PARSEC evolutionary tracks and isochrones including seismic properties

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In the recent years it has been generally accepted that seismic parameters add an important observational constraint for the study of stellar populations and galaxy evolution. Padova-Trieste (PARSEC) evolutionary tracks are widely used to characterize stellar objects and stellar populations. Stellar models at the base of these studies suffer from uncertainties and, more important, degeneracy among different input parameters: stellar mass, chemical composition, central chemical mixing, age, etc. Adding seismic properties to the classic parameters for stars at different evolutionary states, from the H main-sequence to the asymptotic giant brach, is a powerful tool to calibrate physical processes in stellar models, and hence to improve our interpretation of Galactic and extra-galatic observations.

There are different seismic "observables" that may be classify by their potential deriving stellar properties and/ or by the demanding computation time (and sometimes observation as well):

Level 0: Scaling relations for solar-like oscillations link T_{eff}, M and R with the global seismic param. $\Delta\nu$ & ν_{max}
No need of additional computations, they have been used e.g. Rodrigues et al.2014 , Miglio et al. 2013 …

Level 1: Seismic indices from asymptotic theory using integrals over the stellar structure of PARSEC models:

- Large frequency separation $$\Delta\nu_0 = \left(2\int_0^R \frac{dr}{c_s}\right)^{-1}$$ c_s : sound speed
- Period Spacing $$\Pi_0 = 2\pi^2\left(\int_{r_{t1}}^{r_{t2}} \frac{N(r)}{r}dr\right)^{-1}$$ N (~ g^2), Brunt-Vaisala freq.
- Coupling parameter for gravity and pressure cavities

Linked with stellar mean density and density stratification, respectively, they contain important information about evolutionary state (e.g. Beding et al. 2011, Mosser et al. 2014, Bossini et al. 2017). They can be computed in principle for all models along ev. tracks

Level 2: Radial oscillation frequencies from adiabatic and linear computations for PARSEC (Bressan et al. 2012,13) stellar structure models using the oscillation code LOSC (Scuflaire et al. 2008)

- $\nu_{n\ell}$ with radial order (n=1 => 50) and l=0 will be used to estimate $\Delta\nu$ from fit of linear relation $$\nu_{n\ell} = (n + \frac{\ell}{2} + \varepsilon)\Delta\nu$$ for the expected domain of solar-like oscillations and corrected of surface effects from calibration with the Sun
- 5 values of ν(n) around ν_{max} will be delivered, or the fundamental + 4 first overtones for high luminosity red giants.

Level 3: As stars evolves, central density increases and their oscillation spectra become complicate increasing dramatically the computation time.

Depending on the density stratification we:
1. compute non-radial (NR) modes (l=1, & 2) for solar-like domain and provide mean linear fit for small frequency separations, linked to the age of the star and to the size of convective core (mainly for MS and SubG);
2. skip non-radial modes computation;
3. compute only p-dominated NR modes (see Fig.1 and Panel: TP-AGB)

