

Distances Scale Determination for a Planetary Nebula in Galactic Bulge

Sundus A. Abdullah¹, Nathera A. Ali², Mohamed A. Sallih³

¹Department of Astronomy and Space, Baghdad University, Baghdad, Iraq

²Department of Physics, Baghdad University, Baghdad, Iraq

³Ministry of Electricity, Baghdad, Iraq

Email: Sundusalbakri70@yahoo.com

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ABSTRACT

Planetary Nebulae (PN) distances represent the fundamental parameter for the determination the physical properties of the central star of PN. In this paper the distances scale to Planetary Nebulae in the Galactic bulge were calculated related to previous distances scales. The proposed distance scale was done by recalibrated the previous distance scale technique CKS/D82. This scale limited for nearby PN ($D \leq 3.5$ kpc), so the surface fluxes less than other distance scales. With these criteria the results showed that the proposed distance scale is more accurate than other scales related to the observations for adopted sample of PN distances, also the limit of ionized radius (R_{io}) for all both optically thick and optically thin in the rang of sizes ($0.45 > R_{io} \text{ (pc)} > 0.03$).

Keywords: Planetary Nebulae; Masses; Distances Planetary Nebulae

1. Introduction

There are several methods available to determine individual distances, independent of any assumptions concerning the information on the properties of the Nebula. These distances give independent information on the properties, of the nebula, especially mass and density for the nebulae [1,2].

By making certain assumptions on the nebular structure, distances can be calculated by measurement of fluxes, angular sizes, and electron densities. These methods called statistical distances [3]. As well determined distance scale for Planetary Nebulae (PN) is necessary for the investigation of the space density, galactic distribution, total number of PN, and the birth rate of PN in the galaxy [2,4].

2. Previous Distances Scales

The previous statistical distances rely on Planetary Nebulae sharing certain common physical properties and the previous distances are derived from the measurement of two or more nebular parameters [1]. A number of theoretical mass-radius relationships have been constructed based on the H-burning tracks of Schonberner and Blocker (BS90) and various models of nebular expansion as Zhang and Kwok (1993) and Mellema (1994) [5,6].

During the last decade several such distance scales have been proposed, notably Cahn *et al.* (1992) (here after CKS), Van de Steen and Zijlstra (1995) (VdSZ), Zhang (1995) (Z95), Schneides and Buckley (SB96), and Stanghelline and Shaw with Villaver (2008) (SSV). The previous scales which will be indicated in this work as the following:

Daub in 1982 used an empirically relation between the ionized masses of Planetary Nebulae and a particular function of observational quantities was used to calculate the distances to the samples of Planetary Nebulae. These distances are used to investigate the scale height of the galactic distribution of Planetary Nebulae (125 pc), the rate of formation of Planetary Nebulae ($5 \pm 2 \times 10^{-3}$ PN $\text{kpc}^{-3} \cdot \text{yr}^{-1}$). The effective ionized mass (μ) define as [4]

$$\mu = \frac{M_{io}}{\epsilon^{1/2}} = \sqrt{2.26 \times 10^{-21} S_{5 \text{ GHz}} D^5 \theta^3} \quad (1)$$

where M_{io} : is the ionized mass of PN in Sun mass unit (solar mass); ϵ : is the filling factor used to allow for the non spherical geometry of the nebula

θ : is the angular diameter in arcs unit

$S_{5 \text{ GHz}}$: is the radio flux at 5 GHz in $\text{W} \cdot \text{m}^{-2} \cdot \text{Hz}^{-1}$ unit, or called Janskys (Jy) unit where $\text{Jy} = 10^{-26} \text{ W} \cdot \text{m}^{-2} \cdot \text{Hz}^{-1}$;

D : is the distance in parsec unit (pc).

The optical thickness parameter, T is given by [2]

$$T = \log\left(\frac{4\theta^2}{S_{5\text{GHz}}}\right) \quad (2)$$

Daub plotted the quantity of Equation (1) ($\log\mu$) against the quantity of Equation (2) optical thickness ($\log T$) as shown in **Figure 1**, from the relations obtained by a least-squares analysis, the equations of the two mean lines, the effective ionized mass and optical thickness are given by the following relations [2,4]:

$$\log(\mu) = T - 4.5 \quad \text{at } T < 3.65 \quad (3)$$

$$\log(\mu) = -0.85 \quad \text{at } T > 3.65 \quad (4)$$

1) For optically thick PN

$$D = 324\left(\frac{\theta}{S_{5\text{GHz}}}\right)^{1/5} \text{ pc} \quad (5)$$

