

# Détection systématique de champ magnétiques dans les coeurs de géantes rouges par l'astérosismologie

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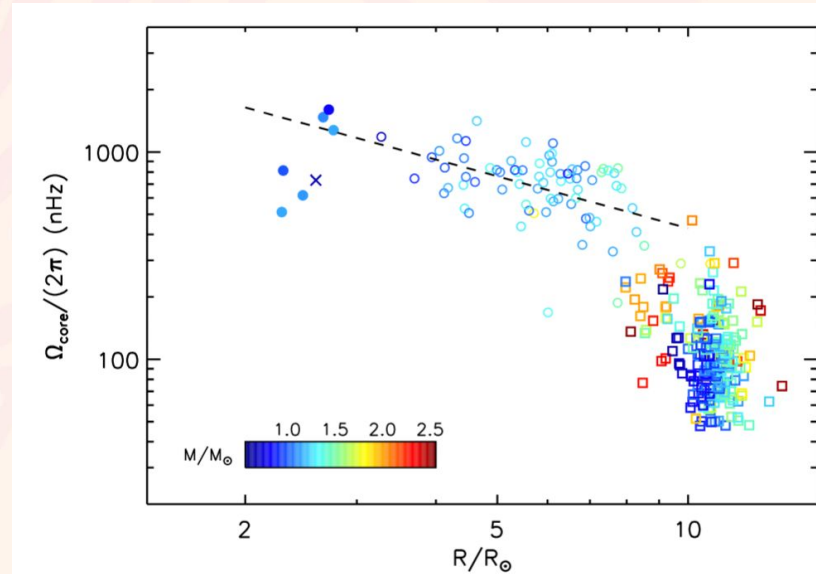
## Seismic measurements of core rotation in red giants:

- Core rotation is overestimated in models
  - Observed in other stars as well
- Spin down of red giant cores despite contraction

→ Need for an efficient additional transport of AM

Promising candidate:

Magnetic fields in the core



Core rotation rates of subgiants and red giants  
(Deheuvels et al 2014)

## Direct detections :

- **RGB stars since 2022 : 80 stars out of ~20.000**

(Li et al 2022,2023 ; Deheuvels et al 2023,2026 ; Hatt et al 2024, Villate et al 2026)

- **MS stars :  $\gamma$ -Dor and B-Cep**

(Ihallaine et al 2026 ; Takata et al 2025 ; Vandersnickt et al 2025)

## Indirect detections :

- **Suppressed dipole stars**

(e.g. Mosser et al 2012,2017 ; Fuller et al 2015 ; Stello et al 2016)

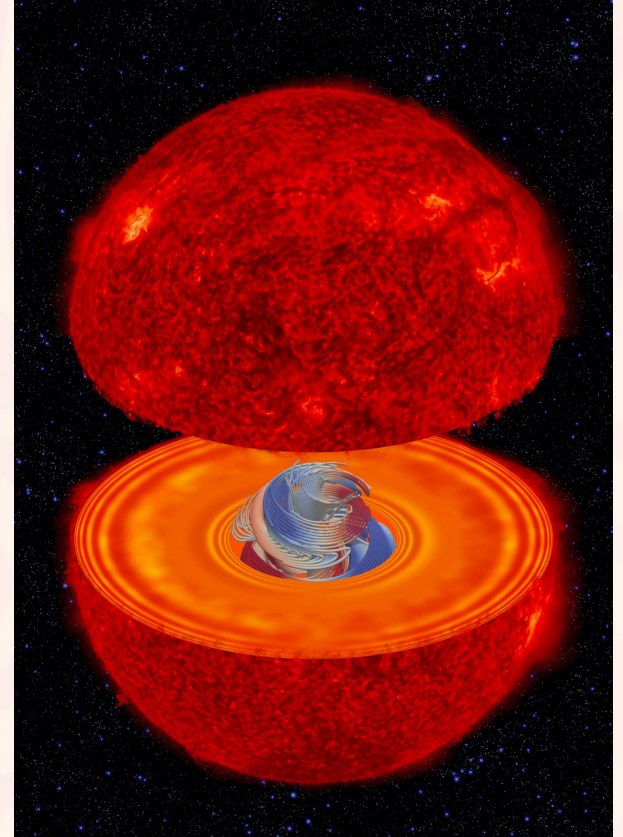
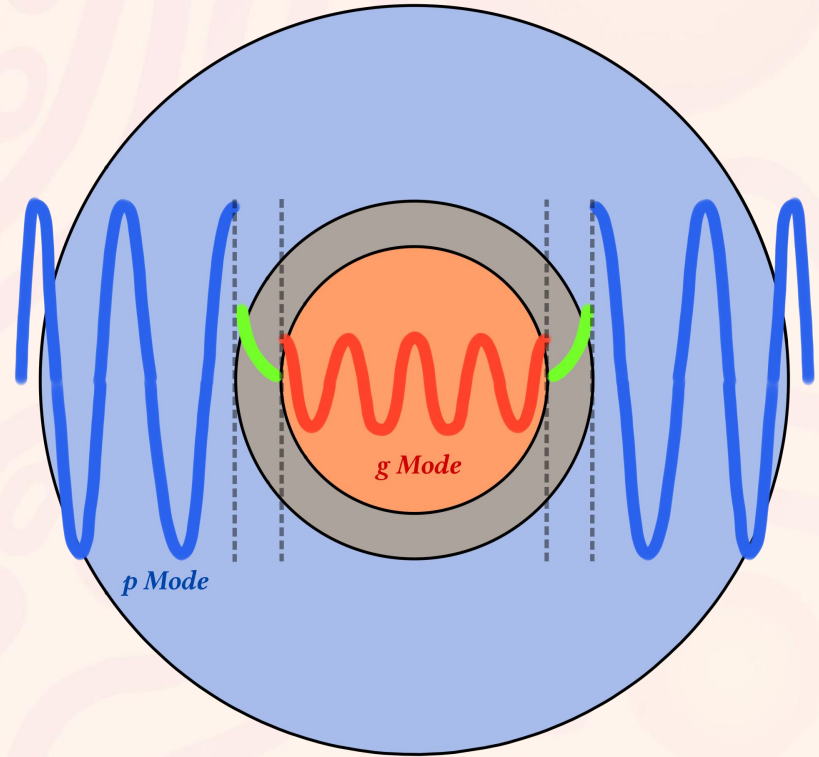


