Asteroids: New Observations, New Models
Proceedings IAU Symposium No. 318, 2015
S.R. Chesley, R. Jedicke, A. Morbidelli & D. Farnocchia, eds.

DOI: 00.0000/X000000000000000X

Sizes, Shapes, and Satellites of Asteroids from Occultations

David W. Dunham[1], David Herald[2], Steve Preston[3], Brad Timerson[4], Paul Maley[5], Eric Frappa[6], Tsutomu Hayamizu[7], John Talbot[8], and Atila Poro[9]

[1]International Occultation Timing Association (IOTA)
3719 Kara Ct., Greenbelt, MD 20770-3016, USA
email: dunham@starpower.net

[2]IOTA, 3 Lupin Place, Murrambateman, NSW 2582, Australia
email: drherald@bigpond.net.au

[3]IOTA, 7640 NE 32nd St., Medina, WA 98039, USA
email: stevepr@netstevepr.com

[4]IOTA, 623 Bell Rd., Newark, NY 14513-8805, USA
email: btimerson@rochester.rr.com

[5]IOTA, 4535 Cedar Ridge Trail, Houston, TX 77059, USA
email: pdmaley@yahoo.com

[6]Euraster, 1B cours J. Bouchard, F-42000 St-Etienne, France
email: frappa@euraster.net

[7]Sendai Space Hall, 2133-6, Nagatoshi-Cho
Satsumasendai City, Kagoshima Prefecture, 895-0005, Japan
email: uchukan@bronze.ocn.ne.jp

[8]Royal Astronomical Society of New Zealand, Occultation Section
3 Hughes St., Waikanae Beach, NZ
email: john.talbot@xtra.co.nz

[9]IOTA/Middle East Section, Tehran, Iran
email: iotamiddleeast@yahoo.com

Abstract. For 40 years, the sizes and shapes of many dozens of asteroids have been determined from observations of asteroidal occultations, and over a thousand high-precision positions of the asteroids relative to stars have been measured. Some of the first evidence for satellites of asteroids was obtained from the early efforts; now, the orbits and sizes of some satellites discovered by other means have been refined from occultation observations. Also, several close binary stars have been discovered, and the angular diameters of some stars have been measured from analysis of these observations. The International Occultation Timing Association (IOTA) coordinates this activity worldwide, from predicting and publicizing the events, to accurately timing the occultations from as many stations as possible, and publishing and archiving the observations.

Keywords. minor planets, asteroids; occultations

1. Introduction

The first-observed occultation of a star by an asteroid, (2) Pallas, was recorded photoelectrically from Naini Tal, India, in 1961 (Herald, 2014), who also notes that an occultation by (3) Juno reported in 1958 by a visual observer under difficult conditions is too inconsistent with Hipparcos data for the star and the modern ephemeris for Juno. The next event was not observed until 1975, when (433) Eros occulted kappa Geminorum as seen by several observers in southern new England (O'Leary et al., 1976). That success spurred observers at Lowell, Lick, and the Royal Greenwich Observatories to obtain accurate astrometric observations with wide-field astrographic plates to refine the predictions, with several more successes noted by (Millis & Elliot, 1979) and (Millis & Dunham, 1989).

The release of the Hipparcos and Tycho catalogs in 1997, from ESA's Hipparcos astrometric space mission, revolutionized asteroidal occultation work, increasing the routine accuracy of the predictions and the annual number of observations by more than an order of magnitude (Dunham et al., 2002). IOTA developed an efficient procedure for predicting occultations using a combination of star catalogs, based on Hipparcos and new star catalogs generated mainly at the U. S. Naval Observatory (USNO), and new high-precision observations of asteroids relative to the improved astrometric nets mainly from USNO's Flagstaff Astrometric Scanning Transit Telescope (Stone et al., 2003) and JPL's Table Mountain Observatory.