2) For optically thin PN

$$D = \frac{9300}{(\theta S_{5\text{GHz}})^{1/5}} \text{ pc} \quad (6)$$

Cahn recalibrated the Daub's distance scale by using samples of 19 Planetary Nebulae with well observed distances [2], as shown in **Figure 2**. The fit to the distance scale

$$\log(\mu) = T - 4 \quad \text{at } T < 3.13 \quad (7)$$

$$\log(\mu) = -0.87 \quad \text{at } T > 3.13 \quad (8)$$

The calculated distances by CKS scale were split in two types [2,6].

1) For optically thick PN

$$\log(D) = 2.71 + 0.21\log(\theta) - 0.6\log(S_{5\text{GHz}}) \quad (9)$$

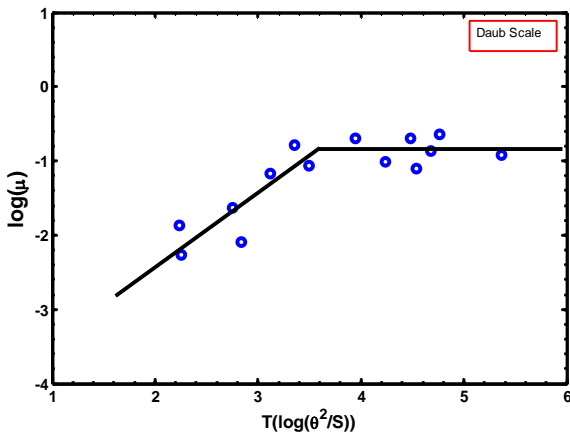


Figure 1. The relation between ionized mass and the optical thickness according to Daub scale (D82).

2) For optically thin PN

$$\log(D) = 3.96 - 0.6\log(\theta) - 0.2\log(S_{5\text{GHz}}) \quad (10)$$

For the distance determination CKS used radio fluxes and optical diameters except for nebulae with very small angular sizes, where radio diameters obtained with Vela Large Array (VLA) were used [6]. Stanghellini *et al.* calculated the distances for PN by re-calibrated the distance scale of CKS using the nebular parameters relative to the LMC and SMC PN observed by Hubble Space Telescope (HST), as shown in **Figure 3** [7].

The fit lines of distances scale which were found by SSV scale based on the Magellanic Clouds PN are

$$\log(\mu) = 1.21T - 3.93 \quad \text{at } T < 2.1 \quad (11)$$

$$\log(\mu) = -0.86 \quad \text{at } T > 2.1 \quad (12)$$

This method based on transformation between 5 GHz and $H\beta$ flux [8]. SSV scale calculated the distances for the samples of PN, by using the following equations [2]:

1) For optically thick PN

$$\log(D) = 3.06 + 0.37\log(\theta) - 0.68\log(S_{5\text{GHz}}) \quad (13)$$

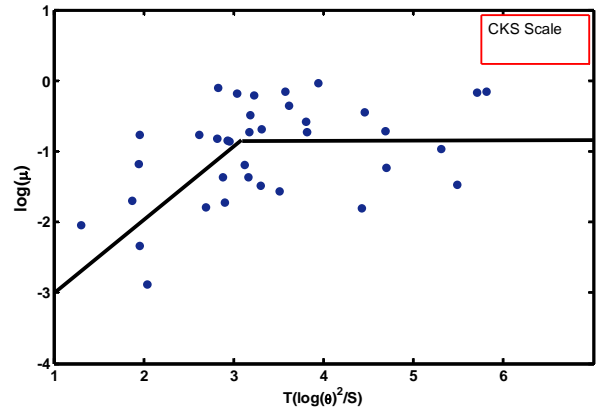


Figure 2. The relation between ionized mass and the optical thickness according to CKS scale.

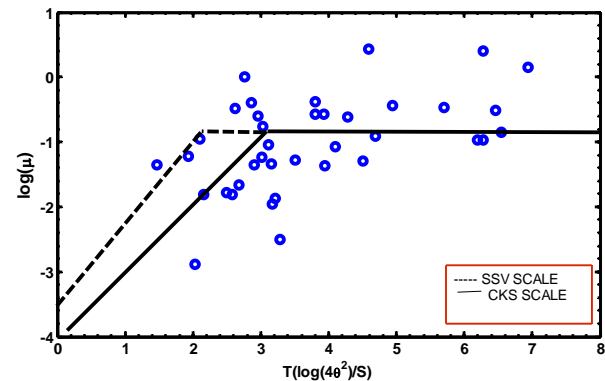


Figure 3. The relation between ionized mass and the optical thickness, SSV distance comparing with CKS distance.

