1990MNRAS.243..236M

Mon. Not. R. astr. Soc. (1990) **243**, 236–240

New old PN in the southern sky

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Accepted 1989 September 7. Received 1989 August 18; in original form 1989 May 8

SUMMARY

From a search of 417 ESO R and 112 SERC J film copies, 16 new planetary nebulae have been found. All of them are of very low surface brightness and range in angular diameter from 0.1 to 6 arcmin. They are highly evolved objects. The central stars have apparent magnitudes of $17.5 \leq m_J \leq 22.0$; for these estimates, we have carried out a series of direct measurements of image diameters for stars of known magnitude to provide a calibration. Three of our nebulae are coincident with *IRAS* point sources; for two of them, several physical parameters could be derived.

1 INTRODUCTION

During 'quality control' examinations and special searches for planetary nebulae (PN), a number of these objects were found on plates or films of the ESO/SERC survey (Kohoutek 1977; Longmore 1977; Longmore & Tritton 1980; Hartl & Tritton 1985; Saurer & Weinberger 1987). In the latter paper, we pointed out that a considerable number of PN should still be detectable in the southern sky, and that conclusion led us to start an extensive inspection of *R* and *J* film copies.

As our institute is supplied with the second edition of the *ESO/SERC Atlas*, we were able to examine all the film copies contained in the shipments 1–12, i.e. half of the complete atlas. By excluding the 72 *J* films already searched by Saurer & Weinberger (1987) we inspected 417 *R* films and 112 *J* films.

The film copies were scanned by eye which permitted us to identify objects down to a diameter of 15–20 arcsec (i.e. 0.2–0.3 mm); consequently there is a bias towards the discovery of the more extended nebulae. It is difficult to estimate the completeness of our search, but due to independent checks on about 20 films, and our detection rate of already known faint PN, we are confident that we have found more than 90 per cent of the detectable extended PN. However, a survey (with a microscope) of areas in the galactic plane for rather small nebulae might be rewarding; we carried out this time-consuming search on the film copy R 226 and thus detected one of our objects.

We would like to mention that several of our results discussed in the following two sections could be verified or completed by us by a brief check of those *J*, *R* and *B* film copies at the ESO headquarters in München/Garching that are relevant for our work but are not available up to now at our institute.

Our discovery of 20 new PN (11 obvious and five possible objects presented in this paper, and four described in Saurer & Weinberger 1987) on 50 per cent of the atlas is a conclusive indication that another one or two dozen, low surface brightness nebulae could be found.

2 THE NEBULAE

In Fig. 1, the 16 nebulae are shown, reproduced from ESO *R* film copies; a list is given in Table 1. The distinction between 'true' and 'possible' PN generally refers to a characteristic morphology of the nebulae and the presence of a faint, blue star. The nebulae are arranged according to increasing α in Table 1; in addition to equatorial and galactic coordinates, the numbers of the *R* film and rectangular coordinates (measured in millimetres from the south-eastern corner of a field) are listed for identification purposes. In the last column, the size of *R* is given in arcmin. The 1950 equatorial coordinates refer to the central stars (which could be identified in 10 of the 11 true PN) and were measured from four SAO stars. The average error is ± 3 arcsec, which is consistent with the measurement precision of 0.05 mm. The coordinates of the residual nebulae are given for the optical centres of the nebular images and have an average accuracy of 10 arcsec.

As can be seen from the reproductions, the surface brightnesses of all objects is very low (because we obtained high contrast photographs the surface brightnesses are exaggerated). A comparison of the surface brightnesses in *R* (SB_R) with those on *J* (SB_J) and ESO *B* (SB_B) showed that, with the exception of 'true' nebulae 2, 4, 6 and 9, and the 'possible' nebulae 4 and 5, $SB_J > SB_R$ (and SB_R is always $\gtrsim SB_B$). This result, and the fact that most of the central stars appear to be very blue, can be interpreted as indicating small or negligible interstellar extinction (less than a few tenths of mag in E_{B-V}) along the line-of-sight to the majority of our PN. In Section 4 we shall demonstrate this reasoning for two cases of very distant nebulae. As a consequence, our nebulae are in late phases of their evolution and can be regarded as 'old PN'.

The diameter of the possible PN no. 1 in *J* is distinctly smaller than in R; probably ionization stratification is the cause. A similar case holds true for PN no. 6 that is obviously the most reddened object of our sample of PN.

Several of our objects are located near the borders of the fields and therefore are visible on more than one film in the same colour.

