EPSC Abstracts
Vol. 6, EPSC-DPS2011-915, 2011
EPSC-DPS Joint Meeting 2011

On the origin of the Almahata Sitta meteorite and asteroid 2008 TC_3

J. Gayon-Markt, M. Delbo', A. Morbidelli, S. Marchi, L. Galluccio and. C. Ordenovic
Université Nice Sophia Antipolis, CNRS, Observatoire de la Côte d'Azur, France (julie.gayon@oca.eu / Fax: +33-492003121)

Abstract

Asteroid 2008 TC_3 is a Near Earth Asteroid (NEA) that impacted the Earth on October 7, 2008 [5]. At present, about 600 meteorites - called Almahata Sitta - coming from 2008 TC_3 have been recovered [9] from the same strewn field. A mineralogical study of Almahata Sitta fragments shows that the asteroid 2008 TC_3 was consisting of meteorites of different types (H, L, E chondrites and urelites). Understanding the origin of this body and how it was put together remain a challenge. Here we perform a detailed spectroscopical and dynamical investigation to show that the most likely source region of Almahata Sitta and 2008 TC_3 is in the inner Main-Belt at low inclination where the so-called Nysa-Polana family is located. We also provide a workable explanation about how asteroid 2008 TC_3 was formed by low velocity collisions between asteroid fragments of very different mineralogies.

1. Introduction

A mineralogical study of Almahata Sitta samples shows that about $70-80\%$ of fragments are achondritic ureilites and the remaining $20-30\%$ correspond to different types of chondrites such as H and L ordinary chondrites and E-chondrites (enstatite) [9]. Because falls of meteorites of different types are rare, the question of the origin of an asteroid harboring both primitive and evolved characteristics is a challenging and intriguing problem.

It is known that NEAs come from several intermediate source regions of the Main-Belt: mainly the $3/1$ mean motion resonance, the ν_6 secular resonance, Mars crossing objects (MC) and the outer belt. According to the dynamical model of [1], asteroid 2008 TC_3 has a probability of 0.00, 0.00, 0.31, and 0.69 to come from the $3/1$ resonance, the outer-belt, MC, and the ν_6 resonance respectively. Escape by the ν_6 resonance largely retains the inclination of the orbit so that the current $2.47°$ inclination is near its original inclination in the Main Belt. As a consequence, the source family of 2008 TC_3 should be located in the inner Main Belt at low inclination.

In addition, the spectrum of 2008 TC_3 was linked to B-type primitive asteroids [6], according to the classification of Bus-DeMeo [3]. The Nysa-Polana family is in the inner-belt, at low inclination and contains B-type asteroids: thus this is a very good candidate for the origin of 2008 TC_3. As a consequence, we investigate more thoroughly the link Nysa-Polana family - asteroid 2008 TC_3 - Almahata Sitta meteorite.

2. Asteroid spectral classification

Amongst astrometric position and proper motion of 10^9 stars, the ESA mission Gaia (launch 2013) will observe about 10^5 asteroid spectra. Our group is in charge of asteroid spectra analysis and classification of asteroids. To this purpose, an algorithm of classification has been developed using a non-supervised method and based on the properties of Minimal Spanning Trees [7]. Here, we applied that algorithm to spectro-photometric data of asteroids of the Nysa-Polana family. In particular we used visible light photometry from the Sloan Digital Sky Survey Moving Object Catalog 4 (SDSS MOC4).

Applying this new algorithm to the Nysa-Polana

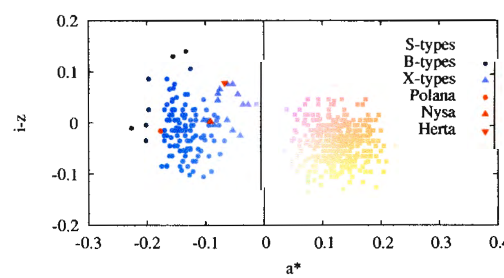

Figure 1: Distribution of S-type (■), B-type (●), X-type (▲) objects as a function of a^* and $i-z$ (calculated from SDSS magnitudes; color palette coming from [8]). Polana is a B-type asteroid. Herta and Nysa are X-types. More precisely Nysa is a E-chondrite.

family we obtain 3 different groups (Fig. 1). The two groups corresponding to S-types and B-types were already known [2]. However, we find that the family also contains another group of X-type asteroids. In [4], we show that S-types and B-types match with Almahata Sitta fragment spectra (respectively ordinary chondrites and achondritic polymict ureilite) whereas X-types fit with some other enstatite meteorites. Given that spectral classes analogous to enstatite chondrite, ordinary chondrites and urelites are all present in the Nysa-Polana family, the question is how these pieces were put together through collisions.

