**Near-infrared Spectroscopy of 3:1 Kirkwood Gap Asteroids 695 Bella, 714 Ulula, and 3066 McFadden.**

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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 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 $\nu_6$ secular resonances [1-4].

Asteroids and collisionally-ejected fragments with semi-major axes in the range of 2.47-2.53 AU 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 ($10^6$–$10^7$years) transferred to Earth- and Mars-crossing orbits making the 3:1 resonance a major potential source for meteorites and near-Earth asteroids [10-13].

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 Eger, and 6 Hebe account for ~40% of terrestrial meteorite falls. Thus, the sources of ~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.

Near-infrared data (0.8-2.5 µm) for most asteroids adjacent to the 3:1 resonance have not been published. The NIR spectral coverage is needed for detailed characterizations of their surface minerals. This research explores possible links between three asteroids located near the 3:1 resonance (695 Bella, 714 Ulula, and 3066 McFadden) and potential meteorite analogs in the terrestrial collections.

**Observations/Data Reduction:** Near-infrared spectra were obtained on the nights of May 25, 2009 (695), May 23, 2008 (714), and November 18, 2002 (3066) 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 Bella, Ulula, and McFadden. The increased noise and/or fine structure near 1.4 & 1.9 µm are due to imperfect correction of atmospheric water absorptions.

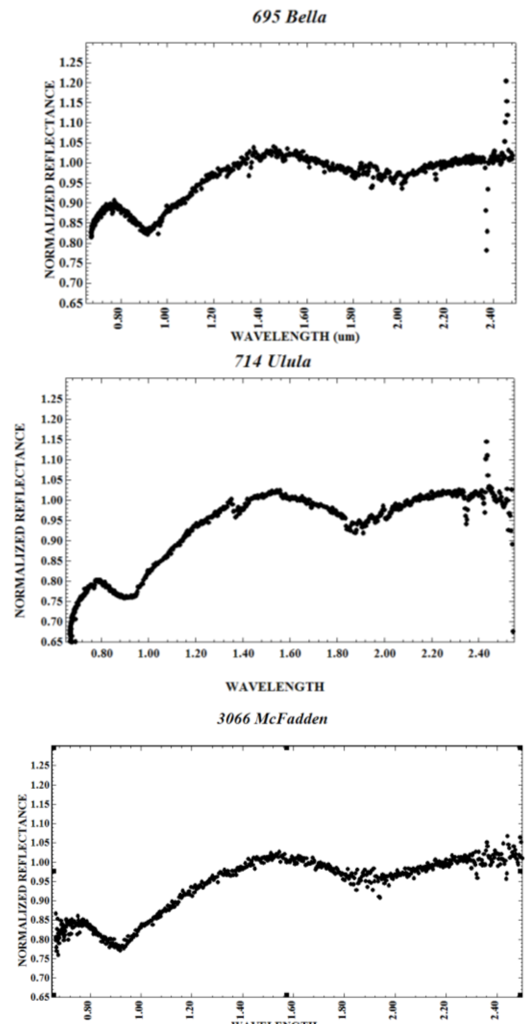


**Figure 1**

**Analysis:** The spectra of Bella, Ulula, and McFadden exhibit two absorption features typical of olivine-pyroxene mixtures. After dividing each spectral interval by a straight-line continuum, band centers were determined by fitting an n-order polynomial to each feature. The calculated Band I & II centers for each asteroid are listed in Table 1.

**Table 1**

| | 695 | 714 | 3066 |
|---|---|---|---|
| **Band I** (μm) | 0.93 ± .01 | 0.92 ± .01 | 0.92 ± .01 |
| **Band II** (μm) | 1.92 ± .04 | 1.93 ± .02 | 1.91 ± .01 |
| **BAR** | 1.00 ± .20 | 1.40 ± .15 | 1.33 ± .05 |
| **Avg Pyx Composition** | $Fs_{14}$ (±5) $Wo_2$ (±3) | $Fs_{34}$ (±5) $Wo_3$ (±3) | $Fs_{29}$ (±5) $Wo_5$ (±4) |

