

Accelerated acoustic prediction of aging and failure



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Wet Systems (Project Review #2, 2025)

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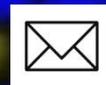
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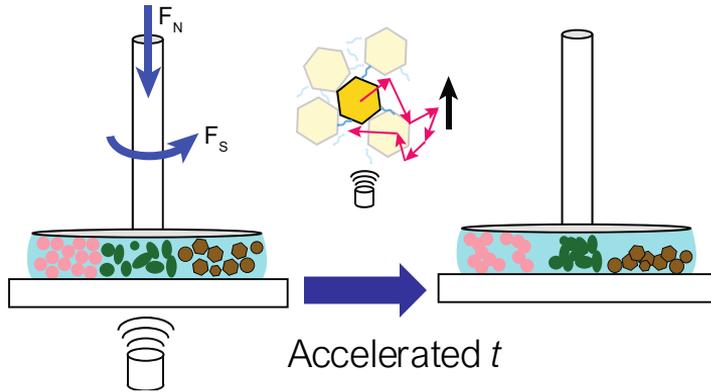


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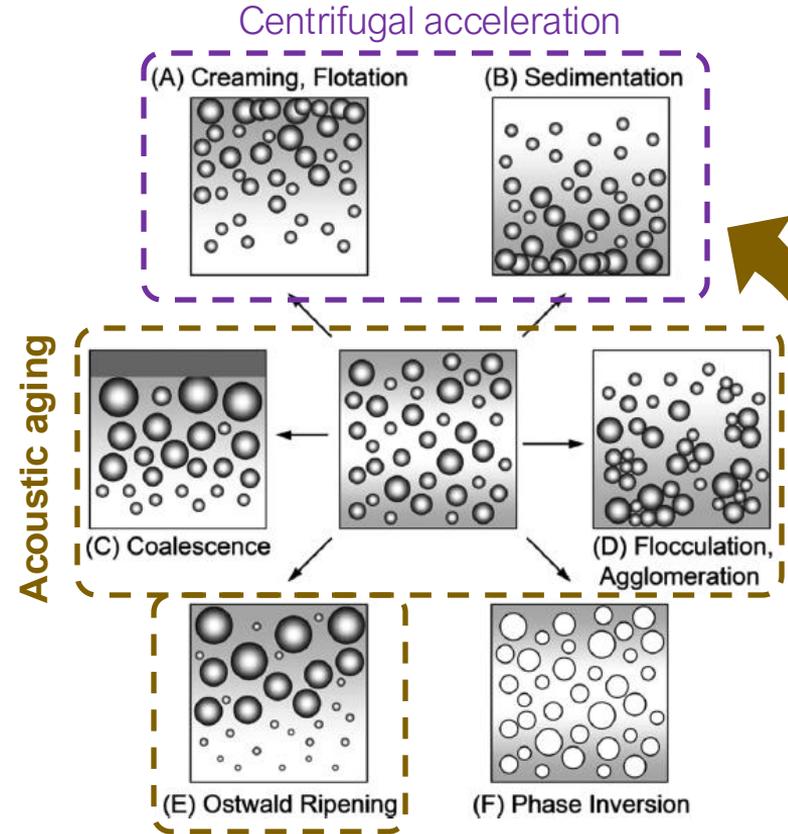
Project summary



Goal: Develop an acoustic platform to speed up aging without heating or centrifuging

Main findings in Y2

1. Phase separation is accelerated by 1.5-4x
2. There is often a delayed phase separation
3. Microscopic changes can be subtle

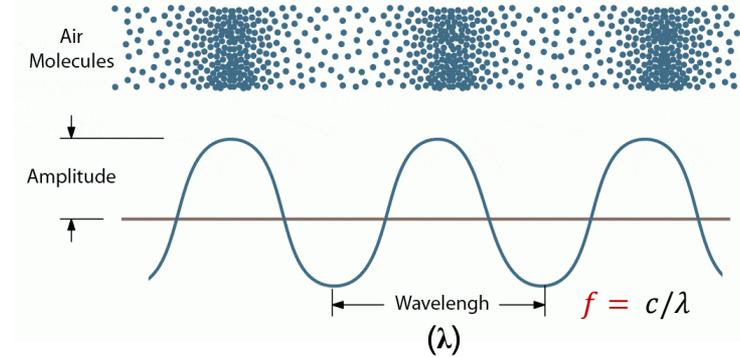


Acoustics as an alternative aging method

Amplitude (a): Maximum distance a wave moves from its resting position

Frequency (f): Number of oscillations or vibrations that the particles of the liquid undergo per second

Intensity (P): Amount of power a sound wave carries per unit area



Acoustic power

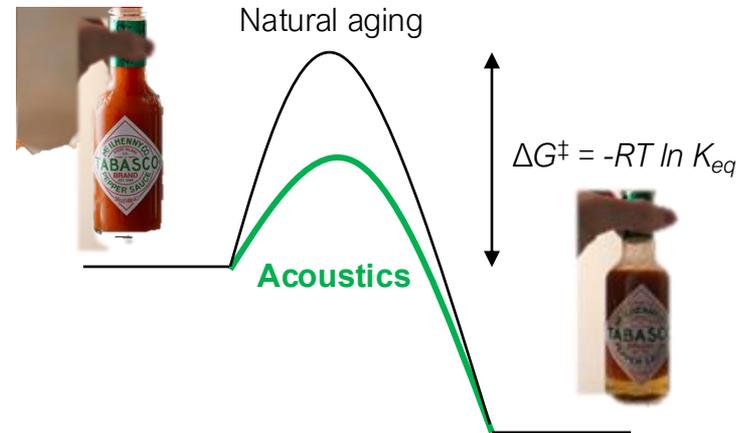
$$P = \frac{p^2}{\rho c}$$

Acoustic pressure

$$p = 2\pi f a \rho c$$

f from power amplifier (10 – 50 kHz)

a measured by laser doppler vibrometer

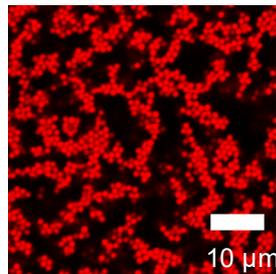
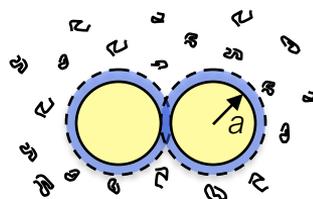


