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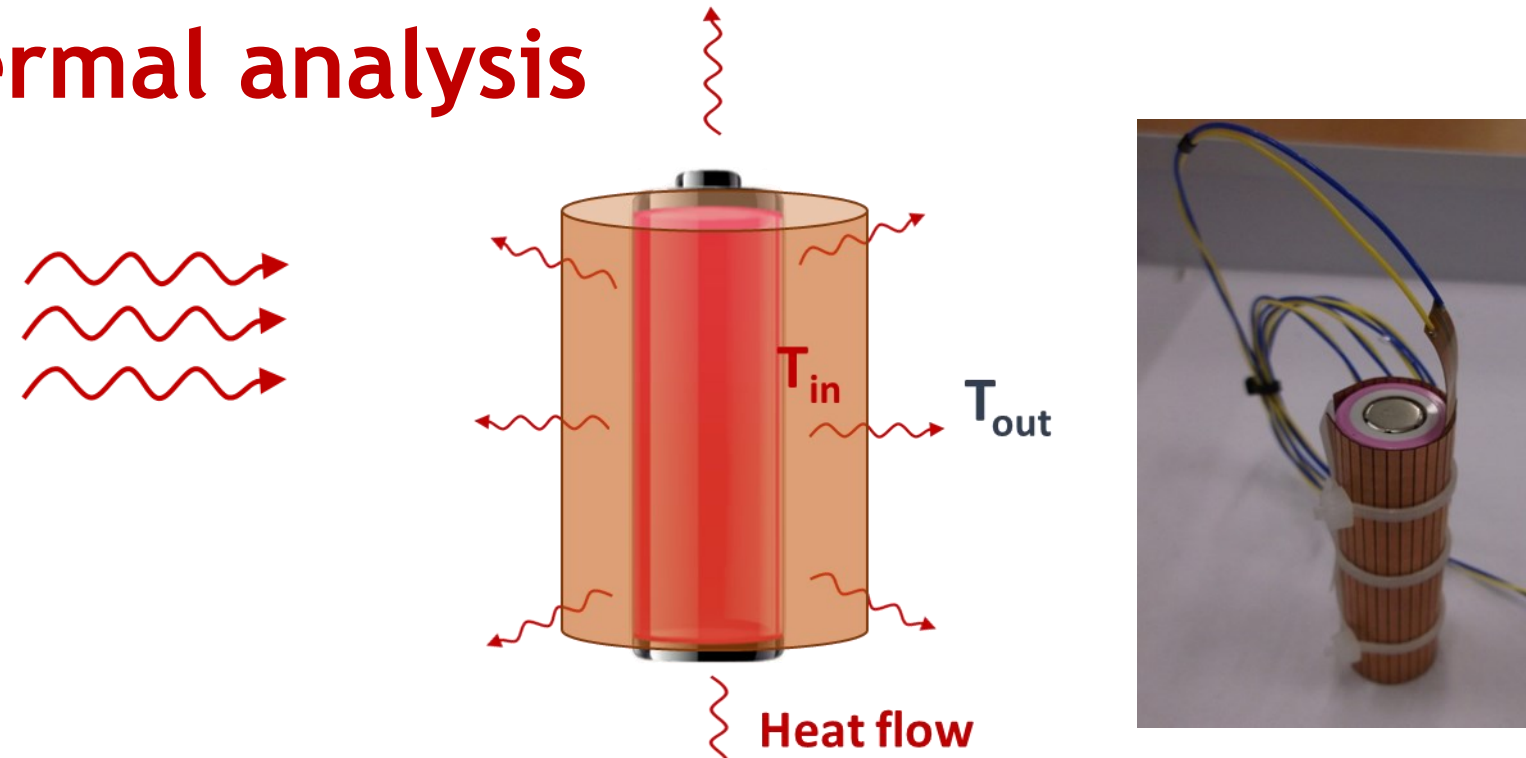
In-operando techniques for battery monitoring and safety issues prevention

Nicolas Guillet ^{a,b,*}, Clément Primot ^{a,b}, Vincent Maigron ^{a,b,c}, Florence Degret ^{a,b,c} and Pierre-Xavier Thivel ^c

