Bar-mode instability of differentially rotating NS with realistic equation of state

Dynamical bar-mode instabilities develop also with realistic EOSs but show slightly different features

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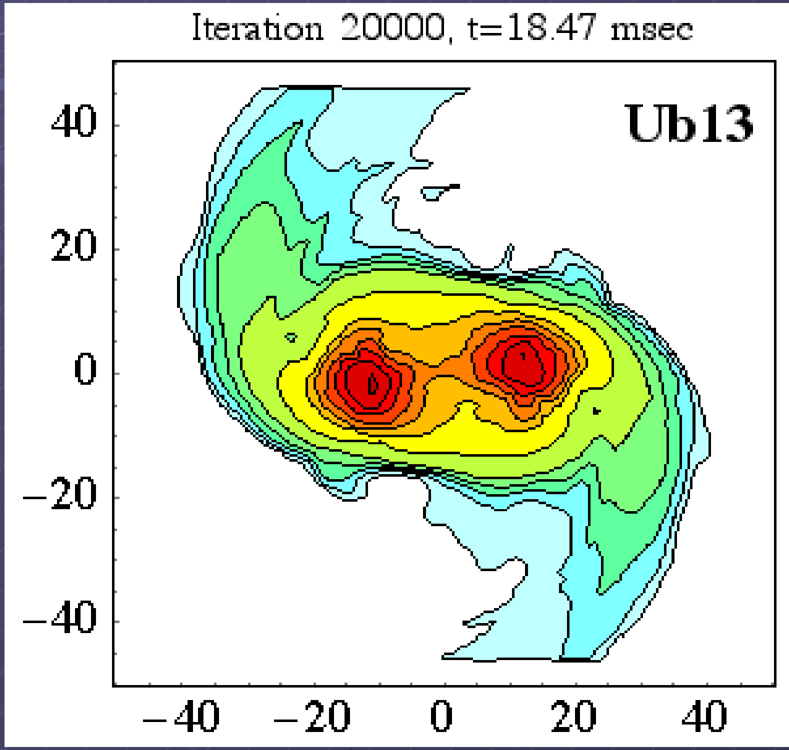
Bar-Mode instability

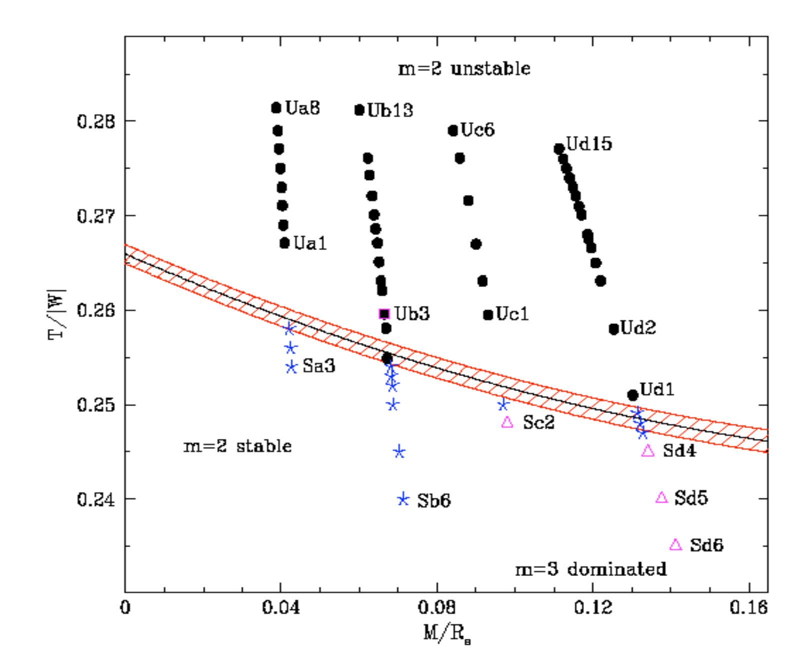
- Non-linear, dynamical instability
- Onset for $\beta = T/|W|$ over a critical value β_c
- Non-axial deformation of the star, explained with interaction of non-axisymmetric modes
- Differential rotation law
- Polytropic eos: $p = K\rho^{\Gamma}$



Picture courtesy of Roberto De Pietri, Gianmario Manca, Luca Baiotti, Luciano Rezzolla

