National Aeronautics and Space Administration

FY23 Strategic Initiatives Research and Technology Development (SRTD)

PARVI Commissioning and Science

Principal Investigator: Gautam Vasisht (326); **Co-Investigators:** Charles Beichman (793), Kittrin Matthews (337), Thomas Lockhart (398), Christopher Paine (382), Mahmood Bagheri (389), Bryson Cale (326), Jennifer Burt (326), Samuel Halverson (383), Rose Gibson (UCLA), Rebecca Oppenheimer (AMNH), Dimitri Mawet (Caltech), Jason Fucik (Caltech), Peter Plavchan (George Mason Uni)

Strategic Focus Area: Extreme Precision Radial Velocities | **Strategic Initiative Leader:** Charles Lawrence

Objectives:

The main objectives of this project were as follows:

1. PARVI instrument commissioning to ensure functionality and performance readiness
2. Demonstrative scientific exploration
3. Showcase stability by maintaining a fiber-to-fiber radial velocity drift of less than 30 cm/s
4. On sky RV error of approximately 1 m/s limited by infrared telluric absorption
5. Maturation of data analysis methods to capitalize on advantages offered by single-mode spectrographs
6. Demonstrate the feasibility of the single mode fiber approach

Background:

1. Departing from conventional methods, the PARVI Instrument employs an AO feed coupled to a single mode fiber-fed compact spectrograph (R = 100,000; covering wavelengths from 1200 to 1800 nm).
2. It is carefully calibrated and continuously monitored using an infrared laser frequency comb and a stable etalon. PARVI achieved its first light in July 2019 on the P200 telescope. Following a period of eased restrictions during the pandemic, PARVI recommenced its commissioning in May 2021
3. The project explores novel technologies, techniques, and strategies aimed at overcoming current limitations in PRV measurement.

Approach:

Our approach in this previous year FY23, focused on three key areas:

1. PARVI's Polarization Challenge: In FY23, we tackled an unexpected polarization sensitivity issue within PARVI. Despite its single-mode fiber setup, PARVI accommodated both polarization modes of the incoming E-field, causing temporal polarization changes due to fiber-induced birefringence. Subtle polarization dependencies were traced to the silicon CX-prism in the spectrograph, leading to a slight angular separation in the Point Spread Functions on the detector. This issue was resolved through a three-step strategy: re-machining cryogenic mounts, annealing the prism, and introducing polarization scrambling equipment in both starlight and reference arms. This approach ensured balanced polarization conditions during starlight integration, allowing PARVI to achieve 10 cm/s fiber-to-fiber stability, surpassing our 30 cm/s goal.

2. Improvements in Wavelength Calibration: In FY23, the PARVI LFC faced two challenges during on-sky operations. Firstly, its spectral coverage spanned 1450 to 1700 nm, leaving half of the spectrograph orders insufficiently calibrated, resulting in RV data loss. Secondly, flattening the comb introduced temporal amplitude disturbances among LFC modes. We addressed these issues by adopting in-situ calibrations using a hermetically packaged Fabry-Perot etalon fed with unpolarized thermal light. While the etalon's stability is lower over multi-day timescales than the comb, it is precisely calibrated against the LFC through weekly daytime procedures. This transition simplified nighttime operations and resolved both calibration challenges.

3. Developmental Work and Scientific Campaigns: Throughout FY23, we conducted technical and scientific campaigns at Palomar, showcasing our progress through publications. Our efforts in these three areas collectively enhanced the functionality and performance of PARVI, marking significant achievements in precision spectroscopy. In the coming few years, we plan to extend PARVI's scope beyond conventional nighttime astronomy by venturing into the realm of infrared wavelength (RV monitoring of the Sun. This endeavor is unique, as at present, most RV monitoring of the Sun is conducted at optical wavelengths.

