Multiple ejections during the 1975 outburst of A0620−00

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ABSTRACT

The well-known black-hole X-ray transient A0620−00 was a bright radio source during the first part of its outburst in 1975. We have revisited the available data and find for the first time evidence that the source exhibited multiple jet ejections. Rapid radio spectral changes indicate the addition of at least three new components which are initially optically thick. From single baseline interferometry taken about three weeks after the start of the X-ray outburst we find that the source is extended on arcsec scales and infer a relativistic expansion velocity. Some of the other (soft) X-ray transients, such as GS 1124−68 and GS 2000+25, show very similar X-ray outburst light curve shapes to that of A0620−00, while their radio outburst light curve shapes are different. We suggest that this is due to the radio emission being strongly beamed in outburst, whereas the X-ray emission remains isotropic. Since this effect is stronger at higher jet velocities, this strengthens our conclusion that the jets in A0620−00 and other soft X-ray transients move with relativistic speeds.

Key words: accretion, accretion disks – binaries: close – stars: individual: A0620−00 – X-rays: stars

1 INTRODUCTION

A0620−00, a low-mass X-ray binary black-hole transient, was discovered in outburst almost 25 years ago. It was detected by the Sky Survey Experiment onboard Ariel V on August 3rd 1975 (Elvis et al. 1975), and subsequently at various other wavelengths (see Kuulkers 1998 for a recent review). The radio source associated with the (soft) X-ray transient was detected almost two weeks after the start of the outburst and was visible for about a fortnight (e.g. Davis et al. 1975; Owen et al. 1976). The initial model to explain the radio outburst light curve was the synchrotron ‘bubble’ model (homogeneous adiabatically expanding sphere of relativistic electrons; e.g. van der Laan 1966; Hjellming & Han 1995). However, this model often does not describe those radio transient light curves which have sufficient coverage (see e.g. Ball 1994), and the reality of relativistic ejections from X-ray binaries is in all likelihood considerably more complex.

Since we have now a bigger sample of (black-hole) radio transients, in several of which the radio emission following X-ray outburst has been clearly resolved into relativistic outflows (e.g. Mirabel & Rodriguez 1994; Tingay et al. 1995; Hjellming & Rupen 1995; Mioduszewski et al. 1998), we decided to re-investigate the radio outburst of A0620−00. We report here on the outburst light curves, spectral evolution, and a comparison with its X-ray outburst. We find some evidence from single-baseline interferometry for expansion of the source to an angular size of a several arcsec. We also discuss the radio observations in the framework of the radio transient sample for the black-hole X-ray transients which have similar X-ray properties to A0620−00 and have been reasonably well covered in the radio, i.e. GS 1124−68 and GS 2000+25.
Figure 1. Radio light curves during the outburst of A0620−00 at three frequencies, i.e. 962 MHz (top), 1400–1420 MHz (middle) and 2380/2695 MHz (bottom). Upper limits are indicated by an arrow. This figure is an update of the light curves presented by Hjellming et al. (1988) and Hjellming & Han (1995). Also indicated are simplistic single synchrotron bubble fits which are clearly inadequate representations of the data. At the top we indicate the approximate times of the start of possible jet-ejections, see text.
2 RADIO EMISSION FROM A0620−00

2.1 Observations

We have collected all available radio observations of A0620−00 during its 1975 outburst as reported in the literature. For convenience we give these observations in chronological order in Table 1. Note that for some of the radio observations no exact times were available in the literature; these have been updated by us from private communications. The measurements by Davis et al. (1975) were used after a reassessment of errors.

In the text we will refer to time as given by JD−2442000.

We note that, apart from an account of the radio observations of A0620−00, Lequeux (1975) mentions that ‘there is a 0.33 Jy radio source following by 27’s’. At the declination of A0620−00 this implies an angular separation of ~6.8 arcmin; as such this second, bright radio source is unlikely to be related to A0620−00. Inspection of the NRAO VLA Sky Survey archive (NVSS; Condon et al. 1998) reveals several sources at about the correct location and flux densities; Lequeux’s following source is in all likelihood then this group of relatively unvarying field objects.

2.2 Light curves and spectral evolution

In Fig. 1 we present the radio outburst light curves of A0620−00 at frequencies of 962 MHz, 1400–1420 MHz and at 2380/2695 MHz. This is an update of figure 2 of Hjellming et al. (1988; see also Hjellming & Han 1995). Together with the data points we also show synchrotron bubble model light curves as given by them at the various frequencies.

