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GRAVITATIONAL WAVE DETECTION SYSTEMS BASED ON SATELLITE CONSTELLATIONS

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Abstract. Currently, there are three observatories worldwide specialized in detecting gravitational waves, with 93 such events already recorded. In the field of space measurement technology, a new system designed for registering gravitational waves has been introduced, named "S-LIGO-NxR-zy". To analyze and calculate the kinematic characteristics of this system, specialized software has been developed using RAD Studio version 10.4.2 and programmed in the C# programming language. Furthermore, as part of the research, a detailed analysis of various satellite group configurations based on the use of planetary bodies as components has been conducted.
Key words: satellite systems, gravitational waves, satellite space detector.

СИСТЕМЫ ДЕТЕКТИРОВАНИЯ ГРАВИТАЦИОННЫХ ВОЛН НА ОСНОВЕ ГРУППИРОВОК СПУТНИКОВ

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Аннотация. На данный момент в мире функционируют три обсерватории, специализирующиеся на обнаружении гравитационных волн, и было зафиксировано уже 93 подобных событий. В сфере космической измерительной технологии представлена новая система, предназначенная для регистрации гравитационных волн, и она называется «*S-LIGO-NxR-zy*». Для анализа и расчета кинематических характеристик данной системы было создано специальное программное обеспечение, использующее среду разработки *RAD Studio* версии 10.4.2 и написанное на языке программирования *C#*. Кроме того, была проведена аналитика различных конфигураций группировок, основанных на использовании планетарных тел в качестве составных элементов.
Ключевые слова: спутниковые системы, гравитационные волны, космический детектор.

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Introduction

Since the discovery of gravitational waves in 2015 and the subsequent observation of many unique events such as black hole mergers and neutron stars, the scientific community has ushered in a new era of space exploration. However, accurately studying and analyzing these gravitational waves requires high-precision equipment and specialized instruments. Satellites offer distinct advantages in the detection and study of gravitational waves. Unlike terrestrial detectors, they are free from atmospheric and terrestrial influences, allowing them to operate at higher frequencies and with higher sensitivity. This opens up possibilities for registering new classes of gravitational events and accurately studying their characteristics.

Satellite systems for detecting gravitational waves

Several satellite system designs for gravitational waves are already in development and are planned for launch in the coming decades (figure 1). The best known of these include:

– LISA (Laser Interferometer Space Antenna): This is an ambitious international project being developed by the European Space Agency (ESA). It consists of three free-floating satellites forming a large-scale laser interferometer in space. LISA will be able to record gravitational waves in the low-frequency range and will allow the study of black hole and neutron star mergers in the far reaches of the universe;

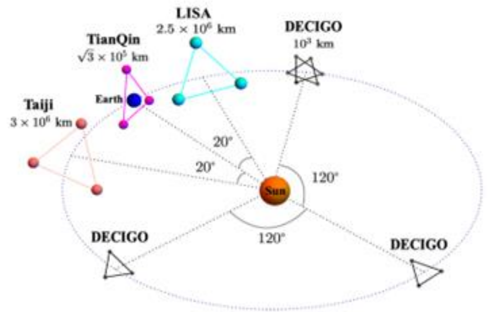

Figure 1 – Scheme of constellations of known space detectors of gravitational waves

– DECIGO (DECi-hertz Interferometer Gravitational Wave Observatory): This Japanese project aims to build a space-based system to detect gravitational waves in the decihertz (0.1 to 100 Hz) range. DECIGO will provide new data on gravitational waves, including their sources and origins;

– BBO (Big Bang Observer): BBO is a conceptual project considered as a potential future satellite to study gravitational waves associated with the early Universe. It may help us understand the origin of the universe and provide information about cosmological events;

– TianQin: This is a Chinese satellite project to detect gravitational waves. It aims to record black hole and neutron star mergers in the low-frequency range.

– Taiji: This is a Chinese space project to detect and study gravitational waves in space.The main goal of the Taiji project is to build a space system capable of detecting gravitational waves in the low-frequency range (0.01 to 0.1 Hz).

Modeling of gravitational detector satellite constellations

It is proposed to investigate the model of space detector of gravitational waves based on the configuration of satellites that use "Platonic bodies" as their basis. A space-based GW measurement system of x satellites with the conventional designation "S-LIGO-NxR-zy" Space – Laser Interferometer Gravitational-Wave Observatory) is proposed, where X is the number of satellites of Z type of orbit (low-orbit – L, medium-orbit – M, geostationary – G, highly elliptical – H-orbits, Z – does not depend on the type) located on Y – the number of orbits of the planet of name N (planet Earth – E).

The temporal spatial evolution and capabilities of the space HW detector with a system of satellites located in geostationary orbits are investigated (figure 2). We consider 6 configurations of satellites, which periodically form regular polyhedrons in space

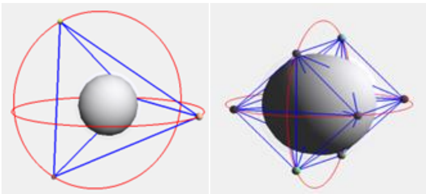

Figure 2 – Software interface and schematic of the satellite constellations of the proposed detector

The spatial configurations of space systems can be specified in many ways, depending on the choice of the number of orbits and the variation of the dependent placement of satellites in these orbits. In general, it is possible to have different numbers of satellites, denoted as N, and hence the system can be organized into different polygonal configurations. This is an area that requires further research and investigation. In addition, the satellites can be in different orbits and have different orbital characteristics. In such a situation, a space object monitoring system capable of detecting and determining the orbital parameters of these objects makes it possible to deploy a space gravitational wave detector or a system of satellites, even if their orbits and kinematic parameters are diverse and undefined. The tool used to develop Taraxacum's software was the Unity engine, similar to the engine used to create computer games. In this program, the user can set and control the following parameters: satellite assignment, calculating satellite coordinates, setting satellite direction, altitude and other important parameters, plotting satellite system motion graphs, 3D modeling of satellites, Import/export satellite configurations, video recording capability (figure 3).

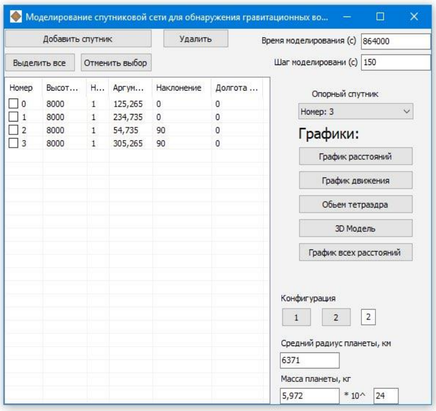

Figure 3 – Software interface

Conclusion

Satellite systems for observing gravitational waves offer several advantages, including freedom from atmospheric and terrestrial influences. Several major projects, such as LISA, DECIGO, and BBO, are in development and planned for launch in the coming decades. These projects will provide a unique opportunity to explore gravitational waves of different frequency ranges and will reveal new aspects of the nature of the universe.

We have developed a separate system for space detection of GWs based on a system of satellites. We have proposed a space measurement system of N satellites with the conventional designation "S-LIGO-NxR-zy", where X is the number of satellites of Z type of orbit (low-orbit – L, medium-orbit – M, geostationary – G, highly elliptical – H-orbit, Z – does not depend on the type), located on Y – the number of orbits of the planet of the name N (planet Earth – E).

Software has been developed that allows to set different initial configurations of satellite systems and to study their mutual position over time with a visualization function, which is important for building a near-Earth gravity detector and other research systems based on a constellation of satellites.

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