

Mineralogical characterization of near-Earth Asteroid (1036) Ganymed

Sherry K. Fieber-Beyer^{a,*,1}, Michael J. Gaffey^{a,1}, Paul A. Abell^{b,1}

^a Department of Space Studies, University Stop 9008, University of North Dakota, Grand Forks, ND 58202, United States

^b NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058, United States

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ABSTRACT

We present a mineralogical assessment of near-Earth Asteroid, (1036) Ganymed, using data obtained May 18, 2006 UT combined with 24 Color Asteroid Survey data to cover the spectral interval of 0.3–2.45 μm . Results of the analysis indicate (1036) Ganymed is an S (VI) asteroid with a surface silicate assemblage consisting primarily of orthopyroxene, ($\text{Fs}_{23(\pm 5)}\text{Wo}_{3(\pm 3)}$), consistent with calculated band centers and band area ratios (BAR). (1036) Ganymed appears to be once part of a large mesosiderite containing howardite, eucrite, and diogenite (HED) pyroxenes mixed with metal that was broken apart and dispersed. The calculated composition of the average pyroxenes in the surface material of (1036) Ganymed is consistent with mesosiderite pyroxenes, in particular the diogenites. A second possibility could be (1036) Ganymed is not yet represented in the meteorite collection. Our investigation has confirmed Ganymed is not a parent body of the ordinary chondrites and is not genetically related to (433) Eros.

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1. Introduction

Asteroid (1036) Ganymed is the largest Amor asteroid in the Near Earth Object (NEO) population with a measured Supplemental IRAS Minor Planet Survey (SIMPS) diameter of 31.66 ± 2.8 km, as compared to 433 Eros with an IRAS diameter of 20 km, and has an IRAS albedo of 0.2926 ± 0.059 (Tedesco et al., 2002). (1036) Ganymed has a rotational period of 10.31 ± 0.002 h (Hahn et al., 1989), and is a member of the S taxonomic class (Tholen, 1989; Bus and Binzel, 2002a,b). The study of (1036) Ganymed is of particular interest because of its proximity to Earth ($a = 2.66$ AU, $q = 1.23$ AU), its future – albeit distant – potential as an impact hazard to our planet, its accessibility for space missions, as well as a potential candidate as a meteorite source body (McFadden et al., 1985).

Previous investigators have observed (1036) Ganymed, but have not been able to provide a robust characterization of the asteroid's surface composition or meteorite affinities either due to limited wavelength (0.30–0.90 μm) coverage (McFadden et al., 1984; Clark et al., 1995) or due to inconsistent spectral data (Gaffey et al., 1993). Fig. 1 is a compilation of all previously published visible and near-infrared spectra obtained for Asteroid (1036) Ganymed. The goal of the present work is to provide a sound

mineralogical characterization and resolve ambiguities from past work.

Asteroids (1036) Ganymed and (433) Eros have been suggested as former members of the Maria asteroid family that were expelled into near-Earth space via the 3:1 Kirkwood Gap (Zappala et al., 1997). Subsequently, the NEAR mission provided *in situ* studies of Eros revealing its physical, chemical, and mineralogical make-up. Mineralogically, Eros was found to have a homogeneous mineralogical make-up and was classified as an S (IV) (e.g. Izenberg et al., 2003). Using the spectrum presented in this paper and the NEAR data, we explore the postulated genetic relationship between Ganymed and Eros.

2. Observations/data reduction

Observations of (1036) Ganymed were obtained on the night of May 18, 2006 UT at the NASA Infrared Telescope Facility located on Mauna Kea, Hawai'i. The asteroid parameters and observational instrumentation from the observing run are listed in Table 1. The spectra were obtained using SpeX in the low-resolution spectrographic mode. A total of sixty spectra were obtained of Ganymed, of these, 44 were used in the analysis. Spectra were taken in sets of 10. The first spectrum of each set was discarded due to image persistence on the detector chip (a residual signal from the previous spectrum that contaminates the new spectrum), a single spectrum was discarded because it was incomplete, and the last set of ten spectra was discarded due to poor quality because of deteriorating weather conditions.

Asteroid and local standard star observations were interspersed within the same air mass range to give optimal modeling of atmo-

* Corresponding author.

E-mail address: sherryfiebb@hotmail.com (S.K. Fieber-Beyer).

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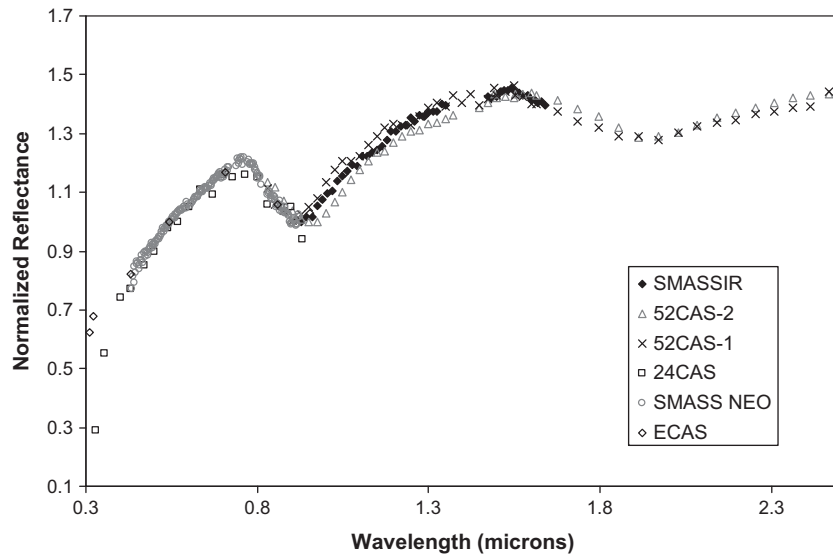