3 THE CENTRAL STARS

We assume that the real central stars are those that are very blue and located at or near the centres of the nebulae. There is one exception, however, as can be seen from Fig. 1, the star that is assumed to be the real nucleus of the 'true' PN no. 4 is

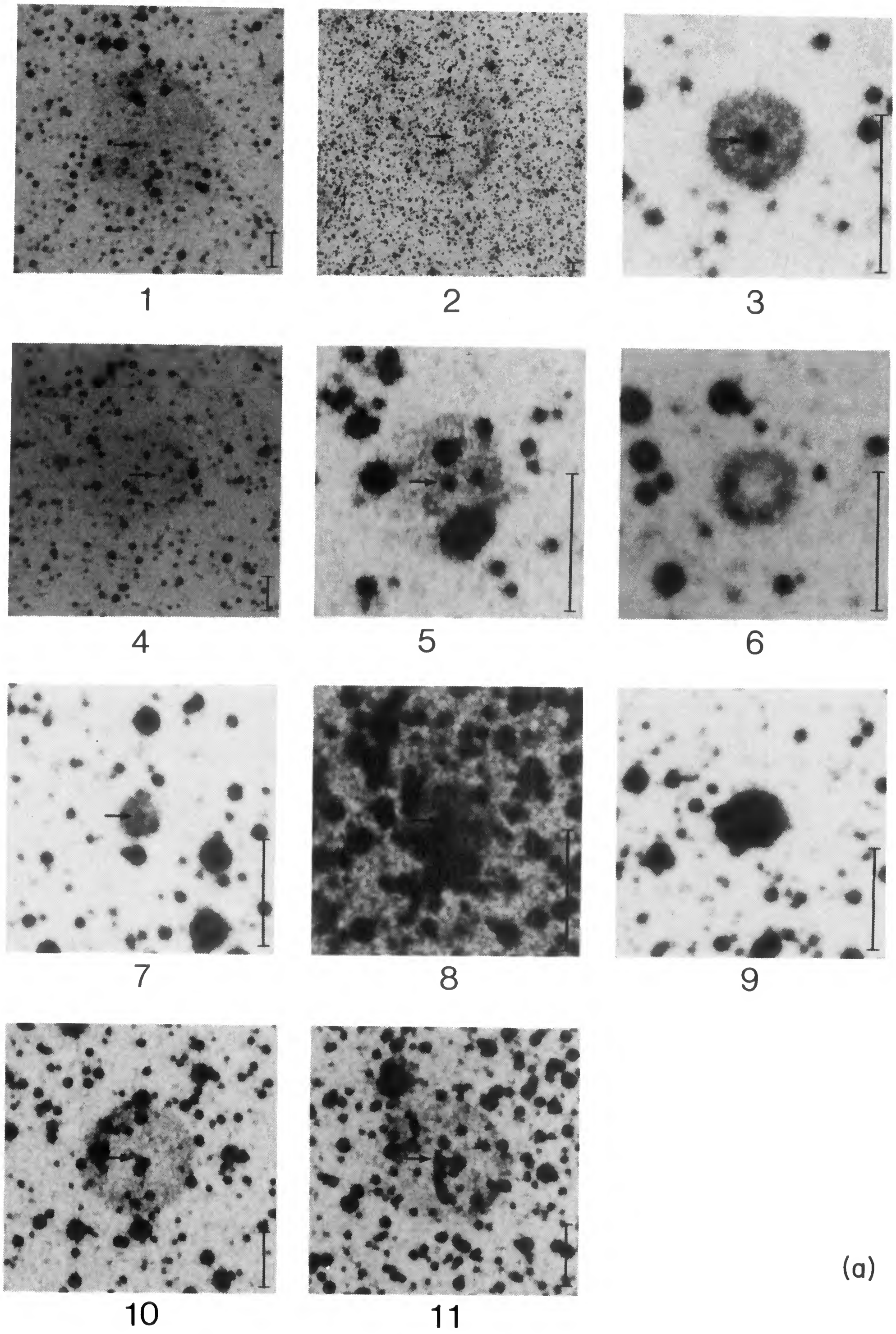

Figure 1. Reproductions of the new planetary nebulae candidates listed in Table 1, reproduced from ESO R film copies by permission from the European Southern Observatory. North is at the top, East to the left. The arrows mark blue central stars and the bars indicate $\frac{1}{2}$ arcmin. (a) True PN, (b) possible PN.

