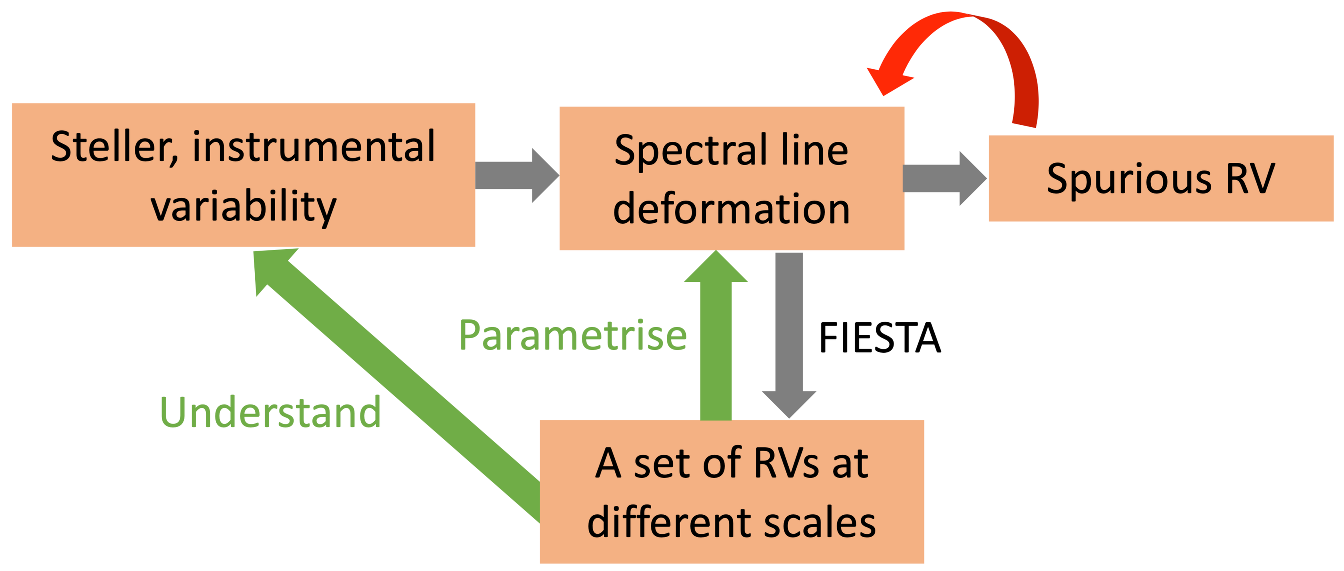
Parametrising and modelling stellar variability in the study of the “Sun-as-a-Star”

PennState

Jinglin Zhao jzhao@psu.edu, Eric Ford, Ashley Villar – Department of Astronomy & Astrophysics, Pennsylvania State University

Motivation

Intrinsic stellar variability (e.g., dark spots and bright faculae) and instrumental instability deform stellar spectral lines and induce an apparent, spurious radial velocity (RV). In order to disentangle the planetary Doppler RVs from stellar and instrumental effects, we develop and apply FIESTA (Zhao et al., 2022) on the spectral cross-correlation function (CCF). We use a set of RVs (corresponding to various length scales) to quantify the spectral line deformation.



