(1000x) Stability boosting, and characterization, of high resolution spectrographs using an externally dispersed interferometer

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Both On-sky and Off-sky uses benefit Doppler precision

Extreme Precision Radial Velocity 5 Mtg.
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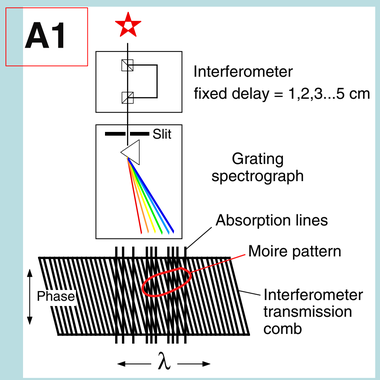
A1

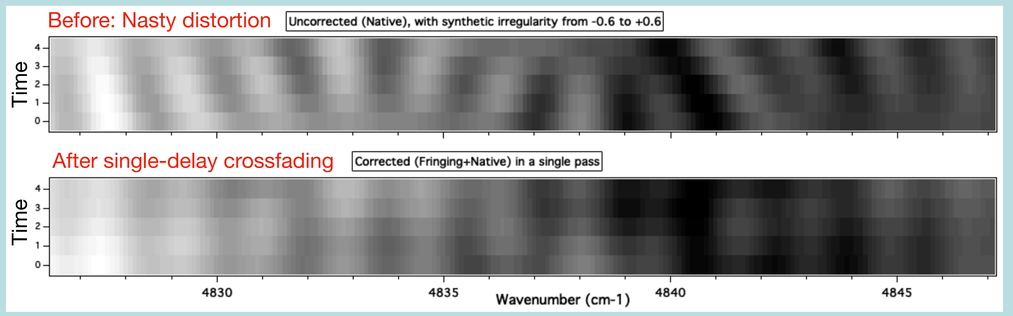


On-sky stability topic

"Crossfading EDI" uses an in-series interferometer to stabilize against unknown and irregular on-sky spectrograph drifts by combining fringing and nonfringing components. These react oppositely in phase to a disperser or detector wavelength drift, and thus can be made to cancel in analysis. This stability gain (~1000x) multiplies conventional stability mitigations. Since the periodic comb *multiplies* rather than adds, science and calibration signals fall on exactly the same pixels, maximizing ability to compensate for instrumental distortions– improving RV precision.

Demo stabilizing the most egregious type of drift: bipolar

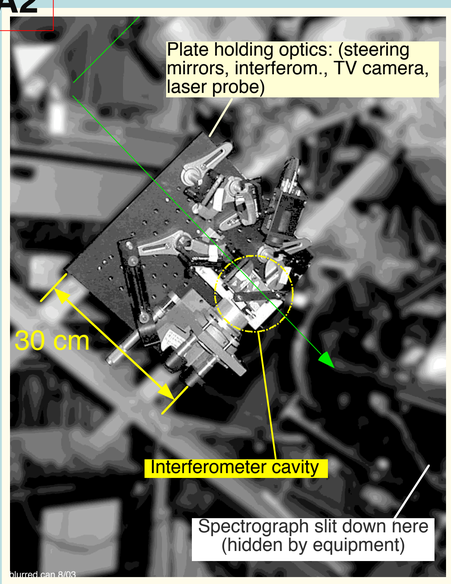
A5



You can't repair this type of drift by a simple translation, but crossfading fixes it!

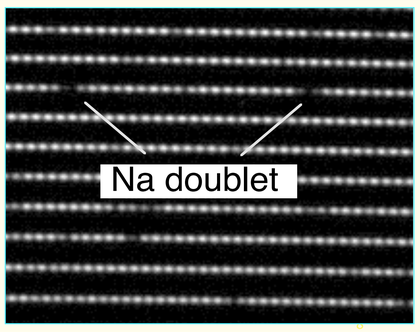
(A1) Externally Dispersed Interferometer (EDI) scheme. (A2) EDI inserted into beam prior to Hamilton echelle spectrograph at Lick Obs. (A3) Snippet of echelle spectra around sodium doublet (589 nm) showing extremely periodic interferometer comb multiplying stellar spectrum. (A4) Demo of deliberately shifting raw data (dashed lines showing native spectral shift)--yet the crossfaded output (red peak) does not shift. (A5) Demo on the worst kind of shift: irregular and bipolar. (A6) Demo on data from Hale telescope. (A7) Demo showing 1300x stability after 3 iterations, and optional 2x resolution boost.

