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USING PLANETARY NEBULAE TO PROBE THE STRUCTURE OF THE GALACTIC THIN DISK

J. P. Phillips

Instituto de Astronomía y Meteorología
Universidad de Guadalajara, México

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RESUMEN

La mayoría de nebulosas planetarias parecen provenir de progenitores con masas $M_{\rm PG} \approx 1\ M_{\odot}$, y es probable que estén relacionadas con estrellas localizadas dentro del disco delgado de la Galaxia. Esto ha sido confirmado a través de una serie de estimaciones de alturas de escala, las cuales implican valores z_0(PNe) del orden de $\sim$ 220 pc. Mostraremos que es también posible evaluar la variación de z_0(PNe) con la distancia galactocéntrica R. Aunque tal análisis está sujeto a varias incertidumbres, incluyendo las asociadas con las distancias de las nebulosas, es posible demostrar que cuando se incrementa R, aumenta z_0(PNe). Esta variación espacial es congruente con lo que conocemos sobre otros componentes del disco.

ABSTRACT

Most planetary nebulae appear to arise from progenitors with mass $M_{\rm PG} \approx 1\ M_{\odot}$. One would therefore expect them to be closely associated with stars located within the galactic thin disk. This has been confirmed through a series of recent estimates of scale height, which imply values z_0(PNe) of order $\sim$ 220 pc. We shall show, in the following, that it is also possible to evaluate the variation of z_0(PNe) with galactocentric distance R. Although such an analysis is subject to several uncertainties, including those associated with the distances to these outflows, it is nevertheless possible to demonstrate that z_0(PNe) increases with increasing R. This spatial "flaring" is consistent with what is known of various other disk components.

Key Words: **ISM: JETS AND OUTFLOWS — PLANETARY NEBULAE: GENERAL**

1. INTRODUCTION

The local galactic disk is usually characterized as having a range of differing structures. Many lower mass stars, for instance, appear to be contained with the so-called "thin disk", which appears to have a median scale height z_0 of order $\sim$ 300 pc (although estimates have varied between 240 pc and 325 pc; see for instance Bahcall & Soneira 1984; Gilmore 1984; Kuijken & Gilmore 1989; Ojha et al. 1999; Chen, Stoughton, & Smith 2000; Siegel, Majewski, & Reid 2002, and Du et al. 2003). The more massive OB stars, by contrast, together with CO and H I clouds, appear to be concentrated within relatively narrow layers with width $\sim 100 \rightarrow 200$ pc (e.g., Bronfman et al. 1988; Malhotra 1994; Wouterloot et al. 1990; Merrifield 1992; Reed 2000).

Finally, there is also evidence for a further structure with very much lower density, and a stellar population which extends out to $\sim$ 5 kpc from the mid-plane (e.g., Du et al. 2003). The scale height of this "thick disk" component is of order $z_0 \sim 850$ pc (Gilmore et al. 1984; Kuijken & Gilmore 1984; Ojha et al. 1999; Robin, Reylé, & Crézé 2000; Chen et al. 2001; Siegel et al. 2002; Du et al. 2003).

It is thought that most planetary nebulae arise from stars with mass $\sim 1\ M_{\odot}$. This is implied by the vertical distributions of PNe compared to galactic stellar populations (see e.g., Phillips 2001, and references therein), and also by central star mass functions (e.g., Kaler & Jacoby 1991; Zhang & Kwok 1993; Weidemann 1989), and the initial/final mass functions of Weidemann (1987) and Jeffries (1997). Given that this is the case, then one would expect that their scale heights z_0(PNe) would be similar to that of the thin disk cited above. Various analyses of z_0(PNe) appear to confirm that this is the case.

Phillips (2003a), for instance, finds that nebulae with high 5 GHz brightness temperatures have z_0(PNe) $\sim$ 240 pc (where we have used the revised statistical scale of Phillips 2004), whilst Corradi & Schwarz (1995) determine that z_0(PNe) $\sim$ 260 pc. Phillips (2001), by contrast, has investigated de-reddened scale heights for a variety of nebular morphologies. He finds very much reduced values z_0(PNe) $\sim$ 156 pc for PNe as a whole, and scale heights $\sim$180$\rightarrow$233 pc for sources having circular morphologies (the precise value depends upon the distance scale which is adopted). It is likely that these latter morphologies derive from lower mass progenitors (e.g., Phillips 2003b,c), and occupy a similar spatial regime to that of the thin-disk structure.

Values prior to 1988 have been summarized by Phillips (1988). These are, for the most part, based upon less reliable procedures, and result in estimates of z_0 extending over a broad range of values. The mean of these scale heights is nevertheless similar to those cited above.