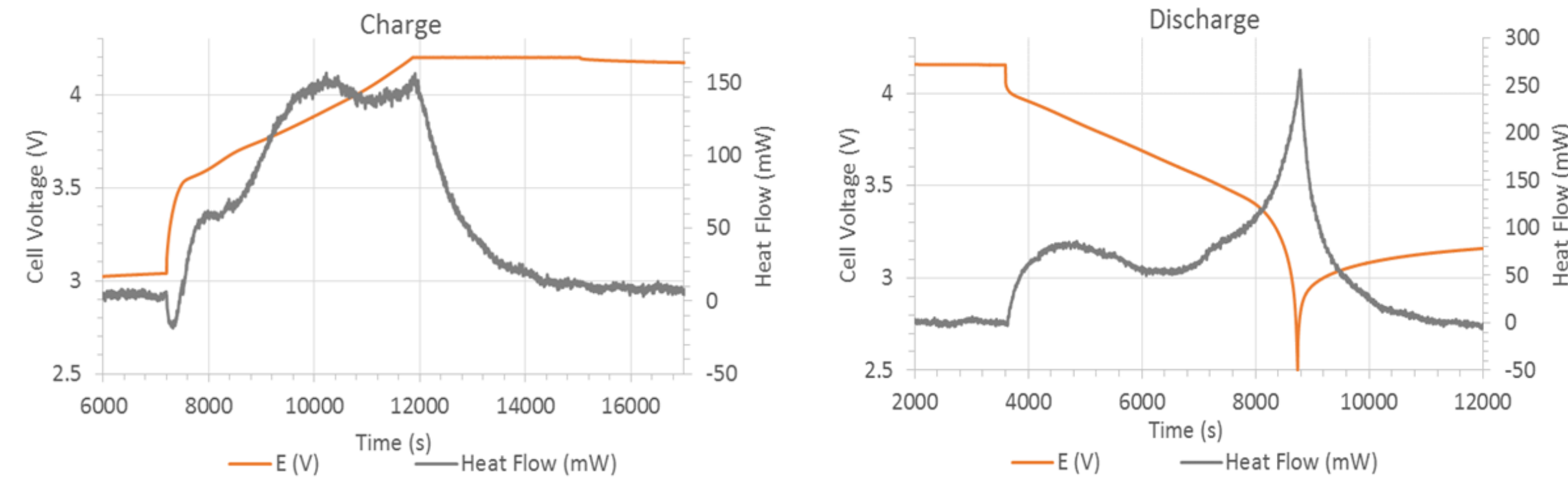
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Three different monitoring techniques

Thermal analysis



Thermal flux sensors principle, thermal flux sensor (Captec <http://www.captecenterprise.com/>) wrapped around a 18650-type battery.



Example of cell voltage and heat flow measured on a 18650 battery during charge (CC at C/2 and CV) and discharge (C/2).

• Direct measurement of the heat flow exchanged with surrounding $Heat\ flow = \frac{dQ}{dt} (J \cdot s^{-1} = W)$

