Gaia Research for European Training in Astronomy

Sientific Report on the Exchange Visit Grant

- **Grantee:** Dr. Bojan Novaković, Department of Astronomy, Faculty of Mathematics, University of Belgrade, Studentski trg 16, 11000 Belgrade, Serbia (email: bojan@matf.bg.ac.rs)
- **Host:** Dr. Alberto Cellino, INAF-Osservatorio Astronomico di Torino, Via Osservatorio 20, I-10025 Pino Torinese, Italy (email: cellino@oato.inaf.it)
- **Grant No:** 3535
- **Dates (start/end):** 01.02.2012 / 13.03.2012
- **Title of the project:** An automatic algorithm for asteroid family membership determination

Purpose of the visit

The main purpose of the visit was to perform a new classification of main-belt asteroids into dynamical families and to develop an automatic algorithm for a future family membership assessment. During this work it was expected to find very interesting families which deserve immediate attention. Thus, our aim was to study such groups as well.

Asteroid families, which are believed to have originated from catastrophic inter-asteroid collisions, are very important subject in asteroid-related science and almost any kind of research in this area leads sooner or later to face problems related to the families. For each study related to asteroid families it is essential to know reliably the list of the families, and the asteroids that belong to each of these groups. This is a challenging problem, due to the difficulty to distinguish between members of different families, especially when they overlap, and to avoid contamination of possible background interlopers. Another danger is that of not being able to recognize large numbers of real family members.

Families have been commonly identified in recent years by analyzing the distribution of asteroids in the space of three proper orbital elements: semi-major axis, eccentricity,

and inclination, using statistical tools like the Hierarchical Clustering Method (HCM). As a number of known asteroids increases quickly, even the newest published family memberships are led to become rapidly obsolete. On the other hand, proper elements used as the input for the HCM are freely available for large numbers of asteroids through the AstDys web site. Our aim here was to use an improved version of the HCM to identify asteroid families. Then, to develop an automatic procedure to identify further members of these families among smaller (fainter) objects. These results are to be made freely available, and regular updates will be performed through the year, each time a new asteroid database is released.

This approach has some important advantages. First, availability of new, updated family memberships for objects brighter than completeness limit will be much welcome for various studies, including but not limited to the behavior of the size distribution of different families. Second, more extended data on family membership using all known asteroids at any time, including those below the completeness limit, will significantly increase the membership lists of known families.

Description of the work carried out during the visit

At the beginning of the visit we focused on the analysis of asteroid population and estimation of the appropriate completeness limits at different parts of the main asteroid belt. Our main goal was to estimate these limits as a function of the semi-major axis, eccentricity and inclination. Simultaneously we started to make experiments with the HCM code in order to identify its week points. This was basically done during the first week of the visit.

In the next step, which took about two weeks, we implemented several improvements in the procedure of the HCM application and, using this modified approach, performed preliminary classification of the asteroids (up to the completeness limit) into families. As this calculations are computationally demanding, while waiting for it to be finished, we analyzed intermediate results with a particular attention to the small and compact groups. First such result that we focused on was the membership of the Lorre cluster (discovered in our previous joint work). As we found new members of the cluster, it was studied in more detail, particularly its dynamical stability and its age. Having found very nice results we started writing a paper about it.

After completing a classification of main-belt asteroids into families, the next activity (performed during the 4th week) was to test and improve an algorithm for attaching asteroids smaller than observational completeness limit to the cores of the families. This procedure, together with the HCM, is a core of our automatic family membership algorithm (AFMA). During this test, it was suggested by our colleague Henry Hsieh (University of Hawaii) that it would be a good idea to apply our codes to a main-belt comet P2006VW$_{139}$. By doing this we were able to identify a new asteroid family around this object. Such result was of a grate importance and we decided

that our priority at this moment was the study the new group. For this reason we temporary stop working on the paper about the Lorre cluster.

During the 5th week we were able to finish both, our attaching algorithm and all planned analysis of the P2006VW$_{139}$ group. At this stage, two of three main parts of the AFMA code were finished. The last one is the automation of the code for the on-line use, and its test at AstDys web page. However, as the visit started significantly earlier than it was planned, a pre-requested work on the AstDys was not done. Thus we were not able to continue our work on the AFMA code at that time, and we postpone it for a few weeks. Given that, at the end of fifth week we started writing a paper about a new classification of asteroids into families as was originally planned.

