Canceling Spectrograph PSF Drift Error by Mixing Interferometer Delay Pairs

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EDI = interferometer in series with your spectrograph

Benefits:
- 3x-10x+ **boost in resolution** across native spectrograph bandwidth,
- 20x - 350x+ **boost in robustness** against PSF drift,
- (these stability benefits *multiply* your existing environmental control measures)
- Complete **rejection of bad pixels**, detector bias, other fixed pattern noises,
- **Defeat classical limits imposed by slit width**, focal blur, wandering focal spot, sparse pixel density, irregularly manufactured pixel position, atmospheric distortions, thermal drifts, changing gravity vector, changing fiber mode shape, changing pupil shape, drifts in detector bias,
- Use of a **spectral comb calibrator** without spending $$$,
- **Precision Doppler radial velocimetry** (exoplanet discovered in 2006, J. Ge group)
- **Competitive** overall photon SNR similar to native having classically reduced slitwidth
- Photon noise **uncorrelated** with native so net SNR improved
- Local photon SNR at **high feature frequencies** vastly exceeds native

Cost: more complicated data analysis, some parasitic flux loss, read noise increase

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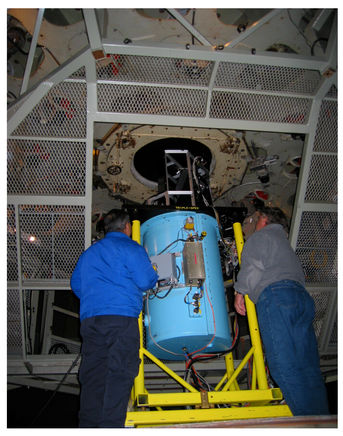
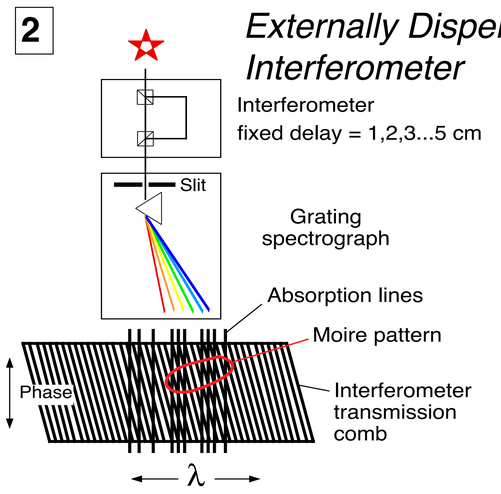


Hale 200 inch telescope, Cassegrain output, EDI (black) sits atop (blue) NIR TripleSpec
(2700 res, 4100-11,000 cm-1, 2.4-0.9 micron)

2

Externally Dispersed Interferometer



Moire patterns produced by apparatus.
What if moire patterns are shifted by Δλ spectrograph error?
No worry, opposite moire slopes cancel!

Horribly large and irregular PSF drifts afflicted native spectrograph

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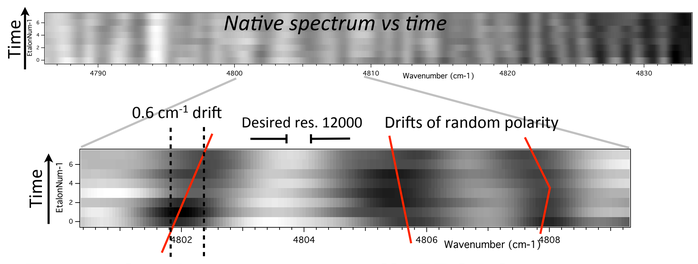

But this does not spoil EDI hi res output spectra!

Explain in Fourier space

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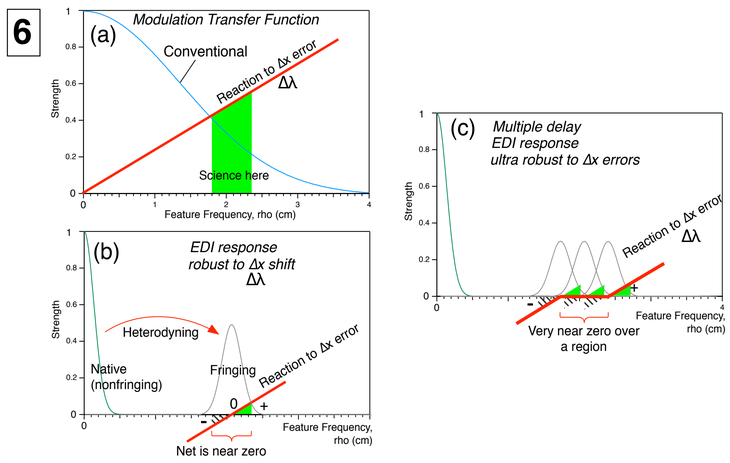