Experimental method and materials

Acoustic aging setup

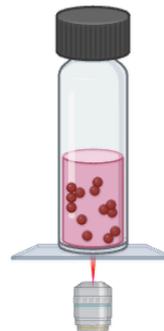
- Frequency range: 10 - 50 kHz
- Transmittance: 20 - 30%
- Minimal attenuation from viscous losses
- Acoustic power range: 0.2 - 0.6 W
- Acoustic pressure range: 30 - 50 kPa

Colloidal gel ($\sigma_y \sim 0.1$ Pa)

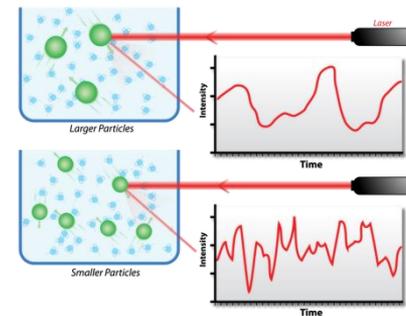


10% charge-stabilized PMMA colloids, PS depletant ($c/c^* = 1.1$)

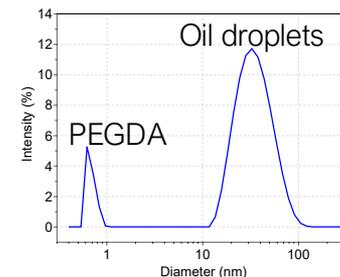
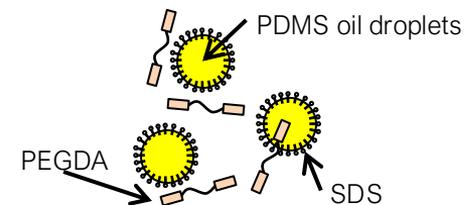
Microscopy



Dynamic light scattering

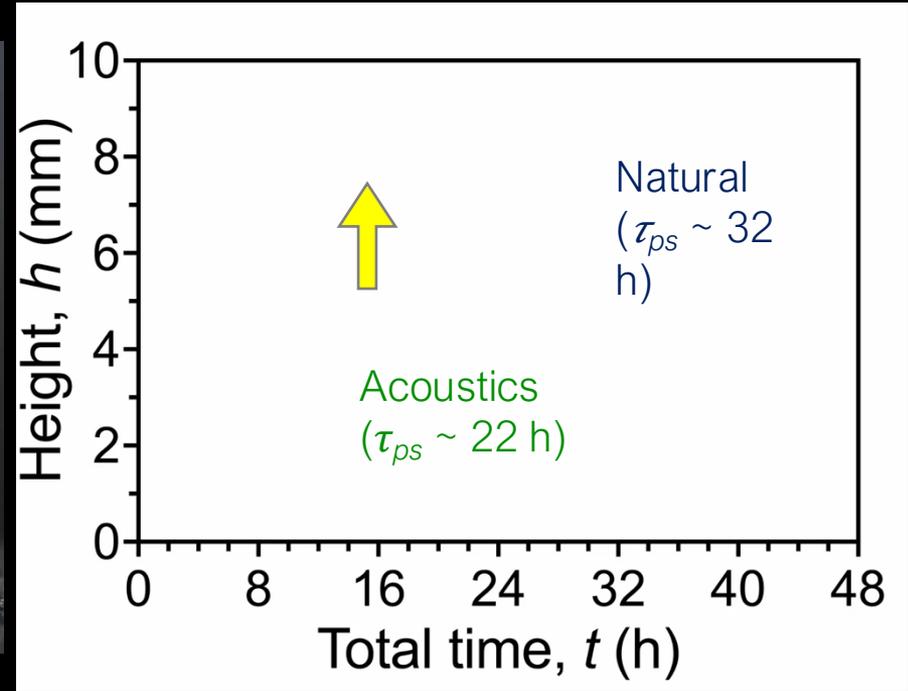


Oil/water nanoemulsion ($\sigma_y \sim 1$ Pa)



