Astron. Astrophys. 352, L91–L94 (1999)

ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

Evidence for an ~ 80 day periodicity in the X-ray transient pulsar XTE J1946+274

Sergio Campana[1], **Gianluca Israel**[2], **and Luigi Stella**[2]

[1] Osservatorio Astronomico di Brera, Via Bianchi 46, 23807 Merate (Lc), Italy
[2] Osservatorio Astronomico di Roma, via Frascati 33, 00040 Monteporzio Catone, Roma, Italy

Received 30 August 1999 / Accepted 9 November 1999

Abstract. We report evidence for an ~ 80 d periodicity in the X–ray flux of the hard transient pulsar XTE J1946+274. The 1.3–12 keV light curve obtained with the RossiXTE All Sky Monitor shows five regularly spaced flares over a $\sim$ 1 year baseline starting from the outburst onset in Sept. 1998. The first and strongest flare is somewhat longer than the subsequent four flares, which recur in a fairly periodic fashion. This suggests that the profile of the first flare is dominated by the time variability of the Be star ejection episode, while the following four flares are primarily caused by the neutron star motion along an eccentric orbit.

Key words: stars: pulsars: general – stars: individual: XTE J1946+274 – X-rays: stars

1. Introduction

The hard X–ray transient (HXRT) source XTE J1946+274 was discovered with the RossiXTE All Sky Monitor (ASM) during a scan of the Vul-Cyg region on Sept. 5, 1998. The source was detected at a flux level of ~ 13 mCrab (2–12 keV; Smith & Takeshima 1998), which raised steeply in the following days, reaching a peak of ~ 110 mCrab around Sept. 17, 1998 (Takeshima & Chakrabarty 1998). X–ray pulsations at 15.8 s were discovered by BATSE (GRO J1944+26, Wilson et al. 1998a) and subsequently confirmed through RossiXTE pointed observations (Smith & Takeshima 1998). The 1998 outburst of XTE J1946+274 was extensively monitored also through a BeppoSAX observational campaign (Campana et al. 2000; Santangelo et al. 2000).

The position error circle obtained with RossiXTE ($2'.4$ radius, 90% confidence level; Takeshima & Chakrabarty 1998) was reduced to $30''$ (95% confidence level) through pointed observations with BeppoSAX Narrow Field Instruments (Campana et al. 1998). The best X–ray position is R.A.= $19^{\rm h}\ 45^{\rm m}\ 38^{\rm s}$ and Dec.= $+27^{\rm o}\ 21'.5$ (equinox 2000). XTE J1946+274 lies in the error box of the 1976 Ariel V transient 3A 1942+274 (Warwick et al. 1981). Assuming ~ 1000 HXRTs in the Galaxy (e.g. Bildsten et al. 1997), we estimate a chance probability of $\sim 7\%$ of of finding a new transient within the 3A 1942+274 error box. This probability is such that we cannot infer a firm association of the two sources.

The likely optical counterpart has been recently identified (Verrecchia et al. 2000) with a $\rm R \sim 14$ mag Be star, showing a strong H_α emission line. Earlier reports of a B counterpart (Israel, Polcaro & Covino 1998; Ghavamian & Garcia 1998) has been ruled out by the BeppoSAX error circle, lying $10''$ outside.

All these characteristics testify that XTE J1946+274 is a Be star HXRT. Here we report the discovery of an ~ 80 d X–ray flux modulation in RossiXTE-ASM data of the source and argue that this (or its double) likely represents the orbital period of the system.

2. Period determination

The ASM (Levine et al. 1996) on board the RossiXTE (Bradt, Rothschild & Swank 1993) routinely scans about 80% of the X–ray sky every orbit. It consists of three Scanning Shadow Cameras with a 1.3–12 keV energy band, an intrinsic angular resolution of a few arcmin and a large field of view ($6^{\rm o} \times 90^{\rm o}$ FWHM). A sensitivity of $\sim$5–10 mCrab is reached over one day. The intensity is calculated in three energy bands (1.3–3, 3–5 and 5–12 keV) and normalized in units of source count at the center of the field of view. Errors are computed considering the uncertainties due to the counting statistics and a $\sim 2\%$ systematic error obtained from the Crab calibration. A description of the ASM and its light curves can be found in Levine et al. (1996) and Levine (1998)[1].

