Non-adiabatic pulsation computations in rotating ESTER models

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Abstract: Taking into account non-adiabatic effects in stellar pulsation calculations is important because it allows us to determine excitation or damping rates, and is important for obtaining the variations of effective temperature at the surface, which in turn play a key role in mode visibilities. Calculating these effects in rapidly rotating stellar models is a theoretical and numerical challenge due to the complexity of the equations and the stiffness of the numerical system. In the present poster, we describe the latest progress in validating and computing non-adiabatic modes in ESTER models using the TOP pulsation code.

Equations

- the equations that need to be solved are the perturbed continuity equation, Euler's equation, Poisson's equation, energy conservation equation, and radiative flux equation
- we apply the frozen convection approximation ($\delta F^C \approx 0$), and neglect the variations in energy production ($\delta\epsilon \approx 0$)

$$0 = \frac{\delta\rho}{\rho_o} + \vec{\nabla}\cdot\vec{\xi}$$

$$0 = [\omega+m\Omega]^2\vec{\xi} - 2i\vec{\Omega}\times[\omega+m\Omega]\vec{\xi} - \vec{\Omega}\times\left(\vec{\Omega}\times\vec{\xi}\right) - \vec{\xi}\cdot\vec{\nabla}\left(s\Omega^2\vec{e}_s\right) - \frac{P_o}{\rho_o}\vec{\nabla}\left(\frac{\delta P}{P_o}\right) + \frac{\vec{\nabla}P_o}{\rho_o}\left(\frac{\delta\rho}{\rho_o} - \frac{\delta P}{P_o}\right) - \vec{\nabla}\Psi + \vec{\nabla}\left(\frac{\vec{\xi}\cdot\vec{\nabla}P_o}{\rho_o}\right) + \frac{\left(\vec{\xi}\cdot\vec{\nabla}P_o\right)\vec{\nabla}\rho_o - \left(\vec{\xi}\cdot\vec{\nabla}\rho_o\right)\vec{\nabla}P_o}{\rho_o^2}$$

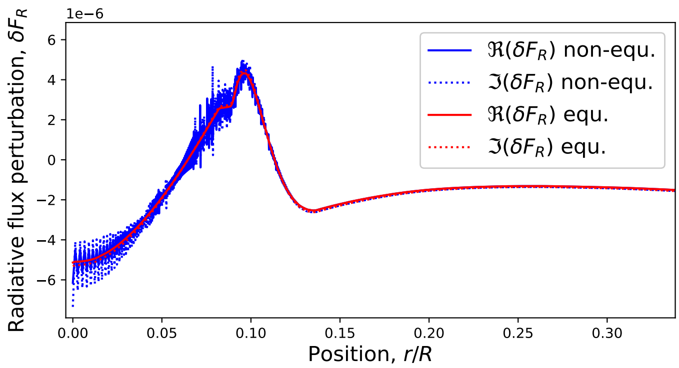
$$\Delta\Psi = 4\pi G\rho$$

$$i(\omega+m\Omega)\rho_o T_o\delta S = \epsilon_o\rho_o\left(\frac{\delta\epsilon}{\epsilon_o} + \frac{\delta\rho}{\rho_o}\right) - \vec{\nabla}\cdot\delta\vec{F} - \vec{\xi}\cdot\vec{\nabla}\left(\vec{\nabla}\cdot\vec{F}_o\right) + \vec{\nabla}\cdot\left[\left(\vec{\xi}\cdot\vec{\nabla}\right)\vec{F}_o\right]$$

