Tidal Evolution and Oscillations in Binary Stars
ASP Conference Series, Vol. 333, 2005
A. Claret, A. Giménez and J.-P. Zahn, eds.

Non-adiabatic seismic study of the triple system DG Leo

A. Grigahcène, J. C. Suárez, M.-A. Dupret and R. Garrido

Instituto de Astrofísica de Andalucía-CSIC, Apartado 3004, 18080 Granada, Spain

Abstract. The interest in studying multiple systems comes from the fact that they give a good number of constraints on their components. From the multiplicity we have constraints on mass and age. Moreover, if one or more components of the system show oscillating properties as the DG Leo triple system, additional constraints provided by seismology can be obtained once the modes are identified. In this work, we consider an equilibrium model of the DG Leo system constrained by its multiplicity properties, we attempt to check our new Time Depending Convection treatment on the modes identification of the DG Leo system.

1. Introduction

New photometric and spectroscopic observations of the triple system DG Leo (Frémat et al. (1999) and P. Lampens Communication in this Workshop) give a complex frequency spectrum (Table 2).

The study of this pulsating system will improve our understanding of pulsation, multiplicity and rotation coupling. More, in our study using our new Time Dependent Convection treatment (TDC) (Grigahcène et al. (2004); Dupret et al. (2004)), we are able to show the effect of the Pulsation-Convection interaction on the photometric observables allowing a better mode identification.

2. Observational Data

Star	Aa	Ab	B
T_{eff}	7470 ± 220	7390 ± 220	7590 ± 300
$\log g$	3.8 ± 0.15	3.8 ± 0.15	3.8 ± 0.15
$V \sin i \ (km\, s^{-1})$	42 ± 2	28 ± 2	31 ± 2

Table 1. Fundamental Parameters of the DG Leo triple system.

Set	Freq. cd^{-1}
F2	11.98536
F3	11.90471
F4	12.12024

Table 2. Analyzed Frequencies.

The fundamental parameters of the observed system are shown in Table 1. In Table 2 are given the frequencies obtained by the analysis of the data obtained by a multi-year multi-site photometric observations (Lampens et al. (2004)).

3. Modeling

In our modeling we have chosen a set of models with different values of the mixing length parameter α and with global parameters fitting the system's parameters within the observational uncertainties. In Table 3 we give the set of models used in the TDC non adiabatic calculations, and in Table 4, those used in the rotational investigation.

α	$T_{eff}\,(K)$	X	$\log g$	$L/L_{\odot}$	$R/R_{\odot}$	Age (Myr)
0.5	7518.2	0.70	3.9827	1.1680	2.2654	1098
1	7518.6	0.70	3.9828	1.1680	2.2652	1098
1.8	7521.4	0.70	3.9834	1.1680	2.2635	1098

Table 3. Fundamental Parameters of the models used in the TDC. M= 1.8 $M_{\odot}$, $\alpha_{ov} = 0.2$

The components of this multiple system can be considered as relatively slow–moderately rotating objects. In the present work, the rotational velocity considered is $v \sin i = 30$ km/s. As no information for the angle of inclination of components can be retrieved, this value gives us a range of rotational velocities as a function of i, moving from the star being observed equator on, to be observed pole-on. In principle, in the present work two possibilities are considered: $i = 90$, 45 deg, which yields $V_{rot} = 30$ and 42 km/s respectively. For these rotational velocities, equilibrium models have been computed with the evolutionary code CESAM (Morel (1997)). They take into account the spherically symmetric contribution of the centrifugal force due to rotation to the hydrostatic equilibrium equation. This is done by means of an effective gravity.

	V (km/s)	i (deg)	$logT_{eff}$	$logg$	X_c	Age (Myr)
Model 1	30	90	3.87	3.99	0.358	1000
Model 2	42	45	3.87	3.99	0.358	1000
Model 3	100	18	3.88	3.98	0.315	1050

Table 4. Fundamental Parameters of the models used in the Rotational Calculations.

4. Theoretical Results

4.1. TDC Treatment

Using the MAD non adiabatic non radial pulsation code, we calculate the frequencies spectrum for each model given in Table 3 up to $\ell = 2$. Our "best" modes fitting the observed frequencies are given in Table 5.

The normalized amplitude ratio $f_{\rm T} = |\delta T_{\rm eff}/T_{\rm eff}|$ and phase difference ψ_T between the local effective temperature perturbation and the radial displacement

ℓ /n	$\alpha = 0.5$	$\alpha = 1$	$\alpha = 1.8$
0/1	12.075113	12.075111	12.081506
$1/-1$	12.351574	12.351570	12.357858
$2/-3$	10.268694	10.268703	10.269958
$3/-4$	10.952943	10.952997	10.958246

Table 5. Theoretical frequencies (cycles per day) calculated from each model in Table 3.

are computed with our non-adiabatic pulsation code. These two quantities are basic ingredients for the determination of the amplitude ratios and phase differences between different photometric passbands (Dupret et al. (2003)). Their accurate determination is crucial for the photometric identification of the mode degree ℓ. An important problem to address is the effect of our TDC treatment on the amplitudes and phases.

