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# EXPLORING THE KUIPER BELT WITH THE MAGELLAN TELESCOPES

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RESUMEN

Desde 2001 hemos realizado observaciones astrométricas y fotométricas de objetos del cinturón de Kuiper con los telescopios Magallanes en el Observatorio de Las Camapanas. Describimos algunos de nuestro principales resultados de clasificaciones dinámicas, descubrimiento de binarias, correlación de colores y ocultaciones estelares.

ABSTRACT

Since 2001 we have been carrying out astrometric and photometric observations of Kuiper belt objects with the Magellan telescopes at Las Campanas Observatory. Here we describe some of our main results for dynamical classifications, binary discoveries, color correlations, and stellar occultations.

*Key Words:* **KUIPER BELT — OCCULTATIONS**



Since 2001 March, shortly after the commissioning of the first Magellan telescope (Baade) at the Las Campanas Observatory, our planetary astronomy group at MIT has been carrying out several related observational programs that explore the Kuiper belt (a group of icy bodies orbiting the sun beyond Neptune). Many of our results have been enhanced by the superb image quality of the Magellan telescopes. A key observational base for our work has been a four-year program, the Deep Ecliptic Survey (DES; Millis et al. 2002; Elliot et al. 2005) that has used the Mosaic cameras on the 4m telescopes at Cerro Tololo and Kitt Peak National Observatories to search for Kuiper belt objects (KBOs). The DES has discovered over 800 KBOs, of which nearly 500 have received provisional designations from the Minor Planet Center. With the 6.5m Baade and Clay Magellan telescopes we have followed up well over 200 DES discoveries of KBOs, primarily with astrometric observations using the Raymond and Beverly Sackler Magellan Instant Camera (MagIC, which was built at MIT in collaboration with our Magellan partners at the Center for Astrophysics; Osip et al. 2004). We have established a rigorous dynamical classification scheme for KBOs, based on the behavior of orbital integrations over 10 Myr (Elliot et al. 2005). The dynamical classes are: “Resonant,” “Centaur,” “Scattered-Near,” “Scattered-Extended,” and “Classical.” With these results, Elliot et al. (2005) have determined the orientation of the Kuiper belt plane (KBP), for which the Classical objects with inclinations less than 5° from the mean orbit pole yield a pole at (J2000) RA = 273.92° ± 0.62° and Dec. = 66.70° ± 0.20°, consistent with the invariable plane of the solar system. They also find that the inclination distribution confirms the presence of “hot” and “cold” populations; when the geometrical $\sin i$ factor is removed from the inclination distribution function, the cold population shows a concentrated “core” with a full-width at half maximum of approximately 4.6°, while the hot population appears as a “halo,” extending beyond 30°. Unbiased inclination distributions for the dynamical classes appear in Figure 1.

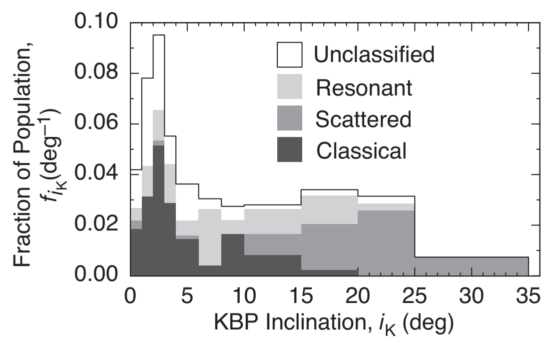


Fig. 1. The unbiased inclination distribution as a function of KBO classification. Each bin is shaded to reflect the proportion of objects by classification. The low inclination “core” is primarily composed of Classical objects while the higher-inclination “halo” is primarily Scattered objects. Along the inclination axis, the boundary between Classical and Scattered objects is not distinct.(Fig. 17; Elliot et al. 2005).

