

# "Measured" Newtonian Noise: Implications for Advanced Detectors

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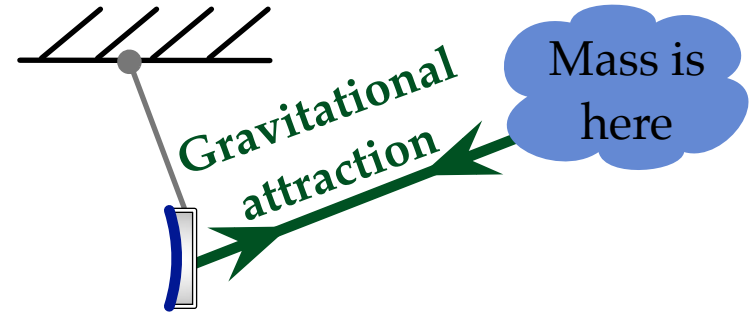
Motivation - why low frequencies?

Past Newtonian noise estimates

Simulation of subtraction ability

Array measurement at LIGO Hanford

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



## Low frequencies have interesting scientific targets

More SNR at lower frequencies:

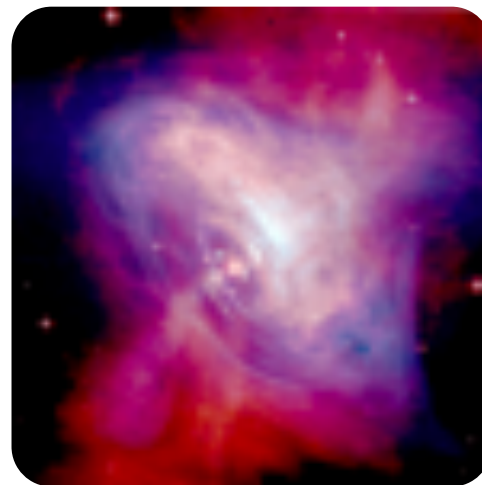
Better matched filtering

Longer lead time for EM triggers



Palomar

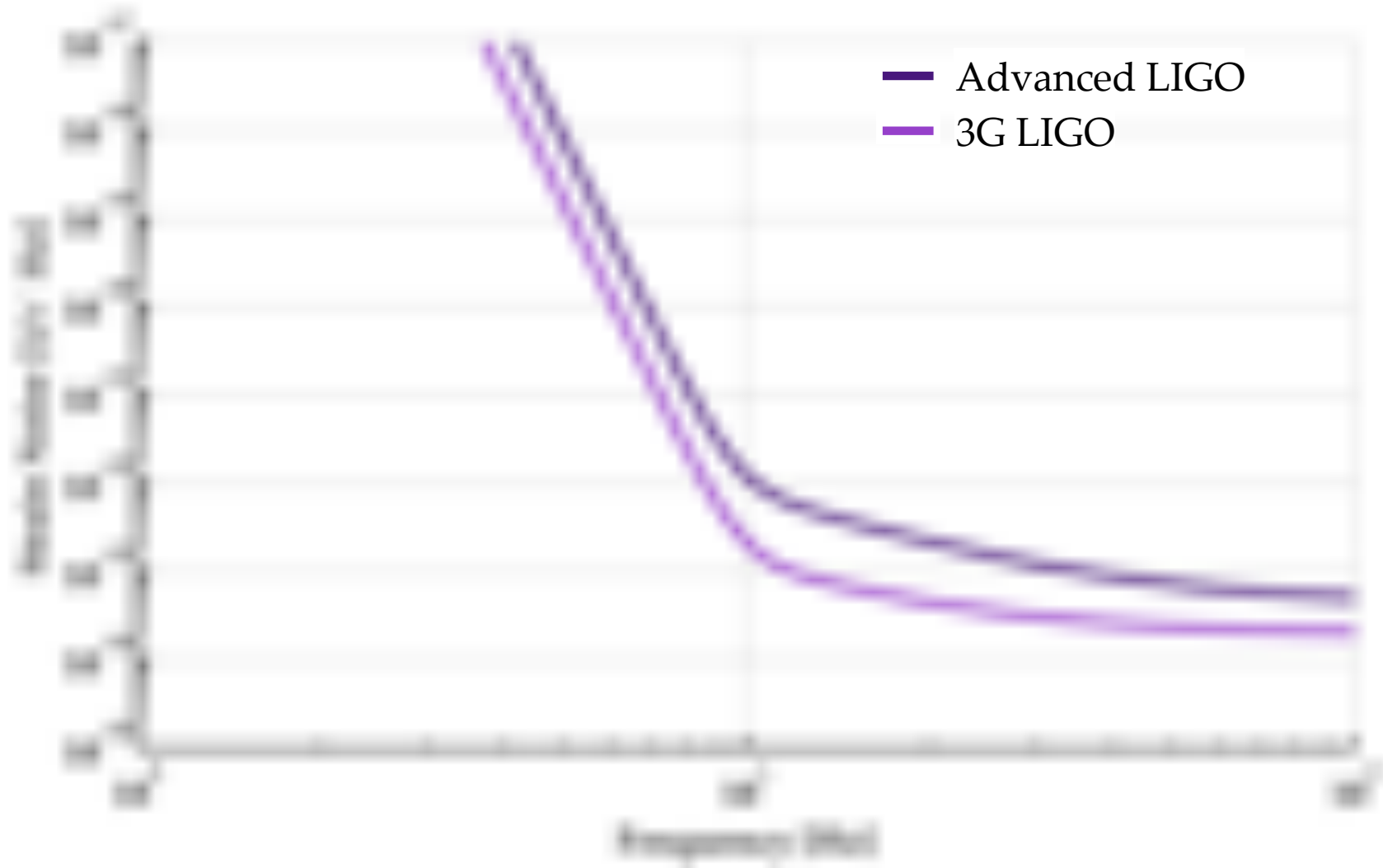
Intermediate mass black holes: possible discovery or exclusion



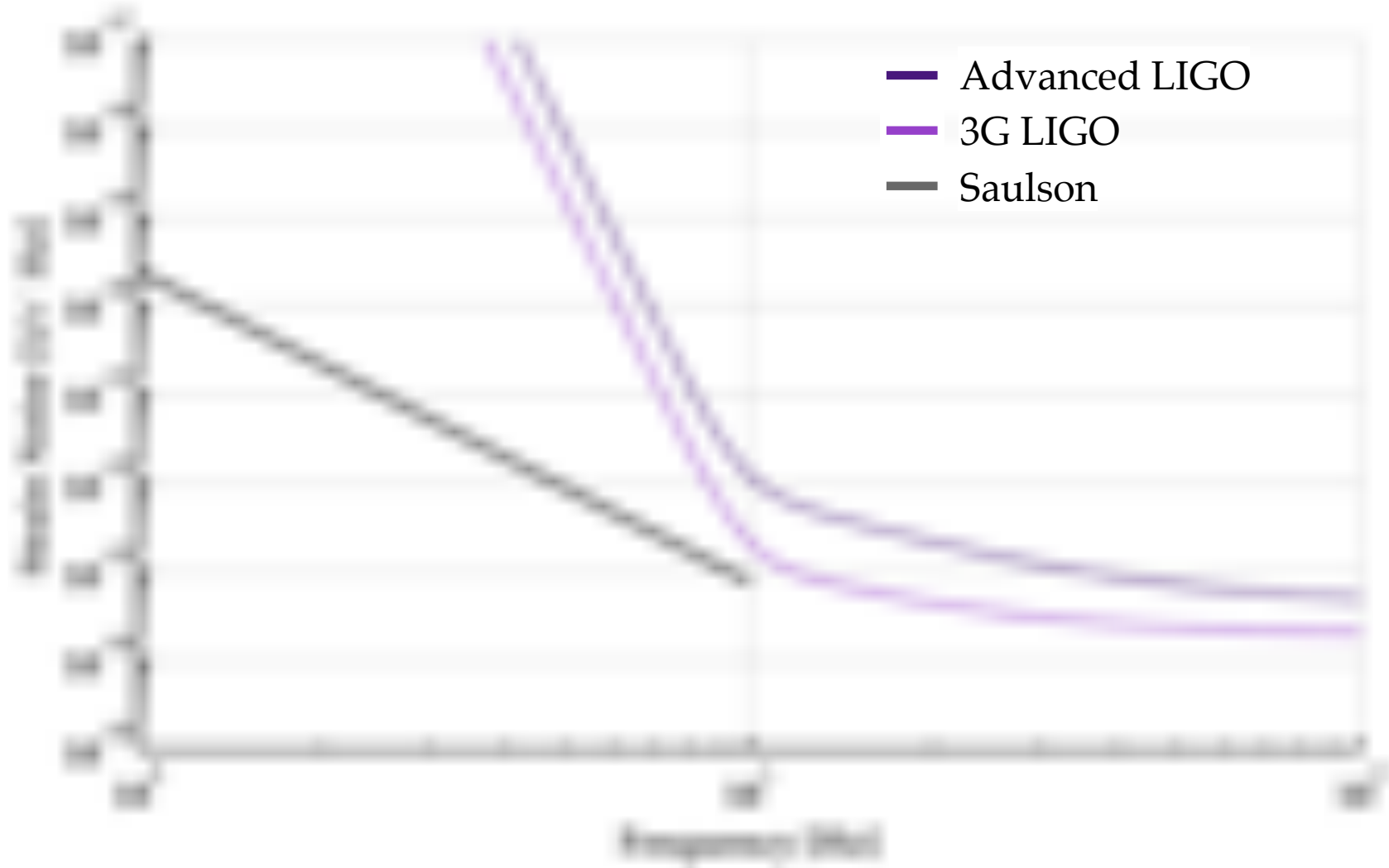
Crab Pulsar

Possibility of interesting pulsars

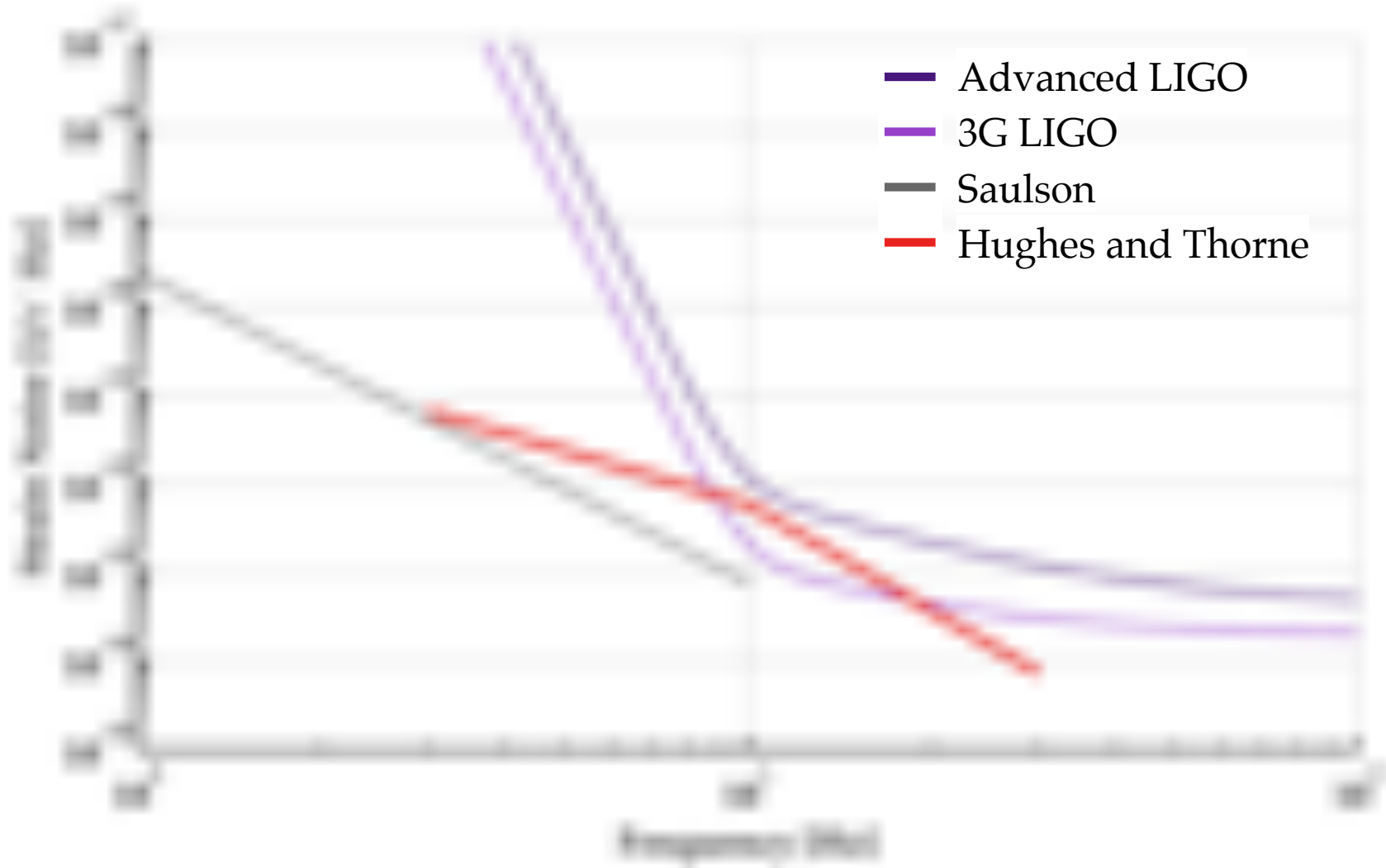
## Advanced LIGO and 3rd Generation Strain Curves



