A novel perspective of deciphering p-mode oscillation – the autocovariance domain

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We propose studying the stochastic behaviour of p-mode oscillations in the autocovariance domain to reveal asteroseismology information not apparently available in the time domain, in an effort to model and predict the oscillation radial velocity (RV) for future EPRV observations.

Background

P-mode oscillations are acoustic mode oscillations stochastically driven and damped by convection near the stellar surface. The induced RV is neither deterministic (due to its stochastic nature) or totally unpredictable. Solar p-modes, for example, have a lifetime between 2 and 4 days. The solar p-mode oscillation (both RVs and photometry) also show a higher correlation at 4 hours.

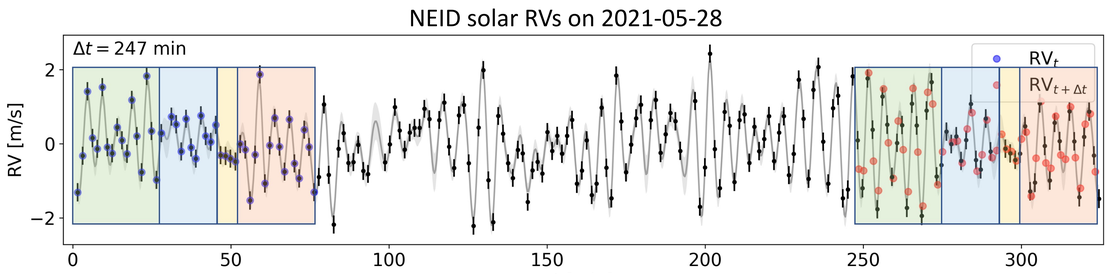

Figure 1: The RVs tend to be highly correlated every 4 hours (corresponding to the beat frequency of two neighbouring oscillation modes). The 4 coloured sections are used to guide the eyes to compare the RVs at Δ*t* = 247 minutes apart.

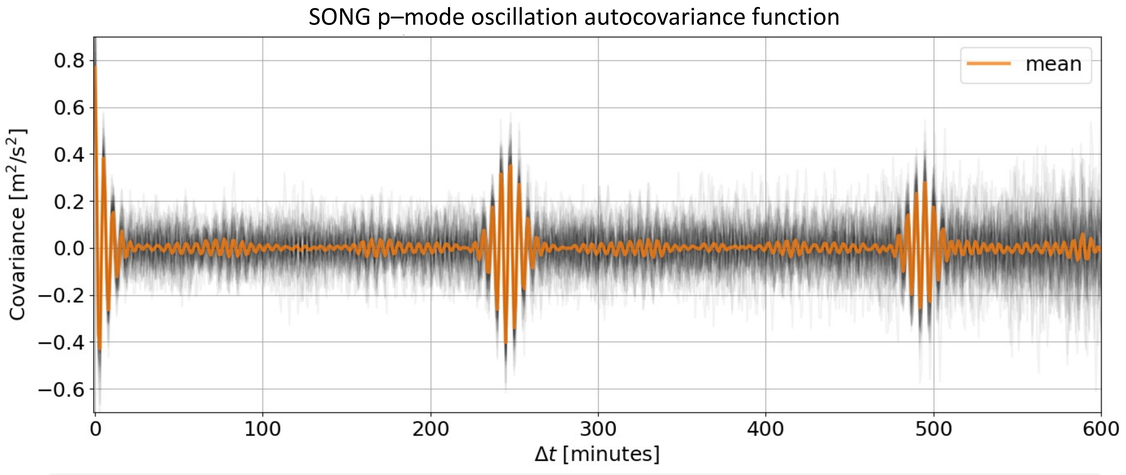

Figure 2: The autocovariance function of ~2 months SONG solar oscillation RVs (Fredslund Andersen et al. 2019). The autocovariance function of RVs per day is in the grey background. Overall, the covariance at ~4 hours is similar to that at 1 oscillation cycle, indicating we are capable of predicting solar oscillation RVs 4 hours away as much as for those 5 minutes away!

