PHYSICAL PARAMETERS OF STARS IN CLOSE BINARIES DERIVED FROM GAIA PHOTOMETRY

P.G. Niarchos, V.N. Manimanis, K.D. Gazeas

Department of Astrophysics, Astronomy and Mechanics, University of Athens, Zographou, Athens, Greece

ABSTRACT

The physical parameters of ten eclipsing binaries (eight contact and two semi-detached) are derived by using ground-based photometric observations and Hipparcos/Tycho photometric data, which mimic the photometric observations that are expected to be obtained by Gaia. The results are compared and the achievable precision of the basic stellar parameters derived by Gaia photometry is discussed.

Key words: Stars: interacting binaries, eclipsing variables.

1. GAIA'S CONTRIBUTION TO THE STUDY OF ECLIPSING BINARIES

Gaia is designed to obtain for a large sample of stars extremely precise micro-arcsecond astrometry, multi-band photometry and medium resolution spectroscopy. The main scientific objectives and technical guidelines of the Gaia mission and the expected benefits for astrophysical research are described in the ESA *Concept and Technology Study* (ESA 2000), in papers by Gilmore et al. (1998) and Perryman et al. (2001), and in the proceedings of Gaia conferences (Straižys 1999, Bienaymé & Turon 2002, Vansevičius et al. 2002 and Munari 2003). An overview of the Gaia spacecraft is presented by Pace (2003), while the goals of Gaia spectroscopy and photometry are discussed by Munari (1999a,b; 2002) and Høg (2002). The role of Gaia in the photometry and spectroscopy on Eclipsing Binaries (EBs) has been reviewed in detail by Munari et al. (2001) and Zwitter (2002, 2003).

It is expected that about 10^6 EBs (with $V \leq 16$ mag) will be discovered and some 10^5 of these will be characterized as double-lined in Gaia spectral observations. Moreover, most of the Gaia binaries will be of spectral type G or K (Zwitter & Henden 2003) for which accurate solutions exist for only a small number of systems. Even if for only 1% of the observed EBs reliable parameters are derived, this will be a giant leap in comparison with what has been obtained so far from ground based observations. The number of photometric points in the five-year mission lifetime is estimated to be $\sim$ 100 to 150. The observing fashion will be quite similar to Hipparcos operational mode.

The aim of the present investigation is to evaluate the performance of the photometry of Gaia on the study of EBs. The first step for such an evaluation can be accomplished by studying a small sample of EBs, using ground-based and Hipparcos (Gaia-like) observations.

2. SELECTION OF SYSTEMS

There is an intrinsic limit on the number of photometric observations to the Gaia operational mode ($\sim$ 100 to 150 points). Gaia is expected to collect a number of photometric points per band per star similar to Hipparcos. But how can these observations be compared with the state-of-the-art ground-based observations? What is the accuracy to which EBs can be investigated using Gaia data alone? The aim of the present investigation is to give an answer to these questions regarding the semi-detached and contact binaries. Such an investigation for some detached and contact binaries has also been done by Munari et al. (2001), Niarchos & Manimanis (2003), Marrese et al. (2004), and Zwitter et al. (2003). In the present work we extend the sample of contact binaries as far as the spectral types is concerned by considering systems of the basic spectral types A, F, G and K. The selection criteria were: 1) EBs observed by the Hipparcos/Tycho mission (H_P observations). 2) Existing ground-based photometric observations of high quality (V observations). 3) Accurate spectroscopic mass ratios from radial velocity measurements.

Ten systems have been selected according to the above criteria: two semi-detached (near-contact) and eight contact systems. These systems are listed in Table 1 together with some basic data derived from ground-based observations. Detached systems are not included in the present work, since such systems have been successfully studied by Munari et al. (2001), Marrese et al. (2004) and Zwitter et al. (2003).

Table 1. Basic data for the selected systems derived from ground-based observations.

System	State	Spectral type	Mass ratio q	References
V1010 Oph	semi-detached	A5 + F6	0.448	1
RZ Dra	semi-detached	A5 + K2	0.444	2
XZ Leo	contact	A5	0.348	3
ϵ CrA	contact	F2	0.112	4
V566 Oph	contact	F4 + F8	0.237	5
YY CrB	contact	F8	0.243	6
V839 Oph	contact	G0	0.305	3
AB And	contact	G5	0.560	7
XY Leo	contact	K0	0.500	8
AH Vir	contact	K0	0.303	9

1) Shaw et al. 1990; 2) Kreiner et al. 1994; 3) Rucinski & Lu 1999; 4) Goecking & Duerbeck 1993; 5) Van Hamme & Wilson 1985; 6) Rucinski et al. 2000; 7) Hrivnak 1988; 8) Hrivnak et al. 1984; 9) Lu & Rucinski 1993.