↳ Thermal monitoring and management

• Easy way to measure the Cp of the battery

$$\frac{dQ}{dt} = mC_p \frac{dT}{dt}$$

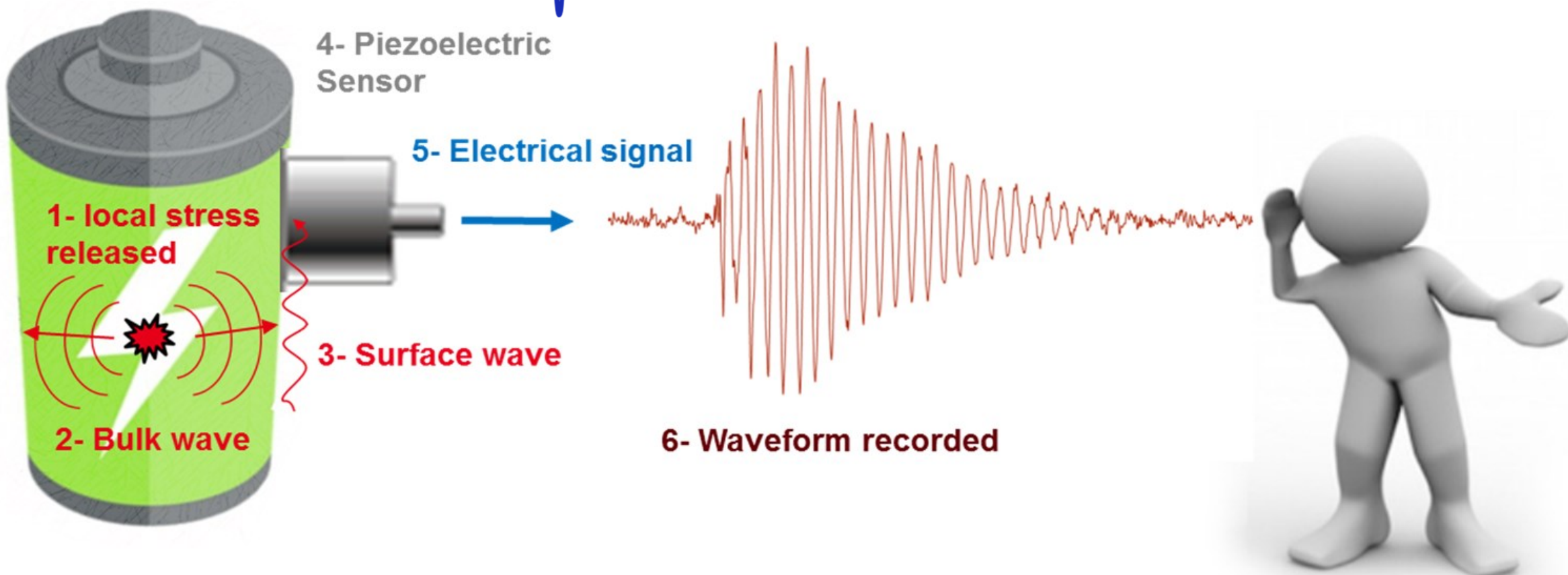
↳ Characterization

↳ Thermal modelling

Acoustic emission



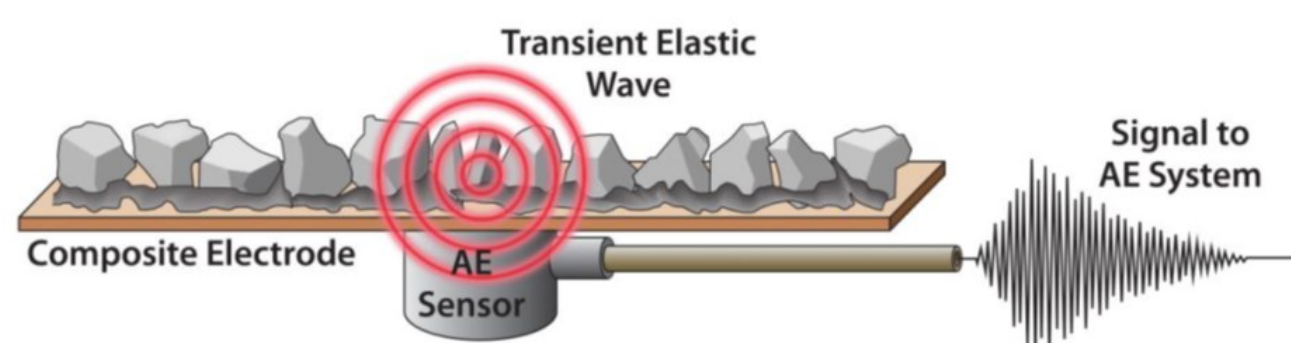
non-destructive test (NDT) method used to detect elastic transient acoustic waves produced by materials



Relaxation of mechanical stresses in materials and at interfaces (e.g. due to volume change associated with lithium intercalation, cracks in the passivation layer of the electrodes, gas evolution during electrolyte degradation, etc...) emit transient elastic waves. They propagate throughout the battery materials to the surface and are recorded by sensors.

