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Coincidences in Gravitational Wave Experiments

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1 – INTRODUCTION

The experimental information about gravitational waves is practically nonexistent. The only available experimental information comes from the binary pulsar PSR 1913+16 by J.H. Taylor and J.M. Weisberg(1), which shows indirect evidence for gravitational waves emitted by a continuous source and their quadrupole nature.

We believe it is likely that the direct observation of gravitational waves will show phenomena at present unpredictable, as most of the times have happened in science for new discoveries.

In designing the experiment we must certainly take into consideration the present theories of gravity , but we must be careful not rely on them too much. We must try to keep our mind open. Our search for gravitational waves will be based on experimental data obtained by applying the technique of coincidences among two or more detectors and by the statistical treatment of the data. We believe that this is one of the most delicate problems.

In the following we shall discuss an experimental method to estimate the probabilities, already used by Joe Weber and by the gravitational waves hunters who had operating detectors. The outcome of this method we call experimental probability. We shall indicate the care needed when applying to the raw data filtering procedures for detecting small signals embedded into noise and finally we shall discuss the importance that the probability be estimated only on "a priori" bases.

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2. THE EXPERIMENTAL PROBABILITY

When measuring a physical quantity x the final result is its value with instrumental and statistical errors. Actually, even when the calculation of the error is possible, it is by far always preferable to determine it experimentally. For determining the instrumental errors one must repeat the experiment with different techniques. For the statistical errors the measurement of the quantity x is repeated N times, with an instrument so sensitive that the N measurements do not always give the same value, because of the unavoidable accidental errors due to several unknown causes. As well known, the statistical error is given by the standard deviation σ and the final result is written as $<x> \pm n\sigma/\sqrt{N}$ n being a chosen number, with the well-known probabilities, if the measurement distribution is of the gaussian type, that the true value of x be in the above interval, for a given n.

In physics, very often, n is required to be large. If we take, for example n=3, the gaussian probability that the true value lies outside the interval $<x> \pm 3\sigma/\sqrt{N}$ is of the order of 0.54 %, and one would think that is small enough to ensure that the true value be inside the above interval. However, it has happened several times in science that new measurements of the same physical quantity made with different instrumentation have given values outside the interval. For this reason most physicists feel (we have had several discussions on this point with colleagues working in high energy physics) that one is safer if he takes an interval with a larger n value, say n=7. This value gives a probability of 10^{-12} that the true value be outside the interval. The reasons why one might find values different from each other more than allowed by the error are clearly the following ones: i) wrong evaluation of the standard deviation σ; ii) systematic errors; iii) use of the gaussian law without having fully tested its applicability.

A similar situation happens when considering measurements leading to the detection of a physical event. In this case one determines the probability that the detected event not be due to noise, and this probability can be also given in terms of standard deviations. Again the problem on the number of standard deviations needed for being confident in the validity of the result arises. We shall show, in the following of this note, that this problem can be solved and the difficulties overcame in the cases when the physical quantities of interest are detected by means of the technique of coincidences between two or more different detectors.

Let us consider two detectors located at large distance one from the other. They measure the same physical quantity, say gravitational waves, or different quantities, say: gravitational waves and neutrinos. They detect "events" that, in the simplest case, are characterized by an amplitude (i.e. the energy of the neutrino or the energy innovation in the g.w. detector) and the time of occurrence: x(t). The definition of event may depend on the chosen threshold and other parameters. The experiment consists in the detection of a phenomenon occurring simultaneously, or with a given delay, in the two detectors. In this case the signal is the number n_c of coincidences in a given time window Δt, at a delay established <u>before</u> starting the data analysis (the delay is zero for real coincidences), subtracting the background. This is given by the number of coincidences found by pure chance. As well known, the accidental coincidences can be calculated for the stationary cases with the formula

$$<n> = N_1 N_2 \Delta t / t_m$$

where N_1 and N_2 are, respectively the number of events for each of the two detectors in the period t_m of data taking. The probability to have n_c or more coincidences while expecting $\langle n \rangle$ on the average can be estimated with the Poisson statistics (which becomes the gaussian statistics for large $\langle n \rangle$ values) using well-known formulas.

This procedure is correct, of course, if the statistics is really poissonian, that is not always true. It is possible to solve the problem in the general case by introducing the experimental probability (Professor Joe Weber made large use of this procedure) as follows. We consider the shifted coincidences $n_c(\partial t)$, that is we look for coincidences after having changed the time of occurrence of the events of one of the two detectors by ∂t (for the real coincidences $\partial t=0$). We repeat this for N different values of ∂t, obtaining N numbers $n_c(\partial t)$. We count how many times m the following unequally is verified

$$n_c(\partial t \neq 0) \geq n_c(\partial t=0) = n_c$$

If n_c is due to chance we expect on the average that the above inequality be verified N/2 times. In general, the quantity

$$p=m/N$$

estimates the probability that the n_c or more coincidences occurred by chance.

