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DISCOVERY OF A PLANETARY-SIZED OBJECT IN THE SCATTERED KUIPER BELT

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ABSTRACT

We present the discovery and initial physical and dynamical characterization of the object 2003 UB313. The object is sufficiently bright that for all reasonable values of the albedo it is certain to be larger than Pluto. Prediscovery observations back to 1989 are used to obtain an orbit with extremely small errors. The object is currently at aphelion in what appears to be a typical orbit for a scattered Kuiper Belt object, except that it is inclined by about 44° from the ecliptic. The presence of such a large object at this extreme inclination suggests that high-inclination Kuiper Belt objects formed preferentially closer to the Sun. Observations from Gemini Observatory show that the infrared spectrum is, like that of Pluto and 2005 FY9, dominated by the presence of frozen methane, although visible photometry shows that the object is almost neutral in color compared to Pluto's extremely red color. 2003 UB313 is likely to undergo substantial seasonal change over the large range of heliocentric distances that it travels; at its current distance, Pluto is likely to prove a useful analog for better understanding the range of seasonal changes on this body.

Subject headings: comets: general — infrared: solar system — minor planets, asteroids

Online material: color figure

1. INTRODUCTION

Since the discovery of the first small objects beyond Neptune (Jewitt & Luu 1993), astronomers have speculated about the existence of objects larger than Pluto in the Kuiper Belt. Extrapolation of the size distribution of smaller Kuiper Belt objects (KBOs) has sometimes been used to attempt to estimate the numbers of such larger objects (i.e., Bernstein et al. 2004), but such estimates have proven inconclusive. One of the goals of our ongoing survey for bright KBOs (Trujillo & Brown 2003) is to find rare objects at the bright end of the Kuiper Belt magnitude distribution. Such bright objects are invaluable as targets for detailed physical study (Marchi et al. 2003; Jewitt & Luu 2004; de Bergh et al. 2005; Trujillo et al. 2005), in addition to being potential beacons of previously unknown populations (Brown et al. 2004; Kenyon & Bromley 2004; Morbidelli & Levison 2004).

The newly discovered KBO 2003 UB313 is currently the fourth brightest object known in the Kuiper Belt (after Pluto, 2003 FY9, and 2003 EL61) and is currently the most distant object ever seen in orbit around the Sun. As an object notable for its brightness, distance, and size, 2003 UB313 is certain to be an object of intensive study. We present here details on its discovery, preliminary observations about its surface characteristics, and some suggestions about physical processes operating on this object.

2. DISCOVERY

2003 UB313 was discovered in data from 2003 October 21 obtained from our ongoing survey at the 48 inch (1.2 m) Samuel Oschin Telescope at Palomar Observatory. At the time of discovery, the object was moving 1″.42 hr^{-1}, slower than the cutoff in our main survey (Trujillo & Brown 2003). Our survey obtains three images over a 3 hr period. With typical image quality of from 2″ to 3″, slower motions are clearly detectable, but we installed a 1″.5 hr^{-1} lower limit to our analysis to cut down the copious false positives at the slow end. The discovery of Sedna (Brown et al. 2004), with a motion of 1″.75 hr^{-1}, however, suggested a need to efficiently search for distant objects that would be moving at lower rates.

We have now reanalyzed all survey data with a second ("slow") detection scheme in addition to the standard ("fast") scheme. This slow scheme searches for motions between 1″ and 2″ hr^{-1} between the first and third image of a triplet. When a potential object is found, it checks for consistency using the second image, but motion need not be detected between either the first and second or second and third images. Finally, to remove the large number of false positives generated by stationary stars, all potential detections that are within 2″ of a cataloged USNO star are removed without examination. The slow scheme generates 10 to 20 times more false positives than the fast scheme, leading to approximately 1200 candidates every month. These candidates are examined by eye and are generally quickly rejected. On occasion we also make use of the Skymorph database[4] to determine that a potentially moving candidate is, in fact, a stationary star. In the 2 years' worth of slow data examined to date, we have found only two real objects: Sedna (previously also found in the fast scheme) and 2003 UB313.

