

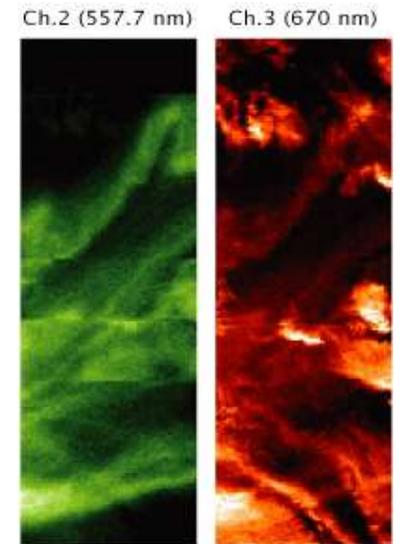
The REIMEI Satellite Li-ion Batteries after more than 13 Years of Operation

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- 2) The Graduate University of Advanced Studies (SOKENDAI)
- 3) German Aerospace Center (DLR)
- 4) Helmholtz Institute Ulm
- 5) National Institute of Advanced Industrial Science and Technology
- 6) Nagaoka University of Technology

REIMEI = 「黎明(れいめい)」 = Dawn

- REIMEI had three cameras for the aurora observation with different wave length.
- It was launched in August, 2005, and injected along the low-earth-polar orbit.

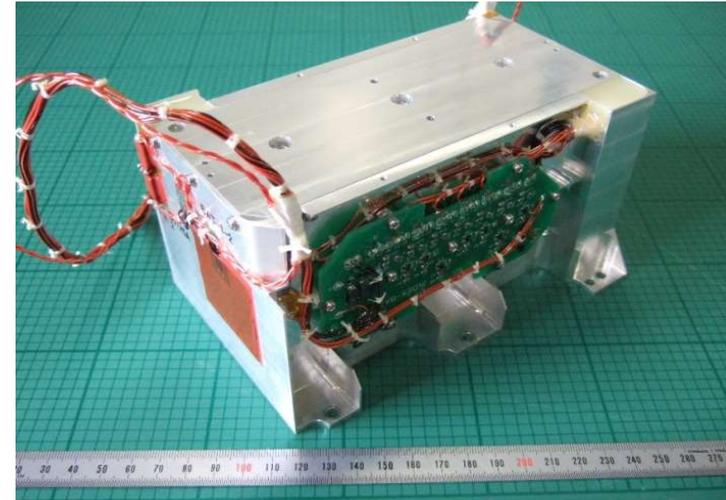


Lithium-Ion cell and battery Specifications



Lithium-Ion pouch cell

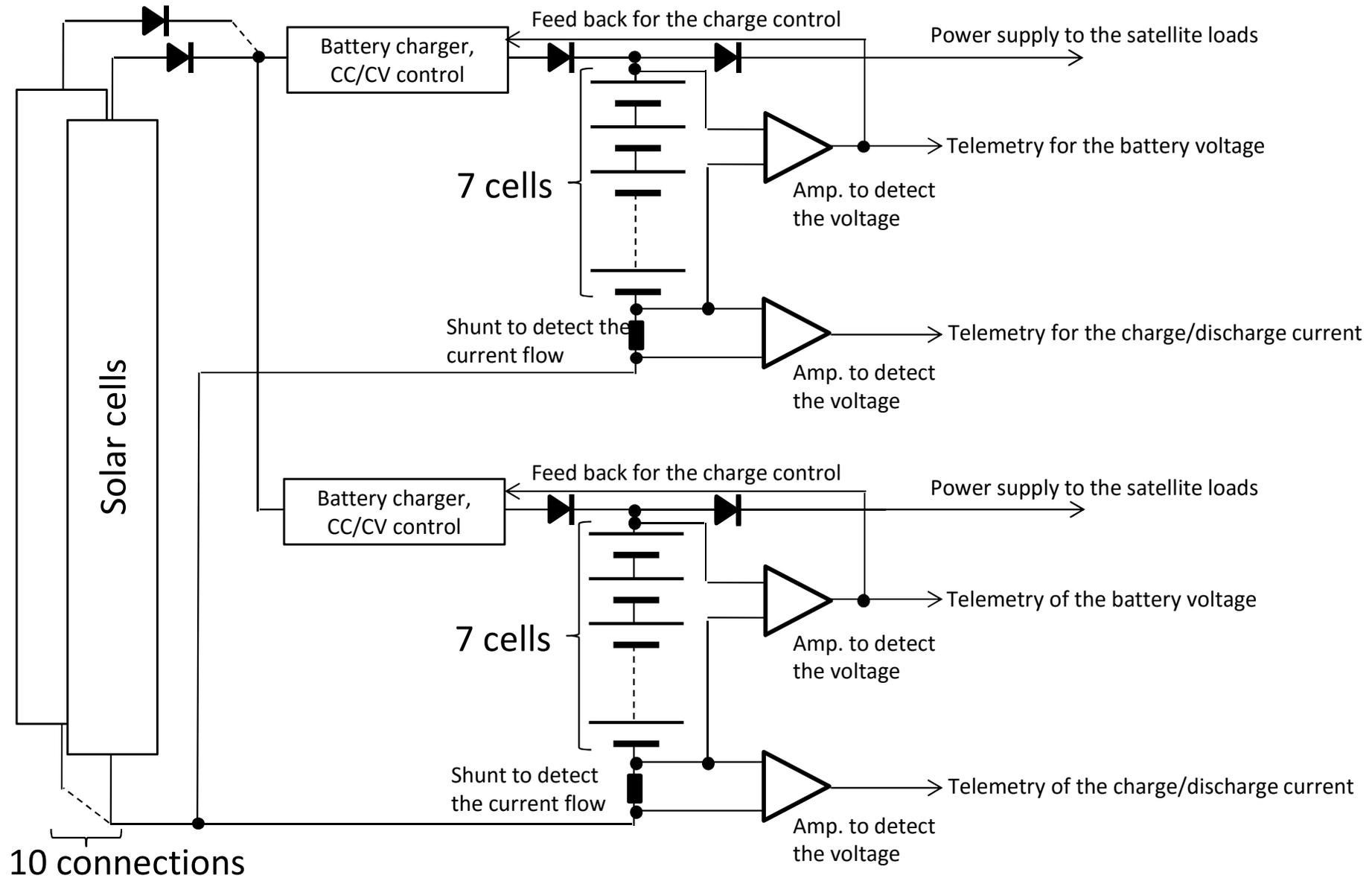
Electrode	Positive	LiMn_2O_4
	Negative	Graphite
Rated Capacity		3 Ah
Weight		75 g
Dimension		145 x 80 x 4 mm
Energy Density	Mass	158 Wh/kg
	Volume	340 Wh/L
Charge Voltage		4.1 V (4.2 V)
Lower Limited Voltage		3.0 V

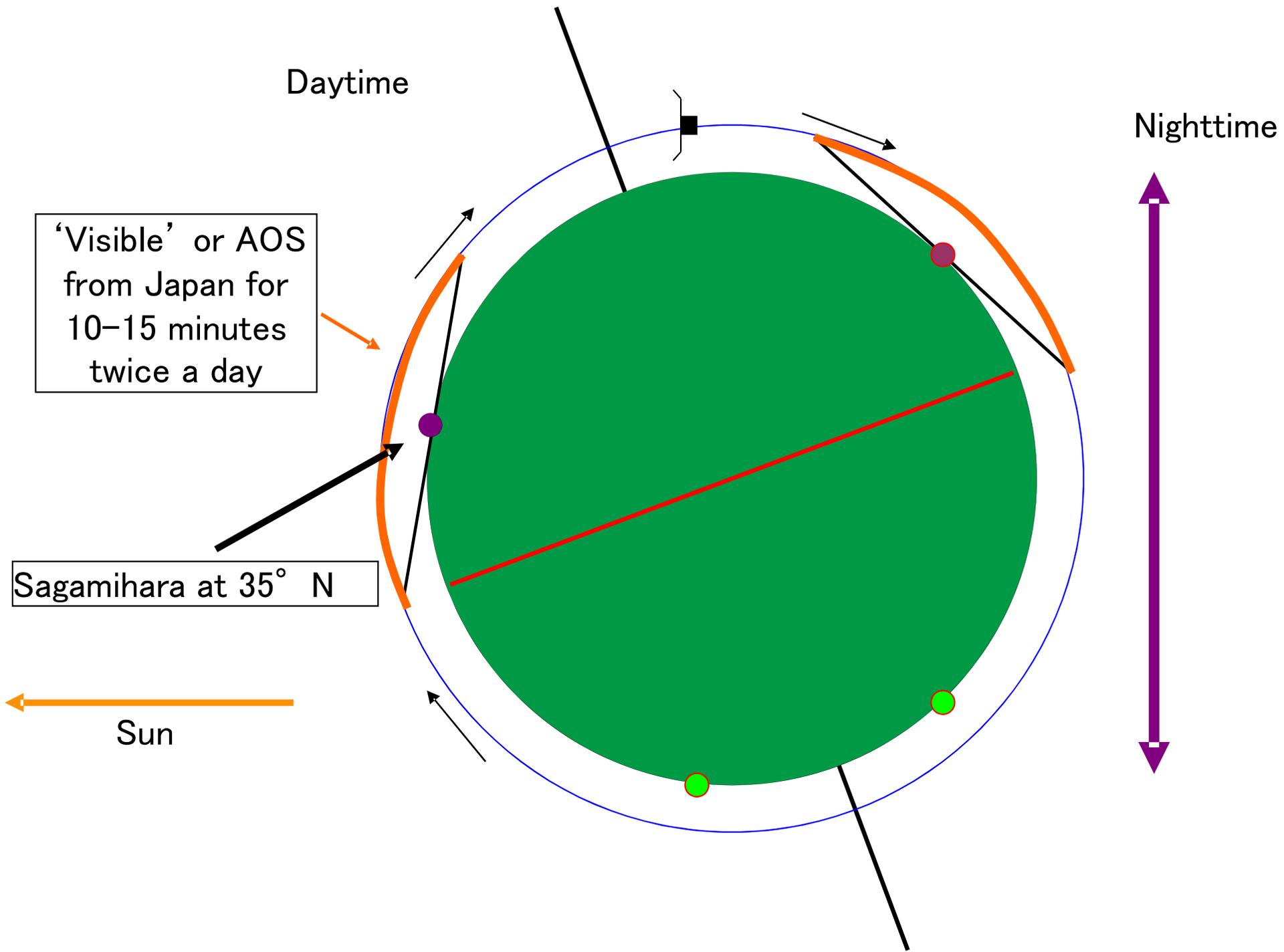


Lithium-Ion battery

Configuration	7 series of the cells 2 module installed to the battery	
Potting Material	Epoxy Resin	
Case Material	Al	
Dimension	$168 \times 102 \times 96 \text{ mm}^3$	
Weight	2.42 kg	
Energy Density	Weight	70 Wh/kg
	Volume	102.2 Wh/L_3

Block diagram of the electrical power subsystem for 'REIMEI'.



