

Individual Distances for a Sample of Planetary Nebulae

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Abstract. This paper is addressed to the important problem in the field of planetary nebulae research, the distances determination. We have applied one of the most powerful individual methods “*Reddening-Distance method*” to determine the distances to eleven planetary nebulae. There are four objects in our sample belong to (or towards) the Galactic bulge. Most of our objects are not well known planetary nebulae with unknown distances. To our knowledge, we have derived the distances for the first time to six planetary nebulae. The distance for the other five objects are compared with the available statistical and individual data in the literature. The derived distances for this small sample will increase the limited number of individual distances known for planetary nebulae. The essential nebular parameters are determined for the sample.

Keywords: Planetary nebulae: individual distance – nebular parameters.

1. Introduction

Planetary nebulae (PNe) are shells of low density ionized gas resulting from ejected layers of dying stars. They are a short-lived phase in the late evolution of low and intermediate mass stars. They considered as the middle phase between red giants and white dwarfs. Planetary nebulae gain a high degree of individuality during their evolution and are among the most diverse and beautiful astronomical objects known. This fact makes every single planetary nebula (PN) a unique object, or individual.

The distance to Planetary Nebulae represents the most important parameter in the study of their sizes, masses and spatial distribution within our Galaxy. Unfortunately the accurate distances are known for a

small number of PNe. Most of the galactic planetary nebulae are distant from us, so the basic distance method in astronomy “trigonometric parallax” was applied to very limited number of objects, see the recent Hipparcos satellite measurements^[1-3].

After many years of efforts, distances to PNe remain controversial. For example, the distances to the well-studied Planetary Nebula NGC 7027 estimated by two different papers published in the same year differ by almost a factor of 10 (178 pc^[4], and 1500 pc^[5]).

According to the different methods used for determining the distance of PNe, we can classify these methods into two main categories: Statistical and individual methods. Statistical methods imply the assumption that one of the physical or geometrical parameters, such as nebular ionized mass and luminosity of the central star, is fixed for all objects and at all phases of evolution.

The pioneering statistical method is the Shklovsky method^[6]. It assumes that all PNe have the same ionized nebular mass, and the distance can be derived by observing both the nebular flux and the angular size of PN. Many different distance scales have been published based on Shklovsky method^[7-9]. Such distance scales are suspected, because it is well known now that the ionized masses of PNe are not constant. Maciel and Pottasch^[10] and Daub^[4] modified Shklovsky method by empirical mass-radius relations, while Van de Steene and Zijlstra^[11,12] proposed a correlation between the distance-independent radio continuum brightness temperature and the distance-dependent radius to determine statistical distances to PNe.

Another statistical distance scale was proposed by Zhang^[13] based on the correlation between the ionized mass and radius, and the correlation between the radio continuum surface brightness and the nebular radius. In (1998), Tajitsu & Tamura^[14] defined a new method to obtain some information about the distance to PNe by using blackbody radiation fitting of IRAS four-band fluxes, which assume that these fluxes are due to thermal emission from the nebular dust envelope. Phillips^[15] has shown that the central stars of highly evolved PNe are expected to have closely similar absolute visual magnitudes. This method gives approximate distances to these objects, where one knows their central star visual magnitudes and levels of extinction. Most of these methods give a rough estimate of the PNe distances with very high uncertainties.

On the other hand, the individual distance methods are more accurate than the statistical ones. Kwok^[16] summarized the recent individual methods for deriving the distances of PNe as follows: (1) Spectroscopic parallax, (2) Trigonometric parallaxes, (3) Expansion parallax, (4) PN with binary central star, (5) Ultraviolet fading, (6) Time-correlation method, (7) The 21 cm HI absorption line method.

One of the fundamental and powerful individual methods of determining the distance of the PNe is the interstellar extinction or Reddening-Distance (R-D) method^[16]. This method is potentially an extremely good method and can be applied to a large number of objects. The method is based on the determination of the relation between the interstellar reddening and the distance along the line of sight of a planetary nebula. If the reddening of the PN itself can be determined, the PN distance follows from the R-D relation. The method has the advantage that, it is independent on any property of the nebula and hence its name of “independent method”. It has the disadvantage that interstellar extinction is subject to changes on a rather small scale, so that the accuracy of the result is difficult to estimate. For more details and summary to its application to planetary nebulae see Pottasch^[17]. Pirzkal *et al.*^[18] used this method to determine the distances of PNe interacting with the interstellar medium. The extinction of the nebula can be obtained by three ways: (1) The UV interstellar bump at λ 2200Å, (2) Comparison of the free-free radio emission with the H β flux, (3) Comparison of the observed Balmer decrement with the theoretical prediction. The second and third methods are the most frequently used methods. The largest number of PNe extinction values has been published by Tylanda *et al.*^[19], who give values for over 900 PNe. Other extensive compilations used are from Aller and Keyes^[20] and Kingsburgh and Barlow^[21]. Unfortunately the values given in the literature are not always consistent with each other, so we have tried to find the most reliable value in each case, and have also used some mean values. More details on using the method in this work are given in section 2.1.

