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LIGO detector response at high frequencies and its implications for calibration above 1kHz

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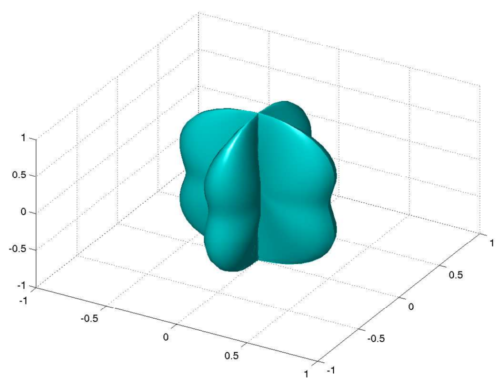
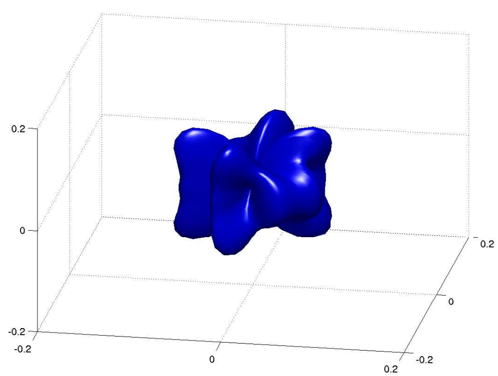


