RVxTESS I: Modeling Asteroseismic Signals with Simultaneous Photometry and RVs

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Introduction

- The **Radial Velocity (RV)** method, measuring the Doppler Shifts from stellar spectra, is widely used for the detection and characterization of exoplanets. For Earth analogs, RV detection typically requires cm/s precision, whereas the stellar jitter becomes an issue at the m/s level.
- **Stellar jitter**, including magnetic and asteroseismic signals, refers to the stellar atmospheric variations that introduces noise to the RV measurements.

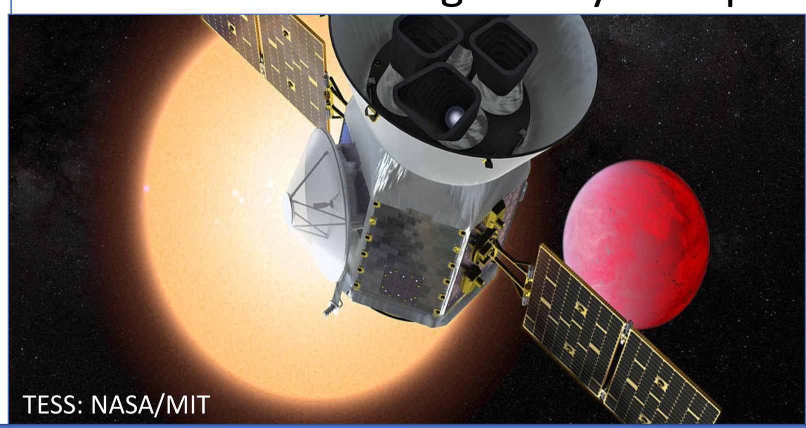
Objectives

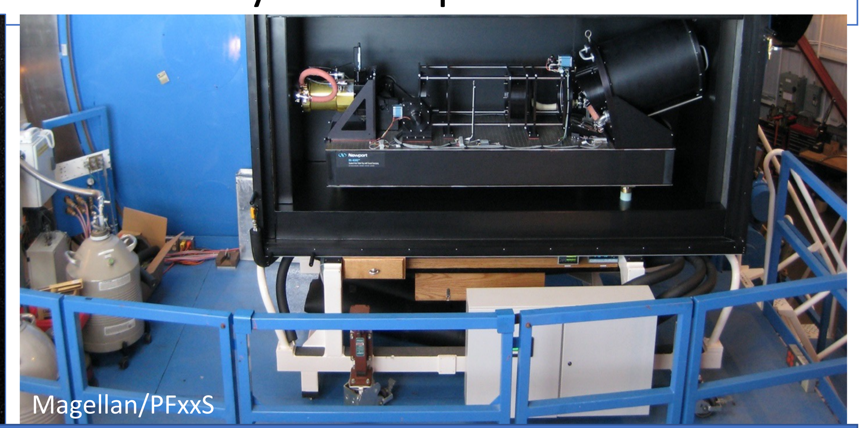
Use **Gaussian Process (GP)** to fit the photometric and RV signals of stellar jitter for the star HD 5562 ($M_\star$ = 0.93$M_\odot$, $R_\star$ = 2.8$R_\odot$ $L_\star$ = 2.3$L_\odot$, V = 7.16, $log(g)$ = 3.5). Particularly, we target at the asteroseismic signal in this project and plan to obtain a model to describe the stellar oscillation.

As the the photometric and RV signal for the same star are consistent in timescale and amplitude, our ultimate goal is to model the stellar jitter for both photometric and RV data, to eventually find a method to break the detection floor and tease out the jitter during observation of exoplanet.

Methods

- Data: From the Transiting Exoplanet Survey Satellite (**TESS**) and the Carnegie Planet Finder Spectrograph on the Magellan II Telescope (**Magellan/PFS**). PFS is a high-resolution optical spectrograph. It is unique and crucial because of its southern location and Magellan's large aperture.
- Fitting method: **GP** is a model capable of describing correlated stochastic signals. In GP, any finite set of variables encompasses a multivariate Gaussian distribution.
- Celerite: a library of fast and scalable GP regression in 1D (Foreman-Mackey et al., 2017). It models the stellar jitter as stochastically driven simple harmonic oscillators (SHOs). Celetite allows us to evaluate the probability of the observed time series using a GP where the power spectral density (PSD) is a sum of terms given by an equation with only limited parameters.