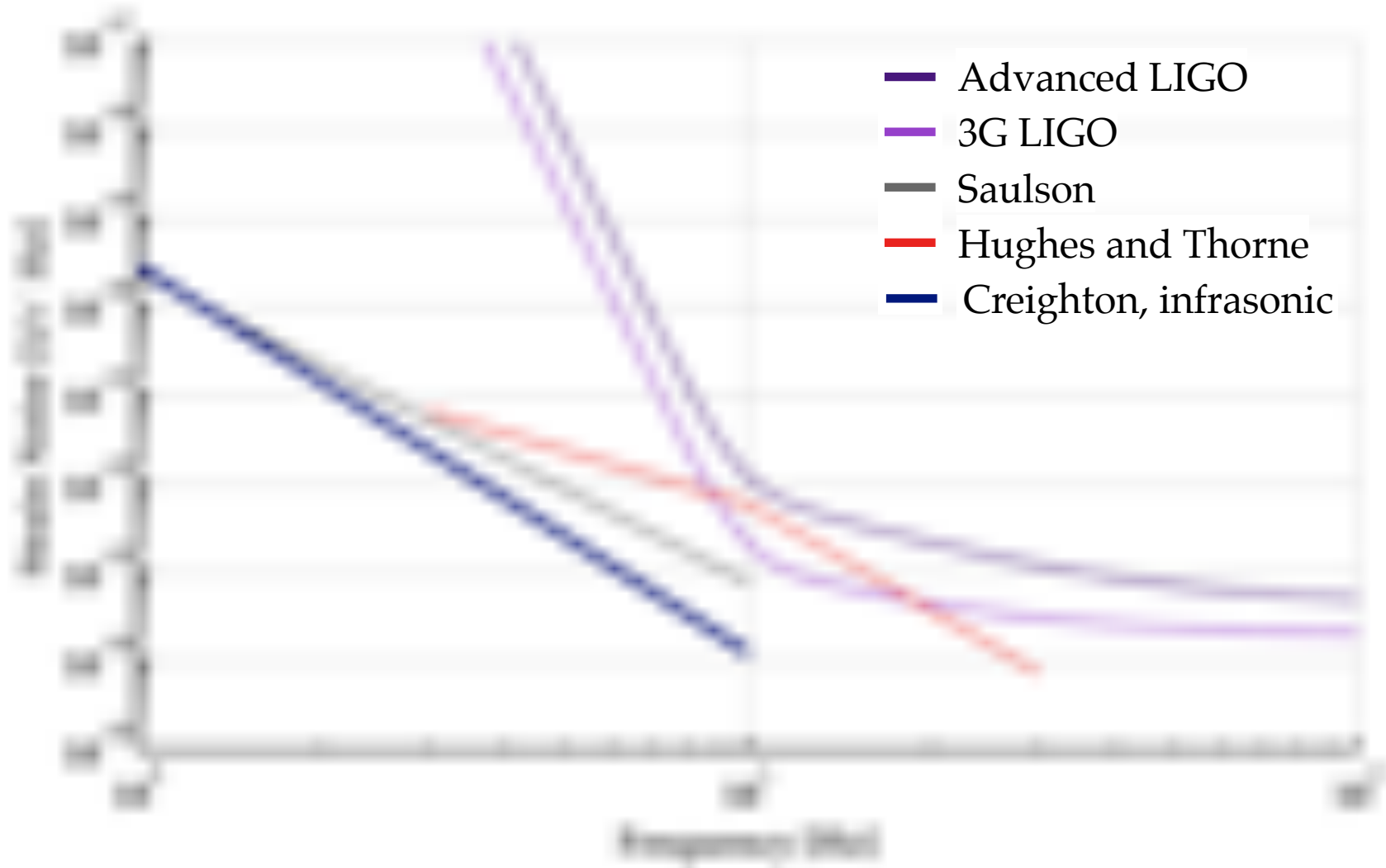
## Saulson, 1984, Average Underground Site



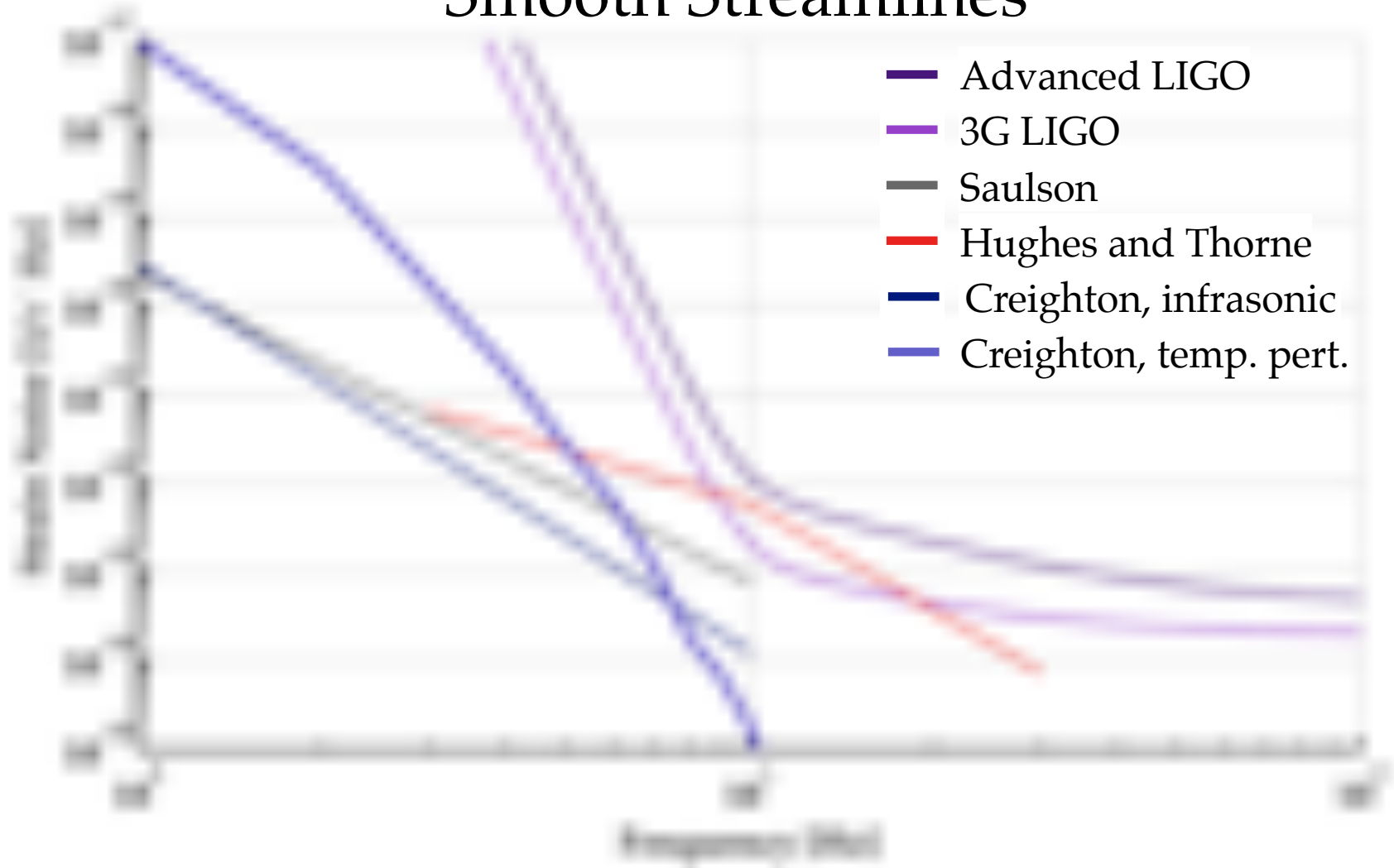
Hughes and Thorne, 1998, Seismic,  $\beta = 0.6$



Creighton, 2008, Infrasonic Atmospheric, 75% Level

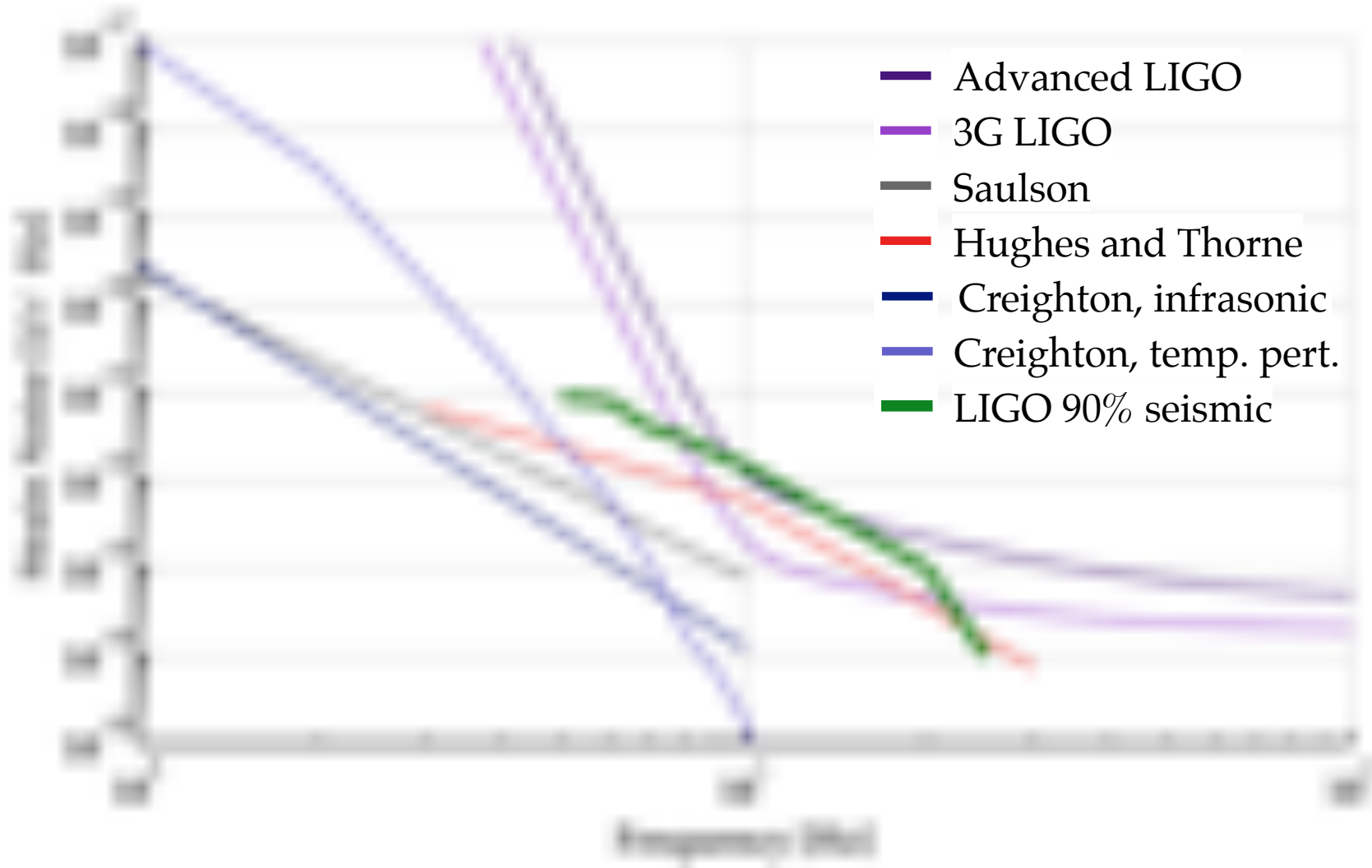


## Creighton, 2008, Temperature Perturbations, Smooth Streamlines





## LIGO 90% Seismic, Measured 2011



## Simulate seismic fields

Need time series, and correlation between many points

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## Calculate resultant Newtonian noise

