Wing-Huen Ip (Editor)

New Results in the Observations and Space Exploration of Asteroids

Proceedings of An International CJMT-1 Workshop
on Asteroidal Science

October 16-17, 2012, Macao

Macau University of Science and Technology

Editors

Wing-Huen Ip
National Central University, Taiwan
Macau University of Science and Technology, Macao
Email: wingip@astro.ncu.edu.tw

Issued Date: March 2014

Publisher and Distribution: Macau University of Science and Technology

Development of an Asian-wide observation network for the solar system small bodies: a JSPS Asia-Africa Science Platform during 2009-2011

Takashi Ito and Fumi Yoshida

National Astronomical Observatory
Osawa 2-21-1, Mitaka
Tokyo 181-8588, Japan
Ito.t@nao.ac.jp

Abstract — During 2009-2011, a group of astronomical scientists worked on a long-term observational program funded by Japan Society for the Promotion of Science. This program was largely focused on observations of the solar system small bodies, particularly those of the young asteroid families and of the potentially hazardous asteroids that have possibility to collide with the Earth. This program involved many scientists in four Asian countries: Japan, South Korea, Taiwan, and Uzbekistan. Major part of the observational activity took place at Maidanak Observatory, Ulugh Beg Astronomical Institute, Uzbekistan. In this article we make a brief summary as to what the program aimed at, what we did during the three year program, and what we have accomplished not only in academic standpoint but in the viewpoint of establishing a community of scientists. The designated budget program was already finished, but our science activity goes on, and we are preparing for an application for the next program along the same scientific objectives, this time including more people from more countries that could make a great scientific partnership between the existing members.

1. Introduction

Japan Society for the Promotion of Science (JSPS) is one of the govenmental agencies in Japan that supports activities of scientists in and around Japan mainly in terms of funding. Nowadays a large number of scientific programs are going on with the help of JSPS, together with numerous employment of young scientists. According to the webpage of JSPS[1], their purposes and objectives are as follows:

> *The Japan Society for the Promotion of Science (JSPS), or Gakushin for short, is an independent administrative institution, established by way of a national law for the purpose of contributing to the advancement of science in all fields of the natural and social sciences and the humanities. JSPS plays a pivotal role in the administration of a wide spectrum of Japan's scientific and academic programs. While working within the broad framework of government policies established to promote scientific advancement, JSPS carries out its programs in a manner flexible to the needs of the participating scientists.*

For scientists working on scientific projects over many countries like us, JSPS is regarded as a major funding agency for international collaboration programs,

[1] http://www.jsps.go.jp/english/aboutus/index2.html

particularly those with countries in Asia. A large number of international collaboration programs with a variety of frameworks are going on under the conduct of JSPS, from a short-term small bilateral collaboration between two countries to a very large multinational collaboration involving a huge amount of grant for several years. For achieving our scientific objectives that we will describe later, we had been looking for a relatively large funding source for multinational collaborations in the Asian region. For that purpose we submitted a grant application to one of the JSPS international programs in 2008 autumn. The category that we chose was called "Asia-Africa Science Platform", specialized in collaborations with countries in the Asian or African regions. The following four items (1-4) are for explaining what Asia-Africa Science Platform is, being largely cited from JSPS's webpage and from their attached materials[2]:

1. Objective: The Asia-Africa Science Platform is designed to create high potential research hubs in selected fields within the Asian and African region, while fostering the next generation of leading researchers. It does this by establishing sustainable collaborative relations among universities and research institutes in Japan and other Asian and African countries. Under the program, these "core institutions" will collaborate in research fields of special importance or significance to Asia and/or Africa and that is deemed to be of high priority within Japan. Core institutions in Japan and other Asian and African countries conduct exchanges under the leadership of Japanese core institutions. These exchanges will take the form of joint research, seminars and other scientific meetings, and researcher exchanges, which are to be organized and carried out effectively under the program. It is anticipated that the hubs formed by the core institutions will continue to carry out research activities after the funded project has ended.
2. Targeted Research Topics: Research topics of special importance or significance to Asia and/or Africa and deemed to be of high priority within Japan. (All fields of the humanities, social sciences and natural sciences.)
3. Eligible Countries: Asian and African countries (core institutions may only be established in Asian and African countries; however, individual researchers from other countries or regions, including non-Asian and non-African, are eligible to participate in projects.)
4. Implementation method: (1) A full-time researcher employed at a Japanese university or research institute acts as the project coordinator. His/her institution or department sets up the implementation framework and carries out the project. (2) JSPS provides financial support for carrying out project-related joint research, scientific meetings and researcher exchanges by Japanese core institutions. (3) JSPS makes a call for proposals to universities/research institutions, and conducts reviews and selections. The actual operation of the selected projects is left to the core institutions themselves. Counterpart core institutions in Asian and African countries are encouraged to obtain financial support from science-promotion agencies or other funding organizations in their respective countries.

For this program we organized a group of scientists that work on observational and theoretical studies of the solar system small bodies. Our application was focused on long-term observation of the solar system small bodies, particularly that of young asteroid families and of potentially hazardous asteroids. Our application involved many scientists from four countries: Japan, South Korea (Republic of Korea), Taiwan, and Uzbekistan. Fortunately our application was approved by JSPS in early 2009, and actual funding began from 2009 April for three years until 2012 March, five million Japanese yen being supplied each year for our research plan (note that 1 US dollar was equivalent to ~80 Japanese yen as of 2012 July).

Not only achieving scientific objectives on the solar system small body study, but our program aimed at building an Asian-wide astronomical observation and human network that can be used in the long-term future not only for the solar system small

[2] http://www.jsps.go.jp/english/e-aaplat/

body studies but for other astronomical observations, such as observation of gamma ray bursts, variable stars, or transit-timing variation of extrasolar planets.

The most important station of our observation network is located in Uzbekistan, called Maidanak Observatory, operated by Ulugh Beg Astronomical Institute, Uzbek Academy of Science. We showed a schematic diagram of how our network worked in Figure 1.

