

MULTI-WAVELENGTH OBSERVATIONS OF THE PECULIAR RED GIANT HR 3126

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ABSTRACT

New ultraviolet observations of the red giant HR 3126 are reported and combined with multi-wavelength data in order to provide a firmer basis for explaining the unique, arc-minute sized nebula surrounding the object.

Keywords: ultraviolet spectrum; peculiar red giant; stellar evolution; symbiotic stars; hybrid stars.

on extinction are too large. Their estimate of the nebular mass based on the surface brightness, assuming graphite as the dust material, is $\sim 0.01 M_{\odot}$, which could be produced in the current mass loss phase of HR 3126.

A light curve between 1963-1977 has been constructed for HR 3126 by Dachs *et al* (1978), who concluded that the star is an irregular variable (V ranges from 6.2 to 7.1), possibly due to variations in the circumstellar extinction, which may occasionally amount to 0^m.10 per day. This behavior is similar to the M0 Iab supergiant CPD-57° 3507 in NGC 3293 or to the M2e Ia supergiant, μ Cep. The light curve of HR 3126 has remained quasi-constant during the 1980's, near V = 6.5 (Dachs 1986, private communication).

1. INTRODUCTION

The M2 II star HR 3126 (HD 65750, V341 Car, SAO 235638, CPD-57° 1028) is remarkable because it sits near the center of a butterfly-shaped nebula of several arc minutes extent (Dachs *et al* 1978) (Figure 1). While other red objects are known to have nebulae (e.g. OH0739-14, Cohen *et al.* 1985), most are much smaller and often explained in terms of binary star ejection mechanisms. If HR 3126 is a member of the nearby open cluster NGC 2516, the distance (375 pc), main sequence turnoff age ($\sim 10^8$ years) and implied mass ($\sim 5M_{\odot}$) suggest that HR 3126 is a red bright giant past the initiation of helium burning in its core and on the Asymptotic Giant Branch (AGB). Observations of circumstellar lines in the optical spectrum of HR 3126 indicate a mass ejection rate of $2-4 \times 10^{-7} M_{\odot} \text{ yr}^{-1}$ and a wind velocity of 13 km s^{-1} (Reimers 1977).

The reflection nebula, IC 2220, associated with HR 3126, has a mass estimated to be $0.7M_{\odot}$ from the mean reddening of the starlight produced in the nebula. Perkins *et al* (1981) proposed the existence of a circumstellar disk, implying that previous mass estimates (of the nebula) based

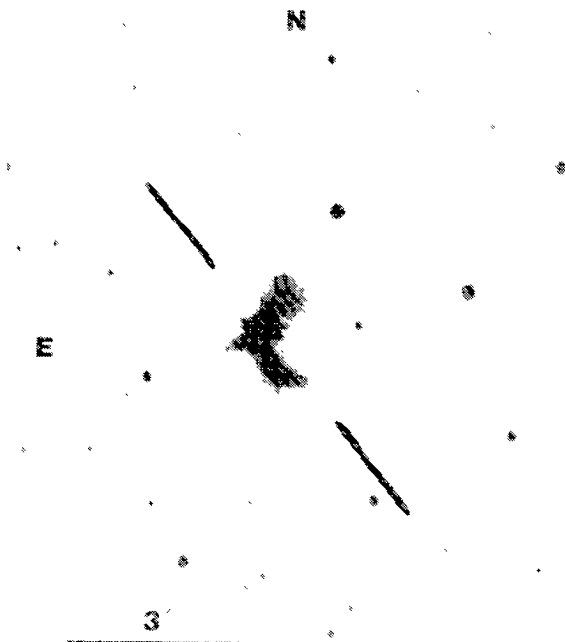


Figure 1. Photograph, of HR 3126 and surrounding nebula, IC 2220, in the V (yellow) spectral region. From a CTIO Schmidt plate of Dachs.

The essentially constant brightness of IC 2220 does not follow the brightness variations of its central star, neither immediately nor with some fixed delay. The B-V and U-B colors of the nebula are bluer than those of HR 3126, as is expected from a pure reflection nebula. Dachs and colleagues have suggested that the nebula appears to be structured by a magnetic field. A spectrum between 5865 and 6745 Å of the brightest knot of IC 2220, about 40" south of the star, was obtained by R. Mundt at ESO on 1987 February 25. The spectrum of the nebula resembles that of the star showing Na-D and H α absorption as well as the TiO band at 6159 Å.

