How asteroseismology can help to precisely constrain properties of planet-host stars

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ABSTRACT: Nowadays more than 500 exoplanets have been discovered, mainly studied by radial velocity and transit measurements. Precise knowledge on their characteristics is crucial to develop theories of planetary formation and evolution. In that aim, not only star and planet(s) masses but also the evolutionary stage of systems are needed. From radial velocity measurements one has to assume the inclination and the stellar mass of the system to disentangle the mass of the planet. When transit is observable, one can measure the ratio of planetary and stellar radii. Finally, the degree of evolution of the system is determined by the one of the star. Thus the host star must be well known to obtain a full set of system properties. However, determination of stellar parameters such as the mass, radius and its evolution from classical observables (Teff, log g, [Fe/H]) suffers of large uncertainties. This is particularly true for dwarf stars on the Main Sequence. Fortunately we can obtain better constrains with the help of asteroseismology. That latter approach probes the stellar properties through observation of oscillations present in stars. With the launches of high-precision photometry space missions, CoRoT and Kepler, we are now able to detect oscillations in a huge number of stars. In particular Kepler photometry, primarily intended to detect transits of planet, can give accurate stellar parameters of planetary systems as it also affords to make asteroseismology. We propose to review different applications of asteroseismology that have already been done on stars hosting planets.

1. Setting the stage: basics on planetary systems

From radial velocity (RV) measurements:

$$M_p \sin i \propto f(P, e, K_*) \times (M_* + \cancel{M_p})^{2/3} \quad (\ll M_*)$$

where M_p, i, P and e are resp. mass of the planet, inclination, period and eccentricity of the planetary orbit and K_* the stellar velocity semiamplitude, all but M_p and i being obtained from RV (see e.g. Torres et al. 08, AJ 677). The mass of the star M_* has to be inferred!

If transit is observable, one gains additional constrains:

$$DF = \left(\frac{R_p}{R_*}\right)^2$$

Limb-darkening!!

$$f(d, t, DF, \omega, e) \propto \frac{a}{R_*} \propto f(P) \times \frac{(M_* + \cancel{M_p})^{1/3}}{R_*} \propto <\rho_*> \quad (\ll M_*)$$

$$f(b, a/R_*, e, \omega) \propto i$$

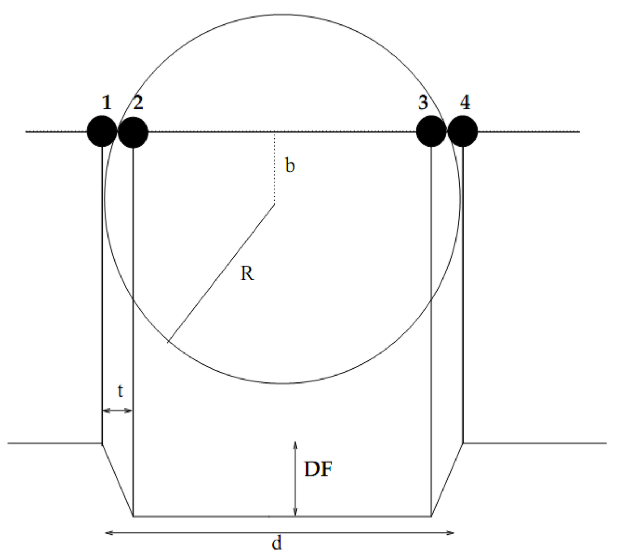

Fig. 1 Schematic representation of a transit. Adapted from Moutou & Pont 05, CNRS school XXVIII.

where R_p/R_* is the ratio of the planetary to the host star radii and ω is the argument of periastron, measured by RV. Other quantities are defined in Fig. 1. Derivation of the above relations can be found in Winn 10 (Transits and occultations, chapter book of "EXOPLANETS") and ref. therein. The radius of the star R_* has to be inferred!

➡ Information on stellar parameters is required to characterize exoplanets

2. Determining the fundamental stellar parameters

Usually, mass, radius and age of planet host stars are derived from stellar models by fitting of the observed quantities: *log g*, T_{eff} and *metallicity*. These atmosphere parameters are derived from spectroscopy or narrow band photometry, with typical respective errors of $\sigma_{\log g}$=0.20, $\sigma_{T_{eff}}$ =200 K and $\sigma_{[Fe/H]}$=0.10 dex.

On the other hand, the characteristics of a planet transit (see Sect.1) allow to derive the mean density $<\rho_*>$ of the host star with a precision of 0.10 g/cm³ which allows to significantly reduce error bars on stellar parameters (Fig. 2 and Fig. 3).

