Burrell Optical Kepler Survey (BOKS) I: Survey Description

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Introduction

Detection of large statistical samples of extrasolar planets is now a major goal of astronomy. A proven method of finding extrasolar planets is searching for planetary transits, where the extrasolar planet slightly dims the star it orbits as it moves across the line-of-sight. Transiting systems allow for measurements of the mass and radii of extrasolar planets, making these systems crucial in our understanding of these objects (see Charbonneau et al. 2006 for a recent review). There are over twenty research groups undertaking photometric surveys to search for transits, and at least ten verified extrasolar planet detections have been made using this method.

Here, we present a new stellar variability survey, entitled **BOKS** (Burrell Optical Kepler Survey). BOKS used the Case Western Burrell Schmidt telescope to survey a portion of the planned survey field for the NASA *Kepler* transit mission (see Figure 1). The goals of BOKS are:
1) to search for transiting Very Hot Jupiter (P = 1-3 days) and Hot Jupiter (P = 3-9 days) extrasolar planets within the survey field and 2) to compile high precision stellar variability data that the *Kepler* mission can later use for comparison purposes. As with all transit surveys, a secondary goal will be 3) to characterize the hundreds of other variable stars within the survey region.

For our particular survey, we attempted to maximize the number of bright stars to be searched, while minimizing the inevitable crowding coming from a Galactic plane survey. We chose a field centered on the open cluster NGC 6811. This allows us to search for extrasolar planets in both the field and cluster environment.

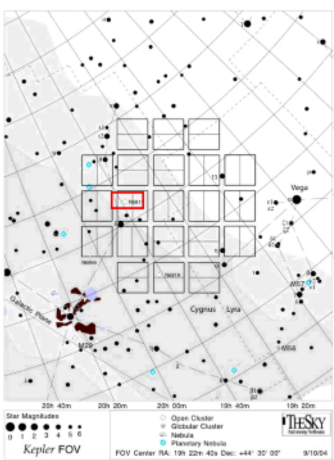

Fig. 1 – The approximate location and size of the BOKS field, which is located inside the overall *Kepler* survey field. It is centered over the open cluster NGC 6811, and has a moderate stellar density for the *Kepler* field.

BOKS Summary:

Telescope: 0.6m Burrell Schmidt, Area:1.36 sq degrees,
Cadence: every 4 minutes, Number of Nights: 38 (27 with data),
Number of Images: 1936 Gunn r images and 20 V,
Located within the *Kepler* field

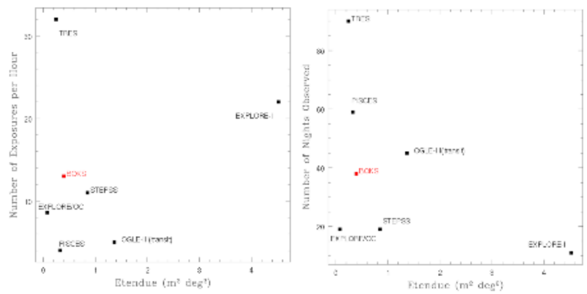

Fig. 2 – A comparison of BOKS to some other representative transit surveys. For reference, the small-apeture, wide-field TRES survey, and the large-apeture, short duration EXPLORE-I survey are also included. BOKS is competitive in terms of survey area, survey length, and in cadence.

Comparison of BOKS to other Transit Surveys

BOKS is a **moderate-field** (1.65 x 0.825 degrees), **moderate apeture** (61cm) transit survey, deeper than the wide-field, small apeture (~10 cm) transit surveys (TrES, BEST, HAT, KELT, Super-WASP), but much shallower than large apeture transit surveys (~400cm; EXPLORE). It is similar in properties to such transit surveys as EXPLORE/OC (von Braun et al 2005), PISCES (Mochejska et al. 2006), and STEPSS (Burke et al. 2006). BOKS has a **larger angular area** than most of these surveys (1.36 sq deg, versus ~0.3 sq. deg), but with **slightly larger pixel scale** (1.45" versus ~0.4"). Figure 2 compares BOKS with other transit surveys, and although the true survey efficiency of each project is a complex combination of observing properties and data reduction procedures, BOKS appears to be competitive with these surveys.