The first goal of the present work is to determine the individual distances “that are reliable than the statistical distances” for 11 planetary nebulae, using R-D method. The second goal is to determine the nebular parameters for these planetary nebulae. These parameters are very important to understand the nature and evolution of these objects. From the accurate distances and nebular parameters we could draw a good

picture on the spatial distribution of PNe in our Galaxy and estimating the amount of materials “contaminated by heavy elements” that enrich the interstellar medium. In addition, this will be useful for building constraints on the theoretical tracks of stellar evolution for stars with different masses, and give more details on the central star that is responsible for ionization state of the PN.

In Section 2, we presented the R-D method used in this work and the sample of planetary nebulae. The nebular parameters calculations are given in section 3, while the results, discussions and error analysis are given in section 4. The last section is dedicated to the conclusions.

2. Materials and Methods

2.1 Reddening-Distance Method in this Work

The method we used to determine the distances of PNe is based on the determination of the relation between the interstellar reddening and the distance along the line of sight of a planetary nebula. If the reddening of the PN itself can be determined, the PN distance follows from the reddening-distance relation. In this section, we will discuss the specific method used in this work to determine the reddening distance using the literature data. The main intention of this work was to increase the number of individual distance known for PNe.

The number of stars, for which the required data are available, has increased tremendously since the pioneering work of Lutz^[22] and Acker^[9]. Also, very recently a number of catalogues for open star clusters have been published to contain a large number of objects with good distance and reddening measurements^[23-27]. Galactic clusters are useful for confirming the quality of R-D relation for the PN. A search was made using a search radius of 1 degree around the PN. Search criteria were applied to select stars with known spectral types, luminosity classes, visual and blue apparent magnitudes. The list of selected star files are modified by a FORTRAN code to exclude variable, binary, peculiar stars and stars belong to star clusters and stars without enough data. In order to determine the color excess $E(B-V)$ and distances “from distance modulus relation” for selected stars, the absolute magnitude (M) and intrinsic color index $(B-V)_0$ are taken from Schmidt-Kaler^[28].

For each PN we downloaded two files. The first one contains only stars with known spectral types and luminosity classes within a circle of 1 degree radius around the proposed PN. Planetary nebulae that have less than 6 stars in the field (with complete information) are ignored. This file is downloaded in ASCII format, which is the source file to the FORTRAN code that has two missions: 1) Exclude variable, binary, peculiar stars and stars belong to star clusters, stars without blue and/or visual magnitude and stars with negative visual extinction. 2) Calculate the visual extinction and distance of field stars. In some cases when some stars in R-D relation not fit well the relation, we select their observed magnitude values from 2MASS “Two Micron All Sky Survey”. The second file is an HTML format file contains all objects (stars, clusters, nebulae, radio sources, etc) around the selected PN. The purpose of this file is to search for open or globular clusters with known distances and visual extinctions. We have used these clusters within a circle of radius 60 arc-minutes (or sometimes of 90 arc-minutes “if there is any”) around PNe to confirm the derived R-D relation. Finally we used the scientific software “ORIGIN” to build the Reddening-Distance relations.

2.2 The Sample of Planetary Nebulae

The overall data of 100 PNe have been obtained from the SIMBAD database. From this long list, we rejected 89 PNe that have unusable Reddening-Distance relations. This occurs for many reasons, some of them are: 1- The very high scattering of stars in the field around the PN, due to the patchiness; 2- The missing of faraway stars “of early type with advanced luminosity class (e.g. O5V, B2Ia, A1II stars)”; 3- The limited number of stars in the field of PN, or very small number of stars with complete information. After detailed analysis we have derived the distances for 11 PNe.

We have divided our sample of planetary nebulae into two groups. The first group (group I) contains 7 objects and the second group (group II) involves 4 objects. These objects are collected from many recent references^{[19],[29-33]}. The usual name of each planetary nebula with its color excess is given in Table 1.

