

MULTIPLE ASTEROID SYSTEMS: NEW TECHNIQUES TO STUDY NEW WORLDS. F. Marchis^{1,2,3}, M. Baek¹, J. Berthier³, P. Descamps³, J. P. Emery², B. Macomber¹, J. Pollock⁴, F. Vachier³, ¹Carl Sagan Center at SETI Institute, CA Mountain View USA (fmarchis@seti.org), ²Dept of Astronomy at UC-Berkeley, Berkeley CA, USA, ³IMCCE-Obs de Paris, Paris, France, ⁴Appalachian State University, dept of Physics and Astronomy, Boone, NC, USA

Introduction: In 1993, the existence of asteroid companions was confirmed without ambiguity when the Galileo spacecraft collected high resolution images of (243) Ida and its satellite Dactyl [1]. To date, ~160 multiple asteroid systems have been discovered (Table 1) in each population of small solar system bodies.

Techniques of observations: We will discuss the recent discoveries in this field, focusing on new techniques which have been used to better determine the characteristics of these systems:

- *Stellar occultations* by an asteroid and its companion were observed successfully using astrometric predictions from our orbital models [2,3] and a large number of observers. The stellar occultation provided independent estimates of the size and shape of i) (22) Kalliope and its companion Linus [4], ii) and the two components of (90) Antiope [5]

- *The photometric signature of mutual events* between a primary and its small satellites also enable accurate determination of sizes. We successfully predicted [6] and observed [4] the mutual events between (22) Kalliope and its companion Linus provided a significantly higher bulk density for this M-type asteroid ($3.35 \pm 0.33 \text{ g/cm}^3$) than [7,8].

- The *complex lightcurve* of (3749) Balam recorded in 2007 [9] revealed the triple nature of this asteroid, which possesses a binary central object. The third and more distant companion was discovered by Adaptive Optics (AO) observations in 2002 [10]. There are two other known multiple systems located in the main-belt (45 Eugenia and 87 Sylvia), two in the Trans-Neptunian object (TNO) population (134430 Pluto, 136108 2003EL₆₁), and 2001SN₂₆₃, a Near Earth asteroid, with two satellites recently discovered by radar observations. The bulk density of Balam, an S-type asteroid system (2.6 ± 0.1 [10]), is significantly higher than the density of C-group binary asteroids ($\sim 1.1 \text{ g/cm}^3$) [2].

- *High angular resolution imaging* recorded using ground-based 8-10m class telescopes equipped with AO systems, and the Hubble Space Telescope, are commonly used to search and study multiple systems [2,3,4,11,12]. 68 multiple systems can be resolved with current instrumentation, including 53 TNOs. Spectroscopic studies which were recently initiated, combined with new AO technology (Laser Guide Star system), will help to constrain the origin of these systems.

- *Thermal infrared spectroscopic* observations of 25 multiple asteroid systems are being conducted using the Spitzer telescope and its IRS instrument. The thermal flux spectra are used to measure the size, albedo, and thermal inertia, leading to an estimate of the bulk density [13,14]. The Mid-IR emissivity spectra will help to infer the composition of their surface [13].

Future work: We will discuss the need for future intensive spectroscopic studies of these multiple systems to better constrain their possible meteorite analog, and thus refine their porosities. We will discuss future theoretical work aimed at explaining the formation and evolution of several members of this population.

References: [1] Belton et al., (1994) IAU 5948, 2 [2] Descamps et al., (2007), Icarus, 187, 482 [3] Marchis et al. (2008a) in press to Icarus [4] Descamps et al. (2008) in press to Icarus [5] Hayamisu et al. (2008) CBET 1263, 1 [6] Descamps et al. (2008b) in press PSS. [7] Marchis et al., (2003) Icarus, 165, 122 [8] Margot et al. (2003) Science 300, 1939 [9] Marchis et al. (2008) IAUc, 8928, 2 [10] Merline et al. (2002) IAU 7827 [11] Marchis et al., (2008b) Icarus, in press [12] Noll et al., (2008) The Kuiper Belt [13] Marchis et al. (2008) ACM poster session [14] Michalowski et al. (2008) ACM poster session.

Population	Total
NEA	12
Aten	5
Amor I	7
Amor II	14
Amor III	3
MB	34
MB I	8
MB II	4
MB IIb	5
MB IIIa	4
MB IIIb	6
Jupiter-Trojan	4
Cubewanos	33
Plutinos	9
SDO	8
KBO	3
Grand Total	159

Table 1: List of companions of minor planets per population (based on SKYBOT population class, see <http://skybotdoc.imcce.fr/?class>)