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He 2–104: A SYMBIOTIC PROTO–PLANETARY NEBULA?

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ABSTRACT

We present CCD observations of He 2–104 (PK 315+9°.1), an object previously classified as both PN and symbiotic star, which show that this is in fact a proto–planetary nebula (PPN) with a dynamical age of about 800 yr. The presence of highly collimated jets, extending over 75″ on the sky, combined with an energy distribution showing a hot as well as a cool component, have convinced us that He 2–104 is a binary PPN. Since the primary is probably a Mira with a 400^d period (as reported by Whitelock in 1988), we propose that the system is, more specifically, a symbiotic PPN. We also determine, using several independent methods, that its distance is a factor of 10 smaller than previously published values.

Subject headings: nebulae: planetary — stars: symbiotic

I. INTRODUCTION AND OBSERVATIONS

There is believed to be a rapid transition phase in the late stages of the evolution of stars of intermediate mass in which these stars move from the upper AGB to the planetary nebulae (PN) locus in the H-R diagram. This phase would be characterized by fast winds and jets producing shock phenomena and a lifetime not exceeding about 1000 yr. The study of the rare objects in this evolutionary phase, the proto–planetary nebulae, is of importance for an understanding of PN formation and the physics of the above-mentioned rapid processes, especially in binary systems where extremely highly collimated jets can occur (Morris 1987).

Here we report the discovery of such an object, He 2–104, which was found during a spectroscopic search for PPNs among a sample of objects selected on the basis of their proximity to the PN locus in the BPT diagram (Baldwin, Phillips, and Terlevich 1981) as adapted by Schwarz (1988) to show evolutionary trends among symbiotics.

Long-slit spectroscopy was used to look for extended emission near the stars. On some spectra of He 2–104, line emission was found up to 30″ away from the star. Since the object was listed as having an optical extent of less than 2″.5 (e.g., Gutiérrez-Moreno, Moreno, and Cortés 1986) we took direct CCD images to check on the spectroscopy results.

All images were taken with the CCD camera on the ESO/MPI 2.2 m telescope at La Silla, Chile, on 1988 March 6. The filters had the following characteristics: Hα, centered on 6565 Å with a FWHM of 15 Å; [N II] 6584 Å with 20 Å FWHM, and [S II] 6730 Å with 13 Å FWHM. The chip was an RCA SID503, thinned, back-illuminated with 640 × 1024 pixels^2 of 15 μm^2, each corresponding to 0″.17 on the sky. The exposure times were 30 m for the [S II] and [N II] images and 20 m for the Hα picture, with a typical seeing of 0″.9 FWHM and photometric conditions. The data were reduced at the Joint Astronomy Center, Hawaii and at La Silla, Chile.

To determine the various velocities in the system, we also observed He 2–104 with long-slit spectroscopy on 1988 May 5. The Boller and Chivens spectrograph was equipped with a 58 Å mm^{-1} grating giving a scale on the CCD of 1.74 Å pixel^{-1} and 1″.88 pixel^{-1} along the slit. The spectral range was 900 Å centered on 6530 Å. The telescope was the 2.2 m at La Silla and the CCD an RCA SID501 with 320 × 512 pixels^2 of 30 μm^2. Weather conditions were similar to those for the direct imaging observations with seeing of 1″.1. The data reduction was done at La Silla.

JHKLM photometry was done on 1988 March 30, using the standard ESO InSb photometer on the 1 m telescope at La Silla. Again, the data were reduced at La Silla.

II. RESULTS

Figure 1 (Plate L2) shows images of He 2–104 taken through narrow Hα, [N II], and [S II] filters. The images extend over 75″ and show a bipolar morphology in the shape of two bubbles with Herbig-Haro object–like "blobs" at their extreme ends. The morphology depends on the particular emission line but is generally similar to that of OH 231.8+4.2 (Reipurth 1987).