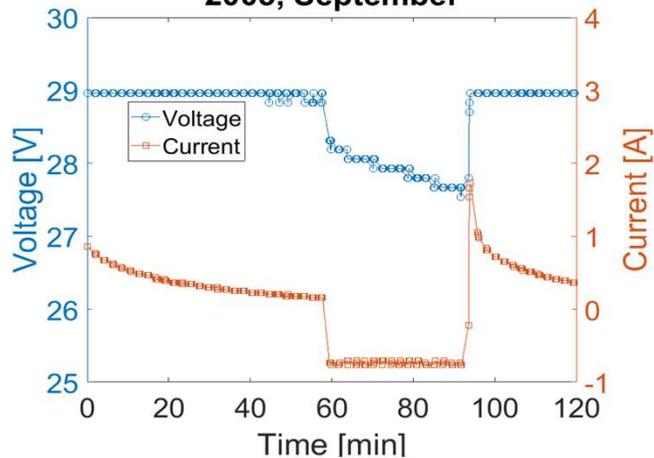


Battery Operation

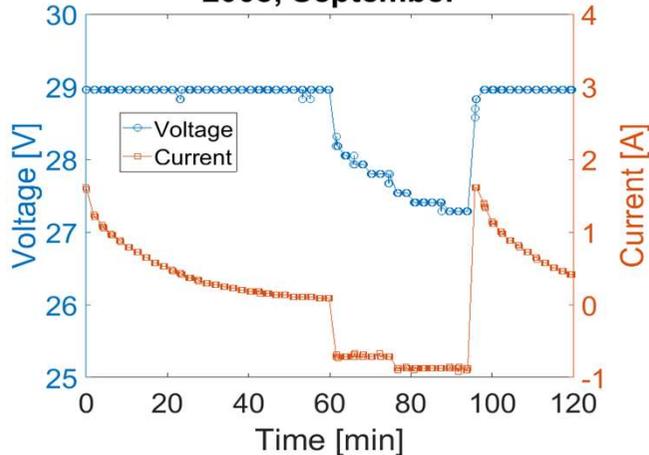
- 15 - 16 cycles a day
 - 1 cycle: charge 60 min. / discharge: 35 min.
 - DOD = 10~20 %
 - Charge by 1.5 A.
 - CC-CV charge : 4.10 V/cell (V2 mode),
or 4.20 V/cell (V1 mode).
 - Discharge rate is less than 0.5 C
 - Temperature controlled between 19 and 22 °C.
- **Over 12 years** has passed
 - Over 60,000 cycles

