Southern Horizons in Time-Domain Astronomy
Proceedings IAU Symposium No. 339, 2019
E. Griffin, ed.
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doi:10.1017/S1743921318002557

The Trans-Neptunian Automated Occultation Survey (*TAOS II*)

M. J. Lehner[1,2,3], S-Y. Wang[1], M. Reyes-Ruiz[4], Z-W. Zhang[1], L. Figueroa[4], C-K. Huang[1,5], W-L. Yen[1], C. Alcock[3], F. Alvarez Santana[4], J. Castro-Chacón[4], W-P. Chen[5], Y-H. Chu[1], K. H. Cook[1], J. C. Geary[3], B. Hernández[4], J. Karr[1], J. J. Kavelaars[6,7], T. Norton[3] and A. Szentgyorgyi[3]

[1]Institute for Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan
email: mlehner@asiaa.sinica.edu.tw

[2]Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, PA, USA

[3]Harvard-Smithsonian Center for Astrophysics, Cambridge, USA

[4]Instituto de Astronomía, Universidad Nacional Autónoma de México, Baja California, México

[5]Institute of Astronomy, National Central University, Taoyuan City, Taiwan

[6]Herzberg Astronomy & Astrophysics Research Centre, NRC, Victoria, BC, Canada

[7]Department of Physics and Astronomy, University of Victoria, BC, Canada

Abstract. *TAOS II* is a next-generation occultation survey with the goal of measuring the size distribution of the small end of the Kuiper Belt (objects with diameters 0.5–30 km). Such objects have magnitudes $r > 30$, and are thus undetectable by direct imaging. The project will operate three telescopes at San Pedro Mártir Observatory in Baja California, México. Each telescope will be equipped with a custom-built camera comprised of a focal-plane array of CMOS imagers. The cameras will be capable of reading out image data from 10,000 stars at a cadence of 20 Hz. The telescopes will monitor the same set of stars simultaneously to search for coincident occultation detections, thus minimising the false-positive rate. This talk described the project, and reported on the progress of the development of the survey infrastructure.

Keywords. Occultations, Kuiper Belt, telescopes, instrumentation: detectors

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1. Introduction

The size distribution of Trans-Neptunian Objects (TNOs) has been measured down to a diameter of about 25 km (Luu & Jewitt 2002; Bernstein *et al.* 2004; Fuentes & Holman 2008; Fraser *et al.* 2008; Fraser & Kavelaars 2008, 2009; Fuentes *et al.* 2009). Pushing that limit down to diameters of ∼1 km would help to constrain further the models of the dynamical evolution of the Solar System (Duncan *et al.* 1995; Stern 1996; Davis & Farinella 1997; Kenyon & Luu 1999a,b; Benz & Asphaug 1999; Kenyon & Bromley 2001, 2004; Pan & Sari 2005; Kenyon & Bromley 2009; Benavidez & Campo Bagatin 2009), as well as help identify the source population of the Jupiter Family Comets (Holman & Wisdom 1993; Morbidelli 1997; Levison & Duncan 1997; Duncan & Levison 1997; Tancredi *et al.* 2006; Volk & Malhotra 2008). Such objects are not directly detectable since their brightnesses in reflected sunlight are typically $r > 28$. However, when such an object passes close enough to the line of sight of a background star it will induce a measurable momentary drop in brightness that can be detected by ground-based telescopes (Bailey 1976; Roques *et al.* 1987; Brown & Webster 1997; Roques & Moncuquet 2000; Cooray 2003; Cooray & Farmer 2003; Roques *et al.*

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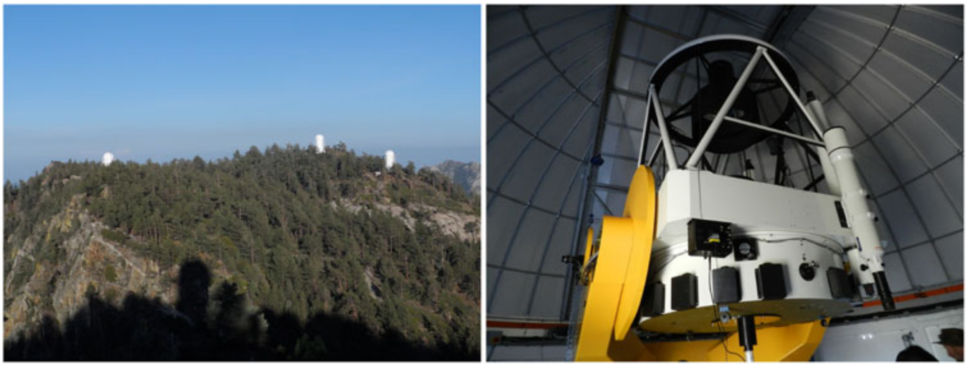

Figure 1. *Left:* The three *TAOS II* telescope enclosures. *Right:* The telescope at Site #2.