Table 2. Absolute elements (physical parameters) in solar units.

SYSTEM	M_1	M_2	R_1	R_2	L_1	L_2
RZ Dra (1)	1.40(4)	0.62(3)	1.62(1)	1.12(1)	10.1(4)	1.01(6)
RZ Dra (2)	1.42(5)	0.59(4)	1.55(1)	1.11(1)	9.60(47)	0.86(5)
% difference	1.4	4.8	4.3	0.9	5	15
V1010 Oph (1)	1.87(12)	0.90(5)	2.08(6)	1.48(8)	10.7(7)	3.47(35)
V1010 Oph (2)	1.88(14)	0.89(7)	2.08(1)	1.46(1)	11.7(8)	3.07(8)
% difference	0.5	1.1	0	1.4	9.3	12
XZ Leo (1)	1.83(5)	0.64(2)	1.71(2)	1.07(3)	7.29(29)	2.56(16)
XZ Leo (2)	1.82(13)	0.63(6)	1.71(2)	1.07(3)	7.26(29)	2.69(19)
% difference	0.5	1.6	0.2	0.2	0.4	5.1
ϵ CrA (1)	1.75(4)	0.21(2)	2.20(3)	0.80(1)	11.1(1)	1.08(1)
ϵ CrA (2)	1.69(7)	0.22(5)	2.12(12)	0.80(4)	10.3(20)	1.07(14)
% difference	3.4	4.8	3.6	1.2	7.2	0.9
V566 Oph (1)	1.40(3)	0.33(1)	1.47(1)	0.79(1)	4.57(4)	1.26(1)
V566 Oph (2)	1.54(11)	0.36(4)	1.518(3)	0.819(4)	4.99(24)	1.26(2)
% difference	10	9.1	3.5	3.7	9.2	0.8
YY CrB (1)	1.41(9)	0.34(2)	1.40(7)	0.77(10)	2.46(26)	0.81(20)
YY CrB (2)	1.37(16)	0.33(4)	1.36(7)	0.74(10)	2.33(25)	0.74(20)
% difference	2.8	2.9	2.9	3.9	5.3	8.6
V839 Oph (1)	1.62(4)	0.49(1)	1.53(6)	0.93(8)	3.12(26)	1.32(23)
V839 Oph (2)	1.61(17)	0.49(5)	1.52(6)	0.92(8)	3.10(26)	1.22(21)
% difference	0.6	0.8	0.7	1.1	0.6	7.6
AB And (1)	1.01(2)	0.56(1)	1.04(4)	0.80(5)	0.87(7)	0.46(5)
AB And (2)	1.00(9)	0.55(5)	1.06(4)	0.83(5)	0.91(7)	0.45(5)
% difference	1.0	1.8	1.9	3.7	4.6	2.2
XY Leo (1)	0.82(4)	0.41(2)	0.87(1)	0.64(2)	0.38(2)	0.14(1)
XY Leo (2)	0.83(21)	0.41(10)	0.86(1)	0.62(2)	0.37(2)	0.17(1)
% difference	1.2	0.7	1.1	3.1	2.6	21.4
AH Vir (1)	1.45(13)	0.44(4)	1.36(1)	0.77(1)	2.45(8)	0.71(2)
AH Vir (2)	1.33(20)	0.40(6)	1.44(1)	0.88(1)	2.76(9)	0.91(3)
% difference	8.3	9.1	5.9	14.3	12.7	28.2

