WHITE DWARFS OBSERVED BY HIPPARCOS

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ABSTRACT

The Hipparcos satellite has measured trigonometric parallaxes for 20 white dwarfs. With the exception of one each of the spectral types DZ, DC, DB, DQ, the majority are of spectral type DA. We compare the parallaxes with the most recent ground-based determinations. From a spectroscopic analysis of new optical observations we have determined atmospheric parameters $T_{\rm eff}$ and $\log g$. From the angular diameters and the parallaxes radii are obtained, and masses are calculated via the spectroscopic $\log g$. These data are used to test the theoretical mass-radius relation.

Key words: distances, fundamental parameters, white dwarfs.

1. INTRODUCTION

Measuring the fundamental parameters of stars – mass, radius, luminosity – with very few exceptions needs a knowledge of the distance. The most direct method to obtain the distance is the geometric method, the trigonometric parallax. Trigonometric distances measured by ground-based telescopes were, at least until a few years ago, limited to distances of about 50 to 100 pc. The realization of the fundamental importance of distances beyond this limit lead to the successful project of the Hipparcos satellite, bringing into the reach of direct distance measurements for the first time many classes of stars.

In a project proposed by one of us (GV) Hipparcos has measured parallaxes of 20 white dwarfs. Most of these are of spectral type DA, but the list also includes one each of the types DZ, DC, DB, and DQ. Accurate distances are very important for studies of the spatial distribution, luminosity function, and mass distribution. In the case of white dwarfs, one additional aspect is the famous mass-radius relation. Although widely accepted as a theoretical relation, the empirical evidence for this relation is not at all convincing (Schmidt 1996). We will study whether the new data improve this situation. Although the white dwarfs are close to the faint magnitude limit of Hipparcos the new data were nevertheless expected to improve this comparison between theory and observation.

2. HIPPARCOS PARALLAXES AND COMPARISON WITH GROUND-BASED MEASUREMENTS

Before the start of Hipparcos errors of ground-based parallaxes were 10 milliarcseconds (mas) or larger. However, during the last 10 years the use of CCD detectors and dedicated telescopes (especially at the U.S. Naval Observatory) has made the ground-based observations much more competitive. In Table 1 we compare the parallaxes obtained by the Hipparcos mission with values obtained by ground-based observations, including the 1 σ errors of the measurements.

For the ground-based values we have in general used the 'General Catalogue of Trigonometric Parallaxes' by van Altena et al. (1995), which is a compilation giving weighted mean values from several observations. Only in those cases where no value was available in that catalogue we have gone back to other sources, mostly the 'Third Catalogue of Nearby Stars' by Gliese & Jahreiss (1991).

The actual errors for the white dwarf subset have an average value around 3.6 mas, which is still smaller than the average error of the ground-based values (5.1 mas), though not by a large margin. In fact, in several cases the modern observations are more accurate than the Hipparcos values, if we take the given errors at face value. In about two thirds of the cases both results are compatible within the mutual errors, which is what one would expect for 1 σ errors.

However, for some objects significant discrepancies exist between different recent ground-based data, or between ground-based and Hipparcos results. In the case of Feige 22 (WD 0227+050) van Altena et al. (1995) report a value of $\pi = 19.3 \pm 13.4$ mas using one observation, while Gliese & Jahreiss (1991) give a value of $\pi = 45 \pm 5$ mas. Since the latter value

Table 1. Parallax values and 1 σ errors (all values in milliarcseconds) measured by Hipparcos and by ground-based observations and V magnitudes. Note: $\star$ The parallax solution for WD 2117+539 was rejected during the Hipparcos reduction process because of errors larger then 100 mas.