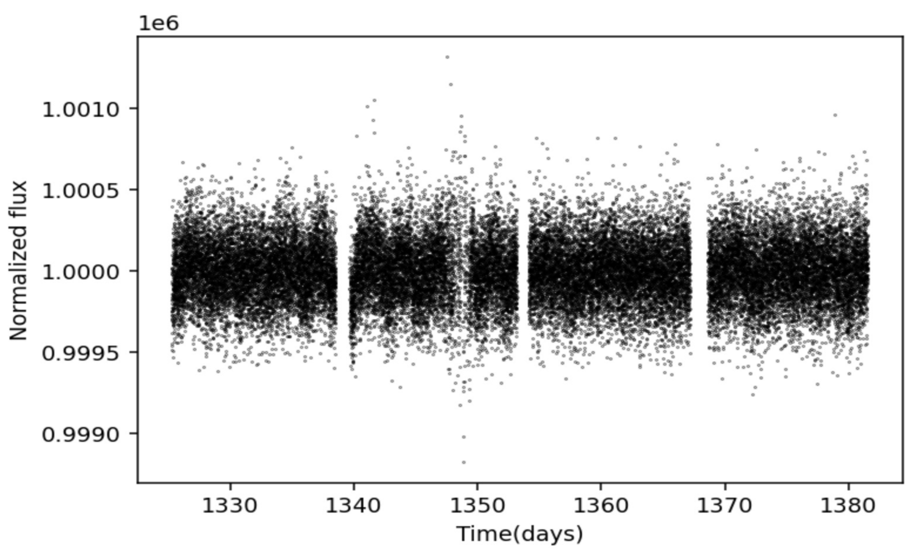


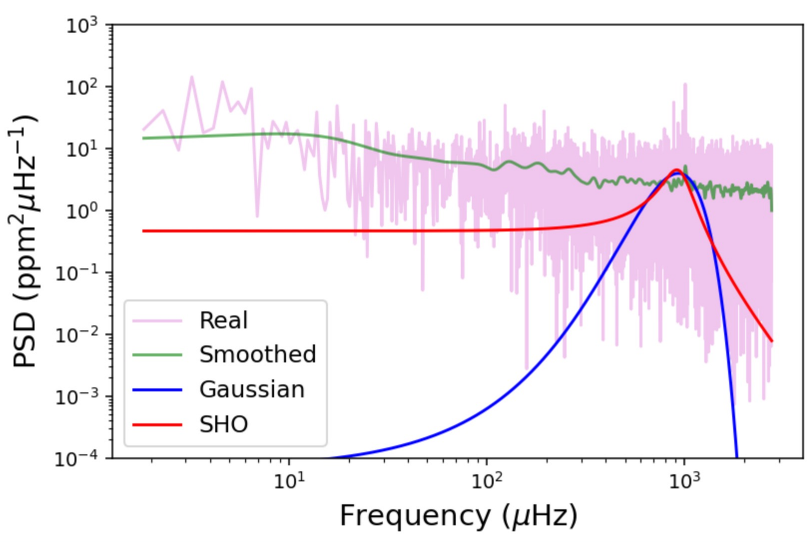
Analyses

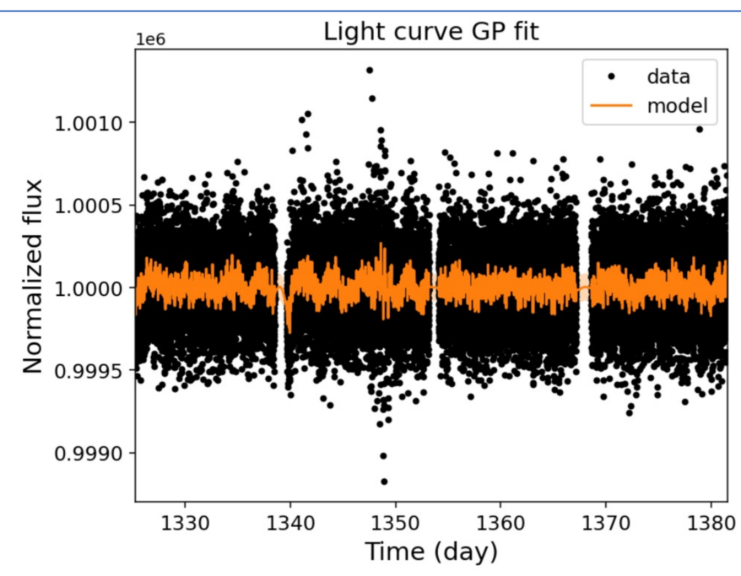
The RV signal have much better SNR in stellar oscillation, as the photometric data from TESS 2-minute cadence release do not have significant asteroseismic signals, the stellar oscillation peak is buried in the white noise signal. To reveal the authentic oscillation signal, we started with the traditional Gaussian fit (Kallinger et al. 2014). The FWHM of the Gaussian model is set to be $\nu_{max}/2$ (Campante et al. 2016). We then fit the traditional model with a model of stochastically-driven damped simple harmonic oscillator (SHO), according to dynamics of the asteroseismic signal (Foreman-Mackey et al. 2017).