From Dachs (1973) the color differences between nebula and star are,

$$(B-V) = -0^m.23 \pm 0^m.03$$

$$(U-B) = -0^m.98 \pm 0^m.11$$

and their ratio,

$$y = 4.3 \pm 0.8$$

are much larger than the nebulosity around the Pleiades. This difference may be due to the fact that a larger fraction of radiation at shorter wavelengths may be scattered by reflection nebulae around M-type stars than around B-type stars, or IC 2220 may not be a pure reflection nebula. Perkins *et al* (1981) state that the degree of polarization is typical of reflection nebulae, indicating that the dust grains reflecting the central starlight are not unusual. Excitation of the gas of the nebula by an unknown, faint, blue companion of HR 3126 may contribute to the ultraviolet radiation of the nebula.

Only a few reflection nebulae connected with red giants are known. Late-type giants are known to lose mass and develop dusty shells which are quite close to the star (arc-sec rather than arc-min scales). HR 3126 and IC 2220 offer a unique and interesting environment in which to observe these processes under extreme conditions.

We have obtained IUE and other wavelength data to test the hypothesis that the nebula surrounding HR 3126 is a fossil of a rapid mass loss epoch during hydrogen shell burning, several million years ago.

2. OBSERVATIONS

Ultraviolet observations were obtained 1987 Sept. 28 by Stencel and Pesce [IUE program MLJRS]: SWP 31915 (30 minute exposure) and LWP 11744 (159 minute exposure). We infer from the lack of signal in the SWP exposure that the central object is not an interacting binary, such as a symbiotic star (*cf.* Nussbaumer and Stencel 1988), because the exposure time was more than adequate to reveal bright emission lines in most of the known members of this class of active binary stars. In the LWP image, only Mg II emission and a photospheric continuum longward of about

2700 Å were detected. The Mg II emission appears normal for the spectral type, suggesting a chromosphere is present (see Figure 2).

Doggett obtained visual (3800-5200 Å region) spectra of HR 3126 on 1987 September 25th and 26th at CTIO. They appear to be typical red giant spectra with the Ca II H and K features, and TiO bands at 4461, 4954 and 5000 Å. The Ba II feature at 4554 Å is present and is possibly enhanced compared to other M giants (see Figure 3). In addition, a 5640-7040 Å region spectrum was obtained by Walter at Cerro Tololo (1987 April 4). The spectrum is normal except for an overly strong Li I line at 6707 Å. Abnormally high lithium abundances have been seen in weak G band and S-type stars (Hartoog 1978, Boesgaard 1970). According to Pilachowski *et al* (1984), a normal K giant [HD 112127] and similar stars show high lithium abundance with otherwise normal spectra. High lithium abundances in evolved stars have been taken as evidence that the stars have undergone helium shell flashes and are second ascent giants. However, strong lithium lines were observed by Pilachowski *et al* in several giants in the old galactic cluster, NGC 7789, indicating an abnormally high lithium abundance on the red giant branch (RGB). These observations remove the constraint that the weak G band stars and the HD112127 stars must be ascending the AGB. In addition, Pilachowski *et al* conclude that lithium abundance declines with temperature on the upper RGB.

In the infrared region, Ten JHKL observations obtained between 1975 and 1982, at the South African Astronomical Observatory, indicate that HR 3126 is a low amplitude variable with $\Delta J \sim 0.2$ mag. Whitelock observed HR 3126 on 1987 September 15/16 and comparison of (J-H), (H-K) and (K-L) colors with a standard star show longwave excesses. She further reports that, although the colors could be those of a Mira variable, the lack of large amplitude variability and the IR spectrum clearly indicate this is not the case. A low resolution ($\Delta\lambda/\lambda \sim 0.01$) spectrum from 1.2 - 4.0 μ m obtained in December 1981 at South Africa is typical of an M giant, the CO strength indicates a type of M3 and there is no sign of Mira-like H₂O absorption.