Table 1. Our sample of planetary nebulae.

| | PN usual name | E(B-V) | Reference |
|-----------------|-----------------|--------|-----------|
| Group I | | | |
| 1 | NeVe 3-3 | 0.56 | [31] |
| 2 | M 1-22 | 0.37 | [19] |
| 3 | K 3-45 | 0.60 | [19] |
| 4 | PNG 301.11-1.49 | 1.20 | [29] |
| 5 | He 2-82 | 0.35 | [30] |
| 6 | He 2-114 | 0.39 | [19] |
| 7 | NGC 2899 | 0.55 | [19] |
| Group II | | | |
| 8 | PTB1 | 1.55 | [33] |
| 9 | PTB25 | 0.69 | [33] |
| 10 | K 5-14 | 1.42 | [32] |
| 11 | M 2-23 | 0.48 | [19] |

3. Nebular Parameters

The scale height above or below the Galactic plane is another important parameter. The linear diameter, LD , is calculated from the small angle formula,

$$LD(pc) = D(pc) \times AD(arc\ sec) / 206265, \quad (1)$$

where LD and AD are the linear and angular diameters, respectively and D is the distance of PN. The scale height, Z , is given as

$$Z(pc) = D(pc) \times b(arc\ sec) / 206265 \quad (2)$$

where b is the galactic latitude.

3.2 The Radio (F_{5GHz}) and Absolute $H\beta$ Fluxes.

The radio continuum flux density at 6 cm (frequency 5GHz) and absolute $H\beta$ flux are two important observational parameters of PNe. Using these parameters we can deduce the radio continuum surface brightness temperature that has a correlation with the nebular radius. Acker *et al.*^[39] presented absolute $H\beta$ flux measurements taken at ESO for about 460 mostly southern PNe. Another catalogue is given by Cahn *et al.*^[40]. It involved $H\beta$ flux for 778 PNe. We have used the empirical relation that given by Zhang^[13] to calculate F_{5GHz} for objects that have not observed $H\beta$ flux.

$$\log D = 1.458 - 0.161 \log \theta - 0.419 \log F_{5\text{GHz}}, \quad (3)$$

where θ is the angular radius in arc seconds, D is the distance in kpc and $F_{5\text{GHz}}$ is the 5GHz radio flux in mJy.

For objects with observed H β fluxes, we adopted the relation given by Cahn *et al.*^[40]

$$\log F_{5\text{GHz}} = 26 - 16.452 + \log F(H\beta) + c_\alpha, \quad (4)$$

where c_α is the optical extinction and $F_{5\text{GHz}}$ is given in Jy units.

3.4 Electron Density (N_e) and Ionized Mass (M_i).

Electron density is one of the key physical parameters characterizing an ionized gaseous nebula. The typical number density in the ionized shell of PN ranges from 10^5 cm^{-3} for young and compact object to about 1 cm^{-3} for large extended evolved object. Accurate measurement of N_e is a prerequisite to the determination of nebular chemical abundances and calculation of the mass of ionized gas. Wang *et al.*^[41] presented comparison of the electron densities derived from optical forbidden lines diagnostic ratios for a sample of over a hundred nebulae. We estimated the electron concentration (density) using Equation (5) that given by Kowk^[16],

$$N_e = 4.8 \times 10^3 F_{5\text{GHz}}^{1/2} \varepsilon^{-1/2} \theta^{-3/2} D^{-1/2} \quad (5)$$

where N_e is the electron density in cm^{-3} . D , θ and $F_{5\text{GHz}}$ are as defined at Equation (3) and ε is the volume filling factor (we adopted $\varepsilon = 0.75$ in the present study).

The ionized mass is an important nebular quantity in that it allows an investigation of possible mass-radius relations and gives information on the optical thickness of the nebula. The ionized mass can be determined from the formula given by Gathier^[42]

$$M_i = 1.18 \times 10^{-8} N_e D^3 \theta^3 \varepsilon \frac{1 + 4y}{1 + y + xy} \quad (6)$$

where M_i is the ionized mass in solar unit, N_e , D and θ are as defined before. y is the helium abundance and x is the fraction of doubly ionized helium. For objects that have no observed y and x we adopted $y = 0.1$ and $x = 1/3$. In some cases, Equation (6) gives overestimate ionized mass

(due to uncertain electron density). For the objects which have overestimated mass, we used another empirical relation that is independent on the nebular density. This relation is presented by Van de Steene and Zijlstra^[12]

$$M_i = 5.2 \times 10^{-5} D^{5/2} \theta^{3/2} F_{5GHz}^{1/2} \quad (7)$$

4. Results and Discussion

We have determined the individual distances using the R-D method for 11 galactic planetary nebulae, four of them are belonging to the galactic bulge. We benefit from the very recent catalogues of open clusters^[23-27] to confirm or enhance most of the R-D relations. We did a search for clusters in the field of each object. The reddening and distances of open and globular clusters are better determined than the stars in the field around each object. So, the presence of these clusters in the field of each PN should emphasize the quality of R-D relation.

