National Aeronautics and Space Administration

Mapping the Evolution of Exoplanets with Precision NIR Radial Velocities

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

Objectives:

Planetary systems around young stars and M-dwarfs offer unique tests of formation, evolution, and habitability models. M-dwarfs provide the best opportunity to find habitable-zone (HZ) planets, due to their low mass, small size, and close-in HZ [1]. Young planets directly test formation and evolution theories, before they transition to their final compositions, radii, and orbits [2]. Measuring the masses of small planets to the precision necessary for atmospheric characterization is difficult [3], particularly for active young stars and M-dwarfs. Stellar activity introduces correlated noise (jitter) that can mask, or masquerade as, a planetary signal. In general, jitter is smaller at longer wavelengths [4; Fig. 1]. This chromatic property of stellar activity is regarded as the key to disentangling stellar and planetary signals, but there does not exist a robust understanding of jitter's dependence on wavelength or stellar properties. To effectively mitigate jitter, we must characterize stellar activity signals across wavelength simultaneously and model the underlying physical mechanisms responsible for the multiple manifestations of jitter. With improved methods to mitigate jitter in hand, it may be possible to precisely measure the masses of young exoplanets, directly determine their formation pathways, and turn them into competitive targets for future atmospheric characterization.

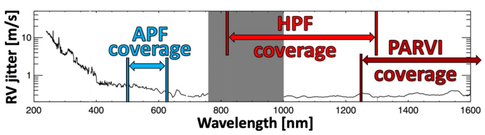

Fig. 1: *RV jitter in the sun [black curve, 7], caused by phenomena such as spots and plages, decreases with wavelength. HPF and PARVI operate in the least active wavelength regime, which is substantially redder than traditional RV instruments like the APF. This makes them especially well-suited to measuring RV masses of planets orbiting active young stars and M-dwarfs.*

Approach and Results:

We have undertaken a multi-semester observing campaign to assess the dependence of stellar jitter on wavelength and stellar properties. As it is crucial to have contemporaneous observations across the entire spectrum (VIS-NIR), to carry out this campaign, we are observing with two state-of-the-art precision NIR spectrographs (HPF at McDonald Observatory and PARVI at Palomar) and one precision optical facility (the Automated Planet Finder (APF) telescope at Lick Observatory). As we observe more targets, we will also determine how this dependence changes for stars of varying masses and ages, in which activity manifests differently. When we begin observing planet hosts, which will happen in coming semesters after this SURP concludes, these three instruments will work in tandem to distinguish achromatic planetary signals from chromatic activity signals.

Our timeline was significantly disrupted by the COVID pandemic which shut down observatories worldwide and stalled the commissioning of the PARVI spectrograph for much of 2020 and 2021. PARVI was further impacted by the Palomar adaptive optics system going down for much of the 2022B semester. Despite this, our team acquired time to monitor multiple active stars with HPF, APF, and PARVI. We have analyzed intensive campaigns for two objects, the young, active M-dwarfs AD Leo and EV Lac, and have lower cadence data for four more stars. We highlight our AD Leo and EV Lac data below which show that stellar jitter has complicated and varied temporal and chromatic behavior, even for two relatively similar stars. While data was also taken with PARVI, the instrument's night-to-night stability is not yet sufficient to contribute to this analysis.

We find significant RV signals at the rotation period (Prot) of AD Leo in both the visible and NIR data and find the amplitude of the signal is smaller in the NIR than the optical, as expected. However, there is evolution in the NIR signal over time: the amplitude decreases by 2.5x between observing seasons, supporting previous results that AD Leo's activity varies on long timescales. This temporal evolution highlights the need for season-specific activity modeling when observing a star for a long period of time.

The jitter signal of EV Lac is even more complicated. There is significant dual periodicity in both the visible and NIR RVs at Prot and Prot/2, which has been observed in some activity signals before [5,6]. The phase curves for EV Lac makes clear that there is a difference in chromatic behavior between these two signals: the NIR amplitude is significantly smaller than in the visible at Prot/2, but is comparable at Prot. This would require a complex (multipole) spot distribution, in addition to changes in active feature contrast across the surface. This dual periodicity is also seen in EV Lac's TESS light curve. We have a campaign underway in 2022B to observe EV Lac with the APF and HPF simultaneously with TESS to combine RVs and photometry in modeling the activity signal.

Significance/Benefits to JPL and NASA:

Advancing precise stellar radial velocity measurements to detect and characterize exoplanets, especially in the quest to discover habitable worlds, is an important capability highlighted in the Astro2020 Decadal Survey in support of exoplanet science questions. As highlighted in the Exoplanet Science Strategy (2018) National Academies report, stellar RV jitter presents the largest roadblock to precision mass measurements of small exoplanets [8], and our investigation seeks to determine new methods to model and mitigate stellar activity signals, which has been marked as a top priority by the NASA/NSF Extreme Precision Radial Velocities WG . Precise mass measurements are necessary for modeling exoplanets and their atmospheres and interpreting spectra measured with current and future NASA missions (e.g., HST, JWST, IROUV). We have laid the groundwork for measuring young exoplanet masses to provide high-quality targets to probe early atmospheric evolution. Our results reinforce that stellar jitter has a complicated and non-uniform relationship with wavelength and time. Even for two stars with similar properties (mass, temperature, rotation, age), we find wildly different RV jitter signals that necessitate unique modeling to understand and mitigate.

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