A Search for Planetary Transits in Open Clusters

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Abstract. We report on the progress of a photometric search for planetary transits of stars in the open clusters NGC 6819, NGC 6940, and NGC 7789. The data were obtained during two allocations of ten nights with the Wide Field Camera on the Isaac Newton Telescope, La Palma, in mid-1999. These old, rich open clusters give numerous bright stars within the WFC field of view, allowing roughly 40 000 lower-main-sequence cluster stars to be monitored with comparable numbers of field stars. We have developed a semi-automated data-reduction pipeline to process the data and highlight potential transit candidates. We report the accuracy achieved in the photometry using a subset of the data and on factors affecting this accuracy, in addition to the variables found and the progress made in searching for transits.

1. Introduction

The regular photometric monitoring of large numbers of stars is the key to any search for planetary transits, given the small probability that the planetary orbit will be suitably inclined (Sackett 1999). With this in mind, Janes (1996) suggested that imaging open clusters would allow sufficient numbers of suitable stars to be monitored frequently enough to detect transit events. From the ground, this technique lends itself particularly well to the detection of “hot jupiter”-type planets, and the Wide Field Camera (WFC) on the 2.5 m Isaac Newton Telescope (INT) gives the large area coverage ideal for this type of study.

Of the clusters visible from La Palma, three were chosen in order to include as many stars as possible, while maintaining a good sampling rate. Bright, rich clusters, not widely dispersed were obviously important potential targets, while old age and high metallicity were the deciding factors. We settled on NGC 6819, NGC 6940, and NGC 7789, which were among those recommended by Janes (1996). Their properties are summarized in Table 1.
Table 1. Selected target clusters

<table>
<thead>
<tr>
<th>Name</th>
<th>RA(J2000.0)</th>
<th>Dec(J2000.0)</th>
<th>Age [Gyr]</th>
<th>Dist [pc]</th>
<th>E(B − V)</th>
<th>[Fe/H]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 6819</td>
<td>19 41 18.70</td>
<td>40 11 05.27</td>
<td>2.51</td>
<td>1689</td>
<td>0.21</td>
<td>+0.07</td>
</tr>
<tr>
<td>NGC 6940</td>
<td>20 34 35.98</td>
<td>28 18 00.00</td>
<td>0.87</td>
<td>1042</td>
<td>0.23</td>
<td>+0.01</td>
</tr>
<tr>
<td>NGC 7789</td>
<td>23 57 30.81</td>
<td>56 43 41.84</td>
<td>1.78</td>
<td>1841</td>
<td>0.25</td>
<td>−0.08</td>
</tr>
</tbody>
</table>

2. The Dataset

2.1. Observations

We were awarded two allocations of ten bright nights each in the 1999A semester on the 2.5 m INT, running June 21–30 and July 22–31, and were fortunate to have very good conditions almost all of the time. The instrument used was the WFC, which consists of four EEV CCDs, each measuring 2k × 4k pixels, allowing us to cover a 34' × 34' field of view (Ives, Tullock, & Churchill, 1996). Our strategy each night was to cycle from cluster to cluster as they became visible, taking two 300 s exposures on each visit, with a readout time of 165 s. This enabled us to monitor the stars in each cluster at least once an hour, sufficient to detect the transits of hot jupiters, which have a typical duration of ∼ 2–4 hours. The majority of our observations were made using the Sloan r filter, though a few images per cluster were taken using the Sloan g, Sloan i, and RGO U filters in order to obtain color data for the stars.

2.2. Data Reduction

We have written a semi-automated data-reduction pipeline based around PSF fitting by the STARMAN photometry package (Penny 1995). This pipeline was developed around the reduction of approximately 2 per cent of the dataset; about half of the central CCD of the first run Sloan-r data on NGC 6819, centered slightly west of the cluster center. From this alone, we find we are covering 5820 stars. To roughly calibrate the photometry, we used the zero points quoted on the INT Wide Field Survey webpage to convert our instrumental magnitudes to magnitudes based in the Landolt (1992) system.

