# Crossfaded* Externally Dispersed Interferometer Testbed for 1000x Improved Doppler Spectrograph Stability

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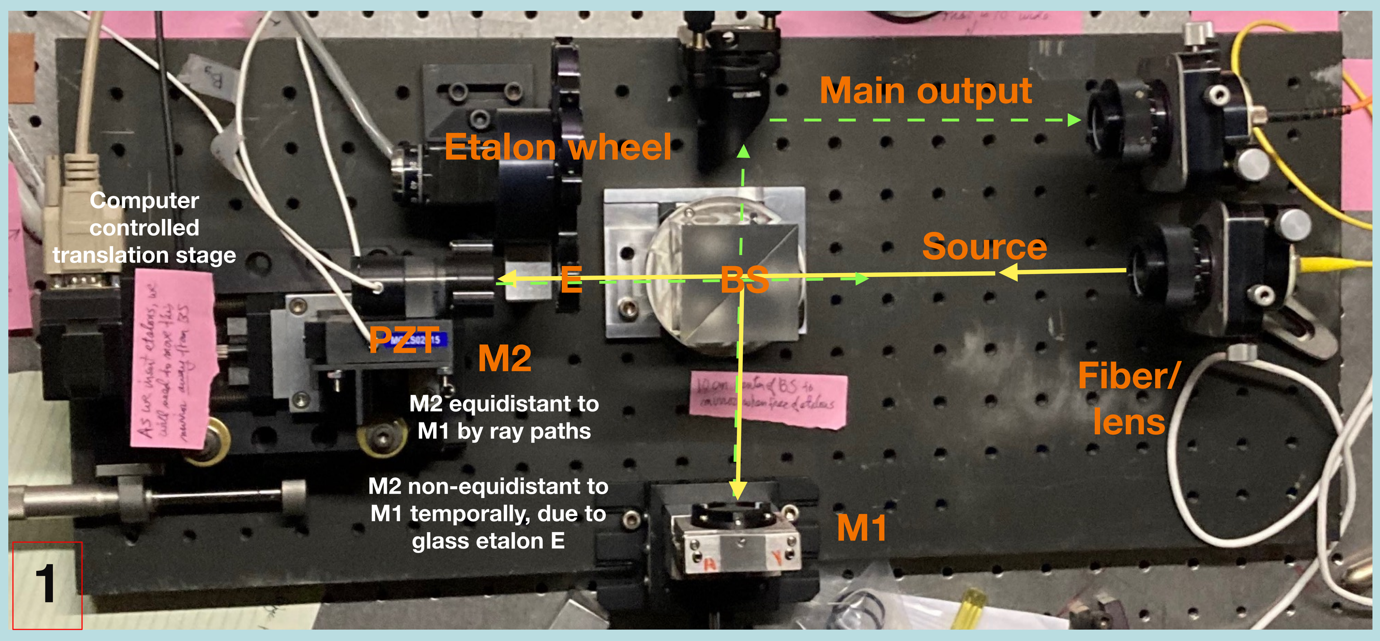
***Crossfading - combining two signal components using frequency dependent weights - can stabilize a grating spectrograph against uncontrolled wavelength drifts by using an external interferometer (EDI). This creates moiré patterns, which are processed into wavelets. The system reduces wavelength drifts by ~1000x, and can sharpen the instrument profile, doubling or more the spectrograph resolution. We demonstrate stabilization on star light data and simulations. We report new focal blur diagnostic work using interferometer combs on the Keck Planet Finder spectrograph (KPF).**

