Pulsations of rapidly rotating stars

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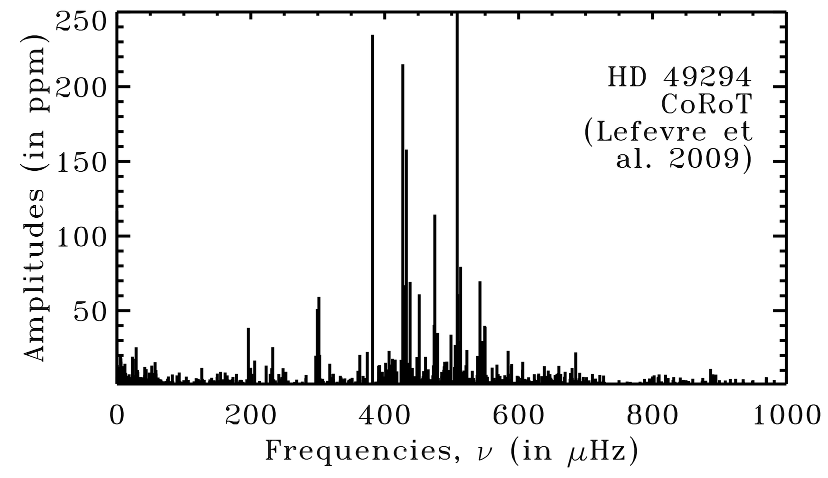
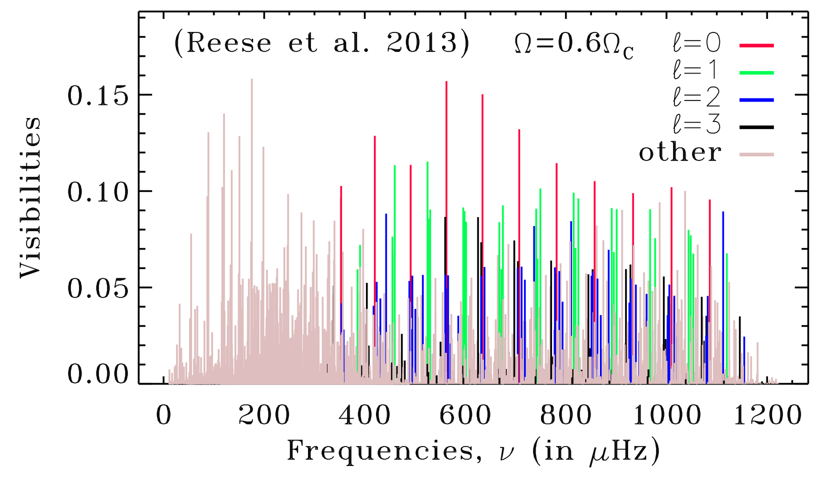
Abstract

Interpreting stellar pulsations is currently the only way to probe stellar interiors. Applying this technique to rapidly rotating stars is challenging for many reasons: complex pulsation spectra, the need for a 2D approach, new classes of pulsation modes, amplitudes determined by non-linear saturation etc. As a crucial first step to interpreting these pulsation spectra, we are developing techniques which help us to correctly match observed pulsation frequencies with theoretically calculated modes.