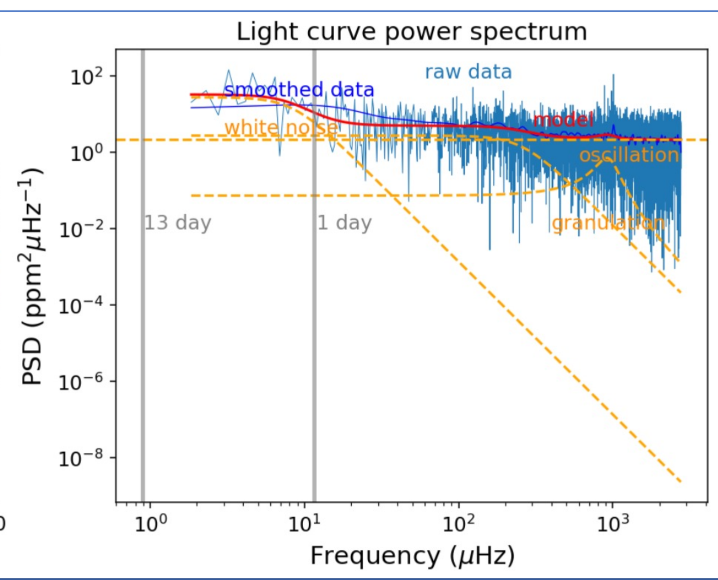
With the help of the two models, we can get more precise priors for GP fit. We apply GP with joint-likelihood on the whole high-cadence data of two different nights separated by over 20 days. The photometric data was initially fitted with un-trained GP, showing significant granulation signal.

We then use GP to model the RV data, utilizing the photometric data's GP parameters as a prior for the RV modeling, which enables us to model granulation and oscillation signals. To assess the effectiveness of photometric model parameters as priors, we conducted tests on two sets of RV data: one with approximately 5 hours of observation each night, and another with only a few data points spanning about 30 minutes each night.



