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# THE PROBLEM WITH REDDENING DISTANCES TO PLANETARY NEBULAE

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RESUMEN

Observamos que la vasta mayoría de NP's galácticas están localizadas fuera de la capa de enrojecimiento interestelar, de manera que los gradientes locales en $E_{B-V}$ son bajos y llegan a ser indetectables. Esto invalida ciertas estimaciones previas de sus distancias de enrojecimiento $D_{RED}$. Significa también que los análisis realizados a gran escala, como los de Pottasch (1984) y Acker (1973), llevan a valores de $D_{RED}$ que son demasiado bajos.

Una crítica similar se aplica a los análisis basados en medidas de la línea D de absorción del Na, y posiblemente muchas de las distancias de Napiwotzki & Schönberner (1995) estén erradas.

ABSTRACT

It is noted that the vast majority of Galactic PNe are located outside of the interstellar reddening layer, to the extent that local gradients in $E_{B-V}$ are low to undetectable. This is likely to invalidate certain previous estimates of their reddening distances $D_{RED}$. It also means that larger scale analyses, such as those of Pottasch (1984) and Acker (1973), lead to values of $D_{RED}$ which are significantly too small.

A similar critique applies to analyses based on measures of Na D-line absorption, and it seems likely that most of the distances of Napiwotzki & Schönberner (1995) are similarly in error.

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



## 1. INTRODUCTION

A variety of more-or-less direct methods have been devised for measuring the distances of planetary nebulae (PNe). These include procedures based upon measures of trigonometric parallax (e.g., Harris et al. 1997; Acker et al. 1998; Gutiérrez-Moreno 1999), kinematic parallax (e.g., Liller & Liller 1968; Hajian, Terzian, & Bignell 1993; Hajian & Terzian 1996; Reed et al. 1999), radial velocities (Acker 1978; Phillips 2001a), spectroscopic parallax (Méndez & Niemela 1981; Ciardullo et al. 1999), trends in nebular extinction (e.g., Kaler & Lutz 1983; Gathier, Pottasch, & Pel 1986; Martin 1994), Na D line absorption (Napiwotzki & Schönberner 1995), and determinations of central star gravities (e.g., Méndez et al. 1988; Méndez, Kudritzki, & Herrero 1992).

Although these distances are among the most accurate which are currently available, they are by no means in all cases trustworthy. Random uncertainties appear to be of order $\Delta D/D \sim 0.3$, for instance. Similarly, certain of the methods appear to be open to systematic errors as well. Distances based upon kinematic parallax, for instance, are affected by the geometrical characteristics of the nebulae (Phillips 2005a), and differences between the pattern and mass velocities of the outflowing shells (Mellema 2004; Schönberner, Jacob, & Steffen 2005). Measures of central star gravities appear to be somewhat suspect as well, and depend upon the sophistication of the modeling which is employed. The values $D_{GRAV}$ of Méndez et al. (1988) are 20% greater than those of Méndez et al. (1992), for instance; a difference which arises because the analysis of Méndez et al. (1992) takes account of stellar winds, as well as the spherical extensions of the central stars. Similarly, it has been noted that although the impact of ion-dynamical effects is small, and has a minor influence upon Balmer line profiles (Napiwotzki & Rauch 1994), the contribution of metals to atmospheric opacities may be of critical importance (Werner 1996).

It is our purpose, in the following, to point out that reddening and Na D line distances may also be prone to error. There are two principal procedures which have been used to date. In the most detailed of these, of which the best is probably that of Gathier et al. (1986), an analysis is made of stars located at small angular distances from the sources. The resulting trend of extinction with distance is then used to constrain the distances to the nebulae. Other examples where this procedure has been applied may be found in Lutz (1973), Martin (1994), Acker (1978), Saurer (1995), Huemer & Weinberger (1988), Pollacco & Ramsay (1992), and Solf & Weinberger (1984).

A second and more broad-brush procedure has also been developed by Pottasch (1984;1996) and Acker (1978). In this, the nebular extinction $C_{NEB}$ is compared to local extinction gradients $dC/dD$, and distances $D_{RED}$ are assumed given by $C_{NEB}/(dC/dD)$. Napiwotzki & Schönberner (1995) have also used a similar procedure, applied to measures of interstellar Na D line absorption. In both of these cases, the authors have used previously published maps of interstellar extinction gradients (Lucke 1978; FitzGerald 1968) and Na D line absorption (Binnendijk 1952). These, in turn, have been derived using brighter O and B type stars alone. Such maps are not spatially well refined, and fail to account for small-scale variations in extinction.

We shall suggest that most PNe are located well above the interstellar (IS) reddening layer, and that the failure to take this into account may lead to misleading results. The most insidious (and wide-ranging) effect is upon the values of Pottasch (1984;1996), Acker (1978) and Napiwotzki & Schönberner (1995), and most of their distances are likely to be in error.

These problems in determining distances are likely to affect our understanding of PNe properties and evolution, and may also influence distance estimates based on statistical procedures. Na D line and reddening distances have been used in evaluating the statistical distances of Acker (1978), Daub (1982), Cahn, Kaler, & Stanghellini (1992) and Phillips (2002;2004a), for instance, as well as being employed to evaluate PNe formation rates, local volume densities (Pottasch 1996; Phillips 2002), and the luminosities of highly evolved outflows (Phillips 2005b).

It will become clear, in brief, that reddening distances are far from reliable, and should be treated in future with a considerable degree of caution.

## 2. THE LOCATION OF PNE WITH RESPECT TO THE REDDENING LAYER

It is important, in evaluating reddening distances, to know exactly where the PNe are located. Certain previous analyses have assumed that they are located within the galactic extinction layer — that reddening in the vicinities of these sources is both detectable and reasonably large.

