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DISTANCES OF GALACTIC PLANETARY NEBULAE BASED ON A RELATIONSHIP BETWEEN THE CENTRAL STAR MASS AND THE N/O ABUNDANCE

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RESUMEN

En el presente trabajo se propone un método para determinar las distancias a nebulosas planetarias galácticas que está basado en una relación entre la masa de la estrella central M_c y el cociente de abundancias nebulares N/O. Esta relación se usa en combinación con algunos parámetros básicos de la estrella central como son el flujo en $\lambda5480$, la gravedad superficial y la magnitud visual, para obtener las distancias a un centenar de nebulosas planetarias galácticas.

ABSTRACT

In this paper, we propose a method to determine distances of Galactic planetary nebulae on the basis of a relationship between the central star mass M_c and the nebular N/O abundance ratio. This relationship is used in combination with some basic parameters of the central stars, such as the $\lambda5480$ flux, surface gravity and visual magnitude in order to obtain distances to a sample of a hundred Galactic planetary nebulae.

Key words: **ISM: ABUNDANCES — PLANETARY NEBULAE**

1. INTRODUCTION

Planetary nebulae (PN) and their central stars (CSPN) are extremely important Galactic objects, as they provide the connecting link between red giants and white dwarf stars (Peimbert 1990a; Pottasch 1992; Schönberner 1997). One of the most fundamental parameters associated with a planetary nebula is the distance, as reliable distances are necessary in any discussion involving the detailed evolution of PN and their central stars. As an example, the most direct method of comparing the theoretical and observed evolution of PN involves the analysis of the HR diagram of their central stars, for which some previous knowledge of the distances is needed (Kaler 1985; Cazetta & Maciel 1994; Pottasch 1997). However, the study of PN distances still presents a real challenge, in spite of the large efforts made in the past few years. Individual distances are scarce, and their uncertainties are frequently not much lower than those associated with statistical distances (Maciel 1995; Maciel & Cazetta 1997). Recently, some progress has been reached from accurate VLA expansion distances (Hajian, Terzian, & Bignell 1995), trigonometric parallaxes (Harris et al. 1997), and *Hipparcos* parallaxes (Pottasch 1997; Pottasch & Acker 1998). However, for the vast majority of PN, one still has to rely on distances obtained by less accurate methods, which frequently have uncertainties of a factor 2 of higher (Terzian 1993, 1997). Therefore, it is appropriate to develop new methods of distance determination, especially when better calibrations are possible, as occurs with the objects for which detailed models for the central stars are available.

A promising method of individual distance determination based on central star properties has been discussed by Méndez et al. (1988). According to this method, the distance can be written as a function of the following CSPN parameters: the monochromatic emergent flux at $\lambda5480$, the surface gravity, the reddening-free visual magnitude, and the core mass. Probably, the largest uncertainty associated with this method lies in the determination of the core mass, as there is no direct method to determine this quantity. Usually, the mass is estimated by a method which implicitly assumes the distance to be known, so that it would be desirable to obtain a distance-independent procedure.

In this paper, we will attempt to develop such a procedure, on the basis of a relationship between the core mass M_c and the nebular N/O abundance ratio. It is well known that in the dredge up processes affecting intermediate mass stars, some nitrogen contamination occurs in the outer atmosphere of the PN progenitor stars, which can be eventually measured as a N/O excess in the planetary nebula (cf. Peimbert 1990a). Since these processes, particularly the second dredge up, are believed to depend rather critically on the central star mass, a relationship between the excess nitrogen and the core mass is expected to exist, in the sense that PN with higher N/O ratios statistically have more massive progenitors. The abundances can be measured with a relatively high accuracy, so that the core mass can be inferred and then used as one of the basic parameters in order to determine the distance.

2. MASSES OF CSPN

Several methods to compute stellar masses have been proposed in the literature. As an example, core mass-luminosity relations can be used in the framework of theoretical models to derive the masses (cf. Paczynski 1971; Schönberner 1981; Wood & Faulkner 1986; Blöcker & Schönberner 1990). The problem with these methods is that they are distance dependent, so that the considerable uncertainties in the distance determinations are implicitly transferred to the stellar masses.

