Proceedings of

GAIA-FUN-SSO 2012

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

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Foreword

The sequence of the observations of Solar System Objects (SSO) by the Gaia space astrometry mission will be constrained by its scanning law. Several detections of interesting objects may occur with no possibility of further observations by the probe. 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 for Solar System Objects, Gaia-FUN-SSO. This network is managed in the frame of the Coordination Unit 4 of the Gaia Data Processing and Analysis Consortium, DPAC-CU4, devoted to the data processing of specific objects. The goal of the network will be to improve the knowledge of the orbit of poorly observed targets by astrometric observations on alert. This activity will be coordinated by a central node interacting with the Gaia data reduction pipeline all along the mission. Taking into account this framework, we can understand how important are the opportunities to create opportunity of direct contacts among the participants of this network.

Two years after a kick-off workshop, we have organized a second Gaia-FUN-SSO workshop in Paris in September 2012 in order to further discuss the coordination of the observing stations, to get information from new participating sites and to discuss the prelaunch training observations which have been performed. 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. Also, they have been 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 and we think that the workshop was a new useful step toward an efficient ground-based organization for supporting this great mission. We thank all the participants for the fruitful exchanges.

Paolo Tanga, Lagrange/OCA
& William Thuillot, IMCCE/Paris Observatory

Co-chairmen of the Gaia-FUN-SSO Workshop 2012

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- Scientific council of Paris Observatory : *www.obspm.fr*
- IMCCE-Paris Observatory : *www.imcce.fr*
- Côte d'Azur Observatory (OCA) : *www.oca.eu*
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Summary

Gaia status

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Introduction

Gaia is an ESA cornerstone mission to map our Milky Way Galaxy in three dimensions. Gaia will provide a census of 1 billion objects by astrometry, photometry and spectroscopy. The science requirements are compiled to answer fundamental questions concerning the structure and dynamics of the Milky Way. Due to the unbiased surveying of the sky, Gaia will not only detect stars in our Galaxy, but also extragalactic sources and solar system objects which are the topic of this meeting. Gaia capabilities in our solar system is reviewed in this proceedings by Tanga and this paper focuses on the general Gaia capabilities and overall status of the mission.

1. Science capabilities

Gaia is primarily an astrometric mission. The high accuracy astrometry can uniquely be achieved only in space. The mission aims to enter into the new μarcsec domain with errors in bright star parallaxes below 10 μarcsec. In order to achieve such a high accuracy many technical requirements are imposed on the spacecraft. But there are also more 'scientific' requirements needed for astrometry. It is essential to make colour dependent corrections to the astrometric measurements. This can be achieved by measuring the spectral energy distribution of each and every object detected on the focal plane. The colour measurement on board Gaia is achieved with spectrophotometry which can also be used to deduce astrophysical quantities for the detected objects. With the astrometric and photometric limiting magnitude of 20, Gaia is anticipated to observe at least 1 billion objects. The third instrument on board is the radial velocity spectrometer. This is needed to get the sixth dimension of the position velocity phase space in addition to the five parameters gained by astrometric means. The line-of-sight velocity is achieved by Doppler shift of spectral lines in recorded spectra. The brighter magnitude limit for spectroscopy will result to a sample of 150 million objects having their radial velocity determined. For the brightest objects more fundamental astrophysical work can be done with the spectra. In addition to the three instruments a fundamental element of Gaia is the observing strategy which allows to cover homogeneously the whole sky in an unbiased way. This survey approach enables Gaia to be not only precise, but also accurate.

2. Science topics

In addition to the primary science goals concerning the Milky Way structure and dynamics, Gaia is going to address many other fields of astronomy. As already the topic of this SSO–FUN meeting suggests, Gaia is going have a significant impact to solar system studies. However, there is more. Accurate distances to stars allow significant progress to be made in all areas of stellar astrophysics. For binaries and multiple stars the high single epoch spatial resolution allows an unprecedented census. The 4π coverage will give better statistics of rare objects such as brown dwarfs, exoplanets and white dwarfs. Also beyond the Milky Way Gaia will provide measurements. In the Local Group the intrinsically brightest stars can be observed individually and any other point like extragalactic object will be observed just as it would be a star. This will result to some 1 million galaxies and half a million quasars which can at a later stage be used to align the radio reference frame to that of Gaia constructed at optical wavelengths. Last but not least Gaia is going to provide data which can be used for fundamental physics. At μarcsec accuracy level relativistic effects have to be fully accounted for as the photons traveling through our Solar System get bent before reaching the Gaia focal plane. At a later stage when accumulated data has been successfully used to compute an astrometric solution, it is possible to use the enormous redundancy in the Gaia data to test general relativity parameters at the highest possible precision.

3. Gaia vs. Hipparcos

The astrometric Hipparcos mission provided milliarcssec accuracies for more than 100,000 sources. By moving the limiting magnitude from 12 to 20, Gaia achieves the huge increase in the number of measured objects by reaching 1 billion stars. The much higher astrometric accuracy done for a much larger sample will result to a quantum leap to the knowledge of our Galaxy. When recalling the spectroscopic capability of Gaia, it is easy to be convinced that the science potential of the mission is orders of magnitude more than that was for Hipparcos.

4. Technical description

The fundamental property of the Gaia payload is the two fields of view which are combined into a single focal plane. The two primary mirrors have a fixed 106.5° basic angle between them. This angle is kept constant at levels below 10 μarcsec and on top of that monitored at levels below 1 μarcsec by dedicated hardware onboard. This well controlled and monitored basic angle is fundamental to Gaia astrometry in combination with high accuracy transit timing and homogeneous scanning of the sky. The combined fields of view are focused on the 106 CCDs in the focal plane providing the astrometric, photometric and spectroscopic measurements. While astrometry is done with a broad band white light filter optimized to provide as many photons as possible, the spectrophotometry is done with two prisms providing dispersion at wavelength ranges 330–680 and 640–1000 nm. The radial velocity spectrometer is operating in the wavelength range 847–874 nm where 11,500 resolution is achieved with a grating. All payload module elements are attached to so called Torus which is made of Silicone Carbide.

The high observing efficiency is gained by integrating on the fly when scanning the sky. In order to maintain the astrometric capabilities this scanning must be in perfect synchronization with the reading of the CCDs. The charge is moved on the CCD chip exactly with the same speed as the satellite is spinning keeping this way the point spread function unsmeared. The spin control is achieved by constant monitoring of the spin speed with on board star detection and speed deduction with attitude corrections done as needed with the micro propulsion system. In addition to the 6 h spin, the spin axis (at 45° with respect to the Sun) is precessing a full circle in 63 days and the spacecraft is located at L2 making a revolution around the Sun in a year. This three movement configuration allows the most homogeneous sky coverage as technically possible. On the average every source is observed 70 times over the 5 year mission. For Solar System studies it is unfortunate that the ecliptic plane is exactly the region where the temporal coverage is in general lower than the average.

5. Science data volume

The hardware technology for Gaia is very demanding, but also the data processing is a challenge. With the sheer volume alone it is easy to be convinced that serious planning is needed to cope with the data. 1 billion objects observed 70 times over 5 years translates to some 40 million objects a day (or some 400 million measurements a day). This requires extremely robust software engineering to cope with all peculiarities that may occur in operations. For spectroscopy due to the brighter limiting magnitude the 150 million objects will be observed 40 times on the average leading to 10 million measurements a day of some 3.3 million stars. These are impressive numbers when comparing with e.g. dedicated ground based spectroscopic surveys which in multi-year campaigns can provide as many spectra as Gaia in a week. In photometry the legacy value of the Gaia data is in the high spatial resolution and simultaneous coverage

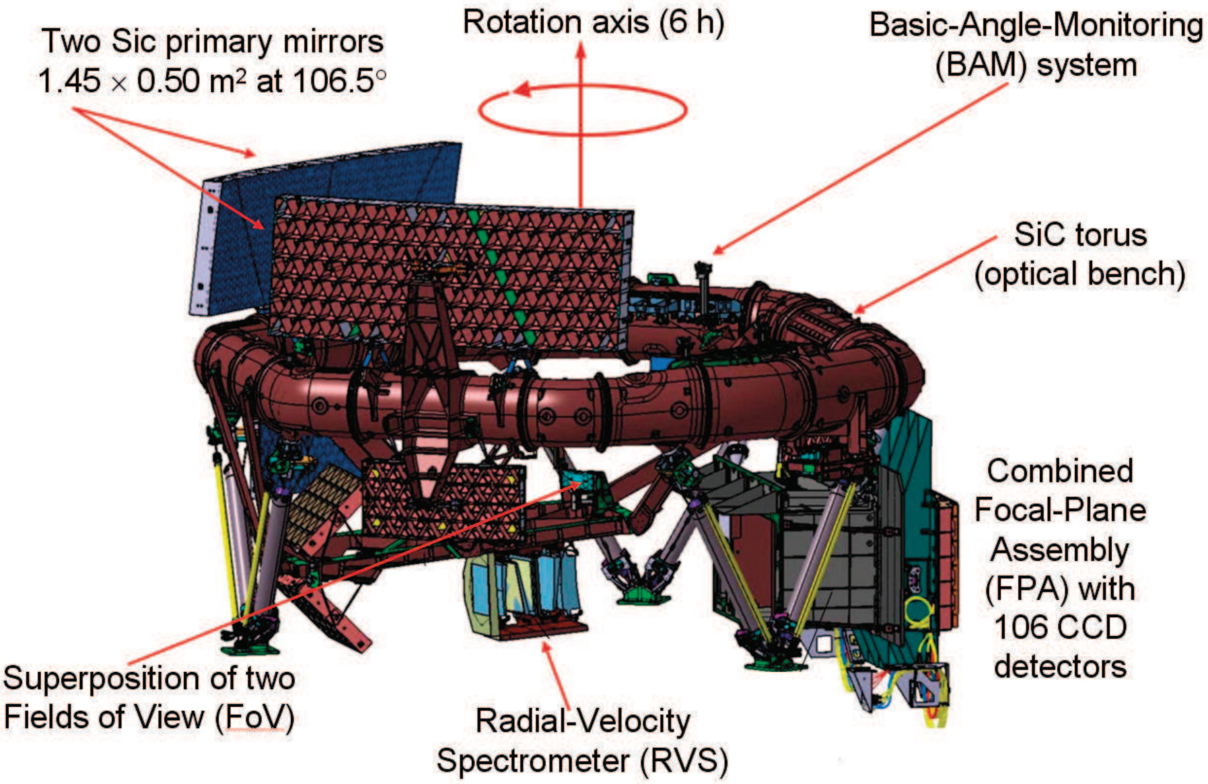

Figure 1: Schematic picture of the Gaia Torus with mirrors, radial velocity spectrometer and focal-plane assembly. Copyright EADS Astrium

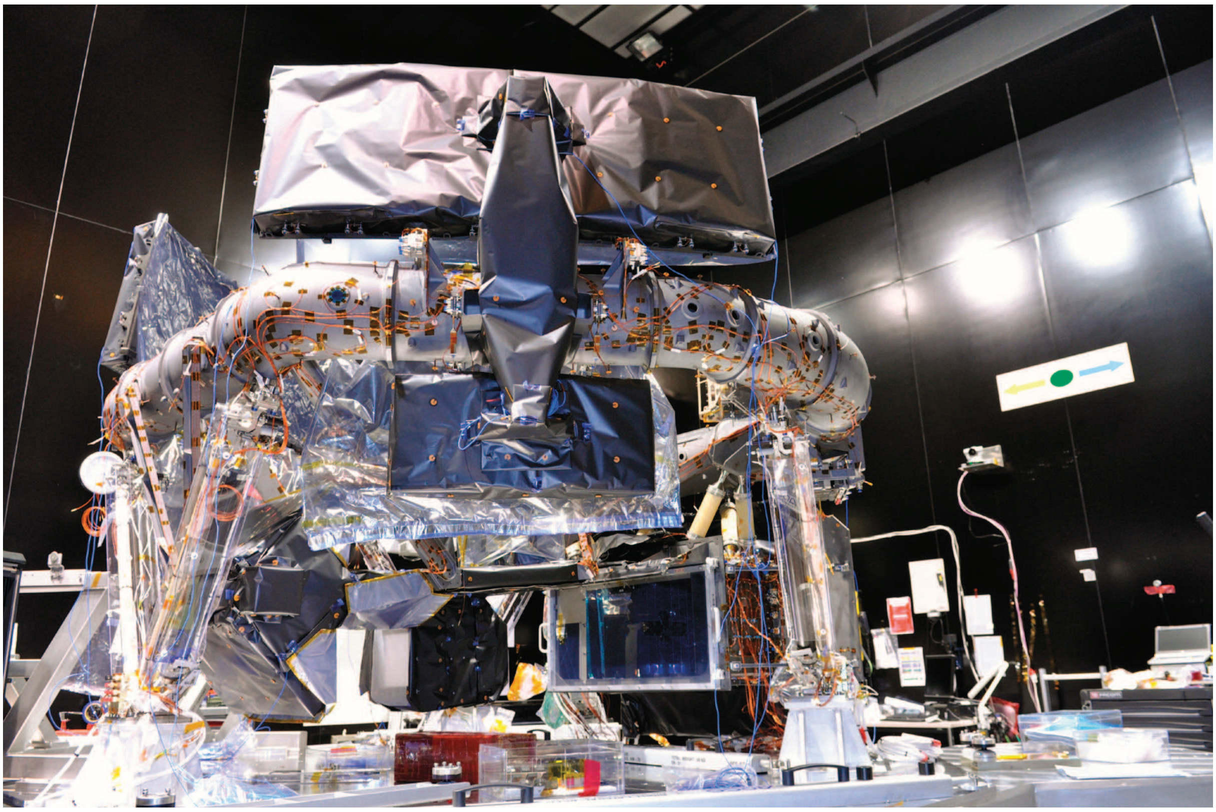

Figure 2: Current status of the Payload Module. Copyright EADS Astrium

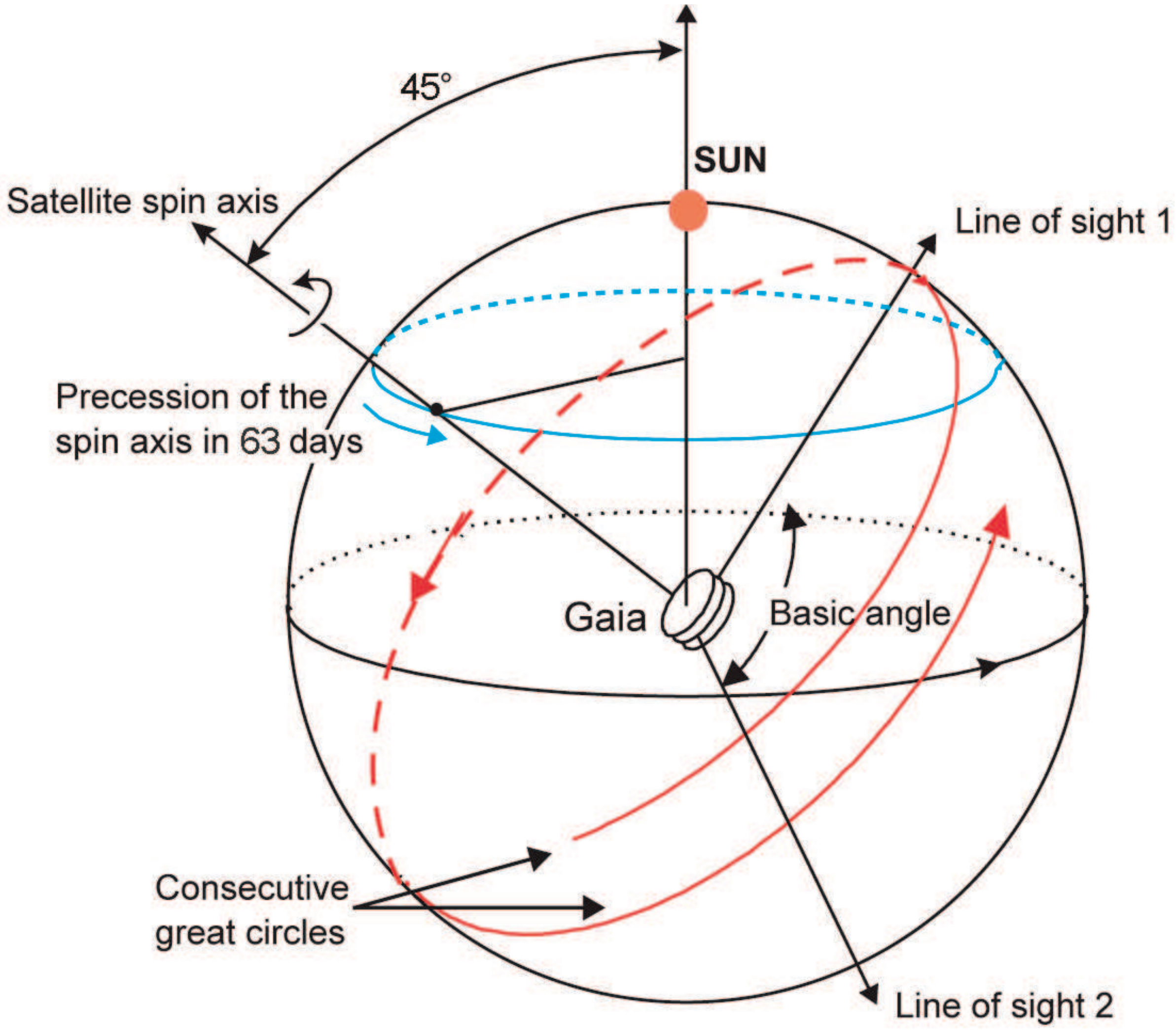

Figure 3: The scanning law.

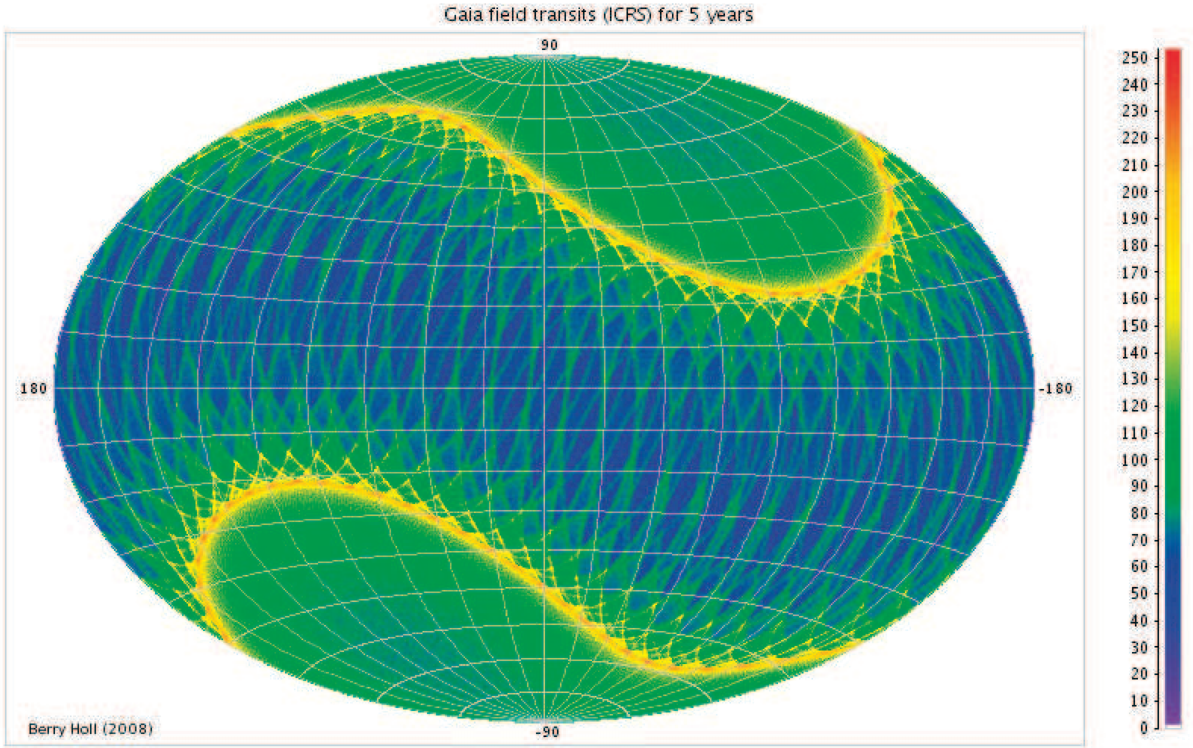

Figure 4: The sky coverage by Gaia after 5 years of nominal operations. Copyright Berry Holl

of the whole wavelength range at 70 epochs. While spectroscopy and photometry remain feasible from the ground and any single Gaia measurement can be repeated and improved if needed, the astrometric part of the Gaia mission remains unique far into the future.

6. Scientific performance

The design of Gaia is based on requirements set at the beginning of the project. As hardware is being built and various subsystems are integrated, it is possible to base part of the scientific performance estimates to real measurements from various tests although a major part of the calculation is still by analysis. A satellite project managed by ESA is subject to a series of reviews which offer occasions to summarize the scientific performance estimates. The last major review was concluded in October 2010 when Gaia successfully passed the Critical Design Review. This review provided the current science performance estimates which have not changes ever since.

Photometry can be summarized with millimagnitude precision for the magnitude range 6–13 and thereafter factor of ten worse at 17 and another factor of ten worse at 20 magnitude. For astrometric white light these precisions can be achieved at single epoch with one CCD (and there are 9 astrometric CCD measurements per transit which allows higher precision for transit photometry) while for the spectrophotometry these precisions are for the end of mission for the full two wavelength ranges. Accordingly epoch photometry, especially when limited to fractions of the spectral ranges, has a lower precision.

The spectroscopic requirements are defined as end of mission radial velocity accuracies. For the bright stars 1 km/s is achieved while for the very faintest ones values between 8 and 13 km/s are reached depending on the stellar spectral type. This performance allows the original aim to do additionally astrophysical parameters from spectra to a rough limiting magnitude of 12.

In astrometry the bright star parallax error is below 10 μarcsec and 25 μarcsec for 15 magnitude stars. At magnitude 20 blue star (B1V spectral type) have parallax error of 330 μarcsec, G2V type star of 290 μarcsec and M6V star of 100 μarcsec. For the solar system targets single epoch astrometry is more

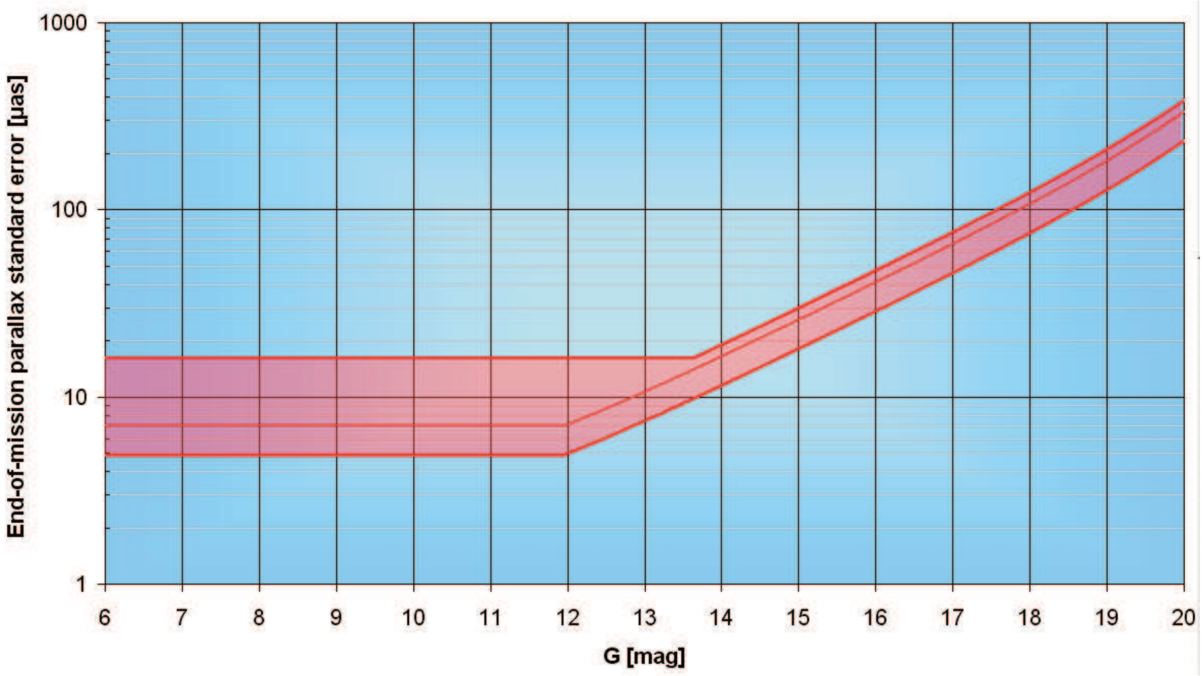

Figure 5: The end of mission astrometric performance estimate expressed in terms of parallax standard error against magnitude. The end of mission parallax standard error gives roughly the single epoch astrometric accuracy in scanning direction (i.e. in one dimension only) when the y-axis values are multiplied by factor of 4.3. For Solar System objects this is a maximum performance as their apparent movement against stars deteriorates the position determination. The faster the movement the worse the precision.

relevant and can be 20 μarcsec at best for the brightest objects in the scanning direction. Naturally the movement of solar system objects with respect to the stars will smear the image on the focal plane making the position determination less precise. All in all Gaia science performance estimates are close to the original requirements allowing the anticipated science topics to be addressed.

7. Schedule

The current schedule for Gaia has the launch date in October 2013. The Service Module has passed all tests and few retrofits of subsystems with changed components is on-going. The Payload Module is at the moment of writing this contribution under thermal balance and thermal vacuum test. These tests will give the best on-ground verification of the in-orbit performances. After completion of the thermal tests the Payload Module and Service Module will be integrated early 2013. The launcher for Gaia, Soyuz-013, is already being manufactured.

Conclusion

Gaia is a cornerstone mission with a tremendous science potential. The current schedule and the scientific performance estimates predict that the first Gaia intermediate releases can be expected 2015. This is noted by the astronomical community. The expectations are high and at the moment all signs are positive that Gaia will indeed change the astronomy just in few years time.

The Gaia Science Alert System: Goals, principles and constraints

by F. Mignard (Lagrange, OCA, France)

Abstract

I will present the current status of the Gaia project, both from the viewpoint of the spacecraft manufacturing and the data analysis preparation. I'll put special emphasis on the acquisition peculiarities for the solar system alert system impacting on the quick availability of the data.

(Article not received)

Gaia and Solar System Objects

by P. Tanga (Lagrange, OCA)

Abstract

The observers in a ground-based network for Gaia support need to be aware of the properties of Gaia data for being able to exploit the information which is provided by the data processing chain. The case of Solar System objects is introduced, along with the potential of scientific exploitation. It is expected that Gaia will mainly contribute in the domain of physical and dynamical properties of asteroids and planetary satellites, whose largest majority will already be known. Nevertheless, a small fraction of discoveries can be expected. New asteroids observed by Gaia can be relevant under several aspects, namely for the completion of the inventory of the Main Belt population and for the identification of new Earth-crossers at small solar elongation. The region of the "Inner-Earth" objects is particularly interesting as it has been poorly sampled by surveys up to now. Also, the possibility of observing Earth and Mars trojans will be discussed. Given the scanning mode of operation, Gaia won't be able to follow individual objects, and the faintest ones close to its investigation limits (V=20) could have very poor sampling of their orbits. For this reason, a ground-based follow up is mandatory.

(Article not received)

Photometric Science Alerts from Gaia

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Introduction

ESA's Gaia mission will be launched in late 2013 and will observe the entire sky for 5 years providing ultra-precise astrometric measurements (positions, parallaxes and proper motions) of a billion stars in the Galaxy. The astrometry will be derived from multiple observations of each source at different scanning angles. Hence, naturally, Gaia becomes an all-sky multi-epoch photometric survey, which will monitor and detect variability with millimag precision down to $V = 15$ mag and about 0.01 mag precision down to $V = 20$mag. Gaia will also be able to detect new objects appearing in its field-of-view thanks to the window allocation system in the first CCDs in the focal plane. This includes most classes of transient phenomena like supernovae, novae, microlensing events, asteroids, etc.

In the first part of this proceedings we describe the design of the Gaia Science Alerts system, which will run daily at the Institute of Astronomy in Cambridge, UK, and is responsible for the detection and classification of photometric transients. In the second part we briefly describe potential scientific opportunities related to Gaia alerts. Thirdly, we present the status of preparations for the alert verification phase in the early days of the mission. We conclude with an invitation to collaborate in the ground-based follow-up Gaia alerts.

1. Gaia Science Alerts system

Data flow

The alerting system, called AlertPipe, will be run on a daily basis at the Institute of Astronomy in Cambridge (part of the Gaia Data Processing and Analysis Consortium, DPAC). Gaia satellite will reside in the 2^{nd} Lagrange Point (L2) and the data gathered during the scanning of the sky will be downlinked to the ground every day during an 8h window of visibility. The data will be then transferred to DPAC nodes in Germany and Spain where it will be pre-processed during the Initial Data Treatment (IDT) process. One of the main tasks of the IDT is to crossmatch all star detections with previous Gaia detections (in early days of the mission it will rely on the Initial Gaia Source List, a catalogue compiled from a variety of existing ground-based observations). As soon as IDT finishes processing a data packet, containing typically about 50 million objects, it will be transmitted to Cambridge and analysed by the AlertPipe. The total lag between an observation and the AlertPipe processing and alerting is expected to vary from a few hours to 48 hours, and depends on many factors, including the region of the sky (high stellar density regions lead to a delay in downlink for faint targets) and brightness of the object (downlinking order depends on the brightness, however not linearly).

