Improving crowded-field multiple target Doppler sensitivity with an interferometer addition to a slitless imaging spectrograph

Abs: 749664

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Habitable Worlds Obs. Cnfrnc. 2026

30 November - 4 December, Paris

Dramatically reduce your spectrograph size & mass while achieving resolution goal

We propose

Idea: add small interferometer filters to a space telescope spectrograph

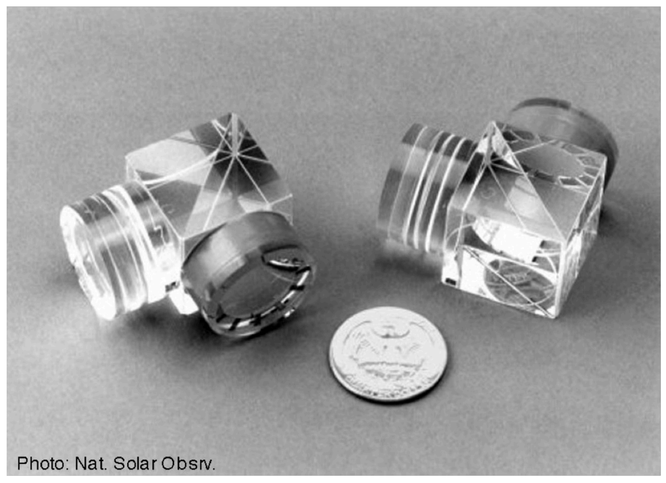
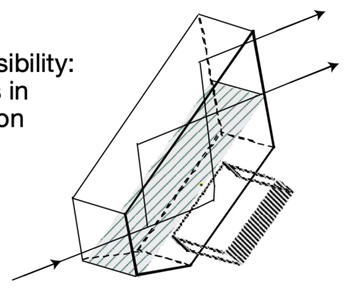


Photo: Nat. Solar Obsrv.

Ref. [h]

Another possibility: Dual outputs in same direction

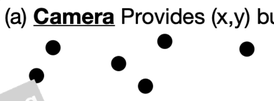


Ref. [i]

1

Existing

(a) **Camera** Provides (x,y) but no Doppler



Existing

(b) **Slitless spctrg**. Adds dispersion, but poor Doppler and low resolution



We propose

(c) **EDI (slitless)**. Adds fringes to greatly improve Doppler and resolution

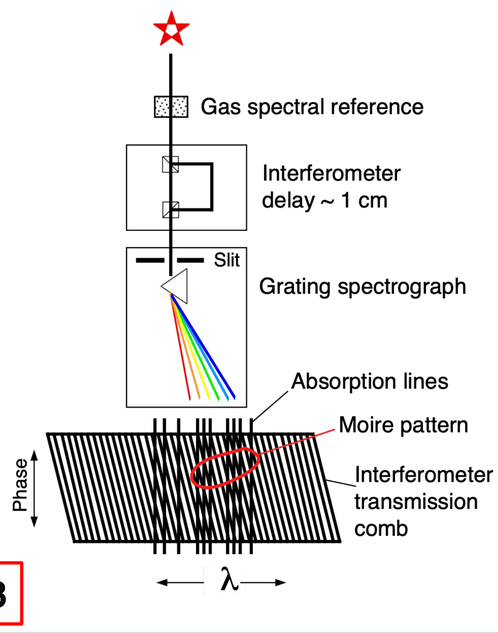


2

Gas cell (**CO2**, **methane** etc) embeds spectral calibration lines to determine precise interferometer delay & phase across image

Existing

EDI (generic)



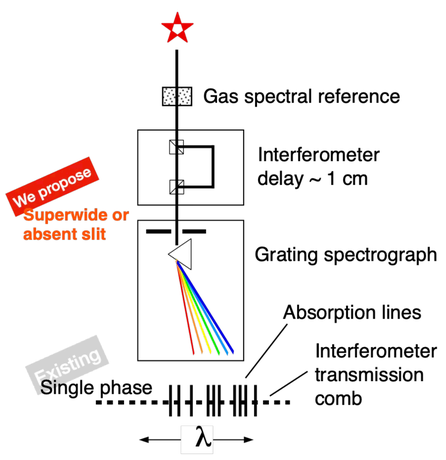
- Phase stepping data collection **eliminates fixed pattern errors**
- Moire **phase** yields Doppler shift
- Moire **structure** yields shape of high resolution spectrum