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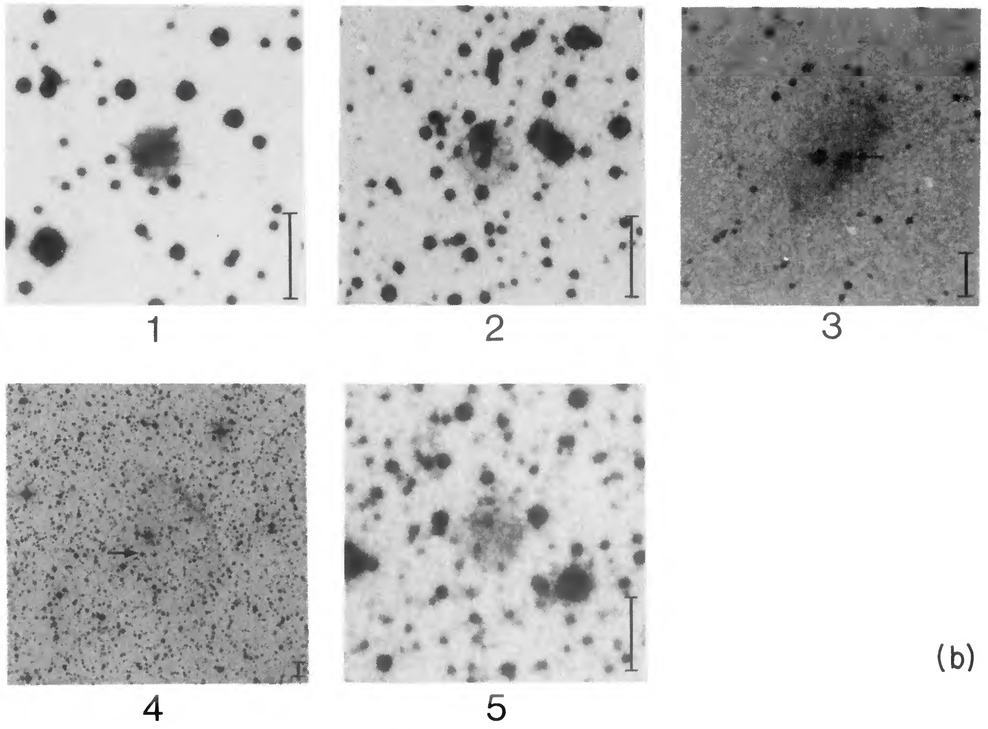

Figure 1 – *continued.*

Table 1. List of new planetary nebulae found on ESO/SRC *R* and *J* films.

No.	α 1950	δ	ℓ	b	R-Film	x	y	Size
			TRUE PN					
1[1]	$08^{h}52^{m}10^{s}0$	−53°53'42"	271°41	−05°97	165	106	202	1:6
2	10 12 38.5	−57 56 54	283.44	−01.40	127	110	244	4.4
3	13 24 56.6	−54 26 25	308.26	+07.79	173	43	169	0.3
4	14 14 08.5	−52 12 26	315.99	+08.24	221	29	22	0.9:
5	14 43 08.2	−50 10 53	321.01	+08.39	222	27	127	0.5
6	16 27 18.5	−50 20 46	334.35	−01.49	226	168	125	0.3
7	16 44 06.3	−50 37 15	335.93	−03.65	226	26	108	0.1
8	16 44 47.8	−51 03 59	335.66	−04.03	226	21	84	0.4
9	16 53 39.4	−49 42 14	337.62	−04.25	227	197	157	0.3x0.2
10	17 30 21.6	−54 26 47	336.98	−11.58	181	188	166	1.0
11	17 49 02.6	−46 41 14	345.42	−10.21	279	99	54	0.9
			POSSIBLE PN					
1[2]	08 18 57.8	−35 07 01	253.90	+00.75	370	196	137	0.3
2	09 56 18.6	−50 25 09	277.11	+03.32	213	178	119	0.3
3[3]	11 54 10.3	−34 09 00	290.27	+27.09	379	211	182	0.6x1.6
4	13 58 01.1	−50 25 44	314.09	+10.68	221	162	118	6:
5	16 31 20.1	−41 57 34	340.94	+03.75	331	110	31	0.3

[1] Described as 'Galaxy, or em neb' (Lauberts 1982).

[2] = Wray 19.07. A 'diffuse nebula' according to Wray (1966).

[3] Described as 'Dwarf? Dif, 2 stars superimposed' (Lauberts 1982).

located off-centre, but its extremely blue colour, the lack of a promising competitor at the nebular centre and the existence of analogous cases (e.g. S 216, S 188, PHL 932, A 35) support our assumption. Central star candidates could be identified in 11 of the 16 nebulae.

To estimate the apparent magnitudes of these stars from the film copies, we first used the magnitude-image diameter calibration of the *J*-survey films, as determined by King *et al.* (1981). The application of this relation, however, led to entirely unreliable results for such faint stars.

