"Measured" Newtonian Noise:

Implications for Advanced Detectors

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Outline

Motivation - why low frequencies?

Past Newtonian noise estimates

Simulation of subtraction ability

Array measurement at LIGO Hanford

Implications of results - what does this mean for future terrestrial detectors?

Motivation

Low frequencies have interesting scientific targets

More SNR at lower frequencies:

Better matched filtering

Longer lead time for EM triggers

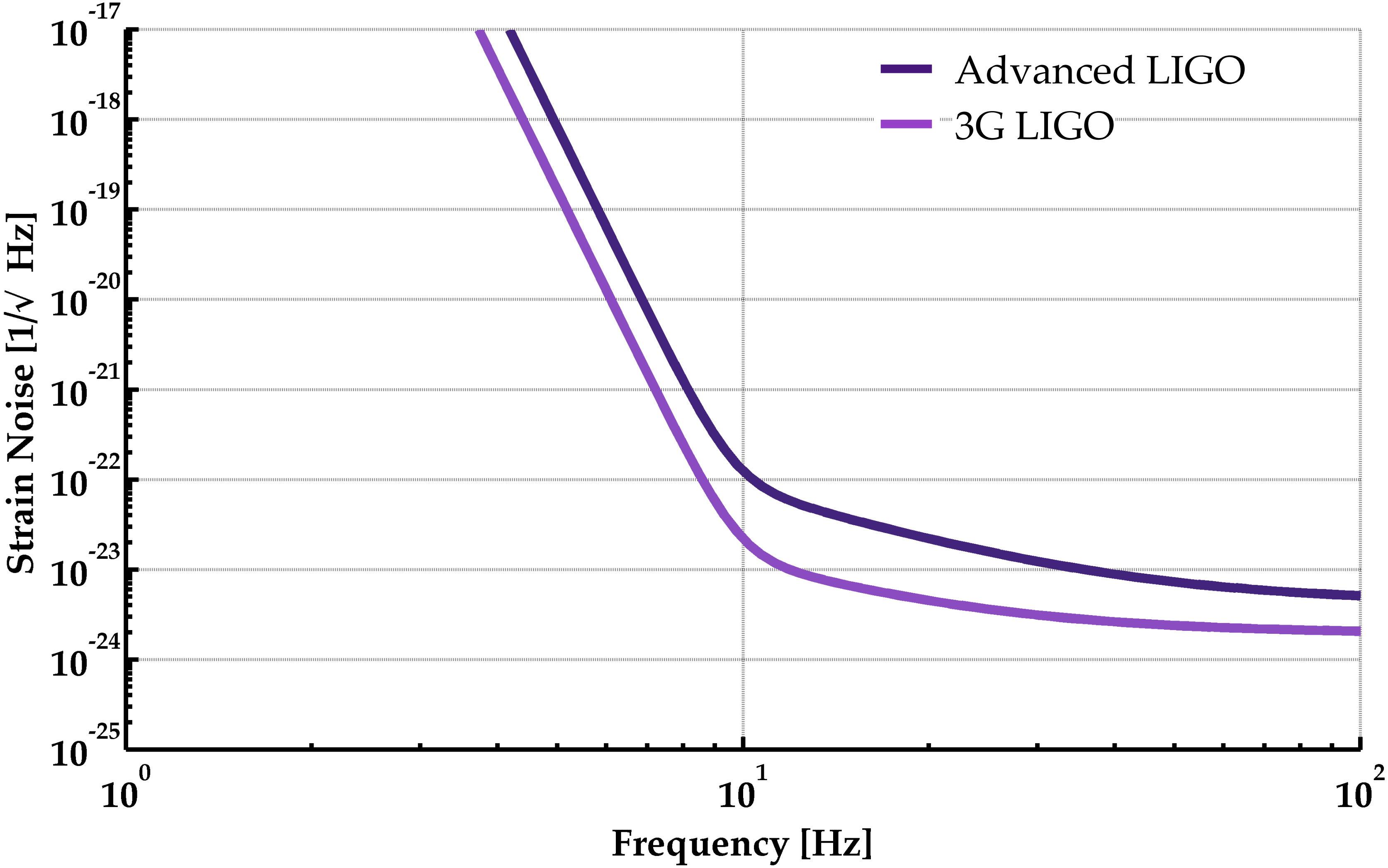
Palomar

Intermediate mass black holes: possible discovery or exclusion

Possibility of interesting pulsars

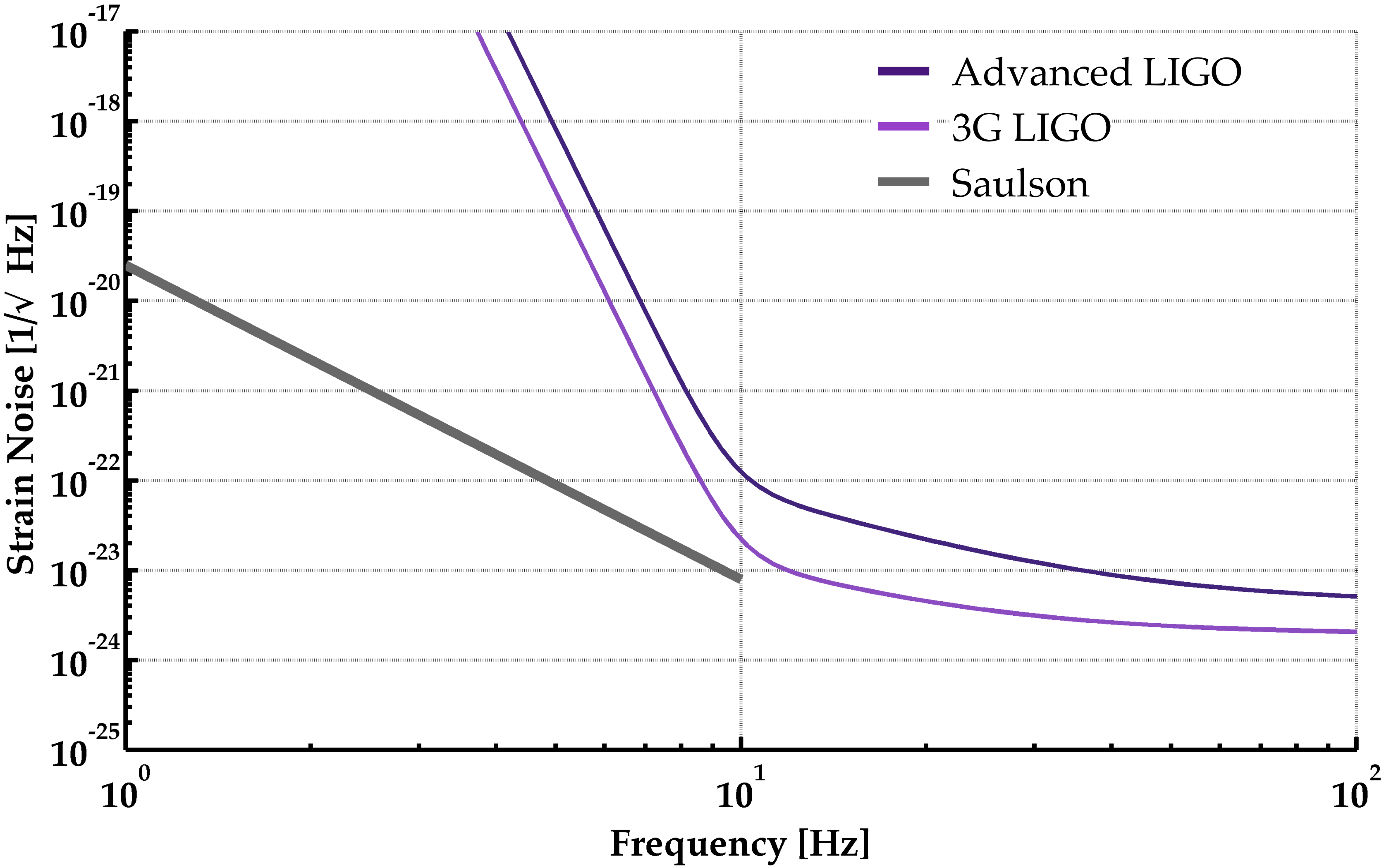
Crab Pulsar

Advanced LIGO and 3rd Generation Strain Curves



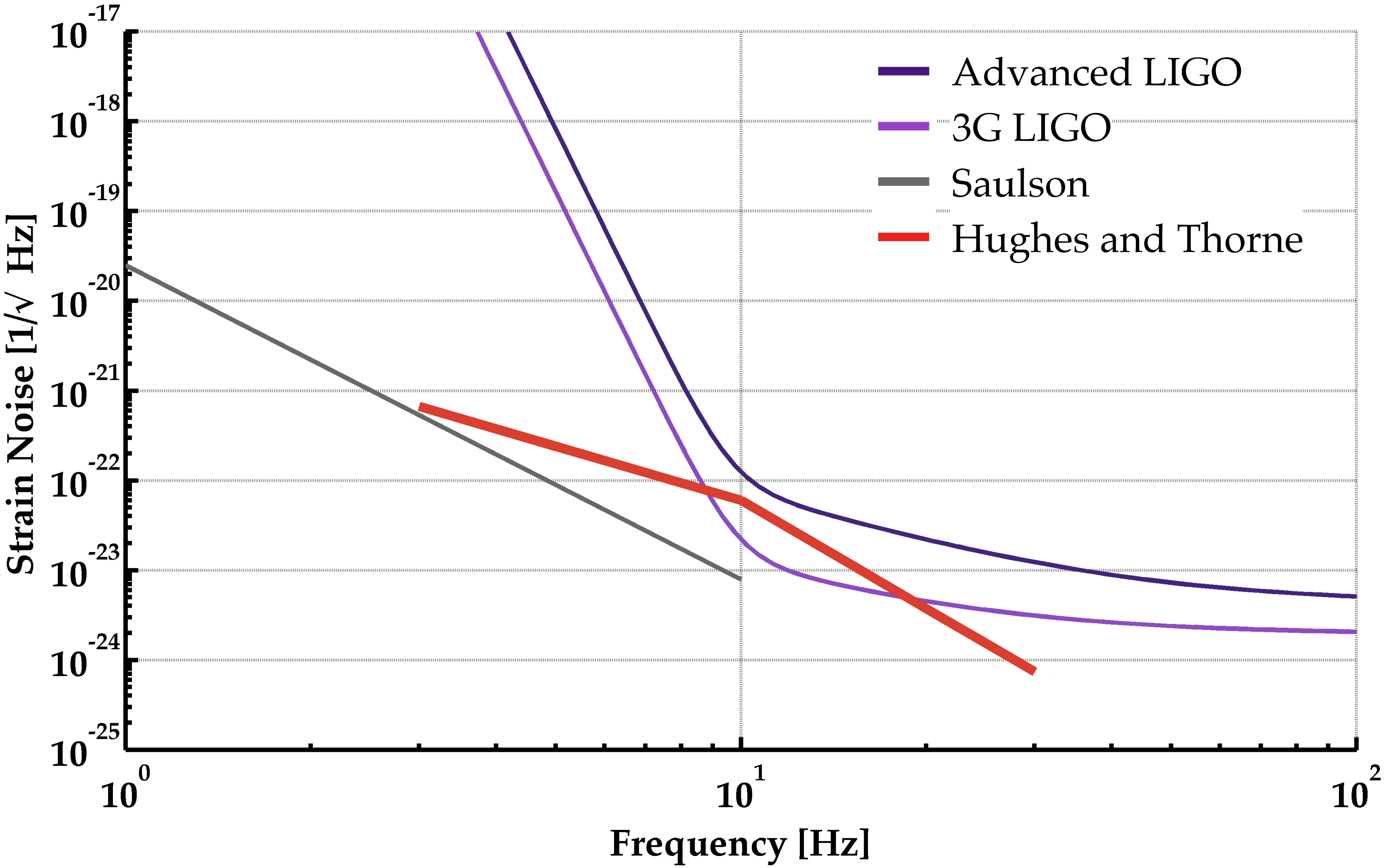
Past Newtonian Noise Estimates

Saulson, 1984, Average Underground Site



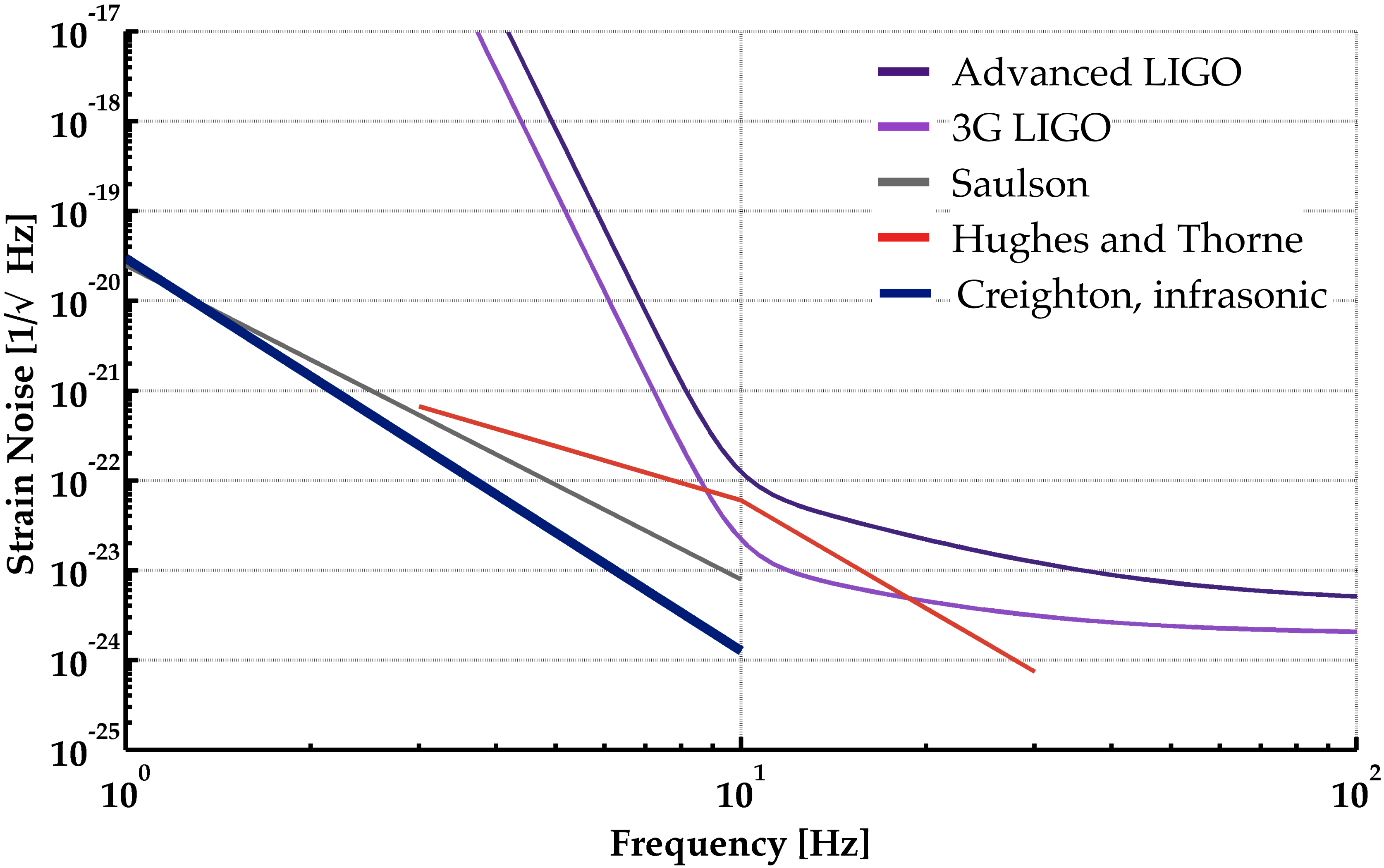
Past Newtonian Noise Estimates

Hughes and Thorne, 1998, Seismic, $\beta = 0.6$



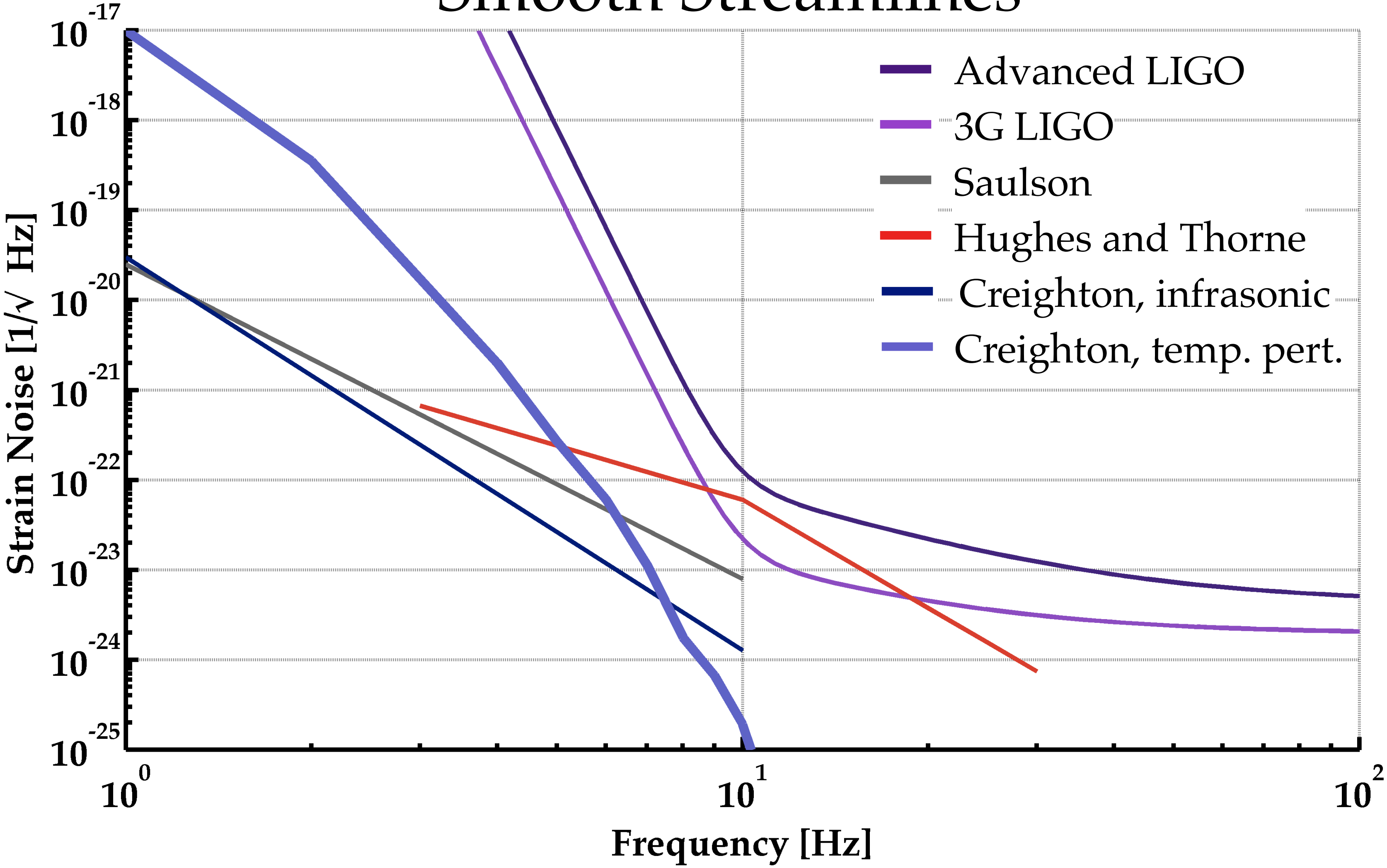
