On the oscillation spectrum of a magnetized core in a giant star

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Some words of context

Many giant stars observed with Kepler do not show, or weakly show, dipolar l=1, modes.

1. Fuller, Cantiello, Stello, Garcia and Bildsten (2015) proposed that this “depression” is caused by magnetic fields hidden in the core of these stars.

Two questions :

1. The analysis showing that this is possible is local (WKB). Can we confirm this by global models ?
2. If yes, can we get more information on the magnetic fields of giants, intensity, geometry, origin ?

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The scene

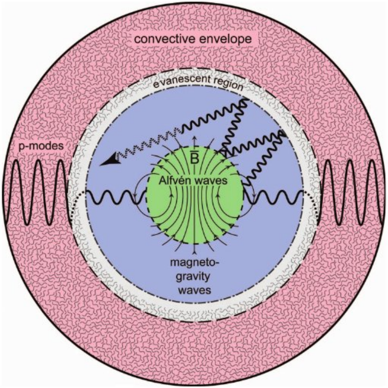


FIGURE : From Fuller et al. 2015

Core conditions

Consider a $1.5\mathrm{M}_\odot$ MESA-model at the right stage of evolution (thanks Sebastien !)

$$10 \leq \rho \leq 10^5 \mathrm{g/cm^3}$$

$$\nu \sim 10^2 \mathrm{cm^2/s} \qquad \eta \sim 10^2 \mathrm{cm^2/s} \qquad \kappa \sim 10^9 \mathrm{cm^2/s}$$

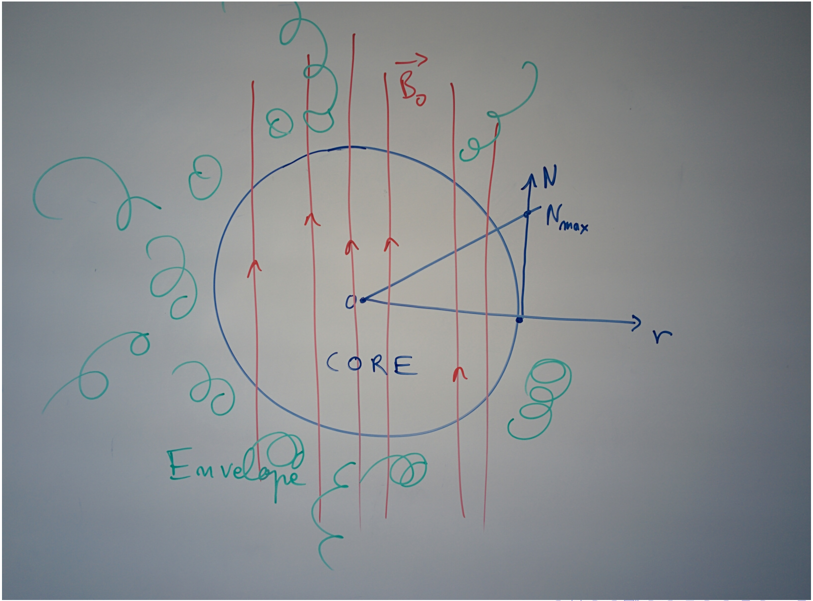
$$\mathcal{P} \sim 10^{-7} \qquad \mathcal{P}_m \sim 1$$

Viscous and ohmic dissipation negligible

The Boussinesq model

- We assume $\rho \simeq \mathrm{Cst}$ not very realistic, but necessary for a first step in a tough problem.
- We impose a uniform $\vec{B} = B_0\vec{e}_z$ magnetic field
- We insert heat absorbers to stably stratify the core

Sketch of the configuration



Equations of motion

Perturbations $\vec{v}, \vec{b}, \delta p, ...$ obey

$$\begin{cases} \partial_t \vec{v} = -\vec{\nabla}\delta p/\rho + (\delta\rho/\rho)\vec{g} + \nu\Delta\vec{v} + (\vec{\nabla}\times\vec{b})\wedge\vec{B}_0/\rho\mu_0 \\ \vec{\nabla}\cdot\vec{v} = 0 \\ \vec{\nabla}\cdot\vec{b} = 0 \\ \partial_t\vec{b} = \vec{\nabla}\times(\vec{v}\wedge\vec{B}_0) + \eta\Delta\vec{b} \\ \partial_t\delta T + \vec{v}\cdot\vec{\nabla}T_0 = \kappa\Delta\delta T \end{cases} \tag{1}$$

Dimensionless form

The equations of perturbations read :

$$\vec{\nabla}\cdot\vec{u} = \vec{\nabla}\cdot\vec{b} = 0$$

$$\partial_\tau\vec{b} = \vec{\nabla}\times(\vec{u}\wedge\vec{e}_z) + \mathbf{E}_\eta\Delta\vec{b}$$

$$\partial_\tau\theta + ru_r = \mathbf{E_t}\Delta\theta$$

$$\partial_\tau\vec{u} = -\vec{\nabla}p + \theta\vec{r} + \mathbf{E}_\nu\Delta\vec{u} + \mathcal{A}\,(\vec{\nabla}\times\vec{b})\times\vec{e}_z$$

where we set

$$\mathcal{A} = \left(\frac{V_a}{NR}\right)^2, \qquad E_\nu = \frac{\nu}{NR^2}, \quad E_t = \frac{\kappa}{NR^2}, \quad E_\eta = \frac{\eta}{NR^2}$$

Parameters range

Diffusion :

