Method for enhanced exoplanet biosignature detection using a small interferometric addition to a low resolution spectrograph

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Habitable Worlds Obs. Cnfrnc. 2026

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Method for ***Resolution Boosting*** called ***Externally Dispersed Interferometry (EDI)***

We propose

Idea: add small interferometer filters to a space telescope spectrograph

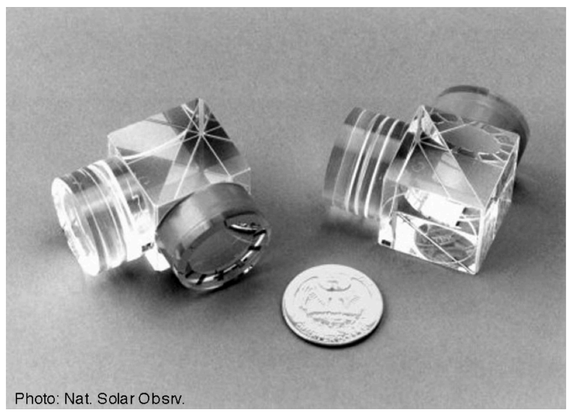
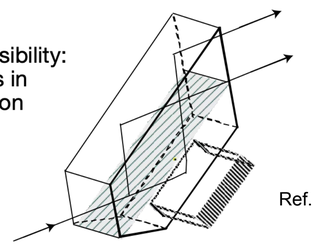


Photo: Nat. Solar Obsrv.

Ref. [h]

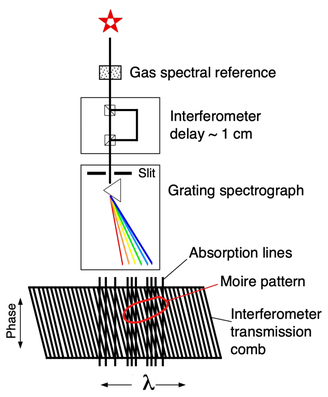


Another possibility:
Dual outputs in same direction

Ref. [c]

1

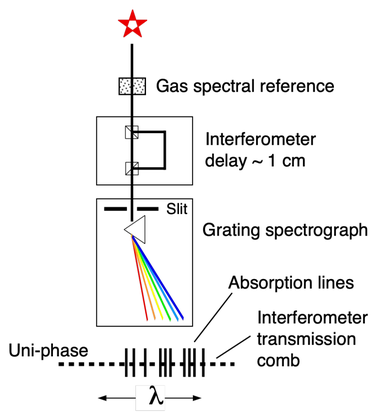
EDI (generic)



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

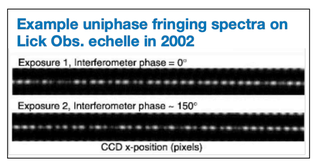
2a

EDI (echelle)

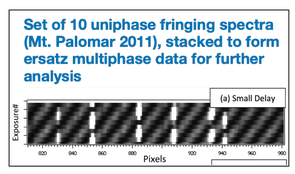


Ref. [c]

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



Ref. [b]



Ref. [e]

2b

Externally Dispersed Interferometry (EDI)

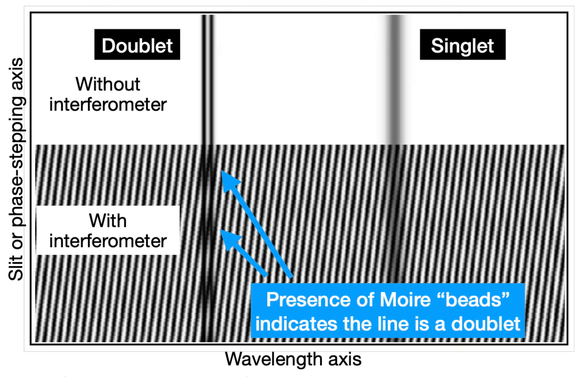
- Demonstrated (single sources) at Lick & Mt. Palomar & other Obs. on linear and echelle spectrographs
- Exoplanets (HD 102195b) found by others [d] using EDI
- m/s scale Doppler measurements demonstrated [a]
- **1000x stability** increase (fringe phase robust to disperser drift). **Correction/discovery 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

