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LETTER

Letter to the Editor

The transient jet of the galactic supersoft X-ray source RX J0925.7-4758*

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Abstract. We report the discovery of a transient jet in the supersoft X-ray source RX J0925.7-4758. The jet was observed in the Hα line during a single night in June 1997 and had disappeared one day later. RX J0925.7-4758 is the third supersoft source to exhibit collimated outflows. The peak jet velocity of 5,200 km s^{-1}, strongly argues in favour of a white dwarf in RX J0925.7-4758. Simple modelling of the jet profile suggests half opening angles in the range of 17° to 41° although the outflow may be narrower if part of the observed spread in velocity is intrinsic to the jet. X-ray spectral modelling (Ebisawa et al. 1996; Hartmann & Heise 1997) indicates distances of the order of 10 kpc or more with the consequence that RX J0925.7-4758 may be the most optically luminous supersoft source known. The overall observational picture points to a massive white dwarf which may be close to the Chandrasekhar limit.

Key words: X-ray: stars – stars: white dwarfs – stars: binaries: close – stars: mass-loss – stars: individual: RX J0925.7-4758

1. Introduction

Supersoft X-ray sources are believed to be accreting white dwarfs burning material on their surface (van den Heuvel et al. 1992) in a more or less steady fashion. Quasi-stable H burning requires high mass transfer rates ($\dot{\mathrm{M}} \sim 10^{-7}$ M$_\odot$ yr^{-1}, Iben 1982). Such high transfer rates which are at least a factor 10 higher than those occurring in cataclysmic variables may be achieved by thermally unstable Roche lobe overflow when the mass donor star is more massive than the accreting object. Steady thermonuclear burning allows the white dwarf to increase its mass since processed material can remain at the surface of the accreting object. A large fraction of SNIa could originate in such systems when the white dwarf mass approaches the Chandrasekhar limit. A recent review of these systems can be found in Kahabka & van den Heuvel (1997).

RX J0925.7-4758 and RX J0019.8+2156 (Beuermann et al. 1995) are the only two luminous and steady supersoft X-ray sources known so far in the Galaxy. RX J0925.7-4758 was discovered in the ROSAT all-sky survey and optically identified with a V$\sim$17 heavily reddened object (Motch et al. 1994). Because of the large interstellar absorption, only the very high energy part (E $\geq$ 0.5 keV) of the intrinsically soft energy distribution is offered to observation. The resulting X-ray spectrum peaks at 0.8 keV and is unique among supersoft sources (Hartmann & Heise 1997). Optical photometric and spectroscopic observations suggest an orbital period of $\sim$3.8 d (Motch 1996).

The existence of bipolar jets with velocities in the range of 1,000–4,000 km s^{-1} has been recently reported in two supersoft sources, (RX J0513.9-6951: Crampton et al. 1996; Southwell et al. 1996 and RX J0019.8+2156: Tomov et al. 1998; Quaintrell & Fender 1998; Becker et al. 1998). In this paper we report on the discovery of a well formed bipolar outflow with a projected velocity of $\sim$5,200 km s^{-1} in RX J0925.7-4758.

2. Observations

RX J0925.7-4758 was observed during two consecutive nights on 1997 June 7 and 8 UT with the ESO-Danish 1.54 m telescope and DFOSC equipped with the LORAL-Lesser 2K3EB-C1W7 chip. All spectra have 15 mn exposure times and on all occasions we used grism #7 with a slit width of 2.5$''$ in order to accommodate the rather bad seeing ($\sim$2$''$) prevailing during the entire run. In addition to these spectroscopic data, several 2 mn long V band exposures were accumulated over the two nights. During the first night, 3 spectra were obtained in about 1 hour from JD start times 2,450,606.5499 to 2,450,606.5821. The 5 spectra collected during the second night span 2.8 hours from JD 2,450,607.4666 to 2,450,607.5823.

All data were reduced using standard MIDAS procedures. Two dimensional spectra were calibrated in wavelength using He + Ne arc lamps exposures closest in time to the science frame. A S/N optimized procedure extracted one dimensional spectra. The spectral range extends from 3,800 to 6,900 Å with a pixel size of 1.47 Å. Spectral resolution is degraded by the large slit width and bad seeing. FWHM resolution estimated from the minimum observed width of Hα is about 7.3 Å.