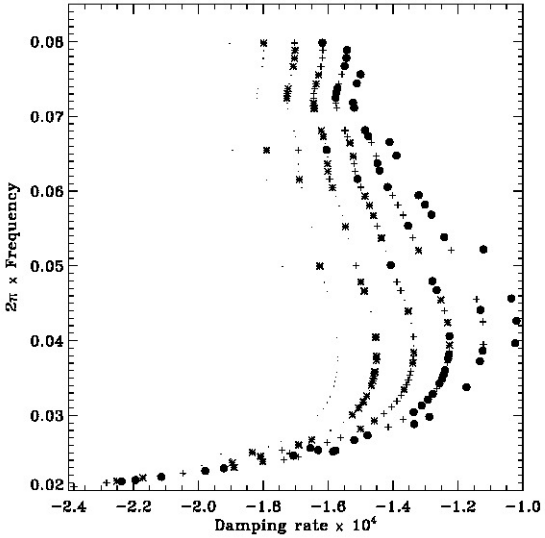
$$E_\nu \sim 10^{-18}, \qquad E_\eta \sim 10^{-18}, \qquad E_t \sim 10^{-11}$$

Numerically, we choose

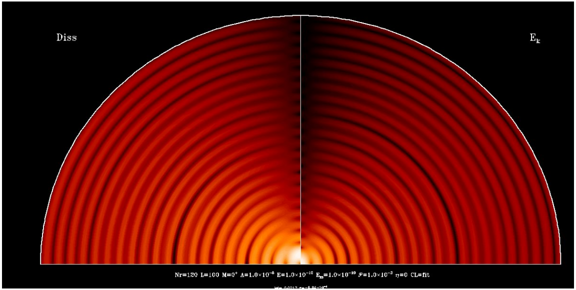
$$E_\nu \sim 10^{-10}, \qquad E_\eta \sim 10^{-10}, \qquad E_t \sim 10^{-7}$$

Brunt-Väisälä frequency : the maximum value is around $10^4 \mu$Hz
if $B_0 = 2 \times 10^5$G then $\mathcal{A} = 10^{-8}$. if $B_0 = 2 \times 10^7$G then $\mathcal{A} = 10^{-4}$.

Evolution of gravity modes eigenvalues with B_0



When perturbed by $\vec{B}_0$



Evolution of gravity modes

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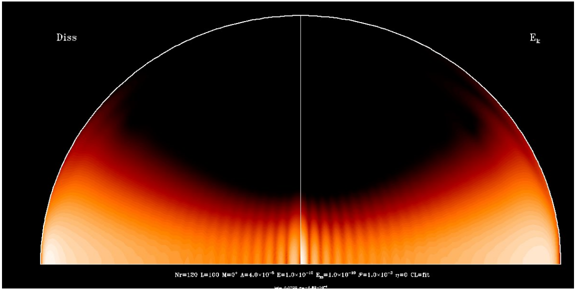
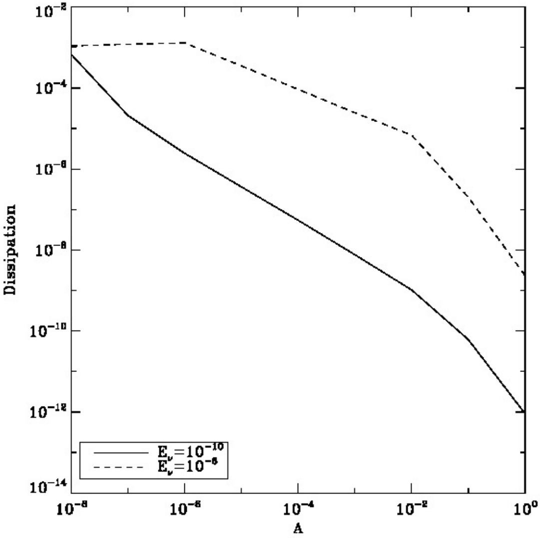


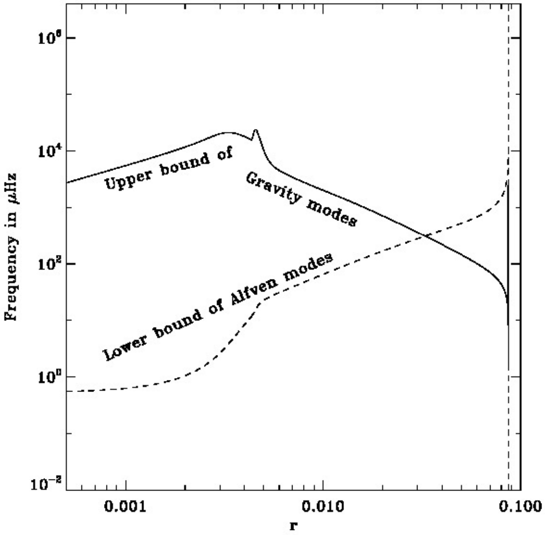
What happens if we force gravito-magnetic modes at 100μHz ?

We impose that the excited acoustic modes shake the core-envelope interface at their frequency.
Some energy is dissipated in the core. How does it vary with the intensity of the magnetic field ?

Answer from the Boussinesq model



propagation diagram



Conclusions

- Alfvén modes are high frequency modes, Gravity modes are low frequency modes
- When they meet/interact their wavelength is the largest possible, thus magneto-gravity modes may not be very good at dissipating energy.
- The Boussinesq model shows that indeed damping is reduced and frequency shifted...
- The field might not be at the largest scale (the radius) but at the scales left by ohmic diffusion. In 700Myrs, all scales below 0.035R$_c$ are erased. However, in dynamo generated field large scales are dominant ...
- The mechanism which weakens the $\ell = 1$-modes of the giants need further investigations : $\vec{B}$-fields may have a more subtle effect than just being absorbers.
- A real difficulty : damping the modes without touching their frequency...

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Thus, magnetic fields may do the job, may be not

communque

Se non è vero, è ben trovato !