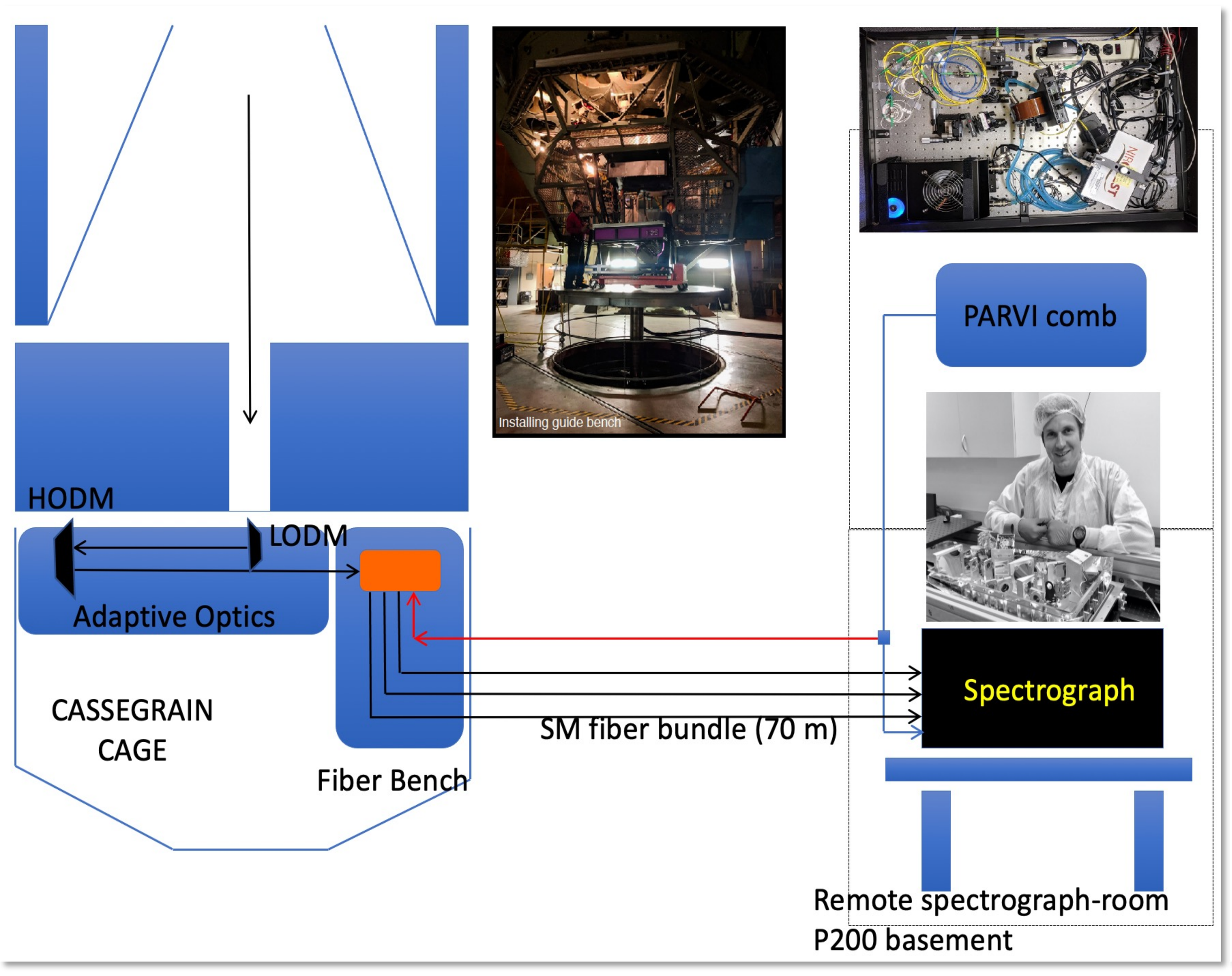

Figure 1: PARVI is a remote spectrograph fed by 70 m of single mode fiber. Light from the telescope is corrected by the Palm 3000 adaptive optics system, and coupled to the fibers. The spectrograph and it's laser frequency comb calibration system is housed in a room in the basement of the 200-in telescope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

