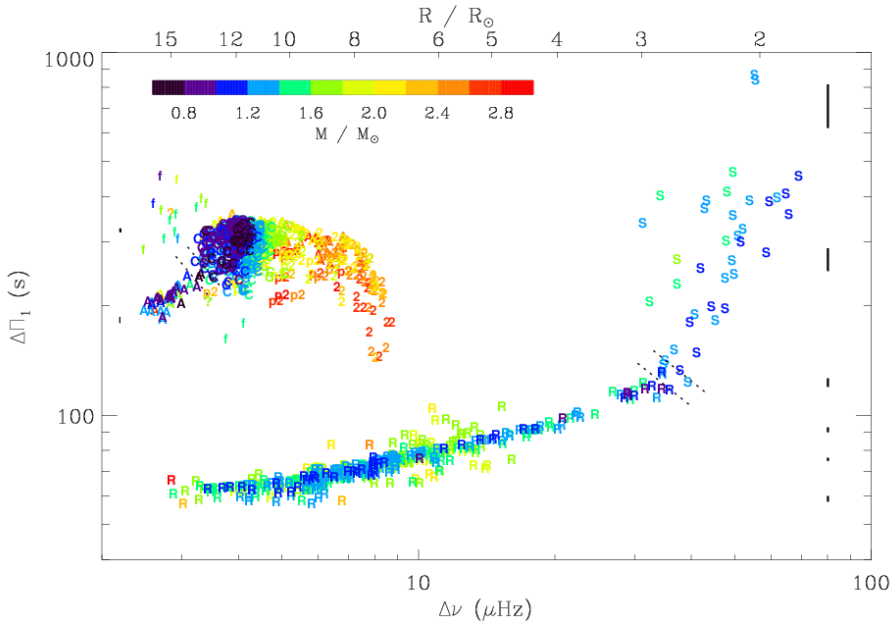
Mixed modes gossips



Benoît Mosser, Kévin Belkacem

+ many colleagues

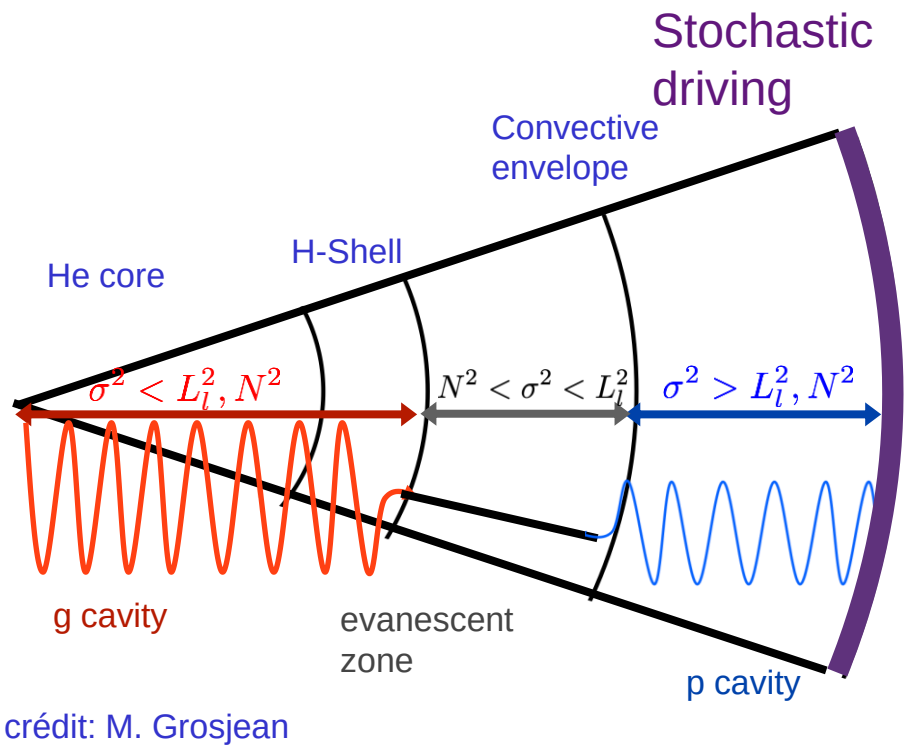
Observatoire de Paris

Kepler

l'Observatoire de Paris | PSL

plato

What is a mixed mode ?



crédit: M. Grosjean

✓ upper cavity in which acoustic modes can exist
the restoring force is dominated by the pressure gradient

✓ inner cavity in which gravity modes can exist
the dominant restoring force is the buoyancy

