The Next Generation Transit Survey Becomes Operational at Paranal

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A new facility dedicated to the discovery of exoplanets has commenced science operations at Paranal. The Next-Generation Transit Survey (NGTS) will deliver photometry at a precision unprecedented for a ground-based wide-field survey, enabling the discovery of dozens of transiting exoplanets of the size of Neptune or smaller around bright stars. NGTS is briefly described and the survey prospects are outlined.

Introduction

Most of our knowledge of the properties of individual exoplanets comes from those that transit their host star. Measurements of the transit lead to an estimate of the planet's radius relative to that of the star and, since its orbital inclination can be recovered from the transit shape, then its mass can be derived. Together these data provide the planet's density, which can be compared to theoretical models of its structure. Even in this new era of directly imaged planets (with high contrast imaging instruments such as the Spectro-Polarimeter High-contrast Exoplanet REsearch Instrument [SPHERE] on the Very Large Telescope, for example) and astrometric orbits from the European Space Agency (ESA) Gaia satellite, transit observations remain the only direct method to determine accurate planetary radii.

However, the detection of transiting planets is not trivial. As the transit probability diminishes rapidly with orbital period, strong selection effects favour the detection of large planets (or, strictly speaking, planets large relative to their host) with short periods. Consequently, transit surveys observe thousands of (Sun-like) stars to find just a handful of large planets. The two leading ground-based survey projects are HAT (Hungarian-made Automated Telescope[1]) and WASP (Wide Angle Search for Planets[2]), which together have discovered the majority of planets that have accurately determined masses.

The instruments used in these surveys are quite modest, but are capable of repeatedly imaging hundreds of square degrees and obtaining accurate photometry (better than 1% precision) for stars brighter than $V = 11$ mag. Each facility has the significant computer resources required to reduce the data for each star in an image and search for brightness variations. In the case of WASP the reduced data products (star brightness as a function of time) grow at a rate of several GB per night. Over ten years of operation, WASP has acquired more than 16 million images covering 30 million stars, a total of more than 0.5×10^{12} photometric data points.

The ESA space mission CoRoT (Convection, Rotation and planetary Transits) and the National Aeronautics and Space Administration (NASA) satellite Kepler (and its continuation as K2) have obtained photometry of sufficient accuracy to enable the detection of smaller, rocky planets. Given the relatively modest fields of view of these instruments, most of their planet candidates have been detected with host stars of $V > 13$ mag. Consequently, given their faintness and the expected size of the reflex motion induced in the star, confirmation and measurement of the planetary mass have generally been beyond our current observational capabilities, and just a handful of the brightest hosts with small planets have been studied.

The need for another (red) survey

In order to characterise small planets we have two options:

a) Employ an extremely wide-field satellite enabling photometry of many bright stars. Both NASA and ESA are planning such missions, respectively the Transiting Exoplanet Survey Satellite (TESS) and the PLAnetary Transits and Oscillations of stars (PLATO);
b) Remembering that the transit depth is dependent on the relative sizes of the planet and its star, observe smaller stars to detect smaller planets for a given photometric accuracy. There are several projects targeting individual M-dwarfs that have recently achieved stunning successes, such as the detection of GJ 1132b (Berta-Thompson et al. 2015) with MEarth[3] and TRAPPIST-1 (Gillon et al., 2016) with the TRAnsiting Planets and PlanetesImals Small Telescope (Jehin et al., 2011; TRAPPIST[4]). While M-dwarfs are common, they are intrinsically faint and spectroscopic

