Title: Discussion Session

Date: Jun 13, 2018 03:30 PM

URL: http://pirsa.org/18060060

Abstract:

- How can we coherently combine information from different observations?

Questions on instrument

High power

- What is the maximum power that Advanced LIGO and Voyager can sustain in the arms?
- How does this number change if Silicon test masses are cooled through fibres?
- Can we passively damp parametric instabilities without increasing thermal noise below 4 kHz?
- How hard is it to correct thermal lens on the beam splitter?
- Can we correct sagitta change by shining CO2 on the front surface of the test masses?

Optical loss

- What is the reasonable level of signal-recycling cavity loss for Advanced LIGO and Voyager?

Future instruments

- What is the sensitivity of Voyager when optimised for high frequencies?
- How can we combine LF and HF designs?
- What is the perspective of implementing optomechanical filters in GW detectors?
- What is the optimal detector length for different scientific purpose?

0.085
300 m
3.7 kHz
3.4 kHz
85.9 Hz
500 W
43 kW
3.0 MW
12 dB
30.3 Hz
200 ppm
70
3
800 ppm
0.25 ppm
1 ppm
500 ppm

tering from their surfaces, $Y_{\mathrm{itmx,y}}$ and Y_{bs} are the losses due to the wavefront distortion in the input test masses and the beam splitter. These factors are given by the equations

$$Y_{\mathrm{itmx,y}} = 1000\,\mathrm{ppm} \times \left(\frac{P_{\mathrm{arm}}}{1\,\mathrm{MW}} \frac{\alpha_{x,y}}{0.5\,\mathrm{ppm}} \frac{30}{\kappa_{\mathrm{itm}}}\right)^2$$

$$Y_{\mathrm{bs}} = 250\,\mathrm{ppm} \times \left(\frac{P_{\mathrm{bs}}}{6\,\mathrm{kW}} \frac{\alpha_{\mathrm{bs}}}{1\,\mathrm{ppm}} \frac{1}{\kappa_{\mathrm{bs}}}\right)^2, \quad (3)$$

where $\alpha_{x,y}$ is the absorption coefficient of the coating of the x- and y- test masses, α_{bs} is total absorption coefficient of the beam splitter and κ_{BS} is suppression factor of the beam splitter wavefront distortion. In these equations we omit power absorbed by the substrates of the test masses since this power is significantly smaller than $Y_{\mathrm{itmx,y}}$ [12]. Power absorbed by the beam splitter Y_{bs} is also significantly smaller than $Y_{\mathrm{itmx,y}}$, but it introduces an imbalance between the two Michelson arms according to the equation

In order to

$$Y_{\mathrm{itmx}} - Y_{\mathrm{itmy}} + Y_{\mathrm{BS}}$$

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Parameter	Advanced LIGO	LIGO-HF
Mirror mass	40 kg	40 kg
Arm gain	260	139
Power recycling gain	60	86
Signal recycling mirror transmissivity	0.32	0.085
Signal recycling length	56 m	300 m
Coupled SRC-arm cavity resonance	4.0 kHz	3.7 kHz
Coupled resonance bandwidth	68 kHz	3.4 kHz
Arm cavity bandwidth	44.8 Hz	85.9 Hz
Input power	125 W	500 W
Power on beam splitter	6.2 kW	43 kW
Arm power	0.8 MW	3.0 MW
Squeezing level (observed)	—	12 dB
Filter cavity (bandwidth=detuning)	—	30.3 Hz
SRC static loss, Y_{st}	500 ppm	200 ppm
Suppression of ITM distortion, κ_{itm}	30	70
Suppression of BS distortion, κ_{bs}	1	3
Heating loss on input test masses, Y_{itm}	1000 ppm	800 ppm
Coating absorption, $\alpha_{x,y}$	0.5 ppm	0.25 ppm
Beam splitter absorption, α_{bs}	1 ppm	1 ppm
Heating loss on beam splitter, Y_{bs}	225 ppm	500 ppm

which is not acheivable in the current facilities. In order to overcome this issue, we increase finesse of the arm and signal recycling cavities and keep the length at a practical level of $\sim 100\,\mathrm{m}$.