✓ intermediate region, in which modes are evanescent, couples the cavities

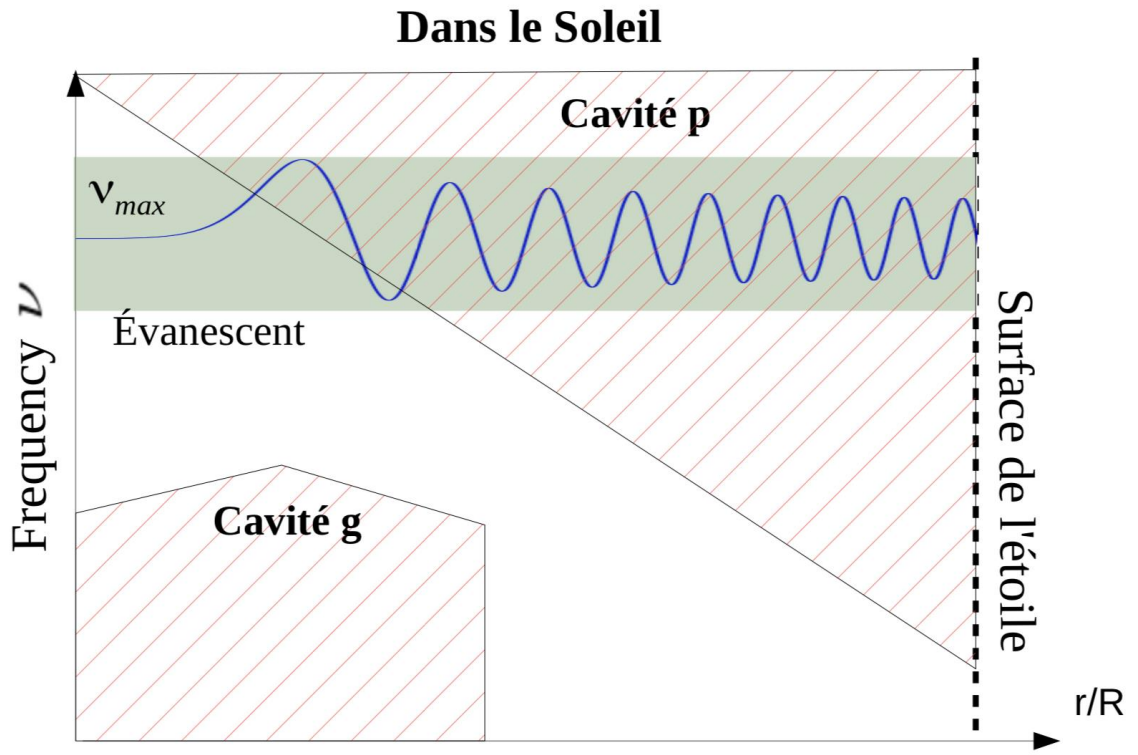
- Mixed modes have amplitude in the enveloppe and in the core

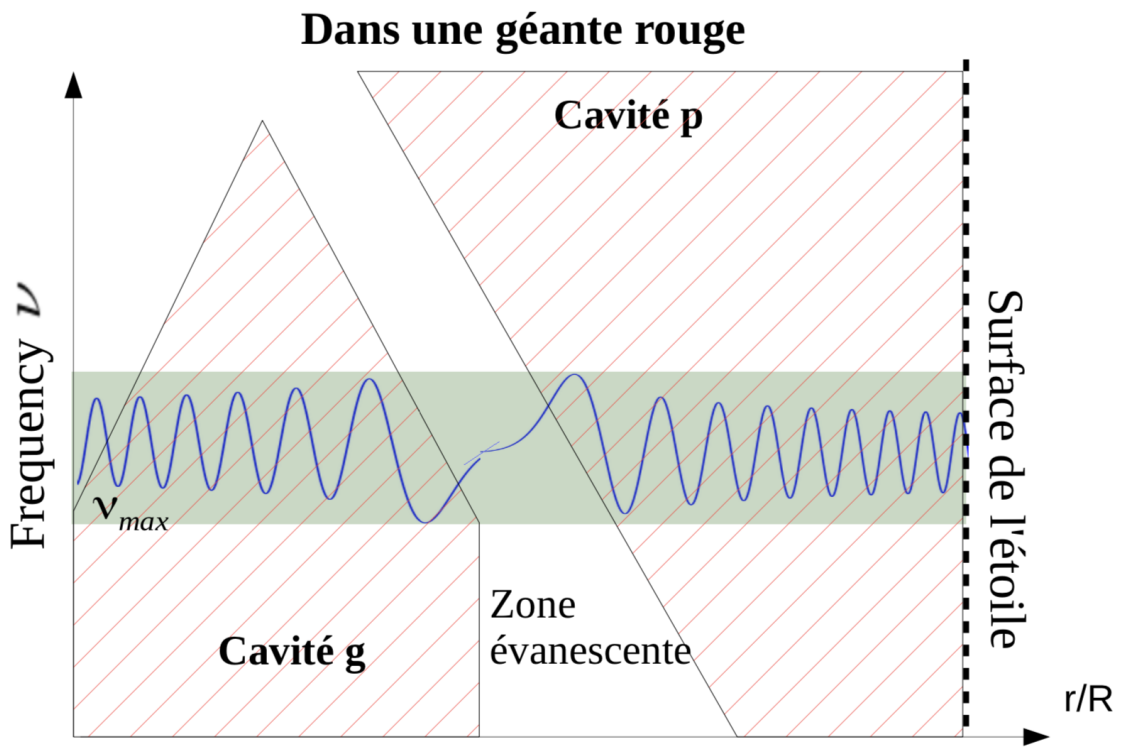
→ can be used to probe the innermost layers

Mixed mode seismology → evolved stars

After the main sequence: - the core contracts → The core density and buoyancy frequency increase