Finally, IRAS observed this object as well, detecting it in all four bands, 12 to 100 μ m and with the Low Resolution Spectrograph (LRS). The infrared colors suggest a far infrared excess remains after a 3250K blackbody is subtracted. Further analysis suggest the source was spatially resolved by the IRAS detectors at all frequencies. In addition, in the LRS spectrum, there is no evidence of the 9.7 μ m feature associated with silicate dust or the 10.3 μ m feature associated with dust composed of SiC. However, spectra obtained by Humphries and Ney (1974) with the 40-inch reflector at Las Campanas Observatory on a system described by Ney and Stein (1968) show the 9.7 and 18 μ m features associated with silicate grains. Their beam size is 15", and the spectrum they obtain is probably not contaminated by light from the nebula. Surprisingly, Thomas *et al* (1976), in observations obtained with the IR photometer attached to the 1.25m telescope at Mt. Stromlo and Siding Springs Observatory, find an infrared excess in the 8- to

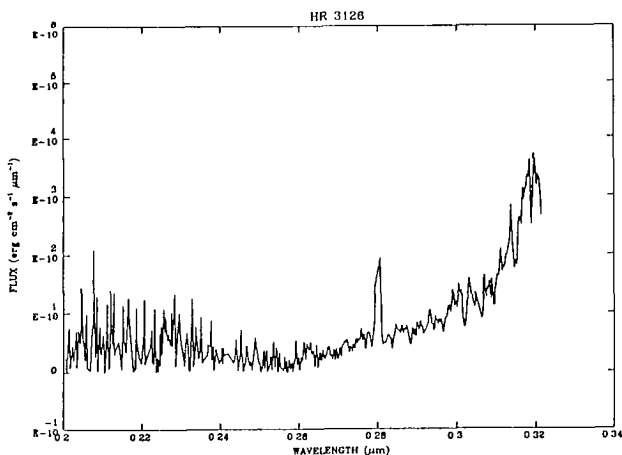


Figure 2 Ultraviolet spectrum of HR 3126 (LWP 11744). Note the presence of the Mg II emission feature and the lack of other high temperature emission lines, which might indicate a hot companion star/ionized nebula.

14- μm region, associated with carbon-rich material. However, it is unclear what their beam size was and, therefore, whether their spectra were contaminated by IC 2220. LRS has a large aperture and probably observed the entire region of HR 3126, including IC 2220. Separate observations of HR 3126 and IC 2220 need to be made in order to clarify the existing, contradictory, data.

Figure 4 is a multi-wavelength plot of HR 3126, combining all of the observations. In the Infrared, the points that do not fit on the curve are the LRS data. There appears either to be some calibration error, or a broad emission feature is present in the short wave infrared. Re-observation seems necessary.

The IRAS 60 μm addscan profile (Figure 5) shows the expected source extension. The full width at 10% maximum corresponds to a shell dimension of 4.12 arc-minutes, compared to 2.49 arc-minutes for the point source, Ceres (see Stencel *et al* 1988 for a thorough discussion of Red Giant/Supergiant infrared source extensions). At 375 pc, this corresponds to a shell of 0.45 pc diameter, or twice the diameter of the optical shell. Assuming the current expansion velocity, the age of the shell is approximately 3.2×10^4 years.

3. CONCLUSION

Several possibilities exist as to the location of HR 3126 on the H-R diagram and to the formation mechanisms of IC 2220:

- HR 3126 is a red giant branch star, having ejected part of its envelope upon initiation of the first dredge-up (at the base of the RGB) 32 000 years ago. This scenario is consistent with the enhanced lithium abundance observed. However, the problem that remains is the mechanism for ejection: it is not clear that the first dredge-up could power ejection of such a large nebula.

- HR 3126 passed through a red giant phase and is now evolving blueward from the top of the RGB. Comparatively high mass loss and dust production during the previous epoch and the continued expansion of that dust shell is the present day IC 2220 nebula. The problem with this alternative is the lithium, which should have been depleted (according to Pilachowski *et al* 1984) as the star neared helium-core ignition (and beyond). The ejection mechanism could be provided by the commencement of core helium fusion, either blowing-off a large amount of material or leading to a mass loss rate approximately two orders of magnitude greater than observed today.

- HR 3126 is at the top of the AGB, perhaps at the beginning of the planetary nebula ejection phase. In this scenario, IC 2220 can easily be explained by the period of thermal pulses that AGB stars experience. Since the star

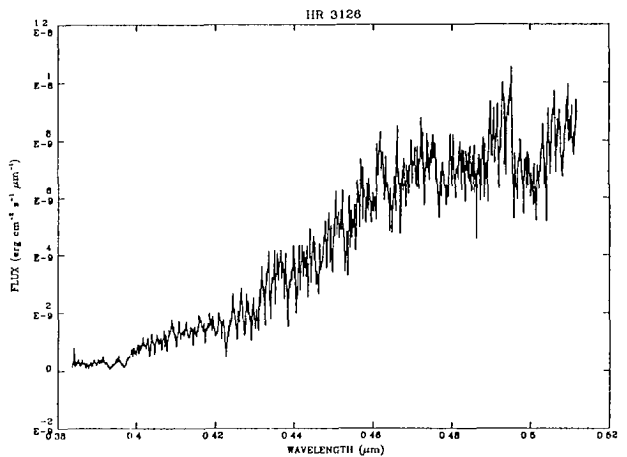


Figure 3 Portion of the blue visual spectrum of HR 3126 obtained by Doggett. Note the Ba II feature at 4554 Å