We want to stress that this probability is determined experimentally and it does not depend on any model. This is very different from the case of one single detector, when the noise cannot be taken usefully into consideration without a convenient modeling. The different behavior of the coincidence background with respect to the one detector noise makes the coincidence technique very powerful for the search of new phenomena. In the writers' opinion this point is not yet fully understood by a large part of the scientific community.

We now go back to the case of one detector only, to better understand the enormous difference with the case of two detectors. We do this with an example. During the Supernova SN1987A the Kamiokande neutrino detector revealed a burst of 11 neutrinos in 13 seconds. It has been stated that the chance to have such a clustering of neutrinos by accident is of the order of once in 100 million years. This is based on the assumption that the neutrino background follows the Poisson distribution. In the paper published by the Kamiokande group(2) they show that data were recorded for 42.9 days. During this period the distribution was poissonian with the exception of the 11-neutrino event. In our opinion the Kamiokande detector alone cannot prove the existence of a new phenomenon, because the observed burst, in spite of the calculated probability of once in 100 million years, could have been produced by unknown noise. The correct way to treat the problem is to consider all the recorded data as the measured background and to compare them with data taken with another detector. For the SN1987A the burst occurred within a few hours from the visual detection of the Supernova. Thus, taking a reasonable window of 6 hours, the probability that such a coincidence may have occurred by chance during the 42.9 days is

$$p \approx 6 \text{ hours} / (24 \text{ hours} \times 42.9) \approx 0.006$$

This probability is equal to that corresponding to 2.8 σ. The probability improves if we consider the coincidence with the IMB burst of 8 neutrinos in 6 seconds. Since the Kamiokande uncertainty on the time is ±1 minute, we calculate the probability

$$p \approx 2 \text{ min} / (1440 \text{ min} \times 42.9) \approx 3\ 10^{-5} \text{ (about } 4\ \sigma)$$

to have the coincidence with IMB by chance. (In the IMB case, however, "a posteriori" considerations on the IMB neutrinos have been made).This is much larger than once in 100 million years.

For completeness we calculate the probability to have the triple coincidence: SN light, Kamiokande, IMB. We have

$$p \approx 6 \text{ hours x } 2 \text{ min} / (1440 \text{ min} \times 42.9)^2 \approx 2\ 10^{-7} \text{ (about } 5\ \sigma).$$

In all cases the number of standard deviations related to the probabilities is not so large as required by the physicist working in other fields. In our opinion, however, the probability is small enough to support the hypothesis that supernova neutrino might have been detected. This is because the above probability estimation is, in this case, just the experimental probability, as it can be understood by considering that, with two detectors, for instance, having just one event each we get $n(\partial t)=0$ at all delays with $\partial t \neq 0$.

3 – EXTRACTING SMALL SIGNALS FROM NOISE

We discuss here the application of two different filtering procedures for pulse detection to the data of our two mode resonant gravitational wave antenna EXPLORER installed at the CERN in Geneva.

The EXPLORER detector of the Rome group(3) is a 3 meter long aluminum bar, weighting 2270 kg and cooled to 2 K. When hit by a gravitational wave the bar starts to vibrate at those resonance modes that are coupled to the g.w. The vibration at the bar's end face is converted into an electrical signal by an electromechanical capacitive transducer. Since we use a resonant transducer we have two resonance modes at 904.7 Hz and 921.3 Hz. The electrical signal from the transducer is amplified with a wide band very low noise SQUID preamplifier. The output signal from the SQUID instrumentation is processed by means of two different procedures:

1) it is sent to four lock-in amplifiers (a lock-in amplifier extracts the Fourier components of the input signal at a chosen frequency) that demodulate the signal at the frequencies of the two modes, at the frequency of the calibration signal used to monitor the gain of the SQUID, and at a frequency of 909 Hz that provides information on the wide band noise in the region between the two modes. The data of the channels processed by the lock-in amplifiers are sampled at a rate of 3.44 Hz (sampling time of 0.2908 s), about equal to the integration time (0.3 s) of the lockin's.

2) it is first filtered with a bandpass filter with flat response in the frequency range (902-927.5) Hz, that includes the resonance frequencies of the two modes, and strong attenuation outside, and then it is directly sampled at the rate of 220 Hz (sampling time of 4.54 ms). As a

result, the signals in the frequency region of our interest between 900 and 927.5 Hz are transposed in the range 20-47.5 Hz (as obtained subtracting 880 Hz from the above values).

In the following we will refer to the two different data processing as the "slow" and "fast" data taking[4].

