Proceedings of

Gaia Follow-up Network for Solar System Objects
Workshop held at IMCCE-Paris Observatory

2010, November 29 – December 1

Institut de mécanique céleste et de calcul des éphémérides
Observatoire de Paris

Dépôt légal – juin 2011
ISBN 2-910015-63-7

Foreword

This workshop was dedicated to the setting-up of a follow-up network for the Solar System Objects observed by the Gaia mission. After several years for getting in touch with candidate observers in many different countries, it was an important step aiming at accompanying this space astrometry mission all along its five year observation period. This workshop allowed us to know more on the status of the project, to propose a work flow for the processing of alerts, to get precise information on the observing sites and their specificities, to organize discussions and try to answer to some questions, to meet each other, to have fruitful exchanges and to simply reinforce the international collaboration. But most of all it was the opportunity to make this network active, and to foresee further actions. These proceedings provide a large overview of the communications and will be a reference document for the setting up and operation of the Gaia-FUN-SSO network. However, some open questions remains. Among them, the number of alerts is probably one of the most important unknowns, since it determines the work load to be carried on by the network, both by the central node and by the observing sites. Another important question appeared and could not be solved: the needs of funding for some observing sites. During the period of time before the launch of Gaia, we hope to get answers to these points.

We would like to thank all the participants to this fruitful meeting.

Paolo TANGA & William THUILLOT
Co-chair of the Gaia-FUN-SSO workshop

Acknowledgements

■ The Gaia-FUN-SSO workshop has been organized thanks to the following people :

– The members of the Scientific Organizing Committee:

- Jean-Eudes Arlot, IMCCE-Paris Observatory, France
- Jérome Berthier, IMCCE-Paris Observatory, France
- Alberto Cellino, Torino Observatory, Italy
- Daniel Hestroffer, IMCCE, France
- Francois Mignard, OCA, Nice, France
- Paolo Tanga (co-Chairman), OCA, Nice, France
- Rama Teixeira, IAG-USP, Sao Paulo, Brazil
- William Thuillot (co-Chairman), IMCCE-Paris Observatory, France
- Zheng Hong Tang, Shanghai Astronomical Observatory, China

– The members of the Local Organizing Committee:

- Jean-Eudes Arlot, IMCCE-Paris Observatory
- Alrick Dias, IMCCE-Paris Observatory
- Maryse Dufay, IMCCE-Paris Observatory
- Daniel Hestroffer, IMCCE-Paris Observatory
- Isabelle Nicolas, IMCCE-Paris Observatory
- Agnès Patu, IMCCE-Paris Observatory
- William Thuillot (Chairman), IMCCE-Paris Observatory
- Cécile Veneau, IMCCE-Paris Observatory

– Several colleagues from IMCCE, in particular Yohann Gominet who deal with the design of the workshop poster, badges and the providing of this book of proceedings.

■ This workshop has received very helpful funds from several institutions:

- Action spécifique Gaia (wwwhip.obspm.fr/gaia/AS/AS-Gaia-bienvenue.html)
- Paris Observatory scientific council (www.obspm.fr)
- Observatoire de la Côte d'Azur (www.oca.eu)
- Institut de mécanique céleste et de calcul des éphémérides (www.imcce.fr)

Summary

Gaia Science Status

Prusti, T.

ESA, ESTEC, Noordwijk, The Netherlands

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 are reviewed in these 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 spectrometre. 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 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 covering 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. 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 spectrometre 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.

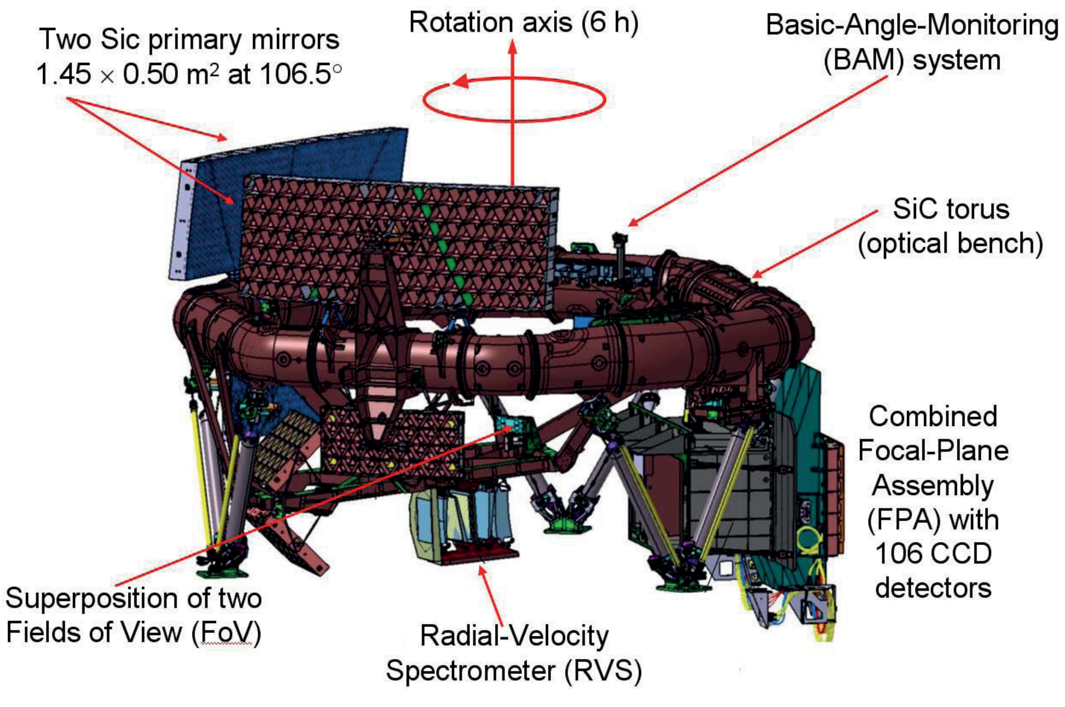


Fig. 1 – Gaia Torus with mirrors, radial velocity spectrometer and combined focal-plane assembly. © EADS Astrium

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 optimal. 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 70 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.

5. Science data volume

The hardware technology for Gaia is very demanding, but also the data processing is a challenge. Already 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 multiyear 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 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 even to unforeseeable future now after cancellation of the 1 μarcsec precision SIM mission.

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.

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 accuracy 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 0.6 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 relevant and can be 20 µarcsec at best for the brightest objects in the scanning direction. 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 March 2013. This schedule has no contingency in it and therefore a risk analysis of possible launch delay has been conducted. The current schedule risk adds up to 6 months. The main element in the schedule risk is in the integration and assembly. Silicon carbide has been previously used in other missions (like the mirror of Herschel), but for the first time a large fraction of the payload elements are built from silicon carbide parts.

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.

Daily Processing of Solar System Object Observations by Gaia

Tanga, P.

UMR 6202 Cassiopée, University of Nice-Sophia Antipolis, CNRS,
Observatoire de la Côte d'Azur, BP 4229, 06304 Nice Cedex 4, France

Introduction

By definition, an alert system has to be activated as fast as possible in response to a selected event. For this reason, a pipeline performing fast processing of Gaia observations of Solar System objects (SSO) is being implemented. Its output will concern moving objects that are not matched against an up-to-date catalogue of known asteroids. These "new" Gaia asteroids will have an approximate short-arc orbit determined which can be used to disseminate alerts toward ground-based observers. Without a preliminary orbit (or a bundle of possible orbits) ground-based recovery would be extremely hard, especially for NEOs passing close to Earth, due to the fact that Gaia will orbit around the Lagrangian point L2, thus resulting in a large parallax (see Bancelin et al., this volume).

1. Main Gaia data properties and the processing of Solar System objects

Solar System objects will be processed by a specific pipeline capable of dealing with their peculiar properties, especially their high apparent speeds. Additionally, the pipeline will produce output quantities that are specific to this category of celestial objects. All the dedicated software is implemented in an architecture provided by the related Data Processing Centre (the CNES in Toulouse, France in this case), and written by the planetology community of the DPAC (Data Processing and Analysis Consortium).

Two separate processing lines exist, in fact. The first one, called "daily processing", will operate on the shortest possible time scale, i.e. as soon as new data will become available. In practice, data sets are made available daily, so this pipeline will run once per day. It will essentially operate on the most recent observations in a ~48 hours window, meaning that a typical object will have up to 2-3 detections in the focal plane.

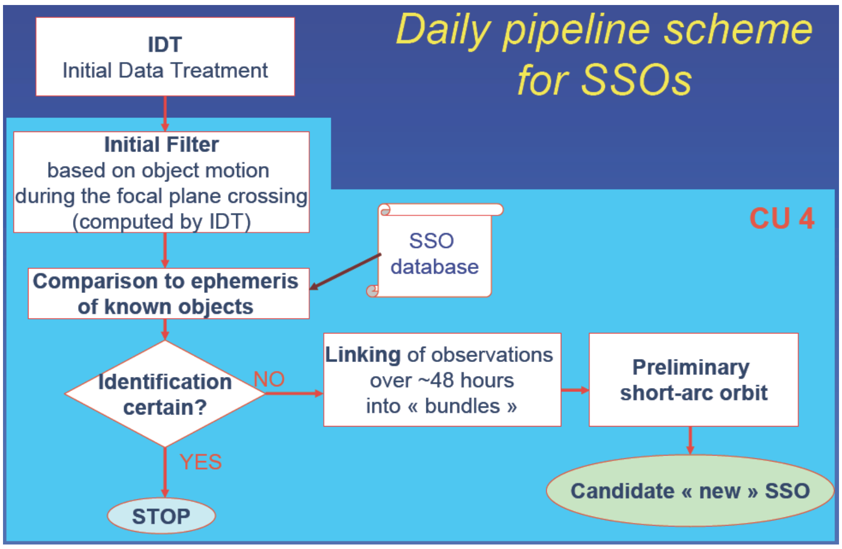


Fig. 1 – Schematic drawing of the main functions accomplished by the Solar System processing pipeline that will run at daily cadence.

The other procedure involves more complex operations, devoted to obtain the best accuracies in the output. It will operate on data obtained from the beginning of the mission and its output will be mostly meaningful at the end of the mission, when all observations will be available.

Clearly, this last context is not related to the fast response required for a ground-based alert/follow-up system, so we will devote this text to provide some details about the "daily processing" only.

For more details concerning Solar System observations with Gaia other publications offer a rather complete technical and scientific overview, such as Mignard et al. 2007 and Hestroffer et al. 2010.

While timescales and delays in processing are discussed elsewhere in this volume (F. Mignard 2011), we can focus here on the peculiar properties of Gaia observations having an impact on the operation of a ground based network, namely: the selection of the sources and the single-epoch astrometric accuracy.

Since Gaia won't use any input catalogue, all sources brighter that V~20 and crossing its FOV are candidate for on-board detection, observation acquisition and transmission of related data to ground stations. In simple terms, on-board detection (relying on a double step for confirmation) determines the position of a source when it begins its passage – under the action of the scanning motion – in the Gaia FOV. If the source obeys to some criteria (involving flux and size, mainly) it attributes a logical "window", representing the portion of the CCD image that is read-out for a given source, for each CCD column. This image is then transmitted to the ground, but for most sources (V>13) the pixel values will be binned in the Across Scan (AC) direction, preserving the maximum resolution "along scan" (AL), only. In other terms, for most objects the signal will be mono-dimensional, retaining 2D information for the brightest sources only.

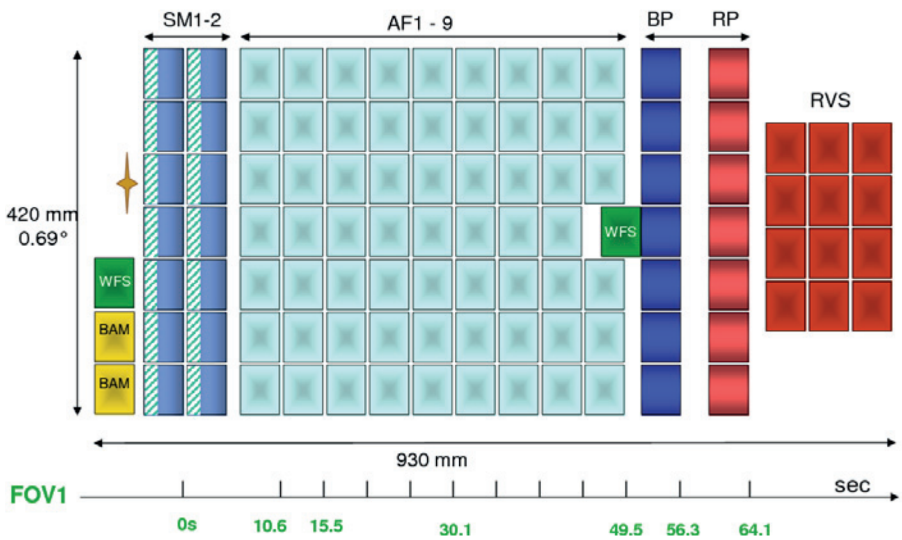


Fig. 2 – The Gaia focal plane array. Each coloured area indicates one CCD 4 X 6 cm^2 in size. The direction of the star image motion is toward the right indicated at the bottom. The bottom lines indicate the time (in seconds) needed to reach the different parts of the field. It takes a star image about 4.4 sec to cross one of the CCDs, this interval defining the effective exposure time. The CCDs in the SM (Sky Mapper) columns operate the source detection. The source is then observed in the Astrometric Field (AF), the BP- RP spectrophotometers (Blue – Red Photometers) and the RVS (Radial Velocity Spectrometer).

This procedure is capable of successfully detecting moving sources belonging to the Solar System, provided that their apparent diameter is not larger than ~500-600 mas – thus excluding the main planets, some planetary satellites and few asteroids at given epochs.

The transmitted data flow will contain the information pertaining to all sources mixed together. Their distinction into specific categories is a task of the software running at ground-based facilities. Mostly relevant for us are the procedures called “First Look” and “Initial Data Processing” (IDT), which are performed as soon as data are available. IDT won’t directly flag Solar System objects, but will try to match the position of any source against the position of sources detected in the same region of the sky, during previous scans. Of course, fixed stars should be matched, while observations of moving objects will not match – in general – the position of other sources.

The Coordination Unit n. 4 (among others) is in charge of processing the sources that are unmatched by IDT, which will reach SSO pipeline.

Several problems are hidden in the details of the process, related to its efficiency (non-SSO, unmatched sources; false matches, etc) or its intrinsic properties (SSO passing very close to stars; evolution of efficiency with the improvement of the source catalogue along the mission, etc.). For this reason, a certain (essentially unpredictable) degree of contamination of the SSO data transmitted to CU4 has to be anticipated.

Another consequence of the windowing procedure and the adopted binning is the strongly correlated uncertainty for single-epoch objet coordinates, resulting from the transformation to astronomical coordinates of the mono-dimensional astrometric measurement, whose uncertainty is directed essentially across-scan.

