Recent developments in Magnetar QPOs and in the low T/W instability

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MARIE CURIE ACTIONS

NewCompStar meeting **“Oscillations and instabilities in neutron stars”**
University of Southampton (13 September 2016)

Outline

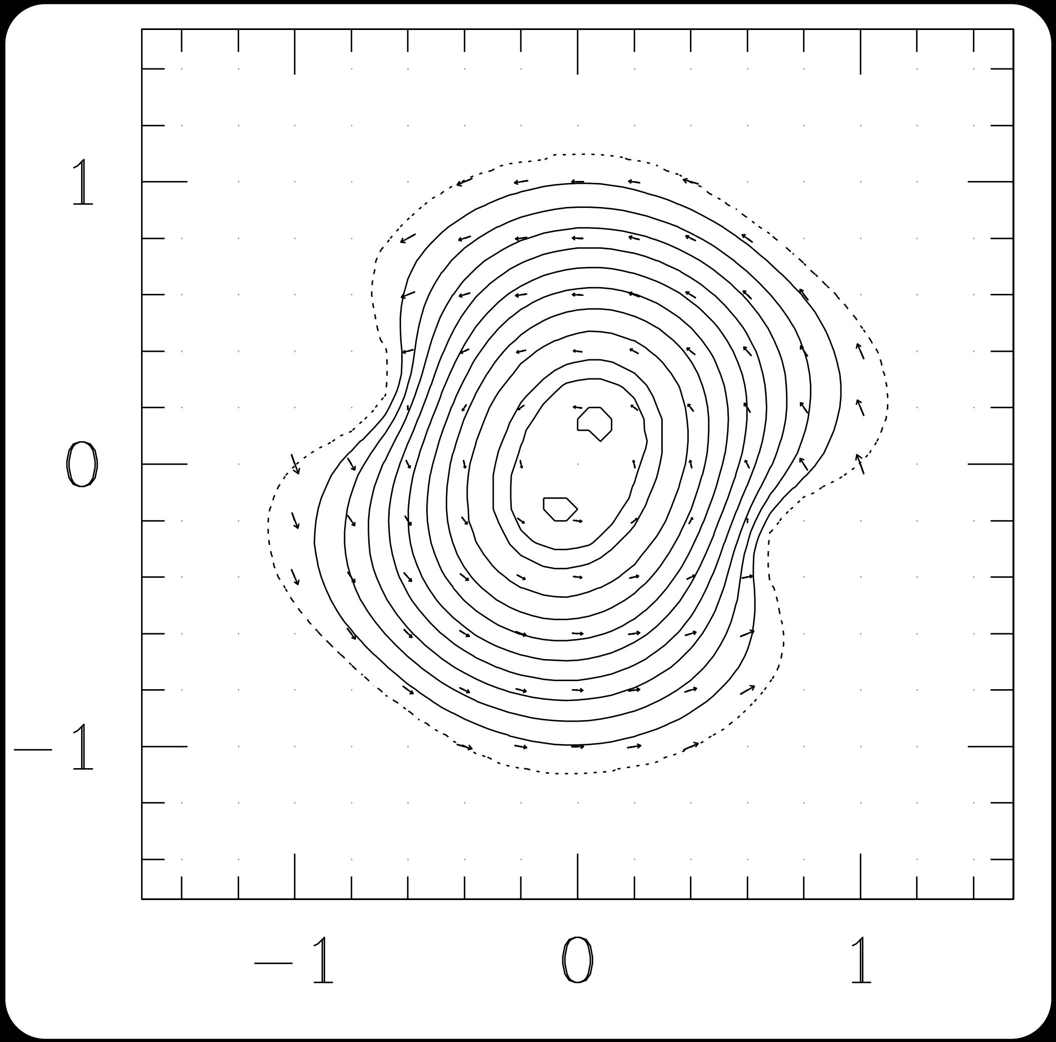
- **Low T/W instability of f and r modes**
  - **AP & N. Andersson 2015, MNRAS 446, 555**
- **QPO spectrum in superfluid and relativistic Magnetars**
  - **AP & J. Pons 2016, MNRAS in press.**

Low T/W instability

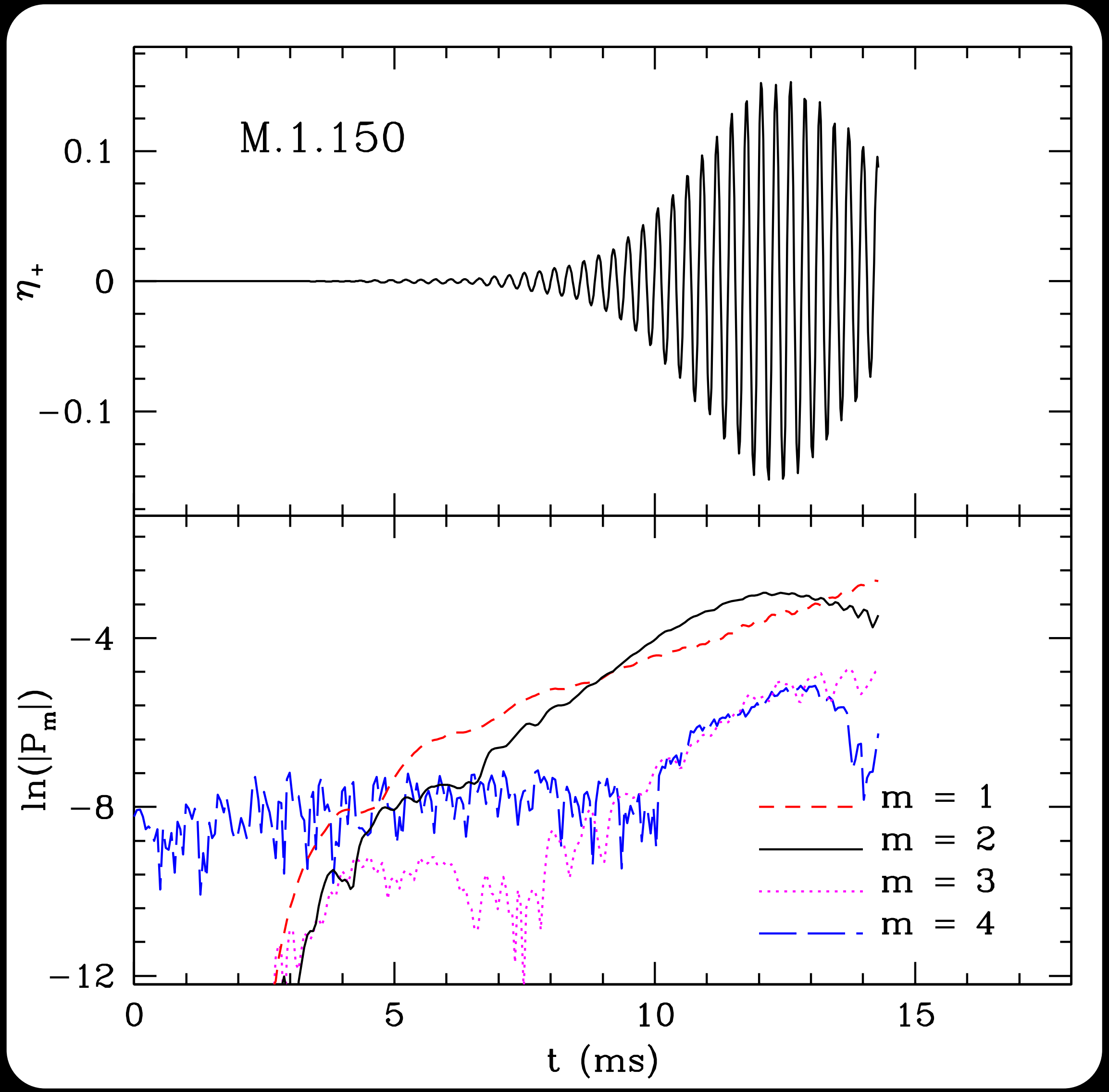
A. Passamonti & N. Andersson 2015, MNRAS 446, 555

Low T/W instability

- Originally found in numerical simulations by Centrella et al. (2001), Shibata et al. (2002)
- It develops in highly differentially rotating stars even for $\beta = T/W \sim 0.01$
- Several modes are excited during the instability
- Growth time ~ 1-4 ms



