Astron. Astrophys. 154, L16–L19 (1986)

ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

The far-infrared (IRAS) excess in HD 161796 and related stars

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Received September 19, accepted October 22, 1985

SUMMARY

The far infrared IRAS measurements of high galactic latitude F-supergiant HD 161796 and related stars are found to show strong far infrared excesses, due to large amounts of dust around them. For HD 161796 the dust mass is found to be of the order of 10^{-2} $M_\odot$ to 10^{-3} $M_\odot$, and for HD 101584 it is of the order of 10^{-3} $M_\odot$. These results suggest that HD 161796 and other similar high galactic latitude F-supergiants have suffered extensive mass loss in the past as a result of superwind phenomenon on their AGB stage of evolution.

Keywords: dust - high galactic latitude F supergiants - population II stars - AGB stars - planetary nebulae - far infrared radiation

I. INTRODUCTION

HD 161796 (F3Ib) belongs to a small group of high galactic latitude F supergiants. The presence of F-type supergiants at high galactic latitude was first noticed by Bidelman (1951). The galactic latitude of HD 161796 is +31°.1 and the radial velocity is -53 km sec^{-1}. The evolutionary stage of these stars is not clear. They may be asymptotic or post-asymptotic branch stars of population II. If they are post-AGB stars they may have lost significant amounts of mass from their surface via stellar wind. The AGB phase is terminated by the ejection of a planetary nebula type shell. The problem of how such luminous F supergiants if young could be so far from the galactic plane led Abt (1960) to study their chemical composition. He found that these stars are metal poor. For HD 161796 Abt found the s-process elements to be underabundant, similar to that of population II stars. However Searle, Sargent and Jugaku (1963) found nearly normal abundances in HD 161796. The star HD 161796 shows no interstellar or circumstellar reddening (Humphreys and Ney, 1974). HD 161796, 89 Her and other stars in this group show small amplitude light and radial velocity variations similar to long period Cepheids (Fernie, 1983; 1981). These stars are near the blue edge of the Cepheid instability strip. However HD 161796, 89 Her and other members of this group show switching of pulsation modes which is uncommon in Cepheids of long period. Recently Fernie and Garrison (1984) studied HD 161796 and reconfirmed Bidelman's original classification of F3Ib and derived T_{eff} = 6300±200 K and log g = 0.1±0.5. However the conflict between MK type HD 161796 and luminosity and temperature suggested by other methods still remain. The strength of the OI λ7774 triplet (Sorvari, 1974) using the calibration of Osmer (1972) yields M_V = -8. For 89 Her Osmer (1972) found M_V = -6.6. Humphreys and Ney (1974) from near infrared photometry suggested that 89 Her and HD 101584 are binary stars with cool companions. Burki, Mayor and Rufener (1980) made a detailed study of velocity variations of HD 161796 and 89 Her and found no evidence for a binary nature, however.

In this paper we report the detection of a strong far infrared excess in HD 161796 and HD 101584 from the IRAS measurements, suggesting that these stars have substantial dust masses around them. This may result from mass loss similar to that found in planetary nebulae. We derive the masses, luminosities and radii of the dust shells around these stars and discuss their evolutionary status.

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II. IRAS OBSERVATIONS

A description of the IRAS survey instrument has been given by Neugebauer et al. (1984). The IRAS measurements of HD 161796, HD 101584 and 89 Her at 12 μm, 25 μm, 60 μm and 100 μm are given in Table 1. The flux distribution of HD 161796 and HD 101584 is shown in Figures 1 and 2 respectively. The observed IRAS far infrared flux of HD 161796 appears to have a maximum between 25 μm and 60 μm. The flux distribution between 0.36 μm to 3.5 μm is determined from the observations

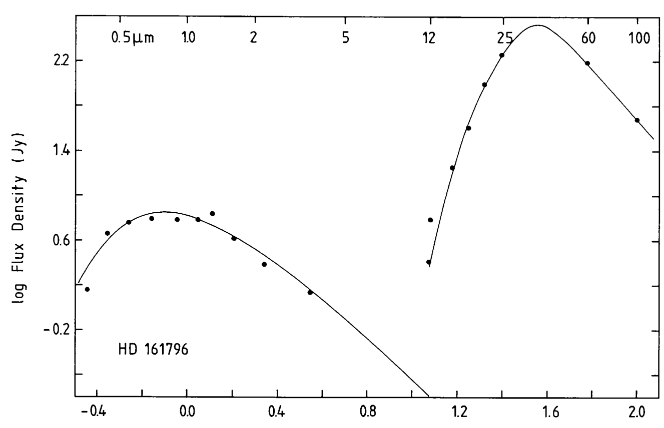

Fig. 1. Flux density as a function of wavelength from the ultraviolet to the far infrared, for HD 161796. All the far infrared measurement have been made by IRAS. The points between 12 μm and 20 μm are from the Low Resolution Spectrograph. There are two points at 12 μm the lower from the LRS and the upper from the survey. The latter overestimates the flux density when the spectrum is steep. The solid curves indicate blackbodies of 6300 K and 100 K.

