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Transit Search for Exoplanets with the Vulcan Camera

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Abstract. The NASA Ames Research Center's Vulcan photometer is being used in a search for close–in giant extrasolar planets. With our current data reduction system we achieve 0.2–0.8% hour–to–hour relative photometric precision on $\sim$ 6000 stars brighter than 13$^{\text{th}}$ magnitude. Three Galactic-plane fields have so far yielded hundreds of variable stars, including $\sim$ 50 eclipsing or interacting binaries per field. Several candidate detections have been followed up with radial velocity observations. High-resolution spectroscopy revealed many of the strongest candidates to be grazing eclipsing binaries.

1. Introduction

Recent discoveries show that many planetary systems are quite different from our Solar System in that they posses giant planets in extremely short-period orbits. To deepen our understanding of planetary system formation and evolution, observations including the number, size, mass, and spacing of planets around a variety of star types are needed. The NASA Ames Research Center's Vulcan camera is being used in a photometric search for transits of these giant inner planets. The 10 cm aperture photometer monitors $\sim$ 8000 stars brighter than 13$^{\text{th}}$ magnitude in a $7^\circ \times 7^\circ$ field continuously every clear night for two to three months. The goal of the project is to detect a significant number of planets, allowing us to better understand the distribution of their sizes, masses, and parent star types. With our current data reduction system we achieve 0.2% to 0.8% hour–to–hour relative photometric precision on $\sim$ 6000 of our target stars (Fig 1). To date we have substantial data on three Galactic Plane fields. Several hundred variable stars have been found in each field, about one quarter of which are eclipsing binaries (Fig 2). Several stars with transit depths of a few percent have been observed with high-precision spectroscopy. Two were found to be binary stars undergoing grazing eclipses (HD 226719, Tyc 2663-607-1; Caldwell, et al. 2000), and a third was found to be part of a triple system with one of the pairs eclipsing (SAO 68464; Posson–Brown, et al. 2000).

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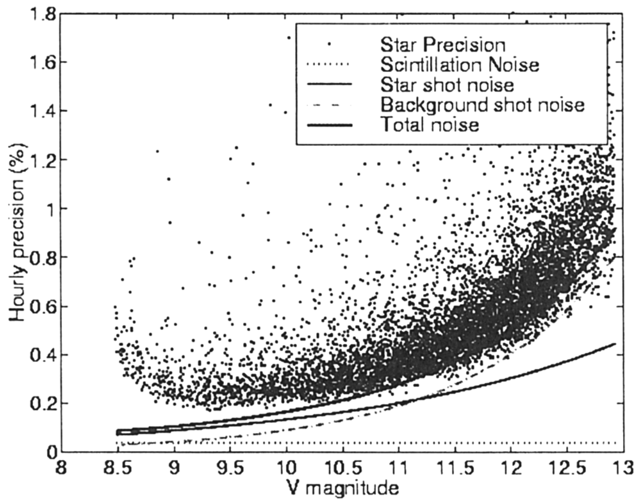

Figure 1. The hour–to–hour precision (standard deviation of the relative flux) for 8000 stars in the Cygnus field over 56 nights in 1999. Also shown are the contributions of various noise sources. Star and background shot noise dominate for all stars. The precision approaches the expected limit for stars fainter than $\sim 11^{th}$ mag.

2. Image Processing and Transit Detection

The first step in processing is to identify a reference frame for the chosen star field. The reference frame, selected near an airmass of one on a photometric night, is used to register the target stars on all other data frames and to track their motions. The current Vulcan camera takes three minute exposures, with about one minute needed for readout and saving, resulting in 100–150 images per night. Vulcan images are processed one night at a time. Each image is bias and flat corrected (dark current is very low). For each target star, a subframe containing star and background pixels is cut out of each image and saved to disk. A small number of bright stars (< 100) are read in from the saved file. A PSF-fitting algorithm developed by J. Jenkins is used to solve iteratively for a PSF model specific to each bright star, and to determine the sub-pixel positions and brightness of each star in each frame. The measured motions relative to the PSF generated for these stars are interpolated across the field, so that the positions of all target stars are known on each frame with high accuracy. The interpolated motions are used to reduce the PSF-fitting problem to a simple least-squares problem, where the flux of each star in each frame is the only unknown parameter. PSF amplitudes for the remaining stars are then fit using these motions.

The data presented here were extinction corrected on a frame-by-frame basis. In this method we fit a surface to the ratios of the measured fluxes to star reference fluxes as a function of position on the frame and an empirically determined color term. It is robust, and can adapt to rapidly-changing extinction caused by weather, so long as the spatial variations in extinction are

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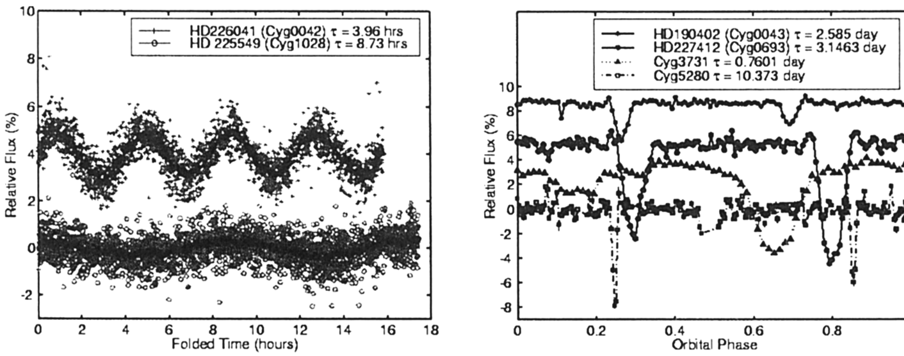

Figure 2. A selection of variable stars seen in the Vulcan photometric database. The left panel shows two short-period variables, including HD 226041—often used as a reference for CI Cyg. The right panel shows five of the ~ 50 eclipsing binaries identified in the Vulcan Cygnus data. The lightcurves are folded at the binary period.

well-characterized by the polynomial surface. The coefficients derived from each frame are smoothed in time using a moving average window.

Relative photometry is done by selecting comparison stars based on their proximity and the correlation of their raw flux with that of the target star. Known variables and stars with variations above some threshold (~ 1%) are excluded from the pool of reference stars on a given night. The relative fluxes are then normalized by their mean for each night. The last process is useful for transit detection, where the timescales are a few hours, but removes variations on times longer than a night.

The transit detection routine uses a matched–filter and returns the period and phase of the maximum (folded) detection statistic (Jenkins, Doyle, & Cullers 1996). Lightcurves of the highest–σ detections (most of which are binaries or other variables) are checked by hand to winnow down the candidate list. Finally, a small list (~ 10 per field) of candidates is chosen for follow–on observations.

References

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