Our design has also a significant advantage compared to the detuned signal recycling cavity proposal. Since both the arm cavity and signal recycling are on resonance, the signal response of the interferometer is balanced for the upper and lower audio sidebands. As a result, there are no optical springs effects in the interferometer. Moreover, the GW signal is in the phase quadrate and only one filter cavity is required for the optical interferometer operation. This is in contrast to the

$$Y_{SRC} = Y_{st} + \frac{Y_{itmx} + Y_{itmy} + Y_{BS}}{2} \tag{2}$$

where Y_{st} is the loss due to clipping on the mirrors and scattering from their surfaces, $Y_{itmx,y}$ and Y_{bs} are the losses due to the wavefront distortion in the input test masses and the beam splitter. These factors are given by the equations

$$\begin{aligned} Y_{itmx,y} &= 1000\,\mathrm{ppm} \times \left(\frac{P_{arm}}{1\,\mathrm{MW}} \frac{\alpha_{x,y}}{0.5\,\mathrm{ppm}} \frac{30}{\kappa_{itm}}\right)^2 \\ Y_{bs} &= 250\,\mathrm{ppm} \times \left(\frac{P_{bs}}{6\,\mathrm{kW}} \frac{\alpha_{bs}}{1\,\mathrm{ppm}} \frac{1}{\kappa_{bs}}\right)^2, \end{aligned} \tag{3}$$

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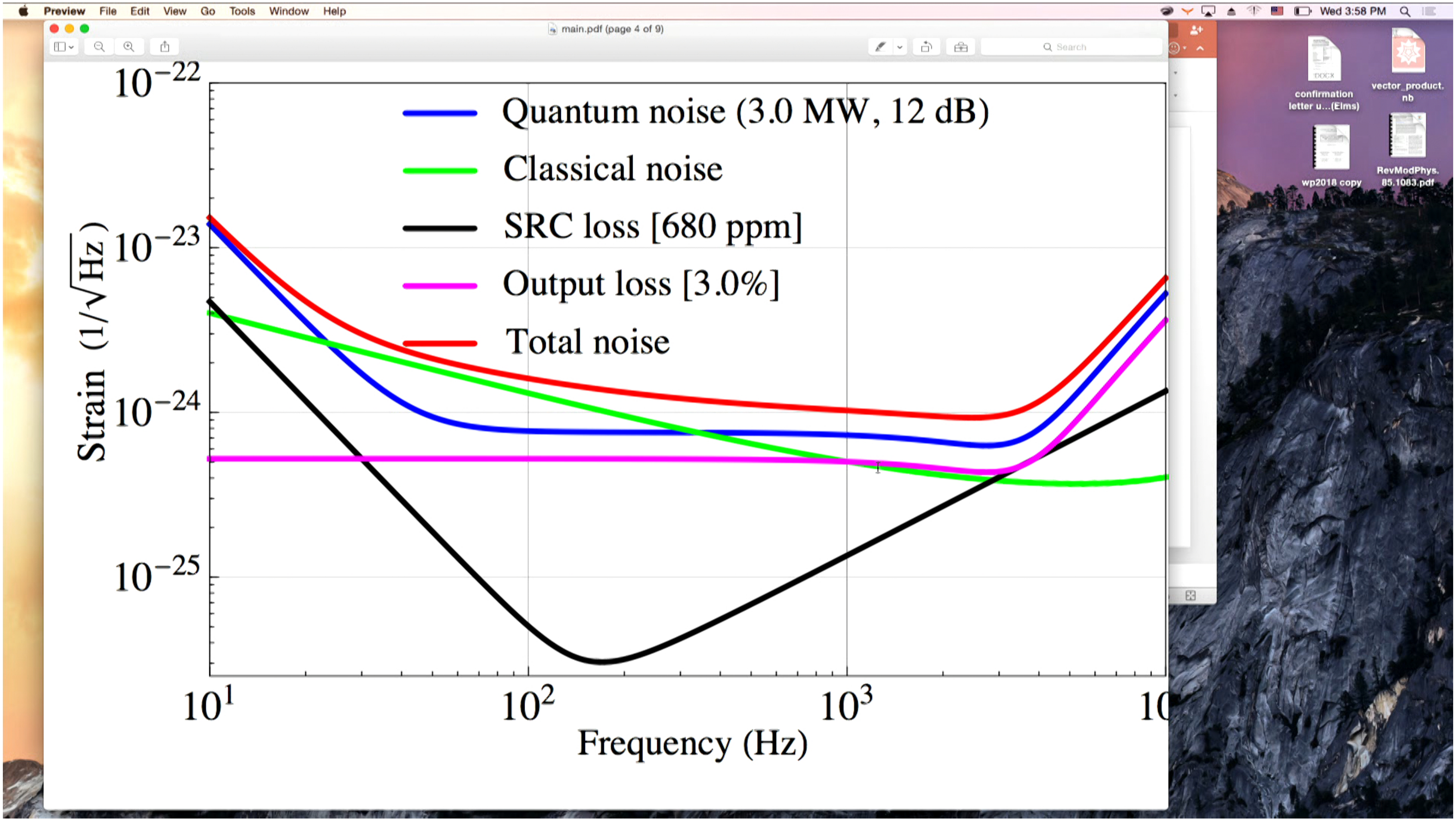
$$Y_{MI} = \frac{Y_{itmx} - Y_{itmy} + Y_{BS}}{2}, \tag{4}$$

