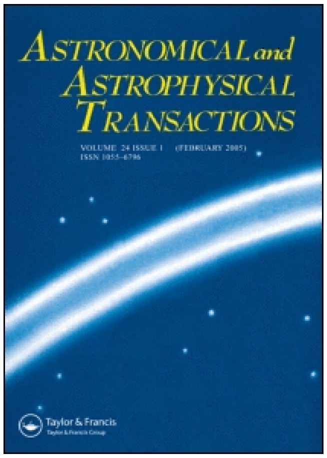

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THE FEATURES OF INFRA-RED EMISSION OF THE GALACTIC BULGE PLANETARY NEBULAE

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302 planetary nebulae located within the sector of galactic longitudes from 345° to 15° have been investigated. All nebulae have been subdivided into four mass classes and different distance scales for each class have been used. Planetary nebulae located within the galactic bulge have been selected. The galactic radial gradients of infra-red luminosities and excesses are obtained for each nebula mass class. Possible explanations of the effect are discussed.

KEY WORDS **Planetary nebulae: general – infra-red radiation – abundances**

1 INTRODUCTION

Planetary nebulae (PN) located in the galactic bulge have been intensively investigated during the last decade (Pottasch *et al.*, 1988; Ratag *et al.*, 1990; Acker *et al.*, 1991; Ratag & Pottasch, 1991; etc.). The reason for interest is in several features which discriminate the bulge PNe (BPNe) from the disk ones (DPNe). According to Ratag (1991), the BPNe have systematically cooler central stars, higher infrared excesses (IRE), their chemical abundances differ from values predicted using the DPN abundance gradients.

During the last decade new objects interpreted as BPNe were discovered in the IR range IRAS data (Pottasch *et al.*, 1988; Ratag *et al.*, 1990). These objects are not seen in optics due to high interstellar extinction, and attributing them to PNe is based on several arguments (e.g. color-color diagrams) discussed in the works of Pottasch *et al.* (1988), Ratag *et al.* (1990).

Usually it is suggested that all BPNe are located at the same distance from the Sun (close to the galactic center distance). The assumption eliminates necessity to use any distance scale but leads to confusion of PN parameter correlations which depend on the PN diameter. So several correlations essential for comparison between observations and theory can also be confused.

Amnuel, Guseinov & Rustamov (1989) subdivided all PNe into four mass classes and determined different distance scales for each PN class. Below we use this PN classification and distance scales for re-estimation of correlations between the BPN parameters and comparison of different BPN classes with the same classes of the DPNe. Section 2 contains selection of PNe attributed to BPNe. The galactic radial gradients of PN central star temperatures are discussed in Section 3. Section 4 contains estimates of correlations between IRE and the BPN and DPN parameters. Sections 5 and 6 contain general discussion and conclusions.

2 SELECTION OF OBJECTS

Because the galactic distribution of PN shows a strong concentration toward the galactic center, Gathier *et al.* (1983), Pottasch (1990), Ratag (1991) have assumed that 80 to 90% of PNe located within the 345° to 15° sector of galactic longitudes (hereafter this sector is called the central sector) really belong to the galactic bulge. Acker *et al.* (1991) removed from the BPN sample all optical nebulae with angular diameters larger than 20 arcsec, and with 6 cm fluxes exceeding 100 mJy. Ratag (1991) used the same suggestion.

According to Ratag (1991) data, 1683 IRAS sources, which can be PNe according to their IR color characteristics and distribution on the sky are located in the central sector. About 200 of them are associated with known PNe and 122 are associated with radio sources discovered in VLA surveys (Ratag, 1991; Pottasch *et al.*, 1988). The reason for this approach is small interstellar extinction in the far IR and radio ranges which allows to collect the majority of BPNe.

For our estimates we have selected all PNe (known as well as recently discovered) located in the central sector which are known as radio sources. For this purpose, the data of surveys and catalogs of Pottasch *et al.* (1988), Ratag *et al.* (1990), Ratag (1991), Ratag & Pottasch (1991), Cahn *et al.* (1992) were used. The objects with only upper limits of angular diameters are excluded from the sample because in this case PN distances cannot be estimated using distance scales Amnuel *et al.* (1989).

Below we assume that the distance of the Sun from the galactic center is 8.5 kpc, and that the galactic bulge stretches to 4 kpc from the center.

302 objects have been selected in this way and classified by Amnuel *et al.* (1989) scheme: 188 low mass PNe (L–PNe), 72 intermediate mass PNe (In–PNe), 20 massive PNe (M–PNe) and 22 anomalous PNe (A–PNe). The sample contains 214 known optical PNe and 86 objects which were classified as PNe using IRAS data and VLA surveys. The mass classes of known and new PNe are distributed as follows:

	L–PNe	In–PNe	M–PNe	A–PNe
Known PNe	140 (65%)	55 (25%)	11 (5%)	11 (5%)
New PNe	48 (56%)	17(20%)	9 (11%)	11 (13%)

Table 1. New A–PNe

VLA position (1950) R.A.	Dec	l^o	b^o	D pc	d kpc	Z pc	R kpc	IRE	Ref.
$17^h41^m10^s.8$	−27°56′53″	0.7	0.7	0.08	5.9	70	2.6	169	1
17 47 26.5	−27 37 32	1.7	−0.3	0.04	2.1	30	6.4	237	1
17 23 29.0	−40 08 40	348.4	−2.8	0.39	9.8	480	2.3	426	2
17 15 16.6	−38 13 44	349.1	−0.4	0.14	6.6	50	2.4	404	2
17 10 18.5	−33 39 45	352.2	3.1	0.27	5.3	290	3.3	87	2
17 23 44.9	−33 59 17	353.6	0.6	0.12	6.1	60	2.5	122	2
17 41 55.5	−33 35 32	356.0	−2.4	0.24	8.9	370	0.8	396	2
17 46 02.4	−31 14 21	358.4	−1.9	0.16	9.9	330	1.4	874	2
17 37 32.4	−30 00 29	358.5	0.3	0.40	9.4	50	0.9	421	2
17 44 23.8	−29 49 46	359.4	−0.8	0.28	9.4	130	0.9	1681	2
17 57 59.7	−31 22 01	359.6	−4.1	0.17	9.9	710	1.4	1832	2

Note. References: 1, Pottasch *et al.* (1988); 2, Ratag *et al.* (1990).