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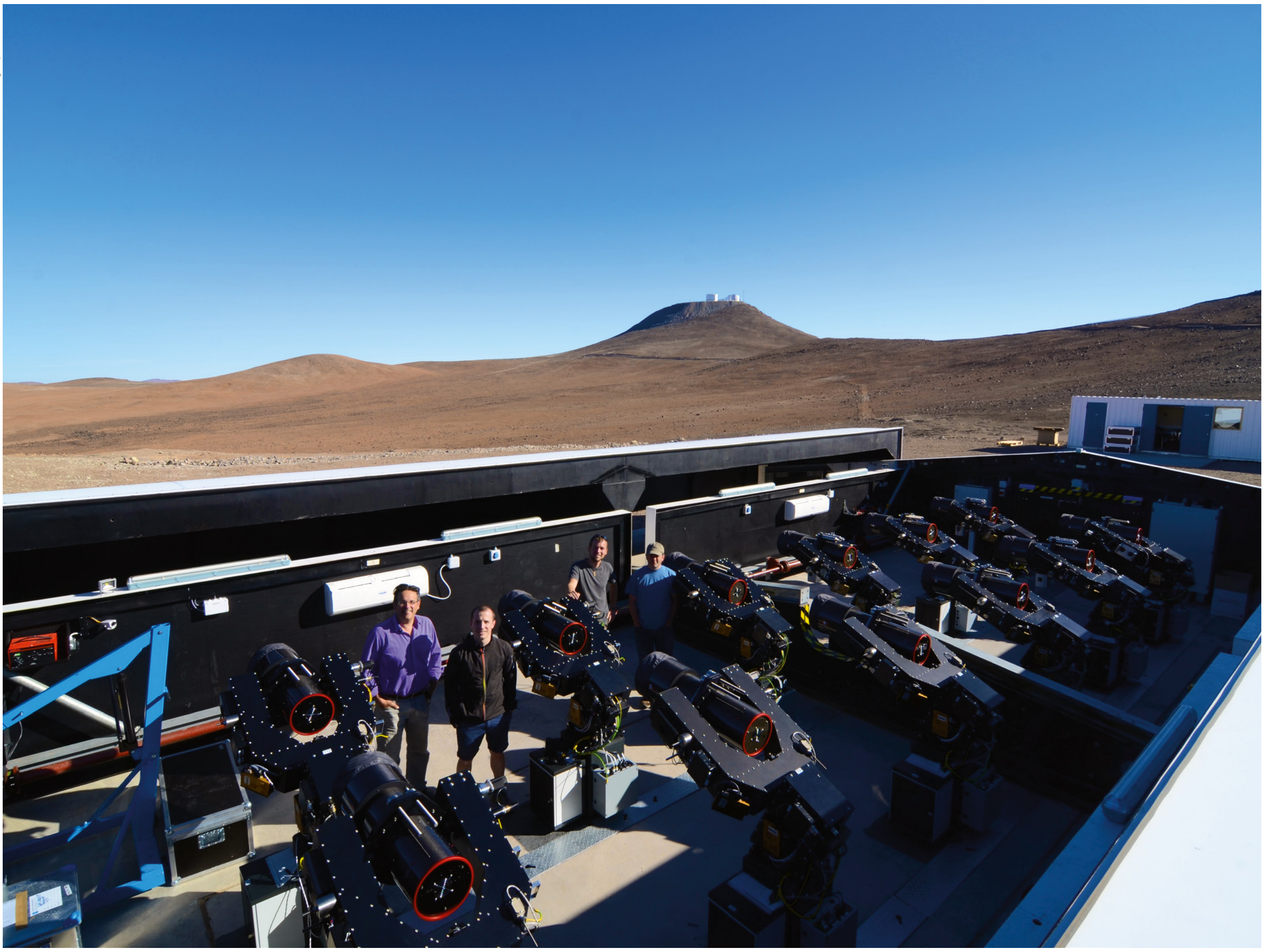

Figure 1. Photograph of the NGTS facility at Paranal with the VLT in the background to the west.

follow up of these targets is challenging. An alternative approach is to optimise the system for the detection of planets around K-dwarfs, which are more luminous. The Next Generation Transit Survey is our attempt to realise this survey.

The scientific goal of NGTS is to discover a population of Neptune-sized planets around bright stars. In order to achieve this, a photometric precision unprecedented in wide-field ground-based surveys (better than 0.1 %) is required. NGTS has therefore been carefully designed to minimise the instrumental effects which have limited the precision of previous surveys.

NGTS has its roots in the hugely successful WASP project[2] but has been developed through two prototypes. The first was set up on La Palma in 2010 and was used to look at the potential use of deep-depleted charge-coupled device (CCD) technology for the detectors and of wider-aperture astrographs. This first prototype led to the final design which was constructed at Geneva Observatory in 2012. This second prototyping phase was then used to further optimise the design, and to develop the control software.

After discussions with ESO it was agreed to site the NGTS at Paranal Observatory. While astronomical seeing was not a prime factor, atmospheric water content and excellent photometric conditions were paramount in this decision.

The NGTS facility

NGTS[5] consists of a cluster of twelve identical telescope units, each unit comprising a 20-cm f/2.8 astrograph and a 2k × 2k deep-depleted CCD camera mounted on an independently steerable fork mount. Each unit has a field of view of approximately 3 × 3 degrees, yielding a total field of view for the whole facility of approximately 100 square degrees (roughly equivalent to that of the Kepler satellite). A photograph of the NGTS facility at Paranal is shown in Figure 1.

In general, NGTS utilises commercial off-the-shelf products which have been modified to optimise their performance. For example, the detectors are deep-depleted e2v (CCD-42) devices packaged into a camera by Andor Technology (model iKon-L). Andor manufactured the original WASP cameras so we already had a good working relationship with this company. Optimisation of these devices proved more demanding than we expected and the company expended considerable effort to produce devices suitable for the extreme accuracies we were trying to achieve. Similarly, the telescopes are H-series astrographs from Astro Systeme Austria (ASA), but fitted with a custom corrector optic designed to NGTS specifications. The NGTS enclosure was designed and fabricated by GR-PRO in the UK; it is of glass-reinforced plastic (GRP) composite construction, and has a footprint of around 10 × 15 metres.

