W3A Eurostar 3000 Li-Ion Battery In orbit Return of Experience

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Summary

1. Saft Li-Ion History : Stentor
2. Eurostar 3000 module design choices
3. W3A Eutelsat satellite In-Orbit Return of Experience
4. Conclusion

Saft Satellite Li-Ion History

- 1993 : Saft Li-Ion cell technology development start
- 1996 : Beginning of development of Li-Ion satellite batteries for Stentor (Satellite de Télécommunication pour Expérimenter des Nouvelles Technologies en Orbite) from CNES
- 1999 : VES140 cell qualification
- 2000 : Stentor battery qualification : First “industrial” application to qualify large batteries.
- 2002 : First orders of Li-Ion batteries for GEO and LEO satellites
- 2003 : Smart1 first ESA Moon Mission with full electric propulsion
- 2004 : W3A Launch

- 2024 : 393 satellites launched with Saft Li-Ion batteries

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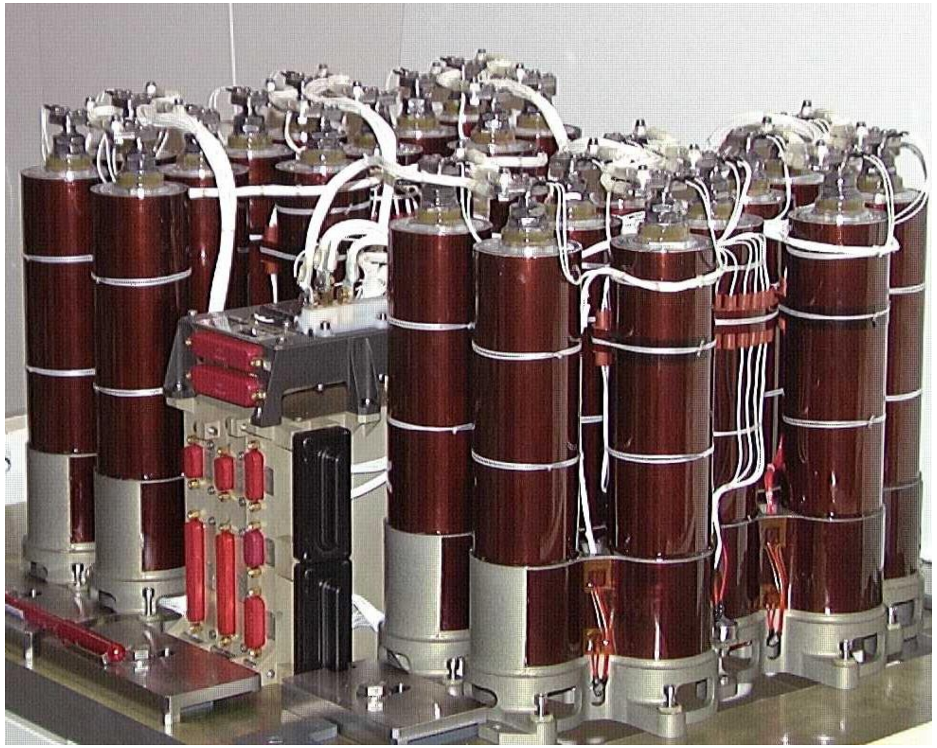
VES 140 S : Qualified cell on Stentor

- Energy > 140 Wh (39 Ah) @ 4.10 V
- Specific Energy 135 Wh/kg
- Dimensions : Diameter 54 mm
  Height 250 mm.
- Qualified in **October 1999**
- Product answer specification for the satellite range :
  - GEO 5 to 30 kW and LEO >1.5 kW
- Smart 1 ESA probe with electric propulsion to Moon Orbit
- Cell launched in orbit onboard 105 satellite programs for a total of 13,805 cells from 2002 to 2020. (6 remaining programs waiting for launch)
- Large range of users : Airbus, TAS, BSS, Northorp Grumman, OHB, CAST, IAI, ISRO, INVAP…

The STENTOR program was supposed to give flight demonstration of Li-Ion battery



- The Stentor program was a CNES funded GEO Satellite embarking innovative technologies and products (Li-Ion Battery, Electric Propulsion, Active antennas…).
- SAFT has developed the STENTOR Li-Ion battery system (Cells, Battery assembly, By-pass system, Balancing Electronics, Management software)
- The STENTOR Li-Ion battery system included two flight batteries of 80 Ah (11 cell packages in series per battery) delivered for AIT in May 2000
- Unfortunately, 11 Dec 2002, Ariane V ECA V157 launch failed.

Lithium-Ion Advantages for satellites applications

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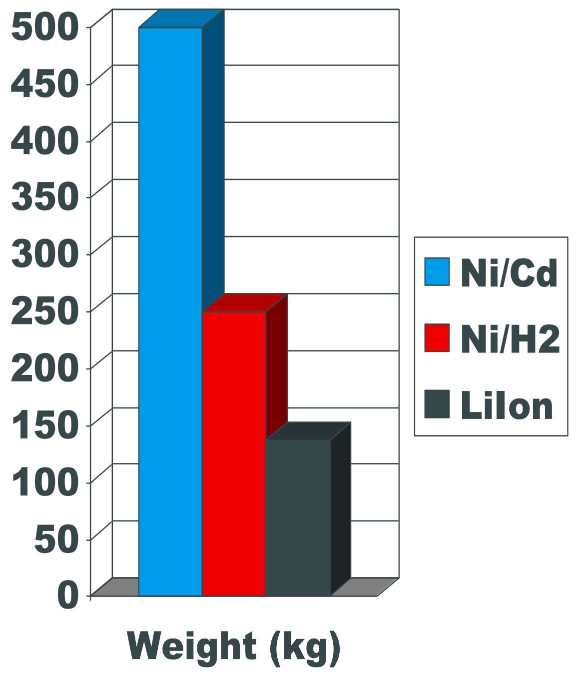
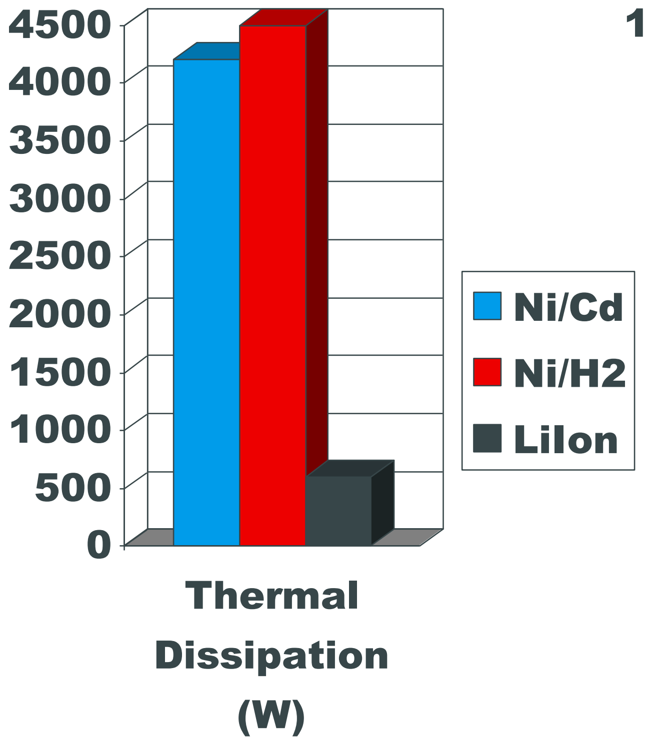
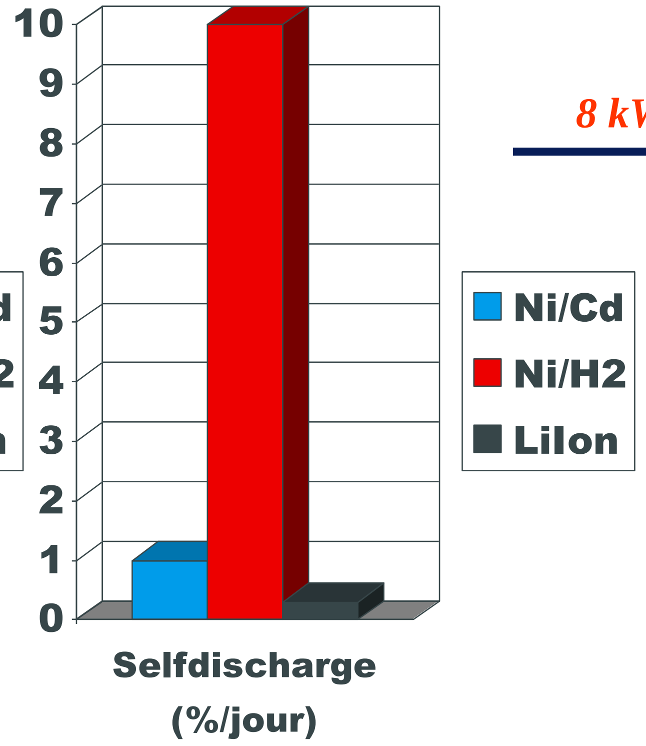
8 kW GEO satellite



50 % weight saving % NiH_2



Radiator size Reduction



Simplified launch operations

Other advantages :

- Energetic efficiency : solar panels size reduction
- No memory effect
- Energy gauge using Capacity = f(voltage)
- Modularity and flexibility based on parallel assembly

