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Correlations between Coincidences of Gravitational Waves Nautilus and Explorer and X-ray Emission of 4U1820–30 and XTE J1550–564

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Abstract We have considered, in the past two years, coincidences between the gravitational wave detector NAUTILUS and EXPLORER in order to study fluxes of projectiles or Gravitational Waves, produced by a limited numbers of cosmic source. We use coincidences between the two distant detectors as a good tool in order to minimize local noise and we have chosen a coincidence time acceptance window of ± 5 s against a ± 0.5 s or less used until now, conscious that we are accepting coincidences accidental in this way. Results are shown.

Key words: accretion disk — star individual (4U1820–30) — gravitational waves – neutrinos — X-ray binaries — star individual (XTE J1550–564)

1 INTRODUCTION

– EXPLORER at 46.45° lat North 6.20° long East Azimuth 39.3E is located in CERN Geneva (P.Astone et al. 1993)
– NAUTILUS at 41.82° lat North 12.67° long East Azimuth 44E is located in Frascati (P.Astone et al. 1997)

The directional power resolution of these resonant wave detectors is poor $\pm 30^\circ$ but good enough to discriminate between sources uniformly distributed in the galactic plane or located in the galactic center. All data are collected with $T_{\rm eff} = 7$ MK and signal to noise ratio $\rm SNR = 19.5$ and the number of the coincidence detected are reported in Table 1.

Table 1 List of coincidence Nautilus and Explorer in 1998, 2001 and 2003

From	To	Period	$dt < 0.5$ s	$dt < 3$ s	$dt < 5$ s
06-Jun-98 (D157 JD2450970)	13-Dec-98 (D347 JD2451160)	190 d	103	670	1132
05-Mar-01 (D 64 JD2451973)	22-Oct-01 (D326 JD2452235)	162 d		186	
10-May-03 (D130 JD2452770)	10-Dec-03 (D344 JD2452983)	214 d			388

Characteristic of these coincidences are: Coincidences are tied up together in groups of $5-10$ days and seems to have a periodicity of 170 days. In the following we use the flux rate, i.e. (coincidence counts)/(time of collection)*(dt coincidence time acceptance) as a good parameter. And in order to study the projectiles flux, the nature, the periodicity, the position of the source with lower statistical error we increase the time acceptance window. For instance in the data collection of 1998 we have 100 coincidences within $\pm\ 0.5$ s but 1132 coincidences within $\pm\ 5$ s. We are conscious that in this way our coincidences are mainly accidentals and we are detecting projectiles hitting each detector independently or a GW train hitting both detectors, inefficiently and therefore after the hit in the first detector, need wait some time to detect a second hit in the second detector.

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In other words increasing dt means increasing GW detection. Data collected with NA+EXP are statistically very poor and with bad directionality. With this in mind we can improve our understanding by looking not only EXP+NA coincidences, but also X-rays collected by satellites from many sources. We found the data in the archive of NASA where it is possible to find X-ray light curves,periodicities, ephemerides, and quasi periodical oscillations (QPO).

By studying behaviour coincident with X-ray emission we have found sources such as the Black Hole candidate XTE J 1550–564 that have emitted projectiles detected by NA+EXP, and a strong X-RAY flare detected by satellites in Sept 1998. Also we find that 4U 1820–30 has been emitting projectiles detected by NA+EXP with periodicity of 171 days.

Figure 1 shows a scatter plot of the arrival time of the projectiles in a 171 day period vs number of the cycle. The number in parenthese next to the year is the total number of coincidences considered.

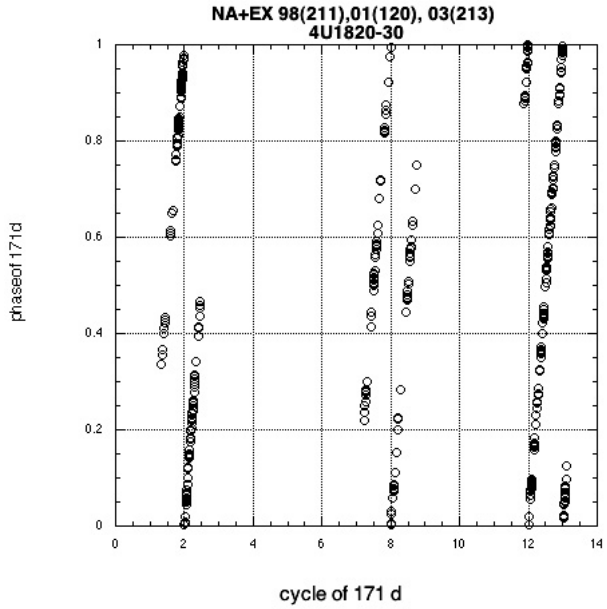

Fig. 1 Scatter plot of Nautilus and Explorer coincidence (1998 – 2003): phase (171 days) vs number of cycles.

