The Windchime Project

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for the Windchime collaboration

Optomechanics for dark matter detection - 2nd edition

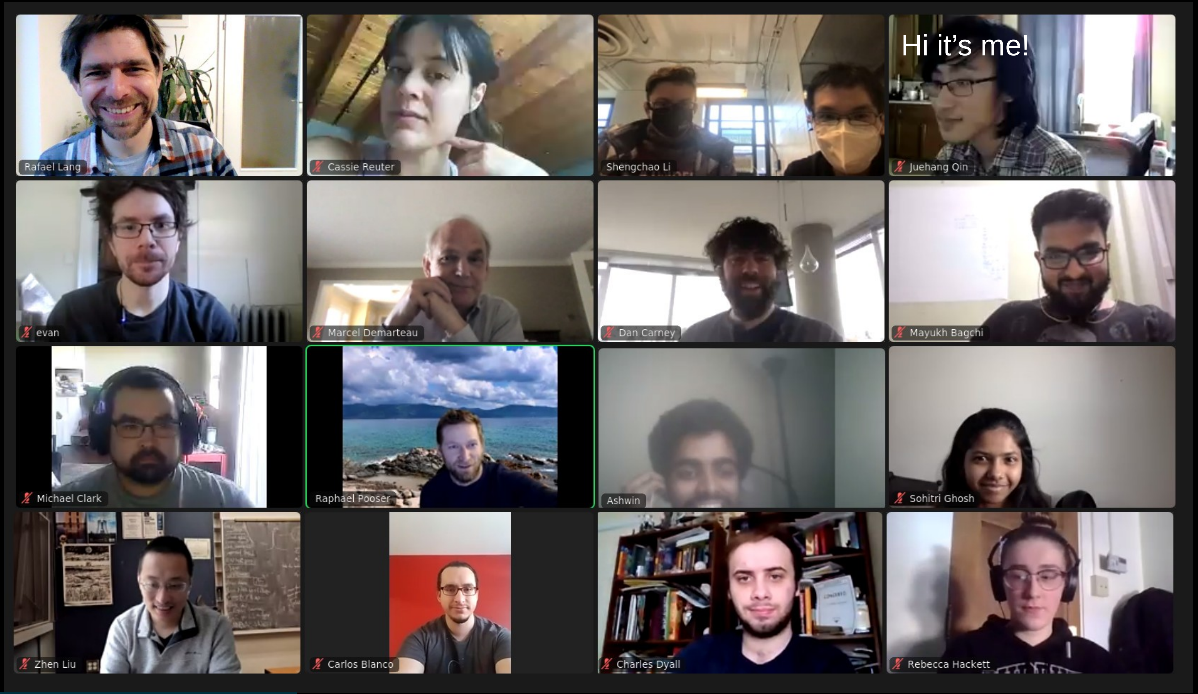
The Windchime Collaboration

Multiple PhD and postdoc positions available!