One of the most important goals in the gravitational wave research is to detect the very short bursts due to gravitational collapses. A short burst is a signal that we may model as a delta function as regards its effect on the detector and the instrumentation. This is possible if its time duration is very small compared with all the time constants of the apparatus, including the sampling time which is different in the "slow" and in the "fast" data.

The noise of the detector is due to the brownian Nyquist noise of the mechanical oscillators, related to the thermal bath of the antenna environment, and to the SQUID and associated instrumentation, that contributes a flat (ideally) noise spectrum with spectral density S_o. This flat spectrum also heats the antenna with a backaction force which adds up to the Nyquist force and increases the brownian noise to an equivalent temperature level T_e giving a narrow-band spectrum with spectral density S_{uu}.

In addition to the fundamental noise that we model, there may exist some excess noise usually of non stationary nature, which shows up as pulses or as spurious resonance peaks.

We consider the optimal filtering of both the "fast" (FF) and the "slow" (SF) data. The best estimation of an input short signal, modeled as a delta function, whose effect is to modify the vibration status of the observed modes, may be obtained by using a Wiener filter or by using a matched filter.

It is possible to show that the actual bandwidth of the detection system, including the filter, near each one of the two modes, is

$$\Delta\nu = \omega_o / (2 \pi Q \sqrt{\Gamma}) \quad , \quad \Gamma = S_o/S_{uu}$$

where Q is the merit factor of the oscillator. In the EXPLORER detector Γ it is of the order of 10^{-7} and $\Delta\nu \approx 1$ Hz.

This bandwidth is much larger than the mechanical bandwidth of the antenna oscillator, as can be understood simply by noting that the bar responds in the same way to an excitation due to a burst of g.w. and to the brownian noise and, therefore, its bandwidth is limited only by the noise of the electronic amplifier. It is necessary to point out that using the "slow" data we process the two modes separately and then we combine properly the information that they both provide. We usually combine the two mode outputs in a single stream by selecting, at each sampling time, the minimum of the two outputs. For short bursts of the incoming gravitational radiation we expect the energy in both the modes be approximately (because of the noise) the same.

The information provided by the "fast" data is quite different, because it is equivalent to averaging the contribution of both modes. In absence of noise and of time discretization effects, for a very short input signal, we expect both the "fast" and "slow" filtered data to have exactly the same energy.

We have applied both the filtering procedures to the EXPLORER data from 19 June to 16 December, 1991. The effective number of days is 122 days, corresponding to a duty cycle of 67 %. The best sensitivity with the optimal filters is:

"slow" data @ 290.8 ms : $T_{eff} \approx 8$ mK, that is $h \approx 7.1\ 10^{-19}$.
"fast" data @ 4.54 ms :$T_{eff} \approx 4$ mK, that is $h \approx 5.1\ 10^{-19}$

We define "events" the filtered signals larger then a certain threshold which we choose E_t=80 mK. We found N_{slow} = 25098 and N_{fast}=19440 events. If the events were only of thermal and electronic origin we would have expected in 122 days of the order of 1600 (above 80 mK) for the slow data and less for the fast data. Thus most of the events were produced by external forces acting on the detector.

We have searched for coincidences between the SF and the FF events. Since they originate from the same experimental data using two optimum filters both aiming at detecting short bursts of g.w. radiation we expected a very large number of coincidences.

Indicating with <n> the average number of the accidental coincidences obtained by shifting all the occurrence times of one of the two data series by given amounts of time δt and with n_c the real coincidences, that is the coincidences we have with δt =0, we found n_c=187 with an expected number of accidentals <n>=8.3 for a window ±0.15 s, as shown in Fig. 1.

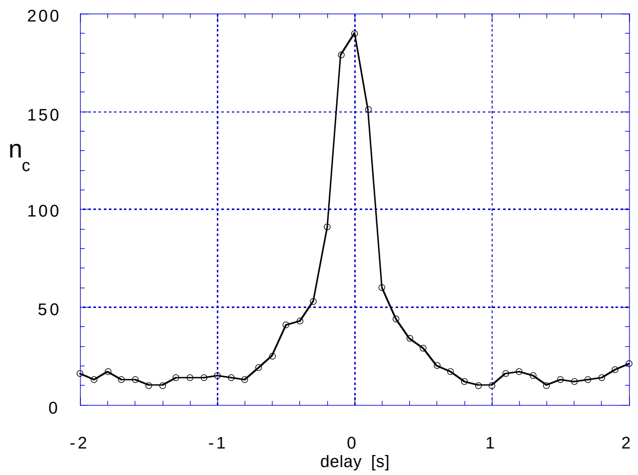

FIG.1 – Coincidences between FF and SF for EXPLORER
Coincidence window ± 0.15 s

The fact that only 187 coincidences are found using two algorithms which are supposed to do the same thing appeared, at a first sight, very strange.

