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***LOI for Gravity Wave Detection using Atom Interferometry  
in the DUSEL Facility***

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To whom it may concern:

We propose the development of a large-scale terrestrial atom interferometer detector for gravity waves. The instrument, which requires a 1 km evacuated vertical shaft, appears well matched to the proposed vertical facility in DUSEL/Homestake. Detector operation is based on proven atomic physics methods and extrapolations from the performance of existing atom interferometric force sensors, which are now in their fifth experimental generation. We are currently demonstrating the core technology features relevant to this proposal in a 10 m facility at Stanford.

Although there have been many experimental attempts to detect gravitational waves, there is yet to be a direct detection. Nevertheless there are many expected sources of gravitational waves [1]. These range from accepted astrophysical sources such as neutron star and black hole binaries, to more speculative sources such as cosmic strings or early universe phase transitions. While even the detection of a gravity wave would be an exciting scientific milestone, the hope is to use gravitational waves as a new window to the universe [2]. Astrophysical objects like black holes, neutron stars and white dwarf binaries which are difficult to observe electromagnetically are bright sources of gravitational radiation. Gravitational waves are unaffected by recombination and can therefore probe the earliest epochs of the universe.

We propose the development of a terrestrial atom interferometer to detect gravitational waves in the 1 Hz to 10 Hz band, intermediate to the sensitivity bands of the LIGO and proposed LISA detectors, based on light pulse atom interferometry [3] in which dilute ensembles of cold atoms in free fall accrue phase shifts by the application of beamsplitter and mirror laser pulses along the direction of motion of the (falling) atoms. Momentum transfer between the laser pulses and atoms during stimulated absorption and emission events leads to a physical separation and subsequent recombination of atomic wavepackets along a vertical axis, in a configuration roughly analogous to an optical Mach-Zehnder interferometer. The phase shift in the atom interferometer, which determines the number of atoms detected in a given output port of the interferometer, arises from differences in the space-time paths of the interfering atomic states and the

laser phase imprinted on the atom during the atom-laser interaction. A gauge invariant calculation of the phase shift in the interferometer due to a gravity wave of frequency  $\omega$  gives  $\Delta\phi \sim h L \sin^2(\omega T/2)$ , where  $h$  is the gravity wave induced strain,  $L$  is the length of the apparatus (in this case, 1 km), and  $T$  is the elapsed time between the mirror and beamsplitter laser pulses. Fig. 1 shows the anticipated sensitivity curves for several experimentally realistic atom interferometer configurations, and compares these sensitivities to existing (LIGO) and envisioned (LISA) detectors and possible astrophysical sources.

Since the atoms used in the detection of the gravitation waves are decoupled from the physical apparatus during their free-fall, terrestrial configurations are expected to be immune from 1 to 10 Hz seismic noise sources which limit the frequency response of the LIGO detector. The upper sensitivity curve represents the anticipated sensitivity of a

