EXPLORE/OC: A Search for Planetary Transits in the Field of the Southern Open Cluster NGC 2660

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Abstract. We present preliminary photometric results of a monitoring study of the open cluster NGC 2660 as part of the EXPLORE/OC project to find planetary transits in Galactic open clusters. Analyzing a total of 21000 stars (3000 stars with photometry to 1% or better) yielded three light curves with low-amplitude signals like those typically expected for transiting hot Jupiters. Although their eclipses are most likely caused by non-planetary companions, our methods and photometric precision illustrate the potential to detect planetary transits around stars in nearby open clusters.

INTRODUCTION

As part of the EXPLORE[1] Project [1], we have recently begun a survey of southern open clusters (OCs) with the aim of detecting planetary transits around cluster member stars (EXPLORE/OC[2]). Probing cluster populations provides a complement to our ongoing deep monitoring studies of rich Galactic fields [1].
Open cluster monitoring provides the following advantages and incentives:

- In general, metallicity, age, distance, and foreground reddening are either known or may be determined for cluster members (more easily than for random field stars). Thus, planets detected around cluster stars will readily represent data points for any statistic correlating planet frequency with age or metallicity of the parent star.
- The planet-formation processes, and hence planet frequencies, may differ between the open cluster and Galactic field populations. This study allows the EXPLORE Project to compare these two different environments.

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[1] `http://www.ciw.edu/seager/EXPLORE/explore.htm`
[2] `http://www.ciw.edu/seager/EXPLORE/open_clusters_survey.htm`

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- Specific masses and radii for cluster stars may be targeted in the search by the choice of cluster and by adjusting exposure times for the target. In general, smaller stars offer better chances to detect the low-amplitude transit signal.

The difficulties and challenges involving open cluster surveys are:

- The number of monitored stars is typically lower than in rich Galactic fields, reducing the statistical chance of detecting planets.
- Determining cluster membership of stars in the open cluster fields without spectroscopic data is difficult due to the contamination by Galactic field stars. Since the clusters are typically concentrated toward the Galactic disk, this contamination may be significant.
- Significant differential reddening across the cluster field and along the line of sight can make isochrone fitting (and subsequent determination of physical parameters such as age, distance, and metallicity) difficult.

Note that both of the latter two difficulties may at least in part be circumvented by obtaining spectra. In this work, we illustrate some of the points mentioned above, describe our observing and data-reduction strategies, and show some of our preliminary results of the southern open cluster NGC 2660. Preliminary results of the study of our second target, NGC 6208, are presented in a companion paper [2] in this volume.

DATA

Our observations of NGC 2660 ($l = 265.9^\circ; b = -3.01^\circ$) were obtained with the Carnegie Institution's Swope 1m Telescope at the Las Campanas Observatory in Chile during the nights of 2003 Feb. 10–28 which were partially hampered by poor weather conditions. Our field of view was approximately 23' $\times$ 15' in size. Only I-band data with a cadence of around 7 minutes were obtained for monitoring. In that filter, a transit will be most easily distinguishable from contaminants such as grazing binaries because color-dependent limb-darkening results in steeper ingress and egress as well as a flatter eclipse bottom in I than in other bands [3]. We show in Fig. 1 our observing window function which indicates the likelihood of our detecting *existing* transits and measuring their periods to within an aliasing factor (we require at least two transits). A necessary condition for detecting existing transits is, of course, high-precision photometry [1]. In Fig. 2, we show our photometric precision as a function of magnitude.

RESULTS

Around 7000 unphased photometric light curves of the stars with the best photometric precision were visually inspected to detect transit-like signals. We show in Fig. 3 three examples of light curves with the low-amplitude signature typically expected for transiting hot Jupiters. Although the eclipses visible in the light curves are most likely not due to planets, we are currently analyzing spectral data on them to determine spectral types of the parent stars as well as their variations in radial velocities. Regardless of whether or not we are able to find a planetary transit in NGC 2660, we have illustrated the potential of our methods to detect (unphased) amplitude variations of less than 1%, the most fundamental requirement to detect planetary transits.