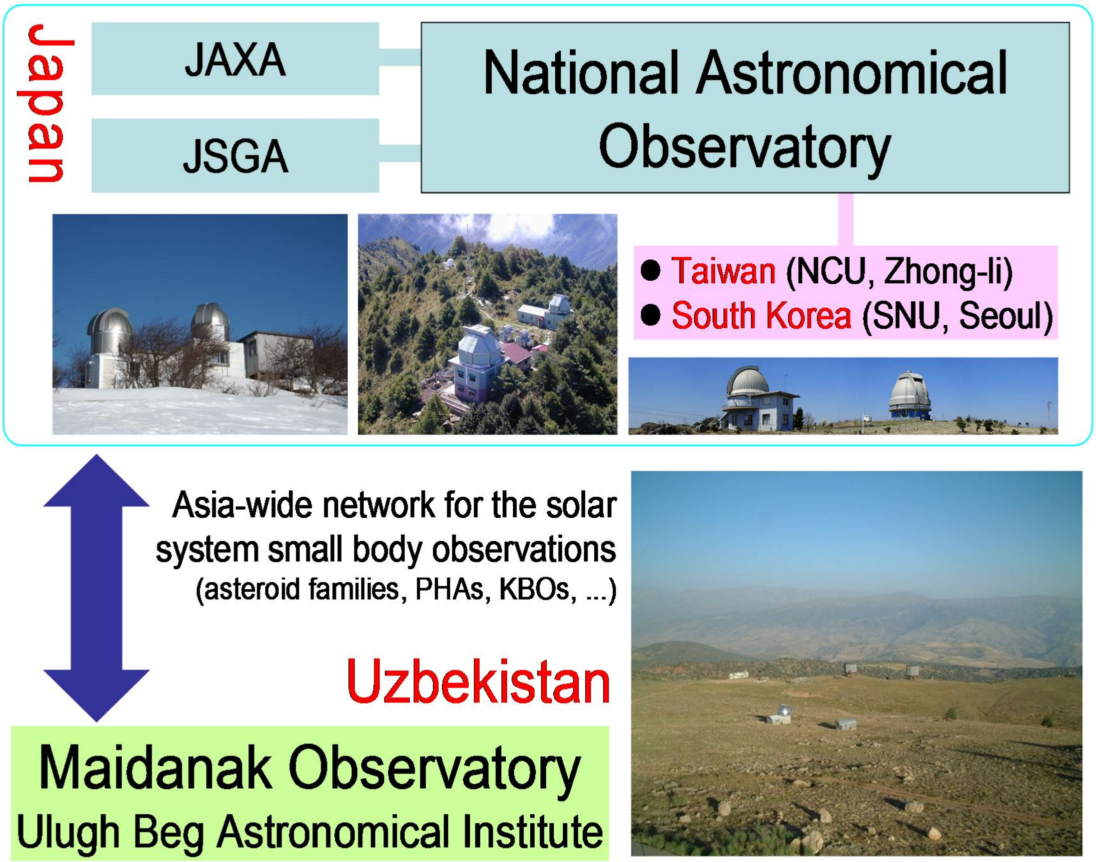

Figure 1. Schematic diagram of how our science platform works between the four relevant countries and institutes. The photos are, from the top left: Mount Nyukasa Station (JAXA, Japan), Lulin Observatory (NCU, Taiwan), Okayama Astrophysics Observatory (OAO) of NAOJ, and Maidanak Observatory (Uzbekistan).

We assigned core institutes in each of the four countries: In Uzbekistan, Ulugh Beg Astronomical Institute (UBAI; corresponding scientist for this program was Shuhrat A. Ehgamberdiev). In Taiwan, National Central University (NCU; Chen Wen-Ping), In Republic of Korea, Seoul National University (SNU; Im Myungshin). And in Japan, National Astronomical Observatory of Japan (NAOJ; Takashi Ito). In Japan, two other major institutes collaborate with and help NAOJ to accomplish the missions of the program: Japan Aerospace Exploration Agency(JAXA), and Japan Spaceguard Association (JSGA). Each country group owns different scientific objective and activity direction at Maidanak Observatory, but in this article we will focus on our (Japanese) activity in and around Maidanak. Detailed plans and activity reports of our program during the three-year grant period are summarized and now accessible on the JSPS homepage[3] for public, although all the contents are written in Japanese.

2. Maidanak Observatory

[3] http://www.jsps.go.jp/j-aaplat/10ichiran_aaplat2.html

Maidanak Observatory belongs to UBAI which is a member institute of Uzbek Academy of Science, and is located at the center of the Eurasian continent (GMT+5). Mt. Maidanak where this observatory resides is close to the border between Afghanistan: longitude +66º.89641E and latitude +38º.67332N, at a distance of about 120 km south of Samarkand, lying on the spurs of the Pamir and Alai mountain system with the altitude of 2593 m. The vegetation of Mt. Maidanak is typical that of high-mountain dry sub-tropics, bushes being prevailing (see the photos in Figure 2).

Figure 2. Maidanak Observatory. (Top left) The main 1.5 m telescope on August 5, 2003. (Top right) An observatory sunset with sheep and a local shepherd, on October 11, 2011. (Middle left and right) The telescope dome for our asteroid observation program and the 0.6 m telescope, on November 11, 2007. (Bottom left and right) Typical views that you will find when you walk around Maidanak Observatory, on November 14, 2007.

The history and the sky condition of Maidanak Observatory are very well described in Ehgamberdiev et al. (2000a), and we would like to make its brief citation summary in what follows: The Maidanak summit was selected for astronomical observations in the late 1960s as a result of a ten-year long site assessment campaign organized by UBAI. In the early 1970s when the high-quality atmospheric condition of Mt. Maidanak has been recognized, the summit was occupied by a Satellite Laser Ranging (SLR) station. Meanwhile the Moscow State University (MSU) and a few other Soviet Union institutions constructed their astronomical facilities at a neighboring summit situated 5 km to the west of Mt. Maidanak. So, there are actually two Maidanak summits. By the early 1990s, about ten telescopes as well as the corresponding observatory infrastructure (roads, buildings, mechanical shops, and so on) were completed at the western summit. At present, all the astronomical facilities belong to UBAI and are operated in the framework of scientific agreements between UBAI and MSU, Ukrainian and Lithuanian astronomical institutions. One of the largest significances of Maidanak Observatory is its longitudinal location. There is practically no other scientific observation facility in the vicinity of the longitude of 70ºE except Maidanak Observatory, and it has been used as a key station of time-variable astronomical observations, such as gamma ray bursts or variable stars. You can get more detailed information about this observatory from UBAI's homepage[4]. Incidentally, we should mention that Maidanak Observatory is operated together with its base station at its mountain foot, the Kitab station, which once used to be famous for a part of the International Latitude Service activity in the early twentieth century (note that International Latitude Observatory of Mizusawa, currently the Mizusawa VLBI observatory of NAOJ, was also one of the stations of this activity together with the Kitab station). See Ehgamberdiev et al. (2000b) for more detail about the Kitab station and its history.

