LLNL-POST-690377

(9908-224)

Canceling Spectrograph PSF Drift Error by Mixing Interferometer Delay Pairs

UC Berkeley, LLNL

SPIE.

D. Erskine, E. Linder, E. Wishnow, J. Edelstein, M. Sirk, P. Muirhead, J. Lloyd, A. Kim

INTRODUCTION

Uncontrolled drifts to spectrograph lineshape (PSF) is a major limit to precision in Doppler radial velocimetry and high resolution spectroscopy (Fig. 1). Traditional countermeasures include heavy expensive temperature controlled vacuum tanks and fiber scramblers.

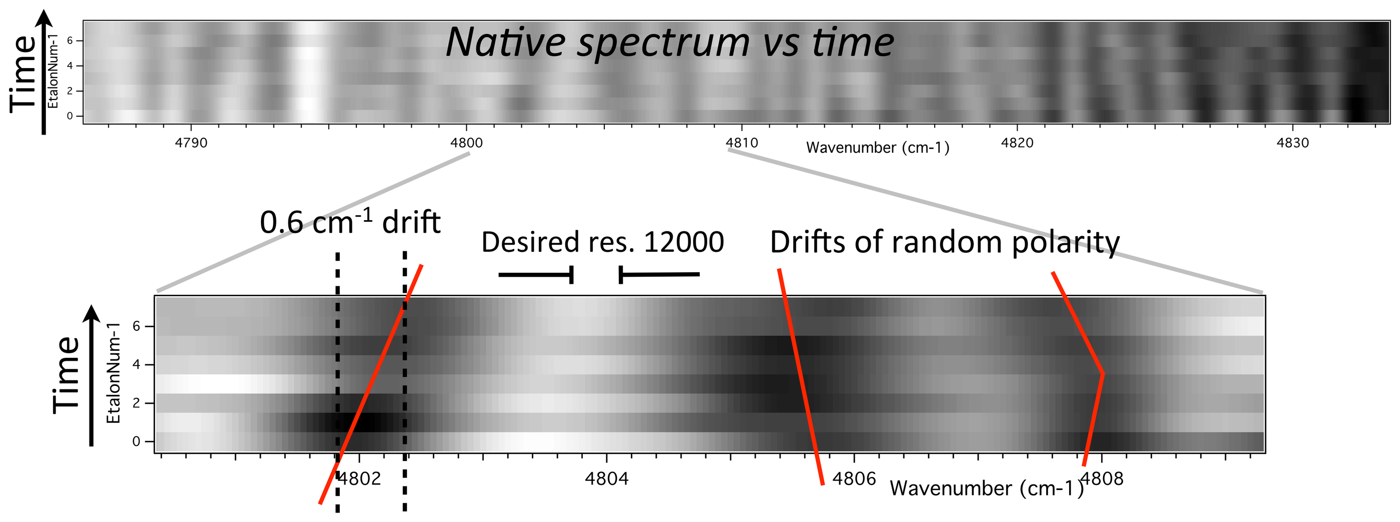

Fig. 1 Stack of native spectra vs time shows severe and irregular PSF drift that would make high resolution impossible without the interferometer. Native resolution ~2700. Resolution with the interferometer is as high as 27,000 at 1.3 micron after processing with multiple delays (0 to 3 cm). TripleSpec spectrograph bandwidth 0.9-2.45 micron. Stellar observations from "TEDI" project at Hale 5m telescope. Here, embedded interferometer fringes removed via summing over phase stepped exposures. Different interferometer delays (EtalonNum) used sequentially, a few minutes each.

METHOD: EDI with multiple delays

We demonstrate that by using an interferometer (EDI) with multiple delays, and mixing delay pairs during analysis, we can reduce effect of PSF drift by a factor of 350 or more. The apparatus "TEDI" tested on starlight at Hale 5 m telescope.

