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NEAR-INFRARED SPECTRUM OF LOW-INCLINATION CLASSICAL KUIPER BELT OBJECT (79360) 1997 CS_{29}

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ABSTRACT

The "cold classical" Kuiper Belt is the only part of the Kuiper Belt where objects show color statistics distinct from the rest of the trans-Neptunian population. Cold classical orbits are also likely to have been among the least dynamically perturbed since the time of accretion. As such, cold classical objects are especially interesting targets for compositional investigation by means of near-infrared spectroscopy. In this paper we report the first published infrared spectrum of a likely member of this unique class of objects. A 1.4–2.5 μm spectrum of the cold classical candidate object (79360) 1997 CS_{29} obtained at Keck I is spectrally featureless.

Key words: infrared: solar system — Kuiper Belt

1. INTRODUCTION

Our current understanding of the Kuiper Belt is analogous to early stages in the development of our understanding of the asteroid belt. There, different classes of asteroids were first recognized based on color and thermal infrared observations and were found to be correlated with orbital position. Near-infrared spectroscopy provided compositional constraints on the different classes, leading to our current picture of a compositionally zoned asteroid belt, with more volatile-rich and organic-rich asteroids at greater heliocentric distances. This picture provides a powerful constraint on our understanding of the formation and evolution of the inner solar system. The Kuiper Belt holds the promise of similar insights into the evolution of the outer solar system, once we have a better understanding of the compositions of Kuiper Belt objects (KBOs).

Much of the current trans-Neptunian population is thought to have been propelled outward by the early migration of Neptune (e.g., Malhotra 1995; Duncan & Levison 1997; Hahn & Malhotra 1999; Ida et al. 2000; Chiang & Jordan 2002; Chiang 2003). The dynamical churning that left the present Kuiper Belt in its wake appears to have shuffled together objects deriving from different compositional reservoirs, frustrating the study of compositional gradients in the protoplanetary nebula by observations of specific dynamical classes of KBOs. Different dynamical classes of KBOs show similar distributions of photometric colors, with all but one subpopulation including objects spanning the gamut from neutral ($B-V=0.6$) to extremely red ($B-V=1.2$) (e.g., Boehnhardt et al. 2003; Tegler & Romanishin 2003).

However, one class of KBOs may have escaped this churning. Classical belt KBOs occupy near-circular, nonresonant orbits concentrated between 40 and 48 AU. Evidence is emerging that the classical belt consists of two overlapping subpopulations (Elliot et al. 2005), a dynamically "hot," high-inclination population with the usual wide range of colors and a dynamically "cold" population with low inclinations, consisting predominantly of red objects (Trujillo & Brown 2002; Tegler & Romanishin 2000, 2003). These "cold classical" KBOs (CCKBOs) are the only dynamical KBO class with distinct colors, and so on both dynamical and compositional grounds they are the most likely subpopulation to preserve some memory of their primordial locations in their present-day orbits, although even these bodies may have been influenced by Neptune's migration (e.g., Morbidelli & Levison 2003; Morbidelli 2004; Gomes et al. 2004).

Infrared spectroscopy currently offers the best compositional probe of KBO surfaces. However, it is only feasible from the largest telescopes, and even there, only for the brightest KBOs. Brown (2003) and Boehnhardt et al. (2003) report the existence of a variety of distinct KBO spectral classes but no apparent correlation between infrared spectral features and dynamical or color classes. Unfortunately, even the brightest CCKBOs are relatively faint, making them especially poorly represented in spectral surveys, despite being the class most likely to exhibit distinctive compositions. Accordingly, we undertook to obtain near-infrared spectra of CCKBOs.

The first CCKBO candidate we selected was (79360) 1997 CS_{29}. The overlap between hot and cold subpopulations creates uncertainty about which subpopulation a low-inclination classical object belongs to. This uncertainty is compounded by the fact that inclinations of classical KBOs change over time, especially inclinations relative to the ecliptic plane, which are the most frequently cited. Inclinations relative to the invariable plane of the solar system are more consistent (Elliot et al. 2005), so we exclusively use inclinations relative to that plane in this paper. The inclination of (79360) 1997 CS_{29} relative to the invariable plane ranged from $3.^\circ2$ to $4.^\circ4$ over a 10^7 yr orbital integration, with a mean value of $3.^\circ8$. Based on fits to the distributions of hot and cold classical KBO inclinations by Elliot et al. (2005), an object with this inclination has a 70% or 85% probability of belonging to the cold subpopulation for the Elliot et al. (2005) double-Gaussian or Gaussian+Lorentzian fit, respectively.

