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Hubble Space Telescope Replacement Battery Performance

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NASA Aerospace Battery Workshop

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The Crab Nebula (July 7, 2016)

Introduction

- **Launched in 1990 and placed in low earth orbit, the Hubble Space Telescope has captured some of the most beautiful and scientifically significant images of space objects ever seen.**
  - After the final servicing mission (SM4) in May 2009, the replacement equipment and upgrades have enabled Hubble to continue to capture more science data and images than ever.
    - To continue to power the spacecraft and support its science mission, the original nickel-hydrogen (NiH_2) batteries were replaced after 19 years and one month on orbit.
    - Presently, the replacement batteries, which are also NiH_2, have been cycling on orbit for 8 years, 6 months with no performance issues.
- **The purpose of this presentation is to highlight the assessment of the replacement battery performance**
  - The assessment period starts at SM4 release on May 18, 2009 and covers through October 1, 2017.

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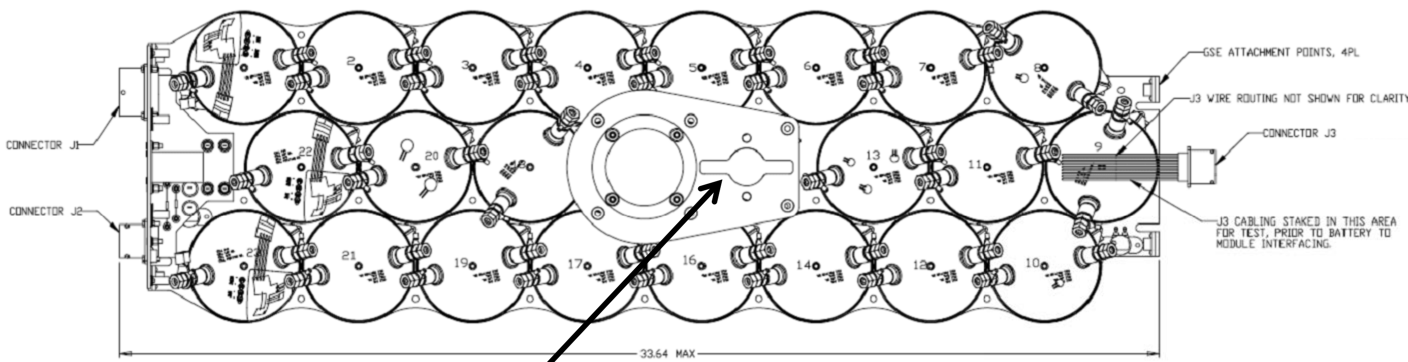
SM4 Battery Replacement

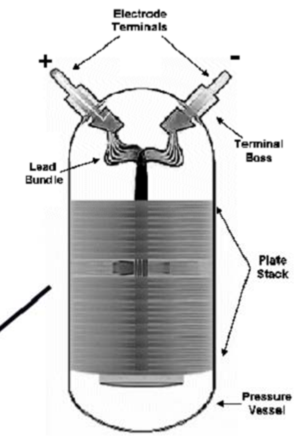
- **The HST original nickel-hydrogen (NiH_2) batteries were replaced during the Servicing Mission 4 (SM4) after 19 years and one month on orbit.**
- **Fabrication of the replacement batteries: January 1995-96**
  - Dry Stored for 4 Years
  - Cells were activated: September 2000
  - The batteries were passively stored until April 2009
    - Total of 9 years wet storage
- **The replacement batteries were installed in May 2009 and have been cycling on orbit for 8 years, 6 months with no performance issues.**
  - Bay 2 contains battery (SN): 1 (1161), 2 (1162) and 3 (1163)
  - Bay 3 contains battery (SN): 4 (1166), 5 (1165) and 6 (1164)
  - Flight Spare Battery (SN) 1160 is cycling at MSFC since Aug. 2009

Battery Description

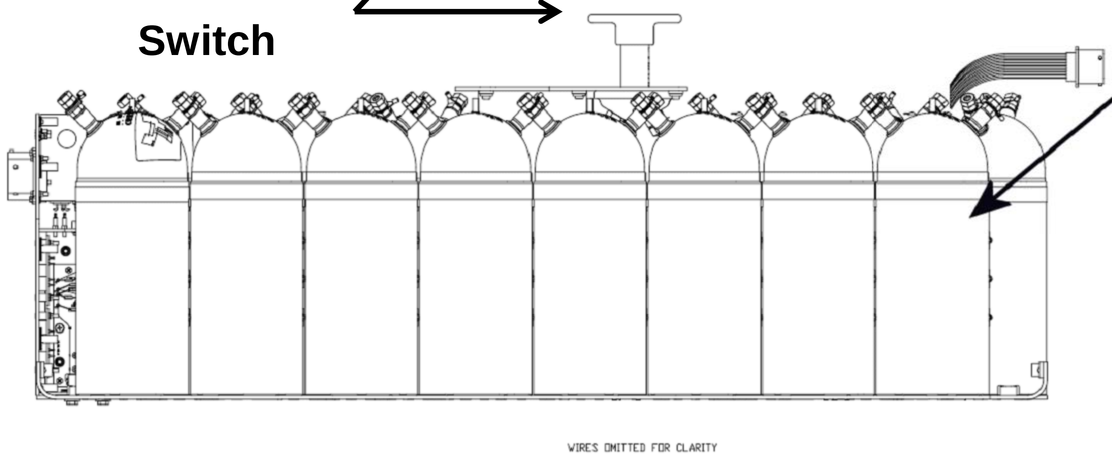
- **Each of the six batteries are comprised of 22 electrically series connected RNH 90-3 NiH_2 cells, nameplate capacity of 88Ah**
- **The cells are wet slurry nickel positive electrodes & double layer zircar separator, nickel precharge**
  - 1990 original: dry sinter – hydrogen precharge
- **Each battery has a Battery Isolation Switch (BIS) (manually operated only)**
- **Current sensor**
- **Individual cell heaters**
  - 2 independent heater circuits, primary (~ -2 to 2 deg C) and redundant (~ -5 to -1 deg C)
- **2 independent strain gauge pressure monitoring circuits**
  - Only one is monitored on orbit
- **Temperature monitoring circuit (telemetered)**
- **4 charge control thermistors (not telemetered)**
- **Individual cell voltage monitoring test connector J3**
  - GSE only (not telemetered on orbit)

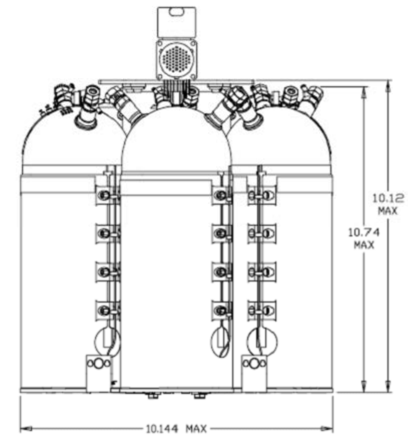
Battery Description (continued)





