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Spectral Resolution boosting GPI's IFS using a small EDI interferometer addition

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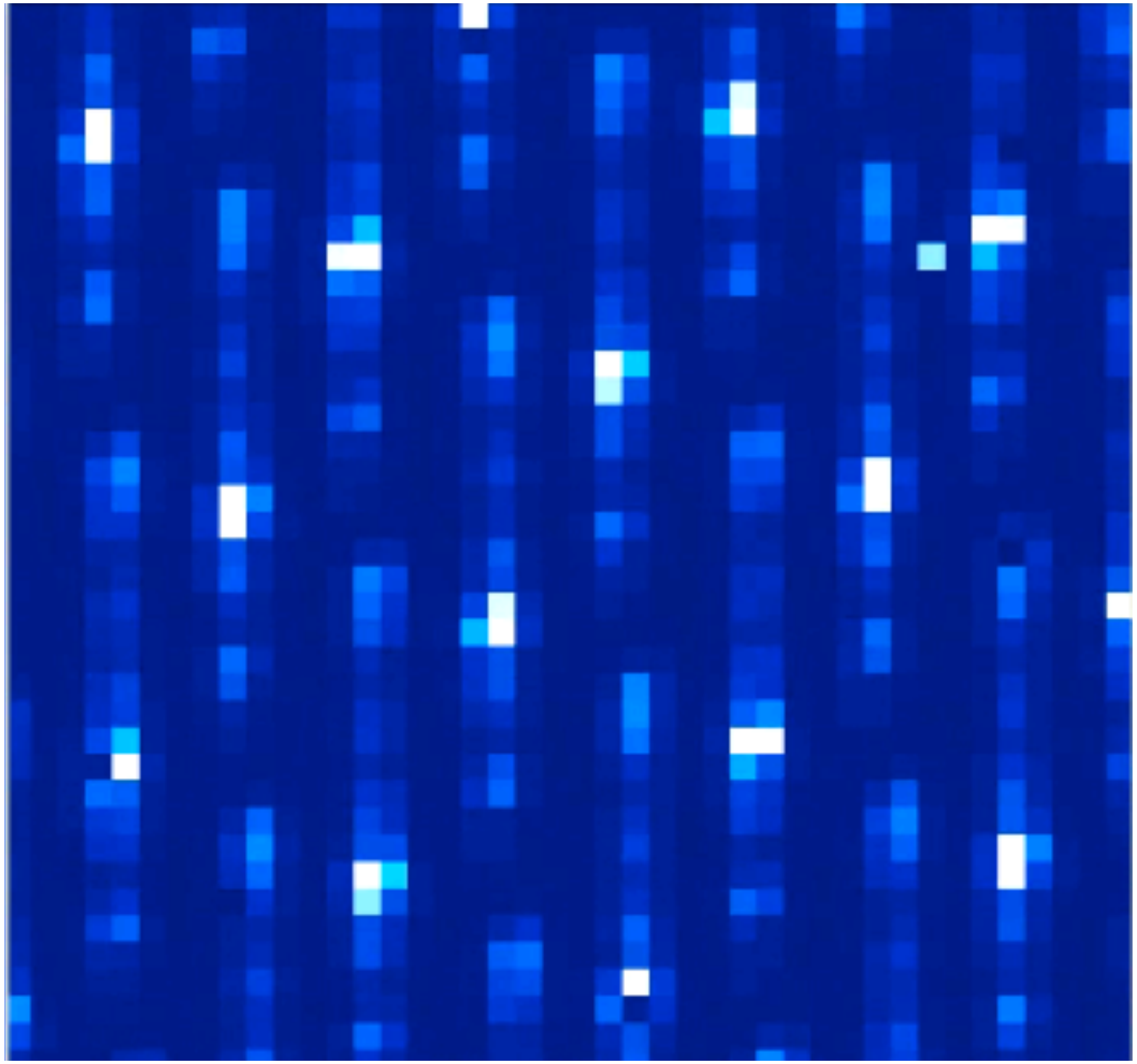
Lawrence Livermore Nat Lab

GPI 2.0 Meeting,
Stanford Univ.
March 9, 2017

Prof. Bruce Macintosh hosting



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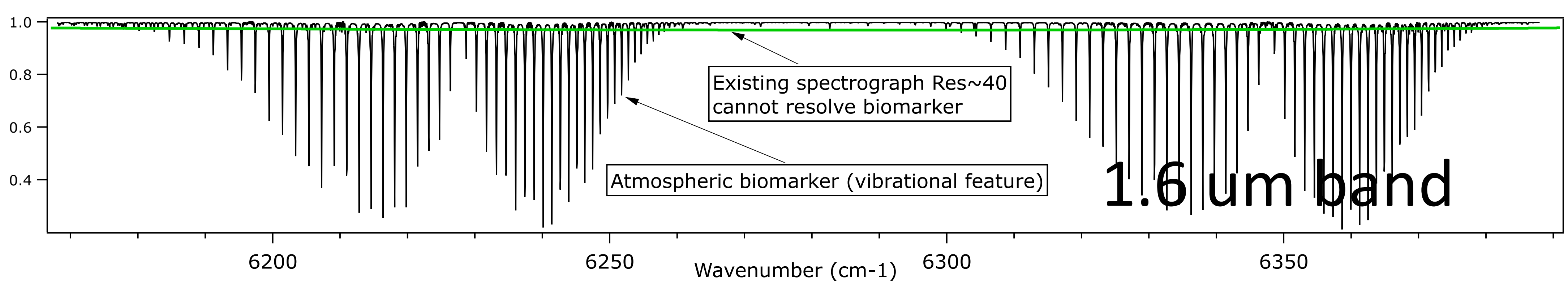
Science motivation: detection of bio-related molecules in exoplanets

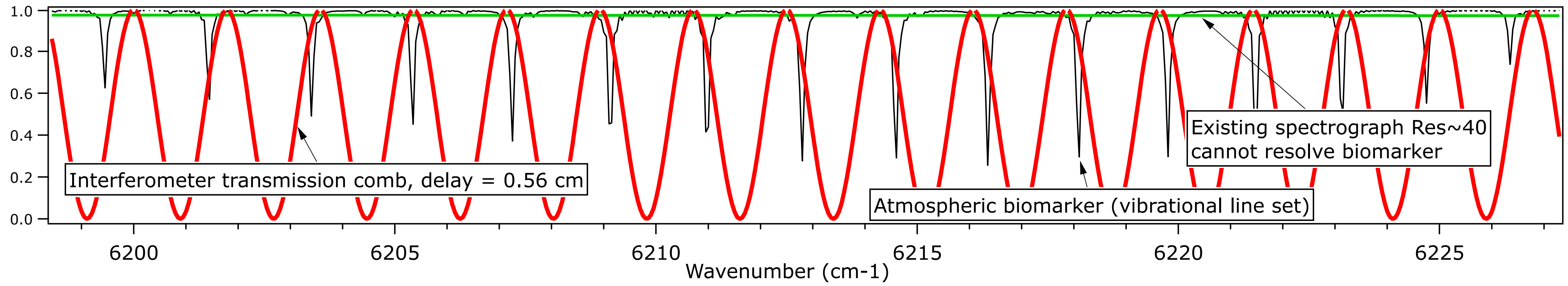
Atmospheric molecules (water, CO2, methane etc) vibrational spectra have a fingerprint which makes them easy to detect using a small interferometer addition

Features consist of set of quasi-periodic 30-40 fine lines



GPI’s Integral Field Spectrograph cannot resolve these features with its low R~40

An interferometer of ~6mm delay has a periodic response almost matched to the feature shape



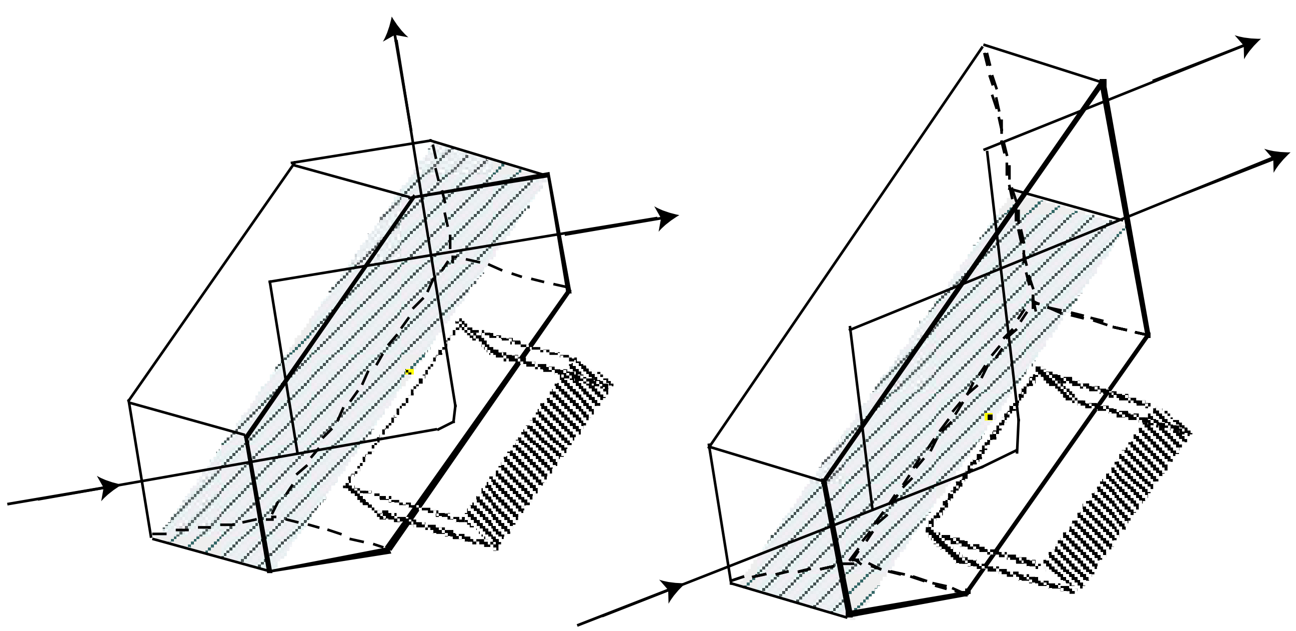
Placing the interferometer in series with the IFS creates moire fringes, which can detect the biomarker. Res~40 has been effectively boosted 100x to Res~4000.