3

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

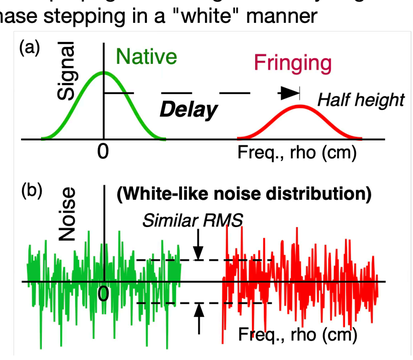


4

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



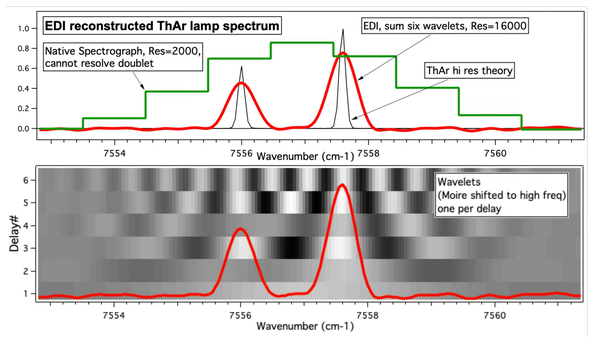
Ref. [g]

5

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

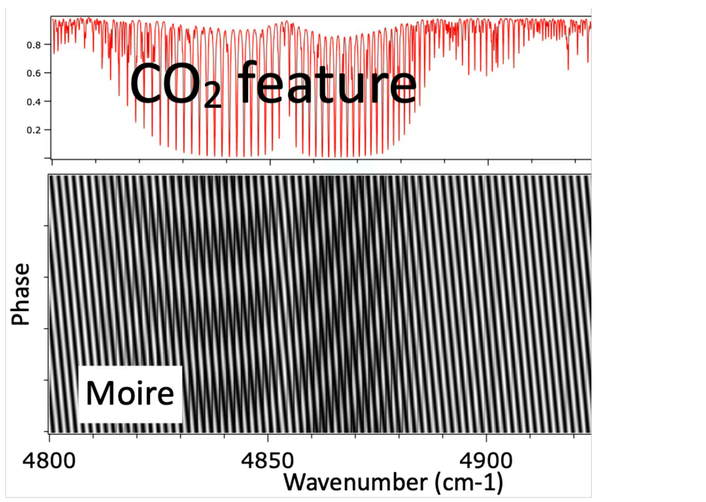
Native (green cityscape) spectrum CANNOT resolve doublet

(Wavelets from processing 6 delays are combined here)

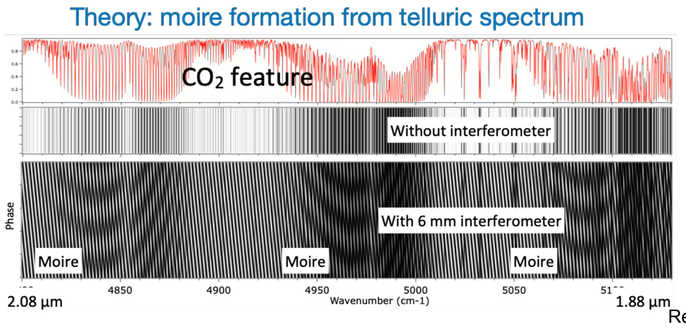


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Moire patterns reveal molecular features without needing high resolution



Theory: moire formation from telluric spectrum



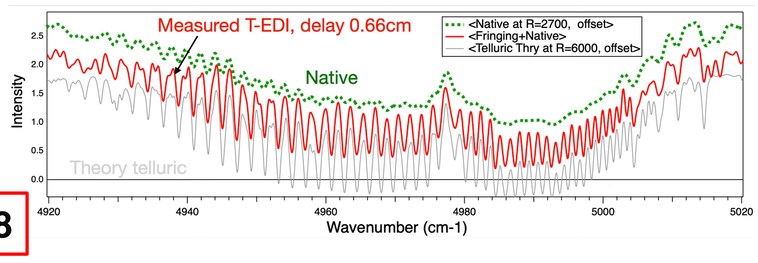
Ref. [f]

