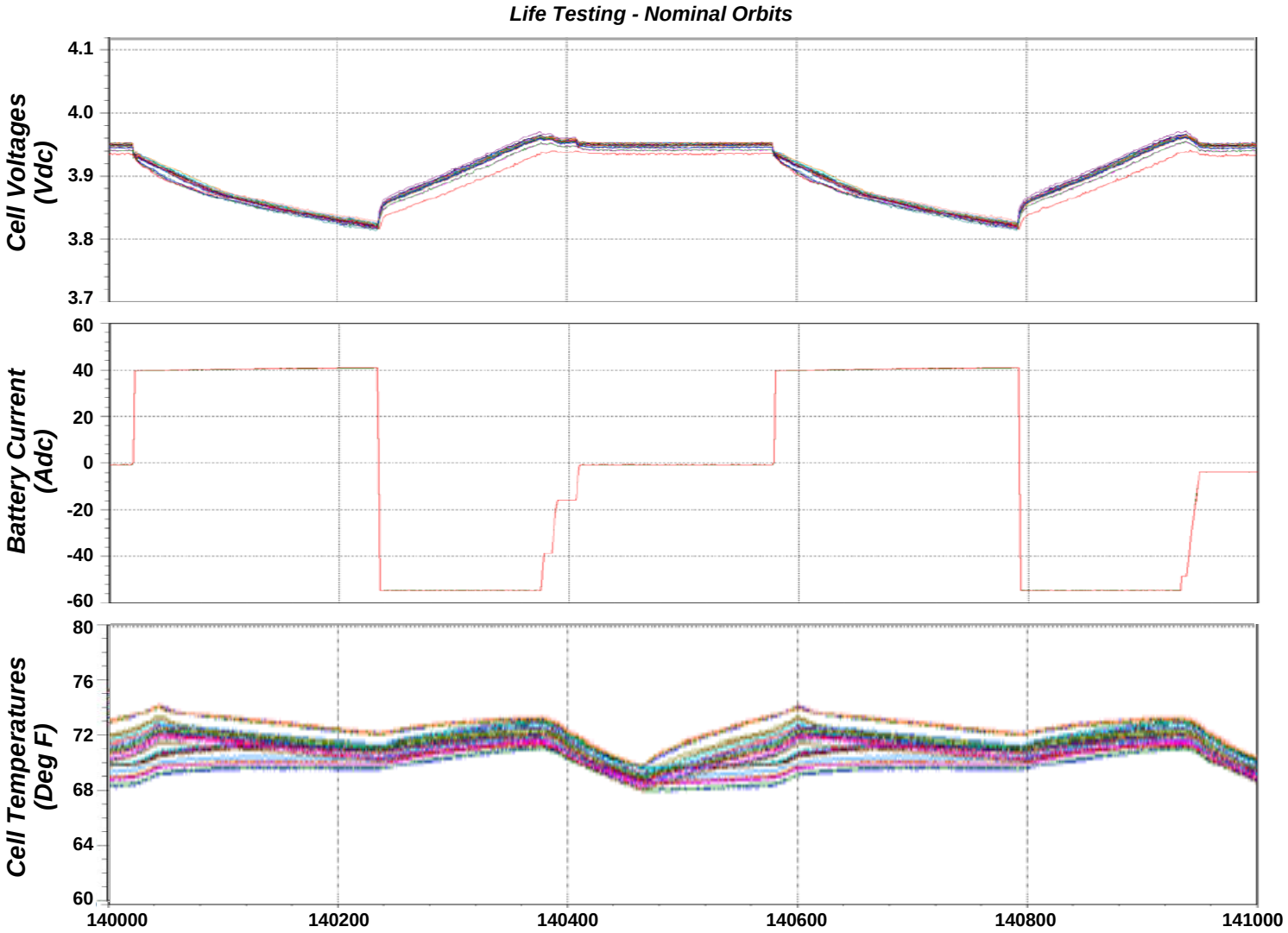


- Approx. 6,300 cycles as of 2/7/2018

