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# Cn 1-1: a peculiar compact planetary nebula

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**Summary.** Cn 1-1 is an emission-line object that shows strong emission lines characteristic of high density planetary nebulae superposed on the stellar spectrum of an F5 III-IV star. By making use of the far-infrared IRAS measurements and other available observational material we estimate the absolute luminosity of the hot star of Cn 1-1 to be $L_* \simeq 63\,L_\odot$. A new estimate of the effective temperature of the star is also made based on the IRAS and IUE data. The position of the star on the HR diagram is discrepant with the young age of the nebula as deduced from the high nebular density. Assuming that the gas and dust are co-extensive in Cn 1-1, the dust to gas mass ratio is anomalously large if the dust grains have properties similar to interstellar graphite, or else the grains are much larger ($a \gtrsim 1\,\mu$m). In addition to the cool dust at $\simeq 215$ K there is a second distinct hot dust component at $\simeq 850$ K that is probably heated by the radiation from the F type star in its neighbourhood, the star being embedded in the cool nebular dust. Cn 1-1 may be a Type I protoplanetary nebula with a massive nucleus ($M \gtrsim 1.2\,M_\odot$) evolving in a binary system.

**Key words:** planetary nebula – central stars – dust – infrared radiation

## 1. Introduction

Cn 1-1 (= HDE 330036 = BD − 48°10371 = PK 330 + 4°1) is a peculiar emission-line object that shows strong emission lines characteristic of high density planetary nebulae superposed on the underlying stellar spectrum of F5 III-IV type (Webster, 1966; Lutz, 1984a, hereafter L84). The object is stellar in appearance and has been classified both as a symbiotic star (Glass and Webster, 1973; Allen, 1979) and as a planetary nebula with a binary nucleus (Lutz, 1977). Near-infrared photometric observations of Cn 1-1 were made by Glass and Webster (1973) and Allen and Glass (1974) who found a large excess of infrared emission longward of 2 $\mu$m. Spectrophotometric measurements by Allen et al. (1982) and Roche et al. (1983) showed that Cn 1-1 has emission features around 3.3 $\mu$m and 11.3 $\mu$m. Lutz (L84) presented ultraviolet and optical spectroscopic measurements of Cn 1-1 and proposed that the object is a dense planetary nebula involved in a binary system with a star of spectral type F5 III-IV.

Far-infrared (four bands at 12, 25, 60, and 100 $\mu$m) measurements of Cn 1-1 by the Infrared Astronomical Satellite (IRAS) have been reported by Pottasch et al. (1984). It turns out, as will be shown below, that Cn 1-1 radiates the bulk of its energy in the IRAS bands. In this paper we discuss the nature of Cn 1-1 in the light of the IRAS observations.

## 2. Observational material

The $U(0.36\,\mu$m), $B(0.44\,\mu$m), $V(0.55\,\mu$m), $J(1.25\,\mu$m), $H(1.65\,\mu$m), $K(2.2\,\mu$m), $L(3.5\,\mu$m) and the IRAS photometric data for Cn 1-1 available in the literature is presented in Fig. 1. Other physical parameters for Cn 1-1 as given in L84 and relevant to the present discussion are the following:

a) Spectral type of the cool star: F5 III-IV; though it could be a less luminous star, i.e. F5 IV-V.

b) Electron temperature $T_e$ and electron density $n_e$ in the emission line region: $T_e = 1.5 \pm 0.5\,10^4$ K; $n_e = 10^{6\pm1}$ cm$^{-3}$

c) Observed flux in the H$_\beta$ line $F(\mathrm{H}_\beta)$(erg cm$^{-2}$ s$^{-1}$): $\mathrm{Log}\,F(\mathrm{H}_\beta) = -11.73$

d) Radio continuum flux density $S_\nu = 34$ mJy at $\nu = 14.7$ GHz (Milne and Aller, 1983).

