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Exoplanets & Habitable Worlds

Seeking to discover habitable planets and life beyond the Solar System.

NEID Sun-as-a-star Observations for Evaluating Stellar Variability Mitigation Strategies

Jason Wright

AAS EPRV Splinter Session
January 9, 2023

Team & Acknowledgments

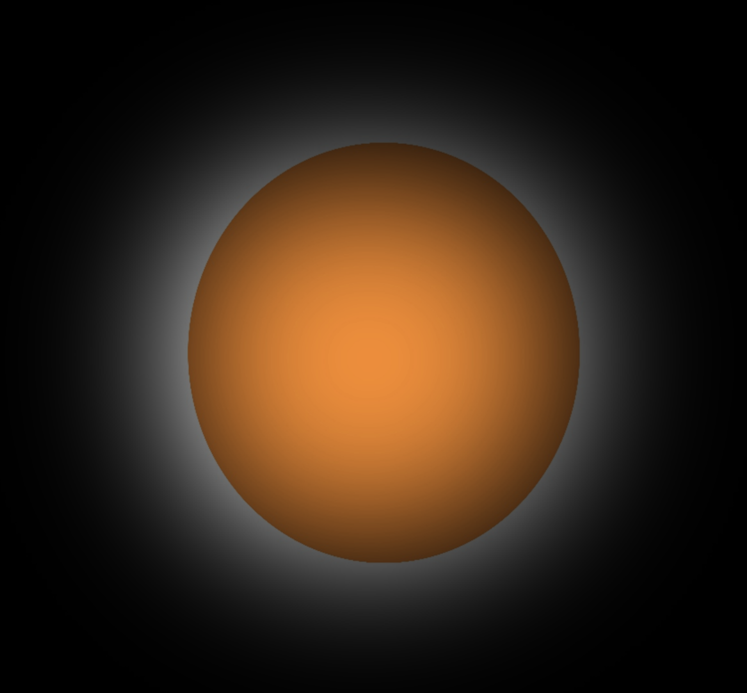
NASA EPRV Grant team members: Eric Ford (PI), Suvrath Mahadevan, Joe Ninan, Ryan Terrian, Jason Wright, Alex Wise; Sam Halverson, Michael Palumbo, Arpita Roy

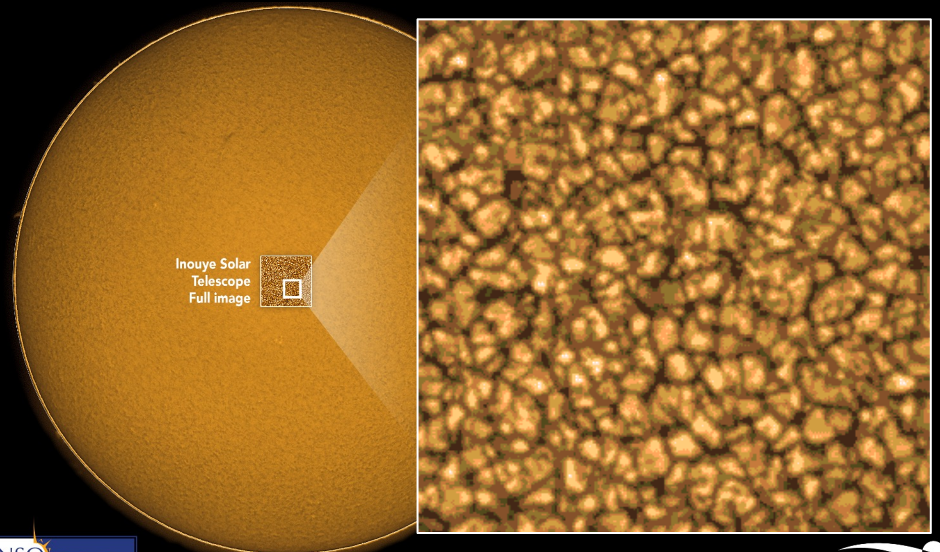
NEID Instrument & Science Teams

NEID Solar Telescope: Andrea Lin, Andrew Monson + rest of the NEID Team

Additional support from: Heising-Simons Foundation (construction & granulation studies), NOIRLab (operations), NExScI (archiving), and Penn State Institute for Computational & Data Sciences (research pipeline)

