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Laser Interferometer Gravitational Wave Observatory (LIGO) Project

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Refer to:	LIGO-T030296-00
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Subject: **Analysis Proposal to Search for Gravitational Waves at Multiples of the LIGO Arm Cavity Free-Spectral-Range Frequency**

Summary:

We propose to initiate an effort to utilize the peaks in the strain sensitivity of the LIGO interferometers at multiples of the cavity free-spectral-range (FSR) frequency ($N \times 37.5\text{kHz}$ for a 4km long Fabry-Perot cavity)[1–3] to search for high-frequency gravitational waves. As described in Ref. [3] the sky-averaged strain sensitivity at the first FSR is expected to be only a factor of ~5 worse than at dc (see Figure 1). This proposal outlines the necessary steps—both in hardware and software—to do a full analysis in a bandwidth of about 200Hz around the FSR frequency.

Scientific Motivation:

Even though it is considered unlikely the existence of exotic massive objects such as boson stars may allow nature to produce gravitational-wave bursts that have frequency components up to several tens of kHz. It is therefore interesting to look for gravitational bursts at all frequency bands that are accessible by observation with LIGO. Even if no new source is found, one can certainly set an upper limit that covers so-far uncharted territory. There are also models of the early universe that predict a stochastic gravitational-wave noise that extends up to several tens of kHz. Due the overlap reduction function only a direct observation might be possible at the FSR. Far more likely one will only be able to establish an upper limit because a stochastic gravitational-wave noise cannot be separated from detector noise.

Setup:

To utilize the information at the FSR the following hardware is necessary:

- A channel that records the information at the FSR to frames. This can be done using a lock-in amplifier as described in Ref. [4], or by sampling at a faster rate[5] and doing the down-conversion in software. A faster sampling rate may also allow us to look at the second FSR of the 4K and at the first FSR of the 2K.
- A resonant gain stage in the frequency stabilization circuit of the mode cleaner[6], since the current design will be dominated by frequency noise at the FSR. An example of such a filter is shown in Figure 2.