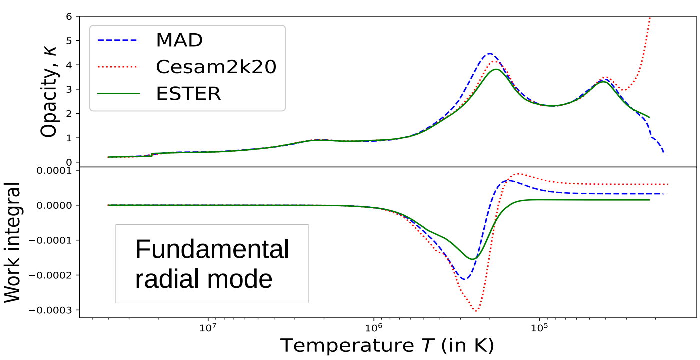
$$\delta\vec{F}^{\mathrm{R}} = \left[4\frac{\delta T}{T_o} - \frac{\delta\kappa}{\kappa_o} - \frac{\delta\rho}{\rho_o}\right]\vec{F}_o^{\mathrm{R}} - \frac{4acT_o^3}{3\kappa_o\rho_o}\left[T_o\vec{\nabla}\left(\frac{\delta T}{T_o}\right) + \vec{\xi}\cdot\vec{\nabla}\left(\vec{\nabla}T_o\right) - \vec{\nabla}\left(\vec{\xi}\cdot\vec{\nabla}T_o\right)\right]$$

Validation and improvements
(work in progress)

- test system with quadruple precision calculations
- the problem is very stiff: equilibrate matrix by scaling rows and columns prior to finding pulsation modes

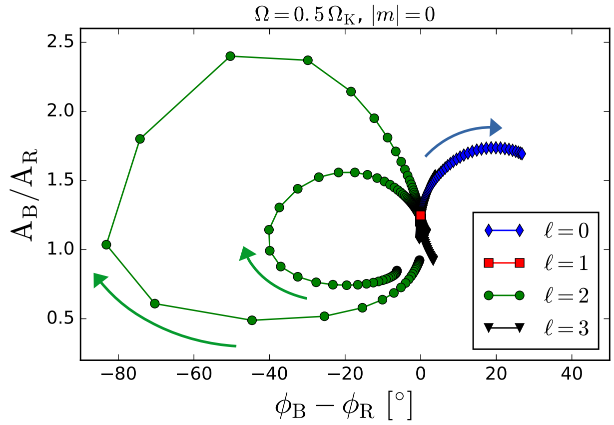


- comparison with non-adiabatic calculations in non-rotating models (Cesam2k20, CLES)
  - this required smoothing opacities in Cesam2k20



Amplitude ratios

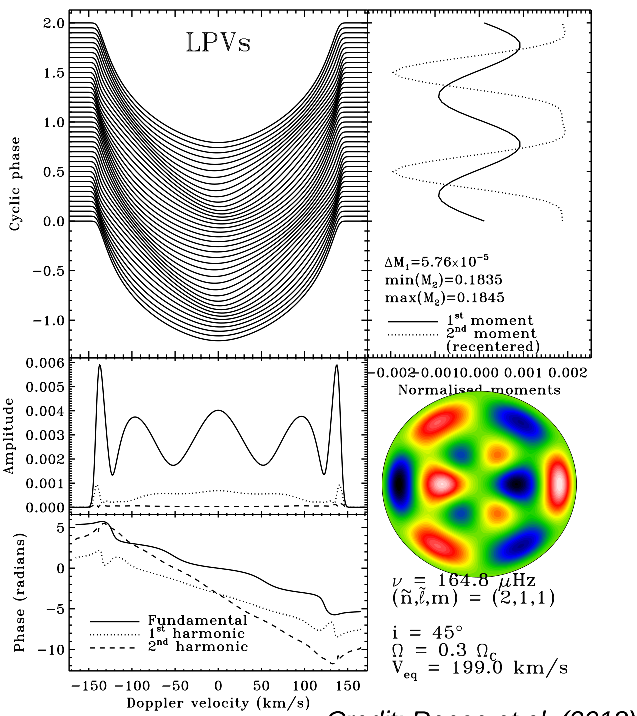
- Useful for identifying modes from multicolour photometry



Amplitude ratios vs. phase differences in a rapidly rotating ESTER model. Inclinations increase from 2° to 89° in increments of 1° as indicated by the arrows. *Credit: Reese et al. (2018), 3rd BRITE conference.*

Line profile variations (LPVs)

- Useful for identifying modes from spectroscopy



Credit: Reese et al. (2018)