Battery Isolation Switch

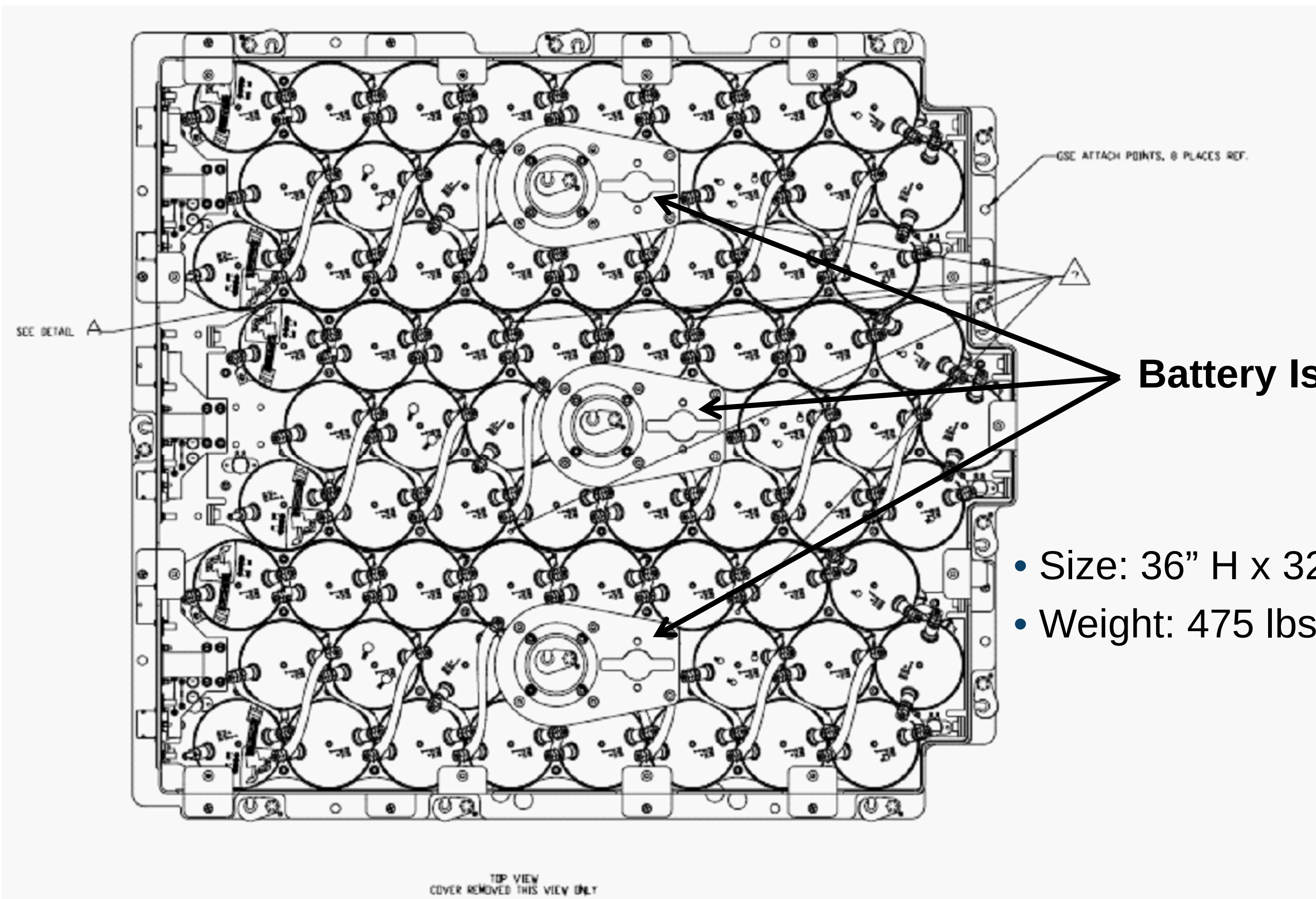




Nameplate capacity: 88Ah

Battery Description

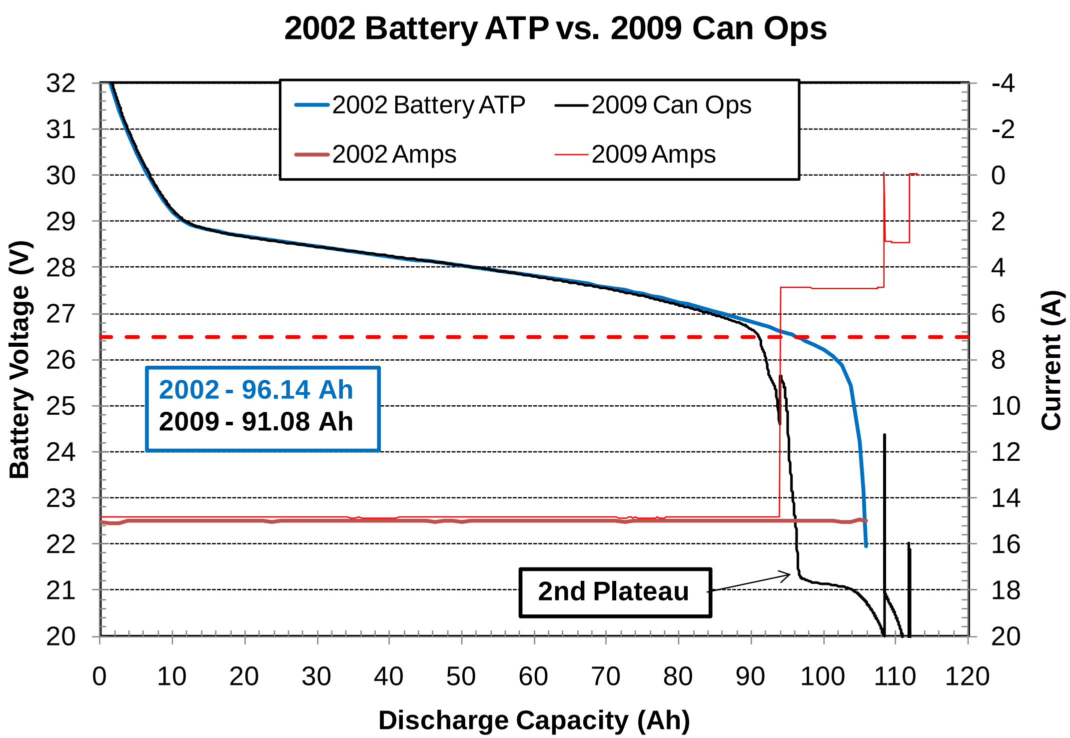
- **The six batteries are housed within two modules (S/N 1032 & 1033). Each module consists of 3 electrically independent NiH_2 batteries mounted to a common battery module base plate.**



