GAIA AND THE FUNDAMENTAL STELLAR PARAMETERS FROM DOUBLE-LINED ECLIPSING BINARIES

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ABSTRACT

The programme on eclipsing binaries we are carrying out in Asiago, is aimed at obtaining the orbits and physical parameters of double-lined A-K eclipsing binaries combining photometry from the Hipparcos-Tycho mission with 8500−8750 Å ground-based spectroscopy (obtained with the Asiago 1.82 m + Echelle + CCD), simulating the photometric+spectroscopic observations that should be provided by Gaia.

Our study proves that Gaia is perfectly suited for an accurate study of the eclipsing binaries of solar type down to the limit of accurate epoch spectroscopy, obtaining a formal accuracy of ∼1–2% on fundamental parameters such as masses, radii and temperature ratio between the components.

Our results can be considered as a lower limit to the Gaia performances because Gaia photometry will be far superior to the Tycho emulation adopted in our study, having more bands of higher diagnostic potential, better measurement accuracy and a larger number of epoch data.

Key words: Surveys: Gaia; Stars: fundamental parameters; Binaries: eclipsing; Binaries: spectroscopic.

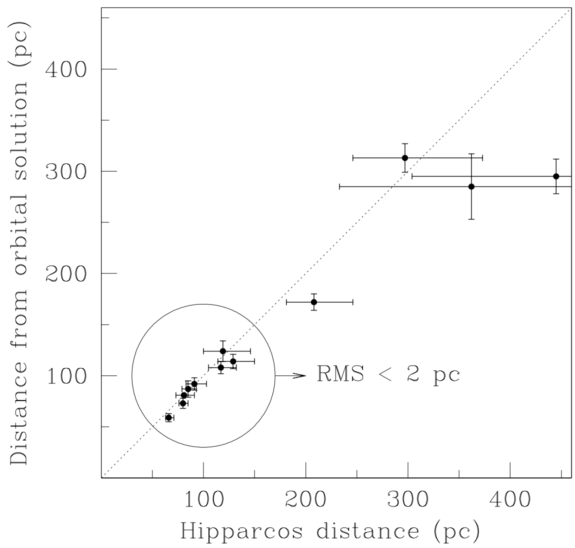

Figure 1. Comparison between the distance obtained from the orbital solution and the Hipparcos parallax for the 12 stars in our sample.

1. INTRODUCTION

Gaia will observe a huge number of double-lined eclipsing binaries. The number of stars brighter than V = 15 (thus bright enough for Gaia to obtain epoch spectroscopy in addition to multi-band photometry) is 5×10^7 with an average spectral type of G7. Scaling the Hipparcos results ($\sim$ 0.8% of the stars observed by Hipparcos are EBs, Oblak & Kurpinska-Winiarska 2000), $\sim 4 \times 10^5$ of them would be eclipsing binaries. It may be estimated that about 25% of them will be double-lined in Gaia spectral observations (cf. Carquillat et al. 1982).

The required accuracy to constrain stellar models and to test evolutionary tracks is 1–2% on masses and radii, when effective temperatures and metallicities are well determined (primarily by spectroscopy and multi-band photometry). Even if for only 1% of the double-lined EBs observed by Gaia it should be possible to derive orbits and stellar parameters at 1% precision, this would still be 25 times more than have so far been collected from devoted ground-based observing campaigns during the last century (cf. Andersen 2002).

The programme on eclipsing binaries we are carrying out in Asiago, was undertaken (a) to determine the performances by Gaia on eclipsing binaries and the accuracy achievable on the determination of fundamental stellar parameters like masses and radii and (b) to evaluate the contribution that Gaia will provide to the study of eclipsing binaries and its influence on our knowledge of the basic parameters of stars.

Table 1. Basic stellar parameters for the 12 stars in our sample as obtained from our Gaia-like orbital solutions (Munari et al. 2001, Zwitter et al. 2003, Marrese et al. 2004, Milone et al. in submission). The last column list the Hipparcos trigonometric distance.

