Use of Sky Fiber to Correct for Solar Light Contamination in EPRV

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Abstract

Solar light contamination from lunar and atmospheric scattering of sunlight, results in systematic errors in stellar radial velocity (RV) measurements. It can significantly reduce the 10 cms^{-1} sensitivity required to detect and characterize terrestrial exoplanets in or near habitable zones of Sun-like stars (Roy *et al.*, 2020). NEID (NN-EXPLORE Exoplanet Investigations with Doppler Spectroscopy) is an optical EPRV Spectrograph on the WIYN 3.5-meter Telescope at Kitt Peak National Observatory, Arizona, USA. The NEID fiber head comprises sky fiber, science fiber, cal fiber, and coherent fiber bundles (CFBs). In this work, I present the effectiveness of using the simultaneous data from the sky fiber to correct for the solar light contamination in the science fiber spectra of the star. This correction technique is expected to reduce this source of sky contamination error to below the photon-noise limit of typical stellar observations.

Introduction

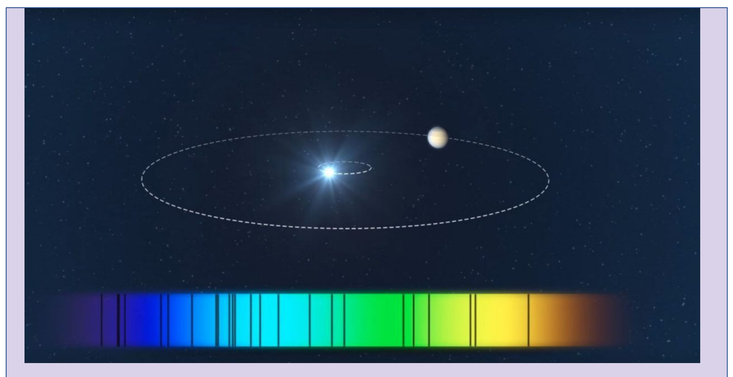

Figure 1: Radial velocity method of exoplanet detection (Image credits: eso.org)

Effect of Solar Contamination on RV measurements:

- Terrestrial-mass planets orbiting Sun-like stars induce Doppler reflex signals of ~10 cm s^{-1} , which nominally defines the precision goal for many next-generation instruments.
- Solar contamination, due to moonlight and atmospheric scattering of sunlight, can cause systematic errors in stellar radial velocity (RV) measurements that significantly detract from the ~10 cm s-1 sensitivity.

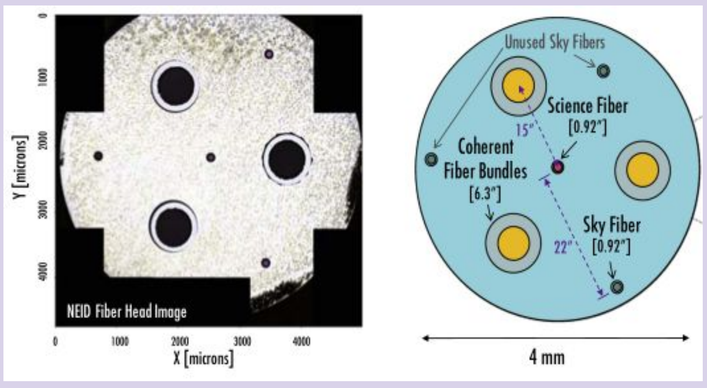

Figure 2: Left: NEID high-resolution (HR) mode port adapter fiber head that collects light from the telescope for transportation to the spectrometer.
Right: Diagram showing the relative placement of the coherent fiber bundles (CFBs), science fiber, and the sky fiber. (Image credits: Roy *et al.* 2020)

- NEID is an astronomical spectrograph deployed on the 3.5-meter WIYN Telescope at Kitt Peak National Observatory in Arizona.
- Uses simultaneous spectrometer sky fibers that could reliably correct for the scattered sunlight noise.

Methodology

Cross-correlation functions (CCFs) :

- CCFs yield the measurements of radial velocity (RV).
- RVs are derived by cross-correlating target spectra with a weighted numerical stellar mask based on spectral type.
- The order-by-order CCFs are then summed, and the sum is fit by a Gaussian to measure a single RV value for the observation.

