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Orientation of planetary nebulae within the Galaxy

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ABSTRACT

Narrow-band CCD images of 209 axially symmetrical planetary nebulae (PNe) have been examined in order to determine the orientation of their axes within the disc of the Galaxy. The nebulae have been divided into the bipolar (B) and elliptical (E) PNe morphological types, according to the scheme of Corradi & Schwarz. In both classes, contrary to the results of Melnick & Harwit and Phillips we do not find any strong evidence for non-random orientations of the nebulae in the Galaxy. Compared with previous work in this field, the present study takes advantage of the use of larger and morphologically more homogeneous samples and offers a more rigorous statistical analysis.

Key words: planetary nebulae: general – Galaxy: structure.

1 INTRODUCTION

In 1975 Melnick & Harwit (1975, hereafter MH75) claimed that axially symmetrical planetary nebulae (PNe) have non-random orientations within the Galaxy, since their long axes appear to be systematically aligned with the Galactic equator. Potentially, this result has important implications on the theories of the formation and evolution of PNe, as well as on the discussion of certain Galactic properties (such as the large-scale structure of the Galactic magnetic field, or the orientations of the stellar rotational axes or orbital planes of binary systems). In spite of that, no further work was done on the subject in the following two decades. Only recently, taking advantage of the much improved present knowledge of the morphologies and dynamics of PNe, Phillips (1997, hereafter P97) has found very similar results to those of MH75: of a total of 56 objects analysed by him, as many as 71 per cent of the nebulae have their major axes orientated within $\pm 45°$ of the Galactic plane, a proportion which has a low probability of arising by chance.

In this paper, we revisit the problem by considering a substantially larger sample of 209 PNe for which high-quality CCD images are available. We also distinguish between *bipolar* and *elliptical* objects, according to the morphological classification of Corradi & Schwarz (1995). By applying a more detailed statistical analysis than those of MH75 and P97, and by considering a larger sample of nebulae, we show that, contrary to earlier findings, there is no conclusive evidence for a non-random distribution of the orientations of axisymmetrical PNe within the Galaxy.

2 THE DATA

Narrow-band CCD images of more than 600 PNe were examined. The main sources are the image catalogues by Balick (1987), Schwarz, Corradi & Melnick (1992) and Manchado et al. (1996), but a number of images were also collected from various papers from the literature. All the objects which are likely to belong to the Galactic bulge according to Acker et al. (1992) were rejected, since we aim to restrict our discussion to the orientation of the nebulae with respect to the Galactic disc. From this extensive list, we selected a final sample of 209 axially symmetrical PNe. Whenever possible, the selection was made by inspecting the published Hα or [N II]6583 (or Hα+[N II]) images. The PNe were then divided into the classes of *bipolar* (B) and *elliptical* (E) nebulae, according to the morphological scheme in Corradi & Schwarz (1995). A B PN is defined to be an elongated, axially symmetric nebula showing an 'equatorial' waist from which emanate two faint, extended lobes. E nebulae are objects the outer contours of which can be reasonably fitted by an ellipse. Owing to a continuity in the variation of the observed shapes, one can find several borderline cases between B and E objects (e.g. NGC 2818 and He 2-119).

Particular care was taken in evaluating the 'quality' of the morphological classification of the objects, and in determining the apparent direction of their outflows. A quality number was assigned to each nebula. B PNe which show two symmetrical lobes defining unambiguously the direction of their polar outflows, as well as E nebulae with a very regular shape and appreciable ellipticity (major to minor axis length ratio ≥ 1.3), were given a quality number equal to 1. All the other nebulae, for which the direction of the axisymmetrical outflow cannot be defined with such accuracy, were given a lower quality number (2). Objects of this kind include B PNe the lobes of which are poorly defined, E PNe with a modest ellipticity and nebulae the outer contours of which are irregularly defined, or which show non-negligible deviations from the pure axial symmetry. For some of these objects, the classification as a B or E PN is quite uncertain. In the present work, we do not consider objects in which an axially symmetrical outflow is defined by small-scale structures, such as the systems of

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fast-moving, low-ionization condensations which characterize a number of Galactic PNe (cf. Balick et al. 1994; Corradi et al. 1996).

