# DISTANCES OF PLANETARY NEBULAE

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## I. Introduction

One of the most fundamental physical parameter in astronomy is the distance to the objects we detect in the universe. For many classes of astronomical objects, accurate and proven methods have been developed to determine their distances. Such classes of objects include stars within ~100 pc from the sun, binary stellar systems, variable stars, stellar clusters, main sequence stars, and other galaxies. It has been, however, more difficult to develop satisfactory methods to determine accurate distances to the more than 1000 planetary nebulae that have been discovered in our galaxy.

During the 1977 IAU Symposium Meeting on Planetary Nebulae, which took place at Cornell University in Ithaca, New York, William Liller (Liller, 1978) reviewed the status of the distance scale of planetary nebulae and he stated: "At the Tatranská Lomnica meeting 10 years ago (1967), there seemed little hope that one day soon planetary nebulae distances would become reliable. That day is near if not here already". Fourteen years later in a recent paper, Lawrence H. Aller (Aller 1991) stated that "the 'bone in the throat' of the PN research is the determination of reliable distances for individual objects".

To be sure, much progress has been made during the last decade and this progress promises to continue. Recently several authors have tried various methods in deriving distances to planetary nebulae, however the amount of disagreement is still considerable.

It may be that statistical methods in deriving distances for many planetary nebulae are very unreliable because, as Julie H. Lutz (1989) clearly described five years ago, these objects are so diverse in their physical parameters such as, nebular masses, morphology and filling factors, and state of ionization that it is unlikely that any single method can be applied to all planetary nebulae. However, the comparison of distances of objects determined by various methods such as (a) binary stars and clusters; (b) HI 21 cm absorption; (c) visual extinction; (d) nebular

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expansion parallaxes, and (e) parameters of central stars, also show serious disagreements indicating large uncertainties inherent in these methods.

## II. Distance Comparisons

Table 1 shows a comprehensive comparison of distances derived or adopted by various authors for fourty planetary nebulae. This Table was formulated to include objects that Gathier (1987) had called "Standard Distances" derived from spectroscopic, expansion, reddening, and HI absorption methods. Most of these objects are the same ones used by Mallik and Peimbert (1988) as objects having distances independent of statistical arguments. The distances given by the above authors were assumed to be much better established than distances derived from statistical methods. The Table also shows Cudworth's (1974) distances from statistical parallaxes which were derived from proper motion measurements. The distances by Daub (1982) and Amnuel, et. al. (1984) were computed from various mass-radius and surface brightness-diameter relations and by using the measured radio fluxes at 5 GHz and 2.7 GHz; these distances are also indicated in Table 1.

Very recently Cahn et. al. (1992) have presented a list of recalibrated absolute H$\beta$ fluxes and have calculated Shklovsky distances according to the Daub (1982) scheme on the scale used earlier by Cahn and Kaler (1971). The recalibration was made from a set of objects with "most dependable known distances". Their extensive compilation includes distances to more than 600 planetary nebulae. Table 1 shows the distances from this work compared to the other studies.

More recently Zhang and Kwok (1992) have also derived distances to 142 galactic planetary nebulae. These distances are based on the stellar mass, surface gravity and luminosity inferred from the modeling of distance-independent parameters. The results of these distance determinations are also shown in Table 1 for comparison with the distances given by other authors.

The collected data in Table 1 give an indication of the degree of agreement or disagreement in the distance determinations and may also reflect on the accuracy of the various methods. In some cases the agreement seems reasonable and in other cases there are large differences. It is important to emphasize that Table 1 contains the planetary nebulae sample that has been claimed to have the most accurate distance determinations.

