LABORATORI NAZIONALI DI FRASCATI
SIS-Pubblicazioni

LNF-98/012(P)
20 Aprile 1998

OPERATION OF THE GRAVITATIONAL WAVE DETECTOR NAUTILUS

P. Astone[1], M. Bassan[2,3], P. Bonifazi[1,4], P. Carelli[3,5], E. Coccia[2,3], V. Fafone[6], S. Frasca[1,7], A. Marini[6], S.M. Merkowitz[6], Y. Minenkov[2,3], I. Modena[2,3], G. Modestino[6], A. Moleti[2,3], G.V. Pallottino[1,7], M.A. Papa[1,7], G. Pizzella[2,6], F. Ronga[6], R. Terenzi[3,4], M. Visco[3,4], L. Votano[6]

[1] *INFN, Sezione di Roma, Piazzale A. Moro 2, I-00185 Roma, Italy*
[2] *Dipartimento di Fisica, Università di Roma "Tor Vergata", Italy*
[3] *INFN, Sezione di Roma 2, Via Ricerca Scientifica 1, I-00133 Roma, Italy*
[4] *Istituto di Fisica dello Spazio Interplanetario, CNR Frascati, Italy*
[5] *Dipartimento di Fisica, Università dell'Aquila, L'Aquila, Italy*
[6] *INFN, Laboratori Nazionali di Frascati, Via E. Fermi 40, I-00044 Frascati, Italy*
[7] *Dipartimento di Fisica, Università di Roma "La Sapienza", Italy*

Abstract

The ultracryogenic resonant-mass gravitational wave (GW) detector NAUTILUS of the Rome group is in continuous operation at the Frascati INFN National Laboratories since December 1995. The detector is cooled at about 0.1 K. The measured spectral amplitude sensitivity is $\tilde{h} \simeq 6 \cdot 10^{-22}$ Hz$^{-1/2}$, with a bandwidth of about 1 Hz, and the best pulse sensitivity is of the order of $h \simeq 4 \cdot 10^{-19}$. We describe the detector performances, the search for monochromatic waves and the first experiment of cross-correlation between the data obtained with NAUTILUS and EXPLORER, the detector of the Rome group located at CERN.

PACS:04.80.Nn;95.55.Ym

Presented at The Eighth Marcel Grossmann Meeting on General Relativity
22-27 June 1997, The Hebrew University, Jerusalem, Israel

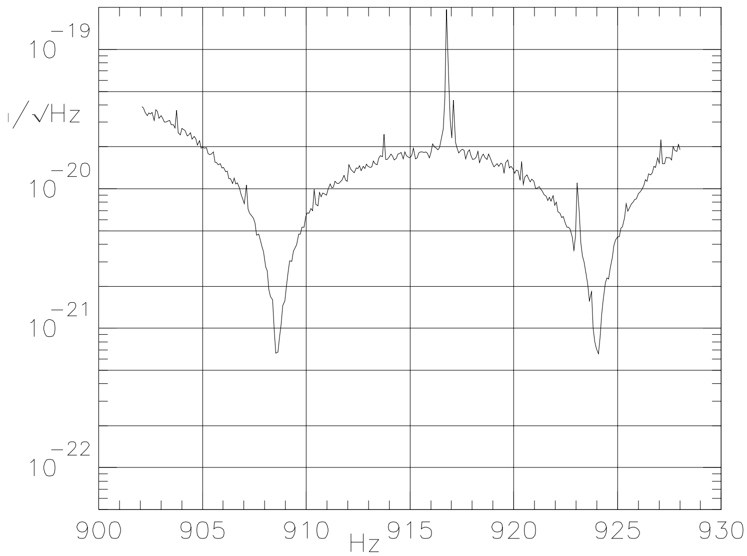

Figure 1: NAUTILUS experimental spectral amplitude sensitivity at 0.1 K.

The ultracryogenic detector NAUTILUS [1] is operating at the Frascati INFN National Laboratory. It consists of an Al5056 cylindrical bar, 2300 kg in weight, cooled to a temperature of 0.1 K, and equipped with a resonant capacitive transducer and a dcSQUID amplifier. The present data taking started in December 1995. The bar has been operating at a thermodynamic temperature below 0.1 K with the SQUID electronics below 0.3 K almost continuously (75% of the total time), except for short interruptions due to maintenance.

The thermal noise of the detector at 0.1 K was measured [1]. The result is in agreement with the detector thermodynamic temperature as measured by a calibrated germanium thermometer located at one end of the bar.