The extreme brightness and slow motion of 2003 UB313 made it easy to identify it as a transient in archival data. The object was identified in multiple images from the Skymorph database and was eventually found in a 1989 plate from the UK Schmidt Telescope at Siding Springs Observatory. From this 16 yr orbital arc, the derived barycentric orbit using the method of Bernstein & Khushalani (2000) gives a semimajor axis, eccentricity, and inclination of $a = 67.89 \pm 0.01$, $e = 0.4378 \pm 0.0001$, and $i = 43.993 \pm 0.001$, respectively. 2003 UB313 is currently near aphelion at 97.50 ± 0.01 AU from the Sun and will not reach perihelion at 38.2 AU until the year 2257.

Based on the semimajor axis and eccentricity, 2003 UB313

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[4] See http://skys.gsfc.nasa.gov/skymorph/skymorph.html.

TABLE 1
PHOTOMETRY OF 2003 UB313

Filter	Magnitude	Relative Reflectance
B ……	19.54 ± 0.01	0.88
V ……	18.83 ± 0.02	0.92
R ……	18.38 ± 0.02	1.00
I …….	18.05 ± 0.02	1.00
J …….	17.82 ± 0.02	0.86
H ……	18.11 ± 0.03	0.51
K ……	18.51 ± 0.05	0.32

would be classified as a typical member of the scattered Kuiper Belt (Morbidelli & Brown 2005). The inclination of 44° is extreme for the scattered belt, however. Only one other object (2004 DG77) has a confirmed orbit with an inclination as high. While initial models of the scattered Kuiper Belt (Duncan & Levison 1997) were incapable of populating high-inclination regions, recent work (Gomes et al. 2005) suggests that a combination of gravitational scattering, mean-motion resonant interaction, planetary migration, and the Kozai mechanism may be able to place objects into orbits such as these. Additional simulations show that objects that are initially in the inner part of the premigration disk (at distances of ∼20 AU) are scattered into orbits with higher inclinations than those further out (Gomes 2003). We expect that on average, these inner regions will lead to the formation of larger objects, owing to both higher nebular densities and shorter accretion timescales. We might therefore expect to find other large objects at high inclination in the scattered Kuiper Belt. Indeed, the other two recently announced scattered KBOs from our survey, 2005 FY9 and 2003 EL61, which are the second and third brightest known Kuiper Belt objects after Pluto, both have inclinations near 30° and approach the size of Pluto.

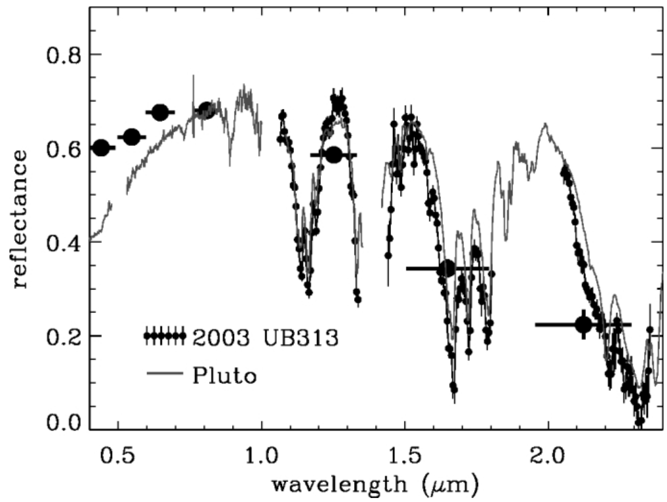

FIG. 1.—Relative reflectance of 2003 UB313 (*filled circles with error bars*) and absolute reflectance of Pluto (*gray line*). The large points show the reflectance derived from *BVRIJHK* photometry. Every reliably identifiable feature in the 1–2.5 μm region of the spectrum of 2003 UB313 is due to absorption by solid methane. The absolute geometric albedo of 2003 UB313 is not yet known. The relative reflectance is scaled to match that of Pluto in the *I* band for comparison. The Pluto spectrum is a compilation from Trafton & Stern (1996), Grundy & Fink (1996), Rudy et al. (2003), and Douté et al. (1999). [*See the electronic edition of the Journal for a color version of this figure*.]