It seems instructive to compare a few distance determinations from Table 1. NGC 6572 has a range in the determination of its distance from 0.41 kpc (G87) to 3.3 kpc (ZK92), however, six of the seven entries have a distance of less than 0.9 kpc. The largest distance for NGC 7009 is 2.4 kpc (MP88) and the lowest is 0.58 kpc (G87) with five other intermediate values. Again the well known nebula NGC 3242 is shown with a large distance of 2.0 kpc (MP88) and a short distance of 0.50 kpc (G87), with five intermediate values. Even the distance to the Ring Nebula

TABLE 1. Planetary Nebulae Distances (kpc)

| Object | C74 | D82 | A84 | G87 | MP88 | CKS92 | ZK92 |
|---|---|---|---|---|---|---|---|
| NGC 40 | 1.8 | 1.1 | 0.70 | - | 1.0 | 1.2 | - |
| NGC 246 | 0.57 | 0.46 | 0.45 | 0.50 | - | 0.47 | - |
| NGC 1514 | 1.1 | 0.67 | 0.65 | 0.50 | - | 0.75 | - |
| NGC 1535 | 3.1 | 1.7 | 1.2 | - | 2.1 | 2.3 | 1.9 |
| NGC 2346 | - | 1.3 | 1.1 | 0.80 | 1.1 | 1.4 | - |
| NGC 2392 | 2.0 | 1.2 | 0.86 | - | 2.7 | 1.3 | - |
| NGC 2440 | - | 1.0 | 0.74 | 2.2 | 2.2 | 1.4 | - |
| NGC 2452 | - | 2.6 | 1.8 | 3.6 | 3.6 | 2.8 | 4.3 |
| NGC 2792 | - | 1.9 | - | 1.9 | 1.9 | 3.0 | 3.5 |
| NGC 2818 | - | 2.0 | 1.6 | - | 3.2 | 2.0 | - |
| NGC 2867 | - | 1.2 | 0.99 | - | 1.4 | 1.8 | 1.6 |
| NGC 3132 | - | 1.0 | 0.80 | 0.60 | 0.54 | 1.3 | - |
| NGC 3211 | - | 2.5 | 1.7 | 1.9 | 1.9 | 2.9 | 3.4 |
| NGC 3242 | 1.7 | 0.73 | 0.52 | 0.50 | 2.0 | 1.1 | 1.5 |
| NGC 3918 | - | 0.58 | 0.54 | 2.2 | 2.2 | 1.0 | 1.7 |
| NGC 5189 | - | 0.51 | 0.49 | 1.7 | - | 0.54 | - |
| NGC 5315 | - | 0.69 | 0.67 | 2.6 | 2.6 | 1.2 | 3.2 |
| NGC 6369 | - | 0.42 | 0.33 | 2.0 | 2.0 | 0.7 | 1.0 |
| NGC 6537 | - | 0.65 | 0.58 | 2.4 | 2.4 | 0.9 | - |
| NGC 6565 | - | 3.5 | 2.5 | 0.90 | - | 4.6 | 4.0 |
| NGC 6572 | 0.90 | 0.47 | 0.43 | 0.41 | 0.68 | 0.66 | 3.3 |
| NGC 6578 | - | 1.4 | 1.2 | 2.0 | 2.0 | 2.3 | 4.3 |
| NGC 6720 | 1.3 | 0.79 | 0.64 | 0.65 | - | 0.87 | 1.9 |
| NGC 6803 | - | 1.7 | 1.5 | 3.0 | 3.0 | 3.0 | - |
| NGC 6804 | 2.4 | 1.2 | 1.1 | - | 1.4 | 1.7 | - |
| NGC 6884 | - | 1.1 | 1.4 | 1.8 | 1.8 | 2.1 | - |
| NGC 6886 | - | 1.8 | 1.6 | 1.7 | 1.7 | 3.1 | - |
| NGC 6891 | 4.7 | 1.8 | 1.4 | - | 3.8 | 3.2 | 2.5 |
| NGC 7009 | 1.9 | 0.76 | 0.59 | 0.58 | 2.4 | 1.2 | 1.1 |
| NGC 7026 | 2.0 | 1.3 | 0.95 | 2.2 | 2.5 | 1.9 | 3.8 |
| NGC 7027 | 0.51 | 0.18 | 0.82 | 1.1 | 0.94 | 0.27 | - |
| NGC 7293 | 0.21 | 0.15 | 0.18 | - | 0.30 | 0.16 | - |
| NGC 7354 | - | 0.88 | 0.64 | 1.5 | 1.5 | 1.3 | 2.7 |
| NGC 7662 | 1.5 | 0.84 | 0.67 | 0.98 | - | 1.2 | 1.9 |
| IC 418 | 0.76 | 0.41 | 0.38 | - | 2.0 | 0.61 | 1.9 |
| IC 1747 | - | 0.19 | 1.2 | 2.5 | 2.5 | 2.9 | - |
| IC 2448 | - | 2.5 | - | - | 3.5 | 4.0 | 3.6 |
| He 2-108 | - | 4.1 | 2.5 | - | 8.3 | 4.3 | 4.0 |
| He 2-131 | - | 0.91 | 0.86 | 0.60 | 0.59 | 1.4 | 3.1 |
| He 2-138 | - | 2.2 | 1.9 | - | 5.0 | 3.6 | 2.3 |