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* Based on observations obtained at the European Southern Observatory, La Silla (Chile) with the ESO-Danish telescope

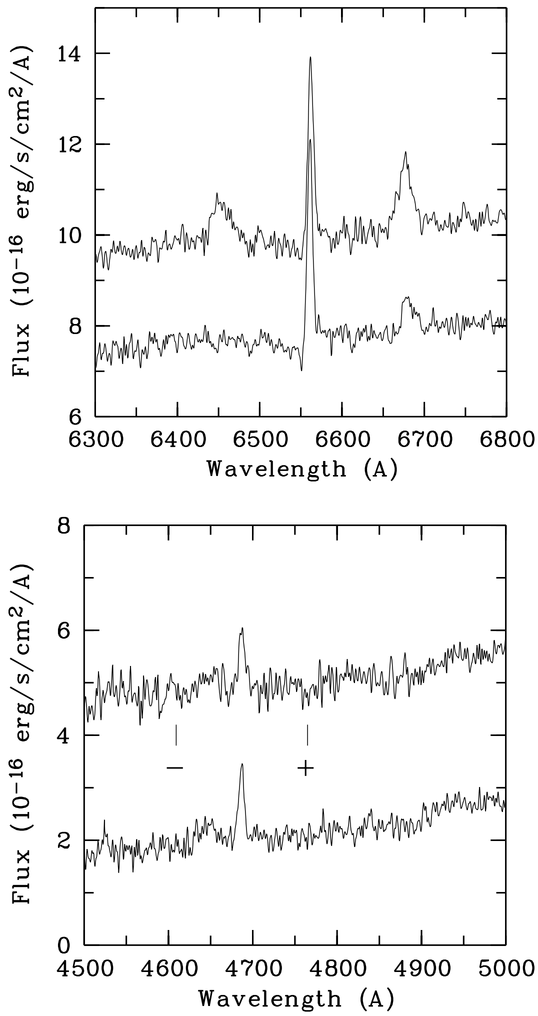

Fig. 1. Mean spectra obtained on June 7 showing the jet feature plotted together with that obtained on June 8 representing the normal state of the source. The June 7 spectrum is shifted up by 3 flux units for clarity. Upper panel: Hα region. Lower panel: No jet feature is detected around the He II λ4686 emission line. The N III-C III $\lambda\lambda$4640-60 complex emission is also visible whereas Hβ is not detected

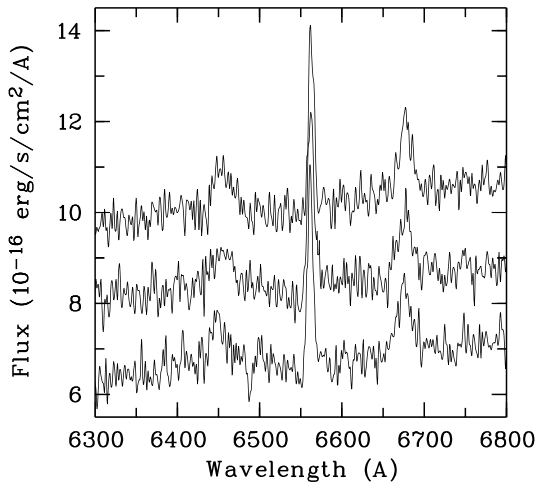

Fig. 2. Individual 15 mn long spectra obtained on June 7. Spectra are shifted in flux for clarity. Time goes from bottom to top

In Fig. 1 we plot the average of the three June 7 spectra exhibiting the jet feature together with the average of the five June 8 spectra which are typical of the normal state of the source. The redshifted Hα component unfortunately coincides in wavelength with the He I λ6678.15 and He II λ6683.2 emission lines. No jet feature is seen at He II λ4686 which is the second brightest emission line in the observed wavelength range. Using Hα jet lines as template, we can put an upper limit of 2.4 Å to the equivalent width (EW) of the blue He II component. Average spectra of both nights show evidence for P Cyg profile in the central Hα emission.

Fig. 2 shows that the jet velocity does not change on a time scale of one hour. Within the statistical uncertainties, the jet profile remains constant, showing a clear asymmetric extension towards low absolute velocities. During the first night, the central Hα line exhibits shoulders moving in velocity from one spectrum to the other ($\sim$ 20 mn). Such variations are not seen during the following night.