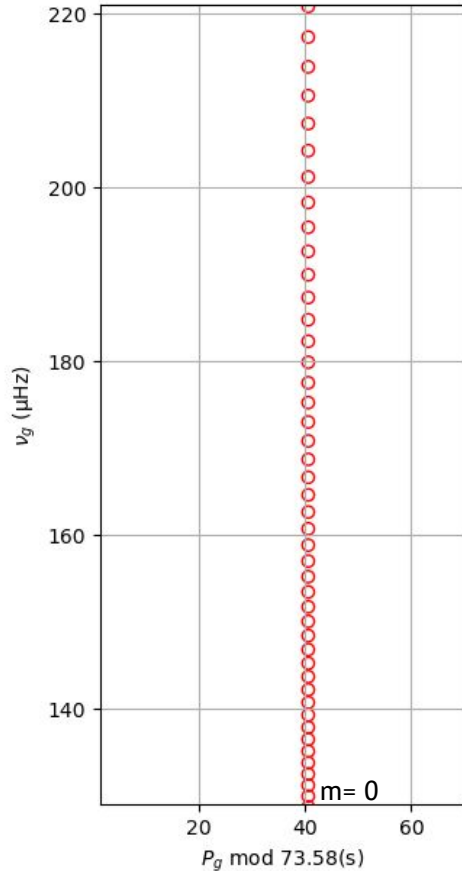
image credit : Ballot, J. ;Jouve, L.

Asteroseismology : study of stellar oscillations

- 2 families of modes:
  - ◆ p modes (acoustic)
  - ◆ g modes (gravity)
- Red Giants : p and g modes are close in frequency
  - ◆ Coupling through the evanescent zone
  - ◆ Mixed modes are created



# Effects of the rotation and magnetic field



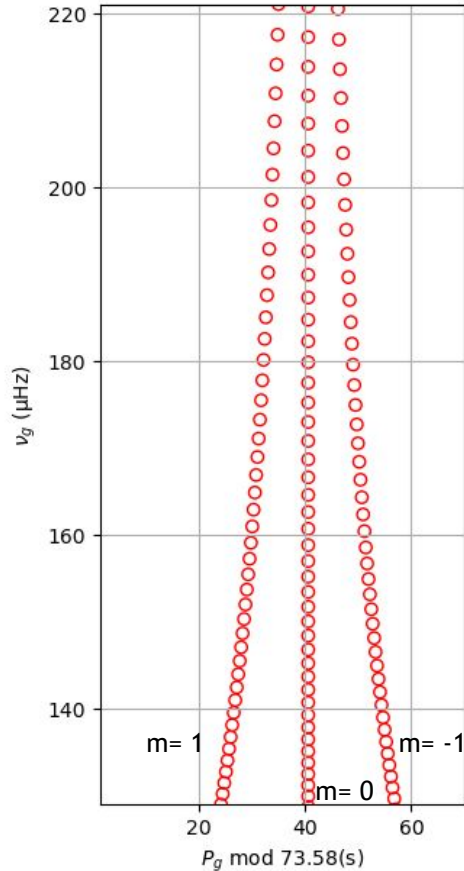
→ Modes align vertically  
in echelle diagrams

$$P_n = \Delta\Pi_1 \left( n + \frac{1}{2} + \epsilon_g \right)$$

*Period spacing*

*Gravity offset*

# Effects of the rotation and magnetic field



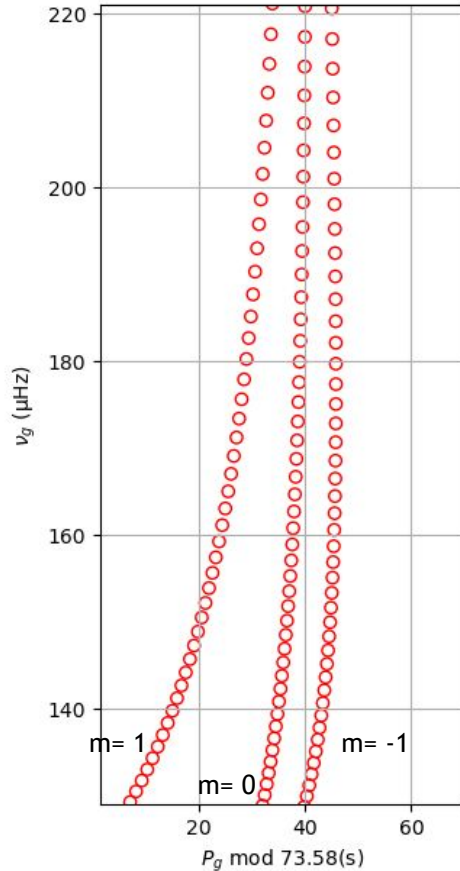
→ Modes align vertically  
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→ Rotation splits dipolar modes in 3

$$P_n = \underbrace{\Delta\Pi_1}_{\text{Period spacing}} (n + \underbrace{\frac{1}{2} + \varepsilon_g}_{\text{Gravity offset}})$$

