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Two transient X-ray sources observed with the WATCH experiment

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Abstract. — We report the detection of an X-ray flare from the low mass X-ray binary 4U 0614 + 09 by the WATCH all-sky X-ray monitor in January 1990. The flare reached a peak flux of 10 Crab units in the 6-20 keV energy band and had the time structure of a Type-I X-ray burst. A similar flare attributed to this source was reported by OSO-8 in 1975. The burst is used to estimate the maximum distance to 4U 0614 + 09. The hard X-ray pulsating transient A 1118-61 was originally discovered by Ariel-V in 1974. This source was observed in recurrence in late January 1992 by the WATCH all-sky X-ray monitor on GRANAT. The distinction from the nearby X-ray source Cen X-3 was established by the detection of pulsations in the X-ray signal with a period of 406.34 s ± 0.12 s, and by the absence of the eclipses characteristic of the Cen X-3 system.

Key words: X-rays: binaries — bursts — pulsars: A 1118-61.

1. Introduction.

The WATCH all-sky X-ray monitor (Lund 1985) on board GRANAT consists of four identical units. Each instrument has a circular field of view of 4 steradians. The instruments are mounted in a tetrahedral configuration covering the whole sky. Position sensitivity is achieved using the rotation modulation collimator principle, with the collimator grids rotating with a frequency of about 1 Hz. Each instrument has an effective area of 30 cm^2 (averaged over the field of view), with the detectors consisting of interleaved strips of NaI and CsI crystals. The energy range is approximately 6-150 keV.

The WATCH all-sky monitor is well suited for detection of transient phenomena in the X-ray sky. Here we report results from the detection of two X-ray transients of a very different nature.

2. Detection of a flare from 4U 0614 + 09.

The low mass X-ray binary 4U 0614 + 09 has been assumed to be a Type-I X-ray burster based on an event seen by OSO-8 in 1975 (Swank *et al.* 1978) and ascribed to this source.

2.1. Observations.

A fast X-ray transient was observed by one of the WATCH units on GRANAT on Jan. 17 1990. The instrument collected count rate data in two energy bands with a time resolution of 3.78 s. The onset of the burst triggered the collection of modulation patterns with 15 s time resolution. This enabled a relative localization in the field of view to a circle of radius 0.5° with 99% confidence. The systematic errors due to mounting and the orientation of the spacecraft were reduced by the presence of the Crab in the same field of view, and the 99% confidence circle on the sky has a radius of less than 1°. The position is fully consistent with an origin on the low mass binary 4U 0614 + 09.

The light curve in the 6-20 keV band is shown in Figure 1 without subtraction of the background. The peak count rate in this energy band corresponded to 10 times the Crab in the same detector. In the 20-150 keV band the source did not exceed the 2 sigma level and a 99% confidence upper limit of 40 counts per bin is set. The shape of the event in the 6-20 keV band is consistent with a Type-I X-ray burst (Haberl *et al.* 1987), with a sharp rise (in this case confined to 1-3 s) followed by a gradual increase to maximum, and then an exponential decay phase. The exponential phase is fitted with a decay constant of 29 s compared to 40 s for the event in 1975.

The spectral information provided by the WATCH instrument is very limited, but the data indicated that the

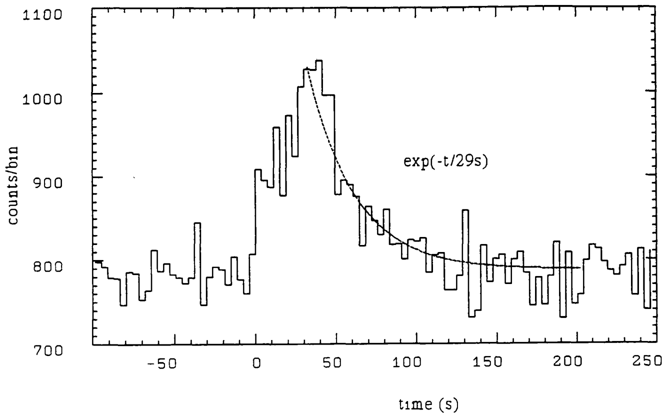

FIGURE 1. The 6-20 keV light curve of the X-ray burst observed from 4U 0614 + 09 without subtraction of the background. The time resolution is 3.78 s. The decay of the burst has been fitted with an exponential with a constant of 29 s.

source was hardest during the beginning of the exponential decay phase, consistent with the behavior of other Type-I bursters like 4U 1820-30 (Haberl *et al.* 1987).

The WATCH detection limit for persistent sources is above 100 mCrab and 4U 0614 + 09 has not been detected in quiescence by the instrument.

2.2. DISCUSSION.

The distance to 4U 0614 + 09 has been estimated, partly by comparing its peak X-ray flux with that of Sco X-1, to be in the range of 4-8 kpc (Davidsen *et al.* 1974). A distance based on the reddening of the optical companion however only sets a lower limit at about 2 kpc (Machin *et al.* 1990).

