The Southern Crab from a new perspective[1]

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ABSTRACT

New HST images and CTIO echelle spectra of the nebula around the symbiotic Mira He 2-104 are presented. The nebula consists of two nested hourglass-shaped structures, and a collimated polar jet. Spatiokinematical modelling shows that all three outflows have been ejected at approximately the same epoch, namely about 5700 yr ago with the adopted distance of 4.4 kpc, in a mass loss event which is not related to the present ongoing outburst. We present a tentative model in which the outer pair of lobes and jets are produced by a high velocity outflow from the white dwarf companion to the Mira, while the inner, slowly expanding lobes are produced by the Mira wind itself.

Subject headings: binaries: symbiotic – ISM : jets and outflows – Stars: mass loss – Stars: He 2−104

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1. Introduction

He 2−104 is one of the most spectacular examples of an ionized bipolar outflow from a Mira in a symbiotic binary system (others being R Aqr and BI Cru). Its large nebula, named the Southern Crab for its characteristic morphology, was discovered by Schwarz et al. (1989) and successively studied by Lutz et al. (1991), Burgarella et al. (1991), and Corradi & Schwarz (1993a, hereafter CS93). The system, previously misclassified as a planetary nebula (PN), was recognized to be a symbiotic star when the presence of a long-period Mira was discovered by Whitelock (1987) by means of near-IR photometric monitoring.

It has been proposed that the extended nebulae observed around He 2−104 and other symbiotic Miras are formed by wind shaping and photoionization during the activity phases of the hot white dwarf (WD) companion of the Miras (Corradi et al. 1999b). The fast winds produced during symbiotic nova-type outbursts are expected to shape the relatively dense, slowly expanding Mira winds (note that during quiescence 1% or less of the Mira wind is accreted onto the WDs, cf. also Livio & Warner 1984). This interaction, together with the photoionization from the WD, gives then rise to the complex nebulae which are observed. The similarity between these symbiotic Mira nebulae and many bipolar PNe raises some suspicion that more of the latter have been misclassified.

In this paper, we present HST [N II] images of He 2−104, as well as new long-slit echelle spectra. These allow us to make a detailed spatiokinematical model of the extended outflow, derive its 3-D geometrical and kinematical properties, and reconsider previous ideas about its formation and evolution.

2. Observations

[N II]λ658.3 nm images of Henize 2−104 (V852 Cen) were taken on 1999 May 22 with the WFPC2 camera of the HST using filter F658N. A deep image of the nebula was obtained by combining ten exposures for a total of 4000 seconds of integration. Linear dithering was used, which after data reduction using the IRAF STSCI drizzle software led to a final pixel size of $0\farcs023$ and $0\farcs050$ in the PC and WFC cameras, respectively.

Long-slit, echelle spectra of the nebula were obtained on 2000 June 18 at the 4m CTIO telescope at Cerro Tololo (Chile). The reciprocal dispersion was 0.008 nm pix^{-1}, corresponding to a spectral resolving power $\lambda/\Delta\lambda$ = 30 000 with the adopted slit width of $1\farcs5$. The CCD was binned ×2 in the spatial direction, resulting in a scale along the slit of $0\farcs54$ per binned pixel. A spectral order which includes both Hα and the [N II] doublet at 654.8 and 658.3 nm was isolated using a narrowband filter centered on Hα and with a width of 7.5 nm. We obtained six spectra with the slit positioned across the central star and oriented along the major and minor axes of the nebula (P.A.=+122° and +212°, respectively), as well at intermediate position angles spaced by 30° to each other (P.A.=+152°, +182°, +242°, and +272°). The exposure time for each spectrum was 600 sec, and the seeing varied between $1\farcs5$ and $1\farcs9$.

3. HST imaging

The HST [N II] image of He 2−104 is presented in Figure 1. As has been known from previous ground-based imagery (Schwarz et al. 1989, Burgarella et al. 1991, CS93), the nebula consists of three main components: a large 'crab-like' pair of bipolar lobes, an inner pair that is similar in shape to the large lobes but about five times smaller, and polar jets extending along the symmetry axis of the system and located at larger distances than the outer lobes. The HST image reveals numerous new details of each component:

- the high density core of the system (≈10^7 cm^{-3}, de Freitas Pacheco & Costa 1996) is resolved even along the short axis of the outflows;
- the inner lobes display three symmetrical 'rings' of enhanced [N II] surface brightness on either side of the central star (Figure 1, bottom left). All rings are well fitted by circles inclined of 60° to the plane of the sky. Because of projection effects, portions of the rings overlap with the bright central region of the nebula;
- the outer lobes are highly fragmented into knots beyond a certain distance. Most of them are barely resolved in the image, and many possess long and narrow tails directed outwards (Figure 1, upper right).

