Transitioning Electrochemical Acoustic Analysis into a Predictive Technique for Understanding Complex Behaviors

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Meeting The Challenge ESS
2017-02-22

Thanks in Advance

arpa·e

andlinger center
for energy+the environment

NSF

CMI

ExxonMobil

ICL

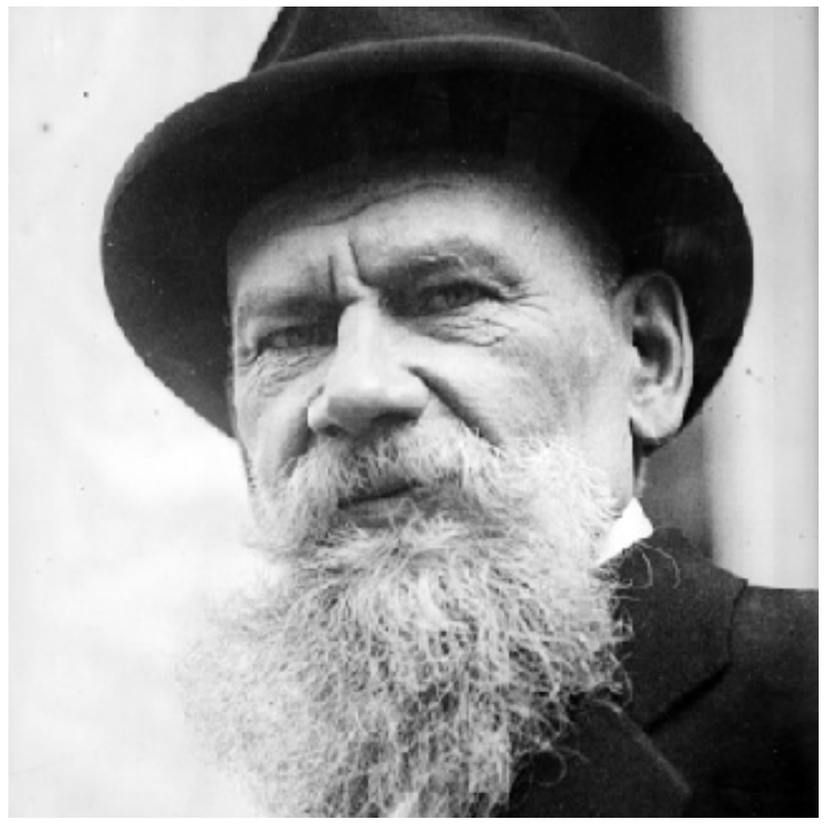
bp

xerox

αlpha En

Anna Karenina was a Battery

“All happy families are alike;
each unhappy family is
unhappy in its own way”



“If you look for perfection,
you'll never be content”

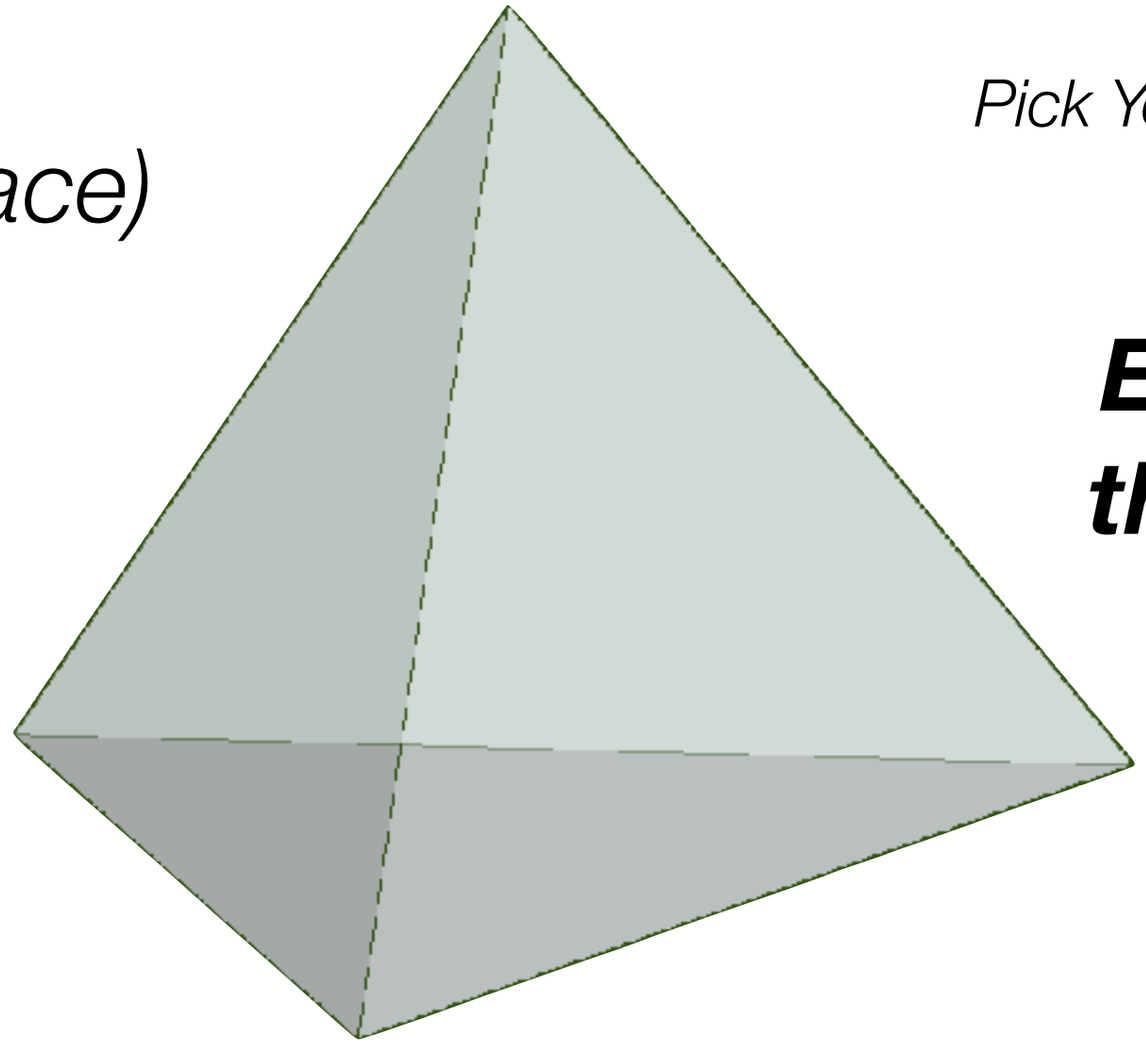
“Anything is better than lies and deceit!”

Group Hypothesis

Many Couplings Create An Unfortunate Tetrahedron

Capital Cost

(Utility Space)



Pick Your Corners

EVs are in the middle

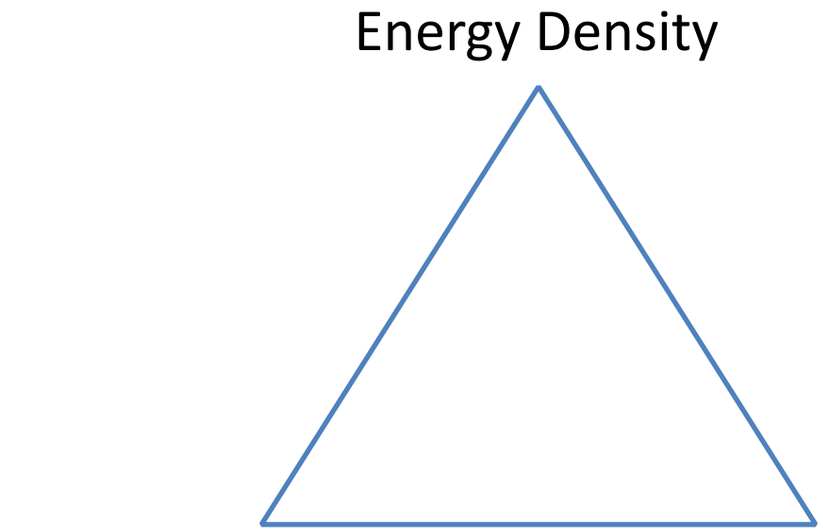
Amortization/ Operating Cost
(Cycle life and Safety)

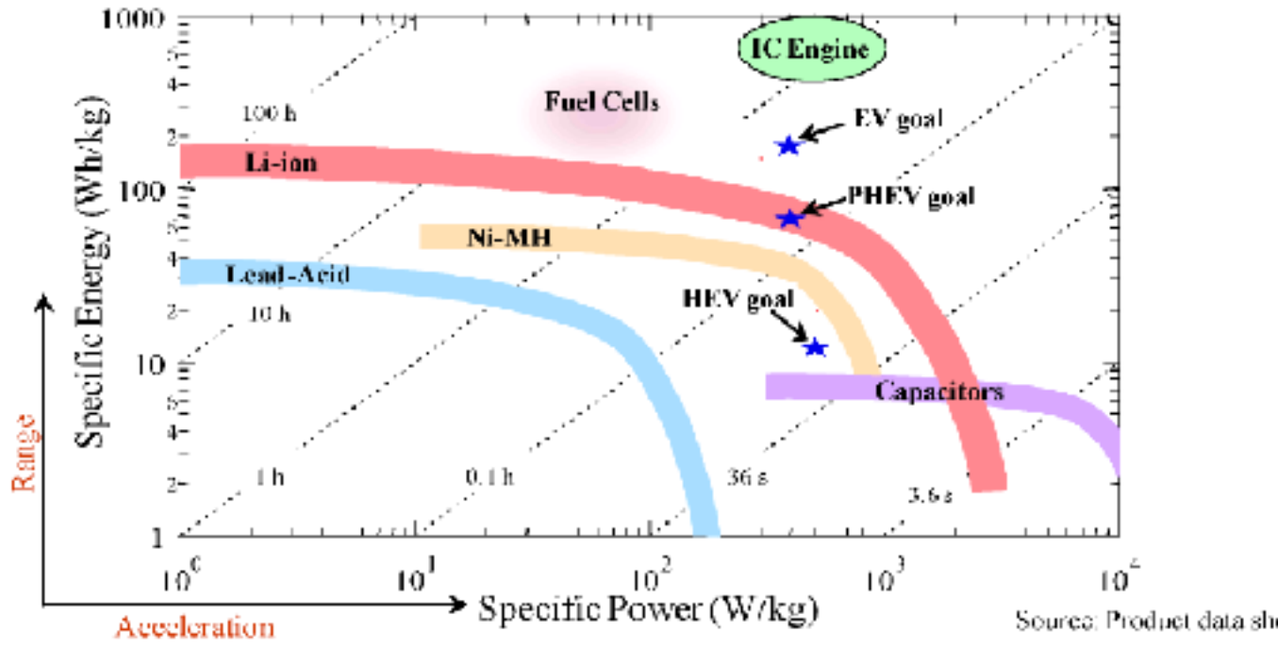
Energy Density

Power Density

(*Ragone Space*)

The Hidden Metric in Ragone





V. Srivansan, GigaOM, 2012

More Energy @ Unlimited Rate

$$\frac{\Delta E}{C_p * m} = \Delta T$$

Less Mass

State Estimation

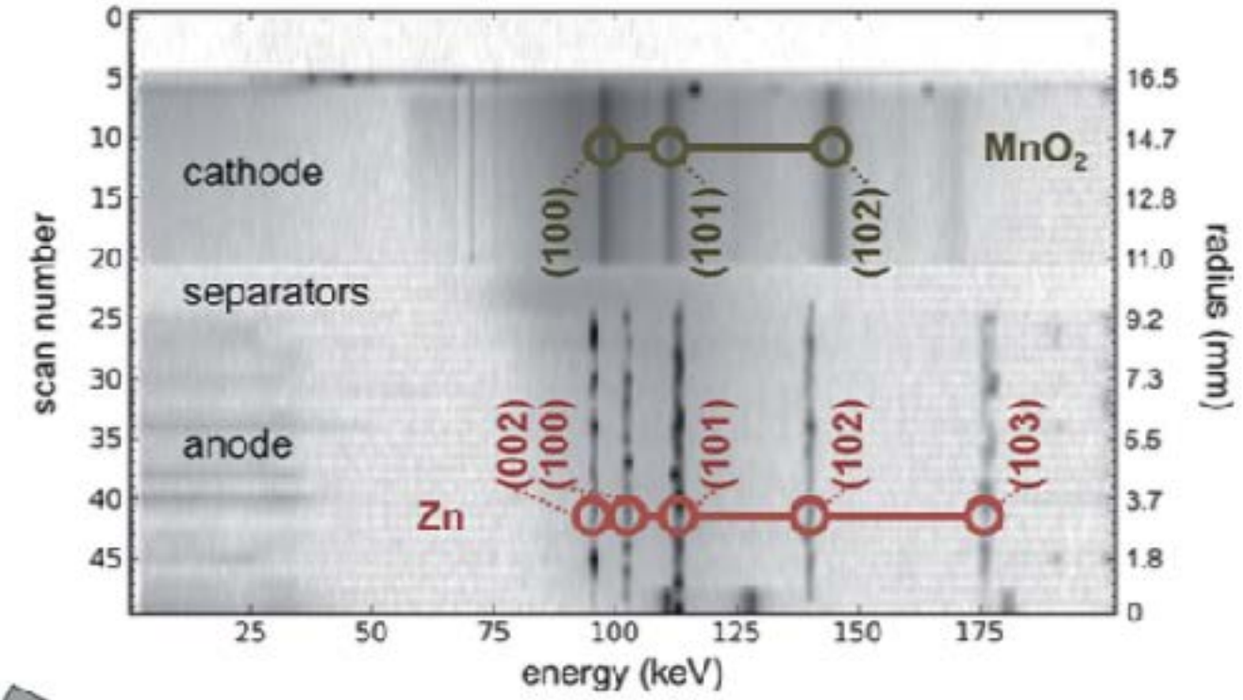
doctor pilot @pilotbacon · 33m

i made it home from manhattan to queens with 1% on my phone the whole time and now i feel like i finally understand the story of Hanukkah