From our IR photometry, *IRAS* fluxes, and *UBV* photometry, we have determined the energy distribution of He 2–104, shown in Figure 2 as filled circles. Note that the *UBV* results could be in error by as much as a magnitude due to steep gradients and strong emission lines (Kaler 1989). This does not affect any conclusions drawn here.

By using the estimate of Whitelock (1988) for the *K* extinction intrinsic to He 2–104 of $A_K = 1.7$ mag and the extinction law of Savage and Mathis (1979) to deredden the observed energy distribution, we obtain the plot shown in Figure 2 as open circles. A strong blue component is present and this could be interpreted as the hot companion to the Mira-like primary star. Clearly, this interpretation has to be viewed with caution since a very heavy dereddening has been applied.

Our interpretation of the images is along the lines of the model proposed by Morris (1987) in which a binary system consisting of a red giant primary and a white dwarf or main-

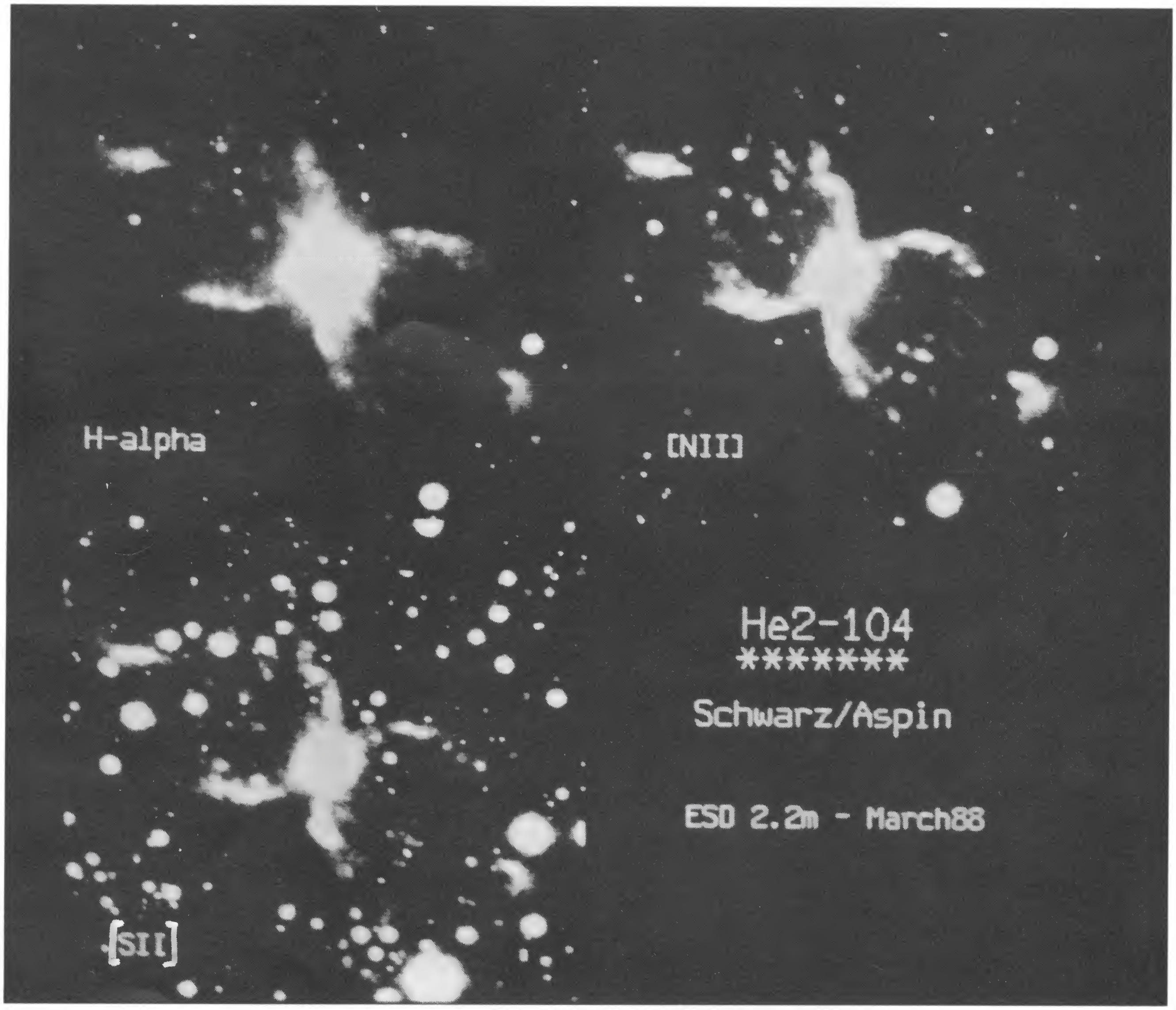

FIG. 1.—Images of He 2–104 in Hα 6563 Å, [N II] 6584 Å, and [S II] 6731 Å. For details of the filters and exposure times used, see text. North is up, east is to the left, and the images are about 90″ × 90″.

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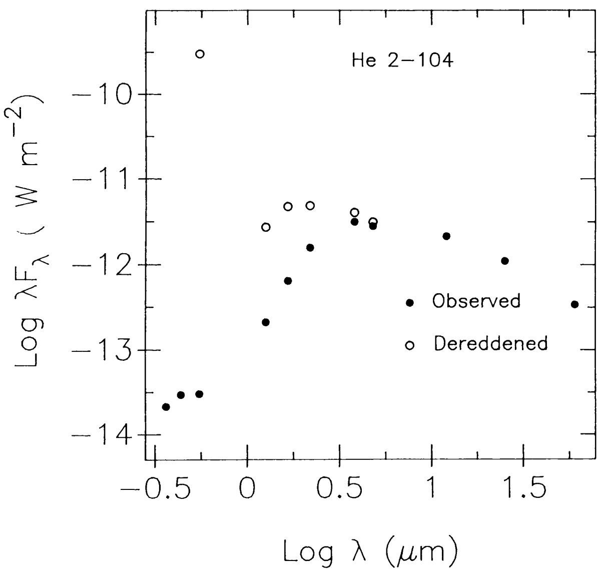

FIG. 2.—The energy distribution of He 2–104 from 0.36 to 60 μm. The filled circles are the observed distribution, and the open circles show the distribution after dereddening with $A_K = 1.7$ mag (see text) and using the extinction law of Savage and Mathis (1979).

