National Aeronautics and Space Administration

PARVI Commissioning and Science

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Program: FY22 R&TD Strategic Initiative
Strategic Focus Area: Precision Radial Velocities - Strategic Initiative Leader: Charles Lawrence

Objectives: The objectives of this work are to commission the Palomar Radial Velocity Instrument (PARVI) and conduct demonstrative exoplanet radial velocity science with it at Palomar's 200-inch telescope. PARVI is an R=100,000 near infrared stabilized spectrograph covering the IR J and H bands. It operates in diffraction limited mode, and is coupled to the Hale telescope and its adaptive optics system by single mode fiber. PARVI's performance goals are as follows -

- Radial velocity precision of σ = 1 m/s on inactive stars, limited by telluric contamination
- With an instrument contribution to the above error of less than 30 cm/s

Background: Extreme precision radial velocities at 10 cm/s precision, is the old method currently available to infer the presence of Earth mass planets in orbit around nearby stars. With this project we are: **Advancing new PRV technologies**: Test and validate adaptive optics coupled SM-fiber feeds, control, and laser frequency comb metrology in diffraction limited spectrographs. PARVI is a pathfinder for ambitious future AO-fed spectrographs, and is a possible model for future vis-AO enabled extreme-PRV instruments targeting sub 10 cm/s performance. **Advancing space capable wavelength calibration**: development of laser comb and etalon technologies including compact, chip-based LFCs suitable for infusion within new instruments or missions. **Training** Pasadena students, postdocs and astronomers in instrumentation, PRV analysis and science.

Approach: Our one remaining technical hurdle pertains to polarization sensitivity in the spectrograph. While PARVI selects a single spatial-mode on the sky, it nevertheless supports both TE and TM polarization modes of the starlight E-field. Delivery of this light via single mode fiber results, inevitably, in temporal changes in E-field polarization-state entering the spectrograph; this is because of time changing mechanical and thermal stress related birefringence in fibers. This behavior in fibers, requires a PARVI-like spectrograph to be totally insensitive to the incoming polarization state. However, in reality, we have discovered the spectrograph to be subtly polarization dependent which was recently localized to birefringence in the internal optics. At the time of writing this report we believe that this birefringence is due to cryogenic stress induced in the cross-dispersion silicon prism used in the spectrograph. The effect of this internal birefringence is to induce shifts in the measured location in the stellar spectral lines as the input polarization state changes due to the optical fiber. Fixing this issue remains our biggest challenge going forward, with two possible solutions: (a) a change in the internal optics of the spectrograph, while conforming to constraints imposed by the cryogenic housing, or (b) lossless scrambling of the polarization state of the starlight before it enters the spectrograph, or rotating the partially polarized light using a rotating half wave plate.

Apart from these outstanding issues related to polarized light, we have achieved the following during the course of the last year **Technical:** (1) Identified polarization as limiting performance, and taken intermediate steps to mitigate its influence on PRV measurement. (2) Replaced the PARVI cryostat from LN2 to mechanical cryocooler operation. This has considerably improved the thermal stability of the optics, which uncontrolled points in the optical train now achieving stability of 1-2 mK per day. The measured absolute RV sensitivity to temperature is about 2 m/s per mK. (3) Added a Fabry-Perot Etalon to monitor the temperature induced drifts; this makes the calibration ruler less sensitive to polarization, because the etalon can be driven by unpolarized thermal light. **Scientific:** (1) Published a paper describing our data calibration and extraction pipeline (2) Are currently preparing a paper demonstrating the measurement of Rossiter-McLaughlin RVs during and exoplanet transit as well as direct measurement of water in the planet's atmosphere during the course of this transit.