Observations



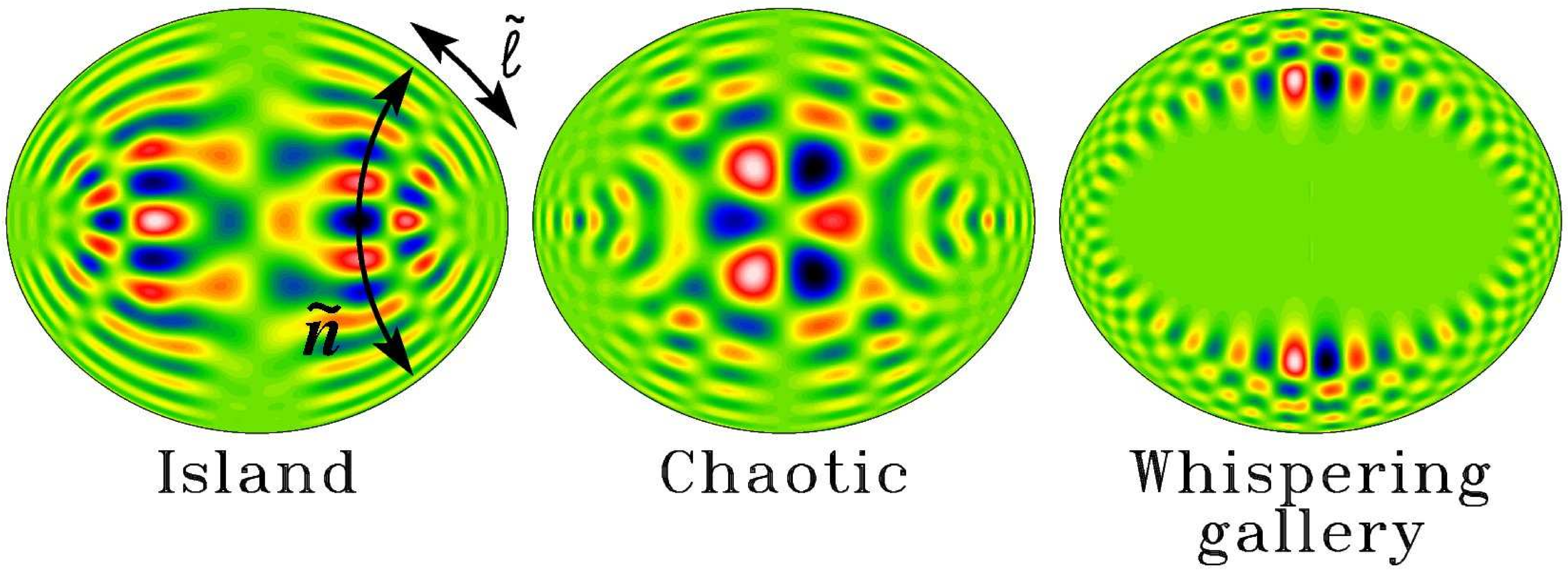
Theory



- Both the observed and predicted pulsation spectra are highly complex, making it difficult to correctly match the two.
- As a result, empirical *mode identification* methods are needed. Two possibilities are multi-colour photometric and spectroscopic mode identification.

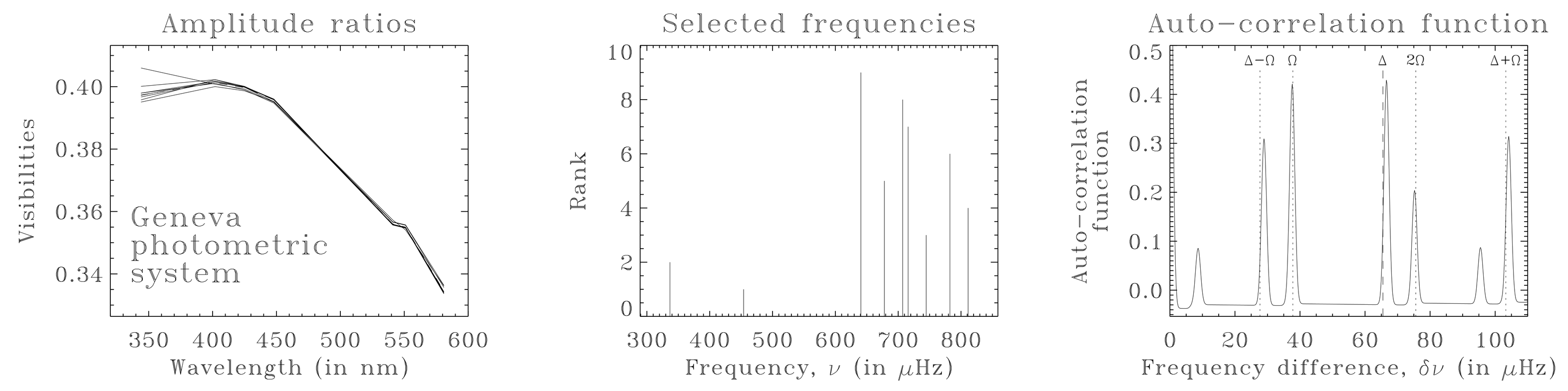
Why are theoretical spectra complex?