2 BINARY SYSTEM 4U1820–30

4U 1820–30 is a binary system of a neutron star and a white dwarf orbiting with a period of 11.4169 min. It is believed that the presence of a third companion rotating with 1.1 days period induces an eccentricity variation $P_{\rm long} = KP2_{\rm third}/P_{\rm inner}$ that is to say (Mazeh 1979), a close approach every 171 d, and a negative and very small derivative of the period P'. The ephemerides of 4U1820–30 are RA=18.20 Sh, Dec$= -30^{\circ}$, $P{\rm o} = 171.033 \pm 0.326$ d, $P' = -7.54{\rm e}^{-13}$, $T_{\rm o} = 2450738.867(\pm 11.66)$ JD (Y.Chou et al.2001) (L.Stella et al. 1997). It is located in the globular cluster NGC 6624 close to the Galactic Center, 24000 light years from us.

Mass is torn from the White Dwarf producing an accreting hot disk before falling in to the neutron star. The temperature rises hundreds millions degrees and thermal X-rays are emitted. The minimum in the X-ray intensity is produced when the distance between the two stars is minimum. This phase is very important in test of Relativistic Gravity. At this phase, some times there is emission of a burst of X-rays due to nuclear reactions (H-He burning to C). Variation with amplitude ranging between from 40 and 5 counts s^{-1} per proportional counter unity (PCU) of the RXTE (Rossi X-ray Timing Experiment) in the Light Curve of 4U1820 are shown in Figure 2. A best fit to the Light Curve (Y.Chou et al. 2001) is shown in Figure 5.

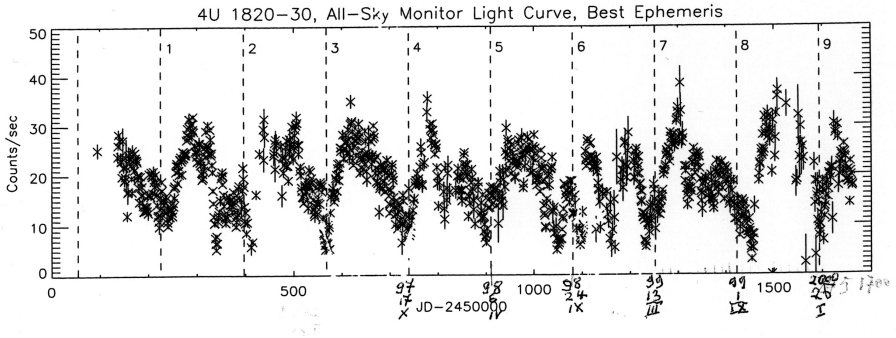

Fig. 2 X-ray light curve of 4U 1820–30 (Y.Chou et al. 2001).

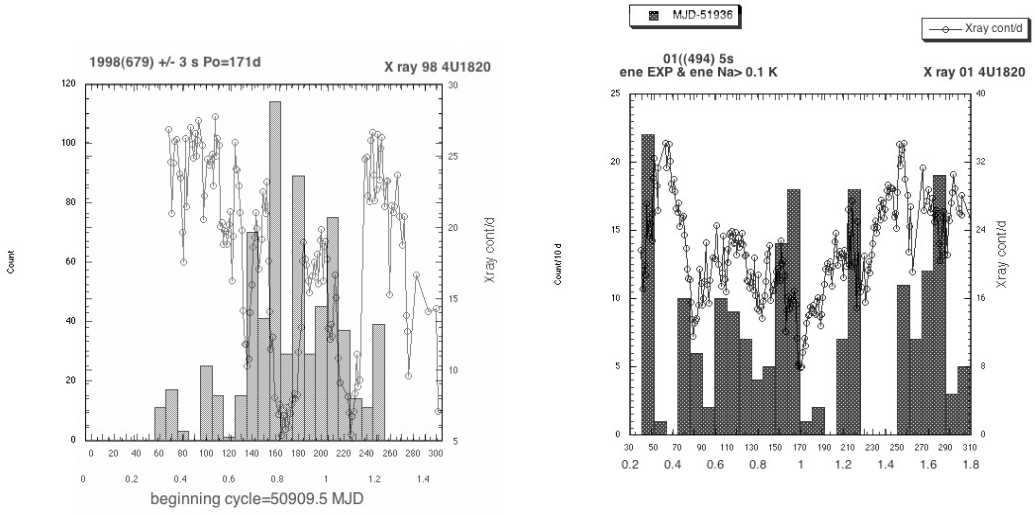

Fig. 3 Coincidence Nautilus Explorer and Xray Light curve for year 1998 (Left) and 2001 (Right).