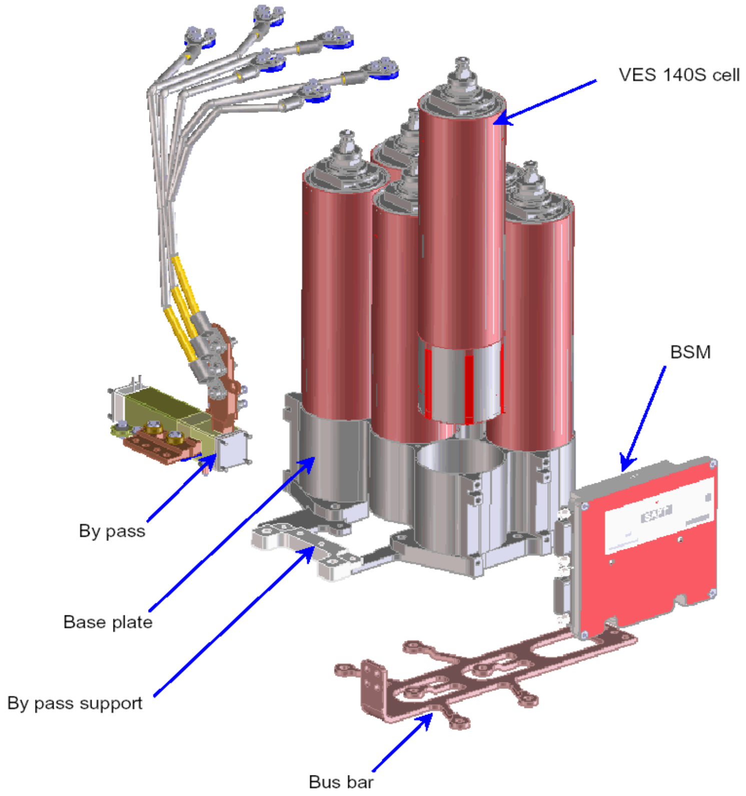
SMART1 : First in Orbit

- SMART1 : First of ESA's small missions to test new technologies, and first European spacecraft to go to the Moon.
- Its main objective was to test solar-electric primary propulsion for future deep-space missions.
- 5P 1S Battery with VES140 cell
- Launched the 27th Sept 2003 by Ariane 5
- 14 months elliptic route toward the moon…using PPS1350
- 15 novembre 2004 : First Moon Orbit
- End of Mission 3 September 2006 : The probe crashed on the Moon

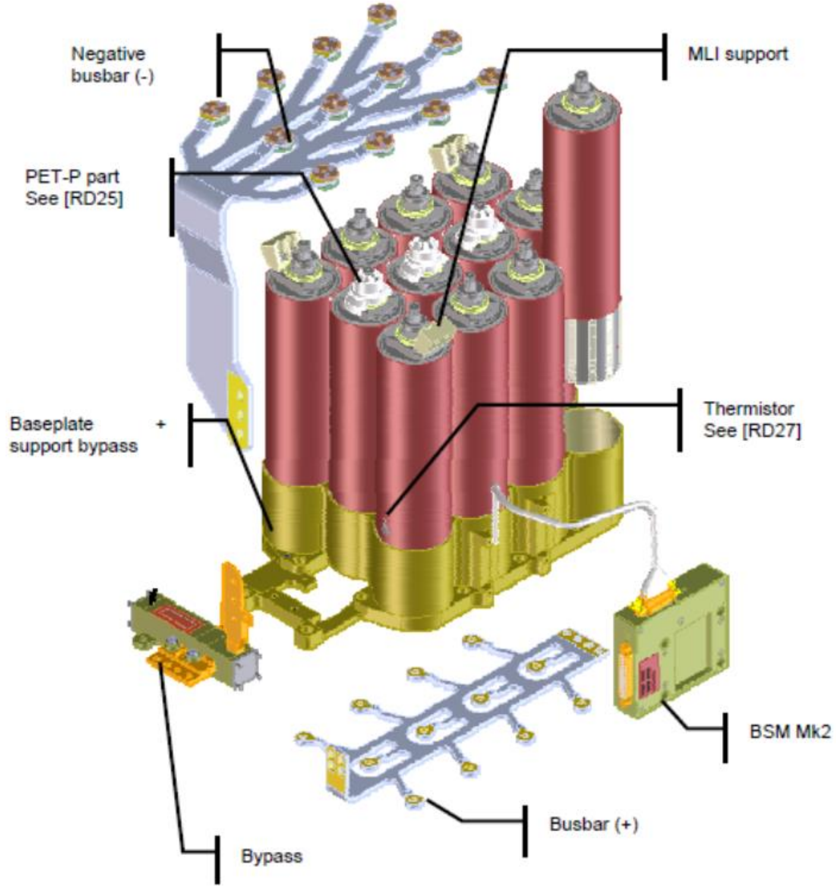
E3000 Battery Development : Cell modules

- Starting 2001 : Development of the Eurostar 3000 Li-Ion battery system:
  - cell and cell module including BSM and By-Pass
  - battery design, EPS and battery management software : Airbus
- Qualification : January 2003

2001 to 2013



Since 2012



VES 140 Cells: from 5P (190Ah BOL) to 12P (460 Ah BOL)

VES 180 Cells: from 5P (225Ah BOL) to 12P (540 Ah BOL)

W3A : First ever launched GEO Communication Satellite powered with Li-Ion Battery

- W3A Eutelsat's telecommunication Satellite with 55 transponders Ku and Ka bands
- First GEO satellite to be powered with Li-Ion Battery (9.3 kW)
- Eurostar 3000 Plate-form from Airbus (previously EADS Astrium)
- Launched the **16th of March 2004**
- Configuration with 2 Li-Ion batteries "6P11S" VES140

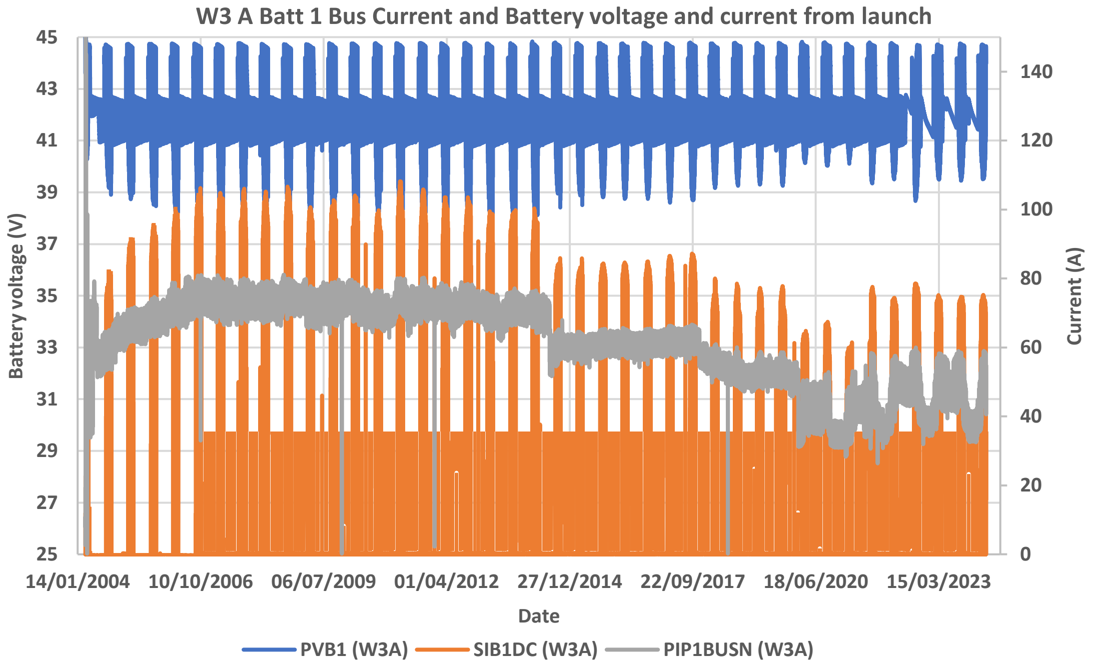
6P Module : 840 Wh- 105 Wh/kg

Airbus Credits

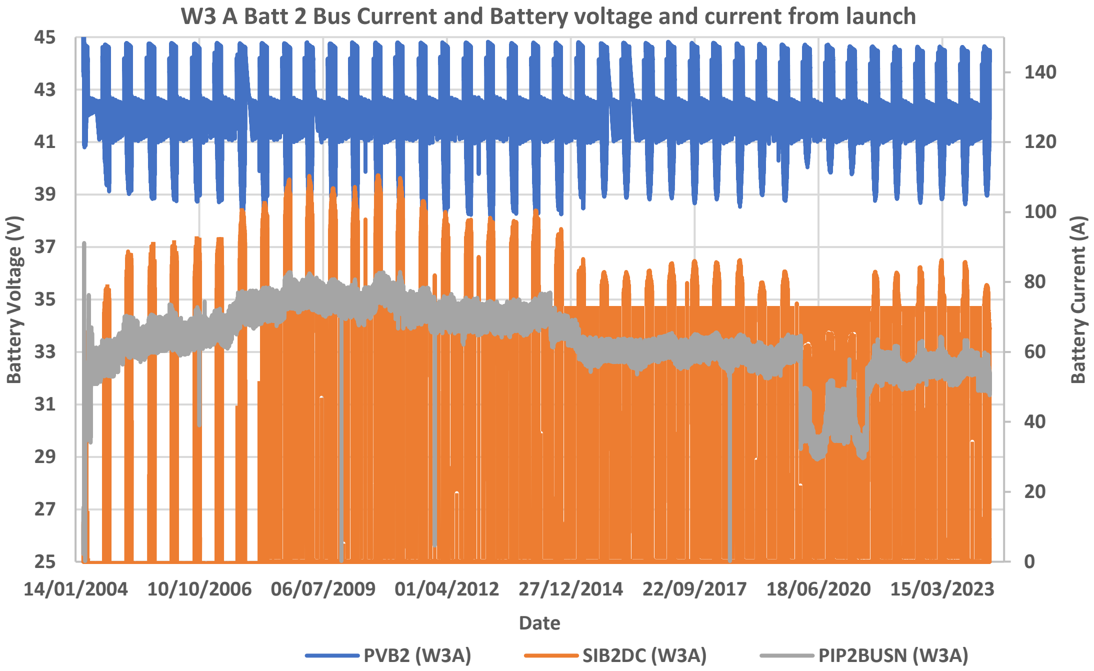
20 years in orbit for W3A lithium batteries reached in March 2024