For studying the problem we have used a simulation procedure, that is we simulated the bar brownian noise and the wideband noise and then we have processed and analyzed these data with both algorithms. The result of 14 hours of simulation (selecting events larger than 80 mK and using a window of ± 0.15 s) are the following:

$$N_{slow} = 273,\ N_{fast} = 476,\ n_c = 16\ ,\ \langle n \rangle = 0.59$$

The calculated accidental coincidences are 0.77 ± 0.9 (one standard deviation).

Only 5 % of the events due to the noise processes coincides. This is a very small percentage although it is greater than the 1 % that we have found on the real data, where we should consider that added up the coincidences due to the noise and those due to the action of external forces. The difference between 1 % and 5 % must be due to the fact that in the real case the events are not only due to the modeled noise fluctuations or to delta excitations due to external forces but also to other unknown non modeled noise that produce non appreciable coincidence excess. The events due to noise fluctuations and/or those due to spurious signals may be different in the two cases. Only those events due to input delta forces, with very large SNR, are expected to be seen at the same time by both the filters.

We have checked this last point by adding to the above noise 40 delta-events with SNR of the order of 1000. All 40 events were seen with the two filters, all of them with equal amplitudes.

We have performed a simplified theoretical analysis of the problem by studying the bar motion when the applied force is constant ≠ 0 for a duration τ_g. This is not a realistic waveform for a gravitational wave signal, but it is useful to understand, roughly, how different the response to the same input signal may be for the "slow" and "fast" filters. The force was applied at the exact time of a sampling.

We calculated the displacements of the bar and the transducer for three different values of τ_g, very close one to each other:

$$\tau_g = 179.05 \text{ ms},\ \tau_g = 179.12 \text{ ms},\ \tau_g = 179.25 \text{ ms}.$$

When the force terminates, the bar oscillation can remain small or large, depending on the energy delivered by the force at the exact time of its termination (Fig.2).

It turns out that the remaining oscillation is very small in the first case, larger in the second case and maximum, equal to the oscillation during the action of the force, in the third case. In all these cases the "fast" and "slow" optimum filters give very different results.

The fast filter gives always the same result, as expected, since, because of the fast sampling of 4.5 ms, in all the three cases the oscillations are identical during the time, longer than 4.5 ms, the force was applied.

The "slow" filter is sensitive, roughly, to the difference between the average energy in the bar at two successive samplings, 0.2908 s apart. The first sampling is the average during 0.2908 s (the averaging begins at the initial time the force was applied), partially covered by the applied force. The next sampling instead gives values due only from what energy was left in the bar. This left energy depends very strongly on the exact time the force terminated. Clearly, in the considered three cases, the differences between two successive samplings differ one from each other.