In Figures 3 and 4, the NA+EXP coincidence flux is compared with the X-ray light curve of 4U1820–30 for the years 1998, 2001 and 2003.

As clearly seen in the 2001 and 2003 , NA+EXP coincidences occur in the phase intervals 0.8–1, 0–0.1 and 0.4–0.5 of 4U 1820–30. It seem that NA+EXP coincidence flux maximizes near rapid variation of the X-ray intensity and is not proportional to the X-ray intensity. We know that the gaseous material pulled out of the White Dwarf forms an accretion disk and before falling to the neutron star goes into a marginal orbit. It is possible to detect this looking at the Xray intensity modulation (Quasi Periodic Oscillation)of 400–1050 Hz. In order to predict when Na+EXP have coincidences we need to know the timing of the QPO but unfortunately the observers were interested in the color of the X-rays and not in the date (as for 4U 1820). For us the date is very important and therefore we asked NASA for the measurement files for the years 97, 98, 99, 203 from the archive. We obtained these plus the software necessary to derive the light curve, frequency of QPO (F. Murtas 2004). Figure 4 shows as an example two power spectra as functions of frequency observed at time intervals of about 23 hours.

Figure 5 shows QPO frequency,phases and best fit to the X-rays intensity. NA+EXP received a strong flux of coincidences when QPO are in the phases $0-0.1$, $0.4-0.6$, $0.8-1$ using period of 171 days and the QPO frequencis are $400-1025$ Hz.

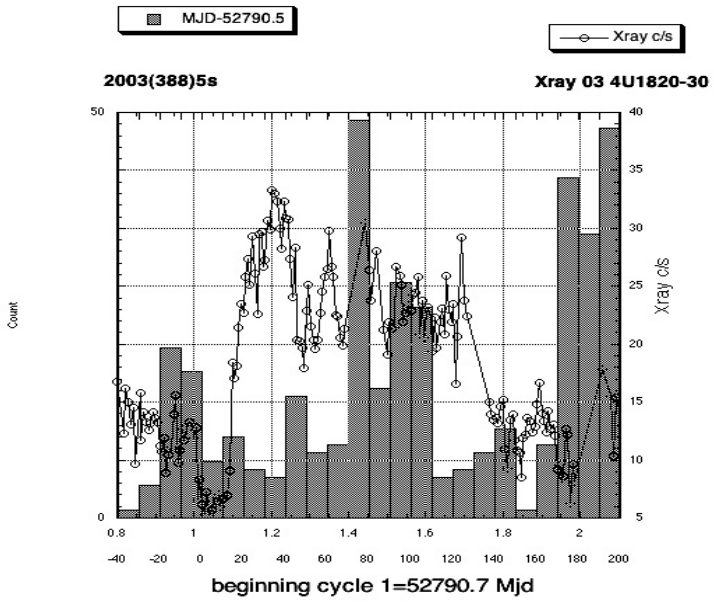

Fig. 4 Coincidence Nautilus Explorer and X-ray light curve for year 2003.

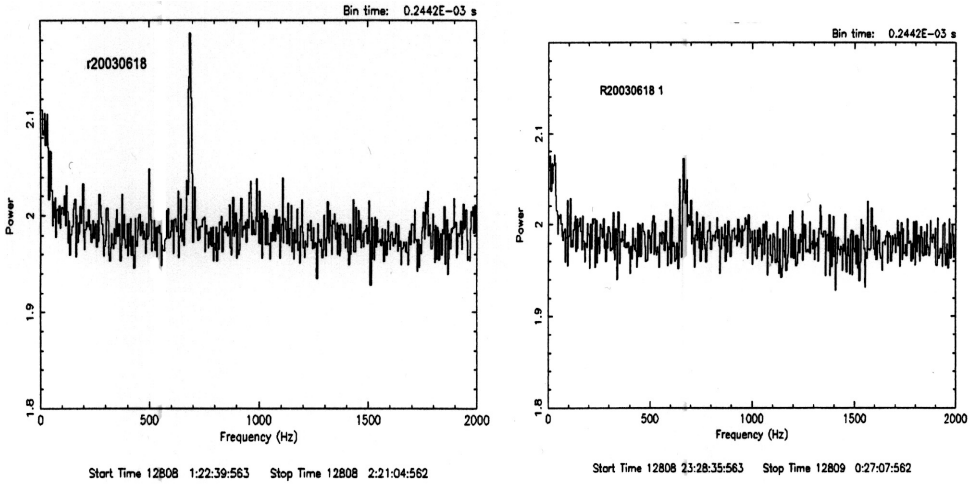

Fig. 5 Power spectra of 4U 1820–30 with a QPO peak (F.Murtas 2004).