Previous results

- Baiotti, De Pietri, Manca, Rezzolla Phys.Rev.D **75** 044023 (2007) and Manca, Baiotti, De Pietri, Rezzolla CQG **24**, 12 (2007)
- Polytropic eos, KEH rotation law (A=1)
- Critical value depends on compactness
- Influence of various factors:
  - symmetries: other than equatorial reflection
  - initial perturbations: influence on growth times and persistence
  - ideal fluid equation of state
- Persistence of the bar depends on overcriticality



We have extended these results with respect to the microphysics, i.e using a realistic cold EOS

Cactus - Whisky - Carpet

- Hydro equations handled by Whisky Code: parallel, 3D general relativistic code, HRSC methods, various Riemann solver and reconstruction methods
- Einstein equations solved in BSSNOK formulation with MoL
- Grid hierarchy managed by Carpet grid driver: AMR driver with possibility to change box extents dynamically
- All the codes written in the Cactus Computational Toolkit: infrastructure for parallel, collaborative codes
- Cactus-Carpet-Whisky already used for BBH, BNS, NS collapse, bar-mode instability, NS perturbation

Equation of state

- 3 tables for different density ranges:
- Sly: Douchin&Haensel A&A **380** (2001) $\rho > 5 \times 10^{10} g/cm^3$
- HP94: Haensel & Pichon A&A **283** (1994) $10^8 < \rho < 5 \times 10^{10} g/cm^3$
- BPS: Baym et al. ApJ **170** (1971) $\rho < 10^8 g/cm^3$

- Table population: analytical fit from Haensel&Potekhin A&A **428** (2004)

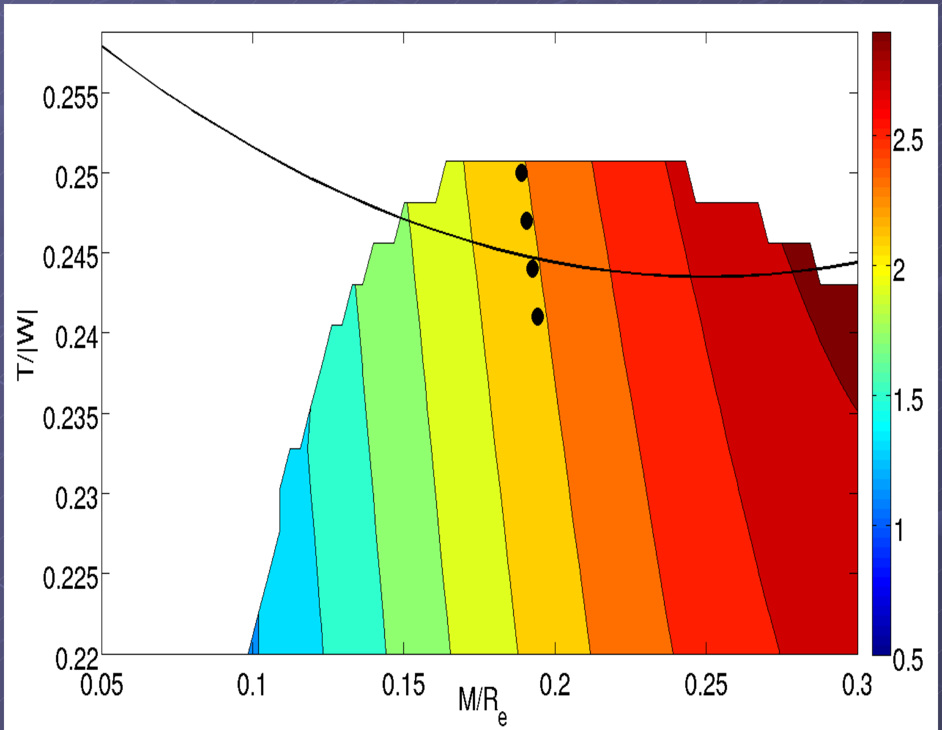
and $P = \rho^2 \frac{d\epsilon}{d\rho}$ for the pressure

