Asteroid-Meteorite Connections in the Hungaria Background Population: Correlations with Primitive Achondrites?
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Introduction: The Hungaria *group* (*group* = asteroids sharing similar orbital space) of ~12,000 small (D <11 km) asteroids is a poorly understood population both compositionally and dynamically. These objects have relatively high inclinations, and populate a zone roughly defined by; 1.78 < a <2.0 AU, e <0.18, and 16°< i < 34° [1]. This orbital space is occupied by the Hungaria *family* (*family* = asteroids with similar orbits, originating from a common parent asteroid via catastrophic collision) of mainly Xe-type objects [1,2,3]. This *family* comprises a significant fraction of the Hungaria *group*, but not all of them [4]. Indeed, the Hungaria family is set among a compositionally diverse *background* (*background* = group minus family) asteroid population [1, this study]. Recent dynamical work has suggested that the Hungaria asteroids are the survivors of an extended and now largely extinct portion of the asteroid belt (E-belt) that existed between 1.7 and 2.1 AU early in solar system history [5].

Deciphering the mineralogy of the Hungaria asteroids may place constraints on the material from which the terrestrial planets accreted. Among asteroids with semi-major axes interior to the main-belt (e.g., Hungarias, Mars-crossers, and near-Earth asteroids), only the Hungarias are located in relatively stable orbital space [5]. Hungaria asteroids have likely resided in this orbital space since the planets completed their migration to their current orbits. The accretion and igneous differentiation of primitive asteroids appears to be a function of chronology and heliocentric distance [6]. However, partially-melted or differentiated bodies that originated in the terrestrial planet region were either accreted or scattered out of this region early in solar system history [5]. Thus, the Hungaria asteroids may represent the last remaining reservoir of the material that accreted to form the terrestrial planets.

We have undertaken a near-infrared (NIR) spectral survey of Hungaria asteroids at the NASA Infrared Telescope Facility (IRTF) to characterize their compositional diversity and to forge connections between these objects and analogous meteorite groups. Thus far, we have acquired NIR spectra for a sample of 30 Hungaria asteroids focusing mainly on the *background* population (Table 1). We hypothesize that primitive achondrites (acapulcoites and lodranites), are petrologically related to asteroids in the Hungaria *background* population. These meteorites are the residues left from low-degrees of partial melting of chondritic material [7]. We test this hypothesis by performing detailed spectral band parameter analyses on Hungaria asteroids and on six primitive achondrite spectra obtained from the Keck/NASA Reflectance Experiment Laboratory (RELAB) database (Table 2).

Observations: NIR spectral data were acquired for 23 asteroids using the SpeX spectrograph [8] in low-resolution prism mode at the IRTF. These data were supplemented with visible (VIS) data where available. Spectra of seven objects were obtained from the MIT-UH-IRTF survey (Table 1). We distinguish our sample between Hungaria *family* (two objects) and Hungaria *background* (28 objects) asteroids using proper orbital elements. Data reduction was performed with IDL-based Spextool provided by the IRTF.

Spectral Band Parameter Measurements: Asteroid spectra are utilized to determine their surface mineralogy from strong 1 μm and/or 2 μm absorption bands caused by the presence of the Fe^{2+} cation in the mafic silicate minerals olivine and pyroxene. Band parameter values (Band I and II centers and depths, and Band Area Ratio) were measured utilizing a new IDL-based code [9]. This routine divides the absorption bands by a straight-line continuum by fitting 5th order polynomials to absorption band shoulders and fitting the continuum tangentially to the shoulders. Band centers and depths are measured three times using 3rd through 5th order polynomial fits to the lower 1/2 of each absorption band. Errors are calculated using Monte-Carlo methods. The averages of the three fits are adopted as the final values. To compare band parameter values to meteorite spectra measured at room temperature in the laboratory, temperature corrections (Δ) as described in [10] are applied after calculating the equilibrium temperature of the asteroid based on the method found in [11].

Results: Preliminary results indicate a compositionally diverse Hungaria *background* population prevalent in S- and S-subtypes (20 out of 28 objects – Figure 1). Furthermore, spectral band parameter analyses of 17 of these S and S-subtypes show that two main meteorite groups appear to be represented, unmelted ordinary chondrites (mostly L chondrites); and the partially-melted primitive achondrite meteorites acapulcoites/lodranites (Figure 2).

Spectral Diversity Among Hungaria Asteroids: We identified the taxonomic class of the 30 Hungaria asteroids using the BusDeMeo asteroid spectrum classification tool (http://smass.mit.edu/busdemeoclass.html). We plotted the spectral classification of our sample asteroids in *H vs. a* space of the Hungaria region. Figure 1 shows that S- and Q-type asteroids dominate the *background* population. Four objects in or near the family zone (blue cone) are likely Xe-types, consistent with the taxonomic classification of the presumed largest collisional fragment 434 Hungaria. Xe-types are thought to be related to the igneous enstatite achondrite meteorites (aubrites) [2].

Table 1. – Hungaria asteroids analyzed in this study.

