ASTROPHYSIQUE

Reddening and dust distribution around V348 Sgr

by N. KAMESWARA RAO
Indian Institute of Astrophysics, Bangalore, India
and K. NANDY (*)
Royal Observatory, Edinburgh

Abstract. — Radio and Brackett γ observations indicate large value of reddening E(B − V) = 1.5 to the nebula surrounding V348 Sgr, where as the star appears to be reddened by only E(B − V) ~ 0.4. The infrared observations both ground based and with IRAS show that there are two dust components present. The hot dust represented by a 600 K black body longward of 3.5 μm and another cool dust $\leqslant$ 100 K black body. The hot dust extends to about 6″ radius from the star. The cool dust component surrounds the nebula and probably is responsible for the high extinction in the nebula. A tilted hollow cylinder or a tilted disc with a cavity type structure seems to be needed to accound for the lack of reddening towards the star. Similarities of the nebular and dust properties of V348 Sgr and R Cr B indicate that they are approaching the red giant stage for a second time.

I. INTRODUCTION

V 348 Sgr is thought to be one of the hottest R Cr B stars known. Its photometric and spectroscopic properties have been discussed extensively by Herbig (1958), Houziaux (1968, 83) and Dahari and Osterbrock (1984). The star is surrounded by an optical nebulosity which extends 8 to 10 arc seconds from the star. The spectrum at maximum light is dominated by emission lines of CII and He I. At minimum light low excitation planetary nebula-like spectrum emerges. Feast and Glass (1973) and Webster and Glass (1974) have detected

(*) Présentés par L. Houziaux.

large amount of infrared excess in the star. Recently Dahari and Osterbrock (1984) (hereafter denoted as DO) discussed the spectrum in detail and interpret the spectral characteristics with a model similar to that invoked for the light variation of R Cr B stars. At maximum light the star is surrounded by a hydrogen poor carbon rich chromosphere where CII, He I and Ne I spectrum originate ($T_e \sim 2 \times 10^4$ K). The minima are caused by the formation of dust from the ejected gas which obscures both the star and chromosphere.

One of the most interesting aspects of Dahari and Osterbrock's study is the distribution of the reddening material. They derived E(B − V) = 1.4 to 1.5 for the nebula from the Balmer decrement.

E(B − V) of 0.9 was obtained for the chromosphere which is presumably located closer to the star from the curve of growth analysis of CII lines.

Earlier Houziaux (1968) inferred spectral type and estimated the reddening of the star from UBV colours observed by Walker as E(B − V) = 0.59.

Heber *et al* (1984) and Rao and Nandy (1984) estimated the reddening of the star by ironing out the λ2200 depression using Seaton's (1979) reddening curve as E(B − V) = 0.43.

The interstellar reddening in the direction of the star is estimated to be E(B − V) $\sim$ 0.4 from Neckel and Klare (1980) and 0.2-0.3 from Fitzgerald (1968).

Thus it appears that most of the reddening is circumstellar and its distribution seems to be peculiar in the sense that the star in the centre has least amount of reddening whereas chromosphere and nebula have more reddening. This raises doubts about the star's association with the nebula; however, the structure and the symmetry of the nebula around the star indicates a generic relationship. In this paper we estimate the reddening of the nebula using radio and Brackett γ observations and further discuss the distribution of the dust in the nebula with the help of ground based and IRAS infrared observations.

II. Reddening and Extinction of the nebulae

a) *Radio continuum and Hβ flux*

V 348 Sgr has been observed by Purton *et al* (1982) with Parkes radio telescope at 5, 6, 2, 8.9 and 14.5 GHz. in the period 1977-1978.