Star	$M_1/M_\odot$	$M_2/M_\odot$	$R_1/R_\odot$	$R_2/R_\odot$	$T_{\rm eff,1}$ (K)	$T_{\rm eff,2}$ (K)	d_{Bin} (pc)	d_{Hipp} (pc)
V505 Per	1.30	1.28	1.40	1.14	6430	6414	59 ± 4	66^{71}_{63}
HP Dra	1.10	1.10	1.72	0.89	6000	6386	73 ± 5	80^{85}_{76}
V781 Tau	0.51	1.15	0.76	1.11	6390	6167	81 ± 1	81^{91}_{73}
SV Cam	0.86	0.65	0.98	1.18	5848	4061	87 ± 8	85^{93}_{79}
UV Leo	1.21	1.11	0.97	1.22	6129	5741	92 ± 6	91^{103}_{83}
V570 Per	1.28	1.22	1.64	1.01	6460	6204	108 ± 6	117^{105}_{132}
V432 Aur	0.98	1.06	1.39	2.13	6100	5900	124 ± 10	119^{100}_{146}
UW LMi	1.06	1.04	1.23	1.21	6500	6500	114 ± 7	129^{114}_{150}
BS Dra	1.29	1.28	1.42	1.40	6619	6626	172 ± 8	208^{246}_{181}
GK Dra	1.46	1.81	2.43	2.83	7100	6878	313 ± 14	297^{373}_{246}
CN Lyn	1.04	1.04	1.80	1.84	6500	6455	285 ± 32	362^{233}_{813}
OO Peg	1.28	1.22	2.19	1.37	8770	8683	295 ± 17	445^{304}_{840}

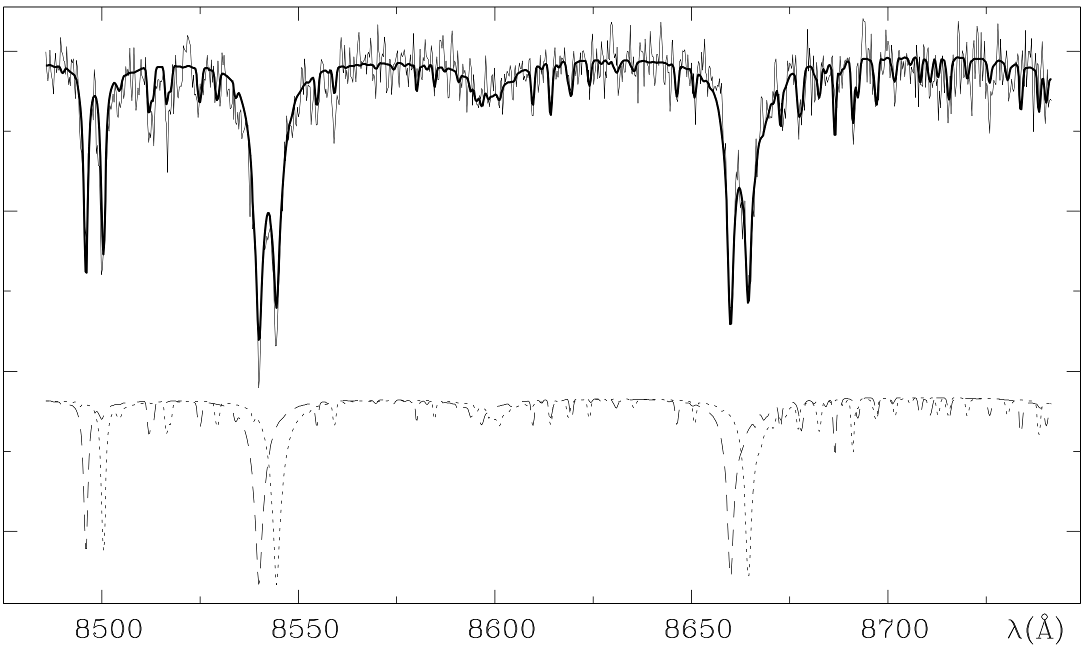

Figure 2. Comparison between observed (thin line) and synthetic (thick line) spectra of BS Dra in the Gaia wavelength region at orbital phase 0.36. The lower curves represent the contribution of each component of the binary to the formation of the observed spectrum. The synthetic spectra are characterized by $T_{\rm eff,1}$=6500,$T_{\rm eff,2}$=6450,$\log g_1$=4.25,$\log g_2$=4.25 and [Fe/H]=$-$0.2.