Fig. 1. Complete set of all previous spectra for Asteroid (1036) Ganymed (Binzel et al., 2004; Burbine and Binzel, 2002; Bell et al., 1995; Zellener et al., 2002; McFadden et al. 1984, 1985; Chapman et al. 1993). Normalized to one at 0.87 μm .

Table 1
Observational parameters for near-Earth Asteroid (1036) Ganymed.

Date	Univ. time	R.A.	DEC	r (AU)	Δ (AU)	ϕ ($^\circ$)	Instrument
18 May 2006	6:23–10:00	13 18 11.2	−10 24 40	3.082	2.198	10.8	SpeX

spheric extinction. Asteroid (1036) Ganymed's spectral observations were 120 s long, local standard star SAO 157621 spectral observations were one second long, and solar analog star SAO 120107 spectral observations were one second long. Extraction of spectra, determination of wavelength calibration, and data reduction were done using procedures outlined by Reddy (2009), Hardersen et al. (2005), Gaffey (2003), and Clark et al. (1980). The local standard star observations are used to make starpacks. The starpack is used to remove the telluric water vapor features from the final spectrum. A starpack is a set of wavelength-dependent extinction coefficients derived from the log-flux vs. airmass plots at each wavelength. The set of slopes and intercepts in the starpack are used to calculate the effective flux of the standard star at the same airmass as each asteroid observation. Each asteroid flux curve was divided by the starpack that most effectively removed the atmospheric water vapor features to produce a final spectrum. Individual spectra were averaged together to produce an average spectrum. During averaging, points were deleted that deviated by more than two standard deviations away from the mean. The solar analog star was used to remove any non-solar properties from the asteroid/local standard star spectrum that may be introduced by using a non-solar type local standard star. This was done by taking the average Asteroid/SAO 157621 spectrum and ratioing it to an average of the SAO 120107/SAO 157621 spectra to correct for any non-solar spectral properties of the local standard star. Since SAO 120107 is a GVIII star, an additional correction was applied to obtain the final spectrum of (1036) Ganymed. This was accomplished by using ThermFlux and generating a curve for a GVIII/G2V star ratio; the curve was then fit with a polynomial to model the behavior, reflectance values at near-infrared wavelengths were then calculated using the polynomial, and subsequently multiplied to the average spectrum/SAO 120107. The result is a true solar correction. Fig. 2 illustrates the corrected near-infrared spectrum of (1036) Ganymed combined with 24 Color Asteroid Survey data to cover the spectral interval of 0.30–2.45 μm .

3. Analysis

The spectrum exhibits two broad absorption features in the near-infrared. Each spectral interval is divided by a straight-line continuum fitted to the spectrum outside the wavelength interval of the absorption band. The use of a straight continuum follows the procedure used to derive the most commonly used interpretive calibrations from laboratory spectra of meteorites (e.g., Adams 1974, 1975; Cloutis et al., 1986; Cloutis and Gaffey, 1991; Gaffey et al., 1993, 2002; Gaffey and Gilbert, 1998). Curve fitting techniques such as MGMPFIT (e.g., Sunshine et al., 1998, 2004) treat the continuum as a two-term variable. Each approach has its advantages and disadvantages; neither is obviously superior.

Band centers were determined by fitting an n -order polynomial to each feature. The first absorption feature was located in the $\sim 0.9 \mu\text{m}$ region and was fit with a fifth order polynomial. The error was estimated from twelve fourth and fifth order polynomial fits, sampling different ranges of points within the Band I spectral interval (i.e. points sampled to the left and right of the center of the feature, deleting any spurious outlying points). The error was determined as half of the difference between the minimum and maximum error calculated from the polynomial fits. See Fig. 3. The second absorption feature was located in the $\sim 1.9 \mu\text{m}$ region and was fit with a fifth order polynomial. The Band II center was calculated at $1.86 \pm 0.01 \mu\text{m}$, and is $\sim 6\%$ deep. Errors were estimated in a manner analogous to Band I, using twelve fourth and fifth order polynomial fits, sampling different ranges of points within the Band II spectral interval. The error was determined as half of the difference between the minimum and maximum error calculated from the polynomial fits. See Fig. 3. The temperature at Ganymed's heliocentric distance of 3.08 AU was $\sim 200 \text{ K}$, and a temperature calibration had to be applied to the asteroid data to match that of the laboratory samples, effectively warming the asteroid, such that the Band II center wavelength was temperature corrected by $+0.025 \mu\text{m}$ to yield a Band II center of $1.89 \mu\text{m}$ (Singer

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