Gaia sampling

The observing strategy across the sky, called the Nominal Scanning Law (NSL), is a pre-defined pattern, optimised for the final astrometric solution [5], and ensures that most of the stars will obtain, on average,

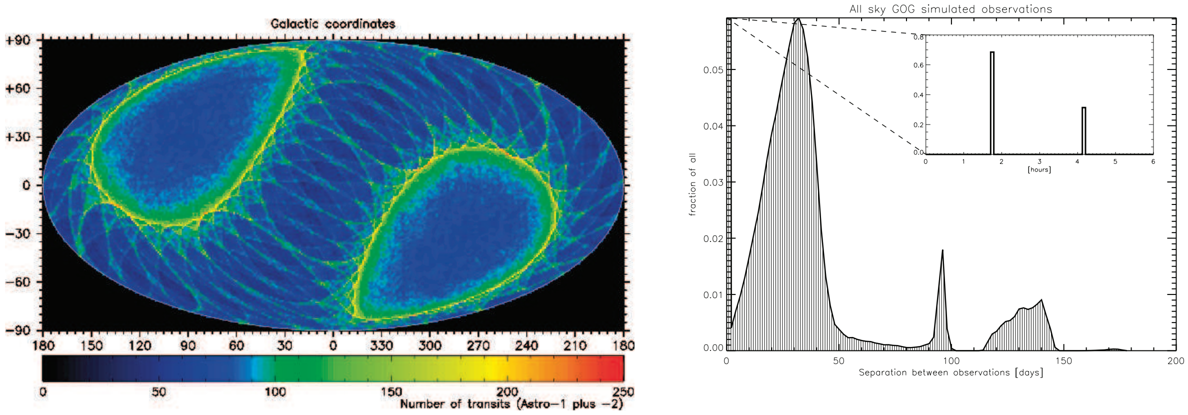

Figure 1: Left: Sky scanning pattern of Gaia showing the number of observations for each object in Galactic coordinates. Regions of the Galactic Centre will have about 50 data points, whereas high density regions, at ecliptic latitude 45 and -45, will have about 200 measurements. Right: Time sampling pattern of Gaia (time difference between two subsequent observations) is dominated by the 106 mins separating the two telescopes. The Gaia spacecraft spins once every 6 hours.

about 70 measurements at different scanning angles. Some areas of high stellar density such as the Galactic Bulge will only have about 50 measurements during the entire mission. On the other hand, regions within a few degrees of ecliptic latitudes of ±45 degrees will be scanned approximately 200 times, see Fig. 1

Gaia consists of two 1.4m mirrors set at angle of 106.5 degrees perpendicular to a slowly precessing spin axis. One full rotation of the satellite takes exactly 6h, therefore the preceding and following fields-of-view will observe the same patch of the sky with a separation of 106.5 minutes. After this pair of observations there may come another pair (and many other pairs at the ecliptic nodes at b±45 deg), but due to the precession of the spin-axis, in most cases the fields-of-view will quickly precess out of that area of the sky. Typically, the same field will be observed again after 30 days or more, see Fig. 1.

Detection

The anomaly detection system within the AlertPipe depends on the crossmatch information from the IDT such that sources not matched with known objects are flagged as “new”. All new objects passing a detection threshold (early in the mission set to about G=19) will be first checked against possible asteroid positional coincidence[1] and all surviving candidates for new transients will pass to the next stage, the classification.

Known sources, namely those with some prior observations, will be checked to see if the new observations are in any way anomalous with respect to the data gathered so far by Gaia. The AlertPipe stores all observations of all objects and at this stage runs various detection algorithms in order to check against anomalies, for example, mean–*RMS* detector or simple *delta-magnitude* threshold detector. Each of the detectors is sensitive to a different kind of anomalies and some are more suitable for different stages of the mission, depending on the amount of historical data available. The thresholds of the detectors are tuneable during the entire mission and will evolve with the increasing amount of gathered data and better understanding of the instruments.

The focal plane of Gaia contains 9 columns of CCDs on which the brightness and position of an object is measured during a scan. This means that a single transit will contains 9 data points, each separated by about 4.4 seconds. This allows not only for immediate ruling out of cosmic rays and other instrumental artefacts affecting the photometry, but also for testing the short-term variability of any source.

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[1] The asteroids are being recognised from these new IDT sources by a parallel alerting system running within DPAC, see papers by W.Thuillot and P.Tanga in this volume of proceedings.

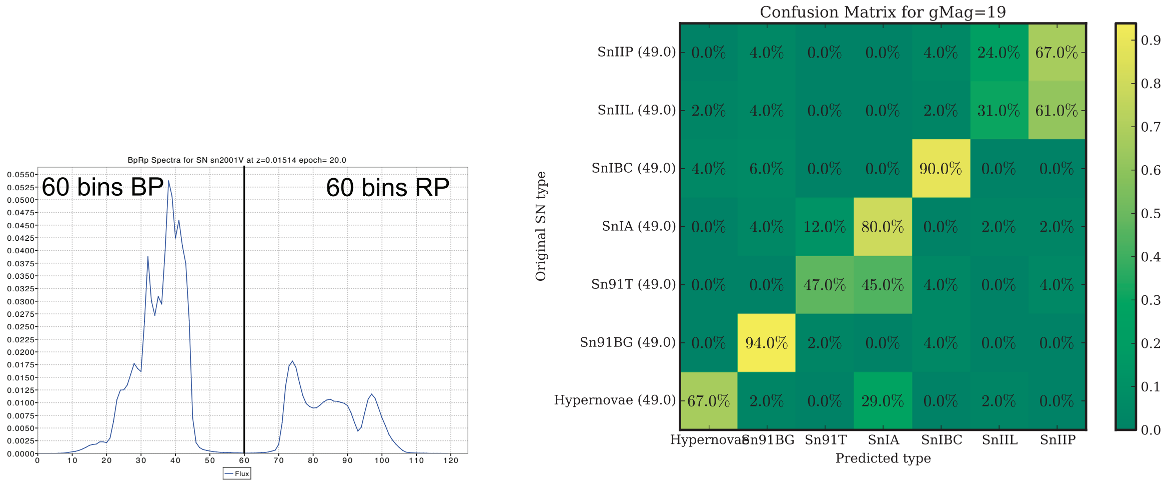

Figure 2: Left: the spectrum of type Ia supernova as seen by Gaia's Blue and Red Photometers (BP/RP). The resolution of about R∼100 is enough to unambiguously derive the type, epoch and redshift of most supernovae down to ∼19 mag. Right: confusion matrix for supernovae BP/RP spectra classification at 19 mag. Most major types are recognised with relatively low confusion.

Classification

The next stage of the AlertPipe data processing is responsible for the preliminary classification and filtering of detected candidates for alerts. This will employ both photometry and low-resolution spectroscopy from Gaia. The Blue and Red prism-based Photometers (BP/RP), installed on the focal plane after the astrometric CCDs, will cover spectral ranges 330-680nm and 640-1000nm, respectively, with resolution of R∼100.

Most of the Gaia observations will come in pairs separated by 106.5 minutes and in case of most transients the downlinked daily portion of data will contain both observations. This will not only provide a double check on the possible transient candidate, but is also suggestive of a light curve classifier which can exploit the flux-gradient as an indicator of object type. For example, a simple slope-amplitude Bayesian classifier can provide a probability distribution for a transient being a cataclysmic variable, supernova or long period variable, popping up from the background. Tests of such classifier performed on the SDSS Stripe82 and OGLE data have shown that with just two data points we are able to distinguish between these major types of transients with relatively high accuracy.

Many more 'features' are available to aid with classification, including the BP/RP spectra. Simulations with Gaia BP/RP spectra for Supernovae have shown that most detections by Gaia can be further subclassified by type, epoch and redshift for transients brighter than 19 mag. This unique capability of Gaia will help to improve our classifications, and will allow for more targeted high-resolution spectroscopic follow-up.

The filtering and classification of the transient events will be supplemented by contextual information obtained from available archival catalogues, for example, 2MASS, SDSS, ASAS, OGLE, HST, VISTA and so on. Known variable stars will be crossmatched with candidate transients and supernova or tidal disruption event classification will be enhanced if a galaxy can be associated with the event. We will also cross-match our candidate alerts with recent alerts reported by other transient surveys, on-going during the Gaia mission.

Data dissemination

All Gaia alerts will be public immediately after discovery and preliminary classification. The alerts will be disseminated to the astronomical community via a number of protocols, including traditional email

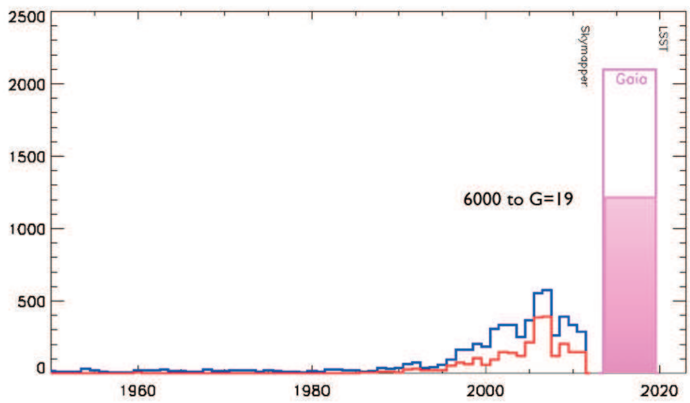

Figure 3: Supernovae detection rate per year. Gaia is expected to detect 6000 SNe down to 19 mag, with 1/3 of them discovered before the maximum brightness. With the detection threshold at 20 mag Gaia might see even 2100 supernovae a year.

and web server, as well as machine readable means like VOEvents. Each alert will provide coordinates of an event, a light curve collected so far by Gaia, BP/RP spectrum and the results of the cross-match and classification analysis.

Early in the mission, during the verification phase, the alerts from Gaia will only be available to a dedicated team of telescopes and astronomers involved in the alerts verification, to assure the robustness of the detection and classification pipeline (see more below).

2. Scientific opportunities

The scanning law and the time lag between observation and analysis makes the Gaia transient survey more sensitive to longer events (those lasting from a couple of hours to months). These include: supernovae, dwarf novae, classical novae, microlensing events, tidal disruption events, R CrB-type stars, FU Ori-type stars and Be stars.

Supernovae and other extragalactic transients

In its unbiased search for supernovae, Gaia will be capable of detecting in total about 6,000 SNe brighter than G=19 (10,000 to G=20) [1]. One third of those will be detected before maximum, which will allow for detailed follow-up and studies of supernova evolution. With 3–4 supernovae discovered every day, it will require well-organised follow-up, as the Gaia data alone will not be enough to provide sufficiently detailed light curves, e.g. needed for cosmological applications of the SNe.

As mentioned above, Gaia will provide an auto-follow-up of its own targets with low-resolution spectra available for every source. This will also allow for rapid recognition of unusual and rare types of supernovae, for example, Super Luminous SNe [6], which reach -23rd mag (absolute), or Luminous Red Novae, which bridge the gap between classical novae and supernovae [4].

Gaia will not be best-suited for real-time discoveries of optical afterglows of Gamma Ray Bursts. Nevertheless, simulations predict that it should be able to detect about 20 brighter and longer GRBs and Orphan Afterglows[3], for which timely follow-up would be critical.

Microlensing Events

Gravitational microlensing events, the temporal brightening of distant stars due to the mass of a foreground lens passing in front, typically occur in the densest regions of the sky, i.e. the Galactic Bulge and the Galactic Plane. About 2000 such events are currently being detected every year by the dedicated microlensing surveys OGLE[10] and MOA[8]. Among the lensing systems more than a dozen planets have been found, e.g. [2]. Significant results would also include detections of brown dwarfs and black holes, studies of stellar atmospheres and investigations of the structure of the Galaxy.

The central regions of the Galaxy will continue to be monitored by the OGLE and MOA surveys during the Gaia mission, however, any microlensing events found outside of these fields will require an intense photometric follow-up in order to make them scientifically useful. We expect Gaia to detect about 1000 microlensing events from all over the sky.

Interestingly, Gaia's astrometry will be able to provide very precise measurements of the lensed source displacements, caused by microlensing. Combination of Gaia's astrometry and photometry, with more densely sampled ground-based photometry could lead to the derivation of the mass of the lens, including discoveries of lenses from the stellar remnant population, like neutron stars or black holes.

R CrB-type stars

These mysterious stars exhibit spontaneous and unpredicted dimmings in their light curves by as much as 8 magnitudes. Catching such events "red-handed" and triggering detailed photometric and spectroscopic studies would allow for a much better understanding of the nature of these stars, thought to be linked with the stellar mergers. This is turn may help decipher supernova progenitor models. There are about 50 R CrB-type stars known in our Galaxy, found mainly during large scale photometric campaigns of MACHO, OGLE and ASAS surveys, e.g. [9]. Gaia should find many new examples of these stars at fainter magnitudes from all over the sky. BP/RP spectroscopy will help with the classification of these objects.

Other types of transients and the Watch List

Gaia will detect numerous cataclysmic variables, located primarily in the Galactic Plane, providing a uniform large sample of these objects. We expect also to alert on very rare events like outbursts FU Ori- or EX Lup-type young stars, of which only a handful is known. Outbursts of Be-type stars will also be detected by Gaia alerting system. There should be up to 600 events during the entire mission for Be stars brighter than 12 mag, giving an opportunity for detailed high-resolution spectroscopy of these objects during outbursts.

We plan also to provide near-real-time Gaia photometry of a limited number of selected interesting targets, known for their erratic behaviour. For example, a known FU Ori-type star can be on the Watch List and whenever it is observed by Gaia, the most up-to-date brightness measurement will be made available, allowing for continuous monitoring of the object.

3. Alerts Verification

Gaia is expected to be launched from French Guyana in the end of 2013. It will take about two months to reach the L2 and another two months to get all the systems fully operational. For the next 1 or 2 months it is planned that Gaia will operate in a special Ecliptic Poles Scanning mode, during which both Ecliptic Poles will be intensively observed (the satellite precession period will be slowed down significantly). During this stage the data analysis systems will be vigorously tested, including the alerting system. After that period, Gaia will start its regular scanning of the entire sky, but the alerting system will be turned on gradually, waiting for enough observations to be gathered for a reference for detections of transients. As soon as there is enough data collected for some regions of the sky, for example, requiring at least 10 prior observations, the alerting system will start operating.

It is ESA's policy that all Gaia data become publicly available. However, before the alerts start flowing to the astronomical community, the detection and classification system has to be verified to assure good quality and robustness of public alerts. Therefore, for the first couple of months of the functioning of the alerting system we envisage a Gaia Alerts Verification Phase, during which the end-to-end alert system will be thoroughly shaken down by a dedicated team of astronomers working in collaboration with the AlertPipe developers. Some aspects of the verification can start during the Ecliptic Poles scanning, for example classification of large numbers of known variable stars [7]. The Verification Team (VT) will see some of the first Gaia data and will have a chance to prepare for the follow-up of the Gaia alerts when they become openly available.

Therefore we issue an invitation to get involved in the early verification of the Gaia Alerts system. Verification observations will validate the outcome of the alerting pipeline and will involve e.g.: confirming the alert, building a detailed multi-band light curve and obtaining a spectrum. Because the magnitude range of Gaia alerts is wide (G=5–20) we welcome observers equipped with telescopes of any size. Longitudinal and latitudinal coverage on the globe will be needed in order to assure accessibility and long-term visibility of the targets.

Potential members of the VT, should pass a couple of infrastructure tests, including performing a number of follow-up observations of alerts from current surveys, e.g. Catalina Real-Time Transient Survey[2]. The data should be reduced promptly and submitted for verification to the central repository. The verification network is currently being formed and should be ready for operation by the end of 2013. For more details visit the pages of Gaia Science Alerts Working Group[3] or contact the authors.

Conclusion

From mid-2014 the Gaia mission will begin to deliver near-real-time alerts on anomalous or transient events from the entire sky down to G=20. The G-band photometry and BP/RP low-dispersion spectrometer will allow early detailed classification, and in the case of supernovae will also provide an estimate of the redshift and epoch. Before the alert stream becomes publicly available, a period of verification will take place in the first months of the mission. For this we encourage an involvement from small and large telescopes from around the globe.

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The SSA NEO Segment and Gaia: present opportunities and future developments

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Introduction

One of the major elements of the ESA Space Situational Awareness (SSA) programme is devoted to NEO hazard monitoring through the set-up and the operation of a dedicated data centre [1]. This implies the availability of advanced systems for orbit computation and impact monitoring, the possibility to store and retrieve all relevant data (orbital parameters, physical properties, raw image archives etc) and the coordination of NEO observations for discovery and follow-up. Thus the aim of the SSA NEO Segment is to become a worldwide reference for potential SSA customers and stakeholders such as the scientific community, governmental institutions, insurance companies and the public at large. The NEO Segment is presently in the Precursor Services phase and the deoployment of a NEO Data Centre at ESRIN (Frascati, Italy) has been successfully achieved.

Within this framework, there are many opportunities for fruitful collaborations between the Gaia Follow-up Network of Solar System Objects (Gaia-FUN-SSO [2]) and the SSA-NEO Segment. The Gaia scanning law determines a peculiar pattern for observing at low solar elongations and the onset of fast and reliable communication between the respective follow-up networks could greatly contribute to optimize the observation of high-priority targets. In this respect the relatively small wide field telescopes characterizing NEO observations and the large-diameter telescopes available to the Gaia-FUN-SSO address complementary observational requirements. The availability of Gaia NEO spectrophotometric observations can also provide valuable information for risk assessment and mitigation. Finally, the involvement of the NEO Segment into the international coordination efforts for hazard warning and mitigation (e.g. UN Action Team 14) would provide the necessary framework for the NEO-related Gaia data products.

1. The NEO Segment

2.1 *System Design*

Because of the intrinsic nature of the asteroid hazard, the SSA NEO Segment needs to be considered in an international context. It represents the European contribution to a world-wide effort for assess and mitigate the NEO impact risk, thus entering a scenario where many countries are actively participating in an international coordination devoted to this end. Since 1998 the contribution of NASA is prominent, acting under a specific mandate from the US Congress : as a consequence there is the need for Europe to provide a contribution which is technologically and scientifically competitive. This has been a key design issue of the architectural studies for the SSA-NEO Segment [3]: to support the already existing European expertise in NEO studies, while further expanding its domain of intervention.

The deployment of a NEO Data Centre exploiting the European worldwide excellence in orbit determination and impact monitoring, as provided by the long-standing operational experience offered by the NEODyS system [4], was recognised as a major design driver of the SSA NEO Segment. The expertise of the European scientific community in asteroid physical characterization and the possibility of an incremental implementation of the NEO Data Centre to become a worldwide authoritative data source on small solar system bodies added further momentum to both the final operational system design and to the Precursor Services scenario.

Federating existing European assets, such as telescopes and radars under NEO Data Centre coordination was also envisaged for follow-up (i.e. tracking) purposes, since this function was (and still largely is) performed by the scientific and amateur communities on a voluntary basis. Dedicated SSA NEO tracking facilities ready to observe even upon short notice could then significantly contribute to the orbit improvement of already known/recently discovered objects leading to a better evaluation of the corresponding impact probabilities. The European expertise in follow-up coordination provided by the Spaceguard Central Node priority list and the availability of European assets such as the La Sagra Sky Survey (LSSS) and the ESA OGS (Optical Ground Station) facility provide the basic observational scenario.

As concerning NEO survey and discovery, the overwhelming US supremacy in the field deserved to be carefully investigated. The efficiency of a European "Wide Survey" scenario aimed at discovering small (10 – 50m in size) NEOs approaching the Earth using innovative "fly-eye" telescope technology was demonstrated by extensive simulations [5]. The aim is to ensure a complete coverage of the whole visible sky at least twice per night with sensors characterized by a large field-of-view (about 45 square deg) and a high sensitivity (reaching down to 21.5 limiting magnitude). A "Wide Survey" as such could guarantee the European competitiveness on a class of small hazardous objects: the US surveys are in fact designed for fulfilling the Government mandate of discovering 90% of NEOs larger than 140m (which is the treshold between a local damage and a global catastrophe).

This choice fulfils at best the SSA NEO Segment users and customers needs because the events that small impactors are likely to produce (fireballs, meteorite falls, small cratering) are less catastrophic and more frequent. Moreover it allows to increase the warning time from discovery to impact, extending also to space the possibility of a mission devoted to early warning especially for objects coming from the direction of the Sun.

Summarizing, the NEO Segment design [3] foresees three major elements:

- *Wide Survey*: a network of optical telescopes performing an all-sky survey focused on the discovery of small size, potentially hazardous objects
- *Small Bodies Data Centre:* in charge of the downstream data processing (astrometric data collection, orbit determination, risk assessment, follow-up coordination) and the provision of NEO-related services (raw image archives, physical properties and fireball databases, precovery etc.)
- *Collaborating Observatories:* for dedicated astrometric and physical follow-up (under Service Level Agreements) as well as for unsolicited and serendipitous observations coordination (e.g. amateurs, space telescopes, etc.)

The set up and the operation of a NEO Data Centre located ast ESRIN (Frascati, Italy) during the SSA Preparatory Programme phase (2008-2012), has been the first step in this direction. The funding of the follow-on NEO Segment activities successfully achieved at the recent ESA Ministerial Council (November 2012) has provided the necessary ground for further developments.

2.2 *Precursor Services*

In order to guarantee all basic functionalities needed for impact monitoring activities, the NEO Data Centre relies on already existing expertise, software systems and databases. In particular :

- NEODyS - Near Earth Object Dynamic Site – developed at the University of Pisa and currently operated by SpaceDys represents an authoritative source of data for NEO orbit characterization and impact monitoring. Access to its data is essential in order to provide state-of-the-art information on the NEO hazard.
- EARN – Near-Earth Asteroid Research Node - maintained at DLR, aims to gather NEO physical data into one single source site. The availability and the update of these data allows to harmonise NEO orbital and physical information.
- SCN – Spaceguard Central Node - developed at INAF, offers on-line services for optimising follow-up observations of NEOs at risk of being lost. In particular the "Priority List" has shown to be extremely effective to this end and has been integrated into the NEODC during SN-III.
- NEO observations are performed by many European amateur and professional observatories, e.g. the highly successful La Sagra Sky Survey and the ESA OGS station. Their collaboration with the SSA program foresees perfroming follow-up observations and contributing to the growth of the image database available at the NEO Data Centre.
- AstDyS - Asteroid Dynamic Site: developed at the University of Pisa and currently operated by SpaceDys represents an authoritative source of data for asteroid orbit characterization, observation quality control and proper elements. Although AstDyS is not primary concerned with NEO data (it addresses other solar system bodies: Main Belt Asteroids, Trojans, TNOs, Centaurs etc) it provides a fundamental service to NEO observers (it is not possible to observe NEOs without observing a much larger number of MBAs).

The NEO Data Centre is organised as a dynamic three-layer structure, including a database, the related services and an interface (Web Portal) allowing interrogations of the database and as placeholder for additional services. The current version provides the necessary tools for searching and visualizing NEO data to external users and applications and other advanced features addressed to more experienced users. The portal is available at the following location: http://neo.ssa.esa.int/

The early deployment of the Precursor Services has allowed gaining an understanding of the technical issues involved and of the interfaces needed to establish and carry out operations, maintenance and upgrading of the system. Moreover the web portal has been designed in order to be ready to further expand both, the functionalities and the services. Near Earth Comets are expected to enter the NEO database as well as Fireball data, thus encompassing all celestial objects which are likely to come in the vicinity or actually hit our planet.

Therefore the SSA NEO Data Centre has the potentiality to represent a unique facility in the NEO scenario because it hosts data and services which are at present addressed by different institutions, often being physically and logically separated (e.g. the share between the Minor Planet Centre and the JPL Near Earth Object program, the former focussed on orbit determination and cataloguing functions, the latter on impact monitoring).

2. Space based assets

The contribution of space-based assets to NEO observations has been investigated during the SSA preparatory phase. Present and future space missions, either specifically devoted to observing NEOs or having a different primary target have been checked for their potential benefits to impact monitoring [6]. Results are summarized in Table 1.

Table 1: Present and future missions which could perform NEO observations from space (note that the Asteroid Finder mission has been recently cancelled)

	Herschel	**BepiColombo**	**Asteroid Finder**	**NEOSSat**	**Venus Express**	**Rosetta**	**NGO**	**Gaia**
Primary mission	Infrared observatory	Mercury exploration	NEOs	NEOs	Venus exploration	Comet exploration	Gravity-wave observatory	Star catalogue
Operator	ESA	ESA	DLR	CSA	ESA	ESA	ESA	ESA
Nominal operation dates	2012-2017	2014-2020 cruise 2020-2021 Mercury	2013-2014	2012-2013	2011-2012	2014-2015	?	2013-2017
Instrument type	IR telescope	3x star trackers	Optical telescope	Optical telescope	2x star trackers	Optical/IR telescopes	Laser interferometer	Dual optical telescope
Limiting Magnitude	- ?	5.2-14?	18.5	20	5.5-14.2?	12 (WAC) 16 (NAC)	N/A	20
Observable region	All sky Sun-LoS angles down to 60.3°	All sky from Mercury	All sky Sun-LoS: 30°-60°	All sky Sun-LoS: 45°-55°	All sky from Venus	Depending on allowable manoeuvres	Objects intersecting the trajectory of Sun-Earth L1 point	Celestial Sphere Sun-LoS: down to 45°
Field of view	0.25°	20° (cone)	2x2°	0.85°	16.4°	2°x2° (NAC) 12.1°x12.7° (WAC)	N/A	0.7°x0.7°
Observation strategy	Fine pointing / scan law modes	Close-range passive detection	Sky survey from sun-synchronous orbit	Sky survey from sun-synchronous orbit	Close-range passive detection	Pointing on demand	Close-range passive detection	Optimized for uniform sky coverage
Type of observations	Follow-up Physical observations	Follow-up	Discovery	Discovery Follow-up	Follow-up	Follow-up	Discovery	Discovery; Physical observations
Expected return	Low	Very Low	Very high CANCELED	Very high	Very low	Low	Very Low	High

We remark the following:

- Infrared observations from space are very effective for both, NEO detection and follow-up; however, the corresponding missions are expensive because of the specialized payload, and have a more stringent operational lifetime because of the cooling requirements.
- When the primary goal of a mission is not NEO detection, there can be consistent limitations to both perform dedicated observations and access the data processing pipeline.
- Low-earth orbiters devoted to NEO observations represent a cost effective option for space-based observations (both Asteroid Finder and NEOSSat are very small -100 kg- satellites).
- Although the WISE mission was devoted to mapping the infrared sky it has been very successful also in observing NEOs, and much can be learned from it. In particular:
    - many low solar elongation objects could be detected;
    - only the objects which were then tracked from ground-based observatories within a few days of their first detection resulted in having good quality orbits.
    - collaboration with the MPC and with the worldwide NEO observation network played a crucial role.
    - objects in peculiar orbital configurations have been found by post processing the image set released after the end of the mission; challenging ground-based follow-up was then necessary to confirm the discoveries (e.g. WISE 2010TK7 needed the 3.6m Canada-France-Hawaii telescope)
- The exploitation of star trackers and cameras on board interplanetary missions could be attempted provided that they are used in a different way (e.g. Venus Express long exposure strategy) or designed ad hoc (BepiColombo). Searching for NEOs by post processing images taken during primary mission operations is also a viable option (presently under study for Rosetta). Even if these techniques are not expected to produce a large amount of detections, nevertheless they could give a significant contribution in peculiar cases

- Gaia is equipped with two telescopes reaching sufficiently high limiting magnitude and its attitude dynamics allows observations at low solar elongations. This favorable configuration can be exploited for detecting NEOs, even if the scanning law is not optimized to this end.

3. Gaia observations simulation

Simulations have been run in order to explore the performances of the Gaia mission when observing small bodies at increasing distances from the Sun [6]. In particular, a fictitious population of low inclination circular orbits with radius between 0.71 and 1.11 AU has been generated; to each object has been given an absolute magnitude of 18.12, which approximately corresponds to an asteroid with albedo 0.1 (C-Type) and 1 km diameter. In this way it was possible to highlight some characteristic patterns of Gaia observing moving solar system objects, which would have been hidden if a more complex (and realistic) NEO population were considered.

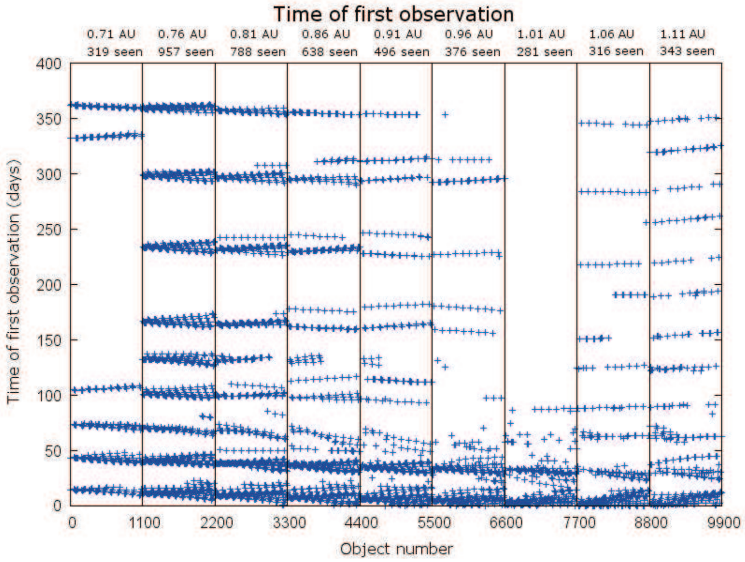

Fig. 2: Time of first detection from Gaia for objects belonging to the fictitious population described in the text. The simulation time was 1 year; only objects with an apparent magnitude less than 20 were accounted as seen.

From Figure 2 it can be seen that the time of detection of new objects is not randomly distributed but it occurs at intervals of about 31.5 days. This periodicity can be explained by the fact that when the Gaia spin axis crosses the ecliptic (which happens twice during a full 63 day precession cycle) then the LoS sweeps through the ecliptic plane at the lowest solar elongation possible (45 deg) thus allowing the detection of the lowest semiaxis objects.

The lack in Figure 2 of objects with semimajor axis close to that of the Earth is possibly due to their long synodic period when compared to the simulation time (1 year). The consequence is that the objects starting in favorable observing conditions are discovered almost immediately, while those in bad observing geometries will slowly exit the 90º "blind zone" centered on the Earth-Sun direction. As an example a 1.1 year revolution period corresponds to a synodic period of 11 years, which in turns gives an angular speed with respect to Earth of about 35.7º/year. An object from our population which initially enters the blind zone takes 2.53 years to leave it, thus remaining unobservable during the whole simulation timespan.

The number of objects actually detected within every semimajor axis bin, initially filled with the same number of objects (1100), is reported on top of the plot of Figure 2. As expected, the 1.01 bin, where the largest synodic period objects reside, has the fewest detections. In general the larger the semimajor axis, the less the discoveries, because lower semimajor axis regions are more densely populated. The only exception is the smallest semimajor axis bin, where the long time span in which no objects are detected is due to being at the very edge of the accessible zone for the Gaia instruments.

Conclusions

The Gaia mission, although not designed specifically for NEO detection, is esxpected to give a significant contribution to NEO observations, when supported by ground-based follow-up as provided by the Gaia-FUN-SSO. The SSA NEO Segment has the goal of significantly contributing to the worldwide NEO hazard monitoring scenario through becoming an authoritative data source on small solar system bodies, coordinating follow-up observations and deploying an high efficiency all-sky survey. Interaction between the Gaia-FUN-SSO and the NEO Segment is therefore highly desirable for the many benefits that it can bring to both projects. In particular :

- the generally large FOV telescopes used for NEO detection/recovery could efficiently deal with the astrometric accuracy produced by Gaia alerts, while the largest Gaia-FUN-SSO telescopes could allow the NEO Segment an easier access to deep follow-up facilities.

- once operational, the NEO Segment « wide survey » will provide on a daily basis an all-sky transient survey ; this can be used to validate both Gaia astrometric and photometric alerts (e.g. searching for precovery observations) ;

- the SSA NEO Data Center is expected to evolve into a full-fledged Small Body Data Center encompassing databases of the dynamical and physical characteristics of all small solar system bodies, and in this respect the Gaia mission can be considered as an European space based asset for small bodies physical data.

A possible cooperation between Gaia-FUN-SSO and the NEO Segment could be realised already in the Precursor Services phase : as a result of routine operations, the NEO Data Centre could provide NEO « astrometric alerts » which can be used test the response of the Gaia follow-up network in real cases.