2. Daily processing

The aim of the daily processing chain is the identification of peculiar asteroids – i.e. objects that are not known, or whose orbits are poorly constrained. All source positions that are sent to the chain will be compared to the predicted positions of known asteroids, as computed from a frequently updated catalogue (maintained by the Minor Planets Center). A probability of identification is then assigned. For objects whose identification is close to “certain”, no further computations are performed at this level (they will enter the “long term” chain). Given the magnitude threshold of Gaia (V~20), it can be expected that most of the observed asteroids will be known by the beginning of the mission, so most of them will be identified.

Among the un-identified sources, potentially new asteroids and comets will be found, and a number of ambiguous identification and contaminants. This difficult situation must be handled by the core of the daily chain, consisting of a numerical procedure trying to link detections belonging to a same source, over the last 2 days of observations. In fact, when an asteroid is observed in one of the two FOVs of Gaia, most frequently it will be (or was) observed in the other over a single rotation of the probe. Longer detection sequences (3, 4 or more observations) have been shown to be possible, but of course with rapidly decreasing probability.

The attribution of 2 or more consecutive detections to a same object requires a so-called “threading” procedure, whose complexity and efficiency grow with the number of unidentified sources and contaminants. However, the task is made easier by the duration of a whole transit over all the CCDs of the astrometric instrument of Gaia, about 60 s. During this interval, a motion (in the AL direction) at the ~1 mas/s level will be detectable by comparing the position on the different CCD columns.

When this procedure is successful, a Monte-Carlo Markov Chain method (Oszkiewicz et al. 2009) is used for computing a bundle of orbits, resulting in a more or less constrained region of the space of orbital elements. This bundles are the main output of the daily chain, and are transmitted (along with the object brightness and other auxiliary data) to the team coordinated the Gaia-FUN-SSO network (currently under the responsibility of W. Thuillot, IMCCE, Paris).

3. Interface toward ground-based observers

An appropriate interface for a network of ground based observers is dictated by the properties of the Gaia observations, for reasons that should appear as obvious at this point. In particular:

- An unknown degree of data contamination could result in an unpredictable amount of "false" alerts. A validation of the output is due before any observation of potentially new asteroid is diffused.
- Gaia will observe from the lagrangian point of the Earth L2, so the parallax for nearby asteroids (NEOs for example) can easily be so high that an object cannot be recovered from the ground, if Gaia astrometry alone was available. For this reason, a representative set of probable short-arc orbits must be used to produce usable sky search areas, to be diffused to the observers.
- Coordination among several observing stations is the most effective way for fast reaction, feedback and optimisation of the recovery efforts.

The points above do not exclude the standard procedures usually adopted for asteroid astrometry, involving the transmission of the measured positions to the MPC. This will be done for all sources that are confirmed to be asteroids. However, the contamination issue forces the adoption of a conservative procedure at least at the beginning of the mission, when a detailed verification of the chain output will be performed. In fact, since the IDT performance in the first few months (i.e. before the first full-sky coverage of Gaia) could be very poor – thus producing a large amount of contaminants – the best approach to filtering will be through motion detection. Only fast-moving sources will be processed, thus ensuring the reliability of the processing.

Along the mission, the performances of the cross-matching by IDT will also improve with the increasing number of Gaia observations of all sources. We thus estimate that a direct transmission to MPC, without filtering or delays, will be possible at a certain point during operations.

Conclusions

Although the discovery space of Gaia will be severely limited by its brightness detection threshold, a number of asteroids that are unknown or have poorly constrained orbits will be observed. This situation will be managed by a processing chain running daily whose specific aim is to allow their recovery by a network of ground-based observers, when possible.

The daily chain will produce sets of preliminary short-arc orbits by a statistical approach. These orbits can be used to produce prediction of sky areas where observers on Earth can try the recovery.

The detected positions should also be sent to the Minor Planet Center, a procedure that requires a validation phase of the whole data processing chain, for avoiding a potentially large number of false alerts.

References

Bancelin, D. 2011, this volume

Hestroffer, Daniel, Aldo Dell'Oro, Alberto Cellino, and Paolo Tanga. 2010. The Gaia Mission and the Asteroids. Lecture Notes in Physics, 790:251-340.

Mignard, F. 2002. Observations of Solar System Objects with GAIA. I. Detection of NEOS. Astronomy and Astrophysics 393 (October 1): 727-731.

Mignard, F., A. Cellino, K. Muinonen, P. Tanga, M. Delbò, A. Dell'Oro, M. Granvik, et al. 2007. The Gaia Mission: Expected Applications to Asteroid Science. *Earth Moon and Planets* 101 (December 1): 97-125.

Mignard, F., 2011, this volume

Oszkiewicz, D., Muinonen, K., Virtanen, J., Granvik, M. 2009, Asteroid orbital ranging using Markov-Chain Monte Carlo, Meteoritics & Planetary Science, 44 (12),1897-1904

Science from NEOs – Limitations and Perspectives

Hestroffer, D.

IMCCE, Observatoire de Paris, UPMC, CNRS
77 av. Denfert-Rochereau, F-75014 Paris, France
hestroffer@imcce.fr

Introduction

The Gaia mission, in addition of doing astrometry of stars and a 3D census of our Milky Way, has specific objectives for solar system objects (Tanga, 2011). In that respect it follows the Hipparcos/Tycho mission that already observed a few solar system objects. The astrometric accuracy involved with Gaia is however 1 to 2 orders of magnitude higher, and the total number of targets observed is incomparably larger. Here we describe several scientific outcomes from the astrometry of asteroids and comets with particular emphasis on the Near Earth Objects (NEOs), their specificities and limitations.

1. Astrometry from Space – Hipparcos & Gaia

The ESA Hipparcos/Tycho mission (1989-1993:1997) observed 48 asteroids, a few planetary satellites, and two major planets. It basically provided positions at 10mas precision level and photometry at 0.05 mag level, which data are catalogued in the Hipparcos solar system annex, and available at the CDS[1] (ESA 1997). These observations provided some scientific output (see Perryman 2008, and reference therein), we will emphasise here that already at that level of astrometric precision the photocentre effect is visible (Hestroffer 1998), and that photometric inversion with sparse data can be applied to targets with enough observation points (Cellino 2009). Besides, the availability of the Tycho catalogue of stars has also been valuable for the science of solar system objects by improving astrometric reductions and stellar occultations predictions. In contrast, the Gaia mission is much more than just a Hipparcos II.

One major technical difference with Gaia comes from the use of CCDs is TDI mode (Hipparcos used an old technology of photomultiplier and a modulating grid) which enables to simultaneously observe all objects brighter than magnitude $V \leq 20$ in the field of view (given it is not in a over-crowded region in the galactic plane). Gaia will also provide photometry in a large G-band as well as low resolution spectrophotometry (high resolution spectroscopy is obtain over a very small range and of little use for asteroids except for the purpose of calibrating the instrument). There will be about 250.000 asteroids observed, about 25 planetary satellites, and JFC as well as LP comets. The images on the CCD will enable to derive sizes of a few thousands of asteroids to compare to those of the IRAS catalogue, and shape or binarity information for several. The photometry will enable to derive the spin state (direction and period) as well shape information (tri-axial model) for almost all observed body. Of course, being an astrometric mission, the main output will be the astrometry. Gaia will provide high accuracy positions for all asteroids over 5 years and directly connected to a homogeneous reference frame of distant quasar (and hence connected to the ICRF).

---

[1] URL: http://cdsarc.u-strasbg.fr/viz-bin/Cat?I/239

2. Gaia

As said before the limiting magnitude is V≤20 (besides the fact that very bright objects won't be observed, as well as in very crowded region a selection will be applied, but all this does not affect asteroids much). There is also a limit of size at about 0.7–0.9 arcsec; objects larger than that will not be detected and hence not be observed, this concerns mainly planetary satellites. Fast moving object should be detected but they might not be observed through all the 9 CCDs of the FOV, unless a specific windowing scheme is applied. The given satellite's scanning law makes that the objects are observed when they cross the FOV (this is no pointing telescope) which results in a random pattern of observation distribution. Nevertheless the observations are rather well distributed in time and in space for a typical main belt asteroid, with 60-70 observations on the average over 5 years (Fig. 1). The situation is not the same for a NEO or an object close to the limiting magnitude, where observations can be scarce and clustered over a short period of time.

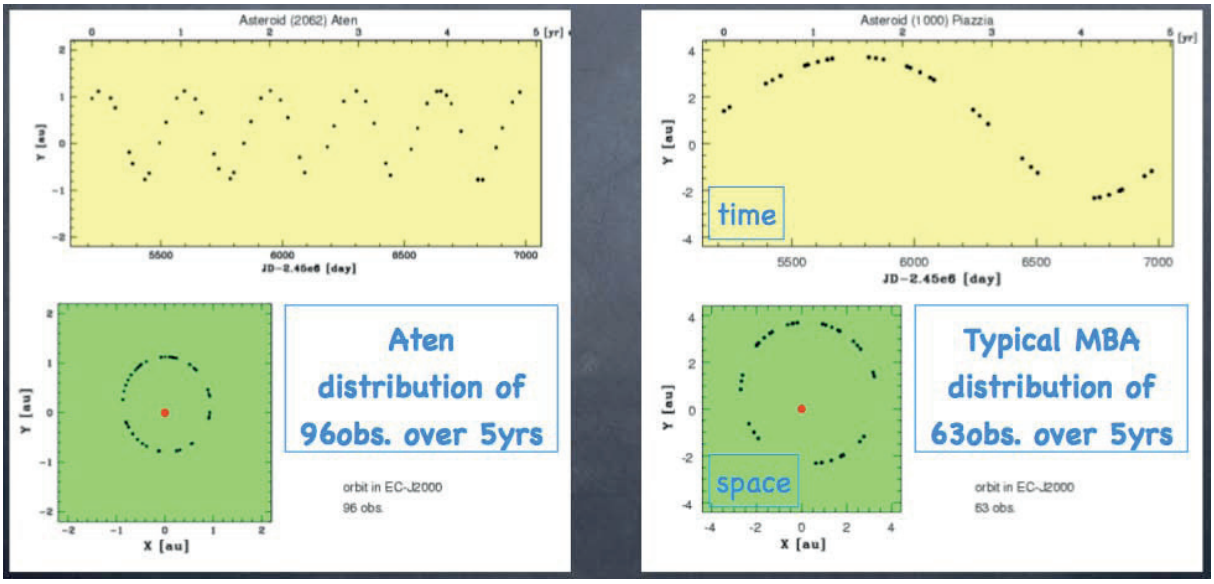


Fig. 1 – Observation distribution in time and space for typical asteroids. The total number of observations can decrease to a few for NEOs and objects close to the limiting magnitude.

Binary asteroids will also be observed by Gaia enabling improvement of their mass, or determination de novo. The cases of binaries can be of particular interest for Gaia, whether the two components are well separated and detected as two different bodies (resolved binary) or whether the system appears as a single object but the motion of the photocentre shows a wobble effect around the centre of mass that is not correlated with the spin of the body (astrometric binary). Further work should be carried out to determine how many resolved or astrometric binaries will be detected as such. The detection of an astrometric binary necessitates to have good absolute positions, with good precision and hence a good stellar catalogue, which Gaia will provide. The signature depends also on the separation of the bodies and mass ratio; it is most sensitive for mass ratio of the order of 0.05–0.5. Application to a known transneptunian binary (TNB) system have shown some interesting potential (Ortiz 2010). Gaia will also observe a handful of trans-Neptunian objects among, which the Pluto/Charon system. Making use of the GIBIS focal plane simulator (Babusiaux 2005) and the Gaia scanning law *rendez-vous* simulator, it is found that about 70 relative positions will be acquired of the system as a resolved binary, which—when combined to future or past astrometric observations—will enable to monitor the orbit evolution over several decades. Making use again of the GIBIS simulator, it is found from a population of synthetic binaries, that system with a separation larger than 0”3 and a magnitude difference smaller than 2 (going up to Δmag=5 at 1” separation, see Fig. 2) will be resolved by the sky mapper.

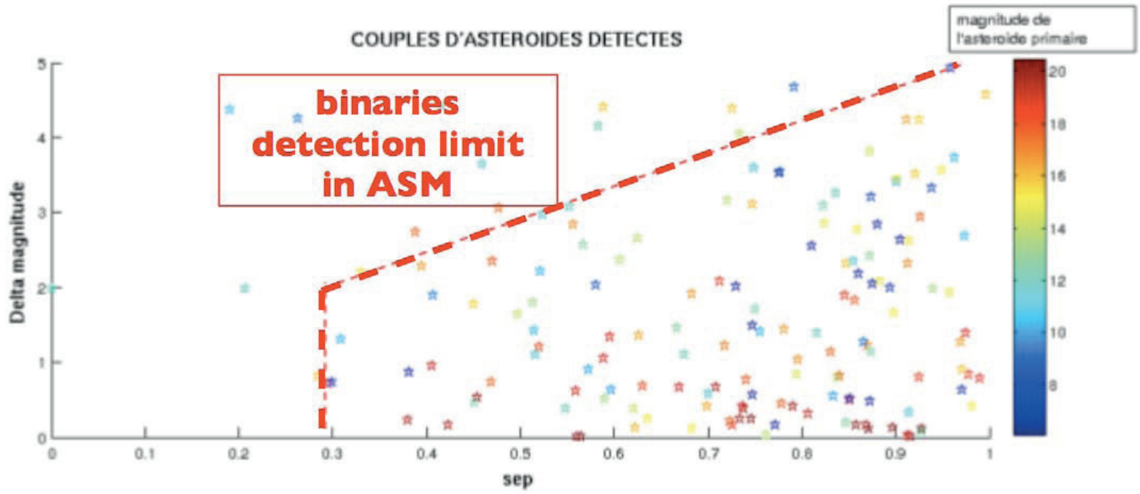


Fig. 2 – Binaries detection limit in ASM. Simulation form a synthetic population as a function of separation and magnitude difference (credit J. Blanchot).

There are several timelines involved in the Gaia mission either in the data reduction pipeline (Berthier 2011) or in the data release (intermediate or in alert, Pristi 2011). For what concerns the long-term treatment of the astrometry of solar system objects, there will be basically two kind of outputs: The catalogue of measured positions (asteroids, comets, and satellites) in the final reference frame, and also derived parameters concerning either a specific object (*local* parameters) or the solar system and physical constant in general (*global* parameters). We describe in the following some of the aspects of the parameters estimation.

2.1 Orbits

Gaia will provide astrometry of solar system objects on a transit level basis, on the order of 0.3 mas for objects brighter than V≤14 mag, going up to approx. 3 –5mas at the magnitude limit V=20. Because a fast moving object will not be observed through its whole FOV transit, we consider in the following the pessimistic case where only one CCD observation is available per crossing. On the other hand, the ephemerides are computed by numerical integration of the perturbed two-body problem, taking into account the perturbations of the planets. The computation additionally takes into account previously selected perturbing asteroids, relativistic effect (for the equation of motion and observation reduction), and the photocentre offset due to phase. In case of comets, we also include non-gravitational forces through empirical A_i parameters. Last, we also perform the integration of the variational equations to derive the partial derivatives with respect of our parameters to estimate. Once the O-C vector and Jacobian matrix are computed, we perform a linear least-squares inversion.

