Near-infrared Spectroscopy of 3:1 Kirkwood Gap Asteroids 1379 Lomonosawa and 974 Lioba: Plausible Parent Bodies of L- and LL-chondrites.

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Introduction: The Kirkwood gaps are severely depleted zones in the asteroid belt located at proper motion resonances with Jupiter. Objects near the 3:1 Kirkwood Gap at 2.5 AU have their eccentricities pumped up and are removed from the resonance by collisions with other asteroids, by collisions or gravitational encounters with Jupiter or other planets, or by collisions with the Sun. Theoretical models indicate the majority of asteroidal material delivered to the inner solar system, particularly to the Earth, originates from the 3:1 mean motion and the ν_6 secular resonances [1-4].

Asteroids and collisionally-ejected fragments with semi-major axes in the 2.47-2.53 AU range undergo chaotic orbital evolution on timescales as short as 10^6 years [5]. Changes in eccentricity, inclination, and semi-major axis due to gravitational perturbations, collisions, and the Yarkovsky effect can deliver nearby meter-to-kilometers-scale objects into the chaotic zone of the 3:1 resonance [6-11]. These objects are rapidly (10^6–10^7years) transferred to Earth- and Mars-crossing orbits making the 3:1 resonance a major potential source for meteorites and near-Earth asteroids [10-13].

Currently, probable parent bodies have been identified for only four [14-16] of the 135 distinguishable meteorite classes [17]. These three parent bodies: 4 Vesta, 3103 Egar, and 6 Hebe account for ~40% of terrestrial meteorite falls. Thus, ~60% of the meteorite flux and ~97% of the meteorite classes still need to be accounted for. Asteroids within the "feeding zone" of the 3:1 resonance are obvious candidates for such parent bodies.

Most asteroids adjacent to the 3:1 resonance have not been observed in the near-infrared (0.8-2.5 µm), which is the minimum wavelength range needed for detailed characterizations of their surface minerals. This research explores possible links between two asteroids loacated near the 3:1 resonance (974 Lioba and 1379 Lomonosawa) and the meteorite types in the terrestrial collections.

Observations/Data Reduction: Near-infrared spectra of 1379 Lomonosawa and 974 Lioba were obtained in May 2008 at the NASA IRTF using the SpeX instrument in the low-resolution spectrographic mode. Asteroid and local standard star observations were interspersed to allow optimal modeling of atmospheric extinction. Data reduction was done using procedures outlined by [18-19]. Figure 1 illustrates the solar corrected near-infrared spectra of 1379 Lomonosawa (top) and 974 Lioba (bottom). Due to poor sky conditions these spectra are somewhat noisier and the atmospheric water band correction is poorer than normal.

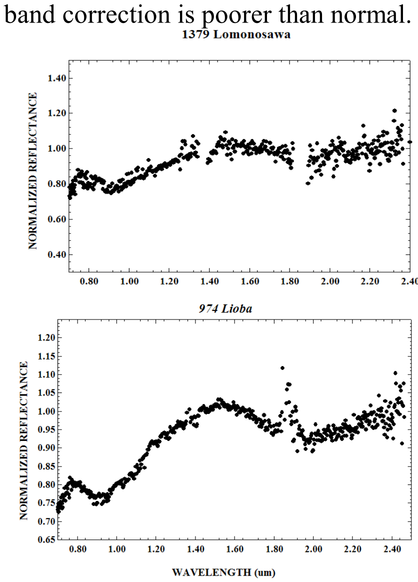

Figure 1

Analysis: The spectra of 1379 Lomonosawa and 974 Lioba both show absorption features located at ~1 and ~2 µm. A straight-line continuum was fitted through the reflectance peaks bracketing each absorption feature and band centers were determined by fitting an n-order polynomial to the resulting continuum-removed feature.

For 1379 Lomonosawa, the Band I center was calculated to be 0.96 ± 0.01 µm. The Band II center was calculated at 1.95 ± 0.02 µm. To correct for the temperature difference between the mean asteroid surface and the lab samples used in the interpretive calibrations (~92K T difference), the Band II center wavelength was increased by +0.02 µm [20-21] to yield a Band II center of 1.97 µm. The Band Area Ratio (BAR) calculated for the features was 2.74 ±0.43.

For 974 Lioba, the Band I center was calculated to be 0.96 ± 0.01 µm. The Band II center was calculated at 1.93 ± 0.02 µm, and temperature-corrected to 1.95 µm. The Band Area Ratio (BAR) was calculated as 0.59 ±0.15.

On a Band I vs. Band II plot [22-23], 1379 Lomonosawa plots within the LL-chondrite zone and on the edges of the L-chondrite and HED zones. 974 Lioba plots within the L-chondrite and LL-chondrite zones.

Using equations outlined by [18], the average pyroxene composition for 1379 Lomonosawa was calculated to be $Fs_{41}(\pm5)Wo_{20}$ ($\pm$3). For 974 Lioba, the average pyroxene composition was calculated to be $Fs_{21}(\pm5)Wo_8(\pm3)$. The derived mineralogy for 974 Lioba (~Fs_{21}~Wo_8) is near the upper limit for L-chondrites (~$Fs_{19\text{-}22}$) and just below the lower limit of the LL-chondrites (~$Fs_{22\text{-}25}$). However, given the uncertainties in the derived pyroxene composition, it is consistent with either an L- or LL-assemblage. The spreadsheet based on the equations presented by [18], includes slightly different parameters for calculating the pyroxene mineral compositions of H-, L-, and LL-chondrites. Using this routine, an LL-chondrite provides a somewhat better fit to the spectral parameters than an L-chondrite, so we tend to favor the LL-option, while recognizing the L-option is still viable.

