Looking towards the detection of exoearths with SuperWASP

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Looking towards the detection of exoearths with SuperWASP

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Abstract: The WASP consortium is conducting an ultra-wide field survey of stars between 8–15 mag from both hemispheres. Our primary science goal is to detect extra-solar 'hot-Jupiter'-type planets that eclipse (or transit) bright host stars and for which further detailed investigation will be possible. We summarize the design of the SuperWASP instruments and describe the first results from our northern station SW-N, sited in La Palma, Canary Islands. Our second station, which began operations this year, is located at the South African Astronomical Observatory. Between April and September, 2004, SW-N continuously observed ~6.7 million stars. The consortium's custom-written, fully automated data reduction pipeline has been used to process these data, and the information is now stored in the project archive, held by the Leicester database and archive service (LEDAS). We have applied a sophisticated, automated algorithm to identify the low-amplitude (~0.01 mag), brief (~few hours) signatures of transiting exoplanets. In addition, we have assessed each candidate in the light of all available catalogue information in order to reject data artefacts and astrophysical false positive detections. The highest priority candidates are currently being subjected to further observations in order to select the true planets. Once the exoplanets are confirmed, a host of exciting opportunities are open to us. In this paper, we describe two techniques that exploit the transits in order to detect other objects within the same system. The first involves determining precise epochs for a sequence of transit events in order to detect the small timing variations caused by the gravitational pull of other planets in the same system. The second method employs ultra-high precision photometry of the transits to detect the deviations caused by the presence of exoplanetary moons. Both of these techniques are capable of detecting objects the size of terrestrial planets.

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Introduction

Over the course of the last decade, around 200 planets have been discovered orbiting stars other than the Sun. This has led to rapid revisions in our understanding of planetary formation and evolution. However, the near future holds a tantalizing prospect: the first detection of an Earth-like planet orbiting another star similar to the Sun. As our terrestrial planet is the only confirmed niche (so far!) for life, a comparable planet system orbiting another star would shed light on the possibilities for the development of life.

The technique of detecting transits has the potential to deliver Earth-mass exoplanets. A transit occurs when a planet's orbit causes it to pass directly between the observer and a star, blocking out a small amount of its light (Fig. 1). When this occurs for planets orbiting stars other than the Sun we cannot resolve the planet superimposed on the stellar disc owing to their great distance from the Earth. However,

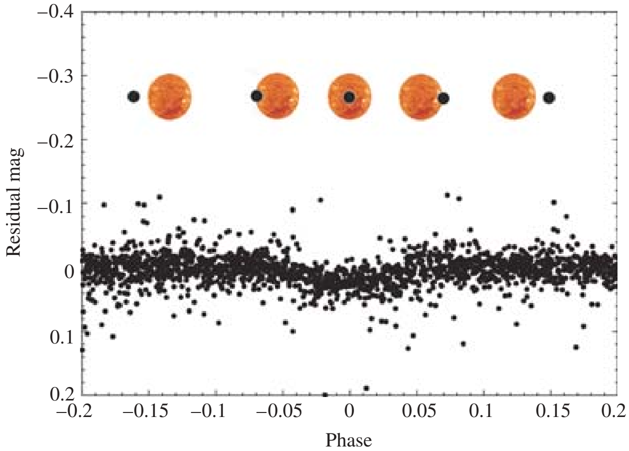

Fig. 1. Schematic diagram of an exoplanetary transit (top) and the corresponding variation in the brightness of the star (bottom).

we can detect the transits by monitoring the star's brightness to high precision (to better than 1%) over long (~months) periods of time. These events are rare because of the precise alignment needed: 1 in ~25 000 stars are expected to have a detectable transiting 'hot-Jupiter' (Brown 2003) – a Jovian-sized planet orbiting very close (~0.05AU) to its host star.

Transiting planets are valuable because their true physical parameters can be measured unambiguously, leading to improved constraints on models of planetary formation and evolution. In addition, a wealth of information can be derived from detailed follow-up observations, including detecting components of the planets atmosphere (Charbonneau *et al.* 2002; Vidal-Madjar *et al.* 2003), and even finding Earth-sized objects in the same system (Brown *et al.* 2001; Agol *et al.* 2005). In the following section we describe the SuperWASP survey for transits of bright stars. We then present the results of our first observing season, and we discuss the exciting future prospect of searching for other objects in the same system.

The SuperWASP project

The intrinsic rarity of transiting planets means that we have to continuously observe hundreds of thousands of bright ($V \sim 8$–15 mag) stars in order to detect significant numbers of events.

