Exploring the Kuiper Belt with Stellar Occultations

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Scientific category: SOLAR SYSTEM
Instruments: HIPO/BLUE, HIPO/RED, FLITECAM/CAM
Hours of observation: 50

Abstract

Inhabiting the region of the solar system beyond Neptune, Kuiper belt objects (KBOs)represent some of the oldest material known in the solar system. Hence knowledge of their fundamental properties is essential to our understanding of the origin and early evolution of the outer solar system. Stellar occultations can probe KBOs with a spatial resolution of a few kilometers, and from these data we can establish their diameters, detect or place limits on any atmospheres, and search for potential nearby companions. Because of the small zones of visibility of these events on Earth and the faintness of most occulted stars, a large, mobile telescope offers nearly two orders of magnitude more opportunities than other approaches. SOFIA observations of ten stellar occultations by KBOs (3 from each main dynamical class, plus the distant object, Sedna) with HIPO and FLITECAM are proposed.

Observing Summary:

Target	RA (hh:mm)*	Dec (•:')*	m_R	Configuration/mode	Hours
55636	00:10	+23:00	19.2	HIPO/BLUE, RED, FC/CAM	†
47171	00:37	–05:15	19.7	HIPO/BLUE, RED, FC/CAM	†
55637	01:35	+09:08	19.6	HIPO/BLUE, RED, FC/CAM	†
84522	01:43	+15:42	20.4	HIPO/BLUE, RED, FC/CAM	†
24835	01:56	+19:28	20.5	HIPO/BLUE, RED, FC/CAM	†
15874	03:07	+12:15	20.6	HIPO/BLUE, RED, FC/CAM	†
(90377) Sedna	03:16	+05:43	20.8	HIPO/BLUE, RED, FC/CAM	†
84922	03:20	+32:36	19.6	HIPO/BLUE, RED, FC/CAM	†
55638	03:33	+09:07	19.5	HIPO/BLUE, RED, FC/CAM	†
2002XV93	04:40	+33:24	20.5	HIPO/BLUE, RED, FC/CAM	†
20000	07:05	+24:57	19.6	HIPO/BLUE, RED, FC/CAM	†
2003AZ84	07:19	+13:40	20.0	HIPO/BLUE, RED, FC/CAM	†
55565	09:06	+08:01	19.7	HIPO/BLUE, RED, FC/CAM	†
90482	09:31	–04:06	18.8	HIPO/BLUE, RED, FC/CAM	†
26375	11:02	+03:08	19.9	HIPO/BLUE, RED, FC/CAM	†
2003FY128	12:18	–07:16	20.0	HIPO/BLUE, RED, FC/CAM	†
38628	14:11	–02:32	19.2	HIPO/BLUE, RED, FC/CAM	†
2002KX14	15:49	–20:19	20.3	HIPO/BLUE, RED, FC/CAM	†
28978	16:32	–21:21	19.2	HIPO/BLUE, RED, FC/CAM	†
50000	16:52	–15:25	18.7	HIPO/BLUE, RED, FC/CAM	†
2002MS4	17:45	–09:53	20.4	HIPO/BLUE, RED, FC/CAM	†
				Grand total hours	50

*These (approximate) KBO coordinates are for planning purposes, not for target acquisition.

†Ten events selected from this target list are requested(3 from each main dynamical class, plus the distant object, Sedna) , each requiring 5 hours of flight time (on average).

- ## Scientific Objectives

Located at the edge of the observable solar system, the Kuiper belt contains ~70,000 objects larger than 100 km in diameter. About 1000 of these small, icy bodies have been identified and catalogued. The inhabitants of this region (Kuiper belt objects, aka KBOs) have likely experienced little thermal modification since their formation 4.5 billion years ago, so the Kuiper belt may be considered a fossil record of the outer solar system. Observations of the Kuiper belt will further our knowledge of the evolutionary processes that shaped the outer solar system that exists today. In its youth, the Kuiper belt might have appeared from afar as a disk of debris, analogous to the those currently observed around young stars (*e.g*. Beta Pictoris), providing a link between our knowledge of processes at work in our solar system to those at work in stellar disks in the early stages of their evolution.

