

PhD Open Days

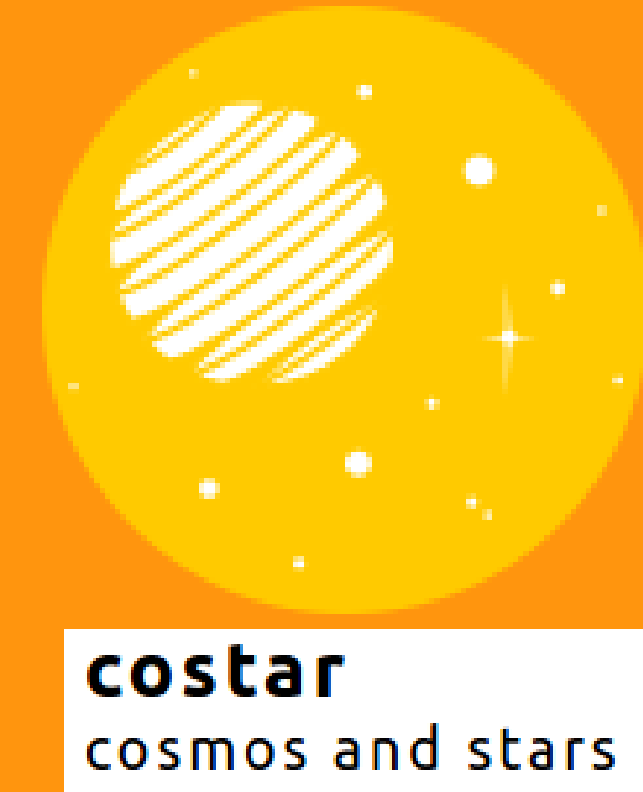
16 - 17 MAY / SALÃO NOBRE

2nd edition!

Asteroseismology of the outer layers of sun-like stars

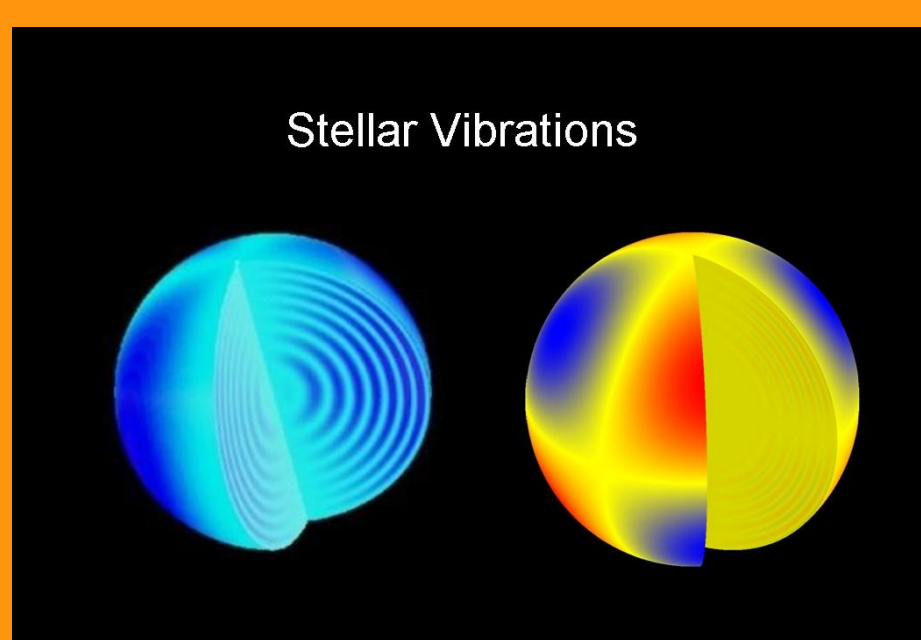
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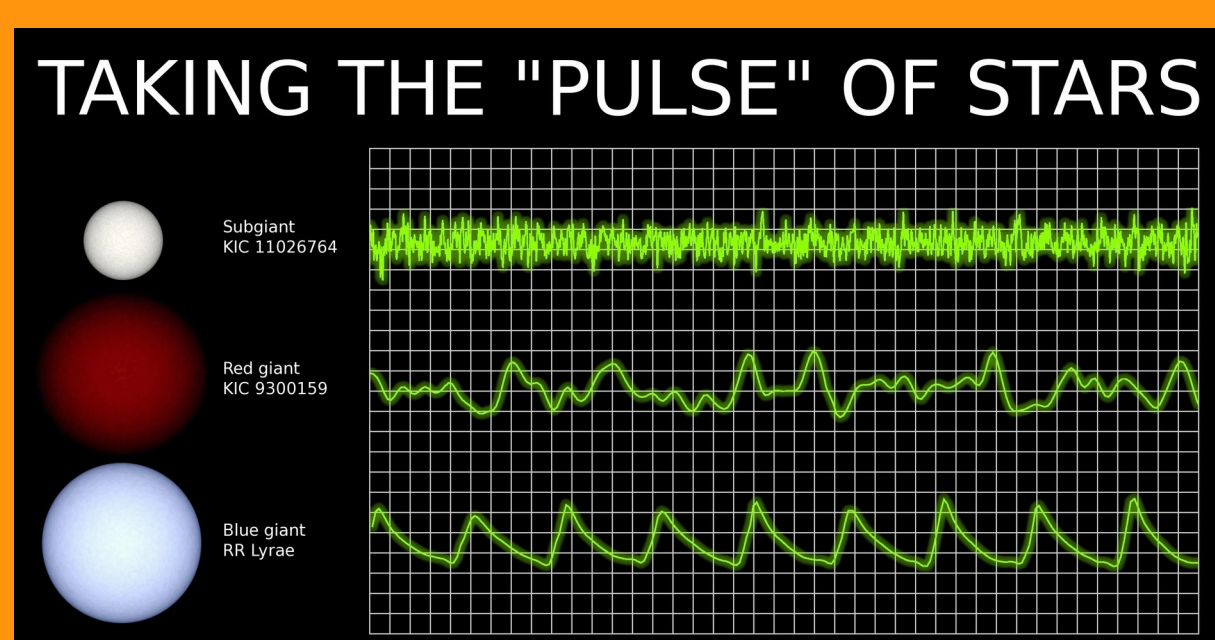


