EPSC Abstracts
Vol. 6, EPSC-DPS2011-355, 2011
EPSC-DPS Joint Meeting 2011

TAOS: An Occultation Survey of the Outer Solar System

M. J. Lehner (1,2,3), C. Alcock (3), T. Axelrod (4), F. B. Bianco (5,6), Y.-I. Byun (7), W. P. Chen (8), K. H. Cook(9), I. de Pater(10), J. C. Geary (3), D.-W. Kim (7,3,11), S.-K. King (1), T. Lee (1), S. L. Marshall (12,9), T. Norton (3), P. Protopapas(11,3), J. A. Rice (13), M. Ruiz Reyes (14), M. E. Schwamb (15,16), A. Szentgyorgyi (1), J.-H. Wang (1), S.-Y. Wang (1), C.-Y. Wen (1), and Z.-W. Zhang (1)
(1) Academia Sinica Institute of Astronomy and Astrophysics, Taipei, Taiwan (mjlehner@gmail.com), (2) Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, PA, USA, (3) Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA, (4) Steward Observatory, Tucson, AZ, USA, (5) Department of Physics, UCSB, Santa Barbara, CA, USA, (6) Las Cumbres Observatory Global Telescope Network, Santa Barbara, CA, USA, (7) Department of Astronomy, Yonsei University, Seoul, South Korea, (8) Institute of Astronomy, National Central University, Jhongli, Taiwan, (9) Institute of Geophysics and Planetary Physics, Lawrence Livermore National Laboratory, Livermore, CA, USA, (10) Department of Astronomy, UC Berkeley, Berkeley, CA, USA, (11) Initiative in Innovative Computing, Harvard University, Cambridge, MA, USA, (12) Kavli Institute for Particle Astrophysics and Cosmology, Stanford Linear Accelerator, Menlo Park, CA, USA, (13) Department of Statistics, UC Berkeley, Berkeley, CA, USA, (14) Instituto de Astronomía, Universidad Nacional Autonóma de México, Ensenada, B.C., México (15) Department of Physics, Yale University, New Haven, CT, USA, (16) Yale Center for Astronomy and Astrophysics, Yale University, New Haven, CT, USA

Abstract

The Taiwanese-American Occultation survey (TAOS) operate four small telescopes in central Taiwan to search for occultations by small ($\sim$1 km diameter) Kuiper Belt Objects. The system is fully robotic, requiring human intervention only in the event of hardware failures. However, the status of the system during observations is monitored remotely via smart-phone. A successor survey, the Transneptunian Automated Occultation Survey (TAOS II)[1] is currently being constructed. This next generation survey will be more than one hundred times as sensitive as the earlier survey. In my talk I will present the results of TAOS I, discuss the future plans of the survey, and provide a detailed description of the TAOS II project.

1. TAOS I

The TAOS I project aims to measure the size distribution of Kuiper Belt Objects (KBOs) with diameters $0.5 \text{ km} < D < 30 \text{ km}$. Such objects are extremely faint, with typical magnitudes $R > 28$, and are thus undetectable by direct imaging. However, a small KBO will induce a detectable drop in the brightness of a distant star when it passes across the line of sight to the star (see [1] and references therein). The goal of the TAOS project is to detect such occultation events.

The TAOS I system is described in detail in [2]. The collaboration operates four small telescopes at Lulin Observatory in central Taiwan to search for occultation events by small KBOs. Such occultation events are extremely rare (estimated rates range from 10^{-4} to 10^{-2} events per star per year), and at the 5 Hz observing cadence used by TAOS I, they result in measured flux drops of typically $\lesssim$30% in one or two consecutive points. This presents a number of challenges, in particular the identification of false positive events of statistical origin and candidate events which are in fact of terrestrial origin (e.g. birds, airplanes, and extreme scintillation events). We reject these false positive events by requiring simultaneous detection in all of the telescopes [3].