Combining an observational characterization of the Kuiper belt today with theoretical ideas, we can hope to understand the early state of the Kuiper belt and reveal how our sun and solar system might have appeared to a distant, outside observer—as we today observe young stars and their associated debris disks in various stages of their evolution. The most basic information about the Kuiper belt is provided by surveys, which have allowed us to divide the orbits of the KBOs into several dynamical classes ("classical," which have low eccentricities; "scattered," which have high inclinations and eccentricities; "resonant," which are objects in the 3:2 and other resonances with Neptune). "Centaurs" are ex-KBOs that Neptune has perturbed inward, rather than outward. Their orbits are unstable, but these bodies provide a more accessible sample of the smaller members of the KBO population.

Fundamental physical parameters—size, density, albedo, and surface composition—for a significant number of KBOs are badly needed to characterize the physical properties of the dynamical classes, since each of these dynamical classes likely originated in a different portion of the solar nebula (e.g. Malhotra 1995; Morbidelli, Brown, & Levison 2003). System masses can be determined for binary systems, of which 14 have been identified. At some time, each of these binaries will undergo mutual occultations and eclipses, from which their diameters can be determined (as was done for the Pluto-Charon system in the 1980's). However, the mutual event season occurs only twice per orbital period, and none are expected soon for the currently known binaries.

Other approaches to determining KBO diameters are (i) calculation from an assumed albedo, (ii) modeling, based on measured optical, IR, and sub-millimeter flux detections, and (iii) stellar occultations. Most current diameter estimates for KBOs are based on an assumed albedo, but this is not satisfactory, since the reason we want to know the diameter is for use in calculating the albedo, which provides a first-order constraint on the surface composition.

The second method for diameter determination has been applied to the handful of KBOs for which we have *Spitzer* IR fluxes (Cruikshank et al. 2005) and/or sub-millimeter fluxes (Altenhoff, Bertoldi, & Menten 2004). Although this is the best information that we currently have about KBO diameters, it is highly dependent on modeling assumptions about the emissivity and thermal inertial of the surface, as well has the (unknown) photometric phase integral. Multi-wave observations remove some of the ambiguity, but a direct measurement of the diameter would be much preferred. With the diameter fixed, the IR and sub-millimeter fluxes could then be used to infer constraints on the surface properties of the KBOs.

An ideal method for directly measuring the diameter of a KBO is with a stellar occultation observed at multiple sites. The largest bodies should be close to spherical, due to symmetry imposed by gravity. Hence two occultation chords are needed to derive an occultation diameter. With only a single chord, however, one can perform astrometric observations before and after the event to determine the distance of the single chord from the center of the body, which allows the diameter to be derived.

In addition to determining accurate diameters, stellar occultation observations can potentially yield other unique information about the KBOs: an occultation is a sensitive probe for a possible atmosphere. By "atmosphere," we include not only bound atmospheres—as exhibited by the largest KBO, Pluto—but unbound structures, such as the jets found around Chiron (Elliot et al. 1995). Occultations are particularly sensitive to concentrated material, while high-resolution imaging is more sensitive to diffuse, comatic features, which have also been found for Chiron (Meech et al. 1994; Luu 1993). This possibility for KBOs having atmospheres has been investigation by Elliot & Kern (2003), who concluded that the larger, more distant KBOs could well have thin atmospheres, akin to the thin nitrogen atmospheres of Pluto and Triton (see Fig. 1).

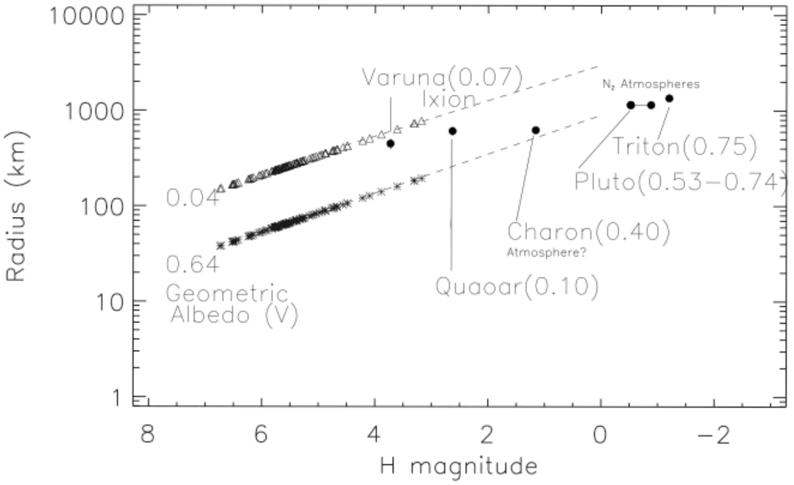

Figure 1. *H*-mag an atmospheric indicator. The *H*-magnitudes for the brightest KBOs are plotted versus radius. The solid circles are actual measurements for individual KBOs while the triangles represent the current population of bright objects if their albedos were determined to be between 0.04 and 0.64. Pluto and Triton have substantially high albedos and also have atmospheres. Charon's albedo is somewhat lower, but significantly greater than that for Quaoar, Ixion and smaller KBOs. Occultation measurements on a number of bright objects, in different dynamical classes, will allow us to determine the diameters, from which their albedos can be derived. Additionally, stellar occultation observations probe for tenuous atmospheres and possibly detect nearby binary companions (Figure from Elliot & Kern 2003)