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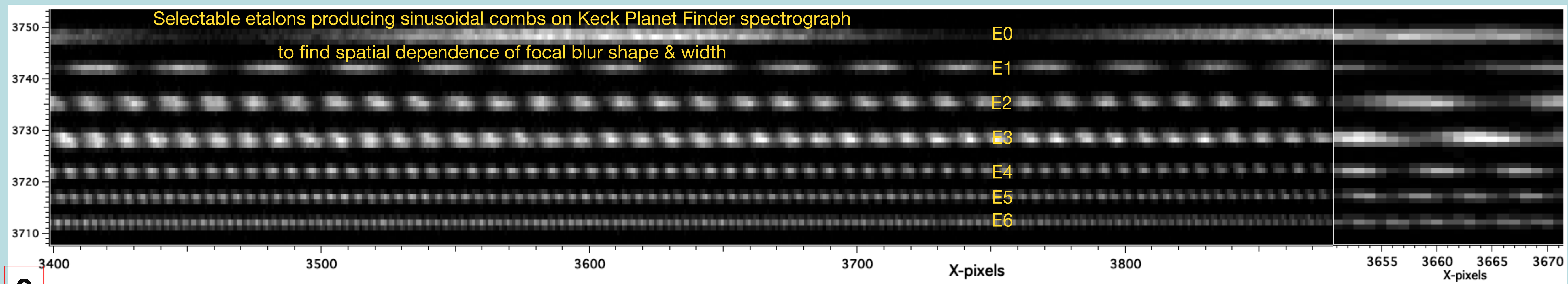
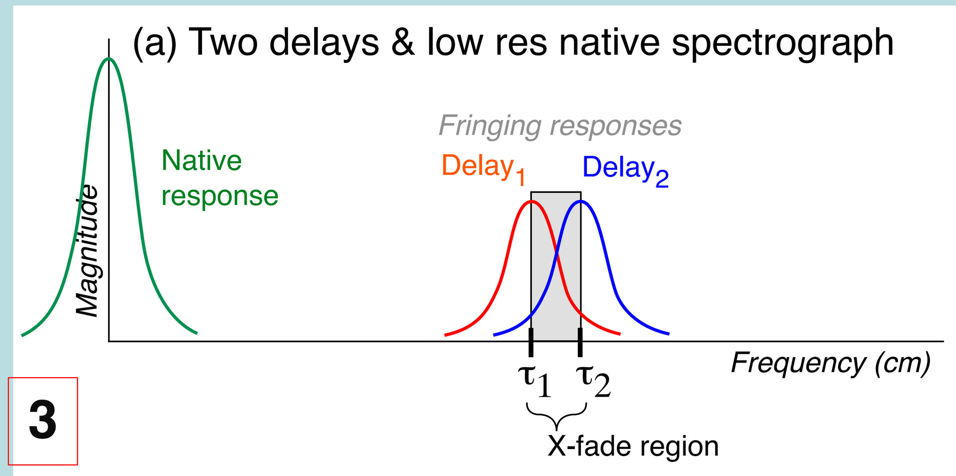
**Testbed EDI (Fig 1) being developed for testing crossfading stability. It has also been applied to the Keck Planet Finder spectrograph (Fig 2) to measure focal blur shape and width on every pixel on chip**




2 Sinusoidal combs from white light source thru EDI, then detected by Keck Planet Finder spectrograph, which is undergoing engineering tests at UC Berkeley Space Sciences Lab. Glass etalons [E] in a rotary holder select delays from 0.03 cm thru 5 cm. Fringe visibility vs spatial frequency fitted to a Gaussian yields a focal FWHM, that can vary spatially across chip.

## Two-delay and single-delay crossfading compared

Modulation Transfer Function (MTF) is Fourier transform of point spread function (PSF)