*Period spacing*

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→ Modes align vertically in echelle diagrams

$$P_n = \underbrace{\Delta \Pi_1}_{\text{Period spacing}} \left( n + \frac{1}{2} + \underbrace{\epsilon_g}_{\text{Gravity offset}} \right)$$

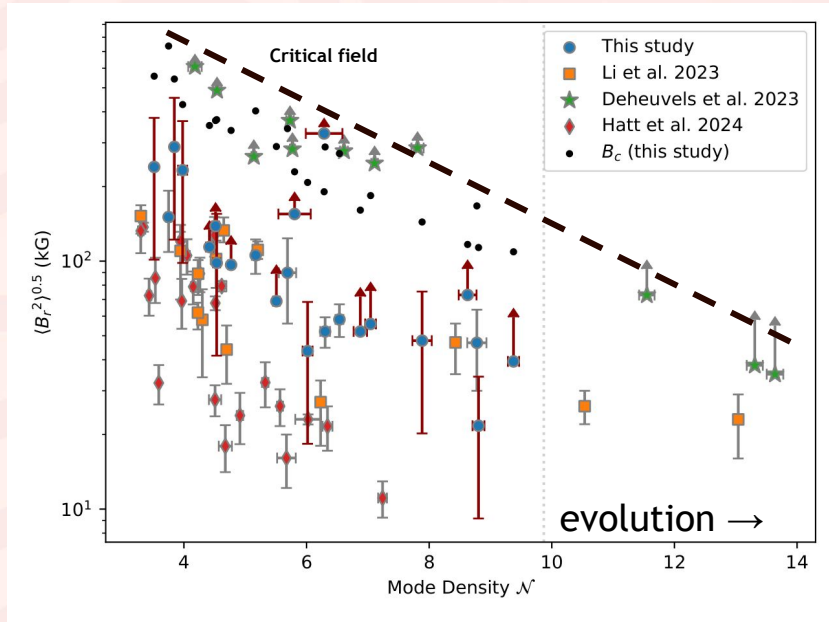
→ Rotation splits dipolar modes in 3

→ Core magnetic fields create a **curvature** in the ridges

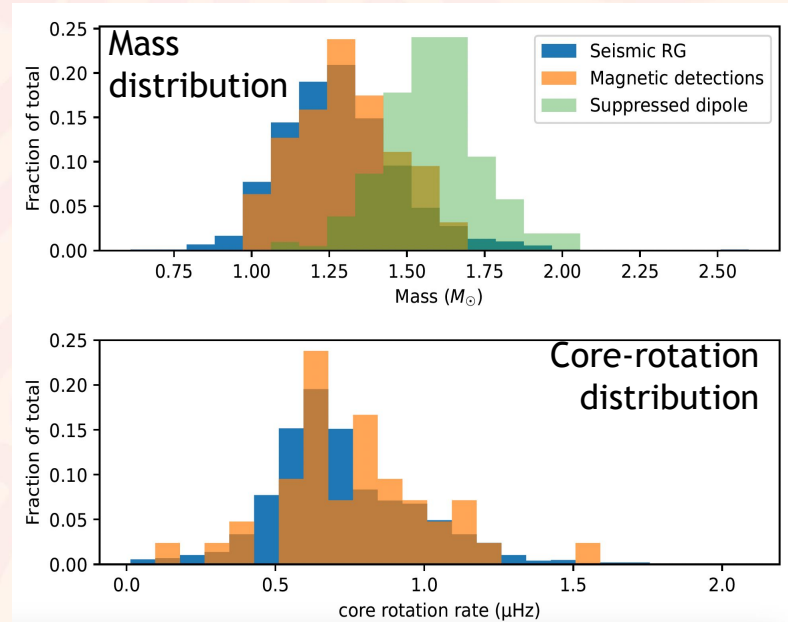
- ◆ Mostly information on :
  - the mean square radial field  $\langle B_r^2 \rangle$  in the core
  - global topology

# Seismic detections : ensemble results

Villate et al. 2026 : 23 detections in Li et al. 2024 subsample → a more **global** picture



Decrease of the intensity with evolution



Stars with magnetic field detections are not peculiar compared to other stars

# An automatic approach ?

All previous studies incorporate sample biases :

- Li et al. 2022
  - Li et al. 2023
  - Hatt et al. 2023
- } Asymmetries
- Deheuvels et al. 2023
  - Deheuvels et al. 2026
- } Near-critical fields
- Villate et al. 2026 → Gravity offset

→ **Need for a systematic approach to reach exhaustivity and a broader picture of core magnetic fields**