In fact however, much of the gas and dust in the Galactic disk appears to be located within a relatively narrow layer, the scale height of which ($z_0(DUST) \sim 50 \rightarrow 100$ pc; see, e.g., Branfman et al. 1988; Malhotra 1994; Wouterloot et al. 1990; Merrifield 1992) is less than that for PNe ($z_0(PNe) \sim 0.22$ kpc, hereafter referred to as $z_0$; see, e.g., Phillips 2001b, 2003, 2005d, and values cited in Phillips 1988). Although this value for $z_0$ is uncertain, it is unlikely to be very greatly in error (Phillips 2005d), and uncertainties in this parameter are unlikely to affect our qualitative results.

Most nebulae are therefore likely to be located outside of this layer —or at least, sufficiently outside of it that local reddening gradients are small.

There are two independent lines of evidence which appear to confirm this supposition. In the first place, we can use the extinction values of Tylenda et al. (1992), and the revised statistical distances of Phillips (2004a), to determine the mean extinction $<C>$ of PNe as a function of distance. This is shown in Figure 1 for various ranges of latitude. Two things are immediately apparent:

a) Extinction $C$ is larger where latitudes are low, as would be expected given the narrowness of the reddening layer cited above.

b) The gradient $d<C>/dD$ is close to zero irrespective of the latitude range.

We can extend this analysis even further. The mean trend of extinction with latitude $<C(b)>$ is shown in Figure 2. We have approximated this by the polynomial fit:

$$\begin{aligned} C(b) >= & - \; 0.0388\,[\log b]^3 + 0.4904\,[\log b]^2 \\ & - \; 2.1195\,[\log b] + 2.314\,. \end{aligned} \quad (1)$$

If this fit is removed from the observed extinctions for PNe (i.e., we calculate a parameter $C_{DIFF} = C_{OBS}(b) - <C(b)>$), and one concatenates the results, then it is possible to determine

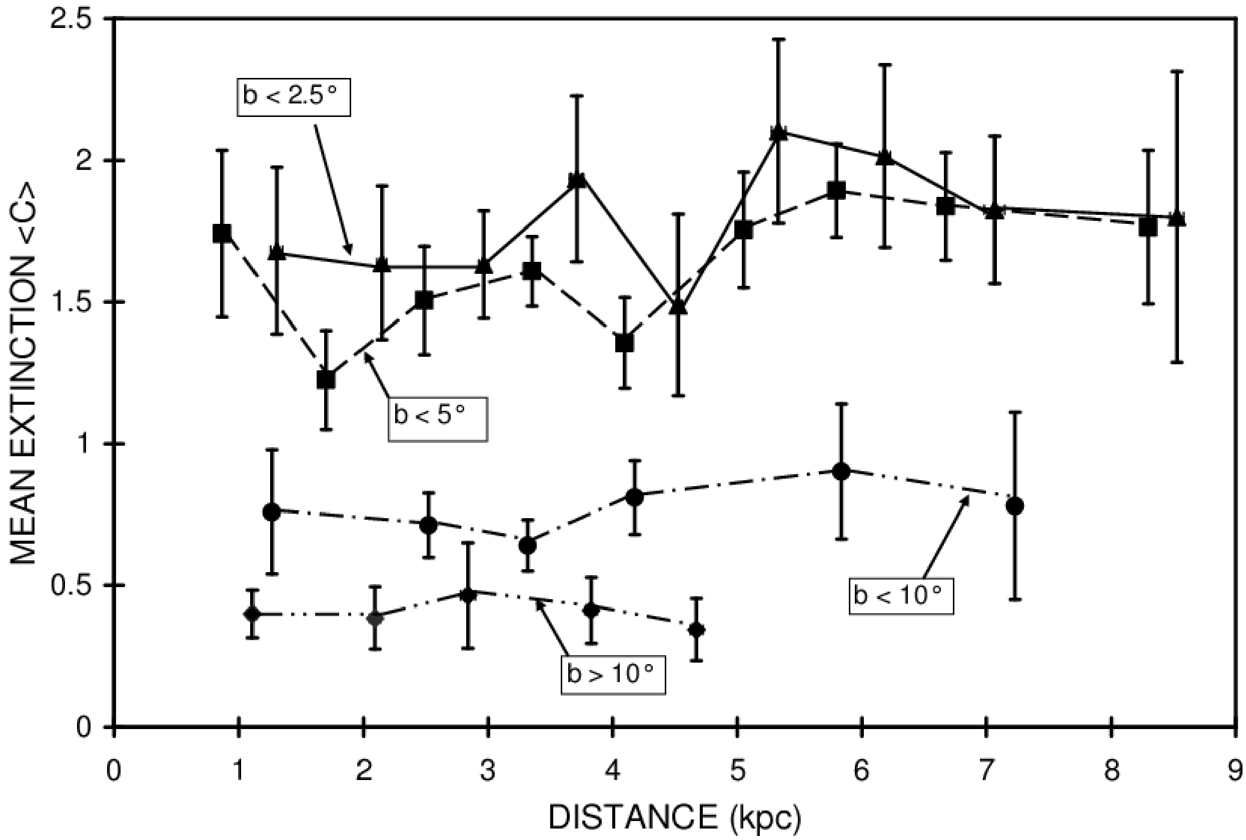


Fig. 1. The variation of mean extinction with distance for differing ranges of latitudes, where we have employed the distances of Phillips (2004), and the reddening coefficients of Tylenda et al. (1992). It will be noted that whilst mean extinctions vary with latitude, they appear to be almost invariant with distance. The horizontal error bars are comparable or smaller in size to those of the symbols.



a mean variation $<C_{DIFF}(D)>$ for all of the PNe. Such a variation is shown in Figure 3. It is apparent that there is again very little variation of $<C_{DIFF}>$ with D, and that gradients $d <C_{DIFF}> /dD$ are no greater than $\sim 0.0015$ kpc$^{-1}$.

This result is surprising, and contradicts the assumptions behind many previous estimates of distance. It is however consistent with most of the sources lying outside of the extinction layer.

