# Compositional Diversity Among Hungaria Region Asteroids: Evidence from the Observatory and the Laboratory

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## Abstract

The Hungaria region of asteroids is a poorly understood population. These neighbors to the terrestrial planets are unique as they are found interior to the Main-belt and have resided in their current location since early in solar system history. Mars-crossing and near-Earth asteroids make closer approaches to the terrestrial planets, but they are dynamically short-lived “escapees” from the Main-belt. The planetesimals that originated near the terrestrial planets were either accreted or scattered out early in solar system history, leaving the Hungarias as the closest remaining “survivors” of the material from which the terrestrial planets accreted.

We have undertaken telescopic observations to record the near-infrared spectra of a sample of 42 Hungaria asteroids to characterize their surface mineralogy through spectral band parameter measurements. By combining these telescopic data with spectral and geochemical laboratory data from meteorites, we can establish connections between Hungaria asteroids and analogous meteorite groups.

We find evidence of three main meteorite-groups represented in the Hungaria region. Five family members are spectrally consistent with the largest collisional fragment 434 Hungaria, which is related to fully-melted aubrite meteorites. Analyses of spectral band parameters for Hungaria background objects reveal evidence for two other groups. Laboratory data for ordinary chondrites compared with our asteroid spectra point to the existence of unmelted L/LL chondrites in the region. Preliminary results from the laboratory analyses of 12 primitive achondrites indicate the existence of partially-melted primitive achondrites as well. These asteroid-meteorite connections suggest that planetesimals in the Hungaria region have experienced varying degrees of petrologic evolution.

## Observatory: Asteroid NIR Spectral Survey

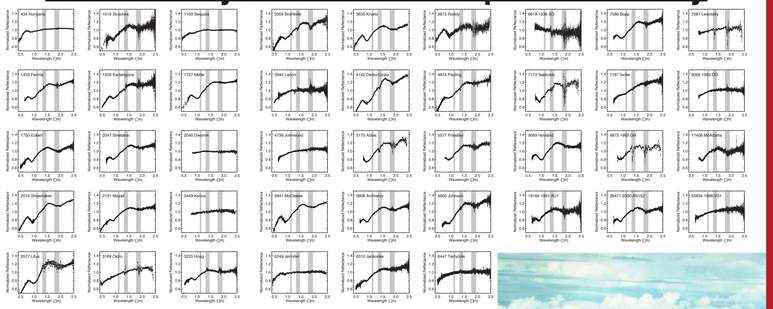



**Figure 1. -** Telescopic visible and near-infrared (VISNIR) spectra of 42 Hungaria region asteroids acquired during our larger spectral survey (~80 objects) to characterize Hungaria asteroid surface compositions. Wavelengths are in microns. The vertical gray bars on each plot denote wavelengths of strong absorption by water vapor in Earth’s atmosphere.


## Hungaria Asteroids: Terrestrial Planet Neighbors

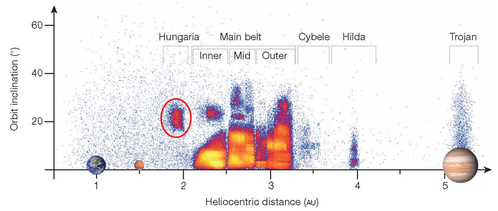



**Figure 2. -** The location of the Main-belt of asteroids in context with the inner Solar Sytem and with distance from the Sun. The number density of the asteroids is color-coded (yellow the highest, blue the lowest). Hungaria asteroids (red oval) are located in a unique place in the solar system, *interior* to the Main-belt and highly inclined to the ecliptic. Among asteroids found interior to the Main-belt (i.e., Hungarias, Mars-crossers, and near-Earth asteroids), only the Hungarias are located in relatively stable orbital space (from DeMeo and Carry, 2014).