↓

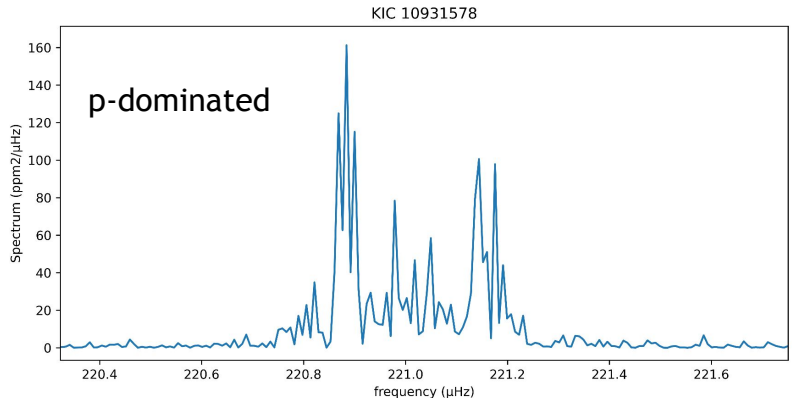
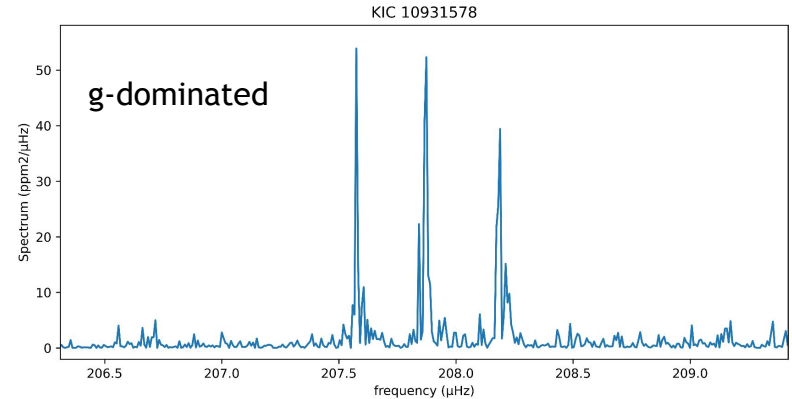
Making the method from Villate et al. 2026 automatic

## Step 1 : identify significant modes

We establish a statistical criterion to:

- Fix false alarm probability  $\rightarrow$  threshold
- Maximise the probability of **detection** for individual modes  
 $\rightarrow$  boxcar smoothing w.r.t mode width

$\rightarrow$  In red giants :  $\Gamma_{l=1} = (1 - \zeta) \Gamma_{l=0}$  (Mosser et al. 2015)

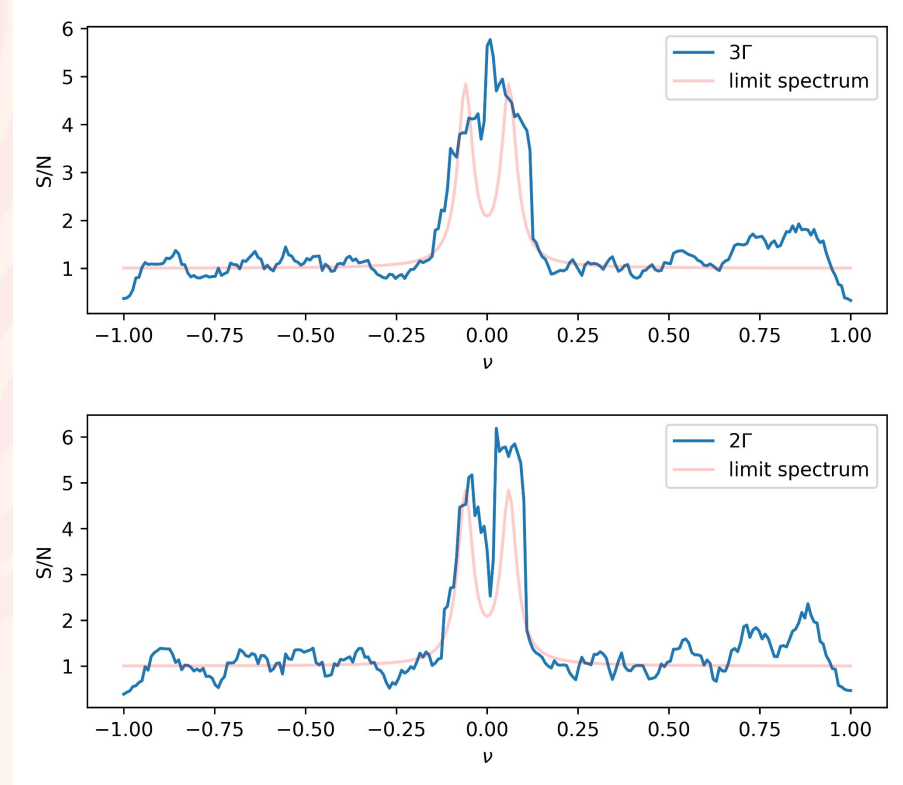


## Step 2 : how many modes?

Ran statistical tests on simulated signal to determine best course of action :

- Smoothing a bit less to **distinguish additional components** !
- Developed a process to separate useful signal from stochasticity effects