Technique is called Externally Dispersed Interferometry (EDI).

Interferometers can be made compact

It could be inserted into the existing beam like a filter

Designs: UCB Space Sciences



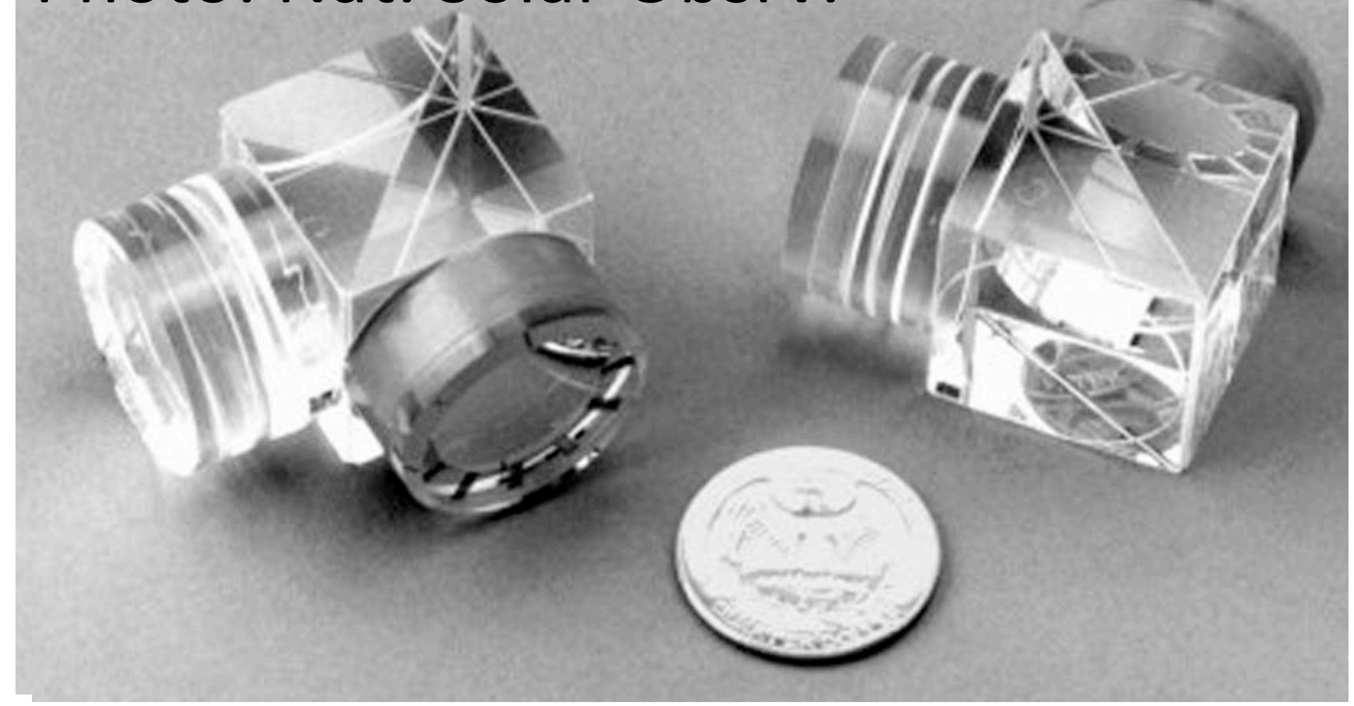


Photo: Nat. Solar Obsrv.

Interferometer "filter" would be inserted prior to IFS

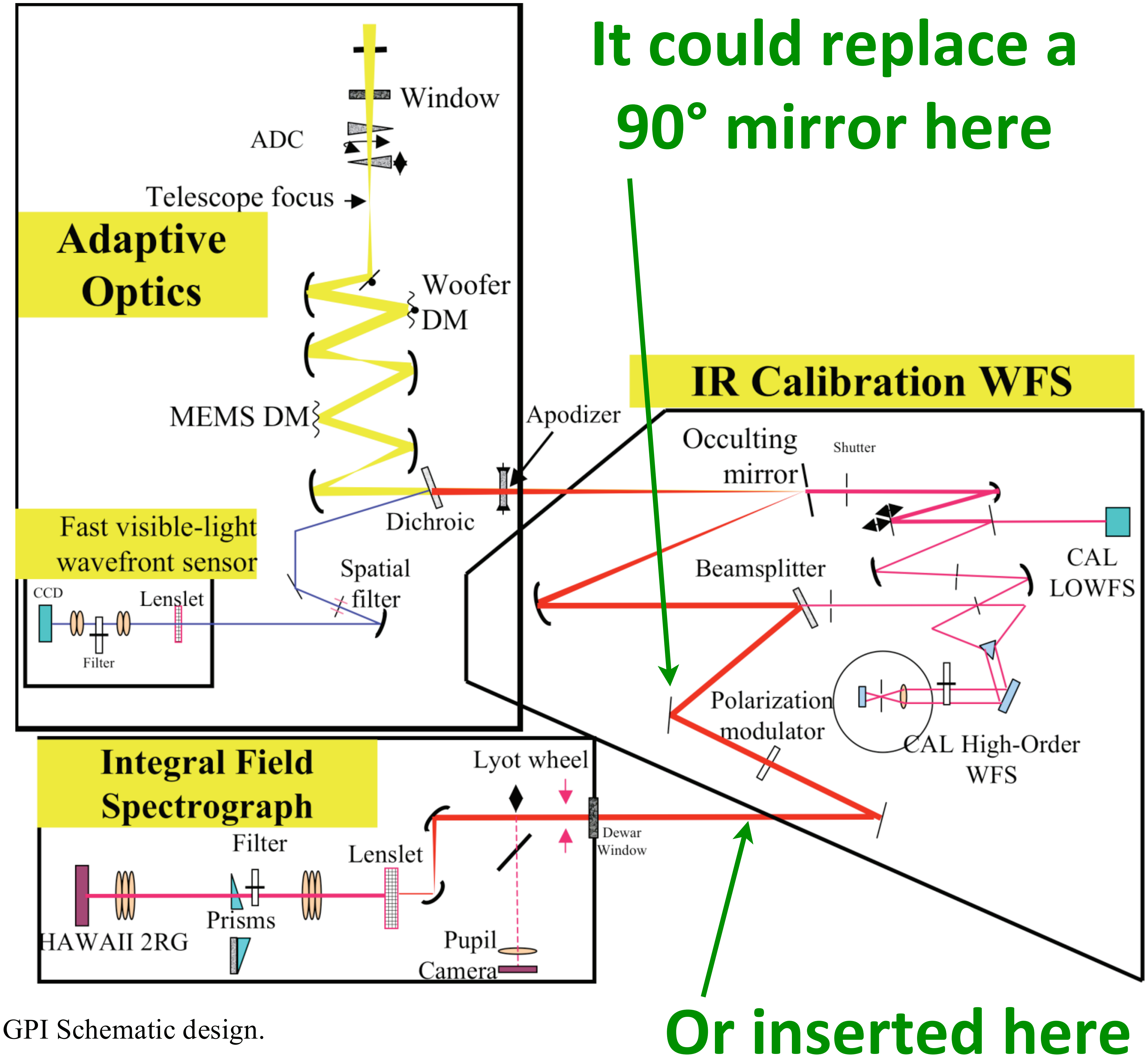
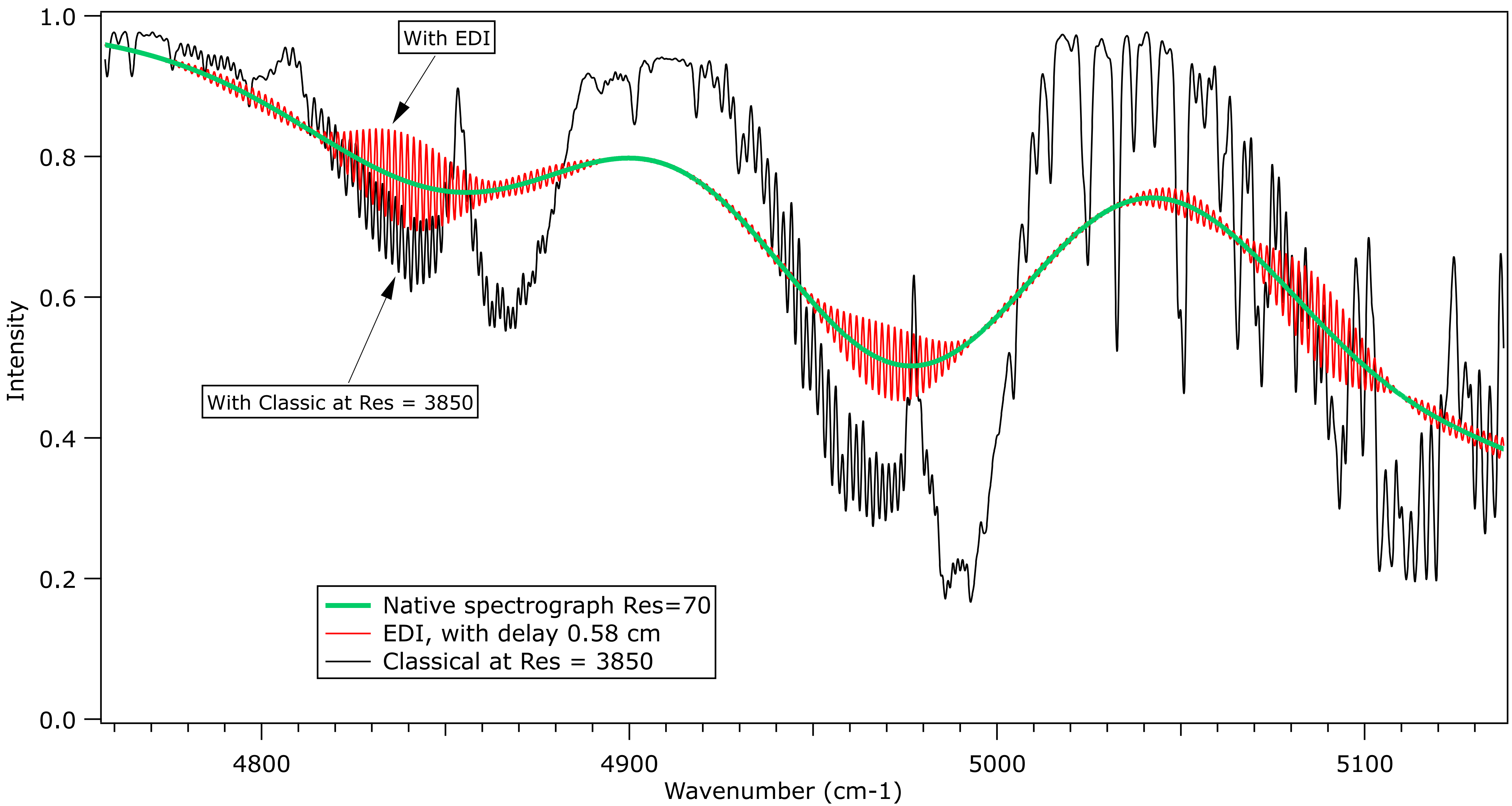