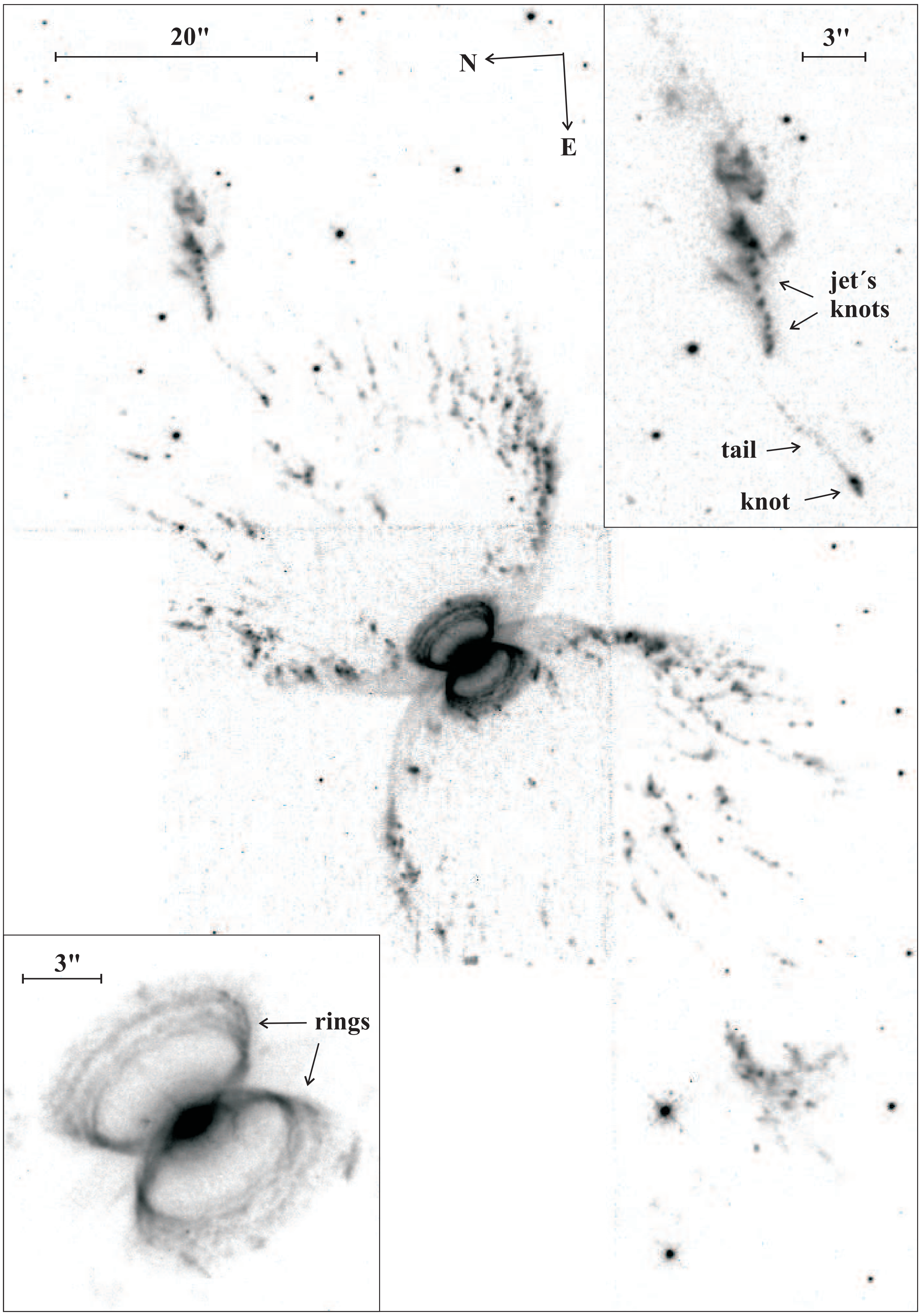

Fig. 1.— The [N II] HST image, on a logarithmic intensity scale. The inset boxes show details of the inner nebula and NW jet.

