Phase stability and lithium loading capacity in a liquid scintillation cocktail

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Neutrino detection by LSC

- Inverse beta decay (threshold 1.8 MeV)

$$\overline{\nu}_e + p \rightarrow e^+ + n$$

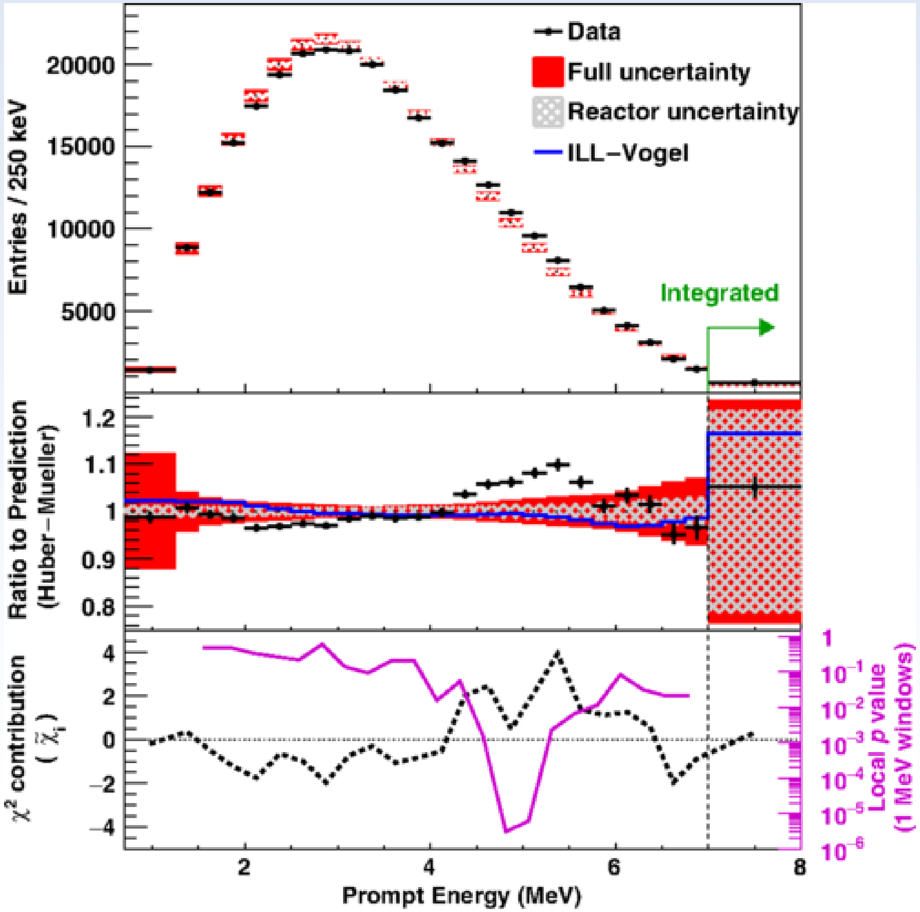
- Proton-rich target for good detection efficiency and energy resolution
- Loading cocktail with a neutron capture agent (Gd or ^{6}Li) further improves performance

$$n + {}^6\mathrm{Li} \rightarrow \alpha + t + 4.78\ \mathrm{MeV}$$

- Timing and pulse shape discrimination to reduce backgrounds from gamma-rays and neutrons

High-background applications

- Many large-scale liquid scintillation detectors are intended for detection of solar or cosmic neutrinos, requiring ultra-low backgrounds*
- Recent interest in the reactor flux and spectrum anomalies** has prompted the design of experiments intended to operate with much higher neutrino flux
    - With volumes measured in thousands of liters, price is a concern



*Benziger and Calaprice (2016), Large-scale liquid scintillation detectors for solar neutrinos, Eur. Phys. J. A 52, 81.
**Ashenfelter, et al. (2016), The PROSPECT physics program, J. Phys. G, 43, 113001; An et al. (2016), Measurement of the Reactor Antineutrino Flux and Spectrum at Daya Bay, Phys. Rev. Lett. 116, 061801.

Picking a LS cocktail to load

- Earlier work at NIST* developed a formula based on Quickszint, loaded with up to 0.40 % ^{6}Li by mass
  - H/C: 1.5
- Quickszint no longer available.
  - Options?