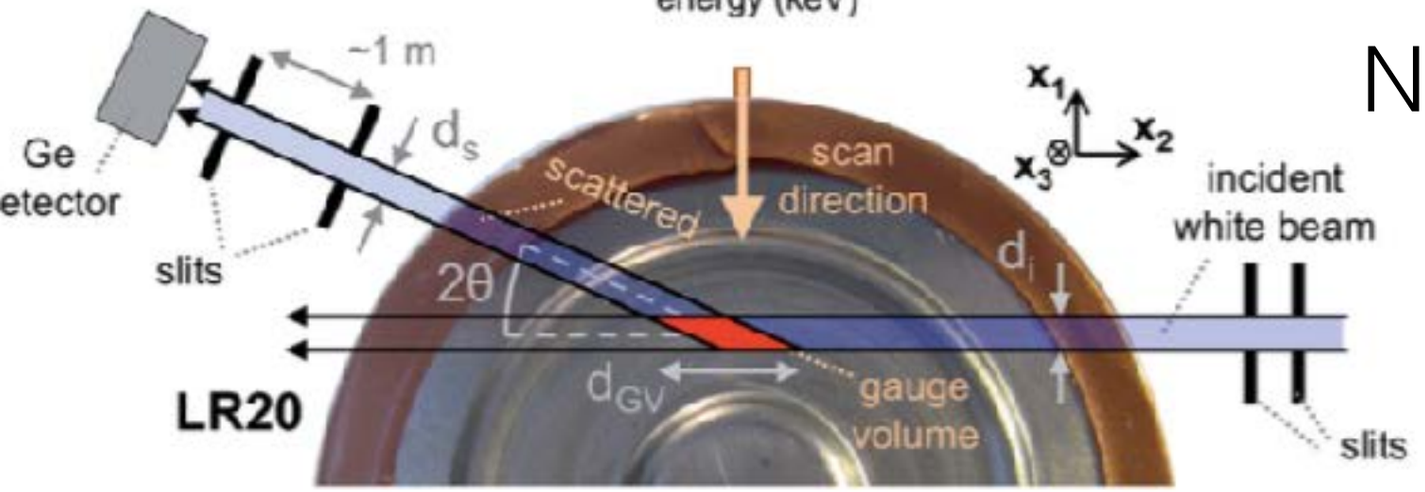
23 70

Cost No Object Tool: EDXRD

A



B



$$d = \frac{n\lambda}{2\sin\theta}$$

	θ	λ
EDXRD	Fixed	Varied
θ-2θ	Varied	Fixed

Near real time reconstruction of a full cell in operation

Requires White Beam And Serious Flux

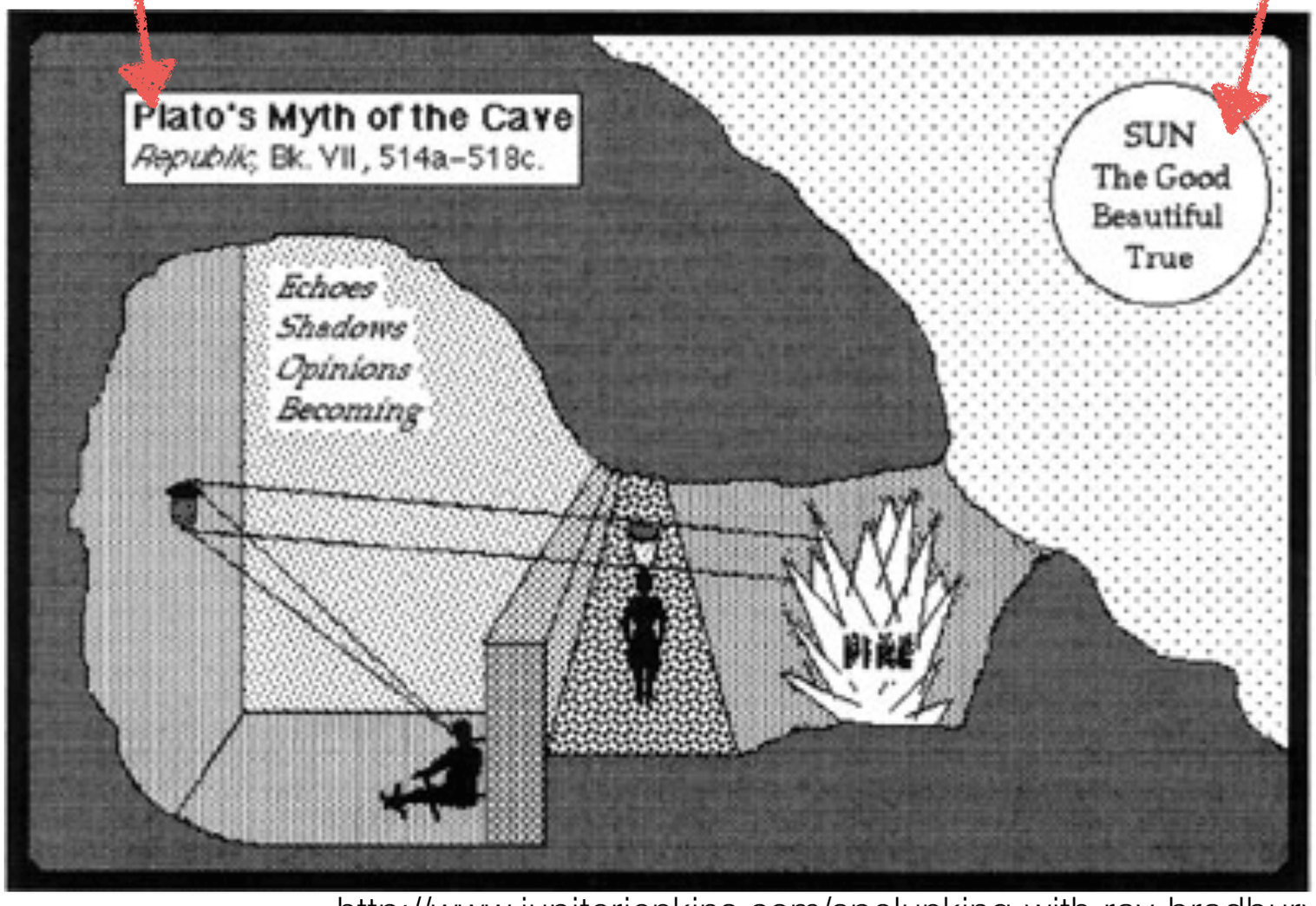
Hope the Wiggler Stays Up

The Allegory of The Cell

(You Cell Phone Estimator)
(Cheap Stuff)

(Synchrotron Radiation)
(Neutron Sources)
(Fancy Stuff)

Working Systems



(Generally) Deconstructed Systems

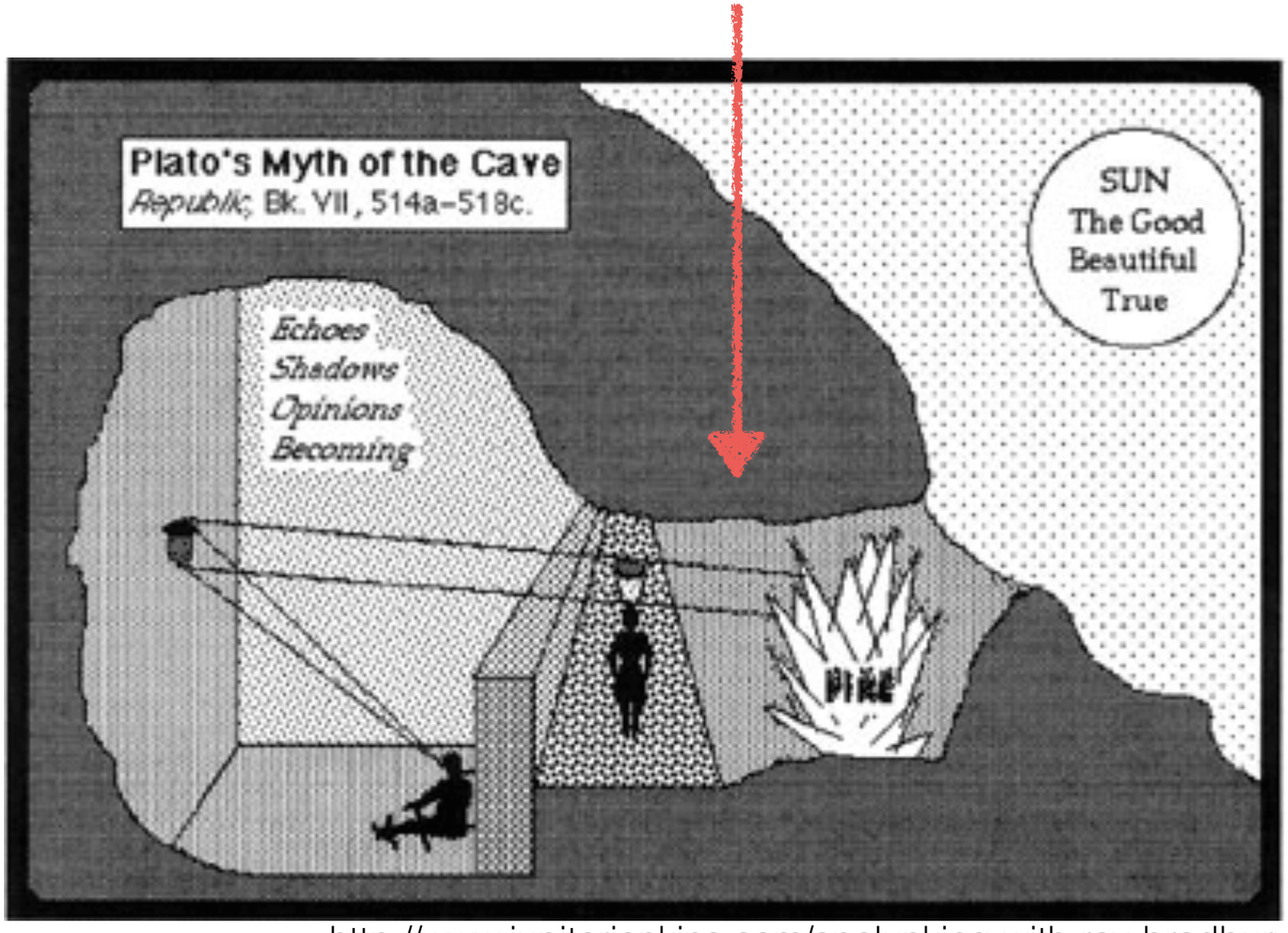
http://www.jupiterjenkins.com/spelunking-with-ray-bradbury/

truth is expensive but uncalibrated estimation is dangerous

The Allegory of The Cave

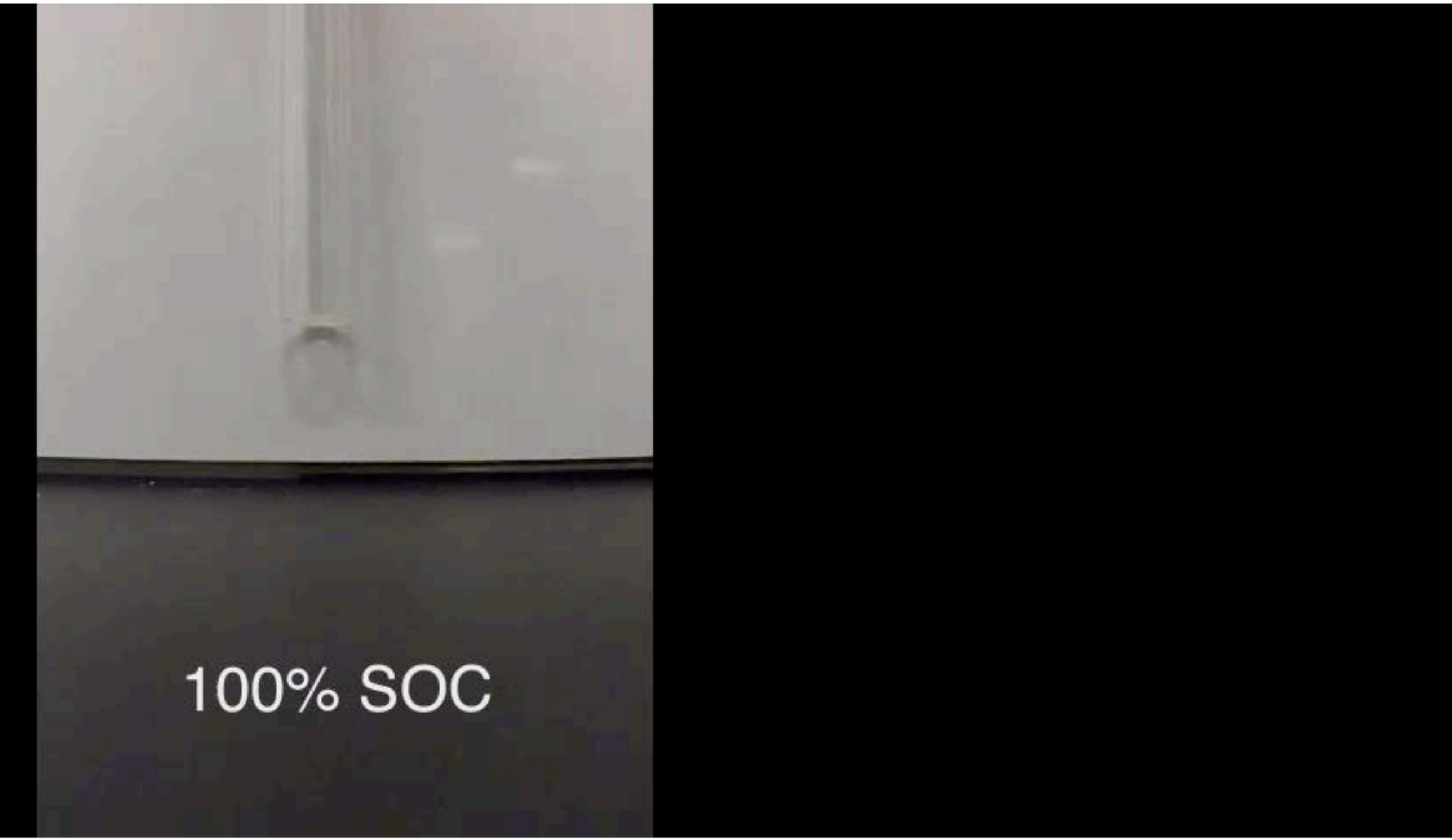
What Can Bridge?

