The EXPRES Stellar-signals Project. I. Description of Data

Lily Zhao[1], Debra A. Fischer[1], Eric B. Ford[2,3,4], Gregory W. Henry[5], Rachael M. Roettenbacher[6], and John M. Brewer[7]

Published 2020 September 18 •

Research Notes of the AAS, Volume 4, Number 9

lily.zhao@yale.edu

[1] Yale University, 52 Hillhouse, New Haven, CT 06511, USA

[2] Department of Astronomy & Astrophysics, 525 Davey Laboratory, The Pennsylvania State University, University Park, PA, 16802, USA

[3] Center for Exoplanets and Habitable Worlds, 525 Davey Laboratory, The Pennsylvania State University, University Park, PA, 16802, USA

[4] Institute for Computational & Data Sciences, The Pennsylvania State University, University Park, PA, 16802, USA

[5] Tennessee State University, Center of Excellence in Information Systems, Nashville, TN 37209, USA

[6] Yale Center for Astronomy and Astrophysics, Yale University, 46 Hillhouse Avenue, New Haven, CT 06511, USA

[7] Department of Physics and Astronomy, San Francisco State University, 1600 Holloway Ave, San Francisco, CA 94132, USA

Lily Zhao https://orcid.org/0000-0002-3852-3590

Debra A. Fischer https://orcid.org/0000-0003-2221-0861

Eric B. Ford https://orcid.org/0000-0001-6545-639X

Gregory W. Henry https://orcid.org/0000-0003-4155-8513

Rachael M. Roettenbacher https://orcid.org/0000-0002-9288-3482

John M. Brewer https://orcid.org/0000-0002-9873-1471

Received 2020 August 31
Accepted 2020 September 16
Published 2020 September 18

Lily Zhao *et al* 2020 *Res. Notes AAS* **4** 156

https://doi.org/10.3847/2515-5172/abb8d0

Exoplanet detection methods ; Radial velocity ; Planet hosting stars ; Stellar activity ; Spectrometers

Abstract

The EXPRES Stellar-Signals Project is providing sets of high-fidelity, spectroscopic and photometric observations to enable direct comparisons of various approaches for disentangling stellar signals and true radial velocities (RVs). We will provide all EXPRES RVs, meta data, and activity indicators as well as high-precision photometric data from the Fairborn Automatic Photoelectric Telescopes (APTs) for HD 101501, HD 34411, HD 217014, and HD 10700. Intrinsic stellar variability and the resulting apparent RVs are widely believed to dominate the error budget for extremely precise radial-velocity (EPRV) measurements. Several new methods to disentangle photospheric velocities from Keplerian velocities are being developed throughout the EPRV community. In addition to releasing data sets for testing these methods, the EXPRES Stellar-Signals Project will publish a summary of the current state of the field circa 2020 to guide next steps toward mitigating photospheric velocities in EPRV data. More information can be found on http://exoplanets.astro.yale.edu/science/activity.php.

1. Introduction

A new-generation of extreme-precision spectrographs is now providing higher precision radial velocity (RV) measurements; the Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations (ESPRESSO) and the EXtreme PREcision Spectrograph (EXPRES) both demonstrate <10 cm s^{-1} instrumental errors and on-star, single-measurement precisions of 20–30 cm s^{-1}

(Pepe et al. 2013; Jurgenson et al. 2016; Petersburg et al. 2020; Suárez Mascareño et al. 2020). Additional EPRV spectrographs, including NEID (Schwab et al. 2016) and the Keck Planet Finder (Gibson et al. 2018) are targeting similar precision and will soon be commissioned.

To take advantage of this exceptional precision, it is important to mitigate "RV noise" from granulation, pulsations, starspots, faculae, and other photospheric sources. These stellar signals produce variations in spectral line shape profiles that can masquerade as Keplerian Doppler shifts.

In the era of one m s^{-1} RV precision, it was sufficient to use correlations between RV measurements and global activity indicators, but these indicators alone do not have enough sensitivity to disentangle stellar signals at the sub-meter-per-second level (Fischer et al. 2016). Many new statistical methods are now being employed or developed to mitigate RV contributions from these stellar signals (e.g., Haywood et al. 2014; Rajpaul et al. 2015; Dumusque 2018). A direct comparison between these methods has not yet occurred.