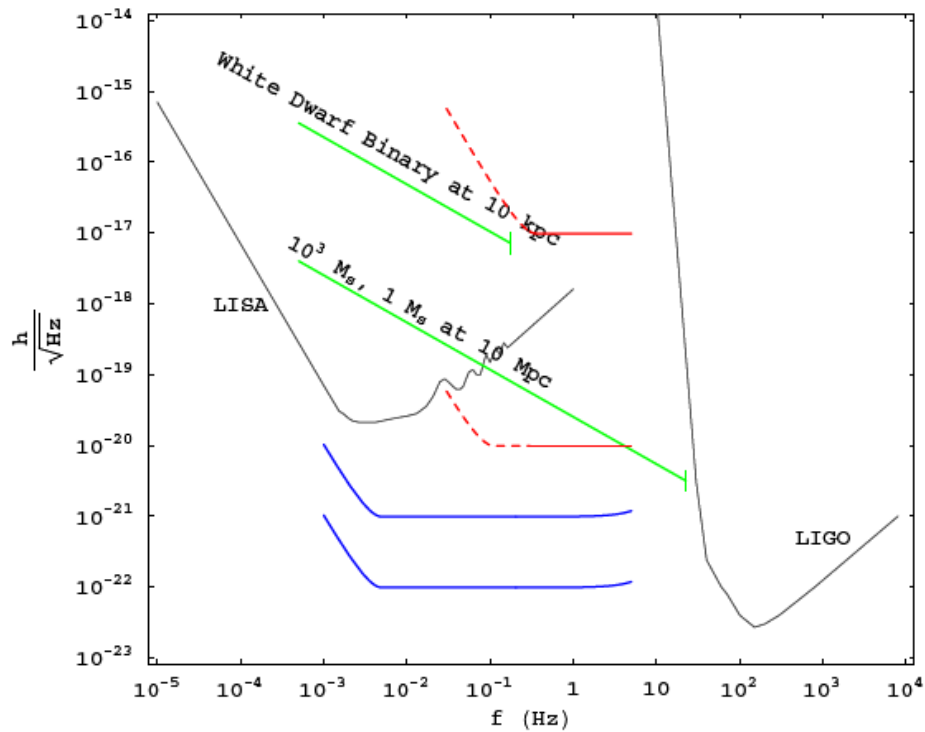


Fig. 1. The projected shot noise power spectra of our proposed terrestrial (red) and satellite experiments (blue) to a gravitational wave of frequency  $f$ . The two terrestrial correspond to 1 km and 10 km baselines. The sensitivity of the terrestrial setup is cut-off (dashed) where it is below time varying gravity gradients. Example sources are shown in green, enhanced by their lifetimes, ending when the binaries coalesce.  $M_s$  refers to 1 solar mass.

first-generation device. We expect a series of improvements which will lower the strain sensitivity (improved atom optics and de Broglie wave metrology techniques) over time. Such a large-scale ground-based detector would serve as a test-bed for future space-based detectors, with substantially larger baselines (sensitivities show in blue in Fig. 1). A detector operating at these levels of sensitivity in the  $10^{-3}$  Hz to 10 Hz band is interesting

for stochastic gravitational wave searches (see Fig. 2). The power spectra of gravitational waves from violent events in the universe at the TeV scale are typically peaked around  $10^{-3}$  Hz to  $10^{-1}$  Hz. Furthermore, the energy density  $\Omega_{\text{GW}}$  in gravitational radiation produced by phenomena such as inflation is flat over several frequency decades.

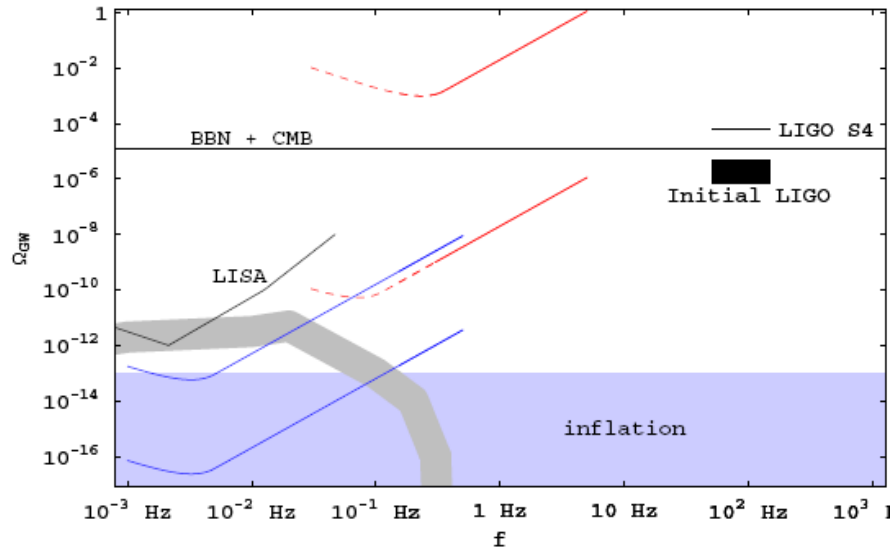


Fig. 2. The projected sensitivity in  $\Omega_{\text{GW}}$  of our proposed configurations shown in Fig. 1 to a stochastic background of gravitational waves. These limits assume a year of integration using uncorrelated detectors. The gray band represents a prediction for the stochastic gravitational wave background from extragalactic White Dwarf binaries. The blue band shows the limit on gravitational waves produced in inflation.

We feel that the DUSEL/Homestake vertical shaft facility represents a unique opportunity to develop these atom interferometric gravity wave detectors.

Sincerely,

Mark Kasevich

#### References

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