Figure 3: GPI Schematic design.

Interferometer creates a sinusoidal transmission comb

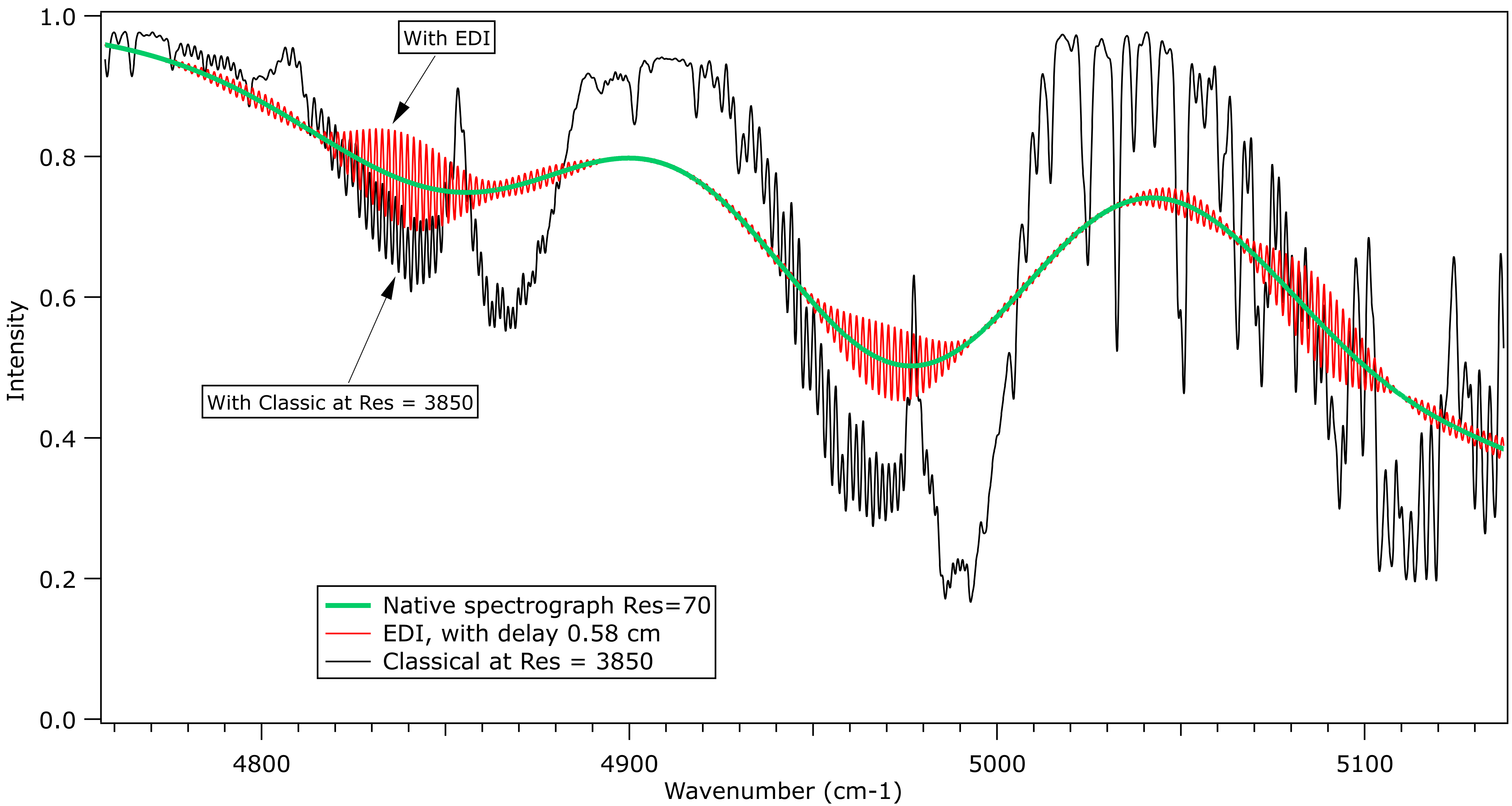
Intrf. peaks and valleys can be used to resolve narrow features well beyond resolution of native spectrograph



Interferometer creates a sinusoidal transmission comb

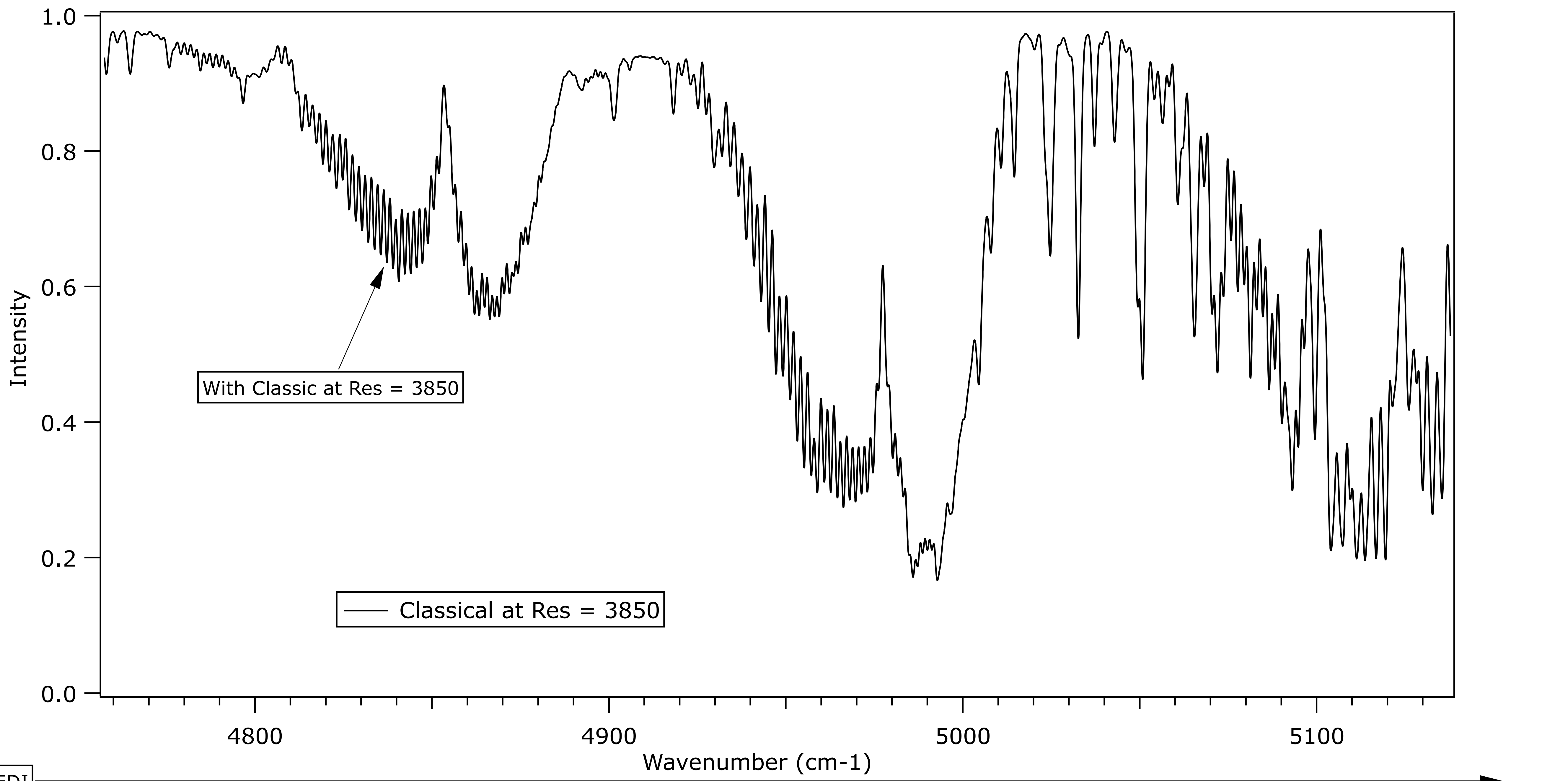
Intrf. peaks and valleys can be used to resolve narrow features well beyond resolution of native spectrograph