On the other hand, during the evolution of intermediate mass stars, dredge-up processes enrich the stellar outer layers with elements such as He, N, and C. As a consequence, the He/H and N/O abundance ratios are expected to increase with the mass of the progenitor star (Becker & Iben 1979, 1980; Renzini & Voli 1981; Kaler 1983; 1985; Kaler, Shaw, & Kwitter 1990; Peimbert 1990a). Furthermore, the initial mass and final (remnant) mass are directly related (Iben & Truran 1978; Kwok 1983; Iben & Renzini 1983; Weidemann 1987; Ciotti et al. 1991), so that the He/H and N/O ratios are also probably correlated with the core mass (Renzini 1979; Iben & Renzini 1983).

This picture has been confirmed by a number of authors, who have found evidences that the positions of N-rich PN on the HR diagram support the view that they have relatively massive nuclei (Kaler 1983; Gathier & Pottasch 1989; Kaler & Jacoby 1989; Cazetta & Maciel 1994). However, it should be mentioned that the results are not clearly conclusive, largely due to the uncertainties in the observational data and their interpretation (see for example Stasińska & Tylenda 1990; Pottasch 1993, 1997; Górny, Stasińska, & Tylenda 1997).

Groenewegen & de Jong (1993) and Groenewegen, van der Hoek, & de Jong (1995) developed a synthetic model for AGB stars based on evolutionary calculations of low and intermediate mass stars. They have obtained a core mass- (N/O) relationship with the application of the mass loss law by Blöcker & Schönberner (1993). We have calibrated this relationship taking into account the results derived from the analysis of NLTE model atmospheres by Méndez et al. (1988) and Méndez, Kudritzki, & Herrero (1992). The resulting relationship can be written as

$$M_c = a + b\ \log(\mathrm{N/O}) + c\ [\log(\mathrm{N/O})]^2\ , \qquad (1)$$

where M_c is the core mass in solar masses and (N/O) stands for the relative N/O abundances by number of atoms. The coefficients are: $a = 0.689$, $b = 0.056$, and $c = 0.036$ for $-1.2 \leq \log(\mathrm{N/O}) < -0.26$ and $a = 0.825$, $b = 0.936$, and $c = 1.439$ for $\log(\mathrm{N/O}) \geq -0.26$. The main difference between this relation and the original relation by Groenewegen & de Jong lies in the range of core masses.

It is important to mention that equation (1) is a first order approximation to a complex relationship between the stellar mass and the nebular chemical composition. Several reasons can be given that will possibly affect such relation, namely *(i)* the theoretical calibration may change as better stellar evolution models are developed. In particular, new models recently presented by Marigo (2000) are now able to predict higher He/H and N/O abundances for massive central stars, which can eventually be used to constrain equation (1); *(ii)* empirical calibrations may be obtained, which could be used both to derive distances and to constrain stellar models; *(iii)* chemical evolution models predict some increase of the N/O ratio over time (see for example Matteucci, Romano, & Molaro 1999). Lower mass central stars originate from lower mass stars on the main sequence, which have in average lower N/O ratios. Therefore, these models reinforce and could possibly be used to constrain our equation (1); *(iv)* the adopted coefficients of equation (1) can be affected if a minimum mass lower than the present value of about 0.67 $M_\odot$ is adopted, as suggested by some authors (see for example Tylenda et al. 1991a); *(v)* the adopted relation can possibly be modified, in view of the recently proposed relationship between the core mass and the circumstellar extinction, obtained for planetary nebulae in the Magellanic Clouds and in M31 (Ciardullo & Jacoby 1999).

Equation (1) has been applied to a sample of relatively well studied Galactic planetary nebulae (cf. Maciel & Köppen 1994; Maciel & Chiappini 1994; Cazetta & Maciel 1994; Maciel & Cazetta 1994; Maciel & Quireza 1999) as shown in Table 1. In this table, column 1 gives the PN name, column 2 shows the logarithm of the N/O abundance ratio, and column 3 gives the core mass M_c in solar masses as obtained from equation (1). The chemical abundances have been taken from the literature, emphasizing the results by the IAG/USP group (see for example Costa et al. 1996). Detailed references can be found in Maciel & Köppen (1994), Maciel & Chiappini (1994), and Maciel & Quireza (1999).

