Passive Balancing of Li-Ion Batteries

Jeremy Neubauer, Blake Cardwell, Jake Dembeck, Chris Pearson

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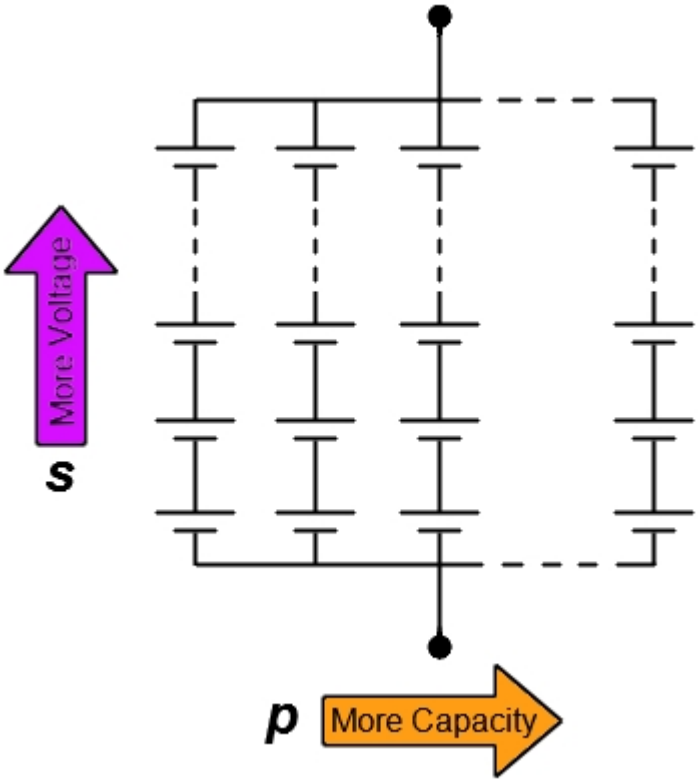
ABSL's Heritage Topology Defined

- S = number of cells in series, determines voltage.
- P = number of strings in parallel, determines capacity.
- Nomenclature: an 8s100p battery has 100 strings in parallel with 8 cells in series per string.



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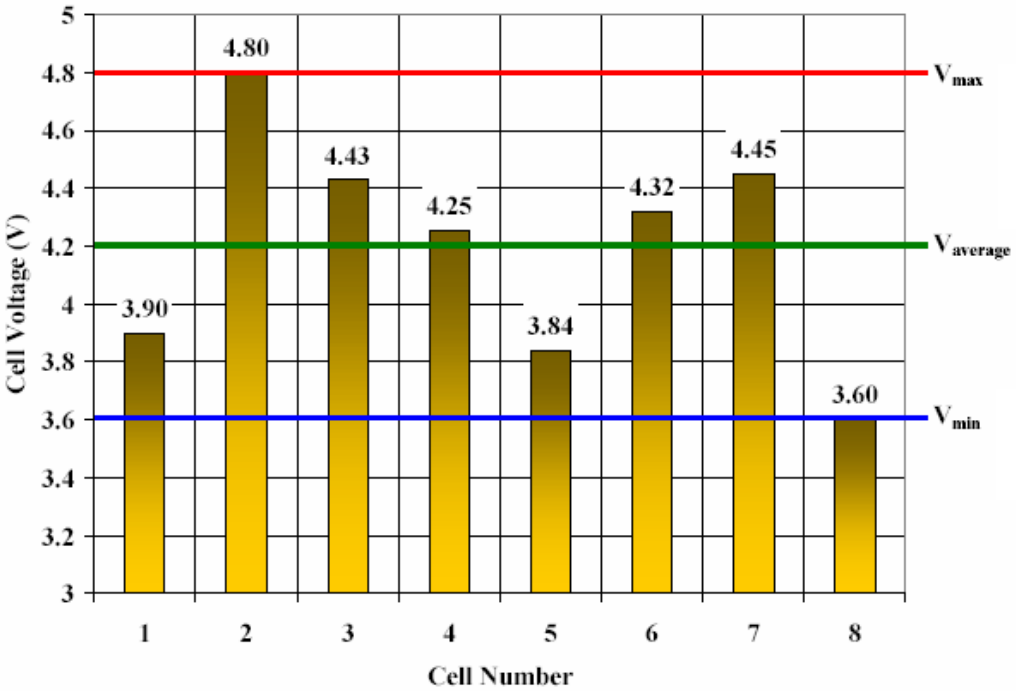
Dispersion

- Consider passive s-p topologies **without active electronics** to control individual cell voltages…

- Voltage dispersion can occur and grow within a string. If it becomes excessive, it can lead to the **over-charge** or **over-discharge** of cells.



- Factors that encourage dispersion:
  - Poor voltage & SOC matching at build
  - Capacity, resistance, and self discharge rate variance within a string
  - Temperature gradients between cells within a string
  - Leakage paths within the battery
  - Abusive operation

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ABSL's Passive Balancing Approach

- **Eliminate Sources of Dispersion:** Uniformity of cells ensured by manufacturing techniques, LAT, and cell screening, enhanced by matching procedures, control of thermal gradients, precautions against short circuits and leakage paths

- **Minimize the Effects of Dispersion:** Employ and prove an architecture that is extremely robust and tolerant to the faults cause by excessive dispersion.

- **Prove the Concept:** Proven extensively by on-orbit success and lifetest at ABSL and customers
  - NASA (GSFC, GRC), ESA, NGC, LM, LORAL, Aerospace Corp
  - Examples exist of abused batteries (shorting, overdischarge) demonstrating robustness of balancing
  - 50+ spacecraft flown employing passive balancing in S-P topology, no anomalies, multiple mission extensions

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Questions to answer…

- Can ABSL really balance cells passively?

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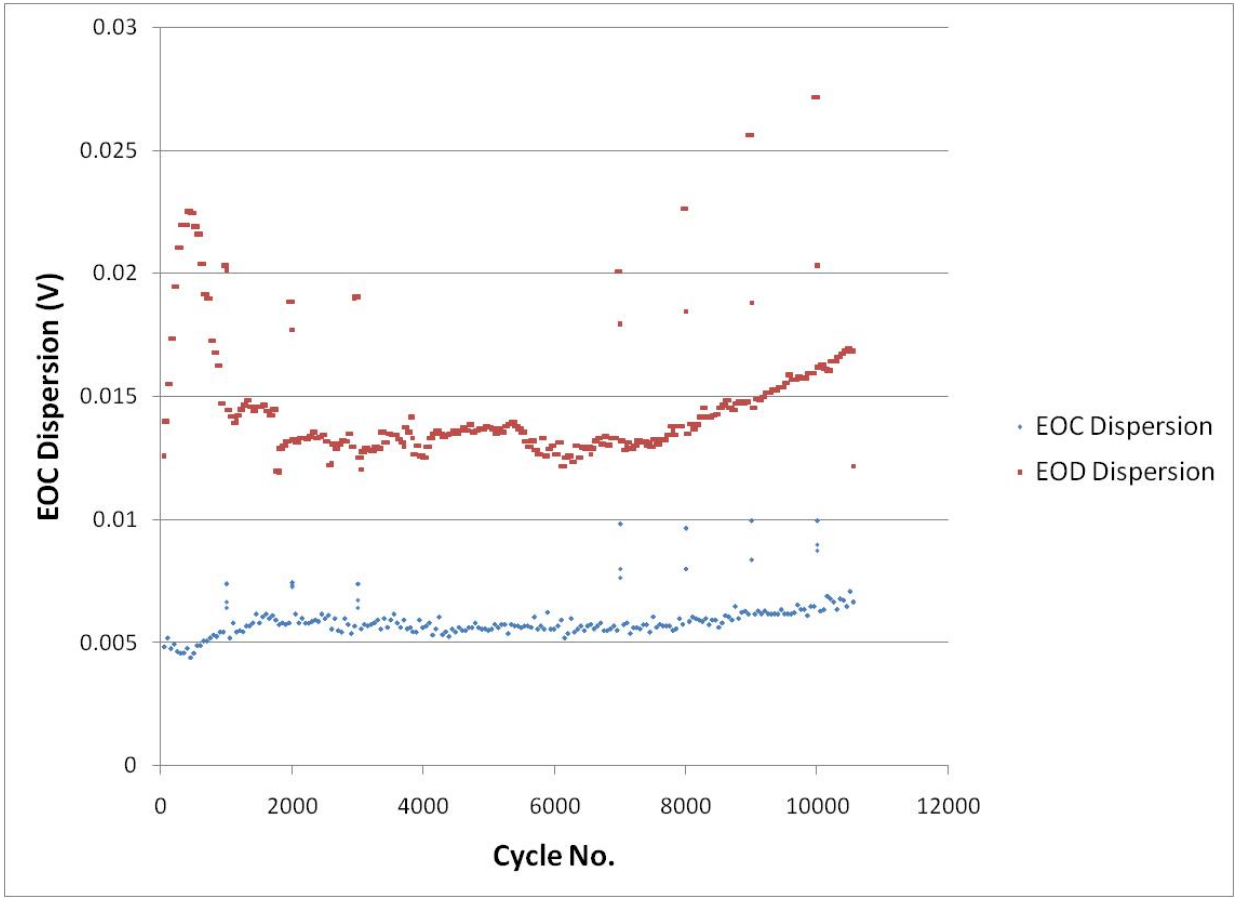
NASA GRC - ABSL Life Test