3

We propose

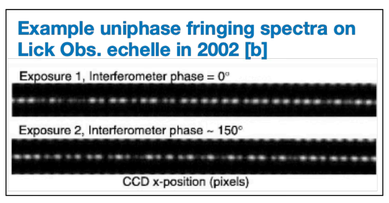
Superwide or absent slit

EDI (slitless)

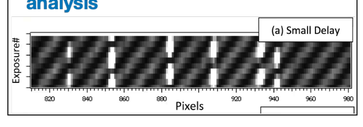


- **Uniphase** data-taking mode: phase uniform across beam, shifted in at least 3 exposures
- Handles small beams found in echelles or slitless

Example uniphase fringing spectra on Lick Obs. echelle in 2002 [b]



Set of 10 uniphase fringing spectra (Mt. Palomar 2011), stacked to form ersatz multiphase data [e] for further analysis



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Externally Dispersed Interferometry (EDI)

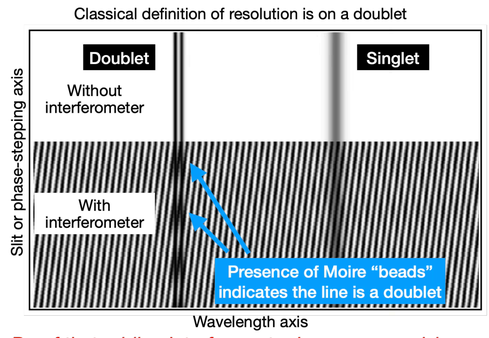
- Demonstrated (single sources) at Lick & Mt. Palomar & other Obs. on linear and echelle spectrographs
- Exoplanets (HD 102195b) found by others [d] using EDI
- m/s scale Doppler measurements demonstrated [a]
- **1000x stability** increase (fringe phase robust to disperser drift). **Correction/discovery of unknown disperser drift** via "crossfading" data analysis algorithm.
- **10x resolution** increase (2.7k to 27k) demonstrated at Mt. Palomar
- 1/10th disperser throw length allows **1000x volume reduction**, 100-300x **mass reduction** for same resolution
- Linear or echelle dispersers, boost performance of any format
- Uses conventional staring mode; not a scanned delay like FTS
- Phase stepped data collection eliminates fixed-pattern errors

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An interferometer creates a sinusoidal transmission spectrum that multiplies stellar spectrum

Benefit: **moire** patterns are created, which
- **Boost Doppler** sensitivity
- **Boost spectral** resolution

Classical definition of resolution is on a doublet

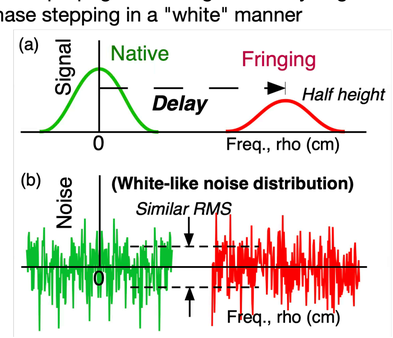


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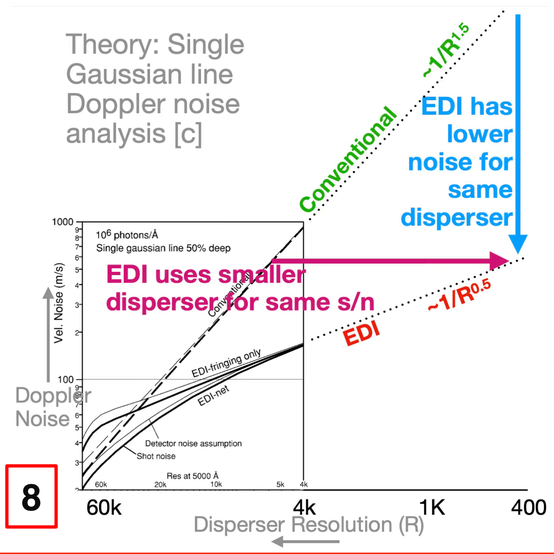
Proof that adding interferometer increases resolving power

Signal: heterodyning shifts sensitivity (red) to higher frequencies beyond native disperser capability (green)

