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Research Note

X-ray Observations of Single-line Spectroscopic Binaries

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Summary. Observations of three single-line spectroscopic binaries with the Imaging Proportional Counter on the Einstein Observatory are presented. None of the three binaries viz π^5 Ori, θ^2 Cru, and 112 Her is detected as an X-ray source, making the presence of a compact secondary in any of these binaries highly unlikely. An extended X-ray source (X-ray size $\sim 3'$) with an intensity of $(2.2 \pm 0.25)\ 10^{-12}$ erg cm^{-2} s^{-1} in the 0.3–3.3 keV energy band has been found at a position 28′ away from π^5 Ori. The X-ray source position is consistent with that of a distant cluster of galaxies, A 520.

Key words: spectroscopic binaries – B stars – X-ray source search – X-ray emitting cluster of galaxies

1. Introduction

It has been suggested that the absence of a secondary spectrum in single-line spectroscopic binaries could be a consequence of the secondary star being a compact collapsed star (Zeldovich and Guseynov, 1965). If the primary star in such a binary loses mass either by stellar wind or Roche-lobe overflow, X-ray emission will occur in the gravitational field of the compact star as a result of accretion and infall of matter towards its surface. Trimble and Thorne (1969) followed up the suggestion and compiled, from the binary star catalogue of Batten (1968), a list of single-line spectroscopic binaries with large mass functions and an unseen component with a probable mass greater than $1.4\,M_\odot$ (Chandrasekhar limit). However, none of these binaries coincided with any published X-ray source position at that time. Suntantyo (1973) pointed out that those binaries which are identified as X-ray sources and do contain collapsed stars all have rather small mass functions. Following this suggestion, Trimble (1974) searched Batten's catalogue again, as well as supplements to it, for single-line spectroscopic binaries that have: (i) an evolved OB primary, (ii) mass ratio less than 0.30, and (iii) binary period less than 20 d. 18 systems satisfied these criteria, 7 with O and BI or II primaries and 11 with BIII primaries. However, none of these falls within 90% confidence error box of any unidentified 3 U X-ray source.

Recently, den Boggende et al. (1979) used the Astronomical Netherlands Satellite (ANS) to search for X-ray emission from the above objects. Soft X-ray (0.16–0.28 keV) emission was detected from the direction of only two of these objects: HR 976 and π^5 Ori. The upper limits obtained from ANS observations in the 1–3.5 keV range, however, did not rule out the existence of any compact dark companion among the objects surveyed. den Boggende et al. (1978) suggested that the soft X-ray emission from HR 976, which contains a primary Am star, most probably originates from a corona around the Am star. Cash and Snow (1980) very recently obtained an X-ray image of the field around HR 976, using the Einstein Observatory. They detected HR 976 and a quasar 4 C 34.13 which is only 13′ from HR 976, as X-ray source of comparable intensities $\sim 2.5\ 10^{-13}$ erg cm^{-2} s^{-1}. Although they confirm HR 976 as a soft X-ray source, it is two orders of magnitude weaker than the intensity reported by den Boggende et al., suggesting the source is highly variable. The ANS detection of soft X-ray flux from the direction of π^5 Ori is not identified with any known star in the ANS field of view (den Boggende et al., 1979).

We have used the Einstein Observatory as guest investigators to obtain X-ray images of fields centered on three very bright (brighter than 6th magnitude) single-line spectroscopic binaries, π^5 Ori, θ^2 Cru, and 112 Her, observed earlier by ANS.

None of the three objects is detected as an X-ray source. We present here 3σ upper limits for the X-ray luminosity of these objects $\gtrsim 200$ times lower than earlier estimates and discuss the implications for the presence of a compact secondary in any of these objects.

A cluster of galaxies, A 520, has been detected as an X-ray source lying nearly 28′ from the π^5 Ori.

2. The Observations

The observations were carried out using the Imaging Proportional Counter (IPC) onboard the Einstein Observatory (Giacconi et al., 1979). The IPC was used without filters to observe a square degree of the sky centered on the pre-selected target stars in the energy range 0.3–3.3 keV. A nominal observing time of 2000 s was scheduled for each target. The detection threshold for these observations is about two orders of magnitude lower than in the earlier survey of den Boggende et al. using ANS, and the spatial resolution is $\sim 1'$.