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

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## Use simulated Newtonian noise models for testing, optimizing:

Filtering methods

Array configuration

## Plane waves describe seismic field

Most sources are distant



Implications if we're wrong:

Complex fields are hard to monitor

## Plane waves describe seismic field

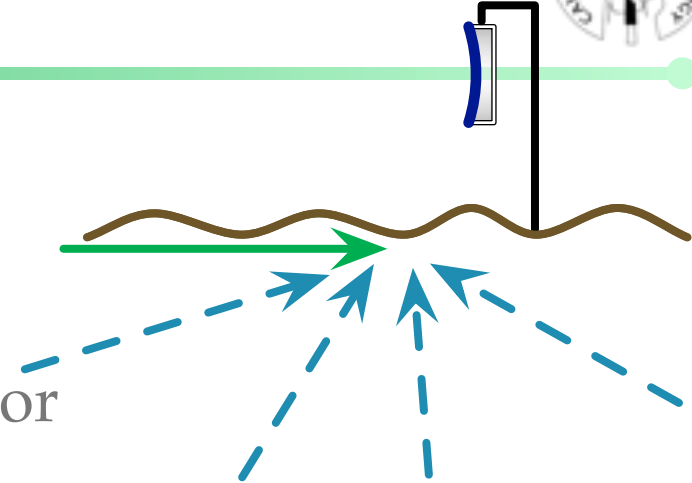
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## No body waves

Assume body wave amplitudes are much smaller than surface wave amplitudes

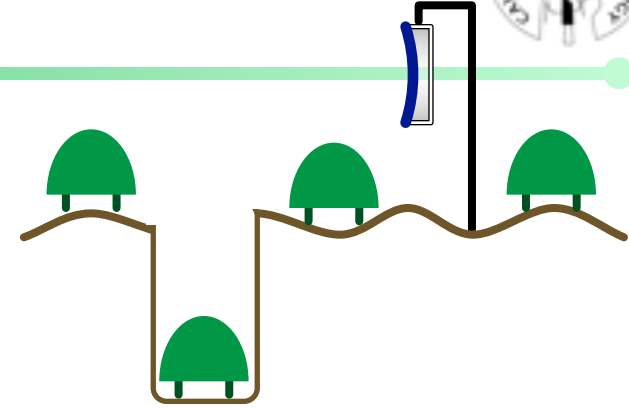


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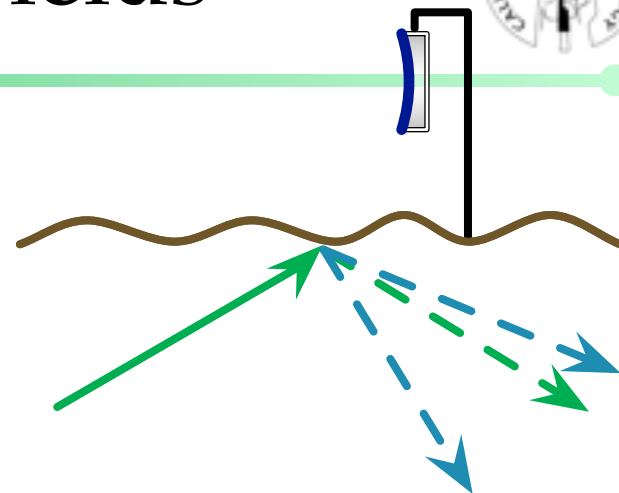
May need to monitor larger radius around test mass

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## No scattering of seismic waves

Assume scattering amplitudes  $\ll 1$

Implications if we're wrong:

Many different wavelengths - hard to monitor



## How to:

Define the subtraction factor at a single frequency

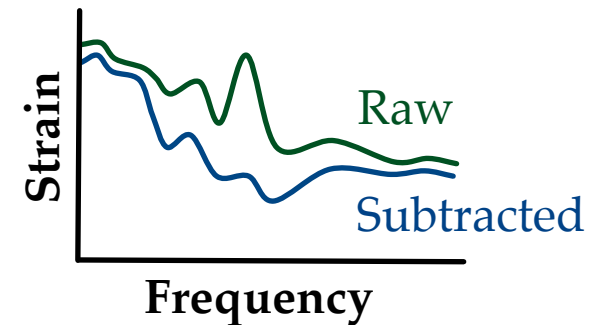
Optimize subtraction factor  $\sqrt{R}$  by changing:

Number of sensors

Array size

Sensor layout

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



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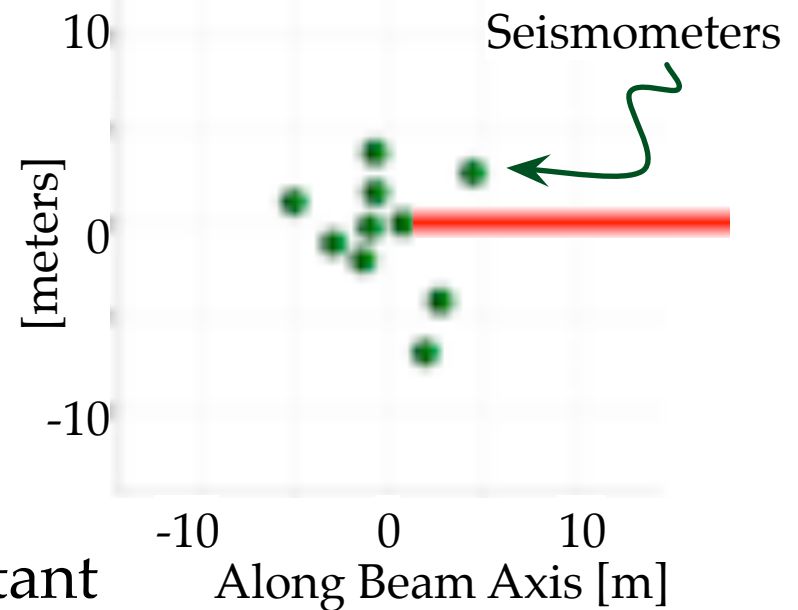
**Results:**

Number of sensors is important

Extent / size of array is important

Specific layout is much less important

Main requirement: "many close, some far"



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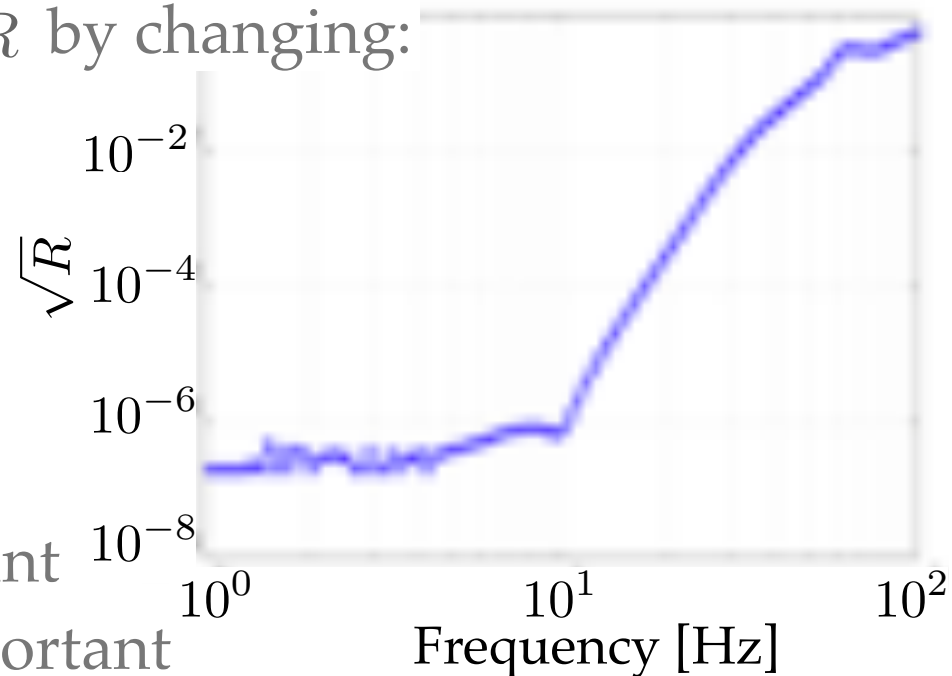
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For 10 Hz optimized array, can achieve  
(theoretical) subtraction factor of  $\sim 1e-6$  with 10 sensors

