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EXPORT: Search for Transits in Open Clusters with the JKT and Lick 1 m Telescopes

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Abstract. A photometric search for transits by extrasolar planets in three open clusters has been carried out as part of the EXPORT project. We discuss the rationale for this program, describe the observations carried out with the 1 m JKT and Nickel telescopes (at La Palma and Lick Observatory, respectively), and give a status report on the data reduction.

1. Introduction

After many years of trying to find extrasolar planets, the first discovery of a planet orbiting the solar type star 51 Peg was made in 1995 by Mayor and Queloz; soon thereafter other planets outside our solar system were found (Butler & Marcy 1996). Their search method, based on variations in the radial velocity of the parent star, is strongly biased towards finding giant planets in very close orbits. The — unanticipated — result of these programs is that planets with several Jupiter masses and orbital periods of just a few days are fairly common. As part of the EXPORT program, we have embarked on a complementary search for similar planets, by looking for transits of the planet in front of the stellar disk.

2. Why Transit Searches in Open Clusters?

The technique of planet transits is based on a photometric method, measuring the brightness drop in the light curve of the star produced by the eclipsing planet. For giant planets in close orbits, like the 51 Peg planet, through transits we have a good chance of assessing the number of such objects and determining their physical size. The latter information cannot be obtained with the radial-velocity method. Furthermore, transiting planets lend themselves to spectroscopic follow-up studies, which may reveal material that evaporates from the planet. According to the recent work carried out by Mayor, Queloz, Marcy,

Table 1. Summary of the observations.

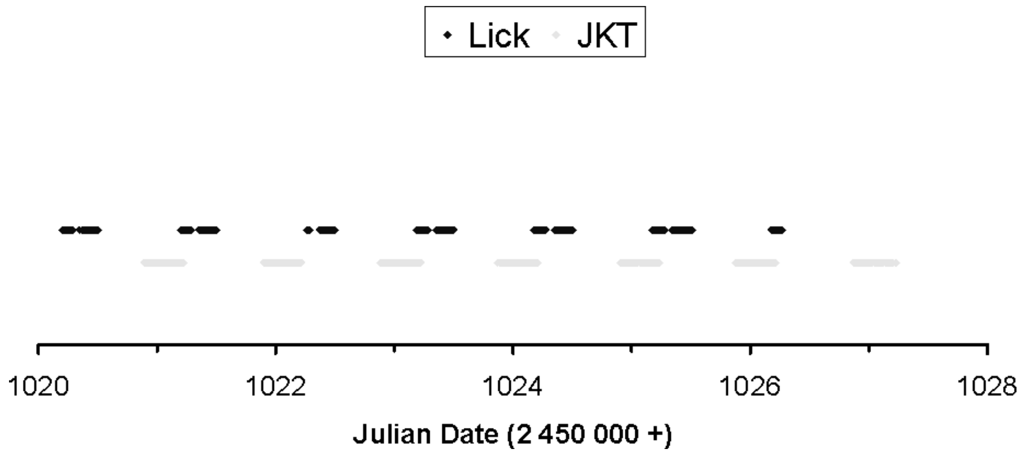
Telescope	Object	# Nights	# Images	Total Hours	Seeing
JKT	NGC 6819	7	302	56	$0''.8$ - $2''.2$
	NGC 7789	9	202	38	$1''.2$ - $2''.0$
	NGC 2682	9	57	11	$0''.9$ - $1''.7$
Nickel	NGC 6819	43	956	212	$1''.0$ - $2''.5$
	NGC 7789	44	909	180	$1''.0$ - $2''.6$
	NGC 2682	9	104	24	$1''.0$ - $2''.7$

Butler and others (see e.g. Marcy & Butler 2000), the probability of a solar-type star having such a Jupiter-like companion is a few per cent and the probability of having a suitable inclination of the system is around 0.05 (for a 0.1 AU orbit). Therefore the probability of success in detecting a transit is about 0.1 % or slightly better, for any randomly chosen main-sequence star. The time of transit of the planet in front of the star is one to a few hours (considering 3 - 10 day orbits). The expected brightness drop for a Jupiter-like planet transiting a star is around 1 %. These numbers mean that we should look at a few thousand stars, which immediately suggests to observe old open clusters with a photometric precision of around 0.5 % or better.

A similar strategy has been suggested by Janes (1996) for searches for Earth-like planets. For these objects, eclipsing systems are rare (because of the comparatively wide orbits), eclipses repeat only about once per year, and are quite shallow (because of the small diameter of Earth). Janes suggested that one or several dedicated 4 m-class telescopes would be needed for such a program. A similar strategy will be used in searches for Earth-like planets in future space missions like COROT, to be launched in 2004, and in the more ambitious proposals for the Kepler (NASA) and Eddington (ESA) missions. In the case of 51 Peg B-like objects, the parameters are much more favorable, and a search with a realistic chance of success can be carried out with 1 m-class telescopes. In order to see planet transits which last one hour or more, the observations need to be repeated at least once every 30 minutes. Furthermore, to successfully detect a 1 % drop in brightness a photometric accuracy of about 0.3 % is needed. This translates to an integration time of 12 - 15 minutes for 17th magnitude stars with a 1 m telescope, if a photometric accuracy close to the photon noise limit can be achieved. Transits repeat every few nights, so that multiple eclipses of the same planet can be observed with a reasonable number of observing nights (about 10 to 15); this gives a robust criterion for successful detections.