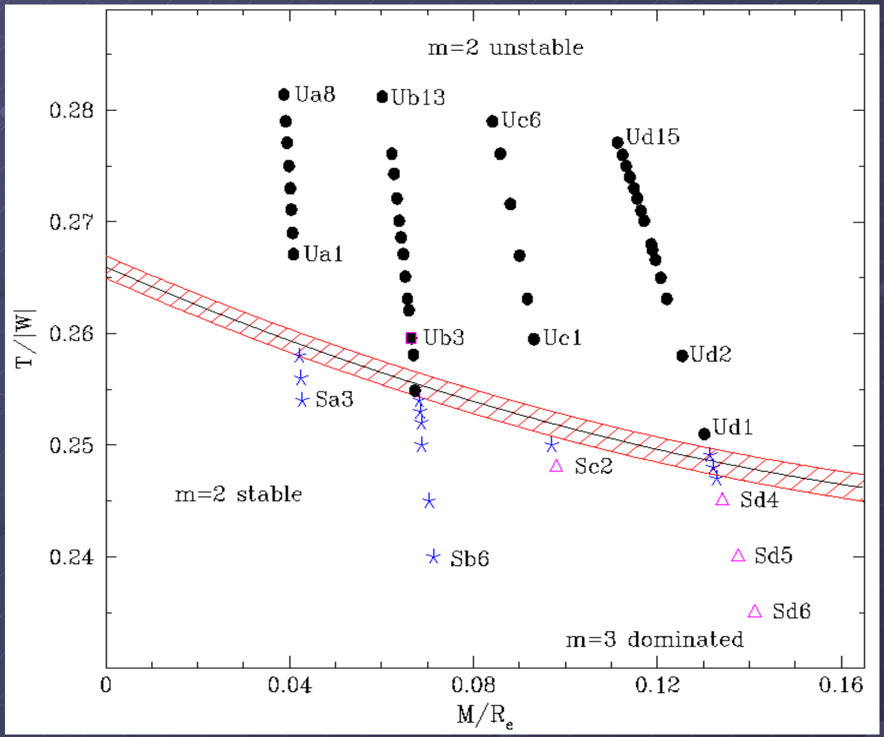
- 640 equidistant points

- Linear interpolation on the populated table

Rotating NS: initial models

- 4 models, values of β close to the threshold for polytropic EOS
- β values: 0.250, 0.247, 0.244, 0.241
- Model name convention: SLy_<axes ratio>_<beta>
- Color code: gravitational mass
- 3 refinement levels, resolution over the star: 0.15 M (~220 m)