For each object, we presented the R-D diagram and brief description on its nebular parameters and evolution phase. The scatter in the R-D diagrams can be attributed to many sources such as, the uncertainties in stellar photometry measurements (that were collected from different sources by the SIMBAD database), intrinsic values, and irregular dust distribution within the field of every object.

The distance and nebular parameters for all objects are given in Table 2. In this table we presented the calculated nebular parameters using equations 1-7, if there are no observed ones. The observed parameters are given in bold style with sign to their references. For objects that have published distances, we presented these values in bold style with their references.

Most of the objects in our sample are newly discovered planetary nebulae with limited observational parameters and unknown distances (e.g. NeVe 3-3, PTB 1, and PTB 25). Our distance estimations are the first distance measurements for these objects. He 2-82, He 2-114 and NGC 2899 are well-known PNe that have some statistical measurements, NGC 2899 the only object in our sample that has previous individual “reliable” distances.

From the results mentioned in Table 2, M 1-22 is the farthest object from the galactic plane, which indicates that the object is out the galactic thin disk, while K 3-45 is the closest object to the galactic disk. NeVe 3-3

Table 2. Summary of the nebular parameters of the 11 planetary nebulae.

| NO | PN Name | Distance (kpc) | AD (arcsec) | LD (pc) | Z (pc) | Log F(H β) (erg cm ⁻² s ⁻¹) | F _{5GHz} (Jy) | N _e (cm ⁻³) | M _i (M _⊙) |
|-----------------|---------------|--|-------------------------------|---------|--------|---|------------------------------|------------------------------------|----------------------------------|
| Group I | | | | | | | | | |
| 1 | NeYe 3-3 | 3.083 | 95''x165'' ^[31] | 1.94 | -72 | -11.7 | 0.041 | 39, < 100 ^[31] | 2.90 |
| 2 | M 1-22 | 4.554 | 7.6 ^[19] | 0.17 | 595 | -12.3 ^[19] | 0.048 | 1590 | 0.09 |
| 3 | K 3-45 | 1.303, 1.9 ^[43] , 4.13 ⁽⁹⁾ | 6.8 ^[19] | 0.04 | -7 | -12.4 ^[40] | 1.000 | 24525 | 0.023 |
| 4 | PNG301.1-1.49 | 3.15 | 3.2 ^[29] | 0.05 | -82 | -13.1 | 0.014 ^[29] | 13000 | 0.018 |
| 5 | He 2-82 | 2.673, 2.0 kpc ^[43] , 2.25 kpc ^[7] | 31.8''x25.4'' ^[35] | 0.37 | 115 | -12.5 ^[39] | 0.104 | 639 | 0.34 |
| 6 | He 2-114 | 2.650, 2.6 ^[40] , 5.0 ^[13] , 1.9 ^[43] , 2.8 ^[44] | 26.1''x21.4'' ^[35] | 0.31 | -95 | -12.3 ^[40] | 0.011 ^[40] | 276 | 0.09 |
| 7 | NGC 2899 | 3.246, 2.7 ^[46] , 1.5 ^[43] , 1.0 ^[40] , 1.8 ^[13] , 1.1 ^[44] | 68.5''x39.8'' ^[35] | 1.01 | -217 | -11.4 ^[40] | 0.086 ^[40] | 4315 ^[20] | 1.66 |
| Group II | | | | | | | | | |
| 8 | PTB 1 | 6.185 | 33 ^[33] | 1.0 | 292 | -13.7 | 0.013 | 930 ^[33] | 1.20 |
| 9 | PTB 25 | 8.634 | 40 ^[33] | 1.67 | -285 | -12.8 | 0.006 | 470 ^[33] | 2.40 |
| 10 | K 5-14 | 5.8 | < 1 ^[49] | | -269 | -11.7 ^[32] | | 8700 ^[31] | |
| 11 | M 2-23 | 8.777, > 7.2 ^[13] , 3.9 ^[40] , 8.4 ^[13] , 8.5 ^[12] | 8.8 ^[40] | 0.37 | -426 | -11.6 ^[40] | 0.070 ^[40] | 4287 | 0.92 |

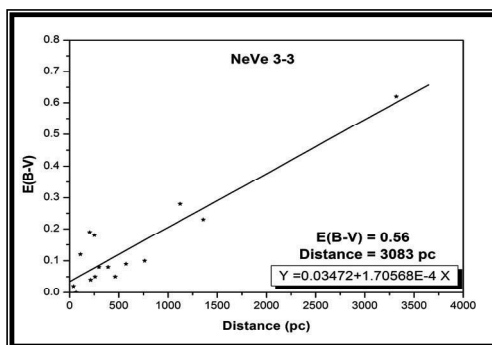
*Observational parameters are given in bold font style.

has the largest size in our sample, while K 3-45 has the smallest size. If the observed angular diameter of K 5-14 is really less than 1 arcsec, then the object will become the smallest object in our samples with linear size < 0.028 pc.

