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Far Infrared Emission from three New Planetary Nebulae

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Abstract. As dust emission in the far infrared (FIR) is a characteristic property of planetary nebulae we searched the Infrared Astronomical Satellite (IRAS) point-source catalogue for confirmatory evidence on the two new possible planetary nebulae S 68 and 248 – 5 identified by Fesen, Gull & Heckathorn (1983) and the high-excitation planetary nebula 76 + 36 detected by Sanduleak (1983). We identify the nebulae 248 –5 and 76 + 36 with IRAS sources 07404 – 3240 and 17125 + 4919, respectively and have determined their dust temperature, total FIR emission and optical depth. We also set a lower limit ranging in value from 1.2×10^{-6} to 3.7×10^{-5} for $M_{dust}/M_{\odot}$ of the nebula 248 – 5 depending on whether its grain material is silicate or graphite. S 68 could not be identified with an IRAS source.

Key words: planetary nebulae, dust temperature—planetary nebulae, optical depth—planetary nebulae, far infrared flux

1. Introduction

Most of the galactic planetary nebulae (PNe) with large angular sizes are now believed to be identified through careful searches of Palomar Observatory Sky Survey (POSS). The few that could have been still missed (Weinberger *et al.* 1983) are likely to be due to planetaries of either large angular size with very low surface brightness, or nebulae of very high excitation which appear extremely faint on the POSS prints due to their emitting very strongly in [OIII] $\lambda\lambda$ 4959,5007 lines where the POSS O and E emulsions are relatively insensitive.

Parker, Gull & Kirshner (1979) carried out a deep, wide-field and low-resolution photographic emission-line survey of the galactic plane. Employing a wide-field camera and narrow passband interference filters, they recorded the galactic plane in [OIII] λ 5007, Hα+ [NII] λ 6570, SII λ 6736, H β 4861 and λ 4225 continuum emissions. Fesen, Gull & Heckathorn (1983) searched these plates for objects particularly strong in [OIII] emission which had not been identified till then or had uncertain classifications. Since the survey recorded emission at very faint levels ([OIII] emission measure ~100 pc cm^{-6}), using a relatively small plate scale and low angular resolution Fesen, Gull & Heckathorn (1983) were able to notice only fairly large and bright nebulae. From the very strong [OIII] emission, symmetrical morphology and the presence of faint blue central stars, Fesen, Gull &Heckathorn (1983) suspected S 68 and an anonymous nebula 248 – 5 to be planetary nebulae.

Sanduleak (1983) detected a new, resolved high excitation planetary nebula (1950 coordinates: $\alpha = 17^h\ 12^m.5$, $\delta = +\ 49°\ 19'$, 1 = 75°.8, b = + 35°.8) containing a 14 magnitude O-type central star on objective prism plates taken for the low-dispersion Northern Sky Survey (Pesch & Sanduleak 1983). The nebula was first detected by its strong emission in [OIII] $\lambda\lambda$ 5007, 4959 lines on the spectrum obtained using an objective prism on Kodak IIIa-J plate. A 45 minute exposure, on a Kodak 103a-F plus GG 455 filter combination plate at a dispersion of 1000 Å mm^{-1} at H_α showed that the (OIII) $\lambda\lambda$ 5007, 4959 emission was stronger than the emission of H_α possibly blended with [N II] $\lambda\lambda$ 6548 and 6584. Their objective prism observations thus indicated a high-excitation planetary containing a central star of moderate brightness with a very strong ultraviolet continuum.

The strong [OIII] lines of 4959 and 5007 arise from transitions between the metastable levels of the ground state electron configuration of O^{++} formed in the plasma either around newly formed young stars or around the central stars of planetary nebulae. They thus serve to identify gaseous nebular regions in the sky. In these plasma dust is intimately mixed with ionized gas and is heated by Lyman α radiation (produced as the end product of recombinations in hydrogen) as well as Lyman continuum photons and photons longward of the Lyman α The dust so heated generally has a characteristic temperature of 60–200 K (see Pottasch 1984) and emits in the far infrared. The availability of the IRAS (Infrared Astronomical Satellite) point source catalogue now enables one to seek confirmatory evidence in the far infrared for the presence of such nebulae by identifying them with sources of FIR and to determine their other physical properties such as temperature and mass of dust *etc.* The field of view of the IRAS survey bands at 12, 25, 60 and 100 μm is 0.75 × 4.5, 0.75 × 4.6, 1.5 × 4.7 and 3.0 × 5.0 $arcmin^2$ and happens to be much larger than the sizes of many planetary nebulae (PN). Thus most of the PN appear as point sources to the IRAS photometric survey instrument and should appear listed in the point source catalogue if emitting in far infrared (FIR). We therefore undertook a search of the IRAS point source catalogue (Beichman *et al.* 1985) to identify and to derive information on the dust in these nebulae.