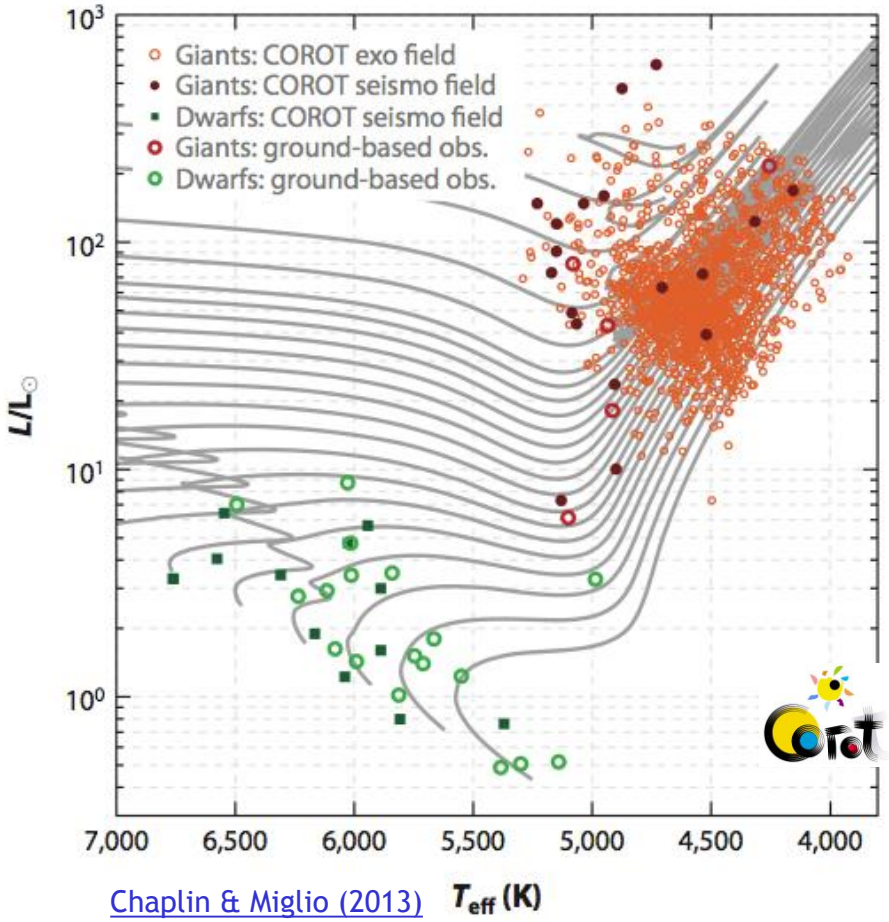
- the envelope expands → The surface gravity decreases so does ν_{max}





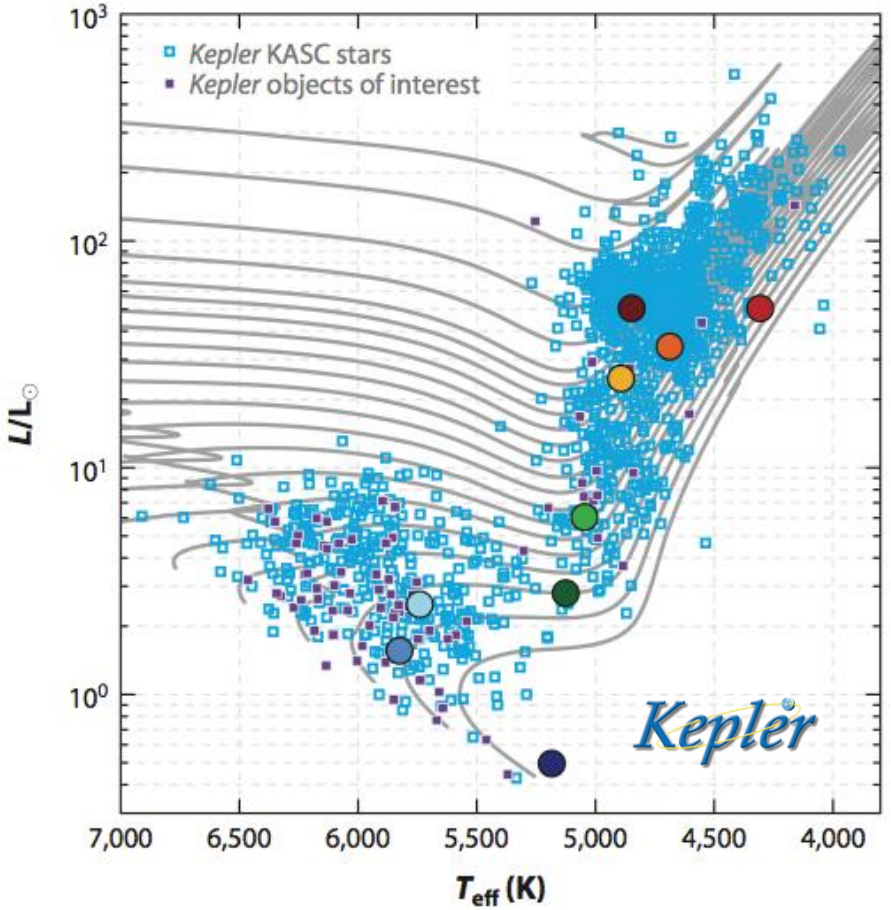
crédit: C. Piçon

Mixed mode seismology → evolved stars



Chaplin & Miglio (2013)

