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MONITORING THE ACTIVITY VARIATIONS OF GALACTIC X-RAY SOURCES WITH WATCH ON EURECA

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ABSTRACT

Among the many instruments carried on the first EURECA mission was also one aimed at doing astrophysical research. This instrument, WATCH, (Wide Angle Telescope for Cosmic Hard X-rays) is sensitive in the 6 to 150 keV energy range and has a total field of view covering a quarter of the sky. During its 11 month operational life, EURECA tracked the Sun, and WATCH gradually scanned across the entire sky. The signals from more than two dozen known galactic X-ray sources have been identified in the data, and the activity state of each source has been recorded as a function of time. For several sources the observation periods extended over more than 100 days. A number of X-ray transients with durations between one and five days were discovered, and, additionally two long duration X-ray transients (GRS 1915+10 and GRO J0422+32) were active and could be monitored. Towards the end of the mission a special "offset pointing" program was initiated on request from the WATCH PI. This program proved very successful and allowed WATCH to scan more than 80% of the sky in the course of only two weeks.

INTRODUCTION

The EURECA (EU-ropean RE-trievable CA-rrier) platform was developed by the European Space Agency (ESA), primarily as a free flying micro-gravity laboratory, but the EURECA-1 mission also carried several experiments from other scientific fields. Among them was a WATCH wide field X-ray monitor.

The WATCH instrument was developed at the Danish Space Research Institute [1], and was also flown on the Russian GRANAT mission. WATCH is a wide field X-ray monitor based on the Rotation Modulation Collimator (RMC) principle. The instrument is designed to detect transient and persistent sources of X-rays. It has a circular field of view with a radius of about 65 degrees. The energy range is 6-150 keV, and the effective area of NaI and CsI scintillators is about 45 cm². For transient events with a duration longer than the rotation period of the RMC (1 s), a conservative estimate of the position accuracy is within a 1 degree radius. The sensitivity is about 100 mCrab for a one day observation, and better than 25 mCrab for long duration observations in uncrowded fields.

The effective observation time during the 318 day EURECA mission was about 120 days, taking into consideration Earth occultations, SAA passages and a few non-operational periods. With the given field of view, this corresponds to about 30 days of continuous all-sky coverage, and a duty cycle of 9%. The coverage was peaked around the equatorial plane with essentially no coverage near the poles. During the EURECA mission, WATCH scanned most of the sky as the pointing of EURECA followed the Sun. During the period of 27 April - 15 May 1993, WATCH was able to scan more than 80% of the sky through several re-orientations of the EURECA spacecraft.

TRANSIENT AND PERSISTENT X-RAY SOURCES

About thirty transient and persistent Galactic X-ray sources were detected with WATCH during the EURECA mission. Most of these systems are binaries, containing a compact object, either a neutron star or a black hole, and a normal star. Matter is transferred from the normal star and accreted onto the compact object. Most of the gravitational energy is released in the form of X-rays. Some of the more interesting X-ray sources observed with WATCH are mentioned in the following.

The Long Duration Transient GRS 1915+10

The hard X-ray transient GRS 1915+10 was discovered by WATCH-GRANAT in August 1992 /2/. The source had been active as early as May 1992, as it was later determined by analyzing data from the BATSE experiment /3/, and the source was also identified in the WATCH-GRANAT data from mid July 1992 /2/.

This new source entered the field of view of WATCH-EURECA in August 1992 and stayed in view until December 1992, when it drifted out of the field of view. During the EURECA offset pointings, WATCH again had the opportunity to observe the source for a week in the period April 27 to May 3 1993 /4/. At this time GRS 1915+10 had developed a much softer spectrum. The light curve of GRS 1915+10 observed with WATCH-EURECA is shown in the 6-22 keV band in Figure 1.

GRS 1915 has been identified in radio /5/. The radio flux of the conjectured radio counterpart has been reported to be correlated with the hard X-ray flux observed by BATSE. Mirabel et al. /5/ report very weak activity in the radio band in an observation on April 27 1993. At the same time BATSE observed the source to be very low in the 20-100 keV band /6/. However, the WATCH observations from this period shows that the source was bright in softer X-rays (6-22 keV).