The flux measurement at 14.5 GHz has less probable error and is 6 ± 3 mJy. The half power beam width is 2.5 and therefore includes the whole nebula. Although the errors are high at other frequencies they still indicate that the radio flux is optically thin at 14.5 Ghz. Using the 14.5 GHz flux density and assuming that this is due to free-free emission Hβ flux is estimated. Following Pottasch (1984)

$$\frac{S_\nu}{F(H\beta)} = 2.51.10^7\ T_e^{0.53}\ \nu^{-0.1} Y\ \frac{\text{Jansky}}{\text{erg cm}^{-2}\text{s}^{-1}}$$

where

$$Y = \left[1 + \frac{n(He^+)}{n(H^+)} + 4\frac{n(He^{++})}{n(H^+)} \cdot \frac{ln(4.95.10^2 Te^{3/2}\nu^{-1})}{ln(9.9.10^2 Te^{3/2}\nu^{-1})}\right]$$

the terms in $n(He^{++})/n(H^+)$ is assumed to be very small and thus neglected; $n(He^+)/n(H^+)$ is assumed to be 0.13 (i.e. all the He is in He^+ stage) and S_ν is the flux density in Jansky, ν in GHz. Taking $T_e = 1.5 \times 10^4$ as given by DO, Hβ flux is estimated to be 1.69×10^{-12} erg $cm^{-2} s^{-1}$. To compare this calculated Hβ flux with observation of DO, which were obtained with a 2.7″ × 4″ slit, a correction for the spectrograph slit not covering the whole nebula has been applied. (A factor of 4.85 assuming that the flux is proportional to the square root of the beam area. The observed flux at light minimum as given by DO is 4.07×10^{-15} erg $cm^{-1} s^{-1}$ which leads to

$$E(B - V) = \frac{1}{1.46} \log \frac{F(H\beta)_{cal}}{F(H\beta)_{obs}} = 1.32,$$

corresponding to normal interstellar medium).

We have attempted to measure the radio flux of V348 Sgr on 1983 Dec. 12 at 2 and 6 cm using NRAO's Very Large Array in the A configuration (Rao, Venugopal and Patnaik 1985). No emission could be detected with σ of 0.114 mJy per beam size of 1″ at 6 cm. This corresponds to an upper limit of (2σ) 2.4 mJy in the beam size corresponding to Hβ observations of DO leading to and upper limit of $E(B - V) \leqslant 1.49$. Thus radio observations are consistant with a value of $E(B - V) = 1.3 - 1.5$.

b) *Brackett γ*

To arrive at an independent estimate of the reddening using Bγ and Balmer lines and recombination theory, we obtained Bγ observations with the 3.9 meter Anglo-Australian telescope on 8 Nov. 1984 at resolution of $\lambda/\Delta\lambda$ = 360, with 3.5 arc sec circular aperture. According to AAVSO the visual mag at the time of this observation $\geqslant$ 13.5. The observations are shown in fig. 1. The error bars correspond to 1σ. The flux in Bγ is 1.65×10^{-13} erg $cm^{-2} s^{-1}$ with an uncertainity of 30 to 50 percent. The Bγ is expected to be least affected by line blending. The expected intensity ratio is Bγ/Hβ = 0.025 (for $N_e = 10^3 cm^{-3}$, $T_e = 1.5 \times 10^4$K) appropriate to Case B (taken from Osterbrock (1974) and Giles (1977)). The observed Bγ flux has been compared with the Hβ flux observed by DO after correcting for the difference in slit widths using a relation flux $\propto$ (beam area)$^{1/2}$ (or even using uniform brightness i.e. flux $\propto$ area, does not make much of a difference). Use of Van de Hulst's curve number 15 as a representative of the extinction curve (Johnson 1968) leads to E(B − V) $\simeq$ 2.47 (2.25 at minimum observed flux of Bγ line). The observed Bγ flux seems to be higher than expected from the radio flux.

Thus these observations confirm the reddening estimate of the nebula derived from the Balmer lines by Dahari and Osterbrock.

