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The South African Astronomical Observatory's Stellar Occultation Program

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Abstract

We present recent work done by the South African Astronomical Observatory's (SAAO) stellar occultation program. The stellar occultation results are obtained from the slightly modified, data-reducing pipeline as originally developed for the Sutherland High-speed Optical Cameras (SHOC). The SHOC pipeline laid the groundwork for two additional pipelines to be developed among which the Las Cumbres Observatory (LCO) pipeline is the most relevant for the work presented here. The prior was developed because we have access to the LCO sites via the SAAO. The inclusion of the LCO Network's telescopes allows the program to be global with access to various sites, instrumentation, and telescopes providing more opportunities for observing stellar occultations. Here, we demonstrate the capabilities of our active occultation program.

1. Introduction

Stellar occultations are capable of spatial resolutions unmatched by any other Earth-based method whilst rivalling that of space probes. Specific imaging cameras combined with Global Positioning devices and optical telescopes, ensure the fast-cadence capture of these events with microsecond timing accuracy. The prior together with the relative speed of the star and the occulting body ensures accurate results with high-resolution. Thus, the spatial resolution provided by stellar occultations allows size determination with kilometric accuracy (confining albedos, providing insight into composition and densities); the detection of atmospheres with atmospheric pressures as little as a few nanobars; and the detection of any physical features like rings, satellites, jets and comas can be achieved with this powerful technique. Since Sutherland provides us with access to telescopes and appropriate instrumentation from both the SAAO and LCO, it makes sense to have a stellar occultation program here. Sutherland, in particular, is located in a geographically unique area and provides more opportunities to observe stellar occultations.

2. Instrumentation and sites

The SAAO's stellar occultation program uses SHOC [1] on the SAAO's 74- and 40-in telescopes, as well as Lesedi (1-m); and the Finger Lakes Instrumentation (FLI) autoguider cameras mounted on the LCO's 1-m telescopes at McDonald Observatory, Fort Davis, Texas (ELP); at the SAAO, Sutherland, South Africa (CPT); at the Cerro Tololo Interamerican Observatory, Cerro Tololo, Chile (LSC); and at the Siding Spring Observatory, New South Wales, Australia (COJ). Observations done with the FLI autoguiders have staggered start times which is an uncommissioned mode for the LCO Network. This mode is only allowed because (1) the events are infrequent with minimal disruption to the network and (2) the long-standing occultation program prior to and now including the program discussed here.

3 Light curves

Datasets are run through the relevant pipelines (SHOC or LCO pipeline), where photometry is performed to produce normalized flux versus seconds from the start of the observation. Below are two examples of light curves done for occultations by Chariklo on 22 June 2017 and by 2014MU$_{69}$ on 17 July 2017. Additional event details can be found in Table 1. The Chariklo event is a good example of SHOC's high-cadence capability which was used to ensure the capture of Chariklo's narrow rings. The 2014MU$_{69}$ event is an example of observations done on the LCO's telescopes and has one of the highest SNRs. These light curves,

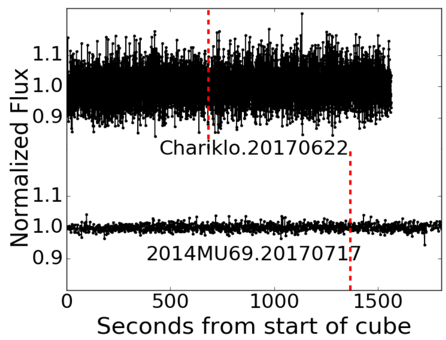

Figure 1: Normalized flux vs. seconds from the start of the observation for the Chariklo.20170622 and 2014MU$_{69}$.20170717 events. The dashed line represents the predicted midtimes of 21:19:58±00:04:28 UT for the Chariklo event, and 03:50:13 UT for the 2014MU$_{69}$ event.

therefore, demonstrate the capabilities of the instruments, telescopes and corresponding pipelines.

4. SNR Equation

Every event's SNR was calculated using the following equation and the normalized light curve:

$$\mathrm{SNR} = \left(\frac{\overline{F}_{n_b}}{\sigma_{\overline{F}_{n_b}}}\right) \times \sqrt{\frac{\left(\frac{\mathrm{d}_s}{v}\right)}{\mathrm{T}}} \tag{1}$$

where $\overline{F}_{n_b}$ and $\sigma_{\overline{F}_{n_b}}$ are the mean and standard deviation of the normalized baseline flux, respectively; d_s is the distance scale (10 km), and; v is the occultation velocity. The distance scale allows for direct comparison between different datasets. The cycle time, T, is the median time between data points and with significant deadtimes associated with the LCO autoguider cameras [2] is the reason for the staggered start times.

5. Results

We present the following characterizations of light curves from our program in Table 1.

6. Summary and Conclusions

Here we present results from the SAAO's stellar occultation program over the past few years. With our access to Sutherland and, therefore, access to all of the LCO 1-m telescopes makes this program an ideal platform to easily observe a number of events. All of these

Table 1: Selected stellar occultation list from our program.

Event	Site	Mag. (V or g)	Cadence (Hz)	Light Curve SNR
Pluto.20160719	74in	13.96	3.3	44.54
Haumea.20170121	1m	18.0	0.3	0.84
	74in	18.0	0.5	4.29
Orcus.20170307	ELP	14.3	0.17	17.16
Ixion.20170505	LSC	12.62	0.85	34.87
2014MU$_{69}$.20170603	CPT	15.33	0.47	17.86
	74in	15.33	10.0	38.76
Chariklo.20170622	74in	13.99	5.0	29.00
Varda.20170629	CPT	16.09	0.4	7.04
	74in	16.09	2.5	21.76
2014MU$_{69}$.20170717	LSC	12.602	0.62	45.76
Chariklo.20170723	CPT	13.89	0.62	19.56
Pluto.20181001	74in	17.3	0.4	48.35
	CPT	17.3	∼0.06	∼18.73
Pluto.20181101	74in	15.0	3.3	25.87
Chiron.20181128	74in	17.3	2	16.45
Orcus.20190407	40in	15.3	4	27.59

facilities offer remote observing which is convenient since stellar occultations are brief events. We can also obtain a considerable amount of time on these telescopes. Since 2016 our program's success is demonstrated by a proposal acceptance rate of 99% with 20-40 events being attempted each year. In addition, the pipeline is also modified to work with data from the Massachusetts Institute of Technology Optical Rapid Imaging System (MORIS) mounted on NASA's 3-m InfraRed Telescope Facility (IRTF).

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