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Composition of hydrated near-Earth object (100085) 1992 UY4

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Abstract

Near-infrared spectra of the near-Earth object (100085) 1992 UY4 are similar to those of P-type asteroids, providing a fitted geometric albedo of 0.052 ± 0.005 and an effective diameter of 1.68 ± 0.08 km. This object, with a likely outer-belt origin, also exhibits a 3-μm absorption feature with a band depth of 3% ± 1%, corresponding to a regolithic bulk hydrogen-to-silicon ratio of 0.30 ± 0.05. The bulk of this hydrogen seems to be present in H_2O-dominated minerals.

Keywords: Asteroids; Asteroids, composition; Spectroscopy; Asteroids, surfaces

1. Introduction

The Apollo-class near-Earth object (100085) 1992 UY4 was discovered on 25 October 1992 by C.S. Shoemaker at Palomar. It has a 0.26-magnitude lightcurve amplitude in V-band with a synodic period of 12.906 h and an absolute magnitude of 17.7 (Warner et al., 2005). In August 2005, near-infrared spectra were taken of the asteroid at the NASA Infrared Telescope Facility, for the purpose of determining composition and albedo. Included in this spectroscopic study was the search for an absorption feature at 3 μm.

The significance of the 3-μm absorption feature is that it is an indicator of regolith hydration and thermal history. Hydroxyl radicals and the first overtone of the 6-μm absorption due to water are found here (Lebofsky, 1978). On NEOs, OH or H_2O would be found in hydrated minerals rather than ice, which would be unstable at their small heliocentric distances. In the case of (100085) 1992 UY4, the maximum subsolar temperature is approximately 400 K.

While just knowing that an asteroid is hydrated is useful, it would be much more informative to be able to determine the extent of the hydration. In this paper, we will express the quantity of any hydration in the form of the bulk hydrogen-to-silicon weight ratio. Through the work of Miyamoto and Zolensky (1994) and Sato et al. (1997), the ratio of the reflectance at 2.9 and 2.5 μm ($R = R_{2.9}/R_{2.5}$) of carbonaceous chondrite powders was linked to their hydrogen-to-silicon weight ratios (H/Si). From this, Rivkin et al. (2003) derived the empirical relationship:

$$\mathrm{H/Si} = 7.38 - 7.29R. \tag{1}$$

Rivkin et al. (2003) went on to link H/Si to the fractional weight of water in a regolith by assuming a bulk SiO_2 concentration of 30%.

Prior to (100085) 1992 UY4, no NEOs had been found with the 3-μm absorption feature. Five other NEOs have been searched for the 3-μm hydration feature: (433) Eros (Rivkin and Clark, 2001), (4179) Toutatis (Howell et al., 1994a), (1036) Ganymed (Rivkin, 1999, unpublished data), (6611) 1993 VW (Volquardsen, 2005, unpublished data), and 2002 CE26 (Shepard et al., 2006). Binzel et al. (2004) observed the visible spectra of 18 C-complex NEOs, with only one showing an absorption feature at 0.7 μm, an indicator of iron-bearing phyllosilicates (Vilas and Sykes, 1996).

In this paper, we summarize the findings regarding the composition of (100085) 1992 UY4. The observations, data reduction, and thermal modeling are also described.

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2. Observations

(100085) 1992 UY4 was observed using the 3-m NASA Infrared Telescope Facility on Mauna Kea from 4 August 2005 (UT) to 6 August 2005 (UT). During this time interval, the phase angle of the asteroid increased from 21° to 34°. The heliocentric distance was 1.05 AU and the geocentric distance was 0.04 AU.

The Spex low-to-medium resolution spectrograph and imager (Rayner et al., 2003) was used in Prism and Long Cross-Dispersed (LXD) modes, producing spectra from 0.8 to 4.2 µm. The Prism mode resulted in a spectrum of wavelength range 0.8–2.5 µm at a spectral resolution ($\lambda/\Delta\lambda$) of 100, while the LXD mode resulted in a spectrum covering the wavelength range 2.2–4.2 µm at a spectral resolution of 960. The $0.8'' \times 15''$ slit was used for both modes. The telescope was nodded so as to move the light from the target between two positions along the slit, creating A–B beam pairs. Prism mode spectra were taken on the first night between 11:30 and 13:00 UT, and on the last night between 9:00 and 10:00 UT, and again between 15:00 and 15:40 UT. At those times, 4 A–B pairs (cycles) were obtained with a total exposure time of 16 min. LXD spectra were taken all three nights, with 20-s integrations that resulted in approximately 2 h of on-source time, six times over the three nights.