TABLE 1 - IRAS OBSERVATIONS

	v	sp.	observed IRAS fluxes (Jansky) 12 μm	25 μm	60 μm	100 μm
HD 161796	7.04	F3Ib	6.1	183.5	151.3	47.6
HD 101584	7.01	F0Iape	92.7	138.3	192.9	102.6
89 Her	5.46	F2Ibe	97.6	54.5	13.2	5.8

Humphreys and Ney (1974), and is in agreement with flux distribution of a 6300 K black body. The flux distribution of HD 101584 shows infrared excess for wavelengths longward of 1.0 μm and it appears to have significant flux beyond 100 μm. The flux distribution of a 7500 K black body is also shown in Figure 2. The recent bright star catalogue gives the spectrum to be F0Iae. We here adopt a T_{eff} of 7500 K appropriate for F0Ia star.

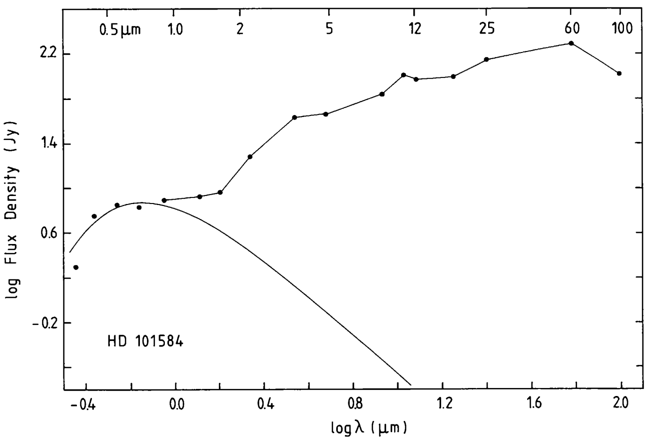

Fig. 2 Flux density as a function of wavelength for HD 101584. Similar to Fig. 1, except that the far infrared points do not fit a blackbody curve. The points are as measured, no multiplicative factors have been applied.

Humphreys and Ney consider HD 101584 is similar to 89 Her. The IRAS flux of 89 Her has a maximum at 12 μm and decreases rather steeply between 12 μm and 100 μm. 89 Her and HD 101584 show 10 μm silicate emission feature (Humphreys and Ney, 1974; Gillet, Hyland and Stein, 1970). It is quite remarkable that Humphreys and Ney report that there is no noticeable reddening for either HD 161796 or HD 101584.

III. ANALYSIS

From the IRAS fluxes given in Table 1, we estimate the temperature, radius and mass of the dust envelopes around these stars. The far infrared fluxes integrated between 12 μm and 100 μm are listed in Table 2, together with the dust temperatures found to give a good fit to the far infrared energy distribution assuming the emission efficiency given by Draine and Lee (1984) for a mixture of larger (see below) silicate and graphite particles. We have not considered a temperature gradient in the dust envelope, which may well exist, especially in HD 101584. In view of the strong near infrared flux from this latter star, it cannot be treated with the same simple model as HD 161796. Thus this dust temperature should be considered as a rough global parameter in this case.

The total fluxes received above the earths atmosphere from HD 161796 and HD 101584 in the spectral region between 3000 Å and 1.3 μm are 4.3×10^{-11} W m^{-2} and 5.0×10^{-11} W m^{-2} respectively. When comparing these values with the far infrared flux measured by IRAS (Table 2) it can be seen that almost as much energy is radiated in the far infrared as is seen coming from the star(s). Since the far infrared is nearly certainly 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. Furthermore the star must actually emit more radiation than is apparent: the observed stellar radiation plus the excess far infrared energy.

This conclusion appears to be in contradiction with the observation cited earlier that no reddening is observed in either of these stars. Two explanations are possible. Firstly, a very peculiar geometry could be the cause. For example, there could be a hole in the shell just in the line of sight. But it must be a small hole, since such a large fraction of the stellar energy is absorbed. This explanation therefore seems unlikely. Secondly, the absorption could be wavelength independent and therefore not cause any observable reddening. This could happen if the absorbing particles are larger than the normal interstellar grains. But very large particles are not required. According to Draine and Lee (1984) minimum sizes of between 3×10^{-5} and 10^{-4} cm will suffice.