The light curves show that the decline is not a smooth power-law or exponential decay. It seems that there are various local maxima. Especially the ‘newly’ added measurement at 2380 MHz near day 640 obtained by Craft (1975) is far from that expected. It is substantially lower than Owen et al.’s (1976) measurement near day 641 at 2695 MHz. This cannot be due to the slight difference in frequency. So, a maximum was reached in the 2380/2695 MHz band near Owen et al.’s (1976) measurement (whether this is the main peak of the radio outburst or an intermediate maximum we cannot say). This is the first time that it has been shown that there are multiple maxima in the A0620−00 radio light curves.

We also plotted the radio spectral evolution as a function of time (Fig. 2). The spectra are drawn from data points which were obtained within a maximum time span of 0.36 days. They have been connected to guide the eye. For convenience we alternated between solid and dotted lines. The symbol □ denotes an upper limit. The times (JD−2442000) of the spectra have been indicated. Negative spectral indices (e.g. day 640, 644, 647) are indicative of optically thin synchrotron emission. Rapid switches to positive spectral indices occur around day 641, 645 and 648 and correspond to increases in the flux density at high frequencies; following such spectral inversions the emission reverts back towards an optically thin spectrum over a few days. These spectral inversions are indicative of emission from new, initially optically thick, components, which peak first at higher frequencies as they expand (see text).

On day 645 another inversion of the spectrum occurs. Possibly a third spectral inversion also occurs on day 648. We have indicated the times of the spectral inversions at the top of Fig. 1 as T2, T3, and T4?, respectively. T1 corresponds to the start of the radio outburst which is not exactly known.

Such spectral changes, corresponding to local maxima in the light curve which peak first at higher frequencies, are indicative of repeated superposition of flares which are initially optically thick. This effect is well observed in a sequence of five major radio flares from Cyg X-3 in 1994 (Fender et al. 1997). Given that much evidence points to the ejection of bright radio-emitting clumps from Cyg X-3 which correspond to these flares (e.g. Geldzahler et al. 1983; Mioduszewski et al. 1998), it seems natural to infer that the secondary maxima and associated spectral changes that we see in the radio light curve of A0620−00 correspond to multiple ejections of synchrotron-emitting components from the source.

2.3 Single baseline interferometry

Based on the suggestion that A0620−00 might exhibit jet ejections we decided to re-examine the radio observations by Davis et al. (1975). These observations were done with the MkII-MkIII interferometer (baseline 24 km) at Jodrell Bank at 962 MHz, where the resolution is 2.5 arcsec. At that time no significant variation with hour angle was detected dur-
Table 1: Radio observations of A0620$-$00

| Time (JD−2442000) | Frequency (MHz) | Flux density (mJy) | Error (mJy) | Reference |
|-------------------|-----------------|--------------------|-------------|-----------|
| 636.5–639.5       | 962             | <5000              | Davis et al. 1975 |
| 640.05            | 2380            | 80                 | Craft 1975; Craft & Davis 1998 |
| 640.09            | 1400            | 300                | Owen et al. 1976 |
| 640.1             | 10600           | <250               | Davis et al. 1975 |
| 640.90            | 962             | 162                | Davis et al. 1975; this paper |
| 641.09            | 2695            | 260                | Owen et al. 1976 |
| 642.052           | 151             | <250               | Davis et al. 1975 |
| 642.96            | 962             | 96                 | Davis et al. 1975; this paper |
| 643.08            | 2695            | 140                | Owen et al. 1976 |
| 643.1             | 1418            | 130                | Owen et al. 1976 |
| 644.04            | 2380            | 80                 | Craft 1975; Craft & Davis 1998 |
| 644.04            | 1420            | <80                | Craft 1975; Craft & Davis 1998 |
| 645.017           | 151             | <250               | Davis et al. 1975 |
| 645.07            | 2695            | 110                | Owen et al. 1976 |
| 645.85            | 1408            | 110                | Lequeux 1975 |
| 645.96            | 962             | 68                 | Davis et al. 1975; this paper |
| 646.017           | 151             | <250               | Davis et al. 1975 |
| 646.9             | 1420            | 55                 | Owen et al. 1976 |
| 647.00            | 962             | 39                 | Davis et al. 1975; this paper |
| 647.822           | 5000            | 20                 | Scott 1975; Scott 1998 |
| 647.96            | 962             | 62                 | Davis et al. 1975; this paper |
| 648.822           | 151             | <250               | Davis et al. 1975 |
| 648.87            | 4600            | 28                 | Bieging & Downes 1975 |
| 648.96            | 962             | 21                 | Davis et al. 1975; this paper |
| 649.96            | 962             | 24                 | Davis et al. 1975; this paper |
| 650.96            | 962             | 28                 | Davis et al. 1975; this paper |
| 651.95            | 962             | <16                | Davis et al. 1975; this paper |
| 661.5–662.5       | 408             | <10                | Little et al. 1976 |
| 662.5             | 4600            | <20                | Bieging & Downes 1975 |
| 663.5             | 4600            | <20                | Bieging & Downes 1975 |
| 672.5             | 408             | <10                | Little et al. 1976 |
| 774.5             | 408             | <10                | Little et al. 1976 |