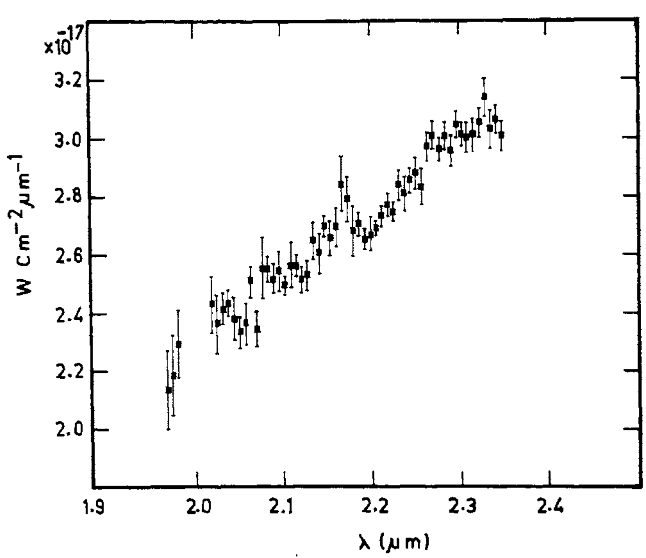

FIG. 1. — 2-2.3 μm spectrum of V348 Sgr obtained with AAT with 3.5 arc sec aperture. Flux is in W cm^{-2} μm^{-1} and error bars are one standard deviation of the mean.

c) *Electron density*

With the above reddening of E(B − V) = 1.5 and using the recombination lines we could also estimate the electron density provided the distance is known. Following Pottasch (1983) assuming a spherical uniform density model with filling factor ϵ.

$$Ne\,\epsilon^{1/2} = 2.74.10^4 \left(\frac{F_{H\beta}Z^{0.88}}{\theta^3 D}\right) cm^{-3}$$

where $Z = T_e/10^4K$, $F_{H\beta}$ is the Hβ flux in units of 10^{-11} erg $cm^{-2}\,s^{-1}$, D is the distance in *kpc*, θ is the optical size in arc seconds. The distance of V348 Sgr has earlier been estimated by Rao and Nandy (1984) as 2.2 *kpc* based on the similarity with other hydrogen deficient stars (taking $E_{B-V} = 0.4$). With $\theta = 1.85$ (taken to be corresponding to the slit size used by DO) the flux gives $N_e = 2 \times 10^3\ cm^{-3}$ for $\epsilon = 1$. This is in better agreement with $N_e \sim 10^3\ cm^{-3}$ determined by DO from forbidden line ratios confirming our distance estimate.

III. Infrared photometry

After the initial discovery of infrared excesses by Feast and Glass several observations both in wide band filters and spectrophotometric observation have been made in the IR. Recently IRAS has also observed this star Figs. 2 and 3 show various observations (gathered from literature) made longward of 1 μm. The stellar continuum makes a contribution at 1.25 μm and to a certain extent at 2.2 μm; beyond this wavelength most of the excess seems to be circumstellar dust emission.

a) *Aperture dependence*

As figure 2 illustrates, infrared emission appears to come from an extended region, particularly at 10 μm. The spectrophotometric observations in 8-13 μm region obtained by Roche and Aitken with a 4.7 arc sec circular aperture lead to much lower fluxes than the wide band measurements of Feast and Glass, at 10.2 μm and 20 μm, obtained with a 12 arc sec aperture. The agreement within the errors of IRAS fluxes, which had much wider field of view, with Feast and Glass measurements shows that the IR emission (in this region) is generally confined to within 6 arc sec radius. Figure 2 also shows the flux averaged over the band width of IRAS 12 μm band for 4.7 arc sec

