RECENT TRANSIENT X-RAY SOURCES

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1. INTRODUCTION

Prior to the launch of the Ariel V satellite in 1974, four transient X-ray sources had been observed. We placed the study of sources of this type amongst the major objectives of the satellite, and so ensured that the spacecraft ground centre was capable of quick reaction, and that experimenters had rapid access to their data, so that new transients could be rapidly recognised, and an observing programme for them produced and carried out. This has been very successful - in its first 18 months of operation the satellite made observations of at least 14 transients.

Of these transients, five form a rather well defined class whose properties are rapidly becoming clearer. This class I shall call the ''classical'' transient. The remainder form a much more miscellaneous collection which cannot be clearly distinguished from the normal X-ray sources. There is some indication that the classical transients include two species, so to start with I shall describe one of each which has been particularly well-observed by Ariel V and SAS-3.

2. THE CLASSICAL TRANSIENTS

2.1 A0535+26

The light curve of this source as determined by 3 of the Ariel V experiments is shown in Fig.1; it is entirely typical of this type of transient. There is an extended period of low emission or a precursor peak prior to the rise to the main peak. Subsequently, the emission decayed quasi-exponentially for about 65d, when a flare amounting to 1.5% of the main peak and lasting 7-8d occurred. On 1975 Nov 7, the peak of a second flare of similar duration but more than 10% of the intensity of the main peak was reached.

Pulse height spectra were obtained near the peak and during the

Edith A. Müller (ed.), Highlights of Astronomy, Vol. 4, Part I, 87-94. *All Rights Reserved.*
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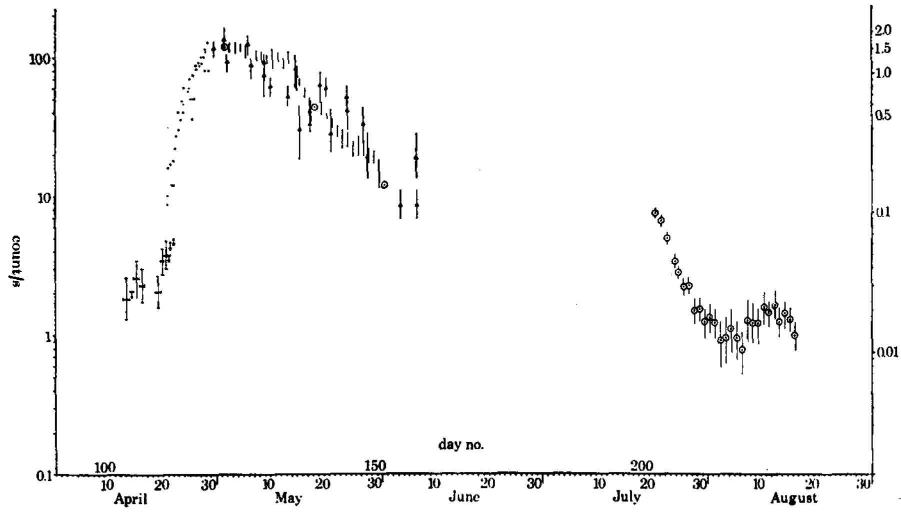

FIGURE 1. The light curve of A0535+26; the result is a composite of data from 3 of the Ariel V experiments (from Willmore, 1976)

decay phase. Power law fits gave photon number indices of -1.0 ± 0.1, showing that the spectrum changed little over this period. Observations above 20keV showed that the development of the high energy spectrum also was confined to the growth phase.

The most important characteristic of this source was that it was found (Rosenberg, Eyles, Skinner and Willmore, 1975) to be modulated at 104s. It was the second ''slow rotator'' to be discovered, the first being A1118-61. Now, of course, it is clear that slow rotators are the rule, rather than exceptional, amongst all the modulated X-ray sources. The discovery of the modulation opened up the possibility of studying any orbital motion of the source through the period changes. Unfortunately, period changes from this cause must be distinguished from those from accretion torques, to which the slow rotators might be expected to be particularly sensitive. The period of A0535+26 was measured near the peak, at two points on the decay and during the flare of 1975 November. There seems to be clear evidence of an overall spin-up, the rate of which was greatest after the peak intensity, so an effect of accretion which will be proportional to the X-ray intensity, seems to be indicated. However, the sequences of observations from 1975 May/June and November yield rates of change of period 7-25 times greater than those which are thus attributed to accretion, suggesting that there is an additional effect which might be due to orbital motion (Rappaport, Joss, Bradt, Clark and Jernigan, 1976).