The four identical telescopes were manufactured by Torus Technologies. Each telescope is built with a fast (F/1.9) Cassegrain design, with a 50 cm diameter primary mirror. Each telescope is equipped with a Spectral Instruments camera using an e2v 2048×2052 CCD42-40 imager with 14 μm pixels. The CCD covers a field of view of about 3 $\square^\circ$. To achieve a 5 Hz sampling cadence, we operate the cameras in a custom readout mode we call *zipper mode* [2]. We plan to replace the cameras in July of 2011 with frame transfer cameras. The cameras are only 1k×1k, so we will lose 75% of our field of view. However, the frame transfer capability allows us to read out full frame at

[1]The name of the successor survey was changed due to the fact that it will be located in Mexico.

a 10 Hz cadence if we use 2×2 binning. Zipper mode operations will no longer be required, and the resulting improvements in signal-to-noise will increase the number of viewable stars by a factor of two to three, despite the loss of a significant fraction of our field of view.

The TAOS I team has analyzed 3.5 years of data from February 2005 through August 2008. No events were found, allowing the project to place the strongest limits to date on objects in the Kuiper Belt and beyond with diameters $0.5 \text{ km} < D < 30 \text{ km}$ [4, 5, 6]. TAOS I has continued to collect data, and we now have more the three times as much data as was analyzed in [6]. This new data set will be analyzed after the new frame transfer cameras are installed.

2. TAOS II

TAOS II is a successor survey that will be more than one hundred times as powerful as TAOS I. The improvements will come from using better and larger telescopes (higher signal to noise), operating at a better site (more data), and using a camera with new CMOS imagers capable of reading out at a sampling cadence of 20 Hz (sensitivity to smaller objects).

TAOS II will comprise three telescopes manufactured by DFM Engineering. The telescopes will be 1.3 m F/4 telescopes with a 3 $\square^\circ$ field of view on a circle of diameter 154 mm. Contracts for all three telescopes have been signed, and they are scheduled to be delivered by early 2013.

The cameras need to be capable of high speed imaging on a large number of stars. TAOS II is planning on using the new monolithic CMOS devices manufactured by Sarnoff Inc. The new devices are back-illuminated, so 100% of the pixel area will be photon collecting. CMOS devices are also capable of sub-aperture readout. This will help keep the data rates to manageable levels. TAOS II will image 10,000 stars simultaneously with three telescopes at 20 Hz. Sub-aperture readout will reduce the data rate from 150 TB/night to about 3 TB/night. The new devices are thinned, and with an AR coating will have a quantum efficiency nearly as good as a CCD. Sarnoff has also reduced the read noise of the devices to 2 e^-.

TAOS II will be installed at San Pedro Mártir Observatory (SPM) in Baja California, México. The site has excellent observing conditions, with a dark sky ($R = 21$ per sq. arc sec), nominal seeing of 0.6", and more than 250 clear nights per year. We are currently in the process of applying for permission to use the site, and we expect to begin site development in the autumn of 2011. All three telescopes will be installed by early 2013, and we expect to begin the survey in mid-2013. At this time, we will cease operations of the TAOS I project.

References

[1] Nihei, T. C. et al.: Detectability of Occultations of Stars by Objects in the Kuiper Belt and Oort Cloud, Astronomical Journal, Vol. 134, pp. 1596-1612, 2007.

[2] Lehner, M. J. et al: The Taiwanese-American Occultation Survey: The Multi-Telescope Robotic Observatory, Publications of the Astronomical Society of the Pacific, Vol. 121, pp. 138-152, 2009.

[3] Lehner, M. J. et al.: The TAOS Project: Statistical Analysis of Multi-Telescope Time Series Data, Publications of the Astronomical Society of the Pacific, Vol. 122, pp. 959-975, 2010.

[4] Zhang, Z.-W. et al: First Results from the Taiwanese-American Occultation Survey (TAOS), Astrophysical Journal Letters, Vol. 685, pp. L157-L160, 2008.

[5] Wang, J.-H. et al.: Upper Limits on the Number of Small Bodies in Sedna-Like Orbits by the TAOS Project, Astronomical Journal, Vol. 138, pp. 1893-1901, 2009.

[6] Bianco, F. B. et al.: The TAOS Project: Upper Bounds on the Population of Small Kuiper Belt Objects and Tests of Models of Formation and Evolution of the Outer Solar System, Astronomical Journal, Vol. 139, pp. 1499-1514, 2010.