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Lessons learned from stellar occultations by Trans-Neptunian Objects and prospects for the future

J. L. Ortiz (1), B. Sicardy (2), F. Braga-Ribas (3), N. Morales (1), R. Duffard (1), P. Santos-Sanz (1), R. Vieira-Martins (3), J. I. B. Camargo (3), M. Assafin (4), F. Roques (2), T. Widemann (2), J. Lecacheux (2), F. Colas (5)
(1) Instituto de Astrofísica de Andalucía-CSIC, Granada, Spain, (2) LESIA, Observatoire de Paris, Meudon, France, (3) Observatório Nacional/MCTI, Rio de Janeiro, Brazil, (4) Observatório do Valongo/UFRJ, Rio de Janeiro, RJ, Brazil, (5) Observatoire de Paris, IMCCE, F-75014 Paris, France (ortiz@iaa.es)

Abstract

The best way to derive physical properties of solar system bodies is to send spacecraft to observe them. Probably the second best means to learn about important physical properties of solar system objects is through stellar occultations. Since October 2009, when the first stellar occultation by a Trans-Neptunian Object other than Pluto was recorded, around seventeen more occultations by Trans-Neptunian Objects have been detected, thanks to the efforts of several teams. Due to the complications of accurately predicting and observing these events, most of the successes have been achieved by an international collaboration of three main teams that coordinate different important aspects, but there have also been other successes in the field. Nevertheless, most of the successes involved large groups of researchers and even amateurs. Here we present a preliminary and brief summary of some of the results obtained thus far as well as a summary on some of the lessons learned to improve the rate of success. A key issue is involving large groups of observers once an accurate prediction has been made.

1. Introduction

Six years ago only Pluto's diameter and that of its largest moon were known accurately beyond Neptune. The rest of the diameter estimates of even the largest Transneptunian objects (TNOs) were crude (e.g. [1], [2], [3]). Spitzer helped to improve the situation [4] and since Herschel Space Observatory came into action with its "TNOs are cool" key project, the situation has improved considerably. Nevertheless we do not expect to get sizes and albedos with precisions better than 10% to 20%, because of the various uncertainties in the thermophysical models required to interpret Herschel's data. Stellar occultations can provide very accurate diameters, albedos and shapes of TNOs. In addition, occultations can provide information on atmospheric properties or constraints on them. Accurately predicting occultations by TNOs is extremely difficult because the angular diameters of the TNOs are much smaller than the typical uncertainties in astrometric stellar catalogs and also the uncertainties in TNO positions are even larger. Hence, very specific techniques have been developed to make accurate predictions and to finally observe the events. In approximately four years since the first success at recording an occultation by a TNO [5], 17 occultations by 9 TNOs have been recorded, in 14 of which we actively participated. Perhaps the most representative of the occultations by TNOs has been that by the dwarf planet Eris on nov 6th 2010 [6]. Initially, this occultation did not seem favorable because the prediction (made in the same way as in [7]) clearly indicated that the shadow path would miss the Earth. However, the intense astrometric runs that we carried out in October and November showed that Eris' shadow would finally cross the Earth on nov 6th. Fortunately three telescopes from two sites could record the occultation and therefore a diameter was obtained [6]. One of the interesting results from the investigation is that Eris' diameter is remarkably closer to, but still smaller than Pluto's, contrary to previous determinations. The geometric albedo of Eris turned out to be extremely high (0.96 ± 0.03), the highest in the solar system except for two of the saturnian moons. Other interesting results on Makemake and Quaoar have also been published [8,9].

2. Successful events

A list of all the successful events detected thus far is shown in table 1. We indicate the name of the TNO involved, the region of the Earth where observations were successful and whether the event was detected from one site (single-chord) or more sites (multichord). We must stress that 26 telescopes were involved in the campaign to record the occultation by Eris, 21 telescopes in the 2002TX300 campaign and 16 telescopes in the occultation by Makemake, which was the most successful one (with detections from 7 telescopes).

TNO	Date	Location
2002TX300	9 Oct, 2009	Hawaii, multi
Varuna	19 Feb, 2010	Brazil, single
Eris	6 Nov, 2010	Chile, multi
2003AZ84	8 Jan, 2011	Chile, single
Quaoar	11 Feb, 2011	USA, single
Makemake	23 Apr, 2011	Chile, Brazil
Quaoar	4 May, 2011	Chile, Brazil
2003AZ84	3 Feb, 2012	Israel, India
Quaoar	17 Feb, 2012	France, single
2002KX14	26 Apr, 2012	Spain, single
Quaoar	15 Oct, 2012	Chile, single
Varuna	8 Jan, 2013	Japan, multi
Sedna	13 Jan, 2013	Australia, single
Quaoar	8 Jul, 2013	Venezuela,single
2003AZ84	2 Dec, 2013	Australia, single
2003VS2	12 Dec, 2013	Reunion, single
Varuna	11 Feb, 2014	Chile, multi
2003VS2	4 Mar, 2014	Israel, single
Orcus' satellite	1 Mar, 2014	Japan, single

Table 1: List of successful occultations by TNOs

3. Some lessons learned

Most of the occultations observed thus far are single chord. These events do not allow us to derive effective diameters and shapes of the TNOs. Hence these are partial successes. One of the lessons learnt is that single-chord occultations did not involve a large enough number of observers. Successful multichord events typically involve 15 to 20 telescopes at different observing sites. Large numbers of observers are needed to cover a large enough north-south band on the Earth to make sure that uncertainties in shadow path predictions are adequately dealt with, and to guarantee that weather or technical problems at different sites do not ruin the observations. The minimum number of sites that gave rise to a 2-chord event was 8. Involving highly trained amateurs with large enough telescopes equipped with CCD cameras is usually beneficial in this regard, as more area of the Earth can be covered than using only telescopes at professional sites or at academic sites. Unfortunately, timing problems are frequent, because different observers use different methods to synchronize their instruments. Another frequent problem is the relative scarcity of fast-readout CCD cameras among the professional and amateur communities. This sometimes causes large gaps in the data acquisition sequences from different sites so that ingresses or egresses are sometimes missed.

4. Summary and Conclusions

More than eighteen occultations by TNOs have been recorded since 2009, not including Pluto system and not including Centaurs. On average only 3 to 4 occultations are observed per year after intense efforts to accurately predict occultation shadow paths, which is a key issue. Several occultations were caused by a few TNOs that move in crowed stellar fields like Quaoar, Varuna, or 2003AZ84, so we only have data on 9 different TNOs. On the other hand, most of the occultations turned out to be single-chord events, which means that neither an accurate diameter nor the shape could be determined. All the cases in which more than one chord was obtained involved at least 8 observing sites and large groups of observers in different countries. Hence, the most valuable occultation results have been achieved through intense international collaboration. This is a key issue. In the near future GAIA will provide a highly accurate astrometric stellar catalog, which will allow making better predictions than we currently do, but large uncertainties in the TNOs positions will still make shadow path predictions uncertain. Hence specific techniques will still be needed to deal with this.

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