A COROT VIEW OF THE ζ AUR BINARY HR 6902

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1. INTRODUCTION

Rationale

HR 6902 is a long period (~385^d), double-lined eclipsing binary belonging to the ζ Aur class. That denotes binaries formed of a late-type giant and a hot dwarf, which are characterized by a composite spectrum showing the superimposed features of both components. These systems, and especially the eclipsing pairs (EB-SB2), are excellent benchmarks of stellar evolutionary models (e.g. Claret 2009 and references therein).

Lately, giants in EB-SB2 have also found another important application, as test objects to validate the asteroseismic "scaling relations", that hold for the solar-like pulsations. These link some, easy-to-determine, global properties of oscillations to the mass and radius of the pulsator, and have widely been used in the study of galactic populations (ensemble asteroseismology, eg. Miglio et al. 2013). Their validity-domain and accuracy is still matter of debate (Huber et al.2012; Baines et al. 2014; Gaulme et al. 2016). HR 6902, with a primary giant component of ~ 4 $M_\odot$, could provide such a test, if pulsations were detected, in an unexplored mass range.

CoRoT photometry and spectroscopic data

HR 6902 was observed in the CoRoT asteroseismic field in two long runs (LRc04 and LRc10). Each run lasted ~ 90 continuous days and provided ~200 000 points with sampling of 32^s and a very high accuracy (0.03%). The radial velocity curves were obtained from extant and unpublished observations by R.E. Griffin and collaborators, with the Cambridge photoelectric radial velocity spectrometer and the Coudé spectrograph @1.2-m DAO telescope, and thanks to an ESO large program (P.I. E. Poretti) with the HARPS spectrograph @ 3.6m ESO telescope.

Details of the light curve treatment: after sigma clipping of the outliers, the curves were detrended by dividing: for the LRC04 curve a linear fit of the out-of-eclipse section, for the LRc10 curve a linear law minimizing the scatter in the phase interval in common with LRc04. For the light curve solution, the resulting curve was binned in bins of 0.4^d and 0.03^d (in- and out-of-eclipse sections, respectively).

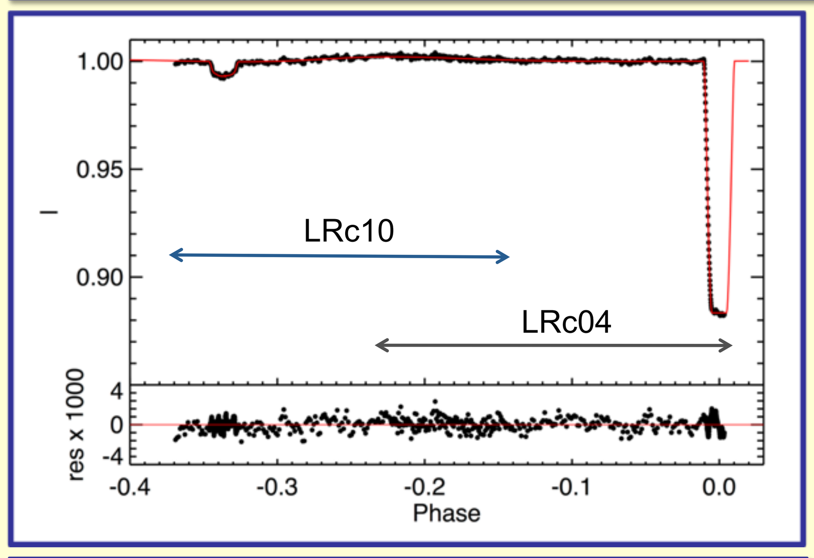


FIG.1. Detrended, binned, and phased light curve of HR6902 for LRC04 and LRc10 and the final fit in red. The residuals, much larger than the photometric accuracy, are assumed to be due to solar-like pulsations.