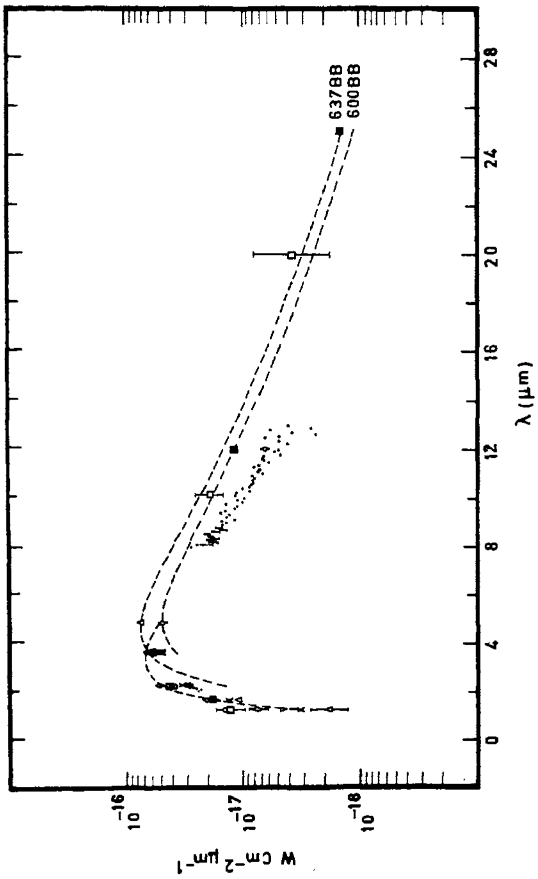

FIG. 2. — Various Infrared observations longward of 1 μm. The symbols denote the following observations. □ — Feast & Glass (1973) ; ∇, △, O-Glass (1978) ; ◇ in the JHK bands-Webster and Glass (1973), X - Sept, 15, 1983 ; ■ — IRAS ; the dots 8-13 μm are spectrophotometric observations of Roche & Aitken (1984) with 4.7 arc sec aperture. The dots at 2.2 μm are spectrophotometric observations with AAT 3.5 arc sec aperture (figure 1). Feast and Glass observations were obtained with 12 arc sec aperture. The ◇ at 12 μm is the average of Roche-Aitken's observations over the 6 μm band width corresponding to IRAS 12 μm band. The dotted lines show the 637 and 600 K black body energy distribution. The dotted curve terminating at 4.8 μm corresponds to a 900 K BB.

aperture measurements of Roche and Aitken (the open diamond), which illustrates this point.

The broad band fluxes longward of 3.5 μm until 20-25 μm can fairly well be represented by a 600-637 K black body. This emission is confined to a radius of 6 arc sec corresponding to 0.06 pc, and is

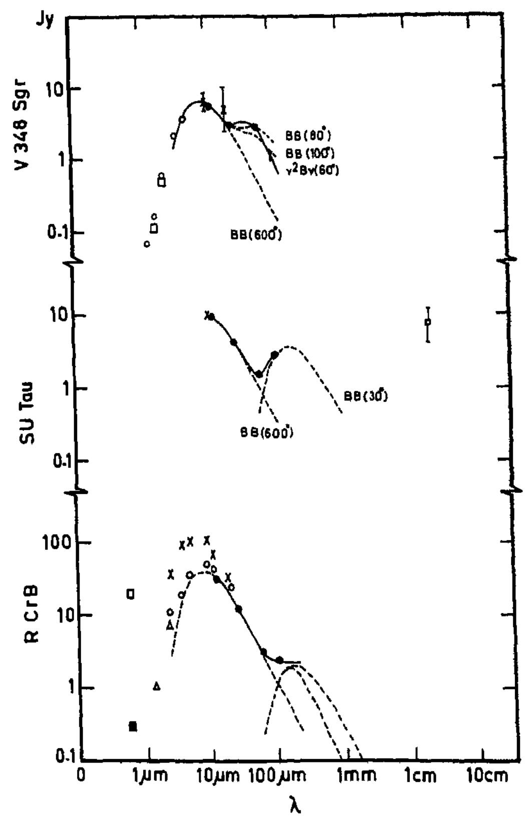

FIG. 3. — The observed infrared flux densities are plotted as a function of wavelength for V348 Sgr (top) SU Tau (middle) and R Cr B. The dots represent the IRAS observations. Crosses and open circles are ground based observations. The dotted lines are R Cr B — 600 K BB + 30 K BB ; SU Tau — 600 K BB + 30 K BB ; V348 Sgr — 600 K BB + 80, 100 K BB, the solid line corresponds to 600 K BB + $\nu^2 B_\nu$ (T = 60 K) emissivity.