Shibata et al. 2002



Corvino et al. 2010

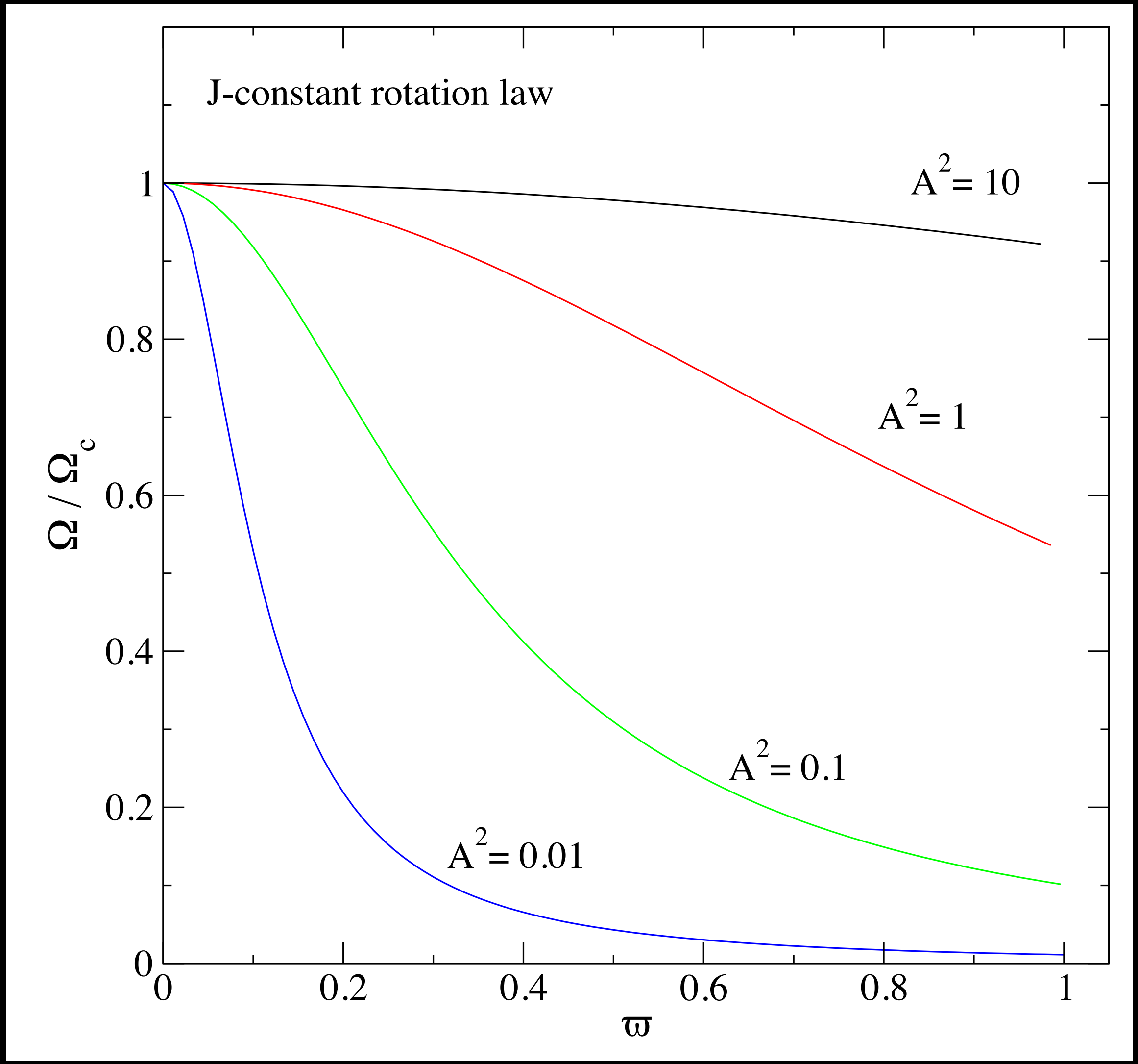
Low T/W instability

$\sigma_{\rm p}$: pattern speed

- It seems to originate at the corotation points, where $\frac{\omega}{m} = \Omega$
  (Watts, Andersson and Jones, 2005)

- Rotation law: j-constant

$$\Omega = \frac{\Omega_c A^2}{A^2 + r^2 \sin^2\theta}$$



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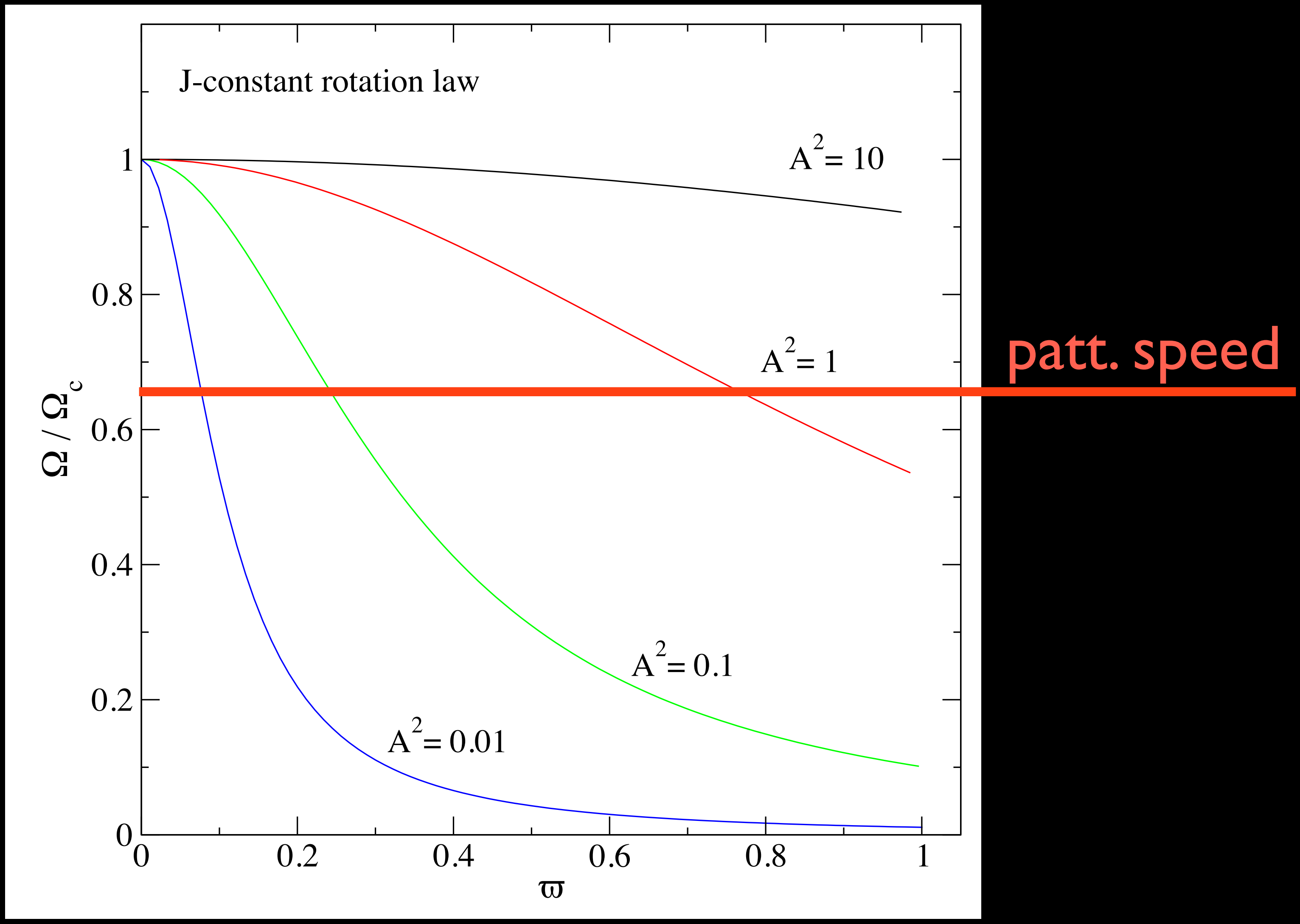

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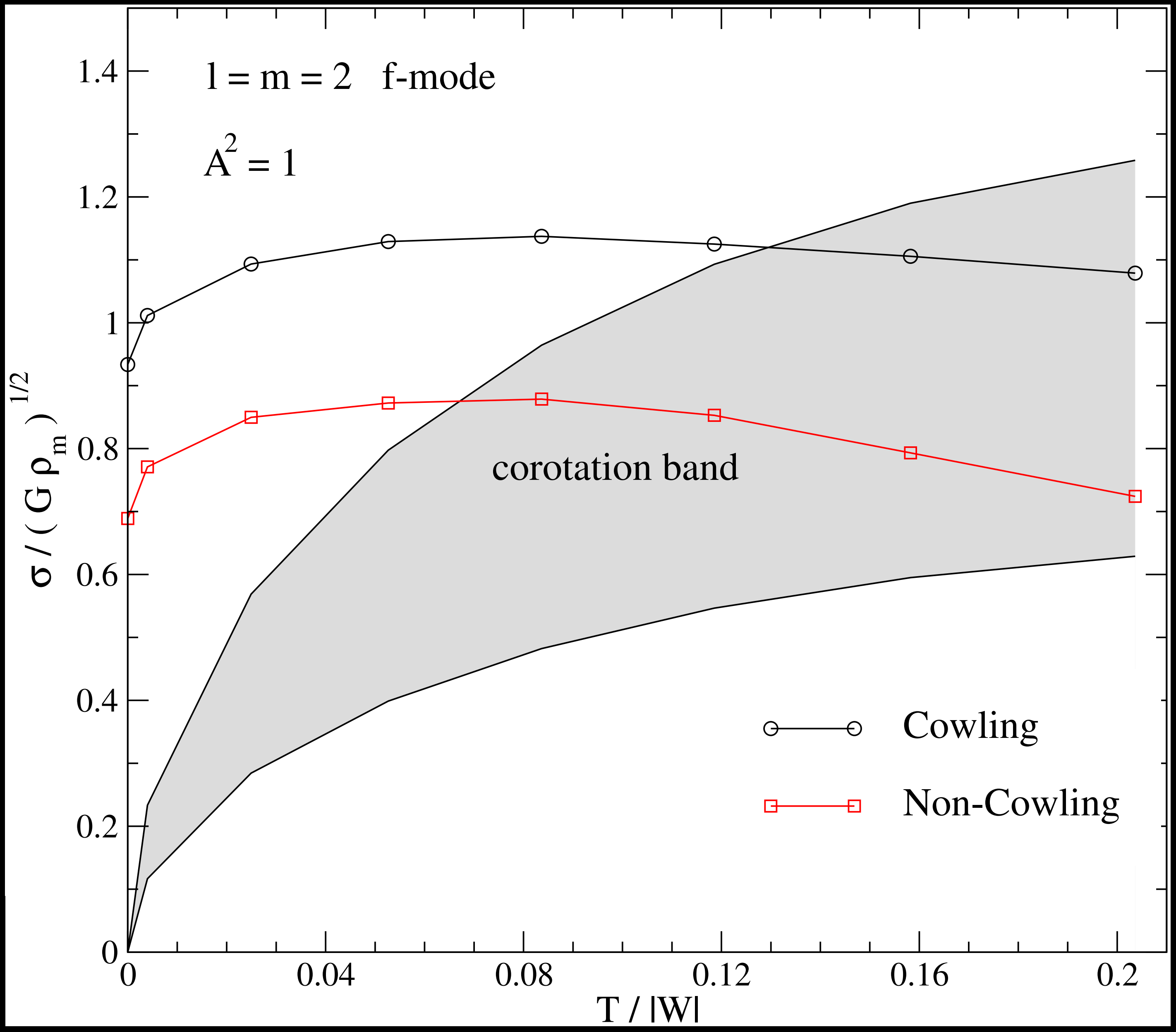


