doi: 10.1038/nature05619

Supplemental Discussion

Infrared spectroscopy

We obtained near infrared reflectance spectra of 26 bright KBOs with NIRC, the near-infrared imaging spectrograph on the W.M. Keck Telescope using standard observational and data reduction methods[19]. The spectra cover from 1.4 to 2.4 μm with a spectral resolution $\lambda/\Delta\lambda$~160 (see Supplemental Figure 1). The region between 1.81 and 1.89 μm has residual contamination by telluric H_2O lines, thus this region is masked out in the spectra. The KBO spectra were normalized to a relative reflectance of 1.0 by dividing each spectra by its median reflectance from 1.7 μm to 1.8 μm. This region is relatively flat in the NIR spectrum of water ice which is seen on some KBOs, thus KBOs with strong water ice features are scaled similarly to those with no water ice. Water ice has broad absorption features at 1.5 μm and 2.0 μm microns. To describe the absorption due to water ice in our spectra, we defined a quantity, A_w, as the fractional absorption at 2 μm. Specifically, we measured the fractional difference in the median reflectance between 1.7 μm to 1.8 μm and 2.0 μm to 2.1 μm. Error bars given for these measurements represent the 1σ uncertainties derived from the dispersions of the reflectance in the wavelength ranges. In addition to the spectra we obtained, we have made estimates of Aw for 1993 SC,1996 TO66, 1996 TL66, 1997 CS29, 2002 VE95, and Orcus, which have published spectra [4,20-24].

Colours

The V band through I band reflectance of KBOs can be well described by a single spectral gradient, G, that can be calculated from V,R, and I band photometric measurements[8]. We obtained visible colour measurements for 30 of the 32 total KBO spectra from published sources[3,8,25,26] and calculated the colour gradient and its uncertainty. The errors given for these measurements are 1σ uncertainties derived by propagating the uncertainties of the individual measurements. Five objects had no I-band measurements and one object had no R-band measurement. The spectral gradient was calculated for these objects using only the two available measurements. We find that the average difference in the gradient calculated using two versus three reflectance measurements is small, and therefore expect that the error introduced by using only a single colour measurement to be small compared to the errors in the colour measurements.

Orbital dynamics

Orbits of objects in the Kuiper belt precess and oscillate over time due to interactions with the giant planets. The instantaneous ("osculating") orbital elements are only a snapshot in time of these oscillating orbital elements. For objects with small eccentricities and inclinations the time-averaged orbital elements can be easily determined analytically, but for the higher inclination and eccentricity objects considered here we must resort to numerical techniques. Using the SWIFT orbital integration package[27], we integrate the orbits of each of the KBOs for a period of 50 Myr including only the gravitational influence of the sun and the four giant planets. We then take the average semimajor axis, eccentricity, and inclination over 50 Myr to be the proper elements. Five of the six KBOs have well behaved orbits which simply oscillate. 2003 EL61, in contrast, is found to be trapped within the 12:7 mean motion resonance with Neptune and thus exhibits large excursions in eccentricity even over the 50 Myr time period (see Supplemental Figure 2).

To examine whether 2003 EL61 could have originally been a member of the very tight central clump we randomly chose 32 objects with proper orbital elements within the semimajor axis range of 43.3 ±0.3 AU, the eccentricity range 0.12±0.025 and the inclination range 27.3±0.5 degrees and integrated their orbits forward 1.5 Gyr. Most objects exhibited stable behaviour like that of the majority of the known fragments. Five of the randomly selected objects, however, became trapped within the nearby 12:7 mean motion resonance (as 2003 EL61 currently is) and suffered an upward diffusion in eccentricity. Results of the orbital integrations are shown in Supplemental Figure 2.

Supplemental Figure