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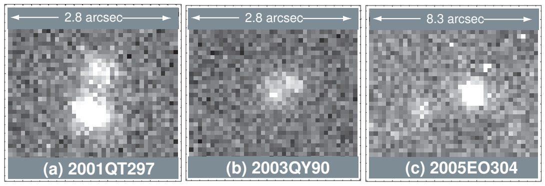


Fig. 2. Sample images taken with MagIC (plate scale of 0.069 arcsec/pixel) on the Clay 6.5m telescope at Las Campanas Observatory, with better than 0.5 arcsec seeing conditions. North is up and East is to the left. (a) 2001QT$_{297}$, collected on 2001 Oct. 10. The separation between the components is $0.606'' \pm 0.005''$ and the difference is 0.55 mag. in the Sloan $r'$ filter (Elliot 2001). (b) 2003QY$_{90}$, collected on 2004 Sept. 13. The separation is $0.38'' \pm 0.01''$ and the difference is $0.43 \pm 0.10$ mag. in the Sloan $r'$ filter (Kern & Elliot, 2006). (c) 2005EO$_{304}$, collected on 2005 April 15. The separation is $2.67'' \pm 0.06$ and the difference is $1.2 \pm 0.1$ in the VR filter (Kern 2005a). (Adapted from Kern 2005b and Kern & Elliot, 2006).

Although aimed at establishing accurate orbits for the newly discovered KBOs so they can be dynamically classified, our Magellan recovery observations have also resulted in the discovery of three KBO binaries (e.g Osip, Kern & Elliot 2003; Kern 2005b; Kern & Elliot 2006). Images of these discoveries are shown in Figure 2. The system mass for a KBO binary can be determined from the binary orbit, and the binaries open the possibility of measuring accurate diameters for the members when the Earth passes through the orbital plane of the binary system (leading to mutual occultations and eclipses). An extensive analysis of Magellan data for the orbits and light curves of KBO binary systems has been carried out by Kern (2005b).

In another KBO program, we are measuring object colors as a function of orbital-pole alignment, with respect to the pole of the mean orbital plane of the Kuiper belt as determined by the DES (Elliot et al. 2005). Using photometric data from MagIC, Gulbis, Elliot & Kane (2006) found that virtually all non-resonant bodies in the Kuiper belt core population are red ($B - R > 1.56$), while those in the halo are slightly more likely to be neutral. The combination of low inclination and red color suggests that the core population may be a relic group of objects.

Finally, we are using stellar occultation observations as a high-resolution probe of outer solar-system bodies. In 2005 July, we observed a stellar occultation with the Clay telescope at Magellan and other telescopes in Chile using our new high-speed frame-transfer cameras. Our results, presented by Gulbis et al. (2006), yield a mean radius

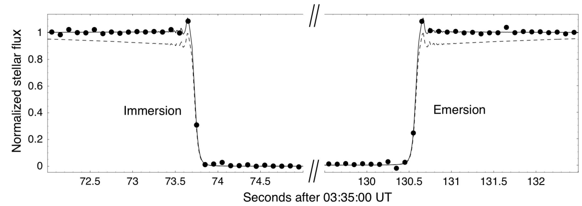


Fig. 3. Atmospheric model fits for the 2005 July 11 stellar occultation by Charon. The segments of the Clay light curve shown here have been expanded such that individual data points are resolved, and the first Fresnel diffraction fringe is clearly visible during immersion and emersion. A diffraction model with a tenuous atmosphere (solid line), from which our 3-$\sigma$ upper limit is derived, is displayed. A second model is also shown (dashed line), which represents a 50-km scale height and a 10% flux drop at the surface ($b = 0.10$). This model merges with the data baseline beyond the limits of the plot. The differential bending in the dashed-line model has been enhanced significantly with respect to our upper limit ($b = 0.015$). (Fig 3; Gulbis et al. 2006)

of $606 \pm 8$ km for Charon, which implies a bulk density of $1.72 \pm 0.15$g cm$^{-3}$ and a rock-mass fraction $0.63 \pm 0.05$. Gulbis et al. (2006) also set a $3\sigma$ upper limit of $2.3 \times 10^{-13}$cm$^{-3}$ on the surface number density of an $N_2$ atmosphere. A lightcurve from the occultation, along with atmospheric model fits, is shown in Figure 3. In the future, we are extending our stellar occultation program to include measuring the radii of KBOs and probing for atmospheres around these bodies (Elliot & Kern 2003).

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