Questions and ideas

- Can we model and predict the p-mode oscillation RVs? To what extent, if not totally, are p-mode oscillation RVs predictable?
- How accurate can we determine the asteroseismology parameters ($\nu_{\max}$, $\Delta\nu$, quality factor *Q*, …) using time domain analysis? How does switching to the autocovariance domain help?
- To be explored – Could additional information, e.g. photometry data, help constrain the RVs, maybe something analogous to the FF' method (Aigrain et al. 2012)?

Gaussian process (GP) model with train-test-split in the time domain

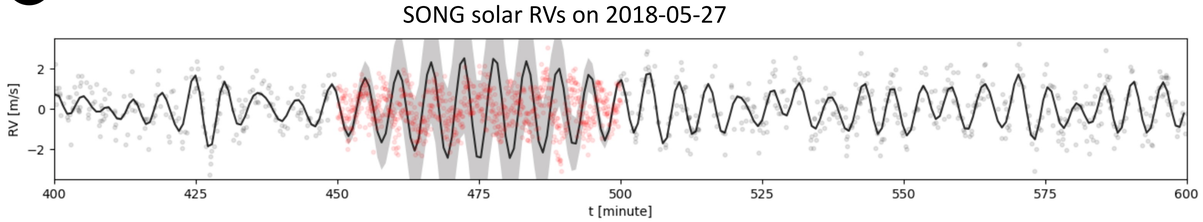

Figure 3: We model 12 hours of SONG solar RVs (grey dots, only showing a 200-minutes session) using a GP model with a series of stochastically damped harmonic oscillation kernels, similar to the work of Foreman-Mackey et al. 2017 but with the *tinygp* toolkit. The GP model (black lines) fails to recover the 50-minutes testing RVs in the middle of the day (red dots). The GP model also struggles to converge due to a large number of oscillation modes.

An autocovariance domain perspective

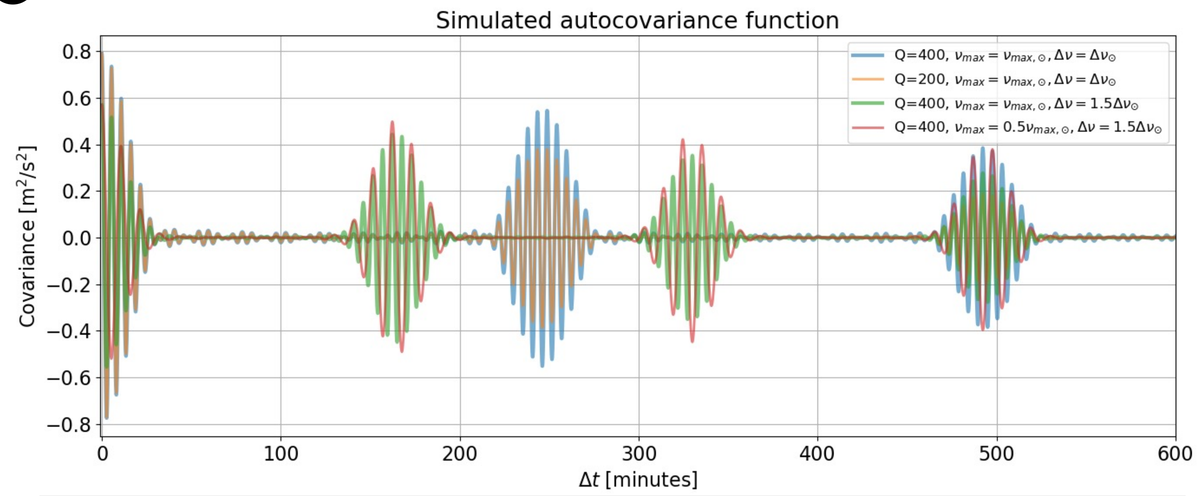

Figure 4: Simulation of autocovariance functions based on asteroseismology parameters of the Sun. The difference in the parameters (e.g., $\nu_{\max}$, $\Delta\nu$, *Q*) is captured easily in the autocovariance domain, which can be a challenge in the time domain (Figure 3). Therefore, the autocovariance function would benefit probing p-mode oscillation parameters not easily recovered in the time domain analysis.