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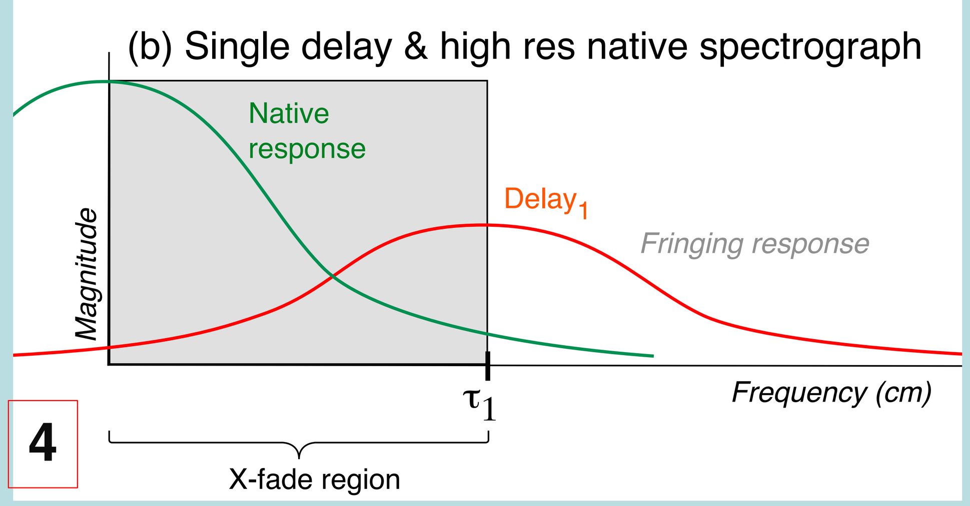


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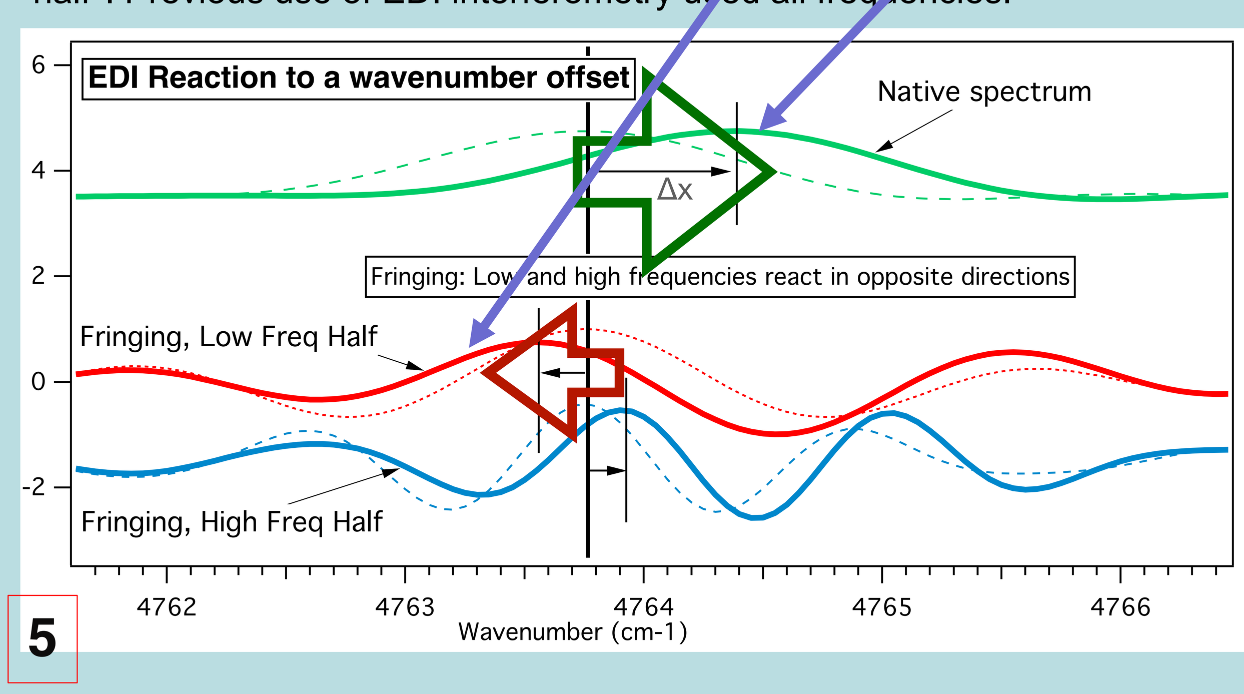
The two curves make an X-like crossing in gray areas, hence the term "crossfading"

## We have discovered a signal component that moves in *opposition* to the native spectrograph drift Δx.

This allows cancellation of drift, ie a stabilized spectrograph. The opposition signal component is the fringing signal, but using *only the lower frequency half*. Previous use of EDI interferometry used all frequencies.