PURDUE UNIVERSITY

Fermilab

RICE



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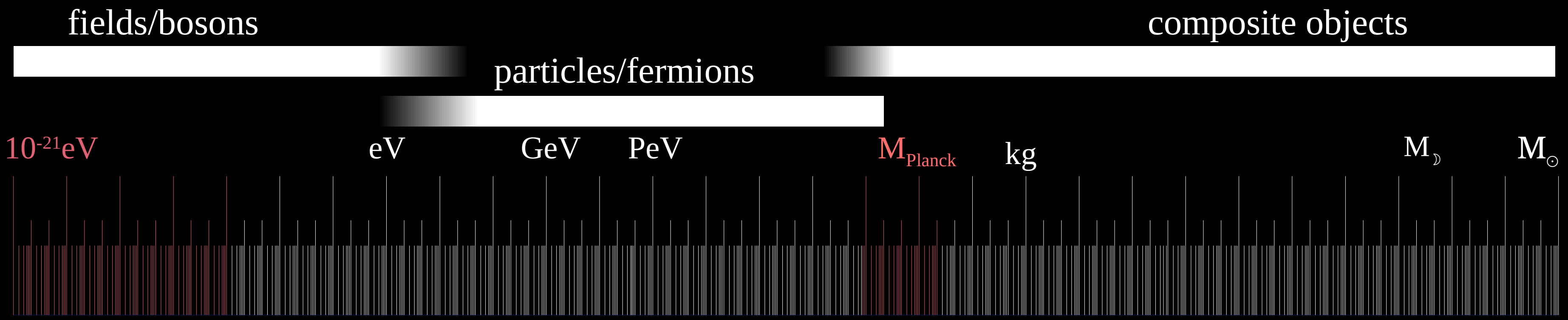
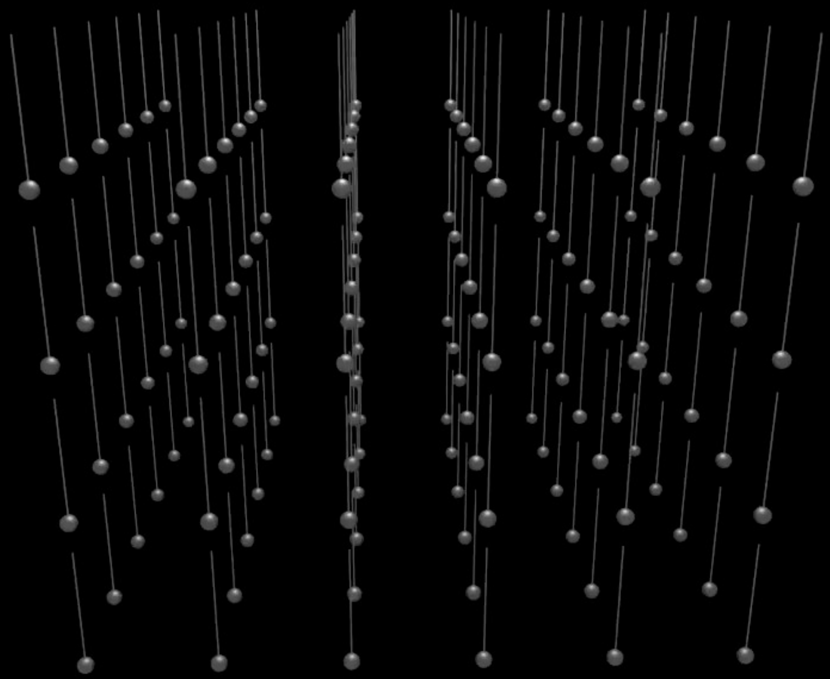
New physics is waiting at the Planck mass

- Direct detection of Planck mass dark matter may be possible through gravitational interactions alone! (Dan et al., arXiv: 1903.00492)
- Well-motivated parameter space: examples include PBH relics, WIMPZillas.





Dark matter particles will induce an acceleration in individual sensors that can then be read out optically.

We need to go below the SQL

$$\Delta I_{SQL} \sim \sqrt{\hbar m_d \omega} = \sqrt{\hbar \times 1\,\mathrm{g} \times 1\,\mathrm{kHz}} \approx 19\,\mathrm{GeV/c}$$

Accelerometer test mass

$$\Delta I_{signal} \sim \frac{2Gm_d m_\chi}{dv} = \frac{2G \times 1\,\mathrm{g} \times 20\,\mu\mathrm{g}}{1\,\mathrm{mm} \times 220\,\mathrm{km/s}} \approx 2.5 \times 10^{-5}\,\mathrm{GeV/c}$$