The known PNe were classified in Amnuel *et al.* (1989) using ten criteria. Some of the PNe were re-classified using new data on their chemical abundances, etc. (Amnuel, 1993).

Classification of new IR-radio PNe is not straightforward because data on chemical abundances, central star temperatures, and PN electron densities (the most reliable criteria) are absent for these objects. New PNe were classified using their spatial and kinematic characteristics only. Assume that new PNe are really located in the galactic bulge (distance from the galactic center, $R < 4$ kpc). Then determine the PN distances, d, and distances from the galactic plane, Z, using all four distance scales (Amnuel *et al.*, 1989). The mass class is accept if the corresponding distance leads to $R < 4$ kpc and to a Z value which does not contradict the mass class mean characteristics.

Note that the fraction of L- and In–PNe in the new PN sample decreased to 76% from 90% (for known PNe), and the fraction of M- and A–PNe increased. Increase of M–PNe and decrease of L–PNe fraction is explained naturally by selection effects because fainter and more distant objects are discovered.

The increase of A–PNe fraction is surprising. We have defined as A–PNe the new objects with anomalously small surface radio brightness. Distances to these objects (listed in Table 1), estimated using L-, In- and M–PNe distance scales, are sufficiently larger than the galactic center distance. Only use of A–PN distance scale allows to place these objects at $d < 10$ kpc. According to Amnuel *et al.* (1989), A–PNe have anomalously low mass of ionized envelope and possibility of their observation at $d > 3$ kpc is very problematic. The majority of known A–PNe are located at $d < 4$ kpc, contrary to new objects located in the galactic bulge. Note that only these objects also have anomalously high values of IRE (Section 4) and, most probably, they are background objects. Without taking into account new A–PNe, distribution of new PNe according to their mass classes is close to the same for known PNe in a selected sector (65% for L–PNe, 23% for In–PNe, and 12% for M–PNe).

3 THE CENTRAL STAR TEMPERATURES

Ratag *et al.* (1990) found that temperatures of central stars in the BPN are lower than those in the galactic disk. They found the median $T_{\rm eff} \sim 85\,000$ for DPNe and $\sim 45\,000$ K for BPNe. We have taken this effect into account for interpretation of high IRE values in BPNe.

Following the method suggested by Ratag *et al.* (1990), we have selected complete data on $T_{\rm eff}$ for 209 PN central stars (Kaler, 1983; Gathier & Pottasch, 1989; Kaler, Shaw & Kwitter, 1990; Ratag, 1991; Zhang & Kwok, 1991; etc.), 106 of them are located in the central sector. The sample contains 23 L-, 21 In-, 3 M-, 3 A–PNe in the galactic bulge and 72 L-, 54 In-, 14 M-, 19 A–PNe in the galactic disk.

Approximating $T_{\rm eff}$ vs. R correlation in the form of

$$\log T_{\rm eff} = a + b \times R$$

we obtain for the DPNe (159 PNe)

$$\log T_{\rm eff} = (4.69 \pm 0.20) + (2.25 \pm 0.75)10^{-2} R$$

and for 50 BPNe

$$\log T_{\rm eff} = (4.81 \pm 0.17) + (0.07 \pm 2.24)10^{-2} R$$

where R is in kpc.

So, mean $T_{\rm eff}$ decreases with decreasing R in the galactic disk, and in the bulge boundary ($R \sim 4$ kpc) $T_{\rm eff} \sim 6\ 10^4$ K. Within the bulge, $T_{\rm eff}$ does not vary and, on average, is $\sim 6\ 10^4$ K. At $R = 8.5$ kpc (the solar distance), $T_{\rm eff} \sim 7.5\ 10^4$ K.

This picture reflects variations in relative fractions of visible different mass classes of PN. Inside each mass class of PNe, $T_{\rm eff}$ varies little when R increases.

Ratag *et al.* (1990) concluded that $T_{\rm eff}$ difference in PBNe and DPNe leads to the observed differences in IRE. It will be shown below that this effect cannot explain the obtained correlations between IRE and R, due to essential difference from $T_{\rm eff}$ vs. R correlations (Section 4.1) and absence of IRE vs. $T_{\rm eff}$ correlations (Section 4.4).

4 INFRA-RED EXCESSES IN PN RADIATION

4.1 The galactic radial gradients

Ratag *et al.* (1990) found that the median value of PN infra-red excess (IRE) for BPNe was larger than for DPNe. This conclusion was obtained using IRE data on 152 objects in the central sector (note that gaussian angular diameters were measured only for 97 of them). Ratag *et al.* (1990) showed that, contrary to known PNe, new PNe (discovered during IRAS and VLA surveys) have IRE values which vary in broad limits.

Table 2a. The radial galactic gradients of IRE (in the form log IRE $= a + b \times R$)

	R, kpc	*a*	Δa	*b*	Δb	*N*	*Correl. coeff.*
L–PN	< 4	1.52	0.33	−0.190	0.041	67	−0.49
	< 7	1.39	0.30	−0.149	0.015	152	−0.64
	> 7	0.76	0.34	−0.050	0.033	77	−0.17
In–PN	< 4	0.95	0.31	−0.110	0.049	42	−0.34
	< 7	0.88	0.30	−0.076	0.019	66	−0.45
	> 7	0.21	0.25	+0.009	0.019	52	0.06
M–PN	all	0.69	0.31	−0.045	0.016	30	−0.47
A–PN	all	1.38	0.37	−0.130	0.043	16	−0.63

Table 2b. The radial galactic gradients of $L_{\rm IR}/L_{\odot}$

	R, kpc	*a*	Δa	*b*	Δb	*N*	*Correl. coeff.*
L–PN	< 4	3.49	0.33	−0.170	0.040	68	−0.44
	< 7	3.26	0.32	−0.120	0.020	150	−0.52
	> 7	3.11	0.52	−0.088	0.050	79	−0.20
In–PN	< 4	3.38	0.29	−0.070	0.052	37	−0.22
	< 7	3.39	0.38	−0.081	0.025	62	−0.39
	> 7	2.54	0.53	+0.018	0.047	45	+0.06
M–PN	all	3.48	0.47	−0.052	0.023	30	−0.39
A–PN	all	3.11	0.55	−0.169	0.063	16	−0.58

We select for the analysis 414 PNe with IRE data compiled from the studies by Ratag *et al.* (1990), Pottasch *et al.* (1988), Zhang (1993), 234 of them located in the central sector.