3. SPECTRUM

Visible photometry of 2003 UB313 was obtained on 2005 January 5, 6, and 7 using the 1.3 m SMARTS Telescope. Data were obtained and reduced in an identical manner to that described in Rabinowitz et al. (2005). Infrared photometry was obtained on January 25 and 26 from the Gemini North Observatory. No evidence for any photometric variation was seen over the short timescale of observation. Table 1 gives photometric and relative reflectance values from the visible to the near-infrared. No attempt is made to correct for solar phase effects, which are of the order of 0.01 mag at Pluto for a 0°.5 phase (Tholen & Buie 1997). The relative brightness of 2003 UB313 is highest in the *R* and *I* filters. We find an absolute magnitude of $H_r = -1.48 \pm 0.02$, which corresponds to a diameter of $(2250 \pm 20)\rho_r^{-1/2}$ km, where ρ_r is the *R* albedo. Even if the surface albedo is an unreasonably high 100% at these wavelengths, the object has a diameter approximately that of Pluto.

Medium-resolution near-infrared spectra were obtained on the nights of January 25–27 UT with the Near-Infrared Imager (NIRI; Hodapp et al. 2003) instrument on the Gemini North Telescope. The *J*, *H*, and *K* bands were measured using three separate grating settings and on-source times of 1, 1, and 2 hr, respectively. The air mass ranged between 1.4 and 2.0 on the spectra. Details of the data-reduction techniques are given in Trujillo et al. (2005). Relative reflectance was computed by dividing the spectra by the spectrum of the G2 V star HD 20339, taken at a single air mass of 1.6. Each spectrum was pair-subtracted to remove detector bias, then flattened and rectified. Bad pixels and cosmic rays were masked out in each spectrum prior to extraction. Extracted spectra were rebinned to a common wavelength scale with a Nyquist-sampled resolution of 0.01 μm and with regions affected by bright OH lines masked out. Error bars were computed from the reproducibility of spectral data in each wavelength bin. Although 2003 UB313 is relatively bright, the signal-to-noise ratio (S/N) of the spectrum is only moderate, owing to the fact that at the time of discovery, the object was quickly setting in the evening sky. The single air mass calibration to observations taken over a wider air mass range suggests that telluric artifacts could be present in the final spectrum. Figure 1 shows the relative reflectance of 2003 UB313, with the individual *J*, *H*, and *K* spectra scaled to match the near-infrared photometry and the relative near-infrared colors of Pluto. Because of telluric uncertainties in spectral slope across the near-infrared, we do not regard the relative scaling between the three separate spectra to be reliable. The near-infrared spectrum is dominated by absorption from CH_4 and closely resembles that of Pluto. At the current S/N and systematic reproducibility level, no reliable detection is made of any other species on 2003 UB313, including, notably, the 2.15 μm line of N_2, the 1.58 μm line of CO, both detected on Pluto (Owen et al. 1993), and the 2.01 and 2.07 μm lines of CO_2 detected on Triton (Cruikshank et al. 1993). With the current spectra, these features could not be detected reliably on 2003 UB313 at the levels they are seen on Pluto and Triton. In many cases there are potential detections of these lines, but most are in spectral regions contaminated by bright sky lines or variable sky absorptions, and none should be believed without additional observation and confirmation.