At the site of Maidanak Observatory (Figure 2), there are more than 200 clear nights per year with a median seeing of 0".69 (Ehgamberdiev et al., 2000a). This observatory was once Soviet Union's center for astronomy and astrophysics. But ever since the collapse of Soviet Union, the observatory had been virtually abandoned mainly due to budget deficit. Our observing project at Maidanak Observatory started in 2004 as a collaboration between Japan and Uzbekistan, but it is not only about asteroid observation but about facility rejuvenation, funding for employing observers, and education of young scientists for future academic activity in Uzbekistan. Using one of the 0.6 m telescopes of this observatory, the Japanese group has been observing the solar system small bodies, particularly some members of the young asteroid families. The 0.6 m telescope that we use for our observing program of young asteroid family members was made by Carlzeiss Jena, initially with a CCD camera FLI IMG1001E (1024 x 1024 pixels, FOV = 10'.7 x 10'.7, and pixel scale = 0".67 at this telescope) that UBAI provided us (note that this CCD camera was later replaced during this program, as we will mention in the following sections). Since the old telescope can do only sidereal tracking, maximum exposure time is around three minutes for typical main belt asteroid observation: Longer exposure time would cause trailing loss. Due to the exposure time limitation, we are only able to observe asteroids with the apparent magnitude of ~17 (in *R* band) by this instrument. We will describe one of our scientific results about the young asteroid families in Section 6.

3. Rejuvenation of observational facilities

As wrote above, Maidanak Observatory had not been virtually invested for a long time since early 1990s. Naturally, many of their facilities are obsolete and not maintained well. For example as to the 0.6 m telescope we use, although the telescope body itself is fine, we had two serious problems: The mirrors attached to this telescope had not been cleaned or re-aluminized for many years, and the CCD camera was quite incompetent mainly due to the low quality CCD chip. Therefore we started our activity first from cleaning the mirrors and replacing the CCD camera for our asteroid observations.

[4] http://www.astrin.uzsci.net/

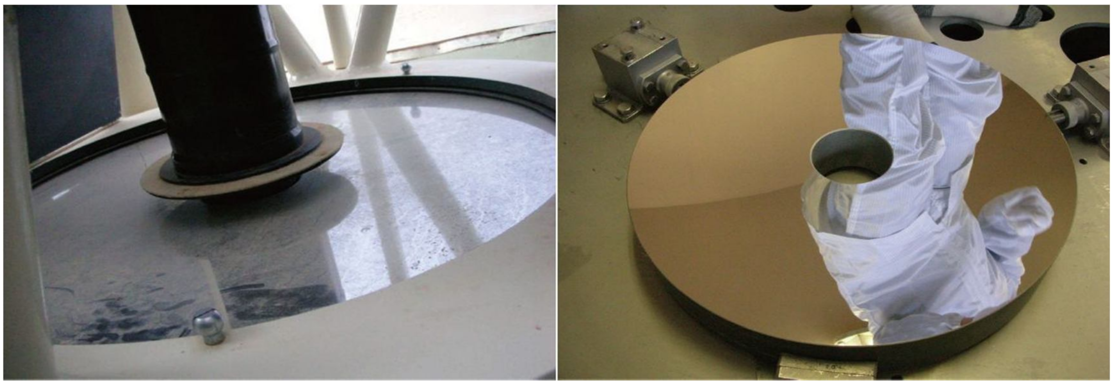

Figure 3. The main mirror of the 0.6 m telescope at Maidanak Observatory that we use for our asteroid observation. (Left) Before cleaning, on November 11, 2007. (Right) Just after cleaning and re-aluminization at OAO, on April 13, 2010.

As for the cleaning and re-aluminizing the telescope mirrors, our plan was as follows: First, detach the mirrors from the telescope (main one and sub one) at Maidanak, send the mirrors to Okayama Astrophysics Observatory (OAO) of NAOJ, Okayama, Japan, that is equipped with a large factory for mirror cleaning and re-aluminizing. After finishing cleaning and re-aluminizing the mirrors, send them back to Maidanak and attach them to the original telescope. The initial state of the main mirror of the 0.6 m telescope was substantially bad – as bad as you even could not see your face at all on the mirror, with the average light reflection rate of ~45% (see the left photo of Figure 3). After a series of complicated paperwork for exporting the mirrors, the mirrors arrived at OAO in early 2010. After that, thanks to the full cooperation of the OAO staff members, the mirrors are cleaned and re-aluminized beautifully to an unbelievable extent (see the right photo of Figure 3). Note that at this time NAOJ took care of the main mirror of another telescope of UBAI: the 0.48 m telescope at Parkent, not so far from Tashkent, along with a request from UBAI's director, Dr. Shuhrat A. Ehgamberdiev.

As for replacement or upgrade of the CCD camera for our observation, at first it looked fairly hopeless, mainly due to very high price of a cutting-edge CCD equipment including its maintenance cost. However, this time we encountered with a luck to get an offer from Department of Astronomy, Kyoto University, Japan. They offered us to release one of their CCD cameras (for free!) that they had stopped using, while it is still usable, for our observation activity at Maidanak. The camera is made by PixelVision with a CCD chip named SITe SI004AB (1600 x 1600 pixels, FOV =

Figure 4. (Left) The Japanese group working on an extensive check of the CCD camera that Kyoto University provided for our program. From the right, Kiichi Okita (NAOJ), Hiroshi Ohtani (Kyoto University), and Fumi Yoshida (NAOJ). (Right) A snapshot when the Japanese group members are giving a detailed instruction to the UBAI staff team as to how to construct, install, and operate the CCD camera and its controlling software. Both photos were taken on November 13, 2011 at the Kitab station of UBAI.

13'.2 x 13'.2 and pixel scale = 0".495 at this telescope, and pixel size = 18 μm), which had been used at Ouda Observatory, Nara, Japan, for several years. Although the camera needed some restoration and repair as it had not been used for a couple of years, we completed them at OAO, and exported the camera to Uzbekistan in 2011 summer. Then in 2011 November, four Japanese members of this program visited Uzbekistan to construct and check the functions of the entire CCD system. Unfortunately, bad weather and heavy snowfall prohibited us to reach Maidanak Observatory in this trip, but we did many kinds of extensive tests about the CCD camera at the Kitab station of UBAI located at the mountain foot of Maidanak Observatory, also giving a comprehensive set of instructions to the UBAI staff members that now take care of the CCD camera at Maidanak for our observation (Figure 4). Currently the Kyoto CCD camera is equipped with a new filter set (*U*-*B*-*V*-*R*-*I*), and is successfully installed at the 0.6 m telescope for the asteroid observation. UBAI organized a local observation team for our program, and it carries out observations scheduled by the Japanese group on a regular basis.