Once extracted, mode frequencies are adjusted to the spectrum

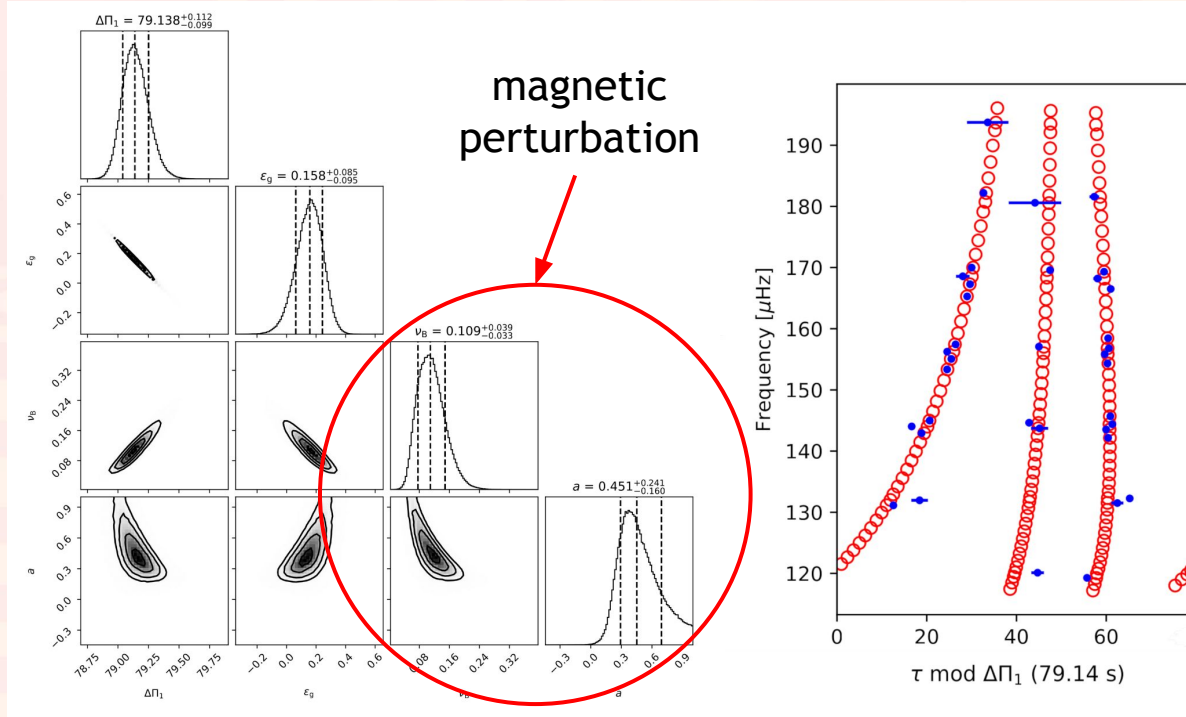


# An automatic approach : Bayesian Inference

Detected modes are used to fit a model accounting for rotation and magnetic field

- Knowing prior information on parameters
- We obtain the posterior distributions

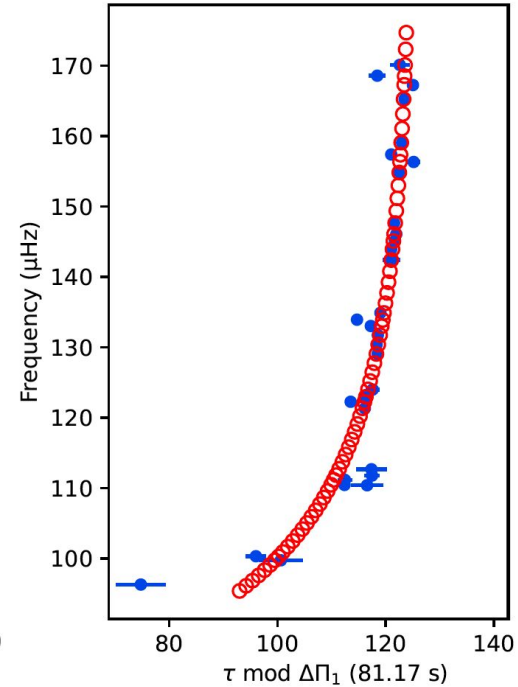
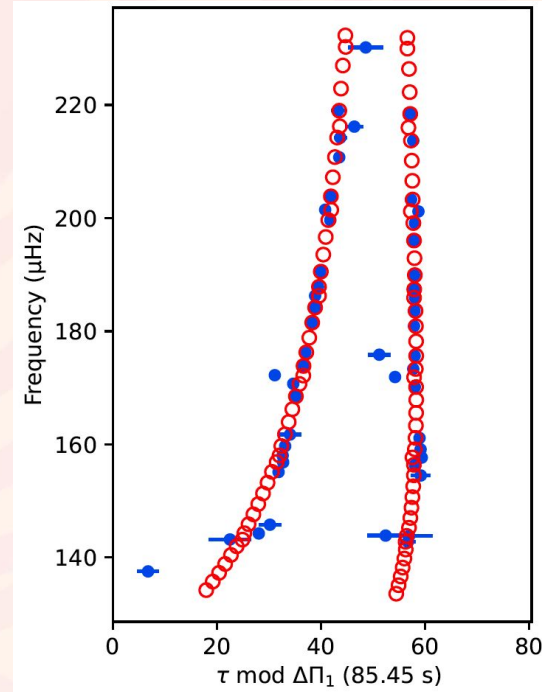
Using model comparison, we assess the detection probability



