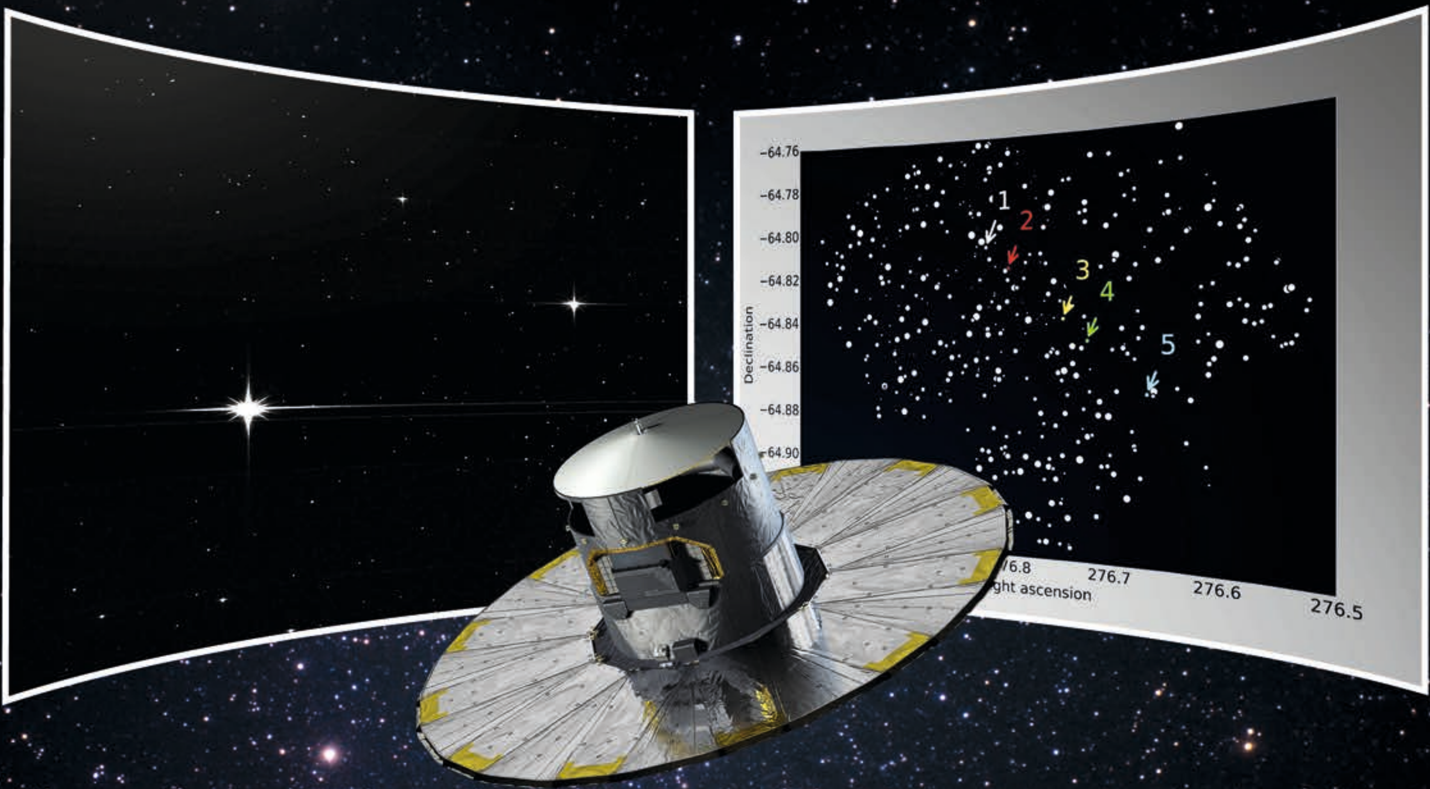
Third Gaia Fun SSO Workshop Proceedings



GAIA

FOLLOW-UP NETWORK FOR THE SOLAR SYSTEM OBJECTS

#3

IMCCE · Paris Observatory

From November 24 to November 26, 2014

77, avenue Denfert-Rochereau, 75014 Paris

Proceedings of

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Third "Gaia Follow-up Network for Solar System Objects" Workshop

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Foreword

The observation of Solar System Objects (SSO) by the Gaia space astrometry mission will be constrained by a scanning law. Much detection of interesting objects may occur with no possibility of further observations by the probe. These objects will then require complementary ground-based observations. Among them, previously unknown Near-Earth Objects, fast moving towards the Earth or going away from it could be found. Several objects discovered by Gaia could also be Inner-Earth Objects, as the probe will observe at rather low Solar elongations.

In order to confirm from the ground the discoveries made in space and to follow interesting targets, a dedicated network is organized, the Gaia Follow-Up Network. This task is performed in the frame of the Coordination Unit 4 of the Gaia Data Processing and Analysis Consortium (DPAC), devoted to data processing of specific objects. The goal of the network is to improve the knowledge of the orbit of poorly observed targets by astrometric observations on alert. This activity is coordinated by a central node interacting with the Gaia data reduction pipeline all along the mission.

In 2010 and 2012, we had organized the first two workshops in order to initiate the network and to meet the participants. In 2014, almost one year after the launch of Gaia, we organize the third Gaia-FUN-SSO workshop in Paris in order to discuss further the coordination of the network of observing stations, to discuss the prelaunch training observations which have been performed and to prepare the network for the operating phase of the alert mode which must begin in 2015. During this workshop, the participants had the opportunity to be informed about the status of the Gaia mission, about the alert process for SSO and the ground-based data processing. They were invited to present their activities in relation with this program, or their equipment, instruments and observing sites. Large time slots have been reserved for discussions. This workshop was fruitful and articles have been gathered in these proceedings with the aim to keep track of these very interesting days.

Paolo Tanga/OCA
& William Thuillot, IMCCE/Paris Observatory
Co-chairmen of the Gaia-FUN-SSO 2014 Workshop

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- IMCCE-Paris Observatory : *www.imcce.fr*
- Côte d'Azur Observatory (OCA) : *www.oca.eu*

We thank also several colleagues from IMCCE their help in this organization and in particular Yohann Gominet for the design of the workshop poster and Sylvie Lemaitre and Yohann Gominet for these proceedings.

PROGRAM

Monday November 24

10:00 – Welcome address by M. Claude Catala, President of Paris Observatory
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Gaia Mission Status

T. Prusti

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Abstract: *Gaia mission is underway conducting its 5 year lasting survey of the sky. At the moment the commissioning period has been completed and half a year worth of routine phase data has been collected. The status of the mission is outlined with a short explanation of some commissioning phase findings and their impact on the mission. With a few examples of early mission data the potential of Gaia is demonstrated and we can conclude that the mission is capable meeting the high expectations imposed on it.*

1. Introduction

Gaia satellite is an ESA corner stone mission launched 19 December 2013 from Kourou. The mission will map more than 1 billion objects on the sky determining their positions, movements and distances. In addition Gaia will conduct photometric survey of all objects and spectroscopy of the brightest ones. Gaia satellite, including its payload, has been built by European industry with Airbus DS in Toulouse as the prime contractor. ESA is responsible of the overall management and operations. The scientific community participates in the data processing effort. This has been entrusted to the Gaia Data Processing and Analysis Consortium (DPAC), which was selected 2007 for the task. At the moment of writing this mission status description the half a year lasting commissioning has been completed and another half a year Gaia has been performing routine phase observations.

2. Launch campaign and commissioning

The launch campaign of Gaia started already summer 2013 when the spacecraft was transported to the launch site in French Guyana. This was done in two Antonov flights with the Deployable Sunshield Assembly (DSA) being moved separately from the rest of the satellite. In Kourou the DSA was mated with the satellite and among many other tests a deployment test was conducted for this critical in-flight activity.

Gaia launch took place 19 December 2013 early in the morning with Soyuz launcher (Fig. 1). The launch was followed with an automatic sequence of operations where the basic functionalities of the spacecraft were checked and the DSA was deployed. The decontamination procedure was initiated to remove all water from the optical elements. After decontamination the Focal Plane Assembly was switched on in January and the commissioning activities could start with full speed. All subsystems of Gaia were verified to function. Notably, all CCD on the focal plane are operational as well as the electronics connecting the devices to the memory modules on-board. The clock on-board provides sufficient accuracy to time stamp the observations correctly. The deletion and transmission priorities are functioning as designed so that the right data was stored and transmitted down. The Phased Array Antenna has sufficient power to allow high data rates. Overall, the power budget is very healthy. The orbit maneouvres have been performed successfully keeping Gaia in the reference trajectory around L2. For the fine tuning of the attitude the micro propulsion thrusters are providing the control at sufficient accuracy. This is achieved with correctly functioning Attitude and Orbit Control System where the finest details are based on science data obtained on-board, analysed on the fly and used to control the micro thrusters.

Fig. 1: Gaia launch 19 December 2013. Credit: ESA-S. Corvaja

3. Unwanted surprises

Although all subsystem of Gaia are functional, there are unwanted surprises discovered during the commissioning activities. Three main issues can be identified: stray light, continuing contamination and unexpectedly large basic angle variation.

3.1 Stray light

The stray light component observed by Gaia has two elements in it. One part is due to strong astronomical sources, which shine into the focal plane through reflections inside the thermal tent. The second source of stray light is directly related to the Sun as the pattern is very repetitive within the 6h spin period. More precisely the repetition is not strictly spin synchronous, but Sun synchronous. The most likely reason for this are fibres which may be sticking out at the edges of the DSA. DSA contained two kinds of panels in it: fixed ones and rolled ones. The edges of the fixed ones were taped, but this was not possible to do for the rolled ones. The fibres are fabricated into the material to strengthen the panels, but have this undesired effect of sticking out from the cut edges. The amount of scattered light from the fibres is sufficient to explain the observed stray light levels in the focal plane. The stray light acts as an additional background reducing sensitivity of Gaia at the faint end. Especially spectroscopy is affected. The scientific impact has been evaluated and published on the Gaia web-pages. Given the nature of the cause, it is not possible to fix or operationally avoid this stray light. However, it is possible to recover some of the lost sensitivity by changing the acquisition software from the assumed readout noise limited case to the in-flight experienced background light dominated case. This activity is on-going.

3.2 Contamination

The decontamination conducted directly after the launch was intended to free all optical elements of water and freeze it in the thermal tent into structures where it does not harm. However, very quickly it was noticed that the water source on-board had not exhausted and transmission through the optical path was degrading. The cause was confirmed to be water as the transmission was recovered after having heated the mirrors to temperatures above the water sublimation point. The subsequent decontamination exercises allowed recovery of the transmission and also marked a point after which the contamination rate decreased. The last decontamination procedure was executed 23-24 September 2014. Since then the transmission loss has continued, but again with a lower rate. As a decontamination is done with heating the mirrors, there is rather significant thermal impact on the spacecraft of this activity. Especially for astrometry the effect is difficult to calibrate and some residual effect will remain for some weeks degrading the overall mission performance. Therefore the decontamination procedure will be executed only when strictly needed due to degradation of data quality. It is clear that at least one more decontamination must be performed, but the timing has not yet been decided.

3.3 Basic Angle variation

The Basic Angle in Gaia is the fixed angle between the two lines of sight. This is a fundamental concept of the mission allowing the whole sky to be tied together into a global astrometric solution. This one will work only if the angle between the telescopes is known and not changing in time. In reality it was already known that the angle cannot be kept constant at the very high Gaia measurement accuracy and therefore a specific device, Basic Angle Monitor (BAM), was part of the payload. BAM is intended to measure the relative variation of the angle so that this can be taken into account in the data processing just like having the Basic Angle being stable and constant. The commissioning phase surprise was that the amplitude of measured Basic Angle variation was 1 milliarcsec instead of 10 microarcsec. The first worry was to be confident that the angle changes measured by the BAM were actually changes between the angle of the two lines of sight rather than changes internal to the metrology instrument. This confidence at 1 milliarcsec level was achieved with a test where one day astrometric solutions of the same part of the sky at different epochs were compared.

The Basic Angle variation is perfectly synchronous to the spin phase with the Sun. This indicates that the impact of the thermal effect due to the Sun is transmitted into the payload and to the two lines of sight. At the moment the most likely scenario is that the Service module, which is facing the Sun, transforms it into a mechanical effect in the Payload module. Currently a very detailed full thermal model of the coupled Service and Payload modules is being constructed in order to understand the way this effect impacts the Basic Angle. BAM is measuring the variation between two specific lines of sight within the two fields of view and for the highest accuracy a full understanding of the whole field of view variation must be understood.

4. Early results

The intrinsic nature of Gaia is self calibration and astrometry which is based on measuring the parallax over a period longer than a year. This has the consequence that Gaia catalogue releases are planned not earlier than middle of 2016. The science alerts have already started in verification mode and the first Gaia supernova has already been detected, but for the rest only data demonstration cases have been made public.

4.1 Astrometry

Astrometric results are available by definition only more than a year into mission. At this stage only the spatial resolving power can be demonstrated with a picture of Omega Centauri. This globular cluster is very challenging even for a space telescope and on top of that Gaia must not only detect all the objects, but also on the fly decide which ones to observe. Figure 2 is a picture (not an image) of the region where every dot represents a detected Gaia source. In the central parts one can see apparent lack of sources at the edges of some CCDs. This is due to limitations of resources on board to follow a maximum number of stars in any CCD pixel row. These gaps will be filled in subsequently when Gaia scans again across the region in a different observing angle.

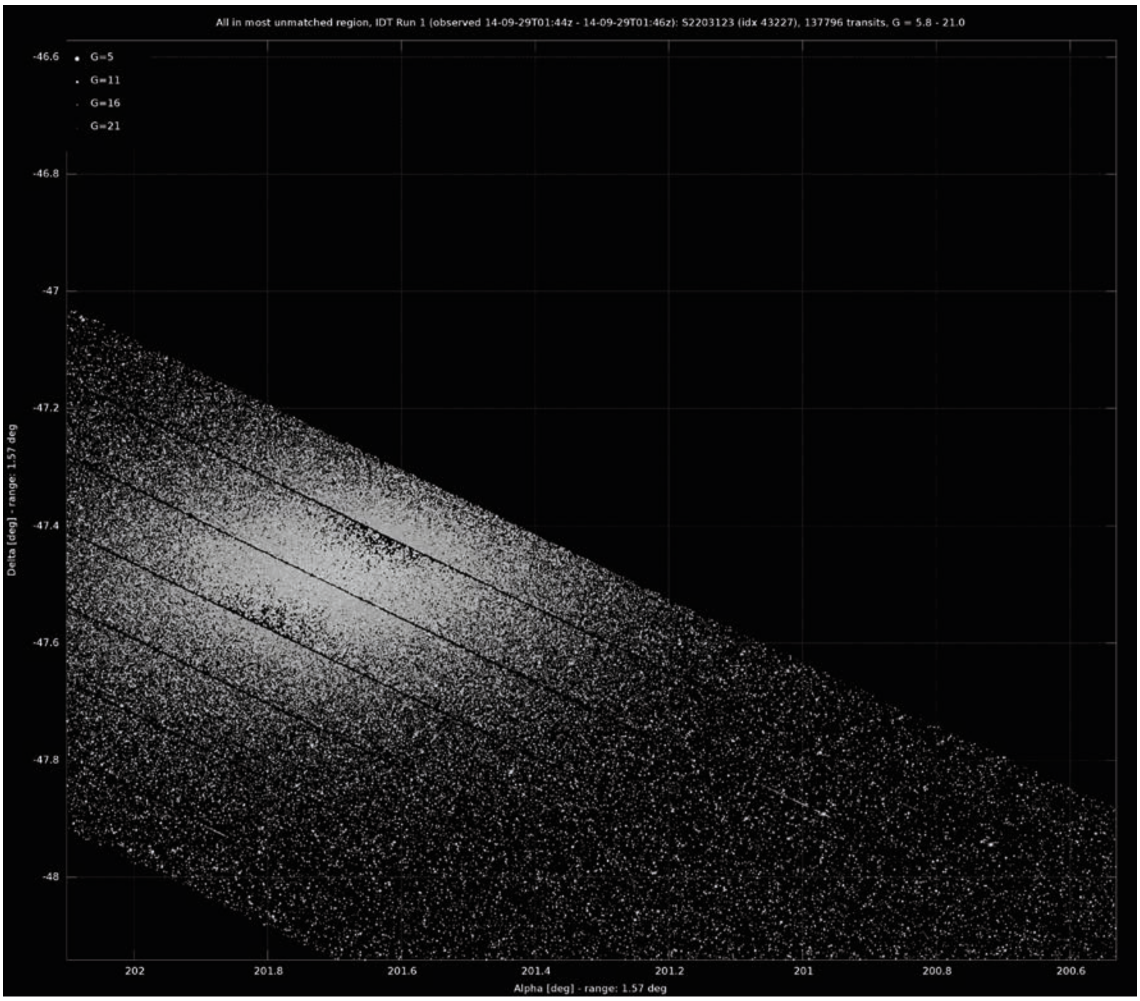

Fig. 2: Gaia on-board detections of point sources in Omega Centauri globular cluster after one pass. Credit: ESA/Gaia/DPAC/UB/IEEC

4.2 Photometry

The Gaia photometry is split into Red and Blue parts where the dispersion is achieved with a prism in front of the focal plane. These spectrophotometric data are collected from all the stars for which astrometry is performed. With the data it is possible to deduce effective temperatures, gravities and extinctions to large samples of stars for population studies. The photometry has also an astrometric goal as knowledge of the colours of the stars is needed for more precise astrometric data reduction. Figure 3 demonstrates the Gaia capability to distinguish stars of different temperatures.

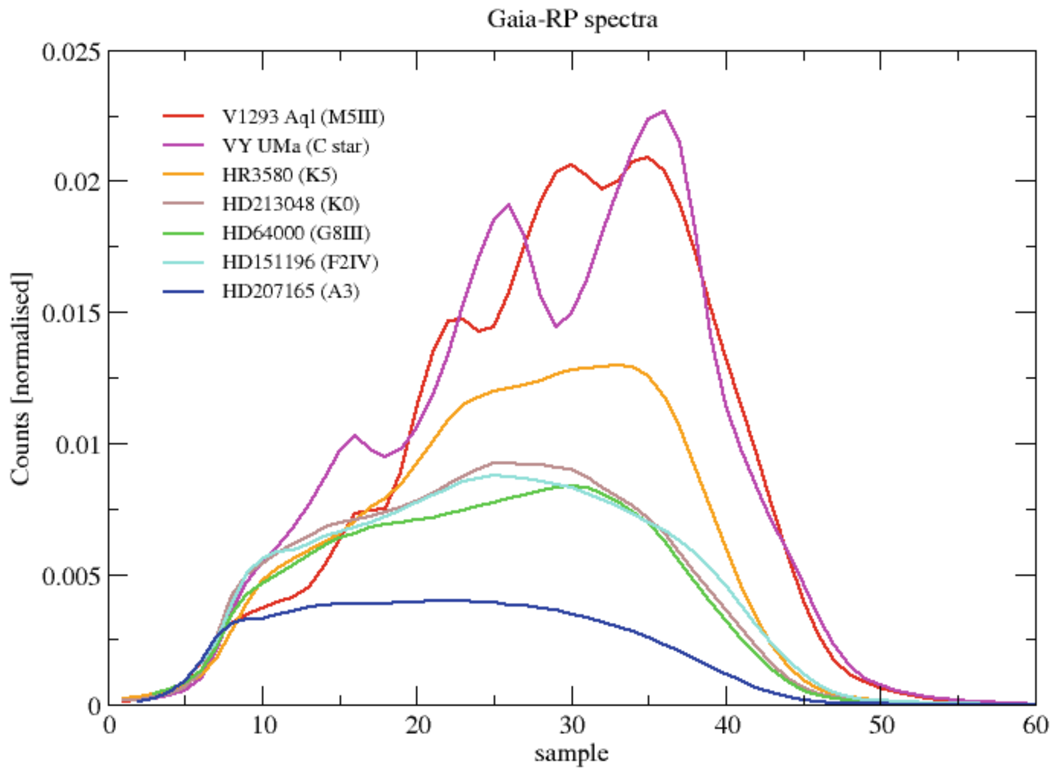

Fig. 3: Red Photometer spectra of stars with different effective temperatures. Credit: ESA/Gaia/DPAC/Airbus DS

4.3 Spectroscopy

The main purpose of Gaia spectroscopy is to obtain radial velocities for a large sample of stars. This is achieved with the Radial Velocity Spectrometer (RVS) on-board Gaia. The wavelength band covers the Calcium triplet allowing accurate deduction of radial velocities for cool stars. For brighter stars the signal to noise ratio is sufficient for additional spectral analysis work. In Fig. 4 RVS spectra of stars with different temperatures are shown to indicate the potential of Gaia spectroscopy.

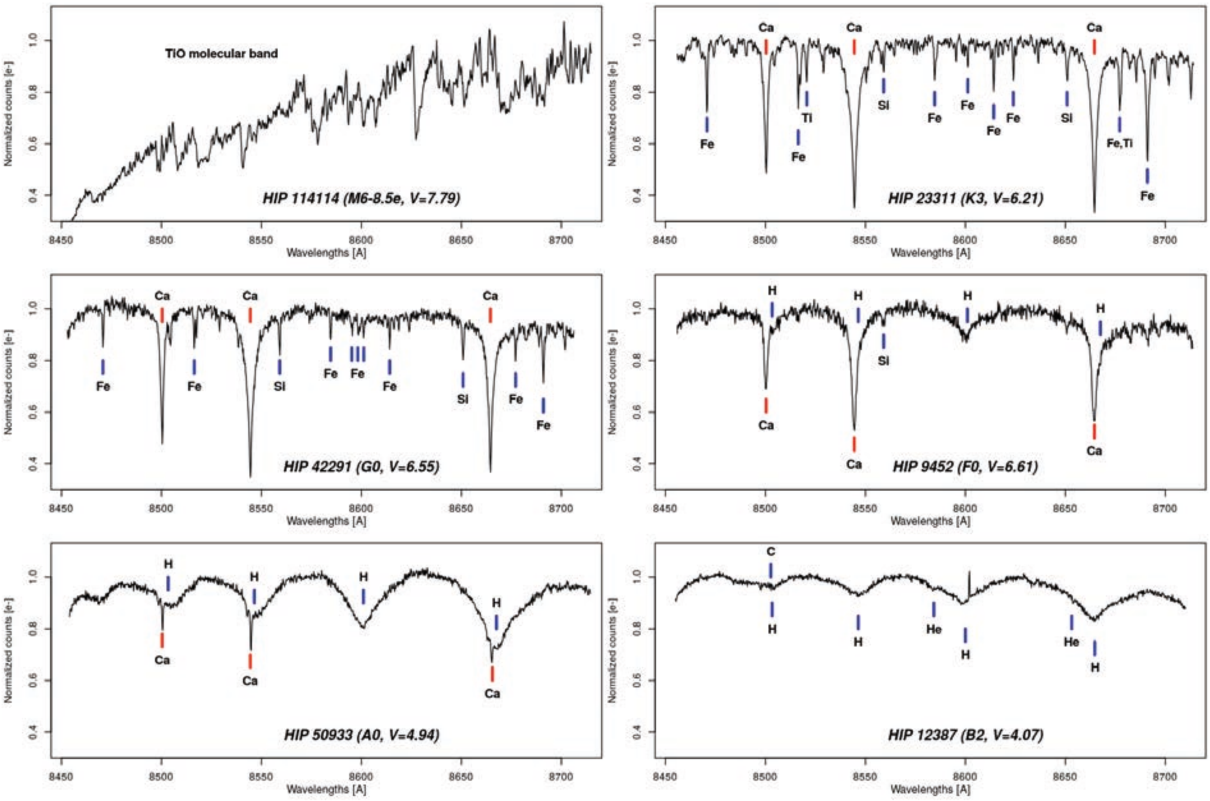

Fig. 4: Radial Velocity Spectrometer data of stars with different effective temperatures. Credit: ESA/Gaia/DPAC/Observatoire de Paris-Meudon/Olivier Marchal & David Katz

5. Next steps and conclusions

Gaia is currently in its first year of routine observations. The nominal mission lasts for 5 years. On average Gaia observes some 40 million stars every day. The current astrometric and photometric magnitude limit has been set to G=20.7 mag. The RVS magnitude limit is currently at G_{RVS}=16.2 mag, but this may be revised pending on the validation of the on-board software aimed to mitigate part of the stray light impact. At bright end the limit has been extended to G=2-3 mag by on-board parameter settings. The brighter stars are also observed, but with a special mode with limitations to accuracy (and no RVS data). The Gaia mission is well underway with the first intermediate catalogue release anticipated 2016.

Updates on Gaia observations of Solar System objects

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Abstract: With this presentation we will review the current status of Solar System object observations with Gaia, especially concerning the plans for the activation of the alerts. Gaia is currently scanning the sky with the Nominal Scanning Law that will remain constant for a long part of the mission duration. Known problems of stray light and mirror contamination don't affect strongly the astrometry of the observed sources. We were able to identify and study the properties of Solar System object observations and the dedicated data reduction pipeline will soon run routinely, producing data for the ground based network.

Introduction

The capabilities of Gaia in terms of completeness and depth of investigation are expected to trigger a long-standing wave of change in several branches of astrophysics. Such high expectations are not only related to our knowledge of the Galaxy, for which the mission was conceived, but also to Solar System (Cellino et al., 2007; Hestroffer et al., 2010; Mignard et al., 2007; Tanga et al., 2007).

During its 5 years of operations, Gaia will observe 350.000 asteroids with a nominal limiting magnitude V=20. Each object will be seen on average ~70 times but large fluctuations of such number are possible. For example, some NEOs can be detected just a few times, and some asteroids on favorable geometry 200 times or more. The small number of detection for fast-moving sources is the main motivation for a ground-based follow up of Gaia observations.

Intermediate data releases of Gaia data, are expected to contain asteroid measurements, with partial accuracy and completeness.

Content of asteroids observations by Gaia

Each observation consists in a sequence of astrometric measurements obtained while the object drifts over the several CCDs of the AF (Astrometric Field). In principle, 9 CCD strips are present in AF, representing the maximum amount of measurements in the small interval of time (about 40 seconds) taken by the source image to transit over all of them.

For sake of clarity, we note here that in the Gaia jargon the word “transit” is often used a synonym of “observation”. This is due to the fact that, for stars, average quantities over a transit are typically considered, as fast changes are not expected. In the case of asteroids, the situation is different, since a Solar System object can move considerably with respect to the stars. Its successive positions can then be considered as independent measurements.

In more quantitative terms, a typical Main Belt asteroid (with an apparent speed of 0.01 arcsec/sec) can move by one full pixel along scan (~60 mas) in just 6 seconds of time. Over a full transit in the AF, this motion can then nearly reach 7 pixels.

Such a displacement specific to asteroids is also the source of a loss of efficiency. Of course, a first concern is image smearing over a single CCD. A second one is related to the “windowing” strategy. In fact, the Video Processing Algorithm onboard Gaia assigns pixel “windows” around each detected sources, of a typical size of 6 pixels in the direction along scan. The window is then propagated along the CCDs following the nominal image motion on the focal plane for a stellar source. Of course, if the asteroid proper motion is large enough a more or less consistent fraction of its signal can leave the window during the transit. For this reason, the typical number of observations per transit can be less than 9, in the AF.

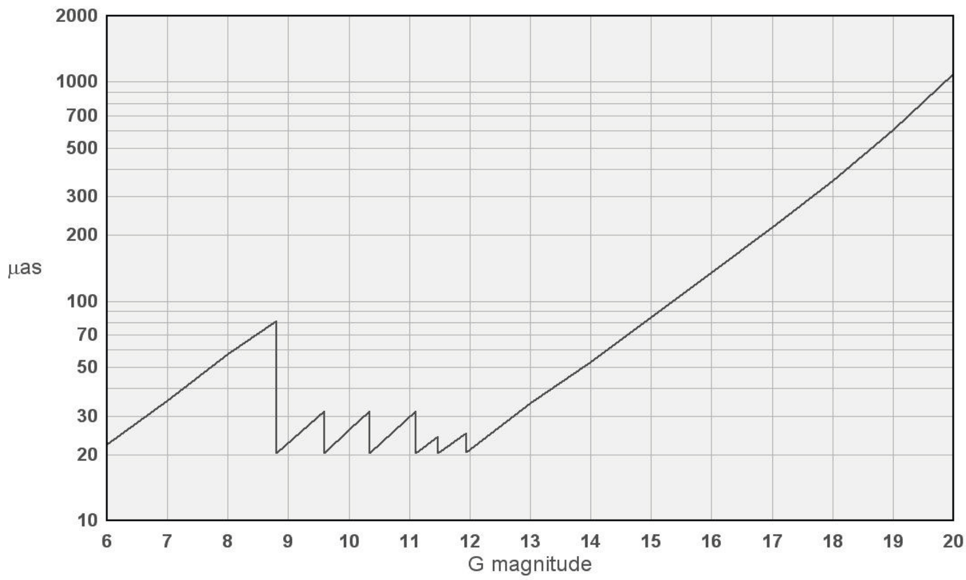

Figure 1. Single-transit accuracy for a point-like stellar source, as a function of apparent brightness. The G magnitude is the “Gaia” spectral response (unfiltered in the visible, for AF CCDs), a proxy of V.

These considerations can, in the end, affect the nominal astrometric accuracy per transit, shown in Fig. 1, but the performance will anyway remain extremely impressive if compared to the average accuracy of CCD astrometry on the MPC database (0.5 arcsec typ.).

Besides astrometry, Gaia also collects low-resolution spectra of all sources by its Red and Blue Photometers (RP and BP). In practice these are two CCD strips optimized for the Red and the Blue part of the spectrum, with a refractive dispersing element in front. The dispersion will be equivalent to ~30 independent wave bands. Performances have been illustrated in more details elsewhere (Delbo' et al., 2012). Here we just stress that the physical characterization (taxonomy) derived from these data is in itself an incredible advance over the currently available asteroid spectro-photometry, whose importance won't be minor relative to astrometric data.

Intermediate data releases from Gaia will contain asteroid astrometry, while spectro-photometry will probably be more delayed in order to provide more complete information, including a totally new Gaia taxonomy.

Processing of daily Solar System observations: preliminary results

Every day, the Gaia telemetry is processed by a software module called "Initial Data Treatment" (IDT) which performs data checks and a first, quick processing. Positions are determined by using a daily, approximate attitude whose accuracy is around 0.05 arcsec.

IDT also cross matches non-moving sources to previous detections of the same sources, thus identifying stars. Un-matched sources should contain, in principle, moving sources mainly. In practice a high level of contamination exists by false "asteroids". Due to this, up to now it was not possible to monitor the discovery of new asteroids. Effective filters are being implemented and tested to cope with this problem.

In the meantime, it has been possible to start testing the daily flux of asteroid data available on known asteroids, identified from their good match to positions computed from the ephemerides. The results show a good overall agreement with the expectations, in terms of astrometric accuracy. This is a very encouraging element for the prosecution of the operations of Gaia, and for the forthcoming access to alerts and the first data releases.

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Gaia's role in understanding asteroid populations

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Abstract*: The existing debiased population models for asteroids describe their orbital, absolute-magnitude, size and albedo distributions. The next step is to develop models that i) self-consistently describe several populations such as near-Earth objects and main-belt objects, and ii) describe the debiased distributions of physical parameters or their proxies such as photometric slope parameters. Gaia will carry out a survey of the entire asteroid population which is suitable for calibrating the next generation of population models. In particular, the accurate photometry and low-resolution spectra will allow physical properties to be modelled at a level which has so far not been possible due to sub-optimal data quality.*

1. Introduction

Debiased[1] models of asteroid populations currently exist for both near-Earth objects (NEOs) and main-belt objects (MBOs). Rabinowitz (1993) used detections of 24 NEOs obtained with the 0.91-m Spacewatch telescope to derive a debiased absolute-magnitude (H) distribution for small NEOs. Bottke et al. (2000,2002) used 138 NEOs also detected by the Spacewatch survey to derive debiased orbital (semimajor axis a, eccentricity e, inclination i) and absolute-magnitude distributions for NEOs. Bottke et al.'s (2000) approach was ground-breaking in that it combined the dynamical evolution of asteroids from the main asteroid belt to the NEO region with population models. Their approach allowed for a true 4-dimensional (a,e,i,H) map of the NEO population. Stuart (2000) used detections of 606 distinct NEOs by the Lincoln Near-Earth Asteroid Research (LINEAR) survey to derive one-dimensional distributions in (a,e,i,H) with particular focus on large NEOs. Rabinowitz et al. (2000) used detections of 45 NEOs by the Near-Earth Asteroid Tracking (NEAT) survey and derived a debiased absolute-magnitude distribution which predicted about 50% less NEOs with $H < 18$ as compared to Stuart (2000). Based on our current inventory of NEOs it is clear that Stuart's (2000) result was the most accurate one of the three absolute-magnitude distributions published in 2000. Stuart & Binzel (2004) combined the model by Stuart (2000) with spectroscopic data of NEOs and a correlation between taxonomic classifications and albedos to derive albedo and size distributions for NEOs. Mainzer et al. (2012) used infrared observations of 428 NEOs obtained by the Widefield Infrared Survey Explorer (WISE) to constrain debiased orbital and size distributions for Potentially-Hazardous Asteroids (PHAs) as well as NEO subpopulations (Atens, Apollos and Amors). Ongoing work by Granvik et al. will extend the debiased NEO absolute-magnitude distribution to $H < 25$ (diameter $D \sim 40$m) in the near future. Despite the above advances a gap still remains in the size distribution between NEOs and meteors. The

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[1] Corrected for observational selection effects.

lack of a debiased taxonomy distribution makes it challenging to correlate the observed NEO population with the meteorite inventory.

For the main asteroid belt the situation is different, in particular because of the lack of dynamical constraints similar to those that allow firm predictions for NEOs. Tedesco et al. (2005) constructed a model of the MBO population by extrapolating the size distribution of an unbiased[2] sample of MBOs down to sizes below the completeness limit of that time. To account for differences in the size distributions, Tedesco et al. (2005) divided the MBO population into 15 dynamical families and 3 different background populations and determined separate power-law slopes for each of these 18 subpopulations. Gladman et al. (2009) carried out the Sub-Kilometer Asteroid Diameter Survey (SKADS) and debiased the absolute-magnitude distribution for $H < 18$. The SKADS results hint at a turnover to a shallower slope at about $H = 18$. The existing debiased models of the MBO population cannot reliably estimate the distribution of small objects, because the extrapolations assume constant power-law exponents. The formulation does not allow for waves in the size distribution similar to those observed for larger objects and interpreted as effects caused by the nonlinear strength-size relation for asteroids.

The next step in population modeling is to produce self-consistent population models of MBOs and NEOs. This means that the models account for the dynamical evolution of asteroids from the main belt to the near-Earth region. If successful, these new multipopulation models will improve our knowledge of both MBOs and NEOs by i) extending MBO models to smaller sizes that match the current NEO models and by ii) allowing the existing knowledge of MBO physical properties to be propagated to the NEO models.

The main source of uncertainty in the current models is in the absolute magnitude, which in turn is based on the photometric data, primarily obtained by NEO surveys as a side product to astrometry. Most of the photometric data available has a scatter of several tenths of a magnitude or even more. The photometry has been obtained in many different wavelength bands, often even without filters, which makes it difficult to establish a common photometric scale for the observations. The derived absolute magnitudes therefore have a random error on the order of tenths of a magnitude and a systematic error which be half a magnitude. Assuming a systematic error in H of, say, 0.3 magnitudes implies that the predicted number of NEOs with $H < 17.75$ ($D > 1$km) will have a systematic error of about 30% which is about 3–5 times larger than the random error. Reducing the photometric errors requires more accurate photometry obtained by well-calibrated surveys.

2. The Gaia mission and asteroids

ESA's Gaia mission will carry out the first large-scale survey that provides a vast collection of astrometry, photometry and spectra of the entire asteroid population. During its nominal 5-year mission Gaia observes all objects with $6<V<20$ including some 300,000-400,000 solar-system objects, mainly previously known asteroids. The upper magnitude limit is set by telemetry considerations rather than photon flux, and may later be extended to V~21. The change would make Gaia’s limiting magnitude similar to the Catalina Sky Survey’s (CSS) 1.5-meter-diameter Mt. Lemmon telescope. Gaia’s survey pattern produces a true all-sky

[2] Typically consisting of objects with sizes larger than the completeness limit.

survey which is essentially free of, e.g., the inclination bias typical for ground-based asteroid surveys.

Mignard et al. (2007) list several areas of asteroid research that will benefit from the Gaia survey, but there is no mention about Gaia's role in the development of population models. The Gaia survey could nevertheless have a major impact on our understanding of the asteroid populations because its current characteristics make it comparable to CSS's Catalina station and in addition it provides superb photometry and low-resolution spectra. The accurate photometry can be used to derive accurate (H,G_1,G_2) parameters where G_1 and G_2 describe the slope of the phase curve. It is a well-established fact that the slope of the phase curve is correlated with an asteroid's spectral classification (Muinonen et al. 2002). Oszkiewicz et al. (2012) showed that the G_{12} parameter, which is a linear combination of G_1 and G_2, can be used to identify compositional trends such as asteroid families in the main asteroid belt. Since photometry will be available for MBOs and NEOs alike, the slope parameters can be used to debias surface properties of MBOs and NEOs.

The estimation of absolute magnitudes and photometric slope parameters require accurate photometric observations covering a wide phase-angle range. The absolute magnitude is particularly sensitive to measurements carried at small phase angles, that is, close to opposition, because H is defined at a phase angle of 0 degrees. Gaia will not obtain any measurements close to opposition and an alternative source for the data is therefore required. As ground-based surveys such as Pan-STARRS have dramatically reduced the typical photometric uncertainty in the recent years it should be feasible to obtain the necessary data from these outside sources once enough observations have been accumulated.

3. The Gaia Follow-Up Network for Solar System Objects and asteroid populations

As mentioned above, Gaia's main strength will not be in the discovery of asteroids but in the physical and dynamical characterization of the known asteroid population. Yet there is a possibility for discoveries, particularly at small solar elongations and high latitudes, that is, directions which are not extensively observed by ongoing, mainly ground-based surveys.

When discoveries are made follow-up astrometry and photometry need to be aquired rapidly in order that enough observations are obtained for a set of unique parameters describing its orbit and physical properties. Systematic follow-up is particularly important if these data are used to constrain population models. If the decision to obtain follow-up observations is random and subjective, it will be challenging to debias follow-up activities. That is, how do an objects parameters affect the likelihood that it will get follow up? For example, a follow-up bias against faint and/or fast-moving objects would mean that population models would tend to underestimate the number of these objects. The reason for this is that whereas Gaia would have a limiting magnitude of, say, 20 only a fraction of the objects with apparent magnitudes close to 20 would have enough observational data to allow accurate parameters to be computed.

A mitigation scenario for this bias is to constrain the population model with brighter objects which, considering Gaia's reasonably shallow limiting magnitude, would imply that there would be substantially fewer objects available for constraining model parameters, perhaps even too few for meaningful population models. Alternatively, one could resort to statistical estimates for the object parameters but this would imply that the model parameters would not be well constrained at the faint and/or fast end. Fortunately, the Gaia-FUN-SSO system set up by IMCCE will be very useful both for organizing systematic follow-up and for establishing the likely reason for missing follow-up.

4. Conclusions

ESA's Gaia mission will not be an asteroid discovery machine, but it can play an important role in understanding the debiased physical and dynamical characteristics of asteroid populations. The success of such an analysis depends on the availability of external photometry, preferentially from other well-characterized surveys, and on the systematic follow-up of asteroids discovered by Gaia.

