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LETTER

Letter to the Editor

A comparison of Hipparcos parallaxes with planetary nebulae spectroscopic distances

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Abstract. The Hipparcos satellite has measured the parallax of a small sample of planetary nebulae. In this paper we consider the results for 3 planetary nebulae (PN) for which spectroscopic distances have also been determined from stellar gravities. These gravities in turn have been derived from profile fitting of selected hydrogen and helium lines (Mendez et al., 1988 a, b, 1992). A comparison of these distances shows that the Hipparcos distances are all considerably smaller. This same effect has been found in two other PN central stars, whose distance has been determined from the VLA measured nebular expansion. The question of the mass of the central star of PHL 932 is also discussed.

Key words: planetary nebulae, planetary nebulae individual, PHL 932, A 36, NGC 1360, HR diagram, stars: distances

1. Introduction

Distances to planetary nebulae are very difficult to obtain by trigonometric methods because the PN are far away. This has led to the development of a host of methods to 'obtain' individual distances. Some of these methods make use of a property of the nebula, which is given a fixed value. An example of this is the "Shklovsky method", which assigns a fixed value to the ionized nebular mass. Such methods, apart from probably being unreliable, preclude the possibility of discussing the evolution of the PN. Other methods which do not make use of nebular parameters are also in use. The most promising of these is the "extinction distance" and the "spectroscopic distance". This last method is at present applicable to all central stars which show an absorption line spectrum, and has been applied extensively in the past 15 years. For example, a summary of the distances obtained in this way for 42 central stars (with references) is shown in Pottasch (1996, Table 6). A comparison of some of these distances with the most recent parallax measurements (Harris, 1997) has been given by Pottasch (1997) and reasonable agreement is obtained. However, a comparison of the distances obtained by Hajian et al, (1995; see also Terzian, 1997) from the (VLA) measured nebular expansion, with spectroscopic distances, shows a poor agreement: the expansion distances are smaller by a factor of 3 than the spectroscopic values. While the number of cases involved is small, the comparison with the trigonometric parallaxes (7 objects) is always made with higher gravity stars (white dwarfs). The expansion distances (2 objects) are compared with distances obtained from analysis of "lower gravity" stars with NLTE models (Mendez et al., 1988). Hipparcos is able to shed some light on this problem: parallaxes have been measured for 3 PN central stars with spectroscopic distances, and for which low surface gravities have been found. In this paper the Hipparcos measurements are presented and a comparison is made with the spectroscopic distances. The significance of the comparison is discussed.

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2. The Hipparcos measurements

These measurements taken from the Hipparcos Catalogue (ESA, 1997), are given in Table 1. Columns 1 – 5 give the Hipparcos catalogue number, the name, the coordinates (positional identifier) and the Hipparcos magnitude. Columns 6 and 7 give the parallax and its standard error in milli-arcseconds. Columns 8 and 9 give the proper motions in RA and Dec together with the standard error in milli-arcseconds per year. The errors on all data are typical for faint stars. The ground based magnitudes are given in the last column. A discussion of the relationship between these magnitudes and the Hipparcos magnitude is given in Acker et al. (1998).

Table 1. Hipparcos measurements

No.	Name	RA(2000)	Dec(2000)	H_P	Π	error	μ_α	μ_δ	V
4666	PHL 932	00 59 56.54	+15 44 13.7	12.032	9.12	±2.79	36.13 ±2.99	7.09 ±2.00	12.14
16566	NGC 1360	03 33 14.65	−25 52 18.2	11.178	2.86	±2.12	1.32 ±1.41	26.15 ±1.76	11.35
66732	A 36	13 40 41.33	−19 52 55.4	11.465	4.12	±2.47	17.78 ±3.30	5.47 ±2.18	11.35
					mas	mas	mas/yr		

Table 2. Values of Eddington flux at λ 5480 Å

T_{eff} (K)	F (10^8 erg cm^{-2} s^{-1} Å^{-1})
120,000	21.0
100,000	17.5
90,000	15.5
75,000	13.0
60,000	10.0
50,000	8.0
40,000	6.2