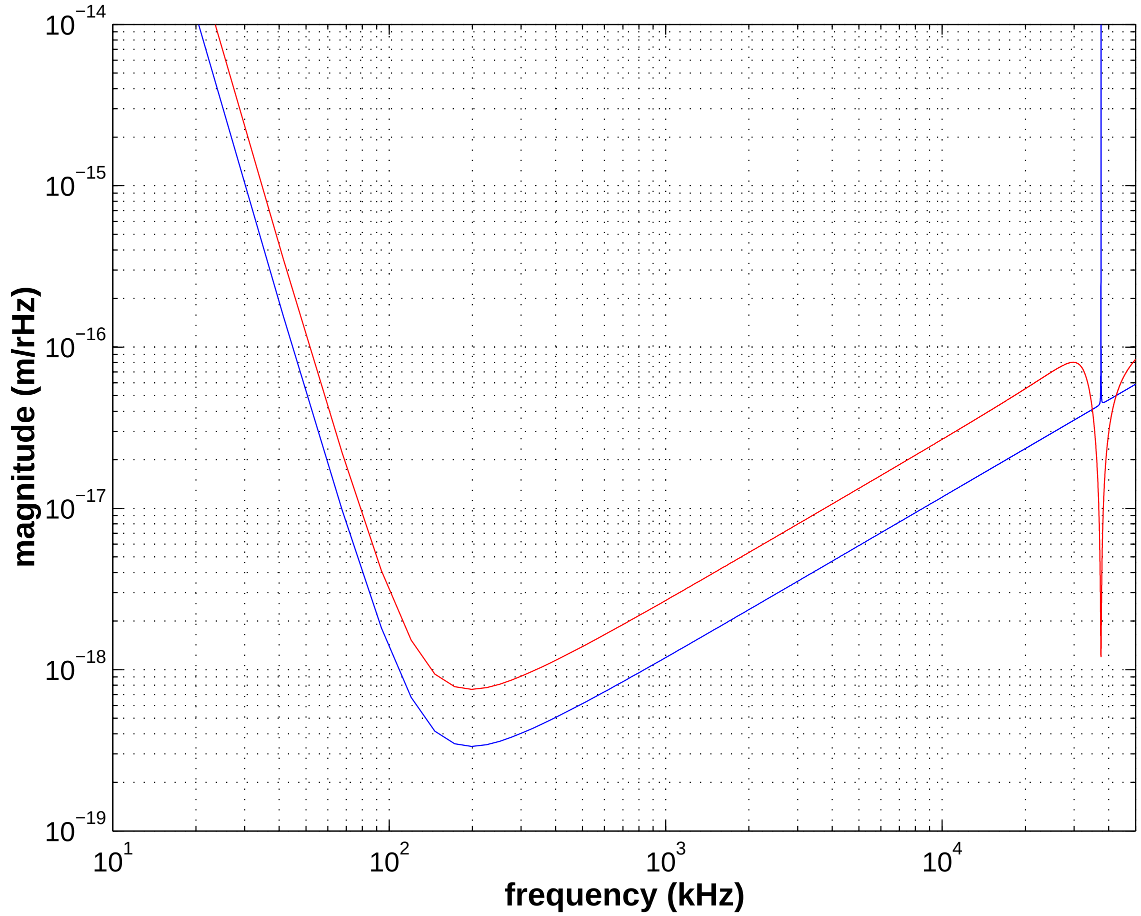


LSC Meeting