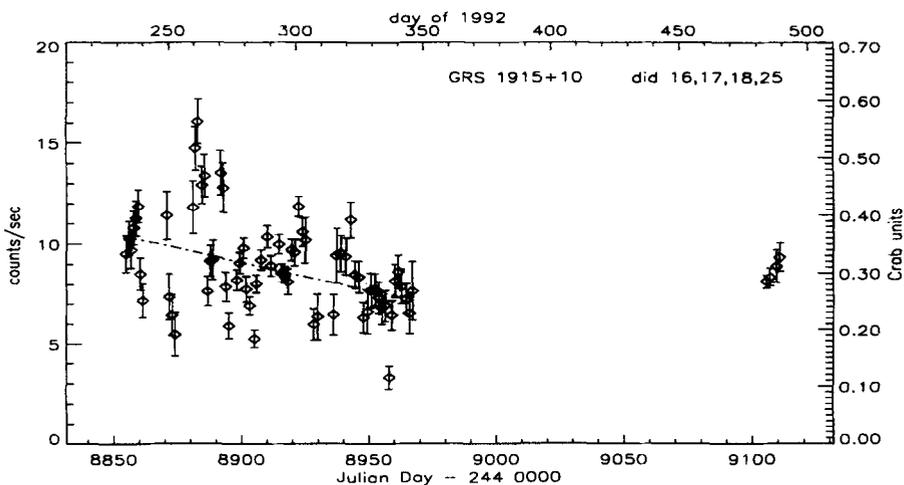


Fig. 1. The X-ray transient GRS 1915+10 observed with WATCH-EURECA in the 6-22 keV band. Note the high level of activity during the observations in late April 1993.

The X-Ray Nova GRO J0422+32

GRO J0422+32 was probably the most interesting transient discovered in 1992 and belongs to the class of X-ray novae. During outburst, the X-ray novae are among the brightest X-ray sources in the sky. The X-ray flux typically decay with an e-folding time of the order of 20-40 days.

GRO J0422+32 was discovered in August 1992 by the BATSE experiment on the American Gamma Ray Observatory /7/, and followed up by WATCH on GRANAT /8/. The WATCH 1 degree radius errorbox enabled the optical identification of the source /9/. The primary X-ray outburst of this source was not observable by WATCH-EURECA, as this source entered the field of view only late in December of 1992, but the early exponential decay was followed by WATCH on GRANAT.

As commonly seen in X-ray novae, GRO J0422+32 underwent a secondary X-ray outburst in December of 1992 /10/, and the decay of this outburst was observed by WATCH-EURECA. The source was observed by WATCH-EURECA for about a month before it decayed below our detection limit (see Figure 2).

The class of X-ray novae has attracted much attention as the systems are generally believed to contain black holes.

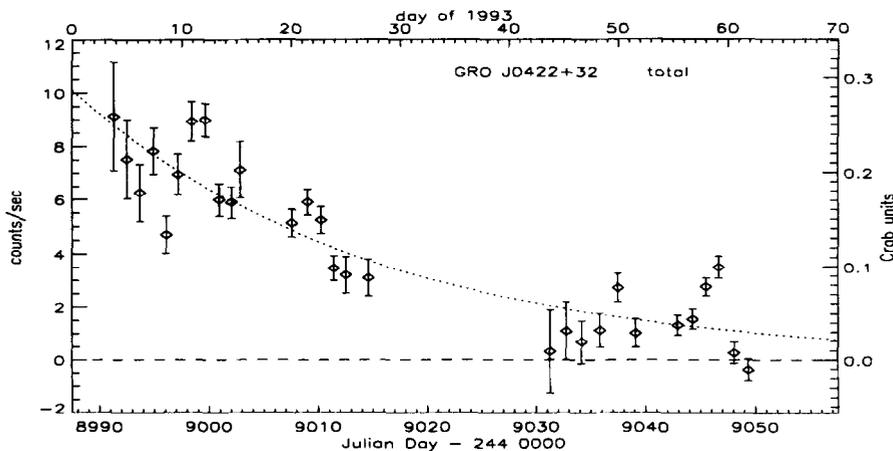


Fig. 2. The X-ray nova, GRO J0422+32, observed with WATCH-EURECA in the 6-50 keV range. The data from January 1993 has been used to fit an exponential decay. The e-folding time derived is 27 days.