Although some allowance must be made for uncertainties in the statistical distances used here, this would not of itself be likely to explain all of the observed trend. Most recent statistical analyses now yield broadly similar results (see, e.g., Phillips 2004a, and references therein), and both absolute and relative PNe distances are reasonably similar. These distance scales are also supported by much ancillary evidence, including measures of galactic radial velocities (Phillips 2001a), nebular sizes (Phillips 2004b), and central star luminosities and magnitudes (Phillips 2005b,c). As a result, qualitatively identical results are obtained where one uses the distances of Zhang (1995), van de Steene & Zijlstra (1995), Bensby & Lundstrom (2001), or Phillips (2002).

Finally, it should be noted that we have excluded all sources in the longitude range $350° < \ell < 10°$, so as to minimize contamination by galactic bulge nebulae. These latter sources are more distant, and partake of differing patterns of extinction.

Apart from this, there is also a further reason for supposing that most PNe are located above the extinction layer.

The number of sources observed in the narrow ranges of latitudes between $b$ and $b + db$, and of lon-

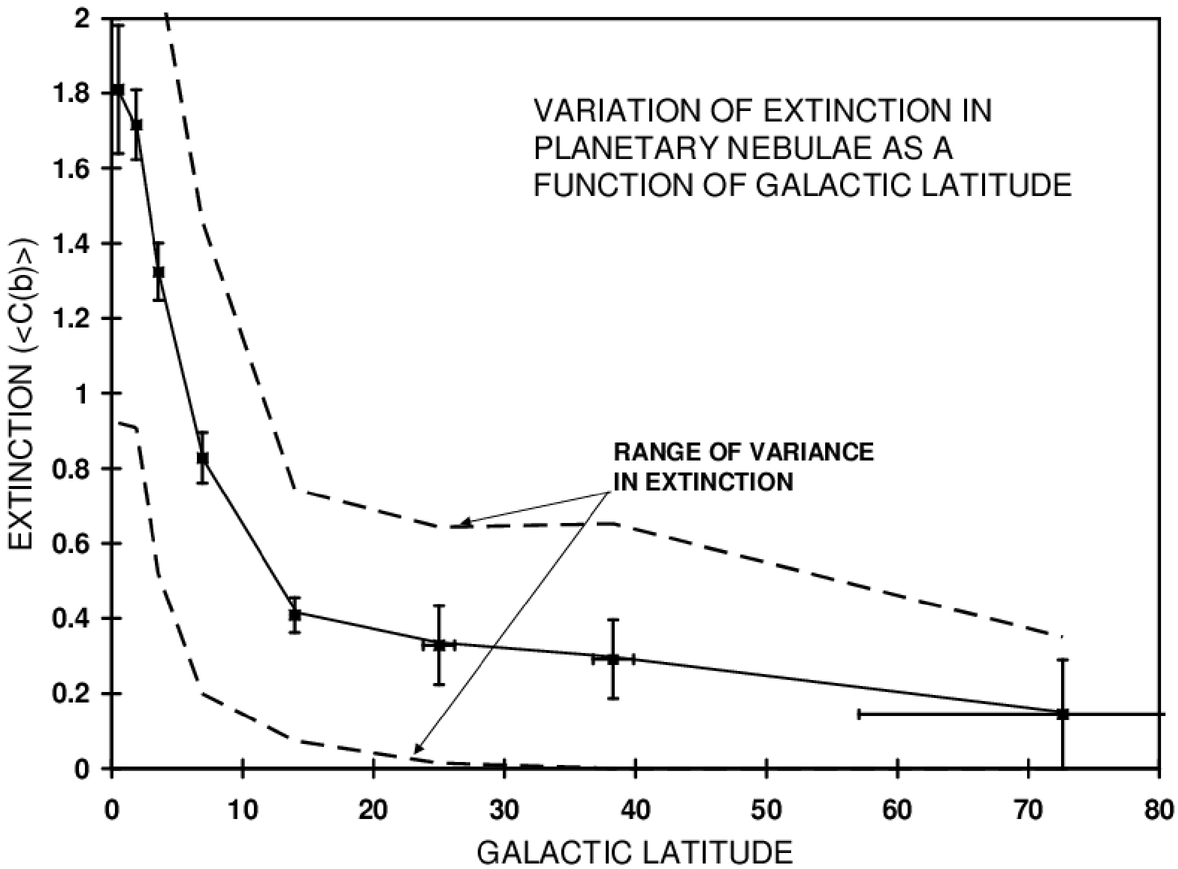


Fig. 2. Variation of mean extinction $<C(b)>$ as a function of Galactic latitude (solid squares with error bars). It will be noted that $<C(b)>$ increases by a factor $\sim 5$ for $b > 10°$. The dashed boundary corresponds to the $1\sigma$ error range in $C$ (i.e., the dispersion range for individual values of $C$).



gitudes between $\ell$ and $\ell + d\ell$ is expected to be given through

$$N(b, D_L, D_U)\, db\, d\ell = db\, d\ell \int_{D_L}^{D_U} n(z) D^2 dD$$
$$= N_0\, db\, d\ell \int_{D_L}^{D_U} \exp\left[-\frac{D \sin b}{z_0}\right] D^2 dD$$
$$= N_0\, db\, d\ell \left[\left(\frac{D_L^2 z_0}{\sin b} + \frac{2 D_L z_0^2}{\sin^2 b} + \frac{2\, z_0^3}{\sin^3 b}\right) \exp\left(-\frac{D_L \sin b}{z_0}\right) - \left(\frac{D_U^2 z_0}{\sin b} + \frac{2 D_U z_0^2}{\sin^2 b} + \frac{2\, z_0^3}{\sin^3 b}\right) \times \times \exp\left(-\frac{D_U \sin b}{z_0}\right)\right], \quad (2)$$

where we have assumed that the volume density of PNe, $n(z)$, declines exponentially with height $z$ above the galactic plane. $N_0$ is the volume density of PNe where $z = 0$, $D_L$ is the lower limit distance to the PNe, and $D_U$ is the corresponding upper limit distance. This relation is strictly applicable where $D_U$ is less than the lateral distance across the galaxy, and $b$ is greater than $\sim 0.7° \rightarrow 1.3°$. Other factors may lead to even stronger constraints upon latitude, however, as we shall note further below.