Example of a magnetic detection

# An automatic approach : Preliminary results

- 900 stars automatically processed : remaining stars from Li et al 2024
  - 3 new core magnetic fields detected : expected from sample choice
    - Representative of the **expected detection probability of such fields** : 26 out of ~1100 stars
  - **Work in progress** : caveats and issues to evaluate and fix



New fully automated method to detect magnetic fields in red giants in validation, allowing for:

- **Extension** of the study to **more luminous** red giants
- Eventual study of **all red giants in Kepler catalogues**.
- Application to **PLATO data** as a **pipeline**
- Possibly help detect peculiar stars (non axi-symmetric magnetic field, mode suppression)
- Exploration of non-axisymmetric effects and mode suppression

**Thank you for listening !**



# Effects of the magnetic field on g-mode pattern

→ In the core, mixed modes follow g-mode periodicity:

$$P_n = \Delta\Pi_1 \left( n + \frac{1}{2} + \varepsilon_g \right)$$

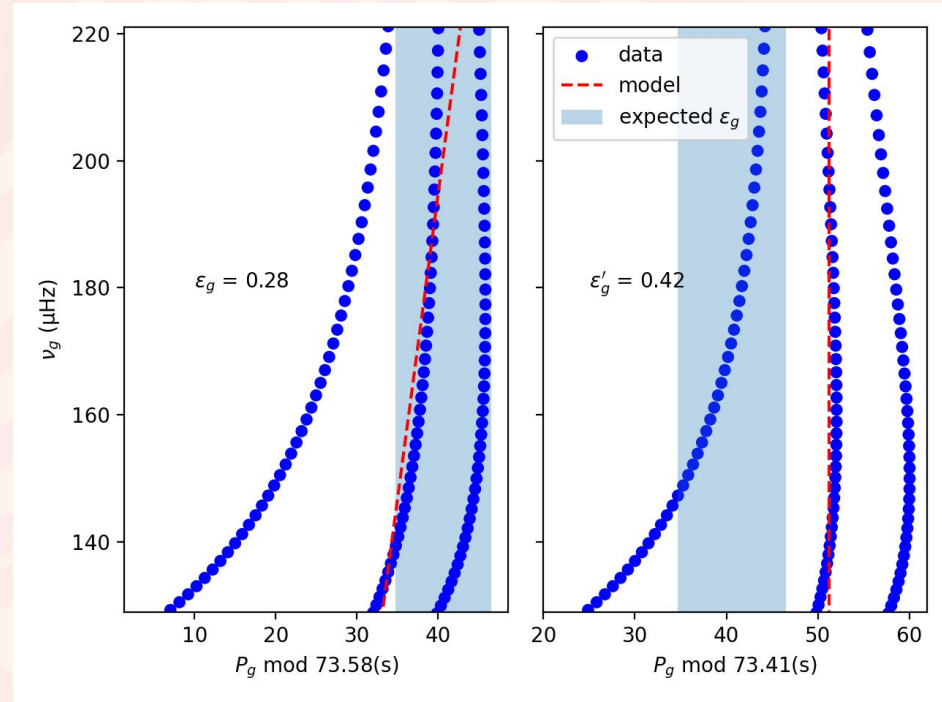
Period spacing

Gravity offset

Magnetic fields **distorts** the measure of these parameters if not taken into account !  
(Li et al. 2022)

$$\varepsilon_g \approx 0.28 \pm 0.08$$

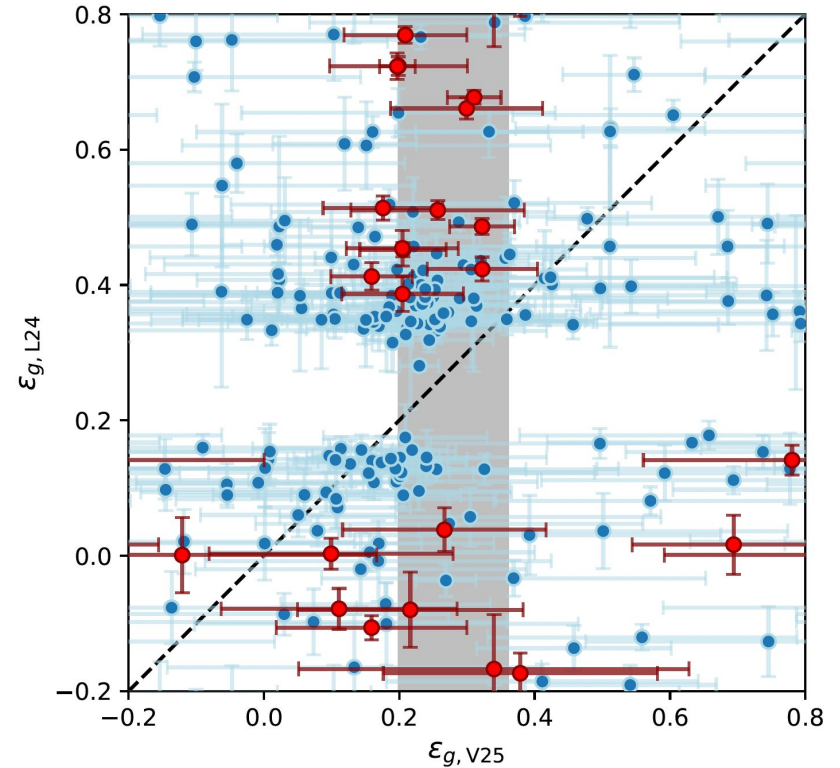
Mosser et al. 2018



Effect of the field in the measure of  $\varepsilon_g$

- Most magnetic stars yield values closer to the expected value
- Non magnetic stars become compatible with the empirical value because of wide error bars