- Size: 36” H x 32” W x 15” H
- Weight: 475 lbs each module

Pre-Installation Battery 0°C Capacity

- **The extended wet storage time did result in some usable capacity loss due to 2nd plateau formation.**
  - Flight battery 1, standard 0°C capacity test, following a 149% overcharge ATP testing in 2002 and canister ops pre-launch capacity test in 2009



State Of Charge (SOC) Performance

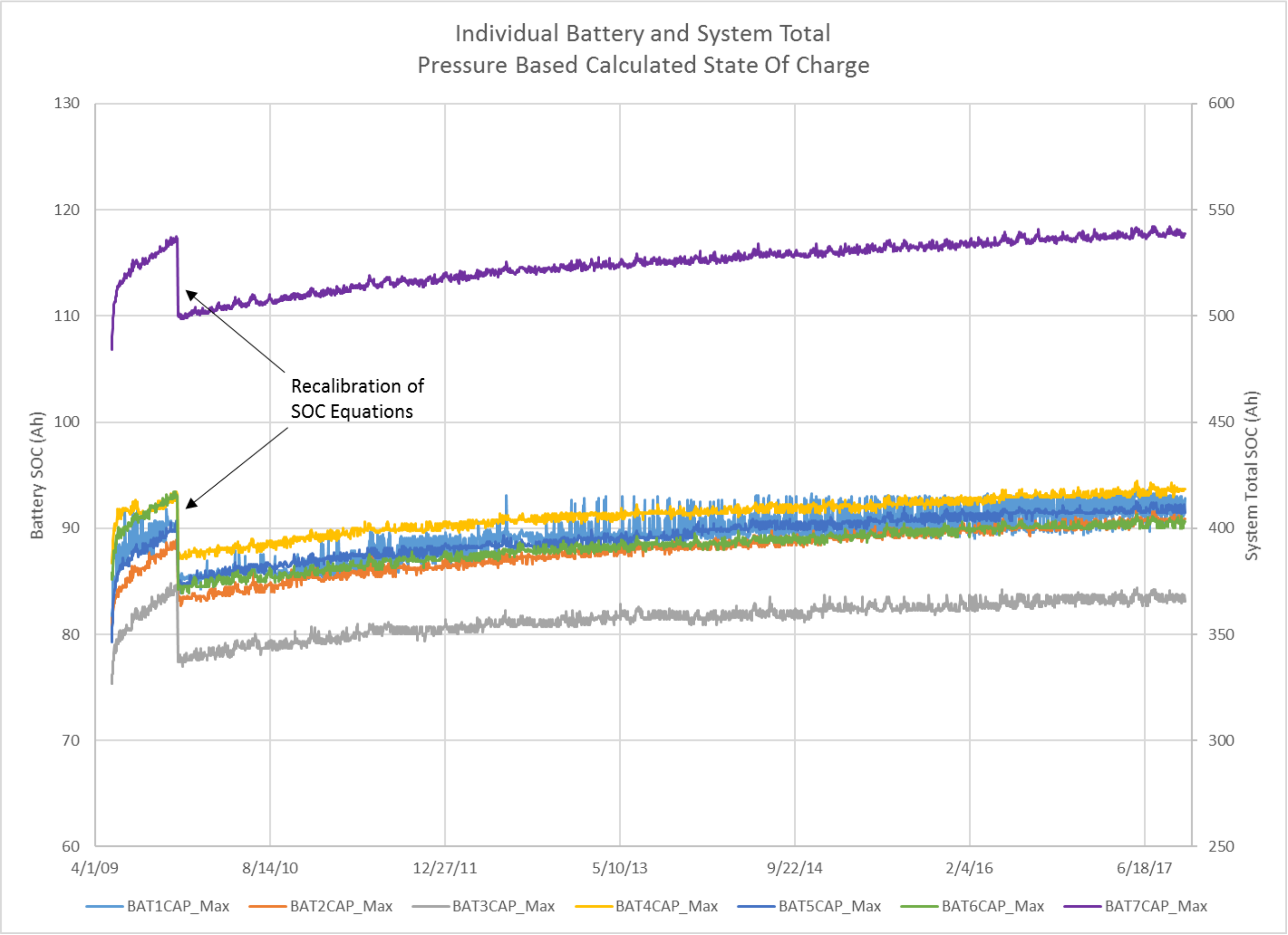
- **No on orbit capacity check has been performed**
  - Three capacity checks have been performed on the flight spare battery at MSFC, which is managed and cycled similar to the flight batteries
- **The table below shows the battery pressure based SOC's at the time of installation, release, release +30 days (DOY 169 / 09), +6 months (301/09) and present (DOY 274/17)**
- **Pressures have shown continuous increases since SM4 release.**

Battery	Install SOC (Ah)	Release Full SOC (Ah)	DOY 169/09 Full SOC (Ah)	DOY 301/09 Full SOC (Ah)	DOY 274/17 Full SOC (Ah)
1	52.3	67.7	86.2	87.5	89.7*
2	53.3	66.8	84.9	87.8	90.0*
3	49.0	62.3	80.4	82.1	82.6*
4	58.0	73.4	92.2	92.0	93.1*
5	52.5	66.9	86.4	89.0	90.9*
6	56.9	67.9	90.4	88.8	90.2*

*An adjustment was made to the pressure based SOC equations to account for plateau settling (11/24/2009)

State Of Charge (SOC) Performance

- At the time of SM4 HST release, the battery SOC was 484 Ah.
- SOC continues to increase and as of DOY 285 is above 535 Ah.