2) For optically thin PN

$$\log(D) = 3.89 - 0.6 \log(\theta) - 0.2 \log(S_{5\text{GHz}}) \quad (14)$$

Using the similar technique we recalibrate the Cahn and Kaller(CK)/Daub distance for the sample of planetary nebulae using the resolved companion central star to determined their distances, a new scale have been found to determine the distance for the a sample of PN in Galactic Bulge as tabulated in **Table 1**.

3. Proposed Distance Scale (Syth10)

This method based on the results of Hubble Space Telescope (*HST*) survey of Galactic Planetary Nebulae (GPN), designed to detect and measure resolved binary PN companions.

The sample of PN in our Scale was chosen using criteria designed to maximize our chances of finding resolved companion stars. First among these criteria was that objects in our choosing had to be nearby. Nearly all of our selections have statistical distances from Cahn, Kaller (1990) (CKS); Zhang (1995) (Z95); Stanghellini and Shaw and Villaver (2008) (SSV) that are less than ~ 3.5 kpc.

Second criteria that the Galactic latitude for PN were chosen to have $|b| > 10^\circ$. A third selection criteria was known of the binarity of the central stars.

Computational Method for the Proposed Scale (Syth10)

The proposed scale in this work were done by recalibrated CKS/D82 scale and used the Equation (1) to find the effective ionized mass and then plot versus optical thickness as shown in **Figure 4**, the fit to the ionized masses as the following equations:

$$\log(\mu) = T - 4 \quad \text{at } T < 3.60 \quad (15)$$

$$\log(\mu) = -0.83 \quad \text{at } T > 3.60 \quad (16)$$

The programming results and figures were performed by using Matlab package.

Distances obtained by proposed scale performed by plot the observed distances values versus optical thickness which were given by **Table 1**, then fit to the distance scale by the following equations:

1) For optically thick PN

Table 1. Represent the values of angular sizes with the optical thicknesses for the samples of PN. The observed and calculated distances are estimated.

PN	θ (ares)	S (Jy)	Log(μ)	T	D (pc) calculated this work	D (pc) observed	Type	Method
A30	63.5	0.023	-0.653	5.08	1120	2020	Thin	RE.
A31	486.0	0.155	-0.149	6.78	244	240	Thin	RE
A33	134.0	0.014	-0.357	6.71	794	1060	Thin	RE
IC4637	9.3	0.132	-2.531	3.40	1525	1500	Thick	RE
K1-14	23.0	0.001	-0.970	6.18	3299	3500	Thin	RE
K1-22	90.5	0.011	-0.517	6.45	1033	1130	Thin	RE
Mz3	12.7	0.649	-0.796	3.24	916	1440	Thick	RE
NGC1535	9.2	0.160	-0.827	3.30	1646	2310	Thick	RE
NGC3132	22.5	0.230	-1.367	3.94	1250	770	Thin	RE
NGC7008	14.0	0.217	-1.756	3.55	1233	870	Thick	RE
SP3	17.8	0.061	-0.582	4.32	1965	2380	Thin	RE
A21	307.5	0.327	-0.754	6.06	278	540	Thin	P
A35	368.0	0.255	-1.424	6.36	255	230	Thin	P
NGC1514	80.0	0.288	-2.070	4.94	540	480	Thin	P
NGC6853	165.0	1.324	-0.455	4.91	310	380	Thin	P
NGC7296	300.0	1.291	-0.715	5.44	220	210	Thin	P
PHL932	135.0	0.0100	-0.678	6.86	540	310	Thin	P
PUWel	200	0.0847	-0.793	6.27	455	430	Thin	P

Where RE: Represents the resolved expansion method; P: Represents the parallax method.

