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HIGH-RESOLUTION SPECTROSCOPY OF V1853 CYGNI (LS II+34°26): BIRTH OF A PLANETARY NEBULA?

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ABSTRACT

High-resolution optical spectra are discussed for the high-latitude B-supergiant V1853 Cyg (LS II +34°26), which has been identified recently as a hot post-AGB star with far-infrared *IRAS* colors similar to those of dusty planetary nebulae. Spectra obtained on eight nights between 1993 August and November reveal strong emission lines of Hα, β, and γ, as well as a variety of profiles (absorption, emission, P Cygni) for the He I lines. A photospheric spectrum of absorption lines, fairly typical of B1-2 supergiants, is present, but the lines are asymmetric and their shapes and equivalent widths vary significantly on a night-to-night basis. The velocity of the absorption lines varies by ~40 km s^{-1}. Emission lines from permitted (C II, N II, Si II, and Fe III) and forbidden ([N II], [O I], [S II], and [Fe II]) transitions are visible at a constant radial velocity over the observing interval. This object may be in the process of becoming a planetary nebula.

Subject headings: ISM: planetary nebulae: general — stars: AGB and post-AGB — stars: individual (V1853 Cygni)

1. INTRODUCTION

Main-sequence stars of masses 0.8 to 8 $M_\odot$ evolved to become red giants with carbon-oxygen electron-degenerate cores and extensive hydrogen-rich envelopes. Such red giants with effective temperatures of ~3000 K are known as asymptotic giant branch (AGB) stars. Evolution of an AGB star ends with severe mass loss such that the stellar remnant evolves rapidly at approximately constant luminosity to an effective temperature of ~100,000 K before rapid cooling at approximately constant radius ensues. The time taken to evolve from a 3000 K AGB star to a 100,000 K compact remnant sustaining a planetary nebula is dependent on the mass of the remnant (M_r) but always very short: e.g., 300 yr for $M_r = 0.84\ M_\odot$, 3000 yr for $M_r = 0.63\ M_\odot$, and 30,000 yr for $M_r = 0.55\ M_\odot$ (Schönberner 1983, 1993). Since the average mass of field white dwarfs (cooled remnants) is ~0.6 $M_\odot$, one expects the progenitors of these stars to evolve from a cool AGB star through the post-AGB star phase to a fully fledged planetary nebula in a few thousand years and the transformation of the ejected material from a dusty cool gas to a hot ionized gas to occur in an even shorter time. Then, there is the possibility that a hot post-AGB star, say a B-type star, may be caught giving birth to a planetary nebula. Indeed, two examples have been suggested recently: SAO 244567 (Parthasarathy et al. 1993) and LS IV −12°111 (Conlon et al. 1993). In this *Letter*, we discuss a third candidate.

The candidate is the B-type supergiant LS II +34°26 (Stock, Nassau, & Stephenson 1960) with the variable star designation V1853 Cyg (see Inf. Bull. Var. Stars, No. 3058). Turner & Drilling (1984) identified the star as a young, massive B supergiant located nearly 2 kpc out of the Galactic plane, assigned it the spectral classification B1.5 Ia-Iabe, and showed it to undergo light variations of ~0.1–0.2 in *U*, *B*, and *V* with a timescale of a few days. The designation "e" was assigned because weak emission was seen at Hβ. Parthasarathy (1993), who identified V1853 Cyg with an *IRAS* source having the *IRAS* colors of a planetary nebula concluded that V1853 Cyg is a low-mass post-AGB star with a cold circumstellar dust shell and not a high-mass young star. On the basis of this identification, V1853 Cyg joins the small but rapidly growing class of hot post-AGB stars (see Conlon et al. 1991; McCausland et al. 1992; Conlon, Theissen, & Moehler 1993). On learning of Parthasarathy's identification, we began to monitor the optical spectrum of V1853 Cyg at high resolution. Here, we present an initial report to show that the spectrum is not simply that of a B1.5 Ia-Iabe star but now includes features, perhaps, indicative of incipient formation of a planetary nebula.

2. OBSERVATIONS

Spectra of V1853 Cyg were obtained with the McDonald Observatory's Sandiford cross-dispersed echelle spectrometer at the Cassegrain focus of the 2.1 m Struve reflector. The Sandiford spectrometer (McCarthy et al. 1993) uses a Reticon CCD of 1200 × 400 27 μm pixels. The 2 pixel resolution is 60,000. Eight observations, spanning 1993 August to November, have been obtained (see Table 1). The two-dimensional raw frames were reduced to single-order one-dimensional spectra using IRAF v2.10 and the 1 hr integrations yielded final signal-to-noise ratios of 40–130. A Th-Ar hollow cathode lamp provided a wavelength calibration accurate to ~0.005–0.03 Å. As an example of the spectra, we show in Figure 1 the spectrum from 6660–6735 Å which illustrates that the spectrum is not simply that of a B supergiant. The O II 6721.4 Å asymmetric line is presumably a photospheric absorption line. The He I 6678.2 Å line has a P Cygni profile. The [S II] lines at 6716.4 and 6730.8 Å must arise from a nebula.

