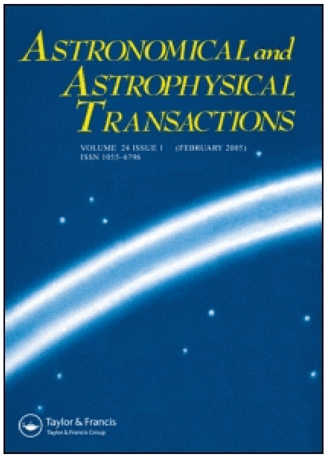

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ON THE PROBLEM OF PLANETARY NEBULA DISTANCE SCALES

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The difference between some galactic planetary nebula (PN) distance scales is analysed and the necessity of several distance scales used for different PN mass classes is suggested. Average PN parameters are estimated.

KEY WORDS Planetary nebula–distance scale

1 INTRODUCTION

The planetary nebula (PN) distance scale problem is one of complicated and unresolved. There are ~1500 known PN in the Galaxy and only for ~100 of them the distances are determined directly, using individual methods. The accuracy of the distance determinations is low, and the distances to some nebulae determined by different methods may differ by a certain factor.

However, nevertheless, no statistical investigation (determinations of the birthrate, the distribution in the Galaxy, etc.) is possible without the distance estimations for a large number of PN. It is the reason why statistical distance scales are often used (Cahn and Kaler, 1971; Acker, 1978; Daub, 1982; Milne, 1979; etc.).

Two basic problems arise when the statistical distance scales are used:

– the choice of PN calibrators having the most reliable distance determinations;

– the necessity to use the same physical parameters (particularly, the same PN masses or luminosities) for the whole PN sample.

Cahn *et al.* (1992, hereafter CKS) have determined distances for the largest recent PN sample (750 objects) using the statistical distance scale.

Amnuel *et al.* (1989, hereafter ARG) have suggested four different distance scales for different PN groups selected according to their mass classes. AGR have suggested that PN and their central star masses directly depend on the mass of the progenitor star (Weidemann, 1981; Weidemann and Koester, 1983; Weidemann, 1984; Amnuel *et al.*, 1987, etc.).

All PN were subdivided by AGR into three basic mass classes:

	Central star mass (in $M_{\odot}$)	Progenitor star mass (in $M_{\odot}$)
low mass PN (L–PN)	<0.57	0.8–2
intermediate mass PN (In–PN)	0.57–0.64	2–3
massive PN (M–PN)	>0.64	3–8

Besides that, the class of anomalous PN (A–PN) was suggested where the second shell of a small mass (<0.08 $M_{\odot}$) was ejected by an In- or M-central star.

According to AGR, the utilization of the four classes of PN calibrators leads to a more precise estimation of the distances to different PN groups and a more reliable investigation of the PN birthrate, distribution in the Galaxy, etc.

Below, statistical CKS (single distance scale for all PN) and ARG (separate distance scale for each PN mass class) distance scales will be compared.

2 COMPARISON OF CKS AND AGR DISTANCE SCALES

Both works use PN radioemission data for the distance scale determination. CKS (unlike AGR) have not constructed direct dependences of radio surface brightness $\sum$ on the PN diameter D, but took into consideration a relation between $T = \lg \frac{\theta}{F}$ (F is the radio flux and θ is the angular diameter) and $\lg \mu$, where $\mu = \sqrt{D^2\theta^3 F}$. In fact, $T \sim -\lg \sum$ and μ is a combination of D and $\sum$.

The range of constant radio luminosities (optically thick PN) corresponds to the slope −2 in the $\lg \sum(\lg \mathrm{D})$ dependence and +1/3 in the $\lg \mu(T)$ dependence. The range of constant PN mass (optically thin PN) corresponds to the slope −5 in the $\lg \sum(\lg D)$ dependence and zero slope in the $\lg \mu(T)$ dependence.

CKS have used 19 PN for the calibration of their $\lg \mu(T)$ dependence. AGR have used 10, 12, 6 and 5 PN for the calibration of the L–, In–, M– and A–PN $\sum - D$ dependences.

Note that AGR have suggested ten criteria for the PN classification (Table 1 lists those criteria as well as the criteria of Peimbert's (1978) classification), and besides, only three of them are related to the distance parameter. Therefore, AGR's PN classification varies little if criteria related to the distance are not used.

