Transiting Planets
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DEMONEX: The DEdicated MONitor of EXotransits

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Abstract. DEMONEX is a low-cost, 0.5 meter, robotic telescope assembled mostly from commercially available parts dedicated to obtaining precise photometry of bright stars with transiting planets. This photometry will provide a homogeneous data set for all transits visible from its location at Winer Observatory in Sonoita, Arizona. We will also search for additional planets via transit timing variations, measure or place limits on the albedos from secondary eclipses, systematically search known radial velocity planets for those that transit, and follow up promising KELT candidates. Despite its modest size, the signal-to-noise ratio per transit is comparable to that obtained with larger, 1m-class telescopes because of its short readout time and high z-band quantum efficiency. However, its main strength is that it will be used every night for transit follow-up and gather an unprecedented data set on transiting planets. With the 24 known transiting planets and 112 radial velocity planets visible from Winer Observatory, over 90% of all nights have at least one full event to observe.

1. Science Goals

With the exploding sample size of transiting planets from the many on-going surveys (figure 1), follow-up of these objects with larger, shared telescopes will be impossible. At the same time, it becomes more scientifically interesting and valuable.

Using DEMONEX, a small, robotic telescope, we will collect a large, homogenous data set on all visible transiting planets. The first transit taken during commissioning is

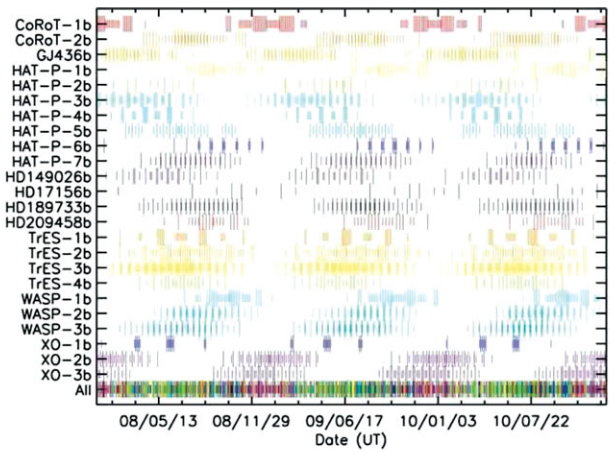

Figure 1. All transits (long lines) and secondary transits (short lines) for every transit visible from Winer Observatory in Sonoita Arizona over the next three years. Visible means the object is below z=3, the sun is below -12 degrees, and the moon is at least 15 degrees away.

shown in figure 2. Individual transits of the same object can be co-added to reduce the uncertainty to the point at which it is dominated by stellar models. The homogeneity of the sample, from data collection to reduction, will allow for robust planet to planet comparisons.

Since we will be observing many transits for every target, each with a precision of ∼30s, we will be able to discover additional planets in resonant orbits in these systems via Transit Timing Variations (Agol *et al.* 2005).

Observing and co-adding many secondary eclipses will allow us to measure or place interesting constraints on the albedos of the planets, similar to Rowe *et al.* (2006). This tells us about the atmospheric composition and energy budget of the planet.

We will conduct a systematic search for transits of the radial velocity planets. Because of the relatively low probability for each object, there has never been a systematic search for transits of the 272 planets discovered via radial velocity. However, just among the 112 planets visible from Winer with periods longer than 10 days, two are expected to transit. These planets would give us a window to a previously unexplored regime of planet parameter space.

We will look at known systems outside of transits for additional transits. Most systems for which the Rossiter-McLaughlin effect has been measured show that the planet's orbit is aligned with the star's rotation axis (e.g. Bundy & Marcy 2000; Queloz *et al.* 2000; Winn *et al.* 2005). This, along with the coplanarity of the planets in our solar system suggests that most systems would be coplanar, and thus the probability of finding additional transits in these systems is greatly increased from the a priori geometric probability.

The Kilodegree Extremely Little Telescope (Pepper et al. 2007) is beginning to produce viable transiting planet candidates. DEMONEX can provide invaluable follow up on these candidates.

Lastly, DEMONEX is generally useful for photometry of any bright objects. With its array of filters, it is well suited for microlensing, supernovae, and many other ancillary sciences.