3. Collision probability

Mixing of material between projectile and target is very rare; in most cases the projectile is pulverized and leaves negligible traces in the fragments of the target. Thus, we think that unusually low impact velocities are needed for mixing. This could prevent the target from pulverizing and could lead to macroscopic projectile fragments being gravitationally bound to target fragments. The fact that 2008 TC_3 is very likely to come from the Nysa-Polana family (see §2), which is characterized by low orbital inclinations, also suggests that a specificity of the members of this family may be unusually low collision velocities with projectiles that are also on low-inclination orbits. Consequently, we did a systematic search for projectiles that could hit Nysa-Polana family members at very low speeds. We did this search using the algorithm for the calculation of the intrinsic collision probability between pairs of asteroids, described in [10]. For our goals, we modified this algorithm in order to take into account only orbital intersections corresponding to relative speeds smaller than 0.5 km/s.

We find that collisions between an S-type asteroid of the Main Belt (impactor) and a B-type asteroid of the Nysa-Polana family (target) is the most probable collision at low velocities. More particularly, S-types generally come from the Flora family, depending on the location (in proper elements) of the target inside the Nysa-Polana family. Eventually some S-type impactors could come from the Massalia family.

4. Conclusion

All these informations and our new classification method shed new light on the the source origin of the Almahata Sitta fragments and the asteroid 2008TC3. From our studies, we can conclude that the Nysa-Polana family gathers the main characteristics of 2008 TC_3: the 3 types (S,B,X) are accumulated in only one dynamical family in the inner main belt. Moreover, we already know that the location of the Nysa-Polana family is close to the ν_6 secular resonance which is the favorite route leading to asteroid 2008 TC_3. Collision probabilities for low impact velocities show a possible scenario of formation with the impact of a S-type object of the Flora family with a B-type of the Nysa-Polana family and probably a second impact with a X-type asteroid.

Acknowledgements

We thank O. Michel and P. Bendjoya for providing us their method of classification as well as A. Cellino, P. Tanga, M. Müller, H. Campins, and B. Carry for helpful discussions. Programming tools made available to us by the Gaia Data Processing Analysis Consortium (DPAC) have been used to complete this work. J. Gayon-Markt is also grateful to the Centre National d'Etudes Spatiales (CNES) for financial support.

References

[1] Bottke, W. F., Morbidelli, A., Jedicke, R., Petit, J.-M., Levison, H. F., Michel, P., and Metcalfe, T. S. 2002, Icarus, 156, 399

[2] Cellino, A., Zappalà, V., Doressoundiram, A., di Martino, M., Bendjoya, P., Dotto, E., and Migliorini, F. 2001, Icarus, 152, 225

[3] DeMeo, F. E., Binzel, R. P., Slivan, S. M., and Bus, S. J. 2009, Icarus, 202, 160

[4] Gayon-Markt, J., Delbo' M., Morbidelli A., Marchi S., Galluccio L., and. Ordenovic C. 2011, Monthly Notices of the Royal Astronomical Society, to be submitted

[5] Jenniskens, P. et al. 2009, Nature, 458, 485

[6] Jenniskens, P. et al. 2010, Meteoritics and Planetary Science, 45, 1590

[7] Michel, O., Bendjoya, P., and RojoGuerra P. 2005, Physics in Signal and Image Processing (PSIP) Proc., January 31–February 2 2005, Toulouse, France

[8] Parker, A., Ivezić, Ž., Jurić, M., Lupton, R., Sekora, M. D., and Kowalski, A. 2008, Icarus, 198, 138

[9] Shaddad M. H. et al. 2010, Meteoritics and Planetary Science, 45, 1557

[10] Wetherill, G. W. 1967, Journal of Geophysical Research, 72, 2429