New Challenges for Precision Doppler Planet Surveys



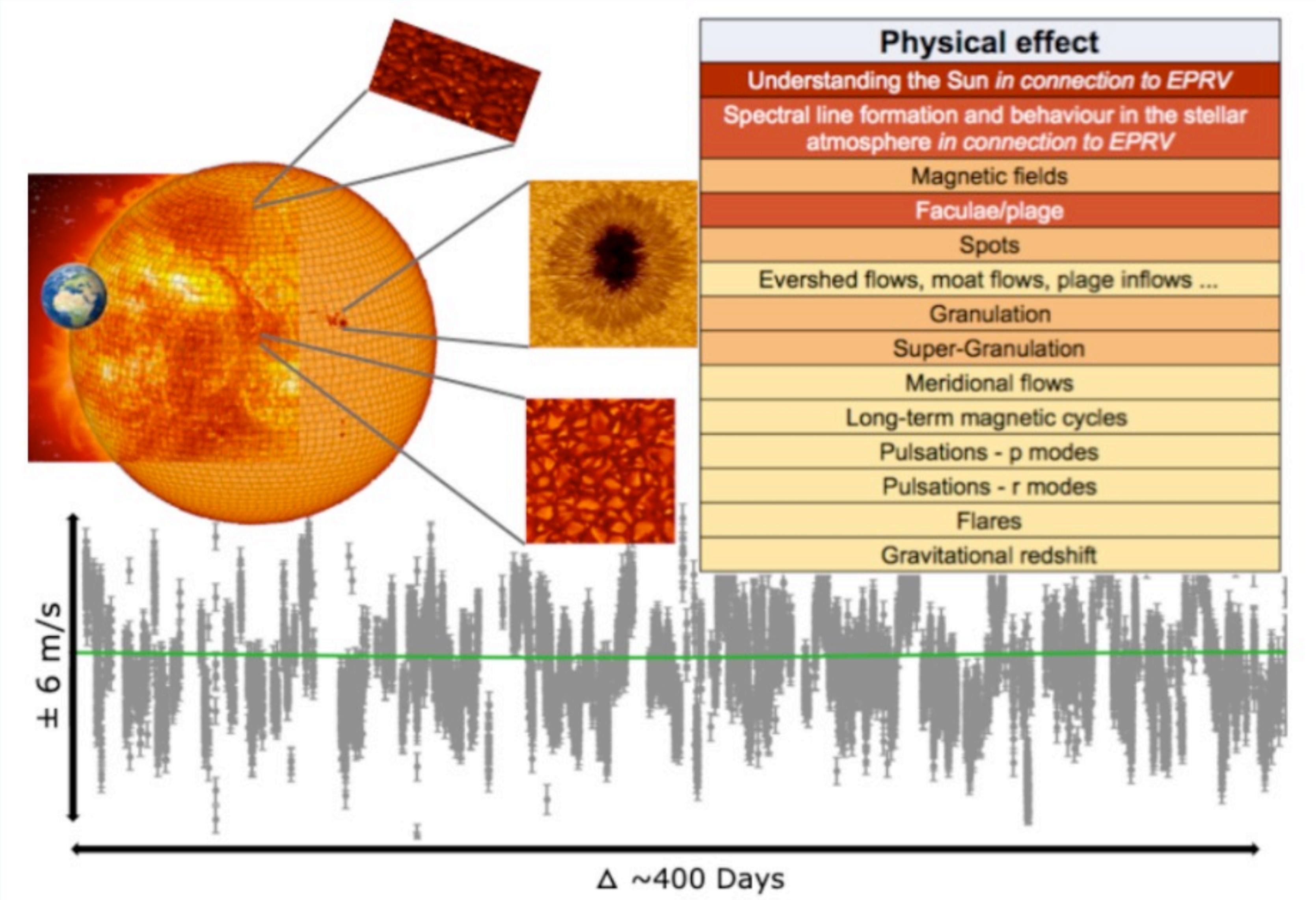


Movie Credit: NSO/NSF/AURA

Spot Simulation: C. Gilbertson

Image Credit: NSO/AURA/NSF

Lots to learn from Sun-as-a-Star Observations



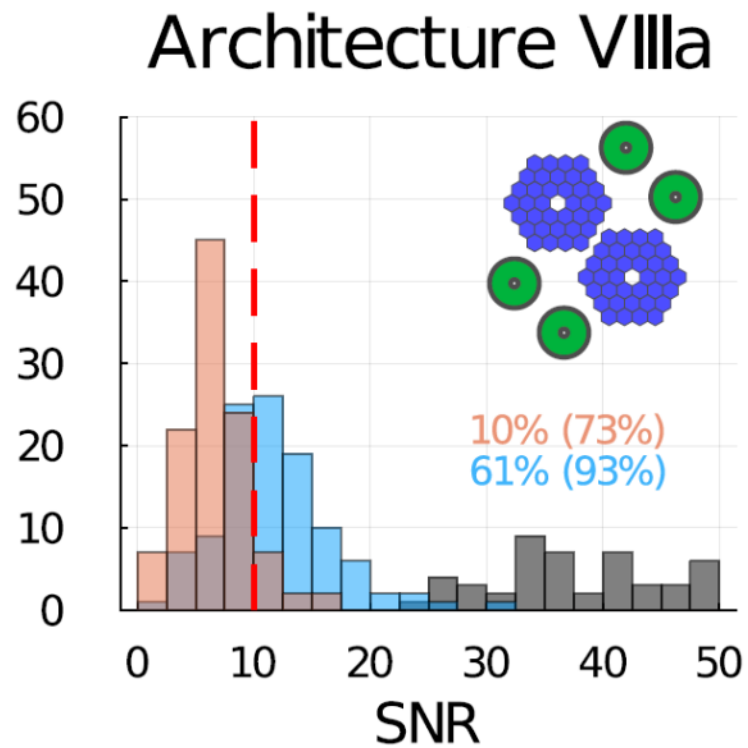
Physical effect
Understanding the Sun *in connection to EPRV*
Spectral line formation and behaviour in the stellar atmosphere *in connection to EPRV*
Magnetic fields
Faculae/plage
Spots
Evershed flows, moat flows, plage inflows ...
Granulation
Super-Granulation
Meridional flows
Long-term magnetic cycles
Pulsations - p modes
Pulsations - r modes
Flares
Gravitational redshift

Credits: EPRV WG Final Report. NASA, ESA, SDO/HMI, MURaM, Big Bear Solar Observatory, Solar RV observations from HARPS-N, Cegla/Haywood/Watson

Stellar Variability Limits RV Planet SurveySensitivity

EPRV WG Report (Crass et al. 2022) demonstrated that intensive observing campaigns could characterize masses of Earth-analog planets to support direct imaging missions, *assuming* that stellar variability could be accurately subtracted (grey histogram).

Luhn et al. (2022) showed that noise due to stellar variability will significantly reduce mass precision of such surveys, unless further progress is made.



