Mon. Not. R. astr. Soc. (1981) 197, 739–743

X-ray observations of symbiotic stars

David A. Allen *Anglo-Australian Observatory, PO Box 296, Epping, NSW 2121, Australia*

Received 1981 April 1; in original form 1981 January 20

Summary. Observations of 19 symbiotic stars made with the image proportional counter of the *Einstein Observatory* are reported. Three were detected as soft X-ray sources. All three have shown slow-nova eruptions in the past 40 years. The data are interpreted as support for a model for slow novae involving thermonuclear events on white dwarfs which accrete from M giant companions. Symbiotic stars in their steady state, not being detected X-ray sources, are presumed to be powered by the accretion process alone.

1 Introduction

The hard X-ray pulsar GX 1 + 4 = 4U 1728–24 has been identified with a symbiotic star (Davidsen, Malina & Bowyer 1977). The principal defining characteristics of such stars are the simultaneous presence of an absorption spectrum of a late-type giant and an emission spectrum of high excitation (Boyarchuk 1970, 1975). In some cases lines are seen which require ionization by photons with an energy of several hundred electron volts.

Currently popular models of symbiotic stars envisage accretion of material from the late-type giant on to a white dwarf (Paczynski & Rudak 1980; Allen 1980). Such accretion, as in dwarf novae, can release soft X-rays (Pringle 1978; Pringle & Savonije 1979), and if the white dwarf is magnetic (as in AM Herculis stars) both hard and soft X-ray components result (Fabian, Pringle & Rees 1976; King & Lasota 1979).

These facts indicate that the study of X-ray emission from symbiotic stars would be a profitable exercise. This paper reports the results from a guest investigator programme to observe symbiotic stars with the *Einstein* X-ray satellite.

2 The programme

Nineteen symbiotic stars were selected to form the basic programme, and 18 of these were observed with the image proportional counter (IPC) on the *Einstein* satellite (Giacconi *et al.* 1979) for ~ 2000 s each. The remaining object, H1-36, lay within the high resolution imager field for the X-ray globular cluster NGC 6441. Observations of the globular cluster from the *Einstein* data bank were examined for a second source coincident with H1-36, but none was

Table 1. X-ray and other data on symbiotic stars.

Name	Flux 0.2–2 keV ($\times 10^{-14}$ erg cm^{-2} s^{-1})	Electron density	Ionization potential (eV)	Circumstellar dust?	2 cm flux (mJy)	Spectral type of cool star	Optical variability
AX Per	<9	low	variable	N	–	M	R
AS 201	<6	high	25	Y	<17	G	N
He 2–38	<6	low	80	Y	<6	M	N
He 2–106	<11	low	100	Y	40	M	N
BD–21° 3873	<7	extreme	70	N	–	G	N
He 2–127	<11	low	100	Y	<12	M	N
Hen 1092	<4	medium	80	N	<18	K	N
HD 330036	<7	low	40	Y	–	G	N
He 2–171	<12	low	120	Y	<12	M	N
Hen 1242	<4	high	70	N	<22	M	N
V 455 Sco	<8	medium	100	N	<12	M	R
AE Ara	<5	high	50	N	<18	M	R
H1–36	see text	low	90	Y	91	–	N
Y CrA	<6	high	90	N	<20	M	R
AS 295B	$<12^{\star}$	high	250	–	–	M	R
HM Sge	83 ± 6	medium	rising	Y	57	M	S
CI Cyg	<5	medium	100	N	–	M	R
V 1016 Cyg	75 ± 5	low	100	Y	110	M	S
RR Tel	18 ± 3	medium	120	Y	54	M	S

* Possible detection, 1.5 σ.

found to a limit which should be comparable to the sensitivity of the IPC observations of other symbiotic stars. In all cases where a positive detection was made, the agreement between optical and X-ray positions left no doubt about the identification. Confusion can further be discounted, since only two sources were detected off position in the 18 IPC fields studied, and these two displayed much harder spectra than the symbiotic stars.

Table 1 lists the programme stars, the X-ray results and a variety of other information mostly abstracted from Allen (1979), where 1950 coordinates may also be found. The following columns require explanation:

Column 2. The X-ray flux between 0.2 and 2 keV, from the *Einstein* IPC data, assumes a blackbody source of 10^6 K without foreground absorption. A discussion of this is given in Section 3. The quoted errors are purely statistical.

Columns 3 and 4. The characteristic ionization potential and the relative electron densities are semi-quantitative descriptions defined in Allen (1979).

Column 8. The type of optical variability is coded as follows: N. No history of variability; R. Rapid variations in the form of minor nova-like outbursts typically every few years and of 3–4 mag amplitude; S. Slow-nova outbursts with time-scales of many decades and amplitudes near 8 mag.