➡ {Log g, Teff} vs {$<\rho_*>$, Teff}

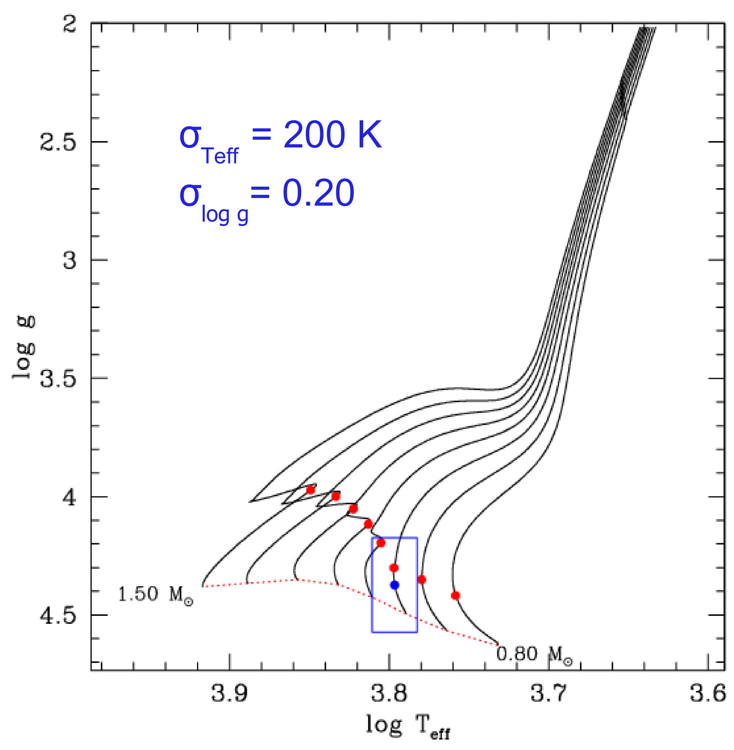

Fig. 2 Evolutionary tracks of models with masses between 0.8 and 1.5 M⊙ (step 0.1 M⊙), solar mixture, X=0.70 and Z=0.01 in a *log g*-T_{eff} diagram. The red dotted line represents the Zero Age Main Sequence (ZAMS). The red dots indicate models with *Xc*=0.10. Blue dot and box represent a model in the middle of the MS and typical observational errors.

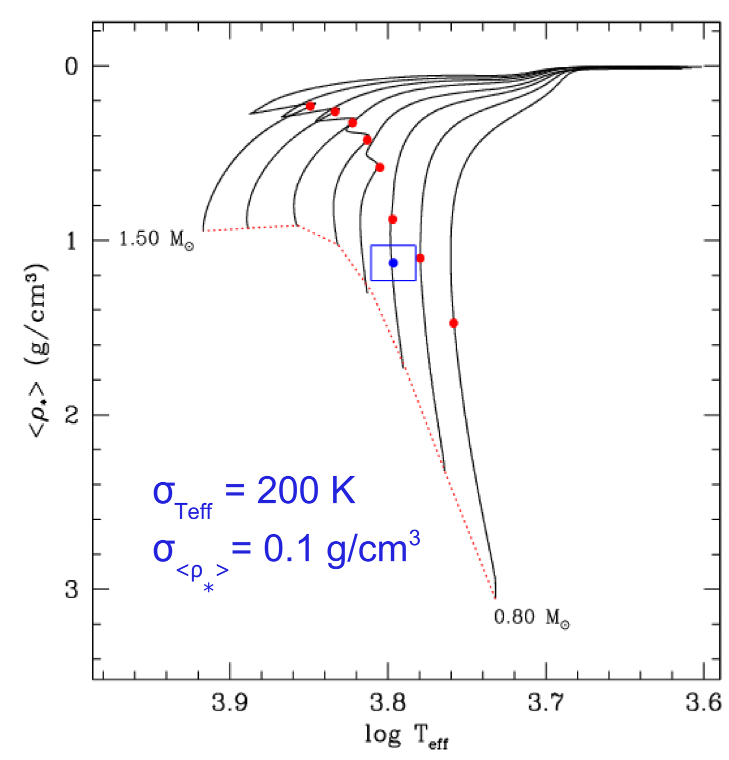

Fig. 3 As Fig. 2 but now in a $<\rho_*>$-T_{eff} diagram.

In Fig. 4 and Fig. 5 are resp. compared *log g* and $<\rho_*>$ used as a proxy for the age of a 1M⊙ star with a solar mixture, X=0.70 and Z=0.01. While *log g* estimation and its errors cover a large range of the evolutionary track, uncertainties on $<\rho_*>$ span on a smaller age interval, as illustrated in Fig. 4 and Fig. 5. Typical spectroscopic and narrow band photometric errors induce large uncertainties on the age, up to 100% of error, see for e.g. Gillon et al. 10, A&A 511.