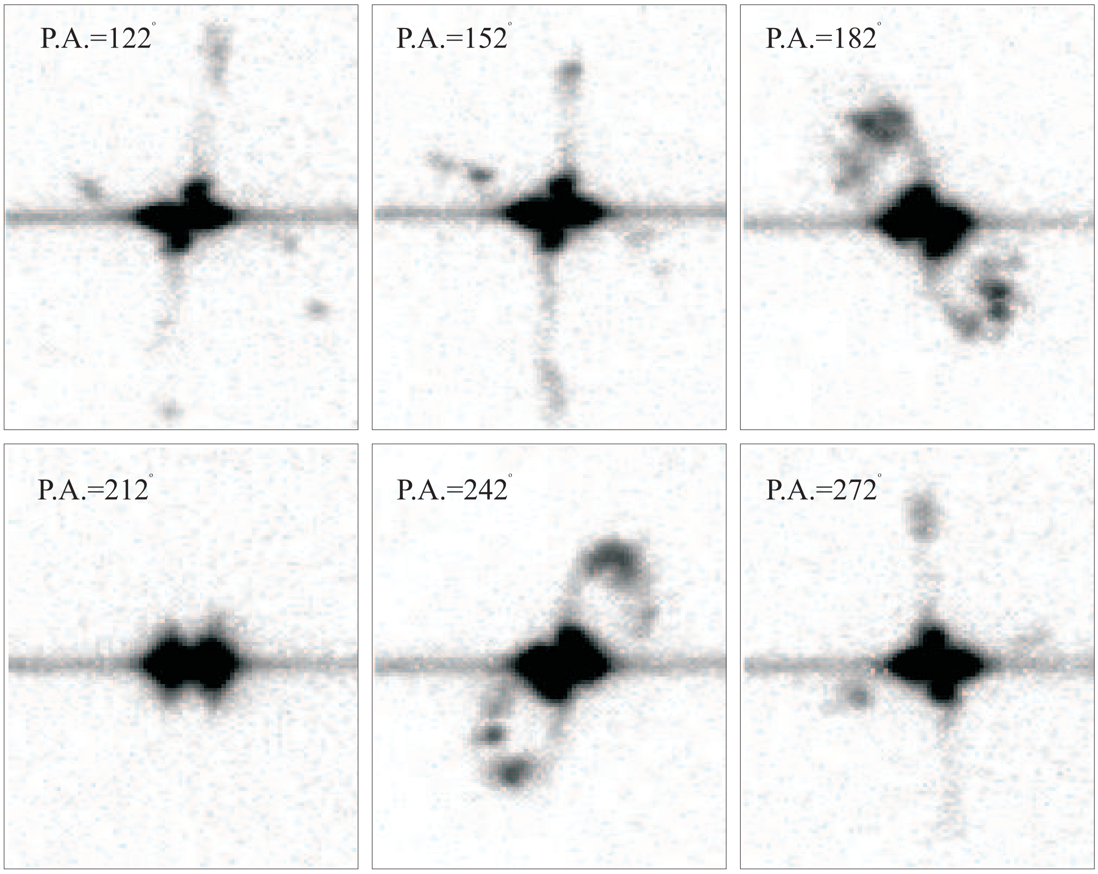

Fig. 2.— The [N II] CTIO spectra of the bipolar nebulae of He 2-104, on a logarithmic scale. The spatial direction is the vertical one (the size of the box is 60 arcsec), while wavelengths increase along the horizontal direction (box size 300 km s^{-1}). The polar jet's emission is not shown here: their position-velocity plots can be found in CS93.

- the polar jets are also knotty, especially the NW one whose innermost portion is a narrow linear string made of nine consecutive knots which crosses the bipolar symmetry axis (Figure 1, upper right).

4. Spatiokinematical modelling

Because of its large thermal broadening, in the echelle spectra of the Hα line it is difficult to distinguish the different velocity components of the nebula. For this reason, in the following we will discuss only the kinematics from the narrower [N II]658.3 nm line. Greyscale representations of the data at all position angles are presented in Figure 2.

4.1. The nested bipolar nebulae

The new spectra, together with the HST imaging, allow us to perform a much more detailed spatiokinematical modelling of the inner and outer bipolar nebulae than was done in CS93. We have adopted the heuristic axisymmetrical model of Solf & Ulrich (1985). In that model, the nebular expansion velocity $V_{\rm exp}$ increases going from the equatorial plane toward the polar axis, following the equation

$$V_{\rm exp}(\phi) = V_{\rm e} + (V_{\rm p} - V_{\rm e}) \sin^{\gamma}(|\phi|), \qquad (1)$$

where ϕ is the latitude angle (=0° in the equatorial plane, 90° in the polar directions), V_p and V_e are the polar and equatorial velocities, and γ a shape parameter. The other parameters involved in the

Table 1
Spatiokinematical model's fitting parameters

Parameter	Inner nebula Best fit	Inner nebula Accept. range	Outer nebula Best fit	Outer nebula Accept. range
V_p	**50** km s^{-1}	40–60	**250** km s^{-1}	210–270
V_p/V_e	**8**	6–10	**20**	15–30
i	**58°**	56–61	**58°**	56–61
γ	**2.7**	2.5–3.1	**3.2**	2.5–3.5
tD^{-1}	**1.3** yr pc^{-1}	1.2–1.5	**1.3** yr pc^{-1}	1.1–1.5
V_{sys}	**95**	93–97	**95**	93–97
$\phi_{\rm max}$	**40°**	38–42	**52°**	51–54
$\phi_{\rm rings}$	**26°, 29°, 33°**			

model are the heliocentric systemic velocity $V_{\rm sys}$, the inclination i of the nebula (angle between the polar axis and the line of sight), and the product tD^{-1} containing the inseparable dependence of the nebular size on the distance D and on the kinematical age t. This model produces nearly circular to extremely elongated bipolar nebulae that grow self-similarly in time (a time independent expansion velocity is assumed). It has proven to provide a good representation of the bipolar nebulae of R Aqr (Solf & Ulrich 1985) and of the PN NGC 6537 (Corradi & Schwarz 1993b).

Considering the morphology of He 2−104, we added two more features to the above model: *i)* a truncation at high latitudes, i.e. we define a maximum latitude $\phi_{\rm max}$ above which no gas is considered to be present; *ii)* enhancements of the surface brightness at specific latitudes ($\phi_{\rm rings}$) to reproduce the rings observed in the inner pair of lobes. In addition, as an initial guess for i we have assumed the value of 60° derived for the rings in the image of the inner nebula (see §3).

We obtained very good fits for the [N II] image and spectra at all position angles, for both the inner and outer bipolar lobes. The fits are presented in Figures 3 and 4. The best fitting parameters, as well as the range in which they are considered to give an acceptable representation of the morphology and kinematics, are reported in Table 1. The fit was performed visually after allowing the different parameters to vary over a large range of values. It should also be stressed that the various parameters are not entirely independent of each other, so that varying one parameter value within the acceptable range implies that other parameters must be changed accordingly. In spite of that, all parameters are constrained within 25% of the best fitting value, and some of them are determined with an even higher accuracy (2% for $V_{\rm sys}$, 5% for i, and 15% for the age parameter tD^{-1}).