C74 (Cudworth 1974); D82 (Daub 1982); A84 (Amnuel, et. al. 1984); G87 (Gathier 1987); MP88 (Mallik and Peimbert 1988); CKS92 (Cahn, et. al. 1992); ZK92 (Zhang and Kwok 1992).

NGC 6720 shows a discrepancy of a factor of three disagreement.

One of the brightest and most studied nebula is NGC 7027, its distance, from Table 1, ranges from 180 pc (D82) to 1100 pc (G87). The recent VLA expansion distance of this object derived by Masson (1986) is 940 pc which is compatible with the best general and thorough discussion on the distance of this object by Pottasch et. al. (1982), who report a distance range from 1 to 1.5 kpc, yet Cudworth's (1974) distance from statistical parallaxes is 510 pc. More recently Masson (1989) revised his expansion parallax distance for NGC 7027 to 880±150 pc., and Terzian, et. al. (1992) using the same method derive a preliminary distance of 1100±330 pc.

Generally, inspection of Table 1 is instructive, and depending on one or another argument, one could decide to ignore one or another entry to show that some (but not all) entries are in general agreement, however such arguments must be substantiated. It is possible to conclude that even with our best efforts, individual distances of planetary nebulae show disagreements of factors of two and three. Such large uncertainties severely limit our ability to study the physical parameters of these objects accurately and does not allow us to correctly assess the population of these objects in the galaxy.

Figure 1 gives a summary of the distances shown in Table 1 in the form of distance histograms. It is clear that there is disagreement in the distance scale. The so called 'long' distance is preferred by Zhang and Kwok (1992), Mallik and Peimbert (1988), and Cudworth (1974) followed closely by Gathier (1987) and Cahn et. al. (1992). The work by Zhang and Kwok represents the most extreme long distance scale where from Table 1 only one object has a distance less than 1 kpc. In contrast, the 'short' distance scale is represented by Daub (1982) and Amnuel et. al. (1984).

If we arbitrarily examine the number of planetary nebulae within 1 kpc from the 40 objects in Table 1, we find the following:

| | |
|---|---|
| Zhang and Kwok (1992) | 1 |
| Cudworth (1974) | 5 |
| Mallik and Peimbert (1988) | 7 |
| Gathier (1987) | 11 |
| Cahn et. al. (1992) | 12 |
| Daub 1982) | 20 |
| Amnuel et. al. (1984) | 23 |

The above comparison is not entirely exact because some authors do not report distances for a few objects, but it is sufficient to demonstrate the significant differences.

The example of the nebula He2-131 indicates the great uncertainty in the various distance methods that have been applied. Maciel (1985) summarized the