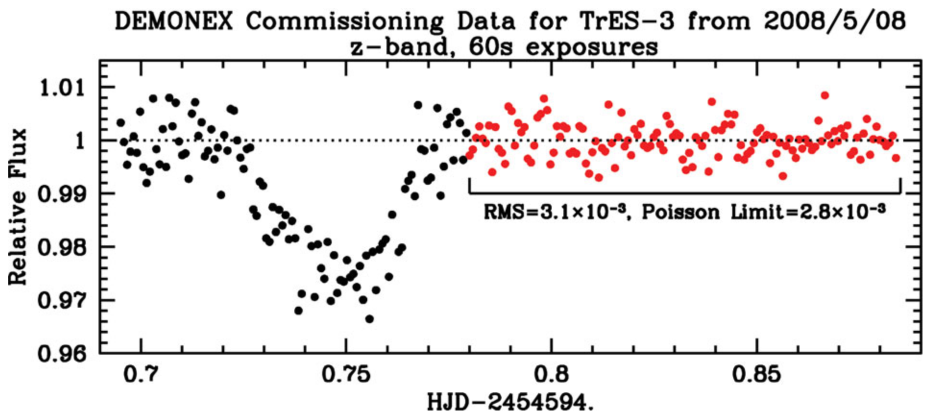

Figure 2. The z-band light curve of the primary transit of TrES-3 on UT 2008-05-08, taken with DEMONEX operating robotically during commissioning. Exposures were 60s with 7.7s dead time in between. The bracketted points denote the out-of-transit data used to normalize the flux and choose reference stars that minimize the RMS scatter. The points before transit were excluded due to high airmass (z > 2.5). The final RMS in this region of the light curve is 3.4millimagnitudes, which is only ∼10% higher than the Poisson limit.

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2. The System

The telescope is an f/8 Meade 0.5 m RCX400 on a MAX Mount (figure 3). The installed dew shield not only prevents dew, but decreases the susceptibility to scattered light, protects the telescope from dust and other debris, and increases the seeing. Poor seeing is acceptable because we are far from the sky brightness dominated regime, and even desired as is reduces systematics induced by flat fielding errors and allows us to take longer exposures before reaching saturation.

The science CCD is a Fairchild CCD3041 packaged by Finger Lakes Instrumentation (FLI). It is a 2K $\times$ 2K chip, with 15 μm pixels, for a field of view of 25.7' $\times$ 25.7', and 0.75"/pixel. The large field of view is required to have an adequate number of bright comparison stars for differential photometry. Its gain is 1.6 e-/ADU, with a read noise of 12 e- and readout time of 6.75 s. Its exceptionally high z-band throughput is well suited to transit observations.

The focuser and filter wheel are also from FLI. The CFW-5-7 filter wheel holds seven 50 mm square filters. Most observations will be done in the z' band to reduce the effects of limb darkening, but g',r',i',z',V,R, and clear are available for auxiliary science and experimentation. An I filter is also available, but not currently installed.

A piggybacked Orion 80 mm ED and SBIG ST402-ME camera are used for autoguiding. An adequate guide star can usually be found with integration times well below a

Figure 3. DEMONEX awaiting twilight flats at Winer Observatory in Sonoita, Arizona.

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second. Differential flexure between the guider and science camera is compensated for by monitoring the position of the stars in the science images and shifting the guide star.

The electronics box contains the telescope power supply and computer controlled relays for each component. This allows us to recover from a variety of failures automatically.

Everything is controlled via computer in the control room 35 feet away, as discussed in the automation section.

The observatory director set up a weather station and closes the roll-off roof if there are threatening conditions. Roof status as well as weather data is posted on a webpage, which is queried and recorded in a log before each exposure.

3. Automation

DEMONEX is completely automated using a Windows XP box equipped with TheSky6, CCDSoft, TPoint and VBScripts for observations, and a Linux box with IDL, SExtractor, and WCSTools for reductions. Each night, DEMONEX begins taking biases and darks then waits for the Sun to set low enough for twilight flats. It takes flats in each band that will be used during the night (usually just z band), then begins observing, prioritizing based on the type of event and the fraction observable. It continues until the sun rises, and then takes another set of flats for quality control. It then goes to its home position, turns off, backs up the data, emails a log for the night, and tells the linux box to begin reductions. If a fatal error is encountered, it shuts down as best it can and sends a text message and email, attaching a verbose engineering log to aide in diagnosis.

The reduction pipeline does the usual bias, dark, and flat field calibrations. Then, for each object, a reference image is selected by determining which has the most stars with the smallest FWHM with SExtractor. A coordinate solution is performed on that image with WCSTools to locate the target, and all other images are aligned to it. Aperture photometry is done with many apertures, and for each aperture, the target star is divided by the ensemble of stars that minimizes its out-of-transit RMS. The aperture with the lowest out-of-transit RMS is used, and further de-trended with airmass, pixel position, temperature, humidity, etc. The resulting lightcurves are emailed for visual inspection an hour or two after the final flat for the night was taken.

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