DG Leo: a triple system with a surprising variety of physical phenomena

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Summary. DG Leo consists of three late A-type stars forming a hierarchic and spectroscopic triple system. Although all components have similar age and mass, in-depth spectroscopic analysis showed that the components nevertheless *behave differently with respect to pulsation and to diffusion in their outer atmospheres*. Inclusion of a speckle measure shortly after periastron passage allows to obtain a much improved orbital solution as well as a reliable dynamical parallax and systemic mass. The orbital parameters also suggest a possible coplanar configuration of both pairs. This object therefore represents a first-class opportunity to investigate the link between multiplicity, chemical composition and pulsation in a coeval system.

1 Introduction

As of 2002 one of our goals is to perform an in-depth study of a pulsating star in a binary or a multiple system. Since pulsation is not yet well understood for some classes of variable stars (for example, theory suggests many more modes in δ Scuti stars than are actually observed and the reasons for a particular amplitude or mode are currently unknown), additional constraints based on accurate physical properties can help understand the factors governing the pulsations. Binary and multiple stars with well-characterized components are prime targets as they provide the component's physical properties in an independent and straightforward way. Furthermore, the "common-origin" scenario eliminates some of the factors (distance, environment, overall chemical composition and age) that are otherwise only poorly known.

In the present case study of DG Leo, a δ Scuti component in a triple system, we will demonstrate the potential of a comparative study of the properties between components of "twin" systems. It appeared as a promising target in a review on pulsating stars of type δ Scuti among stellar systems [1]. This hierarchical system consists of three components of spectral type A8/F0 IV-III, all of which are potential candidates for pulsations as well as for spectral peculiarities of type Am [2].

2 Astrophysical relevance

2.1 The inner binary Aa,Ab

The inner pair is a double-lined spectroscopic binary formed by the components Aa and Ab orbiting in a circular orbit with a period of 4.146751 days [3]. Analysis of photometric data obtained during a multi-site, multi-year campaign showed that the most dominant light changes are caused by tidal distortions in the close binary [4]. Tides stretch the components' shapes into ellipsoids, with the long axes aligned along the line connecting the components' centers. Overall, the light curve resembles a double cosine wave [5]. Furthermore, no eclipses were observed [4]. From the absence of eclipses we derived $i_{orb} < 73°$ [3]. Note that this could also be interpreted as $i_{orb} > 107°$ (in good agreement with the orbital inclination of the outer system, see Table 2). This may hint to a coplanar configuration (additionally requiring similar nodes) and also to a common retrograde motion.

The inner pair is circularized. This is a consequence of the very efficient tidal driving during the PMS evolutionary phase of the close binary [6]. We therefore expect a state of spin-orbit synchronization. In the case of full spin-orbit synchronization, there should be no phase lag between e.g. the time of largest visible surface area and the time at which both components cross the nodes of the inner orbit. This is indeed what is observed in Fig. 1. The same conclusion is valid at the conjunction times (90° in orbital phase apart).

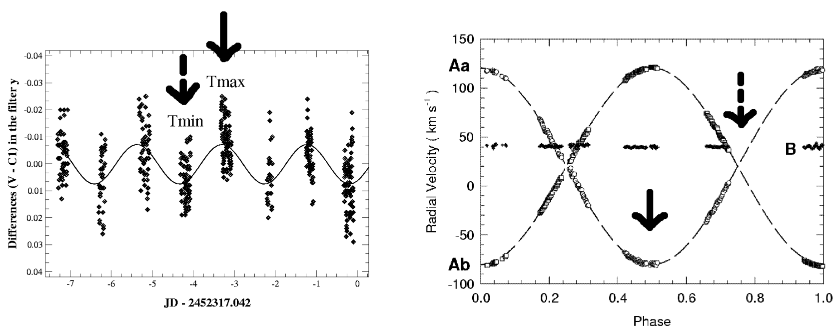

Fig. 1. Ellipsoidal variations (left panel) and radial velocity curves (right panel): arrows indicate the epochs T_{max} and T_{min} corresponding to respectively maximal and minimal flux

The spectral disentangling technique [7] was adopted to study the composite, high S/N spectra acquired with the ELODIE spectrograph at the 1.93-m telescope of the *Observatoire de Haute-Provence* (France). We assumed that the observed spectrum is the combination of three time-independent component spectra that are shifted in wavelength relatively to each other. Using a least-squares method, the code adjusts the variations of the Fourier Transforms of the observed composite spectra with time in order to provide the time-averaged spectrum of each component as well as the relative radial velocities at the various epochs (for more details on this technique, see Hensberge, these proceedings). Analysis of the chemical composition of the time-averaged component spectra showed that both components of the inner pair are mild metallic-lined A-type (Am) stars while the time-averaged spectrum of component B didn't present any peculiarity [3].