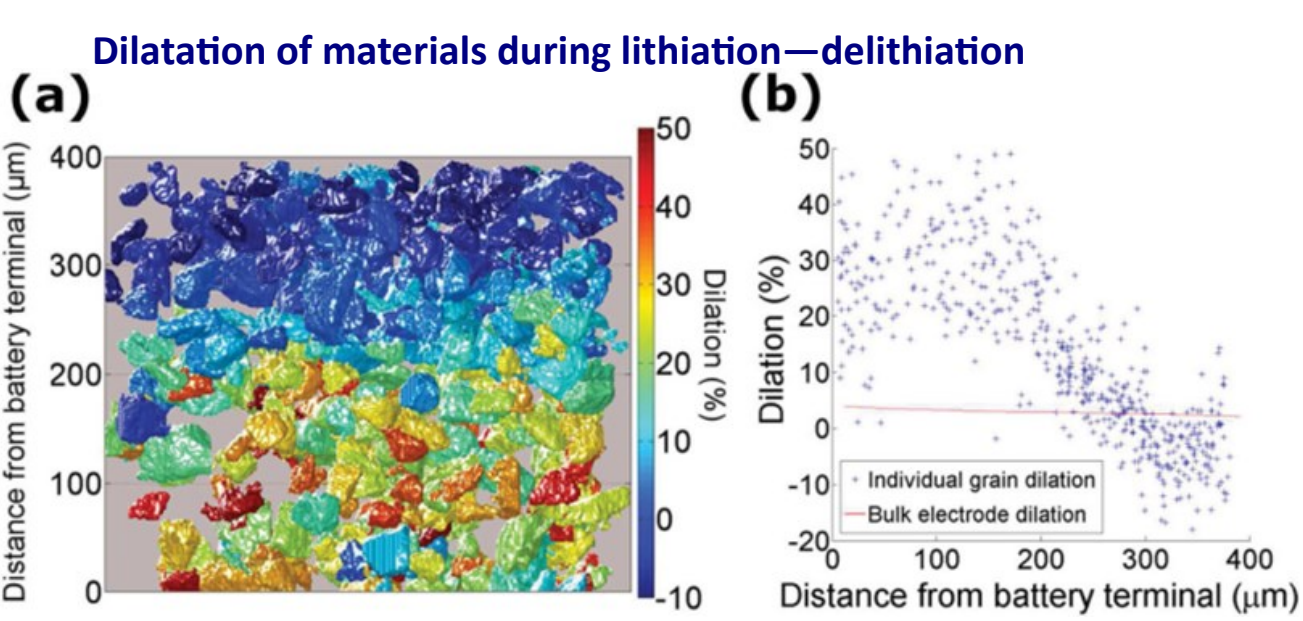
Emission of transient acoustic waves

Piezoelectric sensors

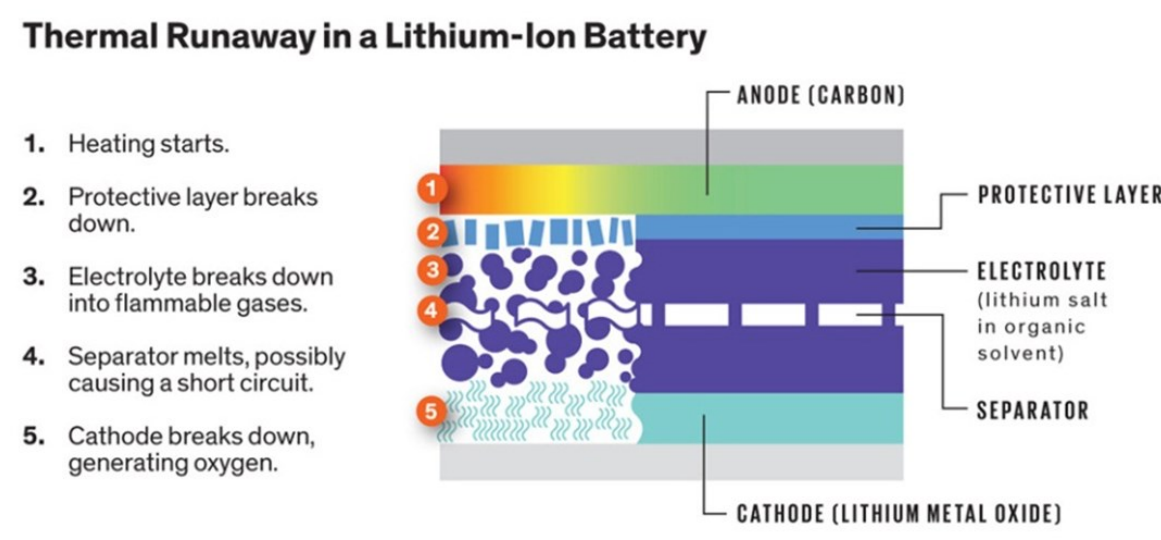


Example of an array of 6 PVDF screen-printed piezoelectric sensors on a 18650 battery type (CEA-Liten)

Possible origins of transient acoustic waves ?



High mechanical constraints during thermal runaway



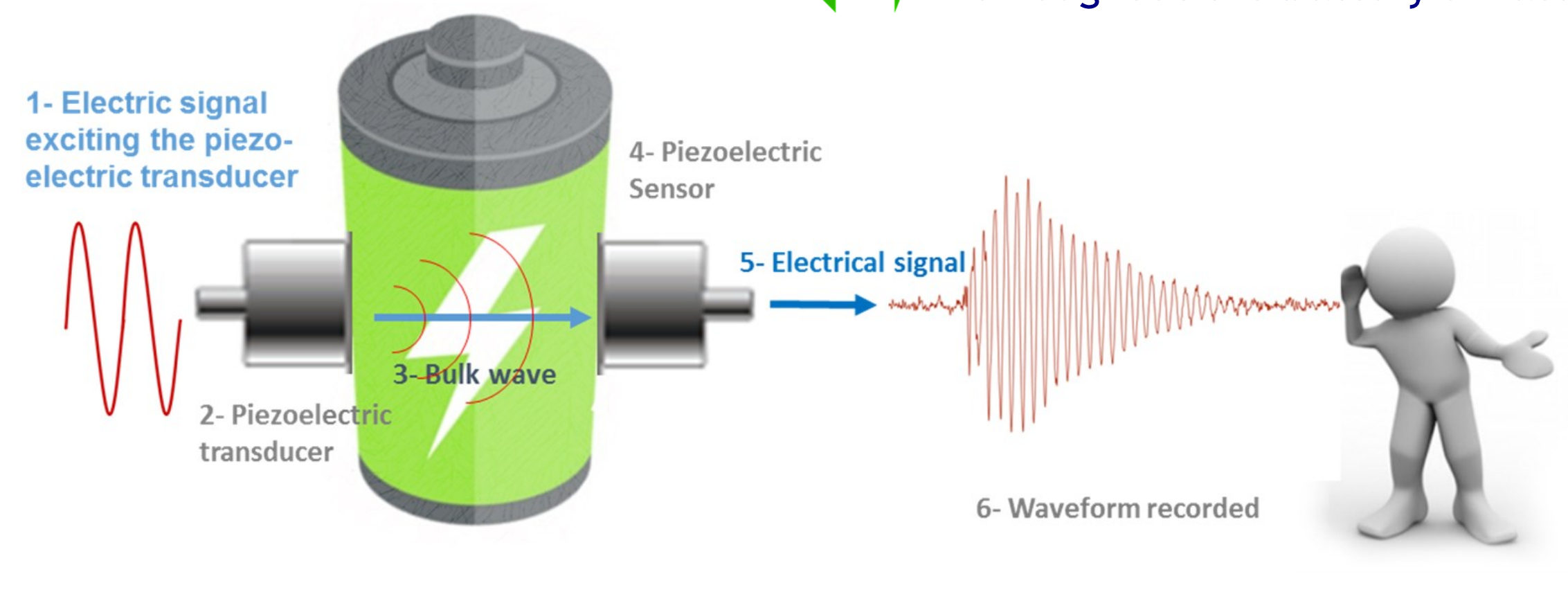
David S. Eastwood et al. "Lithiation-Induced Dilatation Mapping in a Lithium-Ion Battery Electrode by 3D X-Ray Microscopy and Digital Volume Correlation" Adv. Energy Mater. 2014, 4, 1300506