marginally smaller than the nebula ($\sim$ 9 arc sec). The aperture dependence of this excess flux is proportional to the radius at 10 μm. There also appears to be a temperature gradient and hotter dust might be closer to the star. The 2.2 μm spectrophotometric measurements obtained with 3.5 arc sec aperture are roughly in agreement with some of the 12 arc aperture wide band observations. So the dust emission at 2.2 μm is mostly confined within a radius 1.75 arc sec. The 2.2 μm flux is variable and would depend on the stellar variability (since we do not know the visual mag. at the time of these observations we could not account for that variation).

Even the spectrophotometry of Roche and Aitken in 8-13 μm region with 4.7 arc sec aperture indicate a black body temperature of 1130 ± 30 K. Thus there is probably a strong temperature gradient across the dust regions.

b) *Far IR observations and the cool component*

In addition to the hotter dust there appears to be another cool component which is indicated from the IRAS observations (5.56, 3.02. 2.83 and $\leqslant$ 13.2 Jy for 12 μm, 25 μm, 60 μm and 100 μm bands respectively).

This cool component seems to be a common feature of the R Cr B stars. Fig. 3 shows the energy distributions of R Cr B and SU Tau, both show two distinct components of hot ($\sim$ 600 K BB temperature) and cool dust ($\leqslant$ 100 K BB).

The energy distribution beyond 25 μm does not appear to be of single black body nature. It shows better agreement with dust emissivity proportional to ν^2 or ν with T_d of 60 K and 70 K respectively. Although within the uncertainities a 90 K to 100 K black body fit cannot be ruled out, the fits with single black body type emissivity are poor. This behaviour is consistent with optically thin dust emission in these wavelengths. Assuming ν^2 dependence for the IR excess the observed flux due to the cool dust is 1.70×10^{-17} W cm^{-2} and is only 3.4 percent of the hotter dust component.

The mass and angular extent of the cool dust woud depend on its composition, size and the emissivity at long wavelengths (i.e. 60 μm). If this cool dust is assumed to be distributed in a thin shell in thermal equilibrium with the central star, then the angular diameter θ of the shell is given by

$$\frac{\theta_d}{\theta_*} = 0.5 \left(\frac{\epsilon^{vis}}{\epsilon_{ir}}\right)^{1/2} \left(\frac{T_*}{T_d}\right)^2$$

where θ_*, T_* are the angular diameter and effective temperature of the star and ϵ's are the emissivities. Because V348 Sgr spectrum indicates high carbon abundance and of the smooth featureless infrared continuum (Roche and Aitken 1984) it was suggested that dust is composed of small graphite grains. The emissivity of small graphite particles in the long wavelength range is supposed to be proportional to ν^2 or even steeper. Hecht *et al* (1984) have suggested glassy or amorphous carbon grains as possible candidates for extinction in

R Cr B. Small particles of amorphous carbon show emissivity proportional to ν (Koike *et al.* 1980). For V348 Sgr adopting the distance of 2.2 Kpc and $T_* \sim 23000$ K, $L_* \sim 1.5 \times 10^3 L_\odot$ and $T_d \sim 60$ K and emissivity [which was estimated for $T_d \sim 20$ K from Drain (1985)] for 0.01 μm and .1 μm graphite spheres give a radius of the shell as $\sim 2.3 \times 10^{17}$ to 2.8×10^{17} cm. If the dust is optically thin the dust mass (Mosley 1980) $M_d = F_\lambda D^2/k_\lambda B_\lambda(T_d)$ where F_λ is excess flux density, [100 $\mu m \leqslant 1.88 \times 10^{-19}$ cm^{-2} μm^{-1}) and κ_λ is the opacity ($3\,\theta_{abs}/4\,ap$) leads to a dust mass of 1.23×10^{-4} $m_\odot$ for the cool dust.