2.2 The outer binary AB

The outer system is a visual binary with components A and B. At the phases of nodal crossing of the inner orbit the lines of all three components are detectable in the spectra. This allowed previous investigators to derive radial velocities for the individual components. Early 2003, significant and abrupt changes in radial velocity, $\mathrm{Vrad}_{Aa,Ab}$ and Vrad_{B}, were detected when compared to those obtained over the previous decades [8, 9]. The wide binary was also monitored by means of micrometric observations since 1935 and by speckle-interferometric observations since 1976. A complete set of orbital elements was first reported by Frémat et al. [3]: their combined astrometric-spectroscopic analysis revealed an orbital period of the order of 100 yrs and an eccentricity of about 0.9.

Moreover, a recent photometric study allowed the detection and precise determination of at least four pulsation frequencies of type δ Scuti in a narrow range of values, proving that at least one component in the triple system must be a δ Scuti pulsator [4]. Frémat et al. [3], using the disentangled component spectra, reported the existence of line-profile variations in the time-series spectra of the distant and chemically normal companion with time-scales of the same order as the pulsation-related ones found in the photometric study. Their Fig. 10 illustrates the residuals of the time-series KOREL spectra acquired during four consecutive nights.

Table 1 lists the stellar parameters which were determined by fitting synthetic spectra based on Kurucz models (ATLAS9) to the disentangled component spectra. Note the different projected rotation velocity of components Aa and Ab. This can arise because of incomplete synchronization, a difference in radii, a different inclination, as well as by any combination of these factors. In the case of complete spin-orbit synchronization, we expect a synchronous velocity of 36 $\pm$ 6 km/s for stellar radii of 3.0 $\pm$ 0.2 $R_\odot$.

Table 1. Derived stellar parameters (from [3])

Star	**Aa**	**Ab**	**B**
T_{eff} (K)	7470±220	7390±220	7590±220
V sin i (km s^{-1})	42±2	28±2	31±3
Rel. flux (%)	32±2	31±2	37±2
log g	3.8±0.14	3.8±0.14	3.8±0.12

3 New orbital solutions and dynamical mass

3.1 The astrometric and combined orbits

The previous orbital solution shows large errors on several orbital elements due to a lack of data at the crucial orbital phase near periastron passage [3]. Furthermore, it fails to predict well the new speckle position obtained at epoch 2004.99 (i.e. after periastron passage) with the 6-m Russian BTA telescope. Using this datum, Docobo & Tamazian [11] derived a new orbit based on all astrometric data known to-date.

Table 2. Orbital elements and system mass

Orbital element	(1) Docobo [13]	(2) Pourbaix [12]
P (yr)	100.8 ± 1.5	113.1 ± 3.4
T	2000.5± 0.2	2000.3 ± 0.3
e	0.867 ± 0.007	0.887 ± 0.008
a ($''$)	0.195 ± 0.004	0.208 ± 0.006
i ($^\circ$)	104.7 ± 0.5	107.5 ± 0.9
Ω ($^\circ$)	29.4 ± 0.6	27.9 ± 1.3
ω ($^\circ$)	335.3 ± 1.0	332.0 ± 4.1
V_0 (km/s)	-	27.0 ± 0.5
$\kappa = \frac{M_{\rm B}}{M_{\rm A}+M_{\rm B}}$	-	0.36 ± 0.05
π_{dyn} ($''$)	-	4.77 ± 0.54
A (A.U.)	-	43.5 ± 6.1
mass A ($M_\odot$)	-	4.1 ± 1.5
mass B ($M_\odot$)	-	2.3 ± 0.7
K1 (km/s)	-	8.5 ± 1.1
K2 (km/s)	-	15.2 ± 1.7
System mass using π_{dyn} ($M_\odot$)	6.8 ± 2.4	6.4 ± 2.2

However, a combined astrometric-spectroscopic analysis leads to an independent determination of both distance and component masses. We therefore recomputed the orbit by combining all astrometric and spectroscopic data and by making use of the code VBSB2 which performs a global exploration of the parameter space followed by a simultaneous least-squares minimization [12].

Both astrometric and combined solutions with their corresponding standard errors are listed in Table 2 and graphically represented in Fig. 2. These solutions fit the observations well and show only tiny differences which is an indication of the remaining uncertainties. Note that the standard errors of many elements have drastically improved with respect to [3], as expected from the addition of a suitably phased speckle observation [10]. The large error on the mass of the visual components is mainly due to the relative error on the dynamical parallax. Since the error in fractional mass is much smaller, and $M_{\rm Aa} = M_{\rm Ab} > 2.1^{+0.2}_{-0.1}$ $M_\odot$ [3], we conclude that $M_B > 2.0$ $M_\odot$, which gives a useful lower limit on acceptable pulsation models (see [14]).

