

Observation of Background Gravitational Waves

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Abstract

Introduction: We report the discovery of a new phenomenon: high-frequency oscillations (HFO) in the brightness of stars and planets. These were detected during an international campaign to observe variable stars. It was noted that changes in stellar brightness are accompanied by movements in the positions of stars (SIM) in the focal plane of the telescopes. An overview of the observations related to HFO and SIM is provided below. **Methods:** The HFO and SIM data were obtained using a 2-metre Ritchey-Chretien telescope on Mount Terskol in the North Caucasus and a 50-inch reflector at the Crimean Observatory. **Results:** HFO activity manifests itself as bursts of signal intensity with an effective pulse duration of seconds and a frequency of several events per minute. The amplitudes of SIM motion can be estimated at between a few hundredths and a few tenths of an arc second, and their speed at up to a few hundredths of an arc second per second. The SIM light curves show the elliptical orbits of the reference star. **Discussion:** Monitoring of planets from several observation sites using two telescopes situated at a considerable distance from one another has provided us with compelling evidence of correlated fluctuations in brightness. Different objects observed at different locations exhibit the same periodicity. During the monitoring, fluctuations with identical frequencies and amplitudes, expressed in thousandths, were identified. Furthermore, it was established that these harmonics coincide in amplitude, frequency, and phase. It was noted that variations in stellar brightness are accompanied by shifts in the positions of stars in the focal plane of telescopes. The amplitudes of SIM motion can be estimated at between a few hundredths and a few tenths of an arc second, and their speed at up to a few hundredths of an arc second per second. The SIM light curves show the elliptical orbits of the reference star. **Conclusions:** A promising hypothesis is that SIM phenomena are caused by gravitational waves: 1) gravitational waves cause a change in the path length of light, leading to periodic fluctuations in brightness; 2) gravitational waves distort the geodesic lines along which light travels, altering its direction. Ob-

servations of HFO and SIM phenomena confirm the existence of background gravitational waves.

Keywords

Observational, Photometric, Stars, Planets, Gravitational Waves

1. Introduction

HFO activity manifests itself as bursts of signal intensity with an effective pulse duration of seconds and a frequency of several events per minute (see **Figure 1**).

Synchronous observations using two telescopes have demonstrated that the spatial coherence of HFO extends over hundreds of kilometres and its temporal coherence spans several minutes; in other words, the HFO phenomenon is global in nature.

2. Analysis of Object Variability

The observational data were obtained during an international campaign to observe variable stars. The data were obtained using a 2-metre Ritchey-Chrétien telescope on Mount Terskol in the North Caucasus, and a 50-inch reflector at the Crimean Observatory.

On 27 October 2000, multi-site monitoring of Ganymede was carried out using two telescopes located at a distance from one another: a 2-metre Ritchey-Chretien telescope on Mount Terskol in the North Caucasus and a 50-inch reflector at the Crimean Observatory (CrAO). The operation of the telescopes was synchronized to an accuracy of 0.1 seconds.

Even at first glance at **Figure 1**, these curves looked remarkably similar. Statistically, these are strongly correlated at a confidence level of more than 99%. From this, it follows that time variations seen on Ganymede are unrelated to the atmospheric or instrumental effects.

A harmonic with a frequency of ~ 0.04 Hz (22.7 sec) coincides, within the margin of error, in amplitude, frequency, and phase at two locations 900 km apart. It should also be noted that the nature of the harmonic modulation in frequency remains unchanged throughout the several minutes of observation. The amplitude of the harmonic is approximately four thousandths of a magnitude. The power spectrum also demonstrates variability at frequencies of [0.11; 0.22; 0.31; 0.43] Hz, which are multiples of the fundamental frequency of 0.11 Hz.

Figure 2 shows the Moon's brightness curve in white light, obtained using a Sky-Watcher MAK 102 EQ2 telescope in Kyiv on 7 September 2025. The graph shows the variability at frequencies of [0.16; 0.32; 0.48; 0.80] Hz, which are multiples of the fundamental frequency of 0.16 Hz. It is worth noting the small amplitude of the harmonic, amounting to around two thousandths of a magnitude.

