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Development of highly sensitive monolithic interferometer for infrared planet search

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Abstract. We present the design, fabrication and testing of a highly sensitive monolithic interferometer for InfraRed Exoplanet Tracker (IR-ET). This interferometer is field-compensated, thermal-stable for working in the wavelength range between 0.8 and 1.35 μm. Two arms of the interferometer creates a fixed delay of 18.0 mm, which is optimized to have the best sensitivity for radial velocity measurements of slow-rotating M dwarfs for planet detection. IR-ET is aiming to reach 3–20 m/s Doppler precision for J<10 M dwarfs in less than 15 min exposures. We plan to conduct a planet survey around hundreds of nearby M dwarfs through collaborations with Astrophysical Research Consortium scientists in 2011–2014.

1. INTRODUCTION

There are over 400 exoplanets discovered as of 2010, and most of them are detected by radial velocity (RV) technique[1]. However, only a couple of exoplanets around M dwarfs have been discovered. Nonetheless, searching planets around M dwarfs is essential to answer the question of planet occurrence frequency dependence on stellar type. There are several advantages to search for exoplanets around M dwarfs in near infrared (NIR) using the RV technique: 1) stellar reflex motion is enhanced as stellar mass decreases, which favors detection of lower mass planet companion; 2) M dwarfs emit the bulk of their energy in NIR. Reiners et al. (2010) found that precision RV measurements of stellar types later than M4 reaches lower RV uncertainty in near infrared (NIR) than in visible wavelength [1].

While direct echelle method (DE) is still the most widely adopted method in precision RV measurement [2] [3], Ge (2002) proposed the dispersed fixed delay interferometer (DFDI) method [4] and Erskine (2003) proposed the externally dispersed interferometer (EDI) method [5] in precision RV measurement. In DFDI and EDI method, RV is measured by monitoring fringe phase shift of stellar absorption lines. The method is realized by coupling an interferometer with a post-disperser. DFDI and EDI are very attractive for its low cost, compact size, high instrument throughput and multi-object potential [4]. Van Eyken et al. (2010) discussed theory and application of DFDI in detail [6].

2. INTERFEROMETER DESIGN

Fixed delay interferometer plays an crucial role as a fine spectral resolution elements for high precision RV measurement [4, 5, 7]. Doppler sensitivity of DFDI can be optimized by carefully choosing the group delay (GD) of the interferometer. GD is often referred as optical path difference (OPD) in general

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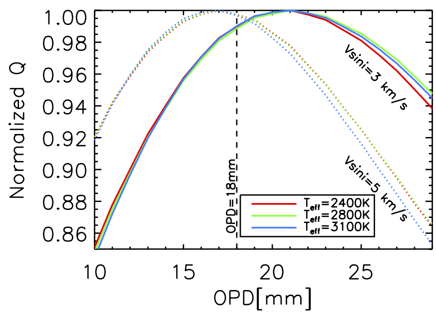

Figure 1. Normalized Q factor as a function of OPD. Normalized Q factor is the Q factor normalized by the maximum of Q factors in the category.

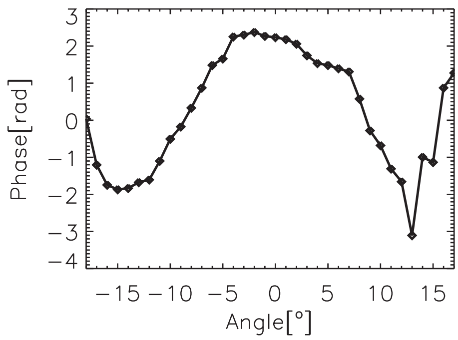

Figure 2. Laser interferogram phase variation as a function of incident angle.

occasions. Numerical simulations have been carried out in order to optimize the doppler sensitivity of IR-ET. The method of calculating Q factor for DFDI can be found in Wang et al. (2011)[8]. The specification of IR-ET is elucidated in Zhao et al. (2010)[9]. We find that doppler sensitivity of IR-ET is optimized when OPD is approximately 18 mm for slow-rotating M dwarfs (3 km/s $\leq V \sin i \leq$ 5 km/s).

3. LABORATORY TESTING

3.1 Field compensation

Light beam is converged onto each arm (mirror) of the interferometer, which requires that the interferometer is field compensated within certain field of view. Otherwise, visibility is reduced and so is the doppler sensitivity of the instrument. Fig. 2 plots phase variation measured from laser interferogram as a function of incident angle. It is shown in Fig. 2 that phase variation is less than π in field of view range of 35°. Field compensation of the interferometer is more than sufficient for a beam with numerical aperture of 0.125 (f-number of 4).

