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Comments on the 2001 run of the EXPLORER/NAUTILUS gravitational wave experiment

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Abstract
The recently published analysis of the coincidences between the EXPLORER and NAUTILUS gravitational wave detectors in the year 2001 (Astone P *et al* 2002 *Class. Quantum Grav.* **19** 5449) has drawn some criticism, reported at this workshop. We do not hold with these objections, even if we agree that no claim can be made with our data. The paper we published reports data of unprecedented quality and sets a new procedure for the coincidence search, which can be repeated by us and by other groups in order to search for the signature of possible signals. As for the reported coincidence excess, we remark that it is not destined to remain an intriguing observation for long: it will be confirmed or denied soon by interferometers and bars operating at their expected sensitivity.

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1. Comments on the experimental results

At the time of this workshop, the 2001 scientific run performed by our gravitational wave (GW) detectors EXPLORER and NAUTILUS [1] constitutes the most sensitive experiment

Table 1. Numbers of observed coincidences n_c and integral numbers of accidentals $\bar{n}$ for various sidereal time intervals around hour 4. The last column gives the Poisson probability that a background fluctuation produces n_c or more counts.

Sidereal time period (h)	n_c	$\bar{n}$	P
4	4	0.92	0.0145
3–5	7	1.69	0.0018
2–6	8	3.45	0.025
1–7	10	5.01	0.032
0–8	13	6.2	0.011

for the detection of GW bursts ever carried out. When we analysed the data collected, we became convinced of the importance of communicating that unprecedented sensitivities were reached by our detectors and that the use of powerful tools in analysis of the data (energy consistency of the events and sidereal time analysis) led to a coincidence excess centred at sidereal hour 4, which was defined in the paper as 'an interesting indication'.

Criticisms of this analysis have been reported at this workshop (and published [2]). A first criticism regards the mere existence of a coincidence excess. It is stated that the potential significance of the peak centred at sidereal hour 4 must be 'diluted' because we did not declare before the analysis (i.e., *a priori*) that we were searching for sources giving excess in that sidereal hour (i.e., galactic sources). In other words, the significance of the peak was recognized *a posteriori*. As a consequence, the probability should be decreased by roughly a factor of 24 because *a priori* the peak could have been found in any of the 24 sidereal hours.

To be quantitative about what we called an 'interesting indication', let us report (see table 1) the Poisson probabilities of the observed number of coincidences with respect to the corresponding number of accidentals in intervals of increasing duration centred at sidereal time 4.

These probabilities are, at most, at the level of a few per cent. Instead, going up to the full 24 h period, the overall number of coincidences (31) with respect to the accidentals (25) gives a Poisson probability of 0.14.

We are well aware that extraordinary claims need extraordinary evidence. By simply looking at these Poisson probabilities, we see that the coincidence excess we reported was certainly not strong enough to claim a detection, and in fact no such claim was made in our paper. However, two remarkable facts need to be underlined and give sense to the words 'interesting indication'.

- The peak is centred at a physically significant sidereal hour, corresponding to the most favourable orientation of the detectors with respect to sources in the Milky Way, and the galaxy is certainly the privileged place of the sources attainable by present GW detectors. Recent work by Paturel and Baryshev [3], quantitatively indicated the signature expected from galactic sources in bar detectors of different sensitivity, and in particular the presence of a peak centred at sidereal hour 4 for EXPLORER and NAUTILUS. So we do not think that the reported Poisson probabilities should be further 'diluted' by a factor taking into account all the possible peak positions in sidereal time.
- There is a strong energy correlation for the coincidence events during the sidereal hour interval 3 to 5 (see figure 8 of [1]). For those events the output of the two detectors has a correlation coefficient of 0.96 and the slope of the linear regression line for NAUTILUS energy with EXPLORER energy is 1.18, which, within the accuracy of the detector calibration, is in agreement with the hypothesis of having equal signals on the two parallel

bar detectors. In contrast, the events at the other sidereal hours exhibit a correlation coefficient of -0.19 (a very poor correlation, as expected for random values).

Another criticism raised in the workshop is that, since a bar detector has a rather broad antenna pattern, one should expect a correspondingly broad peak in the sidereal time distribution of the coincidences, instead of the relatively narrow peak reported in [1]. This argument is very weak, because, given a source distribution, the geometrical antenna pattern of a single detector is not representative of the distribution of the coincidences between two detectors. Each detector has its own detection efficiency, which depends on the detector noise, threshold and on the signal level. The coincidence distribution depends on the product of the efficiencies of the two detectors, and may give a relatively narrow peak if, for instance, the signals are near the thresholds. This is shown, with various examples, in [4]. The fact that the width of the peak depends on the signal level and detector threshold was already shown for a single detector in [3], where the case of EXPLORER was explicitly considered.

For these reasons, we disagree with the objections to our paper, even if we agree that no claim of detection can be made with our data.

Last comment: we were told that some statements in our paper about the possible contribution of real GW signals to our data led the reader to think that we were claiming a discovery. We admit that, in spite of our conservative attitude, in a couple of phrases the possible presence of GW signals in our data was considered. On the other hand, it should be recognized by any experimentalist that it is difficult to take data with detectors of unprecedented sensitivity, containing the reported indication, without at least being open to this possibility.

2. The future

In order to calculate the probability, or the degree of belief, of having observed real GW signals (and not simply the Poisson probability that a background fluctuation produces n_c or more counts), one should introduce astrophysical models for the sources. We deliberately left out this step in our paper, for two reasons: because we wanted to keep separate the observations from the possible astrophysical interpretations and, moreover, because we thought that more data were needed to evaluate the (unexpected) possibility that many GW bursts at the level of $h \simeq 2 \times 10^{-18}$ are bathing the Earth.

The exercise presented by Astone [4] at this workshop outlines how we can proceed in the future: updating the degree of beliefs, adding new pieces of information as more data become available. We think that paper is an important contribution to the debate (now starting) on how to evaluate and compare the results reported by different gravitational wave experimental collaborations.

In conclusion, let us say that we are proud to have crossed the benchmark of 'nihil obstat' upper limit on the strength of the wave: we find that the amplitudes and rate of our candidate events are not only compatible with existing experimental upper limits[10] but also they are permitted by theoretical upper limits on gravitational wave strengths based on cherished beliefs about the astrophysical structure of the galaxy and about the physical laws governing gravitational radiation [5]. This was not the case for the events observed by Weber with the first generation bars at room temperature, in which amplitudes were at least two orders of magnitude larger and which can be explained only by invoking unconventional hypotheses, such as strong beaming by sources near the galactic centre, or today being a very special time in the evolution of the galaxy [5].

[10] See the IGEC contribution to this workshop.

We remark that the indication we reported is not destined to remain an intriguing observation (and source of trouble . . .) for long: the existence of bursts bathing the Earth at the level of $h \simeq 2 \times 10^{-18}$ and at a rate of many per year would be such an unexpected gift from nature that it will easily be confirmed or denied soon with interferometers and bars operating at their expected sensitivity.

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