Illustration: Erik Vrieling, <http://spectrum.ieee.org/aerospace/aviation/boeings-battery-blues>

Ultrasound characterization

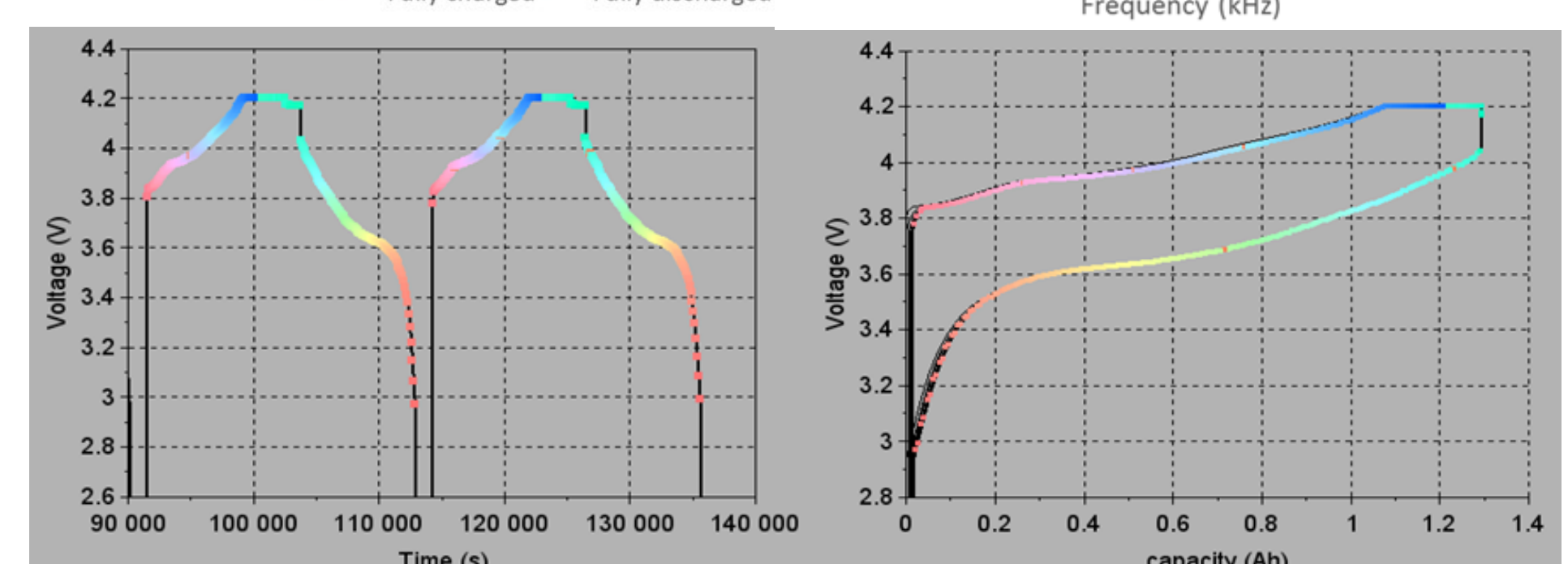
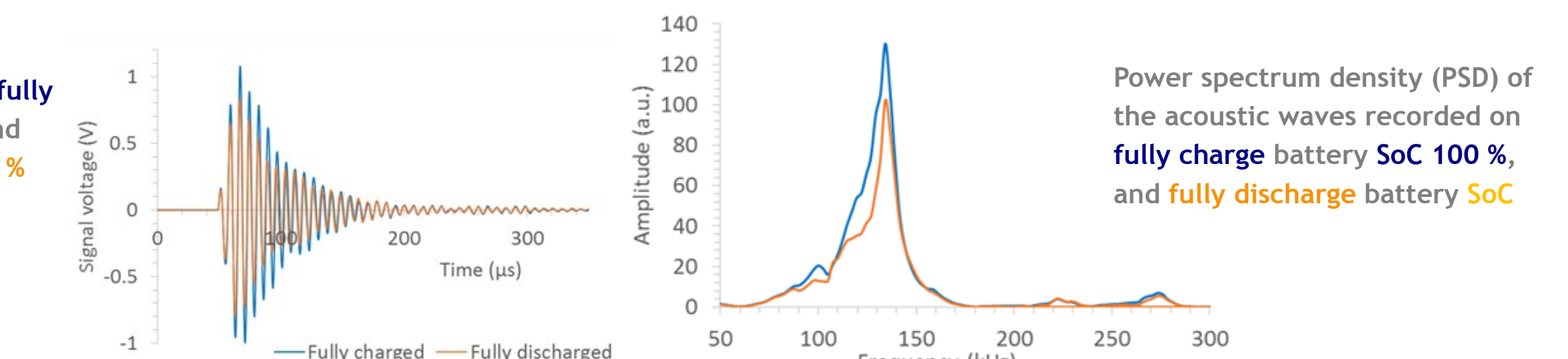


