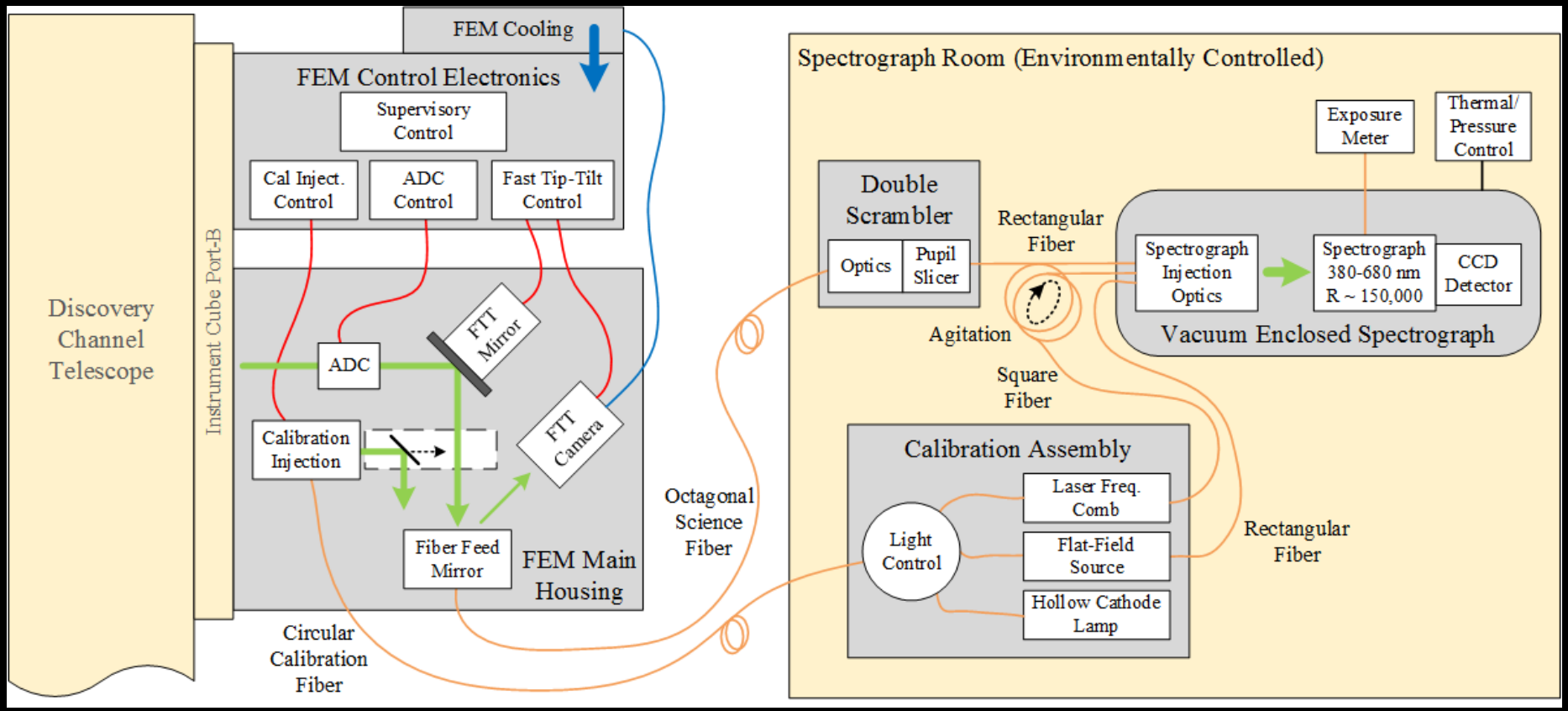
Modal Noise Mitigation for Fiber-fed Spectrographs

Ryan Petersburg

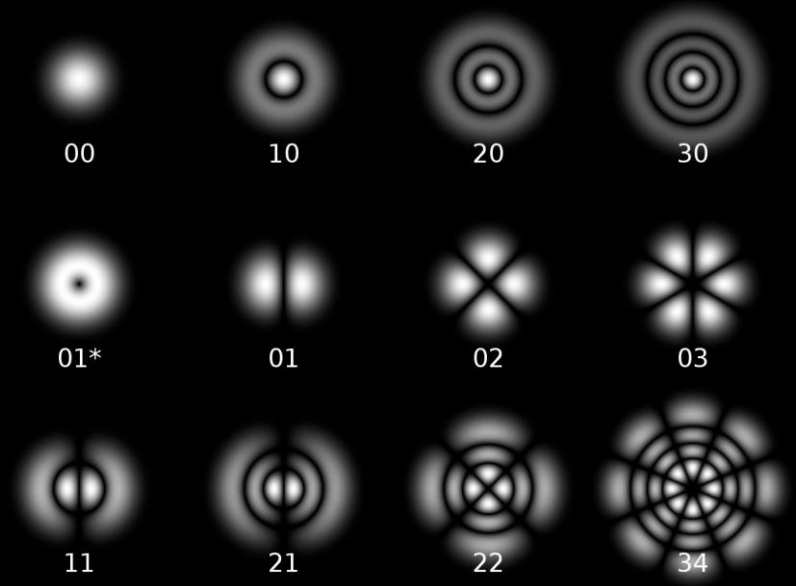
ERES III – Radial Velocity

13 June 2017

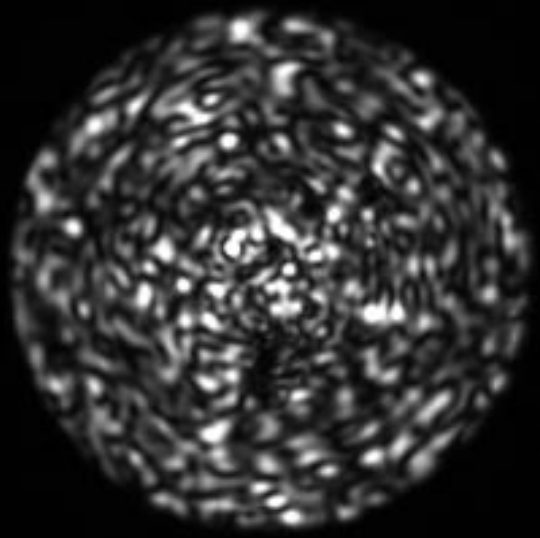
Fiber-fed Spectroscopy



What is Modal Noise?



Fiber Stress (Curvature)
Temperature gradients
Fiber Imperfections
etc. with a
COHERENT LIGHT
SOURCE



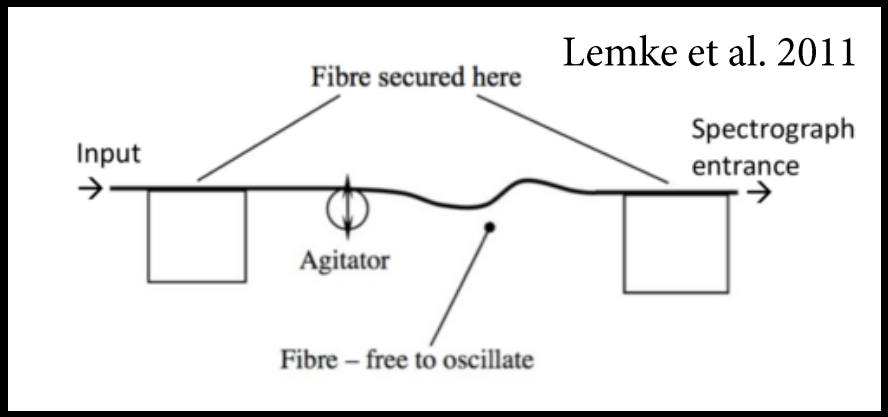
$$N_M \leq \frac{1}{2}V^2 = \frac{1}{2}\left(\frac{\pi d \mathrm{NA}}{\lambda}\right)^2$$