The Recurrent Transient GRS 0834-43

The recurrent transient pulsar GRS 0834-43 was discovered by WATCH on GRANAT in 1990 /11/. The data from WATCH-GRANAT suggests a recurrence period of 114 days /12/, and accordingly a recurrence should have been due centered around 10 April 1993. No activity above the detection limit was seen by WATCH-EURECA during the periods 3-13 February, 14 March- 10 April, and 25-26 April 1993, when the source was in the field of view.

However, during the EURECA offset pointings at the end of the mission, the source, GRS 0834-43, was observed in outburst during the observation 4-6 May 1993 /13/. This outburst does not fit into the pattern of regular recurrences suggested by Lapshov et al. /12/.

X-Ray Sources Discovered with WATCH-EURECA

Several transient sources were discovered near the Galactic Center with WATCH-EURECA. Among them were EU 1737-132, EU 1902+20, EU 2017-01, and EU 2053+316 /14,15,16/. They were typically sources of medium brightness rising above the WATCH detection level for a few days.

EU 2053+316 was a short duration X-ray transient observed with WATCH-EURECA in the end of November 1992 /16/. The duration of the transient was a few days. The light-curve of EU 2053+316 in the 6-8 keV band is shown in Figure 3. The maximum intensity of this source was 200 ± 50 mCrab, which was reached on 22 November 1992.

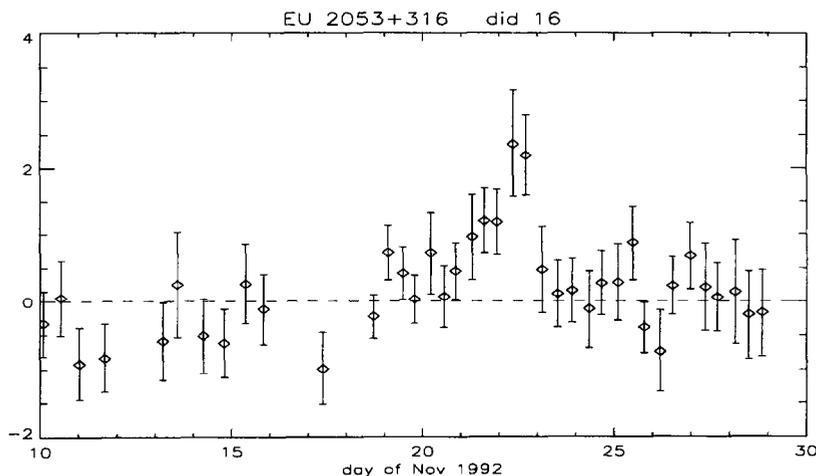


Fig. 3 The 6-8 keV light curve of the X-ray transient EU 2053+316 discovered with WATCH-EURECA in November 1992. The peak flux was 2 counts/sec corresponding to 200 mCrab in this energy band.

X-Ray Bursts from 4U 0614+09

The systems showing X-ray bursts are binary systems containing a neutron star with a relatively low magnetic field ($B < 10^8$ Gauss). The neutron star is very dense, and has a mass of about 1 Solar mass, but a radius of only about 10 km. The neutron star is accreting matter from a low mass companion. The system is emitting X-ray due to the conversion of gravitational energy into heat in the accreting matter.

In an X-ray burster, a layer of He builds up on the surface of the neutron star, and this layer may become unstable and undergo a runaway nuclear burning. The energy is then released as a burst of X-rays lasting a few tens of seconds.

The low mass X-ray binary 4U 0614+09 was proposed to be a Type-I X-ray burster based on a burst seen by OSO-8 in 1975 /17/. This identification was however far from certain. Four X-ray bursts consistent with an origin on 4U 0614+09 within an error circle of radius less than 1 degree were observed with WATCH. This secures the case for 4U 0614+09 as an X-ray burster. The light curve of the four events are shown in Figure 4. The first event was observed with WATCH on GRANAT in 1990 /18/, and the three others were observed by WATCH on EURECA in the spring of 1993 with intervals of two weeks /19,20/.