Past Newtonian Noise Estimates

Creighton, 2008, Infrasonic Atmospheric, 75% Level



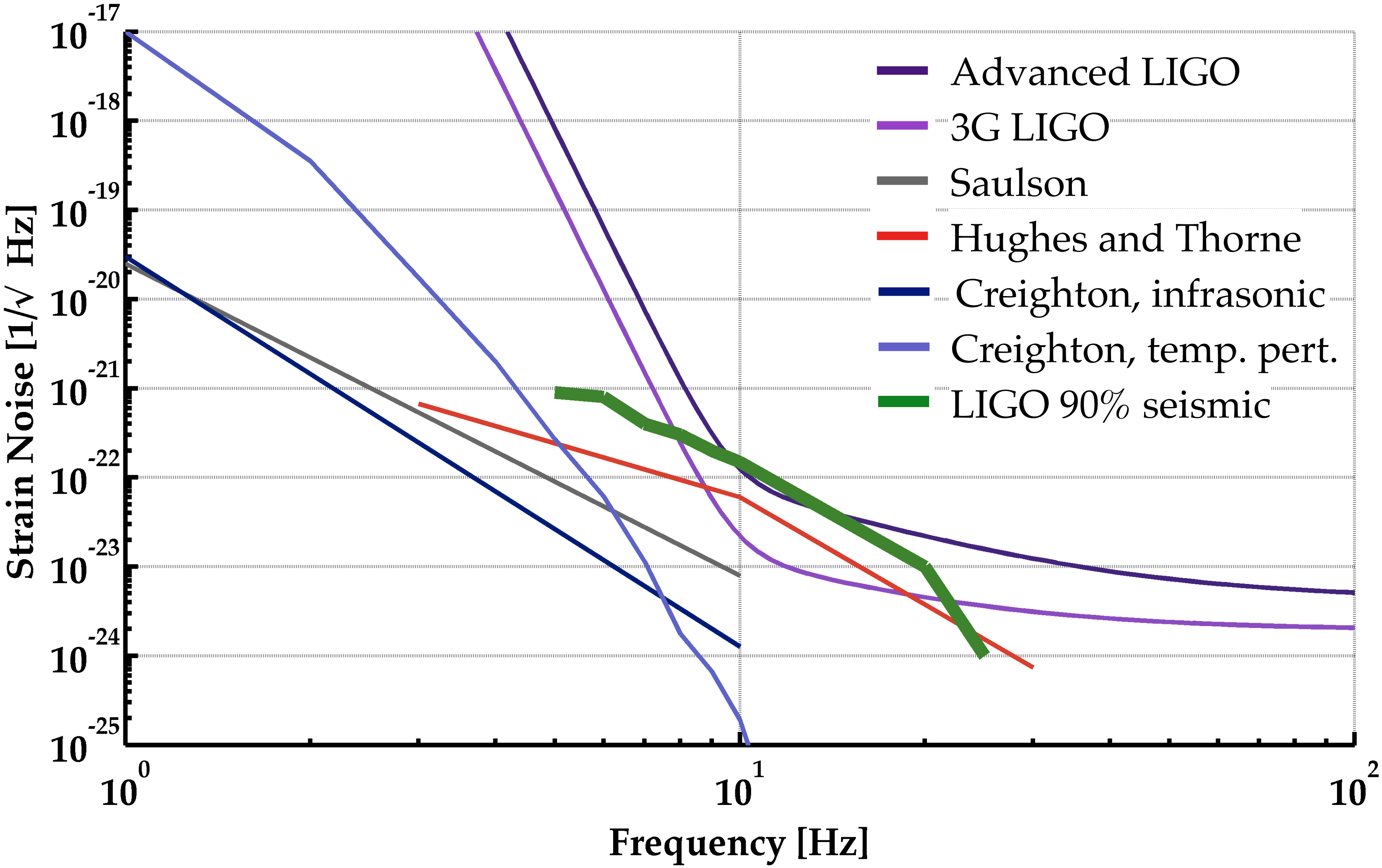
Past Newtonian Noise Estimates

Creighton, 2008, Temperature Perturbations, Smooth Streamlines



Past Newtonian Noise Estimates

LIGO 90% Seismic, Measured 2011



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Along arm cavity axis: $\delta\vec{a}_{NN} = \frac{\delta\vec{F}}{m} = G\,\rho_0 \int \mathrm{dS}\,\frac{\xi_{vert}}{r^2}\hat{r}$

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Use simulated Newtonian noise models for testing, optimizing:

Filtering methods

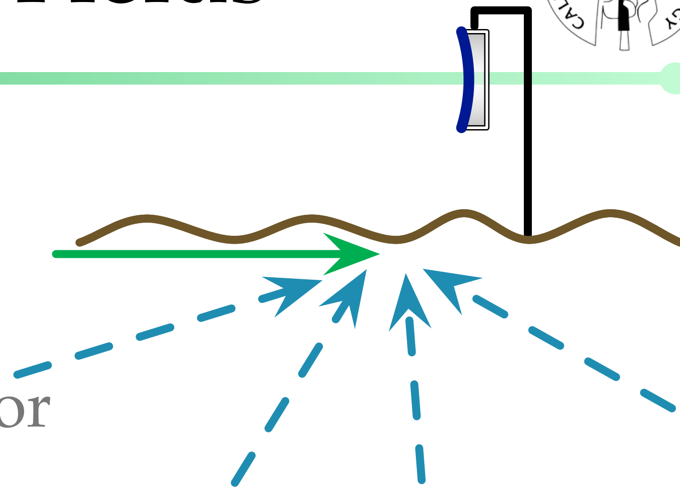
Array configuration

Simulated Seismic Fields

Plane waves describe seismic field

- Most sources are distant
- Implications if we're wrong:
  - Complex fields are hard to monitor

Simulated Seismic Fields



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- **No body waves**
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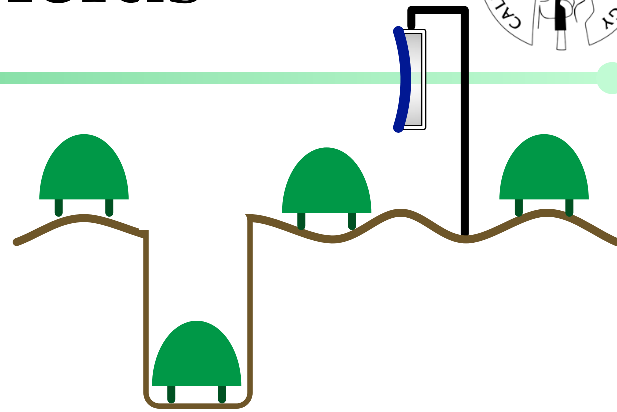