Asteroseismology

Asteroseismology is the study of stellar interiors using the oscillations of stars. More specifically, using the frequencies of the normal modes of pulsating stars. These normal modes are usually called "starquakes". In some aspects, asteroseismology is similar to the seismological studies of the interior of the Earth.



The variations of brightness can be detected and measured with telescopes. We can "hear" the stars.

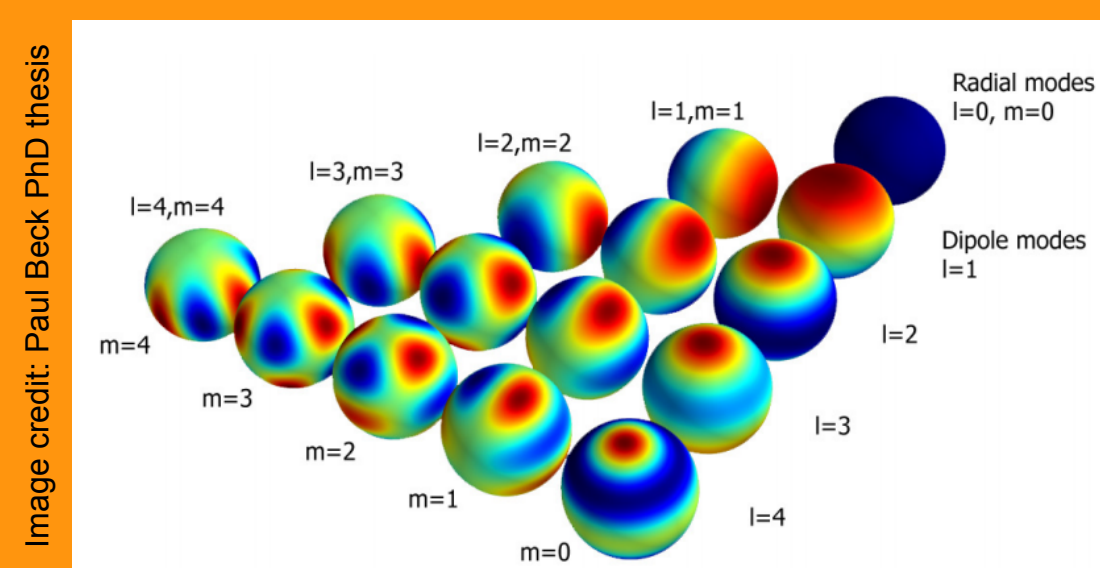


These variations in brightness of the stars are the result of the sound waves (pressure waves) propagating in them.