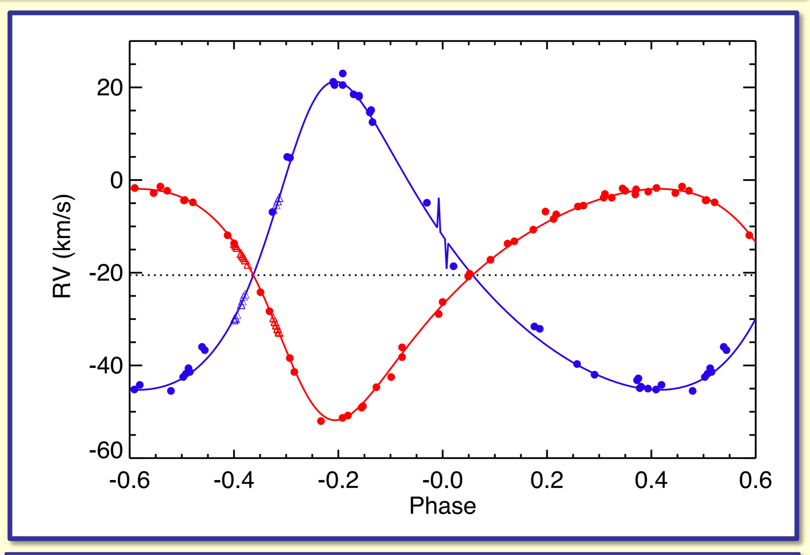
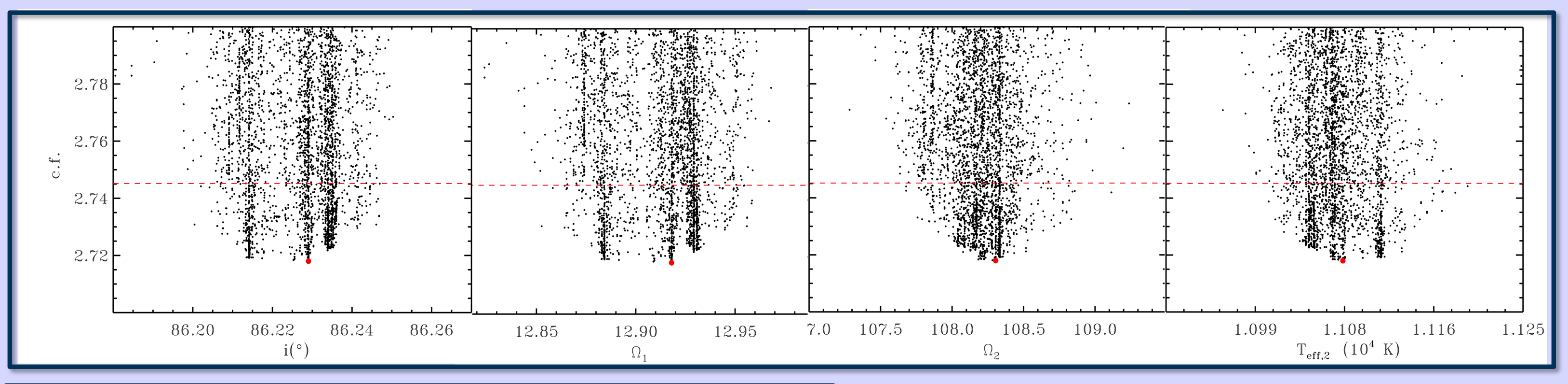


FIG.2. Radial velocity curves of HR 6902 and their fits, the filled symbols correspond to observations by Griffin and collaborators, the open triangles to those by Poretti and collaborators with HARPS (June 2012).

2. DETERMINATION OF THE PHYSICAL ELEMENTS

Preliminary non-simultaneous light and radial velocity curve fits were performed by differential correction with PHOEBE (Prša & Zwitter 2005). The global minimum of the cost function (sum of the squared residuals) was then found with FITBINARY (Maceroni et al. 2014), a wrapper connecting the genetic algorithm PIKAIA (Charbonneau 1995) to the PHOEBE binary modeling code. Different FITBINARY runs were performed for the LC and the RV data.



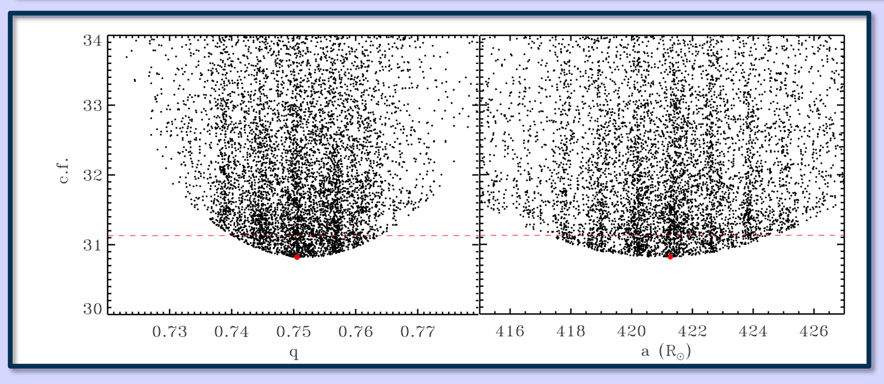


FIG.3 FITBINARY results. Top figures: light curve fit: cost function value vs inclination, potentials and secondary effective temperature. The minimum value is indicated by a red larger dot. The red broken line corresponds to a 1% increment of the cost function minimum value, which was used to define uncertainties. Left figures: cost function value vs mass ratio and semi-mayor axis from the radial velocity fit.