For “real systems” I’d argue that the default is EIS

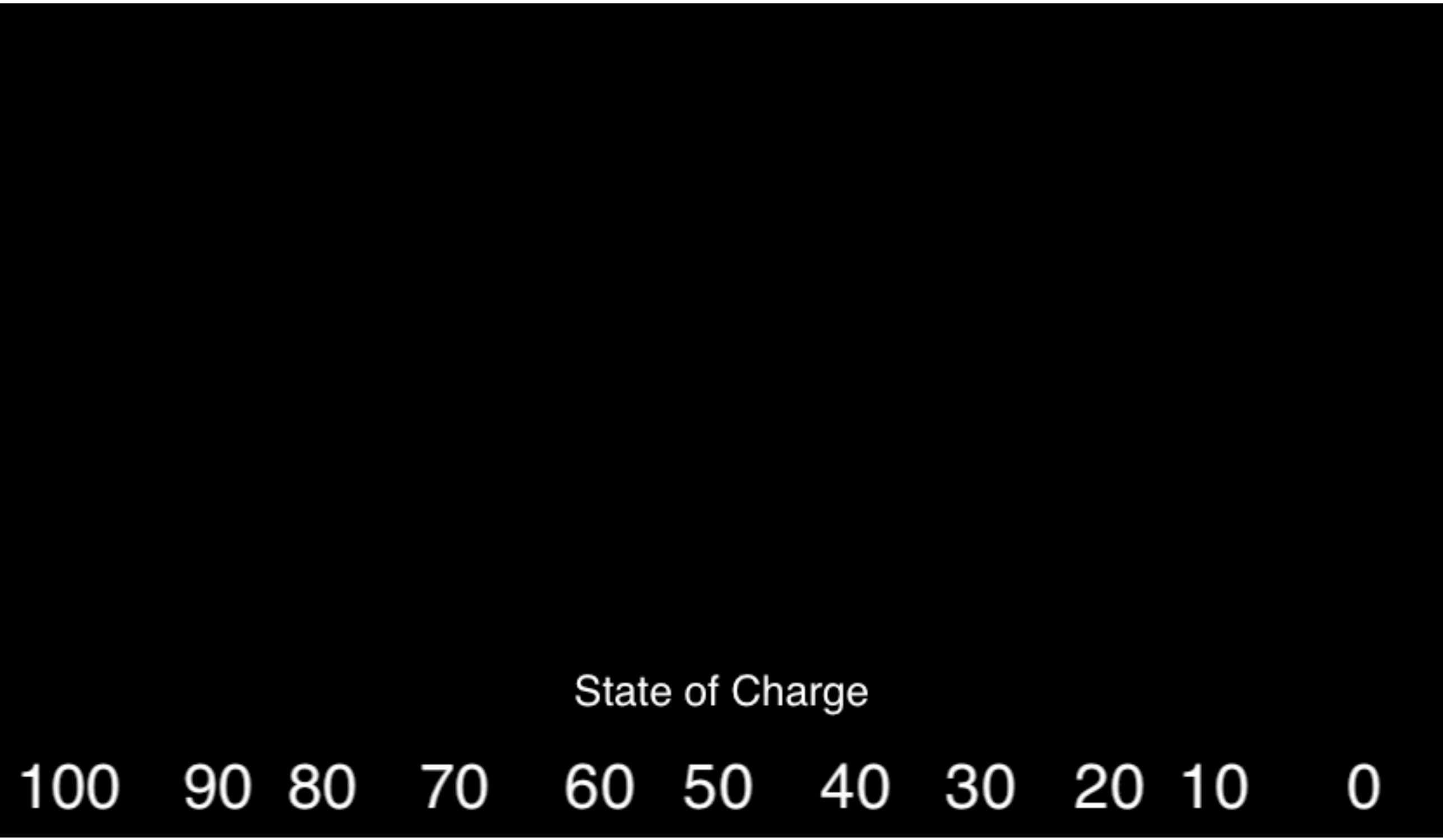


http://www.jupiterjenkins.com/spelunking-with-ray-bradbury/

Why Does This Happen?

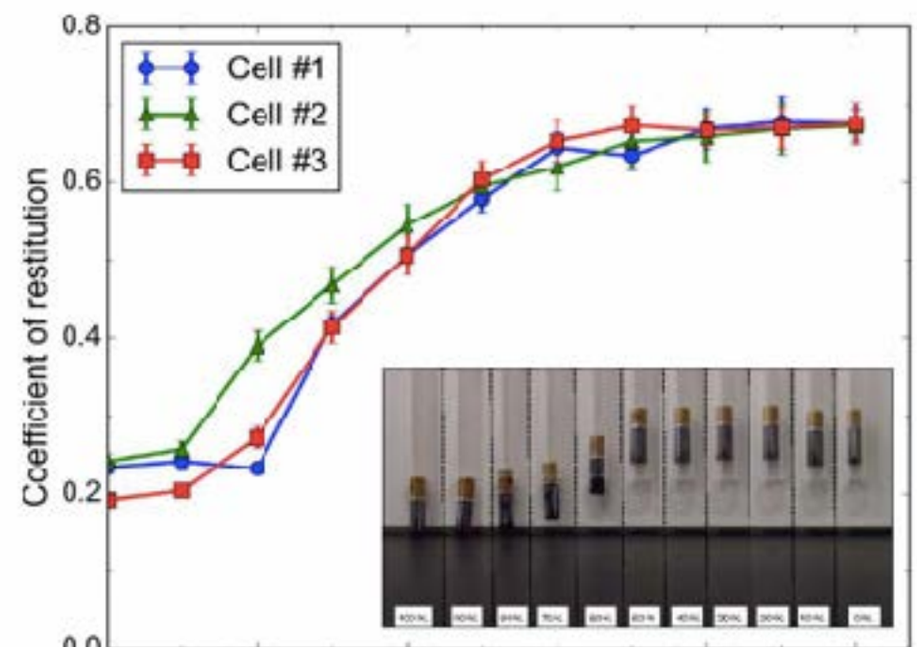


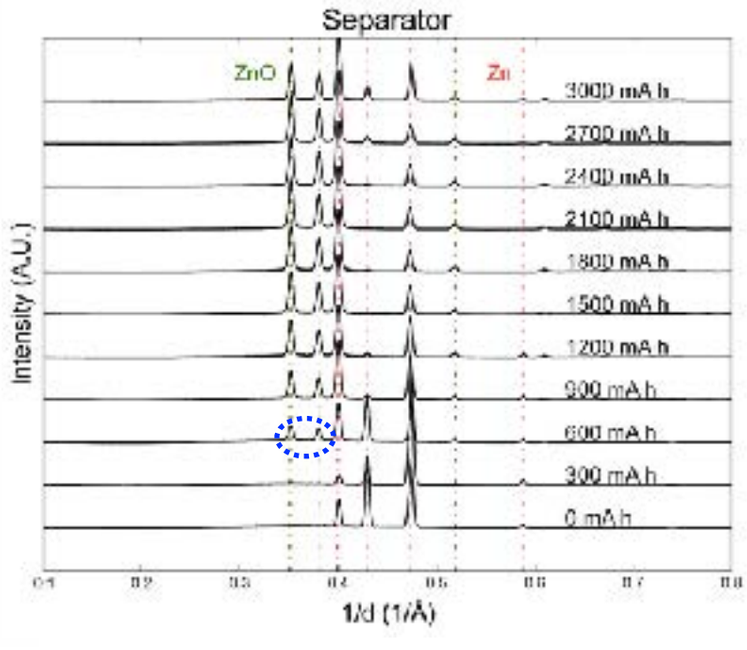
Why does this happen?