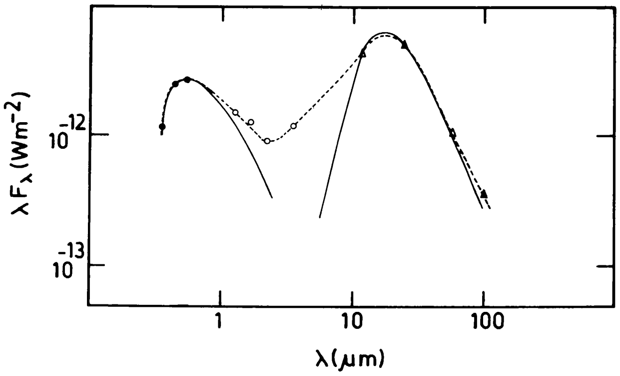

**Fig. 1.** The flux ($\lambda F_\lambda$) distribution for Cn 1-1 based on photometric data. The data are from: (1) *UBV* (Shao and Liller, 1972, quoted in L84; ●), (2) *JHK L*(Allen and Glass, 1974; ○) and (3) IRAS bands (Pottasch et al., 1984; △). The broken-line and the solid-line curves drawn have been explained in the text

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e) H I and He II Zanstra temperatures for the hot star: $T_z(\mathrm{H\,I}) = 68{,}000\,\mathrm{K}$; $T_z(\mathrm{He\,II}) = 76{,}000\,\mathrm{K}$

f) Interstellar reddening $E(B-V)$ and distance $d$: The distance $d$ is an important parameter in the context of this paper. In *L*84 the reddening and distance of Cn 1-1 were estimated by simultaneously solving an observed colour excess versus distance relation and the distance modulus relation (Eqs. 1 and 2 in *L*84) which gave $E(B-V) = 0.28$ and $d = 450\,\mathrm{pc}$. The observed $V = 11.03$ and $B - V = 0.83$. The value $E(B-V) = 0.28$ is less than the value $E(B-V) = 0.41$ obtained by comparing the observed $B-V$ colour with $B - V = 0.42$ appropriate for an unreddened F5 III-IV star (Allen, 1973). This difference could arise if part of the observed reddening were of local origin.

Since the distance estimate depends on the values of $M_v$ and $E(B-V)$ used, we could find the range of possible distances. With a range of $M_v = 3.4$ to 1.4 corresponding to the spectral types F5 V to F5 III (Allen, 1973) and an $E(B-V) = 0.28$, the range of distances obtained is $270 \lesssim d(\mathrm{pc}) \lesssim 525$. If we used $E(B-V) = 0.41$, the corresponding range becomes $190 \lesssim d(\mathrm{pc}) \lesssim 460$. The maximum distance $d \simeq 640\,\mathrm{pc}$ is obtained by assuming that the entire reddening $E(B-V) = 0.41$ is interstellar and using the colour excess versus distance relation (Eq. 1 of *L*84). This, however, is inconsistent with the observations, since the implied $M_v$ for the cool star is then 0.69 which corresponds to a spectral type A5 III.

In view of the above, we adopt $d = 450\,\mathrm{pc}$ (same as in *L*84), $E(B-V) = 0.41$ and $c$, the logarithmic extinction at $\mathrm{H}_\beta = 0.6$ in the rest of this paper. Normal mean interstellar extinction law (Savage and Mathis, 1979) is assumed for extinction corrections.

## 3. The excess infrared emission and the luminosity of the hot star in Cn 1-1

Pottasch et al. (1984) found that Cn 1-1 is a strong source of far-infrared radiation, the total far-infrared flux being $F_{\mathrm{f.i.r.}} = 8.5\,10^{-9}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$. By assuming that the far-infrared emission is thermal continuum radiation from heated dust grains, they computed the dust temperature $T_d = 215\,\mathrm{K}$. It was also noted that the energy available in the Lyman $\alpha$ photons (estimated from the observed radio continuum flux) is too low to provide the observed far-infrared flux, the ratio of the observed far-infrared flux to the flux available in Lyman $\alpha$ photons, the so called infrared excess IRE, being $\simeq 24$. Evidently the dust in Cn 1-1 must be heated by the direct absorption of radiation from the hot central star whose existence has been established by the ultraviolet observations (*L*84). Therefore, the dust must have an optical depth in the ultraviolet $\tau_{\mathrm{UV}} \gtrsim 1$.