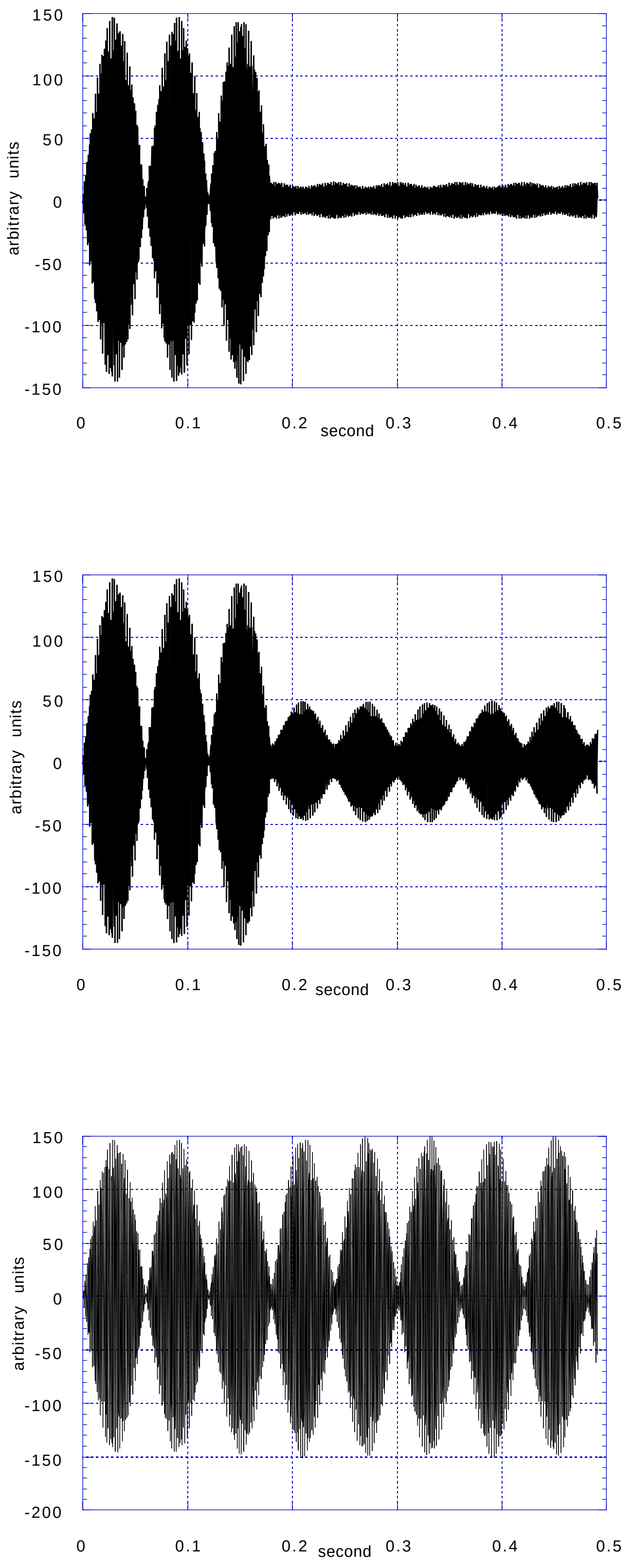

FIG. 2 – Oscillations of the bar ends due to the action of a rectangular force of duration τ_g=179.05 ms, τ_g =179.12 ms, τ_g=179.25 ms, from above.

Thus we realize how much care we must put when considering coincidences between events determined with different filtering procedures, in particular if the filters are based on different sampling times.

Another interesting case is obtained by running a coincidence program for the Louisiana State University data obtained in 1991 during the same period of time of EXPLORER (5). For LSU two different filters (WF and ZF) were applied to the experimental data, giving respectively, for a threshold of ≈ 100 mK, N_1=18606 and N_2=19112 events. One filter (ZF) had a sampling time of 8 ms, the other one (WF) a sampling time of 80 ms. The coincidences that were found within a window of ± 0.15 were only 20 % as shown in Fig.3.

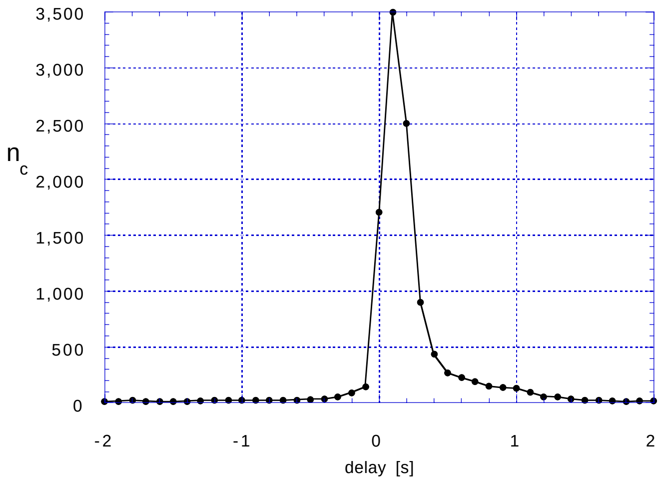

Fig. 3 Coincidence between WF and ZF for ALLEGRO
Coincidence window ± 0.15 s

In conclusion we have learned that, in order to compare data of various antennas, it is necessary to be extremely careful in using different data analysis algorithms. As a matter of facts the actual sensitivity of the coincidence experiments may be considerably reduced if different filters are employed. For instance, the null result of the first coincidence experiment (5) between the LSU and Rome cryogenic antennas should be reconsidered, in the sense that the energy threshold for the null result is certainly rather larger than claimed.

4 – THE "A PRIORI" PROBABILITY

Each one of us has certainly experimented in his life several facts that, by a simple probability estimation, one thinks they should not have occurred. Similar thinking brings some people to worry about what Universe and what Mankind it would had been if the electrical charge of the electron would had been a little bit different from what actually is. The crucial point of this paradox is that the word probability must not even be used for a fact that has already occurred.

We wish now to show an example of misuse of the probability concept.

The gravitational wave antennas ALLEGRO and EXPLORER have collected data during the period 19 June 1991 through 16 December 1991 as already indicated in section 3.

Coincidences were searched(5) for events with energy greater than 200 mK corresponding to h = 4 10^{-18} and none were found. The coincidence window was taken $\Delta t = \pm$ 1 s on the following bases.

As already indicated in section 3, both the ALLEGRO and EXPLORER data were processed each one with two different optimal filters. For ALLEGRO, one filter was developed by Warren Johnson (WF) and the other one by Zhu Ning (ZF). For EXPLORER we developed the "slow" (SF) and the "fast" (FF) filters as described in section 3. For ALLEGRO we looked for coincidences between WF and ZF and for EXPLORER between SF and FF using different windows. The result is shown in Fig. 4.