Table 1. Orbital and physical parameters of HR 6902

	Primary	System	Secondary
P (d)		384.959 ± 0.001	
i (deg)		86.223 ± 0.007	
e		0.315 ± 0.002	
ω (deg)		144.02 ± 0.016	
q		0.750 ± 0.007	
a ($R_\odot$)		421 ± 3.5	
γ (kms^{-1})		-20.50 ± 0.04	
T_{eff} (K)	4804 ± 70		11073 ± 500
M ($M_\odot$)	3.87 ± 0.13		2.90 ± 0.14
R ($R_\odot$)	35.7 ± 0.5		2.97 ± 0.04
log g	1.92 ± 0.02		3.96 ± 0.02

Table 2. Atmospheric parameters from spectra

	Primary	Secondary
T_{eff} (K)	4804 ± 70	11900 ± 1000
log g	1.81 ± 0.4	3.8 ± 0.2
v sin i (kms^{-1})	6.5 ± 1.0	14 ± 2
[Fe/H]	0.15 ± 0.13	

Details of the LC fit: in PHOEBE we adjusted inclination, surface potentials, secondary T_{eff}, primary luminosity (for LC fit), mass ratio, system semi-axis and velocity (RV fit), eccentricity and periastron longitude (iteratively between the two data sets).
Assumed values in the LC fit:
- $T_{eff,1}$ from spectroscopy
- Albedo (A) and gravity darkening (β) fixed at the theoretical values (A = 0.5/1.0 and β = 0.32/1.0 for primary/secondary, respectively)
- square root limb darkening law
- chemical composition and v sin *i* from spectra analysis

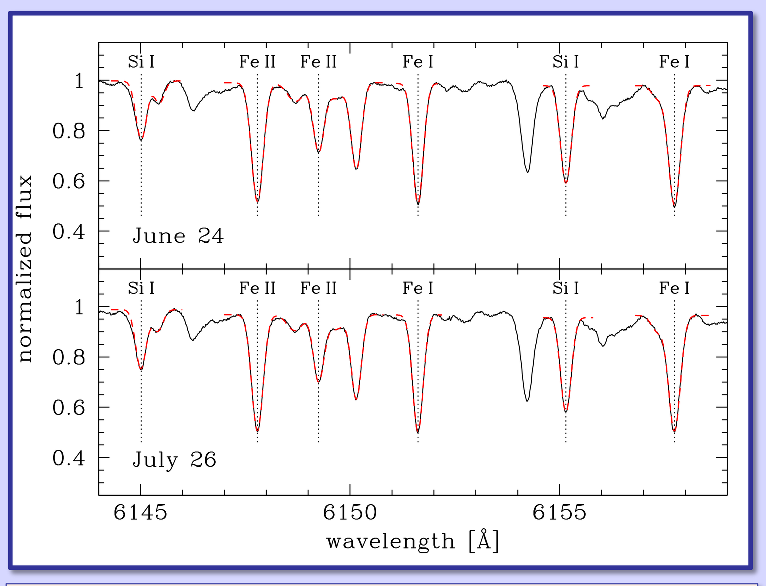


FIG.4 Fit of the spectra obtained with HARPS, strongly dominated in the displayed range by the giant component. Spectra obtained the same night were Doppler shifted and summed. The final S/N @ 5500 Å is ~500.