This imbalance leads to the coupling of the laser noises, such as beam jitter, frequency and intensity noises. For this reason, we require $Y_{bs} < 500\,\mathrm{ppm}$ for our design. At $P_{bs} = 25\,\mathrm{kW}$ we need to reduce wavefront distortion on the beam splitter by $\kappa_{bs} = 3$.

Second, resonating power exerts force on the suspended mirrors. Small beam off-centering results in the radiation pressure torque given by the equation [13, 14]

$$T = \frac{2P_{arm}}{\ldots} x\theta, \tag{5}$$



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main.pdf (page 4 of 9)
Quantum noise (3.0 MW, 12 dB)
Classical noise
SRC loss [680 ppm]
Output loss [3.0%]
Total noise
Strain $(1/\sqrt{Hz})$
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10^{-23}
10^{-24}
10^{-25}
10^{1}
10^{2}
10^{3}
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Some orders of magnitude

FQL for Advanced LIGO (simply the shot-noise limited sensitivity):

$$\sqrt{S_{hh}^{\rm FQL}} \approx 5\times 10^{-25}\,{\rm Hz}^{-\frac{1}{2}} \left(\frac{1\,{\rm MW}}{P_{\rm arm}}\right)^{\frac{1}{2}} \left(\frac{\lambda}{1064\,{\rm nm}}\right)^{\frac{1}{2}} \left(\frac{\Delta f}{1\,{\rm kHz}}\right)^{\frac{1}{2}} \left(\frac{10}{e^{2r}}\right)^{\frac{1}{2}}$$

Internal ponderomotive squeezing (amplification):