Most studies of the PNe spatial distribution end at this point, however. There have been few if any attempts to determine how z_0(PNe) might vary with galactocentric distance R. We shall show however, in the following, that such an analysis is certainly feasible, even though the distances to these sources are still open to uncertainty. We shall also demonstrate that the PNe spatial distribution flares outwards, in a manner reminiscent of various other stellar and gaseous components.

2. THE OBSERVED LATITUDE VARIATION OF GALACTIC PNE

It is useful, in order to estimate the spatial variation in z_0(PNe), to determine the mean latitude fall-off of PNe as a function of galactic longitude ℓ. We have undertaken such an analysis using the catalogs of Acker et al. (1992) and Kohoutek (2001). Sources have been selected only where there is common agreement that they represent PNe; a requirement which excludes $\sim$ 23% of listed outflows. The nebulae have subsequently been folded with respect to both longitude and latitude; a process which involves combining sources at negative and positive latitudes, and concatenating nebulae in the regimes $0° < \ell < 180°$ and $180° < \ell < 360°$. The results have subsequently been binned into a further 8 ranges of longitude, selected so as to permit analyses of angular trends to a reasonably high level of significance. The widths of these bins varies from 10° closer to the galactic centre, to 40° in the anti-centre regime.

Nebulae having b $< 3°$ are particularly strongly affected by interstellar extinction, a factor which may distort apparent gradients $dN(b)/db$. Similarly, the population of sources having $0° < \ell < 10°$ (and $350° < \ell < 360°$) is contaminated by appreciable numbers of Population II galactic bulge nebulae. Both of these subsets are therefore excluded in assessing the variation of scale height with galactocentric distance.

A further bias arises from the fact that PNe have been discovered using differing surveys, and with varying instrumental sensitivities. The observed distribution of these sources therefore has a somewhat patchy level of completeness. Such variations are largely smoothed over in the present analysis, however, and it is unlikely that they will lead to appreciable distortion of the latitude functions. Apparent gradients $dN(b)/db$ are likely to be closely representative of the intrinsic variation in PNe numbers.

Selected functions $N(b)$ are illustrated in Figure 1, where $N(b)$ is the number of sources within unit interval of latitude. It may be seen that all of these follow closely linear trends, such that $\log(N) \propto < |b| >$. We shall later find that this arises as a consequence of the exponential fall-off in PNe numbers, and because of limited levels of completeness at larger distances from the Sun.

Where these trends are characterized by a relation $N(b) \propto \exp(-b/b_0)$, and b_0 is the mean scale latitude, then it follows that $b_0 = 0.434(dN(b)/db) - 1$. The values of b_0 have been estimated using a least-squares analysis, and their variation is illustrated in Figure 2.

It will be noted that b_0 increases with increasing mean longitude. The particularly low value close to $< \ell >= 3.54°$ corresponds to the longitude range $0° < \ell < 10°$ (concatenated with $350° < \ell < 10°$), and is strongly affected by galactic centre bulge sources. This value is illustrated purely for the sake of interest, and should be treated with caution.

The variation in b_0 will be shown to be indicative of an increase in scale height with galactocentric distance.

3. THE INTERPRETATION OF LATITUDE SCALE HEIGHTS b_0

In interpreting the trends determined in § 2, we make the usual assumption that PNe spatial densities $n(z)$ vary as

$$n(z) = n_0 \exp(-z/z_0)\,, \tag{1}$$

with height z above the galactic mid-plane, where z_0 corresponds to the scale height. The applicability of