We tried to correct the red jet component profile for contaminating He I and He II lines by subtracting the mean June 8 spectrum shifted by the 44 km s^{-1} velocity difference. In the wavelength intervals void of sharp line features (i.e. excluding the Hα and He I/He II lines), we smoothed the June 8 continuum with a Gaussian of 7.3 Å FWHM, equal to the spectral resolution. This procedure preserves the best statistics and allows correction for weak water vapour absorption bands which are abundant bluewards of Hα. The resulting 'pure' jet spectrum is shown on Fig. 3. Peak intensities of both components compare remarkably well. After correction, the slight asymmetry of the raw red component profile (see Fig. 2) seems to have vanished. This could be due to changing He I/He II line emission strength between the first and the second night. Independently of any correction error due to He I/He II lines, the red and blue component profiles appear to have different widths, the red profile being about 8 Å (360 km s^{-1}) less extended towards low absolute velocities than the blue one. The EW of the blue component is 4.1Å, slightly larger than those of RX J0019.8+2156 (3 Å, Becker et al. 1998) and RX J0513.9-6951 (2.6 Å, Southwell et al. 1996). In contrast, the EW of the central Hα (4.9 Å) and He II λ4686 (7.8 Å) lines in RX J0925.7-4758 are significantly smaller than those of other supersoft sources exhibiting jets. The upper limit on the He II λ4686 to Hα EW ratio for blueshifted components ($\sim$ 0.6) is compatible with those observed in other sources and does not suggest a lower excitation level in the jet of RX J0925.7-4758.

The V magnitude of RX J0925.7-4758 was 17.213$\pm$0.016 and 17.133$\pm$0.026 on June 7 and 8 UT respectively. These magnitudes are within the range of those reported for the source since 1992 (Motch et al. 1994; Motch 1996) and there is therefore no evidence that the appearance of the jet is accompanied by any large change in optical continuum emission.

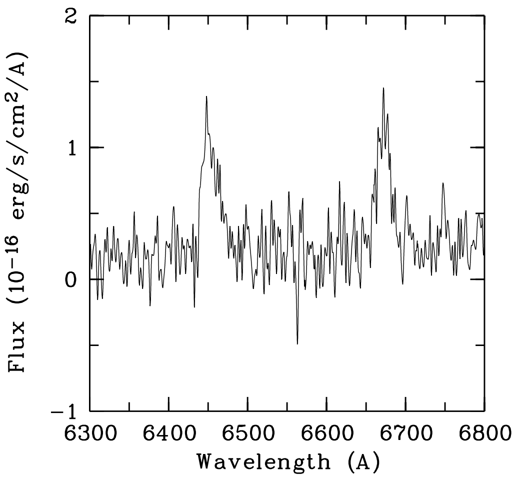

Fig. 3. Jet spectrum obtained by subtracting the average June 8 spectrum shifted in velocity from the average June 7 one.

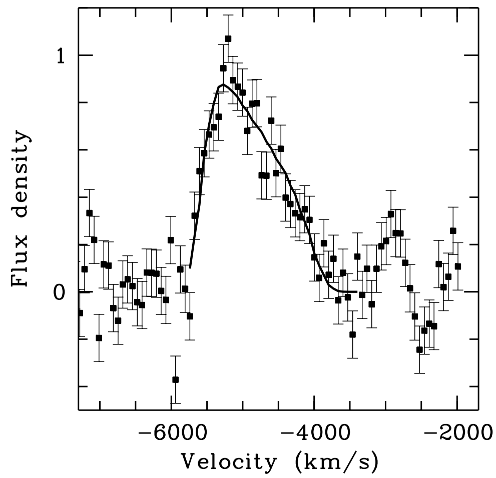

Fig. 4. Blue shifted Hα velocity profile. A best fit model profile (χ^2_{32} = 38.1) with α = 20.7°, i = 24.6°, v_j = 5,600 km s^{-1} is also shown for comparison

3. Jet modelling

The detailed shape of the shifted Hα lines, in particular their extended wings towards small absolute velocities potentially contains valuable information on jet geometry and kinematics. We therefore designed a simple kinematic jet model derived from that used by Becker et al. (1998). The jet is described as a cone of half opening angle α in which all atoms move with velocity v_j. Within the cone, material is assumed to be flowing uniformly per unit solid angle. In order to compute line profiles we further assumed that the outflow emission region is optically thin and convolved the model profile with a Gaussian of FWHM = 333 km s^{-1} (σ = 142 km s^{-1}) representing the instrumental profile.

Since we only have a snapshot observation at an unknown orbital phase, we cannot constrain the orientation of the jet with respect to orbital plane or with respect to the axis joining the two stars. In our case, the only relevant angles are α and the angle i between the line of sight and the jet axis. In this simplified geometry, the jet axis is aligned with the z axis and the line of sight is contained in the x-z plane. A flow making an angle β with respect to jet axis and an angle ϕ with respect to the x axis will have a projected component $V = v_j\ (\sin\beta\cos\phi\sin i + \cos\beta\cos i)$ on the line of sight.