4U 1820 is an Atoll type binary and only in a given condition of X-ray color do we find QPO. Present theoretical models are not well fitted by the data and perhaps some of the difficulties will be resolved taking into account the radiation detected by NA+EXP.

We have QPO in the X-rays light curve simultaneously with NA+EXP coincidences only on two dates: 24/Sep/1998 and 10-17/Jun/2003 because in the 97 and in the 99 NA and EXP were not working. See Figure 6.

We have already NA+EXP coincidences for the year 2004 but in order to see time correlations with the QPO and relative frequencies need to wait the end of 2005 when NASA will release archive data. By the end of 2005 we will have analyzed also 2004 and 2005 data.

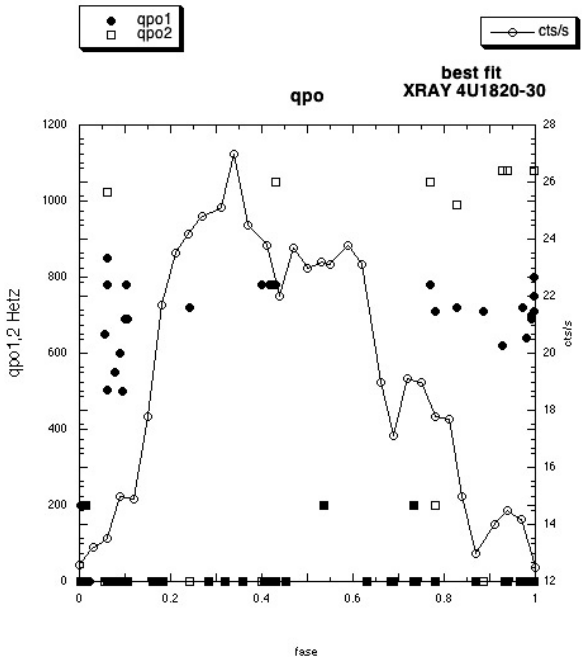

Fig. 6 QPO frequencies (squares and circles dot) vs phase of 4U1820–30 (F. Murtas 2004). Solid line is a best fi t to the X-rays light curve of 4U1820 (Y. Chou et al. 2001).

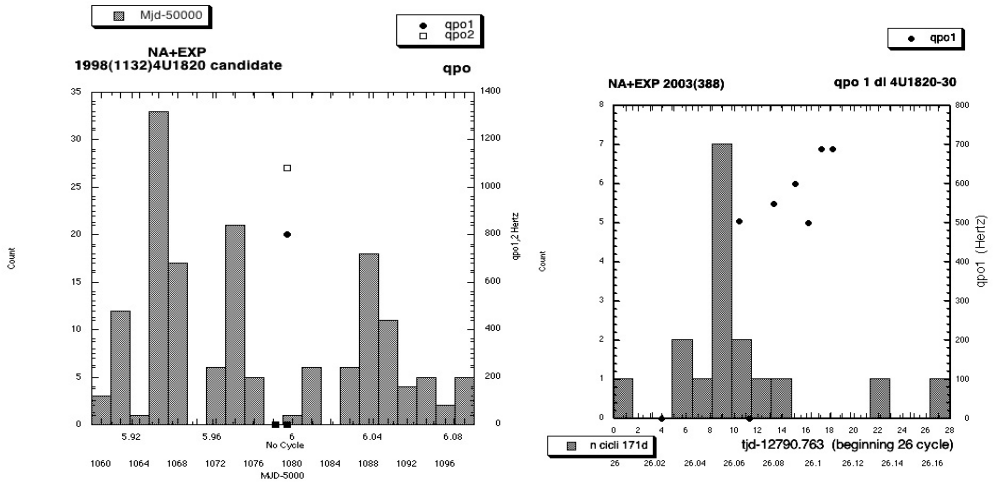

Fig. 7 Coincidence with Nautilus and Explorer (1998 Left) (2003 Right) with QPO date and frequencies (F. Murtas 2004).