4. Tutorial session for young astronomers

As was stated in "1. Objective" in the Asia-Africa Science Platform of JSPS, our program also had to aim at fostering the next generation of leading researchers in each of the countries involved in this field through the program. For this purpose, every year we invited young astronomers or engineers to Japan, mainly from Uzbekistan and sometimes from other countries, dispatching them to the observatories that the Japanese member institutes are operating. Hereafter we call the series of invitations "tutorials" for young astronomers. The major purpose of the tutorials is for the young

Figure 5. (Top left) A tutorial session at OAO with a pair of young astronomers coming from Uzbekistan and Taiwan, on February 18, 2010. (Top right) A photo taken right after a tutorial session at Mount Nyukasa Station was finished for three young astronomers from Uzbekistan, on February 4, 2011. (Bottom left) In the middle of a tutorial session at BSGC/JSGA for a young Uzbek astronomer, on February 9, 2012. (Bottom right) A group photo when we invited UBAI's general director, Dr. Shuhrat A. Ehgamberdiev to the Chofu headquarters of JAXA, on September 7, 2010.

generation people to know how cutting-edge observation systems work with highly advanced digital technology, and how astronomical observations are done automatically, as little human interference involved as possible. Also, we hope that they understand scientific significance of our own observation program – what kind of importance the solar system small bodies have in the context of planetary astronomy, and which type of observational data is particularly important for our specific objectives focused on young asteroid families and potentially hazardous asteroids. In collaboration with several domestic observatories in Japan, we dispatched the invited young scientists there and had them stay at each of them for several days, having them learn and practice how to observe the solar system small bodies using particular observation system and hardware/software (Figure 5). The major observatories that cooperated this tutorials are: OAO (of NAOJ), Mount Nyukasa Station (of JAXA), Bisei Spaceguard Center in Okayama (BSGC of JSGA), and the NAOJ headquarters in Mitaka, Tokyo.

Nowadays most of the astronomical observations carried out in the world are computerized and half-automatic, involving as little human interference as possible. However, unfortunately the facilities at Maidanak Observatory have a long way to reach this standard. What we need in future is a larger investment on this observatory in order to introduce modern telescope operating systems including hardware and software. But more importantly, we need to have young generation scientists and engineers that are very well aware of the world standard of the modern astronomical observations. Most of the participants to the tutorials were quite impressed to see the computerized, semi-automatic observation system for the first time, and we hope that this experience will be the fundamentals when they build a similar modern system in their home institutes in the near future, particularly at Maidanak Observatory.

5. Maidanak Observatory Users' Meeting

Most of the major astronomical observatories hold annual or semi-annual meetings for the observers (users) using there, asking them to present their latest academic achievement and to exchange information about observational details. This is the so-called observatory's users' meeting (UM) which is supposed to be a precious opportunity for the observatory to pick up opinions and comments from their observers for the purpose of future improvement and development of their facility and service. However, Maidanak Observatory (and any other observatories that UBAI operates) had somehow never held its users' meeting before our program began. Now that UBAI wants to have as many international collaborators as possible, the situation at that time where they were away from opportunities to get observers' opinions was obviously not ideal. Hence, Fumi Yoshida (NAOJ), the practical science leader of the Japanese group, took initiative and called upon the first Maidanak Observatory Users' Meeting in 2009 spring. What was very lucky for us was that, right after the call for meeting by Yoshida, the Korean group led by Im Myungshin agreed to this idea, and proposed not only hosting the meeting in SNU, Seoul, but offering substantial amount of funding aid for the meeting.

Figure 6. Group photos taken at each of the Maidanak Users' Meetings during our program period. (Top) At the first meeting in SNU, Seoul, on June 30, 2009. (Mid) At the second meeting in UBAI, Tashkent, on June 21, 2010. (Bottom) At the third meeting in NAOJ, Tokyo, on January 31, 2012.

The monumental first Maidanak Users' Meeting was held on June 30, 2009, at Seoul National University in Seoul, Republic of Korea. More than 50 participants gathered at the meeting not only from the four countries registered in this program, but from Russia and Egypt (Figure 6, top). Most of the participants did not know each other then, but as presentations went on, they began understanding what others are trying to do at Maidanak Observatory, which is exactly what we believe was the commencement of the Maidanak community. At the business session of the meeting there were substantial amount of opinion exchanges including very harsh, hostile, and adversarial comments as to how sloppy and disorganized the operation of Maidanak Observatory is compared with the modern world standard observatories. The Maidanak staff members rebutted against some of the opinions, but accepted most others, and they promised to improve the operation and facilities as soon as possible. At the same time, we agreed to the point that we have to find more ways for investment on Maidanak Observatory for the sake of the community future. Obviously, the meeting in Seoul was a remarkable highlight of the entire three- year program.

Following the great success of the first Maidanak Users' Meeting in Seoul, the second Maidanak Users' Meeting was hosted by UBAI in Tashkent, Uzbekisntan, on June 21-22, 2011. Evidently this was the most authentic form of having a Maidanak Users' Meeting, and the whole institute of UBAI worked very hard on its preparation to have a fruitful meeting with many participants from foreign countries. More than 40 participants gathered at the meeting not only from the four countries registered in this program, but from Russia, Ukraine and Spain (Figure 6, middle). Particularly the participation of Russian scientists and engineers to the meeting was quite meaningful and significant, as a large part of the Maidanak facilities still depend on the experience and expertise of Russian scientists that have been involved with Maidanak

Figure 7. (Top left) The main banquet of the first Maidanak Users' Meeting in Seoul, on June 30, 2009, with Korean traditional palace dishes. (Top right) Takashi Ito, an author of this article, is giving an invited lecture at the second Maidanak Users' Meeting at the UBAI headquarters, Tashkent, on June 22, 2010. (Bottom left) A part-time working woman is preparing a lunch for visitors at Maidanak Observatory by burning wood pieces due to frequent power outages, during the after-meeting tour of the second Maidanak Users' Meeting, on June 24, 2010. (Bottom right) Fumi Yoshida, the other author of this article as well as the main organizer of the third Maidanak Users' Meeting in Tokyo, Japan, is preparing a formal Japanese tea ceremony for the participants, on February 1, 2012.

Observatory for a long time, ever since its site assessment in 1960s. Having their presence at the users' meeting in Tashkent, the participants felt free to ask as many questions as they wanted about technical details and future facility plans at the meeting. And the observatory side, including the helpers coming from Russia and Ukraine, returned satisfactory answers to the questions to a great deal.

The meeting was followed by a three day trip to Maidanak Observatory with nearly 30 visitors. According to a local staff member, a visit of this large group of people to Maidanak "has never happened since the collapse of Soviet Union in 1991," and we continued discussions at the observatory too, not only on scientific activity at Maidanak but at future operational plans of the observatory itself. We cannot say that the accommodation facility of Maidanak Observatory is very good at present, but we hope to return to Maidanak Observatory again within some years and have another, even more intensive discussions about our activity at this place.