- The two Lithium batteries in-orbit on **W3A have very similar behavior in 2024** and continue to meet **the expected performances after twenty years in orbit**.
- Nominal and homogeneous behaviour of the batteries
- Behaviour in solstice and performances during eclipse seasons are fully nominal
- **50 Eurostar 3000 S/C with Li-Ion batteries in flight** are performing perfectly well: they deliver the expected performances, and have very similar and stable behavior

Homogeneous battery behaviour during 20 years

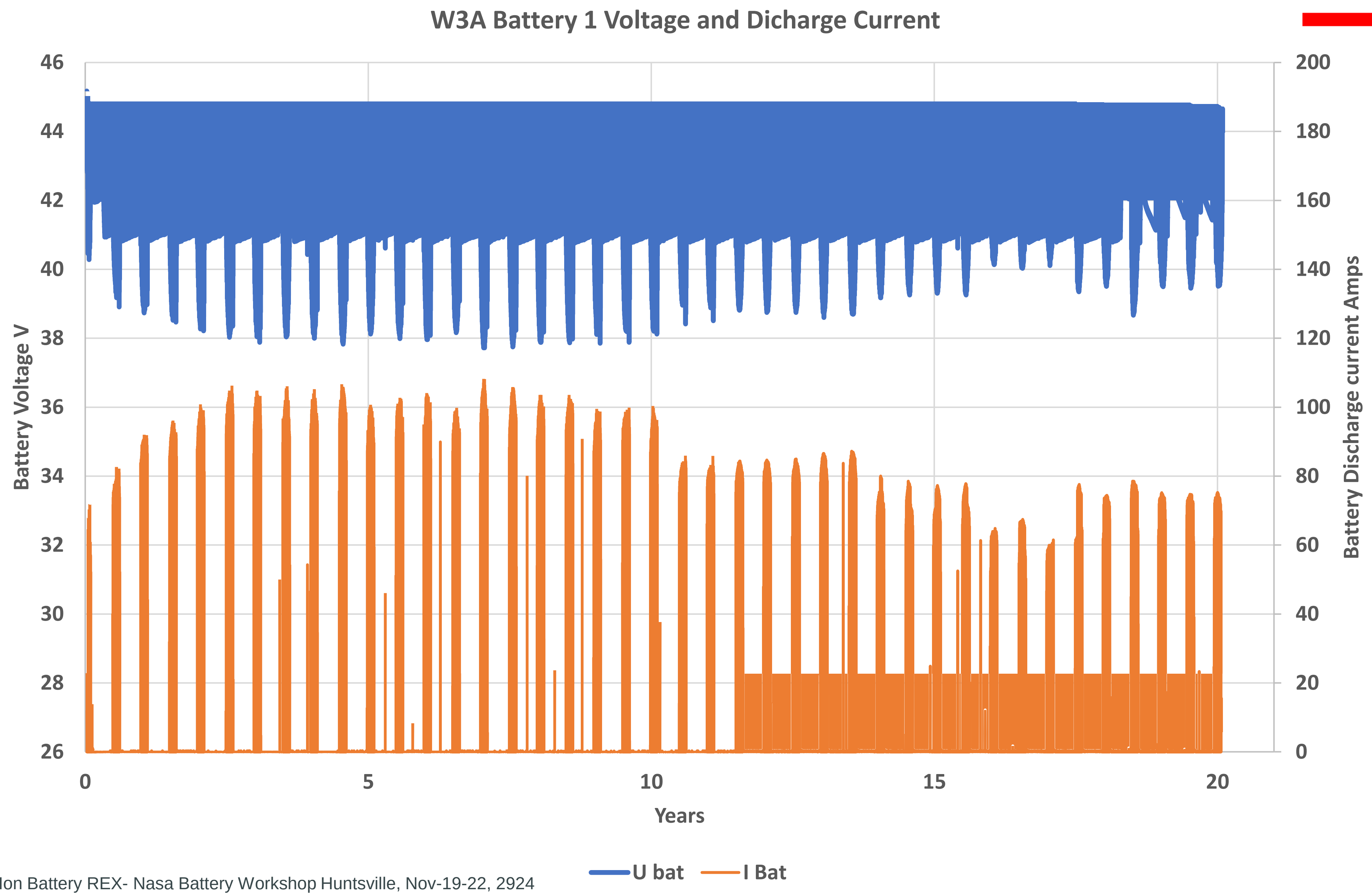


Battery 1



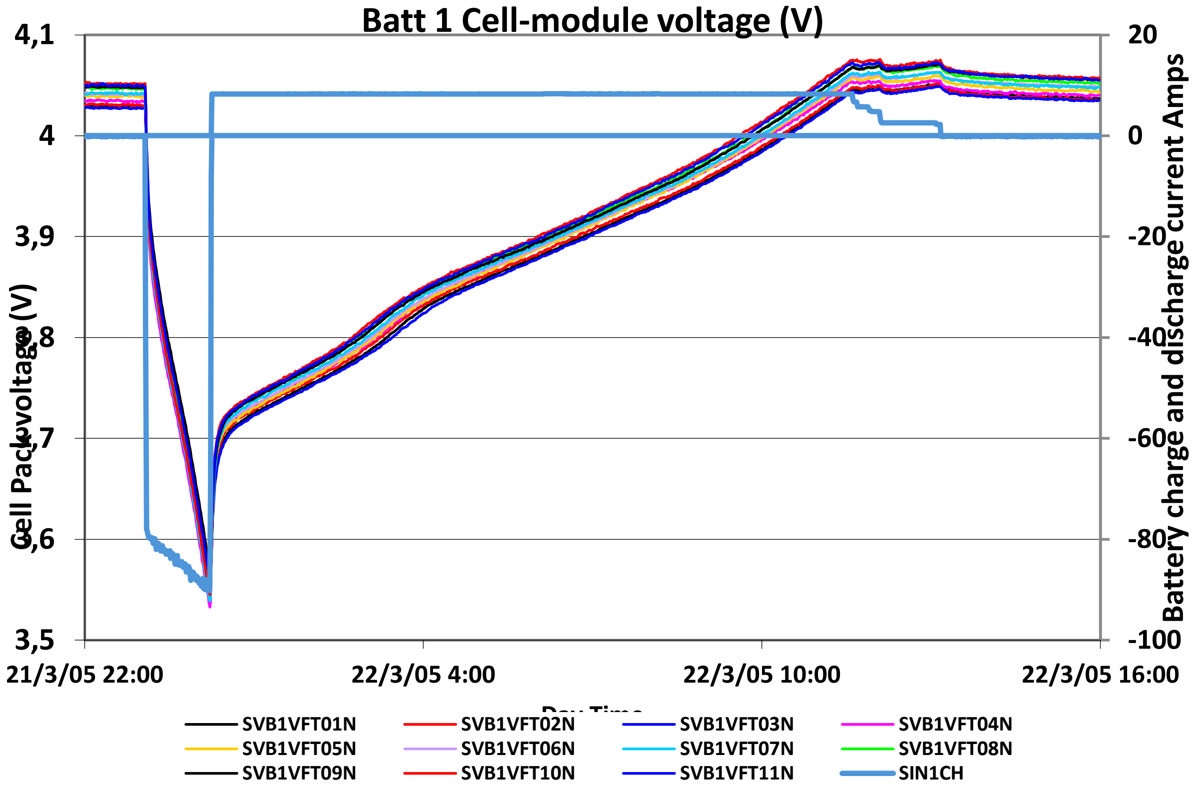
Battery 2

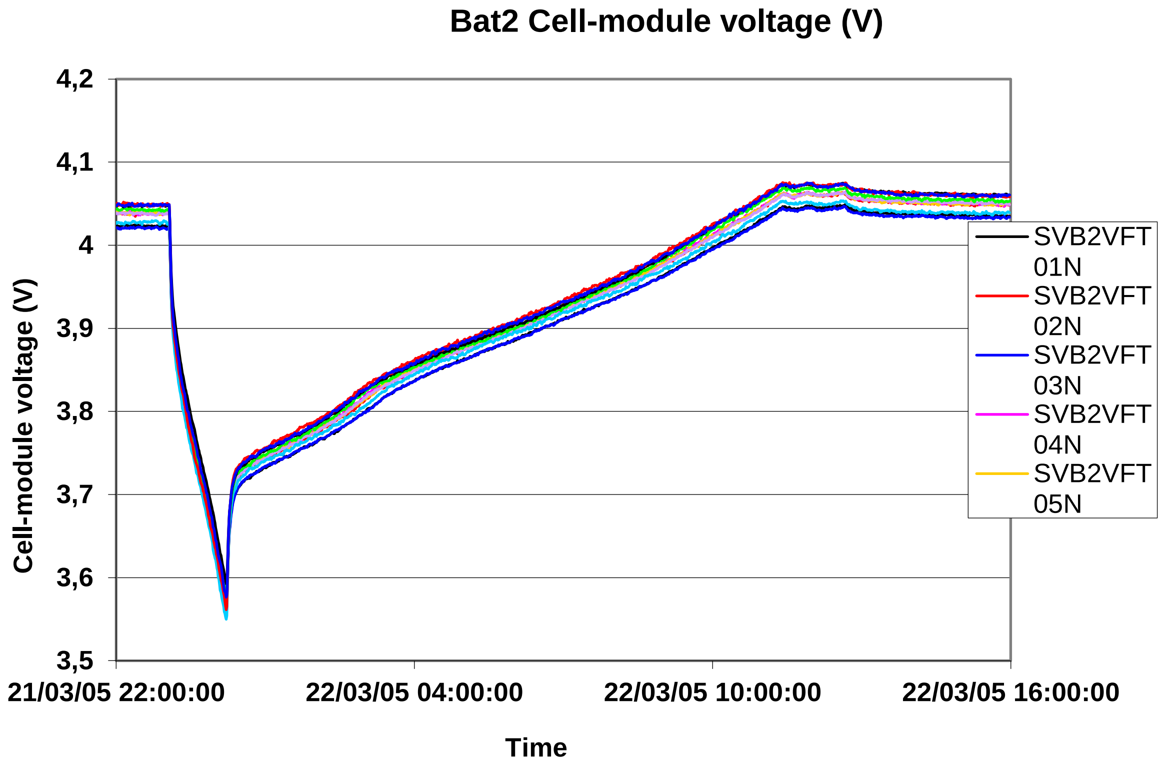
W3A Battery Voltage and Current



Spring Season 2005 : after 1 year mission

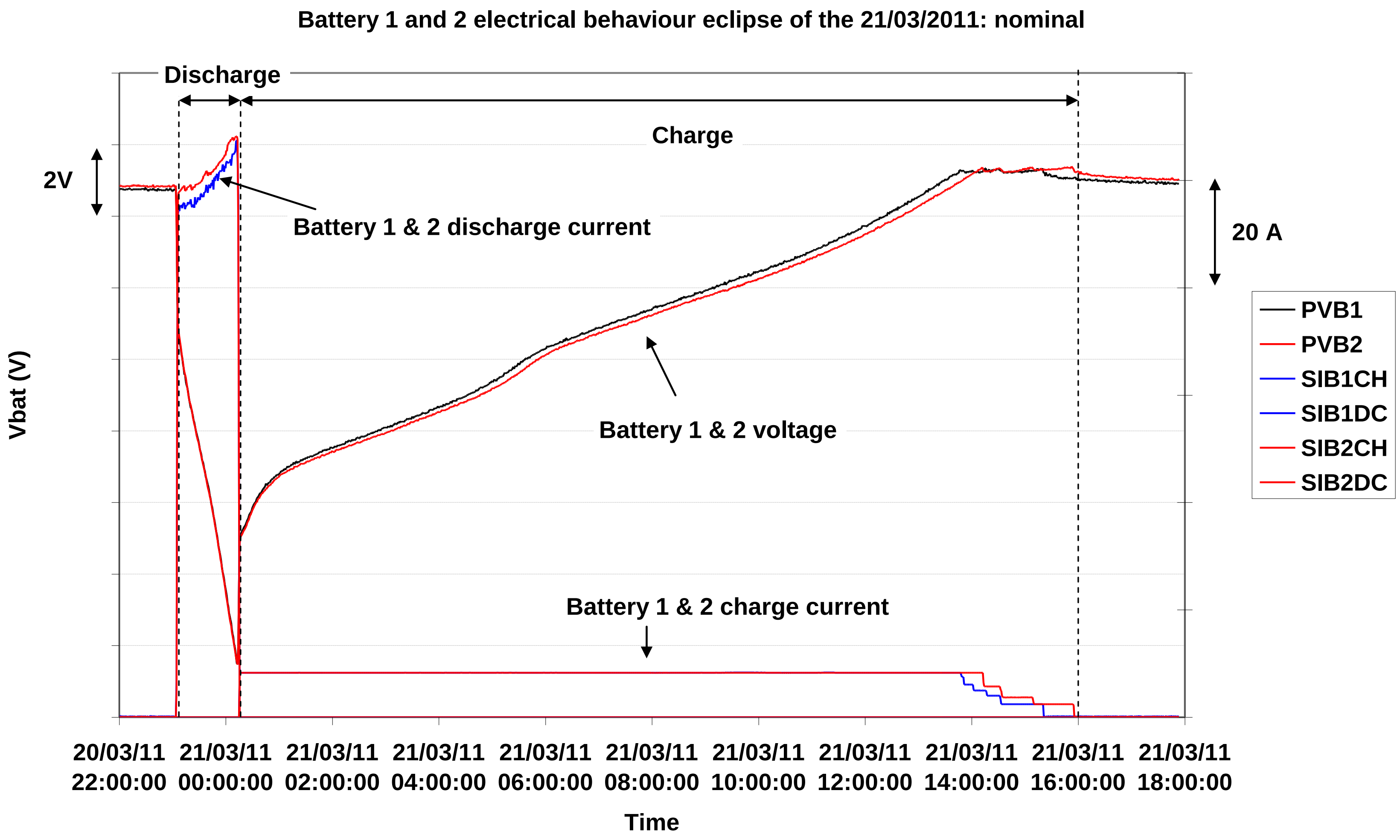
- Same behaviour for the two batteries after 1 year in orbit





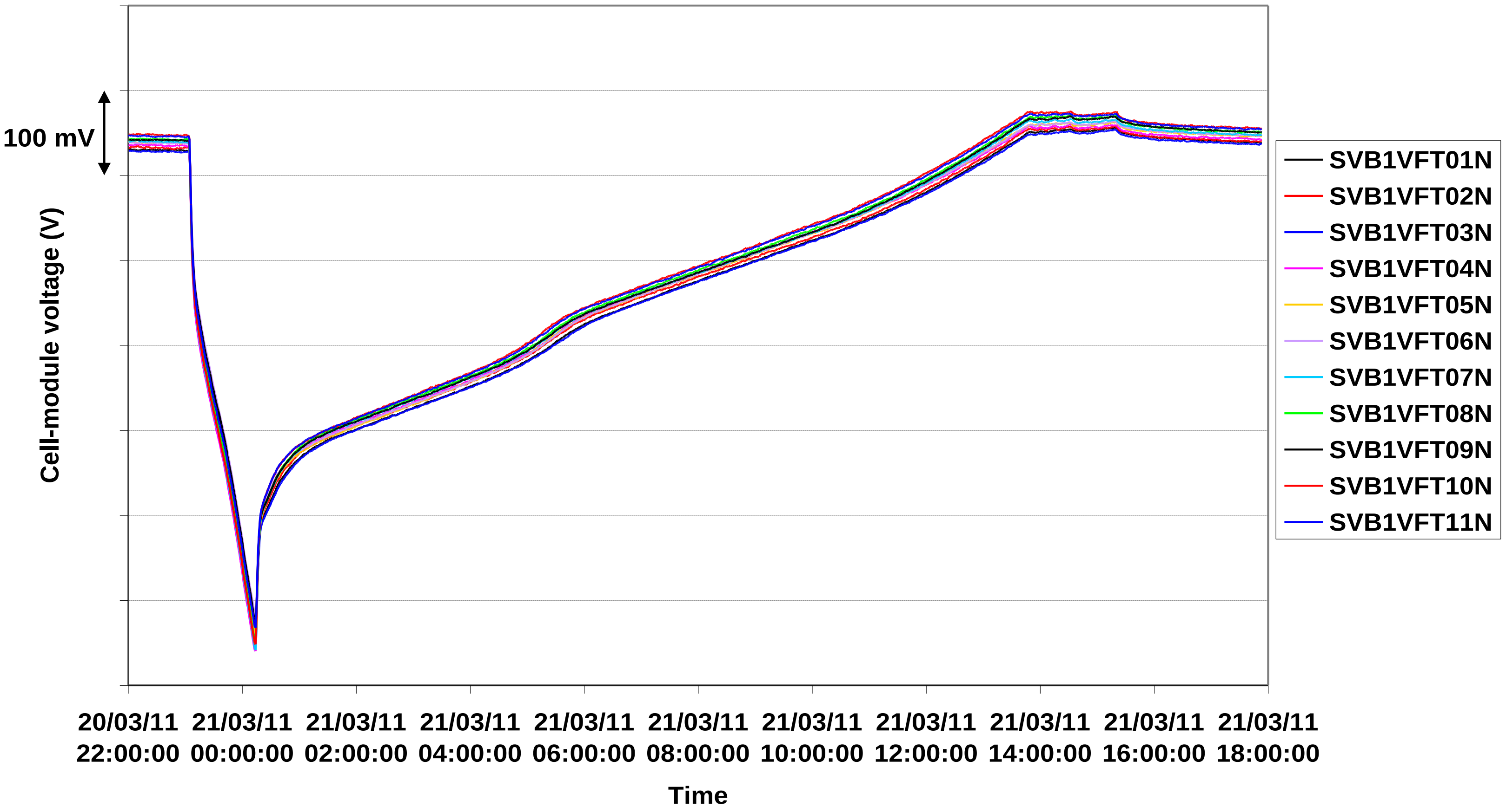
Spring Season 2011 : after 7 years mission (P.Mattesco ESPC 2011)