3 BINARY SYSTEM XTE J1550–56

In 1998 NA+EXP in the 1998 detected a flare probably produced by the binary XTE J 1550–564 wich is a candidate Black Hole with a companion White Dwarf or a magnetic G/K sub-giant (K. Wu et al. 2002) located at 8150 ly of distance and rotating with an orbital period of 1.55 d. In Sept 1998 between

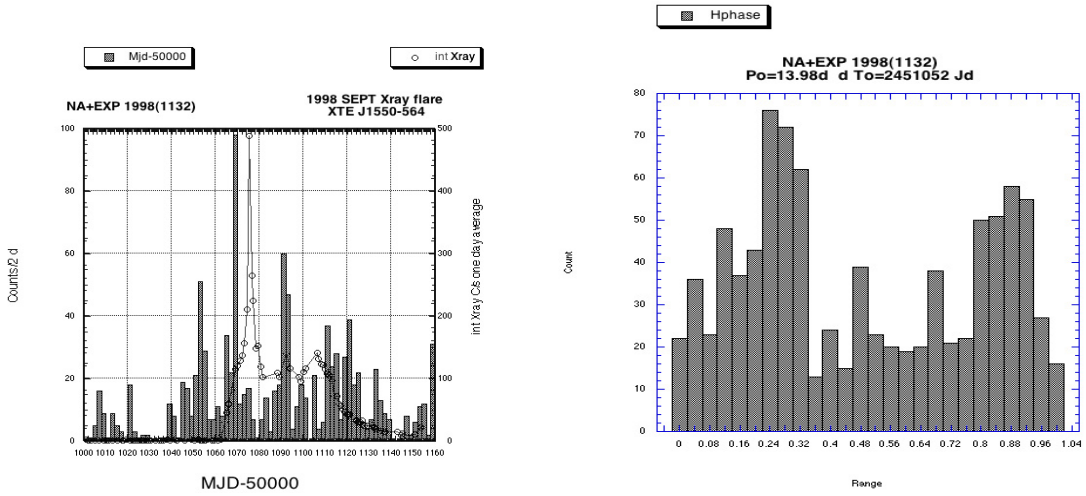

Fig. 8 Light Curve of XTE J1550–564 (Left) and Nautilus + Explorer coincidences periodicity of 13.98 d (Right).

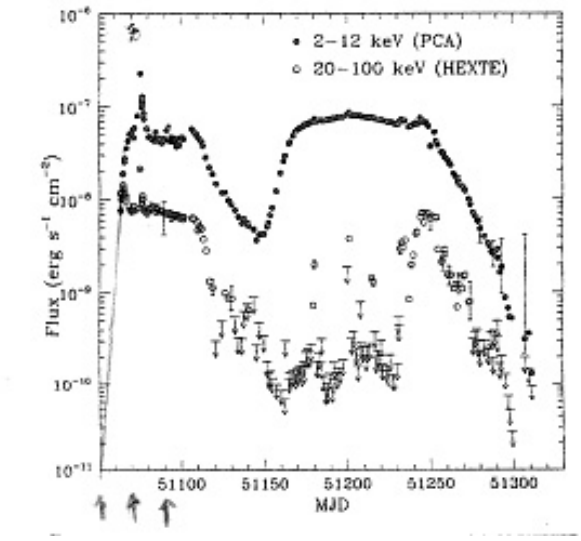

Fig. 9 Light Curve XTE J1550–564(J. Gregory et al.2002) arrows indicate the position of NA+EXP bursts.

$51050 - 51140$ MJD, this system has produced an X-ray peakwith an intensity of 500 cont s^{-1} compared with 25 cont s^{-1} of the 4U 1820–30. This system at the same time has been active in sending projectiles at NA+EXP.

Figure 7 Left shows the light curve of XTE J1550–56 with the Na+Exp coincidence flux. We can detect a modulation of the X-ray intensity with a period of about 15 days.

We found the same periodicity looking at the NA+EXP data. Folding the coincidence rate we found Po=13.98 days starting from To=51050 MJD. See Figure 8 Right.