3. DISTANCES OF PN

From the analysis of NLTE model atmospheres of CSPN, the distance to a planetary nebula can be written as

$$d^2 = 3.82 \times 10^{-9} \, \frac{M_c \, F_*}{g} \, 10^{0.4 V_0} \, , \qquad (2)$$

(Méndez et al. 1988), where d is the distance in kpc, M_c is the core mass in solar masses, F_* is the stellar monochromatic flux at λ5480 in units of erg cm^{-2} s^{-1} Å^{-1}, g is the surface gravity in cm s^{-2}, V_0 is the reddening-free visual magnitude given by $V_0 = V - 2.175\,c$, where V is the stellar apparent visual magnitude and c is the logarithmic extinction in Hβ. The adopted values of the extinction are given in Table 1, column 8. The visual magnitudes are shown in column 7, and the derived reddening-free magnitudes are given in column 9. The sources of these quantities are as follows. Visual magnitudes: Freitas Pacheco, Codina-Landaberry, & Viadana (1986), Jacoby & Kaler (1989), Kaler (1983), Kaler & Jacoby (1989), Kaler et al. (1990), Phillips (1984), Pottasch (1984, 1996, 1997), Peña, Torres-Peimbert, & Ruiz (1992), Preite-Martinez & Pottasch (1983), Reay et al. (1984), Shaw & Kaler (1985, 1989), Tylenda et al. (1989, 1991b), and Viadana & Freitas Pacheco (1985). Extinction: Cahn, Kaler, & Stanghellini (1992), Kaler (1983), Kaler et al. (1990), Peña et al. (1992), Shaw & Kaler (1985, 1989), and Tylenda et al. (1991b).

The stellar flux F_* in equation (2) has been obtained from the central star temperature T_* as follows. Zhang (1993) obtained the stellar emergent flux as a function of T_* and $\log g$ from an interpo-

TABLE 1

ADOPTED AND DERIVED DATA FOR CSPN

Name	log(N/O)	M_c	$10^{-3}T_*$	$\log g$	$10^{-9}F_*$	V	c	V_0	d
NGC 40	−0.71	0.667	31.0	3.60	0.47	11.37	0.76	9.72	1.5
NGC 650	−0.35	0.674	157.0	7.80	2.80	16.30	0.20	15.87	0.5
NGC 1535	−1.07	0.670	68.0	4.65	1.16	12.30	0.10	12.08	2.1
NGC 2022	−0.53	0.669	102.0	4.80	1.79	14.90	0.49	13.83	5.0
NGC 2371	−0.52	0.670	105.0	5.10	1.84	14.98	0.13	14.70	5.3
NGC 2392	−0.12	0.733	67.0	3.80	1.14	11.41	0.22	10.93	3.5
NGC 2438	−0.69	0.667	143.0	6.60	2.55	17.88	0.20	17.45	3.9
NGC 2440	0.10	0.933	245.0	6.70	4.43	14.24	0.42	13.33	0.8
NGC 2452	0.06	0.886	112.0	5.40	1.97	16.11	0.55	14.91	5.0
NGC 2792	−0.20	0.695	122.0	5.10	2.16	15.74	0.79	14.02	4.3
NGC 2818	−0.15	0.717	215.0	6.70	3.88	17.50	0.30	16.85	3.4
NGC 2867	−0.60	0.668	93.3	5.20	1.63	15.00	0.43	14.06	3.3
NGC 3195	−0.52	0.670	88.0	5.20	1.53	17.17	0.66	15.73	7.0
NGC 3211	−0.77	0.667	115.0	5.60	2.03	15.50	0.28	14.89	3.4
NGC 3242	−0.75	0.667	75.0	4.75	1.29	12.10	0.07	11.95	1.9
NGC 3918	−0.50	0.670	102.3	5.40	1.79	13.24	0.27	12.65	1.5
NGC 4361	−0.66	0.668	99.0	5.50	1.73	13.18	0.04	13.09	1.6
NGC 5189	−0.01	0.816	108.0	5.70	1.90	15.10	0.85	13.25	1.5
NGC 5307	−0.74	0.667	86.0	5.10	1.49	14.74	0.44	13.78	3.1
NGC 5315	−0.22	0.689	61.4	4.40	1.04	14.40	0.60	13.10	4.3
NGC 5882	−0.59	0.668	71.0	4.80	1.21	13.62	0.38	12.79	2.5
NGC 6153	−0.11	0.739	100.0	5.40	1.75	15.39	0.18	15.00	4.4
NGC 6210	−0.97	0.669	55.0	4.50	0.92	12.43	0.04	12.34	2.5
NGC 6309	−0.84	0.667	85.1	4.70	1.47	13.74	0.83	11.93	2.1
NGC 6369	−0.47	0.671	80.5	5.00	1.39	15.56	2.09	11.01	1.0

TABLE 1 (CONTINUED)