It is widely known that in the *J* survey a limiting magnitude of approximately $22^{\rm m}.5$ was reached – the faintest stars have an image diameter of about 20 μm (on the Palomar Sky Survey prints: 30 μm), which would correspond to $m_J \gg 22.5$ in King *et al*'s calibration. As a consequence, we determined a new magnitude-image diameter calibration by the use of a total of 55 faint stars out of three deep charge-coupled devices (CCD) sequences taken from McClure *et al.* (1987), Gratton & Ortolani (1988), and Richer, Fahlman & VandenBerg (1988). For the conversion of the *B* and *V* data into m_J, we made use of King *et al.*'s formula

$$m_J = 0.8 m_B + 0.2 m_V = m_V + 0.8(M_B - M_V).$$

The result of our magnitude-image diameter calibration is shown in Fig. 2. The large difference compared with the calibration by King *et al.* is evident from the figure. At present, we cannot offer an explanation for this difference, but we have started a program on which we shall determine calibrations for the ESO/SERC *R* and *J* films based on a number of published deep CCD sequences.

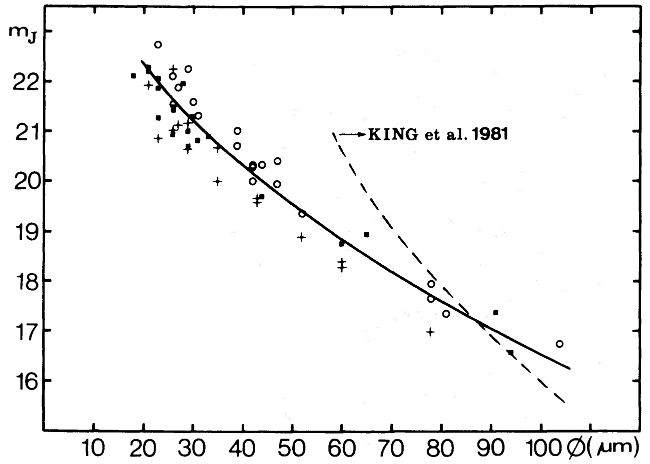

Figure 2. Relationship between magnitude and image diameter for the SERC *J* film copies. The different symbols denote the three sources of deep *BV* sequences referred to in the text.

Table 2. Magnitudes or diameters of the central star candidates.

No.	m_J SERC J	ø (µm) ESO R	ø (µm) ESO B
1	$19^{\rm m}.5$	26	40
2	19.3	30	48
3	17.5	52	70
4	19.4	40	38
5	20.7	33	25
7	21.2	25	40
8	20.4	30	51
9	$22^{\rm m}.0$	–	–
10	19.3	27	40
11	18.8	36	45
3	$17^{\rm m}.6$	56	80
4	19.2	31	48

Our numerical data are presented in Table 2. We are able to list m_J, but could not give m_R and m_B because we found no magnitude-diameter calibrations for those colours in the literature.

All the central stars are very faint and fall within the range $17^{\rm m}.5 \le m_J \le 22^{\rm m}.0$.

All central stars visible on overlapping regions on the *J*, *R* and *B* film copies were checked for possible brightness variations, but none were found.

4 INFRARED (IR) COUNTERPARTS

PN in late evolutionary phases are weak emitters in the *IRAS* IR bands. In a study of 14 southern PN of low surface brightness, discovered by Hartl & Tritton (1985), Iyengar (1986a) found five identifications only. Our PN are, on average, of lower brightness. They are, as we pointed out above, highly evolved objects and few identifications with *IRAS* sources could be expected *a priori*. Indeed, a search using the *Infrared Astronomical Satellite Point Source Catalog* for IR counterparts of our PN resulted in only three identifications. Obviously, for IR studies of the faintest PN that can be identified on the presently available deep photographic surveys, an IR-limiting magnitude larger than the one provided by *IRAS* would be necessary.

In the following section, we shall discuss the three objects separately on the basis of the data contained in the printed version of the *IRAS* catalogue.

4.1 'True' PN no. 2

Within the boundaries of this extended object ($\phi \approx 4'.4$) an IR point source is reported at $\alpha = 10^{\rm h}12^{\rm m}24^{\rm s}.8$, $\delta = -57°57'00''$, at an angular distance 1.82 arcmin to the east of the centre of the nebula. The *IRAS* source appears to be no 'chance' projection, as will be outlined in the following.