The programme objects were selected to span a wide range of all the listed parameters.

3 X-ray spectra

GX 1 + 4 is distinct from other specimens, and may even be a chance alignment of a symbiotic star and an unrelated X-ray source. The other detected symbiotic stars all have extremely soft spectra. That GX 1+4 is a likely example of accretion on to a neutron star was shown by Mason (1977). By inference, the 19 specimens studied do not have neutron star components. Accretion on to white dwarfs is not ruled out.

X-ray spectra of HM Sge, RR Tel and V1016 Cyg can be extracted only crudely from IPC data, but it is apparent that a representative blackbody temperature is, in all cases, about 10^6 K or less. This is the region where absorption by interstellar or circumstellar hydrogen can render a source undetectable. The optical depth at 0.2–2 keV can be calibrated against A_V from the data of Cruddace *et al.* (1974), Gorenstein (1975) and Ryter, Cezarsky & Audouze (1975). For the range of A_V expected of the symbiotic stars (generally < 3 mag, based mostly on unpublished spectrophotometry), there is no reason to believe that the column density of any star is sufficient for sources as strong as HM Sge or V1016 Cyg to be pulled below the detection threshold. Some intrinsically weaker sources may, however, have been lost in this survey by intervening absorption. Additionally, the loss of material from symbiotic stars may generate local neutral hydrogen which is free from dust and thus does not contribute to the reddening.

The undetected sources in Table 1 must generally be cooler than ~ 10^6 K. This in turn adds uncertainty to the values of the upper limits, for cooler sources emit more strongly in the less well-calibrated low-energy channels.

4 Origin of the X-ray emission

Coronal soft X-ray emission is common in many types of star, but is particularly weak in the late-type giants (Vaiana *et al.* 1981). The detection of X-ray emission from some symbiotic stars therefore indicates activity associated with their hot components.

Inspection of Table 1 reveals a striking correlation. Whilst it might have been anticipated that the symbiotic stars of highest excitation (i.e. largest ionization potential) would be the strongest X-ray sources, this is not the case. Instead, the only correlation which appears to be present is between the X-ray flux and the type of variability. Specifically, stars which have undertaken slow-nova outbursts in historic times are detectable X-ray sources. Moreover, the X-ray luminosity, scaled according to the visible magnitude, is greatest for HM Sge (outburst 1975) followed by V1016 Cyg (1964) and RR Tel (1944). The implication is clear; X-ray emission is intense immediately after a slow-nova outburst, and declines thereafter. We may estimate the time-scale of that decline if we assume that the three stars exhibited identical time-dependence of their X-ray/optical outputs. The *e*-folding time is about 7 yr. In contrast, the excitation as measured by optical lines rises steadily for several decades after the outburst (e.g. RR Tel: Thackeray 1977). The nebula probably has temperature stratification; due to expansion or mass loss the gas becomes optically thin at progressively greater depths.

The most attractive models for very slow novae adopt the mechanism believed to occur in normal novae, i.e. a thermonuclear event in accreted hydrogen-rich gas on the surface of a degenerate white dwarf (Prialnik, Shara & Shaviv 1978; Paczynski & Rudak 1980). This process generates effective temperatures a little below 10^6 K (Sion, Acierno & Tomczyk 1979), in agreement with the X-ray temperatures. We can also test the model by computing the size of the blackbody source. For RR Tel a distance may be estimated from the infrared data, along the lines developed by Allen (1980). An estimate of the brightness and spectral type of the Mira component can be obtained from the data of Feast, Robertson & Catchpole (1977) and Allen *et al.* (1977). This leads to a spectroscopic distance of about 1.6 kpc. Similarly the optical data from before the outburst (Mayall 1949) can be used to give a rather cruder distance of about 5 kpc. The second estimate will be too large if interstellar or

Table 2. The hot component in RR Tel.

Blackbody temperature (10^5 K)	Blackbody radius (cm)
3	1.6×10^9
4	1.2×10^8
5	2.5×10^7
6	8.6×10^6

circumstellar reddening intervened before the outburst, as is almost certainly the case. A distance of 2 kpc is adopted.

The derived size is a steep function of temperature, and therefore depends too on how closely the thermal source is a blackbody. The size is given in Table 2 for a range of likely temperatures. The typical radius of a white dwarf is 10^9 cm. It will be seen that the hot component is not larger than a white dwarf. We may eliminate objects smaller than a white dwarf (i.e. neutron stars) because they do not exhibit blackbody components (Kylafis & Lamb 1979), but are hard X-ray sources.