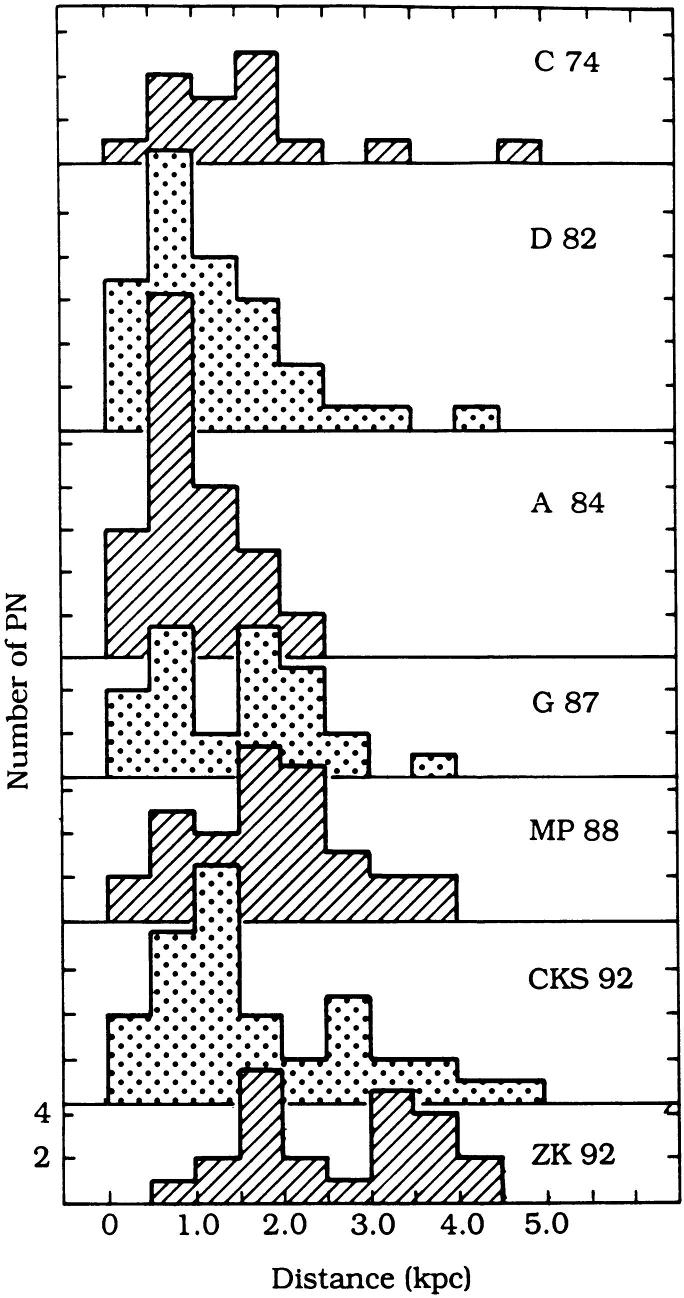

Figure 1. Histograms of Distance Scales

various derived distances of this object and Table 2 brings this data up to date. The reported range for the distance to He2-131 is from 0.6 to 4.5 kpc, and the data shows that the Shklovsky type distance methods prefer large distances and the extinction methods prefer shorter distances. However, Zhang and Kwok (1992) using stellar parameters derive a large distance of 3.1 kpc, and the Cahn, et. al. (1992) recalibrated Shklovsky distance is 1.4 kpc. We are still not converging with good understanding.

TABLE 2. He2-131 Derived Distances

| Reference | Method | Distance (kpc) |
|---|---|---|
| Cahn and Kaler (1971) | Shklovsky (H$\beta$) | 3.3 |
| Cahn and Kaler (1971) | Shklovsky (H$\beta$) | 2.6 |
| Cahn and Kaler (1971) | Shklovsky (red) | 4.5 |
| Milne and Aller (1975) | Shklovsky (radio) | 4.0 |
| Milne and Aller (1975) | Effective absorption | 0.7 |
| Cahn (1976) | Shklovsky (H$\beta$) | 3.9 |
| Pottash (1980) | General extinction | 0.7 |
| Daub (1982) | Mass-radius relation | 0.9 |
| Maciel and Pottasch (1980) | Mass-radius relation | 1.6 |
| Amnuel, et. al. (1984) | Brightness-radius relation | 0.9 |
| Maciel (1985) | General extinction | 1.2 |
| Gathier (1987) | General extinction | 0.6 |
| Cahn, et. al. (1992) | Shklovsky (Recalib. H$\beta$) | 1.4 |
| Zhang and Kwok (1992) | Stellar Model | 3.1 |