Translational Reaction Coefficient
TRC = ΔλOut / ΔλInsult

Using original lineshape: **20x** reduction

EDI result is sum over wavelets. Native spectrograph affects only envelope, not wavelet phase

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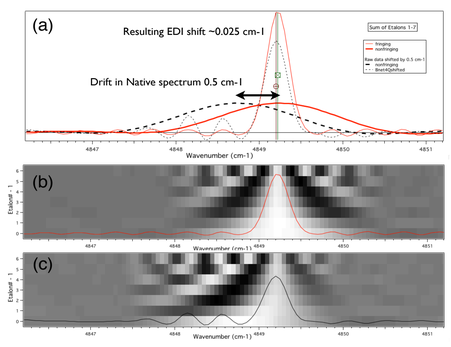

20x smaller reaction to native PSF wavelength shift

Even smaller is expected with special weighting of lineshapes (under investigation)

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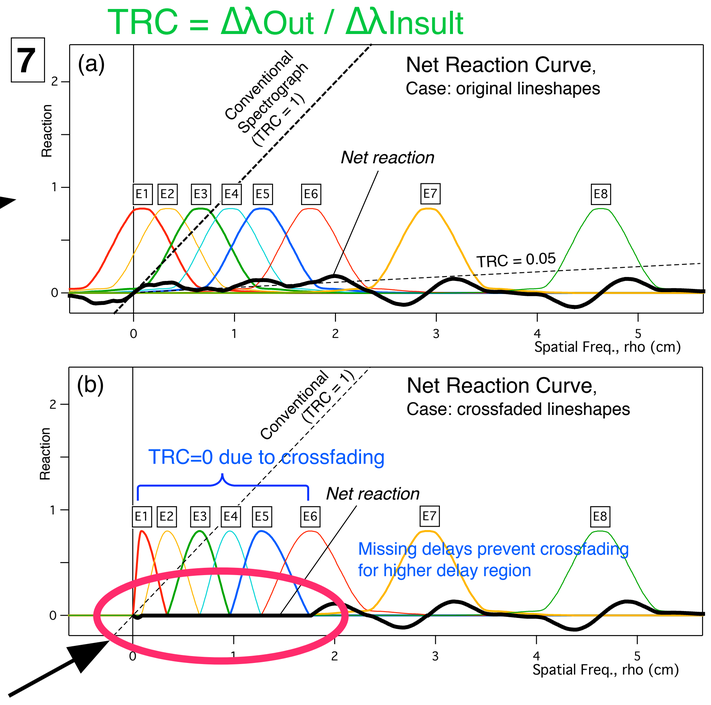

Reshape to Triangle or Sinc function: 350x

Simulation using sinc function lineshape and two delays

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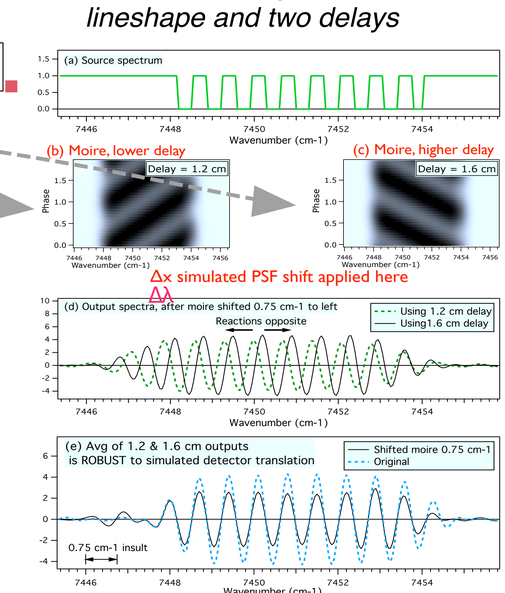

Output shift reduced 350x !

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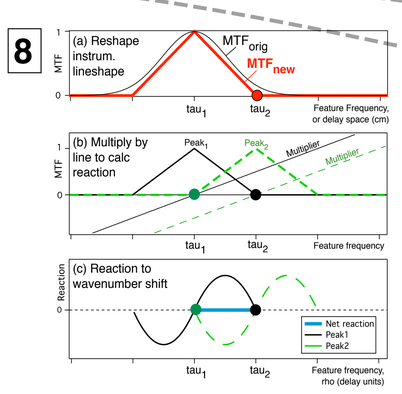