We find that the inner and outer crab-like lobes of He 2−104 have (within the allowed parameter ranges) essentially the same kinematical age, namely tD^{-1}=1.3 yr pc^{-1}. Thus their different sizes are apparently just the result of different space velocities: the velocity of the outer lobes increases from ∼12 km s^{-1} at the equator to ∼120 km s^{-1} at $\phi_{\rm max}$=52°, while that of the inner lobes increases from ∼6 km s^{-1} in the equatorial plane to ∼20 km s^{-1} at $\phi_{\rm max}$=40°. The outer pair of lobes has a somewhat larger opening angle than the inner one, or in other words, a more pronounced equatorial waist. This is illustrated in Figure 5, in which we plot the model fitting nebulae seen edge-on ($i = 90°$). We also find that the two pairs of lobes are coaxial within the present accuracy (∼3°) in the estimate of their inclination to the line of sight and of the projection of their symmetry axes onto the plane of the sky.

Moreover, the location and kinematical signatures of the rings observed in the inner lobes are very well reproduced by the inclusion of real surface brightness enhancements at intermediate, discrete latitudes $\phi_{\rm rings}$ (see Table 1). Analogously,

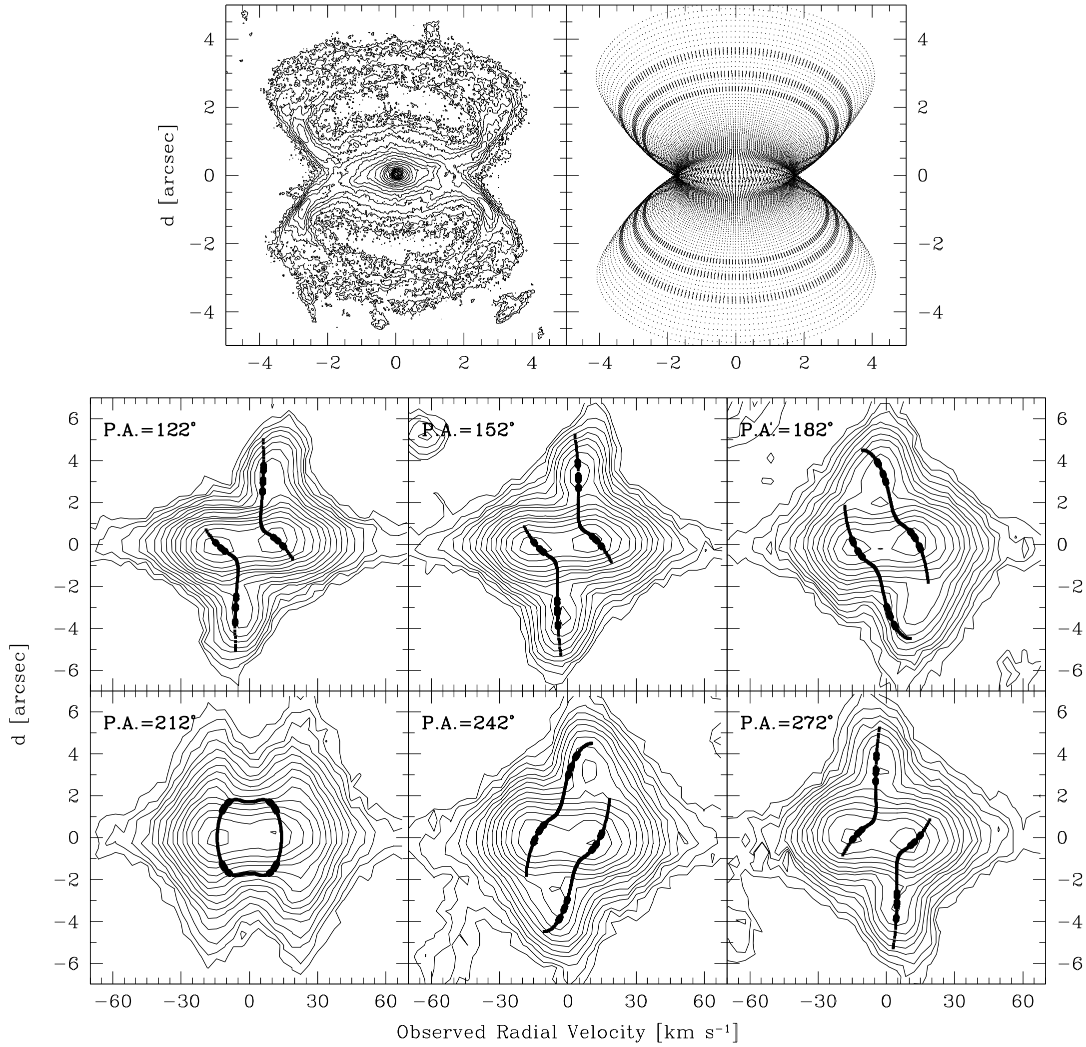

Fig. 3.— The model fit to the inner bipolar lobes of He 2-104. **Top**: at the left, contours plot of the HST image, after rotating it to have its symmetry axis aligned with the vertical direction. Successive levels of the contours plot increment of a factor $\sqrt{2}$. At the right, the model nebula. Note the three rings which are used to simulate the corresponding brightness enhancements in the image (see also Fig. 1, bottom left). **Below**: contours plots of the [N II] line profiles at the different position angles, with superimposed the model's fit (thick solid lines). Radial velocities are corrected for the systemic velocity of the nebula. The positions at which the rings contribute to the [N II] emission are indicated by the thicker portions of the fit lines.

