University of St. Andrews Open Cluster Survey for Hot Jupiters

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Abstract.
We are using the Isaac Newton Telescope Wide Field Camera to survey open cluster fields for transiting hot Jupiter planets. Clusters were selected on the basis of visibility, richness of stars, age and metallicity. Observations of NGC 6819, 6940 and 7789 began in 1999 and continued in 2000. We have developed an effective matched-filter transit-detection algorithm which has proved its ability to identify very low amplitude eclipse events in real data. Here we present our results for NGC 6819. We have identified 7 candidates showing transit-like events. Colour information suggests that most of the companion bodies are likely to be very-low-mass stars or brown dwarfs, intrinsically interesting objects in their own right.

1. Introduction

The technique of discovering planets from their photometric transits enables us to probe fainter stars for planetary companions than are accessible to radial velocity surveys. This allows us to probe a wider variety of stellar environments. The technique also offers us the possibility of discovering statistically significant numbers of hot Jupiter planets from the ground within a relatively short timescale. Such a sample could be used to establish the relationships between planetary formation and key properties such as metallicity, age, etc. Janes (1996) suggested that clusters would be ideal targets for a transit search. They provide large numbers of stars within a relatively small area, the ages and metallicities of which can be determined. Radial velocity (RV) surveys have indicated that stellar metallicity in particular seems to be correlated with the presence...
of planets. Brown et al. (2001) reported surveying the globular cluster 47 Tuc with the Hubble Space Telescope, but interestingly found no transits. In the light of the RV results, this raises the question of whether and how this deficit is related to the low metallicity of the cluster and/or star/radiation density. To address this question, we are surveying a number of open clusters with a range of ages/metallicities. Open clusters do not suffer from the dense crowding of stars present in globulars and so can be studied with ground-based telescopes. They are also generally younger and higher in metallicity.

2. Observations and Data Reduction

We were awarded 30 nights of bright time on 2.5m Isaac Newton Telescope (INT) in 1999/06-07 and 2000/09. The $\sim 0.3^\circ$ field of view of the Wide Field Camera (WFC) is ideal for transit searches. We observed 3 clusters for the first 20 nights, and one cluster continuously for a further 10 nights. PSF photometry was carried out using DAophot (Stetson 1987) while post-processing software was written house. Further details of these observations and our data reduction procedures can be found in Street et al. (2002) and Street (2002). The 20 nights of data on NGC 6819 have been fully reduced for all 4 CCDs, including over 38,000 stars. Figure 1 illustrates that we have reached the photometric precision required to detect hot Jupiter transits.

3. Transit Identification

We have developed a matched-filter algorithm which can reliably detect transit events in a reasonable time scale. Our algorithm initially generates single-transit model lightcurves for a range of transit durations and epochs. These are least-squares fitted to all lightcurves, optimising for transit depth and out-of-transit magnitude in the process. The parameters and the $\chi^2_{\text{transit}}$ of best-fitting
model are recorded and compared with the $\chi^2_{\text{const}}$ of the fit of a constant model. The transit-finder index, $\Delta \chi^2$, is then given by: $\Delta \chi^2 = \chi^2_{\text{const}} - \chi^2_{1-\text{transit}}$.

Candidate transit events are identified by plotting $\Delta \chi^2$ vs. $\chi^2_{1-\text{transit}}$. A cut-off is established by fitting a straight line through the main body of points, then raising it by a specified number of sigma. Genuine transits will lie to the upper left of this plot. All stars lying above the cut-off are visually examined. Multi-transit model lightcurves are then fitted to the selected candidates using a range of periods, and the parameters and $\chi^2$ of the new best-fitting model are recorded. The candidate selection procedure is then repeated.

4. Results and Future Work

In this way we have identified 7 stars showing transit-like events (eclipses of similar amplitude and duration to those of a planetary transit). The lightcurves of these stars are shown in Figure 2 and their details are given in Table 1.

Colour information indicates that in most cases, the companion object is likely to be a very low-mass star or brown dwarf - interesting objects in their own right. However, the eclipses these stars show are very similar to those of planetary transits, indicating that we can detect such events.

Our current analysis has some limitations: the algorithm is susceptible to false alarms caused by blending, stellar activity and scattered data taken in poor conditions. We are currently refining our algorithm and investigating improvements in our reduction to eliminate these effects.

| Star | CCD | V mag | $V - R$ | Amplitude (mag) | Duration (hours) | Period (days) |
|------|-----|-------|--------|-----------------|-----------------|--------------|
| 4619 | 1   | 16.603| 0.283  | 0.027           | 4.0             | 8.29         |
| 2179 | 2   | 19.130| 0.396  | 0.05           | 4.8             | 4.6          |
| 3731 | 2   | 18.700| 0.314  | 0.04-0.09      | 7.2             | 8.28         |
| 6690 | 2   | 18.018| 0.408  | 0.07           | 2.4             | 6.98         |
| 1962 | 3   | 15.979| 0.798  | 0.07           | 1.8             | 1.31         |
| 3382 | 3   | 19.210| 0.624  | 0.06           | 2.0             | 4.11         |
| 6234 | 4   | 20.340| 0.695  | 0.04           | 2.4             | 0.42         |

References

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Figure 2. Lightcurves of stars displaying transit-like events.