The details for the individual objects are presented in the following subsections.

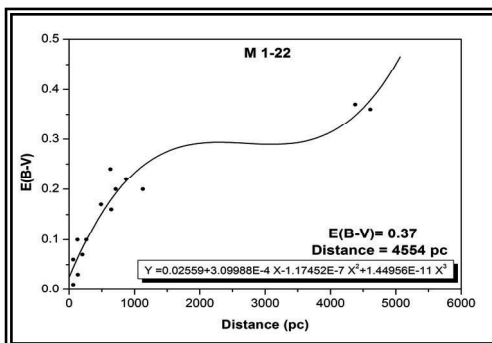
4.1 NeVe 3-3

The object is selected from seven PNe studied by Kerber *et al.*^[31]. From the linear fit of the R-D relation we derived a distance of 3.1 kpc. It is the first “individual or statistical” distance for the object. Based on this distance, the derived electron density agrees with the observed upper limit that given by Kerber *et al.*^[31]. The large ionized mass, large linear size and low electron density emphasize that the object is in late stage of evolution.



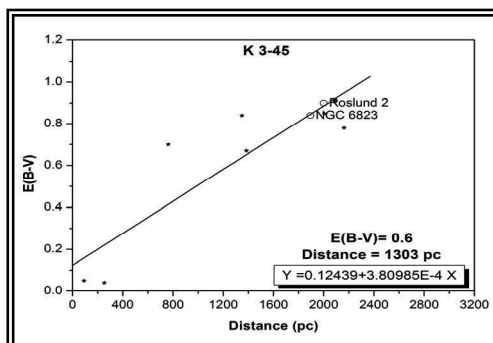
4.2 M 1-22

M 1-22 is far away from the galactic disk. It has the largest scale height (Z) value in our sample, which indicates that the object is out the galactic thin disk. The object has no published distance, so our reliable distance is the first determined one. The object has small size, mass and high electron density, these indicate that the object is in early stage of evolution.



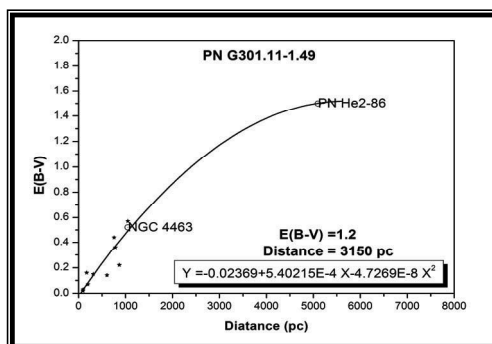
4.3 K 3-45

The R-D relation of K 3-45 is based mainly on the two open clusters Roslund 2^[25] and NGC 6823^[25]. The numbers of stars with complete information in the field are small and most of them are highly scattered around the fitted line. The object is not well-known, but has two statistical distance values 1.9 kpc^[43] and 4.13 kpc^[7]. The average of these two values is ~ 3.0 kpc, which is roughly three order of our reddening distance of 1.3 kpc. This difference could be justified by keeping in mind that the previous two values derived by statistical methods, while our distance is an individual. The derived electron density seems to be high (overestimated). The very high electron concentration, low ionized mass and small size emphasize that the early evolutionary phase of the PN. Based on the reddening distance, K 3-45 is very close to the galactic disk and it has the smallest size in our sample.



4.4 PN G301.11-1.49

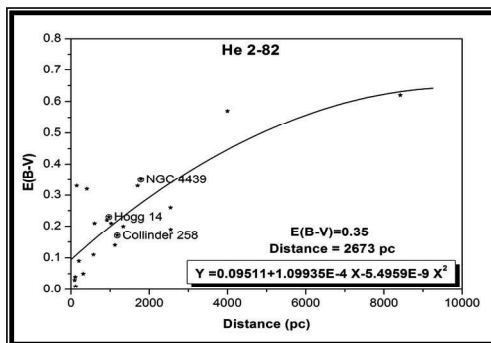
The R-D relation of the object is based on the planetary nebula He2-86. He2-86 has many statistical distances, but there is only one reliable value determined by gravity method (Individual method) which we used in our relation. The relation is confirmed by the presence of NGC 4463 open cluster^[25] in the field around the object.