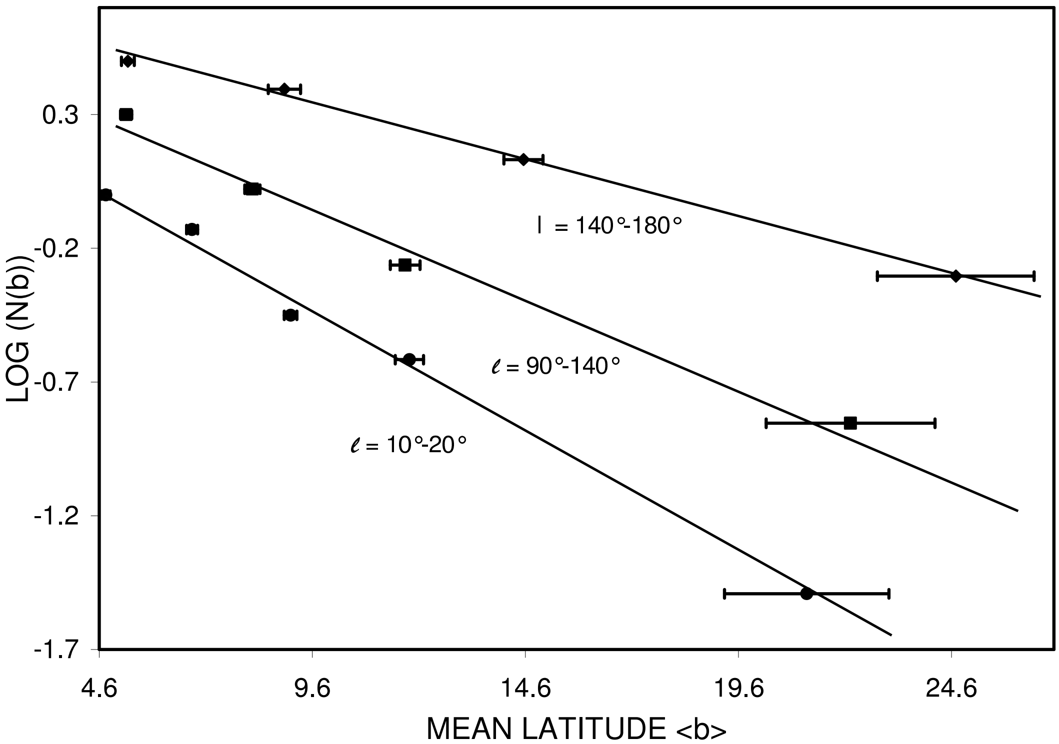

Fig. 1. The variation of source numbers N with latitude b for various ranges of galactic longitude.

this relation is somewhat in doubt, and Haywood, Robin, & Crézé (1997a,b) have commented that single exponential trends are inappropriate where $z < 500$ pc. Such expressions have nevertheless proven useful in modeling a broad range of disk components, including the older stellar population out of which most PNe arise.

Given this variation in $n(z)$, it is then readily shown that the number of PNe observed within a longitude range $\ell + d\ell$, and latitude range $b + db$ is given through

$$N(b,\ell)\,db\,d\ell = db\,d\ell \int_0^{S_{UP}} n(z)\eta(s)s^2 ds =$$

$$= n_0\,db\,d\ell \int_0^{S_{UP}} \eta(s)\exp\left[-\frac{s\,sin\,b}{z_0(s)}\right] s^2 ds$$

$$\equiv n_0\,db\,d\ell\,z_0^3 \int_0^{\Psi_{UP}} \eta(\Psi)\mathrm{exp}\left[-\frac{\Psi sin\,b}{z_0(\Psi)}\right] \Psi^2 d\Psi\,, \quad (2)$$

where s corresponds to distance from the Sun, S_{UP} is the upper limit distance to the nebulae, η is a sample completeness coefficient, and $\Psi = s/z_0$. Note that the scale height z_0 will be expected to depend upon distance s. Given the likely change of z_0 with R (see § 5), and the limited distances over which PNe can be detected, then we find that $z_0(s)$ can be approximated by a linear relation $z_0(s) = z_{00} + gs$, where g is a constant. Numerical solutions of this equation, assuming various gradients in dz_0/ds, show that the results are closely similar to those which would be obtained where z_0 is constant, and equal to the value $z_0(< S(\ell) >)$ occurring at mean distance $< S(\ell) >$. Since the use of a constant scale height greatly simplifies our analysis, we shall employ this value of $z_0(< S(\ell) >)$ in our continuing analysis (hereafter referred to simply as z_0).

The completeness parameter $\eta(\Psi)$ may be approximated by the tripartite function:

$$\eta(\Psi) = 1;\ \Psi \leq \Psi_1 \quad (3a)$$

$$\eta(\Psi) = A + \frac{B}{\Psi z_0};\ \Psi_1 < \Psi \leq \Psi_2 \quad (3b)$$

$$\eta(\Psi) = 0;\ \Psi > \Psi_2\,, \quad (3c)$$

such that source samples are complete (i.e., fully detected) where $\Psi \leq \Psi_1$, and nebulae are undetected at distances $> \Psi_2$. The intermediate case ($\Psi_1 \leq \Psi \leq \Psi_2$) allows for a linear decline between these limits.