This is a branch of research that is developing very rapidly nowadays. The superior quality of the data provided by the space missions **Kepler** and **CoRoT (NASA/ESA)**, are now available in unprecedented numbers, predicting very interesting times for stellar physics. In a nearby future, the missions **TESS** and **PLATO (NASA/ESA)** will improve, even more, the quantity and quality of the observational data.

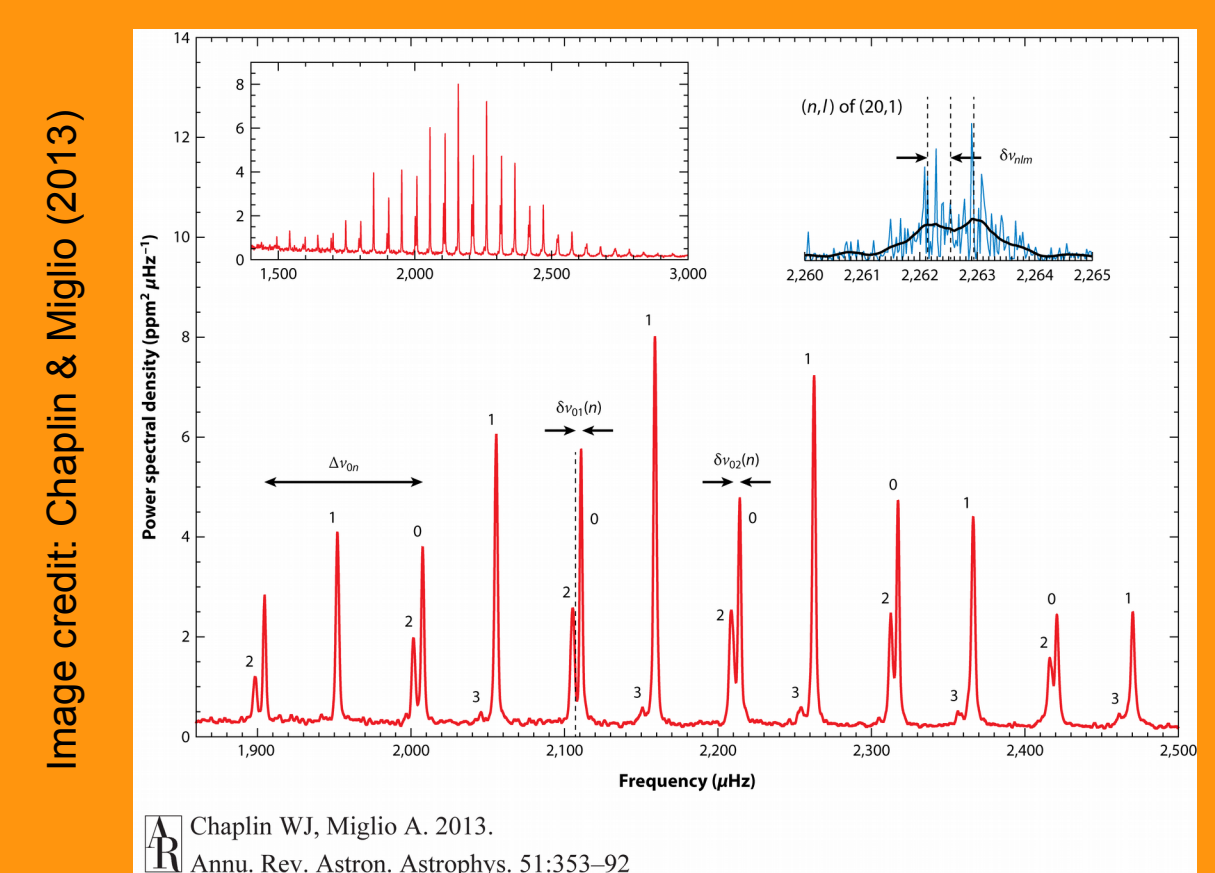
Why do stars pulsate?