3. THE SPECTRUM

Inspection of our spectra shows that the lines may be put into several categories: (1) photospheric absorption lines, (2) permitted and forbidden emission lines, and (3) the H I and He I lines. We next discuss these three categories. (Interstellar features include NaD lines and diffuse interstellar bands.)

3.1. *Photospheric Absorption Lines*

The absorption-line spectrum in the regions observed is dominated by lines of C II, N II, O II, Mg II, and Si III. Lines of

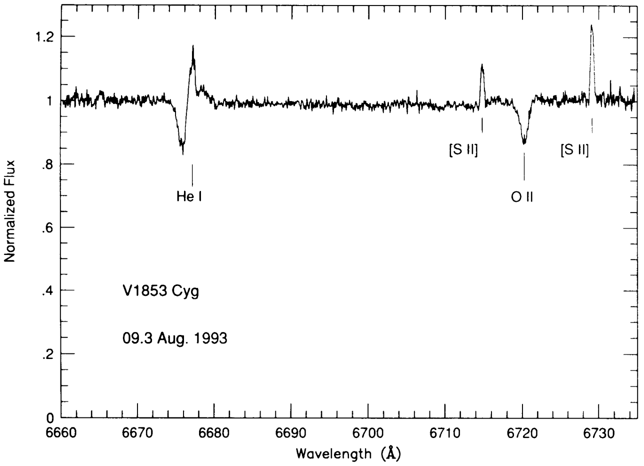

FIG. 1.—Sample spectral region in V1853 Cyg comprising one order of the echelle spectrometer. This particular order was chosen to illustrate some of the variety in the spectrum: the O II line is presumably photospheric in origin (but asymmetric), while the He I line shows a P Cygni profile with some underlying structure, and the two narrow emission lines are the well-known forbidden [S II] doublet.

Fe III multiplet 4 are present but contaminated by weak emission. Turner & Drilling (1984) assigned the star a spectral type near B2 Ia-Iab. Our examination of spectra of standard supergiants from B0 to B3 confirms Turner & Drilling's assignment but we note some anomalies in addition to the obvious presence of many emission lines. For example, the O II, Mg II, and Si III lines in V1853 Cyg (relative to standard B0 to B3 supergiants) appear strengthened with respect to the C II and N II lines.

The line profiles and equivalent widths of the absorption lines can vary significantly over one day timescales; we note that Turner & Drilling (1984) found a quasi-period of ~4 days from photometry. Variable asymmetry in the absorption lines makes it difficult to measure accurate radial velocities; we refer the radial velocity to the deepest part of line profiles and present these velocities in Table 1. The velocities are shown in Figure 2, as a function of the Julian Date: the horizontal dashed line is the average (constant) velocity of the emission lines. The absorption lines show large and rapid velocity changes and it is not yet known whether these changes result from orbital motion or, perhaps, mass-loss episodes. Turner & Drilling (1984) reported a radial velocity (from absorption lines) of -88 km s^{-1} near the lower limit of the photospheric velocities reported here.

TABLE 1

OBSERVATIONS OF V1853 CYGNI

Date (1993)	Wavelength Coverage (Å)	Absorption-Line Velocity (km s^{-1})	Emission-Line Velocity (km s^{-1})
Aug 9.3	5760–7240	-45.6 ± 4.1	-67.5 ± 4.4
Sep 3.2	4330–4870	-66.5 ± 5.3	-64.7 ± 3.3
Sep 4.1	4160–4660	-44.4 ± 3.8	-69.2 ± 2.8
Sep 7.1	4480–5090	-52.7 ± 4.4	-72.1 ± 3.0
Oct 8.1	5810–7280	-47.9 ± 4.7	-69.0 ± 2.8
Oct 11.1	4310–4810	-76.9 ± 4.6	-69.8 ± 2.9
Nov 1.1	4130–4560	-53.1 ± 3.5	-69.9 ± 3.1
Nov 6.1	5990–7520	-72.8 ± 9.2	-67.8 ± 1.8
Nov 8.1	5060–5960	-68.8 ± 5.8	-65.5 ± 2.5