Method for implementing simultaneous multiple delays

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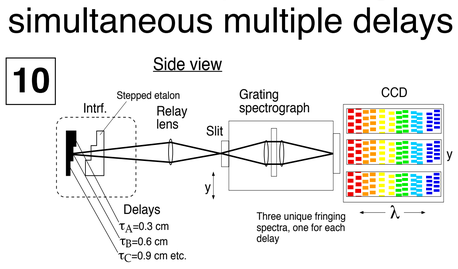

Method called "crossfading"

Output spectra from sum over wavelets, using multiple delays producing different wavelet periods

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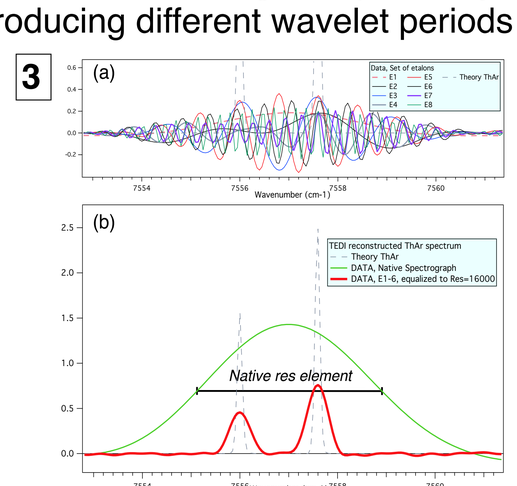

We describe demonstrations of remarkable robustness to instrumental noises by using a multiple delay externally dispersed interferometer (EDI) [Fig2] on stellar observations at the Hale telescope [Fig1]. Previous observatory EDI demonstrations used a single delay. The EDI (also called TEDI) is an interferometer in series with a spectrograph, and has boosted the 2,700 resolution of the native TripleSpec NIR spectrograph (950-2450 nm) by as much as 10x to 27,000, using 7 overlapping delays up to 3 cm.

Remarkably, we observed a ~20x reduction [Fig5, 7a] of reaction in the output spectrum to PSF shifts of the native spectrograph along the dispersion direction, using our standard processing. This allowed high resolution observations under conditions of severe and irregular PSF drift otherwise not possible without the interferometer.

Furthermore, we recently discovered an improved method of weighting [Fig8] and mixing data between pairs of delays that can theoretically further reduce the net reaction to PSF drift to zero [Fig7b]. We demonstrate a 350x reduction in reaction to a native PSF shift using a simple simulation [Fig9]. This technique could similarly reduce radial velocity noise for future EDI's that use two delays that are overlapping in delay space, or a single delay overlapped with the native peak.

We observed superb rejection of fixed pattern noises [Fig13] due to bad pixels, since the fringing signal responds only to changes in multiple exposures synchronous to the applied delay dithering.

We show an extremely high dynamic range EDI measurement [Fig13] of our ThAr lamp compared to a literature ThAr spectrum, observing weak features ~0.001x height of nearest strong line) that occur between the major lines. Because of individuality of each reference lamp, accurate knowledge of its spectrum between the (unfortunately) sparse major lines is important for precision radial velocimetry.

Example EDI output spectra

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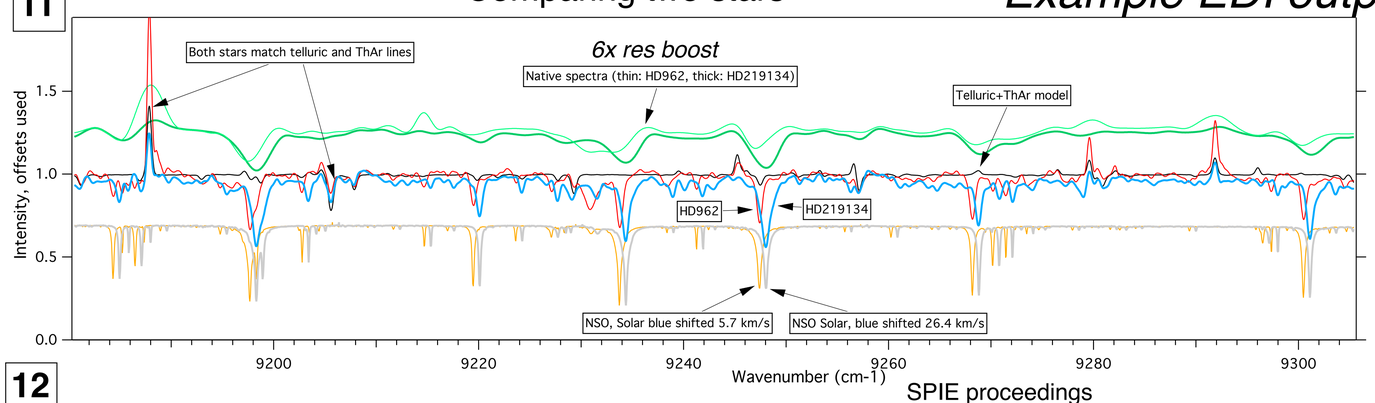
Comparing two stars



