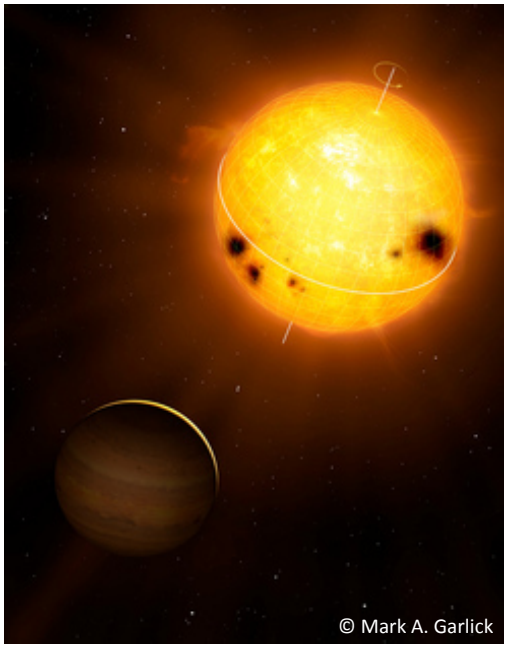
Tidal inertial waves in the differentially rotating convective envelopes of low-mass stars



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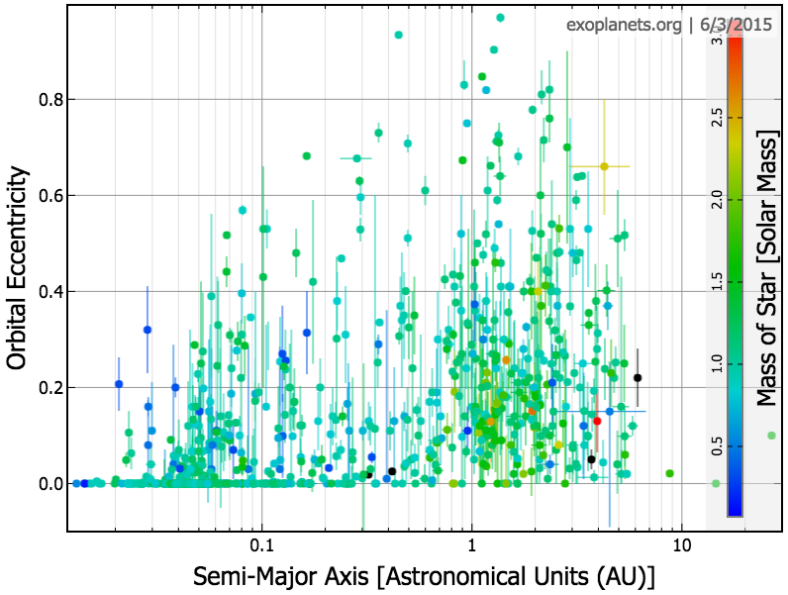
Dynamical evolution of stars hosting planetary systems

- Tidal evolution & dissipation :
  - Modify stellar rotational dynamics :

  tidal torques → synchronization
  - Impact the architecture of the system : migration, circularization, alignment

- Tidal dissipation in host stars
  - Strongly impacts the dynamics of short-period systems
  - Varies over several orders of magnitude (stellar mass, age, rotation) : often roughly parametrized



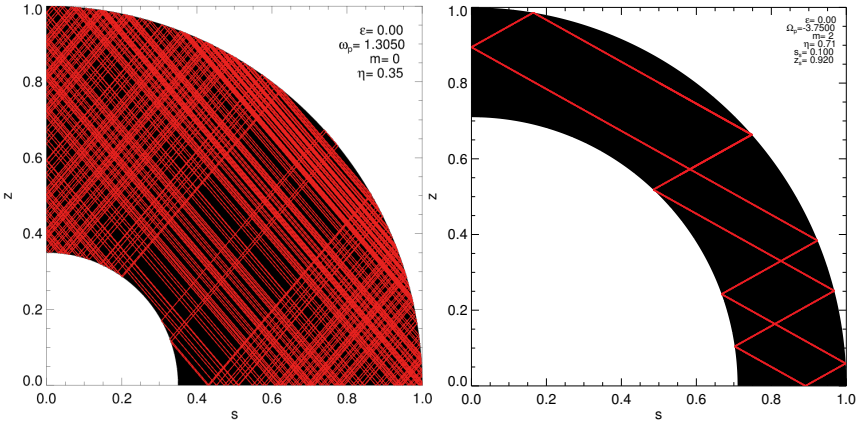
Observational constraints : transits and radial velocities
CoRoT, Kepler, HARPS, CHEOPS, TESS, SPIRou, PLATO