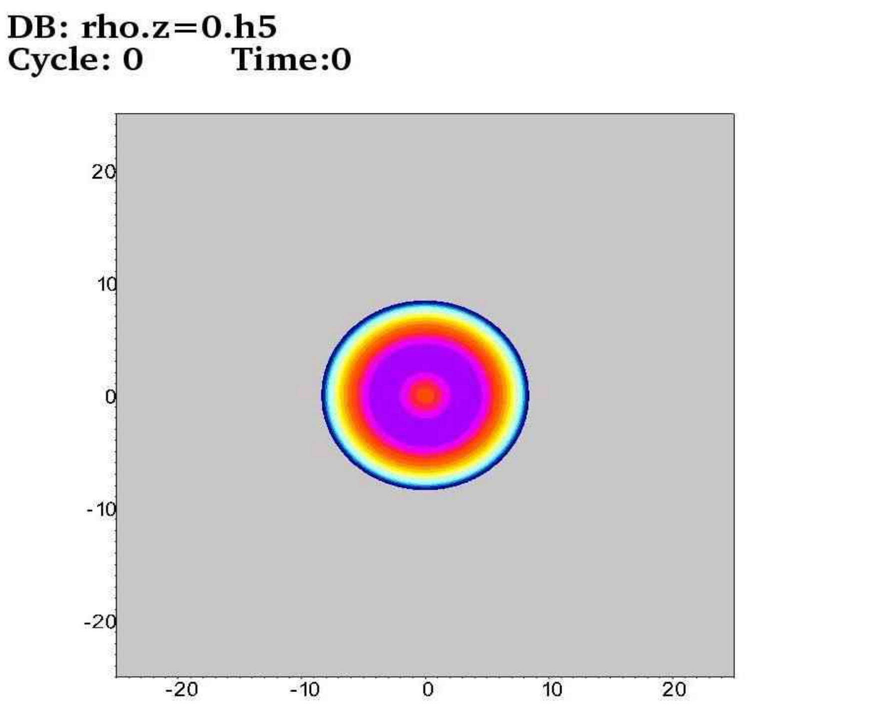


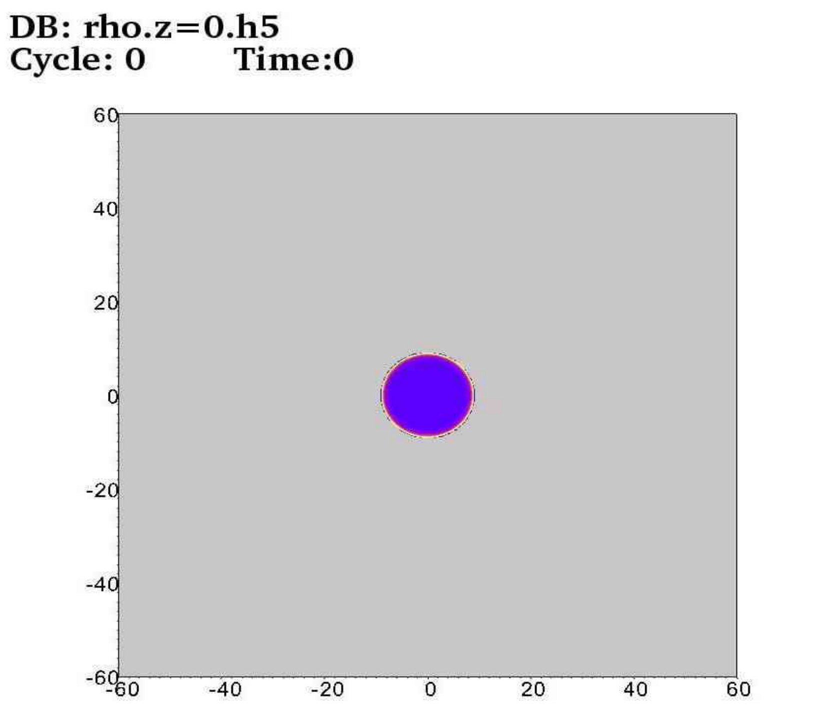
Rotating NS: evolutions

Sly_0.305_0.244

Linear scale

Logarithmic scale





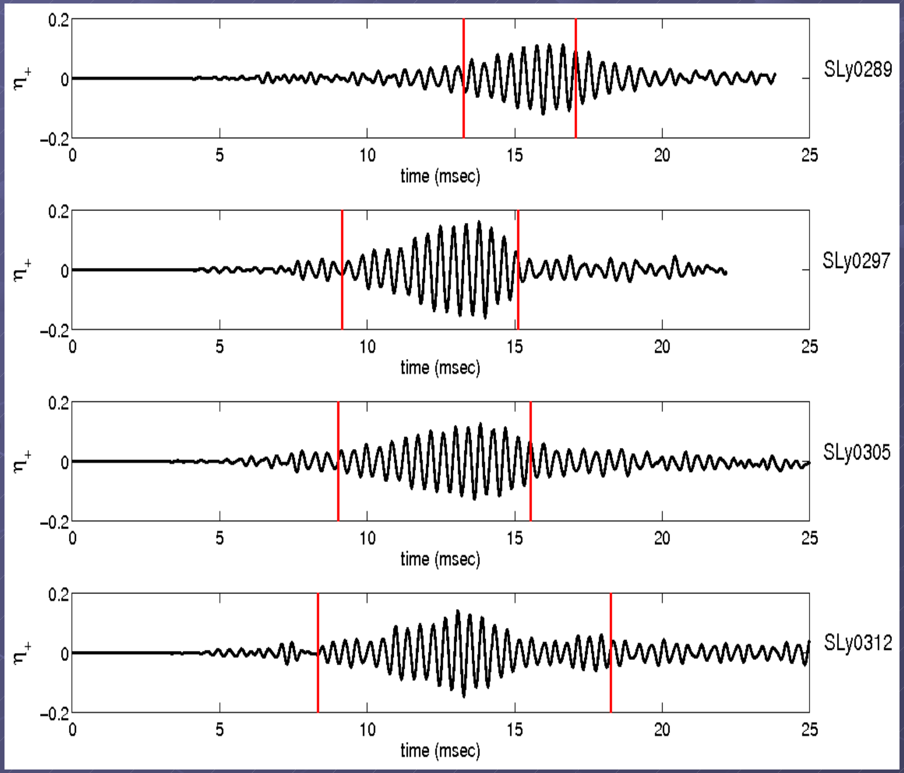
Sly_0.305_0.244