Since Cn 1-1 has a strong infrared excess (IRE $\simeq 24$), consequently a large dust optical depth in the UV($\tau_{\mathrm{UV}} \gtrsim 1$) and also a high nebular density ($n_e \sim 10^6\,\mathrm{cm^{-3}}$), it is reasonable to assume that the sum of the infrared excess flux, the flux in the emission lines and the nebular continuum flux represent the total UV flux from the hot star. To this must be added any continuum flux from the hot star longward of $\lambda$ 912 A that manages to escape from the nebula unabsorbed. Assuming the star to radiate like a blackbody, the fraction of the total flux emitted at $\lambda > 912\,\mathrm{A}$ is small ($\simeq 24\%$ for temperature $T_* = 70{,}000\,\mathrm{K} \simeq$ the Zanstra temperature; and only $\simeq 1\%$ for $T_* = 2.5\,10^5\,\mathrm{K} \simeq$ the temperature estimated later in this paper). Even this radiation may be partly absorbed by the dust in the nebula and reradiated in the infrared. We therefore make no correction for the unabsorbed stellar flux above the Lyman limit. In fact, it turns out that the infrared flux makes the largest contribution to the total.

Figure 1 shows the flux distribution $\lambda F_\lambda$ of the radiation from Cn 1-1 based on the photometric data available. The fluxes have been dereddened for $E(B-V) = 0.41$. The solid curves represent the flux distribution for an unreddened F5 star in the optical and near-infrared, and a cool 215 K dust emission in the far-infrared (Pottasch et al., 1984). It is clear from Fig. 1 that there still remains a substantial excess radiation in the 2–10 $\mu$m region, though the far-infrared IRAS fluxes are well fit by a 215 K blackbody emission. There must be some dust in Cn 1-1 which is much hotter than the cool 215 K dust component. This will be discussed later in this paper.

We now make an estimate of the total flux from the hot star of Cn 1-1 and its luminosity. The various contributions to the total flux are the following:

(i) The infrared excess: Pottasch et al. (1984) found the far-infrared excess flux in the wavelength region of the IRAS bands ($\sim 8$ to $120\,\mu\mathrm{m}$) $F_{\mathrm{f.i.r.}} = 8.5\,10^{-12}\,\mathrm{Wm^{-2}}$. There is additional excess radiation in the near-infrared as seen from Fig. 1. The amount of this excess will depend on the precise flux distribution between 4–8 $\mu$m, which is not yet measured. For the present we will consider the flux under the broken-line curve which is a smooth interpolation between the photometric points as shown in Fig. 1. The near-infrared flux contribution is $F_{\mathrm{n.i.r.}} \simeq 1.6\,10^{-12}\,\mathrm{Wm^{-2}}$. Thus the total infrared excess flux $F_{\mathrm{i.r.}} = F_{\mathrm{f.i.r.}} + F_{\mathrm{n.i.r.}} \simeq 1.01\,10^{-11}\,\mathrm{Wm^{-2}}$.

(ii) The emission line flux: The emission line fluxes for lines in the ultraviolet and the optical have been given in *L*84. Summing these up we get for the observed total line flux $F_{\mathrm{line}} = 4.1\,10^{-14}\,\mathrm{Wm^{-2}}$. The emission line fluxes must, however, be corrected for interstellar extinction. The observed extinction may be partly local to the nebula which does not need correction as the line radiation absorbed would be reemitted in the infrared that has already been counted. An upper limit to the line fluxes can be found by assuming that all of the $E(B-V) = 0.41$ is interstellar. Making an extinction correction with $E(B-V) = 0.41$ gives for the dereddened total emission line flux $F_{\mathrm{line}} = 6.5\,10^{-13}\,\mathrm{Wm^{-2}}$. In these calculations, use has been made of $\mathrm{Log}\,F(\mathrm{H}_\beta) = -11.73$ for the observed $\mathrm{H}_\beta$ flux in $\mathrm{erg\,cm^{-2}\,s^{-1}}$ (Webster, 1966) and a small contribution from the $\mathrm{H}_\alpha$ line (not quoted in *L*84) has been added by assuming $F(\mathrm{H}_\alpha) = 3F(\mathrm{H}_\beta)$. The Lyman $\alpha$ radiation has already been counted in the infrared flux. In any case the total line flux is an order of magnitude smaller than the observed infrared flux; and any error in this estimate will scarcely affect the results.