1379 Lomonosawa exhibits both the 1- and 2- µm absorption features that are associated with pyroxene-rich or basaltic assemblages. Olivine appears rare or absent. The absorption features are subdued. The 1379 Lomonosawa spectrum suggests three possible assemblages with different origins and meteorite affinities. These include a) metal-basaltic assemblage analogous to a mesosiderite, b) an ordinary chondrite assemblage that experienced subsolidous reduction, and c) a shock-blackened ordinary chondrite assemblage analogous to the black chondrites.

1379 Lomonosawa's Band I position, average pyroxene composition, and BAR indicate a silicate assemblage dominated by pyroxene with little or no olivine. How is it possible to reconcile the spectral parameters of 1379 Lomonosawa with a black chondrite since black chondrites have essentially the same olivine-rich mineralogy as normal ordinary chondrites? Fig. 2 plots 1379 Lomonosawa (noisy line) and the black L5 chondrite *Farmington* (smooth line) [24]. *Note: Farmington is used only as an example of a black chondrite spectrum; it does not represent any claim of a specific meteorite-asteroid match.* The absorption features are located in the same regions of the spectrum and the depths of the absorption features are comparable.

When the spectra of black chondrites are compared to the spectra of unshocked (or only lightly shocked) ordinary chondrites of the same types (e.g., L5), spectral parameters (e.g., BAR) are shifted in the direction which would produce a Lomonosawa-like spectrum.

Conclusions: Two plausible meteorite parent bodies have been spectroscopically identified in the chaotic region of the 3:1 Kirkwood Gap. 1379 Lomonosawa is a plausible source of either mesosiderites or black chondrites. These alternatives could be discriminated by determining an albedo for this asteroid. 974 Lioba is an S(IV) asteroid with a surface silicate assemblage consisting primarily of orthopyroxene, ($Fs_{21}(\pm5)Wo_8$ ($\pm$3)) and olivine (BAR~0.6). The calculated delivery efficiency (24.5%) and derived mineralogy indicate that 974 Lioba is a plausible parent body for the LL-type ordinary chondrites, or possibly for L-type ordinary chondrites.

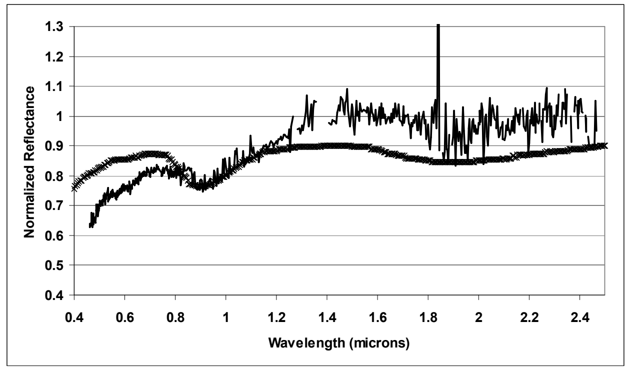

Figure 2

References: [1] P. Farinella et al. (1993) *Icarus* 101, 174-187. [2] A. Morbidelli et al. (1995) *Icarus* 114, 33-50. [3] A. Morbidelli et al. (1995) *Icarus* 115, 60-65. [4] J.H. Ji et al. (2007) *Chin. J. Astron. Astrophys* **7**, 148-154. [5] J. Wisdom (1985) *Icarus* 63, 272-289. [6] W.F. Bottke et al. (2000) *Icarus* 145, 301-331. [7] W.F. Bottke et al. (2006) *Ann. Rev. Earth Planet. Sci.* 34, 157-191. [8] P. Farinella et al. (1999) *Science* 283, 1507-1510. [9] R. Greenberg et al. (1983) *Icarus* 55, 455-481. [10] W.F. Bottke et al. (2005) *Icarus* 179, 63-94. [11] B.J. Gladman et al. (1997) *Science* 277, 197-201. [12] D.L. Rabinowitz (1997) *Icarus* 127, 33-54. [13] P. Farinella et al. (1994) *Nature* 371, 315-317. [14] T.B. McCord et al. (1970) *Science* 168, 1445-1447. [15] M.J. Gaffey et al. (1992) *Icarus* 100, 95-109. [16] M.J. Gaffey et al. (1998) *Meteoritics & Planet. Sci.* 33, 1281-1295. [17] K. Keil (2000) *Planet. Space Sci.* 48, 887-903. [18] M.J. Gaffey et al. (2002) *Asteroids III* Univ. of Arizona Press, pp. 183-204. [19] P.S. Hardersen et al. (2005) *Icarus* 175, 141-158. [20] T.L. Roush et al. (1986) *J. Geophys. Res.* 91, 10301-10308. [21] R.B. Singer et al. (1985) *J. Geophys. Res*. 90, 12434-12444. [22] J.B. Adams (1974) *J. Geophys. Res.* 79, 4829-4836. [23] E.A. Cloutis et al. (1991) *J.Geophys. Res. (Planets)* 96, 22809-22826. [24] M.J. Gaffey (1976) *J. Geophys. Res*. 81, 905-920.

Acknowledgements: This work was supported by NASA Headquarters under the NASA Earth and Space Science Fellowship Program Grant 08AW0414 (SFB) and by NASA Planetary Geology and Geophysics Grant NNX07AP73G (MJG).