- Data shows low dispersion values and growth rates out to >10,000 cycles on the mV scale



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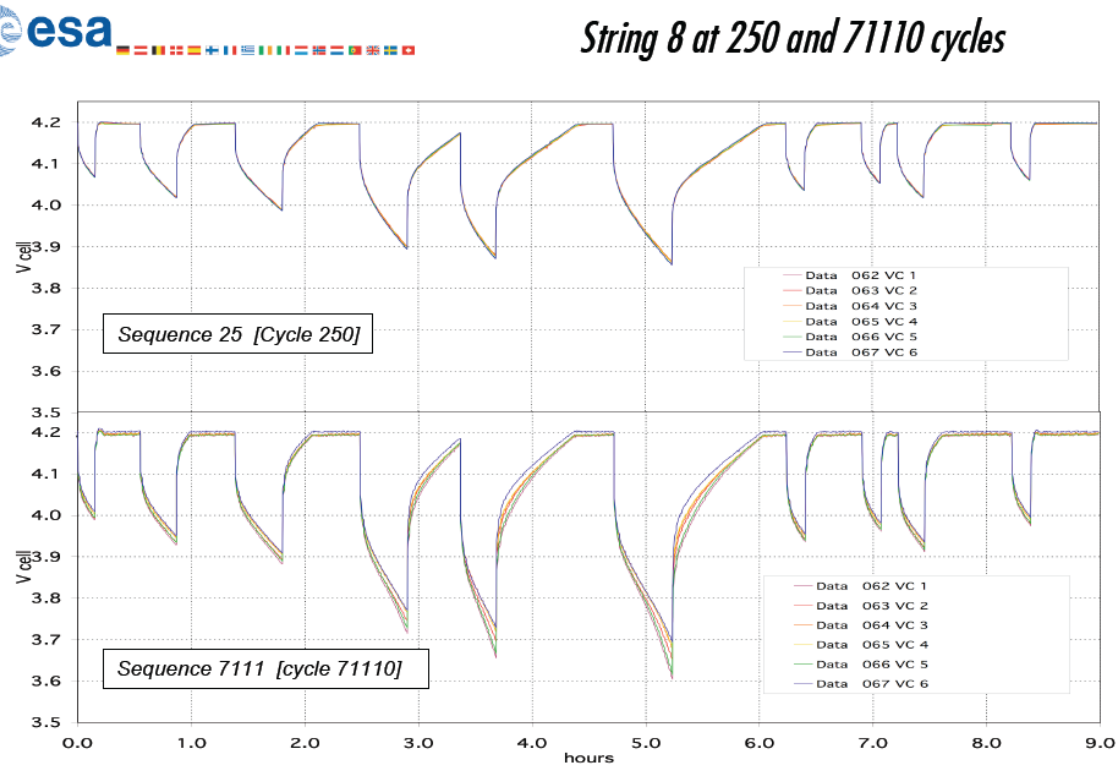
ESA - ABSL Skybridge Test



Courtesy G. Dudley, "LEO Life Tests of ABSL Batteries Using SONY 18650HC Cells", 2007 NASA Battery Workshop

- Typical EOCV Dispersion after 71,000 cycles: 2 to 11 mV
- Battery had been over-discharged three times at BOL

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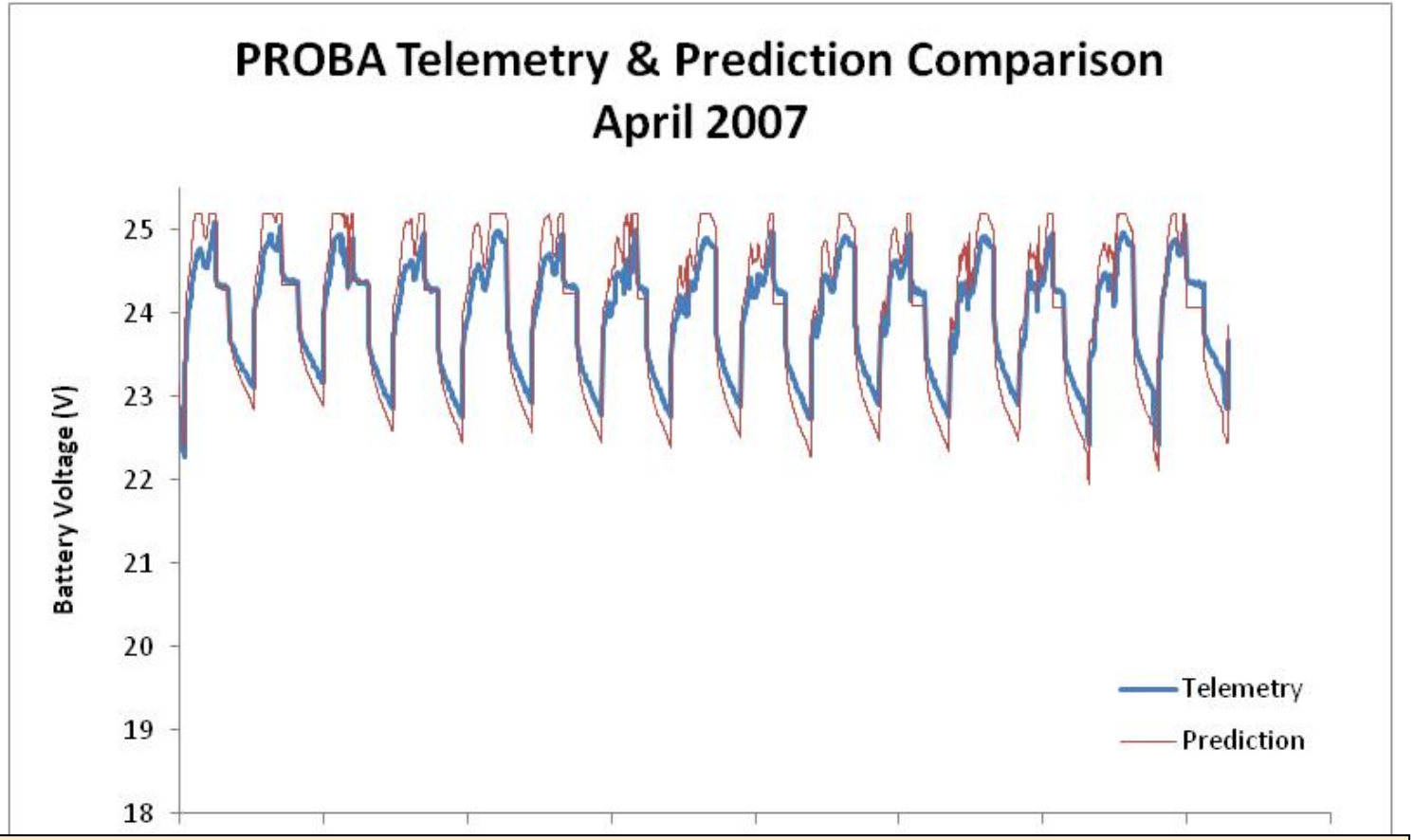
PROBA: Prediction vs. Telemetry



