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Doppler Planet Search with a Novel Spectrally Dispersed Interferometer

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One of the hottest topics in astronomy today is the search for planets outside our solar system by measuring the extremely small Doppler shifts on starlight created by the planet as it tugs the star during its orbit. Jupiter and Saturn-like planets would create 12 and 3 m/s velocity wobbles, respectively. The extra-solar planets discovered to date however have been very different from our own solar system, many as massive as Jupiter and yet orbiting many times closer. These have produced large velocity signatures of order 50 m/s. This begs the question: is our solar system unique or usual? In order to better answer this question, the current Doppler measuring instruments need to be improved to have finer velocity resolution (desire 1 m/s or better). The current instruments based on diffraction gratings have complicated instrument responses which limit current Doppler velocity resolutions to ~3 m/s.

We have developed a new instrument, called a fringing spectrometer or spectrally dispersed interferometer. The Doppler shift is detected by change in phase of fringes created by an interferometer, whose visibility are enhanced by being splayed out in a spectrum by a low resolution disperser. Because the interferometer has a mathematically simpler behavior than a grating, the velocity resolution is improved.

In FY98 we developed hardware and obtained initial fringing spectra. In FY99 we developed the software for extracting the phase of the fringes to yield velocities, added hardware to improve system stability, built a 2nd generation instrument optimized for telescope operation, and developed optical fiber feeding systems for the FY00 tests. At the end of FY99 we successfully passed starlight from the nearby Leuschner 30 inch telescope (UC Berkeley) into an thin optical fiber, which will soon lead to our fringing spectrometer.

Our novel hybrid approach combining interferometry and dispersive spectroscopy has enabled us to reach a new phase measurement precision of 1/20,000th of a fringe, an order of magnitude improvement for interferogram analysis. This allowed us to break the 1 m/s barrier for the first time, compared to the current limit of about 3 m/s for grating instruments. Figure 1 shows a velocity repeatability test using a stationary bromine lamp which simulates the stellar spectrum. The standard deviation in first 16 minutes is 0.76 m/s. Although the long term drift is larger, it is already competitive with conventional instruments (comparison data on a planetless star by Marcy & Butler). This data was taken with the preliminary instrument prior to late FY99 improvements. We expect these to improve long term stability in FY00 to the 1 m/s level.

This technique promises many benefits in other areas of spectroscopy and metrology. This project will enhance LLNL's capabilities in advanced diagnostics essential to the Stockpile Stewardship Management Program and the nonproliferation effort. The mathematical tools we developed enabled more than 100 times faster extraction of velocities from spectra compared to current planet searches, in an instrument that is also inexpensive and compact. In FY00 we will test our instrument on starlight at observatory telescopes to verify its abilities to detect smaller mass planets. In addition, the ~1 m/s resolution will be useful for measuring real time radial velocity oscillations of stellar photospheres analogous to the sun's solar oscillations, which has been tried unsuccessfully by others. This can lead to better understanding of the internal structure of stars as well as help distinguish small mass planet tugging effects from photosphere behavior.

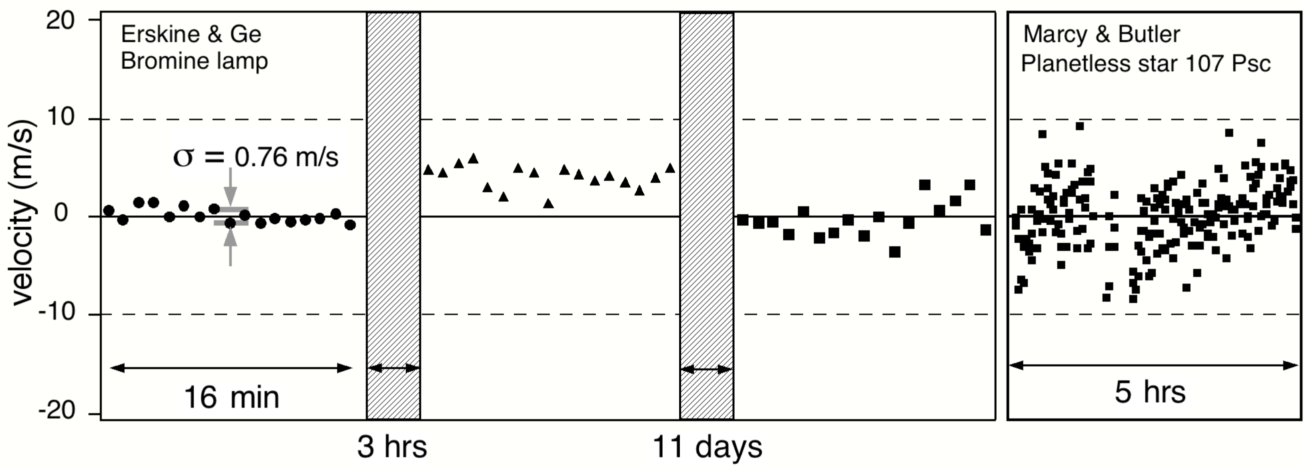

Figure 1. Velocity repeatibility test using a stationary spectral source (bromine lamp), compared to Marcy & Butler's repeatibility test on a planetless star.