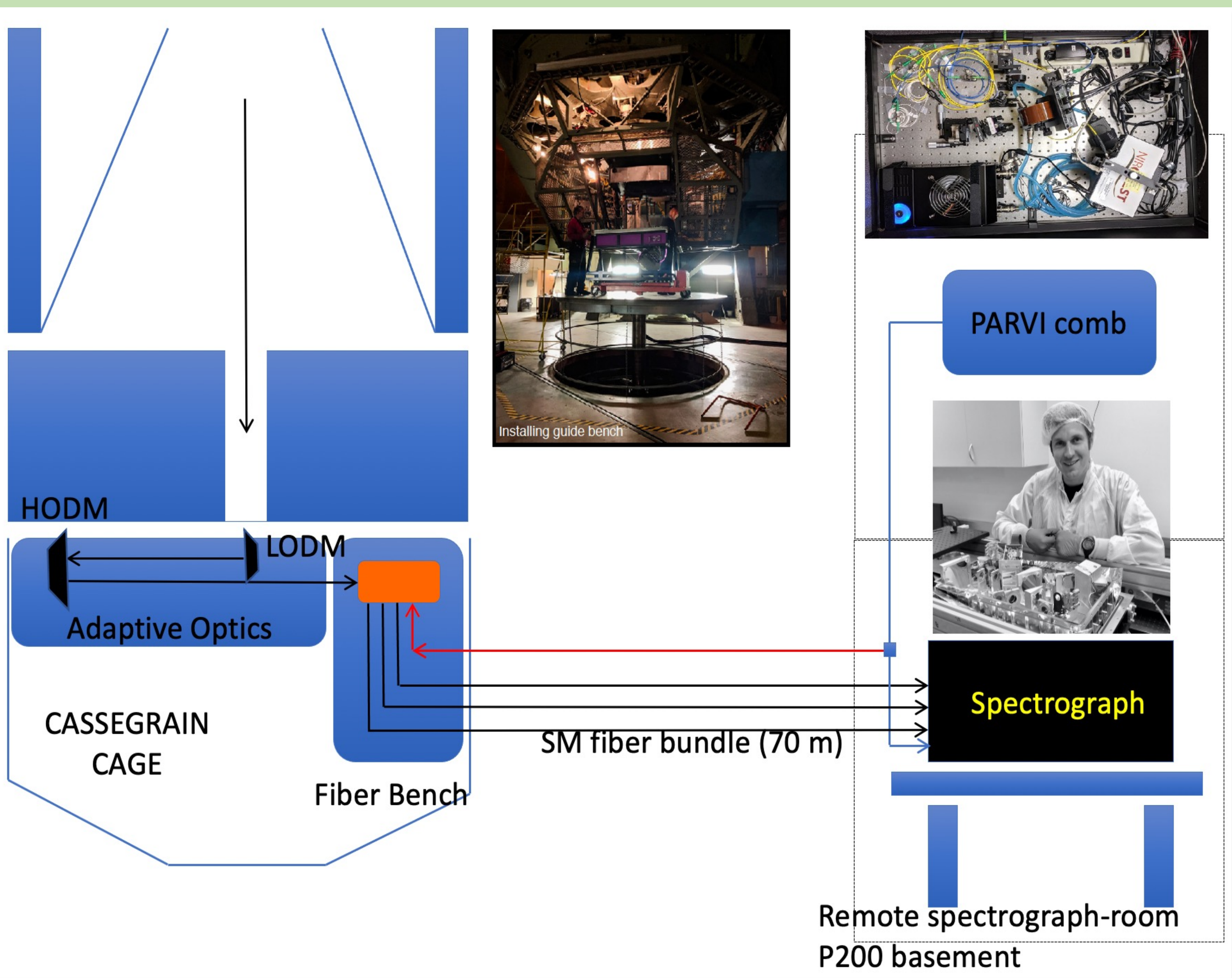

Figure 1: PARVI is a remote spectrograph fed by 70 m of single mode fiber. Light from the telescope is corrected by the Palm 3000 adaptive optics system, and coupled to the fibers. The spectrograph and it's laser frequency comb calibration system is housed in a room in the basement of the 200-in telescope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

