DIVERSITY OF PRIMITIVE ASTEROIDS IN THE HELIOCENTRIC REGION BETWEEN 3 AU and 4 AU.

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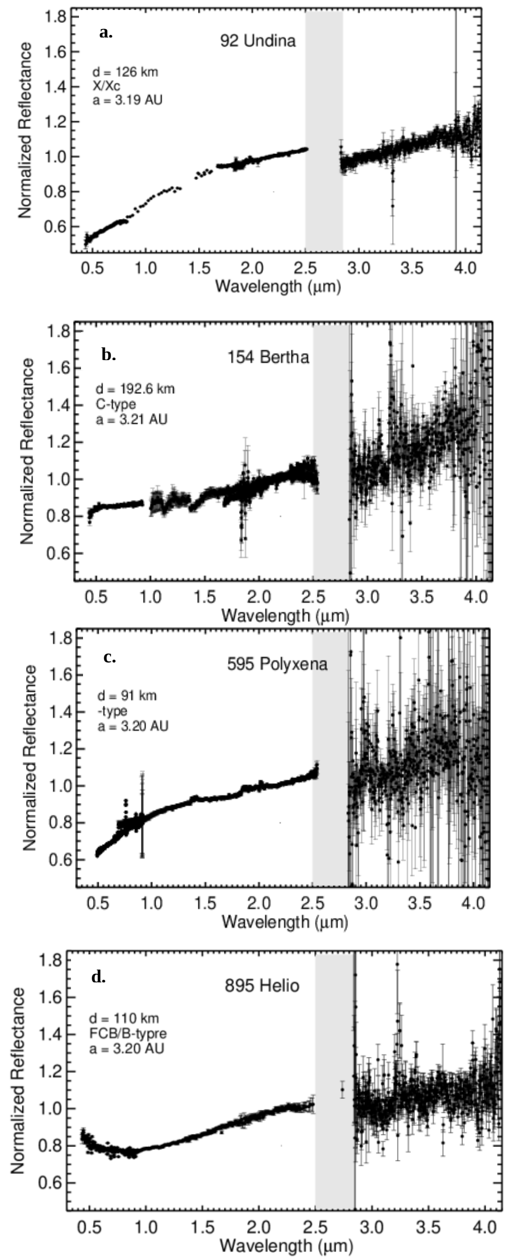
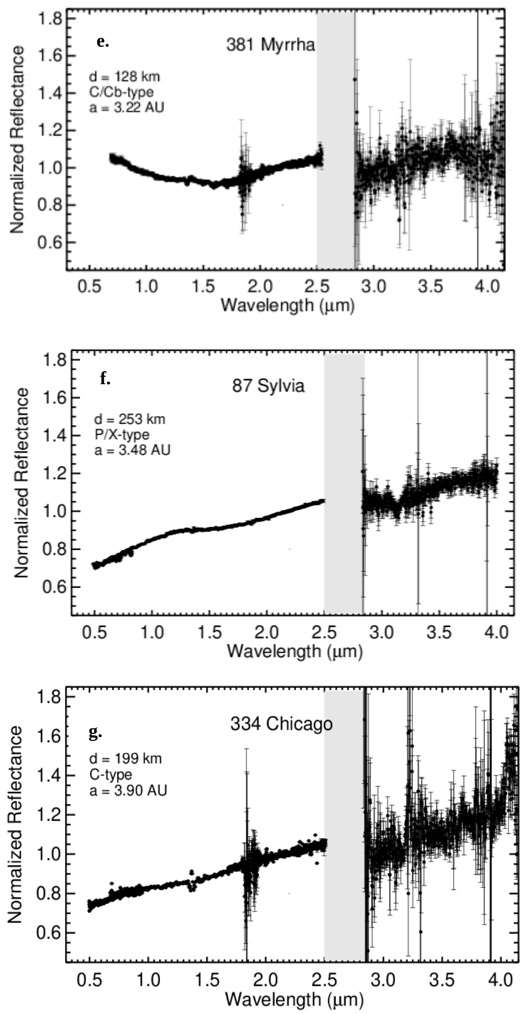
Introduction: Returned samples from the low-albedo asteroid (162173) Ruygu revealed the presence of water- and carbon-rich materials on this asteroid [1]. Low-albedo asteroids are called primitive because they did not experience high-temperature melting and differentiation, unlike evolved asteroids in the inner solar system. Primitive asteroids are thought to be remnants from the formation of the early solar system. The outer main-belt region is dominated by primitive asteroids in the heliocentric area with a semi-major axis a > 2.5 au. This region includes the Cybeles (~3.4 < a < 3.8 au), the Hilda in the 3:2 resonance with Jupiter (~3.9 < a < 4.2 au, and the Jupiter Trojans around L4 and L5 Lagrangian points of Jupiter at ~5.2 AU [2]. Here we present near-infrared (NIR ~0.5-4.0 µm) spectra of seven primitive asteroids located in the heliocentric region between 3 au and 4 au to characterize their surface composition. Studying the surface composition of primitive asteroids in this heliocentric region provides tests to dynamical theories [3].