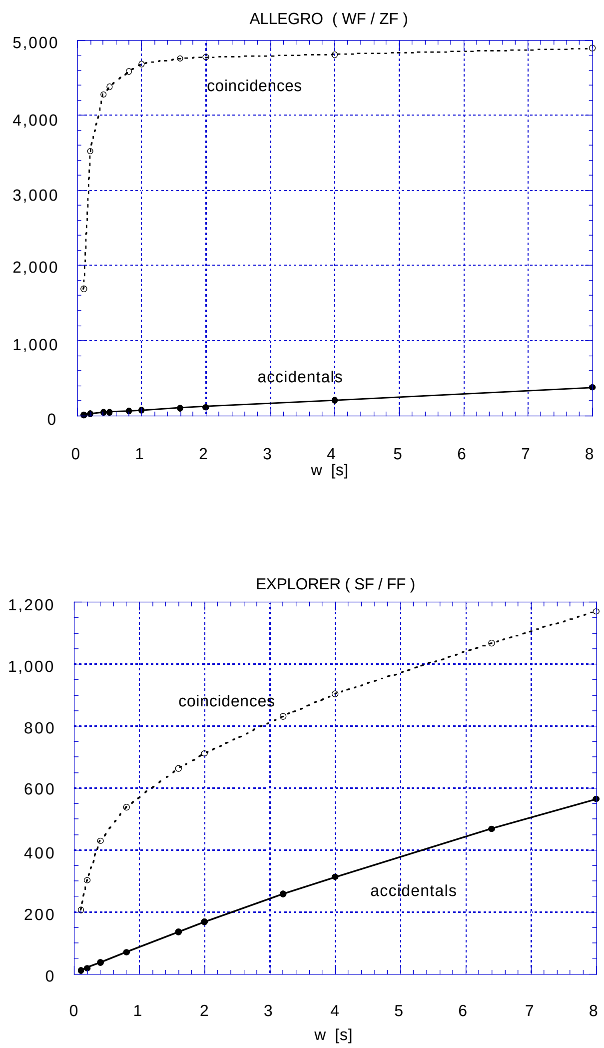

FIG. 4 – Coincidences for ALLEGRO and EXPLORER for various coincidence windows.

In Fig. 5 we show the coincidence excess (coincidences - accidentals) both for ALLEGRO and EXPLORER.

We deduce that if we want to obtain as most coincidences as possible we must employ, for these two detectors, a window of the order of at least ± 1 s, perhaps a little more..

Lowering the threshold to the minimum energy possible with our detectors we find the result shown in Fig. 6 for the window ± 1 s[5] indicating a small, statistically insignificant, coincidence excess.

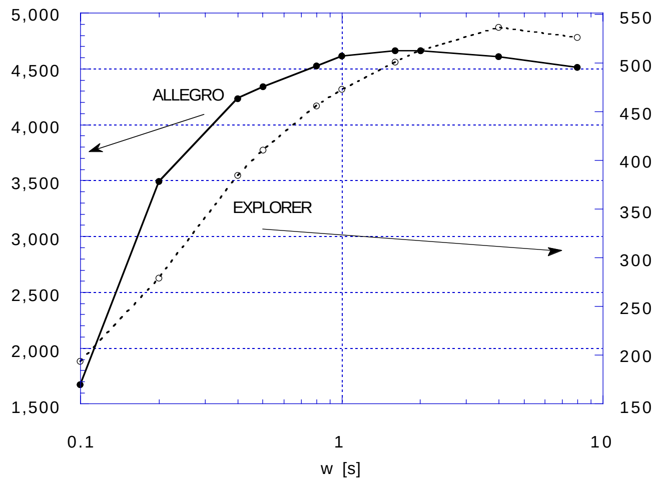

Fig. 5. Coincidence excess for ALLEGRO and EXPLORER.
We notice that a window of at least ± 1 s is needed

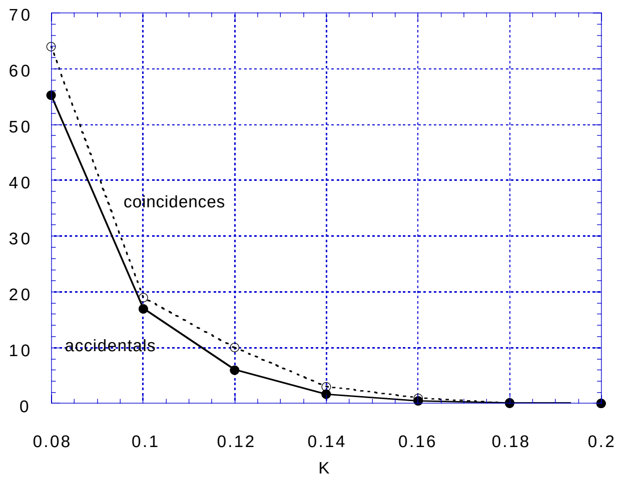

FIG. 6 – Coincidences between ALLEGRO-WF and EXPLORER-SF with a window of ± 1 s, versus the event energy.

