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.

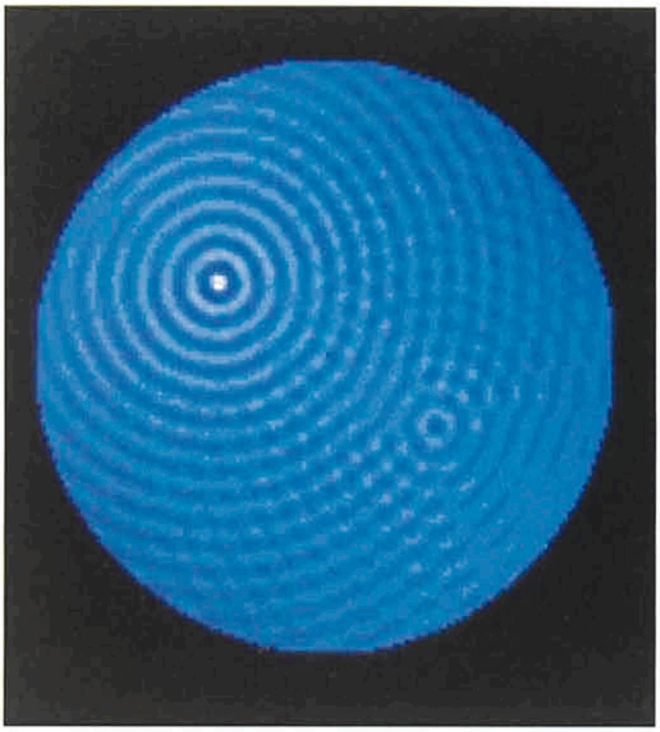

Figure 1: *A correlation map corresponding to 24 hours integration with the WATCH instrument on EURECA-I. Sco X-1, the brightest X-ray source in the sky, is dominating the image. The sidelobes of the strong source are completely hiding the images of other sources in the field. At least five of these 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.*

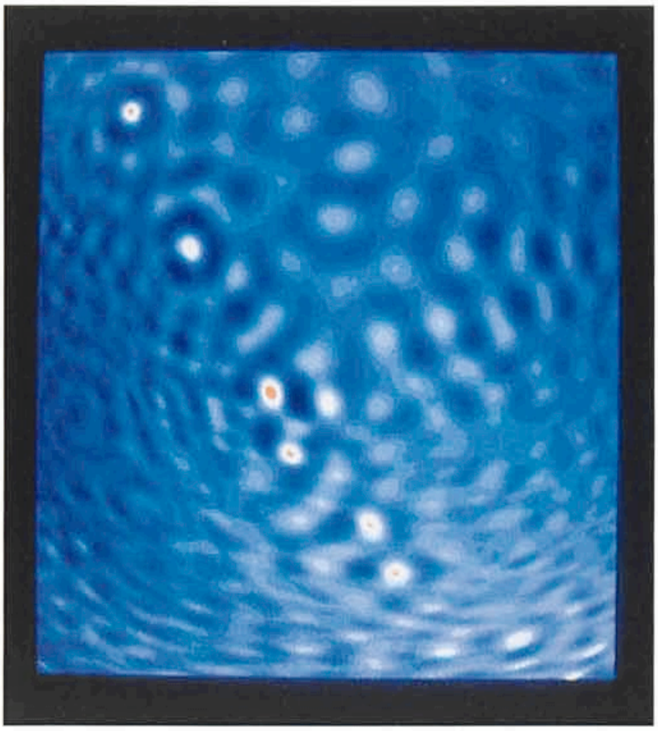

Figure 2: *Global correlation map corresponding to 30 days of integration with WATCH-EURECA. The image is composed of about 90 individual eight-hour maps. In the data processing the signals from the three strongest sources in each sub-image were subtracted before combining the sub-images. Thus Sco X-1 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.*

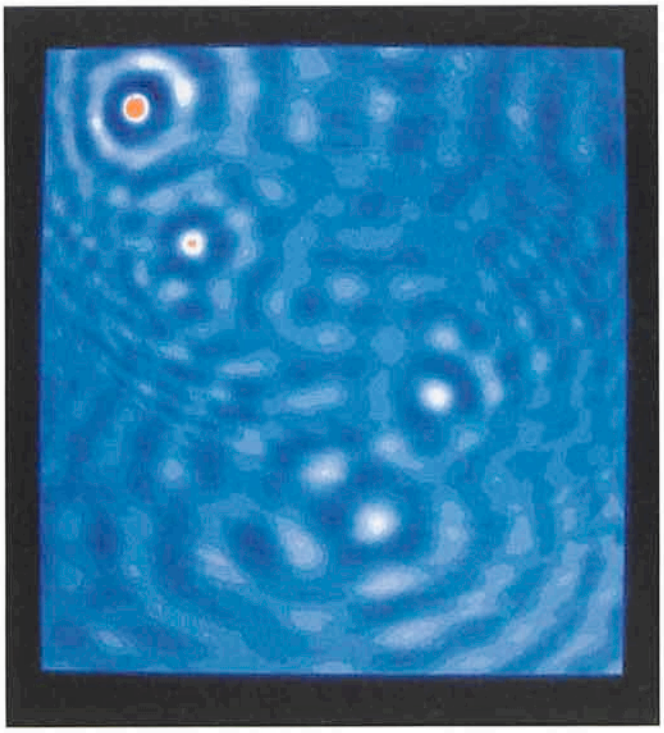

Figure 3: *As Figure 2, but here the energy range is from 15 to 25 keV. No subtraction of strong sources has been performed, so the sources appear with their correct relative intensities. At these higher energies Cyg X-1 (a black hole candidate) is by far the strongest source, while Sco X-1 (at right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