The best sensitivity of the detector is shown in fig. 1: the spectral amplitude sensitivity is $\tilde{h} \simeq 6 \cdot 10^{-22}$ Hz$^{-1/2}$ at the two resonances (due to the two coupled oscillators: bar and transducer) with a bandwidth of about 0.5 Hz on each mode; the corresponding pulse sensitivity, for a conventional GW burst lasting 1 ms, is $h \simeq 4 \cdot 10^{-19}$ and the noise temperature $T_{noise} \simeq 3$ mK (in agreement with the distribution shown in fig. 2). The detector behaviour during 1997 is described in fig. 3, where the distribution of the hourly averaged noise temperatures below 50 mK ($\sim$ 70% of the total time) is reported. More effort is still required to reduce sources of excess noise, mainly non-stationary, so as to continuously operate the antenna at the best noise temperature.

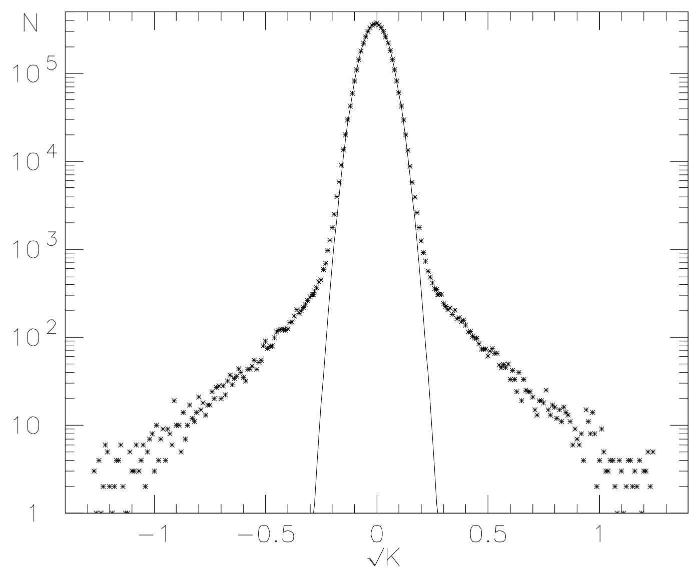

Figure 2: Histogram of six hours of data. The variance of the data expresses the noise temperature of the detector $T_{noise} = 3.0$ mK.

At present NAUTILUS is in data taking as part of a network of resonant mass antennas (ALLEGRO in Louisiana, EXPLORER operated by the Rome group at CERN, NIOBE in Perth and AURIGA, the ultracryogenic antenna recently entered in operation at the Legnaro INFN National Laboratory). The search for impulsive signals using the coincidence technique with ALLEGRO, EXPLORER and NIOBE is in progress [2].

A search for signals due to monochromatic waves and to a stochastic GW background is in progress as well [3,4]. A preliminary measurement of the stochastic background was made by cross-correlating the data of NAUTILUS and EXPLORER, which operates at a temperature of ~ 2.6 K. The measurement was made by tuning the lowest frequency mode of the two detectors to 907.2 Hz. The data were cross-correlated over a period of $\sim$ 13 hours. The result was null with an uncertainty on the spectral amplitude $\simeq 10^{-22}$/Hz$^{-1/2}$, over a frequency band of 0.1 Hz around the mode, in agreement with the expected theoretical noise [3]. If we consider that the two detectors are not co-located [5], this value corresponds to an upper limit on GW stochastic background of $\tilde{h}_{corr} \sim 2 \cdot 10^{-22}$/Hz$^{-1/2}$.

As regarding the search for monochromatic signals, we have approached the problem by organizing a database with the data collected by the EXPLORER and NAUTILUS detectors. The database is constituted by FFT's made by dividing the entire period of mea-

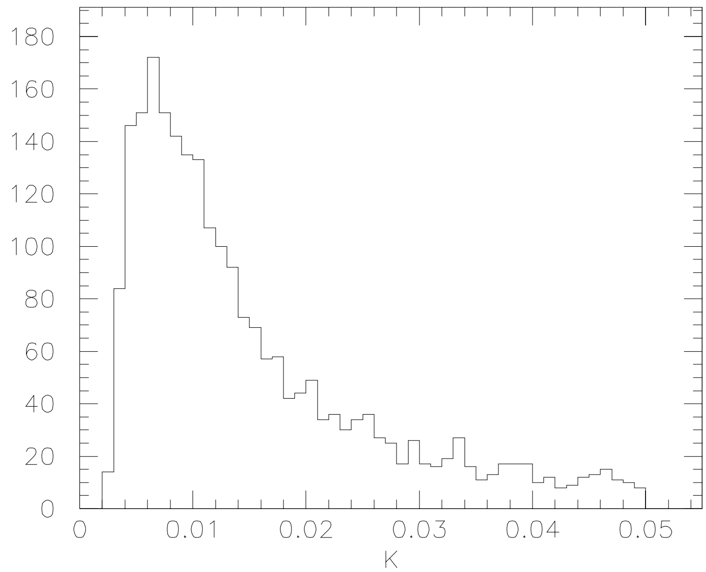

Figure 3: Histogram of the hourly averaged noise temperatures of NAUTILUS from January to June 1997.