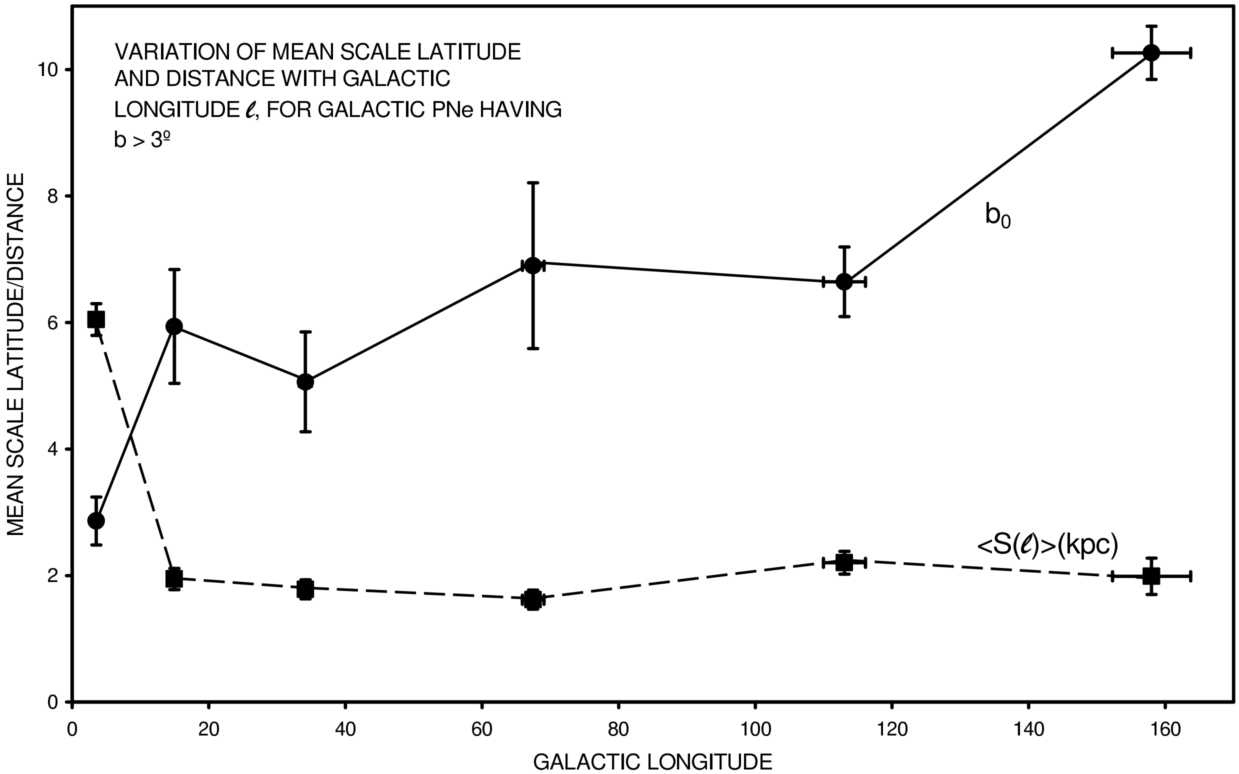

Fig. 2. The variation of mean scale latitude b_0, and mean statistical distance $< S(\ell) >$ with galactic latitude ℓ. It is apparent that distances $< S(\ell) >$ appear more-or-less constant where $\ell > 15°$, whilst estimates of b_0 increase within this same regime. Values close to $\ell = 3.5°$ are affected by sources within the galactic bulge. Note that the longitude axis has again been "folded", as described in Figure 1.

Given this situation, and defining the dimensionless parameter $\Psi_{UP} = S_{UP}/z_0$, it follows that the number density of sources will vary as

$$N(b,\ell)\, db\, d\ell = n_0\, db\; d\ell\, z_0^3\, G_0\,, \tag{4}$$

and the mean distance along the line-of-sight vector (ℓ, b) is given through

$$\langle S(\ell,b)\rangle = \frac{F_0 z_0}{G_0}\,, \tag{5}$$

where

$$\begin{aligned} G_0 = {} & \frac{2}{sin^3 b} + (A-1) exp(-\Psi_1)\,\Xi_2(\Psi_1) \\ & -A\exp(-\Psi_2 sin\, b)\,\Xi_2(\Psi_2) \\ & +\frac{B}{z_0}\,[\exp(-\Psi_1 sin\, b)\,\Xi_3(\Psi_1) \\ & -\exp(-\Psi_2 sin\, b)\Xi_3(\Psi_2)]\,, \end{aligned} \tag{6a}$$

$$\begin{aligned} F_0 = {} & \frac{6}{sin^4 b} + (A-1)\exp(-\Psi_1 sin\, b)\,\Xi_1(\Psi_1) \\ & -A\exp(-\Psi_2 sin\, b)\,\Xi_1(\Psi_2) \\ & +\frac{B}{z_0}\,[\exp(-\Psi_1 sin\, b)\,\Xi_2(\Psi_1) \\ & -\exp(-\Psi_2 sin\, b)\,\Xi_2(\Psi_2)]\,, \end{aligned} \tag{6b}$$