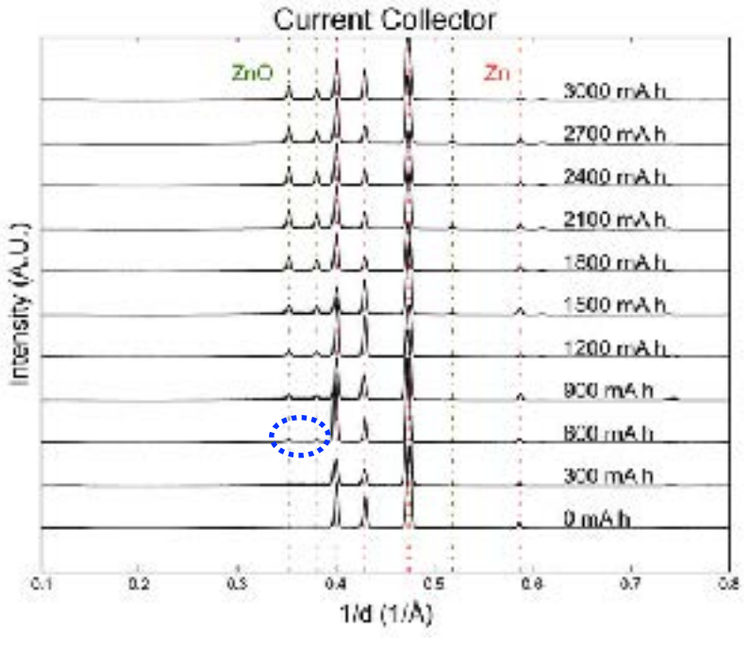


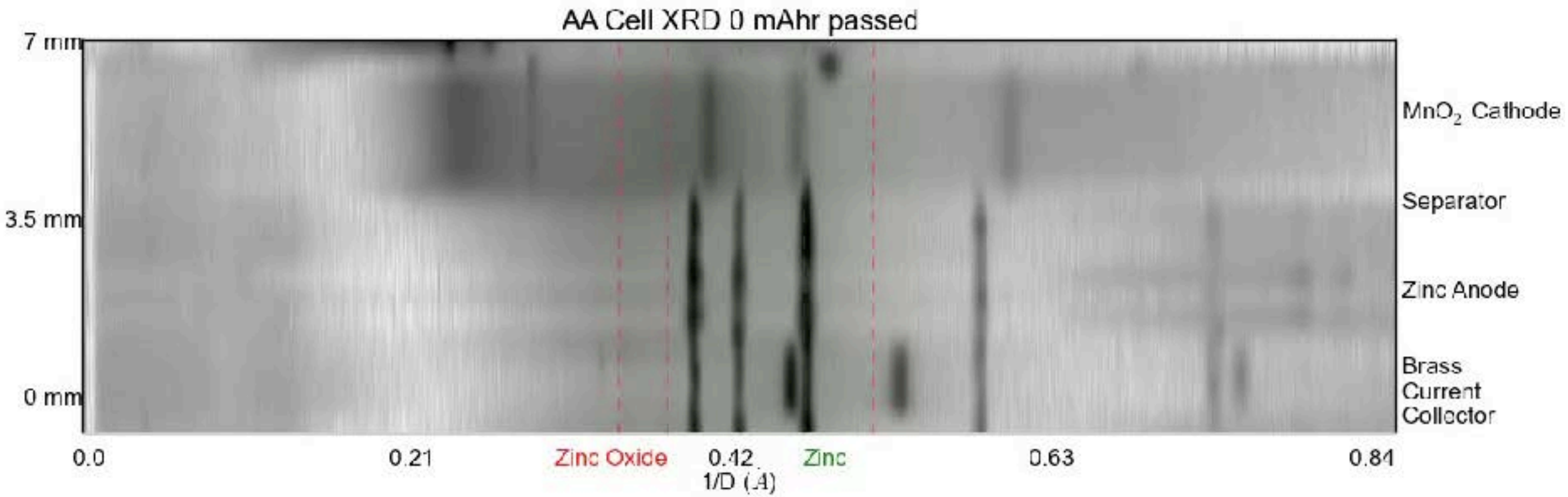
Bhadra *et. al. JMCA 2015*

A Complex Story





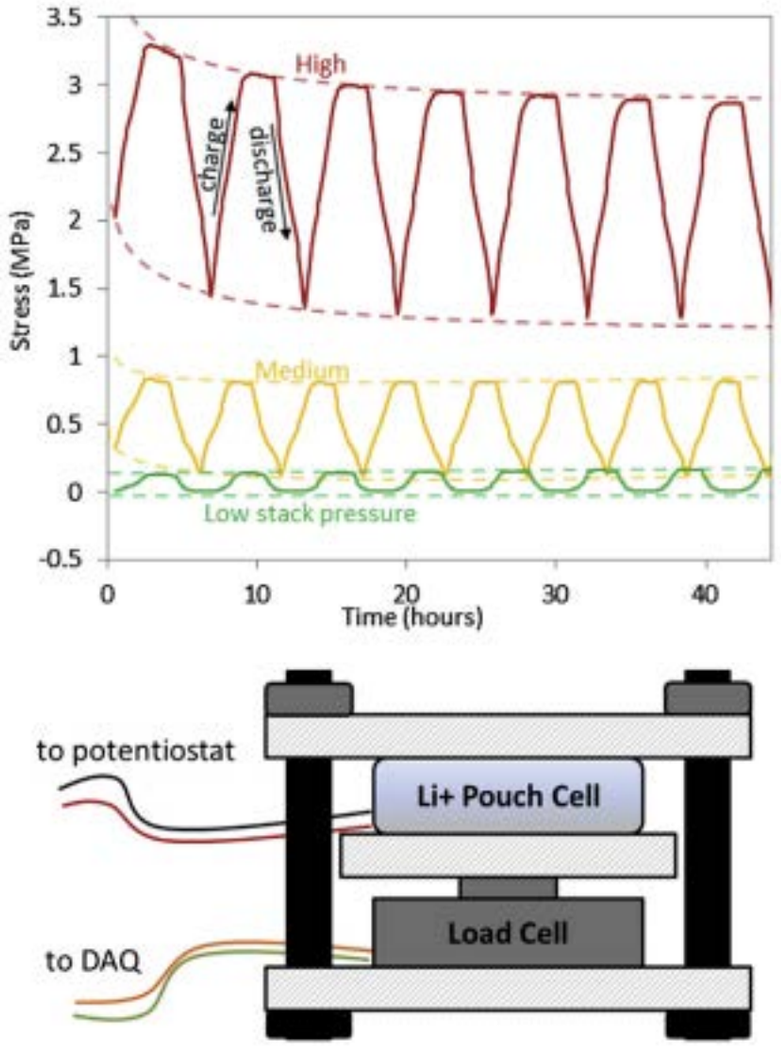




Bhadra *et. al. JMCA 2015*

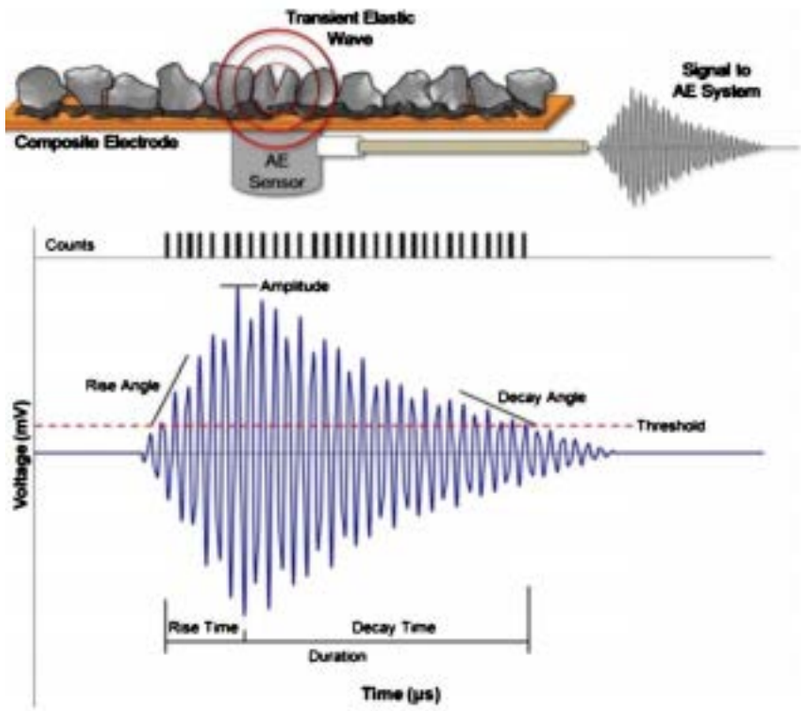
Mechanics and Batteries

Stress-strain



Cannarella et. al. *JOPS* 2014

Acoustic emmission



Rhodes et. al. *JECS* 2010

Large-scale delamination

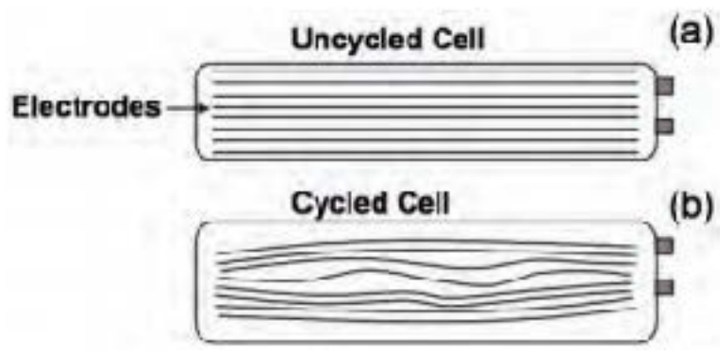
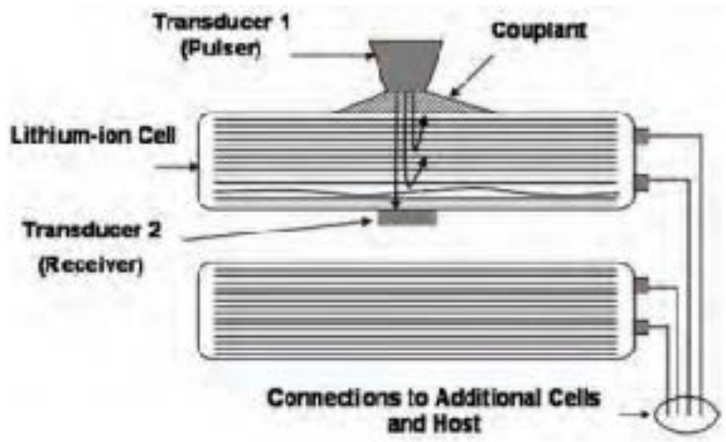


Fig. 2 *Illustration of (a) a new cell and (b) a cell after multiple charge/discharge cycles*



Sood et. al. *IEEE* 2013

Is there a global connection?

- Is there a way to study the electrochemical & mechanical behavior of *all* closed batteries, regardless of chemistry and geometry?
- Can we detect the subtle changes that occur in a battery during cycling?

Thoughts about closed batteries during cycling:

- Density distribution *must* shift
- Modulus distribution will change as well

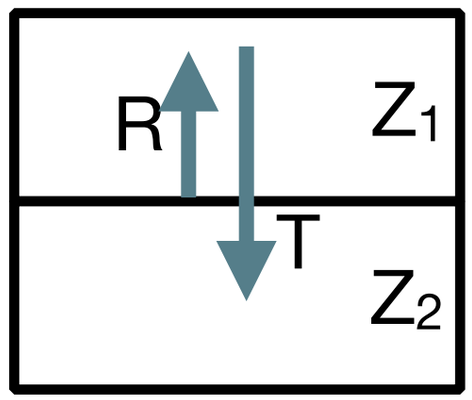
Basic Acoustics

Sound speed $c = \sqrt{\frac{K + \frac{4}{3}G}{\rho}}$

Longitudinal/Shear Modulus

Density

Acoustic impedance $Z = \rho \cdot c$



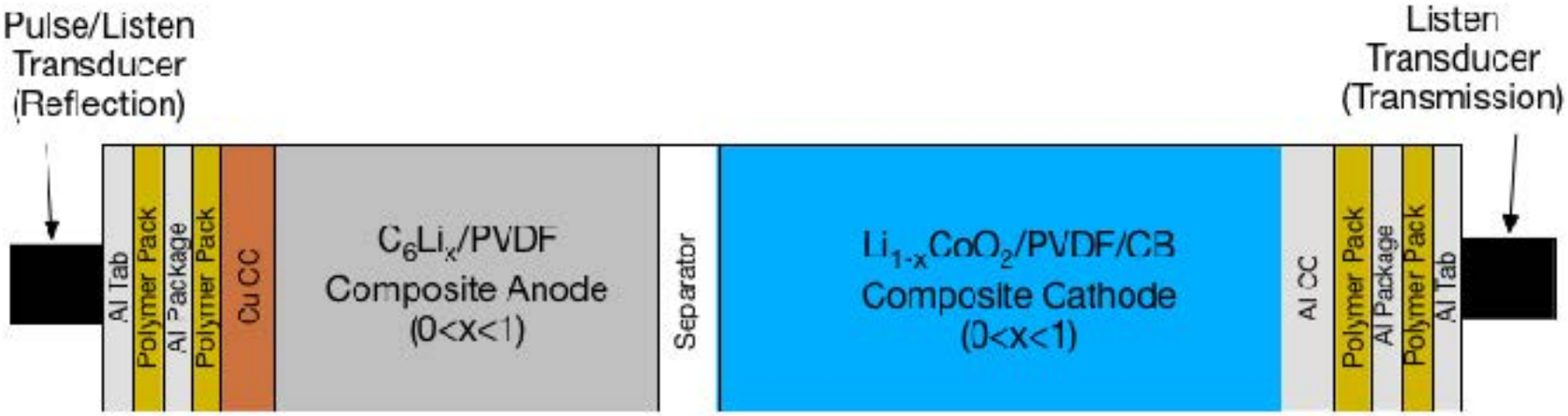
Hypothesis:
Cycling will affect the behavior of sound traveling through a battery