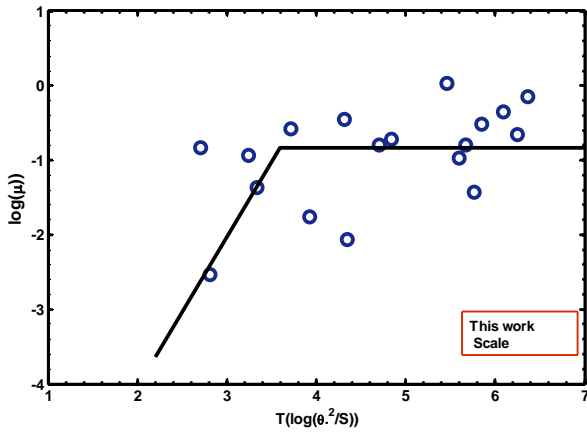


Figure 4. The relation between ionized mass and the optical thickness, the individual nebulae listed in Table 1. This work distance scale.

$$\log(D) = 2.50 + 0.18 \log(\theta) - 0.5 \log(S_{5\text{ GHz}}) \quad (17)$$

Planetary Nebulae (PN) display a positive correlation between the ionized mass and the size. On very general ground that Planetary Nebulae during the first evolutionary stages is optically thick to Lyman continuum radiation, and its ionized mass is considerably smaller than the total mass. As the objects expand and become optically thin the ionized mass also increases, approaching value of the total mass. The whole process suggests that the ionized mass increases proportionally to the radius of the Planetary Nebulae. The simplest form of such a relation is a linear one, which we have established using our data for closing PN. The least squares straight line is

$$M_{io} = aR_{io} + b \quad (18)$$

where $a = 1.225$ and $b = -0.0123$. This equation can be considered a first order approximation to the masses of the Planetary Nebulae, as compared to the zeroth—order constant mass of Shklovsky’s method [9,10]. Our limit of R_{io} for all both optically thick and optically thin in a rang of sizes is given by

$$0.45 > R_{io} \text{ (pc)} > 0.03 \quad (19)$$

These limits are comparing with the previous limits in Pottasch (1992), which is given by [10]

$$0.4 > R_{io} \text{ (pc)} > 0.01 \quad (20)$$

and with the limits of the resents observations which is given by [2]

$$0.5 > R_{io} \text{ (pc)} > 0.03 \quad (21)$$

4. Discussions and Conclusions

The distance was derived by Daub for the optically thin nebulae ($\log 4\theta^2/S_{5\text{ GHz}} > 3.65$) if an available flux is at 5

GHz, an adjustments of that to frequency = 5 GHz. For optically thick the distance derived ($\log \theta^2/S_{5\text{ GHz}} < 3.65$), it is possible that some of the most expanded PN become optically thick for a second time as their central stars contract to near White Dwarf (WD).

From **Figure 1**, it is apparent that most PN are likely to have ionized masses smaller than optically thin PN. This scale (D82) depends on the calibration of few samples PN in Galactic Bulge.

CKS improved D82’s calibration with the use large number of calibrator’s, and he calculated the distances to 778 galactic PN [2]. The scale’s distance of calibration was shown in **Figure 2**.

As a result, the previous distance scales that seem to work well with samples, for example those in Galactic Bulge or External Galaxies, may not be applicable to more divers population of local Planetary Nebulae. The values of (θ) and surface brightness were given in the catalogues of CKS and SSV for the samples which were adopted [2,8].

From these scales we estimated the number of nebulae that are optically thick and optically thin according to the previous scales which were indicated, as shown in **Figures 5 to 8**. Specifically adopted sample tend to have lower surface brightness than the traditional calibration objects. This difference may arise from a selection effect:

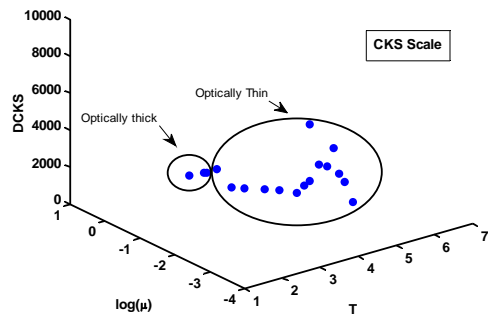


Figure 5. The relation between distance (DCKS) and optical thickness with the ionized mass, three nebulae represent optically thick.

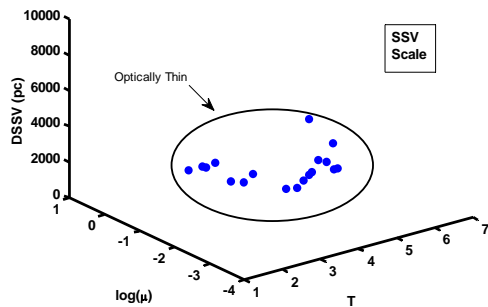


Figure 6. The relation between distance (DSSV) and optical thickness with the ionized mass, all nebulae represent optically thick.