Noise: propagates through heterodyning and phase stepping in a "white" manner



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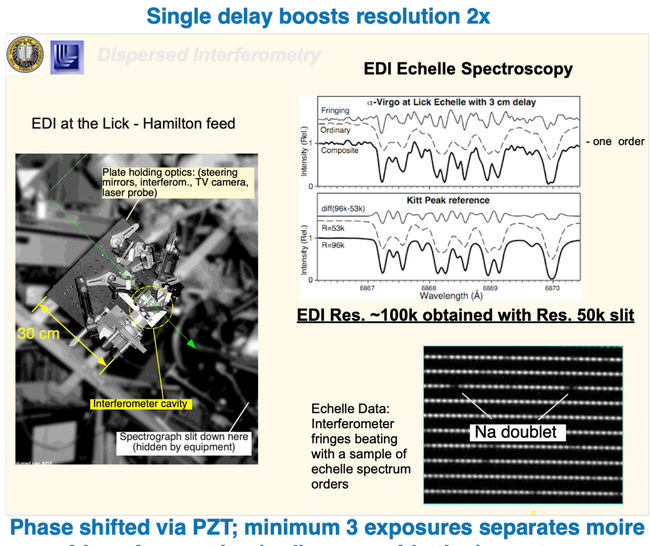
Conventional Doppler measurement occurs ***after*** slit blurring, so linewidth increased and line slope reduced, increasing noise/signal.

EDI Doppler measurement occurs ***before*** slit blurring, when stellar line beats against finely spaced sinusoidal comb, reducing noise/signal.

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Uniphase method on Lick Obs. Hamilton **echelle** in 2002[b]

Single delay boosts resolution 2x



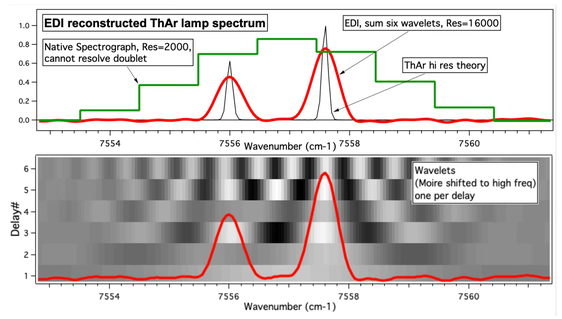
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Phase shifted via PZT; minimum 3 exposures separates moire fringe from native (ordinary nonfringing) spectrum

Demonstration of 8x resolution boost at Mt. Palomar TripleSpec NIR (echelle) spectrograph in 2011[e]

Native (green cityscape) spectrum CANNOT resolve doublet

(Wavelets from processing 6 delays are combined here)

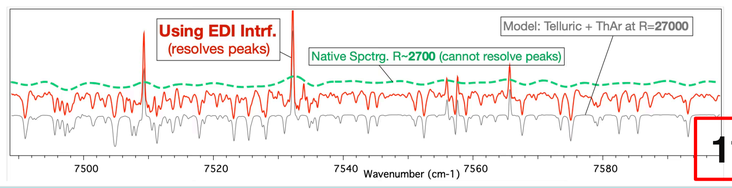


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Dramatically reduce spectrograph size & mass while maintaining resolution

10x EDI resolution boost allows 10x smaller disperser res (throw length of linear grating) to achieve same final resolution
—> 1000x volume reduction
—> mass reduction by 100 ~ 300x?

10x resolution boost (2.7k --> 27k) achieved at Mt. Palomar using multiple delays in 2011 [e]

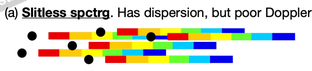


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Crowded field: what happens if spectra from two sources, of two different offsets, partially overlap?

Existing

(a) **Slitless spctrg**. Has dispersion, but poor Doppler and low resolution



Conjecture

EDI: We believe adding fringes will help disentangle partially overlapped spectra, due to new degrees of freedom in instrument parameters we can vary, eg. **fringe delay, and phase,** added to existing freedoms of **dispersion, plate scale, image rotation** etc.