- hundreds of oscillating MS stars and thousands of RG stars



- highly accurate measurements of individual mode properties

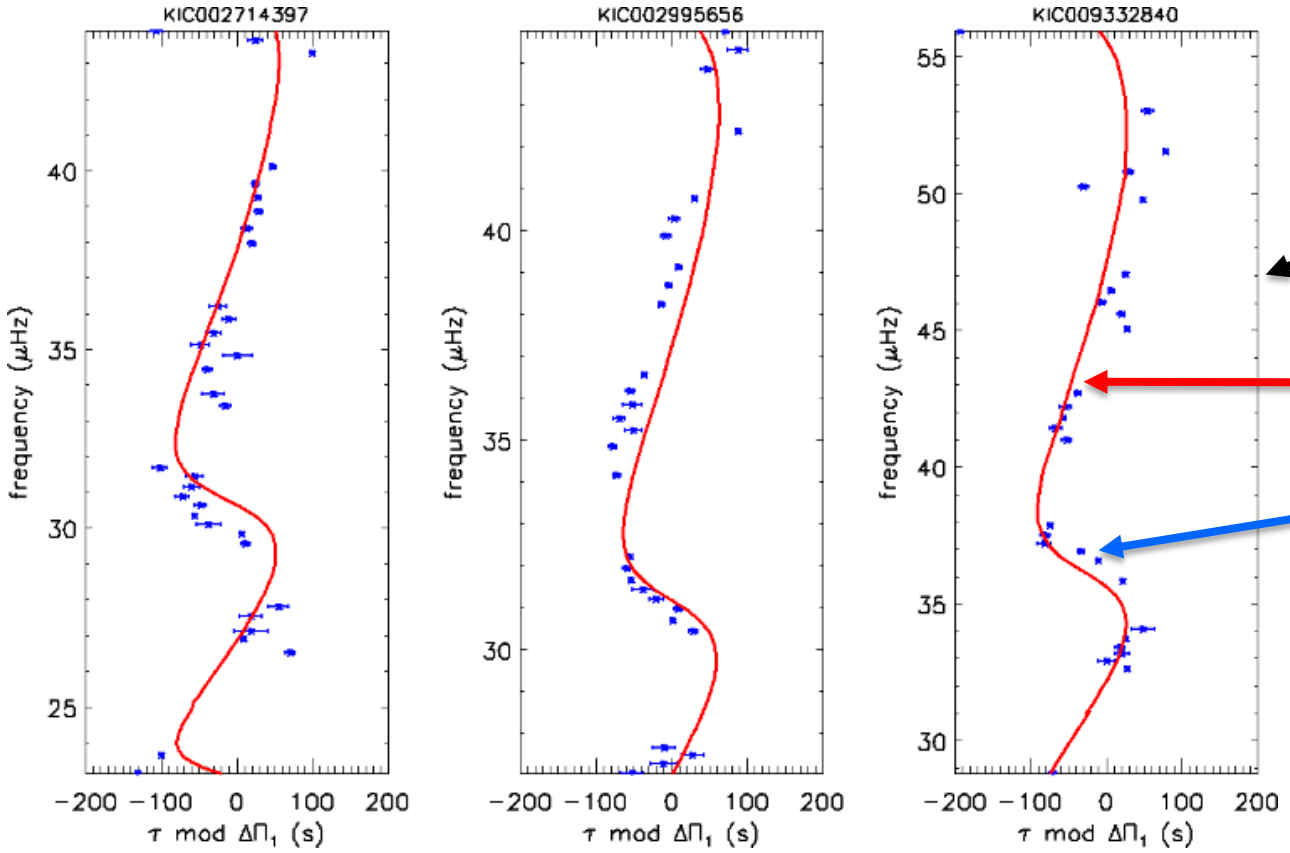
Gossips?

1. Rumor or talk of a personal, sensational, or intimate nature.
2. A person who habitually spreads intimate or private rumors or facts.
3. Trivial, chatty talk or writing.
4. A close friend or companion.

Non-exhaustive list of gossips

- Buoyancy glitches in clump stars
- Subgiants
- Scaling relations
- Gravity offset
- Rotational splittings
- Stellars inclinations

