Assessing the detectability of exoplanets in the Magellanic Clouds

ABSTRACT

A key question in the field of exoplanets today is how whether different stellar populations host different planet populations. Hundreds of extra-Solar planets have been discovered in the Milky Way, but an extra-Galactic exoplanet has never been found since their host stars are so faint and transit signals are relatively small, providing a signal-to-noise challenge. The Dark Energy Camera may provide the first real opportunity to search for extragalactic exoplanets. The properties of exoplanets outside our own galaxy may provide important clues for star and planet formation. Although some exoplanet surveys have targeted planet populations outside the Solar neighborhood (for example the galactic bulge and the globular cluster 47 Tuc), no survey has successfully detected extrasolar planets in a stellar population as dramatically different from the thin disk as those Magellanic clouds. We propose to target the Magellanic clouds, both large and small to both 1) detect the first extra-galactic exoplanet and 2) infer differences in the population of hot Jupiters in the Clouds, contrasted with the hot Jupiter population of the Milky Way. We will observe the Large and Small Magellanic clouds with high cadence over a series of nights in g-band with the Dark Energy Camera. Our simulations demonstrate that our observing strategy is optimal for a search for hot Jupiters. We expect to discover a few hundred hot Jupiters in this survey, providing a statistical sample of exoplanets, perfect for a population analysis. The first detection of even a single extragalactic planet would be a significant milestone for the field of exoplanets and a huge step forward in exoplanet research. This discovery would lead to new insights into the efficacy of planet formation outside the Milky Way.

1. Method

We tested the potential for finding extra-galactic planets and small stars in this survey by simulating light curves with realistic white noise properties, cadence and realistic intermittent time coverage from ground-based observations. We also used these simulations to optimize our observing strategy.

300 Exoplanet transit signals were injected into a set of 300 simulated light curves using the `batman` code **?**. We generated transit signals for planets with a range of randomly generated planet radii and orbital periods, all orbiting a Sun-like star. The orbital periods ranged from around 8 hours to 10 days and the planet sizes ranged from 0.75 to 3 times the radius of Jupiter.

In order to detect the planets in our simulated data set we used the astropy BLS algorithm currently available through the github version of astropy (citation). This algorithm fits an upside-down tophat, or 'box' function, approximating the shape of an exoplanet transit, to a light curve over a grid of orbital periods, transit epochs and transit durations. It reports the log-likelihood (-1/2χ^2) of the light curve data, at each value of orbital period, transit epoch and duration. In high signal-to-noise cases the log-likelihood is greatest at the period, duration and epoch of the injected transit. However, when the relative size of the planet is small compared to the white noise in the light curve, and when its orbital period is long, the log-likelihood may not necessary peak at the true period. When attempting to detect planet transits in our simulated light curves, we required that the maximum BLS log-likelihood was greater than 15 (this threshold was established using simulated light curves with no injected exoplanet transit). If a light curve passed this criterion, we measured the difference between the maximum-likelihood period and the true orbital period of the planet and, if the difference was less than 10% of the period we injected, we classed that as a 'successful' planet detection. Figure **??** shows a completeness map of planet detectability as a function of injected radius and orbital period.

We simulated DEC light curves with a range of cadences and corresponding white noise amplitudes. We tested cadences of 3, 5, 8 and 10 minutes with SNRs of 7.0%, 5.3%, 4.2% and 3.8% respectively and found that the most rapid cadence, 3 minute integrations, resulted in the largest number of successfully detected exoplanets, despite the worse photometric precision per exposure.

There are several caveats to the simulations conducted here. Firstly, we only included white noise in our simulated light curves however time series photometry obtained from the DEC is likely to have correlated noise due to changes in the point spread function as the instruments flex with shifting attitude, temperature and pressure. In addition, planet transits and eclipses may be superposed on time-variable signals from the host star due to its rotation. Another caveat to this study is that we only simulated transit signals with zero impact parameter, *i.e.* planets transit across the center of the star and have the longest duration (and deepest) possible transit.

These simulations indicate that we will be able to detect small stars or giant planets orbiting Sun-like stars with Large and Small Magellanic clouds.

Fig. 1.— The completeness of our exoplanet transit detection pipeline as a function of the radius and orbital period of the planet we injected into simulated DEC light curves.