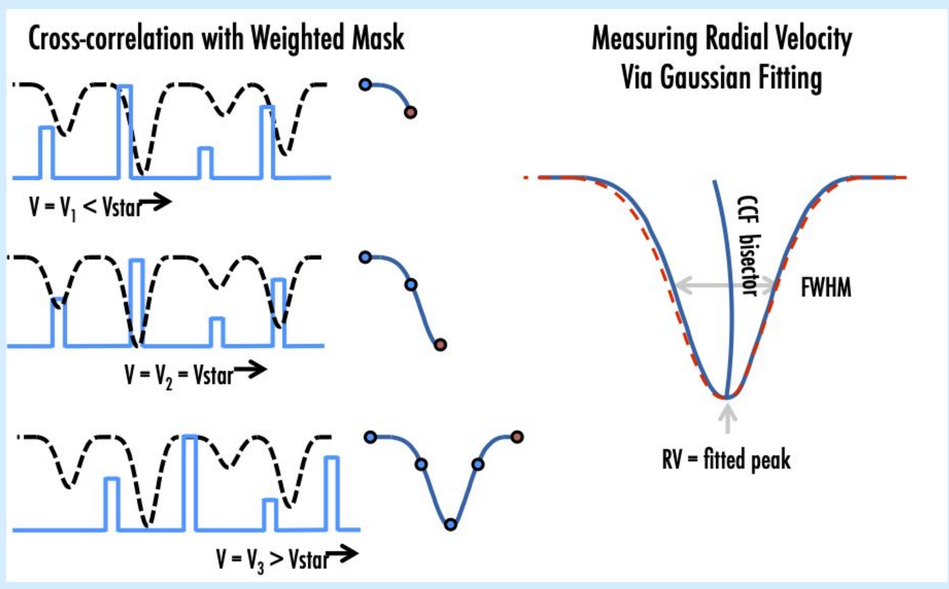

Figure 3: Cross Correlation Function (Image credits: NEID DRP)
The order-by-order CCFs are summed, and the sum is fit by a Gaussian to measure a single RV value for the observation.

In the NEID Data Reduction Pipeline(DRP), NEID data products are defined for three different data levels:

- Level 0: Raw data produced by the NEID instrument control system at the WIYN observatory.
- Level 1: Extracted, wavelength calibrated spectra.
- Level 2: Derived products, including radial velocities, activity indicators, and telluric models.

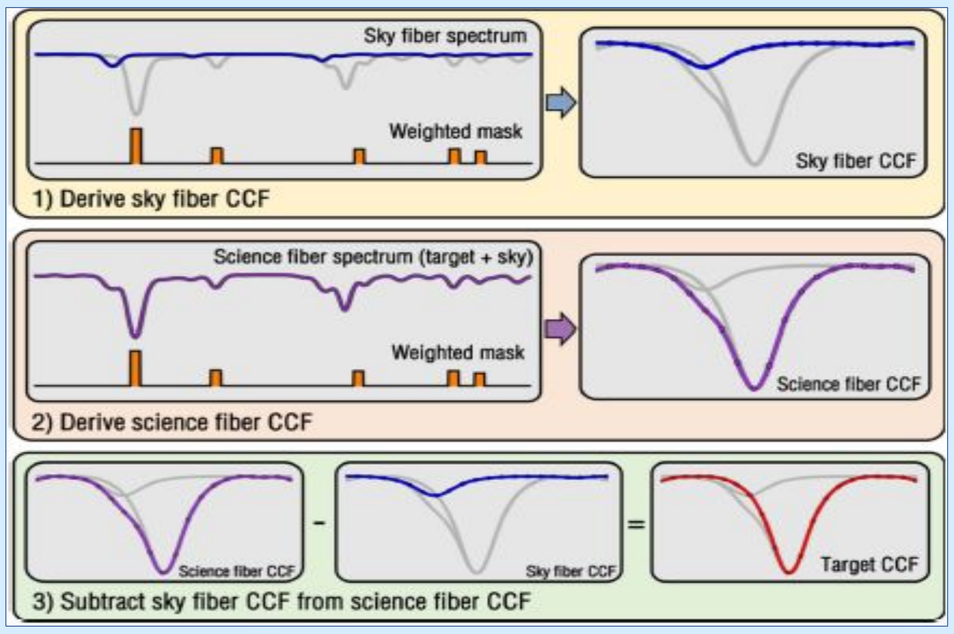

Figure 4: Overview of the direct sky fiber cross-correlation CCF subtraction technique (Image credits: Roy *et al.* 2020)

- The CCF of the sky fiber is computed by cross-correlation with a numerical mask.
- Sky fiber CCF is subtracted from the CCF of the science fiber spectrum.
- The final target RV is derived from the resultant corrected target CCF.