3.2 Thermal instability and bracketing error

We adopt 'Bracketing' scheme in observation in which every science observation is bracketed by two calibrations which are used to track instrument RV drift. Instrument drift is induced by instabilities of different components including the interferometer and the spectrograph. It is essential to know the thermal instability of the interferometer and how well it is tracked by 'Bracketing' method. The RV error of 'Bracketing' is later used to calculate RV error budget contributed by different components. We

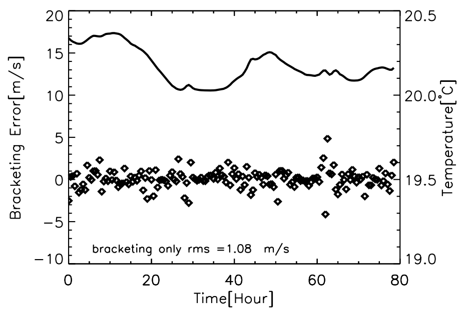

Figure 3. Bracketing error and temperature variation as a function of time in 3 days time baseline.

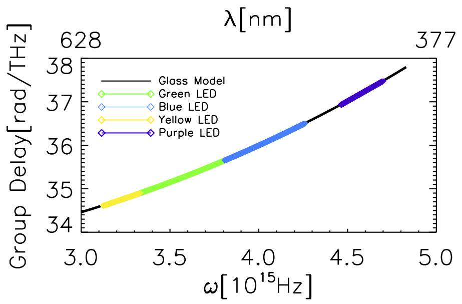

Figure 4. Group delay is measured as a function of optical frequency.

assume each science observation is 20 min and each calibration takes 2 min. RV error due to Bracketing is shown in Fig. 3 with RMS of 1.08 m/s. Note that the experiment is conducted in room temperature without temperature and pressure control. Bracketing RV error is expected to be reduced with active temperature and pressure control, which, however, requires experimental confirmation in the future.

3.3 Group delay measurement

Group Delay (GD) is an important property of the interferometer of IR-ET, which determines phase to velocity scale (PV scale), i.e., a parameter converts the stellar fringe phase shift measured in DFDI method into RV variation. An imprecise GD measurement not only induces artificially annually-varying RV but also undermines RV precision[10]. We demonstrate that GD can be measured at sub-fringe precision ($\leq 0.05\,\mu$m) in visible band. Lack of Near InfraRed (NIR) light source and detector by the time the experiment was performed is the reason why GD measurement has not reached NIR wavelength range. Visible band experiment results are shown in Fig. 4. LEDs of different colors are used as light source and a white-light scanning interferometer (WLI) is used to measure GD of IR-ET interferometer[11]. GD predicted by glass model is over-plotted as solid line. Phase measured by WLI at the frequency of a green He-Ne gas laser (543.0 nm) is then compared with the phase measure by the green laser, disagreements between these two results indicate that the precision of GD measurement by WLI method is better than $0.05\,\mu$m.

4. CONCLUSION AND DISCUSSION

Numerical simulation has shown that doppler sensitivity is optimized for slow rotating M dwarfs when the OPD of the IR-ET interferometer is approximately 18 mm. We have completed the assembling of the IR-ET interferometer and conducted experiments to measure its properties including field compensation, thermal instability and OPD. The field compensation ensures reasonable visibility for light beam with f-number of 4. RV error of bracketing purely due to thermal instability of the IR-ET interferometer is measured at 1.08 m/s under room temperature without temperature and pressure control. Precision of OPD measurement is demonstrated to be better than 0.05 μm in visible band. Measurement in NIR is going to be finished in the near future.

References

[1] Reiners, A., et al. 2010, ApJ, 710, 432
[2] Butler, R. P., et al. 1996, PASP, 108, 500
[3] Bouchy, F., et al. 2001, A&A, 374, 733
[4] Ge, J. 2002, ApJ, 571, L165
[5] Erskine, D. J. 2003, PASP, 115, 255
[6] van Eyken, et al. 2010, ApJ, 189, 156
[7] Wan, X., et al. 2009, Proc. SPIE, 7424, 742406
[8] Wang, J., et al. 2010, ApJ, In Prep.
[9] Zhao, B., et al. 2010, Proc. SPIE, 7735, 773554
[10] Wang, J., et al. 2010, ApJ, In Prep.
[11] Wan, X., et al. 2010, Applied Optics, 49, 5645