We found that A0620−00 was extended by 3–4 arcsec by fitting a double source or gaussian to the visibility curve. We note that if the source was a point then there would not be any significant variation of amplitude with baseline length. The effective field of view of such an interferometer is only a few times the resolution and so the effects seen cannot be caused by confusion. Further inspection of the NVSS does not reveal any obvious radio sources within 5 arcmin which may have been responsible for this apparent extension.

This observation was done on a date ∼20 days after the start of the X-ray outburst. If we assume that the extended source is a result from the primary jet ejection and that this originated at the start of the X-ray outburst, the data imply an apparent expansion velocity of the jet of ∼0.9–1.2 c, assuming a distance of 1050 pc (Shahbaz, Naylor & Charles 1994). The apparent jet velocity, however, is ∼0.45–0.6 c, if there was two-sided ejection in a pair of jets. Association of the extended structure with later ejections we infer to have occurred (Section 2.2) only increases this velocity.
3 A COMPARISON WITH SIMILAR X-RAY TRANSIENTS

3.1 X-ray and radio light curves

In Fig. 4 we show the X-ray light curves and radio light curves of A0620–00 and two other black-hole X-ray transients with similar X-ray light curves (see e.g. Chen et al. 1997), i.e. GS 1124–68 and GS 2000+25. For the radio we show the data at two frequencies in order to get the longest and best coverage. We have also indicated the simple single synchrotron bubble model light curves as derived by Hjellming et al. (1988) and Ball et al. (1995).

As noted before (see Kuulkers 1998, and references therein), the X-ray light curve of A0620–00 shows an enhancement for a brief time just after the outburst peak. In the hard X-rays (6–15 keV) this X-ray flare might be even more pronounced (see Kuulkers 1998). Interestingly, the Ginga hard X-ray (9.3–37 keV) light curve of GS 1124–68 shows such a pronounced reflare just after the peak of the X-ray outburst (Ebisawa et al. 1994; see also Takizawa et al. 1997 and Fig. 6). A similar conclusion was drawn by Brandt et al. (1992) using Watch data. Note that GRS 1009–45 displays a similar hard X-ray feature (see Kuulkers 1998). We suggest that this (hard) X-ray reflare is similar to the one seen in A0620–00.

So, although the X-ray light curves are very similar in the three cases, the radio light curves differ considerably. In particular, while we have shown that there is evidence for multiple small ejections comprising the A0620-00 light curve, it shows nothing like the major secondary radio flare observed from GS 1124–68 (see also below). The radio light curve of GS 2000+25 can not really be compared quantitatively with those of A0620–00 and GS 1124–68 since the parts of the X-ray outbursts covered are different. However, it is interesting to note that GS 2000+25 could have experienced radio outbursts like GS 1124–68, since the covered parts of the X-ray outbursts complement each other. Similarly, if GS 1124–68 had been covered longer it might have shown a similar decay as GS 2000+25.

Fig. 4 shows that it is difficult to compare observed radio light curves in order to infer similar characteristics, especially if the coverage is different. This applies even more when modeling such light curves. Also, the start of the radio outbursts can not be determined, since the very first rise has not been covered. The radio data are all consistent with the start of the outburst being around the time of the start of the X-ray outburst. Although modeling the radio light curves with a synchrotron bubble model gives a start which lags the X-rays by about ten days, it has been shown that such models do not describe the data very well (see above).

The similar X-ray but dissimilar radio light curves for the three X-ray transients are a strong indication that the radio emission for all these sources arises in relativistic outflows. In this case the X-ray emission is more or less isotropic and similar behaviour is observed regardless of the inclination of the binary. On the other hand, the radio emission, if it arises in relativistic outflows, will be strongly beamed, with both brightness and morphology of light curve affected by the angle to the line of sight. Our inferred jet velocities in the case of A0620–00 point to relativistic outflows.