F-mode property extraction

- 2D time evolutions of perturbation equations

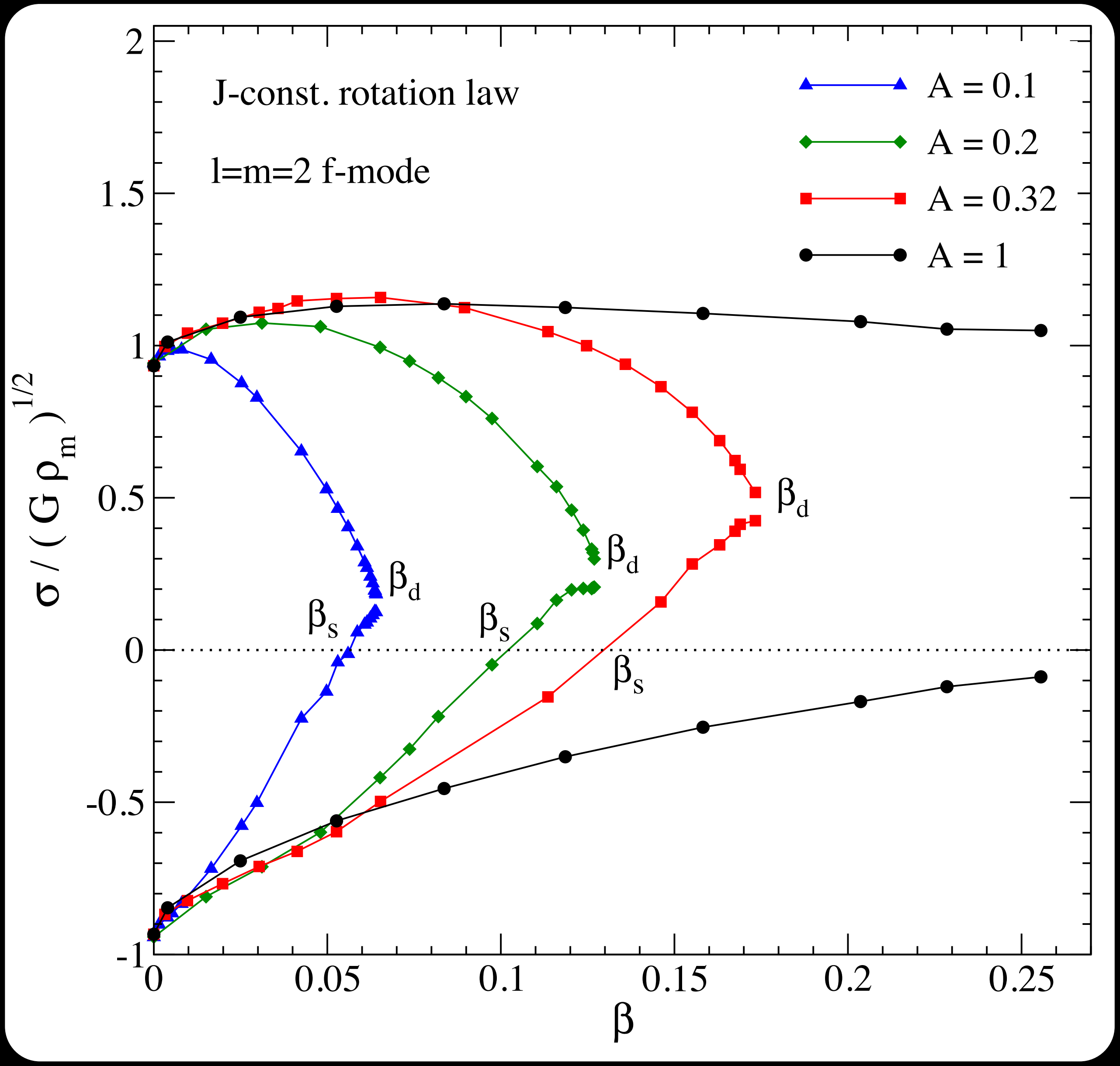
- Extraction of mode frequency with FFT

F-mode growth time

$$E_k \sim e^{2\omega_I t},$$

$$\text{where } \omega_I = \frac{2\pi}{\tau}$$

- Rotation parameter: $\beta \equiv \frac{T}{|W|}$



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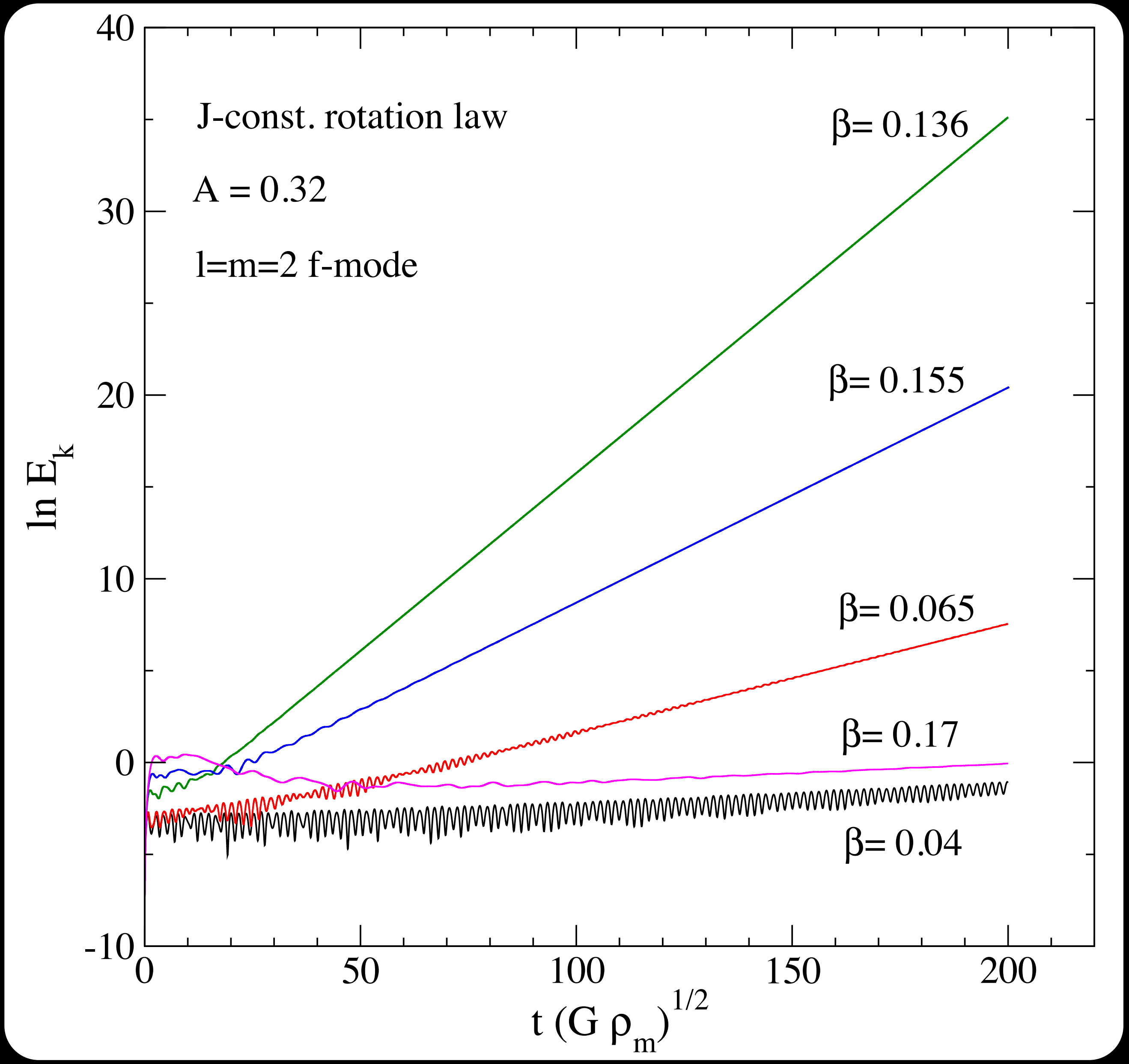

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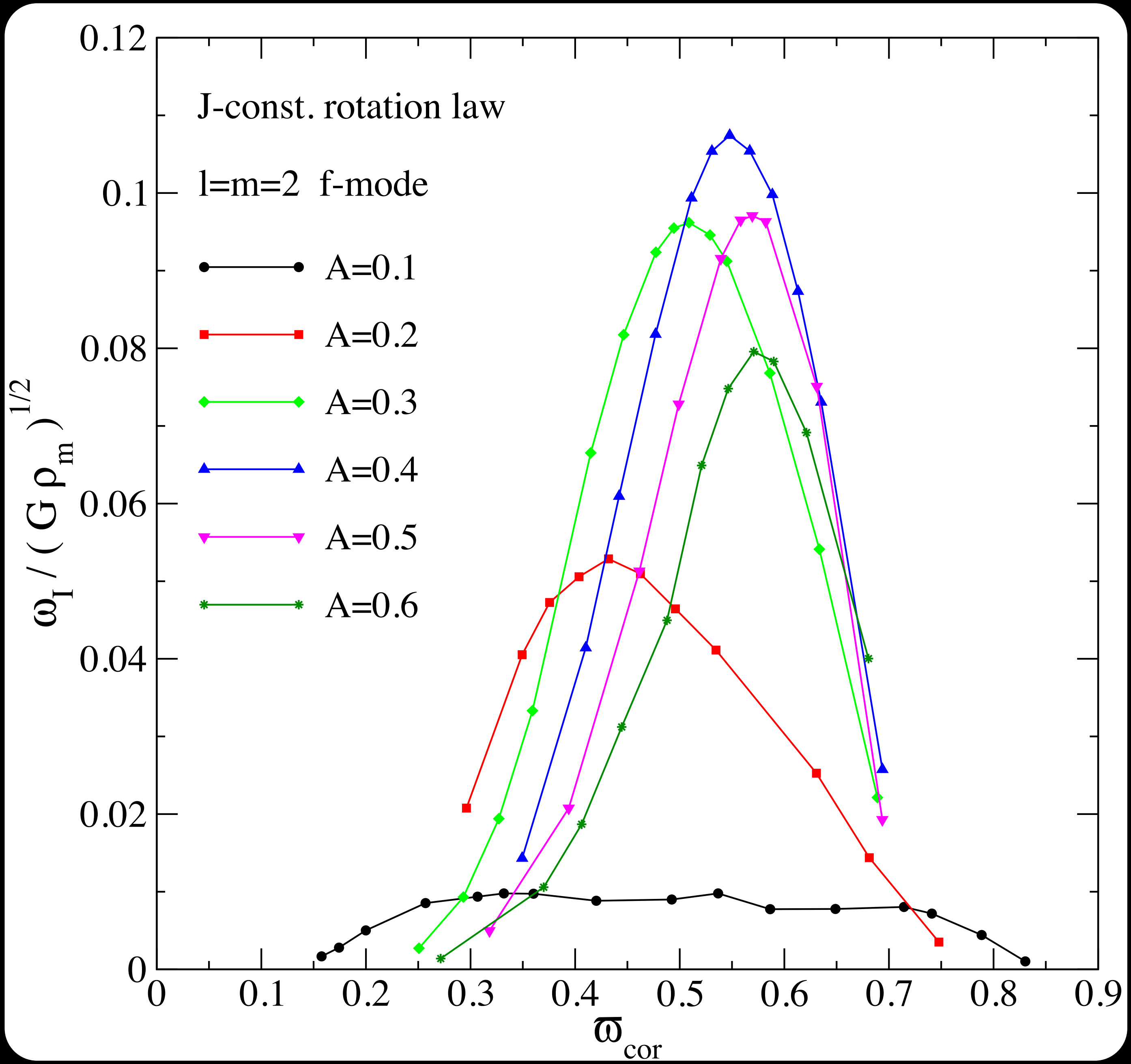