In the long term, the star catalogue produced at the end of the 5-year Gaia mission will allow to improve significantly the orbit determination accuracy for the whole NEO population.

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GBOT - one year before Gaia's launch

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Introduction

GBOT (Ground Based Optical Tracking, [1]) is a part of the Gaia satellie mission, which is being set up to be able to fully exploit the capabilities of the satellite, even for the best measured stars. The GBOT project consists of about half a dozen small (1-2 m class telescopes), which will make daily observations of the Gaia space craft. From these data, the GBOT group will derive astrometric positions, which will be used in the reconstruction of Gaia's orbit.

1. Why do we need GBOT?

The main reason for the creation of the GBOT project, are effects which have a detrimental effect on the accuracy of astrometric observations such as those Gaia will be performing. These are mainly the aberration caused by the transversal motion of the observing platform[1] affecting the accuracy of measurements of stellar positions, and for the much closer solar system bodies, the baseline of parallaxes.

Aberration is a huge (30") effect, caused by the movement of the detecting device (i.e. Gaia or also the Earth) in respect to the observed objects. In order to correct for aberration one needs to precisely know the motion of the detector to some reference, usually the solar system barycentre. The effect is small in small field astrometry, since the displacement of the objects is almost the same - something which is no longer true for whole sky astrometry. However for previous whole sky missions, such as Hipparcos, conventional means to obtain the spacecraft's 3 dimensional motion were sufficiently precise to push the effect of residual aberration far beyond the nominal precision of the astrometry. This is still valid for most stars observed by Gaia, however those which will be measured best, i.e. the bright, well observed stars brighter than $G = 15$ mag require a more accurate knowledge of the satellite's motion than the conventional methods via one radar tracking station can deliver.

While solar system objects are not the main objective of Gaia, it is an important aspect - Gaia will discover many new asteroids, some of them being Near Earth objects, in some cases with the potential to cross Earth's orbit. In order to measure precise enough parallaxes ($\sim 1''$) the baseline needs to be known to a high degrees of precision, i.e. the position of Gaia needs to be measured very well and continuously.

Mainly for these two reasons GBOT was conceived. The commitments of GBOT are to deliver one measurement[2] precise to 20 mas each day (period of 24 hours). The systematic error (accuracy) of the

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[1] Aberration would affect all observations, whether they are done on a moving planet, e.g. Earth, or a moving space craft, such as Gaia. For small field astrometric observations as those usually done with ground based telescopes, the aberration is not of much concern, since the effect influences the positions of all objects in a small field, producing the same shift of all objects, which is therefore not of relevance. For a whole sky scanning mission, like Gaia, with two FOV's having an angle between them, the aberration, which can amount up to more than 20" is a major problem and needs to be taken care of accordingly.

[2] or rather sequence of measurements - GBOT will deliver every measurement; since the apparent trajectory of Gaia is not a straight line, the individual measurements of a sequence cannot be averaged without some loss of accuracy.

measurements needs to be even smaller. We need to point out, that these levels of accuracy are not achievable today, with the current reference catalogue material, but only with using astrometry from Gaia itself - today we can only expect to reach 50 - 100 mas.

2. Requirements - which facilities are suitable for GBOT?

In order to achieve its goal, GBOT requires a small network of about half a dozen telescopes of the 1-2 m class, distributed all over the world. Since the L2, i.e. roughly the location of Gaia (which oscillates on a Lissajous-orbit around the L2) always lies on the ecliptic opposite the Sun, GBOT needs telescopes on both hemispheres, and more than one, to be less dependant on weather conditions at one site, especially since in most location, the weather conditions are more inclement during winter which is the geometrically more favourable observing season.
GBOT has requirements concerning the telescopes/instrumentation, which are:

- Telescope of the 1 - 2 m class. The telescope should be able to regularly make contributions, i.e. observations, ideal are robotic telescopes, or telescopes with long term observing programs.
- CCD detector (monolithic or part of a mosaic) which has a FOV of at least 5'$\times$5', and a image scale of better than 0.4"/pix, somewhat depending on the quality of the site's seeing. As a compromise between depth and severity of differential colour refraction red light filters have been chosen as preferable.
- Further secondary requirements include: precise clocks, well known geographical coordinates of telescope, sufficient connection to the Internet in order to download data, etc.

3. The challenges of GBOT - and where the project stands today

The GBOT team faces several challenges:

- To recruit observatories willing to participate and to set up a small network of 1-2 m class telescopes.
- to determine and test observational procedures, which lead to obtaining the data needed.
- To develop a software pipeline which can cope with data material from highly diverse sources, and is able to derive high quality astrometry.
- To set up a database organising and storing the data, ensuring the dataflow from observatory to the receiving agency, especially keeping in mind that reductions need to be redone more than once, to secure the according hardware infrastructure to maintain such a database system.
- To coordinate a team of astronomers located in different locations.

The following part gives an overview of these challenges and how they are addressed today, less than one year before the launch of Gaia.

3.1 *Telescope recruitment*

This has proven to be a rather difficult task, even if the willingness to help with such a high profile project, such as Gaia is high. However many observatories are facing unsure futures, some are even threatened with closure[3]. Another difficulty is the fact that many traditional observatories are organised in the

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[3] Observatory Hoher List has regrettably been closed down - a big loss and a missed opportunity not only because of GBOT, but also to commute astronomical research to the general public and students in particular. It is only to be hoped that all possibilities however slim, are used to save this observatory

conventional way by distributing observing time to visitor observers who have prior written a project proposal. This means that a campaign demanding daily observations such as GBOT necessarily has to interfere with a visitor's observing program, and in most cases even requiring the visiting astronomer himself to conduct observations for GBOT. Therefore robotic telescopes are much to be preferred, since they operate via queue observing and moreover automatically with minimal human interaction during the night. Another viable option are those non-robotic facilities operating in queue mode, or being used for long term projects, i.e. those with dedicated observers. Fortunately the number of suitable robotic telescopes has grown over the past few years and continues to do so.

At current GBOT is in negotiations with two institutions with robotic telescopes, one of them, Las Cumbres Optical Global Telescope Network (LCOGT, `http://www.lcogt.edu`) currently setting up a worldwide network of 1 m telescopes. This means that together with the second, the 2 m Liverpool telescope, which has thusfar provided the bulk of our test data, they will be able to provide the backbone of the GBOT network, enhanced by a few conventional telescopes. We are also projecting the 1.2 m Euler telescope on La Silla, the 1 m Pic du Midi and the VST on Paranal to join GBOT, several other institutions are still testing.

Therefore despite the rather dire onset, GBOT is actually in good shape and will be once the two main contributors have finally been secured be able to operate. However it must be pointed out that the recruitment is an ongoing task, and will continue until the end of Gaia's operations. Should a reader of this paper have a facility at his disposal which could be of interest to GBOT, please feel free to contact the coordinator of GBOT, M. Altmann under `maltmann@ari.uni-heidelberg.de` and ask for the GBOT information leaflet. There are other groups within the Gaia project, such as GAIAFUN-SSO, and Gaia Science Alerts, which depend on the acquisition of ground based data during the operational phase of the mission. In order to aid each other in finding the required telescopic resources, GBOT has close contacts to these groups.

3.2 *Astrometric reduction pipeline software*

From the very beginning it was decided to develop own software rather than to rely on available products. The key reason for this is to have total control, understanding and influence over the code, and to avoid ”black boxes”. Software development began in 2009 and has reached a level of completion so that it is fully operable [3]. Nonetheless the pipeline gets continuously refined. Currently a detailed documentation and manual is being written.

One challenge was that the software has to be able to ingest data from very diverse sources, with large variations in the number and names of available FITS-keywords. This has been solved by an routine called `headermodif` which reads the header of each incoming file and writes all relevant header information into special GBOT FITS keywords.

Next in line is a program called `findsources` which does the source detection and extraction using various user-selectable algorithms. `astroreduc` performs the astrometric reduction using a reference catalogue and the detected objects, sans the moving target. Apart from some other auxiliary programs, which make plots and graphs, etc. the final step is done with `targetfinder` which extracts the target, again with various options for the extracting algorithm, and determines the position of the moving target object. These components are all operational and have been used for quite some time - currently the main effort is apart from documentation, and diagnostic output. The GBOT pipeline has also been used for other purposes than GBOT, in one case a Kuiper-belt object was found.

3.3 *The database*

Having to store and maintain a rather large set of data from diverse sources justify the need of a dedicated database system. It was decided to develop the database on the basis of a SAADA type database ([2]). Database development started in 2011, and currently the database is operable, but still needs some development in some aspects. The database will receive, ingest and store all data, and available metadata, such as reduction logs, ephemerides, etc. The reduction software can be run from the database, and results can be extracted into the formats required for delivery to ESOC.

Another very important reason for preferring a full-fledged database system over other kinds of storage philosophies is that, because due to the inadequate existing reference catalogue material, initially GBOT cannot reach its targeted astrometric quality; Therefore the astrometric reductions of *all* data collected to the time when Gaia astrometry has become available have to be repeated in an automated batch mode. A final reduction of all data will be done after the operational phase of Gaia to ensure maximum quality results. Additionally, as with all other parts of the Gaia project, all data and information used for GBOT must be archived so that it can be accessed later at any time, should the need arrive.

In terms of hardware, the main database will be located in Paris, with a mirror with less capability in Heidelberg. This mirror will mirror all the data plus provide the platform for daily operations should the main server in Paris fail. Having these servers in two different geographic locations helps prevent complete data loss in the event of a catastrophe.

3.4 *Tests, open issues, etc.*

Since 2009, several test campaigns have been conducted to establish and verify observational methods, with several telescopes, most importantly the Liverpool telescope, the 2.2 m telescope at La Silla, and the 1.2 m of the OHP, and the 1 m on Pic du Midi using the space craft WMAP and Planck as well as various asteroids. Most of these tests have been concluded, in effect showing that we are able to reach the level of precision we have committed ourselves to. Furthermore we have set up a suite of routine tests to evaluate the suitability of potential partner facilities.

One unknown issue in the game is still the brightness of Gaia. While we do have some hints from our observations of other spacecraft, especially WMAP, which overall has had a similar shape as Gaia, there are quite a few unknowns involved, and we will not know the brightness of Gaia until it has reached its final destination. Based on experience we are currently preparing for a brightness of $R \sim 18$ mag, however we are aware that this could be off by more than a magnitude in either direction. Moreover in the hash environment in the L2-region the initially highly reflective Kapton mylar surfaces could degrade to become rough and essentially black, potentially drastically altering the reflective properties and thus the observed brightness of the probe with time. Overall this issue remains to be *the* most problematic unknown quantity for GBOT. In order to monitor the development of Gaia's brightness, observations from simultaneous multi passband photometers, such as BUSCA (Calar Alto) and/or GROND (La Silla) will have to be requested.

Far better known, but also a challenge is the fact that the Full moon is always in the vicinity of the spacecraft. Most telescopes will therefore not deliver useful data for a period of 3-4 days centred round Full moon[4]. We do however have a few telescopes, notably ESO's VST on Paranal, that allow us to observer quite close to the moon and yet achieve good results, this way possibly closing the gap to the Full moon night itself. Apart from this, a recent study by ESOC concerned with the reconstruction of Gaia's orbit, has revealed that small gaps in the coverage of GBOT observations can be tolerated. Therefore the Full moon gap is far less significant than previously thought.

While the measurement of the 3D coordinates of a telescope is straightforward nowadays with GPS, exact timing of the observing time is a challenge. The constraint here is 0.1 sec. Certainly most clocks today easily surpass this requirement. However an open question[5] is to which extent does the time listed as start of the exposure coincide with the actual opening of the shutter[6]?

Recently the GBOT group has compiled an assessment of all potential errors contributing to the overall error budget. It became clear, that this boils down to a couple of really dominating effects, currently the strongest spoiler is the quality of today's reference catalogue material. After the rereduction with Gaia

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[4] Also depending on the distance of Gaia from L2 at a given Full moon

[5] to be answered for every single partner facility

[6] Apart from the fact that a shutter has a finite opening and closing time too - something that needs to be taken into account, especially in the case of barndoor shutters

astrometry as reference the main contributors will be differential colour refraction. However all relevant error sources will be corrected so that the overall error stays below the 20 mas for a sequence.

4. Radio-GBOT

A rather recent development is the idea to use the VLBI network of radio-telescopes to track Gaia. The signal from its communication and data-downlink antenna can be observed, and thus used to measure the state vector of Gaia. Since the ”source” is bright, we do not need a VLBI network consisting of large telescopes. A network of medium to smaller size antennas would be sufficient. However this is nonetheless a major investment of resources, and measurements will not be possible every day; a frequency of once per week, or once or several times per month is much more likely. Thus one the one hand the coordinates (state vectors) of Gaia coming from VLBI measurements will be more accurate than the optical measurements, on the other the temporal density will be much lower. This means that the VLBI observations cannot replace the optical campaign, but will most likely prove to be a major enhancement, compliment and ultimate varification of the optical observations for GBOT, especially if the VLBI observations are well chosen and predominantly carried out at the times when Gaia crosses the celestial equator (and the reconstructed orbit is most sensitive to the transversal motion). Also, VLBI is not affected by the moon cycles.

The preparatory work for VLBI tracking of Gaia is conducted by the Joint Institute for VLBI in Europe (JIVE), involved in similar activities for a broad variety of space and planetary science missions. At present, the work concentrated on the evaluation of an optimal strategy of joint optical and radio observations in support to the Gaia mission. In particular, this includes test observations of operational spacecraft located in the L2 region. Special science-driven Gaia tasks that require the highest level of state vector determination are being investigated too.

Since radio observations of Gaia involve QSO’s that form the International Celestial Reference Frame (ICRF) as reference sources , and these are very sparse, a denser fabric of secondary calibrators (typically - weaker in radio QSO’s) is being considered. Due to the fact, that this approach was considered and started only recently, many aspects are still under study. Nevertheless, we are very confident, that Radio-GBOT will be feasible, and will provide valuable data for GBOT and thus the full exploitation of Gaia’s potential. As a sidenote, GBOT most likely will need to change its name slightly to ”Ground Based *Orbit* Tracking” from ”Ground Based *Optical* Tracking”, since that name would no longer be accurate.

5. Operations and Deliveries

GBOT has the duty to obtain and analyse ground based imaging data of fields containing the Gaia satellite in order to derive astrometric positions of the spacecraft. The data will be observed by the committed partner observatories. In order to be able to operate these must know the position of Gaia, so that they can point their telescopes accordingly. On the other hand the results must be delivered to those who need them to reconstruct Gaia’s orbit, namely the MOC (Missions Operations Control) team within ESOC (located in Darmstadt). This is done via an entity called SOC (Science Operations Control), located at ESAC near Madrid, through which all communication between GBOT and ESOC (MOC) will go. GBOT will receive orbital data from ESOC which will be transformed into ephemerides and supplied to the observatories. This way there is a two way flow of information/data from/to GBOT from/to ESOC and the observatories.

6. The Roadmap to Launch

As one of the Schedule Critical Items (at least partly) GBOT plays a significant role from very early in the operational phase of Gaia. It will kick in as soon as Gaia reaches its final orbit in the L2-region. Therefore GBOT participates in the series of operational rehearsals, which aim at testing and reviewing the orchestrated operation of all components of Gaia operations both during the initial commissioning phase and nominal operations. Four of these rehearsals are planned, each with a larger complexity and greater completion of the participating components. In the first one, in July 2012, GBOT took part only with the delivery of a data file. During the second one, actual data from one telescope will be taken, reduced and delivered, the third one, in late April 2013 will include more telescopes. By the fourth rehearsal the full readiness not only of GBOT needs to be demonstrated. Crucial for the functioning of GBOT is the dataflow as described in Sect. 5..

While, as described in this paper, GBOT is well advanced in all effects, and is shortly before operability, there still needs to be a lot done, such as documentation, fine tuning setting up of daily operations, etc. Many aspects, such as the software development to ever higher degrees of perfection will continue after the launch, even to the end of the operational phase. One thing needs to be made very clear: As noted before in this text, GBOT will at first not be able to reach the aims in terms of accuracy - only after about 2 years, when data from Gaia itself will be available, will GBOT reach its aims. This also means, that during that time all observations done before will need to be reduced again. After data taking is complete, a third round of reduction of all data will be carried out, to ensure the best possible reduction and analysis of the data. After that GBOT will come to an end.

Conclusion

GBOT is a small but important part of the keystone Gaia project, which will have an enormous impact on our view of the Milky Way and the cosmos. GBOT will enable utilising the full potential of the Gaia measurements, even for the brightest best measured stars and objects of the solar system. Less than one year before launch, the GBOT team - like all other teams involved in the project - is working hard to obtain readiness for the initialisation of the active phase of Gaia. While a lot remains to be done, GBOT is well advanced and is confident to be fully operable when the date for the launch has come.

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The possible role of ground-based support for a better determination of asteroid physical parameters based on Gaia data.

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Introduction

The determination of bulk physical properties for the largest possible number of asteroids which will be observed by Gaia is an important task which can be made easier by performing some dedicated ground-based observing campaigns. The proposed actions, consisting of applications of different observing techniques, primarily photometry and polarimetry, are not expected to be triggered by Gaia alarms, nor do they require in principle prompt reaction times triggered by special circumstances. We deal here, conversely, with the problem of improving the amount and quality of data at our disposal concerning some properties of a suitable sample of asteroids, to be used for the purposes of a better calibration of some fundamental relations which are commonly used in asteroid science.
We remind that the excellent astrometric, photometric and spectrophotometric performances of Gaia are expected to make it possible to obtain direct size measurements of main belt asteroids larger than about 25 km, rotation properties and overall shapes for a number of the order of 10^4 objects, and reflectance spectra and taxonomic classification for a number of asteroids which could be 10 times larger. In addition to this, we will have also a formidable improvement in the knowledge of asteroid orbital parameters, and the derivation of mass estimates for a number expected to be of the order of 100 individual asteroids, without taking into account the masses of binary systems derived by determination of their mutual orbital periods. For a small number of near-Earth asteroids, moreover, it is expected that a measurement of the drift in orbital semi-major axis due to the Yarkovsky effect might also be measurable.
Two basic parameters, however, namely the albedo and absolute magnitude, will be difficult to determine based on Gaia data, due to reasons essentially related to the fact that Gaia will never observe asteroids close to solar opposition. The situation, however, is not totally hopeless, and there are possible ways to determine, at least, the albedo. The albedo quantifies the surface reflectance at visible wavelengths, and is a very important physical parameter, being determined by surface composition, roughness and texture, and by the overall thermal history of the body. In this paper we explain why some dedicated ground-based observing campaigns are strongly recommended in order to improve our capability to derive from Gaia data reasonable estimates of the albedo, if not also of the absolute magnitude, for many objects.

1. The size - absolute magnitude - albedo relation

A fundamental relation in asteroid science is the one between size, absolute magnitude and albedo, which can be written as:

$$\log(D) = 3.1236 - 0.2H - 0.5\log(p_V) \tag{1}$$

in the above expression, D is the diameter of the object in km, assuming for sake of simplicity a spherical shape; H is the absolute magnitude (the magnitude which would be measured in standard V light if the object was observed at unit distance from both the Sun and the observer and at zero phase angle, that is at ideal solar opposition; p_V is the geometric albedo, defined as the ratio between the actual brightness in V light at zero phase angle to that of an idealized flat, fully reflective, diffusively scattering (Lambertian) disk with the same cross-section. The value of the constant (3.1236) is a consequence of the definition of magnitudes and of the fact of working in standard V light.

Equation 1. is used to derive one of the three parameters, being provided estimates for the other two ones. For instance, p_V can be derived by means of measurement of linear polarization of asteroid visible light. If H is known, this makes then possible to derive the size. Conversely, thermal radiometry measurements are used to derive reliable estimates of the size. If the absolute magnitude is also known, this leads to determination of the albedo. The most recent application of this procedure has been the huge catalog of asteroid albedos derived from WISE data ([4]). However, albedos derived from thermal IR data alone are subject to significant uncertainties, since the computation requires the use of values of the absolute magnitude H which are both affected by large error bars, and correspond in general to different apparent illuminated areas with respect to those visible at the epochs of thermal IR observations. The bottom line is that even after the WISE mission it certainly makes still sense to try and obtain independent albedo measurements for large data sets of objects.

In the case of Gaia, which has neither polarimetric nor thermal IR capability, it would seem that the situation is hopeless. On the other hand, Gaia is expected to measure the sizes of about $1,000$ main belt asteroids. In the case that the absolute magnitude of these objects could also be derived from Gaia photometric data, this would lead immediately to a derivation of the albedo p_V. Moreover, we will see that there is the possibility that photometry alone could provide some opportunity to derive the albedo in a way which will be explained below. What is important, is that in any case, the possibility to derive values of H and p_V from Gaia data will significantly depend on evidence coming from extensive ground-based observations.

1.1 *Asteroid phase-magnitude curves*

The absolute magnitude H is the magnitude at zero phase angle, the latter being defined as the angle between the directions to the Sun and to the observer as measured from the asteroid. In the real world the asteroid can never be observed at exactly zero phase angle (perfect solar opposition). In many cases, even at opposition the phase angle is far from zero, since the objects are not located on the ecliptic, therefore they are not in the plane containing the observer and the Sun. The absolute magnitudes of the asteroids must then be found by means of some extrapolation of the relation between magnitude and phase angle which can be obtain by photometric observations covering different phase angles around a given opposition (the so-called asteroid phase curves). The morphology of the phase curves consists usually of a linear relation over a wide range of phase angles (the object becoming fainter for increasing phase angle). Unfortunately, at small phase angles, however, below 5 - 7 degrees, a non-linear brightness surge is usually observed. This phenomenon is commonly called the "opposition effect".

Due to the fact that Gaia will never observe asteroids at solar elongations larger than 135 degrees, the opposition effect will not be observed by Gaia. Any hope to derive the absolute magnitude H must therefore be based on the availability of photometric systems to describe the behavior of the asteroids, which are required to be able to derive a correct estimate of the opposition effect based on photometric data collected at phase angles much larger. Recently, [3] have shown that the photometric system which has been adopted for many years to describe the phase curves of the asteroids, namely the so-called (H,G) system, is not sufficiently reliable for the purposes of Gaia. On the other hand, the same authors have developed a new photometric system, called (H,G_1,G_2) which should be more suitable to derive a reasonable estimate of H, even when one has at disposal only observations not covering the opposition effect. As explained by [3], however, the new photometric system has been developed having at disposal a fairly limited number of high-quality phase curves. The base functions which define the (H,G_1,G_2) system can, on the other hand, be easily improved provided new high quality phase curves are made available. This is an ideal task for ground-based observing programs, even using telescopes of modest aperture. In this way, the absolute magnitudes of objects whose sizes will be directly measured by Gaia can in principle be derived, using the (H,G_1,G_2) system, and the Gaia photometric data covering five years of sparse observations. For these objects, therefore, the albedo could also be immediately derived once the absolute magnitude is known. The complication here is that H is not really a constant for any given object, but varies in different oppositions depending on the so-called aspect angle, namely the angle

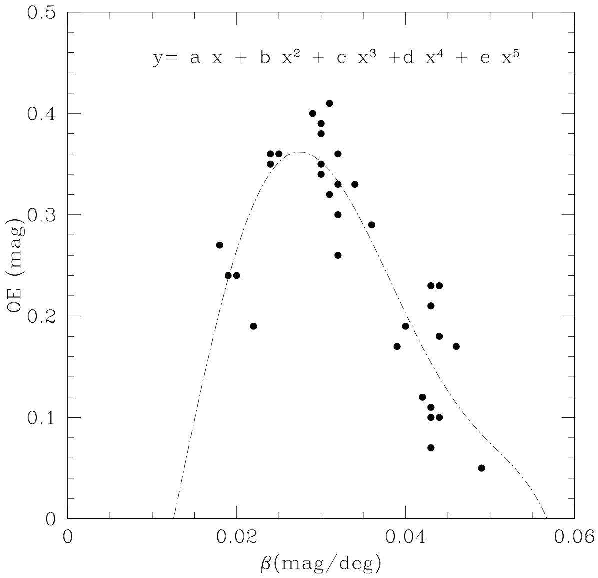

Figure 1: Tentative fit of the photometric opposition effect *versus* slope of the magnitude - phase curve for the sample of asteroids analyzed by [1]

between the polar axis and the direction to the observer, as measured from the asteroid. Since asteroids are not spherical, the illuminated surface area visible from an observer changes as a function of the aspect angle. Gaia sparse photometric data will be inverted to derive the polar axis direction and overall shape of the objects, but it is clear that the uncertainty on the inversion, and on the derivation of the absolute magnitudes, put some practical limits to the reliability of absolute magnitudes and albedos derived in this way. On the other hand, some alternative ways to solve the problem may exist, as explained in the next Subsection.

1.2 *The possible use of photometric data to derive asteroid albedos*

Although a single magnitude measurement is certainly not sufficient to derive the albedo, since the magnitude depends also on the size, there is the possibility that the phase curves, obtained by means of multiple observations at different phase angles, might be used to derive the albedo. An extensive study of the properties of asteroid phase curves was published by [1]. These authors described the phase curves using a simple mathematical description, consisting of a linear term plus an opposition surge occurring at low phase angles. This is interesting from the point of view of Gaia applications, because the slope of the phase curves will be derived by inversion of Gaia sparse photometric data. In [1], the authors looked for possible relations between the slope of the linear part and the extent of the opposition effect, but they did found that the relation is complicated and not monotone, as shown in Figure 1 in which a tentative polynomial fit is also shown. This figure shows that the extent of the opposition effect will hardly be reliably obtained from the linear slope of the phase curves derived from Gaia data. What is more interesting and promising, however, is that [1] found a possible relation directly linking the linear part of the phase curves and the albedo. The authors express this relation as:

$$\beta = 0.013(\pm 0.002) - 0.024(\pm 0.002)\log(p_V)$$

where β is the slope of the linear part of the phase curve. The above relation is based on fairly noisy data (see Figure 4 in [1]), but it is potentially extremely useful for Gaia. In particular, because β can potentially be obtained for several thousands of objects, this would make it possible to derive for these same objects an albedo estimate. In this case, the Gaia albedo data-base would become a very significant achievement, even without being able to derive at the same time also the absolute magnitude of the

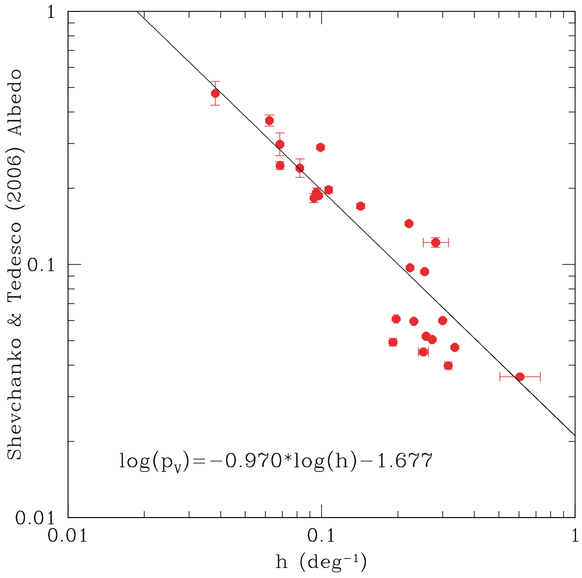

Figure 2: The most recent calibration of the slope -albedo relation used in asteroid polarimetry [2]. ST refers to the asteroid albedo data set published by [5].

objects.

1.3 *Asteroid albedos from polarimetry*

Whatever technique will be applied to derive asteroid albedos from Gaia data, the reliability of the results will have to be determined by means of comparisons with high-quality albedo determinations obtained for some sample of selected objects by means of other techniques.
In this respect, asteroid polarimetry seems to be the best possible options to produce a set of asteroid albedos to be compared with Gaia-based determinations. The relation between the polarization properties and the albedo of atmosphereless solar system bodies have been known since decades, and will not be discussed here. We will limit ourselves to mention that, historically, the albedo has been derived from measurements of the so-called "polarimetric slope" (usually indicated as h), which corresponds to the slope of the linear relation which is found to describe the phase - polarization curves around phase angles larger than about 15 degrees. One of the major problems in asteroid polarimetry has always been that of finding a good calibration of the adopted slope - albedo relation. The most recent, updated calibration has been recently provided by [2], using data which are shown in Figure 2. In this Figure, the vertical axis shows the albedos for objects of the list published by [5], which is thought to include the most reliable albedo estimates currently available for the asteroid population, being based on reliable H values and sizes directly and accurately determined by either *in situ* exploration by space probes, or observations of stellar occultations.

Conclusion

Ground-based observing campaign will be very a very useful support of the activities of determination of asteroid physical properties from Gaia data. At least three major tasks are suggested here:

1. Photometric measurements aimed at obtaining new high-quality phase -magnitude curves of objects which still lack them, to improve the H,G_1,G_2) system, and to derive also new reliable measurements of the linear part of the phase curves of objects with well determined albedo.

2. Measurements of new phase curves of objects already observed in the past, in order to check that the slope of the linear part (β) and/or G_1 and G_2 do not vary as a function of different aspect angle at different oppositions.

3. Polarimetric measurements aimed at further improving the calibration of the slope -albedo relation.

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Global Dynamics and Ephemerides

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Introduction

When speaking of Gaia it is instructive to remember the first ESA mission dedicated to high precision astronometry HIPARRCOS launched in August 1989. HIPPARCOS can be considered as Gaia's precursor, indeed the observing strategy aspects are similar and both missions were designed specifically for high precision astronmetry. After three and a half years of observations HIPPARCOS produced three catalogues. In 1997 the HIPARCOS catalogue of ~ 120000 stars and the first Tycho catalogue containing about one million stars. In 2000 the consolidated catalogue Tycho-2 was released. It contains 99% of all stars down to magnitude 11, approximately ~ 2.5 million objects.
For small solar system bodies (SSSB), HIPPARCOS observed only 48 asteroids, 5 satellites orbiting Jupiter and Saturn, and 2 planets. The accuracy for the HIPPARCOS astrometry was $\sigma \sim 10\,$mas and for the photometry $\sigma \sim 0.05\,$magnitude [1] [2]. These results are certainly spectacular but Gaia is projected to achieve much more.
The expected performances for Gaia compared to HIPPARCOSS are listed in Table 1. It is clear that the performances of Gaia will greatly excede those of HIPPARCOS.

Table 1: Comparison between performance for HIPPARCOS and those expected for Gaia

	HIPPARCOS	Gaia
magnitude limit	12 mag	20 mag
completeness	7.3 – 9.0 mag	20 mag
number of objects	120000	$26\,10^6$ to $V = 15$ $250\,10^6$ to $V = 18$ 10^9 to $V = 20$
effective distance limit	1 kpc	50 kpc
quasars	1 (3 273)	$5\,10^5$
galaxies	none	10^6
accuracy (whole mission)	milliarcsec	7 μarcsec at $V = 10$ 10 – 25 μarcsec at $V = 15$ 300 μarcsec at $V = 20$
photometry	2 – colour (B and V)	low-resolution spectra to $V = 20$
radial velocity	none	$15\,\mathrm{km}s^{-1}$ to $V = 17$
observing programme	pre–selected	complete unbiased survey

It should be underlined that all moving objects down to 20 magnitudes will be detected, so roughly 350000 asteriods will be observed, mainly from the main belt. Orbits are expected to be 30 times better than at present even if a century of previous observations are used in their determination. Spin–axis, rotation periods, and shape parameters will be detrmined for a majority of these. Taxonomical / mineralogical composition versus heliocentric distance will be available while diameters for ~ 1000 to 20 % and masses to 10 % for some 150 asteroids will be determined also (see Tanga et al., this conference).

