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Susceptibility of electromagnetic fields in the Solar System to gravitational wave effects from relativistic binary star systems

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Abstract. Using an eigenvector and signal component analyzer (eigenoscope), the problem of identifying the impact of gravitational waves of relativistic binary star systems (RBSS) with large and small eccentricity on the vertical component of the electric field strength (E_z) in the Earth's atmospheric surface layer in the infra-low frequency (ILF) range at high harmonics of the EDS circulation frequencies has been solved. The results were obtained using monitoring data at four spatially separated E_z observation stations. A model is proposed to explain the effect of the gravitational wave influence of relativistic binary star systems on the vertical component of the Earth's electric field strength in the surface layer of the atmosphere, previously discovered by the authors. The model considers as the mechanism the disturbance of the Earth's orbit by gravitational waves from relativistic binary star systems, leading to small displacements of the Earth relative to the free space charge in the troposphere. The estimates of the amplitude of the E_z components, spectrally localized at the frequencies of gravitational waves of relativistic binary star systems, obtained on the basis of the presented model do not contradict the experimental results.

Keywords: gravitation; gravitational waves; Earth; (stars:) binaries: general; relativistic processes; atmospheric effects; methods: statistical

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1 Introduction

Using an eigenvector and signal component analyzer (eigenoscope), the problem of identifying the impact of gravitational waves of relativistic binary star systems (RBSS) with large and small eccentricity on the vertical component of the electric field strength (E_z) in the Earth's atmospheric surface layer in the infra-low frequency (ILF) range at high harmonics of the EDS circulation frequencies has been solved.

2 Observation

The results were obtained using monitoring data at four spatially separated E_z observation stations (three Rosgidromet stations at Voeikovo, Verkhnee Dubrovo, Dusheti and Experimental base of the Department of General and Applied Physics of Vladimir State University). All these time series have the same sampling time equal to 3600 sec; some data about the series is presented in Table 1.

Table 1. The used time series of E_z observations.

No.	Observation station	Total sample count	Duration, days	Duration, months	Duration, years
1	Voeikovo	170000	7083	236	20
2	Dusheti	120000	5000	167	14
3	Verkhnee Dubrovo	120000	5000	167	14
4	VlSU experimental base	36000	1500	50	4

When forming a sample of eigenvectors spectrally localized at the frequencies of gravitational waves according to eq. (3), six RBSSs were selected from the Johnston list (see the second column of Table 2) having a high eccentricity (0.58–0.89).

Table 2. The selected high-eccentricity relativistic binaries (e is eccentricity, n are the orders of multiples).

No.	**RB**	**T , days**	**e**	**n**	**Frequency range, μHz**
1	J0514-4002A	18.785	0.889	1–90	0.6161338 . . . 55.452045
2	J1811-1736	18.77917	0.82802	1–90	0.6163251 . . . 55.46926
3	J1823-1115	357.7620	0.79461	20–70	0.6470265 . . . 2.2645926
4	J1750-37	17.3	0.71	1–36	0.6690216 . . . 24.084778
5	J2305+4707	12.3395445	0.65837	1–25	0.9379661 . . . 23.449152
6	J1740-3052	231.02965	0.578872	10–16	0.5009779 ∗ . . . 0.8015646

Forty-three low-eccentricity RBSSs were selected from Johnston's list and their doubled orbital frequencies were calculated.

3 Analysis

3.1 Theoretical background

The classical work Zeldovich & Novikov (1975) shows that energy irradiated by the RBSS gravitational waves at the multiplied orbital frequency energy is proportional to

$$g(n,e) = \frac{n^4}{32}[g_1(n,e) + g_2(n,e) + g_3(n,e)], \qquad (1)$$

where

$$g_1(n,e) = [J_{n-2}(ne) - 2eJ_{n-1}(ne) + \frac{2}{n}J_n(ne) + 2eJ_{n+1}(ne) - J_{n+2}(ne)]^2,$$

$$g_2(n,e) = (1-e^2)[J_{n-2}(ne) - 2J_n(ne) + J_{n+2}(ne)]^2,$$

$$g_3(n,e) = \frac{4}{3n^2}\left[J_n(ne)\right]^2,$$

n is the order of the multiplied frequency; e is the eccentricity; $J_n(x)$ is Bessel function.

Use of eq. (1) allows to compute the ratio

$$G_{R.2}(n,e) = \frac{g(n,e)}{g(2,e)}, \qquad (2)$$

which can be used to select promising RBSSs that have GW irradiance at multiple frequencies above the second order. Johnston's list contains many RBSSs with high eccentricity. Those that have the eq. (2) ratio above 1 and multiple frequencies satisfying the condition

$$5T < (n_{k,j}F_j)^{-1} < MT\,, \qquad j = \overline{1:Q}\,, \qquad (3)$$

where T is the sampling time (equals to 3600 sec in our work); $n_{k,j}$ is the allowable order of the multiplied (of order k) orbital frequency of j-th RBSS; F_j, $j = \overline{1:Q}$ are the RBSS orbital frequencies; Q is the high-eccentricity RBSS count (6 in our work); MT is the analysis span of the eigenoscope (1000 hours in the current work), has been selected.