## III. The Nearest Planetary Nebulae

Of special importance are the nearest planetary nebulae recently discussed by Ishida and Weinberger (1987). Most of the nearby objects are of low surface brightness, are highly evolved, and have angular sizes larger than two or three arc minutes. These are difficult objects to detect, however, during the last decade several such objects have been discovered and a comprehensive list has been given by Ishida and Weinberger. These authors indicae that there are 31 planetary nebulae within 500 pc from the sun. Five of these nebulae are included in Table 1 and show reasonable agreement with the distances given by Ishida and Weinberger. Here we present these nebulae in Table 3 with the addition of NGC 6572 and NGC 5189 which from our Table 1 have probable distances within 500 pc from the sun. The peculiar compact object Cn1-1 listed by Ishida and Weinberger has been omitted since its distance is uncertain and has an angular size <1". The objects NGC 3242, NGC 7027 and IC 1747 have probable distances >500 pc even though some authors indicate shorter distances in Table 1 and have not been included. Table 3 lists 32 objects including their positions and angular radii (d/2) mostly as summarized by Ishida and Weinberger.

TABLE 3. Planetary Nebulae Within 500 pc

| Object | R.A. (1950) (h m) | Decl. (1950) (° ') | Distance (kpc) | d/2 (") |
|---|---|---|---|---|
| S176 | 00 29.1 | + 57 06 | 0.27 | 359 |
| NGC 246 | 00 44.5 | - 12 09 | 0.47 | 125 |
| S188 | 01 27.4 | + 58 07 | 0.22 | 270 |
| HFG1 | 02 59.4 | + 64 44 | 0.37 | 450 |
| HW4 | 03 23.8 | + 45 14 | 0.41 | 240 |
| NGC 1360 | 03 31.1 | - 26 02 | 0.30 | 198 |
| IW1 | 03 45.4 | + 49 51 | 0.33 | 390 |
| NGC 1514 | 04 06.1 | + 30 39 | 0.40 | 64 |
| S216 | 04 37.3 | + 46 35 | 0.04 | 3000 |
| A7 | 05 00.9 | - 15 40 | 0.22 | 382 |
| IC418 | 05 25.2 | - 12 44 | 0.48 | 6 |
| WDHS1 | 05 56.6 | + 10 42 | 0.32 | 463 |
| PW1 | 06 15.4 | + 55 38 | 0.24 | 600 |
| K2-2 | 06 49.8 | + 10 02 | 0.48 | 207 |
| A21 | 07 26.2 | + 13 21 | 0.27 | 319 |
| A29 | 08 38.1 | - 20 44 | 0.41 | 201 |
| A31 | 08 51.5 | + 09 05 | 0.24 | 485 |
| EGB6 | 09 50.3 | + 13 59 | 0.35 | 359 |
| He2-77 | 12 06.4 | - 62 59 | 0.33 | 11 |
| A35 | 12 50.9 | - 22 36 | 0.36 | 400 |
| LT5 | 12 53.1 | + 26 10 | 0.40 | 263 |
| NGC 5189* | 13 30.0 | - 65 43 | 0.49 | 70 |
| A36 | 13 38.0 | - 19 38 | 0.38 | 196 |
| NGC 6369 | 17 26.3 | - 23 43 | 0.45 | 15 |
| NGC 6572** | 18 09.7 | + 06 50 | 0.41 | 7 |
| S68 | 18 22.4 | + 00 50 | 0.31 | 199 |
| A62 | 19 30.9 | + 10 30 | 0.50 | 81 |
| NGC 6853 | 19 57.5 | + 22 35 | 0.27 | 208 |
| A74 | 21 14.7 | + 24 00 | 0.23 | 415 |
| IW2 | 22 12.0 | + 65 40 | 0.26 | 449 |
| DHW5 | 22 18.4 | + 70 41 | 0.40 | 264 |
| NGC 7293 | 22 26.9 | - 21 06 | 0.16 | 402 |

Adapted from Ishida and Weinberger (1987).