3 DATA ANALYSIS

3.1 Apparent orientation of the nebulae

For all the selected nebulae, we measured the position angle (*PA*) of their projected symmetry axes. Following the usual convention, *PA* is measured from the north towards the east. In fixing the *PA*, we chose the direction that better matches the main symmetry axis of the nebula, independently of the presence of other morphological subcomponents which often tend to distort the axial symmetry. An example is the point symmetrical distribution of light emission that characterizes the brightest regions of many B PNe (Corradi & Schwarz 1995), and which is not considered in our study.

Of the two symmetry axes which can be recognized in a bipolar or elliptical structure, we measured the *PA* of the longer one, which represents the direction of the polar outflow of the object. The direction of this axis was estimated visually by fixing (on paper or on the computer display depending on the format in which the images were available) the line that better represents the long symmetry axis of the nebulae. The angle that this line forms with the north was then accurately measured. All measurements were repeated independently by two of us, in order to check the errors introduced by the subjective determination of the symmetry axis of the nebulae. For most B PNe with quality number 1, the differences in the computed *PA* were smaller than 5°. These differences were larger but generally contained within 10–15° for B2, E1 and E2 PNe. For the objects in Schwarz et al. (1992), given the uncertainty in the absolute orientation of the frames, an additional error of ±5° should be added to the above errors (see the discussion in the original paper). To limit this additional source of errors, instead of using the original images in Schwarz et al. (1992) the *PA* of the nebulae were measured whenever possible in CCD narrow-band images from various papers in the literature. In summary, we estimate that the typical errors are ±5° for B1 nebulae, and ±10° for B2 and E PNe.

3.2 Transformation to the Galactic system

Position angles are measured relative to the equatorial coordinate system and are transformed into apparent orientations relative to the Galactic system by computing the angle ψ which is subtended at the position of each object by the directions of the equatorial north and the Galactic north. Using standard relations for spherical triangles, for epoch J2000.0

$$\psi = \arctan\left[\frac{\cos(l - 32.^\circ 9)}{\cos b \cot 62.^\circ 9 - \sin b \sin(l - 32.^\circ 9)}\right],$$

where l and b are the Galactic coordinates of the object. The corrections of ψ for precession of the equinoxes are negligible in the present context. We then define the 'Galactic position angle', θ_G, as the position angle of the nebular axis, measured from the direction of the Galactic north towards the east,

$$\theta_G = PA + \psi.$$

Because of the symmetry involved in the problem, the computed values of θ_G can be reported to the interval $(0°, 90°)$ deg. When completed, θ_G is the complement to the apparent inclination of the nebulae on the Galactic equator. The names of the selected nebulae, their Galactic coordinates, their measured *PA* and θ_G are listed in Tables 1 and 2.

3.3 Statistical analysis

The set of the observed θ_G values provides us with the distribution function of the apparent position angles of the PNe with respect to the Galactic coordinate system. The next step is to determine whether this observed distribution of *projected* orientations is consistent, in a statistical sense, with a completely random distribution of the symmetry axes of the PNe in the volume of the Galaxy.

It is straightforward to show that, under the hypothesis that PN axes have an isotropic distribution within the Galaxy, the expected distribution function of the projected position angles, $f(\theta_G)$, is a constant. To show this, let us assume for the moment that all the PNe are located at the same position in the Galaxy, and consider a reference system with the z-axis directed towards the observer and the x-axis pointing to the North Galactic Pole. The isotropic distribution function will have the usual form $f(\theta, \varphi) = \sin\theta/4\pi$, where θ and φ are the polar coordinates (colatitude and longitude) which define the direction of a PN axis in space. In this reference frame, the position angle, θ_G, is nothing but the azimuthal angle, φ: since $f(\theta, \varphi)$ does not depend on φ, it follows that $f(\theta_G) \equiv f(\varphi)$ is a constant. This results also holds if the sample PNe are located at different positions in the Galaxy, since the distribution function $f(\theta_G)$ is a constant for *any* observer–nebula relative position.