The jet components extend in velocity from about 3,800 to 5,800 km s^{-1} with a peak at 5,200 km s^{-1}. Any effect related to orbital motion is likely to be negligible since the K amplitude of the He II line is only $\sim$80 km s^{-1} (Motch 1996) and since the duration of the observation ($\sim$1 h) is small with respect to the suspected orbital period ($P_{\rm Orb}$ $\sim$3.8 d).

Considering the uncertainties resulting from the He I/He II line contamination, we did not try to fit a model jet profile to the redshifted Hα component. The width of the blue component profile and its asymmetry, namely its larger extension towards low absolute velocities, can be accurately represented by a well opened jet seen at rather low inclination. As shown on Fig. 4, the fit is surprisingly good considering the simplicity of the model (χ^2_{32} = 38.1). At the 99% confidence level, the formal accepted ranges of inclinations i are 7° to 13° and 20° to 29° and those of half-opening jet angles α are 17° to 27° and 34° to 41°. Large inclination angles correspond to small jet opening angles. The range of α values compares well with that derived for RX J0019.8+2156 by Becker et al. (1998). In the framework of this simple model the difference in profile shape between the blue and red components could reflect different opening angles (assuming inclinations are identical).

Alternatively, the width and asymmetry of the blueshifted profile could be due to an intrinsic spread of material velocity in the outflow. This would allow much narrower opening angles, more consistent with the conception of a jet. In this picture, the difference in profile shape and extent between the blue and red components may be for instance interpreted in terms of occultation of the low velocity part of an accelerating jet by the accretion disc. Finally, line profiles may also be intrinsically broadened by Keplerian velocity in the inner parts of the accretion disc (Becker et al. 1998).

4. Discussion and conclusions

RX J0925.7-4758 is the third supersoft source in which collimated outflows are observed demonstrating that jets are common phenomena in this class of high mass transfer rate accreting binaries.

However, compared to other supersoft sources, the jet of RX J0925.7-4758 appears to be a rather rare and rapidly variable phenomenon. The jet was detected during only one among 23 nights of observation performed since the identification of the source in 1992, and it disappeared in less than 24 h. For comparison, the jet of RX J0513.9-6951 is almost constantly seen at about the same velocity. Crampton et al. (1996) report non-detection during only one or two nights. On the other hand, the jet of RX J0019.8+2156 is transient on time scales of months (Becker et al. 1998).

The observation of a jet with a projected velocity of $\sim$5,200 km s^{-1} confirms that RX J0925.7-4758 belongs to the

LETTER

class of supersoft sources in spite of its unusual X-ray spectrum. In particular, if the jet velocity is of the order of the escape velocity from the central object (see e.g., Livio 1997) then the M/R ratio of the source is similar to that of a white dwarf. Wind velocities of the order of 6,000 km s^{-1} are indeed observed in some cataclysmic variables (Drew 1997)

Fits of NLTE model atmospheres to ASCA data (Ebisawa et al. 1996) and ROSAT PSPC data (Hartmann & Heise 1997) indicate high effective temperatures close to 70 eV and amazingly small source radii in the range of 160–370 (d/1 kpc) km. The reduced emitting area has been sometimes considered as evidence that the source was in fact a neutron star with an extended atmosphere (Hartmann & Heise 1997, Kylafis & Xilouris 1993). If the jet originates from the close surrounding of the X-ray emitting surface then the source radius is of the order of 10^9 cm for solar masses objects, independently of the actual nature of the central engine, white-dwarf or shrouded neutron star. From this point of view, RX J0925.7-4758 does not look different from other supersoft sources and its distance should be at least 10 kpc in order for the X-ray emitting region to reach a radius similar to that of the jet producing region. At 10 kpc, the bolometric luminosity is 5 10^{37} erg s^{-1} and the radius of the source is at most 3,700 km suggesting a very massive white dwarf. However, as the bulk of the energy distribution of RX J0925.7-4758 is masked by photoelectric absorption, it is still possible that spectral fits give somewhat biased source parameters.