(However on the basis of section 3 this result should be reconsidered in the sense that we know, now, that even if gravitational wave with amplitude h = 4 10^{-18} existed only a small fraction (perhaps a few %) of them would had given coincidences in the two detectors. Only for higher amplitudes, h ≈ 10^{-17}, all possible coincidences would had been detected).

Because of the large uncertainty in the window to be used, we decided to look for coincidences with window Δt = ± 0.1 s scanning the range -5 s through +5 s. We obtain the result of Fig.7, which shows no particular coincidence excess at any delay.

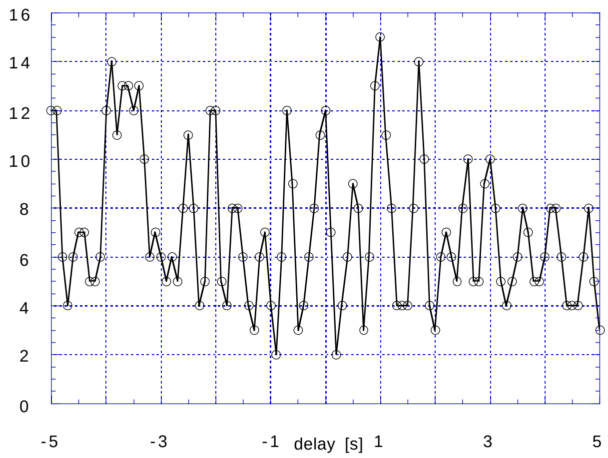

FIG. 7 – Coincidence delay histogram with window ± 0.1 s.

We know that during the period of time under study (19 June-16 December 1991) there were periods of higher disturbances for the EXPLORER antenna. In order to eliminate these periods we can decide to eliminate all the hours of the antenna data taking having a number of events Nh larger than a given number, provided that this data elimination does not reduce to much the observation time.

This criterion has been already used in the preparation of the Explorer event list, as only those hours with less than 60 events were taken. In order to improve the SNR we have applied again this procedure, choosing only those hours with less that 10 events. In doing this we found that while the background decreases by a factor of 5 we loose only about 26% of the total observation time.

The result of such a selection is shown in Fig.8.

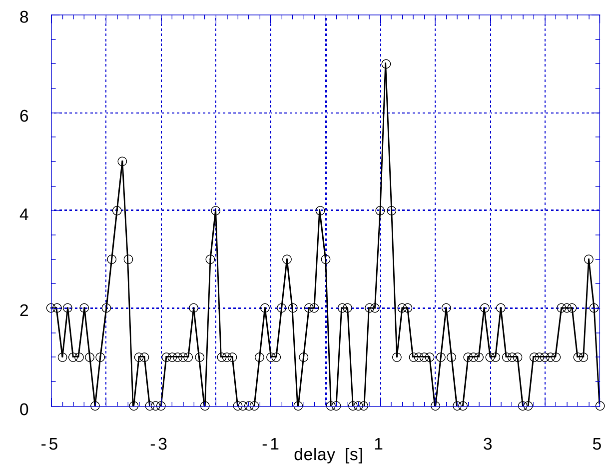

FIG. 8 – Coincidences with data selection Nh≤10 event/hour.

We notice that we have a large peak at a delay of 1.1 s, with a poissonian probability to be accidental of 3.2 10^{-4}, , since <n>= 1.25.

If we take this result seriously we might try to imagine where the sources for the events detected by the antennas could be located. An obvious place is the Galactic Center.

In this case we expect an improvement in the signal to noise ratio by selecting the events recorded when the resonant g.w. bars were favorably oriented with respect to the Galactic Center. Considering the angle δ between the bar axes (ALLEGRO and EXPLORER were oriented such to be nearly parallel one to each other) and the direction to the GC we selected only the events recorded when $\sin^4(\delta) \geq 0.5$ (we recall that the gw cross-section behaves as $\sin^4(\delta)$).

The result of this additional data selection is shown in Fig.9.

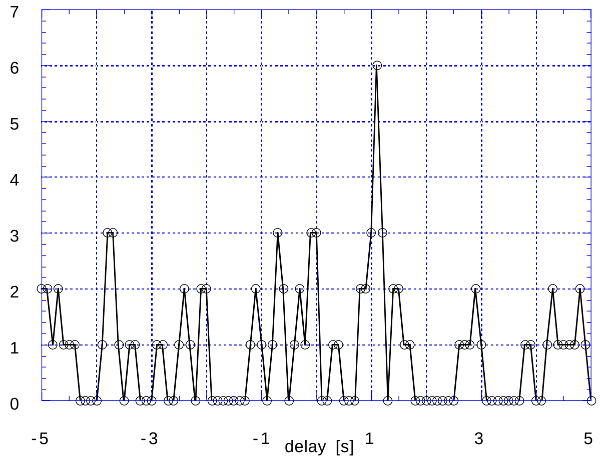

FIG. 9 – Coincidences after data selection with Nh≤10 event/hour and $\sin^4(\delta) \geq 0.5$.