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## Single delay crossfading demo on starlight+ThAr using Mt. Palomar EDI data from 2010, re-analyzed


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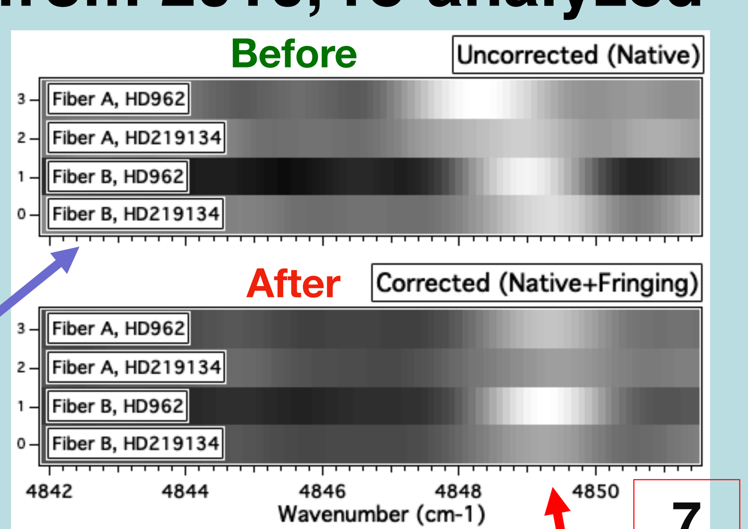


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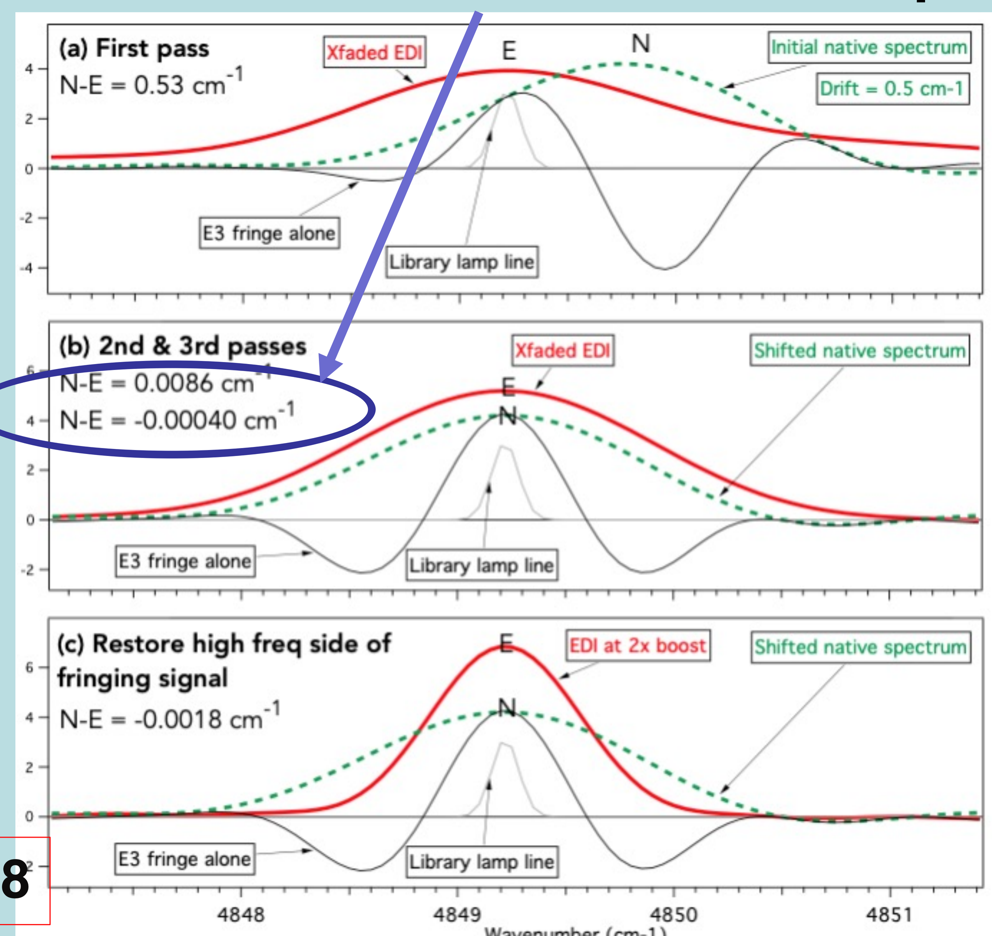
Spectrograph optics create a wavelength offset between A/B source fibers. Additional offset for different stars due to drift over time. Net offset is removed by crossfading. A 4764 cm$^{-1}$ ThAr line (off graph) provides absolute reference for the interferometer phase.