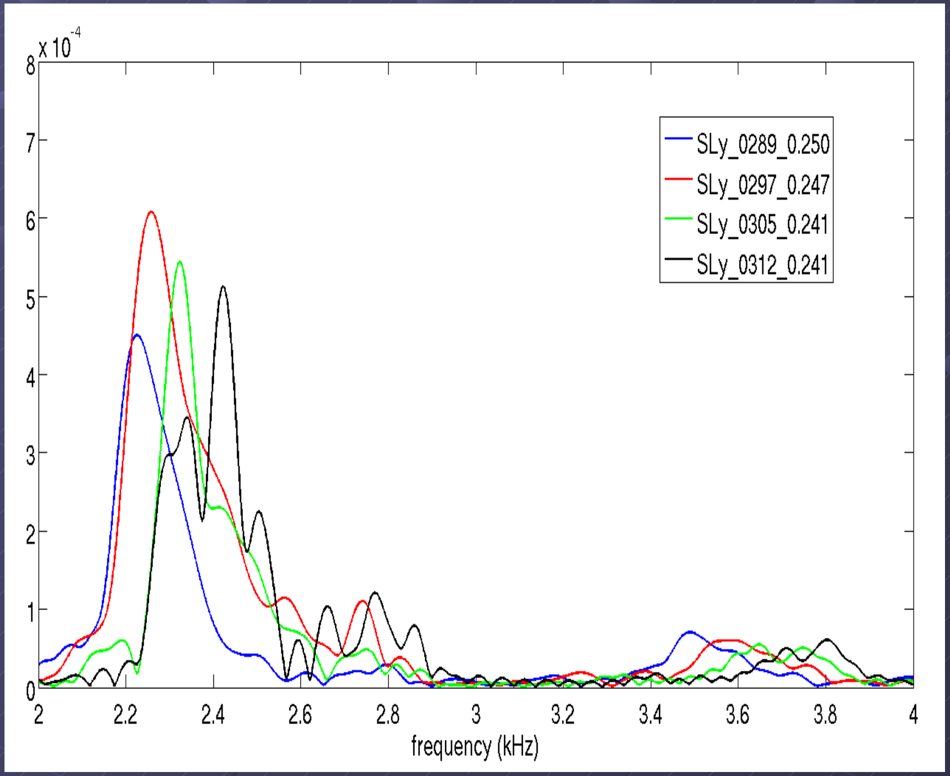
Linear scale

Logarithmic scale

Rotating NS: deformation

- η parameter defined as: $\eta_+ = \frac{I^{xx} - I^{yy}}{I^{xx} + I^{yy}}, \quad I^{ij} = \int d^3x D x^i x^j$