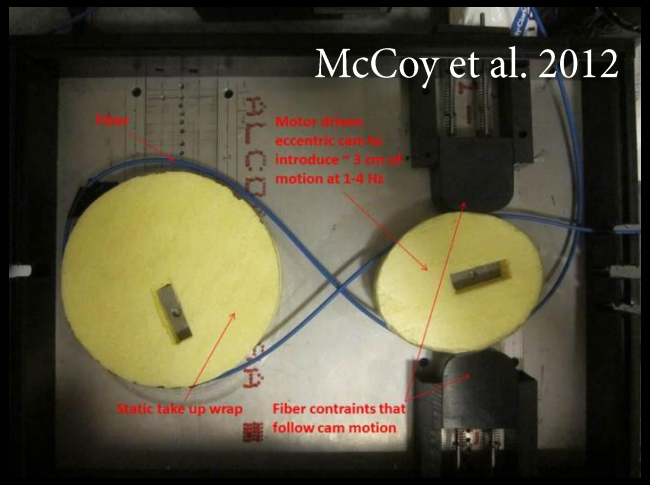
Only *circular* fibers

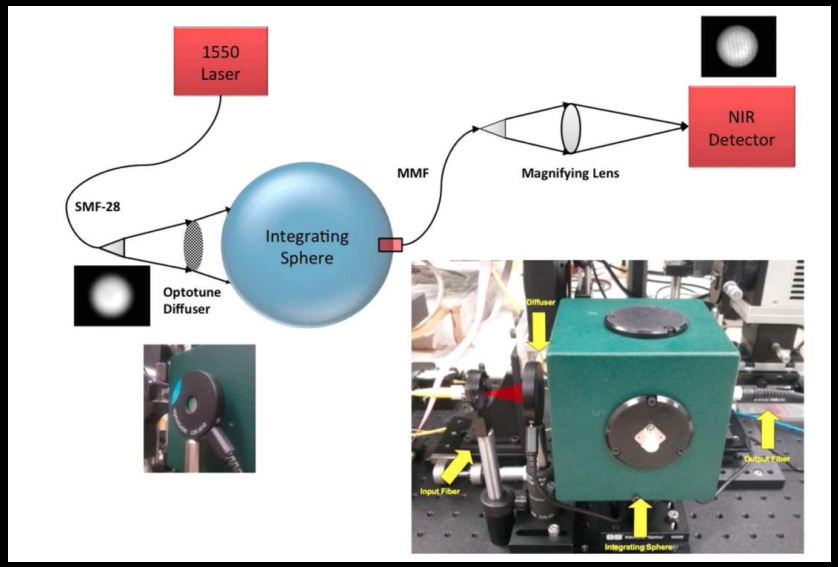
$$N_M \leq 2\pi A\left(\frac{\mathrm{NA}}{\lambda}\right)^2$$

