National Aeronautics and Space Administration

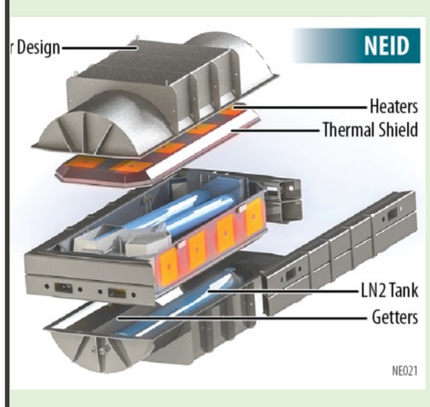
The Sun as a star: exploring stellar activity with NASA's flagship Doppler RV instrument

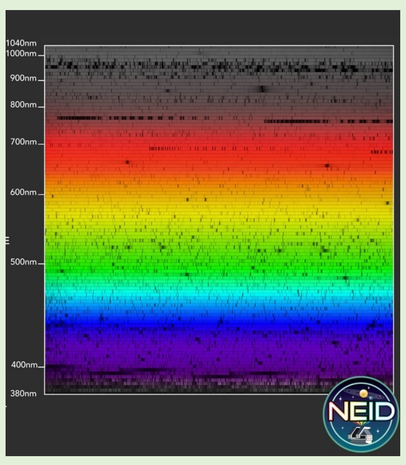
Principal Investigator: Samuel Halverson (383); Co-Investigators: Jennifer Burt (326), Neil Murphy (326), Abby Burrows (Dartmouth College), Tamar Ervin (UC Berkeley), Arpita Roy (Space Telescope Science Institute), Chad Bender (University of Arizona), Jared Siegel (Princeton University)

Program: FY22 R&TD Topics
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 FY22 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.





Line-by-line studies of high resolution spectra

Using data from the NASA/NSF 'NEID' radial velocity facility**, we developed a custom software package that precisely measures individual spectral line radial velocities** and depths. This pipeline leverages significantly more information than standard RV pipelines, which typically measure averaged the velocity of thousands of lines simultaneously. **This yields a powerful diagnostic of activity** (Siegel et al. 2022, Burrows et al in prep.). Figure 1 shows the RV signal of thousands of spectral features (blue points, left) in HD26965, highlighting the trend in RVs as a function of line depth.

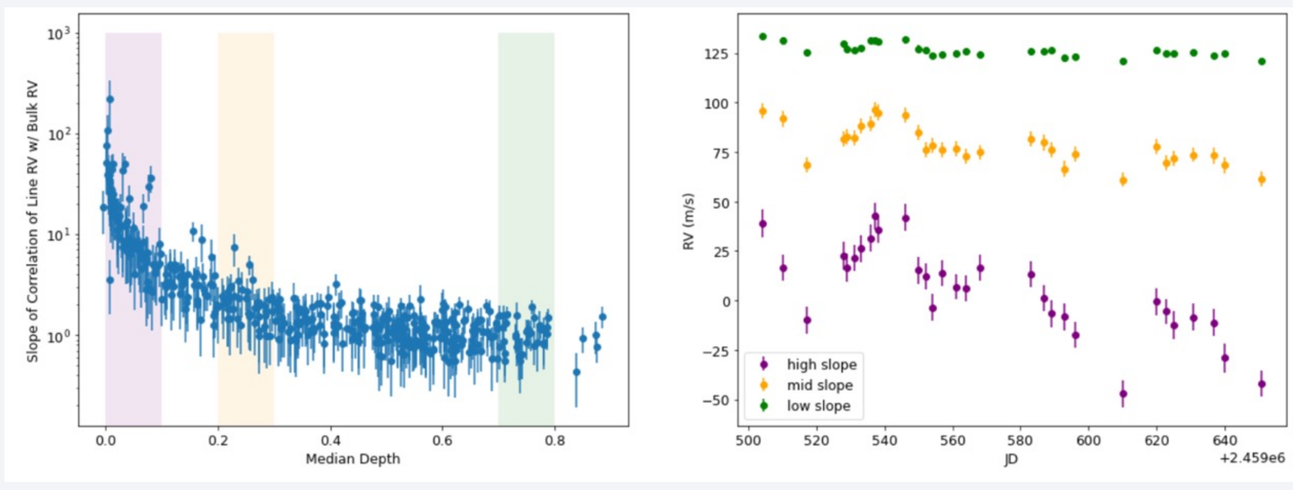


Figure 1: Radial velocity (RV) signal as a function of spectral line depth for known active star HD26965. For Keplerian signals (planets), all spectral lines should have the same radial velocity amplitude. In this case, the measured RV signal varies significantly as a function of line depth, indicative of activity and not an orbiting planet. Shallow lines show significantly higher amplitude than deeper ones, implying the observed RVs are dominated by convective blueshift suppression.

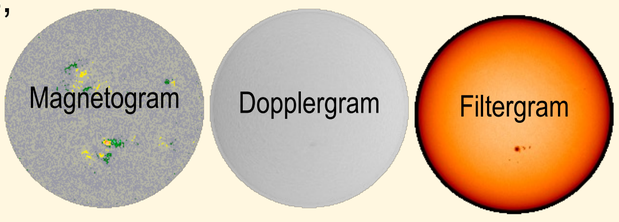
Background

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.

SDO/HMI analysis pipeline

Beyond analysis tools aimed at analyzing ground-based spectra, we have also **developed an independent analysis pipeline** to measure **unsigned magnetic flux**, disc-integrated **solar radial velocity, and spot coverage** Using high spatial resolution Dopplergrams, magnetograms, and continuum filtergrams from the Helioseismic and Magnetic Imager (HMI) aboard the Solar Dynamics Observatory (SDO). This automated pipeline provides a suite of valuable ancillary data products that can be used to better understand the signatures of specific activity phenomena. Comparing these measurements with ground-based RVs from NEID, we find a strong relationship between magnetic activity and RV variation.



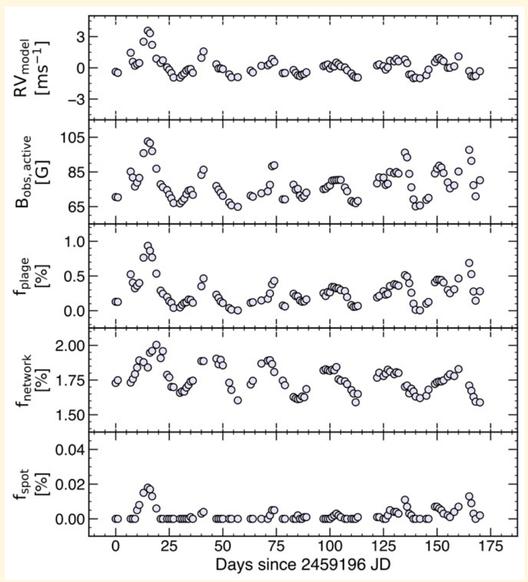


Figure 2. Our SDO analysis pipeline generates a wealth of data products from 2D SDO/HMI images (top row), including disc-integrated radial velocities, unsigned magnetic flux, spot coverage, and more (bottom). These measurements are critical for placing the measured Solar RVs in context, and can be used to understand measured velocities at the line-by-line level.

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Jet Propulsion Laboratory
California Institute of Technology
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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

PI/Task Mgr. Contact Information:
Email: Samuel.Halverson@jpl.nasa.gov