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Spatially resolved spectroscopy of the outflow from the symbiotic Mira RX Pup*

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Abstract. We present and discuss long slit echelle spectra taken at various position angles in the nebula surrounding the symbiotic Mira RX Pup. The spectra were taken in the Hα spectral region and are spatially resolved. The fact that the nebula shows up only in the [NII] lines has enabled us to subtract the underlying point source spectrum, showing clearly the spatio-kinematic structure of the nebula.

We confirm the presence of the elongated feature found by Paresce (1990) at PA=15°, but not its high Hα/[NII] ratio. We also find no evidence for a jet, but a velocity decreasing with distance from the central object.

A new nebular structure is found at $\sim$90° to the main feature. The split lines indicate a nebula expanding with velocities $\geq$ 80 km s^{-1}, probably with a bipolar shape.

Both nebulae are some 100s of times larger than the binary separation of RX Pup.

Key words: binaries: symbiotic – ISM : jets and outflows – Stars: mass loss – Stars: RX Pup

1. Introduction

RX Pup (HD 69190) is a symbiotic binary system containing a long-period Mira variable with $P\sim$580 days (Feast et al. 1977, Whitelock et al. 1983) and a white dwarf companion. Recently, Mikolajewska et al. (1999, hereafter M99) have presented a thorough study of the photometric and spectroscopic properties of RX Pup aimed at determining the basic parameters of the system. They concluded that the the companion of the Mira is a hot $\sim$0.8 M$_\odot$ white dwarf that underwent a nova-like eruption around 1894, as well as a more recent one during the last three decades. During this last eruption, the white dwarf passed through a high luminosity phase lasting for a dozen years (1975-1988), moving toward high temperatures (up to $\sim$120000 K), and then turned down in the Herzprung-Russell diagram toward lower luminosities. During the high luminosity phase, accretion onto the white dwarf from the Mira wind (which is the underlying cause of the nova-like outbursts) was prevented by a strong stellar wind from the white dwarf. The velocity and mass loss rate of this fast wind were estimated by M99 to be of $\sim$140 km s^{-1} and $\sim$10^{-5} M$_\odot$ yr^{-1}, respectively.

These energetic outflows that are produced during the active phases of the hot companions of symbiotic Miras are expected to interact with the relatively dense, slowly expanding circumstellar medium (note that during quiescence only 1% or less of the Mira wind is accreted onto the white dwarfs, cf. M99 and Corradi et al. 1999). This interaction, together with the photoionisation from the hot star, gives rise to the complex, ionized nebulae which are observed around a significant fraction of symbiotic Miras (Corradi et al. 1999). These nebulae contain important information about the geometry, dynamics, and history of the mass loss from symbiotic stars over the last hundreds or even few thousand years. In some cases, (spectro)polarimetric observations also allow us to derive the geometrical orientation of the unresolved central stars, and thus to have the basic information of the orientation of the outflow with respect to the binary system (e.g. Schmid et al. 2000).

In the case of RX Pup, extended nebular emission ($\leq$1″) was found at radio wavelengths at 6 cm and 2 cm (Hollis et al. 1987), as well as in the optical by means of a coronographic, ground-based [NII] image after subtraction of the unresolved core emission of the system (Paresce 1990, hereafter P90). The [NII] image revealed a elongated structure extending toward P.A.=+15° up to about 3″.7 from the centre, which was interpreted by P90 as being a one-sided jet similar to the one of the other symbiotic Mira R Aqr (Hollis & Koupelis 2000 and references therein). In this paper, we present long-slit echelle spectra of RX Pup aimed at obtaining further information about the optically extended outflow discovered by P90. Data and results are described in the next sections.

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* Based on observations obtained at the 3.5m NTT telescope of the European Southern Observatory.

Table 1. Log of the spectral observations

P.A.	Exp. time	Seeing (FWHM)
+15°	1200 sec	0″.95
⋆+15°	1000	1″.00
+105°	1000	1″.20
+60°	1000	1″.40
−30°	1000	1″.30

⋆Offset along the slit to check for instrumental reflections

2. Observations

Long-slit spectra of RX Pup were obtained on May 11, 2000 at the 3.5-m New Technology Telescope (NTT) at ESO, La Silla (Chile). The EMMI instrument was used in the long-slit, high-resolution mode (Corradi et al. 1996), providing a spectral resolving power of $\lambda/\Delta\lambda = 70\,000$ with the adopted slit width of 0″.8. The slit length was 6′. The spectral region containing Hα and the [N II] doublet was isolated using a narrowband filter centred at 656.8 nm and with a full-width at half maximum (FWHM) of 7.3 nm. The detector was the TEK 2048^2 CCD ESO#36, providing a spatial scale along the slit of 0″.27 pix^{-1}.

