Near-infrared Spectroscopy of 3:1 Kirkwood Gap Asteroids III. S. K. Fieber-Beyer[1,2] & M. J. Gaffey[1,2]. [1]Dept. of Space Studies, Box 9008, Univ. of North Dakota, Gr& Forks, ND 58202. [2]Visiting astronomer at the IRTF under contract from the NASA, which is operated by the Univ. of Hawai'i Mauna Kea, HI 97620. sherry-fieb@hotmail.com gaffey@space.edu

Introduction: The mineralogy, petrology, isotope chemistry, and chronology of the meteorites provide insights into the processes & conditions of the early solar system & the relative timing of major processes & events that occurred in the evolving early inner solar system. However, the spatial locations of these events & processes are not well constrained because specific parent bodies of most meteorite types have not yet been identified. Since most of the larger main belt asteroids are still located near their relative heliocentric formation distances, they provide a glimpse of the distribution of inner solar system materials during the formation epoch. Meteorites represent fragments of main belt asteroids that escaped into Earth-crossing orbits, many via the chaotic zones associated with the proper motion & secular resonances with Jupiter &/or Saturn [e.g.1,2]. Similarly, most near-Earth asteroids appear to have originated in the main belt & escaped through these same resonances assisted by the Yarkovsky effect. Researchers use meteorites and asteroids to understand nebular processes & history to formulate & constrain models of the early solar system [e.g., 3-8].

The Kirkwood Gaps (KG) are severely depleted zones in the asteroid belt located at proper motion resonances with Jupiter. Objects in the chaotic regions associated with the 3:1 KG experience large variations in their eccentricities (e) which ultimately remove asteroids/asteroids fragments from the resonance. Theoretical models indicate the majority of asteroidal material delivered to the inner solar system, particularly to the Earth, originates from the 3:1 & ν_6 resonances [2, 9-15]. Asteroids & collisionally-ejected fragments with semi-major axes (a) in the 2.47-2.53 AU range undergo chaotic orbital evolution on short timescales [1]. Changes in (e), (i), & (a) due to gravitational encounters with planets and non-gravitational forces such as collisions with other asteroids & Yarkovsky/YORP effects can deliver nearby meter-to-kilometer scale objects into the chaotic zone of the 3:1 KG [1, 15-19]. These objects are rapidly transferred to Earth- and Mars-crossing orbits making the 3:1 KG a major source for meteorites and NEAs [19-22]. Collisions play a vital role in liberating meteoroids from their parent bodies. Once liberated, the fragments are subjected to gravitational forces & the Yarkovsky/YORP, which are key in delivering bodies from their source region to the chaotic zones capable of moving material into near-Earth space [23]. These fragments spend a majority of their dynamical lifetime undergoing chaotic orbital evolution such that the actual time required to reach a planet crossing orbit ranges from several Myr to Gyr, which accounts for the paucity of long cosmic ray exposure ages seen among the stony meteorites [17]. The shallow size distribution of NEOs suggests collisional injection into the resonance is not the sole mechanism supplying meteorites and NEOs, however an interplay between collisions, Yarkovsky, and YORP act together to bring a robust number of fragments into the resonance [17].

[12] developed The Fragment Injection Model, which predicted specific asteroids that could efficiently deliver material from the 3:1 KG into Earth-crossing orbits via collision/impact acceleration. Even the fragments not directly inserted into the resonance have a high probability of making it to the resonance's chaotic zone via the Yarkovsky effect. Since the chaotic zone of the 3:1 KG is not dominated by any one particular assemblage, observation & characterization of individual 3:1 KG objects is necessary to test possible meteorite affinities [24 -28].

Probable parent bodies have been identified for only five [25, 29-31] of the ~135 meteorite classes [32]. These parent bodies (4) Vesta (HEDs), (3103) Eger (enstatite achondrites/aubrites), (6) Hebe/ (695) Bella (H- chondrites & IIE iron meteorites), & the Maria Asteroid Family (mesosiderites) account for ~40% of terrestrial meteorite falls. Thus, the sources of ~60% of the meteorite flux & ~97% of the meteorite classes still need to be accounted for. Asteroids within the "feeding zone" of the 3:1 KG are candidates for parent bodies. Previous spectral studies of a small set of asteroids near the 3:1 KG in search of the parent bodies of the ordinary chondrites were limited to VNIR spectra [33-37]. Such limited wavelength coverage does not permit detailed mineralogical analysis required to rigorously test meteorite affinities. This research has provided validation of the original work of [36] & has linked several asteroids as probable or plausible parent bodies for some meteorite types as well as the discovery of a small H-chondrite family [38].