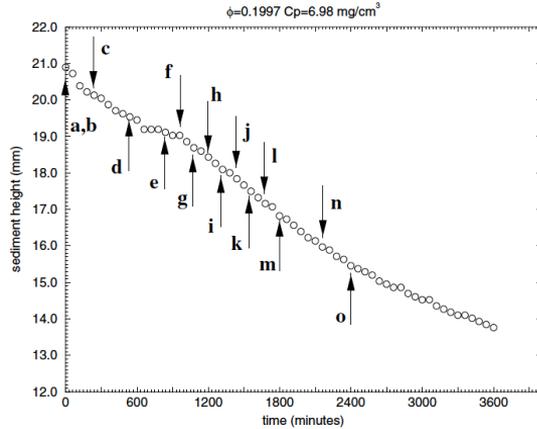
20% oil fraction, 200mM SDS, 33% PEGDA

Acceleration of delayed phase separation in gels

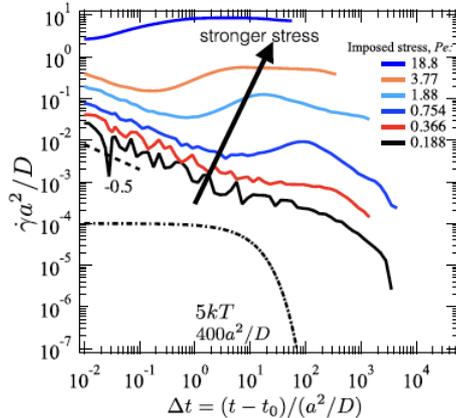


Phase separation acceleration factor $\sim 1.5x$

Colloidal gels are known to exhibit delayed creep

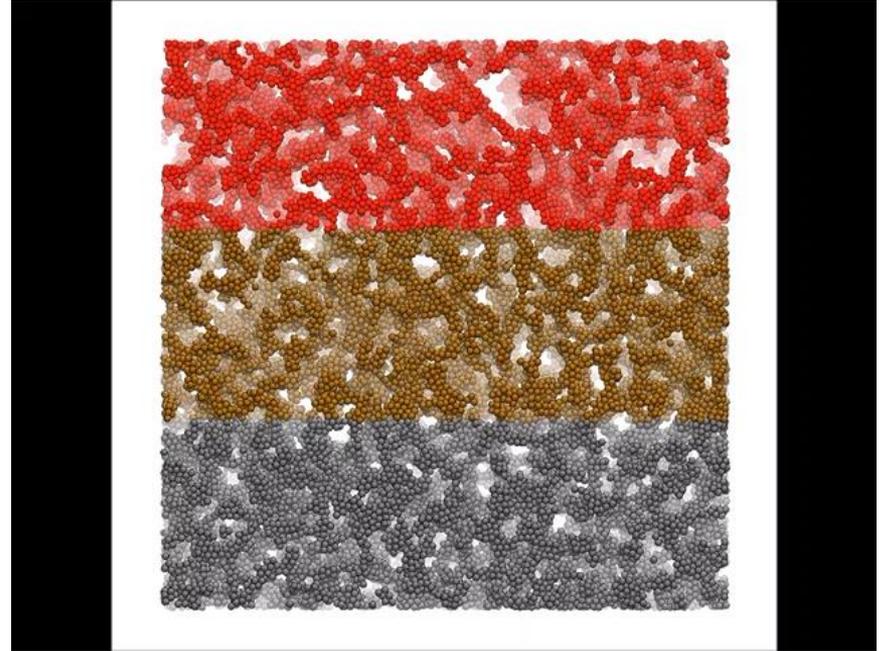


Starrs et al. *J Phys Condens Matter* (2002)



Landrum, Russel & Zia. *J Rheol* (2016)

$$T = \frac{t_{blowup}}{t_{poro-elastic}}$$



Varga, Hofmann & Swan. *J Fluid Mech* (2018)

Hypothesis: Acoustic streaming reduces t_{blowup} and reduces fluidization delay

Particulate gel microstructure



4 h

8 h

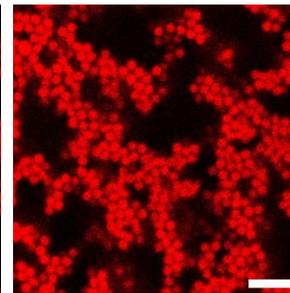
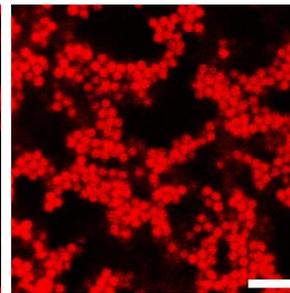
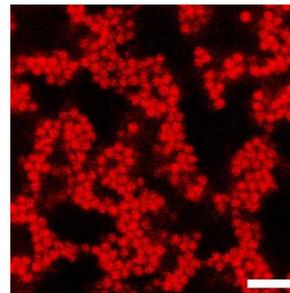
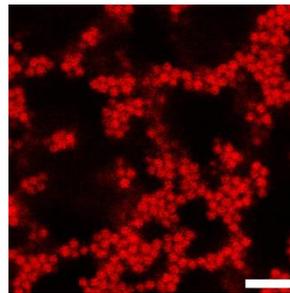
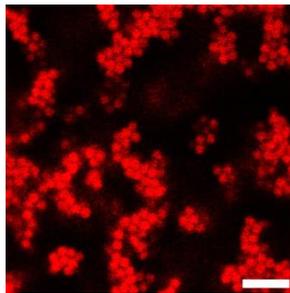
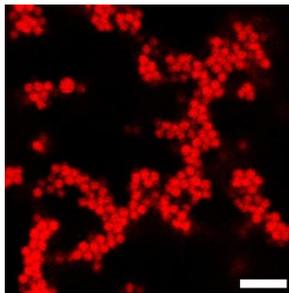
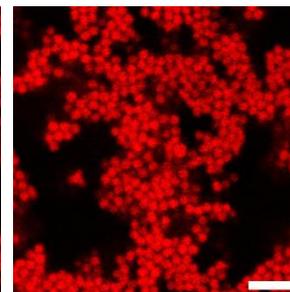
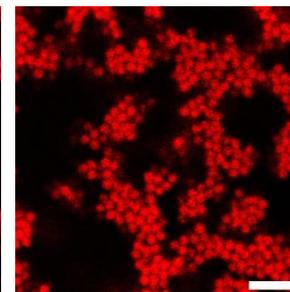
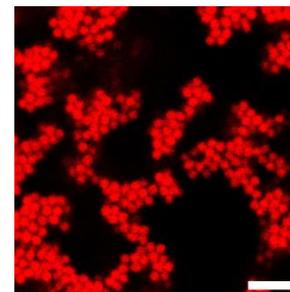
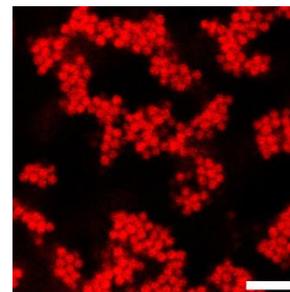
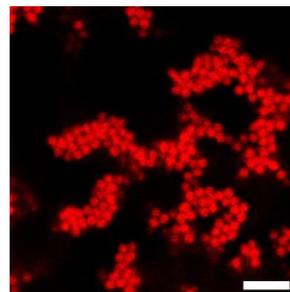
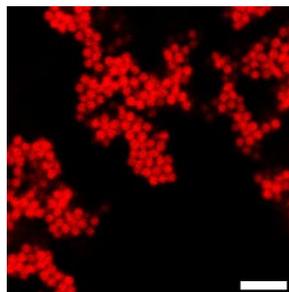
Waiting time after aging
(t_w) 12 h