Despite of the very limited spectral capabilities of the WATCH instrument we are able to derive an upper limit to the distance to 4U 0614 + 09 using this burst. We assume the spectral response of the instrument derived from ground calibrations. Experience during flight has indicated that the sensitivity has been degraded at the lower energies, thus underestimating the luminosity of very soft sources like the present.

The thermonuclear shell flash on an accreting neutron star (Woosley & Taam 1976) is the generally accepted model of Type-I X-ray bursts (Taam 1988). If we assume the spectrum of the burst at the peak to be fitted by a black body spectrum and comparing the detector response to this spectrum and that of the Crab, we arrive at the ratio between the radius of the emitting region and the distance. By further requiring that the peak luminosity does not exceed the Eddington limit, we get an upper limit on the distance as a function of the temperature of the black body. Here we use the Eddington limit of 2.7×10^{38} erg/s for a 1.4 solar mass neutron star with a helium rich atmosphere.

The upper limit derived in this way on the distance to the source is shown in Figure 2. A black body temperature of kT above 3.3 keV is excluded by the non-detection in the 20-150 keV band. We see that an upper limit of about 3 kpc is set under the above assumptions for a black body temperature of around 2 keV at the peak of the burst.

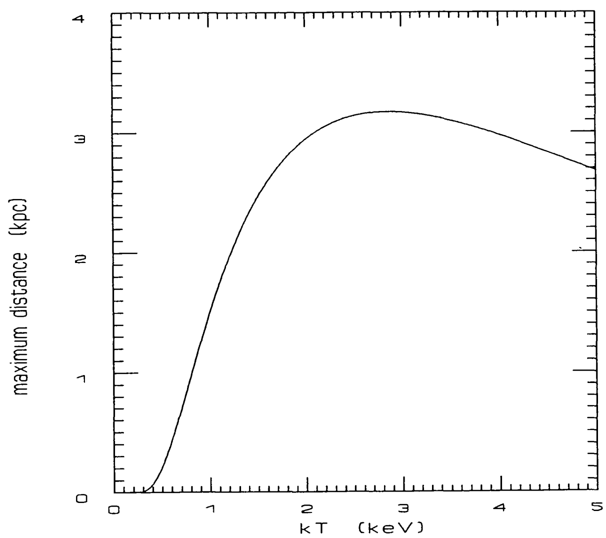

FIGURE 2. The upper limit on the distance to 4U 0614 + 09 based on a black body model of the peak flux of the X-ray burst as a function of temperature.

We should however be aware that the color temperature of the burst may exceed the effective temperature due to Comptonization (Taam 1988). By using the part of the spectrum around 6 keV we may overestimate the peak luminosity. On the other hand we have almost certainly overestimated the response of the detector at the lower end of the energy band.

2.3. CONCLUSION.

The identification as 4U 0614 + 09 as a source of Type-I X-ray bursts has been strengthened. If the event is a type-I burst and the ratio of the peak flux of the burst to the persistent flux is less than one thousand (van Paradijs *et al.* 1988) the identification is unique, by the absence of other sufficiently strong persistent sources in the error box.

The previously accepted distance of 4-8 kpc to 4U 0614 + 09 seems to be overestimated. This analysis shows that an upper limit of 3 kpc should be adopted.

3. Recurrence of the hard X-ray pulsating transient A 1118-61.

The transient X-ray source A 1118-61 was discovered in 1974 by the Ariel V satellite (Eyles *et al.* 1975) and shown to be a pulsar with a period of 405.3 s ± 0.6 s (Ives *et al.* 1975). This source was observed in recurrence in late January 1992 by the WATCH all-sky monitor (Lund *et al.* 1992). The source has been associated in the optical with the massive Be star He 3-640 (Chevalier & Ilovaisky 1975, Janot-Pacheco *et al.* 1981, Henize 1976). The hard pulsating X-ray transients seen from Be systems are, for the systems with longer pulse periods, thought to recur when the neutron star near periastron passes through dense layers of the Be stars envelope (Motch *et al.* 1988).

3.1. Observations.

The position of A 1118-61 is only ~ 1.3° away from the persistent X-ray source Cen X-3. It is therefore impossible for the WATCH all-sky monitor with an angular resolution of about 3° to distinguish the two sources. However, the two sources have properties making a distinction possible by other means. Cen X-3 is an eclipsing binary and A 1118-61 is a pulsar.

The detection of A 1118-61 was done using 45 hours of continuous count rate data with a 7.5 s time resolution starting on January 28.35 UT 1992. The power spectrum of these data is shown in Figure 3. The X-ray pulsar Vela X-1 was also in the 65° radius field of view and shows prominent peaks at its 283 s period and higher harmonics. But also a peak near 406 s is clearly seen, thus making a strong suggestion of A 1118-61, when comparing with lists of known pulsar periods (Nagase 1989). The pulse period was determined to be 406.34 s ± 0.12 s. The pulse shape is shown in Figure 4.