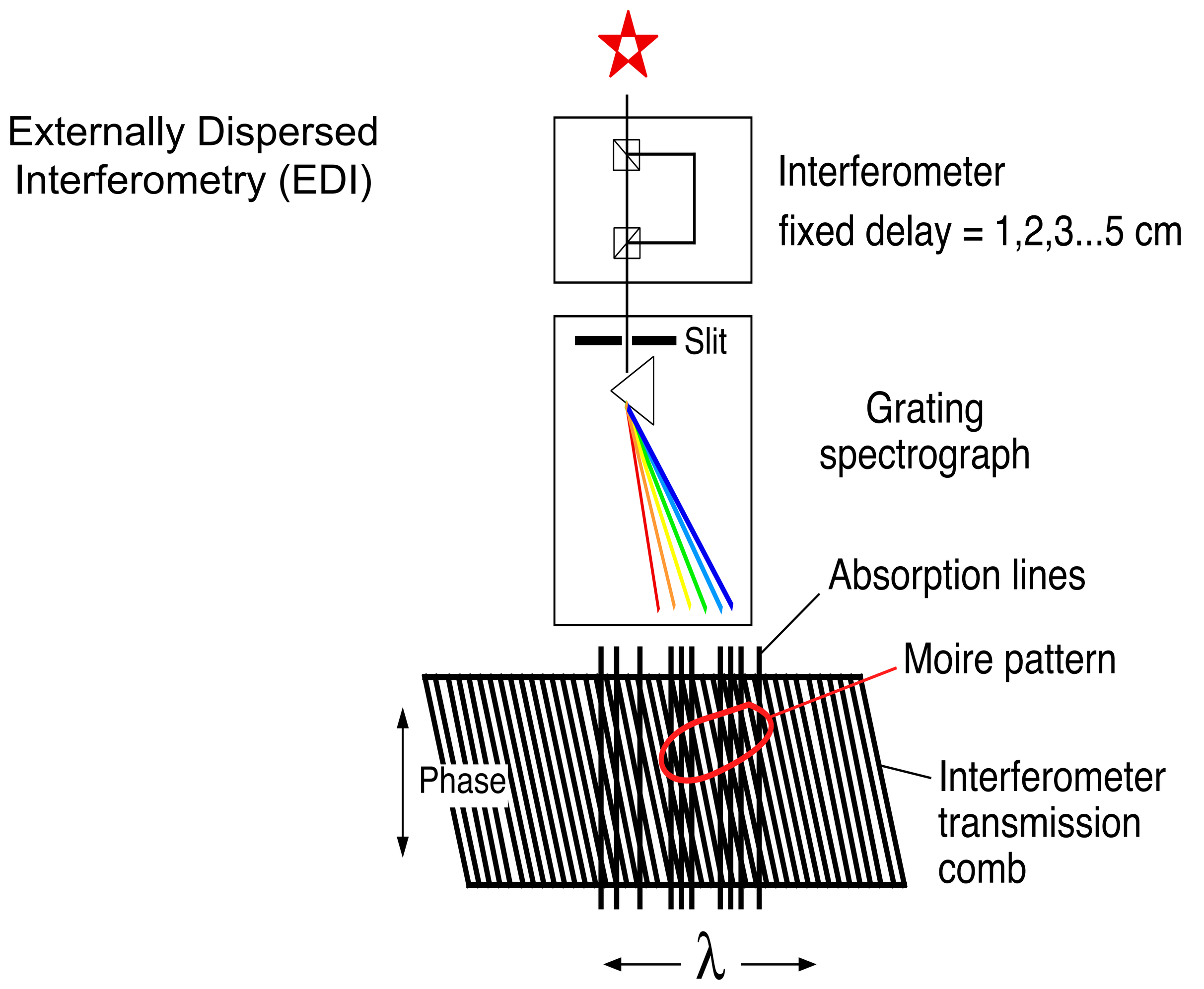

Fig. 2 Adding an interferometer outside the spectrograph multiplies a very uniform sinusoidal comb against the input spectrum. The heterodyning action creates Moire patterns whose shape holds high res information and whose phase shifts proportionally to Doppler radial velocity. The key to cancelling the PSF drift is to use more than one delay, and combine the results during analysis.

We define Translational Reaction Coefficient (TRC) to be the ratio of resulting shift to insulting shift. For the conventional, TRC=1. For EDI using the original lineshape and simple processing, we get ~20x reduction, TRC~0.05. This is due to embedded interferometer comb that acts as calibrant and moves along with insult.