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The European NEO Coordination Centre and the Gaia opportunity

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Abstract: *An operational approach to NEO hazard monitoring has been developed at European level within the framework of the Space Situational Awareness Program (SSA) of the European Space Agency (ESA). Through federating European assets and profiting of the expertise developed in European Universities and Research Centers, it has been possible to start the deployment of the so-called SSA NEO Segment. This initiative aims to provide a significant contribution to the worldwide effort to the discovery, follow-up and characterization of the Near Earth Object population. A major achievement has been the inauguration in May 2013 of the ESA NEO Coordination Centre located at ESRIN (Frascati, Italy). The goal of the NEOCC Precursor Service operations is twofold: to make available updated information on the NEO population and the associated hazard and to contribute to optimize the NEO observational efforts. This is done by maintaining and improving a Web Portal publicly available at* http://neo.ssa.esa.int *and by performing follow-up observations through a network of collaborating telescopes and facilities. Within this framework a summary of the first two years of NEOCC operations is presented, including collaborations with the Gaia-FUN-SSO; the opportunities given by the Gaia mission operations are also discussed.*

1. Introduction

The NEO (Near-Earth Object) Segment is one of the three major service components of the ESA Space Situational Awareness (SSA) programme, together with the SST (Space Surveillance and Tracking of man-made space objects) and the SWE (Space Weather monitor and forecast) segments. The SSA program aims to raise awareness on the population of space objects, the space environment and the existing threats and risks by timely providing data and services to users, customers and stakeholders which range from the scientific community to satellite operators, from governmental institutions for risk monitoring to Space Agencies, from insurance companies to the public at large.
The SSA NEO Segment, according to its design (Perozzi et al. 2011), is intended to play a leading role in the worldwide efforts on NEO hazard and mitigation, fruitfully interacting with known entities such as the Minor Planet Centre (authoritative source of NEO data on behalf of IAU) and the NASA funded JPL Near Earth Object Program (mainly devoted to NEO impact monitoring). In order to reach this goal it is foreseen the development of a

software system for NEO data management and dissemination, the coordination of European-based follow-up astronomical observations and the realization of a network of telescopes for providing a significant contribution to the worldwide efforts for NEO discovery.
Federating already existing assets represents the first step to this end. The European worldwide excellence in orbit determination and impact monitoring is witnessed by the long-standing operational experience of the NEODyS system (Chesley and Milani 1999). The Spaceguard Central Node provides an algorithm to prioritize NEO follow-up observations by ranking them according to their importance for impact monitoring, thus ensuring that the highest possible percentage of these objects, and in particular the newly discovered ones, is recovered at other apparitions (Boattini et al. 2007). EARN (European Asteroid Research Node) keeps on-line updated lists of the available physical characteristics of known NEOs, which are essential in order to evaluate the consequences of an impact, to prepare mitigation actions and to compute high-accuracy long-term orbital evolutions.
NEO observations are in general carried out on a voluntary basis, thus leaving the possibility to optimise their outcome through a coordinated effort. Therefore SSA NEO collaborating facilities ready to observe even upon short notice can significantly contribute to the orbit improvement of already known/recently discovered objects.
Finally, the contribution of space-based assets, and in particular of the ESA Gaia mission, which foresees the issue of astrometric alerts, is envisaged (Perozzi et al. 2013).

2. The NEO Coordination Centre

So far the SSA-NEO Segment activities have been successfully initiated and the ESA NEO Coordination Centre, located at ESRIN (Frascati, Italy), was inaugurated on 22 May 2013. It consists of a NEO software system available on-line through a Web Portal at http://neo.ssa.esa.int, of on-site personnel carrying out daily operations and of the necessary hardware and software assets needed to support, maintain and improve the NEO Segment functionalities and services. Routine operations foresee the execution of all tasks needed to keep the system alive (e.g. update the contents of the web pages, prepare and issue news, support system maintenance), issuing alerts to the professional and amateur observers community on objects bearing a specific interest for NEO science and mitigation as well as representing the reference contact point for external users and stakeholders (e.g. collaborating observatories, ESA, the public at large).
The NEOCC is an is an evolving environment: the services are continuously improved and are designed to ensure complementarity with respect to other NEO systems (e.g. Minor Planet Centre, NASA Near-Earth Object Program) while keeping a high degree of completeness.
In the following sections a summary of the NEOCC functions and services available in the forthcoming NEO software system release is given.

2.1 Databases and Catalogues

The NEO Coordination Centre hosts a large collection of Small Bodies data. The orbital elements of all asteroids (NEOs, Main Belt, TNOs, etc.) for which good quality orbits are available, are regularly provided by NEODyS (http://newton.dm.unipi.it/neodys/) and AstDyS (hamilton.dm.unipi.it/astdys/) and stored in the NEO system. As far as NEO physical properties are concerned, EARN data (earn.dlr.de/nea/) are integrated into a fully searchable database. Thus a single query interface allows to display both the dynamical and the physical properties of any given asteroid or to search for objects within certain parameters range for further investigation.

In order to extend the NEO Segment services, the availability of other solar system objects relevant to NEO hazard is implemented. No impact monitoring is foreseen for comets but an updated catalogue (as provided by JPL: ssd.jpl.nasa.gov/dat/ELEMENTS.COMET) is made available.
Fireballs are considered a crucial population to be better understood for being just located at the lower range of the mass-size NEO distribution. A Fireball database would therefore further complement and extend the NEO Segment services. Due to the widely dispersed data sources maintained by both, scientific and amateur organizations, harmonization of the database content is necessary. To this end ESA has developed an independent Fireball Information System fully compatible with the NEO system.
The NEO Coordination Centre is intended also to receive data from collaborating observatories, to properly archive them and provide users with the necessary tools to retrieve them for dedicated processing (e.g. data reduction, search for precovery observations etc.). Suitable FITS standard have been adopted for the currently available images, at present mostly provided by the La Sagra Sky Survey and by the ESA Optical Ground Station (OGS).

2.2 Visualization tools

Several visualization tools and graphical aids are foreseen for the NEOCC users in order to ease the comprehension of the NEO risk problem. Providing clear and informative material is a key issue in properly disseminating information on the asteroid hazard in order to avoid potentially dangerous misinterpretations of scientifically correct facts and figures, and the availability of visualization tools is a powerful means to this end.
Asteroid orbits can be drawn, as a first approximation, using the Keplerian elements of the selected object. The position along the orbit of a given object can be computed at regular time intervals from well-known formulas thus showing an animation of its past and future motion along the orbit. A three-dimensional animated plot of the asteroid trajectory in space is therefore obtained, with the possibility of changing the viewpoint, the zoom factor, the timescale and the direction of motion. This approach was originally used by the NEOCC Orbit Visualization Tool.

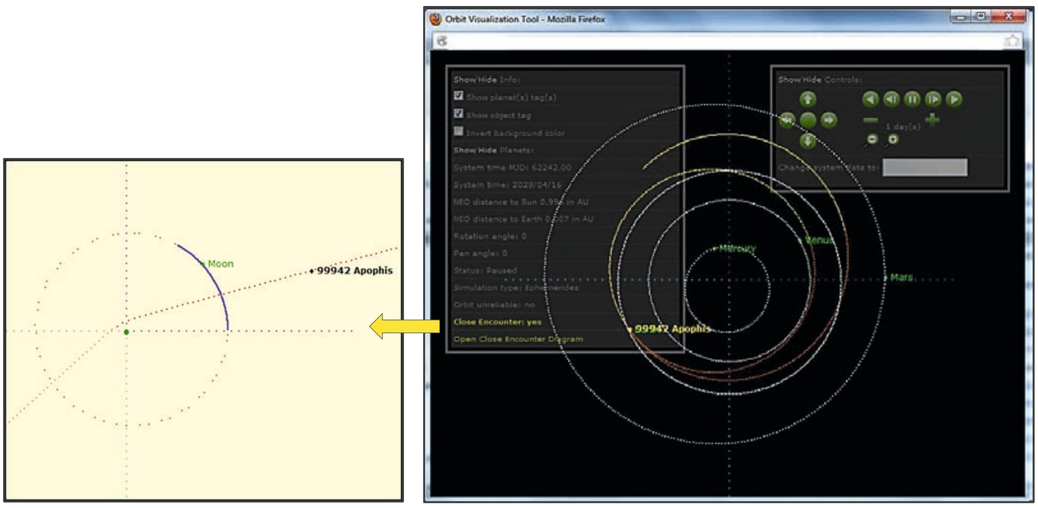

Fig. 1: The NEOCC orbit visualization tool showing the perturbed trajectory of asteroid Apophis before and after its 2029 encounter with the Earth in a heliocentric (right) and geocentric (left) reference frame. Note in the right plot the pop-down control panels, while the plot on the left has been drawn enabling the inverted background option.

Yet, in order to provide orbital plots more closely reflecting the actual dynamical evolution of a NEO, a more refined modelling of the trajectory which includes planetary perturbations is needed. In particular when Earth close encounters occur the availability of enhanced functionalities (e.g. adopting an Earth-centered reference frame, providing a visual evaluation of the orbit uncertainty) is desirable. This involves leaving the simplified 2-body approximation and using pre-computed high accuracy ephemeris instead.
An enhanced orbit visualization tool has been therefore developed. In order to fully appreciate the orbital changes due to close encounters, the perturbed trajectory is drawn for a given time span ahead and behind the running position of the asteroid. Switching to the geocentric reference frame, where the orbit of the Moon is also displayed, can be selected during close encounters for better appreciating the geometry of the encounter and the underlying dynamics. An example is shown in Fig. 1 for the 2029 encounter of asteroid Apophis with the Earth, which raised significantly the aphelion of its orbit.
Following the advances of our knowledge on the NEO population is also well suited for graphical display: by using simple statistical representations it is possible to monitor NEO discoveries on a daily basis.

2.3. Other services

A NEA chronology page listing significant past and forthcoming events - previously hosted by the International Astronomical Union - has been migrated into the NEO System and regularly updated.
News are published on the NEO web portal when appropriate; the publication of a monthly newsletter summarizing the most important events related to NEO hazard monitoring has begun in April 2015 (to subscribe please write to neocc@ssa.esa.int).
Public outreach material is also provided as a collection of images, diagrams and articles.

3. Observation Campaigns

Follow-up observations are essential to prevent newly discovered objects from becoming lost as well as to improve the accuracy of the orbit of risky objects (i.e. those possessing impact solutions, referred to as VIs - virtual impactors).
While large scale surveys are devoted entirely to the discovery of new objects, and some specific projects are focusing on physical characterizations, up to now there has been a lack of centralized effort to coordinate the follow-up of objects. The NEOCC has as a major goal the coordination of a network of observatories that are being alerted when high-relevance objects need follow-up. At the same time, the Centre is directly performing astrometric observations of high-priority targets, both using its own facilities and large aperture telescopes all over the world. Several observational campaigns have been carried out both developed through cooperating partners and directly managed by the NEOCC.
The most accessible resource is the 1.0-meter ESA OGS telescope in Tenerife, which is routinely used to follow-up and recover NEOs, for about 4 nights per month. In addition to the OGS, a very fruitful collaboration has been established with ESO to observe faint VIs, down to magnitude ~26, with the 8.2-meter Very Large Telescope on Cerro Paranal. In 2014 over a dozen VIs were observed, most of which were removed from the risk list thanks to our observations, e.g. the recovery of 2009 FD (Fig. 2, left) and the observation of 2014WF6 at visual magnitude 26.5 (the faintest NEO ever detected).

A collaboration with INAF – Osservatorio di Roma has allowed to access the 8.4-meter Large Binocular Telescope located in Arizona and operated by an international consortium. LBT, with its twin wide-field cameras and large aperture, is the ideal instrument to recover large-uncertainty NEOs, as evidenced by the successful detection of 2014 KC46 in October 2014, at visual magnitude 26.3 (Figure 2, right).

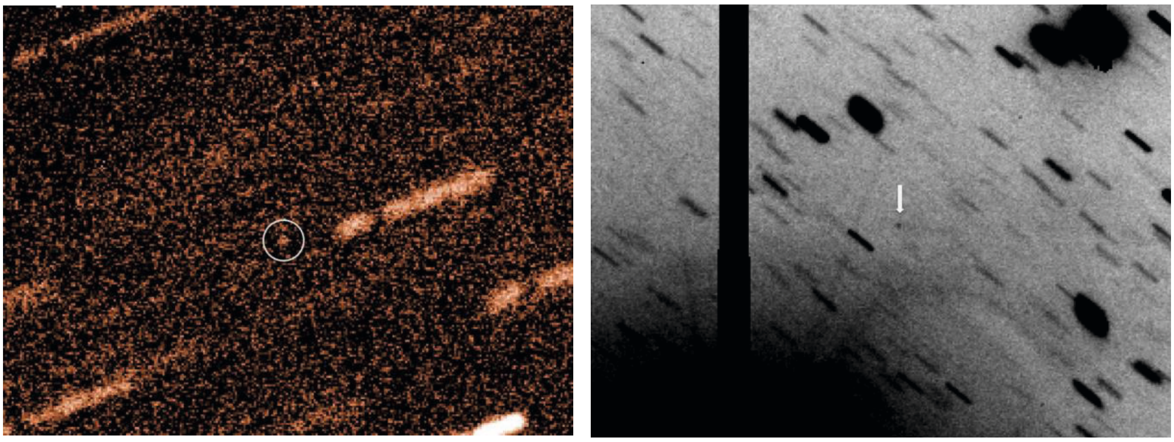

Fig. 2: Challenging recoveries: 2009 FD (left, credit: ESO) and 2014 KC46 (right, credit: LBT)

Archival data have been also used to find precoveries (i.e. serendipitous observations) of virtual impactors: as shown in the last column of table 1, it is an extremely successful technique. Therefore implementing this functionality in the NEO System, either as an ESA-based archive of astronomical images from collaborating observatories or by complementing already existing assets, is foreseen as a future improvement of the NEOCC services.

Tab. 1: VIs removed in one year of activity of the ESA NEO Coordination Centre.

Object	Date	PS_0	Telescope	Instrument	Archive
2007 UW1	2013-11-28	-3.4	CFHT	MegaCam	-
2013 XE2	2013-12-10	-4.0	PS1	GPC	PS1
2008 CK70	2013-12-18	-3.1	CFHT	MegaCam	CADC
2013 BP73	2013-12-20	-3.8	SDSS	SDSS	CADC
2013 YC	2014-01-22	-2.9	VLT (UT1)	FORS2	-
2014 BD33	2014-01-29	-4.2	PS1	GPC	PS1
2004 BX159	2014-02-18	-4.5	CFHT	MegaCam	CADC
2014 AF16	2014-03-11	-2.4	VLT (UT1)	FORS2	-
2012 HP13	2014-04-09	-6.6	VLT (UT1)	FORS2	-
2014 DN112	2014-05-01	-3.6	VLT (UT1)	FORS2	-
2014 HM129	2014-05-22	-4.2	VLT (UT1)	FORS2	-
2014 HM187	2014-05-28	-4.5	VLT (UT1)	FORS2	-
2012 VU76	2014-06-09	-6.1	VLT (UT1)	FORS2	-
2013 YD48	2014-06-30	-4.8	VLT (UT1)	FORS2	-
2014 LU27	2014-07-17	-2.4	PS1	GPC	PS1
2014 PB58	2014-08-12	-4.5	PS1	GPC	PS1
2014 QF392	2014-08-14	-8.0	PS1	GPC	PS1
2014 QJ392	2014-08-14	-6.1	PS1	GPC	PS1
2014 RC	2014-09-04	-7.0	PS1	GPC	PS1
2014 KC46	2014-10-30	-4.1	LBT	LBC	-

4. Opportunities for collaborating with Gaia

As far as NEO detection is concerned, there are many collaborations that can be carried out between Gaia-FUN-SSO and the NEO Coordination Centre. The two telescope networks are somehow complementary in terms of performances and locations. Whereas the Gaia-FUN-SSO is geographically well dispersed in longitude, the NEOCC collaborating observatories are more focused on large FoV instruments and large aperture telescopes. Thus the interchange of information when urgent follow-up observations are needed, either triggered by Gaia astrometric alerts or by objects entering the NEOCC risk list, is likely to increase the chances of successful observations.
This has been, for example, the case of the 2002 GT campaign, which was organised in 2013 in order to characterise the target selected for the NASA EPOXI (former Deep-Space) mission, at its last apparition before the encounter. Photometry and lightcurves were performed from the 1 m-diameter C2PU telescope at the Observatoire de la Cote d'Azur, which allowed the calculation of the rotation period. Spectra and photometric data were collected from the Asiago Observatory (Padova, Italy) allowing the determination of the asteroid taxonomic type; infrared observations were carried out from the Campo Imperatore Station (INAF - Observatory of Rome, Italy); astrometric measurements were provided by six telescopes belonging to the Gaia-FUN-SSO.
A further collaboration involves the possibility of using some of the data displayed on the NEO web portal to test the response of the Gaia follow-up network in a real case scenario. Through properly rearranging the NEOCC priority list, it is possible to select objects which have observational characteristics similar to those expected from Gaia. In this way the NEOCC acts as sort of "Gaia simulator". Providing targets which are in principle observable from Gaia in order to check the efficiency of its moving object detection system is also an appealing possibility currently under study.

Acknowledgments

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Gaia as a Transient Survey

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Abstract: *Gaia has been already operating for one year. We present the capabilities, which turn Gaia into an all-sky near-real-time transient survey. This includes automated detection, classification and follow-up of astrophysical transient objects, e.g. supernovae, cataclysmic variables, microlensing events, tidal-disruption events, etc. We present the survey first results and describe the organization of the ground-based network for the photometric and spectroscopic follow-up of Gaia alerts.*

1. Introduction

Gaia is the premier ESA's mission, launched in December 2013. Its primary goal is to observe more than one billion stars in the Milky Way and provide superb astrometry, photometry and astrophysical parameters for each one of them. Because the entire sky is being scanned multiple times (40 to 200 times, being 70 the average), Gaia is also a time-domain all-sky survey. Thanks to efficient on-board object detection system, Gaia is capable of autonomously detecting newly appearing objects, as contrary to its predecessor, the Hipparcos mission from 1990s. This feature of Gaia enables it to discover transient objects, which appear temporarily on the sky. The Gaia Science Alerts group, based in Cambridge (UK) and Warsaw (Poland), is given a task of rapid analysis of daily Gaia data deliveries. From an average of 50 million observations per day, the group needs to identify and characterize the anomalous or new astrophysical sources. These objects require imminent additional follow-up observations, as their scientific potential degrades very quickly and may be lost forever. This includes, for example, supernovae (SNe), cataclysmic variables (CVs), tidal disruption events (TDE), microlensing events and other rare and unusual astrophysical events. Over its 5 years mission, Gaia is expected to detect about 6000 supernovae of all types down to 19 mag, few thousands of CVs, a hundred TDEs and about a 1000 of photometric microlensing events.

2. Gaia Alerts detection system

Gaia's on-board instrument is a 1 Gigapixel camera, containing 106 CCDs. Due to constrains on the bandwidth and the fact that most of the sky is empty (for the satellite ~20 limiting mangitude), Gaia does not transmit pixels, but just small cutouts (windows) around each detected source. During each scan, as the source crosses the focal plane (Gaia operates in a drift-scan mode), the position and brightness of each source is measured on 9 Astrometric Field (AF) CCDs, followed by low-dispersion blue and red spectrographs (called BP/RP) and, for stars brighter than 16 magnitudes, also by a high-dispersion radial velocity spectrographs (RVS). It takes about 45 seconds for a source to cross the focal plane. Because of the spinning of the satellite, the observations of the same source are likely to come from the second telescope after 106 minutes (unless the spin axis precesses away from that source). Another visit of the same part of the sky typically happens after 30 days, on average. Such sampling pattern is optimal for discovery, however additional follow-up observations are necessary in order to provide more detailed information and classification for each source.

2.1 Detection

The AlertPipe software is run in the Institute of Astronomy, Cambridge, each time there is a new delivery from the first data reduction, provided by the Initial Data Treatment (IDT) at ESAC (Spain). The data is being ingested into the database and the detection system is run. New transient detections may appear from two different sources: new source or old source alert. A new source alert is generated when a new object appears in a position with several previous non-detections. Old source alerts are raised when a variation on the source magnitude is perceived. Different criteria are applied in order to pre-select candidates for alerts. Figure 1 shows a schema of the detection process within AlertPipe.

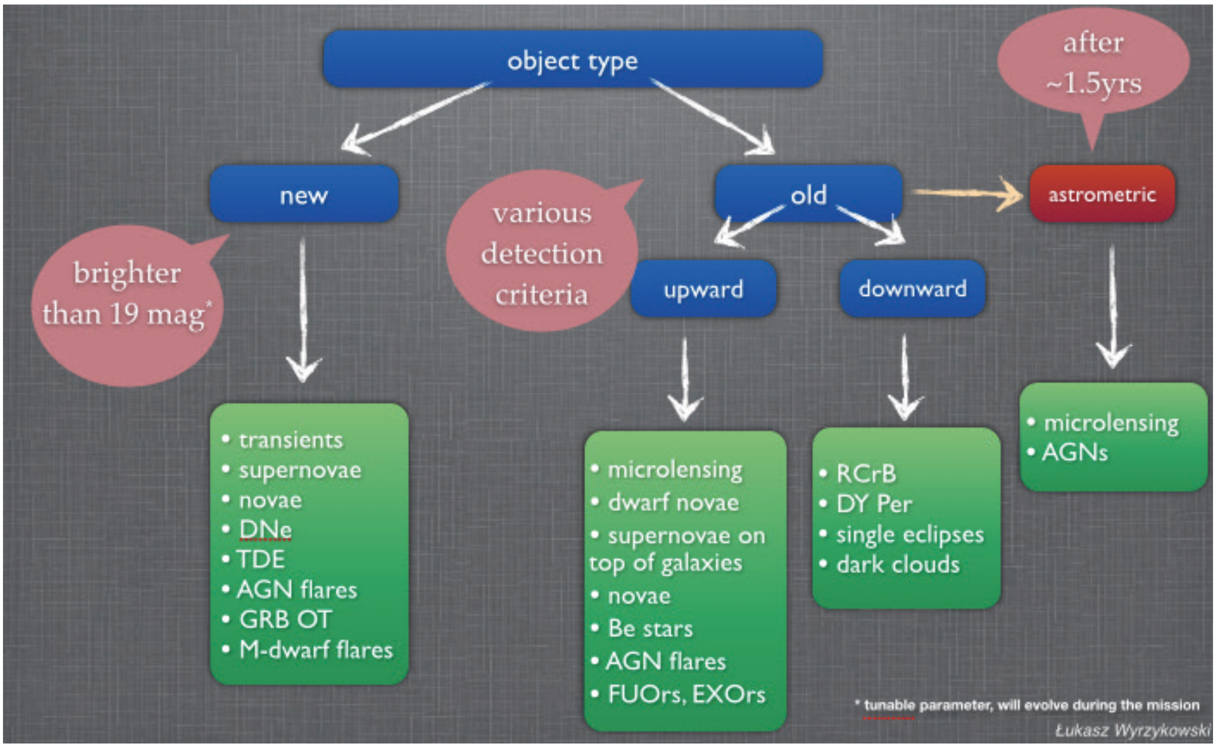

Fig. 1: Gaia Science Alerts detection pipeline schema.

Each candidate is then analyzed internally, by using available Gaia data. If the object is new, has at least two detections and has no flags for being an artifact, it is labeled as TRANSIENT. If the object already has an observing history, but there are two consequent outlying observations, it is labeled as BUMP or DIP, depending on the direction of the anomaly (got brighter or fainter, respectively).

2.2 Cross-match with archival data

The contextual data can provide important information about the nature of an object. Each candidate surviving the detection step is then cross-matched with locally available archival databases. Those include SDSS, DSS2, GSC2, USNOB, Leda, Veron, OGLE and APASS among others. For example, bright stars are being identified in vicinity of a candidate alert and their position is used to rule out artifacts due to bright stars spikes. If a galaxy is present nearby to the position of the Gaia alert, then the candidate is classified as an extragalactic transient, most likely a supernova. If the archival image has no objects at a given position, an orphan transient is found, often caused by a supernova in a low luminous host or a cataclysmic variable. Cross-match is also performed against catalogues of known variable stars, e.g. from CRTS, ASAS or OGLE surveys. If an alert matches the position of a known variable star, it is further ignored and no alerts are raised.

2.4 Spectral classification with BP/RP

An additional powerful feature of Gaia as a transient survey is the presence of low-resolution (R~100) BP/RP data. As shown in Blagorodnova et al. (2014), Gaia's BP/RP spectra can be used for unambiguous classification of transients into major classes, e.g. SNe, stars, AGN and CVs. Moreover, for objects brighter than ~18.5 mag, the spectra can also be used for more detailed analysis of supernovae into types Ia/II and provide estimation on their redshift and epoch to peak brightness.

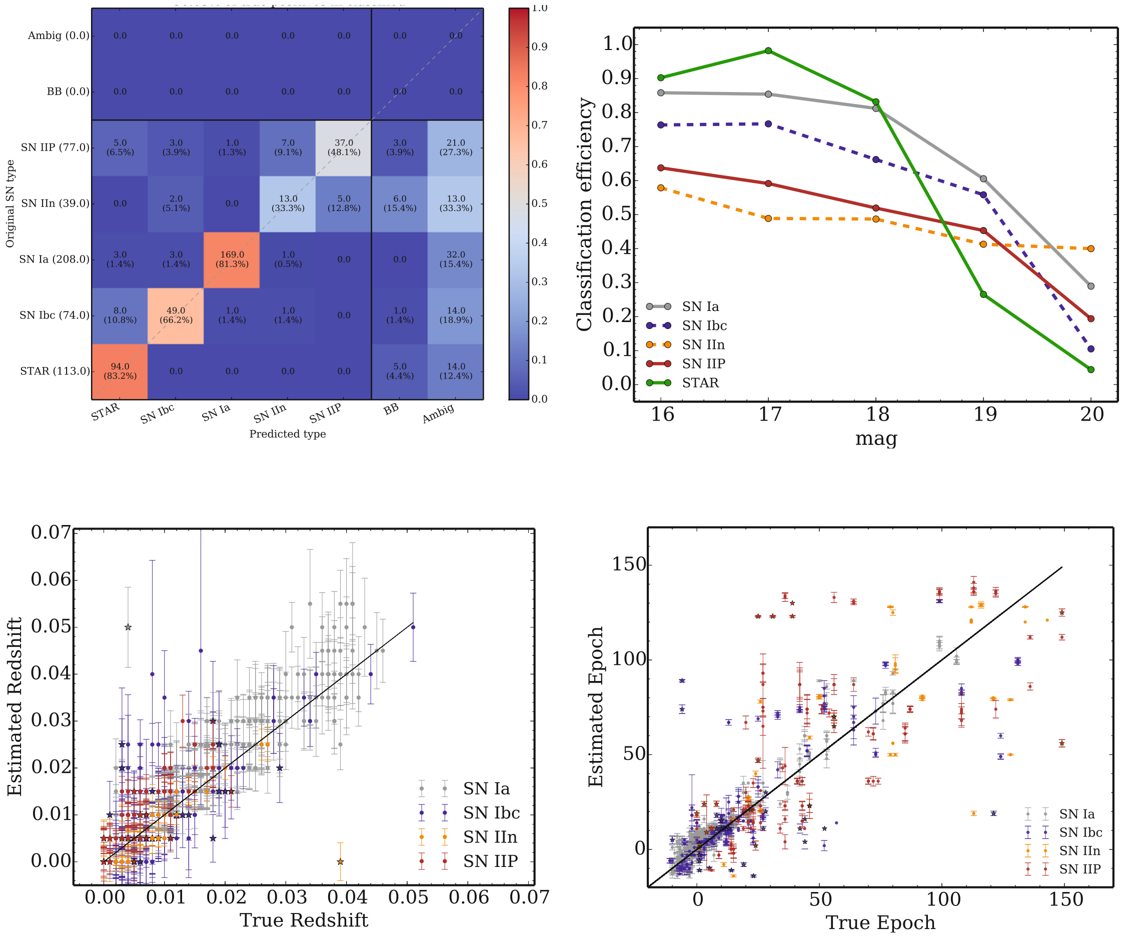

Fig. 2. Results of spectral classification of test set of supernovae using Gaia's on-board low-dispersion BP/RP spectrographs. Gaia can distinguish between various types of SNe and other transients, as shown by the confusion matrix for transients of magnitude 18 (upper left panel). The classification can be performed for objects as faint as ~18.5 with good accuracy (upper right panel). Lower panels show estimates on redshift (left) and epoch (right) of a supernova.

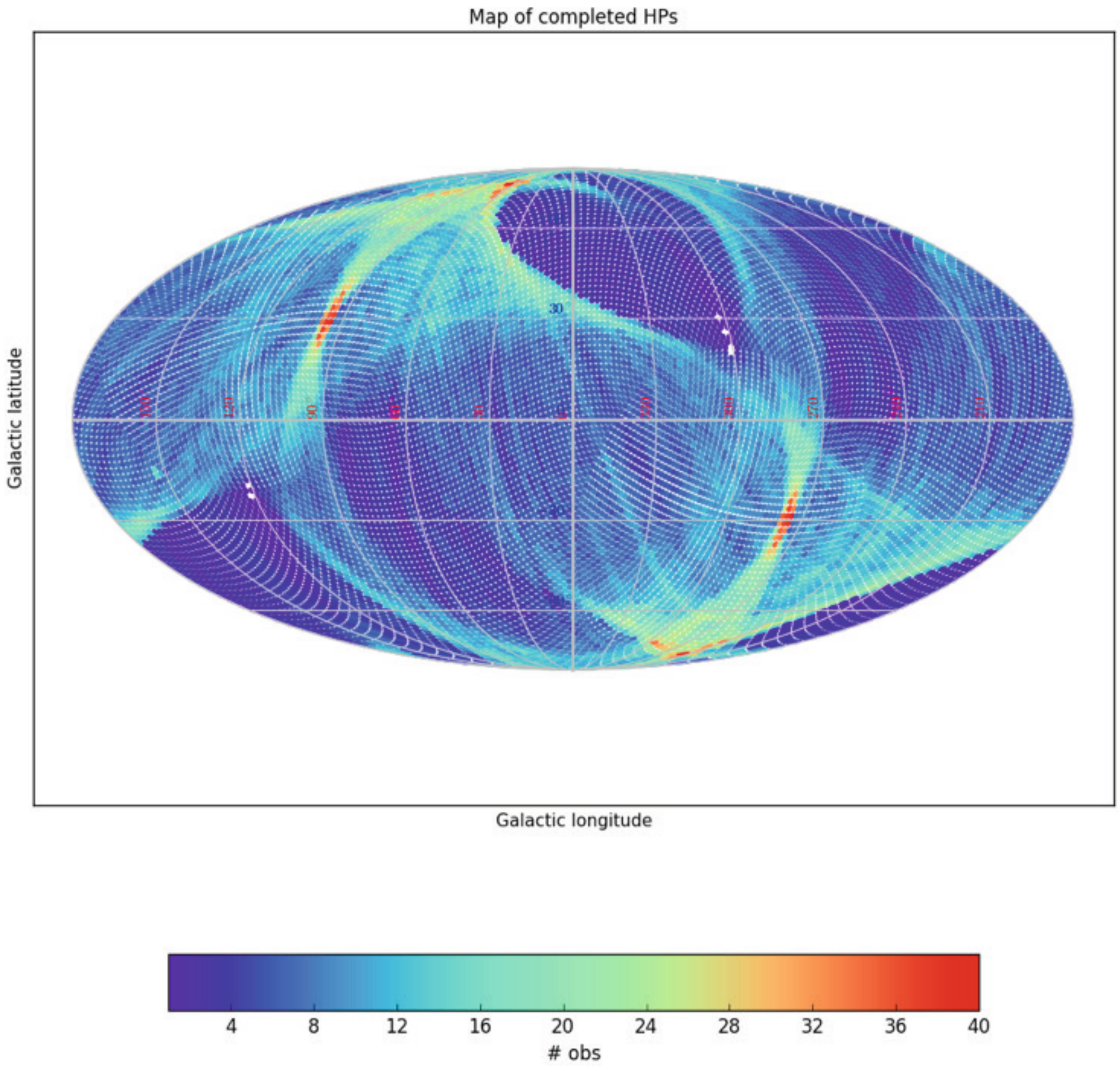

Fig.3. Map of the sky covered by Gaia in November 2014. The colour-coding indicates number of individual visits in a given part of the sky. The Ecliptic Poles observed intensively in June/July 2014 are clearly visible. In November 2014 the entire sky was observed at least once by Gaia, allowing for more unambiguous detections of new sources.

3 First alerts

Figure 3 shows the sky coverage obtained by Gaia in November 2014. By this date, the entire sky was observed at least once and some parts even significantly more often. This allowed for unambiguous detection of new sources using the information on the history of previous non-detections. The first confirmed supernova found by Gaia was Gaia14aaa (Fig. 4), discovered on 30 August 2014 in a region with relatively high cadence of observations.

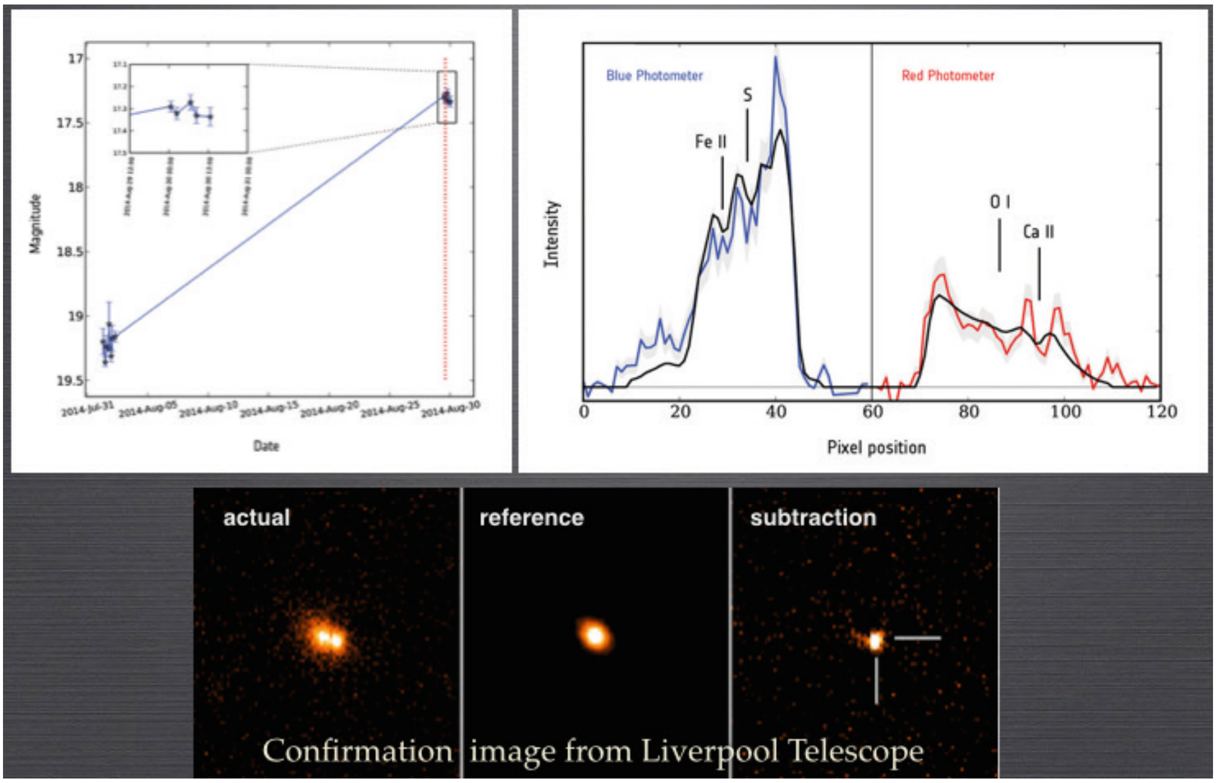

Fig. 4. First Gaia's supernova, Gaia14aaa. Upper left figure shows the light curve, where historic observations of the galaxy are at a level of 19 mag and the red vertical line shows the alert trigger at 17.3 mag. The BP/RP spectrum (upper right) indicated a good match to type Ia supernova (model shown by the black line). The confirmation image with the Liverpool Telescope was obtained a couple of days after the detection in Gaia. (bottom panel).

Gaia Science Alerts are being published on the web-page (http://gaia.ac.uk/selected-gaia-science-alerts) and are available to the entire astronomical community. Some of the first alerts confirmed from ground are listed below:

- Gaia14abz - SN Type Ia at z=0.059 (Asiago)
- Gaia14acg - SN Type Ia at z=0.031 (Asiago)
- Gaia14act - SN Type II at z=0.027 (Asiago)
- Gaia14acz - SN next to SDSS galaxy at z=0.105
- Gaia14aat - Dwarf Nova (Liverpool Telescope)
- Gaia14aae - AM CVn, a'ka ASASSN-14cn (Campbell et al. in prep)
- Gaia14aaf - CV
- Gaia14aai - M flare
- Gaia14aau - M Flare
- Gaia14abg - CV
- Gaia14abq - M Flare
- Gaia14abr - M Flare

4 Gaia Science Alerts Workshops

Since 2010 the Gaia Science Alerts Group has been organizing focused workshops, open to the entire astronomical community. The main goals of the workshops are to make the community aware of the Gaia as a transient survey, provide relevant up-to-date information about the survey and to build links with the follow-up partners.

The slides and talks given at the workshops are archived on the Gaia Science Alerts Working Group Wiki web-pages: http://www.ast.cam.ac.uk/ioa/wikis/gsawgwiki. The wiki pages act also as platform for exchanging information between astronomers involved in the scientific exploitation of the Gaia Science Alerts.

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The bumpy first year of GBOT

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Abstract*: The Ground Based Optical Tracking (GBOT) project was set up to fully exploit Gaia's capabilities for Solar System objects and the most precisely measured stars. Soon after Gaia's successful launch it became apparent that the satellite would be much fainter than anticipated prior to launch, and that therefore the GBOT program needed to be reassessed both in its feasibility and methods. This paper reports on this process, and also deals with some more recent developments, such as the serendipitous detection of asteroids on the GBOT fields*

1. Introduction

ESA's ground-breaking astrometric space mission will reach levels of unprecedented precision. This means, that for those stars whose positions can be measured with Gaia's maximum precision, the normal methods to derive the spacecraft's position and velocity vector are not sufficient. Also, since Gaia aims also at deriving accurate astrometry to Solar System objects, the baseline between the spacecraft position during the few transits associated to a proper direction measurement, needs to be known extremely well. For these reasons GBOT was initiated, the mission of the group being to deliver a set of observations good to 20 mas each day.

It was clear from the beginning that this cannot be achieved for a span of several nights around full moon, especially since the bright moon moves through the vicinity of the target. Another open question remains whether all systematic adverse effect on the astrometric accuracy can be removed, since at current the overwhelming effect is that of the deficiencies of current reference catalogue material – this can only be resolved after the availability of Gaia astrometry to serve as reference catalogue. During the preparatory phase the GBOT group assumed a brightness of Gaia of about R= 18 mag based on the experience of test observations of other space missions in the L2 region. Especially the brightness of the WMAP spacecraft, which has an overall shape rather similar to that of Gaia, but was much smaller made this assumption even rather conservative.

However after Gaia slewed to its operating Solar Aspect angle (i.e. the angle between the rotational axis of Gaia and the vector Sun – Gaia) of 45°, it became clear that the brightness assumptions prior to launch were wrong by about 3 magnitudes, Gaia will be near 21 mag, instead of 18 mag! This immediately led to the need to reassess the GBOT program. This reassessment phase would have to answer several questions:

- Is the daily tracking of Gaia still feasible at all?
- Can GBOT operate with its present set of telescopes, or a larger subset of those?
- What are possible trade-offs to take into account?
- What is the development over one year, i.e. with the varying distance between Gaia and Earth caused by the oscillation of the Sun --Earth – L2 distance over the course of the year and the oscillation of Gaia due to its Lissajous orbit around the L2?

For the latter reason the reassessment was designed to last for approximately one year, i.e. until March 2015. We are reporting here on this on-going campaign. Nonetheless the key issues have been answered, so that the overall outcome as described here is quite representative.