*Fisher, et al. (2011), NIMA 646, 126-134
Bass, et al. (2013), ARI

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Scintillant	H/C
Ultima Gold	1.46
HiSafe 2	1.03
Ultima Gold AB	1.51
HiSafe 3	1.47
HionicFluor	1.73

***Certain commercial materials are identified to foster understanding. Such identification does not imply recommendation by the National Institute of Standards and Technology, nor does it imply that they are necessarily the best available for the purpose.*

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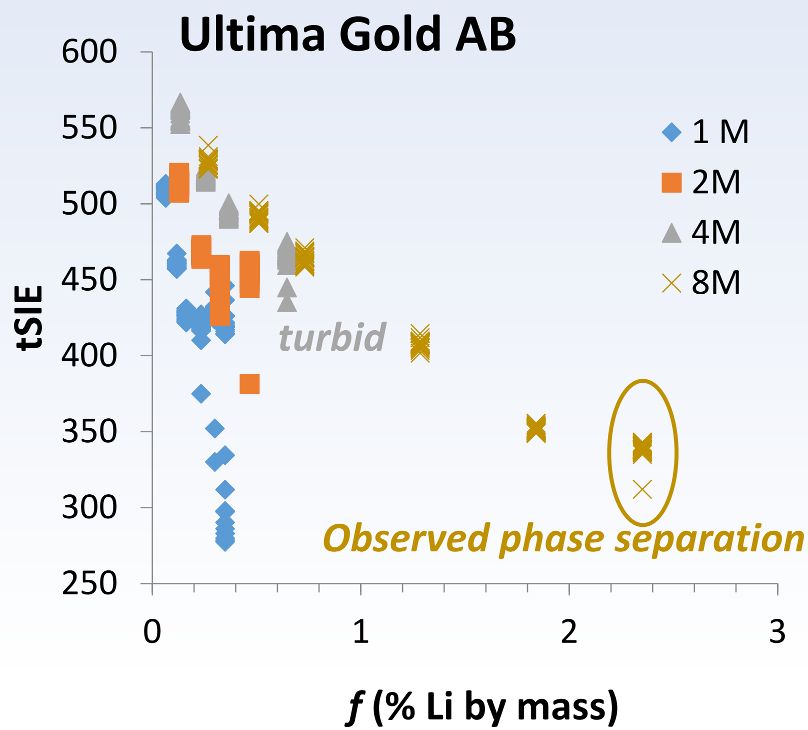
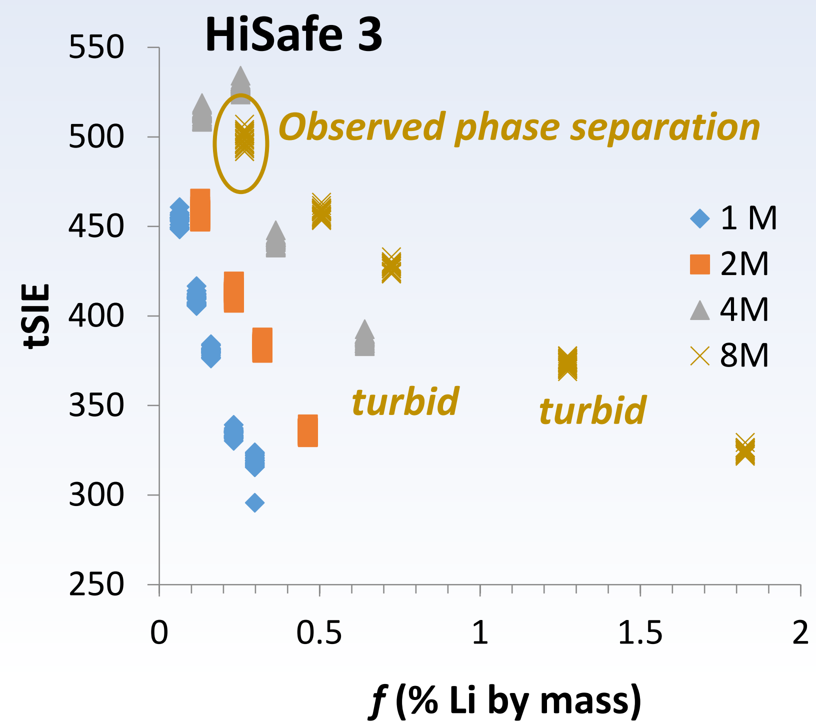
Ultima Gold AB and HiSafe 3 show the best Li loading capacity