Let us select PNe with IRE> 10. 18 of BPNe have IRE> 10, and 17 of them were discovered in the VLA survey (Pottasch *et al.*, 1988; Ratag *et al.*, 1990). Moreover, no In- or M–PNe (both known and newly discovered) have IRE> 10. All new bulge objects classified as A–PNe in Section 2 have IRE> 70. 7 L–BPNe of 42 also have IRE> 50. In the galactic disk, only two PNe have such a high IRE – one of L–PNe and one of A–PNe.

In the IRE< 70 range, no essential difference in IRE between old and new PNe of all mass classes was found.

Moreover, no one of known A–PNe (2 A–BPne and 14 A–DPNe) has IRE> 14, while no one of new objects classified as A–PNe has IRE< 70. Most probably, all new objects with IRE> 70 (also among L–PNe) are really not PNe.

Strong IRE vs. R correlations exist for all PN classes; see Figure 1 and Table 2a.

Excluding new A- and L-type objects with IRE> 70, which, most probably, are not PNe, we obtain that for all PN classes negative IRE vs. R correlations exist in the $R < 7$ kpc range and the module of regression coefficient increases when approaching the galactic center. Both average IRE value and its gradient are the largest in the L–PN sample and the smallest in M–PN sample. In the $R > 7$ kpc

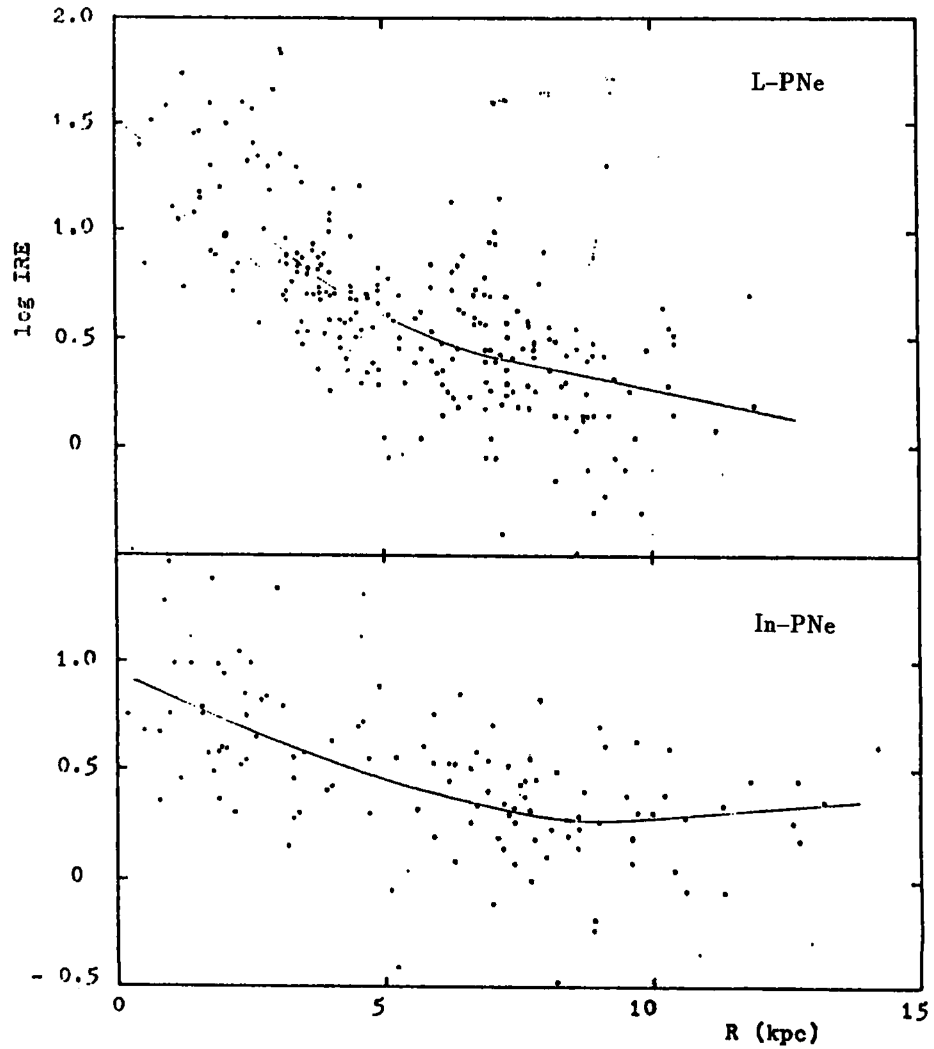

Figure 1 Correlations between IRE and R for each PN mass class. New A–PNe designated by crosses can be background objects.

range, the IRE radial gradients are close to zero for all PN types. In this region of the galactic disk, L–PNe have, on average, IRE $\sim$ 2.5; $\langle$IRE$\rangle$ for In- and M–PN respectively are, approximately, $\sim$ 2 and $\sim$ 1.5. The values of $\langle$IRE$\rangle$ in the galactic bulge are $\sim$ 22 (L–PNe), $\sim$ 10 (In- and A–PNe), $\sim$ 7 (M–PNe). Distribution of IRE for known A–PNe is intermediate between those for In- and M–PN, which corresponds to their physical classification.