2003, 2006; Chang *et al.* 2006; Nihei *et al.* 2007; Chang *et al.* 2007; Bickerton *et al.* 2008; Zhang *et al.* 2008; Liu *et al.* 2008; Bianco *et al.* 2009; Wang *et al.* 2009; Bickerton *et al.* 2009; Schlichting *et al.* 2009; Bianco *et al.* 2010; Wang *et al.* 2010; Schlichting *et al.* 2012; Zhang *et al.* 2013). *TAOS II* is a survey designed to detect such events, and thus to measure the size distribution of TNOs with diameters 0.5 km < D < 30 km.

2. Survey Requirements

Occultation events have been described in detail by Nihei *et al.* (2007). The salient points are that occultation shadows from the objects targeted by this survey range in size from ∼5–30 km across. Objects that are smaller than a few km in diameter lie in the Fresnel regime (assuming they are observed in the visible wavelengths to be used for *TAOS II*). The resulting diffraction effects in the occultation shadows for the smaller objects set a minimum shadow size of about 5 km. The objects are in motion relative to the Earth, with a relative velocity around 25 km s^{-1} if observed at opposition. Event durations thus range from about 0.2–1 sec. For the diffraction dominated events, it is helpful to resolve the diffraction features of the event since they contain information about the size and distance of the occulting objects. *TAOS II* will observe at a cadence of 20 Hz.

The expected rate of occultation events is of course unknown at the outset, but Zhang *et al.* (2013) have shown that it should be less than ∼0.03 events per star per year in the size range of interest to this survey. On the other hand, predictions (referenced above) of the surface density of TNOs required to give rise to the measured number of Jupiter Family Comets range from about $\sim 10^{-4}$ to ∼0.01 per star per year. *TAOS II* will monitor on average 10,000 stars simultaneously to search for occultation events.

Given the rarity of these events and the rapid observing cadence required, we would expect a significant false-positive rate caused by scintillation in the upper atmosphere. That was the reason behind designing *TAOS II* with three telescope separated by a minimum of 100 m, since scintillation is not expected to affect the brightness measurements of a given star in a similar way by such widely separated telescopes. A genuine occultation event will therefore be required to be detected simultaneously by all three telescopes.

3. Survey Design

The *TAOS II* survey has already been described in detail by Lehner *et al.* (2012, 2014, 2016). The survey will operate three telescopes at San Pedro Mártir Observatory in Baja California, México (see Fig. 1). The telescopes have separations of 127, 266 and 323 m.

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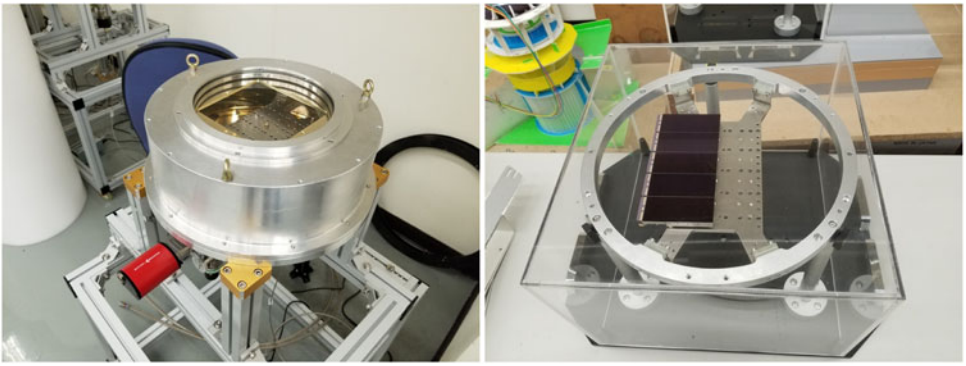

Figure 2. *Left:* One of the three *TAOS II* camera dewars in the lab at ASIAA. *Right:* One of the three focal planes being populated with scientific devices.

They were manufactured by DFM Engineering, Inc. and are identical, with F/4 1.3-m primary mirrors that image a circle of 1°.7 onto a 154-mm field of view.

The cameras will use custom CMOS imagers from e2v (Wang *et al.* 2014; Pratlong *et al.* 2016). By using CMOS imagers, we can restrict the read-out to a small window around each of the target stars; that was necessary in order to read out the pixel data for 10,000 stars simultaneously at 20 Hz. Each imager is a 1920×4608 array of 16-μm pixels. Each camera will have a 2×5 array of these imagers (see Fig 2) so as to cover the field of view of each telescope.

4. Project Status

Site development was completed in 2017 August with the installation of the domes. Telescope installation was completed in 2017 October. The cameras are scheduled to be delivered in 2018 September, and after six to eight weeks for commissioning we will begin science operations. The nominal plan is to run the survey for five years, but we will probably adjust that schedule depending on the rate of events observed.

Acknowledgements

This work was supported in part by Academia Sinica and the Universidad Nacional Autónoma de México. MRR acknowledges support from UNAM-PAPIIT project IN107316.

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