The situation, however, is substantially different if the distribution of the orientations is not random. In this case, the observer–nebula relative position becomes important. For instance, if the PNe have their axes lying preferentially at low inclinations on the Galactic plane, as claimed by MH75 and P97, it will be important to consider the effects due to examining objects at different heights, b, on the plane. To illustrate this, imagine that all PNe have their axes parallel to the Galactic plane. If we consider only PNe with $b = 0°$, the marked anisotropy in the orientations will be clearly seen, and we will observe a distribution function of the observable θ_G which is non-zero only for $\theta_G = 90°$. If the objects are located at $b = 90°$, however, then any position angle from 0° to 90° will have the same probability of being measured. Considering objects at very different Galactic latitudes could therefore mask a real anisotropy in the inclination of PN axes with respect to the Galactic plane.

To avoid these possible effects, and in order to put ourselves in the most favourable situation so as to reveal a systematic orientation of the kind claimed by MH75 and P97, we will restrict the following analysis to objects close to the Galactic plane. In what follows, we will therefore reject all objects in Tables 1 and 2 with $|b| > 20°$. Note, however, that this constraint excludes very few nebulae (one B1, one B2, four E1 and three E2 PNe). In addition, the majority of the objects lie even closer to the Galactic plane, since 73 per cent of B1+B2 PNe and 60 per cent of E1+E2 PNe have $|b| \leq 5°$.[1] Within these constraints, the final, global sample used in the following analysis amounts to 200 objects.

Having defined the expected (theoretical) distribution function, $f(\theta_G)$, according to the hypothesis of random orientations, and taking care to consider only objects at low b, we are now in the position of applying a statistical test to determine whether the observed distribution function represents the theoretical one. Owing to the *continuous* distribution of the variable θ_G, we chose to apply the Kolmogorov–Smirnov (K–S) test. This requires the calculation of D_{max}, the absolute value of the maximum deviation

[1]The higher concentration toward the Galactic plane of *B* PNe is a well-known property, which is ascribed to the fact that this class of PNe would be produced by progenitors with the highest masses among stars which go through the PN phase (Corradi & Schwarz 1995).

Table 1. The sample of bipolar PNe.

B1 PNe				
Name	l	b	PA	θ_G
A 79	102.9	−2.3	17	49
BI Cru	299.7	0.1	31	25
CRL 618	166.4	−6.5	94	45
CRL 2688	80.1	−6.5	14	63
Hb 5	359.3	−0.9	78	43
He 2-25	275.2	−3.7	14	32
He 2-36	279.6	−3.1	144	77
He 2-64	291.7	3.7	81	62
He 2-84	300.4	−0.9	37	32
He 2-104	315.4	9.4	123	39
He 2-111	315.0	−0.3	113	45
He 2-114	318.3	−2.0	2	31
He 2-119	317.1	−5.7	172	23
He 2-145	331.4	0.5	114	23
He 2-428	49.4	2.4	163	45
Hf 48	290.1	−0.4	135	69
IC 4406	319.6	15.7	86	73
IRAS07131−0147	217.3	4.5	99	36
IRAS22568+6141	110.1	1.9	121	34
K 1-10	229.6	−2.7	112	49
K 3-17	39.8	2.1	116	1
K 3-45	60.5	−0.3	18	78
K 3-46	69.2	3.8	102	18
K 3-58	69.6	−3.9	94	31
K 3-72	204.8	−3.5	140	78
K 3-93	132.4	4.7	3	18
M 1-8	210.3	1.9	63	0
M 1-13	232.4	−1.8	154	88
M 1-16	226.7	5.6	150	89
M 1-28	6.0	3.1	16	75
M 1-57	22.1	−2.4	137	20
M 1-59	23.9	−2.3	116	1
M 1-75	68.8	−0.0	157	35
M 1-91	61.4	3.6	77	42
M 1-92	64.1	4.3	130	11
M 2-9	10.8	18.0	178	55
M 2-48	62.4	−0.3	62	59
M 3-2	240.3	−7.6	40	23
M 3-28	21.8	−0.4	2	64
M 3-55	21.7	−0.6	57	60
M 4-14	43.0	−3.0	68	50
MyCn 18	307.5	−4.9	150	19
Mz 1	322.4	−2.6	156	11
Mz 3	331.7	−1.0	7	51
Na 2	25.9	−10.9	72	44
NGC 650	130.9	−10.5	131	60
NGC 2346	215.6	3.6	168	75
NGC 2818	261.9	8.5	88	41
NGC 2899	277.1	−3.8	117	73
NGC 6072	342.1	10.1	65	70
NGC 6302	349.5	1.0	88	38
NGC 6445	8.0	3.9	72	49
NGC 6537	10.1	0.7	40	79
NGC 6881	74.5	2.1	139	16
NGC 7026	89.0	0.3	10	58
OH 231.8+4.2	231.8	4.2	21	40
PC 20	31.7	1.7	87	30
Pe 1-14	25.9	−0.9	45	72
PN G321.6+0.2.2	321.6	2.2	47	77
R Aqr	66.5	−70.3	175	45
SH 1-89	89.8	−0.6	54	80
TH 2-B	307.0	−1.2	80	88
19W32	359.2	1.2	50	72
We 1-4	201.9	−4.1	6	56