16 h

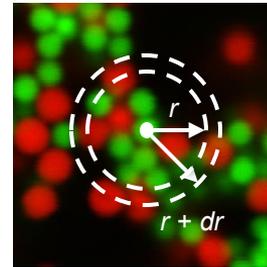
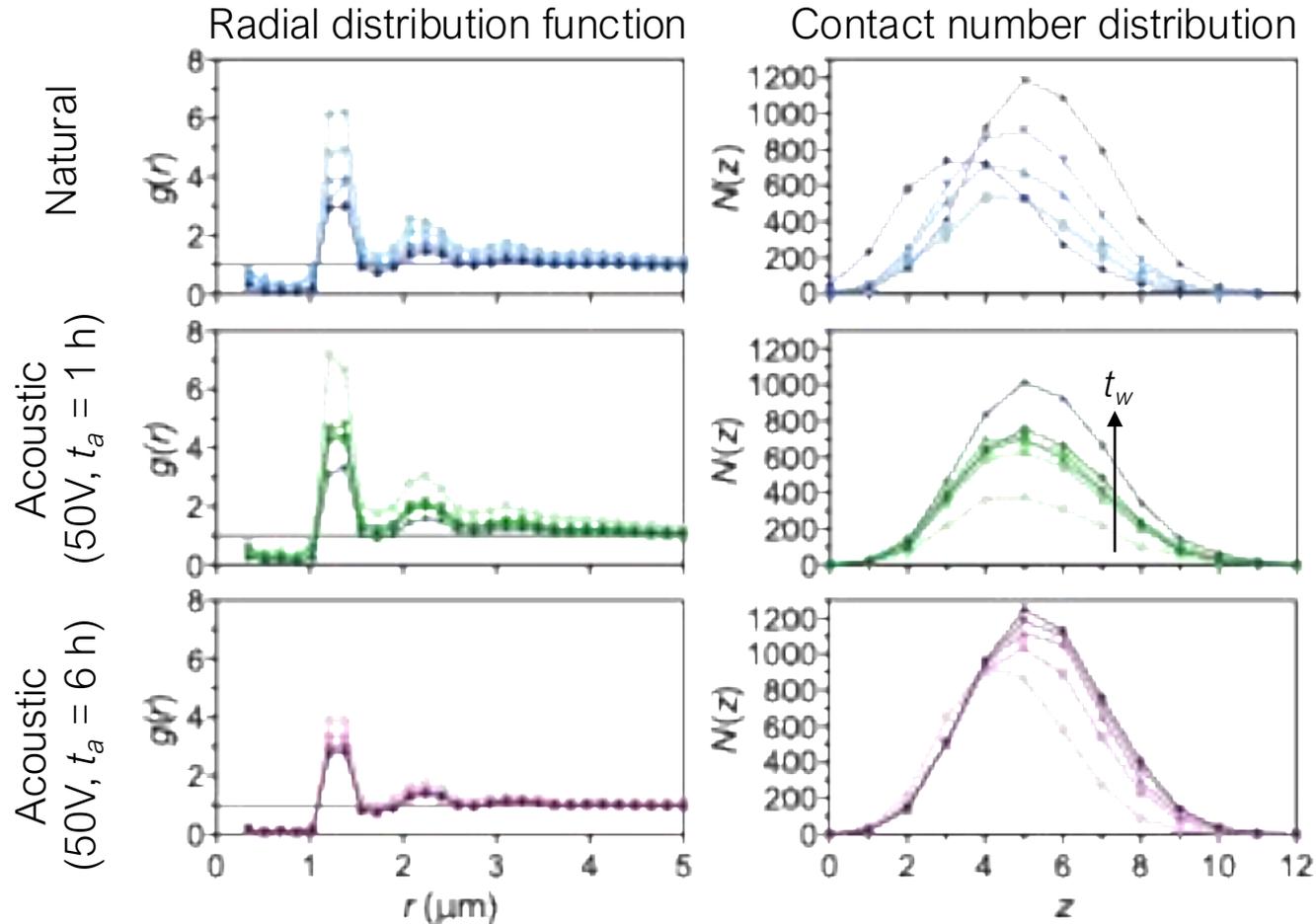
20 h

