IS ASTEROID (3) JUNO THE PARENT BODY OF H-CHONDRITE METEORITES?

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Introduction: Being able to link meteorites to source regions in the main asteroid belt is critical to discerning the environment within which their parent bodies were created. Of the meteorites that fall on the Earth ordinary chondrites are by far the most abundant, making up 86% of all collected meteorites. Several S-type asteroids and families have been identified as possible sources for the H, L and LL types of ordinary chondrites; the Hebe, Agnia, Merxia, and Koronis families as the H chondrite source, Gefion as the H/L chondrite source, and Flora family as the LL chondrite source. Despite these hypothesized links, the composition, and thus meteorite affinity, of several S-type asteroids are poorly constrained. Within these loose constraints lies the possibility that there are more source regions for the ordinary chondrites.

H chondrites make up 34% of all meteorite falls [1], so the simple assumption would suggest that the source of the H chondrites would be easily identifiable in the main belt asteroids and asteroid families. In order to make the connection between the H chondrites and a particular asteroid or asteroid family we used near-infrared spectral observations of (3) Juno, a 250 km diameter S-type asteroid, to best determine the meteorite analog that matches Juno's composition.

Observations: The NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii was used to obtain Near IR spectra of Juno with the SpeX instrument [2]. 30 individual spectra of Juno were acquired when the asteroid had a V=10.8 at a heliocentric distance r = 3.16 A.U., and a phase angle of 18º. Exposure time was capped at 30 seconds to minimize saturation. The G2V-type local extinction star SAO 162210 was observed before and after the asteroid observations, 40 times in total for telluric atmospheric feature correction. To correct for any spectral slope variation due to the non-solar type extinction target, 30 spectra of solar analog star SAO 93936 were also acquired.

Data Reduction: Reduction of spectral data was done using the Spextool package to correct for telluric features, channel shifts, averaging, display functions, and for wavelength calibration [3]. NASA IRTF provides the Spextool package for data reduction.

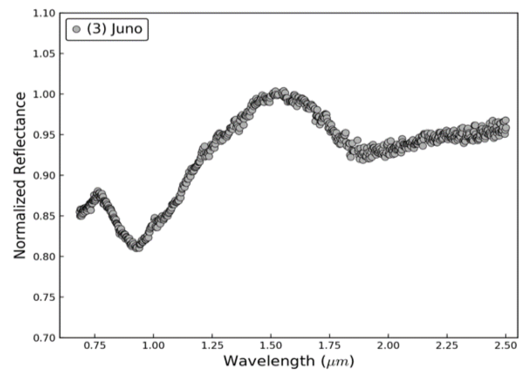

Figure 1. Near-IR reflectance spectrum of main belt asteroid (3) Juno obtained using the NASA IRTF on Mauna Kea, Hawaii.

Results: Juno's spectrum clearly displays absorption bands indicative of olivine and pyroxene at around 1 and 2 μm, as is typical of an S-type asteroid (Fig. 1). The composite band at ~1 µm (Band I) is due to both pyroxene and olivine, but the band at ~2 µm is only produced by pyroxene. Using Juno's spectrum the band centers and band area ratio (BAR) were calculated using a Python code like that implemented in [4]. By inputting the spectral band parameters into equations from [5] we were able to determine the mol% of fayalite (Fa) vs. ferrosilite (Fs) for Juno (Figure 2). The calculated Fa (17.5±1.3%) and Fs (15.5±1.4%) values are supportive of the Juno's surface composition being similar to that of an H chondrite (Figure 3).

To confirm the meteorite analog of Juno the laboratory measured values of Fa and Fs of H, L and LL for the ordinary chondrites were used to to train a discriminative model able to perform Bayesian inference by computing the posterior probability distribution from the meteoritic data [6] (Figure 3). From our Bayes classifier, Juno has 95.76% probability of being H chondrite.

Discussion: This high probability makes it comfortable to conclude that Juno has a surface composition close to that of the H chondrites. Several lines of evidence were identified and investigated to confirm the link between Juno and H chondrites.

