National Aeronautics and Space Administration

PARVI Commissioning and Science

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Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Precision Radial Velocity**

Objectives

The objective of this work is to commission the Palomar Radial Velocity Instrument (PARVI) [1] and use it for demonstrative radial-velocity measurements. PARVI uses a brand new approach to precise radial velocities. It uses adaptive optics (AO) to couple starlight into a single-mode fiber (SMF) echelle spectrograph, which has a very high spectral resolving power of 100,000, and a simultaneous spectral grasp of ~700 nm (1100 -1800 nm). Any drifts in the wavelength scale of the spectrograph are concurrently monitored with an electro-optic modulation (EOM) laser frequency comb. The single mode design of the spectrograph allows it to be radically more compact than conventional PRV spectrographs (1000x in volume), and make the instrumentation (optics, mechanics, vacuum enclosures, thermal control, etc.) far less expensive to implement, and potentially easier to stabilize against thermal-mechanical distortion.

PARVI achieved first observations in the later summer 2019 at the Palomar P200 telescope and then had a few further commissioning nights in Dec 2019 and Jan 2020 prior to the pandemic shutdown in Mar 2020. Commissioning observing restarted tentatively in Apr 2021, but we are pleased to have had nearly normal observing in June, July and August of 2021. We report on recent gains herein.

Background

The research focus covers a variety of radial velocity topics of interest to the PARVI team. *(A) Planets orbiting Cool Dwarf Stars*: The search or follow-up for planets orbiting nearby low-mass stars (including measurements in transiting systems) is a frontier in exoplanet science. These small stars afford important observational advantages that make it possible to detect small planets around these hosts. Low-mass stars often have compact systems of at least two planets with periods less than 50 days [2]. (B) *Planets orbiting Sun-like/Young Stars:* Near infrared radial velocities may become valuable new tool for Sun-like stars. At these wavelengths stellar noise on rotational timescales due to spot activity may be lower than it is in the visible. Others [3] have suggested that for planetary systems requiring the highest possible RV precision (<1 ms^{-1}), a combination of visible/NIR data may be required to remove the star's signature. We are using PARVI to conduct a study of activity in Sun-like and young, magnetically active stars. (C) *Planets in Binary Systems*: Many transiting systems found by Kepler, K2 (and soon by TESS) are located in binary or higher multiplicity stellar systems. Seeing-limited instruments cannot distinguish between stars more closely separated than about 1" whereas by using the AO system PARVI will be able to take spectra of stars separated by <0.2". Planet formation in binaries is of great interest.

