Solar-like oscillations in distant stars as seen by CoRoT : the special case of HD 42618, a solar sister

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Abstract. We report the observations of a main-sequence star, HD 42618 ($T_{\rm eff}$ = 5765 K, G3V) by the space telescope CoRoT. This is the closest star to the Sun ever observed by CoRoT in term of its fundamental parameters. Using a preliminary version of CoRoT light curves of HD 42618, p modes are detected around 3.2 mHz associated to $\ell = 0$, 1 and 2 modes with a large spacing of 142 μHz. Various methods are then used to derive the mass and radius of this star (scaling relations from solar values as well as comparison between theoretical and observationnal frequencies) giving values in the range of $(0.80 - 1.02)M_\odot$ and $(0.91 - 1.01)R_\odot$. A preliminary analysis of $\ell = 0$ and 1 modes allows us also to study the amount of penetrative convection at the base of the convective envelope.

1. Introduction

Solar-like oscillations are stochastically excited by convection in the outer layers of the star. They are produced in all stars with an external convective envelope. In the case of main-sequence stars, mode periods are typically a few minutes with amplitudes of the order of cm/s in spectroscopic data or of ppm in photometric data. Space photometry proved to be an efficient technique for measuring and characterizing these oscillations.

CoRoT (COnvection ROtation and planetary Transits) (Baglin et al. 2006) is a space mission built and operated by the French space agency (CNES) with the participation of ESA, Austria, Belgium, Brazil, Germany and Spain. It was designed to do ultra high-precision relative photometry. It has two scientific objectives: to detect stellar oscillations to probe the interior of stars and to detect small planets around distant stars through their transit. CoRoT was launched on Dec. 27, 2006 and since then it has observed about 150 bright stars and about 150 000 faint ones (11<V<16).

One of the scientific objectives of CoRoT is to detect and interpret solar-like oscillations in main-sequence stars (see e.g. Baglin et al. 2012 and Michel et al. 2012 for recent reviews of CoRoT results). We will focus here on HD 42618 a star observed by CoRoT with fundamental parameters very close to the solar ones.

2. Spectroscopic parameters of HD 42618

HD 42618 is one of the main CoRoT targets for the search for solar-like oscillations. It is a main-sequence star (G3V) whose properties are very similar to the Sun except for its metallicity (Morel et al. 2013), see table 1.

Table 1. Some fundamental parameters of HD 42618 obtained by Morel et al. (2013).

$T_{\rm eff}$	5765 ± 17 K	logg	4.48 ± 0.04
[Fe/H]	-0.10 ± 0.02	vsini	< 3 km/s

3. Analysis of CoRoT seismic data of HD 42618

HD 42618 has been observed by CoRoT during two long observing runs spanning 79 and 94 days, respectively. Data analysis of a preliminary light-curve version is presented here.

A Fourier analysis of the light curves shows an excess power around $\nu_{\rm max}$=(3.2 ± 0.1) mHz as well as a clear series of peaks in the power spectrum, very similar to the solar spectrum (figure 1). By cutting the power spectrum in several pieces and stacking them in order to build an échelle diagram, $\ell = 0$, 1 and 2 modes are detected (figure 2) showing a large spacing of $\Delta\nu$=(142 ± 1) μHz.

4. First interpretations of seismic data of HD 42618

Seismic data can be used to derive some global properties of the star such as its mass and radius. These two parameters are derived from the large spacing ($\Delta\nu$) and the frequency at maximum oscillation power ($\nu_{\rm max}$) using scaling relations (e.g. Kjeldsen & Bedding 1995, Kallinger et al. 2010, Chaplin et al. 2011, Belkacem et al. 2011). Using $T_{\rm eff,\odot} = 5777$ K, $\nu_{\rm max,\odot}$=(3.09 ± 0.03) mHz and $\Delta\nu_\odot$=(135.1 ± 0.1) μHz as in Huber et al. (2011), we found $M = (0.9 \pm 0.1)\ M_\odot$ and $R = (0.94 \pm 0.03)\ R_\odot$.

Another way to derive global properties of a star is by comparing theoretical oscillation mode frequencies to the observed ones. By using the Asteroseismic Modeling Portal (AMP, Metcalfe et al. 2009, Mathur et al. 2012), a mass of $M = (0.99 \pm 0.01)\ M_\odot$ and a radius of $R = (0.96 \pm 0.01)\ R_\odot$ with an age of (3.84 ± 0.12) Gyr have been found for HD 42618. Using Cesam2k (Morel et Lebreton 20008), we found $M = (1.00 \pm 0.02)\ M_\odot$ and $R = (0.99 \pm 0.02)\ R_\odot$. These values are in agreement with the ones found from scaling relations. We stress that these

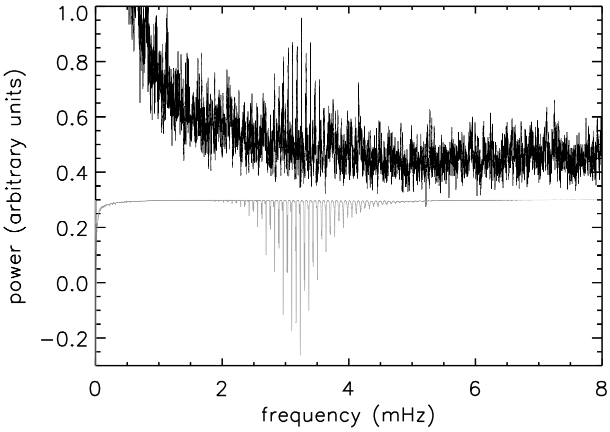

Figure 1. Top: Power spectrum of 175 days of COROT data obtained on HD 42618. Bottom: Power spectrum (upside down) of 175 days of solar data obtained by SOHO/GOLF. The two power spectra have been smoothed over 100 bins ($\sim 7\mu$Hz).