Table 1 – *continued*

B2 PNe				
Name	l	b	PA	θ_G
BV 5-1	119.3	0.3	162	11
CTS 1	19.8	5.6	102	17
He 1-6	65.2	−5.6	130	6
He 2-18	273.2	−3.7	76	29
He 2-48	282.9	3.8	107	76
He 2-70	293.6	1.2	127	70
He 2-76	298.2	−1.7	78	68
He 2-123	323.9	2.1	82	65
He 2-153	330.6	−2.1	30	74
He 2-161	331.5	−2.7	48	87
He 2-169	335.4	−1.1	2	49
HaTr 4	335.2	−3.6	1	50
Hu 1-2	86.5	−8.8	129	8
IC 5217	100.6	−5.4	90	58
K 3-4	32.7	5.6	33	84
K 3-83	94.5	−0.8	100	38
K 3-91	129.5	4.5	128	67
K 3-94	142.1	3.4	139	77
K 4-55	84.2	1.0	90	39
KjPn 8	112.5	−0.1	72	89
M 1-7	189.8	7.7	158	86
M 1-51	20.9	−1.1	29	88
M 2-19	0.2	−1.9	110	10
M 2-52	103.7	0.4	146	1
M 2-56	118.0	8.4	87	80
M 3-3	221.7	5.3	33	29
M 3-39	358.5	5.4	57	67
M 4-17	79.6	5.8	115	7
NGC 2371	189.1	19.8	127	58
NGC 2440	234.8	2.4	84	24
NGC 6309	9.6	14.8	55	68
NGC 7293	36.1	−57.1	122	14
Pe 1-17	24.3	−3.3	45	72
We 1-11	91.6	1.8	93	40
WeSb 4	31.9	−0.3	149	32

between the observed and theoretical cumulative distribution functions. The (two-tail) probability, p, of a given D_{max} is tabulated in the literature. If p is smaller than an assumed 'significance level' (usually 0.05 or 0.01), then the two distributions are considered to be different. In other words, p gives the probability of being wrong if we reject the 'null hypothesis', which in our case is that of random orientations of the PN axes within the Galaxy.

3.4 Results

The histograms of the distributions of the position angles, θ_G, are presented in Fig. 1. B and E types, as well as PNe with quality number 1 and 2, are considered both separately and jointly. All the distributions are relatively flat, and we clearly do not see the strong concentration toward the Galactic plane (higher values of θ_G) claimed by MH75 and PH97. A mild deficiency of PNe with $\theta_G < 30°$ is present in some subsamples, but the K–S test does not allow us to give it a strong statistical significance. In Table 3, the probability, p, of the observed distribution functions in the hypothesis of random orientation is given for the different samples. In most cases, $p > 0.20$, significantly larger than the commonly adopted confidence level of 0.05 needed to reject the hypothesis of completely random orientations. Only for the B1 + E1 subgroup and for the whole sample of PNe is p slightly smaller, but it is still larger than the above significance level.

Very similar results are obtained by choosing different upper limits for the Galactic latitude of the selected PNe.