2. Analysis of data, results and discussion

We present in Table 1 data on two of the three nebulae which could be identified with sources in the IRAS catalogue. Listed columnwise in Table 1 are (1) the name of the nebula and its galactic co-ordinates, the IRAS number of the source with which it is identified, (2) its right ascension and declination, (3) the angular size of the source and its distance, (4) the flux densities in the four IRAS photometric survey bands, and (5) the dust temperature, total FIR flux, optical depth at 25 μm and $M_{dust}/M_\odot$ of the nebula determined from this work.

248 – 5 has been detected by IRAS. Definite values are available for its flux density in the 25 and 60 μm bands although the quality of the measurement in the 25 μm band is moderate (flux uncertainty $\gtrsim$ 20 per cent). The data from IRAS catalogue under the heading ‘confusion’ indicates that this is the only source in the IRAS window at 100 μm. But the cirrus contribution at 100 μm is rather significant. Also 3 small extended sources are detected in the IRAS windows at 25 and 60 μm at this source position. It is well known that planetary nebulae contain density condensations and it is quite likely that the 3 small extended sources detected by IRAS are all density condensations of the same nebula 248 – 5. This nebula has a size 130 × 180 $arcsec^2$, larger than many

Table 1. FIR data on new planetary nebulae.

Name Designation IRAS No.	R. A. (1950)			Dec (1950)			Angular size (arcsec) Distance (kpc)	Flux Density[d] (Jy) 12 μm 25 μm 60 μm 100 μm	Dust Temp (K) Total FIR flux (Wm^{-2}) Optical depth $M_{dust}/M_{\odot}$
248 − 5	07h	40m	28s.9	−32°	40′	42″[a]	130 × 180[a]	0.26L	85
247.56 − 4.73	07	40	28.8	−32	40	29[c]	1.38	0.26:	9×10^{-14}
07404 − 3240[c]								1.10	2.4×10^{-7}
								2.55L	$(1.2-37) \times 10^{-6}$
76 + 36	17	12.5		+49	19[b]		13[b]	0.35L	~ 120[e]
75.8 + 35.8	17	12	30.6	+49	19	20[c]		0.27	$\lesssim 5 \times 10^{-14}$
17125 + 4919[c]								0.64L	$\sim 4 \times 10^{-6}$
								1.00L	

Notes:
a) Data from Fesen *et al.* (1983).
b) Data from Sanduleak (1983); the nebula is circular and the tabulated value is the diametrical size.
c) Data from IRAS point source catalogue.
d) L in column 4 indicates the quoted flux is an upper limit; and: indicates that the quality of measurement is moderate.
e) Estimated assuming the flux density to peak at 25 μm, being the only wavelength band for which we have a definite value for the observed flux density.

planetary nebulae, raising doubts as to its identification (Fesen, Gull & Heckathorn, 1983) as a planetary nebula. However, planetary nebulae with radial sizes > 100 arcsec are not uncommon (see Appendix 1, Pottasch 1984) and cannot by itself be used to question its classification.

From the observed flux densities at 25 and 60 μm we determine a colour temperature of ~ 85 K for the dust radiating in the far infrared and a value of ~ 9×10^{-14} Wm^{-2} for the total flux at earth (in the 4–300 μm interval) and 2.4×10^{-7} for its optical depth at 25 μm.

