WHERE DO H, L, AND LL CHONDRITES COME FROM? TRACING THEIR SOURCE REGIONS USING ASTRONOMICAL TOOLS.

R. P. Binzel[1], F. E. DeMeo[1], B. J. Burt[1], T. H. Burbine[2], D. Polishook[3], [1]Massachusetts Institute of Technology, Cambridge MA (rpb@mit.edu), [2]Mount Holyoke College, South Hadley, MA) [3]Weizmann Institute of Science, Rehovot 0076100, Israel

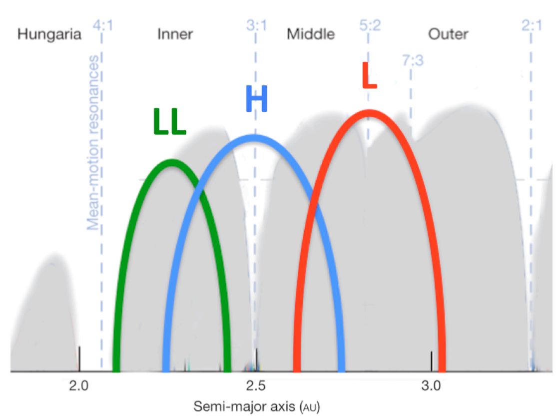
Summary: We find the ordinary chondrite stratigraphy in the main belt to be LL, H, L (in the order of increasing distance from the Sun). We derive this result using spectral information from more than 1000 near-Earth asteroids (NEAs) [1]. Our methodology is to correlate each NEA's main-belt source region [2] with its modeled mineralogy [3]. The result is a probability distribution that shows a signature for the 'preferred source' for each meteorite class. We find LL chondrites predominantly originate from the inner edge of the asteroid belt (nu6 region at 2.1 AU), H chondrites from the 3:1 resonance region (2.5 AU), and the L chondrites from the outer belt 5:2 resonance region (2.8 AU). Each of these source regions has been cited by previous researchers [e.g. 4, 5, 6], but this work reveals the LL, H, L stratigraphy in a unified result from a single methodology. We seek feedback from the meteoritical community on the viability or implications of this stratrigraphy.

Observations: Spectroscopic and taxonomic information is now available for ~1000 near-Earth objects, thanks in large measure to the NASA IRTF long-term reconnaissance program we call the MIT-Hawaii Near-Earth Object Spectroscopic Survey (MITHNEOS) [1]. We obtain our measurements using the SpeX instrument on the NASA Infrared Telescope Facility (IRTF) in prism mode (0.8-2.5 µm).

Dynamical Methodology: For each near-Earth asteroid, we use its orbital parameters as input to the Bottke source model [2] to assign a probability that the object is derived from five different main-belt source regions: Mars-crossers, inner asteroid belt (nu6 resonance at 2.1 AU), mid-belt 3:1 resonance (2.5 AU), outer belt 5:2 resonance (2.8 AU), and Jupiter family comets (JFC). For each object, the sum of all five probabilities equals unity.

Mineralogic Methodology: For the subset of all NEA spectral measurements covering the full wavelength range of 0.45 to 2.45 microns, we apply the Shkuratov model [3] for radiative transfer within compositional mixing. Our implementation of the Shkuratiov model derives an estimate for the ol / (ol+px) ratio (and its uncertainty) that provides the best fit to the spectrum. For our mineralogic modeling, we consider only NEAs whose taxonomic classes fall within the S-, Sq-, and Q-classes that have been linked to ordinary chondrites [7, 8, 9].

Correlation Methodology: The Bottke source region model [2] and the Shkuratov mineralogic model [3] each deliver a probability distribution. For each NEA, we convolve its source region probability distribution with its meteorite class distribution to yield a likelihood for where that class originates. For example, from the orbit of asteroid (25143) Itokawa we find a high source region probability (71%) for the nu6 resonance (and 29% among the other four sources). Modeling Itokawa's spectrum yields a 95% likelihood of being an LL chondrite (and 5% relative to the other classes), consistent with the pre-Hayabusa mission prediction and mission result [10, 11]. Convolving these two probability distributions yields a strong signature for LL chondrites deriving from the nu6 resonance, but most importantly, a non-zero signature across other source regions and meteorite types. (We retain the complete information across all sources and all types for each of the modeled asteroids.) We co-add together the convolved probability distributions for hundreds of asteroids in our sample to obtain an accumulated result where each asteroid contributes information. The result is shown in the figure below.