Buoyancy glitches in clump stars → core overshooting



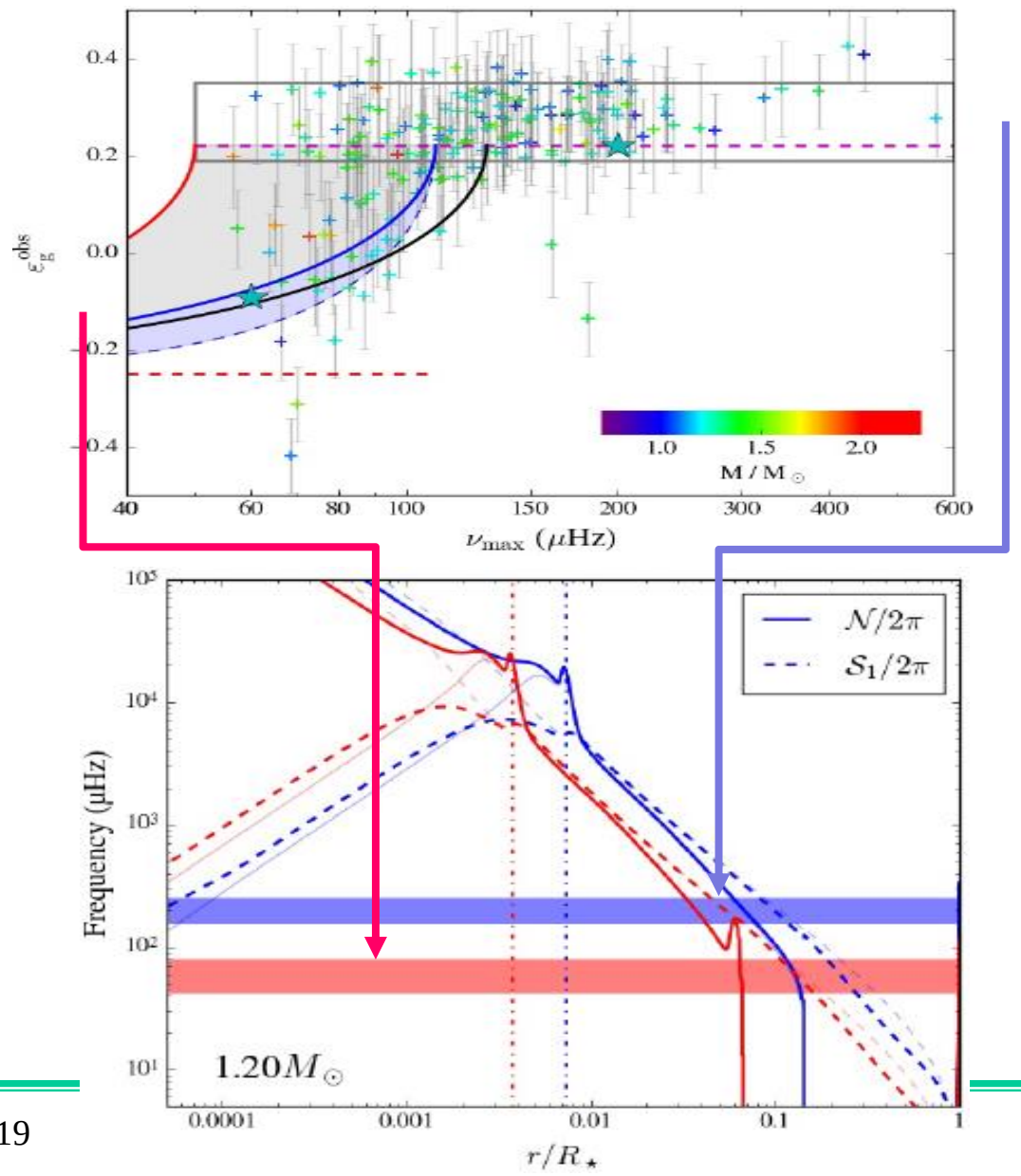
Context: the analysis of the mixed-mode pattern shows modulations with respect to the asymptotic pattern

- Échelle diagram based on stretched modes (Mosser* et al. 2015)
- Theoretical modelling (Cunha* et al. 2019)
- Observed glitches (Vrard* et al. 2019, Vrard et al. in preparation)

[* = AFE mixed modes collaboration]

Deviations in the mixed-mode frequency pattern is characteristic of core structural discontinuities = signature of the core overshooting

Gravity-mode offset → core overshooting



Context: the high quality of Kepler observations allows us to characterize new asymptotic parameters; here the offset of gravity-modes