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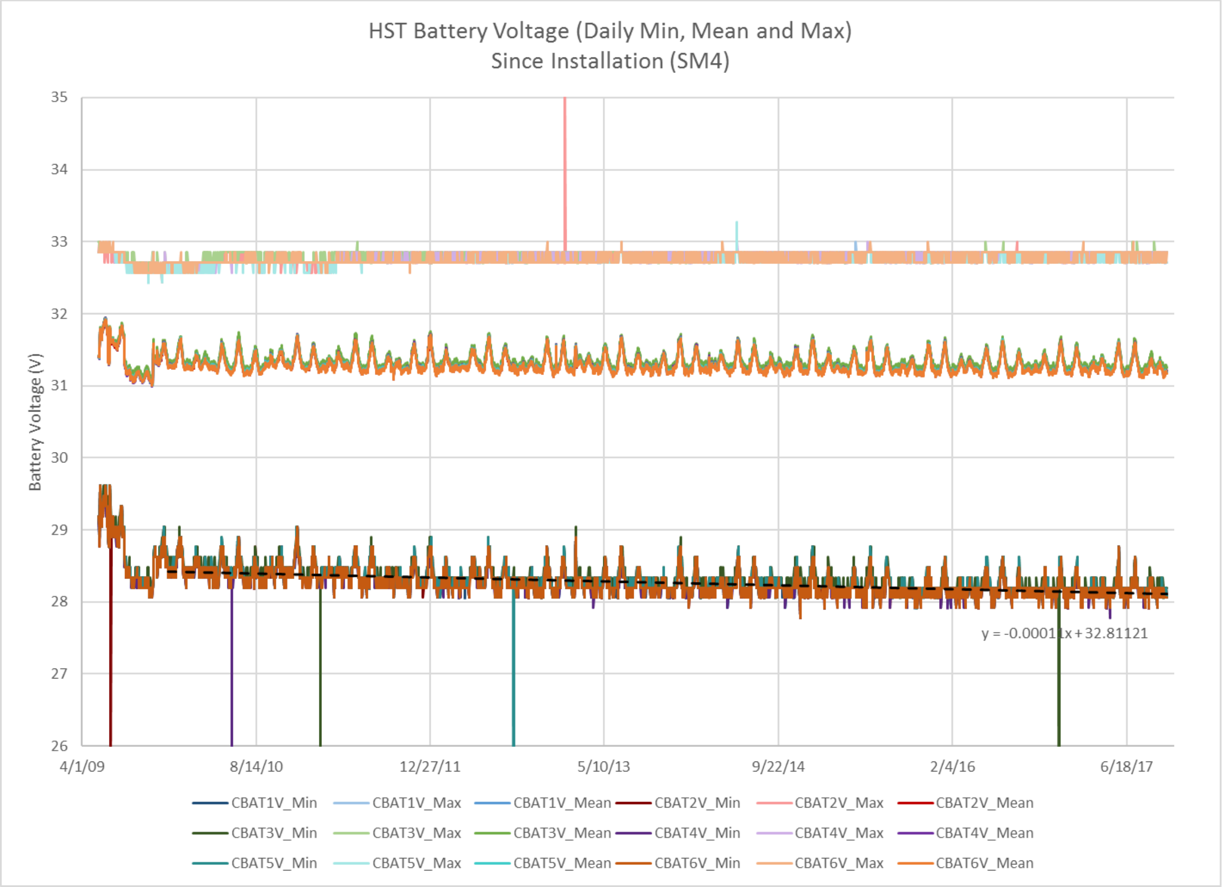
Battery Voltage Performance

- The HST battery voltage range to support operations is 26.4V to 34.3V.
- Battery voltage remains well within this range with a slight decreasing trend in end of discharge voltage.



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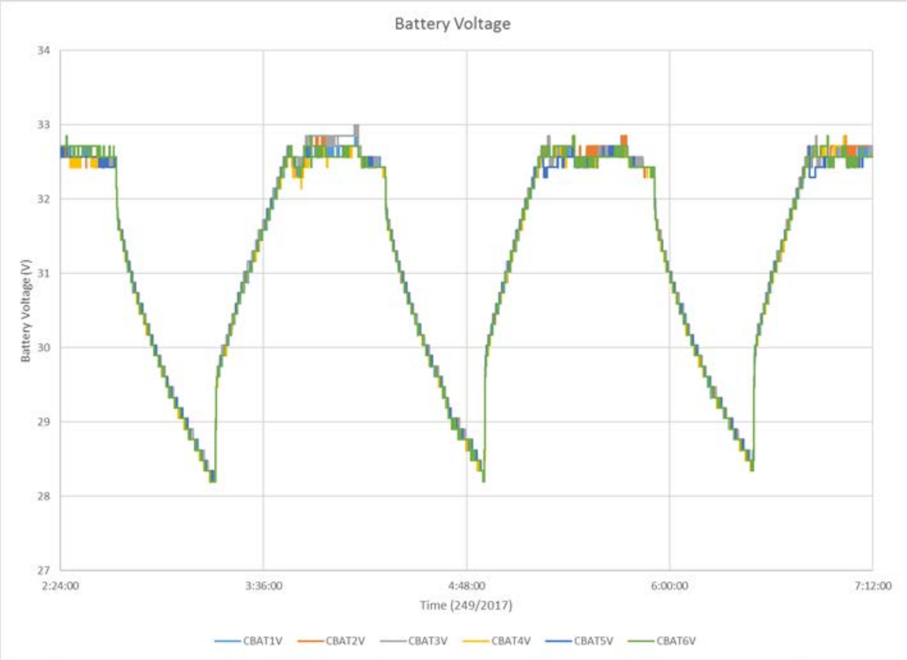
Battery Voltage Performance

- **With an 8% DOD, the batteries operate on the upper slope of the discharge curve.**
  - Plateau voltage is not presently seen in normal operations.



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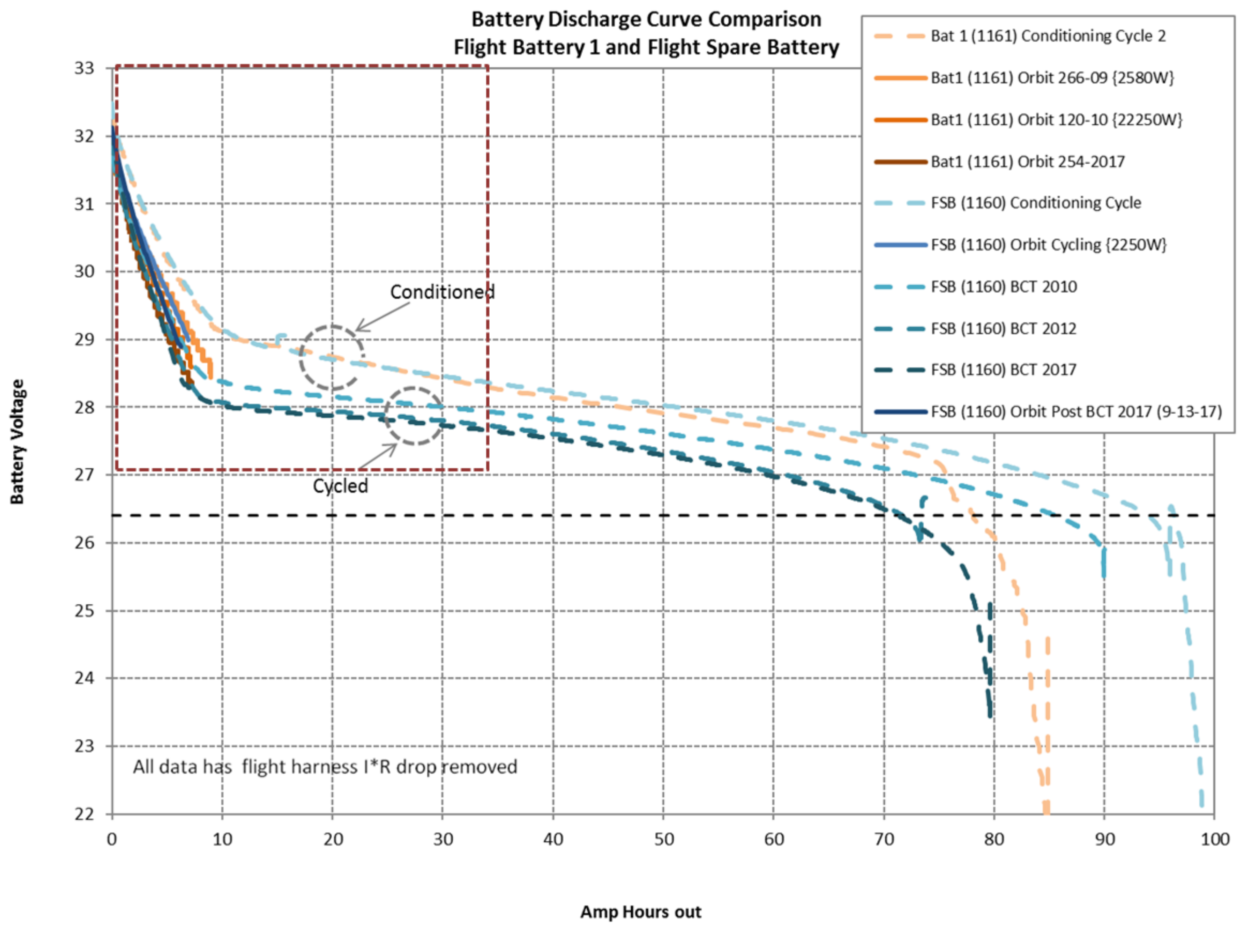
Battery Voltage Performance