* Distance from Amnuel (1984)

** Distance from Gathier (1987)

An inspection of Table 3 shows one large object S216 within 100 pc from the sun, and one object NGC 7293 in the range 100 to 200 pc. In the intervals 201 to 300, 301 to 400, and 401 to 500 pc there are 10, 11, and 9 objects respectively. Ishida and Weinberger have used distances from several recent studies and also Shklovsky distances. They conclude that the number of local objects is a lower limit and that the number of extended faint and old planetary nebulae in the galaxy must be very large. Using the available data for objects in Table 3, they derive a large space density of $\sim 330$ kpc$^{-3}$ and a birthrate of $\sim 8\text{x}10^{-3}$ kpc$^{-3}$ yr$^{-1}$, which is a few times larger than the birthrate of white dwarfs. It is important to keep in mind that if the local sample, which is mostly composed of very extended faint and old nebulae is representative for the galaxy, then these objects must be very numerous. In fact Ishida and Weinberger deduce that the total number of planetary nebulae in the galaxy should be $>10^5$. These numbers could be much smaller if the distance scale of the local objects is increased significantly. It seems of great importance to study this sample more carefully.

Very recently a study of the central star of S216 was made by Tweedy and Napiwotzki (1992) where they report that Napiwotzki has estimated a distance to S216 of $\sim 110$ pc instead of 40 pc as indicated in Table 3. These authors derive an effective temperature for the central star of S216 of $\sim$90,000K, and a surface gravity log g $\sim 7$.

## IV. Galactic Bulge Nebulae

The major problem in the study of the physical parameters of planetary nebulae and their central stars is the great uncertainty of their individual distances. However studies of these objects in other nearby galaxies whose distances are known by other methods can provide luminosity functions for the planetary nebulae which may be used to calibrate the sample in our own galaxy. Such studies will be discussed later and by other authors in this symposium. Here we mention the Galactic Bulge planetary nebulae population with the usual assumption that the distance to the Galactic Bulge is reasonably well known and that most of the planetary nebulae in the direction of the Galactic Bulge are part of it and hence at the same distance. This distance is about 7.8 kpc (Feast, 1987).

The most recent large scale study of planetary nebulae in the Galactic Bulge was performed by Stasińska, et. al. (1991) whose sample contains about 200 objects. These objects lie at a galactic latitude $|b^{II}| < 10°$ and a galactic longitude $|l^{II}| \pm 10°$; they have angular radii $<20$ arc sec; and their radio flux at $\lambda 6$ cm is $<100$ mJy. Indeed Pottasch (1990) estimates that between 80 and 90% of the planetary nebulae in this region of the sky belong to the Galactic Bulge population. Stasińska, et. al. (1991) apply the Shklovsky distance method to these nebulae and determine their distance distribution. They use a nebular mass of 0.2 $M_\odot$ and a filling factor of 0.5, and conclude that their histogram of the distances of planetary nebulae is quite consistent with that of the Galactic Bulge. These authors discuss the possible distance uncertainties including the non-finite size of the Bulge, the absolute error of the Bulge distance, and the unknown variations in the extinction corrections. They conclude that most of the nebulae in the Bulge are density bounded, and hence are optically thin.

Following Stasińska's, et. al. (1991) work, Pottasch and Zijlstra (1992) analyzed a sample of planetary nebulae in the Bulge to judge the validity of the use of the Shklovsky distance method, and contrary to Stasińska, et. al. (1991), they conclude that this method does not give acceptable results.

Both Stasińska, et. al. (1991) and Pottasch and Zijlstra (1992) have used the same basic Shklovsky distance relation with a filling factor of 0.5. However, Pottasch and Zijlstra used only $\lambda 6$ cm fluxes (since the $H\beta$ flux is directly related to the radio flux), while Stasińska, et. al. used both. Both studies used $M_{ion} = 0.2\ M_{\odot}$, but Pottasch and Zijlstra used nebular sizes determined only from radio interferometric observations (primarily Very Large Array results), and Stasińska, et. al. used primarily sizes from optical observations - this is the main difference in their analysis. Figure 2 shows the Shklovsky-distance histograms of the distance distributions from the two analyses. It is clear that there is substantial disagreement - Pottasch and Zijlstra show a median value of 11.5 kpc with a peak at 10.5 kpc and a possible peak at 16.5 kpc, while Stasińska, et. al. show that the maximum distribution peaks between 8 and 9 kpc with a median of 9.5 kpc.