- Homogeneous performances of the two batteries after 7 years



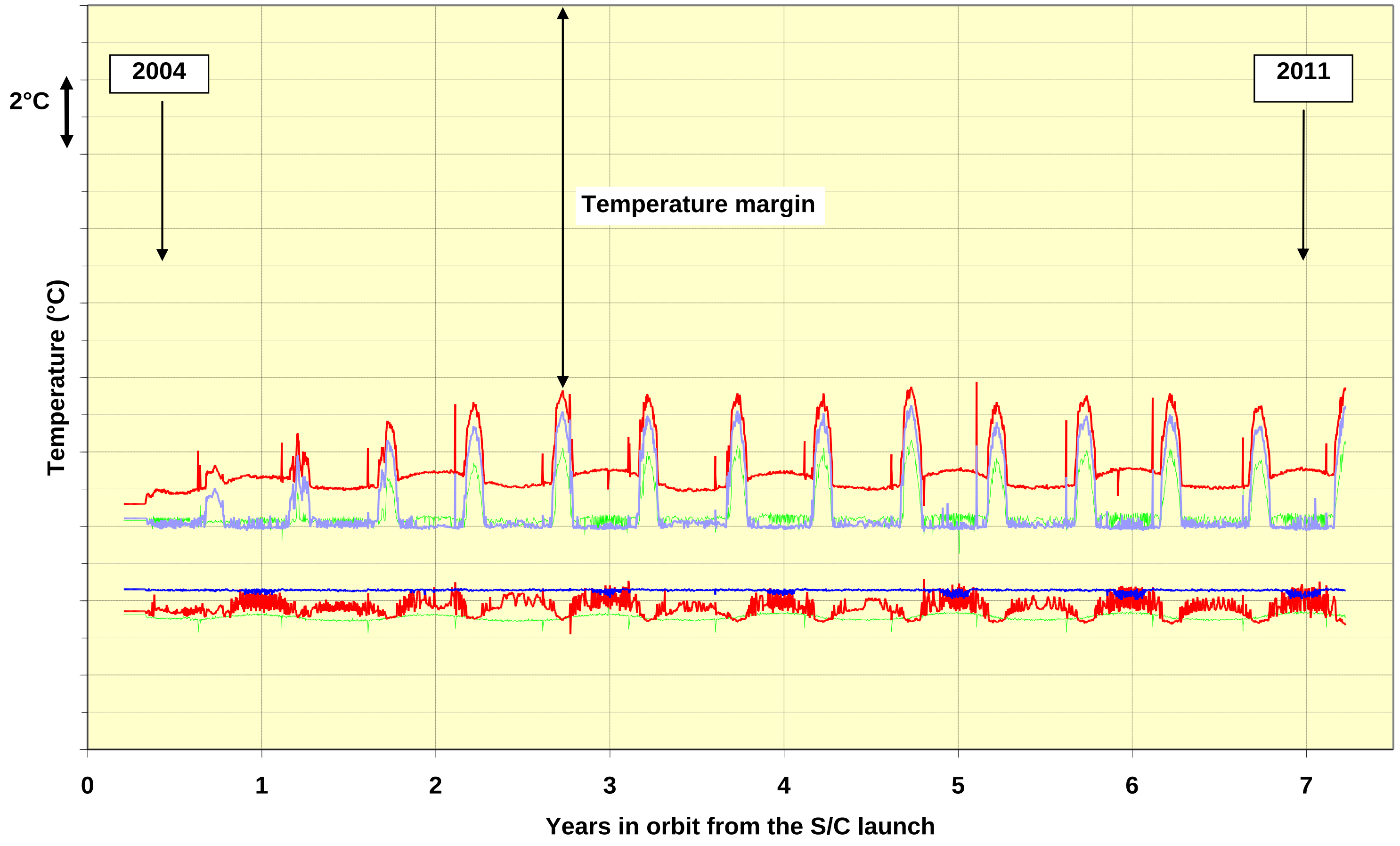
Spring Season 2011 : after 7 years (P.Mattesco ESPC 2011)

- Homogeneous behaviour of the 11 cell-modules after seven years : performing balancing system



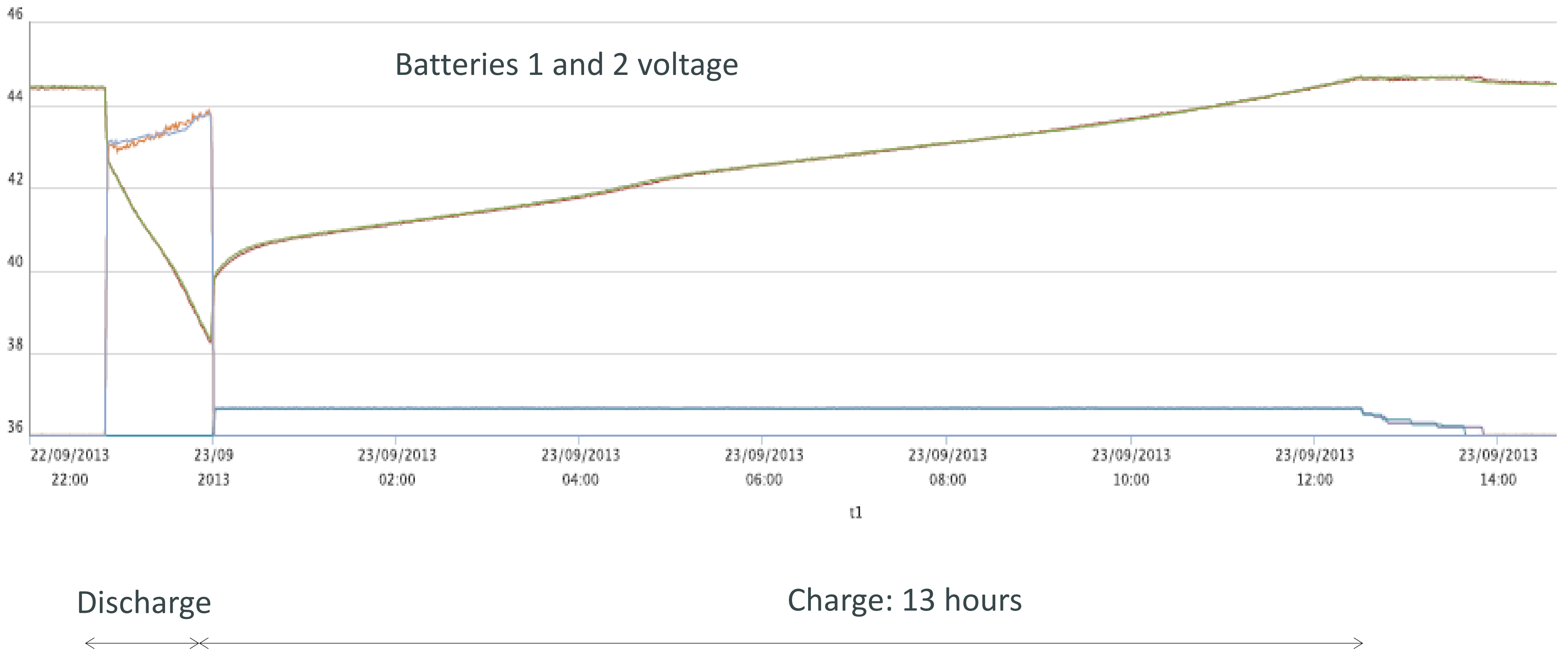
Spring Season 2011 : after 7 years (P.Mattesco ESPC 2011)

- Temperature increase in eclipse in the expected range
- Nominal behaviour, with margin



Autumn Season 2013 : after 10 years (F.Mallet ESPC 2014)

- No degradation measured on the two batteries after ten years

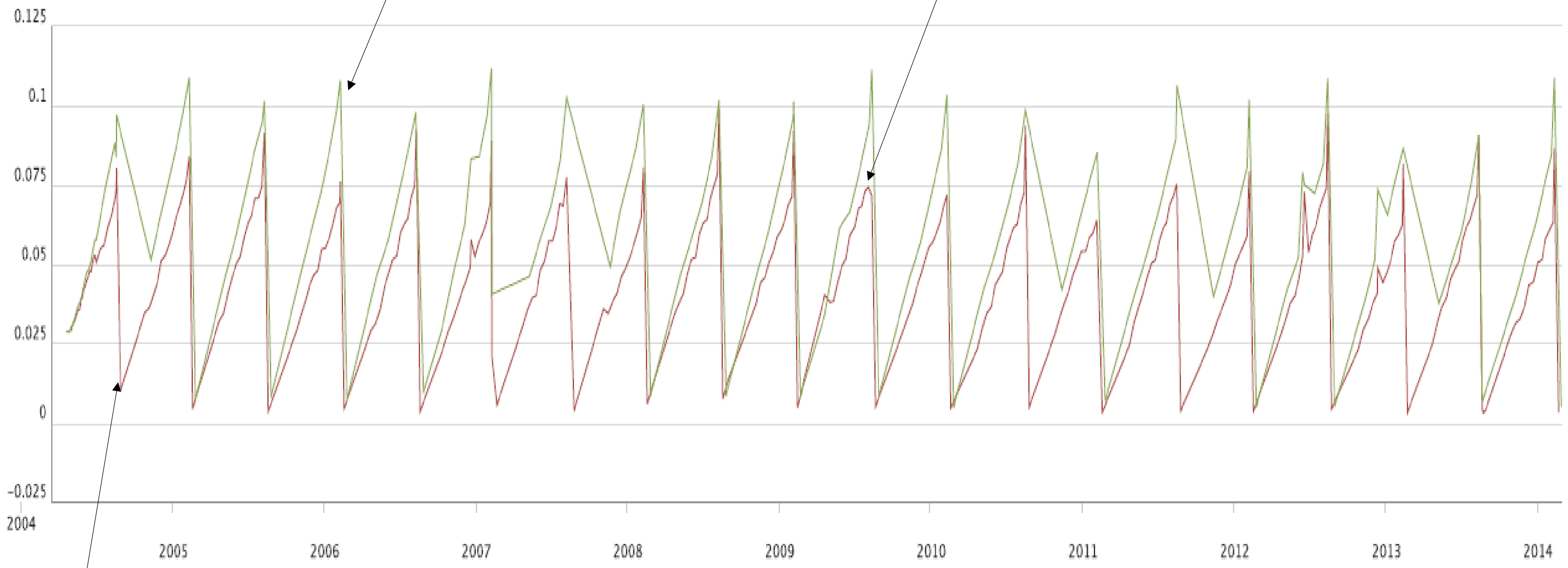


Balancing performance review after 10 years (F.Mallet ESPC 2014)