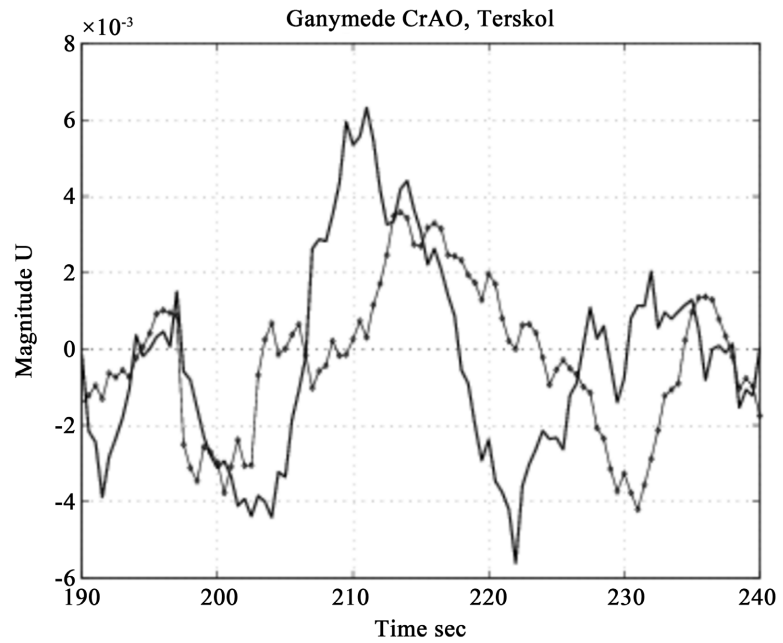


Figure 1. Synchronized light curves of Ganymede based on observations in Crimea and Terskol on 26 October, 2000. A harmonic with a period of 22 seconds. The power spectrum also demonstrates variability at frequencies of [0.11; 0.22; 0.31; 0.43] Hz, which are multiples of the fundamental frequency of 0.11 Hz.

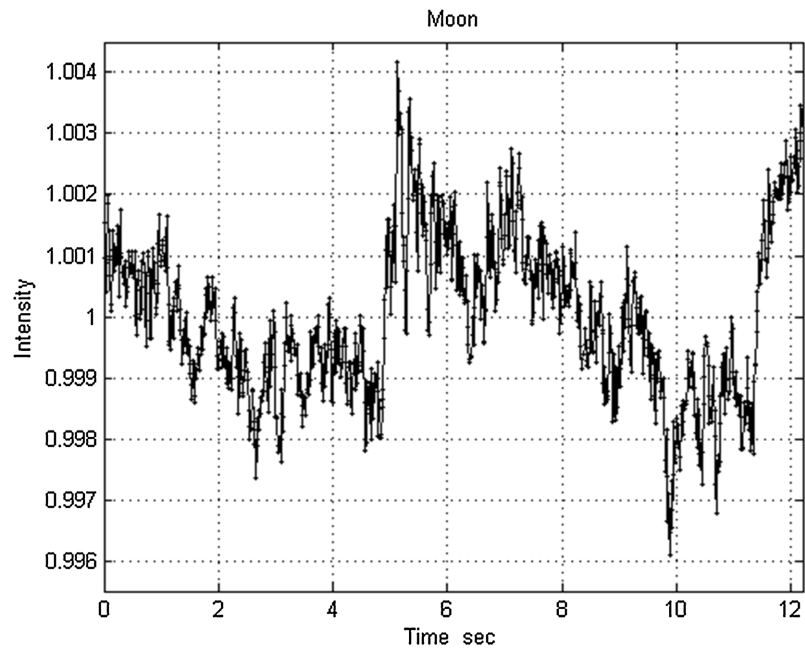


Figure 2. The curve of the Moon's brightness based on observations in Kyiv on 7 September 2025. The power spectrum shows variability at frequencies of [0.16; 0.32; 0.48; 0.80] Hz, which are multiples of the fundamental frequency of 0.16 Hz.

Figure 1 and **Figure 2** clearly show the presence of high-frequency harmonics in the variation in brightness. There are a number of indications that the observed variations in brightness of stars are due to stellar image motion (SIM) in the focal

plane of the telescopes. As spectroscopic observers know, low-frequency image motions mean that good centering cannot be done quickly. If we look at a star for just a second and center on its average position during that time, a minute later it may be several arc seconds away from the set position (Young *et al.* [1]).

Image motion becomes apparent when a bright star crosses the edge of the aperture. **Figure 3** shows an image taken at the edge of the aperture. Observations of the field star PPM119406 were carried out on 28 October 2000 with an image resolution of 2 arc seconds.

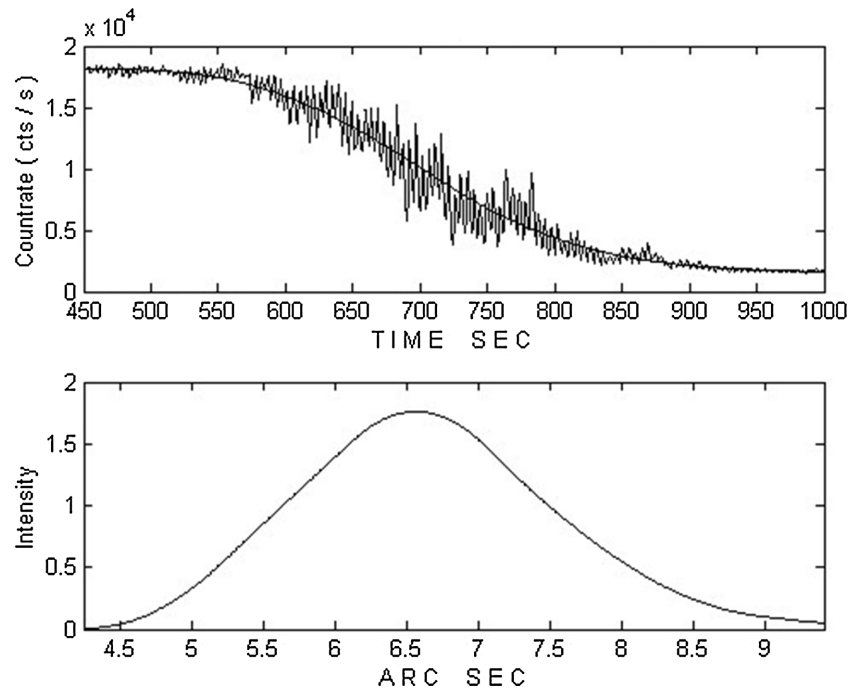


Figure 3. The curve showing the star's path across the edge of the aperture (top graph, Terskol, 2-metre telescope). The bottom graph shows a smoothed cross-section of the star's image, with a diameter of approximately two arc seconds.