1. Gaia SSSB data processing

The Gaia SSSB data processing is divided into two pipelines, a so called short–term pipeline and a long–term pipeline [3]. The short–term pipeline runs daily on the data collected over the previous 24 hours.

This processing characterises the moving source, sorting those which are already known from unknown objects. Basic CDD processing and astrometric reduction are performed. An attempt at threading unknown object positions onto one orbit is undertaken so that in some cases a preliminary orbit can be computed. Results from this pipeline are then stored in a main data base (MDB) for later reprocessing.
The bulk of the accurate characterisation of the objects is achieved by the long–term pipeline. This pipeline improves the results of the short–term analysis by determining the SSSB parameters through dynamic considerations and requires as many observations of the same object as possible, at intervals covering a reasonable part of their trajectory. The long–term pipeline is run on a six month schedule taking as input the cumulated data which has been stored in the MDB. Ideally all SSSB data will be used in the long–term pipeline but this is not guaranteed. In any event, only positions from Gaia observations will be used in this proccessing. The initial conditions required for simulating an orbit are obtained from an auxiliary data base which will be updated at regular intervals during the mission. This data base is fed by the ASTORB, input from the Lowell Observatory, and consequently is indirectly updated through the GAIA–FUN–SSO. This pipeline provides the final, more accurate, orbit determination and parameter estimates which will be published in the final catalogue. Note that only identified asteroids and comets will be used in the parameter estimation. Unidentified sources will only be incorporated when an orbit is available after the short–term processing and only if the GAIA–FUN–SSO has made the source available through the MPC. Furthermore, some technical issues will need to be addressed to include any new object in the parameter estimation procedures (see 2.3).

2. Parameter estimation

Parameter estimation is an inverse problem, and in the case of the Solar System it is ill posed. For Gaia, the chosen method for deriving a solution, is a linear least squares procedure which can be formally written as :

$$\mathbf{y} = \mathbf{A}\mathbf{x}$$

Here **y** is a difference vector of the observed sky coordinnates, **A** is the Jacobian matrix formed with the partial derivative with respect to the parameters of the model and **x** is the vector of corrections. To obtain **y** the equations of motion modeling the orbits of the SSSB observed must be integrated. This is done by a N–body simulation. The matrix **A** can be obtained by simply including the variational equations in the system of ordinary differential equations to integrate.
Local and global parameters, i.e. those parameters which principally affect a given SSSB and those which affect the Solar System as a whole or a subset of SSSB respectively will be determined. These are summarised in Table 2.

Table 2: Parameters which will be determined using asteroid and comet orbits from Gaia

local parameter	description
$(x_0, y_0, z_0, \dot{x_0}, \dot{y_0}, \dot{z_0})$	initial conditions
(A_1, A_2, A_3)	non–gravitational coefficients for comets
(A_4)	non–gravitational coefficients for asteroids
global parameter	description
β	PPN nonlinearity in the superposition law for gravity
J_2	solar quadrupole moment
$(\omega_0, \omega_1, \omega_2, \dot{\omega}_0, \dot{\omega}_1, \dot{\omega}_2)$	rotation and rotation rate of Gaia reference frame
$\dot{G}/G$	variation of the gravitational constant
m_i	mass of the *i*th perturbing body

Most of these parameters appear in the equations of motion as specified below. The solution is obtained

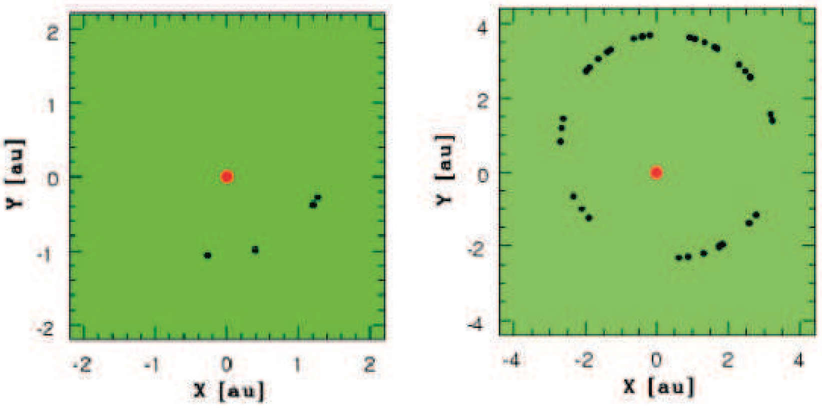

Figure 1: Simulations of the expected sightings of Piazzia, right panel, and the synthetic NEO asteroid 20075, left panel. The expected 63 observations of Piazza covering its whole orbit will allow the determination of all its local parameters whereas for 20075 the paucity in observations will lead to a statistically unreliable solution for the local parameters.

by an iterative process where the corrected parameters are reinjected into the model and a new N–body integration is performed, yielding new positions and Jacobian matrix. Convergence criteria must be given, $\|\mathbf{y}\| \ll 1$ for example. The iteration is stopped once these criteria are satisfied. Tests indicate that 2 – 4 iterations are required when the data quality is good, ie sufficient number of observations with extended coverage of the trajectory (see below 2.1). The technical aspects of the implentation can be found in [4].

2.1 *Orbit improvement*

Although Gaia will observe for 5 years, simulations have shown that not all objects will be equally represented in the final data. Consequently all orbits cannot be improved to the same degree of reliability. In fact, any orbit improvement will narrowly depend on the distribution of observed positions along the trajectory of the SSSB under consideration. For example, using the Gaia simulator of rendez-vous, Aten 2062 will be observed 96 times in the course of the 5 year span of the Gaia mission. The observations for this object will cover the orbit sufficiently well to obtain a new improved set of initial conditions. To the contrary, 1994 BX, a Near Earth Object (NEO), will only be observed a few times (simulations give 4 observations over 5 years forming a short arc of its trajectory ony) due to its high magnitude. The result is that for this object not enough data is available for a reliable determination of the its local parameters. For those asteroids where the data is of good quality we can expect a 30 times better determination of the initial conditions based on Gaia observations only. In the case of poor quality data, the least squares inversion will be rank deficient and a full set of initial conditions cannot be determined. A main belt asteroid such as Piazzia will be seen 63 time by Gaia during, somewhat less than Aten 2062 but nevertheless well enough to determine its initial conditions to reasonable accuracy. This can be seen in Figure 1.

2.2 *Non–gravitational forces*

In the N–body simulation, non–gravitational forces are parameterized in a simplified manner (see for example [5] and [6]). The force acting on an comet close to the Sun can be written as :

$$\mathbf{f}_{p|noGrav} = A_1 \frac{g(r)}{r}\,\mathbf{r} + A_2\, g(r)\,\mathbf{t} + A_3\, g(r)\,\mathbf{n} \tag{1}$$

where the transverse unit vector $\mathbf{t} = \langle \mathbf{v} - (\mathbf{v} \cdot \mathbf{r}).\mathbf{r}/r^2 \rangle$ is normal to the heliocentric position vector $\mathbf{r}$, in the osculating orbital plane, and directed toward the motion, and $\mathbf{n} = (\mathbf{r}/r) \times \mathbf{t} = \langle \mathbf{r} \times \dot{\mathbf{r}} \rangle$ completes the right-handed frame. The coefficients (A_1, A_2, A_3) are the parameters to be adjusted. For an asteroid a similar model is used with only one non–zero component, the transverse one.

For how many comets these coefficients can be determined with a strong degree of confidence remains to be determined. Present estimates give only ~ 5 long period comets observed during the Gaia campaign, which is a minimal number. For the Yarkovsky effect on asteroids we expect more candidates, of the order of 60 (see [7]). For consistency the processing includes only Gaia observations, however after the mission it will be possible to combine the Gaia data with available ground based observation in order to improve these values. Note also that some objects (unexpected degassing for example) may issue an alert for ground based observation by the Gaia–FUN–SSO.

2.3 *Asteroid masses*

Masses for ~ 150 asteroids should be available after processing. It is expected that about 100 with $\sigma \leq 50\,\%$ and about 50 with $\sigma \leq 10\,\%$ ([8]). To determine an asteroid's mass, in addition to those measured in binary systems, its effect on another body must be measurable. In the main belt, about 100000 asteroids will suffer a close encounters with some perturbing asteroids. However, mutual perturbations between all these objects will not be strong enough to yield a mass determination. Thus not all these masses can be recovered. A list of asteroids for which a mass determination is indeed possible has been established using the Gaia simulator, there are roughly 2000 candidate bodies. Although in principle then some 2000 masses of perturbing asteroids could be determined this number is greatly reduced because the data quality is an important factor (see 2.1). A novel implementation for the determination of binary asteroid masses is in the process of being implemented. The method is based on Markov Chain Monte Carlo approach [9].

2.4 *Fundamental physics*

The equations of motion include the relativistic corrections through the Parametrized Post Newton formulation. The more important correction terms are writen below :

$$\mathbf{f}_{p|relat} = \frac{m_\odot}{r^3} \left\{ \left[2\,(\gamma + \beta) \frac{GM_\odot}{r} - \gamma \dot{r}^2 \right] .\mathbf{r}_i + 2\,(\gamma + 1)\,(\mathbf{r} \cdot \dot{\mathbf{r}}).\dot{\mathbf{r}} \right\} + o(c^{-3}) \tag{2}$$

where $\mathbf{r}$ and $\dot{\mathbf{r}}$ are the heliocentric position and velocity, respectively.

Of the 10 PPN parameters only β which measures the degree of non–linearity in the superposition law of gravity, and γ which measures how much space curvature is produced by unit rest mass appear as parameters in the above formula. The parameter γ is to be determined by other means and will be assumed to equal to one in the long–term pipeline, consequently only β will be determined. The NEO will be strongly affected.

The Solar quadrupole also affects object which approach the Sun. The resulting force is written :

$$\mathbf{f}_{p|j_2} = \frac{-3Gm_\odot a_e^2 J_2}{2r^7} \left\{ 2(\mathbf{K} \cdot r) r^2 K_i + \left[r^2 - 5(\mathbf{K} \cdot r^2) \right] r_i \right\} \tag{3}$$

where $\mathbf{K}$ is the solar north pole. For these parameters all objects will be involved in the inversion procedure however NEO will be most affected as they approach the Sun. Finally the determination of $\dot{G}$, the link between the ICRF (optical Gaia) and the dynamical reference frame (Ecliptic and equinox) is also projected.

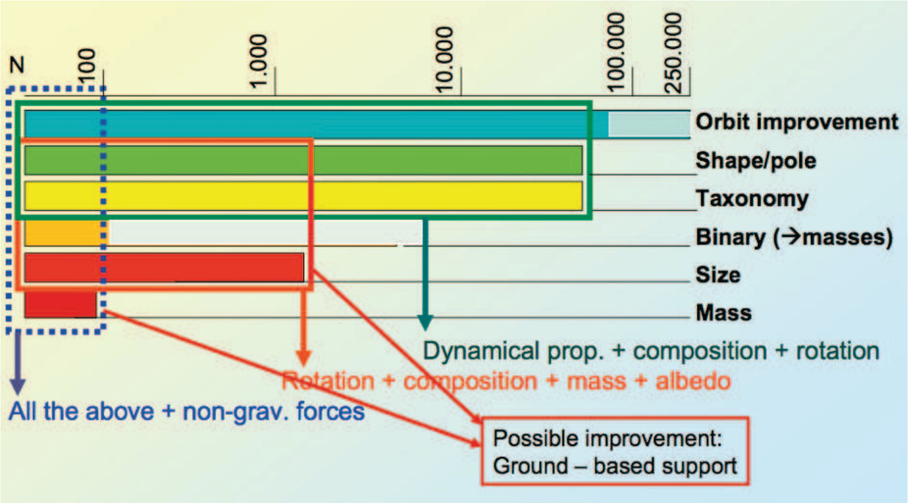

Figure 2: Anticipated improvement with the Gaia data after five years (courtes of Paolo Tanga Observatoire de la Cote d'Azur, Nice, France.

3. Near Earth Objects

NEOs are an important class for confirming the predictions of general relativity. Some 1500 of these are expected to be detected during the projected mission lifetime. As NEO pass close to the Sun non–gravitational effects will be felt, it will then be possible to decouple these forces from the general relativistic corrections (see 2.2 and 2.4). These are fast moving objects, however, and may not be seen in all the field of view and thus escape detection on all of the CCDs of the focal plane. If the identification of the object fails, then it may not be used in the long–term pipeline. Still, there remains a chance that an orbit reconstruction was successful in the short–term pipeline. In this latter case, the object can perhaps participate in the parameter estimation. Evidently it is in our interest to determine accurate parameters for these object because of their potential danger. For a more specific contributions on these objects please refer to the talks by D. Bancelin and B. Carry in these procedings.

Conclusion

Gaia will provide unprecedent high precision data for the objects of the solar system. We emphasise that the Gaia data processing will use only the data colected by the mission, no other data will be imported into the reduction pipeline. This provides a clean and faithful and statistically significant sample for determining the local and global parameters of our Solar System. Figure 1 resumes what we anticipate as possible with Gaia after five years of surveying. The orbits of some 100000 astrids will be improved along with their shape and taxanomical characteristics. For about 1000 objects we will be able to recover masses and ground based data will perhaps be injected into the processing albeit in an indirect fashion. Finally for 100 objects we will be able to determine their non–gravitaional parameters also.
Later, once the mission has completed its course, it will be possible to use data from other source to estimate again these partameters, but even now we can safely state that the Gaia data alone will improve the value of these parametrs at least 30 fold. Also the astrometric stellar catalogue will revolutionise future astronomy of SSSBs. During the mission the Gaia–FUN–SSO will indirectly contribute to the processing by providing ground baesed observations through the MPC, which periodically provides Gaia with the initial conditions and some estimated parameters of thre known asteroid.

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Near-Earth Asteroids Orbit Propagation with Gaia Observations

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Introduction

Gaia is an astrometric mission that will be launched in 2013 and set on L2 point of Lagrange. It will observe a large number of Solar System Objects (SSO) down to magnitude 20. The Solar System Science goal is to map thousands of Main Belt Asteroids (MBAs), Near Earth Objects (NEOs) (including comets) and also planetary satellites with the principal purpose of orbital determination (better than 5 mas astrometric precision), determination of asteroid mass, spin properties and taxonomy. Besides, Gaia will be able to discover a few objects, in particular NEOs in the region down to the solar elongation 45° which are harder to detect with current ground-based surveys. But Gaia is not a follow-up mission and newly discovered objects can be lost if no ground-based recovery is processed. The purpose of this study is to quantify the impact of Gaia data for the known NEAs population and to show how to handle the problem of these discoveries when faint number of observations and thus very short arc is provided.

1. The Gaia mission

During the 5-years mission, Gaia will continuously scan the sky with a specific strategy: objects will be observed from two lines of sight separated with a constant basic angle. The angle between the Sun direction and the spin axis is set to 45°. The initial spin rate is 1″/min and the spin will precess around the Sun-Earth direction with a mean period of 63 days. Because of this specific scanning law and its positioning, Gaia won't be able to observe down to the solar elongation ~45°. But we do expect some observations and/or discovery of Atira asteroids (moving below the Earth orbit). Two other constants are still free parameters: the initial spin phase which has an influence on the observation's dates and the initial precession angle which has an influence on the number of observations for a given target. Because of this specific scanning law, some asteroids can be well-observed – i.e. the Gaia observations cover at least one revolution period of the asteroids – and some others can be poorly-observed – i.e. the Gaia observations are faint and cover less than half the revolution period.

2. Astrometry for known NEAs

Among the NEAs that will be observed by Gaia, we do expect some observations of Potentially Hazardous Asteroids (PHAs). Those asteroids can show particular threat of collision with the Earth in the future. To illustrate the impact of Gaia observations on PHAs orbit, we will consider here the case of the asteroid (99942) Apophis (previously designed 2004 MN_4). This asteroid will have a deep close encounter with the Earth in April 2029 within ~38000 km and because of the chaoticity of the 2029-post orbit, collisions with the Earth are possible after this date [1].

2.1. *Observations of asteroid (99942) Apophis*

Because of the nominal scanning law of Gaia, and in particular the initial precession angle, the number of observations per object can be inhomogeneous. We can have more than 20 observations as well as less than 10 observations. For our simulations, we chose a set with the longest arc length (with 12 Gaia observations) and with a 5 mas accuracy. This set covers half the orbit of Apophis (Fig. 1).

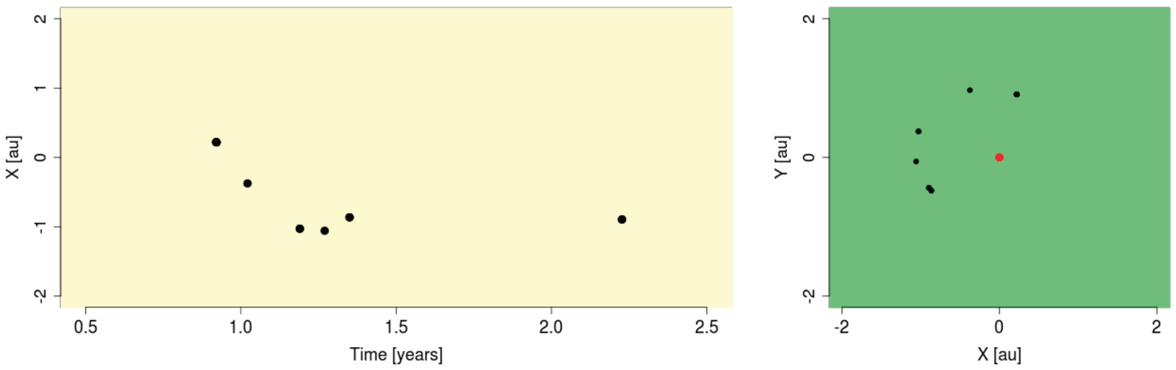

Fig. 1: Left: Gaia observations of Apophis versus time.
The x-axis is expressed in terms of the number of years elapsed since the beginning of the mission.
Right: spatial distribution of the observations in the ecliptic frame and centered on the Sun (●).

2.2. *Orbital improvement*

In the short term, one set of Gaia observations could substantially enhance the current accuracy of the keplerian orbital elements of Apophis (and in general for all the possible observed NEAs). Together with all the available ground-based observations (optical and radar), the Gaia observations will enable to improve the 1σ uncertainty of the semi-major by a factor 1000. Besides, the long term uncertainty can be assessed using a linear propagation of the initial covariance matrix (provided by the least square solution). Comparing various sets of observations (Fig. 2) – each set providing a nominal solution – one can see that one Gaia data (set S_5) is enough to reduce the uncertainty to the same level as for the sets S_3 (with an additional radar data) and S_4 (with an additional optical data). But, the impact of one set of Gaia data is incomparable as the uncertainty is reduced to the kilometer level.

3. Astrometry for newly discovered asteroids

When NEAs are discovered, a strategy of recovery can be undertaken. At the epoch of the discovery, Gaia will provide at most two observations separated by approximately $\Delta t \sim 1.5$ h. Thus, if it is identified as an alert, those coordinates will be sent to the Earth within 24 h. But Gaia is not a follow-up mission and the newly discovered object can be rapidly lost if no ground-based recovery is performed. A follow-up network for Solar system objects (Gaia-FUN-SSO) has been set-up in order to monitor those asteroids after their discovery [2, 3]. In order to optimize the alert mode, we have first to quantify the number of alert expected.

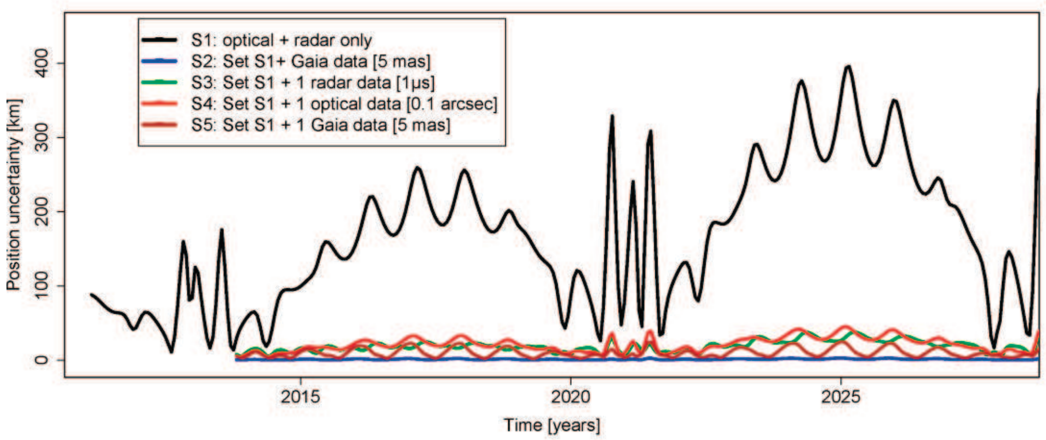

Fig. 2: Position uncertainty propagation considering various sets of observations. While S_3, S_4, S_5 reduce the uncertainty to the same level, S_2 (using a set of Gaia data) decreases the uncertainty to the kilometer level.

3.1. *Near-Earth asteroids alerts*

We presently know more than 9000 NEAs and only ~1/6 of this population could be observed by Gaia. For the discovery quantification, we consider a synthetic population of 30000 NEAs from the model of [4], limited to $H \leq 22.0$. We represented in Fig. 3 both the known and synthetic NEAs population that will be observed by Gaia. These populations are represented in the (a,H) space.

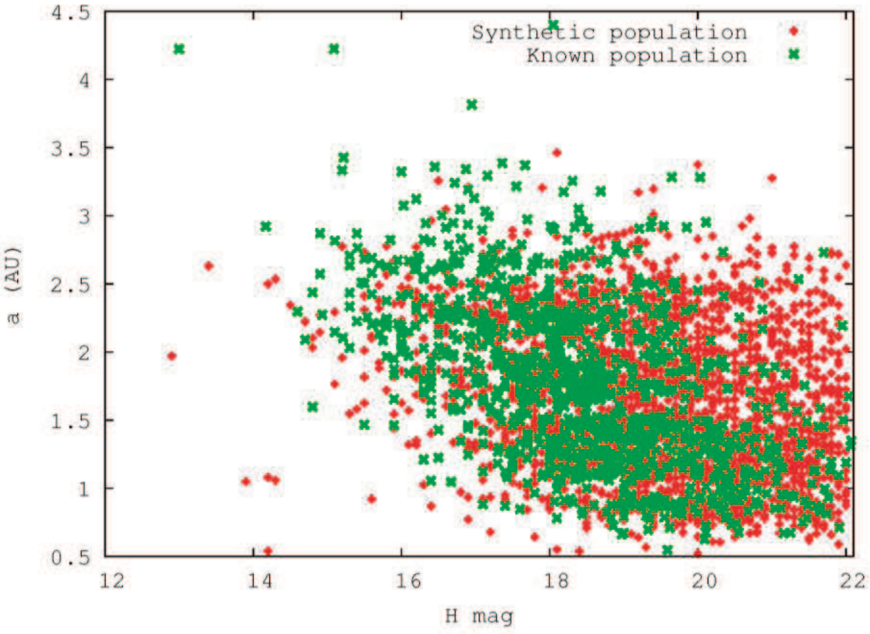

Fig. 3: Representation of the known (×) and synthetic (+) populations possibly observed by the satellite Gaia during the mission.

In order to identify and quantify the number of alerts per year after the beginning of the mission, we removed all the synthetic NEAs for which the semi-major axis *a* and absolute magnitude *H* lie between the minimum and maximum values of (a,H) defining the known NEAs population observed (see Fig. 3). The results are presented in Fig. 4 and show a mean of 4 or 5 alerts per week during the first 4-years after the start of the mission.

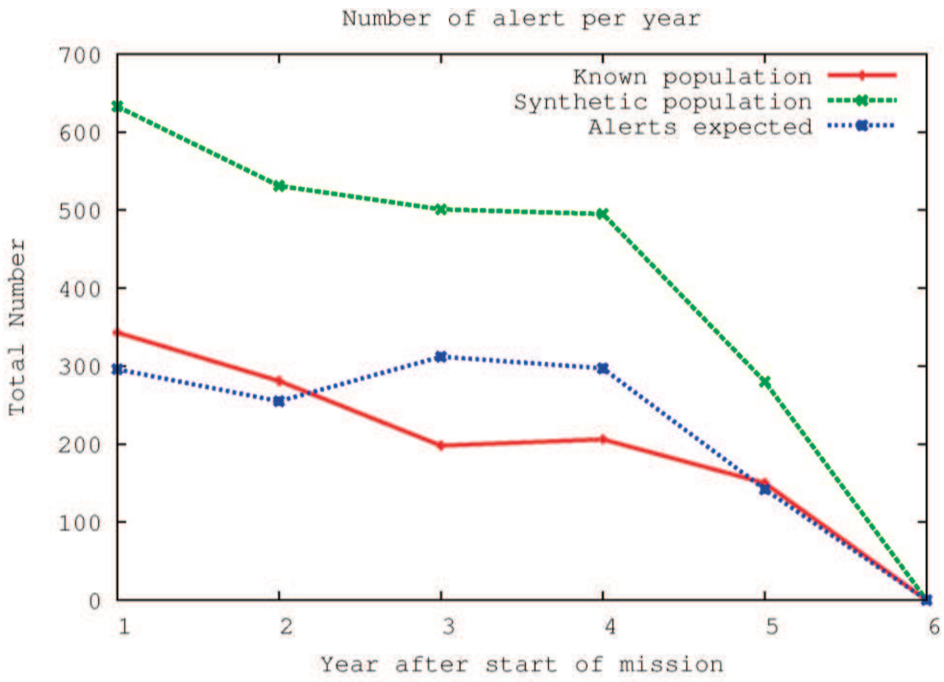

Fig. 4: Number of alerts (🟦) compared with the number of observed synthetic NEAs (🟩) and known NEAs (🟥), per year after the beginning of the mission.

3.2. *Strategy of recovery*

When an alert occurs, a preliminary short arc orbit can be computed with the two (α, δ) Gaia observations using the Statistical Ranging method[1][5]. Thus, a distribution (α, δ) can be assessed until a certain number of days after the discovery. Because the distribution can be quite large, we used statistical tools to extract the maximum likelihood (ML) of the distribution. Compared to the theoretical position of the object (given by the orbital elements from astorb database), we can estimate the minimum field of view (FOV) required to recover this object. As shown in Fig. 5, some asteroids will need typical FOV < 25×25 arcmin^2 (case of asteroid Cuno) until 10 days after their discovery, while some others (case of asteroids Apophis and Phaethon) require a FOV of hundreds of square degrees after their recovery. This behavior can be explained by their relative distance to the Earth – Geographos and Cuno are relatively far from the Earth (> 1 AU) at the epoch of their discovery by Gaia, and less perturbed by the Earth than the others (distance to the Earth <0.5 AU).

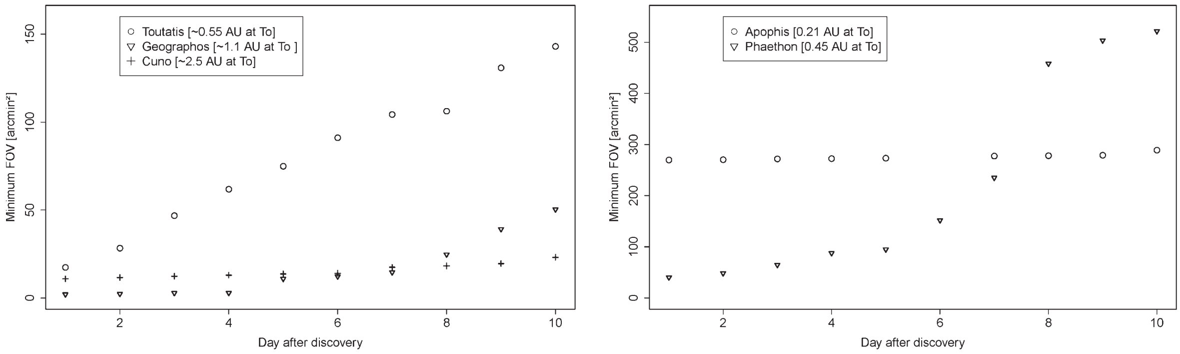

Fig. 5: Variation of the minimum FOV required for the recovery process versus time.
Left panel: for the asteroids Toutatis, Geographos and Cuno.
Right panel: for the asteroids Apophis and Phaethon.

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[1] This method uses Monte Carlo technique on the (α, δ) observations and on the topocentric distances

Finally, when the object is recovered by the Gaia-FUN-SSO, complementary ground-based measurements will enable to improve the orbital elements and the quality of the orbit. This process will enable to optimize the short-term pipeline and the organization of the network in as much as, the orbital improvement will enable to use telescopes with smaller FOV and keep the larger ones for asteroids requiring large FOV during the recovery process.

Conclusion

Even if Gaia will not be a big NEAs discoverer, there is a need of the science community to support the Gaia mission in order to be ready for this opportunity of discovering new NEAs. Among them, there could be some threatening potentially hazardous asteroids and we cannot afford to lose them is no Gaia-FUN-SSO is well organized

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Binary asteroids with Gaia photometric observations

by T. Michalowski (Astronomical Observatory, Poznan, Poland)

Abstract

The basic photometric properties of binary asteroids will be presented. Sparse photometric observations from Gaia will allow to derive the basic parameters for many single and binary asteroids.

(Article not received)

Detection of inner Solar System Trojan Asteroids by Gaia

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Abstract

The Gaia satellite, planned for launch by the European Space Agency (ESA) in 2013, is the next generation astrometry mission following Hipparcos. While mapping the whole sky, the Gaia space mission is expected to discover thousands of Solar System Objects. These will include Near-Earth Asteroids and objects at Solar elongations as low as 45 degrees, which are difficult to observe with ground-based telescopes. We present the results of simulations for the detection of Trojan asteroids in the orbits of Earth and Mars by Gaia.

Introduction

Trojan asteroids share the orbit of a planet and librate about the L4 and L5 Lagrangian points in that planet's orbit. Earlier modelling and simulations for Earth Trojans [3] predict the existence of ~ 17 bodies larger than 100 m, and for Mars Trojans [4, 5, 6] ~ 50 bodies larger than 1 km are predicted. The first discovery of a Trojan asteroid in Earth's orbit (2010 TK7) was announced in 2011 [1], and there are only three known Mars Trojans. Based on those simulations it is possible that more Trojan asteroids exist in the inner Solar System, however detection of such objects by ground-based telescopes are subject to a number of restrictions. This paper describes the results of modelling and simulations for the detection of Trojan asteroids in the orbits of Earth and Mars by the Gaia space mission, which does not share those limitations of ground-based telescopes.