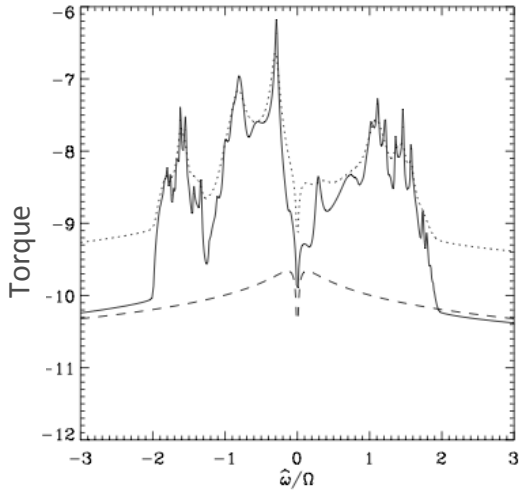
→ Need for a realistic *ab initio* modelling of tidal dissipation in stellar convective zones

Key mechanism : inertial waves in convective zones

- Solid-body rotation : $\frac{\partial \vec{u}}{\partial t} + 2\vec{\Omega} \times \vec{u} = -\nabla P_{eff}$
  - Balance between the Coriolis acceleration, pressure gradient and gravity
  - Transverse waves :
    - Doppler-shifted frequency is in [-2Ω, 2Ω],
    - propagate in the whole convective region along straight rays
  - For given parameters, the kinetic energy of the mode could concentrate and be efficiently dissipated around sheared structures which follow attractor cycles