Only a few mm (6 mm) intrf. delay is needed to resolve biomarkers, to yield effective R~4000

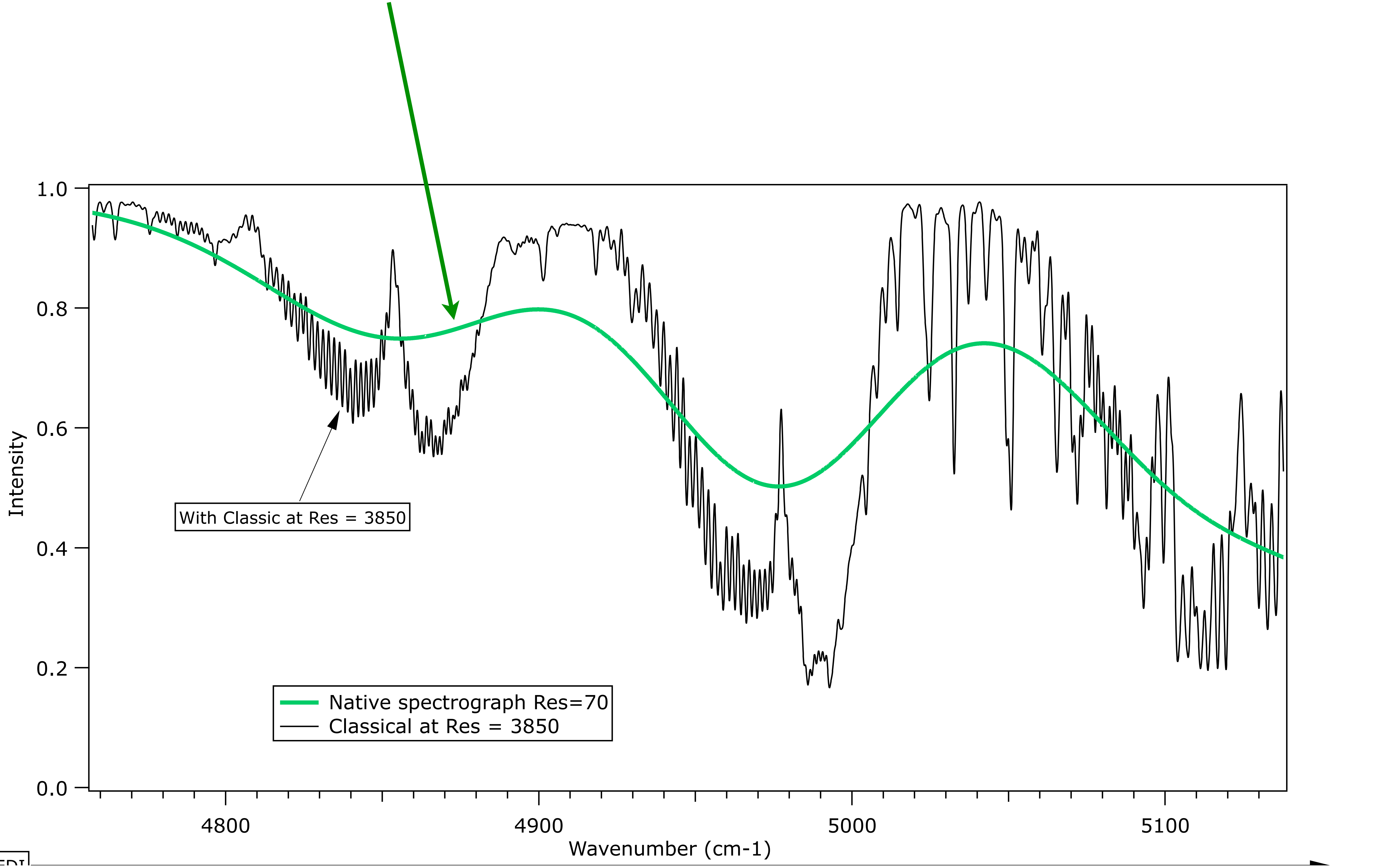


Three atmospheric absorption features at R=3850, at 2 micron

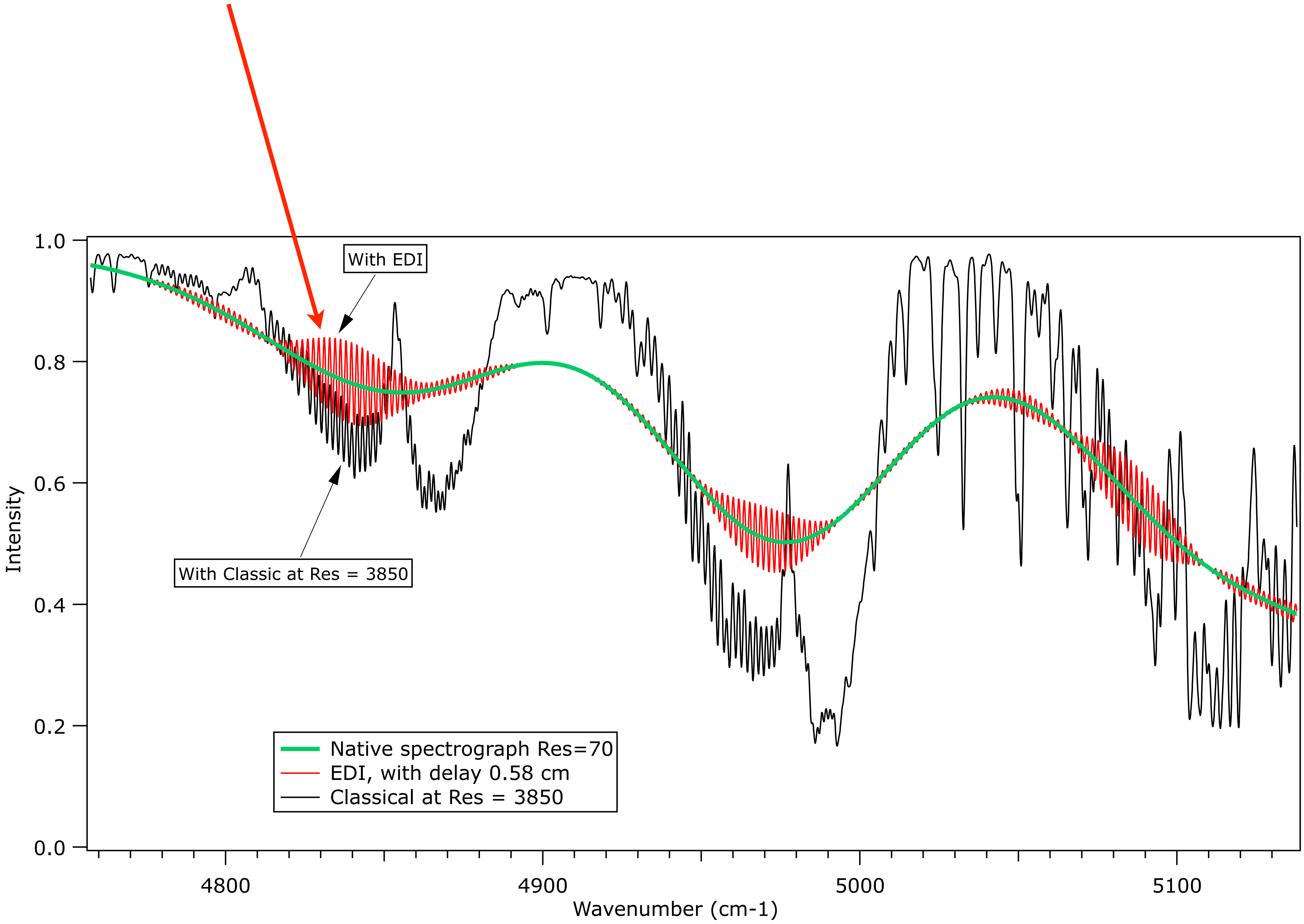
Feature consists of group of about 40 almost evenly spaced lines