* Phenomenological relation

$$\psi = -\beta \left.\frac{\partial \Omega}{\partial \varpi}\right|_{\varpi_{cor}}$$

$$\chi \sim \psi^{10A} \sim \left[\frac{2\beta}{A\Omega_c}(\Omega_c - \sigma)^{\frac{1}{2}}\sigma^{\frac{3}{2}}\right]^{10A}$$

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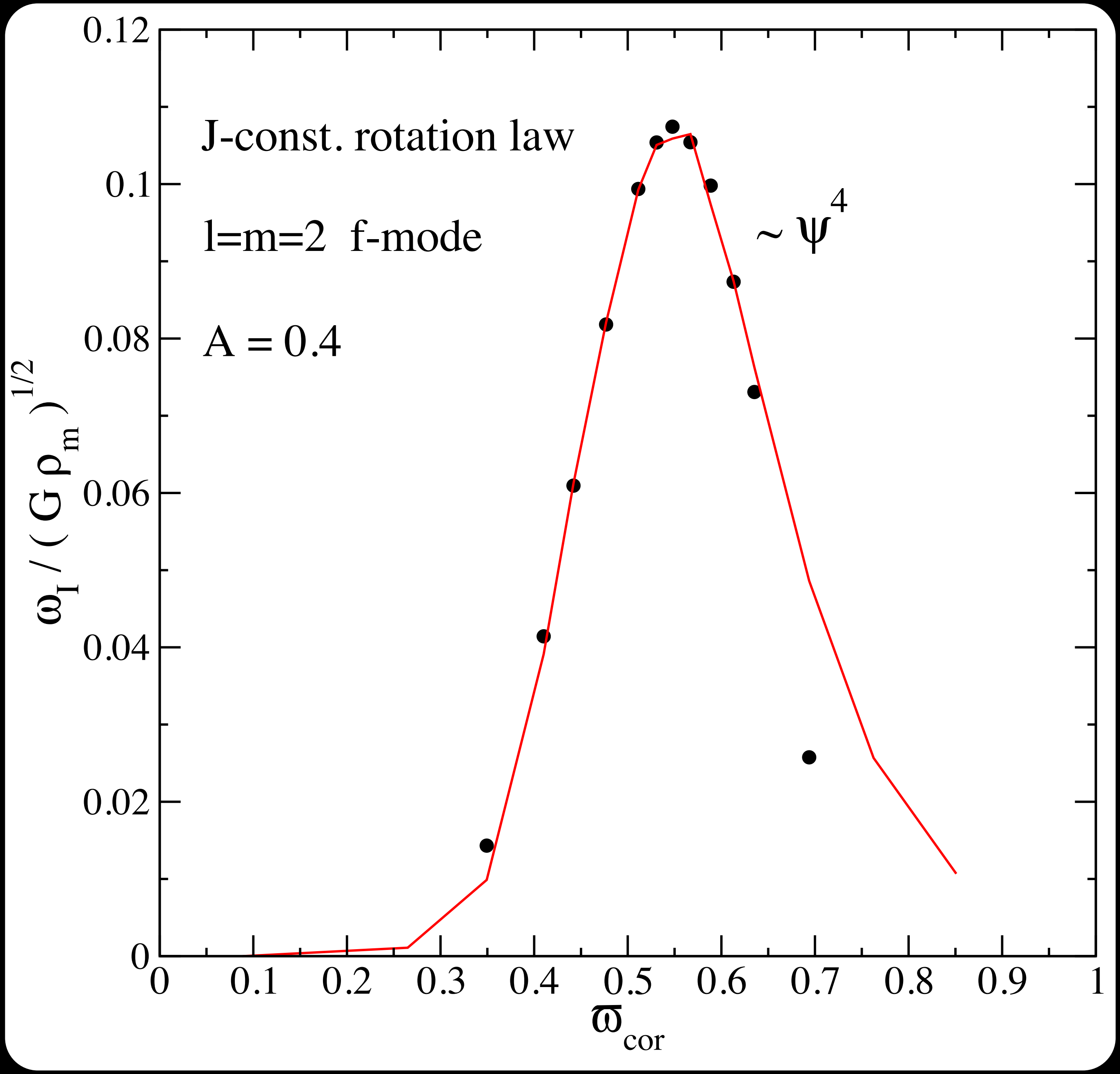

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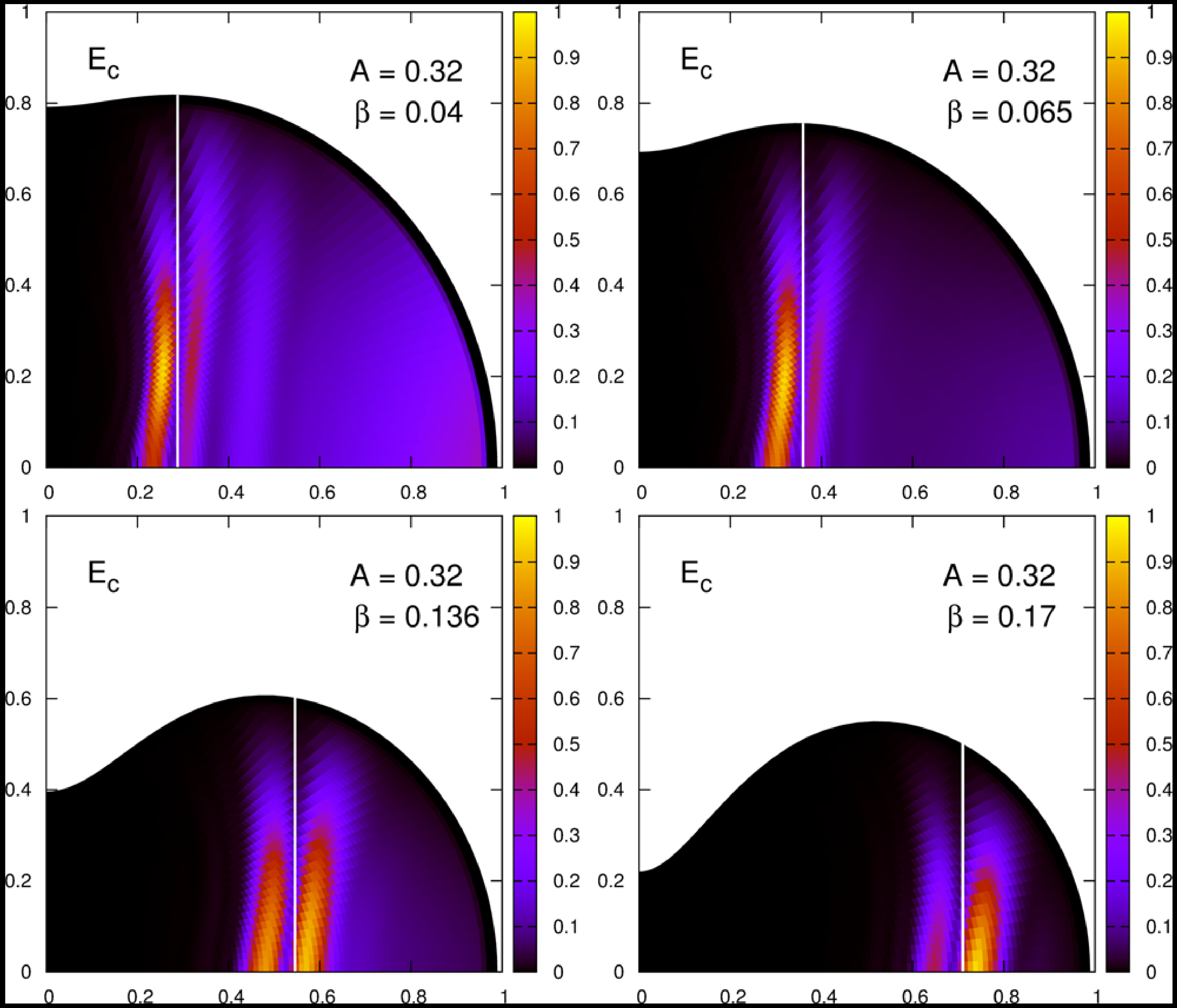
Canonical energy