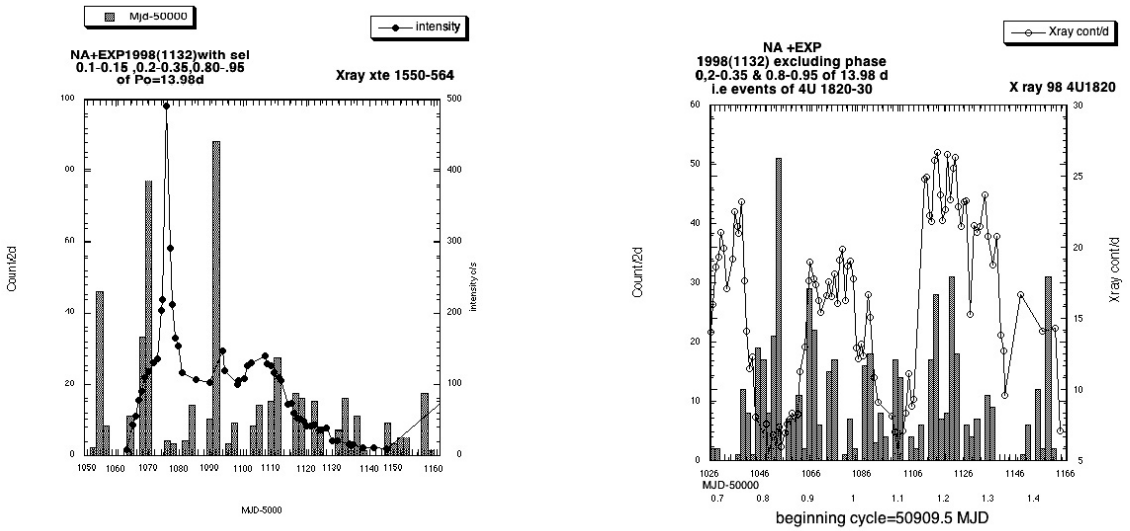

Fig. 10 Coincidence Nautilus Explorer and X-ray light curve for year 1998 candidate XTE J1550–564 (Left) and 4U1820–30 (Right). The biggest peak at 1054 is the same for both fi gure.

There are bumps at phase $0.1-0.15$, $0.2-0.35$ and $0.85-0.95$. Remembering that the orbital period is 1.55 days this means that the Na+EXP show a periodicity corresponding to 9 orbital rotations. Selecting the arrival time coincidences with these phases we obtain the result shown in Figure 10. Left in which we also show the XTE J 1550–564 X-ray light curve. NA+EXP coincidences are mainly concentrated in bursts of 1–2 days and we note that the first one is at Phase 0.15 at 51054 MJD. The signal, which is high and very clear, is exactly at the beginning of the X-ray flare. See also the extrapolated light curve on Figure 9. The NA+EXP burst at 51054 MJD is not found in X-ray light curve (J. Gregory et al. 2002). Can this be a precursor? Selecting the complementary phases of 13.98 days, the coincidences can be attributed to 4U1820 (see Fig. 10 Right). We have retained in the figure the first burst of the XTE J 1550–52 at 51054 MJD. The difference between the bursts of the two systems is impressive. We give here the number of coincidence for the ± 5 s acceptance window and in parenthese the energy in Kelvin detected by NA+EXP for each burst of XTE J 1550: 45 (110 K), 105 (76), 90 (275 K), 40 (78 K). This can be compared with 30 (50 K) for the biggest burst of 4U1820.

4 CONSIDERATIONS ON SIDERAL DISTRIBUTIONS AND BACKGROUND

We consider as background all events not coming from 4U 1820–30 or XTE J1550. Can we evaluate them? It is reasonable to assume, see scatter plot Sh vs phase, Figure 11 Left, that the events collected during phase $0.1-0.4$ to $0.6-0.8$ of 171 days are not coming from 4U1820–30 or XTE 1550–564. With the hypothesis of uniform distribution of the background in all the 171 days, we have in the countersigned G phases : signal events 270 and background events 170 with a total number of 440 events. and In the countersigned BKG phase background events 170. The total events are 610 collected in the 566 days of data taking , Figure 11 Left, with an average ± 1.5 s of time acceptance window. This means that the averaged flux of background is 0.6 eV/ (day*sec of time acceptance windov). Figure 11 Right shows the Sidereal time distribution of all events.

Figure 12 Left shows Sideral distribution of events in the G phase of 4U1820–30. Figure 12 Right shows the sideral time distribution of events not coming from 4U1820–30 and considered as background. Figure 13 shows sideral distribution of candidate events of 4U1820–30 after background subtraction. One bump at 4 Sh, and a bump at 16 Sh are due to “projectiles” hitting the Nutilus and Explorer in a direction perpendicular to the Al cylinder axis (if the source is 4U1820–30). Two slimmer bumps at 10 and 21 Sh are due to “projectiles” hitting NA+EXP in a direction essentially parallel to the cylinder axis.

