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A SEISMIC STUDY OF β PICTORIS

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Abstract. The planet-host star β Pictoris has been observed with multiple ground and space-based instruments, especially at the time of the expected transit of the planet's Hill sphere. This has led to a set of pulsation modes detected in up to 5 photometric bands. Using the multi-colour mode amplitudes, we apply a mode identification technique based on a set of $1.8\,\mathrm{M}_\odot$ rapidly rotating stellar models based on the Self-Consistent Field method. We find various solutions and sets of identifications, including near equator-on solutions, as what is expected based on the inclination of the circumstellar disk and planetary orbit. Nonetheless, large discrepancies remain between the observed values of the pulsation frequencies and amplitudes, and the theoretically predicted ones, thus pointing to limitations in the modelling.

Keywords: stars: individual: β Pictoris, stars: oscillations, stars: rotation, stars: interiors

1 Observations

The discovery of an exoplanet orbiting β Pictoris (Lagrange et al. 2010) has sparked considerable interest in this stellar system. Accordingly, this star has been observed by multiple instruments, especially at the time of the expected transit of the planet's Hill sphere thus leading to the detection of 15 pulsation modes in 2 to 5 photometric bands in the frequency range 34 to 55 c/d. Furthermore, this star is rapidly rotating as indicated by its v sin i value of $124 \pm 3\,\mathrm{km\ s}^{-1}$ (Koen et al. 2003), thus pointing to the need to fully include the effects of rotation prior to seismic interpretation.

2 Seismic interpretation

In order to interpret the pulsations of β Pictoris, we applied an MCMC procedure based on the EMCEE package (Foreman-Mackey et al. 2013) in order to fit the pulsation frequencies, amplitude ratios, and a set of classic constraints including the v sin i value, the mass, and the radius. Three free parameters were used in the fitting procedure: the inclination, the rotation rate, and a frequency scale factor (which corresponds to a homologous transformation of the model). The relevant pulsation frequencies and amplitude ratios were obtained by interpolation in a grid of δ Scuti $\ell \leq 3$ pulsation modes obtained for a sequence of $1.8\,\mathrm{M}_\odot$ models based on the Self-Consistent Field method (Jackson et al. 2005; MacGregor et al. 2007) with rotation rates ranging from 0 to 60 % of the critical rotation rate. Pseudo non-adiabatic mode visibilities were derived for inclinations ranging from 0° to 90° using the method described in Reese et al. (2013) and Reese et al. (2017). Instead of using the observational error bars on the frequencies, an adjustable frequency tolerance was used as a trade-off parameter between fitting the pulsation spectrum and fitting the amplitude ratios.

Figure 1 shows scatter plots and histograms of the MCMC solutions in parameter space using only even modes (as expected if the star is close to equator-on in alignment with the planet orbit and circumstellar disk) and a uniform frequency tolerance of 0.1 c/d. The different hatched and coloured regions correspond to solutions with distinct sets of mode identifications. Although the MCMC procedure finds plausible solutions including near-equator ones, discrepancies remain between the observed and theoretical pulsation frequencies and amplitude ratios. Possible ways to improve the agreement include applying full non-adiabatic calculations using ESTER models (Rieutord et al. 2016) and using larger sets of modes, i.e. with $\ell > 3$. A more detailed description of the observations, time series analysis, and seismic study is provided in Zwintz et al. (2019).