→ Resonant dissipation varying over orders of magnitude for low viscosities

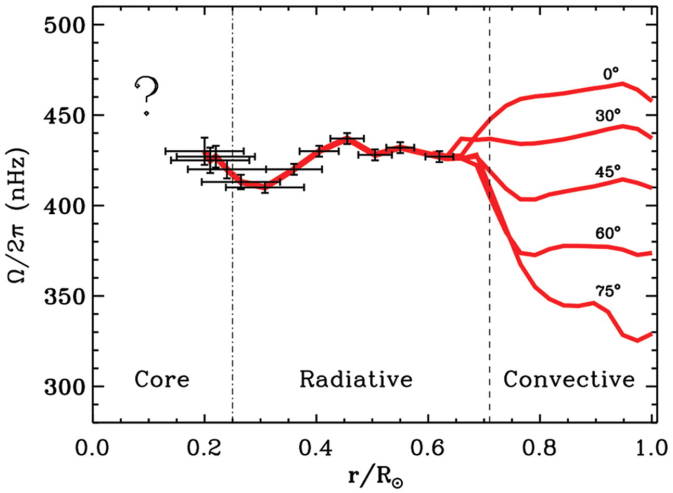




Ogilvie & Lin 2007

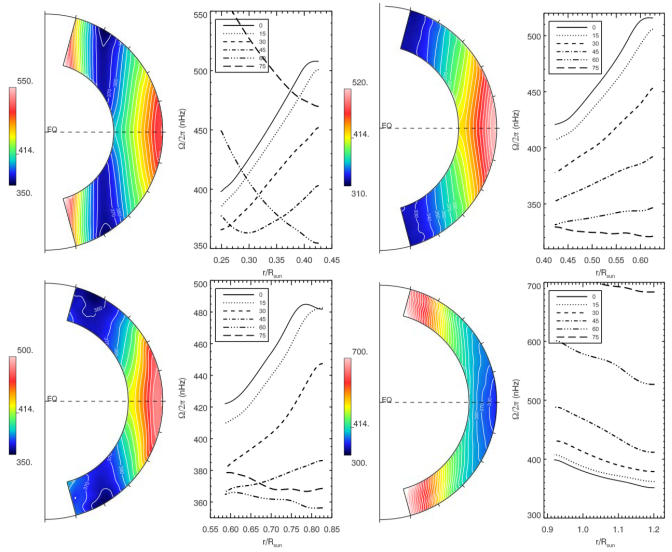
Differential rotation of low-mass stars

- Helioseismic observations



Garcia et al. 2007

- Simulations



Matt et al. 2011; Gastine et al. 2014

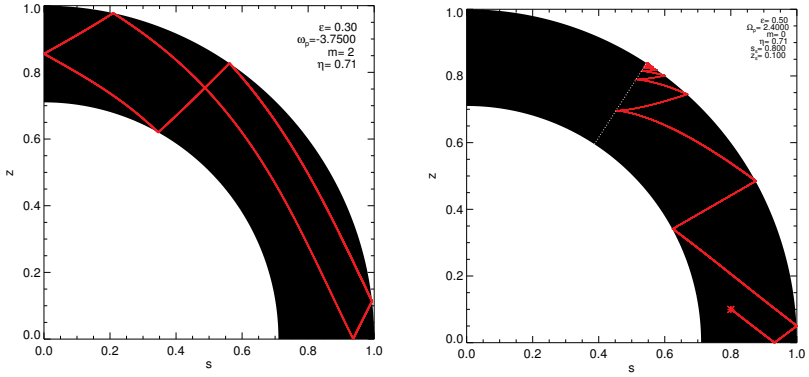
- Differential rotation strongly modifies inertial waves : *e.g.* Baruteau & Rieutord (2013) for cylindrical and shellular rotation profiles

→ In stars, inertial waves in conical differential rotation have to be studied
→ Methodology : understanding the complex behavior of free modes before studying the tidal forced regime

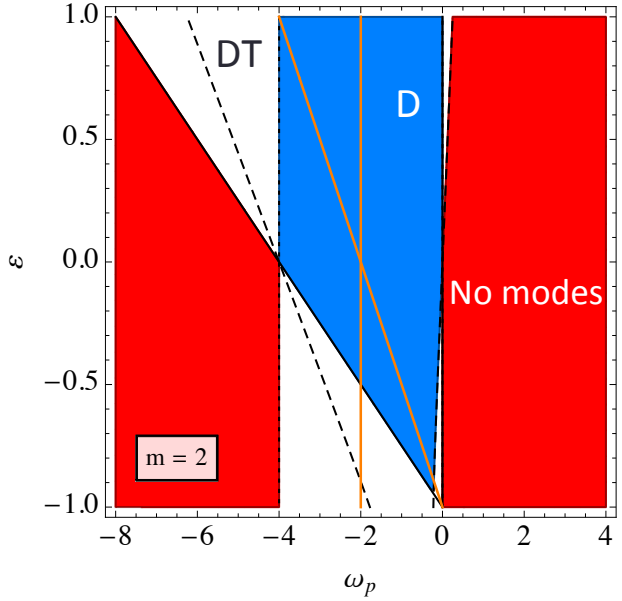
Free inertial waves in conically differentially rotating convective zones : inviscid analysis

- Conical rotation profile :

$$\Omega(\theta) = \Omega_{\rm ref}\left(1 + \varepsilon \sin^2\theta\right)$$



- Analytics shows that new features appear :
  - Paths of characteristics are curved and depend on azimuthal wavenumber m
  - They may still converge towards attractor cycles or focus towards a wedge (Dintrans & Rieutord 1999)
  - Turning surfaces : boundary between hyperbolic and elliptic domains (trapping)
  - Corotation layers (m≠0) : the Doppler shifted wave frequency vanishes