The top graph shows the light curve, smoothed using a spline with a 100-point box-car filter to average out small-scale fluctuations. The spread of the star's image, shown below, was determined by numerically differentiating the light curve. As can be seen, the star has a full width at half maximum (FWHM) of about 2 arc seconds. The intensity drops to approximately 1% within a circle of 4 arc seconds in diameter.

Figure 4 shows the SIM light curves and the elliptical orbits of the reference star. The amplitudes of SIM motion can be estimated at between a few hundredths and a few tenths of an arc second, and their speed at up to a few hundredths of an arc second per second.

On 9 August 1999, multi-site monitoring of Jupiter was carried out using two telescopes located at two points 900 km apart: a 2-metre Ritchey-Chrétien telescope on Mount Terskol in the North Caucasus and a 50-inch reflector at the Crimean Observatory.

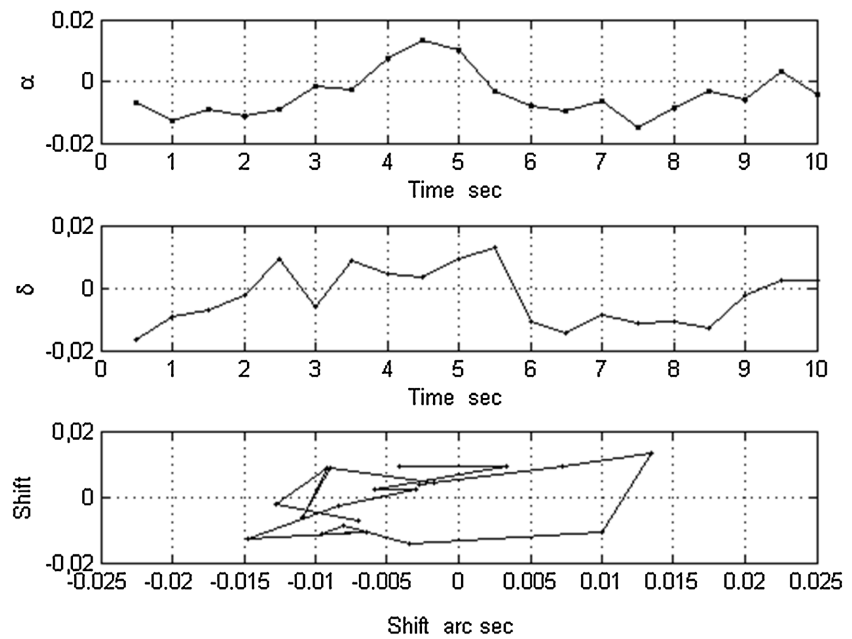


Figure 4. Top graphs show the movement of a star's image at the edge of the aperture along the right ascension and declination axes. The graph below shows the elliptical trajectories of the object's image, with an amplitude of approximately two hundredths of an arc second.

The light curves of Jupiter, plotted on the basis of observations carried out in Crimea and on Mount Terskol, are shown in **Figure 5**.

The brightness spectrogram of Jupiter is shown in **Figure 6** (top graph). The power spectrum in decibels shows fluctuations at frequencies of [0.014; 0.055; 0.11; 0.22; 0.32] Hz (lower graph).