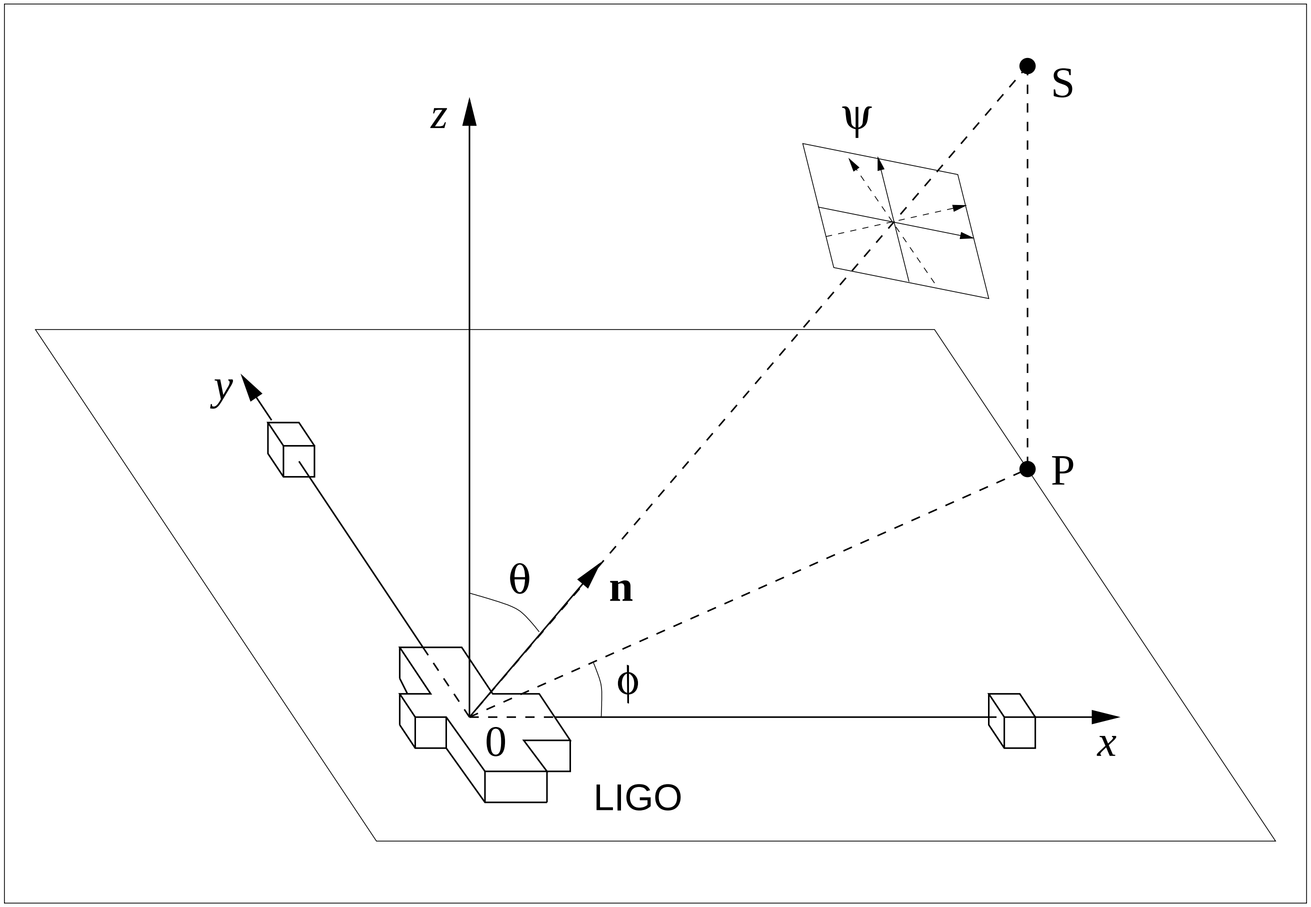
LIGO Livingston Observatory, Livingston, LA