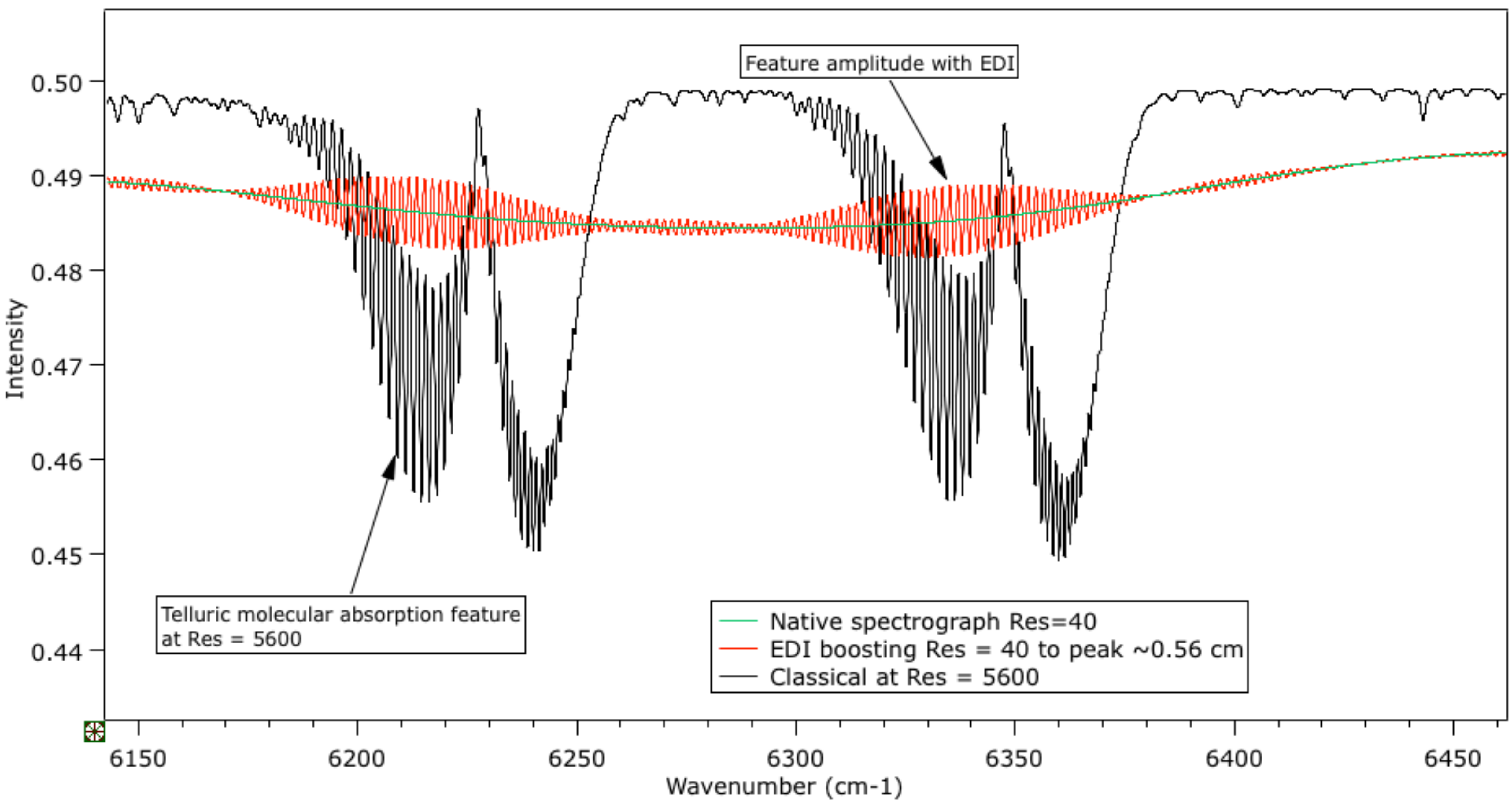
Current GPI resolution R~70 insufficient to detect fine features

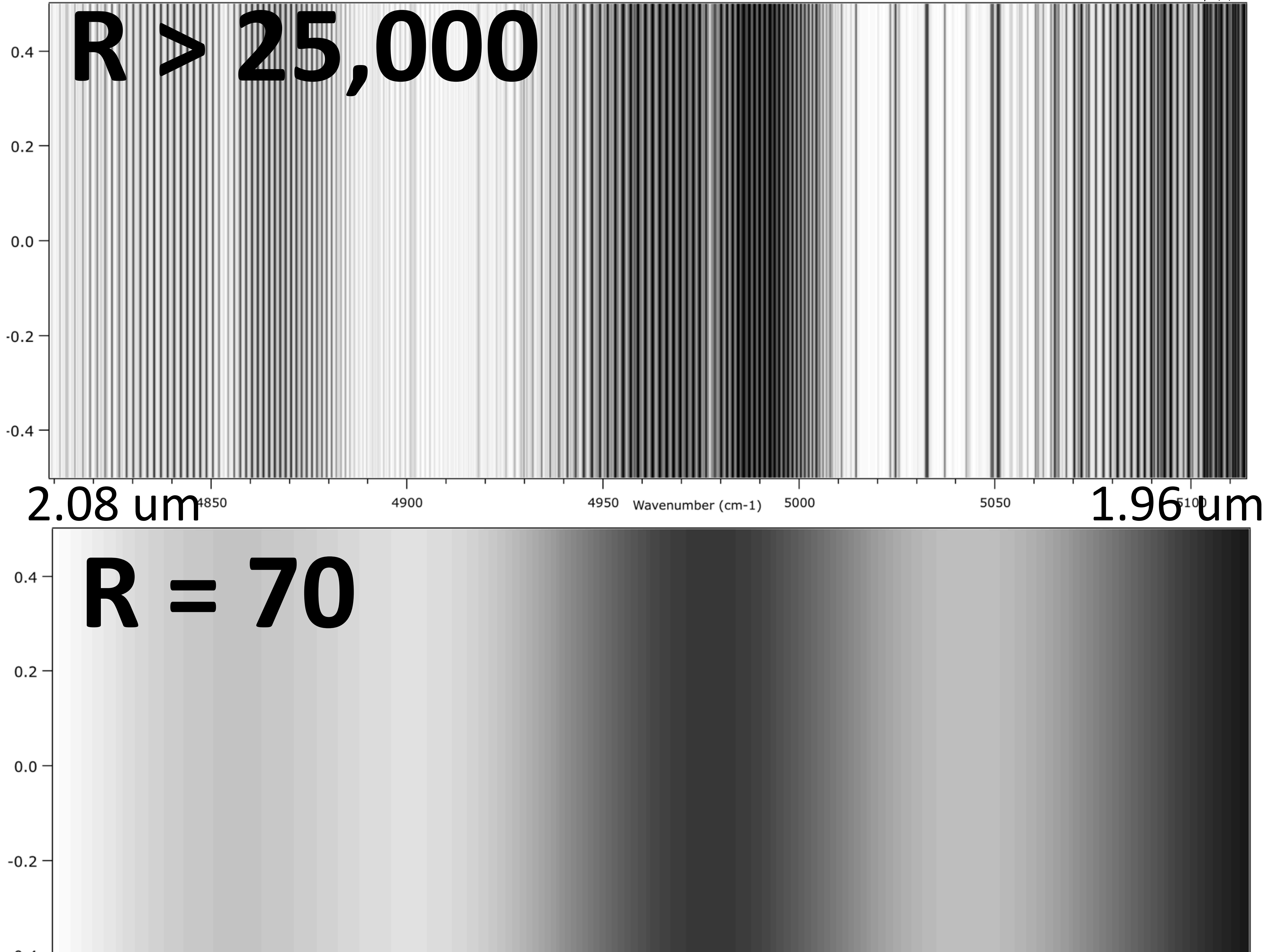


Interferometer (EDI) at 6mm delay has similar sensitivity to fine features as R~3850

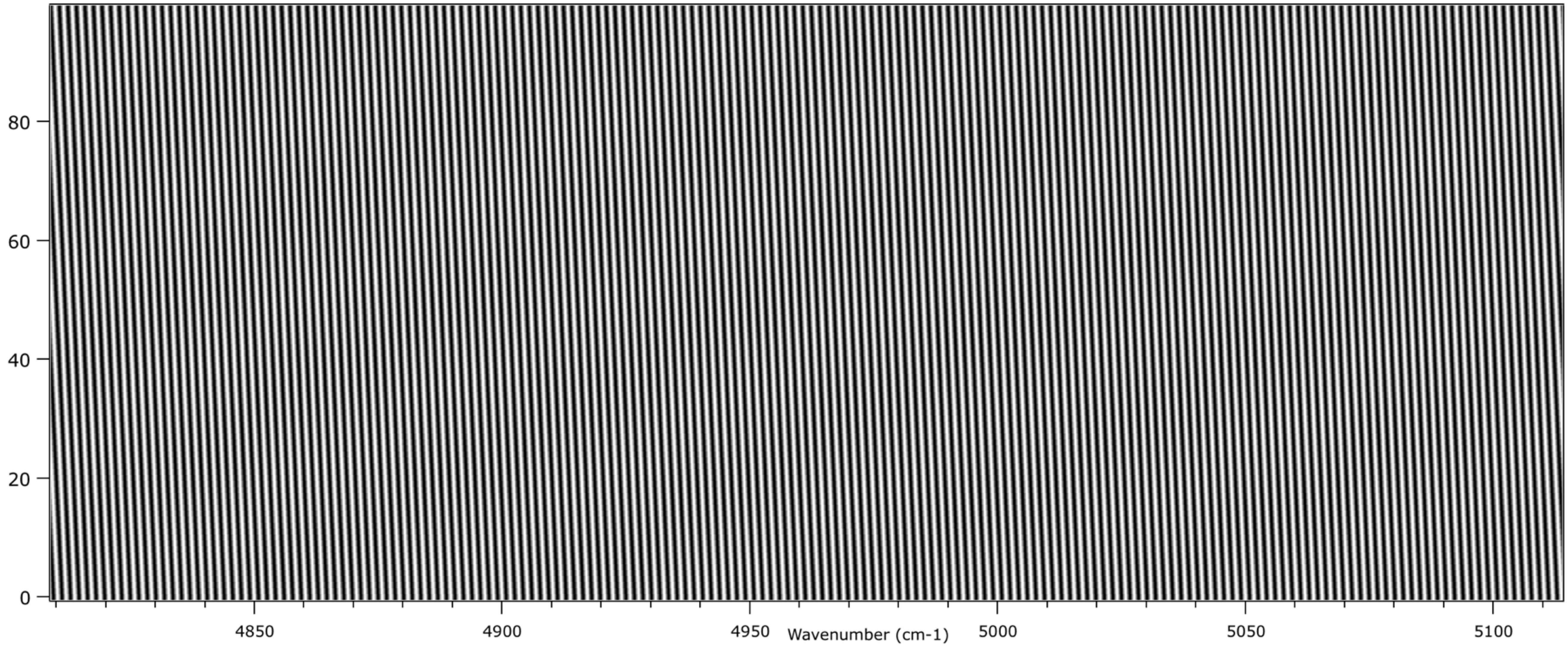


Similar for the 1.6 um band




R > 25,000
0.4
0.2
0.0
-0.2
-0.4
2.08 um
4850
4900
4950
Wavenumber (cm-1)
5000
5050
5100
1.96 um
R = 70
0.4
0.2
0.0
-0.2