2. THE SAMPLE

All the targets are selected among the eclipsing binaries observed by the Hipparcos-Tycho mission. They have A-K spectral types and can be detached, semi-detached or contact binaries. In some cases one or both components are themselves variable stars, while one of the systems was revealed to be triple. Until now 12 eclipsing binaries have Gaia-like orbital solutions, namely OO Peg, V570 Per and V505 Per (Munari et al. 2001), GK Dra, UV Leo and V781 Tau (Zwitter et al. 2003), CN Lyn, V432 Aur and UW LMi (Marrese et al. 2004), SV Cam, HP Dra and BS Dra (Milone et al. to be submitted). Table 1 summarizes, for all the target stars, the basic stellar parameters (masses, radii, temperatures) and distances as obtained from the orbital solutions. The distance from Hipparcos parallaxes is reported for comparison.

3. DISTANCES

In order to check the accuracy of the derived orbital solutions, we compare the astrometric distance by Hipparcos with the distance obtained by the orbital analysis for all the binaries in our sample. Figure 1 shows that for the systems closer than 150 pc (for which Hipparcos parallaxes are accurate) the agreement is very good, with an RMS lower than 2 pc.

4. AN EXAMPLE: BS DRA

4.1. Atmospheric Analysis

The Gaia spectra are used for the atmospheric analysis via synthetic spectroscopy. This constitutes an external check of the $T_{\rm eff}$ and $\log g$ obtained with the orbital solution and allows us to derive [Fe/H] and $v_{\rm rot} \sin i$.

The analysis was performed via a χ^2 fitting procedure, using the large grid of synthetic Kurucz spectra of Munari et al. (2004, to be submitted). The spectra cover the 2500–10 500 Å wavelength range with the same resolving power of the observed spectra ($R_{\rm P}$ = 20 000). The spectra are calculated with the revised solar abundances by Grevesse & Sauval (1998), throughout the whole HR diagram for 12 different rotational velocities, $T_{\rm eff}$ ranging from 3500 to 47 500 K, $\log g$ from 0.0 to 5.0 and [Fe/H] from −2.5 to +0.5. The grid includes also a complete set of spectra calculated for α-enhanced chemical composition ([α/Fe]=+0.4) and for different values of microturbulent velocity (1, 2, 4 km sec^{-1}).

Here we use only the Gaia wavelength region to perform the atmospheric analysis. A comparison between the results obtained for both components of BS Dra with the orbital solution ($T_{\rm eff}$, $\log g$) and the preliminary atmospheric analysis ($T_{\rm eff}$, $\log g$, $V_{\rm rot} \sin i$ and [Fe/H]) is presented in Table 2. Figure 2 shows the combined synthetic spectra superimposed to the observed spectrum of BS Dra at orbital phase 0.36.