Figure 1 shows AGR's calibration curves in the $\lg \mu - T$ plane. Figure 2, in contrast, shows CKS's calibrators in the $\lg \sum - \lg D$ plane (CKS's calibrators are classified using AGR's criteria). PNe stratification is seen and this effect should be taken into consideration.

The number of different PN classes in the CKS and AGR calibrator samples are listed in Table 2.

The CKS distance scale is close to the AGR scale averaged over all PN classes.

The local birthrate of galactic PN is $(4.1 \pm 0.7) \times 10^{-12}$ pc^{-3}yr^{-1} according to CKS and $(4.5 \pm 0.6) \times 10^{-12}$ pc^{-3}yr^{-1} according to AGR. However, the latter value

Table 1 The criteria of PN classification

Criterion number	*AGR criteria*	*Criteria used by Peimbert (1978)*
1	Mass of a central star	no
2	Zanstra temperature of a central star T_z (HI) and T_z (HeII)	no
3	Chemical abundance of PN (N/O–He/H dependence)	Chemical abundance of PN (N/O and/or He/H values)
4	Presence of hydrogen molecules	no
5	Dependence of T_z (HI)/T_z (HeII) ratio on PN radio surface brightness $\sum$	no
6	Dependence of low frequency break in PN radio spectrum on PN diameter D	no
7	Dependence of PN electron density n_e on diameter D	no
8	Morphology of PN	Morphology of PN
9	Proper velocity of PN, V_p	Proper velocity of PN, V_p
10	PN distance from the galactic plane, z	PN distance from the galactic plane, z

is a sum of three birthrates for L–, In– and M–PN (Table 3). The distribution of PN in the Galaxy is approximated by AGR as

$$n(r) = n(0) \cdot 10^{-mr-lz}, \tag{1}$$

where $n(0)$ and $n(r)$ are the spatial number densities of PN in the galactic centre region and at distance r kpc from the centre, and z is the distance from the galactic plane.

Let us discuss the consequences of a single distance scale used for different PN classes.

At present there are independent distance determinations for 91 galactic PN (see AGR) with some degree of reliability. The reliability of the distance scales can be checked comparing the distances obtained by CKS or AGR scales with independent ones of all PN which have corresponding estimates. The CKS scale, on the average, $\sim$ 1.6 times overestimates the distances to 28 L–PN, and $\sim$ 2.0 times, to 14 A–PN. The distances to 12 M–PN are $\sim$ 1.5-fold underestimated. For 37 In–PN, the CKS scale gives, on the average, the distances which are equal to those determined by

Table 2 The number of different PNe classes in calibrator samples

	CKS sample	*AGR sample*
L–PNe	5	10
In–PNe	5	12
M–PNe	5	6
A–PNe	3	5
unclassified	1	–

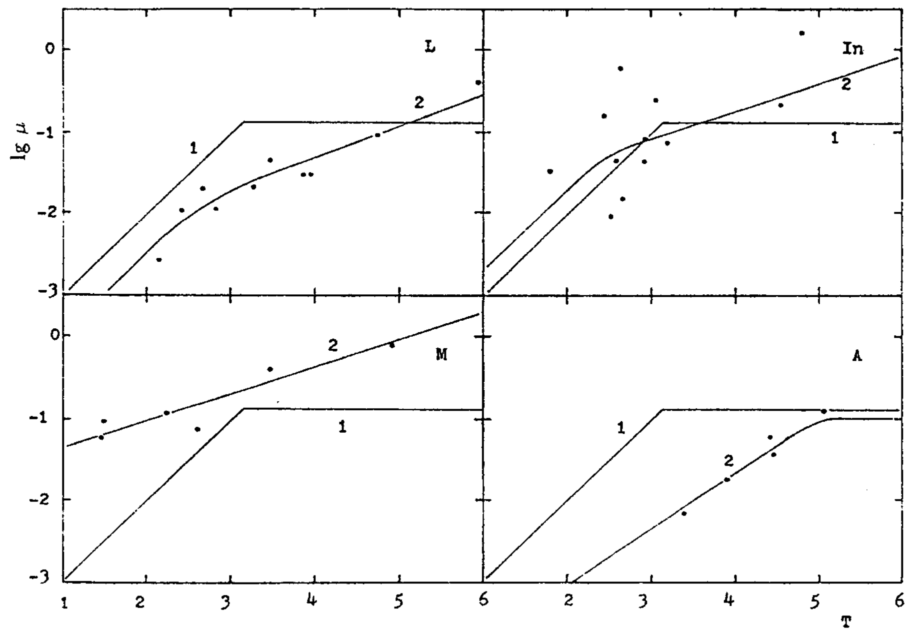

Figure 1 AGR calibrators in the $\lg \mu - T$ plane. Lines *1* correspond to CKS calibration curve, lines *2* correspond to AGR calibration curves for L–, In–, M– and A–PN.