In principle, PN total IR luminosity, $L_{\rm IR}$, decreases with R value like IRE, as it can be seen from Table 2b and Figure 1. In the galactic center region, all PN

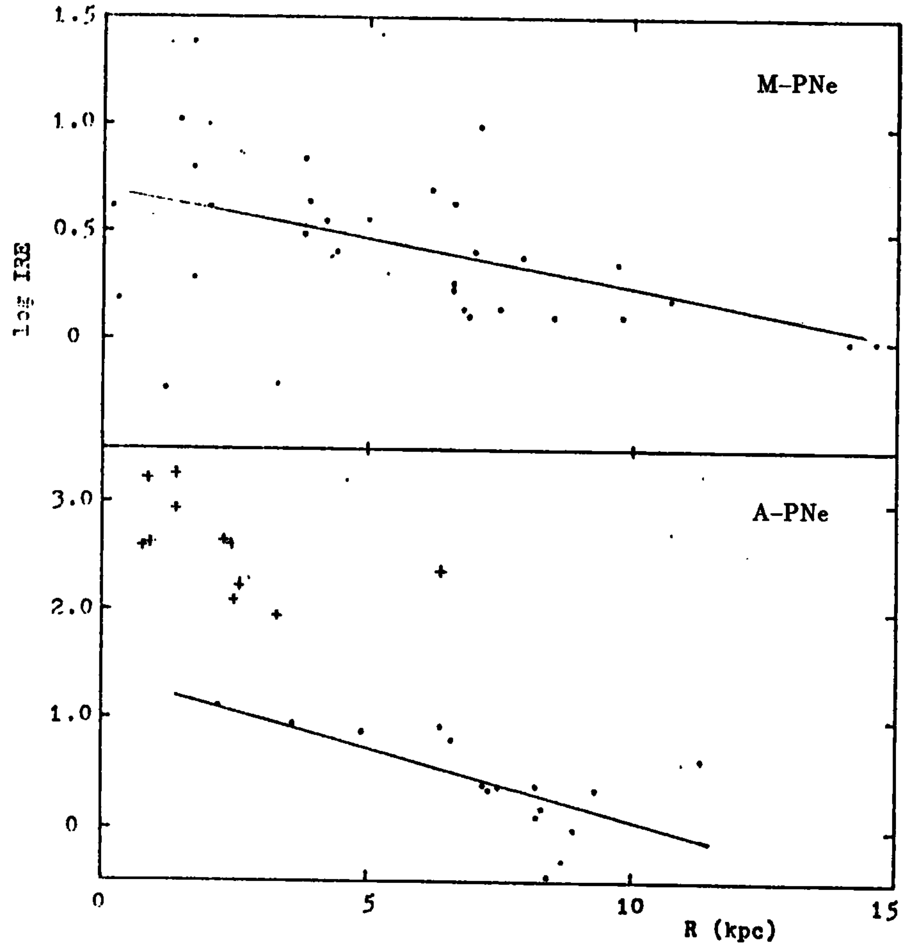

Figure 1 (Continued)

mass classes (excluding A–PNe) have $\langle L_{\mathrm{IR}} \rangle \sim 2,500$–$3,000\ L_{\odot}$. In the galactic disk, $R > 7$ kpc, L–PNe have lower $\langle L_{\mathrm{IR}} \rangle$ than M–PNe ($\sim 200 L_{\odot}$ and $\sim 1,000 L_{\odot}$, respectively), in contrast with IRE behavior.

Change of mass of radiating dust, M_D, with R value can be estimated only qualitatively due to poor knowledge of dust physical parameters. The mass of PN dust envelope is

$$M_D = \frac{a \rho L_{\nu}}{3\pi Q_{\nu} \beta_{\nu}}$$

where Q_{ν} and L_{ν} are dust absorptivity and luminosity at frequency ν, a and ρ are size and density of a dust grain, B_{ν} is Plank function. Since possibly $Q_{\nu} \sim a$ (Pottasch, 1984), the quantity $a\rho/Q_{\nu}$ may be independent of the particle size.

Table 2c. The radial galactic gradients of T_D

	R, kpc	*a*	Δa	*b*	Δb	*N*	*Correl. coeff.*
L-PN	all	2.09	0.12	0.003	0.004	180	0.05
In-PN	all	2.13	0.13	−0.003	0.004	97	−0.08
M-PN	all	2.08	0.13	−0.002	0.010	21	−0.04
A-PN	all	2.03	0.16	−0.011	0.019	16	−0.16

Table 2d. The radial galactic gradients of M_D

	R, kpc	*a*	Δa	*b*	Δb	*N*	*Correl. coeff.*
L-PN	all	−2.81	0.43	−0.095	0.015	180	−0.44
In-PN	all	−2.66	0.43	−0.057	0.015	95	−0.38
M-PN	all	−2.00	0.48	−0.080	0.036	20	−0.46
A-PN	all	−2.52	0.49	−0.130	0.060	16	−0.52

Assuming that $a\rho/Q_\nu \sim 0.05$ (small graphite grains) and using data on 30 μm IR intensity, we can obtain the parameters of correlations between M_D and R listed in Table 2c. As it can be seen, M_D for M–PNe is larger than L–PNe by a factor of ~ 10.

Dust temperature, T_D, decreases with D increasing (see Section 4.3); however, no sufficient correlation of T_D with PN mass-class and R value is obtained using data on 314 PNe (180 L–PNe, 97 In–PNe, 21 M–PNe and 16 A–PNe). It is important for IRE interpretations (Section 5).

4.2 Correlations between IRE and Z

With the goal of search for possible correlations between IRE and PN Z-coordinate, let us take into consideration different mass class PNe located within three R ranges:

Table 3. The scale heights, β(pc), of PNe with different IRE values

	R < 4 *kpc*			*R* = 4–7 *kpc*			*R* > 7 *kpc*		
	IRE	β	*N*	*IRE*	β	*N*	*IRE*	β	*N*
L-PNe	< 10	410± 20	41	< 3	330± 30	31	< 2	270±10	36
	10–20	360± 30	9	3–10	220± 20	48	2–5	130±10	32
	> 20	210± 10	19	> 10	170±110	6	> 5	210±20	10
In-PNe	< 3	210± 30	10	< 3	300± 20	11	< 2	470±20	25
	3–10	220± 20	24	> 3	280± 30	15	2–3	640±20	17
	> 10	170± 30	7				> 3	180±30	10
M-PNe	< 4	340±110	4	< 2	210± 20	4	< 1.5	250±40	5
	> 4	80± 20	7	>2	60± 10	5	> 1.5	60±10	5