In a long term experiment…

- Phase separation: separation into aqueous and organic domains

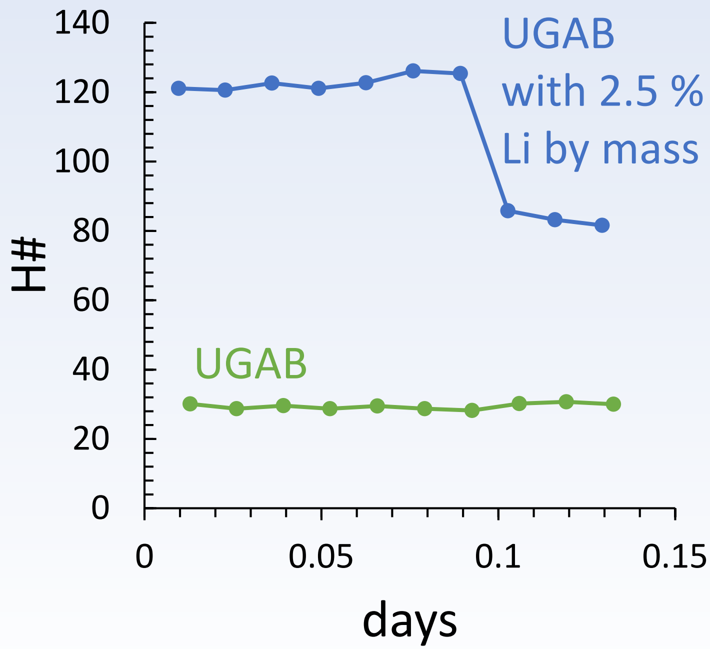
- Turbidity: cloudiness due to presence of many large particles

A true microemulsion is thermodynamically stable, optically isotropic, and has relatively low viscosity. Aqueous domains (reverse micelles) are of nanometer dimension.

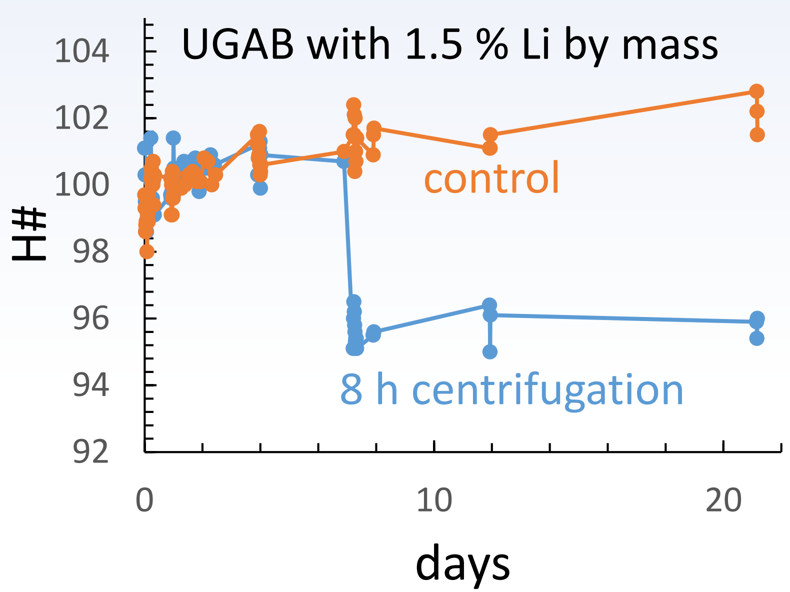
The eye can be deceived

- Sometimes, an agitated emulsion looks like a microemulsion
- Over time, thermodynamic instability drives agglomeration of aqueous domains → phase separation
- In a multi-year experiment, phase stability is absolutely essential

