The Mass of Dwarf Planet Eris

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The discovery of Kuiper belt object (KBO) 2003 UB313 (*1*), now officially named Eris, prompted the recent reevaluation of Pluto's status as a planet and the creation of a new category called "dwarf planets": objects in orbit around the Sun that are large enough to be in hydrostatic equilibrium but have insufficient mass to gravitationally dominate their region of the solar system. Eris is larger than Pluto (*2*, *3*) and thus the largest currently known member of dwarf planets.

The subsequent discovery of Dysnomia (*4*), a satellite of Eris, presented the opportunity to directly measure the mass of Eris by determining the Keplerian orbit of the satellite. Observations of Eris and Dysnomia were obtained on 20, 21, 30, and 31 August 2006 (UT) with the Keck Observatory laser guide star adaptive optics (LGS AO) system (*5*, *6*). Observations from the Hubble Space Telescope (HST) were taken on 3 December 2005 and 30 August 2006. From measurements of the relative positions of Dysnomia on these six nights (Fig. 1 and table S1) plus the position from the discovery on 10 September 2005, we determined the orbit of Dysnomia by using a Powell χ^2 minimization scheme to find the optimal orbital parameters. We first attempted to fit a purely circular orbit in which the five free parameters are semimajor axis, orbital period, inclination, longitude of the ascending node, and mean anomaly. The best fit orbit has a χ^2 value of 6.5 or a reduced χ for nine degrees of freedom (14 x, y coordinates minus 5 orbital parameters) of 0.7, indicating an excellent fit to the model. Expanding the model to allow an eccentric orbit gives a best-fit eccentricity of ~0.007 and only a marginally lower reduced χ^2 of 0.6, suggesting that the current observations contain no statistical evidence for a noncircular orbit. Derived orbital elements along with uncertainties from Monte Carlo analysis appear in table S2.

From the 30 August 2006 HST image at a wavelength of 0.6 μm, we measured a relative brightness ratio between the two objects of only 0.21 ± 0.01 (1-σ) %. The small relative brightness of Dysnomia is inconsistent with the dynamical-friction-aided capture mechanism proposed for the majority of KBO satellites (*7*), but detailed simulations show that such small satellites can be formed from the debris after a giant impact (*8*). A collisionally produced satellite of the size of Dysnomia that tidally evolved outward from an initial location near the Roche limit would be predicted to have a roughly 15-day circular orbit [Supporting Online Material (SOM) text], consistent with the derived orbit of Dysnomia. Owing to the low mass of Dysnomia, this outward orbital expansion would have slowed the spin period of Eris by only a part in $\sim 10^{-5}$.

Whereas the other two KBO systems that appear to be products of giant impacts, Pluto and 2003 EL61, contain multiple satellites, satellites almost an order of magnitude fainter than Dysnomia can be ruled out beyond the orbit of Dysnomia from deep HST observations (SOM text). For a purely tidally evolved system, any satellite beyond the orbit of Dysnomia must be larger than Dysnomia, and thus such a system can be ruled out. Interior to ~0.4 arc sec, however, the expected fractional brightness of a tidally evolved satellite is ~0.0007, which is beyond our detection ability (SOM text). Any additional purely tidally evolved satellites of Eris would be expected to be closer and fainter than these limits. Although such additional small faint satellites cannot be ruled out, the current limits and the apparently circular orbit of Dysnomia suggest that Eris might indeed be a single-satellite system.

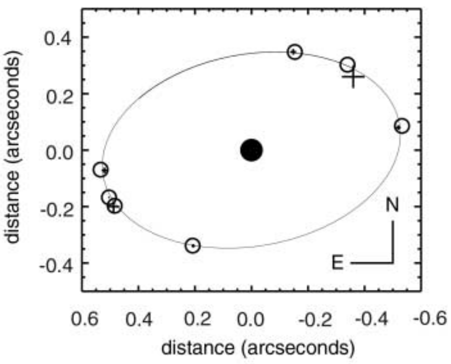

Fig. 1. The projected orbit of Dysnomia around Eris. Observations are show as crosses of the size of the 1-σ uncertainty. The predicted positions at the time of observations are shown by open circles. The solid circle in the center is 10 times the actual angular size of Eris.

From the period and semimajor axis of the orbit of Dysnomia, we can use Kepler's laws to calculate a mass for the Eris-Dysnomia system of $1.66 \times 10^{22} \pm 0.02 \times 10^{22}$ kg or 1.27 ± 0.02 of the mass of Pluto. With any plausible assumptions of albedo and density, Dysnomia's mass in the system is negligible. In addition to being the largest, Eris is also the most massive known dwarf planet.

From this mass measurement and the previous size measurements, we can calculate the density of Eris. The initial indirect IRAM radiometric measurement suggested a diameter of 3000 ± 400 km (*2*), whereas the later HST direct measurement found a smaller diameter of 2400 ± 100 km (*3*). By using the more direct measurement with the smaller uncertainty, we obtain a density of 2.3 ± 0.3 g cm^{-3}. This density is consistent with the moderately high 2.03 ± 0.06, 2.06 ± 0.01, and ~ 2.6 g cm^{-3} densities known for Pluto, Triton, and the large KBO 2003 EL61, respectively (*9*–*11*). Using the earlier indirect IRAM diameter measurement would give a density of only 1.2 ± 0.6 g cm^{-3}, which is significantly lower than other objects of comparable size in the outer solar system, giving confidence, although not confirmation, in the more direct HST diameter measurement with the smaller uncertainty.

Recent direct and indirect measurements of the densities of smaller KBOs (*12*, *13*) suggested lower-than-expected densities for objects in the outer solar system and thus a deficit of rocky material or a surplus of pore space. The similarly high densities of Eris, Pluto, Triton, and 2003 EL61, in contrast, all require rock fractions of ~70% or higher (*14*), as anticipated from expected cosmochemical abundances in the protosolar neighborhood.

References and Notes

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Supporting Online Material

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Materials and Methods
SOM Text
Tables S1 and S1

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