The parameters for the stars observed are listed in Table 1. The size of the detection cell chosen is 3$'$.6. None of the three candidates was detected as an X-ray source above the background. The 3σ upper limits on the X-ray flux (0.3–3.3 keV) are listed in Table 2. Intensity was derived using the standard conversion factor $2\ 10^{-11}$ erg cm^{-2} s^{-1} for one IPC count s^{-1} (Vaiana et al., 1981) and after applying the correction for dead time and scattering. The 3σ upper limits on the X-ray luminosity (Table 2) of these stars have been calculated using the estimated distances of the stars from us (Table 1).

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Table 1. Stellar parameters[a]

Name	R.A. (1950)	Decl. (1950)	Spectral type	m_v	Period (days)	Distance (pc)	M_{bol}	$f(M)$ ($M_\odot$)	Mass ratio ($M_{compact}/M_{pr}$)	m_{bol}[a]
π^5 Ori	$04^h51^m38\overset{s}{.}6$	$+02°21'37\overset{''}{.}2$	B 2 III	3.70	3.700373	235	−5.4	0.0745	0.208	1.6
θ^2 Cru	$12^h01^m43\overset{s}{.}8$	$-62°53'14\overset{''}{.}0$	B 3 IV	4.72	3.4280	170	−3.5	0.048	0.214	3.0
112 Her	$18^h50^m\ 8\overset{s}{.}11$	$+21°21'48\overset{''}{.}6$	B 9 II–III	5.48	6.3624	310	−2.3	0.0036	0.93	5.2

[a] References in den Boggende et al. (1979)
[b] Derived from the data in den Boggende et al. (1979)

Table 2. X-ray data

Binary	X-ray phase during observation	Exposure (Secs.)	IPC counts per second	X-ray flux at Earth (10^{-13} erg cm^{-2} s^{-1}) Fx[a] (0.3–3.3 keV)	X-ray luminosity (10^{29} erg s^{-1}) Lx (0.3–3.3 keV)	$\frac{Lx}{L_{bol}}$[b]	ANS limit on Lx (10^{29} erg s^{-1}) (1.0–3.5 keV)
π^5 Ori	0.95	1597	<0.0065	<1.30	< 8.60	$<2\ 10^{-8}$	2000
θ^2 Cru	0.68	1663	<0.0073	<1.46	< 5.05	$<9\ 10^{-8}$	2000
112 Her	0.44	2179	<0.0066	<1.33	<15.30	$<6\ 10^{-7}$	4000

* X-ray phase 0 (a possible X-ray eclipse) = phase 0.5 for optical observations
[a] 1 IPC count $s^{-1} = 2\ 10^{-11}$ erg cm^{-2} s^{-1}
< indicates a 3σ upper limit
[b] $L_x/L_{bol} = F_x/F_{bol}$ with $F_{bol} = 2.48\ 10^{-5}\ 10^{-0.4 m_{bol}}$ erg cm^{-2} s^{-1} (Allen, 1973), the bolometric flux at Earth

3. X-ray Emission from the Cluster of Galaxies A 520

An extended X-ray source (size $\sim 3'$) has been found close to an edge of an IPC field which was centered on π^5 Ori. The X-ray source position, R.A. (1950) = $04^h51^m39\overset{s}{.}7$, Decl. (1950) = $02°52'39\overset{''}{.}4$ is consistent with the optical position and extent ($\sim 20'$) of a cluster of galaxies A 520, and is 28′ from the position of π^5 Ori. The X-ray flux detected from the source is $(2.2 \pm 0.25)\ 10^{-12}$ erg cm^{-2} s^{-1}, in the energy range of 0.3–3.3 keV. X-rays detected from this source are mostly of energy less than 2.4 keV, indicating a soft spectrum for the source. The observed X-ray flux has been corrected for the dead time, vignetting and scattering in the X-ray telescope. In Zwicky's (1961) catalogue, the cluster A 520 has been classified as belonging to Distance class = 6 (extremely distant: $Z \geqq 0.2$) and Richness class = 3 (population = 185). All the galaxies in this cluster are fainter than 17.4 mag. According to Bautz and Morgan (1970) it is a compact cluster of BM (Bautz-Morgan) type III with no dominant galaxies. Using the value of 100 km s^{-1} Mpc^{-1} for the Hubble constant and a redshift of 0.2, the X-ray luminosity of the cluster is found to be $(9.7 \pm 1.1)\ 10^{43}$ erg s^{-1} in the 0.3–3.3 keV band.