- **With orbit cycling, the voltage plateau of the flight spare battery has settled from the pre-launch conditioning cycles and remains stable.**



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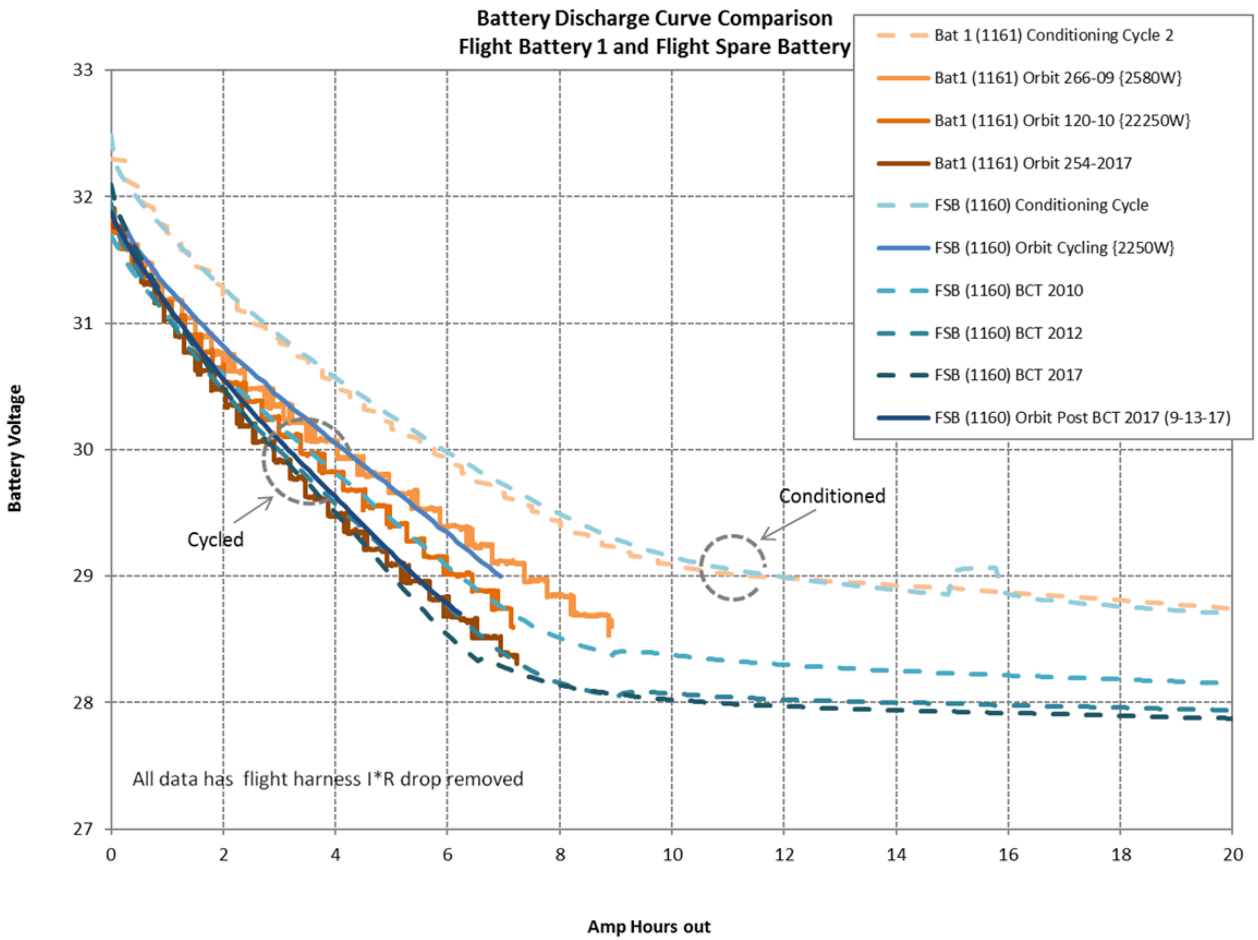
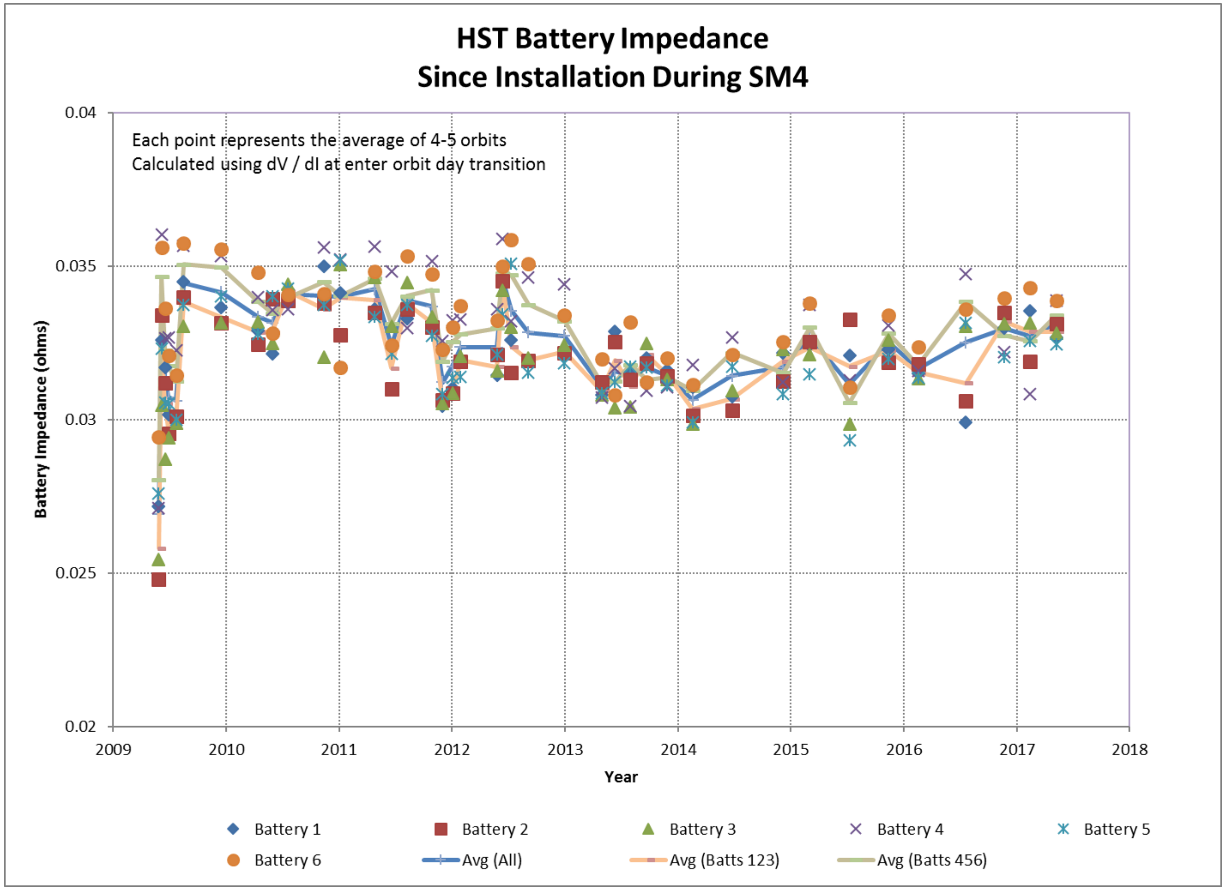
Battery Voltage Performance