WD - number	name	HIP	spectral type	Hipparcos parallaxes [mas]	ground-based parallaxes [mas]	V
0046 + 051	vMa 2	3829	DZ	226.95±5.35	232.5±1.9	12.371±0.018
0148 + 467	GD 279	8709	DA	63.08±3.79	61.0±7.0	12.440±0.030
0227 + 050	Feige 22	11650	DA	41.15±4.96	45.0±5.0	12.799±0.0014
0232 + 035	Feige 24	12031	DA	13.44±3.62	13.1±2.5	12.411±0.003
0310 − 688	LB 3303	14754	DA	98.50±1.46	84.9±15.0	11.387±0.019
0426 + 588	Stein 2051B	21088	DC	181.36±3.67	180.6±0.8	12.440±0.030
0501 + 527	G 191-B2B	23692	DA	14.53±3.09	23.3±2.2	11.781±0.0055
0644 + 375	He 3	32560	DA	64.91±3.37	66.2±2.1	12.057±0.006
0713 + 584	GD 294	35307	sdB?	-1.80±2.97		11.980±0.030
1134 + 300	GD 140	56662	DA	65.28±3.61	70.4±10.9	12.487±0.019
1142 − 645	L 145-141	57367	DQ	216.40±2.11	218.3±6.7	11.503±0.017
1314 + 293	HZ 43	64766	DA	31.26±8.33	15.5±3.4	12.914±0.030
1327 − 083	Wolf 485	65877	DA	55.50±3.77	61.8±2.8	12.313±0.005
1337 + 705	G 238-44	66578	DA	40.33±2.89	30.5±5.9	12.792±0.004
1544 − 377	L 481-60	77358	DA	65.60±0.77	73.5±9.4	12.800±0.030
1620 − 391	CD -38 10980	80300	DA	78.04±2.40	65.5±7.6	11.010±0.011
1647 + 591	G226-29	82257	DA	91.13±2.33	81.9±4.6	12.240 ±0.031
1917 − 077	LDS 678A	95071	DB	89.08±7.16	99.2±2.5	12.280±0.030
2032 + 248	Wolf 1346	101516	DA	67.65±2.32	69.4±2.3	11.528±0.001
2039 − 202	L 711-10	102207	DA	47.39±4.04	42.4±8.4	12.330 ±0.020
2117 + 539	G 231-40	105230	DA	$\star$	50.7±7.4	12.330±0.011
2149 + 021	G 93-48	107968	DA	39.84±4.47	40.8±2.5	12.738 ±0.008

agrees with the Hipparcos measurement we adopt it for our comparison in the table.

A further special case is GD 294 (WD 0713+584), where the Hipparcos parallax is very uncertain and can only be used as an upper limit. In view of the bright visual magnitude of this object and the upper limit for the parallax it is very unlikely that this object can be a white dwarf. The Strömgren colors (Lacombe & Fontaine 1981) are also inconsistent with white dwarf colors. Greenstein & Liebert (1990) give the spectral type as 'sdB?', because the hydrogen lines are rather narrow.

For HZ 43 (WD 1314+293) the Hipparcos parallax differs from the latest ground-based observation by Dahn et al. (1982) by a factor of two, clearly outside their mutual error ranges. Mass and radius determinations from both measurements do not fit the mass-radius relation; the deviations are in opposite directions. We can only speculate that the difficulties are caused by the presence of a very close M dwarf companion in this binary star, a possibility confirmed by the Hipparcos team.

Another famous and often used white dwarf is G 191-B2B, which also shows a disagreement between ground-based and Hipparcos parallax. The ground-based value actually was obtained for the common proper motion companion, which could indicate that this is not a physical pair. However, the Hipparcos value does not fit the mass-radius relation better than the old value, leaving open the possibility of a parallax error slightly larger than the quoted 1 σ uncertainty.

3. EMPIRICAL MASS-RADIUS RELATION FOR WHITE DWARFS

Atmospheric parameters, effective temperature, and surface gravities were derived from high S/N spectra, mostly taken for this purpose by our groups. (Detailed analysis of individual objects will be reported in a forthcoming paper by Vauclair et al. 1997.) From visual magnitudes and stellar energy fluxes we obtain the solid angle, and from this the radius, using the parallax. The surface gravity then leads to the mass, and these values are used for the comparison with the theoretical mass-radius relations.

In Figure 1 we compare the pre-Hipparcos situation with the new results; Figure 2 shows the change for individual objects. If we exclude the two most discrepant objects, the general agreement between empirical and theoretical mass-radius relation has become much better.

In most cases the deviation of an object from the theoretical relation has become smaller with the new parallax measurements. Especially WD 0227+050, WD 0310-688, WD 1134+300, WD 1544-377, WD 1620-391, WD 2039-202 are nice examples where the empirical situation has improved and the objects are shifted towards the theoretical relation. Other objects (like WD 0148+467, WD 0644+375, WD 2032+248) have not changed much their position, while in a few cases (e.g. WD 1327-083 and WD 2149+021) the objects have even moved further away from the theoretical relation.