In our case:

- Using a brightness tool, calculated sky contamination for more abundant target data.
- Following Roy *et al.* 2020, modified the pipeline configuration to get CCF for sky fiber. Plots are attached in the Results section.
- Ran CCF code on science fiber of solar file convolved with not just G2 but M2 and K2 espresso masks as well.
- Made a test pipeline code to predict expected sky contamination, for a given star with a mask of choice, from a solar spectrum convolved with a given mask.

Early Results

- Obtained the CCF of the scattered light in the sky fiber of NEID data.
- For solar type stars, the signal we obtained from sky fiber was orders of magnitude stronger than what we expected. This was found to be fiber to fiber scattered light contamination.
- For m-dwarfs, a scattered solar light signal was observed, which matched our theoretical prediction of solar contamination signal using G2 mask convolved solar spectrum, but it was higher by a scaling factor of around 5.
- But in the exact same conditions, for spectrum observed during dark sky, no signal was seen, thus confirming that sky fiber is working.

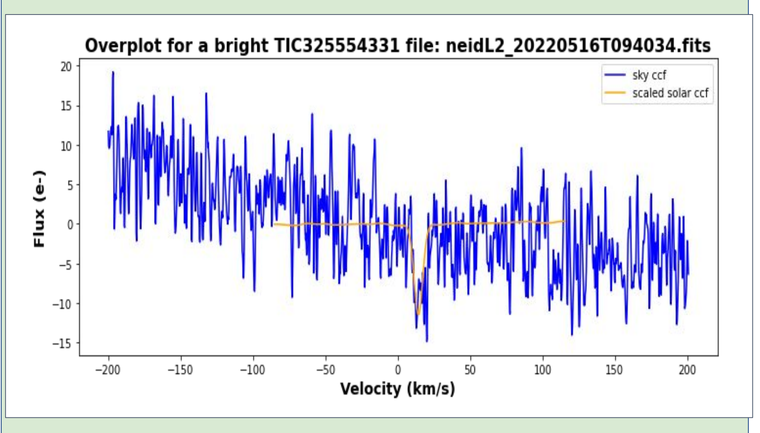

Figure 5: Overplots for scaled-down solar spectrum and sky ccf for Barnard's star (Spectrum observed during bright sky)

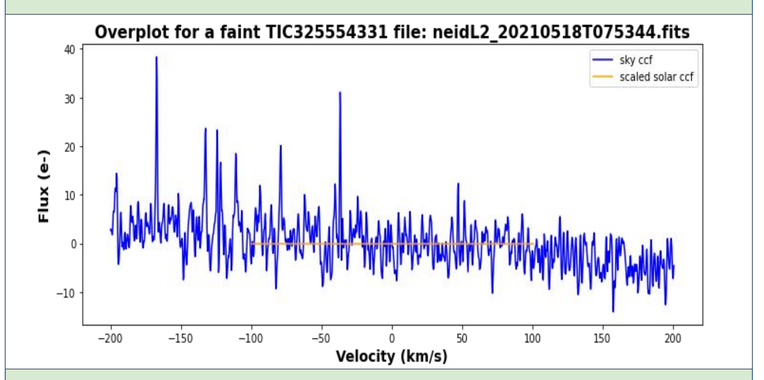

Figure 6: Overplots for scaled-down solar spectrum and sky ccf for Barnard's star (Spectrum observed during dark sky)

Ongoing Work/ Discussion

- Detailed analysis shows that scattered starlight in the science fiber is overwhelming the signal in the sky fiber ccf if the spectral type of the star is close to the Sun.
- Designing a method to predict the sky fiber contamination in solar like stars using the sky fiber data in M type star observations as well as CFB data.
- Will subtract the sky fiber CCF from the science fiber CCF for the masks with the right spectral types. Thus correcting for the contamination.

Hence aiming to mitigate the deleterious effects of solar contamination on RV precision. Thus the work intends to aid in identifying terrestrial planets in the habitable zones (HZs) of other stars.

References:

Roy *et al.* 2020
Massey *et al.* 2000
Yoachim *et al.* 2016
Neugent *et al.* 2010

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More questions? Find me at EPRV or over email: komalbali3011@gmail.com

Find my EPRV 5 poster here: at this qr code.