Scientific Report – Kevin Walsh – Nice, France - 6-June to 15-June
ESF Short Visit Grant (Ref 4967)

Title: “Understanding the Inner Asteroid Belt – Sources for Primitive NEAs”
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Visit: 6-June-2012 to 15-June-2012 (10 days)

Purpose of visit:
I made a short visit at the Observatoire de Nice as part of a continuing collaboration working to understand the origin and properties of the primitive near-Earth Objects (NEO). Myself and collaborator Marco Delbo had recently published a detailed study of a particularly accessible primitive NEO, 1996 FG3, which is the proposed target of the Marco Polo-R sample return space mission (Walsh et al. 2012).

There are currently two funded and one proposed sample-return space missions to primitive NEOs. Because NEOs are merely visitors to NEO-space we don’t know *a priori* where in the Asteroid Belt they came from or where they could have formed. We lack context for any sample that is eventually returned, and therefore myself and Dr. Delbo in Nice have been working to understand the primary source regions for NEOs and develop a strategy to characterize them using current tools and future GAIA observations.

Each of these three space-mission targets are almost certainly (>90%) delivered from the inner region of the Main Asteroid belt (with semi-major axes between 2.1 < *a* < 2.5 AU), following the well-studied dynamical pathway from the Main Beltto NEO-orbits (Bottke et al. 2000,2002). More specifically, they appear to have come from the ν6 resonance at 2.15 AU, which is the dominant supplier of NEOs (Bottke et al. 2002), and their current low inclination is indicative of similarly low inclination orbits in the Main Belt. The low-albedo and low-inclination part of the inner Main Asteroid belt is dominated by the low-albedo members of the “Nysa-Polana complex”, and a larger and seemingly diffuse population of background asteroids (Cellino et al. 2001, Gayon-Markt et al. 2012). The Nysa- Polana complex has been proposed to be the origin of all three of these space mission targets due to similar taxonomies (C- or B-type) and because the family is so extended that its smallest members are now being delivered to the ν6 resonance (Campins et al. 2010, 2012; Walsh et al. 2012).

This previous work motivated our continued study of the main asteroid families in this region beyond just the members of the Nysa-Polana complex: Erigone, Sumlamitis, Clarissa. At the same time, we are beginning to realise the significant contribution made by the background population. It may be more than simply random – rather there are hints that it is an ancient asteroid family.

Therefore we are preparing for a study of these populations using the GAIA low resolution slitless spectrometer (BP/RP), which is ideal for a population study of this breadth. With a better census of each families' population, accurate orbital elements, and spectral data we can start to reconstruct the history of the inner Main Asteroid Belt and start to link accessible NEOs with families of different composition.

Description of work carried out and main results:

The work done in Nice was focused on understanding the structure of the inner main asteroid belt. Primarily, we focused on the location and sizes of the largest low-albedo asteroid families. With results from recent surveys in various wavelengths we can really start to distinguish between different families by isolating different types of asteroids and searching for families among similar populations.

The so-called Nysa-Polana complex of asteroids is a diverse and widespread group that was proposed by Cellino et al. (2001,2002), and a list of family members was recently updated and published by Nesvorny (2010). It carries the name of two asteroids because it appears to be two very close and overlapping families of different asteroid taxonomies: (44) Nysa is an E-type asteroid with the lowest number in the midst of a predominantly S-type cluster and (142) Polana is a B-type asteroid near the B- and C-type cluster (see Campins et al. 2010 Fig. 1). This overlap causes problems for determining family membership when there was no reliable colors or spectra, and has frustrated detailed study.