independent methods. The same results are obtained when CKS's distances are compared with AGR's ones (see Figure 3). The values of $\langle d_{\rm CKS}/d_{\rm AGR}\rangle$ are ~ 1.7, ~ 0.9, ~ 0.6 and ~ 2.0 for 133 L–, 108 In–, 26 M– and 17 A–PN, respectively.

An overestimated distance scale for L–PN ($\sim$ 1.6 times) leads to an overestimated local surface number density of PN σ_0 ($\sim$ 2.6 times). Then, the value of the concentration parameter m decreases from 0.22 to ~ 0.16 which corresponds to more massive progenitor stars. On the contrary, the value of $\langle z\rangle$ increases from 220 to 350 kpc, which corresponds to less massive progenitors. The estimated number of L–PN in the Galaxy decreases three or more times (Table 3).

Underestimated distances for M–PN ($\sim$ 1.5 times) lead to an underestimated local surface number density of PN ($\sim$ 2.2 times), then the number of M–PN in the Galaxy increases to $\sim$ 1500 or more. The $\langle z\rangle$ value decreases from 120 pc to $\sim$ 80 pc, which corresponds to more massive progenitors. On the contrary, AGR find a relation between M–PN and galactic arms, which is not seen if CKS's distance scale is used (Table 4).

For In–PN, the AGR and CKS distance scales give similar distances (Figure 3), then the average parameters of this PN class do not change when CKS or In–PN AGR scales are used.

If In–PN AGR distance scale is used for all PN distance estimations, then the number of PN in the Galaxy decreases to $\sim$ 16 000 as compared with $\sim$ 34 000

Table 3

Sample		$\langle z \rangle$ *pc*	σ_0 *kpc*$^{-2}$	ν *yr*$^{-1}$	$N_{\rm Gal}$
AGR	L–PNe	~220	~6.4	~2.3	2.9 x 10^4
	In–PNe	~150	~2.5	~0.3	5.4 x 10^3
	M–PNe	~120	~0.5	~0.1	3.5 x 10^2
AGR	L–PNe	~350	~2.5	~0.6	7.6 x 10^3
(In)	In–PNe	~150	~2.5	~0.3	5.4 x 10^3
	M–PNe	~80	~1.1	~0.4	1.6 x 10^3
CKS	all	~150	~5.3	~2.5	1.2 x 10^4

Note: in AGR(In) sample all PNe distances are estimated according to In–PNe distance scale only.

as obtained by AGR. The use of the CKS distance scale leads to the estimate of $\sim$ 12 000 for the PN number in the Galaxy.

3 PN IN THE MAGELLANIC CLOUDS

The reliability of the CKS distance scale was checked by the authors by the determination of the distances to the Large and Small Magellanic Clouds. Figure 4 shows the $\sum -D$ dependences for the LMC and SMC PN using CKS's data (the radio intensities and angular diameters) if the distances of 47 and 57 kpc to the LMC and SMC are accepted.

The $\sum -D$ best fit line for 12 PN in the LMC is

$$\lg \sum = -(3.0 \pm 0.4) - (20.9 \pm 0.2) \lg D, \qquad (2)$$

with the correlation coefficient $\rho = -0.93$. No transition from optically thick to thin region is seen (as for the galactic In- and M–PN in AGR's sample). CKS's dependence leads to underestimated values of the PN diameters (or the LMC distance) when $D > 0.4$ pc. The $\sum -D$ line for AGR In–PN (Figure 4) is most close to

Table 4 The galactic distribution of M-PNe

	CKS sample	*AGR sample*
number of PNe in arms	6	12
between arms	7	2
on boundaries of arms	4	3
not determined	4	4