possesses no Mira-like qualities it probably is not in the midst of the AGB, but given the uncertainties in mass and M_{bol} ($\langle M_{bol} \rangle = -4^m.4$ (Reimers, 1977)), HR 3126 could easily be at the base of the AGB or at the top. However, we again run into the problem of non-depleted lithium abundances.

In a recent paper by Whitlock and Catchpole (1985), the three super-lithium-rich stars observed are Mira variables, or AGB stars. Contrary to the Pilachowski *et al* (1984) analysis, these observations support our hypothesis that HR 3126 is somewhere on the AGB. It should be stressed that the effects of stellar evolution on lithium abundances do not appear to be understood, but they are probably an important clue to the evolutionary stage of a red giant star. Could it be that lithium becomes depleted on the upper RGB but is again enhanced as the star moves up the AGB (due to the second dredge-up and thermal pulses)? Much more work needs to be done to determine lithium's significance and variations with evolution. The multiwavelength data appears to offer the possibility to test atmospheric response to evolutionary changes.

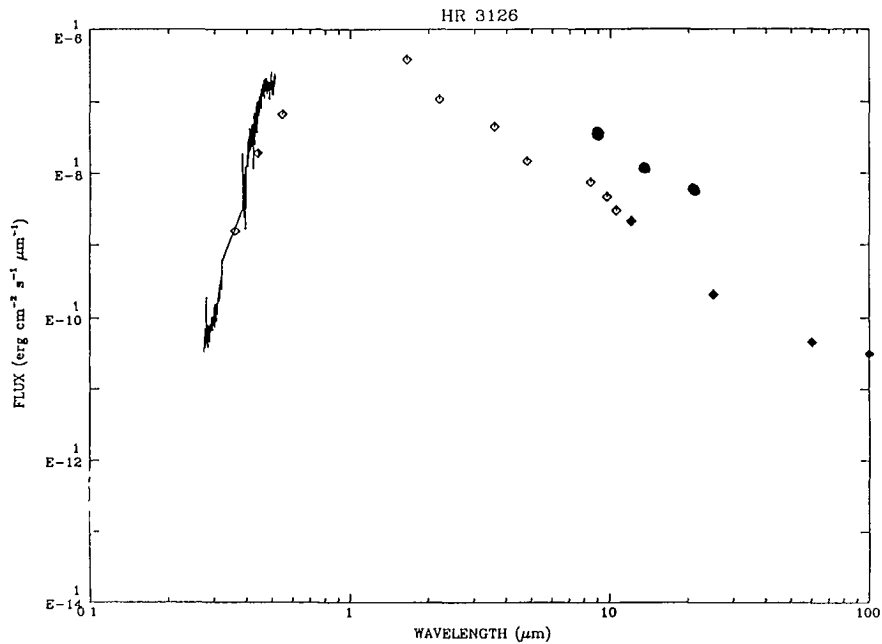


Figure 4: Multiwavelength plot of HR 3126. Filled diamonds are IRAS point source fluxes, open diamonds magnitudes from Gezari *et al* 1987, and filled circles are from the LRS spectrum.

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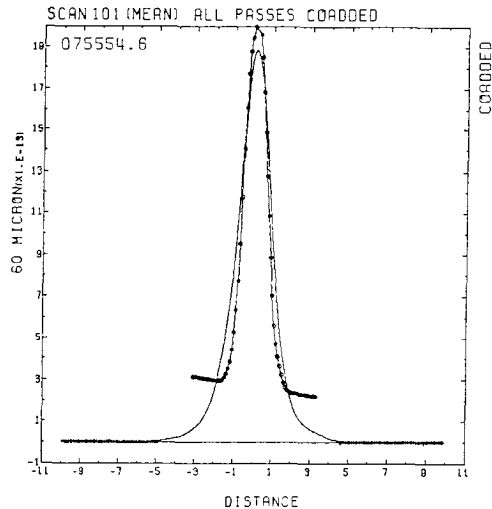


Figure 5: 60 μ m Addscan profile of HR 3126. The aberssa is arc-minutes and the ordinate is $W m^{-2}$

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