24 h

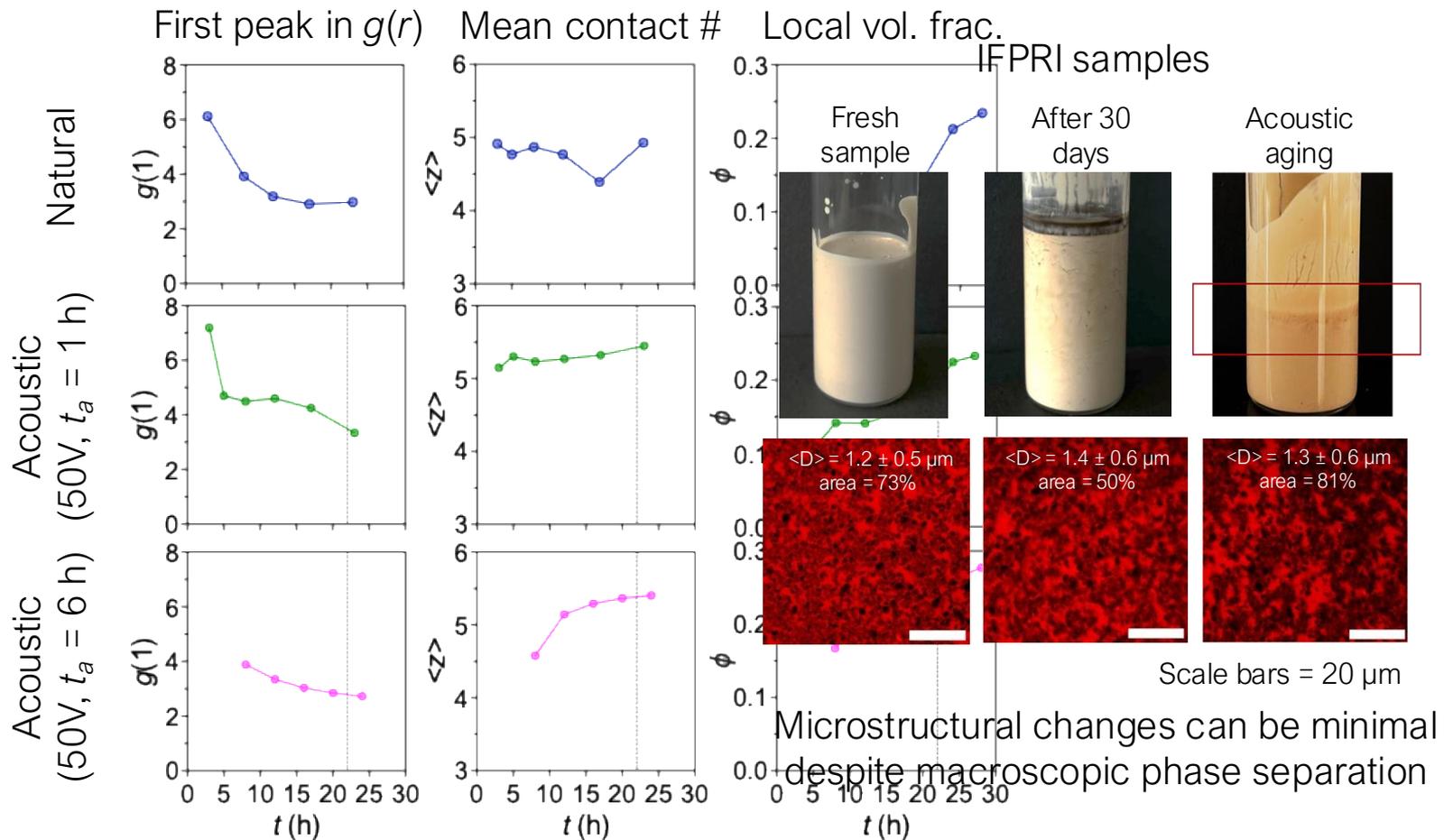
Natural

Acoustic
(50V, $t_a = 1$ h)Scale bars = 5 μm

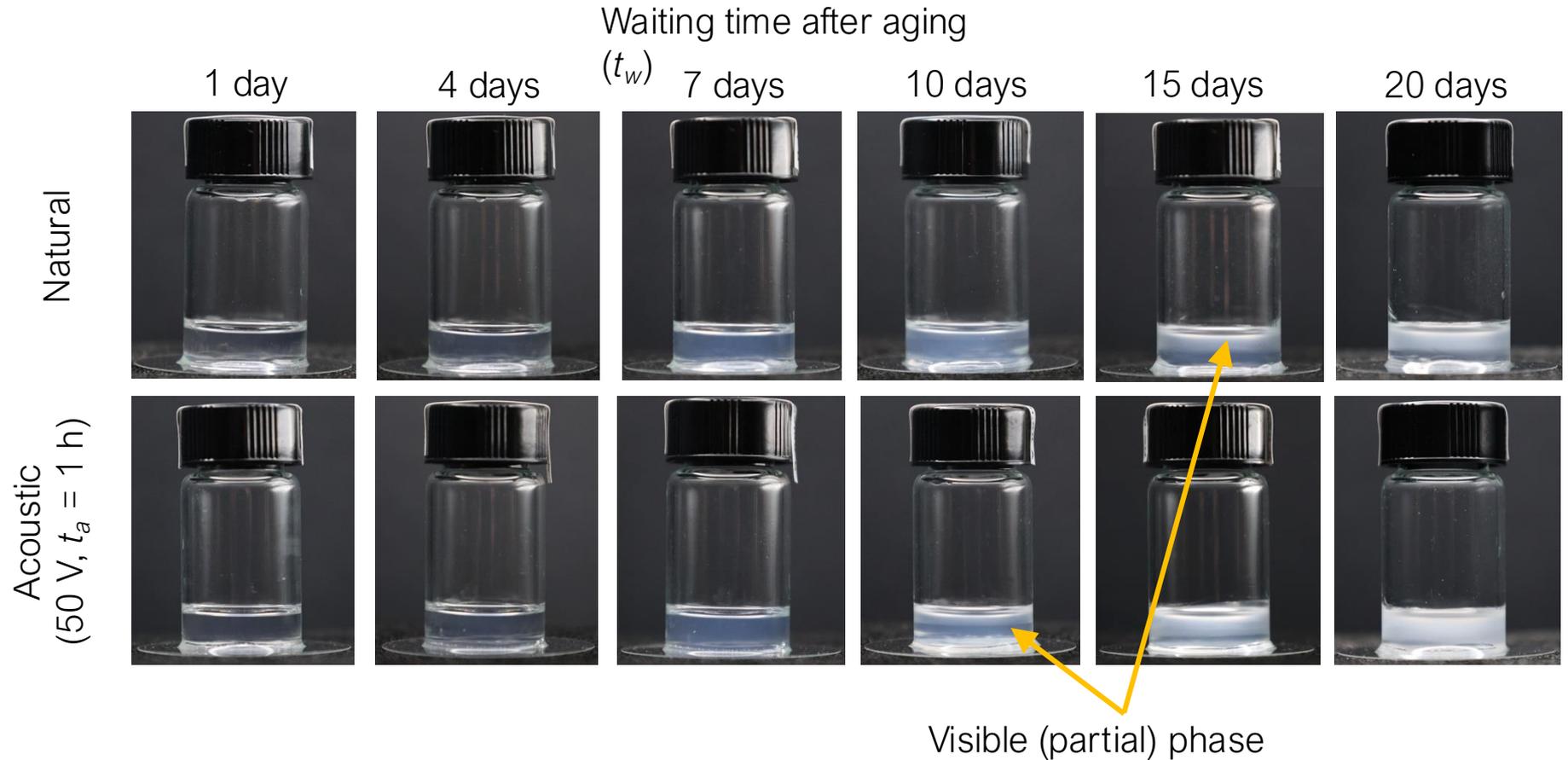
Particulate gel microstructure



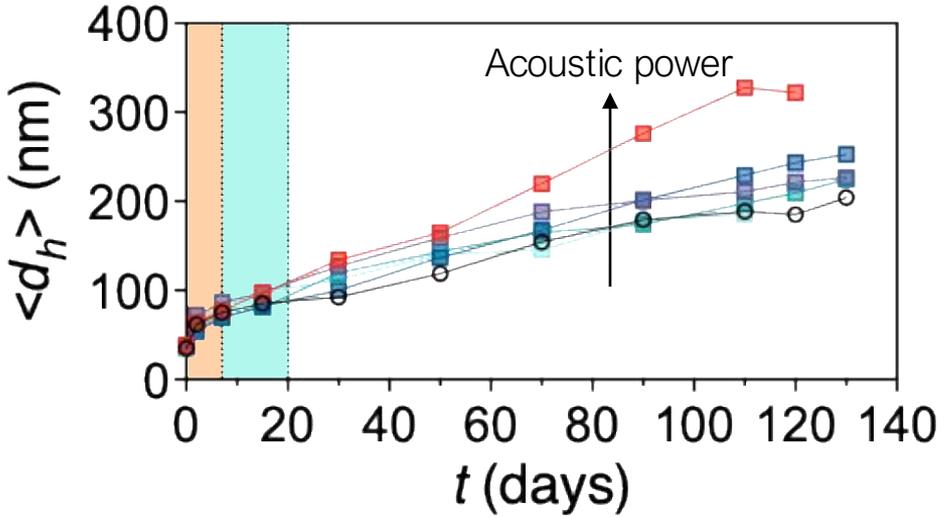
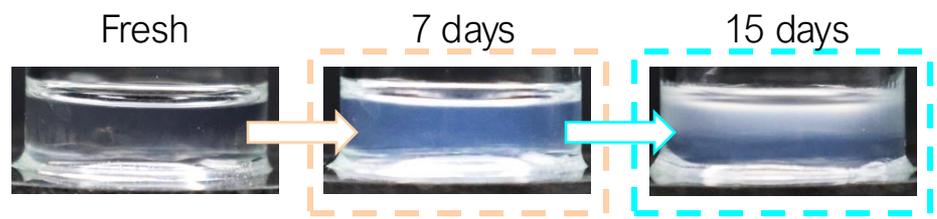
Particulate gel microstructure



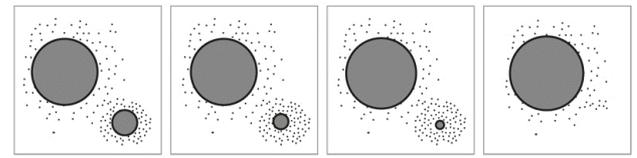
Effect of acoustics on emulsion phase separation



Coarsening kinetics of nanoemulsions

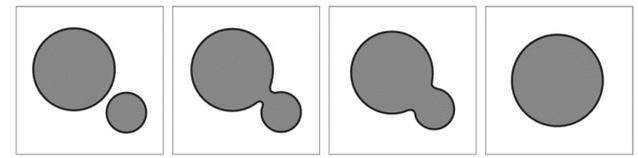


Ostwald ripening
Lifshitz-Slyozov-Wagner theory



$$\langle d_h(t) \rangle \sim D_0 \gamma t^{1/3} \quad \omega = \frac{d \langle r_h^3 \rangle}{dt}$$