→ The use of  $\epsilon_g$  as a probe for core magnetic field is promising



comparison of the value of  $\epsilon_g$  between this study and Li et al. 24

→ In the core, mixed modes follow g-mode periodicity:

$$P_n = \Delta\Pi_1 \left( n + \frac{1}{2} + \varepsilon_g \right)$$

Period spacing

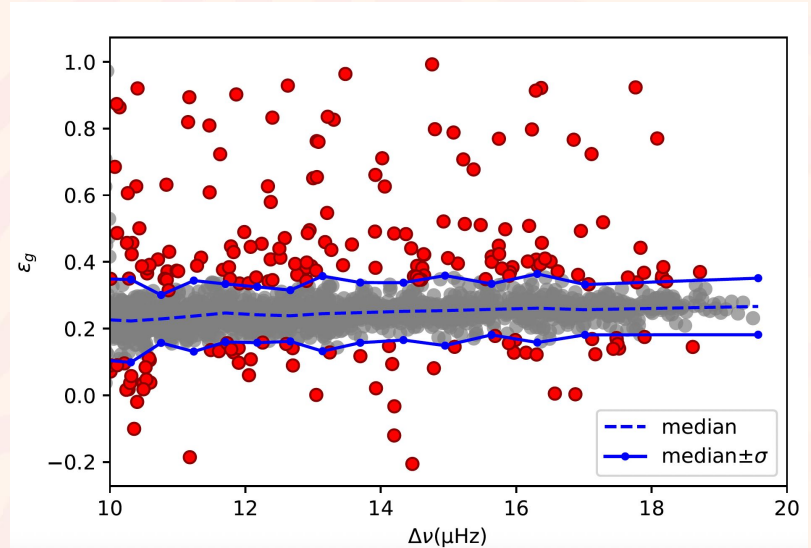
Gravity offset

Magnetic fields **distorts** the measure of these parameters if not taken into account !  
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$$\varepsilon_g \approx 0.28 \pm 0.08$$

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Deviations from the empirical value may be due to the magnetic field !



Data from Li et al. 2024

→ **218** targets chosen with abnormal  $\varepsilon_g$

# Other results: suppressed dipoles

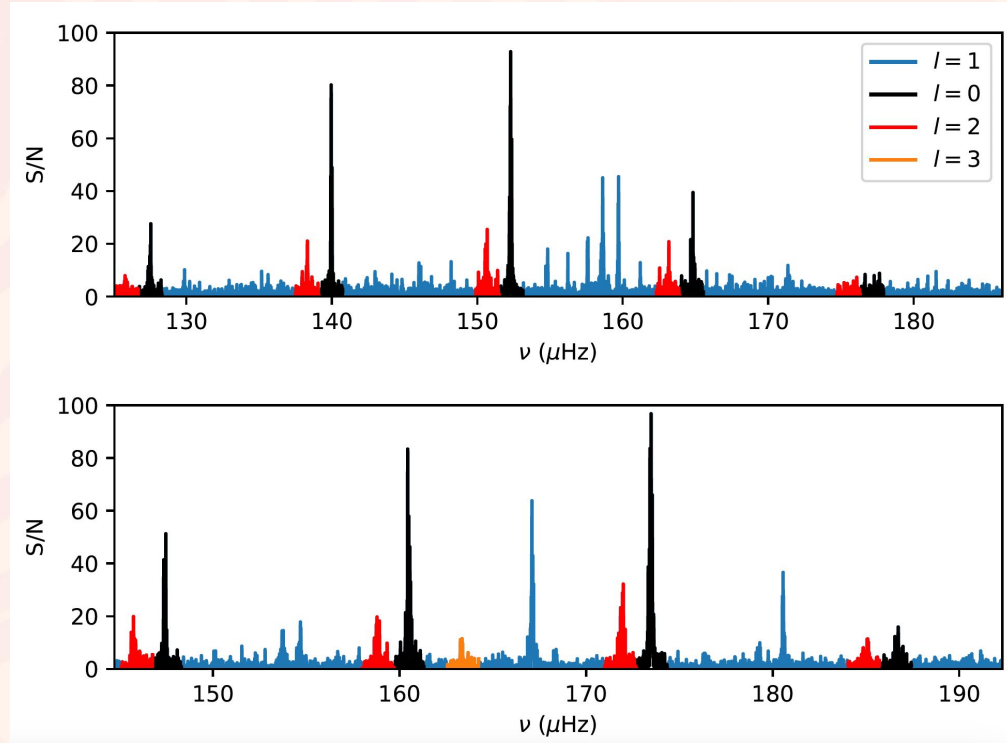
2 magnetic detections show suppressed dipoles

- brutal variation of the visibility of  $l=1$  modes
- only p-dominated modes visible
  - still follows a mixed mode pattern

Highest two  $B/B_c$  ratios (1.72 and 0.68)  
→ perturbative approach not suited

Different behaviour for the same phenomenon ?