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The observations are unfortunately insufficient to define the orbits completely, particularly as it is important to allow for the possibility of a high eccentricity since it has been suggested that in transient sources X-ray emission results from a burst of mass transfer as a compact companion passes peri-astron. However, the observations can be accounted for by orbital periods in the range 17d to 76d, with a preference for the larger values. It is clear that much larger values would be required to account for the modulation of the mass transfer.

An optical counterpart, the emission line B star HDE245770 has been proposed (Liller, 1975a; Murdin, 1975) on the basis of positional coincidence with the Ariel V error box. Distance estimates range from 1.2-4.8 kpc.

The other source which is clearly similar is A1118-61 (Table 1).

2.2 A0620-00

This source attracted a good deal of attention because for 42d its brightness exceeded that of Sco X-1 so that it was the brightest X-ray source in the sky. The light curve was essentially similar to that of A0535+26, including a flare 43d after the main peak. Whilst both these transients have exhibited flaring, it is not at all certain that others have done - it was not observed for example, on A1742-29. On the other hand, the precursor has been observed on every transient for which observations in the appropriate period were made.

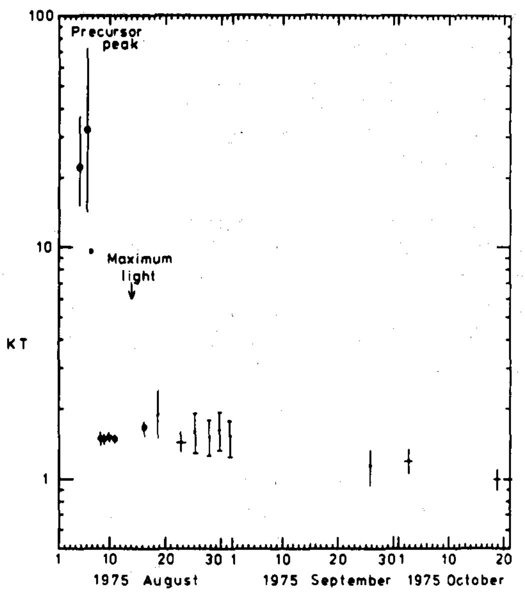

FIGURE 2. Spectrum of A0620-00, indicated by the best-fit temperature (from Carpenter et al, 1976)

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The spectrum of A0620-00 was found to change markedly after the precursor had formed (Carpenter, Eyles, Skinner and Willmore, 1976), the effective temperature of the radiation dropping from kT = 30 keV in the precursor to kT = 2 keV at the intensity peak, after which it dropped only slowly. The spectrum intensity above 20 keV actually tended to very in a somewhat opposite sense from that below 20 keV, since it increased for the first part of the decay phase. This is very reminiscent of the behaviour of Cyg X-1 after the outburst of 1975 May, which has been explained in terms of an accretion disk with a hot central core, which might be applicable here also.

Good positions were obtained for this source both by Ariel V and SAS-3; the latter led to the discovery by Boley and Wolfson (1975) of a star which had brightened by some 8^m as compared with the POSS plates. Liller (1975b) showed from Harvard patrol plates that Boley and Wolfson's star had undergone a similar outburst in 1917 November and was therefore a recurrent nova with a period of 57.8 yr. From the fact that no X-ray emission was detected from Nova Cygni 1975, it is clear that the ratio of X-ray to optical emission can vary over an extremely wide range, to the extent that the emission mechanisms must be different. It is believed that the optical emission of A0620-00 arises from X-ray energy ''reprocessed'' high in the photosphere of the companion star.