HD 213199, HD 217429, and HD 7983 were used as solar analog stars, with exposures of HD 7983 taken only on the last night. For the prism mode spectra, 4 cycles with 3-s exposure times were taken seven times over the two nights. For the LXD mode spectra, 4 cycles with 20-s exposure times were taken approximately every two hours.

3. Data reduction and thermal modeling

The LXD spectra (2.2–4.2 µm) were reduced with the IDL-based Spextool program (Cushing et al., 2004). First, the difference of each A–B pair was taken to remove noise due to sky emission. The resulting images were then registered, flat fielded, and 1-D spectra were extracted. Wavelength calibration was performed by matching arc lines to a model of arc lines vs wavelength in Spextool. Prism mode spectra (0.8–2.5 µm) were similarly reduced with IRAF routines, as described in Rivkin et al. (2004).

Telluric features were removed from extracted spectra of both the asteroid and solar analog using IDL routines that performed the following steps. An ATRAN model atmospheric transmission profile (Lord, 1992) was generated for the zenith distance of the object, altitude of the telescope, spectral resolution, and a range of precipitable water vapor amounts. Each spectrum was shifted with respect to the transmission profile by a range of values corresponding to less than one pixel. The subpixel shift and atmospheric water amount that best removed telluric features was selected. All asteroid spectra were divided by each solar analog spectrum. These resulting spectra were checked for aberrant values by fitting polynomials to sections of the spectra and flagging points where the fitted and measured values deviated widely. Resulting spectra were median combined into a single spectrum for each night, with flagged points not included.

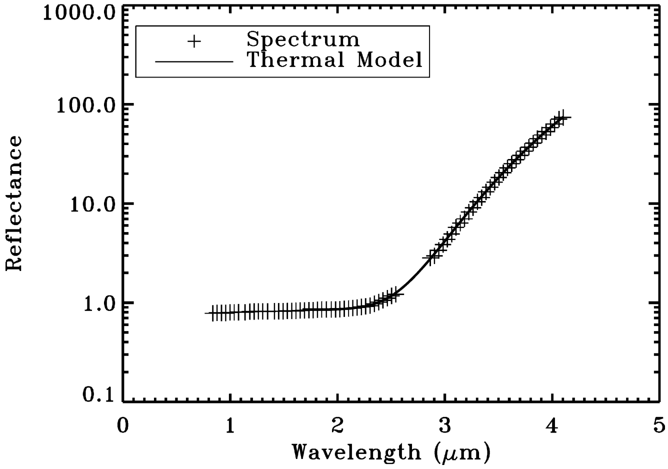

Fig. 1. The spectrum from 0.8 to 4.2 µm and corresponding thermal model are plotted. Uncertainties fall within the plotting symbols.

The near-Earth asteroid thermal model, or NEATM (Harris, 1998), was used to create a thermal model of the asteroid for each night. Thermal models with varying albedos and beaming parameters were created. The model with the lowest residual, as compared to that nights spectrum, was used. The beaming parameter modifies the thermal model to account for the surface roughness and thermal inertia of an NEO. The error in albedo was determined by taking the standard deviation of all the obtained albedos. All spectra were then combined and rebinned to 0.02-µm increments, trading resolution for better S/N.

4. Results

Thermal modeling of our spectra results in a best-fit geometric albedo of 0.052 ± 0.005. Fig. 1 shows a spectrum (0.8–4.2 µm), along with the corresponding thermal model. Since the slope parameter (G) was unknown, we initially used the average for low albedo asteroids (0.09), as determined by Lagerkvist and Magnusson (1990). When we compared the shape of the prism mode spectrum to those of asteroids of various spectral types, it most closely resembled spectra of P-type asteroids. For this reason, we recalculated and applied the thermal model, using the average slope parameter for P-type asteroids (0.08). It should be noted that this does not make substantial changes in the resulting spectrum, as using the standard default slope parameter of 0.15 produces best-fit albedos that fall within the uncertainties we cite above.