The ratio eq. (2) obviously corresponds to the condition

$$\lim_{e \to 0, n \neq 2} \frac{g(n,e)}{g(2,e)} = 0$$

therefore the small-eccentricity RBSSs irradiate GW at the doubled orbital frequency only.

The ranges of GW irradiation frequencies for high-eccentricity RBSS indices are shown in Table 2, column 5.

3.2 Analyzer construction

A satisfactory analyzer design (called an igenoscope (Isakevich et al. 2011, 2017)) uses a representation of a time series of observations in a finite range of analysis and decomposes observations into uncorrelated components. It enables spectrally localized components identification and analysis of individual behavior of the non-correlated components. It uses simple, reasonable and widely known criteria for component identification and decision making.

Eigenoscope is an analyzer which use signal representation at the covariance matrix eigenvectors orthonormal basis; the covariance matrix is computed for an ensemble consisting of the signal pieces (duration of each piece is 1000 hours). The signal analysis takes place in the basis which is not given apriori but adapted for the specific covariance matrix. Eigenoscope decomposes signal to non-correlated components which have the same shape since the covariance matrix eigenvectors and the eigennumbers are equal to a mean component capacity in the ensemble. Therefore individual properties of the signal non-correlated components at a finite analysis span are freely exposed while we analyze the signal using eigenoscopy.

The ensemble for the current task is formed as a trajectory matrix which consists of all the signal pieces of a predefined length.

Eigenpairs has been computed for each covariance matrix. Each eigenpair consists of an eigenvector and a corresponding eigennumber. An amplitude spectrum has been computed for each of the eigenvectors; this spectrum has been normalized to its maximal value in order to estimate the eigenvector spectral localization band. The frequency band of spectral localization is estimated as a band in which the normalized amplitude spectrum exceeds $1/\sqrt{2}$. We suppose that an eigenvector is spectrally localized at some frequency if this frequency lays in the eigenvector's spectral localization band.

Indices of the eigenvectors which are spectrally localized near the RBSS irradiation frequencies are listed separately. To estimate the spectral localization of each eigenvector, the coherence coefficient was used, which is the ratio of the maximum amplitude value to the average amplitude in the spectrum of the eigenvector amplitude.

A set of coherence ratios of eigenvectors spectrally localized near the frequencies of gravitational waves and a sample of eigenvalues (which are the mean square values of uncorrelated components) corresponding to these eigenvectors are formed. For further comparison, test sets of coherence ratios and eigennumbers are formed. A statistical decision is made concerning abnormal behavior of uncorrelated components of E_z, which are spectrally localized at the frequencies of RBSS gravitational waves .

Decision for the components which are localized at the GW frequencies of low-eccentricity RBSS is made using the Bernoulli test scheme. Smirnov-Kolmogorov criterion is used for the high-eccentricity GW irradiation frequencies.

4 Estimations of influence

Probability of the case that the samples belong to random variables having the same distribution law is estimated using Smirnov-Kolmogorov criterion. Probability estimation for coherence ratios for each of the time series is less than 10^{-7}; estimation for the normalized eigennumbers is less than $7 \cdot 10^{-8}$ for each time series. The difference between the sets of eigenpairs is significant and is extremely unlikely to be occasional. This means that at all observation stations the coherence ratios and eigenvalues have different distribution laws for the eigenvectors spectrally localized at gravitational waves frequencies and for the eigenvectors spectrally localized at test samples frequencies. So, until proven otherwise it must be assumed that the differences are due to factors that distinguish the compared samples, i.e to the gravitational-wave impact of RBSS on E_z (Grunskaya et al. 2023).

Median value have been estimated for all eigennumbers and all coherence ratios for each of the time series. The estimates are exceeded by eigenvalues and coherence ratios for eigenvectors that are spectrally localized at each of the forty-three doubled RBSS rotation frequencies. Estimations of the Bernoulli test false alarm probability are less than 10^{-9} (Grunskaya et al. 2014, 2023).

5 Summary

Using eigenoscopy (analysis of a time series in the basis of eigenvectors of their covariance matrix at a finite analysis span) made it possible to reveal the non-correlated components spectrally localized at the gravitational irradiation frequencies of the known relativistic binary star systems; these components have been revealed in the Earth electric field vertical projection at the infra-low frequency range. Coherence ratios of these components differ from those of the components spectrally localized at the other frequencies; the difference is statistically significant. The same effect is observed for the components amplitudes. The revealed components are not observable using classic spectral analysis; they are mixed with the other components in the analysis channel and are perceived as a noise.

A model is proposed to explain the effect of the gravitational wave influence of relativistic binary star systems on the vertical component of the Earth's electric field strength in the surface layer of the atmosphere, previously discovered by the authors. The model considers as a mechanism the disturbance of the Earth's orbit by gravitational waves from relativistic binary star systems, leading to small displacements of the Earth relative to the free space charge in the troposphere. The estimates of the amplitude of the E_z components, spectrally localized at the frequencies of gravitational waves of relativistic binary star systems, obtained on the basis of the presented model do not contradict the experimental results.

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