7

Demonstrated at Mt. Palomar: boosted resolution of molecular telluric features

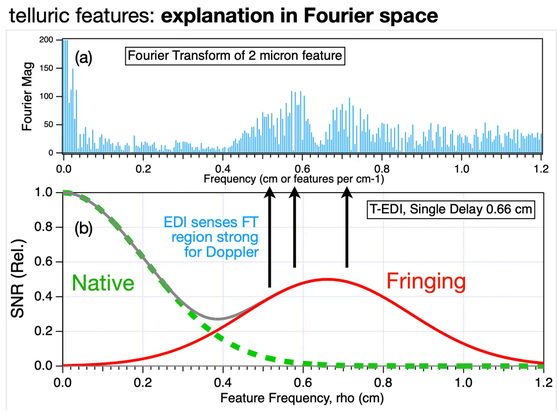
Measured fringing spectra on Mt. Palomar with TripleSpec NIR Spectrograph, 2008-11

Ref. [e]



8

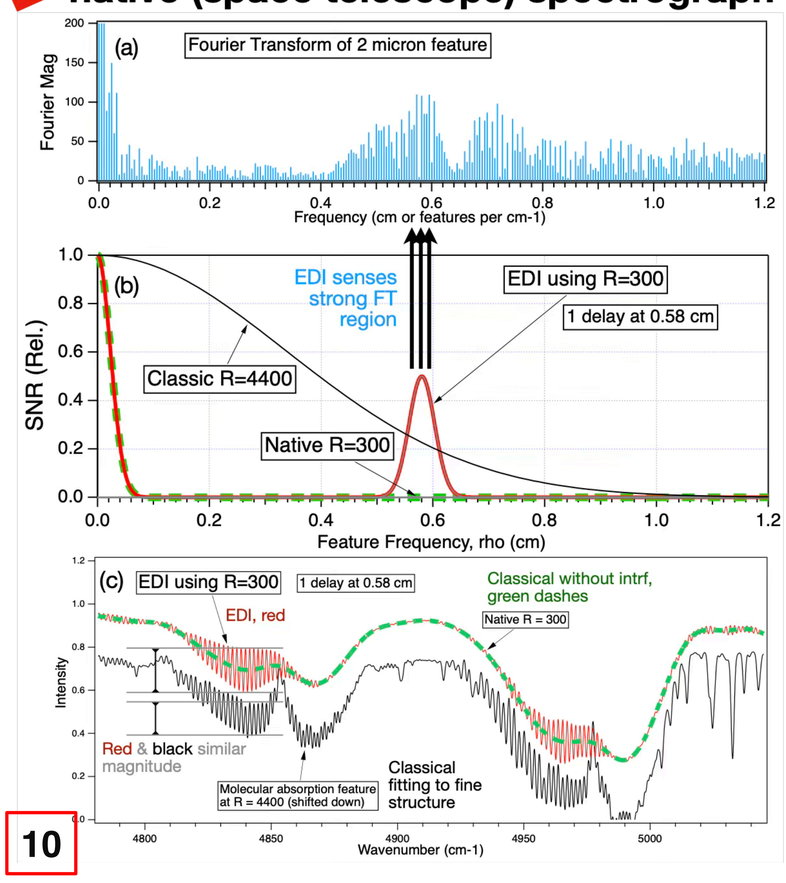
Demonstrated at Mt. Palomar: boosted resolution of telluric features: **explanation in Fourier space**



9

We propose

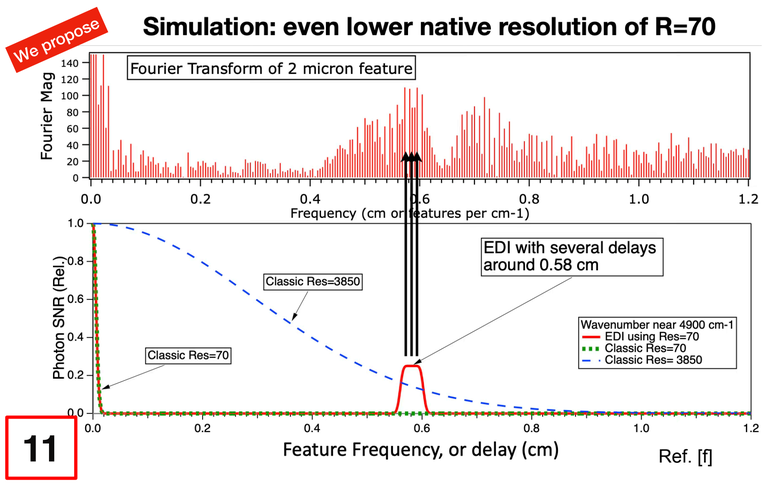
Simulation: using lower resolution native (space telescope) spectrograph