A2



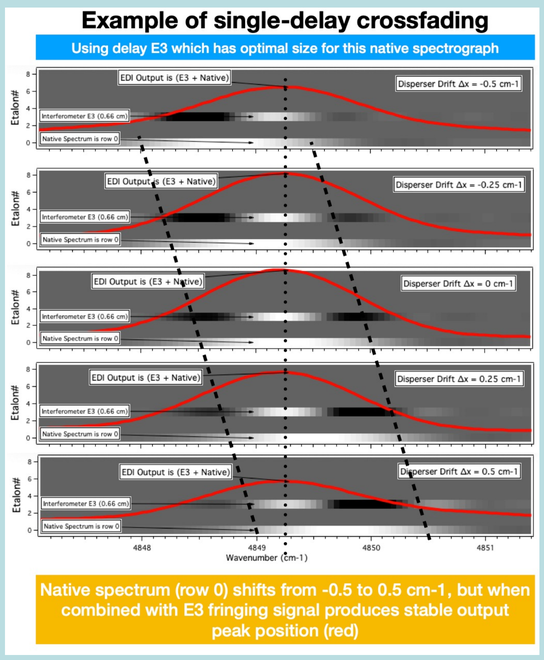
Lick – Hamilton feed
(single output)

A3

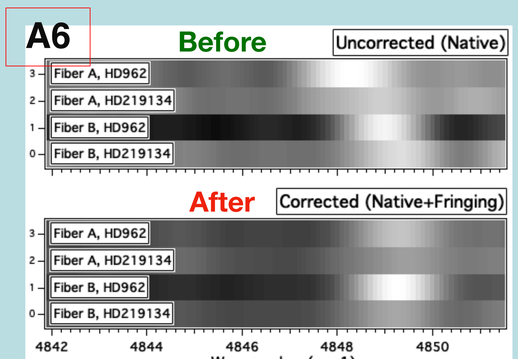


Echelle Data: Interferometer fringes beating with a sample of echelle spectrum orders

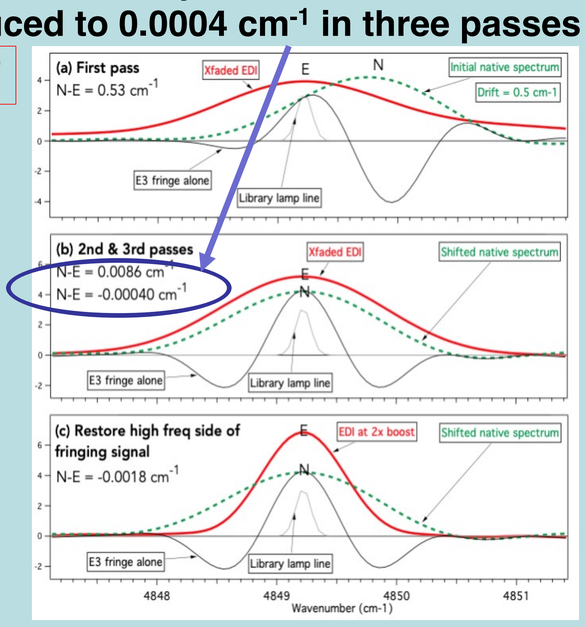
A4



A6



A7



1300x stability: 0.53 cm^{-1} initial insult reduced to 0.0004 cm^{-1} in three passes

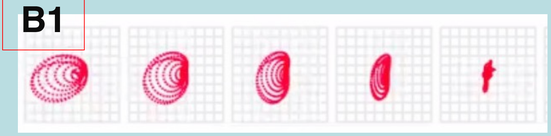
On-sky stability topic
Off-sky characterization topic