The final week of the visit was devoted to the writing of the papers. The paper about the P2006VW$_{139}$ group was almost finished, while the significant part of the paper about the classification was also written. In mean time, the former paper was finished and submitted, while the latter one is about 80% ready, but its further writing is postponed until installation of the AFMA code at AstDys is performed. Finally, about 2/3 of a paper about the Lorre cluster was done.

Description of the main results obtained

The first important result is the improvement of the HCM. We introduced some changes to take into account (i) some specificities of considered regions; (ii) some intrinsic limits of the statistical approach, mainly for what concerns the definition of the membership of identified families; (iii) the fact that we know a priori that any asteroid sample cannot be complete beyond some value of magnitude, and family classifications tend to evolve as larger data sets of asteroid proper elements, corresponding to increasing number of discovered objects, become progressively available.

On the top of this, an efficient attaching algorithm able to link newly discovered asteroids with existing families was developed. Its main characteristics is computational complexity proportional to a number of objects N. This is serious advantage over the HCM approach where computational complexity scales as N^2.

As a result of the development of the improved HCM a completely new classification of main belt asteroids into families is obtained. At first, only asteroids larger than completeness limit were considered. In this step we did not find any new asteroid family, however, the new membership list that we obtained may be very useful for future studies of the size-frequency distribution of asteroids that belong to these families. Second, by analyzing asteroids above the completeness limit we have discovered several small asteroid clusters for the first time. Most of these newly discovered groups are young and, thus, very suitable for many possible studies as their post-impact evolution should be limited. Finally, the number of known members is increased for all families, what is particularly important in the cases of families where only a few members were previously known.

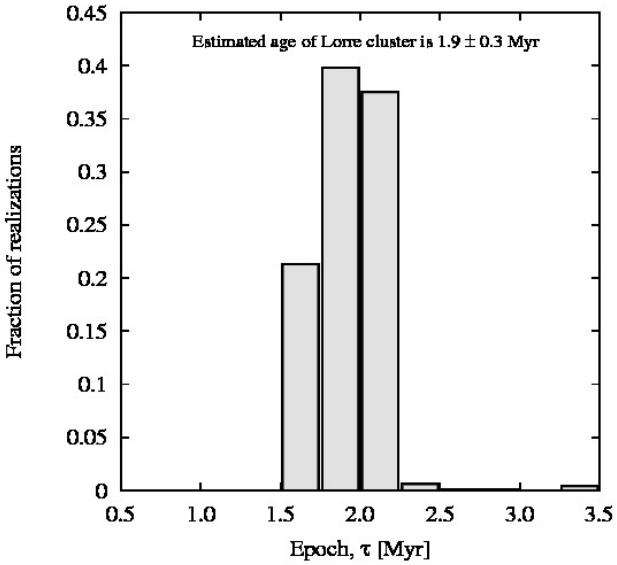

Figure 1: The histogram of possible ages of Lorre cluster. It is constructed using 10^6 different estimations based on orbital clones.

As expected, several very important results are obtained as by-products of our main work. The first such result is our study of the Lorre cluster of asteroids. This cluster was discovered in our previous work but only a few asteroids were assigned to it. Now, we applied the HCM to the set of newly computed asteroid proper elements and analyzed the number of objects dynamically linked with the Lorre cluster obtained using different limits of mutual distances. At the lowest tested value of 10 m/s the HCM links 14 asteroids with Lorre, while the number of members raises to 19 for 20 m/s. The number of dynamically associated members remains a constant until 80 m/s, when one body, asteroid 2006 AX_{67} is added. Later on, no additional body is linked to the cluster even for the largest used value of 200 m/s. Thus, we identified many new potential members, doubling the number of known asteroids that belong to the Lorre cluster. This allowed us to perform detail study of the cluster. We showed that it is an example of a young asteroid cluster located in a dynamically stable region, which was produced by partial disruption of a primitive body about 30 km in size. We estimated its age to be only 1.9 ± 0.3 Myr (Fig. 1). The large difference in size between the largest object and the other cluster members means that this was a cratering event. The parent body had a large orbital inclination, and was subject to collisions with typical impact speeds higher by a factor of 2 than in the most common situations encountered in the main belt. Thus, this findings provide, for the first time, at disposal the observable outcomes of a very recent event to study high-speed collisions involving primitive asteroids.