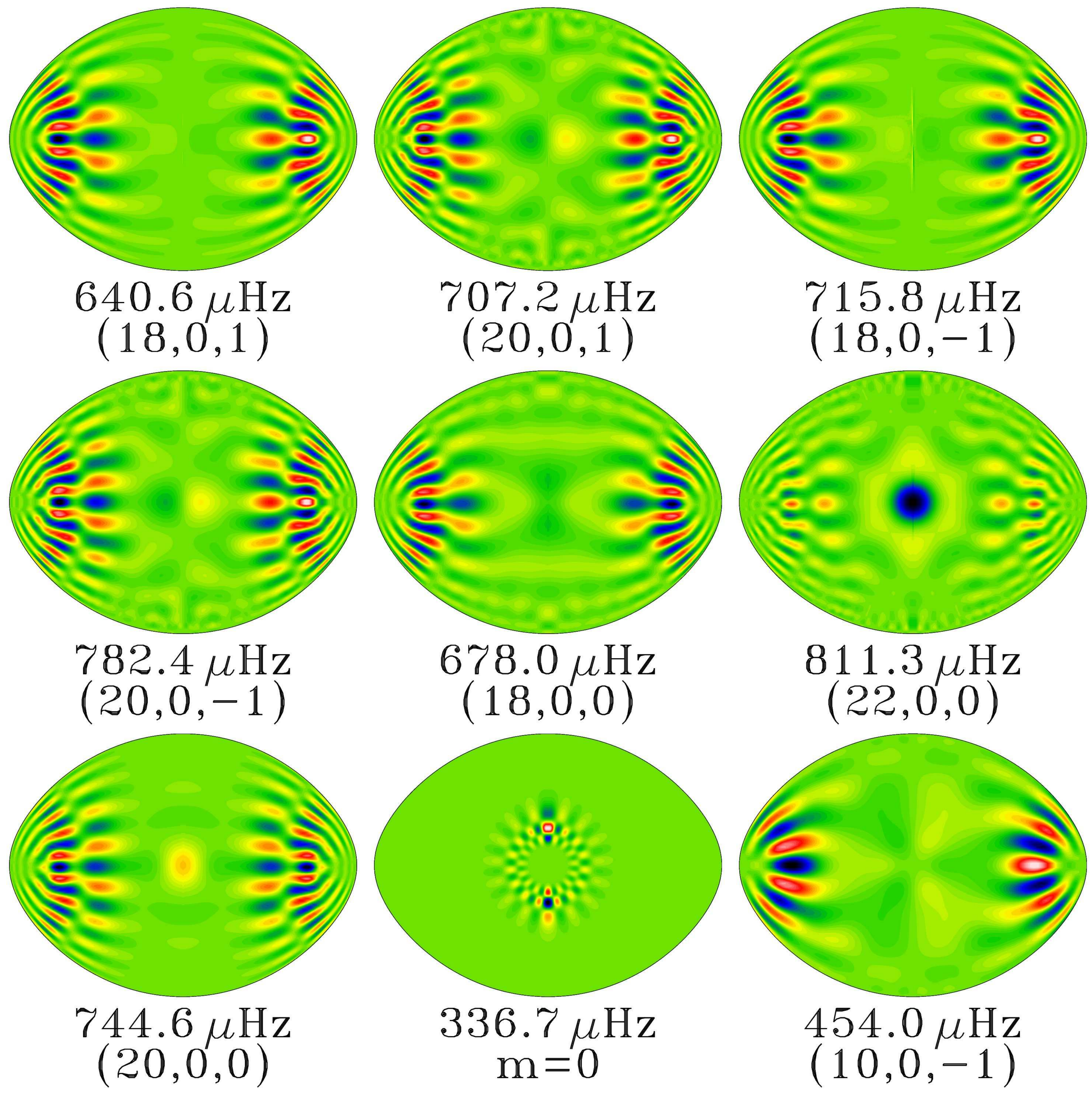
- **p-modes**: At high rotation rates, new classes of p-modes appear (Lignières & Georgeot 2008, 2009, Reese et al. 2009). Each class has its own characteristic geometry (as illustrated to the right), and its own independent frequency organisation which overlap in the complete spectrum.
- **g-modes**: In the rotating case, the period spacing is no longer uniform but a function of Ω/ω, the ratio of the rotation rate to the frequency (*e.g.* Ballot et al. 2011). Further complications include rosette modes with a distinctive geometric pattern (Ballot et al. 2011, Takata & Saio 2013).