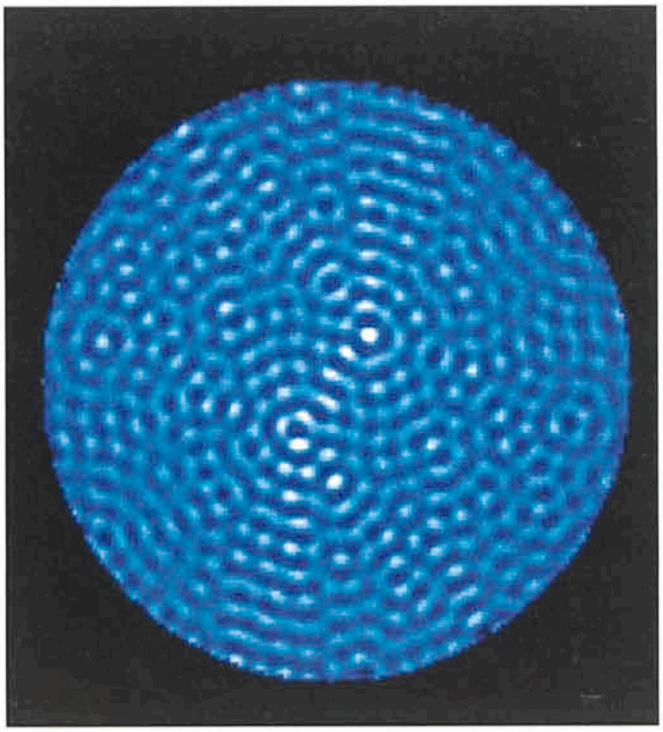

Figure 4: *The cross correlation map of a cosmic gamma burst observed with GRANAT-WATCH. This image corresponds to only 4 seconds of integration. Despite the noisy image the burst source position can be determined. Before a gamma-burst position is accepted we require several independent images like this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

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. Jugded 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 episode of intense emission of electron-positron annihilation radiation (Ballet et al., 1992).

Gamma-Ray Bursts

This is a branch of X-ray astronomy where optical follow-up so far has yielded only negative or inconclusive results. The importance of finding counterparts in any waveband is however so obvious, that the search has to be continued and improved despite all disappointments in the past. The confusing situation regarding our (lack of) understanding of these enigmatic events has recently been discussed in this journal (Boer et al., 1992), so here only the main points will be mentioned: The bursts appear isotropically distributed over the sky, yet they are not homogeneously distributed in space since the number of bursts does not increase as rapidly as the volume of space accessible by instruments of different sensitivity. There are simply not enough weak bursts observed (Meegan et al., 1992). The burst durations span the range from tens of milliseconds to hundreds of seconds with a great variability of time structures and no obvious subclasses. The X-ray energy spectra are extremely hard, extending far up in the gamma-ray regime. In fact, the bursts are so deficient in soft X-rays that they cannot originate close to any stellar surface (Imamura and Epstein, 1986) – still some of the bursts exhibit lines in the X-ray spectra very reminiscent of the cyclotron resonance lines thought to be associated with strong magnetic fields surrounding neutron stars.

No model has been put forward as yet which can encompass all these apparently conflicting bits of evidence. And so far our only information channel are the X- and gamma-ray data. To progress further we must find new ways of observing emissions from the gamma-burst sources.

WATCH was one such attempt of designing an instrument which could provide positions useful for Schmidt camera follow-up with a minimal delay. But the average detection rate of gamma-bursts with WATCH has been only one per month or less, and in practice the delay between the localization of a burst by WATCH and the exposure of a Schmidt plate is typically 48 hours or more. These exposures are definitely interesting even if no object can later be found, because they set important constraints for the source models. Particularly if the bursts are assumed to originate at cosmological distances they must involve energy releases corresponding to supernova explosions and the absence of optical emission a few days after the event is disturbing. But, of course, the identification of one real counterpart would be a lot more fun than ten interesting non-detections!

Outlook for the Future

Both the WATCH instruments and the BATSE instrument will continue to provide rapid but rough gamma-burst locations for some time to come. Combining data from these instruments with those from space probes such as ULYSSES will yield more accurate positions, but with some time delay. The next improvement in the space segment may come with the launch in 1994 of HETE, a small satellite carrying conventional gamma-burst instrumentation supplemented with X-ray and UV cameras. The positions determined by HETE will be accurate to some arcminutes based on the X-ray camera and accurate to maybe 0.1 arcminute if sufficient UV emission is present to allow the UV cameras to pick up the source. The main limitation of the HETE cameras is that they cover effectively less than 10 % of the sky. But, as stated above, one good catch will be worth a lot.

On the ground, the availability of large-format CCDs for astronomical research will no doubt improve the prospects of searching for counterparts of transient X-ray sources. Such CCDs when mounted on suitable telescopes could provide a field of view matching the limited precision of the X-ray positions. The gain in sensitivity and ease of data analysis should allow much more rapid and effective searches to be performed. An alternative route, hopefully to be exploited in space astronomy, is to supplement a wide field X-ray monitor with gimballed X-ray and optical precision telescopes on the same satellite. But, with the established development times for space instrumentation, the ground observers are likely to have still another 10 years to find the elusive sources of the cosmic gamma bursts.

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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