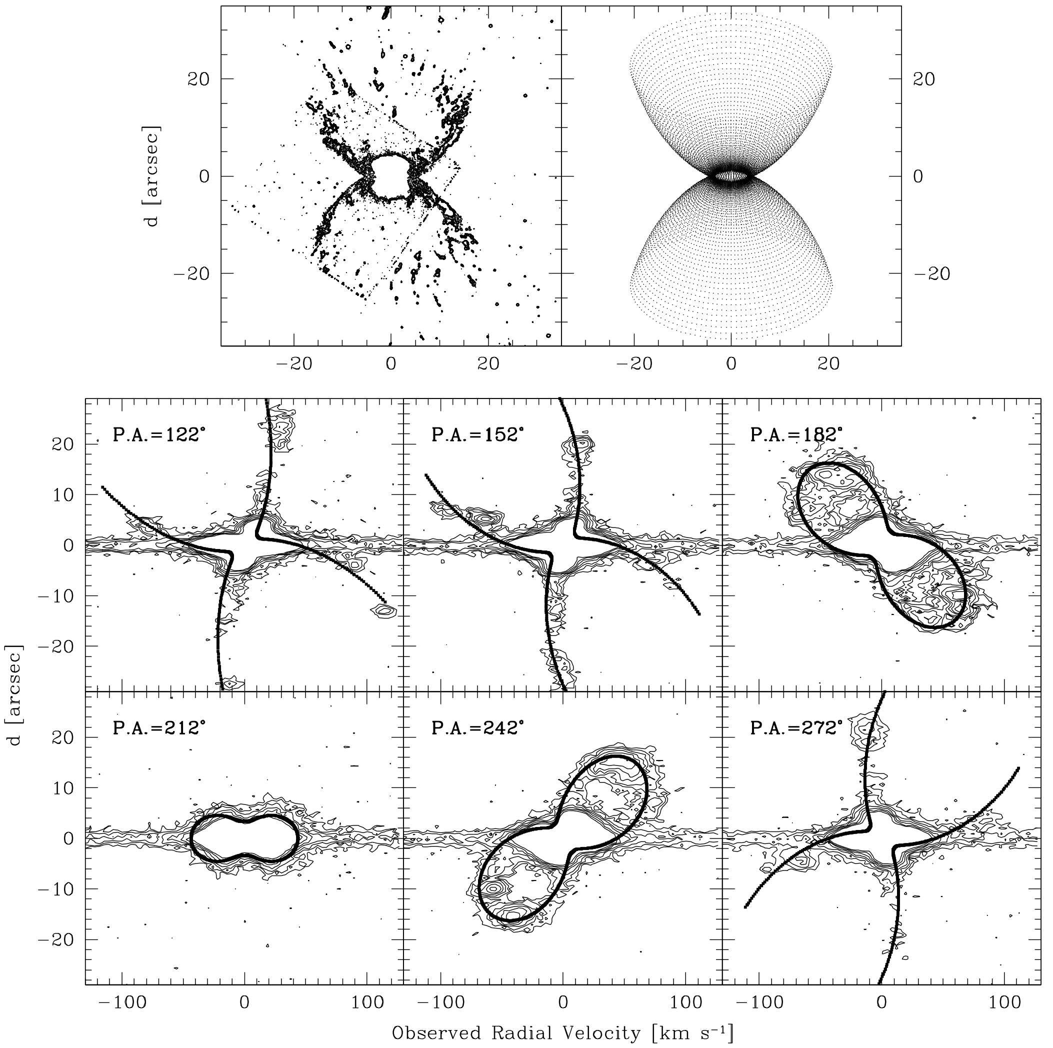

Fig. 4.— As in Fig. 3, but for the outer lobes. The high intensity contours, corresponding to the emission of the inner nebula, are not plotted.

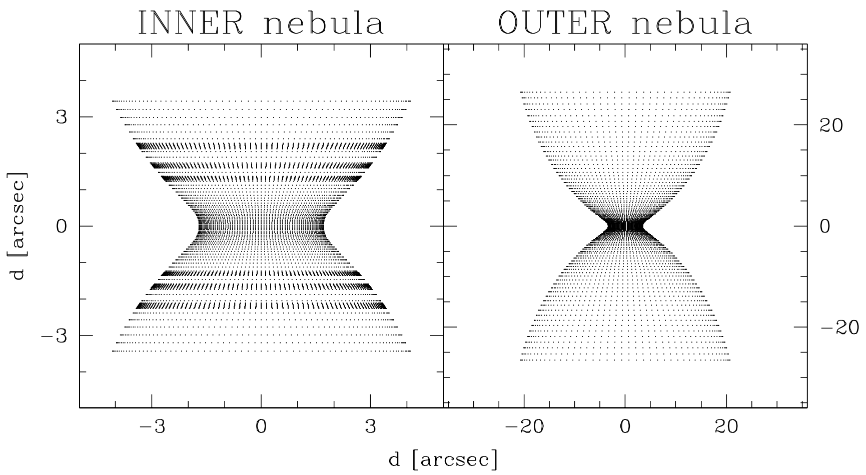

Fig. 5.— Model's nebulae as if they were seen from $i = 90°$

there is an increase in the number of knots at latitudes between ϕ=38° and 46° in the outer lobes.