1. Detection by Gaia

By definition, Trojan asteroids are found in the L4 and L5 Lagrangian regions in a planet's orbit. The probable orbits of Earth and Mars Trojans [7, 8] show that peak detection longitudes are consistent with classical Lagrangian points, but that bodies are unlikely to be co-planar as the stable orbits have significant inclinations. The sky area in which these bodies may be located is quite large but this is not a significant problem in the context of Gaia's mission to survey the whole sky.

The apparent magnitude for an Earth Trojan ranges from $V = 17.9$ to $V = 19.5$ [7] and for a Mars Trojan is between $V = 16.2$ to $V = 20.7$ [8], assuming 1 km diameter and an albedo of 0.20, and neglecting atmospheric extinction. This variation is effected by phase angle and distance, with distance being the dominant influence. Since Earth Trojans are co-orbital then these would be brightest when nearest to Earth in their orbits. By comparison the Mars Trojans have greatest brightness at opposition, which is a region outside Gaia's scanning area. The brightness of the Mars Trojans, when within Gaia's scanning area, is $V >\sim 18$.

The limits from the models were used to construct orbits for 20 000 objects each for Earth and Mars Trojans, for simulation of possible detection by Gaia. The instantaneous positions of these are shown in Figure 1.

For the simulated Earth Trojans, 969 orbits never crossed Gaia's field of view. A further 146 had brightnesses $V > 20$, placing them below the detection threshold of $V = 20$. The result of the simulation is that

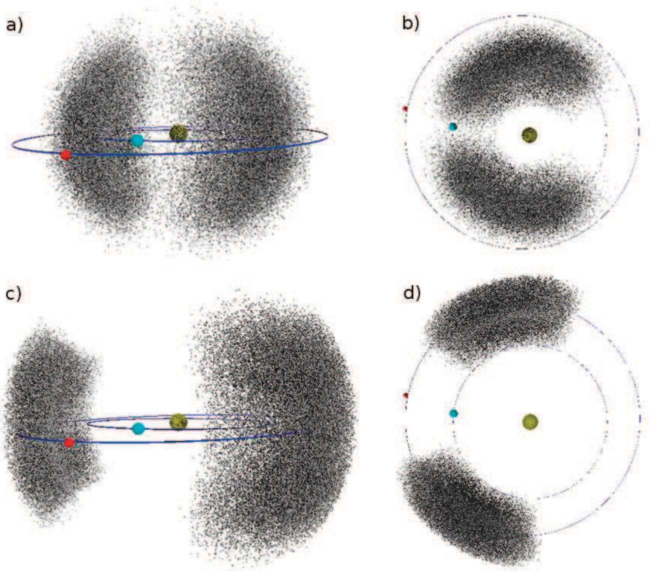

Figure 1: Positions of simulated bodies at JD 2456000.5. a) Distribution of simulated Earth Trojans; b) Projection on the ecliptic plane of the positions of the simulated Earth Trojans; c) Distribution of Mars Trojans; and d) Projection on the ecliptic plane of the positions of the simulated Mars Trojans.

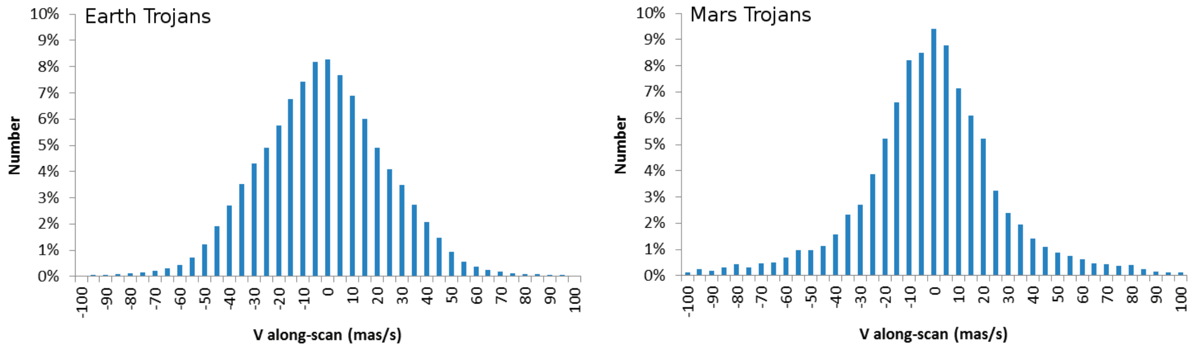

Figure 2: Statistical distribution of the along-scan velocity during observation for the simulated objects.

$\sim$ 94 per cent of objects were detected.

For the simulated Mars Trojans, 142 orbits never crossed Gaia's field of view. In contrast to the detection results for the Earth Trojans, only 2096 were detected with brightness $V < 20$. However 420 of these were detected in only one telescope, which would prevent any orbit calculation and subsequent recovery. The result of the simulation is that $\sim$ 8 per cent of the objects were detected where possible follow-up study could be performed.

In both cases the along-scan velocity is significant. The along-scan velocity for Main Belt asteroids is typically less than 10 mas/s [2] whereas for both Earth Trojans and Mars Trojans along-scan velocities much greater than 10 mas/s is quite common (Figure 2). The length of the window defined for sources $V > 16$ is six pixels (354 mas). For an along-scan drift $>\sim$ 3.5 mas/s a source will travel $>$ 175 mas from the centre of the defined window in the along-scan direction in the $\sim$ 50 seconds it takes to travel the length of the CCD array, with the result that the source drifts outside its window.

In both cases the across-scan velocity is also significant. The across-scan velocity for Main Belt asteroids is typically less than 15 mas/s, whereas the across-scan velocities for Earth and Mars Trojans are much greater (Figure 3). The bimodal distribution of the across-scan velocities for Earth Trojans in Figure 3 is a product of the geometry. The width of the window defined on the CCD is 12 pixels (2124 mas), and so an across-scan drift $>\sim$ 21 mas/s results in the source drifting outside the window. In addition, for across-scan velocity $>$ 195 mas/s, from a mean starting point at the centre of the CCD, the source will

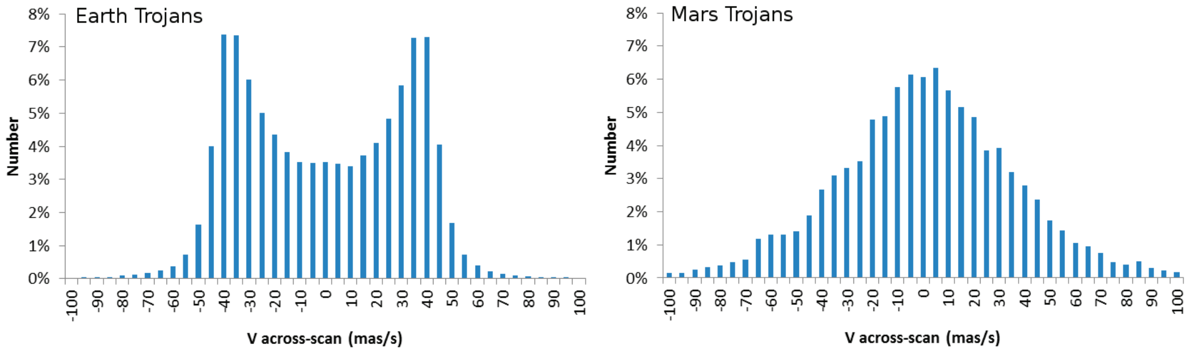

Figure 3: Statistical distribution of the across-scan velocity during observation for the simulated objects.

only be observed in one telescope.

Due to their orbits, the simulated Earth Trojans are observed more frequently than Main Belt whereas the simulated Mars Trojans are observed less frequently. This over-representation of the Earth Trojans in the detection statistics is expected; these are co-orbital and are observed at least once during each scanning cycle. However it is unlikely that there are any Earth Trojans of this size. The known Earth Trojan (2010 TK7) is estimated to have a diameter of ~ 300 m [1], with an apparent magnitude between $V = 20.9$ to $V = 22.7$, and a mean sky motion calculated to be between 25 mas/s to 100 mas/s (see Table 1), making it unlikely to be detected by Gaia. By comparison the three Mars Trojans are much brighter and have a smaller apparent motion, making it probable that they will be detected by Gaia.

Table 1: Inner Solar System Trojan Asteroid magnitudes and mean sky motions.

Designation	Magnitude	Mean Sky Motion (mas/s)
2010 TK7	$20.9 < V < 22.7$	25 - 100
5261 Eureka	$17.1 < V < 19.2$	4.5 - 23.5
1998 VF31	$17.3 < V < 20.1$	6.5 - 35.5
1999 UJ7	$17.4 < V < 19.6$	4.5 - 23.0

Conclusion

The regions where Earth and Mars Trojan asteroids may be found occupy a very large sky area, however Gaia will survey these regions multiple times during its mission. Because of the co-orbital nature of Earth Trojans, that region will be over-observed by comparison with any other field since Gaia will observe that region each scan cycle. In contrast with this, the Mars Trojan region will be observed much less frequently because of the different geometry. For both cases the high along-scan and across-scan velocities may present a problem due to loss of signal as the source will tend to drift out of the window defined on the CCD.

It is unlikely that any Earth Trojans exist which are larger than 2010 TK7. The consequence is that any other Earth Trojans will be too small and hence too faint for Gaia to detect. In the case of the Mars Trojans there is some uncertainty but it is expected that Gaia would detect any additional bodies which are of sizes comparable to those already known. An analysis for the detection of the known Earth and Mars Trojans by Gaia will be forthcoming.

Acknowledgements

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Gaia-FUN-SSO: a network for Solar System transient Objects

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Abstract: *During the Gaia mission, Solar System Object alerts will be triggered toward the ground. We have set up the Gaia-FUN-SSO network in order to coordinate fast reaction for the observation of these targets. In this article, we describe this network at the present stage, its recent activity for training campaigns of observation, and its next activity. We discuss also some points related to this organization and the strategy of observation.*

1. Introduction

Solar system objects will be observed by the Gaia probe during its five year mission. Among the daily flow of data, some of these objects will be not identified as known objects, or some detection of moving objects could be uncertain and will require confirmation. The Gaia-FUN-SSO network has been set up for being devoted to that kind of task through a follow-up of some critical Solar System Objects. Contrarily to other space missions, the possibility of such complementary ground-based observations for Solar System objects has been early identified during the preparation of the data processing. The triggering of alerts has been included in the process and the need of a dedicated ground-based network to deal with these alerts was foreseen since the beginning of the project. Another article (Carry et al., ibid.) gives information on the alert processing and on the tools for monitoring the network. In this article we describe the setting up of the network, its organization, and the activities already performed.

2. Gaia framework and goal

The main reason why during the Gaia mission we need a ground-based network for Solar System objects is the difficulty to monitor an object in space due to the observing mode of the probe. Gaia is not a space observatory which could point on demand but it is a scanning system. This observing mode will not allow to re-observe and confirm a newly detected moving objects. Only the ground-based follow-up network will allow this.

The Gaia data processing workflow includes an auxiliary orbital parameters data base which is used for identifying known Solar System objects during the operation and needs to be regularly updated. This update is due to the Minor PLanet Center collecting work and to the update of the Lowell database "astorb". In this context, the goal of our ground-based network is to detect from the ground the newly detected critical object after receiving an alert from the Gaia data processing system and to provide complementary astrometric measures. But these data will not be directly used by the Gaia data processing but indirectly. It will be sent by the observers to the Minor Planet Center in order to feed this international database of orbital elements. This will permit subsequently to update the auxiliary database of Gaia.

Despite preliminary analysis already done (Tanga et al. 2008, Bancelin et al 2012), it is still difficult to foresee the number of alerts that we will really get. During the first months of the mission several alerts, true or false alerts, could be triggered for validation of the detection of moving objects and will be useful for the tuning of the discrimination in the data processing system. During the main period of the mission, the alerts could concern mainly faint objects, NEAs, perhaps comets, close to magnitude 20, the limiting magnitude of Gaia. We are also awaiting detections at low Solar elongation since the zone at 45 degrees of elongation will be explored by the probe.

3. The Gaia-FUN-SSO network

The network has been developed on the basis of contacts with observers who are using instrumentation adapted to astrometric measurement on alert. The alerts must be triggered almost 48h after the detection. The minimum requirements are the following: to access the instrument in the nights following the alert; to perform short observing runs with CCD camera, pixel size of less than 1 arcsec; to use a field of view not too small (greater than 10 arcsec is useful in order to get reference stars); and to reach a limiting magnitude down to 20 similar to the Gaia limiting magnitude.

Fig. 1: Localization of the observing sites registered (in blue) in the Gaia-FUN-SSO network

At the date of this workshop, the Gaia-FUN-SSO network is composed of 39 observing sites rather well spread in longitudes (fig. 1). Obviously getting more observing sites in the south hemisphere, in Russia and in North America would be very useful. The observing sites have registered, giving the main parameters of their instrumentation: 55 telescopes are operating covering several classes of diameters from small robotic telescopes (Tarot telescopes with diameter 25cm) to the 2.4m telescope of the Chinese Lijiang observatory (fig. 2).

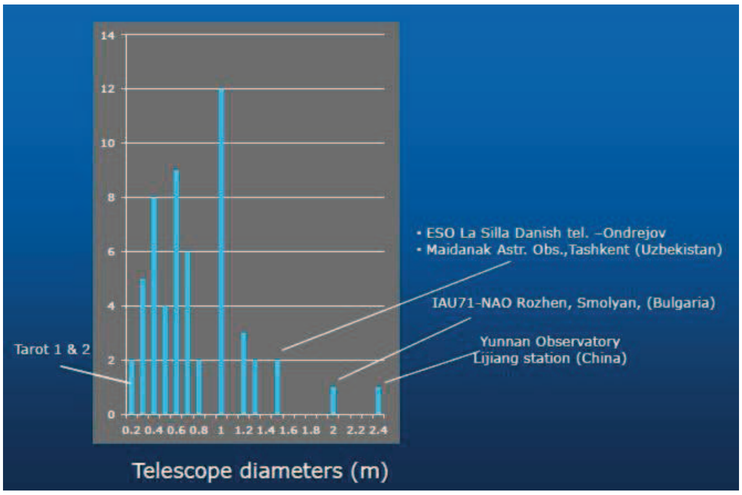

Fig. 2: Histogram of the telescope diameters involved in the Gaia-FUN-SSO network

4. Activity of the network

Since 2011, a wiki server is used for the coordination of the Gaia-FUN-SSO network. These pages, at the address https://www.imcce.fr/gaia-fun-sso/ give much information on the network, on the method for observing, on the tools well adapted and the useful links. Only the home page is public, registration is necessary to access to all this information. Registered observers can access to the ephemerides and the results of the campaign on this wiki.

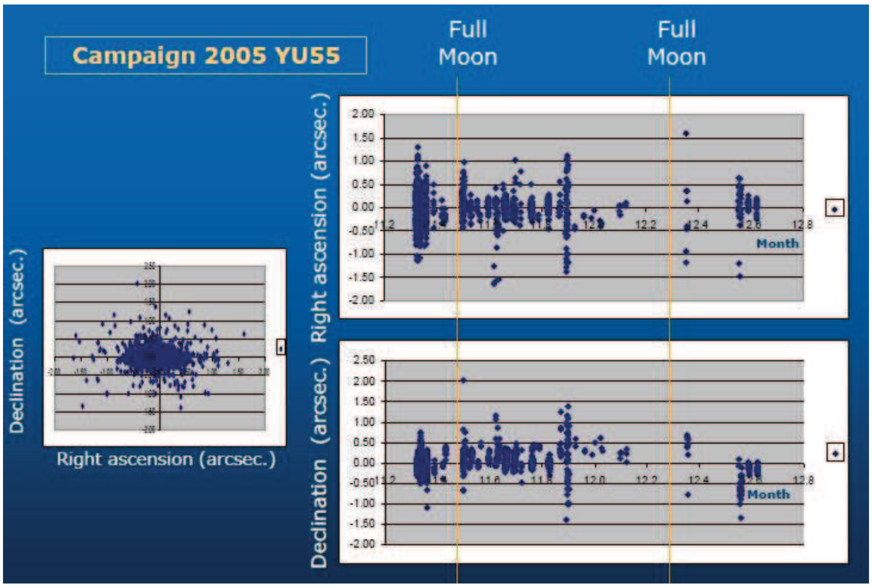

Fig. 3: Observed-Calculated (o-c) values obtained during the 2005 YU55 campaign in November-December 2011.

In this preliminary period, before the launch of Gaia in autumn 2013, several campaigns of observations were organized for the training of the observers and the testing of the network. The first one was organized in November 2011 (Todd et al. 2013), taking the opportunity of the close approach of the NEO 2005 YU55. 14 stations could participate (almost 40% of the network) and 1556 measures were obtained by the observers, leading to a fit of a dynamical model to the whole set of observations known (on 2187 days since the discovery) and a R.M.S. of 0.30 arcsec (fig. 3).

The second experiment was less successful by means of the number of observing stations, but was very successful as a real simulation of alert. On 17 January 2012, Th. Pauwels (Uccle, Royal Obs. Of Belgium, Brussels) detected an object, magnitude 20, at Solar elongation 133 degrees which will be a zone of observation of Gaia. An alert was triggered in the Gaia-FUN-SSO network, only 4 stations (MPC codes H15, A84, C20 and 461) could react, starting 1.4 day later. But the object (TP3522, renamed 2012 BS67) was successfully detected and followed.

We organized also a campaign for the observation of 99942 Apophis in March 2012 which was the first step of a longer campaign spanning up to March 2013. This asteroid is a famous PHA intensively studied since its discovery in 2004. Every new period of observation must not be lost and the Gaia-FUN-SSO network can give an important contribution. Further information will be provided at the end of this long campaign.

Conclusion

The Gaia mission will detect new Solar System Objects. Among them we will certainly have Near Earth Objects and in particular some with low Solar elongation or faint magnitude. Due to the observing mode of the probe, these objects could be lost. The ground-based follow-up network Gaia-FUN-SSO will have the goal to avoid that and to provide further observations in order to improve their ephemerides. This structure is well in shape but will be again improved in the next months in order to get the maximum efficiency for monitoring and automatization of the diffusion (see Carry et al, ibid.)

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Current status and development of the SSO FUN alerts

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Introduction

The astrometry mission Gaia of the European Space Agency (ESA) will scan the entire sky several times over 5 years, down to a visual apparent magnitude of 20. Apart for its primary targets, the stars, that will be mapped during the course of the mission, Gaia is expected to observe more than 300,000 asteroids (Mignard et al., 2007). Although our census of asteroids is about complete at a such magnitude limit, the location of Gaia at L2 may allow the detection of yet-unknown near-Earth asteroids (NEAs). The predefined and smooth scanning law of Gaia, however, is not meant for pointed or follow-up observations. A ground-based network of observers has therefore been set up, the Follow-Up Network for the Solar System Objects (FUN SSO), centered around a central node (the DU459 of the Gaia Data Processing and Analysis Consortium, the DPAC). The aim of this network is to quickly observe from the ground the NEAs newly discovered by Gaia to secure an accurate orbit.

Following the description of the overall organization and status of the network presented by Thuillot et al. (2012), we present here the details of its central node host at the Institute for Celestial Mechanics and Ephemeris Computation (IMCCE) in Paris, France. The role of the node will be, upon detection by Gaia of a target judged as interesting for or requiring a follow-up, suitable for observations by the network, to release calls for observations, and to provide support to the observers. We describe in particular the current implementation and development of the system that will be used by the node and of the various solutions envisaged to interact with the network of observers.

1. Organization of the central node of the network

Each observation of a non-fixed source by Gaia will be handled by the forth Coordination Unit (CU4) of the DPAC. Any source entering the pipeline will be first checked against the list of known Solar System Objects at that time. The Gaia Follow-up Network for the Solar System Objects (FUN SSO) will deal with all the sources not yet cataloged at the time of their observations. For each of these, we will

1. Receive a bundle of possible orbits as determined by the DU459,
2. Predict the future positions of the targets as seen from Earth,
3. Select appropriate targets for follow-up according to their observability,
4. Release a call for observations, *i.e.*, the so-called **alert**,
5. Provide support to and manage the network of observers,
6. Update the alert continuously with incoming observations from the network,
7. Withdraw the alert upon completion.

The proper completion of these different points, hence the success of the FUN SSO, present several challenges both in delay of execution and in the influx rate of new detections (we expect a few alerts per week). Time constraints add to the complexity of observing geometry the observers will face: the FUN SSO alerts will concern faint ($V > 18$-19) and fast-moving (rate > 50-$100''$/h) objects, most likely at a low solar elongation ($\psi < 70^\circ$). Moreover, the *a priori* unknown parallax between Gaia and the Earth for a given target may result in up to a degree of uncertainty on the apparent position.

Regarding the timing, the central node will receive the bundle of orbits 24 h to 48 h after the observation by Gaia at the earliest. Such a delay is imposed by the time line of the data flow and telemetry scheme: for each *operational day*, Gaia will observe without communicating with the Earth during 16 h, storing the observations on-board into a *backlog*. These 16 h will then be followed by 8 h during which Gaia will both observe and download all the observations performed during the 16+8 h (*i.e.*, both backlog and real-time). Upon reception of the data by the Mission Operation Center and transfer to ESA, the initial data treatment will take place (*e.g.*, decompression, decoding, PSF-fitting). Identification of an unknown moving target can only be done after these first steps are performed. Hence, depending if the targets was observed during the backlog or real-time part of the operational day, the delay between its observation by Gaia and its acknowledgment to the central node may last between 24 h and 48 h.

The central node must therefore avoid any further delay: with a typical non-sidereal motion of $\approx 100''$/h, NEAs move by about a degree on the plane of the sky each day. Additionally, because of the poor preliminary knowledge on the orbit and parallax, the predictions for the position and apparent magnitude of each newly discovered asteroid may be valid for only a very short period of time, typically a few days. A short reactivity time for both the node and the observers will therefore be required to quickly trigger the first observations and subsequently updates the alerts.

2. Current development at IMCCE

2.1 *Subjacent structure*

Owing to the timing constraints described above, most of the processes within the node must be automatized. Nevertheless, a regular human supervision for reliability and sanity checks is still required. The observations, linked with the observers of the network, will be used to compute the orbital elements of each target, which will be used in turn to predict future positions (Fig. 1). Based on a series of threshold on the viability of the prediction (*i.e.*, is such target observable by the network?), an alert containing all the necessary information for completion is released. The orbital elements, predictions, and alert will be updated upon follow-up observations by network (*i.e.*, steps 2 to 6 in Sect. 1.) until the orbit of the target is secured.

Observing campaigns on already known targets have already been issued by the node. We will continue these campaigns before the launch to test the data flow structure and improve our dialog with the network from the feedback provided by the observers on our services. Also, in the earliest stages of the mission, the thresholds will likely require adjustments so a workable compromise between too few and too many alerts (including possible false-positive) is reached.

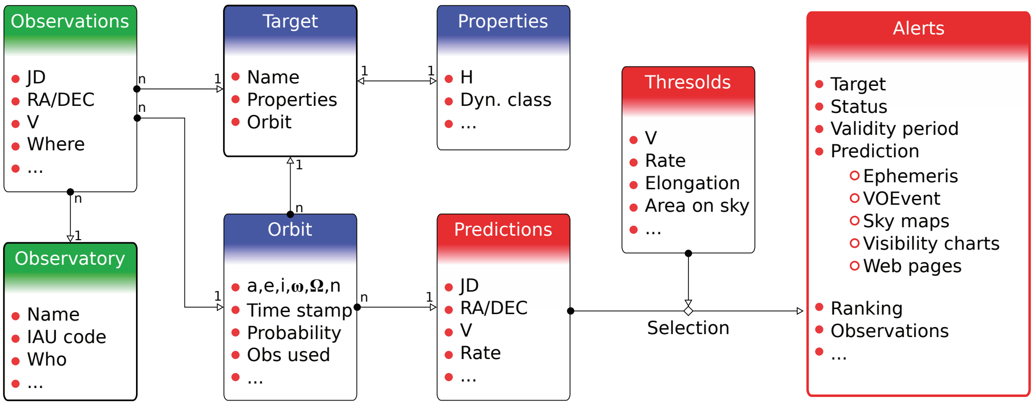

Figure 1: Overview of the work flow and data organization within the central node.

2.2 *Means of interaction with the network*

During the course of the Gaia mission, the network will have to deal with many concurrent alerts linked to different targets, with different levels of priority, feasibility, and urgency. The central node will have to manage the observing efforts to maximize the number of target recovery and orbit determinations. We have selected a series of tools to help the observers in choosing the alert(s) to follow at a given epoch. The base of the central node outputs will be machine-readable packages (VOEvent) containing all the required information to follow the alert. These packages are planned to be available via news feed (*e.g.*, RSS flux) to ensure direct dialog with robotic telescopes without delay. A suite of human-readable displays (sky map, observability charts, interactive web pages) are also under development to help decision-making at the telescope.

VOEvent: VOEvent are XML files following the Virtual Observatory standards describing all the information needed to perform an astronomical observation (Fig. 2.A). The information is structured using simple markups, such as `Who` released the package, `WhereWhen` was it released, `What` should be observed (*e.g.*, coordinates), and so on. VOEvent packages are routinely used to trigger observations of gamma-ray bursts or micro-lensing events, and most robotic telescope systems can interpret them.

Sky map: We will predict the apparent position of the targets from the preliminary orbits determined first by the DU456, then upgraded internally by the central node. These predictions will define the area of the sky to be covered to search for the target and will be available through the Aladin Sky Atlas[1]. Displaying the evolution of these area with time (Fig. 2.B) will also provide an efficient criterion to attribute priority to alerts and define the period of time during which they are valid.

Visibility charts: For each object, indications on when and where to search will provided by the VOEvent and sky maps described above. We will also provide an overview of all the alerts observable from a given site to help observers optimizing their observing time during the nights. Over the last year, IMCCE has developed an efficient tool to generate visibility charts from a target list called ViSiON[2] (Fig. 2.C). Once the location and specific constraints (*e.g.*, minimum elevation, limiting magnitude) of each observatory filled in the system by the observers, we can generate on-the-fly dedicated visibility charts for current alerts. ViSiON will greatly help observers as only the targets observable from their location and with their instrumentation will appear in the charts.

Web pages: We will also generate web pages for each alert, containing all the relevant information on the target and listing the observations performed by the network. A portal page is also foreseen. It will present a summary of all the alerts: status, validity period, observations, etc. We also study the possibility of displaying these quantities under a time line format (Fig. 2.D) for convenience. These pages will be accessible to the observers of the network. Several pages will also have to be created to upload observations and telescope characteristics to populate the data base (Sect. 2.1) and automatically generate ephemeris, visibility charts, etc. for the given site.

Conclusion

With the launch of Gaia in less than a year ahead, the central node is currently developing the tools required to interact with the network of observers with minimal delays and in a sustainable way given the expected inflow of alerts. During the course of 2012 up to Gaia start of operations, we will test these tools with the help of the network. Once the first real alerts from Gaia will be issued, in early 2014, a period of adaptation and definition of the different thresholds to trigger alerts will be undertaken.

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[1] Aladin Sky Atlas: http://aladin.u-strasbg.fr/

[2] ViSiON: http://vo.imcce.fr/webservices/miriade/?vision

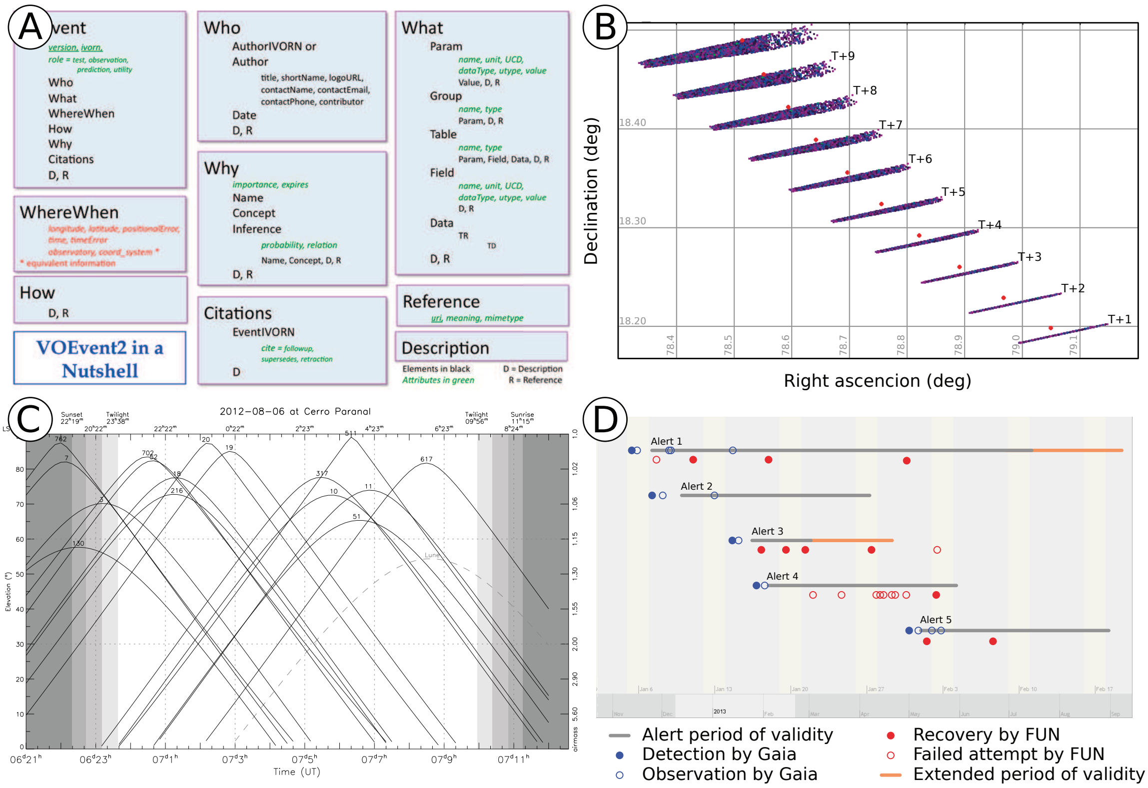

Figure 2: **A:** Schema diagram of the VOEvent table (credits IOVA). The detailed description can be found there http://www.ivoa.net/Documents/VOEvent/. **B:** Example of a possible representation of the area of the sky to cover for a simulated alert, displayed in Aladin. The series of red bullets represent the real trajectory of the NEA at 1, 2,..., 10 days after detection (T). The bluish areas represent the predicted positions from the bundle of preliminary orbits. **C:** Example of a visibility chart for an arbitrary list of targets produced by ViSiON. All-sky views with trajectories are also generated by the system. ViSiON has a built-in source-selection algorithm and each curve corresponds to a target which is observable from the requested location under a set of specified constraints (*e.g.*, apparent magnitude, solar and lunar elongation). **D:** Example of the typical usage of a time line representation of concurrent alerts. All the alerts and corresponding observations are summarized and this helps in identifying which alert need new observations.

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ISON-NM Observatory: capabilities for Gaia-FUN-SSO support. CoLiTeC image processing pipeline for moving objects detection

by L. Elenin ,V. Savanevich, I. Molotov, A. Kozhukhov, A. Bryukhovetskiy, V. Vlasenko, E. Dikov, A. Yudin (Keldysh Institute of Applied Mathematics RAS)

Abstract

We present capabilities of ISON-NM remote observatory for task of follow-up newly discovered minor bodies of Solar system, detected by GAIA mission.