There are several mechanisms driving the oscillations in stars. Two of the most important are the **κ -mechanism** (related with changes in opacity) and the **stochastic driving**. The κ -mechanism acts like an heat engine, converting thermal into mechanical energy. The stochastic driving is the main mechanism acting in sun-like stars and thus particularly important for our work. Here, the modes are driven stochastically by the turbulence of the subsurface convective zone.



The oscillation modes may be conveniently represented in terms of spherical harmonics, radial eigenfunctions and oscillation frequencies.

Example of an observed oscillation spectrum of a G-type main sequence star (16 Cyg A, KIC 12069424, HD 186408).



Specific combinations of frequencies, usually known as seismic parameters, are linked to properties of the stars. The **large frequency separation** $\Delta_{n,l} = \nu_{n,l} - \nu_{n-1,l}$, and the **small frequency separation** $\delta_{n,l} = \nu_{n,l} - \nu_{n-1,l+2}$, are two examples of seismic parameters. The former gives us information about the mean density of the star, and the latter is related to the age of the star.

The outer layers of sun-like stars: magnetic activity, differential rotation, ionization

The Sun and sun-like stars have an outer convective zone, which is a region where uncertainties are exacerbated if we aim to give a physical description of this region.



Image credit: NASA

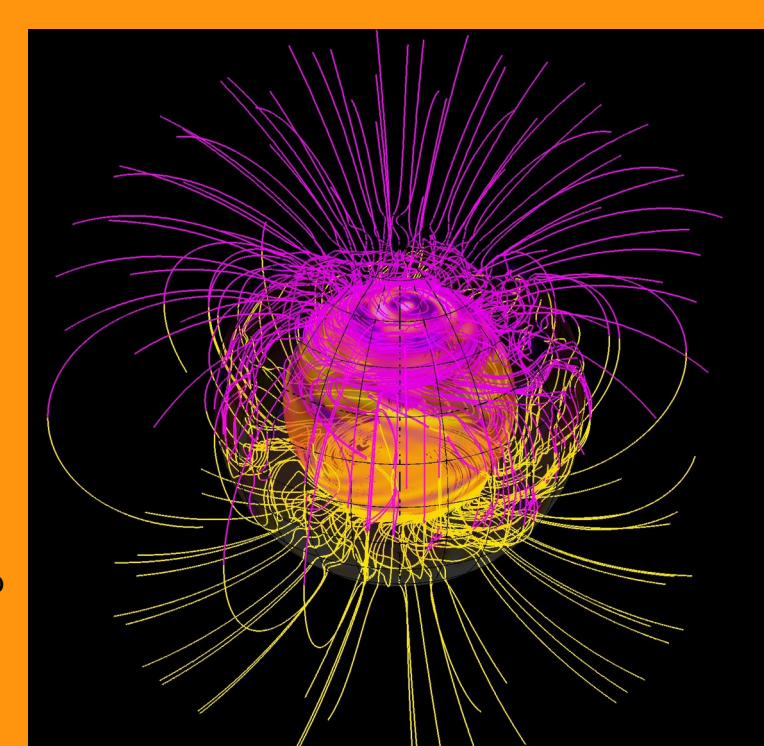


Image credit: www.stars2.eu

In these layers we have an intricate web of different processes occurring and interacting in the same region and in the same time scale: convection, magnetic fields and pulsations. Beneath the stellar surface (a few percent of the star's radius) this interaction becomes even more complicated due to the partial ionization of hydrogen and helium (and possibly of heavier elements). All these processes contribute to a complex background structure that affects the frequencies of stellar oscillations in several ways.

The study of magnetic activity in solar-type stars is of fundamental importance for stellar structure and evolution. It is also crucial for better understanding our star, the Sun.

Right: the first detection of a magnetic cycle in the F-type star HD49933, using seismology (anti-correlation between amplitude variation and frequency shifts).