4.2. The polar jets

The new spectra confirm the results of CS93. Assuming that the jets lie along the symmetry axis of the bipolar nebulae, the new, accurate determination of the inclination allows us to refine the estimates of their average expansion velocities and kinematical age parameter to ∼240 km s^{-1} and 1.2 yr pc^{-1}, respectively. Thus, the kinematical age is again strikingly similar to that of the small and large bipolar lobes of the system (1.3 yr pc^{-1}). The spatial extension and the linear increase of the velocities along the jets also suggest that the jets constitute of material ejected in a short burst.

5. Discussion

5.1. Basic parameters of the system

Before discussing the origin of the outflows of He 2−104, some discussion about the basic properties of its central stars is in order. As mentioned in §1, the cool component of this symbiotic system is a long-period Mira (P=400 d, Whitelock 1987). A total extinction of 1.6 mag in the K band is estimated from near-IR photometry (Feast 1996, Munari et al. 1992). This corresponds to a huge extinction in the optical, namely 14.7 mag in the V band for a standard $R_V = 3.1$ extinction law. Thus the Mira is engulfed in a thick dust envelope which completely prevents its direct observation in the visible range. If we assume that the extended outflows are collimated toward the polar directions of the orbit, the inclination computed in the previous section (58°) indicates that the dust is not strongly confined in the orbital plane, but covers higher stellar latitudes. The radius of a Mira pulsating in the first overtone mode with a 400 day period is of about 480 $R_\odot$ (2.23 A.U., Feast 1996). With reasonable assumptions of the Mira and WD masses (2 $M_\odot$ and 0.6 $M_\odot$, respectively) and of the orbital period ($\geq$ 30 yr, Whitelock 1987), the Mira Roche lobe is of the order of $\geq$6 A.U.. Thus the whole Roche lobe is likely to be filled with dust, and the cool source of He 2−104 closely resembles an OH/IR source loosing mass at a very high rate (10^{-4}–10^{-5} $M_\odot$ yr^{-1}).

The companion of the Mira is a hot WD which has been undergoing a powerful thermonuclear outburst for at least $\geq$50 yr. Comparing the spectral atlases of symbiotic stars of Allen (1984) and Munari and Zwitter (2000), the nebular spectrum of He 2−104 has not changed in the last 20 yr, indicating stable thermonuclear burning on the surface of the WD. Symbiotic novae containing a Mira show decline rates in luminosity from maximum ranging from 1 mag in 19 years for HM Sge (Yudin et al. 1994), to less than 0.1 mag in 15 years for V1016 Cyg (Munari 1996). The decline for He 2−104 is so far imperceptible, and thus its outburst might last for several hundred years more. From the presence of strong C IV 155 nm and weak

He II 164 nm lines we estimate a temperature for the WD of $\sim$75000 K; the value of 30000 K quoted by de Freitas Pacheco & Costa (1996) appears too low to account for the above-mentioned circumstellar emission lines. No evidence for strong ongoing mass loss from the WD is found in the UV IUE and optical spectra.

Distance estimates in the literature range from 0.8 to 6.3 kpc (cf. Schwarz et al. 1989). Using the Feast (1996) period-luminosity relationship for Miras, the observed K magnitude and the estimated total extinction, we derive a distance to He 2−104 of 4.4 kpc, similar to the value of 4.7 kpc determined by Whitelock (1987) using the same method but different data and period–luminosity relationship. At this distance, the nebula would have a deprojected size of 2.5 pc (including the polar jets), which is huge among PNe, but not unusual within the subclass of bipolars (cf. Corradi et al. 1997). With a 4.4 kpc distance, He 2−104 would also be located at 720 pc above the Galactic plan, an unusually high latitude for bipolar PNe, which are strongly confined in the Galactic plane (Corradi & Schwarz 1995). Among symbiotic stars, the scale-height of those containing a Mira (D-types) such as He 2−104 is uncertain, while the ones containing a non pulsating red giant are likely to belong to the bulge/thick disk component of the Galaxy (Whitelock & Munari 1992).

In the following, we will discuss kinematical ages for the nebulae adopting a distance of 4.4 kpc from the period-luminosity relation for Miras, bearing in mind that the distance could be smaller (as adopted by Schwarz et al. 1989 and CS93[3]). For instance, if the Mira of He 2−104 were not pulsating in the first overtone mode (as field Miras do) but instead in the fundamental one, the usual period–luminosity relationship would not hold and the distance would be shorter. Clearly, having a robust distance determination, such as the expansion parallax of the nebula, would be very important to better understand the properties of the Mira of He 2–104 and of its surrounding nebula.

[3]Note that, for a distance of 1 kpc, the total extinction needed in K to preserve the period-luminosity relation for Miras would be of 4.8 mag, i.e. 44 mag in V!

5.2. On the dynamics of bipolar nebulae

The spatiokinematical modelling of the lobes and jets of He 2−104 suggests that the gas streamlines are purely radial and matter is expanding at a constant velocity, so that the nebular structures grow self-similarly. This 'Hubble law" expansion (velocity proportional to distance) is also a property of many bipolar PNe, such as NGC 6537 and He 2−36 (Corradi & Schwarz 1993b, 1993c), or Mz 3 (Redman et al. 2000). The evidence for self-similar expansion with 'ballistic' motions might appear to argue against the popular model of hydrodynamical shaping of bipolar PNe by Interacting-Stellar-Winds (ISW, e.g. Mellema & Frank 1995). However, according to these models the shape of the nebula only evolves until the wind-heated bubble breaks out of the near-nuclear confining disk. At this point the lobe edges are no longer effectively constrained by ram or thermal pressure of the external environment, so the gas continues outward under its own inertia in a Hubble-like flow. Thus, the existing data indicate that the basic shape of bipolar nebulae is reached during their early evolution, within the first $\approx$10% of their present lifetime, and at a region close to the star.