In order to do this, we have constructed two robotic observing stations (Pollacoo *et al.* 2006), surveying the skies of both hemispheres from La Palma, Canary Islands (SW-N) and the South African Astronomical Observatory (SW-S). Each observing station is comprised of a robotically operated fork mount (produced by OMI inc.) housed in a dedicated enclosure with its own GPS and weather systems, capable of shutting down the system in the event of inclement weather. The fork mount supports up to eight cameras per station, where each camera consists of a 2K × 2K e2v CCD (made by Andor Technology PLC.) and a 200 mm F/1.8 Canon lens. This gives a field of view of 7.8 deg × 7.8 deg per camera, and a total field of view per station of 486.7 deg². Both stations are capable of running robotically with minimal human supervision.

The SW-N station was completed first, beginning full-scale observations in April 2004 and operating continuously until September of that year with a complement of five cameras. SW-S was completed in 2006 and both stations are now operational. For more details on the SuperWASP instruments, please refer to Pollacco *et al.* (2006) or the project website (www.superwasp.org).

Each station gathers an impressive ~6 TB or more of images per year. In order to process and analyse these data effectively, our consortium has developed fully automated data reduction software as well as algorithms to detect the transit signatures (described in detail by Cameron *et al.* 2006). Once the analysis is complete, the information is stored in a customized database held by the Leicester database and archive service (LEDAS) at the University of Leicester.

SuperWASP-N (La Palma) 2004 season results

In our first observing season, SW-N observed ~6.7 million stars continuously for 1–5 months. Around 1.2 million of these were measured with the precision required for transit detection (see Fig. 2). Our transit detection algorithm produced an initial list of ~72 000 candidates which were visually inspected and evaluated in conjunction with all the publicly available catalogue information for these objects. This procedure is necessary to eliminate data artefacts and the various astrophysical phenomena capable of masquerading as transiting planets, such as eclipsing binary stars whose light may be contaminated by the light of nearby objects, for example. These candidates are described in forthcoming publications (e.g. Christian *et al.* 2006).

While this procedure makes effective use of all the data at our disposal, it is not possible to reject 100% of non-transiting candidates. Experience from other transit surveys has led us to expect that a high fraction (~90%) of the candidates will turn out to be low-mass binaries or blended stars. We are therefore conducting a careful series of follow-up observations to confirm the nature of each of the candidates. Once this is established, we will obtain the time series radial velocity information required to measure the true physical and orbital parameters of these systems.

With a new sample of bright, well-characterized planets, there is an extensive range of future investigations that we will undertake. Here we discuss two particular techniques that could discover earth-sized bodies in the same systems as the transiting planets.

Exoearths in transiting hot-Jupiter systems

If one planet from a multiple-planet system transits the host star, the gravitational pull of the other planets will cause the transits to occur slightly ahead or behind the times predicted for a single-planet system (Agol *et al.* 2005); see Fig. 3. If the orbital period of the second planet is an integer multiple of the period of the transiting planet,

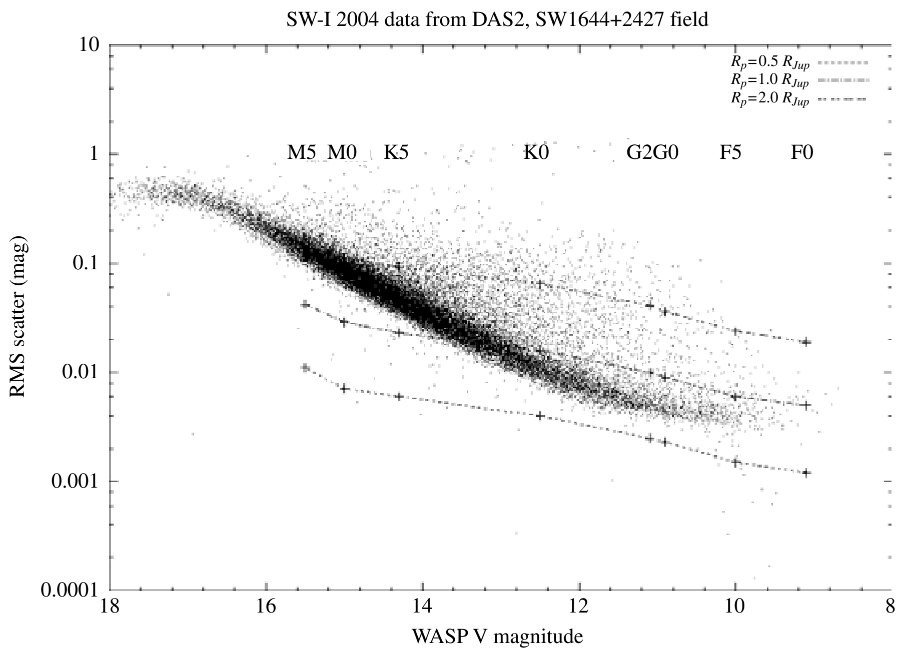

Fig. 2. The root mean squared (RMS) precision achieved for the measured brightness of stars over the course of the observations is plotted against the mean stellar brightness. Superimposed are curves representing the theoretical amplitude of transit signature expected for planets of 0.5, 1.0 and 2.0 Jupiter radii orbiting stars of various masses. To illustrate this example, the distance to (and hence apparent magnitude of) the stars has been scaled such that the lowest mass objects coincide with the faint limiting magnitude of our sample.