- **While the flight system does not reach the primary plateau, the upper slope tracks well with the flight spare battery**



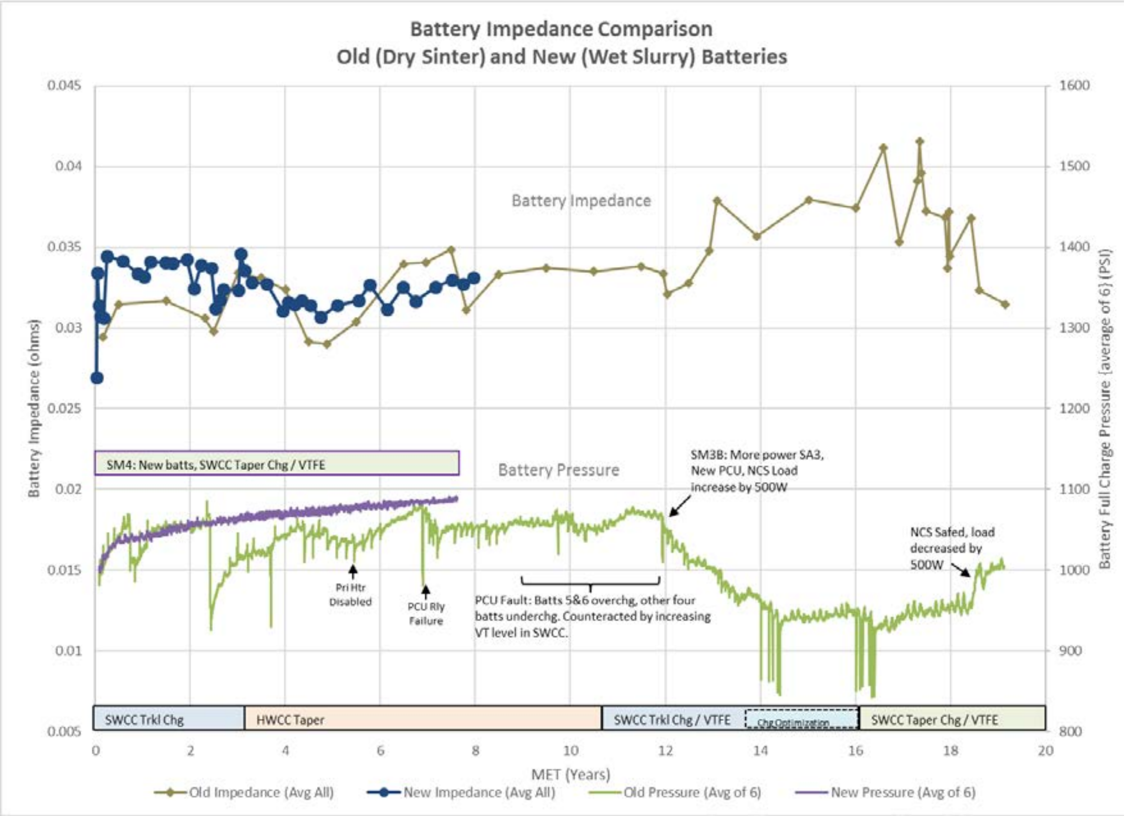
Battery Impedance

- **The battery impedance is computed using the change in battery voltage divided by the change in battery current during the night to day transition**
  - Flight battery impedances appear to be stable.



Battery Impedance

- **Comparison of old dry sinter battery impedance and new wet slurry battery impedance and pressure trends**
  - Pressure variation in the old batteries is due to on-orbit capacity checks, configuration changes to the charge control and component failures in the Power Control Unit.
  - The new batteries have little variation as there have been no significant configuration changes and no on-orbit capacity checks.



Battery Thermal Performance

- **The battery temperatures range between -5°C and -1°C with excursions to 0°C**
- **Battery temperatures are trending down over time**
- **The redundant heaters typically cycle between one and two times within a 24 hour period with a heater setpoint of approximately -5 deg C**
  - The primary heaters remain disabled to allow the batteries to dictate the operating temperature
- **Since the 2nd software VT (VTFE) was added prior to SM4, the batteries no longer experience temperature excursions due to orbit day duration peaks (beta angle peaks)**
  - Historically, the batteries tended to heat-up during solar beta angle peaks
  - Manual intervention was sometimes needed to reduce charging.
  - Now the system automatically removes additional charge current as needed.