It is important to obtain a distance estimate for this source in view of its very high apparent brightness. A value of about 2 kpc seems most likely, indicating a peak luminosity above 1 keV of 5.10^{38} ergs/sec., which is above the Eddington limit for a neutron star. Assuming therefore that accretion on to a compact object is actually involved in this source, and that the Eddington limit applies, the compact object may be a black hole. This would be consistent with the absence of periodic modulation, but Matilsky et al (1976) have observed intensity variations during 1976 Jan-Feb with a periodicity of (7.8 ± 0.7)d, and similar periodicities have been reported in the optical emission. These may be indicative of an orbital period.

The existence of radio emission from this source was also reported. Similar sources were A1742-28 and A1524-61. The first of these is very probably close to the Galactic Centre which indicates that it also had a maximum luminosity of 5.10^{38} ergs/sec. The ratio of radio to X-ray luminosity for A1742-28 was higher than for any other transient for which radio observations are available.

2.3 Summary

Table 1 summarises data for 4 Ariel V transients. If it is accepted that the first two sources and the last two sources in the table each represent two classes of classical transient, then it is the case that the behaviour of the transients shows more striking regularity than the ordinary X-ray sources, especially in the behaviour of the light curve. The two suggested classes are distinguished by the first class having somewhat shorter decay times and harder spectra than

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TABLE 1

Source	Precursor Amp.	Rise D	Decay D	Peak Uc/s	Slope	Period Min.	Optical
A1118-61	-	-	8	130	-0.91	6.755±0.01	?Be star
A0535+26	0.03-0.10	11	15	1600	-1.0	1.737±0.003	?Be star
A1742-28	-	-	16	2800	-3	-	
A0620-00	0.4	5	27	19500	-5.1 [-1.65	[7.80d] precursor]	[K dwarf?] [M giant?]

the second, and by exhibiting periodic modulation and a possible association with Be stars, whilst the second class is unmodulated, and may be associated with appreciable radio emission. On the basis of the rather uncertain distance estimates at present available, it seems likely that the luminosity of the second class is rather high, 5.10^{38} ergs/sec, whilst that of the first class may well be an order of magnitude or more less. Such a rather low luminosity would be more in line with that of the normal X-ray sources thought to be associated with Be stars, such as 3U0352+30 = X Per.

If all the Ariel V transient sources with a peak brightness > 65 Uhuru counts/sec are plotted in galactic coordinates, they show a very striking confinement to the region of the plane. Despite the different character of the only reliable counterpart, that of A0620-00, this suggests an association with extreme Population I stars. The occurrence rate of transients with an apparent peak brightness greater than 100 Uhuru counts/sec has been estimated (G.K.Skinner, private communication) to be about 35/year. The total rate in the Galaxy is likely to be a few times higher. Taken with the high peak luminosity of the longer-lived transients, this suggests that the transient sources together make a not inappreciable, though not dominating, contribution to the X-ray luminosity of the Galaxy.

3. OTHER TRANSIENTS

Thus far, our remarks have concerned less than half the observed transient sources. It is far more difficult to see any regularity of behaviour in the remainder, or what distinguishes them from the standard X-ray sources. As a practical matter, we have considered a source to be a transient if it is not listed amongst the Uhuru, OSO-7 or Ariel V sources, and if it reaches a peak intensity exceeding about 65 U counts/sec. This means that its intensity at the time of observation is 10-20 higher than during the extended periods when the data for those catalogues was being gathered. Under this criterion sources like Cir X1 and Aql X1 would come close to being classed as transients, though of a recurrent behaviour that actually has not been observed in any source that has been called a transient. Moreover, these sources were much more active a few years ago. It would be wise

