National Aeronautics and Space Administration

FY23 Topic Areas Research and Technology Development (TRTD)

The Sun as a star: exploring stellar activity with NASA's flagship Doppler RV instrument

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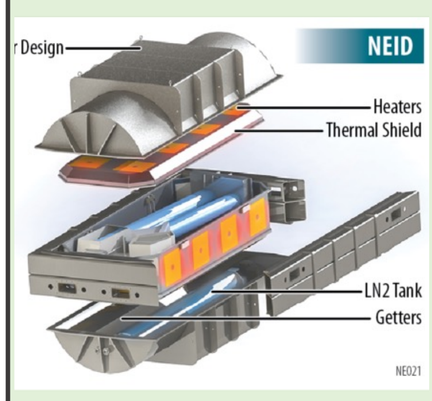
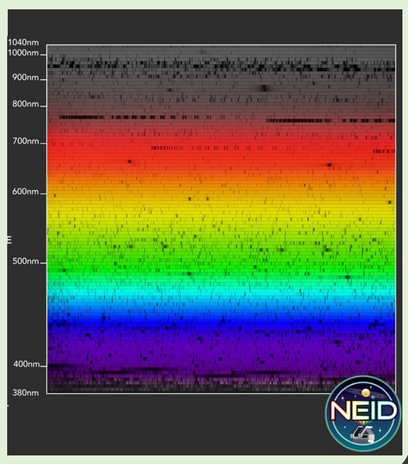
Strategic Focus Area: Extra-solar planets and star and planetary formation

Objectives

We aim to **improve our understanding of the effects of stellar magnetic activity on high precision radial velocity (RV) measurements** For FY23 specifically, we aimed to 1) better characterize the activity signatures in the Sun and other active stars, as seen by ground-based spectra collected from the NEID precision RV instrument, 2) develop an automated pipeline for analysis of disc-resolved Solar images from SDO/HMI, and 3) derive new metrics for characterizing activity using line-by-line radial velocity measurements.





Background

RV measurements play a central role in exoplanet discovery. By measuring the minute spectral Doppler shifts in stellar spectra induced by orbiting planets, the RV technique had led to hundreds of planet detections in the past 30 years. **Critically, RVs provide precise planetary mass estimates** that are otherwise unattainable with other detection techniques (e.g. transit photometry). While highly successful, the RV field has **hit a precision floor of ~1 m/s**. This precision **prohibits the detection of Earth-like planets** orbiting Sun-like stars, **which imprint a mere ~10 cm/s Doppler signature** on their host stars.

With instrumentation improving, **the dominant source of noise is now the stars** themselves. Magnetic activity adds structured noise to RVs, and must be modelled and removed to push below the ~1 m/s barrier.

Line-by-line studies of high resolution spectra

We used a combination of data from the recently-commissioned NEID RV spectrometer and a suite of images from SDO/HMI to better understand the relationship between magnetic activity and disc-integrated stellar radial velocity in the Sun. We developed several techniques to characterize the spectral signatures of activity, and tie observed variations in the NEID spectra to measured solar variability derived from SDO/HMI images. Together, these tools represent a major step towards enhancing our understanding of stellar activity.

Figure 1: Physically-motived radial velocity model developed using a line-by-line spectral analysis framework. This model uses a relatively simple spot model to fit for activity-induced Doppler signals. Using this technique, we are able to accurately recover the solar activity signal (colored points) observed in the SDO-based measurements (gray).