Simulation of pulse through a cell

1D continuity equations*

$$p_t + B \cdot u_x = 0$$

$$u_t + \frac{1}{\rho} \cdot p_x = 0$$



Hsieh et. al. E&ES 2015

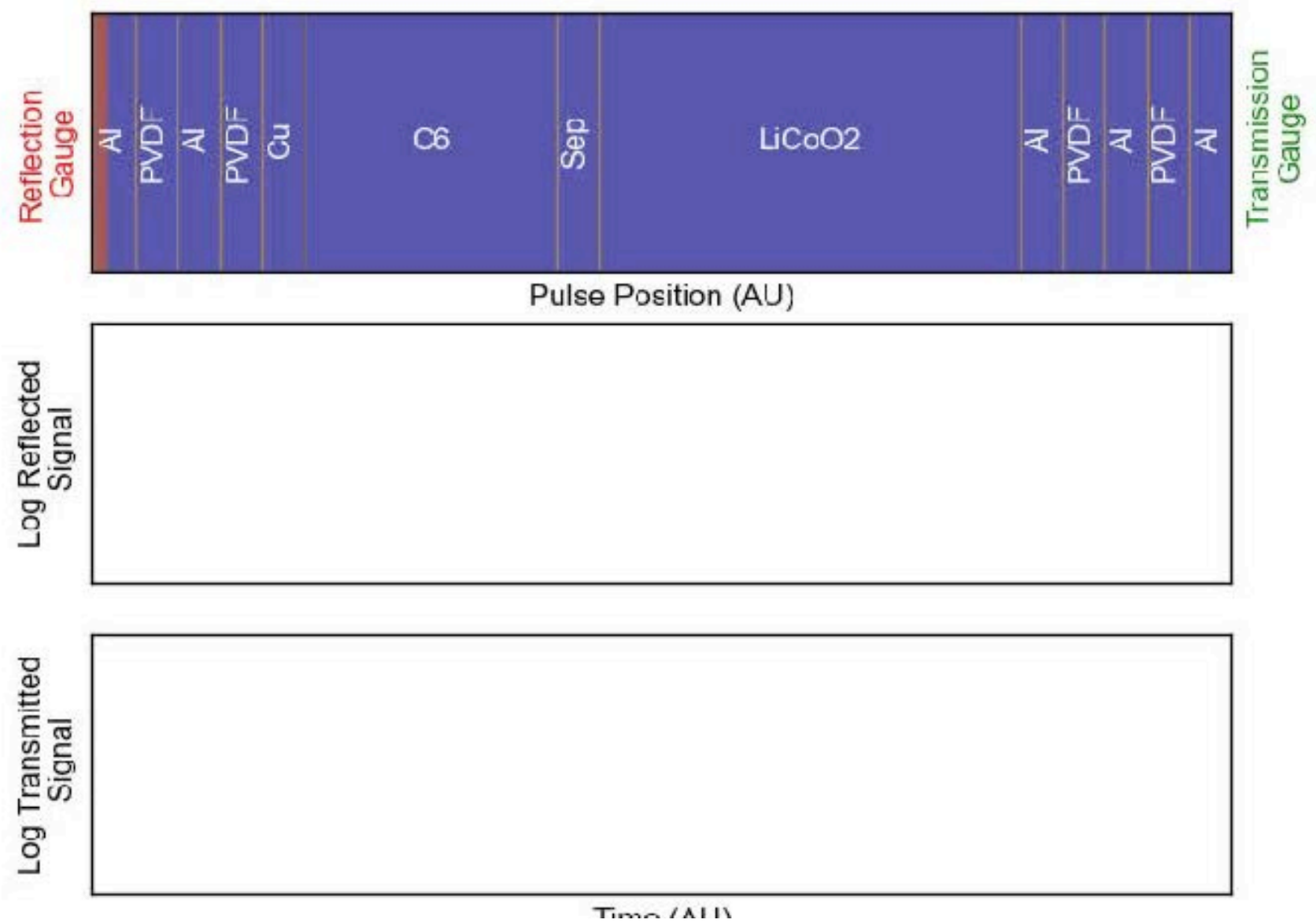
Simulation of pulse through a cell

1D continuity equations*

$$p_t + B \cdot u_x = 0$$

$$u_t + \frac{1}{\rho} \cdot p_x = 0$$

*solved in Clawpack

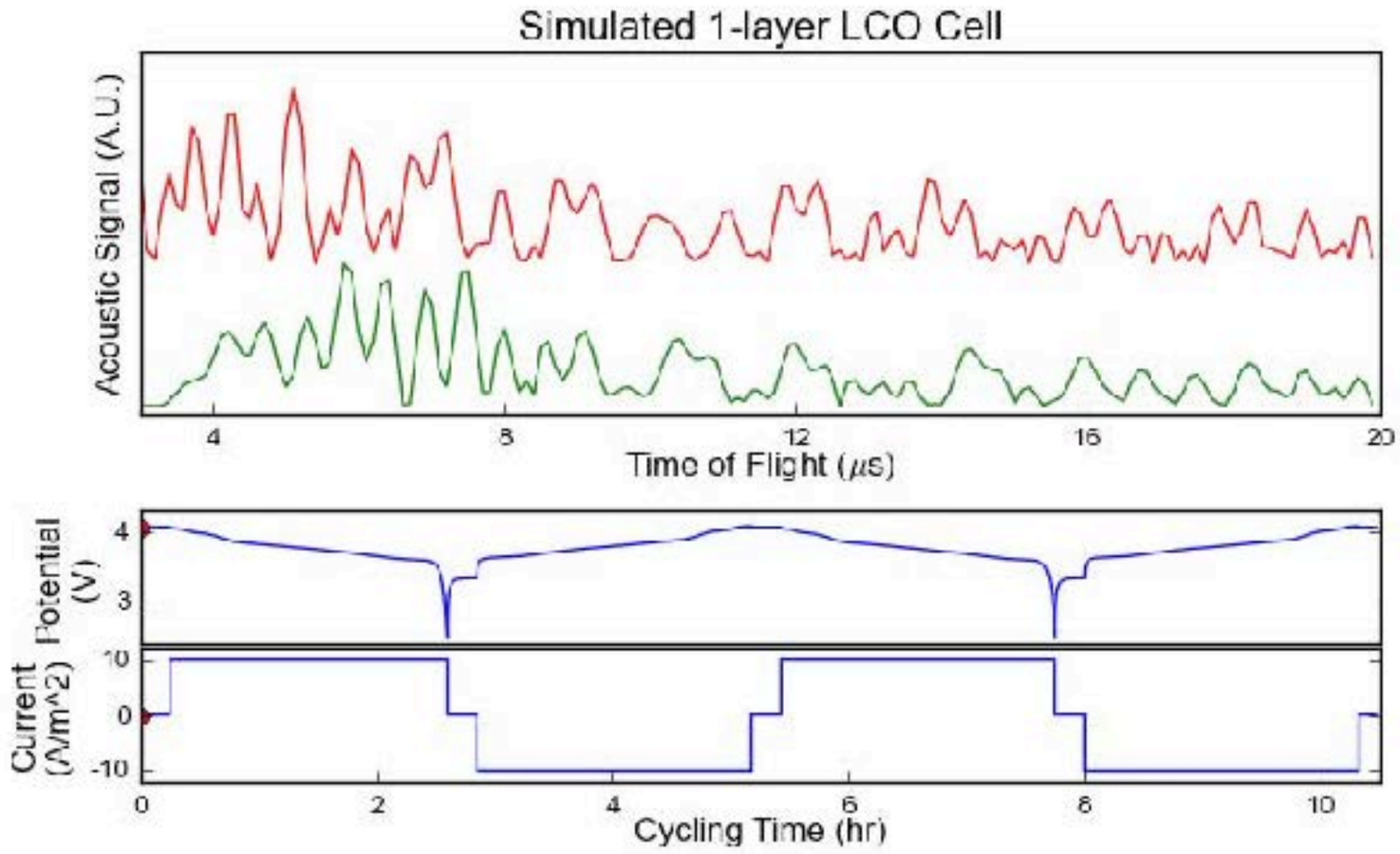


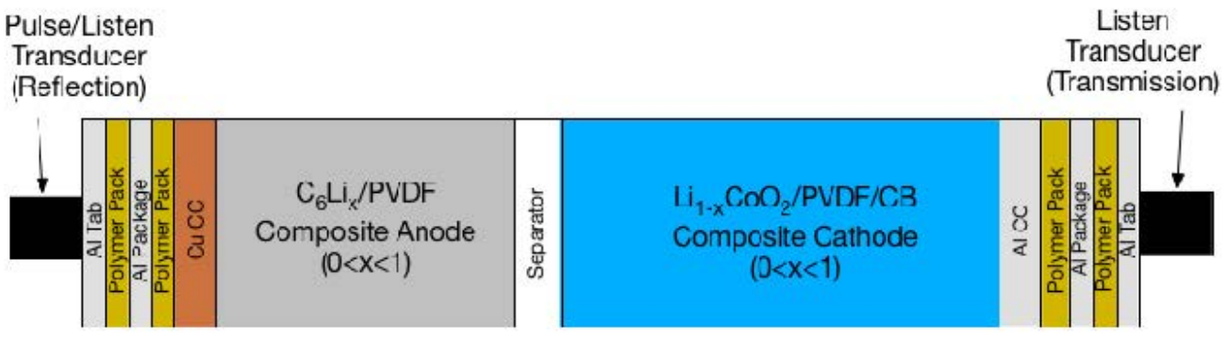
*Constant SOC

Hsieh et. al. E&ES 2015

EA Simulation

Waveform evolution
as f(SOC)*



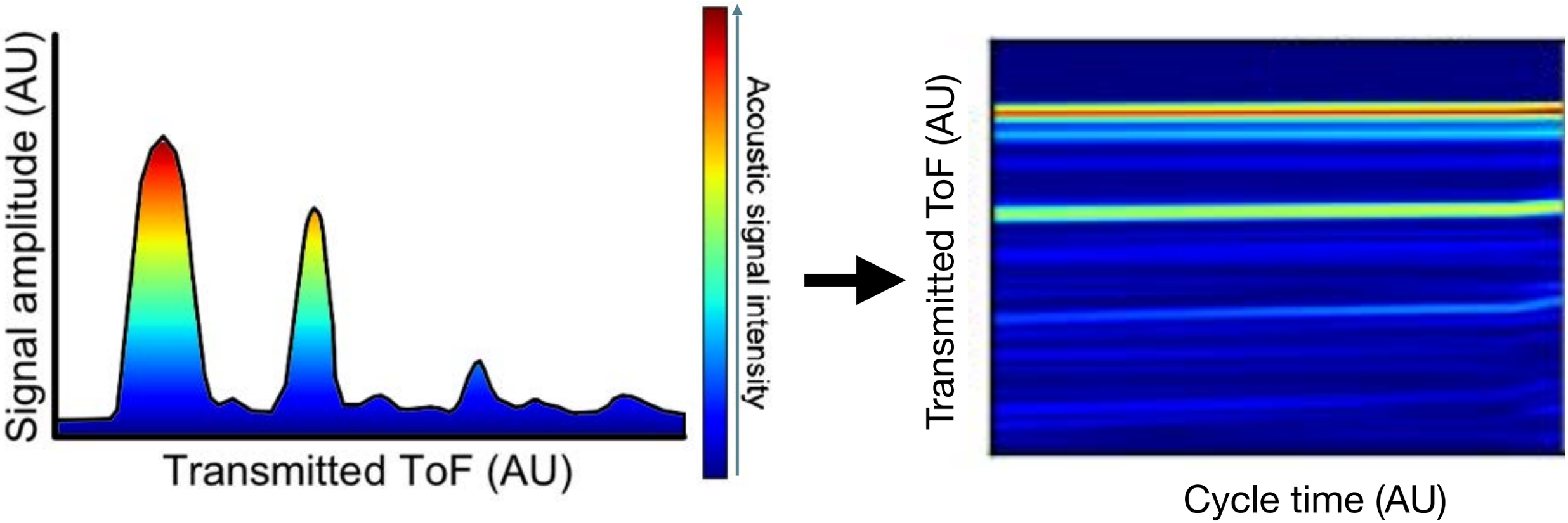


*calculated assuming only density changes

* $t_{ToF} << t_{cyc}$

Hsieh et. al. E&ES 2015

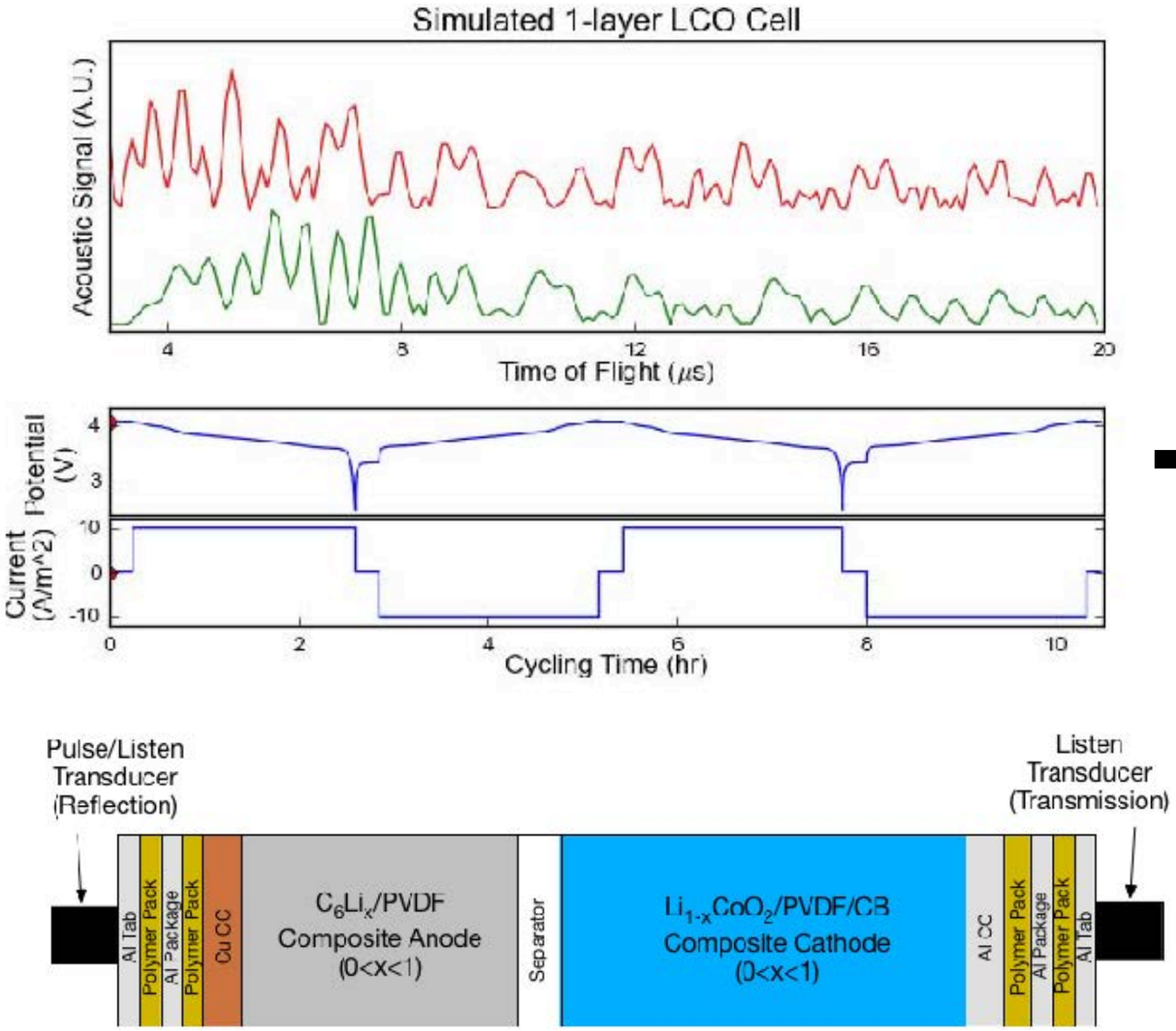
Visualizing EA data

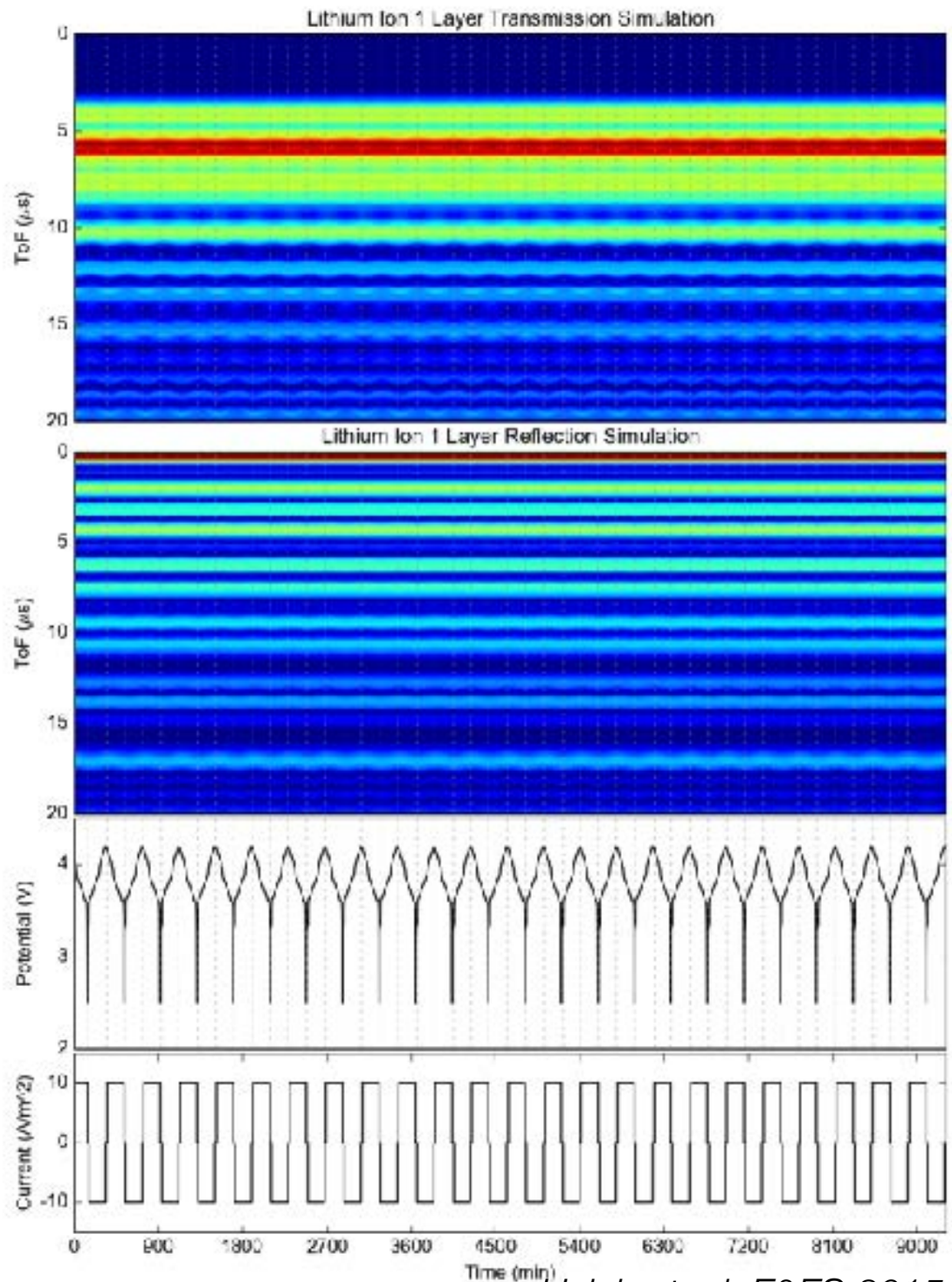


snapshot in cycling time, single SOC

