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Search for Low-Amplitude Stellar Motions in NGC 752[1]

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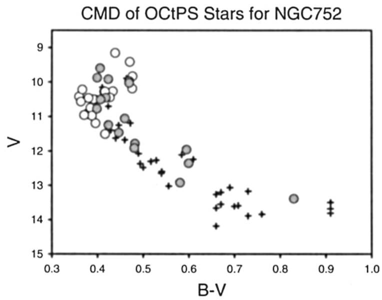
Abstract.
We report preliminary results of a radial velocity study of the old open cluster NGC 752 using an ensemble mean approach with Hydra multi-fiber spectroscopy on the 3.5-m WIYN telescope. The goal is to detect the higher amplitude extra-solar planetary systems and brown dwarf binaries that might reside in the cluster. The oscillation modes of mid-F stars at the redward edge of the instability strip can also be observed. The observation of NGC 752 is the first step in an ongoing study of a variety of clusters with different ages and metallicities.

1. Introduction

The use of star clusters for brown dwarf and planet searches offers advantages over surveys of field stars. Clusters provide samples of stars that are well-defined in age, distance, and metallicity. They include stars over a range of spectral types in statistically significant numbers. And finally, with multi-object fiber spectroscopy, dozens of cluster members can be observed simultaneously, dramatically increasing the efficiency of the search. For all of these reasons, the use of star clusters as targets for searches for extra-solar planets is an obvious idea. For example, D. Duncan, T. Gilliland, T. Brown, & S. Barden attempted to survey Jupiter mass planets in open clusters in the early 1980s using a plugboard

[1]The WIYN Observatory is a joint facility of the University of Wisconsin-Madison, Indiana University, Yale University, and the National Optical Astronomy Observatory



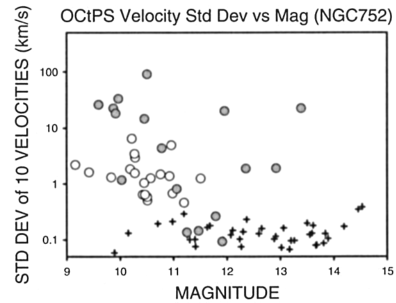


Figure 1. *Left:* The color-magnitude diagram of stars observed in NGC 752 using photometry from Daniel et al. 1994. Known binaries are shown as filled circles, stars with variable velocity as indicated by a high standard deviation in the measured velocity relative to the cluster mean are shown as open circles, and stars included in the ensemble velocity mean are shown as crosses. Note the stars on the left at the main sequence turnoff are near the instability strip.

Figure 2. *Right:* The standard deviation of 10 measurements (not the standard deviation of the mean!) on 4 nights over about a 100 day baseline. The average standard deviation of the stars used for the zero point correction is ~140 m s^{-1}, but likely still includes binaries that will eventually be rejected through further observation and iteration. Symbols are as in Figure 1.

fiber feed to the echelle spectrograph on the Kitt Peak 4-m telescope. They achieved a velocity precision of 80 m s^{-1} (Barden, private communication), then thought to be too crude to detect planets around other stars. Similar investigations of giants in the globular cluster M71 in the early 1990s by S. Barden, T. Armandroff, & T. Pryor (private communication) achieved sub-km s^{-1} velocity precision, even with a spectral resolving power of only 4000.

Previous searches for planetary-mass stellar companions have focused on studies of individual field stars using ultra-high precision radial velocity measurements, yet of the more than 100 candidate extra-solar planetary systems discovered to date, more than a third have velocity amplitudes greater than 100 m s^{-1}, and 16% have velocity amplitudes greater than 200 m s^{-1} (Marcy et al. 2000). Detection of these large amplitude systems places less stringent requirements on the necessary precision of velocity measurements, and many low mass companions can be discovered with velocity precisions of only 100 m s^{-1}.