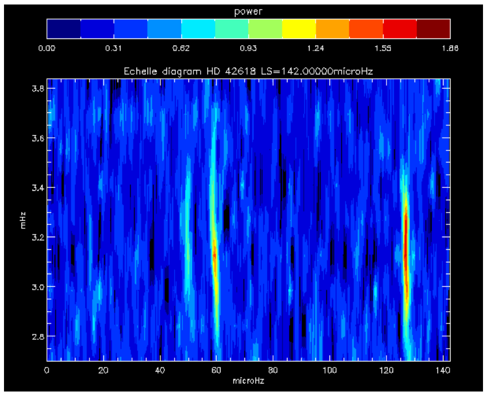

Figure 2. Echelle diagram computed from a smoothed version of the power spectrum of COROT data obtained on HD 42618 assuming a large spacing of 142 μHz.

results have been obtained for a given set of input physics; more detailed modelling studies are in progress.

Other preliminary results have been obtained regarding the penetrative convection at the base of the convective envelope. Using Cesam2k evolutionary code (ESTA version, Morel et Lebreton 2008) and the ADIPLS pulsation code (Christensen-Dalsgaard 2008), theoretical frequencies have been computed for HD 42618.

Figure 3 shows the seismic indices $rr01$ and $rr10$ frequency combination based on $\ell = 0$ and $\ell = 1$ modes as defined in Roxburgh (2009). The observations reveals a clear oscillation of these quantities with the frequency. The same seismic indices for two stellar models are also plotted for comparison. One model includes convective penetration below the convective envelope computed following Zahn (1991)'s prescription. In that approach, the amount (i.e. radial extent) of convective penetration is represented by an adimensionned free parameter ξ. When no penetrative convection is included ($\xi = 0$), the corresponding model in Fig.3 does not show any oscillation unlike what is observed for HD42618. On the other hand, when enough penetration is included ($\xi = 1.5$), the model does show an oscillation similar to that of HD42618. No effort has been made here to fit the data. Rather we illustrate the fact that the presence of some connvective penetration is able to reproduce the $rr01, rr10$ oscillation for HD52618. Neither the phase nor the amplitude and the period are really reproduce by the $\xi = 1.5$ model. A minimisation must be performed to optimise the modelling and fit the data (work in progress). These results nevertheless tend to indicate that a larger amount of convective penetration is necessary, larger than for the Sun and another star HD52265 (Lebreton, Goupil, 2012).

5. Conclusions and perspectives

Oscillations, like the famous 5 min oscillations of the Sun, have been observed in many stars thanks to the space missions COROT (CNES) and *Kepler* (NASA, Borucki et al. 2010). Among them is HD42618 ($T_{\rm eff} = 5765$ K, G3V), a solar sister observed by CoRoT. P modes are detected with a frequency at maximum power of 3.2 mHz and a large spacing of 142 μHz. These data obtained on HD 42618 are already very promising to test stellar models.

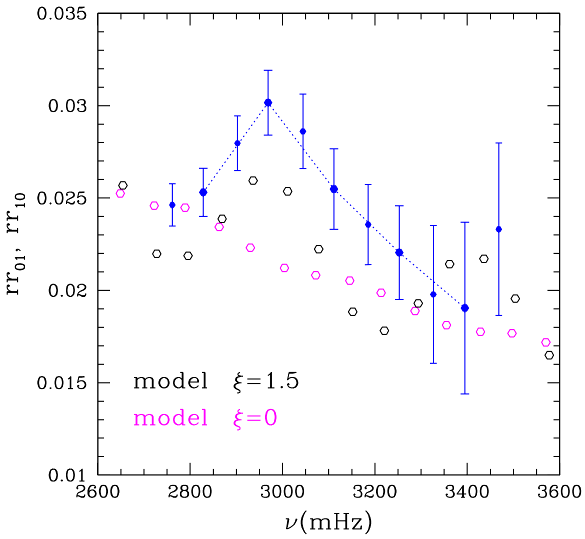

Figure 3. In blue, observed ratios $rr_{01/10}$, a seismic indicator based on $\ell = 0$ and $\ell = 1$ modes (Roxburgh 2009), as a function of mode frequency for the CoRoT data obtained on HD 42618. In black and magenta, modelled ratios $rr_{01/10}$ without ($\xi = 0$) and with penetrative convection ($\xi = 1.5$). See Lebreton & Goupil (2012) for more details.

Futur space missions are foreseen to study solar-like oscillations in main sequence stars. Among them, PLATO (PLAnetary Transits and Oscillations of stars) is a a medium class (M class) mission studied in the framework of the ESA Cosmic Vision 2015-2025 program (e.g. Rauer & Catala 2012). The objectives of this mission are to detect Earth Analogue systems around bright stars, and to reveal the interior structure of planets and their host stars.

5.1. Acknowledgments
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