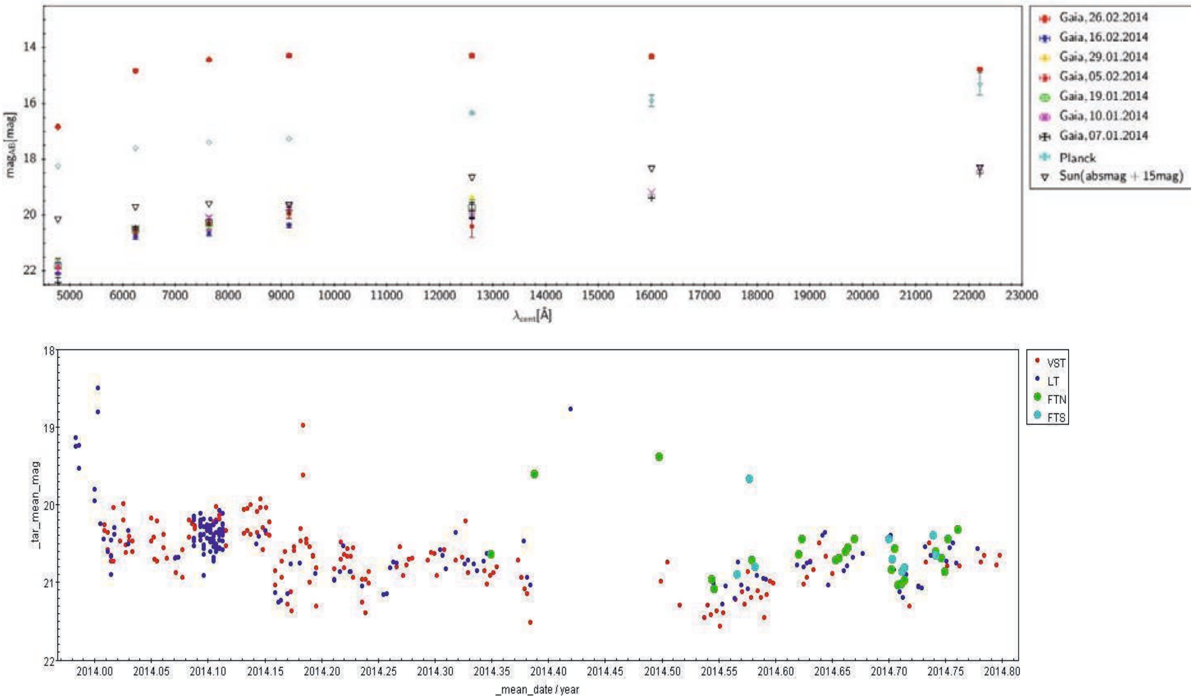


Fig. 1: Brightness development of Gaia during 2014. The upper panel shows GROND multicolour values measured on various occasions, see panel legend. The brightest sequence, with magnitudes near 14, was obtained during one of Gaia's diagnostic slews to a SAA of 0°. For comparison reason, we have also included the values for the Planck mission, obtained with the same instrument, and the absolute magnitudes of the Sun, incremented by 15 mags. The lower panel shows the magnitudes derived by the GBOT team during from the regular data taking. Again, the strong peaks were obtained during the SAA=0° manoeuvres. The different symbols denote the different telescopes as seen in the panel legend. The brightness development shows no unexpected trends, those that are present are in agreement with the changes in distance and earth aspect angle.

2. Gaia's brightness

Of course, one of the most important issues to solve was the question of Gaia's brightness, once in its final location in the L2 region. While the post SAA=45° slew brightness development clearly showed the 18 mag assumption cannot be maintained, there were enough uncertainties to prevent the final magnitude to be estimated in this phase to better than 0.5-1 mag. Moreover it could be expected to be variable to some degrees, mainly due to geometrical reasons, such as the variable Earth Aspect Angle (EAA, the angle between Gaia's rotation axis and the vector Earth – Gaia) and distance variations. Another issue is the long term effect on the optical properties of the kapton material which forms the largest part of the area of Gaia's sunshield panel. For these reasons we requested some observations by the GROND O/NIR simultaneous camera distributed over the first couple of months. These would potentially allow us to detect colour changes due to aging effects of the cover material.

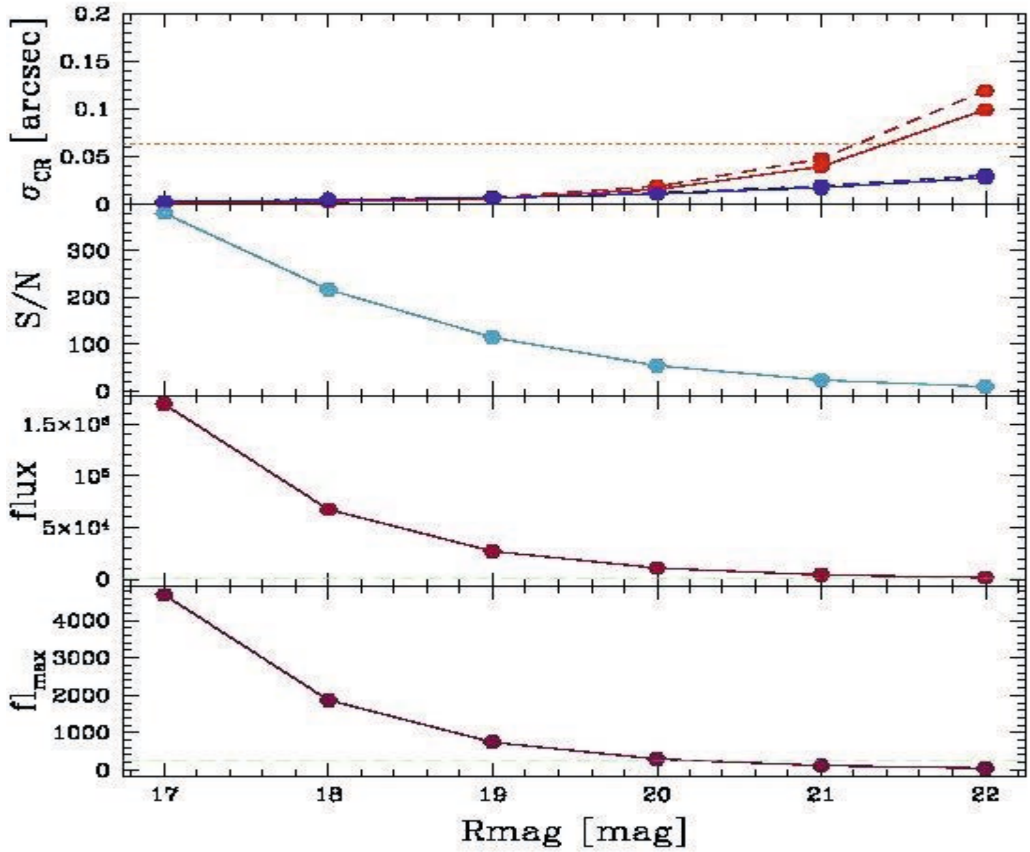


Fig. 2: The Cramer-Rao limits for the astrometric centroiding as derived using Mendéz et al. (2013) for objects of the magnitude range of 17-22. This example shows the situation for the ESO VST. The three lower panels show the S/N, the flux and flux peak. The Cramer-Rao limit is shown in the top panel, with the blue (lower) graph showing the approximation for sources fainter than the sky background, and the upper graph (red in the online version) for objects significantly brighter than the sky background. This means that in reality (sky brightness 20.5-21.5 mag) the bright object approximation is the relevant one for the left part of this plot and the faint object part for magnitudes fainter than about 22. Our situation is in the middle, but we assume the more pessimistic faint object solution to be the relevant one. The dotted horizontal line depicts the 63 mas limit for a sequence of 10 exposures in order to achieve an error of 20 mas. As can be clearly seen, for a 21mag object the uncertainty is significantly below the line.

The concordant results, both from GROND and our own measurements show no evidence for unusual tendencies, which could be attributed to material aging due to micrometeorites or the harsh radiative environment in the L2 region. The brightness varies between about 20.5 and

21.7 mag, being faintest in July, and brightest near the equinoxes, when Gaia is at the perigeum of its Lissajous orbit and thus closest to us.

3. The GBOT reassessment campaign

3.1. Theoretical considerations

The 3 magnitude brightness deficit means that questions concerning the overall feasibility of GBOT had to be raised, leading to investigations of the theoretical limits. The recent paper by Mendéz et al. (2013), dealing with the Cramer Rao limits in astrometric data, i.e. the theoretical limits of information of astronomical sources on CCD arrays proved to be of great help. Together with R. Mendéz we started exploring his method for moving sources such as in our case, see Bouquillon et al. (2015, in prep.). The results of applying the mechanism developed by Mendéz et al. came to the conclusion, that the 2.5 m VST can cope with the situation, the 2.0 m class telescopes can do so just, with some changes to the observational cadence in each observing sequence (see Fig. 2).

3.2 Measurements

36+While the theoretical considerations described in the previous section indicate that the GBOT effort is nonetheless feasible with some adaptations to our telescope suite, this needs to be confirmed using observations. Since GBOT had to start routine observations anyway, these observations were used to assess the data quality (which would have been done anyway).

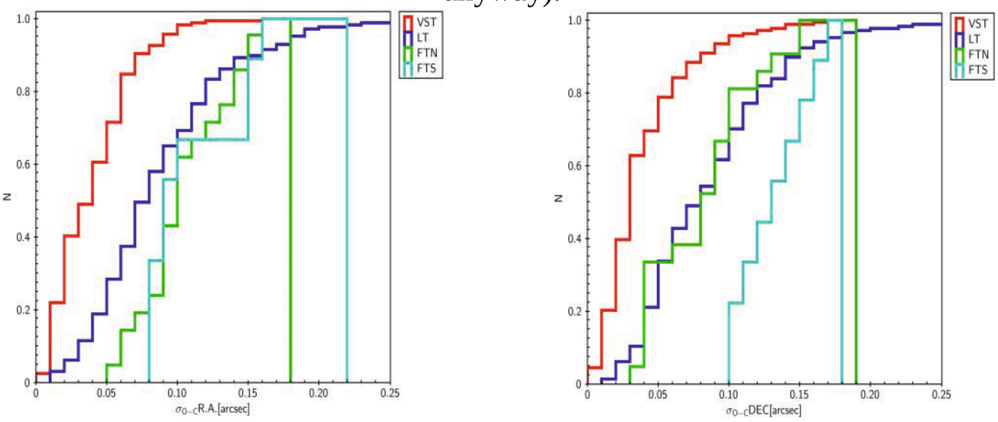
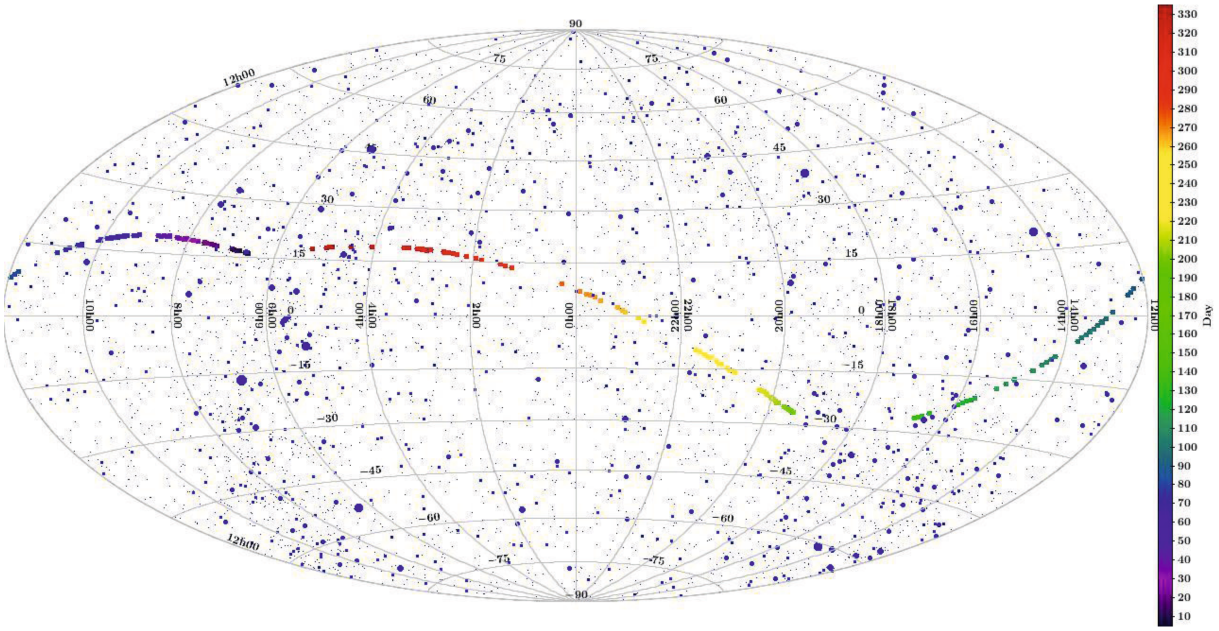


Fig.3: Cumulative histograms showing the percentiles of precision for the VST, Liverpool telescope, Faulkes North and South telescopes. Clearly the VST, the largest telescope, delivers data which is sufficient in about 80 % of observations, the Liverpool in about 40 % of the cases, while the 2 Faulkes units, which started observing later the available number of datasets is not yet sufficient

As shown in Fig. 3 the VST does indeed deliver generally data within specifications, about 80-85 % of the received data being within or near specifications. This translates to useful VST data in about 60 % of nights - this includes Full moon breaks when no data is obtained, bad weather and other reasons that observations can take place. The Liverpool telescope (LT) delivers good data on about 40 % of all observations or about 15 % of all nights. The two Faulkes telescopes started observing regularly only in summer, so the number of observations is too small for any definite results. There is however a discrepancy between the S/N obtained with the different telescopes, which was investigated, but is still not entirely understood. Increasing the number of exposures per standard observing sequence for the 2m telescopes to 15 increases the yield significantly, it would however be desirable to increase this number to 20 or even 25, and possibly more for the Faulkes telescopes. This is however not feasible on a daily basis, which means that a change in the observing strategy is desirable. It is clear that the larger 2.5 m VST forms the backbone for GBOT operations.

3.3 Consequences, changes in strategy, etc.

Both theoretical considerations and observational experience show the basic feasibility of GBOT despite Gaia's faintness. It is however wise to adapt GBOT's observation strategy. While for the VST, which became the main source of GBOT data the standard 10x60 sec exposures observing sequence is sufficient, the other telescopes need more exposures per sequence. For these a modified sequence of 15x60 sec was adopted, however it would be better to increase this even more, something not feasible on a daily basis. As a result, the strategy was changed to a so-called « triggered mode », with the VST continuing to observe as before and observations on the other telescopes being triggered when the VST is not available. Such events can occur, if the Paranal weather forecast is bad, the night after not receiving VST data until the first night after new VST data is received, or if advised from ESO that there will be a gap in observational coverage. This way the fewer observations on the smaller telescopes make longer sequences feasible, and also help reduce the number of duplicate observations. The triggered mode was started in November and is currently the



modus operandi for GBOT observations.

Fig. 4: Trajectory of Gaia on the sky during Jan. – Nov. 2015 as measured by GBOT. Each dot in the trajectory represents one set of GBOT data. Gaps are due to full moon breaks, spells of bad weather and the June Galactic centre problem, which caused the large gap in data coverage seen in the lower right of this whole sky map. The other dots show the naked eye stars, as taken from the Hipparcos catalogue. The track of Gaia starts north of Orion moving leftwards, and ends almost in the same region.

Another problem, this time unrelated to the brightness issue came up during June 2014. The data taken in this time did not yield useful results. The cause of this was the stellar density of the fields through which Gaia moved during this month – only a couple of degrees from the position of the Galactic centre. While GBOT did investigate dense fields, even those fields, optimised for observations on the northern sky (because the main telescope at our disposal during the preparations prior to launch was the Liverpool telescope which is on the northern hemisphere), were by far not as dense. During this time the astrometric solution failed, most likely due to the insufficient reference catalogue material. It may well be, that with Gaia data some results can be retrieved.
GBOT has been operating now for about one year in this combined operational/reassessment mode. Data have been delivered to ESOC since April. Because of the residual systematic offsets most likely caused by the known problems with the reference catalogue quality, the GBOT results are not yet used for the orbit reconstructions. This was deemed likely during the 2nd GBOT meeting in Heidelberg 2011. It will be the goal of the re-reduction effort using the first suitable Gaia astrometry to eliminate the systematic errors introduced by the current reference catalogues. Before this becomes available in mid-2016 the GBOT team will continue to collect data and prepare itself for the re-reduction phase optimising software and database, etc. - the current status of the pipeline is described in Bouquillon et al. (2014).
To conclude, the GBOT team has responded to the unexpected challenge and determined a solution. GBOT is now in almost the same position as we would have been in the original scenario. Now it all depends whether the systematic effects can be overcome (see Altmann et al. 2012). For more details about the GBOT reassessment process, see e.g. Altmann et al. (2014).

4. GBOT goes asteroid hunting

The L2 region is approximately opposite the Sun, i.e. near the ecliptic in the region where asteroids are located when in opposition. Therefore recently, GBOT started to consider using the obtained data to search for known and unknown asteroids. Early tests show that on average 3 objects can be found on the VST chip used to observe Gaia alone, for the whole array of 32 detectors this sums up to about 100. At current only the chip with Gaia on it is investigated, the GBOT team is however working on automated detection mechanisms, so that the time consuming inspection process can be done without much human interaction, allowing us to search the complete array. Also ways to ensure follow-up observations, not covered by the GBOT agreements with observatories, are being investigated, e.g. via the GaiaFUN network. Once properly set up, the GBOT asteroid program has the potential to make contributions of the study of minor planets when close to opposition.

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The Gaia-FUN-SSO network : status and objectives

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Abstract: *The Gaia Follow-Up Network for the ground-based follow-up of Solar System Objects (Gaia-FUN-SSO) has been set up starting from 2008. Since this date many participants joined it and several have contributed to training campaigns. Now, almost three months after Gaia came into the operation phase, this network is still awaiting the triggering of Solar System Objects alerts but is ready to react. In this article we recall the structure of the network, the goals and the status of this activity.*

1. Introduction

The Gaia Follow-Up Network for the ground-based follow-up of Solar System Objects (Gaia-FUN-SSO) has been set up in the frame of the DU459 task of the DPAC consortium in order to ensure ground-based observations for the follow-up of Solar System Objects which require additional observations with respect to the Gaia ones. This is the case of newly detected objects by the probe which provides only a limited number of their orbital positions due to its scanning law.

The Gaia Solar System Objects short term (SSO-ST) provides alerts to the task DU459 which computes topocentric ephemerides and disseminates them to the Gaia-FUN-SSO network (see fig. 1). The update of the SSO data base is then operated through the Minor Planet Center.

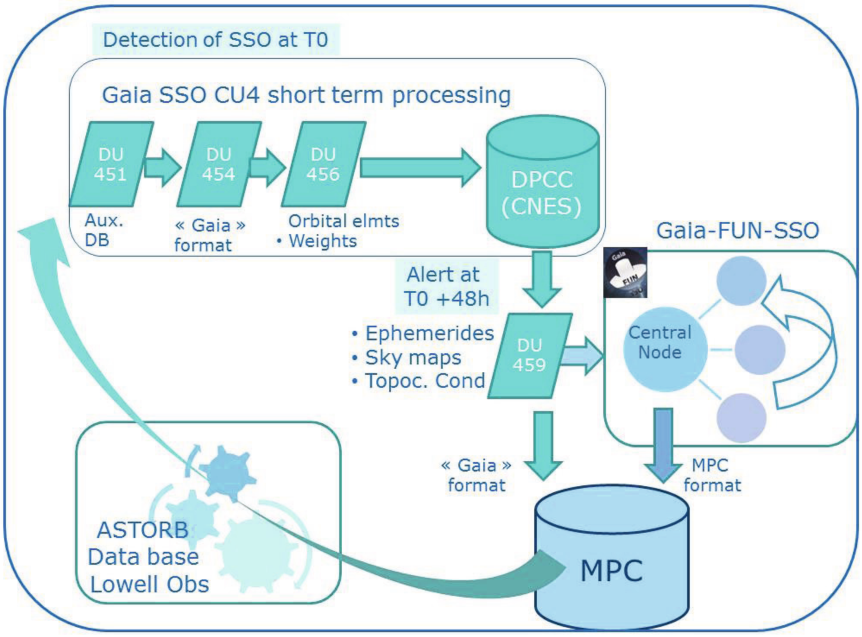

Fig. 1: Data flow of the Gaia short term data processing, involving the Gaia-FUN-SSO observation, their processing by the Minor Planet Center and the updating of the Gaia auxiliary data through the ASTORB database.

Up to the date of the workshop such alerts could not be triggered but the network participants took benefit from several Near-Earth Objects approaches to the Earth and could participate to training campaigns.

During the last period, we developed a new method for automatically disseminating the alerts (Carry et al. 2015) and Gaia-FUN-SSO is now ready to enter in an operational phase.

2. Description of the Gaia-FUN-SSO network

The Gaia-FUN-SSO network has been set up on a volunteering base and gathers a wide panel of different observatories which intends to ensure reactions on alert on a large geographical coverage and can overcome bad meteorological conditions in some places.

2.1 Structure of the network

Until the date of the Gaia-FUN-SSO workshop in 2014, many observatories declare their interest for participating to the follow-up observations of future detected Solar System Objects: 57 observing sites equipped with 80 telescopes registered through our wiki server at https://www.imcce.fr/gaia-fun-sso/. Most of these observatories are located in Europe unfortunately, with only a few locations in China (Zhang et al., 2015), Australia (Todd et al., 2013) and South America (see fig. 2). In order to get a better celestial covering, the network would get much benefit by extending to southern hemisphere and North America. Nevertheless, such a big number of participants will ensure certainly a good reaction when alerts will be triggered.

In terms of telescopes, the figure 3 shows the distribution of the diameters. Considering that we are awaiting mainly alerts for the faintest moving objects which are detected by Gaia, i.e. magnitude close to 20, almost 30 telescopes (those with diameter larger than 0.8m) of the network could be operating. In case of low moving objects or bright objects, the smaller diameters will be useful.

Fig. 2: Localization of the observing sites registered (in blue) in the Gaia-FUN-SSO network up to November 2014.

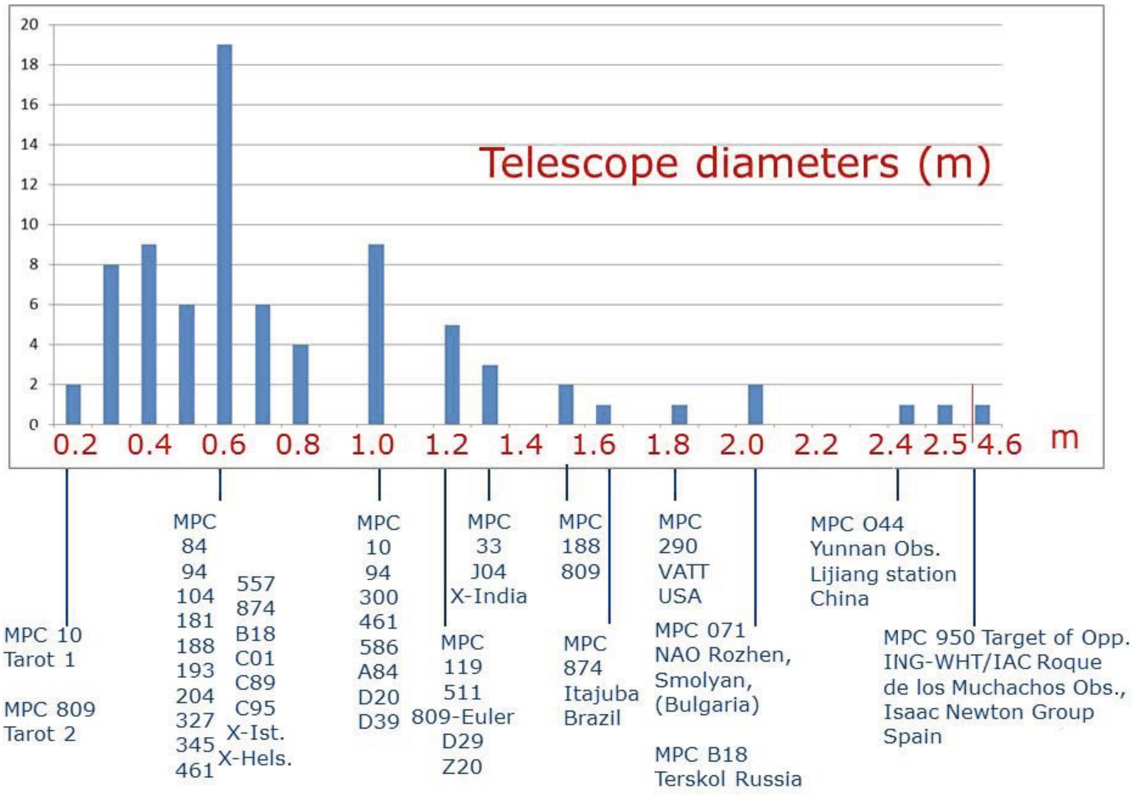

Fig. 3: Histogram of the diameters of the telescopes registered in the Gaia-FUN-SSO network. Most of the observatories are identified by the Minor Planet Center code related to their location

2.1 Observing campaigns

Starting from 2011, several training campaigns have been organized. The goal was to train the network and to test the ability to perform astrometric measurements. Some of the participants were not accustomed to observe moving objects and these campaigns allowed us to have exchanges in particular upon the protocols for observing and the tools for the reduction.

We got benefit from close approaches of some Near Earth Asteroids, or we proposed the observation of some targets for space missions (Tab. 1). In one case the target was really too faint and fast and no observation was performed, but for all the other campaigns, the participants got astrometric data which have been posted on the Gaia-FUN-SSO wiki. Most of them have also been sent to the MPC.

We organized in particular a campaign for during the appearance of 99 942 Apophis which gave a large amount of data which have been analyzed in detail and used to test the impact of such a focused campaign on the improvement of its orbit (Bancelin et al. 2015, Thuillot, Bancelin et al., 2015). We also organized specific observations for a triangulation experiment (Eggl et al., 2015).

Dates	SSO	Stations Number: MPC codes	Nbr. Obs.
2011 Nov-Dec.	2005 YU55	**16**: 071, 084, 089, 181, 345, 461, 585, 586, A84, B04, B17, C20, D20, D39, G96, O44	1792
2012 Jan. 17-28 (on alert from MPC 012)	2012 BS667	**4:** 461, A84, H15, C20 (H15 reaction time 1.4 day after detec.)	35
2012 Feb.-March	1996 FG3	**3**: B04, H15, O44	18
2012 Feb.-March	99 942 Apophis	**2**: B04, H15	51
2012 Dec.2013 Apr.	99 942 Apophis	**19**: 010, 071, 089, 119, 188, 300, 511, 585, 586, 950, A84, B04, B17, B18, C01, C20, D20, O44, Z20	4000
2013 Feb.-March	2012 DA14	**8**: 071, 084, 300, B04, C60, Istanbul, C20, O44	1465
2013 Aug.	2002 GT	**7**: 010, 971, 089, 300, 585, B04, C01	1331
2013 Oct.2014 Jan.	2013 TV135	**13**: 071, 089, 119, 121, 168, 981, A84, B04, B18, C01, C20, H15, O44	810
2014 Apr. (on alert from ESA SSA)	2007 HB15	**0**	0
2014 June (triangulation)	2014 HQ124	**3**: 089, 585, C20	217

Table 1: List of the campaigns of observavtions carried out by the Gaia-FUN-SSO network

3. Entering a new period of activity

On date of the Gaia-FUN-SSO workshop, we are entering in a new period of activity since after the start of the operating mode of Gaia, we are entering in a verification phase of the SSO-short term processing. But we are also shifting to the use of a new tool for the dissemination of the alerts. This tool intends to automatically distribute sky maps and ephemerides useful for retrieving the SSO detected in space by Gaia from the Lagrange point L2. Every registered participant to this pipeline accessible at https://gaiagunsso.imcce.fr will be able to access data as described in Fig. 4. More details are given by B. Carry et al. (2015).

The important information is that the wiki is no more used now for the dissemination of observational data but is only used for the diffusion of general information. All the participants, even those who registered previously through the wiki, must register again on this pipeline (https://gaiafunsso.imcce.fr) in order to get their credentials for login and to provide the telescope and location characteristics necessary for the topocentric calculations..

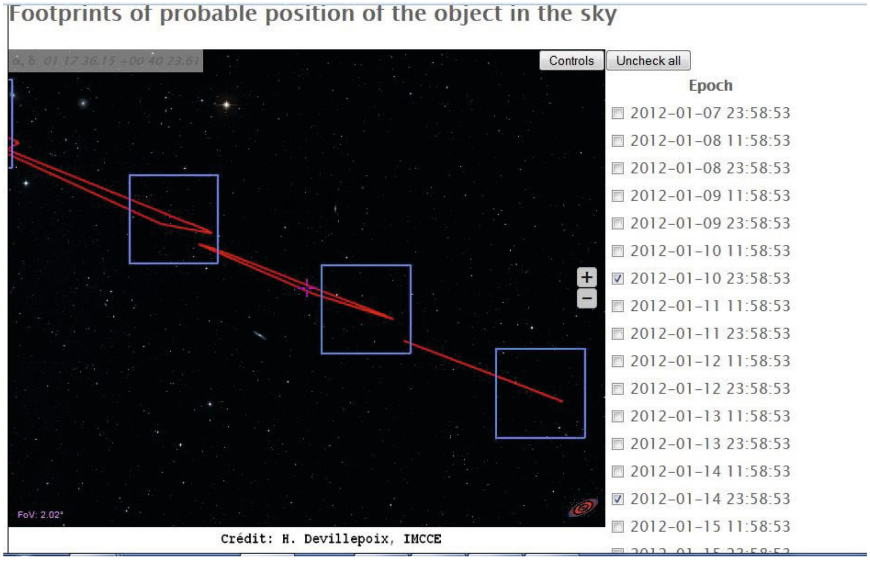

Fig. 4: Example of sky map which will be accessible on the web interface https://gaiafunsso.fr. The blue zone represents the field of view of the telescope; the red zone is the probable zone where the SSO can be retrieved several days after an alert.

4. Conclusion

The Gaia-FUN-SSO network has been set up on a volunteering base in order to perform complementary observations of Solar System Objects detected by Gaia which could be lost due to the too few number of observations constrained by the scanning law. Since several years, participants of this network succeeded to collaborate in the framework of training observations of Near-Earth Asteroids in close approach. After the last development of a new pipeline for automatically disseminating Gaia alerts, this network appears ready to operate.

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The reservoir of solar system objects available to discovery by Gaia

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Abstract: *The ESA astrometry mission Gaia started its operations in June 2014 and will repeatedly scan the entire celestial sphere down to magnitude 20 over the course of its five years mission. About 250,000 solar system objects will be observed, 60 to 80 times each on average, providing an homogeneous high-precision data set of astrometry and photometry for orbit determination and physical properties characterization. We investigate here how many* ***new*** *objects can be detected by Gaia, by extrapolating currently known population toward smaller size down to Gaia apparent limiting magnitude.*

1. Introduction

The mission Gaia of the European Space Agency has been designed to provide a magnitude-limited (V<20) catalog of the whole celestial sphere, with astrometric precision below the milli-arcsec, by observing the sky repeatedly during five years. We do not go here into a description of the mission and its general scientific goals, nor the expectation for solar system science, as it has already been discussed elsewhere (e.g., Tanga et al. 2008).

The operation mode of Gaia is based on a regular scanning law, slowly evolving to cover the whole celestial sphere. This implies that there is no target-pointing observations realized by Gaia. Discoveries of Solar system objects (SSOs) are possible by Gaia, thanks to the non-sidereal motion of the sources, but follow-up observations cannot be handled by the probe. The Gaia Follow-Up Network for Solar System Objects (Gaia-FUN-SSO) has been set up for this tasks.

Unknown SSO are treated separately in Gaia pipeline, requiring additional identification and source cross-matching steps. Characterizing their orbit in “real” time, i.e., shortly after discovery, is critical to soften the burden on the pipeline. We investigate here the potential reservoir of yet-unknown SSOs that can be detected by Gaia.

2. Simple SSO population model

The apparent magnitude of SSOs of similar absolute magnitude (H, used here as proxy to solve the albedo/diameter degeneracy) is dictated by the observing geometry: heliocentric distance, range to observer, and phase angle. It would be therefore misleading to use the size-frequency distribution (SFD) of all known asteroids to evaluate the reservoir of yet-to-be-discovered objects. Indeed, main-belt asteroids dominate current census of SSOs while objects from other populations like near-Earth asteroids or transneptunian objects are seen under radically different geometries.

In what follow, we will consider five different SSO populations, sorted in semi-major axis (see Fig.1): near-Earth asteroids (NEAs), main-belt asteroids (MBAs), Jupiter Trojans, Centaurs, and transneptunian objects (TNOs). For each, we compute their SFD (shown as cumulative number of objects as function of their absolute magnitude in what follow), extrapolate it to small size (large H) by power laws to estimate the completeness of current census.

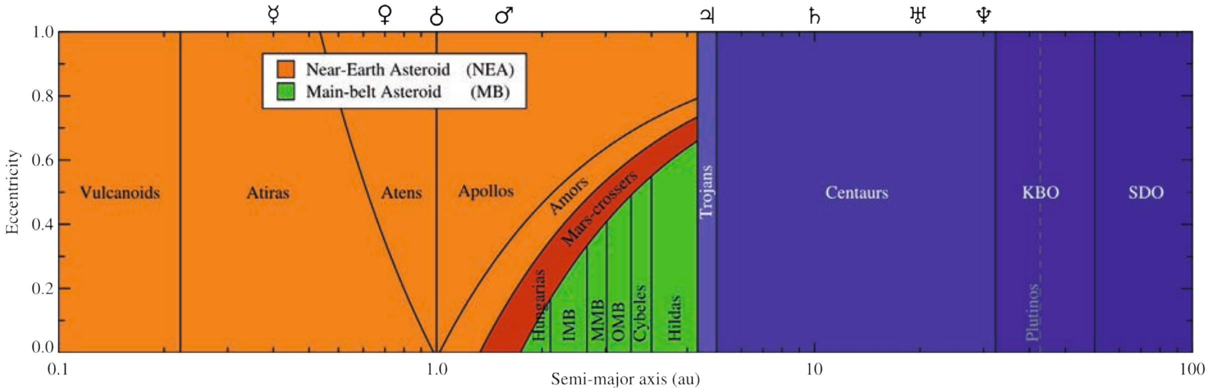

Fig. 1: Definition of the different SSO populations. Figure from SkyBoT (Berthier et al. 2006) documentation (http://vo.imcce.fr/webservices/skybot/?documentation)

2. Relations between population, Gaia observing geometry, and apparent magnitude

For practical purposes, we model each population by 9 synthetic particles, which orbital elements (semi-major axis a and eccentricity e) are given by the Q25, Q50, and Q75 quartiles of the population orbital elements (Table 1). Furthermore, we consider three possible cases: observations at perihelion, aphelion, and at the average heliocentric distance. With these definitions, we have to consider 27 different heliocentric distances for each population at the time of observations. The phase angle and range to Gaia are then simply computed using usual relations within the Sun-Target-Gaia triangle (Fig.2).

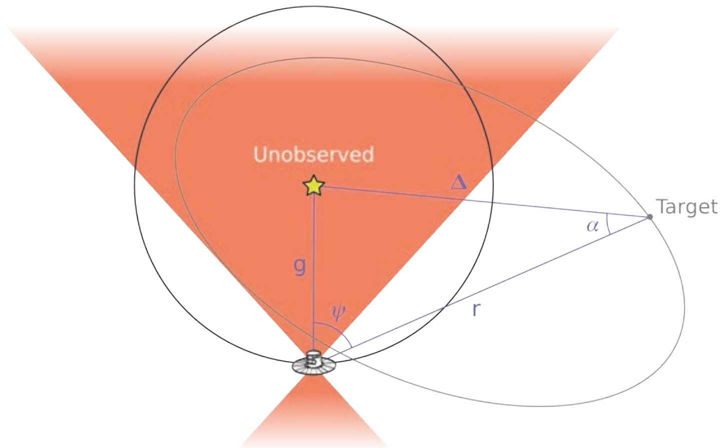

*Fig. 2: Gaia observing geometry. Knowing Gaia and the target heliocentric distances (g and **Δ**) and the solar elongation (ψ) of the observation, the target-Gaia distance (r) and phase angle (α) are easily computed.*

	Semi major axis (a)			Eccentricity (e)		
	Q25	**Q50**	**Q75**	**Q25**	**Q50**	**Q75**
NEA	1.330	1.750	2.222	0.329	0.467	0.577
MBA	2.400	2.646	2.985	0.095	0.145	0.196
Trojan	5.157	5.201	5.243	0.047	0.072	0.105
Centaur	7.110	12.067	19.424	0.297	0.881	0.710
TNO	41.446	43.966	46.357	0.057	0.122	0.244

Table 1: Semi-major axis and eccentricity quartiles for each population.

3. Results

We present in Figs. 3, 4 & 5 the SFD of each population (black curve), the extrapolation by a power law (blue line), and the expected number of discoveries for the 9 tests particles observed at the three heliocentric distances described above (vertical dashed red lines). Owing to the 0.5 binning in absolute magnitude, many of the 27 different cases result in similar limiting absolute magnitude, and only a few vertical lines are visible.

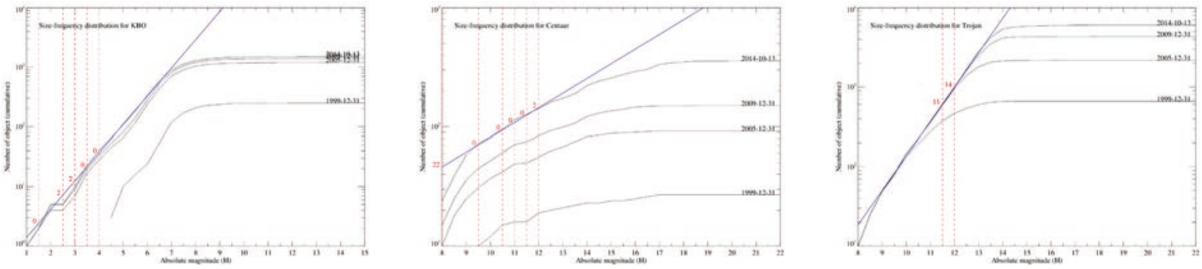

Fig. 3: Size-frequency distribution and expected available discoveries for TNOs, Centaurs, and Jupiter Trojans, observed at 90º elongation.

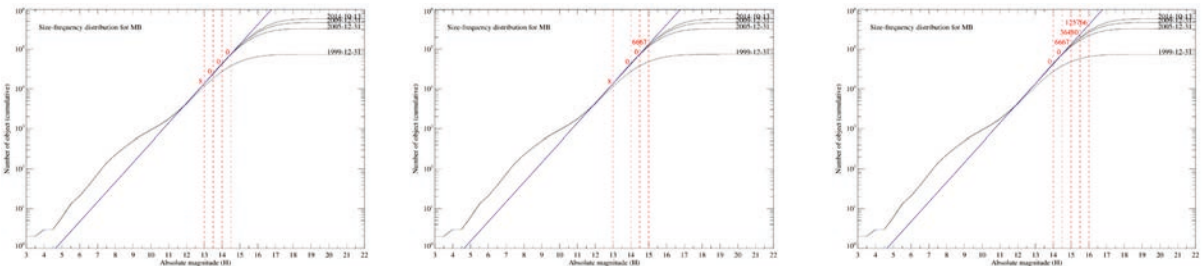

Fig. 4: Size-frequency distribution and expected available discoveries for MBAs, considering three different solar elongation : 45º, 90º, and 135º.

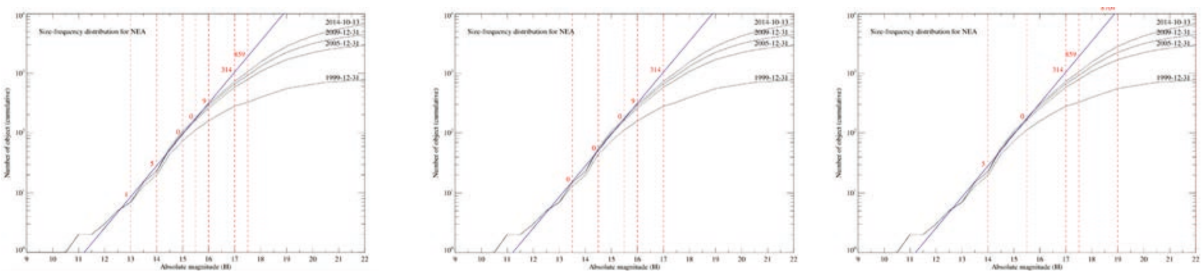

Fig. 5: Size-frequency distribution and expected available discoveries for NEAs, considering three different solar elongation : 45º, 90º, and 135º.

4. Discussion

From Fig. 3, it seems unlikely that Gaia will discover any Centaur or transneptunian object. This is supported by the recent analysis of Catalina and Siding Spring sky surveys concluding that current surveys of the outer solar system are complete at V=19.8 (Brown et al. 2015). Discoveries of Trojans are possible but would remain limited in any case.

The case for main-belt is much more influenced by the observing geometry, dictated by Gaia's orientation and corresponding to the solar elongation of the observation, ranging from 45° to 135°. Due to the increased distance to Gaia and higher phase angle at low elongation, the apparent magnitude drops on average by 1.2 ± 0.2 from solar elongation 135° to 45°. Because Gaia is an *apparent magnitude* limited survey, it will not probe the SFD equally at all solar elongation, the largest being more favorable.

A reasonable estimate for the number of MBA yet-to-be-discovered by Gaia is likely to fall between 5000 and 30,000, corresponding to the most favorable and average observing conditions at 90° and 135° solar elongation.