The astrometry acquired will enable orbit *improvement* by a factor≈30 when compared to what is obtained presently from ground-based data only. In the case where the number of Gaia observations for a given object is insufficient however, there will be no particular orbit improvement but the data will be useful to derive global parameters, and later, for orbit improvement when combined to all existing ground-based observations. Besides given the relatively short period of observations, one will cover a full orbital period of a typical main-belt asteroid, but not enough to derive longer-term effects as can be present for instance in the planetary satellites motion, or Trojans long term librations.

Mass of asteroids can be derived from the monitoring of the relative orbit in binary system as seen before, but also from monitoring the orbit of a target asteroid when perturbed by a massive perturber asteroid; there will be about 150 mass determination of asteroid involving several thousands of asteroid-asteroid close encounter. In some cases the mass determination of a few asteroids can be enhanced by complementary ground-based astrometric observations (Ivantsov et al. 2011), the same holds for the density determination by considering additional observations from ground to better characterise the shape and size of the object. Other global parameters entering the dynamical model for the equations of motion can also be adjusted. For instance by monitoring the precession rate of all the asteroids' perihelion together, one will enable to derive the relativistic PPN parameter ß as well as a direct estimation of the solar dynamical flattening J_2. Besides one will be able to derive the link of the dynamical reference frame to the Gaia (and hence ICRF) reference frame, and a possible time variation dG/dt of the gravitational constant (Hestroffer et al. 2009).

2.2 NEOs

The astrometry of asteroids will also enable orbit *determination* or linking in case a new object is discovered. Given the modest limiting magnitude when compared to ongoing and future ground-based surveys, Gaia will not discover a huge amount of asteroids. However being in space and free of atmospheric diffusion and airmass, it might be more efficient at discovering objects at low solar elongations (down to 45°) and in particular objects orbiting inside the orbit of the Earth (IEOs). Orbit determination in this case will be done on the short-term level by use of an MCMC algorithm which will provide a whole set of possible solutions (Granvik et al. 2009). In such cases it is of importance to have additional observations and astrometry in support to avoid loosing the object and help further identification when the object crosses back the satellite's FOV several weeks or months later (Thuillot 2010).

As seen in Bancelin (2011) there will be about 1600 NEOs observed; only objects that can be identified will enter the long-term reduction pipeline. The number of observations per object is varying (about half of them will have less than 10 observations), but even if no orbit improvement can be obtained, they all enter into the global effects parameters estimation scheme. Moreover the NEOs with low semi-major axis and large eccentricity are the most sensitive to the General Relativity test. In that case, combination of long-term observations – because the effect is a secular drift – gives a higher leverage for the test. We shall here consider combination of present radar (Margot 2009) with future Gaia observations. For small objects close to the Sun the Yarkovsky effect and other non-gravitational effects can be noticeable. In a few cases a simple inversion can be performed to provide a basic scaling parameter for the Yarkovsky effect to better than 20%. This can be the diameter and thermal inertia, all other parameters of the model being assumed; or more generally a parametric force in the along track direction that is inversely proportional to the square of the heliocentric distance. Here again ground-based observation can be useful to constrain the dynamical system to be used.

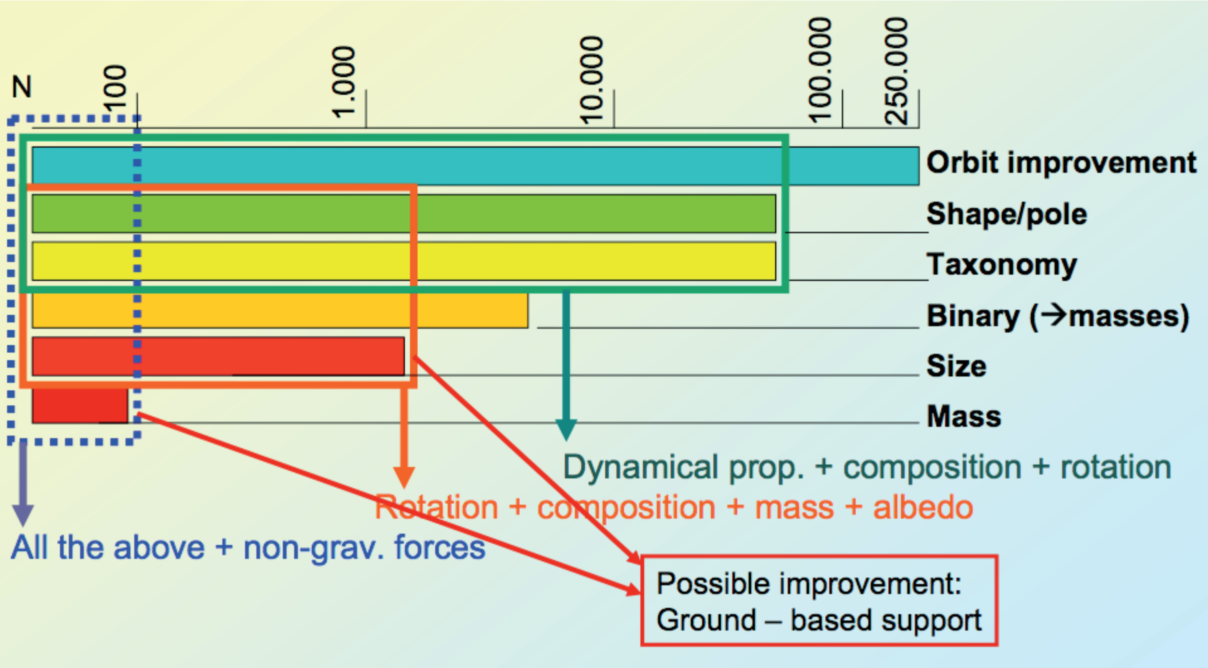


Fig. 3 – General scientific output from the Gaia observation of asteroids (credit: P. Tanga).

Conclusion

Gaia will observe a large number of solar system objects, much more than Hipparcos and Tycho could do. These will essentially be main belt asteroids, but about 1600 Near Earth Objects will be observed too, including some inner-Earth objects that might be discovered by Gaia. The astrometry, photometry, and colour-spectroscopy acquired will enable direct output by considering the Gaia data alone (Fig. 3). In some cases complementary ground-based data is mostly valuable.

Acknowledgement

The author wishes to thank D. Bancelin, J. Blanchot, P. David (IMCCE) and the colleagues of the DPAC CU4 SSO group for their help, discussions, and inputs.

References

Babusiaux, C. 2005: The Gaia Instrument and Basic Image Simulator (GIBIS). In : The Three-Dimensional Universe with Gaia, ESA-SP 576, 417.

Bancelin, D. et al. 2011: Gaia FUN-SSO workshop, this volume.

Berthier, J. 2011: Gaia FUN-SSO workshop, this volume.

Cellino, A., Hestroffer, D., Tanga, P., Mottola, S., Dell'Oro, A. 2009: Genetic inversion of sparse disk-integrated photometric data of asteroids: application to Hipparcos data. A&A 506, 935-954.

Granvik, M.; Virtanen, J., Oszkiewicz , D.; Muinonen, K. 2009: OpenOrb: Open-source asteroid orbit computation software including statistical ranging. Met. & Planet. Sci. 44, 1853

Hestroffer, D. 1998: Photocentre displacement of minor planets: analysis of HIPPARCOS astrometry. A&A 336, 776-781.

Hestroffer, D. et al. 2009: IAUs 261.

ESA 1997. The Hipparcos and Tycho Catalogues. VizieR online data catalog I/239.

Ivantsov, A. et al. 2011: Gaia FUN-SSO workshop, this volume.

Margot, J.-L. et al. 2009: IAUs 261.

Perryman, M.A.C 2008: Astronomical Applications of Astrometry: A Review Based on Ten Years of Exploitation of the Hipparcos Satellite Data. CUP, Cambridge, 670 p.

Pristi, T. 2011: Gaia FUN-SSO workshop, this volume.

Ortiz, J.L. et al. 2011: A mid-term astrometric and photometric study of Trans-Neptunian Object (90482) Orcus. A&A, in press.

Tanga, P. 2011: Gaia FUN-SSO workshop, this volume.

Thuillot, W. 2011: Gaia FUN-SSO workshop, this volume.

Ground Based Optical Tracking of Gaia

Altmann, M.[1], Andrei, A[2], Bastian, U.[1], Bouquillon, S.[3], Mignard, F.[4], Smart, R.[5], Steele, I.[6], Tanga, P.[4], Taris, F.[3]

[1] Zentrum fűr Astronomie der Univ. Heidelberg, Mőnchhofstr. 12-14, 69120 Heidelberg, Germany
[2] Observatório de Valongo, UFRdJ, Ladeira Pedro Antônio, 43 CEP 20080-090 Rio de Janeiro, Brazil
[3] Observatoire de Paris, 61, Av. De l'Observatoire, 75014 Paris, France
[4] Observatoire de la Cote Azur, Boulevard de l'Observatoire B.P. 4229, 06304 Nice, France
[5] Osservatore Astronomico di Torino, Via Osservatorio 20, 10025 Pino Torinese, Italia
[6] Astrophysics Research Institute, JMU, 12 Quays House, Egerton Wharf, Birkenhead, Wirral, CH41 1LD, United Kingdom

1. Introduction: What is GBOT and why is it needed?

Gaia's unprecedented ambitions regarding astrometric accuracy and precision require a level of knowledge of the position and velocity vector of the satellite itself not required in other satellite mission. Thus the usual methods of determining these quantities do not suffice and new approaches must be invoked. One of these is the Ground Based Optical Tracking (GBOT) campaign. There are two main reasons for these high precision needs:

1. Global astrometry is severely affected by aberration, caused by the finite nature of the speed of light. This is a large effect, which means that in order to correct for aberration in the precision regime of Gaia (i.e. a few microarcseconds), the motion of the detector and hence the satellite must be known to very great precision. The resulting tolerance in Gaia's velocity vector is 2.5 mm/s.

2. Apart from stars, Gaia will also measure faint Solar System objects. These are several orders of magnitude closer than even the closest stars, their distances being comparable to Earth's distance to the Sun. Errors in the baseline therefore have a far larger effect on the precision of the parallax of an asteroid than they have on stars, meaning that if Gaia is to measure sufficiently precise parallaxes to these objects, the 3D position of Gaia itself needs to be known to about 150 m.

Unfortunately the ranging of one radar-tracking station can only deliver 2000 m in position and 10 mm/s (75 m, 1 mm/s in radial direction). This means that additional measures need to be taken to ensure Gaia's aims. There are several approaches to accomplish this, one of them being GBOT.

GBOT will consist of a network of a small number of telescopes distributed worldwide, and is committed to deliver positions of Gaia on a daily basis. This network will consist of about half a dozen facilities. Although the aforementioned requirements translate to 20 mas/d and 30 mas on the sky, GBOT has committed itself to a precision of 10 mas/d in order to not exploit the complete error budget. Since all current reference catalogues are not precise enough to reach such a level of precision, GBOT's astrometry will initially have significantly higher errors, about 50 mas. Only after the first release of Gaia astrometry (which will be approximately 2 years after launch) we will be able to reach our aims, meaning that the analysis of all data obtained before will have to be repeated using Gaia as reference catalog in order to meet the requirements.

2. GBOT Requirements and Challenges

One of the first steps in the preparation of GBOT was the establishment of a set of minimum requirements on instrumentation. Given the probable faintness of Gaia and also the fact that most comparison stars will be at the faint end of the Gaia catalogue, participating telescopes should not be smaller than about 1 m. A well matched pixel scale is mandated, to allow a good sampling of the PSF. Given that mean ambient conditions in different sites can be quite different from each other, we decided on a minimum pixel scale of 0.3 x median seeing conditions. We also need to set a lower limit of 5' x 5' on the field of view, since we need a certain number of background stars in order to perform the astrometric reduction.

Apart from these hard constraints concerning the telescope/instrument, we also need to know the geographic coordinates of a telescope and whether a facility can observe and deliver on a daily basis. In the end, we intend to work with 3-6 observatories on both hemispheres. Ideal would be robotic telescopes, since they only need to be programmed with the target coordinates and they will conduct the observations autonomously. Telescopes with dedicated observing programs are a second possibility, as are telescopes operated in queue mode and remote controlled appliances. All of these usually ensure regular observations and a dependable stream of data.

As a compromise between depth and minimizing the differential colour refraction (DCR), we chose Cousins-*R* or similar passbands for our observations. While *I*-band-like filters are much less affected by DCR, this advantage is more than offset by the much higher background level resulting in significantly lower S/N and depth. The nature of Gaia as a moving object sets limitations on the exposure times. Typically it moves about 1 degrees per day, translating to 40 mas/s. This sets an upper limit on the exposure time of 30 – 120 seconds somewhat depending on seeing, pixel scale and centroiding method. Therefore usually more than one image should be taken, we aim at sequences of about 10 exposures. These will be summed up, so that the S/N of the background stars – most of them presumably fainter than the Gaia satellite itself (the limit of Gaia astrometry, thus the faint limit of our reference stars is 20 mag) is optimized. Our group has been investigating various methods of centroiding and also guiding during the observations. This is described in more detail in the contribution by Andrei et al. elsewhere in these proceedings.

Another, still mostly open question is the brightness of Gaia which we will only know for certain once Gaia is in L2. However we have to make assumptions, especially to choose the right aperture range for our partner telescopes. Gaia is in principle shaped like a hat, with the "brim" pointing towards us but inclined by 45°. This means that the bulk of sun light will be reflected 90° away from Earth, i.e. the observers. We thus have to rely on diffuse reflection, caused by imperfections, wrinkles in the Kapton material of which most of the surface of Gaia is made, or reflection of structures, solar panels, etc. How large this amount of light is, remains unknown. However we were able to get some part of the answer by observing other space craft in the L2 region, especially WMAP, which was an object with a rather similar layout as Gaia, just with an inclination angle of 22.5° and half the diameter, and the current Planck mission – however its shape is completely different. Both spacecraft turn out to be faint, but bright enough to make GBOT feasible with the modest telescopes we plan to use. WMAP was of about 18-19 mag in *R*-magnitude, Planck is somewhat brighter, i.e. about 17-18.5 mag. Both satellites show a considerable amount of brightness variation. Given the size of these two satellites compared with the overall larger size of Gaia we assume that Gaia will be at about R=17 – 18 mag. Keeping our estimate on the conservative side, we consider Gaia for our preparations to be at R=18 mag, keeping in mind all the uncertainties, which could lead to quite substantial deviations from this value in both directions, not to mention intrinsic variability.