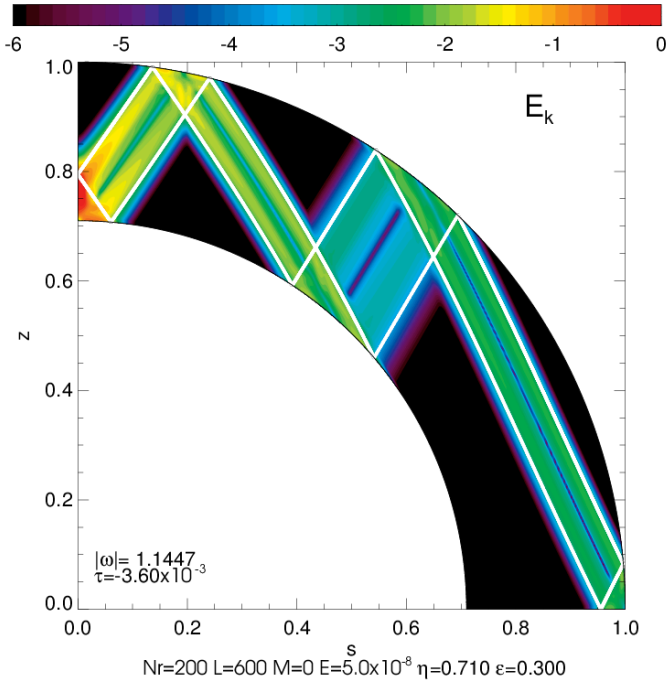


Viscous dissipation induced by waves (important for tides)→ need to treat the viscous problem

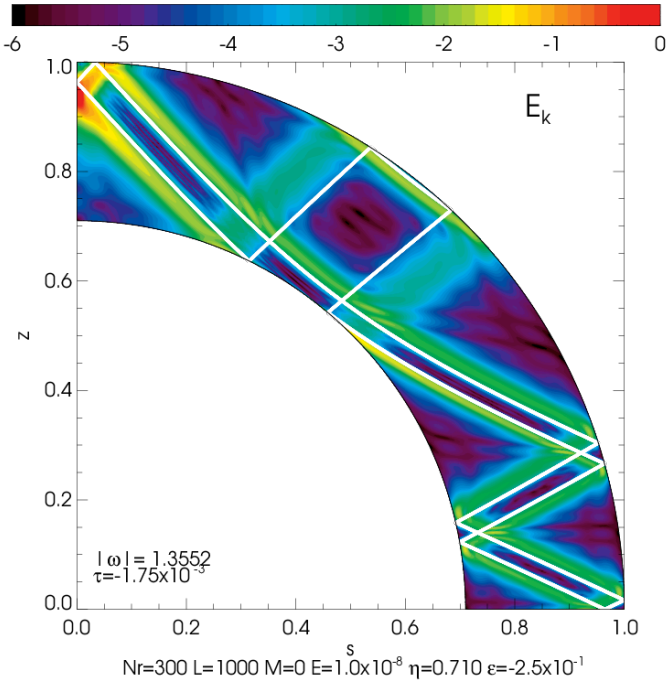
D modes

- Method : numerical simulations using the LSB linear solver after analytical projection of the equations on vectorial spherical harmonics (Rieutord 1987, Baruteau & Rieutord 2013)

- Curved propagation in the whole shell
- Overall properties similar to the solid-body rotation case



