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Status report on the EXPLORER and NAUTILUS detectors and the present science run

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Abstract

We report on the present scientific run (04–05) of the two detectors EXPLORER and NAUTILUS. The 04–05 run of the two detectors started in March 2004. The strain sensitivity is about 7×10^{-22} Hz$^{-1/2}$ and the bandwidth is about 5 Hertz. The sensitivity for 1 ms bursts is $h = 3 \times 10^{-19}$.

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(Some figures in this article are in colour only in the electronic version)

1. Introduction

A good gravitational wave (GW) detector must have high sensitivity and high stability to allow steady performance over long periods of time. The resonant bars have shown the possibility of

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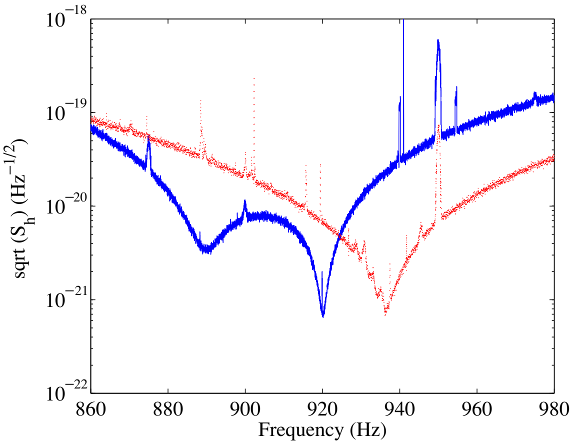

Figure 1. EXPLORER (continuous line) and NAUTILUS (dotted line) present two-sided strain sensitivity.

being on the air for periods of years in continuous operational mode [1]. EXPLORER was the first detector to perform long-term operations at the beginning of the 1990s and NAUTILUS was the first resonant antenna of the ultra-cryogenic class (working at a thermodynamic temperature of about 100 mK) and started to operate in 1995. During the past years, the largest database of signals from GW experiments was created. The data were used to set upper limits on the flux of GWs from different possible sources [1–4].

2. Present experimental configuration and performances

In the present run, the two detectors have a very similar readout. They are equipped with a high performance resonant capacitive transducer [5] coupled to a commercial dc-SQUID amplifier through a superconducting transformer needed to match the impedances of the two devices.

EXPLORER has been working in this configuration since 2000, after a significant upgrade. At the beginning of 2004 minor changes were done in the transducer and since then the antenna is in data taking. The present is one of the longest continuous runs of this antenna: in the past, runs were interrupted by the the annual closure of CERN. This year an effort was made to maintain the experiment in operation even during Christmas time, extending the continuous data taking well beyond the usual 10 months.

During the first part of the run EXPLORER was working with a sensitivity $h = 5 \times 10^{-19}$ for short conventional bursts of GWs. In March 2005, increasing the electromechanical coupling of the readout (i.e. increasing the electrical field inside the transducer from 4.6×10^6 V m^{-1} to 7.5×10^6 V m^{-1}) a significant improvement of the performances was obtained, reaching a sensitivity for short bursts of $h = 3 \times 10^{-19}$. Presently the overall sensitivity of the experiment (figure 1) is limited by the electronic noise.

NAUTILUS has been operating in the current configuration since March 2003, after a hardware upgrade. It is operating at the thermodynamic temperature of about 3 K. In January 2004, after a tune-up period, the apparatus reached its best sensitivity of $h = 3 \times 10^{-19}$ for short (1 ms) conventional bursts of GWs. Presently the overall sensitivity of NAUTILUS (figure 1) is limited by the thermal noise of the detector, better performances can be obtained cooling down the antenna to 100 mK temperatures.

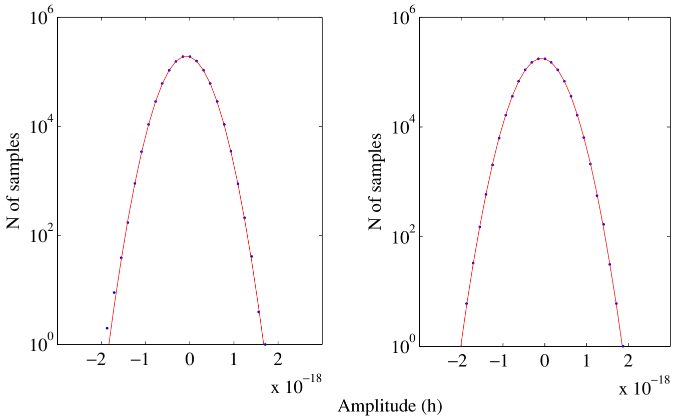

Figure 2. NAUTILUS distribution of filtered data in units of input equivalent strain for 1 ms burst. On 5th April 2005, a common working day, at 11 am on the left, at 11 pm on the right.