2. Preliminary Observations of NGC 752 Stars

Our Hydra observations of NGC 752 include 77 cluster stars, including 60 of 90 stars brighter than V=13 and 70 of 120 stars brighter than V=14. The observations are made in the spectral region including the Mg II triplet at 5170 Å. A color-magnitude diagram of the observed sample of stars in NGC 752 is shown in Figure 1 and demonstrates the range of color and apparent magnitude reached with Hydra.

The early multi-fiber searches for low mass companions in clusters achieved such remarkable velocity precision through an internal velocity calibration technique, rather than an absolute approach. The same stars are observed repeatedly with the same fiber configurations, and velocities of the individual stars are then determined relative to the mean of the ensemble of stars observed. The ensemble-mean technique uses the average velocity of the stars in the sample that are not varying. An iterative process is used to remove obvious and highly suspected variable stars. As more data are collected, the low amplitude systems are detected and removed from the stars used to set the zero point.

Preliminary evaluation of the first four nights of our NGC 752 data (taken over a 100-day baseline) demonstrates a velocity precision of $\sim$100 m s^{-1} (0.013 pixels) with the Hydra multi-fiber spectrograph using its high dispersion echelle grating configuration. Velocities are determined by cross-correlation using the IRAF *fxcor* task with twilight or day sky spectra as the velocity template. Velocities can be determined for solar-type stars as faint as 14th magnitude in V, and through range of B-V color from 0.4 to 0.8, corresponding to spectral types from early F through early K. Figure 2 shows the standard deviation of each individual star's velocity versus magnitude of the four night data set.

Hydra velocity measurements for known binary stars in NGC 752 compare well to published velocity data and velocity curves for known binaries. Published measurements from Daniel et al., though precise only to the 1-2 km s^{-1} level, allow calibration to an absolute velocity scale. The Hydra observations can be phased with published orbital parameters for two known binaries in NGC 752, BD +37 444 (Pilachowski et al. 1989) and DS And (Schiller & Milone 1988), although our preliminary sample of Hydra data is insufficient to derive new orbital parameters.

Sample data are shown in Figure 3 for two possible new velocity variables detected in our preliminary analysis. In both cases, the left panels include both the Daniel et al. velocity data and the Hydra observations, while the right panels show just the low-amplitude variation observed in the Hydra data. In the upper pair of panels, the velocity amplitude observed from the Hydra observations is $\sim$450 m s^{-1}, while in the lower pair of panels, the velocity amplitude observed with the Hydra data is $\sim$800 m s^{-1}.

3. Improving Velocity Precision

Use of the Hydra fiber spectrograph clearly allows the simultaneous spectroscopic observation of a large sample of stars with precise relative determinations of their radial velocities. Limitations to the precision of our velocity measurements from the ensemble mean technique appear to come primarily from the wavelength calibration. A study of the wavelength coefficients shows a variation of 50 to 100 m s^{-1} from fiber to fiber. The current technique uses an independent wavelength calibration for each fiber. In reality, a global solution is possible

