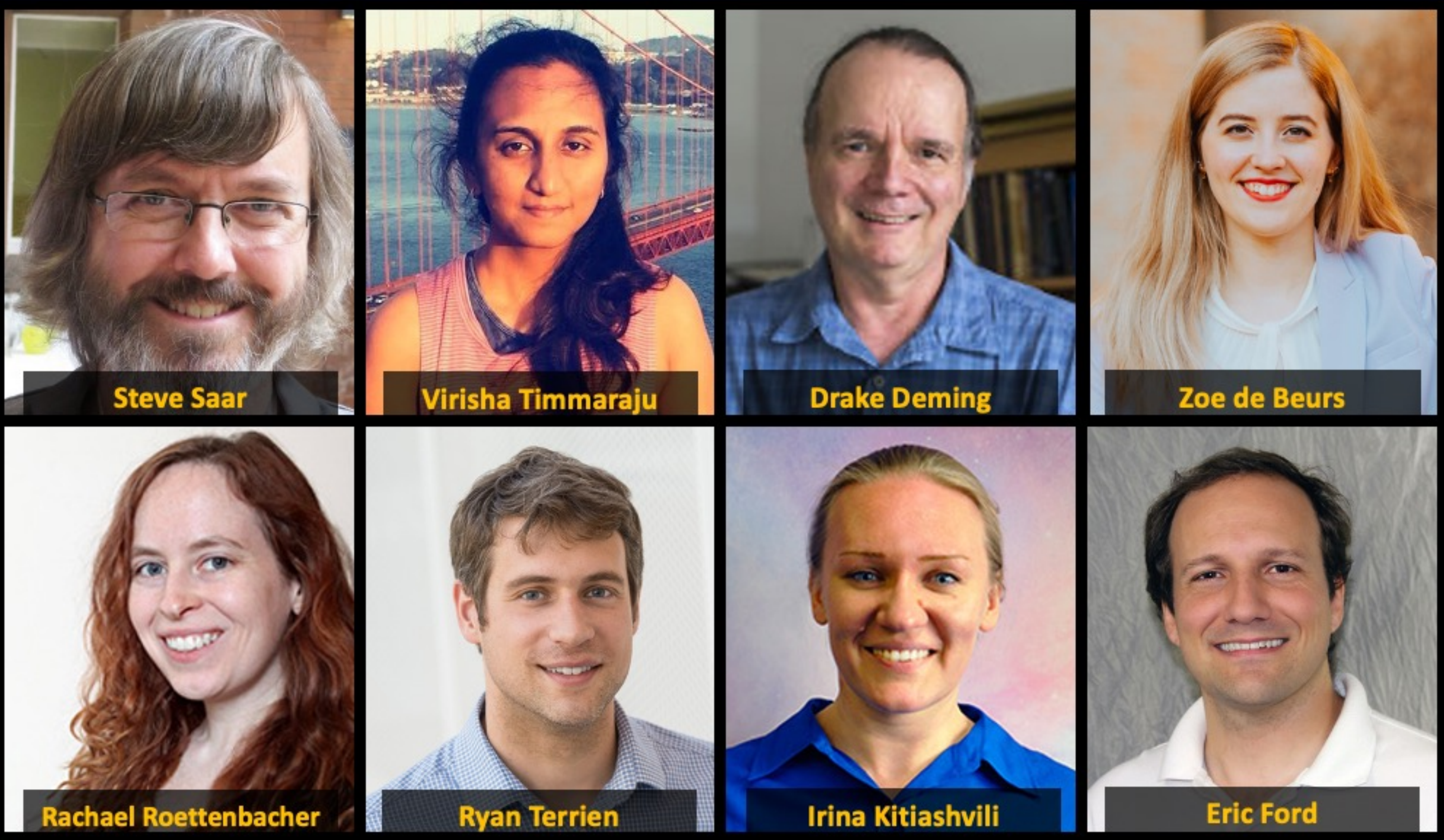


# Extreme Precision RV Foundational Science Seminar

Featuring updates and Q&A with the key scientists of NASA's EPRV call on mitigating stellar activity

**April 26th, 2022**
**10am -2pm Pacific**

Presented by the EPRV Research Coordination Network

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**10:00am - 10:10am** Welcome and brief overview of the EPRV Research Coordination Network

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**10:10am - 10:35am** **Irina Kitiashvili : Characterization of Stellar Jitter Using 3D Realistic Modeling of Solar-Type Stars**

Recent progress in the ab-initio modeling of solar and stellar magnetoconvection makes it possible to simulate the surface dynamics of solar-type stars with a high degree of realism. These simulations are used to characterize stellar photospheric disturbances, which contaminate the radial velocity signals and limit our capabilities to detect Earth-mass exoplanets. We use the 3D radiative MHD "StellarBox" code to obtain realistic (magneto)convection models of the upper convection zones and atmospheres and to characterize the photospheric noise. The initial conditions for the numerical simulations are generated using the MESA stellar evolution code. We have developed numerical models of several solar-type planet-host stars and the Sun and evaluated the stellar jitter using synthetic time series of spectral lines calculated for these models. Synthesis of observations has been performed for a series of FeI lines using the radiative transfer "Spinor" code. We present the stellar jitter modeling results for the selected stars and discuss the origin of the noise and possible ways to remove it from observations.