TABLE 2

LUMINOSITIES, TEMPERATURES, RADII AND MASSES OF DUST ENVELOPES

	T_* °K	R_* ($R_\odot$)	d (kpc)	F_{total}^{IR} $10^{-12}Wm^{-2}$	L_{IR} ($L_\odot$)	T_d °K	R_d 10^5 $R_\odot$	$M_d/M_\odot$
HD 161796	6300	300	10	26.5	7.9	100	20.	8.1
		150	5		2.0		10.	2.0
		105	3.5		1.0		7.	1.0
HD 101584	7500	300	10	32.5	1.02	120	16.	1.3
		150	5		0.25		8.	3.2
89 Her	7000	130	2.37	13.745	2.41	500	0.13	2

The assumption of spherical symmetry and that the infrared emission comes from a relatively thin shell can be used together with the optical depth in the visual discussed above, the measured infrared fluxes and the shape of the spectrum, to determine the radius of the emitting shell, the dust temperature, and the infrared efficiencies. The main equation used is

$$\tau_\nu = \frac{d^2}{R_d^2} \frac{3}{2\pi} \frac{F_\nu}{B_\nu(T_d)}$$

where d is the distance to the source, R_d the radius of the dust shell, F_ν the observed flux density and $B_\nu(T_d)$ the Planck function with dust temperature T_d. This equation is for the optically thin case, which is close to the truth in the far infrared. The values of R_d found for various estimated distances are given in Table 2. We find further that the value of Q (12 μm) must be close to its value in the visual wavelengths; Q then decreases at longer wavelengths. This indicates that the size of the dust particles is not much higher than the minimum value quoted above, otherwise according to Draine and Lee Q would not decrease at longer wavelengths. We shall use as radius of the particles a $= 10^{-4}$ cm in determining the mass of the emitting dust. The mass is computed from (e.g. Hildebrand, 1983; Barlow, 1983)

$$M_d = \frac{4}{3} \frac{a\rho}{Q_\nu} \frac{d^2 F_\nu}{B_\nu(T_d)}$$

where ρ is the grain density, assumed 3 gm cm^{-3} and the other parameters have been discussed earlier. The derived values of the mass are listed in Table 2.

Notice that the mass is not dependent on any assumption regarding the heating mechanism of the shell or its optical depth. The model used fits the observations for HD 161796 very well and the derived parameters are probably a good approximation. The simple model will not reproduce the high near infrared flux observed in HD 101584 however. This is probably because the dust is not distributed in a thin shell but it fills the emitting region, with the consequence that a temperature gradient is present.

IV. DISCUSSION

The mass and size of the dust envelopes around HD 161796 and HD 101584 suggest that these stars suffered extensive mass loss. If the ratio of gas to dust mass is about 100, as it is in the interstellar medium, the total shell masses are between 0.3 and 1 $M_\odot$. This is really quite similar to that found in planetary nebulae and might suggest a connection between these objects and nebulae. There are differences, however; the most striking is the higher luminosity of the F supergiants by about an order of magnitude compared to nebulae. Furthermore the particle size appears larger, but this could be a temporal effect.

On the other hand, these stars are very far from any star-forming regions and are definitely at very large distances above the galactic plane. Abt (1960) estimates the z distance of HD 161796 to be 6 kpc. Abt (1960) suggested three possibilities for the origin these high galactic latitude F supergiants: (i) these stars (similar to O-B runaways) left the plane at velocities ~1000 km sec^{-1}; (ii) they originated in the plane but have spent most of their lifetime as stars of considerably lower luminosities than their present ones; (iii) they originated at considerable distance above the galactic plane. Searle, Sargent and Jugaku (1963) suggested that HD 161796 and 89 Her could have reached their present high galactic latitude in the course of their expected lifetime of ~10^7 years, if they had left the plane at the time of their formation with a z-velocity of about 100 km s^{-1}. Humphreys and Ney (1974) suggested that HD 101584 and 89 Her are binary systems having M supergiants as their companions. The presence of massive envelopes around these stars clearly suggests that mass loss is the answer and these stars are in the asymptotic post asymptotic (AGB-PASGB) giant stage of evolution. The significant characteristic feature of AGB phase of evolution is mass loss from the surface. The Reimers mass loss rate or low mass loss rate will not be able to account for the large mass of dust around these stars. The superwind type of mass loss which leads to the ejection of a planetary nebula shell accounts for the size and mass of the dust envelopes or disks around HD 161796 and HD 101584. The color temperature of the dust around 89 Her is ~500 K, and the size and mass of the dust is relatively small, suggesting that 89 Her may have suffered mass loss only in the recent past.