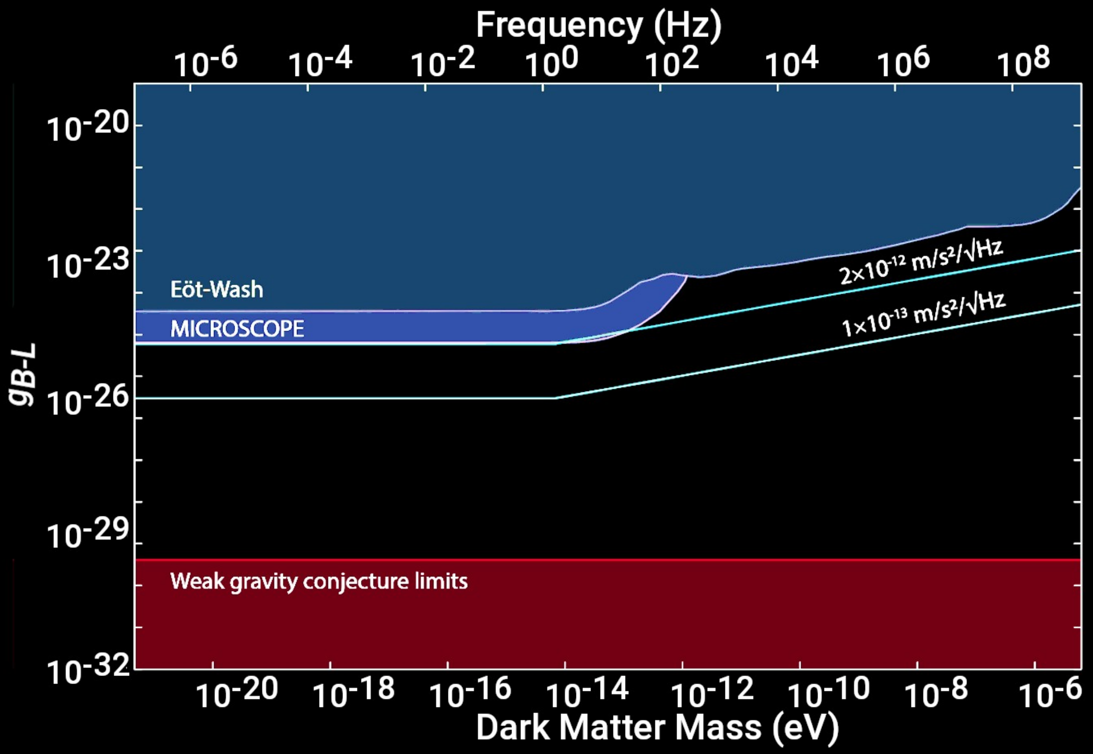
Dark matter particle mass (Planck mass, 20μg)

arXiv: 1903.00492

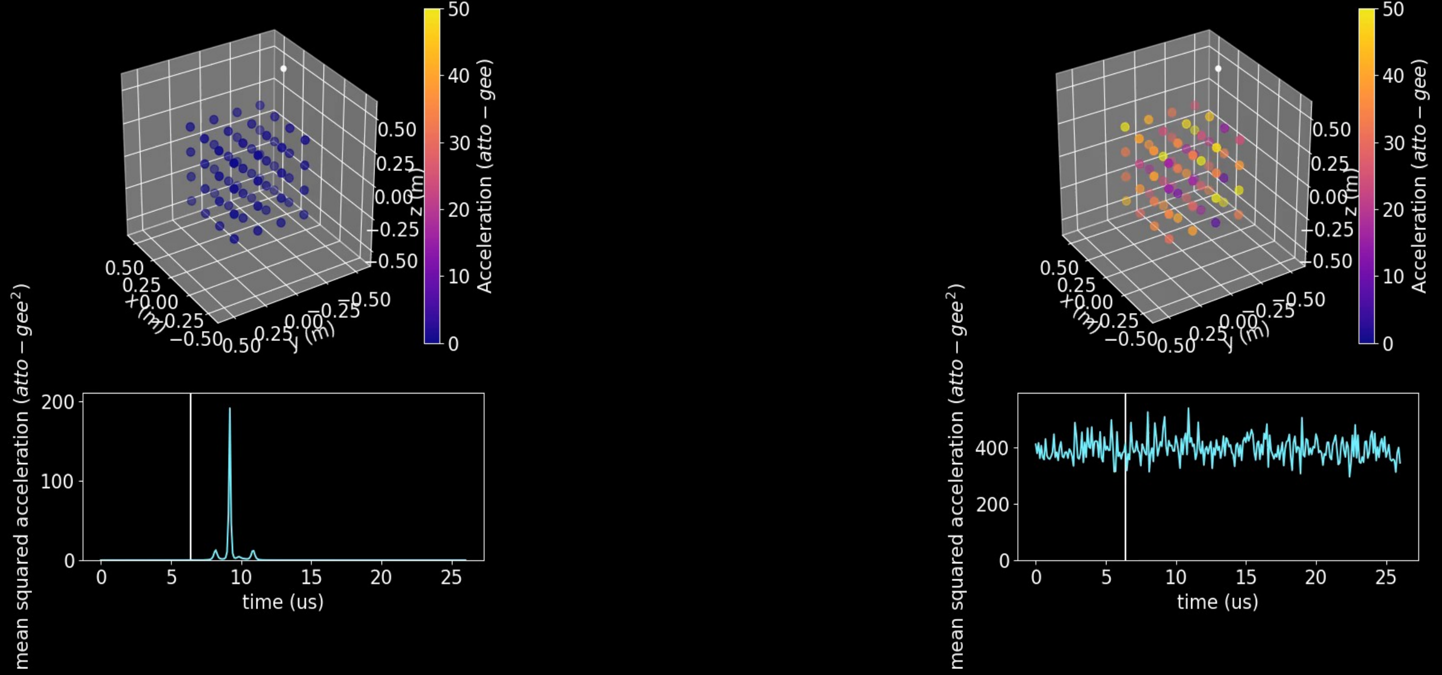
To get there, we need both quantum noise reduction (squeezing and backaction evasion) and large numbers of sensors for sqrt(N) enhancement.