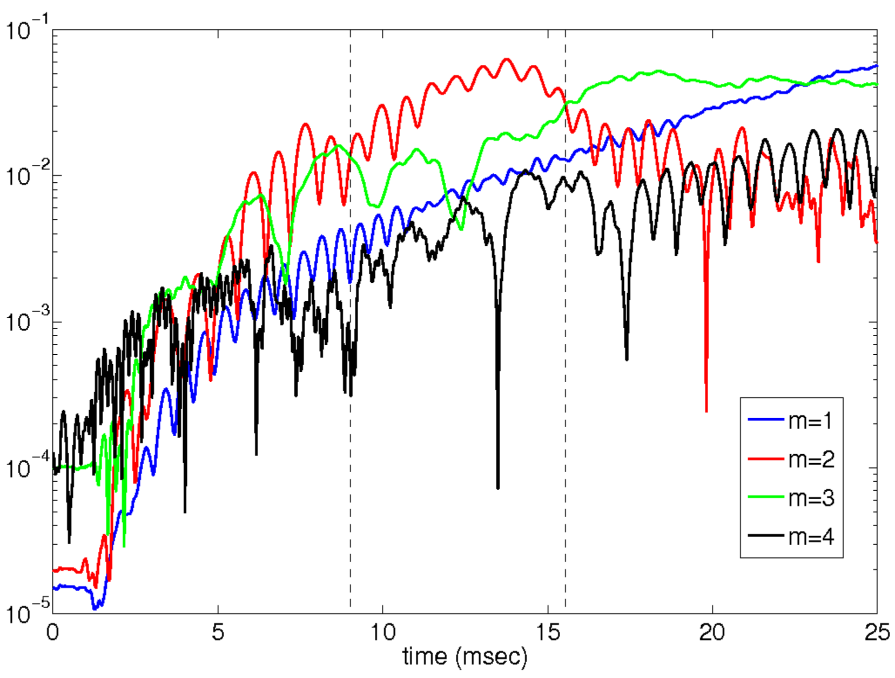




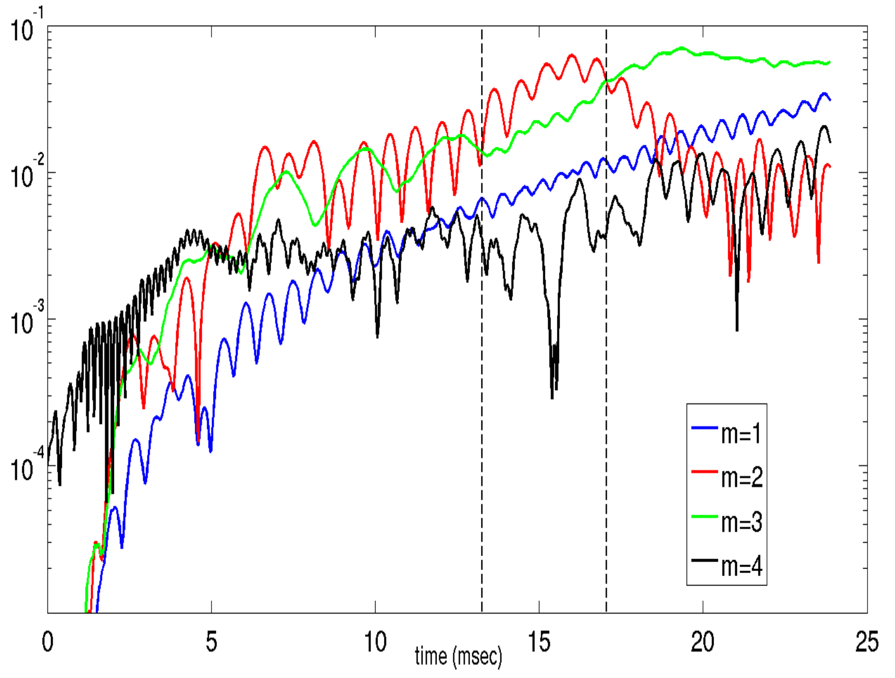
Rotating NS: global modes

- Mode computed as: $P_m = \int d\phi\, \rho e^{im\phi}$ m = 1,2,3,4
- Bar duration: from 3.8 ms to 9.9 ms
- Bar duration for polytropic: from 5 to 40 ms