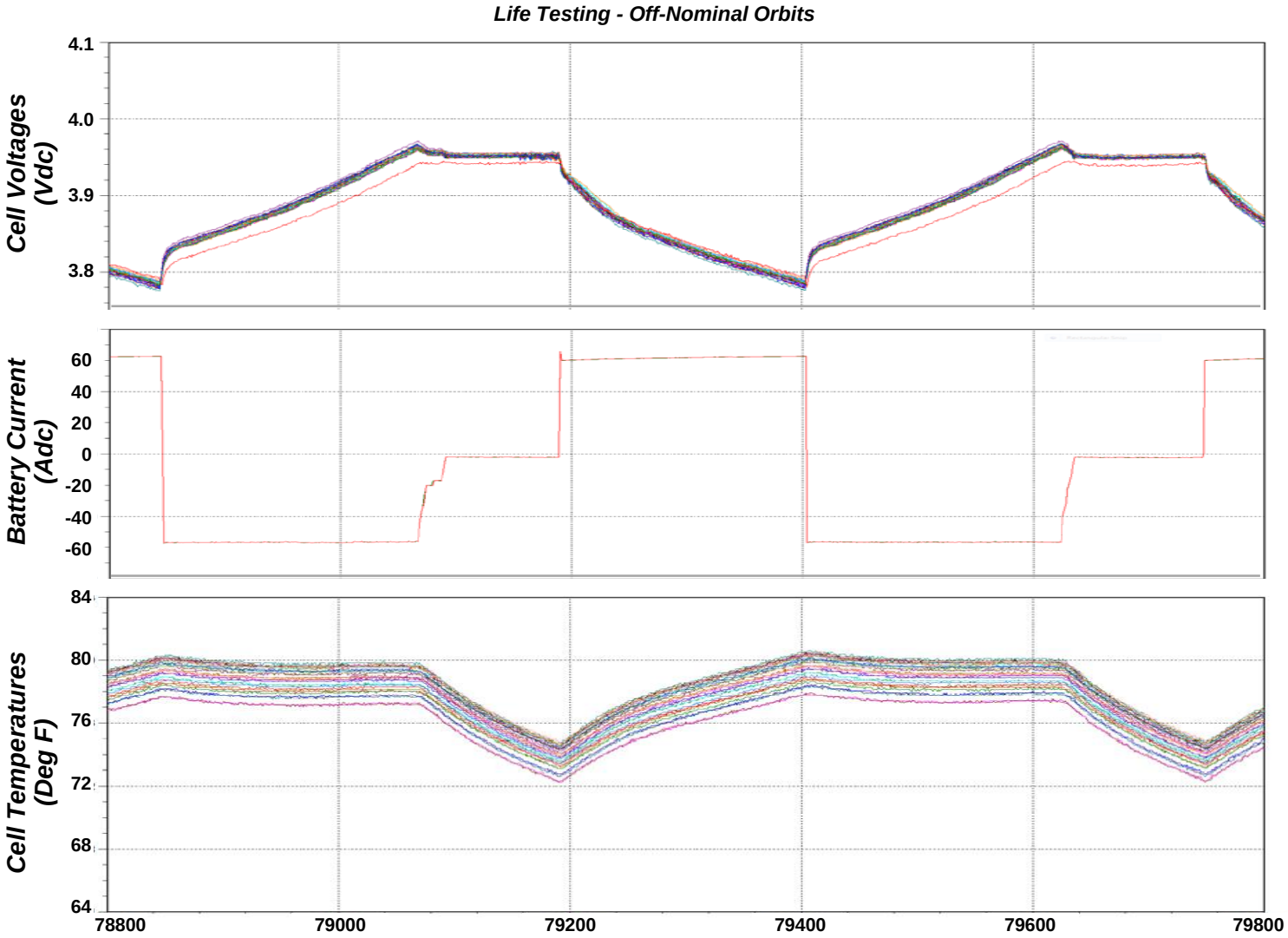
ORU Life Test Program at Aerojet Rocketdyne Charge Retention Test