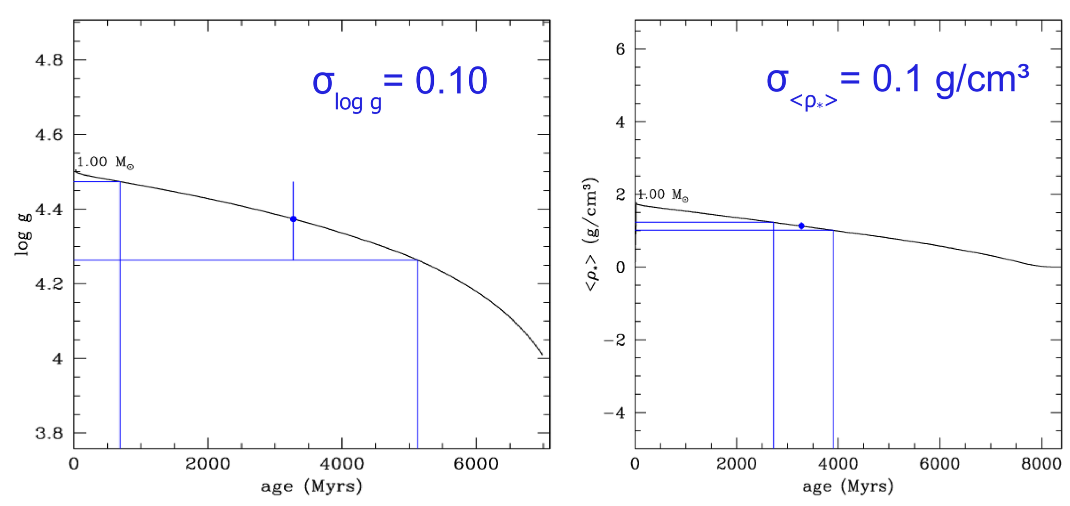

Fig. 4 & 5 To the left (resp. right) beside: evolutionary track of a 1 M⊙ model represented according to *log g* (resp. $<\rho_*>$) vs age. The location of a model at the middle of the MS evolution is represented in the *log g* (left) and $<\rho_*>$ (right) plots with corresponding representative error box.

3. Unveiling host-stars from solar-like oscillations

Asteroseismology can help to access the stellar information. Stellar frequencies of oscillation are defined by three numbers: *n* the radial order, *l* the angular degree and *m* the azimuthal order. In particular for solar-like oscillators (~0.80 to 1.50 M⊙), the frequency spectra show a regular pattern (Fig. 6) mainly characterized by :

$$< \Delta\nu > \propto < \rho_* >^{1/2}$$

$$\delta\nu_{02} = \nu_{n,0} - \nu_{n-1,2} \quad \text{and} \quad < r_{02} > = \frac{< \delta\nu_{02} >}{< \Delta\nu >}$$

where $<\Delta\nu>$ is the large separation (Tassoul 80, ApJS 43), related to the mean stellar density. Combined to $<r_{02}>$, these seismic diagnosis tools help to constrain fundamental stellar parameters as shown in asteroseismic diagram in Fig. 7.

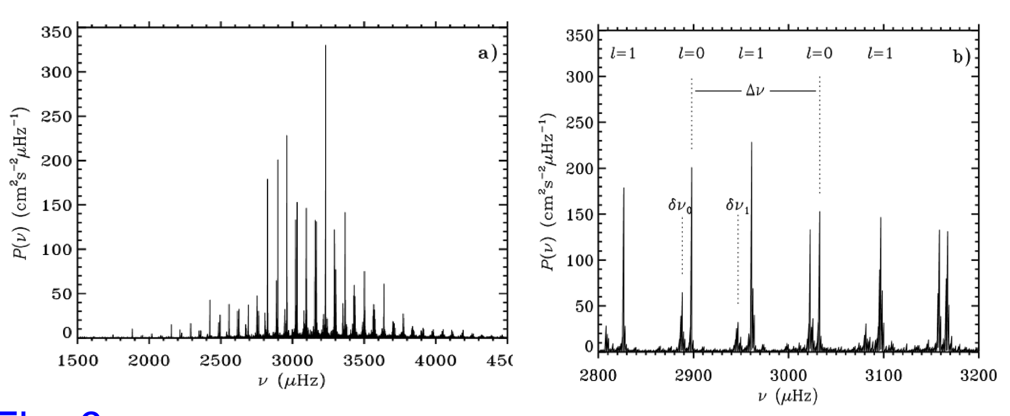

Fig. 6 To the left : power spectrum of oscillations in the Sun. To the right: zoom in the 2800-3200 µHz region of the power spectrum. Angular degree of modes are labelled and large and small separations represented. Figures are from Christensen-Dalsgaard, "Asteroseismology" lecture notes.