Fig. 1 shows the light curve of the XTE J1946+274 outburst, which began in Sept. 1998. The source took ~ 25 d to reach the peak and then decayed smoothly, leading to a markedly asymmetric profile during the first ~ 80 d of the outburst. Following

Send offprint requests to: S. Campana
Correspondence to: campana@merate.mi.astro.it

[1] See the web page http://heasarc.gsfc.nasa.gov/docs/xte/asm_products.html#access

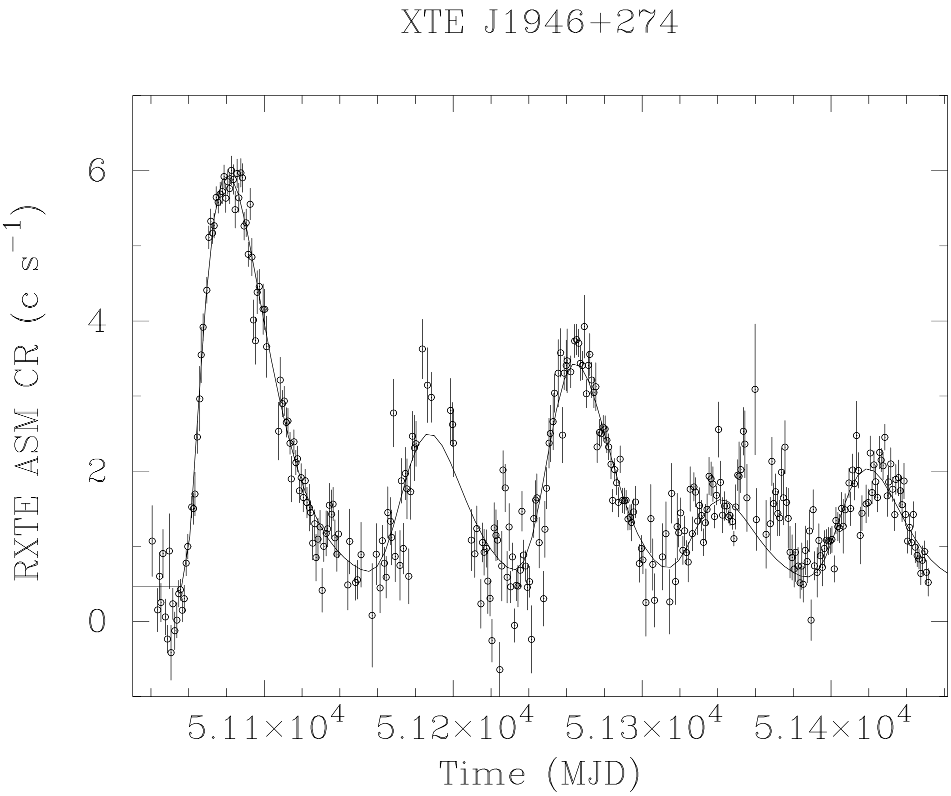

Fig. 1. Light curve of the XTE J1946+274 as observed with the RossiXTE-ASM. The continuous line shows the fit described in the text. Points with an error larger than 0.5 c s^{-1} have been discarded.

the main flare four secondary flares are evident in Fig. 1. Fig. 2 shows the light curves in the three ASM energy channels. The low energy curve contains only a small signal, a result of the fact that the source is heavily absorbed. The hardness ratio from the higher energy channels is consistent with being constant.

The overall behaviour of the light curve is suggestive of a relatively intense outburst in the initial phases, during which the neutron star mass capture rate was likely driven primarily by the time variations in the mass ejection from the Be star. The recurrent behaviour and lower flux of the following four flares suggest instead that later in the outburst the mass capture rate variations were induced mainly by the motion of the neutron star in an eccentric orbit. The fairly regular ~ 80 d recurrence of the four secondary flares is more apparent by looking at the light curve minima, which are evidently less influenced by the varying amplitude and shape of the outburst.

A simple power spectrum analysis of the four secondary flares (from MJD 51140 to MJD 51450) reveals a significant periodicity ($\sim 3.3\,\sigma$ in the 10–250 d range) at $\sim 73 \pm 5$ d. The inclusion of the first flare (from MJD 51040 to MJD 51450) lowers considerably the significance. Similarly, by adopting an epoch folding analysis of the light curve we detect a significant power at a frequency corresponding to $\sim 79{\pm}6$ d. The inclusion of the first flare causes the folding peak to shift to $\sim 87{\pm}6$ d. We also fitted the light curve of the last four flares with a sinusoid plus a constant: we determined a best fit period of ~ 77 d. The same fit on the total light curve provides instead a period of ~ 95 d.