The absence of detectable X-ray emission from the remaining symbiotic stars, but the presence in their optical spectra of emission lines of species having ionization potentials greater than 100 eV, indicates temperatures for the hot components $\sim 10^5$ K. A temperature of this order was derived from ultraviolet data for the symbiotic star RW Hya by Kafatos, Michalitsianos & Hobbs (1980). This is too cool to be consistent with significant thermonuclear burning. Hence it seems more natural to account for their luminosities by the accretion mechanism alone, as proposed by Bath (1977), or by accretion with mild steady-state burning (Paczynski & Rudak 1980; modelled by Weast *et al.* 1980).

An alternative interpretation of the X-ray data could be made by attributing the flux to thermal bremsstrahlung from a corona (or other gas) excited to $\sim 10^6$ K. This is not considered here.

The star GX 1 + 4 remains unique because of its pulsed hard X-ray emission. No flux density has been reported in the 0.2–2 keV region, where interstellar absorption would be quite severe. Between 2 and 6 keV the flux is 10^{-9} erg cm^{-2} s^{-1} (from the compilation by Amnuel, Guseinov & Rakhamimov 1979), about 4 orders of magnitude more intense than the objects in Table 1.

Acknowledgments

It is a pleasure to report my satisfaction with the *Einstein* guest investigator programme, and to thank the many people involved in it. John Whelan and Alex Czerny contributed suggestions which were greatly appreciated.

References

Allen, D. A., 1979. *IAU Coll. 46,* 125.
Allen, D. A., 1980. *Mon. Not. R. astr. Soc.,* **192,** 521.
Allen, D. A., Beattie, D. H., Lee, T. J., Stewart, J. M. & Williams, P. M. 1977. *Mon. Not. R. astr. Soc.,* **184,** 601.
Amnuel, P. R., Guseinov, O. H. & Rakhamimov, Sh. Yu, 1979. *Astrophys. J. Suppl.,* **41,** 327.
Bath, G. T., 1977. *Mon. Not. R. astr. Soc.,* **178,** 203.
Boyarchuk, A. A., 1970. *Eruptive stars. Nonstationary stars and methods of their investigation.* Ch. 3, eds Boyarchuk, A. A. & Gershberg, R. E., Moscow (in Russian).
Boyarchuk, A. A., 1975. *IAU Symp. 67,* 377.

Cruddace, R., Paresce, F., Boyer, S. & Lampton, M., 1974. *Astrophys. J.,* **187**, 497.

Davidsen, A., Malina, R. & Bowyer, S., 1977. *Astrophys J.,* **211**, 866.

Fabian, A. C., Pringle, J. E. & Rees, M. J., 1976. *Mon. Not. R. astr. Soc.* **175**, 43.

Feast, M. W., Robertson, B. S. C. & Catchpole, R. M., 1977. *Mon. Not. R. astr. Soc.,* **179**, 499.

Giacconi, R. *et al.,* 1979. *Astrophys. J.,* **230**, 540.

Gorenstein, P., 1975. *Astrophys. J.,* **198**, 95.

Kafatos, M., Michalitsianos, A. G. & Hobbs, R. W., 1980. *Astrophys. J.,* **240**, 114.

King, A. R. & Lasota, J. P., 1979. *Mon. Not. R. astr. Soc.,* **188**, 653.

Kylafis, N. D. & Lamb, D. Q., 1979. *Astrophys. J.,* **228**, L105.

Mason, K. O., 1977. *Mon Not. R. astr. Soc.,* **178**, 81P.

Mayall, M. W., 1949. *Harvard Bull. 919,* 15.

Paczynski, B. & Rudak, B., 1980. *Astr. Astrophys.,* **82**, 349.

Prialnik, D., Shara, M. M. & Shaviv, G., 1978. *Astr. Astrophys.,* **62**, 339.

Pringle, J. E., 1978. *Mon. Not. R. astr. Soc.,* **178**, 195.

Pringle, J. E. & Savonije, G. J., 1979. *Mon. Not. R. astr. Soc.,* **187**, 777.

Ryter, C., Cesarsky, C. J. & Audouze, J., 1975. *Astrophys. J.,* **198**, 103.

Sion, E. M., Acierno, M. J. & Tomczyk, S., 1979 *Astrophys. J.,* **230**, 832.

Thackeray, A. D., 1977. *Mem. R. astr. Soc.,* **83**, 1.

Vaiana, G. S. *et al.*, 1981. *Astrophys. J.,* **244**, 163.

Weast, G. J., Durisen, R. H., Imamura, J. N., Kylafis, N. D. & Lamb, D. Q., 1980. *IAU Coll. 53,* 140.