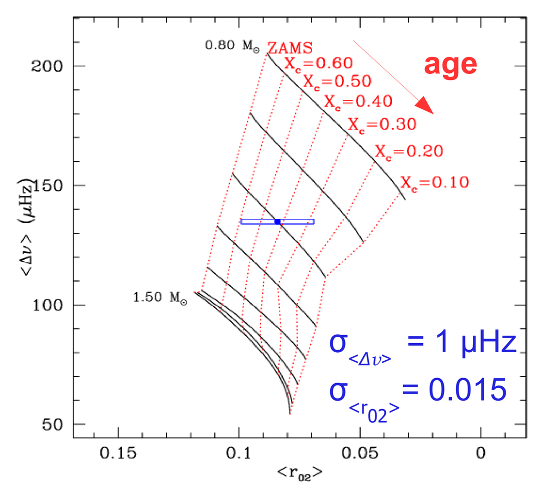

Fig. 7 Evolutionary tracks for models from 0.80 to 1.50 M⊙ (step 0.10M⊙) with X= 0.70 & Z=0.01 in a $\Delta\nu_0$ vs $<r_{02}>$ plot. $<r_{02}>$ is defined as Mazumdar 05, A&A 441. Adiabatic frequencies are computed with LOSC (Liège OScillation Code).

Solar-like pulsations can further constrain stellar parameters particularly from the determination of $\delta\nu_{02}(n)$ that gives information on the evolutionary state (or age) of Main Sequence stars, e.g. Miglio & Montalbán 05, A&A 441. In Tab.1, relative errors on stellar mass and radius for known exoplanetary systems are obtained resp. from classical determination and from fitting to individual frequencies, being cautious to surface effects.

Relative error on	M (spectro)	R (spectro)	M (seismo)	R (seismo)
HAT-P-7 [1,2]	44 %	9 %	2 %	1 %
HD 46375 [3,4]	15 %	4 %	5 %	3 %
µ Arae [3,5]	8 %	1 %	2 %	4 %
HD 17156 [6,7]	8 %	10 %	2 %	<1 %

Tab. 1 References are [1] spectro from Pál et al. 08, AJ 680 - [2] seismo from Christensen-Dalsgaard et al. 10, ApJ 713 - [3] spectro from Valenti & Fischer 05, ApJS 159 - [4] seismo from Gaulme et al. 10, A&A 524 - [5] seismo from Soriano & Vauclair 10, A&A 513 - [6] spectro from Fischer et al. 07, AJ 669 - [7] seismo from Gilliland et al. 11, ApJ 726

4. Other types of stellar pulsations

•HR 8799 is a system with 4 known "exoplanets" (Marois et al. 10, Nature, in press) and exhibing a debris disk. Determining estimate of the age of this system is of prime importance to understand how it formed and to determine its nature. As illustrated in Fig. 8 for the members of HR 8799 system, an age > ~300 Myrs would mean they are brown dwarves while earlier age, planets. Its host-star shows 3 freq of pulsation identified as γ Dor-like (Zerbi et al. 99,MNRAS 303). A first seismological study shows than 2 families of models reproduce observed freq. One has ages <400 Myrs and the other >1100 Myrs (Moya et al.10a,b; MNRAS 405;MNRAS 406). Refined seismological analysis based on more and more precise frequencies is essential to get a good estimation of the age of the system and hence distinguish the nature of these 4 objects.

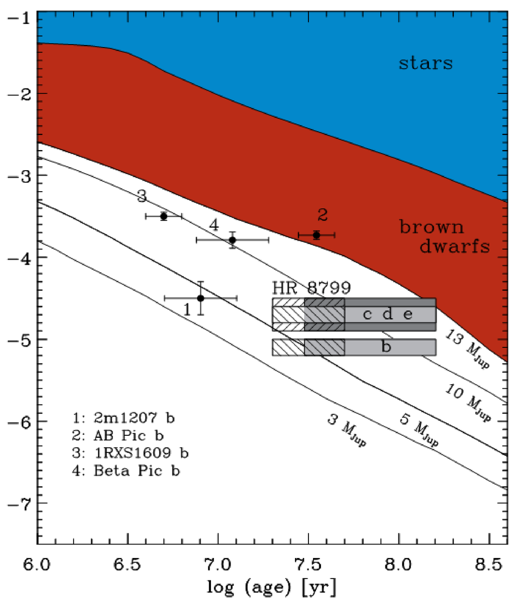

Fig. 8 Log L-age of the 4 objects orbiting HR8799.Taken from Marois et al. 10, Nature, in press.

•V391 Peg is a sdB pulsator, that is a star on the Extreme Horizontal Branch. Silvotti et al. 07 (Nature 449) found a planet orbiting it. The new detected frequencies (Lutz et al. 09, A&A 496) in this star will allow to determine the system properties and understand how a planet can survive the Red Giant evolution phase of its host-star.

•For more details on the physical nature of stellar oscillations and their application in other frameworks, we invite you to refer to Arlette Noels' lectures during this CPS school.