Keeping an Eye on the X-Ray Sky

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Introduction

Ground-based, optical observations of the counterparts of celestial X-ray sources are essential for the understanding of the physics of these sources. Since the typical X-ray source is quite inconspicuous in the optical, we need X-ray-sensitive wide-field monitors working in space to alert the ground-based astronomers to any unusual activity in the X-ray sky.

Most X-ray sources are highly variable, and many are in fact impossible to observe between their outbursts with present-day X-ray telescopes. On the other hand, during the outburst they can outshine the brightest persistent X- and gamma-ray sources, and new phenomena may become observable.

The WATCH Instruments

Since December 1989, three X-ray monitors built at the Danish Space Research Institute have been in orbit on board the Russian space observatory GRANAT. Since August 1992, a fourth instrument of the same type has been in operation aboard ESA's EURECA satellite. Each instrument covers about one quarter of the celestial sphere, and they are capable of locating strong X-ray sources within their field of view to a precision of about 45 arcminutes.

The instruments use a rotating shadow grid to modulate the signal from the X-ray sources, and the observed modulation function can be used to construct sky images (correlation maps) in a number of X-ray energy bands. This imaging technique is simple and requires only a small amount of data to be transmitted from the satellite, but the images require additional data treatment to extract weak sources in the presence of stronger ones. Around each source, and extending to the edge of the image field, is a sequence of circular ridges, slowly decreasing in amplitude (Fig. 1). Nevertheless, it is possible to clean away the sources sequentially, and in this way identify several sources in the same sky image. Another technique which has turned out to be particularly useful for the treatment of the EURECA data is the generation of global correlation maps, adding together data from many days with slightly different pointing. In these global maps the source sidelobes, visible in the individual images will be significantly suppressed (Fig. 2 and 3).

The rotation rate of the instrument modulators has been chosen so high, one revolution per second, that the instruments can localize also many of the so-called cosmic gamma-ray bursts. It is one of the primary objectives of the project to provide gamma-ray burst positions rapidly to observatories on the ground to enable a search for optical counterparts. An example of a correlation map based on only four seconds of data during a gamma burst is shown in Figure 4.

Figure 1: A correlation map corresponding to 24 hours integration with the WATCH instrument on EURECA-I. Sco X-1, the brightest X-ray source in the sky, is dominating the image. The sidelobes of the strong source are completely hiding the images of other sources in the field. At least five of these sources can be identified once the Sco X-1 signal has been removed. The energy range is 6 to 8 keV, the lowest energy band accessible to WATCH. The full image is 130 degrees across.

Figure 2: Global correlation map corresponding to 30 days of integration with WATCH-EURECA. The image is composed of about 90 individual eight-hour maps. In the data processing the signals from the three strongest sources in each sub-image were subtracted before combining the sub-images. Thus Sco X-1 is completely removed, and the two next brightest sources for any given period are reduced in intensity in this composite picture. The eight sources visible are from top left to bottom right: Cyg X-1, GRS 1915+105, GX 17+2, GX 9+9, GX 5-1, 4U 1700-37, GX 340+0 and Cir X-1. The energy range is from 6 to 8 keV. The image covers from 14 h to 21 h in right ascension and from -65 to +45 degrees in declination.
telescopes have sufficiently large fields of view to be able to cover the WATCH error box. As it were, a candidate counterpart was identified first at ESO (Della Valle et al., 1991) and the association of the ESO candidate with the new X-ray position was confirmed a few days later by the ART-P and SIGMA observations (Sunyaev et al., 1991). The accurate position provided by the ESO team paved the way for a major observation campaign covering all wavelengths from radio to gamma-rays. The early results of this campaign were discussed at a workshop at the Danish Space Research Institute in May 1992 (Brandt, 1992).

The observations of the recent Nova Persei 1992 have followed a very similar pattern. Originally discovered as a strong X-ray source by the BATSE instrument on NASA's COMPTON satellite (Paciesas et al., 1992) the object was optically identified from the Crimean Astrophysical Observatory making use of an improved X-ray position provided by WATCH. (Castro-Tirado et al., 1992 a, 1992 b). Following the optical identification a steady stream of IAU Circulars have testified to the breadth of the ongoing observation campaign.