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**10:35am - 11:00am** **Drake Deming : Orthogonal Spectroscopy for Detection of Rocky Exoplanets**

Detection of Earth-mass rocky exoplanets using the radial velocity (RV) technique must deal with intrinsic variations in apparent stellar RVs due to magnetic suppression of photospheric convection. While it is clear that magnetic signatures can be distinguished from center-of-mass RV shifts in absorption lines, it is less clear that those effects can be separated cleanly when both are present. We advocate transforming spectral line bisectors so that activity and center-of-mass effects become statistically independent (i.e., orthogonal) in the product of the analysis. We are developing this concept using archival spectra of integrated sunlight (the Sun-as-a-star) taken with two high resolution spectrometers: the HARPS spectrometer (High Accuracy Radial velocity Planet Search), and the SOLIS project (Synoptic Optical Long-term Investigation of the Sun) operated by the National Solar Observatory. The SOLIS data are especially valuable for this investigation because they cover a full solar cycle (since 2006), in contrast to the more recent data using HARPS. Preliminary results from the SOLIS analysis indicate that activity effects over Cycle 21 can be cleanly separated from the center-of-mass RV, at a level sufficient to detect Earth-mass planets. However, the Sun-as-a-star is a favorable case, because (among other reasons) the solar spectrum does not shift strongly in wavelength with respect to microtelluric lines. Consequently, we are investigating how our orthogonal technique can be extended to real observations of stars obtained from the orbiting Earth.

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**11:00am - 11:25am** **Zoe de Beurs: The Future of Using Machine Learning to Model Stellar Activity in RV Searches**

Exoplanet detection with precise radial velocity (RV) observations is currently limited by spurious RV signals introduced by stellar activity (i.e. faculae, starspots). Here we show that machine learning techniques such as linear regression and neural networks can significantly remove the activity signals (primarily starspots/faculae) from real center-of-mass RV shifts. Many EPRV efforts have focused on carefully filtering out activity signals in time using Gaussian process regression. Instead, we separate activity signals from true center-of-mass RV shifts using only changes to the average shape of spectral lines, and no information about when the observations were collected.

We have tested our machine learning methods on both solar observations from the HARPS-N Solar Telescope and extrasolar observations from EXPRES and HARPS. For the solar observations, we find that these techniques can successfully predict and remove stellar activity and reduce the RMS by a factor of ~1.7 or about 40%. For extrasolar observations from EXPRES, we found a similar reduction in RMS for the most active stars in our sample. Lastly, we were able to successfully apply our methods to reveal the mass of K2-167, a planet which was first found using the transit method in 2015 and where stellar jitter previously limited our ability to measure its mass. This promising result inspires us to now apply these or similar techniques to stars spanning the HR diagram such that we can derive metrics for how well stellar activity can be mitigated as a function of parameters like spectral type, projected rotational velocity, and age. We then plan to perform a blind search for planets using a modified Lomb-Scargle periodogram that simultaneously corrects for stellar activity with our simplified linear model. Ultimately, we hope these results will form the basis of a master training set to remove activity signals from observations of many different types of stars to pave the way towards detecting habitable-zone Earth-mass exoplanets.

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**11:25am - 11:50am** **Ryan Terrien : Disentangling RVs and magnetic activity at very high resolution with laser heterodyne spectroscopy**

Stellar magnetic activity obfuscates the interpretation of radial velocity (RV) measurements at and below the 1m/s level, masking exoplanetary signals. Spatially resolved magnetic field measurements have shown promise for correcting this effect on the Sun. Such spatially resolved measurements are unavailable for most other stars, and it is unknown whether disk-integrated magnetic field measurements can be made at the required level of sensitivity. We are using a laser heterodyne spectrometer to measure individual Solar spectral line profiles at very high resolution (R>106), with the aim to empirically determine the disk-integrated spectral fingerprints of magnetic activity. By targeting individual lines at very high resolution, this approach is complementary to similar efforts that survey a variety of lines at lower resolution. We describe here our early progress and heterodyne spectroscopic measurements, and look forward to near-future improvements and observing campaigns. Data from these campaigns, combined with ongoing RV and magnetic field monitoring of the Sun, will help determine the extent to which disk-integrated spectroscopic monitoring can allow for magnetic activity correction in the Solar case.