surements into several sub-periods of duration t_0, such that the sweeping in frequency due to the Doppler effect caused by the Earth motion is smaller than $1/t_0$. Thus if there is no source motion and if the source emits a purely sinusoidal GW, a signal will appear only in one channel of the spectrum of each sub-period. For the different sub-periods it will appear in different channels, with frequency and amplitude that are a function of the source location. The procedure, once a "candidate" spectral line is found, is to study its frequency and amplitude for successive spectra and then to fit them with the expected modulations for various sources in the sky. We expect sidereal and annual modulation of the frequencies, mainly due to the Doppler effect of the Earth motion. To give an example of the procedure, fig. 4 shows the change in frequency of one candidate line and also the best fit for the right ascension and declination. The study of the amplitude modulation is more difficult since we expect a pattern modulated by the sidereal day and also by the wave polarization, which is not simple to take into account.

It can be shown that the sensitivity that can be reached considering the FFT's made on subperiods of duration t_0 is reduced with respect to the sensitivity of a long FFT made on the whole measuring time t_m by a factor $(t_m/t_0)^{1/4}$, roughly a factor ten over one year (the present sensitivity over one year for EXPLORER and NAUTILUS is $h_0 \simeq 10^{-25}$ in a bandwidth of $\sim\ 0.5$ Hz around the two resonance frequencies and a factor ten worse

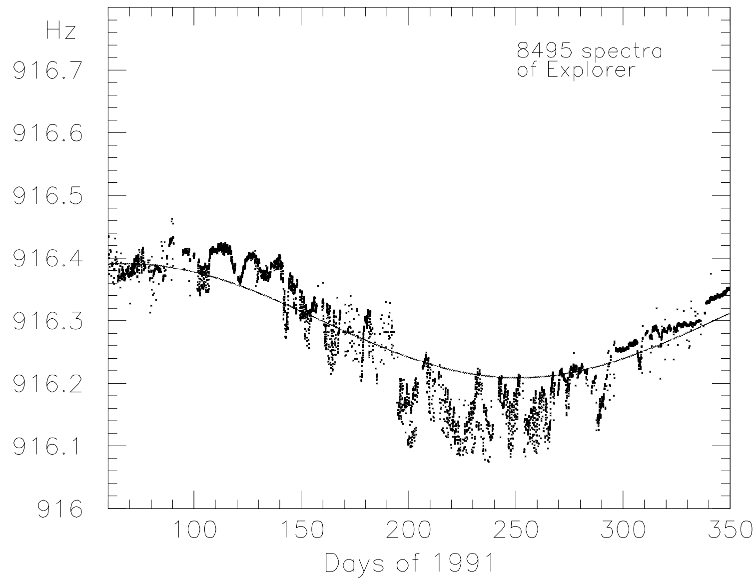

Figure 4: Frequency behaviour of a “candidate” line in the EXPLORER 1991 data, and the best fit which gives: right ascension $\alpha = 17.0$ h and declination $\delta = 22.5$ deg.

in a bandwidth of ~ 20 Hz between the two resonances). Nevertheless, the advantage of this technique is that it takes into account the non-stationarities of a “real” detector and the indetermination in the source parameters. In the case that interesting frequencies and directions are found in the first step of the analysis it is possible to recover the full sensitivity by properly combining the single FFT's in the data-base, avoiding the use of lots of templates.

References

[1] P. Astone et al., *Astrop. Phys.* 7, 231 (1997).

[2] E. Mauceli et al. LSU, P. Astone et al. ROG, *Phys. Rev. D* 56, 6081 (1997).

[3] P. Astone et al., *Phys. Lett. B* 385, 421 (1996).

[4] P. Astone et al., Proc. of the International Conference on Gravitational Waves: Sources and Detectors, Cascina (Italy) 1996 (World Scientific, Singapore, 1997), I. Ciufolini, F. Fidecaro (eds.).

[5] S. Vitale et al., *Phys. Rev. D* 55, 1741 (1997).