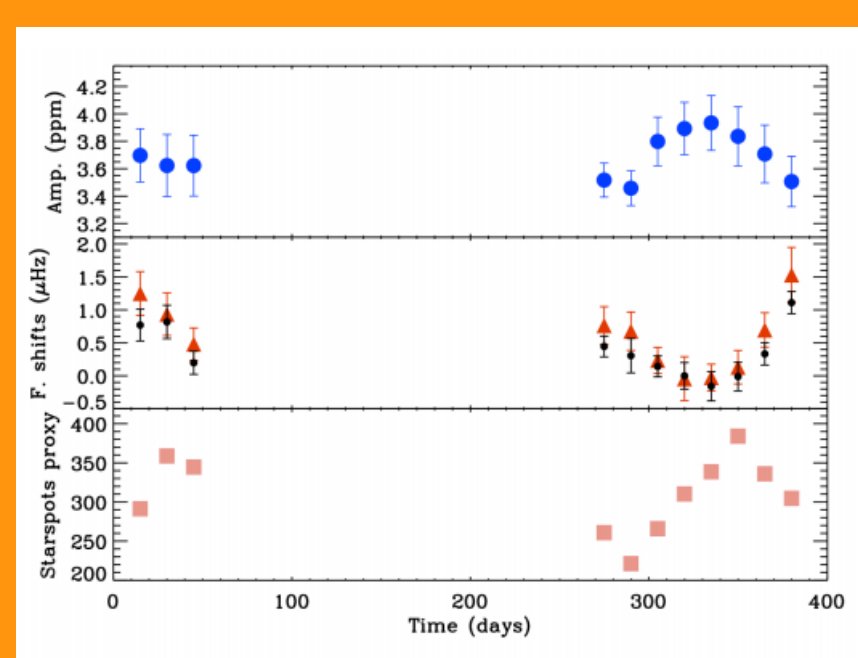
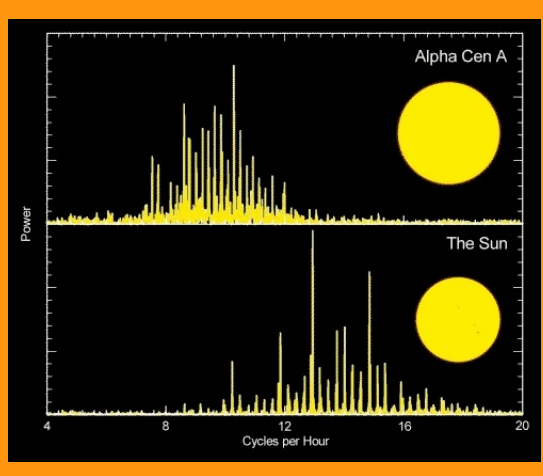


Image credit: Garcia et al (2010)

α Centauri A: first detection of a glitch located between the helium ionization zone and the base of the convective zone



The phase-shift diagnostic of the external layers is a seismic tool particularly suited to the study of the external layers. It is usually known as the seismic parameter β . This quantity measures the phase shift experienced by acoustic waves when reflected by the surface of the stars.

We used the seismic parameter β as a probe tool to investigate the disagreement between theory and observation. Our tests revealed that a **small rapid variation on the sound speed (a glitch)** located 6% under the surface of the star could explain the observed disagreement.