Table 4a. Correlations between log IRE and PN diameter (in the form log IRE = $a + b \times \log D$)

	a	Δa	b	Δb	N	*Correl. coeff.*
			The galactic bulge PNe ($R < 4$ kpc)			
L-PNe	1.44	0.36	0.48	0.17	69	0.33
In-PNe	0.98	0.32	0.28	0.13	40	0.33
M-PNe	1.08	0.33	1.00	0.36	11	0.68
			The galactic disk PNe (4 kpc$< R <$ 7 kpc)			
L-PNe	0.58	0.27	0.01	0.08	85	0.01
In-PNe	0.57	0.23	0.11	0.16	25	0.14
M-PNe	0.04	0.19	−0.49	0.26	9	−0.58
			The galactic disk PNe ($R > 7$ kpc)			
L-PNe	0.17	0.36	−0.18	0.09	79	−0.22
In-PNe	0.22	0.24	−0.10	0.07	52	−0.20
M-PNe	0.19	0.30	−0.21	0.24	10	−0.30
A-PNe	−0.29	0.27	−0.60	0.22	11	−0.68

<4, 4–7, and >7 kpc. For PNe in these R ranges, the values of scale heights for different IRE ranges have been calculated, with the results listed in Table 3. It can be seen that strong IRE vs. Z correlations exists for all PN mass classes separately. If all PNe (without subdividing into mass classes) are taken as a sample, then no correlation between IRE and Z is found due to different $\langle$IRE$\rangle$ for different mass classes of PNe.

For each PN class, the objects with large IRE values are distributed more broadly with respect to the galactic plane. Combining this effect with the increase of mean interstellar gas (and dust) density towards the galactic plane, IRE vs. R correlation also turns out to be the consequence of interstellar matter concentration towards the galactic center.

4.3 Correlations between IRE and D

Ratag (1991) investigated IRE correlation with BPN angular diameter (which directly corresponded to linear PN diameter, D, because BPN distances in the sample were assumed the same). Earlier a strong negative correlation between IRE and nebular age was indicated for nearby PNe (Pottasch *et al.*, 1984). However, Ratag (1991) found no correlation between IRE and PN angular diameter for his BPN sample.

An interesting effect is obtained when three PN samples are taken into consideration (PNe located at $R < 4$ kpc, 4–7 kpc and $R > 7$ kpc). As it can be seen from Table 4a, for all classes of PNe located at $R > 7$ kpc (including nearby PNe investigated by Pottasch *et al.*, 1984), a really essential negative correlation (IRE $\sim D^{-0.2}$) between IRE and D exists which conforms to the conclusion of Pottasch *et al.* (1984). The slope decreases to − 0.11 for the DPNe located at R between 4

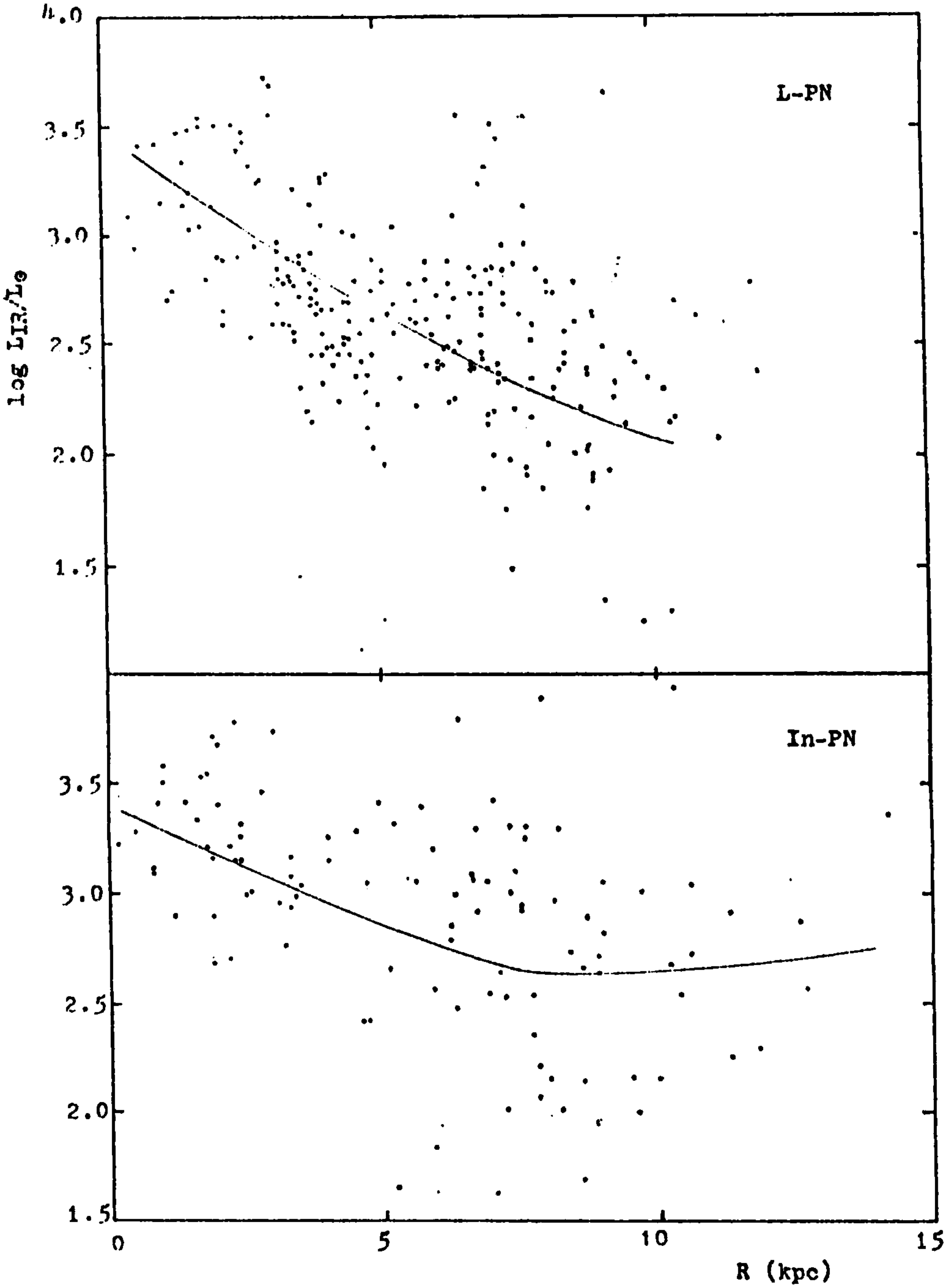

Figure 2 Correlations between L_{IR} and R for each PN mass class.