(iii) The nebular continuum flux: The total nebular continuum flux calculated by assuming $n_e = 10^6\,\mathrm{cm^{-3}}$, $T_e = 1.5\,10^4\,\mathrm{K}$ and $\mathrm{Log}\,F(\mathrm{H}_\beta) = -11.73$ with $E(B-V) = 0.41$ is $F_{\mathrm{n.c.}} = 1.04\,10^{-14}\,\mathrm{Wm^{-2}}$. This is three orders of magnitude smaller than the infrared flux.

The total flux $F_*$ from the hot star can be written as:

$$\begin{aligned} F_* &= F_{*\lambda<912\,\mathrm{A}} + F_{*\lambda>912\,\mathrm{A}} \\ &= F_{\mathrm{i.r.}} + F_{\mathrm{line}} + F_{\mathrm{neb.cont.}} + F_{*\lambda>912\,\mathrm{A}} \\ &\simeq 1.1\,10^{-11}\,\mathrm{Wm^{-2}}\,. \end{aligned}$$

Clearly the infrared flux dominates the above sum. We will adopt $F_* = 1.1\,10^{-11}\,\mathrm{Wm^{-2}}$.

Combining the distance estimate and the total flux, the bolometric luminosity $L_*$ of the hot star in Cn 1-1 can be easily estimated.

$$\begin{aligned} L_* &= 4\pi d^2 F_* \\ &= 2.52\,10^{35}(d/450\,\mathrm{pc})^2(F_*/1.1\,10^{-11}\,\mathrm{Wm}^{-2})\,\mathrm{erg\,s}^{-1} \\ &\simeq 63\,L_\odot \end{aligned} \tag{1}$$

The uncertainty in $L_*$ arising from the uncertainties in the IRAS flux calibration (Pottasch et al., 1984) and the uncertainties in the distance (*L*84) should be quite small, at most a factor of 2.

## 4. The temperature of the hot star and its evolutionary status

Lutz (*L*84) estimated the Zanstra temperatures for the hot star in Cn 1-1 to be: $T_z(\mathrm{H\,I}) = 68{,}000\,\mathrm{K}$ and $T_z(\mathrm{He\,II}) = 76{,}000\,\mathrm{K}$. However, the absorption of the ionising radiation from the central star by the dust in the nebula can result in Zanstra temperatures that may be gross under-estimates of the actual temperature if the dust optical depth $\tau_{\mathrm{UV}}$ is $\gtrsim 1$ (e.g. Helfer et al., 1981). For Cn 1-1, as shown above, the ratio of the dust infrared flux to the nebular emission line plus continuum flux $F_{\mathrm{i.r.}}/(F_{\mathrm{line}} + F_{\mathrm{n.c.}}) \simeq 15$. The dust absorbs about 94% of the stellar flux so that only about 6% of the stellar flux is utilised for ionisation. We can make an estimate of the true temperature of the central star by making use of the total stellar flux $F_*$ (found above) and the dereddened continuum flux at $\lambda = 1300\,\mathrm{A}$ ($F_\lambda \simeq 10^{-13}\,\mathrm{erg\,cm^{-2}\,s^{-1}\,A^{-1}}$; from *L*84). Assuming the star to behave like a blackbody, the corrected effective temperature can be found from

$$\frac{F_*}{F_{\lambda\,1300\,\mathrm{A}}} = \frac{\sigma T_*^4}{\pi B_{\lambda\,1300\,\mathrm{A}}(T_*)} \tag{2}$$