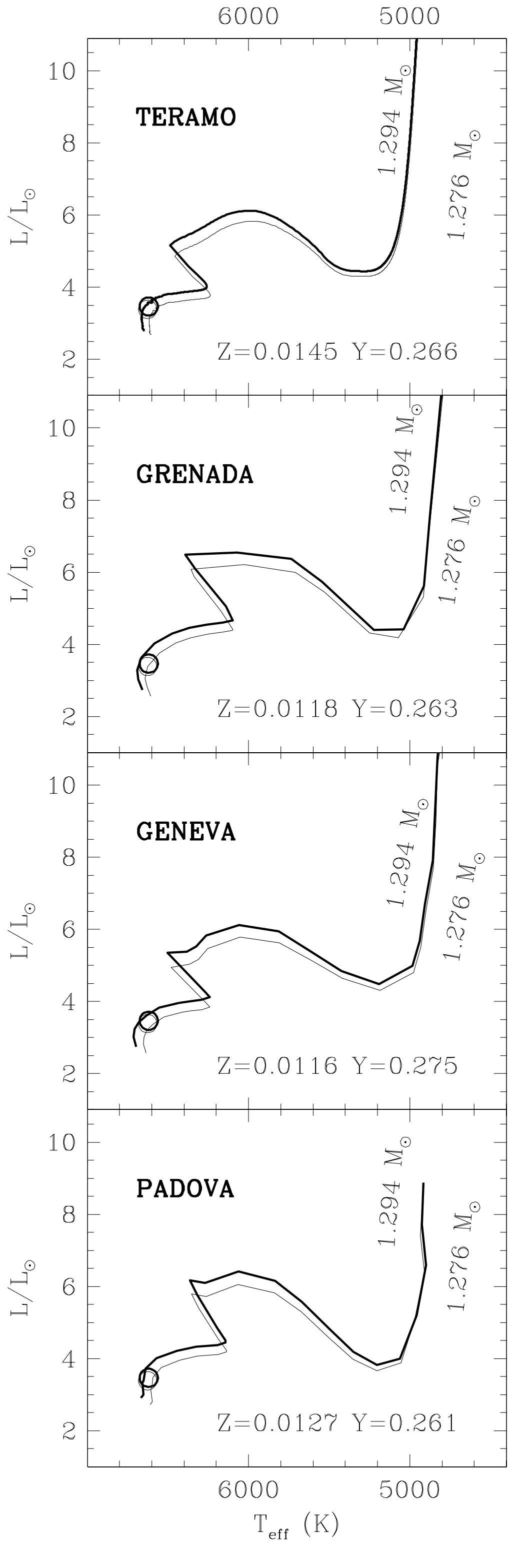

Figure 3. Comparison between $T_{\rm eff}$ and $L/L_\odot$ as derived from the orbital solution and those of different families of theoretical stellar models for the masses of the two components of BS Dra (1.294 and 1.276 M$_\odot$). In each panel best match tracks in metal content Z are shown.

Table 2. Atmospheric parameters of BS Dra from a χ^2 fit to Kurucz synthetic spectra. The results from the orbital solution for $T_{\rm eff}$, $\log g$ are given for comparison.

		χ^2 fit to synth. spectra	orbital solution
$T_{\rm eff}$ (K)	prim. (1)	6500 ± 25	6619 ± 100
	sec. (2)	6450 ± 25	6626 ± 100
$\log g$	prim. (1)	4.25 ± 0.13	4.25 ± 0.01
	sec. (2)	4.25 ± 0.13	4.25 ± 0.01
$V_{\rm rot} \sin i$ (km sec^{-1})	prim. (1)	20 ± 5	
	sec. (2)	20 ± 5	
[Fe/H]		-0.23 ± 0.05	

Table 3. Metal (Z) and Helium (Y) content, [Fe/H] and age for BS Dra as obtained from comparison with different families of theoretical evolutionary tracks.

	TERAMO04	GRENADA	PADOVA	GENEVA
Z	0.0145	0.0118	0.0127	0.0116
Y	0.266	0.263	0.261	0.275
[Fe/H]	−0.06	−0.15	−0.12	−0.15
Age (Gyr)	1.7	1.45	1.26	1.54

4.2. Comparison with Theoretical Stellar Models

The determination of accurate masses, radii, temperatures and thus luminosities allows us to place the stars on the theoretical plane $T_{\rm eff} - L/L_{\odot}$.

We compare on the Temperature/Luminosity plane the position of the two components of BS Dra (from the orbital solution) with the tracks from the Padova (Bertelli et al. 1994, Fagotto et al. 1994, Girardi et al. 2000), Geneva (Schaller et al. 1992, Schaerer et al. 1993a, 1993b), Grenada (Claret 1995, 1997 and Claret & Gimenez 1995) and Teramo-04 (Pietrinferni et al. 2004) families of stellar models. We interpolate the models in both mass and metal content (Z) by Newton polynomials of second order. We assume that the components of BS Dra share the same metallicity (as we did in the atmospherical analysis) and we take the masses of the two components from our orbital solution, while we minimize in luminosity ($L/L_{\odot}$), temperature ($T_{\rm eff}$) and age difference between the components ($\tau_{\rm a} - \tau_{\rm b}$).

Each panel of Figure 3 shows the best fit in metallicity provided by the given family of stellar models after interpolation of closest published tracks. The results are summarized in Table 3. The fit with the various families of stellar models covers a range in age between 1.3 and 1.7 Gyr and in metallicity from [Fe/H]=-0.06 to -0.15.

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