10

We propose

Simulation: even lower native resolution of R=70

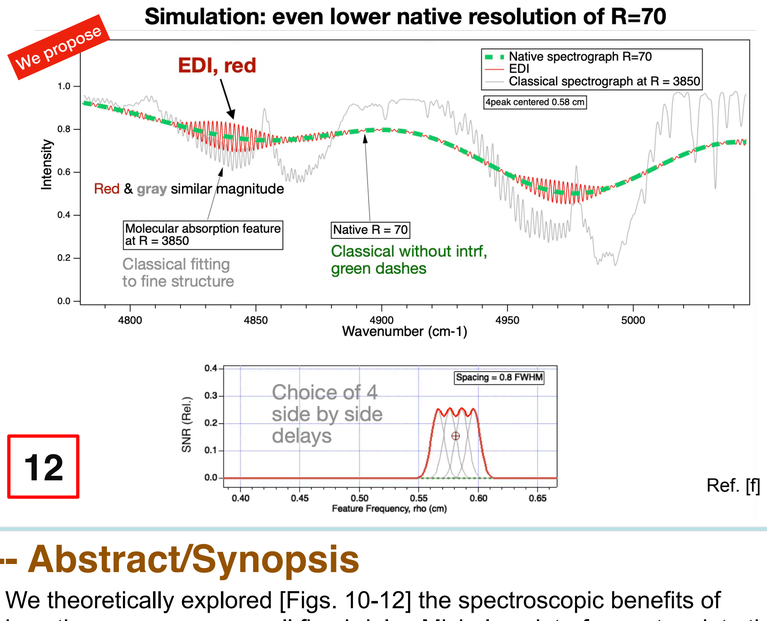


Ref. [f]

11

We propose

Simulation: even lower native resolution of R=70



Ref. [f]

12

-- Abstract/Synopsis

We theoretically explored [Figs. 10-12] the spectroscopic benefits of inserting one or more small fixed-delay Michelson interferometers into the beam of a low resolution spectrograph similar to that in the James Webb Space Telescope, or integral field spectrograph of ground-based Gemini Planet Imager. This forms an Externally Dispersed Interferometer (EDI) [Figs. 1-6]. An EDI measured the CO_2 telluric feature using this resolution boosting technique [Fig. 7-9] at the Hale telescope using R~2700 TripleSpec in NIR. We believe EDI will also benefit lower resolution spectrographs. For observing telluric features at 2 micron (5000 cm-1) at native resolution R=300 [Fig. 10], or R=70 [Fig. 11-12], the interferometer delay is optimally set to the periodicity of molecular signature fine structure, in this case delays near 0.58 cm. This is easily accomplished by a one or several small monolithic interferometer prisms inserted into the beam. The interferometrically boosted photon-limited sensitivity to detecting 2 cm-1 fine structure was shown [Fig. 12] to be similar in magnitude to a R=3850 native spectrograph. The signal to noise ratio was thus boosted by many orders of magnitude relative to the infinitesimally small ability of a ~71 cm-1 wide point spread function to detect ~2 cm-1 molecular fine structure. The fixed-delay nature of interferometer allows conventional long exposure staring mode for low flux sources-- the delay is not scanned as in a Fourier Transform spectrometer. However, net exposure time is distributed into several phase stepping exposures to allow separation of nonfringing and fringing spectra. Nonfringing spectra provide a conventional output. Fringing spectra detect presence of molecular fine structure signal with boosted sensitivity.

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

[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] D. J. Erskine, P. S. Muirhead, A. M. Vanderburg, A. Szentgyorgyi, SPIE 10702, 107024G (2018); doi:/10.1117/12.2303586

[g] D.J. Erskine, J. Edelstein, E. Wishnow, M. Sirk, P. Muirhead, M. Muterspaugh, J.P. Lloyd, JATIS 2(4):045001 (2016); doi:/10.1117/1.JATIS.2.4.045001

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

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More references and info

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