Below we publish a brief summary of a paper by I. M. Belousova, L. F. Vitushkin *et al.* that was presented on March 26, 1980 at a scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the USSR Academy of Sciences (March 26-27, 1980), the materials of which were published in Usp. Fiz. Nauk **132**, 387 (1980) [Sov. Phys. Usp. 23, 704 (1980)].

I. M. Belousova, L. F. Vitushkin, I. P. Ivanov, M. I. Ivanovskaya, N. I. Kolosnitsyn, V. N. Sintosov, and V. P. Chebotaev. *Design of a Gravity-Wave Experiment Using a Laser Interferometer.* A number of methods for detection of gravitational radiation from cosmic sources have recently been developed.[1] One version of the gravity antenna is a system of free masses with a laser interferometer as a displacement indicator. Unlike resonant antennas of the Weber type, laser-interferometer gravity antennas (LIGAs) are broad-band systems,[2] and this significantly broadens opportunities for the detection and study of gravitational radiation.

The relative change in the distance between free bodeis in the field of a gravitational wave (GW) is determined by the dimensionless amplitude a_0 of the wave:

$$a_0=\frac{\Delta l}{l},$$

where Δl is the absolute displacement of the bodies and l is the distance between them.

According to recent estimates, the amplitude a_0 of the gravitational radiation that reaches the Earth from a number of hypothetical astrophysical sources—the asymmetric collapse of stars, supernova outbursts, collisions of small black holes, etc.—lies in the range $a_0^* \sim 10^{-19}$ to 10^{-21}, and the most probable durations of the gravity pulses from these sources are $\tau_{gr} \sim 10^{-2}$ to 10^{-4} sec.

To obtain the LIGA sensitivity needed for detection and measurement of gravity pulses with the above characteristics, it is necessary to ensure high sensitivity of the laser interferometer to the absolute displacements of the test masses and a sufficiently long optical path for the light beam in the interferometer.

There are several fundamental limits on the absolute sensitivity of LIGAs:

1. The limit that is imposed on the accuracy of measurement of the test-mass displacements by the Heisenberg uncertainty principle and determined, as Braginskii showed, by the formula[4]

$$\Delta l \geqslant \sqrt{\frac{h\tau_{\text{гр}}}{m}},$$

where m is the mass of the test body. For $\tau_{gr}=10^{-3}$ sec and $m=10^4$ g we obtain $\Delta l \gtrsim 10^{-17}$ cm.

2. The limit imposed on displacement-measurement accuracy by the photon noise of the laser radiation.

The photon noise arises out of the discrete nature of the interaction between the radiation and the photodetector and results in fluctuations of intensity $I_n : I_n = \sqrt{Ihc/\lambda\Delta f}$, where h is Planck's constant, λ is the wavelength of the electromagnetic radiation, c is the velocity of light, and Δf is the frequency band to be received. Hence the following estimate for the smallest measurable displacement $\Delta l_{\min}$ in two-beam interference:

$$\Delta l_{\min} \approx \frac{1}{2\pi} \sqrt{\frac{\lambda ch\Delta f}{I}}.$$

For example, with $\lambda = 6328$ Å (He–Ne laser) $I = 0.3$ W, and $\Delta f = 10^3$ Hz, we obtain $\Delta l_{\min} \sim 3 \cdot 10^{-13}$ cm.

Sensitivity to mirror displacement can be increased by making the light ray pass through each arm of the interferometer several times. After N passes, displacement of the mirror by Δl will change the optical path of the ray by $N\Delta l$. The relative sensitivity of the interfererometer will then be described by the expression $\Delta l/Nl$, i.e., multiple passage of the light beam (N passes) is equivalent to an increase in the base line of the interferometer (by N times).

In lengthening the effective baseline lN, it must be remembered that the total optical path $L = lN$ of the light beam, which is equal to it, is limited by the requirement that the light propagation time $\tau_0 = L/c$ in the interferometer not exceeded the duration of the gravitational pulse: $\tau_0 < \tau_{\mathrm{gr}}$. We therefore obtain the following limiting values for $\tau_{\mathrm{gr}} \sim 10^{-2}$–$10^{-4}$ sec: $L \sim 3 \cdot 10^8$–$3 \cdot 10^6$ cm.

It would appear possible to attain the necessary optical sensitivity in the LIGA by means of a two-beam Michelson interferometer with a baseline $l \sim 10$–100 m and with each arm incorporating a system with multiple passage and spatial separation of the light rays (so-called optical periodic systems). Assuming that the absolute sensitivity to displacement is limited only by photon noise, detection of a GW with $a_0 \sim 10^{-19}$ would require 10^3–10^2 passes of the beam.

Optical periodic systems are already in use in LIGA,[5,6] but the numbers of passes of the beam have been small and the relative sensitivities have reached 10^{-15} to 10^{-16}.