(1): ground-based observations, (2): Gaia (expected) observations

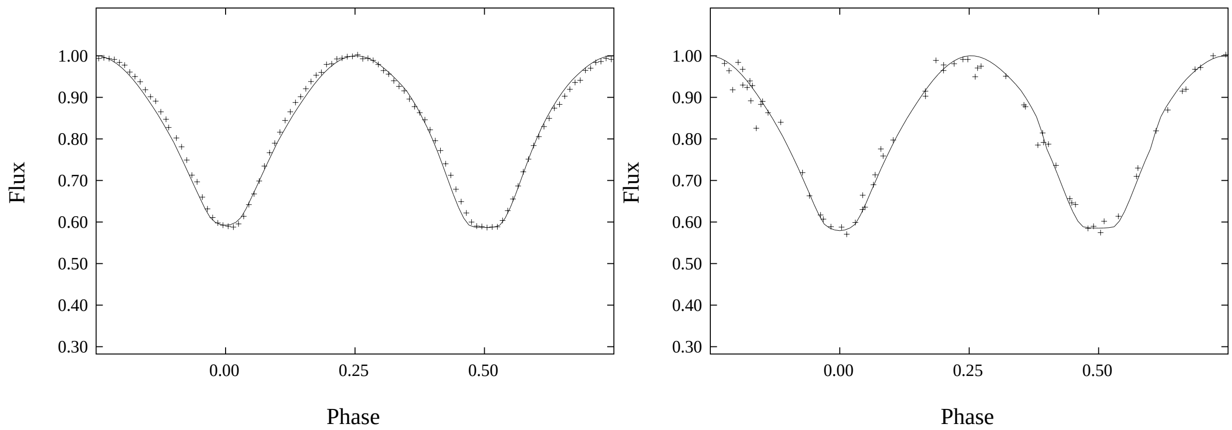

Figure 1. Light curves of the contact system V839 Ophiuchi, based on ground-based (V filter) observations (left) and on Hipparcos data (H_P filter) (right). The solid lines represent our light curve solutions.

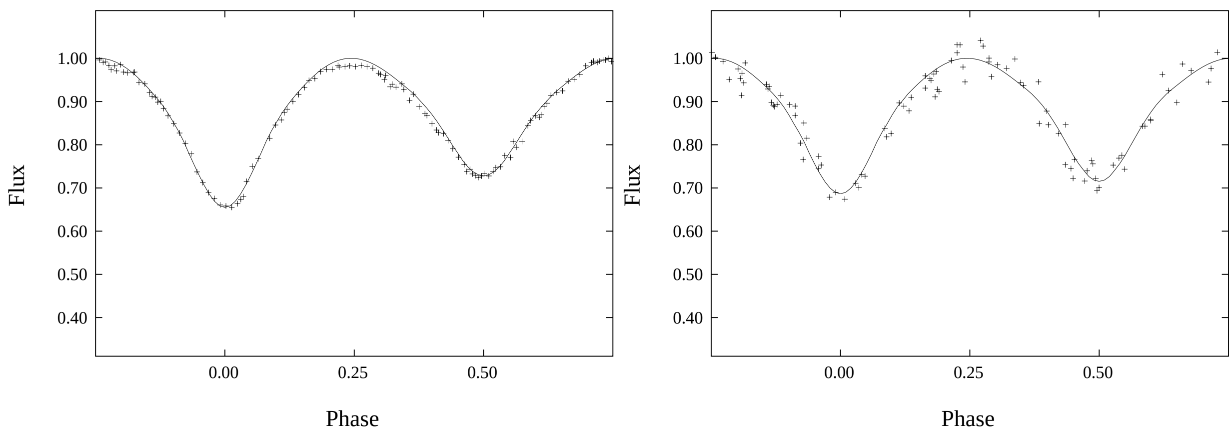

Figure 2. Light curves of the contact system XY Leonis, based on ground-based (V filter) observations (left) and on Hipparcos data (H_P filter) (right). The solid lines represent our light curve solutions.

3. METHOD OF ANALYSIS AND COMPARISON OF ABSOLUTE ELEMENTS

- The Wilson-Devinney DC program was used in Modes: 4 for V1010 Oph, 5 for RZ Dra and 3 for all contact systems.
- The free parameters of each run were: $\phi_\circ, i, T_2, \Omega, L_1$ (according to the mode used).
- The fixed parameters were: T_1 (from spectral type); g (0.32 and 1.0) and A (0.5 and 1.0) for convective and radiative envelopes, respectively; x (from tables by Claret et al. 1995 and Dí?az-Cordovés et al. 1995).
- The spectroscopic mass ratio q was used as fixed parameter.
- There was no additional light from a third star in the field affecting any of the light curves.

The elements derived from the light curve analyses were combined with the available spectroscopic elements in order to compute the absolute elements (physical parameters) of the systems for both cases, the case of ground-based observations and that of Hipparcos (Gaia-like) observations, and to compare them. These parameters are listed in Table 2 together with their percentage difference. Two examples of the light curves are given in Figures 1 and 2.