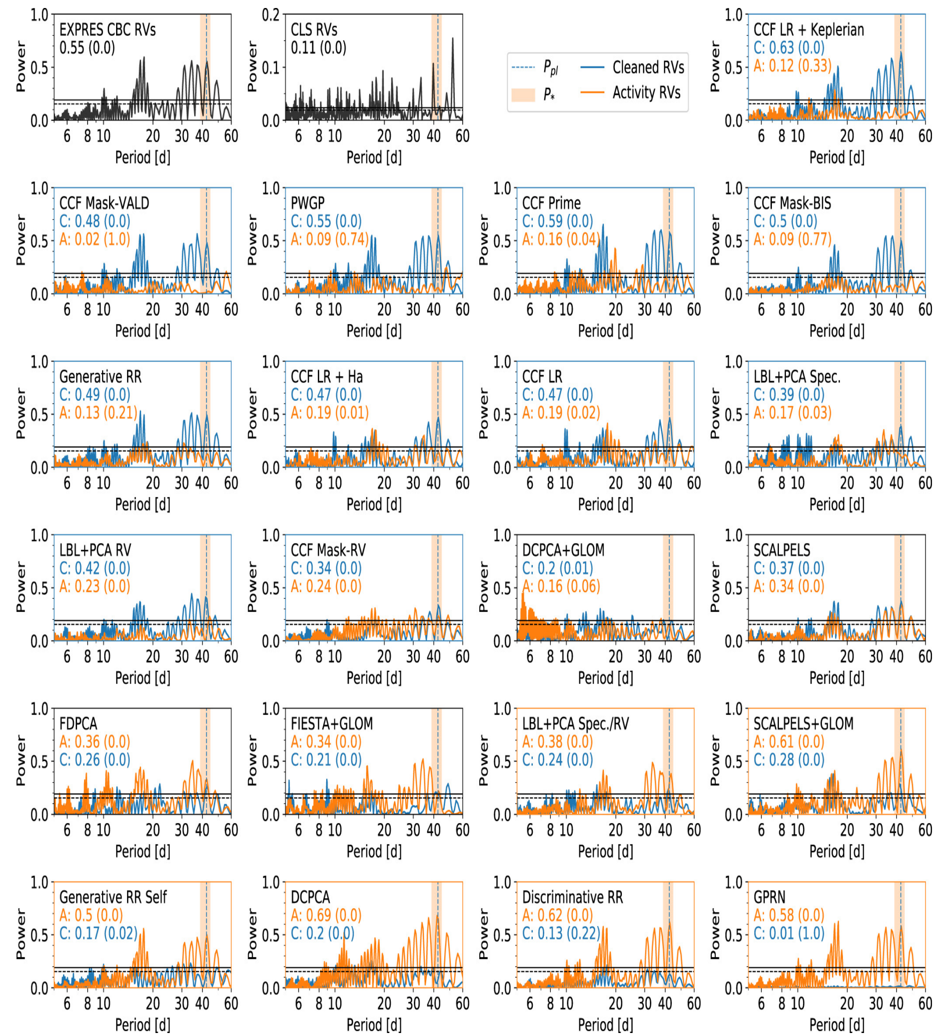
J. Luhn, Ford et al. 2022

Need further research in modeling stellar variability to characterize Earth-analogs

Several groups have proposed strategies to separate stellar variability from true Doppler shifts.

EXPRES Stellar Signals Project

- Compared 22 different methods for mitigating effects of stellar variability on EXPRES RVs
- Each method appeared to help (e.g., reduce RMS of RVs).
- But… they didn't agree.
- How can we know which (if any) were accurate?



Lily Zhao et al. 2022

NEID Sun-as-a-Star Observations

NEID Sun-as-a-Star Observations

Exoplanet Survey Characteristics

- ~ 50 – 100 target stars
- ~ 1 – several spectra / star / night
- ~ 5 – 15 year survey duration
- Sparse and irregular sampling
  (weather, conflicts with other targets)
- True stellar velocity is ***unknown***
- Only spatially unresolved data

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Solar Observations

- Only 1 Sun
- ~200 spectra / day
- Same duration as exoplanet survey
- Dense sampling, still irregular
  (weather)
- True solar velocity is ***known***
- Spatially resolved data is available

NEID Solar RVs archived at NExScI

https://neid.ipac.caltech.edu/search_solar.php

Solar Radial Velocity Archive

NN·EXPLORE NExScI

SEARCH | NEID ARCHIVE | HELP | CONTACT | username | password | Login

Search the Solar RV Archive

Modern extremely precise radial velocity spectrographs are now being built with the capacity to feed light from the sun into the instrument in order to aid our understanding of the instrumental characteristics and the Doppler noise caused by convective motion on the surface of stars. The NASA-NSF Exoplanet Observational Research (NN-EXPLORE) program and the NASA Exoplanet Science Institute (NExScI) located at the California Institute of Technology are working together to provide the community access to the solar data products from as many instruments as possible. Reduced solar data products from the NEID spectrograph built by the Pennsylvania State University are currently available for download.

News

Files flagged for rejection are now hidden from the results table by default. These files may be flagged for low signal-to-noise, a poorly determined wavelength solution, or other data quality issues. Check the "Include files flagged for rejection" checkbox below if you wish to display the rejected files.

The EXTSNR value, which is a measure of the signal-to-noise in the extracted spectrum at the wavelength specified in the target submission GUI, is now displayed in the results table.

Pyrheliometer data is available here.