Adapted from
Nikitin et al. 2011

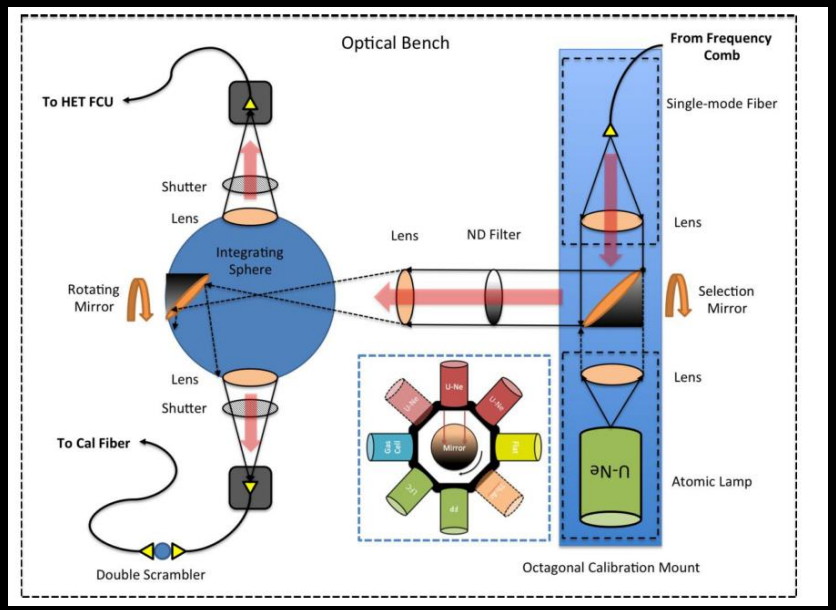
Modal Noise Mitigation





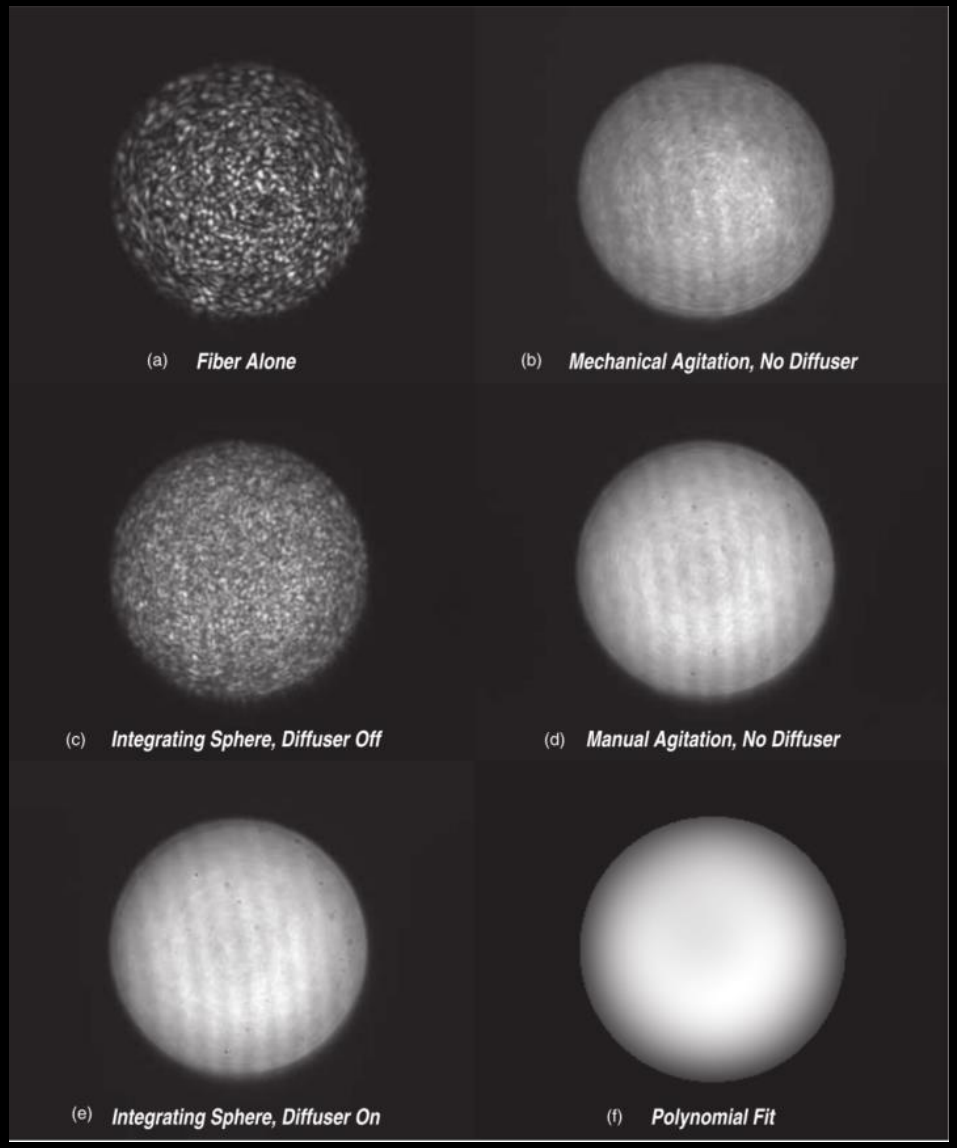


Mahadevan et al. 2014



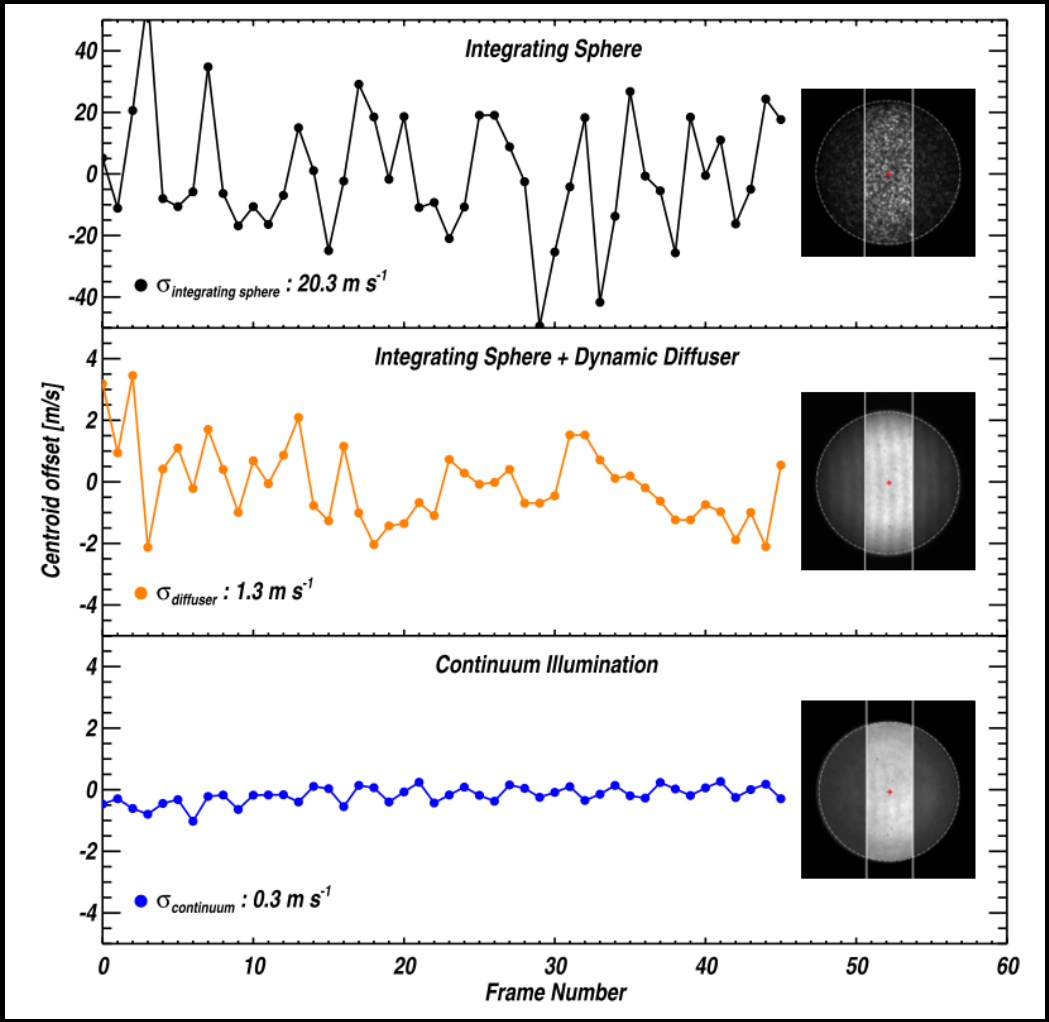
Halverson et al. 2014

Modal Noise Mitigation



Mahadevan et al. 2014

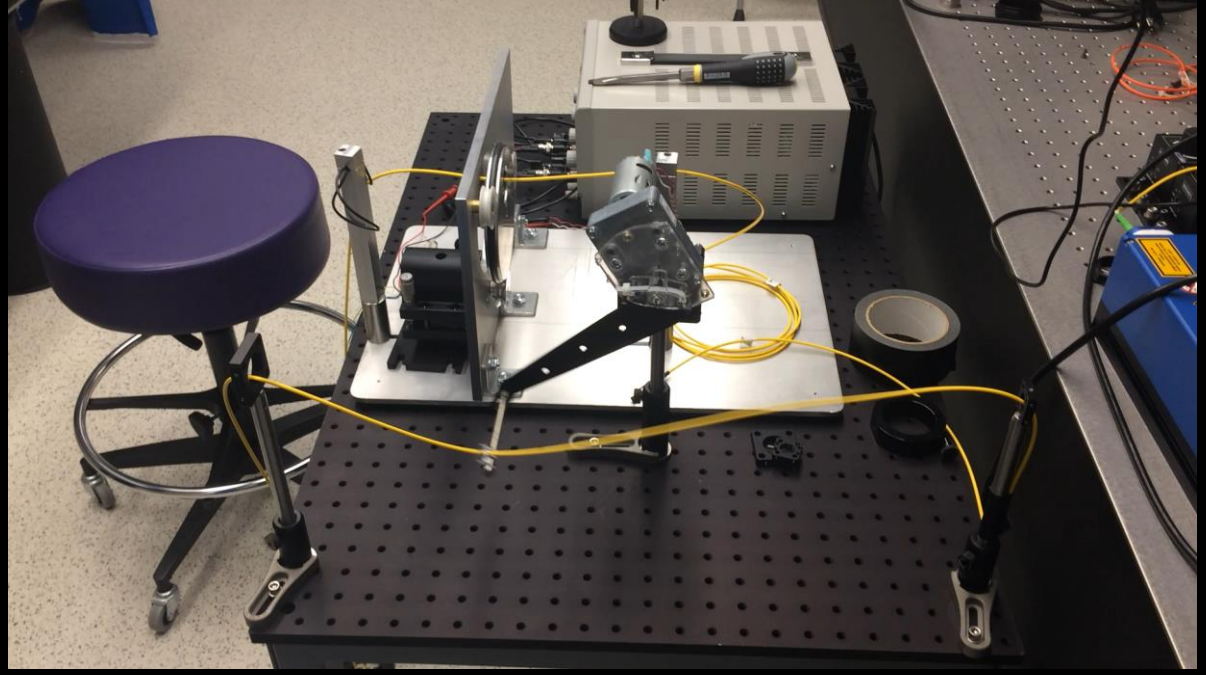
Effect on Radial Velocities