Name	log(N/O)	M_c	$10^{-3}T_*$	$\log g$	$10^{-9}F_*$	V	c	V_0	d
NGC 6439	−0.37	0.673	93.5	4.70	1.63	16.10	1.57	12.69	3.2
NGC 6445	−0.21	0.692	180.0	6.40	3.23	19.04	1.02	16.82	4.3
NGC 6563	−0.23	0.686	136.5	5.90	2.43	15.00	0.07	14.85	2.6
NGC 6565	−0.44	0.671	105.0	7.30	1.84	18.50	0.42	17.59	1.6
NGC 6567	−0.72	0.667	64.0	5.50	1.08	14.27	0.75	12.64	1.0
NGC 6572	−0.57	0.669	60.0	4.30	1.01	12.70	0.37	11.90	2.7
NGC 6578	−0.71	0.667	62.5	4.20	1.06	15.74	1.51	12.46	4.0
NGC 6620	−0.44	0.671	114.5	7.00	2.02	16.25	0.72	14.68	0.6
NGC 6629	−0.88	0.668	35.0	3.90	0.55	12.96	0.90	11.00	2.1
NGC 6644	−0.79	0.667	106.0	5.70	1.86	15.63	0.32	14.93	3.0
NGC 6720	−0.55	0.669	120.0	7.40	2.12	15.29	0.29	14.66	0.4
NGC 6741	0.04	0.865	125.0	7.70	2.21	17.60	0.96	15.51	0.5
NGC 6751	−0.18	0.703	76.0	4.60	1.31	15.45	1.08	13.10	3.9
NGC 6790	−0.62	0.668	75.9	4.60	1.30	15.50	0.83	13.69	5.0
NGC 6803	−0.27	0.677	72.0	4.50	1.23	15.20	0.79	13.48	5.0
NGC 6818	−0.64	0.668	109.6	5.60	1.93	14.90	0.31	14.23	2.5
NGC 6826	−0.93	0.668	35.0	4.00	0.55	10.05	0.03	9.98	1.2
NGC 6853	−0.23	0.686	120.0	7.30	2.12	14.75	0.18	14.36	0.4
NGC 6881	−0.36	0.674	77.0	3.80	1.32	16.70	1.77	12.85	8.6
NGC 6886	−0.35	0.674	129.0	5.80	2.29	18.00	0.76	16.35	5.7
NGC 6891	−0.97	0.669	55.0	4.00	0.92	12.44	0.30	11.79	3.5
NGC 6905	−0.58	0.669	132.0	4.70	2.34	15.50	0.93	13.48	5.4
NGC 7009	−0.63	0.668	72.0	4.90	1.23	12.54	0.11	12.30	1.8
NGC 7026	−0.45	0.671	80.0	4.40	1.38	14.20	0.66	12.76	4.2
NGC 7293	−0.12	0.733	110.0	7.60	1.94	13.58	0.04	13.49	0.2
NGC 7354	−0.08	0.759	91.0	4.60	1.58	16.20	1.77	12.35	3.2
NGC 7662	−0.66	0.668	100.0	5.40	1.75	13.20	0.15	12.87	1.6
IC 418	−0.72	0.667	38.0	3.45	0.60	10.17	0.31	9.50	1.9
IC 2003	−0.58	0.669	111.0	4.90	1.95	15.00	0.29	14.37	5.9
IC 2149	−0.24	0.683	49.0	4.10	0.81	11.59	0.25	11.05	2.1
IC 2165	−0.97	0.669	118.0	5.50	2.08	14.99	0.45	14.01	2.6
IC 2448	−0.31	0.675	81.3	4.80	1.40	14.09	0.12	13.83	4.4
IC 2501	−0.77	0.667	55.5	4.00	0.93	14.48	0.53	13.33	7.1
IC 2621	−0.42	0.672	106.0	4.30	1.86	15.39	0.87	13.50	7.7
IC 3568	−0.87	0.668	52.0	4.05	0.86	12.31	0.18	11.92	3.4
IC 4593	−1.08	0.671	50.0	3.60	0.83	11.27	0.05	11.16	3.9
IC 4634	−1.42	0.682	70.0	4.10	1.20	13.98	0.55	12.78	5.7
IC 4673	−0.43	0.672	115.0	5.50	2.03	17.58	1.20	14.97	4.0
IC 4776	−1.08	0.671	53.0	4.30	0.88	14.47	1.00	12.30	3.1
IC 4997	−0.76	0.667	56.5	4.20	0.95	12.20	1.07	9.87	1.2
A 21	−0.19	0.699	120.0	7.40	2.12	15.99	0.13	15.71	0.7
BD+303639	−0.64	0.668	35.0	3.10	0.55	10.20	0.46	9.20	2.3
Cn 3–1	−0.42	0.672	53.0	3.50	0.88	12.40	0.42	11.49	5.3
Hb 4	−0.39	0.673	89.0	5.00	1.55	17.00	1.94	12.78	2.3
Hb 5	−0.05	0.782	131.0	5.90	2.32	17.40	1.88	13.31	1.4
Hb 12	−0.74	0.667	53.5	3.10	0.89	13.60	1.43	10.49	5.3
He 2–5	−0.63	0.668	59.0	4.40	0.99	14.74	0.29	14.11	6.7
He 2–15	0.22	1.101	86.0	7.20	1.49	21.63	2.41	16.39	1.2
He 2–86	−0.35	0.674	88.0	4.70	1.53	18.40	2.11	13.81	5.1

