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Lunar LIGO: A New Concept in Gravitational Wave Astronomy;

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For three decades, physicists have been in search of an elusive phenomenon predicted by Einstein's general theory of relativity: gravitational radiation. These weak vibrations of spacetime have, thus far, eluded conclusive Earth-based detection due in part to insufficient detector sensitivity and noise isolation. The detection of gravitational waves is crucial for two reasons. It would provide further evidence for the validity of Einstein's theory of relativity, the presently accepted theory of gravitation. Furthermore, the ability to identify the location of a source of a detected gravitational wave event would yield a radical new type of astronomy based on non-electromagnetic emissions. We continue our study of a lunar-based system [1,2] which can provide an important complement to Earth-based analysis because it is completely independent of the geophysical sources of noise on Earth, while providing an Earth-Moon baseline for pin-pointing burst sources in the Universe. We also propose for the first time that a simplified version of the LIGO beam detector optical system, which we will call LLIGO (Lunar LIGO), could be emplaced on the Moon as part of NASA's robotic lander program [3] now under study (Artemis).

The Earth-based investigation has two major programs underway. Both involve large interferometer-type gravitational wave antennas. The incoming waves cause the lengths of the two arms of the interferometer to fluctuate at the same frequency but 180° out of phase. Detection occurs via the resulting motion of the interference fringes at the detector. This type of antenna is more responsive than the bar antennas used in early work because signals propagate at the speed of light rather than the speed of sound. Increasing the length of the arms increases the sensitivity of the interferometer to the waves (as $\sqrt{n}$ where n is the number of waves). These programs are the following: (1) The Laser Interferometer Gravitational-Wave Observatory (LIGO) is an MIT/Cal Tech effort to build two interferometers at different sites in the U.S., each one having arms four kilometers in length [4]. This antenna will be sensitive to waves down to around 10 Hz. (2) A similar program to build an antenna with three kilometer arms, and comparable sensitivity range to LIGO, called VIRGO, is headed by a group of French and Italian investigators [5]. A third proposal is the Laser Gravitational Wave Observatory in Space (LAGOS), which is a large LIGO-type interferometer antenna involving three spacecraft in near-circular orbit around the sun [6]. This is a "LIGO in space" with arms roughly 10^6 km in length. This antenna would be sensitive in the range between roughly 10^{-5} to 10^0 Hz. This proposal is in a conceptual stage, is extremely tedious, and appears unrealistic due to its life-cycle operations cost.

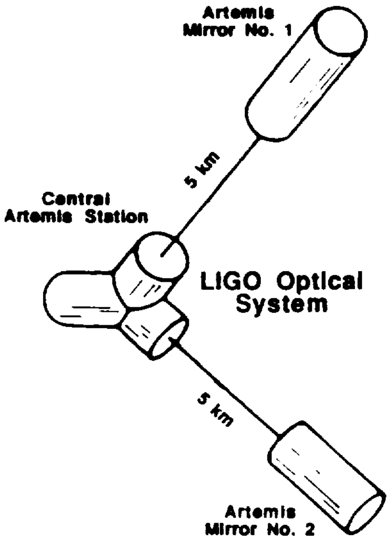

Figure 1. Lunar LIGO using Artemis

It is our contention that a lunar-based LIGO interferometer antenna (Fig. 1), in conjunction with these other projects, would provide an important contribution to this effort in both the physics and astronomy arenas. The reasons are as follows:

(a) The lunar antenna will be sensitive down to 0.25 Hz [1]. This covers most of the range for which LIGO, VIRGO, and LAGOS are not sensitive (see Fig. 2). This increased sensitivity is due to smaller noise sources, especially seismic noise (100 times greater on Earth in the range between 0.25 and 1.0 Hz), gravity gradient noise (no large moving masses near detector on the Moon), tidal noise, and acoustic noise. Estimates of photon shot noise tend to be a factor of three higher for the lunar antenna above about 30 Hz. Cosmic ray noise, a source unique to the space-based antennas, should not cause significant disruption, except during solar flare events. Thermal noise should be comparable.

(b) The lunar antenna will not be mechanically or geophysically coupled to the terrestrial antennas, thus providing a good method of removing spurious seismic noise via concidence with terrestrial antennas over their common frequencies. It will also provide a significant confidence or voting factor for detected events.