(Article not received)

Observations of asteroids with Pulkovo observatory ZA-320M and MTM-500M telescopes for GAIA FUN SSO program

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Introduction

Laboratory of observational astrometry of Pulkovo astronomical observatory of Russian Academy of science takes part in prelaunch training observations of GAIA-FUN-SSO program. Two asteroids were observed for this program after training alerts in 2011–2012.

1. Instruments

Two telescopes of Pulkovo observatory made observations for the GAIA-FUN-SSO program. ZA-320M telescope (Cassegrain system, $D = 32$ cm, $F = 320$ cm, FoV $\approx 28' \times 28'$) is situated in Pulkovo observatory at the edge of Saint-Petersburg city, Russia. MTM-500M telescope (Maksutov – Cassegrain system, $D = 50$ cm, $F = 410$ cm, FoV $\approx 21' \times 21'$) is situated in Mountain astronomical station of Pulkovo observatory at Nothern Caucasus near Kislovodsk city, Russia, at 2070 meters above sea level. The telescopes are equipped with CCD-cameras with identical CCD-chips (1024 × 1024 pixels of 24 × 24 μm) and sets of *BVRI* filters.

To make positional and photometrical processing of CCD-observations, we use APEX-II software [1] developed in Pulkovo observatory. The software works automatically and makes following operations:

- Calibration — fitting or synthesis and application of darks and flats
- Sky background smoothing
- Object detection using threshold algorithm
- Deblending
- Object center detection using PSF method
- Flux measurement using aperture or PSF methods
- Noise rejection
- Identification of measured objects with a reference catalogue (USNO-A2, USNO-B1, TYCHO-2, HIPPARCOS, UCAC-3, UCAC-4, XPM, 2MASS, user's catalogues)
- Astrometric reduction using several methods
- Identification of unknown objects using EPOS module (asteroid and comet searching)
- Creation of report in standard format (e.g. MPC).

There is possibility to mark objects and reference stars manually using graphical interface.

To make computations on Solar System bodies' motion, we use the EPOS software [2] developed in Pulkovo observatory too. The software provides a number of kinds of celestial-mechanics calculation and visualization including:

- ephemerides,
- O–C,
- orbit determination and improvement,
- motion of Solar System bodies in various coordinate systems.

2. 2005 YU55 asteroid

2005 YU55 Near Earth Asteroid was observed with ZA-320M and MTM-500M telescopes during its close approach to Earth in November 2012. We observed its light-curves to examine its period of rotation and made observations in *BVRI* filters to determine its color-indices. Most of the observations were used to get the asteroid positions.

The previous value of the asteroid rotational period determined with radar observations is 18 hours (see http://ssd.jpl.nasa.gov/sbdb.cgi?sstr=308635). To determine the period, all our observations that were made without filter were collected and processed. The period was calculated using Scargle's [3] and CLEAN [4] methods. Its value is 16.3 hours. Our observations light-curve with the period is shown in the Figure 1. The black curve is averaged values.

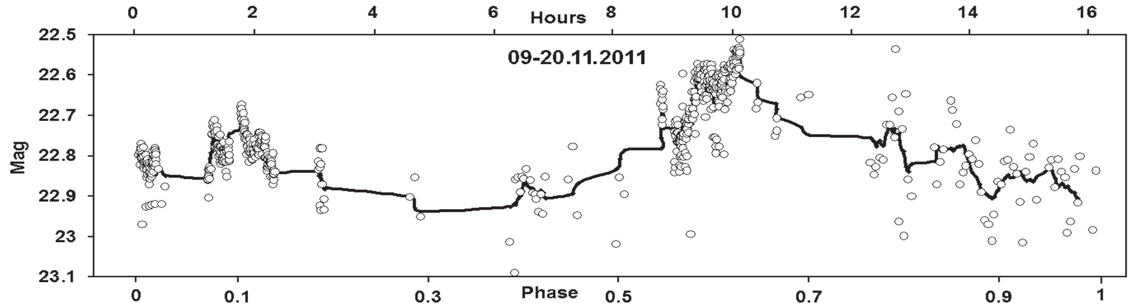

Fig. 1: The light curve of 2005 YU55 asteroid with period of 16.3 hours.

During processing of the data, one more period was noticed in observations with both the telescopes in several nights. Its value varies in different nights from 0.9 to 1.2 hours. The magnitude span is about zero-point-fifteen here. As an example, light-curve with this small period from one night observations is shown on the Figure 2. Durations of the observations were long (ten hours) and included several period durations. We are not sure about reality of this period. But if it is real this may mean that the asteroid is binary.

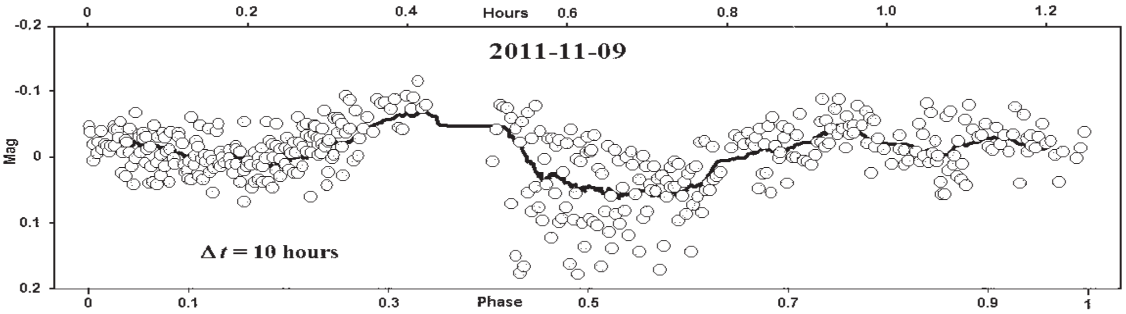

Fig. 2: The light curve of 2005 YU55 asteroid with period of 0.9 hours (one night observations).

The weighted means of color-indices from our observations are following:

$$B\!-\!V = 0.67^m \pm 0.07^m, \quad V\!-\!R = 0.34^m \pm 0.09^m, \quad R\!-\!I = 0.30^m \pm 0.07^m.$$

The effective color measured from spectrum of the asteroid in [5, 6] is $V\!-\!R = 0.37^m$. Our value is in agreement with it.

Authors of article [5] have classified 2005 YU55 asteroid by its spectral observations. They have fitted analogues asteroid spectra: C_{gh}, C, C_h (Bus), G (Tholen). These reflectance spectra are flat in visible wavelength range.

We have tried to classify 2005 YU55 asteroid using our wide-band photometry. The authors of article [7] classify asteroids on Tholen's classification using wide-band photometry: *BVRI* and additional *Z* band at 0.91 μm. We have no *Z* filter. But using their method in this narrower (0.44–0.83 μm) spectral diapason, the spectrum form of the asteroid is close to B, F, C, G (Tholen) classes — the classes with flat spectra in visible range too. B class is closest.

Authors of article [6] have built phase curve for 2005 YU55 asteroid in *R* band and determined its absolute magnitude and slope parameter. Figure 3 is sketch from the article [6] containing the phase curve. We put our *R* band observations into the sketch. And the observations lay on the same phase curve but have greater scattering. They are made with lower phase angles than in [6] and this confirms the values of absolute magnitude and slope parameter of the asteroid.

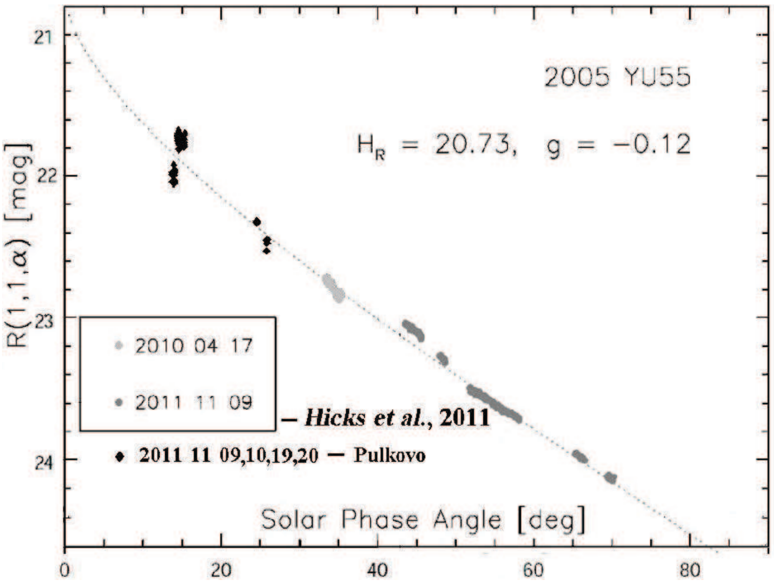

Fig. 3: The graph of phase curve of 2005 YU55 asteroid from [6]. The results of Pulkovo *R*-band observations are added to the graph — black dots.

Using our observations, we calculated 926 positions of the asteroid with mean accuracies of 0″.1–0″.4. The results were sent to Minor Planet Center.

This asteroid has approaches to Venus, Earth and Mars. During a close approach to a planet, it changes its orbit sharply. The modeling of the changes was made using EPOS software. Figure 4 shows the orbit changes during two close approaches of the asteroid to planets — to Earth and to Venus. Large changes in the node line position are clearly seen. And graphs of Figure 5 show changes of the orbital elements during the approach to the Earth in November of 2012. One can see that value changes of some elements are not monotonous.

3. TP3522 = 2012 BS67 asteroid

After discovery of TP3522 asteroid on Royal Observatory of Belgium on 17-th of January 2012, we got an alert about it. On 20-th of January, we made 24 observations of the asteroid with MTM-500M telescope. This amount is about 1/3 of all observations of the object in MPC database (77 observations). Mean accuracy of our observations is 0″.2 on each coordinate. These observations (along with observations of other observatories) allowed confirmation of discovery of the asteroid and its orbit improvement.

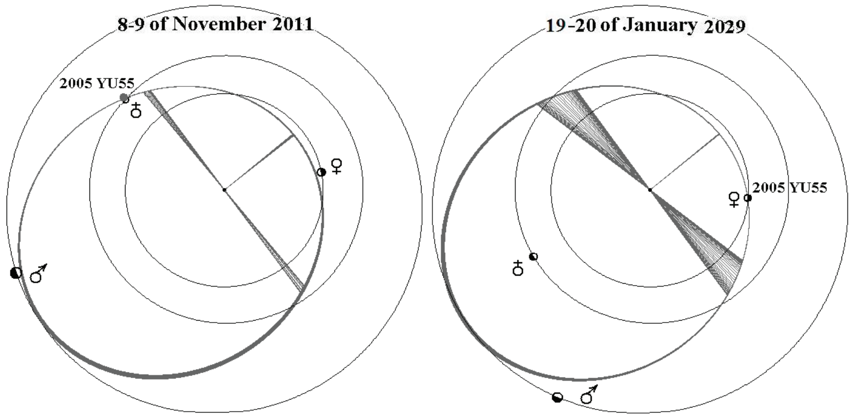

Fig. 4: Changes of 2005 YU55 orbit during close approaches to Earth and Venus.

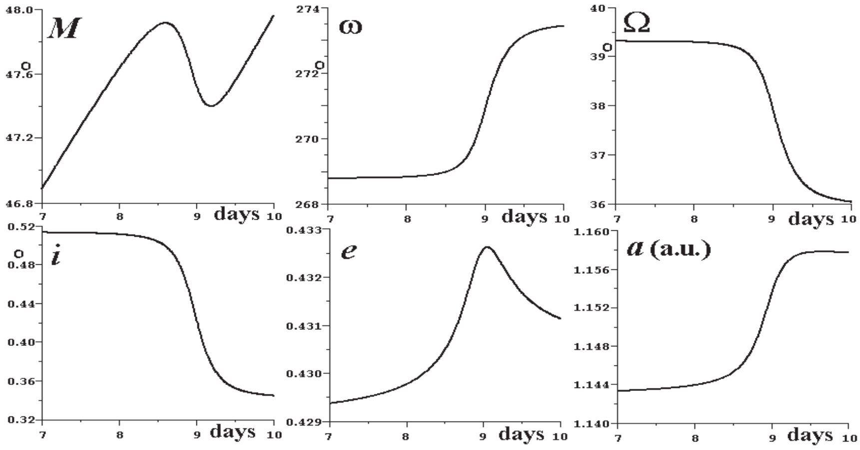

Fig. 5: Changes of 2005 YU55 orbital elements during close approaches to Earth on 8-9 of November 2012.

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Gaia-FUN-SSO at the Konkoly Observatory: First Results and the Prospects for Future Work

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Introduction

The Konkoly Observatory is the largest astronomical institute in Hungary. It is now a part of the Research Centre for Astronomy and Earth Sciences of the Hungarian Academy of Sciences. The main observing station is the Piszkéstető Observatory located in the Mátra mountains, about 80 km from the headquarters to NE direction at about 950 m above the sea level.

The current observing equipments in the Piszkéstető Mountain Station are as follows:
- 0.5 m Cassegrain-type telescope, equipped with a photoelectric photometer. This telescope has been used for observing bright variable stars (up to about 11th magnitude in *V*).
- 0.6 m Schmidt-telescope, used for wide-field imaging. In the photographic era, it had a 5-degree field of view and was very successful in discovering comets and supernovae. This was the first telescope in Piszkéstető, installed in 1962.
- 1 m Ritchey-Chrétien-Coudé telescope, used for photoelectric and CCD photometry.
- 0.4 m RC telescope installed in 2010. The main program carried out with this remotely controlled small telescope is CCD photometric follow-up of known transiting exoplanets but we also envisage studies of minor objects in the Solar System.

Both the 0.6 m Schmidt and the 1 m RCC telescopes will be upgraded to remote-controlled instruments, meaning that the reaction time to rapid alerts will be sufficiently short.

These telescopes (except the smallest one) were manufactured by Carl Zeiss Jena. While the telescope mounts are still the original ones, the control systems in the Schmidt and the RCC have been upgraded several times over the years. As of writing, all of these telescopes are regularly used for CCD imaging, equipped with various CCD cameras (including an EMCCD camera) that are partly interchangeable between the 0.5 m Cassegrain and the 1 m RCC telescopes.

Scientists affiliated with the Konkoly Observatory have been involved in studies of:
- variable stars: stellar pulsations, asteroseismology (ground based as well as space photometry by CoRoT and Kepler), stellar activity, eclipsing binaries;
- interstellar matter, star formation (in addition to ground based data, studies in infrared based on data obtained with the instruments on board ISO, Spitzer, and Herschel space probes);
- small bodies in the Solar System (ground based astrometry, comets studied with HST and Spitzer, trans-Neptunian objects with Herschel);
- exoplanets (both ground- and space-based photometric observations).

1. Astrometric results

The most effective astrometric instrument is the 60/90/180 cm Schmidt telescope that was equipped with a Photometrics 1.5k × 1k CCD camera between 1996 and 2010. In 2010, this camera was replaced by an Apogee Alta U16 4k × 4k CCD camera, with a 1.2° × 1.2° field of view. This corresponds an increase by a factor of 10 in the imaged sky area, resulting in a dramatic jump in survey efficiency.

There has been a very successful astrometric program at the Konkoly Observatory since 1998. The observations have been reported under the Minor Planet Center observatory code 461 [1]. 19-20th magnitude near-Earth asteroids have regularly been captured with the Schmidt, indicating that the sensitivity reaches the expected limits of Gaia. With the recently upgraded CCD system, the efficiency has improved by over an order of magnitude, making our telescope a potentially very useful instrument for Gaia Solar System follow-up.

In the framework of the Gaia-FUN-SSO we took part in each campaign in 2011 and 2012. The summary of observations is given in the following tables.

1.1 *Campaign on (308635) 2005 YU55*

Date	Magnitude	Motion	Tel.	Exp. time	Number of positions	Residuals in arc sec	
9 Nov. 2011	11.5 R	44"/min	60S	3 sec	36	0.3" RA	0.1" Dec
12 Nov. 2011	14. R	2.7	60S	60 sec	12	0.3" RA	0.4" Dec
15 Nov. 2011	16.0 R	0.9	60S	90 sec	9	0.2" RA	0.3" Dec
17 Nov. 2011	16.5 R	0.6	60S	90 sec	3	0.1" RA	0.3" Dec
22 Nov. 2011	17.8 R	0.3	60S	120 sec	3	0.2" RA	0.4" Dec
23 Nov. 2011	17.9 R	0.3	60S	120 sec	3	0.2" RA	0.4" Dec
27 Nov. 2011	18.7 R	0.3	60S	120 sec	2	0.5" RA	0.5" Dec
28 Nov. 2011	18.9 R	0.3	60S	120 sec	2	0.2" RA	0.3" Dec
29 Nov. 2011	19.0 R	0.3	60S	120 sec	2	0.2" RA	0.4" Dec
30 Nov. 2011	19.0 R	0.3	60S	120 sec	3	0.3" RA	0.4" Dec

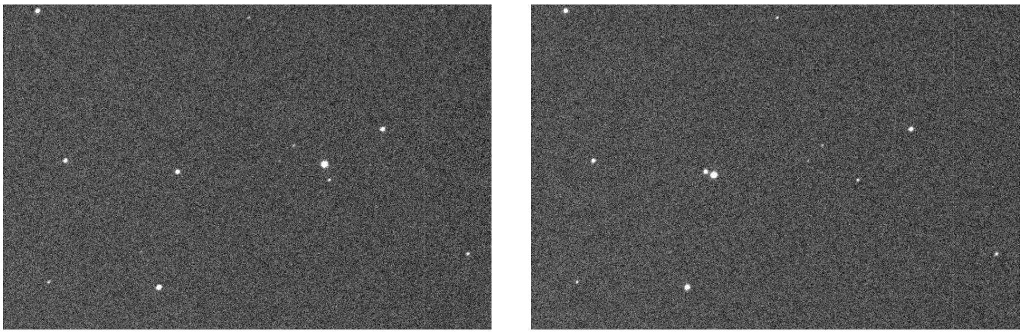

Fig. 1: Two images of (308635) 2005 YU55

1.2 *Campaign on TP3522 = 2012 BS67*

Date	Mag.	Motion	Tel.	Exp. time	Number of positions	Residuals in arc sec	
25 Jan 2012	19.5 R	0.6"/min	60S	150 sec	3	0.3" RA	0.7" Dec

From the observations available in January 2012, K. Sárneczky determined the orbital elements of this asteroid, including the moment of the perihelion passage: 2012 Mar 22.56993 TT.

1.3 *Campaign on (175706) 1996 FG3*

Date	Magnitude	Motion	Tel.	Exp. time	Number of positions	Residuals in arc sec	
23 Mar 2012	20.1 R	1.1"/min	102RC	10×60 sec	4	0.3" RA	0.7" Dec

1.4 *Campaign on (99942) Apophis*

Date	Magnitude	Motion	Tel.	Exp. time	Number of positions	Residuals in arc sec	
23 Mar 2012	20.8 R	2.2"/min	102RC	10×60 sec	3	0.3" RA	0.7" Dec
23 Mar 2012	20.9 R	2.2"/min	102RC	12×60 sec	3	0.3" RA	0.7" Dec

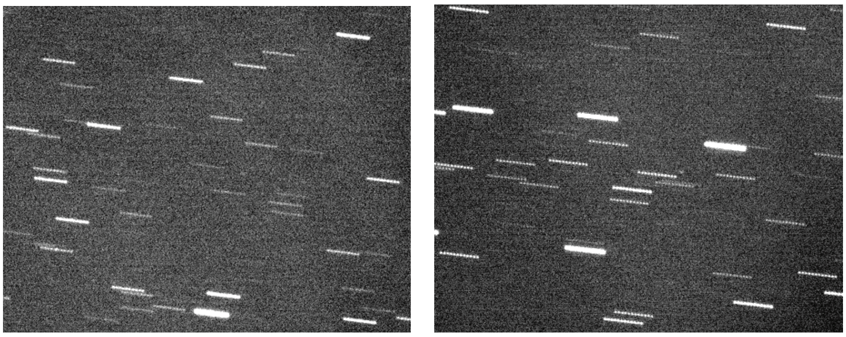

Fig. 2: Two consecutive observations of Apophis

1.5 *Summary of astrometric observations at Piszkéstető*

Statistics of astrometric data since Sept. 2010, our last report [1]:
49455 accurate positions were determined on 8967 asteroids and 17 comets;
1281 newly designated objects, 4 new NEOs were detected, as well as 1487 one-night stands by 20 observers involved in the Konkoly Gaia-FUN-SSO project.

2. Our other involvement in the Gaia project

Our current involvement in the Gaia preparations includes the work carried out by the Konkoly Observatory Gaia Team (KOGT). The KOGT has been involved in the following projects:

- CU7 Specific Object Studies Working Group (Cepheids & RR Lyrae stars Work Package, secular evolution Work Package);
- DPAC Ground Based Observations for Gaia:
- Gaia Science Alerts Working Group;
- Gaia Research for European Astronomy Training (GREAT): Gaia Alerts (WGA5), Distance Scales (WGA8), Stellar Variability (WGB2), Binaries & Multiple Systems (WGB3).

These studies have been supported by ESA and the Hungarian Space Office, through the PECS programme.

In the Cepheid related studies, our main task is to reveal companions to Cepheids by photometric and/or spectroscopic observations. Binarity of Cepheids is an important aspect because physical companions can falsify the trigonometric parallax in the astrometric solution. We have pointed out that all negative Hipparcos parallaxes of Cepheids within 2 kpc belong to those stars which are members in known binary (or multiple) systems.

We initiated a photometric search for close visual companions of Cepheids by lucky imaging technique with an EMCCD camera at the 50 cm Cassegrain telescope. Figure 3 visualizes the improvement in the angular resolution using this technique, via the example of CE Cas, a double Cepheid, whose both components are Cepheid variables with a 2.3" separation.

Fig. 3: Improvement of imaging by the lucky image technique: the binary Cepheid CE Cas (*left*: without lucky imaging; *right*: with lucky imaging)

Conclusion

With the telescopes at the Piszkéstető Mountain Station we took part in observing each target suggested for following in the Gaia-FUN-SSO alert system. Our observations belong to the faintest ones (up to 21st magnitude), i. e., the latest data on targets reported by the contributors to the Gaia-FUN-SSO project. During the active period of the Gaia spacecraft we plan to be involved in the Gaia alerts with observing transient astrophysical object/phenomena at short notice.

The recently completed and planned upgrades in instrumentation make the site very suitable to provide astrometric support to Gaia. Providing a ground based photometric and astrometric support for the Gaia, the most important space project of this decade allows the Konkoly Observatory to contribute to the cutting-edge research.

Acknowledgements

This work has been supported by the European Space Agency (ESA) and the Hungarian Space Office via the PECS programme (ESTEC Contract No. 4000106398/12/NL/KML). The modernisation of the Piszkéstető Station has been funded by the “Lendület” Young Researchers Program of the Hungarian Academy of Sciences and the Hungarian OTKA Grant MB08C 81013.

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Astrometrical observations of the near-Earth asteroid 308635 (2005 YU55) in Nikolaev

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Introduction

A near-Earth asteroid 308635 (2005 YU55) was discovered by Spacewatch group at Kitt Peak Observatory (691) on December 28, 2005. The asteroid belongs to the Apollo group, moreover it is a potentially hazardous asteroid presented in the critical list of the Minor Planet Center, the minimum orbit intersection distance of the asteroid with the Earth is 0.000454 a.u. As to the radar observations in 2010, the diameter of the asteroid is 0.4 km. Due to the high eccentricity of its orbit, the asteroid has close encounters not only with the Earth and the Moon, but also with Venus and Mars, so the orbit of this asteroid can be a subject of special interest for studying different gravitational perturbations.

During the period of close encounter with the Earth, the visible angular speed of near-Earth asteroids increases greatly, so such asteroids may cause difficulties for observations by classical methods. Nevertheless these observations allow to reveal and estimate possible errors in observation. The aim of the article is to discuss results of astrometric observations in Nikolaev Observatory of the asteroid 308635 (2005 YU55) during its close encounter with the Earth in November 2011.

1. Instrumentation, observations and reduction

There were two close approaches with this asteroid in 2011. The first one took place at 0.00217 a.u. with the Earth on November 8.98, the second one took place at 0.00160 a.u. with the Moon on November 9.30, 7.7 hours later. The maximum brightness of the asteroid was 11.2 mag, the maximum visible speed achieved 8.6 degrees per hour. The solar elongation was 84º, and increased with time, so the conditions of observations allowed to observe the asteroid even with small telescopes and the Moon visible all the night within the dates of close encounters.

The asteroid was observed with the telescope Mobitel of Maksutov system (D=0.5 m, F=3.0 m) by two different groups in Nikolaev Observatory (089) on three nights November 9, 17, 18; however we shall study solely the results obtained in the first two nights by the author of the present article. The telescope is equipped with the CCD camera Alta U9000 (3056 x 3056, 12 x 12 mkm^2) of Apogee Imaging Systems. The peculiarity of the telescope consists in using solely time delay and integration mode for observations which allows to get imaging strips 42' in width and scale 0.82″/pixel. The observations were made in R Johnson-Cousins-Bessel band. The field of view allows to get number of reference stars enough for reduction in the UCAC catalogs.

The greatest difficulty in observing the asteroid was its great speed on November 9 in comparison to the one on November 17. The mean components of asteroid velocities calculated for the observed times using the HORIZONS service of JPL [1] (http://ssd.jpl.nasa.gov/?horizons) as well as visual magnitudes are given in Tabl. 1. The length of exposure was adjusted to the ephemeride speed of the asteroid as to get images stretched due to its relative visible speed for no more than two full width at half maximum; the later one was estimated in 2.6″. This idea allowed to get slightly stretched images of the asteroid and to simplify further measurements by using the circular Gaussian function for profile fitting. It is easily seen in Tabl. 1 and can be demonstrated on the motion of Ceres (1) on the same dates, that the visible speed of the near-Earth asteroid on November 17 was comparable to the one of the main belt asteroids, so these observations on this date give estimations of astrometric precision which can be reached using current imaging and classical methods of reduction.

Table 1: Mean visible velocities and brightnesses of the asteroid during the observations

Evening dates	$v_\alpha \cos\delta$, arcsec/min	v_δ, arcsec/min	Visual brightness, mag.
09/11/11	39.67	–4.17	12.0
17/11/11	0.24	–0.12	16.6

So, the astrometric results are represented by 160 positions, which were obtained in two different nights on November 9 and 17 [2]. The differential reduction was made with the UCAC2 catalogue using full second order polynomials. We have found them appropriate for elimination of the possible errors produced by inaccuracy in position caused by small arbitrariness in choosing the projection center for the given field of view.

2. Analysis of observations

For analysis purposes, there were calculated differences between observed (O) and calculated (C) positions which are plotted on the Fig. 1. The calculated positions represent ephemeride positions of the asteroid found using the HORIZONS service of JPL. The orbit of the asteroid used by HORIZONS has been fitted to 2555 observations except for the discussed ones. The overall precision of the orbit is represented with RMS of residuals equal to 0.36”.

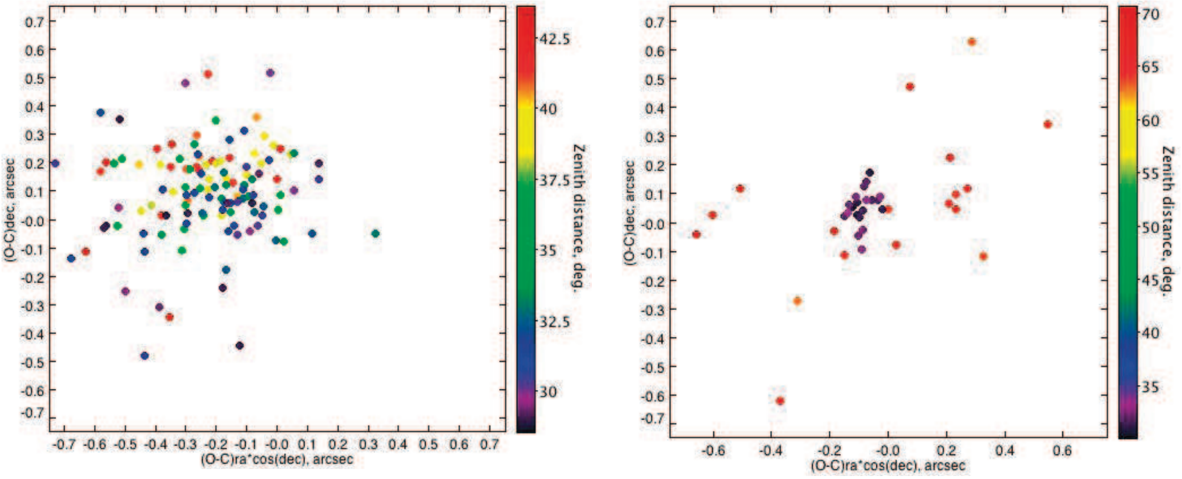

Fig. 1. Distribution of (O–C) in positions for two dates of observations: the left figure corresponds to observations made on November 9, the right one to November 17.

As one can find from Fig. 1, the series of Nikolaev observations made on November 9 has the same mean value and dispersion, while it is easily revealed two series of observations made on November 17. Simple hypothesis testing on the homogeneity of the residuals suggests only a significant difference in dispersion between two series of observations on November 17. The summary basic statistics of the residuals is presented in Tab. 2, where there are given mean values of the residuals and RMS errors for a single position of the asteroid. Besides, one can find that the precision of a single observation depends on zenith distance of the asteroid.

Considering the change in speed of the asteroid in November 2011, Tabl. 1, the corresponding astrometric precision obtained, Tabl. 2, and also zenith distances of the observations (Fig. 1), one can make a conclusion that the precision of astrometric measurements using classical reduction for a star-like object can be as smaller as 0.07″ that corresponds to 0.08 pixel in the focal plane, while the significant motion increases it to 0.25″ or 3 times.The increase of zenith distance of the observations deteriorated considerably the precision to 0.43″ on November 17.

Table 2: Basic statistics of the astrometric results

Evening dates	Numbers of positions	$(O–C)_\alpha\cos\delta$, arcsec	$\sigma_\alpha\cos\delta$, arcsec	$(O–C)_\delta$, arcsec	σ_δ, arcsec
09/11/11	122	–0.22	0.19	+0.09	0.16
17/11/11 (1)	20	–0.09	0.03	+0.05	0.06
17/11/11 (2)	18	–0.02	0.34	+0.05	0.27
Total/ Weighted	160		0.20		0.17

Conclusion

For two nights on November 9 and 17, there were obtained 160 positions at the Mobitel telescope in Nikolaev Observatory during the apparition of the near-Earth asteroid 308635 (2005 YU55) in the end of 2011. The best achieved precision in astrometric measurements for a slowly moving object was estimated 0.07″, while for fast moving object it was 0.25″. These results support the adopted technique of observations of the fast moving objects.

As far as the weighted RMS error 0.26″ of the discussed astrometric positions of the asteroid obtained in Nikolaev on November 9 and 17 is less than RMS error 0.36” of the orbit used, and considering numbers of observations used for calculation both of them, we expect 2% decreasing of the RMS error orbit fit after subsequent improvement.