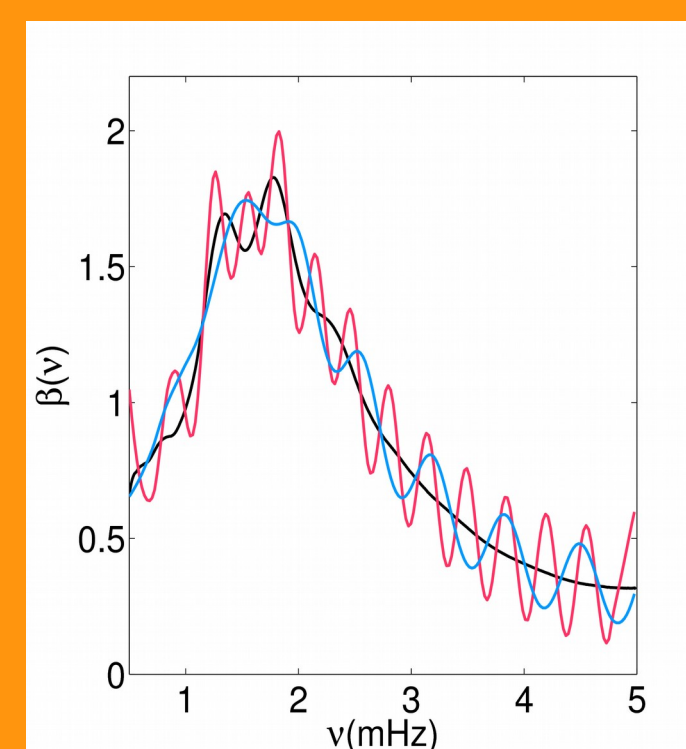
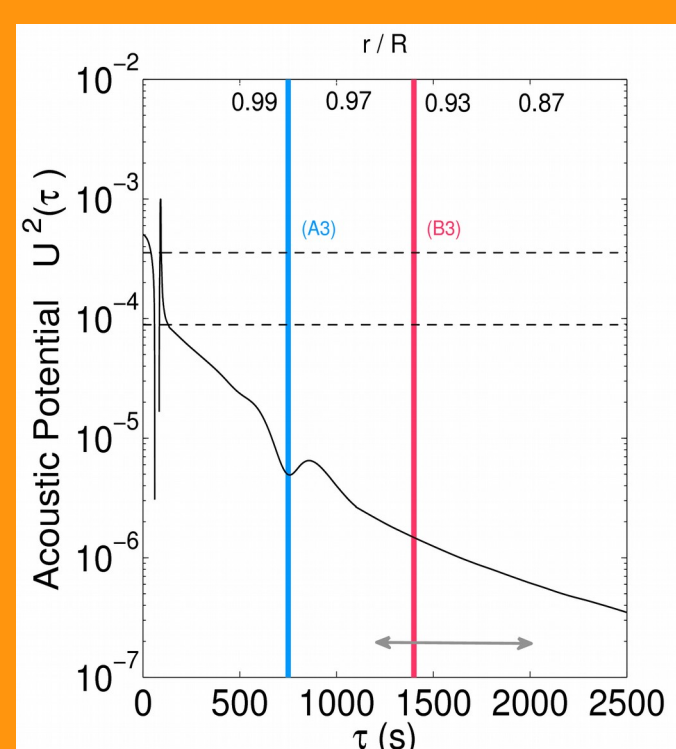


Image credit: Brito & Lopes (2014)

Left: theoretical (black lines) and the observational (color lines) seismic signature β for the star α Centauri A. We notice a dispersion in the observational modes that is not present in the theoretical modes. This dispersion, carries information about the oscillatory character present in each set of individual acoustic modes with the same degree.

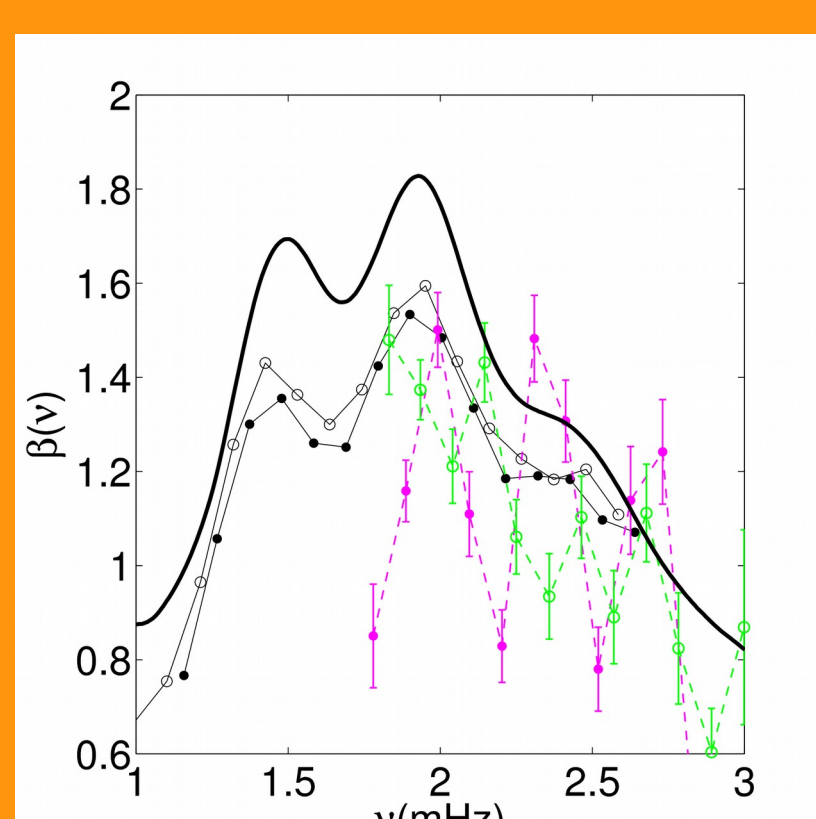


Image credit: Brito & Lopes (2014)