sequence secondary produces an accretion disk. Due to heavy mass loss from the primary star, this becomes an excretion disk surrounding the complete system and producing an equatorial torus of dust. The primary starts blowing a fast wind which can escape freely only in the polar directions because of the equatorial dust torus. Shocks are formed where this fast wind overtakes the old spherically symmetrical wind from the red giant. Due to limb brightening, we see the "sides" of the optically thin bubbles in the light of the emission lines. That the light is indeed due to emission lines is supported by the fact that in Gunn z and continuum (near [S II] 6730 Å) images the extended structure does not show up, indicating the lack of reflected light. This is also borne out by polarization measurements made by us, which show that He 2–104 is not significantly polarized. The presence of reflected or scattered light would produce strong polarization.

Then the hot component surrounded by the thick accretion disk produces a highly collimated jet which pierces the bubbles and produces the two outer blobs. If this is the case the outer blobs should have high velocities in directions away from the central object. We have determined the velocities of these blobs from our long slit spectroscopy to be: north blob, -36 km s^{-1} $\pm$ 18 km s^{-1}, south blob -235 km s^{-1} $\pm$ 15 km s^{-1}, and the central object -139 km s^{-1} $\pm$ 12 km s^{-1}. These are the projected space velocities and from the lack of overlap between the bubbles the minimum projection factor can be found to be about 2. The lower limit on the space velocity of the blobs is therefore about ± 200 km s^{-1}. These velocities are typical of moving shocks and support the idea of jets producing the blobs at the extreme end of the bubbles.