We obtained several spectra with the slit positioned across the central star and oriented at P.A.=+15° (the position angle of the jet-like feature found by P90), as well at perpendicular and intermediate position angles (P.A.=+105°, +60°, and −30°). Exposure times and seeing for the different spectra are detailed in Table 1.

The observations were reduced in a standard way using both the IRAF and MIDAS packages.

3. Kinematical analysis

The long-slit spectrum of RX Pup at P.A.=+15° is presented in the upper panel of Figure 1. Its most notable feature is the spatially extended emission at the wavelengths of the [N II]658.3 nm and (fainter) [N II]654.8 nm doublet lines. This emission extends up to ∼3″.2 from the centre toward P.A.=+15°, and to ∼2″.4 (albeit fainter) in the opposite direction.

In the lower box of Fig. 1, we plot the spatially integrated spectrum that includes all the emission from the core as well as from the extended [N II] components. Several features can be recognised:

– the very bright and double–peaked Hα emission which is typical of symbiotic stars (cf. van Winckel et al. 1993), but which has developed in RX Pup only in the last decade (M99). The two peaks of Hα have an heliocentric velocity $V_\odot\sim -20$ km s^{-1} and $\sim +40$ km s^{-1}, while the central absorption has $V_\odot\sim 0$ km s^{-1}. Asymmetrical, slowly decreasing wings span the full observed spectral region;

– a broad emission bump (labelled 'Bump' in Figure 1) which is redwards of the Hα peak by a few 100 km s^{-1}. The heliocentric velocity of the point where the bump intensity abruptly turns down is +550 km s^{-1}. This bump is present in the spectra presented by M99, but fainter.

– broad [N II] lines corresponding to the spatially extended emission, and which are resolved into at least two components:

– a narrow peak (labelled 'FeII?'), at an heliocentric wavelength of 658.64 nm and with a FWHM of 13 km s^{-1} (corrected for the instrumental broadening). This narrow line was not visible in recent spectra taken by other authors (Mikolajewaska, private communication). We can exclude that the peak is [N II] emission at $V_\odot$=+135 km s^{-1}, since the [N II]654.8 nm companion line is not observed (after scaling to the relative line intensities of the doublet and corrected for the instrumental responses at the two wavelengths). Neither is the peak an Hα component at $V_\odot\sim +1100$ km s^{-1}, because its width is not consistent with any reasonable temperature for the ionized gas (for T=10000 K, a thermal broadening of 22 km s^{-1} FWHM is expected

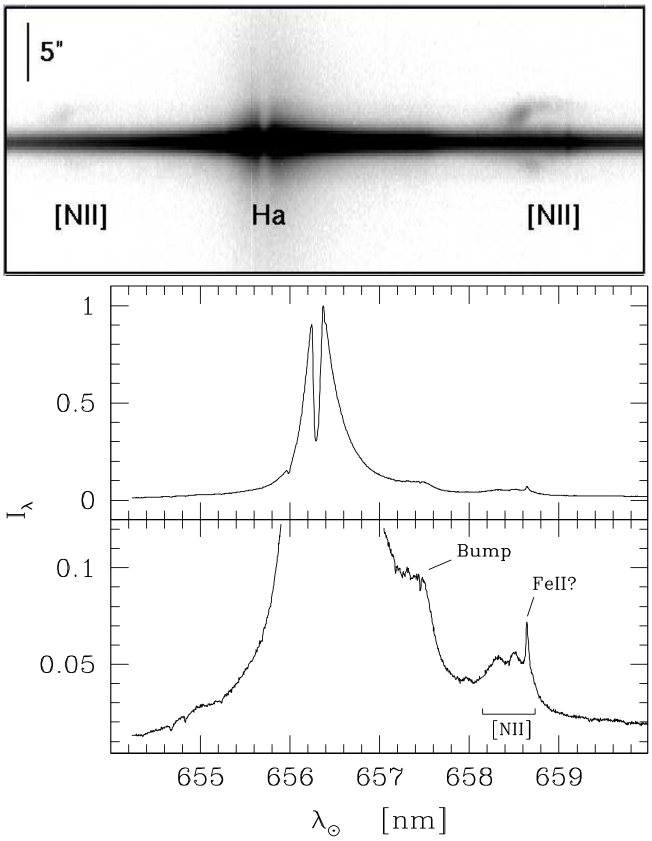

Fig. 1. Above: the long-slit spectrum at P.A.=+15°. The spatial direction runs vertical, while wavelengths increase along the horizontal axis. **Below**: the integrated spectral profile obtained by spatial binning in the inner 6″.5, with two different intensity cuts to highlight both the low and high intensity regions.