As can be seen from Fig. 1, the optical brightness is larger in the eastern part of the nebula, i.e. around the position of the *IRAS* point source. According to the confusion block in the catalogue, five 100-μm only sources are located within a $\frac{1}{2}° \times \frac{1}{2}°$ box centred on the source. The presence of considerable structure in the 100 μm emission on a $\frac{1}{2}°$ scale is reported. Four-hour confirmed and 1-week confirmed point sources and more than nine 1.2-μm, six 25-μm, five 60-μm, and seven 100-μm hour confirmed small extended-source detections, within a window of 6 arcmin in-scan × 4.5 arcmin cross-scan (half-widths), centred on the source, could be located.

It was not feasible to assign a single *bb*-temperature to the (colour-corrected) flux values.

It should be noted that the upper limit at 25-μm and the strong 100-μm flux, with a point source 12-μm detection, contrasts with the properties of the other two less-confused identifications. It is possible that the 12-μm source is coincidental.

To conclude, it is possible that the numerous nearby small extended sources and point sources represent, at least in part, condensations in the nebula.

4.2 'True' PN no. 3

An *IRAS* point source is reported, only 0.08 arcmin distant from the optical position. There are more than nine 100-μm only sources within a $\frac{1}{2}^\circ \times \frac{1}{2}^\circ$ box centred on the source and the ratio of the $\frac{1}{2}^\circ$ extended emission to the source flux is moderate (4). No nearby point or small extended sources were detected.

Both the 12-μm and the 100-μm flux are upper limits. The 25–60 μm colour-corrected band emission of the source corresponds to a *bb* temperature of 115 K. We estimate the total IR flux in the 4–300 μm band as 0.8×10^{-13} W m^{-2}.

Further parameters can be calculated provided that a distance can be determined. In this case of a planetary of very low surface brightness in *R*, such an estimate is indeed possible. From the red-sensitive Palomar Sky Survey prints (that have a similar limiting magnitude), it is known that unreddened nebulae at the limit of visibility have linear radii of typically 0.5–0.8 pc. We think that this small source has in fact a negligible interstellar extinction, because (i) it surrounds a nucleus that appears very blue and (ii) a number of galaxies are visible in the angular vicinity of the PN. An assumption of a linear radius of about 0.4 pc is therefore realistic and the resulting distance of 9.2 kpc can well compete in accuracy with the usual Shklovskii distances.

At $D = 9.2$ kpc, and with the above total flux, the total IR luminosity is then $L_{\mathrm{IR}} = 8.0 \times 10^{28}$ W or $213\,L_\odot$. Using the formulae listed in Iyengar (1986b), we also estimated τ_{25}, the optical depth at 25-μm and the mass of the dust $M_{\mathrm{d}}/M_\odot$ and found 6.8×10^{-6} and 1.4×10^{-4}, respectively. Compared to the data that were estimated by Iyengar (1986b) for 46 faint PN, τ_{25} for this source is distinctly lower, but lies near to the extrapolated least-squares fit line to the data. The dust mass, however, is near the average mass of dust of $\approx 1.2 \times 10^{-4}$ $M_\odot$ that Iyengar estimated for those PN (excluding four extremely massive ones).

4.3 'True' PN no. 8

This object is located in a region of high star density, that is, in a rather transparent region and has a very blue central star. The angular distance between the IR point source and the optical position amounts to 0.09 arcmin only.

There are more than nine 100-μm only sources within a $\frac{1}{2}^\circ \times \frac{1}{2}^\circ$ box centred on the source, and the ratio of the $\frac{1}{2}^\circ$ extended emission to the source flux is 5. Two-hour confirmed and 1-week confirmed nearby point sources are reported, as well as two nearby hour-confirmed small-extended sources in the 12-μm band and four in the 60-μm band. One or more nearby week-confirmed small-extended source(s) is (are) present in the 12-μm band.

Both 12- and 100-μm fluxes are upper limits. The 25–60 μm *bb*-temperature of the colour-corrected emission was found to be 101 K and the total 4–30 μm flux amounts to 1.7×10^{-13} W m^{-2}.

By applying analogous arguments to those for the preceding object, a distance of 8.6 kpc (assuming $R = 0.5$ pc) was estimated. We then calculated $L_{\mathrm{IR}} = 1.5 \times 10^{29}$ W or $396\,L_\odot$. For τ_{25} we found 1.3×10^{-5}, again a value that is near to the extrapolated least-squares fit line for Iyengar's faint PN. Eventually, we calculated a dust mass $M_{\mathrm{d}} = 4.2 \times 10^{-4}$ $M_\odot$, three times the dust mass evaluated for the former PN.

ACKNOWLEDGMENTS

We are grateful to Dr R. West for permission to use the film copy archive of the ESO Headquarters in Garching. We also thank W. Benger for making the photographic reproductions.

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