The NGTS facility is fully robotic and operates unsupervised, following a pre-generated schedule that is prepared on a daily basis. The survey data are transferred to the NGTS Data Centre at the University of Warwick, UK, to be analysed using sophisticated automated algorithms that search for the tell-tale signatures of an exoplanet transiting its host star. Detections made by these algorithms are further vetted by automatic and manual means, and the highest quality candidates are passed for photometric and spectroscopic follow-up using larger facilities (e.g., the CORALIE spectrograph on the EULER telescope at La Silla). Processed NGTS light-curves will be made available to the community via the ESO Science Archive Facility after a proprietary period (two years for the first release, one year for subsequent releases).

First results and the future

First light at Paranal was achieved with the first NGTS telescope in January 2015 and the transit survey began with five telescopes in August 2015. The full complement of twelve telescopes became operational in February 2016 and, despite the poor weather associated with El Niño, NGTS has already acquired more than 3.5 million science images. The quality of the data produced by NGTS is exceptional, and the instrument has proven itself well capable of delivering the required sub-millimagnitude photometric precision. As an example of the step-change improvement that NGTS represents over previous ground-based surveys, Figure 2 compares the light-curve of a single transit of a known exoplanet (the "hot Jupiter" WASP-4b [Wilson et al., 2008]) taken with NGTS, with the best quality transit in the WASP survey data. The WASP data show instrumental effects that have a magnitude similar to that of the transit signal, so WASP required coverage of many transits in order to make a significant detection. NGTS on the other hand could have detected WASP-4b with a single transit.

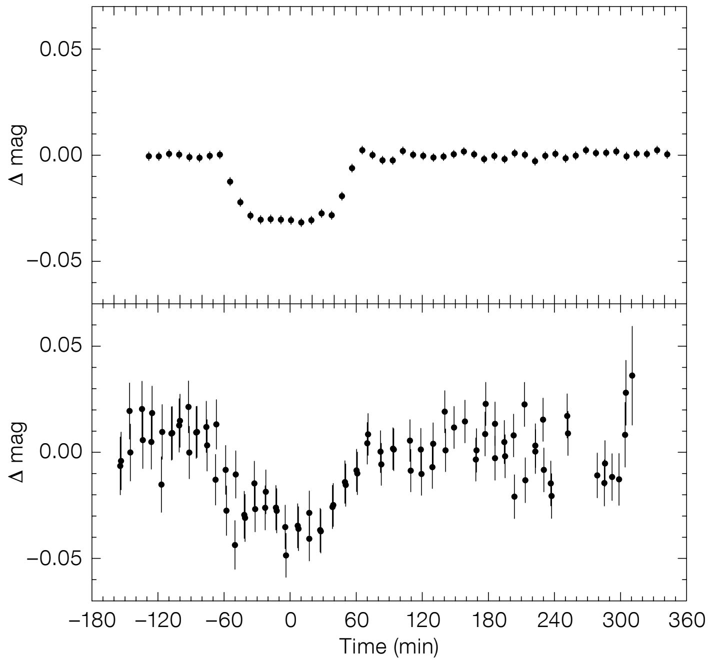

Figure 2. Light curves of single transits of the Jupiter-sized exoplanet WASP-4b measured with NGTS (upper) and WASP (lower).

A preliminary analysis of the data from the first six months of the full NGTS survey has yielded several dozen candidate planets which are we currently following up. Recent simulations based on the actual performance of NGTS have shown that the full NGTS survey can be expected to detect several super-Earths (planets with a radius less than twice that of the Earth), tens of Neptune-sized planets (2–6 Earth radii), and more than 200 planets with a radius larger than Saturn's (6–22 Earth radii). NGTS is most sensitive to planets with orbits of less than 20 days.

NGTS Consortium

The NGTS Consortium consists of the following institutes: University of Warwick, UK; Observatoire de Genève, Switzerland; Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany; University of Leicester, UK; Queen's University Belfast, UK; and the University of Cambridge, UK. The Chilean astronomical community is currently represented by the Pontificia Universidad Católica de Chile and the Universidad de Chile.

References

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Wilson, D. M. et al. 2008, ApJ, 675, L113

Links

[1] HAT Exoplanet Surveys: https://hatsurveys.org/
[2] WASP: https://wasp-planets.net/
[3] MEarth project: https://www.cfa.harvard.edu/MEarth/Welcome.html
[4] TRAPPIST Telescope Network: http://www.orca.ulg.ac.be/TRAPPIST/Trappist_main/News.html
[5] NGTS: http://www.ngtransits.org