SLy_0.305_0.244



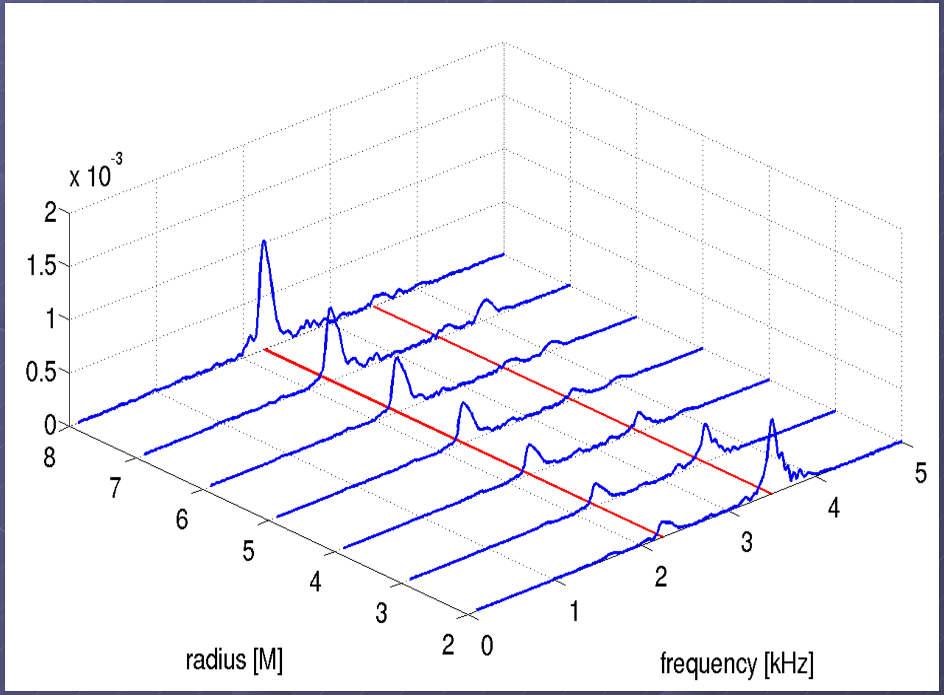
SLy_0.289_0.250



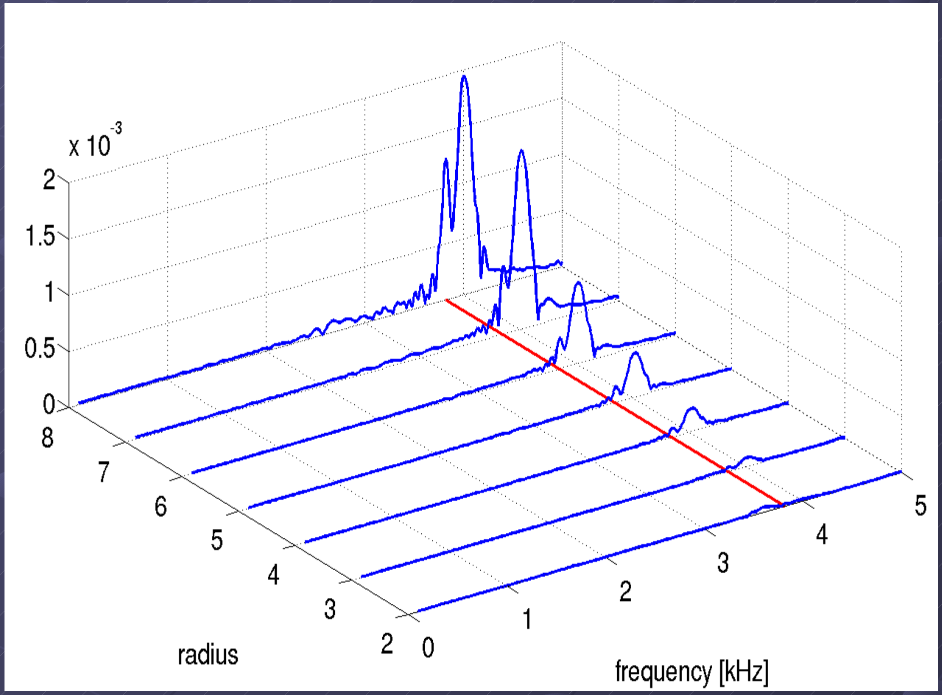
Rotating NS: local modes

- Mode computed as: $\tilde{P}_m = \int_{z=0} d\phi\, \rho e^{im\phi}$, m = 2,3
- R values: from 2 to 8
- Frequencies: 2.25 and 3.50 kHz in m=2, 3.82 kHz in m=3

m=2



m=3



Comparison with polytropic
(from the few data we have)

Similarities

- The instability is present
- Spiral arms are formed
- Initial m=2 and m=3 exponential growth
- Final m=1 deformation dominant

Differences

- Star less deformed
- Bar is less persistent
- Spiral arms are thinner
- No m=3 dominated models (m=3 grows before m=2) has been found, so far
- m=2 and m=3 modes present at the same time

Bar-mode instability: summary

- 4 models simulated around polytropic $(\Gamma = 2)$ threshold value
- The instability does not develop into a single pure mode but m=2 and m=3 deformations are coexistent (although with different strengths in different parts of the star)
- The different behaviour and the simultaneous excitation of different modes offer the possibility of deducing the EOS from the observation of the gravitational wave signal
- Caveats: these sources are potentially detectable only within the Galaxy and their event rate is therefore very small

- Future work
  - more models to explore parameter space
  - new EOS