## Spectral Band Parameter Analysis with SARA

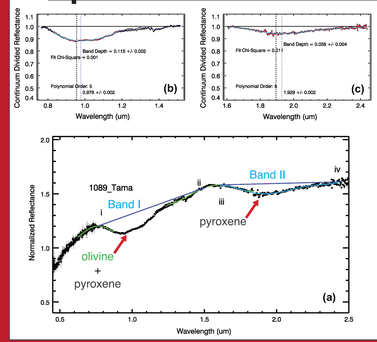



**Figure 7. -** Comparisons of asteroid spectra aquired at the telescope with meteorite analyses obtained in the laboratory are performed with an IDL-based routine called the Spectral Analysis Routine for Asteroids (SARA) developed by Lindsay *et al.* (2015). Surface compositions of asteroids can be derived by performing band parameter analyses on the Band I and/or Band II absorptions caused by the presence of the $Fe^{2+}$ cation in mafic silicate minerals olivine and pyroxene, which are common on asteroid surfaces and in stony meteorites. Mineral abundances such as the ol/ol+px ratio, and mineral compositions of olivine Fa (fayalite; $Fe_2SiO_4$) and pyroxene Fs (ferrosilite; $FeSiO_3$), can effectively be extracted for asteroids by comparing the band parameters of asteroid spectra with calibrations derived in the laboratory from “free” asteroid samples that arrive to Earth as meteorites. **(a)** Example of SARA band parameter analysis for the VISNIR spectrum of asteroid 1089 Tama, band analysis points (i-iv) and Band I and Band II indicated, linear continua (blue) shown for both bands. Continuum-divided Band I **(b)** and Band II **(c)** with band depth (thick-dashed) and band center (thin-dashed) measurements shown (modified from Lindsay *et al.*, 2015).

## Hungaria Asteroid Spectral Types

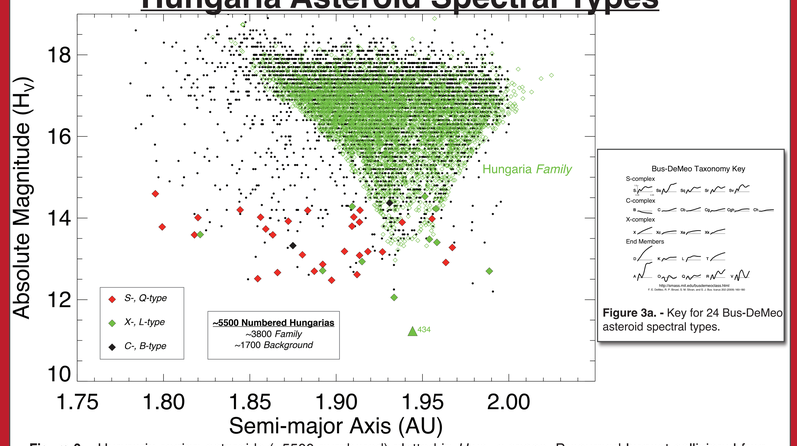
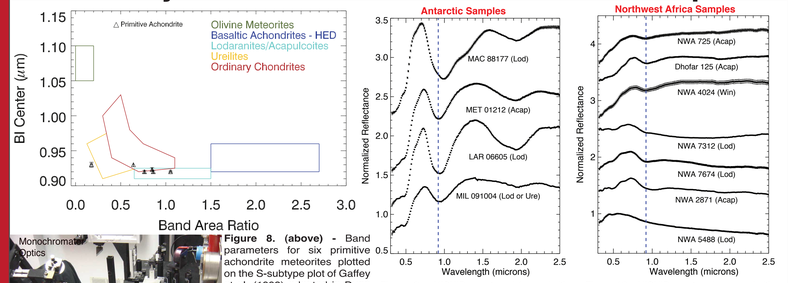



**Figure 3. -** Hungaria region asteroids (~5500 numbered) plotted in *H* vs. *a* space. Presumed largest collisional fragment of the Hungaria *family* 434 Hungaria (large green triangle) and *family* members (green diamonds) indicated. Large diamond symbols represent our sample of 42 Hungaria asteroids. S-type asteroids (red diamonds) are prevalent among the Hungaria *background* (black dots) population.

**Figure 3a. -** Key for 24 Bus-DeMeo asteroid spectral types.

## Laboratory: Primitive Achondrite Meteorite Spectra



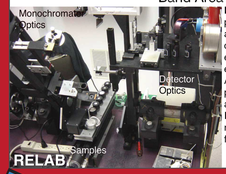




**Figure 8. (above) -** Band parameters for six primitive achondrite meteorites plotted on the S-subtype plot of Gaffey et al. (1993) adapted in Dunn et al. (2013) as in Figure 6. Acapulcoite and Iodranite powder (<125 micron) spectra are from the RELAB database. Image of the bidirectional reflectance spectrometer **(left)** from Pieters and Hiroi (2004).