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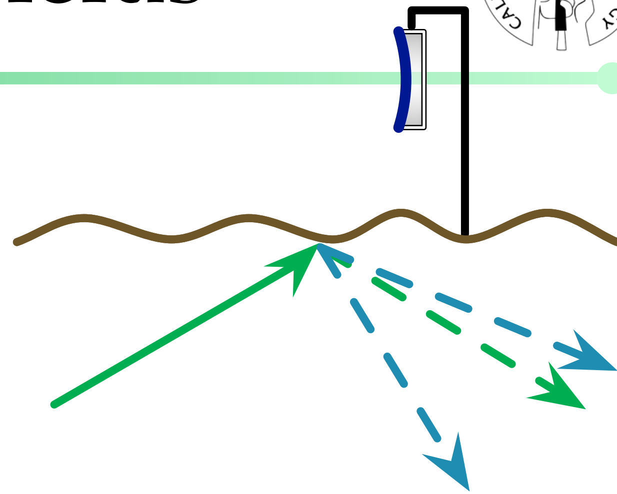

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No scattering of seismic waves

- Assume scattering amplitudes << 1
- Implications if we're wrong:
  - Many different wavelengths - hard to monitor

Optimal Seismic Arrays

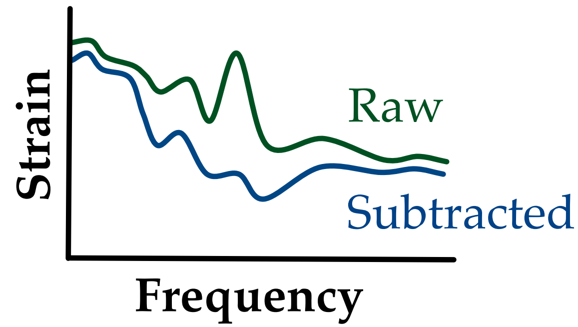
How to:

Define the subtraction factor at a single frequency

Optimize subtraction factor $\sqrt{R}$ by changing:

- Number of sensors
- Array size
- Sensor layout

$$\sqrt{R} = \sqrt{\frac{S_{NN_{Sub}}}{S_{NN_{Raw}}}}$$



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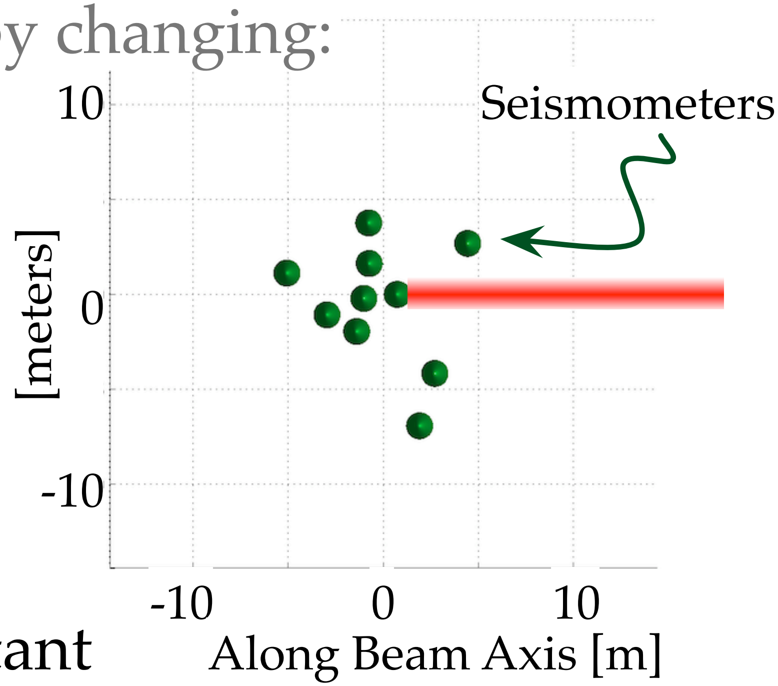

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Extent / size of array is important

Specific layout is much less important

- Main requirement: "many close, some far"

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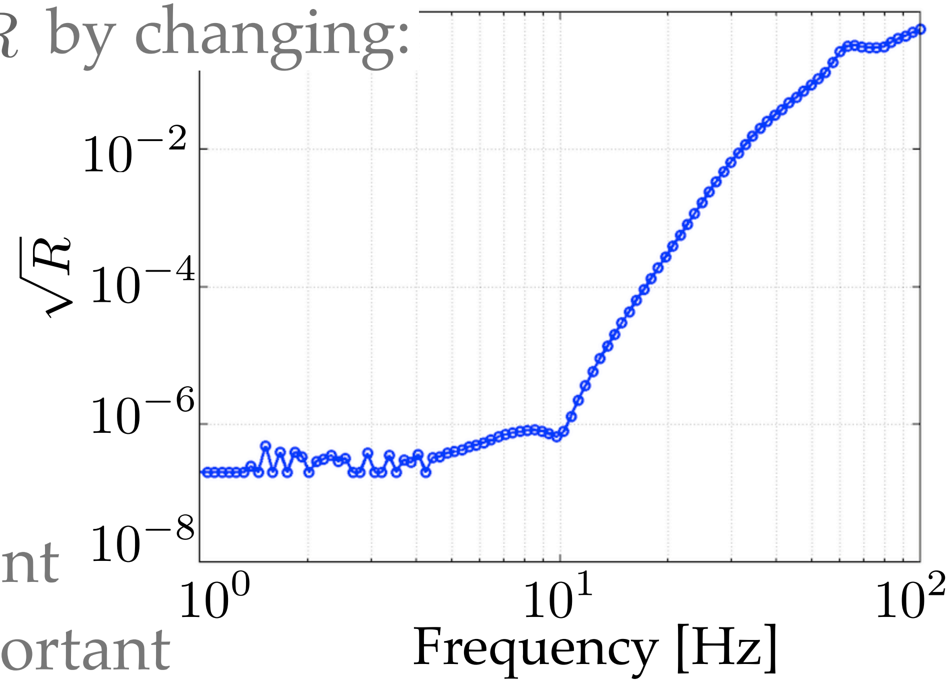

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For 10 Hz optimized array, can achieve (theoretical) subtraction factor of ~1e-6 with 10 sensors

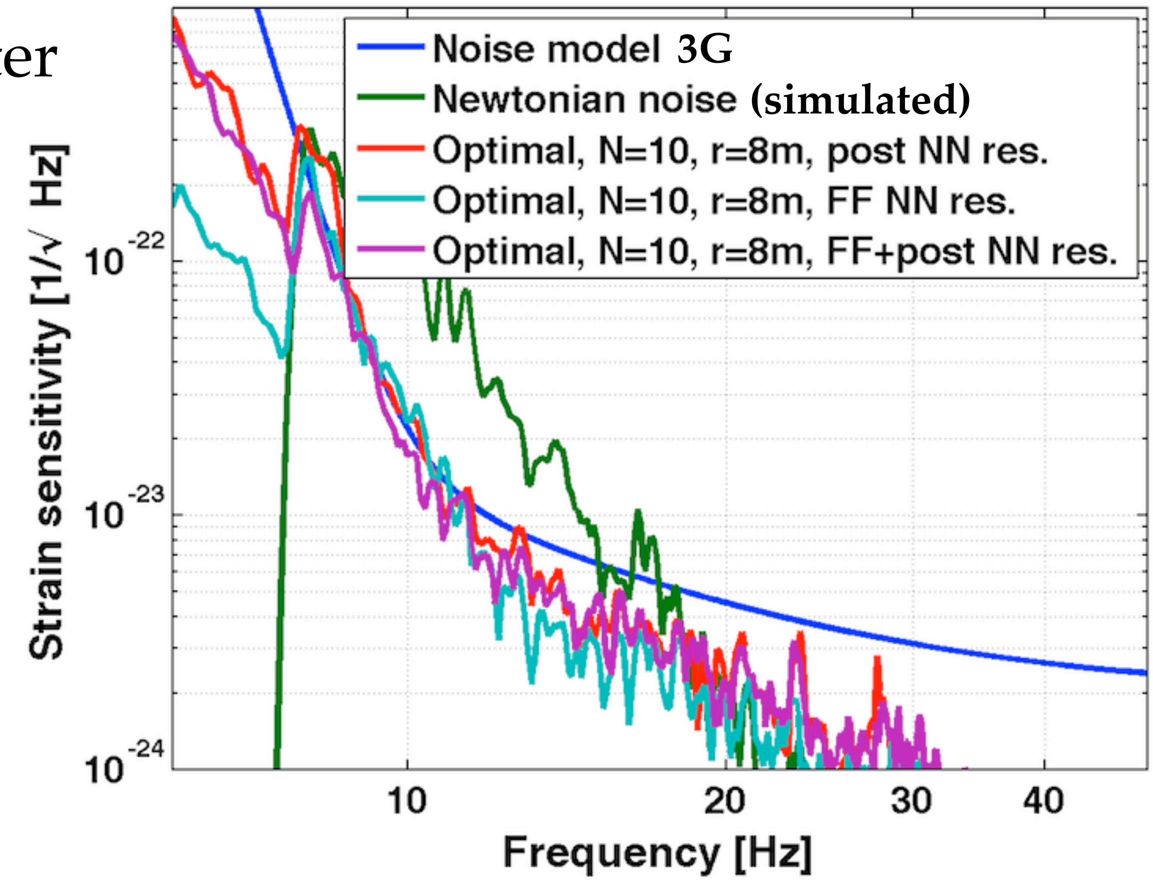
Subtraction of Simulated Noise

Comparing

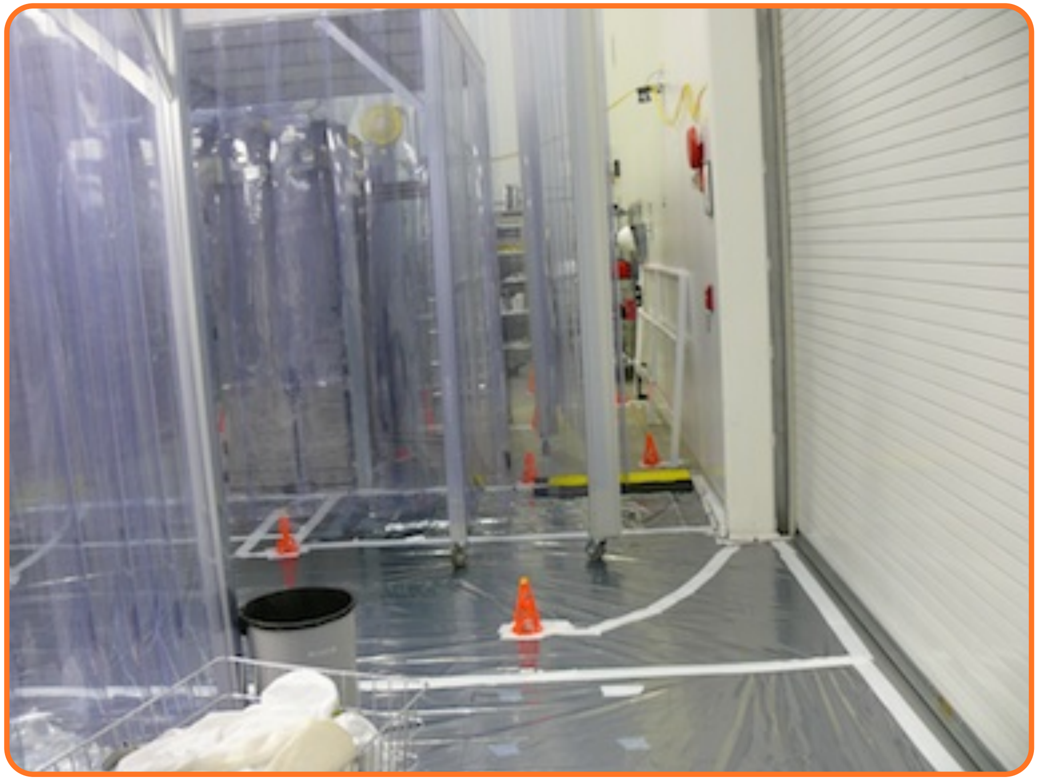
- Online feed forward cancellation
- Offline Wiener filter cancellation
- Online, then offline later

Take-home message:

We think we can suppress Newtonian noise for Advanced LIGO and 3G detectors



Actual Measurements



Installed: April 2012

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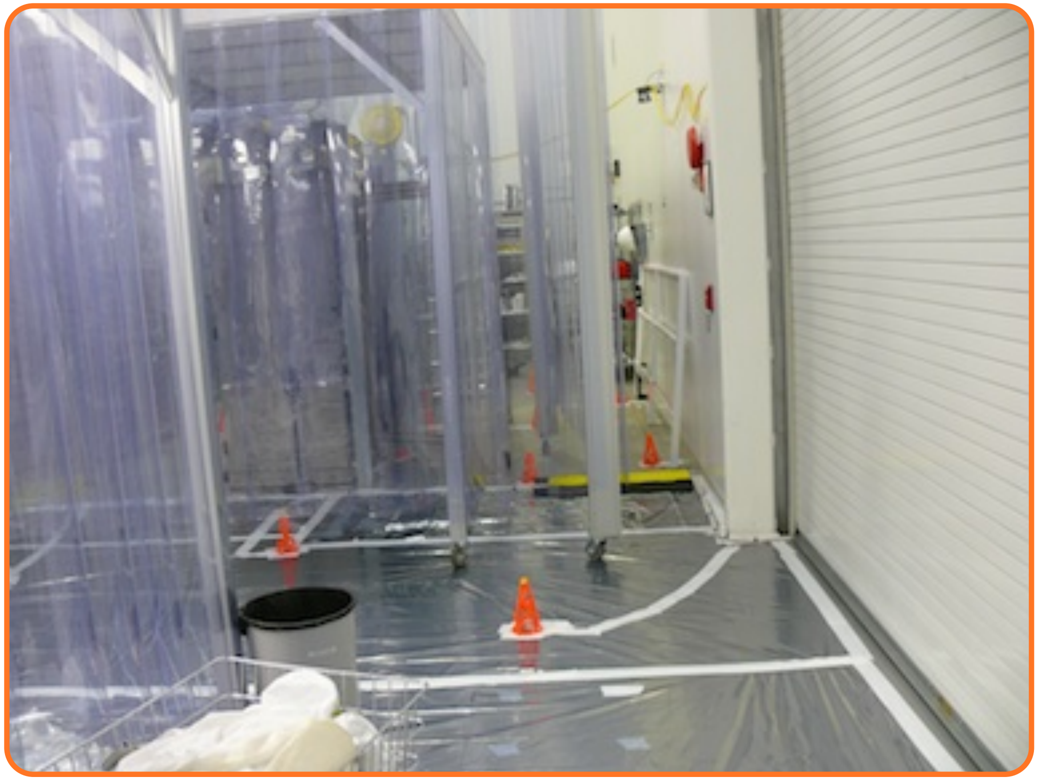

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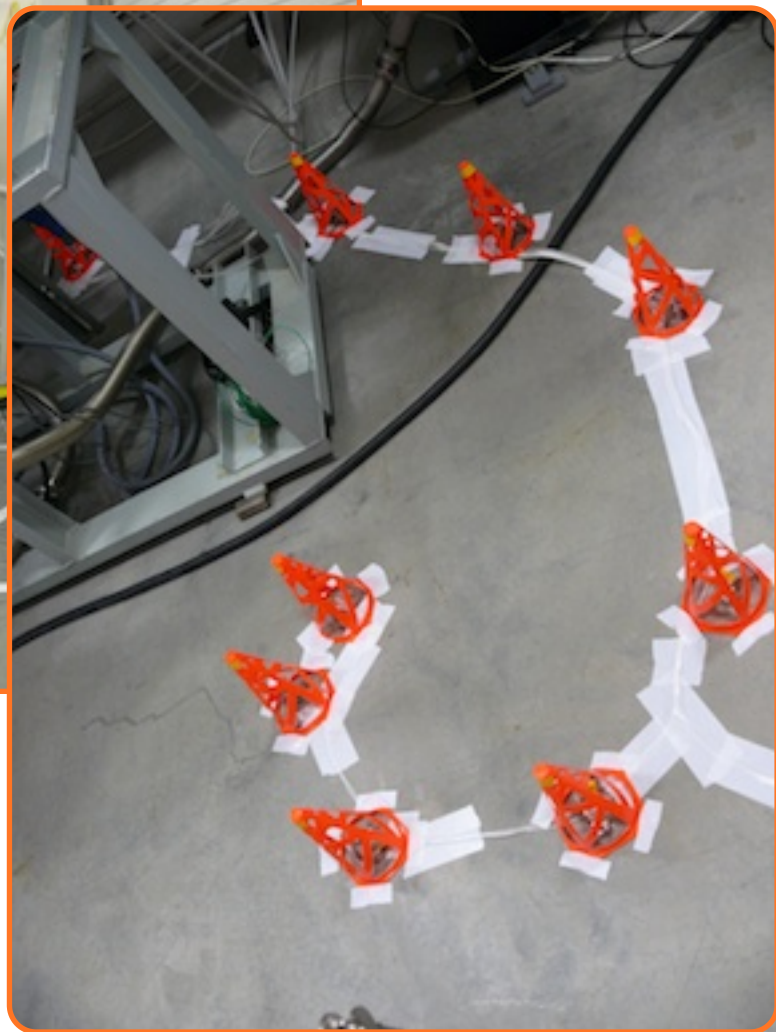

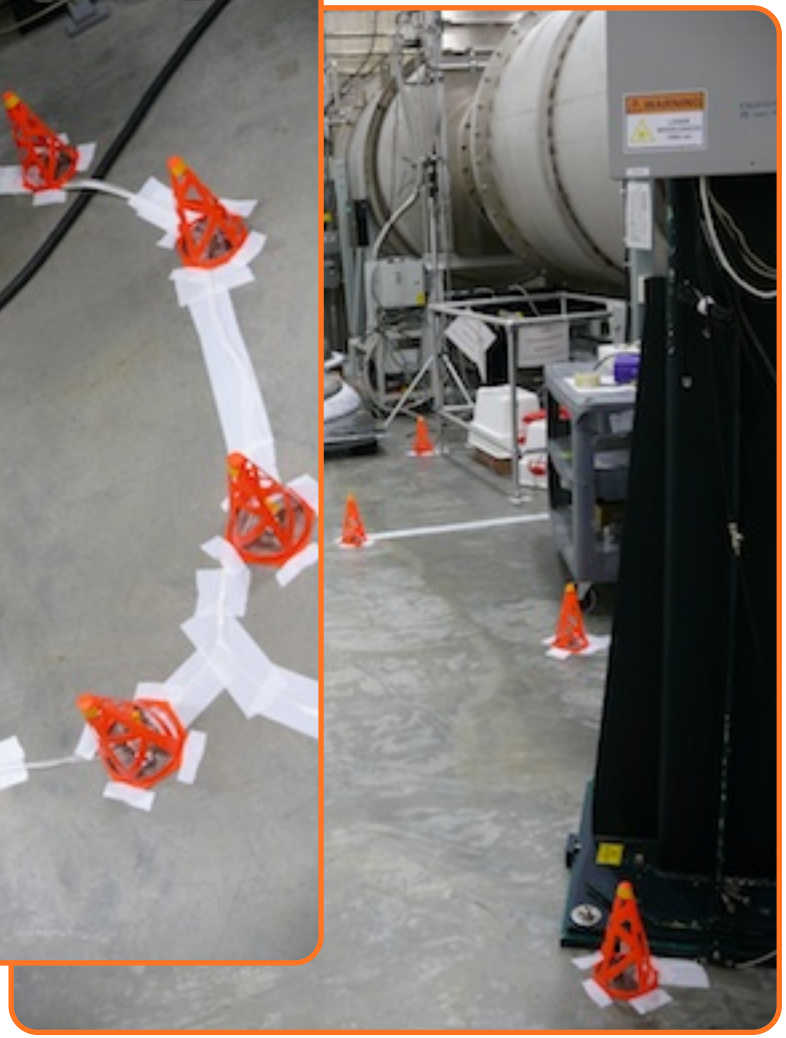

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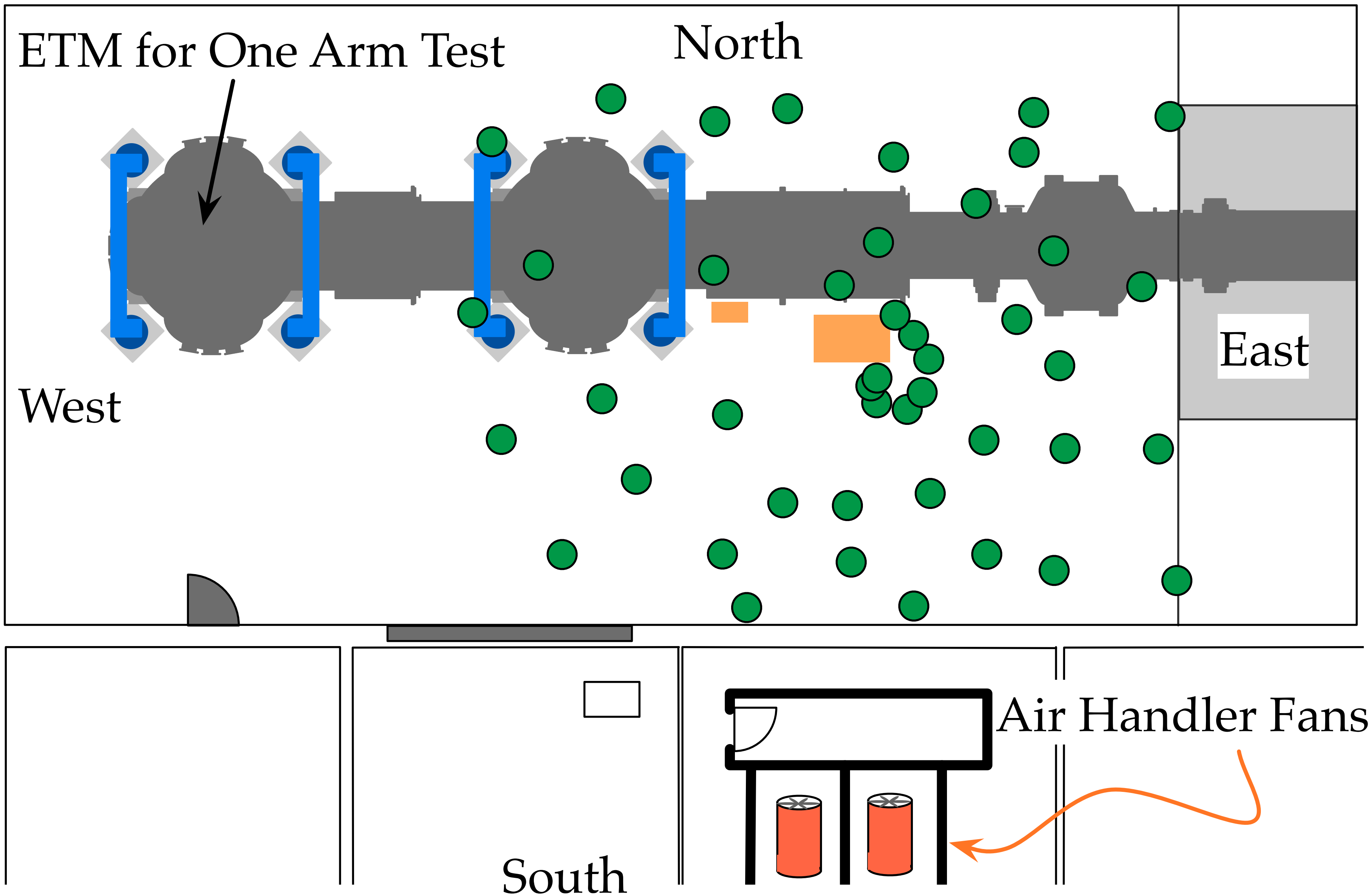
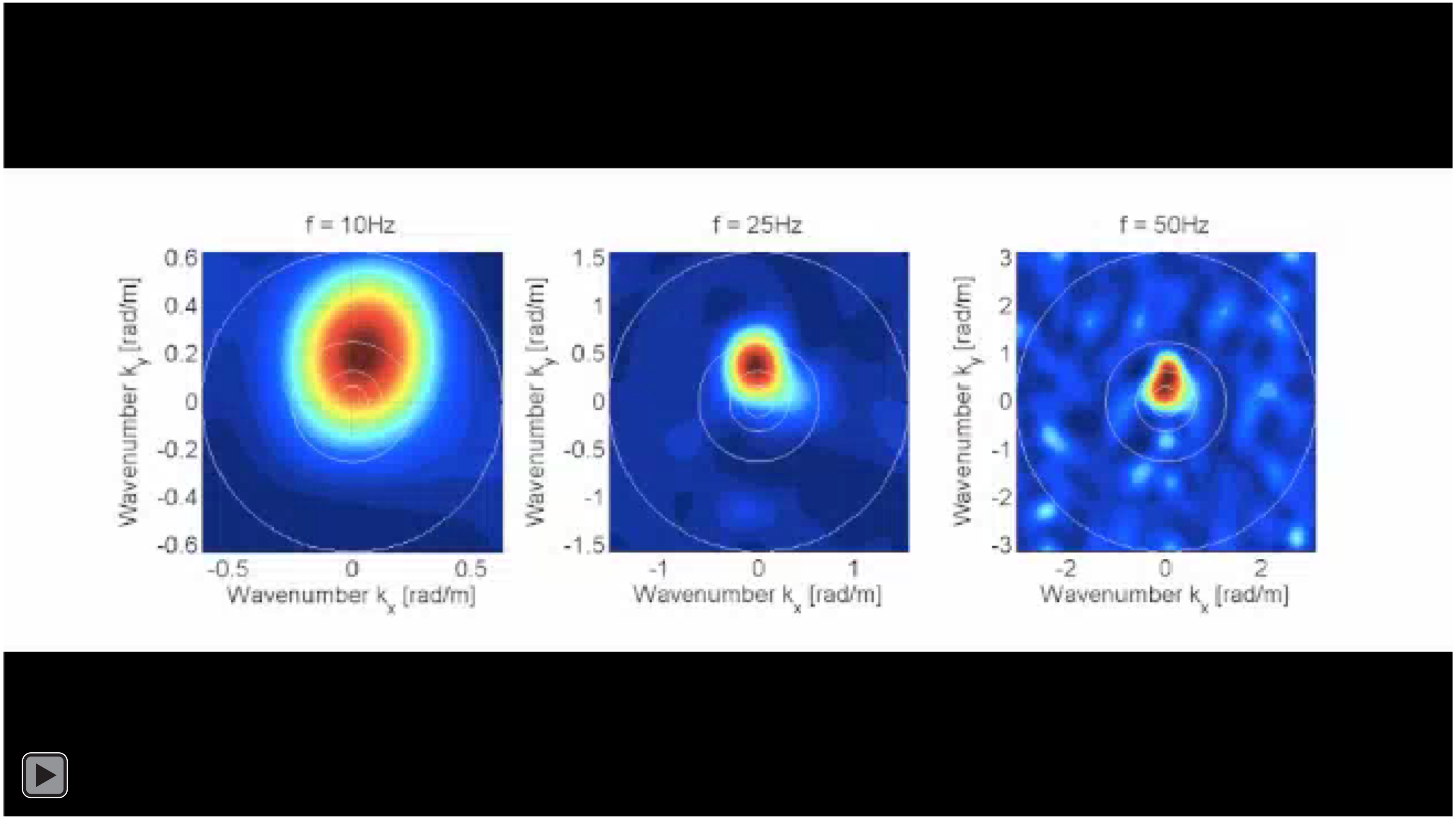
Spiral Layout - 44 Sensors