Simultaneously with the optical identification of Nova Persei 1992 another bright X-ray transient, GRS 1915+105, was discovered by WATCH (Castro-Tirado et al., 1992 c). Unfortunately no optical counterpart for this source has as yet been identified despite intensive search both at ESO and at Crimea. Even the availability of a much improved X-ray position from the SIGMA experiment has not resulted in finding a counterpart. This source is located right in the Galactic plane and apparently the object is hidden behind dust clouds. Consequently our knowledge about this source is likely to remain quite limited. Judged from the X-ray spectrum alone, this source may also be different from the X-ray novae discussed above.

The X-ray novae are exciting objects because they seem to be our major source of information concerning black holes in our Galaxy. Since 1975 where the British ARIEL-V satellite discovered the first X-ray nova (Elvis et al., 1975), a total of six have been observed. In all cases the eruption appears to come from a binary system in which a dwarf star of spectral type G or later orbits a massive compact object. The masses of the compact objects have been determined by optical observations of the systems in quiescence, and they all exceed the theoretically predicted maximum masses for stable neutron stars, thus they must be assumed to be black holes. The X-ray spectra observed during the outbursts are quite variable but in all cases the sources have, at times, exhibited power-law-like spectra without sharp cut-offs toward the high energy end. Such spectra are also present from time to time from Cyg X-1, a persistent X-ray source also believed to harbour a black hole. A major surprise, which may be very important also for our understanding of some of the X-ray sources near the galactic centre, was the observation from Nova Muscae 1991, of a relatively short duration.

Figure 3: As Figure 2, but here the energy range is from 15 to 25 keV. No subtraction of strong sources has been performed, so the sources appear with their correct relative intensities. At these higher energies Cyg X-1 (a black hole candidate) is by far the strongest source, while Sco X-1 (at right centre) is rather insignificant. GRS 1915+105 (an unidentified hard X-ray transient) and 4U 1700-37 are also visible.

Figure 4: The cross correlation map of a cosmic gamma burst observed with GRANAT-WATCH. This image corresponds to only 4 seconds of integration. Despite the noisy image the burst source position can be determined. Before a gamma-burst position is accepted we require several independent images like this one. The energy range here is 6 to 8 keV.

X-Ray Novae

One class of X-ray transients where optical follow-up of space observations have been particularly rewarding are the X-ray novae. The most recent such events are GRS 1124-683 (Nova Muscae 1991) and GRO J0422+32 (Nova Persei 1992).

Nova Muscae was discovered in January 1991 by one of the WATCH detectors on GRANAT, and, independently, by the Japanese GINGA satellite (Lund and Brandt, 1991, Makino et al., 1991). The uncertainty in the early X-ray positions were too large to allow effective follow-up in the radio- or UV-range, but, in the optical, the ESO Schmidt group began a search for a counterpart. Simultaneously, preparations got underway to reorient the GRANAT spacecraft to allow the Russian ART-P and the French SIGMA telescopes to observe the source. These X- and gamma-ray telescopes have sufficiently large fields of view to be able to cover the WATCH error box. As it were, a candidate counterpart was identified first at ESO (Della Valle et al., 1991) and the association of the ESO candidate with the new X-ray source was confirmed a few days later by the ART-P and SIGMA observations (Sunyaev et al., 1991). The accurate position provided by the ESO team paved the way for a major observation campaign covering all wavelengths from radio to gamma-rays. The early results of this campaign were discussed at a workshop at the Danish Space Research Institute in May 1992 (Brandt, 1992).

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Looking Through the Dust – the Edge-on Galaxy NGC 7814 in the Near-Infrared

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1. Introduction

To study the photometric and morphological properties of spiral galaxies like our own, large nearby galaxies, which are assumed to be characteristic, are usually investigated in detail. To study the radial properties of galaxy disks, one looks at galaxies with a low inclination angle, while the vertical distribution of gas and stars is studied in highly inclined galaxies.

A complicating factor for the investigation of edge-on galaxies is extinction by dust in the disk. Apart from S0 galaxies, whose disks might be transparent, the disks of most edge-on galaxies are opaque in the inner regions in optical

References


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