We do not study here the case of Mars Trojans nor Mars-crosser asteroids, as the former have been studied by Todd *et al.* (2014) and the later are similar to NEAs discussed below. Todd *et al.* concluded Gaia could detect possibly up to 10^2 Mars Trojans (compared with the 4 known today), and any Earth Trojans larger than 600m diameter. Gaia may therefore bring a major improvement in our knowledge of these inner-planet Trojan populations.

Finally, the case of NEAs is similar to MBAs, and depends strongly on the observing geometry. An additional feature is that Gaia will not observe the same NEA sub-populations at all solar elongations. Large solar elongations will favor Amor and Apollos types, while low solar elongations will allow the observation of Atira asteroids, which orbit is fully enclosed within the orbit of the Earth. A few 10^2 NEAs may be discovered, i.e., only a few percents increase of the already 10^4 known. Any Atira discovery would however be a major improvement: only 6 Atira asteroids are currently known, owing to the difficulty of observing inner-Earth orbital region.

Overall, Gaia is unlikely to detect any new outer solar system object. Most discoveries will concern main-belt asteroids (about 100 per week), with a few additional near-Earth asteroids (1-3 per week). These numbers are small compared with current populations, and Gaia will not contribute significantly to SSO discoveries, with the exception of a few specific dynamical classes such as Atiras and Mars/Earth Trojans. These numbers are, however, large enough to require orbital characterization of these objects soon after their discovery by Gaia, to allow their identification in subsequent observations by the probe.

We note that the figures given above represent the upper limit of the number of potential objects that remain to be discovered: Gaia is not guaranteed to observe each. Furthermore, ground-based observatories discover new SSOs on a daily basis, constantly reducing the reservoir available to Gaia. The discovery statistic is of about 500 MBAs and 25 NEAs each week (based on 2013 and 2014 records).

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The Gaia FUN SSO pipeline and user interface

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Abstract: *During the five years of its all-sky survey, the ESA astrometry mission Gaia is expected to discover about a hundred asteroids per week, a small fraction of which being near-Earth asteroids. Because unknown moving sources must be treated separately in Gaia pipeline, requiring additional identification and source cross-matching steps, they significantly increase the burden of the so-called long-term pipeline, ran every 6 months. We present here the pipeline and user interface of the Gaia Follow-Up Network for Solar System Bodies, designed to provide ground-based additional observations of newly discovered asteroids to determine their orbit, thus softening the work load on the long-term pipeline.*

1. Introduction

The operation mode of Gaia is based on a regular scanning law, slowly evolving to cover the whole celestial sphere. This implies that there is no target-pointing observations realized by Gaia. Discoveries of Solar system objects (SSOs) are possible by Gaia, thanks to the non-sidereal motion of the sources, but follow-up observations cannot be handled by the probe. A dedicated short-term pipeline (SSO-ST) has been set up, ran daily at CNES, to analyze the transit of unknown moving sources, measure the successive positions of the objects, determine their orbit, and disseminate call for observation alerts.

The DU459 is the front-end of this chain, responsible for ephemeris computation, prediction, and dissemination based on the sets of orbital elements it receives. Associated with the DU459 pipeline, is the Gaia Follow-Up Network for Solar System Objects (Gaia-FUN-SSO), a network of telescopes spread worlwide, willing to observe the alerts released by the DU459 (see Thuillot et al., 2015). We propose here an overview of the DU459 pipeline, and present the user interface used to disseminate the alerts.

2. Workflow within the DU459

The SSO-ST runs daily at the CNES, in Toulouse. The chains encompass astrometric measurements of moving sources, bundling of observations, and orbital inversion. For each new source observed by Gaia, the main unknown is the Gaiacentric distance. The orbit inversion thus leads to many ambiguous solutions, corresponding to different distances at the time of observation. As a results, the CNES delivers around 2000 possible orbits for each new source. Each projects differently on the plane of the sky as seen from Earth, making the recovery of the source a challenge. The DU459 workflow was designed to provide topocentric coordinates and regions on the plane of the sky to search the object for. Due to telemetry and initial data treatment delays, the orbits will be delivered to DU459 between 24 and 48h after discovery by Gaia. Delay during which the solid angle of the cloud of predicted positions on the plane of the sky increases. The DU459 workflow is therefore fully automated, and results of ephemeris are available to users (through the web pages) in “real time”.

The chains ingests data provided by the CNESS, and is structured as follow (Fig. Fig.):

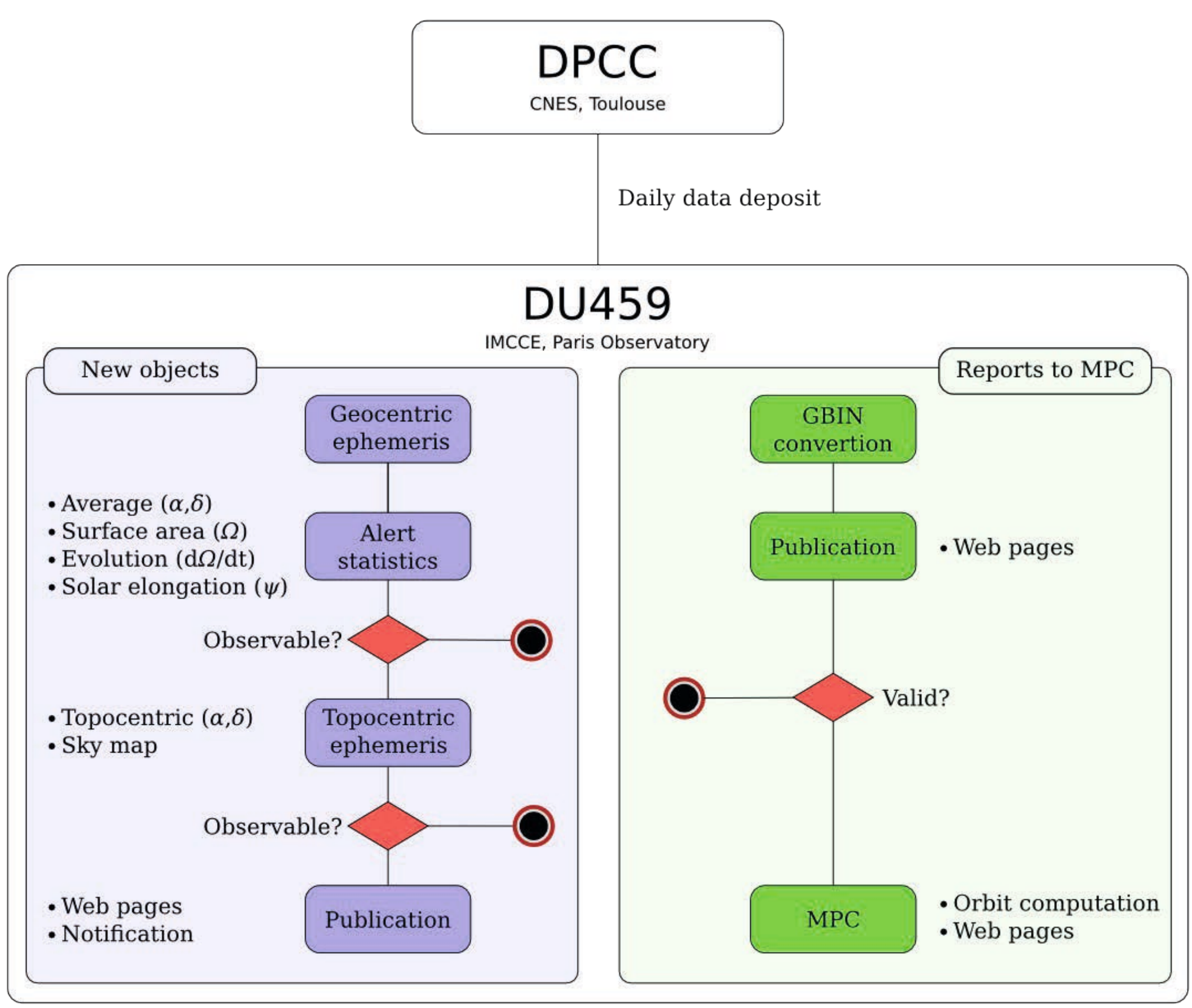

Fig. 1: Schematic view of the DU459 workflow. ***Left:*** *the alert processing leading to diffusion.* ***Right:*** *Astrometry reports for transmission to the Minor Planet Center.*

2.1. New objects

This part of the chain deals with the predictions of the position of newly discovered SSOs. For each object, the different steps are :

1. Geocentric ephemeris are computed
2. Statistics on the prediction are gathered. Critical points are the total surface area covered by the prediction, and its evolution with time. If these quantities are deemed unrealistic (total surface area above 10 sq. deg. or observability window lasting less than a couple of days, the object is not longer considered and the chain stops.
3. Otherwise, the object is considered suitable, and will be released as an alert. Topocentric ephemeris are computed for each observer registered in the Gaia-FUN-SSO. Based on their personal criteria for observability (minimum elevation above horizon, minimum solar elongation, *etc.*) the objects is defined as suitable for a given station.
4. Each observer can access the entire list of currently valid alerts ***for his station and observability criteria*** at any time from the web interface (http://gaiafunsso.imcce.fr).

2.2. Astrometry reports

This part of the chain was developped in the Royal Observatory, in Bruxelles by T. Pauwels. Gaia measured positions, delivered in the gbin (Gaia binary) format, are converted to the MPC format for submission of astrometric data and sent via email to the MPC. This part of the SSO-ST chain could have been host at CNES, like the other (the DU459 is an exception in that respect). However, because this task required open connection to the internet, it was chosen for security reasons to run it outside CNES, and it is host with the DU459.

3. User interface for alert dissemination

The alerts are accessible from a suite of web pages host at IMCCE : http://gaiafunsso.imcce.fr. After registering (Fig. 2), users can define their observing station (Fig. 2), and specify their own criteria for target observability (Fig. 3). These choices allow the system to **select the alerts visible to the observer only**. The list of alert is the accessible, and for each alert, a dedicated page can be loaded (Fig. 4). This way, observers can concentrate on a few alerts at once. The detailed page was designed to help planning the observations : the topocentric ephemeris are listed, and the corresponding successive positions and areas to search for on the plane of the sky are displayed, together with the field of view of the observer's instrument. One can thus see in a glimpse if the field of view is larger or smaller than the region to search.

After observing, observers fill a simple summary indicating the date of observation and status (success or failure), and a copy of their report to MPC if the target was indeed succesfully observed. The detailed page list these reports, to help guiding the observer. The alert pages presented in Fig. 4 are still likely to evolve, once the SSO-ST will provide new alerts daily, following the first feedback from observers.

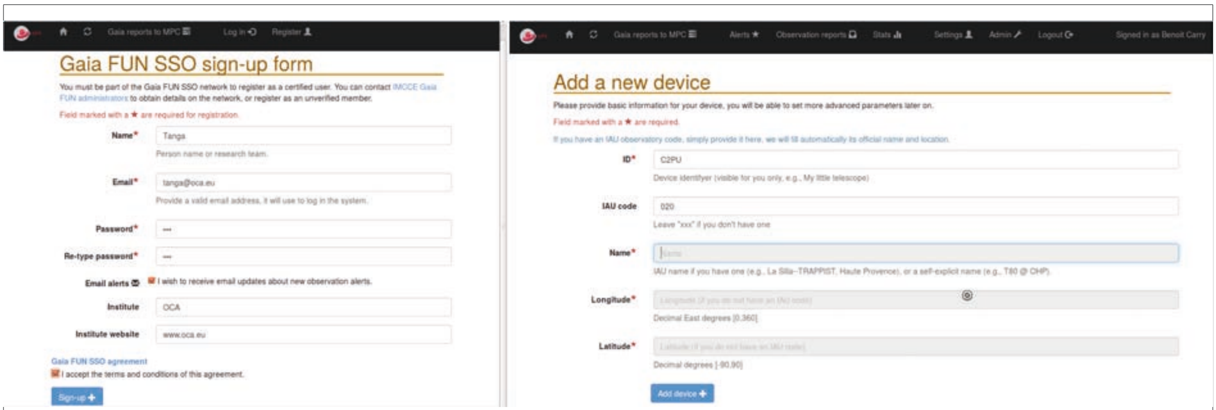

Fig. 2: ***Left :*** *Registration form.* ***Right :*** *Definition of an observing station : Name, IAU code (if available) or coordinates (longitude,latitude).*

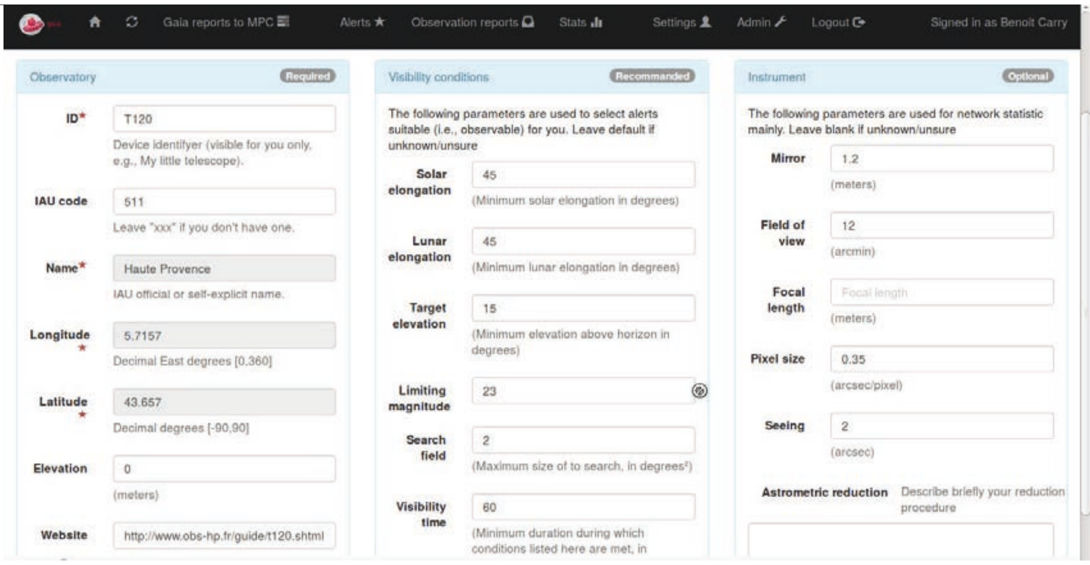

Fig. 3: Observer's preferences, used to select observable alerts. Details on the observing station can be specified (left), observability conditions (solar and lunar elongation, elevation above horizon, etc.) can be set (centre), and general information on the device can be filled for statistical purposes within the network (right).

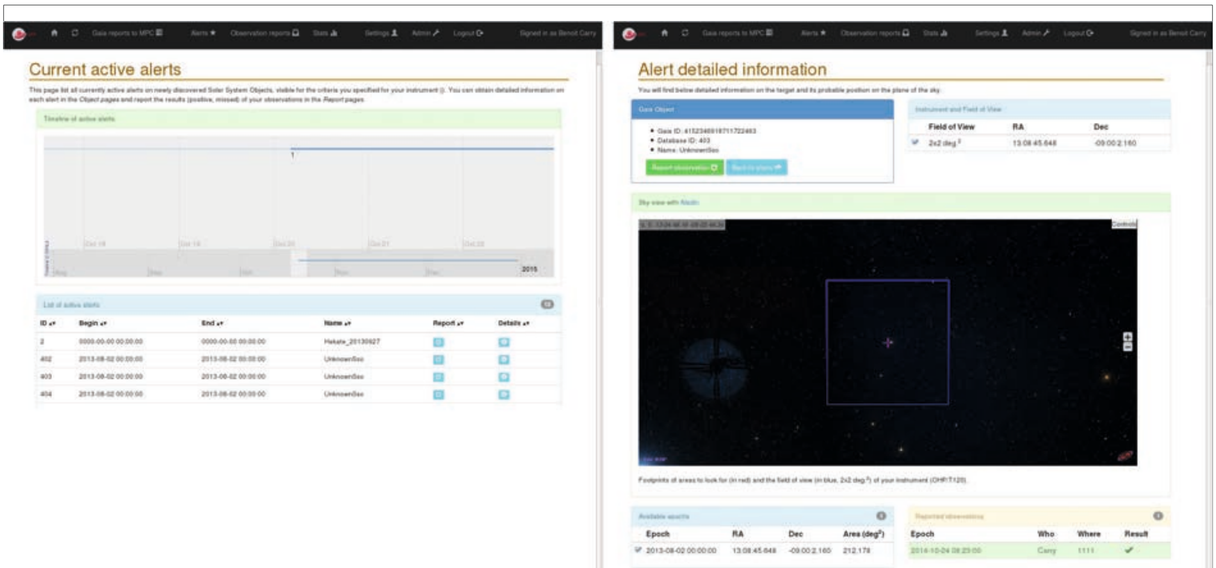

*Fig. 4: Example of alert pages. **Left:** The alerts available to the observer (from the preferences specified in Fig. 3), shown in a timeline and listed in a table below with links to details. **Right:** The detail page of each alert providing basic information on the object ; a view of the sky with the observer field of view and expected region to search for ; the topocentric ephemeris ; and a summary of the result of previous attempts of recovery from network members.*

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The Gaia-FUN-SSO observation campaign of 99942 Apophis: A preliminary test for the network

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1 Abstract

In order to test the coordination and evaluate the overall performance of the Gaia-FUN-SSO, an observation campaign on the Potentially Hazardous Asteroid (99 942) Apophis was conducted from 12/21/2012 to 5/2/2013 providing 2732 high quality astrometric observations. We show that a consistent reduction of astrometric campaigns with reliable stellar catalogs substantially improves the quality of astrometric results. We present evidence that the new data will help to reduce the orbit uncertainty of Apophis during its close approach in 2029.

2 Introduction

In the framework of the Gaia mission, an alert mode (a ground-based follow-up network [Thuillot, 2011]), has been set up in order to identify newly detected objects and trigger complementary observations from the ground, since the satellite cannot keep monitoring its discoveries. Specific training campaigns have been organized during the past three years. In particular, the observation campaign of Apophis from 12/21/2012 to 5/2/2013, providing 2732 valuable astrometric measurements among the collection of extensive observations. Some of the observations performed, already submitted to the MPC, have been reduced by the observers themselves, using their preferred tools and astrometric catalogs. However, we decided to conduct a complementary homogeneous reduction, with all CCD images recorded during this campaign using the PRAIA reduction pipeline [Assafin et al., 2011] and the UCAC4 astrometric catalog [Zacharias et al., 2013]. This yields to consistent set of 2732 astrometric measurements of Apophis. In the following we will discuss data analysis of the observations acquired by the Gaia-FUN-SSO. We will show that a consistent analysis can decrease systematic errors and boost the quality of astrometric positions.

3 Data analysis

Among the 2732 astrometric measurements, 629 had already been sent ot the MPC by the observers. This gives us an unique opportunity to compare the consistency of these observations according to the catalog used for the data reduction. We thus define:

- D_{MPC} as the 629 duplicated Gaia-FUN-SSO astrometric measurements already sent to the MPC by the observers. The corresponding observations were reduced with various astrometric software packages and catalogs.
- D_{PRAIA} as the same 629 Gaia-FUN-SSO observations, but re-reduced with PRAIA using the UCAC4 astrometric catalog.
- S_{NEW} as the 2109 unsent observations.

3.1 Alert and recovery process

Using a similar approach as Bancelin et al. [2012], we aim to assess how far the predicted position can drift from the real one in a given amount of time. Let us consider a hypothetical discovery of an asteroid during the Gaia-FUN-SSO campaign. We will use the observational data of Apophis, but we shall assume its orbit was previously unknown. Furthermore, we assume that the hypothetical discovery has happened on the first night recorded in the duplicated measurements D_{PRAIA} and D_{MPC}. This first night set is used to determine the orbit and orbital elements covariance matrix of the new object. We then propagated the orbit solutions and uncertainties obtained from both sets up to six days after the discovery. One week after the discovery the coordinate differences $\Delta\alpha$ and $\Delta\delta$ between D_{PRAIA} , D_{MPC} and the "true" position of Apophis (obtained with the 2004-2014 optical and radar data) are evaluated. Figure 1 shows how the differences in astrometric coordinates evolve for both sets of measurements during the six days following the discovery. The opposing orientation of the $(\Delta\alpha,\Delta\delta)_{MPC}$ and $(\Delta\alpha,\Delta\delta)_{PRAIA}$ curves is due to the different preliminary orbital elements found using D_{PRAIA} and D_{MPC} . One can see that $(\Delta\alpha,\Delta\delta)_{MPC}$ and $(\Delta\alpha,\Delta\delta)_{PRAIA}$ are of the same order of magnitude. Consequently, the method of data reduction is unlikely to have a significant impact on the recovery process within the network.

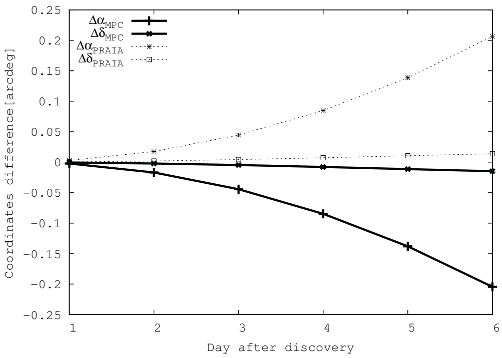

FIG. 1 – *The graph shows the time evolution of the coordinate differences $(\Delta\alpha,\Delta\delta)_{MPC}$ and $(\Delta\alpha,\Delta\delta)_{PRAIA}$ between orbit solutions derived from different data sets with respect to the nominal solution (obtained using all the optical and radar data available)*

3.2 Position uncertainty propagation for new discoveries

We are now interested in how the position uncertainty evolves when more observations become available during the nights following an asteroid's discovery. As we assume the asteroid to be newly discovered, a preliminary orbit determination is conducted after the first night of the sets D_{PRAIA} and D_{MPC} and an orbital improvement is performed. Uncertainties on the geocentric position is then calculated. This allows us to compare the impact of the reduction pipeline on the uncertainty evolution of a newly found object. Figure 2 shows that at the discovery night (first night), uncertainties are large for both sets. However, it is only after the 10^{th} night that the difference D_{MPC} - D_{PRAIA} drops permanently below 10 km. Since between the first and the 10^{th} night span an arc of 26 days, there is a real advantage in consistent reduction regarding the position uncertainty propagation of follow up campaigns.

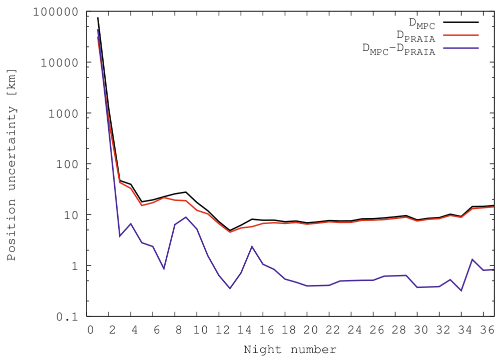

FIG. 2 – *Geocentric position uncertainty evolution as a function of the number of observation nights for the duplicated measurement. The difference between the sets* D_{MPC} - D_{PRAIA} *is also indicated*

3.3 Orbit propagation for Apophis

We will now proceed to study whether orbits and initial uncertainties constructed from different sets of observations can cause a significant change in the propagated uncertainties of Apophis' orbit. The process then works as follows. After an initial orbit determination, an orbit adjustment based on a differential correction is performed. This results in the uncertainties of the asteroids orbit in form of an orbital element covariance matrix. The resulting uncertainties can then be propagated to the 2029 b-plane and its long axis was used to indicate the 1σ uncertainty value. A quick first check can be performed using the duplicated measurement sets D_{MPC} and D_{PRAIA}. The propagated uncertainty with D_{PRAIA} improves the 1σ uncertainty obtaines with D_{MPC} by $\sim$ 14% which is non negligible for the impact probability assessment with short arc data.

3.4 Impact of Gaia-FUN-SSO Observations on Orbit Uncertainties

Our aim is to investigate whether the consistent data produced during the Gaia-FUN-SSO campaign can impact orbital solutions and b-plane uncertainties through the example of Apophis. To this end we compare orbits and uncertainties derived from five observational data sets:

- S_1 = $[2004\text{-}2014]_{MPC}$ + radar
- S_2 = $[2004\text{-}2014]_{MPC}$ - D_{MPC} + D_{PRAIA} + radar
- S_3 = S_1 + S_{NEW}
- S_4 = S_2 + S_{NEW}
- S_5 = S_{NEW} + D_{PRAIA} + radar

where $[2004\text{-}2014]_{MPC}$ refers to the 4138 optical data as present in the MPC database. We propagated each nominal orbit resulting from the individual sets of observations together with its covariances up to 2029 where we evaluated the position uncertainties projected onto the b-plane. Table 1 summarizes the quality of the orbital fit and the 2029 b-plane uncertainty resulting from the orbit propagation. The presented results suggests the sets containing D_{PRAIA} instead of D_{MPC} result in smaller uncertainties in Apophis' positions in the 2029 b-plane. Indeed, even for a well-known orbit (with a 10-years arc data length), both optical and radar χ^2 values show better results when D_{PRAIA} measurements are used. Hence, we speculate that current orbit solutions of NEAs can be improved using consistent data. Furthermore, consistent data reduction with a good astrometric catalog can also result in smaller uncertainties in the b-plane

Tab. 1 – *Orbital accuracy information – fit residuals and b-plane uncertainty – computed with different sets of observations. We also computed the difference in b-plane distance Δ_i for each set with respect to the distance Δ_1 obtained from S_1*

	χ^2_{opt}	χ^2_{rad}	σ_ξ [km]	Δ_i - Δ_1 [km]
S_1	0.227	0.434	2.99	0
S_2	0.224	0.426	2.94	0
S_3	0.157	0.175	2.45	1.5
S_4	0.155	0.174	2.43	1.5
S_5	0.021	0.095	3.24	3

coordinates of PHAs, as was shown for the 2029-b-plane of Apophis. Moreover, we see that the Gaia-FUN-SSO observations and radar data (S_5) suffice to produce b-plane uncertainty values that are very close to those sets that contain all available observations.

4 Conclusion

A large amount of astrometric data was collected during the latest period of observability of Apophis in 2012-2013 and processed in a homogeneous fashion using the PRAIA reduction software and the UCAC4 catalog data. Using the 629 duplicated data from the 2732 precise astrometric measurements provided by 19 observatories, we could show that the recovery process of new objects when their observational data arcs span less than one night won't be impact when considering MPC or PRAIA data. However, a consistent data reduction of a newly discovered asteroids during this observation campaign would have led to a greater reduction of NEO position uncertainties. Finally, the example of Apophis reveals that, even for well-known orbits, the use of consistent data can improve the current χ^2 of both optical and radar data.

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On visual encounters between asteroids and background stars

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Abstract: *Our ability to predict the orbital motion of asteroids crucially depends on the accuracy of astrometric measurements. The limited angular resolution of ground-based observations can be a source of identification errors, especially when fast moving objects cross background stars during a sequence of recorded images. During automatic image processing, visual overlaps may lead to misidentifications or bad positioning which in turn cause a degradation of the astrometric accuracy. In practice such measurements should either be weighted lower in the orbital fitting process, or eliminated entirely from the set of observations. Here, we present results from a search of close visual encounters between asteroids and background stars of comparable magnitudes. Asteroid observations over the past 25 years collected in the Minor Planet Center database have been scanned and visual encounters with stars from the UCAC4 and USNO-B1.0 catalogues have been recorded. Such a procedure can be shown to improve the orbits of near-Earth asteroids, and it can facilitate the dynamical linking of the newly discovered objects.*

1. Introduction

One of the causes of systematic errors in the astrometry of asteroids is the shift in an object's photo-center due to closely spaced images of asteroids and stars, galaxies, other background objects in the field of view of a telescope caused by inappropriate modelling of general light distribution from different sources. For ground-based observations, for instance, a distance of one arcsecond between the images of asteroid and star can be close to the optical resolution limit due to atmospheric turbulence. Such a configuration may lead to a significant error in astrometry or in the worst case even a confusion of astrometric positions depending on the magnitude difference between the objects.

In principle, observers have the possibility to add a qualitative characteristic (alphabetic note) to the position measured to be included in the observational database of the IAU Minor Planet Centre (MPC). However, the aforementioned issue is only one of 40 foreseen difficulties occurred during observation or measurement processes. As the majority of astrometric measurements are now taken automatically without visual inspection, this solution can not be considered satisfactory at present, since visual encounters between asteroids and background objects are rarely flagged.

In order to quantify this issue, we have searched the MPC's database of astrometric observations for visual encounters of asteroids with background objects observed during the last 25 years. Stellar positions were extracted from the astrometric catalogs UCAC4 and USNO-B1.0 and propagated to the time of each observation to identify problematic configurations. In the following sections, we will present our findings. Also, we will show that the idea of alphabetic notes in the current observational format of Minor Planet Centre should be reconsidered.

2. Two issues of visual close encounters in image processing

Processing images of objects that are very close to each other in the focal plane of a telescope always presents a major difficulty. The first issue is caused by the limited spatial resolution of every telescope, which does not allow to separate individual sources if they are located within a certain minimum distance. Ideally, it is proportional to the limiting angular resolution due to diffraction of light and atmospheric turbulence. In practice, the spatial resolution of the telescope is further dependent on the properties of the CCD camera, the optical aberrations of the telescope, etc. beside the focal length, and always corresponds to the angular resolution degraded with respect to the ideal conditions.

It is convenient to choose the angular size of the stellar disk (FWHM) as a measure of angular resolution of telescopes. The angular resolution of telescopes with diameters larger than 0.2 m is determined by the local seeing conditions. In practice, the angular size of the stellar disk is found by observers from direct measurements on the particular telescope and in most cases its value exceeds one arcsecond several times due to suboptimal seeing and optical aberrations. In this article we shall, therefore, define images of objects to be «unresolved», if the angular distance between them is less than one arcsecond at the time of observation, although usually this value can be significantly greater. Since the random error of the best astrometric observations is about 0.1″ or less, the importance of identification of these unresolved cases for astrometry of asteroids is evident. If one knows definitely this is the case, and the magnitudes of the objects are also known, and the contribution of light from other objects or noise, but the asteroid is negligible, then it is possible to associate the made measurement with the asteroid (we emphasise the necessity to report the observational note «involved with star» in this case).

It may seem that the mentioned above issue in measurements disappears if the images of asteroid and star are resolved in the aperture, and one can safely take smaller apertures for doing separate measurements. This is the case only if there is no background gradient present within the chosen aperture. Otherwise both images have to be modelled together, in order to separate light contributions from different sources.

In Fig. 1 one can find a slight visual deviation of the group of four positions in the motion of NEA (99942) Apophis. Since all the positions were recorded within a few hours of observations the trajectory should resemble approximately a straight line. There is no factual deviation in the motion of Apophis here; the measurements appeared to be shifted towards a visual double star due to the lack of modelling of light distribution in the group of sources. Also, the upper measured position of Apophis is probably affected by the light from the nearby star. If the positions of the asteroid were not plotted on the map with reference stars, it would be difficult to discover the cause of the apparent visual curvature of the trajectory.

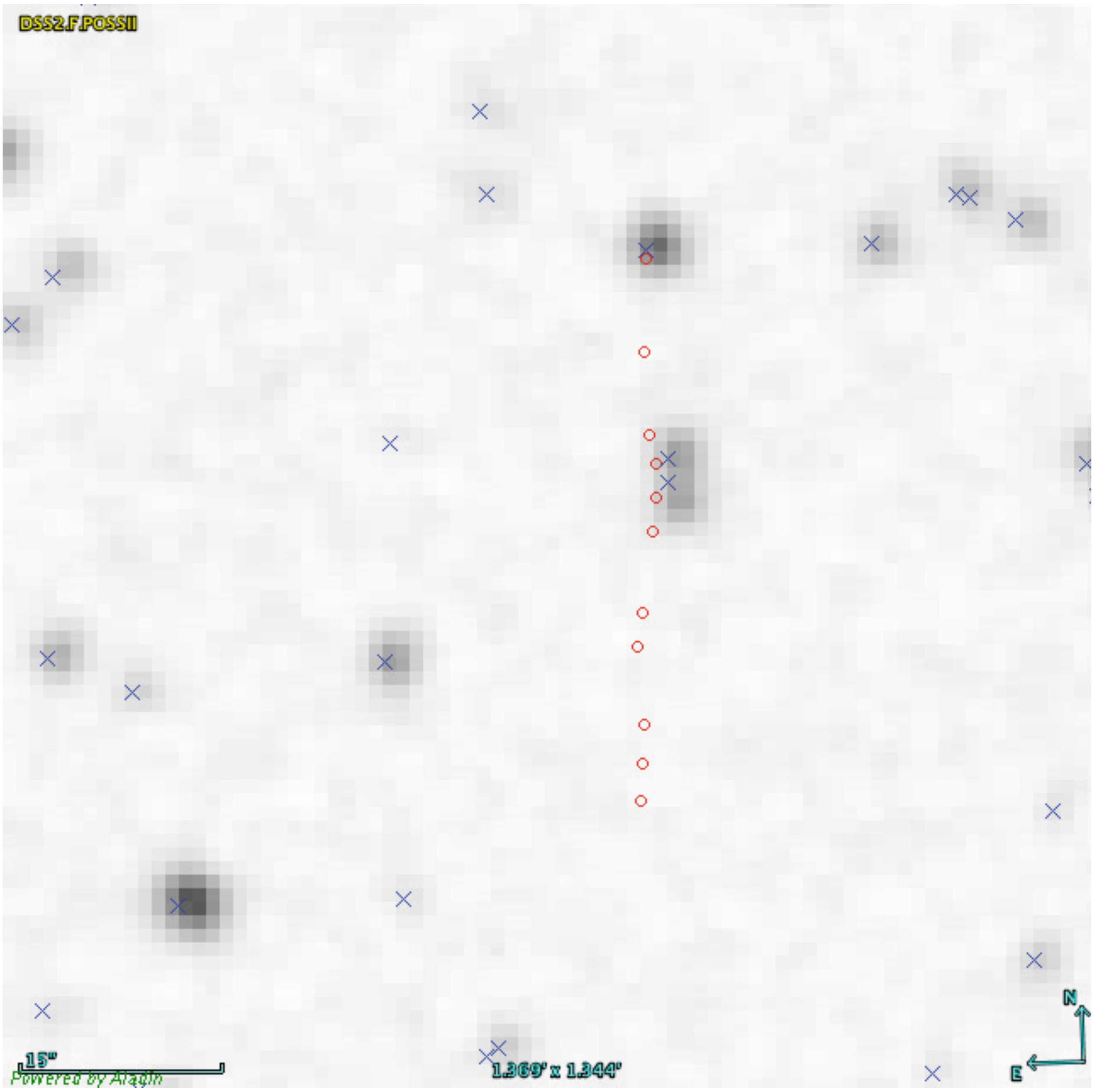

Fig. 1: A series of positions of the asteroid (99942) Apophis recorded within a few hours of observation. The asteroid's positions (red open circles) are plotted using the Aladin sky atlas tool (Bonnarel et al. 2000) against the negative image of the Second Palomar Observatory Sky Survey (POSS II). The exact stellar positions have been extracted from the NOMAD1 Catalog and are given by blue crosses (Zacharias et al. 2004). The small shifts of the stars in the NOMAD1 catalog with respect to the negative image of the Second Palomar Sky Survey are caused by the proper motions of stars. The apparent curvilinear motion of the asteroid results from the pollution of its astrometric position due to background objects.

It is possible to qualitatively explain the observed deviation in the astrometric position of Apophis. Since there is no made modelling of light distribution for a group of sources, the photo-centers of the stars and the asteroid «attract» each other. This is a consequence of the fact that the collected photons from the individual sources sum arithmetically per pixel, so that the apparent positive asymmetry in the profile wings will appear in the direction of the other source (radial symmetry of profiles is assumed). This effect will shift both, the wings and peaks of the images, so choosing smaller measurement apertures will not help. This virtual attraction occurs as long as other sources of noise can be neglected.

3. Comparing numbers: close visual encounters against MPC observational notes

Observers can report difficulties occurred during observations or measurements in the observational data format by choosing only one case among 40 alphabetical notes[1]. In Table 1 we present statistics on how often flags have been used to characterise observations of numbered asteroids during the past 25 years.

Table 1. Statistics of several observational notes reported since 1988

MPC Note	Alphabetic Code	Total Number
Involved with star	I	16245
crowded star field	c	129
Measurement difficult	M	60
poor image	p	36
Position uncertain	P	0
Uncertain image	U	11
unconfirmed image	u	0

Since alphabetical notes are qualitative descriptions they do not offer quantitive estimates on the quality of the presented data. This is a rank classification, which is, unfortunately, often confusing, especially for entries such as «M», «p», «P», «U», see Table 1; it is not clear whether the fact of «crowded star field» influenced the measurements of the asteroid or not. Furthermore, which flag should an observer report, if an observation would require several notes? Also, if the position in the database is corrected, the previously existing note will be deleted or overwritten. As we have pointed in the previous sections of this article, the rank classification is important to identify specific sources of errors in astrometric positions. Currently, such information is lost on a regular basis. Therefore, we recommend to reconsider rank classification policies.

Looking for visual close encounters between asteroids and background objects within one arcsecond is a good test for the quality and quantity of observational notes. For each astrometric position of asteroids observed since 1988 (more than 65 million of positions after omitting occultation, radio & space observed derived positions) that were included in the MPC's observational database, we have extracted the stars within a cone of R_{max}=5″ from the USNO-B1.0 (Monet et al. 2003) and UCAC4 (Zacharias et al. 2013) catalogs using the

[1] http://www.minorplanetcenter.net/iau/info/ObsNote.html

VizieR CDS service (Ochsenbein et al. 2000). The stars which have non-zero proper motions were moved to the positions they should have had at the epoch of the respective observation. Among these stars there the brightest star which was the closest to the asteroid’s position was selected and saved. Also, the total number of stars within distances of R=1.0″…3.5″ from the asteroid's astrometric position were reported. The summary statistics are presented in Table 2. A high percentage of all positions may actually contain systematic shifts due to bright background objects ignored. Unfortunately, the number of potential problems with astrometric data does not coincide with the number of observational notes. In fact, we have found that less than 0.02% of all cases that may have significant systematic errors bore the correct flag. Even more astonishing is that observers reducing their measurements with the UCAC4 catalog did not report any visual close encounter. Also, one should note that the great number of the cases that were flagged «involved with star» in Table 1 encompassed all possible catalogs used by the observers, while Table 2 is referring to USNO-B1.0 and UCAC-4 catalogs solely.

Table 2. Statistics of visual close encounters of numbered asteroids with the background stars of the USNO-B1.0 and UCAC-4 catalogs since 1988

Distance limit, arcsec	USNO-B1.0	Reported observational notes, USNO-B1.0	UCAC4	Reported observational notes, UCAC4
1.0	188298	34	14	0
1.5	417047	52	23	0
2.0	723056	83	46	0
2.5	1108474	130	76	0
3.0	1572919	198	121	0
3.5	2109278	257	183	0

Next, we searched for visual close encounters of (99942) Apophis with background stars. Again, stellar positions were extracted from the USNO-B1.0 catalog, see Table 3. Apophis is classified as a Potentially Hazardous Asteroid, so the knowledge of its orbital evolution is of high importance. At present there are 4168 observations of it in the MPC database, yet, the latest orbit published by NASA's Jet Propulsion Laboratory uses only 496 observations for orbital fitting. This highlights the enormous percentage of observations that has to be discarded. One reason to scrap several measurements may be related to the influence of background objects on the astrometric positions of Apophis. In Table 3 we can see that over two hundred of the 4168 observations of it in the MPC database may be affected by the systematic error. Twenty two are most likely heavily compromised.

Table 3. Visual encounters of (99942) Apophis with the background stars of the USNO-B1.0 catalog

Distance limit, arcsec	1.0	1.5	2.0	2.5	3.0	3.5
USNO-B1.0	22	41	70	121	178	232

4. Conclusions

We conclude that visual close encounters between asteroids and background objects can lead to a degradation in astrometric measurements. The identification and modelling of closely spaced images of objects in astrometric images is necessary in order to produce accurate astrometric positions. Any image reduction software should be tested against such examples.

Alphabetical notes in the MPC's observational format are currently the only means to report difficulties with observations or positions to the Minor Planet Centre. As the motivation to provide correct notes is seemingly very low, we consider it necessary to reconsider this strategy. Including additional information in MPC reports could be a good solution. Access to the measured FWHM for the recording telescope, for instance, will at least to account for visual encounters between asteroids and background objects a posteriori.

If visual close encounters between asteroids and background objects are identified in measurements, one should avoid to use them for orbital fitting as they may contain systematic errors.