Interferometer response and sensitivity

$$y(\omega) = \frac{\sqrt{S_V(\omega)}}{c_0 \times |H(\omega)|}, \qquad \delta L(\omega) \neq \frac{1}{2} L h(\omega).$$



Source location and polarization



Detector response to gravitational waves

Polarization tensor of gravitational wave and the vector pointing to the source $\vec{n}$:

$$E_{gw} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \qquad \begin{aligned} n_x &= \sin\theta\cos\phi \\ n_y &= \sin\theta\sin\phi \\ n_z &= \cos\theta \end{aligned}$$

Transformation from G.W. frame to detector frame: $R = R_z(\psi)R_y(\theta)R_z(\phi)$. Polarization tensor in the detector frame: $E_{det} = R^T\, E_{gw}\, R$. The key components are:
$E_{xx} = E_{det}(1,1), E_{yy} = E_{det}(2,2)$. Distances to ITMs: l_i and the delays: $t_i = l_i/c$.

$$A_i = \frac{1 - e^{-(1-n_i)sT}}{1-n_i}, \qquad B_i = \frac{1 - e^{-(1+n_i)sT}}{1+n_i}$$

Equivalent phase due to gravitational wave (unity strain):

$$\phi_i = e^{n_i s t_i}\,\frac{A_i - B_i e^{-2sT}}{2sT}$$

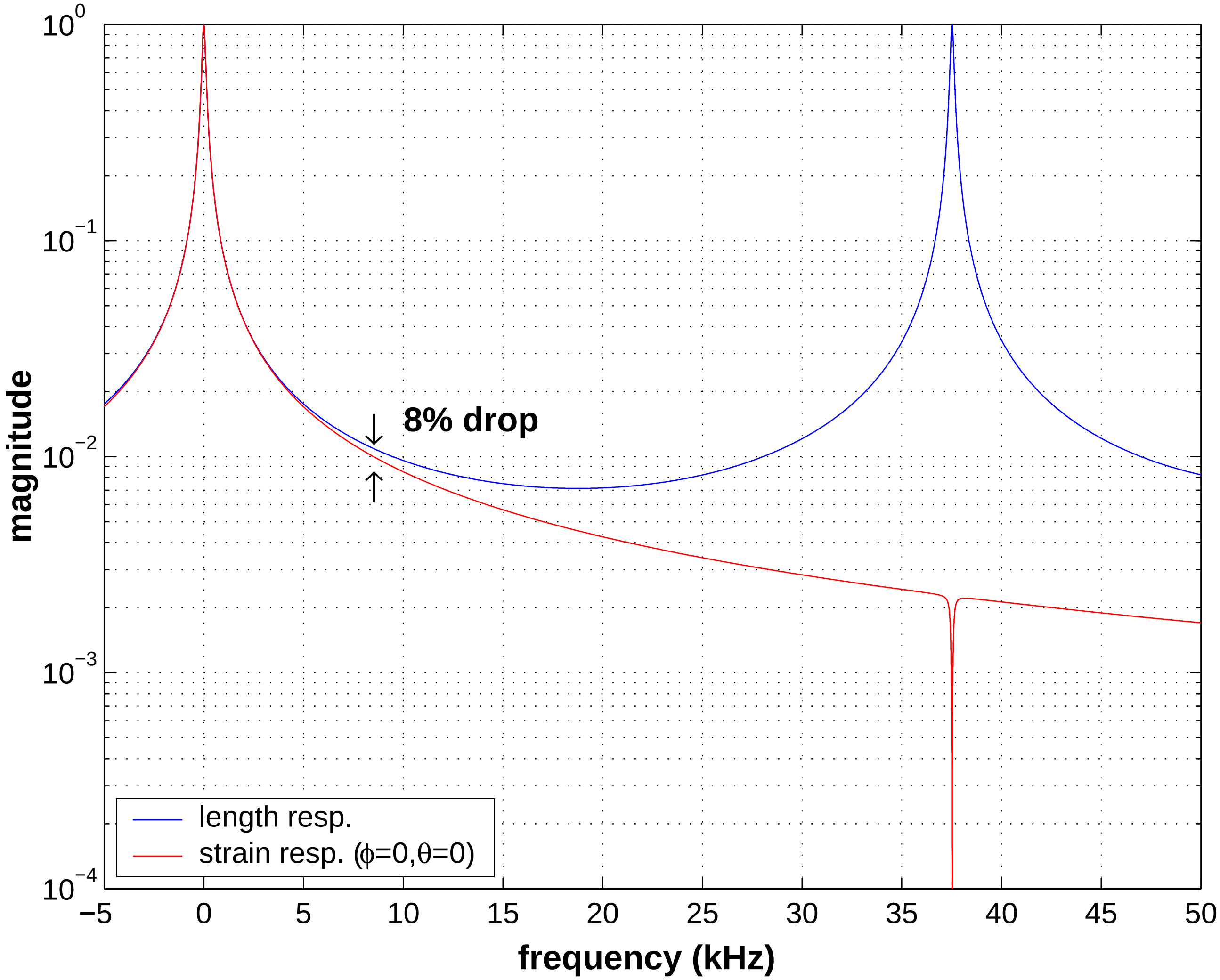
The response to gravitational waves is

$$H = \frac{1}{2}\, H_{cav}(s)\, (E_{xx}e^{-st_x}\phi_x - E_{yy}e^{-st_y}\phi_y).$$

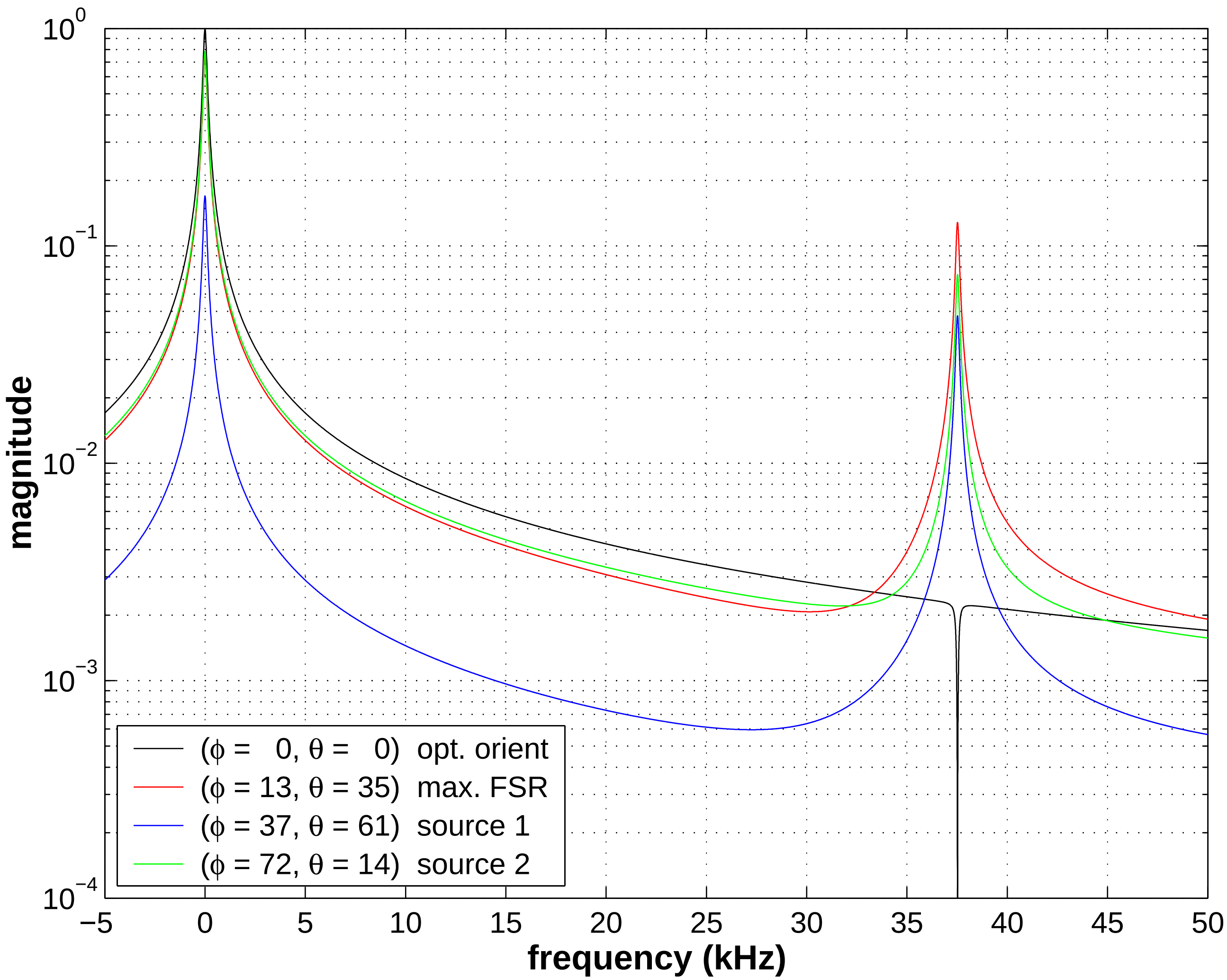
Here $H_{cav}(s)$ is the cavity response function:

$$H_{cav}(s) = \frac{1 - r_a r_b}{1 - r_a r_b e^{-2sT}}.$$

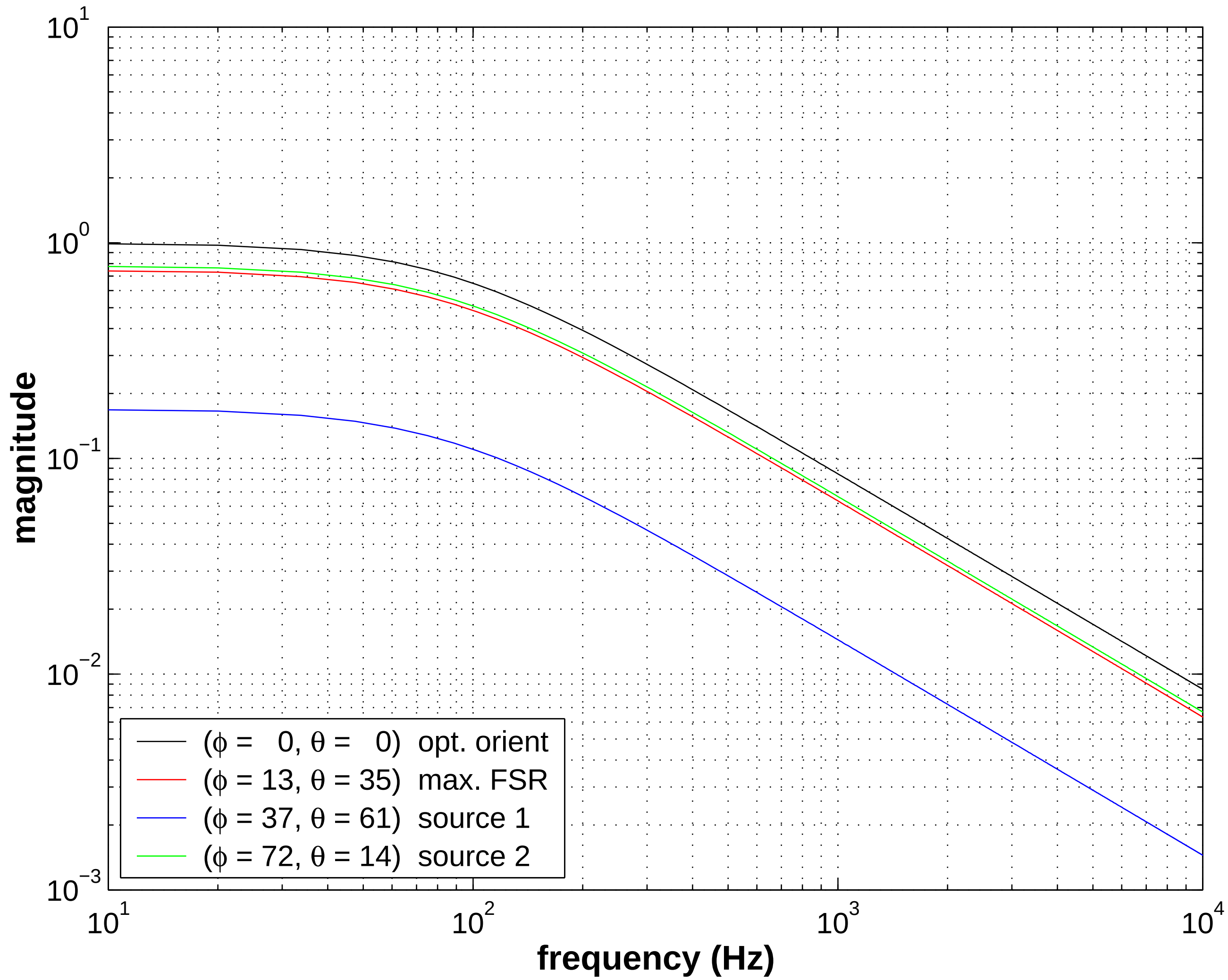
Length vs strain response



Detector response as a function of source location (1)

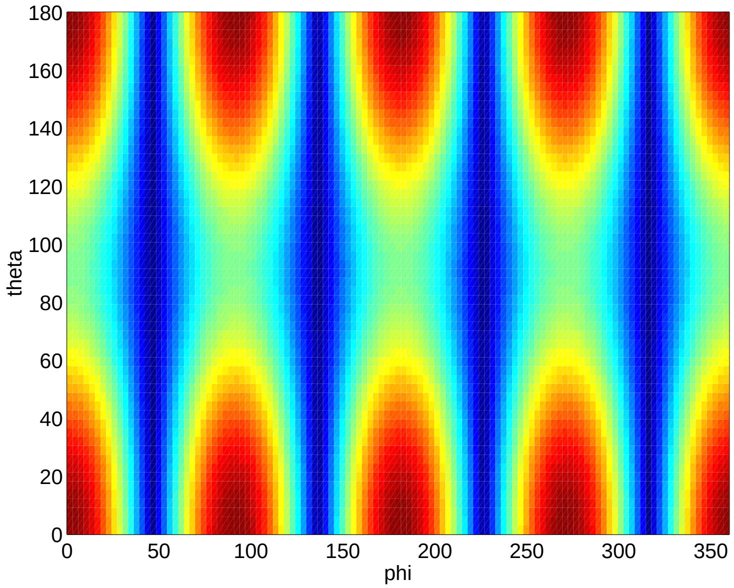


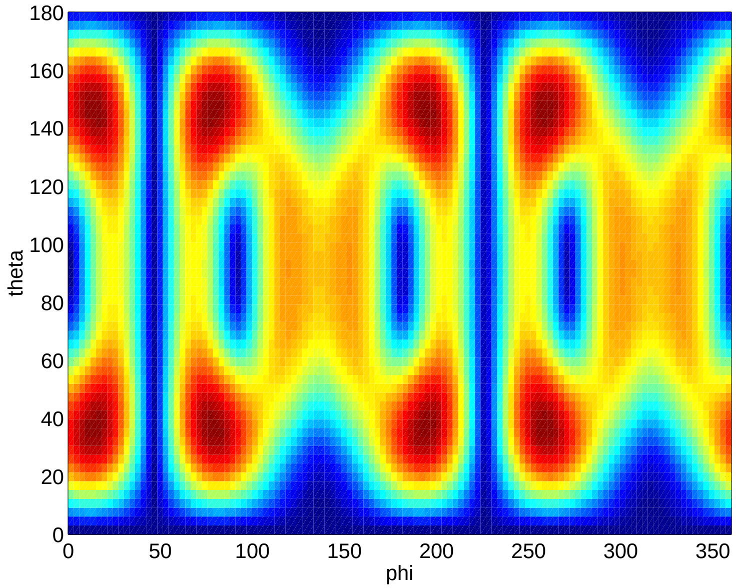
Detector response as a function source location (2)



Directional sensitivity of interferometers (1)