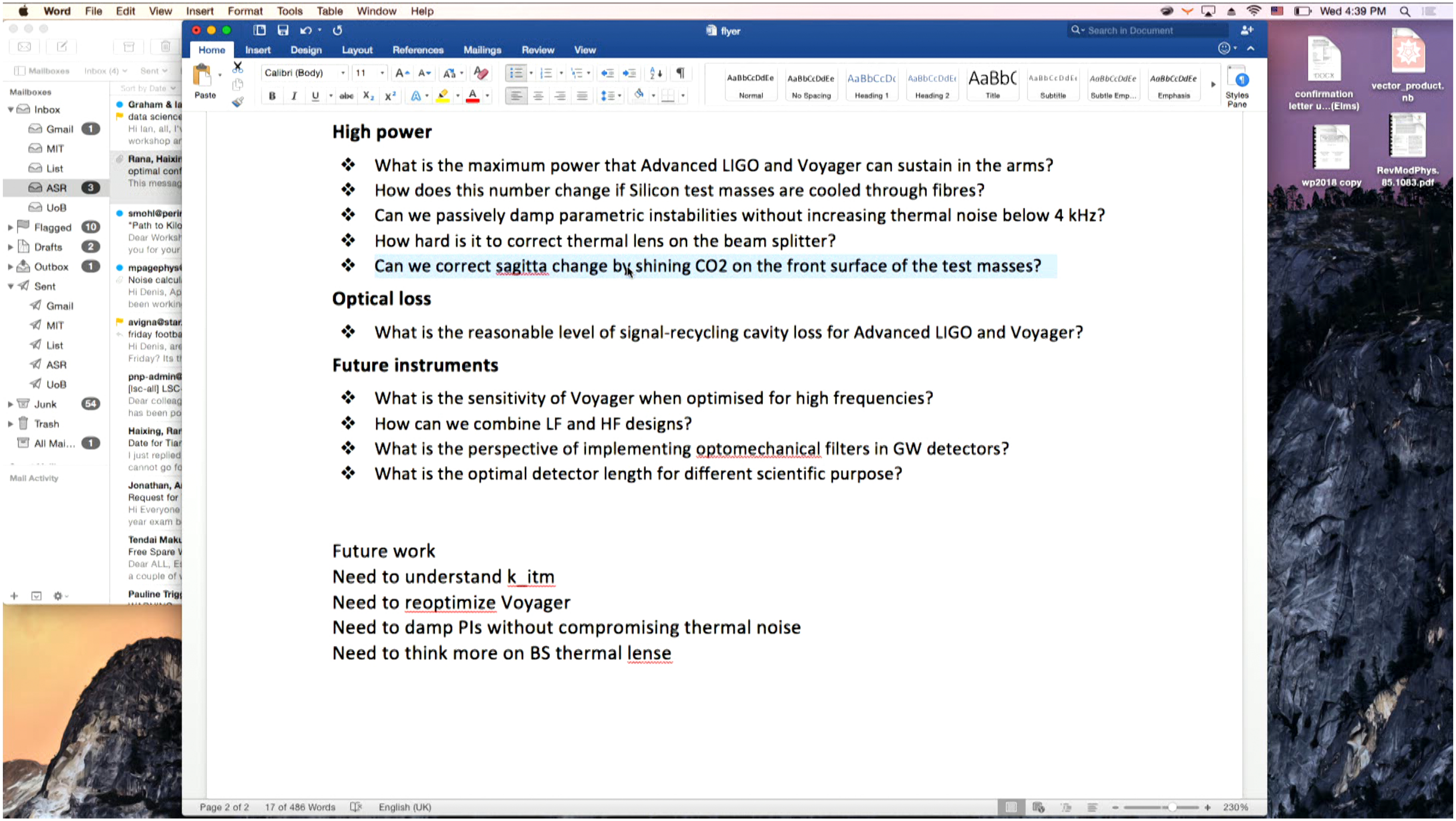
$$\mathcal{K} \approx 10 \left(\frac{10\,{\rm Hz}}{f}\right)^2 \left(\frac{40\,{\rm kg}}{M}\right) \left(\frac{1\,{\rm kHz}}{\Delta f}\right)$$

SRC loss:

$$\sqrt{S_{hh}^{\rm SRC}} \approx 4\times 10^{-25}\,{\rm Hz}^{-\frac{1}{2}} \left(\frac{1\,{\rm MW}}{P_{\rm arm}}\right)^{\frac{1}{2}} \left(\frac{\lambda}{1064\,{\rm nm}}\right)^{\frac{1}{2}} \left(\frac{f}{1\,{\rm kHz}}\right) \left(\frac{0.015}{T_{\rm ITM}}\right)^{\frac{1}{2}} \left(\frac{\epsilon_{\rm SRC}}{10^{-3}}\right)^{\frac{1}{2}}$$

Notations:

GW frequency: $f = \Omega/(2\pi)$ Detector bandwidth: Δf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Need to reoptimize Voyager
Need to damp PIs without compromising thermal noise
Need to think more on BS thermal lense

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Future work
Need to understand k_itm
Need to reoptimize Voyager
Need to damp PIs without compromising thermal noise
Need to think more on BS thermal lens
Correct sagitta using ring heaters?