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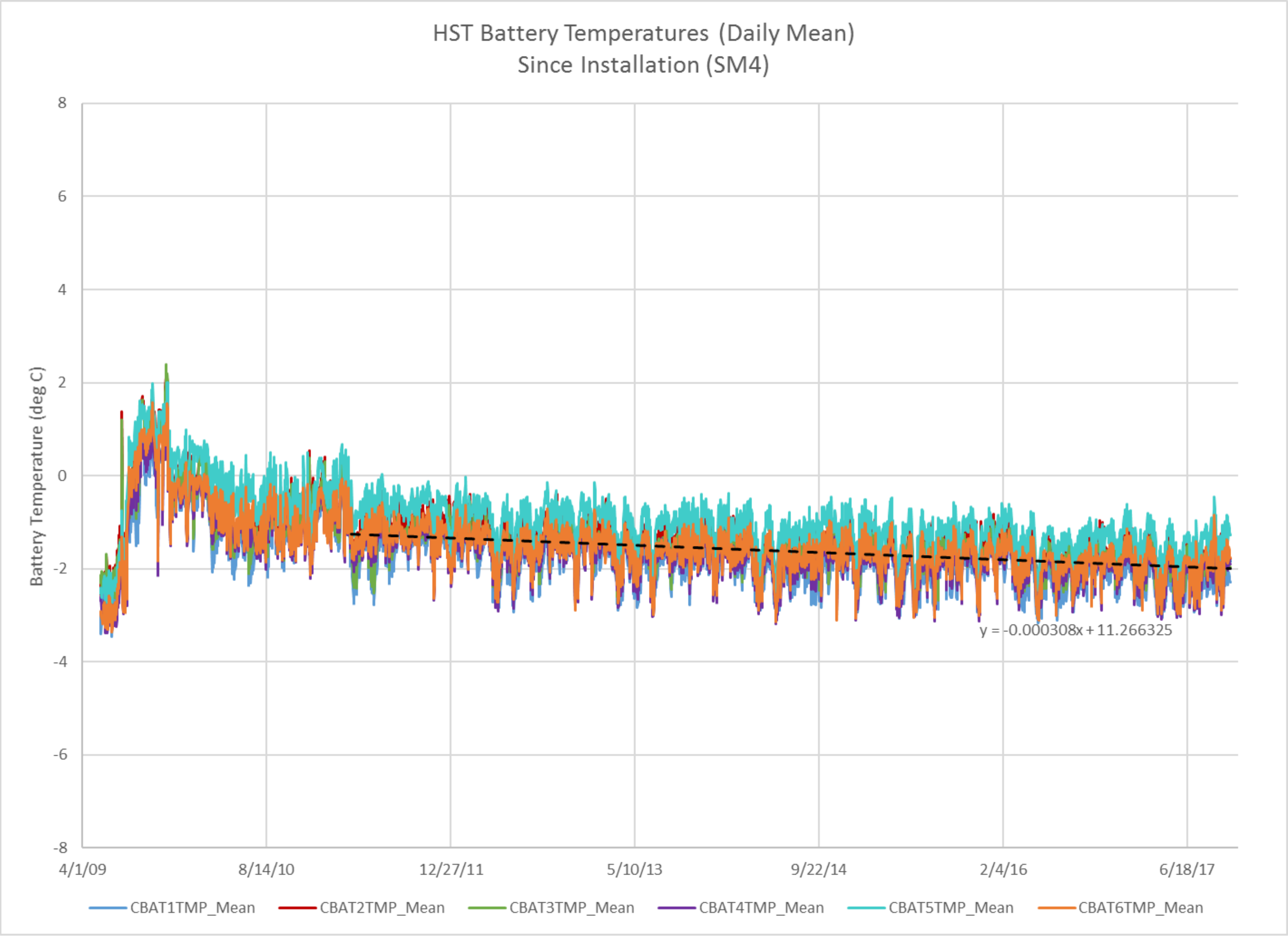
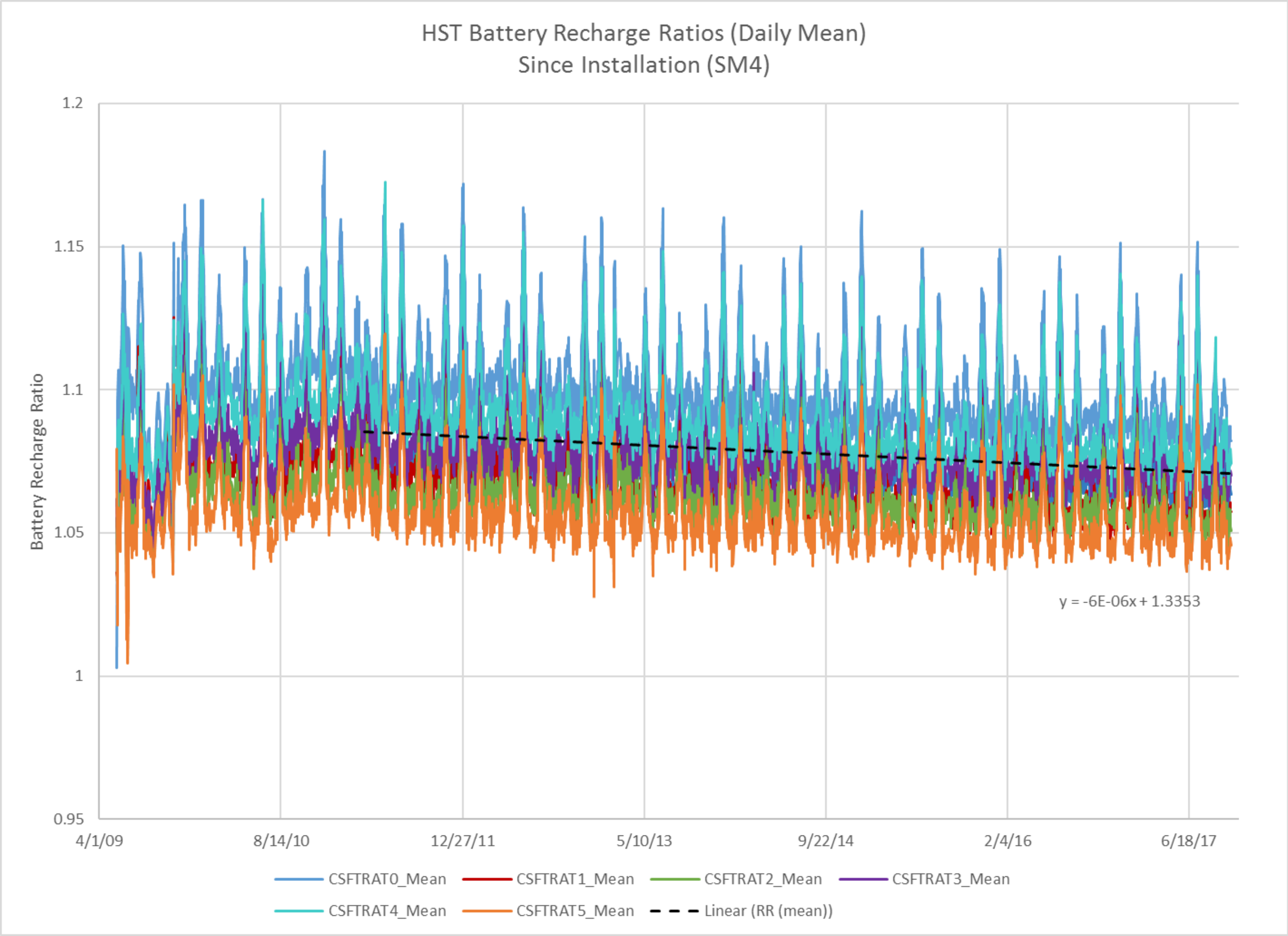
Battery Thermal Performance



Battery Recharge Ratios

- **The mean battery recharge ratios typically range from 1.05 to 1.10 and are trending down over time.**
- **The declining recharge ratios and battery temperatures are due to the decreasing altitude of HST.**
  - Orbit day charge period becomes shorter and orbit night discharge period becomes longer.
  - Considering increasing recharge ratio by increasing the VT cut-off level in order to counter act the recharge ratio decline.