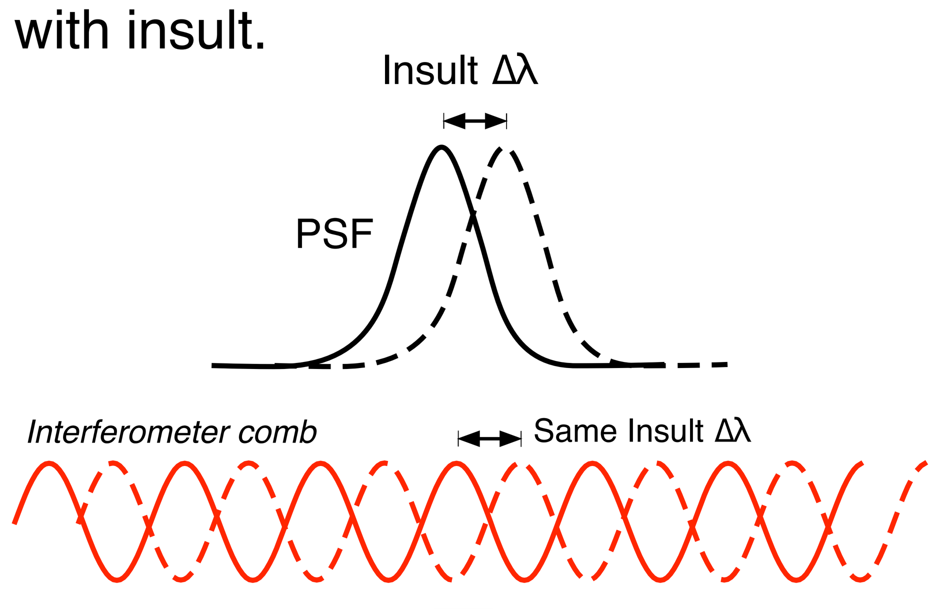

Fig. 3 When the environmental insult shifts the native spectrograph PSF by Δλ, the embedded interferometer comb (red) is shifted by the same amount. Hence the phase of the Moire patterns, which depends on the relative difference between input spectrum and comb, remains about the same, and TRC ~ 0.05, whereas for the native alone TRC=1.

Crossfading two Moire cancels PSF shift

However, we can do better. By using two or more delays, we can theoretically make TRC=0. We use a technique called crossfading which modifies the lineshape prior to summation into a special shape and width.