FIESTA RVs

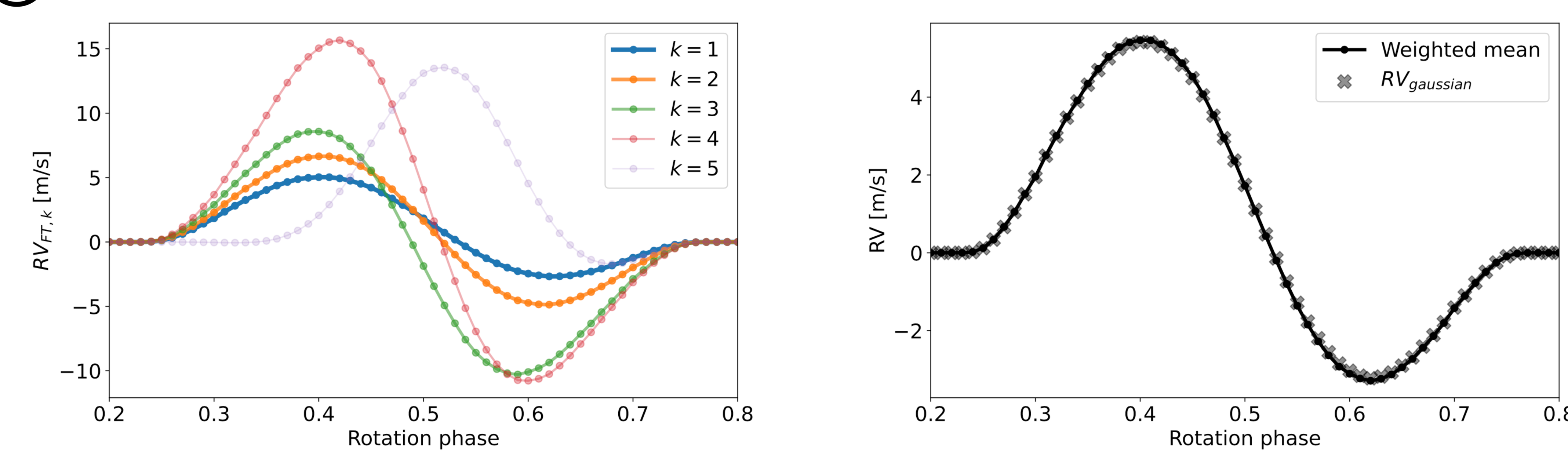


Figure 1: In the presence of stellar variability, individual Fourier modes $RV_{FT,k}$ have different RV shifts. In contrast, a radial velocity shift due to orbiting planets would only result in the same RV shifts for all the Fourier modes. The weighted average of Fourier RV shifts is equal to (i.e., degenerate into) the single apparent RV shifts $RV_{gaussian}$.

HD 26965

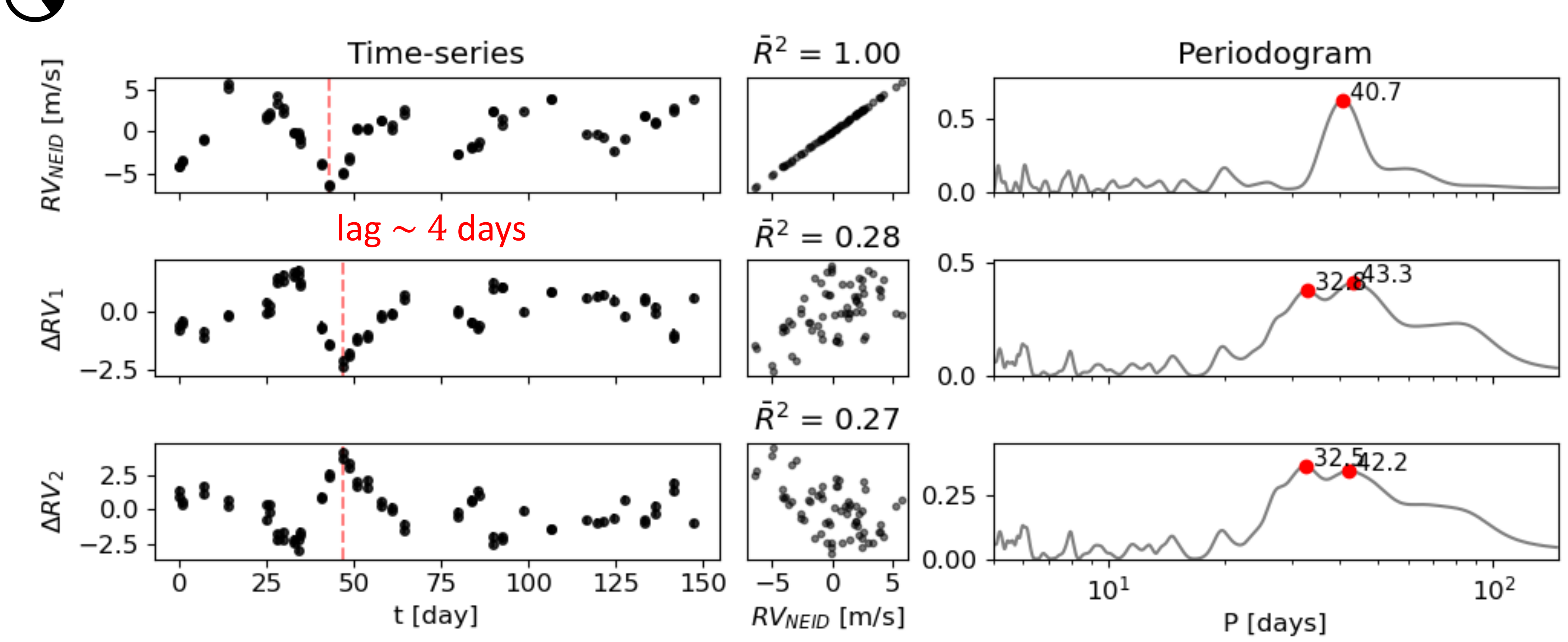


Figure 2: We define $\Delta RV_k = RV_{FT,k} - RV_{gaussian}$, so that the planetary Doppler RVs are cancelled out and ΔRV_k is only sensitive to spectral line variability. For HD 26965, ΔRV_k strongly detects the rationally induced RV variation and shows a lag of 4 days.