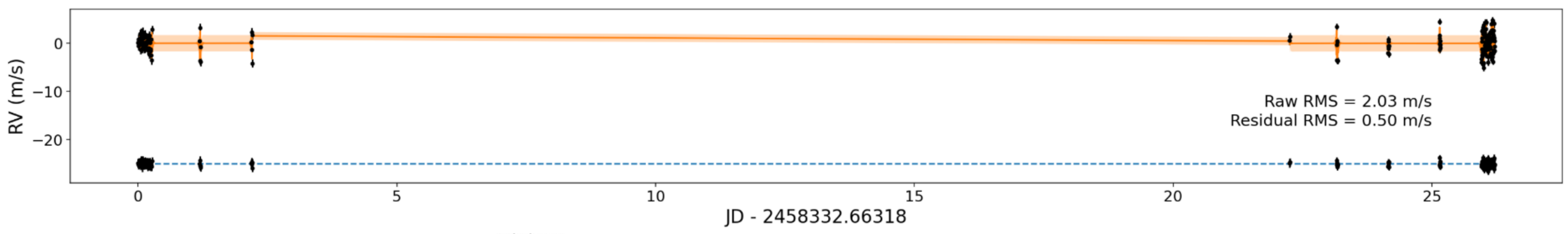


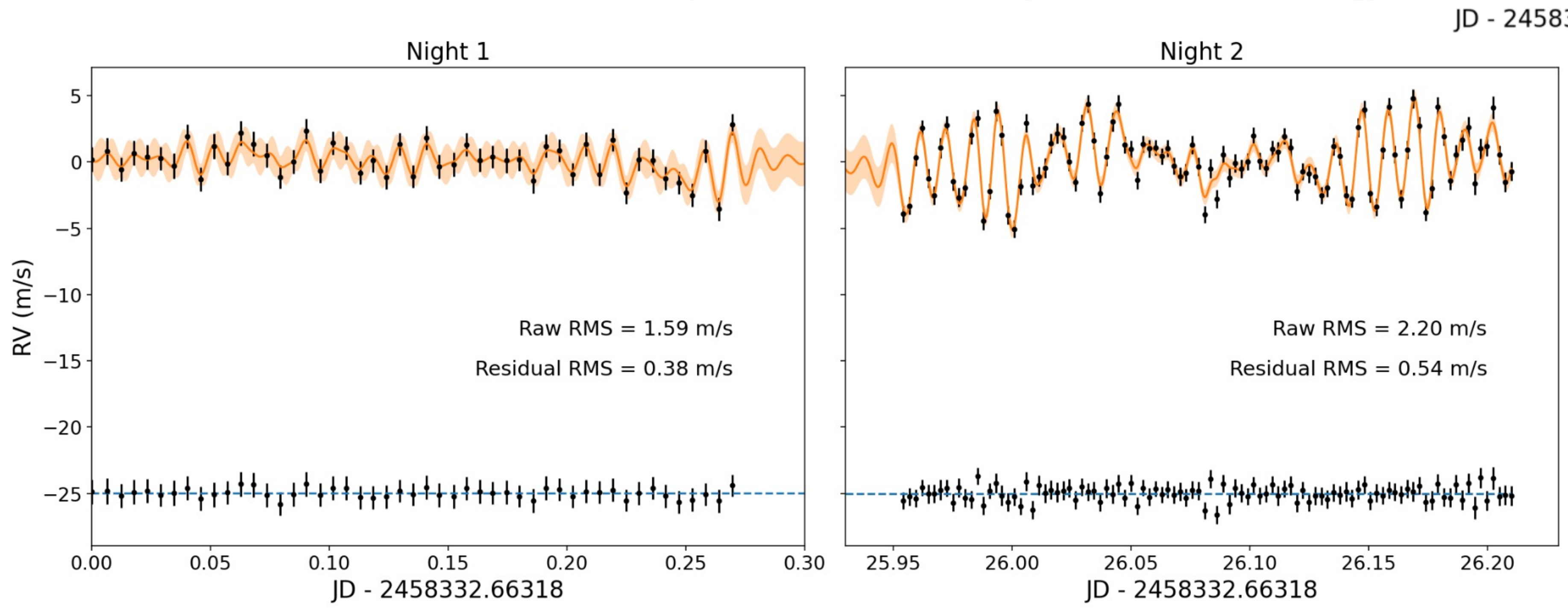


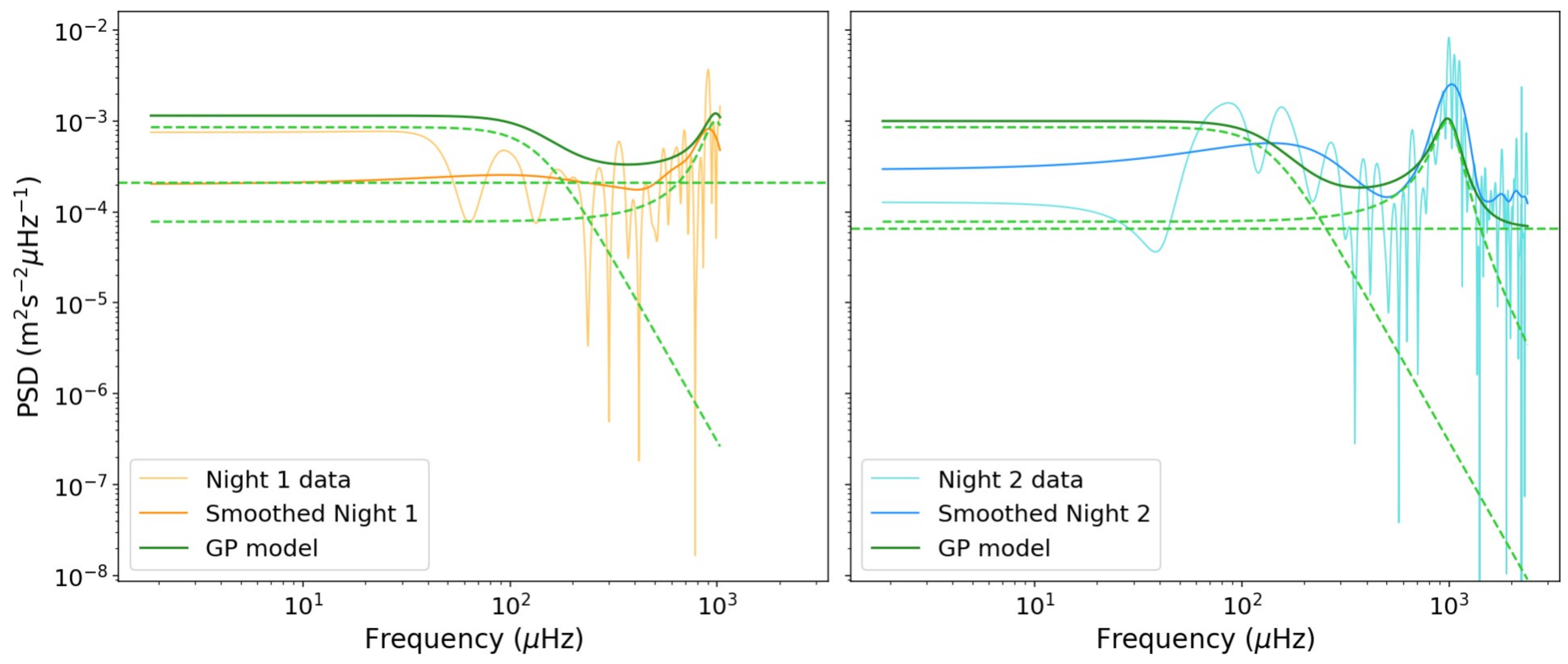


Results

- The RV model shows a strong oscillation signal with characteristic frequency around 15 minutes, shorter than the previous prediction of 44 minutes (Kjeldsen et al., 2011) derived from its mass and luminosity.
- We have reduced the RV scatter from 2.26 m/s to 0.40 m/s.
- Granulation is not significant in RV signal but is rather distinct in photometric data. We also explore multiple ways to model the oscillation in the photometry.
- With the prior from photometric data modeling, we were able to effectively minimize the RV scatter by accurately modeling granulation and oscillation amplitudes, as well as peak frequencies. While fitting RV data alone may suffice for GP analysis, incorporating light curve data allows for a more precise and realistic model of RV.







Future work

(1) Compare different methods of reducing the stellar jitter signal to quest a effective algorithm for low-mass planet detection
(2) Test the long-term behavior of the GP model over multiple mode life times
(3) Do a simulation for applying the model in exoplanet detections to help in planet detection and characterization

For more information, please visit our website: **RVxTESS.com**

Reference

Foreman-Mackey, et al. 2017, The Astro-nomical Journal, doi:10.3847/1538-3881/aa9332
Kjeldsen, H., et al. 2011, Astronomy Astrophysics, doi:10.1051/0004-6361/201116789
Campante, T. L., et al. 2016, The Astrophysical Journal, doi: 10.3847/0004-637x/830/2/138
Kallinger, T., et al. 2014, Astronomy &amp Astrophysics, doi: 10.1051/0004-6361/201424313