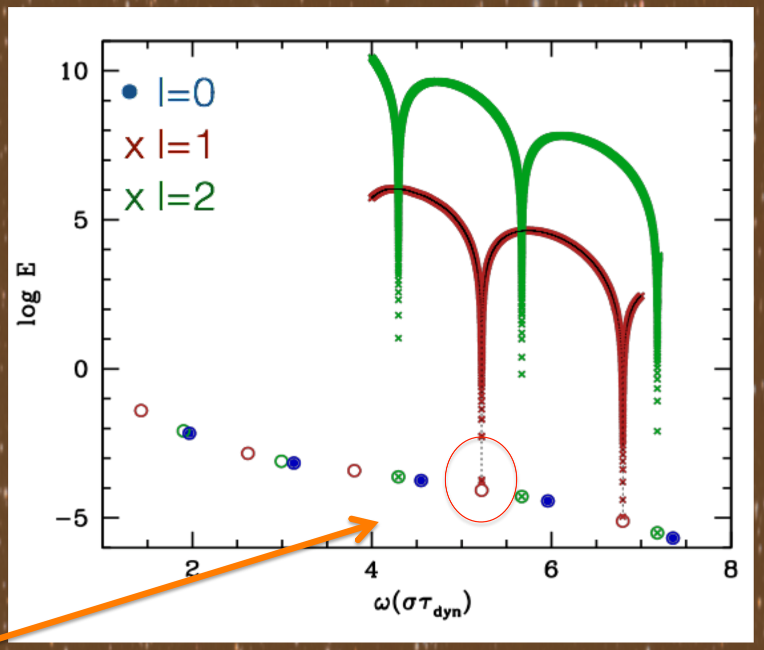
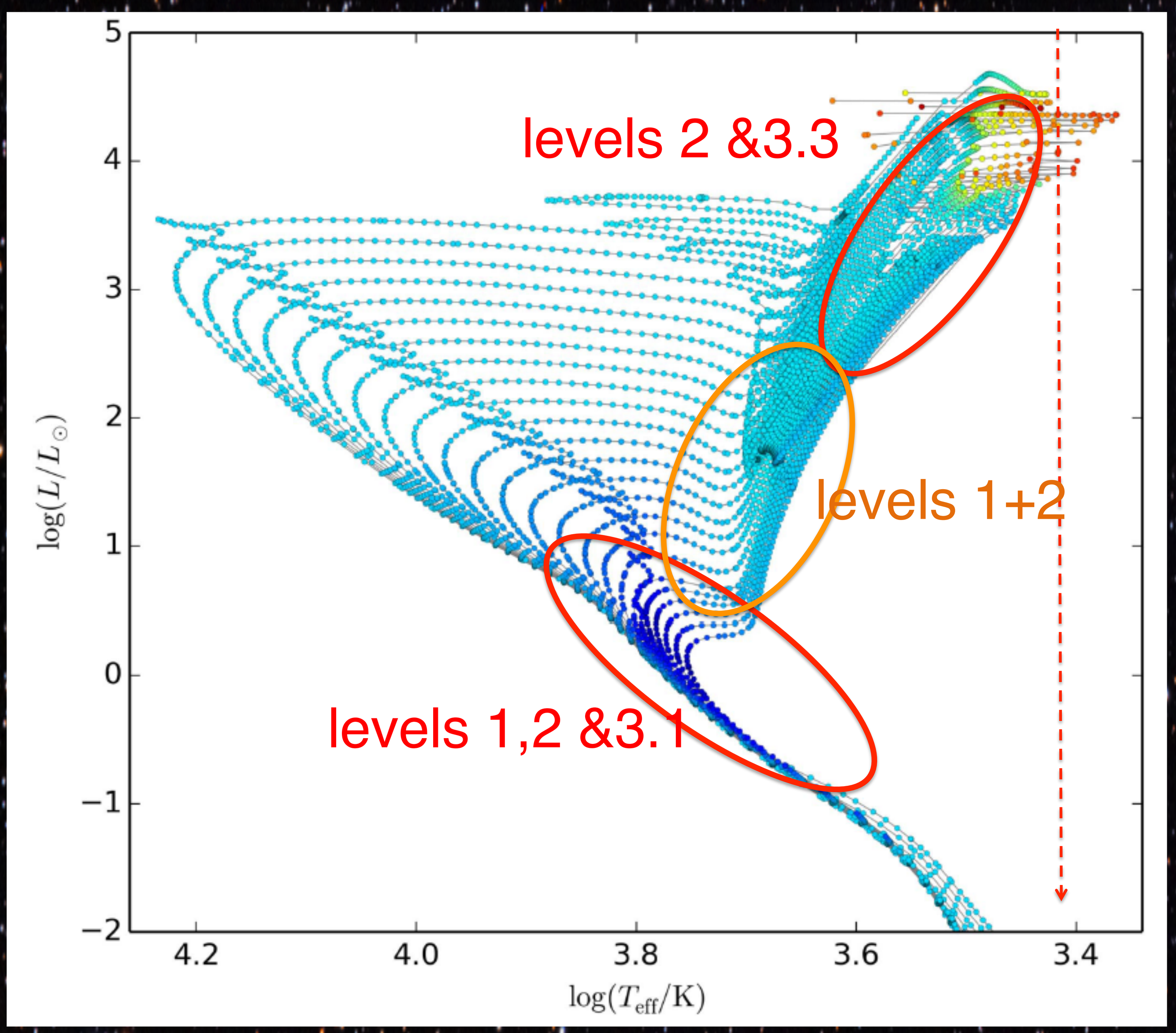


Fig1. Adiabatic oscillations frequencies of p-modes (min. E) an AGB model. Good agreement between results from complete structure and convective envelope only(circles), including dipole mode That method reduces significantly the computation time, and it is valid for high luminosity red giants,



Panel : TP-AGB

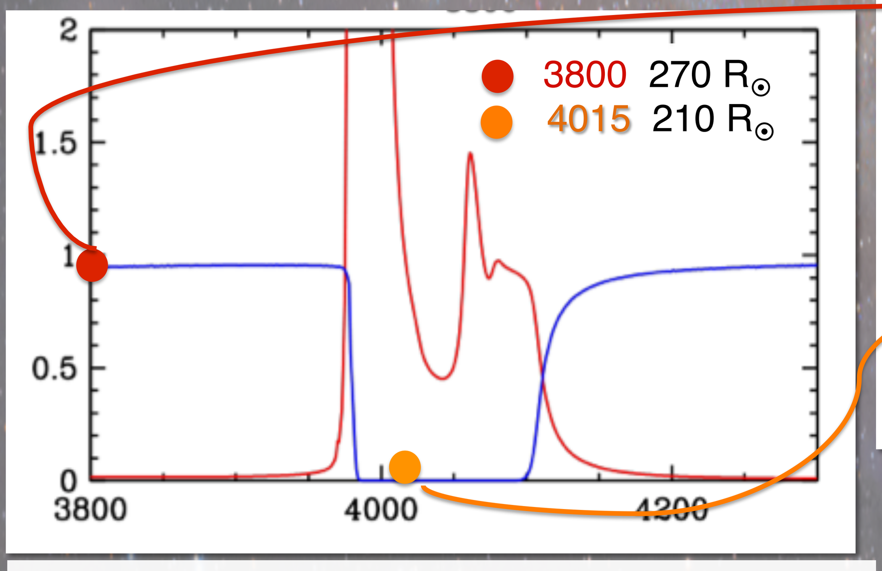


Fig. 2 Variation of H-shell luminosity and He-shell luminosity during a thermal pulse, as a function of model number.