4 COMPARISON WITH THE PREVIOUS STUDIES

The statistical analysis presented above shows that there is no clear evidence for a non-random distribution of the orientation of axisymmetrical PNe in the disc of the Galaxy. According to the K–S test, the apparent slight deficiency of objects with $\theta_G < 30°$ must be considered to have a marginal significance.

Our results clearly contradict those of MH75 and P97, who claimed to find strong statistical evidence of systematically low inclinations of the PNe on the Galactic plane. In order to understand this discrepancy, we have applied our analysis to the samples in MH75 and P97.

The study by MH75 clearly suffers from the much poorer knowledge of PN morphology and physics of more than two decades ago. Of the 73 PNe listed in fig. 1 of MH75, five are not PNe (one is a galaxy!), and another 15 appear almost spherical, or very irregular, in modern CCD images, so that a symmetry axis cannot be unambiguously defined. Of the remaining nebulae, 40 are included in our present sample, and the distribution of their θ_G as measured by us (MH75 do not quote the values of their adopted position angles) is essentially flat for any choice of adopted limits in Galactic latitude. This is fully confirmed by the K–S test, which gives $p \gg 0.20$, thereby providing no evidence at all for a systematic orientation of the nebular axes.

As for the analysis of P97, all but five of the objects in his study are included in our sample. Three of these five objects (IC 4634, J 320 and He 2-186) were excluded from our analysis in accordance with the discussion given in Section 2, because their outflow direction is defined by a system of point-symmetrical knots.

In several cases, the differences between the position angles quoted in P97 and those presented in this paper are found to be larger than those expected from our estimates of the errors and are

Table 2. The sample of elliptical PNe.

	E1 PNe			
Name	l	b	PA	θ_G
A 13	204.0	−8.5	56	6
A 43	36.0	17.6	86	29
A 49	27.3	−3.4	31	86
A 58	37.5	−5.1	174	57
A 68	60.0	−4.3	13	72
A 72	59.7	−18.7	172	47
A 80	102.8	−5.0	8	38
DeHt 2	27.6	16.9	56	61
He 2-52	285.5	1.5	105	76
He 2-159	330.6	−3.6	2	48
He 2-136	322.1	−6.6	148	7
He 2-429	48.7	1.9	87	31
He 2-430	51.0	3.0	136	18
Hu 1-1	119.6	−6.1	9	14
IC 1295	25.4	−4.7	69	48
IC 2448	285.7	−14.9	128	78
IC 4663	346.2	−8.2	80	40
IC 4699	348.0	−13.0	28	88
JnEr 1	164.8	31.1	41	44
K 1-9	219.0	1.1	161	82
K 3-3	31.2	5.9	4	67
K 3-21	47.1	4.1	177	60
K 3-26	35.7	−5.0	48	69
K 3-38	53.2	−1.5	85	34
K 3-57	72.1	0.1	33	90
K 3-61	96.3	2.3	164	27
K 3-64	151.4	0.5	120	77
K 3-76	73.0	−2.4	134	9
K 3-84	91.6	−4.8	3	45
K 3-88	112.5	3.7	50	72
K 3-90	126.3	2.9	131	56
M 1-73	51.9	−3.8	104	15
M 2-40	24.1	3.8	80	38
M 2-50	97.6	−2.4	52	90
M 2-53	104.4	−1.6	96	53
M 2-55	116.2	8.5	38	56
M 3-9	359.0	5.1	125	1
M 3-34	31.0	−10.8	45	71
M 3-35	71.6	−2.3	48	77
MaC 1-13	22.5	1.0	64	54
NGC 1501	144.5	6.5	117	75
NGC 3195	296.6	−20.0	13	25
NGC 6058	64.6	48.2	161	74
NGC 6720	63.1	13.9	60	54
NGC 6853	60.8	−3.6	123	2
NGC 6886	60.1	−7.7	54	69
NGC 6905	61.4	−9.5	161	37
NGC 7009	37.7	−34.5	85	30
PB 9	46.3	−3.1	165	47
PC 4	275.0	−4.1	35	11
Pe 1-20	28.2	−4.0	12	75
ScWe 2	311.0	2.2	128	38
Vy 1-2	53.3	24.0	138	29
We 1-9	65.1	−3.5	74	49
YM 16	38.7	1.9	156	39