IV. Stellar temperature

The stellar temperature is estimated based on the following considerations. From the absorption features in in the blue region Dahari and Osterbrock estimated the spectral type as B1 supergiant.

The spectral type from the UV is about B3. The Zanstra temperature method of Morton (1969) using radio flux (E(B − V) of 0.43 for the star) leads to $T_* \sim 25000$ K.

The energy distribution in the UV corrected for E(B − V) of 0.43 fits a black body of 24000 K.

The infrared flux comes mainly from the reradiated stellar flux. The infrared luminosity puts the constraint on the temperature. The observed IR luminosity is $1.6 \times 10^2 D^2 L_\odot$. The stellar luminosity following the dereddened magnitudes and bolometric corrections for helium stars (Heber and Schönberner 1981) of $T_{eff} \sim 19500$ K and 25000 K are $1.6 . 10^2 D^2 L_\odot$ and $3.4 . 10^2 D^2 L_\odot$ respectively. Thus $T_{eff} > 19500$ K is needed to explain the infrared luminosity. We estimate $T_{eff} = 23000 \pm 3000$ K.

V. Discussion

There appears to be a large difference between the reddening of the star and the reddening of the nebula. The UV observations of the star indicate E(B − V) = 0.43 from the strength of 2200 feature, compared to E(B − V) = 1.4 for the nebula. It is likely that the material in the nebula causing the reddening does not produce the λ2200 feature. Adams and Barlow (1983) find that this feature is weaker than predicted from radio $-\mathrm{H}\beta$ extinction towards some planetary nebulae which show 10 μm silicate emission. No such 10 μm feature occurs in V348 Sgr. It is often suggested that the $\lambda 2200$ feature is produced by small graphite particles, which might also be absent in the reddening material around V348 Sgr. If only bigger particles are present they are expected to cause less reddening and thus the smaller E(B − V) value = 0.6 obtained from the spectral type. U, B, V colors towards the star also probably could be accounted for. But in this case a drastic grain size difference has to be invoked toward the star and the nebula ; this seems to be very unlikely. The (extinction) reddening law toward the nebula seems to be similar to that of general interstellar medium, because both Balmer decrement and radio-Hβ method gave the same value for E(B − V). Thus it appears that there is genuine lack of reddening material toward the star. A similar situation is seen for the planetary nebula NGC 2346 (Mendez and Niemela 1981) where a bipolar structure was invoked to explain the occurrence of reddening of the nebula and lack of it in the central star. M4-18 which spectroscopically is similar to V348 Sgr also shows E(B − V) $\approx$ 0.4 from the strength of the $\lambda 2200$ feature and E(B − V) = 0.90 from the Balmer decrement (Goodrich and Dahari 1985). From the anology of NGC 2346 even in V348 Sgr a bipolar structure seems probable or a titled disc of dust and gas with a central clear portion to explain the lack of reddening to the star.

The hot infrared emitting dust (~ 600 K BB) is confined to the 6 arc radius of the star. Although the energy distribution longward of 3.5 μm can be reproduced by 600 K black body, it is quite unlikely to be physically real. It possibly results from a distribution of temperatures and steeper emissivities such as ν^2 etc. It is interesting to see whether this dust can also cause the extinction in the nebula. Assuming graphite spheres of radius 10^{-5} cm, $\rho = 3$ g. cm^{-3} and infrared emissivity ~ 10^{-3} for $L_{ir} = 7.8 \times 10^2 L_\odot$ the dust mass (upper limit) estimated is $2 \times 10^{-6} m_\odot$ [$M_d = a\rho L_{ir}/3\sigma Q_{ir} T_g^4$] whereas the dust mass needed to cause $A_V = 3.52$ mag in the nebulae with graphite particle of radius 10^{-5} cm, $Q_{ext}(vis) = 2.1\ 10^{-3}$ (following Mendez & Niemela). Thus the hot dust is not the source of extinction in the nebula. From the IRAS observations the cold dust mass has been estimated as ~ $10^{-4} m_\odot$ (see 3.2) which is within the order of magnitude estimated for dust causing extinction. With all uncertainities in Q_{IR}/a etc., we consider that these estimates are in agreement. The radius of the cold dust shell estimated earlier is the same as the outer extent of the nebula

($\sim 2.2 \times 10^{17}$ cm), so most of this cold dust occurs surrounding the ionized nebular shell.