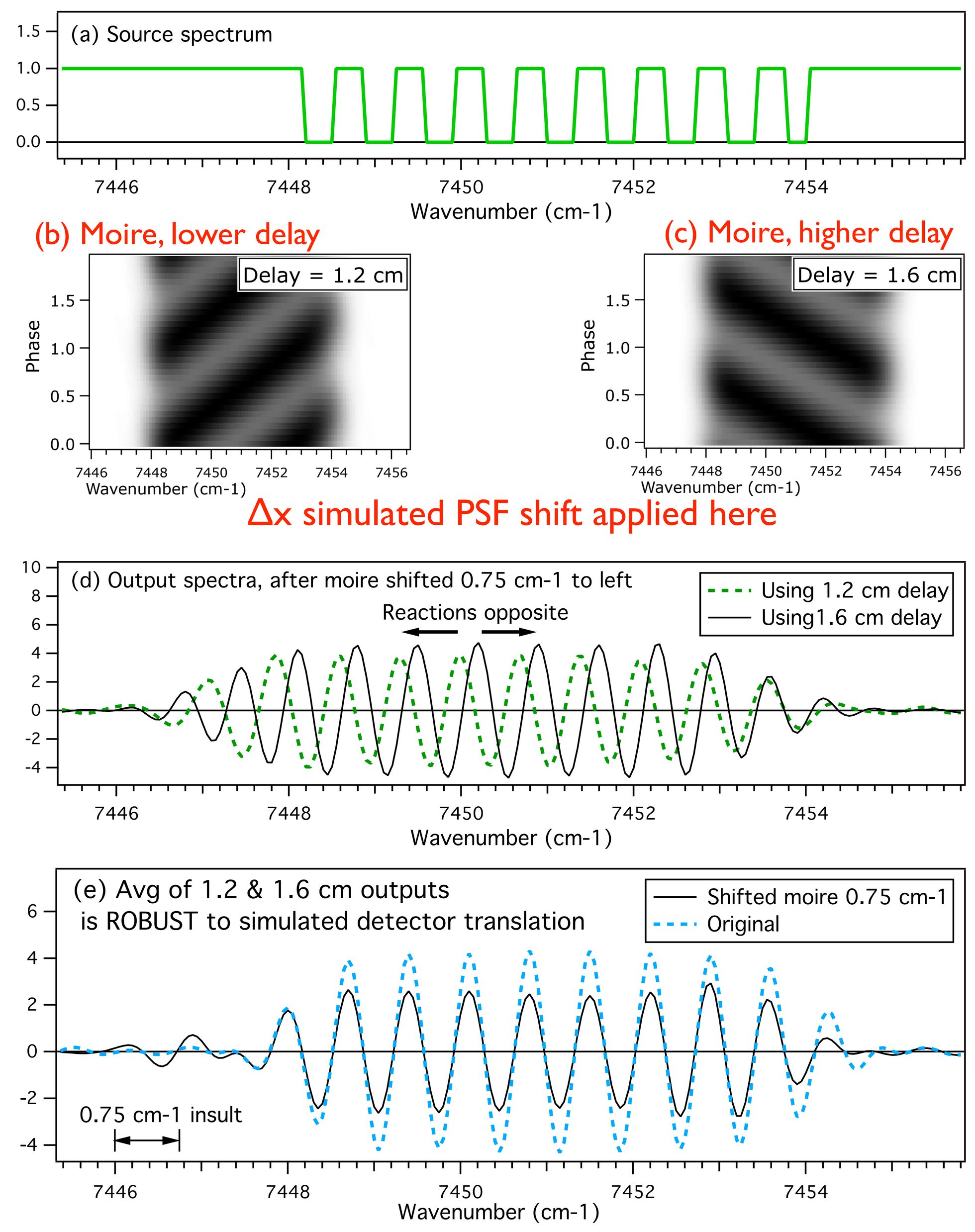

Fig. 4 Simulation showing that for two different delays, the Moire patterns can have opposite slopes in phase vs λ. Hence under a Δλ insult shift, they will react oppositely, so combining them can cancel the net reaction. The numerical simulation results in TRC=0.003, which is 350x smaller reaction than the native spectrograph alone. A special crossfading lineshape of triangle or sinc function produced this effect (sinc produces less ringing artifact). (b)(c) Moire patterns of two delays 1.4, 1.6 cm, were deliberately shifted to left by 0.75 cm-1. (d) Output spectrum reacts oppositely for different delays (dash, solid). (e) Crossfaded output, which is avg of two delays. The original (blue dash) and deliberately shifted data (black) align almost perfectly.