- Balancing operation : Spread between max and min cell module voltage increases according to time.
- **Spread is below 10 mV before equinox season**

Vcell max – Vcell min for battery 2

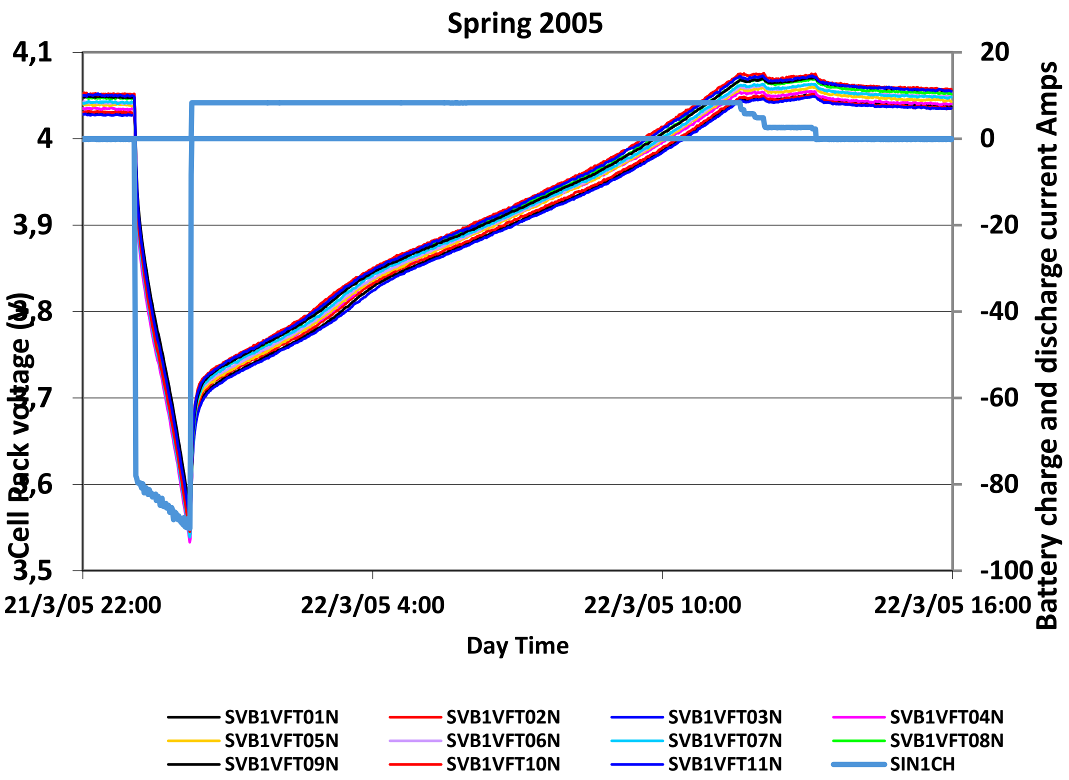
Vcell max – Vcell min for battery 1

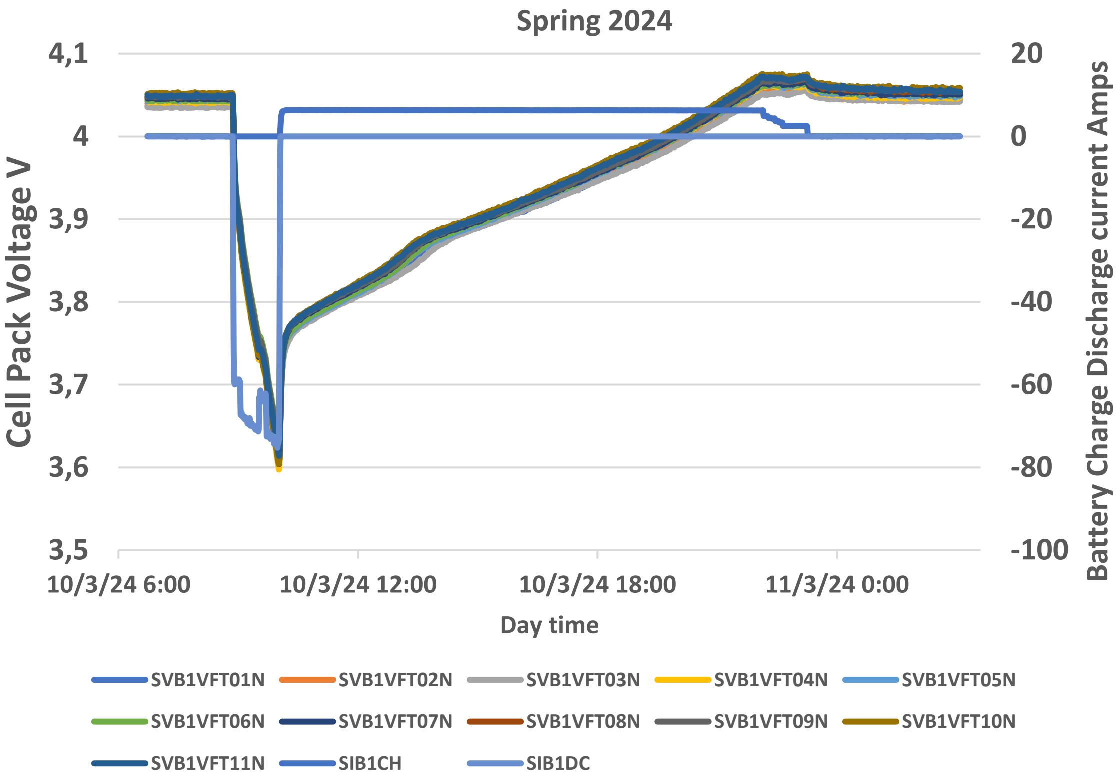


Balancing before equinox season

Comparison Spring Season 2005/2024

- The two Lithium batteries in-orbit on W3A have exactly same similar behavior from Spring Season 2005 to 2024.
- Cell to cell spread is constant during the 20 years with less than 15 mV at EOC