The fitted amplitude of a signal in the 6-15 keV band from the direction of A 1118-61 is shown in Figure 5. With the angular resolution of 3° a signal from Cen X-3 will however be mixed into this fit. The periods where Cen X-3 was in eclipse, and therefore definitely did not contribute to the signal, are marked in the figure. The maximum flux was observed around Jan. 29.0 1992 and reached 500 mCrab.

The source was possibly also active during an observation on Jan. 4 1992, but a highly variable background in the detector due to particles made a definite identification by the presence of pulsations impossible.

3.2. Discussion.

An outburst from A 1118-61 has not been observed since its discovery in 1974. This could be taken as an indication for an orbital period of the binary system of 17 years, but X-ray outbursts during this interval could have been missed due to lack of observations or confusion with Cen X-3 nearby . A 1118-61 was observed by EXOSAT to a have a quiescent X-ray luminosity of about 10^{34} erg/s, and the analysis of that observation and the optical companion does not exclude a period as long as 17 years (Motch *et al.* 1988).

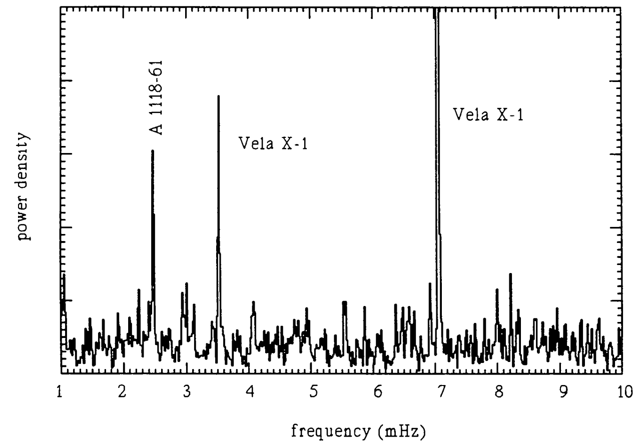

FIGURE 3. Part of power spectrum obtained using 45 hours of continuous count rate data with a 7.5 s time resolution starting on January 28.35 UT 1992. The detector also had Vela X-1 in the field of view producing prominent peaks at its period of 283 s and higher harmonics. The peak at 406.3 s identifies the presence of A 1118-61.

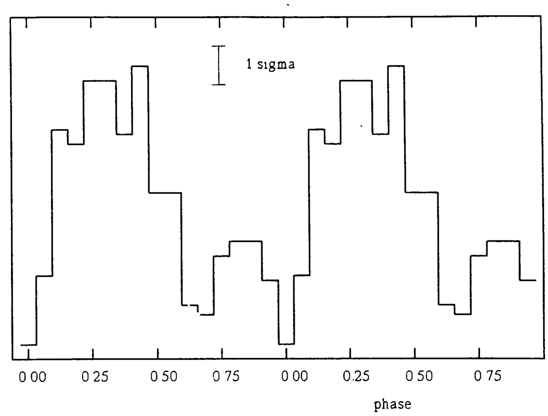

FIGURE 4. The pulse shape of A 1118-61 using 45 hours continuous count rate data with a 7.5 s time resolution starting on January 28.35 UT 1992. The data have been folded into 16 bins at a period of 406.34 s.

3.3. Conclusion.

The transient X-ray pulsar has been shown to recur after 17 years. This time span may reflect the underlaying orbital period. The pulse period has not changed significantly since the detection by Ariel-V in 1974, as would be expected when the accretion rate in quiescence is very low.

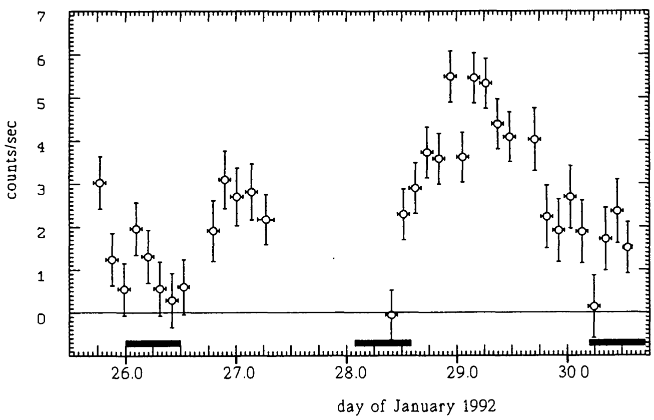

FIGURE 5. The X-ray light curve in the 6-15 keV energy band of the recurrent transient A 1118-61 around the major outburst by the end of January 1992. The curve includes contributions from Cen X-3 which cannot be separated. The eclipses of Cen X-3 are indicated by black bands. The flux of the Crab in the same detector is 10.3 ± 0.2 counts/sec.

Acknowledgements.

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