We propose

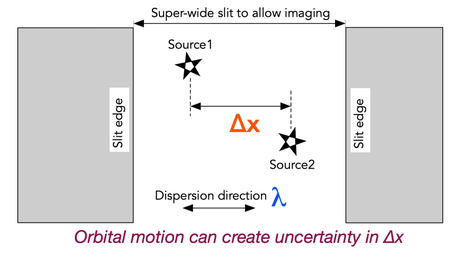
(b) **EDI slitless**. Has fringes to greatly improve Doppler and resolution



For example, our crossfading algorithm **breaks ambiguity** between target **position** uncertainty and **wavelength** offset

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Problem with conventional slitless spectrographs:
Δx creates **Δλ**



Orbital motion can create uncertainty in Δx

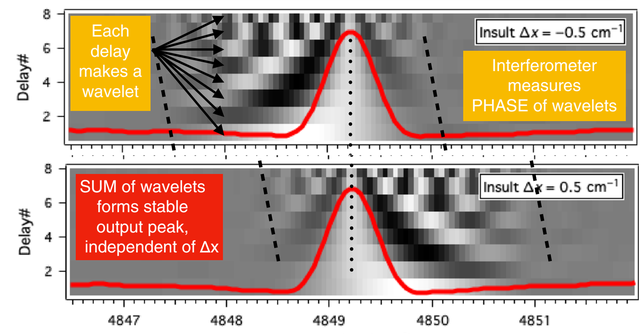
13

This is solved by our **crossfading** algorithm [f,g]. Fringing info is inherently much **less** sensitive to Δx than nonfringing spectra. Strategic filtering of fringing data reduces net reaction to Δx by 1000x or better; then comparison to nonfringing data **discovers the unknown Δx**.

1000x stability improvement

Recent work

Disperser drift Δx shifts wavelet envelope (dashes); but (red) output peak (sum fringes) is robust!!



Crossfading simulation [f,g]. Note that **sum of wavelets (red peak)** has same position in output wavenumber space, even though native disperser shifted by Δx of 1 cm-1. Takeaway: fringes can be very robust to wavelength offsets. Disperser alone is not-- it is directly linked 1 on 1 to Δx.

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-- Abstract/Synopsis

We conjecture potential benefits of inserting a small Michelson interferometer into the beam of a slitless imaging spectrograph (Figs. 1-8) , especially those having a severe constraint on size and mass. Figures 8 & 11 show that a 10x reduction of disperser resolution is enabled by use of EDI while meeting Doppler signal/noise or resolution goals. This can lead to 1000x reduction in a linear grating spectrograph volume, and commensurately high reduction in instrument mass. The EDI advantages stem from the heterodyning that produces moire patterns (Figs. 6, 7, 9, 10). We are also interested in expanding the usage of dispersed interferometry from single sources to multiple sources in an imaging mode (Figs. 2, 4, 12 - 14).

-- References --

[a] D.J. Erskine and J. Ge, in Imaging the Universe in Three Dimensions, W. van Breugel and J. Bland-Hawthorn, Eds., ASP Conf. Series 195, 501 (2000); http://digital.library.unt.edu/ark:/67531/metadc780974/

[b] D.J. Erskine, J. Edelstein, et al., ApJ 592, L103 (2003); doi:/10.1086/377703

[c] D.J. Erskine, Publ. Astron. Soc. Pacific 115, 255-269 (2003); doi:/10.1086/345995

[d] J. Ge, J. van Eyken, S. Mahadevan et al., Astrophys. J. 648, 683–695 (2006); doi:/10.1086/505699. <Exoplanet HD 102195b>

[e] D.J. Erskine, J. Edelstein, E. Wishnow, M. Sirk, P. Muirhead, M. Muterspaugh, J.P. Lloyd, et al., JATIS 2(2):025004 (2016); doi:/10.1117/1.JATIS.2.2.025004

[f] David J. Erskine, J. Astr. Tele. Instrum. Sys., 7(2):025006, June 10, 2021; doi:/10.1117/1.JATIS.7.2.025006

[g] David J. Erskine, Jerry Edelstein, Ed Wishnow, et al., J. Astr. Tele. Instr. Sys., 12(2), 025006 (2026); doi:/10.1117/1.JATIS.12.2.025006

[h] P. Scherrer, et al., Solar Physics 162(1), 129–188 (1995); doi:/10.1007/BF00733429

[i] J. Edelstein and D.J. Erskine, SPIE 5898 (2005); doi:/10.1117/12.618061

Vers-8b

PDF of this poster

spectralfringe.org/EDI/MyPubs9/PosterHWO2026_Slitless-Gen.pdf

More references and info

spectralfringe.org/EDI/MyPubs9/EDI-Slitless-Details-HWO2026-Gen.pdf