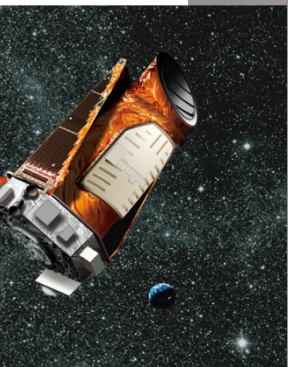
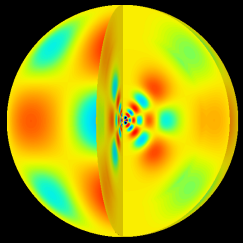




Asteroseismology and Stellar Physics

Savita Mathur





Seismology

- Oscillation eigenmodes characterized by:

- ℓ : Degree

- m : Azimuthal order

- n : Radial Order

- Acoustic (p) modes:

- Restoring force:

- Pressure

- Equidistant in frequency

- Gravity (g) modes:

- Restoring force:

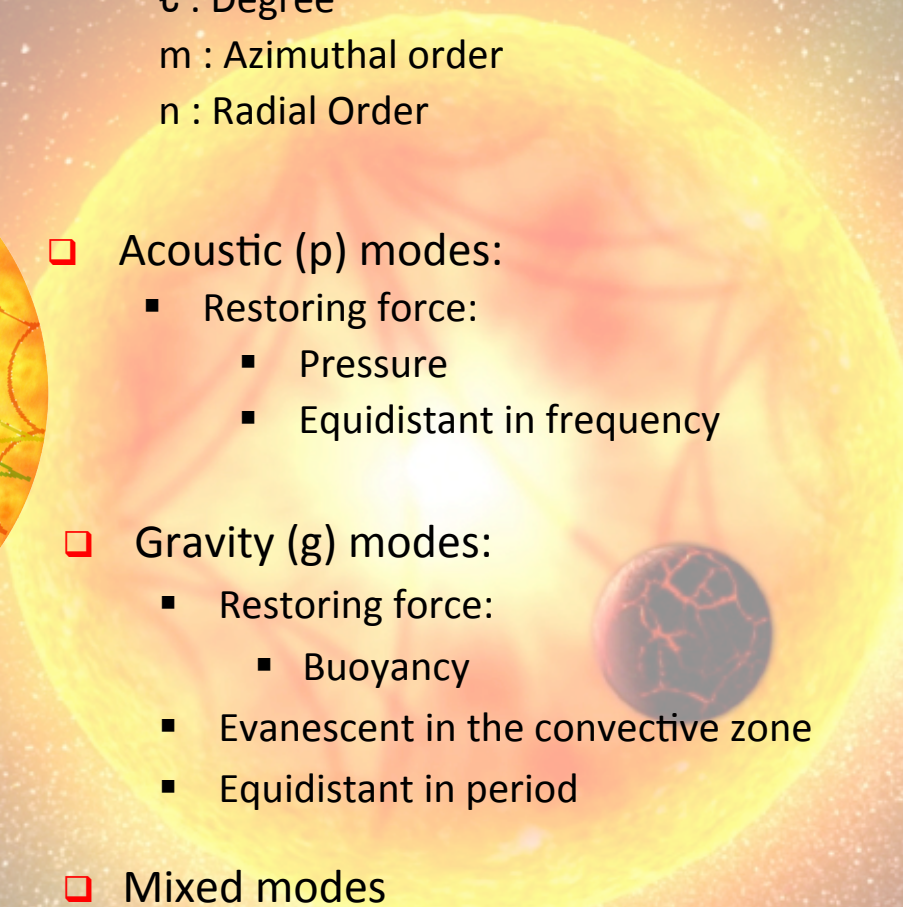
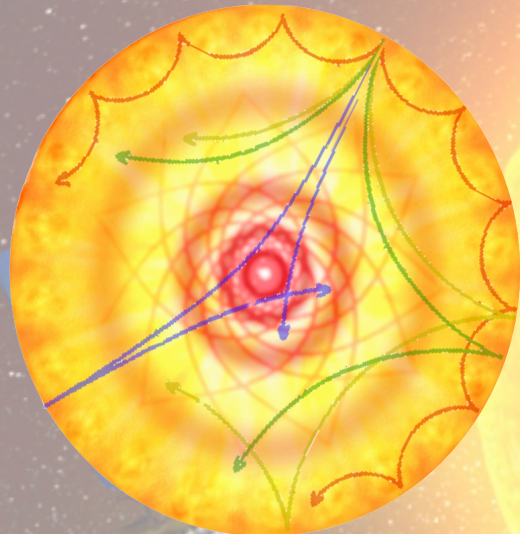
- Buoyancy