Table 3. Comparison of Hipparcos and spectral data

	HIPPARCOS			LITERATURE
Nebula	Dist.	T_{eff}(K)	log g	
PHL 932	110pc	40,000	6.80	5.5(2)
NGC 1360	350	110,000	6.09	5.4(1); 6.0(3); 6.0-6.5(4)
A36	240	93,000	6.42	5.3(5)

(1) Mendez et al., 1992; (2) Mendez et al., 1988a;
(3) Hoare et al., 1996;
(4) Hoare et al., 1995; (5) Herrero et al., 1990.

3. Comparison with spectroscopic parallax

The analysis of the stellar spectra gives values for the effective temperature ($T_{\rm eff}$) and the surface gravity g. To derive a distance from these quantities a model of the atmosphere is necessary, as well as the stellar mass and the magnitude corrected for reddening. Since all three stars have been studied by Mendez et al. (given in Table 3), the model atmospheres calculated by these authors will be used. This leads to the following relation between surface gravity and distance (Mendez et al., 1988b):

$$d^2 = 0.382 \frac{M}{M_\odot} F g^{-1} 10^{0.4 V_0} \qquad (1)$$

where M is the stellar mass, g the surface gravity (cm s^{-2}), V_0 the visual magnitude of the star corrected for extinction, and d is the distance in Kpc. The extinction correction is small, and is based on the measured $B-V$, assuming $(B-V)_0 = -0.38$ (see Pottasch, 1996). F is the stellar flux of a model atmosphere in the visual in units of 10^8 erg cm^{-2} s^{-1} Å^{-1}. To a first approximation F depends only on the effective temperature, and its value is given in Table 2. We have chosen to make the comparison by first converting the Hipparcos distance into a surface gravity. The results are given in Table 3, where the second column gives the Hipparcos distance, the third column the effective temperature of the star. The fourth column gives the gravity determined from Eq. (1), assuming M = 0.6 $M_\odot$. The values of T_{eff} given are taken from the spectroscopic determinations. The values could have an error of 30%, which is the difference between what Hoare et al. (1995) and Mendez et al. (1992) give for the central star of NGC 1360. Incidentally, Hoare et al. (1995) notice the difference, and explain it by noting that the model profiles for the Hγ line from the $T_{\rm eff}$ = 80 000K and $T_{\rm eff}$ = 110 000K models are almost identical, and state that it was pure chance that Mendez et al. picked the lower temperature. Hoare et al. were able to distinguish between the two values by fitting more than 6 Balmer line profiles. In the case of the other two central stars only a single value of temperature is available. Since in the analysis the temperature and the gravity are coupled, if one is wrong, so is the other. If the gravity should be increased, the temperature should be increased as well.

The values of surface gravity reported in the literature are given in the last column of Table 3. Those from Mendez et al. (1988a and 1992) and Herrero et al. (1990) are found by fitting the observed Hγ line profile to an NLTE model. The range of values given by Hoare et al. (1995) are from comparing ROSAT X–ray measurements with NLTE models, none of which was completely satisfactory. The value given by Hoare et al. (1996) is from a comparison of EUV (70 to 760 Å) measurements with NLTE models. The conclusions which can be drawn from Table 3 are subtle. Each of the PN will be discussed separately. Consider first NGC 1360. Here the parallax error is large and the gravity has sufficient error to encompass any of the literature values listed in Table 3 for this object. However, we feel that the evidence points to a more likely value of log g between 6.0 and 6.3; the value of log g = 5.4 is seen to be 0.5 too low.