and

$$\Xi_1(\Psi) = \frac{\Psi^3}{sin\, b} + \frac{3\Psi^3}{sin^2 b} + \frac{6\Psi}{sin^3 b} + \frac{6}{sin^4 b}\,, \tag{7a}$$

$$\Xi_2(\Psi) = \frac{\Psi^2}{sin\, b} + \frac{2\Psi}{sin^2 b} + \frac{2}{sin^3 b}\,, \tag{7b}$$

$$\Xi_3(\Psi) = \frac{\Psi}{sin\, b} + \frac{1}{sin^2 b}\,. \tag{7c}$$

The mean distance along any particular longitude, summing up over all sources above the lower limit latitude $|b_{\rm LOW}| = 3°$, is obtained by appropriately integrating the expressions F_0 and G_0 with respect to b. This leads to integral values $F_{\rm INT}$ and $G_{\rm INT}$, and an estimate for mean distance $< S(\ell) >= z_0 F_{\rm INT}/G_{\rm INT}$.

Finally, we may now fit the theoretical latitude variation $N(b, \ell)$, calculated using Eq. (3), with a least squares trend $\log(N(b)) = mb + n$. This is used to define an angular scale height b_0 ($\equiv \log_{10} e\, m^{-1}$) comparable to the observed values in Fig. 2. We shall also define a mean angle $b_A = tan^{-1}(z_0/ < S(\ell) >)$ $= tan^{-1}(G_{\rm INT}/F_{\rm INT})$. The ratio b_0/b_A is of some importance for this analysis, since if b_0/b_A is known (see below), and b_0 and $S(\ell)$ can be separately evaluated, then it is a relatively straightforward matter to determine the scale height z_0.

We shall consider two extreme cases in determining the ratio b_0/b_A. For the first of these, we assume that $A = 1$ and $B = 0$, such that $\eta(\Psi) = 1$ where $\Psi \leq \Psi_2 \leq \Psi_{\rm UP}$, and $\eta(\Psi) = 0$ for larger values of Ψ. Given this simplifying case, and using Eqs. (3) and (4), we then determine that $b_0/b_A \simeq 1$ where $\log(\Psi_{\rm UP}) \simeq 0.5 \rightarrow 1.0$.

What values should we actually expect for upper limit parameter $\Psi_{\rm UP}$, however?

We show, in Fig. 3, a comparison between the trend in source numbers $N(\Psi)$ expected for an exponential fall-off with height z above the galactic plane, and that for sources whose distances have been determined by Phillips (2004). This is far from being a perfect indication of the variation of source detectability. The sources of Phillips are biased towards outflows having larger brightness temperatures T_B, for instance, and this will inevitably bias trends in $N(\Psi)$. Such a comparison nevertheless gives a reasonable indication of how η might vary with D. We have assumed that $z_0 = 220$ pc in determining the values Ψ (see e.g., our discussion in § 1).

It is apparent, from Fig. 3, that the agreement between the trends is excellent where $\Psi < 5$, but declines linearly towards zero for $5 \leq \Psi \leq 12$. If one therefore assumes that $\Psi_{\rm UP}$ lies somewhere within these limits (i.e., between 5 and 12), then we determine that $b_A/b_0 \simeq 0.98 \rightarrow 1.0$.

Alternatively, a more detailed analysis of the trends in Fig. 3 would suggest that $A = 5$ and $B = 13$, and again determining $< S(\ell) >$ for all latitudes $b \geq b_{\rm LOW} = 3°$, one then obtains $b_A/b_0 = 1.028$.

We shall therefore assume, given the analysis above, that $b_A/b_0 = 1$ to within quite narrow limits. However, this is not the case for all values of Ψ. b_A/b_0 declines to ~ 0.37 where $\Psi > 10$, and to 0.67 where $\Psi < 3$. In addition, it is worth noting that the regime over which $b_A \simeq b_0$ also corresponds to the range in which $\log(N(b)) \propto b$. The theoretical trends are therefore in accord with the variations deduced from observations (see § 2 and Fig. 1).

This does not however apply outside of this range; the linear $\log(N(b)) - b$ relation fails significantly where $\Psi_{\rm UP}$ is either very large or very small. It is therefore apparent that the observed $\log(N(b)) - b$ relation is an artifact of sample incompleteness; it arises because of the approximate exponential fall-off in source numbers with distance above the galactic plane, the likely drop-off in source detectability beyond some limiting distance, and the fact that the parameter $\Psi_{\rm UP}$ is neither too large nor too small. The violation of any of these requirements may lead to significant non-linearity between $\log(N(b))$ and b.