Ultralight dark matter

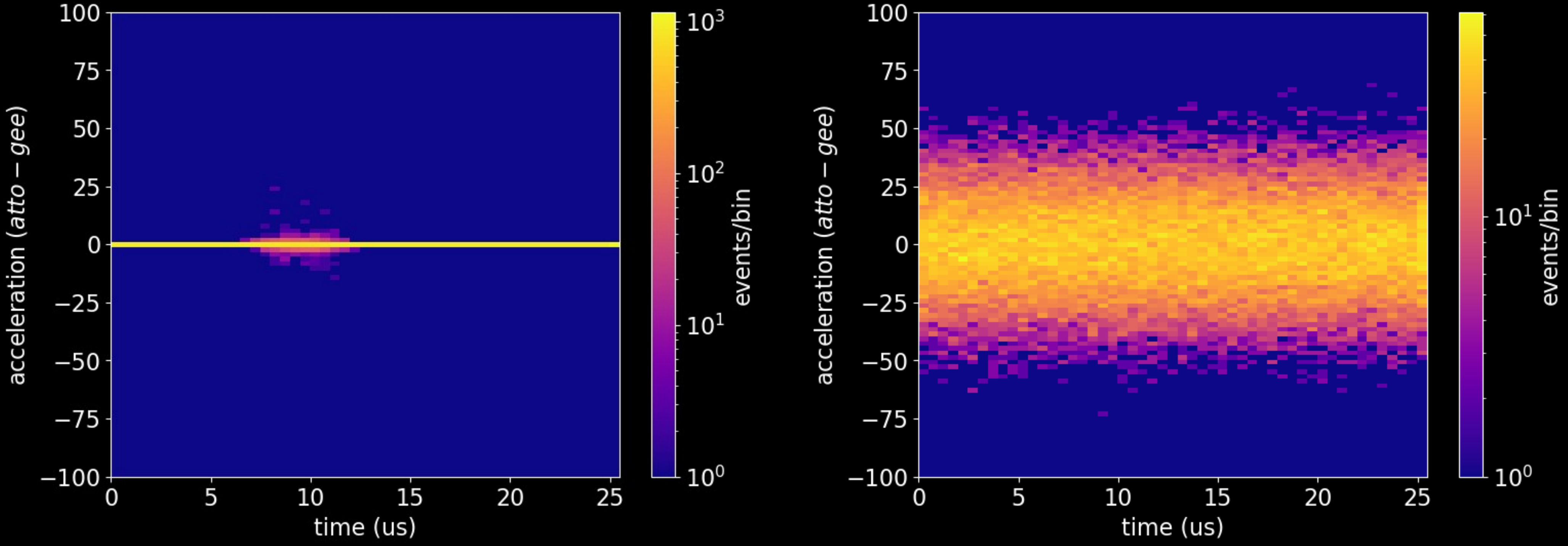
- Gravitational detection of dark matter is the long term goal.
- In the medium term we expect to be sensitive to models such as dark matter that couples to the baryon number minus the lepton number.