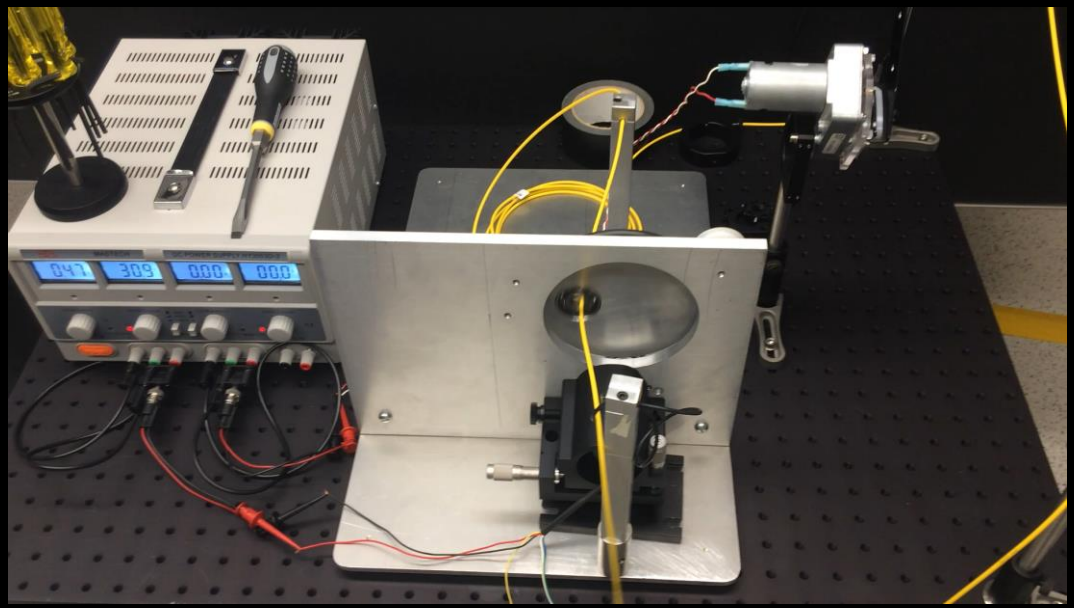


Mahadevan et al. 2014

Agitation

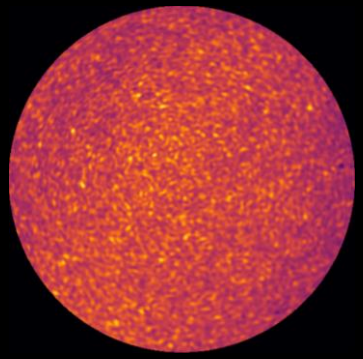
Linear →



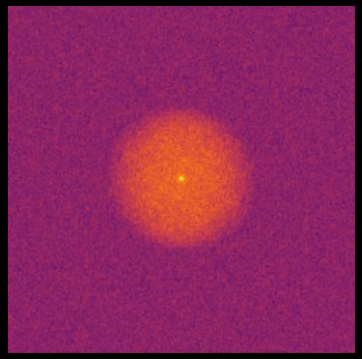


← Circular

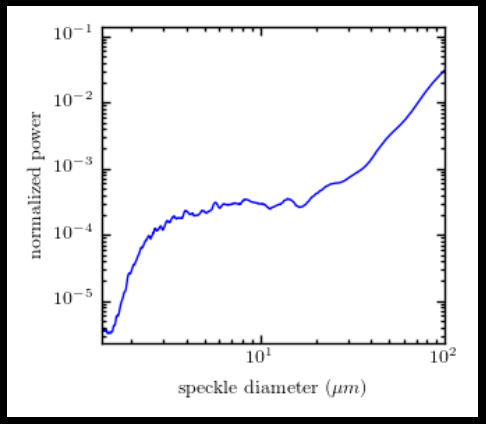
Modal Noise Quantification

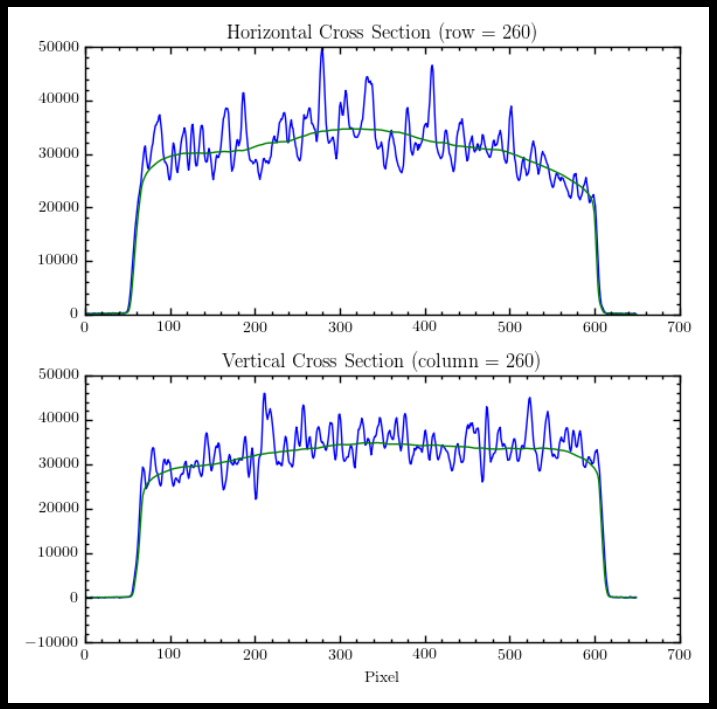


Hann-Poisson Window and 2D FFT



Azimuthally Average and Invert



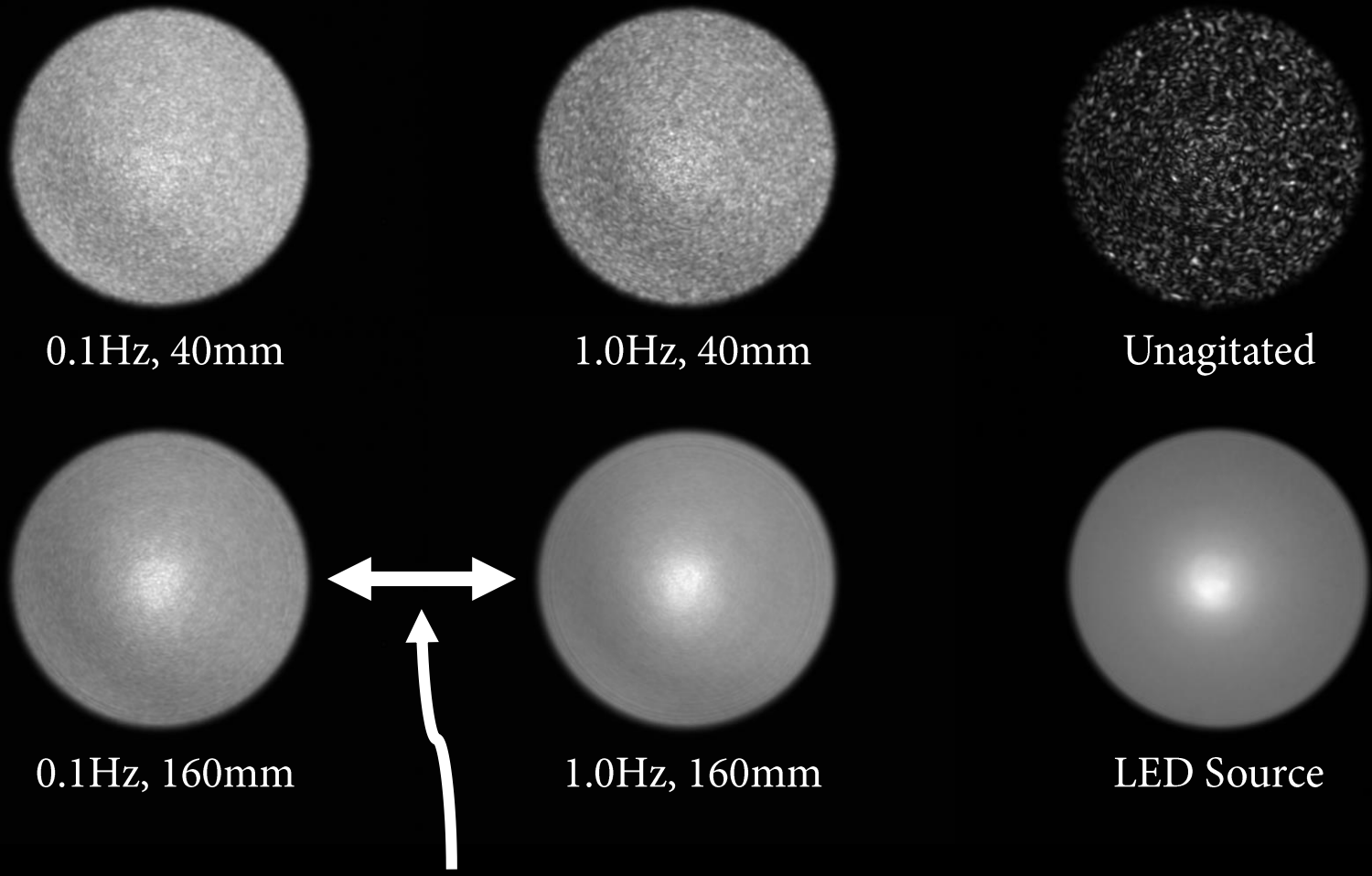