5.3. A new scenario for the formation of the nebulae around He 2-104

The most striking result of our kinematical analysis is that, within the uncertainties, all three outflows of He 2−104 (inner and outer lobes, and polar jets) appear to consist of matter which was released from the central source at approximately the same epoch, 5700 yr ago with the adopted distance of 4.4 kpc, and in a relatively short burst. If this conclusion is correct, then the extended nebular structure of He 2−104 has not been produced during the present ongoing outburst.

The kinematical ages are not consistent with the previous interpretation (CS93, Corradi et al. 1999b) that the nested bipolar nebulae of He 2−104 are the result of two "identical" mass loss events from the hot companion of the Mira, separated by $\approx 10^3$ yr (using the smaller distance scale adopted by CS93, i.e. 0.8 kpc), corresponding to two similar nova-like outbursts. There is still the possibility, as we will discuss below, that the events forming the two pairs of bipolar lobes are separated by a time interval which is hidden in the errors on our age estimates — say, <800 yr. Nonetheless, it is clear that the kinematics of the two outflows, and therefore the characteristics and energetics of the corresponding mass ejection events, are significantly different. Note also that in R Aqr, which was considered by Corradi et al. (1999b) to be the other good example of multiple bipolar nebulae produced by recurrent nova-like outbursts, it was recently found that there is in fact only one large hourglass nebula, while the supposed inner one is instead a helical jet (Hollis et al. 1999). Thus the idea of multiple nebulae in symbiotic Miras produced by recurrent outburst with timescales of 500–1000 yr may no longer be supported by the most recent observations.

The question is therefore: what mass loss scenario correctly represents that of He 2−104? Blackman et al. (2000) presented a model (based on a suggestion by Livio & Pringle 1997) in which nested bipolar nebulae are created by magnetized winds from an accretion disk, where the latter results from the disruption of a secondary star in a binary system going through a common envelope phase. However, the nature of symbiotic Miras such as He 2−104 appears different from the binary evolution considered by Blackman et al. (2000). There is a general consensus that symbiotic Miras are detached binaries with periods of a few tens, or even hundreds of years, and that they therefore never develop a common envelope (e.g. the orbital period of the longest pulsation period –745 days– symbiotic Mira, V407 Cyg, was estimated to be ∼43 yr by Munari et al. 1990). Some ingredients of the modelling in Blackman et al. (2000), which were already proposed by Soker & Livio (1994; see also Morris 1987), can still apply to He 2−104. Accretion disks, in fact, may form around the hot WDs of these systems, and they could be the sources of additional winds from the systems. As mentioned in the introduction, fast winds lasting for tens of years are also produced by the hot WDs during the (possibly recurrent) nova-like thermonuclear runaways which characterize the evolution of these binary systems. In the case of RX Pup, for example, Mikolajewska et al. (1999) quote a wind velocity and mass loss rate of $\sim$140 km s^{-1} and $\sim 10^{-5}$ M$_\odot$ yr^{-1}, respectively, during the high luminosity phase of the WD, after its nova-type eruption.

Another basic property of the outflows of He 2–104 that needs to be taken into account is the large difference in the expansion velocities of the inner and outer lobes. In particular, the inner pair shows expansion velocities just within the range of a standard Mira wind. Thus, we may tentatively associate the formation of the inner lobes with enhanced mass loss from the Mira of the system, with no intervention of fast winds from the WD companion and its associated accretion disk. This is an essentially new idea, as the most popular models for the formation of bipolar nebulae, both in young and evolved stars, require the shaping action of a fast wind upon a highly asymmetrical slower outflow.

All of this leads to the following (at this stage rather speculative) scenario for the formation of the three different outflows of He 2−104. During long periods (some 10^4 yr?) of 'quiescence', the Mira wind is focussed onto the orbital plane by the binary interactions (Mastrodemos & Morris 1999, Soker & Rappaport 2000), producing a quite massive, strongly flattened (torus-like), and slowly expanding circumbinary nebula. It is this equatorial torus that will subsequently provide (at least partially) the collimation toward the polar directions of both the inner and outer bipolar nebulae of He 2-104. Later on, a temporary increase in the mass loss from the Mira, maybe during a thermal pulse, results in an increased accretion rate onto the WD, the formation of an accretion disk, possibly a nova–like outburst on the hot component, and concomitant high speed bipolar outflow and jets. This outflow is responsible for the formation of the outer high velocity nebula, with the fast ejecta from the WD sweeping up the older, denser and highly asymmetrical Mira wind forming the outer pair of lobes (see also Soker & Rappaport 2000). The knotty structure of this nebula might in turn originate at the time of the somewhat chaotic ejection, or, more likely, be the result of dynamical (e.g. Rayleigh-Taylor) instabilities, and long ablation tails may be added to the knots by photoionization at a later stage. At approximately the same time as the formation of the outer bipolar nebula (it does not matter whether slightly after or before), the highly collimated polar jets are produced by a magnetized wind from the accretion disk (Livio 2000), which is also powered by the increasing Mira mass loss. The linear increase in velocity observed along the jet is consistent with magnetic collimation, and the string of knots observed on its NW side might be the result of magneto-hydrodynamical instabilities (cf. also the knotty jet recently discovered in Hen 2–90 by Sahai & Nyman 2000). A few tens to some hundreds of years later, the fast wind from the hot component of the system switches off. Then the inner lobes can be built up by the slow, still enhanced Mira wind, using the same collimator's nozzle as the outer bipolar nebula, i.e. the massive circumstellar torus built up during quiescence (which might have been further compressed near the equatorial plane by the WD fast wind, as proposed by Soker & Rappaport 2000). Eventually, the system reverts to a more quiescent mass loss activity.