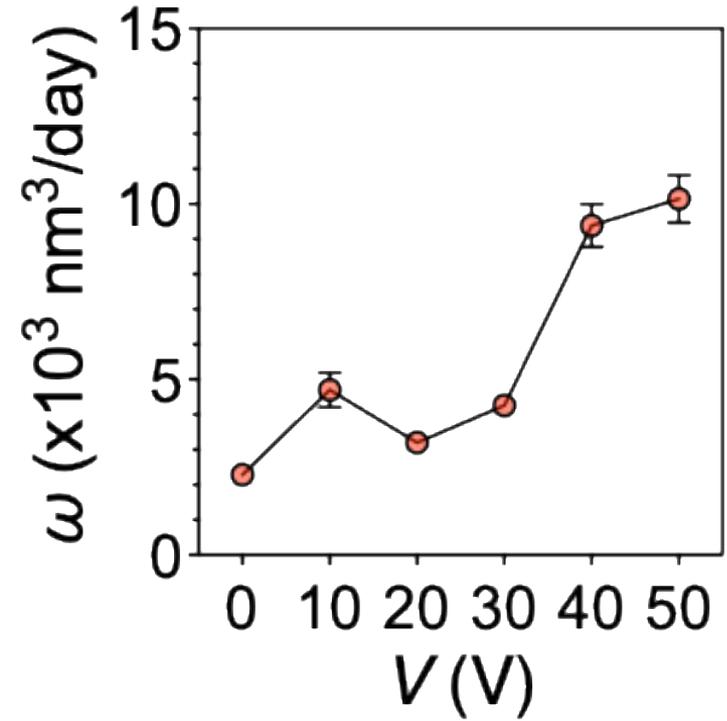
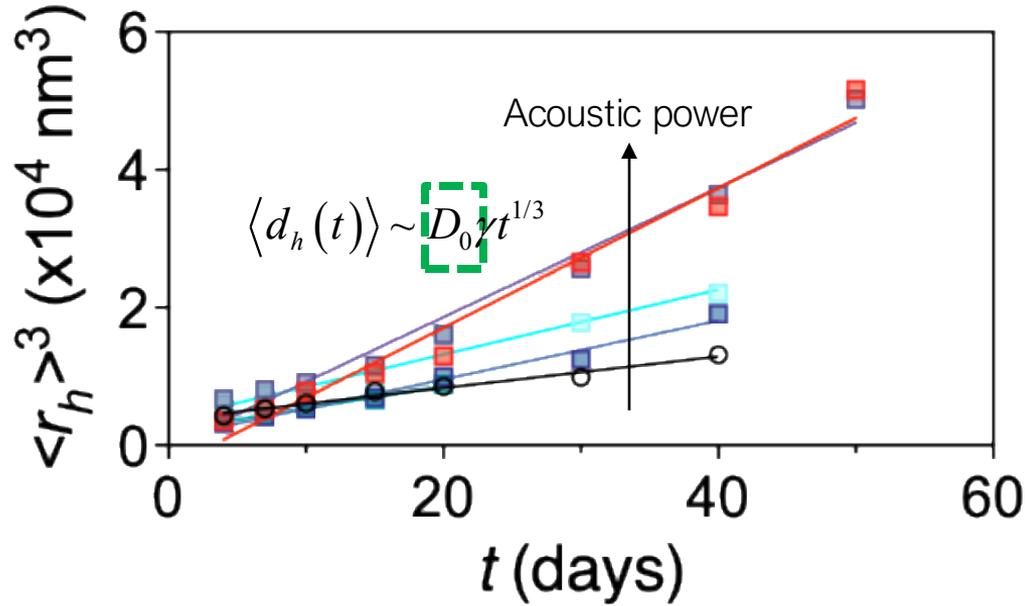
Coalescence model



$$\frac{1}{\langle r_h \rangle^2} - \frac{1}{r_0^2} = -\frac{8\pi}{3} \alpha t$$

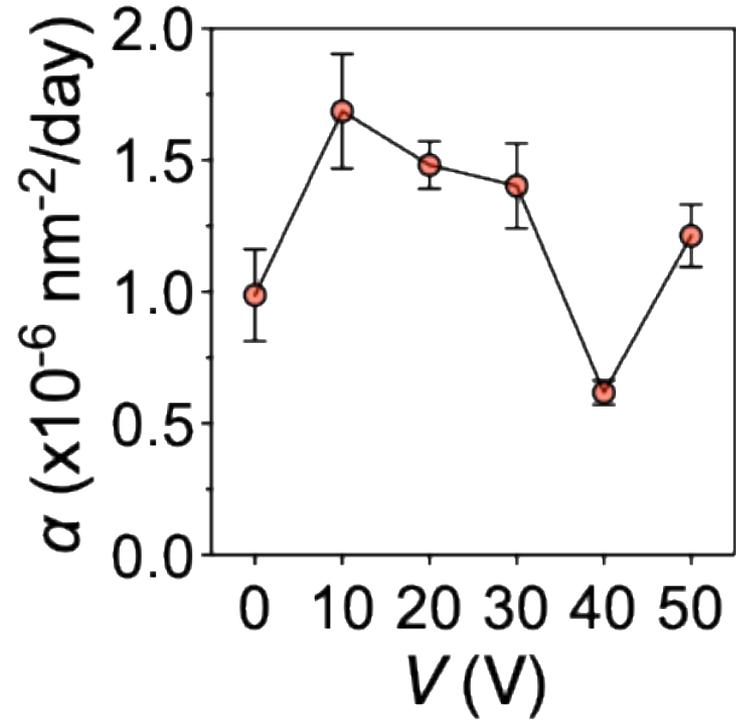
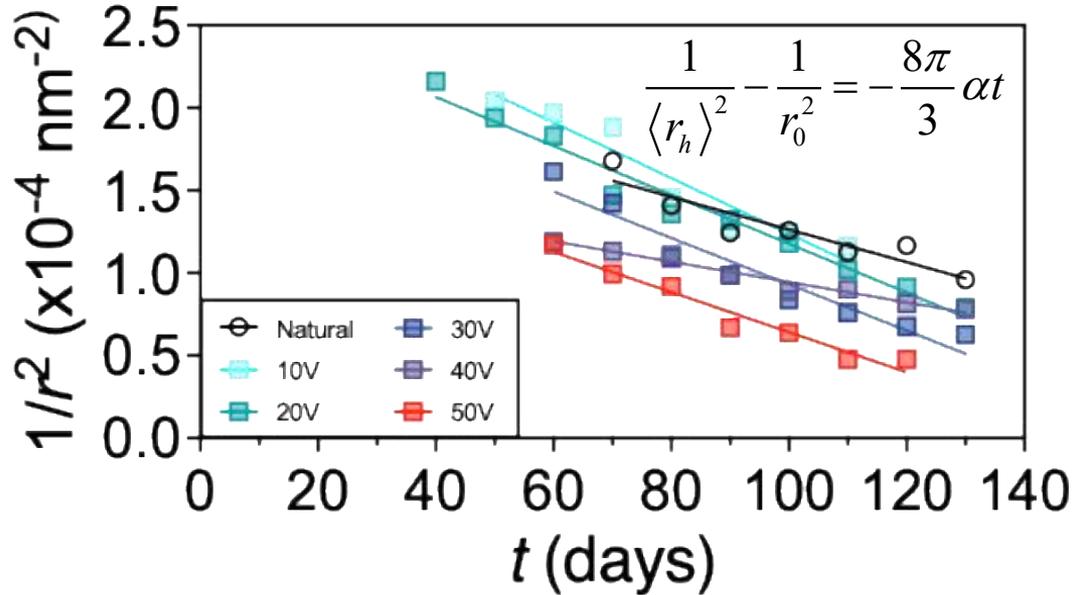
Destabilization sequence:
Ostwald ripening → Creaming → Coalescence