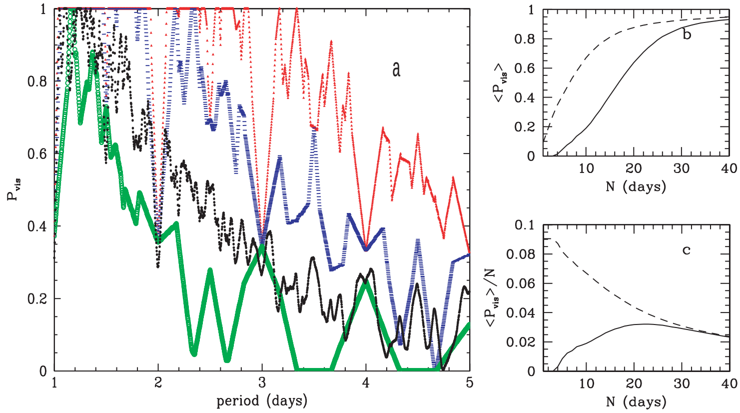

FIGURE 1. Probability P_{vis} of detecting existing transiting planets with different orbital periods. P_{vis} is calculated with the requirement that two transits must be observed. **Panel a**: P_{vis} of detecting 2 transits of an existing transiting planet with a period between 2 and 5 days after 21 (top curve), 14 (second curve from the top) and 7 (bottom curve) consecutive, uninterrupted nights of observing (10.8 hours per night). The difficulty of detecting some phase angles is shown by the dips in the curves (e.g., orbital periods of an integer number of days may always feature their transits during the day and are therefore statistically harder to detect). All phases are considered for each period. The second curve from the bottom shows the real P_{vis} for our monitoring study of NGC 2660 (19 nights of 7-8 hours per night, with interruptions due to weather and telescope scheduling; see Fig. 3). **Panel b:** The mean P_{vis} as a function of number of consecutive nights in an observing run (10.8 hour nights). The solid line is for the requirement to detect two transits and the dashed line for one transit. This figure indicates how much the likelihood of finding existing transits grows with an increasing number of nights of observing. **Panel c:** The efficiency of $<P_{vis}>$ per night. For the two-transit requirement (solid line) and 10.8 hour long nights, an observing run of 21 nights is most efficient. For the single transit requirement, the efficiency decreases monotonically with the number of nights since additional nights have progressively lower probabilities of detecting "new" transits.

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3. Seager, S., & Mallén-Ornelas, G. 2003, ApJ, 585, 1038

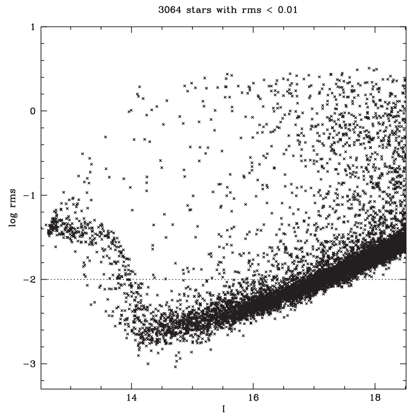

FIGURE 2. Photometric precision of night 1 of our monitoring run of NGC 2660. Of the roughly 21000 monitored stars, slightly more than 3000 have photometry of precision 1% or better. This rms is measured as the scatter around the mean magnitude of the star under investigation. The 1%-photometry stars cover a magnitude range of slightly more than 2.5 mags. By adjusting the exposure time, one can therefore target OC member stars of a range of certain spectral types to maximize the likelihood of detecting a transit (taking into account distance to the cluster and foreground reddening).

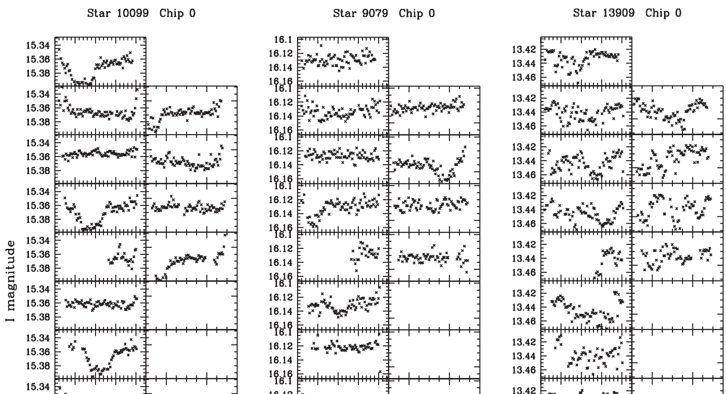

FIGURE 3. Examples of real-time (unphased) light curves from our monitoring run of NGC 2660. Every panel represents data taken during one night, starting on the bottom left with night 1. Night 2's data are directly above it, night 3 above that and so on. We did not obtain any data during nights 13-15. All three panels display the low-amplitude signal that we are looking for in the search for planetary transits even though they are most likely caused by a larger-sized companion (left panel) or grazing binaries (middle and right panels) [3].