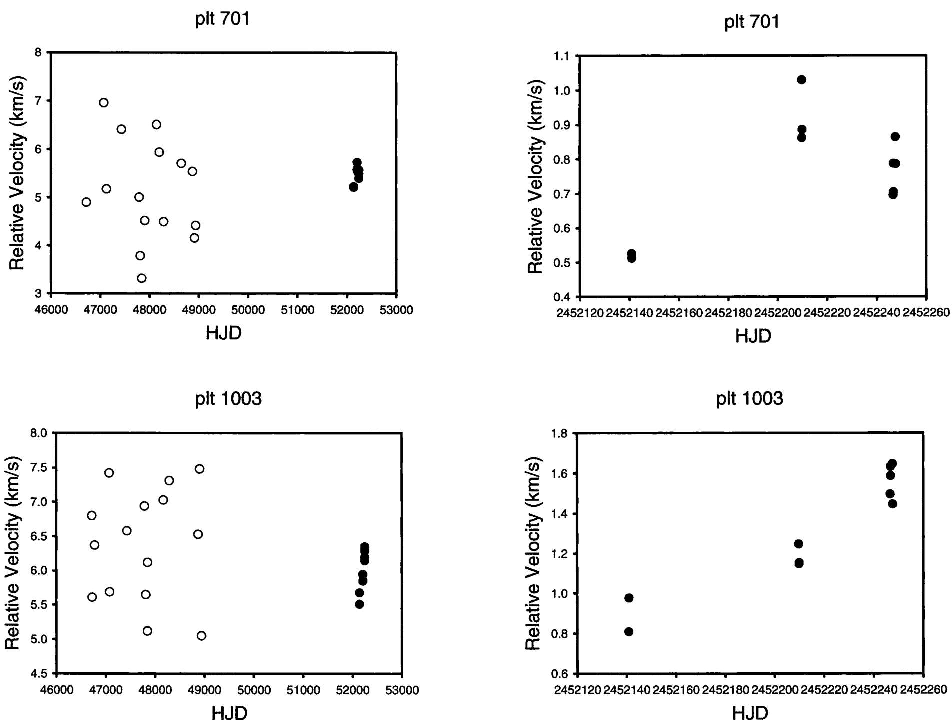


Figure 3. Two possible low-amplitude binary candidates. Left panels include published velocities from Daniel et al., while the right panels show only the higher precision Hydra data. The Hydra observations suggest velocity variability with amplitudes of a few hundred km s^{-1} can easily be detected with the ensemble mean technique.

since only the wavelength zero point, not the dispersion coefficients, varies from fiber to fiber, to first order.

The dispersion coefficients are dominated by the optics and should therefore vary smoothly across the CCD, and hence from fiber to fiber. Unfortunately, we have not yet incorporated an algorithm to do wavelength calibrations in a global sense. Our velocity precision should improve to about 50 m s^{-1} when a global dispersion algorithm is implemented.

Further improvement in velocity precision may be possible by inserting an image scrambler into the fiber optic train. Evaluation of how well individual stars are centered on the fiber input aperture indicates that decentering contributes an error less than our current velocity uncertainty. Photon noise becomes the limiting factor only in stars near 15th magnitude.

4. Future Directions

The brighter stars near the main sequence turnoff of NGC 752 show significant velocity variations (of order 600 m s^{-1}; see Figures 1 and 2) that may be attributed to p-mode oscillations. These stars lie near the red edge of the pulsational instability strip. The short period of such oscillations (30 minutes to a few hours) would explain the stochastic nature of our detections with integration times of about an hour. We are monitoring these stars with 15 minute exposures during some of the observing runs in order to better sample the oscillation periods that may be present. These observations may constrain the upper limit on the main sequence for which velocity techniques may be suitable for the detection of low mass companions.

Monte Carlo simulations suggest that we need on the order of 18 epochs to derive adequate orbital information. We are targeting the high amplitude end of the extra-solar planet distribution, and orbital periods are expected to only be a few days. Orbital periods for brown dwarf companions with comparable velocity amplitude may be considerably longer, but binaries with orbital periods greater than a few months are most likely due to low inclination stellar companions. Simulations of what we can expect from a set of 18 observations of a cluster sample, with realistic assumptions about the distribution of companion masses, orbits, and inclinations, and the velocity precision that we can obtain, suggest we should detect most "short to mid" period systems with amplitudes exceeding 100 to 200 m s^{-1} with our full planned dataset.

References

Daniel, Scott A., Latham, David W., Mathieu, Robert D., Twarog, Bruce A. et al. 1994, PASP, 106, 281

Liu, Michael C., Fischer, Debra A., Graham, James R., Lloyd, James P., Marcy, Geoff W., & Butler, R. Paul 2002, ApJ, 571, 519

Marcy, G. W., Cochran, W. D., & Mayor, M. 2000, in Protostars and Planets IV, V. Mannings, B.P. Boss, and S. S. Russell, eds.; the University of Arizona Press (Tucson); p. 1285

Pilachowski, Catherine A., Willmarth, Daryl W., Mathieu, Robert D., Latham, David W., Booth, John, & Armandroff, Taft 1989, PASP, 101, 991

Schiller, S. J., & Milone, E. 1988, AJ, 95, 1466