Effect of acoustics on Ostwald ripening



Ostwald ripening sped up by $\sim 5x$ with acoustic aging

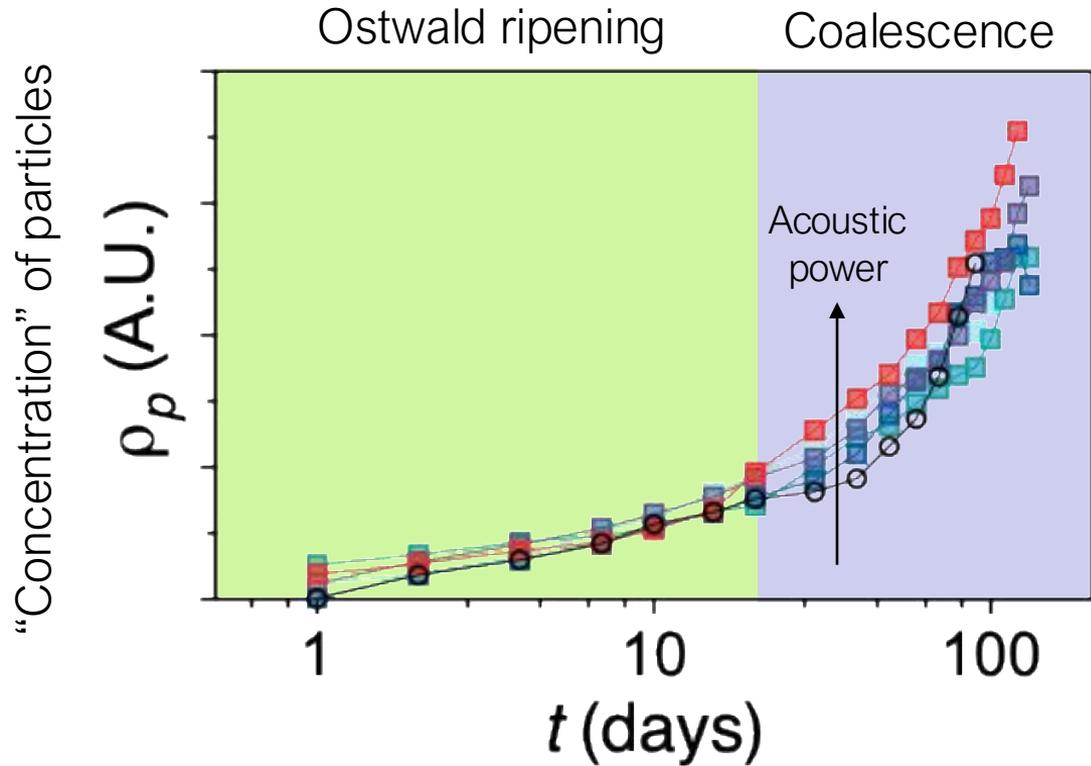
Effect of acoustics on coalescence



Negligible effect of acoustic power on coalescence

Coalescence is a secondary consequence of earlier phase separation

Creaming and phase separation



Phase separation correlates to a rapid increase in the local density of oil droplets

Summary and future plans

Acoustic aging accelerates microscale coarsening that leads to delayed phase separation

STUDENTS		YEAR ONE				YEAR TWO				YEAR THREE			
Shourie Yerabati, Nazanin Shakoury													
#	TASK TITLE	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Develop industry model formulations	✓	✓										
2	Develop academic model formulations		✓	✓	✓	✓							
3	<i>Ex situ</i> rheology with and without acoustics		✓	✓	✓	✓	✓						
4	Imaging of particle dynamics					✓	✓	✓					
5	Generate stability phase diagrams						✓	✓					
6	Obtain predictive correlations of stability							✓					

Upcoming plans for Y3:

- Correlate microscopic and macroscopic destabilization phenomena
- Determine stability criterion for phase separation based on acoustic pressure
- Translate findings to IFPRI samples