Comparing

Online feed forward cancellation

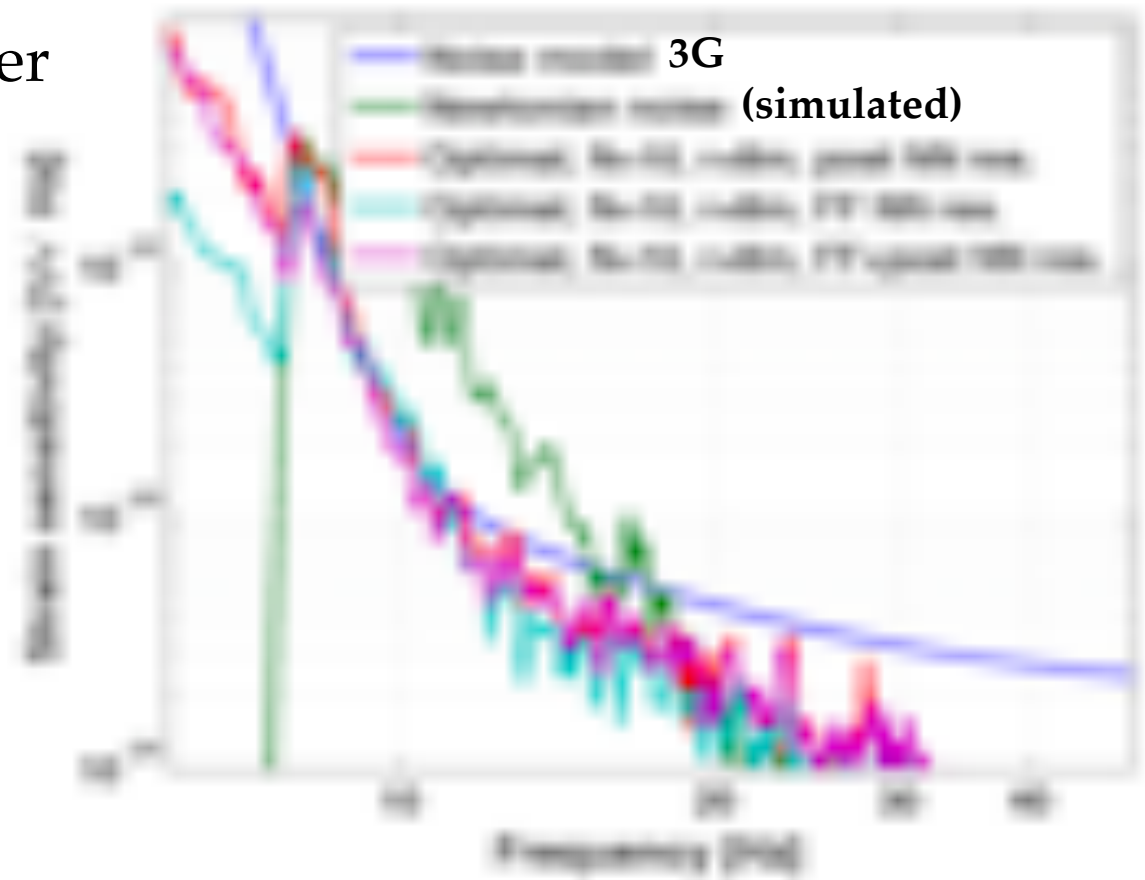
Offline Wiener filter cancellation

Online, then offline later

**Take-home message:**

We think we can  
suppress

Newtonian noise for  
Advanced LIGO and  
3G detectors



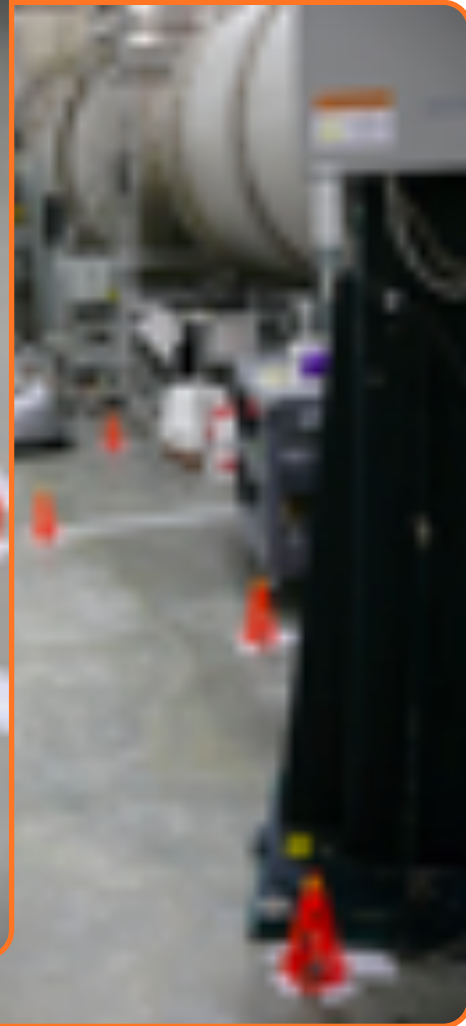


Installed: April 2012



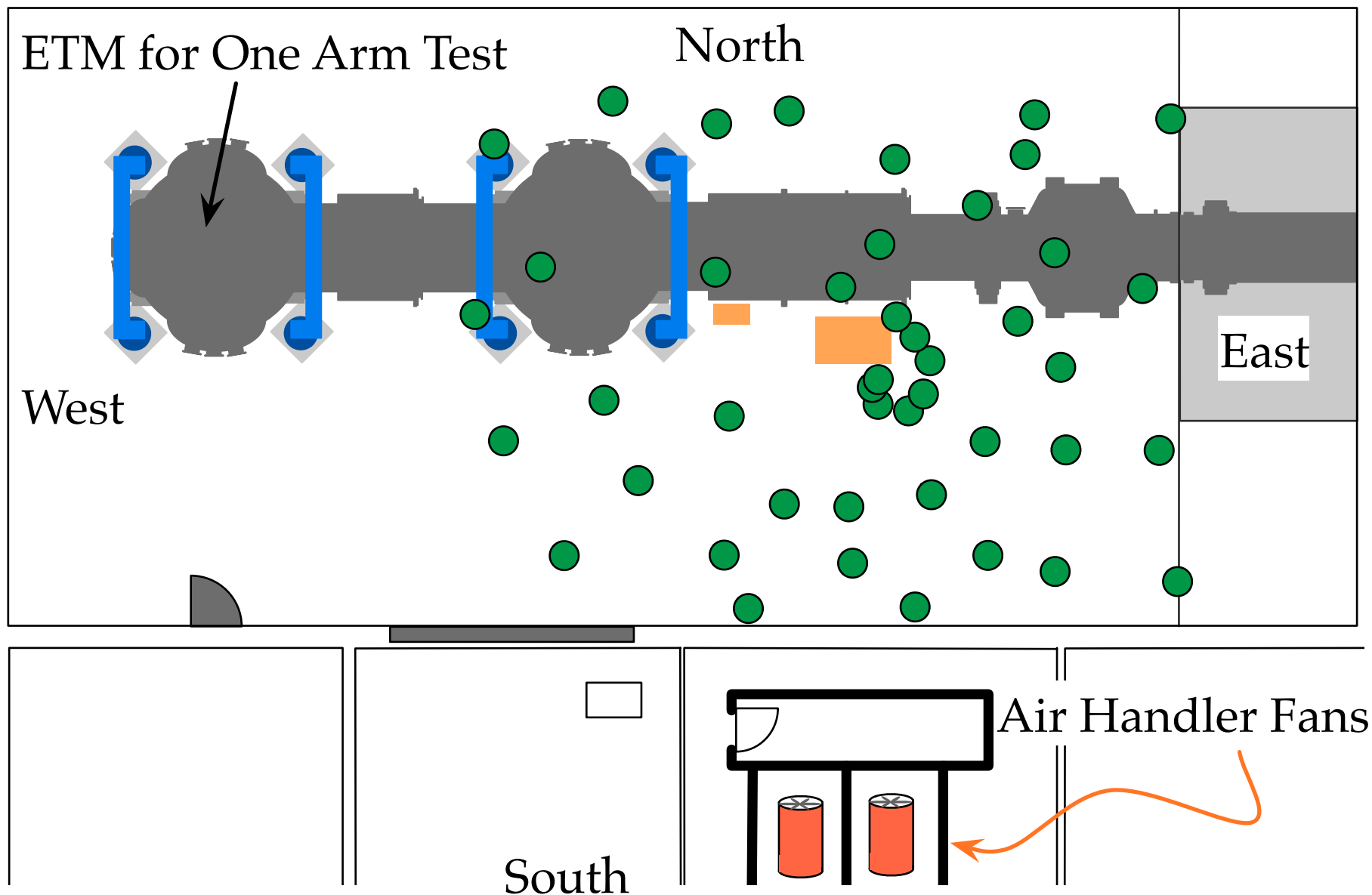
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# LIGO Dominant Wave Vector vs. Time



10 Hz

25 Hz

50 Hz

Wavenumber  $k_y$  [rad/m]

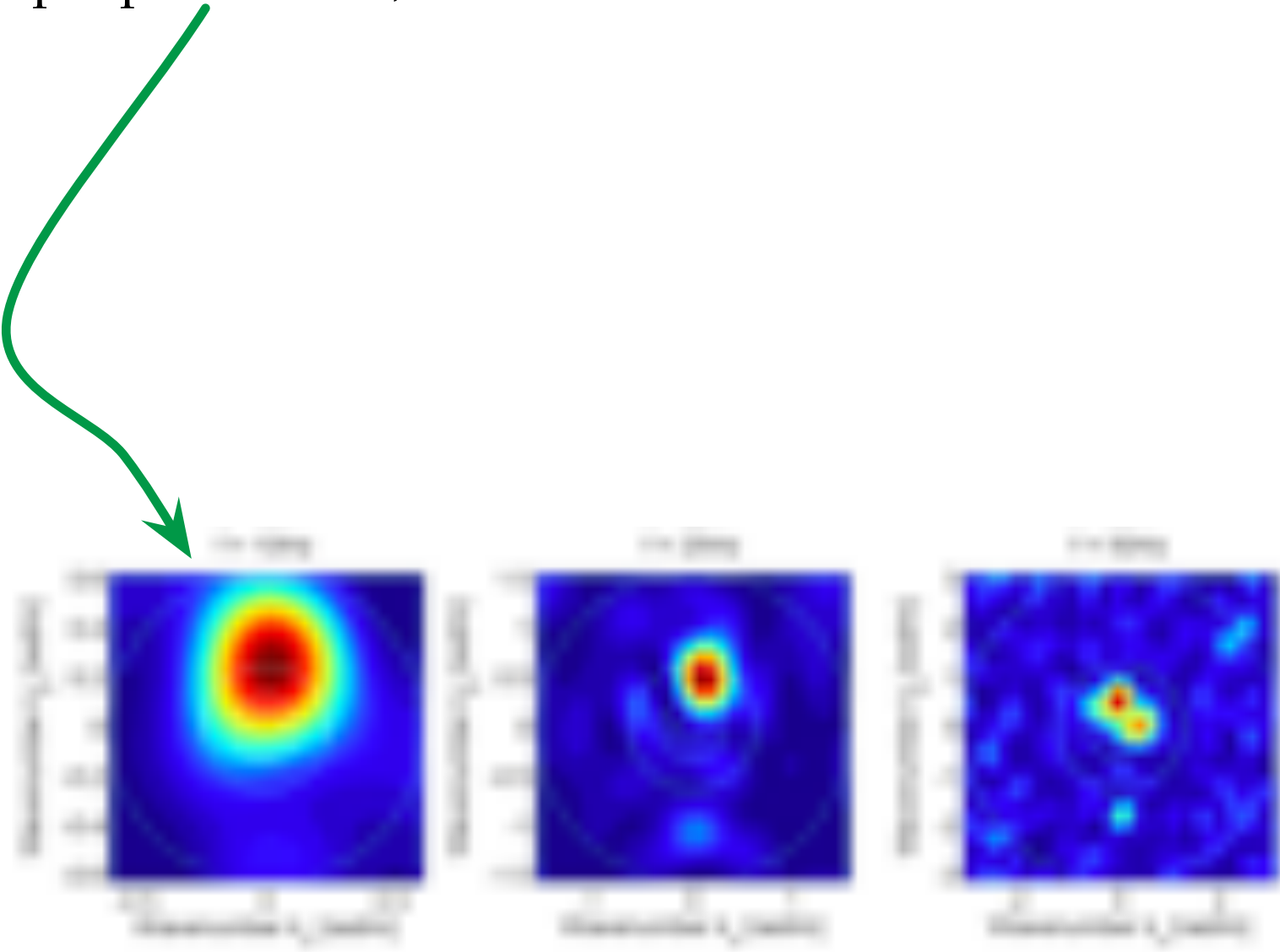
If you do not see a movie here, please download it separately from the DCC

Wavenumber  $k_x$  [rad/m]