RESULTS

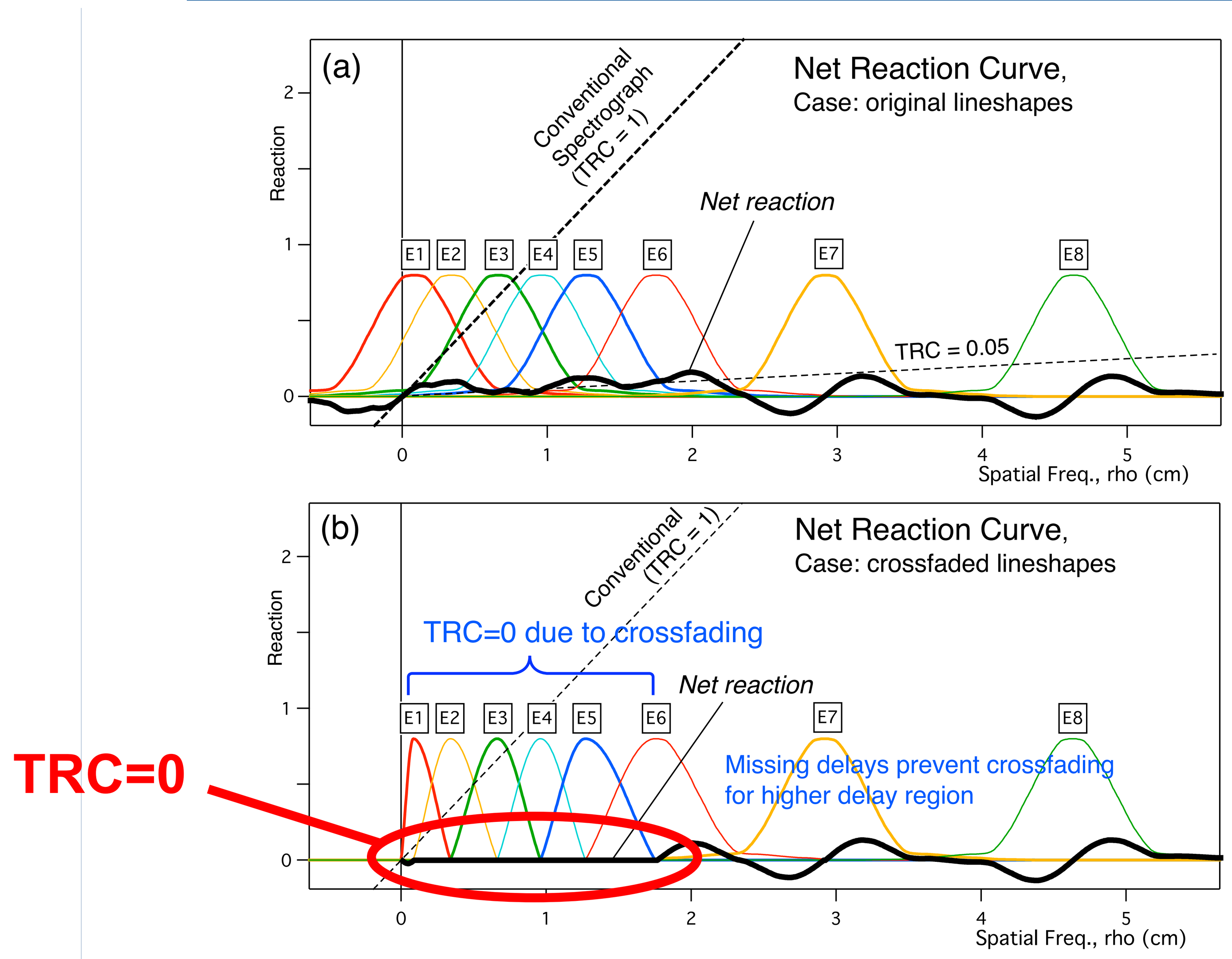

Fig. 5 Calculated reaction under a PSF shift, between original lineshape (a) and crossfading sinc function lineshape, in Fourier space (features per cm-1), using the actual delays and lineshapes from the TEDI project. Thick black curve is net reaction. (a) For original lineshape, TRC~0.05 for the six lowest delays E1-E6 (0-2 cm) being used. (b) For the sinc function crossfading lineshape TRC=0 for the region 0 to 2 cm. This means the output spectrum can be amazingly stable, despite PSF shifting insults shown in Fig. 1. Adding more delays to fill gaps between E7, E8 would allow crossfading to be applied to frequencies up to 5 cm, producing extremely stable spectra with resolutions as high as ~45,000 at 1.3 micron wavelength.

CONCLUSIONS

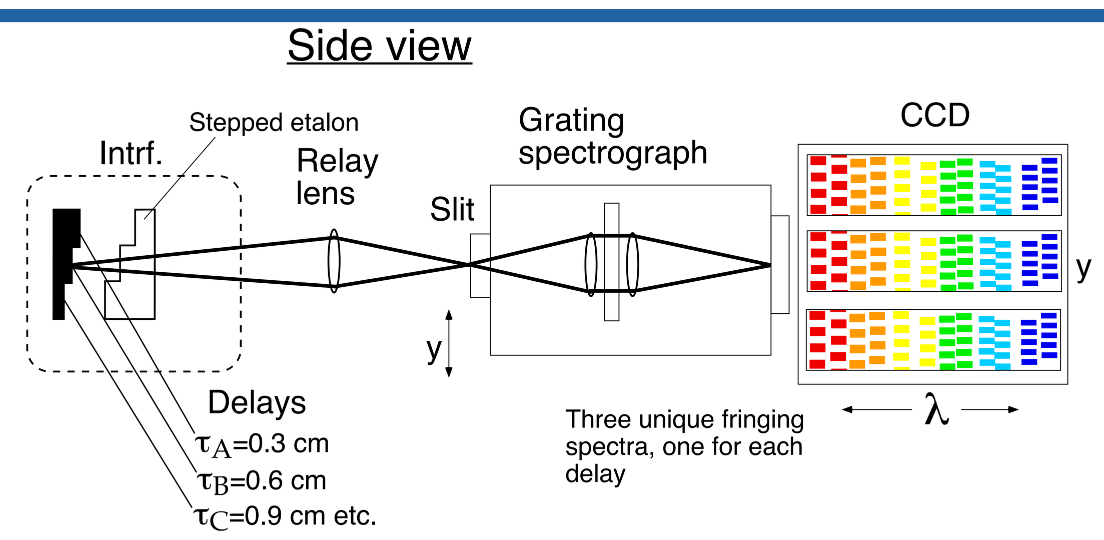

Fig. 6 Scheme for implementing multiple simultaneous delays in an interferometer, externally dispersed. Staircase stepped mirror and glass etalon produce a virtual image that appears as a single flat mirror.

Users of externally dispersed interferometers should modifying their apparatus to use 2 or more delays. This could dramatically reduce radial velocity instrumental noise, if PSF drifts are the dominant noise source.

A single delay can also stabilize the native peak, but at 1x resolution boost (hence useful if native is already high res.)

Prepared by LLNL under Contract DE-AC52-07NA27344.

http://spectralfringe.org/EDI/MyPubs4/EdinburghSPIEgen.pdf

SPIE Proceedings

http://spectralfringe.org/EDI/MyPubs4/TediTenxPart1gen.pdf

JATIS Journal Article

erskine@ssl.berkeley.edu

REFERENCES

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