5.8 mm delay interferometer comb

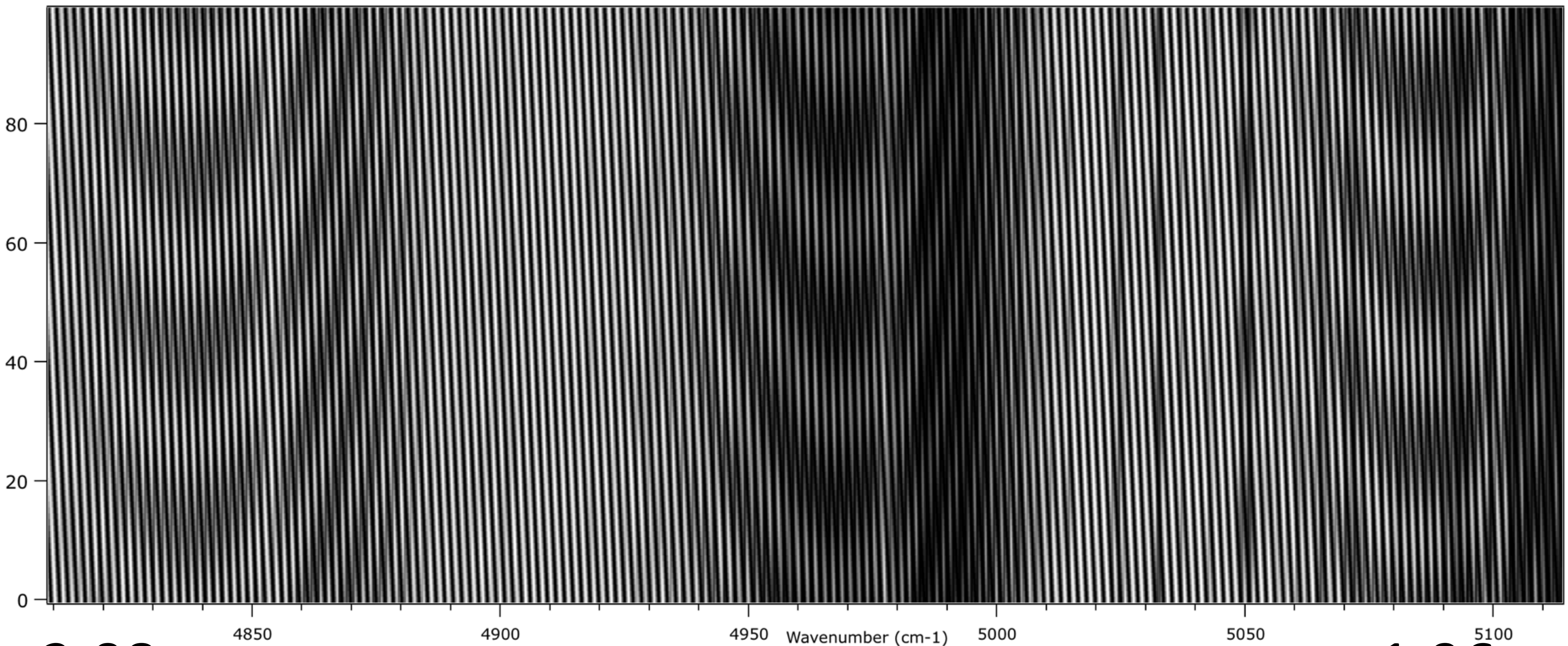


2.08 um

1.96 um

Period in wavenumber (cm^{-1}) space is reciprocal of delay (cm)

interfrmtr_comb * spectrum



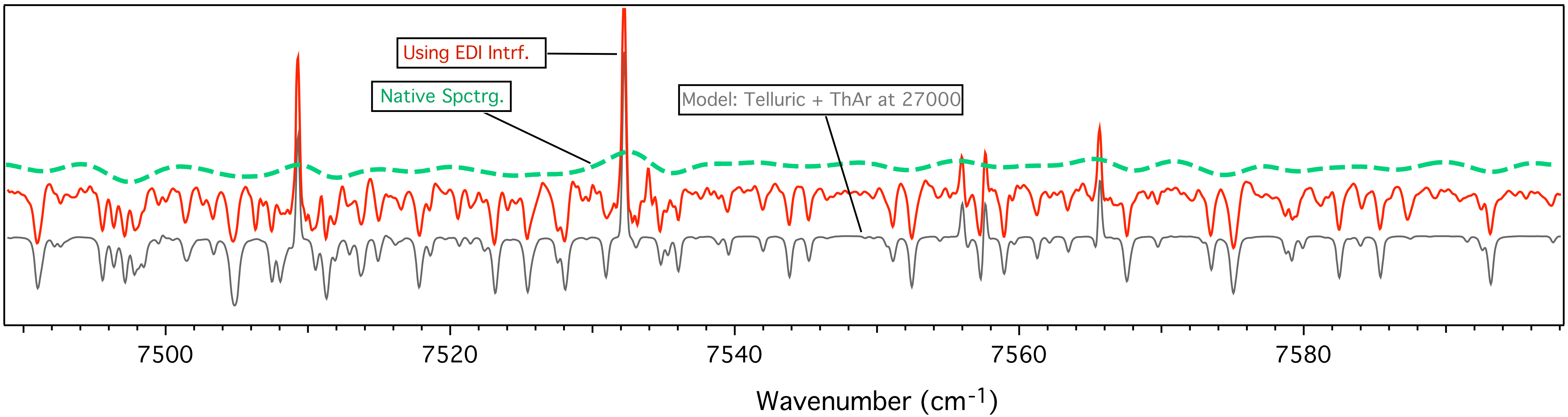
2.08 um

1.96 um

Moire fringes are produced which encode spectral information

We have software which reverses this process to deduce the high res spectrum from the moire

