Rotating neutron stars as sources of gravitational waves

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1 Introduction

Gravitational waves (GWs), predicted by Einstein's theory of general relativity, are oscillations of the space-time itself. GWs pass through space almost unaffected. This gives rise to the expectation that the detection of GWs may provide a different view on astrophysical processes hidden from electromagnetic astronomy. A spinning neutron star is a source of continuous GWs, if its mass distribution is non-axisymmetric along the rotation axis. It can be caused by various instabilities (Andersson, 2003; Gondek-Rosińska et al., 2003) and deformations, e.g., due to magnetic field. It is estimated that 10^8 neutron stars exist in our Galaxy. They are considered important sources for future GWs detectors: Advanced LIGO, Advanced Virgo and the Einstein Telescope. Advanced LIGO will start observations in 2015.

In this contribution we report a study of the gravitational wave signal from a population of 10000 neutron stars using a realistic model of their distribution in the Galaxy. Up to now only the signal from the Crab pulsar was studied (Bonazzola & Gourgoulhon, 1996) and the simplified model of GWs signal from neutron stars population by Giazotto et al. (1997). Regimbau & de Freitas Pacheco (2000) estimated the probability of the detection of GWs from galactic radio pulsars by the 1st generation Virgo detector.

2 Population of neutron stars

Most of the observed radio pulsars rotate with frequency below 10 Hz. But there is a fraction of neutron stars with frequency from 10 Hz up to few hundreds of Hz being in the frequency range of the advanced detectors (10 Hz - a few kHz, the frequency of GWs is twice the spin frequency). In our model a neutron star is born every hundred years, i.e., with the mean birth rate of neutron stars in the Milky Way. With this assumption we obtained the population of 10000 objects with the age below 1 million years. It is far from the real age of the Galaxy and the number of neutron stars, but it is sufficient for the initial calculations of the collective signal from an ensemble of neutron stars. A neutron star is characterised by its initial values of the rotation period P, the kick velocity, the position in the Milky Way (x, y, z) and the magnetic field B. Then the change of the position and velocity are calculated taking into account the gravitational field of the entire Galaxy; the period is assumed to decrease according to the dipole formula.

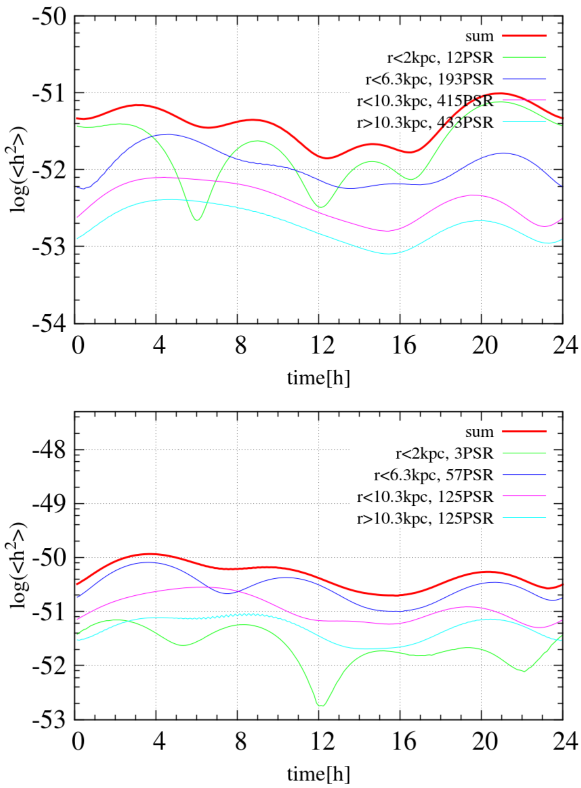

Fig. 1: The mean squared signal in the logarithmic scale for the population of the objects over the 24 h period. The top panel corresponds to the 10-30 Hz range and the bottom panel corresponds to the 30-100 Hz range. The red line corresponds to sum of all objects within this rotation frequency range, while other lines are the components for different distance ranges: green line - up to 2 kpc, dark blue - 2÷6.3 kpc, pink - 6.3÷10.3 kpc, light blue - more than 10.3 kpc. For each line we show the number of neutron stars in this distance range. The results are for a single particular realisation of the distribution of sources. The shape of the GWs signal is dominated by the nearest or/and fastest neutron stars.

3 The gravitational waves from an asymmetric neutron star

All neutron stars have random orientations of the rotation axis and the distortion axis, they are described by the following parameters: i - the projection of the rotation axis on the celestial sphere, α - the angle between the rotation axis and the distortion axis and the angle ψ - the relative orientation of the line of sight to the object and of the detector. We have also determined the values for each object: the moment of inertia as 10^{38} kg m^2 and the distortion 10^{-5}. With this assumptions we calculated the amplitude of GWs emitted by a neutron star as a function of time. The combined signal of the ensemble of neutron stars is calculated as the average of all amplitudes $h^2(t)$. The signal is taken in the time interval τ, with the assumption that τ is much greater than the rotation period and much less than a 24 h period. Finally we obtained the squared signal from a single neutron star averaged over τ. By adding them together we obtain the total squared signal from the population of neutron stars.

4 Results and conclusions

We have calculated the signal for two frequency ranges within the sensitivities of the Advanced detectors and the Einstein Telescope. We present our results in the Fig. 1. In the top panel are results for the rotational frequency range 10-30 Hz, in the bottom panel are results for rotational frequency 30-100 Hz. The red line corresponds to the sum of the signal from all objects within each frequency range. The other lines correspond to the values components coming from neutron stars located at different distance ranges from the Earth. The 24 h variation of the signal is caused by the Earth rotation and is related to the change of the detector orientation with respect to the sky. The level of the average total signal and of the components is higher for greater frequency for about one order of magnitude. It is due to fact that the signal depends proportionally on the square of the rotation frequency. The objects that are up to 6.3 kpc have the strongest influence on the total signal. The signal from more distant objects is less significant. The shape of the signal from the numerous distant objects is the same. Component of the signal at distances 6.3-10.3 kpc and above 10.3 kpc have the same shape and differ only by normalisation. The plots were made for a single particular realisation of the distribution of sources. Other realisations lead to different patterns due to small number of bright nearby pulsars, but are similar for the component coming from the numerous distant ones. The GWs signal is dominated by the nearest or/and fastest neutron stars. Our conclusions confirm results obtained by Regimbau & de Freitas Pacheco (2000).

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