A second order polynomial fit has drawn for the data points that give a reddening distance of 3.2 kpc. The object has very small linear size and consequently very small ionized mass according to the mass-radius correlation. The high density is in favor of early evolutionary phase.

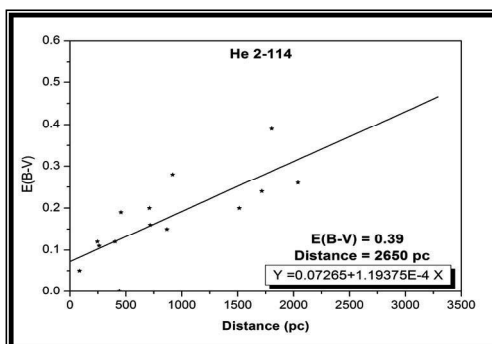
4.5 He 2-82

A 2nd order polynomial fitting has been constructed for the data points. The first part of the relation is confirmed by three clusters NGC 4439^[25], Collinder 258^[25], and Hogg 14^[24]. The reddening distance of 2.7 kpc is slightly higher than the statistical distances 2.25 kpc and 2.0 kpc that given by Acker *et al.*^[39] and Maciel^[43], respectively. The electron density and ionized mass reveal that the object is in late phase of evolution.



4.6 He 2-114

He 2-114 is a well known PN considered in many publications. A number of distances have been published for the object using different statistical scales. The values are differing from one reference to another. Cahn *et al.*^[40] and Phillips^[44] give roughly the same distances of 2.6 kpc and 2.8 kpc, respectively. The largest distance of 5.0 kpc is given by Zhang^[13], while the smallest distance of 1.9 kpc is given by Phillips^[45]. The average statistical distance from the previous publications is ~ 3.1 kpc, which is relatively close to our distance of 2.7 kpc. The electron density is roughly small, which displays that the PN approached the evolved stage of evolution.

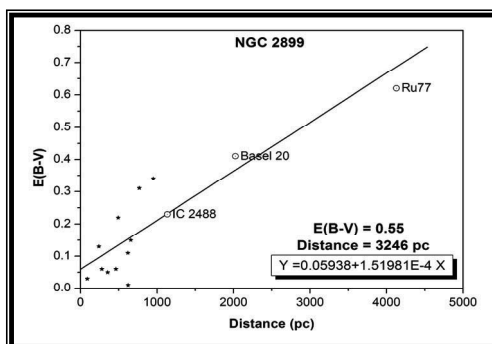


4.7 NGC 2899

The object is well known PN that mentioned in large number of publications. The diagram displays a linear fit for the data points. The fit depends on three galactic clusters (Basel 20^[24], Ruprecht 77^[24] and IC 2488^[25]) in the line of sight to the object. Our reddening distance is in

agreement with the individual distance of 2.7 kpc^[46]. Our distance of 3.2 kpc and that of Cazetta & Maciel^[46] are higher than the published statistical distances (Table 2). Our reddening distance is the second individual distance given for the object. The observed density is the average values of densities

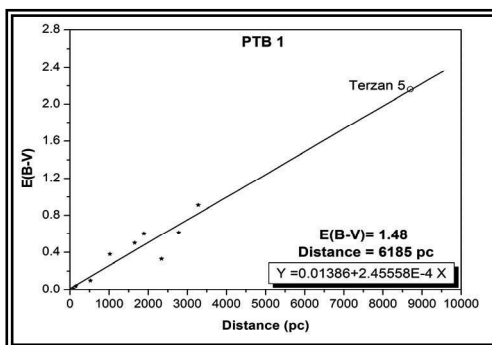
derived from three different forbidden lines. It makes the object in middle phase of evolution, while the high ionized mass is in favor of advanced phase of evolution. We can attribute this difference to uncertainty in ionized mass estimation. According to Equation 6, this could be due to an error in angular radius measurement.



4.8 PTB 1

The object is discovered through the [O III] survey for PNe in the galactic bulge^[33]. Schneider & Buckley^[47], derived a mean distance of 8.3 ± 2.6 kpc to Galactic center using PNe in the Galactic bulge. The linear fit of R-D relation is based on usage of the globular cluster Terzan 5, that has a reddening

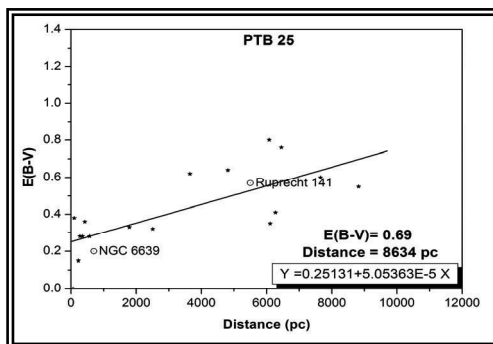
factor of 2.16 and heliocentric distance of 8.7 kpc^[48]. Our reddening distance is of great importance, because it emphasizes that the object is belonging to the galactic bulge region^[47]. The estimated ionized mass seems to be high due to the large linear size of the nebula. This makes clear that the object is undoubtedly an evolved PNe.