- The canonical energy explodes around the corotation point

$$E_c = \frac{1}{2}\int d\boldsymbol{r}\,\Big[\rho|\partial_t\xi_i|^2 - \rho|v^j\nabla_j\xi_i|^2 + \rho\,\xi^i\xi^{j*}\nabla_i\nabla_j\,(h+\Phi) + \frac{\partial h}{\partial\rho}\,|\delta\rho|^2 - \frac{1}{4\pi G}|\nabla_i\delta\Phi|^2\Big]\,,$$

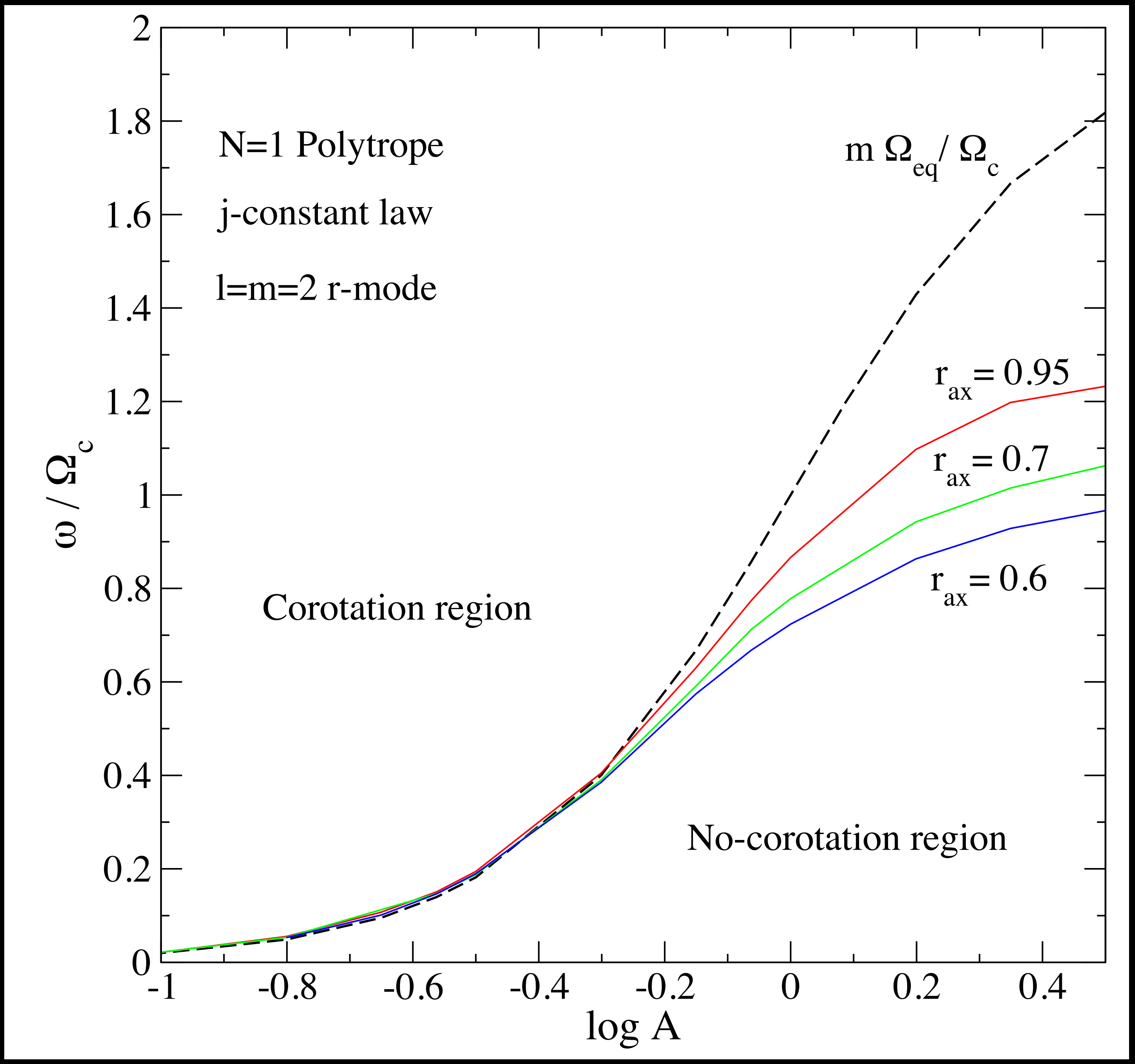
(Friedman & Schutz 1978)



Low T/W instability of r-mode?

- The r-mode enters in corotation only marginally for highly differentially rotating stars

- The growth time should be ~ infinite



Conclusions Part I

- Low T/W instability
  - The association with corotation points appears now evident
  - We found a fenomenological relation to describe the growth time
  - Can this relation be extended to other models?

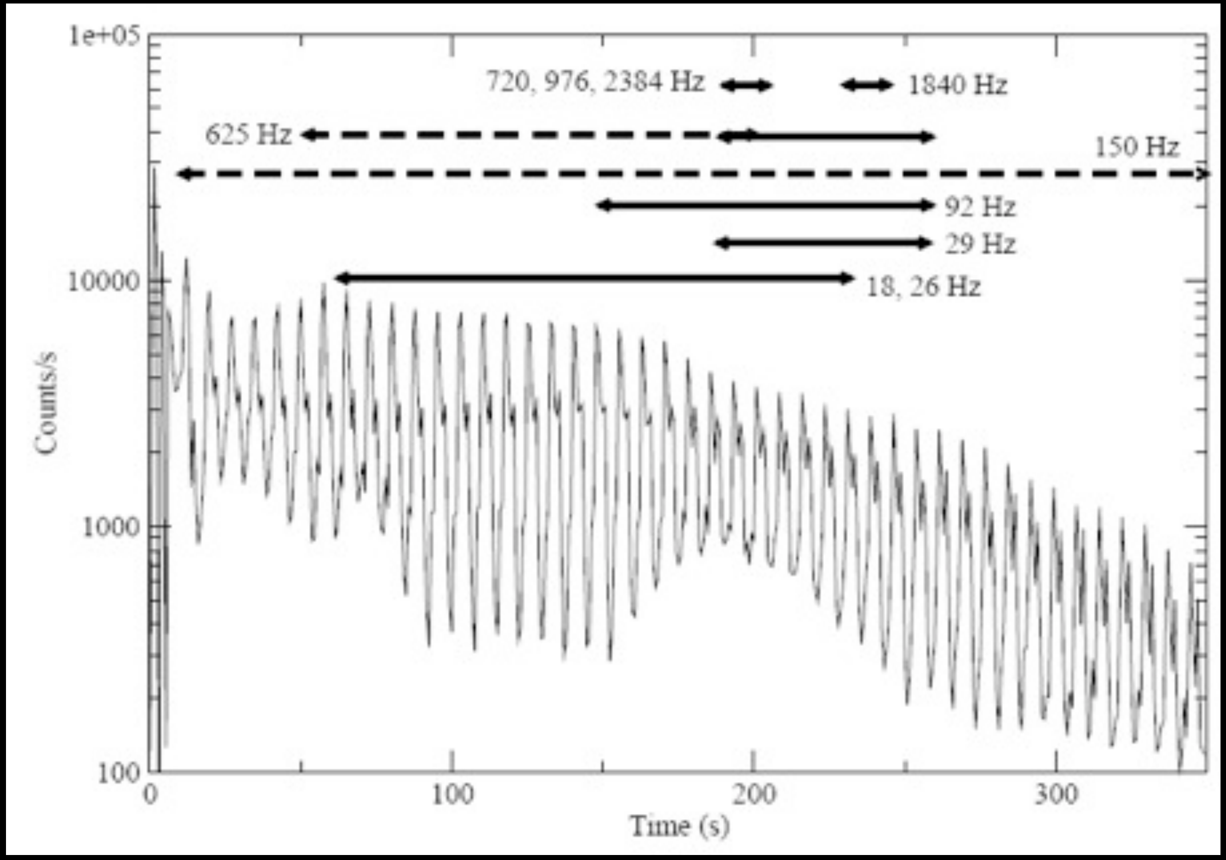
Magnetar QPOs and effects of nuclear pasta

A. Passamonti & J. Pons 2016, MNRAS in press

Quasi-Periodic Oscillations

- Observed in

SGR 1806-20



* three ***giant flares:*** **SGR 0526-66 (1979), SGR 1900+14 (1998), SGR 1806-20 (2004),** with frequency 18-1800 Hz. (Israel et al., 2005; Strohmayer & Watts, 2005; Watts & Strohmayer, 2006)

* An ***intermediate flare:*** **(SGR J1550-5418)** with frequency 93, 127 Hz and maybe 260 Hz (Huppenkothen et al., 2014)

- Possible origin

* The giant flare tail is generated by radiation coming from a hot fireball trapped into the magnetosphere close to the surface

* QPOs might originate from seismic vibrations which modulate the fireball radiation