The parallax of A 36 is better determined although the error is still large: the distance being between 150 pc and 600 pc. Even at the largest distance the derived gravity (log g = 5.6) is still somewhat high compared to the value of 5.3 ± 0.2 given by Herrero et al. (1990). The parallax of PHL 932 has a much smaller error and the distance is between 84 and 160 pc, which leads to a log g of between 6.5 and 7.0 assuming a mass M = 0.6$M_\odot$. This is much higher than the value of 5.5 ± 0.2 given by Mendez et al. (1988a). These authors have suggested that the mass is much lower. Using the Hipparcos distance, the gravity derived from Eq. (1) can be reduced to log g = 5.5 by lowering the mass by a factor 20. This would reduce the stellar mass to M = 0.03 $M_\odot$. Such low mass is unlikely, since such a star would evolve very slowly and would still be on the main sequence. In that case it should not be so hot. Mendez et al. (1988a) sug-

Table 4. Comparison of expansion and spectral data

Nebula	log g (exp.)	log g (spectro.)
NGC 3242	5.99 (+0.28, −0.42)	4.75 (± 0.2)
NGC 6210	4.92 (+0.20, −0.25)	3.9 (± 0.2)

gest that it is unlikely that the mass of the star could be less than $0.2M_\odot$. With this mass, a value of log $g = 6.3$ would be derived from the Hipparcos distance, still considerably higher than found from the spectroscopic analysis of Mendez et al.

4. Discussion

Taken together, the 3 observations discussed above suggest that the gravities determined from the spectroscopic analysis of the Hγ profile may be too low by at least 0.5 in the log. There are two other central stars where this also appears to be true. The central stars of NGC 3242 and NGC 6210 have been determined by the reasonably reliable method of measuring the expansion at two (or more) epochs (Hajian et al., 1995). The surface gravities determined from these distances (Pottasch, 1997) are shown in the second column of Table 4 and are compared to the spectroscopic gravities in the third column. Again the differences are large, at least 0.5 in the log.

The conclusion that the analysis of the Hγ profiles always gives too low a value of gravity for PN central stars is too extreme. The central star of the PN in M 15 has a spectroscopically determined gravity which leads to a distance which is in good agreement with the distance to the cluster. However the 5 cases presented here are evidence that sometimes the spectroscopic gravity is too low.

5. Further discussion

5.1. Nebular mass

The nebular mass can be calculated in the usual way, assuming it to be a homogeneous sphere. The result is only approximate, not only because of this assumption, but also because it is difficult to accurately measure the nebular flux for low surface brightness objects. The results are given in column 6 of Table 5. The nebular masses span a large range. The mass of NGC 1360, 0.3 $M_\odot$, is about the average mass expected for PN, while that for A36 is about a factor of 5 lower. The mass of PHL 932, although uncertain, is about 2 orders of magnitude lower than the average PN. It is not an extreme value, however. Several other PN have similar values (see Table 9 of Pottasch, 1996). The lowest nebular mass is that of HW 5 with a mass of 5×10^{-4} $M_\odot$.

The two other PN with spectroscopic surface gravities and distances from VLA expansion as discussed above, have also been listed in Table 5 for comparison. Their masses are less than the average PN value, but in these two cases, a considerable amount of neutral material could exist outside the ionized nebula. This is not likely for PHL 932, A36 or NGC 1360, since

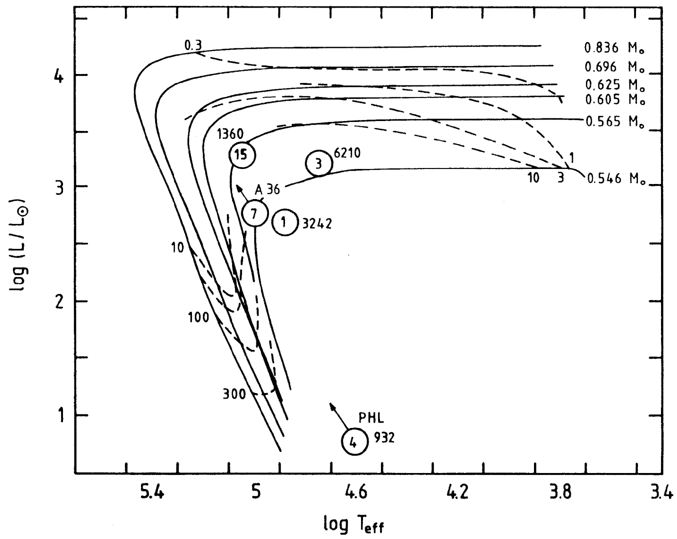

Fig. 1. An HR diagram showing the results of theoretical evolution of stars of different masses (from Blocker, 1995). The dotted curves indicate constant theoretical times in 10^3 years. The position of the 5 central stars discussed in the text are shown. The kinetic age of the nebula (in 10^3 years) is given in the centre of the circle for each nebula. The arrows indicate the effect of an increase in temperature of the central star.