Dominant Wave Vector vs. Time

10 Hz 25 Hz 50 Hz

Wavenumber k_y [rad/m]



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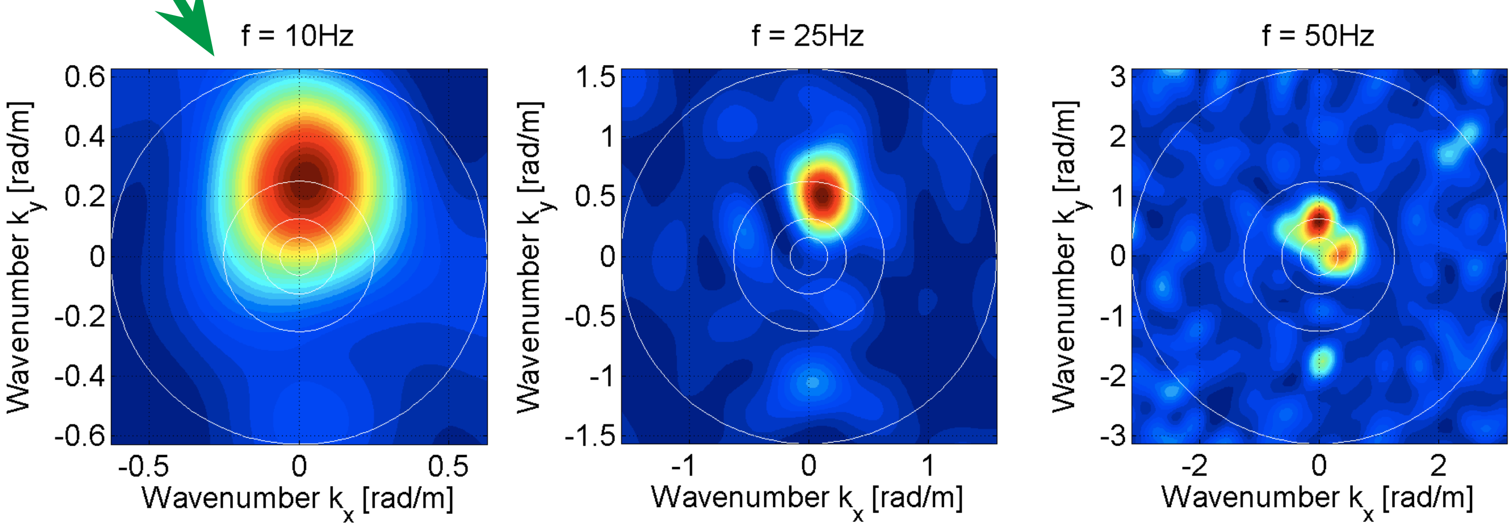
Summary of Results from Movies

Simple plane wave, most of the time



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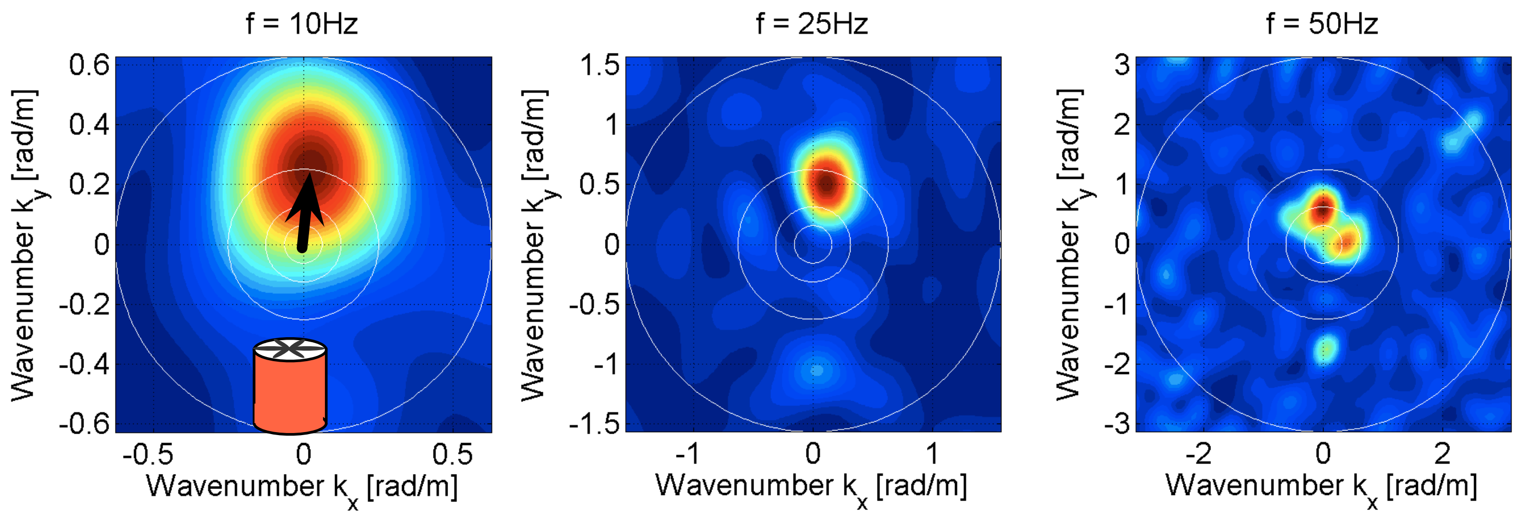

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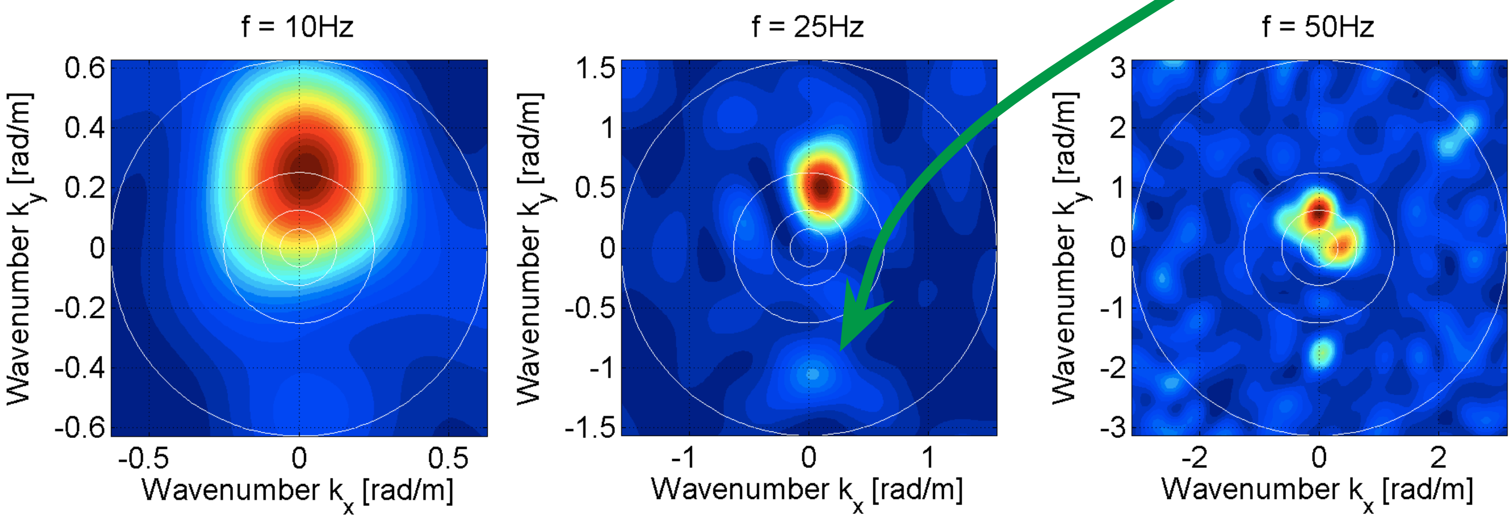

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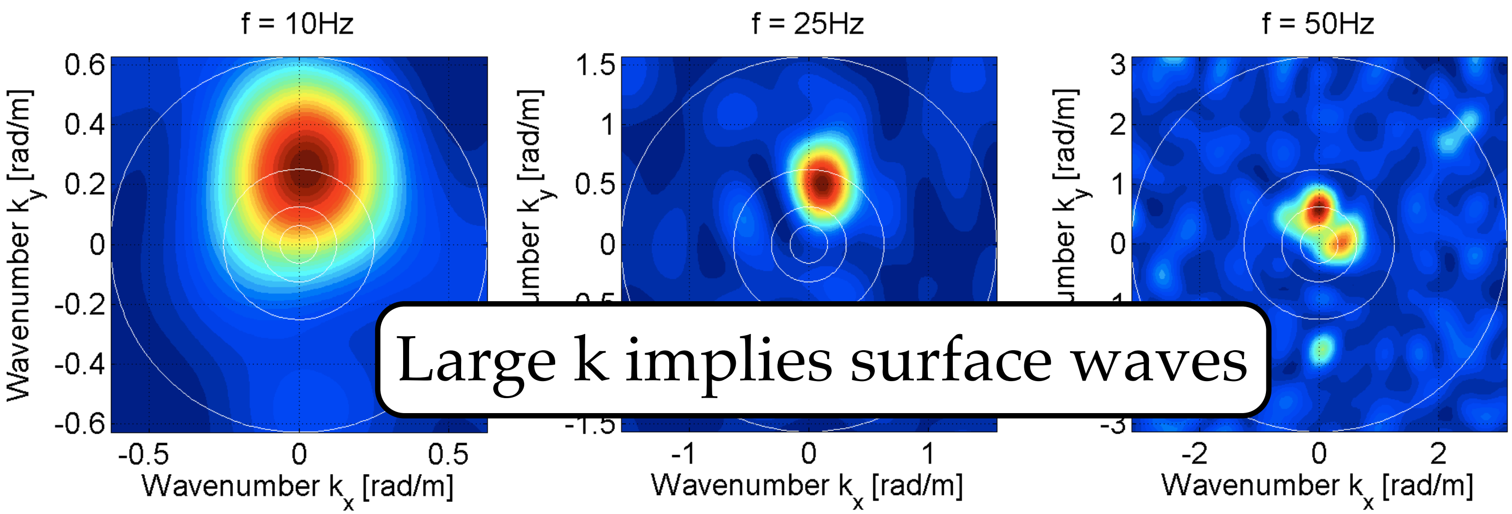