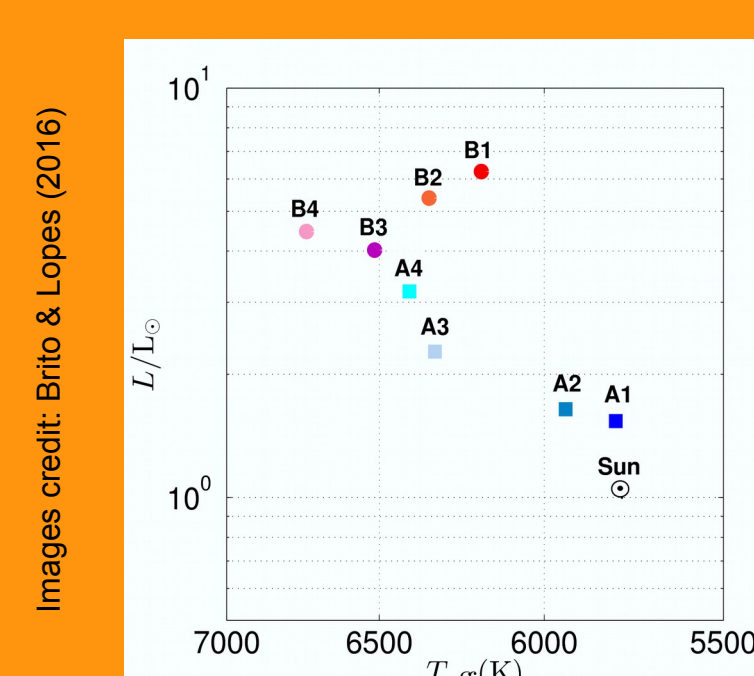
Based on:

Brito, A., & Lopes, I. 2014, The Astrophysical Journal, 782, 16

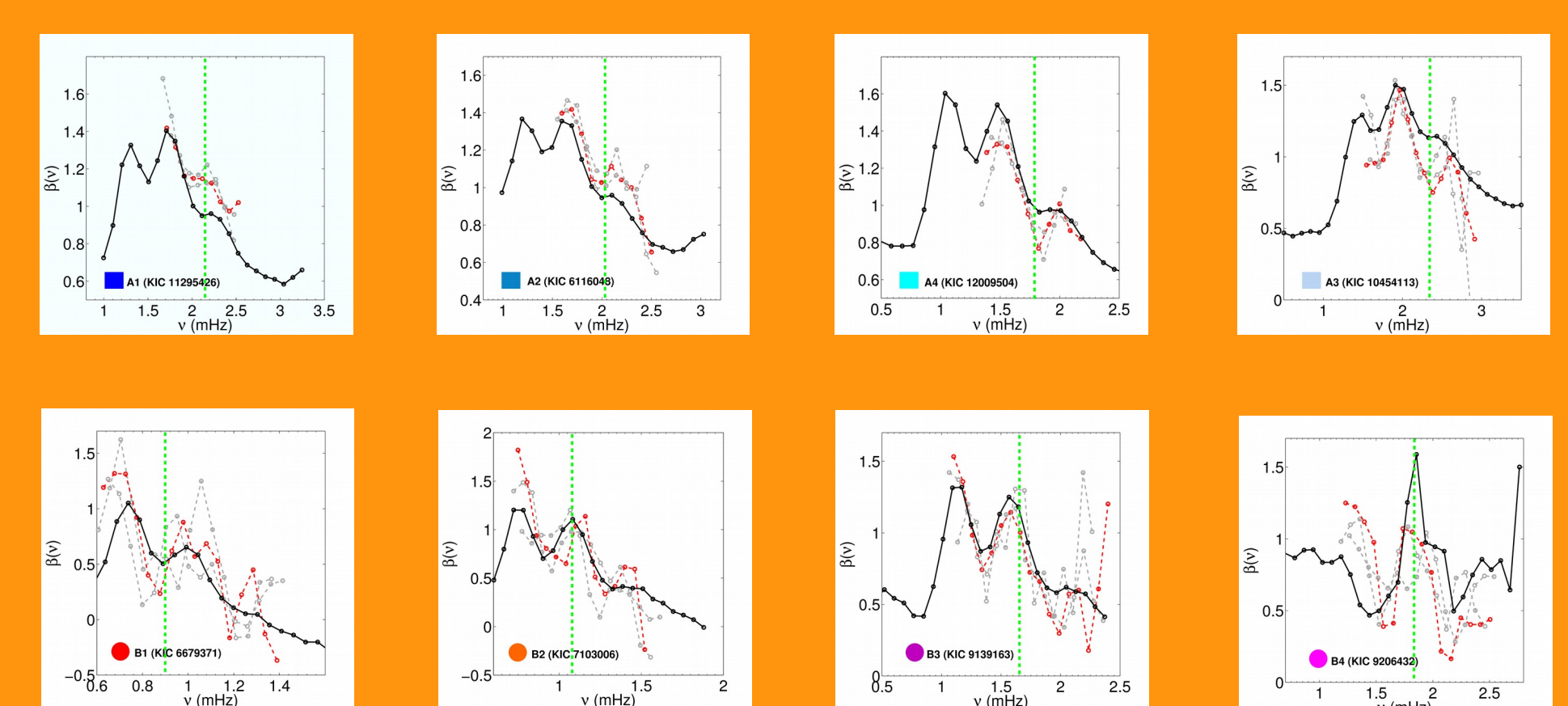
Brito, A., & Lopes, I. 2016 (submitted to ApJ)