non-destructive test (NDT) method used to study the propagation of acoustic waves throughout the battery's materials



Acoustic waves of a defined wavelength are injected from a transducer within a material to detect absorptive or reflective defects such as fatigue cracks. According to their interaction with the materials, some wavelengths may be absorbed or reflected and/or transmitted. From this analysis, one can determine the existence of discontinuities within the sensed materials that prefigures the existence of cracks, defaults, bubbles etc...

Acoustic waves recorded on fully charge battery SoC 100 %, and fully discharge battery SoC 0 % during cycling at C/2



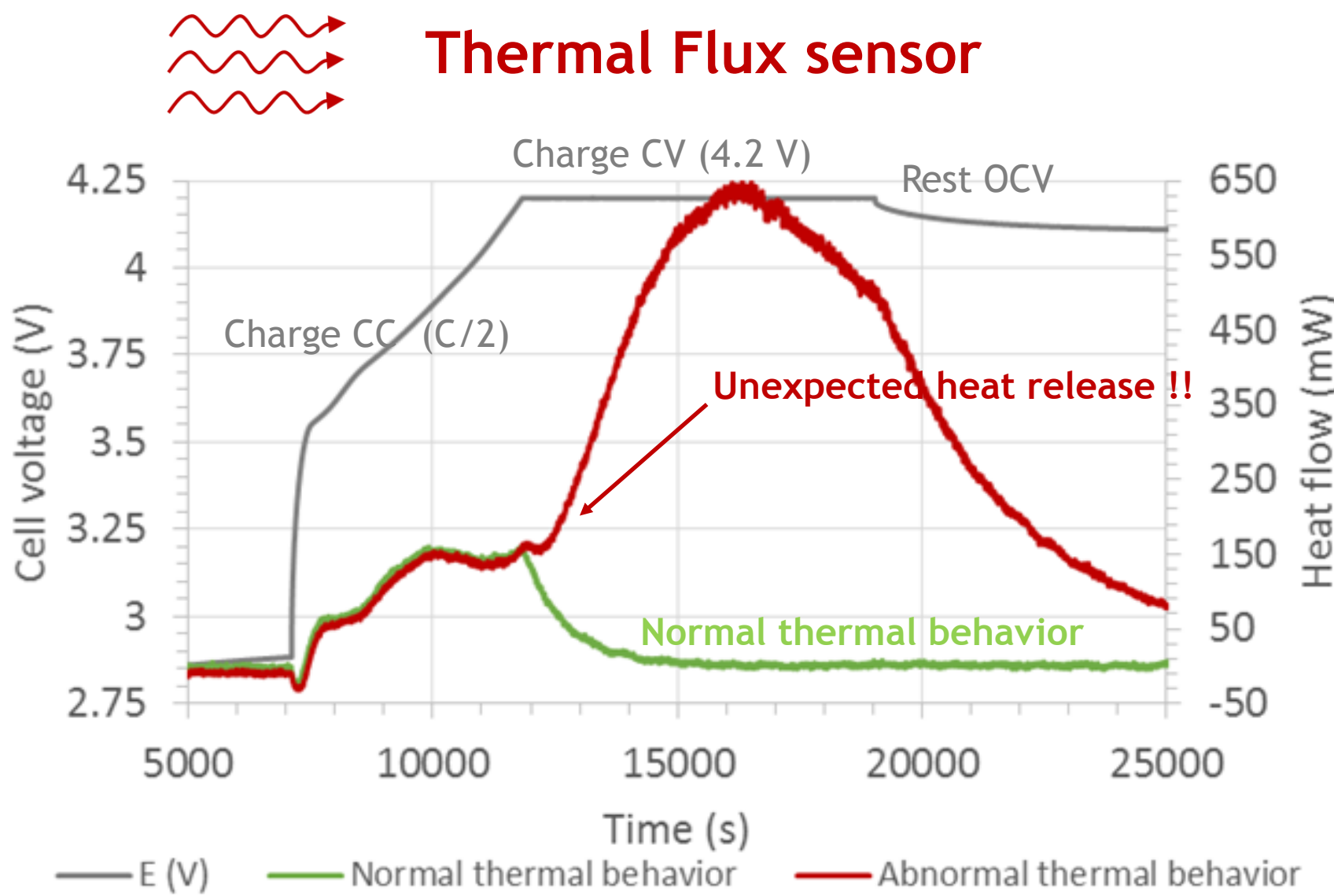
Example of result obtained using UsC technique. Left evolution of the cell voltage versus time during two successive cycles charge-discharge at C/2 and 25 °C. Colored dots superimposed on cell voltage correspond to each UsC measurement. Coloration is related to the variation of the physical properties of the acoustic signal detected. Right: representation of the cell voltage vs. capacity for the same data.

