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FIVE THOUSAND GALACTIC BINARIES AS A DETECTOR OF GRAVITATIONAL WAVES

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Gravitational waves from stellar binary systems have not yet been detected. We however conjecture that there might be other, relic in nature, monochromatic gravitational-like radiation in the Universe (particularly with a period near 160 min discovered in the 1970s in the Sun). To check this hypothesis, we analyse all available data on the orbital motion of close binaries in the Galaxy, anticipating that the distribution of their periods might reveal statistical resonance at those "universal" frequencies. For the range of frequencies 5–160 μHz, we found only one significant ($\gtrsim 3.5\sigma$) frequency ≈ 104.2 μHz which modulates the distribution of about 5000 binaries with periods $P < 10$ d. The "resonant" period, 160.0 ± 0.8 min, well coincides with that of the solar pulsation $P_0 = 160.0101 \pm 0.0001$ min. This finding strongly supports earlier speculations on a cosmological origin of the "universal" P_0-oscillation.

KEY WORDS Close binary stars, gravitation, cosmology

Gravitational waves (GWs) represent a gravity field torn off accelerated masses. The possibility of the existence of GWs is a long-standing problem which remains to be solved. Many astrophysicists consider close binary systems (CBSs) as the most favourable sources of extraterrestrial gravitational radiation (GR). The reaction of GR is most powerful near periaster where it tends to make the orbit more circular and thus leads to a decrease of period with relative rate (in the case of mass $M = M_\odot$ of each point-like component, with the usual notation; Press and Thorne, 1973)

$$\frac{1}{P}\frac{dP}{dt} = -\frac{192}{5}\frac{(GM)^3}{c^5a^4} \sim -2.9 \times 10^{-6} P^{-8/3}\,(\mathrm{s}^{-1}) \tag{1}$$

resulting in a "gravitational" life-time $\tau \sim 3 \times 10^7$ yr of a binary with period $P_{\rm orb} \approx 1$ hr. This process might be an important factor in the evolution of binaries with periods of a fraction of a day (Tutukov and Yungelson, 1979); the rate of period change is however below the limit of observational detection. (An exception perhaps is a pair of close neutron stars (pulsar PSR 1913+16; Weisberg *et al.*, 1982), with a measured decrease of period which apparently confirms the theoretical expectations.)

For a binary, the radiation is thought to be emitted at the primary frequency ν, twice the orbital frequency $\nu_{\rm orb} = P_{\rm orb}^{-1}$, and also at higher harmonics. In addition to signals from binaries, some authors also proposed the detection of GR generated, e.g., by a single GW burst from a cosmic catastrophe (e.g., a supernova explosion or the impact of a pair of neutron stars), or just the relic GR noise of the Universe. The evaluations of the spectrum of the GR background from galactic binaries made by Sazhin (1978) and Lipunov and Postnov (1987), showed that it may exceed the GR of cosmological origin for frequencies 10^{-2}–10^{6} μHz.

We suppose that the opposite situation must also be studied: the potential existence of, say, relic GR (or quasi-GR) at some discrete frequency(ies) which can produce an observable effect on CBSs. Thus, the entire sample of CBSs is proposed to be of interest as a test for the existence of those monochromatic GWs (or equally, QGWs) in our Galaxy, even in the Universe.

The resultant action is thought to be rather small, but – for a given binary – it might be accumulated over a substantial part of its life-time τ (in other words, a CBS being considered as *a resonant mechanical system* is supposed to "remember" the long-term action of a GW). Accordingly, we hypothesize that the whole system of galactical CBSs might be considered as a unique GR detector.

The GW effect cannot be seen directly in periodic variations of a binary. We propose instead a quite different method to register the expected signal. Namely, we conjecture that the distribution of orbital frequencies of numerous samples of CBSs might exhibit a noticeable deficit or excess of binaries at frequencies connected by simple resonance relations with the frequency of a hypothetical GW.

In the present study we compare the rates ν_i of various binaries with a running frequency ν, which varies within a given frequency range (i is the ordinal number of the i-th object; $i = 1, 2, \ldots N_O$ where N_O is total number of objects). Following Kotov (1986), we introduce the commensurability function (CF)

$$F(\nu) = (60N_O)^{1/2}\{12^{-1/2} - [\frac{1}{N_O}\sum_{i=1}^{N_O}[x_i - \mathrm{INT}(x_i + 0.5)]^2]^{1/2}\}, \qquad (2)$$

where $x_i = \nu_i/\nu$ if $\nu \leq \nu_i$, and $x_i = \nu/\nu_i$ if $\nu > \nu_i$. By definition, the maximum of $F(\nu)$ corresponds to the best least-squares fit of the ratios x_i by integers. Further, by analogy with the usual power spectrum (PS), we define the commensurability spectrum

$$F_0(\nu) = F^3(\nu)/|F(\nu)|, \qquad (3)$$

which, contrary to the PS, takes into account the sign of the CF: a positive (negative) value corresponds to the case of commensurability (non-commensurability).

