Observations of a successive stellar occultation by Charon and graze by Pluto in 2011

A. A. S. Gulbis[1,2], J. P. Emery[3], M. J. Person[2], A. S. Bosh[2], C. A. Zuluaga[2], J. M. Pasachoff[4], and B. A. Babcock[4], [1]Southern African Large Telescope, P.O. Box 9, Observatory, Cape Town, 7935, South Africa; amanda@salt.ac.za, [2]Massachusetts Institute of Technology, Cambridge, MA, [3]University of Tennessee, Knoxville, TN, [4]Williams College, Williamstown, MA

Introduction: Since the late 1980s, stellar occultations have provided snapshots of the Pluto system and specifically of Pluto's atmospheric evolution. The lower atmosphere, below roughly half-light level in an occultation light curve, has changed distinctly over time (e.g. [1, 2]). Theorized explanations for the lower atmospheric structure include a steep thermal gradient and/or extinction, the latter of which can be characterized as a dependence between occultation flux and wavelength. Pluto's upper atmosphere has remained consistent. However, in 2007, a grazing occultation revealed waves in the upper atmosphere [3-5].

Data: Observations were made at NASA's 3-m Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii, for a predicted occultation of a UCAC2 14.43 magnitude star by Pluto on 23 June 2011. The stellar magnitude is 11.0, 10.1, and 9.7 in *J*, *H*, and *K*, respectively. The star was observed simultaneously with and SpeX [6] and MORIS (the MIT Optical Rapid Imaging System [7]). MORIS recorded visible images of a 1-arcmin by 1-arcmin field of view, with an effective central wavelength of 0.74 microns, at a cadence of 0.3 seconds and negligible deadtime. Low-resolution spectral IR data of the occultation star and a comparison were taken with SpeX, using the 1.6-arcsecond slit, at a cadence of 1.5 seconds including approximately 0.75 seconds of deadtime. The SpeX data cover the range of 0.9-2.5 microns over 474 wavelength channels. Data from both instruments show a full occultation of the star by Charon followed approximately 620 seconds later by an atmospheric graze by Pluto (Figure 1).

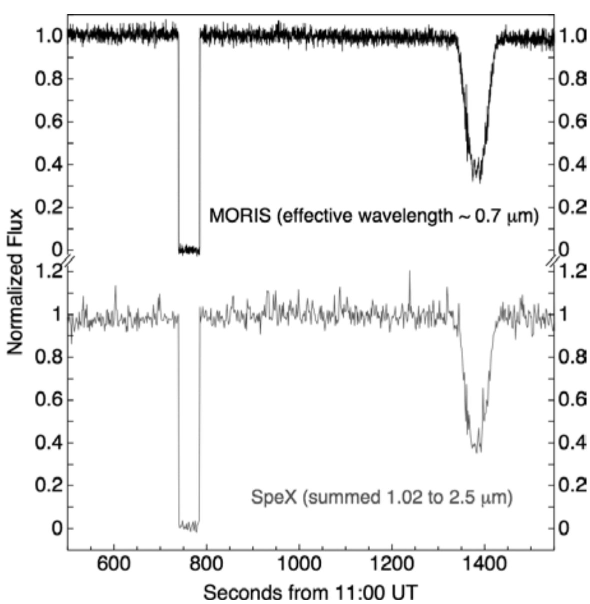

Figure 1. IRTF lightcurves of the 23 June 2011 occultation by Charon (*left*) and Pluto (*right*). The data are visible-wavelength images with MORIS and low-resolution spectra with SpeX. The signal-to-noise ratios of the lightcurves are approximately 125 (MORIS) and 80 (SpeX) per Pluto scale height of 60 km.

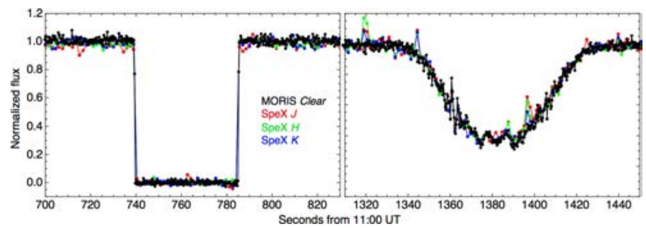

Figure 2. Expanded views of the occultation lightcurve for Charon (*left*) and Pluto (*right*). The SpeX data have been summed into standard filter bandpasses: *H* is 1.164–1.326 μm, *J* is 1.483–1.779 μm, and *K* is 2.027–2.363 μm. The SpeX data are plotted as 2% trimmed means because *H* band is noisy. This trimming drops only 1-2 data points from each filter and does not affect the general characteristics of the lightcurve. No significant variation with color is apparent, except for slight differences in the spikes of the Pluto graze.

Conclusions: Based on model fitting to the MORIS data for light diffraction by an edge, the Charon occultation lasted 45.73 ± 0.01 s, corresponding to a chord length of 1111.70 ± 0.11 km. Assuming Charon's radius is 606.0 ± 1.5 km [8], the impact parameter for the IRTF was 241.4 ± 3.7 km. No diffraction spikes were seen and there is no difference in the flux level as a function of observational wavelength over the entire range of ~ 0.7–2.5 μm (see Figure 2).