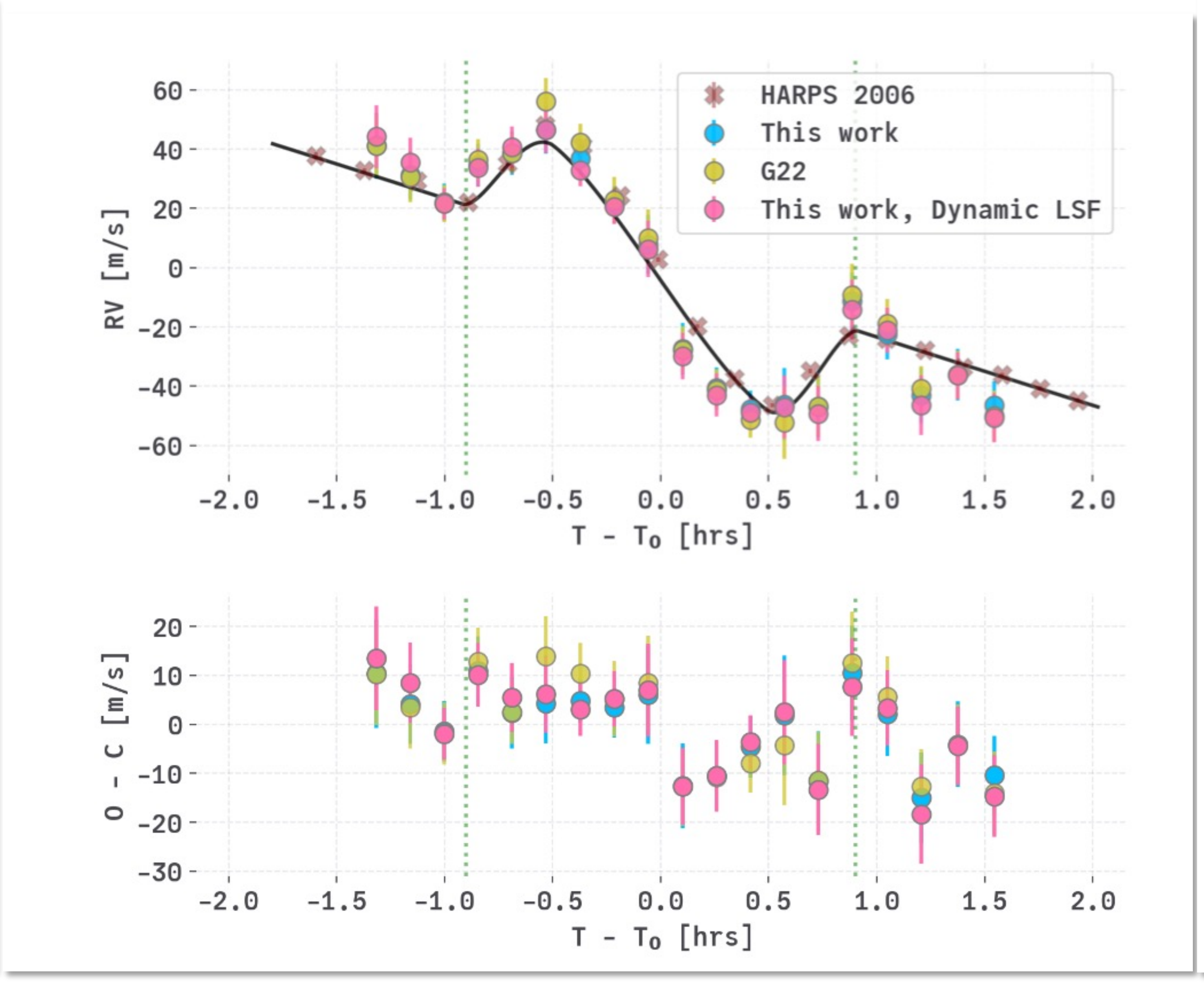

Figure 2: The Rossiter-Mclaughlin signal of the planet HD 189733 b. Top: We plot both sets of PARVI RVs and the the corresponding best-fit RM models in like-colors. In maroon, we plot HARPS RVs from 2006. Ingress start and egress end are marked as vertical dashed green lines. Transit epoch information is generated from the Swarthmore Transit Finder Tool. Bottom: The corresponding residuals for the PARVI RVs.