Asteroid	*a (AU)*	*H*	Band I center	ΔBAR	Taxonomy Bus-DeMeo
1019 Strackea	1.912	12.6	0.918	1.292	Sw
1453 Fennia	1.897	12.5	0.968	0.457	Q
1509 Esclangona	1.866	12.6	0.961	0.318	Sw
1727 Mette	1.854	12.5	1.024	0.081	Sw
1750 Eckert	1.926	13.2	0.926	1.081	Srw
2047 Smetana	1.872	13.9	0.952	0.616	Q
2131 Mayall	1.887	12.7	0.917	1.045	Sw
2449 Kenos*	1.909	14.3	-	-	Xn
3225 Hoag	1.880	13.1	0.922	0.991	S
3635 Kruetz*	1.794	14.6	0.920	0.726	Srw
3940 Larion	1.988	12.7	-	-	L
4142 Dersu-Uzala*	1.912	12.9	0.968	0.398	Srw
4674 Pauling*	1.859	13.7	-	-	K
4736 Johnwood	1.958	13.4	-	-	Xe
5477 Holmes	1.917	14.0	-	-	Q
5577 Priestly*	1.844	14.1	0.978	0.497	Q
5641 McCleese*	1.819	14.0	0.953	0.390	Sw
5806 Archieroy	1.963	12.9	0.925	0.907	Sq
6249 Jennifer*	1.914	12.9	-	-	Xc
6310 Jankonke	1.913	13.9	-	-	Sw
6447 Terrycole	1.952	14.3	-	-	Xe
6618 (1936 SO)	1.875	13.3	-	-	B
7086 Bopp	1.909	13.8	0.984	0.387	Q
7187 Isobe	1.937	13.9	-	-	K
9068 (1993 OD)	1.820	13.5	-	-	L
9069 Hovland	1.913	14.2	1.017	0.265	Q
17408 McAdams	1.883	14.2	-	-	Sr
19164 (1991 AU1)	1.856	14.0	0.917	1.501	S
26471 (2000 AS152)	1.918	13.2	0.917	0.914	Sq
55854 (1996 VS1)	1.930	14.2	-		C

* Data from MIT-UH-IRTF spectral database; **Δ** – temperature corrected value

Asteroid-Meteorite Connections: Figure 2 plots Band I Center vs. BAR for 17 S-subtype Hungaria *background* asteroids (Table 1) and six primitive achondrites (Table 2). Eight asteroids and four meteorites cluster in the spectral region of the primitive achondrite group. These spectral comparisons suggest that at least some *background* objects have experienced low-degrees of petrologic evolution. Spectral and geochemical characterization of additional primitive achondrites is crucial to corroborate these connections.

Table 2. – Primitive achondrites analyzed in this study.

Meteorite	Group	RELAB ID	Band I center	BAR
Acapulco	acapulcoite	TB-TJM-043	0.923	0.879
ALH81187	acapulcoite	TB-TJM-040	0.930	0.294
ALH81261	acapulcoite	TB-TJM-039	0.930	0.655
EET84302	acapulcoite	TB-TJM-042	0.920	1.113
GRA95029	lodranite	TB-TJM-044	0.920	0.841
Lodran	lodranite	TB-TJM-041	0.920	0.882

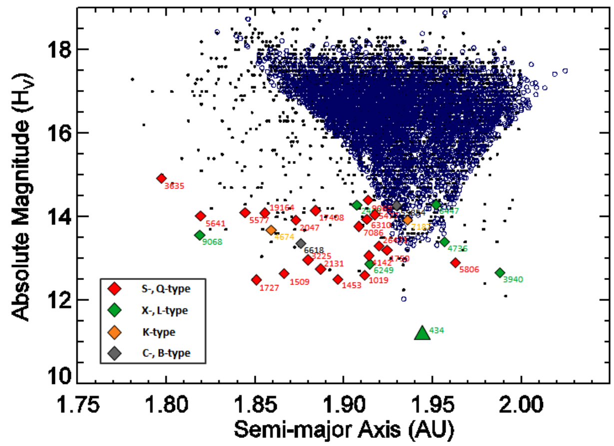

Figure 1. – Numbered Hungaria asteroids (~5000) in *H* vs. *a* space. 434 Hungaria (large green triangle) and *family* members (blue circles) indicated. Diamond symbols represent our sample of 30 Hungaria asteroids.

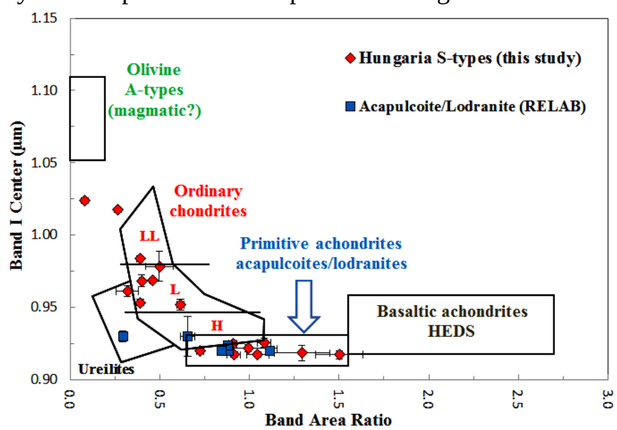

Figure 2. – S-type Hungaria asteroids (red diamonds) and primitive achondrites (blue squares) plotted on the S-subtype plot of [12] adapted in [13] to illustrate spectral regions analogous to various meteorite groups.

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