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

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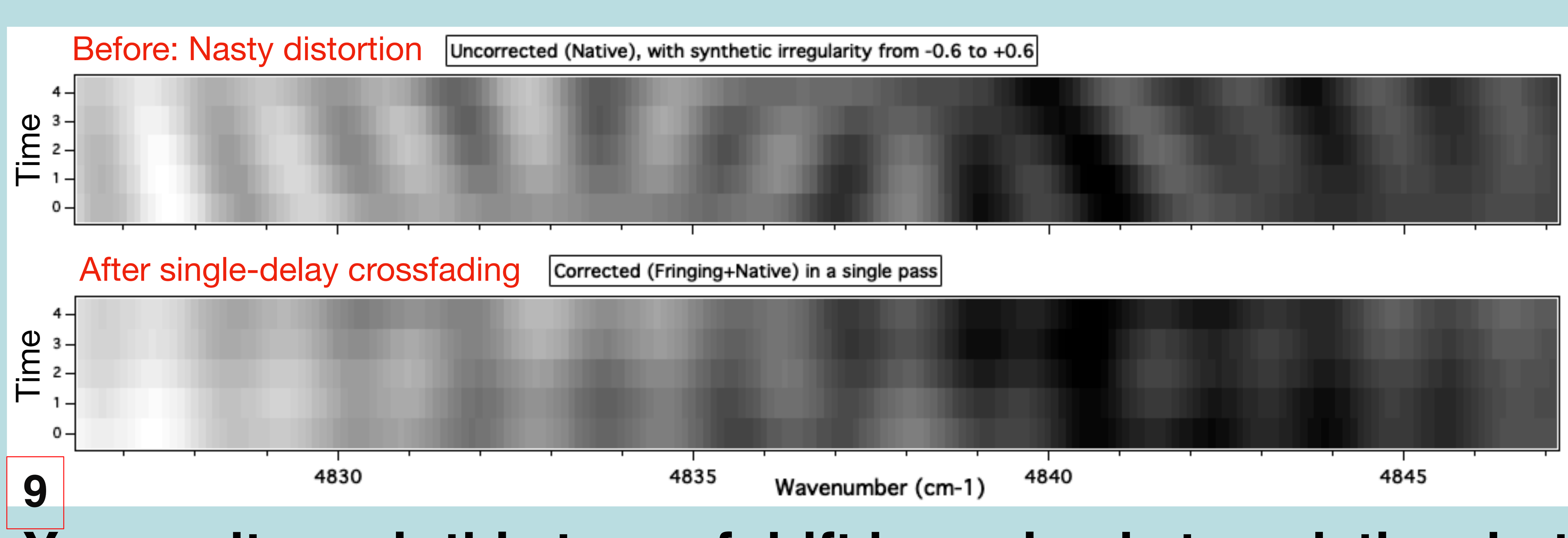
## Demo of crossfading on the nastiest type of drift: bipolar