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Figure 4. X-ray and radio light curves of A0620−00 (top), GS 1124−68 (middle) and GS 2000+25 (bottom). The X-ray measurements of A0620−00 are those obtained by the Ariel V SSE (2–18 keV), Ariel V ASM (3–6 keV) and SAS-3 CSL-A (1.5–6 keV), see Kuulkers (1998). The Ariel V SSE and ASM light curves have been scaled to match the SAS-3 CSL-A light curve. The X-ray measurements of GS 1124−68 are those obtained with the Ginga LAC (1.2–37 keV; Ebisawa et al. 1994) and the Ginga ASM (1–20 keV; Kitamoto et al. 1992). The rise of the X-ray outburst of GS 2000+25 is taken from Tsunemi et al. (1989), while the rest of the light curve is from Kitamoto et al. (1992). For the radio light curves we have plotted the measurements at two frequencies. The radio measurements of A0620−00 are tabulated in Table 1, the GS 1124−68 measurements are from Ball et al. (1995) and those of GS 2000+25 are obtained by Hjellming et al. (1988). Drawn with solid and dashed lines are fits to the lowest and highest radio frequency measurements, respectively, with single synchrotron bubble models as presented by Hjellming et al. (1988) and Ball et al. (1995).
from the radio light curves. Ellipsoidal light curve modeling of the orbital light curves indicate that GS 1124−68 has a larger inclination (∼54 degrees) than A0620−00 (∼37 degrees), whereas the radio light curve is more peaked in the case of GS 1124−68 and thus one would infer a smaller inclination than compared to A0620−00. Although we recognize this problem we note that other factors may complicate the light curves, such as the time between two ejections and their relative strength and their speed. At least we have shown that qualitatively radio light curves change as a function of inclination when jets move near the speed of light, which may explain the observed radio behaviour.

3.2 A closer look at GS 1124−68

Brandt et al. (1992) concluded that the hard X-ray peaks in the outburst light curve of GS1124−68 were ∼13 days apart, i.e. very similar to the time span between the first radio measurement and the peak of the radio reflare. However, according to Brandt et al. (1992) the radio was delayed by ∼7 days with respect to the X-rays. In Fig. 5 we plot the Ginga hard X-ray (9.3–37 keV) light curve and the radio light curve near the start of the outburst. Indeed the correlation between the X-rays and radio is striking, but a detailed look reveals that a ∼7 day delay does not fit both light curves. We conclude that the first rapid decline in the radio follows the rapid decline in the hard X-rays by about ∼3 days, whereas the peak of the second radio flare is ∼10 days after the second hard X-ray flare. Such radio delays with respect to hard X-rays are not uncommon in X-ray transients; an example is GRO J1655−40 which has shown similar hard X-ray and radio light curves near the beginning of its outburst (e.g. Harmon et al. 1995).

4 CONCLUSIONS

We have shown that the radio outburst of A0620−00 in 1975 is consistent with multiple ejection events, with the jets most probably moving at near the speed of light, as has been inferred for GRO J1655−40 and GRS 1915+105. This strengthens the suggestion (e.g. Hjellming & Rupen 1995) that most, maybe all, (soft) X-ray transients undergo radio outbursts at the time of their X-ray and optical outbursts, and that they generally consist of multiple ejections, presumably of a significant fraction of the accretion disc.
Figure 6. Ginga hard X-ray (9.3–37 keV; Ebisawa et al. 1994) and radio (843 and 4700 MHz; Ball et al. 1995) light curves of GS 1124−68 during the beginning of the X-ray outburst.

We note that recently it has been reported that sources showing similar X-ray (spectral) behaviour as A0620−00 (e.g. GS 1124−68 and GS 2000+25) do not contain a rapidly spinning black hole and it has been suggested that such systems can not form relativistic jets (Zhang, Cui & Chen 1997; see also Cui, Zhang & Chen 1998). Our single baseline interferometry suggests, however, relativistic jet speeds in the case of A0620−00, which is in contradiction with their suggestion. Determining whether black-holes spin or not from fairly simplistic X-ray modelling may therefore be rather uncertain.

By comparing (soft) X-ray transients with similar X-ray behaviour we find that the radio emission displays different light-curve shapes and strengths. This strongly supports isotropic X-ray emission, whereas the radio emission is beamed (i.e. in the form of jets). A first qualitative modeling of such a geometry seems to match the observed variety of radio light curves, and seems to strengthen the hypothesis that the jets are moving at considerable speed.