Multi-colour mode identification

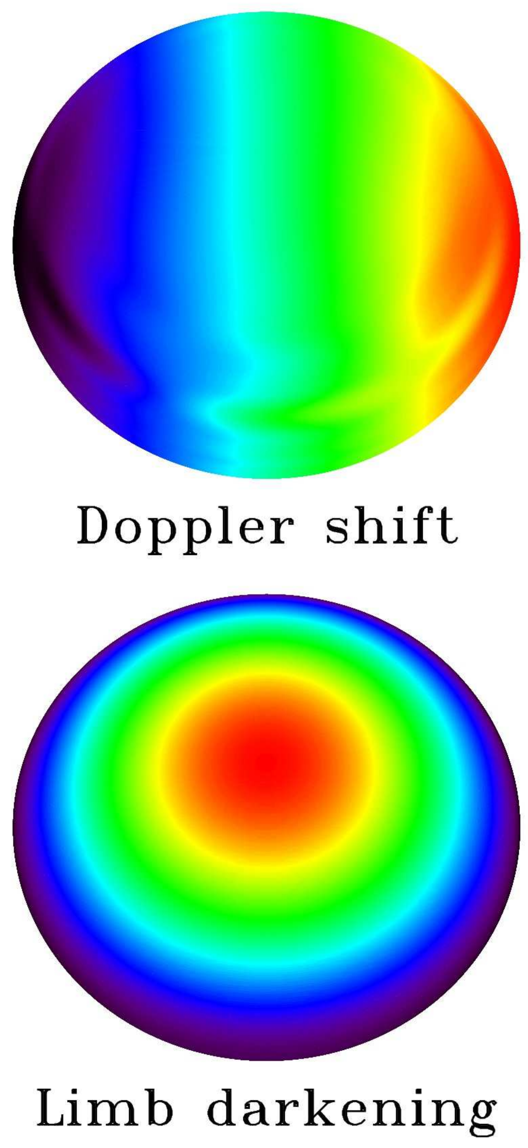
- **How does it work?** One measures the amplitudes of pulsation modes in different photometric bands and calculates their ratios (Heynderickx et al. 1994). Modes with similar amplitude ratios also have similar identifications, *even at rapid rotation rates*. Their frequencies follow typical patterns which constrain the large frequency separation, rotation rate, and identifications (see Reese et al. 2013 & submitted).
- **An example:** The $(\tilde{n}, \tilde{\ell}, m) = (18, 0, 1)$ island mode was chosen along with 8 other modes with the most similar amplitude ratios from an entire spectrum. The plots below show the amplitude ratios, resultant frequency spectrum and auto-correlation function, and mode cross-sections (left to right, top to bottom).