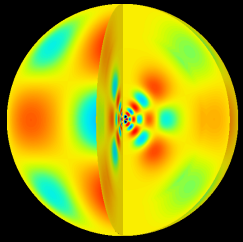
- Evanescent in the convective zone

- Equidistant in period

- Mixed modes

- Coupling between p- and g-mode cavities





Seismology

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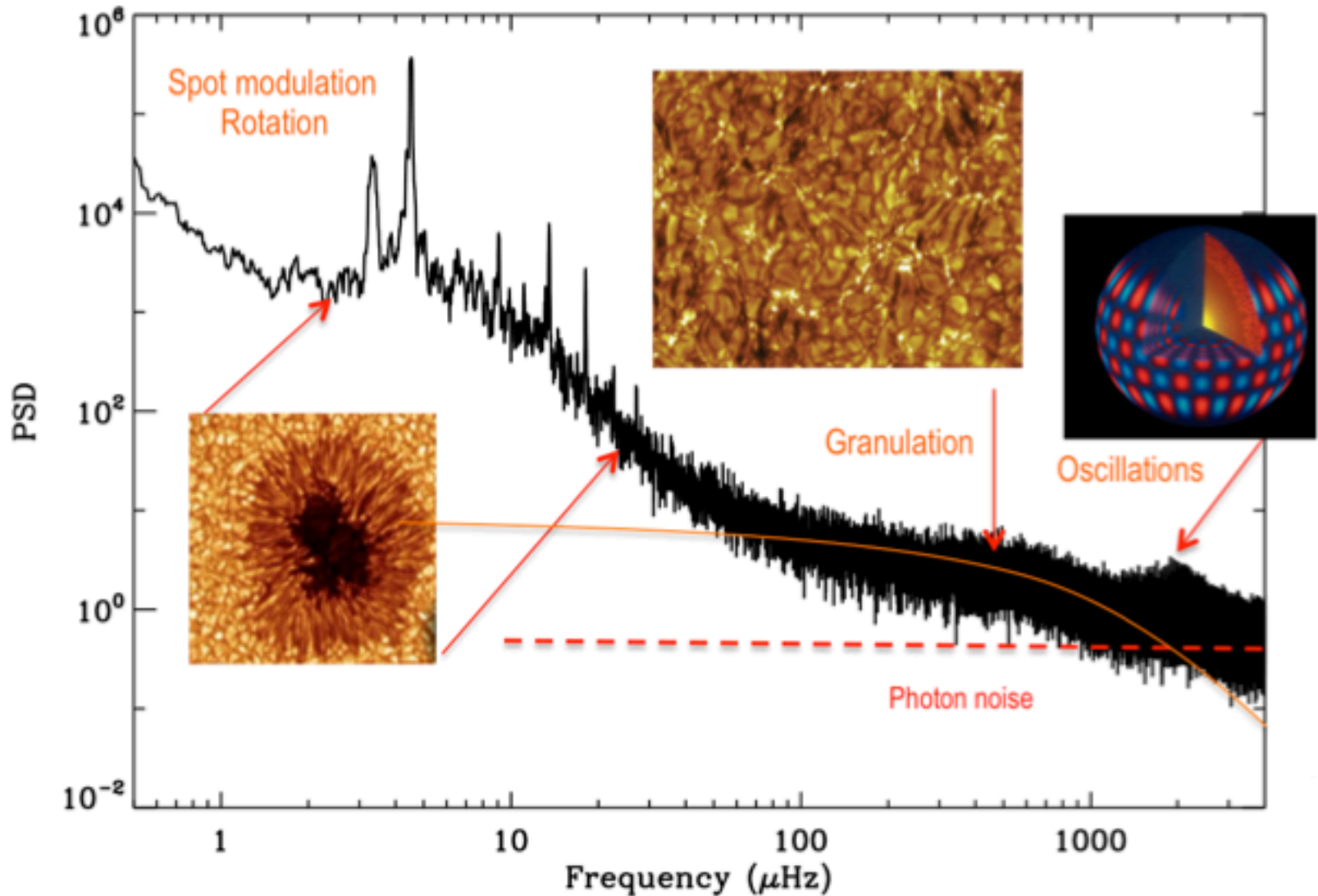
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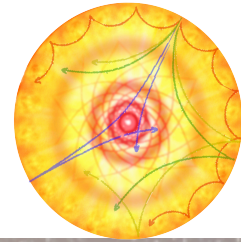
- Mixed modes

- Coupling between p- and g-mode cavities

Directly probes the deeper layers of the sun and the stars

Power Spectrum



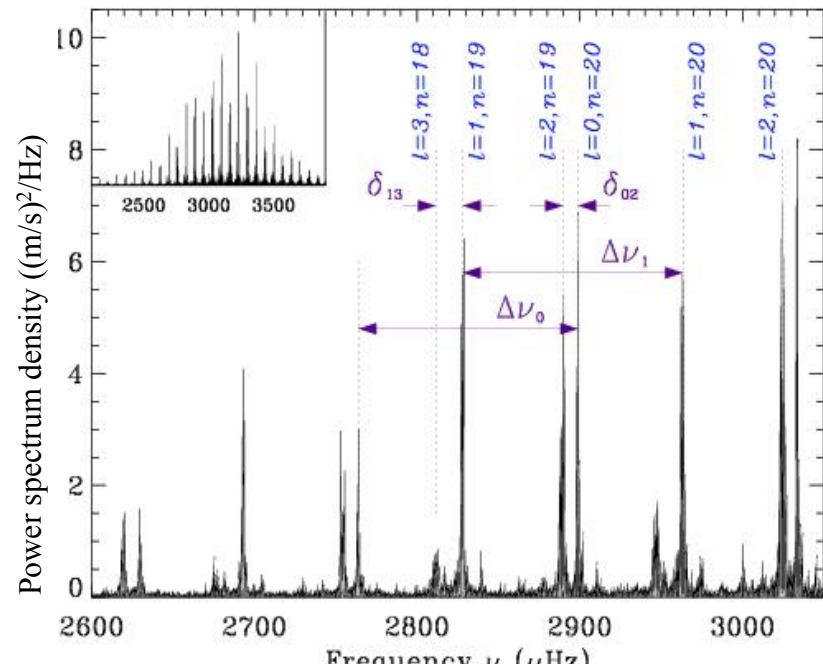
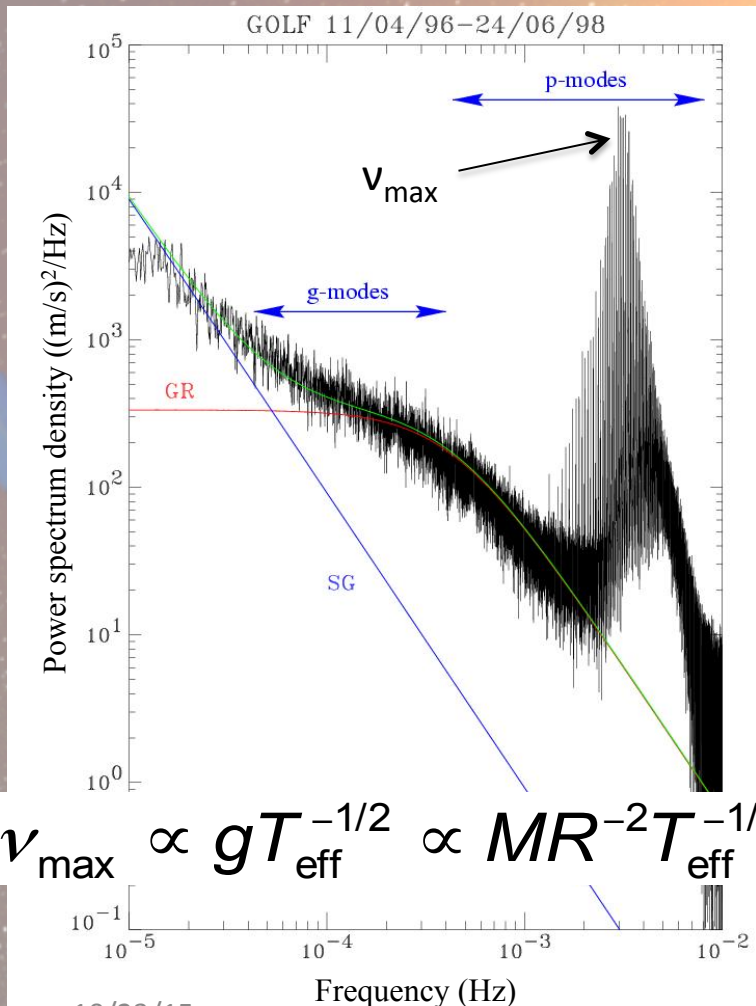


Power Spectrum

➤ Frequency at maximum power

➤ Large separation: $\Delta\nu = \nu_{n,\ell} - \nu_{n-1,\ell}$

- Average properties of the star:



$$\langle \Delta\nu \rangle \propto \langle \rho \rangle^{1/2} \propto M^{1/2} R^{-3/2}$$