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References

[1] Vasisht et al. 2022, in preparation

[2] Dressing & Charbonneau 2015, Astrophysical Journal, 807, 45

[3] Marchwinski et al. 2015, Astrophysical Journal, 798, 63

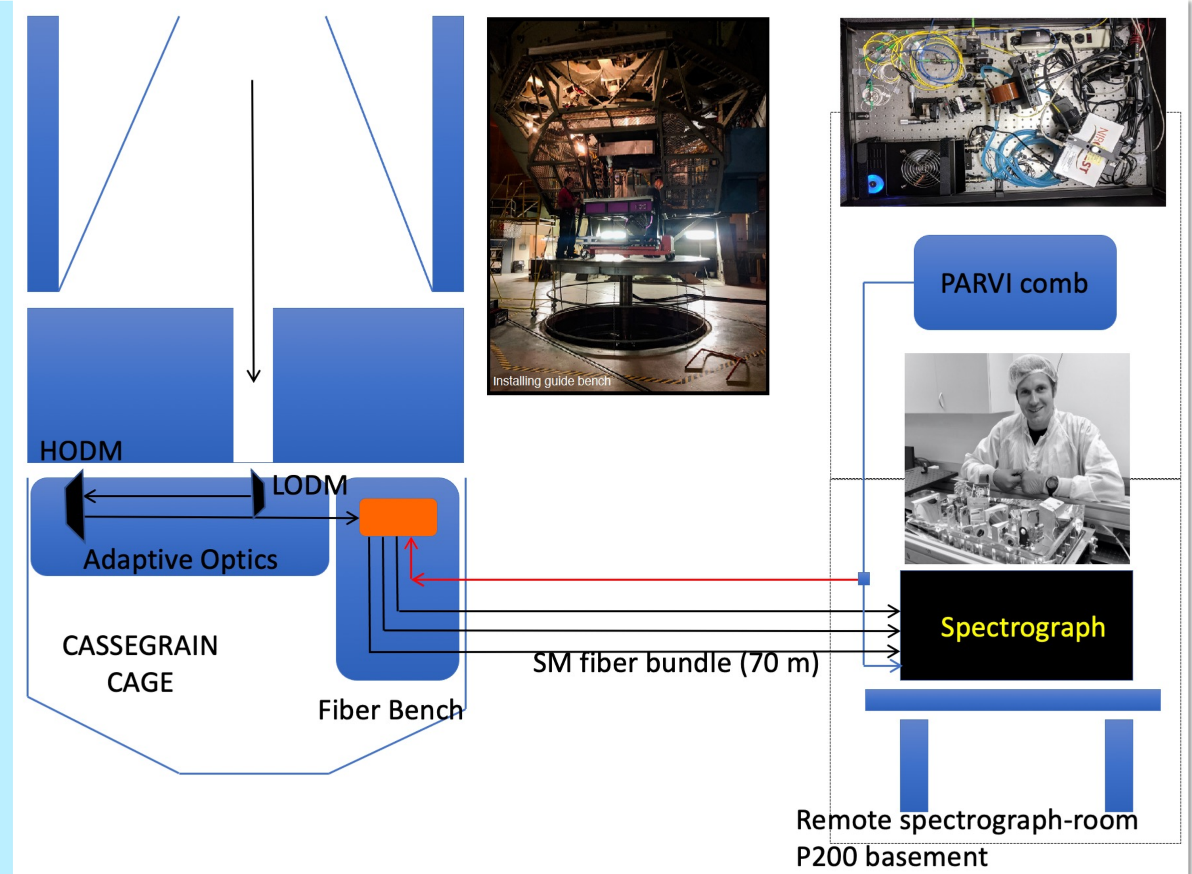

Figure 1: PARVI is a remote spectrograph fed by 70 m of single mode fiber. Light from the telescope is corrected by the Palm 3000 adaptive optics system, and coupled to the fibers. The spectrograph and it's laser frequency comb calibration system is housed in a room in the basement of the 200-in telescope dome.

Figure 2: Laser frequency comb spectra projected along the spectrograph's cross dispersed orders. Since the comb lines are strictly determined in frequency, such projections can be used to determine the stability of the spectrograph. PARVI is stable to about 50 cm/s or 1 part in 10^9 in the short term (2 hr) but suffers diurnal drifts of a few m/s.