4. CONCLUSIONS

- There are special advantages of the Gaia mission (with combined astrometric, spectroscopic and photometric observations) compared to classical ground-based EB studies.
- For the systems studied, the derived absolute elements from Gaia-like observations differ from those of ground-based observations within the limits of the combined errors. The exception is the case of AH Vir where these differences are rather large. This is due to fact that AH Vir is an active system showing variable light curves from season to season. Moreover the observations, both the ground-based and those of Hipparcos, used in the analysis are of low quality.

- More definite conclusions for the expected Gaia performance on the photometry of EBs could be drawn when enough stars will be investigated to cover both various spectral types as well as various kinds of interaction (detached, semi-detached and contact binaries).
- Such a study based on ground-based and Hipparcos (Gaia-like) observations and a comparison of the results should be done for rather 'well-behaved' systems. The reason is that, for systems showing temporal activity and/or seasonal variabilities affecting the shape of the light curves, observations obtained at various epochs could lead to different model parameters (as in the case of AH Vir). For systems of the later case only simultaneous (or at least of the same epoch) ground-based and Hipparcos observations can be used for such a study.

REFERENCES

Bienaymé, O., Turon, C., 2002, eds., *Gaia: a European space project*, EDP Sciences

Claret, A., Díaz-Cordovés, J., Giménez A., 1995, A&AS 114, 247

Díaz-Cordovés, J., Claret, A., Giménez, A., 1995, A&AS 110, 329

ESA, 2000, 'Gaia Concept and Technology Study Report', ESA–SCI(2000)4

Gilmore, G., et al., 1998, Proc. SPIE Conference 3350, 541

Goecking, K.-D., Duerbeck, H.W., 1993, A&A 278, 463

Høg, E., 2002, in *Gaia: A European Project*, O. Bienayme and C. Turon eds., EAS Pub. Ser. 2, p. 27

Hrivna,k B.J., 1988, ApJ 335, 319

Hrivnak, B.J., Milone, E.F., Hill, G., Fisher, W.A., 1984, ApJ 285, 683

Kreine,r J.M., Pajdosz, G., Tremko, J., Zola S., 1994, A&A 285, 459

Lu W.-X., Rucinski, S.M., 1993, AJ 106, 361

Marrese, P.M., et al., 2004, A&A 413, 635

Munari, U., 1999a, in *Proceedings of the ESA Leiden Workshop on GAIA*, 23-27 Nov. 1998, Baltic Astronomy 8, 73

Munari, U., 1999b, in *Proceedings of the ESA Leiden Workshop on GAIA*, 23-27 Nov. 1998, Baltic Astronomy, 8, 123

Munari, U., 2002, in *GAIA: A European Project*, O. Bienayme & C. Turon eds., EAS Pub. Ser. 2, p. 39

Munari, U., 2003, ed. , *GAIA Spectroscopy, Science and Technology*, ASP Conf. Series, vol. 298

Munari, U. et al., 2001, A&A 378, 477

Niarchos, P., Manimanis, V., 2003, A&A 405, 263

Pace, O., 2003, in *GAIA Spectroscopy, Science and Technology*, U. Munari ed., ASP Conf. Ser. 298, p. 13

Perryman, M.A.C., et al., 2001, A&A 369, 339

Rucinski, S.M., Lu, W.-X., 1999, AJ 118, 2451

Rucinsk,i S.M., Lu, W.-X., Mochnacki, S.W., 2000, AJ 120, 1133

Shaw, J.S., Guinan, E.F., Garasi, C.J., 1990, BAAS 22, 1296

Straižys, V., 1999, Baltic Astronomy 8, 109

Van Hamme, W., Wilson, R.E., 1985, A&A 152, 25

Vansevičius, V., Kučinskas, A., Sudžius, J. eds., 2002, *Census of the Galaxy: challenges for photometry and spectrometry with GAIA*, Kluwer

Zwitter, T., 2002, in *Exotic Stars as Challenges to Evolution*, C.A. Toot & W. Van Hamme eds., ASP Conf. Ser. 279, p. 31

Zwitter, T., 2003, in *GAIA Spectroscopy, Science and Technology*, U. Munari ed., ASP Conf. Ser. 298, p. 329

Zwitter, T., Henden, A.A., 2003, in *GAIA Spectroscopy, Science and Technology*, U. Munari ed., ASP Conf. Ser. 298, p. 489

Zwitter, T., et al., 2003, A&A 404, 333