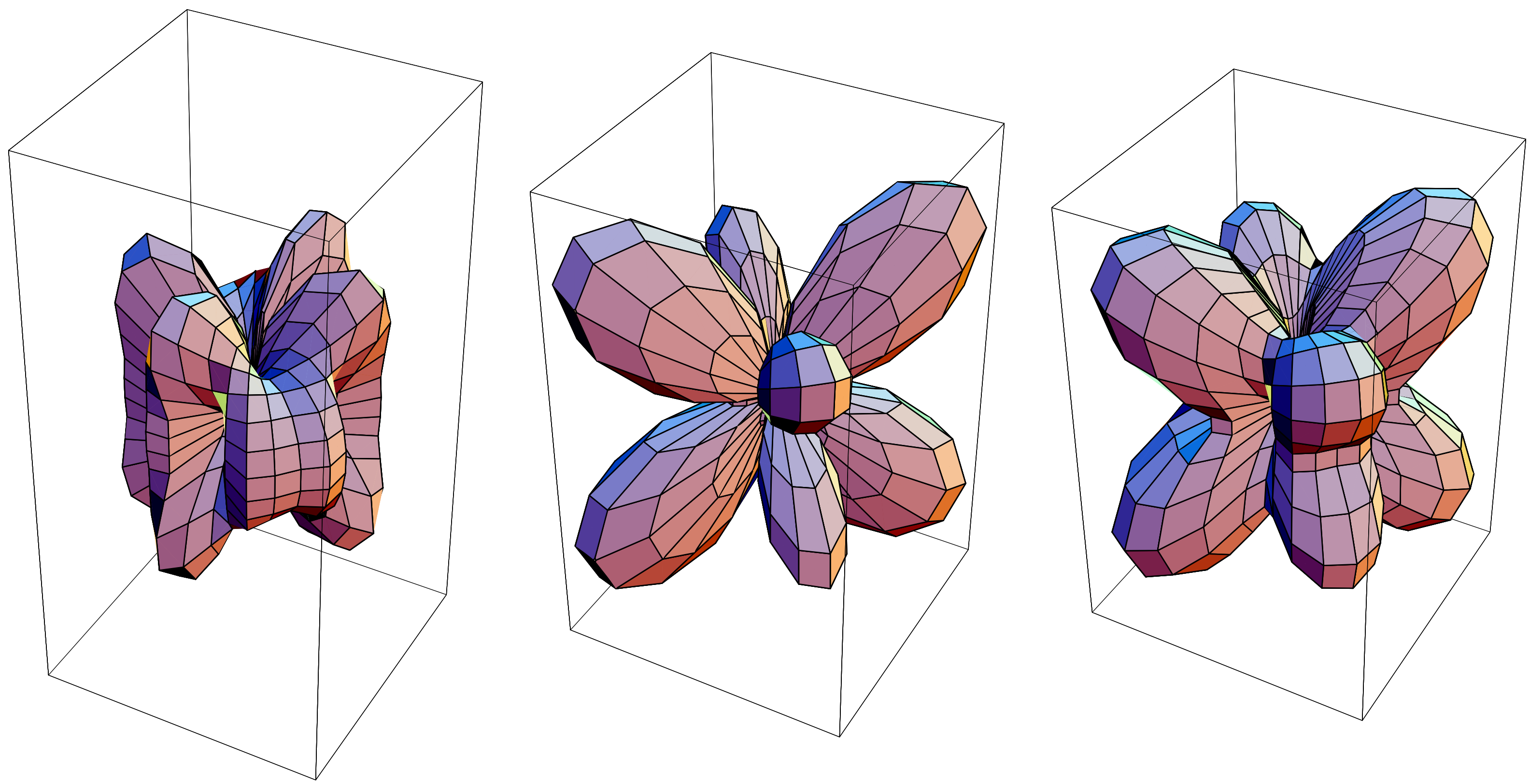
Sensitivity of the detector as a function of the source location: (*left*) at DC, (*right*) at FSR.





