Pulsar Search & Doppler Effect

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Periodic sources of gravitational waves (GW) like slightly asymmetric pulsars are expected to be rather weak, but the signal to noise ratio could be enhanced by integrating the data over long periods of time. We will detail the problems arising from this long integration focusing on those related to the Doppler effect coming from the motion of earth.

1 Introduction

One of the possible sources of GW for detectors like VIRGO are the pulsars. The expected amplitude is very weak but permanent and therefore the signal can be integrated for a very long time. This long integration time increase the sensitivity to small frequency variations of the signal. These variations can come from various effects like the very slow spin down of the neutron star due to the energy losses, the Doppler effect in the case of binary stars or the Doppler effect due to the earth motion. In this paper, we will focus on this last effect, especially in the case of blind search and we will discuss the constraint on a possible search algorithm.

2 Constraint on earth position

In the case of an known pulsar the Doppler effect due to the earth motion relative to the pulsar direction is only defined by the earth position. To properly integrate the GW signal we should know the signal arrival time within a fraction of period which is equivalent to know the wavefront or the earth position within a fraction of wavelength. With simple algebra one can show that to lose less than 5% of signal we need to know the earth position better than $15km(1kHz/\nu_{GW})$ where ν_{GW} is the signal frequency in kHz. Such a constraint requires the use of a detailed solar system model to compute the earth position. Fortunately a function of "Bureau des longitudes" in Paris [a] gives us this position with an accuracy of $2km$.

3 Constraint on pulsar position

In the case of an unknown pulsar (blind search) we have to assume a direction to be able to correct the data for the Doppler effect. Therefore the search algorithm splits the sky in small search area. The size of this search area and therefore the total number of search directions is determined by limiting the signal losses to a given number (5% in this study) in any direction within the

[a] *Astron. Astrophys. 128, 124-139 (1983)* G. Francou et al.

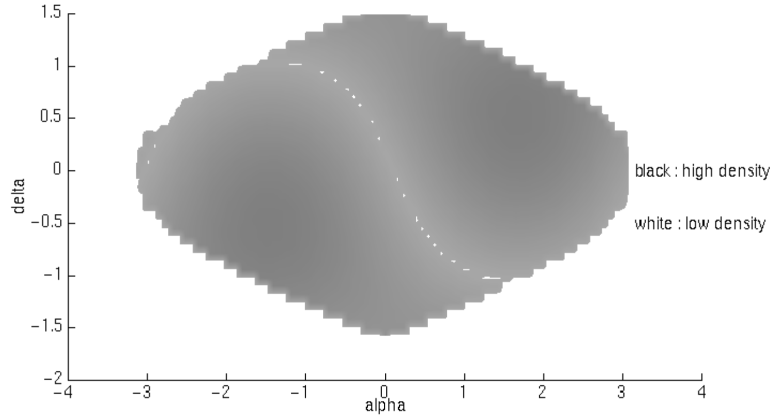

Figure 1: Search direction density in galactic coordinates

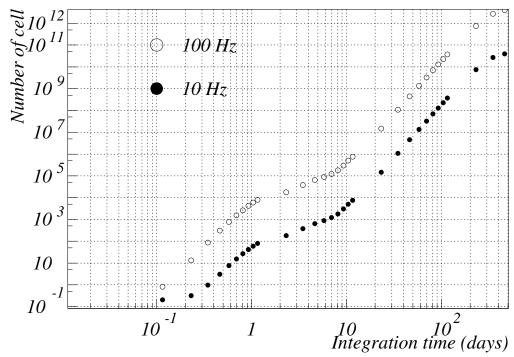

Figure 2: Total number of search direction versus the integration time

search area. Figure 1 shows the result of a numerical computation of the cell density in galactic coordinates for 90 days of integration. The low density area (light grey) correspond to the ecliptic plan and also include the galactic center. By integrating several of these maps one can get the fig. 2 which shows the total number of search directions versus the integration time for two GW frequencies.

4 Consequences on a search algorithm

The huge number of search directions shown by fig. 2 for several month of integration requires that other search techniques be investigated. One well known technique uses more simple trigger algorithms to search for candidates which are later on validated by a full analysis. In the case of periodic sources, instead of performing a single long FFT one can average the results of several shorter FFT.

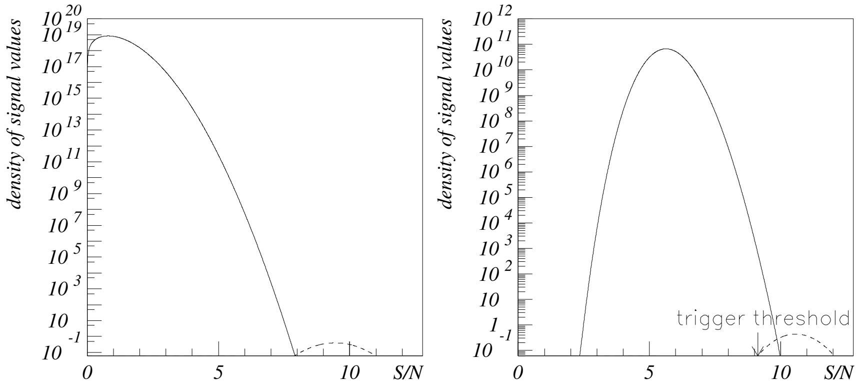

Figure 3: Signal values for 4 months of data for 1 FFT (left) or 32 FFT (rigth).

To illustrate this approach fig. 3_{left} shows the distribution of the power spectrum values of all the needed FFT to analize the full sky in the case of 4 months of data. This corresponds to 3.10^{10} search directions for signal up to 100 Hz with 10^9 entries per FFT and is computed using a white Gaussian noise. For a signal to be observed, its amplitude has to be above the tail of the noise distribution. This is 9.5 times the mean noise level in this case when we take into account the spreading due to the noise as presented by the dashed line on fig. 3_{left}. If we split the initial data sample in 32 subsamples the expected distribution of the noise power spectrum has an average value which increases by a factor $\sqrt{32}$ as shown by fig. 3_{right}. But the distribution becomes more symetric, the number of search directions and therefore the number of entries is largely reduced and the tail of this distribution shifts only slightly. The increase of the noise level move also the observed amplitude (dashed line) of our reference signal. Therefore if we do not want to miss any good signal we have to select all the candidates above the threshold indicate on fig. 3. This corresponds to only a few hundreds of frequency/direction couples. The frequency range and sky surface where the full analysis has to be performed is then reduced by several orders of magnitude.

This approach which dramatically reduces the required computing resources has now to be optimized and exercised with more realistic noises.

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