TABLE 1 (CONTINUED)

Name	log(N/O)	M_c	$10^{-3}T_*$	$\log g$	$10^{-9}F_*$	V	c	V_0	d
He 2–99	−0.96	0.668	26.0	3.30	0.38	13.84	1.12	11.40	4.2
He 2–108	−0.37	0.673	52.0	3.30	0.86	12.63	0.55	11.43	6.4
He 2–112	−0.15	0.717	86.0	5.20	1.49	17.10	1.51	13.82	2.9
He 2–115	−0.87	0.668	37.0	3.00	0.58	16.24	2.27	11.30	7.0
He 2–117	−0.21	0.692	51.0	4.50	0.84	17.90	2.96	11.46	1.6
He 2–123	−0.11	0.739	47.0	3.90	0.77	16.84	1.65	13.25	7.4
He 2–131	−0.44	0.671	42.0	3.40	0.68	11.01	0.19	10.60	3.5
He 2–138	−0.52	0.670	26.0	2.90	0.38	10.98	0.40	10.11	3.7
He 2–140	−0.50	0.670	44.5	3.90	0.72	17.20	1.91	13.05	6.2
J 320	−1.45	0.683	60.0	4.10	1.01	14.44	0.30	13.79	8.3
M 1–25	−0.67	0.668	73.0	4.50	1.25	17.70	1.49	14.46	7.8
M 1–26	−0.49	0.670	31.0	3.30	0.47	12.83	1.65	9.24	1.7
M 1–40	−0.23	0.686	83.0	5.50	1.44	18.30	2.96	11.86	0.8
M 1–57	−0.51	0.670	76.0	5.00	1.31	16.30	1.85	12.28	1.6
M 2–9	−0.92	0.668	44.0	3.90	0.71	15.65	1.34	12.74	5.3
M 3–5	−0.21	0.692	90.0	6.00	1.57	17.90	0.97	15.79	2.9
M 3–6	−1.27	0.676	58.0	4.50	0.97	13.91	0.63	12.54	2.9
M 4–3	−0.42	0.672	63.2	4.40	1.07	17.90	1.49	14.66	8.9
Me 2–1	−0.76	0.667	107.2	5.10	1.88	16.03	0.14	15.73	8.6
Mz 3	−0.11	0.739	83.0	5.10	1.44	16.00	2.34	10.91	0.9
PB 4	−0.52	0.670	79.0	5.00	1.36	16.15	0.74	14.54	4.8
PC 14	−0.74	0.667	81.0	4.80	1.40	16.51	0.66	15.07	7.8
PW 1	0.18	1.040	90.0	7.50	1.57	15.40	0.14	15.10	0.5
SwSt 1	−0.93	0.668	35.5	3.60	0.56	11.76	0.01	11.74	4.2
Tc 1	−1.04	0.670	28.0	3.30	0.42	11.38	0.28	10.77	3.3
Vy 2–2	−0.79	0.667	59.5	3.60	1.00	14.45	1.80	10.54	3.2

lation of these parameters in the tabulated values of the model atmospheres by Clegg & Middlemass (1987) and Husfeld et al. (1984). Since his sample is larger than that of Méndez et al. (1988, 1992), we have chosen the stellar flux calibration by Zhang (1993). We have adopted Zanstra He II temperatures, as these better represent the CSPN temperatures (Kaler & Jacoby 1990; Méndez et al. 1992; Cazetta & Maciel 1994). In a few cases, Stoy temperatures and Zanstra H I temperatures have been considered. Taking into account the stellar fluxes as given by Zhang (1993), we have examined the correlations of the flux both with the stellar temperature and gravity. As a conclusion, we have obtained a linear flux-temperature relation of the form