The most obvious disagreements are for the well known white dwarfs HZ 43 and G 191-B2B. With the ground-based parallax for the companion (van Altena et al. 1995), G 191-B2B falls between the relation of Hamada & Salpeter (1961) and Wood (1994),

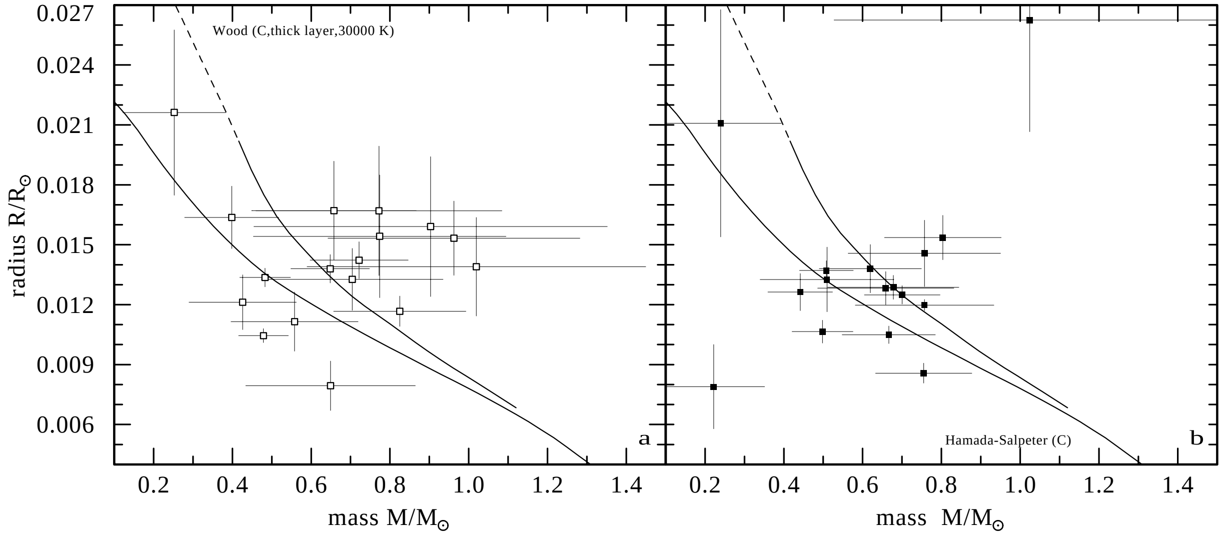

Figure 1. Empirical masses and radii for the DA white dwarfs determined with **a** *ground-based and* **b** *Hipparcos parallaxes in comparison to the zero temperature relation of Hamada & Salpeter (1961) and the evolutionary models of Wood (1994) for a carbon white dwarf with $T_{\rm eff} = 30\,000$ K with a thick hydrogen layer.*

