Studying the coincidence excess between EXPLORER and NAUTILUS during 1998

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Received ..../ Accepted ....

Abstract. The coincidences between EXPLORER and NAUTILUS during 1998 (Astone et al. 2001) are more deeply studied. It is found that the coincidence excess is greater in the ten-day period 7-17 September 1998 and it occurs at the sidereal hour 4, when the detectors axes are perpendicular to the Galactic Disc. The purpose of this paper is to bring our results with the GW detectors to the attention of scientists working in the astrophysical field, and ask them whether are they aware of any special phenomenon occurring when EXPLORER and NAUTILUS showed a coincidence excess.

Key words. Gravitational waves – methods: data analysis

1. Introduction

Since the initial claims by Weber (Weber 1969), which were not confirmed with successive experiments by other groups, the underlying idea has been to consider the gravitational wave (GW) emission as a phenomenon somewhat uniform in time.

The search for short GW bursts within the IGEC collaboration (Allen et al. 2000, Astone et al. 2003) covering the period 1997-2000 produced upper limits for the GW flux over extended periods of time. The ROG collaboration has also presented the results obtained with the EXPLORER and NAUTILUS cryogenic bar detectors alone in the years 1998 (Astone et al. 2001) and 2001 (Astone et al. 2002). For 1998 the EXPLORER and NAUTILUS data show a small coincidence excess with a data selection favouring the Galactic Centre. An excess of events with respect to the expected background was found also in 2001, concentrated around sidereal hour four, when the two bars are oriented perpendicularly to the galactic plane, and therefore their sensitivity for galactic sources of GW is maximal.

If the GW emission is a local (in time as well in space) phenomenon, as, for instance, a supernova in a galaxy or a magnetar like that in December 2004, one should also investigate whether a deviation from the background occurs in relatively short periods of time.

A deviation from the background has, indeed, occurred in 1998 for the EXPLORER/NAUTILUS experiment, as we shall discuss in the following. This paper is especially addressed to astronomers, asking whether they may have observed peculiar phenomena at the same time.

2. Experimental data

During 1998 the resonant mass GW detectors NAUTILUS, installed at the INFN Frascati Laboratory, and EXPLORER, installed at CERN, operated from 2 June to 14 December for a common total measuring time of 94.5 days. Both detectors consist of an aluminium cylindrical bar having a mass of 2.3 tons. The principle of operation of these detectors is based on the idea that the GW excites the first longitudinal mode of the bar, which is isolated from seismic and acoustic disturbances and is cooled to cryogenic temperatures to reduce the thermal noise. To measure the strain of the bar, a capacitive resonant transducer, tuned to the cited mode, is mounted on one bar face, followed by a very low noise superconducting amplifier.
The data are filtered with an adaptive filter matched to delta-like signals for the detection of short bursts (Astone et al. 1997). The variance of the filtered data is called effective temperature and is indicated with $T_{\text{eff}}$. In order to extract from the filtered data sequence events to be analyzed we set a threshold at $E_{\text{thr}} = 19.5 T_{\text{eff}}$. When the signal energy goes above the threshold, its time behaviour is considered until it falls back below the threshold for longer than a waiting time of ten seconds\(^1\). The maximum energy $E_x$ and its occurrence time define the event.

Computation of the GW amplitude $h$ from the energy signal $E_x$ requires a model for the signal shape. A conventionally chosen shape is a short pulse lasting a time of $\tau_g$, resulting in the relationship

$$h = \frac{L}{\nu^2} \frac{1}{\tau_g} \sqrt{\frac{kE_x}{M}},$$  

(1)

where $\nu = 5400$ m/s is the sound velocity in aluminium, $L$ and $M$ the length and the mass of the bar and $\tau_g$ is conventionally assumed equal to 1 ms (for instance, for $E_x = 10 \text{ mK}$ we have $h = 7 \times 10^{-19}$ which requires, using the classical cross-section, a total conversion into GW of about $10^{-3}$ solar masses at the Galactic Centre).

The main characteristics of EXPLORER and NAUTILUS in 1998 are reported in Table 1 of the paper Astone et al. 2001.

The sensitivity of EXPLORER and NAUTILUS during 1998 was not a very good one, worse than that obtained in the following years. The pulse sensitivity for 1 ms bursts is of the order of $h \sim 1.5 \times 10^{-18}$ for EXPLORER and of $h \sim 10^{-18}$ for NAUTILUS. In Fig. 1, we show for the two detectors the distribution of the $T_{\text{eff}}$ values associated to each event, obtained by averaging the filtered data during the ten minutes preceding each event.

### 3. Search for coincidences

In the previously published paper (Astone et al. 2001) we found a small coincidence excess during 1998 ($n_c = 61$, $\bar{n} = 50.5$) when the detectors were favourably oriented towards the Galactic Centre. The coincidence search was based on the use of an energy filter consisting in verifying that the two measured energies of the coincidence events be both compatible within 68% with the same excitation (see Astone et al. 2001 for details).

With the present paper we have decided to study in more detail this small coincidence excess, by dividing the entire period of analysis from 2 June 1998 through 13 December 1998 in ten-day periods and applying to each period the same coincidence search as in Astone et al. 2001 with the same coincidence window $w = \pm 1$ s and considering all events with $T_{\text{eff}} \leq 100$ mK. The result is shown in Fig. 2. We notice that a large fraction of the small coincidence excess already found is concentrated in the period 250-260 day (7-17 September 1998), where we found $n_c = 21$, $\bar{n} = 8.14$.