4. Results and Discussion

The X-ray observations in the energy range of 0.3–3.3 keV of the three candidate binary systems show that the upper limits of the X-ray luminosities $\sim 10^{30}$ erg s^{-1} (Table 2) are about two orders of magnitude lower than the ones obtained by den Boggende et al, thus lowering the requirement of mass loss rates from the primary star by two orders of magnitude. The upper limits of the expected mass loss rate as given by den Boggende et al. are $\sim 10^{-10}\ M_\odot$ yr^{-1} for π^5 Ori and 112 Her and $10^{-11}\ M_\odot$ yr^{-1} for θ^2 Cru. Our results imply that the mass loss rate is less than these limits by an order of magnitude in the case of π^5 Ori, and by a factor two to three in the case of θ^2 Cru and 112 Her. These results suggest that the B-star binary π^5 Ori does not contain a collapsed secondary and also the chances of finding a collapsed secondary in θ^2 Cru or 112 Her systems appear to be small. Hutchings (1981), who searched for a compact companion among 23 single-line spectroscopic binary systems, using the IPC on the Einstein Observatory, also failed to find any evidence for a compact companion in any of the 23 systems.

It is now well known that almost all stars emit X-rays (Vaiana et al., 1981), with the early type stars (O 3–A 5) having X-ray luminosities proportional to bolometric luminosities (Long and White, 1980; Pallavicini et al., 1981). The observed upper limits for the ratio of the X-ray luminosities to bolometric luminosities (Table 2) for the three B-type primary stars in π^5 Ori, θ^2 Cru, and 112 Her are in the range of 10^{-8}–10^{-6}, consistent with the results of Long and White and Pallavicini et al. However, longer exposures with detectors like IPC on the Einstein Observatory would be required to detect X-rays from the B-type primary stars in π^5 Ori, θ^2 Cru, and 112 Her and hence establish them as belonging to X-ray emitting early-type stars.

A soft X-ray (0.16–0.28 keV) source, with an incident flux of $(2.9 \pm 1.0)\ 10^{-12}$ erg cm^{-2} s^{-1}, detected by ANS in its field of view (circular FOV, 34′ FWHM) around π^5 Ori could not be identified with any known star in the field (den Boggende et al.). However, if A 520 was in the ANS field of view while observing π^5 Ori, as seems likely, then the X-ray emission detected from A 520 in our observation can explain almost all of the X-ray flux detected by ANS from the direction of π^5 Ori.

In conclusion then, it appears unlikely that any of the three binaries viz. π^5 Ori, θ^2 Cru, and 112 Her, harbours a compact secondary, as no significant flux could be detected from any of them. Our result combined with that of Hutchings suggests that the weak galactic binary X-ray sources must be very few.

X-rays have been detected from a cluster of galaxies (A 520) which is close to the binary star π^5 Ori.

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References

Allen, C.W.: 1973, Astrophysical Quantities, 3rd Ed., London, Athlone Press
Batten, A.H., Fletcher, J.M., Mann, P.J.: 1968, *Publ. Dominion Astrophys. Obs.* **13**, 119
Bautz, L.P., Morgan, W.W.: 1970, *Astrophys. J. Letters* **162**, L149
Cash, W., Snow, Th.P.: 1980, *Astron. Astrophys.* **91**, L7
den Boggende, A.J.F., Mewe, R., Heise, J., Brinkman, A.C., Gronenschild, E.H.B.M., Schrijver, J.: 1978, *Astron. Astrophys.* **67**, L29
den Boggende, A.J.F., Lamers, H.J.G.L.M., Mewe, R.: 1979, *Astron. Astrophys.* **80**, 1
Giacconi, R., et al.: 1979, *Astrophys. J.* **230**, 540
Hutchings, J.B.: 1981, *Publ. Astron. Soc. Pacific* **93**, 55
Long, K.S., White, R.L.: 1980, *Astrophys. J. Letters* **239**, L65
Pallavicini, R., Golub, L., Rosner, R., Vaiana, G.S., Ayres, T., Linsky, J.L.: 1981, *Astrophys. J.* **248**, 279
Suntantyo, W.: 1973, *Astron. Astrophys.* **29**, 103
Trimble, V.L., Thorne, K.S.: 1969, *Astrophys. J.* **156**, 1013
Trimble, V.L.: 1974, *Astron. Astrophys.* **34**, 461
Vaiana, G.S., et al.: 1981, *Astrophys. J.* **245**, 163
Zel'dovich, Ya.B., Guseynov, O.H.: 1965, *Astrophys. J.* **144**, 841
Zwicky, F., Herzog, E., Wild, P.: 1961, Catalogue of Galaxies and of Clusters of Galaxies, published by Cal. Inst. of Tech.