5.5 years into the mission, predicted performance agrees well with on-orbit telemetry. Small errors attributed to conservative resistance growth prediction

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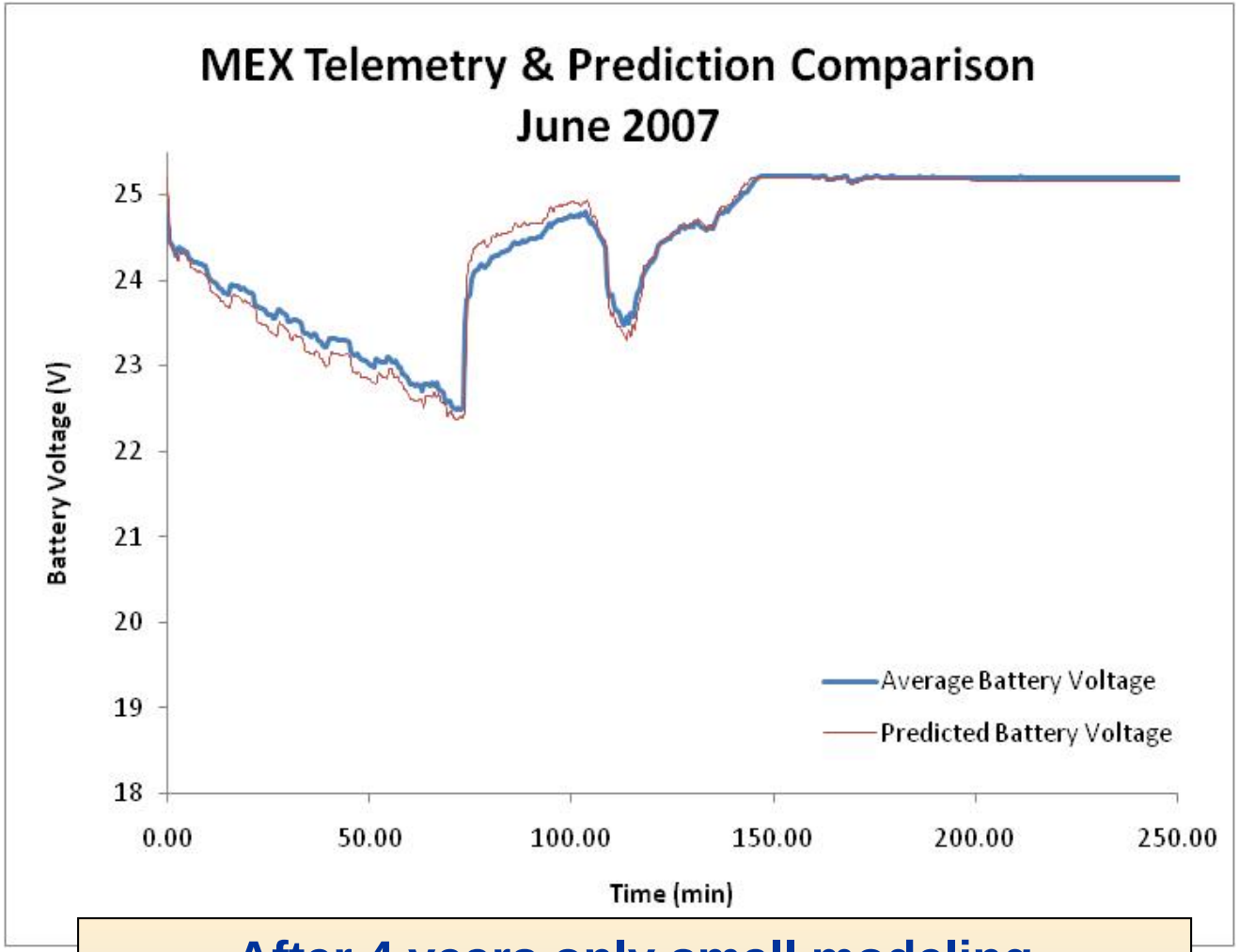
MEX: Prediction vs. Telemetry



After 4 years only small modeling imperfections are present

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Questions to answer…

- Can ABSL really balance cells passively?
- What happens if dispersion is introduced into an ABSL battery?

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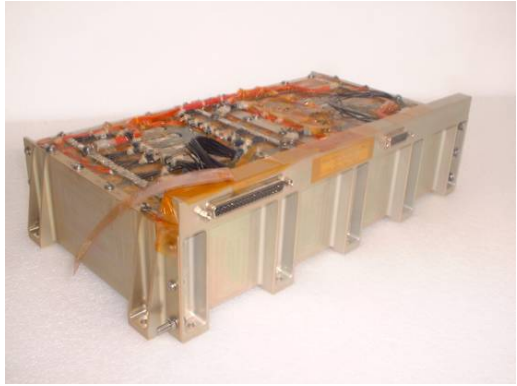
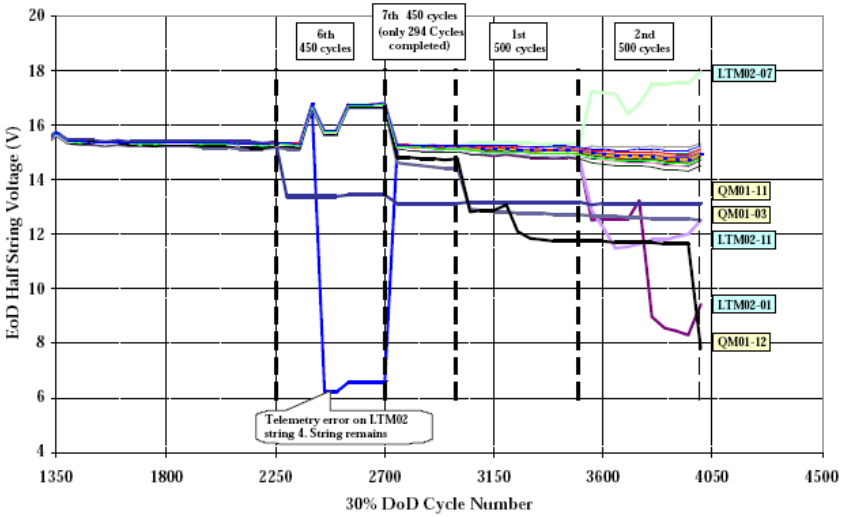
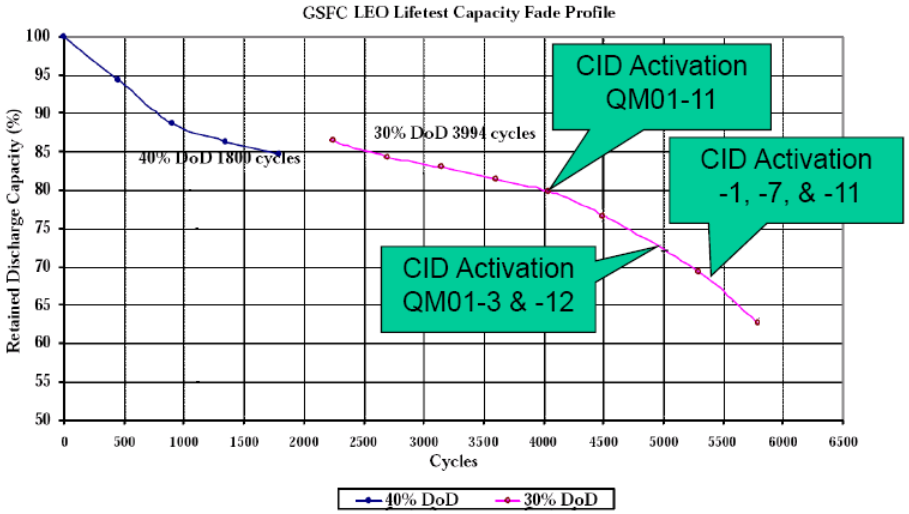
NASA GSFC - ABSL 60 Ah Life Test

