SEARCH OF MONOCHROMATIC GRAVITATIONAL WAVES USING RESONANT DETECTORS

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Abstract

The search for monochromatic waves has begun using the data obtained with the Explorer detector of the Rome group that cover a period of a few years (since 1990). We present the algorithms we are using for this search.

1 Introduction

As well known[1,2] if $S_h(\omega)$ represents the (two-sided) detector spectral energy and t_m is the measurement time, in the case one knows the source location and frequency then, ideally, performing one single Fast Fourier Transform (FFT) over the time t_m, the detector sensitivity to the continuous signal is given by

$$h_0^{long} = \sqrt{\frac{2S_h(\omega)}{t_m}} \tag{1}$$

We indicate with $\tilde{h}(\omega)$ the noise spectral amplitude, that is the square root of $S_h(\omega)$. Using Eq.1, t_m=1 year and the data of the Explorer detector[5] during the 1991 run we obtain

$$h_0^{long} = 2 \cdot 10^{-25} \tag{2}$$

in a bandwidth of $\simeq 2\ Hz$ around the two resonance frequencies, $\nu_- = 904.7\ Hz$ and $\nu_+ = 921.3\ Hz$, and $h_0^{long} \simeq 2 \cdot 10^{-24}$ in a bandwidth of 16 Hz between the two resonances.

The expected sensitivities with the **Nautilus** (and **Auriga**) detector is $\simeq 1 \cdot 10^{-26}$, using one year of data. The sensitivity for the resonant detectors improves with the square root of the ratio T/MQ, where T is the detector temperature, Q its merit factor and M the mass. The above sensitivity is what we plan to reach by the year 2000, in a bandwidth of $\simeq$ 6 Hz around each of the resonances.

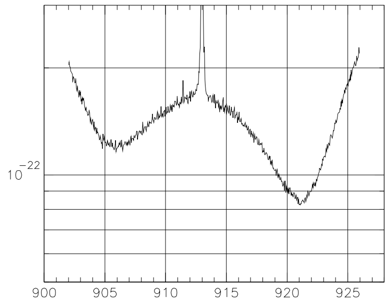

Figure 1: Nautilus 2000, noise spectral amplitude The y-axis gives the expected $\tilde{h}(\omega)$ and the x-axis the frequency.

It is worth notice that, even if one detector alone, at least for "big" signal to noise ratioes, can do this analysis and can measure the source parameters, joint searches between different detectors (including bars and interferometers) may really be helpful.

2 The spectral data base

We have approached the problem organizing a **Spectral data base**. Due to the Doppler effect, considering only the Earth motion, the maximum sweeping in frequency at 1 kHz is $\simeq 0.62$ Hz during one year and $\simeq 0.011$ Hz during one day. Hence it is simple to evaluate that over a time $t_0 = 0.6617$ hours, that is with frequency step $\delta_\nu = 0.42$ mHz, the maximum Doppler frequency variation is smaller than the step, $\delta_{\nu_d} = 0.28$ mHz. Thus if there is no source motion and if the source emits a purely sinusoidal g. w. signal, a signal will appear only in one channel in each spectrum. Actually in our detector we sample the data in a bandwidth of the order of 27.5 Hz in a frequency range from 900 to 927.5 Hz, with a sampling time of $\simeq 18.18$ ms. Then in the time t_0 covered by one spectrum we have 131072 samples. A proper analysis of the spectra, 13239 in one year, will lead us to the detection of the continuous wave, if it exists and if, obviously, the SNR is big enough.

The idea of the data base (DB) is important as we need to face with the non-stationarity in the detector noise and with data taking interruption. Hence it is necessary to characterize each spectrum with information that can be used for vetoing the data or for weighting them differently in the analysis. These information are, for example, the brownian noises of the modes, the wide band noise level, the two resonance frequencies, the modes merit factors, and information regarding the calibration signal and the status of the operation flags. From the behaviour and the distribution of these data it is possible to decide a threshold for vetoing the data. Fig. 2 a) shows the noise spectral density of one spectrum of the 1991 DB. The experimental sensitivity is at the resonances, $h_0 = 3 \cdot 10^{-23}$ during the time t_m=0.66 hours, and, between the resonances, $h_0 = 3 \cdot 10^{-22}$. To obtain the amplitude of one spectral line

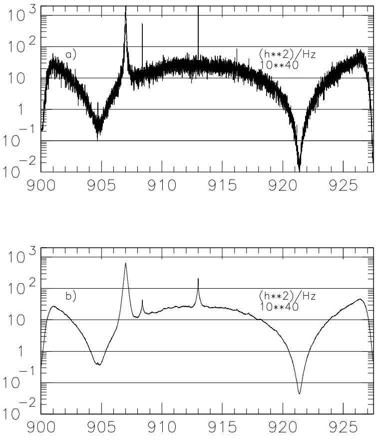

Figure 2: a) One spectrum in the data base (1 august 1991), b) Its smoothing filter. The y-axis is $S_h \cdot 10^{40}$ in units of $1/Hz$, the x-axis is the frequency, [Hz].

it is necessary to eliminate the contribution of the noise, subtracting from the spectrum its smoothed version, shown in fig. 2 b). The line at 913 Hz is the calibration. It is possible to note another line at $\simeq$ 906 Hz, very likely due to unknown noise, present in the data. The spectral line candidate selection will be described in detail in a paper in preparation. Here we limit ourselves to the basics of the analysis procedure, once we have a "candidate" spectral line to analyze.