Band centers were plotted on the Band I vs. Band II plot [20-21] (Fig. 2). Bella plots within the HED and H&L-chondrite regions. Ulula and McFadden are outside the ordinary chondrite and on the outer edge of the HED regions. The three asteroids lie along the pyroxene trend line indicating assemblages composed primarily of orthopyroxene. Using equations outlined by [18], the chemical composition of the average pyroxene for each asteroid was calculated and listed in Table 1. The derived mineralogy for Bella (~$Fs_{14}$~$Wo_2$ ) is just below the lower limit of the H-chondrites (~$Fs_{14.5-18;}$~$Wo_{6-7}$), but given the uncertainties, it is consistent with an H-assemblage. Ulula's and McFadden's pyroxene chemistries are consistent with the chemistries of the mesosiderites/HED meteorites. Spectrally neutral phases such as feldspar (common in eucrites and basalts) could also be present, but species such as olivine, which have significant absorption features are either rare or absent. Using the calculated BAR and Band I center values, each asteroid was plotted on the S-Asteroid sub-type plot (Fig. 3) derived by [22] Bella lies within the H-chondrite portion of the S (IV) region, while Ulula and McFadden lie within the S (V) region.

**Conclusions:** The pyroxene features and measured parameters of 695 Bella suggest an additional possible source of the H-chondrites. Ulula and McFadden indicate assemblages spectrally dominated by pyroxene. The calculated composition of the average pyroxene in the surface material of Ulula and McFadden are consistent with a mesosiderite pyroxene and are potential sources of mesosiderites. Bella, Ulula, and McFadden are members of the Maria Family[23].

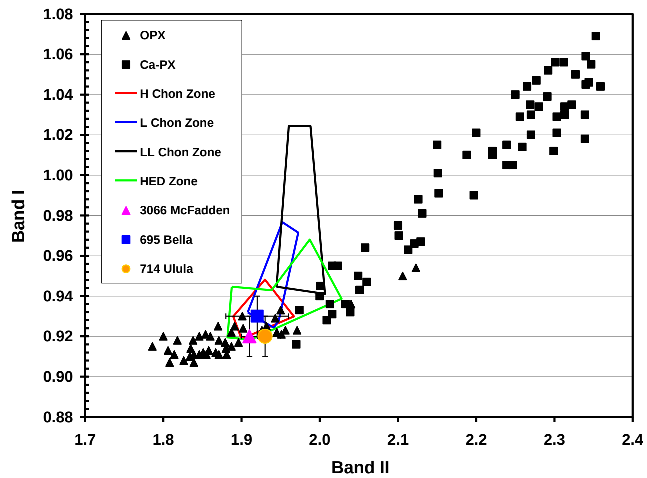


**Figure 2**

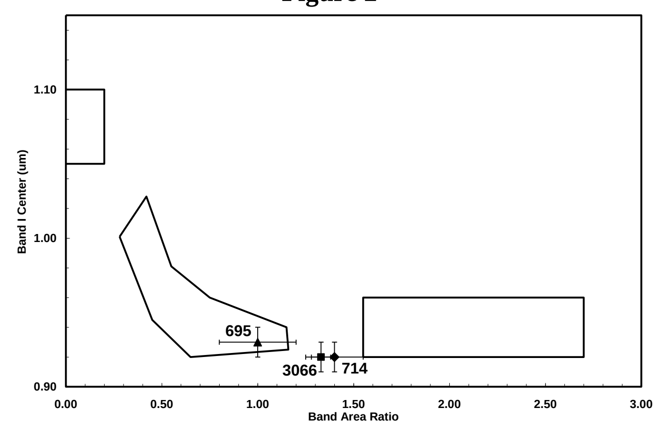


**Figure 3**

**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) MAPS 33, 1281-1295. [17] K. Keil (2000) *Planet. Space Sci.* 48, 887-903. [18] M.J. Gaffey et al. (2002) *Asteroids III* U. Arizona Press, pp. 183-204. [19] P.S. Hardersen et al. (2005) *Icarus* 175, 141-158. [20] J.B. Adams (1974) *JGR* 79, 4829-4836. [21] E.A. Cloutis et al. (1991) *JGR. (Planets)* 96, 22809-22826. [22] M.J. Gaffey et al. (1993) *Icarus* 106, 573-602. [23] V. Zappalà et al., (1995) *Icarus* 116, 291-314.

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