Optical data do not rule out such large distances. The interstellar absorption towards the source ($N_H \sim 1.3\ 10^{22}$ cm^{-2}, Motch et al. 1994) is similar to the integrated galactic value while a large part of the reddening probably takes place rather locally in the Vela sheet molecular cloud located at 425 pc. At 10 kpc, the intrinsic V magnitude of RX J0925.7-4758 is $M_V = -4$, two magnitudes brighter than the brightest of the Magellanic supersoft sources, RX J0513.9-6951. This high optical luminosity could reflect the long orbital period and large accretion disc of RX J0925.7-4758. In supersoft sources, the white dwarf luminosity due to nuclear burning is much larger than the total accretion luminosity of the disc and X-ray reprocessing in the disc and on the secondary atmosphere should play an important role (see e.g. Popham & DiStefano 1996). If as for low-mass X-ray binaries M_V scales as $1.67\times\log(P_{\rm Orb})$ (van Paradijs and McClintock 1994), then the larger orbital period and accretion disc in RX J0925.7-4758 may already explain a 1.2 magnitude difference. Different disc rim structures (Meyer-Hofmeister et al. 1997) and uncertainties on A_V could account for the rest of the difference in absolute magnitude between RX J0925.7-4758 and RX J0513.9-6951. In addition, a large visual flux emission from the X-ray heated structures of the binary would explain the absence of detectable late type features in the optical spectrum. In a $\sim$3.8 d orbit, the Roche lobe filling evolved star is expected to have $M_V \sim 0$ (Motch 1996).

For stable shell burning, the nuclear luminosity mainly depends on the mass of the burning envelope and is thus insensitive to short time scale changes in mass accretion rate (Fujimoto 1982). Only for the most massive white dwarfs which undergo high accretion rates and retain light envelopes can the nuclear luminosity vary significantly on a time scale of a week. If the appearance of the jet is due to a sudden increase of the mass accretion rate onto the white dwarf, only the much weaker accretion luminosity may vary on short time scales. Therefore, no large and fast change in bolometric nor optical luminosity is expected to accompany the jet, in agreement with the V band photometry.

Jet inclinations larger than $\sim 60^\circ$ seem unlikely as they would imply outflow velocities in excess of the escape velocity of the most massive white dwarfs ($V_{esc} \sim 11{,}000$ km s^{-1}). On the other hand, if the velocity dispersion is mainly of geometric origin then the shape of the Hα blue component profile implies $i \leq 29^\circ$. Since the jet is likely to be emitted perpendicularly to the plane of the accretion disc (Becker et al. 1998) it is probable that RX J0925.7-4758 is seen at low inclination angles, consistent with the lack of detected X-ray eclipses. As for RX J0019.8+2156 (Becker et al. 1998), such low inclinations may be incompatible with the relatively large amplitude of the photometric light curve. However, possible jet precession in RX J0925.7-4758 does not allow to draw definite conclusions.

As a whole, the high effective X-ray temperature, small source radius and large jet velocity hint at a massive white dwarf, which may be close to the Chandrasekhar limit.

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References

Becker, C.M., Remillard, R.A., Rappaport, S.A., McClintock, J.E., 1998, preprint astro-ph/980545

Beuermann, K., Reinsch, K., Barwig, H., Burwitz, V., de Martino, D., et al., 1995, A&A 294, L1

Crampton, D., Hutchings, J.B., Cowley, A.P., Schmidtke, P.C., McGrath, T.K., et al., 1996, ApJ 456, 320

Drew, J.E., 1997, ASP Conference Series, Vol 121, Eds. D.T. Wickramasinghe, L. Ferrario, G.V. Bicknell, p465

Ebisawa, K., Asai, K., Mukai, K., Smale, A., Dotani, et al., 1996, in "Supersoft X-ray sources", Ed. J. Greiner, p91.

Fujimoto, M., 1982, ApJ 257, 767

Hartmann, H.W., Heise, J., 1997, A&A 322, 591

Iben, I., 1982, ApJ 259, 244

Kahabka, P., van den Heuvel, E.P.J., 1997, ARA&A, 35, 69

Kylafis, N.D., Xilouris, E.M., 1993, A&A 278, L43

Livio, M., 1997, ASP Conference Series, Vol 121, Eds. D.T. Wickramasinghe, L. Ferrario, G.V. Bicknell, p845.

Meyer-Hofmeister, E., Schandl, S., Meyer, F., 1997, A&A 321, 245

Motch, C., Hasinger, G., Pietsch, W., 1994, A&A 284, 827

Motch, C., 1996, in "Supersoft X-ray sources", Ed. J. Greiner, p83

Popham, R., DiStefano, R., 1996, in "Supersoft X-ray sources", Ed. J. Greiner, p65.

Quaintrell, H., Fender, R.P., 1998, A&A 335, L17

Southwell, K.A., Livio, M., Charles, P.A., O'Donoghue, D., Sutherland, W.J., 1996, ApJ 470, 1065

Tomov, T., Munari, U., Kolev, D., Tomasella, L., Rejkuba, 1998, A&A 333, L67

van den Heuvel, E.P.J., Bhattacharya, D., Nomoto, K., Rappaport, S.A., 1992, A&A 262, 97

van Paradijs, J., McClintock, J.E., 1994, A&A 290, 133