The discrepancy between the periods determined with and without the first flare arises because this starts some $\sim$ 30 d before the extrapolation of the ephemerides derived from the subsequent four flares. In order to model the flare profiles more accurately we adopted a model consisting of a smooth burst profile with a power law rise and an exponential decay, namely $CR = CR_0 \left((t-t_0)/(t_{\rm c}\,\alpha)\right)^{\alpha}\ \exp{(t-t_0)/t_{\rm c}}$. Here t_0 is the starting time of the flare, CR_0 is the count rate normalization, α the power law slope of the rise and $t_{\rm c}$ the exponential decay timescale; for time smaller than t_0 the function value is 0. This model was fitted to each of the four secondary flares by forcing all parameters but the normalisation to be the same and by imposing a periodic recurrence of the outbursts, with the period a free parameter. Only the first flare, for the reasons described above, was allowed a different rise and decay profile and a shift in time.

Fig. 1 shows the best fit obtained in this way. The reduced χ^2 is 2.5. The rising exponents are 2.0 and 8.2 and the decay times $\alpha = 12$ and 6 d for the first and the other flares, respectively. These values are significantly different and confirm 'a posteriori' the differences between the first and the subsequent flares. The best separation between the flares is 77.3 d with a nominal statistical uncertainty of ~ 1 d (90% confidence level). We speculate that the slightly different result obtained with epoch folding search and the power spectrum density are due to the small number of points, the strength of the first and third flares and the width of the second and forth flares for which the maximum cannot be identified with certainty. The onset of the first flare is shifted by –7 d with respect to the other flares, moreover the different behaviour of its decay makes it occur some 30 d before the value extrapolated by the following flares. The

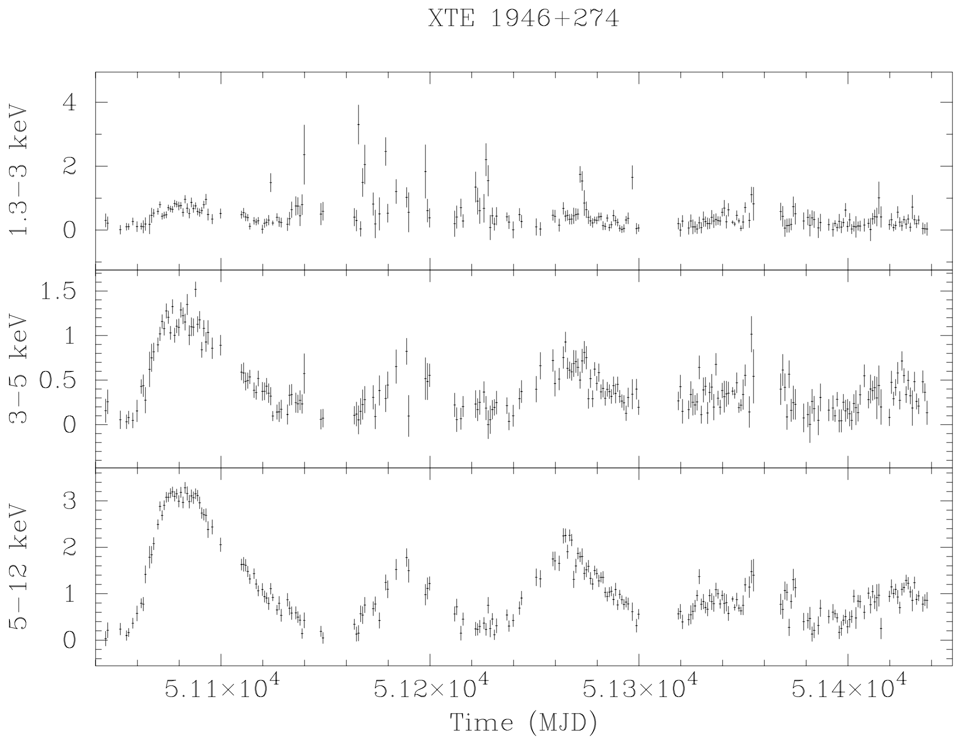

Fig. 2. Light curve of the XTE J1946+274 in the three energy bands of the RossiXTE-ASM.

approximate epoch of the maxima are MJD 51080.5, 51187.4, 51264.8, 51342.1 and 51419.5.