2. New Observation Techniques

Video recording. In the late 1990's, many IOTA observers began using inexpensive low-light-level video cameras and specially built GPS video time inserters to accurately time the events. This automation has also allowed some observers to deploy multiple remote video stations across occultation paths. Then, one observer can record several "chords" across the asteroid. The cameras are sensitive enough that easily-hidden telescopes, many of which can be packed in standard air travel suitcases, can be used for many of the predicted occultations. IOTA member Scott Degenhardt substantially reduced the size of the equipment needed to record asteroidal occultations. For the brighter events, he developed the "Mighty Mini", using a 50mm lens from an inexpensive pair of binoculars, coupled with a low-light-level security camera (Supercircuits PC164C-EX2), a 0.5 focal reducing lens, and a small photographic tripod. Canon MiniDV tape camcorders are used to record uncompressed video in digital format. Several of these systems, capable of recording 9th-magnitude stars, can be packed in an air carry-on bag (Degenhardt, 2009). For fainter events, with rugged components packed in checked suitcases, short-tube refractors are used, with 80mm scopes reaching 11th magnitude and 120mm telescopes at least a magnitude fainter. John Broughton has designed a collapsible 10-inch reflector for occultations, two of which can be packed in the airline size and weight limits for a standard suitcase. Modern systems can record directly to a PC. Some current tablets, smaller than the MiniDV camcorders, hold promise to replace the increasingly difficult-to-find MiniDV-tape camcorders.

CCD Drift Scanning. Most amateur and professional observers do not have video systems capable of recording occultation, but many have CCD imagers for other purposes that can be used for occultations using exposures of a minute or two (Broughton, 2014).

3. Results

IOTA deposits all collected observations annually in NASA's Planetary Data System, where they are available to researchers worldwide (Dunham et al., 2014a), and also as high-precision astrometric observations to the Minor Planet Center. Results, including plane-of-sky plots of the better-observed events, are posted more quickly by (Timerson, 2015). The best or most interesting events are published in The Minor Planet Bulletin and in other astronomical publications. Two examples of Trojan asteroids with known or suspected satellites are given by (Buie et al., 2015) and (Timerson et al., 2013).

IOTA works with Josef Durech and other investigators to fit asteroidal occultation

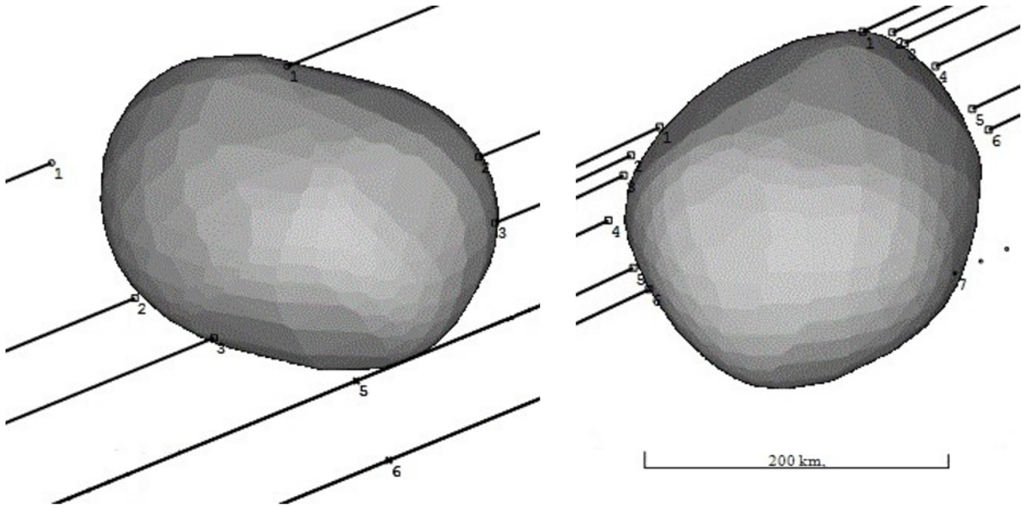

Figure 1. Plane-of-sky plot of the 2015 observations of two occultations of stars in Libra by (107) Camilla. The plot on the left is for the occultation of the 11.9-mag. star TYC 5597-0234-1 that occurred on May 6th; the observers were D. Caton (chord 1), S. Messner (2), and R. Venable (3, 5, and 6) with Venable's close miss line (5) being at the predicted center. The plot on the right is for the occultation of the 10.8-mag. star TYC 5595-00982-1 that occurred on August 23rd; the observers were S. Preston (1), A. Dobson and L. North (2), T. George (3), C. Ellington (4), C. Anderson (5), and D. Becker (6) with the predicted center shown by the dotted line (7). The scale is the same for both plots.

observations to the latest asteroid shape models derived from other observations (Durech et al., 2011) and (Viikinkoski et al., 2015). The occultation data are especially useful for determining the scale of the shape models. Fits of Database of Asteroid Models from Inversion Techniques (DAMIT, Durech et al., 2010) Model 151 to the observations of two occultations observed from the USA during 2015 are above (Fig. 1). A few hundred occultations have been observed as well as, or better than, this, from which shape models can be accurately scaled.