$$F_* = 1.85 \times 10^4\ T_* - 9.97 \times 10^7\ , \qquad (3)$$

where T_* is in K and the flux in units of erg cm^{-2} s^{-1} Å^{-1}. This equation reproduces the stellar fluxes by Zhang (1993) with an average uncertainty of under 5% for temperatures lower than 2.5×10^5 K. The adopted temperatures are shown in column 4 of Table 1 in units of 10^3 K. The references for the temperature are: Freitas Pacheco et al. (1986), Gleizes, Acker, & Stenholm (1989), Golovatyi (1988), Jacoby & Kaler (1989), Kaler (1976, 1983), Kaler & Jacoby (1989), Martin (1981), Méndez et al. (1992), Peña et al. (1992), Pottasch (1984, 1996, 1997), Preite-Martinez & Pottasch (1983), Preite-Martinez et al. (1989, 1991), Sabbadin (1986), and Shaw & Kaler (1985, 1989). The derived fluxes are given in column 6 of Table 1 in units of 10^9 erg cm^{-2} s^{-1} Å^{-1}. Finally, the adopted surface gravities are shown in column 5 of Table 1, in cm s^{-2}. The sources are: Méndez et al. (1992), Pottasch (1996, 1997), Zhang (1993), and Zhang & Kwok (1993). It is clear that our distances are strongly dependent on the surface gravity, as shown by equation (2). As a consequence, the total uncertainty will also depend on this quantity. However, our method relies basically on the N/O abundances and their relation to the central

TABLE 2

DISTANCES OF SELECTED PN

PN	Method	d (Pottasch 1997)	d (this work)
NGC 3242	expansion	0.5	1.9
NGC 6210	expansion	1.6	2.5
NGC 6572	expansion	1.2	2.7
NGC 6720	parallax	0.7	0.4
NGC 6853	parallax	0.4	0.4
NGC 7009	expansion	0.6	1.8
NGC 7293	parallax	0.2	0.2
NGC 7662	expansion	0.8	1.6
A 21	parallax	0.5	0.7
BD+303639	expansion	1.5	2.3
PW 1	parallax	0.4	0.5

star mass, so that the derived distances may be different from other results using similar gravities. The effect of the surface gravity is better seen in the so-called "gravity distances", as proposed by Maciel & Cazetta (1997) and recently applied to the present sample by Cazetta & Maciel (1999). As mentioned at the end of § 4, the results of that method are very similar to those given in the present paper.

4. RESULTS AND DISCUSSION

The calculated distances, which we call *N/O distances*, are shown in the last column of Table 1 (kpc). Formal uncertainties of the derived results can be estimated considering that, according to the original sources, the uncertainties in the stellar magnitudes, extinction, surface gravity, electron temperature and abundances are $\sigma(V) \simeq 0.20$, $\sigma(c) \simeq 0.03$, $\sigma(\log g) \simeq 0.23$, $\sigma(\log T_*) \simeq 0.06$ and $\sigma(\log \mathrm{N/O}) \simeq 0.15$ (see for example Cazetta & Maciel 1994; Maciel & Köppen 1994; Maciel & Chiappini 1994; Pottasch 1997). As a consequence, the derived uncertainty in the distances is typically of 60%.

Distances to a small group of nebulae are known with a relatively high accuracy, particularly for those objects for which recent trigonometric parallaxes and VLA expansion distances are available, as these distances are independent of any assumed properties of the nebulae and/or of their central stars. Pottasch (1997) has recently discussed a group of such objects, based on parallaxes from Harris et al. (1997) and expansion distances from Terzian (1997). Table 2 shows a comparison of these distances with the results from Table 1 for the objects in common. It can be seen that the agreement is generally good for these nebulae, suggesting that the correct application of the method presented here is expected to produce distances similar to those obtained by the best individual methods. However, it should be kept in mind that the basic parameters necessary for the application of equation (2) are not always accurately known, so that some discrepancies should be allowed for. In fact, the main differences between the distances given in Table 2 are due to the adopted surface gravities shown in Table 1. As discussed by Pottasch (1997), spectroscopic gravities as adopted here are somewhat uncertain, so that a direct effect is observed on the distances. For example, if we take into account the average gravities calculated by Pottasch (1997) for these objects, our method produces essentially the same distances as the parallax and expansion methods given in column 3 of Table 2.