Collecting data from a network of different telescopes means having to cope with non-uniform data. FITS header keywords will be different, some data will come detrended others not. In order to accommodate for this, we are developing a data reduction pipeline and a database system. This is also necessary to keep the time demand of daily routine a low as possible – after all these operations need to be done on about every day for five or more years! Furthermore, all reductions will need to be repeated, after the first data release of Gaia (see the introduction of this paper). The pipeline is at this point already working, and reductions within our test observing program have been carried out, resulting in precisions of better than 50 mas even with the current reference catalogs, see. Fig. 1

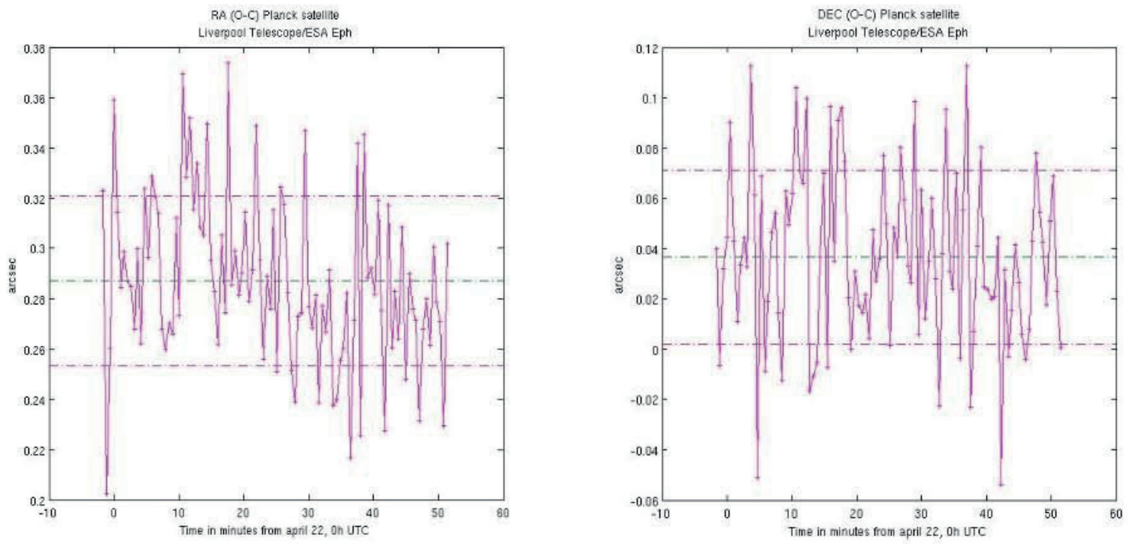


Fig. 1 – Set of observations of the Planck satellite obtained with the 2 m Liverpool telescope with RATCAM reduced with the GBOT pipeline. Shown are the O-C (i.e observation vs. Ephemeris) residuals versus time. The R.M.S. Error in both coordinates is about 35 mas. UCAC2 (Zacharias et al. 2002) was used as reference catalog.

In order to establish the best possible observational methods, intensive tests had to be carried out. For this we used data taken mainly at the 1.06 m Pic du Midi telescope, the 1.23 m at Observatoire de Haute-Provence, and the 2.2 m telescope at ESO's La Silla observatory with its WFI mosaic detector (since mosaiced detectors present additional complications and residual effects on the field mapping, we restrict ourselves to one chip of a mosaic). The main work horse however became the 2 m Liverpool telescope located on Roque de los Muchachos (La Palma), since it fits to our nominal requirements in an almost ideal way.

Once we enter the operational phase, we will make weekly deliveries to ESOC, which will mainly be used for the derivation of geocentric ephemerides which are then in return relayed to GBOT. We will then convert them to topocentric ephemerides for each observing site and supply our partners with these. Data will be delivered to GBOT on a daily basis, fed into the database system and analyzed. A schematic view of the structure of GBOT is shown on fig. 2.

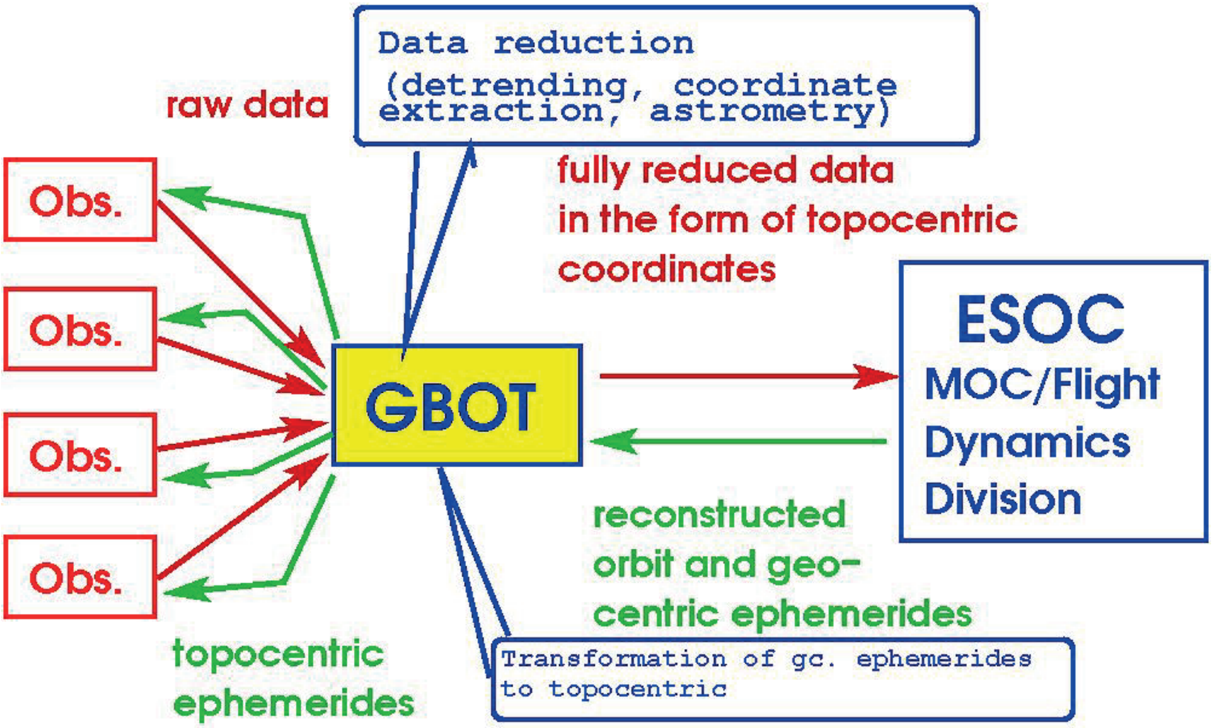


Fig. 2 – Schematic view of the GBOT in relation to its outside connections, i.e. the data recipient, ESOC MOC/Flight dynamics Division, and our data suppliers, namely GBOT's partner observatories.

3. Contact informations for institutions willing to help GBOT

Readers who have access or own a telescope which fulfills our constraints (see Sect. 2), can contact the GBOT group under the following email address: gbot@ari.uni-heidelberg.de or maltmann@ari.uni-heidelberg.de giving us information about your facility. We will then contact you back in order to arrange for a test campaign to evaluate your facility for our purposes.

Acknowledgements

The GBOT group would like to thank Francois Colas (Observatoire de Paris) for the observations at Pic du Midi, and Dominique Albanese (Observatoire de la Côte d’Azur) for observation at the MeO telescope. We would also like to thank PATT for granting the observing time at the Liverpool telescope for our asteroid observing campaign, and our national funding agencies.

References

Zacharias, N., Urban, S.E., Zacharias, M.I., et al.: 2004, The Second US Naval Observatory CCD Astrograph Catalog (UCAC2), AJ 127, 3043

SYRTE and PARSEC Contribution for the GBOT/GAIA Moving Target Astrometry

Andrei, A.H.[1,2,3,4], Bouquillon, S.[4], Taris, F.[4], Smart, R.[2], Altmann, M.[5]

[1] Observatório Nacional/MCT, R. Gal. Jose Cristino 77, Rio de Janeiro, CEP 24910-400, RJ, Brasil

[2] Osservatorio Astronomico di Torino/INAF, Via Osservatorio 20, 10025 Pino Torinese, Italia

[3] Observatório do Valongo/UFRJ, Ladeira Pedro Antônio 43, Rio de Janeiro, CEP 20080-090, RJ, Brasil

[4] SYRTE/Observatoire du Paris, 61, Av. De l'Observatoire, 75014 Paris, France

[5] Zentrum fűr Astronomie der Univ. Heidelberg, Mőnchhofstr. 12-14, 69120 Heidelberg, Germany

Introduction

GAIA will measure to unprecedent precision positions, movements, and parallaxes, by the superposition of two fields apart by 174deg, taken from the L2 Earth-Sun, about 1.5 million km from the ground. To achieve the aimed precision for stars, and particularly for solar system bodies, the instantaneous position and speed of the satellite must be known respectively to 150m and 2.5 mm/s. This translates to the GBOT (Ground Base Optical Tracking) requirement to deliver quasi-daily positions of the satellite at the accuracy of 10mas relatively to the GAIA´s reference frame itself (Altmann et al., 2010, this proceeding). The challenge increases because the satellite will probably be dimmer than R 17th magnitude and will be moving on average at 30mas/s, and switching hemispheres between summer and winter. We will present the strategies worked out for the satellite centroid´s determination, including tracking mode, binning, super-gaussian fit, blind co-addition of images; as well as the astrometric reduction open code designed to cope with this variety of conditions. We will show applications of these resources to observations of the satellites WMAP and PLANCK, and to fast asteroids. All these topics, on the other hand, make for an exchange of experiences and ensuing of scientific programs with other groups targeting fast, dim objects prior and during the GAIA mission.

1. Goals and feasibility

The main issues of the campaigns aiming to emulate the observation conditions of the GAIA satellite are speed, magnitude, and their variations. For the observational band there were two main a priori choices, between V-band or clear against the near infrared. In the first case maximum light is gathered, but atmospheric extinction and chromatic refraction are also large. On the near infrared atmospheric extinction is less important but the satellite and the reference stars are dimmer, demanding longer exposures. A compromise on the R-band, which is readily available from all envisaged observatories, favors also the closeness to GAIA's band. In particular the early studies made with WMAP have shown the important magnitude modulation brought by the satellite´s spin.

Here, we focus on the other important issue, which concerns the astrometric pipeline, given the precision required and movement of the target. All this considered, observations are being taken of satellites within the Lagrange zone L2 (WMAP and PLANCK), and asteroids with large tangential motion (mostly double or suspected, in order to mimic the satellite spin).

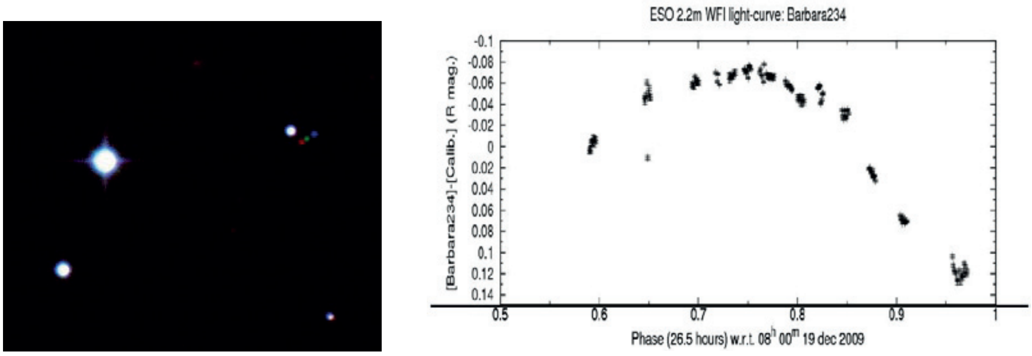


Fig. 1 – On the left the very first images of the test campaigns, taken of the WMAP satellite on April 5th, 2008. On the right light curve of double asteroid Barbara234, taken on December 19th, 2009, and which is part of a larger campaign for this object. Both observations were made at the ESO2.2m/WFI telescope, in Chile.

2. Astrometric handling

The astrometric pipeline is preceded by a database, which rectifies headers´ inconsistencies and makes the images available for reduction. Specific routines are being developed for the GAIA´s case. The first step is the recognizing of objects, using variable thresholds and local boundaries of search and adjustment. The routine can deal with crowded fields as well as with fields affected by Moon´s illumination gradient. In particular, it is able to recognize GAIA either as an elongated or particularly dim object. The derivation with the equatorial coordinates can use pre-existing catalogs of earlier version of the GAIA catalog itself.

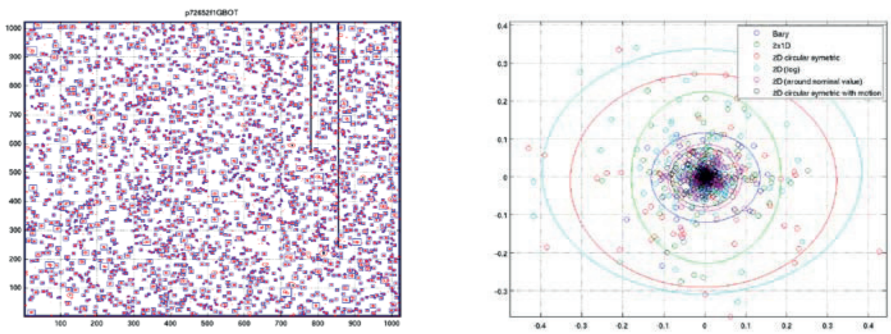


Fig. 2 – On the left an example of object recognition in a dense field and wildly different magnitudes. On the right the improving on the centroid determination of a moving object from a barycentric fit (outer circle) to a fitting through a bi-dimensional Gaussian plus a displacement term (inner circle).

3. Blind co-addition

The Moving Gaussian approach (Fig. 3) describes to mathematical exactness the displacement of the GAIA satellite or, for instance, of an asteroid. To tackle the problem of the intrinsic faintness of the object, another approach is proposed, which we term as Blind Co-addition. It borrows from the standard co-addition procedures used to pile up images, enhancing the signal to noise ratio of faint objects without worsening the centroid´s determination.

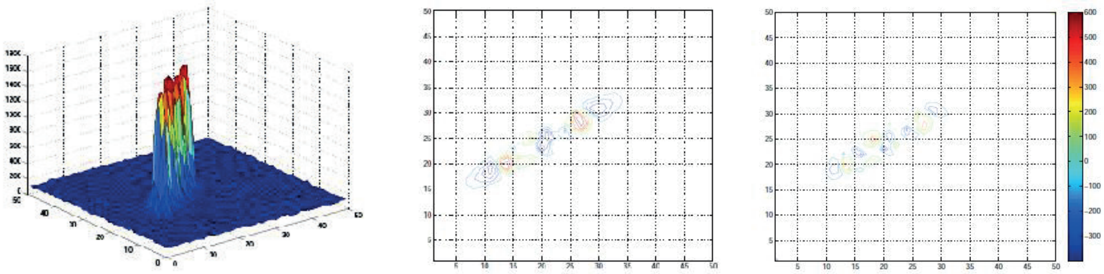


Fig. 3 – For the simulated moving object appearing on the left, the middle figure shows the residuals for a fitting by a bi-dimensional Gaussian, while the left figure shows the much smaller residuals resulting from the fitting by the Moving Gaussian procedure developed for the GAIA (and asteroids) case.