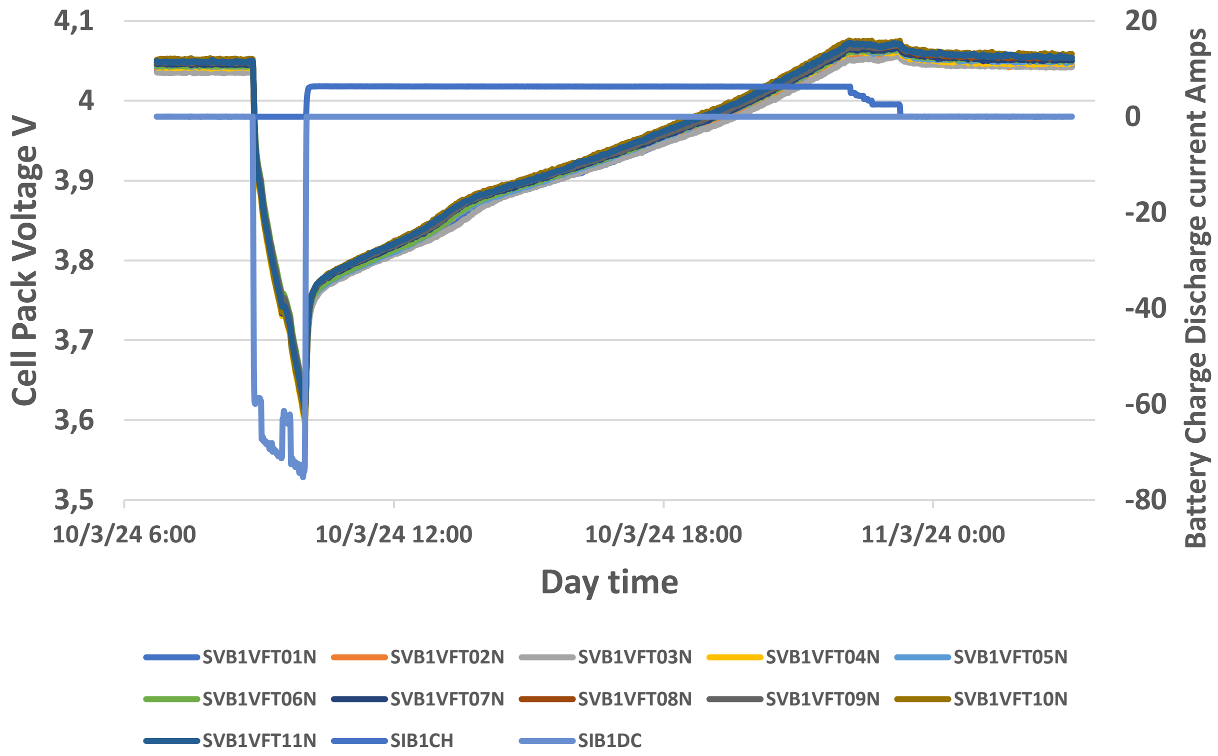




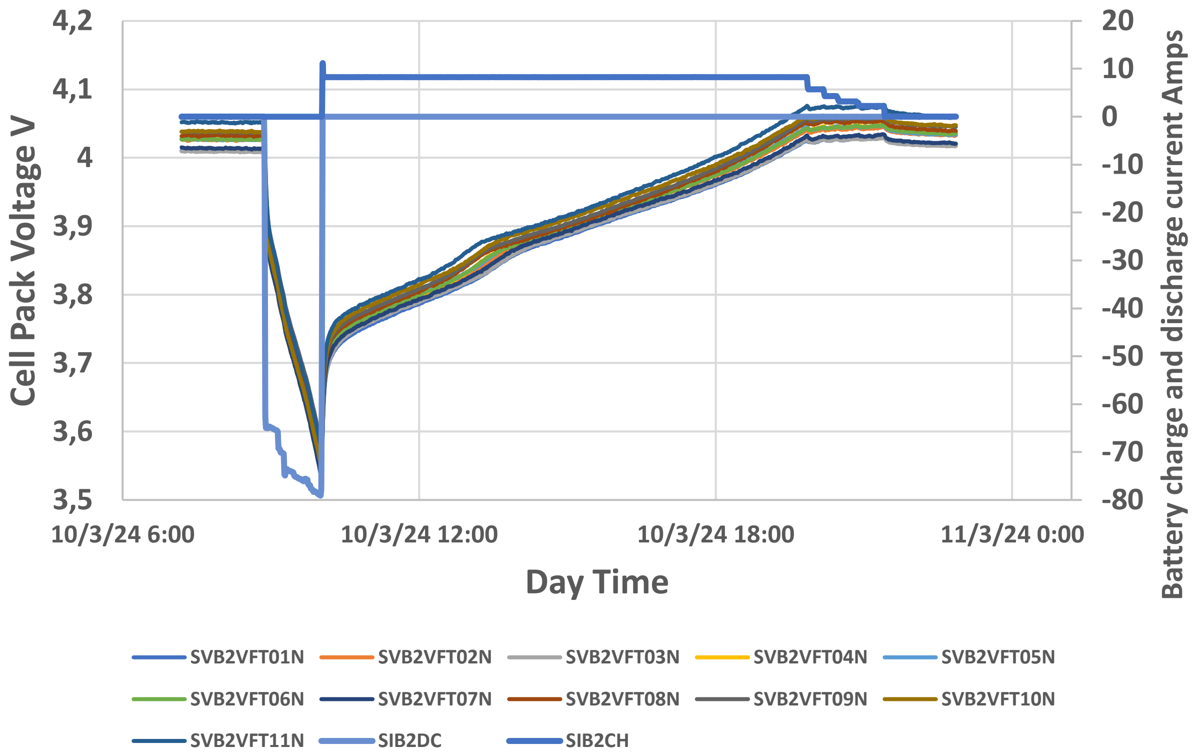
Longest Eclipse Day March 2024

- The two Lithium batteries in-orbit on W3A are showing very similar behavior (39.5 and 39 V).
- Cell Pack Voltage
  - Batt 1 from 3.597 V to 3.627 V (75.2 amps discharge) : 30 mV spread
  - Batt 2 from 3.543 V to 3.581 V (79 Amps discharge) : 38 mV spread

W3 A Batt 1 : Longest eclipse day Spring 2024

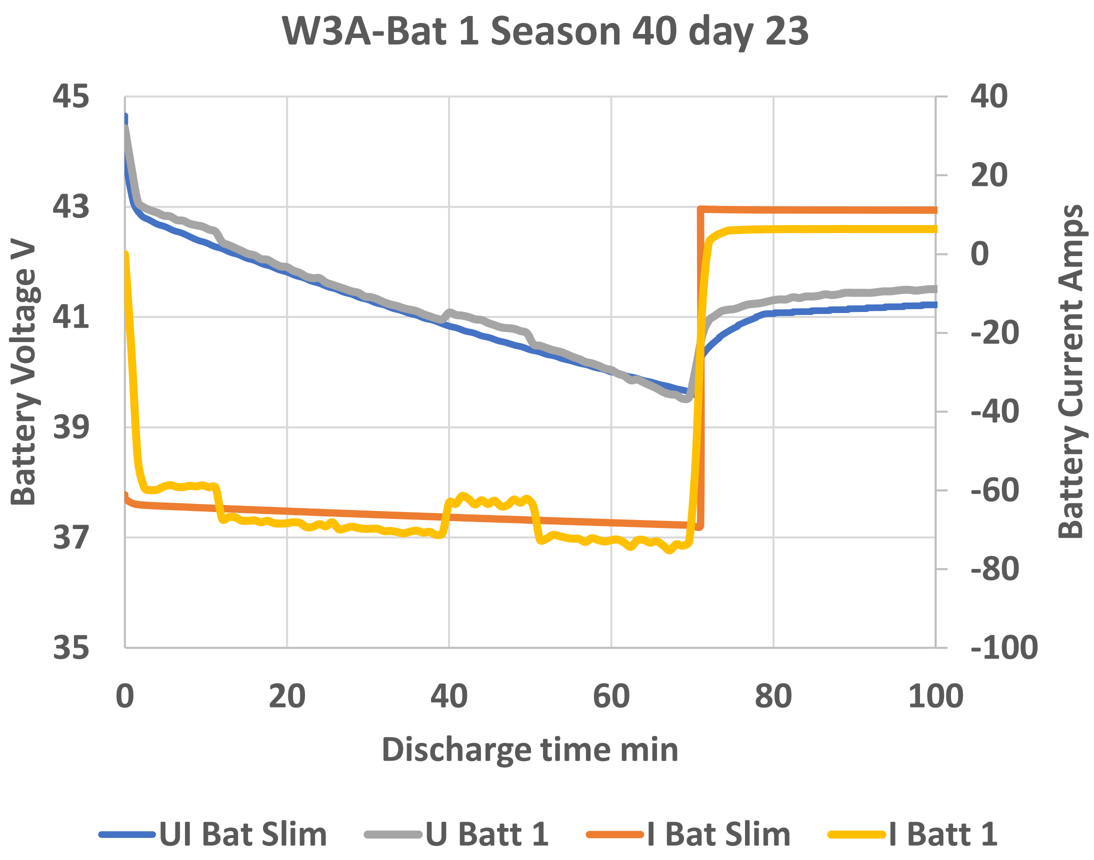


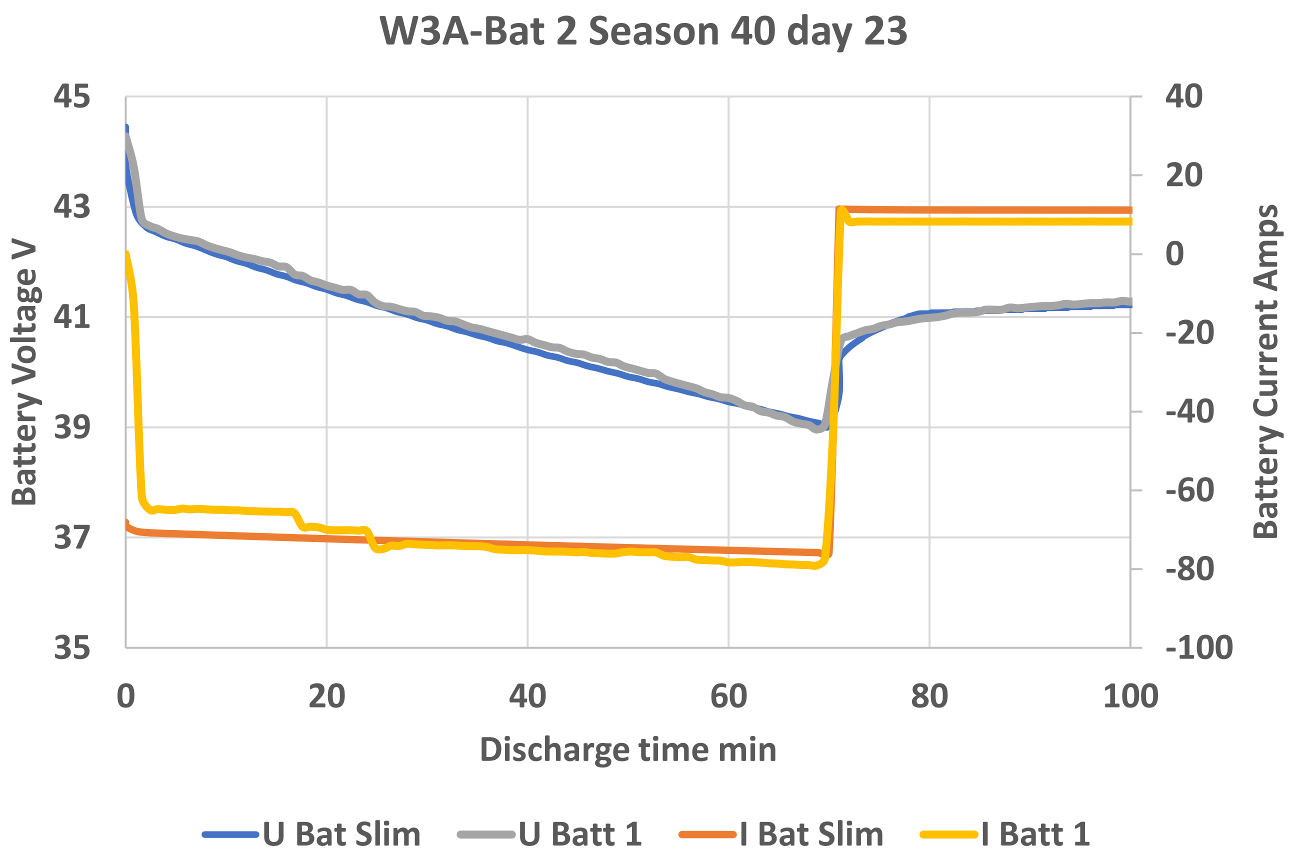
W3 A Batt 2 : Longest eclipse day Spring 2024



