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# LS II +34°26 IS A LOW-MASS POST–ASYMPTOTIC GIANT BRANCH B SUPERGIANT AND NOT A MASSIVE POPULATION I B STAR LOCATED NEAR THE OUTER EDGE OF THE GALAXY

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## ABSTRACT

LS II +34°26 is an 11th magnitude low-gravity, high-velocity and high Galactic latitude B1.5 Ia–Iabe supergiant star. It is found to be an *IRAS* source with far IR colors, flux distribution, and dust shell parameters similar to those of planetary nebulae. Based on these observations it is concluded that LS II +34°26 is a low-mass post–asymptotic giant branch (AGB) B1.5 Ia–Iabe supergiant with a detached cold circumstellar dust shell and not a young massive B star of Population I located at 17.8 kpc near the outer edge of the Galaxy. It is the hottest post-AGB supergiant discovered so far. With this detection the sequence of post-AGB supergiants were found to extend from K to B type which indicates the evolution sequence of these objects from the tip of the AGB toward the left in the H-R diagram. LS II +34°26 may be rapidly evolving toward hotter spectral type and into the region of planetary nebulae.

These results demonstrate that some of the high-Galactic latitude and/or high-velocity, low-gravity, OB stars are not massive Population I stars; instead they are low-mass post-AGB stars. These stars may hence be closer than presumed and may not be suitable for the study of Galactic rotation law at large galactocentric distances.

*Subject headings:* stars: AGB and post-AGB — stars: circumstellar matter — stars: early-type — stars: individual (LS II +34°26) — stars: mass loss

## 1. INTRODUCTION

From the analysis of the *IRAS* Point Source Catalog (version 2, 1988, hereafter the *IRAS* PSC) a new class of stars were detected. These stars have circumstellar dust shells with far-infrared colors and flux distribution similar to the dust shells of planetary nebulae (PNe) and most of them show A, F, G, and K supergiant-like spectra in the optical region (Parthasarathy & Pottasch 1986; Lamers et al. 1986; Pottasch & Parthasarathy 1988). Parthasarathy & Pottasch (1986) interpreted that the dust shells around these stars are the result of severe mass loss during their asymptotic giant branch (AGB) stage of evolution. It is likely that these objects are in a hitherto unseen post-AGB phase of the stellar evolution. Some of these stars are at high Galactic latitudes, have high velocities, and are metal-poor, indicating that they have evolved from low-mass stars and are now in post-AGB stage of evolution, evolving toward the left in the H-R diagram into the region of PNe.

The AGB phase of evolution of low- and intermediate-mass stars is terminated by the ejection of most of the hydrogen-rich outer envelope resulting in a PN (Iben & Renzini 1983). The post-AGB stars detected by *IRAS* data extend from nonvariable OH/IR stars to M, K, G, F, A, supergiant-like stars with circumstellar dust shells. This sequence appears to represent the evolution of the post-AGB stars toward hotter spectral types (Parthasarathy 1989, 1990). A few B-type peculiar emission line stars were also found to show far-infrared (*IRAS*) colors similar to those of known PNe (Parthasarathy & Pottasch 1989) and these are probably evolving rapidly into the early stages of PNe. The duration of the transition phase (from the tip of the AGB to young PN) is relatively short as is evident from the case of SAO 244567 (Parthasarathy et al. 1993).

Similar to the high Galactic latitude and high-velocity A and F supergiants which are now understood to be in the post-AGB stage of evolution (Parthasarathy & Pottasch 1986), there exist high Galactic latitude, high-velocity, and low-gravity O–B stars. A number of studies in recent years (Tobin & Kilkenny 1981; Kilkenny & Lydon 1986; Kilkenny & Pauls 1990; Tobin 1987; Kilkenny 1989; Carrasco et al. 1980) have established the existence of a significant number of O and B stars lying at distances in excess of 1.5 kpc above or below the plane of the Galaxy. Several of these high Galactic latitude, high-velocity, and low-gravity O–B stars are considered as normal massive Population I stars. Turner & Drilling (1984) find LS II +34°26 (Stock, Nassau, & Stephenson 1960) to be one such star. They concluded that LS II +34°26 is a massive B1.5 Ia–Iabe supergiant located at a distance of 17.8 kpc near the outer edge of the galaxy and 1.8 below the Galactic plane. In this *Letter* I report the detection of detached cold circumstellar dust shell around LS II +34°26 with far-IR colors similar to those of planetary nebulae and post-AGB A–F supergiants, and conclude that LS II +34°26 is a low-mass post-AGB B supergiant and not a massive Population I B star located near the outer edge of the galaxy.