where $\sigma$ is the Stefan-Boltzmann constant and $B_{\lambda\,1300\,\mathrm{A}}(T_*)$ is the Planck function at the temperature $T_*$. The result is: $T_* \simeq 2.5\,10^5\,\mathrm{K}$. The large discrepancy between the values of the Zanstra temperatures quoted in *L*84 and the temperature estimated here is not surprising in view of the extreme infrared excess observed in Cn 1-1. The uncertainty in $T_*$ arising from the uncertain dust extinction law and the possible non-blackbody nature of the stellar radiation is difficult to estimate. The derived $L_*$ and $T_*$ can now be used to place the central hot star of Cn 1-1 on the HR diagram. The difficulties are immediately obvious – the luminosity is very low compared to other central stars of planetary nebulae and the temperature is much too high. If the theoretical evolutionary tracks due to Paczynski (1971) and Schönberner (1981, 1983) are now superposed, the position of this star on the HR diagram would correspond to a mass $\gtrsim 1.2\,\mathrm{M}_\odot$ and an evolutionary age $t \sim 5\,10^3$ yrs. This in turn would imply a massive progenitor. The observational facts are not inconsistent with this possibility. The nebula in Cn 1-1 is dense and being nearby ($d \lesssim 500\,\mathrm{pc}$) its stellar appearance indicates its youth. No direct age estimate is possible. However, if one adopts a mass of $\sim 0.5\,M_\odot$ for the nebular shell and assumes a uniform expansion velocity $v_{\mathrm{exp}} \sim 10\,\mathrm{km\,s^{-1}}$, a density of $n_e \sim 10^6\,\mathrm{cm}^{-3}$ should be achieved in a few times $10^3$ yr consistent with the evolutionary age indicated by the position of the star on the HR diagram. The presence of the 3.3 $\mu$m and 11.3 $\mu$m emission features (Allen et al., 1982; Roche et al., 1983) indicates that the nebula is carbon-rich. The large N/O abundance ratio (~1.0, *L*84) and the carbon-rich nature of the nebular matter in Cn 1-1 is typical of Type I planetary nebulae (Peimbert and Torres-Peimbert, 1983) which are believed to evolve from massive progenitors ($2 < M/M_\odot \lesssim 6$). The central star of Cn 1-1 would then lie to the extreme right of the Schönberner distribution (Schönberner, 1981) and would also belong to the class of very hot central stars that Pottasch (1985) claims to have found and Kaler (1985) concedes the existence of.

If $T_z \simeq 70{,}000\,\mathrm{K}$ truly represented the temperature of the central star, its position on the HR diagram would still be discrepant, because with a luminosity as low as $\simeq 63\,L_\odot$ it would not be a young object. In fact, the matching evolutionary track would then be of a nucleus with mass $\sim 0.54\,M_\odot$ and the age would correspond to $t > 10^5$ yr. The high nebular density argues against this possibility.

Arguments against the possibility that Cn 1-1 could be a symbiotic star have been given in *L*84 and also in Lutz (1984b). In fact, except for the combination spectrum (high excitation emission lines plus stellar absorption spectrum) there is no other supporting evidence for the symbiotic-star nature of Cn 1-1. We will return to this question later.

## 5. Heating of the dust and the nature of dust grains in Cn 1-1

Most of the radiation from the nebula in Cn 1-1 is emitted in the far-infrared IRAS bands. The IRAS fluxes are well fit by a 215 K blackbody radiation (Pottasch et al., 1984). We can estimate the total mass of the far-infrared emitting dust if we know the dust-grain properties.

The total far-infrared luminosity emitted can be written as:

$$4\pi d^2 F_{\mathrm{f.i.r.}} = (4\pi a^2) N \langle Q(T_d, a)\rangle \sigma T_d^4 \tag{3}$$

where $a$ is the grain radius, $N$ is the number of grains, $T_d(= 215\,\mathrm{K})$ is the dust temperature, $\langle Q(T_d, a)\rangle$ is the Planck-averaged emissivity (Draine and Lee, 1984) and $F_{\mathrm{f.i.r.}}$ is the measured far-infrared flux.