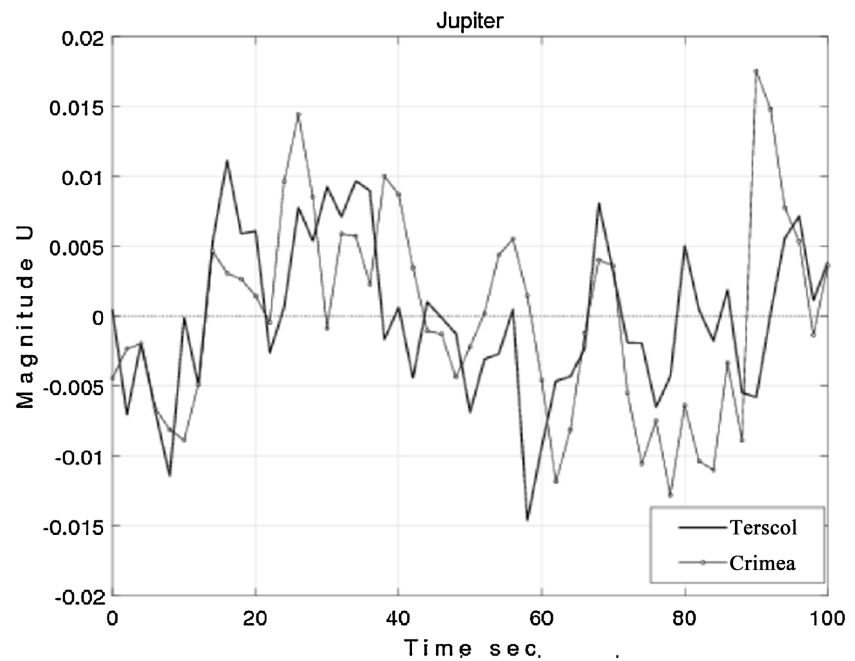


Figure 5. The brightness curves of Jupiter, plotted on the basis of observations made in Crimea and Terskol on 9 August 1999.

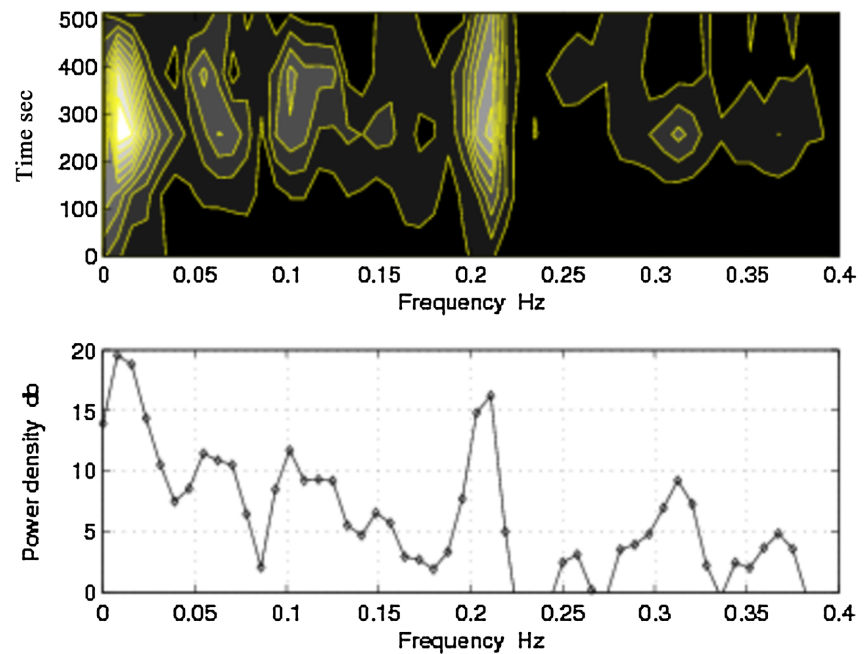


Figure 6. A brightness spectrogram of Jupiter, based on observations made in Crimea and Terskol on 9 August 1999 (top graph). The power spectrum in decibels shows fluctuations at frequencies of [0.014; 0.055; 0.11; 0.22; 0.32] Hz (lower graph).

3. Some Results

The HFO and SIM phenomena observed on stars, planetary moons, and the Moon exhibit identical characteristics.

The detected HFOs are non-stationary modulated waves with a discrete spectrum spanning a range from fractions to tens of Hertz, and probably considerably higher. Their amplitudes range from thousandths to hundredths of a magnitude.

SIM curves show elliptical orbits.

The power spectrum also exhibits variability at a number of frequencies that are multiples of the fundamental frequency of approximately 0.10 Hz.

4. HFOs on the Moon

It is important to note that HFO phenomena have been observed on planetary moons and on the Moon. Furthermore, all of them exhibit HFO phenomena with identical characteristics. It should also be noted that the HFO phenomenon has been observed for 20 years; in other words, it is a persistent phenomenon.

Figure 7 shows an image of the Moon taken using a Sky-Watcher MAK 102 EQ2 telescope in Kyiv on 7 September 2025. The graphs in **Figure 8** illustrate the effect of the SIM phenomenon on the Moon. It can be seen that the Moon's brightness varies, and fluctuations in its position are also observed (**Figure 9**).

Fluctuations in intensity are very slight, just one-tenth of a per cent. Fluctuations in the Moon's position amount to tenths of an arc second (**Figure 10**).

The image movements cannot be caused by errors in the telescope's drive speed, as they manifest themselves in exactly the same way in both the right ascension

and declination directions (**Figure 9**).

The motion graphs in **Figure 10** demonstrate that the image traces a closed path around a point with its true coordinates, as its phase portrait shows a closed cycle.

Figure 11 and **Figure 12** show the SIM phenomenon on the Moon on 16 August 2025 at a frame rate of 19 frames per second. The power spectrum shows variability at frequencies of [0.21; 0.63; 0.84; 1.27] Hz.