# LIGO Summary of Results from Movies



Simple plane wave, most of the time

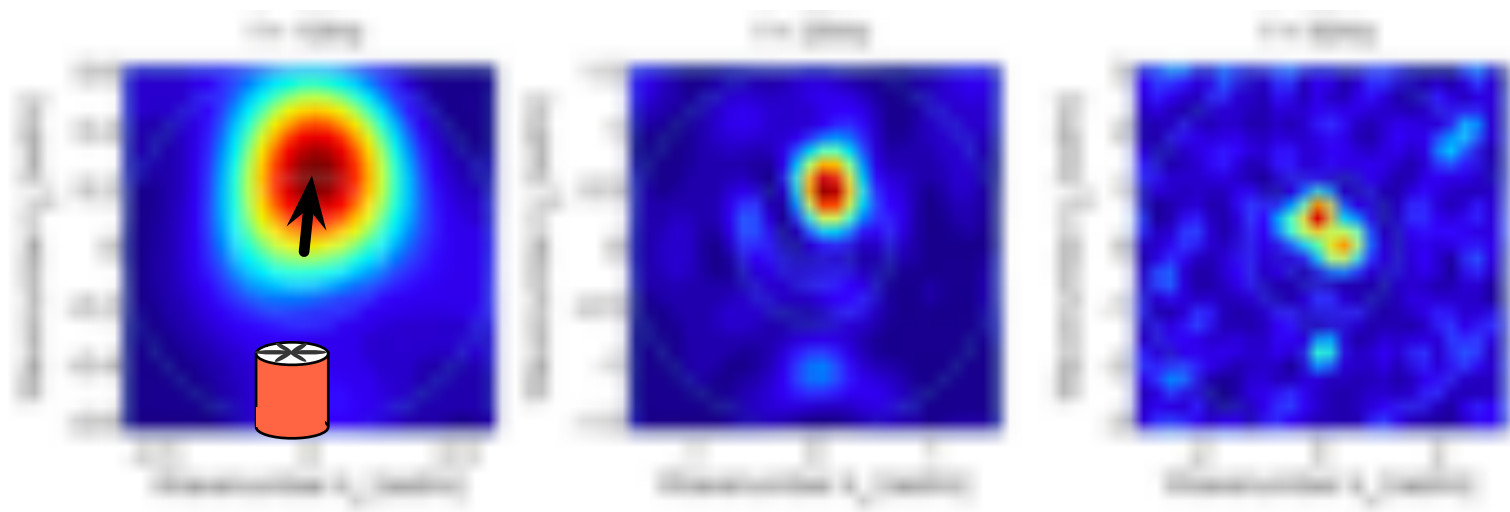


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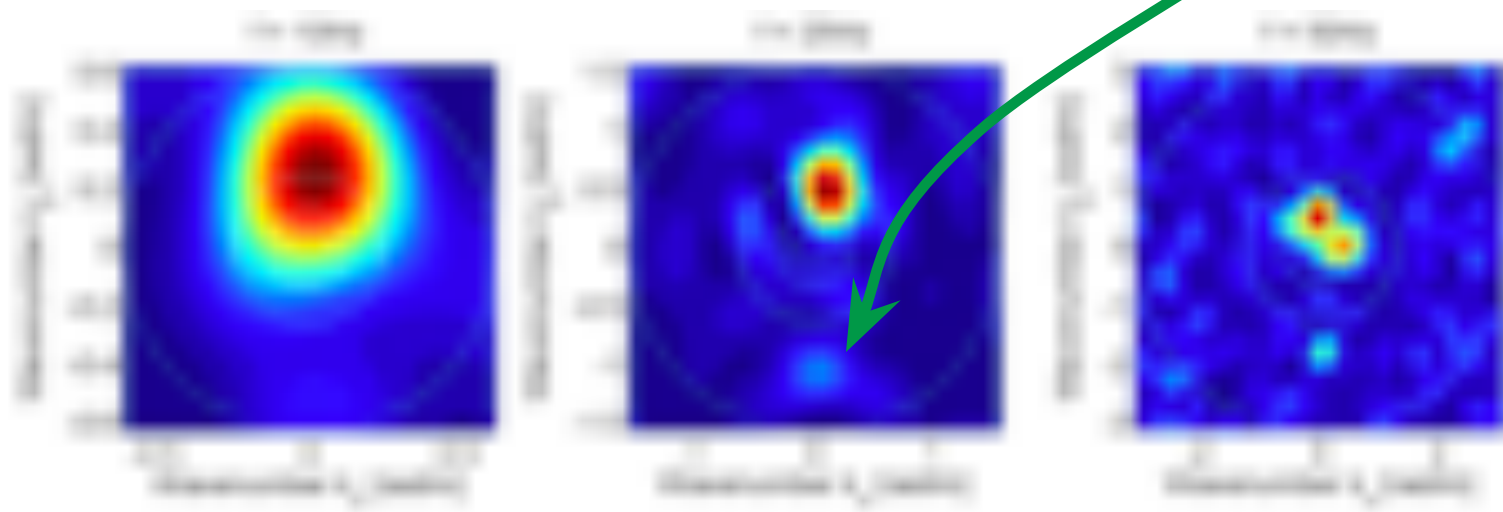


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Possibly seeing some reflections

Need further analysis, why is the speed so small?



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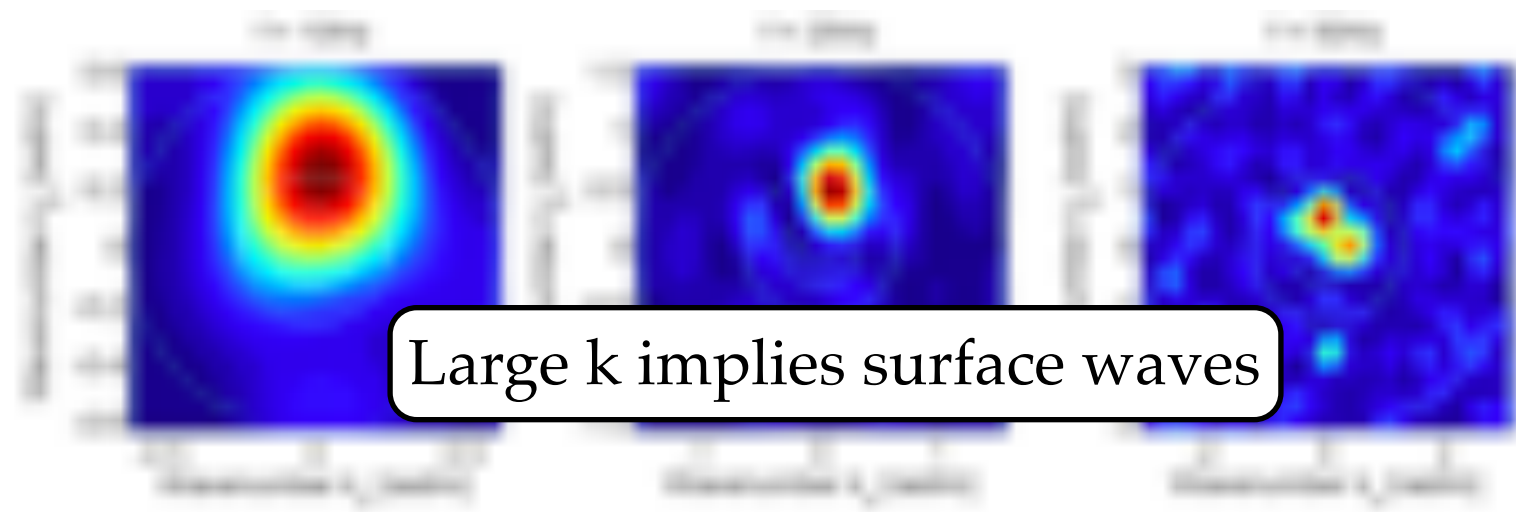
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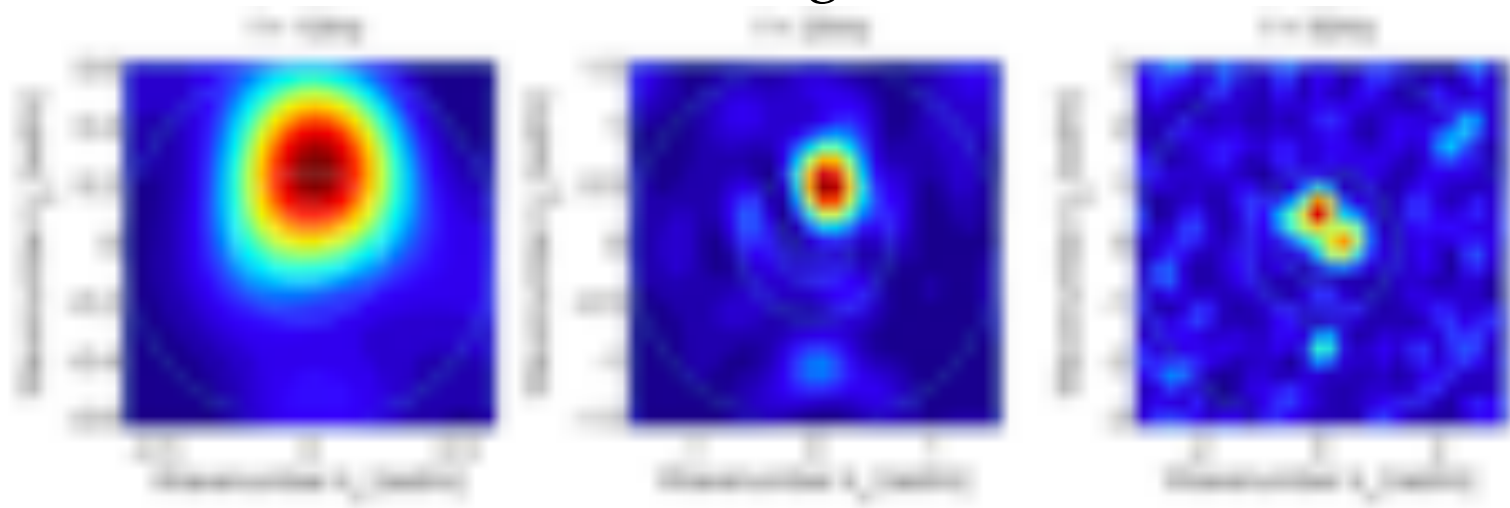
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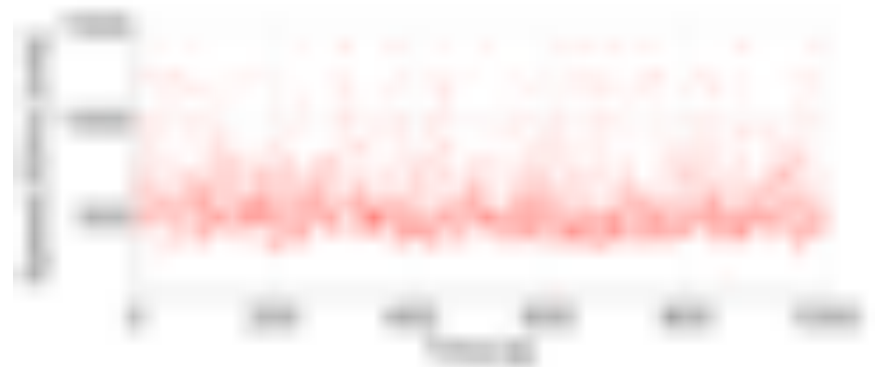
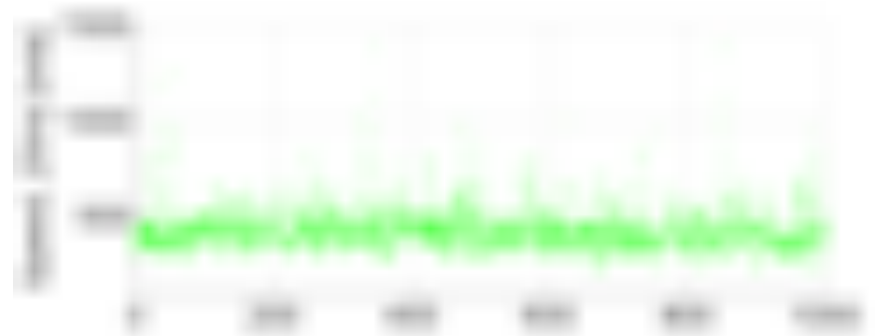
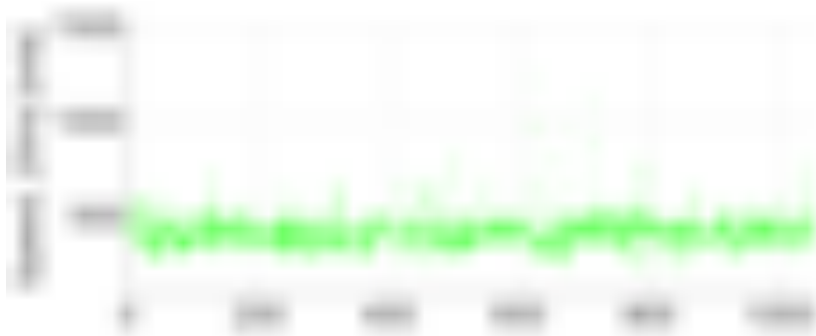
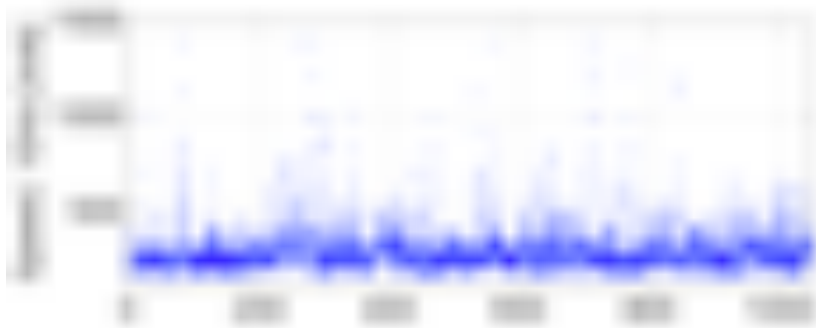
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Not much evidence of scattering