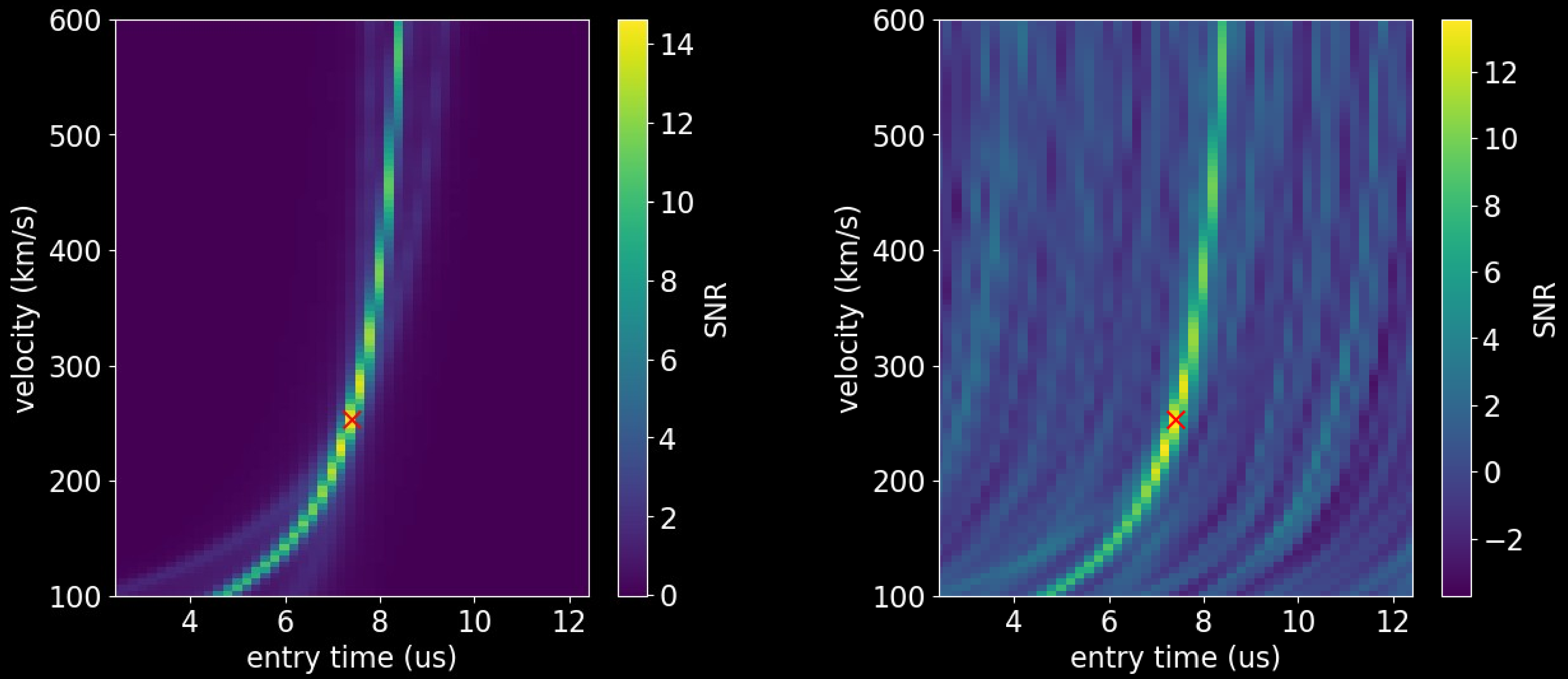
arXiv:2008.06074, with additional projected limits included



Left: simulated detector readout without noise. Right: with quantisation and noise.
Planck mass DM particle and noise of ~10^{-22} g per root-Hz. 4x4 array of accelerometers sampled at 10MHz.