The third Maidanak Users' Meeting, which was supposed to be the final one during the grant period of three years, was once planned to take place in Tokyo, Japan, in

2011 May. However, an unexpected disaster totally changed the original plan, as well as the entire future of that country – the Great East Japan Earthquake that happened on March 11, 2011, which caused deaths of nearly 20,000 people as well as financial damage of ~20 trillion Japanese yen (more than 200 billion US dollars) to the entire country. In addition to the direct damages of human casualties and economic mayhem, the country ended up with suffering from yet another disgusting problem: Severe radiation leak from a half-collapsed nuclear power plant in Fukushima caused by a huge tsunami that immediately followed the earthquake. It eventually turned out to be an accident of a nuclear power plan that is as serious as the Chernobyl disaster in 1986 in the former Soviet Union. Obviously it is impossible to describe in this short article how terribly the people in Japan got confused, scared, lost hopes, and angry in those days. It was just clear that we could never prepare a Maidanak Users' Meeting as planned in May of the same year as the disaster under a situation like that. Therefore we just had to cancel the initial plan, putting off everything until things have got settled and people have got their daily life back, which actually took a very long time.

We had to wait until the next year when we got ready to host the Maidanak Users' Meeting in Japan. Having a large amount of help and support from the NAOJ local members and its administration office, the third Maidanak Users' Meeting finally took place at the end of 2012 January at NAOJ's headquarters in Mitaka, Tokyo, Japan. Nearly 40 participants gathered at the meeting not only from the four countries registered in this program, but from Russia, Ukraine and India. For the first time the meeting was broadcast to foreign countries (such as to Taiwan) through an Internet video conference system. Now that it was nearly the end of the three-year budget plan of our Asia-Africa Science Platform, the academic achievement reported by the Maidanak users in each of the countries was quite rich and established, and the discussions there were quite intensive. Also, as most of the participants are quite aware that who are operating the facilities at Maidanak and who are responsible for them, we saw very little hesitation for anyone to ask quite straight and honest opinions and criticism against the observatory administrative people, including the UBAI director. As a result, there remained several questions that UBAI could not satisfactorily answered, and the discussions are still going on the Maidanak users' mailing list.

As a whole, we believe that the series of Maidanak Users' meeting sure worked for organizing a community in and around Maidanak Observatory – a community including not only astronomers but also engineers, technicians, administrative associates, and local residents that share the same space with scientists. This kind of community is inevitable for future development of scientific activity that will be carried out at Maidanak Observatory, and we cannot stop going on toward the direction that expands this kind of community. Fortunately, the series of Maidanak Users' Meeting seem to continue even after the JSPS budget program was terminated: It was already announced that the fourth meeting will happen in Tarusa, a small town near Moscow, Russia, on July 1-4 in 2013, by the courtesy of IKI (Space Research Institute), Moscow. The Maidanak Users' Meeting series will remain a fundamental of the development of the Maidanak community, and we feel quite happy to be a part of its initiation and establishment.

6. An example of scientific achievement

In this section we briefly review what we have scientifically achieved through our observing program at Maidanak Observatory, taking lightcurves of young family asteroids as a typical example.

Asteroid families are outcome of catastrophic collisions of asteroids that lead to their breakup into fragments (Hirayama, 1918). They may provide important clues to how disruption events occurred and to what dynamics/physics have dominated over the history of the solar system. However, it has been believed that asteroid families are as old as 10^2 to 10^3 million years, undergoing significant orbital and collisional evolution that masks the properties of the original collisions. Newer, fresher information about the formation of asteroid families has long been sought.

In 2002, a sophisticated numerical technique identified a very young asteroid family, the Karin family, formed only 5.8 million years ago (Nesvorny et al., 2002). Later, more young asteroid families were reported (Nesvorny et al., 2003) such as the

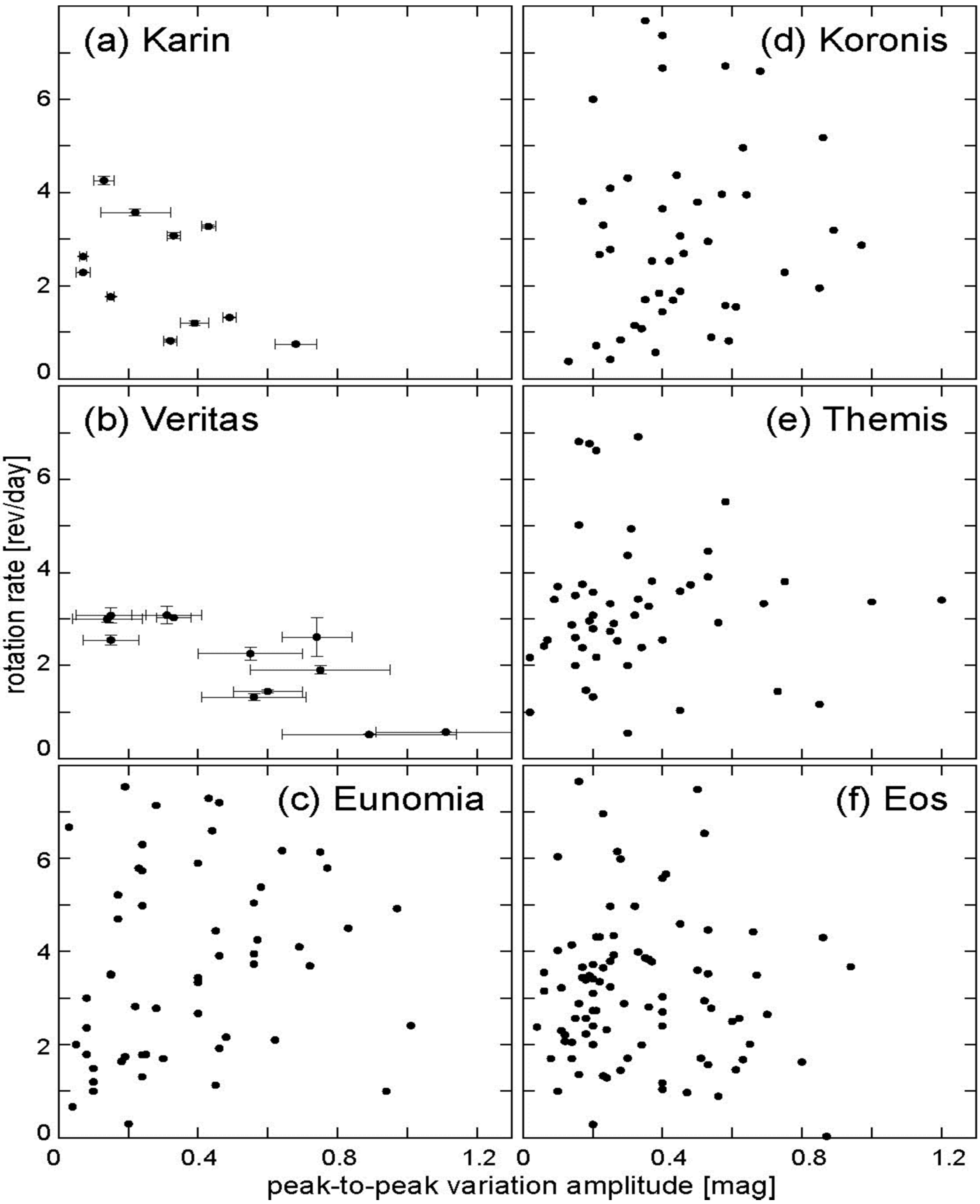

Figure 7. Peak-to-peak variation amplitude and rotation rate of the young (a, b) and old (c-f) family asteroids. (a)(b) are from our own observations.