The best-fit value of the beaming parameter (η) and phase angle (α) for all combinations of asteroid and standard star spectra were calculated. Beaming parameters were calculated and the corresponding phase angles ranged from 21° to 34°. The following relationship was obtained:

$$\eta = 0.87 + 0.01\alpha \pm 0.01. \quad (2)$$

This is consistent with the relationship between η and α found by Delbo et al. (2003). Using the equation relating geometric albedo (pV) and absolute magnitude (H) to effective di-

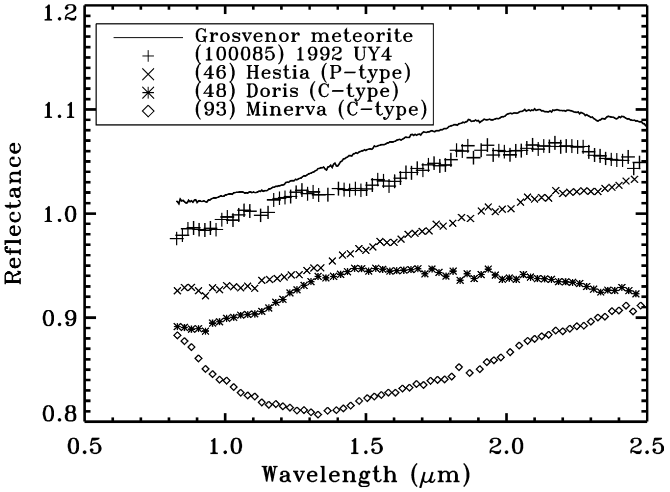

Fig. 2. The thermally corrected spectrum of (100085) 1992 UY4 from 0.8 to 2.5 μm is plotted with spectra representing the two different forms of C-type asteroids (48 Doris and 93 Minerva) and a P-type asteroid (46 Hestia). Uncertainties fall within the plotting symbols. Spectra of (46) Hestia, (48) Doris, and (93) Minerva were taken with Spex as part of the small main-belt asteroid spectroscopic survey in the near-infrared (SMASSIR). The CM2 meteorite spectrum is from the NASA RELAB sample MP-TXH-017 of Grosvenor mountain. The spectrum of the meteorite was scaled (multiplied by 5) to enable feature comparison. Spectra were offset for clarity.

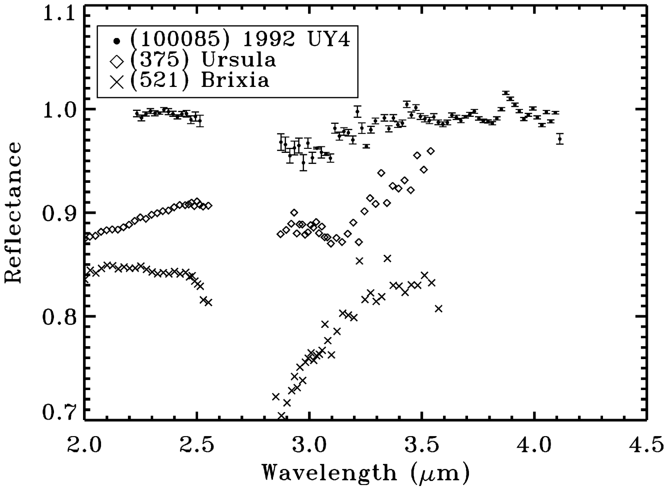

Fig. 3. Thermally corrected spectrum of (100085) 1992 UY4 from 2.2 to 4.2 μm with H_2O-dominant spectrum of (375) Ursula and the OH-dominant spectrum of (521) Brixia are plotted. Spectra of (521) Brixia and (375) Ursula (Rivkin et al., 2003) have been scaled (divided) by a factor of 2 to enable feature comparison and have been offset for clarity.

ameter (D_{eff}) (Harris, 1998) yields an effective diameter of 1.68 ± 0.08 km.

Fig. 2 shows the thermally corrected prism mode spectrum (0.8–2.5 μm). For comparison, two C-type spectra and a P-type spectrum are plotted. The C-type near-infrared spectra show two distinct forms as first described by Howell et al. (1994b). (48) Doris shows a concave downward form and (93) Minerva shows a convex downward form. (46) Hestia shows a typical P-type (Tholen, 1984) form with a relatively featureless red slope. The spectrum of (100085) 1992 UY4 seems to most closely match the spectrum of (46) Hestia. This is supported by the results of doing a chi-squared goodness-of-fit between the spectrum of (100085) 1992 UY4 and the other asteroids, after removing the average spectral slopes.

The spectrum of CM2 meteorite Grosvenor Mountains, scaled (multiplied by 5) to compare spectral shape features, is also shown. While we cannot conclude that (100085) 1992 UY4 is the parent body of any known meteorite, the similarities suggest that it can be modeled by carbonaceous chondrite powders. As such, we can use Eq. (1) to determine the H/Si ratio. Additionally, there are no significant indications of silicate features, such as olivine or pyroxene.