The duty cycle of the two detectors is higher than 90%, limited only by the periodic cryogenic operations necessary to keep the apparata at low temperature. The two experiments show constant performances and the data are not affected by human activity. The data quality is constant all over the week and no night–day dependence is observed. An example of a typical distribution of the filtered data is reported in figure 2. These data are from the output of NAUTILUS and are relative to a common working day: the distribution of data is Gaussian during both the night and the day.

Both antennas are equipped with cosmic rays telescopes, one layer of particle detectors is above the cryostat and one below it. In EXPLORER plastic scintillators are used, in NAUTILUS streamer tubes are adopted. These apparata are used not only to veto signals produced by cosmic rays crossing the antennas, that presently are only a few per week, but also as a powerful probe to test the behaviour of the detectors [6]. Cosmic ray showers produce in the antennas real burst signals, that can be used to study the time and amplitude response of the detectors.

In figure 3 is reported, as an example, the time delay between signals found in coincidence at the output of the cosmic ray detector and the antenna EXPLORER during 2003. The data are well fitted by a Gaussian distribution with a standard deviation $\sigma = 3.6$ ms; this is a good direct measurement of the time resolution of the whole detection apparatus.

3. Future upgrades of the detectors

The performance of a gravitational resonant detector is limited by three main sources of noise: the environmental seismic noise, the thermal noise of the bar and of the transducer and the electronic noise of the first stage of amplification.

The cryogenics and the mechanical filters, that must fight against the first two sources of noise, are built into the initial design of the apparatus and not much can be done in the following to modify them. Suspensions are anyways adequate for the present level of sensitivity. The electromechanical transduction readout is periodically upgraded in order to reduce the contribution of the electronic noise and increase the sensitivity of the apparatus.

Nowadays NAUTILUS is working at a thermodynamic temperature of 3 K. A fast increase of the performance of the experiment can be obtained by cooling the antenna to a temperature around 100 mK. The cooling operation requires a few days, followed by a tune-up period of a

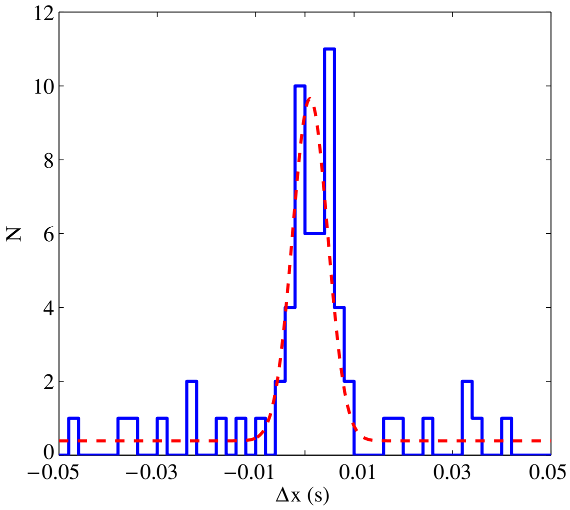

Figure 3. Distribution of the time differences between events in coincidence at the antenna output (EXPLORER) and in the cosmic ray detector.

few weeks; until now this operation was postponed to take advantage of the present large duty cycle and steady performance of the apparatus. It is expected to obtain a sensitivity increase of about a factor 3 in energy.

On the other hand a short-term improvement of EXPLORER sensitivity can be obtained only by decreasing the contribution of the electronic noise that presently limits the sensitivity. The dc-SQUID used shows a noise larger than its intrinsic one (i.e. an energy resolution of about $3 \times 10^4\hbar$ against a value of $3 \times 10^3\hbar$ expected), but we had to trade off sensitivity for long time stability: at different setups the SQUID becomes unstable and unlocks too frequently.