Despite these restrictions, it is adequate (for most latitudes) to assume that $D_U = \infty$. In the limit where $D_L = 0$ and $D_U = \infty$ we determine that

$$N(b, 0, \infty)\, db\, d\ell = N_0\, db\, d\ell \frac{2\, z_0^3}{\sin^3 b}\,. \quad (3)$$

Using these expressions, it is then possible to determine the fraction $\Im(b)$ of PNe residing within an extinction layer having half-width $Z_D$

$$\Im(b) = \frac{N(b, 0, Z_D \operatorname{cosec} b)}{N(b, 0, \infty)}\,. \quad (4)$$

We shall assume, in the following, that nebular scale-heights are of order $z_0 \simeq 0.22$ kpc (see our comments above). Although this parameter is uncertain,

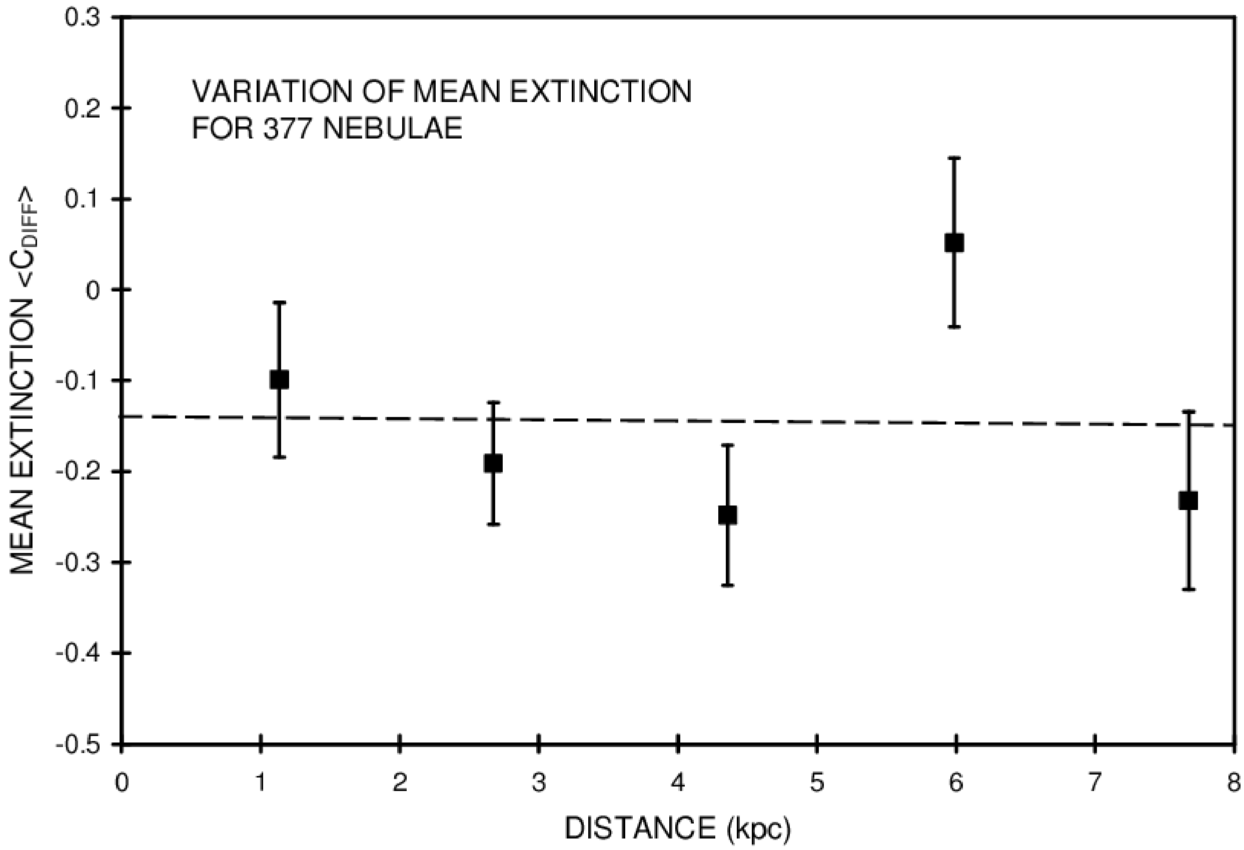


Fig. 3. The variation of extinction with distance for a total of 377 planetary nebulae, where we have subtracted mean latitude trends in extinction from the individual values of $C$. The line corresponds to a least-squares fit, and suggests a negligible variable of $C$ with $D$. The horizontal error bars $\sigma(D)$ are smaller than the symbols.



it is unlikely to be greatly in error. Not only do the more reliable estimates tend to congregate about this value, but it is also comparable to the scale-height of the Galactic thin disk (see, for instance, Bahcall & Soneira (1984); Gilmore (1984); Kuijken & Gilmore (1989); Ojha et al. (1999); Chen, Stoughton & Smith (2001); Siegel, Majewski, & Reid (2002), and Du et al. (2003)). Similarly, we shall take $Z_D$ to correspond to the height at which reddening gradients become undetectable. Evidence for the size of this parameter comes from measures of the extinction distances themselves, which show that reddening gradients flatten out for distances $D > D_D \sim 0.7 \rightarrow 5$ kpc, corresponding to heights $Z_D \sim 0.1 \rightarrow 0.25$ kpc above the Galactic mid-plane. These limits upon $Z_D$ are also confirmed through our analysis in § 3.

If one takes an upper limit value $Z_D = 0.25$ kpc, and therefore maximizes the estimates for $\Im(b)$, it turns out that no more than 11% of sources will be contained within the reddening layer where latitudes $b$ are in excess of 4° (see Figure 4). This rather small value of $\Im(b)$ may seem rather surprising, but arises from two primary causes. Firstly, the majority of PNe are located above the reddening layer even where $Z_D$ and $z_0$ are comparable. Similarly, the volume element $\Delta\ell\Delta b\Delta D$ increases as $D^2$, so that one is sampling increasingly larger volumes of PNe as distances from the Sun increase.