Acknowledgements. This research was supported by the State Agency of Science, Innovations and Information of Ukraine (contracts No. M/415-2011 and No. M/331-2012) and Campus France (dossier No. 764429J).

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Follow-Up observation for Gaia's asteroids: orbit improvement and shape determination

by H. Zhao, B. Li, Y. Xia, H. Lu (Purple Mountain Observatory, China)

Abstract

Firstly, this talk will introduce the history of the study of asteroid dynamics in Purple Mountain Observatory. Secondly, the progress of Chinese Near Earth Object Survey (CNEOS), which is the primary scientific objective of 1.2 m Schmidt telescope, will be introduced. Thirdly, a new survey program on asteroid lightcurve will be start, and some shape determination result will be presented.

(Article not received)

Observations and New Astronomical Facilities in Lijiang Observatory

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Introduction

To achieve the scientific purposes, ground-based follow-up network (GAIA-FUN) for Gaia mission is necessary because of imposed date and position (Arlot 2011). The 2.4m optical telescope at Lijiang Observatory of Yunnan Astronomical Observatory (YNAO), Chinese Academy of Sciences, has the potential to play an important role in Gaia Follow-up Network (GAIA-FUN) in East Asia, especially for the follow-up of faint solar system objects (SSO) and Gaia itself (Thuillot 2011)[1]. Lijiang Observatory has joined the GAIA-FUN observation since 2010, and made some observations in collaboration with IMCCE, Paris Observatory in 2011 and 2012. New astronomical facilities like robotic telescopes have been installed in the observatory, and are possible to automatically response the VO-Event like GAIA-FUN observations.

1. Lijiang Observatory of YNAO

1.1. Lijiang Observatory

The Lijiang Observatory of YNAO is located at 100° 2'(E), 26° 42'(N), in Yunnan, China. It is 3200m in altitude, and has the best seeing and astronomical conditions in southern China[1]. The observatory was built together with the Lijiang 2.4m telescope, which was open to astronomers since May 2008.

More facilities were installed at Lijiang Observatory since then. The spectrograph at Coude focus is now in commisioning on the 1.8m telescope, and is expected to open to astronomers in 2013. The 60cm robotic telescope of BOOTES-4 has been operated since March of 2012. The Lijiang site of Taiwan Automated Telescope Network was built in winter of 2011. There is a coating machine at the observatory, capable to re-aluminizing 2-meter or smaller mirror. The iner diameter of the vacuum chamber is 3.2 meter.

1.2. Lijiang 2.4m telescope

The 2.4m optical telescope is the largest one at Lijiang Observatory at present. It was open to astronomers in May 2008 and jiont the GAIA-FUN collaboration since 2010[1]. Lijiang 2.4m telescope is equipped with the Yunnan Faint Object Spectrograph and Camera (YFOSC) as the main instrument. Other insturments like the Lijiang Exoplanet Tracker (LiJET, see Figure 1), PI-CCD camera are mounted on the Cassegrain folding position. Observer may switch to each one of the instruments on demand[1]. The telescope could be remotely controled by the observer who is not going to visit the observatory and sit behind his own laptop.

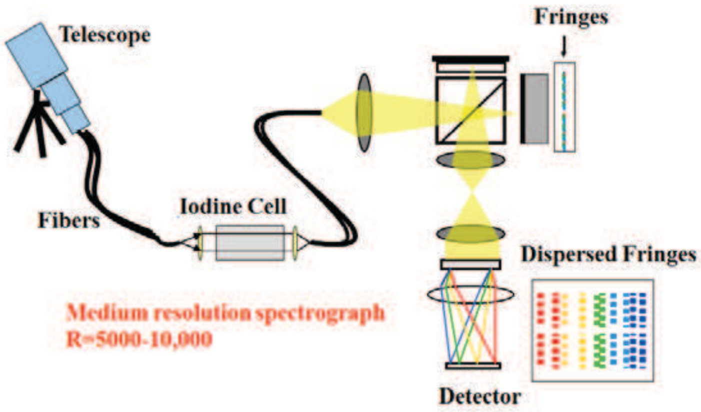


Fig. 1: Layout of Lijiang Exoplanet Tracker (Erskine & Ge 2000, 2002)

2. Observations of asteroids 2005_YU55 and 1996_FG3

Some observations of asteroids had been made by Q.Y. Peng (tpengqy@jnu.edu.cn), using the 2.4m telescope at Lijiang observatory, the asteroid of 2005_YU55 was observed for three nights during Dec 16-18, 2011 and 1996_FG3 was observed on Feb 19, 2012. Following we will take the asteroid of 2005_YU55 for an example to describe the observation, and measurement and reduction. Detailed information can be got from the website https://www.imcce.fr/gaia-fun-sso/.

2.1. Observation

No filter was used during the observations, and usually 120-180s was used for each CCD exposure time. After clipping and magnifying, the objective 2005_YU55 can be found (see Figure 2) duiring the observation.

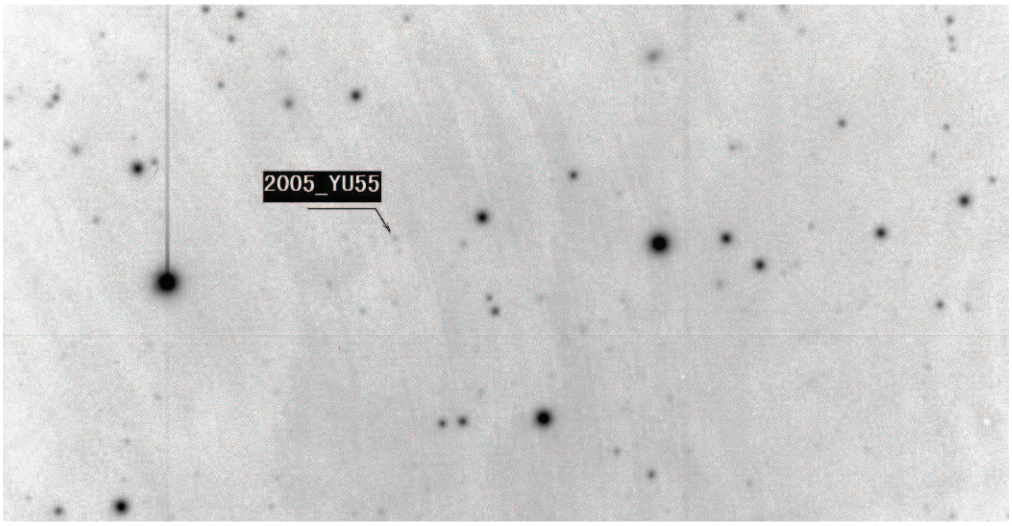


Fig. 2: Part of the CCD frame is clipped and the objective is found

2.2. Measurement and reduction

All CCD frames were measured by a 2D Gaussian fit (via our own codes) to obtain the pixel positions for both reference stars and the objective 2005_YU55. In total, 44 CCD frames were derived in 3 nights with the 2.4m telescope.

Because of the obvious geometric distortion[4] (called GD later on) for the CCD FOV, only some reference stars (about 5-7 stars in UCAC2[3]) around the objective asteroid were used as calibration. Specifically, a 6-constant plate model was used to calibrate the CCD FOV. The theoretical positions of reference stars were computed into their topocentric positions and the atmospheric refractions were also added to them. The topocentric positions of the objective asteroid was transformed from its geocentric apparent positions (via the website http://www.imcce.fr/), taking the atmospheric refractions into account. Figure 3 displays the observed minus computed (O-C) positional residuals of the asteroid 2005_YU55. The mean (O-C) residuals are 0."035 and -0."089 in r.a. and declination, respectively. The positional precision (the standard deviation) is about 0."10 in each direction.

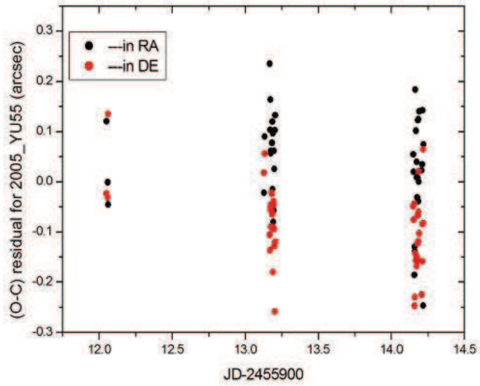


Fig. 3: (O-C) residuals for 2005_YU55 in 3 nights

2.3. Conclusions of the observation

The Lijiang 2.4m telescope is capable to take observations for faint asteroids like 2005_YU55. In order to improve its positional precision, some works will be needed, such as to derive its GD at the observational period of time (the pattern of GD is changing). The CCD frames obtained for 2005_YU55 cannot be corrected by its former results in [2] because of the mounting difference. Besides, the removal of its fringes would be interesting to refine its observational capability.

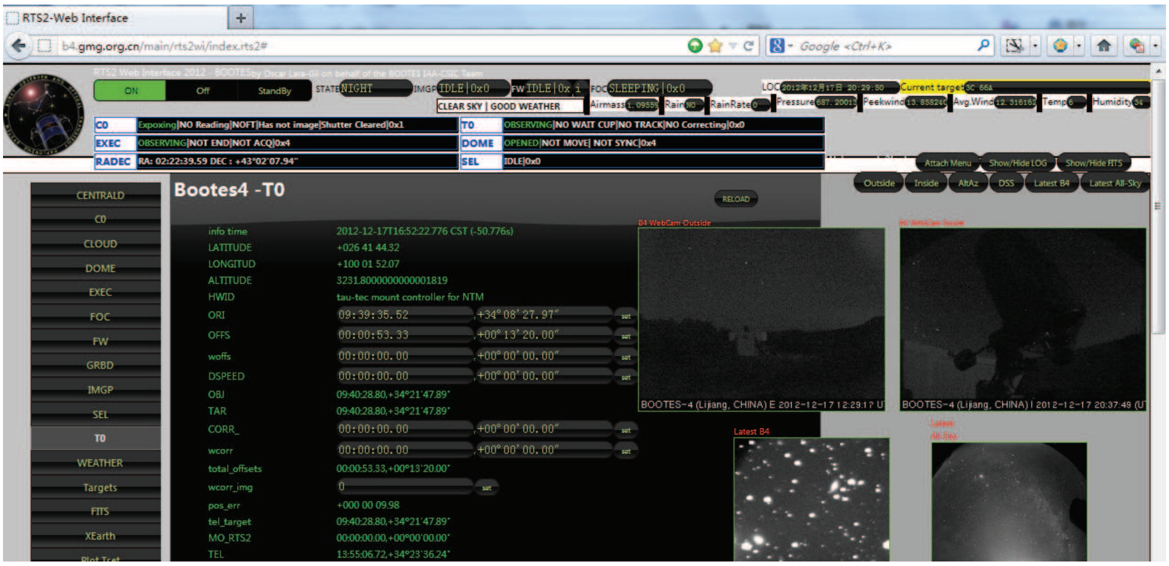
3. BOOTES-4 Robotic telescope

The Burst Observer and Optical Transient Exploring System, is a network of astronomical observatories with sites in Southern Spain, New Zealand and China. It has four sites mostly installed with 0.6m diameter telescope and EMCCD camera and a g'r'i'ZY filterset. The main goal of the network is to quickly observe transient events within few seconds/minutes of being detected by scientific satellites. The network now has four operating sites and few more under construction in south Africa and America(Figure 4).

The fourth station (BOOTES-4) was completed in spring of 2012, and starts operation as an autonomous observatory. It is the result of the collaboration between the Spanish Research Council (CSIC) and the Yunnan Astronomical Observatory (YNAO) signed in 2011.

The robotic control software used for BOOTES is the Robotic Telescope System version 2 (RTS2). RTS2 is being developed by P.Kub´anek, starting in 2000. The source code is open, and widely used in GRB searches. At present the pipeline for automatic data analysis, both astrometry and photometry is under developed. RTS2 has a triger to response alerts from scientific satellites to make ToO observation automaticly. It is posible to code the VO-event triger for BOOTES4 to make ToO for GAIA-FUN. Figure 5 shows the web interface of BOOTES monitor and observe system.

Fig. 4: Location of four existing BOOTES sites on Google map



STATE NIGHT
IMGP IDLE | 0x0
FW IDLE | 0x 1
FOC SLEEPING | 0x0
CLEAR SKY | GOOD WEATHER
Airmass 1.09559
Rain NO
RainRate 0
Pressure 687.20013
C0 Expoxing|NO Reading|NOFT|Has not image|Shutter Cleared|0x1
EXEC OBSERVING|NOT END|NOT ACQ|0x4
RADEC RA: 02:22:39.59 DEC : +43°02'07.94"
T0 OBSERVING|NO WAIT CUP|NO TRACK|NO Correcting|0x0
DOME OPENED|NOT MOVE| NOT SYNC|0x4
SEL IDLE|0x0

Bootes4 -T0

info time 2012-12-17T16:52:22.776 CST (-50.776s)
LATITUDE +026 41 44.32
LONGITUD +100 01 52.07
ALTITUDE 3231.8000000000001819
HWID tau-tec mount controller for NTM
ORI 09:39:35.52 , +34° 08' 27.97"
OFFS 00:00:53.33 , +00° 13' 20.00"
woffs 00:00:00.00 , +00° 00' 00.00"
DSPEED 00:00:00.00 , +00° 00' 00.00"
OBJ 09:40:28.80,+34°21'47.89"
TAR 09:40:28.80,+34°21'47.89"
CORR_ 00:00:00.00 , +00° 00' 00.00"
wcorr 00:00:00.00 , +00° 00' 00.00"
total_offsets 00:00:53.33,+00°13'20.00"
wcorr_img 0
pos_err +000 00 09.98
tel_target 09:40:28.80,+34°21'47.89"
MO_RTS2 00:00:00.00,+00°00'00.00"
TEL 13:55:06.72,+34°23'36.24"

Fig. 5: Web interface of BOOTES observe monitor (Gil 2012)

Conclusion

Lijiang Observatory has joined the GAIA-FUN since 2010 and made observations with the 2.4 meter telescope in collaboration with IMCCE in recent years. The new build 60cm robotic telescope has the capability for automated observation response to triger like VO-Event.

References

[1] Bai J.M., Liu Z.:2010, Introduction of Astronomical Telescopes and Instruments in Yunnan Astronomical Observatory, Gaia-Fun-Sso Workshop Proceedings

[2] Thuillot W.: 2011, Objectives and management of Gaia-FUN-SSO network, Gaia-Fun-Sso Workshop Proceedings

[3] Zacharias N., Urban S.E. Zacharias, et al.: 2004, AJ 127, 3043-3059

[4] Zhang Q.F., Peng Q.Y., and Zhu Z.: 2012, Preliminary results of solving the problem of geometric distortion for the 2.4 m telescope at Yunnan Observatory, Research in Astron. Astrophys., 12, 1451-1456.

[5] Castro-Tirado A. J.:2011, Robotic Astronomy and the BOOTES Network of Robotic Telescopes, Proceedings of the 7th Integral/BART Workshop, Vol. 51, No. 2., p. 16

Astrometric Observations of Some MBAs and NEAs at TUG and Observational Facilities of Akdeniz University

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M. Helvaci[1,2], M. Kaplan[1,2]

1. TUBITAK National Observatory
2. Akdeniz University

Introduction

We will give some information about observational facilities at Akdeniz University Space Sciences and Technologies Department and observations of NEO's at TUBITAK National Observatory (TUG)

Also the astrometric reduction method followed and the observational results will be presented.

1. Observational Facilities at Akdeniz University Space Sciences and Technologies Department

1.1. Akdeniz University Observatory

Akdeniz University plans to build a new observatory. The architectural drawings are ready for the main building and the telescopes. At the beginning, it is planning to start the observations with three telescopes which have 1m, 60cm and 25cm in diameters.

60 cm and 25 cm telescopes have bought. The observations have started with remote-controlled 25 cm telescope and 60 cm is under construction. Whole telescopes are planning to be remote-controlled.

1m and 60 cm telescopes may be good candidates for GAIA-FUN-SSO Collaboration.

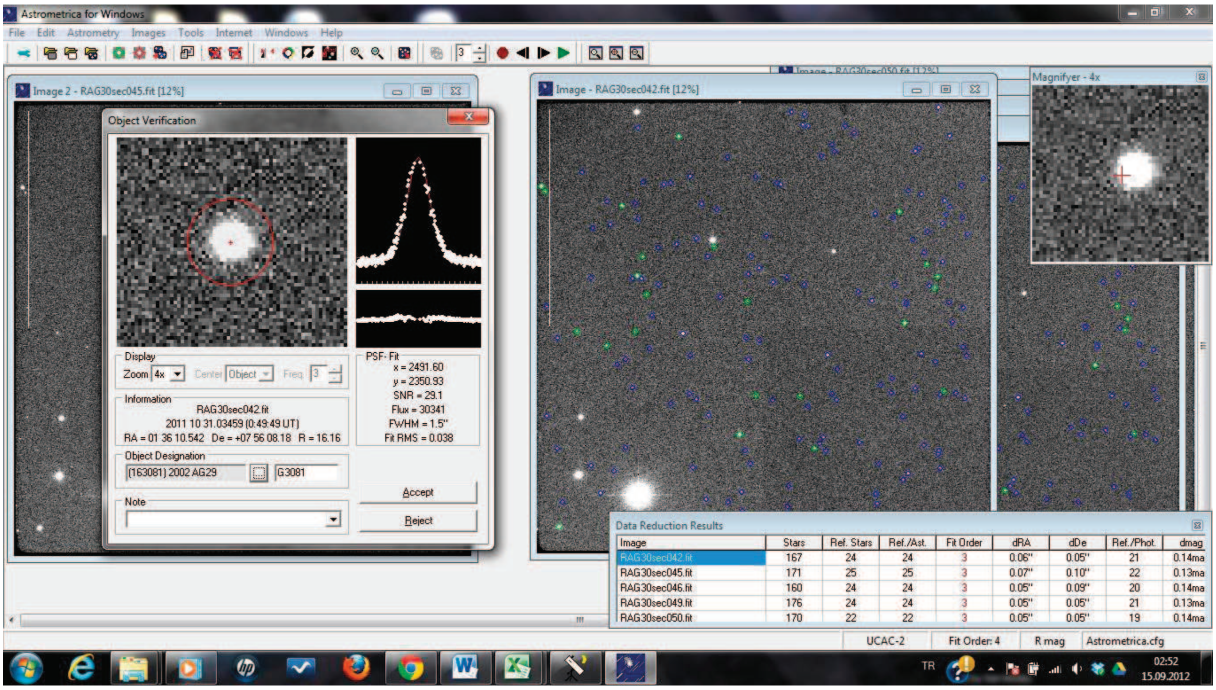
1.2. Space Sciences and Technologies Department

The academic life of this department has begun one year ago. This year forty students are accepted to study for barchelor's degree.

2. Observations of NEO's at TUBITAK National Observatory (TUG)

2.1. The Astrometric Reduction Method Follwed

TUG T 100 Telescope is used for obtaining the data. We have used 121 exposures for 2002 AG29 (NEO) and 66 exposures for 2000 SP43 (PHA) in three months period [1]. After that, the coordinates of asteroids are calculated with Astrometrica software.



Display
Zoom 4x
Center Object
Freq 3

Information
RAG30sec042.fit
2011 10 31.03459 (0:49:49 UT)
RA = 01 36 10.542 De = +07 56 08.18 R = 16.16

PSF- Fit
x = 2491.60
y = 2350.93
SNR = 29.1
Flux = 30341
FWHM = 1.5"
Fit RMS = 0.038

Object Designation
(163081) 2002 AG29
G3081

Note

Image	Stars	Ref. Stars	Ref./Ast.	Fit Order	dRA	dDe	Ref./Phot.	dmag
RAG30sec042.fit	167	24	24	3	0.06"	0.05"	21	0.14ma
RAG30sec045.fit	171	25	25	3	0.07"	0.10"	22	0.13ma
RAG30sec046.fit	160	24	24	3	0.05"	0.09"	20	0.14ma
RAG30sec049.fit	176	24	24	3	0.05"	0.05"	21	0.13ma
RAG30sec050.fit	170	22	22	3	0.05"	0.05"	19	0.14ma

UCAC-2
Fit Order: 4
R mag
Astrometrica.cfg

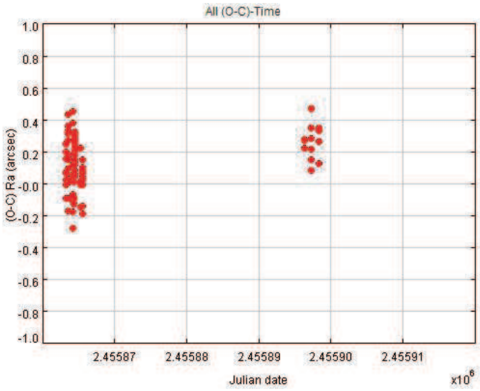
Figure 1. Obtaining the coordinates of an asteroid using Astrometrica software.

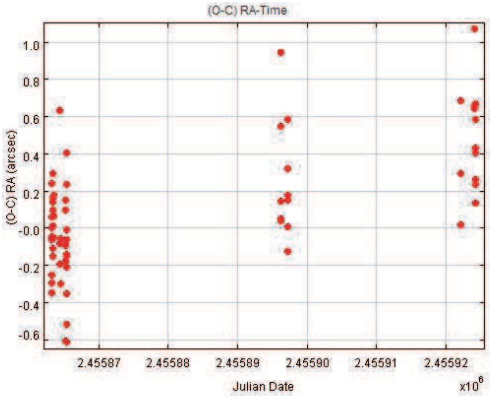
The O-C values are calculated using NASA JPL Horizons System data[2]. Finally O-C graphs are drawn according to these information.

2002 AG29

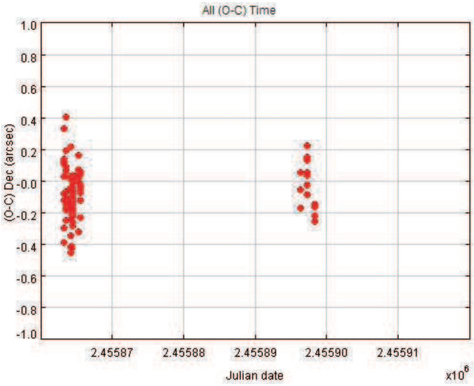
2000 SP43

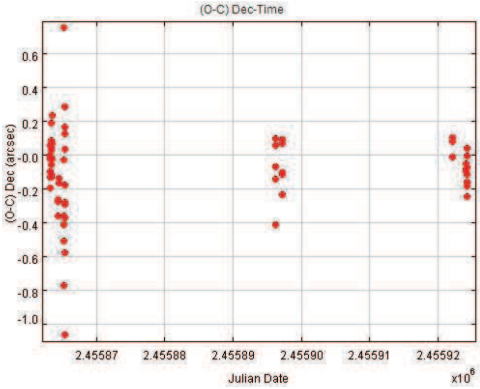
(O-C) RA-Time



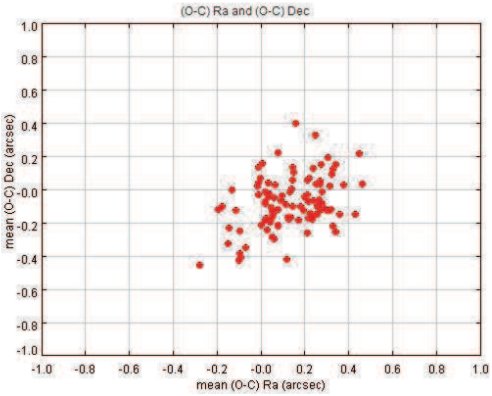


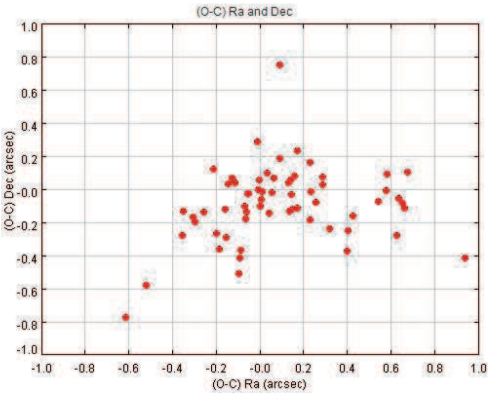
(O-C) Dec-Time





(O-C) RA-Dec





Conclusion

- These graphs have shown that we have a little systematic error (~0.2″) We are working on this problem to solve it.

- According to NASA NEO Program information:
  Fit RMS for 2002 AG29 is 0.55″
  Our fit RMS is 0.2″
  Fit RMS for 2000 SP43 is 0.41″
  Our fit RMS is 0.3″

- These results show that our observations can be useful for improvement of the orbits of these objects

References

[1] C. Stone R. Astrometry of Asteroids 1997, AJ, 113, 2317

[2] http://ssd.jpl.nasa.gov/?horizons

Astrometric Observations of (1665) Gaby, and (1565) Lemaître Asteroids at TUBITAK National Observatory (TUG)

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1. *TUBITAK National Observatory, Antalya/TURKEY*
2. *Akdeniz University, Dept. of Space Science and Technologies, Antalya/TURKEY*
3. *Nikolaev Astronomical Observatory, Nikolaev/UKRANIA*

1. Introduction

In this study, we are providing the accuracies and precisions of our observations made with a 100 cm in diameter telescope (T-100) at TUBITAK National observatory (TUG) located in Antalya, in order to determine the efficiency of T-100 telescope for GAIA's ground base observations. In this respect, we have studied 1565 (Lemaitre) and 1665 (Gaby) which are well-known main belt asteroids using T100 telescope and by obtaining new orbital parameters of Lemaitre with a fit with RMS around 0.2 for both asteroids, respectively. Our results indicate that T100 telescope and our observational equipments are sufficient to participate GAIA follow up ground base observational tasks. T100 and capacity of other observational equipments seem very convenient for astrometric observations.

2. Site Characteristics and Observational Equipments at TUG

All of the observations of Lemaître and Gaby were obtained by using the remote control T-100 telescope which has 1 meter R-C type mirror with 10 meters focal distance, 0.3 arc sec pixel scale and 22 arc minutes field of view (see ref.1). T100 telescope located in TUG (TUBITAK National Observatory) Bakirlitepe Mountain (2500 meters high above the sea level) close to Antalya, which has 260 clear nights in a year and 0.8 arc sec median seeing (Fig.1).

- Mirror : Ritchey-Chrétien
- Aperture : 1000 mm
- Focal Length : 10000 mm
- Focal Ratio : f/10

SI 1100 CCD Camera

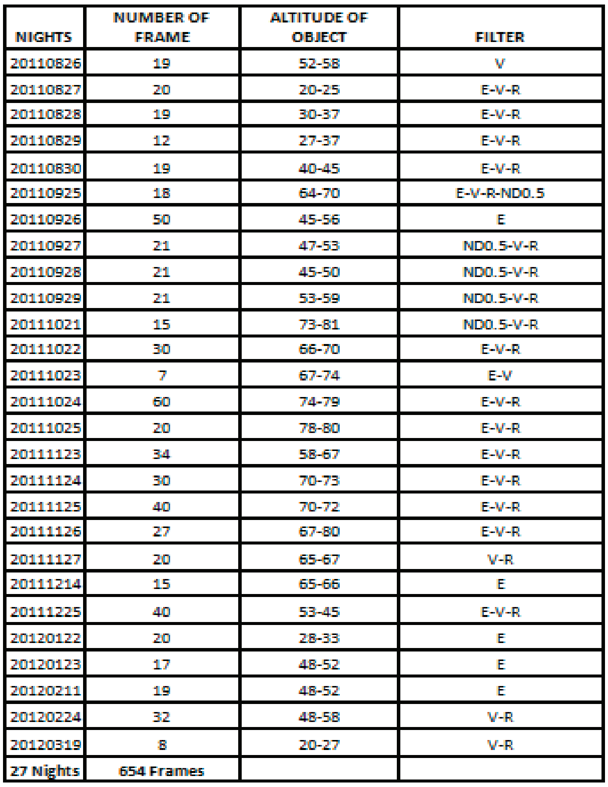
Model:	SI 1100 Cryo, UV, AR, BI
Chip Type:	Fairchild 486 BI, 4 Readin Chanal
Format	4096 x 4037 pixel
Pixel Size:	15 x 15 micron
Chip Size:	61.44 x 61.44 mm
Gain	0.55 e-/ADU (100KHz, Ch:A)
Noise (RMS):	4.19 e- (100 kHz, Ch:A)
"Bias" Level	500 (count)
Dark Current:	0.0002 e-/pixel/sn
Binning:	1x1, 2x2, 3x3, 4x4
Exposure Time	1 - 300 sn
Cooling	Cryo-tiger, -100 C
PC interface:	Gigabit F/O kart (PCI)
Transfer rate:	45 sn (1x1), 13 sn (2x2)
Pixel Scale:	0.31"/pixel
FOV :	21.5' x 21.5'
Software:	Maxim DL 5.12
Filter whell:	76x76 mm, 8 hole, 2 pair
Filters:	Bessel UBVRI, SDSS, Hα, Hβ, SII, OII, CaII K, ND0.5, ND1.0, ND2.0

Fig. 1: T-100 Telescope Technical Specifications

We have used 1100 series 4K x 4K CCD camera attached with V, R and Clear bands and limiting magnitude interval for moving objects is 14-20 magnitude.

3. Observations

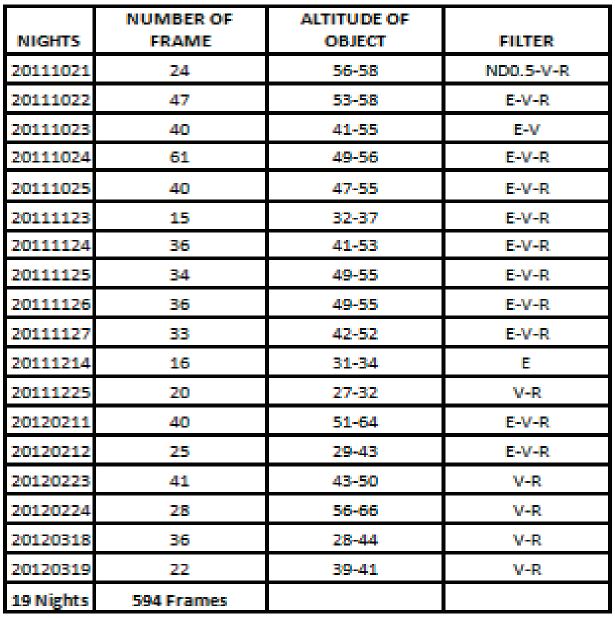
We have observed Lemaitre in 27 nights and obtained 654 frames in V, R and E (empty) bands (Table 1). The minimum altitude of Lemaitre was 20 degrees.