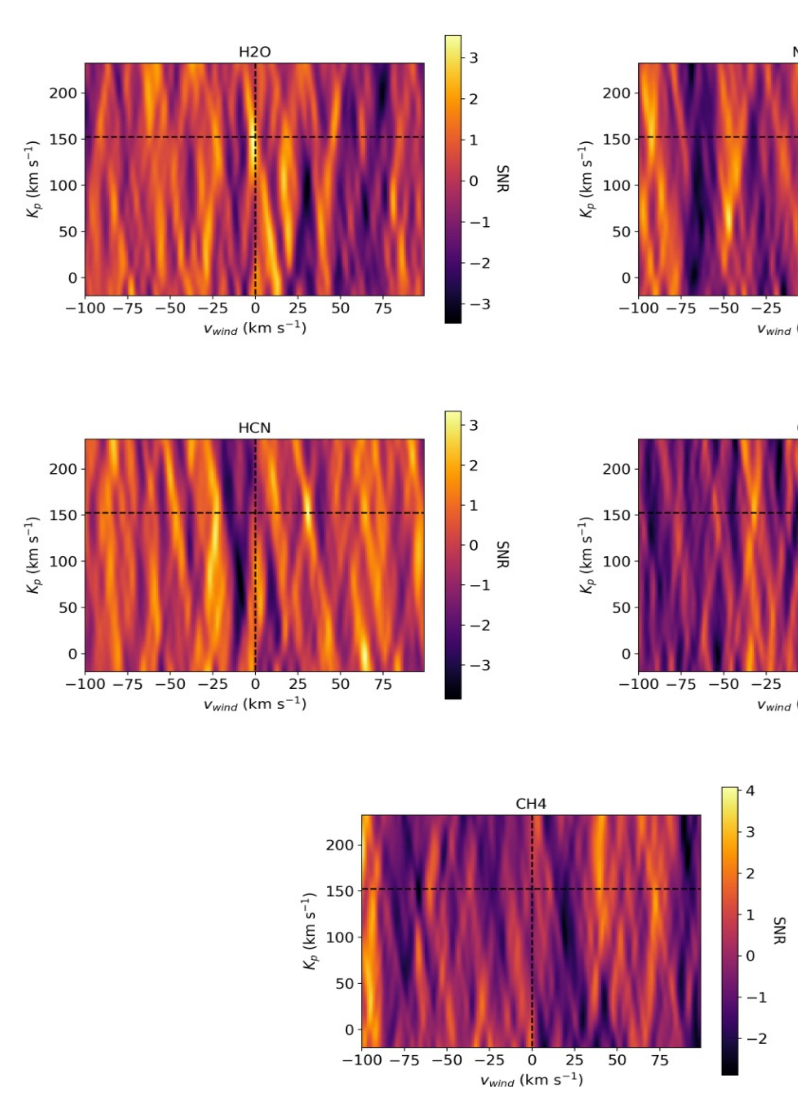

Figure 2: H_2O detection at a S/N of 4.0 using 4 orders of PARVI data near the 1400 nm H_2O band-head, and CO with a S/N of 4.1 using two orders near the 1600 nm band-head. We do not detect any evidence for HCN, NH_3, or CH_4..

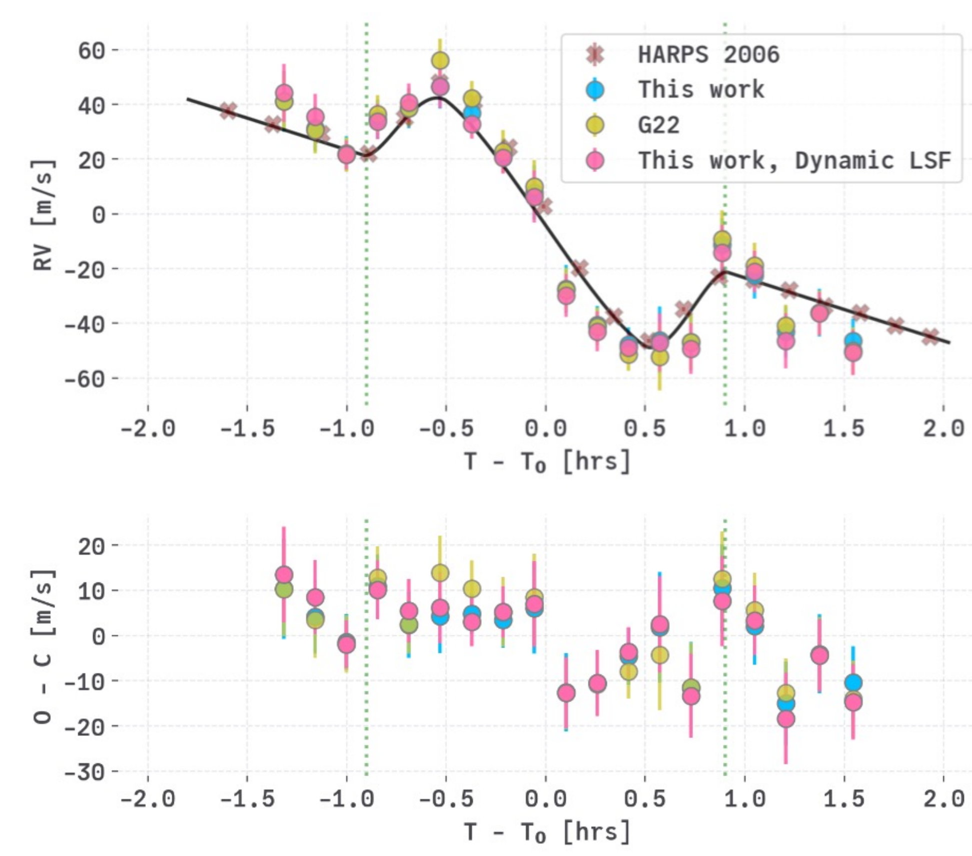

Figure 3: The Rossiter-Mclaughlin signal of the planet HD 189733 b. Top: We plot both sets of PARVI RVs and the the corresponding best-fit RM models in like-colors. In maroon, we plot HARPS RVs from 2006. Ingress start and egress end are marked as vertical dashed green lines. Transit epoch information is generated from the Swarthmore Transit Finder Tool. Bottom: The corresponding residuals for the PARVI RVs.

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Publications:

1. Gibson, R. et al. 2022, "Data reduction pipeline and performance for the Palomar radial velocity instrument," *J. Astron. Telesc. Instrum. Syst.* **8**(3), 038006 (2022), doi: 10.1117/1.JATIS.8.3.038006
2. Cale, B. et al. 2022, "Commissioning Observations of HD189733b with the Palomar Radial Velocity Instrument," submitted to J. Astron. Telesc. Instrum.

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