Of course, most PNe along any particular line-of-sight are likely to be faint, distant, and unobserved. The fraction $\Im(b)$ for known (and brighter) PNe will be significantly larger. Similarly, the depth to which one can actually observe PNe is a strong function of latitude; extinction towards lower values of $b$ will cause values of $<D>$ to be reduced. In real situations, therefore, it is clear that the analysis above is likely to be somewhat pessimistic. One expects that $\Im(b)$ will be greater than is indicated in Fig. 4. This would not however, for all but the lowest latitudes, cause $\Im(b)$ to approach anywhere near to unity. Most PNe are expected to remain outside of the reddening layer.

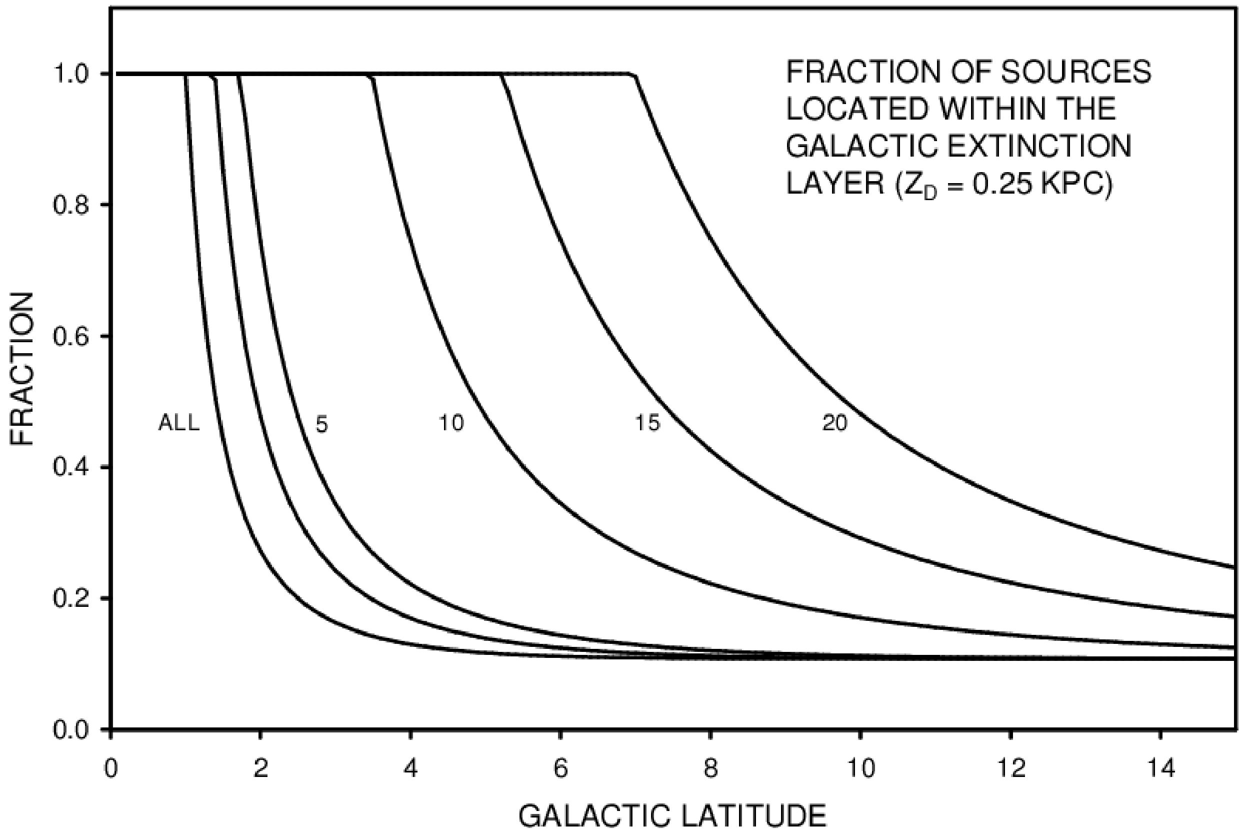


Fig. 4. The number of PNe $\Im(b, \theta_{LIM})$ within the interstellar extinction layer, as a fraction of the total numbers of nebulae along any particular line of sight. The curves correspond to differing values of $\theta_{LIM}$ (4, 5, 10, 15, and 20 arcsec), the lower limit nebular diameter, whilst the left-most curve is for $\theta_{LIM} = 0$; that is, for all of the sources irrespective of size.



One further way of achieving higher values of $\Im(b)$ is by selecting nebulae whose angular dimensions $\theta$ are larger than some limiting diameter $\theta_{LIM}$. A value $\theta_{LIM} \sim 10$ or 20 arcsec would probably be considered reasonable. The restriction upon $\theta$ ensures that the PNe are mostly located close to the Sun, and this will increase the fraction $\Im(b)$ of PNe which are located within the Galactic reddening layer.

To determine precisely how this restriction upon $\theta$ might affect the function $\Im(b)$, we have assumed that the typical radii of PNe are of order 0.1 pc. We have also assumed, yet again, that $Z_D$ is of order 0.25 kpc. The results for various values of $\theta_{LIM}$ are illustrated in Fig. 4.

The variation of the $\theta_{LIM} = 10$ arcsec curve with $Z_D$ is also shown in Figure 5, and gives an idea of the level of error associated with uncertainties in $Z_D$. A variation in $Z_D$ from 0.05 kpc to 0.25 kpc causes the curves to shift by just 3° degrees to the right (i.e., to higher latitudes $b$).

It is clear, from these figures, that most PNe are located outside of the galactic extinction layer, and that this applies even where angular sizes are large, and latitudes are modest. Values of $\Im(b, \theta_{LIM})$ are for the most part extremely small. The only exception to this occurs where $b$ is small: where $b < 3.5°$ when $\theta_{LIM} = 10$ arcsec, and where $b < 7°$ when $\theta_{LIM} = 20$ arcsec.