One should note that for an external GR a binary must appear as a two-fold object: (1) it may be perceived as a single "quasi-rigid" body (like dumbbells), especially in the case of ellipsoidal, contact and semi-detached binaries (e.g., those of the W UMa-type, with intense transfer of matter), and (2) just a pair of separate stars (without interaction, bound only by gravitation). Accordingly, we conjecture that there might also be a two-fold effect of a potential GW (with a frequency

ν'): (A) a simple resonance at frequencies most commensurate with ν', and (B) complementary resonance at frequency $\nu'/2$ and its integer harmonics. The effects (A) and (B) however might be in opposite directions, if we consider the sign of the $F(\nu)$-function. For (A)-resonance, one expects the presence of an excess of objects with frequencies near-commensurate with ν' (Gough, 1983; Kotov and Koutchmy, 1985). But in the case of (B)-resonance one must observe a lack of binaries with $\nu'/2$-frequency and its integer hatmonics, due to a relatively rapid change of the binary period at those frequencies caused by a gain of energy and angular momentum transferred to it by GR.

We expect to find, therefore, *an excess* of binaries with frequencies $\approx \nu'/Z$ and $\approx Z\nu'$, and also *a lack* of binaries with frequencies $\approx \nu'/(2Z)$ and $\approx 2Z\nu'$, where Z is a positive integer. To sum-up both effects, we introduce a generalized CF $F_1(\nu)$ and corresponding spectrum $F_1(\nu)$:

$$F_1'(\nu) = [F(\nu) - F(\nu/2)]/2^{1/2}; \quad F_1(\nu) = [F_1'(\nu)]^3/|F_1'(\nu)|. \tag{4}$$

The maximum of $F_1(\nu)$ at some frequency ν'' will indicate the (A)-type resonance at integer harmonics of ν'', and simultaneously the (B)-type resonance (a deficit of objects) at integer harmonics of $\nu''/2$.

To check the above hypothesis, we analysed all orbital periods of eclipsing and spectroscopic binaries with $P < 10$ d (Kopal and Shapley, 1956; Batten *et al.*, 1978; Brancewicz and Dworak, 1980; Popova and Kraicheva, 1984; Kholopov *et al.*, 1985–1987). The total number of periods of binaries (with $P < 10$ d and an error in the period not exceeding ± 0.005 d) equals $N_O = 5845$. The spectrum $F_1(\nu)$ computed for binaries with $P < 5.5$ d ($N_O = 5280$) is shown in Figure 1 where the highest feature corresponds to a period of 160.0 ± 0.8 min ($\nu = 104.2 \pm 0.5$ μHz); its formal confidence level (CL) is nearly 4.3σ. (Notice that the chance probability of this peak should not be multiplied by the number of independent frequencies tested, $m \approx 100$, since the period of the peak coincides well, within the error limits, with the a priori period suggested by previous investigations (Brookes *et al.*, 1976; Severny *et al.*, 1976; Scherrer *et al.*, 1993; Kotov *et al.*, 1994), $P_0 = 160.0101 \pm 0.0001$ min.)

If we take into account the possibility that some of the CBSs overlap between catalogues of binary stars, so that the true number of actually different binaries $N_O \approx 5000$, the CL of the peak is still found to be $\approx 4\sigma$. There are no other significant peaks in the $F_1(\nu)$-spectrum (Figure 1) computed for the wide frequency range 5–160 μHz (from about 1.7 hr to ≈ 2.3 d in period).

It is interesting to know what resonance, (A) or (B), is mostly responsible for the P_0-peak in the $F_1(\nu)$-spectrum. For this we computed the spectrum $F_0(\nu)$ plotted in Figure 2. We see the presence of a positive peak at frequency 104.2 ± 0.5 μHz (period $P = 159.9 \pm 0.8$ min; $\approx 2.9\sigma$ CL) and the remarkable negative peak at $\nu = 52.0 \pm 0.5$ μHz (period 321 ± 3 min; $\approx 3.3\sigma$ CL). All other peaks have no relevance to the discussion: they might be real (but with rather small CL) or appear just by chance, and have no noticeable traces in the generalized F_1-spectrum. One must conclude therefore that the 160-min feature in Figure 1 arises from both resonance effects, (A) and (B), as was supposed for the action of a hypothetical GW.

