SEARCH OF MONOCHROMATIC AND STOCHASTIC GRAVITATIONAL WAVES

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The cryogenic resonant antennas can be used for searching continuous and stochastic waves, in addition to search for the bursts due to gravitational collapses. Results obtained with Explorer for the stochastic g.w. are presented. It is also shown that crosscorrelating two ultracryogenic antennas (Nautilus, Auriga) a spectral amplitude of the order of $8 \cdot 10^{-25} 1/\sqrt{Hz}$ in one year of operation can be reached. The search for monochromatic waves has started using the Explorer data, which cover a period of a few years (since 1990). The procedure that is being developed is presented and discussed.

1 Monochromatic waves detection

The signal observed by the detector, if the source emits a purely sinusoidal g. w., is frequency and amplitude modulated, due to the relative motion between the detector and the source [1,2]. If we know the location and the frequency of the source it is possible to demodulate the measured data and then to achieve a sensitivity that improves with the square root of the observation time [3] t_m: $h_0 = \sqrt{2S_h/t_m}$, where S_h is the (two-sided) spectral density of the dimensionless amplitude h that can be detected with $SNR = 1$. At the resonances the sensitivity becomes:

$$h_0 = 2.04 \cdot 10^{-25} \sqrt{\frac{T}{0.05\ K} \frac{2300\ kg}{M} \frac{10^7}{Q} \frac{900\ Hz}{\nu_0} \frac{1\ day}{t_m}} \tag{1}$$

Using eq.(1), t_m =1 year, and the parameters of Explorer [4] during the 1991 run ($T = 2\ K, Q = 10^6$) we obtain $h_0 = 2.3 \cdot 10^{-25}$, in a bandwidth of $\simeq 1\ Hz$ around the two resonances and about 10^{-24} in a bandwidth of 15 Hz between the resonances. With the 1994 parameters ($T = 2\ K, Q = 10^7$) $h_0 = 7.2 \cdot 10^{-26}$,

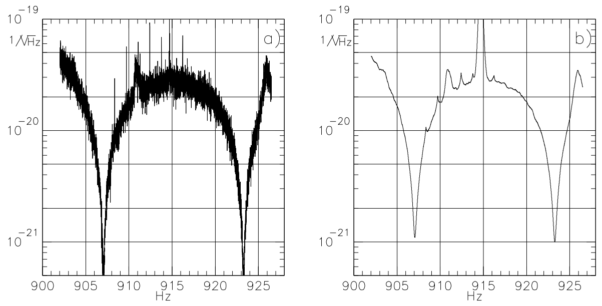

Figure 1: *a) One spectrum,* $t_0 \simeq 0.66$ *hours; b) Spectrum after the smoothing filter*
(Data from the 1994 data base)

over a bandwidth of $\simeq 0.1\ Hz$ at the resonances. The planned sensitivity with the Nautilus detector is $h_0 = 1.1 \cdot 10^{-26}$. If we don't know the source location then we can do an "overall sky search". An approach to the analysis is to organize a spectral data base and then to analyze the spectra by combining their information. Each spectrum should be estimated in a period in which the Doppler effect is not important. Over $t_0 = 0.6617$ hours, with frequency step $\delta_\nu = 0.42\ mHz$, the maximum frequency variation is $\delta_{\nu_d} = 0.28\ mHz$, smaller than the step. We have 13239 spectra in one year of operation. Each spectrum of the data base has an **header** that contains the date and information for vetoing the experimental data. Fig.1a) shows the spectral amplitude of one spectrum of the 1994 data base. At the resonances the experimental sensitivity is $h_0 = 1.7 \cdot 10^{-23}$. By averaging different periodograms over a total time t_m we gain as $(t_m/t_0)^{-1/4}$, being $h_0 = 2\sqrt{S_h \cdot \delta_\nu / \sqrt{t_m/t_0}}$. A signal will appear in different channels of the spectra, with frequency and amplitude function of the source location. To obtain the amplitude it is necessary to eliminate the noise, subtracting from the spectrum its smoothed version (fig.1b)). The spectra can be averaged shifting the spectral channels to fit given locations in the sky. Actually we analyze the frequency and amplitude patterns of chosen[a] lines in order to identify, or to exclude, a certain locus of points as possible g.w. emitters. As an example let us consider, in fig.1a), the line at $\simeq 916\ Hz$. We study, within a chosen bandwidth, its frequency and amplitude for successive periodograms and then we fit them with the expected modulation for various sources. Using right ascension α and declination δ we divide the sky into equal

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[a] We don't discuss here the selection criteria, that can be both statistical or based on the experimenter feeling.