F- type stars: unveiling a connection between rotation and ionization

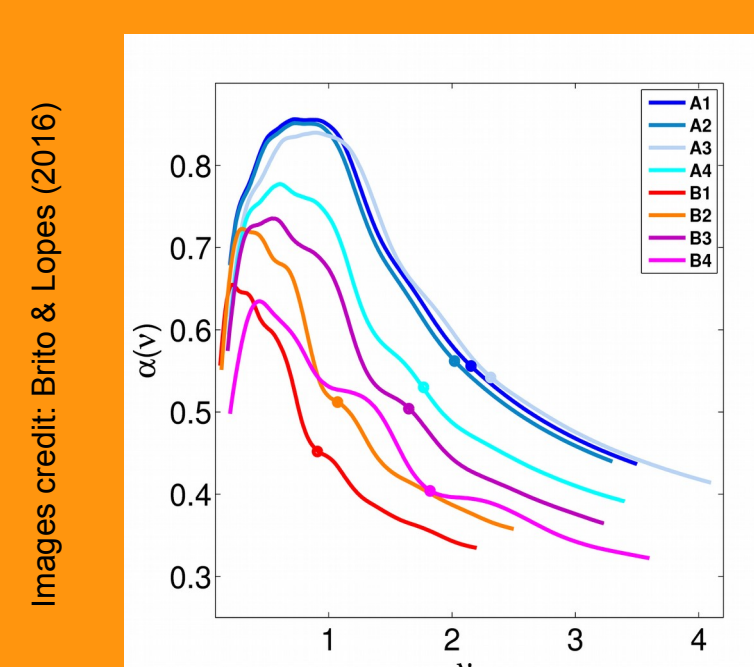
We analyzed the outer layers of eight Kepler F stars. Several F-type stars have observations suggesting that they may harbor magnetic cycles. They are particularly interesting because they establish a bridge between stars like the Sun with big external convection zones and A-type stars with convective cores.



H-R diagram of our models. Luminosities of the ensemble of Kepler stars plotted as a function of temperature. The stars are divided in two groups A and B. Squares represent the group A of stars, circles represent the B group and the usual black symbol stands for the Sun.



The theoretical and observational seismic parameter β was computed for eight stars. The agreement between theory and observation is better in the group A of stars (stars with weaker ionization of light elements) than in group B (stars with stronger ionization patterns).



The phase shift as a function of the cyclic frequency.

The distinction between the groups A and B seems to suggest that stars in group B are more active magnetically than stars in group A. We also found a **linear relation between the heights that characterize the sinusoidal component of the seismic signature $\beta(v)$ and the rotation period of the star.**