The distinctive feature of the blind co-addition when applied to enhance a moving target is that it cannot no longer rely on the reference of the bright stars positions, since the target position is varying with respect to them. Thus, the piling up of the target images relies on the constancy of its underlying distribution of incoming photons. In practice, though the PSF shape is disrupted, the barycenter of the illuminated region around the object would remain the same. The blind co-addition procedure entails taking short images, so that a large number of references stars are still well sampled and for which the centroid can be determined to derive the required astrometric precision, orientation and scale. At the same time the moving target remains effectively circular.

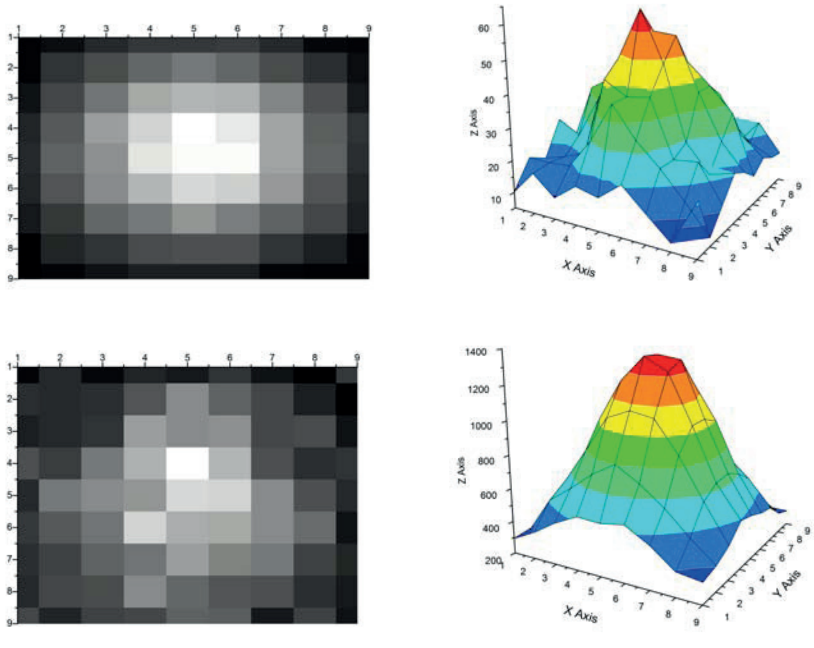


Fig. 4 – Principle of the Blind Co-addition. From an actual observation of WMAP, with 12sec exposition, at the ESO 2.2m/WFI, on the top panel it is seen the local region (left) and reconstructed photon distribution (right). On the lower panel are the corresponding compound region and photon distribution of the co-addition of 20 frames.

The first step of the blind co-addition procedure is to take several frames, preferably in a fast sequence, up to theoretically being able to reach the signal to noise ratio goal. Next a region around the moving object is cropped centered on the ephemeris position. For each frame the orientation and pixel scale are obtained by the astrometry of the well imaged stars. The ensemble of orientation and pixel scales values (in practice much alike) are used to normalize all of the target´s regions coming from the several frames. If the target motion is not linear, the regions orientation is also compensated for. Then in each region the barycenter of the illuminated portion is calculated. All regions are now co-added by the barycenter, at the nominal precision aimed at, and a bi-dimensional Gaussian is adjusted to the resulting distribution. The centroid is de-convoluted towards the orientation and scale of each frame, so that the original region is replaced by the compound one, but particular to the original frame instead of common to all of them. In this way one independent measurement is extracted for each frame. The independent measurements can finally be averaged, either using the ephemeris speed if it can be taken as correct for the total time range, or leaving a correction to the ephemeris speed as unknown.

4. Results and Conclusion

A series of observations of PLANCK was conducted at the 2m. Liverpool Robotic Telescope, at La Palma, from 10th to 18th August 2010. The integration time was 20sec and a sequence of 10 measurements was made daily. On these conditions, namely, brighter probe, longer integration time, and limited number of daily observations, the blind co-addition still improved the correction to the ephemeris. Relatively to a local frame of 2MASS stars, on the best observation night the error on R.A. went to 46mas and the DEC. error went to 58mas, respectively a reduction of 8mas and 2mas in comparison with the average of individual reductions. On the worst night, however, the same comparison shows an improvement on R.A. by 35mas but a worsening on DEC. by 24mas.

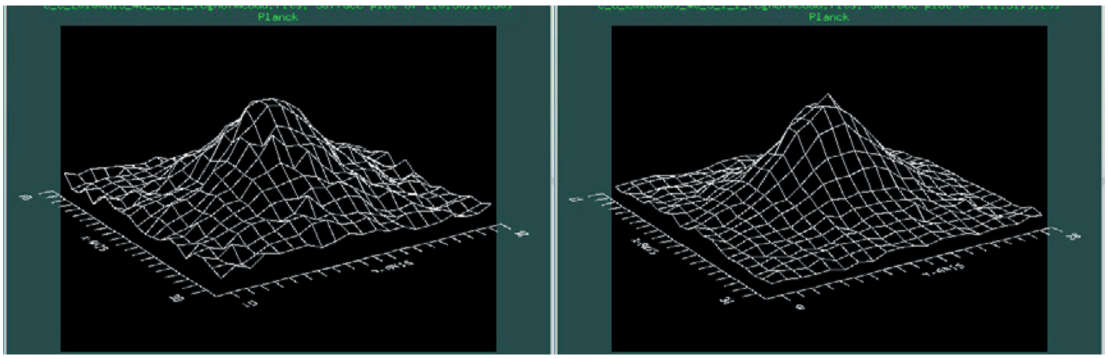


Fig. 5 – Compound images of PLANCK taken at the 2m LT at La Palma, for series of 10 exposures of 20sec. On the left the night of best seeing is depicted, and on the right that one of worst seeing. Though nominally the error on the centroid is nearly the same (1mas), on the worst night there was no net improvement upon the results from the average of standard astrometric reductions.

Both the Moving Gaussian and the Blind Co-addition offer a substantial improvement for the determination of the centroid of the GAIA satellite during its mission. Their utilization in the astrometric pipeline used by the GBOT/GAIA will hence depend of the actual satellite brightness, and variation, during the mission, as well of observational conditions, like seeing, number and length of exposures. The series of tests using PLANCK and selected asteroids will continue to improve the present procedures.

The Evolution of the Networks of Observers of Phenomena

Arlot, J.-E.

IMCCE, UMR 8028 du CNRS, Paris Observatory, UPMC, USTL
77 av. Denfert-Rochereau, F-75014 Paris

Introduction

Astrometric observations are commonly measurements of angular positions of bodies on the celestial sphere in a given reference frame. However, the precision of such measurements is limited by the instruments and by the receptors used for these observations. Astronomers saw very early that celestial bodies were often involved in phenomena such as eclipses of the Sun or the Moon. Such phenomena correspond to specific positions of the involved bodies in space. At least, one may say that the topocentric positions of the Moon and the Sun are very close at the time of an eclipse. This is an astrometric observation. Since the possible phenomena are numerous in the solar system thanks to the velocity of the moving objects, astronomers made predictions of such events and made observations as precise as possible in order to deduce astrometric positions from these events. Of course, a model was necessary for that purpose but this was the main way to improve our knowledge of the solar system at the beginning of astronomical research.

1. What phenomena?

1.1 Jovian satellites eclipses

After the eclipses of the Sun and the Moon, the phenomena the most observed by the astronomers were the eclipses of the satellites of Jupiter by the planet Jupiter. As soon as Galileo observed these satellites, he understood the phenomenon of the eclipse occurring very often (Io makes a revolution around Jupiter in one day and an half and is eclipsed each time!). It was then easier to date each eclipse in order to get the period of the satellites than measuring the relative positions of the satellites.

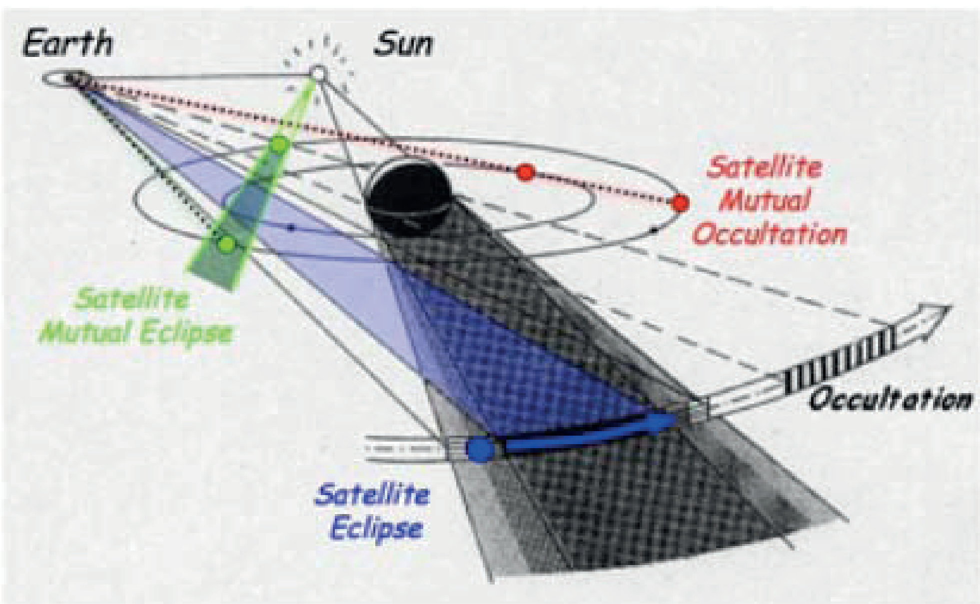


Fig. 1 – The principle of the phenomena of the Galilean satellites of Jupiter

From Galileo until the beginning of the XXth century, Jovian eclipses of the satellites were extensively observed and were the basis for the building of the dynamical models of the motion of the Galilean satellites. The theories by Laplace (end of the XVIIIth century) and Sampson (beginning of the XXth century) are among the most achieved analytical models and are based on eclipses. However, the precision of these observations is limited by the refraction of light in the upper atmosphere of Jupiter determining the shadow cone. The progress of the direct astrometry thanks to the apparition of the photographic technique led to the decline of the use of eclipses. During the XXth century, the photographic technique was the main source of observations of the Galilean satellites.

1.2 Mutual events of the natural planetary satellites

As seen on figure 1, the eclipses by Jupiter are not the only phenomena occurring in the Jovian system: the satellites may eclipse and occult themselves since they are in the same orbital plane. Then, when the Sun (and the Earth which is close to the Sun as seen from Jupiter) crosses the common orbital plane of the satellites, mutual eclipses and occultations occur. Note that this occurs at the equinox on Jupiter since the orbital plane of the satellites is the equatorial plane of Jupiter. The interest of these events is that the satellites have no atmosphere so that the precision of the observations is higher than the one of the eclipses by Jupiter and also higher than the one of the photographic data. However, these observations started only after 1973 because of the need of computers to make the prediction of the events.

These events occur not only in the Jovian system but also in the systems of Saturn and Uranus since they have large satellites orbiting in their equatorial plane. Note that these events occur at the equinox on the planet i.e. every 6 years for Jupiter, 15 years for Saturn and 42 years for Uranus. These observations are then a complement of high accuracy to the direct ground based astrometric measurements as data from space probes available only on short intervals of time. It is easy to understand that these events occur at any time and that the observations are possible only from selected geographic area. More, the observers may not wait for favorable weather, so that an organized network of observers is necessary.

1.3 Occultations of stars

All the moving objects of the solar system may occult a star on their way on the celestial sphere. Such an occultation is similar to a solar eclipse, the Sun being replaced by a star and the Moon by any moving object. For small objects for which the resolution of the telescopes does not allow to measure the size, each occultation provides one measurement of the size of the object. Several occultations observed from close sites will provide a complete profile of the object. As for solar eclipses, the total occultation is observable only from a central path where the observers should be placed. A network of observers is necessary to get useful observations.

2. Mutual events: the history

Galileo observed the first eclipse by Jupiter in 1612 but it was only in 1693 that Arnoldt observed an occultation of Europa by Ganymede. Such observations occurred only by chance when observing the satellites but the calculation of prediction was not possible at that time. The calculations were difficult because of the sensitivity of these events to the accuracy of the position of the satellites near 100 km. Such accuracy needs the use of a complete dynamical model for the calculations. At the beginning of the XXth century, the Sampson's theory was sufficient for such predictions but the algorithm needed too many calculations. From the 1970's, computers were used for astronomical calculations and precise predictions of mutual events were published (Arlot, 1973, Brinkman, 1973). Since these events were rare and could provide relative positions and diameters of the satellites, observers were numerous to try to catch some events during the favorable occurrence of 1973. Even the Galilean satellites are bright, the recording of the events needed a fast photometric receptor associated to a telescope the aperture of which being larger than 50 cm: an occultation or an eclipse was only a few minutes long. Since made by photometrists, the observations were of good quality, well calibrated. The only problem was to be sure of the time scale: each event must be observed in the Universal Time scale in order to be linked to the other events and to the theoretical model.

3. The observers, the material and the network

1.1 The first observers

The first observers were professional astronomers using 50cm-telescope or larger. They were photometrists using a photoelectric photometer. Some amateurs tried to make visual observations using the methods developed for variable stars observation.

Table 1 – Evolution of the size of the telescopes and of the receptors

Occurrences	**Size of the telescopes** < 60cm (amateurs)	> or = 60cm (professionals)	**Photometry** 1 D	2 D
Jupiter				
1973	4	20	24	0
1979	3	7	10	0
1985	12	12	21	3
1991	37	19	39	17
1997	35	10	15	30
2003	34	15	8	41
2009	52	10	0	62
Saturn				
1980	0			0
1995	5	11	8	8
2009			0	
Uranus				
2007	4	11	0	15

Table 1 provides the evolution of the telescopes and receptors used for the observation of the mutual events. Seven Jovian occurrences allowed the observation of the mutual events of the Galilean satellites and about 1800 observations were made. At the beginning, large telescopes managed by professional astronomers equipped with single channel photoelectric photometers were the more numerous systems of observations. From 1985, 2D receptors such as CCD cameras appeared and were used allowing recording a reference object at the same time than the occulted or eclipsed satellites: observations were possible even in difficult conditions such as twilight or fog. The problem was to record images with a high frequency (more than one image per second) that was difficult at the beginning of the use of the CCD's. The progress of that type of 2D receptors led to the disappearance of the 1D receptor for the 2009 occurrence. Correlatively, the part of amateur's observations grew rapidly due to increase of the sensitivity of the receptors allowing using small telescopes. Specific training of the observers was made in order to learn the basis of photometry and also to understand the need of the use of an accurate time scale linked to UTC.

