Detection of Gravitational Waves II
Cumulative Enhancement of Phase Difference

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Abstract

We propose novel technique for detecting gravitational waves using facilities at LIGO with certain easy changes in the process of detecting gravitational waves based upon a novel technique of adding up of the extremely small phase difference in two laser beams generated through passing of one wavelength of a gravitational wave. The change suggested in performing of the gravitational wave detection experiment that is carried out at present will be aimed at achieving adding up such phase difference that is produced through passing of each successive wavelength such that the cumulatively obtained phase difference through passing of sufficiently many wavelengths of gravitational wave automatically becomes detectable. The new suggested experiment in brief will proceed as given below. We begin with usual experiment using high energy well regulated pulsed laser source. When one pulse of laser beam will be emitted to move towards beam splitter we remove the source and replace it by a perfectly reflecting mirror kept orthogonally to the direction of laser beam incident on the beam splitter, and further this mirror can be moved in backward/forward direction as per requirement, by keeping it orthogonal to the direction of incident laser beam. Suppose there is squeezing along arm A and stretching along arm B of the interferometer producing the (very small) phase difference in the interfering light waves reaching back to beam splitter and let this phase difference is undetectably small so that almost all light is directed back to this new perfectly reflecting mirror, the one that replaced the source. Now, keep this mirror at such distance that the light that will reflect back from this newly kept mirror that replaced the source to act as source and to proceed again to fall upon the beam splitter and again will start running through two arms of interferometer for second round there will be again squeezing along arm A and stretching along arm B of the interferometer. Because of such arrangement the same amount of phase difference will result again and this will add up in the phase difference created in the first round. After sufficiently many bounces on newly introduced perfectly reflecting mirror replacing the laser source this phase difference will build up to a value so that now all light will no more be directed towards mirror that replaced the source but some light will go towards detector to offer a conclusive proof for the existence of gravitational waves!

1. **Introduction:** Experimental detection of gravitational waves is a big challenge of this time and enormous efforts are on world over by people working in highly sophisticated gravitational wave detection laboratories. Gravitational wave laboratories will be leading laboratories in the coming future to offer new important insights in our study of large scale phenomena. Detection and study of gravitational waves of different types and of different intensity and frequency will make revolutionary contributions to our knowledge about galactic dynamics. It will add greatly to our knowledge about astrophysical sources and about processes driven by strong gravitational fields. Objects of fundamental importance, such as astrophysical black holes, merge and radiate with luminosity larger than the entire electromagnetic universe, and these events will become clearly detectable only through a tool for detection of gravitational waves that are mainly associated with detectable amplitude with such unimaginably huge events [1]. When observed with gravitational waves these intrinsically interesting astronomical sources such as massive black holes and their merger, extremely compact stellar binaries and their collisions, supernovae events etc will surely yield many new surprises. Thus, the discovery potential associated with detection of gravitational waves is immense.

   Gravitational radiation was detected indirectly in 1974 by J. Taylor and R. Hulse, who observed its effects on the orbital period of a binary system containing two neutron stars, one of them a pulsar (PSR 1913 + 16). Efforts to detect gravitational waves directly have been severely challenged by the extreme weakness of the waves impinging on the Earth. However, as the 21st century begins, observations of the gravitational waves from astrophysical sources such as black holes, neutron stars, and stellar collapse are expected to open a new window on the universe [2].