Veritas family (8.3 Myr old) and the Iannini family (~5 Myr old). Until now, even younger asteroid families have been discovered through the same numerical technique. One example is an S-type cluster, the Datura family, presumably an outcome of a disruptional collision of asteroids of only 450±50 thousand years ago (Nesvorny et al. 2006a). Also, three more candidates for quite recent asteroid breakups were confirmed (Nesvorny et al. 2006b): The Emilkowalski cluster with an estimated disruption age of 220±30 Kyr ago, the 1992 YC2 (16598) cluster of 50-250 Kyr ago, and the Lucascavin cluster of 300-800 Kyr ago. In addition, roughly sixty pairs of main-belt asteroids with nearly identical orbits have been reported, most of which were identified pairs formed within the past 1 Myr (Vokrouhlicky et al. 2008). The origin of the paired objects are probably collisional disruption of larger parent bodies, i.e. the smallest version of young asteroid families. More and more young asteroid families will be detected in the near future. Nothing to say, accumulation of lightcurve data of the young family asteroids will eventually provide significant information about their shape, which we can compare with the result of laboratory and numerical experiments of disruptive collisions of the solar system objects.

Driven by these motivations, we have begun a long-term program to observe lightcurves (multicolor, whenever possible) of the young asteroid family members. Lightcurve observations in general yield important clues as to spin state, shape, and various surface properties of the small solar system bodies. Potential results derived from our observation of the young family asteroid members will be a strong constraint on laboratory and numerical experiments of collisional fragmentation (e.g. Michel et al. 2003; Nesvorny et al. 2006c; Kadono et al. 2009; Ito & Malhotra 2006, 2010) and of space weathering (e.g. Sasaki et al. 2001). In addition, as the age of the young family asteroids is literaly young, we may be able to detect their tumbling motion (a.k.a. non-principal axis rotation, similar to Earth's Chandler wobble) in their lightcurves. Although tumbling motion can give us important insights into energy dissipation and excitation processes as well as that into internal structure of celestial bodies, it gets damped very quickly particularly for small bodies unless the excitation continues. This is the main reason why the tumbling motion of the small solar system bodies has been confirmed only for handful of cases (e.g. Mueller et al. 2002). Very young family asteroids possibly keep tumbling motion yet, and they can put epoch-making exceptions in this field.

So far we have observed lightcurves of some of the three young asteroid family members: The Karin, Veritas, and Iannini families. As for the multicolor photometry, we particularly carried out extensive observations of the largest member of the Karin family, (832) Karin, and detected potentially heterogeneous surface on this asteroid at a particular phase (Sasaki et al. 2004; Yoshida et al. 2004; Sasaki et al. 2006). In this section we give a brief summary of our preliminary results on the relationship between the peak-to-peak variation amplitude of the young asteroid family members and their rotation rate as well as their absolute magnitude. For more detail of our observation strategy and results, such as lightcurves themselves, solar phase curve, and color information, see Ito & Yoshida (2006, 2010), Yoshida et al. (2009), or Yoshida et al. (arxiv preprint).

We plotted the observation data for some members of the two young asteroid families (Karin and Veritas) in Fig. 7 and Fig. 8 together with four old and larger family asteroids, Eunomia, Koronis, Themis, and Eos for comparison. Note that the number of lightcurves that we have obtained for the Iannini family members is still too small for statistical discussion so far, and they are not plotted here.

It is well known that the peak-to-peak variation becomes larger as the solar phase angle increases. An empirically derived correction formula is well known (Zappala et al. 1990): $A(0) = A(\alpha)/(1+m\alpha)$ where $A(0)$ and $A(\alpha)$ are the peak-to-peak variation