Stellar properties: direct methods

Use of scaling relations

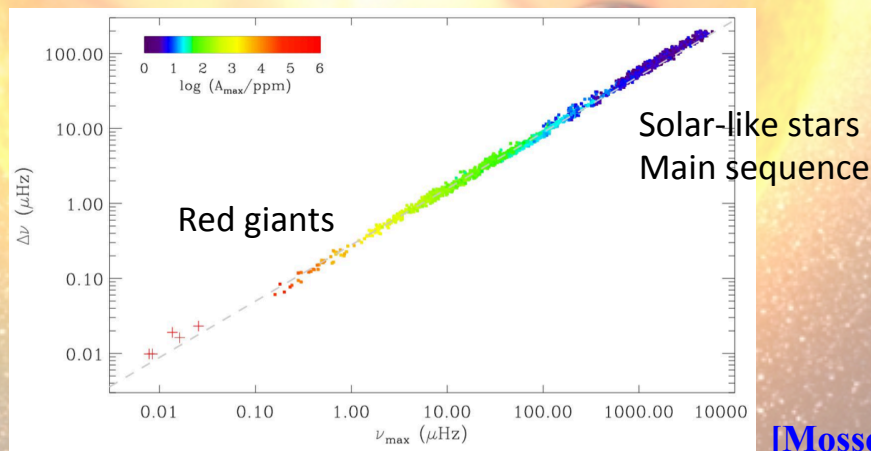
From global asteroseismic parameters and a good estimation of T_{eff}

$$R \propto \nu_{\text{max}} \langle \Delta \nu \rangle^{-2} T_{\text{eff}}^{0.5} \quad (\sim 5\%)$$

$$M \propto \nu_{\text{max}}^3 \langle \Delta \nu \rangle^{-4} T_{\text{eff}}^{1.5} \quad (\sim 10\%)$$

Tested both theoretically and observationally

[Kjeldsen & Bedding 1995; Huber et al. 2012; Mathur et al. 2012; Silva Aguirre et al. 2012]



[Mosser et al., 2013 SF2A]

Stellar modeling

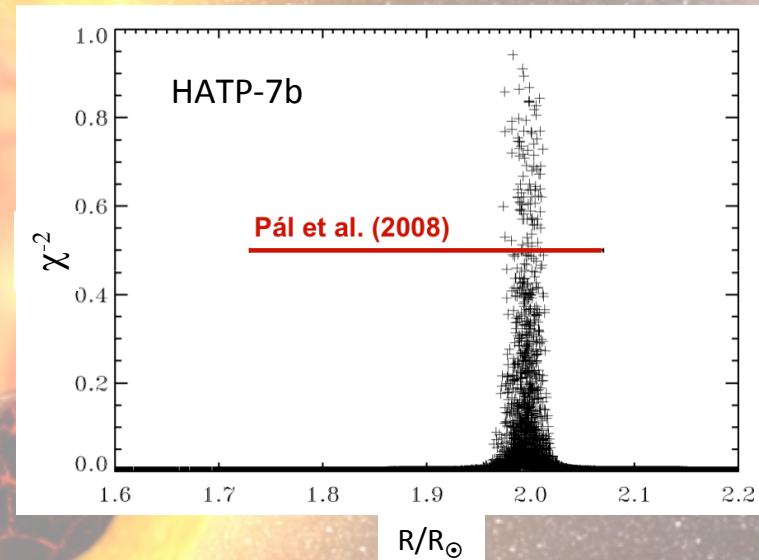
- Best-fit model to spectroscopic and seismic constraints

- Grid-based models

[Chaplin et al. 2014]

- E.g. Asteroseismic Modeling Portal

[Metcalf et al. 2009]



[Christensen-Dalsgaard et al. 2010]

- Large sample of stars

[Mathur et al., 2012; Metcalfe et al. 2014]

- Improve precision on M, R, age

- Structure:

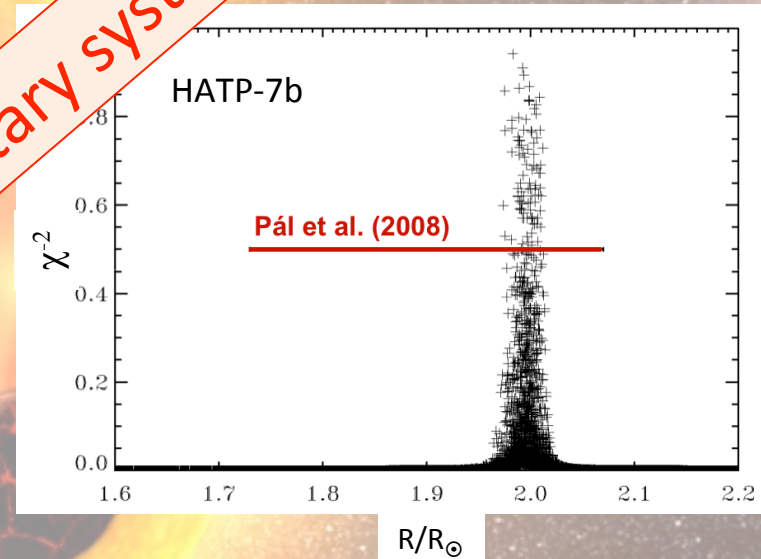
- base of convection zone

Model-dependent...

Stellar modeling

- Best-fit model to spectroscopic and seismic constraints

- Grid-based models
[Chaplin et al. 2014]
- E.g. Asteroseismic Modeling Portal
[Metcalf et al. 2009]



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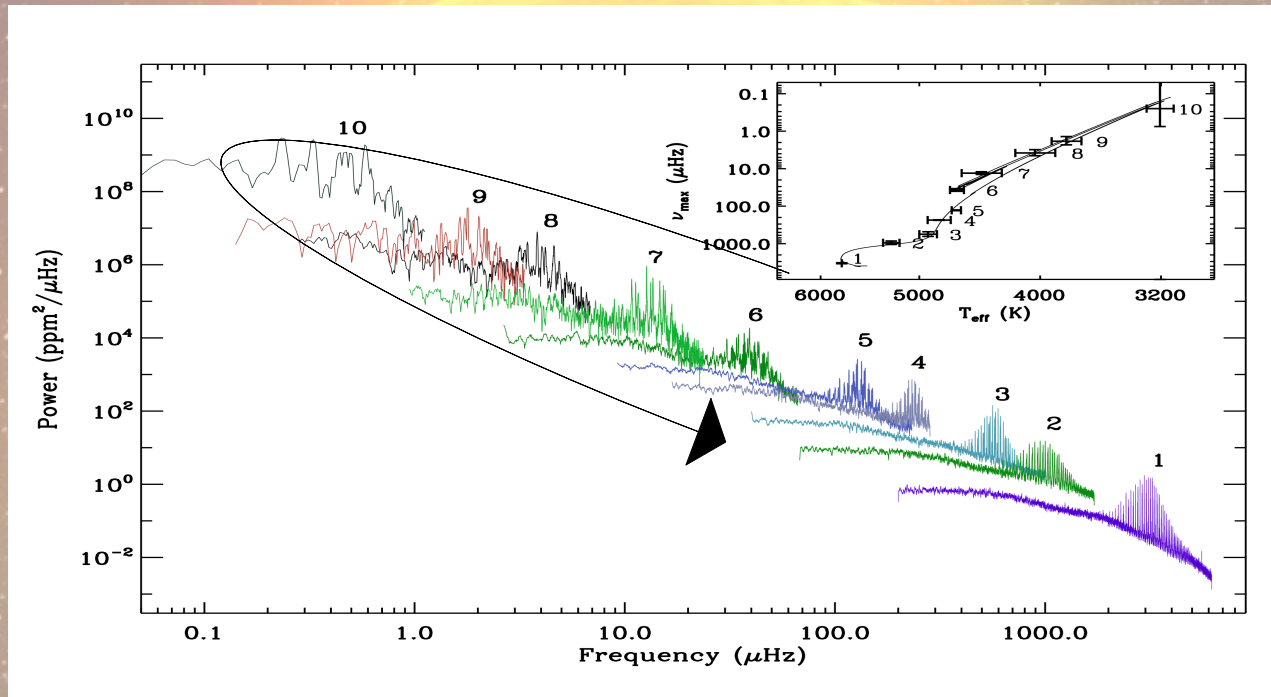
- Improve precision of age
- Structure:

■ base of convection zone

Model independent...

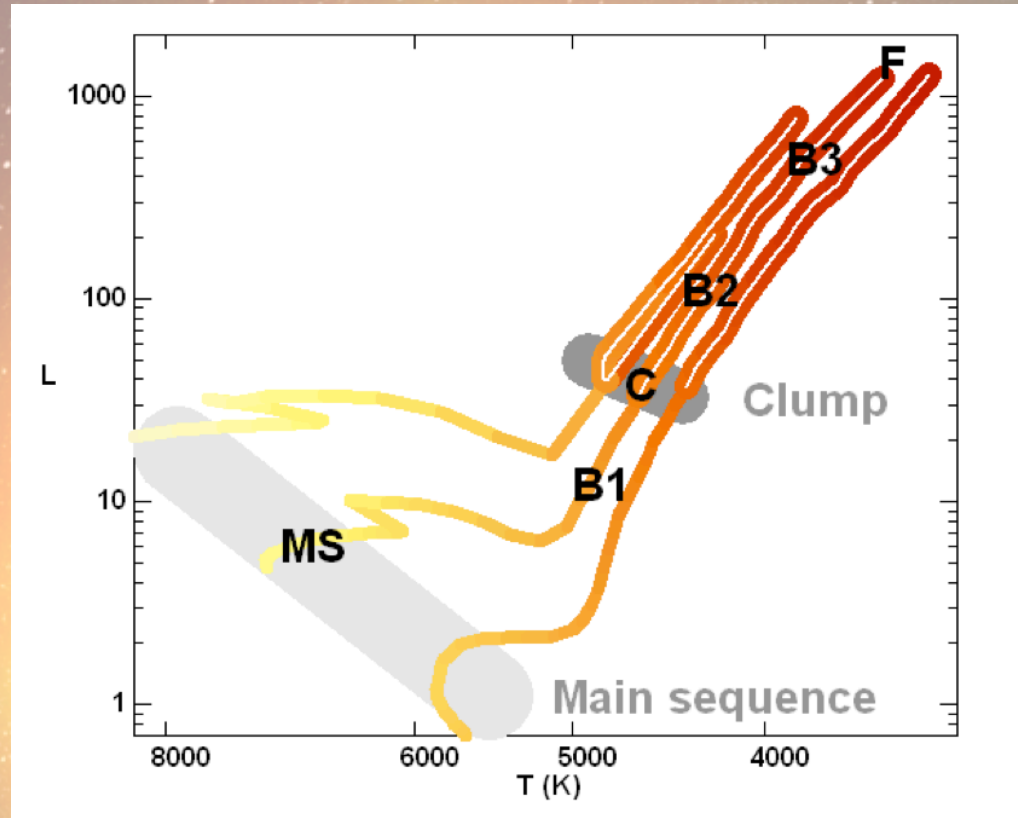
Important constraints for planetary systems

Stellar evolution



[García & Stello in Extraterrestrial seismology, CUP, 2015]

The RG revolution

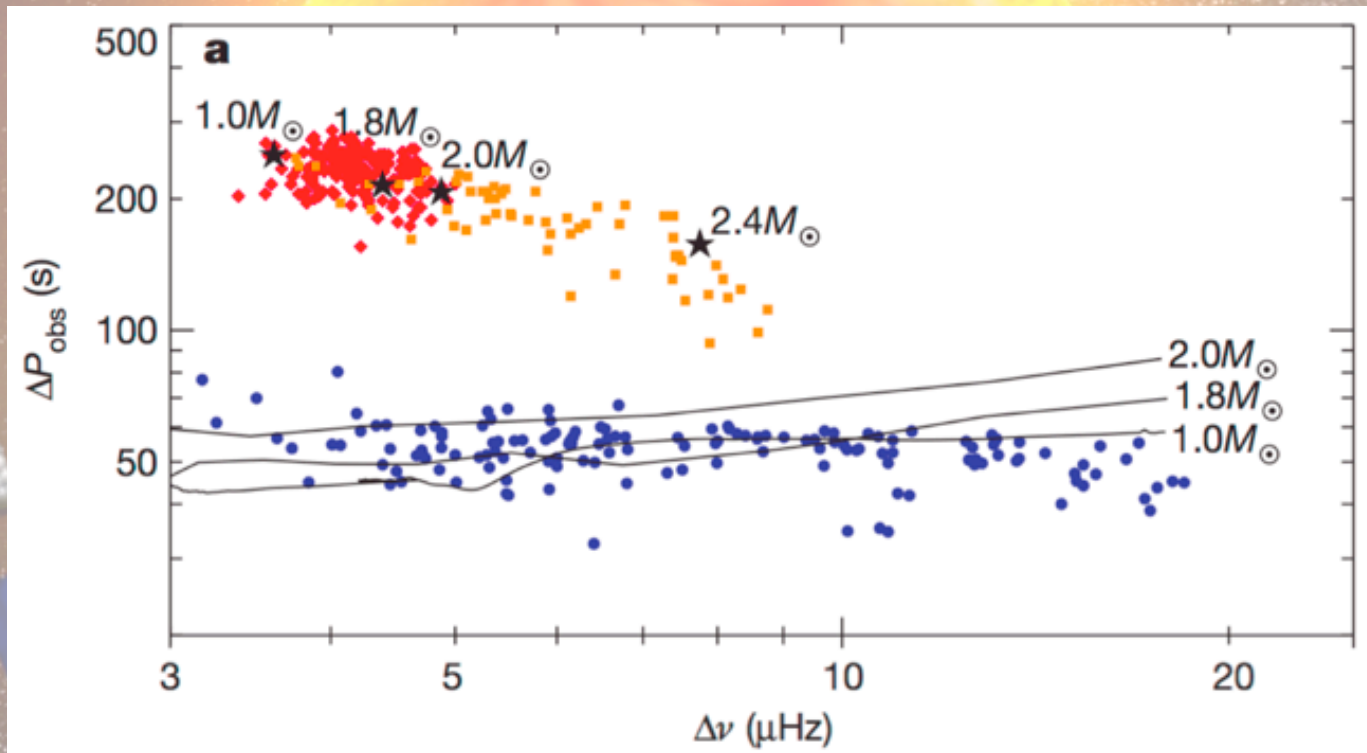


Confusion in the HR diagram:

- From their global properties a RGB star and a Red Clump giant are the same
- Same HR position, same envelopes, same large frequency spacings...
- “Just as in Hollywood, the age of a star is not always obvious if you look at the surface”

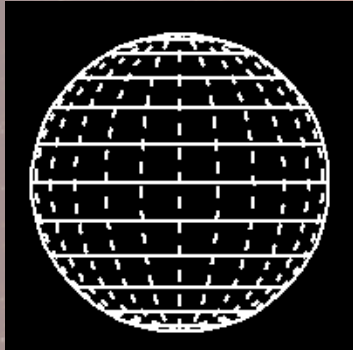
Probing interiors of red giants

- Determination of period spacing of mixed modes ΔP
- Two regimes:
 - Large values of ΔP : burning He in their core
 - small values of ΔP : burning H in a shell



Effect of rotation on modes

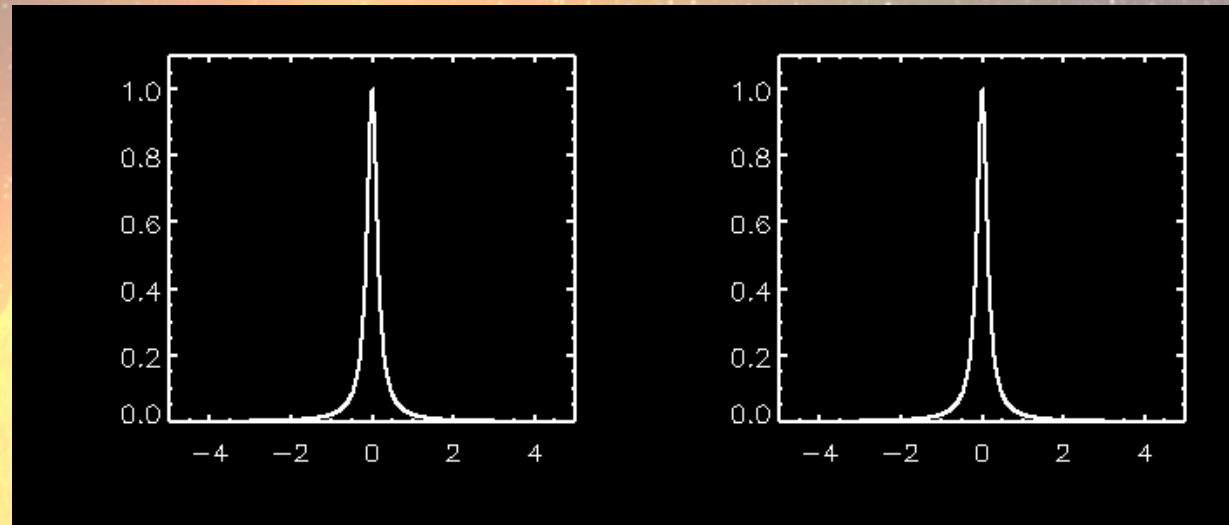
$$\Omega = 0,0$$



$$i = 90^\circ$$

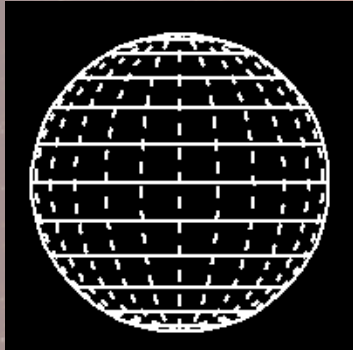
$\ell=1$ mode

$\ell=2$ mode

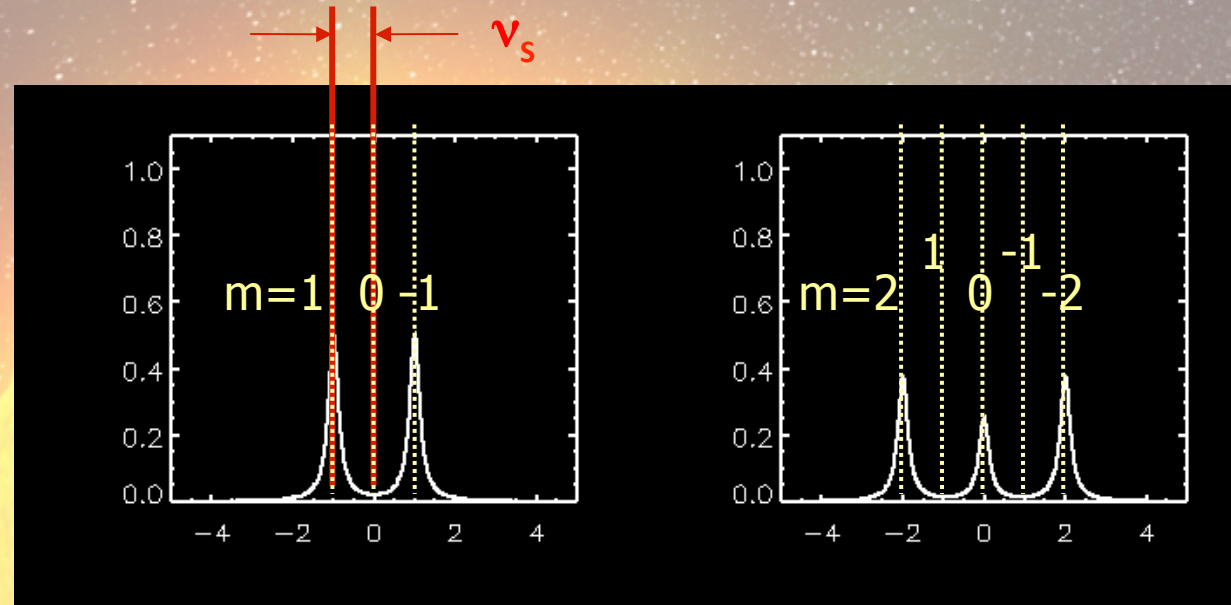


Effect of rotation on modes

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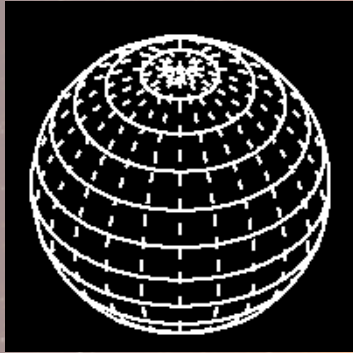


Internal rotation:

- Rotational splittings

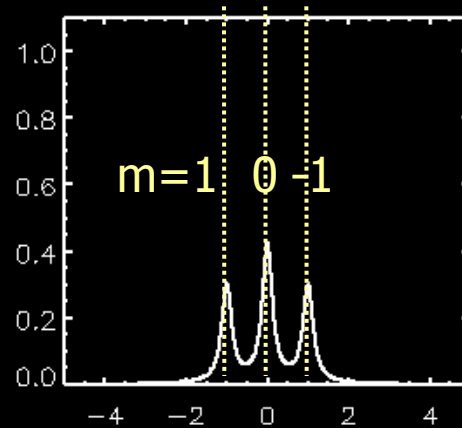
Effect of rotation on modes

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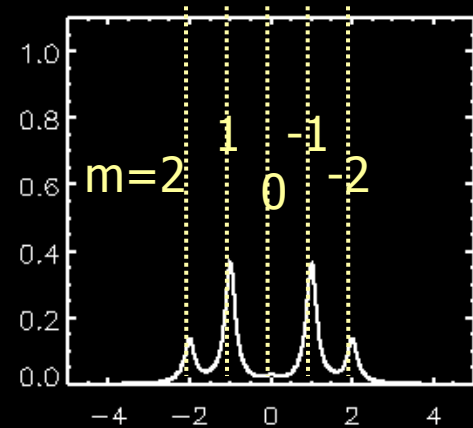


$$i = 50^\circ$$

$\ell=1$ mode



$\ell=2$ mode

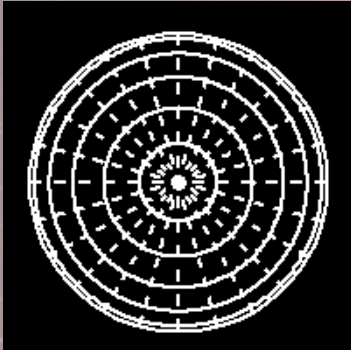


Internal rotation:

- Rotational splittings
- Complicate measurement:
Inclination angle of the star

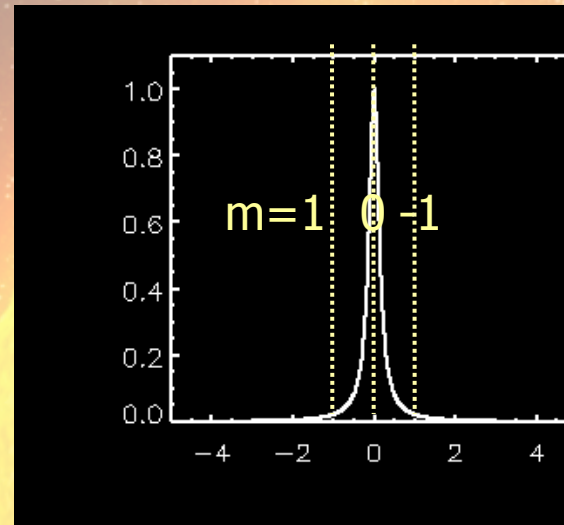
Effect of rotation on modes

$$\Omega = 1,0$$

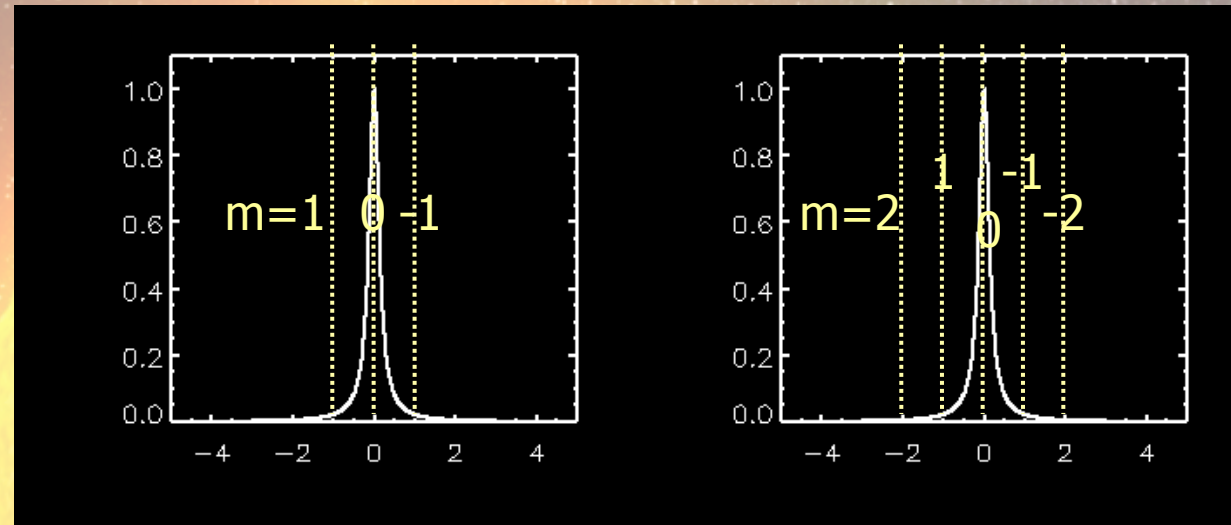


$$i = 0^\circ$$

$\ell=1$ mode



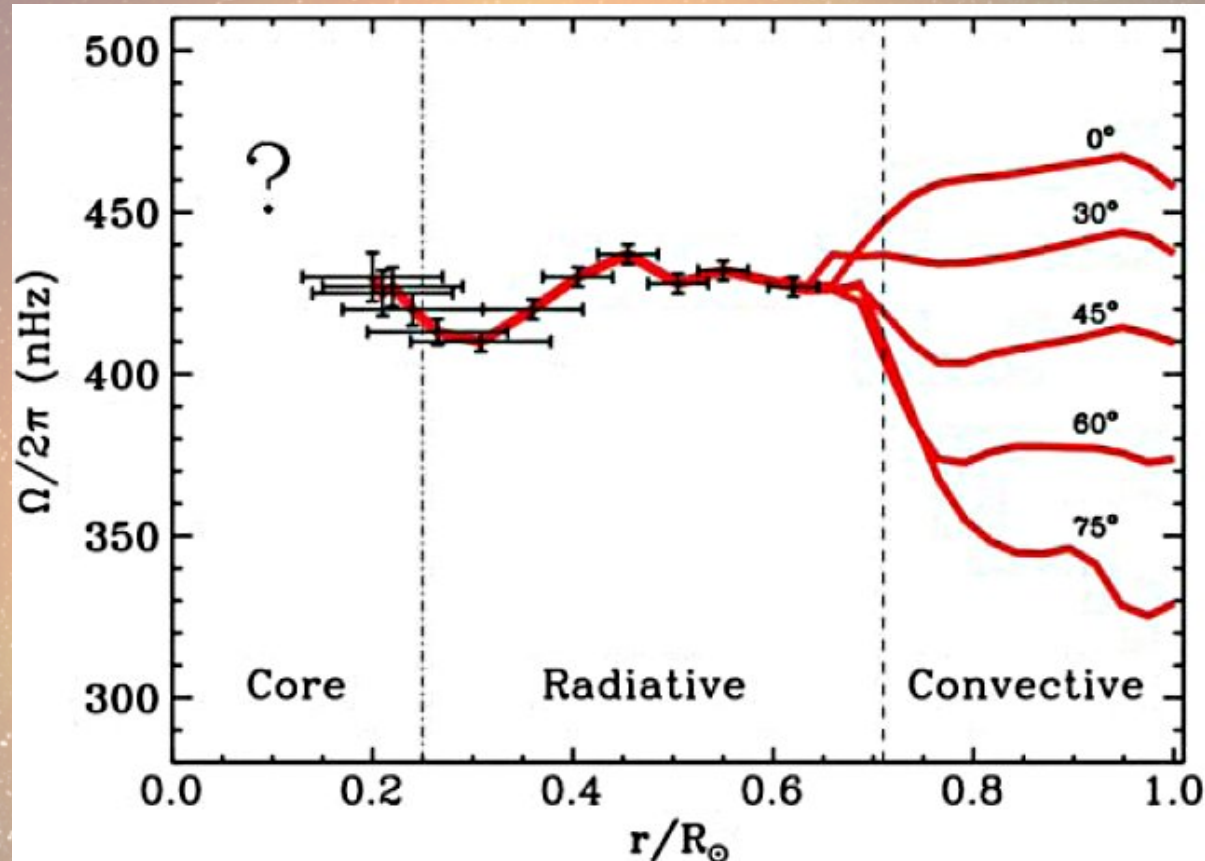
$\ell=2$ mode



Internal rotation:

- Rotational splittings
- Complicate measurement:
Inclination angle of the star

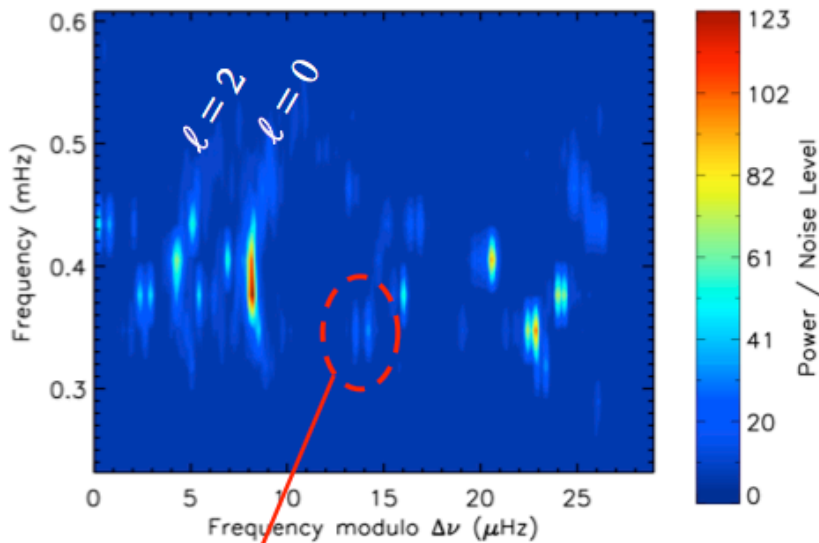
Rotation profile of the Sun



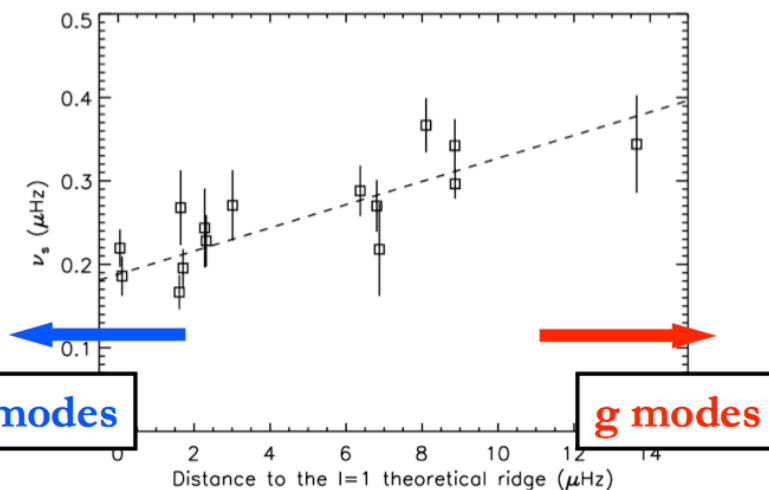
[García et al., 2007 Science]