Figure 1 shows the $f_{\rm T}$ and ψ_T obtained for different values of the mixing length parameter α (from top to bottom $\alpha = 0.5$, 1, 1.8) and for different TDC treatement: TDC1 and TDC2 (for more details see Grigahcène et al. (2004)) compared with the Frozen Convection (FC) calculations. As can be seen both quantities show a great sensitivity to the α value. The larger is the value of α the larger is the separation between the TDC treatment results and FC results. There is no great difference between TDC1 and TDC2.

In Fig. 2 are displayed $(b-y)/y$ as function $\Phi(b-y) - \Phi(y)$ (left) and $(v-y)/y$ as function of $\Phi(v-y) - \Phi(y)$ (right) for $\ell =$ 0-3 modes and for the model with $\alpha = 1.8$ (Strömgren photometry). Confrontation between theory and observation enables mode identification. For F2 and F3, the best agreement with observation is obtained for radial modes, but $\ell = 1$ mode could not be totally eliminated (left panel in Fig. 2). The frequency F4 may be $\ell = 2$ or $\ell = 3$.

4.2. Seismological study considering rotation

The effects of rotation have been considered up to second order (including thus the effects of coriolis and centrifugal forces) for the computation of the adiabatic oscillations using the code FILOU (Suárez (2002)).

We analyse here the possibility that the observed frequencies belong to a rotational splitting coming only from one component. Therefore, the "observed" rotational splitting around 4 μHz would suppose a rotational velocity around 40 km/s (that is, i around 45 deg) for a typical 1.8 $M_\odot$ δ Scuti star with a radius of 2.30 $R_\odot$.

Decreasing the inclination angle up to the values shown in Table 4, equivalent to increase the rotational velocities indicated in the same table, no match between the observed and theoretically calculated frequencies was possible. New spectroscopical observations carried out in (Frémat et al. (2004)) will allow us to identify the stellar component(s) actually pulsating. Details of this theoretical analysis are being now in progress.