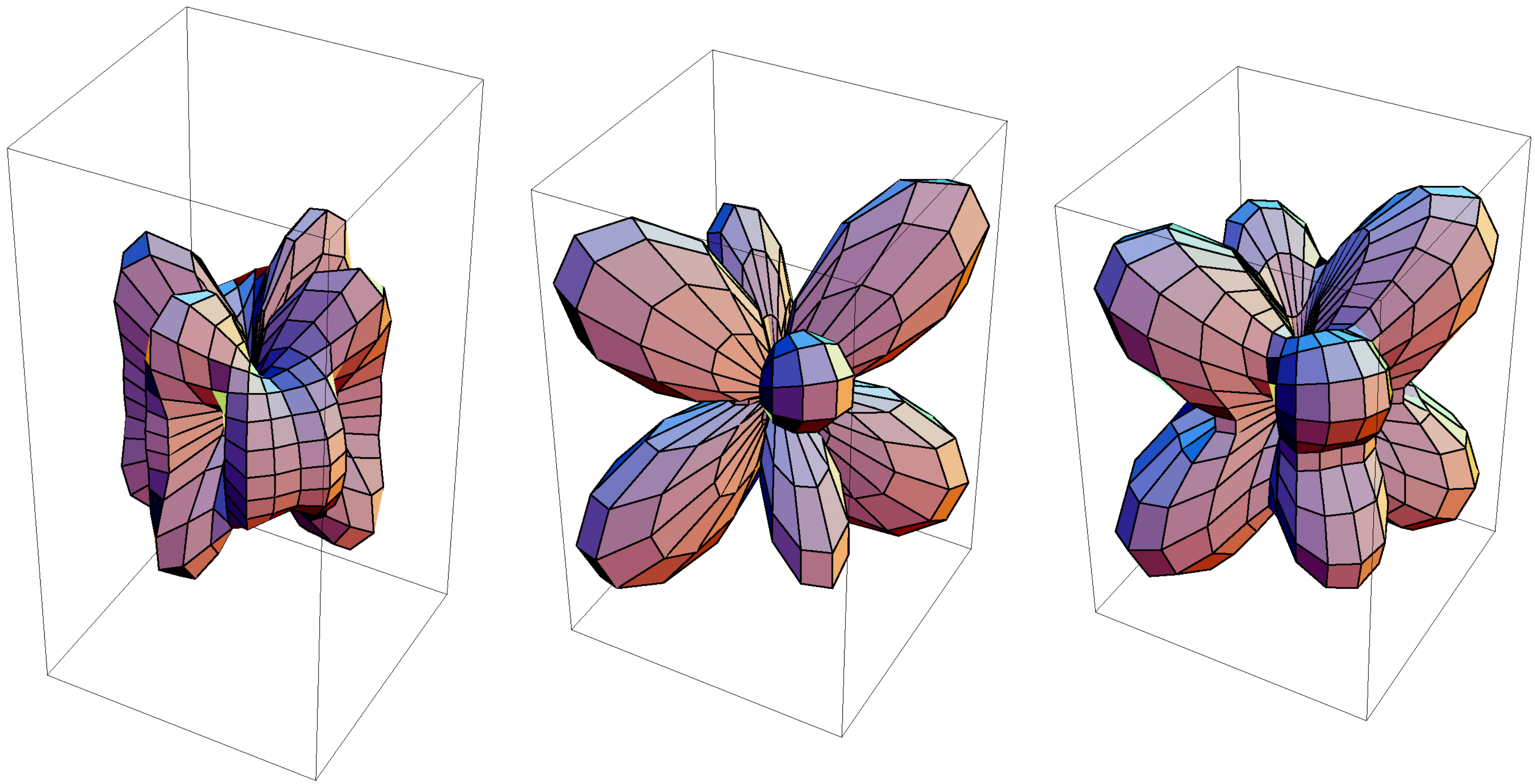

Figure 1: ***h*** **sensitivity for arm length λ/2 as function of angle for the "+" polarization (left), the "×" polarization (center) and the averaged polarization (right). The boxes are about 5 times smaller than the corresponding ones at dc.**