2am

10am

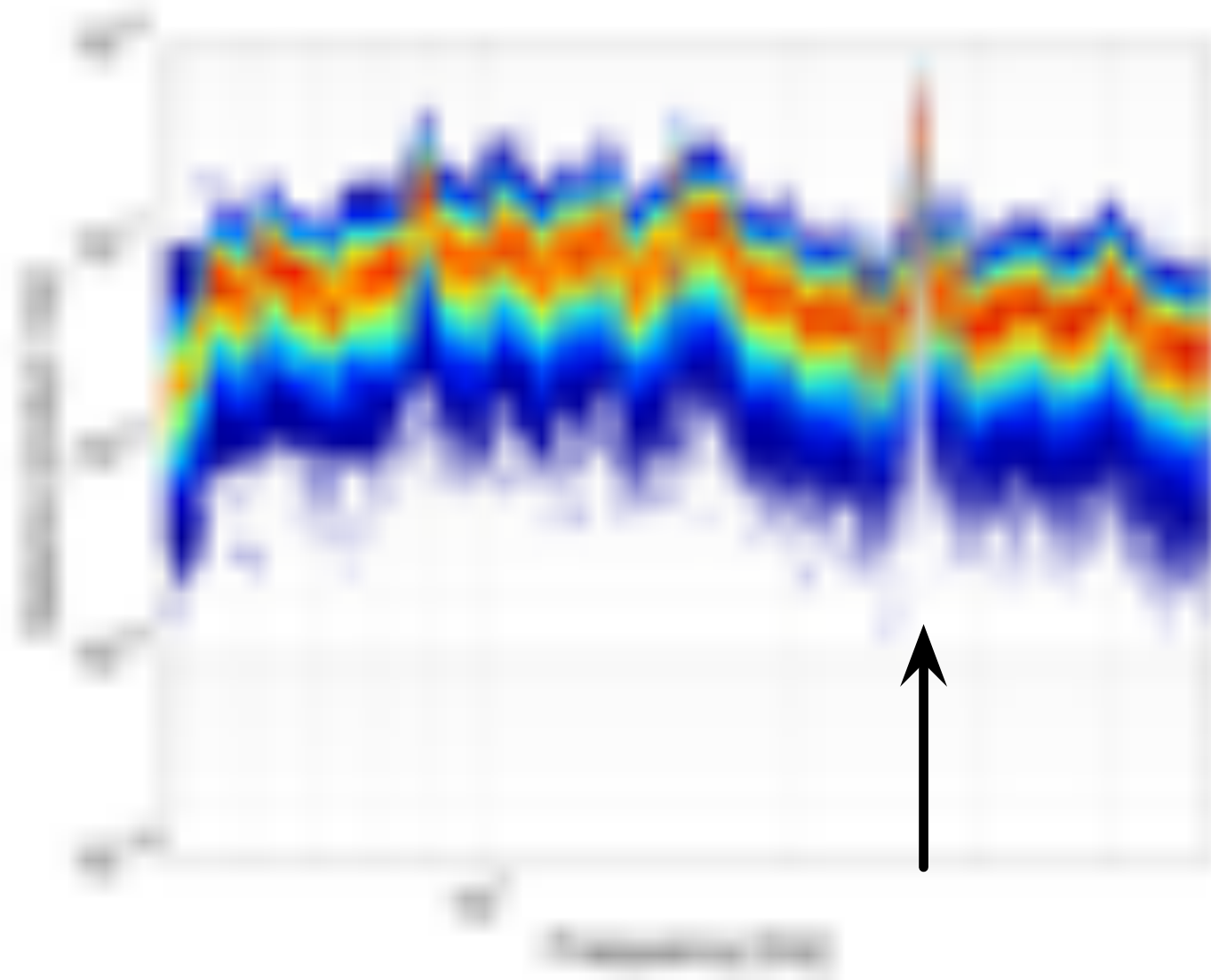




# No Body Waves at 25 Hz?

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

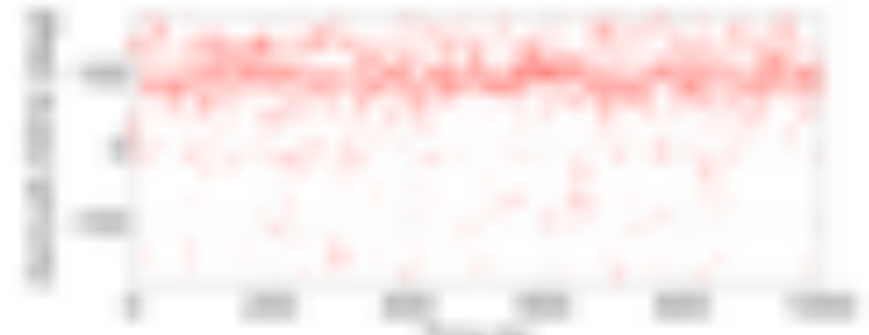
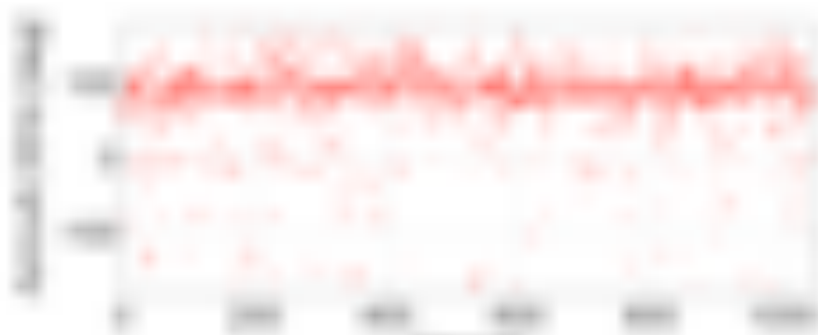
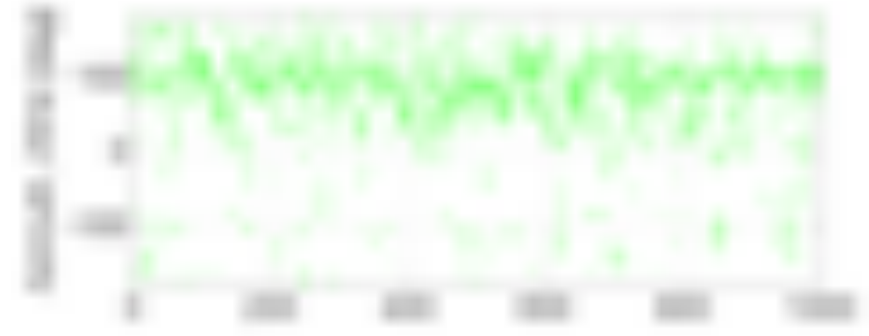
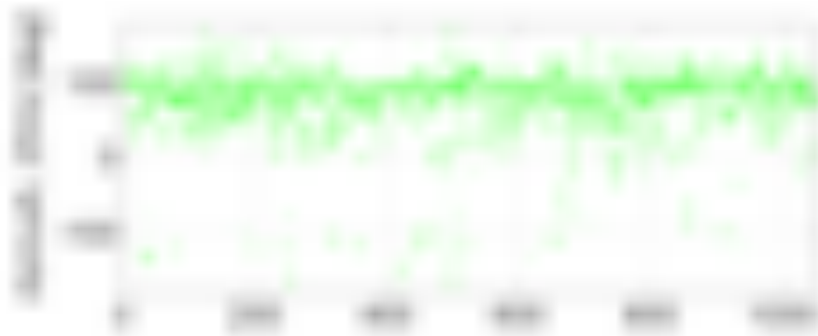
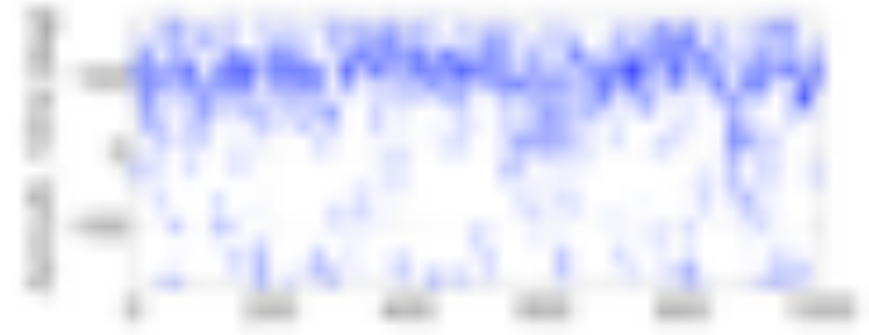
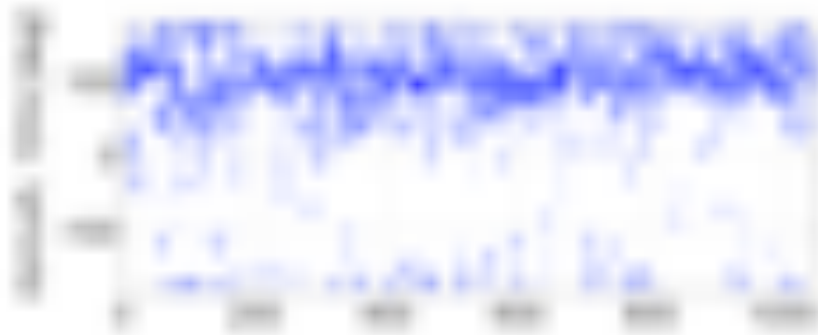
Accelerometer #32