The Cepheid like pulsations of these stars (Fernie and Garrison, 1984; Fernie, 1981) and their high luminosities suggests that these originate from intermediate mass stars. The lifetime of a core helium burning star as a Cepheid is about ~10^6 years, and the lifetime of an AGB star of intermediate mass brighter than M_{bol} ~ -6 is of the order of 10^5 years (Iben, 1985). Schönberner (1983) and Iben (1982) suggest that superwind type mass loss occurs while the star is still on the AGB. The superwind mass ejection should terminate AGB phase (Iben, 1985) of HD 161796 and similar stars. Their high luminosities may be due to their evolution towards 'born-again' AGB stars.

We have also examined the IRAS fluxes of a few other high galactic latitude F supergiants and several galactic plane F supergiants in the same temperature and luminosity domain as HD 161796 and others. HD 46703 and HR 4912 are high galactic latitude supergiants and are metal deficient. HD 46703 was found to be a weak-lined F star on a Michigan objective prism plate by Bidelman (1966). Recently Luck and Bond (1984) made a detailed abundance analysis of this star and concluded that it is metal deficient [Fe/H] = -1.6, and carbon and oxygen are overabundant relative to iron by more than a factor of 10. For HR 4912 Luck, Lambert and Bond (1983) found [Fe/H] = -1.0. For HD 161796 and 89 Her Luck, Bond and Lambert (1985) find [Fe/H] ≃ -0.5. The metal abundances in all these stars are similar to those found in population II stars. The IRAS fluxes for HD 46703 are 0.46 Jy (12 μm) and 0.42 Jy (25 μm) and for HR 4912 1.25 Jy (12 μm), 1.60 Jy (25 μm) and 0.54 (60 μm). If we assume a dust temperature of T_d ≃ 200 K we find the dust masses around those stars to be of the order of 10^{-6} $M_\odot$. The dust mass around these two stars is much smaller than that found in HD 161796 and HD 101584. 89 Her, HD 46703 and HR 4912 may not have yet experienced the superwind mass ejection completely, or the gaseous matter ejected is still too hot for dust to have condensed out yet. The large mass around HD 161796 and HD 101584 may be in motion around them. Humphreys and Ney (1974) suggested that BL Tel, a long period F supergiants eclipsing binary, is an example of a system similar to HD 101584. We have examined the IRAS fluxes of BL Tel and find no far infrared excess similar to what we found in HD 101584. The irregular light variations other than the Cepheid like pulsation seen in HD 161796, 89 Her and HD 101584 (Fernie, 1981, 1983) may be due to the patchiness of the dust around these stars.

We have not found substantial far infrared excess in the galactic plane F supergiants in the same temperature and luminosity range as HD 161796, HD 101584 and 89 Her are. However we find excess flux at 60 μm in HR 4110 (F0Ia). The IRAS fluxes for HR 4110 are 3.42 Jy (12 μm); 1.24 Jy (25 μm) and 14.8 Jy (60 μm). Assuming HR 4110 is at a distance of 3.4 kpc as suggested by its luminosity we find a dust mass of the order of 0.59 × 10^{-4} $M_\odot$ from the flux at 60 μm. Further investigation of this star is needed.

V. CONCLUSIONS

The substantial far infrared excesses found in HD 161796 and HD 101584 from IRAS measurements are due to large amounts of dust around these stars as a result of mass loss. The dust masses around HD 161796 and HD 101584 are similar to and perhaps somewhat larger than found in average planetary nebulae (Pottasch et al., 1984). These high galactic latitude metal deficient F supergiants originated from low mass population II stars and are in the AGB or post-AGB phase of evolution as suggested by several investigations (Fernie, 1981; Luck and Bond, 1984; Luck, Lambert and Bond, 1983). The presence of large amounts of dust around these stars is a direct observational evidence that they have suffered significant mass loss in the past through superwind phenomenon on the AGB phase of evolution. These stars may be near the termination of the AGB phase of evolution. Some of the high galactic latitude planetary nebulae may have originated from this type of stars. If their initial mass was about 2 $M_\odot$ they must lose ~1.2 $M_\odot$ during the AGB phase by ordinary mass loss before developing a C-O core of mass about ~0.6 $M_\odot$. If they originated from a 4 $M_\odot$ star then a superwind type of mass loss arrests the growth of the core on their AGB phase (Iben, 1985). The Cepheid like pulsations and high luminosities suggests that their initial mass may be about 4 $M_\odot$. Another less likely possibility is that these are high galactic latitude low mass long period binaries in which the evolved companion loses mass, some of which is accreted by the companion which is a present F supergiant and the rest formed a circumstellar dust envelope or disk around the system.

The cases presented here are certainly not unique. We have recently found that SAO 163075 has a far infrared flux very similar to HD 161796. It is an even more extreme case, since the visual brightness is only 9 magnitude. But it has not been investigated in detail, and the only reference to it is its listing in the Henry Draper catalogue. It is likely that these objects are a small part of a hitherto unseen phase of stellar evolution.

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