3.2. *Permitted and Forbidden Emission Lines*

Numerous permitted lines of C II, N II, Na I (the D-lines), Si II, and Fe III are observed in emission. The forbidden lines in emission [N II] (6583.6 and 6548.1 Å), [O I] (6300.2 Å), [S II] (6716.4 and 6730.8 Å), and several [Fe II] multiplets (4.7, and 20). Average velocities from the permitted and forbidden lines (Table 1) are equal. This velocity is also constant over the 3 months spanned by these observations and appears immune to the processes causing the variable photospheric velocity. The only obvious difference between the two groups of lines is that the forbidden lines are narrower (FWHM = 20 km s^{-1}) than the permitted lines (FWHM = 40–50 km s^{-1}).

The [N II], [O I], [S II], and [Fe II] lines are lines emitted by low-excitation planetary nebulae. A search for the [O III] lines at 4363, 4959, and 5007 Å was unsuccessful; the lines, if present, do not have peak fluxes more than 1% of the local continuum. The flux ratio of the [S II] lines is $F(6716)/F(6731) = 0.52$, which is close to the limit of 0.45 (Osterbrock 1989) predicted for high electron density.

3.3. *The* H I *and* He I *Lines*

The three observed Balmer lines show strong emission cores (Fig. 3). Turner & Drilling (1984) refer to "weak emission visible at Hβ, as well as an obvious weakening of Hγ and Hδ." Profiles shown in Figure 3 show the emission is not "weak." The equivalent width of the emission core is ~10.7, 2.5, and 0.8 Å for Hα, β, and γ, respectively. The width of the Balmer emission (FWHM = 60 km s^{-1}) is slightly larger than the widths of the other emission lines, as expected from the larger thermal

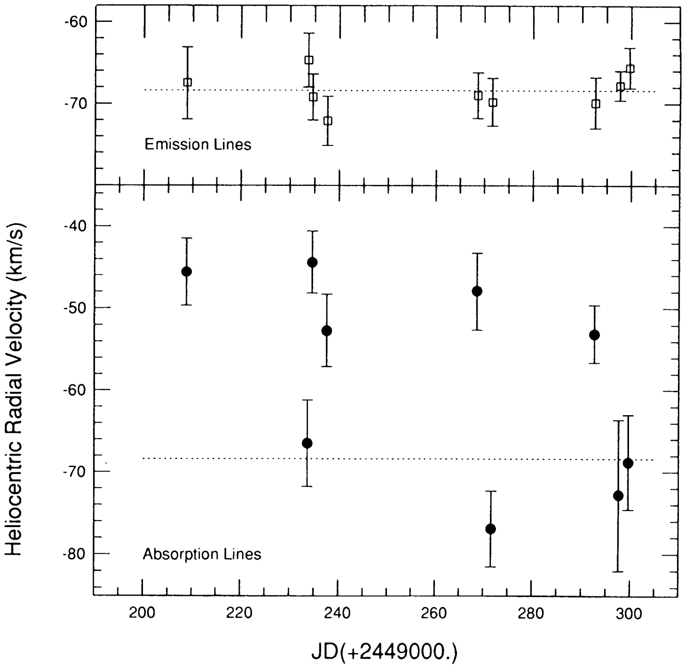

FIG. 2.—Measured radial velocities for the two groups of lines in V1853 Cyg, excluding the H I and He I lines. Photospheric absorption lines have been measured and averaged for each date to comprise the bottom panel, while the permitted and forbidden emission lines have been measured and averaged for the top panel. The horizontal dashed line in each panel represents the average for all the dates of the emission line velocities. The error bars represent standard deviations of the mean and the emission lines appear to represent a region of constant velocity (over the 3 months of observations), while the absorption (photospheric) lines vary by almost 40 km s^{-1} over these dates.