Off-sky characterization topic

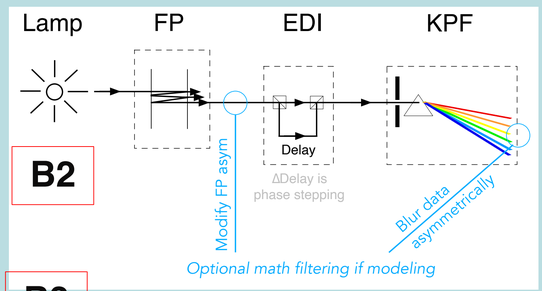
A symmetric PSF is optimal for Doppler stability. We used an EDI with the Keck Planet Finder spectrograph during off-sky engineering tests at UC Berkeley to characterize PSF asymmetry

A white light illuminated Fabry-Perot generated high frequency spectral information at discrete frequencies (simplifying analysis). By comparing fringing and nonfringing signal components that observe the same source spectrum simultaneously but using different signal routes (due to the heterodyning of fringing), we are able to tease out the effect of spectrograph point spread function (PSF) asymmetry independent of source asymmetry.

B1



B2



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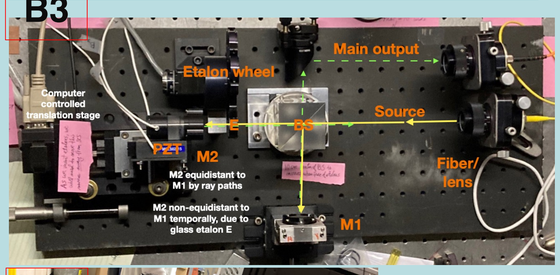
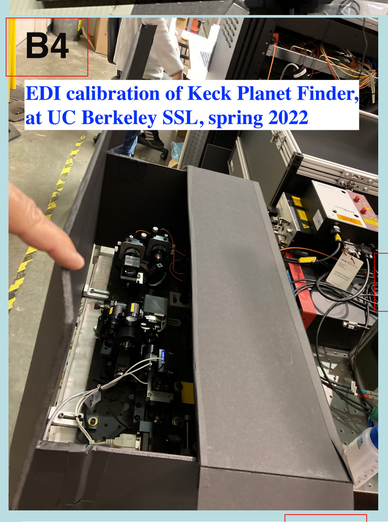
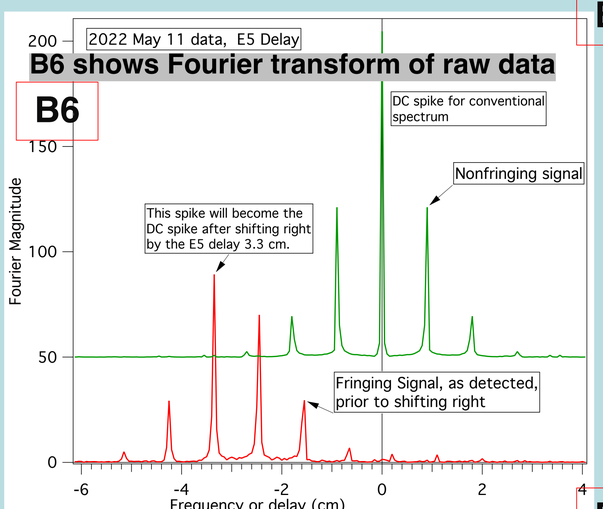