The choice of open clusters as target fields has the added benefit of providing a well-defined, chemically homogeneous parent population. It has been suggested that most of the stars with planetary companions found in radial-velocity surveys are metal-rich with respect to the Sun and the general field (e.g. Gonzalez, Wallerstein, & Saar 1999). Two possible explanations have been advanced for this phenomenon. High metallicity may favor the formation of rocky planets

Figure 1. Combined time coverage of the Lick and JKT data on the cluster NGC 6819 for July 1998.



(or rocky cores that form the nuclei of giant gaseous planets); the existence of a planet may thus be the consequence of high metallicity. Conversely, the metallicity may get enhanced through the capture of rocky material by the star; in this scenario the high metallicity is a consequence of the existence of a planetary system. Planet searches in open clusters can provide the means to distinguish between these two hypotheses. In the first case, the detection rate of planets is expected to depend strongly on the cluster metallicity, whereas in the second case it should be nearly independent of it, but individual parent stars of planets should have metallicities significantly above the cluster mean.

3. Observing Strategy

The target clusters should be relatively old, metal-rich, and compact, and provide a large number of target stars within the field-of-view of the CCD. Based on these criteria, and a suitable distribution over the sky, three target clusters were selected for the EXPORT planet search program: NGC 6819, NGC 7789, and NGC 2682. We concentrated on NGC 6819 and NGC 7789, and observed NGC 2682 only at times when the two other clusters were not accessible. We decided to observe only one field in the center of each cluster; mosaicing would have resulted in a larger total number of observed stars, but poorer time coverage.

The first observations were carried out with the 1 m Nickel Telescope at Lick Observatory. Two intensive campaigns were scheduled simultaneously at this telescope and at the 1 m Jacobus Kapteyn Telescope (JKT) at La Palma. Both telescopes are equipped with cameras that provide a field-of-view of about $6' \times 6'$. All observations were carried out in R band with an exposure time of 10 minutes for each frame. (A few additional exposures in V, B, and I were taken at Lick for each field to determine the colors of the stars.) We alternated between

Figure 2. $6' \times 6'$ field towards NGC 6819 in R band.

NGC 6819 and NGC 7789 whenever both clusters were visible, and took repeated exposures on a single position when only one of these clusters was accessible. Table 1 gives an overview of the amount of images obtained in this way. Most of the data were taken in photometric conditions. The longitude difference between La Palma and Lick Observatory resulted in fairly good time coverage during the two simultaneous campaigns; an example is given in Figure 1.

4. Status of the Data Reduction

The initial steps of the data reduction follow standard procedures: bad pixel removal, bias correction, and flat-fielding. Figure 2 gives an example of an image of NGC 6819 processed in this way. It is obvious that a few bright stars are saturated and must be discarded in the following photometric reduction. The crowding is sufficiently strong that it has to be taken into account for most of the stars. However, we selected a few isolated stars for tests with a simple simulated aperture photometry algorithm. These tests show that the systematic errors are sufficiently small so that light curves with rms variations of $\lesssim 0.3\%$ for the individual frames can be obtained. We have developed a photometric data reduction pipeline for crowded fields, based on the psf-fitting package DAOPHOT in IRAF. Good results have been obtained with this pipeline in tests on partial data sets (see Figure 3), again with frame-to-frame variations of $\lesssim 0.3\%$ for many of the brighter stars. We are currently working on getting consistent photometry also for the nights that had less than optimum conditions (seeing variations, cirrus, focus drifts). It appears that psf-fitting is not the optimum method for these data. A hybrid approach using aperture photometry on images in which models for all stars but one have been subtracted will be tested soon.

5. Outlook

We expect that we can extract light curves with rms variations of 0.3% to 0.5% for several hundred stars in each of the target clusters. These light curves will be searched for the characteristic dips due to planetary transits. Because of the dense sampling (about 15 minutes to 30 minutes between exposures of the same cluster), each transit must show up in a number of successive frames. Stars showing at least two dips will be considered candidate planetary systems. Further observations would then be needed to establish periodic transits, and to rule out grazing eclipses by stellar companions or contamination by background eclipsing binaries.

A follow-up program to the EXPORT planet search project has been initiated at the Isaac Newton Telescope (INT) on La Palma. This program takes advantage of the large area covered by the Wide Field Camera, and of the larger aperture size, to monitor a much larger number of fainter stars in the same clusters. A status report on the INT project is given by Street et al. (2000).

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Figure 3. Light curves of two stars in NGC 7789 for a good night.