Noise to Signal Ratio:

$$\frac{\sqrt{\langle I^2 \rangle - \langle I \rangle^2}}{\langle I_0 \rangle}$$

$$I = I_0 - I_{med\_filt}$$

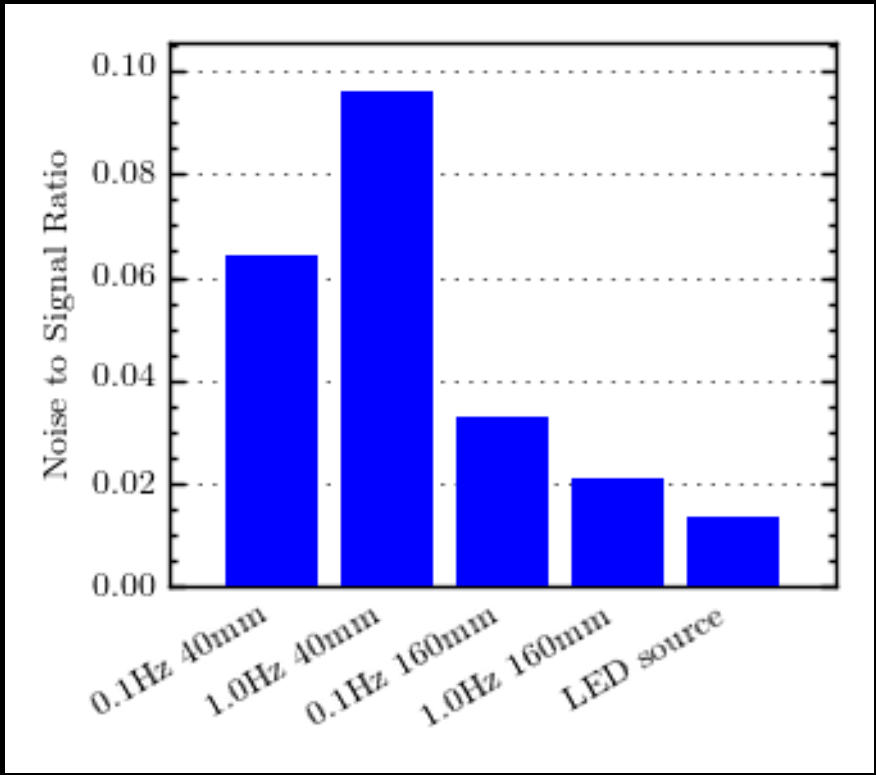
Agitation Amplitude and Frequency

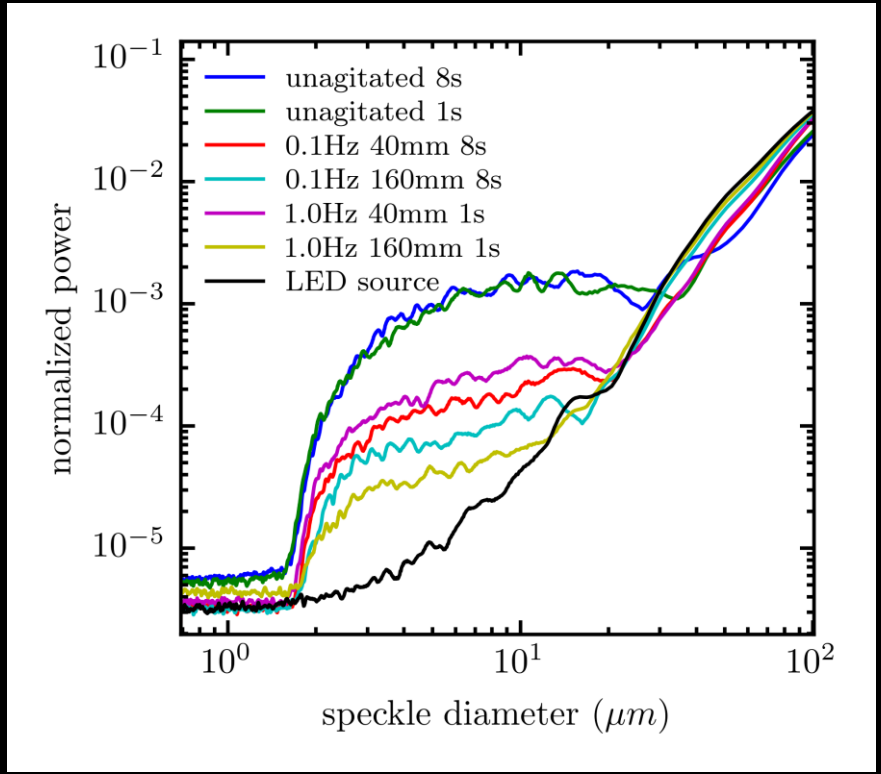


Improvements between these two most likely due to "tweeter" high frequency shaking (Plavchan et al. 2013)

