Mode identification in fast rotating classical pulsators

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Introduction

- Classical pulsators - WP 164000 of the Additional Science Program
- Most pre-main-sequence and main-sequence massive and intermediate mass pulsators are rapid rotators
  PMS, SPB, β Ceph, δ Scuti, γ Dor, Hybrids
  - Centrifugal effects on p-modes $\Omega >\sim 0.15 \left(\frac{GM}{R_{\rm eq}^3}\right)^{1/2}$
  - Coriolis effects on low frequency g modes $\omega < 2\Omega$
- Today, we are not able to interpret the frequency spectra of rapid rotators
  $\rightarrow$ no detailed seismic diagnostic of the interior of typical $M > 2\ M_\odot$ stars

Mode identification of fast rotating classical pulsators is a key issue for the scientific return of Plato Additional Science program

Towards mode identification in rapidly rotating stars

New perspectives for an old problem

New data

- CoRoT/Kepler
- Spectroscopy
- Interferometry

New models

- Accurate mode calculations
- A ray-based asymptotic theory
- 2D stellar structure models

- A lot of work is still needed to know whether it will be sufficient to establish reliable mode identification schemes
- This should be a priority of the Additional Science program on classical pulsators

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Outline

- Recent progress in modeling
  - Mode calculations
  - Mode physics : mode classification and spectrum organization
- Building and testing mode identification methods
  - Using the asymptotic structure of the spectrum
  - Direct approach
  - Constraints from spectroscopy and multicolor photometry
- Conclusion in the context of the Plato preparation

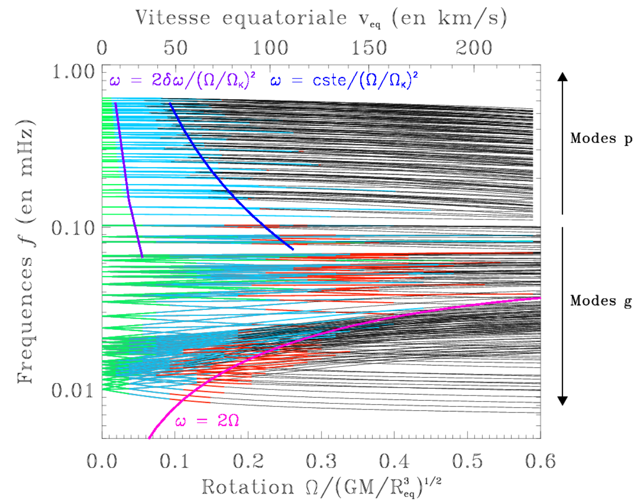
Mode calculations in rotating stars

Tools

- Perturbative methods $\omega = \omega_0 + \Omega\omega_1 + \Omega^2\omega_2 \ldots$
- Traditional approximation for low frequency modes
- First order centrifugal deformation + truncated spherical harmonics expansion
- Complete calculations (no simplifying assumptions)
  - TOP code (Reese et al., 2006)
  - NRO code (Clement 1998)
  - New code in development at Meudon Observatory

- Accurate computations are now possible
- Approximate calculations can be tested

Perturbative methods vs complete calculations



$\delta\nu = 0.1\mu$Hz

- 1^{st} order
- 2^{nd} order
- 3^{rd} order

- low degree modes $\ell \leq 3$
- M = 3 $M_\odot$, R= 2 $R_\odot$

(Reese et al. 2006, Ballot et al. 2010)

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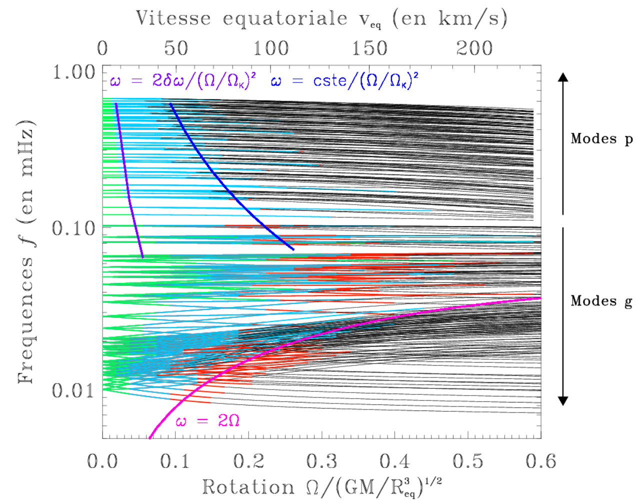

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(Reese et al. 2006, Ballot et al. 2010)