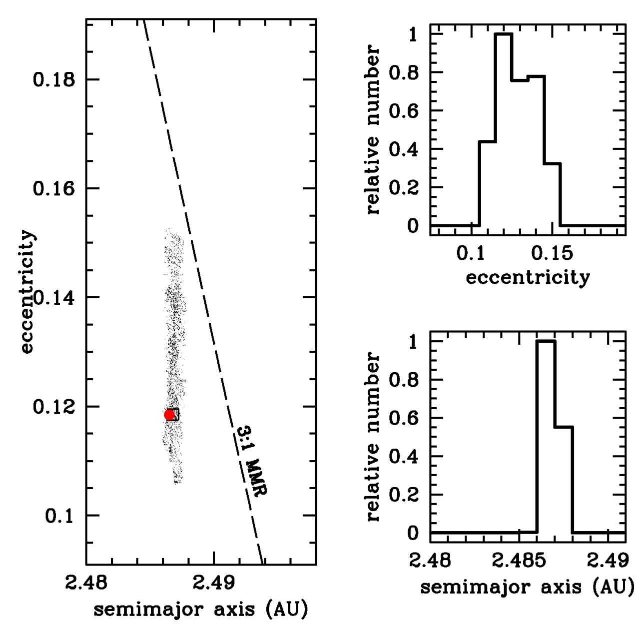


Illustration 1: The evolution over 500 Myr of 200 clones of (495) Eulalia. The left panel shows a large red dot as the starting location for one body, the dots show the evolution of the orbits averaged over 10 Myr timescales, and the dashed line is the nominal location of the 3:1 MMR plotted as eccentricity as a function of semimajor axis. The square marks the current proper elements of (495) Eulalia, and these simulations show that bodies on similar orbits can diffuse dramatically in eccentricity on 100~Myr timescales. The panel on the upper right shows the relative time spent for 200 clones of Eulalia at different eccentricity – finding that its diffusion over time leaves it equally likely to have any eccentricity between 0.1-0.15.

Separating the Nysa-Polana members into low albedo and high albedo bodies just became significantly easier – thanks to the results of the WISE survey (Masiero et al. 2011, Mainzer et al. 2011a,b). This survey in mid-infrared wavelengths obtained precise photometry of over 100,000 objects in a range of infrared (IR) wavelengths. Combined with previous optical studies, these observations allow for a calculation of each bodies' diameter and visible albedo (pV). We rely on this observational database to focus on only those bodies with low albedo, which is strongly correlated with primitive asteroid classes, C-, B-, D- and P-type asteroids (see Burbine et al. 2002). This is not a perfect correlation, but rather the WISE results serve as a well-calibrated net with which to catch most primitive bodies.

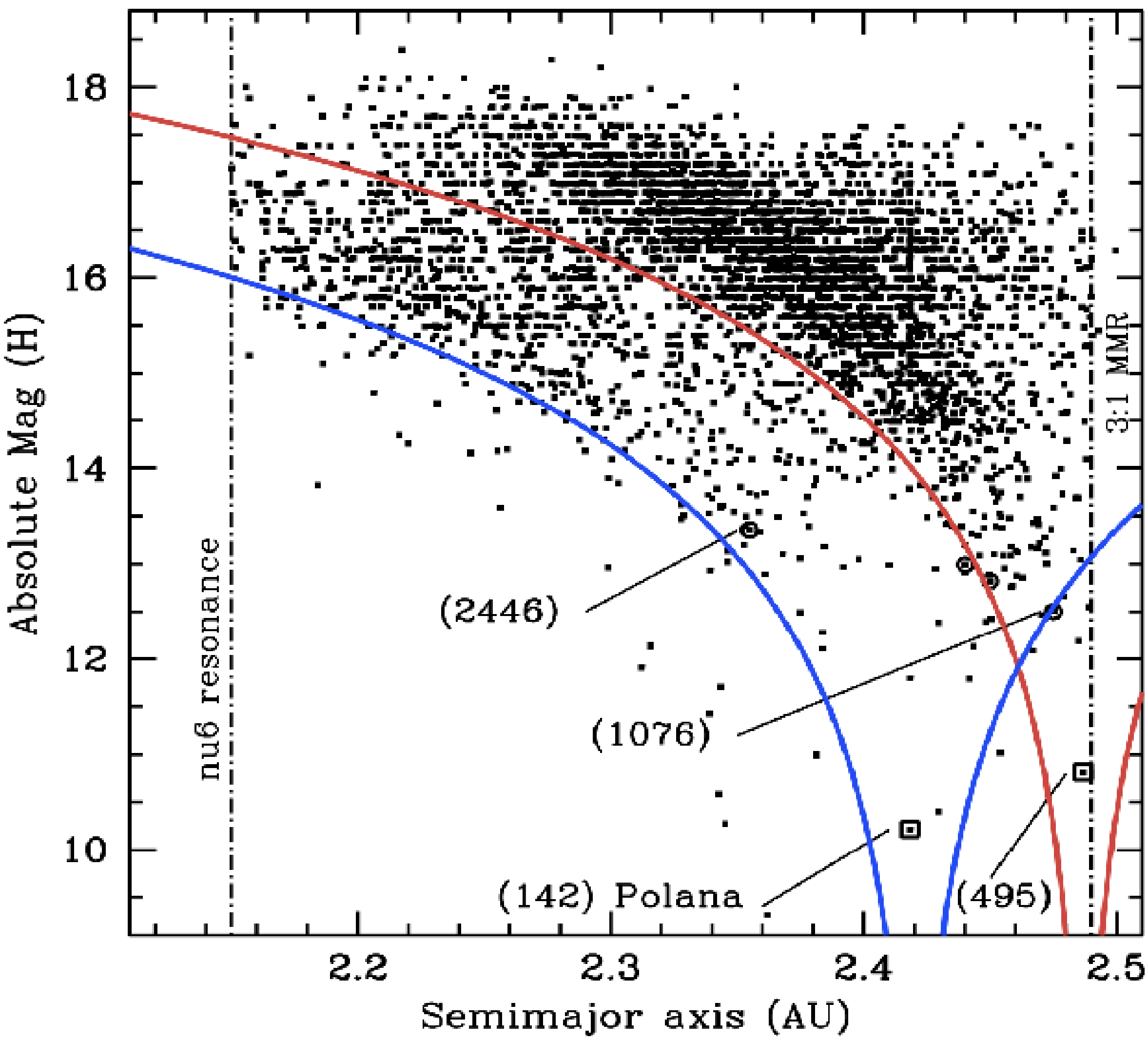
Using the WISE data we can focus on only the low-albedo bodies, and using this we have re-analyzed the region around the Nysa-Polana complex in the inner Main Belt. What we found is that (142) Polana does not appear to be a member of the family of low-albedo asteroids in the Nysa-Polana complex. Rather, our study indicates that the parent is most likely asteroid (495) Eulalia due to its placement at the ideal semimajor axis and orbital inclination. Surprisingly, this body has never before been linked to this complex for an important dynamical reason – its orbit is so close to the 3:1 mean motion resonance with Jupiter that its eccentricity diffuses (between e~0.1-0.2) over short timescales (~10 Myr) and it currently has an eccentricity slightly below the range of most of the family members (see Illustration 1 above). This strongly suggests that despite its current orbit, (495) Eulalia could have recently been at an orbit very central to the family and be its parent member. (see Illustration 2 below).