B4

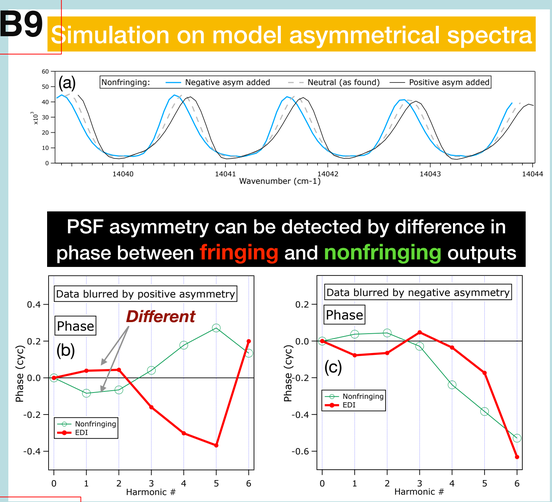


(B1) Ray tracing shows potential asymmetry (graphic courtesy KPF team). (B2) Schematic: continuum lamp into Fabry-Perot (FP) into EDI interferometer into KPF spectrograph. (B3 & B4) Photos of Michelson EDI interferometer with selectable delays and phase stepping PZT mirror. (B5) Example phase stepped data. (B6) Fourier transform of raw data showing harmonics of fringing (red) and native (green) components. The optical heterodyning shifted red harmonics to left. These will be restored to original frequencies via shifting 3.3 cm (the delay) to right by math. This increases effective sensitivity envelope to higher than native KPF used without EDI (B7 & B8) Results for fringing (red) and native (green) spectra agree well. (B9) In simulations with deliberate asymmetric slit blur the fringing and nonfringing curves differ in phase behavior, independent of source asymmetry, providing means for measuring PSF asymmetry. (B10) Results for a small section of KPF: little asymmetry for low harmonics and possible asymmetry at higher harmonics. (This particular low finesse FP emits few high harmonics.)

B6

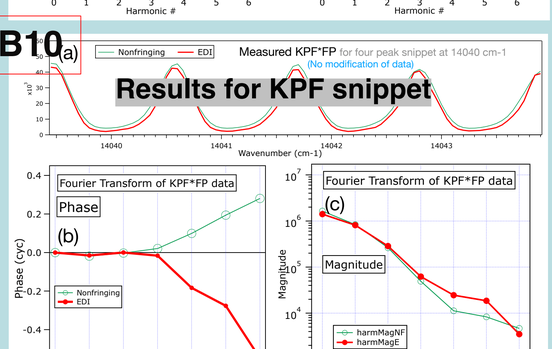


B9

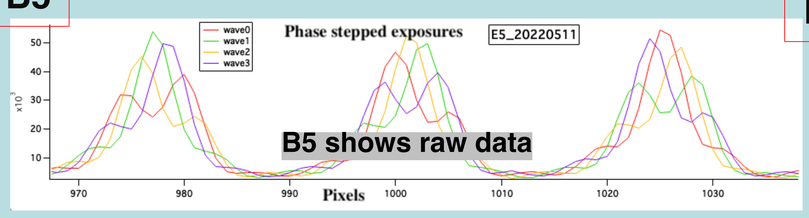


Future use with Laser Frequency Comb instead of this low finesse FP would provide more energy in higher harmonics. LFC was not operational the day we took data.

B10



B5



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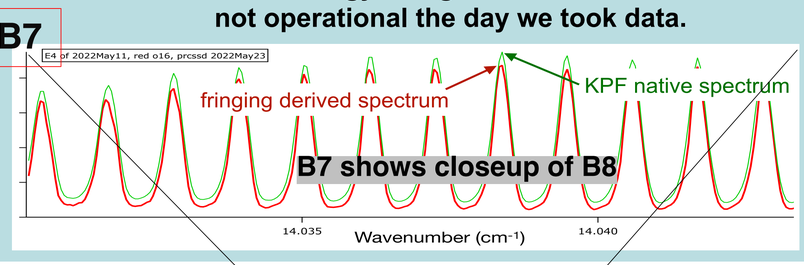
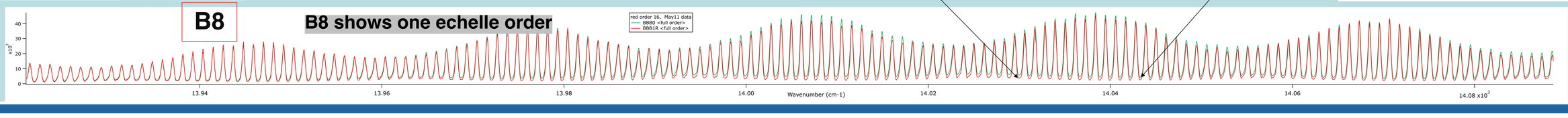


B8



Paper (2021) on crossfading stability method
https://doi.org/10.1117/1.JATIS.7.2.025006

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doi: 10.1117/12.2628388 (More details on single delay stability, SPIE 2022)

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doi: 10.1117/12.2627160 (More details EDI on KPF, SPIE 2022)

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