3. Discussion

In recent years, growing evidence has been gathered that the two classes of outburst from HXRT sources (type I: normal; type II: giant, cf. Stella, White & Rosner 1986) are associated with wind and disk accretion, respectively (Bildsten et al. 1997). Raguzova & Lipunov (1998) described the Be disk-fed accretion in HXRTs, finding that the outburst peaks occur at phase 0–0.5, depending on the wind characteristics and/or orbital eccentricity (i.e. the wind rose effect). The fairly regular spacing of the last four flares in XTE J1946+26 hints for their classification as Type I outbursts, even if the flux at minimum does not drop to very low values as, e.g., in the case of V 0332+53 (Stella, White & Rosner 1986). The different rise and decay timescales, as well as the larger intensity, make however the first flare markedly different from the others. This would argue in favour of a type II outburst. Despite the small number of cases, type II outburst peaks have been observed to be delayed in orbital phase with respect to periastron (e.g. 4U 0115+63, Whitlock et al. 1989; A 0535+26, Motch et al. 1991; Bildsten et al. 1997, see however 2S 1417–624 ibidem) and sometimes they last for several orbital cycles (e.g. V0332+53; Stella, White & Rosner 1986). The phasing of this outburst should therefore be dictated mainly by the time variability of the Be star mass outflow rate, especially in the first phases of the shell ejection episode.

As can be noted in Fig. 1, the first, third and fifth flares are stronger than the second and the forth. This might suggest that the neutron star is orbiting the Be companion in an inclined orbit and it crosses twice the Be disk plane, giving rise to two outbursts per orbit. In this case the orbital period would be ~ 155 d. Two flares per orbit have been already observed in 4U 1907+097 (with an orbital period of 8.4 d) at orbital phases ~ 0.04 and ~ 0.48 (Makashima et al. 1984) and in GRO J2058+42 (110 d) with the two flares separated in phase by ~ 0.5 (Wilson et al. 1998b).

4. Conclusions

We discovered in the RossiXTE-ASM data of XTE J1946 +274 an ~ 80 d modulation. This periodicity likely represent the orbital period of the system or, perhaps, half this value if the neutron star is orbiting the Be out of its shell ejection plane. A correlation between the spin and orbital periods of Be star/X–ray pulsar binary systems was described by Corbet (1984, 1986). Despite the considerable scatter in this relationship, given the 15.8 s spin period of XTE J1946+274, one would obtain for an orbital period of $\sim$ 77 d a moderate eccentricity ($e \lesssim 0.4$) and for its double a somewhat more eccentric system ($e \lesssim 0.6$).

An orbital solution, affording an independent accurate measurement of the orbital period and eccentricity, might be obtained from the analysis of the pulse arrival times during the pointed RossiXTE observations.

Acknowledgements. We acknowledge the use of quick-look results provided by the RossiXTE-ASM team and useful comments from H. Bradt and an anonymous referee.

References

Bildsten L. et al., 1997, ApJS 113 367
Bradt H.V., Rothschild R.E., Swank J.H., 1993, A&AS 56 415
Campana S., Israel G.L., Stella L., Santangelo A., 1998, IAUC N. 7127

Campana S. et al., 2000, in preparation
Corbet R.H.D., 1984, A&A 141 91
Corbet R.H.D., 1986, MNRAS 220 1047
Ghavamian P., Garcia M., 1998, IAUC N. 7022
Israel G.L., Polcaro V.F., Covino S., 1998, IAUC N. 7021
Levine A.M. et al., 1996, ApJ 469 L33
Levine A.M. et al., 1998, Nuclear Physics B (Proc. Suppl.) 69/1-3 196
Makashima K. et al., 1984, PASJ 36 679
Motch C., Stella L., Janot-Pacheco E. & Mouchet M., 1991, ApJ 369 490
Raguzova N.V. & Lipunov V.M., 1998 A&A 340 85
Santangelo A. et al., 2000, in preparation
Smith D.A., Takeshima T., 1998, IAUC N. 7014
Stella L., White N.E., Rosner R., 1986, ApJ 308 669
Takeshima T., Chakrabarty D., 1998, IAUC N. 7016
Verrecchia F. et al., 2000, in preparation
Warwick R.S. et al., 1981, MNRAS 197 865
Whitlock L., Roussel-Dupre D. & Priedhorsky W., 1989, ApJ 338 381
Wilson C.A., Finger M.H., Wilson R.B., Scott D.M., 1998a, IAUC N. 7014
Wilson C.A. et al., 1998b, ApJ 499 820