Outlook



### Introduction

### Stellar structure

Physical phenomena Recent models

### Pulsation modes

The frequency spectrum Mode geometry Ray dynamics

### Outlook

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Physical phenomena Recent models

# Physical phenomena

Daniel Reese Modelling rapidly rotating stars

Physical phenomena Recent models

# Physical phenomena

centrifugal deformation



(MacGregor et al., 2007)

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Physical phenomena Recent models

### Physical phenomena

- centrifugal deformation
- gravitational darkening



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(MacGregor et al., 2007)

Physical phenomena Recent models

# Physical phenomena

- centrifugal deformation
- gravitational darkening
- baroclinicity



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(MacGregor et al., 2007)

Physical phenomena Recent models

# Physical phenomena

- centrifugal deformation
- gravitational darkening
- baroclinicity
  - differential rotation
  - meridional circulation



(MacGregor et al., 2007)



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Altair *i*=63.9

Physical phenomena Recent models

# Physical phenomena

- centrifugal deformation
- gravitational darkening
- baroclinicity
  - differential rotation
  - meridional circulation
- transport processes



(MacGregor et al., 2007)



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Altair *i*=63.9

Physical phenomena Recent models

### Recent models

Meynet & Maeder (2000), and other papers

- shellular rotation profile,  $\Omega(r)$  (see Zahn, 1992)
- 1D formalisme
- stellar evolution
- transport processes (chemical elements and angular momentum)





Jackson et al. (2004, 2005), MacGregor et al. (2007)

- barotropic models
- conservative rotation profile:  $\Omega(s)$
- attempt to describe Achernar



(MacGregor et al., 2007)

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- Roxburgh (2004)
  - barotropic uniformly rotating model
- Roxburgh (2006)
  - transforms 1D models into 2D models
  - arbitrary 2D rotation profile
  - thermal equilibrium not solved



Physical phenomena Recent models

The ESTER project

- Rieutord (2006)
  - boussinesq model with baroclinic flows
- Espinosa & Rieutord (2007)
  - compressible baroclinic model in spherical container



Image: A mathematical states and a mathem

The frequency spectrum Mode geometry Ray dynamics

### Pulsation modes

many uncertainties remain in models

need for observational constraints

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## Pulsation modes

- many uncertainties remain in models
  - need for observational constraints
- difficulties
  - pulsation modes are not given by a single spherical harmonic: this is a 2D eigenvalue problem
  - unfamiliar mode geometry and frequency spectrum

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# The frequency spectrum

Inadequacy of perturbative methods at rapid rotation rates

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# The frequency spectrum

Inadequacy of perturbative methods at rapid rotation rates



Image: A math a math

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## The frequency spectrum

Inadequacy of perturbative methods at rapid rotation rates



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#### A new frequency organisation



(Lignieres et al., 2006, Reese et al., in preparation)

$$\omega_{n,\ell,m} = n\Delta_n + \ell\Delta_\ell + |m|\Delta_m + \alpha^{\pm}$$

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# Mode geometry



mode energy concentrated around equatorial region

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## Mode geometry



- mode energy concentrated around equatorial region
- there are 10 "radial" nodes ( $\tilde{n} = 10$ )

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# Mode geometry



- mode energy concentrated around equatorial region
- there are 10 "radial" nodes ( $\tilde{n} = 10$ )
- there is 1 "latitudinal" node  $(\tilde{\ell} = 1)$

Image: A math a math

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$$\tilde{n}=10, \quad \tilde{\ell}=0$$

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$$\tilde{n} = 11, \quad \tilde{\ell} = 2$$

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$$\tilde{n} = 11, \quad \tilde{\ell} = 3$$

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**Question**: what is the link between this mode geometry and the geometry of modes in non-rotating stars?



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$$egin{array}{rcl} \widetilde{n} &=& 2n+arepsilon, \ \widetilde{\ell} &=& rac{\ell-|m|-arepsilon}{2}, \ arepsilon &\equiv& \ell+m\,[2] \end{array}$$

 $\omega_{n,\ell,m} = \tilde{n}\tilde{\Delta}_n + \tilde{\ell}\tilde{\Delta}_\ell + |m|\tilde{\Delta}_m + \tilde{\alpha}$ 

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What needs to be done:

- search for asymptotic patterns using realistic stellar models
- search for equidistant patterns in observed pulsation spectra
- improve stellar models
- b do detailled asteroseismic comparisons

Image: A matrix

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