Aging samples

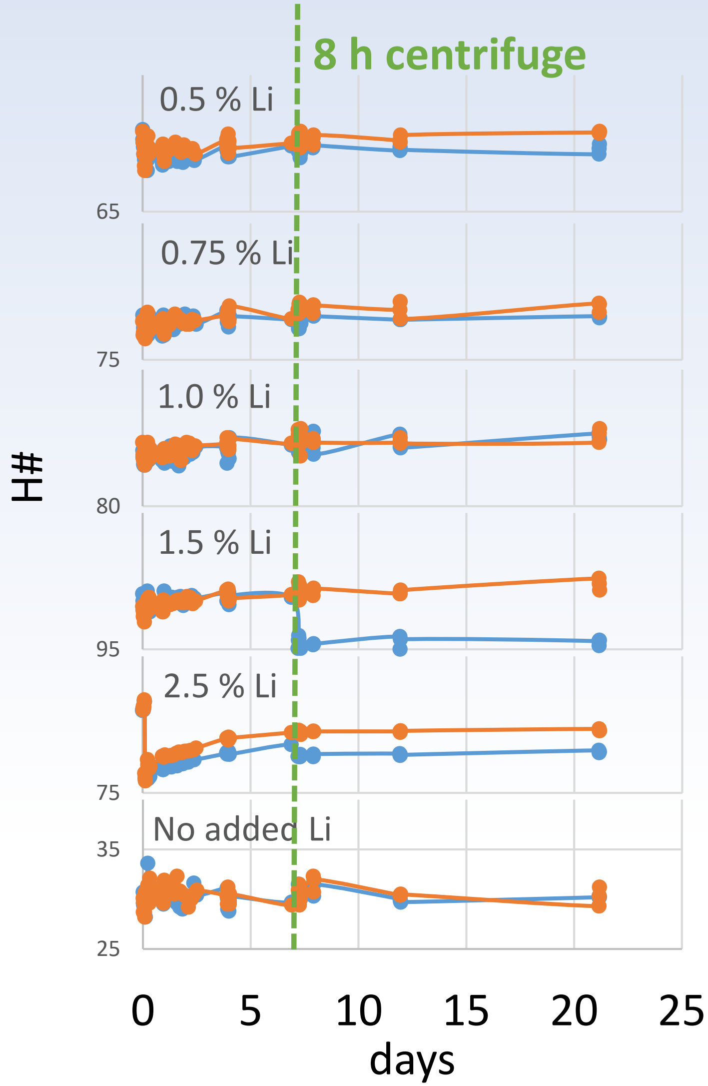


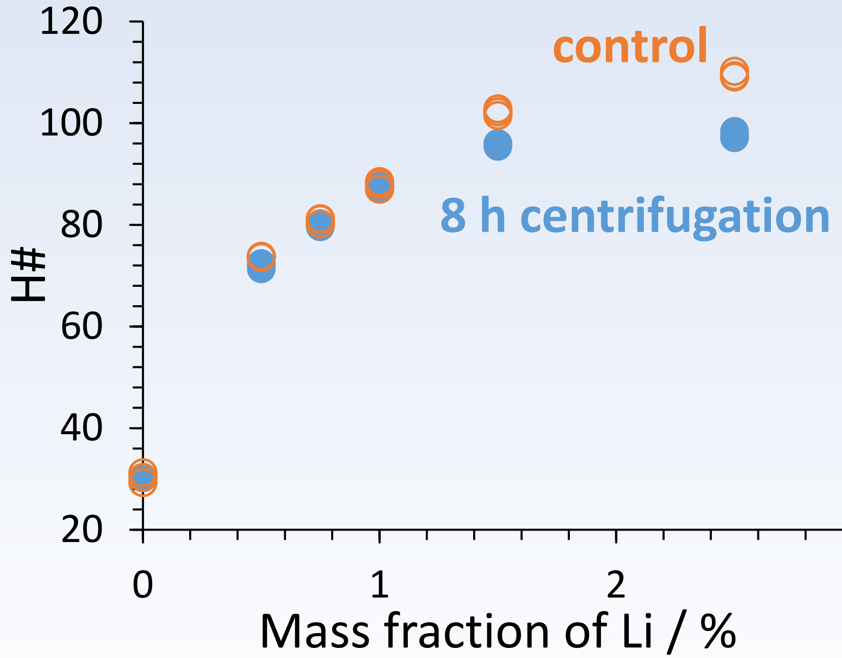
- Quench indicating parameters based on the Compton spectrum of a scintillant are sensitive to phase dynamics