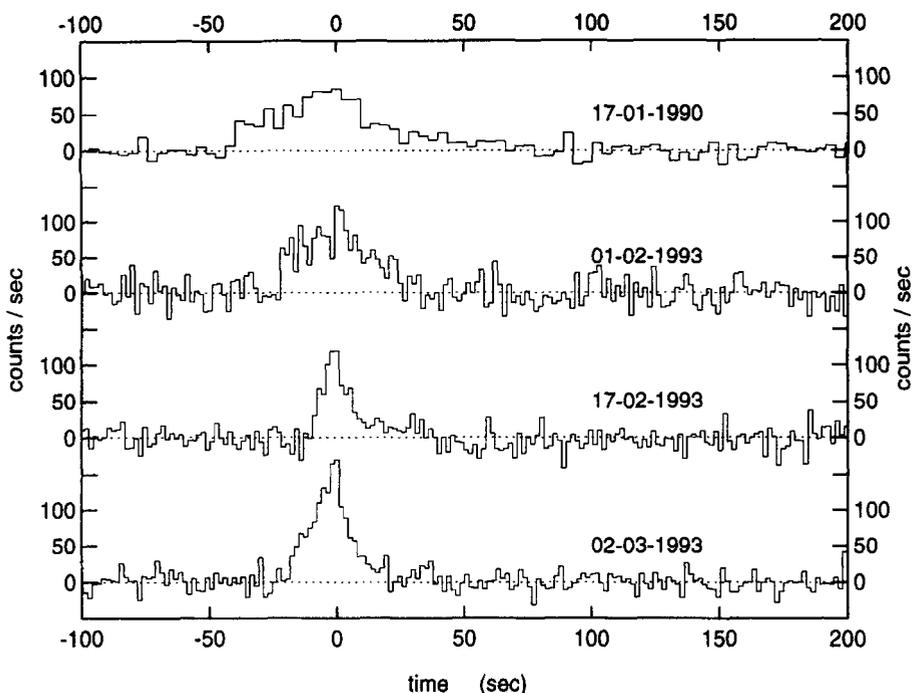


Fig. 4. Comparison of the 4 X-ray bursts observed from 4U 0614+09. The burst on 17 Jan 1990 was observed with WATCH on GRANAT. The 3 other bursts were observed with WATCH on EURECA. Zero time corresponds to the peak of each burst. The background has been subtracted. The count rates have been compensated for the projection angle of the source. With the WATCH-EURECA instrument, the quiescent emission from 4U 0614+09 was detectable by integrating many observations, and the source was clearly detected at a level of 25 mCrab in the 6-12 keV energy range.

We may estimate the alpha parameter of the X-ray burster defined as the ratio of energy in the persistent flux and the energy output in burst flux. However, this is not possible in a strict sense, since the observation of the source was not continuous due to occultations by the Earth, and we may not have observed all bursts from the source. But the following estimation may be useful. The source was favorably located in the field of view from mid January 1993 until the end of April 1993. With an efficiency of a little more than 40% this gives a total effective observation time of a little more than 40 days. During this time 3 bursts were observed, thus the average interval between bursts may be taken as 14 days. Note that the 3 bursts observed were separated by nearly equal intervals of about 14 days. If these are 3 consecutive bursts, this gives alpha approx. 100. This is in perfect agreement with the ratio expected if the persistent flux is powered by release of gravitational energy and the bursts are powered by runaway Helium burning.

CONCLUSION

The results presented here demonstrates the usefulness of a wide field X-ray monitor, like WATCH. The X-ray sky is very variable and some events are rare. The X-ray novae are recurrent with time scales of 50-100 years and it is estimated that only about one outburst is observable per year in the Galaxy. The establishment of 4U 0614+09 as an X-ray burster may also serve as another good example. The seemingly very low frequency of bursts from this source makes it highly unlikely, that a large instrument with narrow field of view would be able to afford to spend sufficient time to observe a burst. Also, an all sky monitor working by occasionally scanning the sky by making short exposures with a sensitive instrument would miss events of this type. The efficient system of network distribution of the data from the EURECA experiments was essential for the successful operations of the WATCH X-ray monitor.

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