Battery Telemetry data

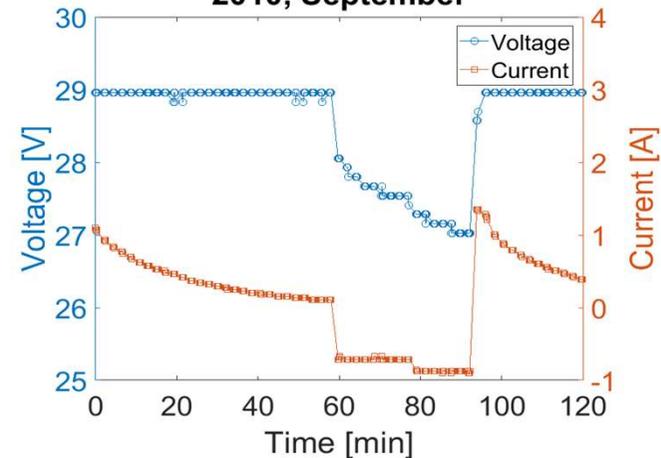
2005, September



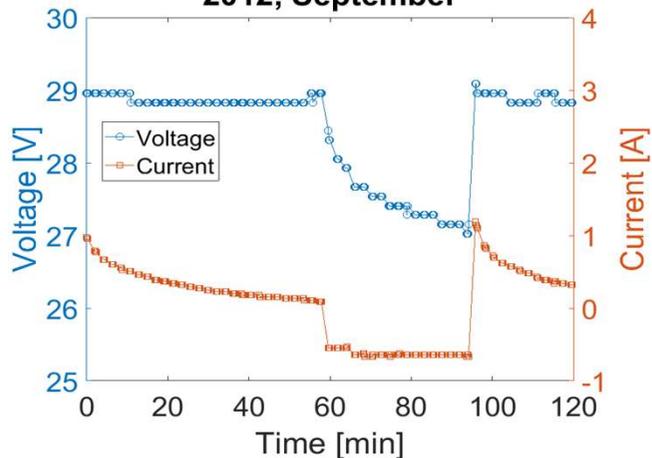
2008, September



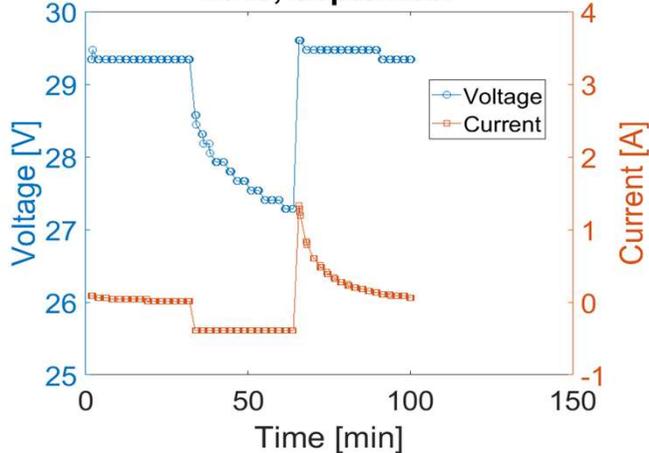
2010, September



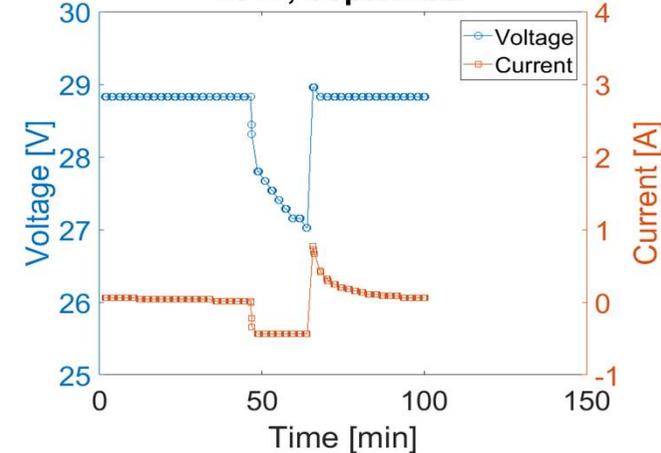
2012, September



2015, September



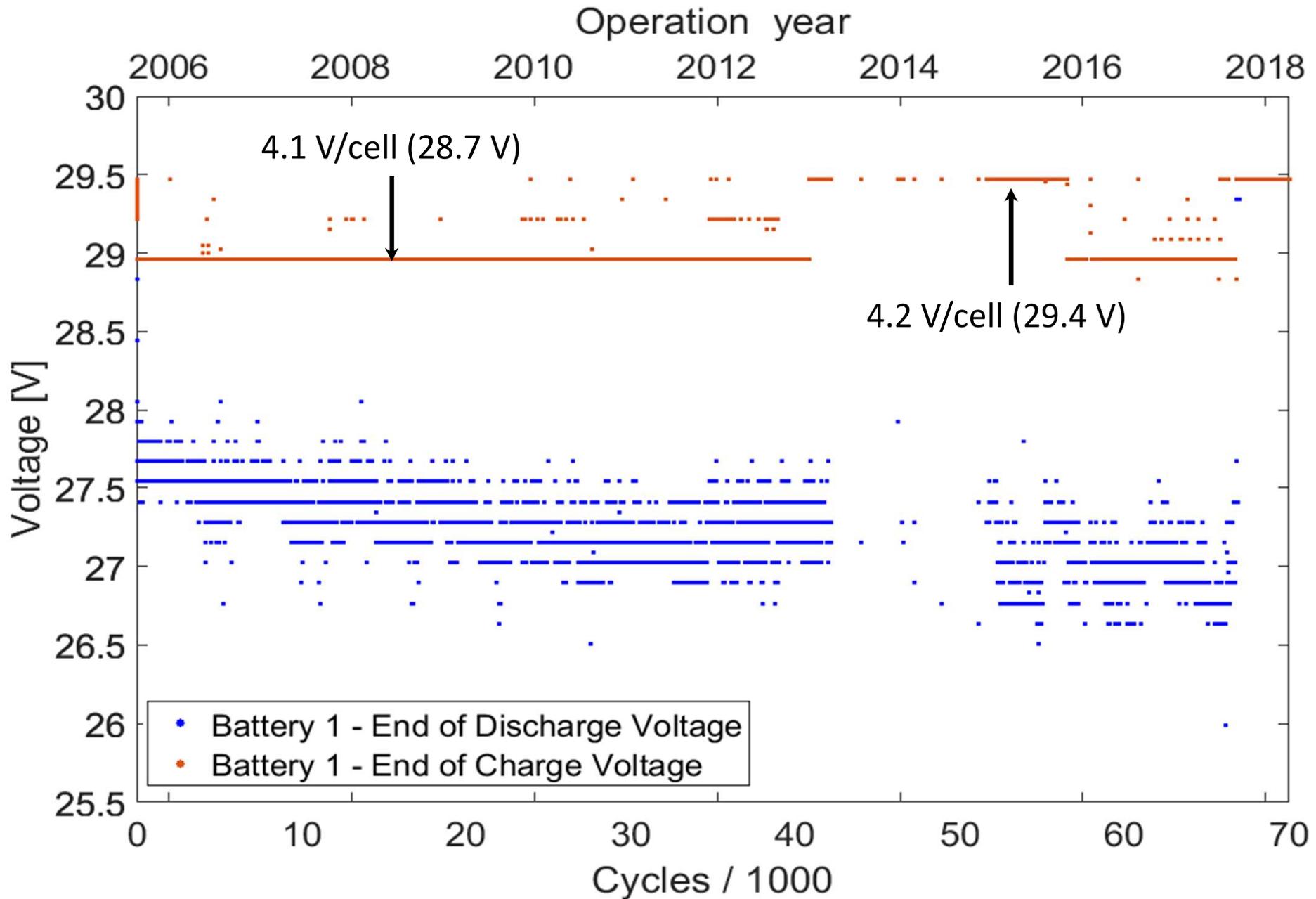
2017, September



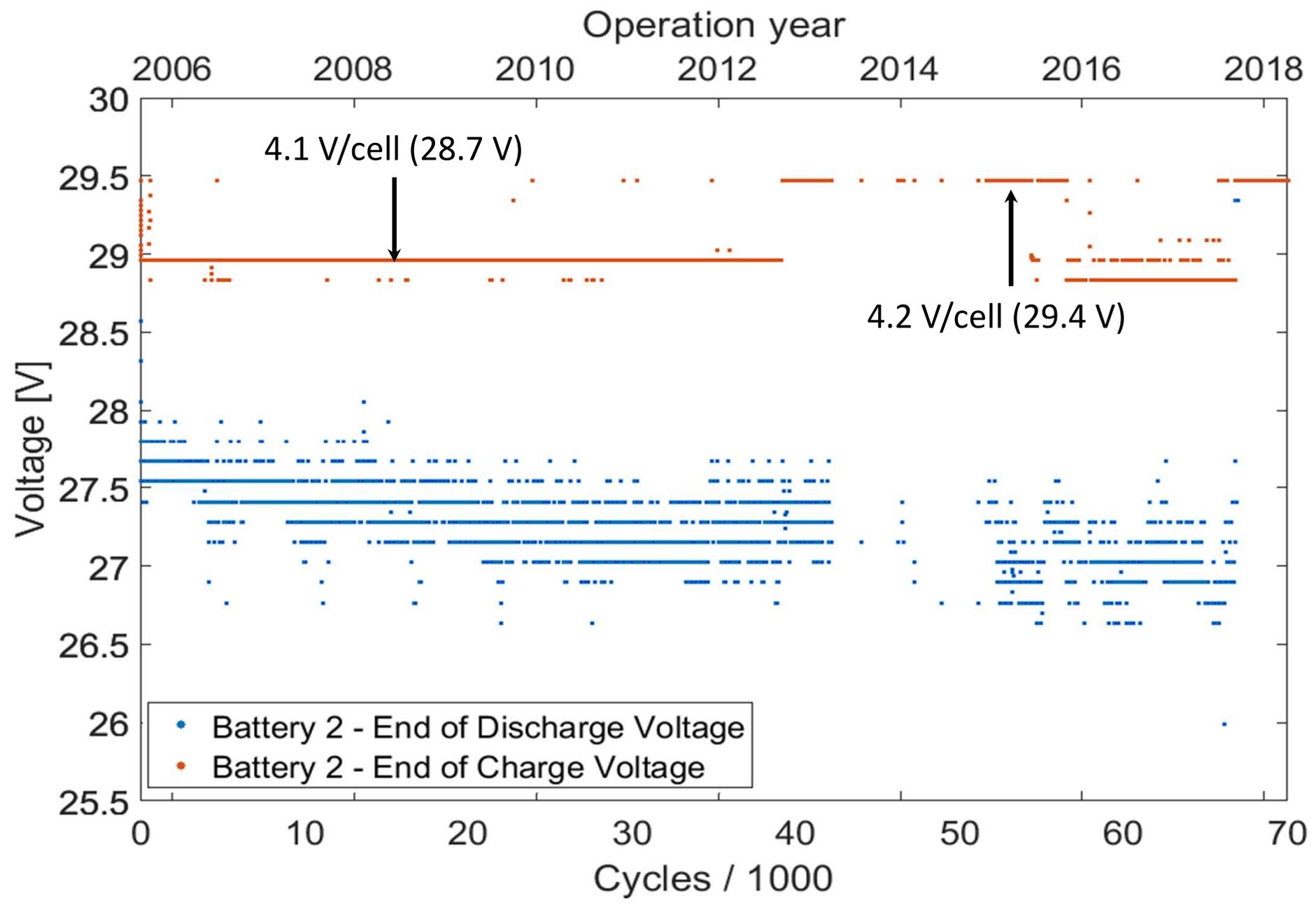
REIMEI's Battery

End of Discharge Voltage

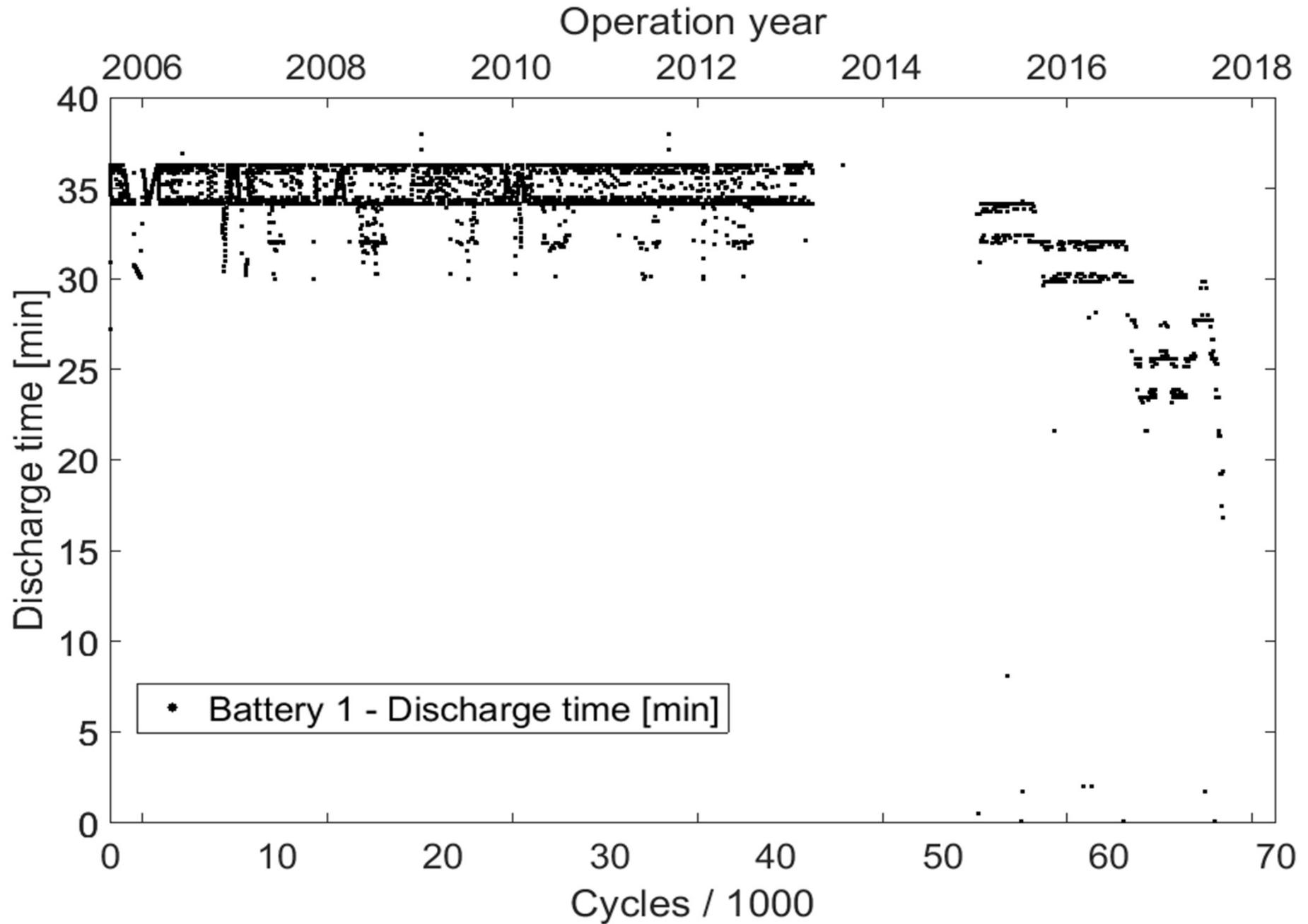
End of Discharge Voltage and End of Charge Voltage BATTERY 1