3. ASTEROSEISMIC ANALYSIS

Scaling relations

The oscillation spectrum of solar-like pulsators (as G-K red giants) can be described by two global parameters, the frequency at the maximum power, ν_{max}, and the mean frequency separation between consecutive radial modes, $\Delta\nu$. These quantities, combined with an estimate of T_{eff}, allow to estimate the star surface gravity and mean density with respect to the sun (Ulrich 86; Brown et al.1991; Kjeldsen & Bedding 1995; Belkacem et al. 2011), as :

$$\frac{g}{g_\odot} = f_{\nu_{max}} \frac{\nu_{max}}{\nu_{max,\odot}} \left(\frac{T_{eff}}{T_{eff,\odot}}\right)^{1/2} \qquad \frac{\rho}{\rho_\odot} = f_{\Delta\nu} \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^2$$

$f_{\nu max}$ and $f_{\Delta\nu}$ represent correction factors to be estimated/calibrated for stars different from the Sun. The current knowledge of excitation/damping of solar-like oscillations does not allow a forward estimate of $f_{\nu max}$, but empirical tests such as comparisons between seismic and spectroscopic log g (e.g. Morel et al. 2014), or values from binary systems (Brogaard et al. 2015; Gaulme et al. 2016), have shown that $f_{\nu max} \approx 1$. On the contrary, $f_{\Delta\nu}$ can be estimated from theoretical calculations, and results to depend on stellar mass, effective temperature, evolutionary state, chemical composition, and even on the method used to estimate the reference value (Rodrigues et al. 2017, Huber et al 2017 and references therein). The scaling relations for M and R are :

$$\frac{R}{R_\odot} = f_{\nu_{max}} \frac{\nu_{max}}{\nu_{max,\odot}} \left(f_{\Delta\nu}\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2} \left(\frac{T_{eff}}{T_{eff,\odot}}\right)^{1/2} ; \qquad \frac{M}{M_\odot} = \left(\frac{R}{R_\odot}\right)^3 \left(\frac{f_{\Delta\nu}\Delta\nu}{\Delta\nu_\odot}\right)^2$$

Independent determination of mass and radius for giants indicate an accuracy of 5-11% for the asteroseismic radius (Miglio 2012; Huber et al 2017; Gaulme et al. 2016) and 10-25% for the mass (White et al. 2011; Miglio et al.2013; Brogaard et al. 2016; Gaulme et al. 2016). To be noticed that most targets studied in these works are stars of low-mass (<2 $M_\odot$) and relatively small radius (0.8 - 15 $R_\odot$).

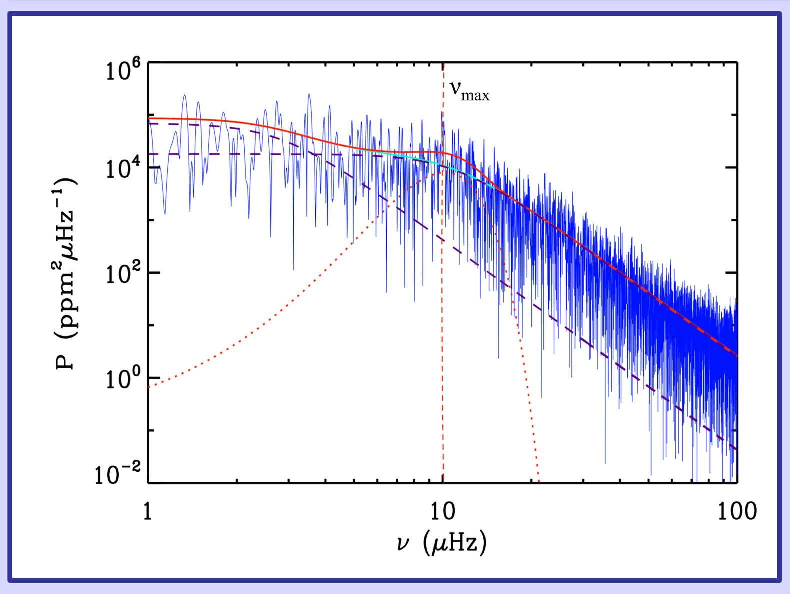


FIG. 5 Power spectrum of HR 6902 fitted with two background components (dashed lines) and a Gaussian excess power centered on ν_{max} (dotted line).