Revising the shape and parent of the Nysa-Polana complex was an important step, but recent work has shown that the background of asteroids is an even more important NEO source. Gayon-Markt et al. (2012) and Campins et al. (2012) have both noted that the background of low-albedo inner Main Belt asteroids dominate in numbers over the known low-albedo population of the Nysa-Polana complex. However, a diffuse "background" does not imply a correlation in physical properties. Also, a simple background would not be systematically expanding in a measureable way due to the Yarkovsky effect. This is the most important implication of our findings of a possible background family. If the background is a family it should be correlated physically, and it is then also systematically expanding into the ν6 resonance contributing many bodies to NEO orbits – in a way that we can quantify. According to the preliminary Yarkovsky expansion boundaries of the background family illustrated in Illustration. 2, the background family is currently sending bodies of H~16 (D~3.5 km for pV=0.055) into the ν6 resonance. Meanwhile the Nysa-Polana complex, is only sending bodies of H~18 (D~1.4 km for pV=0.055) into the ν6 resonance. The background family is contributing more and larger bodies to NEO orbits.

We found near-IR spectra for one other object on an ideal orbit (asteroid 2446) that could be a member of the proposed background family, and we have plotted it with (142) Polana which is the candidate parent for the same family (see Fig 4, de León 2012). The candidate parent body we have proposed for the low-albedo component of the Nysa-Polana complex is (495) Eulalia (see Fig. 4; Fieber-Beyer et al. 2008). There is no clear feature at 1.0 or 1.2 μm for (495) Eulalia, while there is a hint of one with (142) Polana. There is a clear slope difference between the two beyond 1.0 μm, which has recently been studied as a diagnostic tool by de León et al. (2010) and Ziffer et al. (2011). The hint of distinction between candidate background family members and a candidate Nysa-Polana family member is tantalizing.

Work in the field of linking NEOs to Main Belt source regions or specific asteroid families has accelerated recently due to planned sample return space missions (Campins et al. 2010,2012, Walsh et al. 2012). Recent progress on many fronts have made these links more viable, but we have found that there is a population that has not yet been seriously considered or closely studied. The need to characterize the background population, now proposed to be a family, is clear, and we are moving forward on this project with ground-based observing proposals (TNG fall 2012). This work will help to prepare for the deluge of optical spectra data available from GAIA in the near future.

Illustration 2: The low-albedo members of theNysa-Polana complex (the bodies bracketed by the right/red curves) and the proposed "background family" (bodies bracketed by the leftmost/blue curves). The plot includes all low-albedo asteroids from the WISE database (pV <0.1) with 2.15 < a < 2.5, inclination <10° and eccentricity between 0.1-0.2. The WISE measured absolute magnitude (H) is plotted as a function of each asteroid's semimajor axis (AU). The location of the two most important dynamical pathways (the v6 and the 3:1 mean motion resonance with Jupiter) are illustrated with dotted lines.