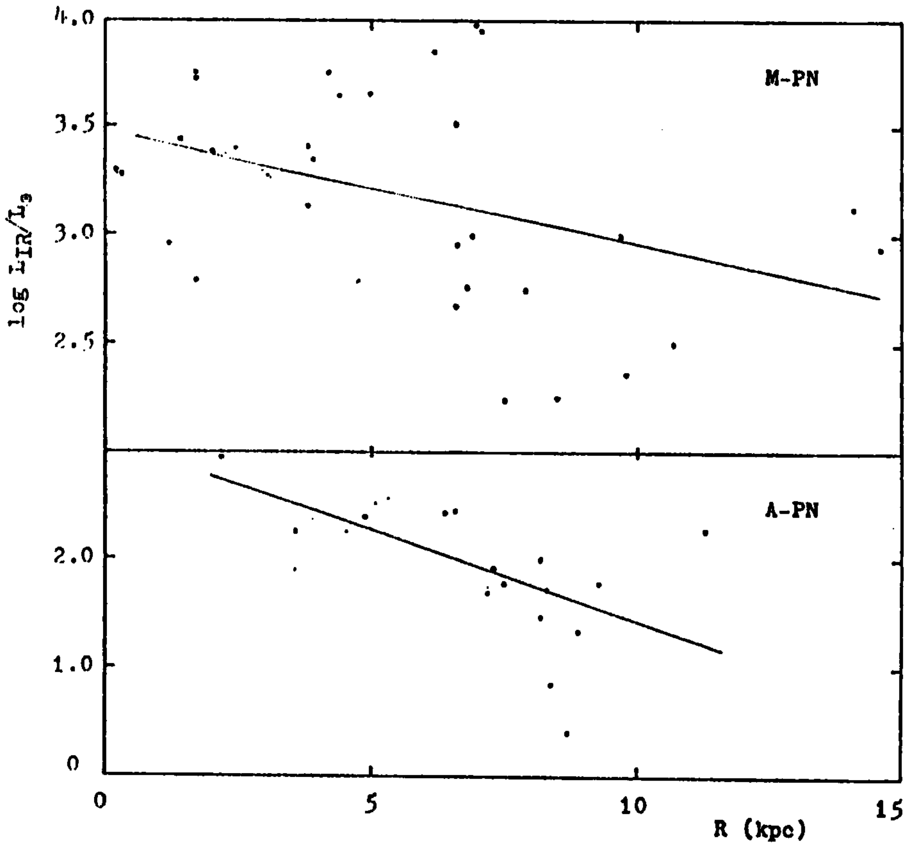

Figure 2 (Continued)

and 7 kpc. Contrary, for the BPNe a strong positive correlation between IRE and D exists (IRE $\sim D^{0.3}$). The same behavior (positive correlation at $R < 4$ kpc and negative one at $R > 7$) is indicated also if each PN mass class is taken into account separately (Table 4a).

L_{IR} vs. D correlations also vary with PN distance from the galactic center. For L–PNe the regression coefficient varies from positive (L–BPNe) to negative values (L–DPNe). For the bulge In- and M–PNe, L_{IR} do not vary with D while in the galactic disk an essential negative correlation exists (Table 4b).

4.4 Correlation between IRE and T_{eff}

Pottasch *et al.* (1984) found that high IREs are typical for small, high dust temperature PNe, which are excited by comparatively bright, low temperature stars. Following this, Ratag (1991) concluded that the BPNe are, basically, younger objects that the DPNe, due to their high IRE.

Table 4b. Correlations between log $L_{\mathrm{IR}}/L_{\mathrm{O}}$ and PN diameter

	a	Δa	b	Δb	N	*Correl. coeff.*
			The galactic buldge PNe ($R < 4$ kpc)			
L–PNe	2.96	0.37	−0.01	0.18	69	−0.01
In–PNe	3.02	0.28	−0.24	0.12	40	−0.32
M–PNe	3.31	0.30	−0.02	0.33	11	−0.02
			The galactic disk PNe ($R =$ 4–7 kpc)			
L–PNe	2.17	0.27	−0.38	0.08	85	−0.45
In–PNe	1.86	0.25	−1.27	0.15	25	−0.87
M–PNe	2.29	0.29	−1.40	0.39	9	−0.80
			The galactic disk PNe ($R > 7$ kpc)			
L–PNe	1.53	0.41	−0.77	0.11	79	−0.64
In–PNe	1.84	0.28	−1.12	0.11	52	−0.85
M–PNe	2.38	0.30	−1.41	0.25	10	−0.90
A–PNe	0.79	0.40	−0.99	0.32	11	−0.72

Note, however, that in the range of PN central star temperatures (30–120 thousands of K) theoretical IRE vs. T_{eff} dependence is weak and nonmonotonous (Zijlstra *et al.*, 1989). So, the conclusion about the BPN young age needs confirmation. There is no evidence that BPNe disappear at systematically smaller diameters than DPNe. Taking into consideration all PNe located in the central sector, it can be shown that 50% of the observed DPNe have $D > 0.1$ pc while among BPNe this fraction reaches 69%.

To search for correlation between IRE and T_{eff}, let us select 141 PNe in three R ranges ($R < 4$ kpc, 4–7 kpc, and > 7 kpc) with the aim to decrease IRE vs. R correlation influence. PN IRE data were averaged in four T_{eff} ranges: < 50, 50–70, 70–100, and > 100 thousand K. The results are shown in Figure 3. Only one effect can be definitely seen: decrease of IRE in selected T_{eff} range when R increases. Weak increase of IRE in $T_{\mathrm{eff}} < 50\,000$ K range (by a factor of ~ 1.5) can be noticed, but the reality of the effect is doubtful due to large statistical errors.