The total mass of the far-infrared emitting dust grains is $M_d = \frac{4}{3}\pi a^3 \rho_d N$, where $\rho_d$ is the density of the grain material. Therefore

$$M_d = \frac{4\pi a \rho_d d^2 F_{\mathrm{f.i.r.}}}{3\langle Q(T_d, a)\rangle \sigma T_d^4} \tag{4}$$

With $d = 450\,\mathrm{pc}$, $T_d = 215\,\mathrm{K}$, $F_{\mathrm{f.i.r.}} = 8.5\,10^{-12}\,\mathrm{Wm}^{-2}$ we obtain

$$M_d = 1.08 \times 10^{26}(\langle Q(T_d, a)\rangle/(a/\mu\mathrm{m}))^{-1}(\rho_d/2\,\mathrm{gm\,cm}^{-3}) \tag{5}$$

For grain sizes typical of the normal interstellar dust ($a \simeq 0.1\,\mu\mathrm{m}$) since the condition $2\pi a/\lambda \ll 1$ (as $\lambda > 10\,\mu\mathrm{m}$ in this case) is satisfied, the ratio $\langle Q(T_d, a)\rangle/(a/\mu\mathrm{m})$ is independent of the grain radius and depends only on the grain material, the values of the ratio being $\simeq 5\,10^{-2}$ for graphite and $\simeq 0.4$ for silicates (Draine and Lee, 1984) at $T_d = 215\,\mathrm{K}$.

The absence of the 9.7 $\mu$m silicate feature, and the presence of the 3.3 $\mu$m and the 11.3 $\mu$m emission features (associated with carbon-rich material: e.g. Allamandola and Norman, 1978; Duley and Williams, 1981) strongly suggest that the dust in Cn 1-1 is graphite dominated. If we use $\langle Q(T_d, a)\rangle/(a/\mu\mathrm{m}) = 5\,10^{-2}$ at $T_d = 215\,\mathrm{K}$ for graphite dust for which $\rho_d \simeq 2.3\,\mathrm{gm\,cm}^{-3}$ the dust mass in Cn 1-1 is

$$M_d \simeq 2.5\,10^{27}\,\mathrm{gms}\ (= 1.25\,10^{-6}\,M_\odot).$$

The ionised gas mass can be estimated from the dereddened $H_\beta$ flux and the values $n_e \simeq 10^6\,\mathrm{cm}^{-3}$ and $T_e \simeq 1.5\,10^4$ K. At this $T_e$ the $H_\beta$ luminosity of the nebula

$$4\pi d^2 F(\mathrm{H}_\beta) \simeq 8.6\,10^{-26} n_e^2 V. \qquad (6)$$

where $V$ is the volume of the ionised gas. The mass of the ionized gas $M_g = 1.4\, m_\mathrm{H} n_e V$, where $m_\mathrm{H}$ is the mass of the hydrogen atom and the factor 1.4 includes 10% by number of helium atoms in the nebula. Thus

$$M_g = 3.27\,10^2 d^2 F(\mathrm{H}_\beta) n_e^{-1} \qquad (7)$$

With $d = 450$ pc, $n_e = 10^6\,\mathrm{cm}^{-3}$ and the dereddened $H_\beta$ flux $F(\mathrm{H}_\beta) = 7.4\,10^{-12}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ we obtain

$$M_g = 4.4\,10^{27}\,\mathrm{gms}\ (=2.2\,10^{-6}\,M_\odot)$$

The dust-to-gas mass ratio, a distance-independent quantity, can then be obtained from Eqs. (5) and (7) and written as

$$\frac{M_d}{M_g} \simeq 0.6\left(\frac{n_e}{10^6\,\mathrm{cm}^{-3}}\right)\left(\frac{\langle Q(T_d, a)\rangle/(a/\mu\mathrm{m})}{5 \times 10^{-2}}\right)^{-1} (\rho_d/2.3\,\mathrm{gm\,cm^{-3}}) \qquad (8)$$

Assuming that the grains in Cn 1-1 are of typical interstellar dimensions, the dust-to-gas mass ratio in Cn 1-1 is $\sim 0.6$. This is large compared to the mean interstellar value ($\sim 10^{-2}$) and much larger than the values obtained by Pottasch et al. (1984) for less compact planetary nebulae ($10^{-4} \lesssim M_d/M_g \lesssim 10^{-2}$). Even if $n_e$ were as small as $\sim 10^5\,\mathrm{cm}^{-3}$ the dust-to-gas mass ratio remains at least an order of mangitude larger than the maximum possible with the cosmic C abundance (C/H $\simeq 4\,10^{-3}$ by mass; Allen, 1973). However, the nebula in Cn 1-1 could have a higher carbon abundance; but in that case extreme enhancement in C is needed before the observed dust-to-gas ratio is achieved.