III. DISTANCE TO He 2–104

Distance determinations to planetary nebulae form an important but controversial field of investigation. See, for example, Gathier (1984) and Lutz (1989) for reviews of the different methods and results. In the case of He 2–104, there have been several attempts at determining its distance: Wright and Allen (1978) give 7.92 kpc, Maciel (1984) gives an upper limit of 6.3 kpc, and Gutiérrez-Moreno, Moreno, and Cortés (1987) calculate 6.32 kpc using the Cudworth (1974) scale. Since these methods use the published optical extent of 2''.5, we claim that the found distances are severe overestimates. Here we use several different methods to obtain the distance, some based on the true extent of 75''.

Bolometric magnitude.—Whitelock (1988) found a 400^{d} period for the object using IR photometry. This is typical for Mira variables of type M5–M6, which have bolometric magnitudes between -3 and -5. From the observed energy distribution of He 2–104 (Fig. 2), we derive a bolometric luminosity $L = 4.2 \times 10^{-3} d^2 L_\odot$, where d is the distance in pc. Taking $M_{\mathrm{bol}\odot} = 4.8$ (Allen 1973) we obtain $560 \le d \le 1400$ pc.

Extinction.—Using the Burstein and Heiles (1982) data on $E(B-V)$ and assuming $R = 3.1$ and an absorption $A_V = 1.9$ mag kpc^{-1} (Allen 1973), we get for $E(B-V) = 0.35$ in the direction of He 2–104, a distance of 600 pc.

Ejected mass.—Assuming a mass for the ejected material equal to the median mass of planetary nebulae ejecta of 0.12 $M_\odot$ (Gathier 1984) and using number densities, n, in the range $10^3 \le n \le 10^4$ cm^{-3}, we arrive at a distance between 400 and 900 pc.

Balmer line flux reddening.—The measured flux reddening for the Balmer lines (Hβ, Hγ, and Hδ) gives a best value of $A_V \approx 1.8$ mag. Since some of the reddening is likely to be intrinsic to the system, this yields an upper limit to the distance of 950 pc.

Galactic latitude.—Finally, since the galactic latitude of He 2–104 is 9° and taking the scale height of PN as 120 pc (Aller 1984), the distance to He 2–104 is expected to be on the order of 750 pc.

For want of something better we take the unweighted mean of these numbers and come up with a distance of 794 pc with a standard deviation of the mean of 305 pc. We therefore adopt a distance to He 2–104 of 800 pc, a factor of 10 smaller than that published 10 yr ago.

Using the distance of $\approx$800 pc and the likely lower limit to the space velocity of the blobs of ± 200 km s^{-1}, we derive an upper limit of $\approx$800 yr for the dynamical age of He 2–104. The PN-like appearance of the object suggests that it is at the final stage of its transition phase. This is compatible with a typical lifetime of this phase on the order of 1000 yr or a few percent of the lifetime of a typical PN.

IV. CONCLUSIONS

From our observations, we conclude that He 2–104 is a well-evolved PPN which is actively producing bubbles and jets made visible by shocking the ambient environment, probably the old red giant wind. The lack of extended structure in Gunn z and continuum images, and of significant polarization, is interpreted as being due to the absence of reflected light.

We determine the distance to He 2–104 to be $\approx$800 pc, a value which is nearly an order of magnitude smaller than previously published.

By dereddening the energy distribution we show that there might be a strong hot component present, indicating the symbiotic nature of He 2–104. Since there is no stellar continuum observed, except in the IR, this last conclusion has to be taken with caution.

Further work on this object will include IR imaging to study the dust distribution, and a more detailed kinematical investigation, and using old plate material, an attempt will be made to determine the proper motion of the blobs over a long time base.

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