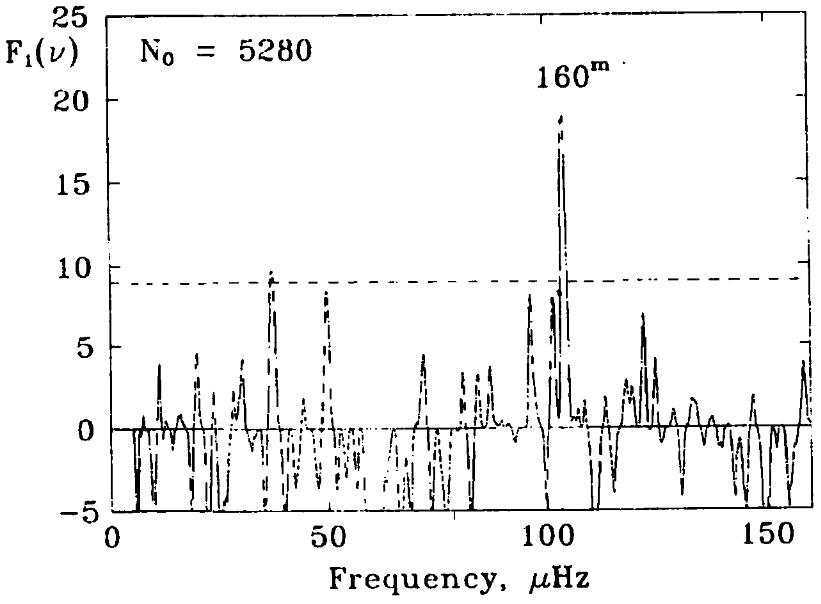

Figure 1 The spectrum $F_1(\nu)$ computed for close binary stars with periods $P < 5.5$ d (the total number of periods $N_O = 5280$). The dashed line indicates a formal 3σ CL. The major peak corresponds to a period of $P = 160.0 \pm 0.8$ min.

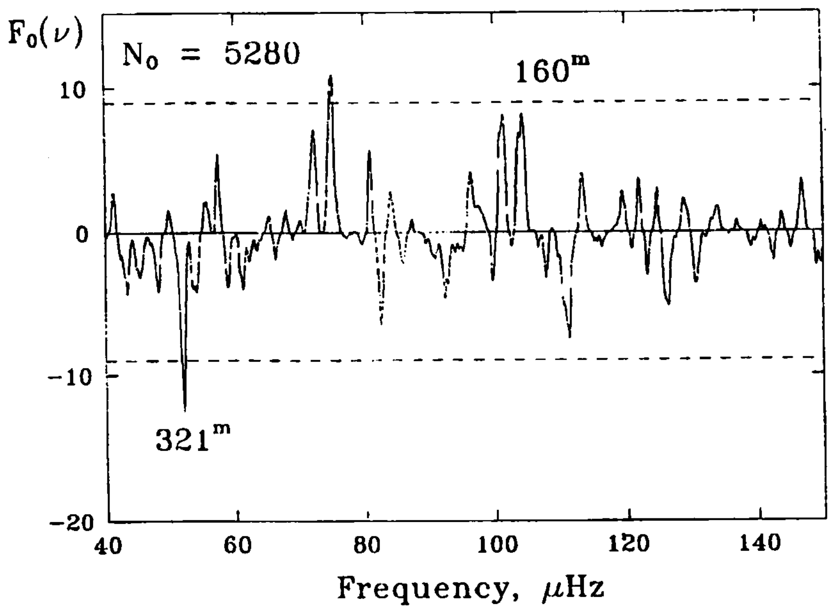

Figure 2 The resonance spectrum $F_0(\nu)$ for 5280 orbital periods (for binaries with $P < 5.5$ d). The dashed lines correspond to a formal 3σ CL for positive (upper) and negative (lower) peaks of the spectrum.