10x res boost demo'd on Mt. Palomar

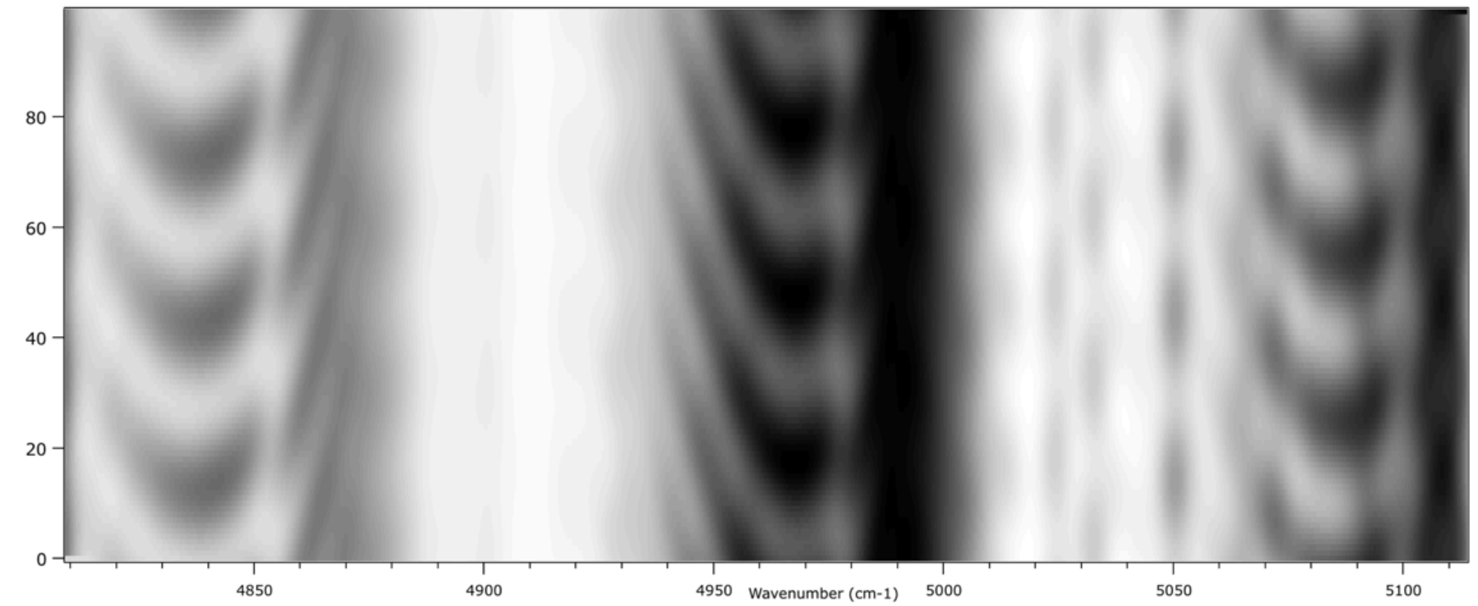


2700 --> 27,000 using 7 delays, up to 3 cm

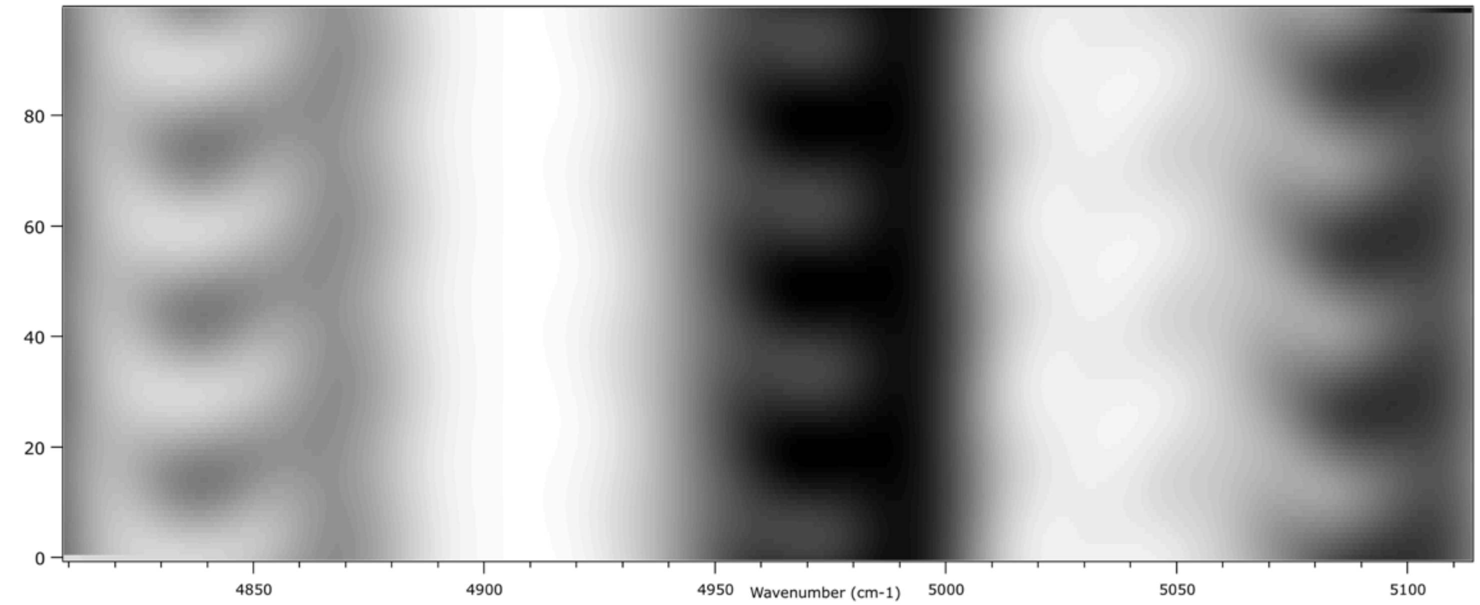
"**High-resolution broadband spectroscopy using externally dispersed interferometry at the Hale telescope: Part 1, data analysis and results**", D.J. Erskine, J. Edelstein, E. Wishnow, M. Sirk, P.S. Muirhead, M.W. Muterspaugh, J.P. Lloyd, Y. Ishikawa, E. McDonald, W. V. Shourt, and A. M. Vanderburg, J. Astr. Tele. Instrm. Sys. 2(2), 025004 (2016), doi: 10.1117/1.JATIS.2.2.025004.

"**High-resolution broadband spectroscopy using externally dispersed interferometry at the Hale telescope: Part 2, photon noise theory**", D.J. Erskine, J. Edelstein, E. Wishnow, M. Sirk, P.S. Muirhead, M.W. Muterspaugh, and J.P. Lloyd, J. Astr. Tele. Instrm. Sys. 2(4), 045001 (2016), doi: 10.1117/1.JATIS.2.4.045001.