3 Candidate spectral lines analysis

A signal will appear in different channels of the different spectra, with frequency and amplitude that are a function of the source location. We study its frequency and amplitude for successive periodograms and then we fit them with the expected modulation for various sources in the sky. For the amplitudes we expect a pattern modulated with the sidereal day. Hence we average the energies of the candidate line as a function of the sidereal time and we fit the averaged experimental data with what we expect from various sources in the sky. We have to consider also the modulation due to the wave polarization. As this is not simple to be modeled we have taken into account only the case of random polarization of the wave. We expect a sidereal plus an annual modulation of the frequencies, due to the Doppler effect of the Earth motion, plus other causes of frequency variation that in general are not easy to model. We study the frequencies behaviour as a function of the time and we fit them with the expected modulation due to the Earth motion. Using the right ascension α and declination δ we divide the sky into equal solid angles. Using $\simeq$ 20000 points in the sky the frequency indetermination is less than our frequency step and the energy indetermination is of the order of 10%. Hence we consider 20000 points as a reasonable number, at this stage of the analysis.

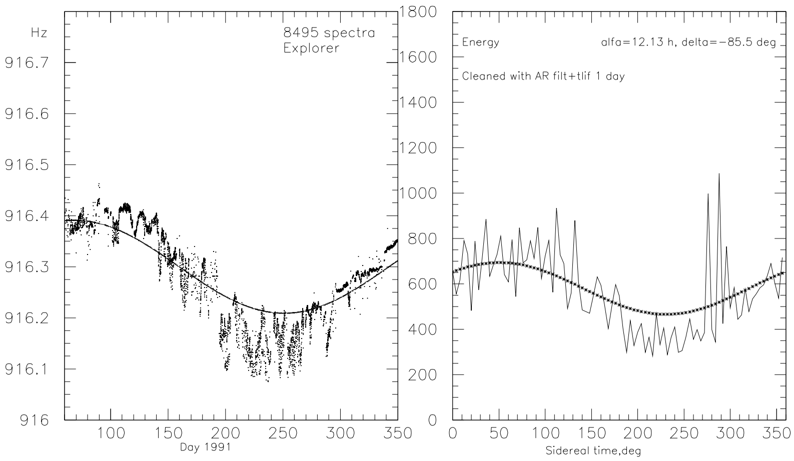

Figure 3: March-december 1991; 8495 spectra. Experimental data and the fit expected if the source was at α=17.03 hours, δ=-22.5 degrees, for the frequencies. The experimental amplitudes are fitted with the source at α=12.13 hours,δ=-85.5 deg.

Just to give an example of the procedure, fig.3 shows the change in frequency of one candidate line and also what we expect if the source is at $\alpha = 17$ hours and $\delta = -22.5$ degrees, which happens to be the best fit. The result of this fit is quite interesting, but, in order to be "convinced" that this could be due to an astrophysical source a **lot** of further analysis, both physical and statistical, should be done. The second step is to analyze the amplitude pattern. The figure shows the averaged amplitudes, as a function of the sidereal time and the result of the best fit for the amplitudes (in case of random polarization of the wave). The expected behaviour, assuming the source be the same as for the best fit for the frequencies, does not fit the experimental data. Anyway, we can calculate the amplitude of our candidate signal: $h_0 \simeq (500\ 10^{-40}\ 0.4\ 10^{-3})^{1/2} \simeq 5\ 10^{-21}$ This level seems too high, compared to what we expect from the Galactic Center, that is rougly the direction of the best fit for the frequencies.

4 The sensitivity of the procedure

It can be shown that the sensitivity that can be reached averaging the information of spectra, done during a time t_0, over the time t_m is given by

$$h_0 = \sqrt{\frac{2S_h}{\sqrt{t_m t_0}}} \tag{3}$$

The ratio of eqs. 3 and 1 is

$$h_0/h_0^{long} = (t_m/t_0)^{1/4} \tag{4}$$

(roughly a factor ten over one year)

5 Why we suggest it: some advantages

The proposed procedure, to divide the entire period of measurements in several subperiods of lenght t_0, has some advantages, that regard both the detector and the source properties. It is very simple and it is useful even if we want to consider it only as a first step of a more complicated procedure that can be applied only to those frequencies and directions that gave interesting results. In this way we can avoid, considering only these few frequencies, the use of lots of templates.

The standard analysis tecniques based on the use of very long FFT have to face with the problem of non stationary noise in the data and with the indetermination in the source parameters, i.e. frequency and location, and also with a source frequency variation that cannot be modeled. In addition, the time precision and the sampling frequency precision during the whole observation time become very crucial.

In a "real" detector, even if it works properly, it is not possible to have always the same sensitivity and the same level of stationary noise. The idea of the data base, where each spectrum is completely characterized, is important in the sense that one can decide, in each step of the analysis, to weight differently information coming from data with different sensitivity. Both the frequency and amplitude patterns of the lines are measured and hence one can measure, for example, the source frequency variation and relate it with the amplitude and with the location of the source in the sky.

6 Conclusions

We have explained some aspects of the analysis procedure we are using with the Explorer detector to search for pulsar in the sky.

The analysis is presently in progress.

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