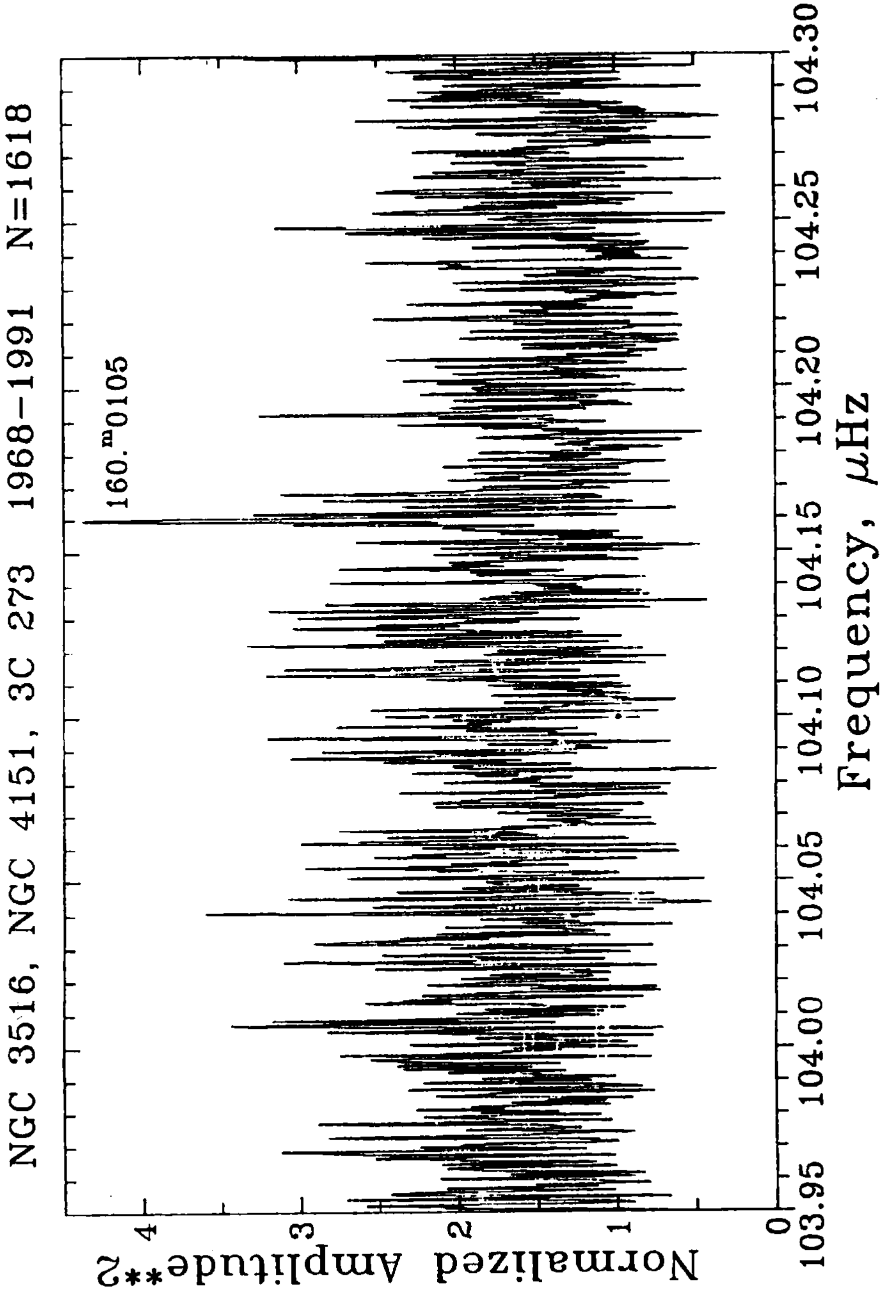

Figure 3 The average power spectrum of luminosity variations of three AGNs, NGC 3516, NGC 4151 and quasar 3C 273 (1968–1991 data, with the total number of measurements $N = 1618$). The major peak corresponds to a period of 160.0105 ± 0.0006 min (after Kotov *et al.* 1994).

One may imagine that the 160-min peak (Figure 1) is merely an artifact caused by the long-period boundary of the period data we applied for the CF calculation, i.e., by the 5.5 upper limit. This explanation however does not work, as was shown by computations with various upper boundaries, from 3 to 10 d. For the total sample of CBSs with $P < 10$ d ($N_O = 5845$) the peak 159.6 ± 0.6 min is nearly 3.5σ significant. So one should stress again that the P_0-effect is statistically significant and thus might bear on studies of the origin and evolution of CBSs.

Since (a) the absolute majority of binaries under consideration have periods $P > 2P_0$, and (b) both resonances, (A) and (B), emerge as $F_0(\nu)$-peaks of opposite signs, the resultant action of a hypothetical GW, on the average, can also be formulated in this way: A-resonance corresponds to an excess of binaries at periods $P \approx (2Z+1) \cdot P_0$ (odd commensurability), and B-resonance corresponds to a lack of binaries at periods $P \approx (2Z) \cdot P_0$ (even non-commensurability).

The nature of the 160-min (P_0-) oscillation of the Sun remains controversial (Kotov 1986; Scherrer *et al.* 1993). About a decade ago there was wide discussion about the possibility of an excitation of this oscillation by GR from the binary system Geminga (Delache, 1983; Walgate, 1983). This interesting hypothesis however was immediately discarded by theoretical considerations (see, e.g., Fabian and Gough, 1984); it was explicitly shown that if the general concept of GR is correct, the P_0-oscillation in the Sun could not have been excited to the observable amplitude by any binary source of stellar mass.

Irrespective of any reasonable explanation of the P_0-resonance observed in the period distribution of CBSs, we suppose that its nature might be of great interest for the study and detection of GRs (QGRs) in the Universe. The phenomenon might relate also to some peculiar property of gravitation and time, and perhaps to cosmology. In conclusion, we would like also to refer to the recent discovery (Kotov *et al.*, 1994) of the same P_0-periodicity (Figure 3) in luminosity variations of the most massive objects of the Universe – AGNs.

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