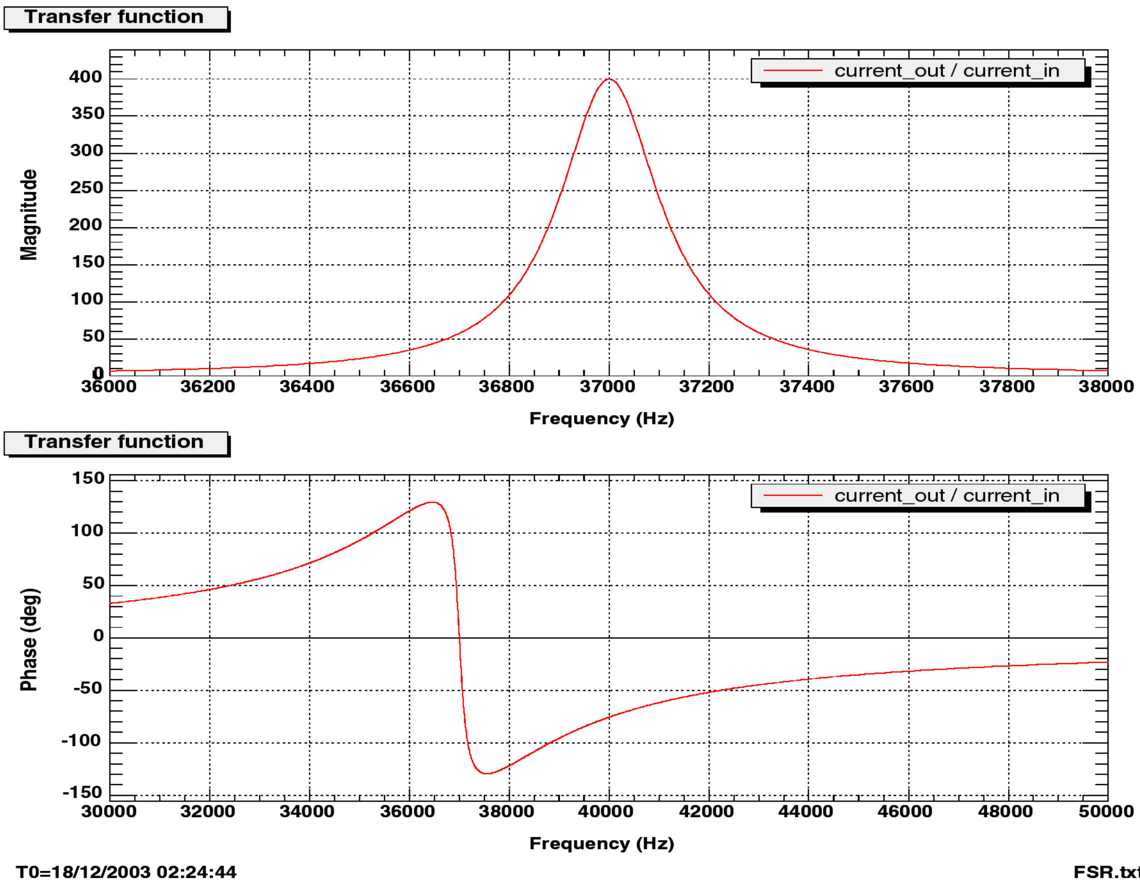

Figure 2: An example of a resonant gain stage at the FSR consisting of two complex poles at 37 kHz (Q of 150) and two complex zeros at 37 kHz (Q of 7.5). This filter adds 6 degrees of phase at 100 kHz.

For S3 both 4K interferometers at LHO and LLO use a lock-in amplifier and send the down-converted signal to a DAQ channel that is sampled at 2048 Hz. It is our opinion that this channel isn't ready yet for a search for gravitational waves but can be used to develop the methodology of the analysis, to investigate the use of vetoes and to learn how to do the calibration.

Analysis:

Two types of analysis can be performed:

- A bar-like burst analysis that looks for excess noise in a 200 Hz region around the FSR and forms the coincidence between the LHO 4K and the LLO 4K.
- A direct measurement of the noise spectrum and a corresponding upper limit on stochastic noise.

The burst analysis is envisioned to be much simpler than the standard burst search due to the small bandwidth of the signal. Much like a bar analysis one can form the optimal filter for a delta-like burst and use its output to threshold on events. Because the FSR of the LHO 2K is at approximately twice the frequency than the one of the 4K, only a two-fold coincidence between

LLO and LHO can be formed. Since environmental disturbances are unlikely to reach the interferometer at the FSR and since most channels are sampled at a much lower frequency, an epoch veto such as the one used by the standard burst analysis and a possible veto on the frequency noise (assuming this channel is available at the FSR) are the most likely veto candidates. A direct comparison with other gravitational-wave detectors in the world won't be possible due to the differences in FSR frequencies.

References:

[1] R. Schilling, *"Angular and frequency response of LISA,"* Class. Quantum Grav. **14** (1997) 1513–1519.

[2] M. Rakhmanov, R. Savage, D. Reitze, and D. Tanner, *"Dynamic resonance of light in Fabry-Perot cavities,"* Phys. Lett. **A305** (2002) 239–244.

[3] D. Sigg, *"Strain Calibration in LIGO,"* T970101-B.

[4] J. Markowitz, R, Savage, and P. Schwinberg, *"Development of a readout scheme for high-frequency gravitational waves,"* T030186-00.

[5] A proposal to develop a fast readout channel with a 100kHz bandwidth for diagnostics purposes has been added to the FY04 budget.

[6] M. Mageswaran, *"Mode cleaner servo,"* D000347-B.