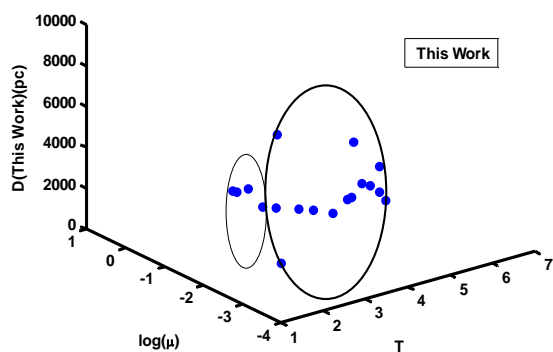


Figure 7. The relation between distance (this work) and optical thickness with the ionized mass, four nebulae represent optically thick.

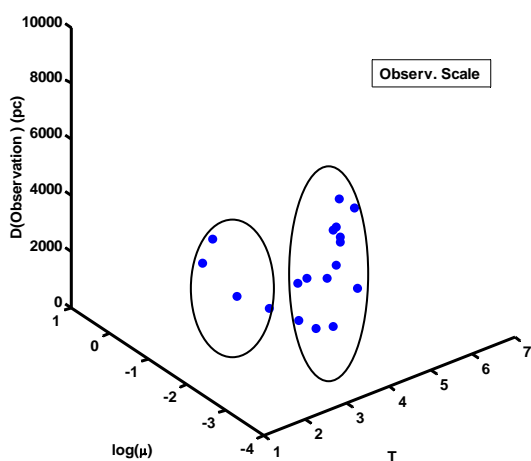


Figure 8. The relation between distance and optical thickness with the ionized mass, four nebulae represent optically thick.

PN in our survey are typically nearby, old nebulae, whereas most of the objects that calibrate statistical techniques are low-latitude, high surface brightness, and more distant nebulae.

Comparison of our proposed distances with those obtained from most various distances scales shows that all of the latter have systematically overestimated the distances by factors ranging up to factor of 2. The various distances were plotted versus angular expansion; the best fitting equations were obtained as

$$f(D) = aD + b \tag{22}$$

where a and b represent the coefficients of fitting equations. The comparison of our scales with the different previous scales was illustrated by plotting the distances with versus best fitting equations ($f(D)$) as shown in **Figures 9 and 10**. The results estimated the accurate scale and demonstrated the fitting lines for the CKS and SSV with the scale of this work in compare with the observation distance. We show these errors most likely due to

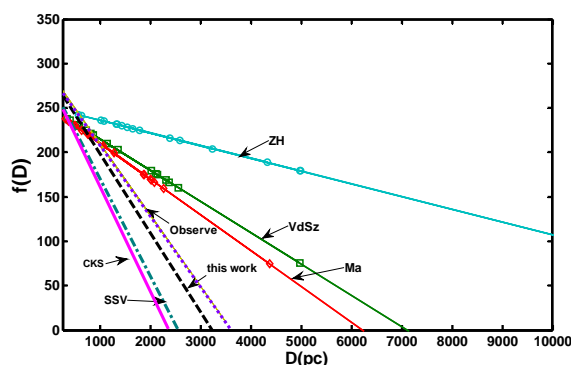


Figure 9. Comparison the proposed scales distance with the different previous distances, all lines represents fitting lines.

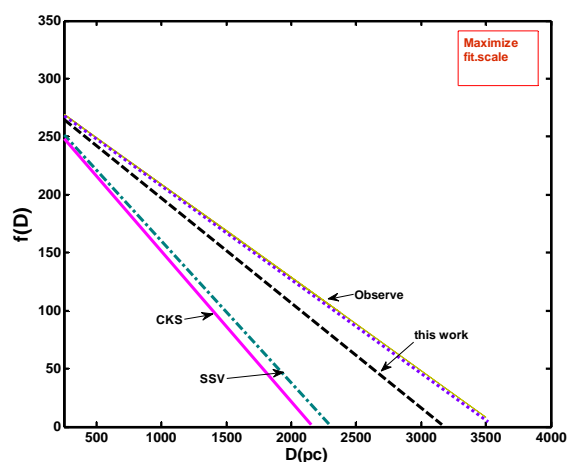


Figure 10. Represents maximized for fitting lines distance scale according to four distances scale. Our scale appear more approaching to the observing distance than other scales.

the fact that the properties of our Planetary Nebulae with binary nuclei are systematically different from those of PN used to calibrate statistical methods.

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