Table 2 – *continued*

	E2 PNe			
Name	l	b	PA	θ_G
A 18	216.0	−0.2	3	60
A 41	9.6	10.5	149	27
A 47	30.8	3.4	136	19
A 55	33.0	−5.3	158	41
A 70	38.1	−25.2	163	46
A 84	112.9	−10.2	4	18
H 1-7	345.2	−1.2	66	60
HaTr 10	31.3	−0.5	3	66
He 2-29	275.8	−2.9	88	44
He 2-37	274.6	3.5	123	83
He 2-67	292.8	1.1	120	78
He 2-85	300.5	−1.1	135	50
He 2-86	300.7	−2.0	48	43
He 2-99	309.0	−4.2	103	63
He 2-107	312.6	−1.8	22	41
He 2-116	318.3	−2.5	59	88
He 2-117	320.9	2.0	156	6
He 2-120	321.8	1.9	178	29
He 2-132	323.1	−2.5	76	68
He 2-434	320.3	−28.8	169	81
Hf 2-1	355.4	−4.0	40	81
IC 351	159.0	−15.1	3	37
IC 2553	285.4	−5.3	7	29
IC 4673	3.5	−2.4	120	1
IC 4776	2.0	−13.4	34	80
J 900	194.2	2.5	84	22
K 1-1	252.6	4.4	58	4
K 1-17	51.5	6.1	3	66
K 3-92	130.4	3.1	3	13
KjPn 6	111.2	7.0	4	32
M 1-18	231.4	4.3	130	69
M 1-40	8.3	−1.1	44	75
M 1-42	2.7	−4.8	21	83
M 2-13	11.1	11.5	40	82
M 2-55	116.2	8.5	43	61
Mz 2	329.3	−2.8	3	47
NGC 40	120.0	9.8	15	24
NGC 2022	196.6	−10.9	14	46
NGC 2610	239.6	13.9	83	27
NGC 2792	265.7	4.1	146	81
NGC 3242	261.0	32.0	143	76
NGC 3918	294.6	4.7	102	88
NGC 4071	298.3	−4.8	41	30
NGC 5873	331.3	16.8	116	31
NGC 5882	327.8	10.0	15	47
NGC 5979	322.5	−5.2	127	15
NGC 6741	33.8	−2.6	87	30
NGC 6751	29.2	−5.9	87	30
NGC 6772	33.1	−6.2	158	41
NGC 6778	34.5	−6.7	26	89
NGC 6804	45.7	−4.5	50	68
NGC 6818	25.8	−17.9	13	79
PC 14	336.2	−6.9	106	21
PC 22	51.0	−4.5	3	64
Sa 2-21	238.9	7.3	138	80

certainly much larger than the (probably too optimistic) errors ($\pm3°$) given by P97. The reason for these discrepancies, however, is not that we have underestimated the errors due to the subjective determinations of the direction of the PN axes. One illustrative example is M 1–91 (Goodrich 1991), which possesses a highly collimated morphology so that its symmetry axis is unambiguously defined to within an accuracy of 2–3°, whereas the difference between P97 and the present work is of 20°. We carefully checked all the cases in which the difference in the position angle is larger than 15° and we are confident that the values quoted in Tables 1 and 2 are correct to within the errors adopted in this paper.

If we exclude the five cases mentioned above, all the other PNe in P97 are classified, according to our scheme, as B1 or B2, and form a quite homogeneous morphological sample. In the lower half of Fig. 2, we present the distribution which results from using our determinations of θ_G for these objects. In the upper half of the figure, the distribution of the original data of P97 is shown for comparison. In both cases, two objects at high Galactic latitude, R Aqr and IRAS 09371+1212, were rejected, according to the prescriptions in Section 3.3. The original data of P97 have an irregular distribution with a peak between 45 and 60°, and the K–S test recognizes a significant deviation (to 0.01 confidence level) from uniformity. This result, however, is removed by adopting our measurements, which we believe to be more accurate than those of P97, and by considering the more homogeneous sample which is obtained by rejecting the five non-bipolar objects in P97. The distribution arising from our data is in fact flatter than that of P97 and, as expected, is similar to that of our B1 sample. By applying the K–S test to this sample, we obtain $p = 0.15$, which again refutes the existence of strong evidence for a non-random distribution of PN axes.