- Flight like 8s16p **abusively shorted** during integration
- Excessive cell **dispersion created by short**, grew through subsequent 30% DOD life testing
- Dispersion became sufficient to activate the first CID during charge 2250 cycles following the short; **within 4000 cycles post-short 6 CIDs had similarly activated**
- No venting or extreme temperatures were observed







J. Neubauer, "Reliability Through Life..", Space Power Workshop 2007

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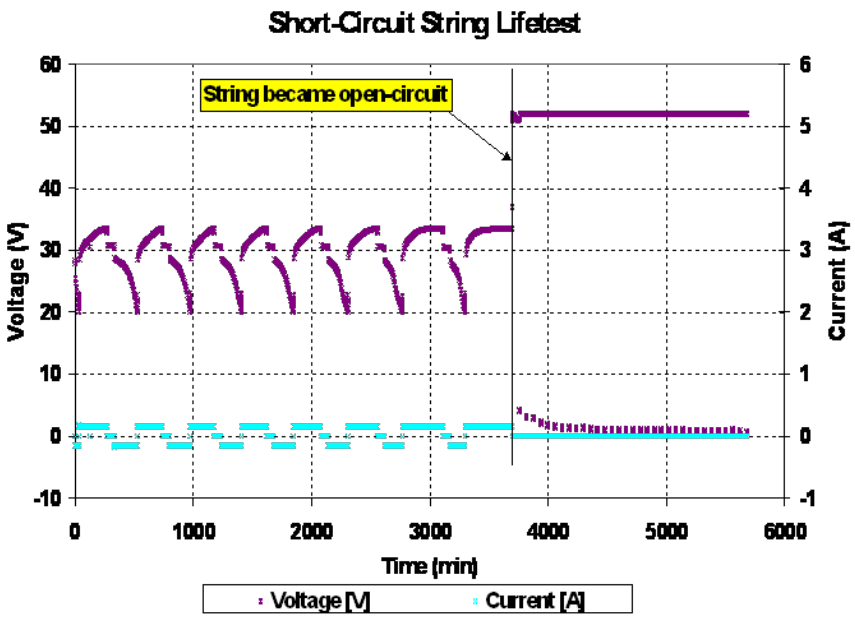
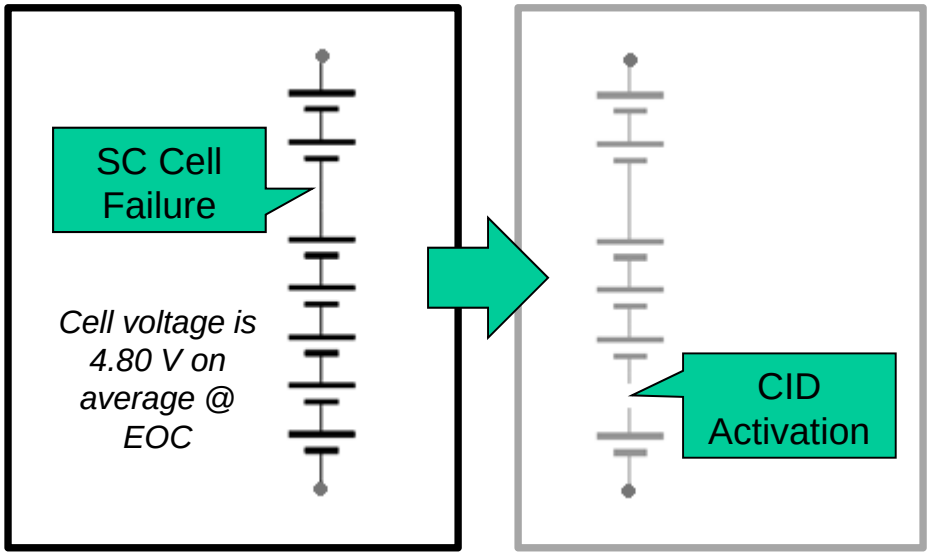
NASA GSFC – ABSL 60 Ah Life Test

- Post test examination of the previous case discovered a string with **a cell that failed short-circuit**
- This string was then isolated, equipped with cell voltage monitoring, and **cycled at 100% DOD**
- After 68 cycles, a CID in another cell of the string activated and **the string shut down safely without venting, fire, or other incident**





J. Neubauer, "Reliability Through Life..", Space Power Workshop 2007

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Questions to answer…

- Can you really balance cells passively?
- What happens if dispersion is introduced into an ABSL battery?
- Do all Li-Ion batteries work this way?

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HR Cycle Life Testing

- ABSL 18650HR Cell: high rate, space qualified & proven
- 8s block with individual cell voltage monitoring
- Medium Rate (~0.6C), High DOD (~100%) cycling
- Standard capacity measurement every 200 cycles

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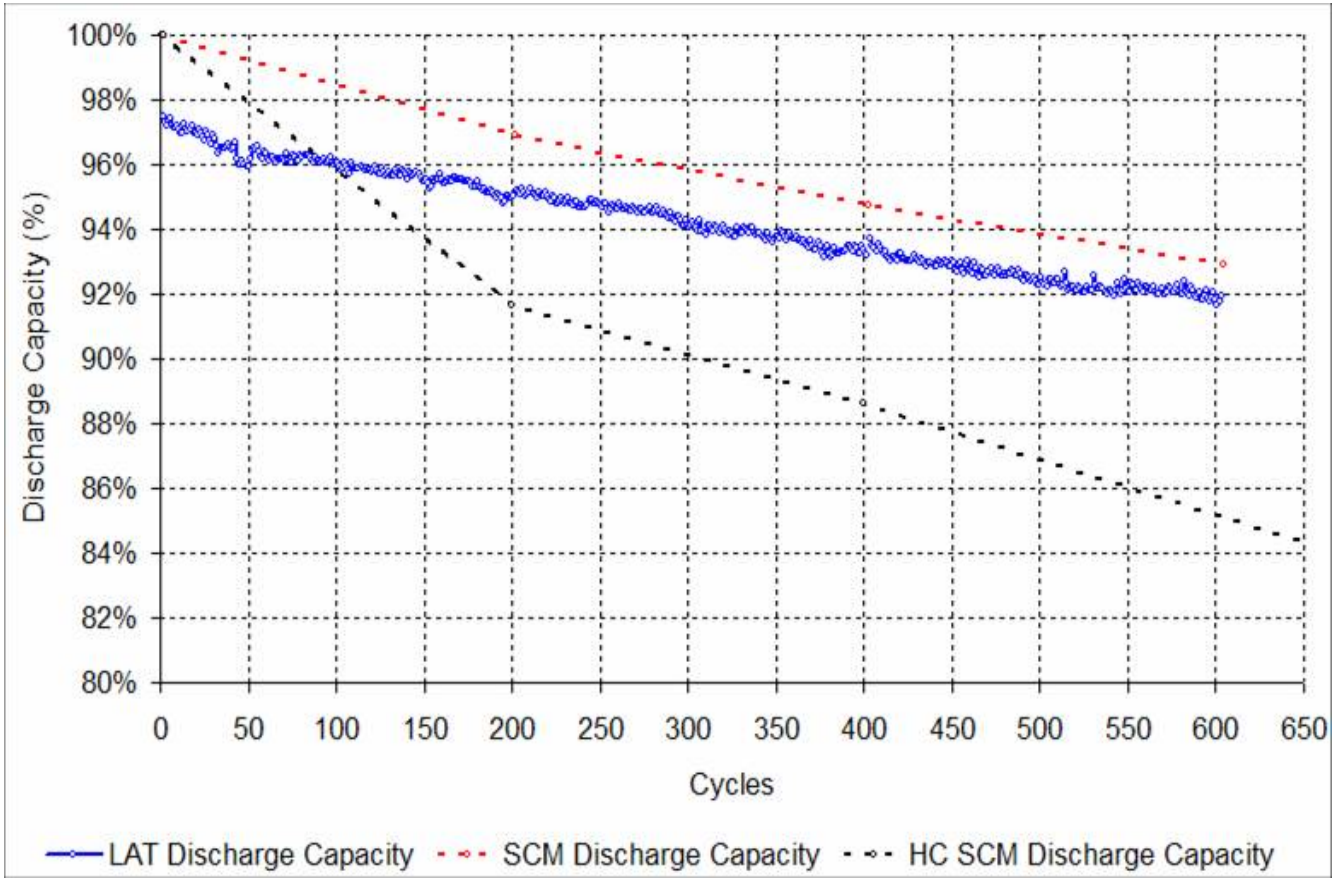
HR Capacity



- Capacity degradation is low and consistent.