4.9 PTB 25

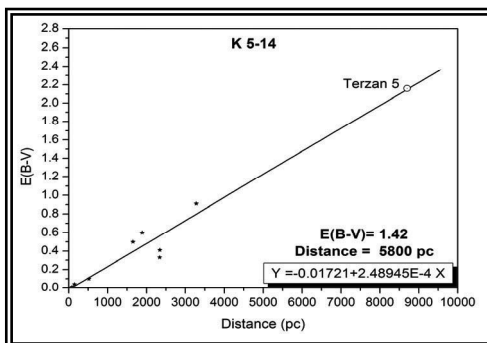
PTB25 is similar to PTB1, it is detected by Boumis *et al.*^[33] when they survey for PNe in the galactic bulge region. Our R-D relation displays a least-square linear fit. The relation is confirmed by the

presence of two open clusters NGC 6639 and Ruprecht 141^[25] in the line of sight toward PTB 25. The reddening distance estimation emphasizes that the object is not only belonging to the galactic bulge region, but it also close to the galactic center according to Schneider & Buckley^[47]. PTB25 fits the galactic bulge region better than PTB1 (6.3 kpc) and K 5-14 (5.8 kpc). The large mass, large size and low electron density reveal that it is in the late phase of evolution.



4.10 K 5-14

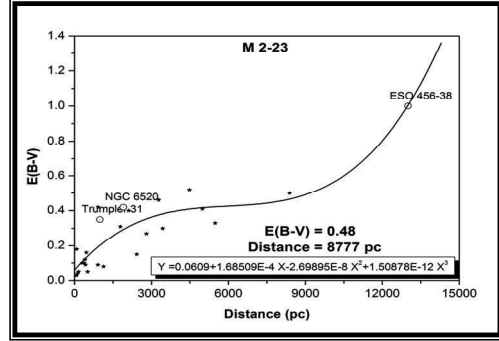
Escudero & Costa^[32] reported a spectro-photometric observation of K 5-14 through a sample of 44 PNe towards “probably belong to” the galactic bulge. They observed reddening, H β flux and electron density of the object. The R-D relation is mainly similar to that of PTB1. Both relations are



linear and based on the globular cluster Terzan 5. The two objects have nearly the same equatorial and galactic coordinates. The object has a reliable distance of 5.8 kpc. It makes that the object exists at the border of the galactic bulge. The observed angular diameter is less than 1 arcsec, based on the radio observation taken by Kohoutek^[49]. There is no published optical size for the object. According to the very small angular diameter and the derived distance, we could expect a very small linear diameter and ionized mass. The previous two parameters in addition to the high electron temperature (~ 16000 K) and electron density suggest that the object is in early phase of evolution. It needs a narrow band image in certain emission lines to measure its real size.

4.11 M 2-23

M 2-23 is a known nebula that has many distance measurements. Our R-D relation is based on the globular cluster ESO 456-38^[50] that exist in the direction towards to the object. The first part of the relation is confirmed by the presence of the two open clusters Trumpler 31 and NGC 6520^[51]. Our



reddening distance is in a good agreement with the lower limit individual distance, of 7.2 kpc that given by Cazetta & Maciel^[46]. The object is mentioned in some publications as a galactic bulge PNe. Our estimated distance not only agrees with the size limit of the galactic bulge, but also makes the object close to the galactic center. The statistical measurements of 8.4 kpc^[13] and 8.5 kpc^[12] are nearly the same as our reddening distance, while that given by Cahn *et al.*^[40] of 3.9 kpc is completely different from us.

Error Analysis

To estimate the errors in the distances, we followed the relation given by Gathier *et al.* (1986)^[34]

$$\sigma_{\text{PN}}^2 = \frac{\sigma_{\text{E(B-V)}}^2}{\gamma^2} + \sigma_{\text{RD}}^2$$

where σ_{PN} is the error of the PN distance, $\sigma_{\text{E(B-V)}}$ is the error in E(B-V) of the PN, γ is the slop of the R-D relation and σ_{RD} is the error in R-D relation that estimated from the observed scatter in the R-D diagram at the level of E(B-V) of the PN. Since it is obvious that the scatter is mainly due to the error of the distance of stars in the field around the PN, σ_{RD} is determined by the standard deviation of the fit. The distance, its error and error ratio for every object is given in Table 3. The table shows in column (2) the name of the objects, column (3) the distance of the PN with its uncertainty, column (4) the error ratio in percent, column (5) the correlation coefficient (R), column (6) the slop of the fitted curve (γ), column (7) the standard deviation of the fit (SD), and (8) the number of

data points (N). Most of the observed reddening factors of PNe have no error measurements. We adopt the values given in literatures; otherwise we suggested error of order 5%.