Note that the binomial statistics used by P97 do not provide a suitable statistical test in analysing the observed distribution functions. One reason is that, owing to the internal errors in the measurements, it is not possible to assign objects unambiguously to one of the two bins that must be defined in the binomial test. P97 found that 71 per cent of the PNe have $\theta_G > 45°$, a proportion which has a very low one-tail probability of arising by chance according to binomial statistics ($p = 2 \times 10^{-3}$). If we choose only slightly different θ_G limits for the bins, however, then the results of the binomial test are different. If for instance we choose the bin limits to be $0° < \theta_G < 50°$ and $50° < \theta_G < 90°$ (having probabilities equal to 0.56 and 0.44, respectively), then the observed proportion of nebulae in the two bins (26 and 30, respectively) has a considerably higher probability of occurring ($p = 0.11$). The result of P97 appears essentially to be based on ten PNe with $45° \leq \theta_G \leq 50°$, which, because of their internal errors, cannot be considered to belong unambiguously to either of the two selected bins. Considering the continuous distribution of the variable θ_G, the internal errors of the measurements, and the kind of analysis required (comparison of an observed and a theoretical distribution function), we believe that the K–S test is more suitable than the binomial test in the present context.

5 CONCLUSIONS

The basic conclusion of this paper is that, contrary to the results of MH75 and P97, no strong evidence is found for a preferential orientation of the symmetry axes of PNe within the Galaxy. This holds for both the B and E morphological classes of PNe.

Compared with the previous studies, the present analysis takes advantage of a more complete statistical analysis, the use of a larger

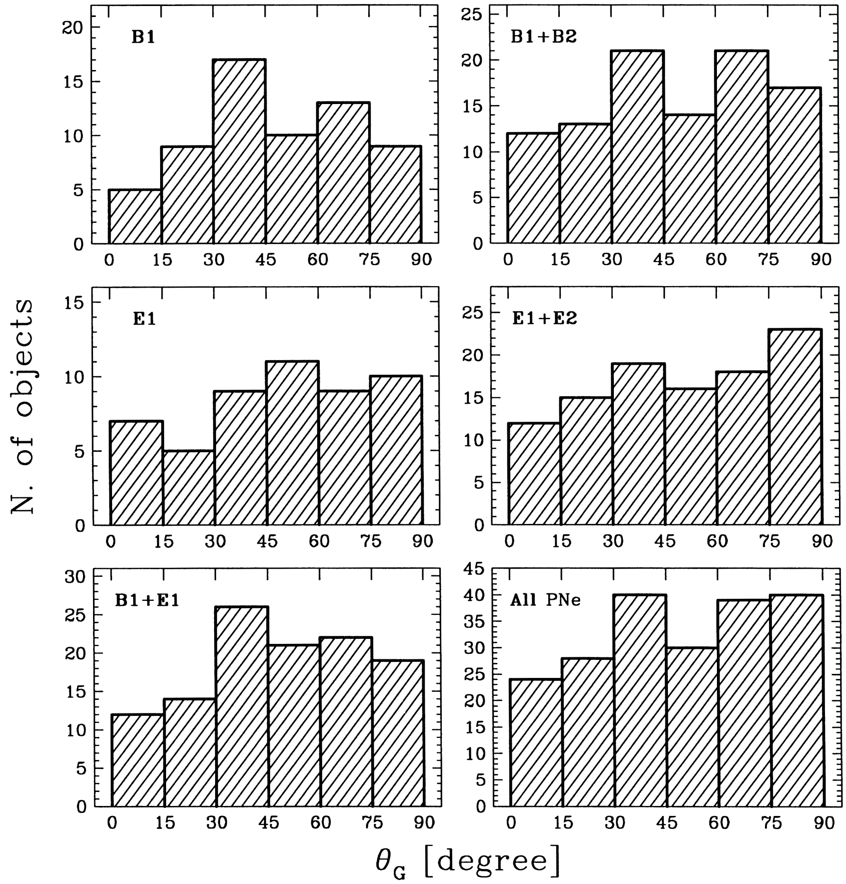

Figure 1. Observed distributions of the Galactic position angle, θ_G, for the sample PNe.