We have developed a medium and long-term strategy to improve the performances of our two experiments. Two alternative readout schemes are under development. The first one is based on a double dc-SQUID amplifier. A prototype of this new readout, that uses a very low noise chip [7], has been tested in the laboratory and exhibited an energy resolution as low as $70\hbar$ at a thermodynamic temperature of 2 K [8]. Mounting a similar readout in the NAUTILUS antenna, using a double gap transducer, already developed and presently under test, a sensitivity for short bursts of $h = 2 \times 10^{-20}$ can be obtained.

A second readout is under development with a longer term programme. It is based on a parametric transduction scheme [9]. We expect to have the whole readout ready in a couple of years. This scheme takes advantage of shifting the detection problem at high frequencies where commercial and reliable amplifiers with performances close to the standard quantum limit are available. This transduction apparatus could also be easily modified to implement back-action evading (BAE) or quantum non demolition (QND) measurements.

4. Data analysis

The large database of the data gathered by the EXPLORER and NAUTILUS is analysed looking for different possible sources.

In the periods 2001–2003 EXPLORER and NAUTILUS were the only operating resonant detectors. Some analyses relative to the 2001 run were published [10, 11]. A preliminary

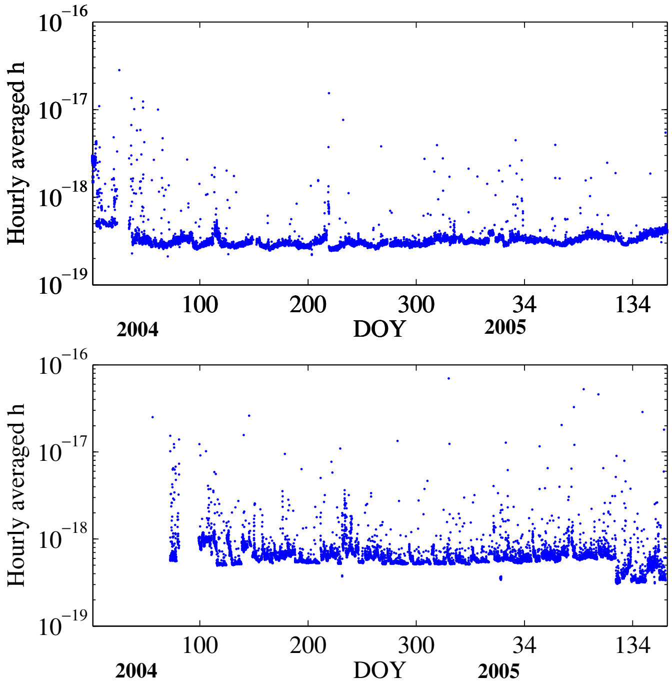

Figure 4. The hourly averaged value of the sensitivity to short bursts for NAUTILUS (upper) and EXPLORER (lower) during the present run, no veto is applied.

analysis of the data gathered during 2003 by the two experiments was recently completed and preliminary results, including a new upper limit for the flux of pulses of GWs, have been presented at this conference [12].

We are confident that better results can be obtained using the data of the present run 2004–2005 during which the experiments showed better overall performances with respect to the past (figure 4). During this period two other resonant detectors, AURIGA and ALLEGRO, were taking data and a new collaboration called IGEC2 was established for data exchange and joint analysis among the four experiments that are all parallel and can act like a single observatory.

The data of the present run will be used for a first joint search, over given periods of time, with the VIRGO and AURIGA experiments. The four detectors are of different kinds but nearly co-planar. In progress is a study whose target is to define techniques and methods to be applied in the joint analysis between signals from interferometric and resonant detectors, considering different possible categories of sources.

A search for monochromatic signals using the data of EXPLORER and NAUTILUS is underway in collaboration with the group of the University of Warsaw [13].

Recently the data from EXPLORER and NAUTILUS gathered in the period 1991–1999 were used for a cumulative analysis with the signals from gamma ray bursts (GRBs) detected by the satellite experiments BATSE and BeppoSAX. A search for correlated excess of energy in the two detectors, within 10 s around the GRB flux peak times, was done. Using the data relative to 387 GRBs an upper bound for the corresponding GW burst amplitude of $h = 2.5 \times 10^{-19}$ was given [14].

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