3. First Reduction Results

3.1. Color–Magnitude Diagram for NGC 6819

Figure 1 shows the color–magnitude diagram for the region of NGC 6819 covered by our data subset. This clearly shows the cluster main sequence, as well as a substantial "tail" of background stars. Our exposure times were tailored towards lower-main-sequence cluster stars of approximately 1 M\(_{\odot}\); therefore, any stars below the main sequence on Figure 1 will be underexposed and subject to levels of noise that make them unsuitable for transit detection. The unsaturated stars
in our dataset comprise roughly equal numbers of cluster and background stars. Unfortunately, the cluster main-sequence stars saturated prior to the turn-off point, accounting for the bulge in the figure.

3.2. Achieved Photometric Precision

Figure 2 illustrates the photometric precision achieved so far on a typical night of the run. The effects of saturation are clearly visible for stars brighter than about 18th magnitude, and the accuracy of the fainter stars is dominated by the sky brightness, owing to the observations having been made in bright time. For comparison, we also plot the expected transit depths for a planet with Jupiter's radius transiting cluster main-sequence stars of masses ranging from 0.4 to 1.0 $M_\odot$. Any star lying below this line therefore has the measurement accuracy required to detect planetary transits. This figure clearly shows that this accuracy has been reached for some of the brighter stars and illustrates the levels of the various sources of noise in the data. Given the importance of sky brightness as a source of noise, future surveys should consider dark time as being more appropriate.

3.3. Systematic Effects

One reason for the larger-than-expected scatter in magnitude is a number of systematic effects we have discovered in the data. To illustrate these problems, we include the lightcurves of two example stars (see Figure 3). The first has one of the smallest rms scatters in the sample, while second has one of the largest. Both lightcurves display two noticeable systematic effects, seen in every star: an apparent steady decrease in brightness during each night (subsequently
Figure 2. Magnitude scatter versus magnitude for the 17 images from the first night. Various sources of noise have been plotted, together with the predicted transit depth for a Jupiter-radius planet transiting a main-sequence cluster star.

attributed to secondary extinction effects), and a sinusoidal-like trend across the ten days.

Identifying and removing these and other systematics is our priority for the next stage of the project. We are currently applying a linear regression to the magnitudes and spatial positioning of the stars in order to identify and correct for these systematic effects.

3.4. Discovered Variable Stars

In spite of the improvements that remain to be made in the measurement precision our observational strategy lends itself quite naturally to the discovery of variable stars, and several large-amplitude candidates have already presented themselves. Of these, three stars have been found to be unequivocally variable; their respective lightcurves are shown in Figure 4. Star 3801 may be a dwarf nova, while star 3563 is clearly an eclipsing binary with a period of about 1.462 days. Star 4512 remains unclassified, although it may be a dwarf Cepheid. Further detailed study of these variables is planned and will be published in due course.

4. Conclusions

We have acquired a large dataset and are approaching the photometric accuracy required to detect transits for some of the stars in our sample. Ongoing investigation into the various systematic effects should enable us to considerably
Figure 3. Two example lightcurves, showing the systematic variations in magnitude.

Figure 4. The lightcurve of star 3801, a suspected dwarf nova.

Figure 5. The lightcurve of star 4512, a suspected Cepheid.
Figure 6. The phase diagram of star 3563, an eclipsing binary with a period of about 1.462 days.

increase the number of stars measured with an accuracy below the detection threshold. Some of these improvements are already in place. We have identified a number of variable and binary stars within the small-sample dataset that has been reduced as well as a number of potential candidate variables, and plan further investigation of these as soon as is feasible. Naturally, we expect many more to be discovered when the full dataset is reduced.

5. Acknowledgements

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References

Janes, K. 1996, JGR, 101, Iss. E6, p. 14853
Penny, A. 1995, Starlink User Note 141.2 (Rutherford Appleton Laboratory)

Discussion

William Borucki: How do you correct for extinction?

Rachel Street: As yet we have included no correction for extinction in our pipeline data reduction—this issue is a priority for us to address in the very near future.