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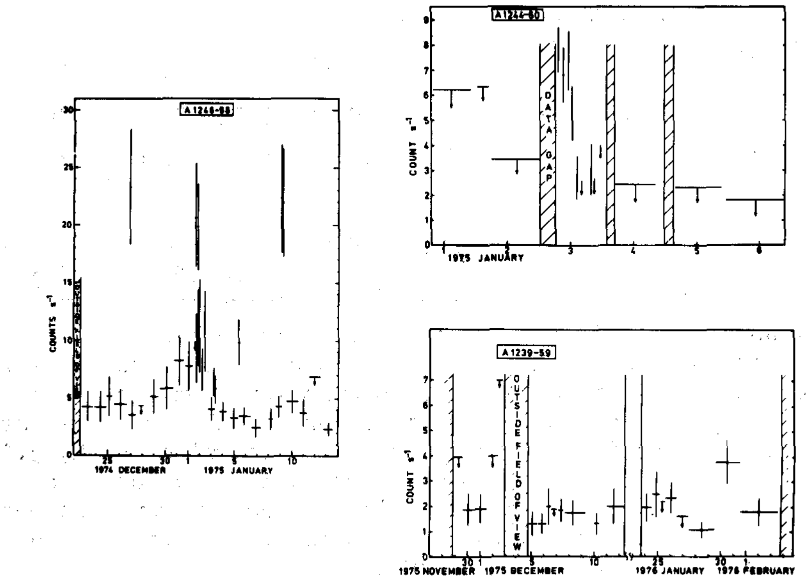

FIGURE 3. Light curves of a remarkable group of three transients which occurred in the Crucis region.

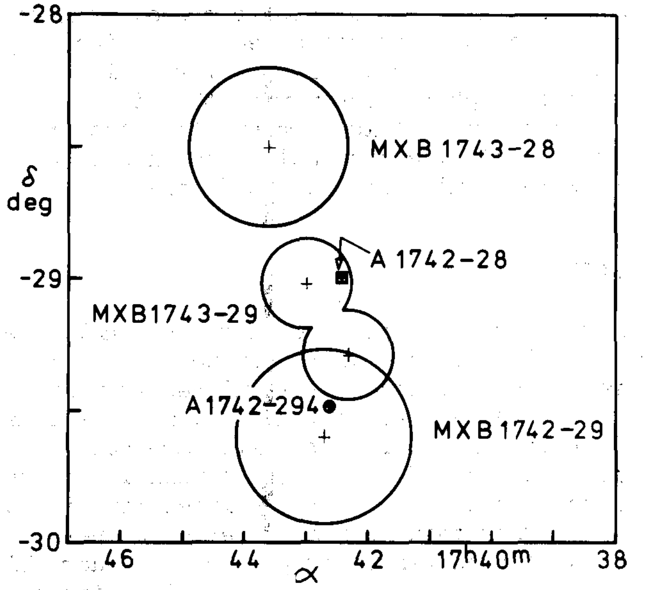

FIGURE 4. Positions of the 2 Galactic Centre transients observed by Ariel V in 1975 and 1976; the SAS-3 burst sources are also shown.

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to suppose that the difference between transients of this sort and the standard X-ray sources is more a matter of degree than kind. Fig.3 shows the light curves of a remarkable group of three sources in Crux. A1246-58 (Fig.3(a)) showed repeated flaring superposed on a lower base level. A1244-60 (Fig.3(b)) showed a single flare lasting for only a few hours, the base level being absent or undetectable. This region was observed for two extended periods separated by about a year; none of them was observed in both of these.

The very short period when A1244-60 was observed is notable but not necessarily exceptional. Ricketts, Cooke and Pounds (1976) have described a short-period transient A1103+38 lasting only a few days. It differs from all the other transients discussed here in that it occurred at a high galactic latitude (65°); it is also rather less intense and does not quite meet the criterion of a peak intensity of 65 U counts/sec.

The Ariel V rotation modulation collimator has scanned the Galactic plane from Circinus to Aquila for 3 month periods early in 1975 and 1976. On the first scan, the only transient to be observed was A1742-28, the very strong source which has already been mentioned. On the second scan, three weaker transients - A1744-36, A1710-33 and A1742-294 - were observed. The position, close to the Galactic Centre, of the last of these is noteworthy. Fig.4 shows the position of the two transient sources and the MIT burst sources. The two transients are quite evidently distinct sources. It appears that activity of this kind must be common in this region - the two transients were in total detected for > 90% of the time when the Galactic Centre was within 12° of the centre of our field of view.

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DISCUSSION

L. Maraschi - The subdivision illustrated for transients also emerges among permanent X-ray sources. Pulsating sources show hard spectra (spectral index $\sim$ 1) and tend to be associated with early-type primaries. This is a general fact that requires some theoretical explanation.

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