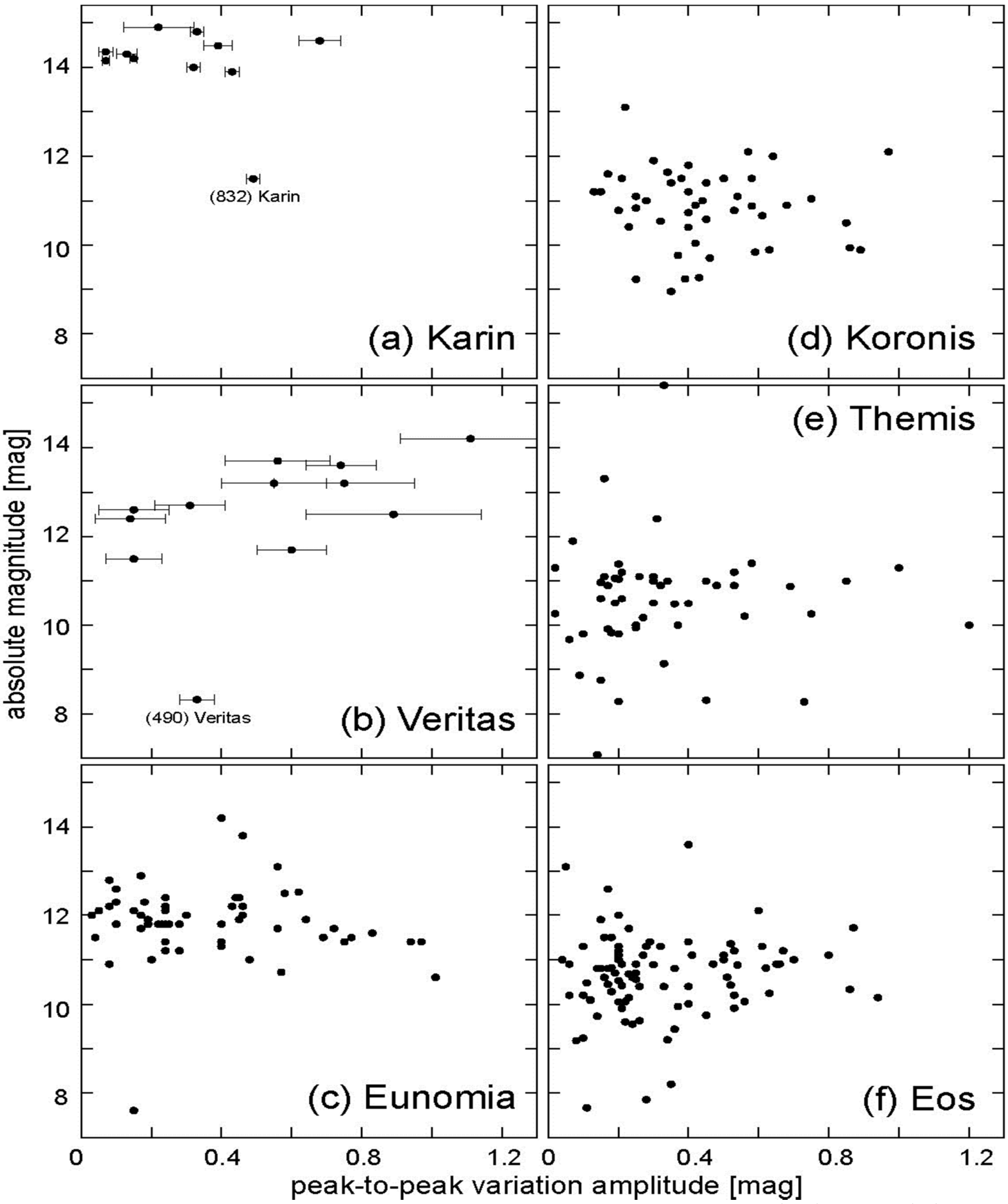

Figure 8. Peak-to-peak variation amplitude and absolute magnitude of the young (a, b) and old (c-f) family member asteroids.

amplitude of lightcurves when the solar phase angle = 0 and = α. We adopted m = 0.030 for the typical S-type asteroids (the Karin family asteroids) and m = 0.015 for the C-type asteroids (the Veritas family asteroids). We included this correction into all the data that we are going to show here. Note that the errorbars for the Veritas family members is much larger than those for the Karin family members. This is because the lightcurve data for the Veritas family asteroids is mostly from the 0.6-m telescope at Maidanak Observatory, while that for the Karin family members is to some extent from our previous observing campaign using larger telescopes, such as the Steward 2.3 m telescope ("Bok") of the University of Arizona at Kitt Peak or the 1.8 m telescope ("VATT") at the Vatican Observatory at Mt. Graham, also in Arizona. Data for the older asteroid families is from the Asteroid Data Sets at Planetary Science

Institute[5] and the Asteroid Orbital Elements Database at Lowell Observatory[6].

Compared with those of the older and larger asteroid family members, the relationship between peak-to-peak variation amplitude and rotation rate of the young asteroid families (Fig. 7) is very different. Although it is clear that we need more samples in future observations, both the Karin (a) and the Veritas (b) family members have the same trend in the panels: The larger the peak-to-peak variation amplitude is (i.e. the more elongated the asteroid is), the slower the asteroid rotates. This trend is not seen in any of the old asteroid family member data (the panels (c), (d), (e), (f) of Fig. 7). This trend might have an implication for the angular momentum distribution of asteroid fragments at the time of disruption. Particularly for the Karin family members that have all similar absolute magnitudes (hence similar size, see Fig. 8(a)) except the largest member ((832) Karin), this trend could mean that the angular momentum was distributed rather uniformly to each of the fragments at the disruption event. Another interesting thing, although still ambiguous until we have accumulated more data points, is that the young family asteroids do not seem to have members near the lower left corner of the panels (a) and (b) in Fig. 7. The contrast is remarkable when you compare panels (a)(b) with (c)-(f). This literally means that there are fewer members with a long rotation period and with nearly a spherical shape among the young asteroid families, while this kind of asteroid is pretty common among the old asteroid families. So far we do not have any ideas about whether this tendency is just an observation bias (i.e. it is generally difficult to observe lightcurves of asteroids with longer period and with smaller amplitude) or real dynamical characteristics particularly to the young asteroid families that were already lost from the older asteroid families due to long-term evolutions.

Note that there are very few asteroids in the upper right corner of all the panels in Fig. 7. This probably indicates the break-up limit of rubble pile asteroids: Assuming asteroids are rubble piles, they will simply break up into pieces when their rotation rate is too high, particularly when their shape is elongated. (i.e. Assuming that the volume and the density of asteroids are the same, the break-up spin rate of an elongated asteroid is lower than that of a spherical asteroid due to its higher centrifugal force when they have the same rotational angular velocity.) This is why we have few asteroids in the upper right corner of the panels (i.e. lack of fast-rotating, elongated asteroids). In other words, when we have observed young family asteroids that are not on this trend, we might want to say that they are not rubble piles but monolithic bodies.

The relationship between peak-to-peak variation amplitude and asteroids' absolute magnitude (H) is shown in Fig. 8. For some of the Karin (the panel a) and the Veritas family (the panel b) asteroids, we calculated their absolute magnitude through our observation data with different solar phase angles. For the old family members (the panels c to f), we consulted "astorb.dat" provided by Lowell Observatory[7] in order to know their absolute magnitudes. Although it does not seem that there are any strong correlations between peak-to-peak variation amplitude and asteroid absolute magnitude, we may find an interesting feature in panel (b) for the Veritas family asteroids: the darker the asteroid is (i.e. with larger H, hence the smaller in size, assuming the same albedo for all the family members), the more elongated its shape is (i.e. the larger its peak-to-peak variation amplitude is). On one hand it might sound

---

5 http://www.psi.edu/pds/archive/asteroids.html
6 ftp://ftp.lowell.edu/pub/elgb/astorb.html
7 ftp://ftp.lowell.edu/pub/elgb/astorb.html

fine because at a disruption event when a large number of small fragments are created, it is natural that many of them become irregular-shaped or elongated. However, this trend is not clear for the Karin family (a) and for the older families (c-f), for which we do not yet have a good explanation.

In the very near future, an impending deluge of large-scale sky surveys such as HSC, Pan-STARRS and LSST will yield a far larger amount of information with much higher accuracy about younger asteroid families including more smaller members. They will sure be critical keys to understand the collisional and dynamical evolution of the solar system small bodies. We too will keep our series of photometric observations on the young asteroid families at Maidanak Observatory, hoping to contribute to this line of research activity.

7. Final remark

Our budget program that lasted for three years in and around Maidanak Observatory might be regarded as a middle-scale academic experiment involving several countries in an effort to answer to quite a few interesting questions that may arise in other international collaborations as well: Is it really possible to establish an Asia-wide observational network without continuous supply of million dollar money? How can we sustain a human network for this kind of observations, having a variety of people that have different scientific interest and background? What kind of way is the most efficient and effective to make the next generation scientists grow up, particularly in an international environment like this? Would it be fine to make use of economic disparity between particular countries (such as between Uzbekistan and Japan), even when the purpose is purely academic and not for profit? And, to ourselves: Was our scientific goal accomplished even to a small extent as we had expected before? Honestly, we do not have clear or appropriate answers to any of these questions now. But one thing is sure – our experiment just goes on and on, with or without budget, until our scientific objectives have been achieved and the human network that can be exploited by the future generation has been established. Also, the next generation program of this line will involve two Asian powers as well: China and India that already have extremely large resource in planetary astronomy that we rely on. It will enforce our program and hopefully accelerate the accomplishment of our scientific goals that otherwise might be rather far away.

