Status Report on Sherlock

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Abstract.
The most significant challenge currently facing photometric surveys for transiting gas-giant planets is that of confusion with eclipsing binary systems that mimic the photometric signature. A simple way to reject most forms of these false positives is high-precision, rapid-cadence monitoring of the suspected transit at higher angular resolution and in several filters. We are currently building a system that will perform higher-angular-resolution, multi-color follow-up observations of candidate systems identified by Sleuth (our wide-field transit survey instrument at Palomar), and its two twin system instruments in Tenerife and northern Arizona.

INTRODUCTION

Over the past decade, radial velocity measurements of G, K and M stars with a precision of several meters per second has made it possible to detect planets around other stars. With the discovery of planets of masses similar to Jupiter but extremely short periods around these stars, interest in finding more such objects has risen. An alternative method to radial velocity is the usage of precise photometry of stars over long periods of time. This can detect the slight (/ 1/between that star and our line of sight. With the advent of stable, digital methods of quantifying the amount of light coming from a star and systems to automate telescope operation (allowing easy collection of large quantities of data) our ability to detect and examine these planets has come within our reach.

Two planets have already been detected in this method, HD 209458b [1] and OGLE TR-56b [2]. Of these, OGLE TR-56b is the first (and so far only) planet intially detected through transits; HD 209458b was already known through radial velocity surveys before its transit detection. These detections have motivated a transit detection system at Palomar Observatory, named Sleuth. Sleuth is operated by Dr. David Charbonneau and Francis T. O'Donovan (for further details on this, see [3]). Surveys using this technique lead to a considerable number of false detections that mimic the photometric signature of a transiting planet. More details on this can be found in the next section.

TRANSIT SEARCHES AND THE NEED FOR SHERLOCK

Wide-field photometric surveys for transits of short-period gas-giant planets consist of several months of single band observations of typically 5000 targets in a six degree

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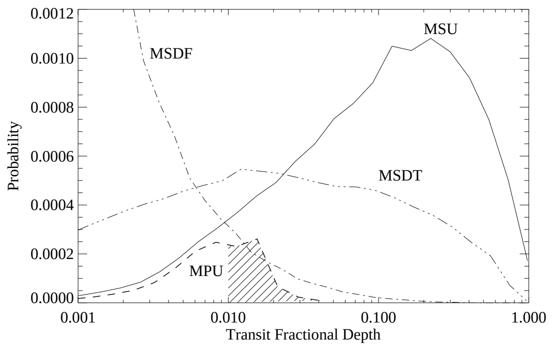

FIGURE 1. Taken from [5], the estimated probability of detection of a transit per unit log transit depth. The shaded area is represents planets detectable in current surveys.

square field of view. A number of such surveys, including the network consisting of Sleuth (Palomar, PI: D. Charbonneau, see [3]), STARE (Tenerife, PI: T. Brown) and PSST (Lowell, PI: E. Dunham) have been running for some time (the oldest has been in operation for 3 years) and have produced candidates. One current challenge facing surveys is not the difficulty of obtaining the requisite precision and phase coverage, but rather the ability to rule out the large number of false positives that are typically encountered. These false positives can be removed through radial velocity studies, as was done in the case of the OGLE-III transit candidates by Konacki et al [4]. However, for relatively bright stars, there is an easier way to reject such candidates.

Brown [5] discusses various apparent transit candidates typically identified by searches similar to Sleuth and classifies them into a number of specific types. There are three types of false detection that are the primary sources of these false positives. The first of these are binary stars undergoing a grazing eclipse (MSU). The second and third types involve blends between a binary star undergoing a deep transit and a third star, either a foreground object (MSDF) or a third member of the system (MSDT). Using a typical transit campaign for the STARE instrument, Brown calculates that for every 10000 stars observed, 0.39 planets will be observed with three transits. However, 2.27 false positives of type MSU will also appear, 1.26 false positives of type MSDF will be present, and 0.98 candidates of type MSDT will be observed. Combining these figures, one finds that a transit survey will observe more than 10 false positives for every true planet that it finds. This is demonstrated by Figure 1, which shows the probability of finding different classes of object at a given transit depth. In the regime of fractional depth which we study, clearly all the sources of non-planetary objects are more significant than the planets we seek.