Large k implies surface waves

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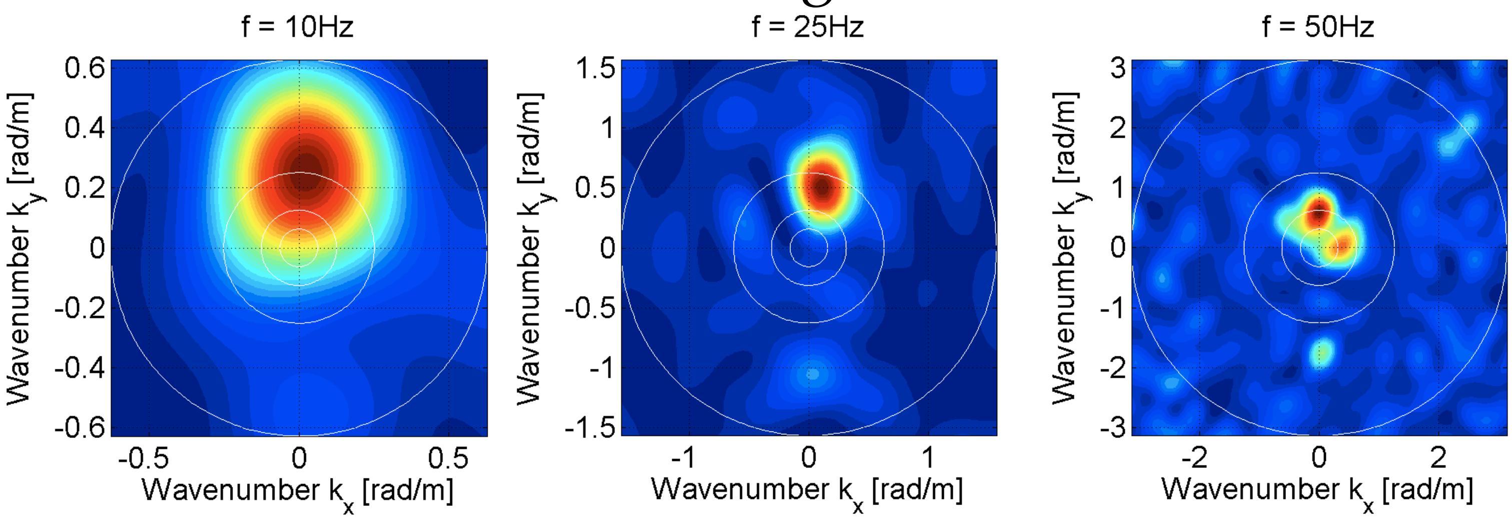
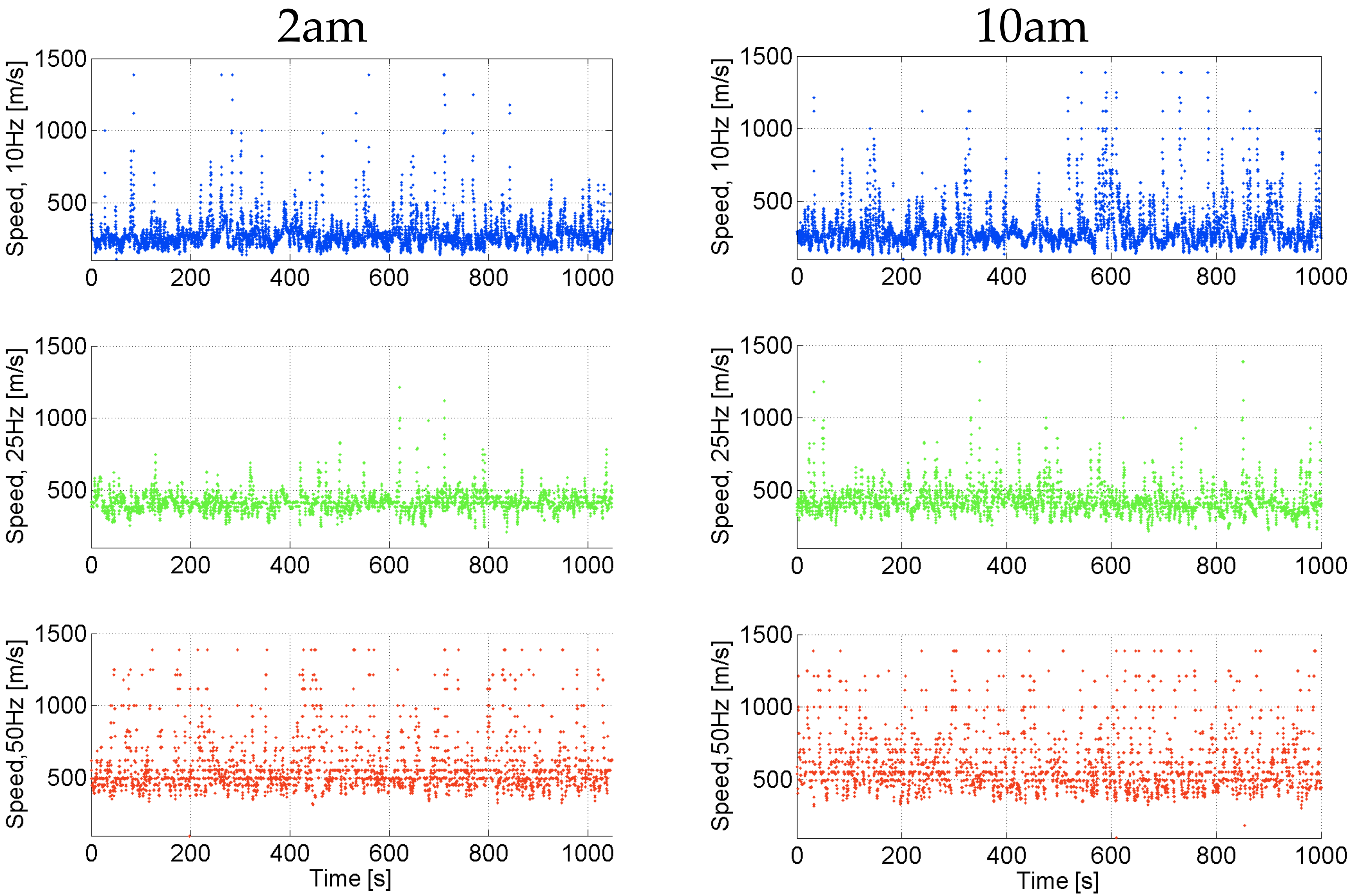
Not much evidence of scattering

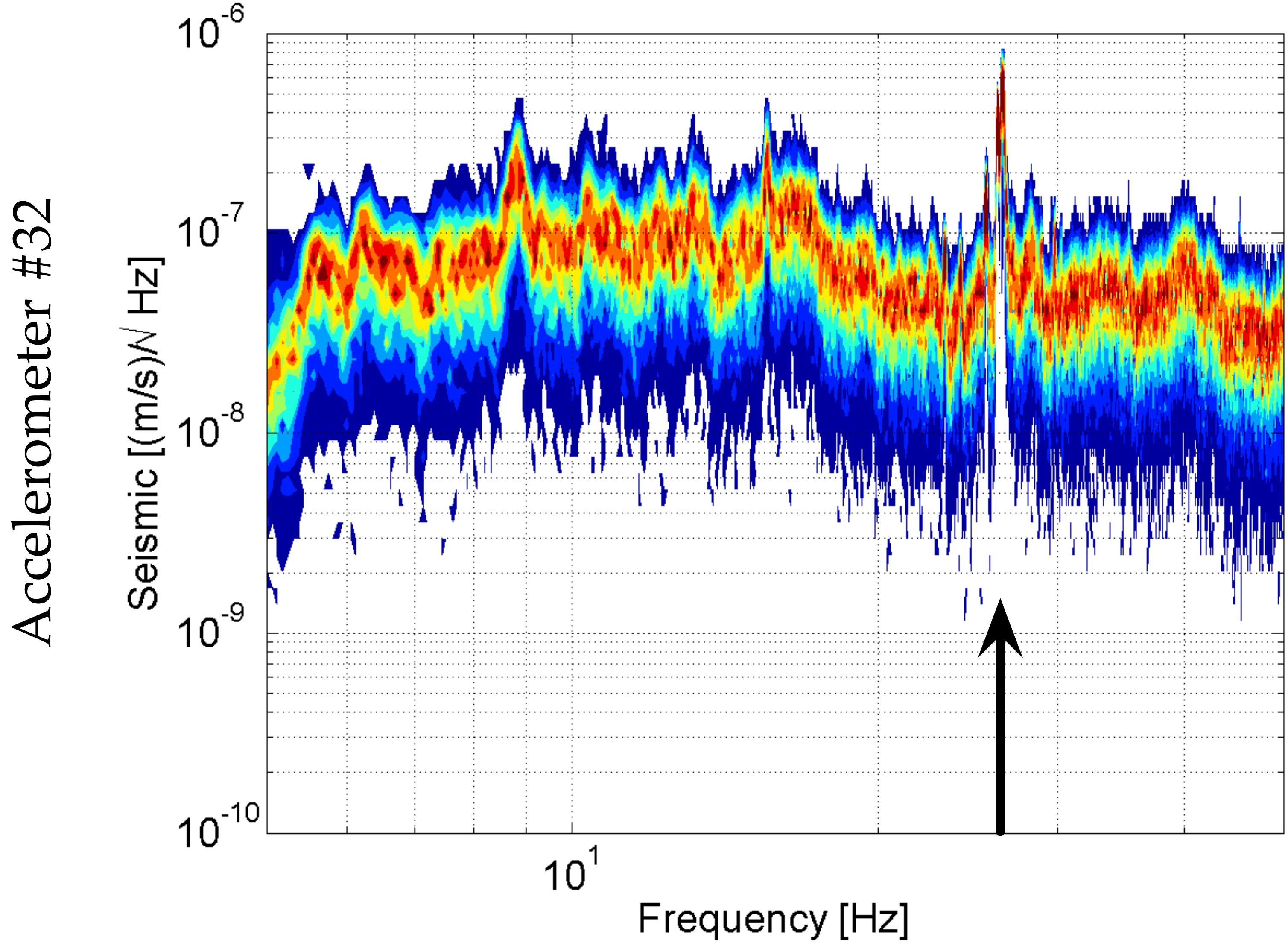


Wave Speed vs. Frequency



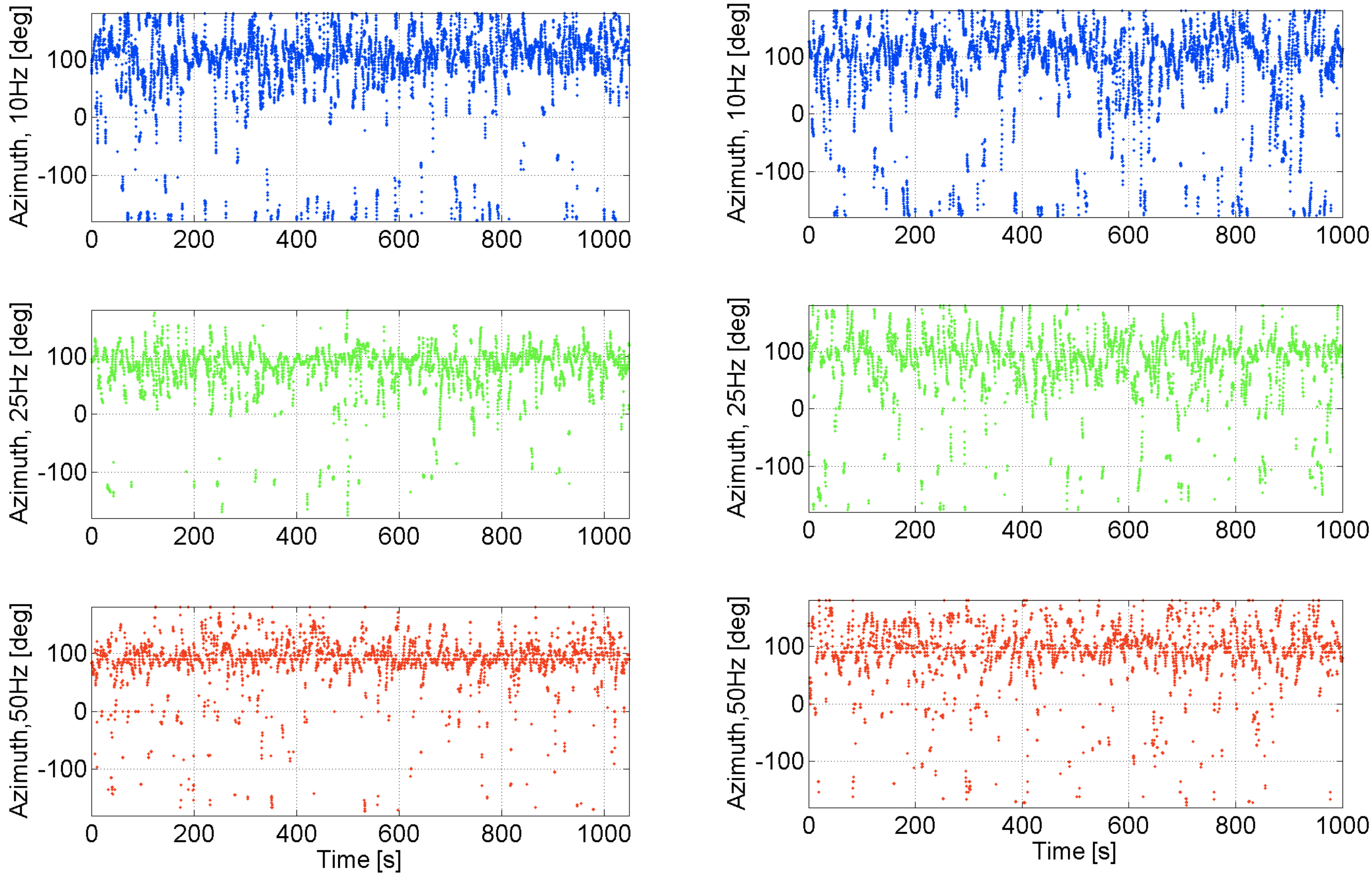
No Body Waves at 25 Hz?

