Dispersed Interferometer for Doppler Planet Search at Mt. Palomar 200 inch Telescope

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Abstract: An interferometer mounted in the Cassegrain opening of Mt. Palomar's 200 inch telescope and dispersed by Cornell's TripleSpec near infrared spectrograph has been field tested for M-star Doppler planet search and high resolution spectroscopy.

OCIS codes: (300.6300) Spectroscopy, Fourier Transform; (300.6310) Spectroscopy, Heterodyne

1. Introduction

Externally dispersed interferometry (EDI) is a relatively new technique[1-3] using a series combination of a fixed delay interferometer with a disperser, and has applications in Doppler velocimetry[4-8] and high resolution spectroscopy[9-10]. The advantage of EDI is that it effectively boosts the resolution and stability characteristics of a given spectrograph, allowing use of lower resolution spectrographs for precision Doppler work otherwise not feasible. We describe initial field tests of an EDI at the 200 inch Mt. Palomar telescope coupled to the Cornell near infrared Triplespec[11] spectrograph, for a Doppler planet search in the near infrared (1 to 2.5 µm), (instrument name is "T-EDI"). Without the EDI, this spectrograph has insufficient resolution (~3000) to be practical for Doppler planet detection work.

In prior EDI's used for velocimetry, data was taken in *multiphase* format with linear spectrographs, where by tilting an interferometer mirror the interferometer phase was made to vary linear along the slit, which was many tens of pixels high. However, the use of echelle spectrographs such as in this project requires *uniphase* format where the

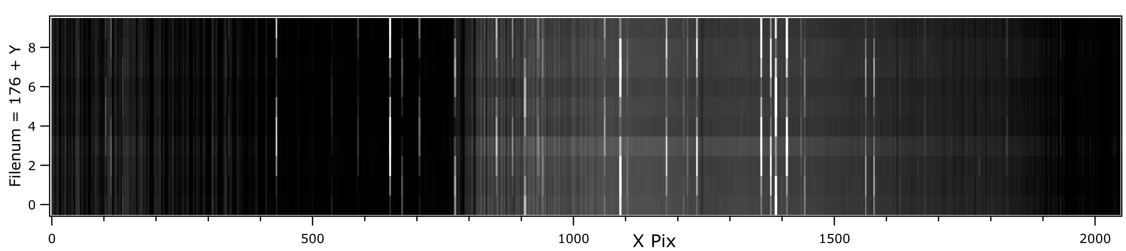

Fig. 1. Stacked set of ten phase stepped exposures, for star GJ15A plus ThAr lamp, middle order of spectrum. In this manner, modern uniphase EDI echelle spectrograph data (essentially 1 pixel high) appears as if in the multiphase format of earlier EDI instruments using linear spectrographs, having phase sloping across a slit many pixels high. Horizontal pixels cover approximately 6742 to 8852 cm-1. Y-axis is filenumber of exposure above first one, #176. Since phase steps are approximately regular, this axis is approximately interferometer phase. Each row is the middle order spectrum. Fringes vs Y are clearly seen in the bright narrow ThAr lamp lines. Starlight is much weaker than ThAr (starlight appears as smudge from x=800 to 1500). Stellar fringes are too faint (few percent) to be seen in this Figure. Variations in stellar component intensity due to seeing and clouds is evident, and is removed during analysis.