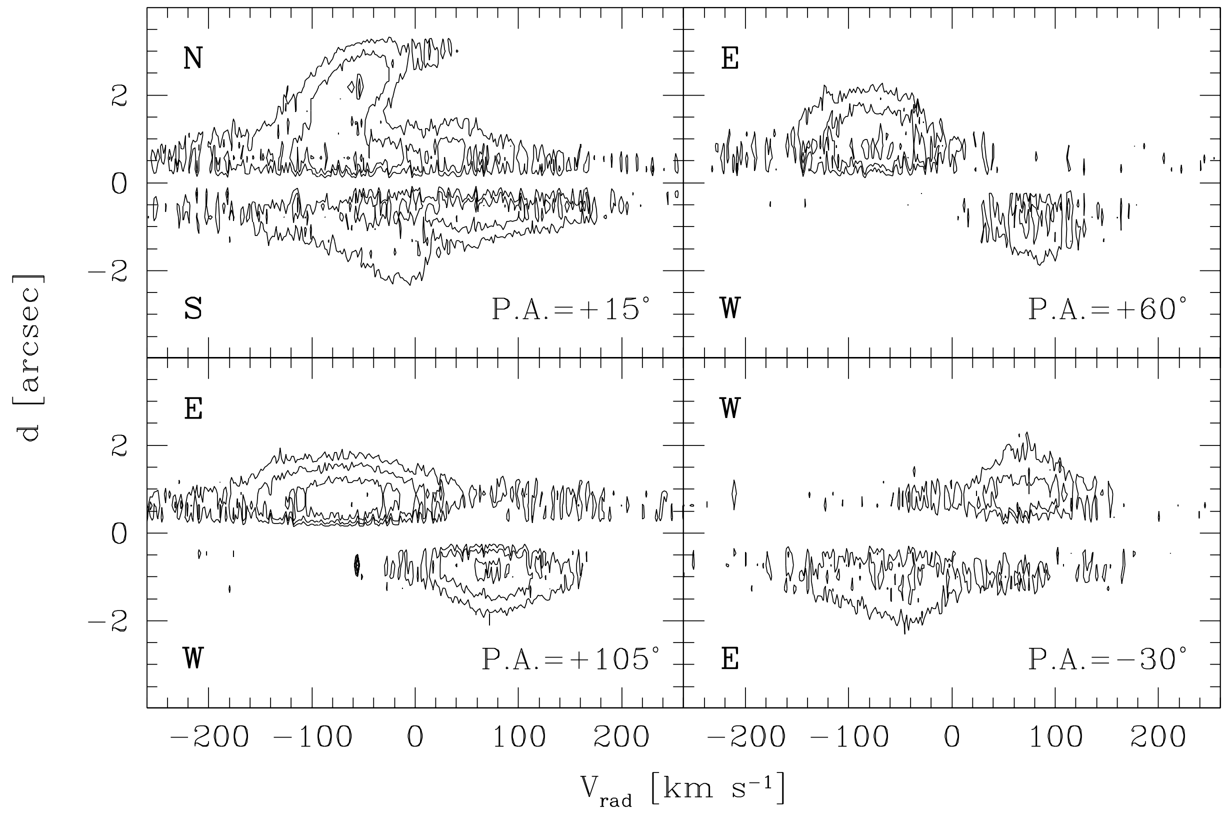

Fig. 2. The [NII]658.3 nm spectra of RX Pup, after subtraction of the unresolved core spectrum (see text). V_{rad} are the observed radial velocities corrected for the adopted systemic velocity. Successive levels of the contour plots increment of a factor $\sqrt{3}$.

for the hydrogen lines). The only two possibilities left are: *i)* the peak is (recently developed) FeII emission as observed in RR Tel (Crawford et al. 1999 list the presence of FeII emission at $\lambda = 658.65$ nm and with a FWHM of 13 km s^{-1}); *ii)* it is an instrumental artifact (possibly contamination from an adjacent order of the echelle grating). Since this narrow peak is not relevant for the discussion of the extended outflow of RX Pup, we do not discussed it further in this paper.