It is now pertinent to ask whether mean distances $< S(\ell) >$ can be determined for the present corpus of PNe, thereby permitting z_0 to be evaluated using observed values of b_0.

4. THE DISTANCES OF THE PNE

The distances of PNe are notoriously uncertain. Whilst more-or-less reliable distances are available for a small proportion of PNe, acquired using trigonometric and spectroscopic parallax, estimates of central star gravity and so forth, these values are prone to random errors of order $\sim 30\%$ (see e.g., Phillips 2002). So-called statistical parallaxes are available for a larger corpus of nebulae, and might therefore be of use for estimating mean distances for our present sample of sources. These are even more uncertain that the previously cited distances, however, and may be subject to appreciable systematic errors.

On the other hand, a recent analysis by Phillips (2004) has noted that the standard sources of Phillips (2002) and Zhang (1995) are complementary, and appear in excellent accord with theoretical trends. It has therefore proven possible to determine a new distance scale which appears to be much more reliable. These distances are also similar (within $\sim 30\%$) to the statistical values of Zhang (1995), Cahn, Kaler, & Stanghellini (1992), Daub (1982), and van de Steene & Zijlstra (1995).

We shall employ the distances of Phillips (2004) in our present analysis.

These sources represent only $\sim 56\%$ of PNe having $|b| > 3°$, however, and it is therefore possible that the statistical values of $< S(\ell) >$ are somewhat unrepresentative. In particular, the statistical sources are located towards the higher end of the 5 GHz flux range, and will likely give values of $< S(\ell) >$ which

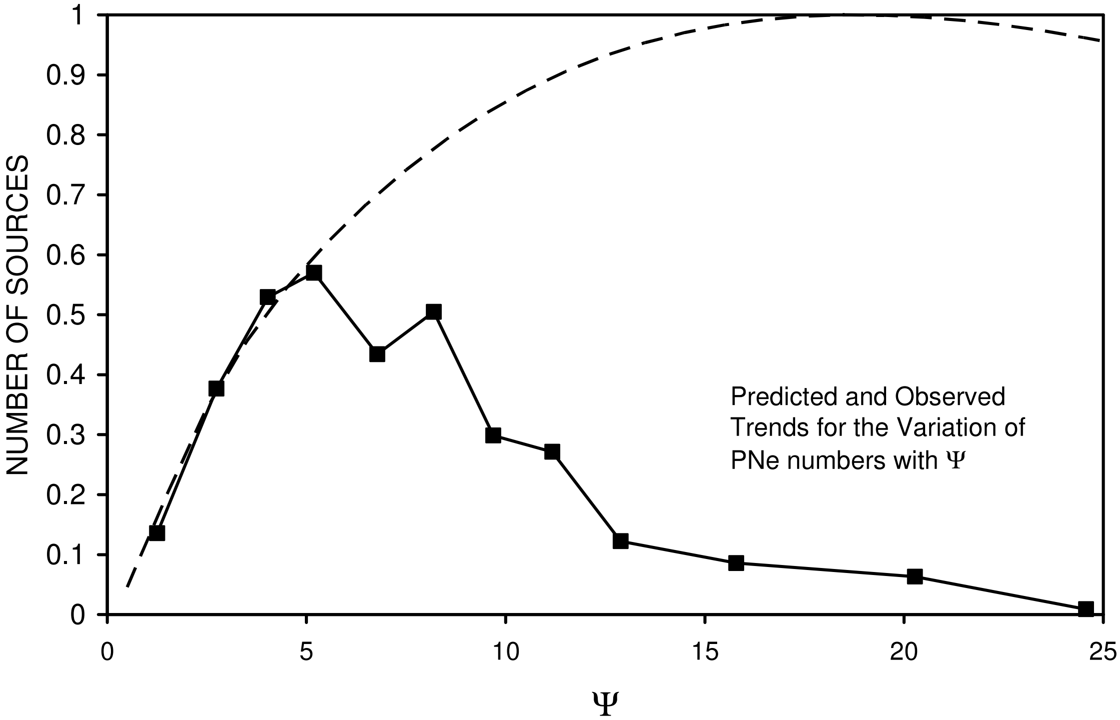

Fig. 3. The variation of source numbers with normalized distance Ψ, determined using the statistical results of Phillips (2004). We have also shown the trend expected for an exponential fall-off in population with height z above the galactic plane (dashed curve). It will be noted that observed trends are in close accord with theory where $\Psi < 5$, but that there is an increasing disparity for larger values of Ψ. The theoretical variation of $N(\Psi)$ has been normalized to unity.

are somewhat too small. Such values nevertheless represent our best hope for evaluating $< S(\ell) >$, and are likely to be reasonably accurate to first order.