Schematic result for the main-belt source region locations of LL, H, and L chondrites. Depiction of the main-belt background is from DeMeo & Carry [12].

Discussion: The LL chondrites being derived from the nu6 resoance has been previously proposed by Vernazza et al. [4]; the 3:1 resonance for the H chondrites by Thomas & Binzel [5]; and the L chondrites from the outer belt Gefion family by Nesvorny et al. [6]. Our results are consistent with the Gaffey & Gilbert [13] proposition of asteroid 6 Hebe as the H chondrite source, but our results do not require Hebe to be the H chondrite parent body. Vernazza et al. [14] show an abundance of H chondrite-like bodies in the vicinity of the 3:1 resonance that provide multiple possibilities as H chondrite sources.

We find that the heliocentric order of the source region probabilities to be robust: LL chondrites appear to have formed closer to the Sun than H chondrites. The L chondrites appear to have formed at the most distant location out of the three major meteorite classes. Our next step is to explore the consistency (or lack thereof) of this LL, H, L formation distribution with nebular condensation models, mindful that compositional mixing within the asteroid belt has likely occurred [15].

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References: [1] Binzel, R. P., Rivkin, A. S., Thomas, C. A., DeMeo, F. E., Tokunaga, A., Bus, S. J. (2005), LPSC XXXVI, Abstract 36.1817. [2] Bottke Jr., W.F., Morbidelli, A., Jedicke, R., Petit, J.-M., Levison, H.F., Michel, P., Metcalfe, T.S., (2002). Icarus 156, 399–433. [3] Shkuratov Y.G., Kaydash V.G., Opanasenko N.V. (1999). Icarus 137, 222-234. [4] Vernazza, P., Binzel, R.P., Thomas, C.A., DeMeo, F.E., Bus, S. J., Rivkin, A.S., Tokunaga, A. (2008). Nature 454, 858-860. [5] Thomas, C. A., and Binzel, R. P. (2010). Icarus 205, 419-429. [6] Nesvorný, D. Vokrouhlický, D., Morbidelli, A., Bottke, W. F. (2009). Icarus 200, 698–701. [7] Wetherill G. W., Chapman C. R. (1988). In *Meteorites and the Early Solar System* (J. F. Kerridge and M. S. Matthews, eds.), pp. 35–67. Univ. of Arizona, Tucson. [8] Binzel, R. P., Bus, S. J., Burbine, T. H., and Sunshine, J. M. (1996). *Science* **273**, 946-948. [9] Binzel, R.P., Morbidelli, A., Merouane, S., DeMeo, F.E., Birlan, M., Vernazza, P., Thomas, C.A., Rivkin, A.S., Bus, S.J., Tokunaga, A.T. (2010). *Nature* **463**, 331-334. [10] Binzel, R. P., Bus, S. J., Sunshine, J., and Burbine, T. (2001). *Meteoritics & Plan. Sci.* **36**, 1167-1172. [11] Nakamura T., et al. (2011). *Science, 333,* 1113–1116. [12] DeMeo F. E. and Carry B. (2014). *Nature, 505,* 629–634. [13] Gaffey M. J. and Gilbert S. L. (1998). *Meteoritics & Planet. Sci., 33,* 1281–1295. [14] Vernazza P., Zanda B., Binzel R. P., Hiroi T., DeMeo F. E., Birlan M., Hewins R., Ricci L., Barge P., Lockhart M. (2014). *Astrophys. J., 791,* 22 pp. [15] Walsh,K.J.,Morbidelli,A.,Raymond,S.N.,O'Brien,D.P., Mandell,A.M. (2011) Nature 475, 206–209.