Another way to investigate the accuracy of the present results consists in the comparison of the distances given in Table 1 with some individual distances in the literature. Figure 1*a* shows our N/O distances as a function of the spectroscopic distances by Méndez et al. (1988; 1992), and Figure 1*b* compares our distances with the calibration distances by Cahn et al. (1992). Both sets are generally considered as accurate, and the distances given by Cahn et al. (1992) shown in Fig. 1*b* have in fact been used as calibrators for their distance scale. It can be seen that our distances are in very good agreement with the spectroscopic distances; the agreement is also good with the Cahn et al. (1992) calibration distances, although the scattering is somewhat larger. We have obtained an average slope $d(\mathrm{N/O}) \simeq 1.10\, d(\text{Méndez})$, with an uncertainty $\sigma \simeq 0.05$ and a correlation coefficient $r \simeq 0.99$ (Fig. 1*a*, dashed line). For the Cahn et al. (1992) calibration distances, the slope is 1.04, $\sigma \simeq 0.09$, and $r \simeq 0.91$ (Fig. 1*b*, dashed line).

Since our distances can be considered as statisti-

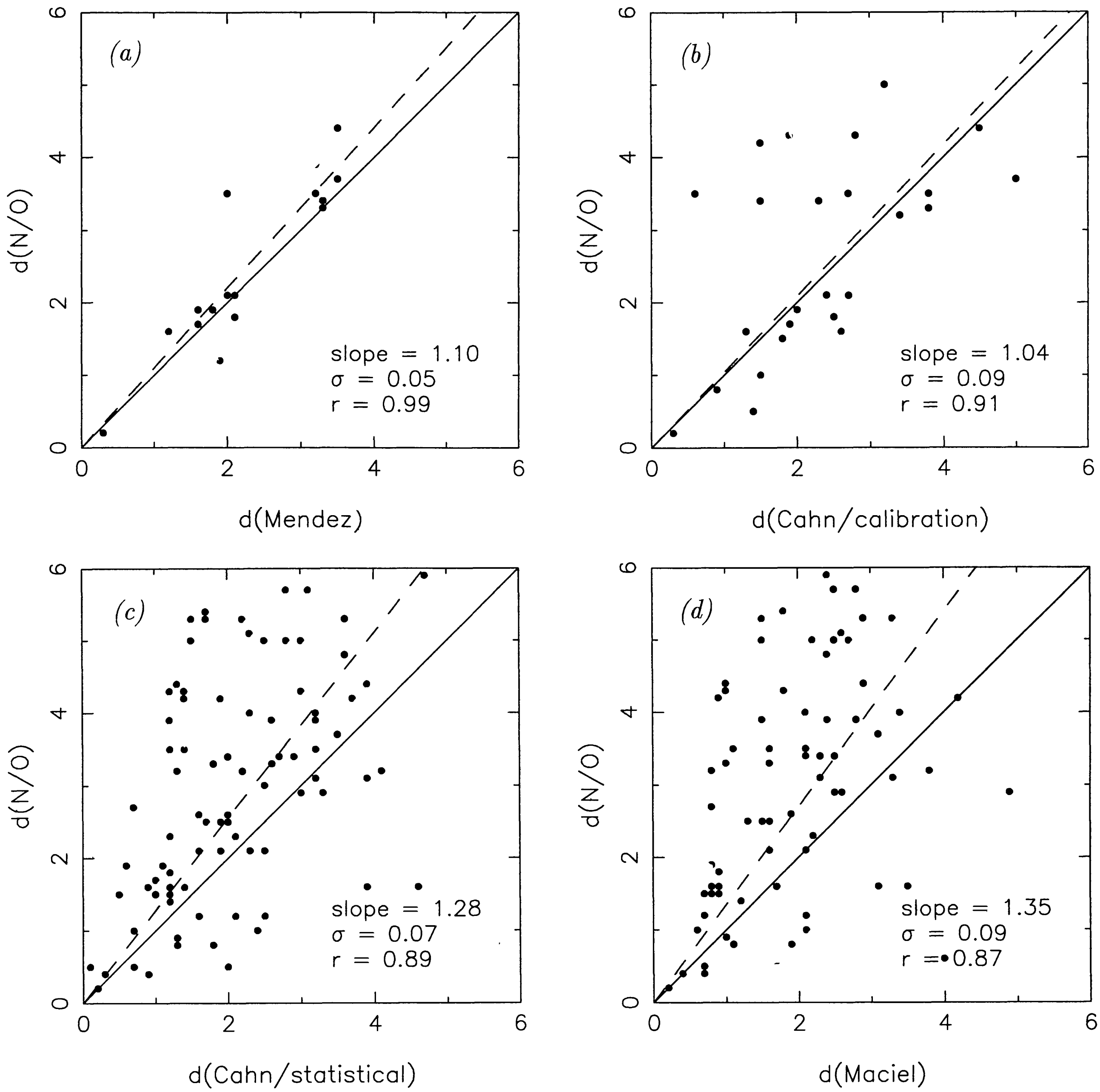

Fig. 1. Comparison of the N/O distances with *(a)* spectroscopic distances by Méndez et al. (1988; 1992); *(b)* calibration distances by Cahn et al. (1992); *(c)* statistical distances by Cahn et al. (1992), and *(d)* statistical distances by Maciel (1984).

cal, it is also interesting to compare them with some recent statistical scales in the literature. The first is the scale by Cahn et al. (1992), who obtained a list of recalibrated absolute Hβ fluxes, and determined Shklovsky distances according to the scheme used by Daub (1982), which was essentially based on a method proposed earlier by Maciel & Pottasch (1980). A direct comparison of our distances with the results by Cahn et al. (1992) is shown in Figure 1*c*. The scatter is relatively large, as expected from the comparison of two statistical distance scales. The derived slope is 1.28 ($\sigma \simeq 0.07$, $r \simeq 0.89$, dashed line in Fig. 1*c*), so that our scale is in average longer than that of Cahn et al. (1992) by about 30%. In all plots of Figure 1, we have taken into account objects closer than 6 kpc, for which the average uncertainties of the scales are lower and a comparison is meaningful.