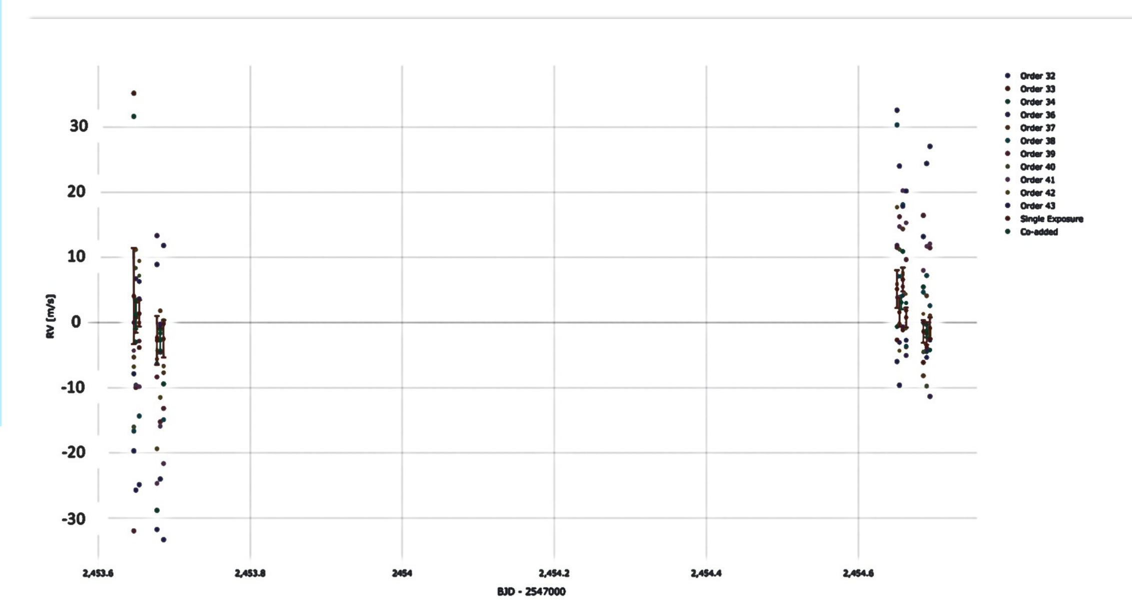

Figure 3: Short term radial velocities on the radial velocity standard, Barnard's star, are about 1-2 m/s. However, the night to night zero point is only determined to 5-10 m/s due to significant drifts in the instruments. Spectrograph upgrades planned in Dec/Jan of FY22 will eliminate these drifts.

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Significance/Benefits to JPL and NASA

The advancement of precise radial velocities (instrumentation, analysis, modeling, etc.) is of high high strategic importance to NASA and JPL. The goal is to routinely reach the precision levels needed to detect (and measure masses of) earth-mass planets orbiting solar analog stars. The PARVI work responds directly to the 7x strategic initiative (section 5), the recommendations of the 2018 NAS Exoplanet Science Strategy Report, as well as the charter of the joint NASA-NSF E-PRV Working Group to explore new technologies, techniques, and strategies for overcoming RV's current roadblocks. RVs are not only relevant to current NASA missions such as TESS and JWST, importantly the future ones, specifically the decadal flagship contenders such as HabEx and proposed probe missions such as EarthFinder. If the astrophysical decadal surveys strongly endorses RV science, as we expect, then $400 M is expected to be spent on advancing the technique over the next 5-10 years.

Approach and Results

After a interruption in FY20-21, we have used improved access to the observatory to work on instrument performance and to restart the observing program. Since late April, we have conducted a total of three runs, and have obtained a total of ~ten nights of cloud free on-sky commissioning data. The main accomplishments this FY may be summarized as follows:

1. We have made important strides in improving the internal alignment of the spectrograph to finally achieve diffraction-limited line spread functions. This directly impacts the detection sensitivity, and the quality of the detector wavelength calibration. 2. We have made observing mostly "remote", with just one person needed at the observatory for hardware set-ups and for executing daily calibrations. This has greatly reduced travel need and simplified execution of the observing during the still on-going pandemic. 3. We have achieved an instrumental stability of 50 cm/s over ~2 hour timescale. We continue to observe instability on longer timescale resulting from diurnal effects related to liquid nitrogen boil-off (liquid cryogen is currently used for cooling the spectrograph) and impulse disturbance from daily liquid fills. We will remedy this during Dec-Feb by replacing the LN2 cryostat with a new one driven by a pulse-tube mechanical cooler. 4. We have diagnosed and fixed instabilities in the PARVI wavelength solution arising from the laser frequency comb, and are currently working on expanding the frequency span (a new non-linear fiber designed together with NIST partners) of the comb to cover all orders of the spectrograph. 5. We have completed a first end-to-end RV analysis pipeline with telluric correction. To improve the pipeline and analyze PARVI data over the next two years, we have hired Bryson Cale as NPP postdoc. 6. Current PARVI performance: We achieve SNR =100 in 900 seconds on H=8.2, G=10.1 stars. This performance is seeing dependent and that we are still making improvements in the coupling to the input single mode fiber. PRV precision is 1-2 m/s on a bright star and 2-3 m/s on fainter ones within a single night. The cool down after a LN2 refill produces a jump of a few 10 s of m/s which we are still working on calibrating out. We expect to being this down to 5 m/s overall as we improve our as we improve our calibration procedures but upgrades to the new cryostat this winter will completely eliminate this as an issue.

Acknowledgements

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