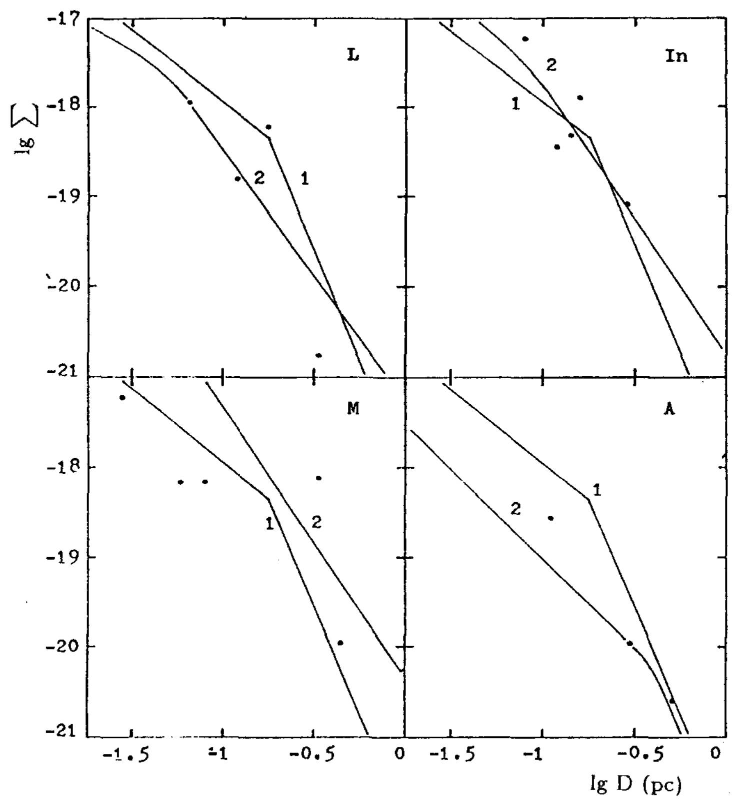

Figure 2 CKS calibrators subdivided into four classes according to AGR criteria in the lg $\sum$ −lg D plane. Lines *1* correspond to CKS calibration curve, lines *2* correspond to AGR calibration curves for L–, In–, M– and A–PN.

line (2) in all diameter values. The LMC distance estimated using the AGR In–PN $\sum -D$ line is 51 ± 8 kpc.

The $\sum -D$ dependence for 7 PN in the SMC (CKS data) is less reliable ($\rho = -0.77$)

$$\lg \sum = -(3.5 \pm 1.3) - (21.2 \pm 0.6) \lg D, \tag{3}$$

and better corresponds to the CKS line. The SMC distance estimate using the AGR In–PN line is 60 ± 19 kpc.

The determination of the mass classes for the Magellanic Cloud PN is a more complicated problem than for galactic PN since six of ten criteria cannot be used (Amnuel, 1994). In particular, the $n_e - D$ dependences are practically the same for all PN classes in the Magellanic Clouds. The scarcity of angular diameter data does not allow now to select a sufficient number of the Magellanic Cloud PN for the $\sum -D$ construction. 6 of 12 PN in the LMC (Figure 4) belong to the M–class, 2 PN to the In–class and for 4 PN, the mass class cannot be determined. As for the