It is therefore clear that any protocol for evaluating reddening distances should consider only lower latitude sources having large angular sizes.

Such constraints appear not to have been applied in most previous such analyses, however. Whilst limits upon $b$ and have been used in a recent investigation by Navarro et al. (to be published), most prior investigations have not been so punctilious. It has usually been required that latitudes are small in an indefinite kind of way, without specifying the ranges

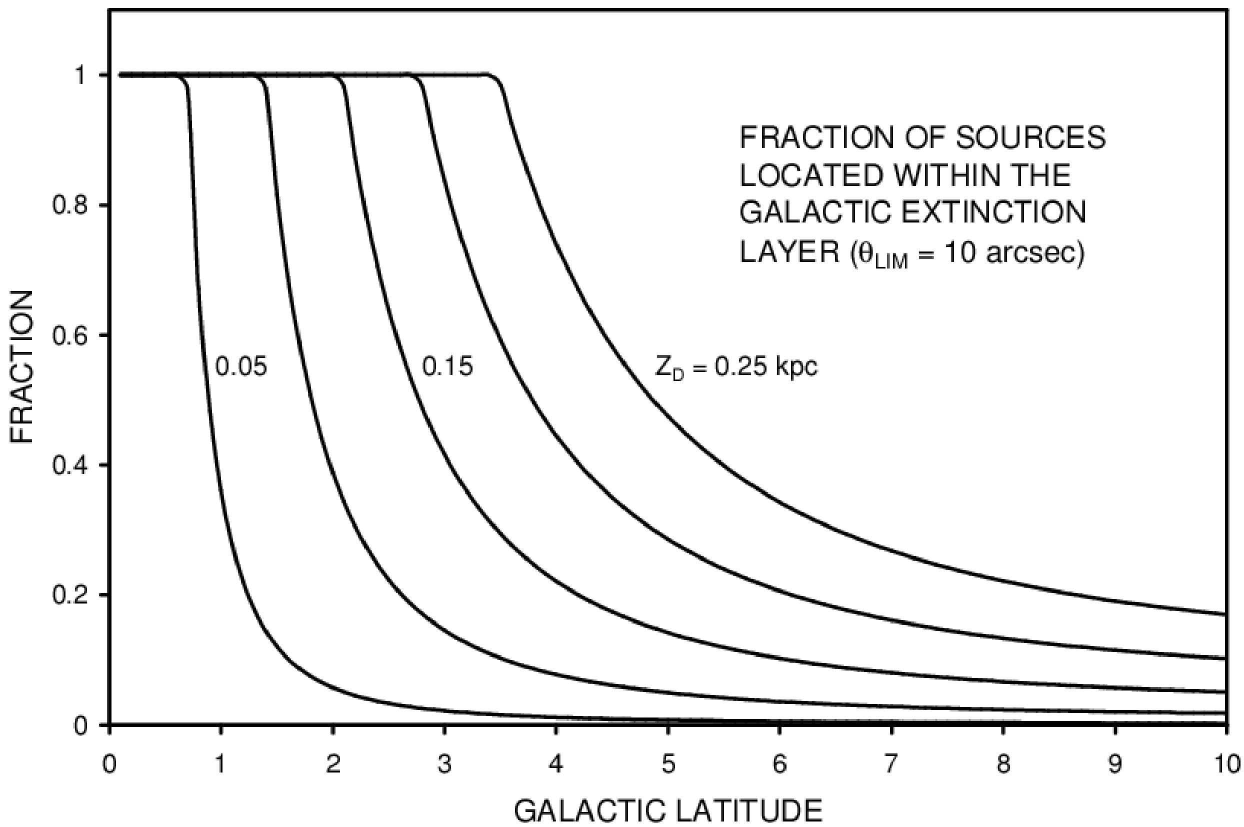


Fig. 5. The variation in the parameter $\Im(b, \theta_{LIM})$ for $\theta_{LIM} = 10$ arcsec, and various values of the extinction layer height $Z_D$. It will be noticed that $\Im(b, \theta_{LIM})$ varies only slightly as $Z_D$ increases.



consistent with a rational analysis of distance. The consequences of this failure are outlined in the following section.

## 3. POTENTIAL ERRORS IN REDDENING DISTANCES $D_{RED}$

Where PNe are located at greater distances from the Sun than $D_D$, the depth of the reddening layer along the line-of-sight, then it is impossible to determine their distances. The best that can be said is that distances determined using the reddening distance procedure, $D_{RED}$, must be $> D_D$. A danger in this case, however, is that the nebula may be assumed to be located at the limits of the extinction layer (i.e., that the reddening distance to the nebula is taken to be equal to the depth $D_D$), an error which will cause PNe distances to be significantly under-valued. This is particularly the case where nebular reddening $E_{B-V}(NEB)$ is comparable to the maximum reddening for line-of-sight stars ($E_{B-V}(MAX)$) —where the PNe are, as it were, perched at the limits of the reddening curve.

Errors of this kind are not entirely a cause for concern, since such mis-analyses can be detected (and rectified) post facto. It is apparent for instance that the distances of NGC 3132, NGC 3918, and NGC 5315 due to Gathier et al. (1986); of IC 1747, IC 289, and NGC 6741 determined by Lutz (1973); of (possibly) Sh 1-89 determined by Huemer & Weinberger (1988); and $\sim 65\%$ of the distances of Acker (1978) should be treated with caution, and probably in most cases thrown out. The particularly unfortunate situation with the Acker (1978) distances is fairly easy to understand, since her reddening-distance diagrams are determined over small ranges of $D$. This does not permit her to probe to the depths required in this type of analysis.