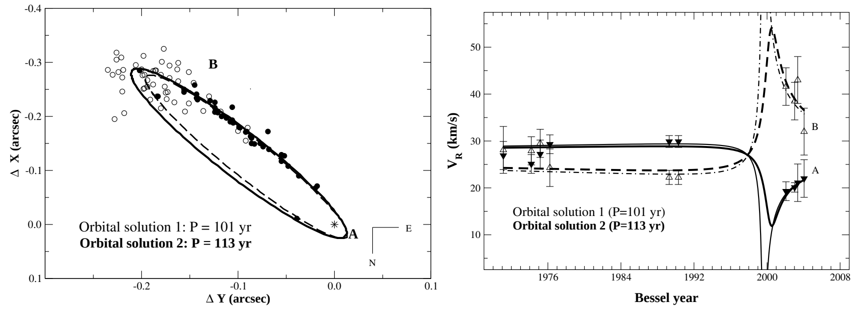

Fig. 2. Orbital solutions 1 (dashed/thin line) and 2 (solid/thick line) corresponding to astrometric (left panel) and spectroscopic (right panel) data

3.2 Dynamical mass and components' location in the HR diagram

The value of the dynamical parallax, though requiring further improvement, is consistent with a systemic mass of about 6 $M_\odot$ (Table 2), as expected from the derived component's physical properties. This also removes the marginal inconsistency that exists if the Hipparcos parallax (π_{Hip}=6.34 $\pm$ 0.94 mas [15]) is used (leading to a systemic mass of about 3 $M_\odot$). The difference between both values is at the 1.5 σ-level. Fig. 3 shows the location of DG Leo's components in the HR diagram using both parallaxes. We stress that the position inferred on the basis of π_{Hip} is only just compatible with the lowest acceptable limit for the component masses. For these various reasons we currently adopt a distance of 210 $\pm$ 24 pc, corresponding to the dynamical parallax reported in Table 2.

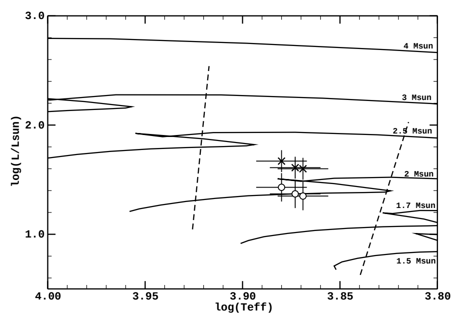

Fig. 3. Location of the components of DG Leo in the HR diagram. X-symbols are based on π_{dyn}. Blue lines denote the edges of the lower Cepheid instability strip. Allowed masses on theoretical evolutionary tracks correspond to a mass $>$ 2.0 $M_\odot$.

4 Conclusions

Significant progress on the long (resp. short)-period orbit of the wide (resp. close) binary can be achieved provided new speckle (resp. VLTI) data are obtained in a few years from now. As the angular separation of the wide pair is rapidly increasing from 0.05 in 2006 to $0.10''$ in 2010, a 3 or 4-m telescope will soon be sufficient. The precise determination of both orbits will provide accurate masses for three A-type stars (including a chemically normal δ Scuti pulsator and 2 mild Am stars which do not seem to pulsate). This remarkable system will thus allow to gain new insights on the link between multiplicity, chemical composition (diffusion) and pulsation in this intriguing region of the HR diagram.

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References

1. Lampens, P. & Boffin, H. 2000, In: *Delta Scuti and Related Stars: A Reference Handbook*, ASP Conf. Ser. **210**, eds. M. Breger & M.H. Montgomery, 309
2. Landstreet, J.D. 2004, In: *The A-star puzzle*, Proceedings of IAU Symp. **224**, eds. J., Zverko, J., Žižňowskí, S.J. Adelman & W.W. Weiss, 423
3. Frémat, Y., Lampens, P. & Hensberge, H. 2005, MNRAS **356**, 545
4. Lampens, P., Frémat, Y. et al. 2005, A&A **438**, 201
5. Wilson, R. E. 1994, IAPPP Communications, spring 1994
6. Zahn, J.-P. 1977, A&A **57**, 383
7. Hadrava, P. 1995, AAS **114**, 393
8. Fekel, F. C. & Bopp, B. W. 1977, PASP **89**, 216
9. Rosvick, J. M. & Scarfe, C. D. 1991, PASP **103**, 628
10. Lampens, P. & Frémat, Y. 2005, ASP Conf. Ser. **338**, eds. K. Seidelmann & A. Monet, 276
11. Docobo, J.A. & Tamazian, V. 2005, IAUDS **157**, 1
12. Pourbaix, D. 1998, AAS **131**, 377
13. Docobo, J.A. 1985, Cel. Mech. **36**, 143
14. Grigahcène, A., Suárez, J.C. et al., 2005, In: *Tidal Evolution and Oscillations in Binary Stars*, ASP Conf. Ser. **333**, eds. A. Claret, A. Giménez & J.-P. Zahn
15. ESA 1997, The Hipparcos and Tycho Catalogues ESA-SP 1200