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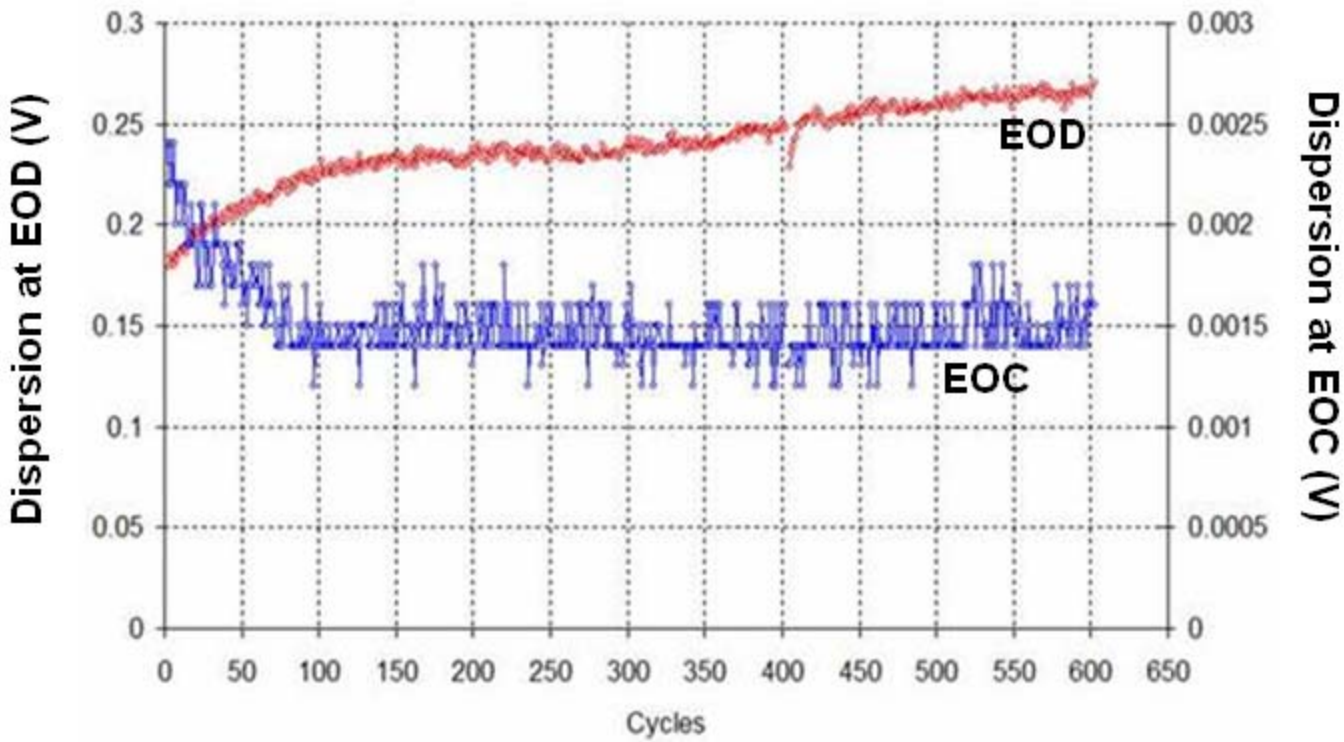
HR Dispersion



- EOCV dispersion holds steady at ~1.5 mV
- EODV dispersion growing slowly toward ~270 mV

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BC Cycle Life Testing

- **Exploratory testing** performed during assessment of new “BC” cell for use in future space programs
- 10s2p block with individual cell voltage monitoring
- **One cell shorted during build (string 1)**
- **High Rate (~1C), High DOD (~100%) cycling**
- Standard capacity measurement at cycle 100, 1100, 2100, …

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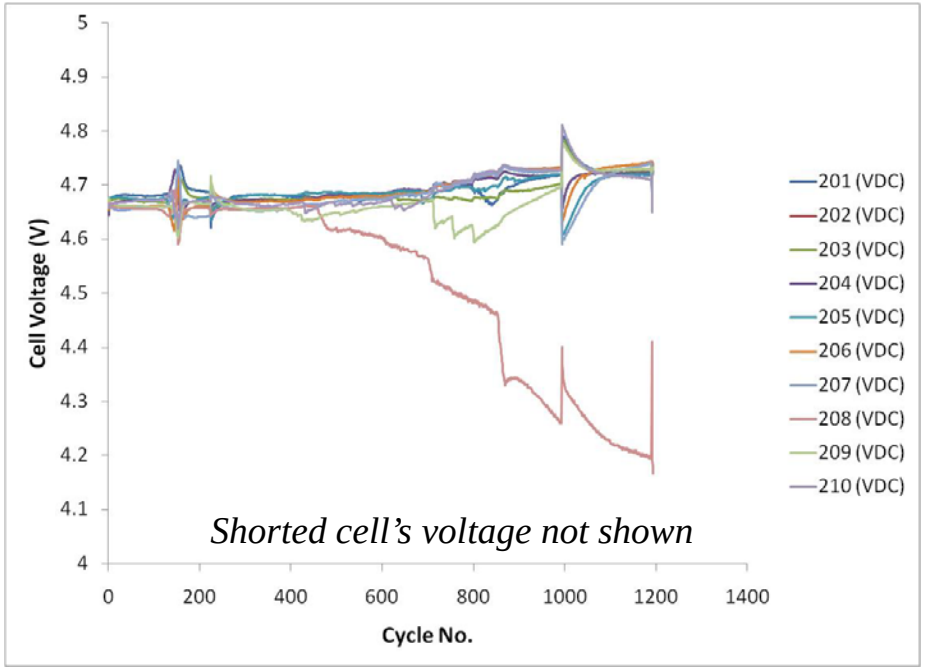
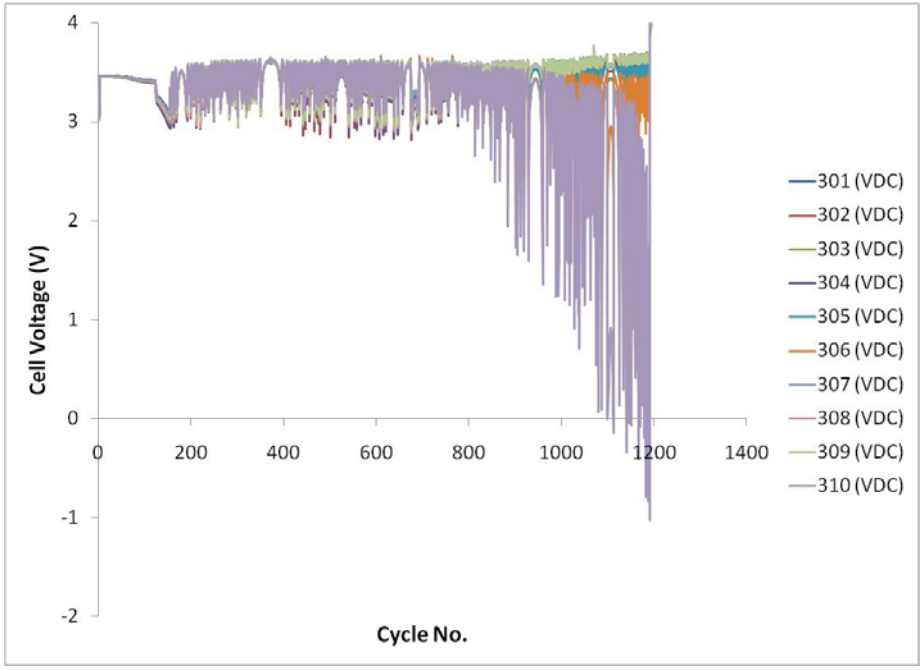
BC Cell Voltages