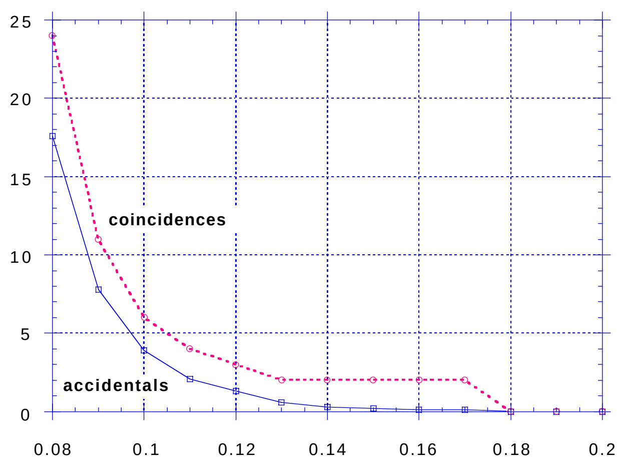

FIG. 10 – Coincidences between Allegro and Explorer for Nh ≤ 10 event/hour and for a window of ±1.5s.

The accidentals reduced to <n>=0.69, and the coincidences to 6, for a poissonian probability of 8.3 10^{-5}. The experimental probability is also found to be of the same order.

Finally it is interesting to search again for coincidences at zero delay by making use of the last selection criteria, Nh≤10 event/hour, and with a window of ± 1.5 s , as it appears more reasonable from Fig. 5. We obtain the result of Fig. 10, where the coincidence excess is more pronounced than that reported in Fig. 6.

5 – **CONCLUSIONS**

From the above analysis one is tempted to conclude that a coincidence excess was found. The probability for the excess to be accidental is small, even considering a worsening because the delay of 1.1 s was found "a posteriori" (but within the coincidence window uncertainty). This result could also indicate that a time error of the order of 1 s was made either by EXPLORER or ALLEGRO, but to check it now it is not possible.

In our opinion the above conclusion is absolutely wrong.

In a statistical data analysis only "a priori" considerations are valid. The reason we brought to discussion the above example was simply to show the danger hidden in certain kind of reasoning.

The only result we can use from our analysis is having found a procedure to be applied to new experimental data, when they will be available.

Sometimes a blind procedure has been suggested, as exchanging many sets of data (say 1000 sets) only one of which be the true one. This would bring the probability, if one finds the true set, to 10^{-3}, "only 3 σ" and, if the result is very striking, as expected for new physics, nobody would believe it, any way, and the work done would result just in a waist of human resources.

It is difficult to accept a result that does not find its location in the known physical theories and we agree with what we have learned on the textbooks: a new experimental result must be obtained also by another group with different instrumentation.

We must keep our mind open but if a result occurred just once, it is of no use in science.

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REFERENCES

1) J.H. Taylor, J.M. Weisberg "A new test of general relativity: gravitational radiation and the binary pulsar PSR 1913+16"
Astrophysics J. 253, 908 (1982)

2) K.S.Hirata et al.
Phys. Rev. D, 38, 448 (1988)

3) P.Astone, M.Bassan, P.Bonifazi, P.Carelli, M.G.Castellano, G.Cavallari, E.Coccia, C.Cosmelli, V.Fafone, S.Frasca, E.Majorana, I.Modena, G.V.Pallottino, G.Pizzella, P.Rapagnani, F.Ricci, M.Visco
Phys. Rev. D47, 2 (1993).

4) P.Astone, S. Frasca, G.V.Pallottino, G. Pizzella
"Comparison between different data analysis procedures for gravitational wave pulse detection"
First Edoardo Amaldi Conference on Gravitational Wave Experiments
Frascati, 14-17 June 1994

5) P.Astone, M.Bassan, P.Bonifazi,M.G. Castellano, G. Cavallari, E.Coccia, C.Cosmelli, V.Fafone, S.Frasca, K. Geng, W.O. Hamilton, W.W. Johnson, E.Majorana, E.Mauceli, S. Merkowitz, I.Modena, A. Morse, G.V.Pallottino, G.Pizzella, P.Rapagnani, F.Ricci, N. Solomonson, M.Visco, N. Zhu
"Result of a preliminary data analysis in coincidence between the LSU and Rome Gravitational wave antennas". Proceedings of the X Italian Conference on General Relativity and Gravitational Physics. Bardonecchia, 1-5 September 1992