Many photometric observations of (79360) 1997 CS_{29} have been reported (e.g., Barucci et al. 2000; Davies et al. 2000; Boehnhardt et al. 2001; Jewitt & Luu 2001; Stephens et al. 2003). From reported V, R, and I colors, we computed a spectral slope of 19% per 100 nm relative to V, as described by Boehnhardt et al. (2002). This reddish spectral slope is typical of CCKBOs, as well as the redder members of other KBO classes. Infrared photometry by Boehnhardt et al. (2001) yields an $H-K$ color of 0.28 ± 0.23, redder than solar, but the uncertainty is so large that a solar $H-K$ color is not excluded.

An additional noteworthy feature of (79360) 1997 CS_{29} is that it is almost certainly a close binary pair rather than a single

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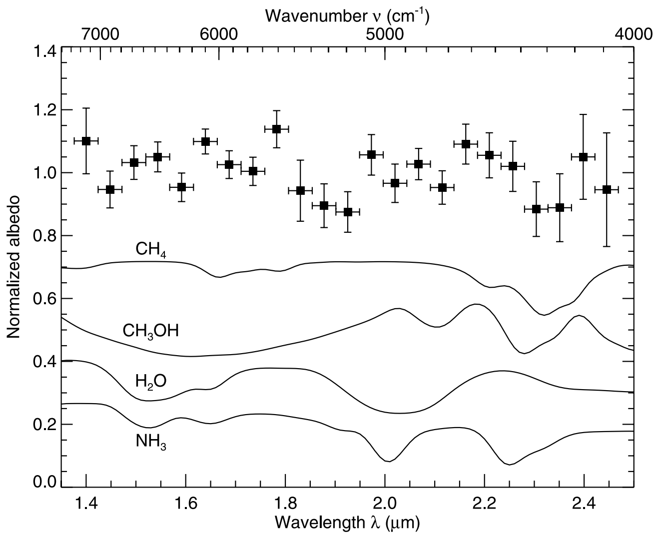

FIG. 1.—Normalized albedo spectrum of the CCKBO (79360) 1997 CS_{29} obtained with NIRC at Keck I, compared with absorption spectra of four ices, convolved to the same spectral resolution and offset downward for clarity. Statistically significant absorption bands are not apparent in the CCKBO spectrum. The four ice spectra are simple Hapke (1993) models based on spectral data from Grundy et al. (2002), Cruikshank et al. (1998), Grundy & Schmitt (1998), and Sill et al. (1980) for CH_4, CH_3OH, H_2O, and NH_3, respectively.

object (Stephens et al. 2004). As a result, we can expect to eventually know its mass, and from that we will be able to estimate its size and albedo.

2. OBSERVATIONS AND DATA REDUCTION

The observations of (79360) 1997 CS_{29} reported in this paper were obtained at the Keck I telescope on Mauna Kea during 2005 January 24 between 07:50 and 10:58 UT. We used the Near Infrared Camera (NIRC) spectrometer's Gr120 grism and 3.5 pixel slit to cover the wavelength range from 1.4 to 2.4 μm at a spectral resolution $\lambda/\Delta\lambda$ of about 100 (where λ is wavelength and $\Delta\lambda$ is the FWHM of an unresolved spectral line). Weather conditions above Mauna Kea were initially good, being clear and dry, with excellent transparency and about 0.″7 seeing, but after about 11:00 UT the seeing deteriorated drastically, and we were not able to obtain useful data on the KBO after that time. Geometric circumstances during our observations were that (79360) 1997 CS_{29} was 42.57 AU from the Earth and 43.55 AU from the Sun, and the Sun-object-Earth phase angle was 0.°01.

We recorded 41 usable integrations of the KBO, each 150 s in duration, dithering among five different positions along the slit. Optimal extraction (Horne 1986) was done on pairwise-subtracted images with Gaussian spatial profiles (smoothly varying in wavelength) being fitted to the much brighter star spectral images and then used to extract the star spectra, as well as the much fainter KBO spectra, the traces of which could barely be discerned in subtracted image pairs.

Observations of the KBO were interspersed every 2 hr with observations of the nearby G-type star PPM 125127 (BD +19° 1977). The spectrum of this star was compared with spectra of faint solar analogs SA97-249, SA101-321, and SA103-487 (B. A. Skiff 1998, private communication) and the C-type asteroid (128) Nemesis and was found to be indistinguishable from all four. Since PPM 125127 is apparently an excellent solar analog in our wavelength and spectral resolution range, we present spectra of (79360) 1997 CS_{29} divided by spectra of that star obtained at similar air masses to remove telluric and instrumental effects. These ratio spectra are proportional to albedo spectra, but the constant of proportionality is unknown because we know neither the magnitude of slit losses nor the size of the KBO.

To increase signal precision, we binned the data eight columns at a time, resulting in a final spectral resolution of about 40 with a signal-to-noise ratio ranging from 10 to 20. The final spectrum is shown in Figure 1.