time-resolved, changing SOC

EA Simulation

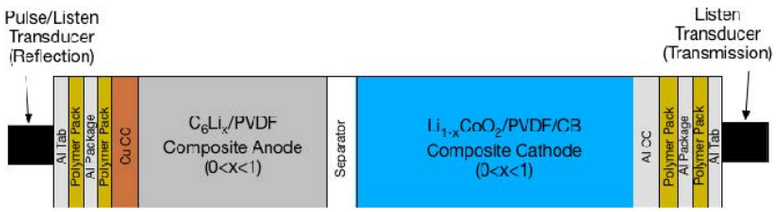


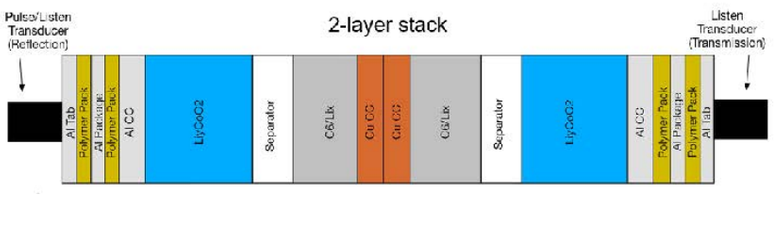


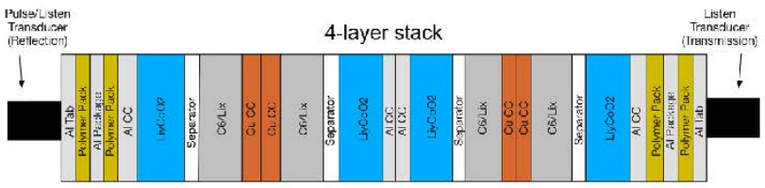
*assuming only density changes

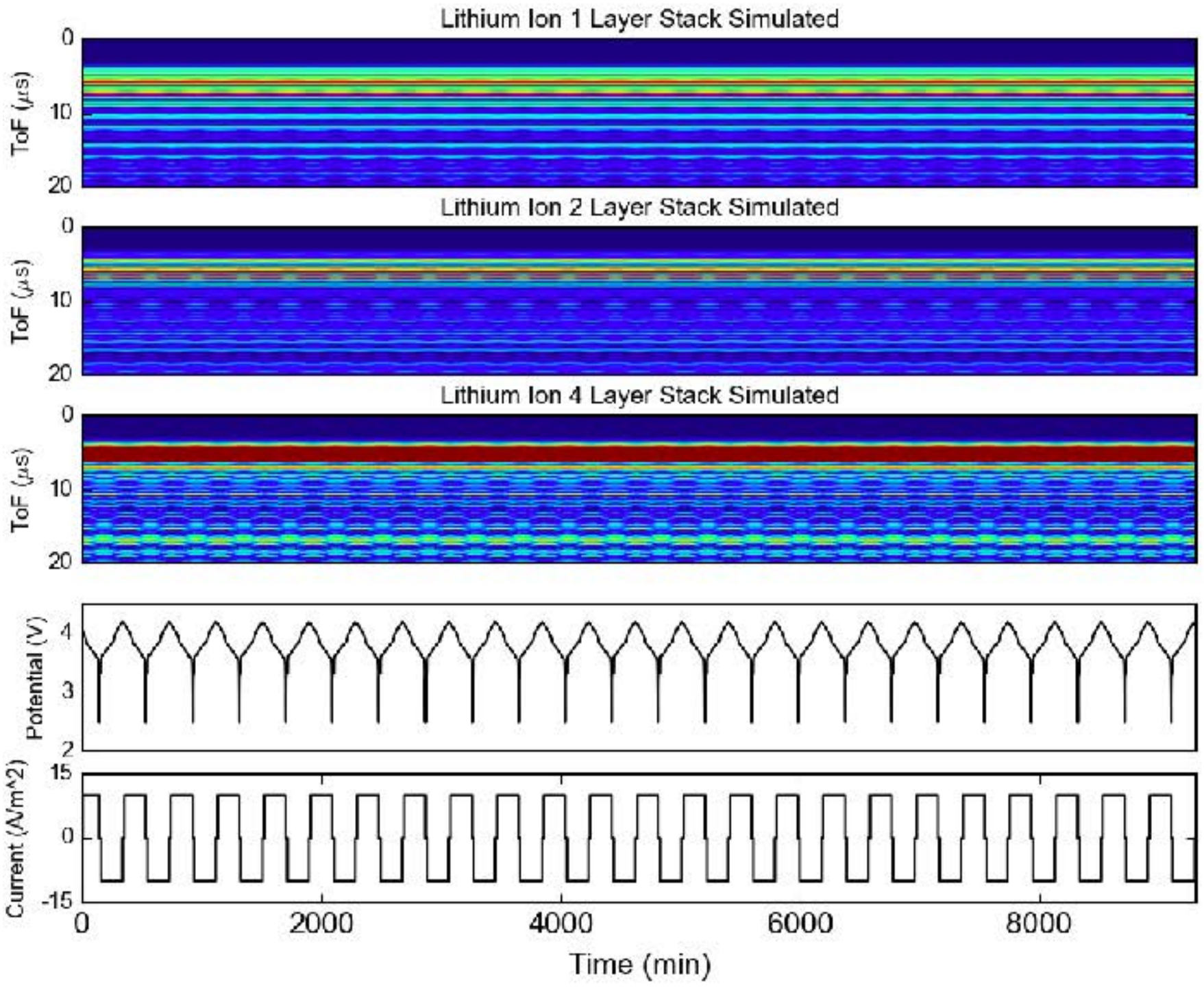
Hsieh et. al. E&ES 2015

More layers, more complexity









*assuming only density changes

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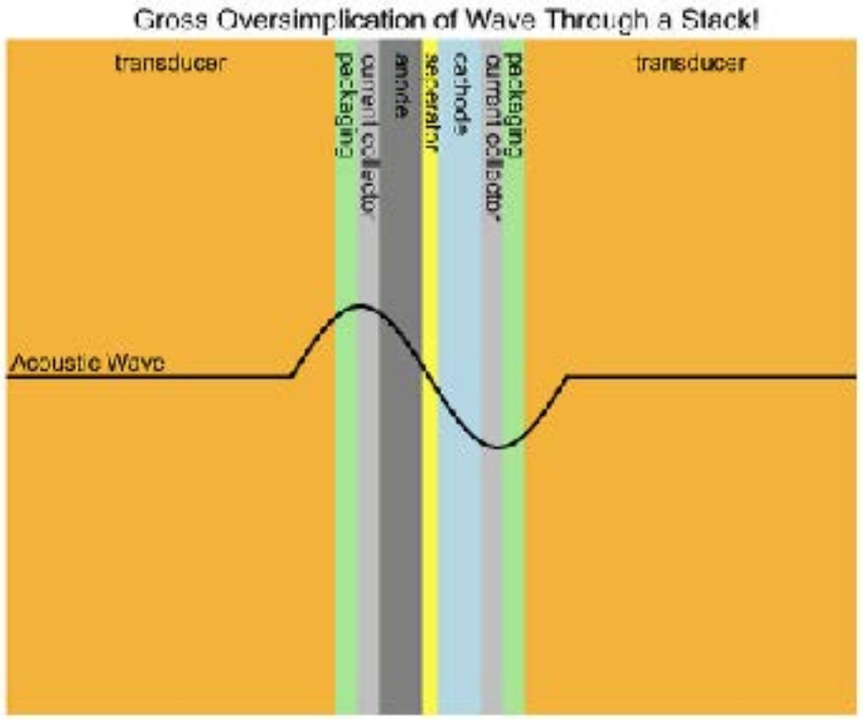
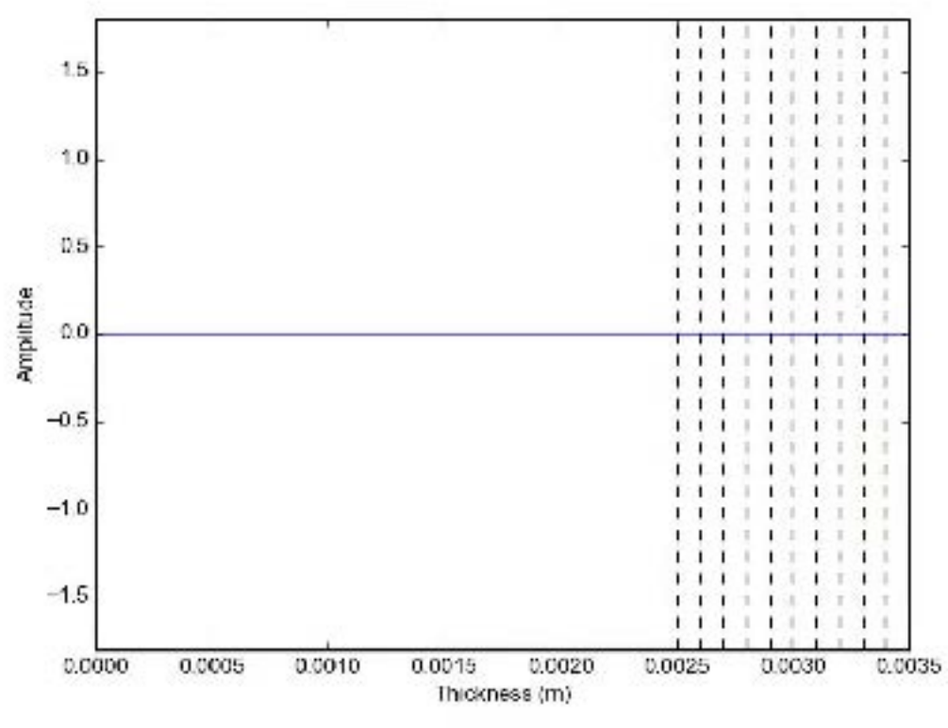
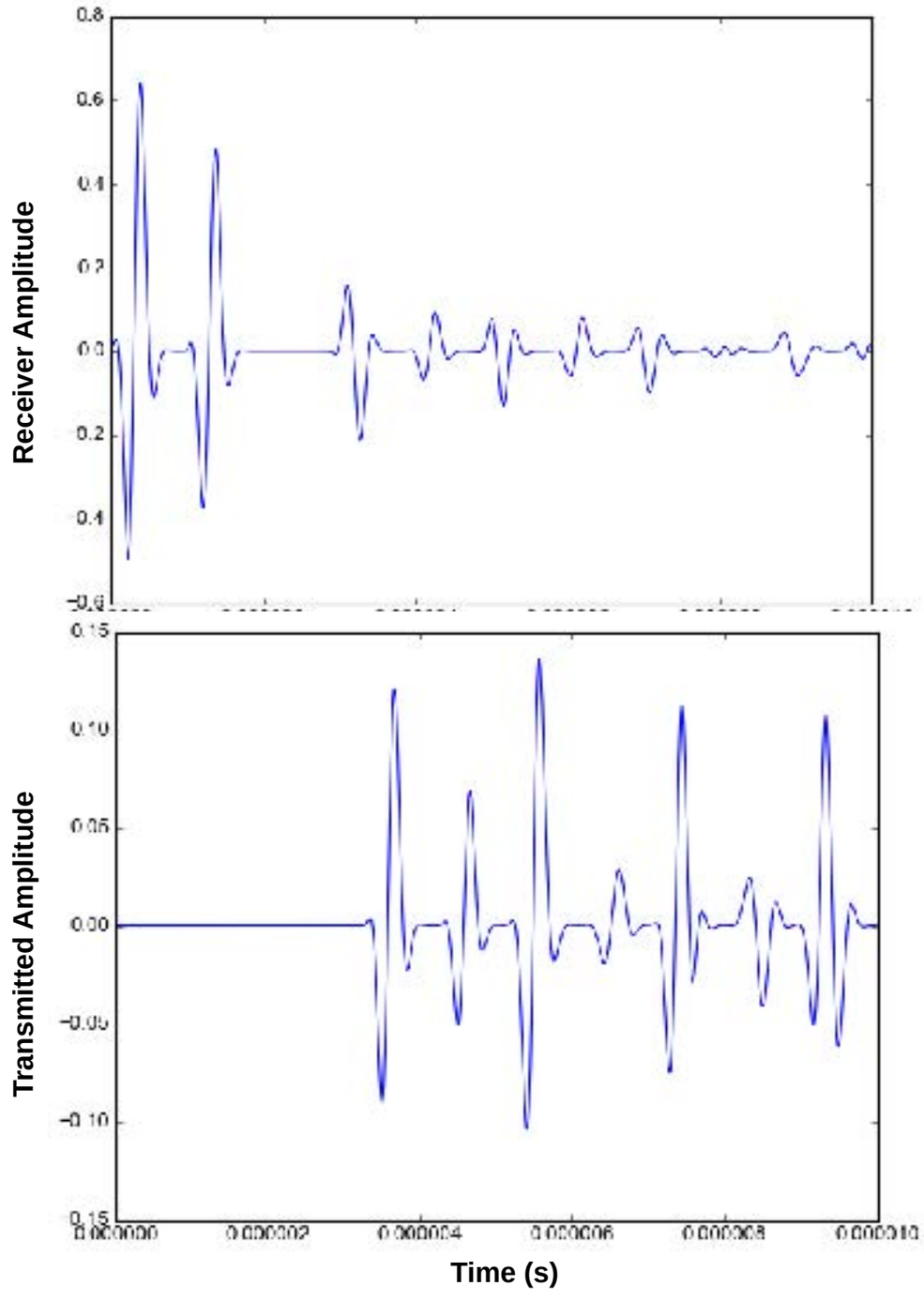
Sub Wavelength Handwave



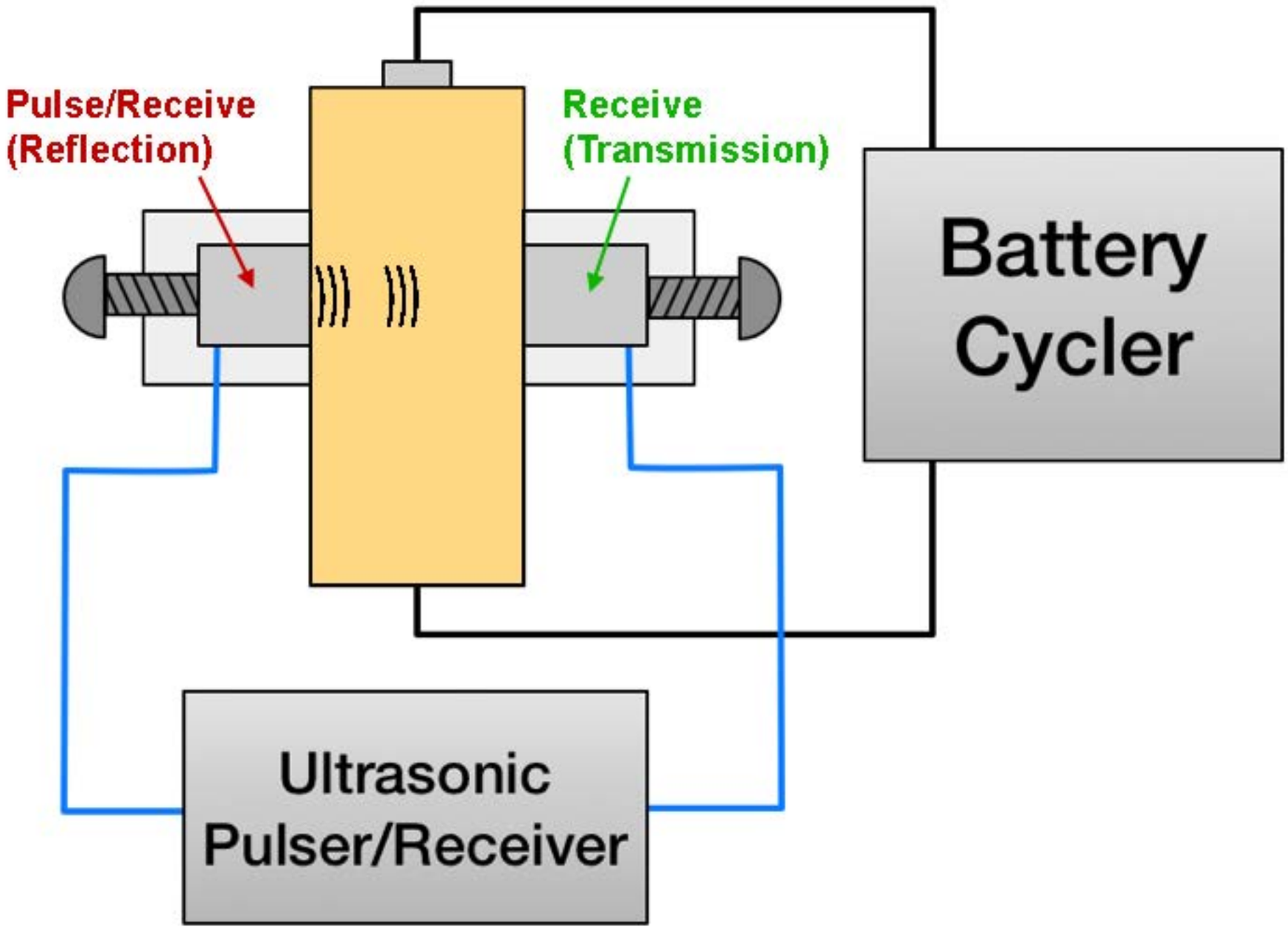


Effective Density Change *doesn't* show up if the frequency is too low (mass is conversed)

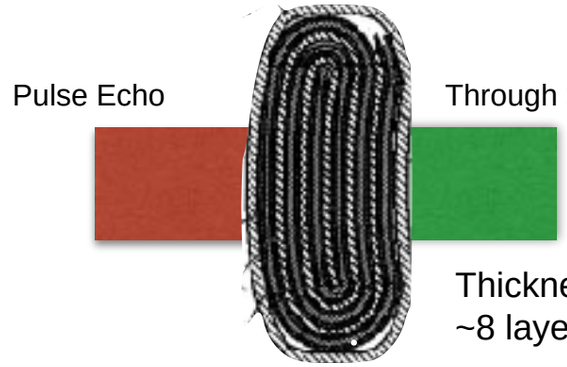
Elastic Modulus has no need to be conserved, so at low frequencies we are measuring a composite stack