Rather more concerning are situations such as those of Pottasch (1984;1996), Acker (1978), and Napiwotzki & Schönberner (1995), where attempts are made to apply more rough-and-ready procedures to larger numbers of PNe. For these cases, if the nebula is located at height $Z > Z_D$ above the galactic plane (as in most cases they will be), it will nevertheless be assigned a distance $D_{RED} = D_D$, and height $Z_{RED} = Z_D$; the heights of such sources would appear similar and constant, irrespective of their latitudes $b$.

That this is actually the case in practice is apparent from Figure 6, where we have illustrated the heights $Z_{RED}$ of nebulae investigated by Pottasch (1984) and Napiwotzki & Schönberner (1995). These two nebular samples are not entirely equivalent. Whilst the Pottasch (1984) sources appear to have been selected because they lie within the bounds of the extinction mapping of Lucke (1978), those of Napiwotzki & Schönberner refer to more highly evolved outflows. The radii of these latter nebulae will therefore be greater than those of Pottasch, and the value $R = 0.1$ pc employed in the analysis above. Nevertheless, it is clear (from Fig. 6) that the trends for both of these samples are similar.

It may be seen that the heights are mostly small ($Z_{RED} < 0.075$ kpc) where $b$ is less than $\sim$3.7°, and these nebulae are almost certainly located within the primary extinction layer. It is apparent that there is a strong and discontinuous jump in heights close to $b \simeq 3.7°$, however, after which $Z_{RED}$ appears to be more-or-less invariant of $b$. Although the scatter is large, it implies a mean height close to $<Z_{RED}>\sim$ 0.17 kpc, and a maximum value not much in excess of 0.25 kpc. If there are any gradients in these parameters, then it seems unlikely that they exceed $d(Z_{RED})/d(b) \sim 0.01$ kpc/degree of latitude.

To see more clearly what is happening here, and why the change in heights is so rapid and so steep, it is as well to consider the trends noted in Fig. 4. Let us take the curve corresponding to $\theta_{LIM} = 5$ arcsec —that is, the trend for sources whose diameter is greater than 5 arcsec. This is, as it happens, reasonably appropriate for the nebulae selected by Pottasch (1984), although a few of his PNe also extend down to smaller angular sizes.

If one now considers latitudes $b < 1.7°$, then it is clear that all of the PNe are located within the reddening layer. The factor $\Im(b, \theta_{LIM}) = 1$, and the procedures of Pottasch (1984) and Napiwotzki & Schönberner (1995) should give reasonably accurate values of distance. Close to $b = 1.7°$, however, there is a sharp (and almost discontinuous) decrease in the function. If one takes latitudes slightly above the limit of 1.7°, say $b = 2.4°$, then 48% of sources would be located beyond the reddening regime (i.e., $\Im(b, \theta_{LIM}) = 0.516$). Increase $b$ just a little further to 3°, and the majority of PNe now reside outside of this layer ($\Im(b, \theta_{LIM}) = 0.34$). It follows that the transition from all of the PNe being inside the reddening layer, to most of them lying outside of it is very rapid indeed.

Where one now, for these latter sources, determines $D_{RED}$ according to the procedures described above (i.e., one assumes that $D_{RED} = C_{NEB}/(dC/dD)$), then this would place most of the nebulae at the limits of the extinction layer. The distances of the sources would be equated with $D_D$.

Whilst the height of the reddening layer undoubtedly varies somewhat, and estimates of $Z_{RED}$ will change with the line-of-sight vector $(\ell, b)$, one nevertheless expects a rough invariance in $Z_{RED}$ towards larger values of $b$, as is suggested in Fig. 6.

Finally, we note that Pottasch (1996) has also used this procedure for a somewhat differing sample of outflows: nebulae which for various reasons have claims to be located close to the Sun ($D = 1$ kpc). Most of them, in consequence, have large angular dimensions, and one would expect the "discontinuous" increase in $Z_{RED}$ to occur at greater values of $b$.

This appears in fact to be the case. There is again a rapid increase in values $Z_{RED}$ close to $b \sim 6°$, after which nebular heights are more or less consistent. Although the mean heights $<Z_{RED}>$ of higher latitude sources are somewhat less than is apparent in Fig. 6 ($\sim$ 0.11 kpc, as opposed to 0.17 kpc), the trends are sufficiently similar to cast doubt on these distances as well. Having said this, the analysis of Pottasch (1996) seems to have been performed in a rather careful manner, and there is little doubt that many of his sources must have low values of $D_{RED}$. It is not possible to be entirely certain concerning which of his distances are in error.

We shall look at the consequences of this analysis in the following section. Before doing so, however, we should like to point out one further property of these results. If our interpretation of the heights $Z_{RED}$ is correct, then it follows that the values of $Z_{RED}$ in Fig. 6 imply a reddening layer height of between 0.1 and 0.25 kpc; a range which is identical to that determined in § 2.

## 4. THE CONSEQUENCES FOR PUBLISHED EXTINCTION DISTANCES

We have shown that:

a) It is very likely that most PNe reside well above the IS extinction layer, and that this even applies to sources with large angular sizes. This results in reddening gradients $dC/dD$ which are low to undetectable at the locations of the PNe.

b) As a consequence, individual reddening distance estimates (such as those of Gathier (1986) and