1.2 The observers today

To day, small fast CCD cameras such as Watec are widely used associated to 20 or 30cm-aperture telescopes: such material is easy to get and the number of observing sites of the network increases. Nowadays, the network (cf. figure 2) allows observing as many events as possible and includes ninety percent amateur astronomers. Internet provides help and software for the reduction to the observers and images are broadcasted through the Web.

Fig. 2 – The present PHEMU network of observers

1.3 The Saturnian and Uranian events

The success of the observation of the mutual events of the Galilean satellites led to try the observation of the same events for the Saturnian and Uranian satellites. For those systems, some difficulties arose: the field was smaller because of the increased distance of the satellites from the Earth leading to a smaller apparent distance satellites-planet and the bright planet (plus ring for Saturn) made difficult the observations. More, for the Uranian satellites, their faint magnitude made the use of large telescope necessary. For example, only one event was observable through a small telescope in the visible wavelength thanks to its distance to the planet at the time of the event: all the other events occurred too close to the planet Uranus, too bright in the visible wavelength. Then, these events needed the use of infra red filters making the planet very dark. However, such K' filter implied the use of large telescopes from the 3.5m-NTT (cf. an image in figure 3) to the 8m-VLT (Arlot et al., XXX).

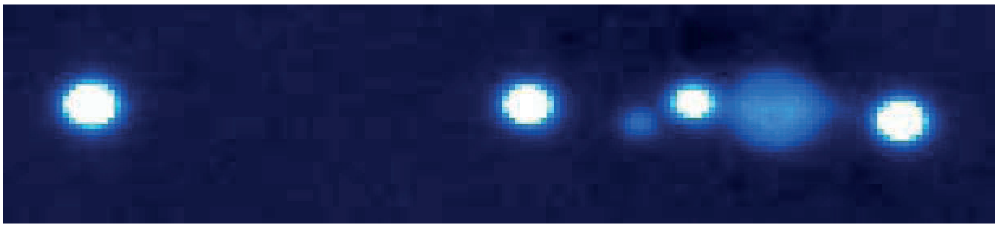


Fig. 3 – The Uranian satellites as seen with the NTT in the K'-band.
The planet Uranus is darker than the satellites (except the small Miranda)

4. The results of thirty years of campaigns

1.1 Using the data

The first use of the observations of mutual events has two purposes: the determination of relative positions between two satellites and the measure of the radii of the satellites (at that time, the space probes had not yet provide these data). These quantities were correlated but numerous observations permitted to de correlate them. After the accurate determination of the radii by the space probes, it appeared that the mutual events were sensitive to the law of reflection of the light at the surface of the satellites which was the explanation of non symmetrical light curves. More, it appeared that the observation in infra red should show the hot spots at the surface of Io (Descamps et al., XXX) through their occultation (figure 4).

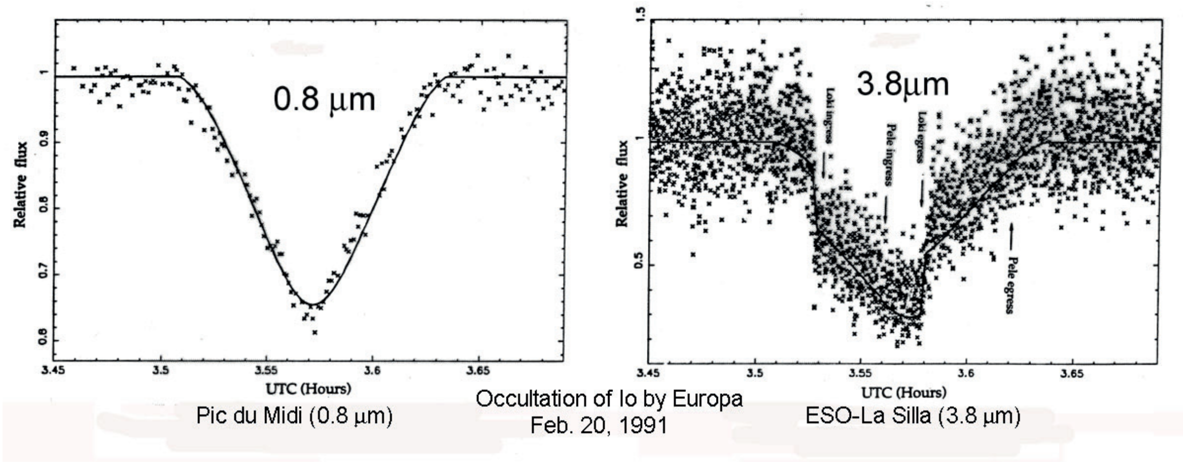


Fig. 4 – Occultation of Io by Europa:
the occultation of the hot spots are visible on the light curve at right

Nowadays, the hot spots may be observed through specific 2D infra red receptors. The analysis of the light curves allows now to determine highly accurate relative positions of the satellites used for the fit of the new theoretical dynamical models. After 30 years of observations of mutual events and one century of photographic observations, small effects in the orbital motion of the satellites such as tidal effects may be detected (Lainey et al., XXXX, Lainey et al. 2009).

1.2 Reusing the old data

Table 2 provides the number of observations gathered since the beginning of the observational campaign. The first light curves were analogical and their analysis very simple. It is possible to digitize them and to apply a better algorithm to determine the relative positions of the satellites. The search for older data allowed us to find in publications the measurement of the time of conjunction between satellites with a poor accuracy, not useful nowadays.

Table 2 – Observations made since the beginning of the campaigns

	Number of observations	Number of observing sites	Number of observed events	Number of observable events
Jupiter				
1973	91	26	65	176
1979	18	7	9	60
1985	166	28	64	248
1991	374	56	111	221
1997	275	42	148	390
2003	361	42	116	360
2009	523	68	206	237
Saturn				
1980	14	6	13	213
1995	66	16	43	182
2009	26	15	17	131
Uranus				
2007	52	19	36	193

Conclusion

The example of the network of observers of the mutual events of the natural planetary satellites shows an evolution which depends on the progress of the receptors. More and more amateur astronomers may participate to the observations of phenomena that allows the increase of the number of observations. The network of observers of occultation of stars, using the same material, are more dependant of each event, observable only on a small area: in this case, the observers must move towards the best observing places. For any other observational campaign, specific constraints may appear but the technical progress of the material to be used and of the communication through Internet makes the things easier for observers.

References

Arlot, J.E.: 1973, Les occultations et les eclipses mutuelles des satellites galiléens de Jupiter, L'Astronomie, 87, 287.

Arlot, J.E., Dumas, C., Sicardy, B.: 2008, Observation of an eclipse of U-3 Titania by U-2 Umbriel on December 8, 2007 with ESO-VLT, A&A 492, 599

Brinkmann, R.T., Millis, R.L.: 1973, Mutual Phenomena of Jupiter's Satellites in 1973-74, Sky & Telescope 45, 93.

Descamps, P.; Arlot, J. E.; Thuillot, W.; Colas, F.; Vu, D. T.; Bouchet, P.; Hainaut, O.: 1992, Observations of the volcanoes of Io, Loki and Pele, made in 1991 at the ESO during an occultation by Europa, Icarus 100, 235.

Lainey, V.; Arlot, J. E.; Vienne, A.: 2004, New accurate ephemerides for the Galilean satellites of Jupiter. II. Fitting the observations, A&A 427, 371.

Lainey, V., Arlot, J.E., Karatekin, O., van Hoolst, T.: 2009, The thermal equilibrium of Io, Nature, 459, 957-959

Gaia and ESA's Space Situational Awareness' Near-Earth Object programme

Koschny, D.[1], Drolshagen, G. [1], Carry, B.[2]

[1] ESA/ESTEC, Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands
[2] ESA/ESAC, P.O. Box 78, 28691 Villanueva de la Cañada, Madrid, Spain

Introduction

In 2008, ESA started a new optional programme called Space Situational Awareness programme. One part of it deals with the impact threat of near-Earth objects for the Earth. This paper intends to inform the Gaia asteroid community about this programme and explores possible synergies.

1. What is Space Situational Awareness?

The SSA Programme Declaration, ESA/C/SSA-PP(2008)2 states: "The objective of the Space Situational Awareness (SSA) initiative is to support the European independent utilisation of and access to space for research or services, through providing timely and quality data, information, services and knowledge regarding the environment, the threats and the sustainable exploitation of the outer space."

Thus, SSA will provide a service to inform the customers (governments, disaster management, scientists, the public/press…) about the situation of natural and artificial objects in space. This will allow us to better protect our satellites and our planet.

The SSA programme is split in three so-called *segments*:

(a) Space Surveillance and Tracking of satellites and space debris (SST)
(b) Space Weather (SWE)
(c) Near-Earth objects (NEO).

While each of these segments are managed separately and satisfy different communities, SSA will build up a 'system of systems' combining all three of these segments.

During ESA's Ministerial Council meeting in November 2008, the preparatory phase for SSA was approved and is funded with about 50 *MEuro*, which is shared between the three segments. During this phase, precursor services are being set up and thorough studies are being performed to assess the architecture and system requirements. At the end of the preparatory phase, all elements for a functioning service shall be in place.

2. The near-Earth object segment of SSA (SSA-NEO)

The Near-Earth Object segment of the SSA programme, hereafter called SSA-NEO, has the following key tasks:

(1) It shall provide information on the impact probability and/or miss distances of NEOs including associated uncertainties. To do this properly, it shall assess impact analyses, results, and perform its own impact risk assessments.

(2) It shall classify the risk of a NEO impact and issue warnings if the risk is higher than the background risk.

To perform these tasks, a network of sensors is being set up for the discovery and follow-up observations of asteroids and in particular also for the characterisation of these objects. It will also set up data centres for processing the information. ESA representatives participate in discussions on the level of the United Nations to set up the political framework for issuing impact warning. In addition, the SSA-NEO team will maintain close links to groups working on mitigation strategies, *e.g.* ESA's Advanced Concept Team. SSA-NEO contributes to what the Association of Space Explorers call the Information, Analysis, and Warning Network (IAWN) in a recommendation to the United Nations.

The main building blocks of SSA-NEO will be (Drolshagen *et al.* 2010):

(a) Network of sensors. This will be mainly optical telescopes, but also radar systems should be involved – in a later phase this can also include space-based sensors. It includes a measurement, coordination and planning function.

(b) Data processing centers to

- Perform impact risk computations;
- Maintain a NEO property database;

(c) Interface to studies on risk mitigation;

(d) Support the decision-making process in case of an imminent impact threat by participating in the Action Team #14 of the United Nations discussing the NEO impact threat.

A graphical view of the SSA-NEO segment is shown in Figure 1.

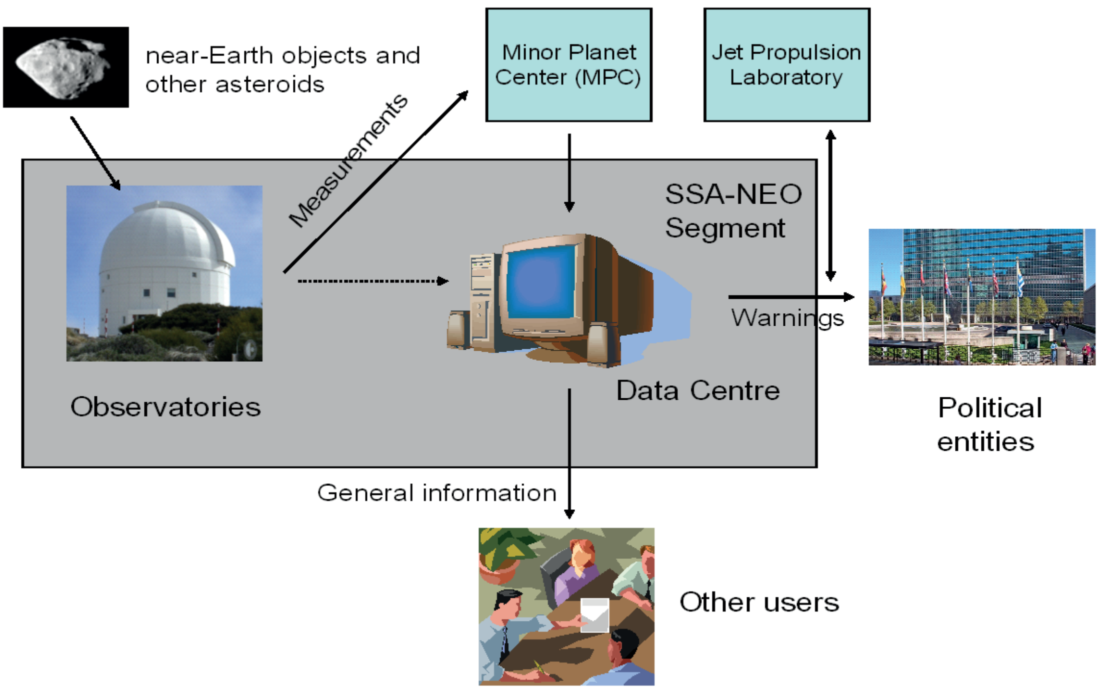


Fig. 1 – Block diagram of the SSA-NEO segment.

3. SSA-NEO needs for observations

To support the goals of the SSA-NEO segment the following observational tasks have to be performed:

(a) Discovery of new NEOs;

(b) Follow-up of recently discovered objects;

(c) Understand the orbital evolution of asteroids;

(d) Catalogue the physical properties of asteroids.

Ad (a): A large number of asteroids, in particular smaller objects below ~200 m, are not yet discovered. Ground-based survey telescopes try to map the complete sky regularly, however, have limitations due to sky coverage close to the sun, the transparency of the sky, and weather conditions. A space-based telescope has much less limitations in this respect and can contribute to discovering new objects significantly. However, it is expected that most objects which have magnitude of about 20 mag have been discovered already (the currently assumed detection limit for Gaia). Thus it is not expected that Gaia will be a major contributor to new NEO discoveries. In addition, to allow follow-up observations of objects before these have deviated too much from there predicted position, quick data dissemination in the order of hours is important.

Ad (b): When an object is newly discovered by a survey, more observations are required within a few hours and later a few days to extend the observed orbital arc. This is needed to get an orbit solution with accuracy good enough to not loose the object again. Ground-based telescopes can be pointed in the direction of an object in need of observation to perform these so-called follow-up observations. Gaia does not have the possibility to command its pointing. However, one should analyze the possibility of using by chance observations of asteroids in need of follow-up observations as the high astrometric accuracy of the Gaia observations will allow a very good orbital solution compared to ground-based observations. This, in turn, will mean that the objects orbit will be known much better than from ground, decreasing the chance of loosing it again. An important point in this respect is that a fast turn-around time of the data is needed – one should be able to assess whether an object was observed successfully within say less than a day to avoid other observatories wasting time on observing the same object.