- Centrifugation can drive phase separation

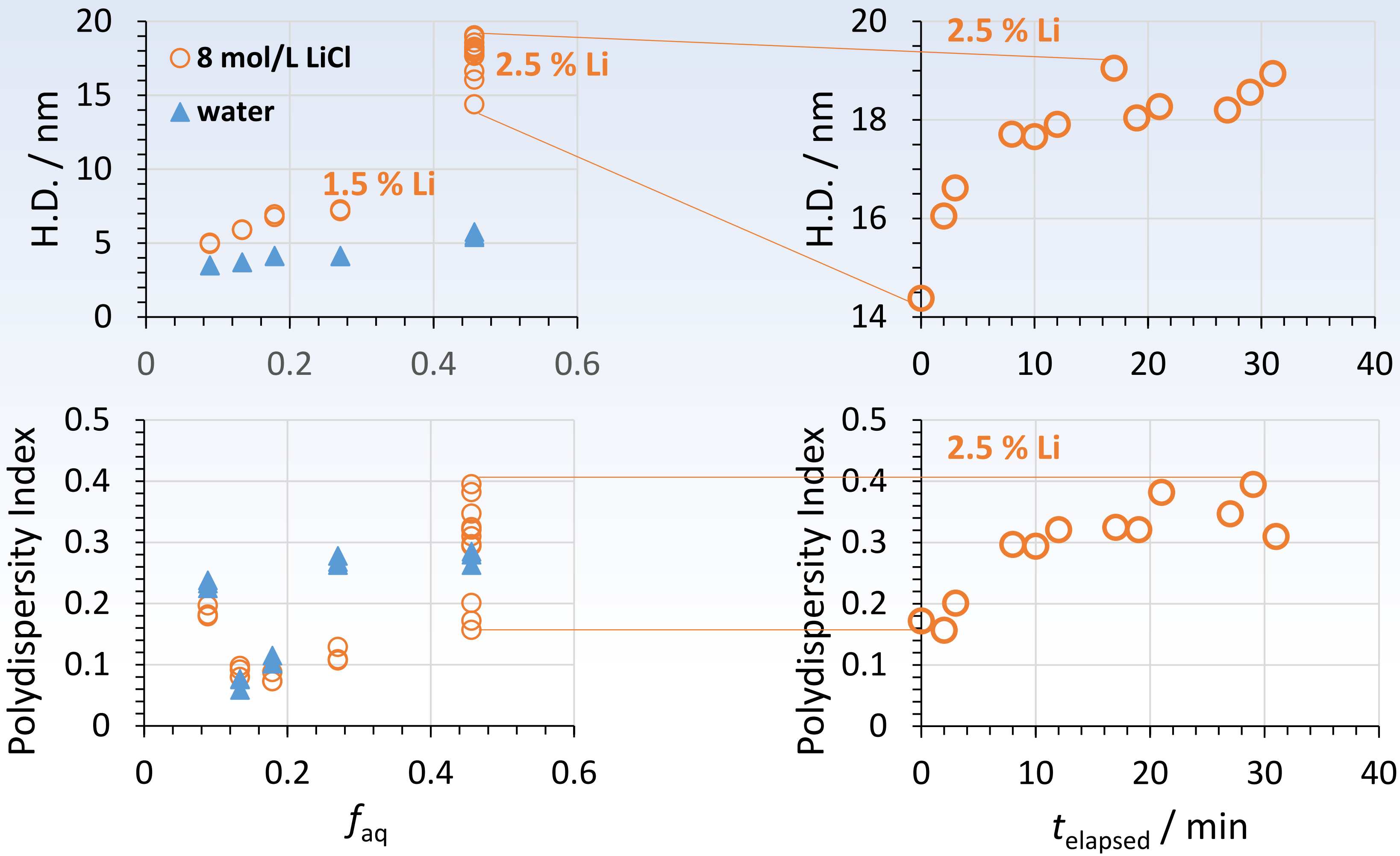
Aging samples





- Loading up to 1.0 % Li by mass (with 8 mol/L LiCl) produced stable microemulsions

Dynamic light scattering



Conclusions: it works

- Very high loading
  - Using 8 mol/L aqueous LiCl, we achieved stable loading of up to 1 % Li by mass in Ultima Gold AB
- Cheap
  - Commercially available scintillant and a simple loading procedure
- Our formulation is being deployed in experiments at NIST
- We have investigated light yield, optical transmission, and material compatibilities for the loaded UGAB (to be reported)

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