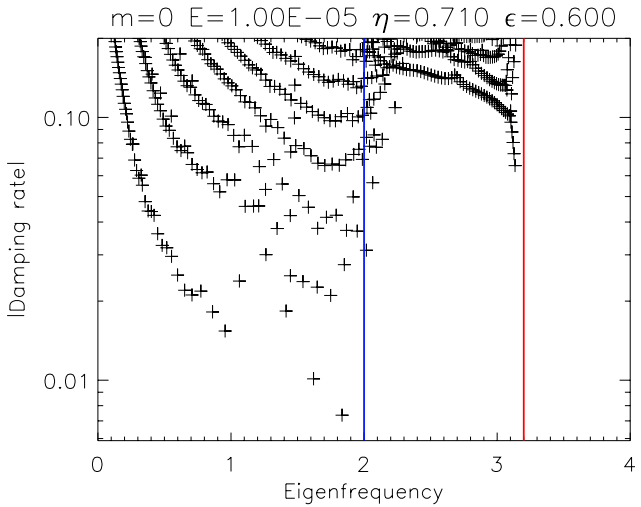
Solar case

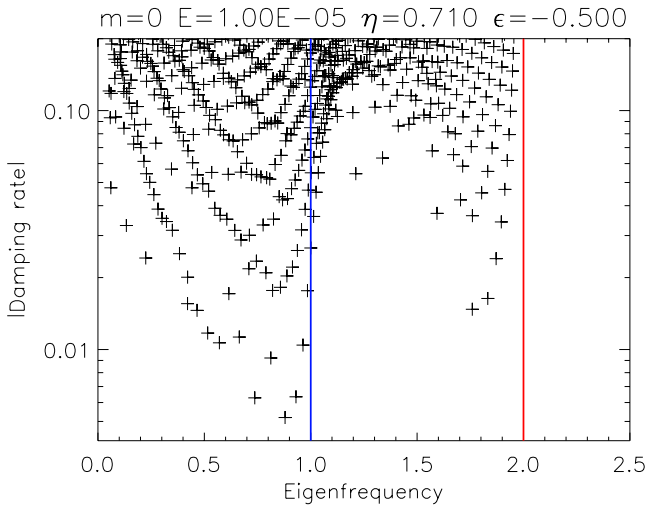


Anti-solar case

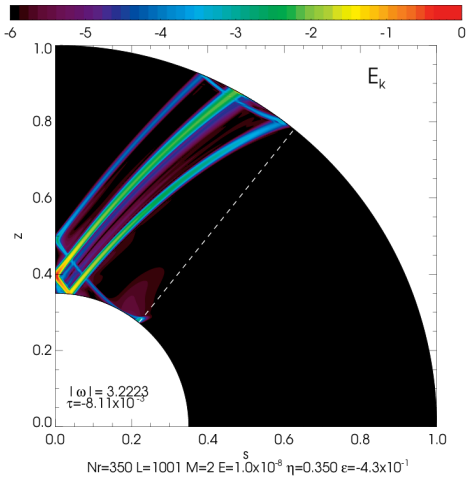
Existence and behavior of DT modes ?

Population diagrams : resonant DT modes seem to be less common than D modes for all m



