On-Sky Tests of Fiber Scrambling with the Habitable-zone Planet Finder & NEID

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Fiber Illumination Errors are Uncalibratable!

Instrumental effects such as thermo-mechanical and detector variations can be calibrated out using a stable wavelength reference such as a Laser Frequency Comb or etalon cavity. However **fiber & illumination errors are uncalibratable and therefore must be understood and mitigated during design, fabrication and testing.** We discuss some of the on-sky tests performed with the Habitable-zone Planet Finder (HPF) and NEID to validate the lab tests of our ball lens double scrambler for both these instruments, and also demonstrate a viable option for the next generation of EPRV instruments to mitigate these errors.

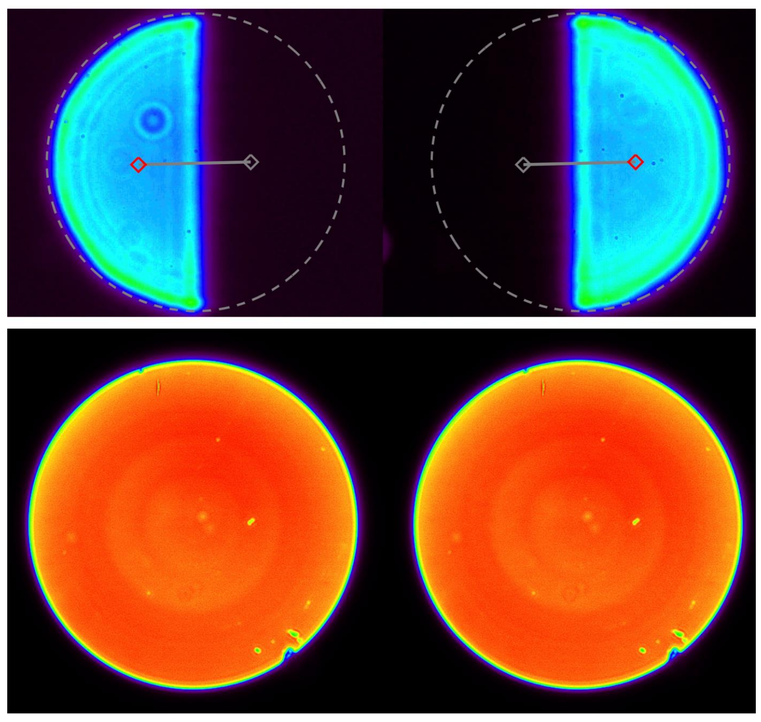
Ball-Lens Double Scrambler

Described in Halverson & Roy et al. (2015), the double-scrambler used in HPF and NEID utilizes a single ball lens of refractive index $n \approx 2$ to efficiently exchange fiber near & far field.

Lab tests (right) demonstrate high scrambling gains (> 10,000) which desensitize the fiber output from input illumination variations.

Very important for fiber-fed EPRV spectrographs without gas-absorption cells!