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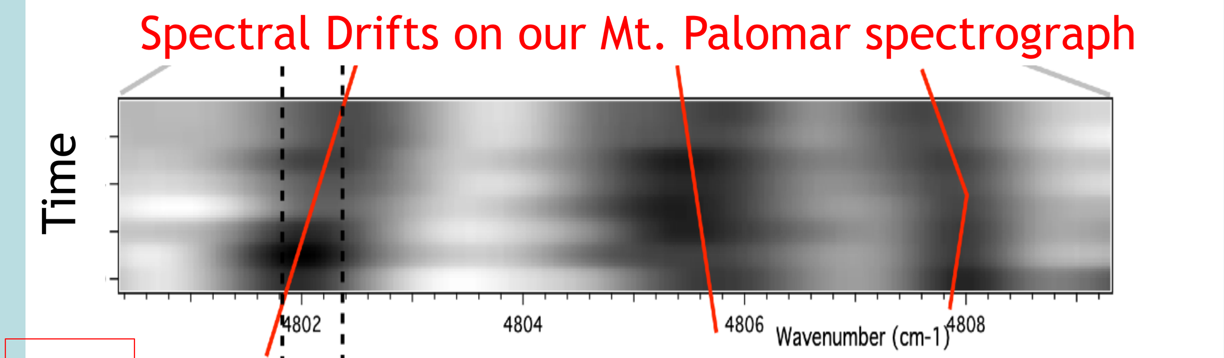
**You can't repair this type of drift by a simple translation, but crossfading fixes it!**




10 Irregular polarity(!) drifts due to grating instabilities(?) — not fixed by simple math translation

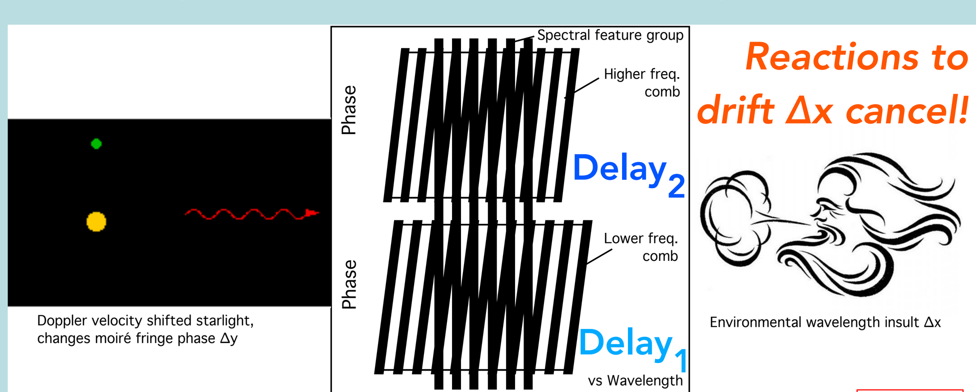
**Example of nasty bipolar drift at Mt. Palomar in 2010 data**

## Multiple-delay crossfading

**Delays in pairs create moiré which have opposite slopes, thus cancel under an insult Δx**

### A pair of delays

(In detector-space, moiré are recorded)