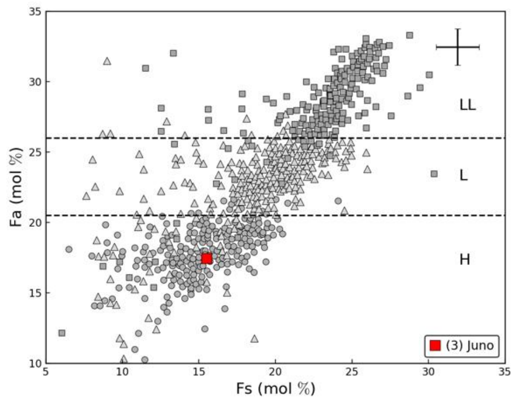

Figure 2. Fayalite (Fa) vs ferrosilite (Fs) plotted as mol % for (3) Juno and H chondrites from [7]. Figure adapted from [7].

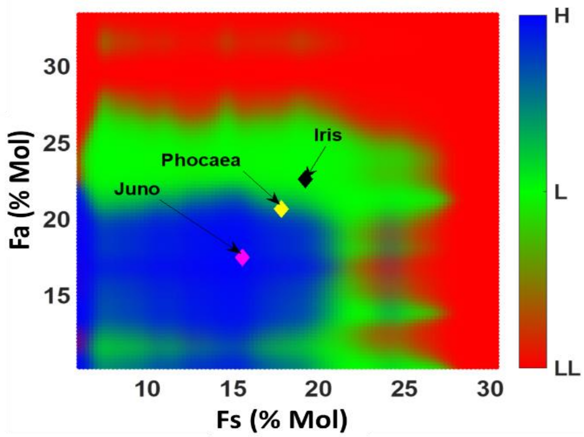

Figure 3. Color-coded posteriori probability distribution evaluated by the naïve Bayesian classified in (Fa, Fs) space.

Meteorite Cosmic Ray Exposure Ages: Of all studied H chondrites approximately half have CRE ages of 7-8 Ma [8], a trait unique to the H chondrites. Such a unique trait would suggest that a single parent body or family is the sole source or dominates other sources. In addition to this, the single 7-8 Ma peak in CRE ages is brief enough to entertain the notion that the H chondrite source may be close to a major resonance in the main belt, increasing the efficiency of delivery to the Earth.

^{40}Ar-^{39}Ar Shock Degassing Ages: The distribution of ^{40}Ar-^{39}Ar ages for H chondrites and howardite-eucrite-diogenite (HED) meteorites, likely from Vesta, are shockingly close to one another for > 3.5 Ga (e.g., [9]). Both distributions show a cluster of events > 4.4 Ga, a comparative low between 4.1-4.4 Ga, and a significant number of events between 3.4-4.0 Ga. According to "Bogard's rule" [10], which states that an increase in parent body size correlates to increased number of shock-reheated samples, we can conclude that both the H chondrite and HED parent bodies saw similar impactor populations and that both bodies are large. A small logical leap then leads us to argue that the H chondrite parent body is likely a larger asteroid in the main belt.

Thermal Modeling Results: Many studies attempt to constrain the size of the H chondrite parent body from a combination of meteorite constraints and thermal modeling (e.g., [11], [12], and more). A large portion of these works support our conclusion in the subsection above, with a parent body larger than 200 km as likely. More recent studies are event supportive of a parent body larger than 275 km [12].

Paleomagnetic Evidence: The Portales Valley meteorite is a metallic melt impact breccia that is defined as H6. [13]. Dating of the melt has shown it is~ 4.5 Ga [14] and has a clear paleomagnetic signature [15]. Preliminary work also shows that the H chondrite parent body was generating a stable, 10 µT magnetic field at the time the impact melt cooled to the Curie point[15]. Dynamo and accretion models seeking to constrain the accretion time and size of the H chondrite parent body point to a diameter between 230-320 km, with the highest probability of a 280 km diameter.

When these separate lines of evidence are combined the conclusion that the H chondrite parent body was at least 200 km in diameter and could be linked to a relatively young family is supported, providing the correct interpretation of the young ^{40}Ar-^{39}Ar ages. The current and presented knowledge of (3) Juno and its family matches these constraints, but it is unclear if the match is unique.

Acknowledgements: This research was supported by NASA NEOO Program Grant NNX17AJ19G (PI: Reddy).

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