## 2. *IRAS* MEASUREMENTS

From a search of the *IRAS* PSC for *IRAS* sources associated with high Galactic latitude and high velocity O–B stars it is found that LS II +34°26 is an *IRAS* source (IRAS 20462 +34°26). The 12, 25, 60, and 100 $\mu$m fluxes of LS II +34°26 are given in Table 1.

## 3. ANALYSIS

Turner & Drilling (1984) carried out photometric and spectroscopic observations of LS II +34°26 and found it be a B1.5 Ia–Iabe supergiant. They derived $E(B-V) = 0.38$, $M_v = -6.35$, and a distance of 17.8 kpc. At this distance LS II

TABLE 1

THE FAR-INFRARED (*IRAS*) AND OPTICAL DATA OF LS II +34°26

| Parameter | Value |
|---|---|
| 12 μm Flux (Jy) | 0.34 ± 0.03 |
| 25 μm Flux (Jy) | 13.74 ± 0.55 |
| 60 μm Flux (Jy) | 11.81 ± 0.47 |
| 100 μm Flux (Jy) | 5.66 ± 0.45 |
| $V$ | 11.06 |
| $B-V$ | +0.18 |
| $U-B$ | −0.76 |
| Spectral Type | B1.5 Ia–Iabe |
| $(B-V)_0$ | −0.20 ± 0.02 |
| $E(B-V)$ | 0.38 ± 0.02 |
| $M_v$ | $-6.35^{+0.35}_{-0.70}$ |
| $d$ (kpc) | $17.8^{+8.4}_{-3.7}$ |

TABLE 2

TEMPERATURE ($T_d$), LUMINOSITY ($L_{IR}$), AND MASS ($M_d$) OF THE DUST ENVELOPE[a]

| Distance (kpc) | $M_v$ Star | $L_{IR}$ ($L_{\odot}$) | $M_d$ ($M_{\odot}$) |
|---|---|---|---|
| 17.8 | −6.35 | $2.111 \times 10^4$ | $2.176 \times 10^{-3}$ |
| 4.6 | −3.5 | $1.417 \times 10^3$ | $0.145 \times 10^{-3}$ |
| 2.9 | −2.4 | $5.630 \times 10^2$ | $0.577 \times 10^{-4}$ |

[a] $T_d = 100$ K.

+34°26 would lie 1.8 kpc below the Galactic plane. Since the warp in the Galactic plane is toward positive latitudes of this Galactic longitude (76°.6), LS II +34°26 must lie well below the main disk of the Galaxy.

The far-infrared *IRAS* flux distribution of LS II +34°26 (Fig. 1, Table 1) shows flux maximum around 25 μm while the 12 μm/25 μm, 25 μm/60 μm, and 60 μm/100 μm colors are similar to those of planetary nebulae. The total flux received above the Earth's atmosphere from the dust shell in the spectral region between 12 and 100 μm is found to be $f_{IR} = 2.142 \times 10^{-12}$ wm$^{-2}$. Since the far infrared flux is almost certainly due to the energy absorbed by the dust shell from the star, it must be concluded that the shell has a considerable optical depth in the visual and near-UV spectral range. A value of $\tau_{vis} = 0.5$ is necessary. However, the observed reddening of $E(B-V) = 0.38$ appears to be mostly interstellar in origin (Turner & Drilling 1984). It was noted by Turner (1983) that most of the interstellar extinction in this region takes place between 500 and 950 pc from the Sun, with additional reddening occurring at greater distances.