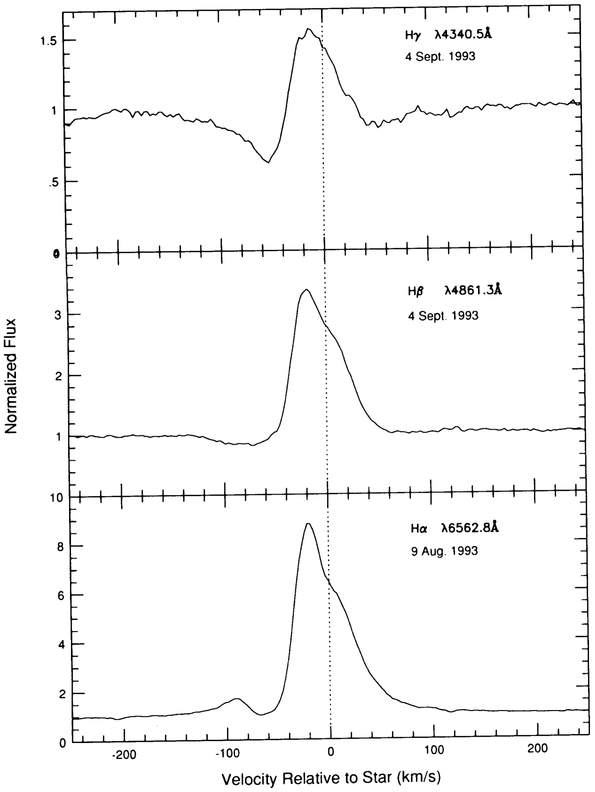

FIG. 3.—Sample spectra showing typical profiles of the H I features: the spectra are plotted in velocity-space, with zero velocity taken as that given by the absorption lines for that date. Note from Figure 2 that on the dates represented here, the photospheric velocity was ~20–25 km s^{-1} redshifted relative to the emission lines, and this is reflected in the velocities of the peak emission in the H I lines.

broadening of H atoms with possibly an additional augmentation because the emitting region may be slightly optically thick.

The observed He I lines (Fig. 4) originate from a lower level of $2p\,^1P$ or ^3P. Of the four triplet lines, the two with the strongest emission cores are 5876 Å ($2\,^3P$–$3\,^3D$) and 7065 Å ($2\,^3P$–$3\,^3S$). Comparison of 4471 and 4713 Å suggests that the core of the former is filled in with emission. Since the gf-value of the 4471 Å line is an order of magnitude larger than that of the 4713 Å line, the relative depths of the two "components" to these He I lines are not easily reconciled unless emission fills in the 4471 Å line. Among the six singlet lines, those with an upper level from the $n = 3$ suite show emission which is possibly part of a P Cygni profile. Weak emission is present in the 4921 Å line ($2\,^1P$–$4\,^1D$) but not in the much weaker lines at 5047 Å ($2\,^1P$–$4\,^1S$) and 4437 Å ($2\,^1P$–$5\,^1S$). It is clear that the emission intensity is determined more by the principal quantum number of the upper level than by the gf-value of the line and that emission is more pronounced in the triplets than equivalent singlets. Emission is strong when $n = 3$ is the upper level and strongest for the $n = 3$ triplets. These clues indicate that the source of the emission is an overpopulation of the $n = 2$ levels arising from the metastability of the $2\,^3S$ level.

Estimates of the emitted fluxes in the He I lines may be made from our spectra assuming that the stellar flux is approximately that of a reddened B1 or B2 supergiant: Turner & Drilling (1984) estimate $E(B-V) = 0.38$. For the 5875, 6678, and 7065 Å lines all observed on 1993 August 9, we estimate the flux ratios to be $R_1 = F(6678)/F5875) = 0.3$ and $R_2 = F(7065)/F5875) = 0.9$. The ratio R_1 agrees well with that predicted for recombination over a wide range of densities and temperatures in case B (Osterbrock 1989), but R_2 is much larger than the case B predictions which range from 0.1 to 0.2.