Medium res



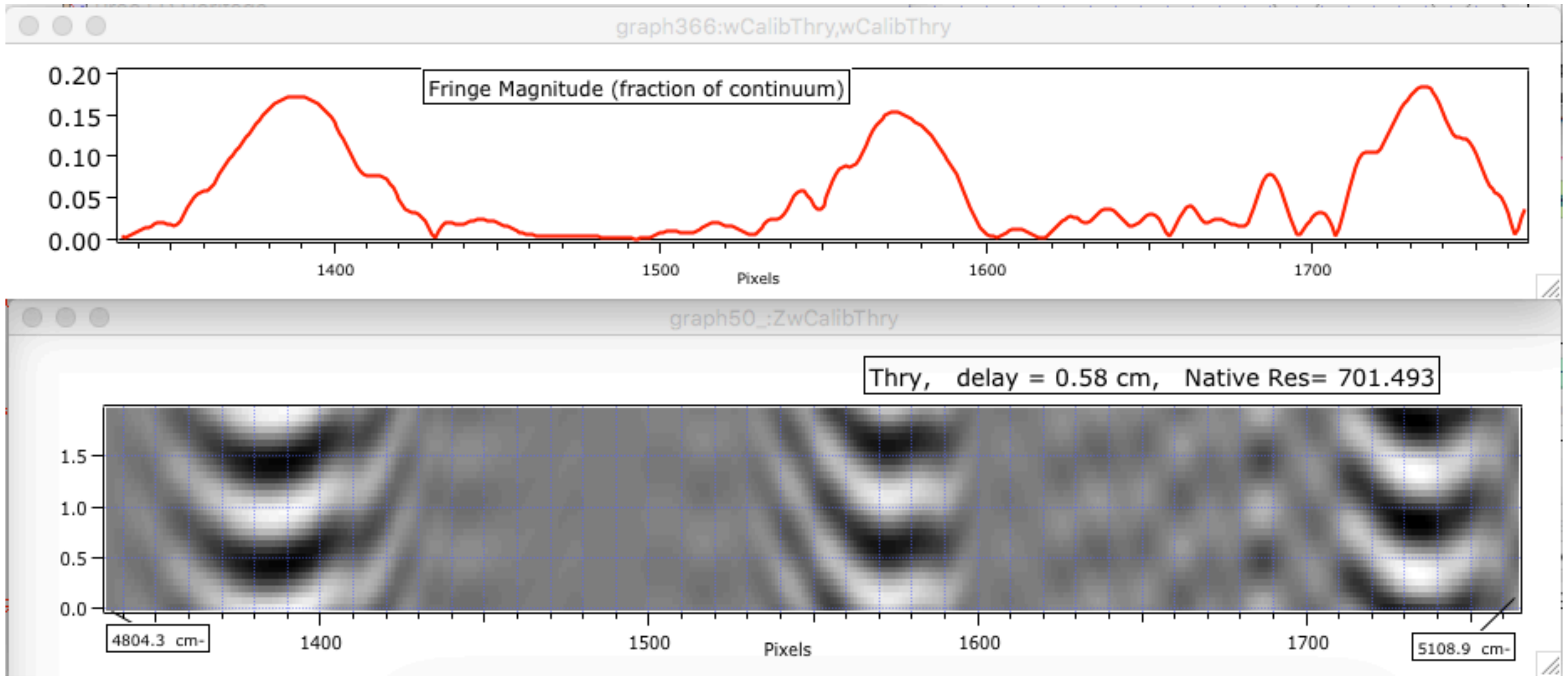
Low res



Moire fringes survive the spectrograph blurring

Native R~700

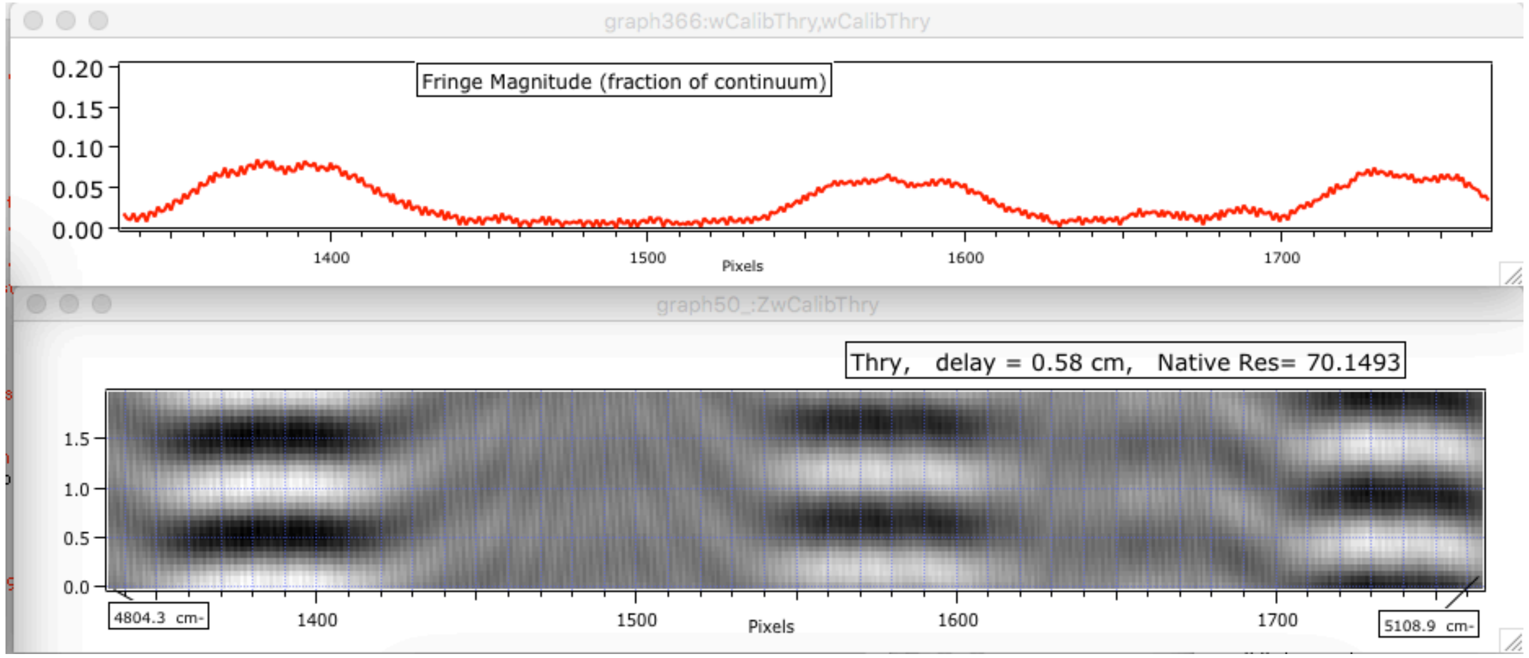
Mag ~ 16% of continuum

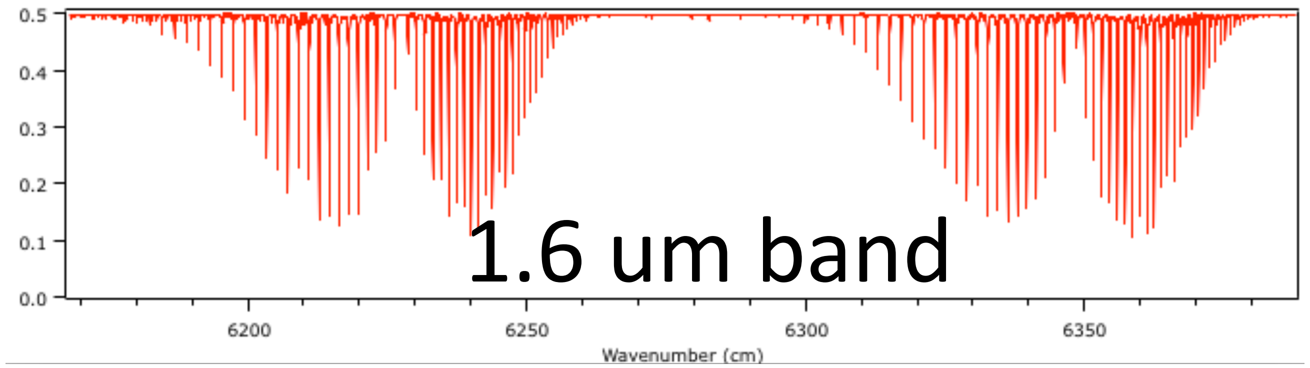


Plots subtract the nonfringing portion

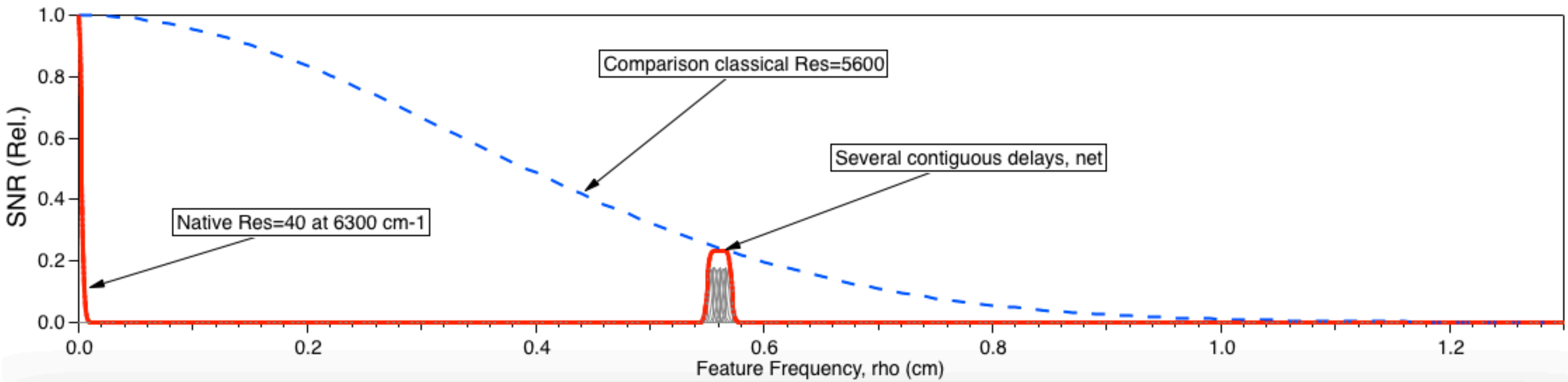
R~70

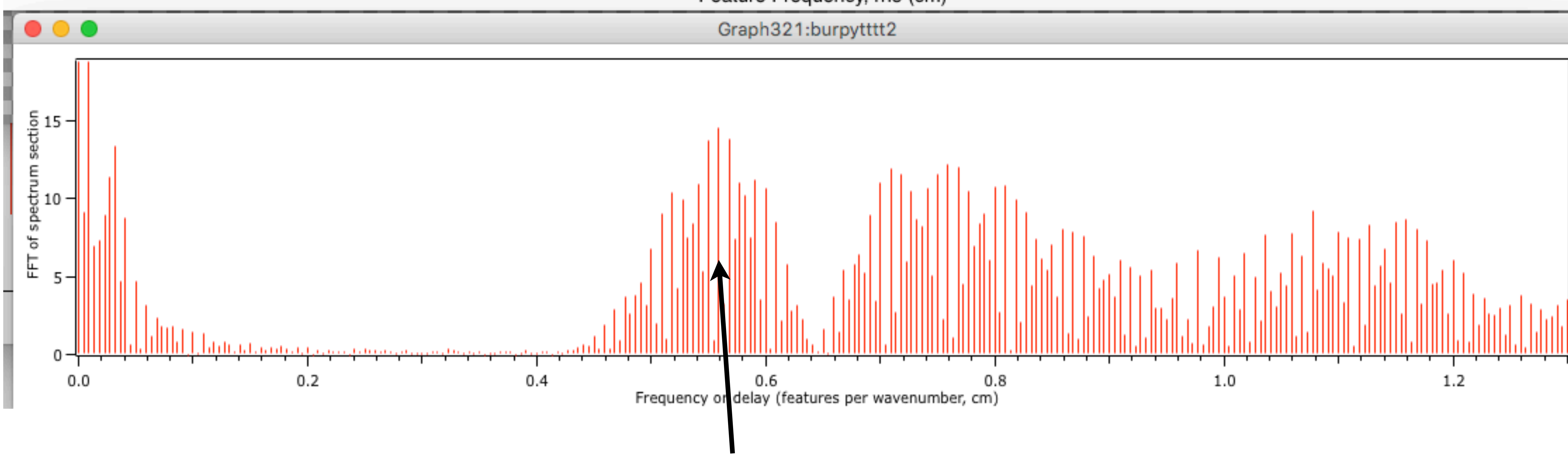
Mag ~ 7% of continuum





Fourier Transform of feature shows concentration of signal at high frequencies

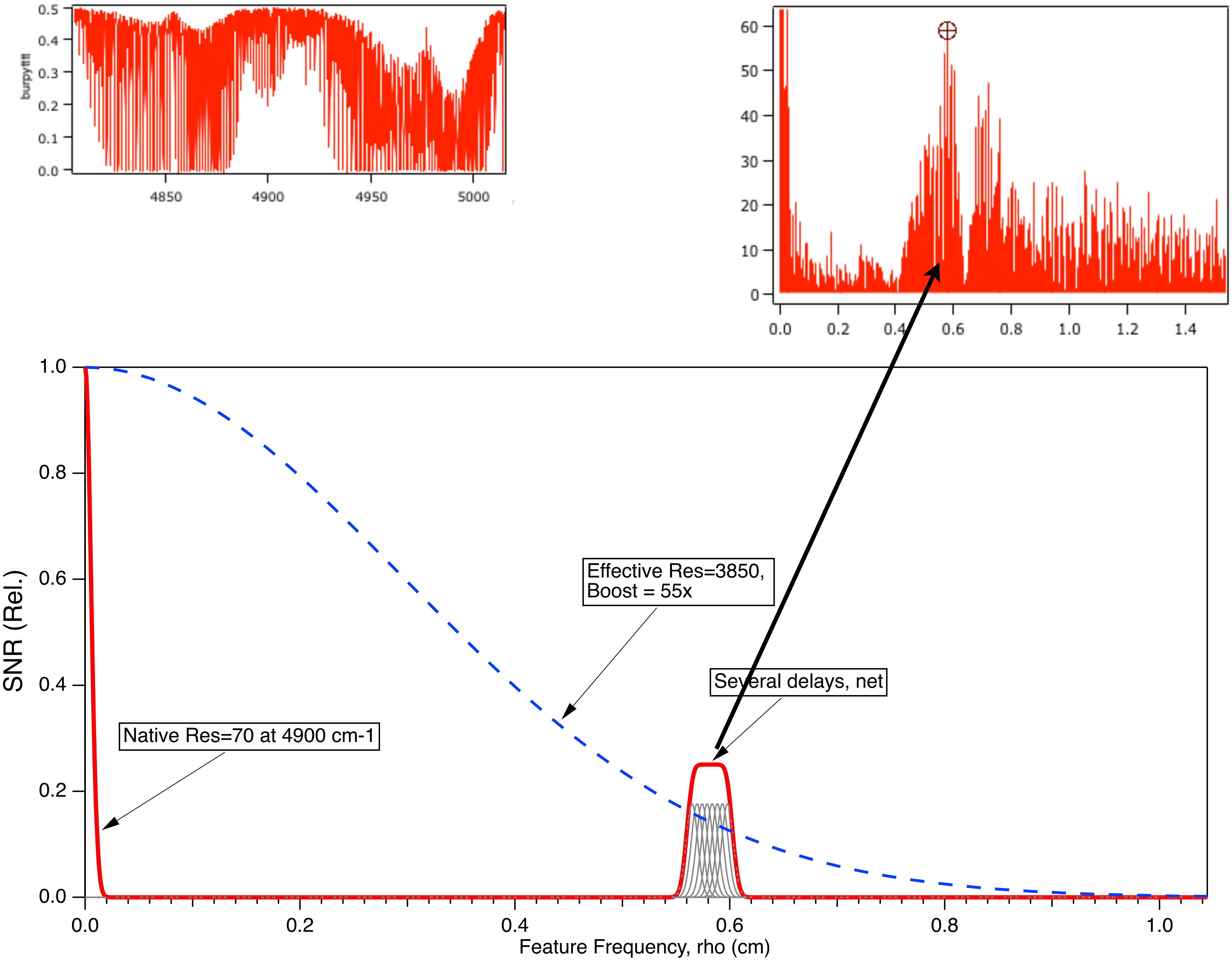




We have picked delay to probe this frequency

2 um band

FFT



burpyttt
0.5
0.4
0.3
0.2
0.1
0.0
4850
4900
4950
5000
60
50
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
SNR (Rel.)
1.0
0.8
0.6
0.4
0.2
0.0
Effective Res=3850,
Boost = 55x
Several delays, net
Native Res=70 at 4900 cm-1
Feature Frequency, rho (cm)