A high value for the dust-to-gas ratio could result if the gas and dust were not mixed together and the far-infrared emitting dust were occupying a larger volume outside the ionised region. However, this is unlikely to be the case for optically thick planetary nebulae with hot central stars, as these stars emit most of their radiation shortward of $\lambda = 912$ A. Far-infrared maps of NGC 7027 by Bentley (1982) and Aitken and Roche (1983) support a common emitting region for the dust and the ionised gas. In any case, for Cn 1-1, we know that the dust absorbs (and re-emits in the infrared) most of the stellar radiation before it is utilised for ionisation of the gas, so that the dust must lie within the ionised region.

It is possible that the grain properties in dense and young planetary nebulae like Cn 1-1 are very different from that of the interstellar dust. If we require the dust-to-gas mass ratio in Cn 1-1 to have a more reasonable value $M_d/M_g \lesssim 10^{-2}$, then Eq. (8) may be used to put constraints on the grain properties:

$$\langle Q(T_d = 215\,\mathrm{K}, a)\rangle/(a/\mu\mathrm{m}) \gtrsim 3.0(n_e/10^6\,\mathrm{cm}^{-3}) \qquad (9)$$

When compared with the dust-grain emissivities given in Draine and Lee (1984), we find that Eq. (9) is satisfied only for large grains ($a > 1\,\mu$m) even if $n_e = 10^5\,\mathrm{cm}^{-3}$ is used. If the density is more like $n_e \sim 10^6\,\mathrm{cm}^{-3}$, then the ratio $\langle Q(T_d = 215\,\mathrm{K}, a)\rangle/(a/\mu\mathrm{m}) \gtrsim 3$, and $a \gtrsim 3\,\mu$m is required. Thus it seems possible that Cn 1-1 has graphite grains with $a \gtrsim 1$ m, much larger than the interstellar variety. Larger dust grains would also be consistent with the observed fact that the He II lines are very weak in the spectrum of Cn 1-1 (*L*84) in spite of the high effective temperature for the central star estimated here. The dust grains must be capable of absorbing the He$^+$ ionising far-ultraviolet stellar radiation, which the larger dust grains can because their absorption efficiency in the far-ultraviolet $Q_\mathrm{UV}$ attains the value $\simeq 1$. The dust grain absorptivities in the ultraviolet, however, do not affect the dust mass calculations which depend only on the emissivity in the far-infrared.

As noted earlier Cn 1-1 emits substantial excess radiation in the near-infrared that can be explained neither as a short-wavelength extension of the 215 K cool dust component, nor by the nebular continuum which is too low. After subtraction of the F star continuum plus the contribution due to the cool dust, the rising continuum in the 3–4 $\mu$m region is found to have a colour temperature $T_d \simeq 850$ K. Spectrophotometry in the 8–13 $\mu$m region by Roche et al. (1983) also shows the infrared flux rising towards the shorter wavelengths. Thus in Cn 1-1, there is a second, hot ($\simeq 850$ K) component of dust, distinct from the cooler ($\simeq 215$ K) component.