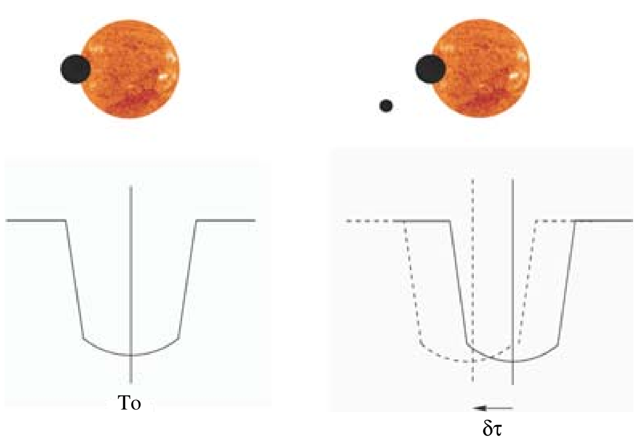

Fig. 3. Schematic diagram of the variation in the mid-point of the transit signal of the hot-Jupiter caused by gravitational interaction with the second planet.

they are said to be in resonance. In this instance, the gravitationally induced variation in transit times is amplified. Agol *et al*. (2005) showed that the predicted variation in the times of mid-transit of a hot-Jupiter orbiting in resonance with an Earth-mass companion planet can be as much as ~3 min.

Detecting Earth-mass companion planets to transiting hot-Jupiters

Low-mass companion planets to SuperWASP's transiting exoplanets can therefore be discovered by determining the midpoints of a *series* of transits to high precision.

To achieve sufficiently accurate timing, each transit will have to be measured with a frequency of greater than two images per minute throughout each event.

SuperWASP's candidates are ideally suited for this, as their relative brightness makes it easier to monitor them with high cadence and precision. Instruments capable of imaging these stars every few seconds are already available; for example, the rapid-observation camera Ultracam (Dhillon & Marsh 2001).

Detecting exomoons

There is another way in which we can exploit high-cadence/high-precision observations to find Earth-sized objects. Supposing that a transiting Jovian planet has an Earth-sized satellite, this second body will also transit the star causing very low-amplitude (~few millimag) deviations in the light curve lasting ~30 min (see Fig. 4). We propose to use Ultracam mounted on an 8 m-class telescope to obtain the required timing and photometric precision.

Conclusions

The SuperWASP project is now producing a substantial list of new transiting exoplanet candidates, and we are in the process of investigating the nature of these objects. Once confirmed, the newly discovered exoplanets will present a unique opportunity to reveal the presence of other bodies in the same planetary systems, even those as small as terrestrial-sized planets and moons. Such discoveries will improve

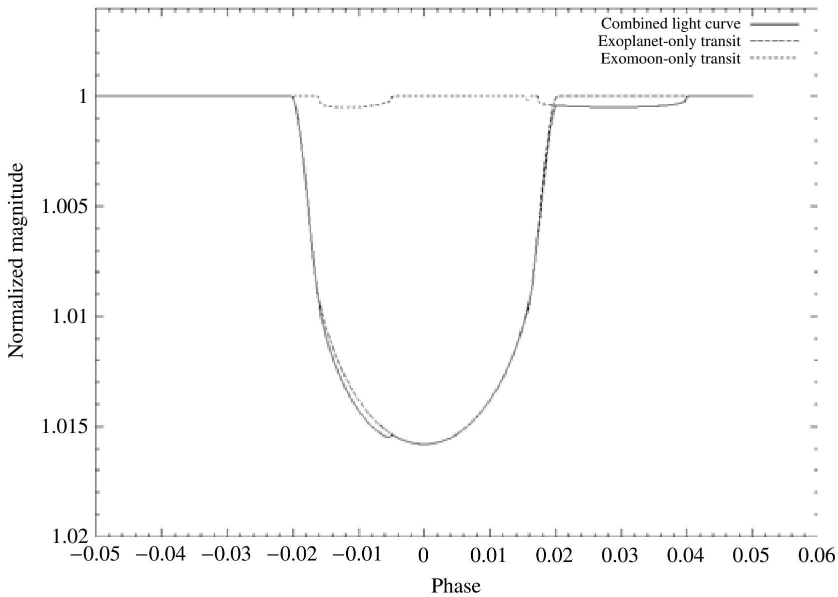

Fig. 4. The light curve of the transit of a Jovian exoplanet, folded on its period of 3 days. Superimposed is the transit light curve of a two-Earth-radii moon orbiting the planet every 0.2 days.

the empirical constraints on the prevalence and evolution of terrestrial planets by widening the sample of known Earth-mass objects.

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