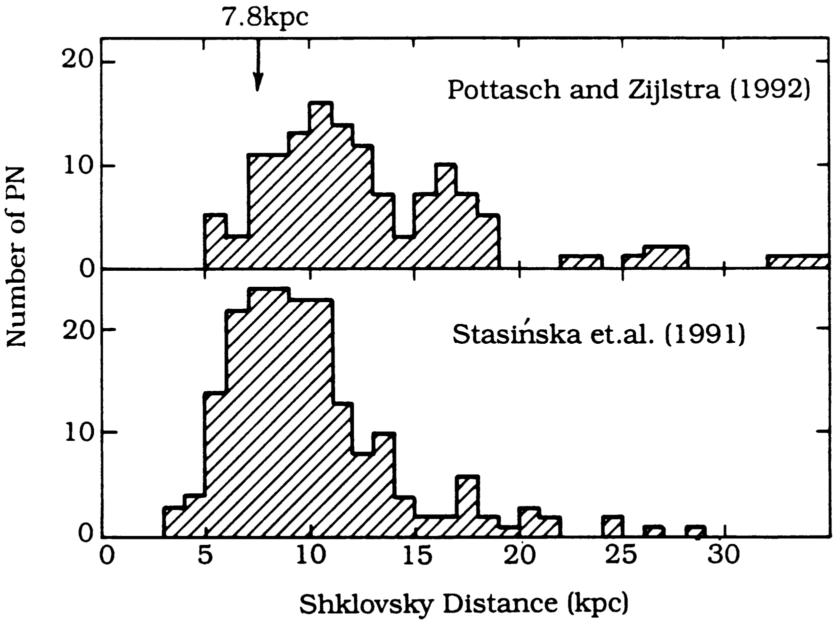

Figure 2. Galactic Bulge Distance Histograms

These results indicate that the Shklovsky distances are probably wrong and that the assumption of a constant ionized mass cannot be correct. It is more probable that a range of nebular masses exists. The data require a range from 0.01 to 0.3 $M_\odot$ to obtain agreement. A mean of 0.2 $M_\odot$ or larger will have the effect of overestimating the distances. A careful evaluation of the nebular radio/optical sizes should be performed to better assess the above conclusions.

## V. Expansion Parallaxes

One promising method for obtaining distances to planetary nebulae is to use their observed angular expansions together with the measured expansion velocities. Such a method has been used to determine distances to novae and the Crab Nebula. This method has been applied by Liller and Liller (1968) and a few other authors using optical images. Terzian (1980, 1987) suggested that this method can be applied by using radio images produced from VLA observations. Masson (1986) using VLA maps of NGC 7027 separated by only 2.8 years was able to derive a distance of 940 ± 200 pc, in good agreement with previous estimates for this object. In 1989, he refined this distance to 880±150 pc (Masson 1989). However, the same technique showed distances for the objects BD+30°3639 and NGC 6572 which were 2 to 4 times larger than previous estimates (Masson 1989). Terzian, et. al. (1992) have also obtained VLA observations of NGC 6210, NGC 6572, NGC 2392, NGC 3242, BD+30°3639 and NGC 7027 at two epochs separated by ~7 years and the results are being analyzed. Preliminary results show that the distance to NGC 7027 is 1100±330 pc, and that of BD+30°3639 is 3.3±1.1 kpc. A detailed analysis will be given elsewhere.

It is important to realize that the method of expansion parallaxes can provide important lower limits to the distances of the observed objects in the cases where no expansion is detected. Indeed Seaquist (1991) using VLA observations derived a lower limit of 5 kpc to the young planetary nebula Vy 2-2. Various authors have derived widely different distances to Vy 2-2. Acker (1978) reports a distance of 1.9 kpc from optical calibrations, Davis, et. al. (1979) adopt a kinematic distance of 20 kpc, Knapp and Morris (1985) find a distance of 9 kpc assuming a bolometric luminosity of $10^4$ $L_\odot$, but adopt 1 kpc due to the observed mass loss rates, and Clegg, et. al. (1989) give a distance of 2.5 kpc based on a calibration of planetary nebulae in the Magellanic Clouds. Clearly we do not know the distance to this object!