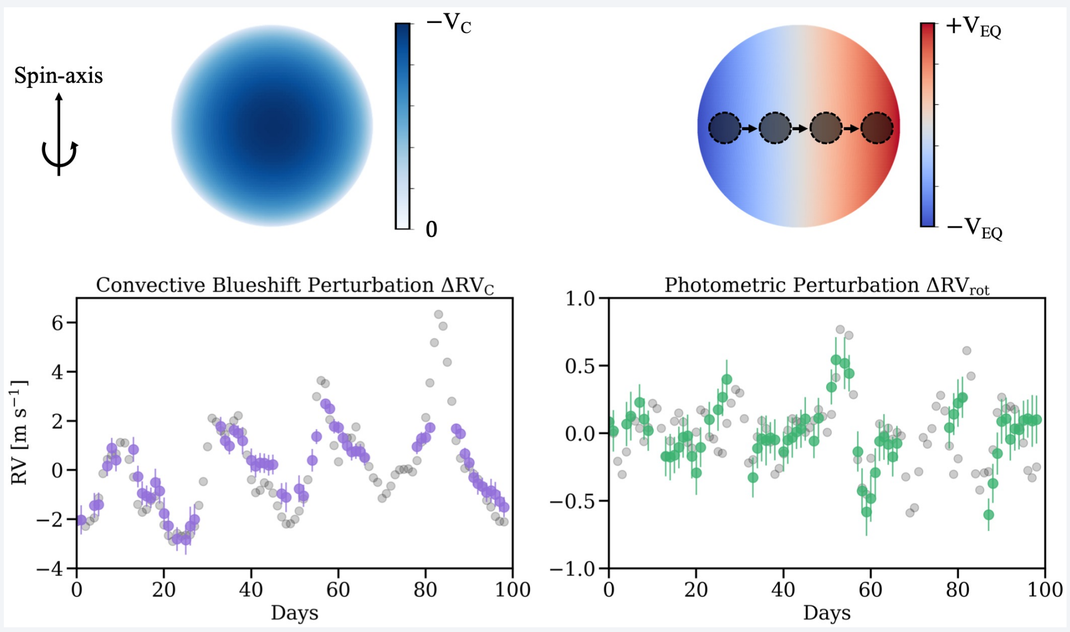
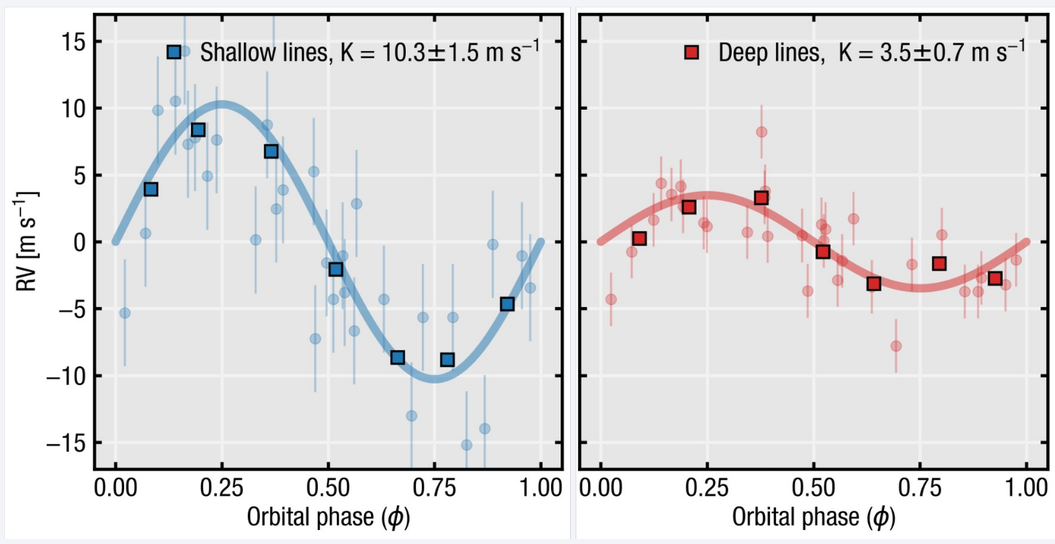


Figure 2: Example application of our line-by-line analysis pipeline, applied to the standard star HD26965. This star has a claimed super-Earth (detected via Doppler measurements), but our analysis shows that the amplitude of the velocity signal varies significantly depending on which spectral features are used, implying the signal is entirely due to activity.



Significance to NASA/JPL

Building off of the innovative platform of NEID, this pathfinder study will influence the development of future EPRV instruments and survey strategies, both of which were highlighted in the recent NASA/NSF EPRV working group report (Crass et al. 2021). **It specifically addresses a NASA technology gap ('Stellar Reflex Motion Sensitivity: Extreme Precision Radial Velocity') and two science gaps** (SCI10: 'Precursor observations of direct imaging targets' and SCI8: 'Mitigating stellar jitter as a limitation to sensitivity of dynamical methods to detect small temperate exoplanets and measure their masses and orbits'). Our deep **exploration of and stellar activity will set the stage for the next generation of EPRV instruments and surveys developed by the community**.

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Publications: Into the Depths: A New Activity Metric for High-precision Radial Velocity Measurements Based on Line Depth Variations. Siegel, J. C., Rubenzahl, R. A., Halverson, S., & Howard, A. W., AJ, 163, 260, 2022.
Leveraging Space-based Data from the Nearest Solar-type Star to Better Understand Stellar Activity Signatures in Radial Velocity Data. Ervin, T., Halverson, S., Burrows, A., Murphy, N., Roy, A., Haywood, R. D., Rescigno, F., Bender, C. F., Lin, A. S. J., Burt, J., & Mahadevan, S., AJ, 163, 272, 2022
The death of Vulcan: NEID reveals the planet candidate orbiting HD 26965 is stellar activity. Burrows, Halverson et al in prep.

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