Lots of noise at 25Hz - probably a surface source dominating



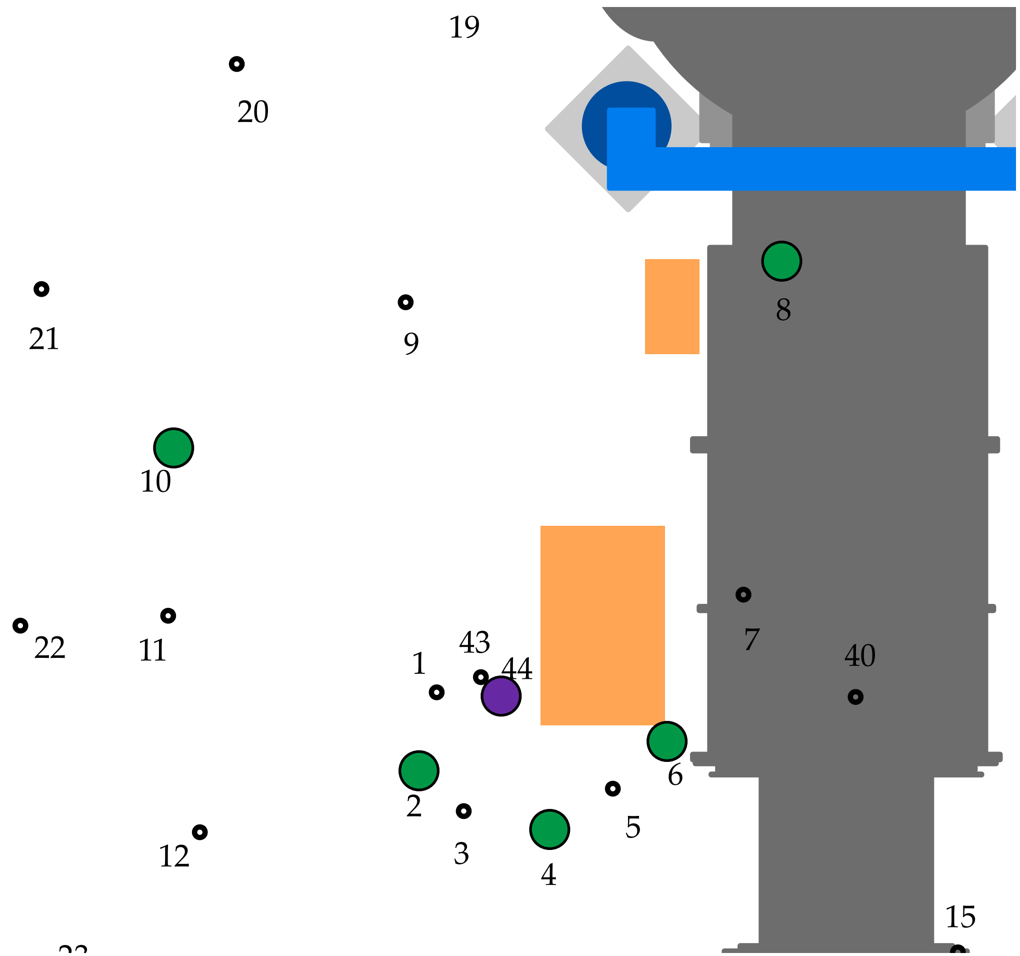
Propagation Direction vs. Freq

2am | 10am



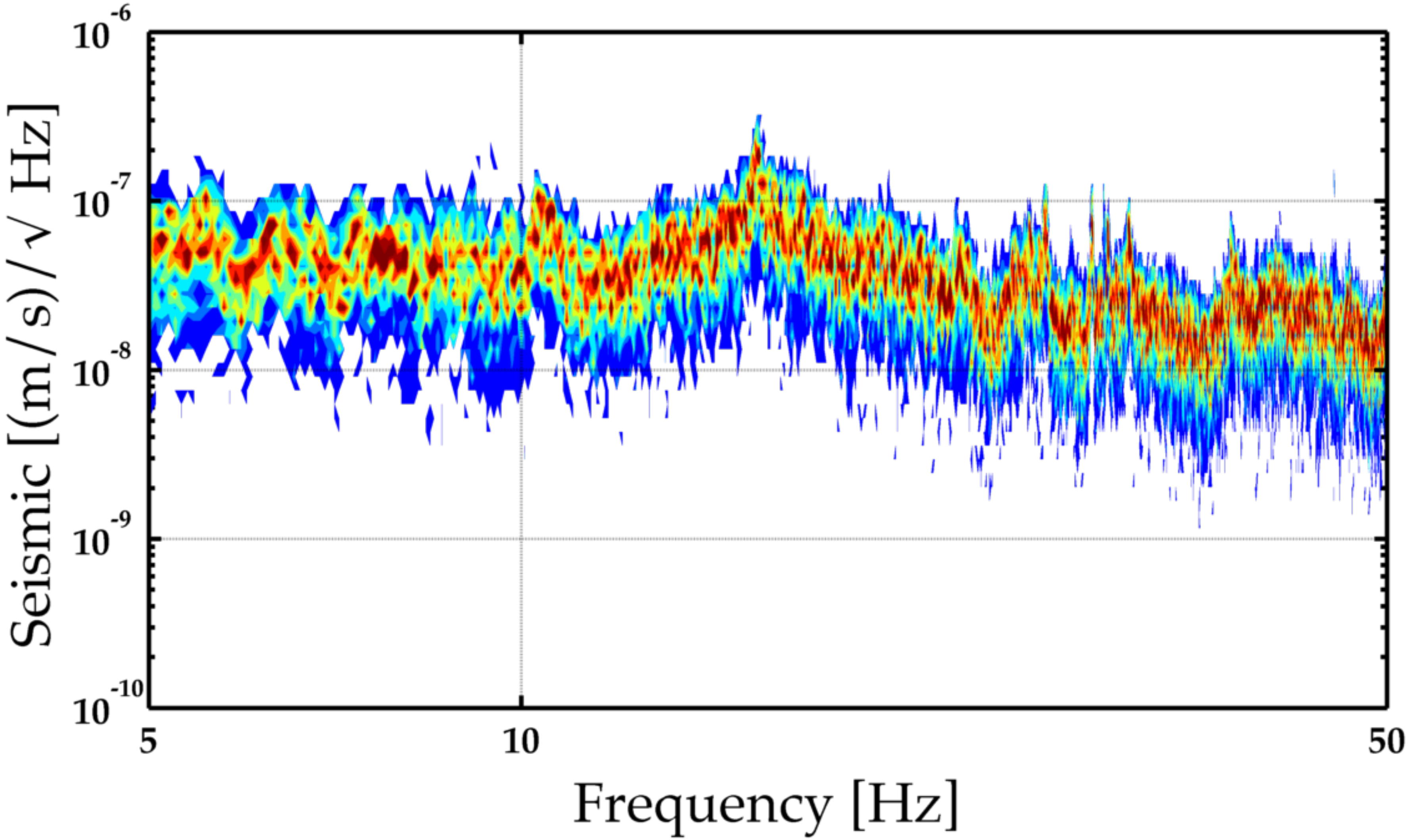
Testing the Filtering Code

Subtract seismic noise from one sensor, using surrounding sensors



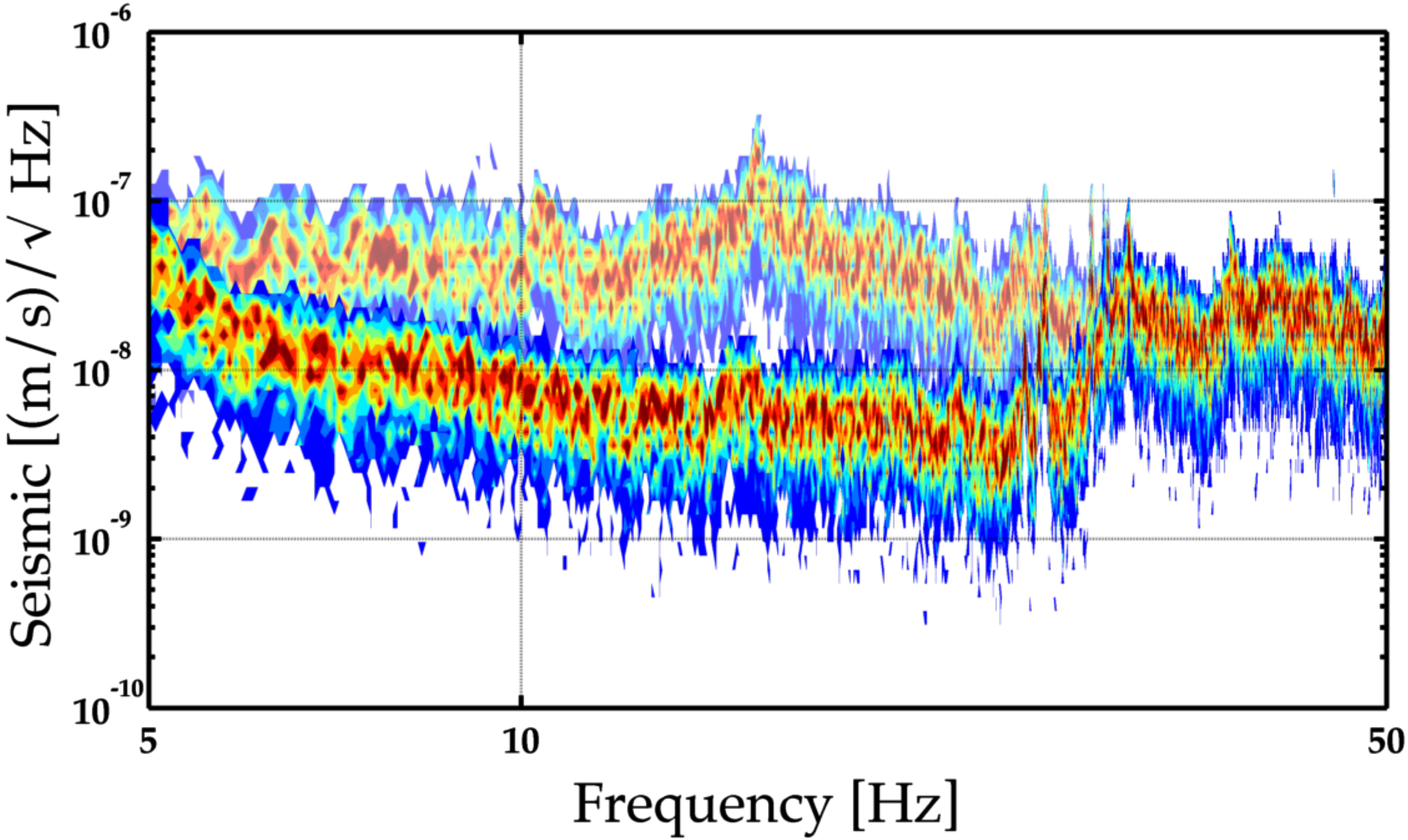
Testing the Filtering Code

Accelerometer # 44, raw data



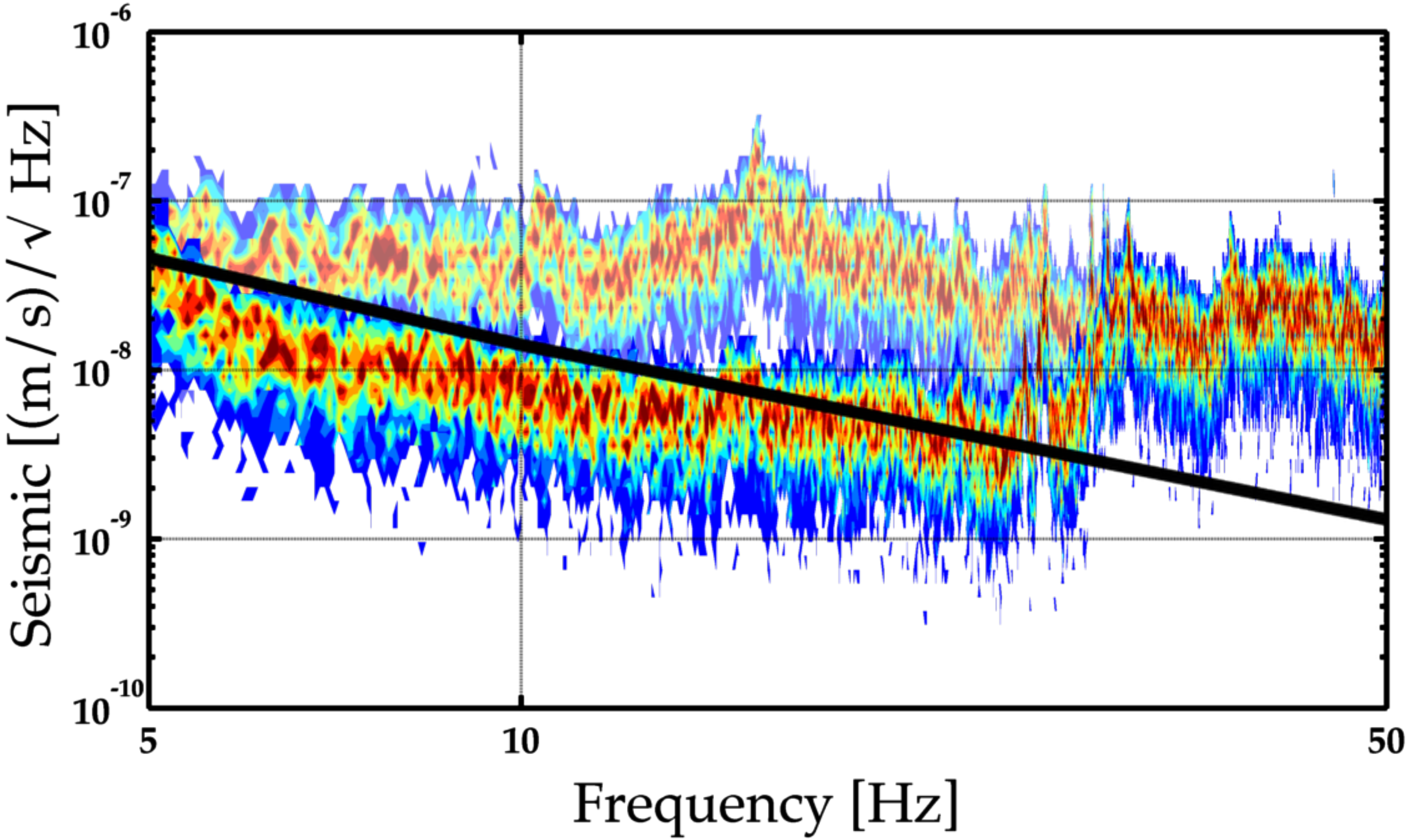
Testing the Filtering Code

Accelerometer # 44, residual, after subtraction



Testing the Filtering Code

Removed all seismic signal, down to noise floor



Implications for Future Detectors

Surface seismic waves really do dominate - good!