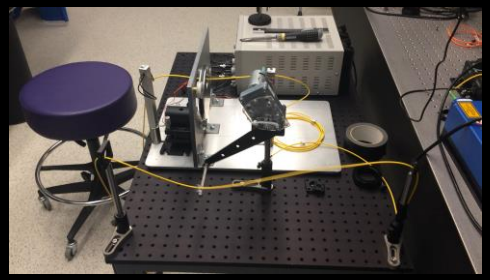
Far field images yielded similar results

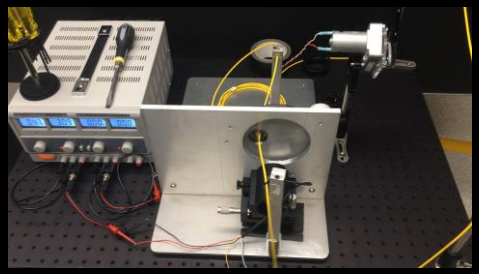
Agitation Amplitude and Frequency

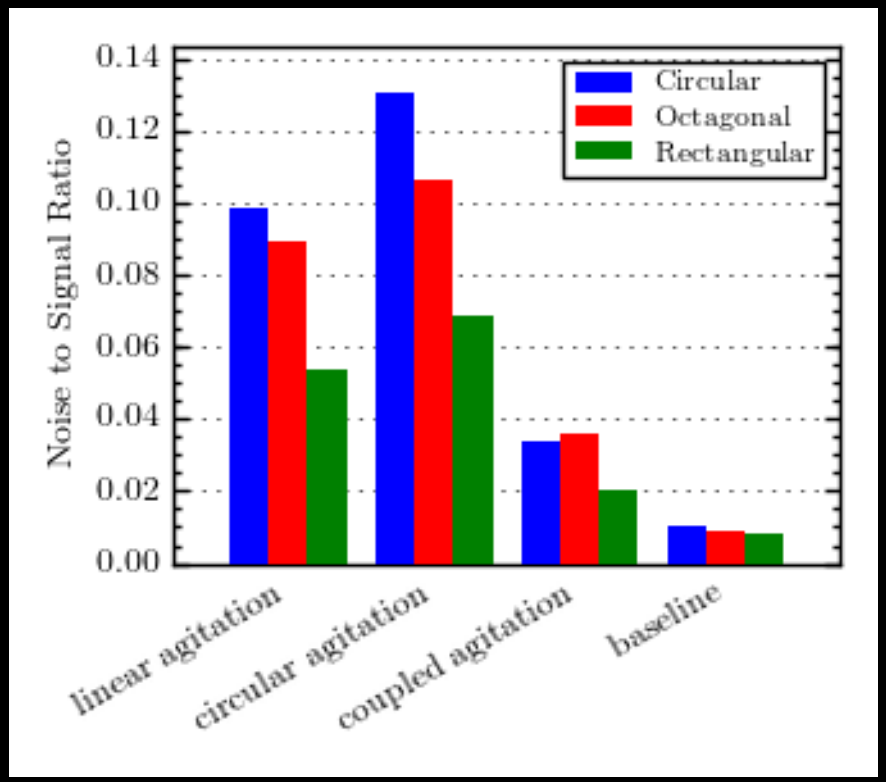




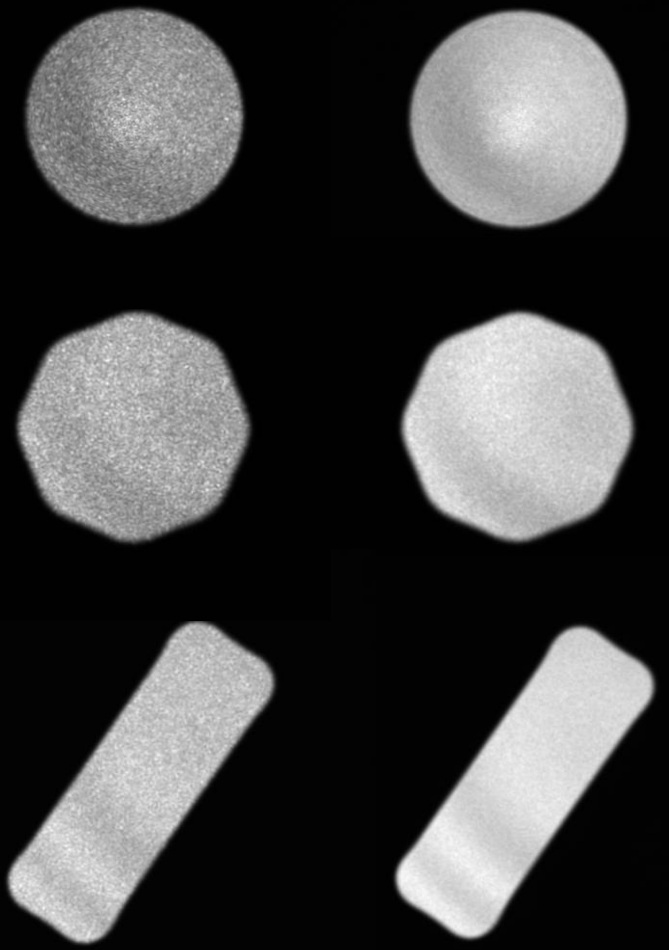
Linear and Circular Agitation





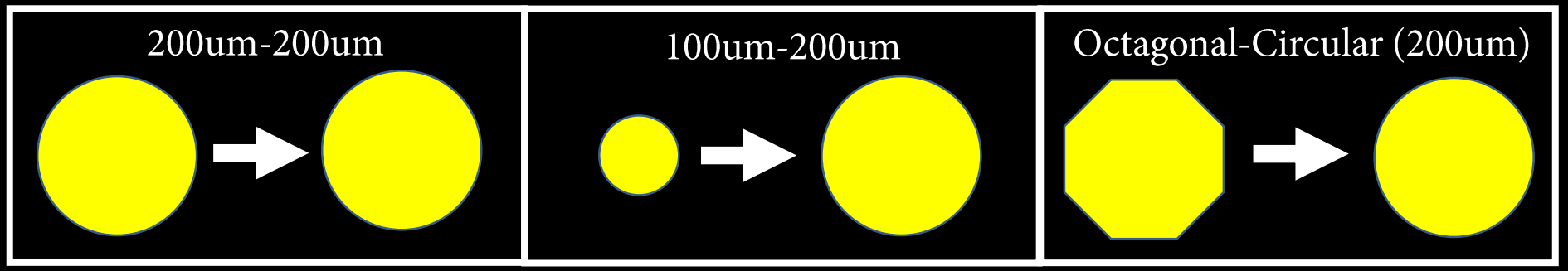


Linear Coupled

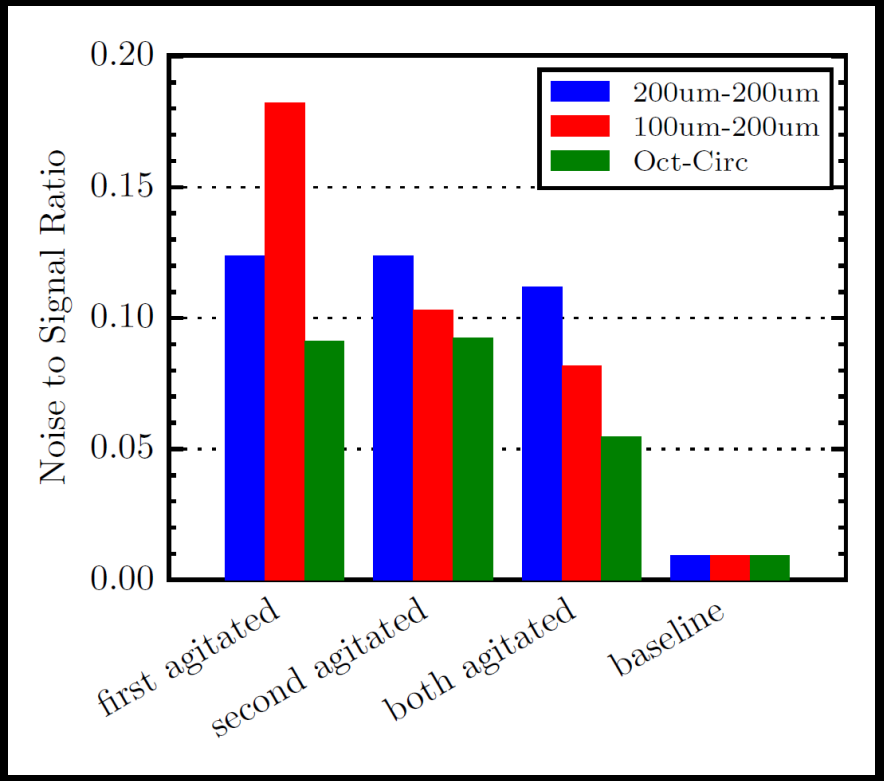


Far field images yielded similar results

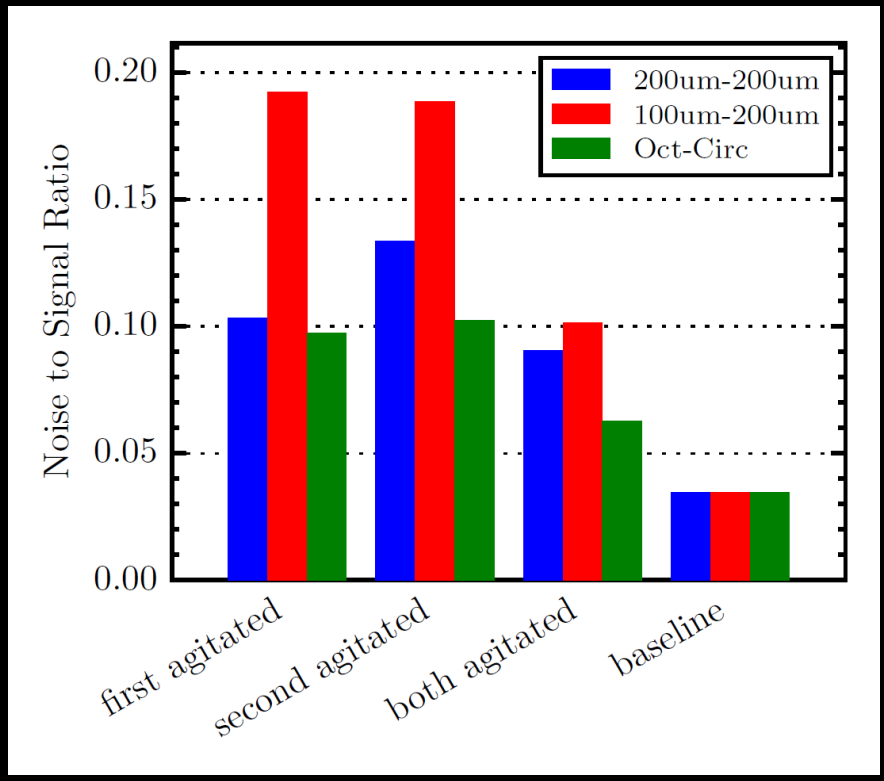
Coupled Fibers



Near Field



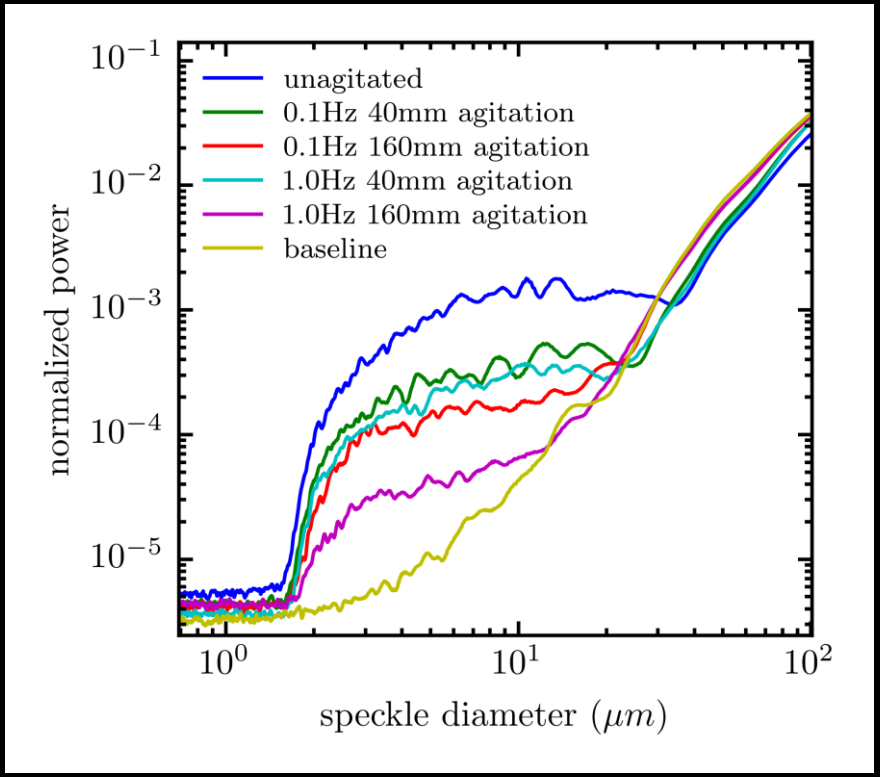
Far Field

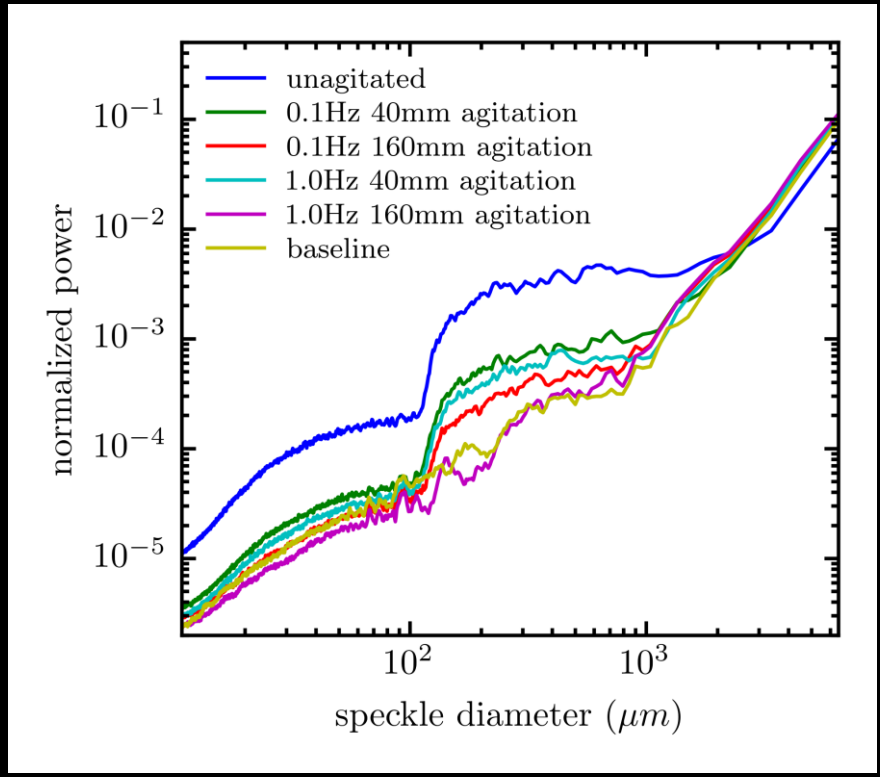


Conclusions

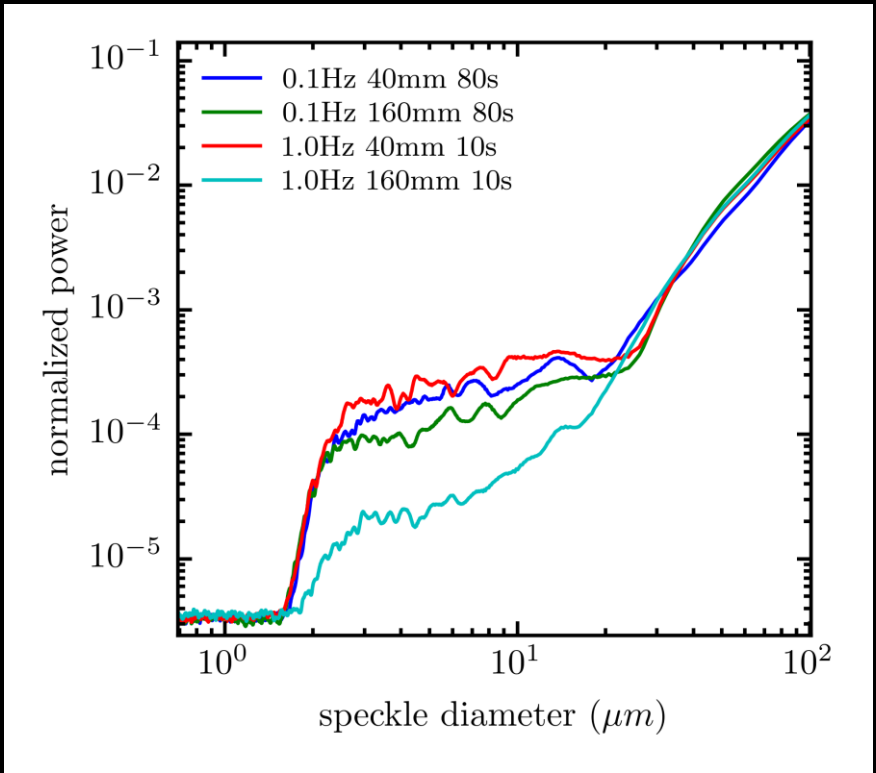
- Idealized fiber agitation method
  - Simultaneous linear and circular agitation
  - “Chaotic” frequency coupling to get many “configurations”
  - Maximum amplitude without sacrificing fiber safety and spectrograph stability
  - At least one oscillation per exposure
  - Possibly add high frequency, low amplitude “tweeter”
- Fiber core geometry
  - Less azimuthal symmetry = easier mitigation
  - Rectangular fiber shows best mitigation, for example
- Coupled fibers
  - The largest fiber in a system should definitely be agitated
  - If there is some variation in fiber size or geometry, as many fibers as possible should be agitated to minimize modal noise