Instrument: NEID | Observation date (UTC): 04/19/2022 - 04/25/2022 (mm/dd/yyyy) | Data level: select | Search | Clear Form

Include files flagged for rejection ☐

1,257 rows returned (1,257 downloadable files)

Create script to download files

Level 2 × 1 of 3 (1 - 500 of 1,257)

filename char	obsdate char	exptime double	obsmode char	obstype char	program char	piname char	sunagl double	seeing double	ccfjdsum double	ccfrvmod double	dvrms double	swversion char	extsnr double	rejected int
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Our Project Goals

- Provide value-added data products
  - Identify high-quality observations
  - Account for peculiarities of sun-as-a-star observations (i.e., differential extinction, apparent solar rotation rate)
  - CCFs & RVs based on curated line lists

- Beta release available via Globus
  - Contact Eric Ford eford@psu.edu for details

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- Compared "cleaned" RVs based on multiple strategies for mitigating stellar variability:
  - Doppler-constrained PCA (Jones et al. 2017, 2022)
  - SCALPELS (Collier Cameron et al. 2020)
  - FIESTA (J. Zhao et al. 2022)

We'll be working on these for 2023.

Characterizing Solar Granulation Model with NEID Solar Observations

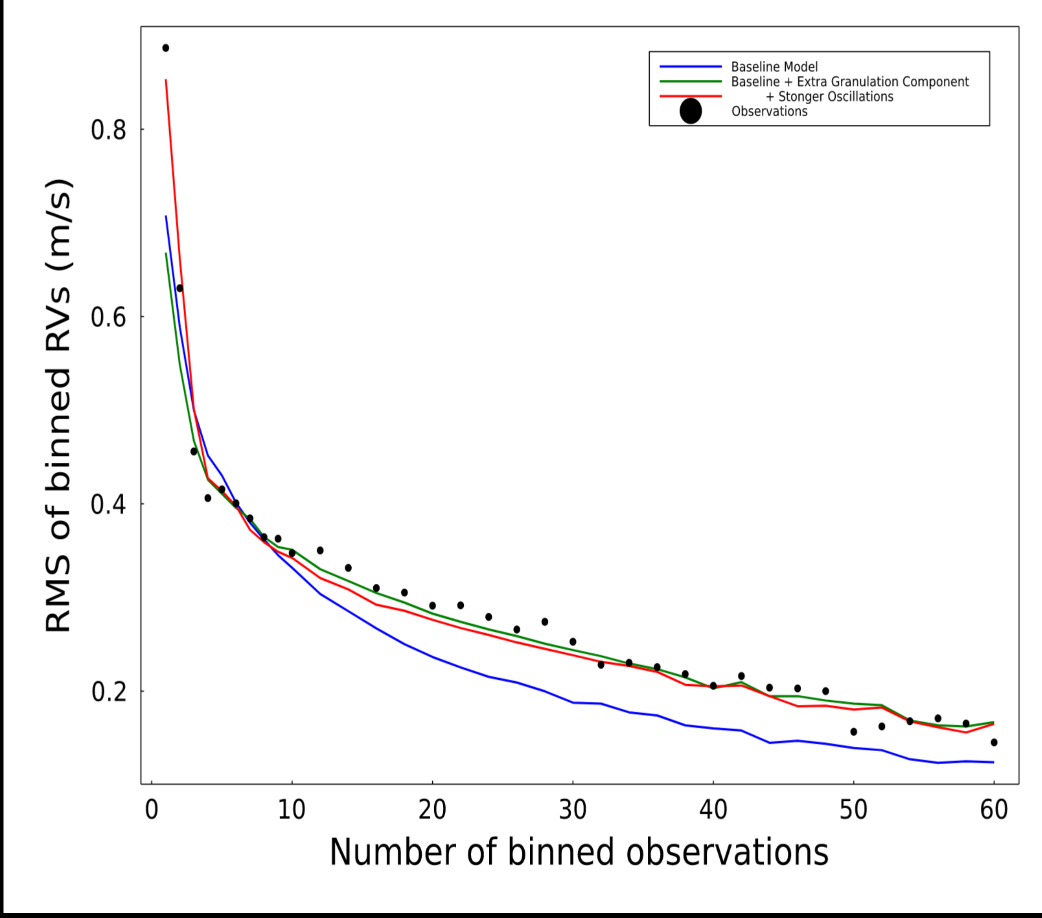
Compute RMS of binned consecutive RVs as a function of number of bins

- 55 sec exposures
- 28 or 38 sec dead time

⇒ RMS decreases more slowly than $1/\sqrt{n}$ due to oscillations & granulation

Developed physically motivated GP model for oscillations, granulation & active regions (Guo et al. 2022, Luhn et al. 2022)