The impact parameter in Pluto's shadow was 1138 ± 3 km as determined by a fit to six lightcurves from four stations that observed the event, including SOFIA (the Stratospheric Airborne Observatory for Infrared Astronomy, [9]). From the IRTF, the graze reached a minimum normalized flux level of roughly 0.35 and probed as deep as 1255 km from Pluto's center. As shown in Figure 2, there is no obvious difference in flux over the observed wavelength range. Atmospheric model fits to a nearly central chord from SOFIA suggest that if a haze layer were present it would start at 1244 km from Pluto's center (~1103 km in the shadow) [9]; therefore, this graze did not probe deeply enough in the atmosphere to detect a trend between flux and wavelength.

There are multiple features in the Pluto graze that deviate more than 2σ from a smooth, atmospheric model fit. These bumps and spikes are due to atmospheric density variations. Unlike the graze in 2007 in which waves were detected [3-5], the 2011 data are asymmetric from immersion to emersion, excluding the bump at the very bottom (Figure 3). The flux variations are the strongest between ~ 1200–1300 km in the shadow (~ 1280–1335 km from Pluto's center). The features vary with observed wavelength: in particular, a spike was detected during emersion in the SpeX data, but not with MORIS (Figure 2).

We will present a detailed analysis of the SpeX and MORIS occultation data, taking into consideration how this dataset fits into our overall understanding of Pluto's atmospheric evolution.

References: [1] Elliot J.L. et al. (2007) *AJ, 134, 1-13*. [2] Young E.F. et al. (2008) *AJ, 136, 1757-1769*. [3] Person M.J. et al. (2008) *AJ, 136, 1510-1518*. [4] McCarthy D. et al. (2008) *AJ, 136, 1519-1522*. [5] Hubbard W. et al. (2009) *Icarus, 204, 284-289*. [6] Rayner J.T. et al. (2003) *PASP, 115, 362-382*. [7] Gulbis A.A.S. et al. (2011) *PASP, 123, 461-469*. [8] Person M.J. (2006) *AJ, 132, 1575-1580*. [9] Person M.J. et al. (2013) *AJ, submitted*.

Acknowledgements: Funding for this work was provided in part by the South African National Research Foundation and NASA grants NNX08AO50G & NNX12AJ29G (Williams), NNX10AB27G (MIT), and NNX10AB23G (UT). AASG and JPE were visiting astronomers at the IRTF, which is operated by the University of Hawaii under Cooperative Agreement no. NNX-08AE38A with the National Aeronautics and Space Administration, Science Mission Directorate, Planetary Astronomy Program.

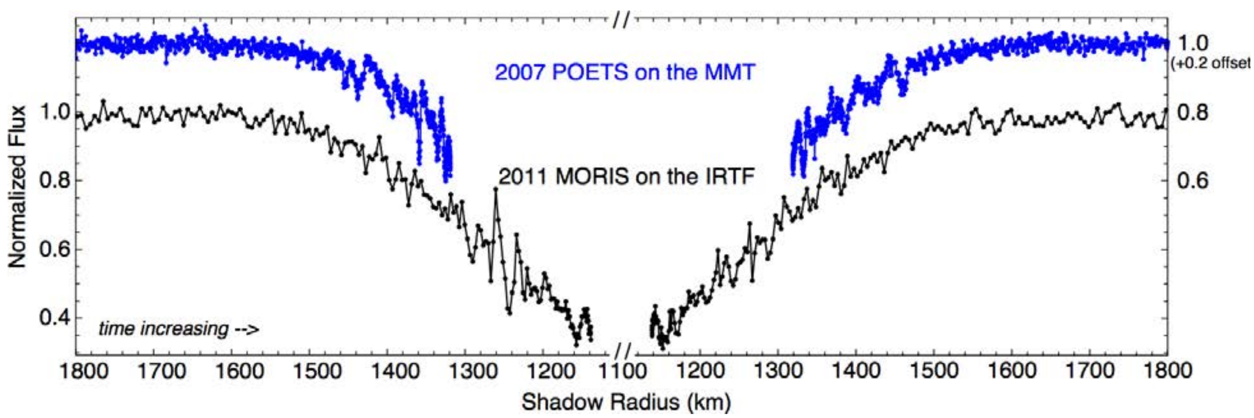

Figure 3. The 2011 Pluto occultation graze as a function of radius in the shadow, compared with an occultation graze in 2007 [3] observed on the 6.5-m MMT with a Portable Occultation Eclipse and Transit System (POETS, which is a similar instrument to MORIS). The calculated shadow radius at half-light level is comparable for these two events [9]. The 2011 graze goes significantly deeper into the atmosphere, but is at lower resolution: the occultation velocity in 2007 was 6.8 km/sec versus 24.3 km/sec in 2011. Other than the bump at the lowest flux level, the 2011 lightcurve does not display symmetric features like those determined in the 2007 data to be internal gravity waves [3-5].