Similar results, as shown in Figure 1, can be derived from a comparison with other distances in the literature. For example, Zhang (1993) derived distances to 145 PN using a method based on stellar parameters obtained from the modelling of distance-independent parameters. A comparison of his distances with our results gives a slope of 1.07 ($\sigma \simeq 0.06$, $r \simeq 0.92$), so that there is also some tendency for the Zhang (1993) distances to be lower than our results. More recently, Zhang (1995) used the earlier sample by Zhang (1993) to investigate the mass-radius and temperature-radius relationships in order to calculate distances of 647 PN from the list of Cahn et al. (1992). A comparison of these distances with our results gives a slope of 1.14 ($\sigma \simeq 0.06$, $r \simeq 0.90$), confirming the previous results.

A longer distance scale has been proposed by Kingsburgh & Barlow (1992) and Kingsburgh & English (1992), who derived distances to optically thick nebulae assuming the Hβ flux as constant, and for optically thin objects using a mass calibration for Magellanic Cloud nebulae, based on [O II] electron densities and radio fluxes. A comparison of our distances with their results gives a slope of 0.79 ($\sigma \simeq 0.06$, $r \simeq 0.91$).

Finally, Figure 1*d* shows a comparison of the N/O distances with the modified Shklovsky distances by Maciel (1984), which were derived on the basis of the mass-radius relationship of Maciel & Pottasch (1980). The slope is 1.35 ($\sigma \simeq 0.09$, $r \simeq 0.87$), so that the new distances show a systematic increase of about 35% relative to the distances by Maciel (1984), as indicated by the dashed line in figure 1d. This is an interesting result, as some investigators have suggested that the scale by Maciel (1984) should be increased somewhat in order to be comparable with the "long" distance scale as proposed for example by Cudworth (1974) (cf. Peimbert 1990a,b; Mallik & Peimbert 1988). Since the distances by Maciel (1984) are approximately 20% larger than the well-known Seaton-Webster scale, the new results would correspond to distances larger by about 60% relative to the Seaton-Webster scale. As discussed by Peimbert (1990a,b), "long" distance scales are to be favoured on the basis of the PN and white dwarf birth rates in the Galaxy, and the comparisons discussed above confirm that the N/O distances clearly belong to this class.

A long scale has also been recently obtained by Cazetta & Maciel (1999) as an application of the so-called gravity distance method of Maciel & Cazetta (1997) to a sample of Galactic PN. For objects closer than about 6 kpc, these scales are remarkably consistent, so that it is interesting to assemble some conclusions applied to them. Taken together, these scales suggest an increase of 20–30% relative to the Cahn et al. (1992) scale, and of 10–20% for the Zhang (1993, 1995) distances. Also, the Kingsburgh & Barlow (1992) and Kingsburgh & English (1992) distances are to be decreased by 10–20%, and finally both scales are consistent with an increase in the distances by Maciel (1984) of about 35–50%.

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