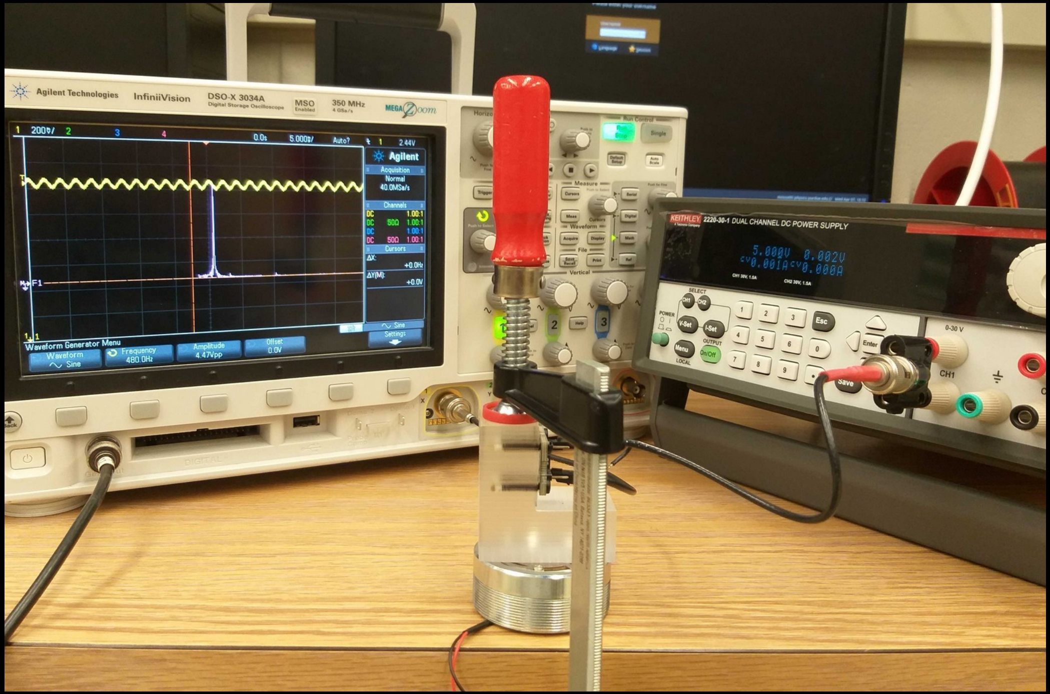


Same data as before, plotted onto histograms of acceleration magnitudes.
Left: without noise. Right: With noise.



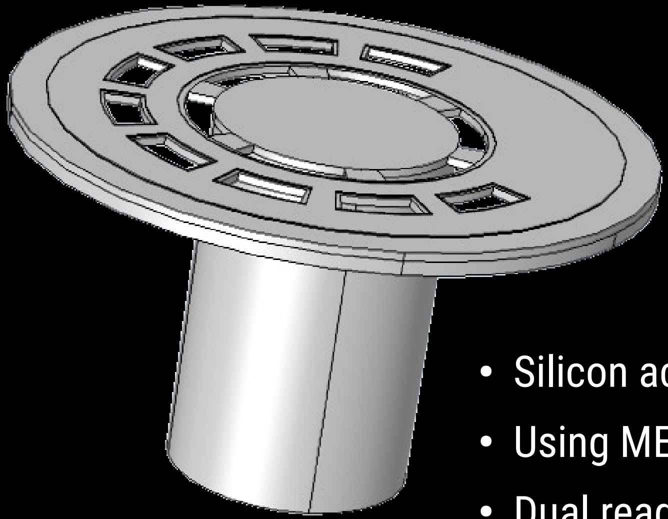
Recovering signal below the individual sensor noise level via template fitting across all sensors.
Same data as previous slide!

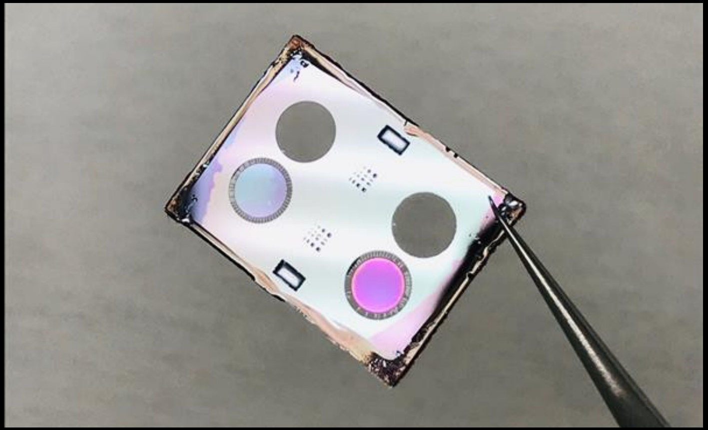
Protochime



- Commercial accelerometer array to evaluate data pipeline and analysis framework, and other possible pitfalls.
- Accelerometers have arrived and circuits are working.
- Current work focused on programming NI-5751 ADC and building the mechanical system.