Ad (c): The orbits of asteroids can be disturbed by non-gravitational forces. One major effect is the so-called Yarkovsky effect, a thermal effect which changes the semi major axis of the orbit of an asteroid. This effect may change an asteroid's orbit over several tens of years enough to change it from a non-threatening to a threatening object. To better characterize and understand this effect one needs very high accuracy position measurements of the asteroids, something which cannot be done from ground but which would be possible using Gaia (see *e.g.* Delbo *et al.* 2008).

Ad (d): A good knowledge of the physical properties of a potential Earth impactor is important to estimate the consequences of an impact and the strategy for a possible deflection mission. The physical properties also influence the non-gravitational forces on the orbit and thus have an effect on the accuracy of the orbit determination. Gaia can contribute precise light curve measurements which would allow the determination of the rotation period of an asteroid. In many cases, the shape of an asteroid can be reconstructed from light curves. Unlike typical ground-based programs for light curves, where one object is followed over many hours or even days, Gaia will only provide 'sparse' observations. Recent studies have shown that these can also be used successfully, in particular if at least one complete light curve has been observed from ground (Durech et al. 2007).

Conclusion

The major contribution of Gaia to the field of asteroid science – and the prediction of potential impacts in particular – will be the high-precision star catalogue which it will produce. This star catalogue will reduce the uncertainties in the astrometry and photometry of asteroids dramatically. Even existing data could be reprocessed to improve their accuracy.

Additional contributions from Gaia will be the detection and follow-up of asteroids. The precise photometry can be used for the determination of rotation periods and shape models.

To achieve these goals, the following items should be taken into account:

(a) Data should be available in a timely manner. New asteroid discoveries should typically be available a few hours after obtaining the data. Note that photometric data is less critical, it can be processed after the normal release of the data;

(b) To enable the search for asteroids in historical data *before* the actual discovery of the object (so-called *precovery* searches), objects which cannot be identified by the pipeline immediately should be stored and not discarded for possible later confirmation;

(c) Coordination between ground-based observers and Gaia will increase the quality of the results;

(d) The exchange of information between the SSA-NEO and the Gaia community should continue to ensure that the synergies of the two projects are maximized.

References

Delbo, M., Tanga, P., Mignard, F.: 2008, On the detection of the Yarkovsky effect on near-Earth asteroids by means of Gaia, Planet. Space Sci. 56, 1823-1827.

Drolshagen, G., Koschny, D., Bobrinsky, N.: 2010, The Near-Earth object segment of the European Space Situational Awareness program, Cosmic Research, 48/5, 399-402.

Durech, J., Scheirich, P., Kaasalainen, M., Grav, T., Jedicke, R., Denneau, L.: 2007, Physical models of asteroids from sparse photometric data, Proc. Int. Ast. Union 2006, 2, 191-200.

Near-Earth Asteroids Astrometry with Gaia and Beyond

Bancelin, D., Hestroffer, D., Thuillot, W.

IMCCE, Paris Observatory, 77 avenue Denfert-Rochereau, 75014 Paris, France.

Introduction

Gaia is an astrometric mission that will be launched in 2012 and will observe a large number of Solar System Objects down to magnitude 20. The Solar System Science goal is to map thousand 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 the solar elongation (45°) which are harder to detect with current ground-based surveys.

In the first section, we detailled the nominal scanning law of Gaia and its impact on the number of observations of NEAs. Then we focus our study on asteroid Apophis were we analyze the effect of Gaia observations on the actual position uncertainty, and on the 2029-target b-plane. In the last section, dedicated to the astrometry of newly discovered objects by Gaia, we analyze the combination of ground-based and space-based data on the short-term ephemerides.

1. Nominal Scanning Law of Satellite Gaia

During the 5-years mission, Gaia will continuously scan the sky with a specific strategy (fig. 1): objects will be observed from two lines of sight separated with a constant basic angle. Five constants already fixed determinate the nominal scanning law but two others are still free parameters: the initial spin phase and the initial precession angle. These latter will be fixed at the start of the nominal scientific outcome (possibility of performing test of fundamental physics) together with operational requirements (downlink to Earth windows).

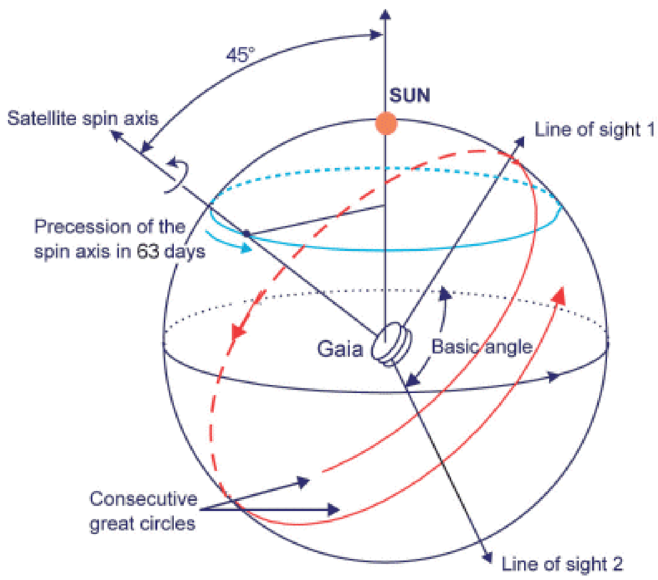


Fig. 1 – Nominal Scanning Law of Gaia. (Credits: ESA)

Several sets of observations of NEOs will hence be provided according to the initial precession angle. We used a Java *rendez-vous* simulator which provided us 35 sets of Gaia observations. Figure 2 shows the number of NEAs and PHAs that could be observed by Gaia. The number of asteroids does not really change according to the value of the initial precession angle. The mean values of possible observed asteroid are ~1650 NEAs and ~ 405 PHAs.

2. Study case of asteroid 99942 Apophis (previously 2004MN4)

We study here the effect of Gaia observations on Apophis orbit. This asteroid has a so deep close-approach with the Earth on April 2029 that its post close-approach orbit becomes chaotic. Thus, the uncertainty on the geocentric position and distance becomes large. From a linear propagation of the covariance matrix, figure 3 shows the impact of Gaia astrometry done in 2014 (date of last Gaia observations) on the position uncertainty of Apophis. To this purpose, we considered only one of the sets provided by Gaia.

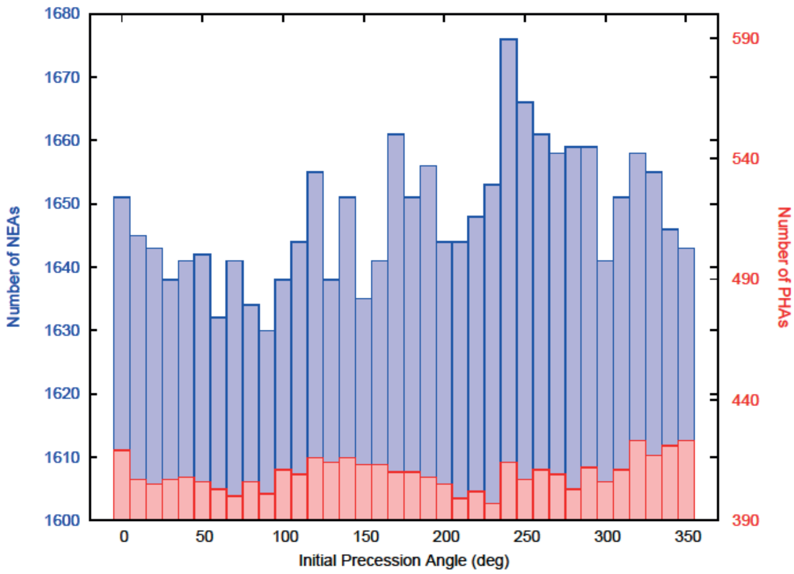


Fig. 2 – Number of NEAs and PHAs observed by Gaia with respect to the initial precession angle.

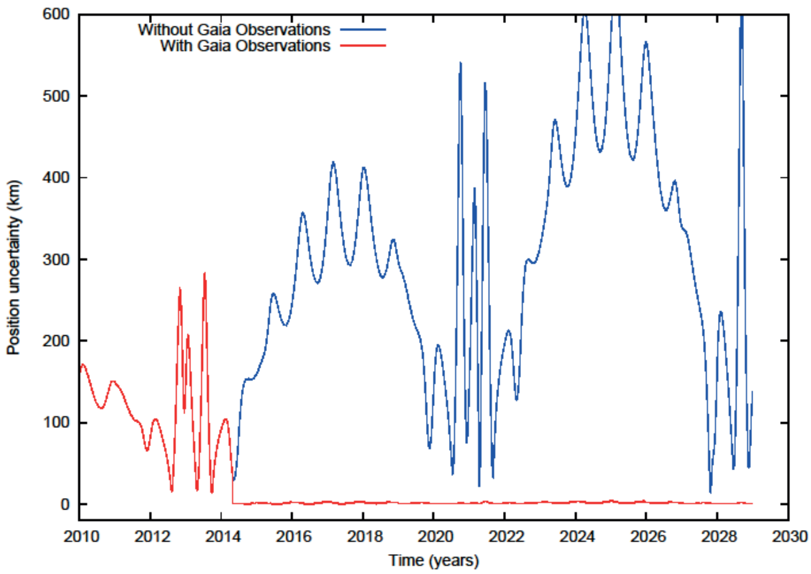


Fig. 3 – Position uncertainty of Apophis considering Gaia observations.

The position uncertainty is reduced to less than 2 km with Gaia observations. This value remains almost constant until the 2029 close approach (at distance 38000 km to Earth) where the uncertainty will start increasing. We can also analyze the impact of Gaia observations on the geocentric coordinates (ξ, ζ) of the 2029-target b- plane [1]. The b-plane passes through Earth's center and is perpendicular to the geocentric velocity of the asteroid. The initial covariance of the (ξ, ζ) elements are propagated to this date. Figure 4 represents the 3σ scattering ellipse where the semi minor axis is defined by $3\sigma_\xi$, the semi major axis by $3\sigma_\zeta$ and its center by the values of (ξ, ζ) on the nominal solution.

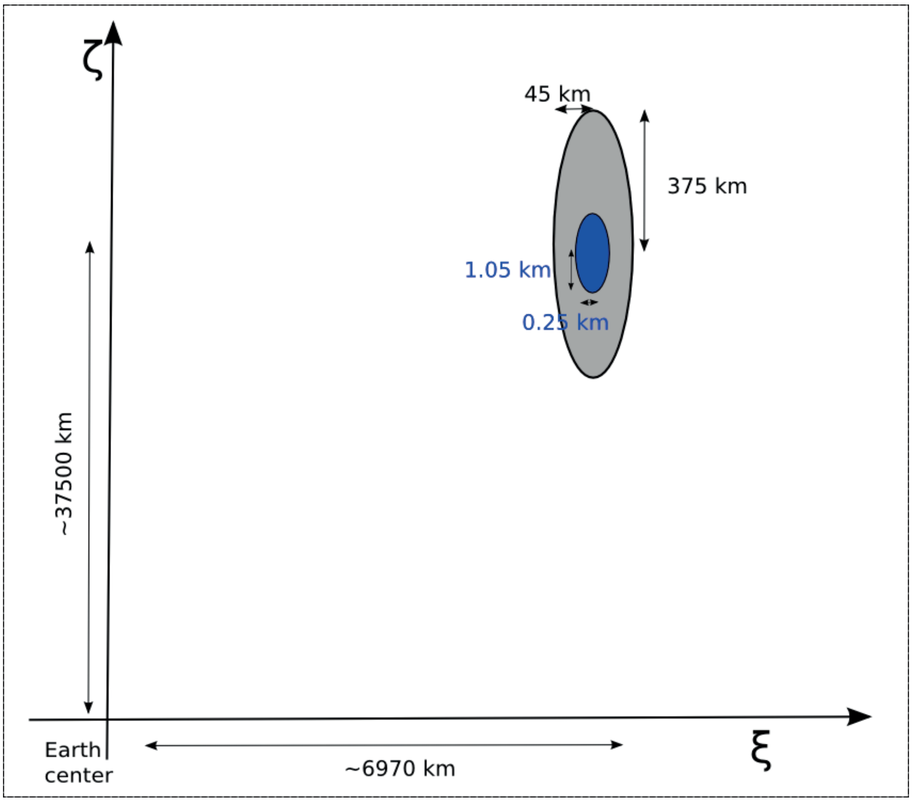


Fig. 4 – Scattering ellipse on the target plane on date of close approach (2029/01/13.907) with (blue) and without (grey) Gaia observations.

The uncertainty ellipse size is strongly reduced and the geocentric position of Apophis, at the date of closest approach, is better determinated, considering Gaia observations.

3. Astrometry for newly discovered objects

By combining, in real-time, ground-based to space-based data, it is possible to drastically improve the short-term ephemerides. Figure 5 shows an illustration of this improvement for the prediction of a newly discovered object by combining the two kinds of data. For our simulation, we considered a hypothetic Apophis that would be discovered by Gaia. When observing a new object, the satellite will send to Earth, as an alert, the coordinates of the unknown object. Thus, it is possible to make a prediction of the position of the hypothetic Apophis on the sky plane by computing a preliminary orbit (using Statistical Ranging method [2]). This prediction was made three days after its discovery by Gaia and the 1σ distribution is large (1 degree) and quite far from the expected value (triangle). If we make a geocentric observation on the 4th day after its discovery and combine it with the late Gaia observations, the (α, δ) uncertainty is reduced by a factor 30 and the ephemeris is well improved (note that here the 10σ distribution is given).

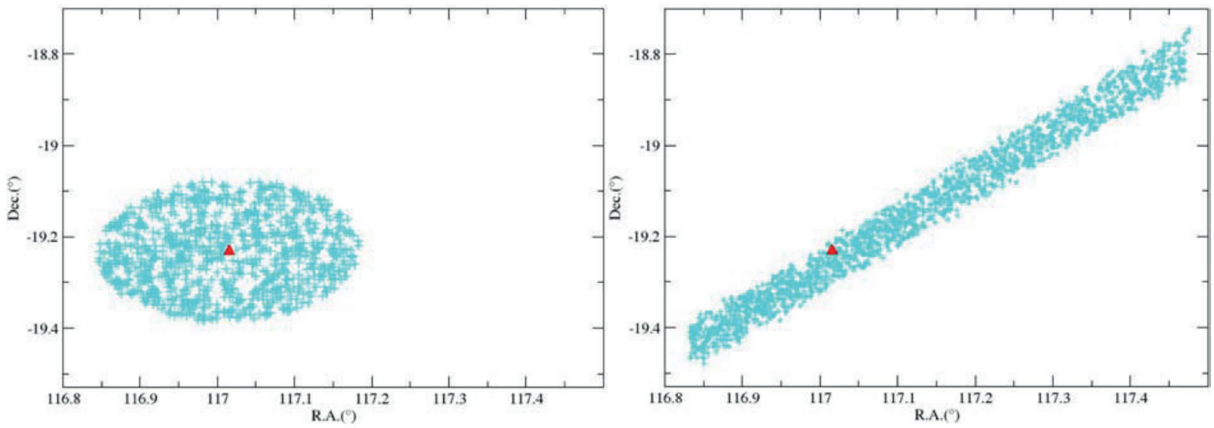


Fig. 5 – Example of geocentric distributions (α, δ) for the predicted positions on the 3th day after discovery with only Gaia observations (left 1σ uncertainty) and on the 4th day with an additional geocentric observation (right 10σ uncertainty). The triangle represents the expected value.