Concerning the formation of the rings at intermediate latitudes of the inner lobes of He 2–104, modulation in the radial density of AGB outflows has been predicted *(i)* as a consequence of quasi-periodic fluctuations of the stellar mass loss caused by dust drift and drag on the gas (Simis et al. 2001), or *(ii)* induced by the gravitational effects of a stellar companion in a detached binary system (Mastrodemos & Morris 1999). The mechanisms above are expected to form distinct shells with timescales of some hundreds of years as observed in many proto-PNe or PNe (e.g. CRL2688, Sahai et al. 1998), but it is not clear whether they can also apply to the bipolar geometry and ejection timescales of the outflow of He 2−104. It is worth noting that in spite of considerable effort the origin of the large rings in Supernova 1987A is still unclear.

He 2-104 is certainly not unique. Mz 3 (VV80) is another extreme bipolar nebula with an active stellar nucleus. Much like He 2-104, the nebula shows a nested set of inner and outer lobes with a common symmetry axis. The echelle spectrum obtained by Redman et al. (2000; see their Fig. 2) shows that, also like He 2-104, both sets of lobes share the same type of 'Hubble-like' flows with a common expansion age. The similarity of He 2-104 with Mz 3, as well as with the 'Hourglass' PN MyCn 18 and other symbiotic Miras (like BI Cru and R Aqr), suggests that shaping mechanisms of the type discussed in this paper may be operating in many systems.

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REFERENCES

Allen, D.A. 1984, Proc. A.S.A., 5, 369

Blackman, E.G., Frank, A., Welch, C. 2000, ApJ, in press

Burgarella, D., Clampin, M., Paresce, F. 1991, A&A, 249, 199

Corradi, R.L.M., Schwarz , H.E. 1993a, A&A, 268, 714 (**CS93**)

Corradi, R.L.M., Schwarz , H.E. 1993b, A&A, 269, 462

Corradi, R.L.M., Schwarz , H.E. 1993c, A&A, 273, 247

Corradi, R.L.M., Schwarz, H.E. 1995, A&A, 293, 871

Corradi, R.L.M., Villaver, E., Mampaso, A., Perinotto, M. 1997, A&A, 324, 276

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

de Freitas Pacheco, J.A., Costa, R.D.D. 1996, A&A, 309, 629

Feast, M.W. 1996, MNRAS 278, 11

Hollis, J.M., Vogel, S.N., van Buren, D., Strong, J.P., Lyon, R.G., Dorband, J.E. 1999, ApJ, 522, 297

Livio, M. 2000, in 'Asymmetrical Planetary Nebulae II: From Origins to Microstructures', ASP Conf. Series, Vol. 199, J. H. Kastner, N. Soker, and S. Rappaport eds, p. 243

Livio, M. & Warner, B. 1984, Observatory, 104, 152

Livio, M. & Pringle, J.E. 1997, ApJ, 486, 835

Lutz, J.H., Kaler J.M., Shaw R.A., Schwarz H.E., Aspin C. 1991, PASP, 101, 966

Mastrodemos, N., Morris, M. 1999, ApJ, 523, 357

Mellema, G., Frank,A. 1995, MNRAS, 273, 401

Mikolajewska, J., Brandi, E., Hack, W., Whitelock, P.A., Barba, R., García, Marang, F. 1999, MNRAS, 305, 190 (M99)

Morris, M. 1987, PASP, 95, 1115

Munari, U. 1996, in 'Physical Processes in Symbiotic Binaries and Related Systems', ed.s J.Mikolajewska, Polish Academy of Sciences, pag. 37

Munari, U., Margoni, R., Stagni, R. 1990, MNRAS, 242, 653

Munari, U., Yudin, B. F. Taranova, O. G., Massone, G., Marang, F., Roberts, G., Winkler, H., Whitelock, P. A. 1992, A&AS, 93, 383

Munari, U., Zwitter, T. 2000, A&A, in press

Redman, M. P., O'Connor, J. A., Holloway, A. J., Bryce, M., Meaburn, J. 2000, ApJ, 312, L23

Sahai, R., Trauger, J.T., Watson, A.M., et al. 1998, ApJ, 493, 301

Sahai, R., Nyman, L. 2000, ApJ, 538, L145

Schwarz, H.E., Aspin, C., Lutz, J.H. 1989, ApJ, 344, L29

Simis, Y.J.W., Icke, V., Dominik, C. 2001, A&A submitted

Soker, N. & Livio, M. 1994, ApJ, 421, 219

Soker, N. & Rappaport, S. 2000, ApJ, 538, 241

Solf, J., Ulrich, H. 1985, A&A, 148, 274

Whitelock, P.A. 1987, PASP, 99, 573

Whitelock, P.A., Munari, U. 1992, A&A, 255, 171

Yudin, B.F., Munari, U., Dalmeri, I. 1994, A&AS, 105, 169

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