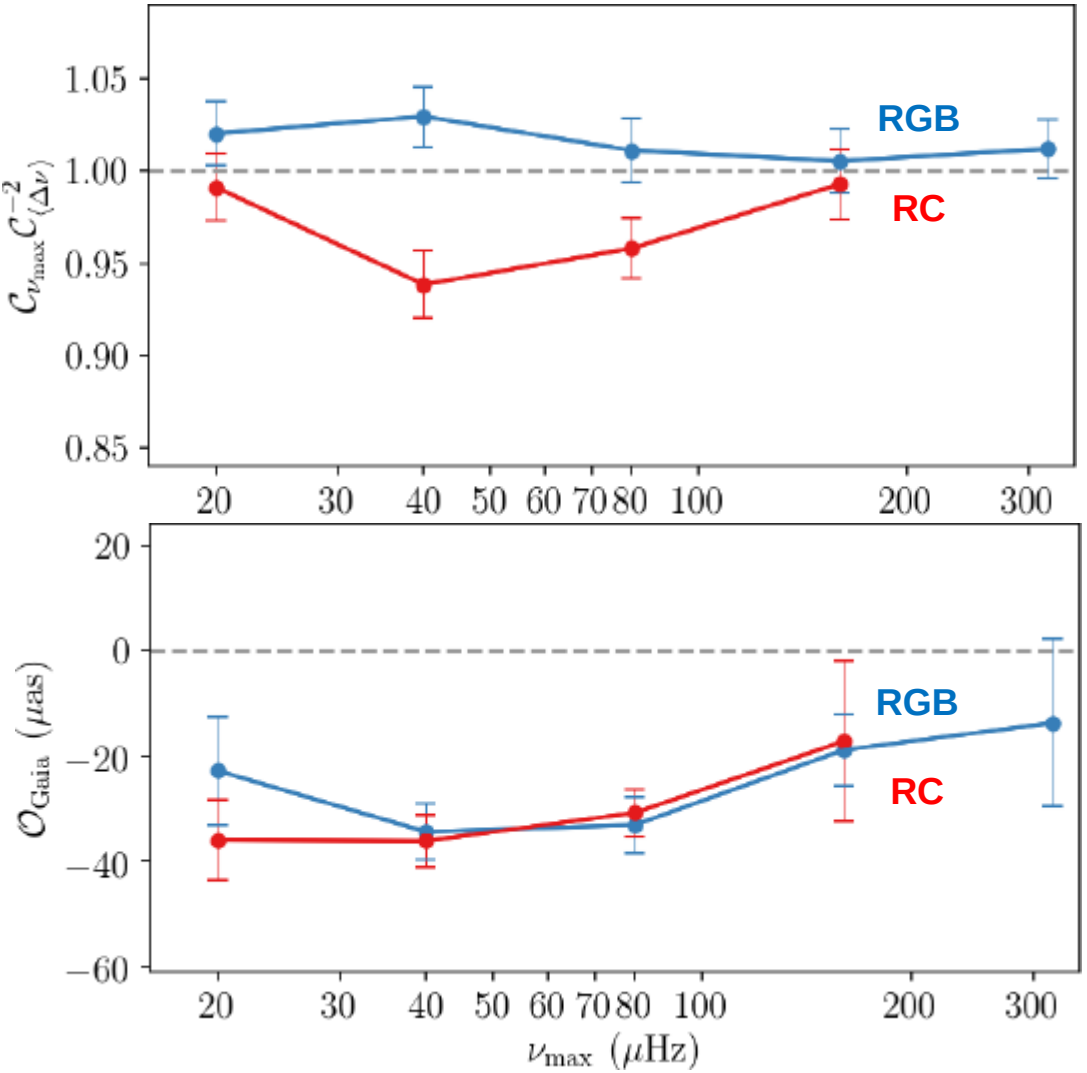
- Gravity mode periods: $P = \Delta\Pi_1 (-n_g + \varepsilon_g)$

(Pinçon* et al. 2019)

[* = AFE mixed modes collaboration]

The potential of ε_g to probe the value and slope of the Brunt–Väisälä frequency below the base of the convective region is clearly highlighted.

Scaling relations → new model-independent calibration



Context: combined analysis of seismic (Kepler) and astrometric (Gaia) data

- Definition of the seismic parallax

$$\varpi'_{\rm scaling} = c_\lambda C_{\nu_{\rm max}} C^{-2}_{\langle\Delta\nu\rangle} \left(\frac{\nu_{\rm max}}{\nu_{\rm max,\odot}}\right)^{-1} \left(\frac{\langle\Delta\nu\rangle}{\langle\Delta\nu\rangle_\odot}\right)^{2} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{-5/2}$$

- Comparison with the Gaia parallax

$$\varpi_{Gaia} - O_{Gaia} = C_{\nu_{\rm max}} C^{-2}_{\langle\Delta\nu\rangle} \varpi_{\rm scaling}$$

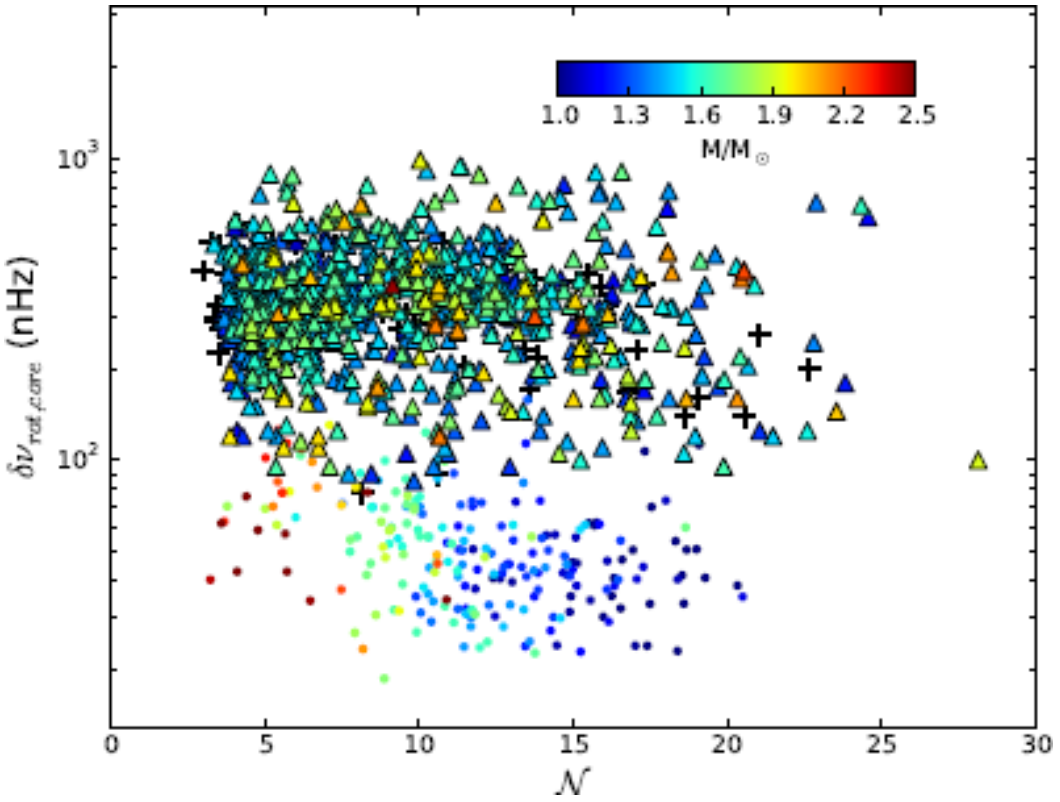
Gaia offset — Seismic calibration factor