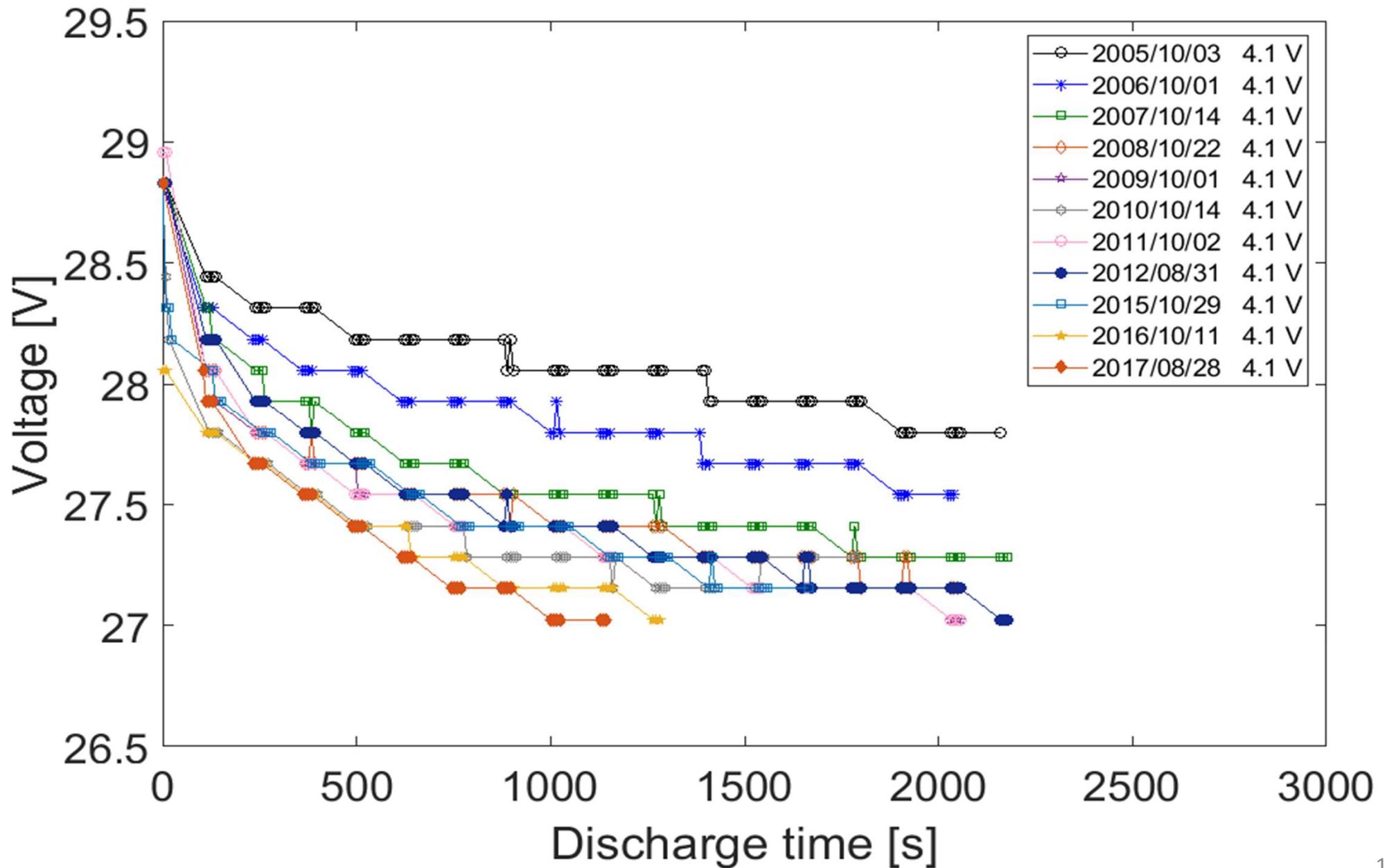
End of Discharge Voltage and End of Charge Voltage BATTERY 2



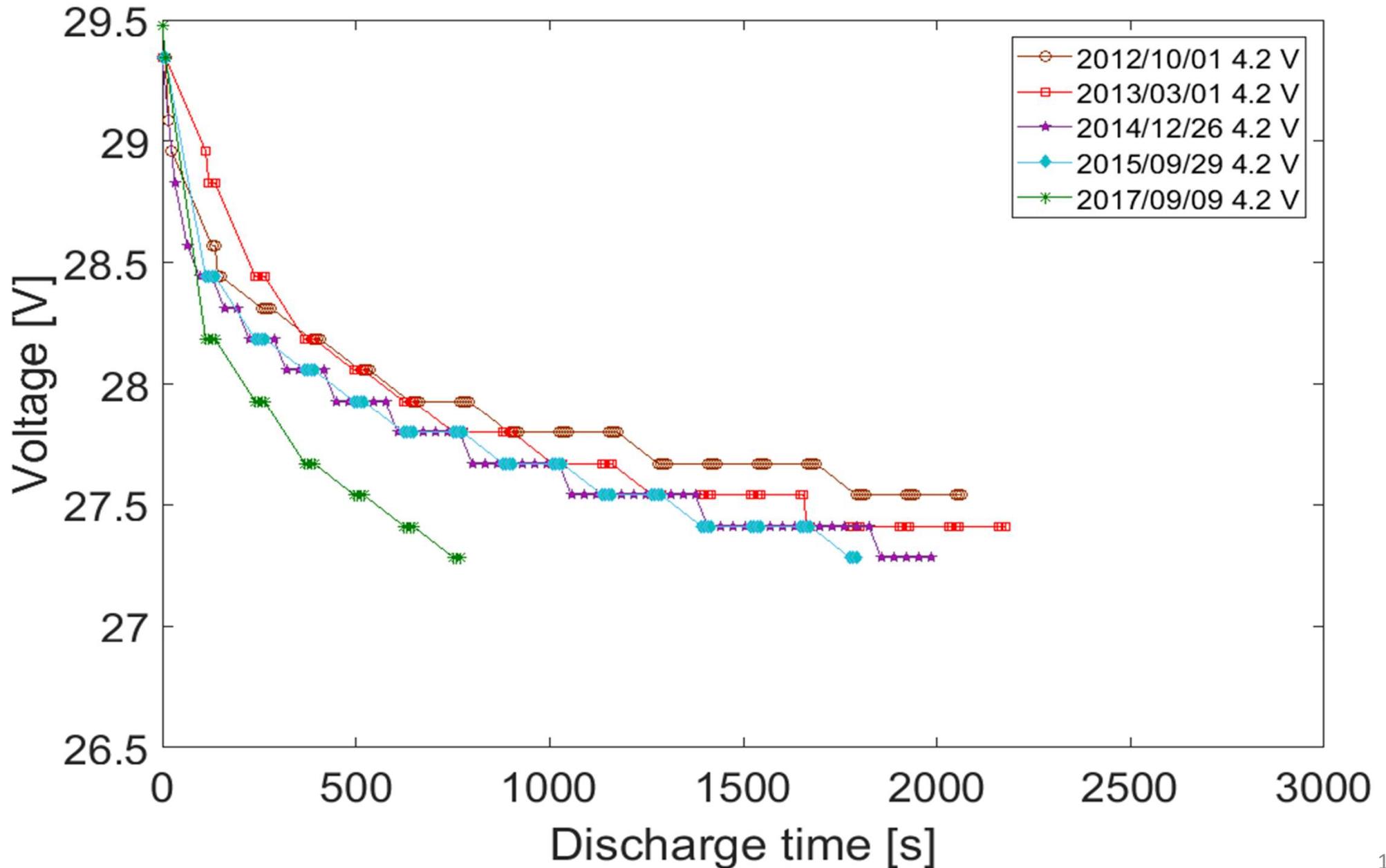
BATTERY 1 Discharge Time



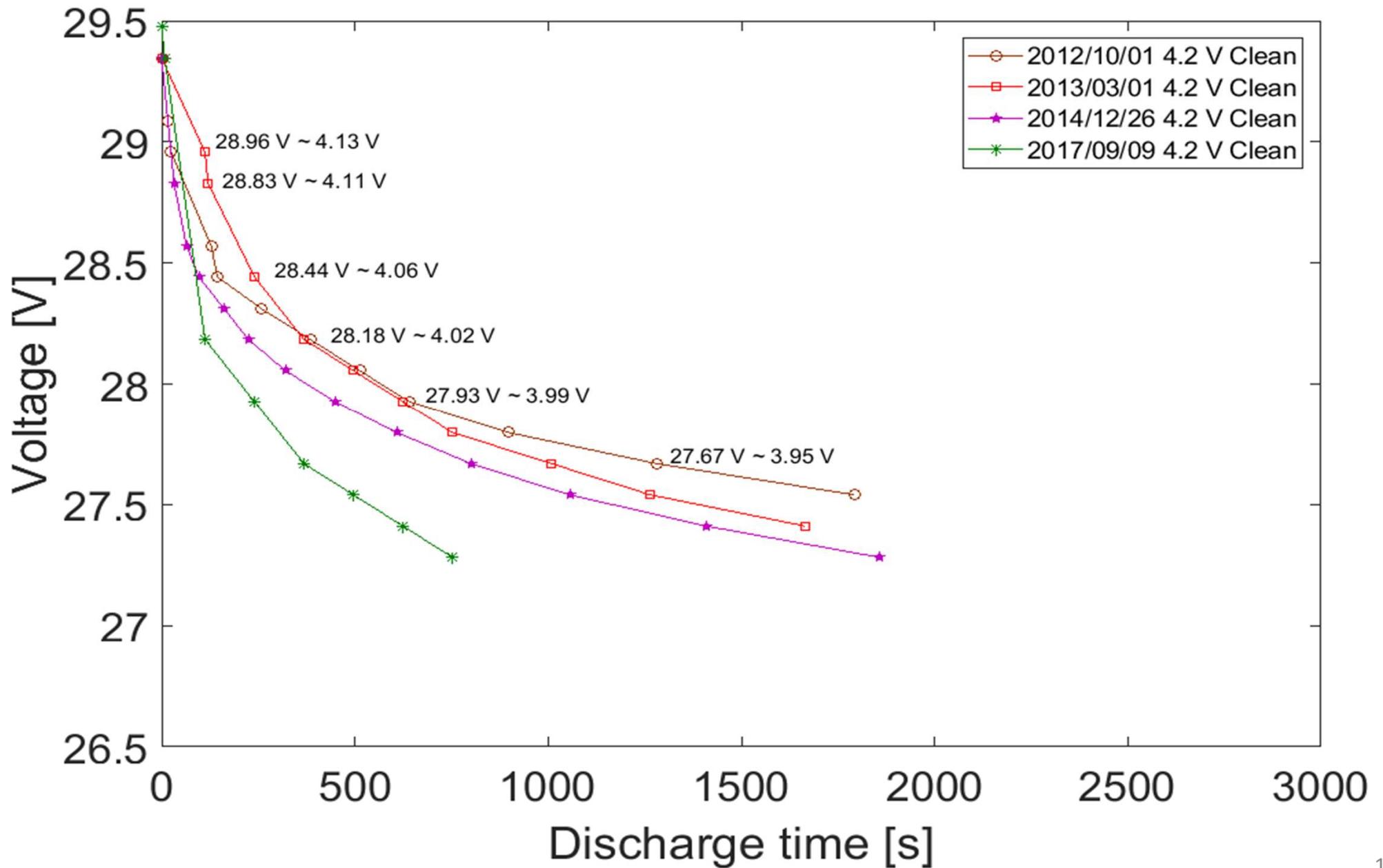
Discharge Curves from REIMEI Telemetry data