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REFERENCES

Ball, L., 1994, ApJS, 90, 889
Ball, L., Kesteven, M.J., Campbell-Wilson, D., Turtle, A.J., Hjellming, R.M., 1995, MNRAS, 273, 722
Bieging, J., Downes, D., 1975, Nat, 258, 307
Brandt, S., Castro-Tirado, A.J., Lund, N., Dremin, V., Lapshov, I., Sunyaev, R., 1992, A&A, 254, L39
Charles, P.A., 1998, in: Theory of Black Hole Accretion Disks, M. Abramowicz, G. Bjornsson & J. Pringle (eds.), CUP, p. 1
Chen, W., Shadrake, C.R., Livio, M., 1997, ApJ, 491, 312
Condon, J.J., Cotton, W.D., Greisen, E.W., Yin, Q.F., Perley, R.A., Taylor, G.B., Broderick, J.J., 1998, AJ, 115, 1963
Craft, H.D., 1975, IAU Circ. 2822
Craft, H.D., Davis, M.M., 1998, private communication
Cui, W., Zhang, S.N., Chen, W., 1998, ApJ, 492, L53
Davis, R.J., Edwards, M.R., Morison, I., Spencer, R.E., 1975, Nat, 257, 659
Ebisawa, K., Ogawa, M., Aoki, T., Dotani, T., Takizawa, M., Tanaka, Y., Yoshida, K., Miyamoto, S., Iga, S., Hayashida, K., Kitamoto, S., Terada, K., 1994, PASJ, 46, 375
Elvis, M., Page, C.G., Pounds, K.A., Ricketts, M.J., Turner, M.J.L., 1975, Nat, 257, 659
Feldman, P.A., 1975, IAU Circ. 2822
Fender, R.P., Bell Burnell, S.J., Waltman, E.B., Pooley, G.G., Ghigo, F.D., Foster, R.S., 1997, MNRAS, 288, 849
Fender, R.P., Garrington, S.T., McKay, D.J., Muxlow, T.W.B., Pooley, G.G., Spencer, R.E., Stirling, A.M., Waltman, E.B., 1999, MNRAS, in press
Geldzahler, B.J., Johnston, K.J., Spencer, J.H., Klepczynski, W.J., Josties, F.J., Angerhofer, P.E., Florkowski, D.R., McCarthy, D.D., Matsakis, D.N., Hjellming, R.M., 1983, ApJ, 273, L65
Hjellming, R.M., Han, X., 1995, in: Lewin, W.H.G., van Paradijs, J., van den Heuvel, E.P.J. (eds), X-ray Binaries, Cambridge, Cambridge University Press, p. 308
Hjellming, R.M., Johnston, K.J., 1988, ApJ, 328, 600
Hjellming, R.M., Rupen, M.P., 1995, Nat, 375, 464
Hjellming, R.M., Calovini, T.A., Han, X.H., Córdova, F.A., 1988, ApJ, 335, L75
Harmon, B.A., Wilson, C.A., Zhang, S.N., et al., 1995, Nat, 374, 703
Kitamoto, S., Tsunemi, H., Miyamoto, S., Hayashida, K., 1992, ApJ, 394, 469
Kuulkers, E., 1998, NewAR, 41, [astro-ph/9805031]
Lequeux, J., 1975, IAU Circ. 2822
Little, A.G., Crawford, D.F., Murdoch, H.S., 1976, Nat, 261, 113
Mioduszewski, A.J., Hjellming, R.M., Rupen, M.P., Waltman, E.B., Pooley, G.G., Ghigo, F.D., Fender, R.P., 1998, in: IAU 164 – Radio emission from Galactic and Extragalactic compact sources, ASP Conf. Ser. 144, p. 351
Mirabel, I.F., Rodriguez, L.F., 1994, Nat 371, 46
Owen, F.N., Balonek, T.J., Dickey, J., Terzian, Y., Gottesman, S.T., 1976, ApJ, 203, L15
Scott, P.F., 1998, private communication

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Radio observation of A0620−00

Scott, P.F., 1975, IAU Circ. 2823
Shahbaz, T., Naylor, T., Charles, P.A., 1994, MNRAS, 285, 607
Spencer, R.E., 1979, Nat 282, 483
Takizawa, M., Dotani, T., Mitsuda, K., et al., 1997, ApJ, 489, 272
Tingay, S.J., Jauncey, D.L., Preston, R.A., Reynolds, J.R., Meier, D.L., Murphy, D.W., Tzioumis, A.K., McKay, D.J., Kesteven, M.J., Lovell, J.E.J., Campbell-Wolson, D., Ellingsen, S.P., Gough, R., Hunstead, R.W., Jones, D.L., McCullough, P.M., Migenes, V., Quick, J., Sinclair, M.W., Smits, D., 1995, Nat, 374, 141
Tsunemi, H., Kitamoto, S., Okamura, S., Roussel-Dupré, 1989, ApJ, 337, L81
van der Laan, H., 1966, Nat, 211, 1131
Zhang, S.N., Cui, W., Chen, W., 1997, ApJ, 482, L155

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