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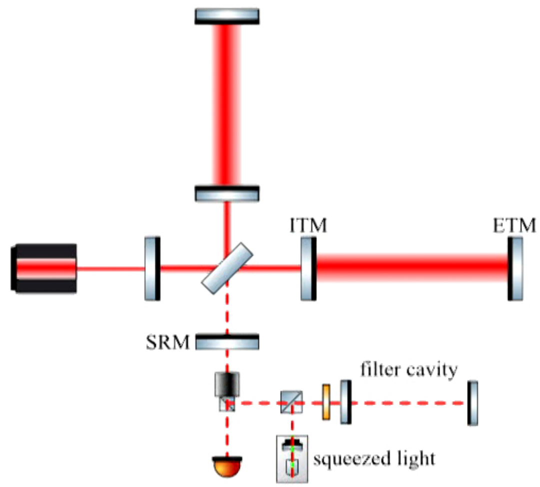
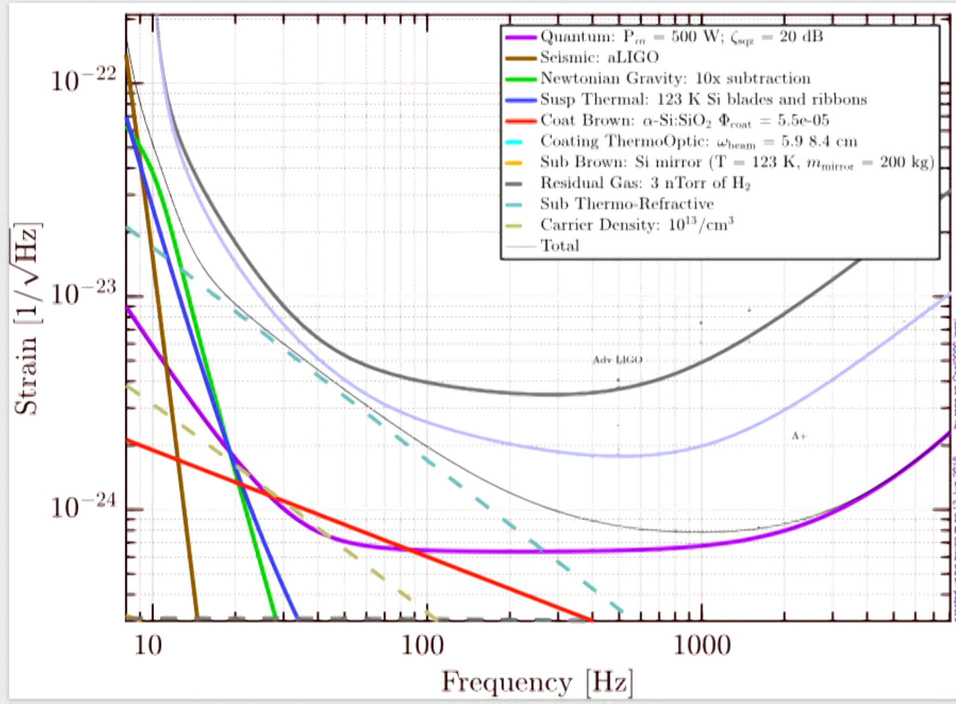


FIG. 1. Schematics showing the detector design (left) and the result
Advanced LIGO plus (A+) [6], LIGO Voyager [7], Einstein Telesco



where Ω_m and Q_m is frequency and quality factor of the me
chanical mode, c is the speed of light, λ = 1064 nm is th
laser wavelength, $Re[G_n]$ is the real part of the optical gain
and $B_{m,n}$ is the overlap between the mechanical mode m an
optical mode n. If the parametric gain $R_m > 1$, the mode be
comes unstable and ultimately saturates the photodiodes. Fo
Advanced LIGO operating at full power, the largest expected parametric gain is $R_m \sim 10$ and the number of unstable modes is ≈ 40 in the frequency range 10–50 kHz. In the proposed detector, we plan to increase P_{arm} and have maximum parametric gain of $R_m \sim 50$ and see unstable modes up to 80 kHz. The