4. Predictions

Worldwide predictions are posted by (Preston, 2015) and in regional publications such as the Handbook of the Royal Astronomical Society of Canada (Dunham et al., 2014b). Many other resources can be found on IOTA's Web site at http://www.occultations.org .

References

Broughton, J. 2014, http://www.asteroidoccultation.com/observations/DriftScan/Index.htm

Buie, M.W., Olkin, C.B., Merline, W.J., Walsh, K.J., Levison, H.F., Timerson, B., Herald, D., Owen, W.M. Jr., Abramson, H.B., Abramson, K.J., Breit, D.C., Caton, D.B., Conard, S.J., Croom, M.A., Dunford, R.W., Dunford, J.A., Dunham, D.W., Ellington, C.K., Liu, Y., Maley, P.D., Olsen, A.M., Preston, S., Royer, R., Scheck, A.E., Sherrod, C., Sherrod, L., Swift, T.J., Taylor, L.W. III, & Venable, R. 2015, *AJ*, 149, 113

Degenhardt, S. 2009, *Small Telescopes and Astronomical Research*, (Collins Foundation Press, Kimball, MI), 103

Dunham, D.W., Goffin, E., Manek, J., Federspiel, M., Stone, R., & Owen, W. 2002, *MemSAIt*, 73, 662

Dunham, D.W., Herald, C., Frappa, E., Hayamizu, T., Talbot, J., & Timerson, B. 2014, V12.0. EAR-A-3-RDR-OCCULTATIONS-V12.0. NASA Planetary Data System https://pds.nasa.gov/ds-view/pds/viewDataset.jsp?dsid=EAR-A-3-RDR-OCCULTATIONS-V12.0

Dunham, D.W., Stamm, J., Maley, P., Preston, S., & Breit, D. 2014, *Observers Handbook 2015*, (Royal Astronomical Society of Canada, Toronto), 247

Durech, J., Sidorin, V., & Kaasalainen, M. 2010, *A&A*, 513, A46

Durech, J., Kaasalainen, M., Herald, D., Dunham, D., Timerson, B., Hanus, J., Frappa, E., Talbot, J., Hayamizu, T., Warner, B.D., Pilcher, F., & Galad, A. 2011, *Icarus*, 214, 652

Herald, D. 2014, *J. Occultation Astron.*, 1404, 9

Millis, R.L., & Dunham, D.W. 1989, *Asteroids II*, (Univ. Arizona Press, Tucson), 148

Millis, R.L., & Elliot, J.L. 1979, *Asteroids*, (Univ. Arizona Press, Tucson), 98

O'Leary, B., Marsden, B.G., Dragon, R., Hauser, E., McGrath, M., Backus, P., & Robkoff, H. 1976, *Icarus*, 28, 133

Preston, S. 2015, http://www.asteroidoccultation.com

Stone, R.C., Monet, D.G., Monet, A.K.B., Harris, F.H., Ables, H.D., Dahn, C.C., Canzian, B., Guetter, H.H., Harris, H.C., Henden, A.A., Levine, S.E., Luginbuhl, C.B., Munn, J.A., Pier, J.R., Vrba, F.J., & Walker, R.L. 2003, *AJ*, 126, 2060

Timerson, B., Brooks, J., Conard, S., Dunham, D., Herald, D., Tolea, A., & Marchis, F. 2013, *Planetary & Space Sci.*, 87, 78

Timerson, B. 2015, http://www.asteroidoccultation.com/observations/

Viikinkoski, M., Kaasalainen, M., & Durech, J. 2015, Proc. IAU Symposium No. 318, Paper S318p.06, in press