3. DISCUSSION

The spectrum in Figure 1 is best described as spectrally neutral. The suggestion of an absorption band between 1.80 and 1.95 μm is probably spurious, as water vapor in the terrestrial atmosphere absorbs most strongly in that interval, and perfect cancellation of its absorption is unlikely. No strong evidence is seen for absorption by cosmochemically abundant ices such as H_2O or CH_4. Although the dip around 2.33 μm may well arise from absorption by an organic ice, it would be premature to base an identification on data of such low signal precision.

It is possible to put quantitative limits on the abundances of various ices, but only in the context of specific models for how the ices are distributed. Furthermore, since the albedo of (79360) 1997 CS_{29} is not known, derived abundances are extremely sensitive to what albedo and model configuration is assumed (e.g., Grundy & Stansberry 2003). For example, if the near-infrared albedo is assumed to be 10% (consistent with a 4% *V* albedo), as much as about 50% CH_4 ice intimately mixed with dark, opaque particles is consistent with the spectral data. But if the dark absorber is spatially segregated from the CH_4 ice, no more than about 6% CH_4 ice can be admitted. For an equally plausible 15% visible albedo (e.g., Stansberry et al. 2004; Grundy et al. 2005), the near-infrared albedo would be about 36%, comparable to that of Charon, and the maximum possible CH_4 ice percentage for an intimate mixture scenario would rise to about 85%. Clearly, these are not usefully constraining abundance limits. To do better will require knowledge of the albedo, as well as spectra of higher signal precision.

The new spectrum of (79360) 1997 CS_{29} is compared with two other representative spectra of small, distant bodies in Figure 2. The spectrum of Centaur (5145) Pholus (Luu et al. 1994)

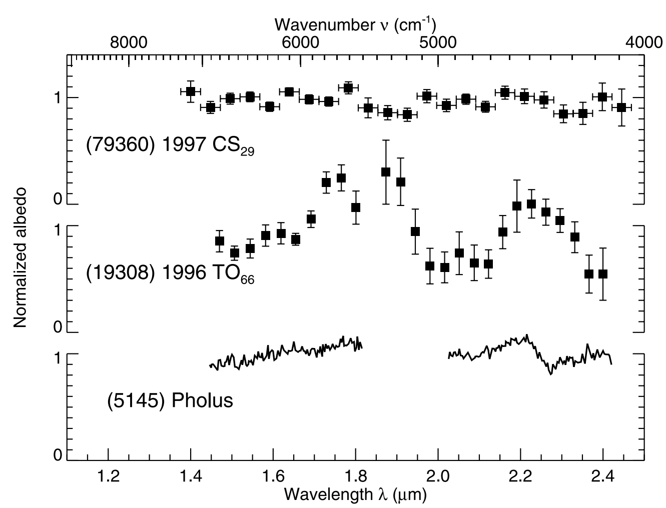

FIG. 2.—Comparison between the spectrum of (79360) 1997 CS_{29} (this work) and spectra of trans-Neptunian object (19308) 1996 TO_{66} (Brown et al. 1999) and Centaur (5145) Pholus (Luu et al. 1994), both of which show prominent absorption features not seen in the spectrum of (79360) 1997 CS_{29}. All three spectra are normalized at the *H* band, with separate vertical axes.

shows a reddish slope in the *H* band (1.5–1.8 μm) attributable to the presence of organic tholin residues, as well as a weak H_2O ice absorption band around 2.0–2.1 μm and a stronger absorption band at 2.3 μm indicating the presence of an organic material such as methanol ice (Cruikshank et al. 1998). A very different infrared spectrum is presented by the trans-Neptunian object (19308) 1996 TO_{66} (Brown et al. 1999), which shows prominent H_2O ice absorption bands around 1.5–1.6 μm, around 2.0–2.1 μm, and beyond 2.3 μm. If (79360) 1997 CS_{29} has spectral features, they must be much more subtle than the features seen in the spectra of (5145) Pholus and (19308) 1996 TO_{66}.

Spectra lacking absorption features at these wavelengths have been reported for KBOs of other dynamical classes (e.g., Jewitt & Luu 2001; Boehnhardt et al. 2003; Brown 2003), so the neutral spectrum of (79360) 1997 CS_{29} is not particularly surprising. But in view of the unique dynamical and visual color characteristics of CCKBOs, more spectra of CCKBO candidates are needed to determine if this important but spectroscopically undersampled subpopulation shares a distinct set of infrared spectral characteristics along with its distinct coloration statistics. The overlapping nature of cold and hot classical subpopulations requires comparison of ensemble spectral properties in order to overcome uncertain classifications of individual objects, but unfortunately no other spectra of probable CCKBOs have been published to date.

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