A specific case: abnormal heat release during charge



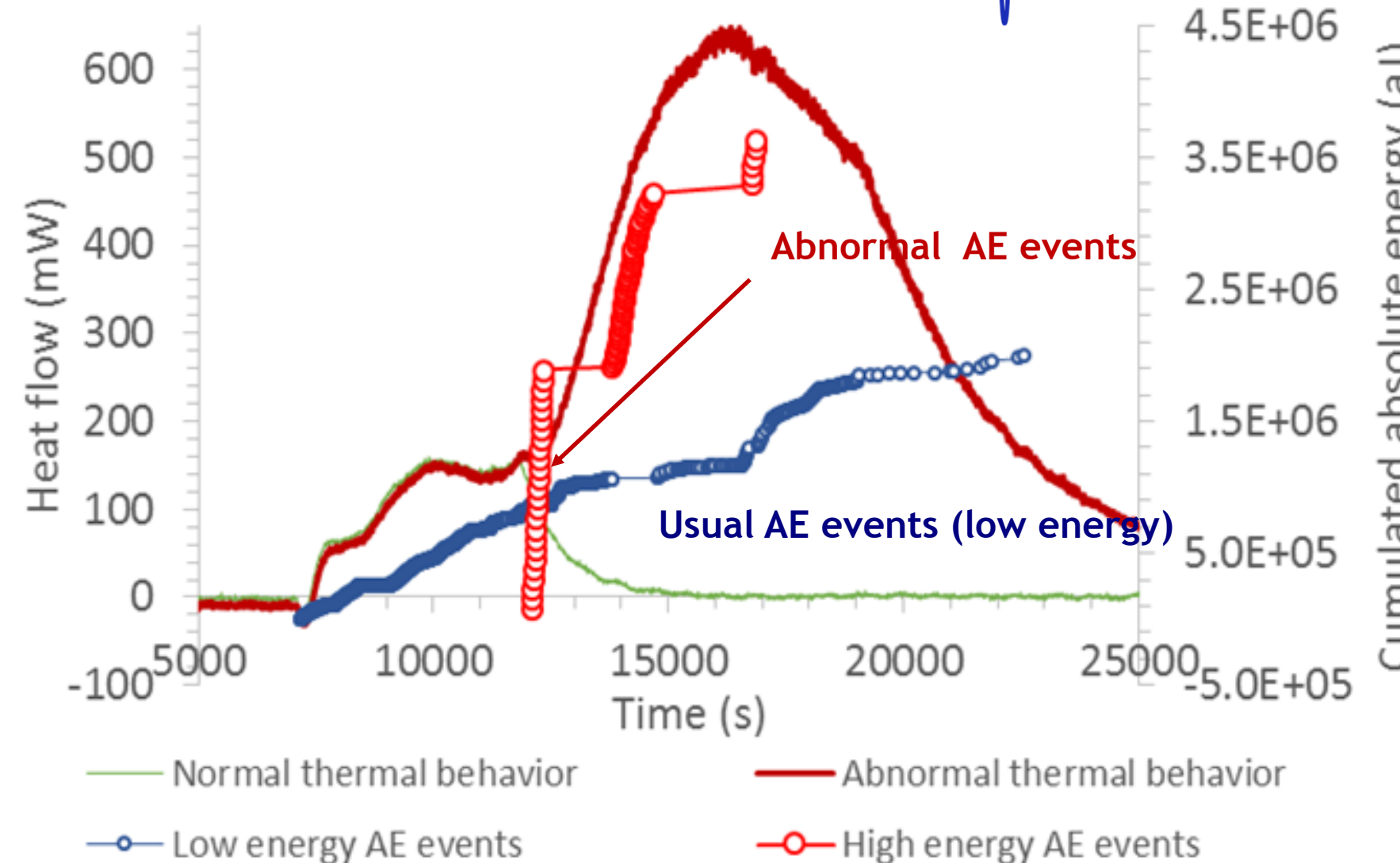
- Commercial 18650-type battery
- Abnormal and unreliable heat release noticed on aged batteries (~85 % SoH)
- ↳ Degradation of performance
- ↳ Safety issues

Detect early signs of abnormal thermal behavior ??