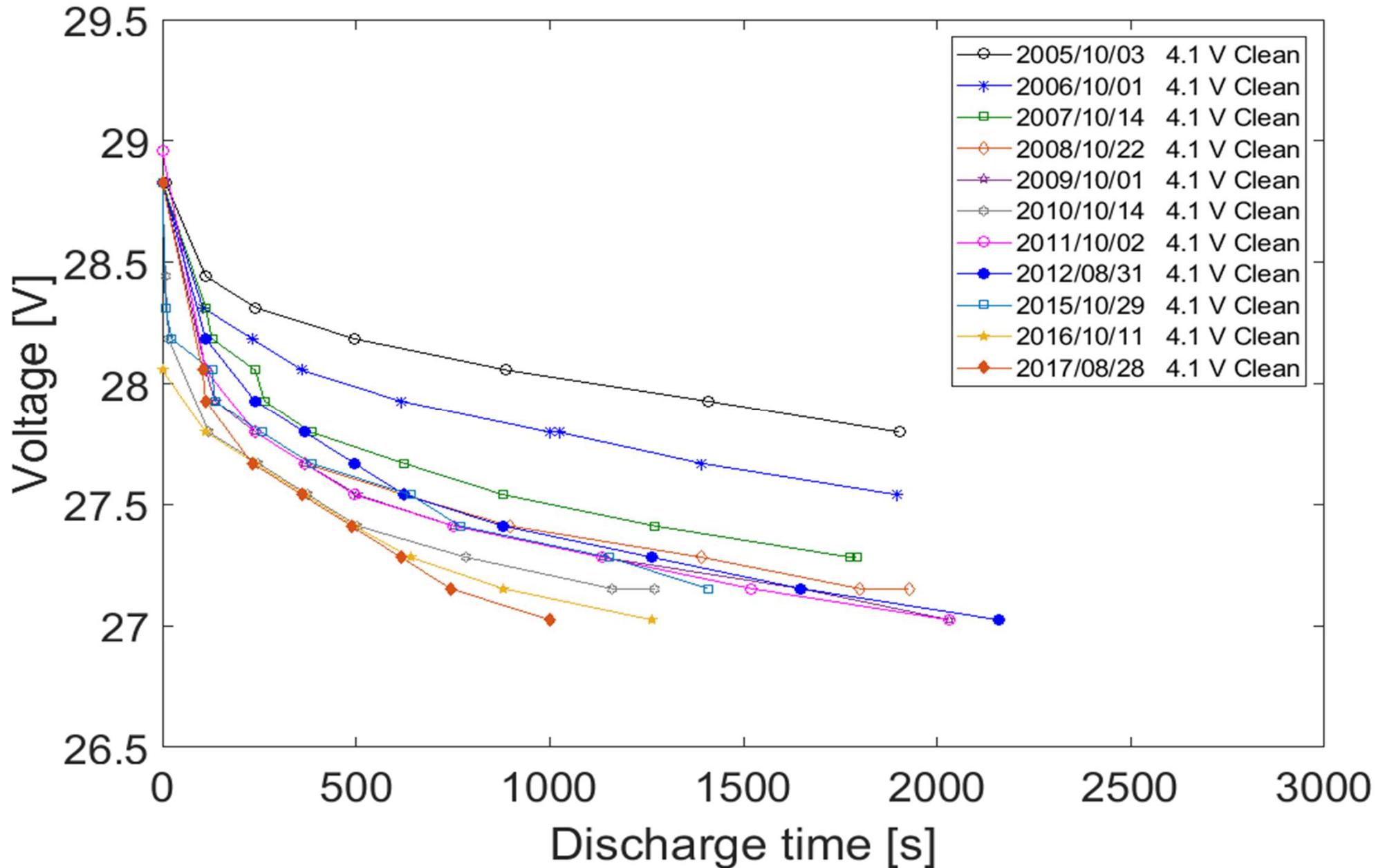
Discharge Curves from REIMEI Telemetry data



Discharge Curves from REIMEI Telemetry data

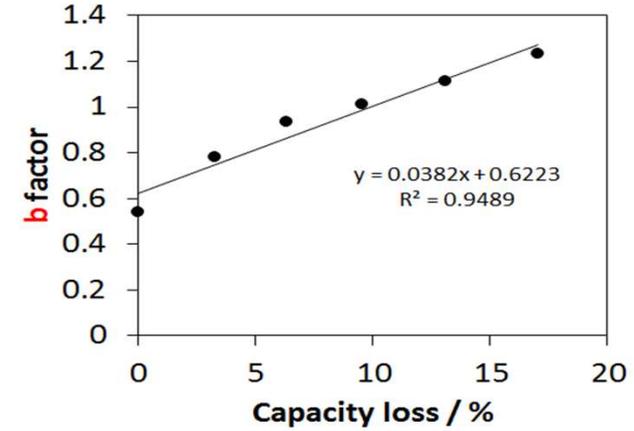
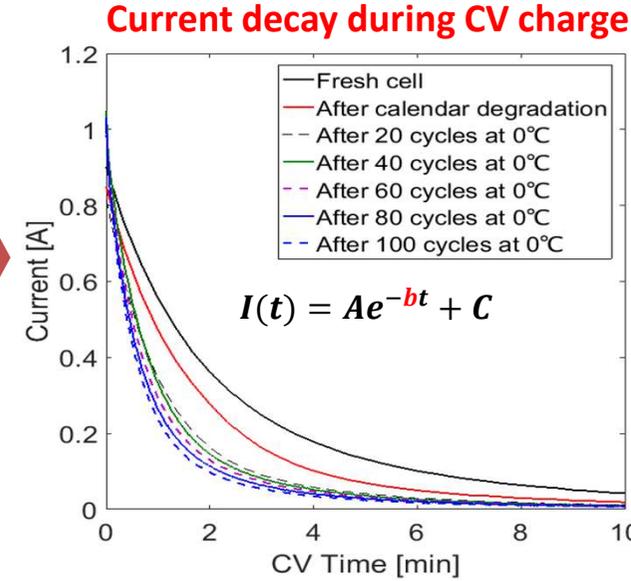
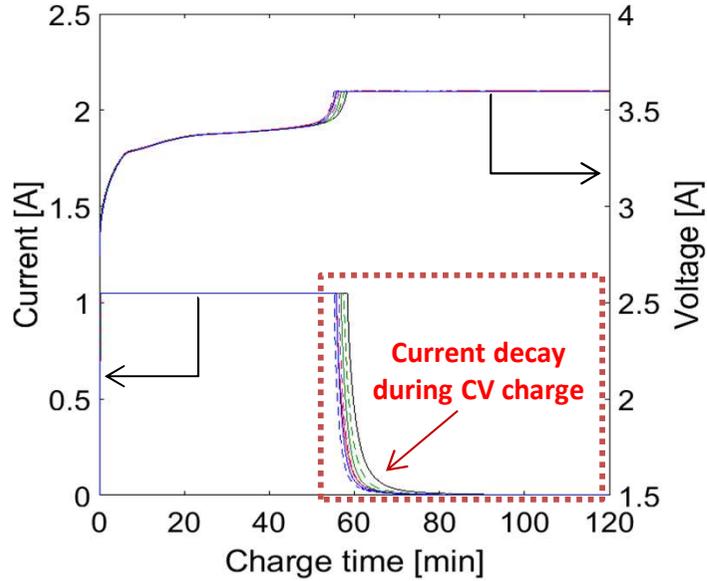