In fact, PN dust temperature, T_D, depends on D for PNe located at $R > 7$ kpc, as it was shown by Pottasch *et al.* (1984). Use of PN D values determined with Amnuel *et al.* (1989) distance scales does not change this conclusion. It is interesting that T_D values, averaged within each PN class and three R ranges ($R < 4$, 4–7, and > 7 kpc), are very close to each other. T_D vs. D dependence (using T_D data for 399 PNe from Zhang & Kwok, 1993) is very flat for L–BPNe; in the disk the slope increases, $T_D \sim D^{-1/6}$. For In–PNe the slope of the T_D vs. D dependence is approximately constant in the bulge and in the disk, $T_D \sim D^{-1/4}$. Note that at $R > 7$ kpc, T_D for all PN classes is ~ 85 K when D approaches 1 pc. However, the slope is largest for M–PNe and smallest for L–PNe: at small PN diameters dust is cooler in L–PNe than in M–PNe.

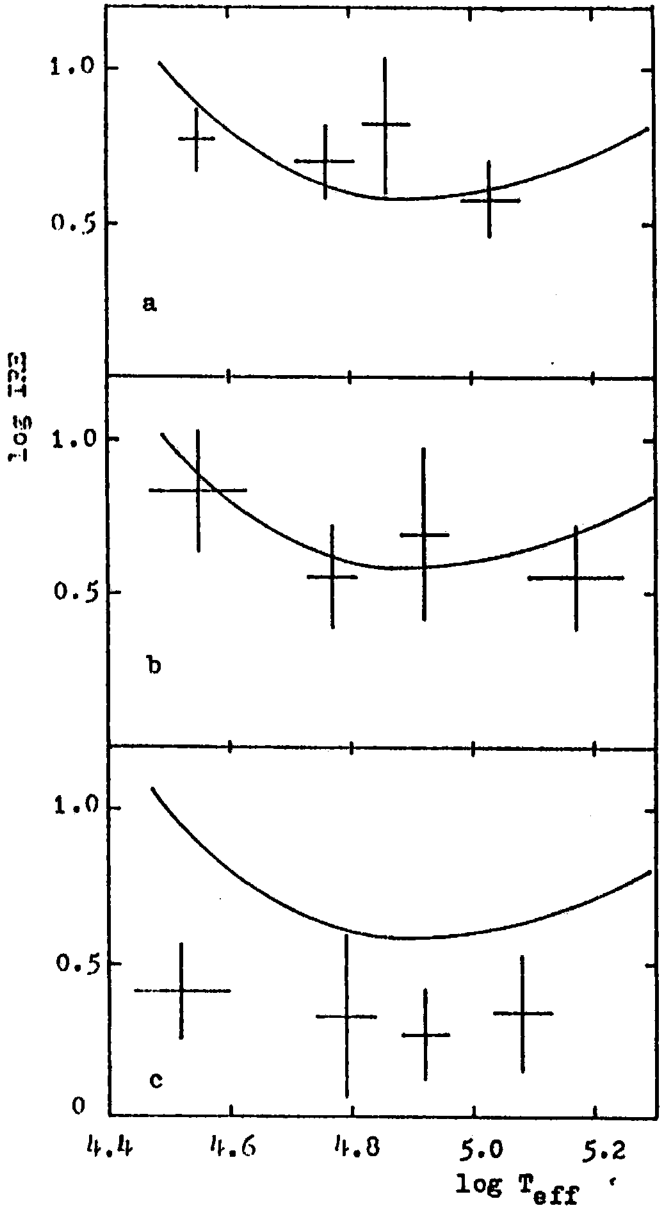

Figure 3 Correlations between IRE and central star temperature T_{eff}. The theoretical curve (Zijlstra *et al.*, 1989) is shown by a solid line. a, The bulge PNe, $R < 4$ kpc; b, the disk PNe, $4 < R < 7$ kpc; c, the disk PNe, $R > 7$ kpc.

So the conclusion about negative IRE vs. PN age correlation is confirmed only for objects at $R > 7$ kpc. For BPNe, on the contrary, a positive correlation between IRE and D (and age) exists.

5 DISCUSSION

As it was shown by Pottasch *et al.* (1984), Ratag *et al.* (1990), Ratag (1991), high IREs can be explained in terms of both PN central star radiation and interstellar radiation field. According to these authors, the basic reason for high IRE in the BPNe is the young age of objects. Really, correlation between PN age and IRE was derived for nearby PN (Pottasch *et al.*, 1984), but extrapolation of the effect to the BPN sample is not correct without safe arguments.

Zijlstra *et al.* (1989) have selected 12 PNe among OH emitting young galactic objects. Excluding the M–PN NGC 6302, these PNe have IRE> 4 (7 of 12 objects have IRE> 10). Most of new high IRE objects from the lists of Pottasch *et al.* (1988), Ratag *et al.*, (1990), Ratag (1991) belong to A-type and/or are not PNe as it was shown above. For the remaining PNe, $N(D)$ distributions in the disk and in the bulge do not confirm the suggestion of youth of the BPNe.

Several hypotheses are being discussed for the explanation of high IREs in the BPNe (Ratag *et al.*, 1990; Ratag, 1991). One of them is higher abundances in BPNe, which results in more dust to be formed and, correspondingly, in higher infrared radiation. Ratag (1991) noted that the effect was small because the abundances in the BPNe and DPNe did not differ essentially.

Another hypothesis of Ratag *et al.* (1990) explains high IREs in BPNe in terms of low $T_{\rm eff}$, which leads to smaller number of Lyman photons. However, it has been shown in Section 3 that the difference between central star temperatures in BPNe and DPNe is not essential. Moreover, within a PN mass class (particularly, L–PNe) $T_{\rm eff}$ differs only slightly while essential radial IRE gradients exist. So, $T_{\rm eff}$ changes cannot solve the IRE problem.