Table 3. Fitting statistical parameters and error estimation of the distances.

| | PN | Distance (pc) + σ_{PN} | Error ratio (%) | R | γ | SD | N |
|-----------------|-----------------|-------------------------------|-----------------|------|----------|------|----|
| Group I | | | | | | | |
| 1 | NeVe 3-3 | 3083±164 | 5.3 | 0.86 | 1.71E-4 | 0.06 | 15 |
| 2 | M 1-22 | 4554±127 | 2.8 | 0.93 | 1.45E-4 | 0.04 | 14 |
| 3 | K 3-45 | 1303±79 | 6.1 | 0.78 | 3.80E-04 | 0.18 | 10 |
| 4 | PNG 301.11-1.49 | 3150±246 | 8.2 | 0.95 | 2.44E-04 | 0.09 | 13 |
| 5 | He 2-82 | 2673±217 | 8.9 | 0.66 | 8.05E-5 | 0.10 | 21 |
| 6 | He 2-114 | 2650±163 | 6.2 | 0.63 | 1.19E-04 | 0.07 | 14 |
| 7 | NGC 2899 | 3246±230 | 7.1 | 0.78 | 1.52E-4 | 0.09 | 14 |
| Group II | | | | | | | |
| 8 | PTB1 | 6185.0±733 | 11.7 | 0.97 | 2.46E-04 | 0.12 | 10 |
| 9 | PTB25 | 8634.0±1980 | 22.9 | 0.53 | 5.05E-05 | 0.15 | 17 |
| 10 | K 5-14 | 5800.0±562 | 10.0 | 0.97 | 2.49E-04 | 0.13 | 9 |
| 11 | M 2-23 | 8777±407 | 4.6 | 0.81 | 5.9E-5 | 0.10 | 26 |

5. Conclusion

From the least-squares fitting of stellar data around 11 planetary nebulae, we have determined their distances with error ratios in the range from 3% to 23%. A comparison is made with existing statistical distances and other existing individual distances if available. We find a very good acceptable degree of agreements between our reliable distance for M2-23 and NGC 2899. For other objects that have statistical distances only, we found also a good agreement. The distances are well determined for all objects, four of them are except for k3-45 to be in (or towards) the Galactic bulge. Six objects of the sample have no published distances up till now. Distances to more and greater variety of objects are needed to get a better understanding of the PN phenomenon. We conclude that the reddening distance using literature data can successfully be used when proper procedures are used. Most of our objects are in an advanced phase

of evolution, while the other few are in early stage. Nebular parameters are calculated for our sample. Evolutionary phase description is given for each object according to the derived nebular parameters.

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تعيين المسافات المنفردة لعدد من السدم الكوكبية

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المستخلص. يركز هذا المشروع على دراسة واحدة من أهم المشاكل التي تواجه المجال البحثي للسدم الكوكبية، ألا وهي تعيين المسافات لهذه الأجرام. وتعتبر طريقة تعيين المسافات الكوكبية عن طريق استنتاج العلاقة البيانية بين معامل الاحمرار والمسافة في اتجاه السديم من أفضل طرق تعيين المسافات المنفردة، والتي تم تطبيقها في دراستنا الحالية، حيث تم تعيين المسافات المنفردة لـ ١١ سديماً كوكبياً، تقع أربعة منها في انتفاخ المجرة. معظم السدم في العينة المختارة هي سدم كوكبية لم يتم دراستها سابقاً (غير معروفة جيداً)، حيث لا تتوفر لها مسافات سابقة في الدوريات العلمية. وحسب معلوماتنا، فإن المسافات المقاسة لستة منها تُعد هي الأولى على الإطلاق. وقد تمت مقارنة المسافات المحسوبة للسدم المتبقية مع المسافات المنشورة في الدوريات العلمية (المحسوبة إما باستخدام الطرق الإحصائية أو الطرق المنفردة) إن وجدت. رغم العدد الصغير من السدم المدرج في هذا البحث، إلا أن نتائج هذا البحث ستزيد المسافات (المنفردة) المعروفة سابقاً لعدد محدود من السدم الكوكبية. وقد تمت الاستفادة من المسافات في تعيين بعض أهم العوامل الفيزيائية لهذه المجموعة من السدم الكوكبية.