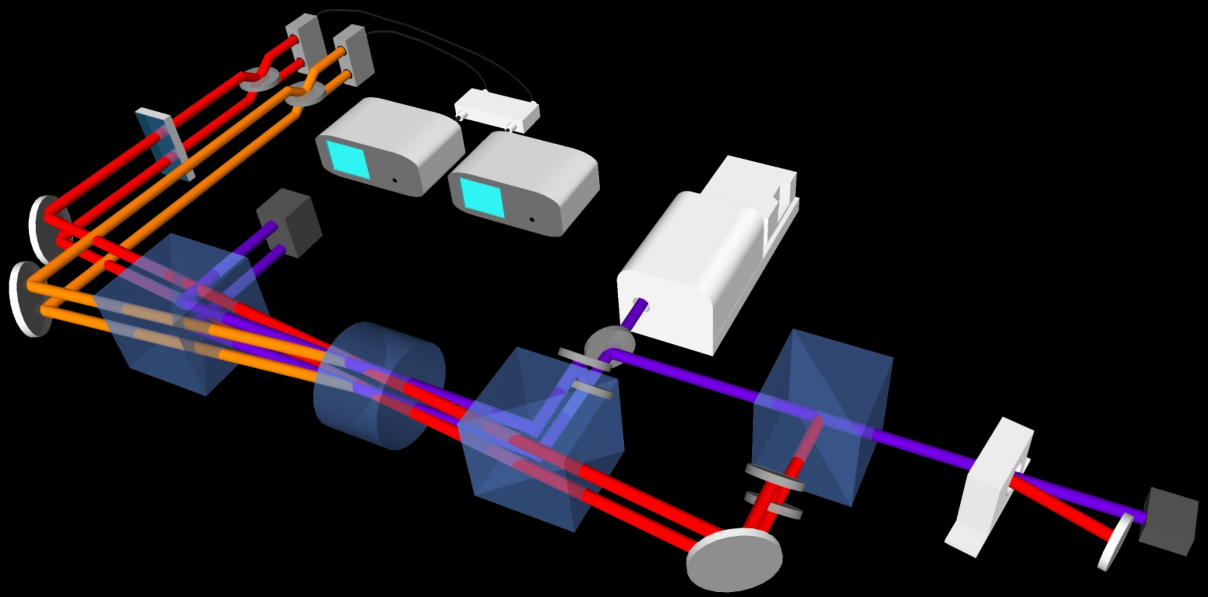
First generation sensors





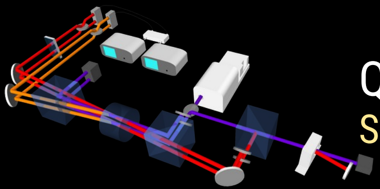
- Silicon accelerometers, 96 per wafer
- Using MEMS technology allows us to scale up
- Dual readout, with free-space optics and wave-guided photonics
- In the above picture, the lower two accelerometers are working while the springs for the top two buckled
- Year 1 target: $1\,\mu g/\sqrt{\mathrm{Hz}}$

Squeezed light readout



- First thrust: read out one single sensor as well as possible.
- Non-linear interferometric readout, near drop-in replacement for coherent optical readout, allows pushing below standard quantum limit.
- 3dB of noise reduction demonstrated in AFM.
- Second thrust: On-chip integrated squeezed readout, such as demonstrated in arXiv:1904.07833

Phys Rev Lett 124 (23), 230504 (2020)

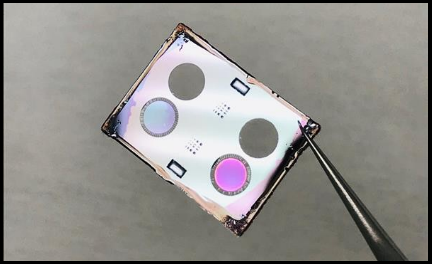


Quantum noise suppression

Short impulse signals (particle detection)

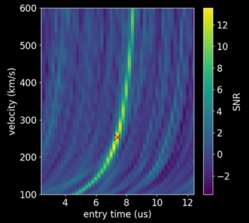
Environmental isolation

Improved mass and force metrology



Scale (number of sensors)

Ultralight DM



Data pipeline and analysis

Improvements in data analysis techniques for large datasets