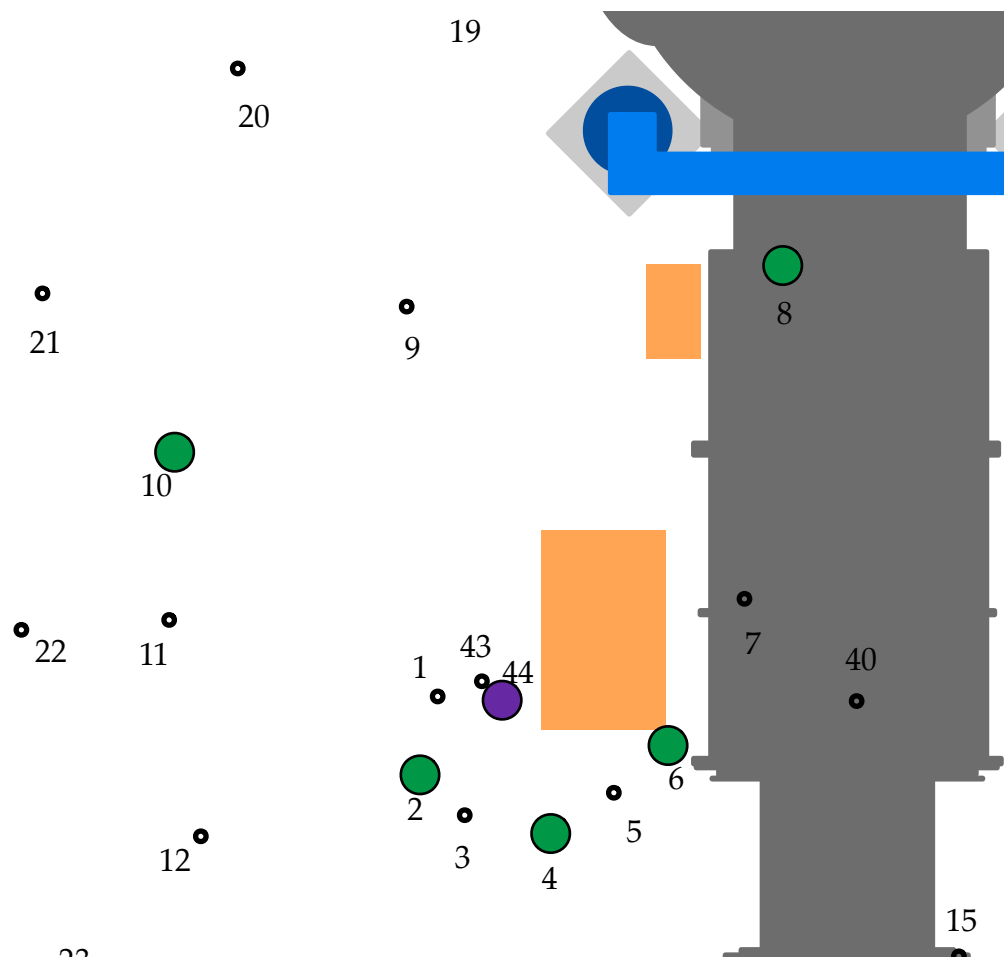




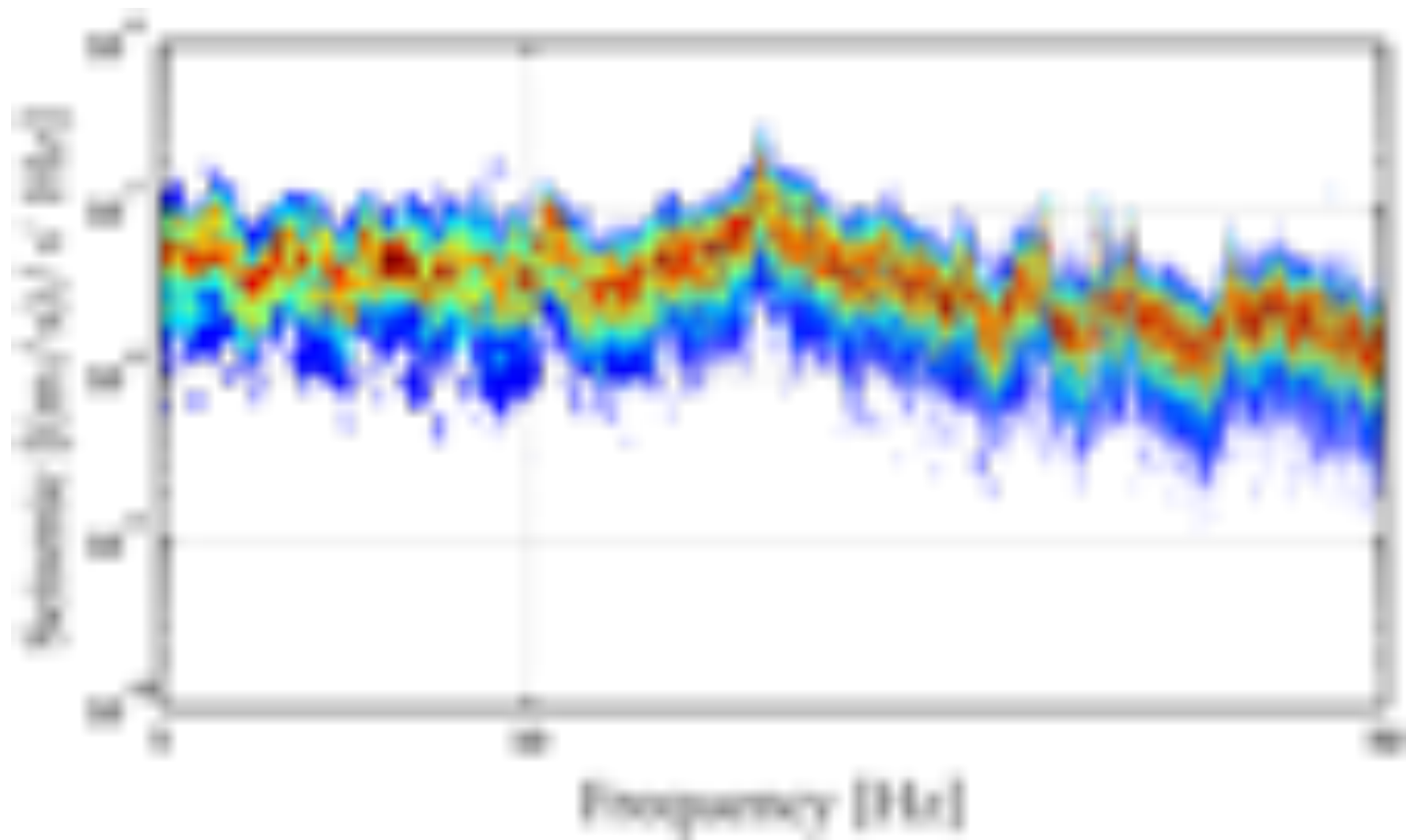
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10am

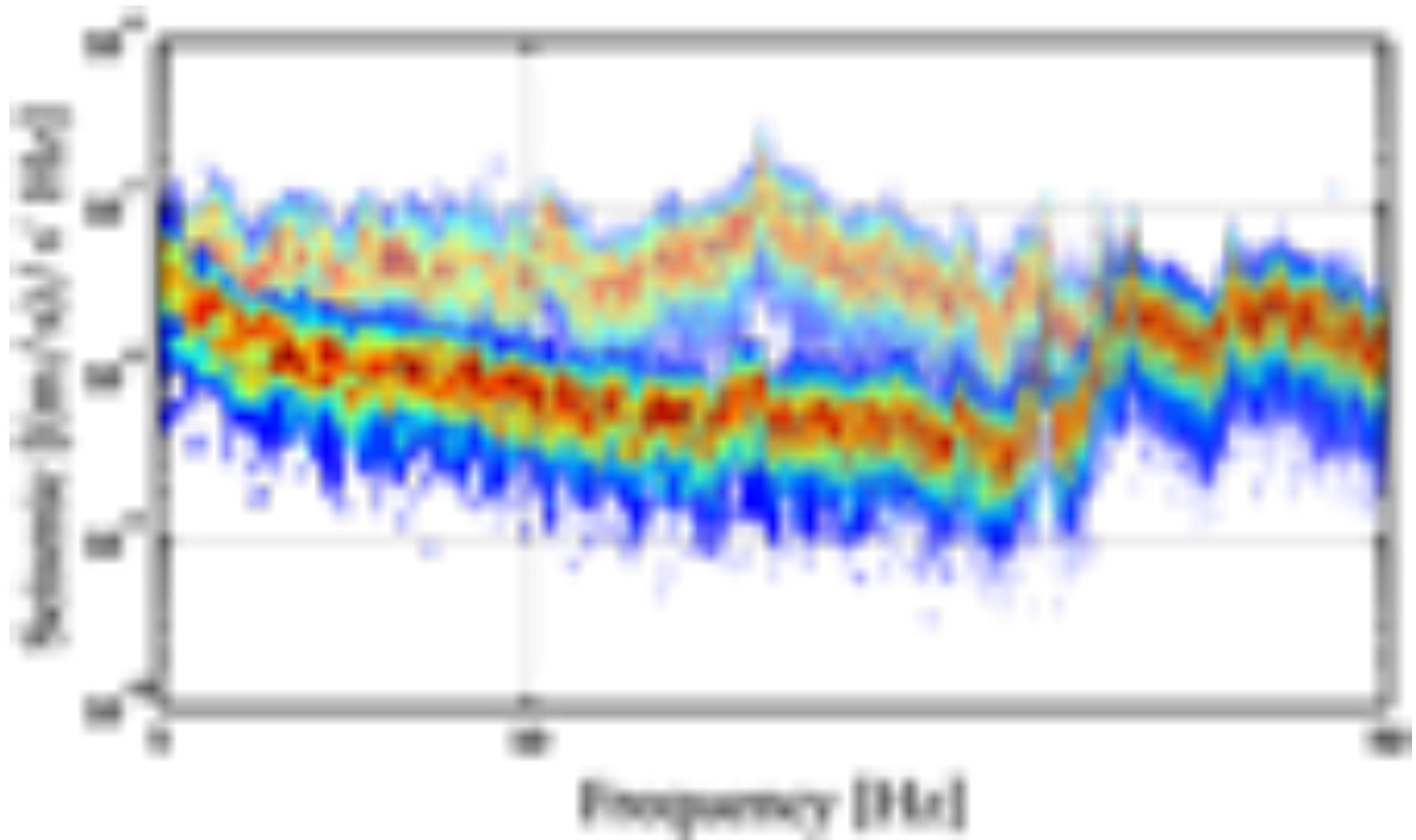




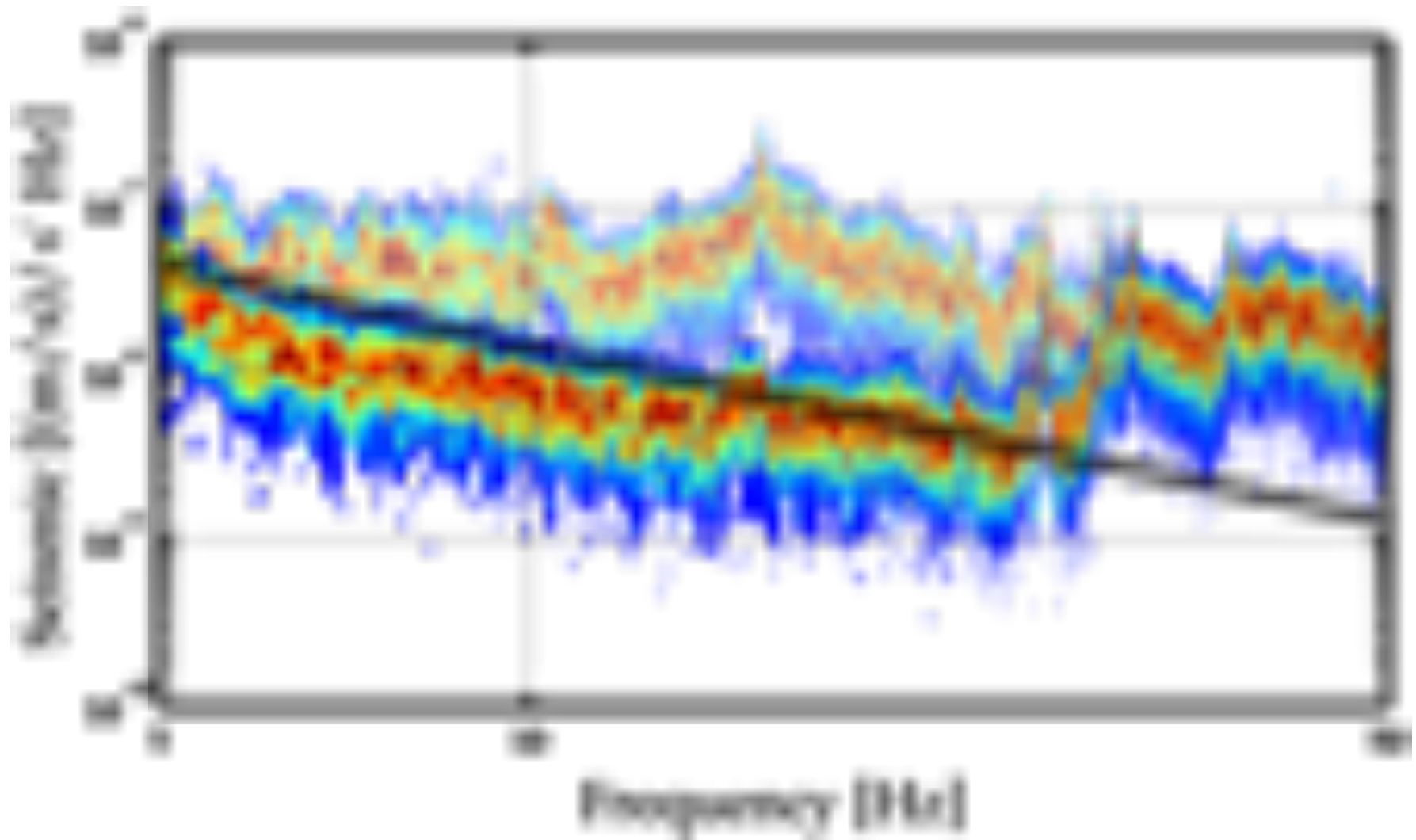
Accelerometer # 44, raw data



Accelerometer # 44, residual, after subtraction



Removed all seismic signal, down to noise floor





# LIGO Implications for Future Detectors

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Surface seismic waves really do dominate - good!

Not much scattering - good!