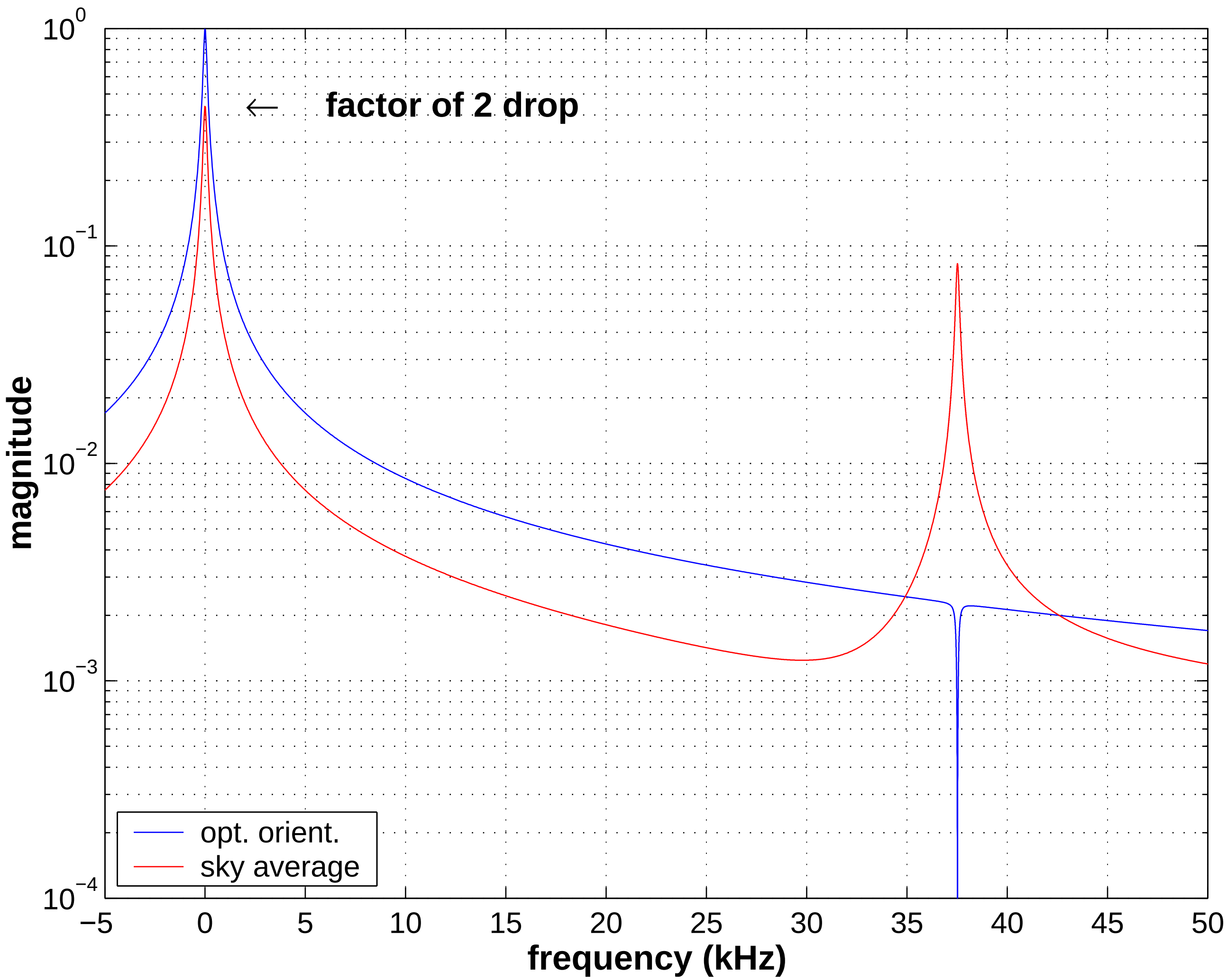
Directional sensitivity of interferometers (2)

Antenna patterns at FSR: response to +polarization ($\psi = 0°$), response ×polarization ($\psi = 90°$), averaged response.



T970101-B-D, D.Sigg, *Strain Calibration in LIGO*

Optimal orientation and sky averaged responses



Conclusion

- High frequency response depends on the source location
- The sensitivity of detectors can be described in terms of sky-averaged strain response
- Sky-averaged sensitivity at DC is factor of 2 less than that of the optimal orientation
- The response at FSR is factor of 5 less than at DC