ORU Life Test Program at Aerojet Rocketdyne Nominal Orbits



ORU Life Test Program at Aerojet Rocketdyne Off-Nominal Orbits



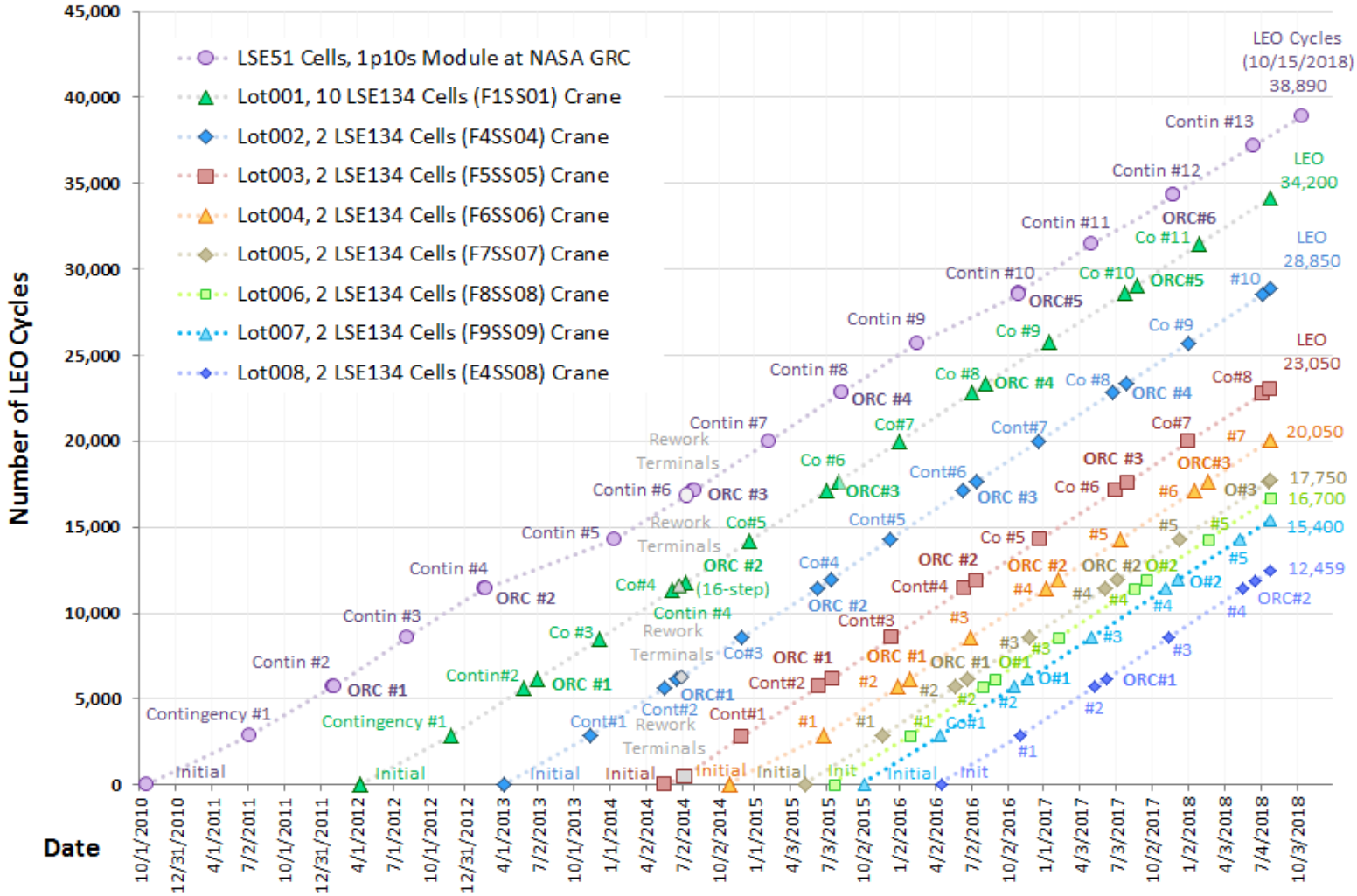
ORU Life Test Program at Aerojet Rocketdyne Orbital Rate Capacity Tests

Test	Battery Capacity (A-hr)	Date
Initial Orbital Rate Capacity	108.2	May 2016
Orbital Rate Capacity post-retention test	103.7	Nov 8, 2017
Orbital Rate Capacity post-53 Orbit cycles	103.1	Jan 8, 2018
Orbital Rate Capacity post-1530 Orbit cycles	103.5	June 26, 2018

Note: GS Yuasa model predicted loss of 1.5 Ah after 3 months off-nominal orbit cycling