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10 or fewer sensors per test mass

Wilcoxon accelerometers sensitive enough

< \$1,000 per single-axis sensor





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Wilcoxon accelerometers sensitive enough

< \$1,000 per single-axis sensor

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





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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Array measurements with controlled sources

- Systematic study of types of sources

  - Scattering around a hole

  - Waveguiding

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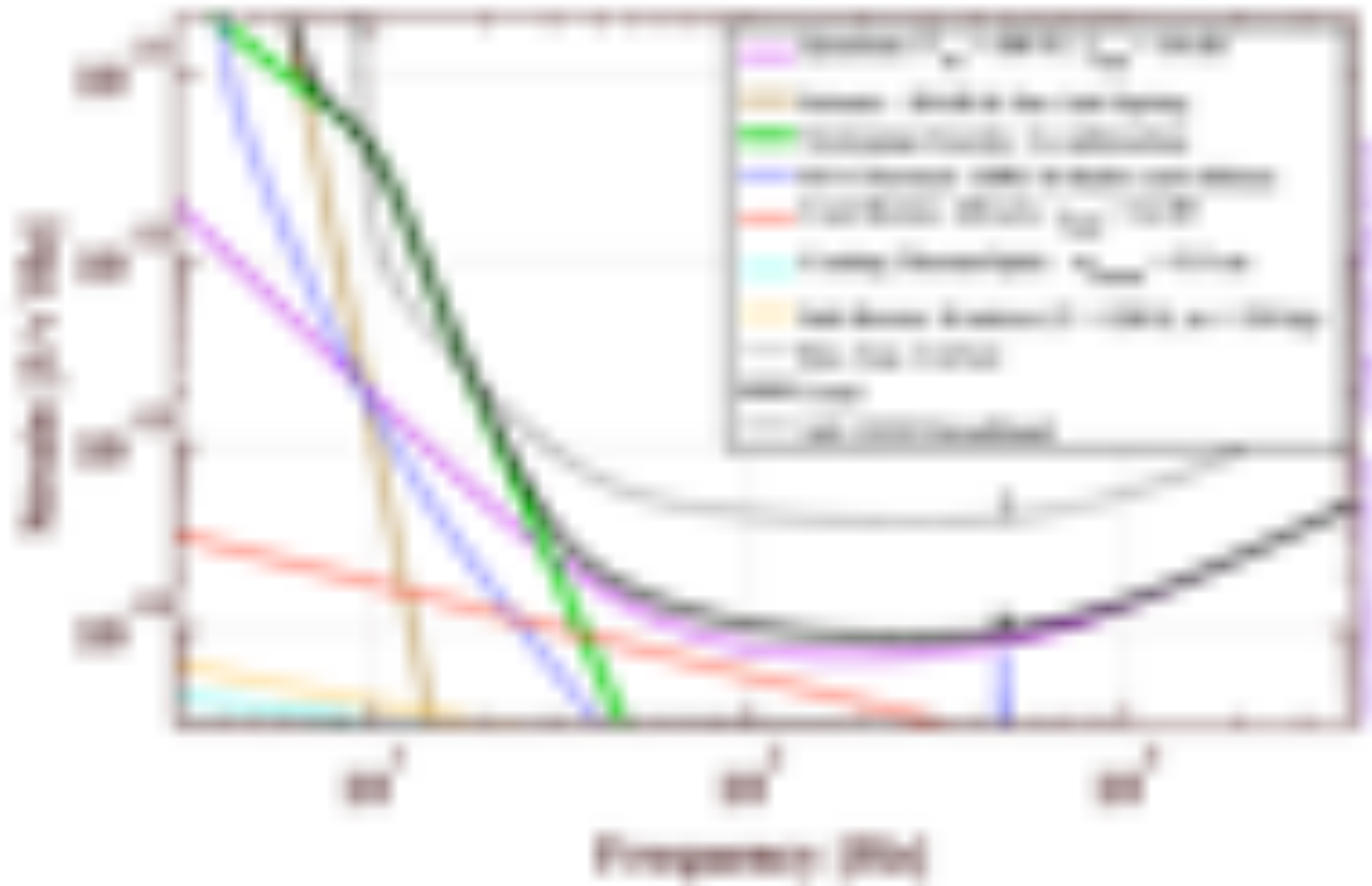
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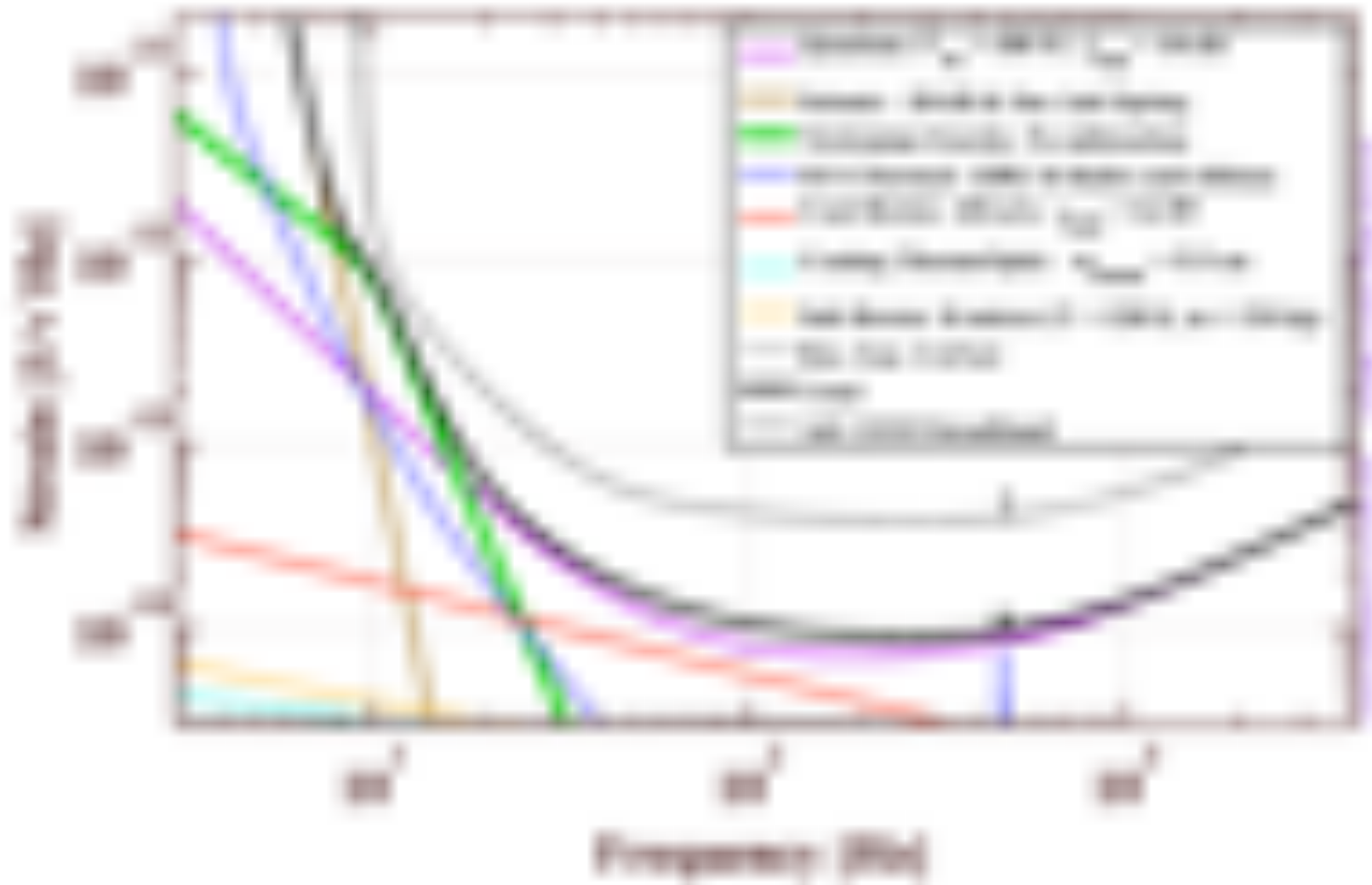
- Compare with measurements

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

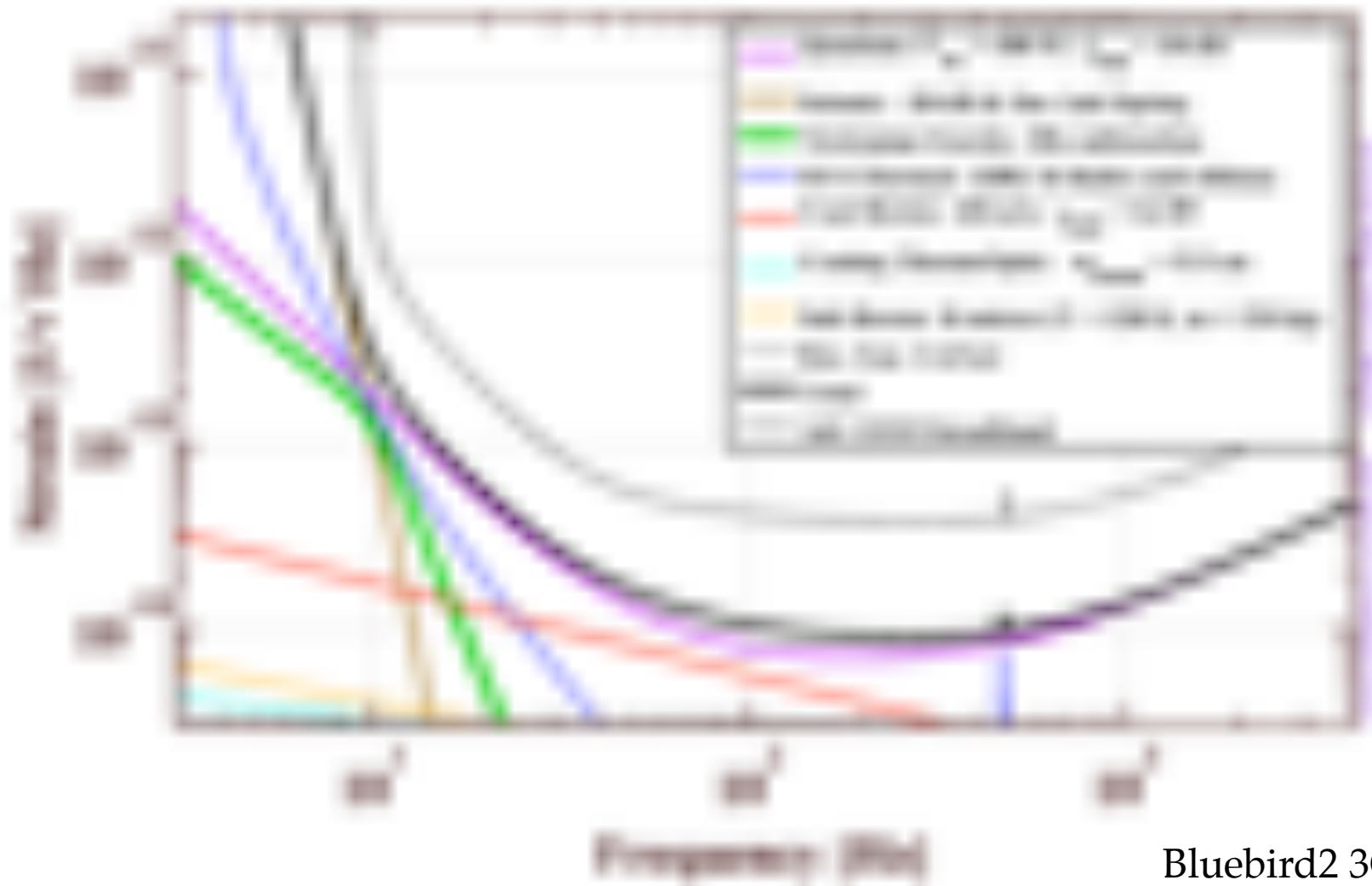
## No Newtonian noise subtraction



## 5x Newtonian noise subtraction



## 3G GWINC curve with 30x Newtonian noise suppression



Bluebird2 3G design