Enabling 1000x more sensitive spectrographs for exoplanet search

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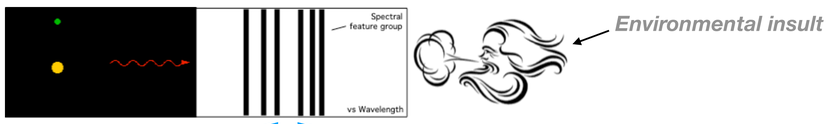
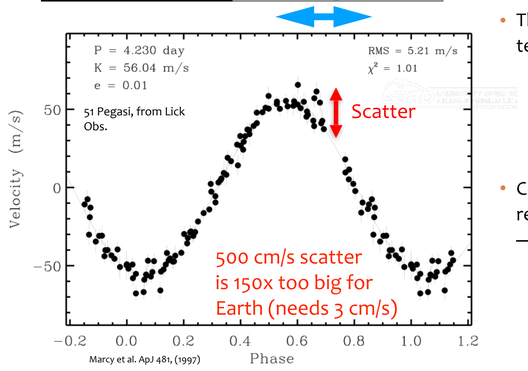
Exo-Planets are discovered by Doppler velocity shifts of starlight



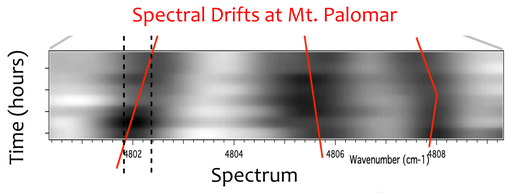
Environmental insult



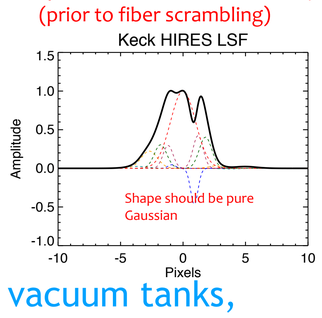
- The fundamental problem with current technology is the stability of the diagnostic.
  - Changing temperature, air pressure, vibration, gravity vector, accelerations shift spectrum with an offset (insult or drift).
- Conventional measurement of Earth requires sub-pixel (10^{-5}) stability over 1 year — incredibly difficult!
  - Manufactured detector pixel placement irregularities worsen the resolution
  - Earth has only 0.1 m/s amplitude signature

Spectrograph Drift and focal irregularities define the system resolution

Spectral Drifts at Mt. Palomar



Focal spot drifts at Keck Observatory (prior to fiber scrambling)



- Irregular polarity drifts in wavelength spectrum due to instabilities cannot be corrected for

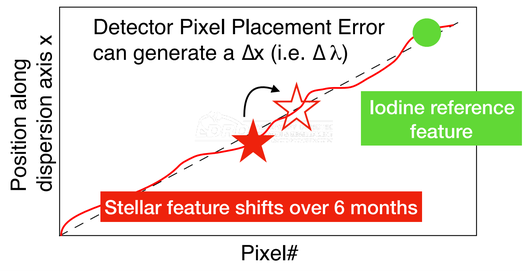
Conventional mitigations: large vacuum tanks, bulky thermal blankets, massive sturdy mounts

Still, the required 10^{-5} pixel stability needed is not achieved

A fundamentally different approach is needed to advance the sensitivity of Doppler spectroscopy

Another problem: Manufactured Pixel Placement is Irregular on Detector

This error (~milli-pixel) is a "baked in" drift— not reduced by conventional mitigations (vacuum tank, thermal control, fiber scrambling).



6 month Earth orbital velocity change causes different pixels to be used, which can cause different Δx error

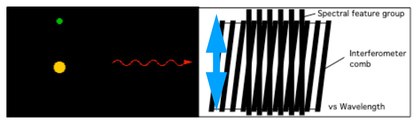
These could be much larger than the 10^-5 pixel tolerance needed to detect Earth-like planets

Externally Dispersed Interferometry* (EDI), advantage for Doppler planet search:

Horizontal Moire are perfectly robust to wavelength distortions

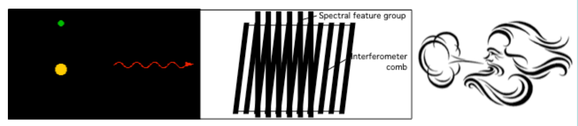
Under a Doppler shift:

(Feature moves relative to comb, producing phase change)



Under a environmental wavelength shift:

(Feature and comb move together since they are embedded in same beam, producing NO phase change)



Horizontal Moire occurs when feature frequency matches interferometer comb

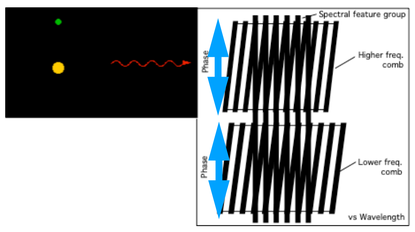
Problem: realist spectra have a variety of frequencies— will generate Moire with variety of tilts

4

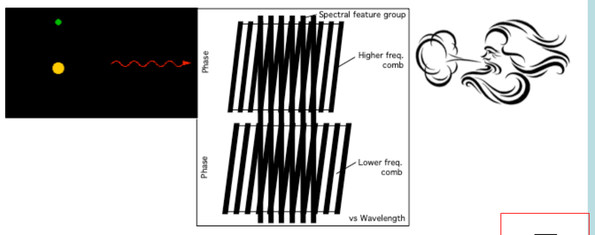
New Idea: use two slightly different interferometers simultaneously

For each frequency, select weights and combine data to effectively cancel slope of moire

Under Doppler the pair produces phase shift as usual



Under wavelength offset, the two moire behave like a horizontal moire and have zero net phase reaction to offset

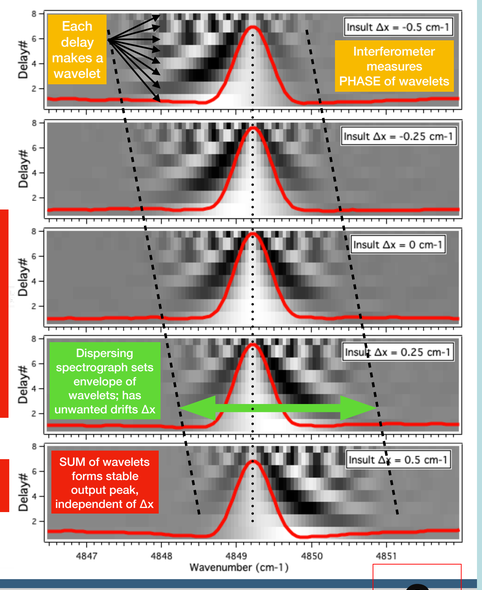


5

Demo of software using multiple pairs of intrfr. delays

Using EDI measured data of ThAr lamp at Mt. Palomar project

but simulated insult Δx



The wavelet location is deliberately shifted sideways to simulate Δx.

The EDI output is the sum of wavelets which is the red peak, which is nearly stationary.

1000x reduction in drift!

We recommend using BOTH conventional mitigations and EDI

Conventional mitigations: reduces environmental insult Δx

EDI: reduces TRC to ~0.001 - 0.1

Output spectrum shift $\Delta\lambda_{out} = \Delta x * TRC$

TRC is Translational Reaction Coefficient

(Conventional: TRC = 1)

7

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*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