Probing small bodies in the outer solar system with stellar occultations

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Abstract
We present a summary of results from the last decade of stellar occultation studies by members of the MIT-Williams consortium. Research goals included investigations of the atmospheres and figures of small bodies in the outer solar system, focusing on Triton, Pluto, and Charon. We concentrated on the prediction, observation, and analysis of stellar occultations by these bodies.

The method of observing stellar occultations provides higher spatial resolution than any other Earth-based observing method when examining bodies in the outer solar system. It also allows for direct measurements of atmospheric conditions, if any, as the observed starlight is refracted through the atmospheres of these planetary bodies during the occultation. This large spatial resolution (about 1 km in the atmosphere of Pluto) and direct interaction with any atmosphere allows for great sensitivity to the detailed pressure/temperature structure of a planetary atmosphere, and multiple observations over several years allow the monitoring of changes to that structure.

Prediction Methodology
Recent years have seen great improvements in the accuracy and depth of astrometric catalogs [21]. However, even with these improvements, only now is it becoming possible to rely upon catalog positions for occultation predictions. Independent confirmation of both star positions and planetary ephemerides is still necessary to insure successful observations [10; 11]. Here we detail the prediction efforts of our group and give a survey of our results when deploying based upon these predictions. We prefer a method of refining the prediction using numerous strip scans so that the star and occulting planet appear on the same strip well before the event. Our prediction efforts and results are documented on our website: http://occult.mit.edu/research/.

Charon
The surface figure of Charon has been greatly constrained by the observation of stellar occultations. Observations of the C313.2 event on 11 July 2005 by our group [8] (and others [17; 20]) resulted in our establishing the radius of Charon at 606.0 ± 1.5 km and placing upper limits on any possible asphericity of the overall structure [15].

![Charon figure solution: Occultation immersion and emersion points are plotted in the (f,g) plane. The chord designations (“Paris,” “MIT,” “SWRI”) refer to data from Sicardy et al. (2006), Gulbis et al. (2006), and Young et al. (2006) respectively. The best-fitting circular solution is plotted as a solid circle, while the best-fitting elliptical solution (oblateness is 0.006 ± 0.003) is dashed. Points from co-located stations (e.g. du Pont and Clay) appear on top of each other at this scale. The reported formal error bars are smaller than the plotted points. Note the clear deviations of the SOAR and Gemini points from the best-fit solutions. Figure adapted from Person et al. (2006).](image-url)

This newly constrained radius allows us to place greater constraints on the density and rock mass fraction of Charon, which in turn allows us to discriminate between various formation models. Our calculated rock mass fraction of 0.58 ± 0.04 indicates that the most likely scenario for the formation of the Pluto-Charon system is that of a low velocity, oblique, two-body collision with Charon coalescing from the debris disk rather than surviving the initial impact [3; 12; 9].

Our observations also place an upper-limit on any bound atmosphere of Charon. For example, we calculate a maximum surface pressure for a N₂...
atmosphere at <0.11 µbar given the constraints of our observations [8].

Atmospheres of Pluto and Triton

Pressure Changes

Early occultation observations of Triton’s atmosphere, such as those obtained from the 1993 Tr60 and 1995 Tr148 events [13], showed no measurable pressure changes during the time between them although there was a small increase in pressure compared to that measured during the Voyager encounter in 1989 [19]. Surprisingly, measurements of the Tr176 and Tr180 events in 1997 revealed a large increase in atmospheric pressure in the intervening years [7; 6]. This increase continued through the observations of the Tr231 occultation in 2001 [14]. This period of increase corresponded to a period of observed change in Triton’s overall albedo, possibly indicative of a large-scale resurfacing of portions of the body corresponding to the motion of surface ices in response to changing insolation [1; 2].

Similarly, the 2002 observations of the Pluto stellar occultations P126A and P131.1 [18; 4] showed a marked increase in Pluto’s atmospheric size over the 1988 measurements of the P8 occultation. In contrast to the continuing increase seen at Triton, the 2006 P384.2 [5] and 2007 P445.3 [16] observations indicated that this increase has ceased, with the atmospheric pressure being stable between those events.

Wave structures in atmospheres

Inversion analysis of the 1997 Tr180 light curve [7] revealed significant, although disorganized, oscillations in Triton’s upper atmosphere indicative of vertically propagating waves. Unfortunately, the limitations of this observation (resulting mostly from the speed of the occultation event) did not allow detailed analysis of the wave structures.

This is contrasted to the 2007 occultation of P445.3 by Pluto, in which the conditions were perfect for a detailed scan through Pluto’s upper atmosphere, resulting in clear signatures of vertically propagating waves [16].

Future Work

Finally, we discuss plans and methodology for our program to identify likely KBO occultation candidates, which requires observations to improve both KBO ephemerides and star positions. In particular, we would like to be able to constrain figures and atmospheres for Eris and other of the larger dwarf planets.

References

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Fig. 2 Atmospheric number density from inversion of the light curve: the dots give the number density excursions of Pluto’s atmosphere from a smooth exponential in the 1340 km to 1460 km radius range. This excursion value is the result of the inverted number density profile being divided by the best fitting exponential profile. The red line shows an empirical model of a vertically propagating wave in Pluto’s atmosphere. Figure adapted from Person et al. (2008).