(c) The vacuum of the lunar environment provides significant advantages. It will eliminate the need to maintain a vacuum in the interferometer over the life-cycle of the antenna **[1,2]**. A minimal antenna could be placed on the Moon using three dedicated Artemis landers, one containing the laser source/beam-splitter/detector, and the other two containing the end mirrors (**Fig. 1:** A 2m Artemis creates a 5.27 km osculating line-of-sight for a lunar radius of 1738 km). The lack of arm enclosures allows the arms to be extremely long, limited only by the Moon's surface curvature. The arms could be easily altered by moving the landers containing the end mirrors.

The extreme distance between the Earth and Moon provides a long parallax baseline with terrestrial antennas for locating the sources of a gravitational wave event. A factor of 50 times better angular resolution may be obtained in the plane of the source, the Earth, and the Moon for short-burst sources. For signals which recur several times during a period of a week or more, and are out of the ecliptic plane, the accuracy of source localization may be improved [1].

These arguments provide compelling support for the development of a lunar-based gravitational wave antenna to complement the programs currently under development on Earth.

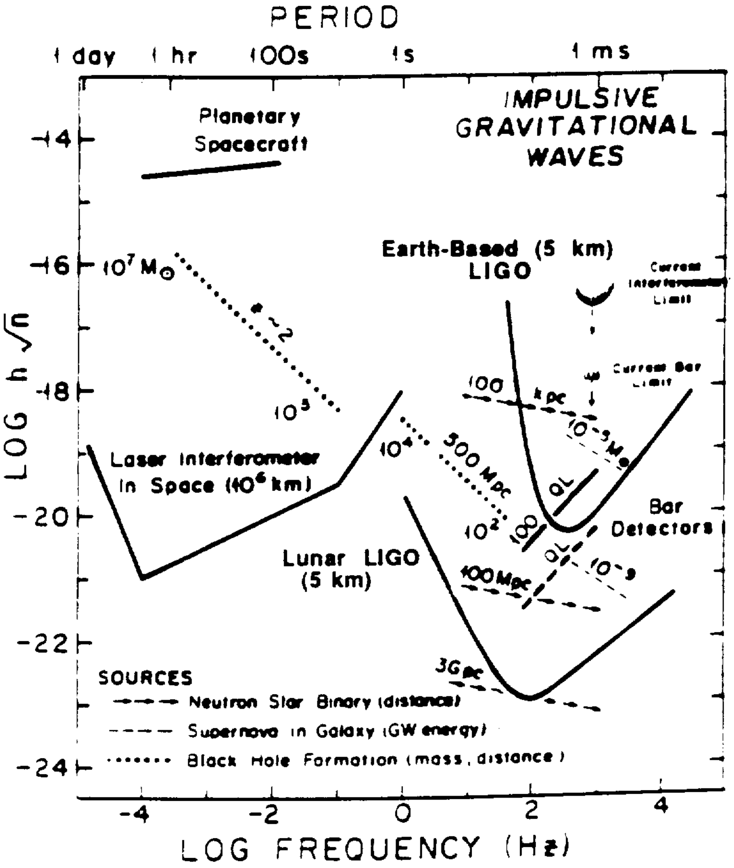

Figure 2. Lunar LIGO & Burst Sources [Adapted from **4** and **6**]

References:
[1] LaFave, N., and Wilson, T.L., *23rd LPSC*, Vol **2**, 751 (1992). **[2]** Wilson, T.L., in *Physics and Astrophysics from a Lunar Base*, Potter, A.E., and Wilson, T.L., eds., AIP Conf. Proc. **202**, ix, 53, and program organizer (1990); in *Astrophysics from the Moon*, Mumma, M.J., and Smith, H.J., eds., AIP Conf. Proc. **207**, 608 (1990), Ref. 37. **[3]** *LPI Workshop on Early Robotic Missions to the Moon* (Lunar & Planetary Institute, Houston, February 4, 1992); *Artemis Phase 2 Study Results* (NASA JSC New Initiatives Office, March 10, 1992). **[4]** Thorne, K.S., in *300 Years of Gravitation*, Hawking, S., and Israel, W., eds., (Cambridge University Press, 1987), Sect. 9.5.3; Figs. 9.4; 9.6; 9.7. **[5]** Bradaschia, C., *et al.* Nucl. Instr. & Meth. **A289**, 518 (1990). **[6]** In: *Physics Through the 1990's: Gravitation, Cosmology, & Cosmic Ray Physics*, Figs. 6 (National Academy Press, Washington, 1986).