**Figure 9. -** VISNIR spectra of four primitive achondrite meteorite “chips” from the Johnson Space Center ANSMET collection measured at RELAB. Blue-dashed line indicates average Band I center of 0.92 microns from the seven asteroids illustrated in Figure 5. Spectral analyses of meteorite powders forthcoming.

**Figure 10. -** VISNIR spectra of seven primitive achondrite meteorite “slabs” from Northwest African (NWA) meteorites measured at RELAB. These meteorites suffer from varying degrees of terrestrial weathering. Blue-dashed line indicates average Band I center of 0.92 microns from the seven asteroids illustrated in Figure 5.

## Hungaria Background: S-types Dominate

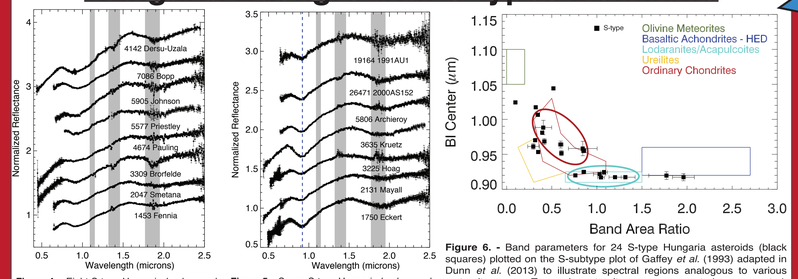



**Figure 4. -** Eight S-type Hungaria *background* asteroids which plot in the ordinary chondrite region of the S-subtype plot in Figure 6 (right).

**Figure 5. -** Seven S-type Hungaria *background* asteroids which plot in the primitive achondrite region of the S-subtype plot in Figure 6 (right).

**Figure 6. -** Band parameters for 24 S-type Hungaria asteroids (black squares) plotted on the S-subtype plot of Gaffey *et al.* (1993) adapted in Dunn *et al.* (2013) to illustrate spectral regions analogous to various meteorite groups. Two main meteorite groups appear to be represented; ordinary chondrites (red oval) and the partially-melted primitive achondrite meteorites termed acapulcoites/lodranites (light-blue oval).

## Asteroid-Meteorite Connections: Hungaria Region

***Family*: Aubrites**

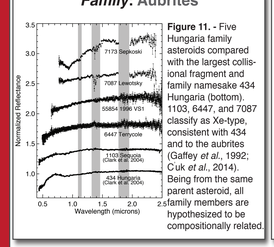



**Figure 11. -** Five Hungaria family asteroids compared with the largest collisional fragment and family namesake 434 Hungaria (bottom). 1103, 6447, and 7087 classify as Xe-type, consistent with 434 and to the aubrites (Gaffey *et al.*, 1992; Cruk *et al.*, 2014). Being from the same parent asteroid, all family members are hypothesized to be compositionally related.

***Background*: Ordinary Chondrites**

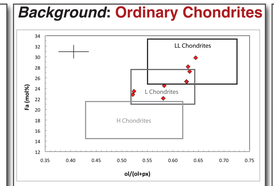



**Figure 12. -** mol% Fa in olivines as a function of the ol/ol+px for the eight S-type asteroids from Figure 5. The crossbar represents the uncertainties for spectrally derived values (0.03 for ol/ol+px; 1.3 mol% for Fa). Calibrations for ordinary chondrites from Dunn *et al.* (2010).

***Background*: Primitive Achondrites**

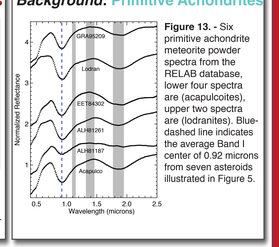



**Figure 13. -** Six primitive achondrite meteorite powder spectra from the RELAB database, lower four spectra are (acapulcoites), upper two spectra are (lodranites). Blue-dashed line indicates the average Band I center of 0.92 microns from seven asteroids illustrated in Figure 5.

## Summary

- We find evidence of three main meteorite-groups represented in the Hungaria region:
  - 1) fully-melted enstatite achondrites (i.e., aubrites) > Hungaria *family*
  - 2) unmelted ordinary chondrites (i.e., L and LL) > Hungaria *background*
  - 3) partially-melted primitive achondrites (acapulcoites/lodranites) > Hungaria *background*
- Forthcoming analyses on primitive achondrite meteorites: bidirectional reflectance spectra of powder fraction (< 125 micron), X-ray diffraction (XRD) to derive modal mineral percentages, mineral chemistry of olivine and pyroxene via electron probe microanalysis (EPMA)

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