## VI. Extragalactic Planetary Nebulae

In recent years, significant progress has been reported in the identification of planetary nebulae in other galaxies other than the LMC, SMC, and M31 (e.g. Jacoby, et. al. 1990). Indeed the total number of identified planetary nebulae in other galaxies now rivals the number of known planetary nebulae in our galaxy. As an example, Jacoby, et. al. (1990) have catalogued 486 planetary nebulae in six early type galaxies in the core of the Virgo cluster, and Ford, et. al. (1989) reported on 665 planetary nebulae in other galaxies including those in the Leo Group of galaxies. It is ironic that since the distances of these galaxies are known to a reasonable accuracy by a variety of methods, then the distances of the planetary nebulae in these galaxies are also known with higher percentage accuracies than we know the distances to the ones in our own galaxy.

This wealth of new information has prompted Jacoby (1989) and his collaborators to use the planetary nebula luminosity functions to derive distances to other galaxies. The method used is to observe many planetary nebulae in a galaxy and to form their luminosity function, which is then compared to that observed in the calibrated galaxy M31. Using this method, Jacoby, et. al. (1990) derived a distance to the core of the Virgo cluster of $14.7 \pm 1.0$ Mpc, and a Hubble constant between 81 and 94 km $s^{-1}$ $Mpc^{-1}$. However, Bottinelli, et. al. (1991) have argued that the six galaxies selected in the Virgo cluster were among the brightest and may not be representative of the whole Virgo population, hence they suggest that the derived distance to Virgo by Jacoby, et. al. (1990) is an underestimate, and indicate that the Hubble constant is more likely to be in the range 71 to 83 km $s^{-1}$ $Mpc^{-1}$.

Clearly the debate has begun, but the above already demonstrates significant advances in the study of planetary nebulae in other galaxies and points into a new powerful method in determining the distances of nearby galaxies.

## VII. Discussion and Conclusions

Accurate distances of planetary nebulae are crucial in order to study and understand their physical parameters. Due to lack of good distance determinations, in addition, several other important problems remain uncertain - such as the space density and total number of planetary nebulae in the galaxy which have implications on the galactic ultraviolet radiation from the central stars, the total processed mass returned to the interstellar medium, and in general to the chemical evolution of the galaxy.

Other important examples, where accurate distances are essential, include the study of the object M1-78 by Puche, et. al. (1988) which was classified as a planetary nebula, but the new large HI absorption distance determination now indicates that this object is more likely an HII region. Also the recent detection of helium-3 in the planetary nebula NGC 3242 (Rood, et. al. 1992) could provide information on the $^3$He/H abundance which may have cosmological implications. Unfortunately the uncertainty in the distance of NGC 3242 prevents accurate abundance determinations.

Due to the uncertain distance scale of planetary nebulae, their total number in the galaxy is not well known. Following Phillip (1989) the lowest estimate is ~2000 and the largest is 430,000, with most determinations in the range from 10000 to 30000. However, Ishida and Weinberger (1987) derive 140,000 planetary nebulae in the galaxy when they take into account the larger diffuse and old objects that they have been able to detect. Similarly their space density and birthrate have large uncertainties, and are in the range 30 to 100 $\mathrm{kpc}^{-3}$, and 1 to $3\mathrm{x}10^{-3}$ PN $\mathrm{kpc}^{-3}$ $\mathrm{yr}^{-1}$, although larger values have been suggested.

The near future looks somewhat more promising for distance determinations of planetary nebulae. Pier, et. al. (1992) and Anguita, et. al. (1992) have already begun studies of trigonometric parallaxes for a few dozen nearby objects. It is estimated that CCD techniques can determine parallaxes with an error of the order of 0.001 arcsec in a time period of three years. Emphasis should also concentrate in finding planetary nebulae with binary central stars and deriving spectroscopic parallaxes.

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