2015-2018 HARPS-N Solar Observations

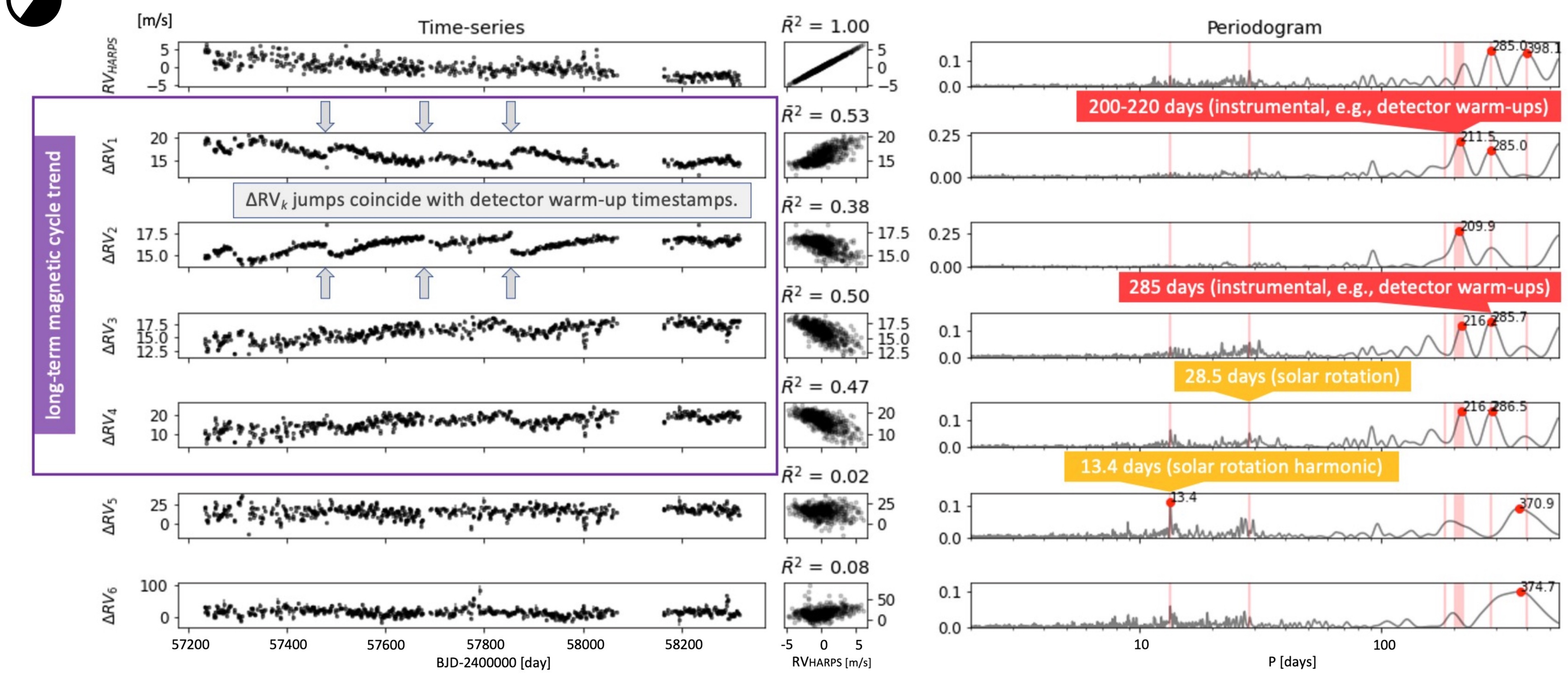


Figure 3: Using principal components of ΔRV_k as features, we model RV_{HARPS} with multiple linear regression (regularisation applied for both the principal components and the lags). We are able to reduce the RMS from 1.89m/s to 0.94 m/s. We also separate the solar rotationally induced RVs, which accounts for 0.5 m/s or 7% of the total RV variability. The ΔRV_k shows a lag of 3 days behind RV_{HARPS}.