However, there are a few features of BOKS that may improve its efficiency in detecting extrasolar planets. Over the past few years, the Burrell Schmidt has been extensively optimized for deep surface photometry and tests show that it has both a well defined flat-field and an extremely small scattered light profile (Mihos et al. 2005; Feldmeier et al. 2007). These features can only improve our light curves, and reduce the amount of "red noise" that appears to be endemic to transit surveys (Pont, Zucker & Queloz 2006). Another important advantage for BOKS was the ability to devote a large amount of dedicated telescope time to this survey. Numerical simulations have shown that increasing the duration of the transit survey has a large impact on the number of extrasolar planets that can be detected (von Braun et al. 2005; Burke et al. 2006)

Observations, Data Reduction and Analysis

The observations for BOKS began on September 1, 2006, and continued for the next 38 days. Of these nights, 27 had useful data acquired, including a 22 day consecutive sub-section. There are approximately 60,000 stars within the BOKS field, with magnitudes between r = 14-20.

The data was electronically transferred to the Michelson Science Center, and Youngstown State University for independent reduction and analysis. Our data reduction pipeline, using differential apeture photometry over small sub-regions of the image is almost identical to that of Everett & Howell (2001) and Everett et al. (2002), with some small adjustments and additional tests included.

With the Burrell having a larger pixel scale than the average CCD, there might be concerns about the potential photometric precision of the survey. To ensure this would not be a problem, we undertook a small pilot photometric survey to test the entire system before BOKS began (Feldmeier et al. 2006; Feldmeier et al. 2007). From that pilot survey, our photometric noise floor appears to be 2-3 milli-magnitudes, before any systematic corrections normally applied to transit surveys (Tamuz, Mazeh, & Zucker 2005). Figure 3 shows an example light curve from the pilot survey, showing the photometric precision we can achieve with the Burrell.

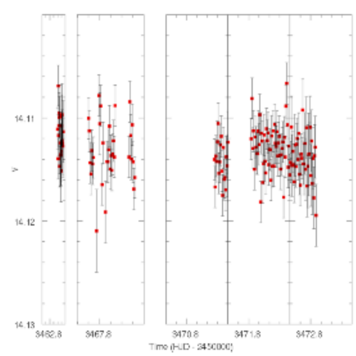

Fig. 3 – A light curve of a constant star taken from the Burrell Schmidt in Spring 2005 (pre-BOKS). This survey was undertaken in very poor weather conditions, and without the improved field flattener that was later installed for the BOKS survey. Nevertheless, the standard deviation of this light curve is 2.4 milli-mag, with the worst offset being 0.014 mag (peak-to-peak). These precisions are comparable with many other transit surveys.

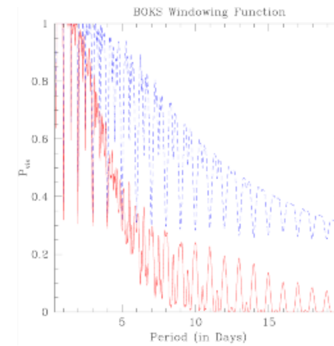

Fig. 4 – The window function for the BOKS dataset, including all 27 visible nights. The blue dashed line gives the probability that BOKS would have detected a single transit of that period, while the red solid line gives the probability that BOKS would have detected two transits of that period.

Observability of Extrasolar Planets

The probability of observing an extrasolar planet in transit is related to the window function of the observations. We have calculated this in simplified form for the BOKS data, and it can be seen in Figure 4. For the requirement of two transits for a detection, we are approximately 89% complete for Very Hot Jupiter planets, 45% complete for Hot Jupiter planets from short periods (P = 3-6 days), and 31% complete for all Hot Jupiter planets (P = 3-9 days). These estimates do not include assumptions about the distribution of extrasolar planet sizes, nor do they correct for lunar phase. We plan on undertaking extensive Monte-Carlo simulations to better quantify our survey efficiency.

However, since this field will be re-observed with *Kepler*, there will be opportunities to follow-up any single transits of high enough statistical significance to place stronger limits on the planetary fractions. Given that BOKS has been completed two years before the launch of *Kepler*, we should be able to place a limit on longer-term transits as well.

Acknowledgements
We wish to thank the Case Western Reserve Astronomy Department for their generous allocation of observing time
And the Michelson Science Center for supporting funds.