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Gaia-FUN-SSO: Triangulation Observations of 2014 HQ_{124}

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Abstract*: In the framework of a Gaia-FUN-SSO observation campaign between June 8th and June 11th 2014 simultaneous observations from different observatories were conducted during the Earth flyby of NEO 2014* HQ_{124}*. The aim was to explore the merits of triangulation based orbit improvement for Near Earth Objects that have close encounters with the Earth. Here, we present preliminary results regarding the predicted and achieved improvement of the orbit of 2014* HQ_{124}*.*

1. Introduction

Triangulation of trajectories using simultaneous observations by several ground-based observers is a well established practice in meteoroid orbit determination (e.g. Ceplecha 1987). The main benefit of this technique lies in the possibility to acquire ranging data which is otherwise only accessible via radar observations. That this technique has not been used on a regular basis for Near Earth Objects (NEOs) is mainly due to the fact that baselines between two Earth-bound observers become negligible for distances approaching astronomical units. The combination of small baselines and astrometric uncertainties tends to make NEO ranging via triangulation difficult. Several ideas have been proposed to enlarge the baselines, for instance, by using space-based telescopes with or without simultaneous ground-based observations (Gromaczkiewicz 2006; Chubey et al. 2010; Eggl 2011). While the potential benefits of such observations have been pointed out several times, the cost of launching a space-craft for such a purpose is mostly prohibitive. Using ESA's Gaia mission together with an Earth-bound site has been suggested recently (Eggl & Devillepoix 2014), since optical ranging can be performed at no additional cost. The fixed scanning law of Gaia, however, does not permit any follow up observations that are required to perform a fully independent orbit determination via triangulation. Nevertheless, Eggl & Devillepoix (2014) demonstrated that triangulation can at least serve to substantially reduce the admissible ranges of orbital elements for newly discovered objects, if they are observed at roughly the same time by the Gaia satellite and by one of the currently active all sky surveys. In order to benefit from a complete optical ranging via orbit triangulation by Earth-bound observers alone one would have to reduce the distance between the observing stations and the target objects. Fortunately, many NEOs pass by the Earth at comparatively small distances. Such close encounters (CEs) can be exploited to improve NEO orbits using triangulation even from Earth-based observers (Fig. 1). In the framework of GAIA-FUN-SSO, we proposed to investigate the merits of such an approach by attempting simultaneous observations of the NEO 2014 HQ_{124} during its close approach between June 8^{th} and June 11^{th}, 2014.

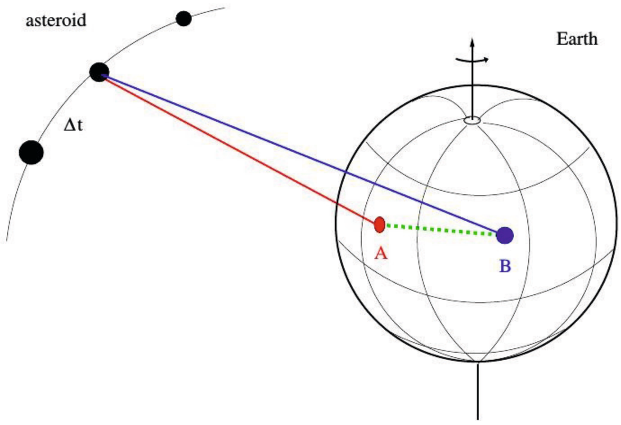

Fig. 1: Simultaneous observations of an asteroid by two Earth-bound observers. The dotted green line corresponds to the baseline between the observing stations. Simultaneous observations can be used to perform optical ranging of a NEO during its flyby.

2. The NEO 2014 HQ_{124}

With a diameter of 325m the NEO 2014 HQ_{124} has roughly the same size as the well known asteroid (99942) Apophis.[1] However, in contrast to Apophis, the closest encounter of 2014 HQ_{124} with the Earth took place on June 9th, 2014. A similarly small encounter distance of 0.0083 au will not be reached for the next two centuries. Since this NEO was only discovered in early 2014, the close flyby was the perfect opportunity to test the capabilities of Earth-bound triangulation.

Table 1 shows the current orbital elements of 2014 HQ_{124}. Although the current quality of the orbital elements of 2014 HQ_{124} is reasonably high, its orbit uncertainty was substantially larger before its close approach, see Fig. 2. In fact, in order to see whether triangulation measurements would make sense, we have simulated the improvement in the topocentric distance uncertainty for 2014 HQ_{124}. Thereby we have assumed several triangulation measurements during the NEO's close encounter in June 2014. The green squares and red circles represent triangulation results based on simulated astrometric measurements performed with an angular precision of 0.1 and 1 arcsec by the observatories C01 and 562, respectively (see Table 2). The black triangles denote the uncertainties predicted by the JPL Horizons system in May 2014. One can see clearly in Fig. 2. that a range uncertainty improvement of orders of magnitude is possible depending on the quality of astrometric observations used for triangulation. It is also clear that delaying observations much beyond the close approach will lead to a substantial decay in power of triangulation based ranging.

a [au]	e	i [deg]	w [deg]	Ω [deg]	M [deg]	H [mag]	MED [LD]
0.850797	0.2591471	26.36970	144.49392	257.572365	106.07481	18.9	~3.23

Table 1: Heliocentric orbital elements of the NEO 2014 HQ_{124}, reference epoch J2000. The asteroid is counted to the Atens class of NEOs. Numbers for the Keplerian orbital elements are given to the last significant digit. The Minimum Encounter Distance (MED) is given in Lunar Distances. This data has been retrieved from JPL Horizons in January 2015.

1) Amy Mainzer, pers. com. May 2014

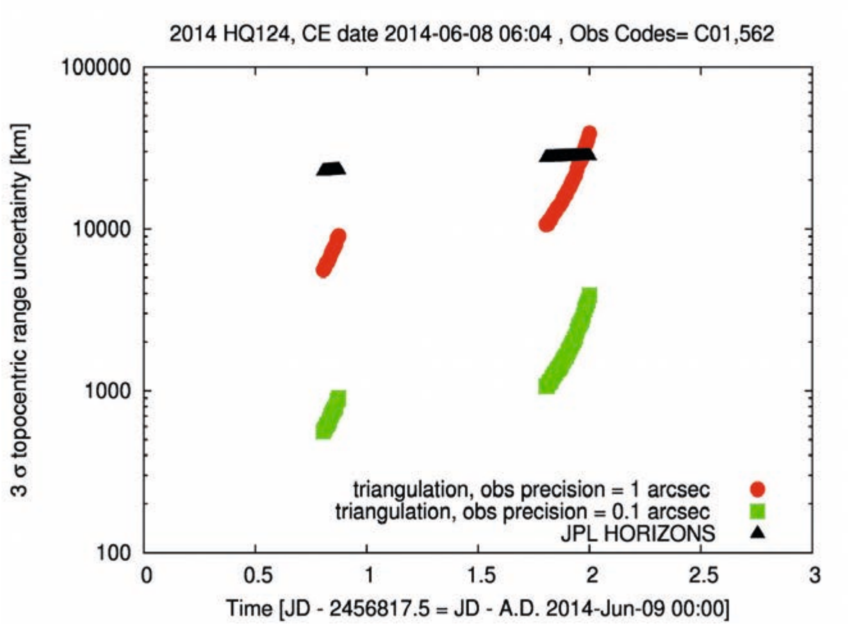

Fig. 2: Expected improvement of the topocentric range uncertainties for 2014 HQ_{124} due to simulated triangulation measurements with different precisions for the close encounter (CE) date. See text for details.

3. The Triangulation Campaign

In order to assess the predicted capabilities of triangulation based orbit improvement in reality, we proposed to conduct observations during the close approach of 2014 HQ_{124} in the framework of a Gaia-FUN-SSO test campaign (Thuillot et al. 2014). Originally, six observatories followed the call. They are listed in Table 2. The aim was to produce simultaneous observations of the target NEO, if possible during its approach, otherwise during the following two nights. Observation series were to be conducted at specific times to facilitate coordination. Long baselines between the observatories are essential to make triangulation ranging less sensitive to uncertainties in the astrometric measurements (e.g. Eggl, 2011). We were, therefore, happy to have access to various baselines up to ~2500km between the participating observatories. However, due to unfavorable weather conditions in central Europe during the observation campaign, three stations could not produce reliable measurements. Fortunately, three observatories, namely 089, 585 and C20 were still able to observe the target on June 10th 2014. The baselines covered by the participants still ranged from roughly 500km to 1200km. The corresponding results are presented in the next section.

MPC Code	Observatory designation
089	Nikolaev Astronomical Observatory, Ukraine
113	Volkssternwarte Drebach, Drebach, Germany
562	Figl Observatory, Vienna, Austria
585	Kyiv comet station, Ukraine
C01	Lohrmann Observatory, Triebenberg, Dresden, Germany
C20	Kislovodsk, Mtn. Astronomical Stn., Pulkovo Obs., Russia

Table 2: Observatories participating in the 2014 HQ_{124} triangulation campaign. Unfortunately, the local weather conditions were unfavorable for the stations highlighted in red. They could not produce reliable measurements.

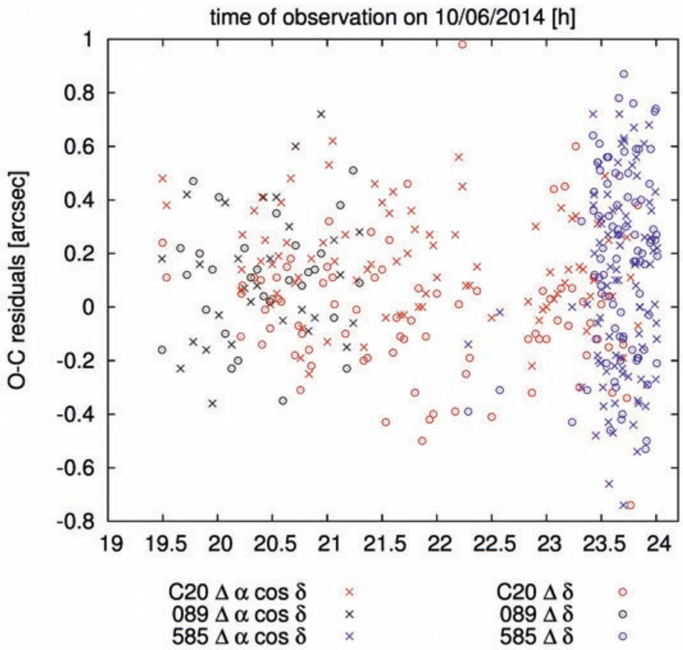

Fig. 3: Residuals in the astrometric measurements performed during the triangulation campaign of the NEO 2014 HQ_{124}. Observatories are color coded, whereas the residuals for the astrometric angles are denoted by circles and crosses, respectively.

4. Preliminary Results

The quality of the astrometric measurements performed by the participants can be seen from Fig. 3. Residuals were calculated using the latest orbit model for 2014 HQ_{124} (see Table 1). One can see that only measurements from C20 span a sufficient fraction of the night. They can be used for triangulation with the other two observatories. The limited observation period of 585 and 089 is mostly due to geolocation and visibility conditions. In Fig. 4 the actual improvement in the positioning of 2014 HQ_{124} is compared with simulated results. As can be seen from Figs. 2 and 4, the observations were performed too late after the close encounter to improve the orbit of 2014 HQ_{124} significantly. Nevertheless, we would like to stress that the here presented triangulation observations were recorded during a single night. The corresponding uncertainties can still outperform regular orbit fits with data arcs of several months (cfg. Fig. 2, JPL data and Fig. 4). It is also clear from Fig. 4 that our triangulation simulations approximate the real data rather accurately. In fact, the impact of the peak to peak amplitudes of the measurement residuals in Fig. 3 (~1 arcsec for C20 and 089 and ~1.8 arcsec for 585) on the ranging precision is captured extremely well by the simulations based on a model by Eggl (2011), see Fig. 4. It is, thus, possible to predict when triangulation observations will be useful to improve orbits of objects with close approaches to the Earth in the future.

5. Conclusions

We have conducted a successful triangulation measurement campaign of the asteroid 2014HQ_{124} shortly after its close encounter with the Earth on June 9th, 2014. Our preliminary results suggest that it will be possible to use triangulation to improve orbits of newly discovered objects. Furthermore, we have shown that the improvement in the positioning uncertainty of NEOs through optical ranging via triangulation can be predicted by the theory developed in Eggl (2011) and Böttger (2014). Hence, the merits of triangulation observations during future close approaches of NEOs can be assessed beforehand.

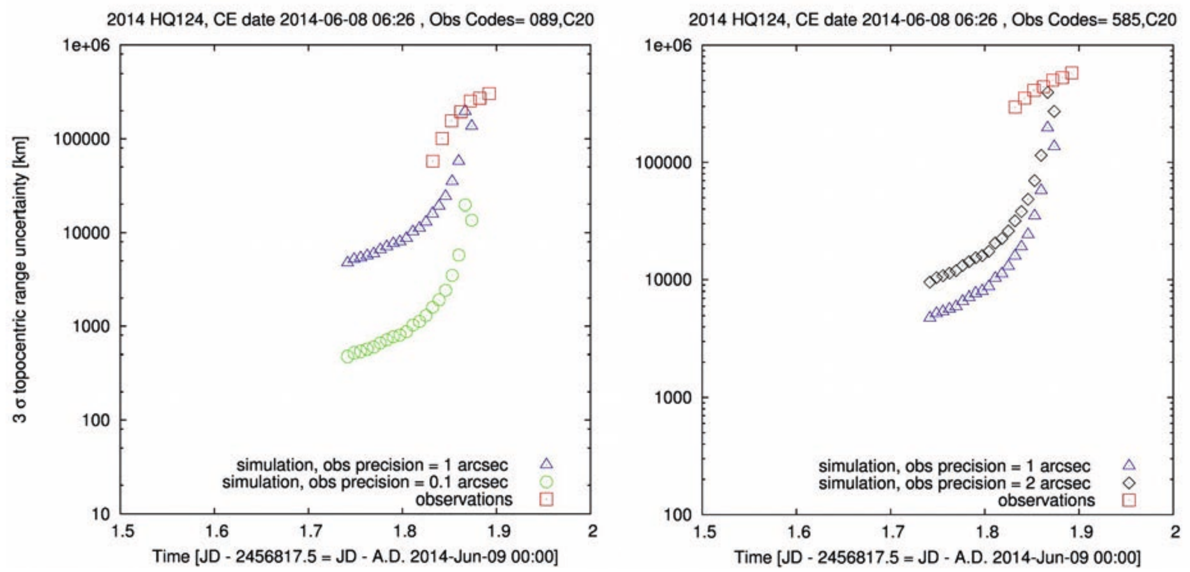

Fig. 4: A comparison between simulated and actual triangulation observation results. The graphs show the remaining topocentric positioning uncertainty of 2014 HQ_{124} for triangulation based ranging measurements at specific times. Left : Triangulation was performed with observations by 089 and C20. Right : Only observations by 585 and C20 were considered. A cut-off below 20 degrees of telescope elevation was considered for the simulations.

Acknowledgments

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The SBG Telescope of the Astronomical Observatory of the Ural Federal University: Opportunities for Gaia-FUN-SSO

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Abstract: *An observing site, telescopes, equipment and the first results of our participation in Gaia-FUN-SSO network are presented. Regular astrometric observations of small bodies of the Solar System are conducted using a SBG telescope of the Kourovka Astronomical Observatory of the Ural Federal University. The four-axis telescope with a 788 mm focal length is equipped with a Schmidt optical system and a 500 mm diameter main mirror. Same results for campaigns of observation are presented. With the SBG telescope observations are carried out large number of the small Solar System bodies and other objects. This telescope can efficiently participate in Gaia-FUN-SSO Network.*

1. Introduction

Kourovka Astronomical Observatory of the Ural Federal University was found on 12 January 1965. The SBG telescope has been used since 1974. The SBG telescope has used to curry out observations of small Solar System bodies, artificial satellites of the Earth and open clusters. The CCD observations have carried out since 2005.

The observatory is located on the west slope of the Urals Mountains near Europe–Asia border. The observatory is the most eastern observatory in Europe. Distance between the observatory and Ekaterinburg city is approximately 100 km.

The observatory has 6 instruments for astrometric (SBG telescope, Master-II), photometric (AZT-3 telescope, 70 cm telescope, Master-II) and spectroscopic (1.2 m telescope, ACU-5 horizontal solar telescope) observations of stars, small bodies and the Sun.

2. SBG telescope

Regular astrometric observations of small bodies of the Solar System are conducted using a SBG telescope (fig. 1) of the Kourovka Astronomical Observatory. The four-axis telescope with a 788 mm focal length is equipped with a Schmidt optical system and a 500 mm diameter main mirror. An Alta U32 CCD camera with a KAF-3200ME-1 CCD matrix containing 2184 × 1472 elements, each of size 6.8 × 6.8 μm is mounted at the main telescope focus. The scale of the CCD image is 1.8 arcsec/pixel. The field of view of the system is 65 × 44 arcmin. Limiting magnitude is 19 mag.

The precision timing system uses a 12-channel GPS receiver Acutime 2000 GPS Smart Antenna.

Fig. 1: The SBG telescope Kourovka Astronomical Observatory

Initially, the SBG telescope was supplied with photo plates as radiation receivers. In 2005, the telescope was modernized, which allowed us to use the CCD camera instead of photo plates (Glamazda, 2012a). The SBG telescope and the CCD system are operated by the SBGControl program software (Glamazda, 2012b) developed at AO UrFU.

The astrometrical processing of the CCD observations of minor planets from the telescope is carried out in the Astrometrica software (Raab, 2013).

3. The first results

There are same results for campaigns of observation for Gaia-FUN-SSO test. The asteroid 2013 TV135 was observed in October 2014 (fig. 2).

The asteroid 2007 HB15 was not detected because it was very faint object for the SBG telescope.

The NEO 2014 HQ124 was not observed because the sky was very light in a nautical twilight near a day of summer solstice.

Several asteroids were observed by the SBG telescope for other programs of observation. With the SBG telescope it carried out observations of large number of the Small Solar System bodies and other objects.

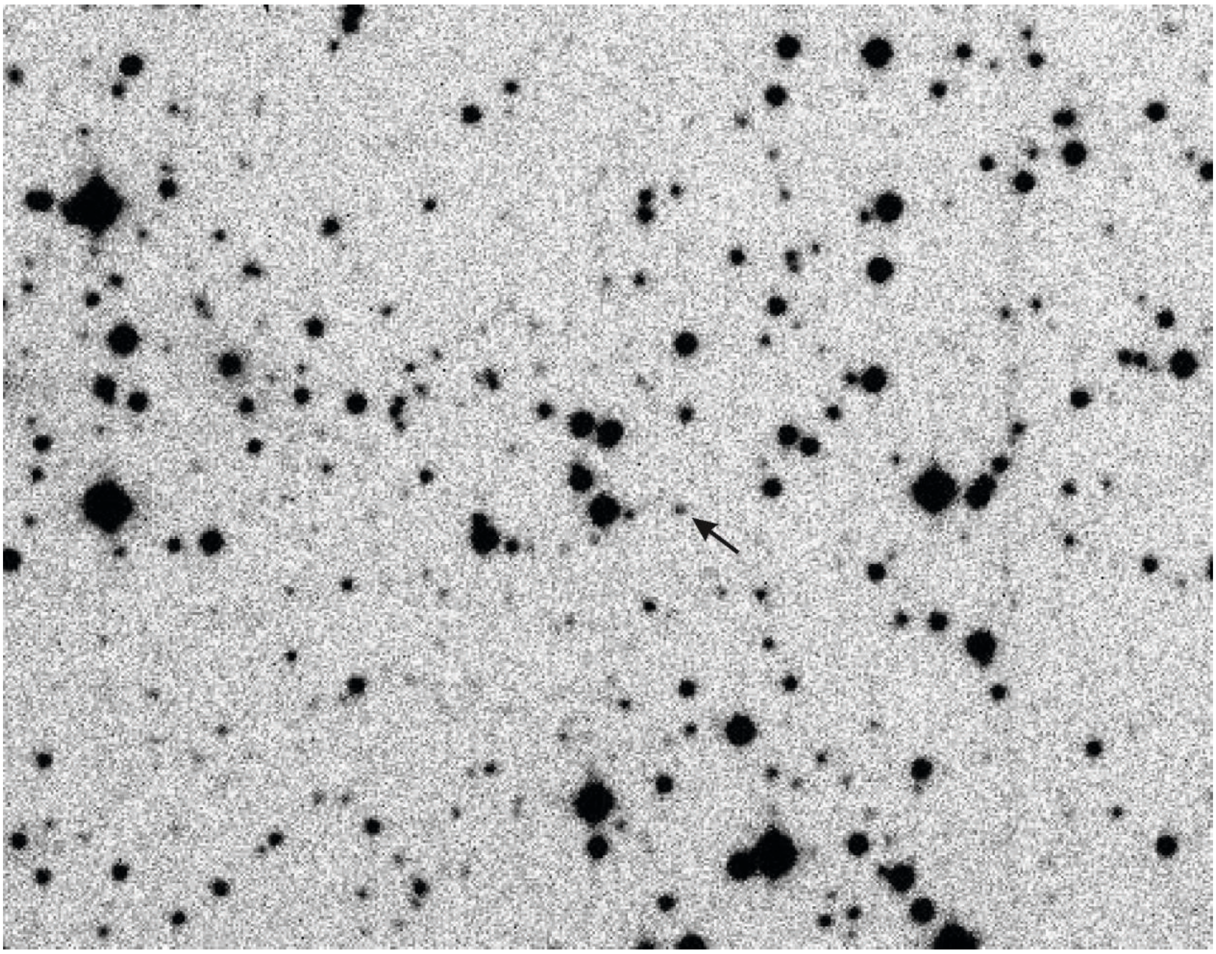

Fig. 2: The asteroid 2013 TV135 from the SBG telescope

4. Plans to the future

We plan to use 1.2 m telescope of Kourovka Astronomical Observatory (fig. 3) in future. Limiting magnitude is not less than 20 mag. Field of view is 1.15 deg.

The 1.2 m telescope constructed by APM Telescopes was mounted in Kourovka in 2009. It is a Cassegrain system with an alt-azimuth mounting equipped with two spectrographs, UFES and ANNA set in Nasmyth foci and a photometer-polarimeter is planned to be set in primary focus.

The instrument is aimed at fundamental research of open clusters, star-forming regions, variable stars as well as observations of near space objects and studies of the Earth atmosphere.

5. Conclusions

The SBG telescope can efficiently participate in Gaia-FUN-SSO Network.

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Fig. 3: 1.2 m telescope of Kourovka Astronomical Observatory

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Astrometry and Photometry in Sky Areas of Karin Asteroids Family Members

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Abstract*: Karin family of asteroids is composed by approximately 100 hundred objects. Backward integrations show that the break-up of the parent body occurred approximately 6 million years ago. Spectroscopic campaigns of some of the most massive asteroid of Karin family reveal homogeneity of their surface and associate their surface properties to S-type taxonomic class of asteroids. Our observational program aims to increase the knowledge of physical properties of Karin family and thus strengthen the statistics concerning its physical parameters. Photometry of family members will allow not only characterizing theirs synodical periods but also to determine parameters such as pole orientation and reconstruct their shapes from rotational light curves. Astrometry of asteroids recorded on the images was also performed and reported to the Minor Planet Center (MPC). Faint asteroids were also discovered and reported to the MPC. This exercise of identification of new objects of the Solar System is an excellent training of doing good quality astrometry thus becoming operational for the futures Gaia alerts and follow-up of new discoveries from the ground. The presentation will give few examples of photometric targets among Karin family of asteroids using the 1 meter telescope facility in Turkish National Observatory (TUBITAK) as well as the astrometry of few newly discovered objects.*

1. Introduction

Karin family of asteroids is a cluster of objects identified inside the Koronis family (Nesvorny et al, Nature 2002). Backward integrations show that the break-up of the parent body occurred approximately 6 million years ago (Nesvorny 2004). This age is relatively recent into the Solar System history and suggests that a catastrophic disruption of a larger body estimated at 33 km in diameter occurs at that moment (Nesvorny et al, 2006). The hypothesis of a single parent body is supported also by spectroscopic observations in the range of visible. Vernazza et al. (2006) published the results of their spectroscopic survey for 24 objects of Karin family on which they conclude that all objects exhibit similar spectral trends and very close to ordinary chondrite composition. Several speculation concerning the spectral heterogeneity of (832) Karin's surface was avoided after some intensive observational runs during several oppositions (Vernazza et al, 2007, Birlan & Nedelcu, 2010).

Rotational periods of Karin family members are still unknown. There are few information concerning observational runs for systematic light curves devoted to the members of this family and no conclusion on a possible/probable Slivan steady-state of their spin axis. We mention here few results of synodical periods for the asteroid (832) Karin (Yoshida et al 2004, Birlan & Nedelcu 2010). Its rotational period of approximately 18.35 hours assess the slow-rotator object and suggests a rubble pile internal structure of this object. Some other ten objects of Karin family have also known periods and the results are published (Hahn et al 2006) or under revision (Yoshida et al 2012). These observational results are limited and biased mainly by the size of the objects inside the family. Indeed, a larger part of these objects are faint and thus the SNR for good astrometry requires medium 1-3m aperture telescopes.

2. Observational program

Our observational program aims to increase the knowledge of physical properties of Karin family and thus strengthen the statistics concerning its physical parameters. Photometry of family members over several oppositions will allow not only to characterize theirs synodical period but also to determine others parameters such as pole orientation and reconstruct their shapes from rotational light curves. Accessory, the astrometry of asteroids serendipitously recorded on the images was also performed and reported to the MPC.

The main goal of this project is to obtain light curves of at least 25% of Karin family members. This is a good statistics in terms of light curves for characterizing the rotational state inside the family and to bring forth constraints concerning the origin of catastrophic collision at the origin of the family.

The observational program started in 2013 by awarded proposals on TUBITAK 1m telescope (a Ritchey-Chretien model mounted on an equatorial mount, of Turkish National Observatory). The telescope operates on F/10 using a 4x4k CCD camera. The field of view is 21.5x21.5 arc-minutes. In the case of asteroids could reach a magnitude of 18.5 for a SNR range between 38 and 45 for an exposure time of 240 sec. A total of 35 nights were awarded for this program (Figure1).

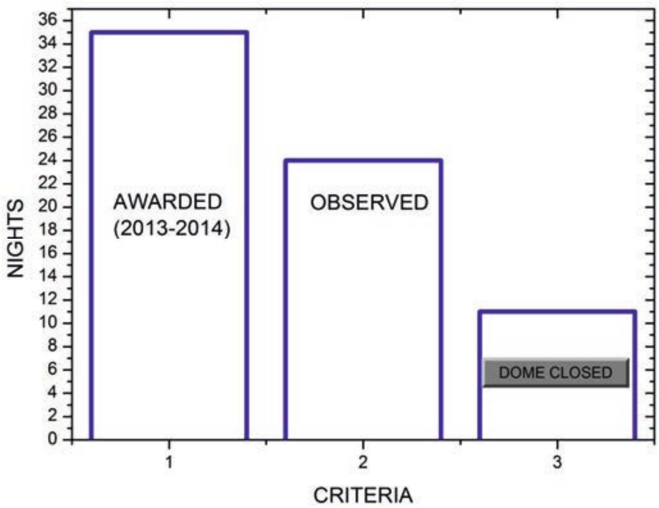

Fig. 1: Statistics of the observed nights until November 2014. 35 nights were awarded during 2013 and 2014. A total of 60 hours of this awarded time was favorable and exploited for photometric purposes.

2.1 Photometry

The program allows observations for ten objects of Karin family. We do not take into account new observations for (832) Karin into our investigation. Data reduction was performed using MIDAS and MaxImDL routines. The observations allows relative good differential photometry for the objects 2000 EV136, (11728) Einer, (13807) 1996 XE13, (20095) 1994

PG35, 4153 T-2 and 2000 GO17. Partial results show promising data (Figure 2) with larger magnitude excursions during the observing time. This is the pattern of some relatively elongated shape asteroids. For some of these objects (2000 EV136 as example presented in Figure 2) precise investigations using periodograms should be used.

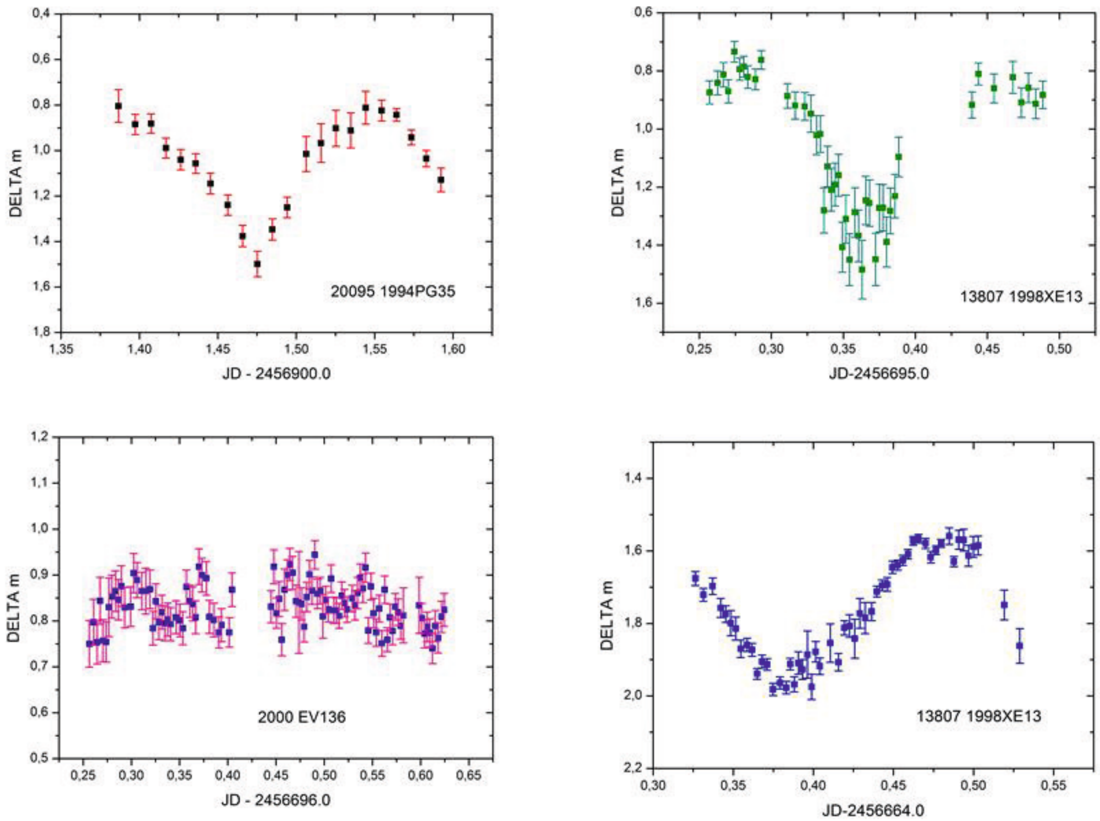

Fig. 2: Example of light curves for asteroids (20095) 1994PG35, (13807) XE13 and 2000 EV136. The asteroid 2000 EV136 exhibits small variation in magnitude during the observations which makes difficult an intuitive synodical period.

2.2 Astrometry

Astrometric data for asteroids serendipitously presented in sky areas of Karin family members were obtained as a secondary objective. Meanwhile, the survey for new discoveries was also performed. This exercise was also performed in the framework of future GAIA-alert program for the network of ground based telescopes. For data reduction Astrometrica software (Raab, 2014) and NOMAD catalogue together with SkyBoT (Berthier et al, 2006) service of ephemerides for asteroids were used. A preliminary statistics shows that approximately 800 individual positions for more 90 asteroids were reported to MPC. This represents 10% of total observations reported to MPC using the IAU Code A84 (TUBITAK).

Ten newly discovered objects were detected in the images and reported to MPC (Figure 3). The observations of one of these objects were used to confirm the new object 2013QQ19 which is now into the MPC registered catalog.

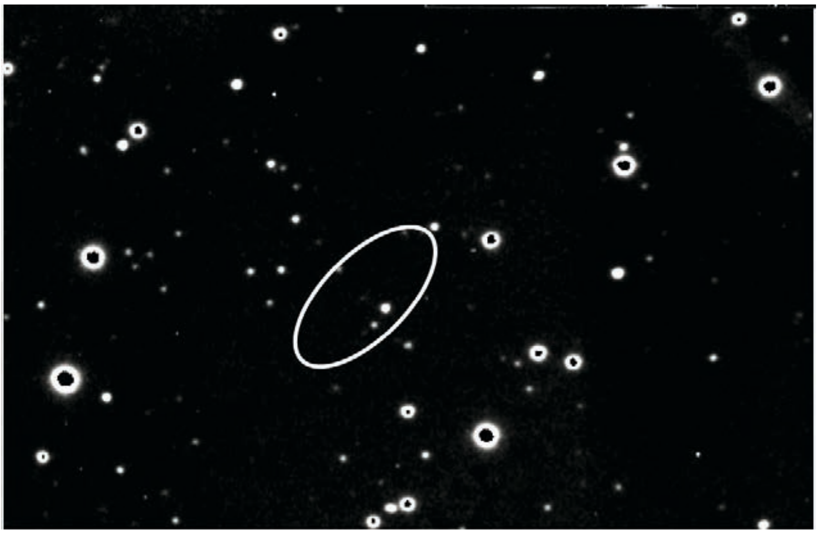

Fig. 3: New discovery in the field of asteroid (47640) 2000CA30 obtained in 5th of February 2014. Newly discovered object is the faint object located in the middle of the ellipse. Part of the stars in the image is saturated (black dots in the middle of images).

2. Conclusions

The experience acquired through this program allows us to answer in a positive manner to future GAIA alerts for asteroids. The program established the performances and the limitations of facilities, allows training of students, transfer of knowledge and homogenization of procedures for good observational performance.

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Turkish Facilities to Meet GAIA Solar System ToO Observations

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Abstract*:* ***The three telescopes of TUBITAK National Observatory (TUG) were dedicated to GAIA target of opportunity (ToO) observations with a limited amount of observing times. Operated by Russian (Kazan Federal University, Kazan and Russian Academy Of Sciences, IKI, Moscow) and Turkish (TUG) cooperation, the RTT150 telescope with 150 cm aperture and 0.39 arcsec/pixel resolution is reserved just for GAIA ToO observations 5 days in a year. Having Ritchey-Chretien Cassegrain focus, RTT150 telescope is able to do interchangeably spectroscopy, photometry, and astrometry. The T100 telescope with 100 cm aperture and 0.32 arcsec/pixel resolution is dedicated 80 hours per year, while T60 robotic telescope with 60 cm aperture and 0.51 arcsec/pixel resolution is promised to allow 15% of its observing time to be used for ToO observations which will follow up the GAIA alerts. Activities and preparations and eligibility of a newly established group of astronomers who are interested in GAIA Solar System ToO observations will be summarized.***

1. Introduction

The TUBITAK National Observatory (TUG) is a governmental institution serving to Turkish universities with departments of Astronomy, Astrophysics, Physics, Space Physics and related sciences which are interested in astronomical observations. The administration building of the observatory is within the University Campus of Akdeniz University, Antalya, Turkey. While, the observing site, where the telescopes were located, resides on the top of one of the hills (Bakırlıtepe) of the western Taurus Mountains, which has an altitude of 2500 m from the sea level and about 60 km northeast of Antalya. The geographical coordinates of the observing site are 36º 49' 27" N and 30º 20' 08" E.

The observatory is young since its establishment was quite recently about 20 years ago (Eker et al, 2013). The optical site testing on Bakırlıtepe was published first by Aslan et al. (1989) before the telescopes and observatory campus were established. Recently, daytime and nighttime site seeing performances was updated by TUG S-DIMM (Özışık and Ak, 2004) and TUG DIMM observations. Nighttime median seeing is 0.9 arc-second and daytime median seeing is 1.5 arc-second. Seeing obtained at the telescopes is mainly affected by the "dome seeing" and typical value is 1.5 arc-second for TUG telescopes during the most of the year. The sky background is 22nd magnitude and night sky is clear 220 days in a year in average. Avarege temperature is 5ºC while maximum and minimum temperatures were recorded 22 ºC and –27 ºC respectively. Mean relative humidity is 50% ranging between 2% to 99%. The mean wind speed is 17 km/h. Maximum recorded wind speed is 267 km/h as "wind gust" . The dominant wind direction is the south east.

TUG is established to meet observational demands of astronomers and astrophysicists in Turkey; therefore observing proposals and targets varies as much as the needs of scientists in Turkey. Solar system objects are among the observing interests. At present, 8032 asteroids' astrometric positions, four asteroid discoveries, and one confirmation were reported by the International Astronomical Union Minor Planet Center between the years 2002 to 2014. TUG is one of the worldwide observatories agreed to follow GAIA Solar system objects after their discovery.

In this contribution, TUG facilities and related activities to meet GAIA Solar System Target of Opportunity (ToO) observations will be presented.

2. Dedicated Telescopes

2.1 RTT150

Built by LOMO Company in St. Petersburg, Russia, RTT150 telescope (Fig. 1) was installed on Bakırlıtepe in the years 1998-2001. The first light was taken in September 2001. Since then it is operated jointly by TUBITAK (TUG), Kazan Federal University (KFU), and Russian Academy of Sciences (IKI), Moscow. It has 150 cm aperture main mirror and Ritchey-Chretien optical system. It can be operated interchangeably by Cassegrain and COUDE mode with focal ratios of f/7.7 and f/48. Three different spectrographs (TFOSC, COUDE, DEFPOS) and various CCD cameras (2048x2048, 15μ at TFOSC, 2048x2048, 13.5 μ at COUDE, 2048x2048, 13.5 μ for imaging at ANDOR DW436, 1024x1024, 13 μ for fast photometry at ANDOR IXON+) according to programmed observations are used. With a 0.24 arcsec per pixel and 8x8 arc minutes field of view with Andor DW436 camera, it is suitable to follow up solar system objects up to 21st magnitude. The time allocation to follow up GAIA ToO observations on RTT150 telescope is 5 days in a year.

Fig. 1: RTT150 telescope on Bakırlıtepe

2.2 T100

Built by ACE Company in USA, T100 telescope (Fig. 2) was installed on Bakırlıtepe in the year of 2009. The first light was taken on October 7, 2009. It is a fully automatic, remotely controllable telescope with 100 cm aperture main mirror and Ritchey-Chretien, f/10 optical system. With SI 4Kx4K BB, "Cryo-cooled" CCD, it is the telescope actively operated with largest field of view (21.5'x21.5'). With a 0.32" per pixel on the focus, T100 is perfectly suitable to follow up solar system objects up to 21th magnitude. Astrometric observations are reduced through a pipeline in time. The time allocation to follow up GAIA ToO observations on T100 telescope is 80 hours in a year.

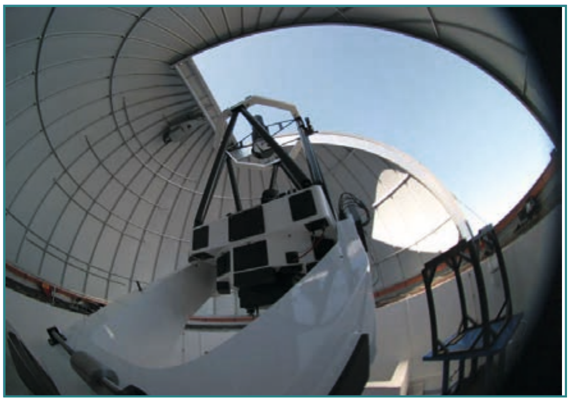

Fig. 2: T100 telescope on Bakırlıtepe.

2.3 T60

Built by OMI Company in USA, T60 telescope (Fig.3) was installed on Bakırlıtepe in the year of 2008. The first light was taken on September 5, 2008. It is fully robotic telescope with 60 cm aperture main mirror and Ritchey-Chretien, f/10 optical system. It is nightly scheduled robotic mode with FLI Proline 2Kx2K BB CCD. With a 0.51" per pixel on the focus and 17.5'x17.5' field of view, T60 is suitable to follow up solar system objects brighter than 17th magnitude. The time allocation to follow up GAIA ToO observations on T60 telescope is 10-15% of the total observing time in a year.