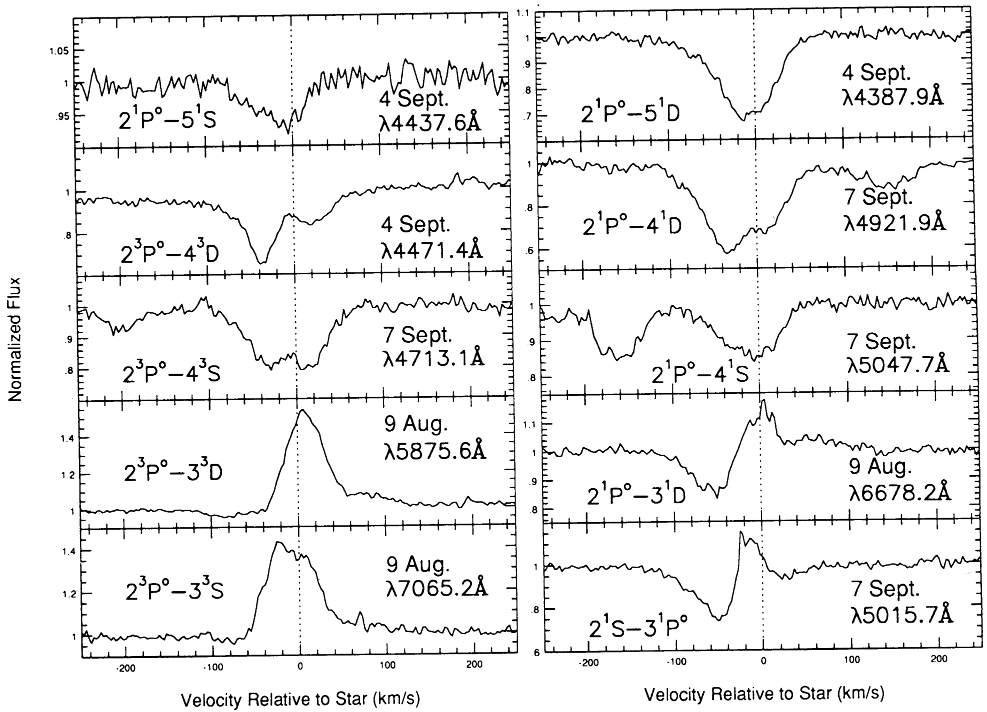

FIG. 4.—Sample line profiles of the He I lines illustrating the great variety of lines observed in these transitions (all He I lines included in our wavelength coverage and detected are shown here). As in Fig. 3, these spectra are plotted in velocity space, with zero velocity given by the average of the absorption lines for that date and, for the dates included here, this will be from 15 to 25 km s^{-1} redshifted relative to the emission lines.

In light of the deduction that the metastable level $2\,{}^3S$ influences the emission fluxes, the optical depth of the emitting gas to transitions from this metastable level is likely to influence the flux ratios. Almog & Netzer (1989) computed the He I line fluxes for a large model atom under conditions of high optical depth in the 3889 Å line and high electron density; the optical depth of the 3889 Å ($2\,{}^3S$–$3\,{}^3P$) line is a convenient way to characterize the column density of He I atoms in the $2\,{}^3S$ metastable level. Inspection of Almog & Netzer's results show that the required optical depth in the 3889 Å is a decreasing function of electron density: $\tau \gtrsim 70$ for $\mathrm{Ne} = 10^6$ to $\tau \gtrsim 10$ for $\mathrm{Ne} = 10^{12}\ \mathrm{cm}^{-3}$. The ratio R_1 remains close to 0.2–0.3 for all the conditions required to fit the ratio R_2.

4. CONCLUDING REMARKS

There is no doubt that the 1993 spectra of V1853 Cyg show clear differences with spectra obtained more than a decade ago. The photospheric radial velocity varies on short (<1 day) timescales, but it is not yet known whether this is due to orbital motion or some type of photospheric disturbance, such as mass loss. The Balmer emission cores in 1993 are obviously much more intense than they were on spectrograms acquired by Turner & Drilling (1984) in 1977 and 1981. Case Schmidt plates also show no evidence of strong Balmer line emission (W. P. Bidelman, private communication). Earlier spectra were probably of too low a quality to detect the forbidden and permitted (excluding the Balmer lines) emission lines reported here.

We suppose the star's variable velocity is due to pulsation, mass-loss episodes (perhaps related to pulsation), or to orbital motion around a companion. If pulsation, the amplitude must be $\sim 20\ \mathrm{km\ s^{-1}}$ and the period might be a few days (say 4 days; Turner & Drilling 1984). If the star is a spectroscopic binary, we might assume that the systemic velocity is near the emission line velocity of about $-70\ \mathrm{km\ s^{-1}}$. Our observations allow a period near 25 days for an eccentric orbit. One can construct a physically plausible system of detached stars with $P \sim 25$ days but, in earlier times when V1853 Cyg was a cool extended AGB star, the stars would have formed a common envelope system. The gas emitting the forbidden lines is presumably exterior to the binary's orbit. The line width of the forbidden lines suggests an expansion velocity of $\sim 10\ \mathrm{km\ s^{-1}}$ if the front and rear of the expanding shell contribute about equally to the observed profile. This velocity is typical of mass-losing AGB stars, so that the emitting gas may be part of the mass shed by the former AGB star but ionized by the B star or by a faster moving wind colliding with the old shell of gas. Dust in the mass shed by the AGB star is presumed to give the large infrared excess noted by Parthasarathy (1993).

Clearly, if V1853 Cyg is a post-AGB star its conversion to a planetary nebula is imminent. Although the differences between the 1993 spectra and earlier reports do suggest that V1853 Cyg may now be a low-excitation planetary nebula with a central star at the top of its cooling track, additional observations are sorely needed in order to show that the changes in spectrum are not reversed and are not, for example, correlated with phase in an orbit about a companion.

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