- String 1 EOCV's show high overcharge levels due to shorted cell, and one cell diverging considerably
- String 2 EODV's show high over-discharge of cell 10





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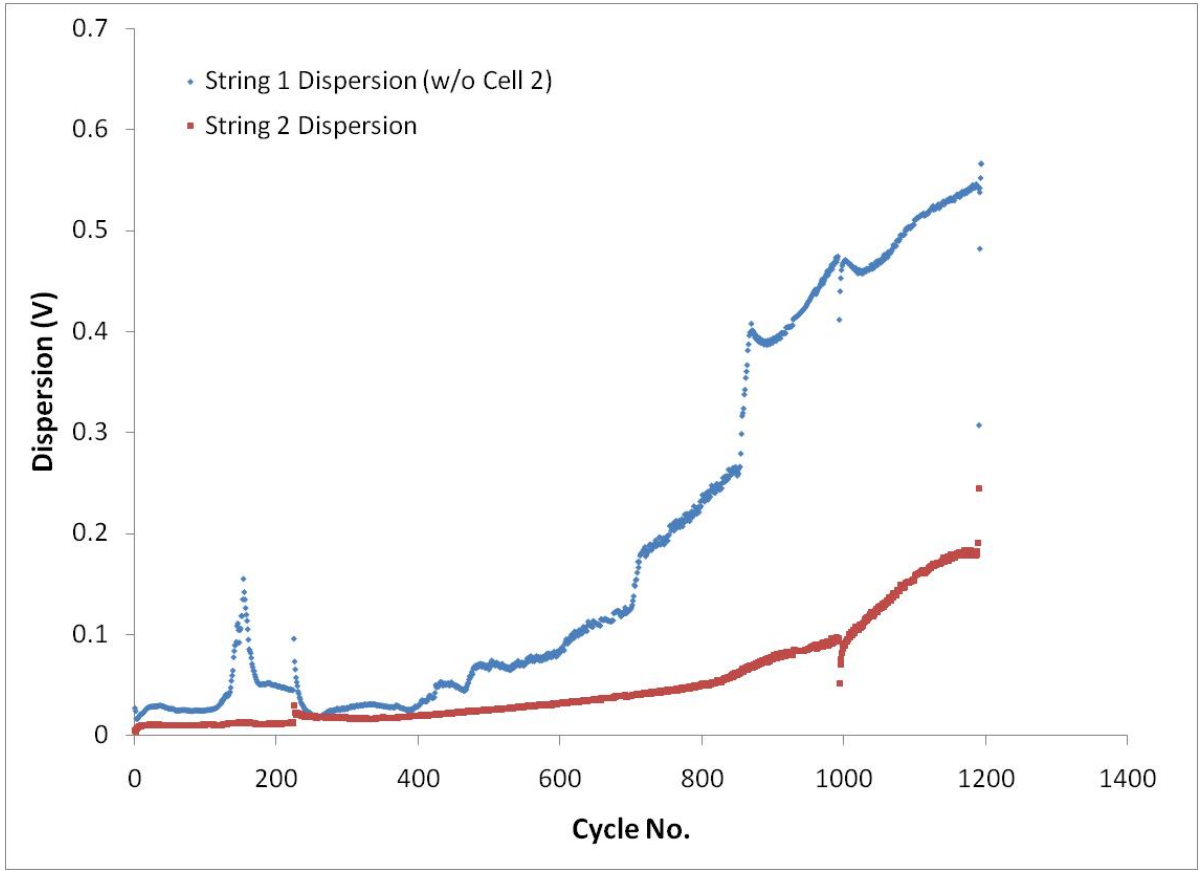
BC Dispersion @ EOC

- String 1 dispersion growth expected due to overcharge
- String 2 dispersion growth due to increasing rate?



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Effects of BC Dispersion

- After ~1200 cycles, at least one **CID activated in String 2**
- String 1 continued to operate, but due to **very high resistance** almost no capacity was deliverable on discharge and test was stopped
- This test showed the battery capable of operating with dispersion and **safely shutting down after substantial abuse**
- **Moving Forward:** Perform a similar life test using multiple screening / matching algorithms to investigate dispersion under nominal operating conditions

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A123 Cycle Life Testing

- **Exploratory testing** performed during assessment on **A123 Nano-Phosphate cell** for use in future space programs
- 8s2p block with individual cell voltage monitoring
- **Different experimental matching algorithms on each string**
- **High Rate (~1.5C), High DOD (~100%) cycling**
- Standard capacity measurement (SCM) at cycle 100, 1100, 2100, …

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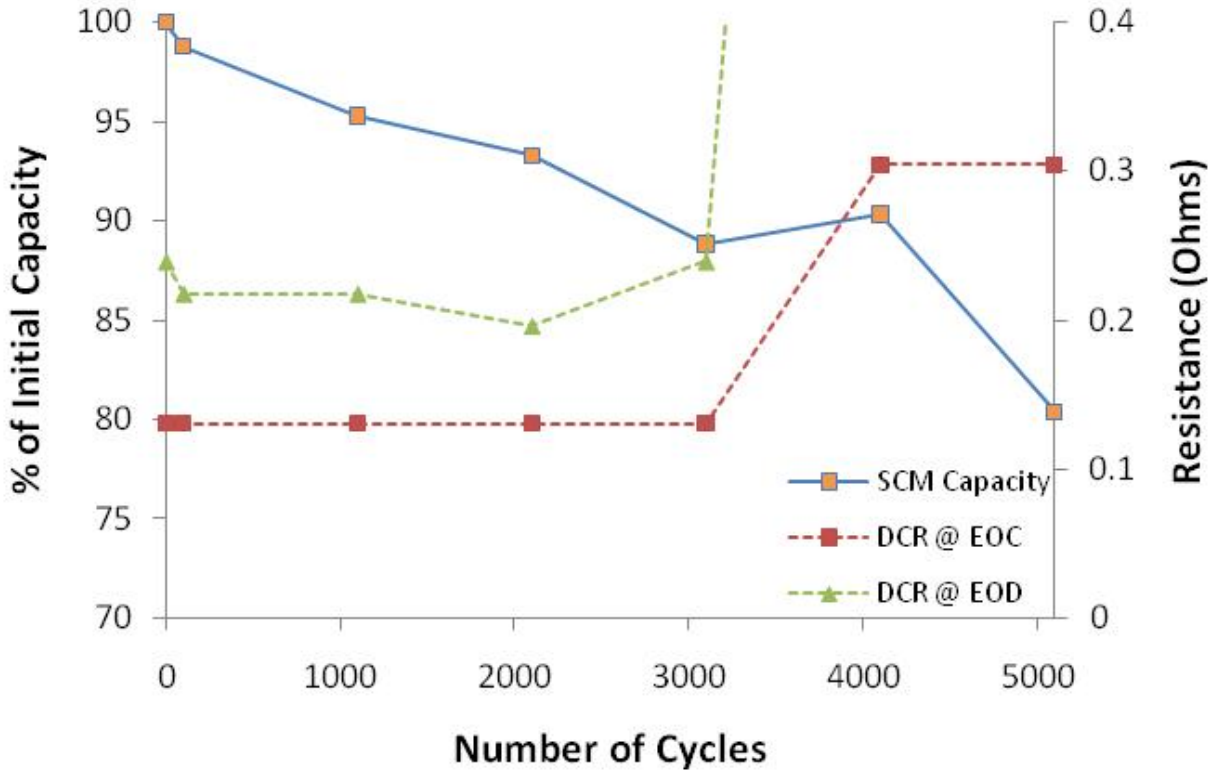
A123 SCM Capacity & Resistance