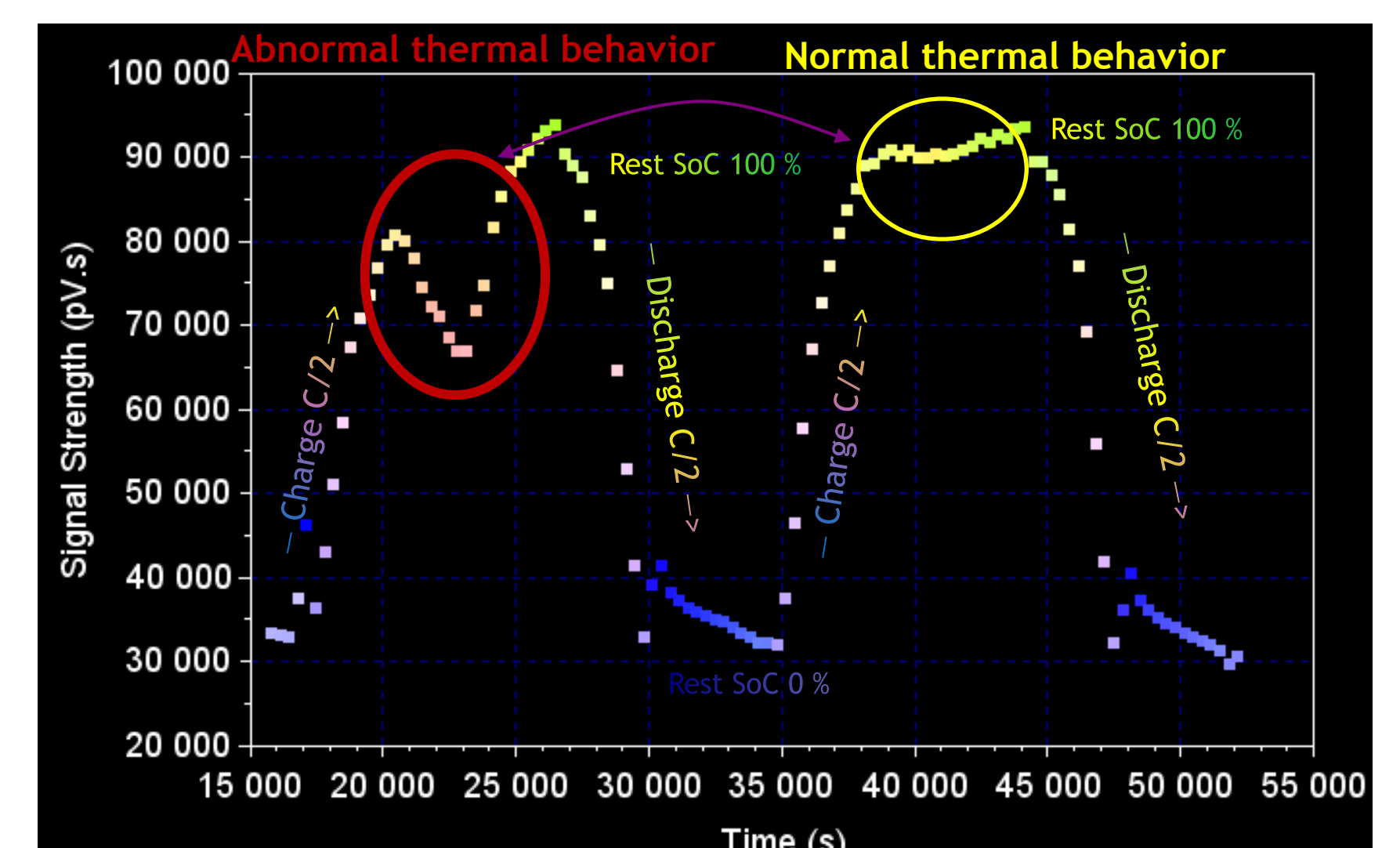
- Normal thermal behavior (max .150 mW released)
- Abnormal thermal behavior (max. 650 mW released)
- ↳ Detection and quantification of the unexpected heat release

Acoustic Emission



- Usual AE events (2.1 fJ / AE event)
- Abnormal AE events (44 fJ / AE event)
- ↳ high energy acoustic events early detected during heat release

UltraSound Characterization



- Color gradient (waveform evolution) with SoC
- Specific signal noticed during abnormal thermal behavior
- ↳ Significant change in the material's sound wave transportation properties

↳ Three different in-operando and non intrusive techniques for battery monitoring and prevention of safety issues

Acknowledgements

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement No. 608575, project Hi-C "Understanding interfaces in rechargeable batteries and super-capacitors through in situ methods" (01-09-2013 - 28-02-2017). Project website: www.hi-c.eu

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