Table 3. Results from the K–S test for the samples of PNe.

	N	D_{max}	p
B1	63	0.10	> 0.20
B1 + B2	97	0.08	> 0.20
E1	51	0.14	> 0.20
E1 + E2	103	0.10	> 0.20
B1 + E1	114	0.10	0.15
All PNe	200	0.09	0.10

sample of objects and a more precise and homogeneous definition of their morphological properties (which are likely to be related to their formation processes and stellar progenitors; see Corradi & Schwarz 1995). In particular, the study of MH75 suffers from the poor knowledge of the detailed PN morphology in 1975. At that time, deep narrow-band images were available for only few PNe. This is an important point, considering that, for instance, the lobes of a B PNe are often very faint. In a short exposure, only the bright equatorial waist is therefore visible, and one could identify it as the long symmetry axis of the object. The work of P97, on the contrary, is affected by the use of a simple but unsuitable statistical analysis on a sample which is smaller and morphologically less homogeneous than the present one (the accuracy of the measurements might also be smaller).

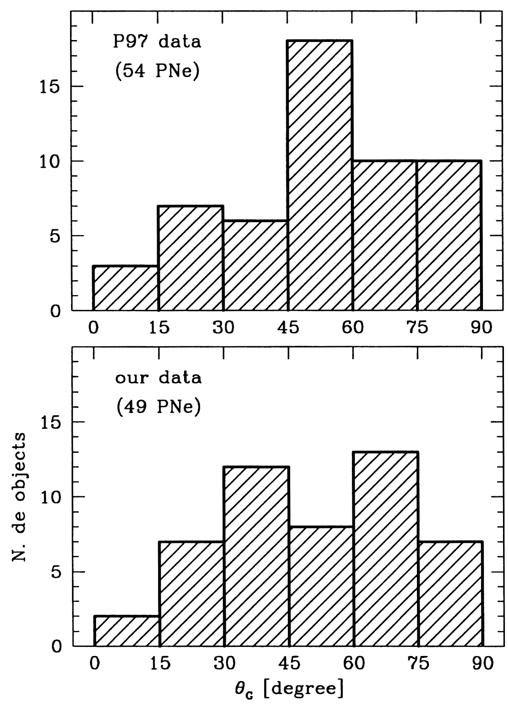

Figure 2. Observed distributions of the Galactic position angle, θ_G, for the PNe in P97, using the data in the original paper (upper box) and our measurements for the same sample (lower box).

Our results remove the apparent problem that all the mechanisms which may be responsible for the formation of B and E morphologies, such as the stellar rotation or magnetic fields, or the orbits of binary systems, appear to be randomly orientated within the Galaxy (see the discussion in P97).

Nevertheless, according to our data we cannot completely rule out the presence of moderate anisotropies in the orientation of the nebulae. The observed, small deficiency of objects with $\theta_G < 30°$ has little statistical significance but appears both in the B and in the E samples. In addition, it has to be recalled that moderate anisotropies can be partially masked by the projection effects. To get a deeper insight on this point, a further step in the analysis is required. At present, however, it appears to be difficult to obtain a substantially larger sample of axisymmetrical PNe. Here, we have analysed more than 600 CCD images of PNe, which is about the half of the complete sample of known Galactic PNe (but many of the remaining ones are small PNe in the Galactic bulge). The most promising way to proceed would therefore be to derive the real inclinations of the nebulae with respect to the Galactic plane for a sample of, say, 50 objects or more. The information on the third dimension, i.e. the inclination of the objects on the plane of the sky, can be obtained by means of detailed spatio-kinematic modelling. At present, however, accurate determinations of the inclinations are available for no more than 15 B PNe (cf. Corradi & Schwarz 1995), so that this kind of analysis is likely to be postponed for another few years.

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