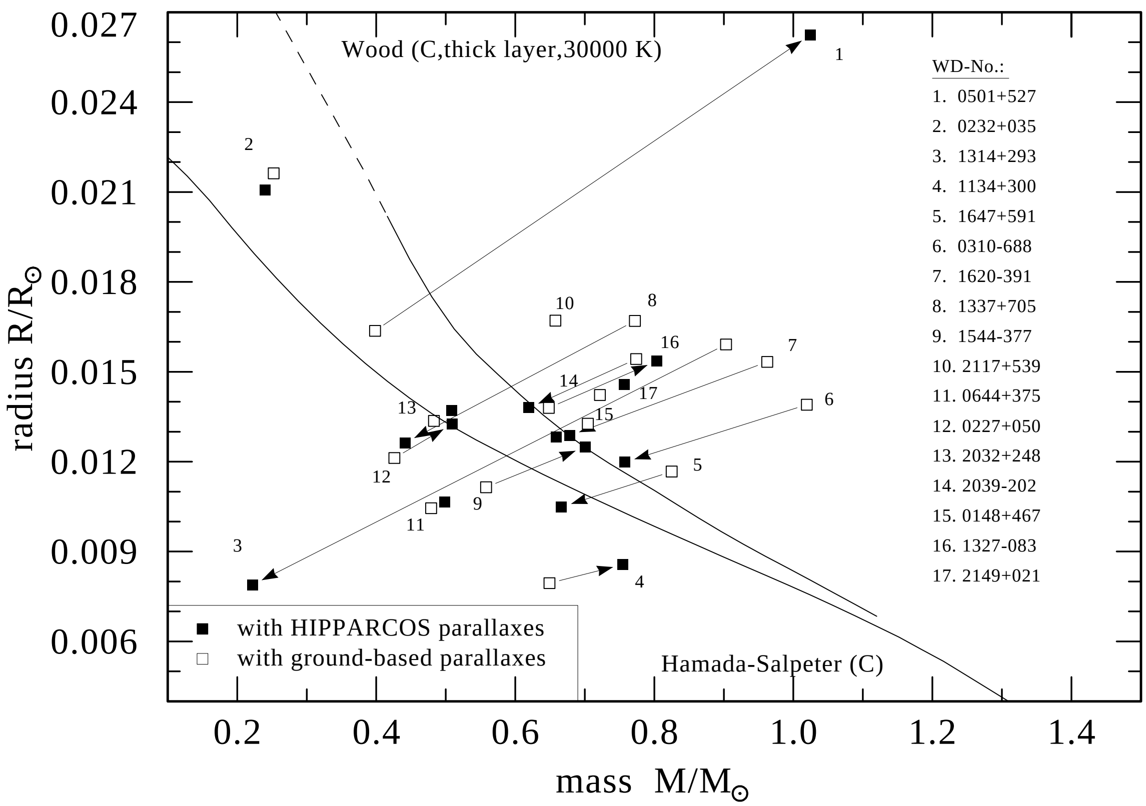

Figure 2. Comparison of masses and radii obtained with ground-based and Hipparcos parallaxes. The arrows show the change from the position with the ground-based parallax to the position calculated with the Hipparcos parallax for all 17 DA.

despite its rather high $T_{\rm eff}$ of 62 000 K. With the Hipparcos parallax its position is far away from the theoretical relations, although due to the relatively high uncertainty of the parallax measurement, it is still compatible with the theoretical relation. HZ 43 (WD 1314+293) has moved from above the relation to very small masses and radii with the new parallax. We assume that in this case the Hipparcos parallax measurement is affected by the close companion.

The position in the mass-radius diagram of Feige 22 (WD 0227+050) indicates that the parallax value given by van Altena et al. (1995) seems to be wrong.

The situation for Feige 24 (WD 0232+035) has not changed much with the new parallax value. With the used atmospheric parameters from Finley et al. (1997) the deduced mass is inconsistent with the minimum mass of $M = 0.438\,M_{\odot}$ derived from orbital parameters of this close binary system (Vennes & Thorstensen 1994). If we adopt the values from Kidder (1991) or Marsh et al. (1997), both having a significantly higher $\log g$, we get a mass of $0.478\,M_{\odot}$ or $0.551\,M_{\odot}$. With the atmospheric parameters of Marsh et al. (1997) Feige 24 lies almost on the Wood relation for carbon white dwarfs with thick hydrogen layers at $T_{\rm eff} = 63\,000$ K (not shown in the figure). However, in this case the mass would be incompatible with the range found by Vennes & Thorstensen (1994). This indicates that the true parallax is very likely close to the upper limit of the error range and a consistent solution could be found for an intermediate mass and gravity.

4. CONCLUSIONS

Hipparcos measurements have improved the parallaxes for 20 white dwarfs compared to the available data ten years ago. Although in the meantime ground-based parallax measurements using CCD detectors and dedicated telescopes have also made great progress, sometimes reaching or even exceeding the accuracy of the Hipparcos data, there is still substantial progress in the agreement between empirical and theoretical relations. Together with the improvements in spectroscopic observations and analysis we are confident of knowing the fundamental parameters mass, radius, and luminosity for typical bright white dwarfs with good precision.

The general location of white dwarfs in the mass-radius diagram agrees with theoretical predictions, but the shape of the relation can still not be confirmed empirically, mostly because the observed white dwarfs are concentrated in a small interval around 0.6 $M_{\odot}$. A distinction between zero-T and evolutionary models, or 'thin' and 'thick' hydrogen envelopes is not yet possible with the data.

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