- Capacity degradation ~20% over first 4,100 cycles
- Significant resistance increase at last SCM
- **Degradation at last two time stamps due to off-nominal behavior**



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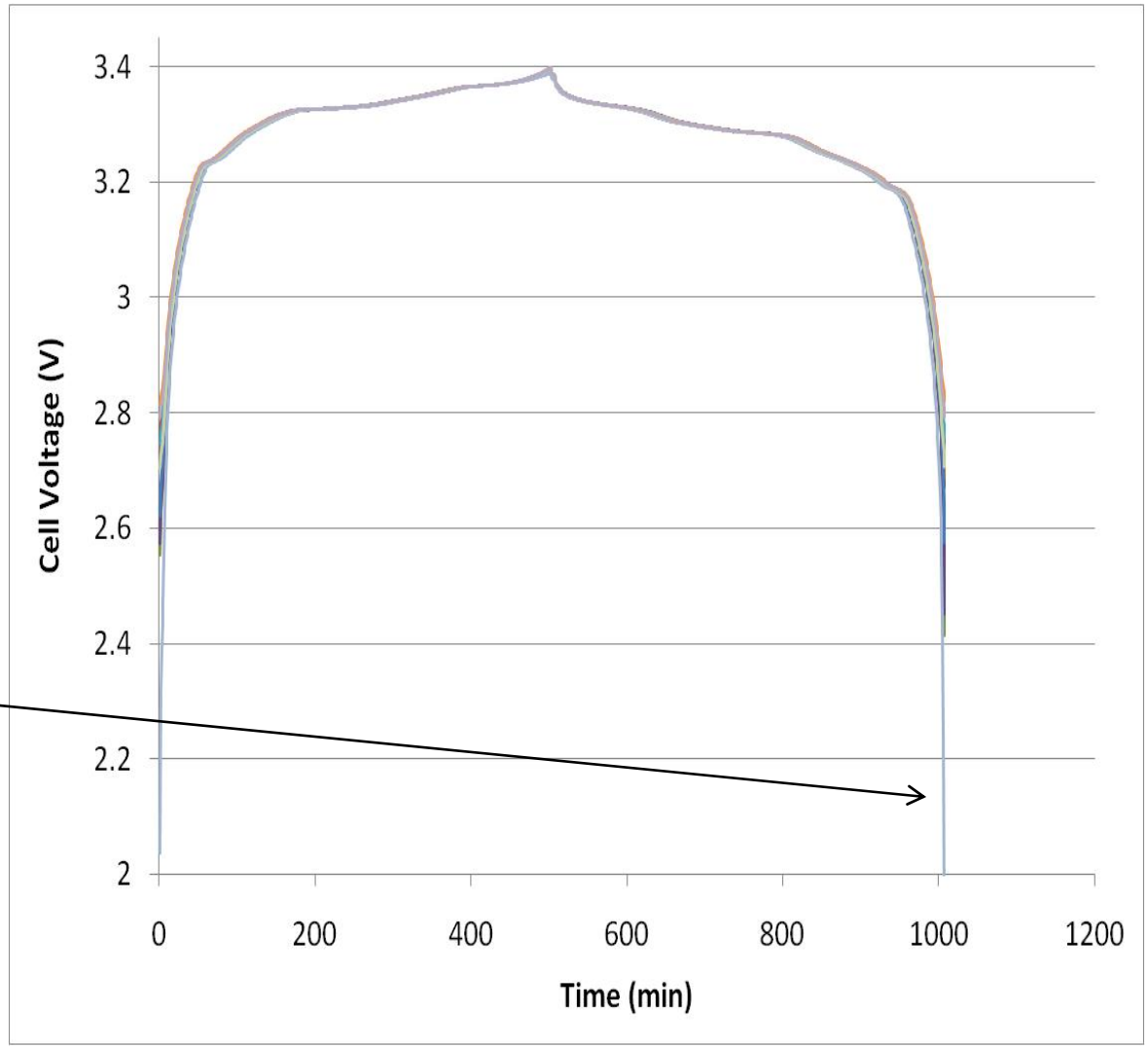
Cell Voltages: SCM @ 1100 cycles

- String 1 dispersion is very low until last few % of discharge
- String 2 is similar, but **one cell shows excessively low voltage**



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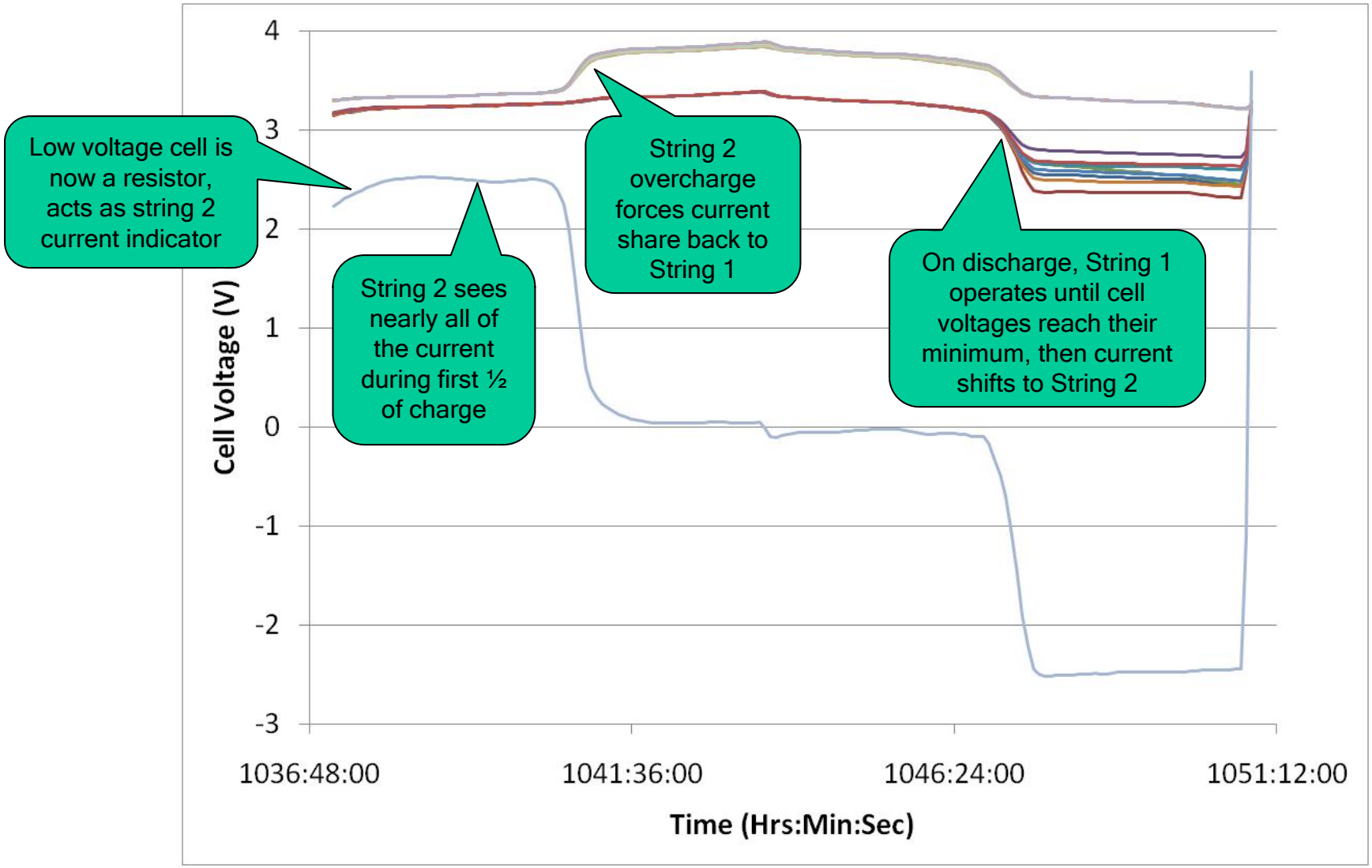
Cell Voltages: SCM @ 5100 cycles