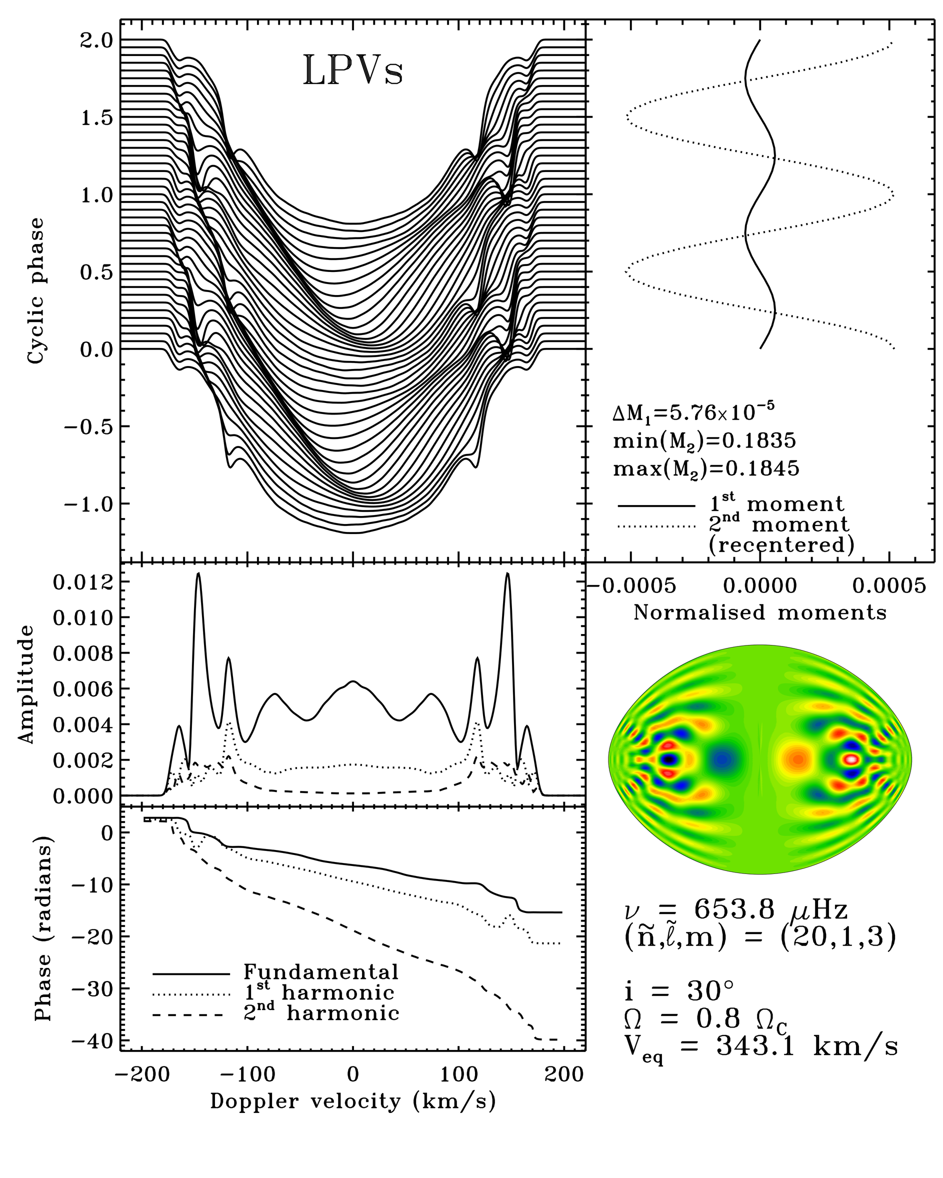




Line profile variations (LPVs)

- **How does it work?** The velocity field of a pulsation modes induces Doppler shifts which cause periodic variations in spectroscopic line profiles. These LPVs can be observed through a time series of spectroscopic observations, then used to constrain the surface geometry of the underlying mode.
- **An example:** The plots to the left show the Doppler shift from an island mode and the limb darkening as a function of position on the stellar disk, the angle between the rotation axis and line-of-sight being $i = 30°$. The plots to the right show the LPVs, associated harmonic decompositions including amplitude and phase (Schrijvers et al. 1997), moments (Aerts et al. 1992), and the mode's cross-section.





Perspectives

The next steps include implementing non-adiabatic effects in theoretical amplitude ratios and LPVs (Dupret et al. 2003) and interpreting existing and future observations, based on these results. This could then lead to a breakthrough in understanding the pulsation spectra of rapidly rotating stars.

References

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