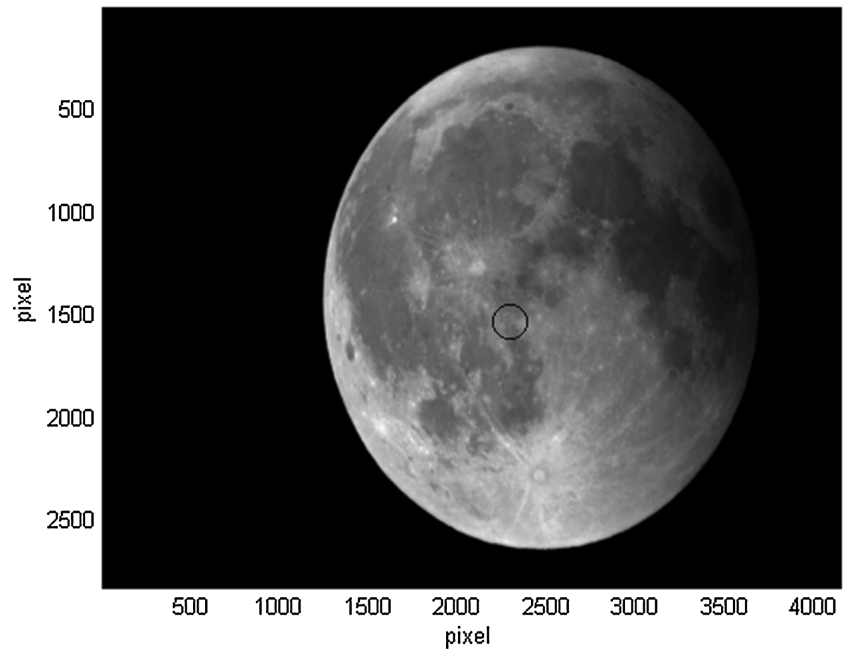


Figure 7. An image of the Moon. The optical center of mass is marked with a circle.

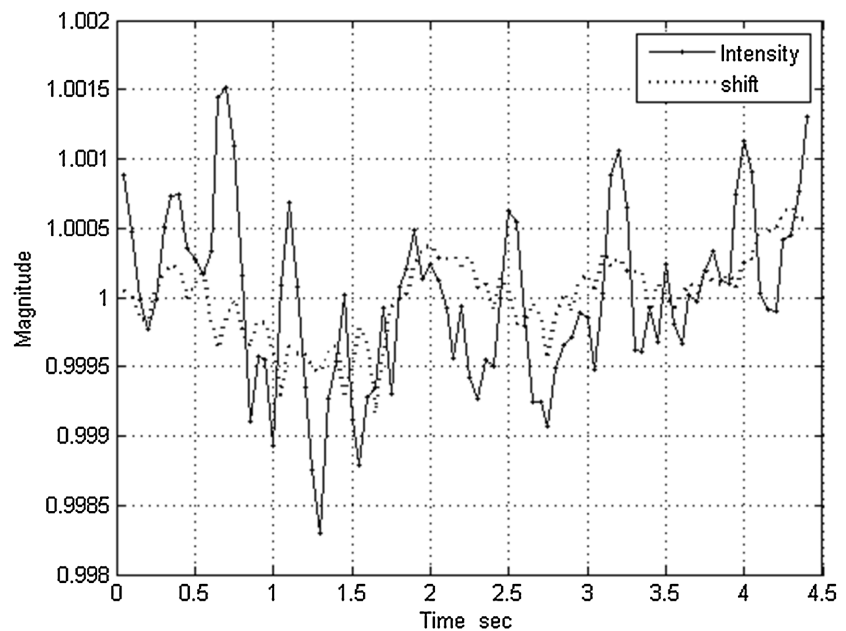


Figure 8. The integral brightness curve and the normalized shift curve of the Moon. The power spectrum shows variability at frequencies of [0.20; 0.60; 0.79] Hz.

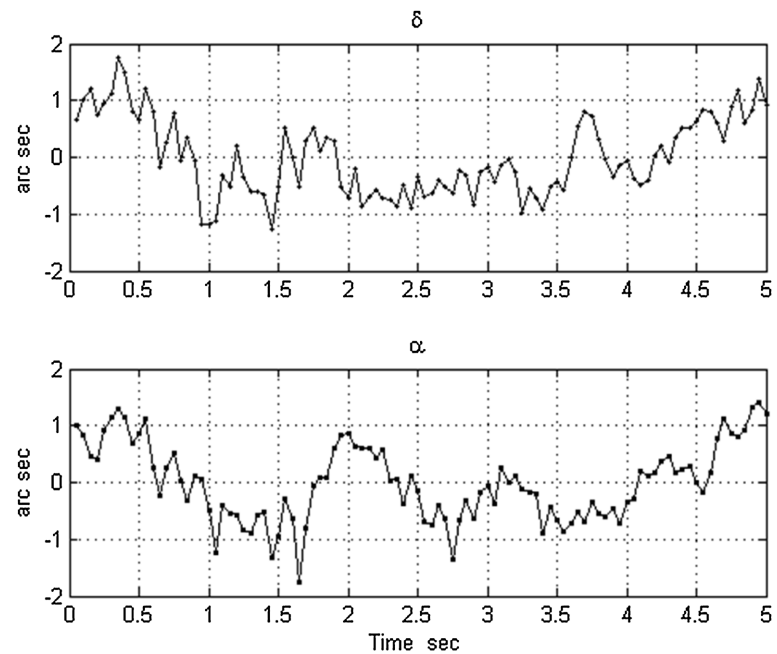


Figure 9. Image shifts in the right ascension (bottom panel) and declination (top panel) directions.