Magnetar Model

- Haensel-Duchin EoS

$$R = 11.6\,\mathrm{km}$$

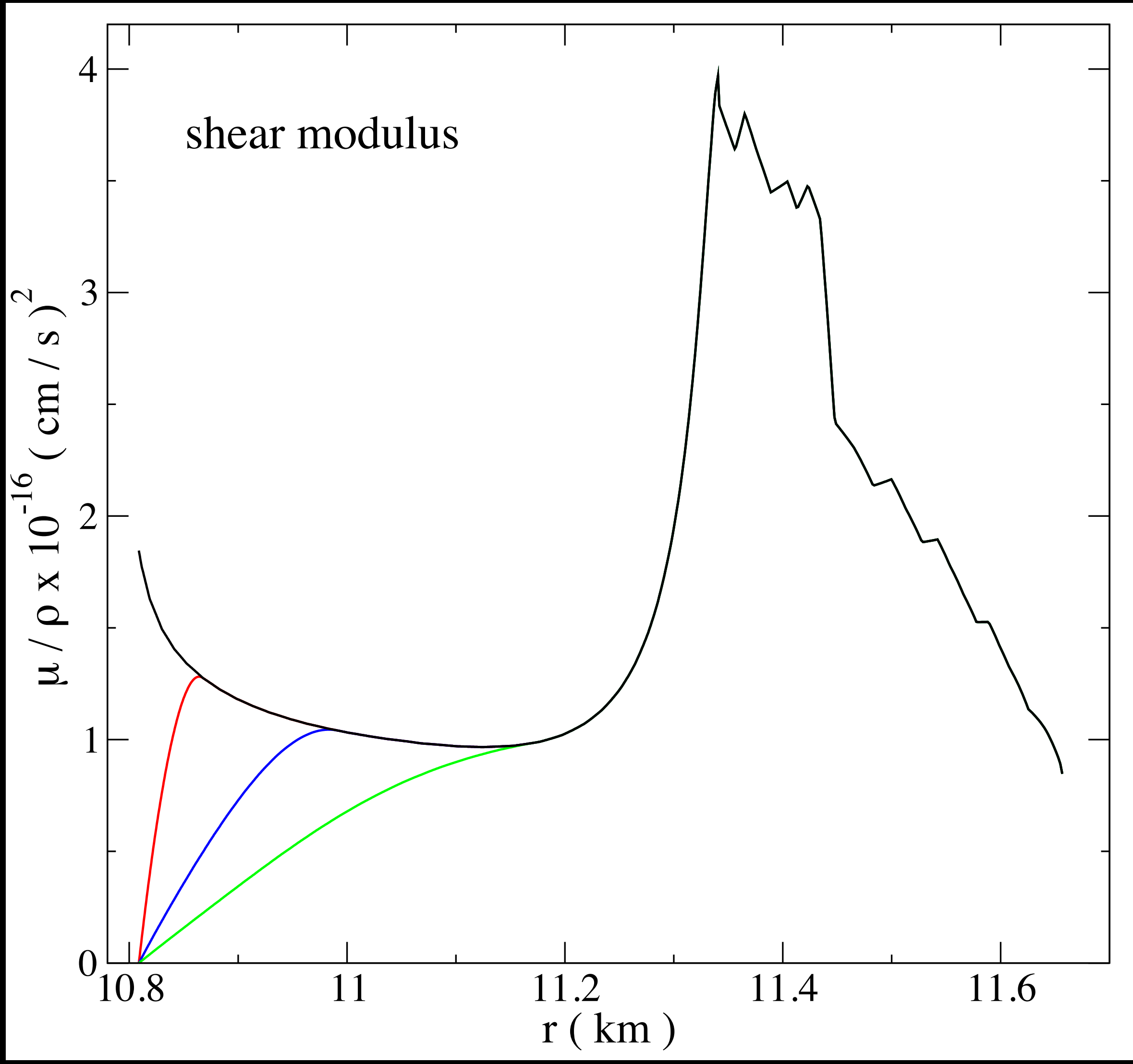
$$M = 1.4 M_{\odot}$$

- Two-fluid relativistic perturbation theory

- Poloidal Magnetic field

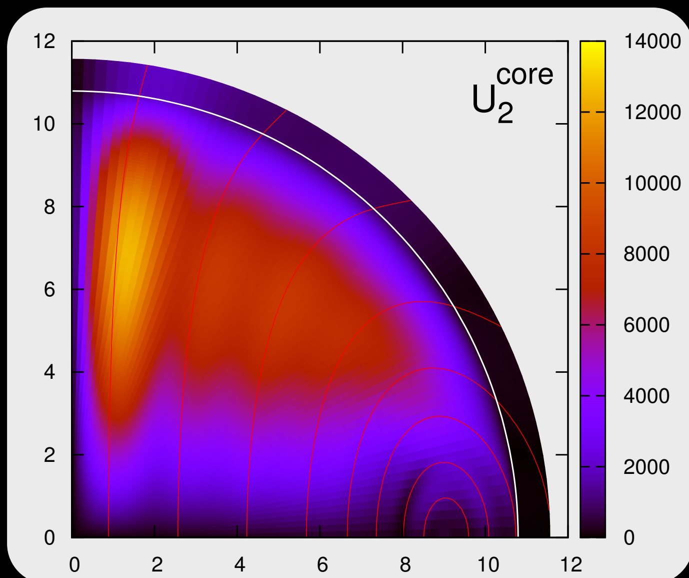
- Superfluidity
(strong entrainment in the crust)