The second very important by-product result is discovery of young asteroid family

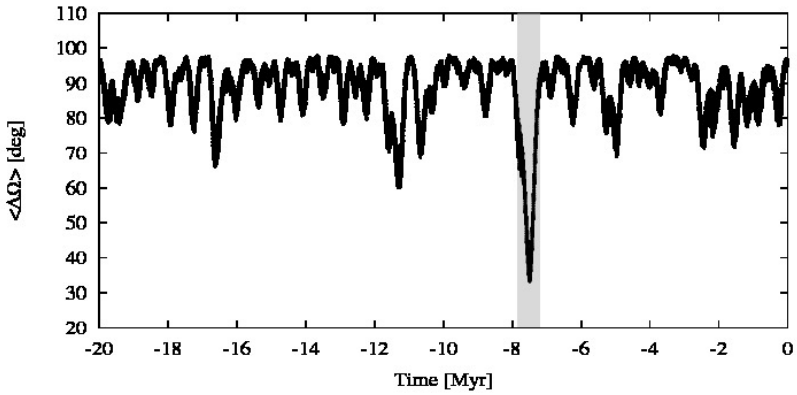

Figure 2: The average of differences in the mean longitudes of the ascending nodes Ω for 11 dynamically stable asteroids that belong to the P/2006 VW_{139} group. The most important feature is clustering at 7.5 ± 0.3 Myr ago, the likely age of the sub-group.

around newly discovered main-belt comet P/2006 VW_{139}. This objects was recently discovered by the Pan-STARRS1 survey telescope. By analyzing its dynamical environment we found a group of 24 asteroids dynamically linked to main-belt comet P/2006 VW_{139}. Thus, we apply different methods to examine the possibility that this group of objects shares a common physical origin. By applying the Hierarchical Clustering and the Backward Integration Methods, we found strong evidence that 11 of these asteroids form a sub-group which likely originated in a recent collision event, and that this group includes P/2006 VW_{139}. We determine the age of this sub-group, which we designate as the P/2006 VW_{139} family, to be 7.5 ± 0.3 Myr (Fig. 2), and estimate the diameter of the parent body to be about 11 km. Results show that the family is produced by an impact which can be best characterized as a transition from catastrophic to cratering regime. The dynamical characteristics of this family are studied as well, including the identification of the most influential mean motion and secular resonances in the region. Our findings make P/2006 VW_{139} now the second main-belt comet to be dynamically associated with a young asteroid family, a fact with important implications for the origin and activation mechanism of such objects.

Finally, recently Catalina sky survey announced discovery of one new main-belt comet, namely P2012F_5 (Gibbs). As it is very important to establish a possible link between such objects and asteroid families, we have also checked whether this new object could be linked to any asteroid family. Remarkably, we found that it belongs to another small group that we discovered during the visit. Although in this respect we've got only preliminary results, available evidence is very convincing. Further investigations of the group is in progress.

Future collaboration with host institution

We are planning to continue our joint research on the problems related to asteroid families and to extend it by including other people from our institutions in this collaboration. Our immediate plan is to finished the works that we started during the visit. Many other aspect of the collaboration are planned as well. For example, we will participate together in the proposals for observing time. Definitly, the visit was very stimulating for the exchange of ideas and had very positive effect on our joint work. Therefore, the future collaboration is of great interest for both sides and we expect it will be a very productive.

Projected publications resulting or to result from the grant

The first outcome will be the presentation of the obtained results at a very important international ACM meeting[1] in Niigata (Japan), from 16th to 20th May, 2012. There, the results for two new young families will be presented. The results on the young Lorre cluster will be an oral presentation, while the group around the main-belt comet P/2006 VW_{139} will be presented on a poster.

The full publication of the results is expected in the pear reviewed scientific journals. The paper entitled "P/2006VW_{139}: Main Belt Comet Born In Asteroid Collision?" is currently under review in the MNRAS journal, while the second paper, on the young Lorre cluster is almost ready and will be submitted in the same journal in the next few days. The third paper about the second young family related to the main-belt comet is in preparation. It will be finished and submitted within the next 5-6 weeks. Finally, the fourth paper describing our automatic algorithm for a family membership assessment will be prepared and submitted when the algorithm becomes fully operated on the AstDys web page.[2]

Other comments

The dates of the visit were changed. Originally, it was proposed to start the visit on 12th March. However, due to the unexpected changes in the obligations of visitor (Bojan Novaković), the visit started earlier, on 1st February and it was finished on 13th March 2012. The duration of the visit was as proposed (six weeks).

[1] http://chiron.mtk.nao.ac.jp/ACM2012/

[2] In the case that resolving a technical problems at AstDys takes too long (more than 2 months), we will temporary launch an alternative web page where the algorithm will be available.