(Khan*,** et al. 2019)

[* = AFE mixed modes collaboration ** = AF Gaia]

→ New model independent calibration of the Gaia offset and of the seismic calibration factor

Rotational splittings → core overshooting



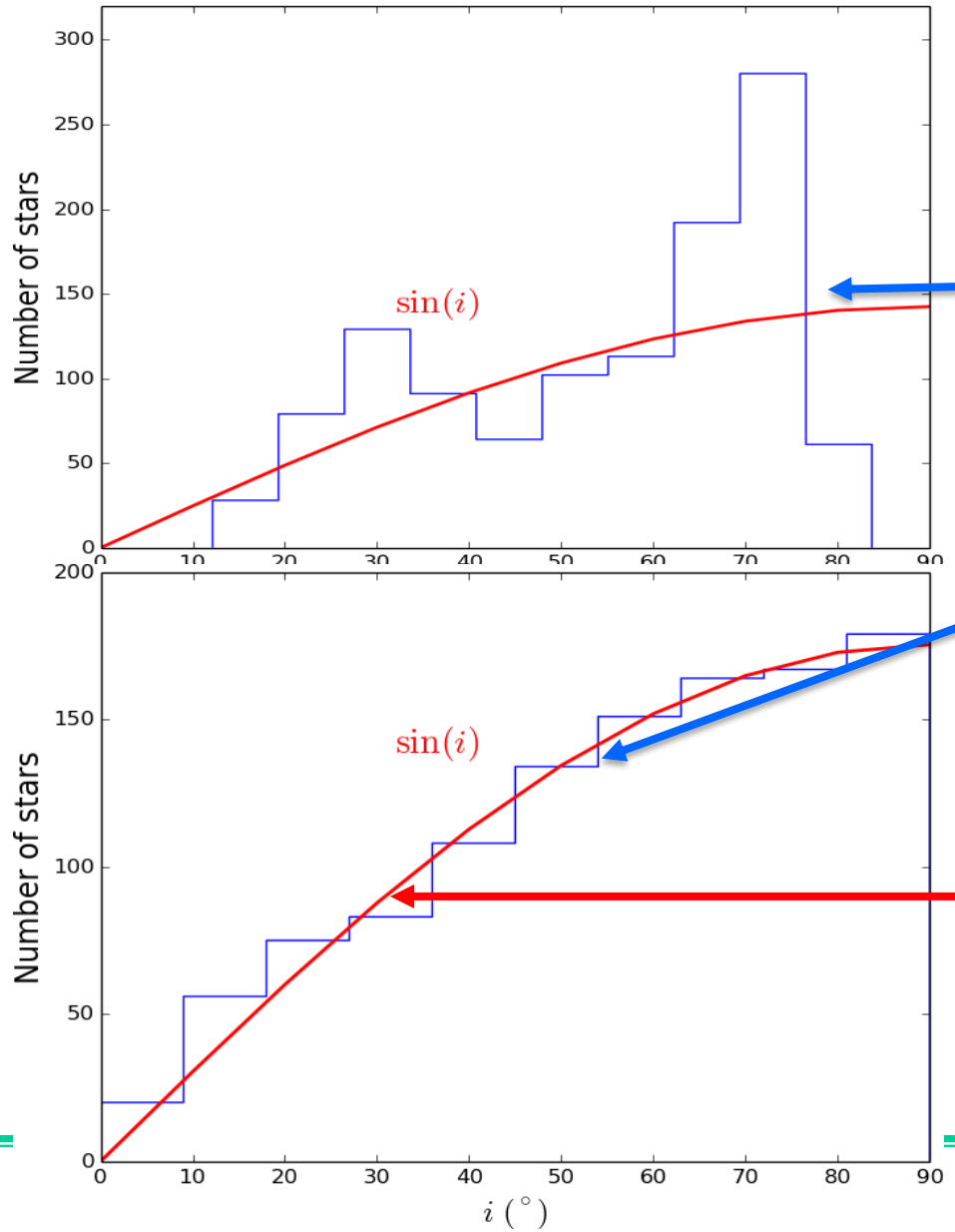
Context: the high quality of Kepler observations allows us to measure the core rotation