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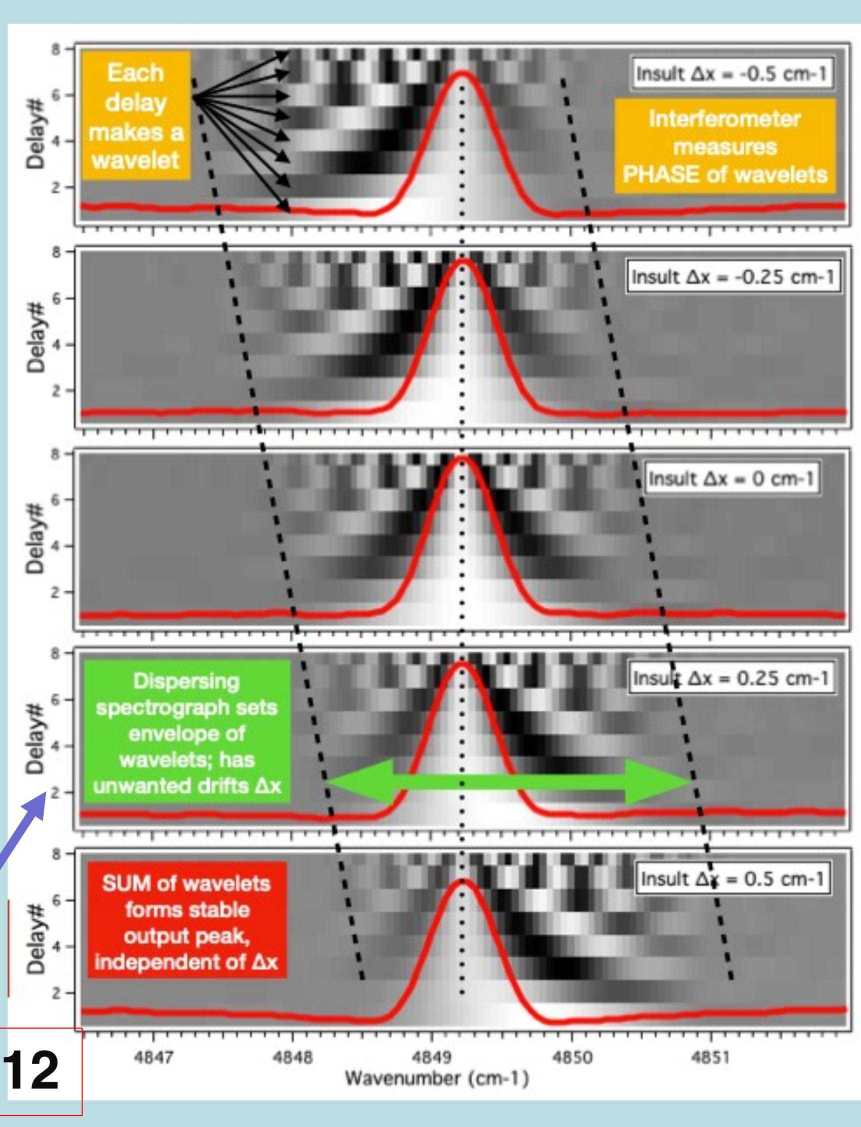
Moiré patterns are generated when sinusoidal interferometer transmission multiplies input stellar spectrum. Heterodyning shifts high frequency features down to low frequencies, which are more resolvable by spectrograph. Doppler shifts create moiré phase shifts Δy, the same polarity for each delay. But the two delays have opposite polarity moiré slopes for certain frequencies– thus phase reactions to disperser wavelength drift Δx can cancel!

### Multiple pairs of delays

(In output spectral-space, moiré becomes wavelet)

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**Spectrograph offset Δx shifts envelope of wavelets, yet the red output peak is stable! by ~1000x in one pass**

(For high resolution spectroscopy, each moiré is restored to its original high frequency, becoming a wavelet)

*See "Method for boosting dispersive spectrograph stability 1000x using interferometry with crossfaded pairs of delays", David J. Erskine, J. Astr. Tele. Instrum. Sys., 7(2):025006, June 2021 https://doi.org/10.1117/1.JATIS.7.2.025006

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