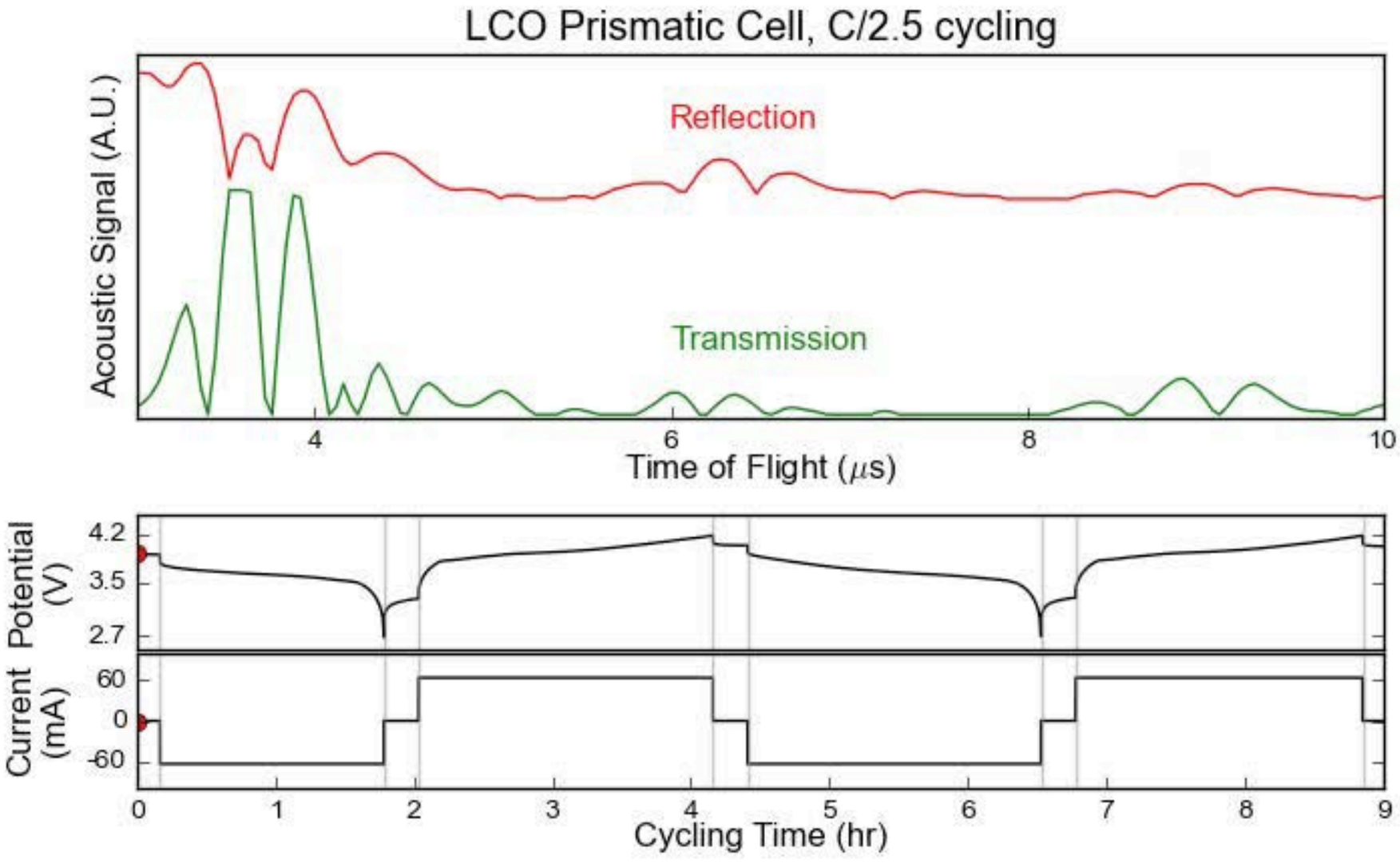


Experimental Setup



LCO Prismatic





*experimental data

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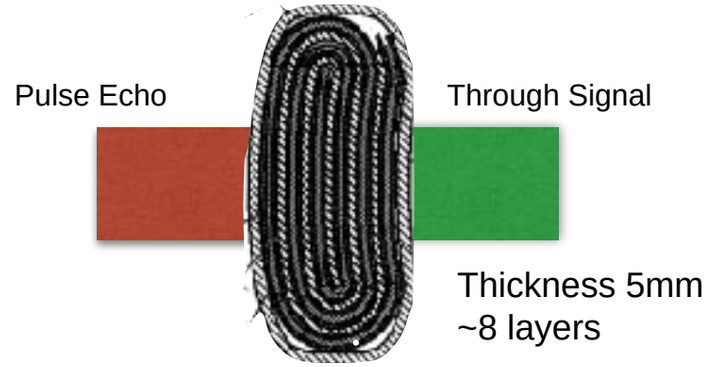
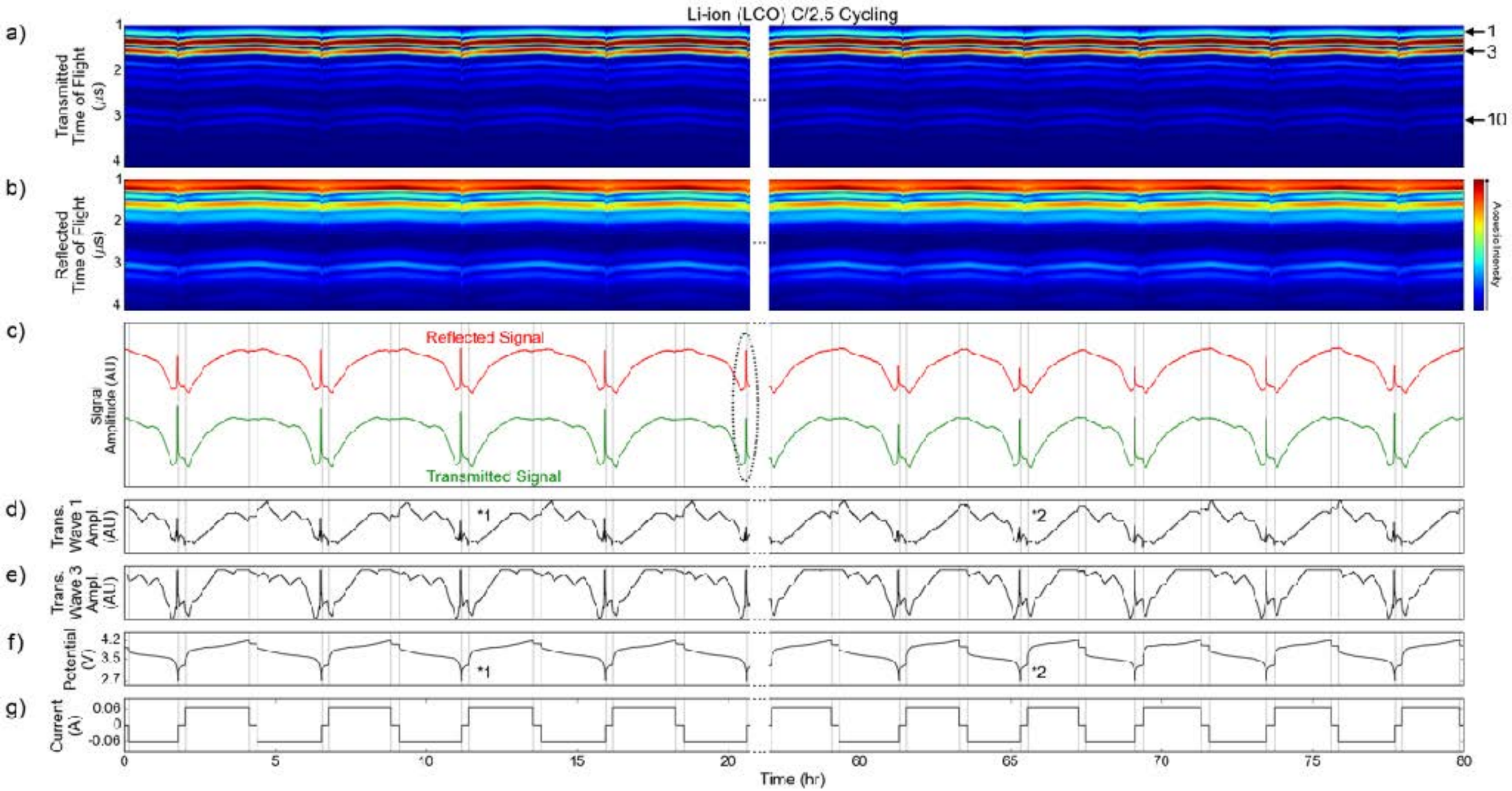
LCO Prismatic





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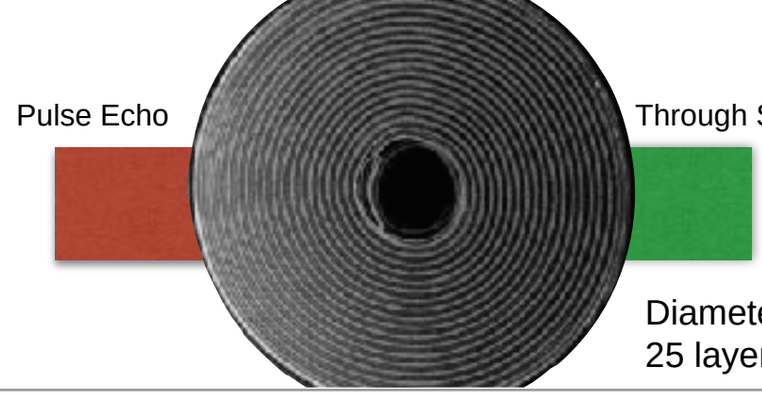
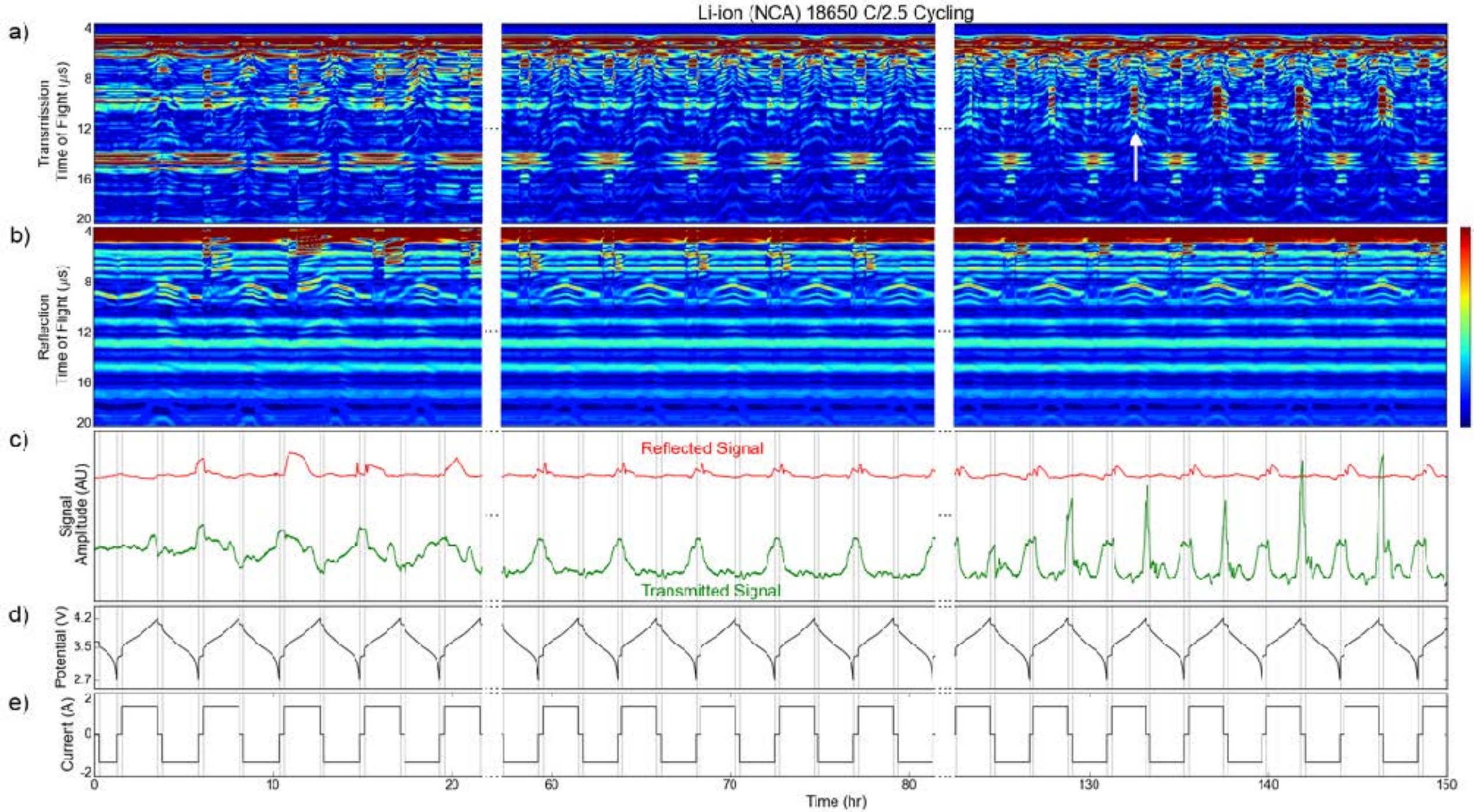
NCA 18650





