Disentangling exoplanet transits with NestAR

Ajinkya J. Naik[1] , Will Handley[2]

1. Inter-University Centre for Astronomy & Astrophysics, Pune, India
2. Institute of Astronomy, University of Cambridge, Cambridge, UK

Introduction

1. Stellar variability is a rich source of astrophysical information for stellar physicists. However, in the context of exoplanet detection, it is a challenging noise source.

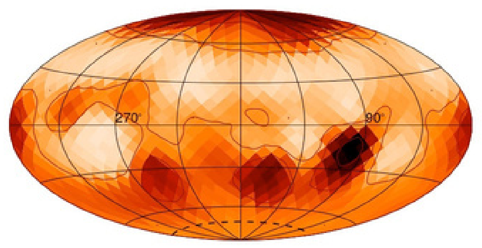

Figure 1: Starspots map of zeta Andromedae. Image credit: Rachael Roettenbacher

2. Starpots, differential rotation, and magnetic activity can induce quasi-periodic variability in photometric light curves which is hard to model analytically.

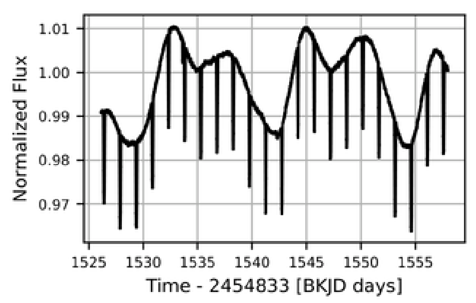

Figure 2: Kepler 17 light curve showing spot-modulation due to stellar activity and transit signal from Kepler 17-b.

3. Periodic dips from the exoplanet transits must be disentangled from a correlated, non-white noise background for preliminary detection (See Fig 2).

4. *NestAR* aims to address this problem by modelling the correlated variability statistically using autoregressive models chosen by nested sampling.

NestAR

(ARIMA x Nested Sampling)

- ARIMA (Autoregressive Integrated Moving Average) framework can model time-correlated stellar variability, but selecting the optimal model order (p,d,q) is often challenging.
- Bayesian inference enables parameter estimation and model selection through the Bayesian evidence (Z), which is efficiently evaluated using **nested sampling**.

$$\hat{y}_t = c + \sum_{a=1}^{p} \phi_a y_{t-a} + \sum_{m=1}^{q} \theta_m \epsilon_{t-m} + \epsilon_t$$

$$P(\theta|D;\mathcal{M}) = \frac{P(D|\theta;\mathcal{M})P(\theta|\mathcal{M})}{P(D|\mathcal{M})} = \frac{\mathcal{L}(D|\theta)\pi(\theta)}{Z}$$

NestAR: GPU-accelerated nested sampling and ARIMA to simultaneously identify the preferred ARIMA model and infer its parameters from the data.

Results

1. NestAR picked ARIMA (1,1,5) as the model with highest log evidence.

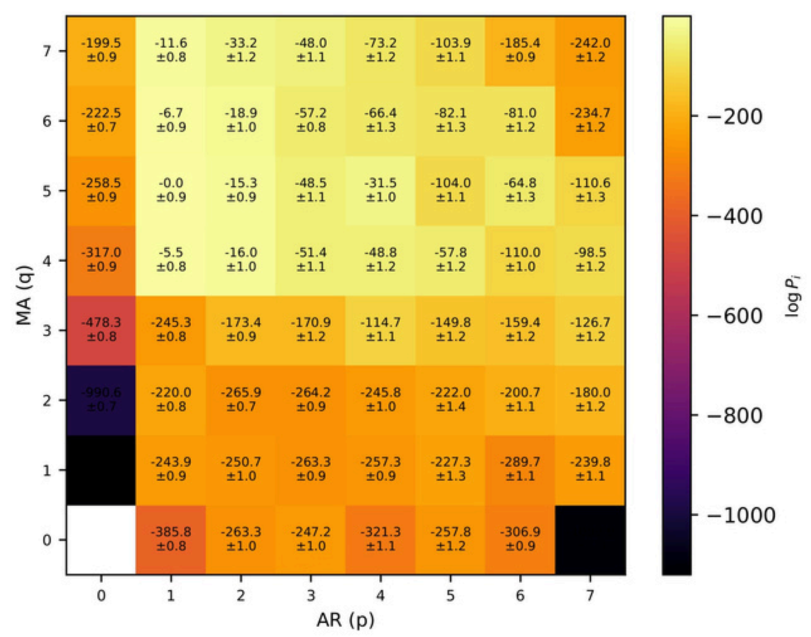

Figure 3: Heatmap of log evidences evaluated on a grid of ARMA models for Kepler 17 light curve data (Fig. 2) with first order differencing (d=1).

2. The model captures the stellar variability well but the residual time series still depicts a periodic structure corresponding to the transits of Kepler 17-b.