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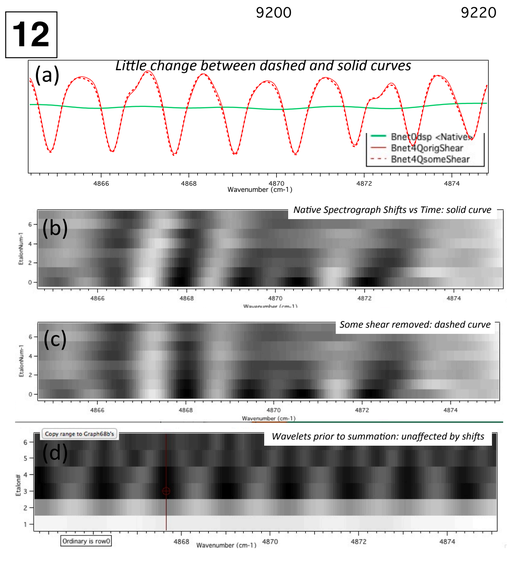

Telluric feature under two different PSF drifts
(Dash & solid red curves)

Original
(Solid red curve)

Bulk slant removed
(Dashed red curve)

Underlying wavelets

SPIE proceedings
http://spectralfringe.org/EDI/MyPubs4/EdinburghSPIEgen.pdf

Jrnl artcl. on Data Anal & Instr. Noise
http://spectralfringe.org/EDI/MyPubs4/TediTenxPart1gen.pdf

Jrnl artcl. on Photon Noise
http://spectralfringe.org/EDI/MyPubs4/TediTenxPart2gen.pdf

Comparing our ThAr lamp to NIST lamp

Extremely high dynamic range

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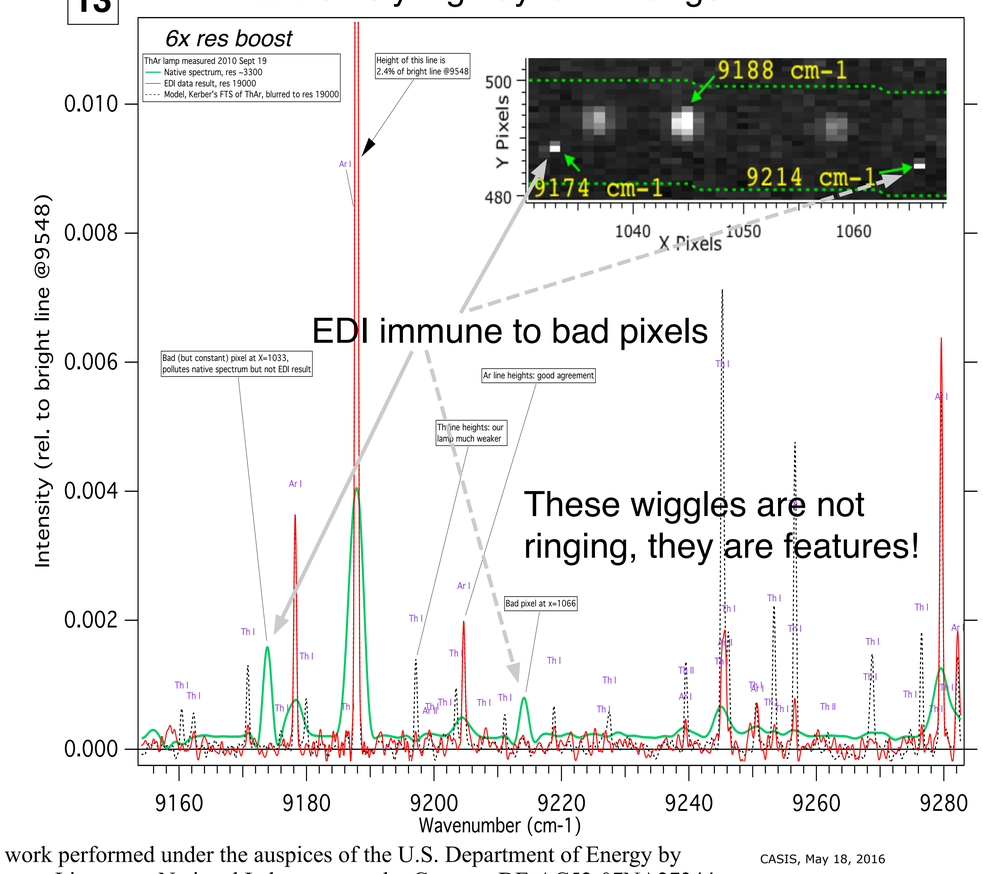

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