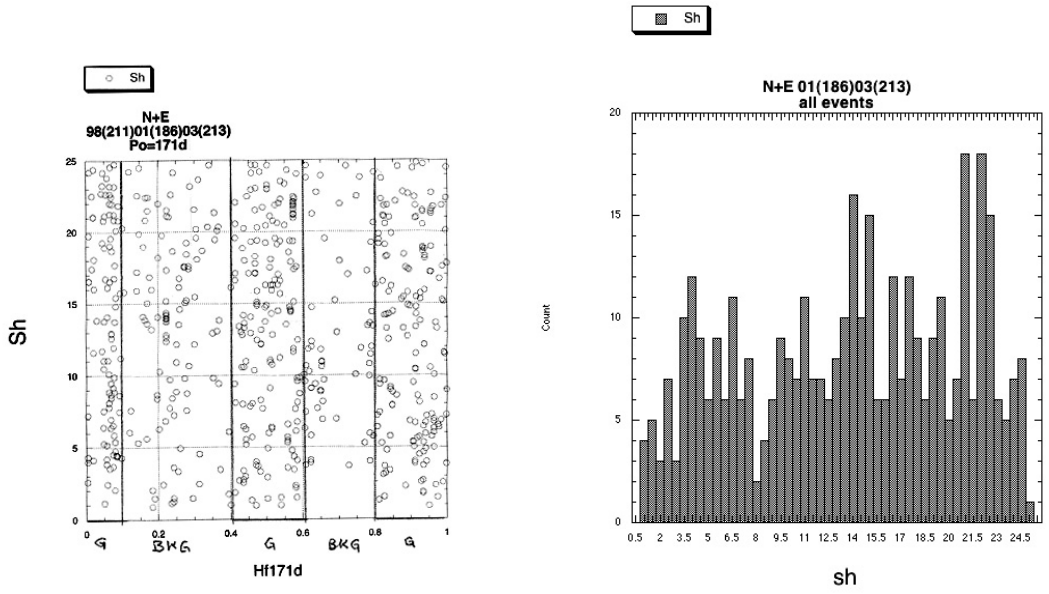

Fig. 11 Scatter plot of coincidences sideral hour vs phase (171 days) (Left). Sideral hour distribution of all events (Right)

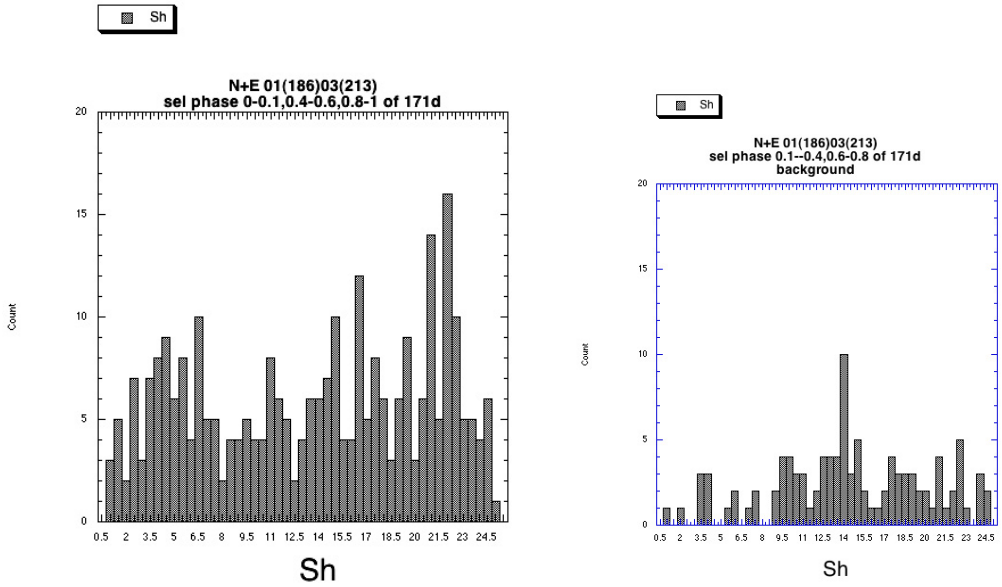

Fig. 12 Sideral hour of 4U1820–30 candidates (Left) and background (Right).

Bumps at 4 and 10 Sh are due to projectiles that, coming from 4U1820, have passed trought the Earth. Therefore they are uncharged. Thei could be be gravitational wave, neutrinos or other particles but not Gamma Rays. Projectiles comings from XTE J1550–564 always cross the Earth before hitting NA*EXP. Looking at the distributions in sideral time it seems that the antennas are very sensitive when projectiles are hitting in a direction parallel but also normal to the cylinder axis.

