Icarus 257 (2015) 113–125

Contents lists available at ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus

Near-infrared spectroscopy of 3:1 Kirkwood Gap asteroids III

Sherry K. Fieber-Beyer [*,1], Michael J. Gaffey [1]

Department of Space Studies, University Stop 9008, University of North Dakota, 58202, United States

ARTICLE INFO

Article history:
Received 5 March 2015
Revised 15 April 2015
Accepted 24 April 2015
Available online 6 May 2015

Keywords:
Asteroids
Resonances, orbital
Asteroids, composition
Infrared observations
Mineralogy

ABSTRACT

The research is an integrated effort beginning with telescopic observations and extending through detailed mineralogical characterizations to provide constraints on the composition and meteorite affinities of a subset of fourteen asteroids in/near the 3:1 Kirkwood Gap. Eight asteroids were identified as having either one or two absorption features, while six were deemed featureless. The compositional analysis of Asteroids (*355*) Gabriella and (*1447*) Utra reveal Fs and Fa values which are consistent with values for the L-type ordinary chondrites (Fs_{19-22} and Fa_{22-26}). The location of these two bodies with respect to each other and to the previously identified L-chondrite parent body Asteroid (*1722*) Goffin, suggests a small L-chondrite genetic family. These results support the model that the L-chondrites come from an asteroid family rather than from a single object. Asteroids (*1368*) Numidia, (*1587*) Kahrstadt, (*1854*) Skvortsov, (*2497*) Kulikovskij, and (*5676*) Voltaire were analyzed and determined to have "basaltic" silicate mineralogies similar to those of the HED (howardite–eucrite–diogenite) meteorite group. In particular, we found that the compositions of (1368), (1587) and (1854) are consistent with olivine-orthopyroxenitic diogenites, while (2497) and (5676)'s compositions are consistent with harzburgitic diogenites. The Band I and Band II absorption feature depths are much shallower than seen in diogenite spectra, typically ~70% depth (Burbine, T.H. et al. [2000]. Forging asteroid–meteorite relationships through reflectance spectroscopy. Lunar Planet. Sci. XXXI. Abstract 1844). The nature of the weak features seen in the asteroid spectra when compared to measured band depths of in situ diogenite samples indicate an additional mechanism(s) acting to weaken the features, most likely space weathering. The aforementioned five asteroids are plausible sources for the olivine-orthopyroxenitic diogenites and harzburgitic diogenites, and very well may be fragments of Vesta. Asteroid (*46*) Hestia is an interesting object whose surface minerals may be consistent with a CR2 chondrite; however, the unique spectrum deserves further study in the future. Featureless Asteroids (*248*) Lameia, (*1960*) Guisan, (*3345*) Tarkovskij and (6212) 1993 MS1 surface materials are likely organic assemblages consistent with the Type 1 or 2 carbonaceous chondrite meteorite class; however specific terrestrial meteorite analog could not be identified. The spectra of Asteroids (*3228*) Pire and (*3999*) Aristarchus are consistent with each other and have been assigned to the Eulalia by Walsh et al. (Walsh, K.J. et al. [2013]. Icarus 225, 283–297). Spectrally they are similar to (*495*) in terms of blue-slope and albedo (Fieber-Beyer, S.K., et al. [2012]. Icarus 221, 593–602), thus increasing our confidence the three bodies are truly related dynamically and genetically. By extrapolation and due to their location adjacent to the 3:1 Kirkwood Gap, (*3228*) and (*3999*) are plausible sources of the $CV3_{OXB}$ carbonaceous chondrites.

1. Introduction

Understanding the nature of and the relationships between asteroids and meteorites is vital in understanding the nature and processes of the late solar nebula and the earliest Solar System. The main belt asteroids between Mars and Jupiter are the sole surviving pristine remnants of the inner Solar System's early planetesimal and planetary embryo populations. Although most of the asteroid parent bodies of the meteorites arriving at Earth have experienced significant post-accretionary heating (e.g., Keil, 2000), this heating event predated the formation of the terrestrial planets. The planetesimals that accreted to form the Earth and other terrestrial planets were composed of diverse samples of heliocentrically varying nebular compositions that had been processed and modified to a greater or lesser degree by this heating event.

---

[*] Corresponding author.
E-mail address: sherryfieb@hotmail.com (S.K. Fieber-Beyer).

[1] Visiting Astronomer at the Infrared Telescope Facility, which is operated by the University of Hawaii under Cooperative Agreement No. NNX-08AE38A with the National Aeronautics and Space Administration, Science Mission Directorate, Planetary Astronomy Program.

http://dx.doi.org/10.1016/j.icarus.2015.04.034

Meteorites provide samples of some of the types of materials that were present in the early inner Solar System. The mineralogy, petrology, and chronology of the meteorites provide insights into the processes and conditions of the early Solar System and of the relative timing of major processes and events that occurred in the evolving early inner Solar System (e.g., Keil, 2000). However, the spatial locations of these events and processes are not well constrained because specific parent bodies – and hence early Solar System locations – of the majority of meteorite types are yet to be identified.