→ more research needed



## 44 stars with measured asymmetry $a$

→  $a$  is between  $-1/2$  and  $1$

- $a = -1/2$  → concentrated at the equator
- $a = 1$  → concentrated at the poles
- $a \in [-1/2 ; 1/2]$  → dipolar field

→ significant number of stars have topologies incompatible with dipolar fields

## Non axisymmetric effects ?

$$b = 2\omega_B / \omega_{R,g}$$

Effects can be ignored as long as  $b < 1$

8 stars have conditions where  $b > 1$

→ No effects observed as of yet

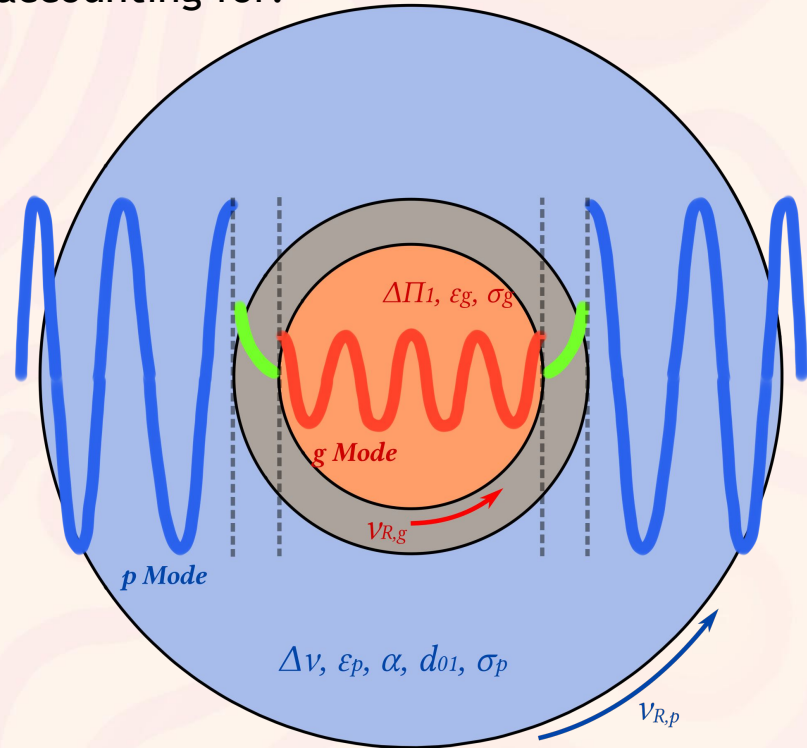
## Previous studies :

- Small perturbation of oscillation equations (Gough & Thompson 1990)
- on pure g modes + axisymmetric dipolar field (Hasan et al 2005)
- Red giant mixed modes (Gomes & Lopes 2020 ; Mathis et al 2021 ; Bugnet et al 2021)
- Inclined dipolar fields (Loi 2021)
- Generalized case + radially dominant (Li et al 2022)

→ Weak magnetic fields cause a departure from the asymptotic expressions of g-mode frequencies

We used an asymptotic expression for mixed modes accounting for:

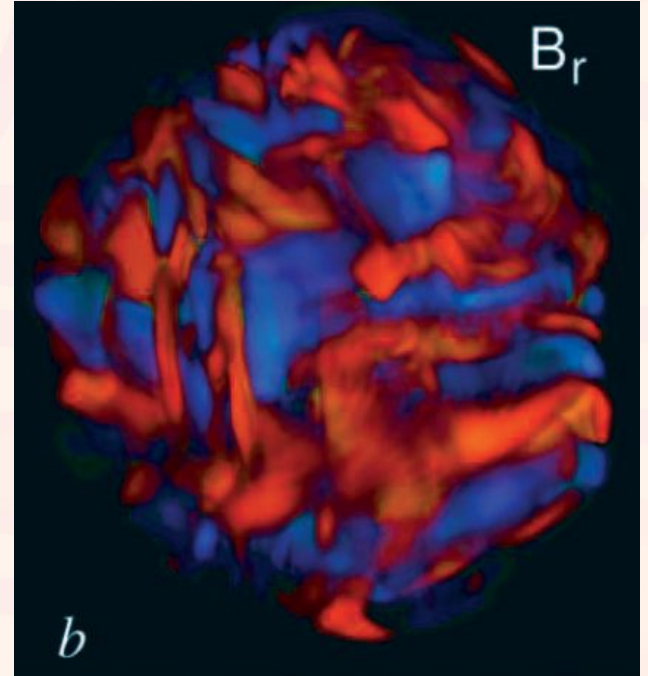
- p-modes ( $\Delta v$ ,  $\varepsilon_p$ ,  $\alpha$ ,  $d_{01}$ ,  $\sigma_p$ )
- g-modes ( $\Delta\Pi_1$ ,  $\varepsilon_g$ ,  $\sigma_g$ )
- the coupling between p and g-modes (q)
- rotation of the core and envelope ( $v_{R,p}$ ,  $v_{R,g}$ )
- Magnetic shift ( $v_{\text{mag}}$ )
- Magnetic topology (a)



Idea : Fields created by a dynamo in the convective core

- Stars generally have convective cores at one point
  - (Before or during the Main Sequence)
- A field can survive in a radiative core
  - ohmic diffusion time  $>$  stellar lifetime (Cantiello et al. 2024)

Inaccessible to observation  
until recently



*Simulation of a dynamo generated field in a convective core (Brun et al 2005)*