Dahari and Osterbrock proposed that the deep light minima are caused by the formation of dust clouds around the star similar to the conventional model invoked to explain the minima of R Cr B stars. However their spectroscopic observations do not show evidence of strong stellar wind or high speed gas ejections around the time of the light minimum unlike the case with R Cr B which shows gas ejections with radial velocities of ~ 250 km s^{-1} (Herbig 1949, Gaposchkin 1963, Rao, 1981).

The IRAS observations of V348 Sgr show many similarities with planetary nebulae. Pottasch *et al.* (1984) studied the far infrared properties of planetary nebulae using IRAS. They show a linear relationship between radius of the nebula with the black body temperature of the dust. The extent of the nebula estimated earlier and the black body temperature of 80-100 K, places V348 Sgr right on the above relation and indicates, as is believed for planetaries, that cool dust is a remnant of the star when it was a red giant.

There seems to be a continuity in the properties between V348 Sgr and R Cr B. Both are hydrogen deficient irregular variables with $T_{eff} \sim 23000$ K and 7000 K respectively. V348 Sgr has an optical nebulosity and R Cr B shows λ3727 of [OII] emission whenever the star is visually fainter than 13 mag (Herbig 1949, 1968) indicating the existence of a very low surface brightness nebula. Apart from the hotter dust, both have cool dust which is characterised by $T_d \leqslant$ *100 K in V348 Sgr and 30 K in R Cr B. The cool dust shell in V348 Sgr has a radius of 2.6* $\times$ *10^{17} cm and R Cr B the cool dust shell radius is estimated to be 2.2* $\times$ *10^{18} cm. The presence of [OII] in R Cr B indicates that the central star cannot by itself ionize the nebula and suggests that it is a remnant of the time when the star was hot. Thus R Cr B indicates a later stage in the evolution of the nebula and dust shell relative to V348 Sgr and indicates that it probably is at the red giant stage for a second time and the cool dust is a remnant of the first red giant phase.*

Thus this picture gives credence to the scheme proposed by Iben *et al* (1983) and Iben (1984) that these stars have passed the normal hydrogen shell burning evolutionary, but then have experienced a final thermal pulse when they were in the nuclei of planetary nebula stage or even white dwarfs. As a result, presently they are approaching or at the second red giant phase as born again AGB stars.

VI. Conclusions

The radio and Brackett γ observations confirm that the reddening and extinction is high in the nebulae E(B − V) = 1.4 as earlier estimated from the Balmer decrement, whereas the star shows only E(B − V) = 0.4 to 0.6.

The energy distribution until mid IR can be represented by a black body of 600 K and this dust region is confined to 6 arc sec radius. There is a temperature gradient across this region with hot dust ($T_B \sim 1130$ K) closer to the star within $\leqslant 2.3$ arc sec. This dust is not the cause of the nebular extinction.

In addition to the hot dust there is a cool dust component which surrounds the nebula and is probably responsible for the nebular extinction. This cool component is probably the result of first red giant phase.

The dust and gas are probably distributed similar to bipolar nebulae discussed by Clavet and Peimbert (1983) such that the star is not reddened but only the nebulae shows the reddening may be like a tilted hollow cylinder or tilted disk with a cavity to allow the star to peep through.

The similarity of nebular and dust properties of V348 Sgr and R Cr B indicate that these stars at or approaching the red giant phase a second time.