Discharge Curves from REIMEI Telemetry data

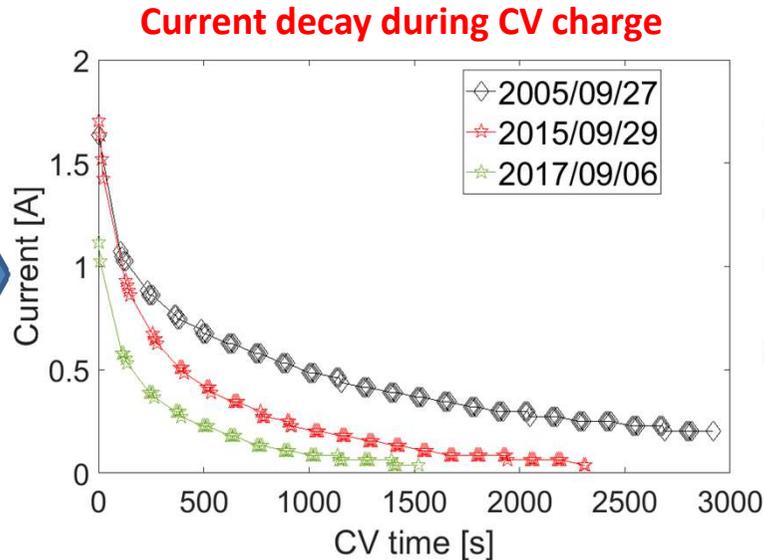
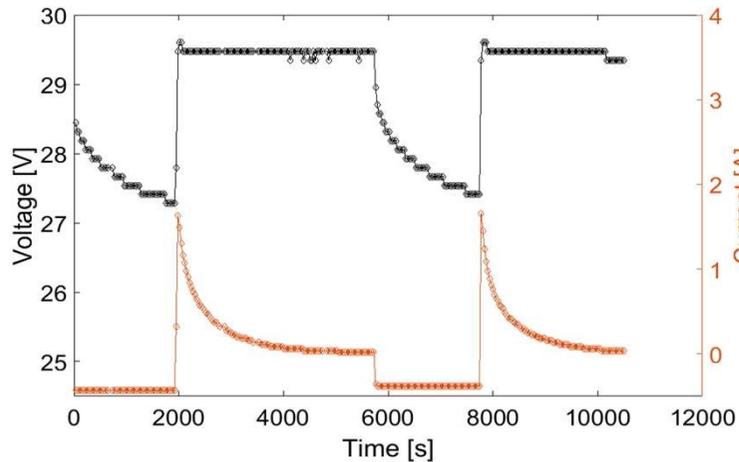


State of Health Estimation for Li-ion Batteries

Experimental Data



Telemetry data from REIMEI Satellite



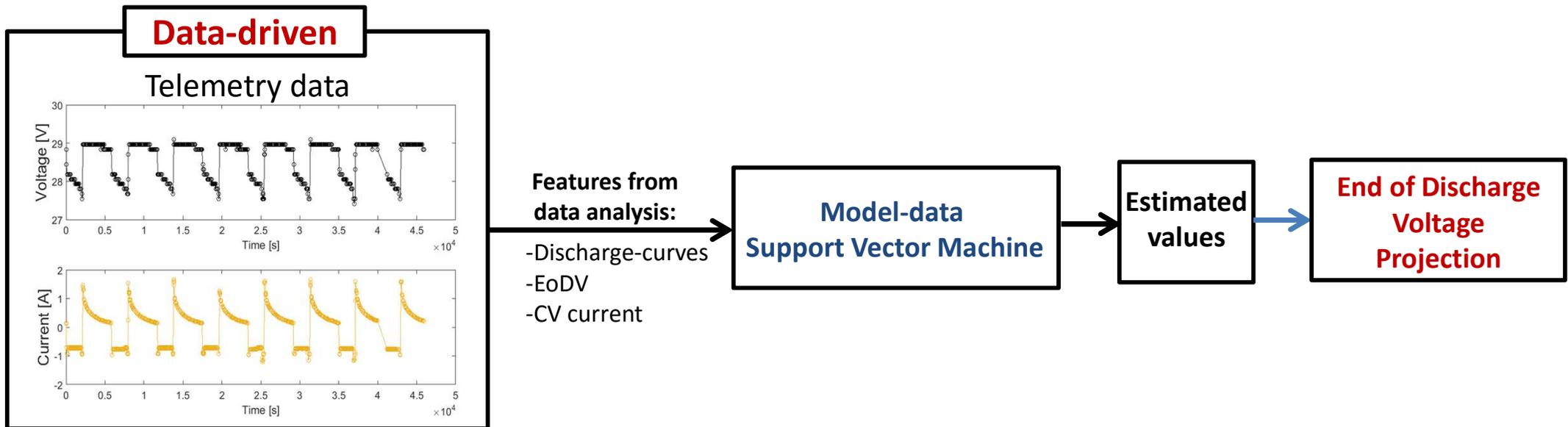
September, 2017
Apparent Capacity loss
for REIMEI Battery
Approx. 10 %

End of Discharge Voltage Prediction

-Prediction Model- Gaussian-Support Vector Machine

Support Vector Machine is a machine learning tool for classification and regression. This regression is considered a nonparametric technique because it relies on kernel functions.

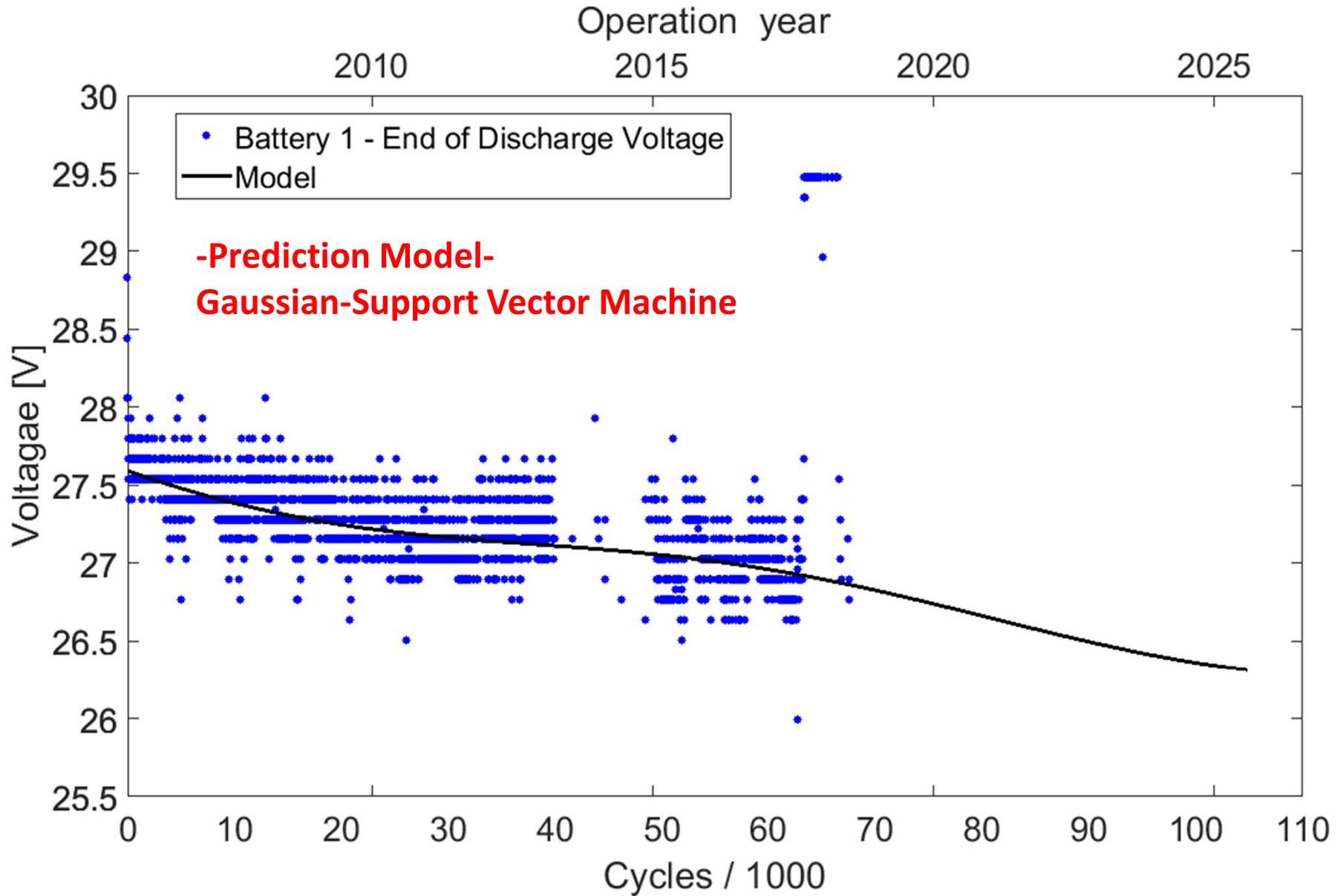
- The prediction model was obtained using the Matlab Statistics and Machine Learning Toolbox



Reference:

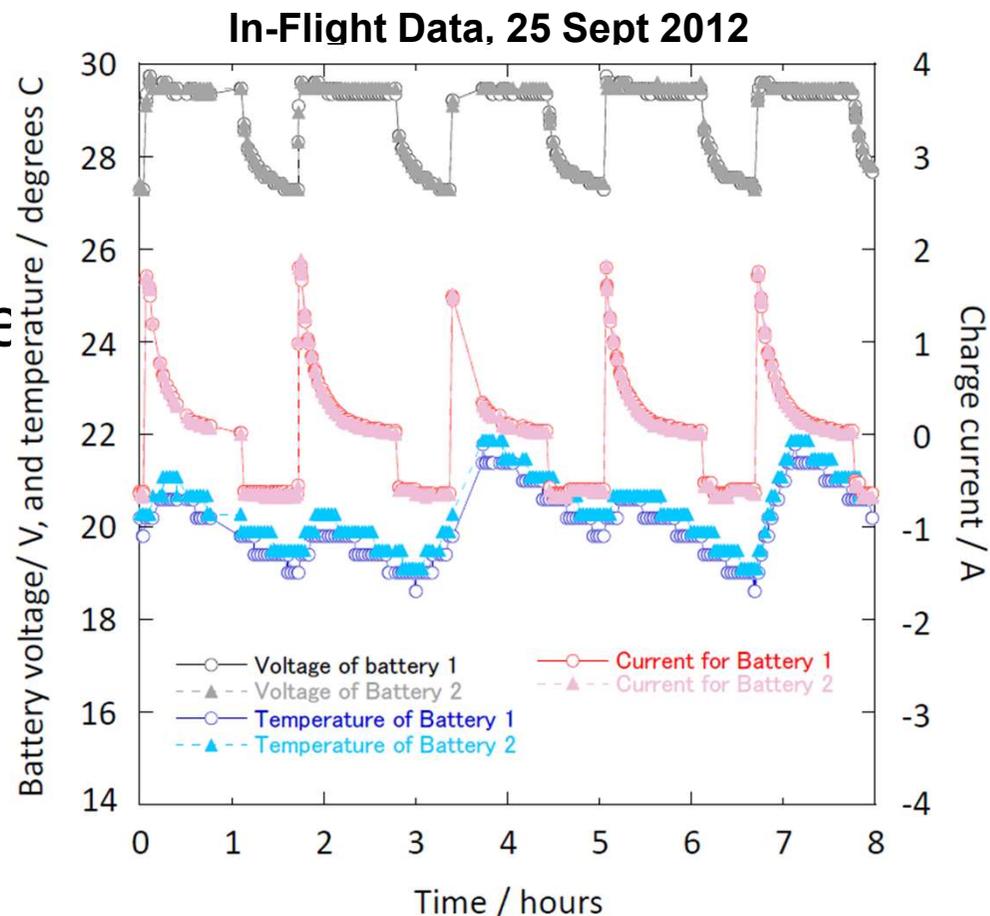
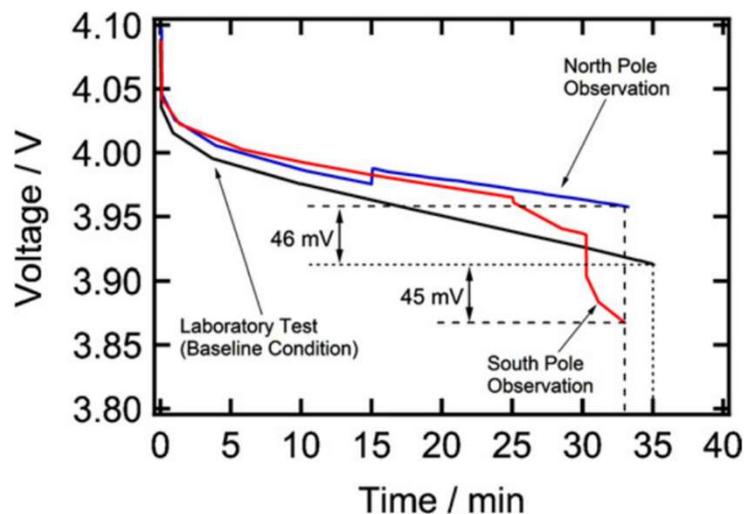
1. *Journal of Power Sources*, **289**, 105-113 (2015).
2. *Journal of The Electrochemical Society*, **165** (2), A1-A15 (2018).

End of Discharge Voltage



REIMEI Battery Data

- Battery Datasets
- Cycle data from 12 years
- Datasets consist of voltage current and temperature



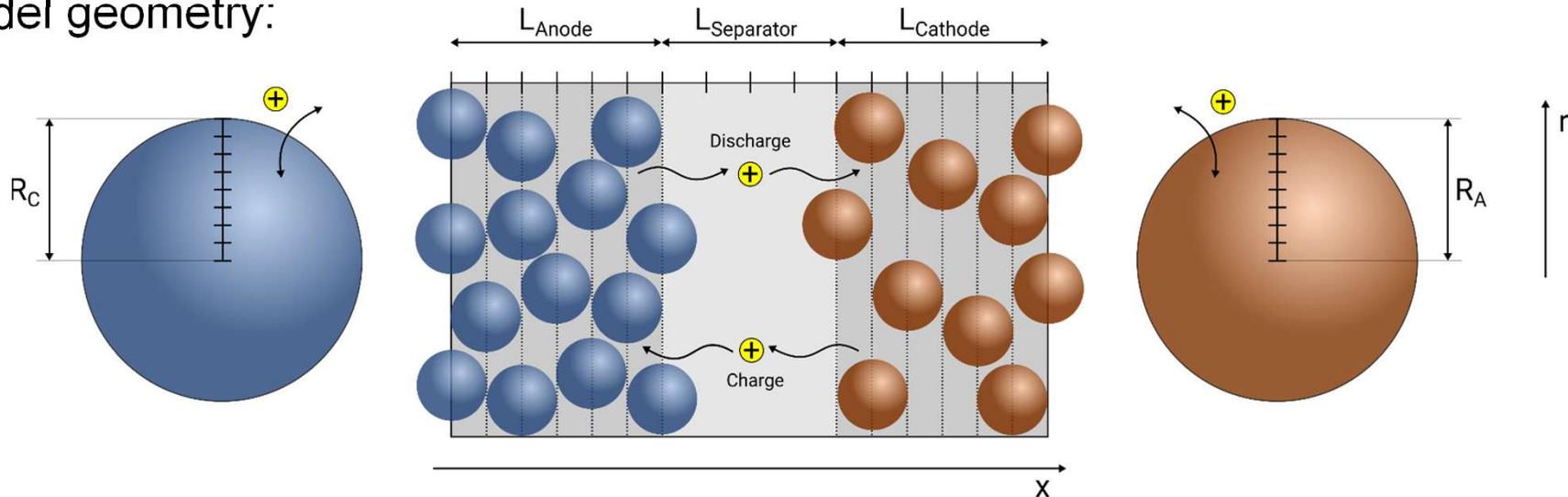
Sone, Y. et al. (2017) E3S Web of Conferences 16, EDP Sciences

Sone, Y. et al. (2011) Journal of Power Sources 196, 8755-8763



Volume Averaged 1D + 1D Model

- The model is based on volume averaged transport theory and reaction kinetics equations.
- Model geometry:



Parameters:

Cell Geometry:

- Electrode thickness
- Porosity
- Tortuosity
- Particle radius

Material:

- Maximal Li-ion concentration
- Specific surface area

Transport:

- Transference number
- Ionic conductivity
- Diffusion coefficient

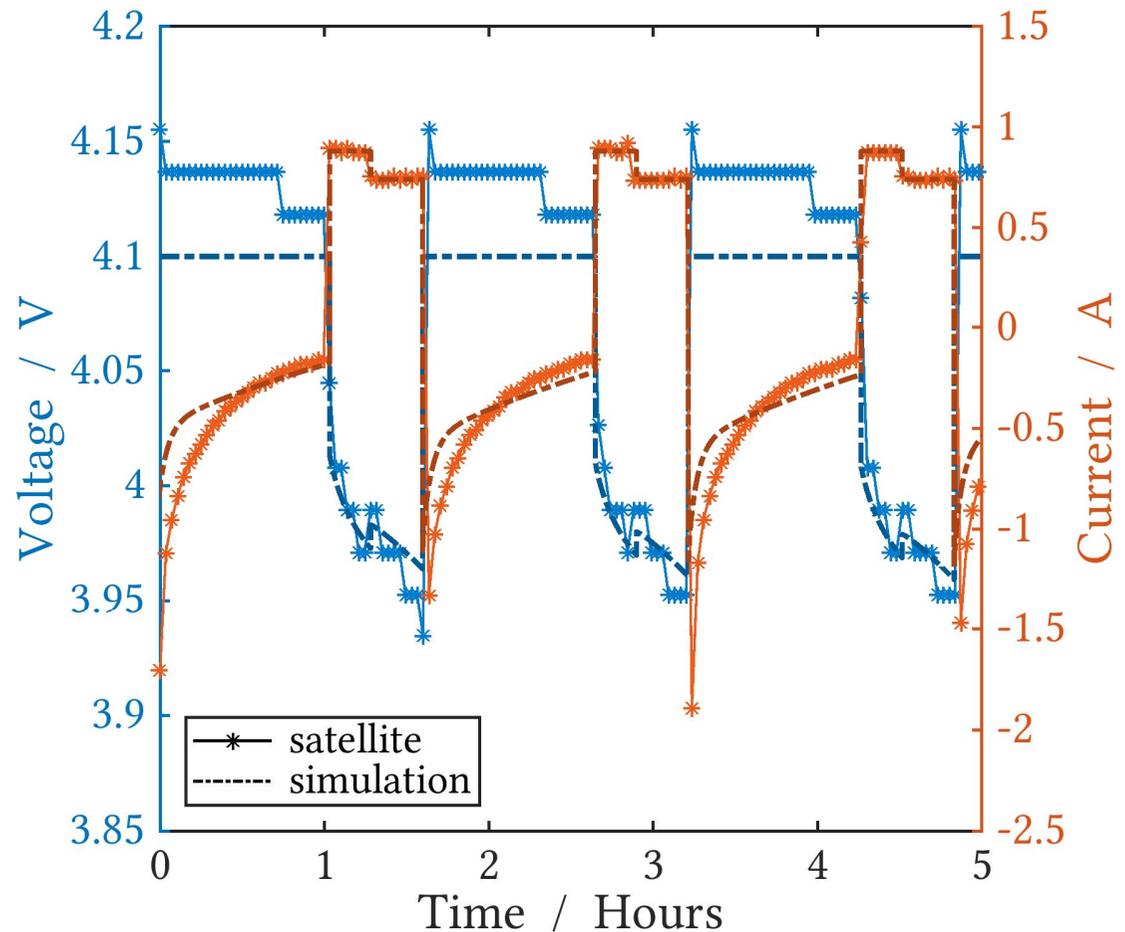
Kinetics:

- Reaction rate constant
- Symmetry factor

Doyle, M., Fuller, T. F., Newman, J., *JES* **140** (6), 1526–1533 (1993).