2021 NEID solar observations with planet-injection-recovery test

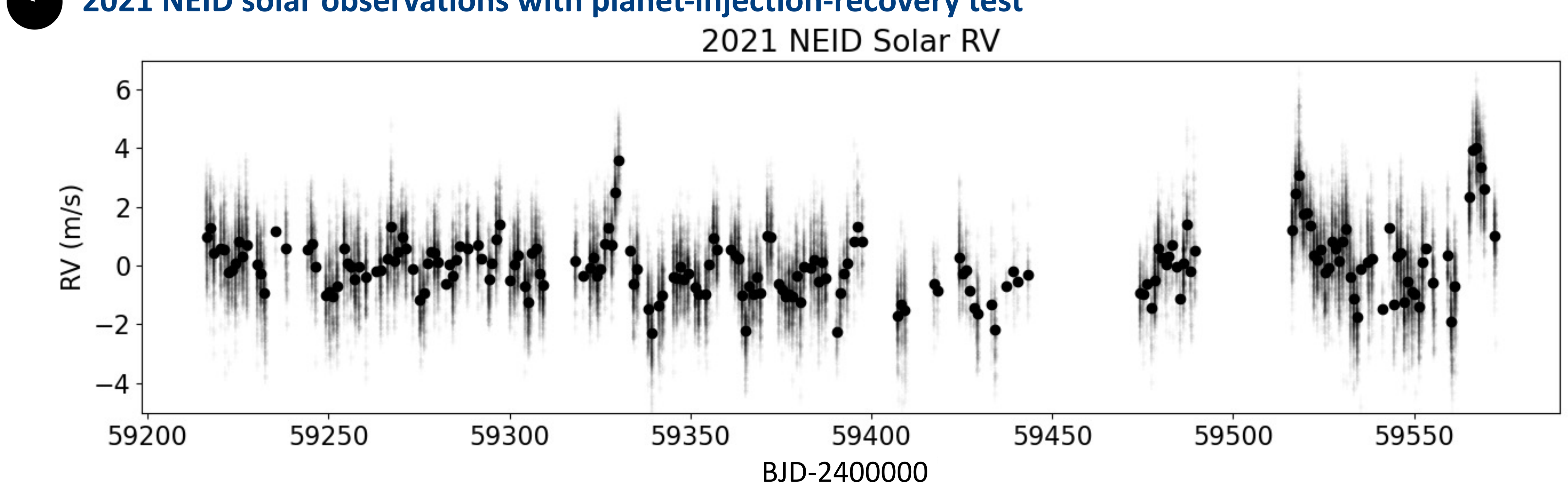


Figure 3: The 2021 NEID solar observations has a smaller daily binned RMS at 1.10 m/s.

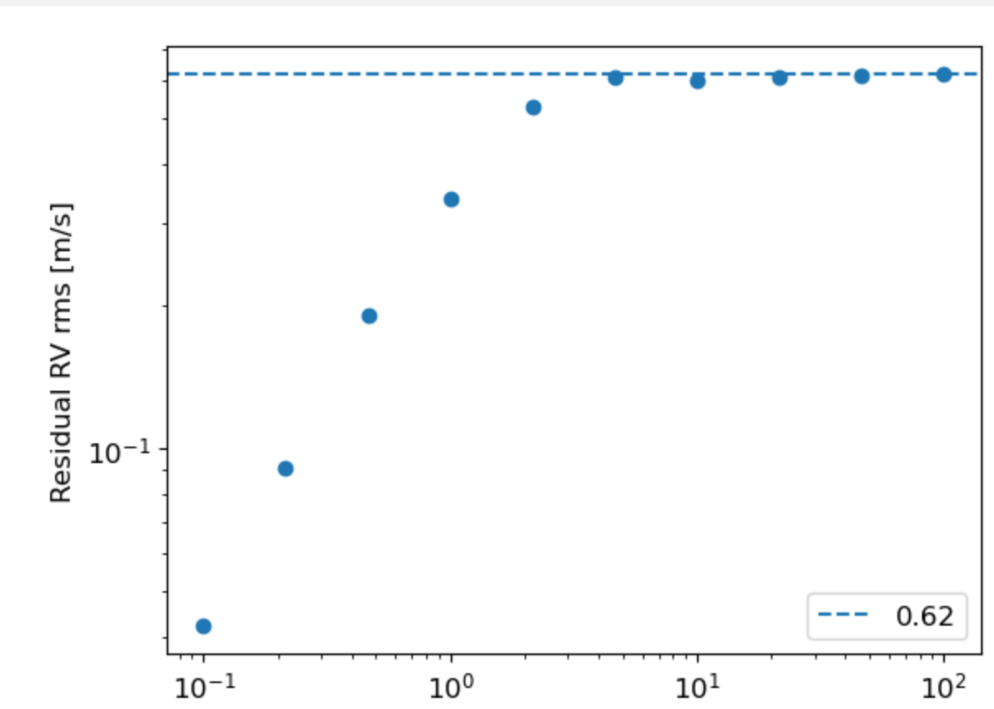


Figure 4: In the planet-injection-recovery test, we use $RV_{FT,k}$ as features to train a model to predict an injected Doppler RV. For a 1 m/s Doppler RV, we can recover the injected signal with < 0.3 m/s residual RMS. The residual RMS increases with the injected Doppler RV but reaches a threshold of 0.6 m/s.