Under the direction of Dr. Charbonneau, I am therefore currently assembling a telescope (Sherlock) dedicated to examining transit candidates from Sleuth, as well as a number of other transit surveys which monitor stars brighter than V=13. Completely automated and observing in SDSS g’, r’, i’, and z’ filters with a better angular resolution than Sleuth (1 arcsec/pixel, compared with 10 arcsec/pixel for Sleuth), Sherlock will be able to reject most of the contaminants from these transit surveys. In so doing, Sherlock will greatly reduce the rate of false positives to a manageable number.

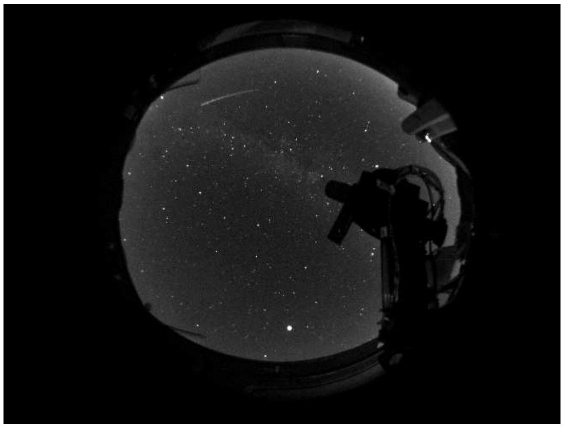

FIGURE 2. A picture taken on the night of September 27, 2003 with the Snoop all-sky camera

TABLE 1. Specifications of Sherlock

Meade LX200GPS 10" f/6.3 Schmidt-Cassegrain Telescope
1024 x 1024 pixel back-illuminated CCD camera
Filter wheel containing SDSS g’,r’,i’,z’ filters
SBIG STV Autoguider
Automated Operation controlled by Linux workstation
Cloud cover monitored by Snoop, the Palomar All-Sky Camera

Measurement of the color dependence of the transit depth should remove both grazing incidence binaries (due to the effect of limb-darkening on the eclipse depth), and blends of eclipsing binaries (due the change in relative brightness of the blended and occulted stars as a function of color). When stars of different colors eclipse one another, this also causes variation of depth over colors, which does not happen in a planetary transit. Furthermore, the increased angular resolution will separate the light from blended stars, and subsequent photometry will reveal which object is undergoing eclipses. Sherlock will not be able to reject all sources of false detection. For example, some eclipses with very dim stellar objects (such as M dwarfs) will not show variation with color. In addition, blends of eclipses between identical stars might not be recognizable by Sherlock. Even with these exceptions, however, Sherlock is expected to reduce the ratio of false positives from these surveys such that the rate of actual detections will be manageable. Spectra of those candidates which are not removed by Sherlock will be gathered at the Palomar 60” echelle spectrograph, and surviving candidates will be be monitored with Keck HIRES to determine the radial velocity orbit.

SHERLOCK SPECIFICATIONS

Table 1 lists the specifications for Sherlock. The system will be located in the same clamshell enclosure as Sleuth, our primary transit search instrument. Weather decisions are made by the on-site 200"-telescope night assistant, with additional protection provided by a weather station that can close the clamshell roof. Sherlock will also be completely automated, calculating future times of eclipse for all active candidates, and observing the highest priority object in eclipse each night. The lack of human interaction is an advantage over comparatively labor- and resource-intensive multi-epoch spectroscopic follow-up.

STATUS OF SHERLOCK AND OTHER WORK

At this point, we have purchased all of the various components of Sherlock. However, when assembling the telescope I have had persistent programs with the control software. Specifically, I haven't found a way for Linux to use the serial ports on the desktop PC that is designated to run the telescope. I am attempting to correct this problem by reinstalling Linux and the control software on Sherlock, but it is still unclear whether an immediate solution to past difficulties from this method is forthcoming. The camera software, however, has been installed onto the computer, and awaits the move to the mountain in order for the full system test. Once the telescope control has been successfully activated, only the installation of auto-guider and filter wheel will remain before the telescope can be moved on site. Data will be obtained soon after this is done. Software has also been written to automatically select targets for Sherlock, a necessary step towards a fully automated telescope.

In addition, a new all-sky camera named Snoop has been set up at Palomar, where it operates in the clamshell enclosure that hosts Sleuth and will host Sherlock. This is an SBIG ST-237A all-sky camera hooked up to a workstation running Red Hat Linux 9. A shell script commands the camera, taking an image every 10 minutes. This allows monitoring of clouds in the vicinity. These pictures are processed using C routines devised with the CFITSIO library developed at Goddard Space Flight Center [6]. They are then posted upon the Internet [7], where there is an archive of past images and animations are made showing the conditions every night. As an example of the pictures collected by this camera, see Figure 2.

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