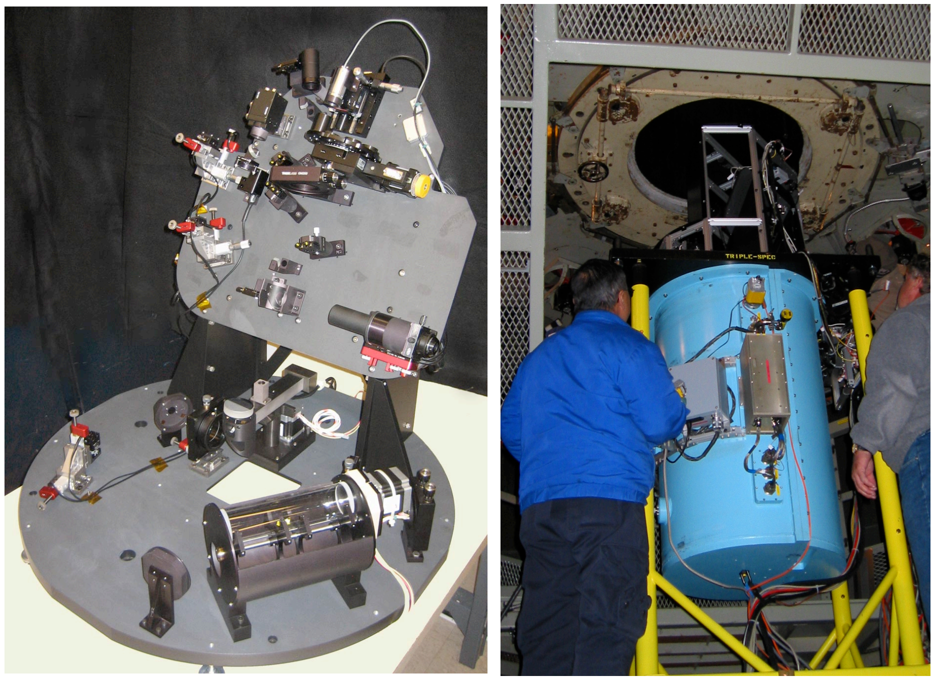

Fig. 2. Photograph of T-EDI interferometer, which sits atop Cornell's TripleSpec spectrograph (blue cylinder). The interferometer fits in the Cassegrain cavity of the 200 inch mirror, while the TripleSpec is bolted to the bottom of the mirror. The TEDI unit captures the starlight, passes it through an interferometer and optional gas cell, then re-injects both main and complentary outputs to form beams having same f/# and focus location as original beam, so that when a swing arm is removed the TripleSpec can operate without the interferometer.

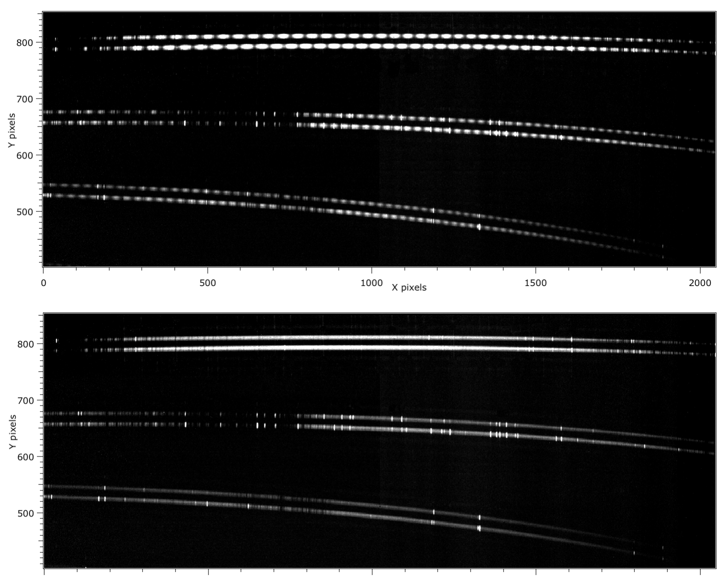

Fig. 3. Three out of five orders of the TripleSpec echelle spectrum for star GJ_338A are shown, with small interferometer delay (top, 0.3 mm) and large delay (bottom, 1.7 cm). Each order has both interferometer outputs (complementary in phase) in adjacent fibers. The period of the sinusoidal fringes vs wavenumber is inversely related to the delay. In the top graph the spacing is broad, mainly for demonstration purposes. In the bottom image the period is finer than the spectrograph resolution, but the effect can be seen in the differing intensities of the ThAr lines between main and complementary outputs. The multiplication of the sinusoidal interferometer transmission against spectral features having similar periodicity generates moire patterns, which are separated from the ordinary spectrum during data analysis using the phase stepping (which cause the fringes to shift but not the ordinary spectrum). The phase of extracted moire pattern for the star relative to the moire from the ThAr reference lamp yields the Doppler velocity. The moire patterns can also be processed to recover the shape of stellar spectral features beyond the resolution limit of the spectrograph or Nyquist limit of the pixel spacing, effectively boosting the resolution of the spectrograph by factors of several.

beam is essentially 1 pixel high. Phase is altered versus time rather than versus space, by taken a sequence of at least three (usually 10) exposures whose overall phase is stepped by a regular increment of 0.2 to 0.4 cycles. Due to the large bandwidth whose wavenumber changes by a factor of 2.5, the size of the phase step is different for different spectral channels. We have developed novel data analysis algorithms to process uniphase data having such a wide bandwidth, unknown phase step size, and where the amplitude of the starlight and superimposed ThAr reference lamp are independently unknown and varying. This was a more challenging task than for previous EDI's using an absorptive spectral reference such as an iodine cell, since there the absorptive (multiplicative) reference scales in magnitude with the stellar intensity, so only one normalization parameter is needed not two.

Figure 1 shows a way of presenting uniphase data in a more intuitive multiphase format. Figure 2 are photographs of the EDI hardware. Figure 3 are sample fringing echelle data taken with two different delays values (from a choice of eight glass etalons on a wheel). The small delay (0.3 mm) produces a visible interferometer comb useful for demonstrations and alignment procedures but not used for velocity. The largest delay of 4.5 cm is useful for slowly rotating stars or very high resolution spectroscopy. This material is based upon work supported by the National Science Foundation under Grant No. AST-0505366, and by LLNL under Contract DE-AC52-07NA27344.

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