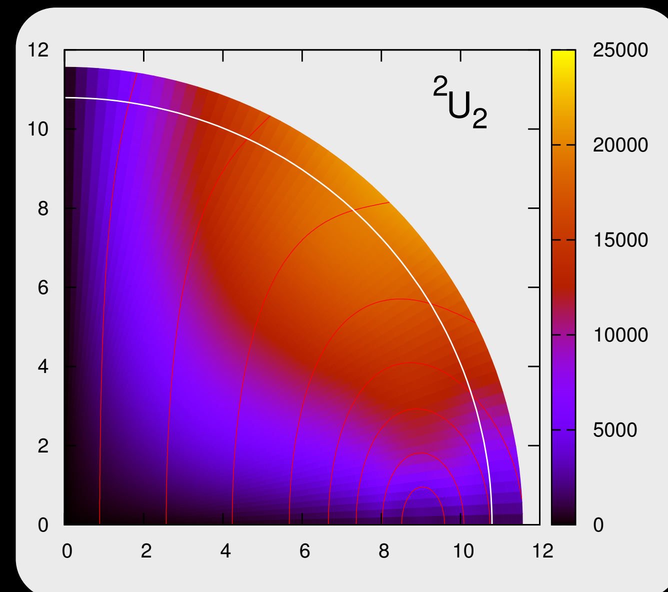
Pasta model

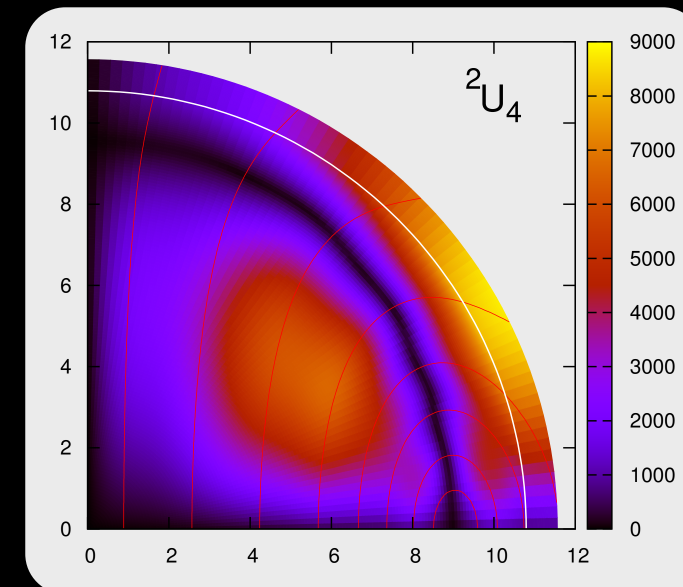


Two classes of oscillations

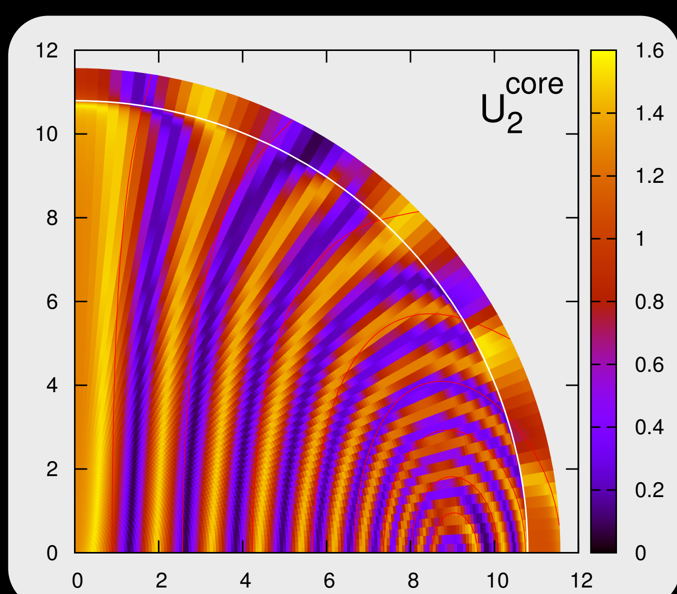
- Mode pattern

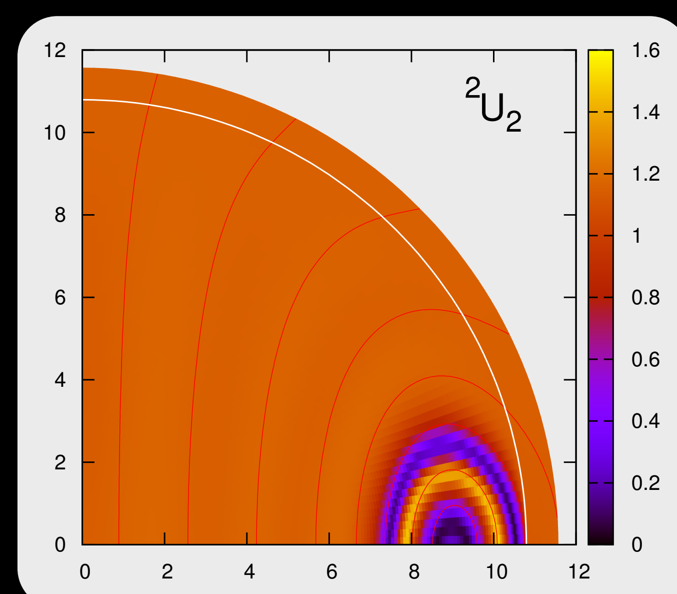


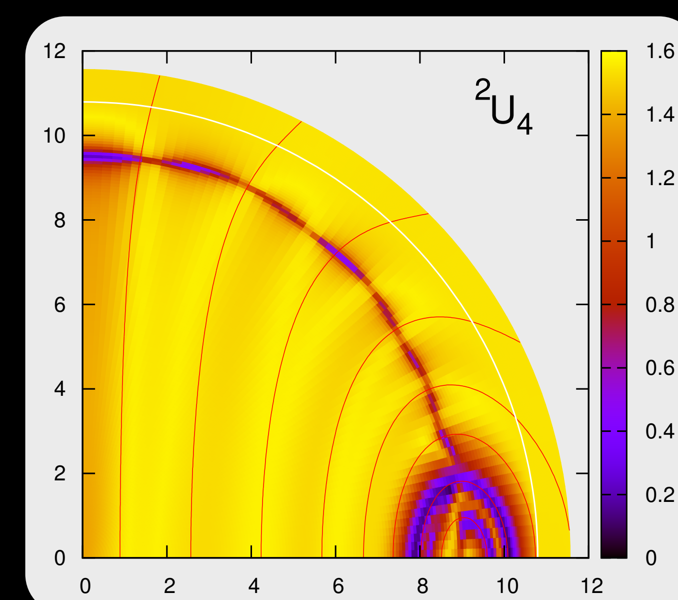




- Oscillation phase



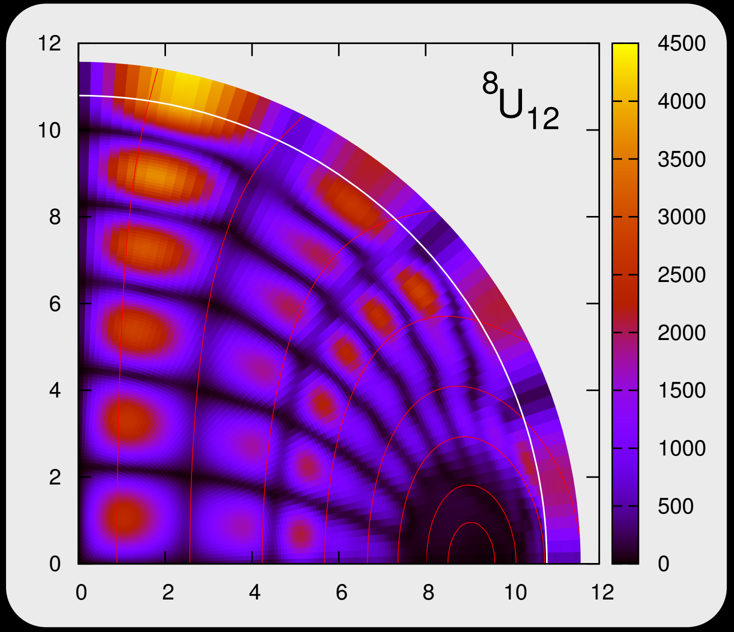




✓ continuum

constant phase

Two classes of oscillations



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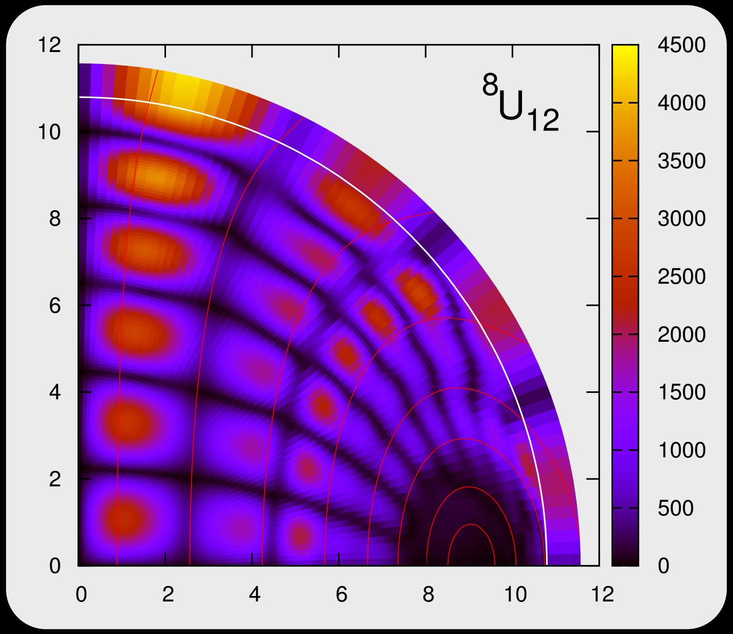


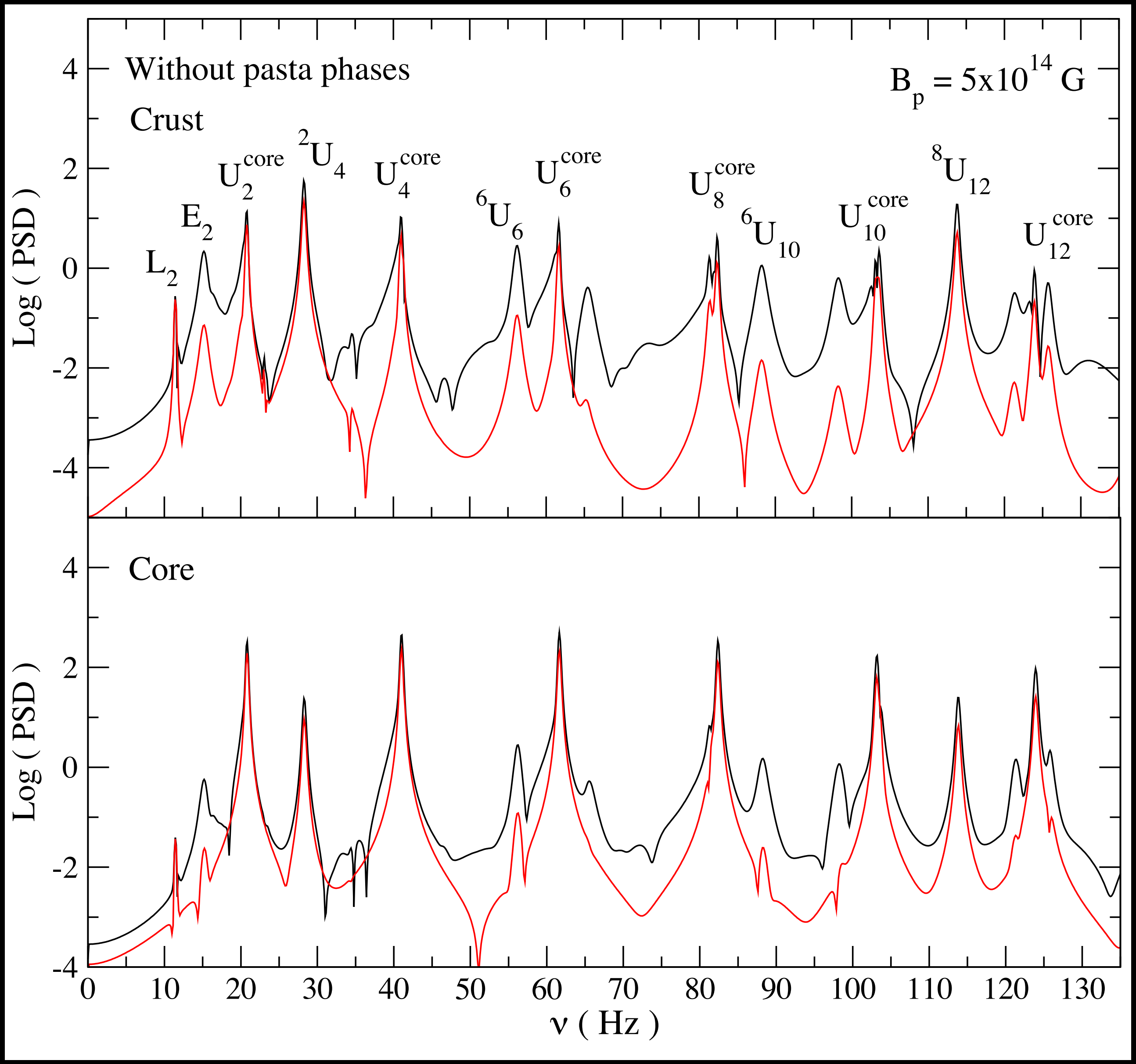
Results consistent with Gabler et al. 2016