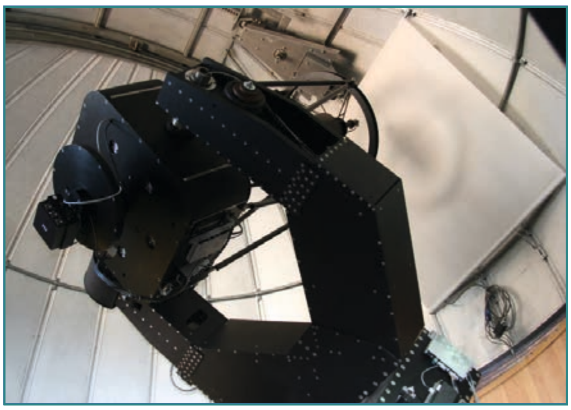

Fig. 3: T60 telescope on Bakırlıtepe

2. Related activities

TUG and a group of Turkish astronomers were interested in observing programs of solar system objects since GAIA Follow Up Network for Solar System Objects (Gaia-FUN-SSO) has been set up in the framework of a task (DU459) of the Coordination Unit 4 (Object processing) of the DPAC GAIA consortium. Summer schools and workshops were already organized with cooperation by IMCCE in Antalya, respectfully, September 5-9, and September 12-13, 2011. Recently a small local group, which is named GGSG - GAIA Solar System Group, is established in February 23, 2014, in order to organize and get ready to meet requirements of ToO observations after GAIA alerts and immediately reduce astrometric observations then submit the results to the Minor Planet Center. The group is open to everyone who is interested in solar system studies, especially related to GAIA alerts on solar system objects. In order to train new members, a workshop was organized in Agust 5-8, 2014. There were twenty students and two instructors, one from KASI, Dr. Myung-Jin KIM and one from IMCCE, Dr. Mirel Birlan. Students were taught how to reduce astrometric observations and produce an asteroid light curve.

3. Conclusion

The newly established dedicated group, GGSG and TUG facilities, three telescopes and related infrastructure are ready to meet GAIA Solar System alerts.

4. Acknowledgements

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Pulkovo observations in last campaigns of GAIA FUN SSO

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Abstract: *ZA-320M and MTM-500M telescopes of Pulkovo Observatory carried out observations of 4 asteroids in the frame of last GAIA FUN SSO training campaigns: (99942) Apophis, (367943) Duende = 2012 DA14, 2013 TV135 and 2014 HQ124. Lightcurves and a lot of astrometric positions for all 4 asteroids were obtained from the observations. Three color indices were obtained for Apophis and Duende. Rotational period of 2013 TV135 was determined. Modelling of tumbling rotation of Duende was carried out. Also, modeling of its orbital evolution was made and changes in its motion respect to the Earth in rotating coordinate system were detected. The observations of 2014 HQ124 were made in the frame of international campaign for its triangulation.*

1. Introduction

Observational Astrometry Laboratory of Pulkovo Observatory takes part in GAIA-FUN-SSO training observational campaigns since 2010. Here, we introduce results of the observations and investigations of 4 asteroids in the frame of the campaigns of last two years.

2. Telescopes

Our team carries out observations with two small robotic telescopes. ZA-320M (D = 32 cm, F = 320 cm) is installed at Pulkovo Observatory (Saint-Petersburg). MTM-500M (D = 50 cm, F = 410 cm) is located in Northern Caucasus Mountains near Kislovodsk at the altitude of 2070 m. Both telescopes are equipped with CCD cameras and *BVRI* filters.

3. Software

CCD images are processed by Apex II software (Devyatkin et al., 2010) developed at Pulkovo Observatory as an all-purpose astronomical image analysis platform. Apex II automatic asteroid pipeline comprises the following basic steps: calibration (including synthesis and application of dark and flatfield frames and cosmetic correction); sky background flattening; object detection; deblending; centroiding by PSF fitting; flux measurement using aperture, PSF, and optimal techniques; rejection of false detections; matching to reference catalog (USNO-A2, USNO-B1, Tycho-2, HIPPARCOS, UCAC4, 2MASS, XPM, user catalogs); astrometric reduction by a set of standard plate models; matching uncorrelated objects to the list of Solar system bodies (EPOS package is used to provide Solar System object ephemerides, see below); report creation in one of the standard formats (e.g. MPC). The software includes special algorithm for measuring of high-speed asteroid tracks. There is a capability to mark objects and reference stars in a visual manner using the dedicated graphical interface.

To calculate the motion of solar system bodies, we use EPOS software (L'vov, Tsekmeister, 2012), also developed at Pulkovo. The software provides several kinds of celestial mechanics calculations and visualization modes, including ephemerides, O−C, orbit determination and improvement, and modeling the motion of solar system bodies in the various coordinate systems.

4. (99942) Apophis

Apophis was observed during its last approach to the Earth at the beginning of 2013. 515 astrometric positions with the accuracy of 0″.07–0″.4 in right ascension and 0″.07–0″.5 in declination were obtained in January and February. Three color indices were estimated using *BVRI* observations: $B{-}V = 0.81^m \pm 0.06^m$, $V{-}R = 0.42^m \pm 0.06^m$, $R{-}I = 0.28^m \pm 0.07^m$.

Several fragments of Apophis lightcurve were observed. Three of them have duration about 5 hours (see Fig. 1).

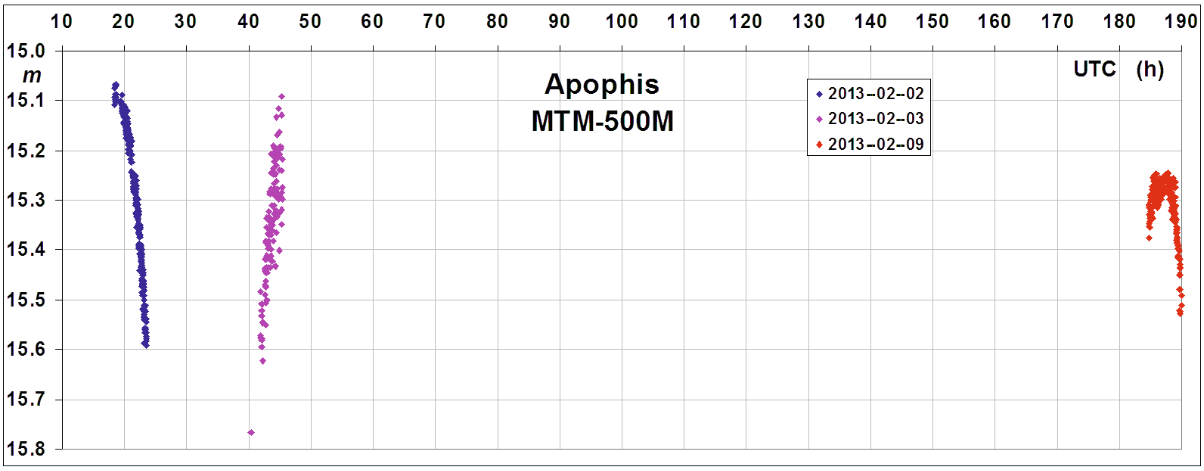

Fig. 1: Three fragments of Apophis lightcurve observed with MTM-500M. The zero-point of the time axis corresponds to 0^h of 02 February 2013.

5. (367943) Duende = 2012 DA14

The asteroid had a very close approach (27700 km) to Earth on 15.02.2013. We obtained 436 astrometric positions with the average accuracy of 0″.46 in right ascension and 0″.23 in declination. Three color indices were estimated from *BVRI* observations: $B{-}V = 0.86^m \pm 0.15^m$, $V{-}R = 0.39^m \pm 0.04^m$, $R{-}I = 0.36^m \pm 0.03^m$. Based on these values, we estimated the possible Tholen taxonomy class of Duende — either G or C.

Using EPOS, we have modeled the orbital evolution of this asteroid. Duende orbits the Sun near 1:1 mean motion resonance with Earth and sometimes closely approaches the latter, which changes its orbital parameters. The latest closest approaches were in 2004 and 2013. At the moments of approaches, orbital elements changed abruptly. Moreover, the asteroid even changes the type of its orbit with respect to Earth. It is useful to consider the motion of such asteroids using a rotating coordinate system with *X* axis going from Sun towards Earth. The possible types of Duende trajectory are shown in Fig. 2. However, this result is extremely sensitive to small changes in orbital elements at the initial moment of calculations. When using pre-April 2013 MPC elements, Duende changes the type of its orbit three times from circulating orbit to a horseshoe one and then (possibly) to the one of an Earth's quasi-satellite. Taking a more recent set of elements leads to the asteroid maintaining a circulating orbit, but moving in the opposite direction with respect to Earth and escaping from 1:1 resonance as a result of the 2013 approach.

We obtained two lightcurves for Duende: on February 16 and 19 2013. Each of them is about 10 hours long, which should roughly correspond to one rotation period, considering their shape. Unfortunately, these two fragments do not allow one to reliably determine the period. Comparing with lightcurves observed by other teams reveals a certain degree of coincidence. However, there are also lightcurves not overlapping with ours in time that do not match ours assuming the period of 9 to 11 hours. This is an indication of a quite complex rotation of the asteroid during approach.

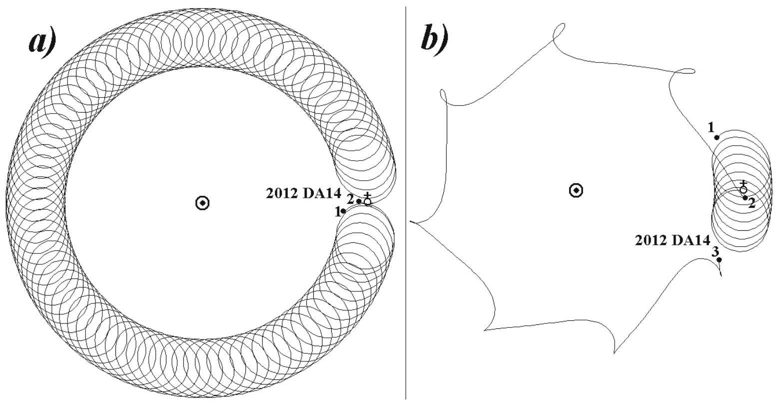

Fig. 2: The possible types of Duende trajectory with respect to Earth in the rotating coordinate system: ***a)*** horseshoe orbit; ***b)*** quasi-satellite (1–2) and circulating (2–3) orbit.

We also made an attempt to model the asteroid rotation based solely on our two lightcurves, both taken separately and combined. The resulting model lightcurves and observed points are shown in Fig. 3. The modelling suggests that the ratio of "photometric" ellipsoid axes is 10:2:1, whereas the ratio of the axes of asteroid body is 4:2:1. Therefore, Duende shape greatly differs from ellipsoid and, possibly, its albedo is non-homogeneous. The axis of rotation of the asteroid has moved by 52º between these two sets of observations. Hence, Duende tumbled near the time of the approach.

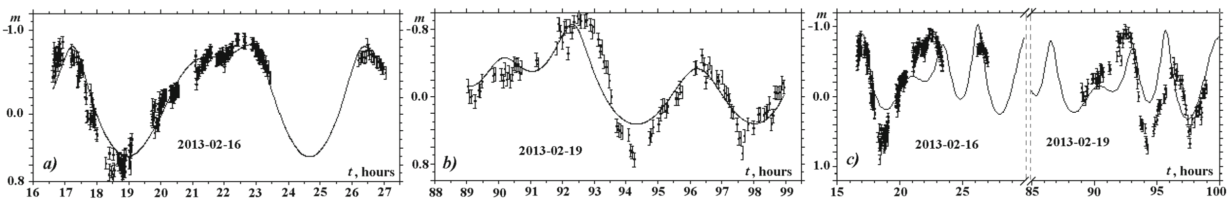

Fig. 3: Model lightcurves of Duende (solid lines) superimposed over the observation data from MTM-500M and ZA-320M. ***a)*** and ***b)*** two separate datasets; ***c)*** lightcurve from two combined datasets.

6. 2014 HQ124

This asteroid had a 0.0086 AU approach with Earth on 08.06.2014. There was a sub-campaign (coordinated by Lohrmann Observatory, Dresden) for synchronous observations of the asteroid during its close approach for the purpose of triangulation. We have got 84 astrometric positions from our observations, with an average accuracy of $0''.19$ in right ascension and $0''.26$ in declination. 18 positions were observed at the planned epochs simultaneously with other observatories.

We also obtained lightcurves from these observations with duration of 4.5 hours. Due to a rapid motion of the asteroid across the sky, the resulting accuracy is very moderate ($\approx 0.08^m$).

7. 2013 TV135

The asteroid had a 0.045 AU approach to Earth on 17.09.2013. We have obtained 335 astrometric positions from our observations, with an average accuracy of $0''.28$ in both right ascension and declination.

Furthermore, we have obtained 5 lightcurves. Using our lightcurves spanning two weeks, we were able to accurately determine the rotation period of the asteroid: $p = 2^h.3512 \pm 0^h.0004$ (see Fig. 4).

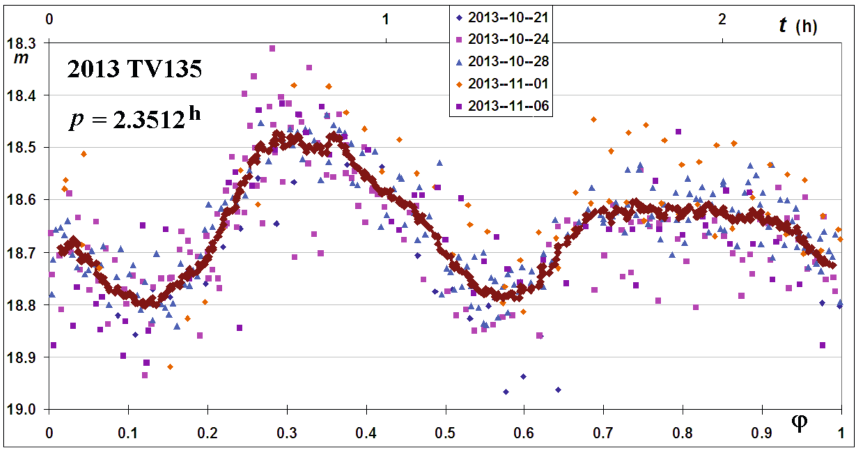

Fig. 4: Lightcurve of 2013 TV135 phased with the period of $2^h.3512$ derived from our observations. It comprises 5 individual fragments obtained with MTM-500M.

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ISON participation in Gaia-FUN-SSO campaigns

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Abstract: *More than 15 of 35 observatories of the ISON network are planning to participate in the supporting observations of Solar System objects newly detected by Gaia space mission. To prepare for this kind of work several ISON's observatories took part in the test campaigns for observations of near-Earth asteroids in 2011-2014. We measured astrometric positions for all selected for observations asteroids and sent the data to the MPC. For some of these asteroids we carried out accurate photometric observations to analyze their rotation properties. The obtained results are presented and analyzed from the point of view of the ISON network capabilities in support of Gaia's future observations. We discuss also prospects of the participation of recently opened observation stations within the ISON network.*

1. Introduction

Started in 2004, the International Scientific Optical Network project (ISON) involves 35 observatories and scientific institutions in 15 countries. More than 70 telescopes are used for astrometric and photometric observations. All telescopes are equipped with modern CCD cameras mainly manufactured by Finger Lakes Instrumentation (USA). The main aim of the project is monitoring of man-made space debris (primarily at the high-geostationary and high-elliptical orbits). Another aim of ISON is tracking of near-Earth asteroids (NEAs) to do the discovery, refinement of orbital parameters, and to study their physical properties. Several CCD-telescopes in the network with the apertures of 0.4 – 2.6 m are involved in carrying out astrometry and photometry of asteroids (see Fig. 1 and Table 1). In the frame of the ISON five wide-field telescopes with the apertures of 40 - 65 cm have been created and are used for searching/follow-up new asteroids at observatories Andrushivka (A50), ISON-NM (H15), ISON- Kislovodsk (D00), ISON-Ussuriysk (C15), and ISON-Hureltogoot (O75).

More than 15 observatories of the ISON are planning to participate in the supporting observations of Solar System objects newly detected by Gaia space mission in the frame of the Gaia-FUN-SSO collaboration. To prepare for this kind of work, several ISON's observatories took part in the test campaigns for observations of selected NEAs in 2011-2014.

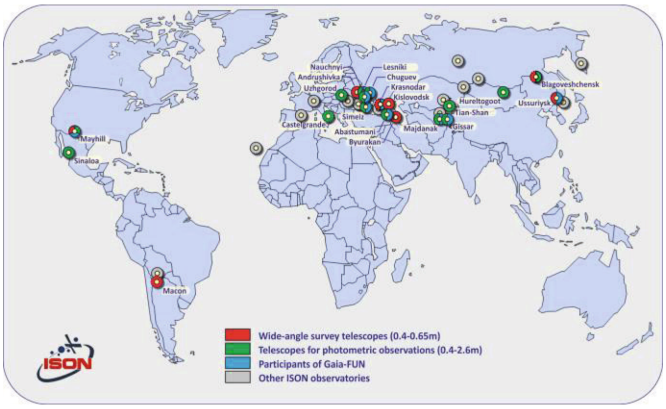

Fig. 1: ISON observatories involved in the asteroid observations

Table 1: Facilities of the ISON network involved in the asteroid observations

MPC Code	Observatory	Telescope m	FOV arcmin	Scale arcsec/px	Coordinates: latitude, longitude	Altitude m
K99	ISON-Uzhgorod	0.4	72	1.4	E22.453, N48.563	235
A50	Andrushivka	0.5	150	4.4	E28.997, N50.001	240
585	**Lisnyky**	0.7 0.48	16.9 x16.4 6 x 4	0.96 0.24	E30.524, N50.298	156
094	**Simeiz**	1.0	9.5	0.19	E33.996, N44.403	350
095	Crimea-Nauchnij	2.6 0.64 0.4	9.3 140.8 130	0.27 2.06 2.6	E34.016, N44.728	596
121	**Chuguev**	0.7	16.9 x16.4	0.96	E36.934, N49.641	151
C40	Kuban	0.5	92	1.35	E39.030, N45.020	60
119	**Abastumani**	0.7 1.25	45 x 30 10.5	0.9 0.3	E42.820, N41.754	1595
D00	ISON- Kislovodsk	0.4 0.65	100 132	2.0 3.9	E42.654, N43.740	2107
186	**Kitab**	0.4	140	1.7	E66.886, N39.134	650
188	**Maidanak**	1.5 0.6	18.3 11.7	0.27 0.69	E66.896, N38.673	2593
190	**Gissar**	0.7	30	1.8	E68.68, N38.49	730
193	**Sanglok**	0.6	60	1.2	E69.218, N38.261	2286
N42	Tien-Shan	1.0	20	0.3	E76.971, N43.474	2735
O75	ISON-Hureltogoot	0.4	138	2.7	E107.051, N47.865	1604
D54	Blagoveschensk	0.5	74	1.45	E127.482, N50.318	226

		0.65	132	3.9		
C15	**ISON-Ussuriysk**	0.65 0.5	132 81	3.9 2.43	E132.166, N43.698	277
-	Cosala, Sinaloa	0.4	78	1.5	W106.609, N24.401	631
H15	**ISON-NM**	0.4	100	1.5	E254.472, N32.744	2225

2. Results of Gaia-FUN-SSO campaigns

In 2011-2014 the ISON network has carried out observations of 8 near-Earth objects within training campaigns in frame of the Gaia-FUN-SSO (Table 2). It was a test mode before starting the Gaia mission. The asteroids were observed at Abastumani, Chuguev, Gissar, ISON-NM, Lisnyky, Maidanak, and Nauchny. The observations were reduced by different software: APEX-2 (V. Kouprianov), AstPhot (S. Mottola), Astrometrica (H. Raab), Canopus (B. Warner), IzmCCD (Izmailov et al., 2010), and MaxImDL (D. George). Astrometric positions for selected asteroids were measured and prepared in the form to send to the MPC. The residuals of the obtained positions are usually less than 1 arcsec. For some of these asteroids accurate photometric observations were carried out to analyze their rotation properties. A typical photometric accuracy of 0.01-0.03 mag has been attained.
More information on some of observed asteroids is given below.

Table 2: Summary on ISON observatories' participation in Gaia-FUN-SSO campaigns

ASTEROID	TIME RANGE	ISON OBSERVATORY	OBSERVING NIGHTS
(308635) 2005 YU55	Nov-Dec 2011	Abastumani, Chuguev, Lisnyky	2011 Nov 17-19, 23-24, 26, 28; Dec 17
(175706) 1996 FG3	Feb-Mar 2012	Abastumani, ISON-NM	2011 Nov 22,25; Dec 1, 17-18, 30; 2012 Jan 21; Feb 24, 25
2012 DA14	Feb-Mar 2013	ISON-NM, Abastumani	2012 Feb 16, 17
(99942) Apophis	Feb-Mar 2012	Chuguev, Abastumani	2012 Feb 18, 24 – asteroid not found
(99942) Apophis	Dec 2012-Mar 2013	Maidanak, Lisnyky, Abastumani	2012 Dec 2,13; 2013 Jan 28, 30, Feb 2-3, 11, 13- 14, 28; Mar 5-6; Apr 1
(163249) 2002 GT	Jun-Aug 2013	Lisnyky, Nauchny, Simeiz, Abastumani, Gissar, Maidanak	2013 Jun 10-13, 19-20, 24-25, 30; Jul 4-5, 12
2013 QW1 (artificial object!)	Aug-Sep 2013	Chuguev	Aug 24
2013 TV135	Oct 2013-Jan 2014	ISON-NM, Abastumani, Chuguev, Nauchny	2013 Oct 17, 19, 20-25, 27; Dec 4
2014 HQ124	8-11 Jun 2014	Chuguev, Abastumani, Lisnyky	2014 Jun 9, 10

2.1. (308635) 2005 YU55 campaign in Nov - Dec 2011

2005 YU55 is a Potentially Dangerous Near-Earth Asteroid (PHA) which approached the Earth within 0.85 lunar distances (324900 km from the center of Earth) on November 8, 2011. The asteroid's diameter was estimated from radar and IR observations (Busch et al., 2012; Müller et al., 2012) to be about 300-400 m. The asteroid was observed at Abastumani Observatory (Georgia) with 70 cm telescope on Nov 17-19, Dec 17; at Lisnyky Observatory (located near Kiev, Ukraine) with 70 cm telescope on Nov 17, 26, 28; at Chuguev Observatory (near Kharkiv, Ukraine) with 70 cm telescope on Nov 18, 23, 24. Astrometry was done using reference stars from USNO-A2.0 and UCAC-3 catalogues and the typical accuracy was 0.1-0.4 arcsec. A limited magnitude 20.4 mag with RMS about 0.3 mag has been obtained for 2005 YU55 at the Abastumani with 70-cm telescope through "Clear" filter on Dec. 17, 2011. Good photometry was obtained in R, V or Clear filters with RMS about 0.02-0.03 mag during observations on Nov 17-23. The measured lightcurves have showed a slow rotated (period is about 19.3 hrs from Warner et al., 2012) and nearly spherical-shape body (amplitude is about 0.13 mag).

2.2. (175706) 1996 FG3 campaign in Feb - Mar 2012

1996 FG3 is a well-studied binary NEA which was intensely observed during 6 apparitions since 1996 (Scheirich et al., 2015). It was a preliminary target of the ESA's MarcoPolo-R mission. In 2011/2012 apparition we observed the asteroid during ten nights in Nov - Dec 2011 and Jan - Feb 2012: at the Abastumani Observatory with 70 cm telescope in Clear filter on Nov 22&25, Dec 1, 17&18, 30 in 2011, and on Jan 21 in 2012; at the Chuguev Observatory with 70 cm telescope in R on Nov 23&24, 2011; at the ISON-NM Observatory (Maihill, USA) with 45 cm telescope in Clear filter on Feb 25, 2012. Astrometry are refered to USNO-A2.0 or NOMAD catalogues with residuals in range 0.1-0.4 arcsec. Besides Feb 25, the lightcurves have been obtained in all other dates. Accuracy of photometry is typically 0.01-0.02 mag. The lightcurve of 1996 FG3 obtained on Dec 30 is shown in fig. 2.

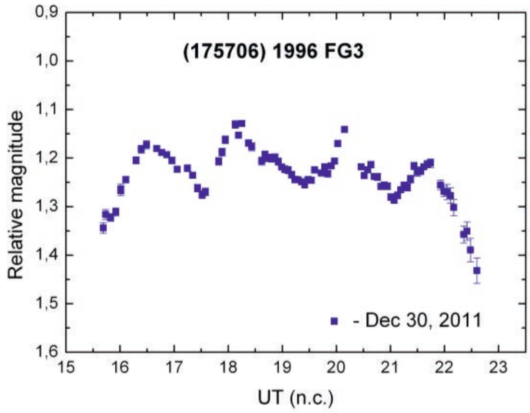

Fig. 2: Lightcurve of 1996 FG3 obtained at the Abastumani Observatory on Dec 30, 2011.

2.3. 2012 DA14 campaign in Feb - Mar 2013

2012 DA14 (numbered and named as 367943 Duende) is a small NEA (H = 24.0, D ~ 30 m), which had a very close approach to the Earth in 2013 apparition with minimal distance 27700 km. It was a very bright (up to 7.7 mag) and very fast-moved object with apparent velocity up to 50 arcmin/sec (the body covered several tens of degrees per hour on the sky). On Feb 16 from 02:11 to 12:17 UT the asteroid was remotely observed with 45 cm telescope at the

ISON-NM Observatory (Elenin and Molotov, 2013). Precise photometry as well as astrometry of 2012 DA14 was obtained. Very elongated shape of the body (amplitude of the lightcurve is about 1.8 mag) and the rotation period 9.5 hrs has been determined (fig. 3). Next observations of the asteroid were done with 70 cm telescope at the Abastumani Observatory during cloudy night Feb 17. The CCD images during a clear sky were used for measurements of the asteroid's positions.

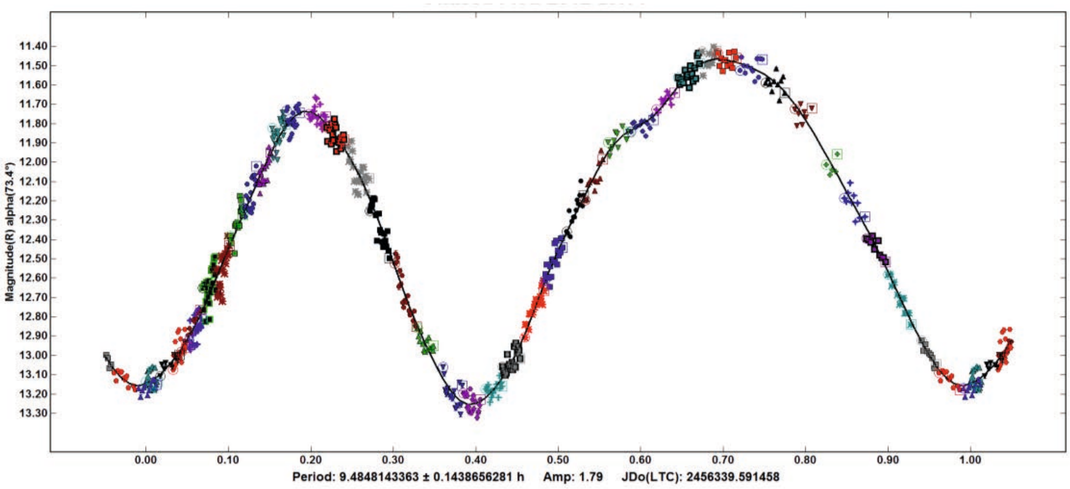

Fig. 3: Composite lightcurve of 2012 DA14 obtained at the ISON-NM on Feb. 16, 2013.

2.4. (163249) 2002 GT campaign Jun - Jul 2013

2002 GT is a Potentially Hazardous Asteroid which can be investigated with the spacecraft Deep Impact during a flyby in 2020. The asteroid's diameter is about 800 m (H = 18.3). Chesley et al. (2013) observations of 2002 GT in April 9-14, 2013 showed brightness variations with period 3.7663 +/- 0.0003 hrs and amplitude about 0.31 mag. Two attenuations from 3.7-hrs periodicity about 7 hours apart were found that could be indicative of a binary nature of the asteroid. Our observations of 2002 GT have been done in June-July 2013: at Lisnyky with 70 cm telescope in R on Jun 10, 24&25; at Nauchny (Crimea) with 2.6 m telescope in UBRI on Jun 10&11; at Simeiz (Crimea) with 1 m telescope in R on Jun 12&13 and 20, Jul 13; at Chuguev with 70 cm telescope in R on Jun 19; at Abastumani with 70 cm telescope in Clear filter on Jun 19&20, 30; at Gissar (Tajikistan) with 70 cm telescope in Clear filter on Jul 4; and at Maidanak (Uzbekistan) with 1.5 m telescope in R on Jul 5. The obtained lightcurves showed variations with period 3.765 +/- 0.002hrs and amplitude about 0.36 mag without any unusual significant fluctuations (fig. 4).

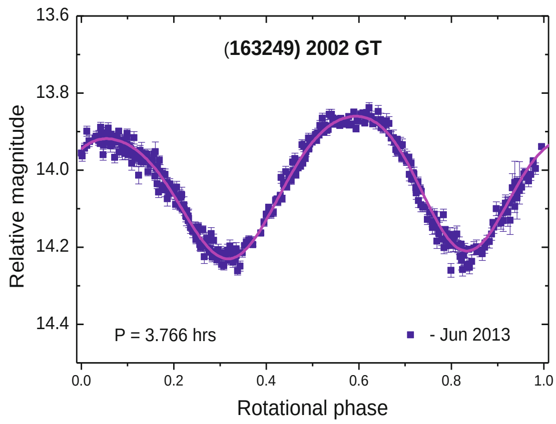

Fig. 4: Composite lightcurve of 2002 GT obtained in June 2013.

3. Conclusions and outlook

The ISON has done test observations of selected asteroids in frame of the Gaia-FUN-SSO and is going to take part in follow-up observations of objects which will be discovered/observed by the Gaia. The observations will include astrometry as well as photometry of the objects.

Presently ten of the ISON observing sites have been registered in the Gaia-FUN-SSO network, and several others are ready to join. Several telescopes of the ISON network (1 m and 2.6 m at Byurakan, Armenia; 1.5 m at Kastelgrande, Italy; 1.25 m at Abastumani, Georgia) is in a stage of upgrading. There are also plans to create several new telescopes which will be installing in different parts of the world (0.65 m for Kislovodsk and Blagoveschensk, Russia; 60 cm in Tarija, Bolivia; 50 and 40 cm for Cerro Macon, Argentina; 40 cm for Nauchny, Crimea). In whole, more than 20 telescopes of the ISON are suitable for follow-up of Gaia's asteroids. They include the 1.5 m and 2.6 m telescopes, 4 telescopes of 1 m, and 18 telescopes of 0.4-0.7 m.

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Astrometry of Three NEAs with Lijiang 2.4m Telescope

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Introduction

During 2013, three near Earth asteroids (367943) Duende, (99942) Apophis and 2013 TV135 were observed with the Lijiang 2.4m telescope of Yunnan Observatories, as a part of observation campaigns organized by the GAIA Follow Up Network for Solar System Objects (GAIA-FUN-SSO) (Thuillot, 2011). The catalogue of UCAC4 was chosen for CCD reduction. The values of means and standard deviations of O-C (observed-minus-calculated) residuals relative to the ephemerides of INPOP10a and DE431 for Apophis and 2013 TV135 are given in right ascension and declination respectively. And the values of mean and standard deviation between the ephemerides of INPOP10a and DE431 for Duende are also shown (Zhang et al. ,2015).

1. Lijiang 2.4m Telescope

The Lijiang Observatory is located at 100º2'(E), 26º42'(N) belongs to the city of Lijiang, Yunnan Province, China, where the altitude is about 3200 meters and has the best seeing and astronomical conditions in southern China. The Lijiang 2.4m telescope is open to astronomers since May 2008.
There are two often used cameras attached to the Lijiang 2.4m telescope, the Yunnan Faint Object Spectrograph and Camera (YFOSC) instrument and PI VersArray 1300B camera (PICCD), whose sizes and effective fields of view are 2148 x 2200 pixels, 10.1 x 10.4 square arcmin and 1340 x 1300 pixels, 4.8 x 4.7 square arcmin respectively, as descibed in the papers of Bai (2010) and Fan (2012). Table 1 shows the specifications of both instruments, where "F-length" means focal length of the system and "FOV" indicates the fields of view.

Table 1. Two cameras attached to the Lijiang 2.4m telescope.

Camera	F-length	CCD FOV	Size of Pixel	Size of CCD	size/pixel
YFOSC	9840 *mm*	10'.1 x 10'.4	13.5*u*m x 13.5*u*m	2148 x 2200	0".283
PICCD	19200 *mm*	4'.8 x 4'.7	20.0*u*m x 20.0*u*m	1340 x 1300	0".215

2. Astrometry of three near Earth asteroids

Both YFOSC and PICCD were used during observing the near Earth asteroids of (367943) Duende, (99942) Apophis and 2013 TV135, and the detailed observational information is given in Table 2.

Table 2. Observational information of the near Earth asteroids.

NEA	Obs Date	Exposure(s)	Filter	Camera
Duende	Feb.15	1	N	YFOSC
Apophis	Feb.18	120	N	YFOSC
	Feb.25	120	N	YFOSC
	Feb.26	120	N	YFOSC
	Feb.27	120	N	YFOSC
	Mar.01	120	N	YFOSC
	Mar.02	120	N	YFOSC
2013 TV135	Oct. 31	60	N	PICCD
	Nov.01	50	N	PICCD
	Nov.02	50	R	PICCD
	Dec.04	120	R	YFOSC
	Dec.06	120	R	YFOSC
	Dec.09	180	R	YFOSC
	Dec.10	180	R	YFOSC

After reduction of the observations, the positions of these three near Earth asteroids were measured with the catalogue UCAC4 (Zacharias, 2012) was chosen to reduce the CCD fields. The values of means and standard deviations of O-C residuals of Apophis and 2013 TV135 relative to the ephemerides of INPOP10a and DE431 were given in right ascension and declination (Table 3. (a) and (b)). Because the difference of the positions between the observed and calculated is very large for Duende, so we just give the means and standard deviations of O-C residuals between the ephemerides of INPOP10a and DE431 here (Table 4.).

Table 3. Mean and standard deviation values of (O-C) residuals of the near Earth asteroids Apophis and 2013 TV135.

Ephemerides	Mean (O-C)		Std Dev (O-C)	
	RA (mas)	Dec (mas)	RA (mas)	Dec (mas)
INPOP10a	1.900	2.830	0.00501	0.13453
DE431	3.330	-5.610	0.00501	0.13469

(a) Apophis

Ephemerides	Mean (O-C)		Std Dev (O-C)	
	RA (mas)	Dec (mas)	RA (mas)	Dec (mas)
INPOP10a	1.900	2.830	0.00501	0.13453
DE431	3.330	-5.610	0.00501	0.13469

(b) 2013 TV135

Table 4. Mean and standard deviation valuses of DE431-INPOP10a in RA and DEC for Duende.

Ephemerides	Mean (")		Std Dev (")	
	RA	Dec	RA	Dec
DE431-INPOP10a	71.72749	199.03512	22.19941	103.39296

3. Conclusion

Comparison results have shown that, the ephemerides of INPOP10a and DE431 are consistent for Apophis and 2013 TV135, however quite inconsistent for Duende. Moreover, we have found that the mean values of the system errors between the ephemerides of INPOP10a and DE431 are about 72 arcsec and -199 arcsec in right ascension and declination respectively for Duende, and the ephemeris DE431 is reliable with the means of O-C (observed-minus-calculated) residuals in right ascension and declination about 2.72 arcsec and 1.49 arcsec.

For Apophis and 2013 TV135, the ephemerides of INPOP10a and DE431 are consistent. For Duende, the difference between the positions of observed and calculated by INPOP10a is very large, what's more, the mean and standard deviation values of DE431-INPOP10a in RA and DEC are very large too (Table 4.). So more accurate astrometric data should be observed for the Duende.

Acknowledgements

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Perspectives of polarimetry for follow-up observations of Gaia's asteroids

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Abstract: *Polarimetric observations are diagnostic for asteroid's albedo and taxonomy. At the phase angles larger 35-40 deg even a single polarimetric measurement can give a prompt estimate of an asteroid's geometric albedo. We discuss main applications of polarimetric observations and possible applicability of polarimetry for near-Earth asteroids discovered by Gaia.*

1. Introduction

Polarimetric observations of asteroids have been started since 1960ties. In the beginning polarimetry together with spectrophotometry and radiometry was one of the main techniques in study of surface properties of asteroids (e.g., Chapman et al. 1975). Later a relative contribution of polarimetric technique became much smaller. At present the number of asteroids for which polarimetric measurements are available reaches less than 400. Recent progress in polarimetric instrumentation gives new opportunities for polarimetry of asteroids. Below we describe main applications of polarimetric observations and discuss a possible applicability of polarimetry for near-Earth asteroids discovered by Gaia.

2. Polarimetry of asteroids: main applications

The solar light scattered by an asteroid's surface became partially linearly polarized as in the case of any solid planetary surface. The polarization plane position is usually either perpendicular or parallel to the scattering plane (the Sun-object-Earth plane). That is why the polarization degree P_r is used to be defined as

$$P_r = \frac{I_\perp - I_{//}}{I_\perp + I_{//}},$$

where $I_\perp$ is the intensity of the scattered light polarized along the perpendicular plane, and $I_{//}$ is the intensity polarized along the parallel plane. Such a definition means that the sign of the polarization degree P_r can be negative when the component $I_{//}$ with the electric vector parallel to the scattering plane predominates over the perpendicular component $I_\perp$. The term "negative polarization" is used to indicate particular case of polarization measured for regolith-like surfaces at small phase angles when the direction of polarization becomes opposite to that which is normally expected. The polarization degree P_r strongly depends on solar phase angle and wavelength.

An example of typical polarization phase curve for low, moderate and high albedo asteroids in the V band is shown in Fig.1. The polarization curve is characterized by the negative branch with the minimum P_{min}~-0.3- -2.1% occurred at the phase angle α_{min}~5-12°, the ascending branch of polarization described by the polarimetric slope h measured at the inversion angle α_{inv}~ 14-28°, where polarization changes the sign, and the positive polarization branch with the maximal degree of polarization P_{max}~3-10% at the phase angle of maximum polarization α_{max}~90-100°. The above-mentioned parameters are used to describe polarimetric properties of an object.

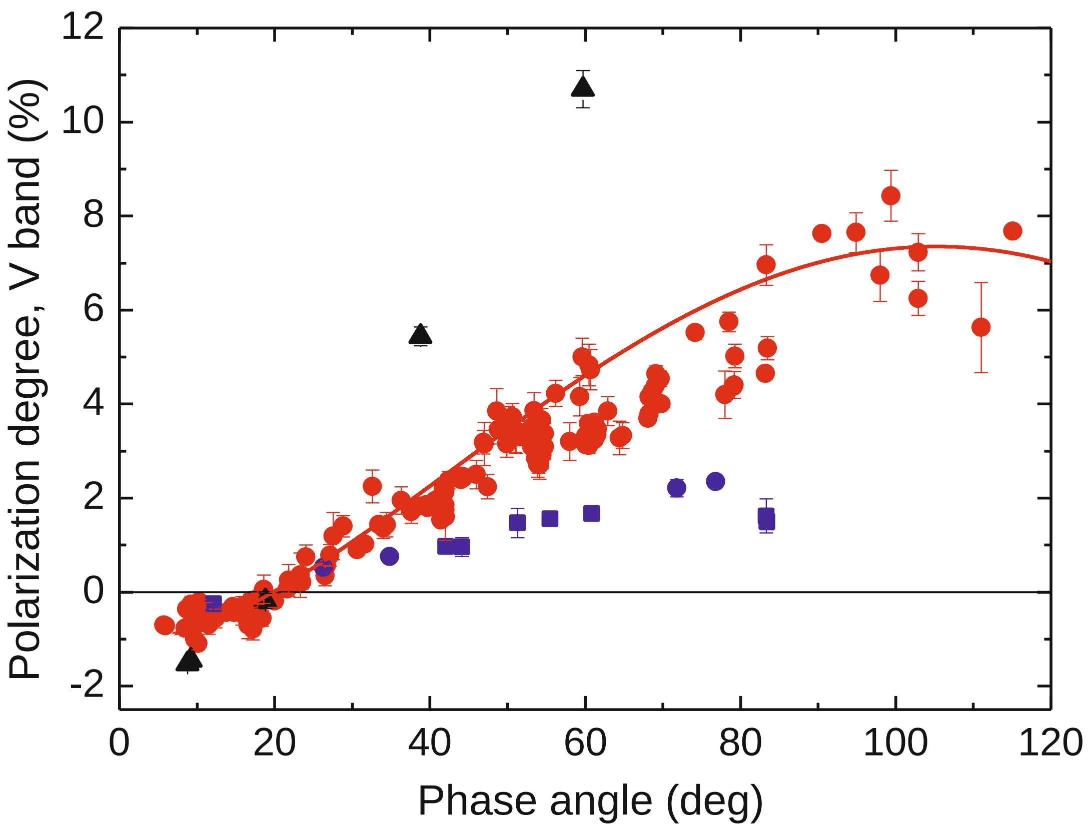

Fig. 1: Polarization phase angle dependence in the V band of low (black symbols), moderate (red symbols) and high (blue symbols) albedo asteroids. The data are taken from the data-base compiled by Lupishko (2014). The solid line displays the fit of the data for moderate-albedo asteroids using the trigonometric function (*Lumme and Muinonen*, 1993).