Longest Eclipse Day March 2024 SLIM comparison

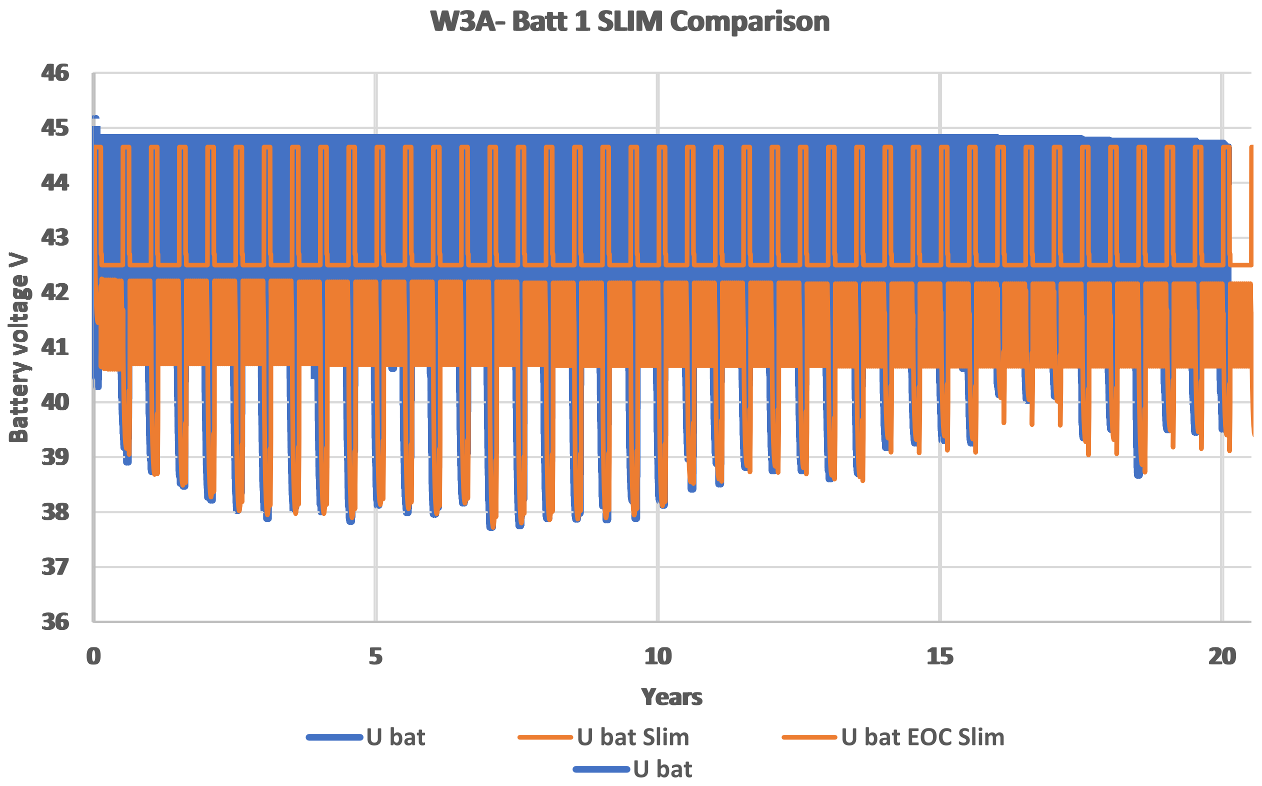
- Good fitting with SLIM 20 years simulation on longest day of Mach 2024 eclipse





W3 A Battery degradation evaluation

- Battery health status have been done after 7 years in 2011 and 10 years in 2017
- Articles presented at ESPC 2011 and 2017
- Analysis with Slim Saft Life model tool after 20 years : **W3A battery energy loss 2.5 %**



Summary : 20 years in orbit for W3A lithium batteries reached in March 2024

- The **two Lithium batteries in-orbit on W3A have very similar behavior in 2024** and continue to meet the expected performances after **twenty years in orbit (40 GEO seasons).**
- Nominal and homogeneous behaviour of the batteries
- Behaviour in solstice and performances during eclipse seasons are fully nominal
- Temperatures and balancing managements are as expected
- Battery Min EODV along the mission is 37,8 V obtained from 2009 and 2014 corresponding to the highest discharge battery current 108-109 Amps.
- **Battery Energy fading after 20 years in orbit calculated at 2.5 % losses** (Slim Model calculation)
- Battery EODV in March 2024 = 40,2V corresponding to 3.64 V/cell package

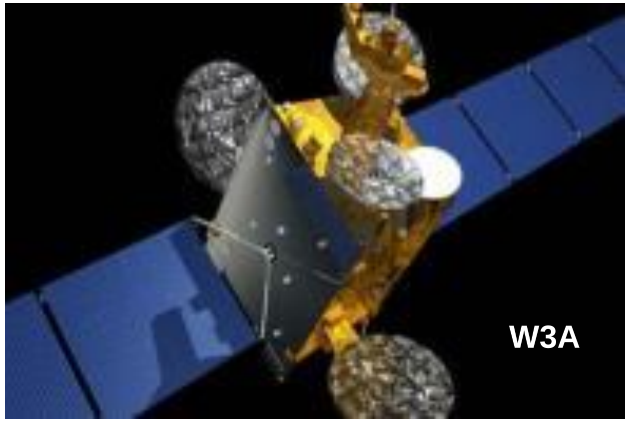
Saft Li-ion in orbit heritage and reliability

393 satellites in-orbit with Li-ion (GEO, MEO & LEO) : 372 operational

More than 3 Billion of cell hours in orbit with **no failure or deviations**

Total over 4.2 MWh in-orbit with 700 batteries and more than 50 000 cells in orbit

- **213 GEO satellites** Launched + **1 Moon Mission** :
  - 2003 : Smart 1 has been able to reach Moon orbit thanks to ion thrusters' engines powered with Li-Ion battery
  - 1rst GEO Telecommunication satellite W3A launched 20 years ago (March 2004) with VES140 batteries



- **5 MEO satellite** flying with VES technology:

- **175 LEO satellites including** :
  - 80 first Iridium Next satellites with VES16 batteries

Conclusion and Acknowledgements

- W3A Battery Energy fading after **20 years is demonstrating very impressive performances**
- **105 satellites powered with VES140 batteries** have been launched are always in operation with limited degradation and no performance deviation
- All Saft cell technology evolutions are exhibiting the same trend with very low degradation as per VES140 : VES16, VES180, VL51ES and the new VL10ES (220 Wh/kg) that is now qualified
- New technology step will be with the Solid State batteries

Saft and Airbus thank Eutelsat, CNES, and ESA, for their contribution and support all over the Eurostar 3000 battery development.

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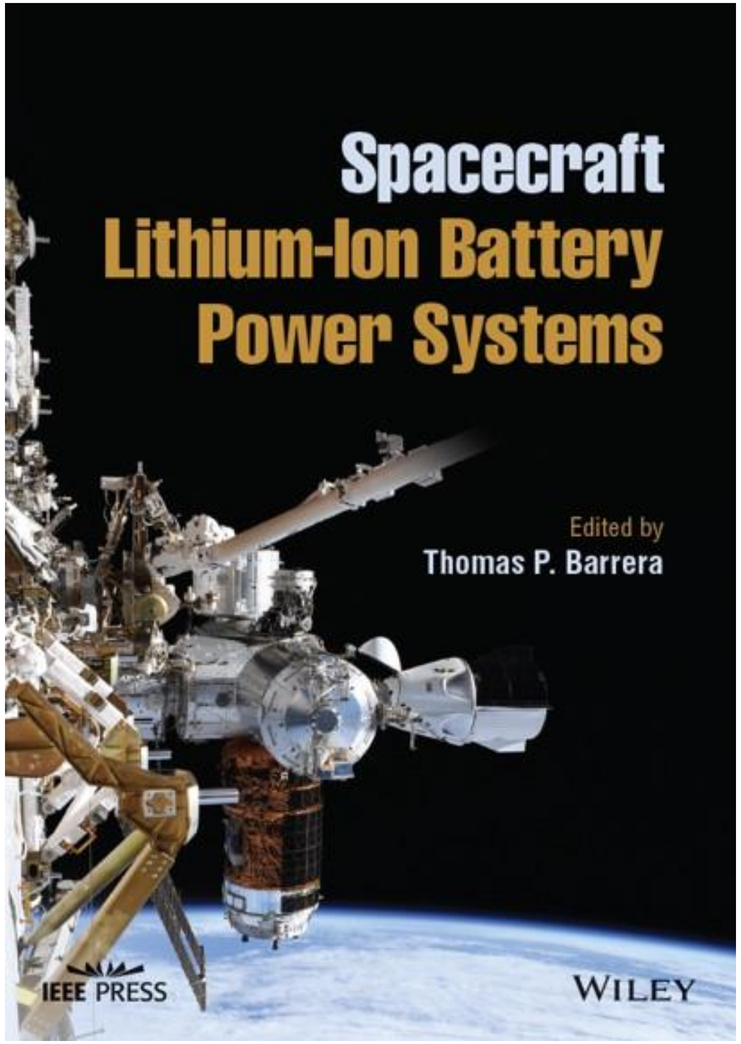

Thank you

TotalEnergies