Not much scattering - good!

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Isolating air handler fans may be a way to "shield" from Newtonian noise

Next Steps

Quantify scattering

- Calculate overlap of detected wave with plane waves

Look at the first **few** dominant waves

- Characterize sources

Quantify body wave vs. surface wave amplitudes

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- Compare with measurements

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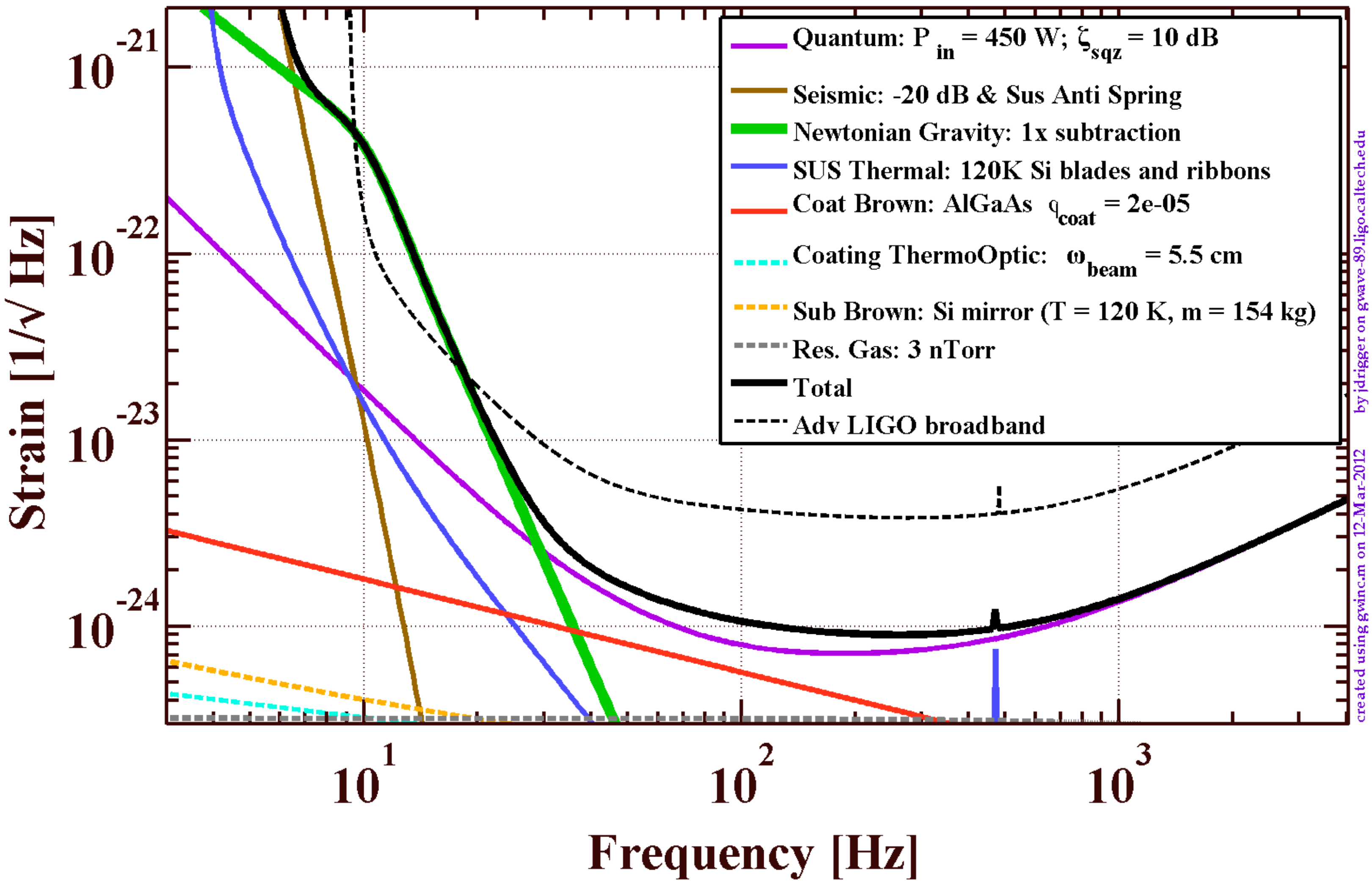
There's lots to do, both with the array and with Newtonian noise studies in general. **The more the merrier!**

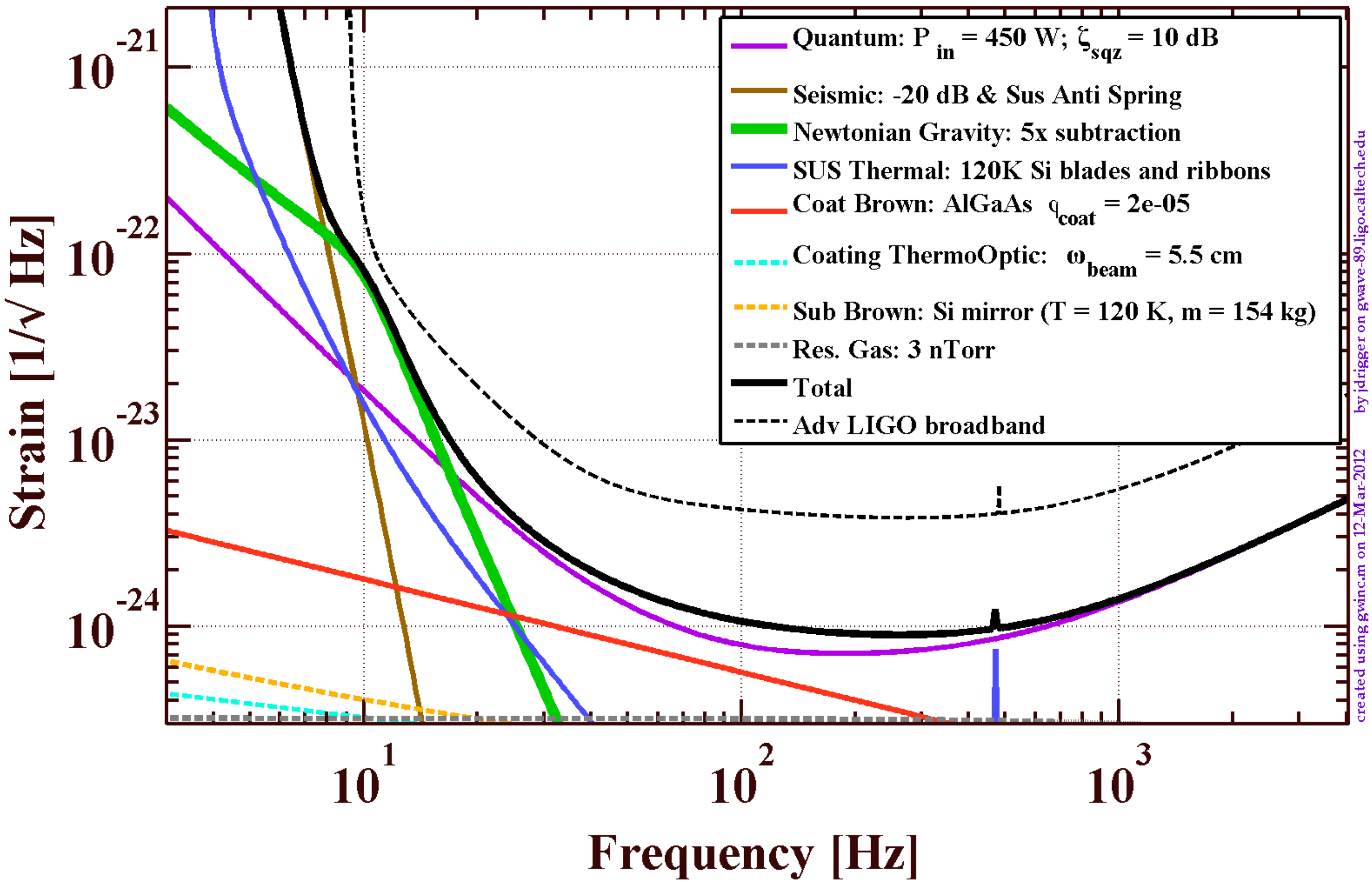
Vision of the Future

No Newtonian noise subtraction



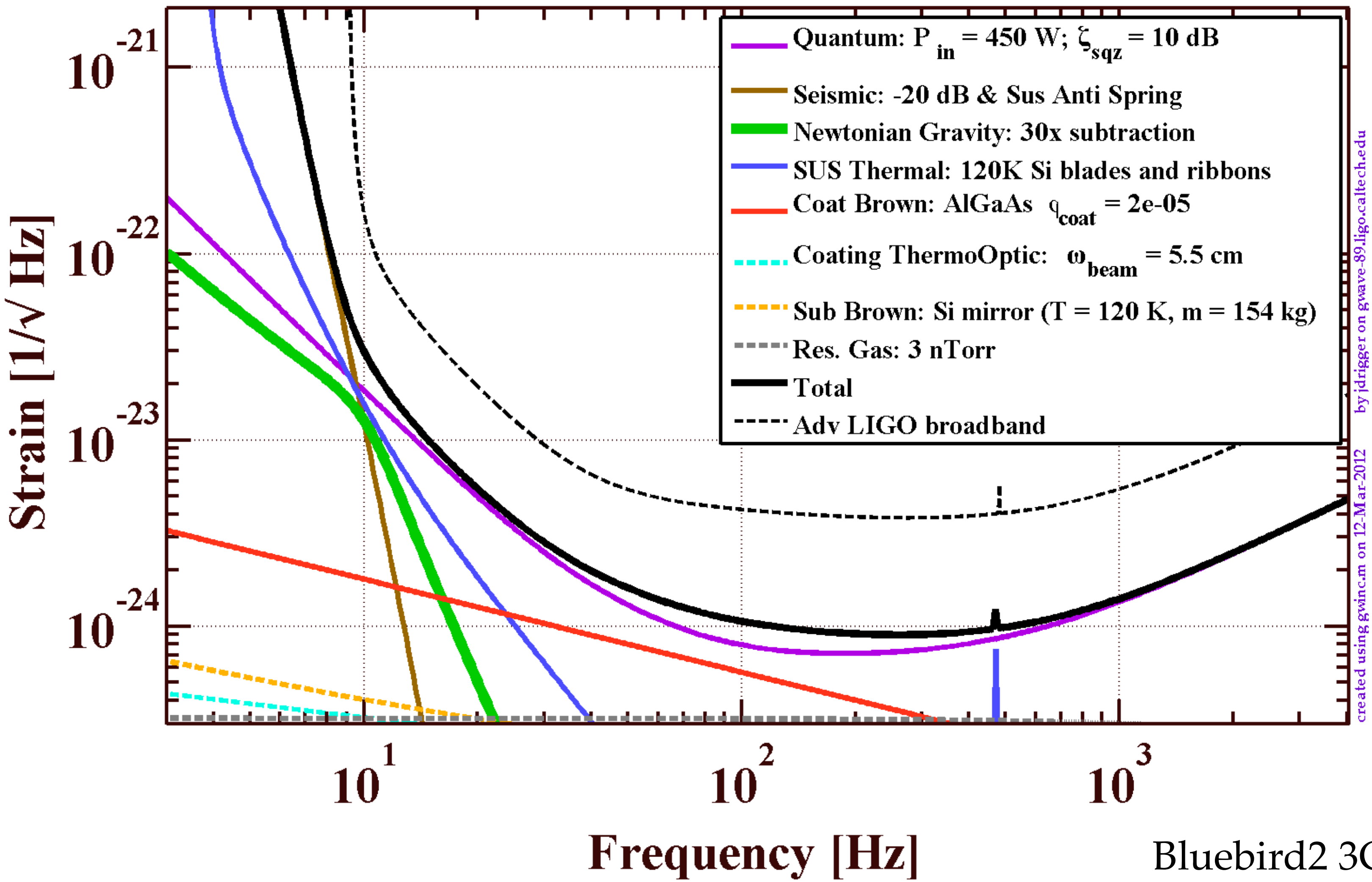
Vision of the Future

5x Newtonian noise subtraction



Vision of the Future

3G GWINC curve with 30x Newtonian noise suppression



Bluebird2 3G design