We use the expression

$$M_{\mathrm{dust}} = \frac{4}{3} \frac{a\rho}{Q_\nu(\mathrm{abs})} \frac{\mathrm{d}^2 F_\nu}{B_\nu(T)}$$

(see formula VIII-5, Pottasch 1984) to estimate the mass of dust (radiating in FIR) in the nebula. We assume Q_ν at frequency ν is proportional to a, the radius of dust grains, and use of a value of $a\rho/Q_{30\mu\mathrm{m}}$ (abs) $\simeq 1.5 \times 10^{-3}$ for silicate materials and 5×10^{-2} for small graphite grains (Pottasch 1984) and use values of F_ν and B_ν (T) at 25μm to evaluate the mass of dust in the nebula. F_ν and B_ν are the FIR flux density and Planck function in frequency units at frequency ν, respectively and T, ρ and Q_ν (abs) are the temperature, specific density and absorption efficiency of the grains, respectively d is the distance to the nebula. Using for d the maximum distance of the nebula viz., 1.38 kpc (see Fesen *et al.* 1983) we obtain for $M_{\mathrm{dust}} \simeq 1.2 \times 10^{-6}\, M_\odot$ to $3.7 \times 10^{-5}\, M_\odot$ depending upon whether the grain materials are silicate or graphite.

A definite value is available only at 25 μm for the flux density of the IRAS source 17125 + 4919 identified with the planetary nebula 76 + 36 discovered by Sanduleak (1983). We have only upper limits to the flux densities at 12, 60 and 100 μm. Assuming the FIR emission from the source to have its peak flux density at 25 μm we assign a temperature of ~ 120 K for the dust. We estimate the total FIR flux from the nebula to be ~ 5×10^{-14} Wm^{-2}, and its optical depth at 25 μm to be ~ 4×10^{-6}.

A search of the IRAS point source catalogue for the FIR counterpart of the nebula S 68 within a radius of 10 arcmin (twice the size of the observing aperture along the direction of its maximum dimension) centred on its optical position did not result in any identification. If this source is an H II region or a planetary nebula it seems to be fainter than the sensitivity limits of detection of the IRAS photometric survey.

Compact H II regions can sometimes be mistaken for planetary nebulae (because of similar sizes). Some of the properties (in the infrared) that can be used to distinguish H II regions from PNe are their, (i) infrared excess, IRE (defined as the ratio of the infrared flux density to the flux density of Lyman-α-radiation produced in the nebula), (ii) dust to ionized gas mass ratio, M_d/M_g and (iii) dust temperature.

The IRE of H II regions is ~ 14 (Panagia 1976) as against an IRE $\lesssim 3$ (see Table 3 of Barlow 1983; Table 2 of Pottasch 1984; and Table 2 of Pottasch *et al.* 1984). M_d/M_g values of H II regions are ~ 10^{-2} as against ~ 5×10^{-4} for PNe (see Table VIII-1; Pottasch 1984, and Pottasch *et al.* 1984). The dust temperature of H II regions covers an extremely wide range (from several hundred degrees to tens of degrees) depending on the wavelength bands of observation, compared to ~ 120 ± 60 K for PNe.

The available infrared data on nebulae (under discussion here) are rather scanty and cannot be decisive in confirming their identification. However, the dust temperatures of the nebulae 248 – 5 and 76 + 36 are consistent with their identification (Fesen, Gull & Heckathorn 1983; Sanduleak 1983) as PNe. Also, the mass of dust in 248 – 5 is typical of mass of dust in PNe (assuming typical values of $M_d/M_g \sim 5 \times 10^{-4}$ and ionized gas mass $M_g/M_\odot \sim 5 \times 10^{-2}$ for PNe).

3. Conclusions

We identity the new planetary nebulae 248 –5, and 76 + 36 with the IRAS sources 07404 – 3240 and 17125 + 4919, respectively. We determine the dust temperature of the nebula 248 – 5 as ~ 85 K and its total FIR emission and optical depth as $\sim 9 \times 10^{-14}$ $\mathrm{Wm^{-2}}$ and 2.4×10^{-7} . We also estimate M_{dust} in the nebula to have a value $(1.2 - 37) \times 10^{-6}$ $M_\odot$. We assign a temperature of ~ 120 K to dust in nebula 76 + 36 emitting in FIR and estimate its total FIR flux and optical depth to be $\lesssim 5 \times 10^{-14}$ and $\sim 4 \times 10^{-6}$ respectively.

The temperature of dust in these two nebulae are similar to those of other planetary nebulae. Also their optical depths are similar to those of other faint planetary nebulae (*viz*., $\lesssim 10^{-5}$). Thus the FIR data from IRAS on these two objects support their identification as planetary nebulae.

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