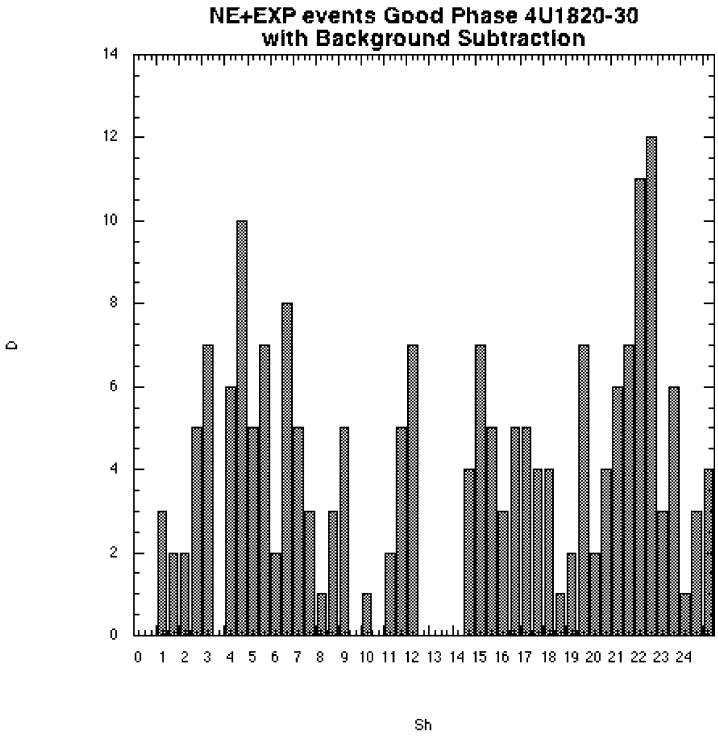

Fig. 13 Candidate events of 4U1820–30 after background subtraction.

5 CONCLUSIONS

We have for the first time performed the analysis of the Nautilus and Explorer coincidences increasing the time acceptance window from ± 0.5 s to ± 5 s fully aware that in this way we increase proportionally the probability of chance coincidences;

Chance coincidences are interesting physically only if there are projectiles hitting NA+EXP or GW detected by the system;

Comparing NA+EXP coincidence flux with X-ray flux detected by satellites we have identified two Systems, 4U1820–30 and XTE J1550–564, as possible sources;

4U1820 sends projectiles, with 171 days periodicity, probably when X-rays QPOs are active. We will need to examine the 2004 and 2005 data before reach any conclusion.

XTE J1550–564 is candidate Black Hole. We saw in 1998 and we hope to see again in next years. Signals are very clear and characteristic;

Sensitivity in antennas is high when projectiles are incident in a direction parallel and also perpendicular to the cylinder axis.

Acknowledgements This research has made use of data obtained from the High Energy Astrophysics Science Archive Research Center (HEASARC), provided by NASA's Goddard Space Flight Center.

Nautilus and Explorer data are produced by the ROG collaboration, after data quality checks realized by G. Giordano (LNF-INFN).

This Work has been presented by G. P. Murtas at the FRASCATI WORKSHOP 2005 may 23–28 Vulcano, Italy and before in the years 2003–2005 at the ROG meetings of Villa Mondragone, Gran Sasso and Frascati Laboratory.

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DISCUSSION

D. FARGION's Comment: I am afraid that only tau meson may pass trought the Eart and shower into the antenna but the probability seem too poor to be realistic.

V. SIMON's Comment: It may be interesting to note that this system (4U1820–30) may display Mazeh and Shaham (1979) mechanism and this may make this system so unusual. Mazeh et Shaham mechanism result of a combination of the orbit of the close stars (here NS+WD) of 11 min orbital period and the orbiting third body (1 day period). It is matter of discussion if this mechanism can make 4U1820–30 so important.

J. BEALL: If this is a Gravitational Wave , how much energy is in the wave?

G. P. MURTAS: Untill now we know only the energy released in the antenna. We hope in the future to give an answer.

G. AURIEMMA: The usual question: What is the confidence level that you would assign to your detection?

G. P. MURTAS: It is difficult and to early give an answer to your question. Essentially I am comparing statistically rough results of NA+EXP with more precise X-RAY satellites. I am at the beginning of my road map. I hope to say more in 1 or 2 years.