Unlike the spectrum at P.A.=+15°, the spectra at the other position angles (+105°, +60°, and −30°) do not show any obvious sign of spatially extended emission, confirming the results of P90 that the [NII] nebula of RX Pup is mainly elongated toward P.A.=+15°.

The analysis of the spatial point-spread function (PSF) of the spectra as a function of wavelength, however, shows that in all the observed position angles the FWHM of the PSF is slightly but systematically increased for the [NII] lines as compared with the Hα peaks, the 'Bump', and the 'continuum' regions covered by the present spectra. We have therefore done the following exercise. In each spectrum, we extracted the empirical PSF in a region far from the [NII] wavelengths. By scaling this PSF to the observed peak intensity at each wavelength, we have then grown along the dispersion axis a 2-D 'core spectrum' of RX Pup. This conservatively assumes that the contribution of the spatially extended emission to the peak intensity at all wavelengths is negligible. The residuals of the subtraction of this core spectrum from the original would then highlight the possible presence of spatially extended emission. In the subtracted spectra, the emission from the continuum, the Hα line, the 'Bump' as well as from the 'FeII?' features is fully, that is correctly, removed; we compute that the residuals in these spectral regions are just the photon noise of the original spectra. At the [NII] wavelengths, however, a pattern appears which is clearly spatially extended (Figure 2), with blueshifted emission to the east (P.A.=+105°, +60°, +150°), and redshifted emission to the west (P.A.=−75°, −120°, −30°). The velocity difference between the peaks of the blue-red/east-west residuals, as measured by Gaussian fitting, is between 135 and 160 km s^{-1}, depending on the position angle under consideration. The average redshift of the two velocity components is $V_{\odot}$=+22±5 km s^{-1}. In the following, we adopt this value as the heliocentric systemic velocity of the RX Pup system. This is not far from the value of $V_{\odot}$=+1±10 km s^{-1} estimated for the hot component of the system (M99, also Mikolajewska, private communication). Corrected to the Local Standard of Rest, the adopted systemic velocity amounts to $+5 \pm 5$ km s^{-1}, which corresponds to a kinematical distance of 1 ± 1 kpc from the Sun, assuming that RX Pup moves around the

Galactic centre according to the circular rotation curve of the Galaxy. In this paper, following M99 we will adopt a distance of 1.8 kpc to RX Pup.

The marginally resolved E-W kinematical pattern is roughly symmetric with respect to the direction of the jet-like nebula at P.A.=+15°; this is confirmed by the fact that at this latter angle the residuals in the innermost regions of the spectrum do not show any clear blue-/red-shifted components on either side of the central object. The extent of this E-W nebula is about $1''.5$, including smearing due to seeing. Using the recipe of Bedding & Zijlstra (1994), its deconvolved radius is between $0''.5$ and $0''.8$, depending on the assumed intrinsic geometry of the nebular model (hollow shell, disc, or uniform sphere). Due to the fact that the emission is only marginally resolved, and considering the simplistic model assumptions about its actual geometry, the figures above should be treated with caution. Note also that the [N II] emission is likely to be more prominent between P.A.=+105° and +60° (and on the opposite side), as suggested by the higher intensity of the residuals in the spectra at those position angles, as well as by their slightly larger velocity split.

Coming now to the jet-like feature at P.A.=+15° which was imaged by P90 (Fig. 2, upper left box), its radial velocities were measured by multi-Gaussian fitting at successive positions along the slit. We found that the velocity of this collimated feature, with respect to the adopted systemic velocity, decreases from about -80 km s^{-1} at a distance $d = 0''.9$ from the centre, to -50 km s^{-1} at $d = 2''.6$, and to 0 km s^{-1} at $d = 3''.2$. On the other side of the object, there is a fainter, narrow component at about the systemic velocity extending out to $d = -2''.4$, while a broad component with a FWHM of $\sim$300 km s^{-1} can be followed out to $\sim 2''$ on both sides of the nebula. It is not clear whether the latter feature is just the low-intensity tails of the innermost E-W velocity pattern described in the previous paragraph.

4. Discussion: which nebular geometry?

The present data confirm the result of P90 that RX Pup possesses an ionized nebulosa which is mainly extended toward the North (P.A.$\sim +15°$) out to $3''.2$ from the central stars (5800 a.u. for the adopted distance of 1.8 kpc). Our spectra detect the extended nebula only in the [N II] light, and thus do not support the estimate of P90 of a large Hα/[N II] line ratio. Also the interpretation of P90 that the extended nebula might represent a jet is not supported by our radial velocity measurements. The decrease in radial velocity with radius is in fact quite peculiar, although it might be due to projection effects of a curved jet.