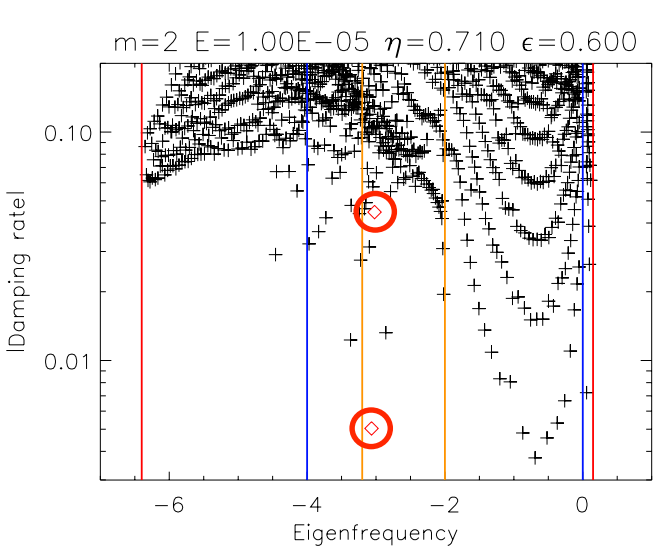


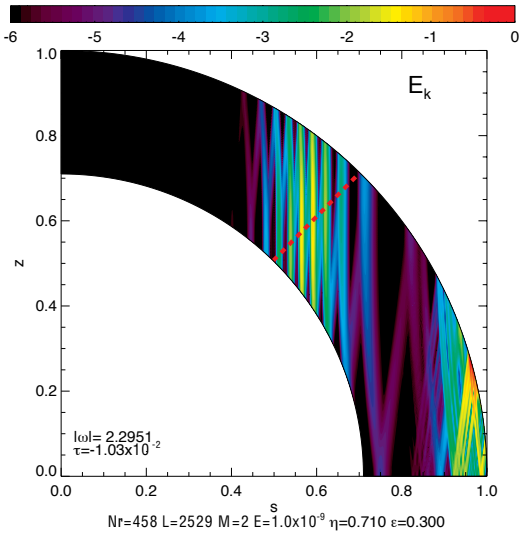
- Strongly differ from the solid-body rotation case : latitudinal trapping
- For m=0, DT modes preferably appear with anti-solar rotation (ε < 0)
- The situation is more complex for m ≠ 0



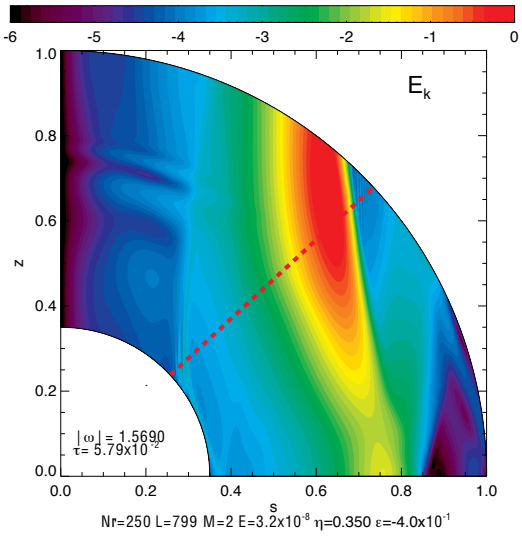
Non-axisymmetric modes & corotation resonances

- When m ≠ 0, the Doppler-shifted frequency may vanish inside the domain → corotation resonance





Stable



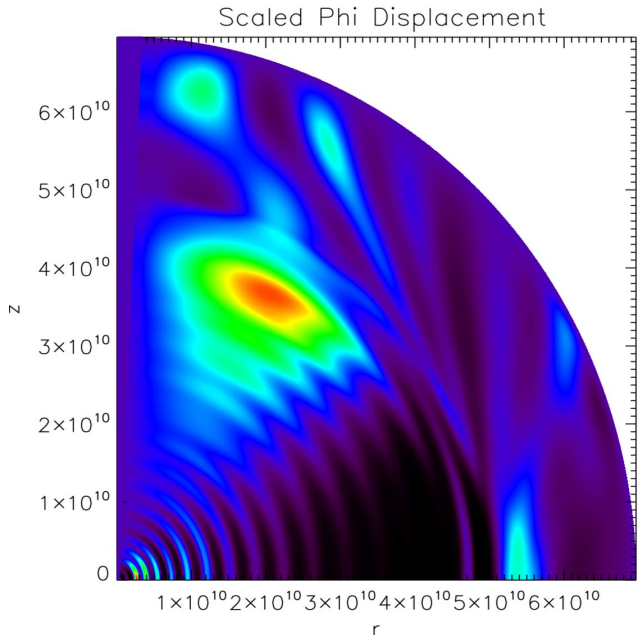
Unstable

- Complex behavior : valve effect / instabilities that require a dedicated study (local model for corotation layers)

Perspectives and ongoing work

- Forced regime : computation of tidal inertial waves dissipation spectra as a function of stellar mass, age and differential rotation and excitation frequency

- Modelling of the low-frequency oscillations of an entire low-mass star, including the stably-stratified radiative core.



Chernov et al. 2013

THANK YOU FOR YOUR ATTENTION !