One major difference between the spectrum of 2003 UB313 and that of Pluto is that the visible region of 2003 UB313 is considerably less red than that of Pluto. If red visible colors on icy bodies are interpreted as due to irradiated complex organics, the difference between Pluto and 2003 UB313 is surprising, given the similarity of the methane spectra of the two bodies. A more subtle difference between the spectra is a slight shift of the positions of the methane absorption lines (Table 2). On Pluto methane exists both as a pure form and as a minor component dissolved as a solid solution inside of N_2 ice. The isolation of the methane molecules leads to a slight but measurable energy shift in the spectrum (Quirico & Schmitt 1997). On Pluto the methane spectral line positions vary slightly with location on the planet but are generally approximately midway between the positions expected for pure and diluted methane (Douté et al. 1999). The four best measured methane lines on 2003 UB313 are, in contrast, shifted an average of only 1.5 ± 0.5 nm from the line positions measured in the laboratory for pure methane, but 3.5 ± 0.5 nm from the positions measured for methane incorporated into N_2. While a small amount of dissolved methane may be present, the line positions suggest that the majority of methane is in essentially pure form.

TABLE 2
POSITIONS OF METHANE LINES AT 30 K

Line Identification	2003 UB31[a] (μm)	Pure Methane[b] (μm)	Methane in Nitrogen[b] (μm)
$\nu_2 + 2\nu_3 + \nu_4$	1.138	1.139	1.135
$2\nu_3 + \nu_4$	1.164	1.165	1.161
$2\nu_3$	1.669	1.670	1.664
$\nu_2 + \nu_3 + \nu_4$	1.722	1.725	1.719

[a] Wavelength uncertainties are approximately ± 0.001 μm.
[b] Laboratory data from Quirico & Schmitt (1997).

4. DISCUSSION

2003 UB313 is the largest known object in orbit beyond Neptune, and like the second largest object, Pluto, its spectrum is dominated by absorption due to methane. The newly discovered near-Pluto–sized KBO 2005 FY9 has also been found to have a surface dominated by methane absorption (M. E. Brown et al. 2005, in preparation). Methane ices subjected to ion and UV radiation irreversibly break down and reassemble into more complex hydrocarbons (Moore et al. 2003), leading eventually to the formation of dark red tholins (Khare et al. 1984). The continued presence of abundant methane on 2003 UB313 suggests the need, as has been suggested for Pluto (Spencer et al. 1997), for an interior source to replenish the methane. The presence of methane on 2003 UB313, as well as Pluto and 2005 FY9, suggests that this process is ubiquitous in the outer solar system. The lack of observed methane on smaller objects suggests either that methane is not retained on smaller objects where escape rates are higher (Trafton et al. 1997) or that the methane source is only present in the larger objects.

The red colors and large spatial albedo variations of Pluto have been suggested to be due to distinct regions covered by these dark red tholins. At Pluto's current heliocentric distance, dark regions absorb enough sunlight to become too warm for methane condensation, while the bright regions serve as methane cold traps, thus reinforcing any albedo contrast in existence (Brown 2002). At the 97 AU distance of 2003 UB313, however, even dark regions will be sufficiently cold that as methane freezes out of the atmosphere or is replenished from the subsurface it will cover the entire body, lowering albedo contrasts and hiding the red tholins. This suggestion leads to the prediction that 2003 UB313 will have significantly less albedo variation than Pluto, and that its albedo will be as high or higher than Pluto.

The lower temperature of 2003 UB313 may also explain the difference in the state of the methane. Expected subsolar surface temperatures of a 70% albedo body at 97 AU are ∼30 K. At this temperature the vapor pressure over pure N_2 ice is 420 nbar, while the vapor pressure over pure methane ice is below a pbar (Spencer et al. 1997). Unlike Pluto's present state, methane on 2003 UB313 is currently essentially involatile and will not be mixed in the atmosphere with nitrogen. As 2003 UB313 moved towards aphelion over the past two centuries, nitrogen and methane may have segregated, perhaps vertically. As 2003 UB313 moves back toward perihelion, a more Pluto-like mixing may occur.

The discovery of 2003 UB313 provides a new lower temperature laboratory for the study of many of the processes discussed for Pluto, including atmospheric freeze-out and escape, ice chemistry, nitrogen phase transitions, and volatile mixing and transport. The temperature variation from perihelion of aphelion of 2003 UB313 is even more extreme than that on Pluto. Higher quality infrared spectra, which should be readily obtainable for this moderately bright object, will be a key component of future studies.

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