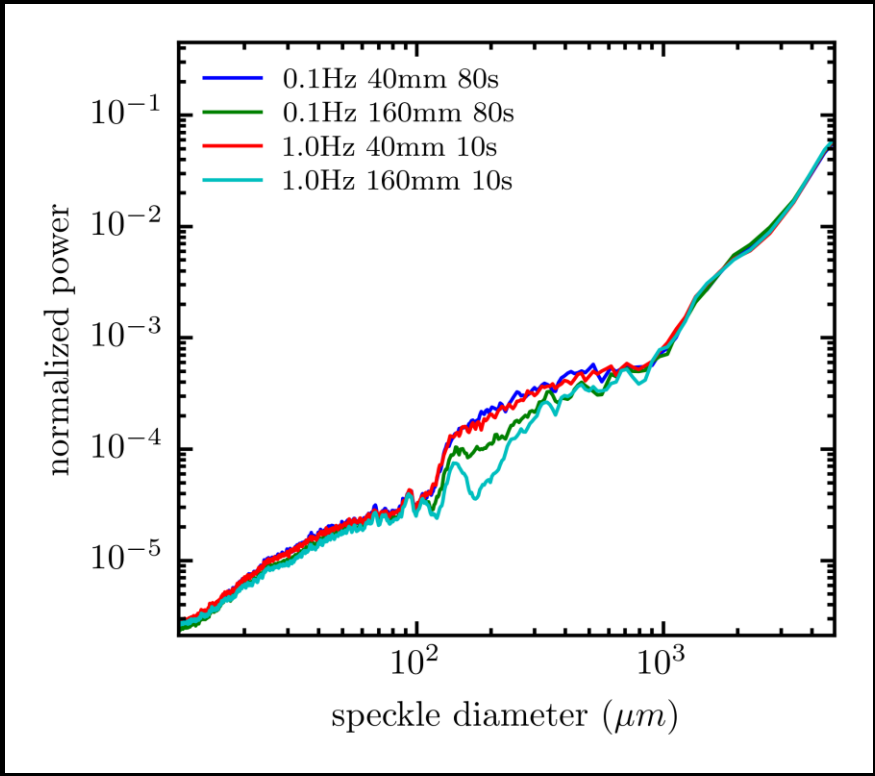
Supp. – 200um circular



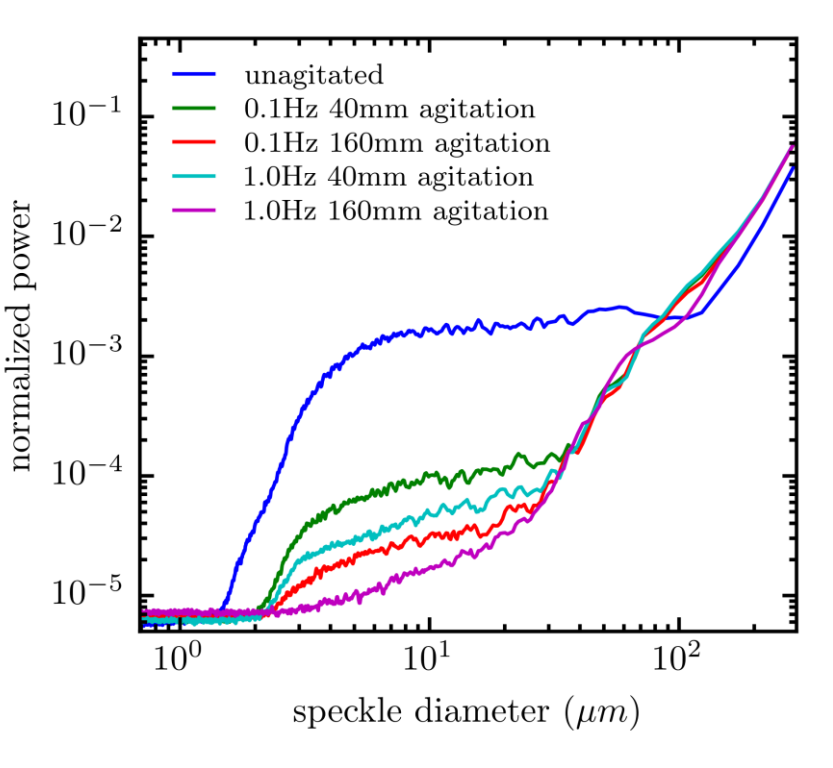


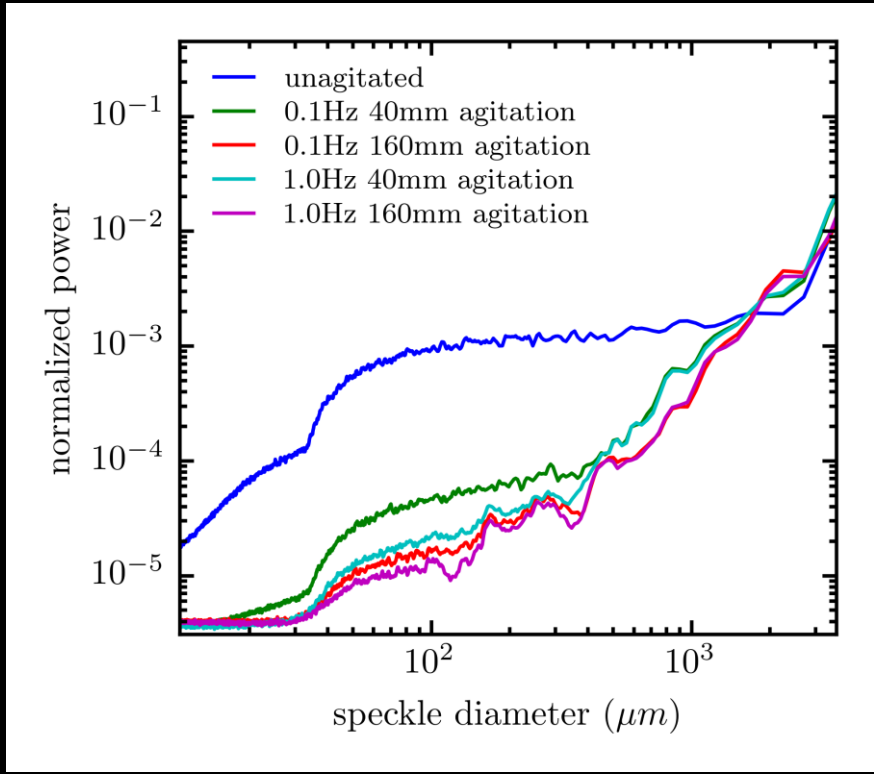
Supp. – 200um circular



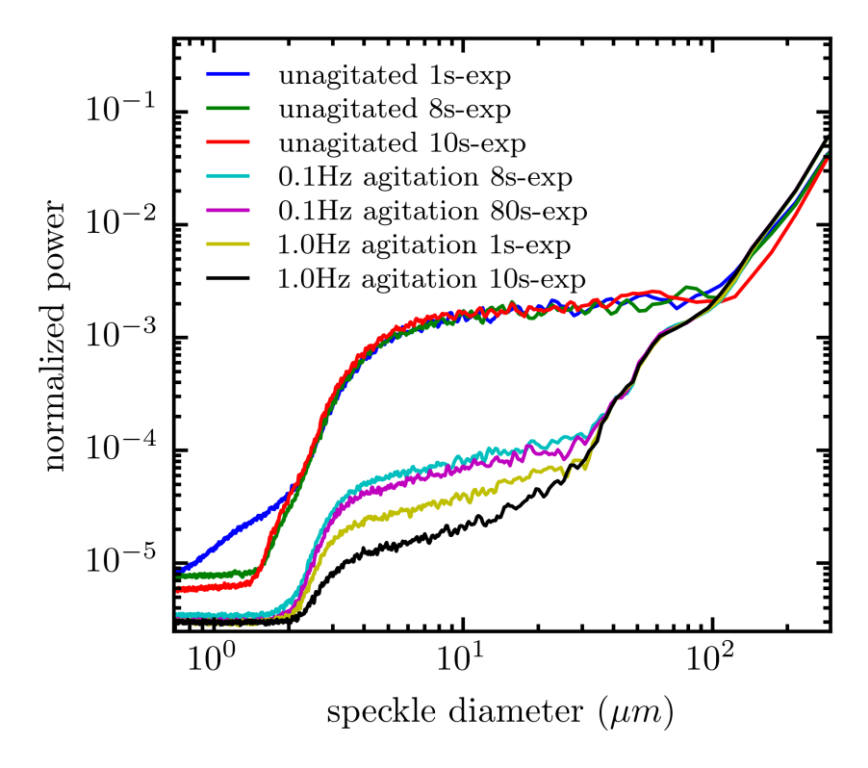


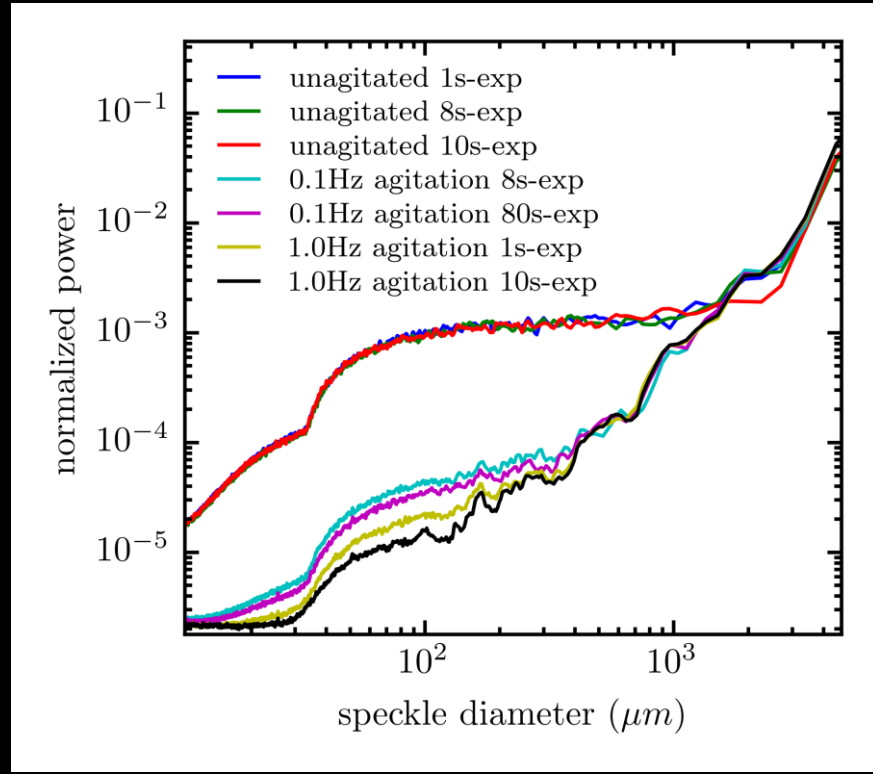
Supp. – 600um circular



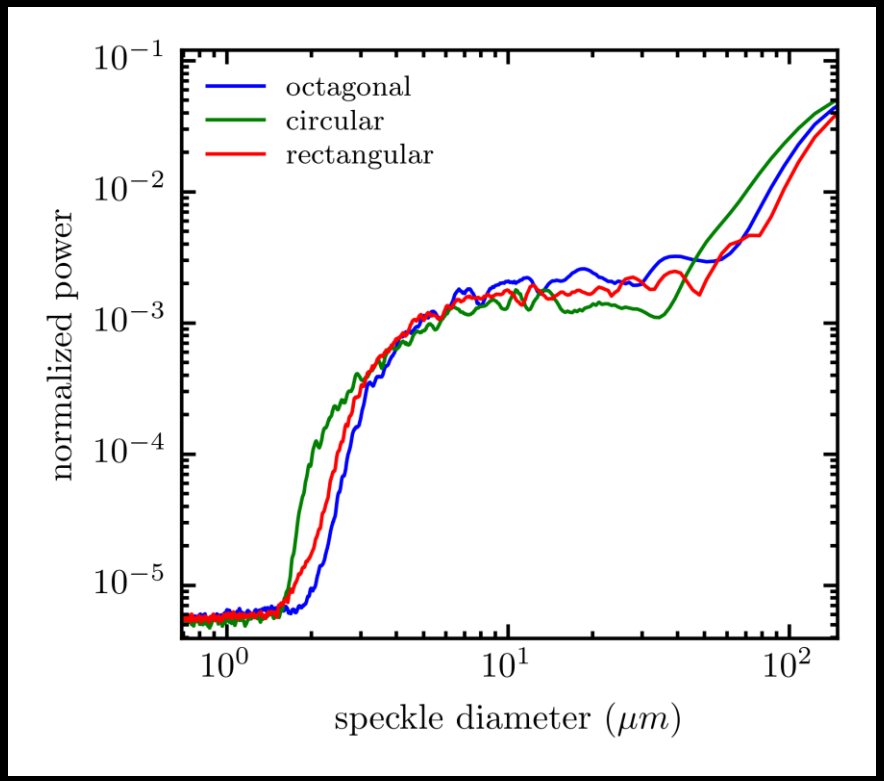


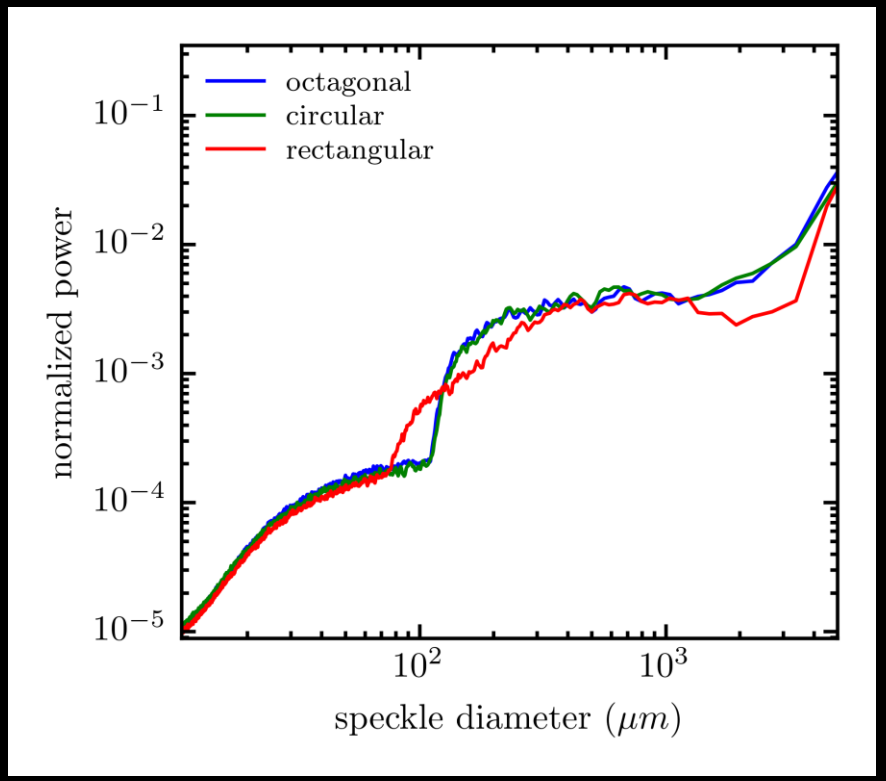
Supp. – 600um circular norm





Supp. – Unagitated fibers





Supp. Coupled agitation