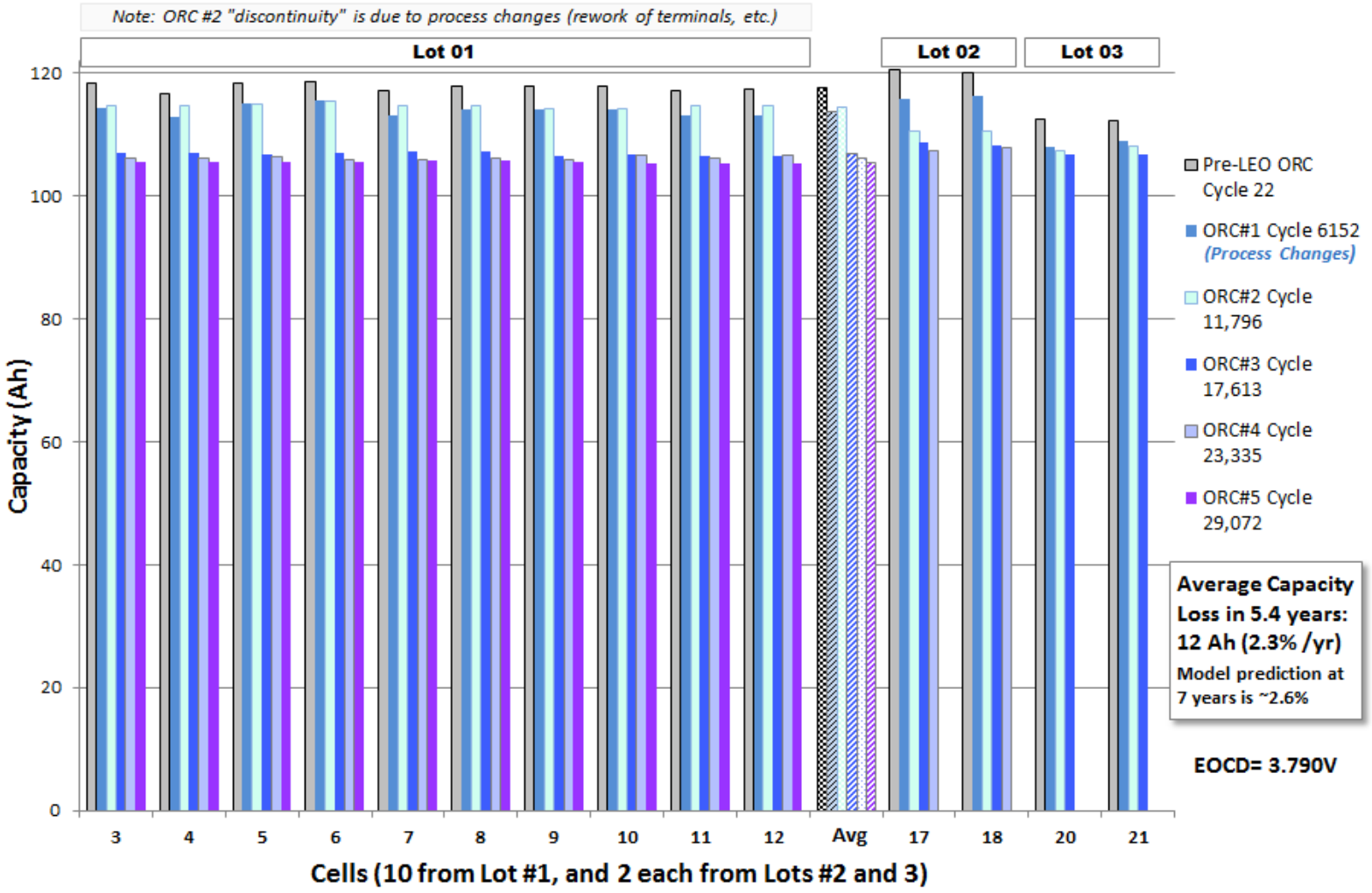
Life Test Program

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



Life Test Program

ORC Capacity Data for Life Test of LSE134 Cells at Crane



In Closing

- The first set of six ISS Li-ion Batteries continues to operate, meeting or exceeding expectations
- It is hoped the next set of six (now temporarily stowed on orbit) will likely be installed in early 2019
- Questions?