We suggest the possibility that the F5 type star is the source of heating for the hot (850 K) component of the dust in Cn 1-1. The F star may be in a wide binary orbit around the hot star and is embedded in the nebular gas and dust. The central star heats the bulk of the dust to $T_d = 215$ K. The F-type star heats the dust in its neighbourhood to the much higher temperature of $\simeq 850$ K. The dereddened flux from the F stars $\simeq 2.4\,10^{-12}\,\mathrm{Wm}^{-2}$ (Fig. 1) whereas the excess flux in the near-infrared (the 850 K component of the dust emission) is $\simeq 1.6\,10^{-12}\,\mathrm{Wm}^{-2}$. An internal dust absorption $A_V \simeq 0.4$ mag (which will cause an internal reddening $E(B-V) \simeq 0.14$) would suffice to explain the hot dust emission in the near-infrared. This is quite acceptable in view of the total $E(B-V) \simeq 0.41$ observed, a part ($\simeq 0.14$) of which could be internal to the nebula as discussed in Sect. 2(f).

Before concluding, we consider the symbiotic-star scenario for Cn 1-1 in the light of the above discussion. In the symbiotic-star model, Cn 1-1 would be an interacting close binary (separation $\sim 10^{14}$ cm) in which the luminosity of the hot component (compact star) is derived from the gravitational potential energy ($L_* \simeq GM_*\dot{M}/R_*$, where $\dot{M}$ is the accretion rate, $M_*$ and $R_*$ are the mass and radius of the compact star and $G$ is the Gravitational constant) by accretion of matter from the stellar wind of the F-type star. For $L_* = 63\,L_\odot$, with $M_* \sim 1\,M_\odot$, $R_* \sim 0.01\,R_\odot$ we obtain an accretion rate $\dot{M} \sim 2\,10^{-8}\,M_\odot$/yr. The stellar wind mass loss rate from the F-type star should be much larger than this. Another estimate of the required stellar wind mass loss can be made by using Eq. (6) for the $H_\beta$ flux. Since $V = \frac{4}{3}\pi R_i^3$, the radius of the ionised region $R_i \simeq 8\,10^{14}(n_e/10^6\,\mathrm{cm}^{-3})^{-2/3}$ cms. The required stellar wind mass loss rate $\dot{M} = 4\pi R_i^2 n_e n_\mathrm{H} \times 1.4 \times v_w$, where $v_w$ is the stellar wind velocity. We obtain $\dot{M} \sim 5\,10^{-7}\,(n_e/10^6\,\mathrm{cm}^{-3})^{-1/3}\,M_\odot$/yr with $v_w = 20\,\mathrm{km\,s}^{-1}$. A low luminosity star of type F5 III–IV ($L \sim 14\,L_\odot$) cannot support such large mass loss rates in its stellar wind (Reimers, 1975). In view of this, and other arguments given in *L*84 we discount the possibility of Cn 1-1 being a symbiotic star.

## 6. Conclusions

The nature of the peculiar object Cn 1-1 has been discussed on the basis of the available observational information. The following conclusions are drawn:

1. Most of the radiation (>90%) from the hot star in Cn 1-1 is absorbed by the dust in the nebula and is re-emitted in the

far-infrared. The luminosity of the central star is $\simeq 63\,L_\odot$ which is abnormally low for a planetary nebula nucleus of characteristic age $\sim 10^3$ yr implied by the high density of Cn 1-1.

2. Since the dust absorbs most of the stellar ionising photons, the Zanstra temperatures in *L*84 must be gross underestimates of the actual temperature of the central star of Cn 1-1. The effective temperature of the central star could be as high as $T_* \sim 2.5\,10^5$ K.

3. The position of the central star on the HR diagram for the central stars of planetary nebulae implies a core mass $M \gtrsim 1.2\,M_\odot$ and hence a massive progenitor star ($4-5\,M_\odot$). Cn 1-1 may be a Type I protoplanetary nebula evolving in a binary system.

4. If the properties of the dust grains in Cn 1-1 are similar to the interstellar graphite dust, then the dust-to-gas mass ratio for the nebular matter is abnormally large. Alternatively, the dust grains in Cn 1-1 could be very large ($a \gtrsim 1\,\mu$m), if the dust-to-gas ratio is normal.

5. There are two distinct components of infrared emitting dust in Cn 1-1: One at a temperature $\simeq 215$ K; and the other much hotter component at $\simeq 850$ K. The hotter dust component is suggested to be heated by the radiation from the F type star which is embedded in the nebular dust.

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