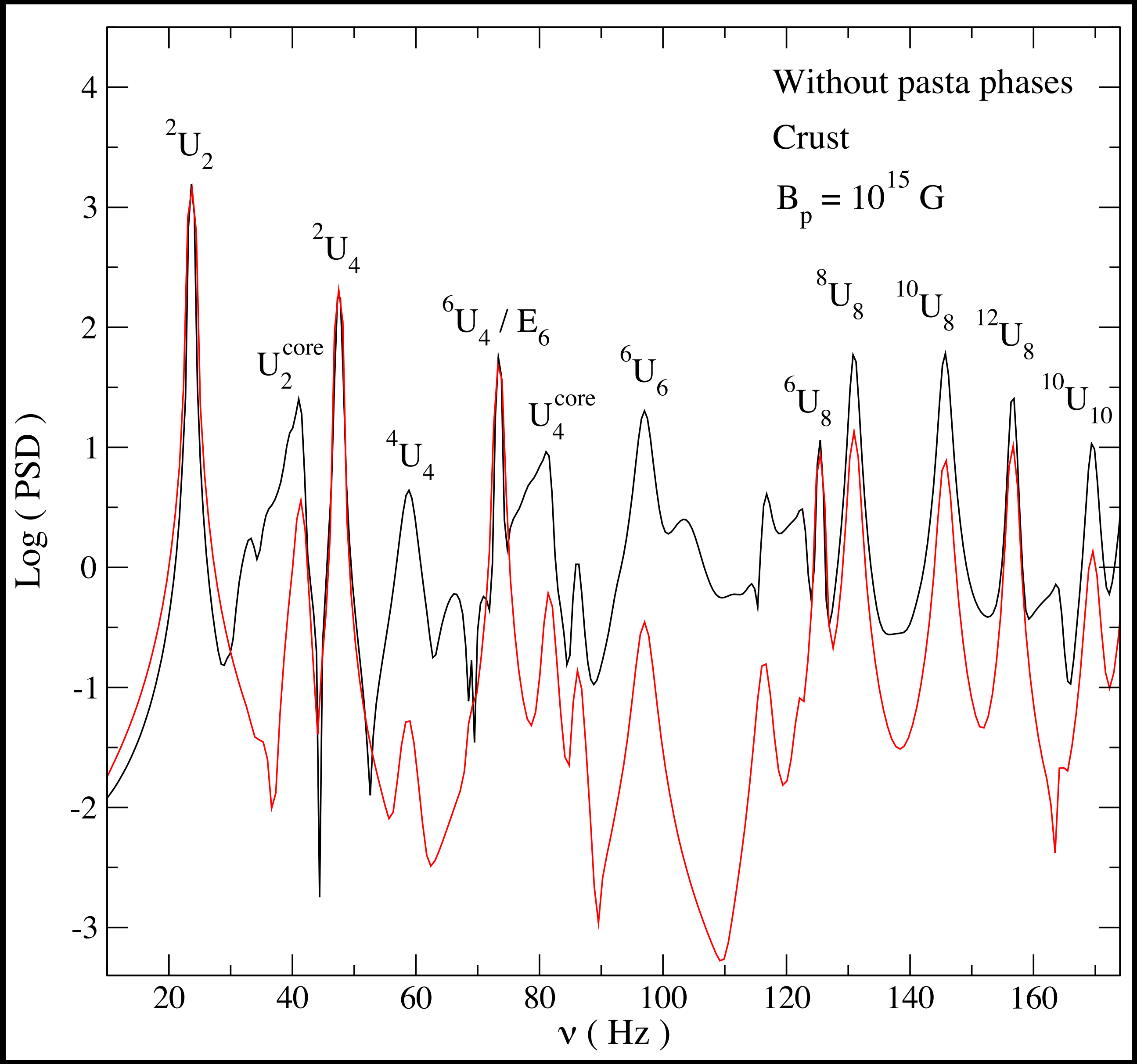
Two classes of magneto-elastic modes

without nuclear pasta

$B_P = 5 \times 10^{14}$ G

$B_P = 10^{15}$ G





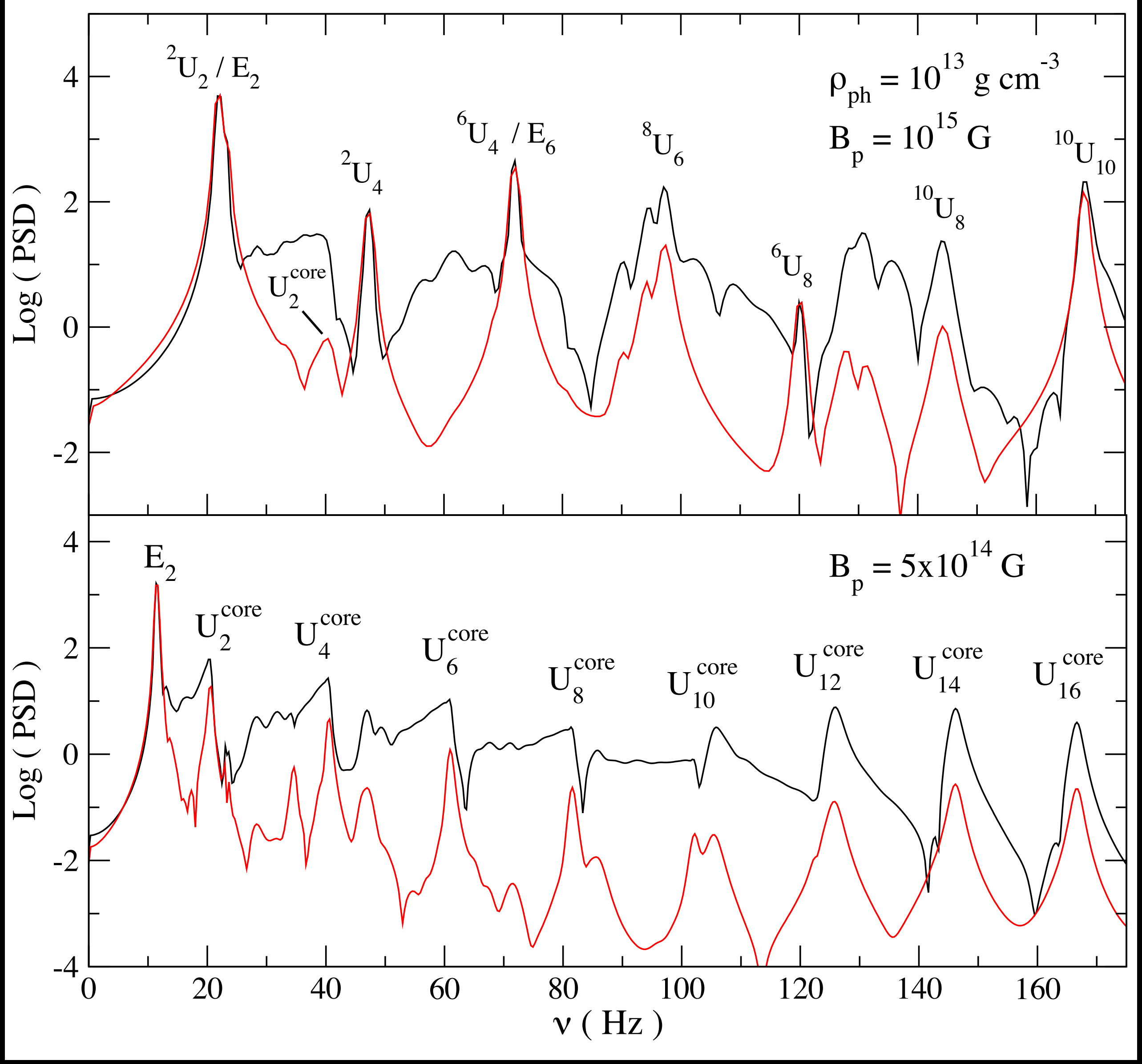
✓ Core confined oscillations dominate

✓ Global magneto-elastic oscillations dominate

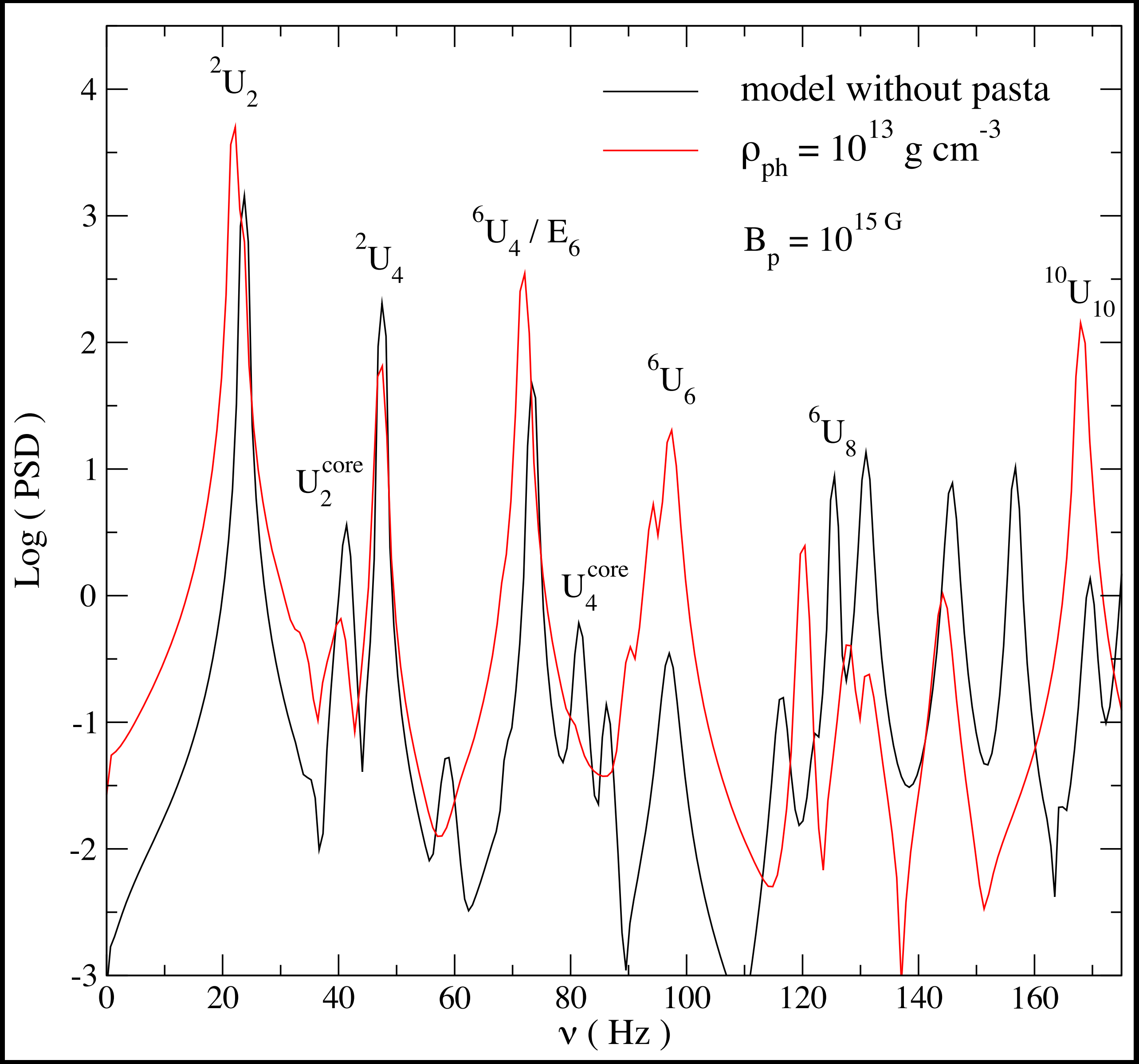
Effects of nuclear pasta

- No drastic change

Pasta model



With and without pasta



Conclusions of Part 2

- QPOs in superfluid magnetars
  - ✱ Coexistence of core confined and global magneto-elastic waves
  - ✱ Nuclear pasta in the inner crust does not change drastically the QPO spectrum