The primary biases against source detectability arise from limits to observational sensitivity, and the influence of interstellar extinction. Both of these factors lead to reduced detectability where nebulae are faint and distant. The nebular population is therefore likely to be characterized by a sharp decline in numbers beyond some limiting distance $S_{\rm UP}$ (see Fig. 3 and § 3). Since both of these biases are similar where $|b| > 3°$, and $10° < \ell < 350°$, it follows that values of $< S(\ell) >$ should be largely invariant with longitude ℓ.

Such a conclusion is borne out by our present results, as may be noted in Fig. 2. The distances have been binned using the same longitude ranges as for the present sample of sources, and again apply for latitudes $|b| > 3°$. All of the values of $< S(\ell) >$ oscillate within a very small range, excepting the distances at $\ell = 3.54°$, which are dominated by galactic bulge sources.

We shall adopt these individual values of $< S(\ell) >$ in assessing mean scale heights.

5. THE DEDUCED VARIATION OF z_0 WITH GALACTOCENTRIC DISTANCE

If we now take the observed values of b_0 (see § 2 and Fig. 2), adopt the mean distances quoted in § 4, and use the relation $b_0 = b_A$ proposed in § 3, then we find the variation of z_0 with R illustrated in Figure 4. We have assumed, in constructing this figure, that the galactocentric distance of the Sun is $R_0 = 7.9$ kpc. Although this is less than the officially sanctioned IAU value for this parameter, it appears consistent with the best recent estimates based upon observations of Sgr B2 (Reed et al. 1988), of masers in W49 (Gwinn, Moran, & Reid 1992), of distances to OH/IR type stars (Moran 1993), using measures of younger stars (Turbide & Moffat 1993), from the analysis of stellar K-bands counts by Lopez-Corredoira et al. (2000), and so forth.

Although errors in z_0 are of order $\sigma(z_0) \sim 0.04$ pc, these are strongly affected by uncertainties in distance ($\sigma(< S(\ell) >) \sim 0.19$ kpc; see § 4). Where one assumes that $< S(\ell) >$ is more-or-less invariant with ℓ, as has been argued to be the case in § 4, and adopts an overall value $< S >= 1.89 \pm 0.08$ kpc