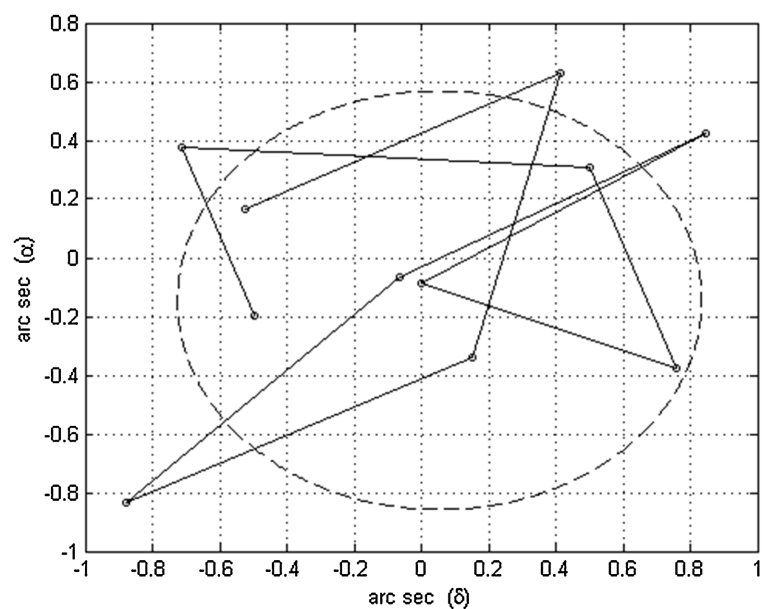


Figure 10. The graph shows the elliptical trajectories of the object's image, with an amplitude of approximately one arc second.

5. Discussion

Monitoring of planets from several observation sites using two telescopes situated at a considerable distance from one another has provided us with compelling evidence of correlated fluctuations in brightness. Different objects observed at different locations exhibit the same periodicity. During the monitoring, fluctuations with identical frequencies and amplitudes, expressed in thousandths, were identified.

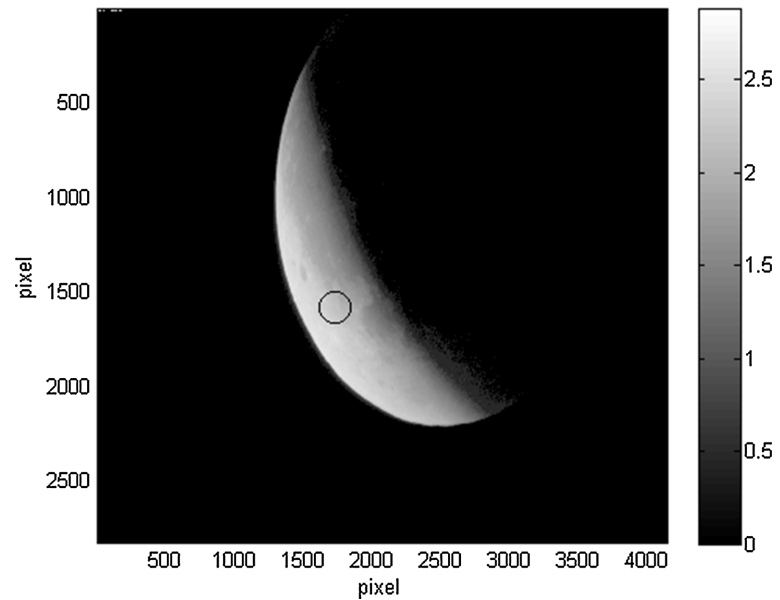


Figure 11. An image of the Moon on 16 August 2025 at a frame rate of 19 frames per second. The optical center of mass is marked with a circle.