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 centered at 2.50 AU are subject to excited eccentricities (e) which ultimately remove asteroids/asteroid 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 and ν_6 resonances (Ji and Liu, 2007; Tedesco et al., 2002; Bycova and Galushina, 2001; Farinella et al., 1993a; Morbidelli and Moons, 1995; Hadjidemetriou, 1993; Yoshikawa, 1990). For the 3:1 Kirkwood Gap, asteroids and collisionally-ejected fragments with semi-major axes (a) in the 2.47–2.53 AU range undergo chaotic orbital evolution on short timescales (Wisdom, 1985). Changes in (e), (i), and (a) due to gravitational encounters with planets and non-gravitational forces such as collisions with other asteroids and Yarkovsky/YORP effects can deliver nearby m-kms scale objects into the chaotic zone of the 3:1 KG (Bottke et al., 2000, 2006; Farinella et al., 1993b; Wisdom, 1985; Rabinowitz, 1997; Yoshikawa, 1990). These objects are rapidly transferred to Earth- and Mars-crossing orbits making the 3:1 Kirkwood Gap a major source for meteorites and NEAs (Bottke et al., 2005; Gladman et al., 1997; Rabinowitz, 1997; Farinella et al., 1994).

Collisions play a vital role in liberating meteoroids from their parent bodies (e.g. Farinella et al., 1993a, 1993b; Morbidelli and Moons, 1995). Once liberated, the fragments are subjected to gravitational forces and the Yarkovsky/YORP effects, which are key in delivering bodies ($D < 20$ km) from their source region to the chaotic zones capable of moving material into near-Earth space (Bottke et al., 2001). 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 a Myr to Gyr, which accounts for the diversity of long cosmic ray exposure ages seen among the stony and iron meteorites (Bottke et al., 2006). 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 (Bottke et al., 2006).

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. With a few exceptions, meteorites represent fragments of main belt asteroids that have escaped into Earth-crossing orbits, many via the chaotic zones associated with the proper motion (e.g., 3:1, 5:2, etc.) and secular (e.g., ν_6, ν_{16}, etc.) resonances with Jupiter and/or Saturn (Ji and Liu, 2007; Tedesco et al., 2002; Bycova and Galushina, 2001; Farinella et al., 1993a; Morbidelli and Moons, 1995; Hadjidemetriou, 1993; Yoshikawa, 1990). Similarly, most near-Earth asteroids appear to have originated in the main belt and escaped through these same resonances assisted by the Yarkovsky effect. Researchers have long used meteorites and asteroids to understand nebular processes and history and used them to formulate and constrain models of the early Solar System (e.g., Chapman and Salisbury, 1973; Gaffey and McCord, 1978, 1979; see proceedings volumes by Kerridge and Matthews, 1988; Lauretta and McSween, 2006; Davison et al., 2013).

Currently, probable parent bodies have been identified for only six (McCord et al., 1970; Gaffey et al., 1992; Gaffey and Gilbert, 1998; Fieber-Beyer et al., 2011b; Vernazza et al., 2008) of the ~135 distinguishable meteorite classes (Keil, 2000). These parent bodies (*4*) Vesta (HEDs), (*3103*) Eger (enstatite achondrites/aubrites), (*6*) Hebe/(*695*) Bella (H-type ordinary chondrites and IIE iron meteorites), the Maria Asteroid Family (mesosiderites), and the Flora Asteroid Family (LL-chondrites) 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 candidates for such parent bodies.

Several previous studies spectrally sampled a small set of asteroids near the 3:1 resonance; however the spectral coverage was limited to VNIR (~0.3–0.95 μm) spectra (Chapman and Gaffey, 1979; McFadden et al., 1984; McFadden and Vilas, 1987; McFadden and Chamberlain, 1991; Vilas and McFadden, 1992). The VNIR wavelength range is suggestive of the surface mineralogy, but is limited by the incomplete Band I coverage and the absence of Band II coverage when performing the detailed mineralogical analysis needed to test possible meteorite affinities. Additionally, ambiguities introduced by space weathering severely undermine the validity of any putative asteroid–meteorite links derived from curve matching, requiring the use of interpretive methodologies insensitive to space weathering (Gaffey, 2001; Gaffey, 2010).

The results currently reported are a continuation of previous spectroscopic investigations of asteroids in/near the 3:1 Kirkwood Gap (Fieber-Beyer and Gaffey, 2014, 2011; Fieber-Beyer et al., 2012, 2011a, 2011b; Fieber-Beyer, 2010). A total of fourteen 3:1 Kirkwood Gap asteroids are described in this paper: six are featureless and eight exhibit either one or two absorption features in the near-infrared.

2. Observations/data reduction

Near-infrared spectral observations were obtained at the NASA Infrared Telescope Facility located on Mauna Kea, Hawai'i. The observational parameters from the observing run are listed in Table 1. Physical properties and osculating orbital elements are listed in Table 2. The spectra were obtained using SpeX in the low-resolution spectrographic mode (Rayner et al., 2003). The first spectrum of each set was discarded due to image persistence on the detector chip and others were discarded due to poor quality because of deteriorating weather conditions.

Asteroid and local standard star spectra were acquired in sets of ten. The spectral observations of the star and asteroids were interspersed (SASASA...) and acquired within the same air mass range to give optimal modeling of atmospheric extinction ("starpacks"). Extraction of spectra, determination of wavelength calibration, and data reduction were done using procedures outlined by Clark (1980), Gaffey (2003), Hardersen et al. (2005), Reddy (2009) and Fieber-Beyer (2010). Individual raw flux spectra were corrected to a standard pixel array to compensate for the generally subpixel shifts of the dispersed spectrum on the array detector. Each asteroid flux curve was divided by the starpack that most effectively removed the atmospheric water vapor features to produce a final spectrum. We averaged the individual spectra for each object, deleting points that deviated by more than two standard deviations from the mean. Each asteroid's average spectrum was then ratioed to an average of the solar analog spectra for their respective night to correct for any non-solar spectral properties of the local standard star.