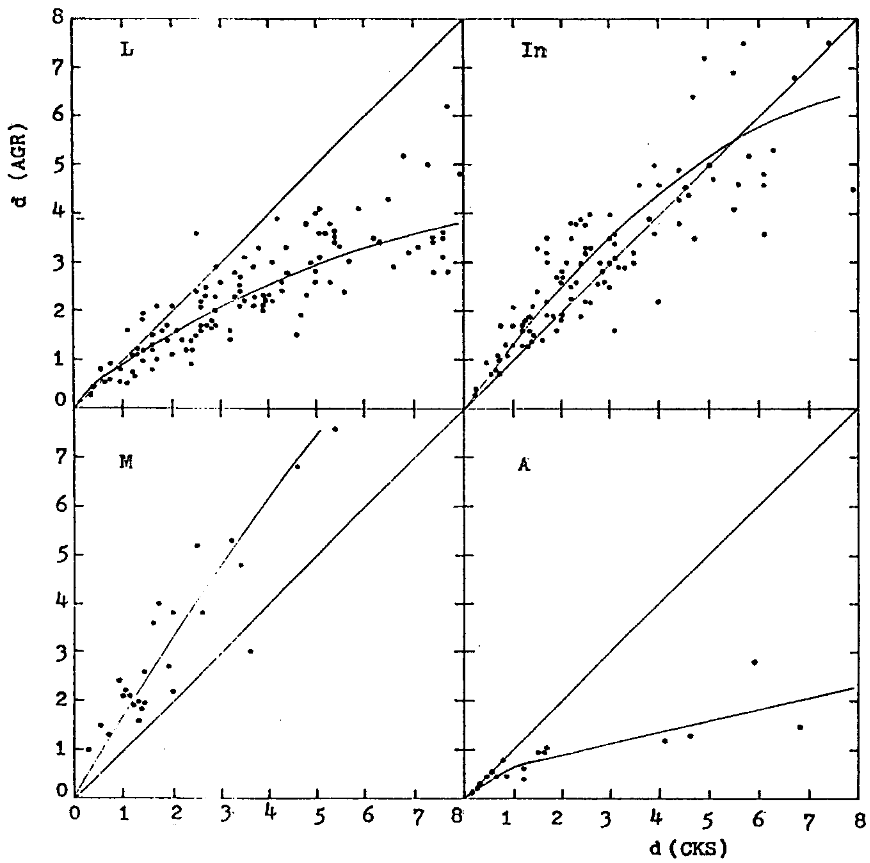

Figure 3 Comparison of PN distances determined by CKS and AGR distance scales.

SMC, only for 3 of 7 PN the mass class is determined (one PN in each of the L–, In– and M–classes).

4 CONCLUSION

A differentiation of the PN distance scales leads to a more precise determination of the birthrates, galactic distributions and other characteristics of the PN belonging to different galactic populations. In particular, a single distance scale leads to overestimated distances for low mass PN and underestimated distances for massive PN.

The essential problems are:

– correct PN classification which would be independent of any distance scale;

– use of reliable samples of calibrators for each PN mass class $\sum - D$ or $\mu - T$ line determination.

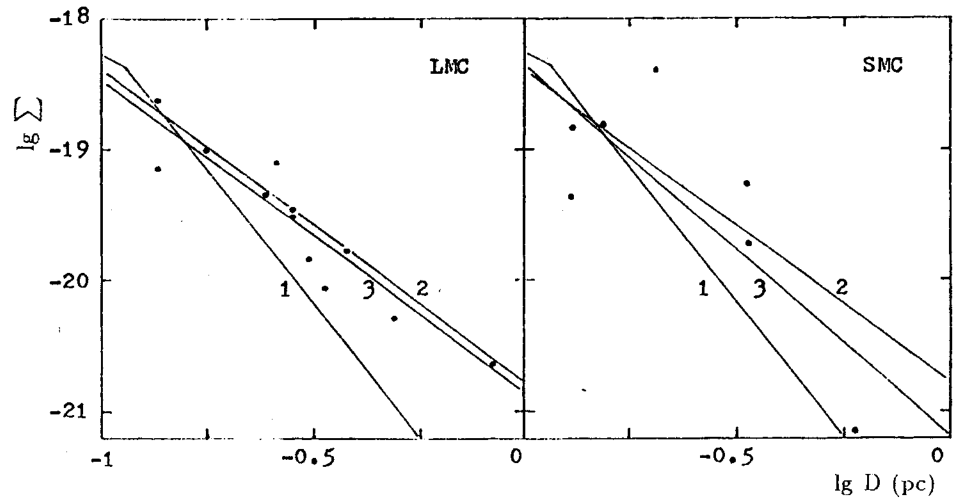

Figure 4 $\sum$–D dependences for the Magellanic Cloud PN. Line *1* corresponds to CKS curve, line *2* corresponds to AGR In-PN curve, *3* is the best fit line obtained for observational points.

Before estimating the PN distance scales, it is necessary to determine the PN mass classes (using the values of He/H and N/O abundances, the Zanstra temperatures of the central stars, molecular hydrogen existence, data on the PN morphology and peculiar velocity). If the classification of a PN is not possible, then the distance can be estimated using the $\sum - D$ dependence for In–PN.

A differentiation of PN onto a larger number of classes is not expedient now because the peculiarities of different PN begin to play a more essential role than the average parameters of a group.

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