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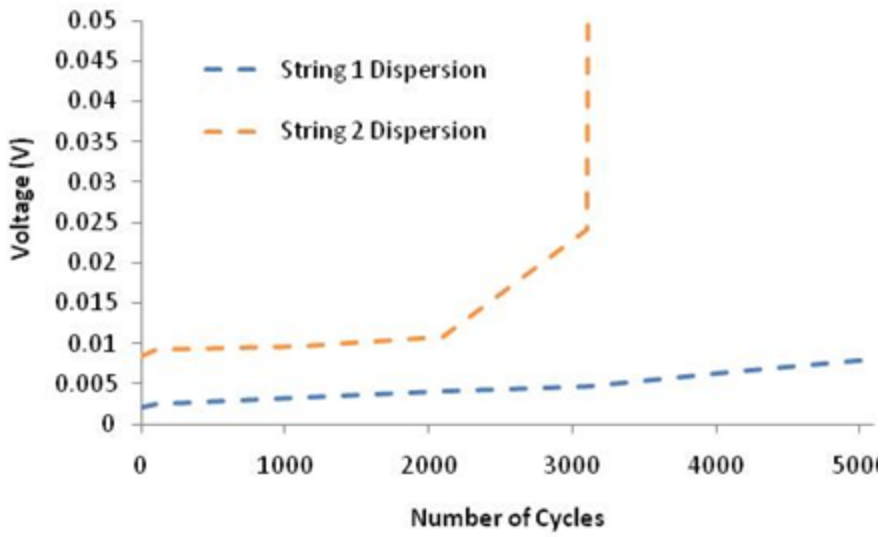
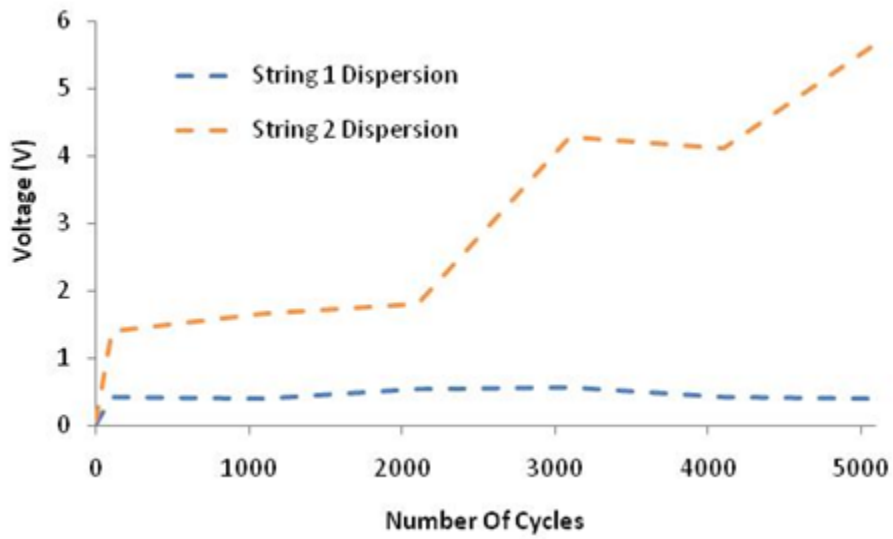
A123 Dispersion

EOC



EOD



- Despite operating at ~3C for the past ~1,300 cycles, **String 1 dispersion is very steady and very low** (<10 mV at EOC)
- Despite the loss of a cell and continual overcharge, **String 2 still provides considerable capacity in an SCM**
- ***Despite all this, the battery continues to operate safely!***
- **Moving Forward:** Refine matching algorithms for additional testing

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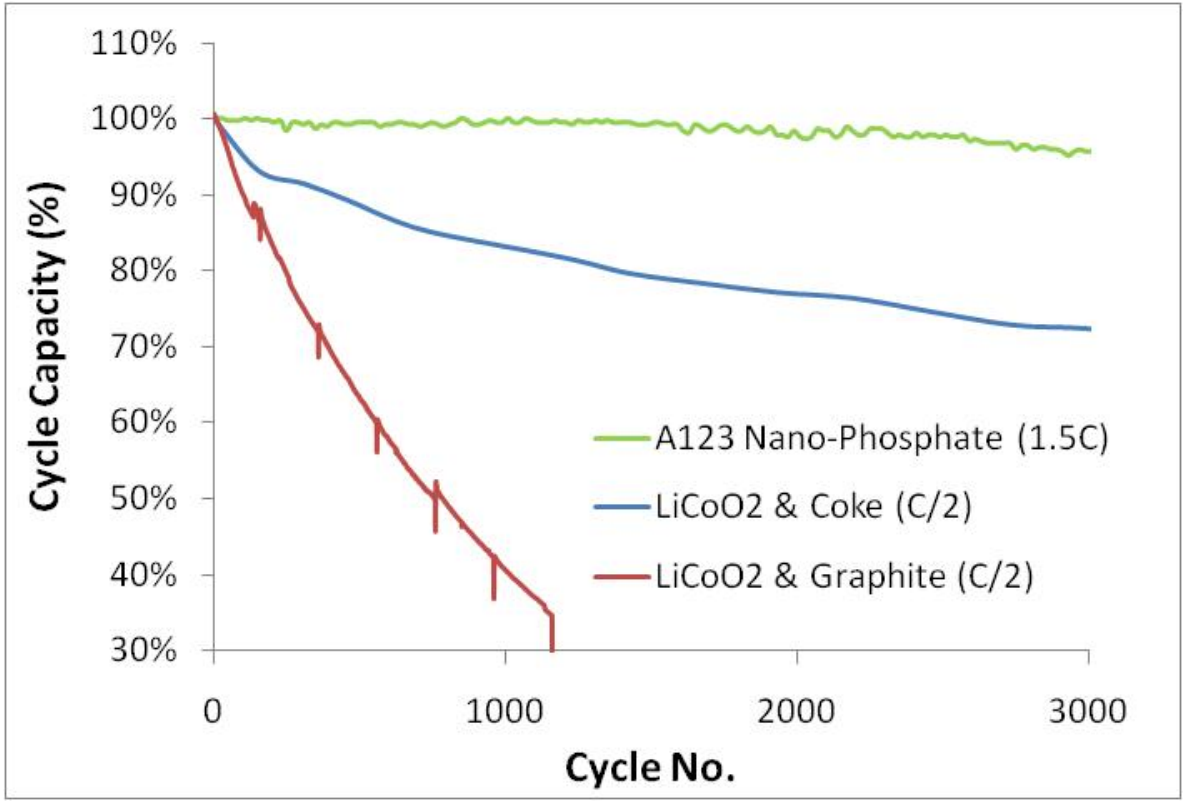
A123 Cycle Capacity

- Cycle capacity shows **excellent long term performance** when operated at **high DOD** when compared to LiCoO2 chemistries, even when operated at **3x higher rates**



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Questions answered…

- **Can ABSL really balance cells passively?**
  - Passive architectures have been **proven to work on the HC cell** for keeping dispersion extremely low for very long missions (>7 yrs and 70,000 cycles)
- **What happens if dispersion is introduced?**
  - This same passive combination has also been **proven extremely robust and capable of safely handling dispersion** if brought about by off-nominal conditions
- **Do all Li-Ion batteries work this way?**
  - Studies on multiple high quality Li-Ion cells show that **some cell models are better suited to passive topologies than others**
  - These studies also show that cell screening and matching processes often offer a means to improve passive balancing performance

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