Input Pupil Changes →

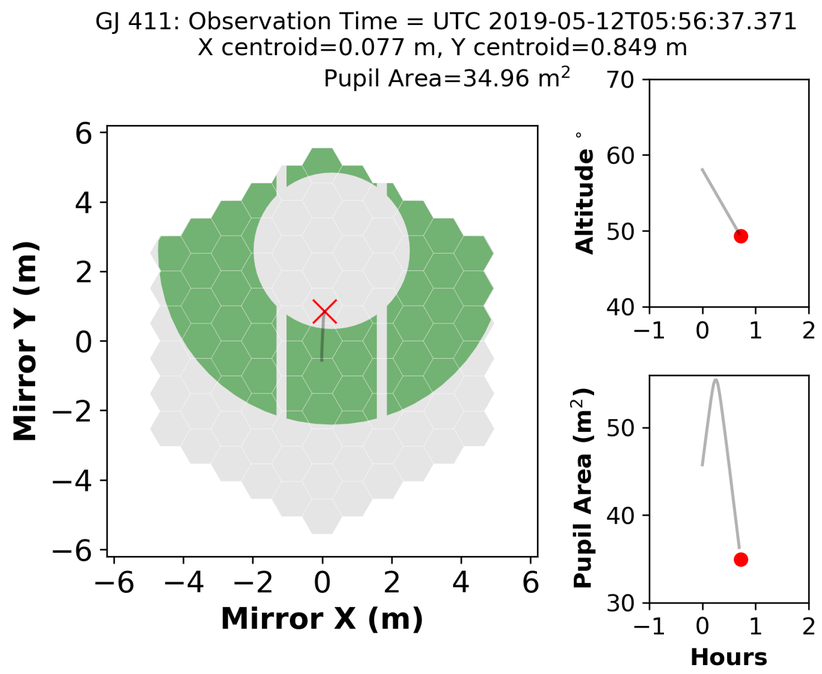


Minimal Changes in Output →

HPF @ HET, McDonald Observatory

0. HPF is a near-infrared RV spectrograph located at the Hobby-Eberly Telescope (HET) which is a 10-m fixed altitude telescope in Texas, USA. As the telescope tracks an object rising (or setting), the effective telescope pupil area can change by almost 2x!

1. We model the telescope illumination as a collection of individual elements to simulate the effective pupil after accounting for changing altitude and obscuration.



2. As part of our engineering tests, we observe the bright M-dwarf GJ-411 over a couple years and obtain 1200 exposures across 40 visits.

3. We then search for linear correlations between these HPF RVs for GJ 411 and telescope altitude, pupil centroid, pupil area) and environmental (temperature, seeing, humidity, sky brightness) parameters.

4. We find no discernable RV trends as a function of these parameters and rule out illumination-based RV errors for at 4.6 ± 26 cm/s.

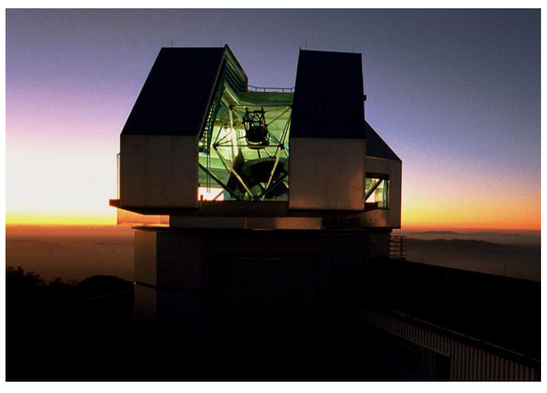
Animations of pupil changes

See Kanodia et al. (2021) for more details

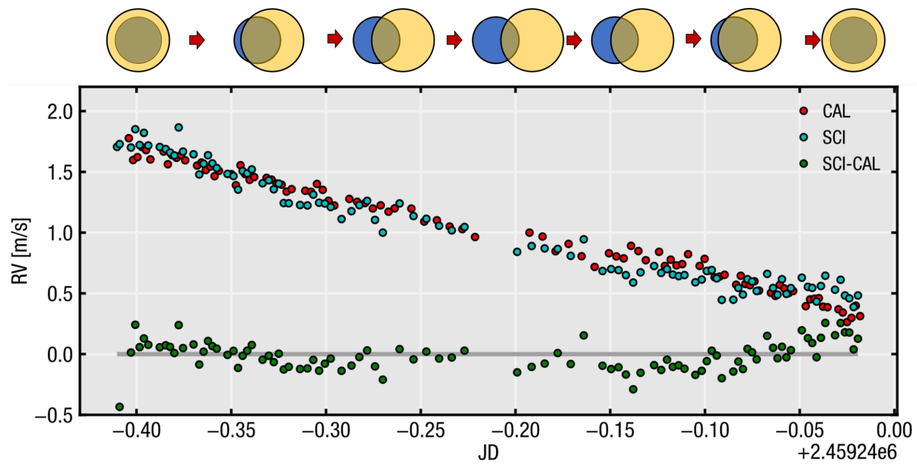
NEID @ WIYN, Kitt Peak

NEID is an optical RV spectrograph located at the WIYN 3.5 m telescope in Arizona, USA. It uses a similar ball lens double scrambler system as HPF.

With an instrumental error budget of only 27 cm/s, the uncalibratable illumination errors must be mitigated by the scrambling system. These also dictate the pointing and guiding tolerances for the telescope and port adapter.



During commissioning, we used a dedicated Calibration fiber and deterministically offset it on the face of the Science fiber to place limits on the scrambling gain >10,000 or roughly near-field scrambling error < 4.0 cm/s.



See Kanodia et al. (in prep.) for more details

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