Rotation profile of a Subgiant

- Mixed modes:
 - Study the internal dynamics



Modes rotationally split

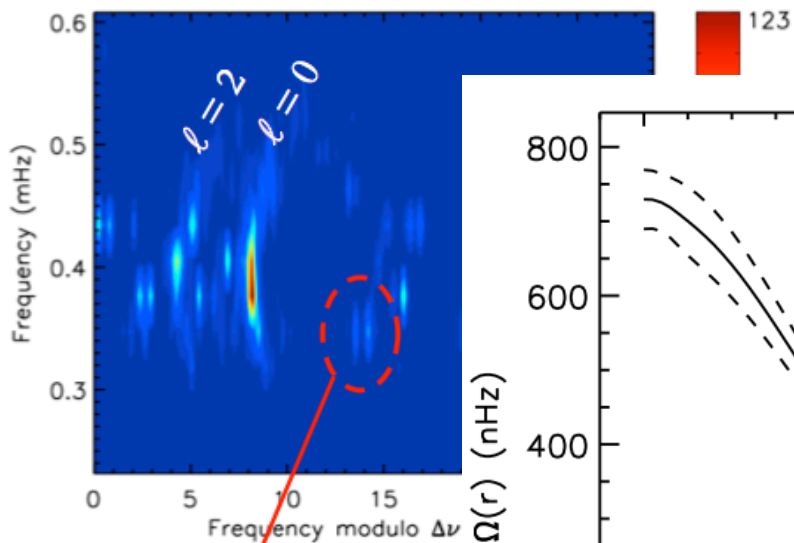


suggests that $\Omega_{\text{core}} > \Omega_{\text{surface}}$

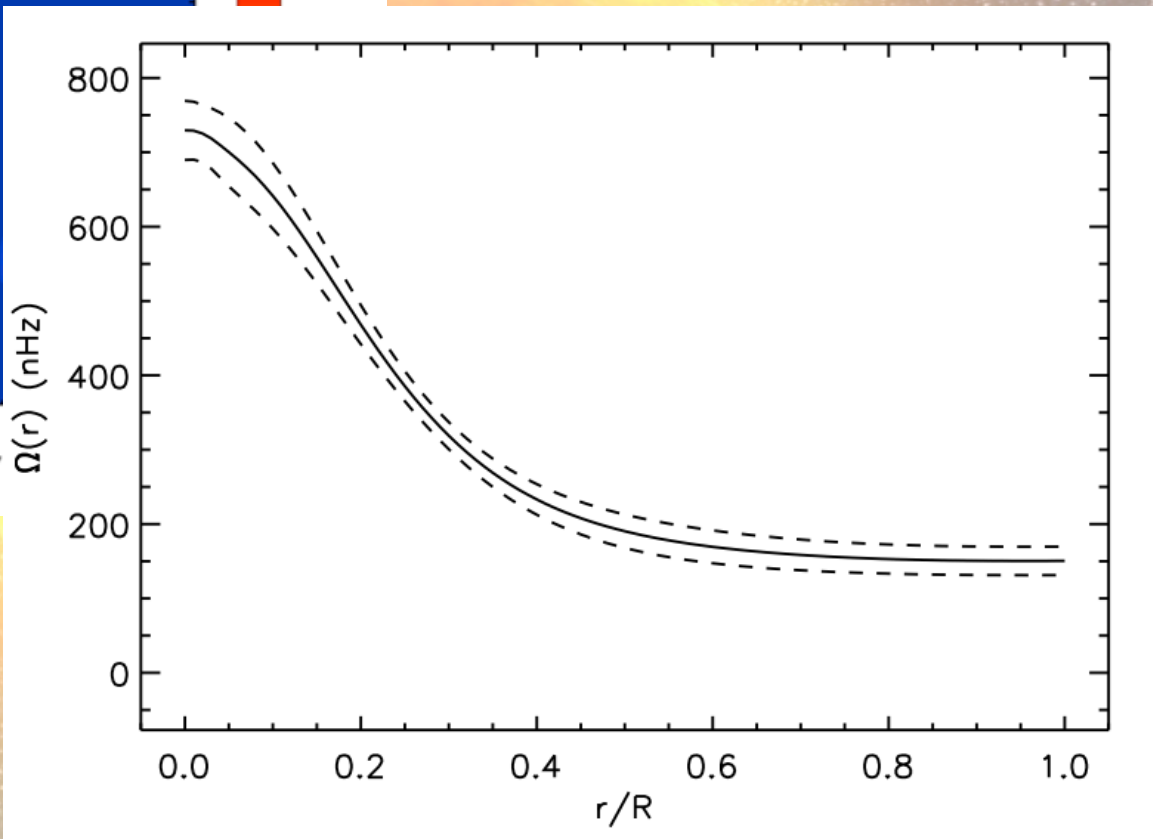
[Deheuvels et al. 2012, ApJ; 2014, A&A]

Rotation profile of a Subgiant

- Mixed modes:
 - Study the internal dynamics

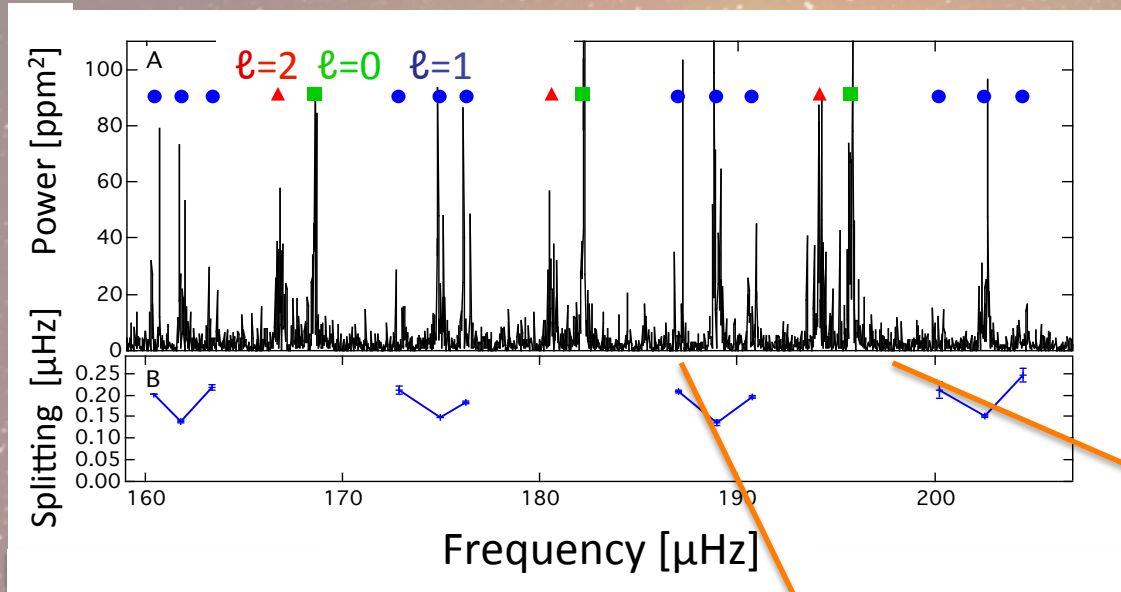


Modes rotationally split



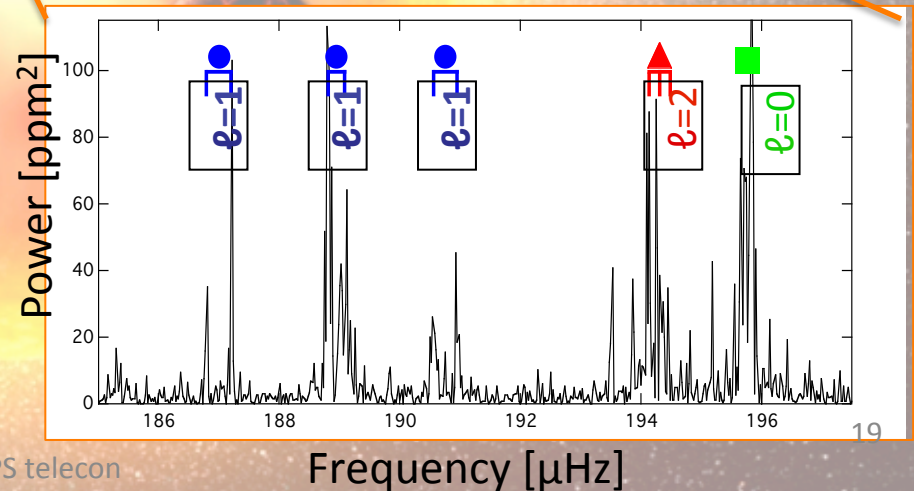
&A]

Rotation profile in red giants



By measuring the splittings

- In more evolved stars
 - Core rotates 10 times faster
 - Radiative region
 - In 3 RG stars [Beck et al. 2012 Nature]
- Extension to 300 RG



Summary

- Asteroseismology:
 - Constrain stellar parameters (M , R , age)
 - Planetary systems
 - Distribution of parameters in the galaxy
 - Study rotation (internal and surface)

Other interests

- *Kepler* star properties catalog:
 - isochrone fitting based on the most accurate observations done to provide stellar parameters of $\sim 200,000$ *Kepler* targets
- Magnetic activity/rotation
- Galactic archeology:
 - In collaboration with APOGEE (SDSS3)