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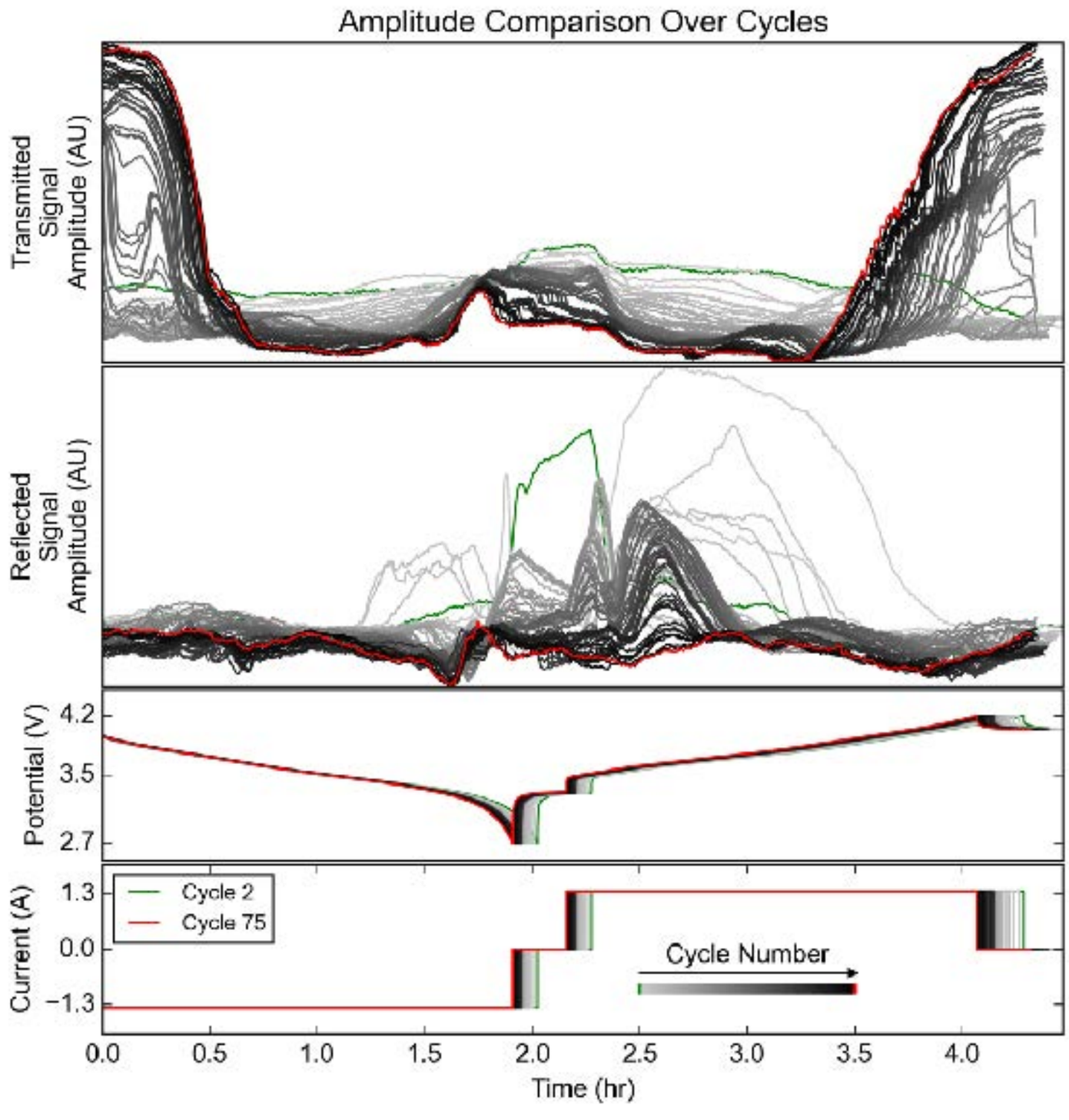
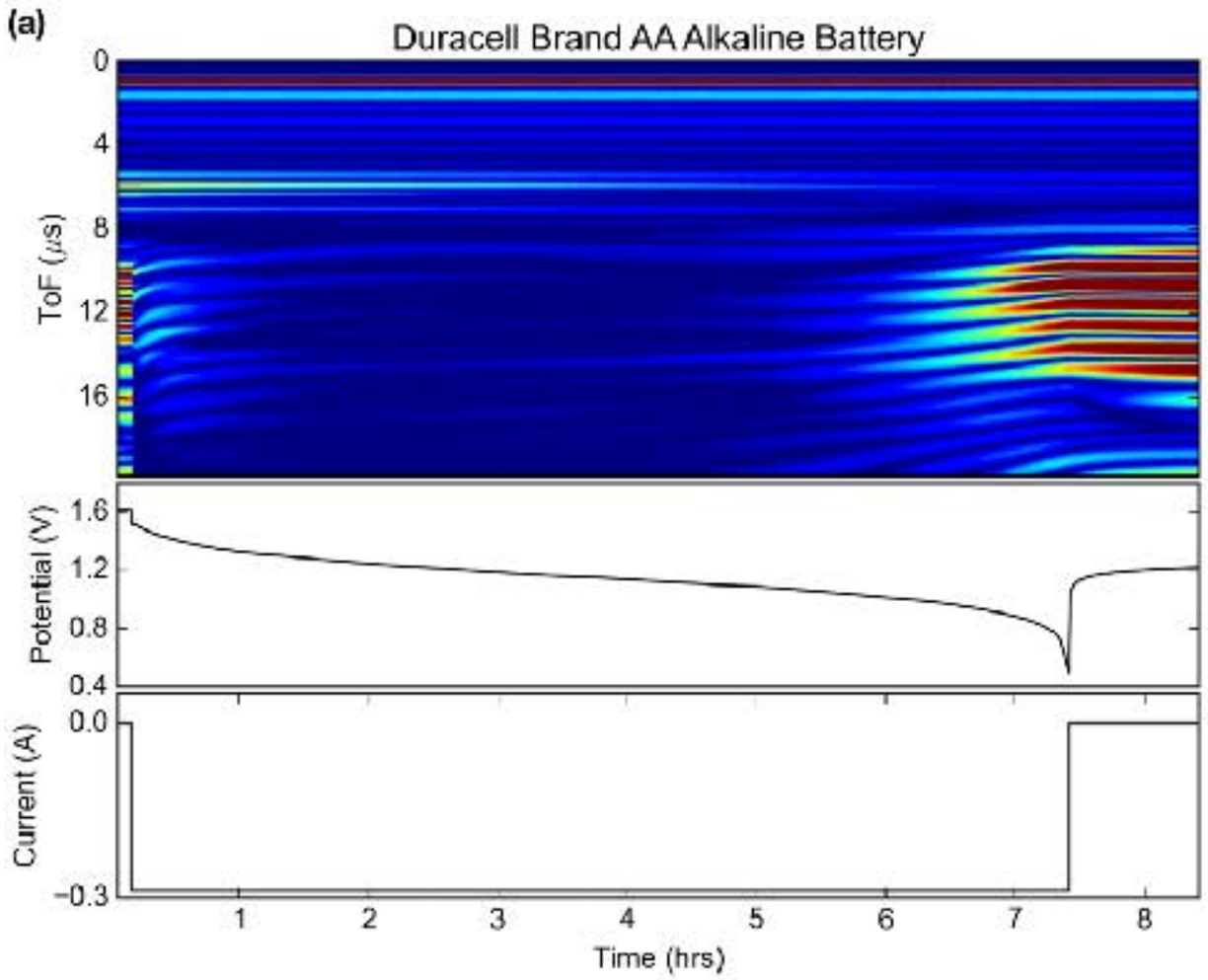
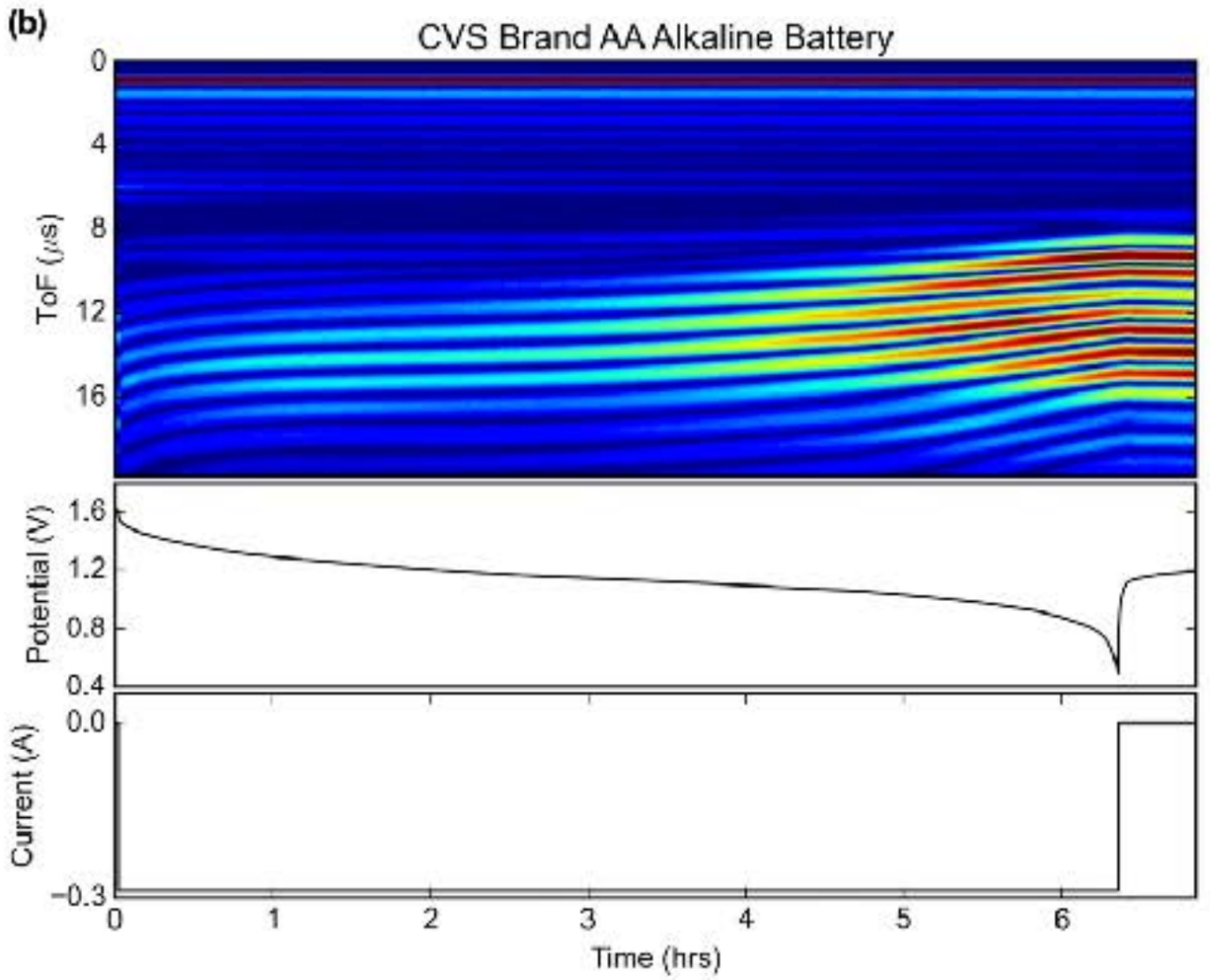
NCA 18650 - cycle by cycle



Hsieh et. al. E&ES 2015

Alkaline Brand Comparison

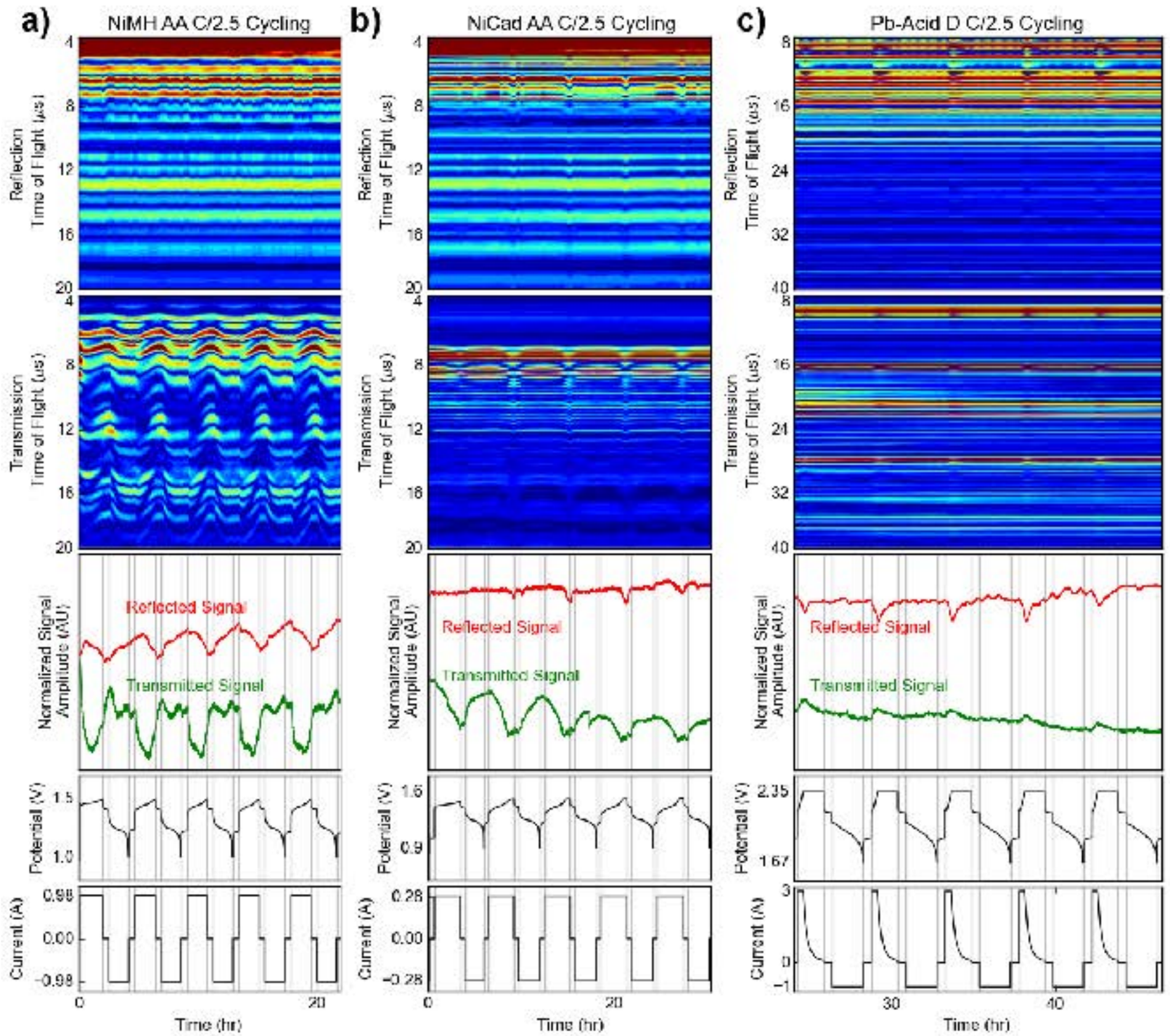




Hsieh *et. al.* E&ES 2015

Bhadra *et. al.* JMCA 2016

Chemistry/geometry specific



In Progress

Summary

- Sound *must* be an indicator of battery structure, state of charge, and state of health due to the basics operation of a closed electrochemical energy storage
- In combination with traditional tools, we can provide direct structural information on real batteries, in real time.