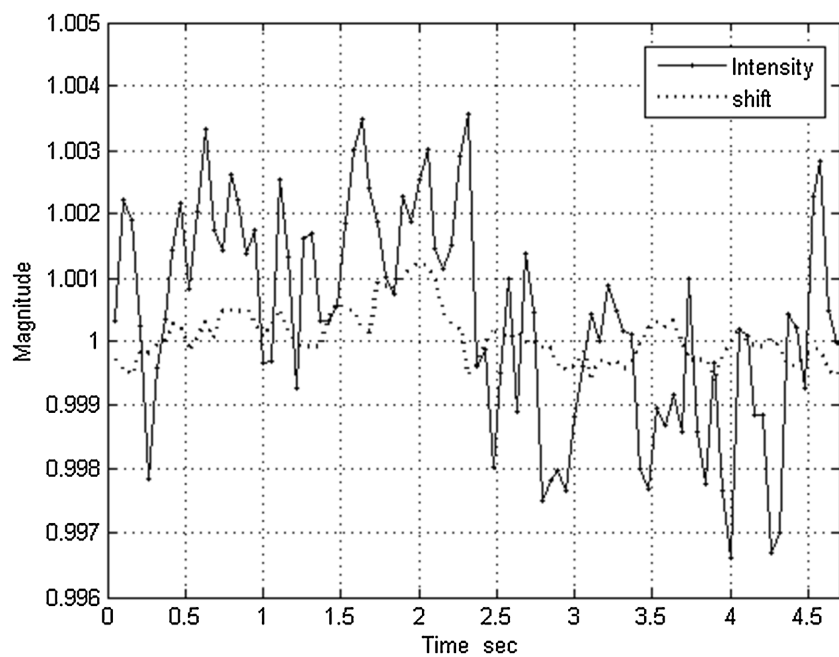


Figure 12. The integral brightness curve and the normalized shift curve of the Moon at a frame rate of 19 frames per second. The power spectrum shows variability at frequencies of $[0.21; 0.63; 0.84; 1.27]$ Hz.

Furthermore, it was established that these harmonics coincide in amplitude, frequency, and phase.

It was noted that variations in stellar brightness are accompanied by shifts in the positions of stars in the focal plane of telescopes. The amplitudes of SIM motion can be estimated at between a few hundredths and a few tenths of an arc second, and their speed at up to a few hundredths of an arc second per second. The SIM

light curves show the elliptical orbits of the reference star.

It should be noted that the measurements of HFO and SIM are at the limit of measurement accuracy. Their reliable determination requires simultaneous observations using two telescopes.

A promising hypothesis is that SIM phenomena are caused by gravitational waves. It follows that the angle of incidence of a light beam fluctuates at the frequency of the gravitational waves and with an amplitude proportional to the amplitude of the gravitational waves.

The physical picture of the propagation of a light wave in a gravitational wave field is discussed in the APPENDIX.

Let us note the key effects of light propagation in a gravitational wave (GW) field: 1) Intensity modulation: GWs cause a change in the path length of light, leading to periodic fluctuations in brightness; 2) Trajectory curvature: GWs curve the geodesic lines along which light propagates, altering its direction.

Observations of HFO and SIM phenomena confirm the existence of background gravitational waves.

The important point is that GWs possess energy that is not accounted for in theories of the structure of the Universe. It is conceivable that GWs could potentially be the source of the phenomenon known as “dark energy”.



Figure 13. A void.

At the peak of a gravitational wave, the gravitational potential reaches its maximum value. A force arises. The particles in the vector wave oscillate. A gravitational wave is a tensor wave and alters the trajectories of the particles.

Gravitational waves create a void (**Figure 13**). Gravitational waves set particles of matter in motion, creating a “Cosmic web” (**Figure 14**). The Cosmic web reflects the structure of relic gravitational waves.

Modelling the effect of a gravitational wave on a material particle (Equation (7) in the **Appendix**) results in the formation of voids (**Figure 15** and **Figure 16**).

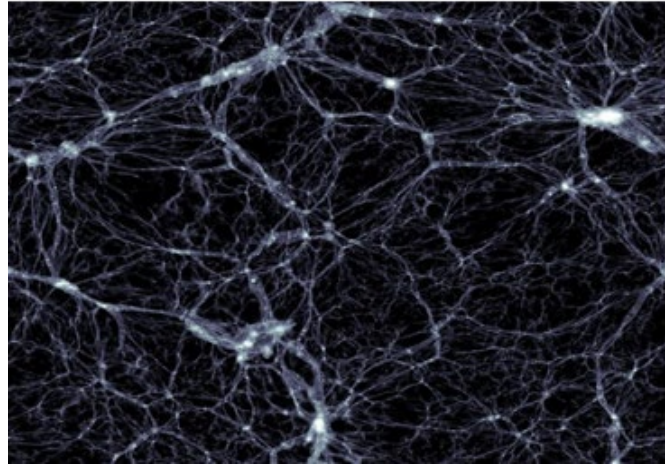


Figure 14. Cosmic web—reflects the structure of relic gravitational waves.

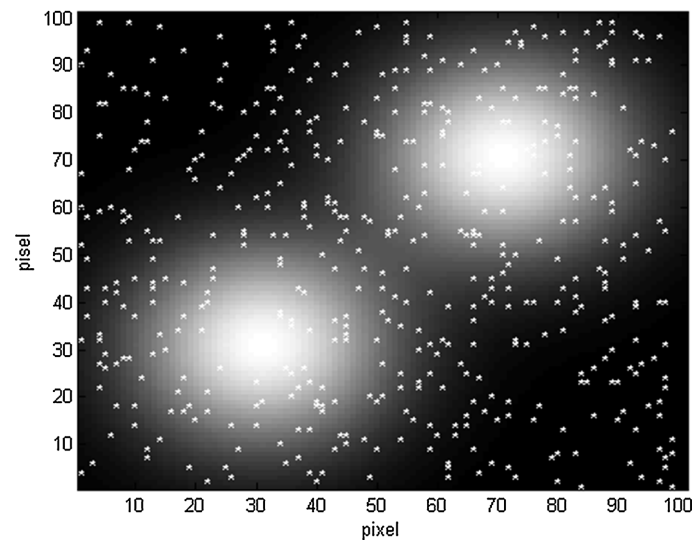


Figure 15. Modelling—gravitational wave peaks.