NIGHTS	NUMBER OF FRAME	ALTITUDE OF OBJECT	FILTER
20110826	19	52-58	V
20110827	20	20-25	E-V-R
20110828	19	30-37	E-V-R
20110829	12	27-37	E-V-R
20110830	19	40-45	E-V-R
20110925	18	64-70	E-V-R-ND0.5
20110926	50	45-56	E
20110927	21	47-53	ND0.5-V-R
20110928	21	45-50	ND0.5-V-R
20110929	21	53-59	ND0.5-V-R
20111021	15	73-81	ND0.5-V-R
20111022	30	66-70	E-V-R
20111023	7	67-74	E-V
20111024	60	74-79	E-V-R
20111025	20	78-80	E-V-R
20111123	34	58-67	E-V-R
20111124	30	70-73	E-V-R
20111125	40	70-72	E-V-R
20111126	27	67-80	E-V-R
20111127	20	65-67	V-R
20111214	15	65-66	E
20111225	40	53-45	E-V-R
20120122	20	28-33	E
20120123	17	48-52	E
20120211	19	48-52	E
20120224	32	48-58	V-R
20120319	8	20-27	V-R
27 Nights	654 Frames		

Table 1: Observational Data for Lemaitre.

We have observed Gaby in 19 nights and obtained 594 frames in V, R and E (empty) bands (Table 2). The minimum altitude of Lemaître was 27 degrees. We also have used ND0.5 filter during the observations.

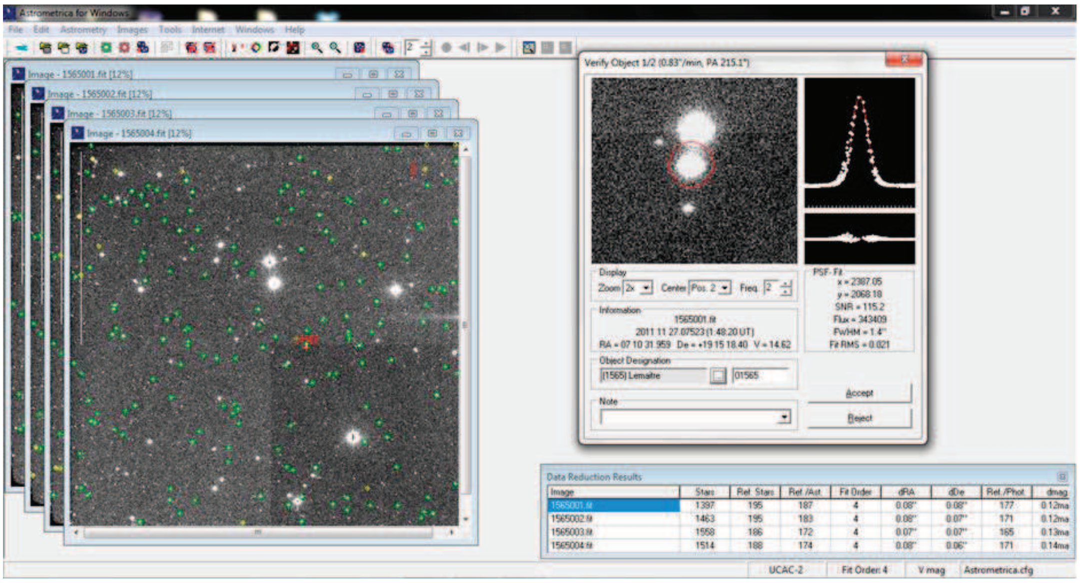


NIGHTS	NUMBER OF FRAME	ALTITUDE OF OBJECT	FILTER
20111021	24	56-58	ND0.5-V-R
20111022	47	53-58	E-V-R
20111023	40	41-55	E-V
20111024	61	49-56	E-V-R
20111025	40	47-55	E-V-R
20111123	15	32-37	E-V-R
20111124	36	41-53	E-V-R
20111125	34	49-55	E-V-R
20111126	36	49-55	E-V-R
20111127	33	42-52	E-V-R
20111214	16	31-34	E
20111225	20	27-32	V-R
20120211	40	51-64	E-V-R
20120212	25	29-43	E-V-R
20120223	41	43-50	V-R
20120224	28	56-66	V-R
20120318	36	28-44	V-R
20120319	22	39-41	V-R
19 Nights	594 Frames		

Table 2: Observational Data for Gaby

4. Reduction Method

We have used Astrometrica software for reduction of the data for both asteroids. We selected UCAC2 catalogue for reference stars. More than 150 reference stars were detected per frame, the fourth order of the polynomial was used and standard errors were around 0.10 to 0.20, respectively.



Verify Object 1/2 (0.83"/min, PA 215.1°)

1565001.fit
2011 11 27.07523 (1:48:20 UT)
RA = 07 10 31.959 De = +19 15 18.40 V = 14.62

x = 2387.05
y = 2068.18
SNR = 115.2
Flux = 343409
FWHM = 1.4"
Fit RMS = 0.021

Object Designation: [1565] Lemaitre 01565

Data Reduction Results

Image	Stars	Ref. Stars	Ref./Ast	Fit Order	dRA	dDe	Ref./Phot	dmag
1565001.fit	1397	195	187	4	0.08"	0.08"	177	0.12ma
1565002.fit	1463	195	183	4	0.08"	0.07"	171	0.12ma
1565003.fit	1558	186	172	4	0.07"	0.07"	165	0.13ma
1565004.fit	1514	188	174	4	0.08"	0.06"	171	0.14ma

UCAC-2 Fit Order: 4 V mag Astrometrica.cfg

Fig. 2: Astrometrica software

5. Data Analysis

We have obtained ephemeris and MPC report for Lemaitre and Gaby using Astrometrica, send these reports to NASA Horizon e-mail address (See ref. 3) to calculate all (O-C) values. Below, Fig 3 shows our observations and distribution of (O-C) values for Ra. and Dec. for Lemaitre and Gaby. Were X, Y axes imply the mean (O-C) values for Ra. and Dec., respectively. Each point in Fig.3 represents the mean value of all (O-C) in both coordinates

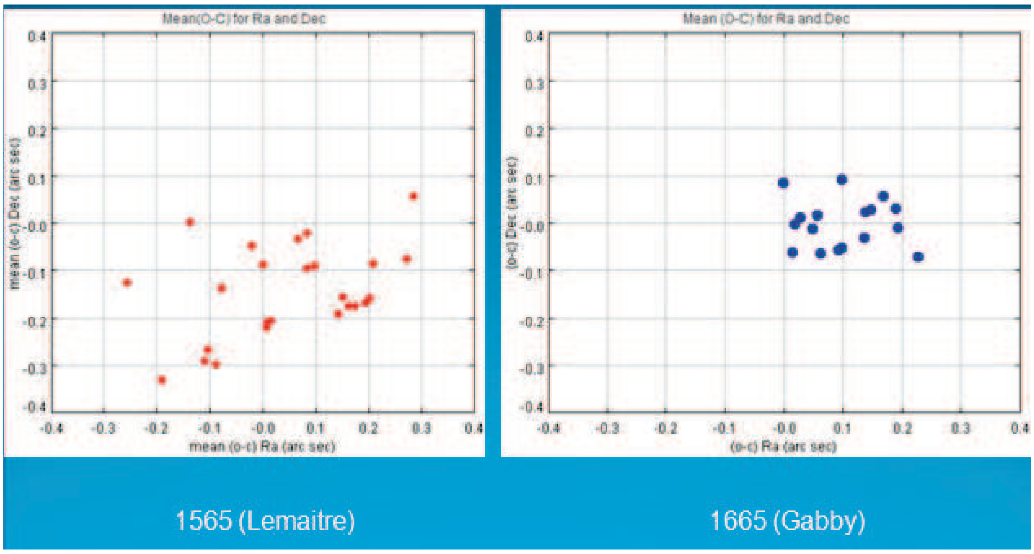


Fig. 3: Distribution of mean (O-C) values for Ra and Dec for Gaby and Lemaitre

Figure 4 shows the standard errors obtained in this study in Ra. and Dec. with respect to the magnitude for Lemaitre and Gaby asteroids. As can be seen, most of the errors are less than 0.15 arc sec in both coordinates.

Fig. 4: Standard errors for Ra and Dec

Conclusion

We made total of 1248 observations; 654 observations in 27 nights for Lemaitre, and 594 observations in 19 nights for Gaby. In our study, systematic error for both asteroids was about 0.2 arc sec while the previous studies have 0.47 arc sec RMS error values for Lemaitre, and 0.53 arc sec for Gaby as listed in the Horizon web site(see ref.2). Our low fit RMS error values listed in Fig. 3 and Fig.4 indicate that our observational facilities, with both quality of equipment, methodology, and experience of our personnel are very promising to carry out these task as GAIA ground based follow up mission.

References

[1] http://www.tug.tubitak.gov.tr/t100_si_ccd.php

[2] http://ssd.jpl.nasa.gov/sbdb.cgi

[3] horizons@ssd.jpl.nasa.gov

The Updated International Joint Project for Research of Dynamics and Physics of Asteroids

by A. Ivantsov (Nikolaev Obs., Ukraine), D. Hestroffer, W. Thuillot (IMCCE Paris Obs., France), R. Gumerov (Kazan Federal University, Russia), I. Khamitov, Z.Eker (TUBITAK National Obs., Turkey), Z. Aslan (Istanbul Kultur University, Turkey), G. Pinigin (Nikolaev Obs., Ukraine), W. Jin, Z. Tang (Shanghai Obs., China)

Abstract

The paper presents an International Joint Project within the international cooperation between institutions of several countries. Some astrometric results for selected asteroids are demonstrated which have been obtained from the reduction of observations made at the Russian-Turkish telescope RTT150 in 2008-2012, Mobitel telescope in 2011-2012, etc.

(Article not received)

The Coming Occultation Observational Program in Purple Mountain Observatory

by S. Ren, H. Zhao, Y. Ping, Z. Cheng, F. Xia, H. Lu, B. Li, Y. Fu (Purple Mountain Observatory, China)

Abstract

The coming occultation observational program in Purple Mountain Observatory will be introduced.

(Article not received)

Groundbased observational campaigns of NEAs

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Introduction

Near Earth Asteroids (NEAs), are defined as minor planets having the perihelion distance $q \leq 1.3$ AU and the aphelion distance $Q \geq 0.983$ AU[1]. NEAs main formation mechanisms include migration of MBAs due to resonances, especially 3:1, 5:2, and 2:1 mean-motion with Jupiter and ν_6 with Saturn[2], possibly combined with the Yarkovsky/YORP effects[3]. Nowadays there are more than 9,200 known NEAs (MPC, 2012a). Potentially Hazardous Asteroids (PHAs) are currently defined based on parameters that measure the asteroid's potential to make threatening close approaches to the Earth. All asteroids with an Earth minimum orbit intersection distance (MOID) smaller than 0.05 AU and an absolute magnitude (H) of 22.0 or brighter are considered PHAs[4].

NEAs observation are important and circumscribe several scientific objectives such are: i) discovery of new objects; ii) confirmation of NEAs newly discovered; iii) secure large uncertainties orbits of NEAs; iv) shape determination from lightcurve analysis; v) scientific interest of specific objects potentially targets of "in-situ" investigations.

The article presents new astrometric observations performed at Pic du Midi Observatory in 2011 using 1-m telescope. In the same sense, the article presents the tentative of astrometry of WMAP satellite performed in the infrared region using 3m IRTF facility.

1. Observations and data reduction

The observations were performed during two runs, in March, 1-4, 2011 and November 17-24, 2011 at Pic du Midi Observatory. These two observational campaigns were conducted in the frame of EURONEAR program for confirming and secure NEAs orbits[5]. For the run of March 2011, the camera iKon-l Andor 2048x2048px in 2x2 binning mode was used. This is the main camera for astrometry and photometry used by 1-m telescope of Pic du Midi. It covers a field of view of 7.5x7.5arcminute. For the second run, the new Atick383L+ camera, in test as a spare camera, was used for both astrometry and photometry. This new camera has a 3326x2504 pixels which covers a field of view of 7.8x5.8 arcminute was used in 3x3 binning mode.

The observations were obtained using a broad-band B+V+R filter, covering the 0.39-0.680 μm spectral interval. The nights were relatively clear; the seeing estimation was 0.8-1.8arcsec for both runs. These conditions and the instruments allow a limit magnitude of V=20.5 for 180 sec of integration time (in the case of the first run) and V=20 for 180sec of integration time. During each night series of calibration images(flats, darks) were taken and used into the data-reduction process.

In order to increase the S/N ratio of the asteroid image the strategy of tracking of the observed fields at half the NEA proper motion was used. Thus, both asteroid and reference stars appear on the images with slightly elongated shape, enough to be detected by an automatic detection procedure.

In the frame of GAIA-FUN, as a training exercise for observations on alert, the asteroid (99942) Apophis was also observed during our campaigns. These observations represent a good test-sample for evaluating the possibilities and limitations of groundbased observations of future GAIA –asteroid discovery alert.

Into the global framework of GAIA missions, the observations were carried out on WMAP satellite, using the 3-m telescope Infra-Red Telescope Facility, located on Mauna Kea- Hawaii. The guiding camera of SpeX spectrograph 30x30 arcsec, 512x512pixels, was used for image acquisition. The images were obtained in the K band on June 27, 2009. While WMAP was never observed at such wavelength, a blind differential tracking calculated from its ephemeris for the image acquisition was used. The individual exposure time used during the run was 120sec. These observations were performed remotely from Paris Observatory, using CODAM facilities[6].

For data reduction, the Astrometrica software[7] was used and specific configuration file specific to the telescope/camera configuration. Astrometry was performed using USNO-B1 catalogue, NOMAD or UCAC2 one, depending on the field density of reference stars. The measured positions were reported as soon as possible to the Minor Planet Center.

Table 1. Summary of the results obtained on March 2011 is presented. Five of the objects were from NEO confirmation list. The columns are: object designation of the MPC database, provisory designation if the object need to be confirmed, number of distinct observations reported to the M.P.C., status of our report, and the M.P.E.C. confirming the newly discovered object.

OBJECT	Provisory	N. Obs	Status	Electronic Telegram
2000 EB14	SEB912A	12	Confirmed	MPEC 2011-E12 : 2000 EB14
2011 ET4	SE308D5	10	Confirmed	MPEC 2011-E14 : 2011 ET4
2011 ES4	SEB87C3	10	Confirmed	MPEC 2011-E13 : 2011 ES4
2007 ES	SEB9730	10	Confirmed	MPEC 2011-E11 : 2007 ES
2003 FC49	-	13	-	-
2011 CM17	-	11	-	-
2010 VN65	-	9	-	-
2010 RO82	-	8	-	-
2001 XB232	-	1	-	-
2011 EW4	-	1	-	-
2011 EX4	BY29967	9	Confirmed	MPEC 2011-E19 : 2011 EX4
2011 AF37	-	9	-	-

In the case of IRTF observations, the choice of the catalogue was oriented to the 2MASS one, because of density of the reference stars and their images obtained in the near-infrared filters (thus, a facility of identification of such a small field of 30x30 arcsec).

2. Results

2.1 *Pic du Midi Observations*

The targets were selected from NEO confirmation list[1] and from EURONEAR planning tool[2] which considers the list of objects desirable for astrometric observations (large uncertainties of the orbit). During 10 nights of observations in March and November 2011, 50 asteroids (34 NEAs) were observed and reported to MPC. Fifteen of them were subject of Minor Planet Electronic

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[1] http://www.minorplanetcenter.net/iau/NEO/ToConfirm.html

[2] http://euronear.imcce.fr/tiki-index.php?page=Planning

Circulars(M.P.E.C.). The rest of observations appear in M.P.C daily orbit update. A sample of our report is presented in Table 1.

A brief statistics of the reported observations of these two runs is presented in Figures 1 & 2. The (o-c) values in right ascension are very well centered to zero value and the FWFM less than 0.7 arcsec shows a good quality of our astrometry. The small shift of the Gaussian fit of observation of about 0.1 arcseconds could be explained to be caused by a data-set astrometry of one (or more) asteroids for which the orbital parameters are not yet well constrained.

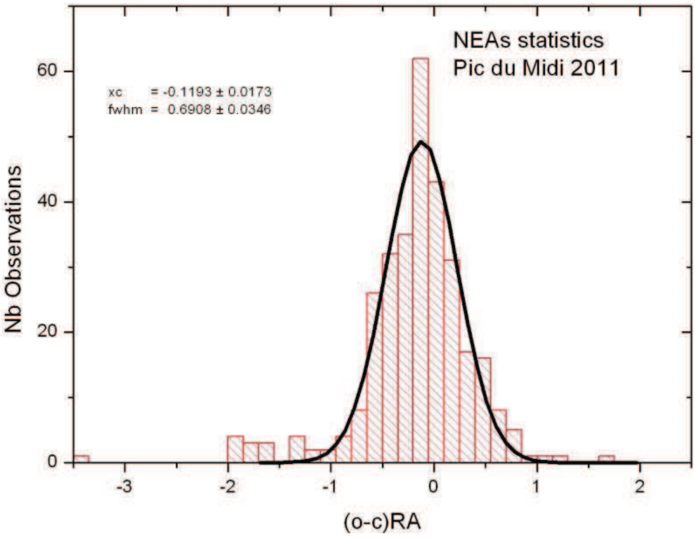

Fig. 1: Observed-Calculated (o-c) values in right ascension for 34 NEAs astrometric positions obtained in 2011 at Pic du Midi Observatory.

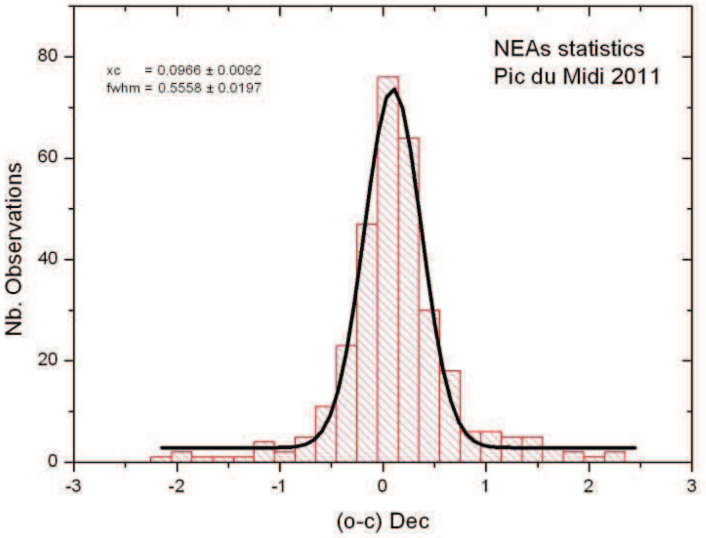

Fig. 2: Observed-Calculated (o-c) values in declination for 34 NEAs astrometric positions obtained in 2011 at Pic du Midi Observatory.

2.2 *IRTF Observations*

The images were centered on RA= +18H28M09.14S; DEC= -14°41'49.1". This field has a good density of star catalogue on the 2MASS one. The small FOV made the identification relatively heavy. Efforts of identification of WMAP in the center of the image (assuming the high quality ephemeris of the satellite) remain unsuccessfully either on individual images or in stacked ones.

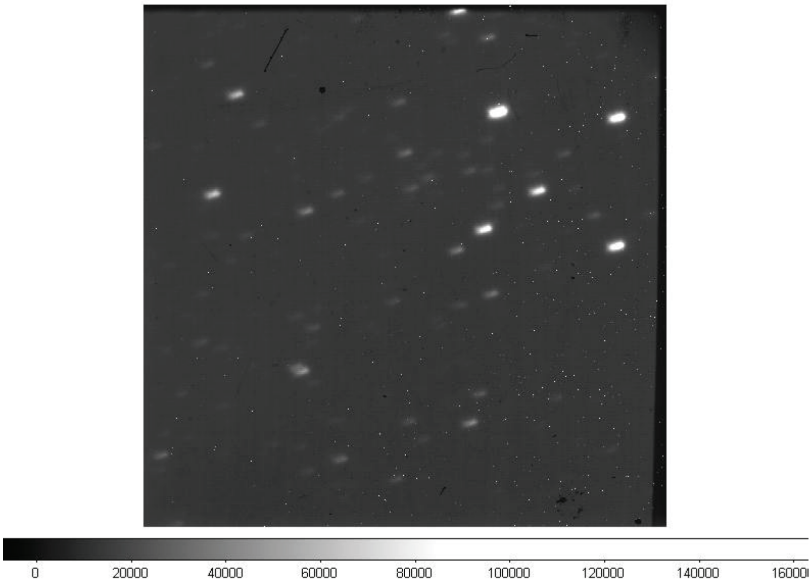

Fig. 3: Image of a 30x30 arcsec FOV obtained with SpeX/IRTF guiding camera. The image was obtained using 120sec integration time, and the stars PSF is slightly elongated because of differential tracking using WMAP ephemeris. WMAP is not visible but it should be in the center of the field. This low magnitude in the K band is explained by the high efficiency of thermal shield of the satellite.

Conclusion

NEAs population is a good laboratory of study for the Solar System dynamics. During two runs in 2011 at Pic du Midi Observatory 34 NEAs were observed and astrometry was reported to MPC. These observations confirmed newly discovered objects and reduce the uncertainty in orbital elements o a good number of observed NEAs. Tests on observations on alert in the frame of GAIA-FUN were performed for the NEA (99942) Apophis, following the strategy of this network.

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Improvements of astrometry from ground based observatories

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Introduction

The analysis of planetary satellites or asteroids ground based observations is quite similar. Our first goal was to improve the astrometric reduction for digitized photographic plates in case of too few reference stars and to propose solutions. We here present astrometric techniques used for old observations of the Galilean satellites made with the 26-inch refractor of USNO in Washington DC from 1967 to 1998 (Pascu, 1977, 1979, 1994). We present some solutions that may be applied to asteroids or any small solar system bodies observations. In fact, we were able to determine an observational error and we discuss the expected improvements necessary in the frame of the GAIA FUN SSO program. A real application in the frame of the Gaia program deals with the new analysis of old photographic plate observations.

1. Improvement of the reduction of an image

1.1 *Centroiding each object*

USNO images were analyzed by using a specific process to identify the planet, its satellites and the available reference stars. This process is analog to a pre-reduction and provided the best results (Robert, 2011). All the available stars (depending on the catalog used) are identified and more, those that are not visible with naked-eyes. The issue consists in looking for relevant objects in specific areas before their identification. Four star catalogs can be used: Hipparcos (Perryman et al., 1997), Tycho-2 (Hog et al., 2000), UCAC2 (Zacharias et al., 2004) and UCAC3 (Zacharias et al., 2010). The identification method can be applied with any objects; tests were succesfully performed with USNO Saturn and Mars images, and with OHP Pluto and asteroid images.

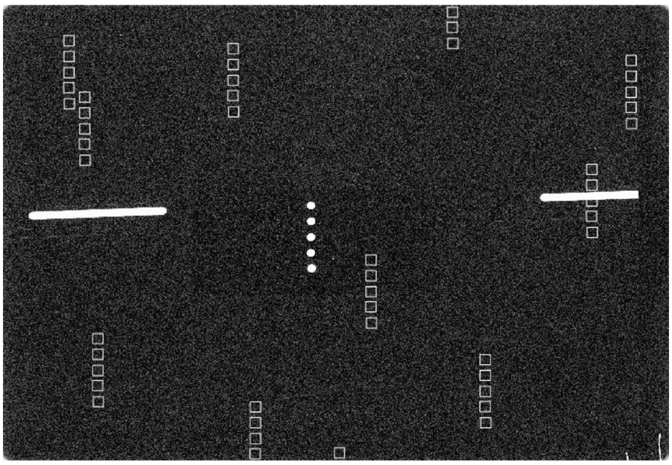
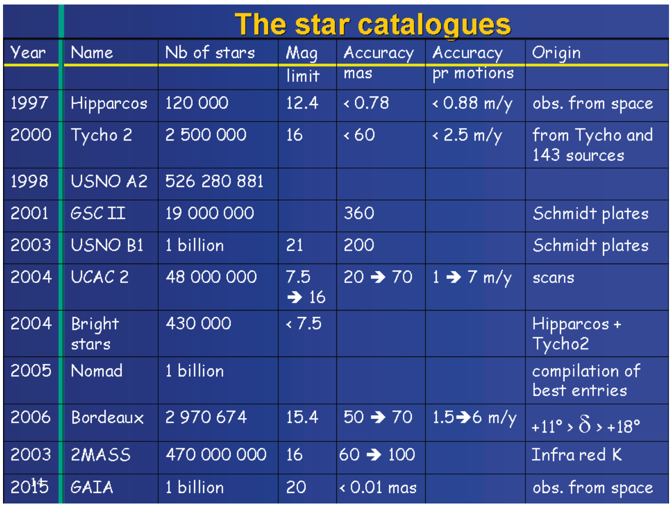


Figure 1: Method to identify relevant objects in an image



The star catalogues

Year	Name	Nb of stars	Mag limit	Accuracy mas	Accuracy pr motions	Origin
1997	Hipparcos	120 000	12.4	< 0.78	< 0.88 m/y	obs. from space
2000	Tycho 2	2 500 000	16	< 60	< 2.5 m/y	from Tycho and 143 sources
1998	USNO A2	526 280 881				
2001	GSC II	19 000 000		360		Schmidt plates
2003	USNO B1	1 billion	21	200		Schmidt plates
2004	UCAC 2	48 000 000	7.5 ➔ 16	20 ➔ 70	1 ➔ 7 m/y	scans
2004	Bright stars	430 000	< 7.5			Hipparcos + Tycho2
2005	Nomad	1 billion				compilation of best entries
2006	Bordeaux	2 970 674	15.4	50 ➔ 70	1.5➔6 m/y	+11° > δ > +18°
2003	2MASS	470 000 000	16	60 ➔ 100		Infra red K
2015	GAIA	1 billion	20	< 0.01 mas		obs. from space

Figure 2: Comparison of star catalogs dedicated to astrometry

At the present time, we use to neglect small biases when the error is smaller than the accuracy of the catalog. Mainly when a catalog with a large number of stars is used, the accuracy of that being very poor. This will change when using the Gaia catalog: all small effects should be corrected.

1.2 *Astrometric reduction*

In the case of few available stars, the astrometric reduction is quite different with a common one. We propose that the star $(\alpha, \delta)_c$ equatorial coordinates should be directly corrected for all-known spherical effects, the star $(x, y)_m$ measured coordinates should be corrected for the evaluated instrumental effects, and the astrometric reduction should be realised through the atmosphere so that (α, δ) equatorial coordinates could be deduced from apparent (X, Y) tangential coordinates. Thus the reference stars only provide position, scale and orientation for the field through an adapted $(x, y)_m \mapsto (X, Y)_{m,a}$ model (Robert, 2011):

$$X_{m,a} = \rho \cos\theta \times x_m - (\rho + \varepsilon_1 \sin(\varepsilon_2 t_m + \varepsilon_3)) \sin\theta \times y_m + \Delta_x + C_x \times x_m \times (m - m_0)$$
$$Y_{m,a} = \rho \sin\theta \times x_m + (\rho + \varepsilon_1 \sin(\varepsilon_2 t_m + \varepsilon_3)) \cos\theta \times y_m + \Delta_y + C_y \times y_m \times (m - m_0)$$

Only 4 parameters are fitted for a minimum of 2 reference stars, the contribution of each plate constant is here separated.

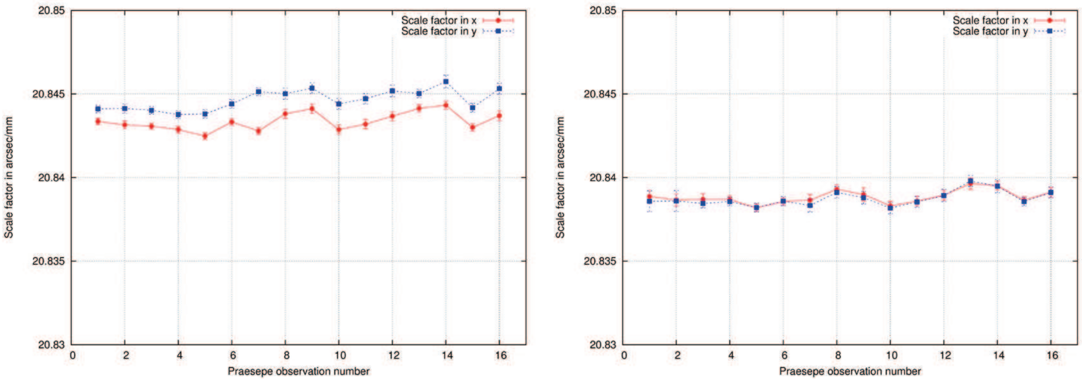


Figure 3: Scale in RA and Dec after correction.

The astrometric method was tested with USNO Galilean observations. As a result, Figure 3 shows on the left the evolution of the scale factors with no corrections applied; on the right the same evolution once the spherical and instrumental corrections are applied to the equatorial and measured star coordinates:

the isotropy of the field is now effective. In conclusion, very small effects may be corrected through a good astrometric modeling of the image.

2. Accuracy and expected improvements

2.1 *Astrometric accuracy*

The final observed position of object is very dependant of the astrometric reduction that may move the objects in the sky. The number and the distribution of the stars in the field must be carefully studied before the reduction.

Exposition		$(O-C)_X$	$(O-C)_Y$
1	(a)	0.060	0.130
	(b)	0.048	0.108
	(c)	0.203	0.188
	(d)	**0.009**	**0.028**
2	(a)	0.059	0.082
	(b)	0.036	0.057
	(c)	0.195	0.139
	(d)	**0.016**	**0.033**
3	(a)	0.096	0.077
	(b)	0.076	0.060
	(c)	0.248	0.125
	(d)	**0.017**	**0.017**
4	(a)	0.098	0.036
	(b)	0.128	0.043
	(c)	0.238	0.066
	(d)	**0.021**	**0.009**

Table 1: Comparison of reduction methods: tangential (O-C)'s in arcsec with secondary PPM catalog 6 stars order 1 (a), 7 stars order 1 (b), 7 stars order 2 (c), and UCAC2 catalog 10 stars order 1 (d).

Table 1 provides the results of the USNO test plate 0216 reduced with four different astrometric methods. Positions determined with our last method are more accurate, the astrometric accuracy is better by a factor between 2 to 15. This shows the interest of new accurate catalogs: Gaia will improve these results again. However the improvement will be limited if we do not improve the astrometric process of observation too.

2.2 *Expected improvements*

The astrometric accuracy depends on many factors and we can expect corresponding improvements in order to provide even more accurate positions:

1. the image pixel sampling → choice of a pixel size depending on the seeing;
2. the centroid of image (trailed images) → use a gaussian fit for the photocenter of punctual sources;
3. the object magnitude → increasing the S/N signal noise ratio;
4. the atmospheric refraction → improving the model of the atmospheric refraction;
5. the sky absorption for moving objects → taking into account the effect for moving object low on the horizon through a photometric monitoring of the exposure;

6. the correction photocentre-centre of mass → better correction photocentre to centre of mass by using a recent modeling of the surface of the object.

Conclusion

The astrometric reduction of digitized photographic plates with new tools made necessary to take into account all instrumental errors and all biases. We succeeded in obtaining very good results and we consider that similar corrections should be applied to modern observations, increasing the astrometric accuracy.

In another hand, some observations are difficult to reduce or present some biases. The astrometric positions provided by these observations will not be precise enough in the frame of the Gaia project. Corrections for instrumental errors, for the atmospheric refraction and for the sky absorption should be made at first. More, when using the Gaia catalog for future reductions, all biases must be corrected.

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