Observations and data reduction: The seven asteroids (Tables 1 and 2) were observed using the Prism (0.7-2.52 µm) and long-wavelength cross-dispersed (LXD: 1.9- 4.2 µm) modes of the SpeX spectrograph/imager at NASA Infrared Telescope Facility (IRTF) [4]. We used the IDL (Interactive Data Language)-based spectral reduction tool Spextool (v4.0) [5] to reduce the data. OH-line emission dominates the background sky through most of the wavelength range, while thermal emission from the sky and telescope is significant longward of ~2.3 µm. Hence, we subtracted the spectra of asteroids and their corresponding standard stars at beam position A from spectra at beam B to correct these contributions. We extracted spectra by summing the flux at each channel within a user-defined aperture. We conducted wavelength calibration at λ > 2.5 µm using telluric absorption lines. We removed the thermal excess in asteroids' spectra using the methodology described in [6] and references therein. We fitted the measured thermal excess with a model thermal excess to constrain asteroids' model thermal flux. Then, we subtracted this model thermal flux from the measured relative spectra of asteroids. To calculate the thermal flux in the 3-µm region, we used the Near-Earth Asteroid Thermal Model (NEATM) [7], which is based on the Standard Thermal Model (STM) of [8].

Results: Figures 1 a-g show the processed NIR spectra of the seven asteroids included in this study. We used the classification of [6] to group the asteroids based on the 3-µm band. The seven asteroids across the heliocentric region between 3 au and 4 au have diverse 3-µm band shapes, depths, and presumably compositions.





Figures 1 (a-g). Near-infrared (0.5-4.0 µm) reflectance spectra of seven primitive asteroids included in the study. All spectra have been normalized to unity at 2.2 µm. The gray bar on each plot marks wavelengths of substantial water vapor absorption in Earth's atmosphere.

Discussion: Asteroids Undina, Chicago, and Polyxena have spectra consistent with CM/CI carbonaceous chondrites, which experienced aqueous alteration [9]. Undina, with a higher albedo than the other asteroids, exhibits a hydration feature at 3 µm. At 3.90 au (where most of the Hildas are located), Chicago is the farthest asteroid from the sun in this sample and has a CM/CI-like spectrum. Helio and Sylvia (large asteroids) show spectra consistent with Ceres' spectra. These asteroids are characterized by highly-porous interiors, accreted relatively late at 1.5-3.5 Myr after forming calcium- aluminum-rich inclusions, and experienced maximum interior temperatures of < 900 K [9]. [9] concluded that Ceres-like asteroids were likely implanted from more distant solar system regions during the giant planet's dynamical instability.

Table 1. Physical properties of the low-albedo asteroids included in this study.
Source: http://ssd.j.nasa.gov/sbdb.cgi.

Asteroid	Type	Albedo	Diameter (km)	*a* (au)	*i* (deg)	*e*
92 Undina	X/Xc	0.251	126.4	3.19	9.92	0.11
154 Bertha	-/C	0.044	192.6	3.21	21.02	0.07
595 Polyxena	-/-	0.145	90.6	3.21	17.83	0.07
895 Helio	FCB/B	0.071	109.6	3.21	26.05	0.14
381 Myrrha	C/Cb	0.064	127.6	3.22	12.56	0.09
87 Sylvia	P/X	0.046	253	3.48	10.88	0.09
334 Chicago	C/-	0.041	198.8	3.89	4.64	0.06

Table 2. Observing parameters for asteroids observed in this study with the LXD mode of SpeX at NASA IRTF.

Asteroid		Date (UT)	Time (UT)	Int. time (min)	Airmass	Standard star
92 Undina		12/19/18	13:34-15:46	120	1.102-1.010	HD 91885
333 Chicago		01/24/19	11:36-16:16	210	1.021-1.871	SAO98993
595 Polyxena		09/08/17	12:29-14:42	120	1.034-1.139	HD 11170
895 Helio		11/13/17	5:24-9:50	180	1.225-1.189	SAO54256
381 Myrrha		09/08/17	10:36-12:15	90	1.338-1.719	HD 19022
87 Sylvia		06/22/17	13:48-15:50	120	1.434-1.263	HD 220066
333 Chicago		01/24/19	11:36-16:16	210	1.021-1.871	SAO98993

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