If we investigate in more detail the coincidences in a period including the ten days, that is day by day, we find the result given in the Fig. 3.

We have evaluated, by means of the Kolmogoroff test, the probability that the distribution of the coincidences, as shown in Fig. 2, be a background fluctuation. The cumulative distribution is given in Fig. 4 showing that the probability the coincidence distribution being a background fluctuation is $P_{\text{Kolm}} = 0.5\%$.

It is important to verify whether the operational conditions of the apparatuses in that period were not such as to cause this abnormal behaviour. We show in Fig. 5 the history of $T_{\text{eff}}$ averaged over each ten-day period for EXPLORER and NAUTILUS, the average number of events per hour and the number of common hours of operation for the various ten-day period. By inspecting this figure we notice a coverage of about 50% for most ten-day periods and a varying number of events per hour, but not such to justify any special behaviour in the period 250-260 days.

A very important test for verifying that the observed number of accidental coincidences is not, with high probability, a background fluctuation and that the apparatus is properly working can be done by studying the delay histogram with a reasonably sufficient number of delays for the estimation of the accidentals (Astone et al. 2000). The accidentals have been obtained by time shifting one of the two event list with respect to the other one by time steps of 2 seconds from -1000 s to +1000 s, as shown in

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\(^1\) In this paper we study in more detail the results published in our previous paper (Astone et al. 2001), thus we maintain the same definition of event. The events used for IGEC were obtained with a different threshold and a different waiting time.
Fig. 2. In the upper graph we show the number of coincidences \( n_c \) (full line) and the average number of accidentals \( \bar{n} \) (dashed line) for the various ten-day periods. In the lower graph we show the Poisson probability that, given the average \( \bar{n} \), we have by chance a number of coincidences equal or greater than \( n_c \).

Fig. 3. Day-by-day average number \( \bar{n} \) of accidentals (dashed line) and number \( n_c \) of coincidences (solid line) in the period 28 August-27 September 1998.

Fig. 4. Cumulative distribution for the coincidences (asterisks) and the accidentals (dashed line) versus the day of the year.

In our previous paper (Astone et al. 2001) we analysed the data taking into consideration that, as the Earth rotates around its axis during the day, the detector happens to be variably oriented with respect to a given source. Thus we expect the signal to be modulated during the day; more precisely the modulation is expected to have a period of one sidereal day, since the GW sources, if any, are certainly located far outside our Solar system.

We proceed here just as done for the 2001 data. Thus we search for coincidences at each sidereal hour. For the calculation of the sidereal hour we use the Greenwich time, instead of the EXPLORER-NAUTILUS local time (longitude = 9.46°), as done in the paper Astone et al. 2001. The time difference is of about 38 minutes. The 1998 result is shown in Fig. 4.

We notice that the coincidence excess occurs at the same sidereal time as found with the 2001 data, when the detectors are well oriented with respect to the Galactic Disc. It turns out that at this time of the year sidereal and solar hour almost coincide: at solar hour 3.5 we have sidereal hour 4. The peak shown in Fig. 4 has a well defined physical meaning with respect to the Galactic Disc, as already found with the 2001 result.

None of the detected coincidences happens to be at a time when the cosmic ray detector operating on NAUTILUS indicates the arrival of a cosmic ray shower.
4. Conclusion

The small coincidence excess between the GW detectors EXPLORER and NAUTILUS, already found (Astone et al. 2001) with the 1998 data, is concentrated in the ten-day period 7-17 September 1998, when the coincidence excess becomes remarkably large. We have checked that the operational conditions of the apparatuses were not such as to justify a special behaviour in those days and, particularly, we checked that the distribution of the delayed coincidences is well behaved, supporting the statistical significance of the coincidences excess.

Nevertheless a warning must be made on the probability estimation. The ten-day period 7-17 September has been chosen \textit{a posteriori}. Thus any probability figure has to be taken with care. However, we remark that the distribution of Fig. 2 has small probability to be a background fluctuation and that the coincidence excess occurs at the same sidereal hours found in 2001.

A problem is encountered if the signal amplitude is considered. In 1998 the signals had energies of the order of one half kelvin or more ($h \geq 10^{-17}$), larger than those found with the 2001 data analysis (Astone et al. 2002). However the signals in 1998 are concentrated in a short time interval with a special sidereal time signature, suggesting that the phenomenon, if any, is local both in space and time, and therefore it may not be expected to happen again in a few year time scale.

Fig. 6. Delay histogram (upper graph) and Poisson distribution (lower graph) of one thousand delayed coincidences for the period 7-17 September 1998. We have $n_c = 21$ coincidences at zero delay, and an average number of accidental coincidences $\bar{n} = 8.14$.

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Fig. 7. In the upper graph we show the coincidences $n_c$ (full line) and the average accidentals $\bar{n}$ (dashed line) versus the sidereal hour for the period 7-17 September 1998. In the lower graph we show the Poissonian probability that, given the average $\bar{n}$ we have by chance a number of coincidences equal or greater than $n_c$. 