Simulation of In-Flight Data

	North Pole	South Pole
Charge (CC/CV)	1.5A/4.1V 63min	
Discharge (CC)	0.88A 15 min	0.78A 25min
	0.74A 18min	0.96A 5min
		1.6A 3min
Δ SOC	14%	16%
Temperature Battery		
Eclipse	20°C	
Sunlight	20°C	
Solar panel		
Eclipse	-70°C	
Sunlight	140°C	



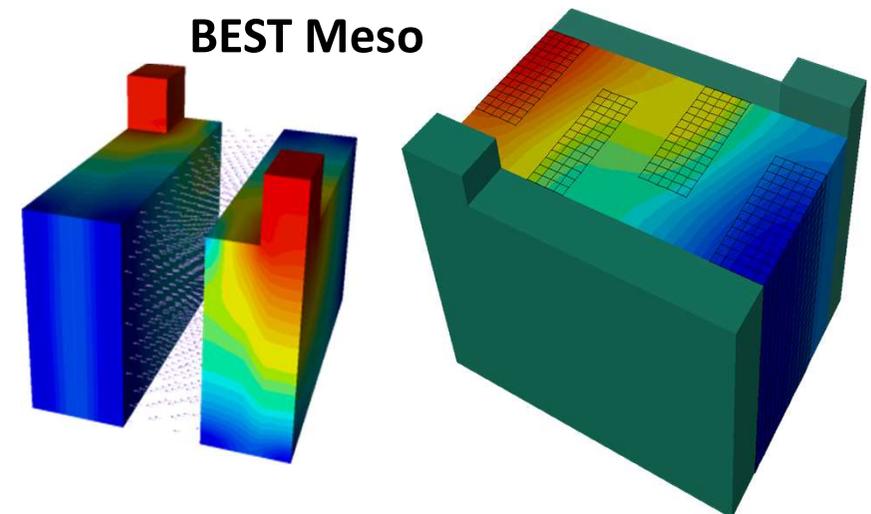
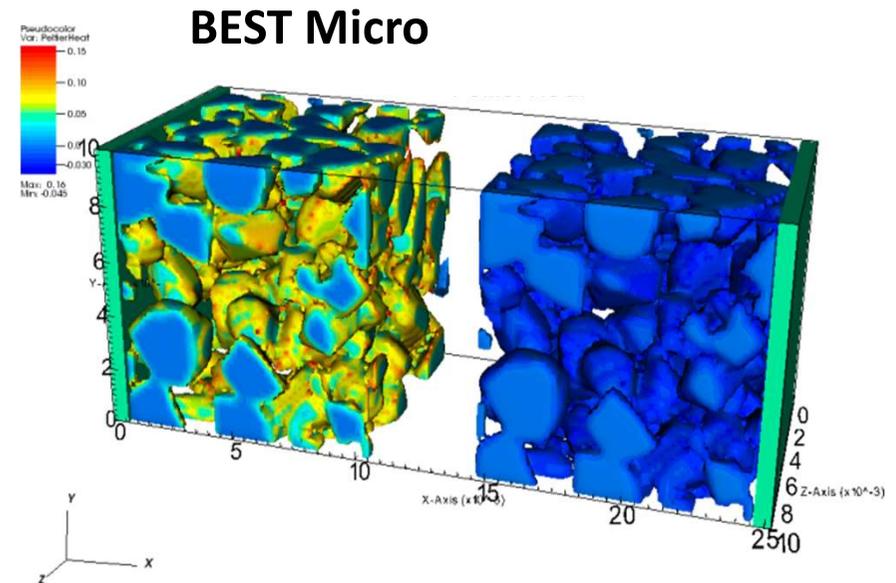
Japan Aerospace Exploration Agency (JAXA)
provided the battery data of satellite REIMEI



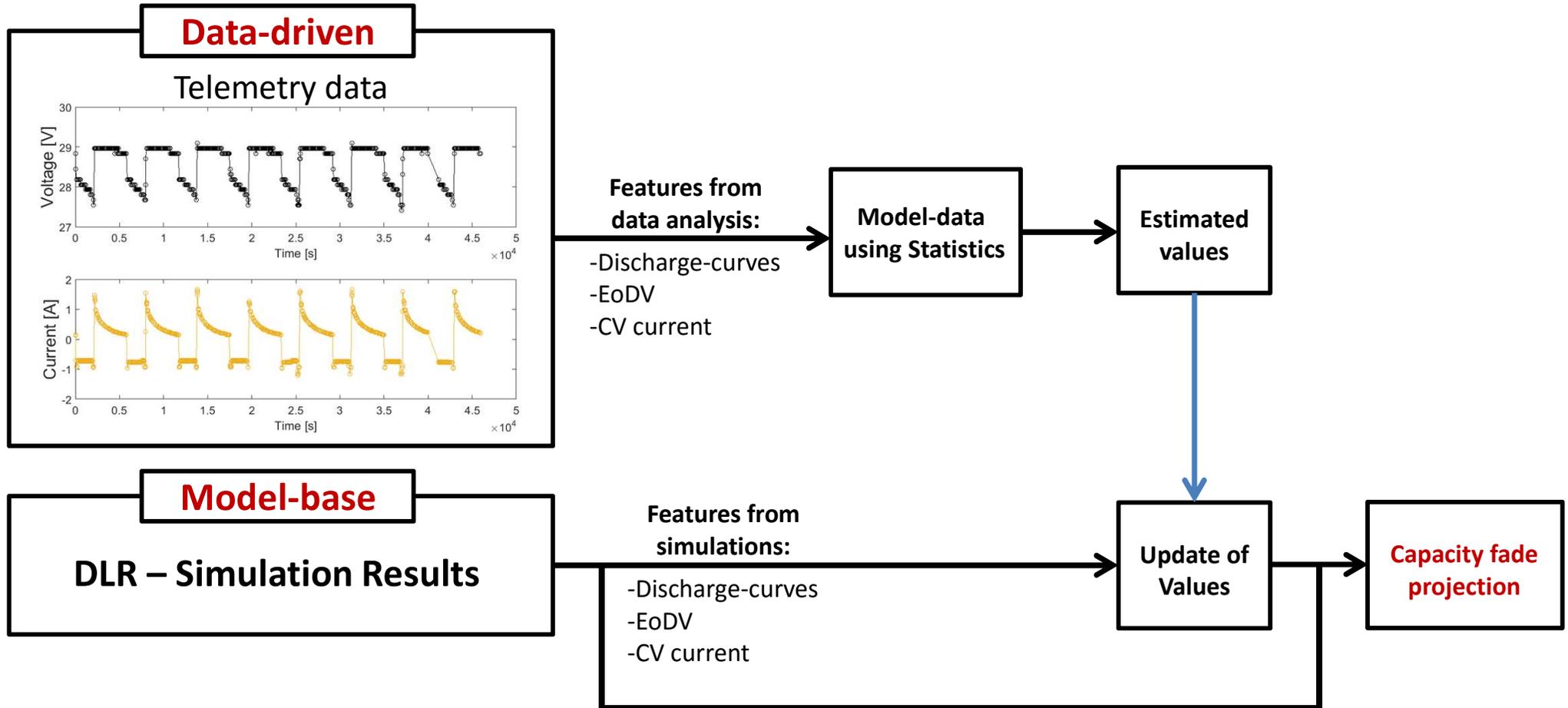
Brown, S. et al. *J. Power Sources* **185**, 1444–1453 (2008).

3D Simulations of Lithium-Ion Batteries

- Thermodynamically consistent multiphysics model
A. Latz and J. Zausch, J. Power Sources 196, 3296 (2011)
- Finite-Volume Code based on the CoRheoS framework of Fraunhofer ITWM
 - Newton algorithm for nonlinear iterations
 - Algebraic multigrid (SAMG) for Linear Algebra
- Input: geometry and material parameters
- Output: Li-ion concentrations c , electric voltages ϕ , temperatures T in each spatial point

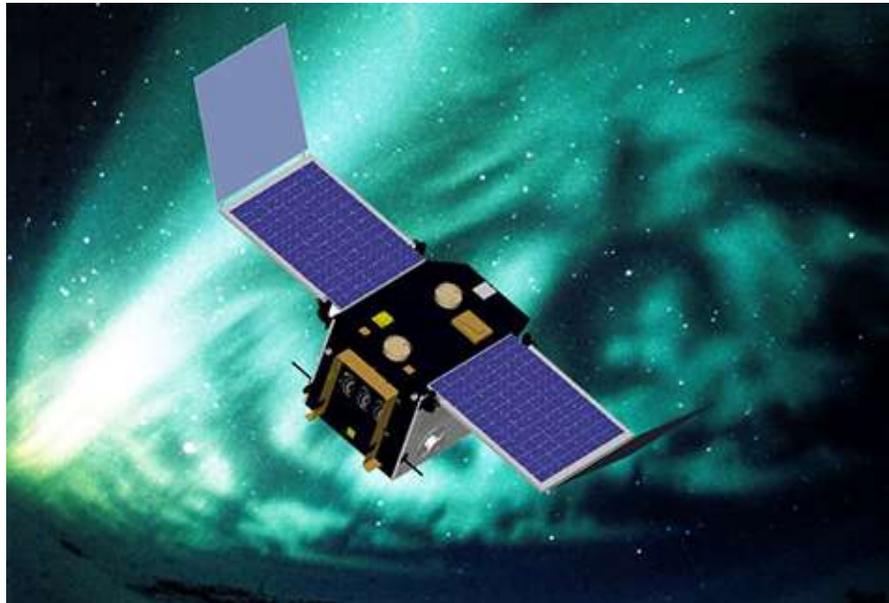


Development of a Hybrid Data-driven/Model-base Method to Estimate and Predict the Capacity fade for the REIMEI Batteries



Summary

- After more than 12 years the REIMEI satellite is still in operation.
- The REIMEI's mission is dedicated to analyze its batteries.
- The end of discharge voltage of the batteries is being monitored.



ACKNOWLEDGEMENT

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