the low Zanstra temperatures computed indicate that ionizing radiation is escaping from the nebula.

5.2. Position in the HR diagram

Since the distance is known, the luminosity can be calculated rather simply. The stellar radius can be calculated from Eq. (1), since

$$\frac{M}{M_\odot} g^{-1} = R^2 G^{-1} / M_\odot \qquad (2)$$

Note that the core mass no longer enters. The stellar temperature used is that given in Table 3. Since in PHL 932 and A36 this temperature has only been determined from the spectroscopic Hγ analysis in which a substantially too low log g was found, the actual effective temperature could be higher, perhaps by as much as 30–40%.

The resultant positions in the HR diagram are shown in Fig. 1. The theoretical curves are those calculated by Schönberner and colleagues, and are taken from Blocker (1995). Also shown in the figure are lines of constant age, which are marked in units of 10^3 years. In addition to the central stars of the 3 nebulae under discussion in this paper, the 2 central stars mentioned earlier, of the PN NGC 3242 and NGC 6210 are also plotted using the distances of Hajian et al., 1995 (the other parameters are those listed in Pottasch, 1997). Further, the effect of increasing the effective temperature by 30% for A36 and PHL 932 is shown. The kinetic age (in units of 10^3 years) is shown for each nebula. As can be seen from Fig. 1, the points for all of the central stars fall close to the tracks corresponding to the lowest core mass. However, there is a tendency for the kinetic

Table 5. Nebular mass and age

Nebula	Radius $\times 10^{17}$cm	Expans. Vel. Km s^{-1}	Age 10^3 year	Hβ Flux erg cm^{-2} s^{-1}	Neb. Mass $M_\odot$	Luminosity log $L/L_\odot$	Theor. Age 10^3 year
PHL 932	2.3	(20)	3.9	2.3×10^{-12}	1.3×10^{-3}	0.8	> 300
NGC 1360	12.5	28	15.0	63.0×10^{-12}	3.2×10^{-1}	3.3	15
A 36	6.7	36	6.5	40.0×10^{-12}	5.7×10^{-2}	2.8	100
NGC 6210	1.9	36	2.5	109.0×10^{-12}	9.3×10^{-2}	3.2	50
NGC 3242	0.78	26	1.0	235.0×10^{-12}	1.0×10^{-2}	2.7	> 100

age to be substantially lower than the theoretical age. This is most obvious for PHL 932 and NGC 3242. Only for the case of the central star of NGC 1360 is there reasonable agreement between the two ages.

6. Conclusions

In this paper the consequences of the Hipparcos parallax measurements have been explored. It is suggested that the surface gravities derived from the measured distances for 3 objects are at least a factor of 3 higher than found from the Balmer line profile fitting method (Mendez et al., 1988b). Two other objects whose distances are known from the VLA expansion method (Hajian et al., 1995) show the same effect: the surface gravity derived from the distances is an order of magnitude higher than found from the line profile fitting. It is possible that the difficulty is related to the uncertain theoretical basis for the Balmer line fitting method. Napiwotzki and Rauch (1994) have shown that in about half of the cases where the method has been applied to different Balmer lines in the same object, different values of T_{eff} and log g are obtained for each line. Presumably this occurs because the temperature variation in the atmosphere is not determined well enough in the models, but it is not clear why this is so.

The 5 difficult cases discussed in this paper should be further investigated. They should not be generalized since for the PN in M 15 the distance obtained from the profile fitting method is in good agreement with the cluster distance.

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