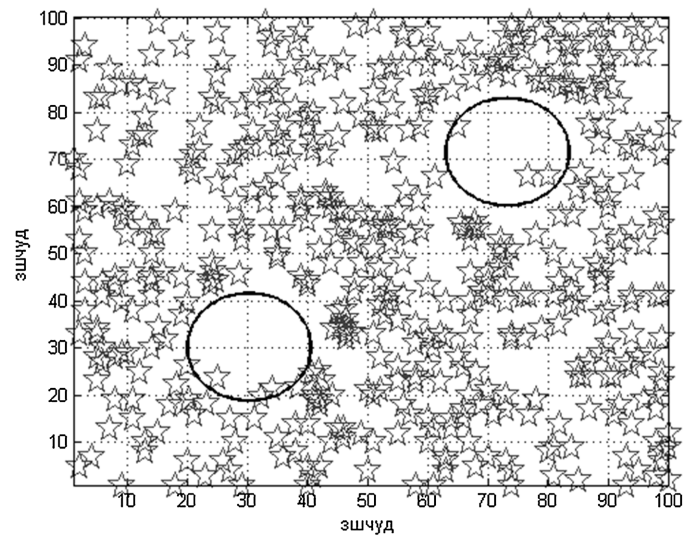


Figure 16. Modelling—voids at the peaks of gravitational waves.

Author Contributions

All the authors make the same contribution to this article.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Consider the motion of a light beam in a GW field. Let the wave propagate along the x -axis and be characterized by the metric

$$ds^2 = c^2 dt^2 - dx^2 - \left(1 + h \sin\left(\frac{2\pi x}{\lambda} - \Omega t\right)\right) dy^2 - \left(1 - h \sin\left(\frac{2\pi x}{\lambda} - \Omega t\right)\right) dz^2, \quad (1)$$

where h is the amplitude, Ω is the frequency, and λ is the GW length (Wheeler [2]). The light wave is characterized by a 4-dimensional wave vector

$$K^\alpha = \frac{\omega}{c} \frac{\partial x^\alpha}{\partial \mu}, \quad (2)$$

where μ is the affine parameter along the beam, and ω is the frequency of the light wave. The equation for beam propagation is the equation of the null geodesic

$$\frac{\partial}{\partial \mu} \left(g_{\lambda\lambda} \frac{\partial x^\lambda}{\partial \mu} \right) - \frac{1}{2} \sum_{\nu=1}^4 \frac{\partial g_{\nu\nu}}{\partial x_\lambda} \left(\frac{\partial x^\nu}{\partial \mu} \right)^2 = 0; \quad \sum_{\nu=1}^4 g_{\nu\nu} \frac{\partial x^\nu}{\partial \mu} = 0 \quad (3)$$

Here, the coordinates x , y , z , and t correspond to indices $\lambda = 1, 2, 3$, and 4 , and the summation condition over λ does not hold. From Equations (1) and (3), for $\lambda = 2$ and 3 , we have

$$\frac{\partial}{\partial \mu} \left(g_{22} \frac{\partial y}{\partial \mu} \right) = 0, \quad \frac{\partial}{\partial \mu} \left(g_{33} \frac{\partial z}{\partial \mu} \right) = 0 \quad (4)$$

Hence, for the components of the wave vector, taking into account (2), we have

$$K_y \approx C_y \left[1 - h \sin\left(\frac{2\pi x}{\lambda} - \Omega t\right) \right], \quad K_z \approx C_z \left[1 + h \sin\left(\frac{2\pi x}{\lambda} - \Omega t\right) \right] \quad (5)$$

where C_y and C_z are constants of integration, and the wave amplitude is assumed to be small, $h \ll 1$.

From Equation (5), it follows that the beam tilt angle oscillates with a frequency and amplitude proportional to the wave amplitude. Oscillations of the wave vector occur in the plane (yz) along the direction $\arctg(-C_z/C_y)$ determined by the state of polarization of the GW.

For a plane electromagnetic wave, the energy-momentum tensor is $T_{44} = T_{33} = W$, where W is the energy density of the electromagnetic field (Landau *et al.* [3]). Hence, for the component of the wave vector Kt we have

$$Kt \approx W \left[1 + h \cdot \sin(2\pi x/\lambda - \Omega t) \right] \quad (6)$$

Gravitational waves therefore cause fluctuations in brightness and shifts in the positions of stars in the focal plane of telescopes.

Let us consider how the distance L between two test articles changes as a gravitational wave passes through. In Equation (1), we shall convert to polar coordinates $y = r \cdot \cos(\theta)$; $z = r \cdot \sin(\theta)$

$$L = r \left(1 + \frac{1}{2} \cdot h_{22} \cdot \cos(2\theta) + \frac{1}{2} \cdot h_{23} \cdot \sin(2\theta) \right) \quad (7)$$

Integration in the wave phase expression is performed over the range from 0 to $\pi/2$.