Future Collaboration:

The collaboration between Dr. Walsh and Dr. Delbo is quite strong. Our findings during this visit will result in at least the one publication mentioned above, and probably one or two more publications on similar projects – dynamical and observational. The current status of the collaboration is as follows:

- Dr. Delbo has proposed to host a conference in Nice next summer on similar topics that Dr. Walsh will participate in.
- Drs. Walsh & Delbo have recently submitted a proposal for the TNG (AOT26, Aug 2012 – Feb 2013) to observe asteroids in the visible and near-IR using DOLORES and NICS instruments.
- Dr. Walsh has submitted a proposal for salary and travel funding to the NASA near-Earth Observation (NEOO) that would help to support aspects of this project.

Projected Publications:

There is currently a publication in preparation authored by Walsh, Delbo and Bottke (co-resident at SwRI with Walsh). This publication details most of the results found during the ESF-funded visit by Walsh to Nice. The findings track those written above: (495) Eulalia has a highly diffusive orbits, and is a good orbital and spectral match to be the parent of the low-albedo members of the Nysa-Polana complex. We will also mention the possibility of the background family and suggest ways to study it in the future. ESF will be acknowledged in this paper that we expect to be submitted by the end of summer 2012 and published before 2013.

References:

Bottke, W.~F., Jedicke, R., Morbidelli, A., Petit, J.-M., & Gladman, B. 2000. Understanding the Distribution of Near-Earth Asteroids. Science, 288, 2190.

Bottke, W. F., Morbidelli, A., Jedicke, R., Petit, J.-M., Levison, H. F., Michel, P., & Metcalfe, T. S. 2002, Debiased Orbital and Absolute Magnitude Distribution of Near-Earth Objects Icarus, 156, 399

Burbine, T. H., McCory, T.J., Meibom, A., Gladman, B., & Keil. K., 2002, in Asteroids III, ed. W. F., Jr., Bottke, A. Cellino, P. Paolicchi, & R. P. Binzel (Tucson, AZ: Univ. Arizona Press), 633

Campins, H., Morbidelli, A., Tsiganis, K., de León, J., Licandro, J.,and Lauretta, D.: 2010, The Origin of Asteroid 101955 (1999 RQ_36). Astrophysical Journal Letters 721, L53-L57

Campins H., de León J., Morbidelli A., Licandro J., Gayon-Markt J.,, Delbo M., & Michel P., 2012 The origin of Asteroid 162173 (1999 JU3) AJ, submitted

Cellino, A., Zappala, V., Doressoundiram, A., di Martino, M., Bendjoya, P., Dotto, E., and Migliorini, F.: 2001 The Puzzling Case of the Nysa-Polana Family. Icarus 152, 225-237.

Cellino, A., Bus, S. J., Doressoundiram, A., & Lazzaro, D. 2002, in Asteroids III, ed. W. F., Jr., Bottke, A. Cellino, P. Paolicchi, & R. P. Binzel (Tucson, AZ: Univ. Arizona Press), 633

de León, J., Pinilla-Alonso, N., Campins, H., Licandro, J., & Marzo, G. A. 2012. Near-infrared spectroscopic survey of B-type asteroids: Compositional analysis Icarus, 218, 196.

Gayon-Markt, J., Delbò, M., Morbidelli, A. and Marchi, S., 2012 "On the origin of the Almahata Sitta meteorite and 2008 TC3 asteroid", MNRAS, in press (doi:10.1111/j.1365-2966.2012.21220.x).

Masiero, J.~R., Mainzer, A.~K., Grav, T., et al. 2011, Main Belt Asteroids with WISE/NEOWISE. I. Preliminary Albedos and Diameters ApJ, 741, 68.

Mainzer, A., Bauer, J., Grav, T., et al. 2011a. Preliminary Results from NEOWISE: An Enhancement to the Wide-field Infrared Survey Explorer for Solar System Science ApJ, 731, 53.

Mainzer, A., Grav, T., Masiero, J., et al. 2011b. Model Calibration for Minor Planets Observed with Wide-field Infrared Survey Explorer/NEOWISE. ApJ, 736, 100.

Nesvorny, D., 2010. Nesvorny HCM Asteroid Families V1.0. EAR-A-VARGBDET-5-NESVORNYFAM-V1.0. NASA Planetary Data System.

Walsh, K. J., Delbo, M., Mueller, M., Binzel, R. P., DeMeo, F. E., 2012 Physical characterization and origin of binary near-Earth asteroids (175706) 1996 FG3. ApJ 748, 104.

Ziffer, J., Campins, H., Licandro, J., Walker, M. E., Fernandez, Y., Clark, B. E., Mothe-Diniz, T., Howell, E., and Deshpande, R.: 2011, Near-Infrared Spectroscopy of Primitive Asteroid Families. Icarus, 213, 538-54.