Fig. 3 shows the 3-μm absorption feature with a band depth of $3\% \pm 1\%$. It is the result of median combining all the thermally corrected LXD spectra (2.2–4.2 μm). The 3-μm absorption feature has been found to exhibit two different shapes (Rivkin et al., 2002). One has a checkmark shape, monotonically rising from the absorption minimum shortward of 2.9 μm, as exemplified by (521) Brixia. The other has a more rounded shape, with the absorption minimum longward of 3.05 μm, as exemplified by (375) Ursula. OH-dominated minerals produce the checkmark-shaped absorption while H_2O-dominated minerals produce the round-shaped absorption. The spectrum of (100085) 1992 UY4 appears closer in shape to the H_2O-dominant form of (375) Ursula. We performed a chi-squared goodness-of-fit test between the spectral values of (100085) 1992 UY4 and the two comparison spectra. The chi-squared value when comparing (100085) 1992 UY4 and (375) Ursula was a much better fit than that obtained when comparing (100085) 1992 UY4 and (521) Brixia (0.036 versus 0.676).

The ratio of 2.9 and 2.5-μm reflectances is 0.970 ± 0.006, yielding a H/Si ratio of 0.30 ± 0.05. Rivkin et al. (2003) reported that the H/Si ratio ranged from 0.0 to 0.2 for samples of CO/CV meteorites, 2.2 to 2.6 for CM meteorites, and 4.8 to 5.2 for CI meteorites. While the H/Si ratio for (100085) 1992 UY4 is closest to that of CO/CV meteorites, its spectrum does not resemble any known meteorite spectra. This is consistent with (100085) 1992 UY4 being a P-type asteroid, as no meteorite analogs have yet been found for P-type asteroids. The spectrum shows no significant indications of an absorption band near 3.4 μm, which might be expected if aliphatic hydrocarbons are abundant on the surface.

5. Implications for the parent body of 100085 (1992 UY4)

There are several details about (100085) 1992 UY4 that point to an outer-belt origin for its parent body. The spectral similarity between (100085) 1992 UY4 and P-type asteroids, common to the outer-belt, suggests an outer-belt origin. Such an origin is possible, as Bottke et al. (in preparation) determined that the outer-belt is a source region for NEOs. Furthermore, the semi-major axis and aphelion distance of (100085) 1992 UY4 are large for an NEO (2.64 and 4.29 AU, respectively).

Since (100085) 1992 UY4 appears to be only slightly hydrated, the question then turns to possible dehydration of its regolith. We would argue that such dehydration, while possible, is not likely. Possible sources of dehydration could be due to temperatures reached while in the asteroids current orbit, space weathering, or the effects of large impacts. The results of Hiroi et al. (1996) indicate that significant reduction in the depth of the 3-μm absorption band does not occur until carbonaceous chondrite powders are heated above 500 °C. Since the maximum subsolar temperature reached by (100085) 1992 UY4 would be approximately 130 °C, regolith dehydration probably did not occur as a result of temperatures reached in asteroid's current orbit.

Space weathering is another suggested source of regolith dehydration. Space weathering primarily takes the form of micrometeorite impacts and solar wind bombardment (Clark et al., 2002). While it has been found to decrease albedos, redden spectral slopes, and suppress olivine and pyroxene band depths in high silicate asteroids (Clark et al., 2002), dehydration caused by space weathering on main-belt asteroids is currently an open question (Moroz et al., 2004). If solar wind bombardment were a substantial vehicle of regolith dehydration, then we should see hydration increase with increasing semi-major axis, due to greater flux near the Sun. However, this is not the case (Jones et al., 1990).

We would expect dehydration of asteroid regoliths to selectively favor larger asteroids, as they should have more mature surfaces. Such an effect is found in the 1-μm absorption bands of S-type asteroids. The depth decreases with increasing diameter (Clark et al., 2002). Smaller asteroids would also have smaller cross-sections and would experience fewer impacts (micrometeorites and larger objects) at a given distance from the Sun. So, the measured hydration level is consistent with formation on an outer-belt parent body, and does not require additional thermal processing to explain the 3-μm band depth. And significant dehydration, while possible, seems less likely.

6. Conclusions

The spectral shape and albedo (0.052 ± 0.005) of (100085) 1992 UY4 are similar to those of P-type asteroids. Silicate and hydrocarbon features are absent. The depth of the 3-μm absorption band is consistent with a regolith that contains H_2O-dominated minerals, with a H/Si ratio of 0.30. Such a low H/Si ratio, combined with spectral similarities to outer-belt asteroids and a large (compared to most NEOs) semi-major axis and aphelion distance, suggest an outer-belt origin.

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