The temperature, luminosity, and mass of the dust shell are estimated and are given in Table 2. The details and equations used in estimating these parameters can be found in Hildebrand (1983) and Parthasarathy & Pottasch (1986). The dust

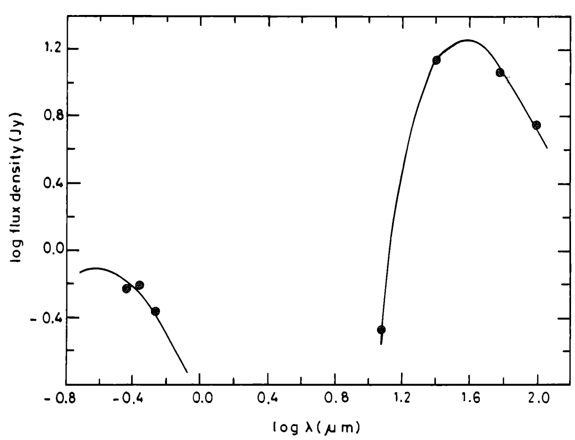


FIG. 1.—Flux distribution of LS II +34°26. The filled circles on the left represent the UBV fluxes (corrected for reddening) and the curve shows the flux distribution of a B1.5 supergiant star. The filled circles on the right are the *IRAS* fluxes and the curve shows the flux distribution of a 100 K dust shell.

temperature is found to be 100 K. The far-infrared luminosity of the dust shell using the distance of 17.8 kpc derived by Turner & Drilling (1984) is found to be $L_{IR} = 2.122 \times 10^4\ L_{\odot}$ which is comparable to the luminosity of the B1.5 Ia–Iabe supergiant. The dust mass $M_d/M_{\odot}$ is found to be $2.176 \times 10^{-3}$. If the ratio of gas to dust mass is about 100, as it is in the interstellar medium, the total shell mass would be 0.218 $M_{\odot}$. The distance $d = 17.8$ kpc derived by Turner & Drilling (1984) is based on well-determined magnitude, $E(B-V)$, spectral type, and luminosity class (B1.5 Ia–Iabe). They have concluded that LS II +34°26 has an absolute magnitude typical of luminosity class Ia and Iab stars. From the calibration of Turner (1980) they estimate $M_v = -6.35^{+0.35}_{-0.70}$ which means $M_{bol} = -8.0$ and luminosity $L/L_{\odot} = 10^5$. Such high-luminosity post-AGB stars are very rare. If we use the calibration of luminosity class and absolute magnitude, the luminosities of the post-AGB supergiants are found to be very high. However, if we adopt $M_v = -3.5$ (which is a reasonable approximation for a post-AGB star), we find $M_{bol} = -5.3$, $L/L_{\odot} = 10^4$ and the distance $d = 4.59$ kpc. If we assume that LS II +34°26 is a relatively low-luminosity post-AGB star of $M_{bol} = -4.7$ ($M_v = -2.4$), we find $L/L_{\odot} = 5.7 \times 10^3$ and $d = 2.9$ kpc. Still lower values of $M_v$ are not consistent with the observed $U-B$, $B-V$ colors and B1.5 Ia–Iab spectrum of LS II +34°26.

## 4. DISCUSSION

The far-IR colors and mass of the dust shell of LS II +34°26 are similar to those of planetary nebulae, LS II +34°26 is not associated with any known star-forming region or OB association or star cluster. The observed circumstellar dust shell around LS II +34°26 is most likely the result of severe mass loss experienced by the star in the recent past during its AGB stage of evolution. It is most likely a low-mass star in the post-AGB stage of evolution.

The circumstellar dust shell with characteristics similar to planetary nebulae and post-AGB A–F supergiants, and the B1.5 Ia–Iab supergiant spectrum of LS II +34°26, clearly demonstrate for the first time that the evolutionary sequence of post-AGB stars in the transition region extends from K, G, F, and A supergiant-like stars to B supergiant-like stars. In fact this is the hottest post-AGB supergiant discovered so far. Several of the bright post-AGB stars found from *IRAS* data (Parthasarathy & Pottasch 1986; Parthasarathy 1993; Hrivnak, Kwok, & Volk 1988, 1989) show F–G supergiant-like spectra which indicates that the time taken by M, K, and G post-AGB supergiants to evolve into F–A post-AGB supergiants is shorter than the time taken by F–A post-AGB supergiants to evolve into B type post-AGB supergiants. This may be one of the reasons for the paucity of post-AGB B supergiants. Also, as the temperature of the star rises further it may ionize the shell around it and appear as a young low excitation planetary nebula similar to SAO 244567 which was recently discovered by Parthasarathy et al. (1993).