Battery Recharge Ratios



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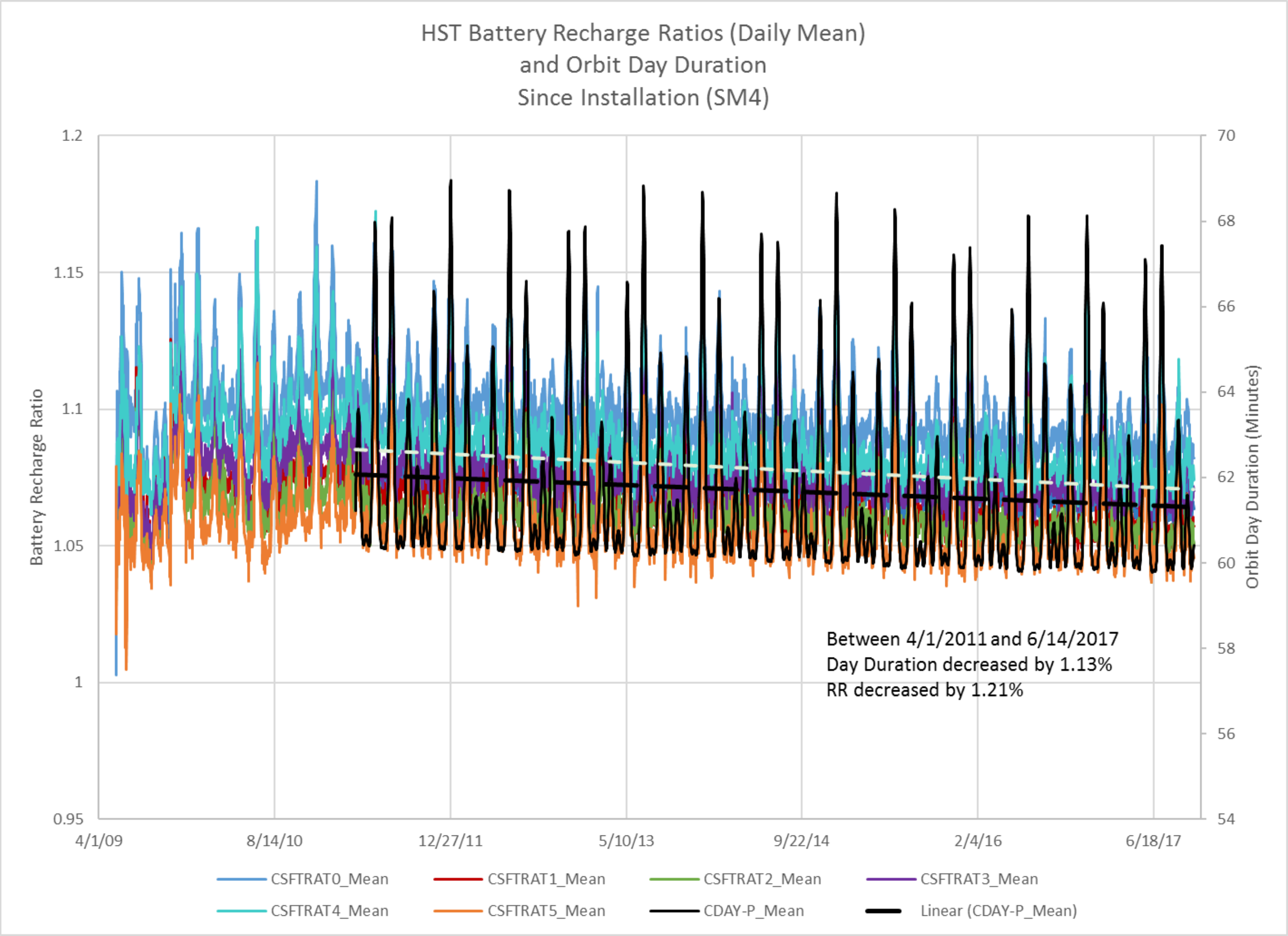
Battery Recharge Ratios



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Conclusion

- **Replacement batteries, installed into HST during Servicing Mission 4, are performing well within specification.**
- **The batteries SOC provides good science margin.**
- **Pressures continue to increase while temperatures remain relatively cool**
  - Question remains if the pressure increase represents usable capacity or if it is going into 2nd plateau capacity.
- **The battery performance maintains the End User equipment well within the operational input voltage specification.**
- **Voltage performance supported by favorable battery impedance**
- **Recharge ratios are high enough to maintain the battery SOC while maintaining battery temperatures below 0°c, however, are declining with altitude decrease.**
  - Considering increasing VT level to improve recharge ratio.

The HST battery system appears healthy.

About the Cover Image

Peering deep into the core of the Crab Nebula, this close-up image reveals the beating heart of one of the most historic and intensively studied remnants of a supernova, an exploding star. The inner region sends out clock-like pulses of radiation and tsunamis of charged particles embedded in magnetic fields.

The neutron star at the very center of the Crab Nebula has about the same mass as the sun but compressed into an incredibly dense sphere that is only a few miles across. Spinning 30 times a second, the neutron star shoots out detectable beams of energy that make it look like it's pulsating.

The NASA Hubble Space Telescope snapshot is centered on the region around the neutron star (the rightmost of the two bright stars near the center of this image) and the expanding, tattered, filamentary debris surrounding it. Hubble's sharp view captures the intricate details of glowing gas, shown in red, that forms a swirling medley of cavities and filaments. Inside this shell is a ghostly blue glow that is radiation given off by electrons spiraling at nearly the speed of light in the powerful magnetic field around the crushed stellar core.

The neutron star is a showcase for extreme physical processes and unimaginable cosmic violence. Bright wisps are moving outward from the neutron star at half the speed of light to form an expanding ring. It is thought that these wisps originate from a shock wave that turns the high-speed wind from the neutron star into extremely energetic particles.

When this "heartbeat" radiation signature was first discovered in 1968, astronomers realized they had discovered a new type of astronomical object. Now astronomers know it's the archetype of a class of supernova remnants called pulsars – or rapidly spinning neutron stars. These interstellar "lighthouse beacons" are invaluable for doing observational experiments on a variety of astronomical phenomena, including measuring gravity waves.

Observations of the Crab supernova were recorded by Chinese astronomers in 1054 A.D. The nebula, bright enough to be visible in amateur telescopes, is located 6,500 light-years away in the constellation Taurus.

Credit: NASA and ESA
Acknowledgment: J. Hester (ASU) and M. Weisskopf (NASA/MSFC)
http://hubblesite.org/