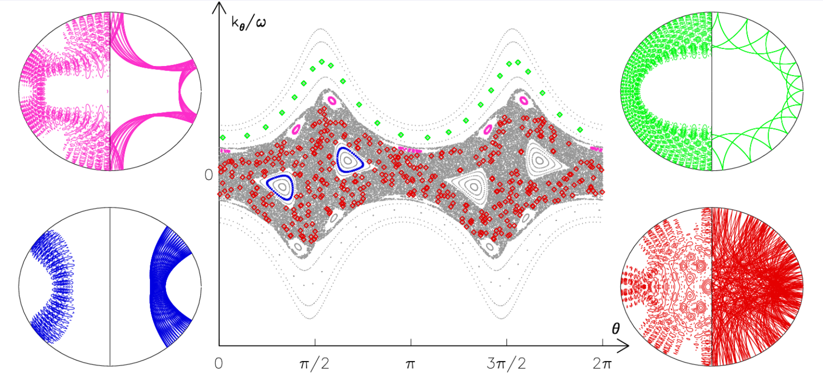
To be done

- Testing the traditional approximation (work in progress)

Mode physics : classification and spectrum structure

P-modes

- A physical mode classification from a new ray-based asymptotic theory



- The frequency spectrum is a superposition of sub-spectra with different properties

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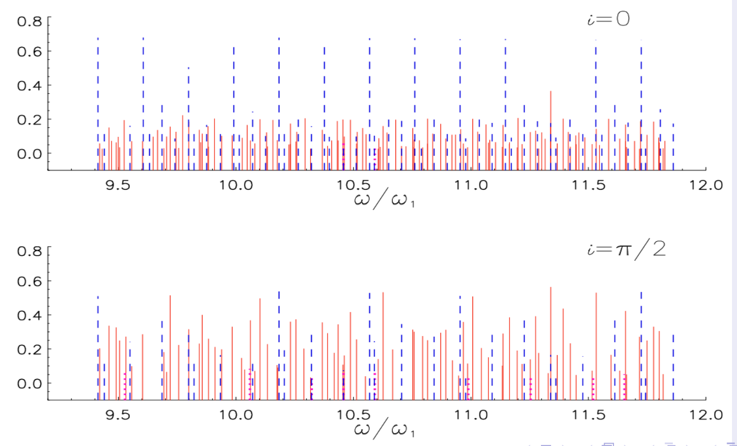

Mode physics : classification and spectrum structure

P-modes

- A physical mode classification from a new ray-based asymptotic theory
- The frequency spectrum is a superposition of sub-spectra with different properties Lignières & Georgeot 2009

To be done

- g-modes in the asymptotic regime (work in progess)
- Mode excitation
- Non-linear saturation

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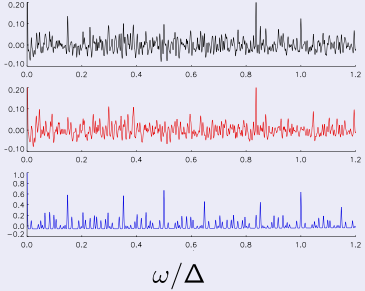
Using the asymptotic structure of the spectrum

Regular frequency spacings in the asymptotic p-mode spectrum

- An equivalent of the large separation should be detectable
- A 2Ω spacing might be also detected



Lignières et al. 2010

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Period spacings in the g-mode spectrum

- The period spacing is not constant Ballot et al. 2009
- A specific tool must be constructed

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Comparison with data

- Large separation in δ Scuti García-Hernández et al. 2009
- Solar-type oscillation in rapidly rotating stars ?

Direct approach

Comparing computed and observed frequencies for a specific star

Model constraints

- Limitations of 2D stellar structure models : ex. ESTER models $M > 3\ M_{\odot}$
- Spherically symmetric models might be OK for low frequency g-modes at moderate rotation rates

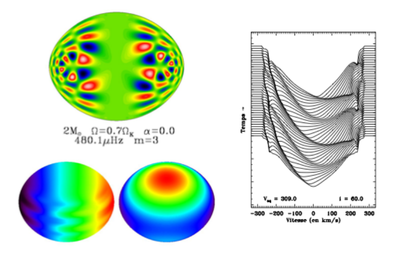
Choice of the best target

- well-known fundamental parameters
- low frequency g-modes (or hybrid stars) in moderately rotating stars (γ Dor, B stars, SdB in close binary system - coll. S. Charpinet)
- special configurations : nearly pole-on stars

Constraints from spectroscopy and multicolor photometry

Mode identification from high-resolution spectroscopy

- Theoretical line profile variations (D. Reese)



- Observations : rapidly rotating pulsators dominated by a small number of modes (coll. T. Böhm, W. Zima)

Conclusion

- Progress on mode identification in rapidly rotating stars are expected but still require a lot of work

- The Additonal Science Program preparation provides a good opportunity to support this type of key modeling issue on mode physics (like excitation, non-linear saturation, ...)