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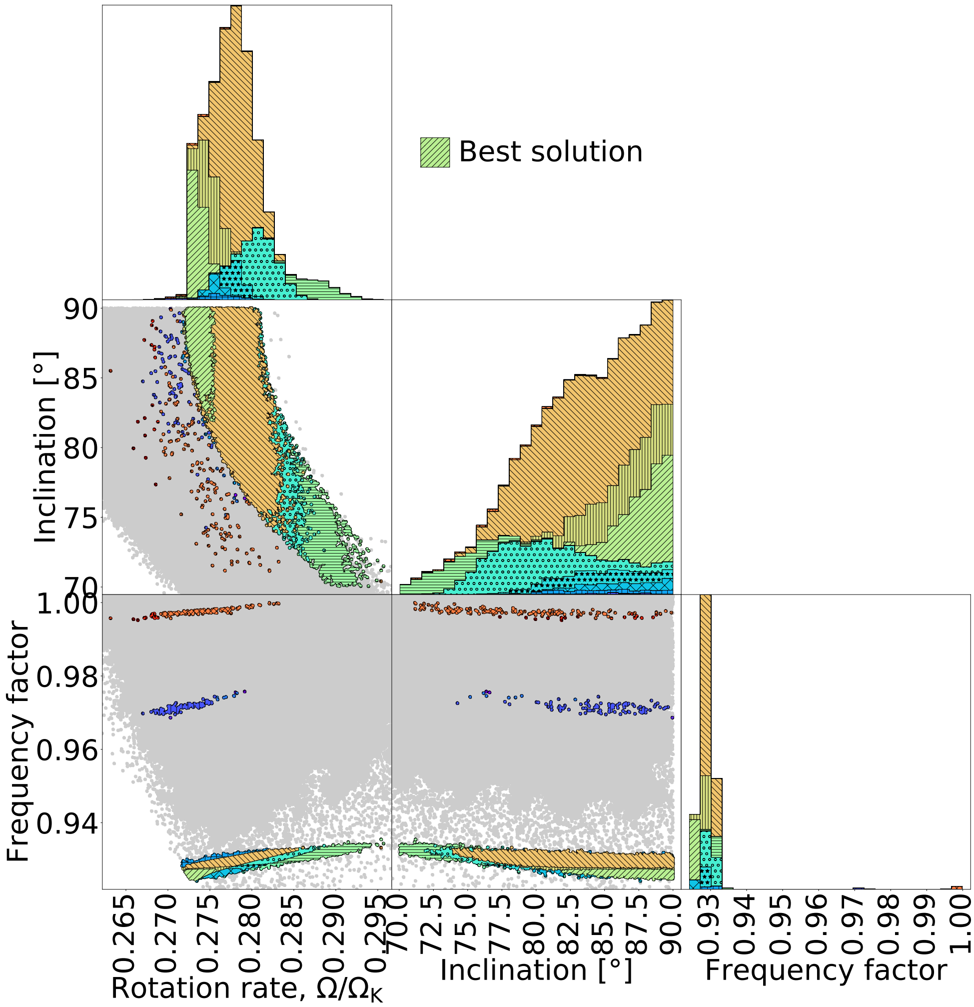

Fig. 1. Scatter plots and histograms depicting the MCMC solutions in parameter space using only even modes and a uniform error tolerance of 0.1 c/d on the frequencies.

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References

Foreman-Mackey, D., Hogg, D. W., Lang, D., & Goodman, J. 2013, PASP, 125, 306

Jackson, S., MacGregor, K. B., & Skumanich, A. 2005, ApJS, 156, 245

Koen, C., Balona, L. A., Khadaroo, K., et al. 2003, MNRAS, 344, 1250

Lagrange, A. M., Bonnefoy, M., Chauvin, G., et al. 2010, Science, 329, 57

MacGregor, K. B., Jackson, S., Skumanich, A., & Metcalfe, T. S. 2007, ApJ, 663, 560

Reese, D. R., Lignières, F., Ballot, J., et al. 2017, å, 601, A130

Reese, D. R., Prat, V., Barban, C., van 't Veer-Menneret, C., & MacGregor, K. B. 2013, å, 550, A77

Rieutord, M., Espinosa Lara, F., & Putigny, B. 2016, Journal of Computational Physics, 318, 277

Zwintz, K., Reese, D. R., Neiner, C., et al. 2019, A&A, 627, A28