Acknowledgements

We would like to thank the Director of AAT for allotment of discretionary time for observation of Brackett γ. We are particularly thankful to Dr. D. A. Allen for making these observations for us. We would like to thank Dr. S. P. Pottasch for sending the IRAS observations of V348 Sgr. We also would like to thank Peggy Perley for making the VLA observations and Dr. A. Patnaik for the reductions.

REFERENCES

ADAMS, S. and BARLOW, M. J., 1982. Planetary nebulae, IAU Symp 103, ed. D. R. Flower, p. 537.

CLAVET, N. and PEIMBERT, N., 1983. *Rev. Astron. y Astrofisica,* **5**, 319.

DAHARI, O. and OSTERBROCK, D. E., 1984. *Ap. J.,* **277**, 648.

DRAIN, B. T., 1985. *Ap. J. Suppl. Ser.,* **57**, 587.

FEAST, M. W. and GLASS, I. S., 1973. *M.N.R.A.S.,* **161**, 293.

FITZGERALD, M. P., 1968. *Astron. J.,* **73**, 983.

GLASS, I. S., 1978. *M.N.R.A.S.,* **185**, 23.

GILES, E., 1977. *M.N.R.A.S.,* **180**, 57 p.

HEBER, U. and SCHÖNBERNER, D., 1981. *Astr. Ap.,* **102**, 73.

HEBER, U., HECK, A., HOUZIAUX, L., MANFROID, J. and SCHONBERNER, D., 1984. Fourth European IUE Conf., ESA, S.P. **218**, 367.

HECHT, J. H., HOLM, A. V., DONN, B. and WU, C. C., 1984. *Ap. J.,* **280**, 228.

HERBIG, G. H., 1949. *Ap. J.,* **110**, 143.

HERBIG, G. H., 1958. *Ap. J.,* **127**, 312.

HERBIG, G. H., 1968. *Mém. Soc. Roy. Sci. Liège,* **17**, 353.

HOUZIAUX, L., 1968. *B.A.C.,* **19**, 265.

HOUZIAUX, L., 1983. *Messenger,* **33**, 25.

IBEN, I. Jr., 1984. *Ap. J.,* **277**, 333.

IBEN, I. Jr., KALER, J. B., TRURAN, J. W. and RENZINI, A., 1983. *Ap. J.,* **264**, 605.

MENDEZ, R. H. and NIEMELA, V. S., 1981. *Ap. J.,* **250**, 240.

MORTON, D., 1969. *Ap. J.,* **158**, 1969.

MOSLEY, 1980. *Ap. J.,* **238, 392**, 1980.

NECKEL, Th. and KLARE, G., 1980. *Astr. Ap.,* Suppl. **42**, 251.

OSTERBROCK, D. E., 1974. *Astrophysics of Gaseous Nebulae* (San Francisco Freeman and Co).

PURTON, C. R., FELDMAN, P. A., MARSH, K. A., ALLEN, D. A. and WRIGHT, A. E., 1982. *M.N.R.A.S.,* **198**, 321. (Microfische).

RAO, N. K., 1981. *IAU Coll. 59.* The effects of mass-loss on stellar evolution eds. C. Chiosi and R. Stalio, p. 319.

RAO, N. K. and NANDY, K., 1984. Fourth European IUE Conference.

RAO, N. K., VENUGOPAL, V. R. and PATNAIK, A., 1985. *J. Astrophys. Astron.,* **6**, 153.

POTTASCH, S. R., 1983. *Planetary Nebulae,* D. Reidel.

POTTASCH, S. R., BAUD, B., BEINTEMA, D., EMERSON, J., HABING, H. J., HARRIS, S., HOUCK, J., JENNINGS, R., and MARSDEN, P., 1984. *Astr. Ap.,* **138**, 10.

ROCHE, P. F. and AITKEN, D. K., 1984. *Mon. Not. R. Astr. Soc.,* **208**, 481.

SEATON, M. J., 1979. *Mon. Not. R. Astr. Soc.,* **187**, 73 p.

WEBSTER, B. L., GLASS, I. S., 1974. *Mon. Not. R. Astr. Soc.,* **166**, 491.