Acknowledgements

We greatly appreciate the effort and courtesy by all the people at all the institutes in all the countries that were kindly involved with our series of observing program, particularly those working at UBAI and Maidanak Observatory, including their director, Shuhrat A. Ehgamberdiev. We also thank two expert admin associates working at NAOJ, Michiru Goto and Hiroko Kikkawa, for helping us take care of cumbersome and complicated paperwork accompanied with the use of funding. Some part of the data analysis was performed at ADC and CfCA of National Astronomical Observatory of Japan. This study is supported by the Grant-in-Aid of the Ministry of Education, Culture, Sports, Science & Technology in Japan (16740259/2004-2005, 18540426/2006-2008, 18540427/2006-2008, 21540442/2009-2011), the Sumitomo Foundation research funding (030755/2003-2004), the NAOJ special research funding by Director's discretion (2004, 2005, 2006, 2007, 2008), the Heiwa Nakajima Foundation research funding for the Asian studies (2009), and the JSPS Asia-Africa Academic Platform (2009-2011) entitled "*Development of the Asian-wide observation network for detecting and investigating potentially hazardous near-Earth objects*."

References

Ehgamberdiev, Sh. A., Baijumanov, A. K., Ilyasov, S. P., Sarazin, M., Tillayev, Y. A., Tokovinin, A. A., and Ziad, A. (2000a) The astroclimate of Maidanak Observatory in Uzbekistan, *Astron. Astrophys. Suppl.*, **145**, 293-304.

Ehgamberdiev, Sh. A., Eshonkulov, S., and Litvinenko, E. (2000b) Kitab as one of the five stations of the ILS: History and present In *Polar Motion: Historical and Scientific Problems*, ASP Conference Series, (Eds. Steven Dick, Dennis McCarthy, and Brian Luzum), **208**, 163-168, ASP, San Francisco.

Hirayama, S. (1918) Groups of asteroids probably of common origin. *Astron. J.*, **31**, 185-188.

Ito, T. and Malhotra, R. (2006) Dynamical transport of asteroid fragments from the ν_6 resonance, *Advances in Space Research,* **38**, 817-825.

Ito, T. and Yoshida, F. (2006) Lightcurves of the Karin family asteroids, in *Advances in Geosciences* (Eds. Anil Bhardwaj and Wing-Huen Ip), **3**, 317-329, World Scientific, Singapore.

Ito, T. and Malhotra, R. (2010) Asymmetric impacts of near-Earth asteroids on the Moon, *Astron. Astrophys*, **519**, A63.

Ito, T. and Yoshida, F. (2010) Young asteroid families and their lightcurve observation at Maidanak Observatory, Uzbekistan, in *Advances in Geosciences* (Eds. Anil Bhardwaj et al.), **25**, 161-172, World Scientific, Singapore.

Kadono, T., Arakawa, M., Ito, T., Ohtsuki, K. (2009) Spin rates of fast-rotating asteroids and fragments in impact disruption, *Icarus*, **200**, 694-697.

Michel, P., Benz, W. and Richardson, D. C. (2003) Disruption of fragmented parent bodies as the origin of asteroid families, *Nature*, **421**, 608-611.

Mueller, B. E. A., Samarasinha, N. H., and Michael, M. J. S. (2002) The diagnosis of complex rotation in the lightcurve of 4179 Toutatis and potential applications to other asteroids and bare cometary nuclei, *Icarus*, **158**, 205-311.

Nesvorny, D., Bottke, W. F., Dones, L., Levison, H. F. (2002) The recent breakup of an asteroid in the main-belt region, *Nature*, **417**, 720-722.

Nesvorny, D., Bottke, W. F., Levison, H., and Dones, L. (2003) Recent origin of the solar system dust bands, *Astrophys. J.*, **591**, 486-497.

Nesvorny, D., Vokrouhlicky, D., and Bottke, W. F. (2006) The breakup of a main-belt asteroid 450 thousand years ago, *Science*, **312**, 1490.

Nesvorny, D. and Vokrouhlicky, D. (2006) New candidates for recent asteroid breakups. *Astron. J.*, **132**, 1950-1958.

Nesvorny, D., Enke, B. L., Bottke, W. F. Durda, D. D., Asphaug, E., and Richardson, D. C. (2006) Karin cluster formation by asteroid impact, *Icarus*, **183**, 296-311.

Sasaki, S., Nakamura, K., Hamabe, Y., Kurahashi, E., and Hiroi, T. (2001) Production of iron nanoparticles by laser irradiation in a simulation of lunar-like space weathering, *Nature*, **410**, 555-557.

Sasaki, S., Sasaki, T., Watanabe, J., Yoshida, F., Kawakita, H., Takato, N., Dermawan, B., Fuse, T., Ito, T., and Sekiguchi, T. (2006) A new-born asteroid 832 Karin with old and new surfaces - SUBARU Spectroscopy, *Adv. Space Sci.*, **38**, 1995-1999.

Sasaki, T., Sasaki, S., Watanabe, J., Sekiguchi, T., Yoshida, F., Kawakita, H., Fuse, T., Takato, N., Dermawan, B., Ito, T. (2004) Mature and fresh surfaces on the newborn asteroid Karin, *Astrophys. J.*, **615**, L161-L164.

Vokrouhlicky, D. and Nesvorny, D. (2008) Pairs of asteroids probably of a common origin, *Astron. J.*, **136**, 280-290.

Yoshida, F., Dermawan, B., Ito, T., Sawabe, Y., Haji, M., Saito, R., Hirai, M., Nakamura, T., Sato, Y., Yanagisawa, T., and Malhotra, R. (2004) Photometric observations of a very young family-member asteroid (832) Karin, *Publ. Astron. Soc. Japan*, **56**, 1105-1113.

Yoshida, F., Ito, T., Takahashi, S., Ibrahimov, M. A., and Marchalkina, A. L. (2009) Photometric observations of young asteroid families at Maidanak Observatory, in *Advances in Geosciences* (Eds. Anil Bhardwaj et al.), **15**, 119-132, World Scientific, Singapore.

Yoshida, F., Ito, T., Dermawan, B., Nakamura, T., Takahashi, T., Ibrahimov, M. A., Malhotra, R., Ip, W-. H., Chen, W-.P., Sawabe, Y., Haji, M., Saito, R., Hirai, M., Miyasaka, S., Fukushima, H., Sato, H., and Sato, Y., Lightcurves of the Karin family asteroids, arXiv:1205.2837.

Zappala, V., Cellino, A., Barucci, A. M., Fulchignoni, M. and Lupishko, D. F. (1990) An analysis of the amplitude-phase relationship among asteroids, *Astron. Astrophys.* **231**, 548-560.