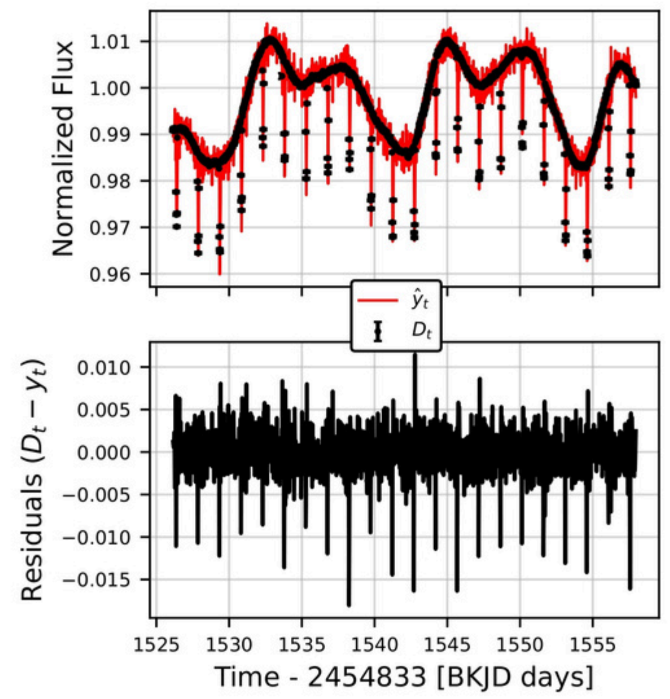

Figure 4: Results of ARIMA (1,1,5) fit (red) to the data (in black). Bottom panel shows the corresponding residual time series.

3. Light curve periodogram shows multiple peaks at low frequncies due to stellar activity, and another peak at 0.67/day due to transit period. These low frequency peaks are relatively suppressed in the residual periodograms, and the transit-period peak emerges with highest power.

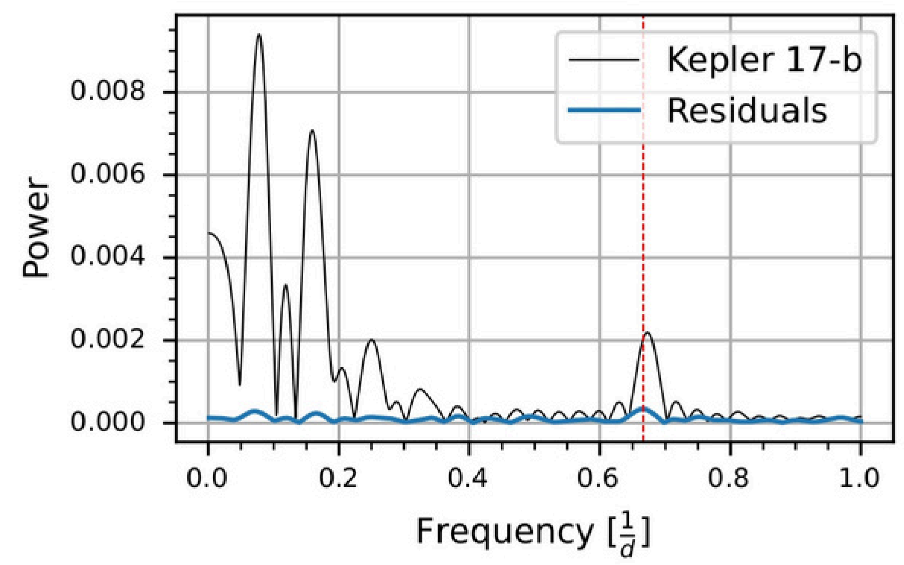

Figure 5: Lomb-Scargle periodogram of the light curve data (in black) and the residual time series (in blue).

Conclusion

- Our results show that even though we have not masked the transits during the fit, the ARIMA model comparison and fit is not completely biased by the transits.
- The framework can thus be applied to many transiting exoplanet systems with highly active host stars.
- Future work can improve this framework by masking the transits or using seasonal ARIMA (SARIMA) to model them if transit period is known.
- This preservation of the unmasked transient features within the residuals could be applied in Bayesian anomaly detection for other time-series datasets in astronomy.

References

1. Naik, A., & Handley, W. (2025). Nested Sampling for ARIMA Model Selection in Astronomical Time-Series Analysis. *arXiv preprint* arXiv:2512.01929 (submitted to MNRAS). https://doi.org/10.48550/arXiv.2512.01929
2. Yallup, D., Kroupa, N., & Handley, W. (2026). Nested Slice Sampling: Vectorized Nested Sampling for GPU-Accelerated Inference. arXiv preprint arXiv:2601.23252. https://doi.org/10.48550/arXiv.2601.23252
3. Frédéric Pont, Shay Zucker, Didier Queloz, The effect of red noise on planetary transit detection, Monthly Notices of the Royal Astronomical Society, Volume 373, Issue 1, 21 November 2006, Pages 231–242, https://doi.org/10.1111/j.1365-2966.2006.11012.x

najinkya1313@gmail.com