Fig.1 clearly demonstrates that the measured polarization phase angle behavior of asteroids strongly depends on surface's albedo. It gives so-called polarimetric method of albedo determination based on well-known relationships between h, P_{min} or P_{max} and geometric albedo A_g, e.g., $\log(A_g) = C_1 \log(h) + C_2$, where C_1 and C_2 are empirically defined coefficients. Recent analysis of the relationships is given by Cellino et al. (2015). An advantage of polarimetric albedos is that they are derived directly from measurements without any need of additional data from other sources and gives more accurate values compared to the radiometric ones.

Another important application of asteroid polarimetry is a possibility to constrain surface texture. Although this inverse problem is very complicated and has not a unique solution, the relationship between P_{min} and α_{inv} is considered as diagnostic of particle size of regolith (Dollfus et al., 1989). Available observational data on main belt asteroids show that the polarimetric properties of asteroids belonging to the same taxonomic classes are essentially identical (e.g., Gil-Hutton et al., 2014). This conclusion has two main consequences. First, it assumes that surface texture of asteroids is rather unified at the visible wavelength scale.

Second, composition types of asteroids may be distinguished based on their polarimetric parameters, i.e. polarimetry gives a complementary approach for taxonomy of asteroids.

3. Follow-up polarimetry of near-Earth asteroids

Polarimetric observations of near-Earth asteroids (NEAs) give a unique possibility to investigate polarization phase dependence at large phase angles close to polarization maximum. Fig.1 demonstrates that at the phase angles larger 40° even a single measurement of polarization degree can be sufficient to obtain an albedo estimation and to discriminate between low, moderate and high albedo asteroids. It gives a unique way to select primitive low-albedo NEAs by a single polarimetric measurement. Moreover, in many cases polarimetric observations represent an exclusive opportunity of reliable estimation of albedos and sizes of potentially hazardous asteroids.

At present polarimetric observations are available only for 15 NEAs (for references see Asteroid Polarimetric Database at http://sbn.psi.edu/pds/resource/apd.html). Major part of observations was made at 1-2-m class telescopes equipped with photopolarimeters. The asteroids were observed in the time of their close approach when their apparent visible magnitudes were about or brighter than 13^m.

Recent progress in the development of imaging polarimeters based on CCD detectors allows to gain the limiting magnitude on 2-3 magnitudes for the same class telescopes. Design of modern multi-mode instruments often includes a polarimetric mode expanding opportunities for polarimetry of asteroids. Successful measurements of NEAs were made using the polarimetric mode of the Faint Object Spectrographic Camera (AFOSC) at the 1.8-m telescope of the Astrophysical Observatory of Asiago (Belskaya et al., 2009) and with the same instrument at the 2.5-m Nordic Optical Telescope (NOT) in La Palma (Fornasier et al., 2015). Two NEAs with the apparent visible magnitudes of $19\text{-}20^m$ were observed with the Focal Reducer/Low Dispersion spectrograph (FORS) in polarimetric mode at 8.2-m Very Large Telescope (VLT) at Cerro Paranal ESO observatory in Chile (Delbò et al., 2007, de Luise et al., 2007). A list of currently available polarimeters at ground-based telescopes can be found in the review by Keller et al. (2015). Follow-up polarimetry of near-Earth asteroids discovered by Gaia requires guaranteed telescope time to cover the optimal phase angles and obtain the best results, e.g., 1-2 nights per month at 2-m class telescopes, and ~1-2 hours per month at 8-m class telescopes.

4. Conclusions

Polarimetric observations can provide complementary data to derive physical properties of asteroids discovered by Gaia. Near-Earth asteroids are the best targets for follow-up polarimetry. Even a single measurement of polarization degree at the phase angles α>40° will give a prompt estimate of an asteroid's geometric albedo and taxonomic type.

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Polarimetric Observations of NEAs at RTT150. First results.

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Abstract: *We present results of polarimetric and photometric observations of three faint NEAs with high proper motion in period of theirs close approaches: 276049, 333578 and 163132 performed at 1.5m Russian-Turkish telescope RTT150 in the end of August 2014. Due to that sources were observed at large phase angles from 40 to 100 degrees for different asteroids the measured linear polarization degree makes it possible to differentiate the taxonomy classes of observed sources even using single shot. The visual magnitudes and proper motions of asteroids are 16^m-17^m and 3"-10"/min. Assuming that the mean inverse angle is 20 degree we estimated slope parameter h and from well-known relation the albedo was calculated and together with present photometry we estimated the diameters of asteroids. Calculated albedos are 0.50±0.19 (E-type), 0.043±0.005 (C-type), 0.250±0.023 (S-type) and diameters are 0.306±0.08 km, 3.106±0.29 km, 0.221±0.03 km, respectively. The applications of new polarimetric device at RTT150 to the GAIA-FUN-SSO are discussed.*

1. Introduction

After the successful launch and calibration of space mission of European Space Agency GAIA the alerts on moving objects of Solar System are expected in the rate about 12000 per day (Tanga, 2015). Among of this large amount only a few will be new discovered. The aims of GAIA Follow-Up Network of Solar System Objects (GAIA-FUN SSO) which consist of 57 observing sites around the world are confirmation of newly discovered sources and improvement of orbits of critical targets. The identification of NEAs in frame of GAIA-FUN SSO has a special interest because they will be observed at different phase angles before the parameters of orbit will be determined with declared accuracy. In this context not only astrometry data but also photometry data of the Network together with additional polarimetric observations can be used for physical parameters estimations of newly discovered NEAs. The polarimetric study of physical properties of asteroids are based on well-known dependence of degree of linear polarization with phase angle (Belskaya and Krugly, 2015). We present results of polarimetric and photometric observations of three faint NEAs with high proper motion in period of theirs close approaches: 276049, 333578 and 163132 performed at 1.5m Russian-Turkish telescope RTT150.

2. Observation of NEAs

Polarimetric and photometric observations of selected numbered NEAs: 163132, 276049, 333578 were performed at RTT150 from 23 to 26 August 2014 in period of theirs close approaches. The criteria of selections are limited with brightness no faint than 17^m and with proper motion no more than 10 arcsec per min which is determined by the telescope performance. The phase angles of observations are 102˚, 71˚ and 39˚, respectively.

Polarimetric observations were performed in V-band on newly integrated into RTT150 observational system polarimeter TFOSC-WP based on the Wedged Double Wollaston (Helhel et al., 2015). The polarimeter makes it possible to measure polarimetric signals simultaneously in four polarization plane 0˚, 45˚, 90˚ and 135˚. So, the first three parameters of Stoke's vector S(*I*,*Q*,*U*) may be estimated and, correspondingly, degree of linear polarization and positional angle of polarization of sources may be determined. The working area of the polarimeter on FOV of the RTT150 is 1′ by 5′. Due to high proper motion of studied NEAs and its faintness the neighbour stars images distorts the polarization signals during exposure. To decrease this affect a set of 5 by 120 sec exposures was obtained using telescope facility of tracking with given trajectory. The combined image with median filtering is quite free from neighbour stars influence (Fig.1).

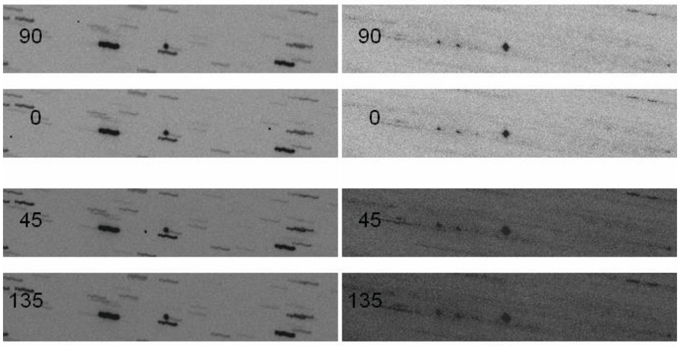

Fig. 1: TFOSC-WP image of 4 polarized beams at 0˚, 45˚, 90˚ and 135˚ separated by 60 arcsec of NEA 276049, V-band. Right is single 120 exposure image, left is result of combining of 5 images using median filtering.

3. Albedo, taxonomy and diameter estimations of selected NEAs

Dates of observations were corresponded to the large phase angles (102˚, 71˚ and 39˚, respectively). It allowed getting a good enough estimation of the geometric albedo p_V and differentiating asteroid on spectral complexes on the base of even single observation (Fig. 2).

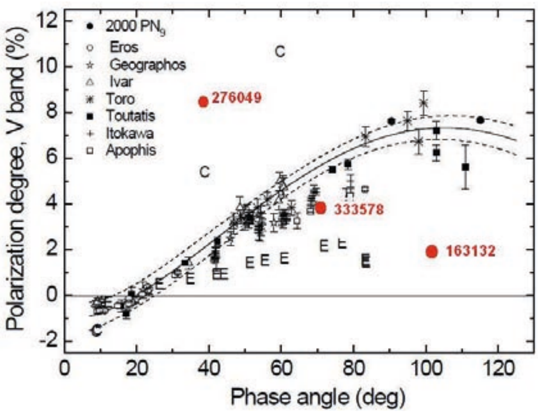

Fig. 2: Polarization phase curves taken from Belskaya et al. (2009) the measurements of polarization of asteroids of this work (red dots) has added.

As a result, we obtained the following values for the albedo and spectral classes in Table 1.

Table 1: Albedo and spectral type for observed 3 NEAs.

Name	Albedo	Spectral Type
163132	0.50±0.19	E-type
276049	0.043±0.005	C-type
333578	0.250±0.023	S-type

In estimations of albedo for 276049 and 333578 the relation *log*(albedo)-*log*(polarization slope) was used. The polarization slope was determined on the base of mean value of inverse angle α_{inv} of given spectral class (Mischenko et al., 2010) and measured degree of polarization on corresponding phase angle. For 163132 the fact that asteroid was observed in region of maximal polarization of phase curve was used and for albedo estimation the relevant relation *log*(albedo)-*log*(maximum polarization) was applied.

The photometric estimations in V-band: 16.80^m, 15.91^m and 17.00^m, respectively, were obtained with photometric accuracy about 1%. New *BV*, *VR* and *RI* color estimations of these asteroids: 0.56, 0.47 and 0.46 for 163132; 0.72, 0.37 and 0.39 for 276049; 0.81 and 0.63 for 333578 were obtained as well. With using mean parameter of photometric slope *G* for given spectral complex (Lagerkvist & Magnusson, 1990) and photometry, the absolute magnitudes *H* of studied asteroids were estimated. Thus, with known (p_v, H) diameters were estimated as in Table 2.

Table 2: Diameters for observed 3 NEAs.

Name	Diameter (km)
163132	0.306±0.08
276049	3.106±0.29
333578	0.221±0.03

The main source of uncertainties of the diameter estimations is uncertainty of photometric slope parameter *G*, which is necessary to specify observationally.

4. Conclusion

RTT150 is owner of new facility – polarimeter. Together with photometry and spectroscopy it gives promising results of NEOs physical parameters investigation. It was polarimetrically and photometrically observed three selected NEAs in period of theirs close approaches: 276049, 333578 and 163132. Albedos, taxonomy and diameters were estimated. Accuracy of diameters estimation is 10-20% even using single observation.

The NEA 276049 is well known asteroid with determined diameter as a 3.5 km by radar observation which is within of uncertainty of measured value 3.106±0.29 km. It is noteworthy, that measured physical parameters of the NEA 333578 close to potentially hazardous asteroid Apophis.

The newly discovered NEAs by Gaia will be observed by sites of GAIA-FUN SSO network. Recommended amount of frames for one set of observations is no less than 5 in R band. Investigation of physical parameters of NEAs may be successfully completed in frame of network photometric observations of astrometric alerts of GAIA (GAIA-FUN SSO) and polarimetric observations on RTT150. Due to that we suggest to observe Landolt standard stars before and after astrometric observations to make photometric calibration of asteroids.

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Precision of astrometry measurements made using CoLiTec software for asteroid surveys

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Abstract*: Software for automated frames processing of asteroid surveys given as series of frames is necessary for the most effective astronomical observations. This possibility is provided by the CoLiTec software that allows not only to detect asteroids, but also to perform astrometric measurements in real time.*

1. Introduction

Detection of moving objects is performed in two stages. Intraframe processing is designed to estimate the objects position at fixed times. Also cosmetic processing and frame alignment are performed in this stage. Interframe processing is used to detect and estimate objects trajectories.

The core of CoLiTec software consists of preliminary objects detection based on accumulation of statistics that are proportional to the signals energy along possible object tracks. Such accumulation is performed by multivalued transformation of the objects coordinates that is equivalent to the Hough transformation.

2. CoLiTec features

Some CoLiTec features are: automatic detection of faint moving objects (SNR> 2.5); working with very wide field of view (up to 10 degrees); auto calibration and cosmetic correction; fully automatic robust algorithm of astrometric reduction; automatic rejection of objects with poor observations; results viewer (LookSky) with graphical user interface; multi-threaded support for multi-cores systems and local network; processing pipeline managed by OLDAS (OnLine Data Analysis System).

These features would allow an effective implementation of CoLiTec in the different observatories in the world.

The OLDAS mode is especially significant. It allows for near real-time data processing and assigns confirmation of the most interesting objects during the night of their preliminary discovery.

OLDAS mode offers the following features: management of FITS files processing; processing images in the real time; obtaining results in 30 minutes after end of astronomical twilight;

working with online catalogues via VizieR: identification of known static object on images (USNO B1.0, UCAC4.0, SDSS v8), supernova search – labelling unknown static objects near galaxies (HYPERLEDA); sending measurements to MPC; inspection detected objects via web-interface.
CoLiTec has abilities for detecting very slow and very fast moving objects. Range of visible velocities of detected asteroids is from 0.7 to 40.0 pix./frame. For example, the fasters NEO is K12C29D asteroid (40.0 pix./frame) or the slowest object is ISON C/2012 S1 comet (0.8 pix./frame).
CoLiTec software equipped with the modern viewer of obtained results with a user-friendly GUI. LookSky runs independently of the main program and it can be used for independent review of CoLiTec processing results when the main program is processing data.
Complex frame reduction was added in the last version of LookSky. This complex processing includes the following features: frame processing by filter, background alignment; coordinates reduction; Track and Stack; search of objects by queries to the world Databases, such as Minor Planet Center, Variable Star Index, HyperLeda; hand measuring.
A mobile version of the viewer is available too. CoLiTec operation results can be monitored from anywhere in the world. All that is required is any modern smartphones, a tablet or laptops running on any OS platform. After connection to our web-interface, you can perform different operations; for example, send a report to MPC, including quick report to NEOCP.

2. Frame storage and publication software

When observing PHA, the reaction time is critical. It can be minimized by reducing the NEA discovery confirmation time.
There is no need to wait for new observations. Often, it suffices to have information contained in public access archives. For this, apart from rapidly processing current night frames, it is necessary to perform a rapid automatic extraction and processing of observation treatment results from MPC archives and publically accessible archive frames from different telescopes.
Frame storage and publication software is a perspective of CoLiTec developers. This software permits to maintain a frame archive and searching for frames by specified parameters (coordinates). External access to the archive is provided via a web interface and the Aladin software. It allows receiving additional frames from such external resources as SDSS and 2MASS. The software has been implemented with the use of VO technologies, including the SIAP (Smart Image Access Protocol).
Initially the frame storage and publication software have been created as components of the Ukrainian Virtual Observatory. Currently ISON-NM observatory is the main consumer of this software. This observatory uses it for the storage of about 50 000 frames made since 2010. This data is in open access in the framework of UkrVO in the RI NASU.

3. Precision of astrometry measurements

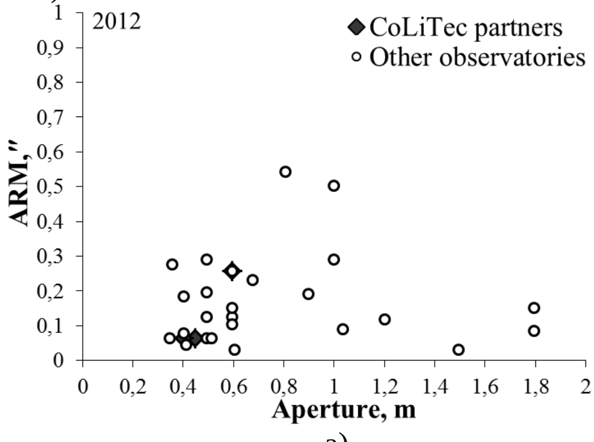
Full reliability of the detection of moving objects is achieved down to the lower limit of SNR equal to 3 units in case of a minimum series consisting of four frames, with no stars covering of asteroid.
By the overall results of last two years, observatory ISON-NM [H15], equipped with a 45-cm telescope and CoLiTec software, ranked 7th worldwide in both the number of asteroids observations and the rate of preliminary discoveries (table 1).

Table 1: Top-10 most prolific observatories in 2011-2012 (Minor Planet Center statistics)

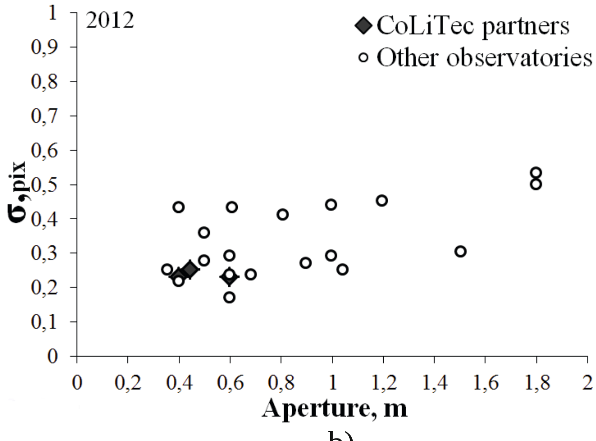
Top-10 observatories from measurements			
№	MPC code	Measurements	Discoveries
1	G96	4186400	39446
2	704	3637872	719
3	F51	3506255	27413
4	703	3235680	5273
5	691	1708543	15956
6	E12	479198	757
7	**H15**	**252848**	**1106**
8	645	227025	7
9	D29	195221	356
10	C51	163006	23

Top-10 observatories from discoveries			
№	MPC code	Measurements	Discoveries
1	G96	4186400	39446
2	F51	3506255	27413
3	691	1708543	15956
4	703	3235680	5273
5	I41	28638	1827
6	644	56878	1286
7	**H15**	**252848**	**1106**
8	461	51885	952
9	J75	51927	802
10	E12	479198	757

The institutes partners of the CoLiTec software hold the leading positions for their class of telescopes when assessed with the module of the average residuals of measurements (fig. 1a). In the last two years this parameter for H15 and A50 observatories was equal 0.06”.
At the same time, these observatories are not among the best ones when ranked with the standard deviation estimations of object position (in arc seconds). The reason for such a deterioration of results, in addition to the size of the aperture of a telescope, is the pixel scale of the used CCD matrix. To take this factor into account, the observatories-partners of the CoLiTec program decided to consider the parameter of standard deviation estimations of object position, in pixels (fig. 1b), for accurately estimating asteroid coordinates on the CCD frame as a principal one during observations.
According to this parameter, the observatories-partners of the CoLiTec program have one of the best results among the observatories in their class of telescopes with small aperture (about 0.24).



a)



b)

Fig. 1: The comparative analysis of the accuracy parameters of object position for the most productive observatories in the number of asteroids measurements in 2012 by: a) module of the average residuals of object position measurements; b) standard deviation estimations of object position, in pixels.

4. Conclusion

The CoLiTec team have developed 3 versions of the CoLiTec software: independent frames viewer LookSky embedded with complex frames processing, CoLiTec-Day and OLDAS-Night. Now LookSky is shared. You can download it on download page of our site (http://www.neoastrosoft.com/download_en/).
Presently, CoLiTec is being used for automated asteroid detection in the following observatories: Andrushivka Astronomical Observatory (Kiev, Ukraine) [A50], ISON-NM (Mayhill, New Mexico, USA) [H15], ISON-Kislovodsk (Russia) [D00], ISON-Ussuriysk (Russia) [C15], Astronomical observatory of Odessa National University (Odessa-Majaki, Ukraine) [583].
CoLiTec has assisted in making over 1,500 preliminary discoveries of asteroids, including 4 NEO, 21 Trojan asteroids of Jupiter and 1 Centaur. It has been used in about 600 000 observations, during which four comets (C/2010 X1 (Elenin), P/2011 NO1 (Elenin), C/2012 S1 (ISON, fig. 2), P/2013 V3 (Nevski)) were discovered.

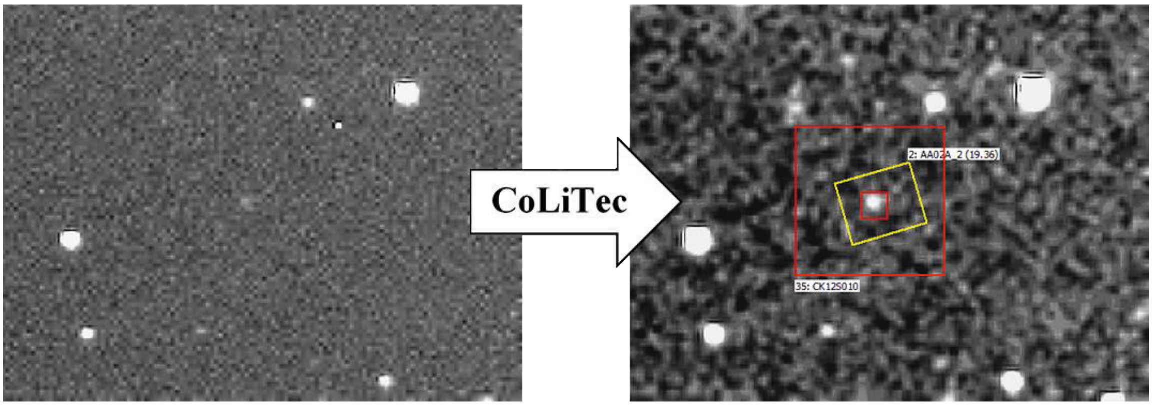


Fig. 2: One of the well-known results of the CoLiTec software. The detected and discovered object, the Comet C/2012 S1 (ISON), having an image size of 5 pixels, has been shifted by 3 pixels on a set of four CCD frames.

The communication describes astrometric reduction of the frame based on UCAC4 catalog and provides an analysis of its results. The comparative analysis of the accuracy was performed between the CoLiTec and Astrometrica software. The analysis showed the benefits of the CoLiTec software using with astrometry of asteroids in relation with Astrometrica using, especially when using widefield and low quality frames.
Considerable attention will be soon given to the astrometry improving with help of reserves for increasing measurement accuracy. Also we planned to provide possibility of individual binding astrometry reduction to telescopes and increasing observations accuracy.

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Asteroid observations for mass determination at RTT-150 during 2004-2013

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Abstract: *We present precise astrometrical observations of 96 selected asteroids perturbed by 28 large asteroids were performed at 1.5m Russian-Turkish telescope RTT150 during 2004-2013. Estimations of masses and errors of the perturbing asteroids are presented using observations from MPC only and from MPC+RTT150. The uncertainties of mass estimates are decreased in average by 12% for second variant of solutions. Comparison of mass values and errors has shown the importance of adding modern observations in fitting process. It will be useful to combine these data with very accurate but shot-time GAIA data for accurate mass determinations.*

1. Introduction

The dynamic method of mass determination is based on gravitational influence of perturbing asteroid on perturbed bodies. Despite the fact that the dynamic method for the determination of the masses is known a long time ago, it became widespread thanks to 3 reasons: increased accuracy of the modern astrometric catalogues, growing number of astrometric measurements, and the most important - increased accuracy of ground-based observations. To form observational program we used calculations of close encounters circumstances made in the works done by Fienga (2003), Galad (2001, 2002) and Mouret (2008). We chose a pair of asteroids (perturbing-perturbed) for which deflections of the perturbed orbits have to change right ascension or declination and the values of minimum change in coordinates have to be not less than 50 mas. We selected 105 perturbed asteroids for determination of masses of 29 perturbing asteroids. All positional observations were performed at 1.5m Russian-Turkish telescope RTT150.

2. Instrumentation and astrometric reduction

Observations were carried out with observational complex of RTT150 (Gumerov et al., 2014) for research of small bodies of Solar System during 2004-2013. A description of the telescope and detectors used for asteroid observations are listed in Table 1.

Table1: Characteristics of instrumentation

Telescope	*RTT150*	
Coordinates, (λ,φ)	*+30° 20′, +36° 49′*	
Height, m	*2500*	
D(mm)/F(mm)	*1500/11600*	
CCD	*Andor DW436*	*TFOSC*
Size, pix	*2048×2048*	*2048×2048*
Pixel, mkm	*13.5 ×13.5*	*15 ×15*
Scale, arcsec/pix	*0.24*	*0.39*
FOV, arcmin	*8.2× 8.2*	*13 ×13*
Filters	*$UBVR_cI_c$, SDSS(u′g′r′i′z)*	

Around 14,000 accurate positions of 231 asteroids were obtained during 9 years. More than 8,000 positions of this number were observations of 96 perturbed asteroids that had close encounters with 28 large perturbing asteroids. The mean number of frames was usually about 6, some objects had long photometric series of observations (up to 140 frames per night). Exposure time ranged from 5 to 300s that allowed us to increase signal-to-noise ratios for the faint asteroid. Distributions of the asteroids in apparent magnitudes are show in figure1.

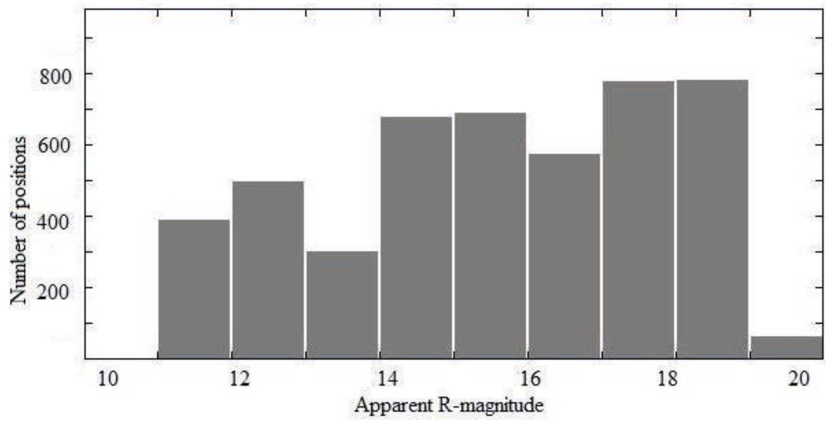

Fig. 1: Distribution of the asteroids in apparent R-magnitudes

2.1 Reduction

Both CCD cameras at RTT150 have low noise levels. No dark current effect was found when applying dark-field calibration at the precision of measured coordinates, so astrometric reductions were made without bias, dark and flat corrections. As function of approximation of image profile we used radially symmetric Gauss function for well-exposured non-elongated images and Moffat function - for faint or slight elongated images. We used Astrometrica software in first case and IZM CCD package (Izmailov, 2010) in second. One of main problems in astrometric reduction of long series of observations of solar system objects is choice of reference catalog. We used UCAC2-4 catalogues (Zacharias, 2013) as reference catalogues. Usage of different versions of UCAC catalogue in celestial sphere is shown in fig.2. Homogeneity of the distribution allows us not to take into account small systematic differences between the UCAC2, UCAC3 and UCAC4 versions, which don't exceed the random measurement errors of asteroid positions.

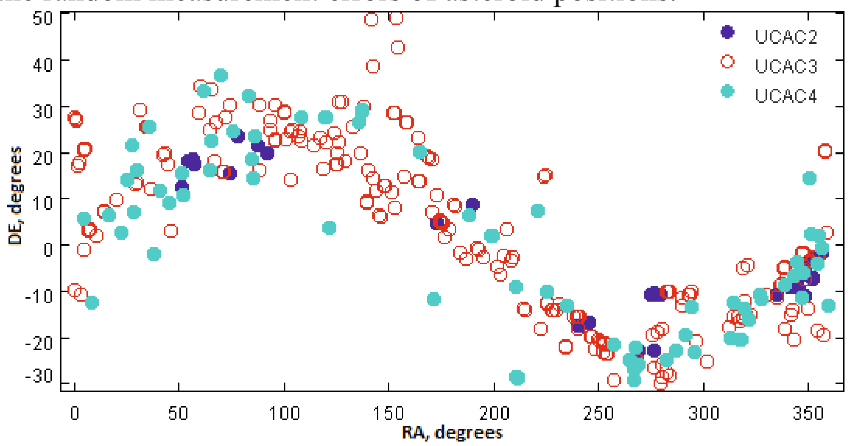

Fig. 2: Distribution of the RTT-150 asteroid observations in celestial sphere.

As an estimate of astrometric precision we used standard errors of differences (O -C) in right ascension and declination. They are plotted as a function of their apparent magnitudes in coordinates in fig.3. The errors do not show the usual exponential growth with increasing magnitude because different exposures were used to observe the asteroids. Mean precisions of 84mas in right ascension and 68mas in declination were achieved for well-exposed images up to magnitudes (10-17.5) which degrade to about 200mas for the faintest asteroids.

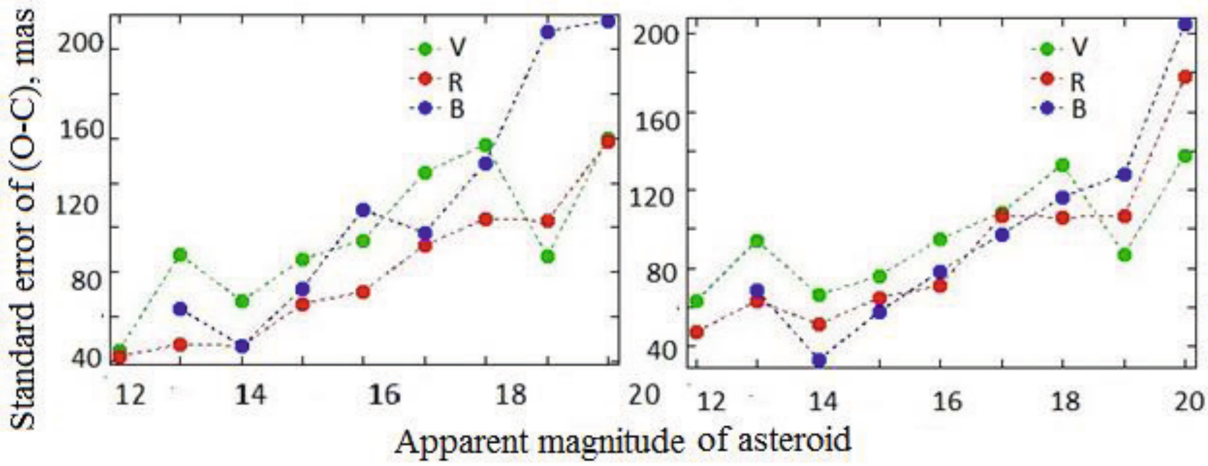

Fig. 3: Standard errors of (O-C) differences as a function of apparent magnitudes in RA (right) and DE (left).

The errors do not show the usual exponential growth with increasing magnitude because different exposures were used to observe the fainter asteroids, thereby improving their accuracies and producing such appearance of the curve.

3. Application: Dynamical masses

High precision positions of perturbed asteroids in ICRF/UCAC2-4 system were selected from the catalog of positions asteroids, obtained from observations in 2004-2013. Selected data were used for mass determinations of the 20 perturbing asteroids. The model of motion includes gravitational perturbations from all the major planets, as well as Ceres, Pallas, Vesta (the perturbations from the Earth and Moon were considered separately). The major planets' coordinates were calculated using ephemeris DE405. Least squares method (LSM) was used to determine the masses of perturbing asteroids for solving systems of conditional equations. We considered two variants of solutions:1) determination of masses using only MPC data; 2) previous variant with MPC data + RTT150 observations. Results of solutions are given in table 3. As seen from table 3, uncertainties of mass estimates are decreased in average by 12% for second variant of solutions. It should be noted, we don’t claim the new mass values for the above-mentioned asteroids here. It’s only attempt to estimate accuracy and influence of our data to masses. We didn’t use any criterions to select the best set of perturbed asteroids for each large asteroid. Probably, it explains appearance of negative masses in table 3.

Table 2 : Masses of perturbing asteroids

Perturbing Asteroid	Mass[1] , (Mass_☼)	Uncertainty[1] , (Mass_☼)	Mass[2] , (Mass_☼)	Uncertainty[2] , (Mass_☼)
1	4.74E-010	1.03E-012	4.73E-011	0.97E-012
4	1.21E-010	0.42E-012	1.21E-013	0.38E-012

9	0.37E-010	0.65E-011	0.37E-010	0.59E-011
10	0.41E-010	0.84E-012	0.41E-010	0.74E-012
11	0.26E-011	0.41E-013	0.26E-011	0.39E-013
13	0.30E-011	0.18E-011	0.31E-011	0.17E-011
15	1.38E-011	1.46E-012	1.25E-011	1.34E-012
16	2.19E-013	2.31E-012	3.98E-013	2.17E-012
24	-1.16E-011	4.43E-012	-1.22E-011	4.12E-012
31	-0.37E-010	0.95E-011	-0.21E-010	0.82E-011
45	-2.71E-011	5.83E-012	-1.70E-011	4.47E-012
52	1.23E-011	1.43E-012	1.25E-011	1.28E-012
64	0.19E-011	0.70E-012	0.16E-012	0.60E-012
72	-0.31E-010	0.94E-011	-0.22E-010	0.82E-011
87	0.59E-012	0.27E-011	0.42E-011	0.22E-011
423	-1.08E-011	3.72E-012	-1.05E-011	3.34E-012
511	2.57E-011	1.69E-011	2.42E-011	1.60E-011
704	1.17E-011	5.27E-012	1.40E-011	4.85E-012
762	6.46E-012	3.76E-012	5.21E-012	3.04E-012
790	2.14E-012	6.86E-012	4.17E-012	5.36E-012

[1] only MPC data on moment July, 2013;
[2] MPC data+RTT-150 asteroid observations.

Conclusion

RTT150 asteroid observations provide a large database of accurate topocentric and homogeneously determined positions and magnitudes for specially selected 96 perturbed asteroids which can be used to calculate dynamical masses for asteroids. Mass values and errors of 20 large perturbing asteroids are presented using observations from MPC+RTT150 and from MPC only. Comparison of mass values and errors has shown the importance of adding modern observations in fitting process. It will be useful to combine these data with very accurate but shot-time GAIA data for accurate mass determinations in the future.

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Observations of small-size and low-elongation NEAs in

RI Nikolaev astronomical observatory

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Abstract*:Small-size NEAs can pose a threat to human settlements, which is confirmed by the example of the fall of the meteorite Chelyabinsk, in result many people were injured, buildings were damaged. Observation of NEAs at low-elongation angle allows to increase the arc of observations, but they are complicated by the low intensity of the NEAs images.*

1. Introduction

NEAs with diameter less than 140 m are the least studied minor bodies of Solar system and may be observed only at a distance less than 0.05 a.u. Discovered NEAs, according to the data of international astronomical union at October 2013 (see Near Earth Asteroids A Chronology of Milestones) consist in:

- 861 NEAs with diameter more then 1000 m, included 155 potential hazardous asteroids (PHA) (predicted number of this size NEAs – 966 ±45);
- 5784 NEAs with diameter more then 140 m, included 1424 PHA (predicted number ~15000)
- 6448 NEAs with diameter more then 100m (predicted number ~20000)
- 8398 NEAs with diameter more than 40 m (predicted number ~300000)

2. Method and equipment

The Combined Observation Method (COM) is used in Research institute Nikolaev Astronomical observatory (RI NAO) for observation of NEAs having high apparent motion at distance to the Earth less than 0.05 a.u.(see Shulga O. et al., 2011).

COM consists in separation of imaging processes of object and reference stars. Time delay and integration mode (TDI) is used to get images of stars and NEA on fixed telescope (without mechanical tracking) (see Shulga O. et al., 2007).

The necessary condition to use TDI mode is fixing of the CCD columns in the direction of NEAs motion, the special device – camera rotator – was developed and applied for this purpose. The camera rotator rotates the CCD camera around the optical axis of the lens.

All observations in RI NAO were carried out using the KT-50 telescope (D=0.5m, F=3.0m). The telescope is equipped with CCD-camera Apogee Alta U9000 (3k×3k) and camera rotator. The field of view of the telescope is 0.7°×0.7°(see Sybiryakova Ye. S. et al., 2013).

3. Observation results

Since 2008, 4000 positions of 219 near-Earth asteroids $(9.5–18.5)^m$ have been obtained on KT-50 telescope. Use of COM allowed us to obtain observations of 15 NEAs with diameter less than 140 m (all observations obtained at the distance from the Earth less than 0.05 a.u.). In 2014 observations of 3 low-elongation NEAs with solar elongation less than 45° were obtained. 62 potentially hazardous asteroids were observed. The follow-up observations of 4 NEA candidates with apparent motion higher then 5.6″/min were conducted in RI NAO.

The observations of NEAs 2014 HQ124, 2013 TV135, 2002 GT, Apophis and 2005 YU55 were obtained under the GAIA-FUN-SSO campaigns of observation.

The results of observation of 15 small size NEAs with diameter less then 140m were obtained in RI NAO. These objects are very difficult for observation because they become observable for the most of ground based telescopes only during a close approach to the Earth. The estimated diameter, number of obtained positions and positions accuracy for observations of small size NEAs carried out in RI NAO are represented in Table 1. The diameter and total number of positions data are extracted from NEODyS service (see Near Earth Objects - Dynamic Site).
The magnitudes are in the range from 14.9 to 18.6, apparent motions are in the range from 4.7 to 306.3″/min. The number of positions obtained in all observatories are showed in the third column (N), the number of positions obtained in RI NAO in percentage is given in the fourth column (N2).

Table 1. Small size NEAs observation results

Asteroid	Diameter, m	N	N2 %	Delta a.e.	Mag.	App. motion ″/min	Mean residual (O-C) ″	
							RA	DEC
2000WL63	20 – 40	263	2.7	0.18	17.8	4.7	0.13	0.22
2011JY1	30 – 80	106	6.6	0.03	18.5	16.0	0.01	0.04
2012EO8	40 – 90	119	5.0	0.01	17.1	82.8	0.11	0.02
2012FQ35	50 – 120	170	4.7	0.04	18.3	15.5	0.21	0.19
2012HM	40 – 100	521	3.6	0.01	15.7	46.3	0.18	-0.1
2012HP13	40 – 90	205	10.3	0.01	15.8	174.7	0.33	0.24
2012LJ	20 – 50	53	13.2	0.005	18.2	306.3	-0.03	0.09
2012TC4	10 – 30	301	4.0	0.001	16.5	19.1	0.15	-0.05
2012XH112	10 – 20	48	41.7	0.01	17.2	90.4	0.00	0.05
2013GK69	50 – 110	65	4.6	0.04	18.1	20.5	0.15	-0.01
2013XY8	30 – 60	248	8.5	0.01	14.9	80.1	-0.35	0.28
2014FD	20 – 50	78	11.5	0.01	18.1	55.6	-0.33	-0.67
2014FO38	10 – 30	79	5.1	0.01	18.0	58.1	0.42	0.53
2014FR52	50 – 110	88	7.6	0.05	18.4	9.4	0.08	-0.3
2014HV2	10 – 40	70	12.9	0.02	18.6	8.1	-0.11	0.28
N – total number of positions, N2 – number of positions obtained in RI NAO (%)								

In 2014 an experiment to monitor low elongation NEOs was performed in RI NAO. The conditions of observation (solar elongation, magnitude and apparent motion) are represented in Table 2. Observations of NEA 2014 HQ124 were obtained under the GAIA-FUN-SSO observation campaign, the results of observations were sent to Institut de Mécanique Céleste et de Calcul des Éphémérides (France).

Table 2. Conditions of observation of low-elongation NEAs

Asteroid	Solar elongation deg	Mag.	App. motion ″/min
3199	36	17.6	2.5
1999 HF1	43	16.5	4.9
2014 HQ124	45	17.0	18.6

The (O-C) of positions of low elongation NEAs obtained in RI NAO and other observatories are represented in the figure 1. (O-C) of RI NAO positions are within ±1″.