Automated measurement of ~900 RGB (Gehan* et al. 2018)

[* = AFE mixed modes collaboration]

Core rotation is constant along the red giant branch, with values independent of M → new constraints on the transfer of angular momentum

Stellar inclinations → core overshooting



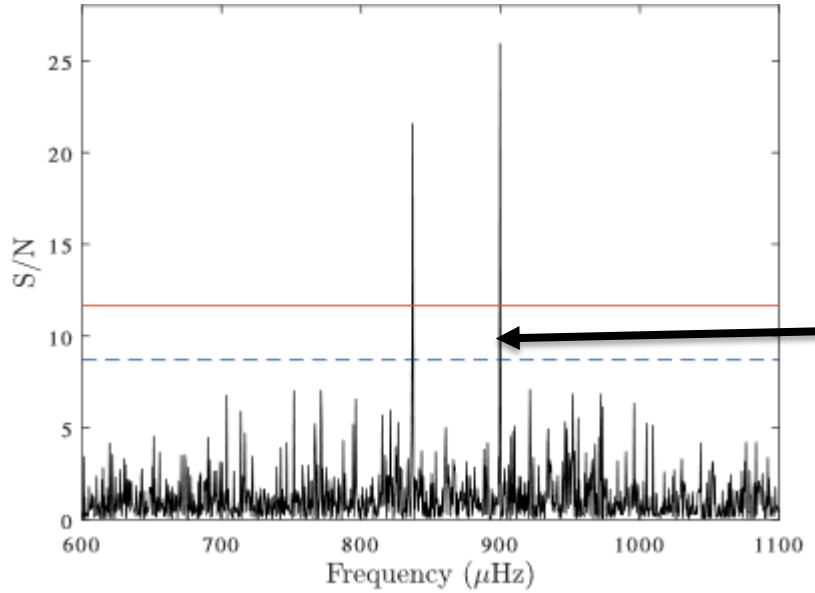
Context: the high quality of Kepler observations allows us to measure stellar inclinations

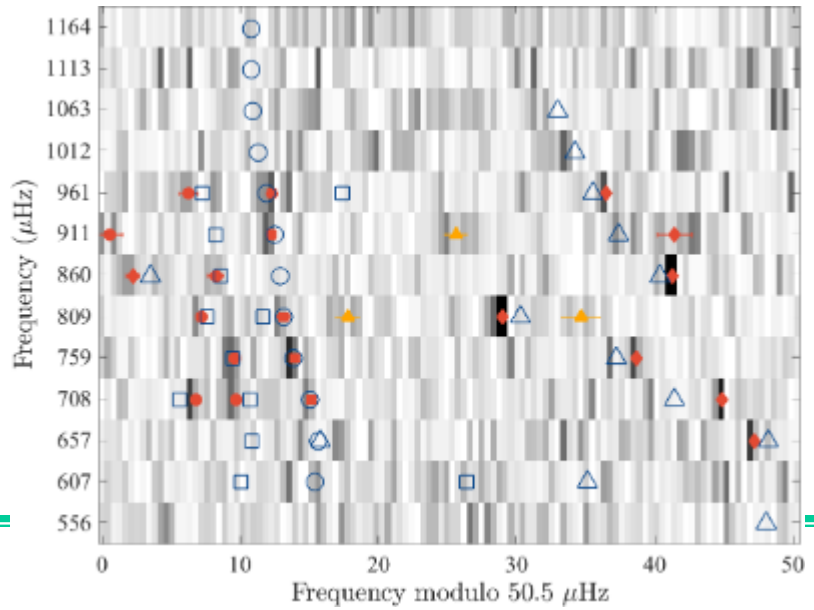
- Automated measurement of ~1200 RGB (no star seen pole-on or edge-on in the raw measurements)
- Correction of the bias for stars seen pole-on or edge-on (Gehan* et al. en préparation)
- Isotropic distribution

[* = AFE mixed modes collaboration]

The correction of the bias based on the noise statistics allows an accurate measurement of the stellar inclination

TESS subgiants → deciphering the oscillation pattern





○ radial modes

△ dipole modes

□ quadru polar modes

Context: TESS observations = low SNR, poor frequency resolution (27-day observation)

- Oscillation pattern of a subgiant observed by)
- Mode identification (Metcalfe* et al, in preparation) derived from the mixed-mode pattern (Mosser* et al. 2015, 2018)

Rotation period much shorter than expected from standard models of angular momentum evolution → New constraint on the angular momentum transfer

Probing the properties of stellar core with mixed modes

Don Diègue	Rodrigue, as-tu du **cœur** ?	*Rodrigue, are you brave?*
Don Rodrigue	Tout autre que mon père L'éprouverait sur l'heure	*Any but my father* *Might test it at this moment*
	Pierre Corneille	**Stone Crow**
	le Cid, Acte I scène 5	*Cider, Act I Scene 5*