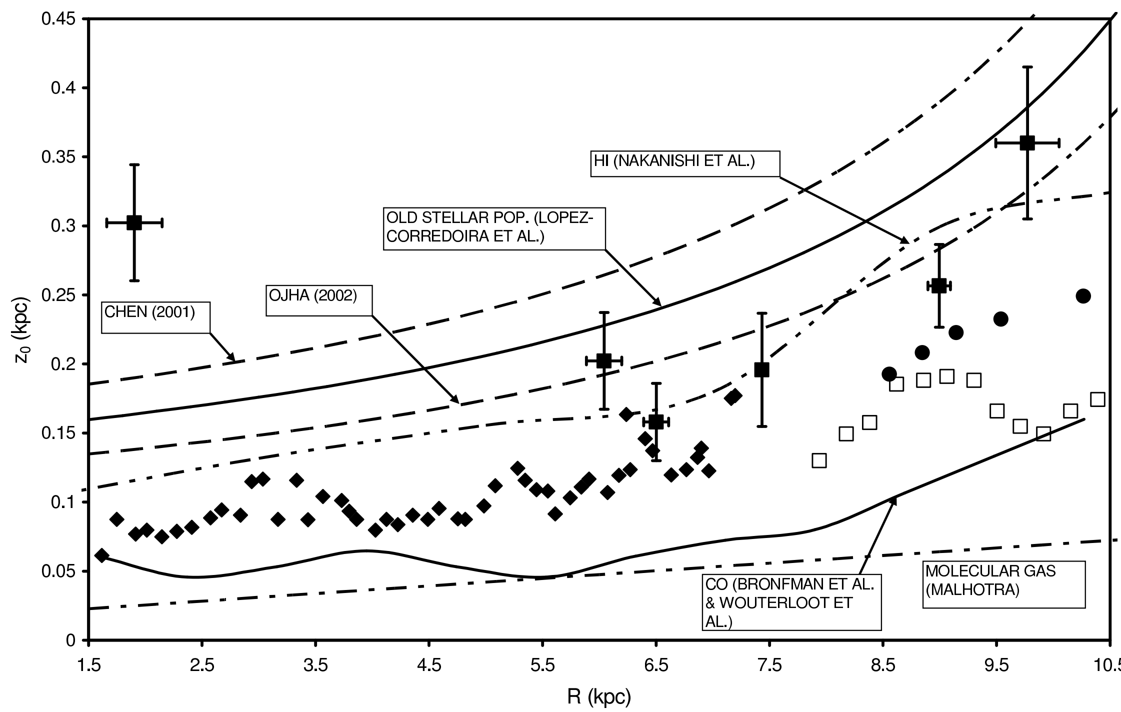

Fig. 4. The deduced variation of PNe scale heights with galactocentric distance R (symbols with error bars). It will be noted that values z_0 increase with increasing R where $R > 6$ kpc, matching the trends observed for various other disk components. The large scale height close to $R \simeq 1.9$ kpc is strongly affected by galactic bulge PNe. We have also illustrated the trends for CO and "molecular gas" (Bronfman et al. 1988; Wouterloot et al. 1990; Malhotra 1994), together with values for H I taken from Nakanishi & Sofue (2003), Wouterloot et al. (1990) (open squares) and Merrifield (1992) (solid bullets and triangles). Note that the Merrifield (1992) results represent "half-thicknesses" of the H I layer, and are therefore likely to be somewhat larger than the exponential scale height. Similarly, Nakanishi & Sofue determine the height at which the volume density of H I has half its maximum value. Finally, we have also shown the trend in z_0 determined for the old stellar population (Lopez-Corredoira et al. 2002). The dot-dashed curves employ the same functional variation of $z_0(R)$, but for larger (Chen 2001) and smaller (Ojha 2002) estimates of scale height.

consistent with the trends in Fig. 2, then the errors in z_0 are reduced by as much as $\sim 64\%$.

It is apparent that our values of scale-height increase with galactocentric distance where $R >$ 5.5 kpc. This is consistent with the trend noted for other disk components. In particular, the present variation appears similar to the flaring function of Lopez-Corredoira et al. (2002), particularly when this is combined with the estimate of thin-disk scale height determined by Ojha et al. (2002). Our present values of $< S(\ell) >$ are likely to be somewhat too small, however, and this will likely to reduce our estimates for z_0 as well (see § 4). Similarly, our sample contains all of the Peimbert classes of PNe, ranging from the higher mass Type I outflows, down to the much more abundant Type II and Type III nebulae. It is these latter sources, in particular, which are likely to be associated with the old stellar population of Lopez-Corredoira et al. By contrast, the Type I sources are likely to be characterized by very much smaller values of z_0, similar to those of the A and B type stars out of which they are formed.

It follows that although the present sample of PNe contains a preponderance of Type II and Type III nebulae, the presence of Type I outflows will reduce mean values of z_0.

In summary, it is apparent that the observed trends in latitude for PNe imply a flaring of the galactic disk towards larger galactocentric distances. This is consistent with what is found for other stellar and gaseous components within the galactic disk. The overall scale heights of PNe are consistent with an origin in lower mass stars, and an association of most PNe with the thin disk structure. Such an analysis therefore represents a further useful way in which PNe origins may be assessed, and the local galactic disk may be probed.

6. CONCLUSIONS

We have shown that it is possible to use the observed latitude distribution of PNe to investigate the variation of scale height with galactocentric distance. In particular, we show that the numbers $N(b)$ of higher latitude PNe vary as $N(b) \propto \exp(-b/b_0)$, and that the angular scale height b_0 is likely to be of order $\tan^{-1}$ $(z_0/ < S(\ell) >)$, where z_0 represents the scale height at mean distance $< S(\ell) >$. Given an estimate of $< S(\ell) >$, it is then possible to determine direct values of z_0 for any particular latitude bin $\Delta\ell$.

We have used the statistical distances of Phillips (2004) to show that $< S(\ell) >$ is likely to be almost invariant with ℓ, providing that $|b| > 3°$ and $10° < \ell < 350°$. We then find, using these values, that z_0 increases with increasing galactocentric distance where $R > 6$ kpc, a trend which is in conformity with what is observed for the older population of thin-disk stars. Although our results are most consistent with the stellar scale heights of Ojha et al. (2002), it is argued that our present values of z_0 may be systematically too low. Not only are the values of $< S(\ell) >$ likely to be somewhat on the low side, but the PNe contain an admixture of higher mass Type I nebulae as well. These latter outflows are likely to be characterized by somewhat lower mean scale heights.

It therefore appears that this procedure offers a further way in which the structure of the local galactic disk may be examined. It also confirms the presence of spatial flaring, and an association between PNe and the older (thin-disk) population.

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John P. Phillips: Instituto de Astronomía y Meteorología, Universidad de Guadalajara, Av. Vallarta No. 2602, Col. Arcos Vallarta, 44130 Guadalajara, Jalisco, México (jpp@cencar.udg.mx).