Let us note a number of limitations and difficulties that arise when periodic systems with $N \sim 1000$ are used in LIGA:

—the large baseline length ($l \sim 1$ m) makes it impossible to use systems with two spherical mirrors,[7] since the mirrors degenerate into plane mirrors and alignment is made difficult by setting tolerances that decrease to 0.01 second of arc;

—a large number of passes N dictates the use of mirrors with high-reflectance coatings (reflectances $R > 0.995$) to reduce the energy losses on multiple reflection;

—preservation of high wavefront quality through multiple reflections in order to obtain a sharp interference pattern dictates the use of optical elements of high surface quality and of shaping systems (single lens or telescopic system) to match the parameters of the laser beam to those of the principal resonator mode of the cavity resonator formed by the mirrors of the periodic system (this is the only way to prevent enlargement of beam diameter on multiple reflection and to keep diffraction losses small).

The requirements listed above make the following types of periodic systems suitable for use in LIGAs:

—A periodic system based on two identical aspherical (slightly toric) mirrors separated by a distance L. In these systems, the baseline l may not exceed 5–10 m, and a value of N of ~500–1000, i.e., a value of $L \sim 5 \cdot 10^5$–10^6 cm, can be obtained.

—A periodic system based on White's system,[8] supplemented with optical elements that provide for line scanning of the beam. Such systems can produce $N \sim 1000$, which gives $L = 5 \cdot 10^6$–10^7 cm with a baseline of 50–100 meters.

—A periodic system based on two prism-reflector assemblies.

Still another possible LIGA scheme is a multibeam Fabry-Perot interferometer formed by two mirrors mounted on test masses. The exact expression for the phase advance of a light beam propagating with any number of rereflections in a system of two mirrors in the presence of a weak GW was derived in Ref. 9, and the action of the GW on the intensity of the light passing through the interferometer was investigated. It was shown as a result that the Fabry-Perot interferometer is sensitive to the action of a GW, first of all on satisfaction of the resonance conditions $k_{\mathrm{gr}} l = \pi j$ and $l = (\lambda_{\mathrm{gr}}/2)j$, $j = 1, 2, 3, \ldots$ ($k_{\mathrm{gr}} \approx 2\pi/\lambda_{\mathrm{gr}}$). At realistic interferometer baselines l, these conditions are satisfied in the high-frequency GW range. Secondly, there is a low-frequency sensitivity range defined by the condition $k_{\mathrm{gr}} lN \ll 1$. In this range, the relative change in the intensity of the radiation at the interferometer output is determined by the formula

$$\frac{\Delta I}{I} = Qa_0 \sin^2\theta \cdot \cos(\omega_{\mathrm{gr}} t),$$

where $Q = 2\pi l/(1-R)\lambda$ is the figure of merit of the interferometer and θ is the angle between the propagation directions of the gravitational and electromagnetic waves. With $R = 0.995$, $\lambda = 6328$ Å, and $l = 100$ m, we obtain $\Delta I/I \sim 10^{11} a_0$. At the lowest relative intensity change $\Delta I/I \sim 10^{-8}$–10^{-9} that can be detected, which is determined by photon noise, this gives the following estimate for the smallest dimensionless GW amplitude that can be recorded: $a_0 \sim 10^{-19}$–10^{-20} (here the low-frequency sensitivity range is found to lie at 0–10^3 Hz).

It must be pointed out that, in addition to the above fundamental limitations on LIGA sensitivity, there are many other limitations of a technical nature that must be taken into account in development of gravity detectors on the basis of interferometer schemes and information-processing systems. They include:

—The limit on the frequency instability $\Delta\nu/\nu$ of the laser radiation, which, with an interferometer arm difference δl, results in a random additional phase lead of the beam. This limitation is expressed by the requirement $\Delta\nu/\nu < a_0 l/\Delta l$.

—The need to evacuate the volume in which the light beam propagates in order to eliminate refraction fluctuations along the path of the beam.

—The noise created by microseismic oscillations in the region of the antenna installation, which is one of the most serious interference sources.

In addition to allowance for the above factors, selection of the site for the gravitational antenna is extremely important in designing the LIGA and the information-processing system. A study of the level and spectrum of microseismic oscillations made with a laser interferometer having a 12.5-meter baseline and a sensitivity ratio of 10^{-10} on the Garm geodynamic test range (Tadzhik SSR) showed that the microseismic level is three-four orders of magnitude lower in mountain massifs than in lowland regions. The low level of microseismic activity and the possibility of obtaining good natural temperature stabilization at the antenna site suggest that it would be expedient to locate the antenna in a tunnel driven into the rocky massif.

It has been proposed that a LIGA complex be built on the grounds of the Baksan Neutrino Observatory of the USSR Academy of Sciences Institute of Nuclear Research. Erection of the LIGA would, in principle, provide in the future for parallel channels of observation of a number of astrophysical processes through the neutrino and gravitational-radiation fluxes.

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