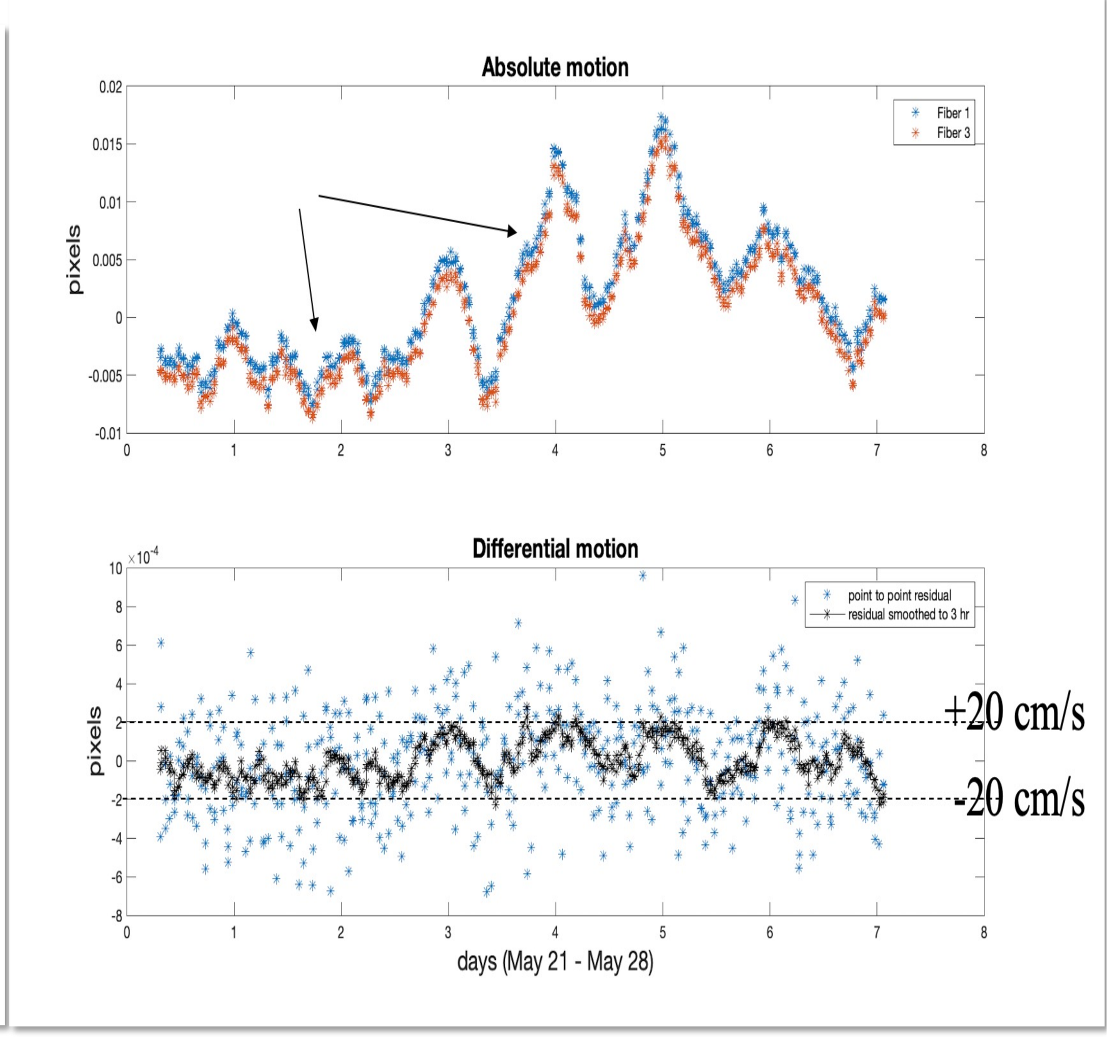

Figure 3: Fiber-2-fiber stability of the instrument. Top: absolute stability over a period of a week is about 15 m/s with diurnal and other environmental variation. Bottom: The differential stability is about 10 cm/s. Differential residuals are primarily diurnal in nature.

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

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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. 2023, "Commissioning Observations of HD189733b with the Palomar Radial Velocity Instrument," *J. Astron. Telesc. Instrum.* 9, 3, 038006 https://doi.org/10.1117/1.JATIS.9.3.03800

PI/Task Mgr. Contact Information:

Gautam.Vasisht@jpl.nasa.gov