The EXPRES Stellar-Signals Project is releasing high-fidelity data for four stars, allowing for a benchmark comparison of the various methods. We are providing EXPRES data, including meta data, RVs, and activity indicators, along with precise photometry from the Fairborn Observatory APTs. The project will culminate in publishing a self-consistent comparison of several methods applied to the same data sets. This can help guide future research and observing strategies that aim to reach Earth-detecting precision. More details, a timeline, and data links can be found at http://exoplanets.astro.yale.edu/science/activity.php.

2. Data

EXPRES is installed at the 4.3 m Lowell Discovery Telescope (LDT) (Levine et al. 2012) near Flagstaff, AZ and is on-sky an average of 125 nights per year. The instrument is an environmentally stabilized, fiber-fed, optical spectrograph with a median resolving power $R \sim 137{,}000$ over a wavelength range of 390–780 nm (Jurgenson et al. 2016; Blackman et al. 2020). The target stars are typically observed with a signal-to-noise ratio of 250 per pixel, and several consecutive exposures are obtained to help understand RV errors and to increase the nightly binned precision (Brewer et al. 2020).

Provided data include flat-relative, optimally extracted data from the EXPRES pipeline with chromatic barycentric-corrected wavelengths and an empirical model of telluric lines (Blackman et al. 2017; Leet et al. 2019; Petersburg et al. 2020). FITS headers contain meta data and measured activity indicators (Ca II H&K, Hα, FWHM, and CCF bisector span). RVs are derived using a chunk-by-chunk, forward-modeling algorithm (Petersburg et al. 2020). We will also make available photometry from the APTs at Fairborn Observatory in southern Arizona (Henry 1999).

3. Targets

The EXPRES Stellar-Signals Project will release data for the four target stars listed in Table 1. HD 101501 (61 UMa) is an active G8V star with clear evidence of photospheric velocities. HD 34411 is a chromospherically quiet G0V star with an rms <1 m s^{-1}. HD 217014 (51 Peg), is a quiet, slightly evolved G2 star with a known exoplanet (Mayor & Queloz 1995). The data set for HD 10700 (τ Ceti) show evidence of p-mode pulsations, and there are claims of several orbiting exoplanets (Tuomi et al. 2013; Feng et al. 2017).

Table 1. Targets

HD Number	Spectral Type (a)	$\log R'_{HK}$ (b)	No. Obs.	Nights	Start/End Date
101501	G8V	−4.54	44	21	2019 Feb 10–2020 Jul 3
34411	G0V	−5.09	120	34	2019 Oct 8–2020 Aug 27
217014	G5V	−5.06	53	23	2019 Jun 5–2020 Nov 17
10700	G8V	−4.98	128	22	2019 Aug 15–2020 Aug 4

References. (a) Gaia Collaboration (2018), (b) Brewer et al. (2014).

HD 101501 will be publicly available and shared upon request starting 2020 September. Data for HD 34411, HD 217014, and HD 10700 will be made available 2020 November.

4. Concluding Report

The EXPRES Stellar-Signals Project will help benchmark the ability of the community to mitigate photospheric velocities, which currently dominate the RV error budget. A published summary, planned for 2021 February, will aim to identify current limitations for the detection of Earth analogs and to clarify the most promising methods for disentangling stellar signals from EPRV data. An additional goal is to establish the data needs of the various methods to inform the design of future planet surveys and spectrographs.

EXPRES is supported by NSF MRI-1429365 and NSF ATI-1509436, Yale University, the Heising-Simons Foundation, and an anonymous donor in the Yale alumni community. Stellar activity studies are supported by NASA XRP 80NSSC18K0443, NSF AST-1616086. This work was supported by a grant from the Simons Foundation (675601 and EBF). G.W.H. acknowledges long-term support from NASA, NSF, Tennessee State University, and the State of Tennessee through its Centers of Excellence program. L.L.Z. gratefully acknowledges support from the NSF GRFP under grant No. DGE1122492.

Facility: LDT. -