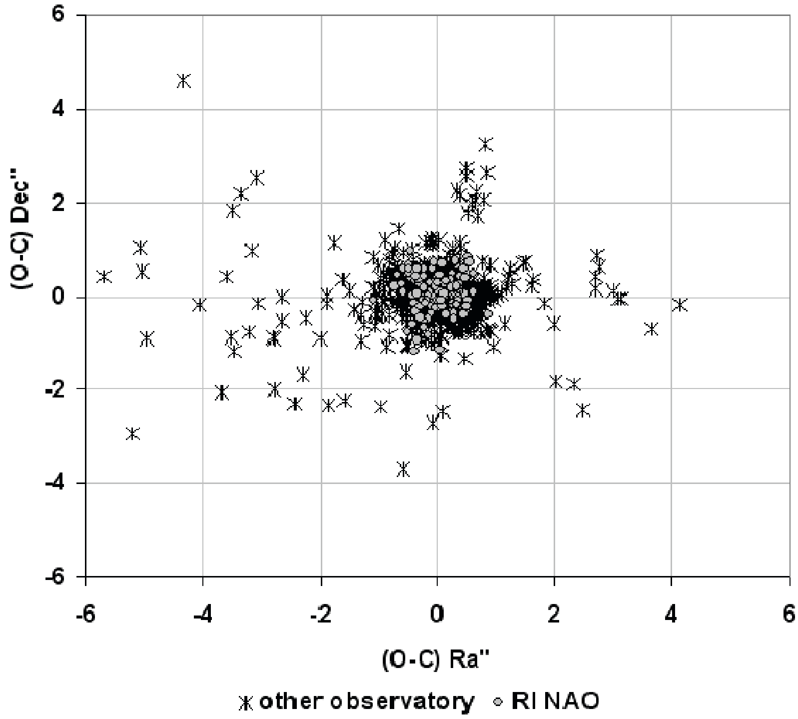

Fig. 1**:** (O-C) of positions of low elongation NEAs

RI NAO has an experience in the follow–up observation of NEAs. During 2012-2014 observation of 4 newly discovered NEAs were obtained. The previously and provisional designation, magnitude, apparent motion, distance to the Earth and diameter of NEA are represented in Table 3.

Table 3. The observation conditions of newly discovered NEAs

Previously designation	Asteroid	Mag.	App. motion ″/min	Delta a.e	Diameter m
TT2E495	2012 TG53	17.3	27.5	0.03	60-150
TT2ED76	2005 JU1	17.3	10.8	0.08	140-320
VJA8CAE	2014 JO25	17.5	7.6	0.20	410-920
S003564	2014 KP4	16.5	5.6	0.16	700-1600

Conclusion

Since 2008, 4000 positions of 219 near-Earth asteroids have been obtained on KT-50 telescope. The observation of 15 small size NEAs (less then 140 m) were received. Observations of 3 low-elongations NEA with solar elongation less then 45° were obtained, (O-C) of positions are within ±1″. RI NAO has an experience in follow–up observation of newly discovered NEAs.

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Method of Determining the Small Bodies Orbits in the Solar System Based on an Exhaustive Search of Orbital Planes

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Abstract. *A universal method of determining the orbits of newly discovered small bodies in the Solar System using their positional observations has been developed. In this method we avoid determining the topocentric distances of an object by iterations. Instead the different orbital planes of object's motion are considered and the most appropriate one is chosen as a first approximation for the differential method of improving orbit. Criterion for choosing the most appropriate plane is the least rms of the observations. For each considered plane the topocentric distances are calculated and the two reference observations are chosen. The orbits for each plane are calculated using the method of determining orbital elements by two heliocentric positions and times. If the orbit can't be improved we consider set of orbits which fit the observations well enough (the rms of which are not so large). Thus we can obtain set of small object's ephemerids that can help to find this object again.*

1 Introduction

Newly discovered asteroids that have short observational arcs and few observations pose a special problem in orbit determination. Gauss developed his method for orbit determination about 2 ages ago but it uses only 3 observations. Nowadays generally the amount of asteroid's observations more than 3 even at the first day of observing the object. The iterations used in this method sometimes can diverge or tend to inappropriate or strange result (e.g. topocentric distances less than zero).

Usually the problem of calculating small body orbit can be divided into two stages: determining the Keplerian imperturbation orbit; improving the orbit by differential method taking significant perturbations into account using Keplerian orbit as a first approximation.

Let's consider this process in details. Let there be $n \geq 3$ positional observations of a body: times t_j, right ascensions α_j and declinations δ_j $(j = \overline{(1, n)})$. Then, unit vectors $\boldsymbol{L}_j$ pointing to the body in the topocentric equatorial coordinate system are $\boldsymbol{L}_j = (\cos\alpha_j \cdot \cos\delta_j, \sin\alpha_j \cdot \cos\delta_j, \sin\delta_j), \quad (j = \overline{(1, n)})$

The relationship between the heliocentric and topocentric vectors of the celestial body positions is determined by the equations:

$$\boldsymbol{X}_j = \rho_j \cdot \boldsymbol{L}_j + \boldsymbol{Y}_j, \quad (j = \overline{(1, n)}) \tag{1}$$

where $\boldsymbol{X}_j$ are the heliocentric vectors of the celestial body position, ρ_j are the topocentric distances, and $\boldsymbol{Y}_j$ are the heliocentric vectors of the observers position. Note that $\boldsymbol{Y}_j$ can be calculated by some planet ephemeris (e.g. DE431, INPOP13c or EPM2013).

The heliocentric vectors $\boldsymbol{X}_j$ are functions of 6 orbital elements. Therefore the unknown variables in the equation system (1) are topocentric distances ρ_j and 6 orbital parameters. Consequently we have $3n$ equations and $6+n$ unknown variables. In order to find the orbit one should solve this nonlinear system. Generally this system is solved by successive approximations including the iterations to find ρ_j that can diverge of tend to inappropriate or strange result especially in cases of short observation arc and few observations.

2 Description of the proposed method

Our goal is to avoid using successive approximations to solve system (1) and finding the imperturbation Keplerian orbit. Instead we find the first approximation of the orbit and then improve it by the differential method or consider set of orbits which fit the observations with fixed accuracy. Note that the topocentric distances can be considered as functions of observations and only two orbital elements: inclination i and longitude of the ascending node Ω (as lengths of vectors $\boldsymbol{L}_j$ pointing from the observer to the object till the intersection with the plane).

This method obtains the first approximation of the orbit by sampling motion planes (inclinations i and longitude of the ascending node Ω) (Bondarenko, Vavilov, Medvedev, 2014). First of all we choose 2 reference observations (generally the first and the last ones but if it's known that some observations have less errors it's better to choose those ones). Then for all considered planes we do the following. Calculate topocentric distances ρ_j and then heliocentric positions by (1). Take into account aberration corrections $t_j = t_j - \rho_j/c$ where c is the light velocity. Further, the orbit is determined by the method of determining orbital elements using two heliocentric positions of reference observations and times (Gauss, 1809). To realize how this orbit fits the whole set of observations rms is calculated:

$$\sigma = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}(\alpha_j - \alpha_j^c)^2\cos^2\delta_j + (\delta_j - \delta_j^c)^2}, \quad (2)$$

where α_j^c and δ_j^c are the calculated equatorial coordinates of the celestial body. If the weights of observations are known one can take it into account in (2).

Then we consider the orbit, which associated with the least σ, as the most appropriate one and use it as a first approximation of the orbit. Then we try to improve it by differential method.

The first advantage of this approach is that we always obtain some approximation that we can try to improve. If the orbit isn't improved we consider more motion planes. The second advantage is that if the orbit can't be improved we can consider set of orbits which fit the observations with fixed accuracy.

3 Results

The efficiency of the technique was verified with 34 newly discovered celestial objects published in the Minor Planet Center circulars between September 17-29, 2010, and May 24-June 3, 2011. This method founded satisfying first approximations of orbits, which were improved by differential method, using step 1° over i and Ω for all considered asteroids. On the other hand using the classical Gauss method, we failed to determine preliminary orbits for 11 asteroids that could be further improved using the differential method. In nine cases the epochs of observations were represented as two groups separated by a fairly long time interval. For one asteroid the accuracy of the mean observation was not well enough. And in one case a problem with the convergence of iterations in the determination of geocentric distances arose while calculating the orbit. The values of geocentric distances for this asteroid obtained using the Gauss method turned out to be negative.

On Fig.1 σ as a function of i and Ω for the asteroid 2010 SG13 is represented. This is a general situation: the function has just one condensation point and the orbit can be improved.

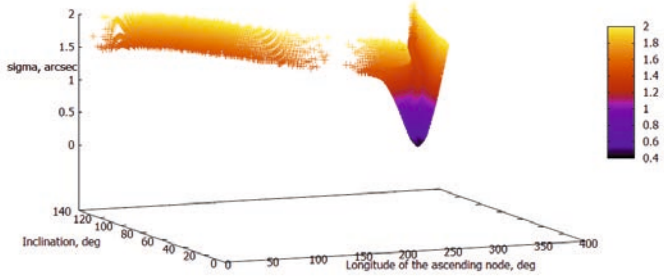

Figure 1: $\sigma(i, \Omega)$ for 2010 SG13

Let's consider another situation when the observation arc is short and we have few observations. We chose 5 satellite observations of the asteroid 2010 BK118 so that the observation arc is about 6 hours and 21 minutes. The function $\sigma(i, \Omega)$ is represented on Fig.2. There is no definite minimum of the function in this situation and the orbit can't be improved. But using the orbits with $\sigma < 1$ we can calculate ephemeris on the epoch equals 10 days after first observation. One can see this set of ephemerides of Fig.3. The figure shows that there is not only one possible position of the object on the sky after 10 days. There are two groups of ephemerides associated with a slow object and a fast one, and some other detached points. The real position of this object is $1^h56^m40^s.29, +45°26^m25^s.7$ which is covered by obtained set of ephemerides.

4 Conclusion

A method of determining the orbits of the Solar system small bodies has been developed. In the method the exhaustive search for inclinations and longitudes of the ascending node is used. This method allows to avoid using successive approximations to find topocentric distances. The first advantage of this approach is that we always obtain some approximation that we can try to improve. The second advantage is that if the orbit can't be improved we can consider set of orbits which fit the observations with given accuracy. The second advantage is shown on the asteroid 2010 BK118 with short observation arc and few observations.

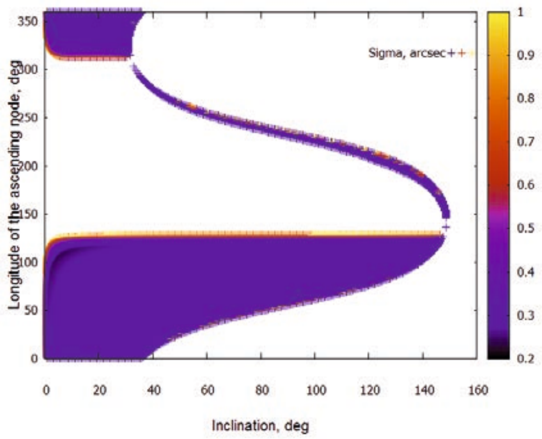

Figure 2: $\sigma(i, \Omega)$ for 2010 BK118

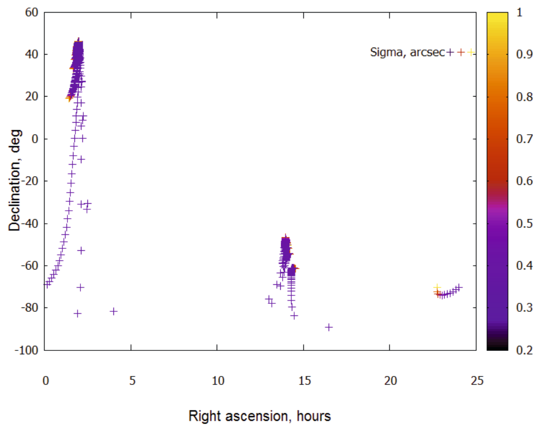

Figure 3: The ephemeris for 2010 BK118

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Determination of the small Solar system bodies orbital elements from astrometric observations with OMT-800 telescope

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Abstract: *From the beginning of operation of the new OMT-800 telescope in late 2012 we were able to recieve the high-precision differential astrometrical observations of geostationary objects, asteroids and comets brighter than 21 mag. In this work, the technique of calculation of the orbital elements and prediction of the geostationary objects and asteroids trajectory are considered.*

1. Introduction

The idea of buildind the telescope with primary mirror diameter 800 mm (OMT-800, i.e. Odessa Multifunctional Telescope, Fig. 1) dates back to the end of 2006. Despite the huge problems in the construction, in late 2012 the telescope was put into operation. (Andrievsky et al., 2013).

Fig. 1: New OMT-800 telescope in Mayaki. 800 mm f/2.67 reflector + CCD

2. OMT-800 control software

The integrated CHAOS (Kouprianov, 2012, Fig. 2) scheduler can work with the following types of objects:

1. Deep-sky and stellar objects with fixed right ascension (α) and declination (δ); arbitrary tracking rates (v_α,v_δ) can be also applied.
2. Major planets of the Solar system, asteroids, comets, and Earth-orbiting objects. Ephemerides of them may be given in tabular form as a text file, and CHAOS can track this objects in real time according to the ephemeris. Arbitrary tracking rates (v_α,v_δ) can be also applied.
3. Geosynchronous objects with fixed hour angle (t) and declination (δ). Arbitrary tracking rates (υ_t, υ_δ) can also be applied.
4. Satellites of major planets may be observed like other moving objects, but CHAOS can apply an offset to move the central planet away from the field of view.

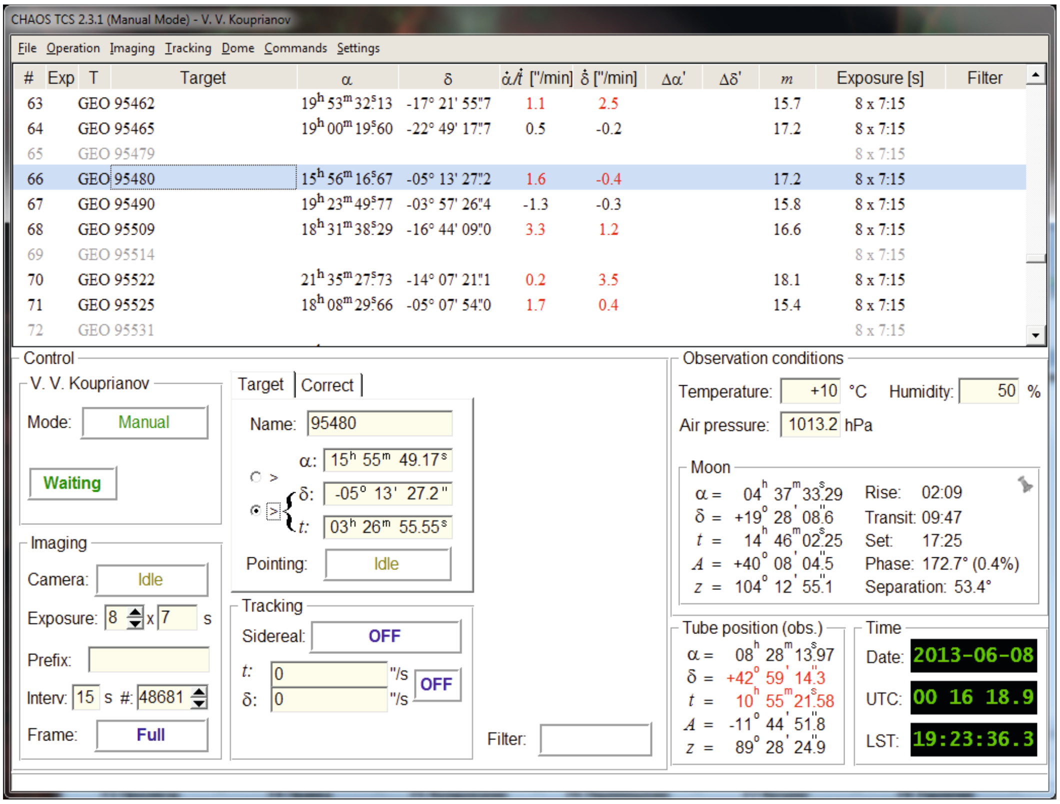

Fig. 2: Screenshot of a working session of CHAOS TCS on the OMT-800 control workstation.

To increase the magnitude limit of the observed objects, as well as to carry out astrometric reduction of images and obtain differential equatorial coordinates of the observed objects, we used OLDAS program module, which is the component of CoLiTec software package (Savanevich et al., 2012), kindly provided us by its developers. This module enables to adjust frames by brightness using median filter and the Fourier analysis, as well as to conduct auto-calibration and correction by eliminating dead and hot pixels. At this stage the vignetting of field of view, comatic aberration, any possible failures of telescope tracking, ambient light which interferes with telescope viewing, as well as diffracted rays can be corrected.

3. Reports about the angular supervisions and calculation of orbit of asteroids.

Frame processing technique still needs to be improved, but as our first results, 90% of our observations reports and results of primary processing for asteroids and comets with magnitude up to 21 meet the Minor Planet Centre Orbit (MPCORB) database (www.minorplanetcenter.net) requirements (Williams et al., 2014).
The Keplerian elements of an asteroid are computed using the Gauss method by three observed positions (Montenbruck et al., 2002).
In questionable cases the fourth observation can be used to choose the correct orbit from several alternative solutions.
Orbital elements of an asteroid are refined using all observations by the method of differential correction of orbits (Bazyey et al., 2005).
That in turn will enable to use the obtained orbital position vectors to solve the asteroid ephemerides problem (Базей et al., 2009).

4. Triple Near-Earth asteroid (136617) 1994 CC.

During testing our method of asteroids ephemerids calculation, we applied it to the study of dynamic of asteroid systems.
The differential equations of celestial motion are solved by numerical integration using the Everkhart's method in the Cartesian coordinates.
In our dynamical model of the motion the gravitational potentials from eight major planets, the Moon and 343 most massive small bodies of the Solar system are taken into account. In addition, oblateness of the Sun, Earth, Moon, Jupiter and Saturn are considered. In the numerical integration, an initial position vector of each major planet and the Moon is taken from the DE431 Jet Propulsion Laboratory numerical theory (ipnpr.jpl.nasa.gov).
We applied our method to asteroid (136617) 1994CC (www.johnstonsarchive.net). Fig. 3 illustrated evolution of the orbits of the asteroid satellites on the 17000 years integration interval.

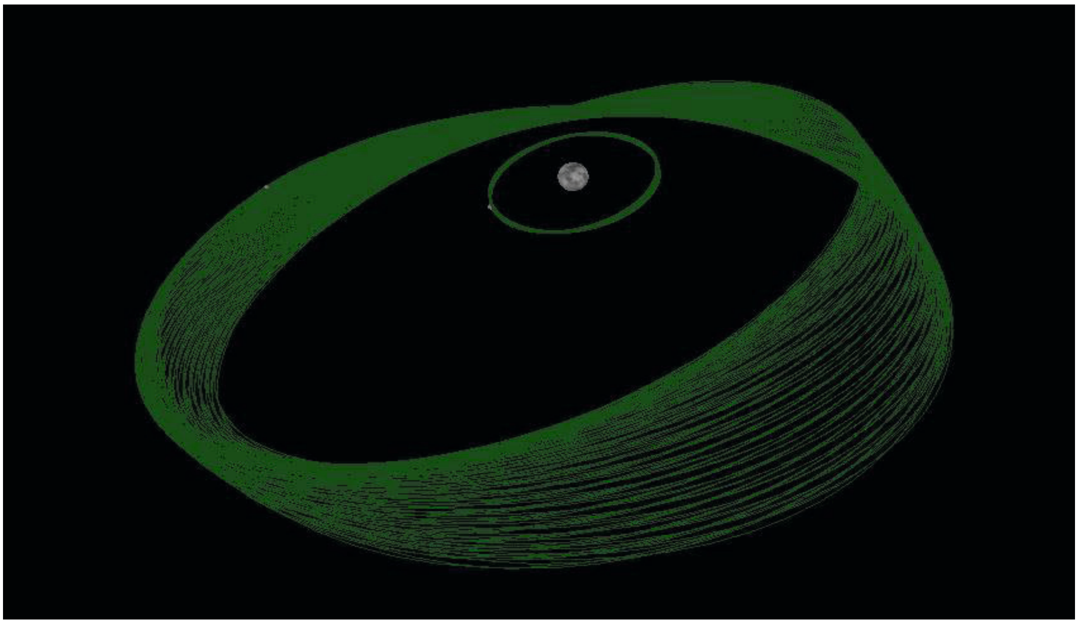

Fig. 3: Evolution of satellites orbits (136617) 1994 CC

5. Conclusion

Using new 800 mm OMT-800 telescope we began to receive positional observations of small Solar system objects and its orbits with precision which corresponding asteroid's orbital elements from the Minor Planet Centre Orbit (MPCORB) database. Results of asteroid observations' processing will be further improved by advancing of the algorithm of frame processing and extension of computational method for orbit calculations. Our computational method was applied to the triple asteroid (136617) 1994 CC.

Acknowledgements

The authors are infinitely grateful to the group of CoLiTec software developers, headed by Prof. Vadym Savanevich, for kindly provided software.

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Follow-up observations of NEAs at the Terskol Observatory

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Abstract: *Starting in the early 2000s, the facilities of the Terskol Observatory have been heavily used for follow-up astrometry, photometry and spectroscopy of asteroids. Objects with V magnitudes down to 21.5^m have been observed during their close approaches to the Earth. In 2003-2014, positions of more than 200 NEAs were detected; an accuracy of about 0.2–0.3 arcsec was achieved. Astrometric observations have been continuously reported to the IAU Minor Planet Center. Appropriate software developed has been applied to derive asteroid's properties and to classify them. In this paper, different aspects of studies of NEAs at the Terskol Observatory are presented; some results obtained from observations of 2007 PA8, 201 2QG42, and 2014 SX261 are provided.*

1. Introduction

In consideration of the importance of finding and studying Earth-approaching objects, which can represent an impact hazard to our planet, one of the priorities of ground-based astronomy must be assigned to discovery and monitoring of these objects.
The decades of successful research at the Terskol Observatory in the Northern Caucasus (43^{O}16'29" N, 42^{O}30'03" E, 3143 m asl) have yielded new data and findings in this field. The available optical telescopes with diameters up to 2 m have been heavily used for studies of small Solar System bodies (Tarady et al, 2010). The 60-cm Cassegrain telescope (Zeiss-600), however, remains the main instrument for follow-up astrometry, photometry and spectroscopy of asteroids. This f/12.9 reflector has two CCD cameras. The one recently mounted is a SBIG STL-1001 based on 1024x1024 CCD with 24 micron pixels that provides a field of view of 10.9 arcmin. The limiting V magnitude for this telescope is 21.2^m.

2. Observations and results

Comprehensive scientific programmes on studies of near-Earth asteroids (NEAs) have been run at Terskol since 2010, whereas astrometric and photometric observations of asteroids started here as far back as the early 2000s. Extremely high emphasis is placed on follow-up observations of potentially hazardous asteroids (PHAs).

2.1 Selection of targets

As for the objects to be observed preeminently, the following selection criteria are applied:

- recently discovered NEAs of visual magnitudes V down to about 21.5^m,
- potentially hazardous asteroids with absolute magnitudes H > 20^m, which have unknown or poorly-defined physical characteristics and which come within 20 lunar distances,

- targets of opportunity (risk lists, Gaia-Fun-SSO training campaigns, etc).

Most observations of NEAs have been conducted during their close approaches to the Earth. For instance, Table 1 presents list of asteroids that were observed at Terskol in 2013-2014.

Table 1. List of asteroids observed at the Terskol Observatory in 2013-2014

NEA	*Orbit type*	*H [mag]*	*Diameter [m]*	*Close approach*	*Distance [LD]*	*Period of observations YYYY-MM-DD/DD/...*
99942 Apophis		18.9	~375	2013-01-09	37.6	2013-02-02/03/07/08/09/10
2013 ET	AP	23.1	~75	2013-03-09	2.51	2013-03-06/07/08
1998 QE2	AM	16.4	~2750	2013-05-31	15.1	2013-06-04/05
2005 WK4	AP	20.1	260-580	2013-08-08	8.08	2013-08-10/11
2007 CN26	AP	21.1	180-400	2013-08-28	11.9	2013-09-03/04/07/08/09/10
2013 RE32	AM	24.6	30-80	2013-09-02	2.16	2013-09-07
2013 RF36	AP	16.9	1300-2800	--	755	2013-09-09
2013 TV135	AP	19.5	379-848	2013-09-16	17.2	2013-10-24/.../27/30/31, Nov 10
2013 VZ11	AM	20.6	220-510	2013-10-20	70.9	2013-11-09
2013 VA12	AP	22.7	80-190	2013-10-16	30.4	2013-11-09
2013 WH	AM	21.3	160-370	--	99.6	2013-11-24
2005 AY28	AT	21.5	150-300	2014-02-07	15.2	2014-02-03/04/05/06
2006 DP14	AP	18.8	200-400	2014-02-10	6.17	2014-02-12/13/17/18
2014 DJ10	AP	23.2	60-150	2014-02-19	55.7	2014-02-23
2014 DB11	AM	21.2	170-380	2014-03-18	70.2	2014-02-23
2002 SR41	AP	20.1	280-640	2014-06-09	16.3	2014-06-14/15/16/17/19/20
2013 XM24	AP	19.0	500-1100	2014-06-29	43.5	2014-06-25/26/27/28, Jul 01/02
2001 RZ11	AM	16.4	1500-3400	2014-08-17	34.2	2014-08-20/21/22/23
2014 RC	AP	26.8	10-20	2014-09-07	0.103	2014-09-05/06
2014 SX261	AP	22.3	65-210	2014-10-03	8.96	2014-10-02/03
2014 TN17	AP	21.6	140-320	2014-10-19	47.4	2014-10-03
2014 SM143	AP	20.3	260-580	2014-10-20	11.2	2014-10-06/07
2011 TB4	AP	25.4	20-50	2014-10-09	4.80	2014-10-06/07
2014 TV	AP	24.4	30-80	2014-10-18	4.42	2014-10-07
2340 Hathor	AT	20.2	~210	2014-10-21	18.8	2014-10-25/26/ 27/28/29/30
2014 UF56	AP	27.4	6-20	2014-10-27	0.422	2014-10-26
2014 WY4	AM	24.0	47-106	2014 -11-19	18.1	2014-11-23
2014 XJ3	AP	20.0	170-540	2014-12-26	12.5	2014-12-16/18

2.2 Astrometry of near-Earth asteroids

Since 2003, precise astrometric data acquired during observations of asteroids at Terskol have been continuously reported to the IAU Minor Planet Center. These data can be found at *www.minorplanetcenter.net*, as well as at *http://newton.dm.unipi.it/neodys/* as “Obs & residuals” of the Terskol Observatory (code B18). During the period from 2003 to 2014, positions of more than 200 NEAs were detected; an accuracy much better than 0.6 arcsec (on average 0.2–0.3 arcsec) was achieved (fig.1).

In 2012-2014, the Terskol team has participated in the Gaia-Fun-SSO training observation campaigns on alert in order to be prepared to work in the framework of the Gaia mission. In particular, the long-term astrometric observations of the PHA 99942 Apophis performed at the Terskol Observatory - along with the data sets from other observing sites - were used to calculate its orbits and to improve predictions about its close encounters with the Earth (Thuillot et al, 2015).

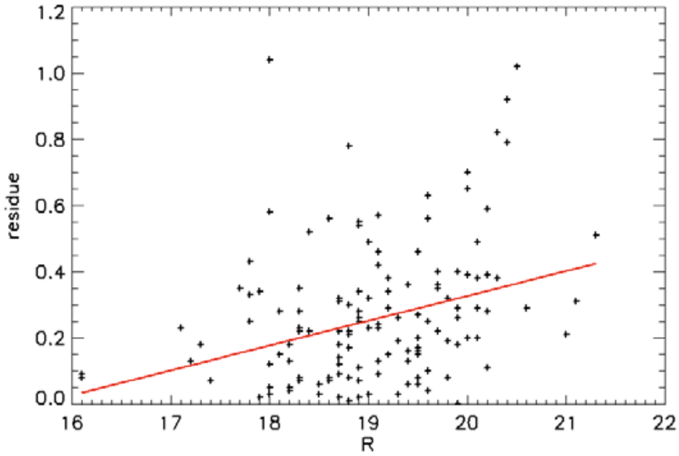

Fig.1: Position uncertainties plotted against R magnitude of NEAs observed in 2013 at the Terskol Observatory

2.3 Asteroid light curve analysis

High-accuracy photometry of asteroids has been used to study their rotation properties. In 2013-2014, complete light curves were obtained for a number of PHAs. For instance, some new results about 2005 AY28, 2007 CN26, and 2013 ET are presented by Godunova (2014).
Photometric observations of asteroids have been conducted with the Zeiss-600 telescope, with individual exposure times of 10-30 s. In order to enhance the signal-to-noise ratio, most CCD images have been taken in “white light”.
To determine the rotation periods of the observed PHAs, we use methods based on Lomb normalized periodogram, or phase dispersion minimization (PDM) (Stellingwerf, 1978) or Hotelling's T-squared statistic (Zhilyaev, 1993). Comparison of the results obtained showed that the PDM technique and a modified version of the Hotelling test are most appropriate for this purpose (Godunova et al, 2014).

Here we provide the recent results about rotation parameters of asteroid 2014 SX261 which approached to the Earth within 0.023 AU on October 3, 2014. Photometric observations of this PHA (D~100-230 m) were performed at the Terskol Observatory before its close approach, on October 2, 2014 when its V magnitude averaged between 15.5^m and 16.1^m.
The raw lightcurve for 2014 SX261 is shown in fig. 2. For proper analysis, the data obtained were reduced to the average magnitude of the asteroid over the night, especially taking into account distance effects and atmospheric extinction. The results of the analysis are presented in fig. 3. Though the PDM plot (fig.3, *left*) shows at least two solutions we discarded a shorter period assuming a two maxima-minima model. Thus the period of 2.801 ± 0.009 h was adopted, with amplitude of about $0.4^{\,m}$ (fig.3, *right*). It should be noted that this is in good agreement with the results obtained by Warner (2015). Moreover, some features of the lightcurve obtained from the observations at Terskol suggest the Warner’s assumption that 2014 SX261 can be a binary.

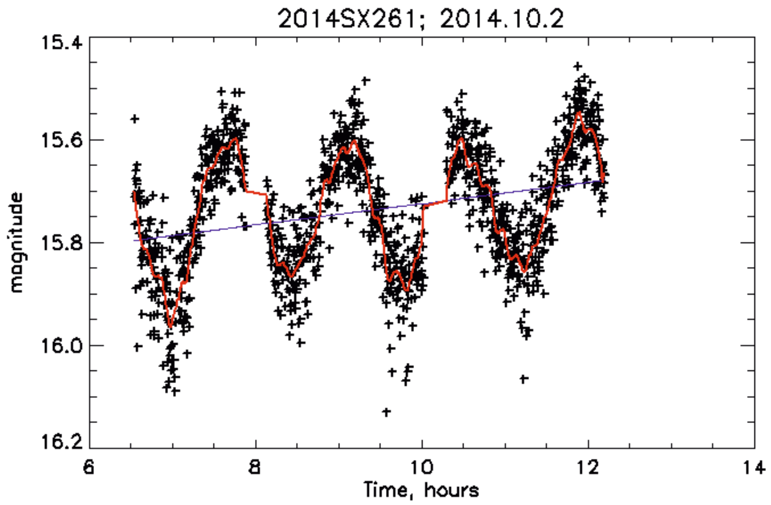

Fig. 2: Raw lightcurve for 2014 SX261 (time reading from the beginning of JD 2456933)

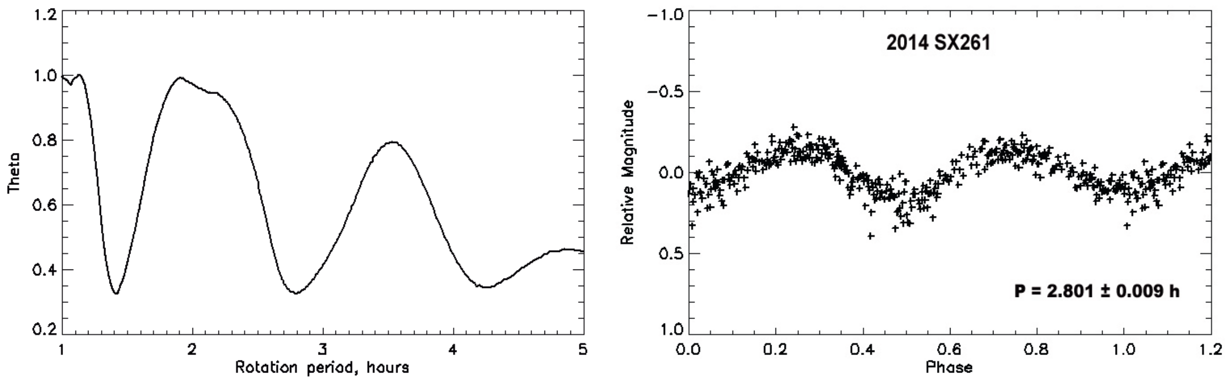

Fig. 3: High-resolution PDM scan for 2014 SX261 *(left)* and its composite light curve *(right)*

2.4 Spectroscopy of near-Earth asteroids

Considerable progress in studying physical properties of asteroids was made in 2010 when a low resolution slitless spectrograph was designed and built to be used on small telescopes. The spectrograph is capable of registering the continuous spectrum in the wavelength range 350–900 nm. It has a resolution of R ≈ 100 in the vicinity of 480 nm and provides a moderate signal-to-noise ratio for objects down to magnitude 16; more specific information on the configuration "60-cm telescope – slitless spectrograph" can be found in (Zhilyaev, 2012). Observations with this instrument have shown that it is an effective tool for the taxonomic classification of asteroids with V magnitude down to 14.5^{m}.

To date, we have already obtained important results for some asteroids. For instance, appropriate software developed has been applied to analyze spectrophotometric data for 2012 QG42 and 2007 PA8. These PHAs were observed at Terskol on September 11-12 and October 06-08, 2012, respectively. Their relative reflectance spectra are plotted in fig. 4 (this appears to be the first relative reflectance spectrum reported in the literature for 2012 QG42). Based on the presence of specific spectral features (a maximum relative reflectance at roughly 700 nm and the silicate absorption with a minimum at roughly 900 nm) these asteroids can be identified as Q-types (Bus et al, 2002). But then again the spectrum of 2007 PA8 is not far different from spectra contained in the O-class.

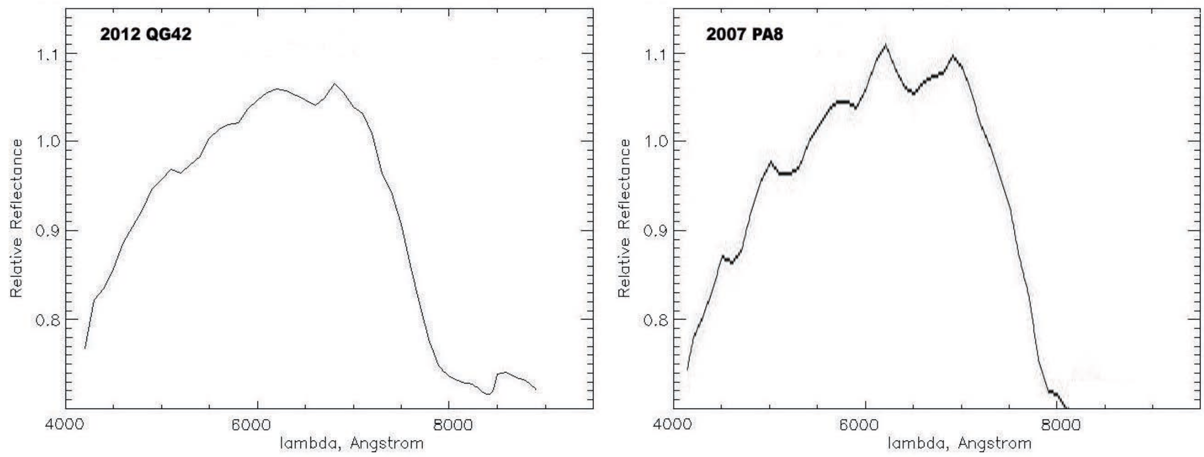

Fig. 4: Relative reflectance spectra of asteroids 2012 QG42 and 2007 PA8

Conclusion

Over the last twelve years, the Terskol Observatory has been produced useful observational datasets that contribute significantly to achieving advances in studies of NEAs. Favorable results in classifying asteroids, as well as in computing their rotational properties were obtained. These results demonstrate that ground-based small and medium-sized telescopes remain a valuable tool for monitoring and investigation of Earth-approaching asteroids.

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Astrophysics in Kazakhstan: past, present and future

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Abstract*: Astronomical observations in Kazakhstan are carried out for over 60 years. The advantage of the geographical location makes it possible to set and conduct programs of stationary ground-based observations that from the most observatories of other countries are difficult or impossible. Today astrophysical research in Kazakhstan is being developed in theoretical and observational aspects. In particular, computational astrophysics and stellar dynamics is gaining more momentum due to international collaboration. Meanwhile one of the main project in observational research is to build a new 3,6 ground telescope and to participate in the international space project "World Space Observatory - Ultraviolet".*

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Asteroid – comet monitoring

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Abstract: *Works on discovering and studying of asteroids and comets approaching the Earth orbit (ACE) are carried out all over the world and directed, first of all, to cataloging of big ACE for which telescopes of average sizes (with apertures from 50 cm to 1 m) are used. Such observations are carried out for astrometric support of newly discovered ACE that is necessary for these bodies cataloging. Also regular observations on defining ACE coordinates, especially, potentially hazardous for the Earth with defining and maintenance of high accuracy of their orbital parameters are conducted.*

Photometric ACE observations which are implemented at these bodies brightest moments during their close approach to the Earth are aimed to define asteroids physical properties such as shape, sizes, surface properties and rotation parameters. Systematic observations within the project will be directed to studying of dual ACE and also detecting of new dual systems among ACE. Contemporary scientific problem for ACE researches is determined by the fact that studying of these bodies physical properties noticeably falls back from total amount of discovered ACE. In particular, at present rotation periods of nearly 300 ACE are known but over 12 thousand are discovered. Knowledge of hazardous asteroids physical properties is necessary for developing and creating protection systems for preventing such bodies fall onto the Earth. Obtained within the project data about ACE physical properties will be published in peer-reviewed scientific journals (in scientific journals with impact-factor) and further on - posted in international databases.

Conducting review observations with CCD - cameras enables to observe big sky regions with deep penetration that gives the possibility to implement all asteroids high accurate astrometry in the field of the telescope and detect new celestial bodies – asteroids and comets. Obtained electronic shots with CCD -cameras will be exposed to operative processing and further on objects positioned and photometric measurements in the field of the telescope. This sky scanning methodology and celestial bodies detecting are the most progressive ones among existing and common all over the world.

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GAIA

FOLLOW-UP NETWORK

FOR THE SOLAR SYSTEM OBJECTS

THIRD WORKSHOP

The observation of Solar System Objects (SSO) by the Gaia space astrometry mission will be constrained by a scanning law. Much detection of interesting objects may occur with no possibility of further observations by the probe. These objects will then require complementary ground-based observations. Among them, previously unknown Near-Earth Objects, fast moving towards the Earth or going away from it could be found. Several objects discovered by Gaia could also be Inner-Earth Objects, as the probe will observe at rather low Solar elongations.

In order to confirm from the ground the discoveries made in space and to follow interesting targets, a dedicated network is organized, the Gaia Follow-Up Network. This task is performed in the frame of the Coordination Unit 4 of the Gaia Data Processing and Analysis Consortium (DPAC), devoted to data processing of specific objects. The goal of the network is to improve the knowledge of the orbit of poorly observed targets by astrometric observations on alert. This activity is coordinated by a central node interacting with the Gaia data reduction pipeline all along the mission.

In 2010 and 2012, we had organized the first two workshops in order to initiate the network and to meet the participants. In 2014, almost one year after the launch of Gaia, we organize the third Gaia-FUN-SSO workshop in Paris in order to discuss further the coordination of the network of observing stations, to discuss the prelaunch training observations which have been performed and to prepare the network for the operating phase of the alert mode which must begin in 2015. During this workshop, the participants had the opportunity to be informed about the status of the Gaia mission, about the alert process for SSO and the ground-based data processing. They were invited to present their activities in relation with this program, or their equipment, instruments and observing sites. Large time slots have been reserved for discussions. This workshop was fruitful and articles have been gathered in these proceedings with the aim to keep track of these very interesting days.

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Co-chairmen of the Gaia-FUN-SSO 2014 Workshop

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