   There are two major gravitational wave detection concepts: acoustic and interferometric detection [3]. The acoustic method deals with a resonance response of massive elastic bodies on gravitational wave excitations. Historically the acoustic method was proposed first by J. Weber [4] where he suggested to use long and narrow elastic cylinders as Gravitational Wave Antennas. Although a significant progress has been achieved in fabrication and increasing sensitivity of such type of detectors [4, 5, 6] the interpretation of obtained data is still far to claim undoubtedly the detection of gravitational waves. On the other hand a considerable attention has been shifted recently to more promising interferometric detection methods. The interferometric gravitational wave detector like Laser Interferometer Gravitational Wave Observatory (LIGO) and VIRGO [7, 8] represents a Michelson interferometer with a laser beam split between two perpendicular arms of interferometer. The principles of operation of such type of detectors are reviewed in Refs [9, 10, 11, 12, 13]. The action of gravitational waves on an interferometer can be presented as relative deformation of both interferometer arms. A gravitational wave with dimensionless amplitude h induces the opposite length changes $\frac{\delta l}{l} = \frac{1}{2} h \cos(\Omega t)$ in each arm of the Michelson interferometer, where l stands for the length of each of the arm, Ω for the gravitational wave frequency. These length changes produce opposite phase shifts between two light beams in interferometer arms, when interference occurs at the beam splitter of Michelson interferometer. The resulting phase shift of a single beam of light spending time τ in the interferometer can be written as [13]

$$\delta\phi = h\frac{\omega}{\Omega}\sin\left(\frac{\Omega\tau}{2}\right), \qquad (1)$$

where, ω is the light frequency. This phase shift results an intensity signal change of the light from interferometer beam splitter hitting the photo detector.

The main problem of the acoustic and interferometric methods that they both deal with gravitational waves with extremely small amplitudes of the order $h \sim 10^{-21}$ [14] reached the Earth from deep space. One can see from equation (1) that for gravitational wave frequencies in the 1 kHz range, $\Omega \sim 10^{3}$ Hz, and for the light in visual frequency range, $\omega \sim 10^{14}$ Hz, one has the maximum phase shift of the order $\delta\phi \sim 10^{-10}$ for interferometer arms length of the order 150 kilometers. Such extraordinarily weak effect requires exceedingly high detector sensitivity for both acoustic as well as interferometric detectors.

2. **The Novel Technique:** As seen above one requires extraordinarily high sensitivity of detectors to conclusively capture signal called gravitational wave and this may be one of the important reasons that we have not yet succeeded in this task even though many gravitational waves would have passed through our apparatus installed at different locations.

In this paper we suggest a technique to add up in cumulative fashion the undetectably small phase difference created due to passing of a single gravitational wave in the beams reflected back from two perfectly reflecting mirrors, fixed at ends of two orthogonal interferometer arms, due to which these beams come back to interfere almost destructively at beam splitter. We take high energy well regulated pulsed laser source and start usual experiment. When the beam of light will start from source to hit the beam splitter, and the moment such pulse is emitted, we replace the source by a third perfectly reflecting mirror kept orthogonal to the beam incident on the beam splitter and further we make a provision that will enable us to move this third mirror in the direction, forward or backward as per the requirement of choosing its distance from the beam splitter, so that the plane of this third perfectly reflecting mirror remains orthogonal to the initial direction of beam that was sent to reach on the beam splitter. Now, suppose when the beams of laser were running through two mutually orthogonal arms and were coming back to beam splitter there was squeezing in the arm A say of the interferometer and reciprocally suppose there was stretching in the interferometer arm B say of the interferometer. Using the identity of the velocity of gravitational waves and velocity of light waves, we choose the distance of newly introduced third perfectly reflecting mirror in place of source from the beam splitter in such a way that when the reflected beam of laser, reflected from third newly introduced perfectly reflecting mirror, will fall again on the beam splitter to split into two beams and once again will be running through two mutually orthogonal arms and will come back to beam splitter again there will again be squeezing in the arm A say of the interferometer and reciprocally there will again be stretching in the interferometer arm B say of the interferometer. As an effect of this specially designed arrangement there will be again same phase difference that will in the beams returning to beam splitter and this phase difference will get added in the phase difference generated in the first round. It is obvious to see that after sufficiently many rounds the value of phase difference will go on building up to such a value that it will cease to remain undetectably small to the instrument and the returning beams will no more interfere destructively sending in effect sizable light towards detector.

The main idea in brief behind the suggestion in this paper is to capture the phase differences that add up cumulatively to become sizable with the number of bounces made by the laser pulse on the third newly introduced mirror kept at predetermined appropriate distance to achieve cumulative addition of phase differences to achieve sizable value of the effective phase difference after sufficiently many rounds.

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