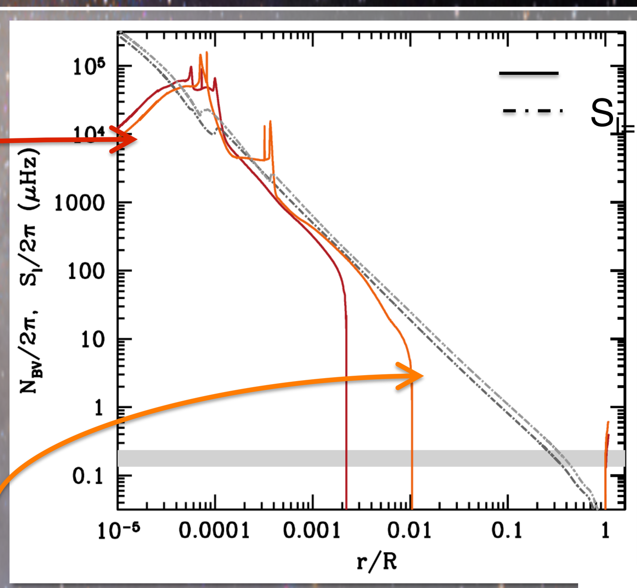
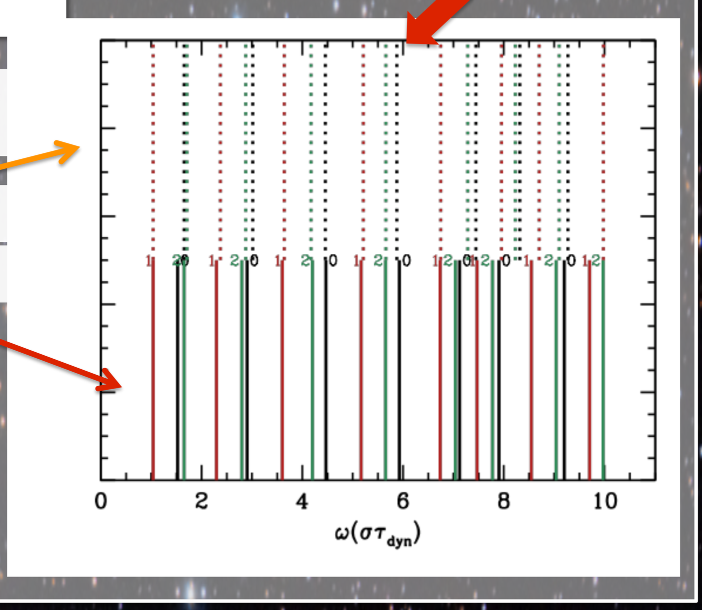


Fig.3 Propagation diagram (Brunt-Vaisala freq. $-N_{BV}$, and Lamb freq. - $S_{l=1}$ – as a function of relative radius) for models 3800 and 4015. Grey band indicate the expected frequency domain of oscillations.

The pattern shown by the acoustic modes change between the two models considered

Fig. 4 Spectrum of acoustic modes (l=0, l=1 and l=2)



model 3800 H-shell luminosity model. Model 4015 during the thermal pulse (the phase decreasing the He-shell flash luminosity).
The energy produced during the He-shell flash => change of density distribution, and a shallower CE, while the total radius change from 270 to 210 $R_\odot$.
Even if both models would show only modes trapped in the envelope (given the extension of the evanescent region the external region they probe have different physical properties. Is that reflected in the spectrum?

- New OUTPUTS from PARSEC evolutionary tracks (for stars at the right side of the diagonal in the HRDlevels 1,2 and 3 (see Fig. 5)
- PARSEC tracks are used in the Stellar Population Synthesis code TRILEGAL (ref) and in the Bayesian stellar parameter estimation tool PARAM, so far, using classical information or scaling relations.
- Evolutionary tracks computed with MESA + seismic (level 1, and 2) have been recently included in TRILEGAL and PARAM and shown the power of the method.
- Adding PARSEC will allow in particular, the studies of systematics in the properties of stellar populations and stellar parameters due to uncertainties in the input physics and to numerical implementation of physical process,of paramount importance for the exploitation of large surveys data, such as CoRoT, Keple/K2, Gaia, TESS and PLATO.

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