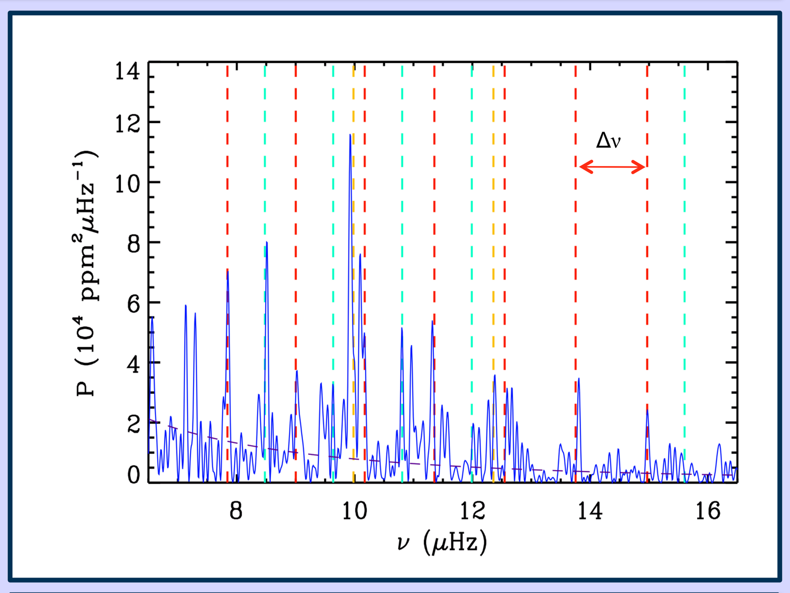


FIG. 6 Identification of the low-degree oscillation spectrum (radial modes in red, dipole modes in light blue, quadrupole modes in orange). The dashed violet line indicates the background.

Analysis of the RG solar-like pulsation

The residuals of the light curve solution were analyzed to detect pulsations. The power spectrum of Fig.5 was fitted with two background components and a Gaussian excess power law, and the "universal red giant oscillation pattern" (Mosser et al. 2011) was used to derive $\Delta\nu$. That yielded:

ν_{max} = 10.2 ± 0.4 μHz $\Delta\nu$ = 1.17 ± 0.01 μHz ;

and, hence:

log g = 1.92 ± 0.09; ρ= (7.5 ± 0.2) 10^{-5} $\rho_\odot$; M_g = 4.7 ±1 $M_\odot$; R_g = 39.5 ± 2.5 $R_\odot$

The comparison with Table 1 confirms and extends the results of Gaulme et al. (2016) to a high mass giant in a wide binary (the Red Giant fractional radius is ~0.08), namely:
- the asteroseismic mass and radius are overestimated by about 20 and 10 %, respectively
- the gravity is in excellent agreement with the dynamical value, while density results to be smaller by ~ 10%.

4. CONCLUSIONS

The unprecedented accuracy of the CoRoT photometry allowed:
- to drastically improve the accuracy of the binary orbit and star parameters (by a factor ~ 10 for the radii)
- to extend the test of validity/calibration of the scaling relations to high mass and radius, and possibly evolutionary state (and with a binary certainly free from tidal effects).

A work still in progress

We could extract the individual frequency values for radial, dipolar and quadrupole modes. We plan to compare these results with the theoretical models best fitting the stellar parameters (masses, radii and age) and the oscillation features, and put constraints on the giant structure and evolutionary state.
We also plan to check the possible signature of acoustic glitches (Miglio et al. 2010) suggested by the modulation with respect to the second order asymptotic pattern (Mosser et al. 2013), see Fig7.

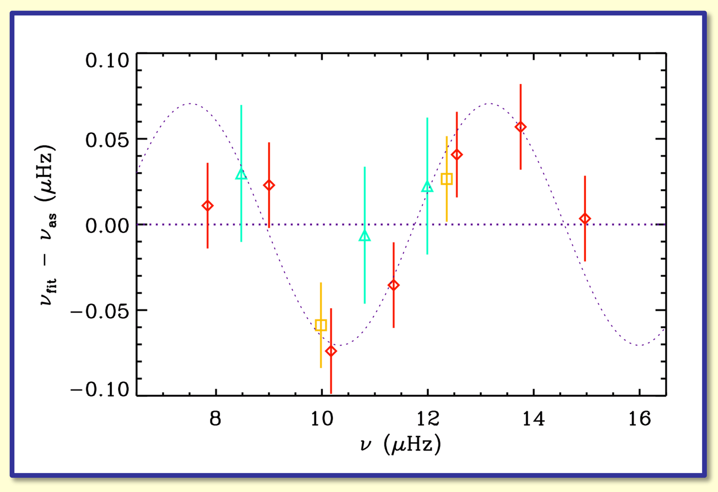


FIG. 7 The modulation between the fitted modes and the second-order asymptotic pattern suggests the signature of acoustic glitches. They account for the modulation typically observed in red giants and are related to the signature of the second He ionization zone.

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