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HIGH FREQUENCY GRAVITATIONAL WAVE SOURCES*

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I review the potential astrophysical sources observable by the high frequency gravitational wave observatories.

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1. Introduction

The interferometric gravitational wave observatories are achieving their design sensitivities. LIGO [1] observatory is already taking data, while VIRGO [2] is to achieve its nominal sensitivity at the end of 2006. At the time of writing, these observatories have not detected any signals but the intense search in the data is under way.

The high frequency domain in gravitational waves encompasses the frequency range from stretching from $\approx 30\,\mathrm{Hz}$ to $\approx 10\,\mathrm{kHz}$. The ground based interferometric detectors are most sensitive between 100 and 1000 Hz. This frequency range is where we expect gravitational waves from stellar mass compact objects. This is because the typical frequency of oscillations from an object of mass M is $f = 2.2\,\mathrm{kHz}\ (M_\odot/M)$.

The future space interferometer LISA shall be sensitive in 10^{-4}–10^{-2} Hz range called the low frequency gravitational waves.

In this paper I will review the sources of gravitational expected to be seen by the existing high frequency detectors, and discuss their event rates.

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2. Binaries

Binary compact objects have been considered as sources of gravitational waves from the time of the discovery of the double pulsar PSR 1913+16 [3]. Since that time additional three galactic binary pulsars with merger times smaller than the Hubble time have been found, one of them J1906+0746 [4] after the conference. The principal issues regarding the detectability of compact object binary mergers are: What are the merger rates? Is the population of radio selected binaries representative of the population of all binary neutron stars? What do we know about compact object binaries containing black holes?

The merger rate has been estimated by many authors from the properties of the observed sample of binary pulsars. The rate is very uncertain due to small number statistics, and systematical errors stemming from the modelling of evolution of compact object binaries in our Galaxy, and the extension of such models to populations in other galaxies. The recent work [5] shows that the galactic merger rate for binary neutron stars lies somewhere between 1 and 800 events per Myr, which corresponds to the LIGO/VIRGO rate of 0.3 to 400 per kyr.

A different approach to the rate calculation is the binary population synthesis. This method relies on the precise evolution of binary stars leading to formation of merging compact object binaries (see *e.g.* [6]). In this approach one can estimate the properties of compact objects containing black holes, that have not been observed yet. However, the estimates of the rates with this method suffer from uncertainties in parametrisation of some stages of binary evolution. The main results of the population synthesis work are that the population of double neutron star binaries should contain a significant number of short lived binaries that are unobservable as pulsars. The typical merger time for these objects is 1–2 Myr, much shorter than the nuclear evolution of their progenitors. Moreover, population synthesis predicts the existence of a small but significant number of black hole neutron star binaries and double black hole binaries. Such binaries should dominate the observable sample of compact object mergers. This is because the signal to noise ratio in an interferometric detector from a gravitational inspiral of a binary is proportional to

$$\frac{S}{N} \propto \frac{M_{\rm chirp}^{5/6}}{D}\,,$$

where $M_{\rm chirp} = (m_1 m_2)^{3/5}(m_1+m_2)^{-1/5}$ is the chirp mass of the system and D is the distance. Therefore, the high chirp mass objects are observable in a much larger volume than the low chirp mass ones. This observability factor compensates for the low numbers of *e.g.* double black hole binaries and makes them the most numerous binary objects in the gravitational wave sky [7].

3. Neutron stars

Solitary neutron stars may be the sources of gravitational waves provided that they are asymmetric. However, an asymmetry of a neutron star is difficult to maintain, due to very strong gravity on its surface. The asymmetry of a neutron star shall also lead to precession and such precession has been observed in radio pulsars and in an anomalous X-ray pulsar. The observational limits on the difference between the moment of inertia along different axes is in the range of 10^{-8}. This is still too low to be observable with the existing gravitational wave instruments. An additional hope may lie in a dedicated monitoring correlated with detailed radio timing on a time scale of years [8].

Instabilities of neutron stars may also be efficient source of gravitational waves. In this field most of the work is connected with the Chandrasekhar–Friedman–Schutz instability. In this scenario a perturbation propagates on a surface of rotating neutron star in the opposite direction to the rotation. The gravitational wave back reaction tends to increase the amplitude of the perturbation if the rotation is sufficiently quick. Moreover, if the viscosity is not too large a quickly rotating neutron star may be an efficient source of a gravitational wave. Such quickly rotating neutron stars may appear just after their formation provided that the collapsing stellar core has sufficient angular momentum, or may be spun up to large rotation rates in binaries. Depending on the actual shape of the instability region in the space spanned by stellar temperature and rotation rate the gravitational wave signal may come in a short burst or as a continuous low amplitude wave. The galactic rate of such bursts is low, a few per Myr, and the amplitude depends on the details of the neutron star equation of state. Thus for a detection one needs an instrument with the sampling distance reaching at least to the VIRGO cluster of galaxies.

4. Supernovae

Supernovae explosions may be efficient sources of gravitational waves. We know that they must be asymmetric from the observations of velocities of young neutron stars. These young pulsars have spatial velocities reaching $1000\,\mathrm{km\,s^{-1}}$, which indicates that they must have been shot out in the explosion. The knowledge of the details of the supernovae explosions can only be explored in numerical simulations. Such simulations are still uncertain and their results depend on the details of the hydrodynamical evolution in an unstable environment. However, the results presented so far indicate that gravitational waves from supernovae are detectable only from sources in our Galaxy [9]. Even with the next generation of detectors with the sensitivity increased by a factor ≈ 30, they would be detectable only in the Local

Group. The supernovae rate in our Galaxy is estimated to be somewhere between 1 and 2 per century, while the rate in the Local Group lies between 1 and 5 per century. Thus a perspective of detecting gravitational waves from supernovae explosions is not very optimistic, but on the other hand it would be a real loss if for some reasons the interferometers were turned off when the next galactic supernova goes off.

5. Summary

In summary the most promising gravitational wave sources are the coalescing compact object binaries. Other sources such as neutron star instabilities or supernovae have low expected rates. Within the coalescing compact object binaries, the double black hole binaries with the masses of about $10M_\odot$ each seem to be most numerous in the population of gravitational wave selected object predicted by the population synthesis method. However, one must not stop the attempts to look for signals from other sources. It may happen that the first sources will be some exotic variety of the supernovae or quickly rotating neutron stars. Intermediate mass black hole binaries originating in Population III stars [10] may also produce gravitational wave signals. If detected, they would provide direct insight into the properties of the very first stars in the Universe. Moreover, like any new window on the Universe, gravitational wave astronomy is bound to provide new discoveries and hopefully surprises.

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