Recently Kilkenny & Lydon (1986) suggested that LB 3193 ($V = 12.7$) and LB 3116 ($V = 12.55$) are high-latitude B supergiants. These authors have shown that for both these stars to be supergiants they must be situated at a large distance from us, 24 and 25 kpc, respectively. In the light of this they suggested that these objects are more likely to be stars similar to the UV-bright stars found in globular clusters. These stars are not *IRAS* sources. A more sensitive far-infrared survey going to fainter magnitudes and low flux level and also near-IR photometry may reveal dust shells around several high Galactic latitude, high-velocity, and low-gravity OB stars.

It may not be possible from low-dispersion spectra to distinguish post-AGB supergiants from normal supergiants. However some of the characteristics that can be used to distinguish post-AGB K to B supergiants from massive and young supergiants are (1) the spatial distribution of several post-AGB supergiants is far from the Galactic plane. Several post-AGB supergiants are high Galactic latitude and/or high-velocity stars. (2) Most of the post-AGB supergiants show hot and/or cold circumstellar dust shells which are caused by severe mass loss in the recent past. Often the far-infrared colors of their dust shells are similar to that of PNe. (3) Several post-AGB A–F supergiants are metal-poor. The depleted refractory elements appear to be locked up in the circumstellar dust grains. (4) The helium abundance and C/N/O abundance ratios indicate that they are evolved low-mass stars. (5) Strong CO emission is often found in these stars indicating mass-loss rates of the order of $10^{-6}\ M_{\odot}\ \mathrm{yr}^{-1}$ in the recent past. (6) Most of the post-AGB super giants show H$\alpha$ line in emission and a few show unusual 3 $\mu$m emission features. Also, some of the hotter post-AGB stars show emission lines due to H, N II, S II, O II, etc. (7) Several post-AGB supergiants show small-amplitude long-period light and radial velocity variations. LS II +34°26 is a low-gravity, high-velocity star with a detached cold circumstellar dust shell with characteristics similar to PNe. Further observations of LS II +34°26 may reveal some more of the above described characteristics of post-AGB stars.

Carrasco et al. (1980) proposed that many of the high-velocity low surface gravity early-type stars are old disk population objects in the same evolutionary phase as that of the hot UV-bright stars in globular clusters. They concluded that up to 39% of the O and 11% of the B stars in their sample may indeed be old disk population objects. The presence of detached cold dust shell with PN type colors around LS II +34°26 lends strong support to the idea that some of the high-velocity, high latitude, and low-gravity OB stars are not massive Population I OB stars; instead they are low-mass stars in the post-AGB stage of evolution. Turner & Drilling (1984) derived the radial velocity of LS II +34°26. They find $V_{\mathrm{LSR}} = -75 \pm 2.1\ \mathrm{km\ s^{-1}}$ and used it to examine the Galactic rotation law at large galactocentric distances. They argued that the linear rotational velocity at 18 kpc from the Galactic center is at least as large as and more likely larger than that established for the Sun's distance from the center. The presence of a detached cold circumstellar dust shell around LS II +34°26 suggests that it is a low-mass star in post-AGB stage of evolution. Most likely it is not located at 17.8 kpc. It may be within 1.8 to 4.8 kpc. The observed radial velocity $V_{\mathrm{LSR}} = -75$ km $\mathrm{s}^{-1}$ suggests that it is a high-velocity star. Stars similar to LS II +34°26 may not be used to study the Galactic rotation law at large Galactocentric distances.

## 5. CONCLUSIONS

The detached cold circumstellar dust shell with far-infrared colors, flux distribution, and dust shell mass similar to those of planetary nebulae suggests that LS II +34°26 is a post-AGB B1.5 Ia–Iab supergiant. It is not a massive Population I B star located at 17.8 kpc near the outer edge of the Galaxy. These results also suggest that some of the high Galactic latitude and/or high-velocity and low-gravity OB stars may be post-AGB stars. It is likely that these stars are closer and are not massive Population I OB stars and may not be suitable to study the Galactic rotation law at large galactocentric distances. From a far-infrared survey more sensitive than *IRAS* and reaching fainter magnitudes one may be able to detect dust shells around the stars similar to LS II +34°26. Near-infrared photometry may also reveal the warm dust if present around these stars. The chemical composition analysis of LS II +34°26 and similar stars may enable us to distinguish the post-AGB stars among the high Galactic latitude and/or high-velocity and low-gravity OB stars. The CO and OH observations and ultraviolet spectra of LS II +34°26 may enable us to further understand its evolutionary stage.

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