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**11:50am - 12:00pm** Digital Coffee Break

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**12:00pm - 12:25pm** **Steve Saar: The Importance of Some Lesser-Known Magnetic Effects on Stellar RVs, and Some Ideas to Mitigate Them**

Spots and plage are well known stellar magnetic features which affect radial velocities (RVs); multiple methods exist to at least partly correct for their effects. We discuss some other magnetic-related phenomena not yet much studied for their RV abuses: penumbral flows, moat flows and so-called active region inflows. We construct simple models to estimate the magnitude and rotational dependence of their RV signatures. All are important at the 10s of cm/s level. Even more important are the magnetic fields themselves, and the magnetic intensification (MI) of line profiles they induce, which vary from line to line depending on wavelength, line strength, and Zeeman properties. The MI effect can introduce a +/- 14 m/s signal for a plage covering 1% of the surface for an average simple triplet line. Measurements of magnetic fluxes will be helpful in accurately tracking these effects - we are working on a simple method for estimating changes in magnetic fluxes by tracking changes in line depths and widths that are correlate with Zeeman properties. Preliminary results indicate we can recover changes in magnetic flux at solar minimum at the ~15% level in HARPS-N spectra. We are also investigating changes in line asymmetry, namely, line skewness and Gray's "third signature of convection", as proxies to track activity driven RV changes. We present some promising initial results.

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**12:25pm - 12:50pm** **Virisha Timmaraju : Measuring Extreme Precision Radial Velocities of Exoplanet-Hosting Stars in the Presence of Stellar Noise With Deep Learning**

Stellar variability is one of the largest contributors to noise in Extreme Precision Radial Velocity (EPRV) measurements. We are developing deep learning-based approaches to measure small injected planet-like RVs in the presence of larger amplitude RV noise caused by stellar activity. Our networks are trained using the HARPS-N sun-as-a-star extracted (order-by-order) spectra from 2015-2018, with the goal of using NEID sun-as-a-star spectra in the near future. The unprecedented signal-to-noise and cadence of sun-as-a-star spectra allow us to evaluate the effectiveness and limitations of neural networks at separating stellar and planet-induced RVs in the wavelength domain at sub-m/s precision, and determine their applicability to the EPRV community's goal of mitigating stellar RV variability.

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**12:50pm - 1:15pm** **Eric Ford: NEID Sun-as-a-star Observations & Establishing Credibility of EPRV Exoplanet Detections**

Detecting and characterizing potentially Earth-like planets will require advanced statistical models to distinguish true Doppler shifts from stellar variability (Crass et al. 2021). Recently, researchers have proposed a variety of strategies for mitigating stellar variability. While each method appears promising individually, they don't always agree and it is difficult to validate their effectiveness, since we rarely know a star's true velocity (Zhao et al. 2022). Sun-as-a-star observations provide a unique opportunity to train, evaluate, improve and eventually validate such strategies, so that astronomers can robustly detect and characterize planets with sub-m/s Doppler signatures (e.g., Collier Cameron et al. 2021, de Beurs et al. 2020, Zhao et al. 2022). The NEID spectrograph at WIYN is collecting ~200 high-resolution, high-signal-to-noise solar observations over a broad range of wavelengths per clear day (Lin et al. 2022), so as to enable such research. In this talk, I will provide an overview of the special characteristics of the NEID solar observations and the NEID solar archive hosted at NExScI, as well as some of the challenges in making scientific use of this dataset. I will describe how the NEID Research Pipeline at Penn State complements the NEID Data Reduction Pipeline (DRP) for processing solar observations and the value-added data products that we will provide to the community. Finally, I will highlight some of the remaining challenges and future research necessary for EPRV surveys to effectively support future direct imaging missions in the hunt for potentially Earth-like planets

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**1:15pm - 1:40pm** **Rachael Roettenbacher: Disentangling Stellar and Planetary Signatures with Interferometric Images and Extreme Precision Radial Velocities**

The contribution of a stellar surface to radial velocity measurements can overwhelm the signal from Earth-like planets, making them difficult or impossible to detect. Even stars as quiet as the Sun have surface features and motions that can contribute radial velocity signals larger than those of a potentially habitable planet. Efforts are being made with a variety of techniques to account for these stellar effects. Here, we describe using images of stellar surfaces and contemporaneous extreme precision radial velocity data. For this technique, we directly image the details of the spotted surfaces of Sunlike stars with interferometry from the MIRC-X beam combiner at the CHARA Array at Mount Wilson Observatory. These images are used to model the radial velocity contribution of the stellar surfaces, which are then compared to contemporaneous radial velocities from the EXPRES spectrograph on the Lowell Discovery Telescope at Lowell Observatory. We share our progress and future directions.

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**1:40pm - 2:00pm** Group Discussion, additional Q&A

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**For connection details and more information about the RCN, please visit:**
**https://exoplanets.nasa.gov/exep/NNExplore/EPRV-RCN/**