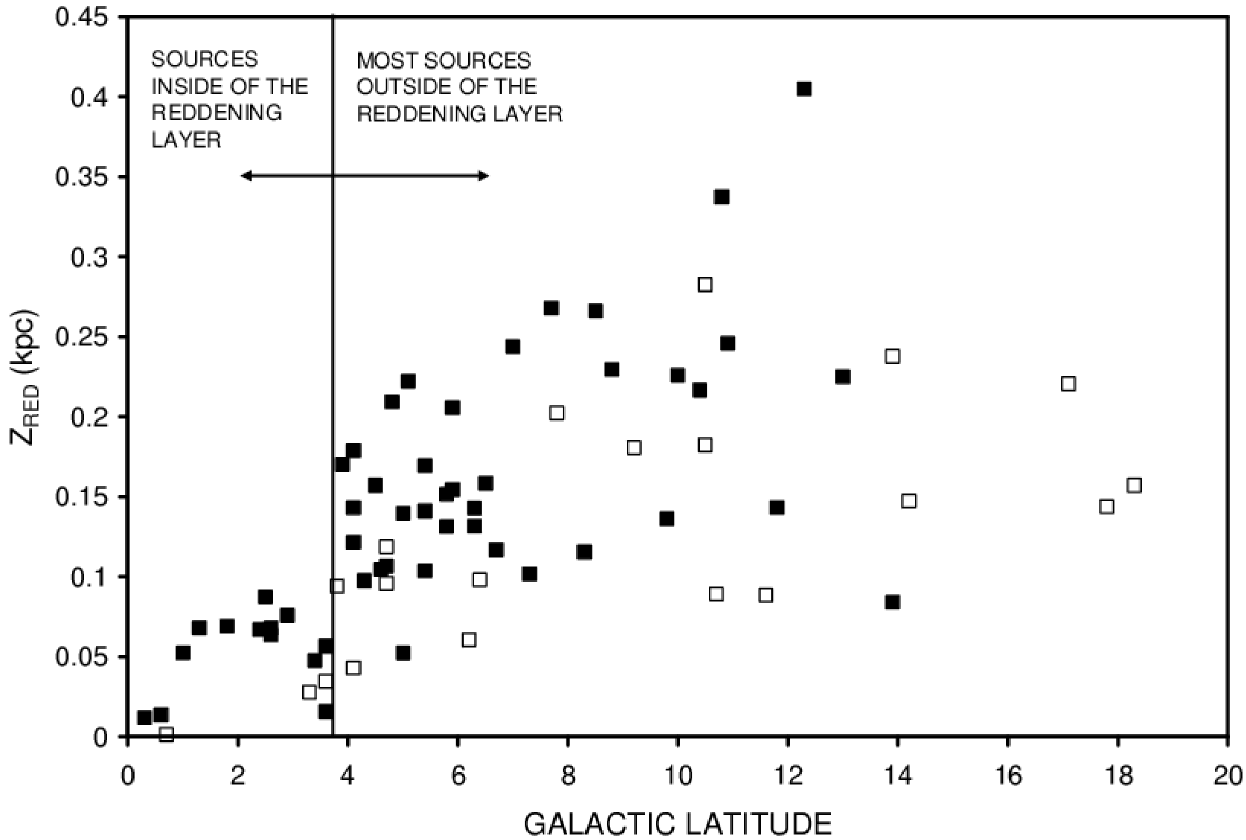


Fig. 6. The variation of heights $Z_{RED}$ above the galactic mid-plane for distances evaluated by Pottasch (1984) (solid squares) and Napiwotzki & Schönberner (1995) (open squares). Note the strong and discontinuous variation in heights where $b \simeq 3.7°$, attributed to a difference in the locations of the PNe with respect to the galactic reddening layer.

Lutz (1983)) are often invalid, and may lead to erroneous results.

c) Similarly, we have shown that larger scale applications of this procedure, such as that of Pottasch (1984), can be appreciably in error. They would tend to lead to distances which are mostly too small.

d) Since the Na D-line distances of Napiwotzki & Schönberner (1995) are determined using equivalent procedures to those of Pottasch (1984), then it is likely that most of these distances are erroneous as well. Having said this, the central star luminosities which they derive are consistent with current post-AGB theory, and imply that their mean distance scale is not too far off the mark.

It follows that the consequences of this analysis for the distances of Pottasch (1984;1996), Acker (1978), and Napiwotzki & Schönberner (1995) may be very profound indeed. We would estimate that by far the larger part of their values (those for sources having $b > 3.7°$) are likely to be in error, and should be discarded from future analyses. This includes all cases (such as those of Daub (1982), Cahn et al. (1992), and Phillips (2002;2004a)) where they have been used to calibrate statistical distance scales, evaluate local densities and formation rates (Pottasch 1996), and determine the luminosities of evolved PNe (Phillips 2005b).

Similarly, we note that certain of the previous, more detailed analyses, are also of limited utility. Sources were often chosen with only minimal reference to constraining protocols, and are located outside of the primary extincting layer —we really do not know where they are located above a limiting height $Z_D$.

In all fairness to these studies, it should be pointed out that $\sim$ 45% of the sources of Gathier et al. (1986), Lutz (1973), Martin (1994), Acker (1978), and Solf & Weinberger (1984) are located at latitudes $b < 4°$, which would certainly be consistent with the most relaxed of the limits cited above. However, this still means that most of their nebulae were inappropriately selected, and unlikely to yield distances which were in any way reliable.

Finally, it should be emphasized that the discussion above is intended to be mostly illustrative. It is not our intention to specify prescriptions for future work in this area. However, it is clear that most estimates of $Z_D$ imply values $\sim 0.1 \rightarrow 0.15$ kpc (see, e.g., Fig. 6 and § 3), and this would suggest that $b$ should be less than 2° where $\theta_{LIM} = 10$ arcsec, and $< 4°$ where $\theta_{LIM} = 20$ arcsec. At the worst, and taking $Z_D \sim 0.25$ kpc, one obtains the limits $b < 3.4°$ and $b < 6.9°$ for these respective values of $\theta_{LIM}$. Sources at slightly larger values of $b$, or having somewhat smaller angular sizes, are most probably located outside of the primary reddening layer.

## 5. CONCLUSIONS

We have shown that most PNe are located above the primary extincting layer, and that procedures for measuring reddening distances are therefore inapplicable. It is also likely that wholesale measures of distance, such as that of Pottasch (1984), are mostly in error, and lead to values of distance which are systematically too small. The same applies to the procedurally equivalent distances of Napiwotzki & Schönberner (1995), in which measures of Na D-line absorption are used in place of estimates of reddening. Such values should be treated with extreme caution in future analyses of PNe. Similarly, we note that any further determinations of $D_{RED}$ should employ very restrictive protocols. Sources should only be selected where they reside within very limited ranges of latitude and size.

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