A third objective for observing stellar occultations by KBOs is the possibility of discovering close binary companions (e.g. Reitsema et al. 1982). Fourteen binary systems are now known in the Kuiper Belt, and their orbital characteristics and rotation periods can constrain collision models, as well as models for binary formation (Weidenschilling 2002; Goldreich, Lithwick, & Sari 2002). These models predict significantly different semimajor-axis distributions for the binaries, so once the sample of binaries is large enough it can be used as a discriminator between the two theories.

To summarize, with stellar occultations we can probe KBOs with a spatial resolution of a few kilometers, and from these data we can establish their diameters, probe for an atmospheres, and search for potential nearby companions.

References

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▪ SOFIA Uniqueness/Relationship to Other Facilities

The main advantage of SOFIA over other approaches for observation of stellar occultations by KBOs is the coupling of large aperture, mobility, and "guaranteed" clear weather in a single telescope. Mobile telescopes are smaller, and clear weather along the occultation path at the time of an event lowers still further the likelihood of successful occultation observations at a given Earth-based observatory. Elliot & Kern (2003) considered the number of observable events per year for a sample of bright KBOs for three different strategies: (i) a set of portable 0.4 m telescopes, SOFIA, and a large, fixed telescope, such as Magellan. The results of their calculations are presented in Table I, below. Here we see that SOFIA offers about 40 times the number of opportunities for either of the other strategies.

TABLE 1: STRATEGIES FOR TARGETED KBO OCCULTATION OBSERVATIONS*

Telescope Strategy (aperture, m)	Limiting Stellar *R* Mag†	Events per Year per KBO, γ_R	Location Factor, f_l	Weather Factor, f_w	Combined Factor, ε	Observable Events per Year§, N_{obs}
Portable (0.4)	16.2	1	0.17	0.75	0.13	~6
SOFIA (2.5)	18.4	12	0.58	0.95	0.55	~200
Fixed (6.5)	19.3	30	0.0067	0.60	0.0040	~4

*adapted from (Elliot & Kern 2003)

†based on SNR = 10 for a 1 second integration for the source-limited case (Dunham, Elliot, & Taylor 2000 and http://sofia.arc.nasa.gov/Science/instruments/performance/HIPO/sensitivity.html).

§for a single telescope and the current sample of 29 KBOs brighter than an *H* magnitude of 5.2.

Observing Strategy

Given a list of potential stellar occultations by large KBOs that can be observed with SOFIA, we will select a target list of specific events that can be observed with SOFIA. Large telescopes (*e.g.* Magellan, Keck) will be used to refine the predictions prior to the event, in order to determine the final flight plan that would be required to observe the event.

Depending on the color of the occulted star, we would plan to use either HIPO (in one of its three optical configurations), FLITECAM, or both (in the HIPO-FLITECAM co-mount configuration) to record time-series photometry (~10 Hz), ideally beginning about 20 minutes prior to the occultation immersion and ending about 20 minutes after emersion. The durations of these occultations would range from a few tens of seconds to about a minute, depending on the size of the occulting KBO and the geometric circumstances of the event.

Special Requirements

Put any special requirements in text here (e.g. like requires FORCAST grism), or just uncomment and fill in parameters below.

Maximum water:	any (non-condensing)
A deployment required to:	TBD (depends on each event)
Minimum exposure time:	0.01 sec
Maximum exposure time:	few sec
Timing precision:	1msec

[Tom: In For each line in this section the proposer needs (i) a definition and (ii) a description of how the information will be used in setting up the instruments and observation plan.]

▪ Precursor/Supporting Observations

The proposed observations would be complementary to photometric observations of the KBOs at visible and IR wavelengths and place a strong constraint on their interpretation. Ongoing wide-field KBO surveys (e.g. Millis et al. 2002; Trujillo & Brown 2003) continue to provide KBO targets for this program.