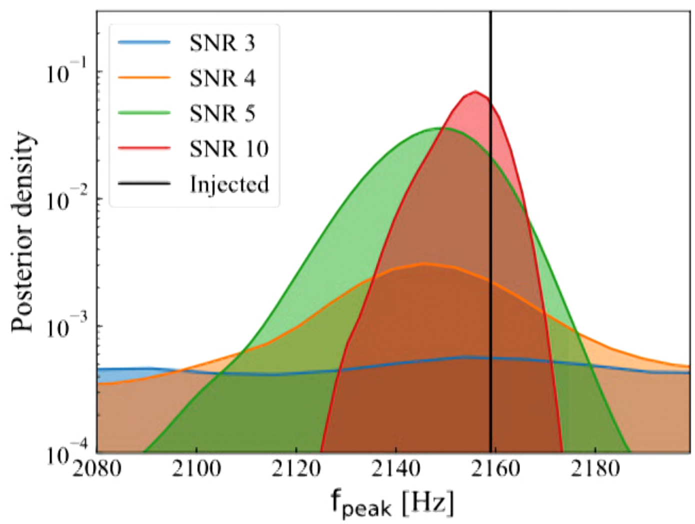
thermal noise, (iii) mirror substrate thermal noise and (iv) unsuppressed laser noises such as beam jitter, frequency and amplitude noises. Fig. 2 shows the classical noise level of the Advanced LIGO detectors. Further in this section, we discuss the proposed improvements to the quantum shot noise.

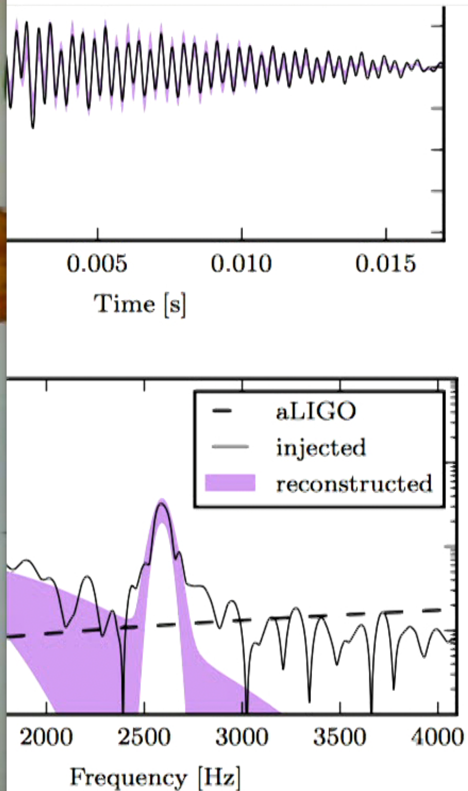
6

ring from systematic uncer-
uncertain numerical simula-

Frequency

nstructed signal (see for ex-
o calculate the posterior for
equency f_{peak}. For each sam-
econstructed signal we sup-
r phases by applying a win-
um time-domain amplitude.
equency of the maximum of
the range $[1500, 4000]$Hz[5]. If
ple does not possess a max-
a sample from f_{peak}'s prior
ll the posterior distribution





reconstructed whitened time-domain
um (bottom) for a signal produced
(1.35, 1.35)$M_\odot$ NSs with the DD2

On the other hand, the absence of a matched filter means that **BayesWave** does not reconstruct the entire signal, but only its most prominent features. We study the reconstruction performance and its relation to the strength of the signal in the following section.

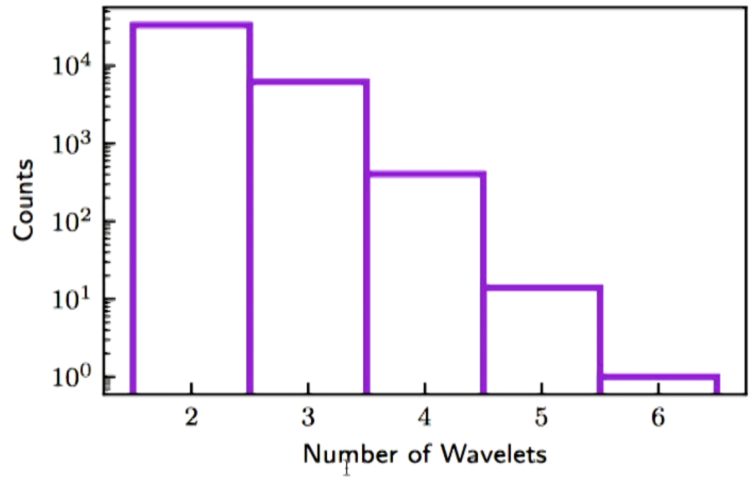


FIG. 3. Histogram of the number of wavelets **BayesWave** used for the signal reconstructions of Fig. 2. **BayesWave** uses model selection to determine the most probable number of wavelets.