Observations & Data Reduction: NIR spectra of asteroids (335), (1368), (1447), (1587), (1854), (2497), & (5676) were taken at the NASA IRTF using the SpeX instrument [39] in the low-res spectrographic mode. Asteroid & standard star observations were interspersed within the same airmass range to allow modeling of atmospheric extinction. Data reduction was done using previously outlined procedures [40,41].

The particular subset of asteroids presented here each have absorption features located near 1- & 2- μm. The band centers & band area ratios (BAR) are diagnostic of abundance & composition of the mafic silicates [e.g.,40-49] & are measured relative to a linear continuum fit tangent to the spectral curve outside the absorption feature [e.g. 44]. To estimate the error, several polynomial fits were used sampling different ranges of points within the Band I & II spectral intervals. The uncertainty was estimated from the difference between the range of determined values.

Analysis: After initial measurement of the Band I & Band II centers, the pyroxene chemistry is determined using [40]. If the pyroxene chemistry is consistent with an HED assemblage, the [48] equations are used to verify the pyroxene chemistry and if the pyroxene chemistry is consistent with an ordinary chondrite assemblage the [49] equations are applied as verification of the derived silicate mineralogy. Meteorite affinities have been identified & reported in Table 1.

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[a]The pyroxene Fs & Wo value were derived using Gaffey et al. 2002
[b]The pyroxene Fs & Wo value were derived using Burbine et al. 2007
[c]Fs and Fa value was derived from Dunn et al. 2010
[d]The olivine abundance was calculated using Gastineau-Lyons et al. 2002

Asteroid	Band I μm	Band II μm	T- corr Band II μm	BAR	Band Depth I ;II (%)	Pyx Chemistry	Ol	Meteorite Affinity
355	0.96 ± .01	1.92 ± .05	1.95	0.52 ± .09	6;14	$Fs_{24.3(\pm5)}Wo_{9.1(\pm3)a}$ $Fs_{20.3(\pm1.4)}Fa_{23.8(\pm1.3)c}$	0.61[d]	L-Chondrite
1368	0.93 ± .01	1.95 ± .05	1.97	1.58 ± .15	12;8	$Fs_{44.6(\pm5)}Wo_{8.7(\pm4)a}$ $Fs_{39.6(\pm3)}Wo_{8.5(\pm1)b}$	0.29[a]	HED - howardite
1447	0.97 ± .02	1.96 ± .02	2.00	0.71 ± .20	6;8	$Fs_{26.9(\pm5)}Wo_{9.0(\pm3)a}$ $Fs_{21.3(\pm1.4)}Fa_{25.5(\pm1.3)c}$	0.56[d]	L-Chondrite
1587	0.94 ± .01	1.87 ± .02	1.88	1.44 ± .03	18;10	$Fs_{20.5(\pm5)}Wo_{9.1(\pm4)a}$ $Fs_{35.4(\pm3)}Wo_{6.9(\pm1)b}$	0.35[a]	unknown
1854	0.93 ± .01	1.89 ± .03	1.90	1.44 ± .11	15;8	$Fs_{25.8(\pm5)}Wo_{4.5(\pm4)a}$ $Fs_{32.4(\pm3)}Wo_{5.7(\pm1)c}$	0.35[a]	unknown
2497	0.93 ± .01	1.90 ± .04	1.92	1.44 ± .33	10;14	$Fs_{31.2(\pm5)}Wo_{8.7(\pm4)a}$ $Fs_{34.4(\pm3)}Wo_{6.5(\pm1)b}$	0.65[a]	HED - diogenite
5676	0.92 ± .01	1.93 ± .03	1.95	1.43 ± .23	11;14	$Fs_{39.3(\pm5)}Wo_{4.5(\pm4)a}$ $Fs_{32.4(\pm3)}Wo_{5.7(\pm1)b}$	0.65[a]	HED - diogenite