Our spectra also reveal the existence of a marginally resolved [N II] nebulosity along the EW direction, with its eastern component blueshifted by $\sim$80 km s^{-1}, and the western one redshifted by the same amount. This nebulosity is contained within a distance from the centre of less than $1''.5$ (<2700 u.a.), but definitely much larger than the separation of the central stars (a few tens a.u.). As for HM Sge and V1016 Cyg (Corradi et al. 1999), we find that the [N II] feature in the spectrum of symbiotic Miras trace the existence of low density, low ionization material located in a very extended (few 100 times the binary separation) circumbinary region. The observed velocity splitting of the EW nebulosity of RX Pup appears to be too high to indicate a rotational pattern possibly linked to the binary motion or to the presence of rotating circumbinary discs. It is more likely that it instead represents an outflow from the system, in the form of an expanding ring (such as the one in the other symbiotic Mira He 2-147, Corradi et al. 1999) or, – more likely given the behaviour of the velocity field with P.A. – a collimated or bipolar outflow extending EW. If so, its kinematical age would be $58 \cdot D \cdot s''/\tan i$ yr, where D is the distance in kpc, s'' is the apparent radius of the outflow in arcsec, and i its inclination to the line of sight. Considering the uncertainties in D and s'' (see previous section), and depending on the (unknown) inclination of the outflow, the EW nebula might well be the ejecta of the 1894 nova-like explosion or even, for moderate to high inclinations, the result of the energetic stellar wind started after 1975 during the present outburst (see Sect. 1).

In any case, RX Pup seems to show two main 'preferred' directions for mass ejection which are roughly pependicular to each other: the EW innermost component, and the more extended structure at about P.A.=15°. The same also appears in the radio data (Hollis et al. 1987); at 2 cm, emission is resolved in three components along the EW direction and located within the innermost $0''.4$, while the 6 cm emission has a northern protrusion. With the present data, it is not possible to get further insight into this complex nebular geometry. In some respect, the situation resembles that of HM Sge (Corradi et al. 1999), whose outflow shows a complex geometry, with different symmetry axes appearing at different observing wavelengths. At this stage, we cannot even exclude, for both systems, the naive possiblity that the direction of mass ejection is drastically changing from one outburst to the next. Clearly, a better understanding of the complex, multiple ionised nebulae of RX Pup and HM Sge requires [N II] imaging with HST resolution. Considering also that polarimetric observations give us strong indications about the apparent orientation of the central binary stars (Schmid et al. 2000, Mikolajewska et al. in preparation), such HST imaging would be especially important to determine the actual direction of the outflows with respect to the orbital planes, which would in turn provide important insights into the mass loss mechanisms from symbiotic binaries and related systems.

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References

Bedding, T.R., Zijlstra, A.A.: 1994, A&A 283, 955
Corradi, R.L.M., Mampaso. A., Perinotto, M.: 1996, ESO Messenger, ESO Messenger, No.85, p. 37
Corradi, R.L.M., Brandi, E., Ferrer, O., Schwarz , H.E.: 1999a, A&A, 343, 841
Corradi, R.L.M., Ferrer, O., Schwarz , H.E., Brandi, E., Garcia, L. : 1999b, A&A, 348, 978
Crawford, F.L., McKenna, F.C., Keenana, F.P., Aller, L.H., Feibelman, W.A., Ryan, S.G.: 1999, A&AS 139, 135
Feast, M.W., Robertson, B.S., Catchpole, R.M.: 1977, MNRAS 179, 499
Hollis, J.M., Yusef-Zadeh, F., Cornwell, T.J., Oliversen, R.J., Michalitsianos, A.G., Kafatos, M.: 1989, ApJ 337, 514
Hollis, J.M., Koupelis, T.: 2000, ApJ 528, 418
Mikolajewska, J., Brandi, E., Hack, W., Whitelock, P.A., Barba, R., García, Marang, F.: 1999, MNRAS 305, 190 (**M99**)
Paresce, F.: 1990, ApJ 357, 231 (**P90**)
Schmid, H.M., Corradi, R.L.M., Krautter, J., Schild, H.: 2000, A&A 355, 261
van Winckel, H., Duerbeck, H.W., Schwarz, H.E.: 1993, A&AS 102, 401
Whitelock, P.A., Catchpole, R.M., Feast, M.W., Roberts, G., Carter, B.S.: 1983, MNRAS 203, 351