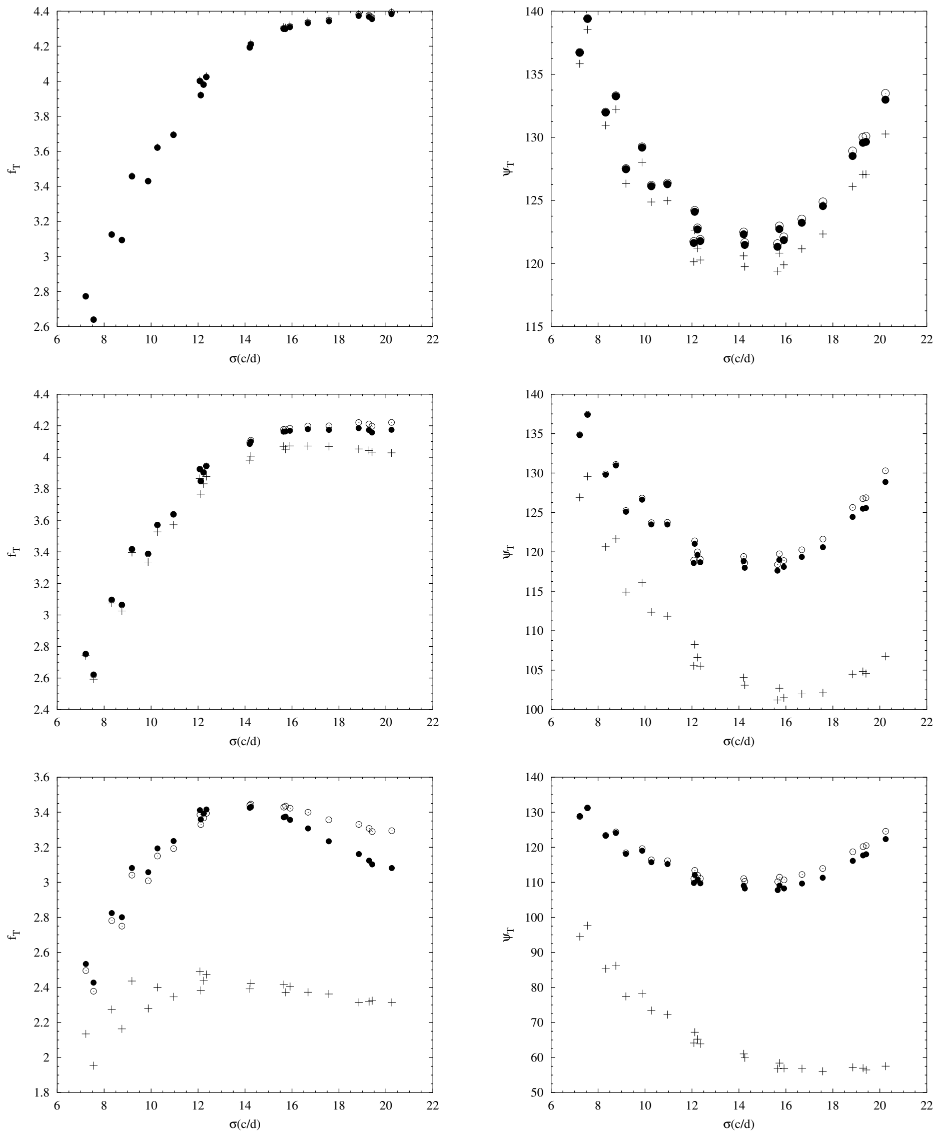

Figure 1. f_T (left) and ψ_T (right) as function of frequency for $\ell = 0$-3 modes and for different models: TDC1 (•): $\frac{\delta l}{l} = \frac{\delta H_p}{H_p}$, TDC2 (⊙): $\frac{\delta l}{l} = \frac{1}{1+(\sigma\tau_c)^2}\frac{\delta H_p}{H_p}$ compared with FC calculations (+). From top to bottom $\alpha = 0.5$, 1, 1.8.

5. Preliminary Conclusions

- Using the TDC treatment and color photometry as a tool for mode identification, we can say that the b-y/y and v-y/y graphics show that probably 2 modes with very close frequencies are $\ell = 0$.

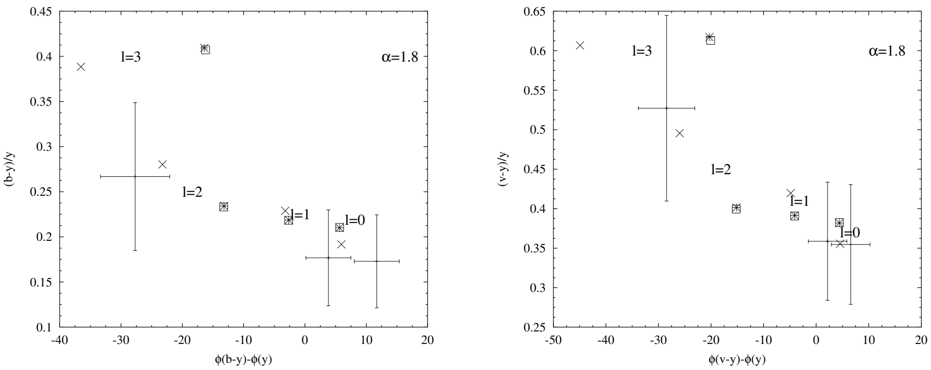

Figure 2. $(b-y)/y$ as function $\Phi(b-y)-\Phi(y)$ (left) and $(v-y)/y$ as function of $\Phi(v-y)-\Phi(y)$ (right) for $\ell = 0$-3 modes and for the model with $\alpha = 1.8$. Theoretical results: TDC1 ($*$), TDC2 ($\Box$) and FC ($\times$) are given for different values of ℓ and $\alpha = 1.8$ model. The observed amplitude ratios and phases are given for three frequencies with error bars.

- The observed frequencies difference between F2 and F4 is much smaller than the theoretical difference between the p_1 and p_2 radial modes. Is there some possibility that 2 stars oscillate in the radial mode ?
- In this work we assumed F4 to be the p_1 radial mode (which lead to a mass of 1.8 $M_\odot$). We will investigate in future work the results obtained fitting the $\ell = 0$ p_2 mode (which could lead to higher mass, ...).
- We find no evidence for considering the observed frequencies as a rotational splitting of a single component of the system. However, exhaustive conclusions are very hard to establish. New spectroscopic observations will help in identify the pulsating component allowing a better modeling.

References

Dupret, M.-A., De Ridder, J., De Cat, P. et al. 2003, A&A, 398, 677
Dupret, M.-A., Grigahcène, A., Garrido, R. et al. 2004, A&A, 414, L17
Frémat, Y., Lampens, P., Hensberge, H. et al. 1999, The Evolution of Galaxies on Cosmological Timescales ASP Conference Series, Vol. 187, 1999 J. E. Beckman, and T. J. Mahoney, eds.
Frémat, Y., Lampens & P., Hensberge, H., submitted to MNRAS
Grigahcène, A., Dupret, M.-A., Garrido, R. et al. 2004, In: JENAM Minisymposium in Asteroseismology, eds. Z. Kollath & G. Handler, CoAst, 145, 9
Lampens, P., Frémat, Y., Garrido, R. et al., submitted to A&A
Morel, P. 1997, A&A, 124, 597
Suárez, J. C. 2002, PhD.: Sismology of stars in rotation. Application to δ Scuti stars (University Paris 7 (Denis Diderot))