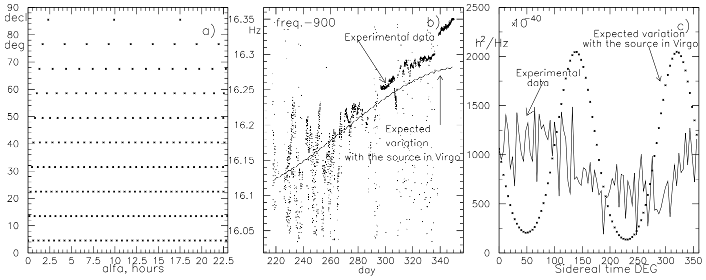

Figure 2: a) Points in the sky:$\delta = 0,90\ deg$ (step 10 deg), $\alpha = 0,23\ hours$ b) Frequency behaviour of the chosen line c) Squared amplitude
(Data from the 1991 data base)

solid angles, as shown in fig.2a). Fig.2b) shows the change in frequency of our selected line and also what we expect if the source is in the Virgo Cluster (which happens to be the best fit). The second step is to compare the behaviour of the amplitude with that expected for the same α and δ. Fig.2c) shows the averaged amplitudes, and the expected behaviour assuming the source be Virgo. The experimental data don't fit the expected behaviour. In the case of interesting results the further analysis may be to apply the "known source search" in that direction and the request to the astronomer of a deeper observation of that region of the sky.

2 Stochastic search

We started to study this problem in more detail after we learned of the model[5] that predicts relic g.w. in a frequency range accessible to our detectors. Using only one detector then its spectral amplitude $\tilde{h}(\omega) = \sqrt{S_h(\omega)}$ represents the **upper limit**[6]. From the Explorer data in fig.3a) we get $\tilde{h} \simeq 5.8 \cdot 10^{-22}\ Hz^{-1/2}$ at the resonances. The sensitivity at the resonances depends only on the bar temperature and on the merit factor[7]. We remark that if we increase the bandwidth of the detector the sensitivity doesn't degrade. Fig.3b) shows the expected strain sensitivity of the Nautilus detector ($T = 0.1\ K$, $Q = 8.5 \cdot 10^6$). The detection bandwidths are those we plan to reach by the year 2000, using an improved transducer. Using two identical, parallel and "near" detectors[b] both with this sensitivity, in operation for $t_m = 1$ year, with a bandwidth of 5

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[b] The cross-correlation analysis is affected by a time delay between the detectors. The separation should be small if compared to the reduced wavelenght $\lambda/(2\pi)$ of the signal. In order to perform an analysis at 1 kHz the separation should be less than $c/(2\pi\nu) \simeq 50km$.

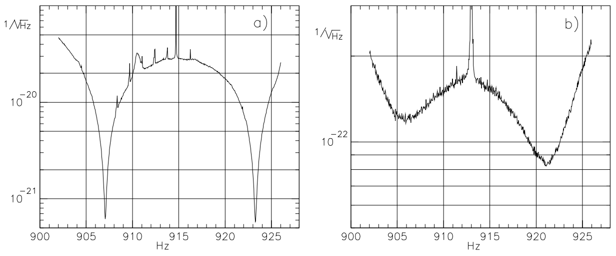

Figure 3: a) Explorer 1994; b) Nautilus 2000

Hz, the upper limit can be reduced to

$$\tilde{h}_{12}(\nu_+) \simeq 7.3 \cdot 10^{-25} \quad 1/\sqrt{Hz} \tag{2}$$

An interesting suggestion, due to the weak dependence of the sensitivity on the bandwidth is to cross-correlate systems made by bars and interferometers [8,9].

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