The effect of interstellar radiation field seems more likely. Taking into account the interstellar radiation field in the solar vicinity allows us to explain only $\sim 2 \times 10^{-3}$ of all IR dust emission in PNe with $D \sim 0.1$ pc. The situation changes essentially in the galactic bulge. Mezger (1989) estimated that PNe with $D \sim 0.1$ pc located near the galactic center intercepted to 100–400 $L_\odot$. Dust reradiates at least 2/3 of this luminosity. For $D \sim 0.3$ pc, $\sim 3,000 L_\odot$ can be reradiated in IR range. For L–PNe the effect is large because the central star luminosity does not exceed $\sim 2,000 L_\odot$.

Probably this effect together with reradiation of the central star emission can explain the observed IRE correlations with PN parameters.

Really, at $R > 7$ kpc the effect of interstellar radiation field is negligibly small. Basically, dust in PNe reradiates the central star emission. Then, the evolution effects may take place (decrease of central star luminosity) which lead to the observed negative correlation between IRE and D. Mean central star temperature increases when passing from L- to M–PNe, and the mean IRE decreases (approximately by a factor of 2–2.5). However, direct correlations between IRE and $T_{\rm eff}$ are very weak (Section 3), and IRE vs. PN mass class dependence arises, most probably due to the increase of central star luminosity when passing from L- to M–PNe.

Table 4c. Correlations between log T_D and PN diameter

	a	Δa	b	Δb	N	*Correl. coeff.*
			The galactic bulge PNe ($R < 4$ kpc)			
L–PNe	2.01	0.15	–0.10	0.08	32	–0.21
In–PNe	1.80	0.12	–0.30	0.08	20	–0.67
			The galactic disk PNe (R = 4–7 kpc)			
L–PNe	1.93	0.10	–0.15	0.04	77	–0.43
In–PNe	1.85	0.10	–0.30	0.07	25	–0.68
M–PNe	2.04	0.05	–0.08	0.07	9	–0.39
A–PNe	1.81	0.06	–0.20	0.07	5	–0.87
			The galactic disk PNe ($R > 7$ kpc)			
L–PNe	1.93	0.09	–0.16	0.02	79	–0.62
In–PNe	1.94	0.08	–0.20	0.03	51	–0.67
M–PNe	1.94	0.15	–0.25	0.12	10	–0.60
A–PNe	1.68	0.14	–0.29	0.11	11	–0.65

Table 4d. Correlations between log M_D and PN diameter

	a	Δa	b	Δb	N	*Correl. coeff.*
			The galactic bulge PNe ($R < 4$ kpc)			
L–PNe	–3.01	0.45	0.11	0.26	30	0.08
In–PNe	–1.83	0.35	0.82	0.22	19	0.68
			The galactic disk PNe (R = 4–7 kpc)			
L–PNe	–2.90	0.40	0.39	0.14	75	0.31
In–PNe	–2.76	0.37	0.20	0.25	25	0.16
M–PNe	–3.26	0.33	–1.06	0.44	8	–0.70
			The galactic disk PNe ($R > 7$ kpc)			
L–PNe	–3.77	0.47	–0.19	0.13	74	–0.18
In–PNe	–3.51	0.42	–0.41	0.15	51	–0.36
M–PNe	–2.96	0.61	–0.60	0.50	10	–0.39

When approaching the bulge, the interstellar radiation field effect increases. In the R = 4–7 kpc range this effect is comparable with central star luminosity for L–PNe while for In- and M–PNe the latter effect remains predominant.

Within the bulge, interstellar radiation field effect becomes the major one, which leads to positive correlation between IRE and D. Really, all mass classes of the BPNe (excluding A–PNe) have similar median values of total IR luminosities (see Section 4.1) while mean central star luminosities vary from $\sim 2,000 L_\odot$ (L–PNe) to $\sim 20,000 L_\odot$(M–PNe). Both IRE and $L_{\rm IR}$ vs. D correlations allow to conclude that dust infrared emission in L–BPNe depends, basically, on the interstellar radiation field. This dependence is also effective for In- and M–PNe, but it is weaker due to larger central star luminosity PNe of these mass classes.

Note that interstellar radiation field has no sufficient influences on the value of T_D (which does not vary with R). The influence is, obviously, through heating of greater dust mass in PNe which leads to increase of IR luminosity and IRE value. Decrease of T_D with PN expansion (independently on PN mass class and distance from the galactic center) shows, probably, that dust heating and cooling processes in PNe depend, basically, on particle size, structure, and number density while external radiation field (stellar or interstellar) influences the mass of heated dust. This conclusion is confirmed by M_D vs. D direct correlations (Table 4d) which depend on R, in contrast to correlations between T_D and D.

Weak correlation between IRE and Z in each PN mass class can also be an argument in favour of IRE interstellar radiation field relation.

6 CONCLUSIONS

Properties of the galactic bulge PNe were investigated and the results were compared with the data on PNe in the galactic disk. All PNe were subdivided into four mass classes according to the classification of Amnuel *et al.* (1989). Different distance scales for each mass class PNe were also used.

302 radioemitting PNe located in the sector of galactic longitudes between 345° and 15° were selected.

Both PN infra-red luminosity and infra-red excess in each PN mass class increase when approaching the galactic center. In the galactic disk (for $R > 7$ kpc), IRE values do not vary essentially with R, and ⟨IRE⟩ depend, basically, on PN mass class: when passing from L- to M–PN, IRE decreases.

The values of $\langle T_{\text{eff}} \rangle$ do not depend essentially on R and, basically, are determined by observed proportions between different PN mass classes located at selected R distance (in contrast to Ratag *et al.*, 1990). Variations in $\langle T_{\text{eff}} \rangle$ cannot explain obtained correlations between IRE and R.

L_{IR} and IRE in PNe, most probably, depend on dust mass, M_D, in different PN classes. M_D in M–PNe is larger than the same in L–PNe by a factor of ~ 10. M_D values decrease when R increases which corresponds to the IRE and L_{IR} vs. R correlations. In contrast, dust temperature, T_D, decreases when PN diameter increases; however, no significant correlation of T_D with PN mass class and R value has been obtained.

Data analysis shows that, probably, increase of interstellar radiation field when approaching the galactic center effectively heats PN dust. This results in M_D increase while T_D practically does not depend on PN mass class and PN location in the Galaxy.

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