Calibrating model with NEID solar observations (Ford et al. in prep)



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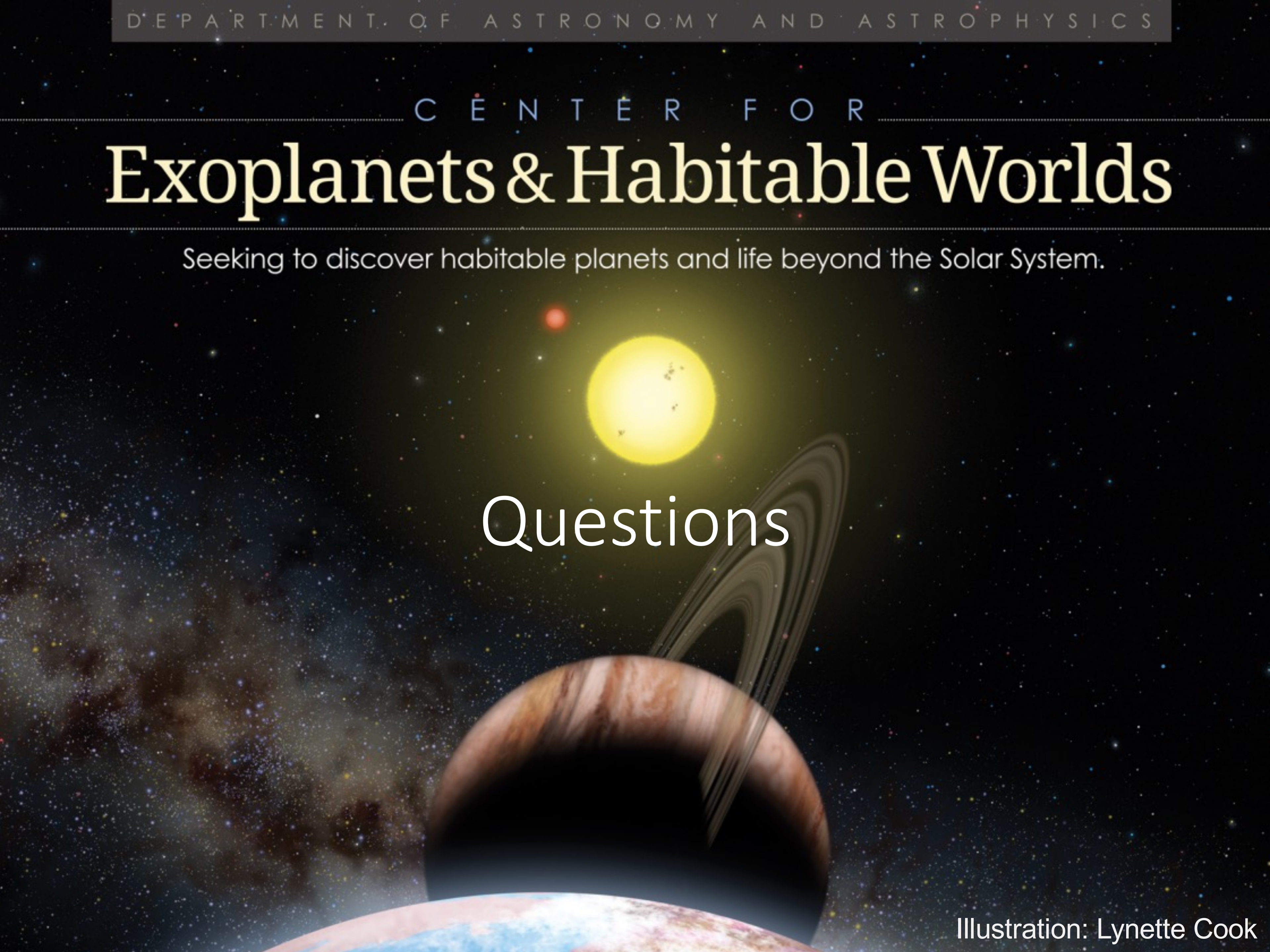
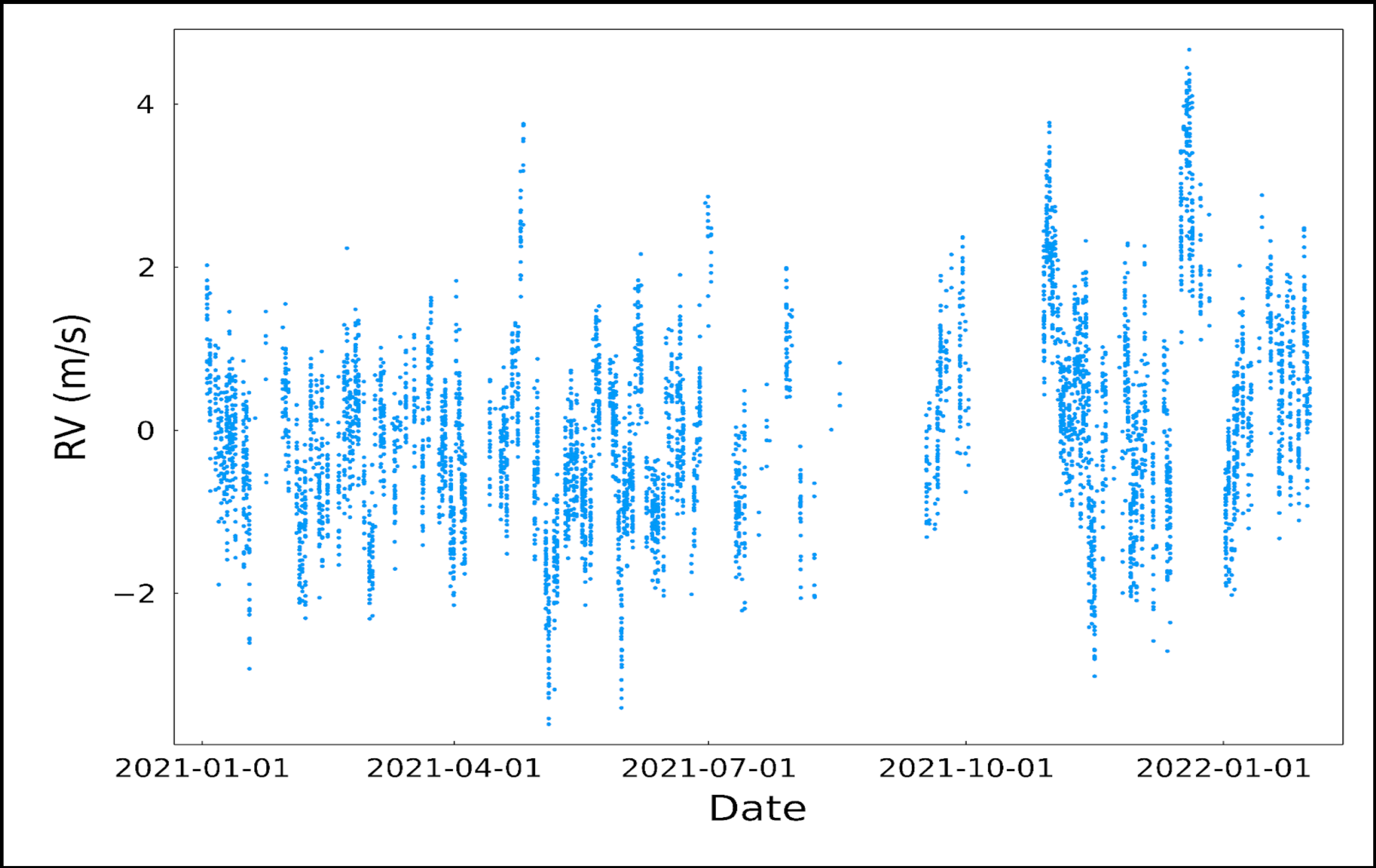
  - SCALPELS (Collier Cameron et al. 2020)
  - FIESTA (J. Zhao et al. 2022)
- Support comparisons with other solar telescopes
  - Comparison Solar observations from HARPS-N, HARPS & EXPRES in progress (L. Zhao et al. in prep)


DEPARTMENT OF ASTRONOMY AND ASTROPHYSICS
CENTER FOR
Exoplanets & Habitable Worlds
Seeking to discover habitable planets and life beyond the Solar System.
Questions
Illustration: Lynette Cook

NEID Solar Observations



NEID's Order RVs are individually precise!