We can wonder now how many alerts are expected. To answer this question, we considered a sample of 20,000 of NEOs which could be either known or unknown objects. Figure 6 shows the statistic of the possible observed objects. This number appears to be around 12%. But if we compare this number to the one of known asteroid that will be observed by Gaia (~29%) we can just conclude that we have more chance to observe known objects than discovering new objects.

Amor	379	1.90 %
Apollo	1313	6.57 %
Atens	205	1.03 %
IEO	24	0.12 %
PHA	583	2.92 %
TOTAL	2614	12.52 %

Fig. 6 – Statistic of objects that would be observed by Gaia among a 20,000 synthetic population.

Conclusion

Even if Gaia will not be a big NEAs discoverer, it will provide unprecedented accuracy for NEAs orbit's improvement. Besides, this study can be continued considering the astrometric reduction due to the stellar catalogue provided by Gaia. As a matter of fact, this catalogue will be more precise and dense and almost free of zonal errors. Thus, classical ground-based astrometry (and concerning hence more objects down to fainter magnitude) will be improved.

References

[1] G. B. Valsecchi, A. Milani, G. F. Gronchi and S. R. Chesley: Resonant Returns to Close Approaches: Analytical Theory, *A&A*, 408:1179-1196, September 2003.

[2] J. Virtanen, K. Muinonen and E. Bowell: Statistical Ranging of Asteroid Orbits, *Icarus*, 154:412-431, December 2001.

Identification of Known SSO in CU4 Object Processing

Berthier, J.

IMCCE, Observatoire de Paris, 77 av. Denfert Rochereau, 75014 Paris

Introduction

The identification of known solar system objects (SSO) that will be observed by Gaia is a key point of the solar system object processing pipeline (CU4.SSO). It aims to associate the provisional tag assigned to observations of probably solar system objects to already known targets. At the time Gaia flies, it can be estimated that about 600,000 solar system objects (mainly small solar system objects) will be known and characterized by an orbit accurate enough to make their identification almost certain.

1. Context of the identification process

SSO, as well as non-single stars and extended objects, cannot be processed by the same pipeline than the stellar objects, mainly because:

- SSO have a proper motion and need a dedicated astrometric solution
- SSO can be extended objects and need a dedicated photometric analysis
- SSO are not observed at the same place at each transit so that we need to link up observations

After being processed by CU3/IDT, a source is either successfully matched to an existing stellar object (i.e. all celestial object which is not SSO) or remains unmatched. In that case, a second processing is performed by CU4/SSO/DU452 to try to identify the source as a known SSO and to assign it an identifier, at the level of short-time processing (1 day), and at the level of long-term processing (6 months). In both cases, the success or not of the identification process decides which treatment is applied or not to the analyzed transit.

2. Identification method

2.1 The problem

The main problem to cross-match sources with SSO in astronomical images resides in the apparent motion and the relatively high number of SSO. The first point implies that the ephemeris of all known objects have to be accurately computed at the epoch of the image to be able to cross-match the sources. The second point implies that we must reckon on a rather long computing time: if we need 1 millisecond to compute the ephemeris of one SSO, then this will take more than 540 seconds (more than 540000 SSO are known at that time) to identify only one source! This is not possible when thousands of sources have to be processed daily.

2.1 A solution

Being moving objects, the cross-matching of an observed source with a known SSO requires to compute the ephemeris of each of them at the time of observation because we don't know *a priori* where they are located in the solar system. To solve this issue, we adopted the solution to compute in advance the ephemerides of all the known SSO at tabulated epochs, and to store them in a dedicated database. The identification process is then reduced to a simple cone-search method, supplemented by the computation of accurate ephemeris of a limited set of bodies.

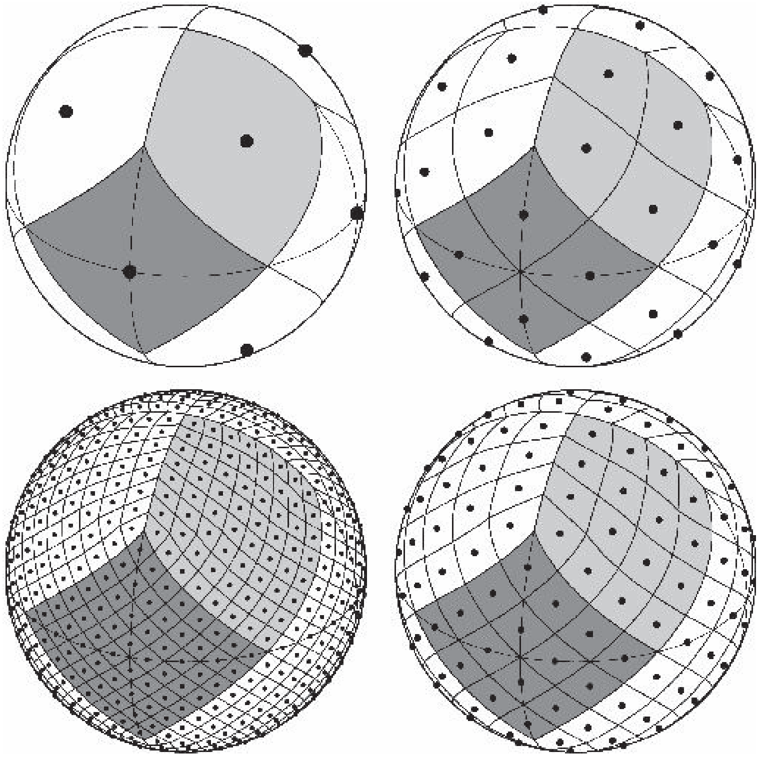


Fig. 1 – Healpix cutting of the celestial sphere

On the base of our experience with such problem (Berthier et al., 2006), we have chosen to use the mathematical structure of Healpix (Górski et al., 2005) to store the tabulated positions in function of time of all known SSO. The sphere is hierarchically tessellated into curvilinear quadrilaterals, with the lowest resolution partition comprised of 12 base pixels. The resolution of the tessellation is then increased by division of each pixel into four new ones. The figure 1 illustrates (clockwise from upper-left to bottom-left) the resolution increase by three steps from the base level (i.e. the sphere is partitioned, respectively, into 12, 48, 192, and 768 pixels). The properties of Healpix implies that areas of all pixels at a given resolution are identical, and that pixels are distributed on lines of constant latitude.

These properties of Healpix makes it very efficient to store the coordinates of SSO because it supports a suitable discretization of functions on a sphere to different levels of resolution, so that it facilitates fast and accurate statistical analysis. We have chosen to use a grid resolution of k = 9 (Nside = 512), so that the sphere is cut in 3145728 pixels of angular size 6.87 arcmin.That ensures us that only very few SSO may be selected at once before cross-matching, and thus that ensures a short computing time.

Conclusion

This work is still in progress, and we don't have numbers to quantify the success and the accuracy of the identification process. But to ensure a high level of success, we know that we need high accuracy orbital elements. That means that, at the time Gaia will fly, we will need complementary astrometric observations of i) unmatched sources in order to confirm or not that it is a SSO, and ii) ambiguous cross-match to improve the accuracy of orbital elements and then, perhaps, properly identify the SSO.

References

Berthier J., Vachier F., Thuillot W., Fernique P., Ochsenbein F., Genova F., Lainey V., and Arlot J.-E. : 2006, SkyBoT, a new VO service to identify Solar System objects, Astronomical Data Analysis Software and Systems XV, 351, 367

Górski K.M., Hivon E., Banday A.J., Wandelt B.D., Hansen F.K., Reinecke M., and Bartelmann M., 2005, **HEALPIX - a Framework for High Resolution Discretization, and Fast Analysis of Data Distributed on the Sphere,** ApJ 622, 759

Objectives and Management of the Gaia-FUN-SSO Network

Thuillot, W.

IMCCE, Observatoire de Paris, UPMC, CNRS
77 av. Denfert-Rochereau, F-75014 Paris, France
William.Thuillot@imcce.fr

Introduction

Ground-based observations in addition to observations by space missions can be a very efficient way to get complementary data, to go beyond the primitive objectives of this mission and actually to increase the scientific return of the mission. This strategy is used in the frame of several missions, for example when a ground-based network is required to get a large coverage of observation, for a fast verification of an event or its follow-up with instruments unavailable on board. For example, the Corot space observatory for asterosismology and detection and study of exoplanets, or the future Swom space mission for the detection and study of Gamma Ray Bursts, apply this strategy. The space-ground synergy is also an efficient strategy for the Gaia mission and in particular for the Solar System Object science (Thuillot et al., 2010). Several ground-based activities are being organized in the frame of the Gaia mission: the GBOT (Ground based Optical Tracking of Gaia, see Altmann et al. ibid) is a specific observing program of the probe itself; observing sites are also foreseen in a Science Alert Network for various science alerts mainly dedicated to astrophysical objects, photometry and spectroscopy; the Gaia-FUN-SSO program, presented here, is focused on an astrometric follow-up of specific Solar System objects.

1. The Gaia Follow-Up Network for Solar System Objects

1.1 Objectives

During its mission, Gaia will observe many Solar System objects and we can easily foresee that several interesting detections will be done during this five year mission. One of the important specificities of its observations is that they could be done at rather low solar elongation, 45 degrees, therefore detections of inner earth asteroids (IEAs, or Atens) could be performed. Detection of some new NEAs at bigger solar elongation could also be done. In these cases, due to the motion of the objects and perhaps to the limiting magnitude, the scanning law of Gaia will restrict the orbit determination to be founded on a very small number of astrometric measurements. In that case, only a ground-based network can avoid the loose of the asteroid and can permit to build an orbital modeling, based on enough astrometric measurements even at a lower accuracy than Gaia, in such a way that future observations remain possible. This is the primary objectives of the Gaia Follow-up Network for Solar System Objects.

In addition to the improvement of the astrometric data used for the orbital modeling of some specific objects, we can also think that some peculiar objects such as new comets, or even asteroids with cometary activity, could be detected. Due to the limiting factors of the Gaia observing method, ground-based networks can be very helpful in order to get fast more information upon the physical characteristics of these objects. Moreover, in particular during the first months of the mission, many unpredictable detections can arise, but the filtering parameters of the data processing will have to be tested and tuned and an important task will be to discriminate these detections, in particular for the detection of moving objects. Ground-based networks, such as the Gaia-FUN-SSO network, will be sollicitated for a contribution to this task.

Fig. 1 – Geographical location of observing sites contacted to participate to Gaia-FUN-SSO

1.2 Observing sites and instruments

In order to be efficient in case of the trigger of an alert by the Gaia data processing system, the network must have a large geographical coverage. This is why several observing stations have been contacted for a participation to this project. Almost 25 observing sites are candidate to be members of the network (cf. figure 1). Alerts from the Gaia data processing system can be received between 24 and 48 hours after detection. Difficulties may arise for the observation of peculiar objects: fast moving objects, faint objects, NEAs close to Earth therefore with strong parallax effect…Thus, even if some small instruments (smaller than 0.6 m) can be useful in this network, some telescopes with larger diameters, large field of view and some with sensitive detectors must be included in it. Furthermore, robotic telescopes could be very efficient instruments for such observations on alert.

The figure 2 shows a histogram of the telescope diameters according to the preliminary information received from the candidate's sites. Among these telescopes, 3 are Schmidt telescopes and 12 are robotic telescopes. Note that these observing sites and instruments will be subsequently much precisely determined thanks to a census organized at the time of this workshop.

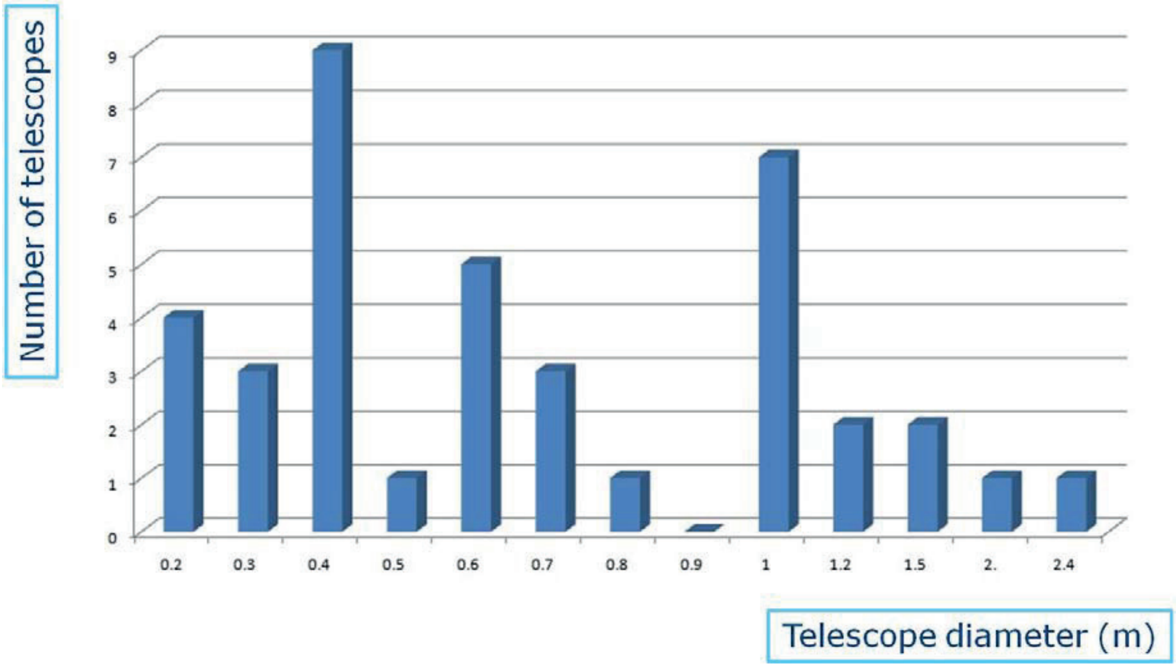


Fig. 2 – Histogram of the telescope diameters of the candidate sites of the network

1.2 Organization

As described in figure 3, the Gaia-FUN-SO network will be composed with a Central Node (CN) and several Observing Sites (OS). The role of the CN will be the coordination of the network, the preparation of ephemerides and the dissemination of the data and results. The alerts related to the Solar System Objects will be received about 24 to 48 hours after the detection by Gaia. The rough format of the data, issued from the Gaia data processing system, will have to be transformed in ephemerides or in celestial coordinates of zone of interest for ground-based detection (depending on the ability to build ephemerides). Once a detection is done in an OS, astrometric measurements must be done and send to the CN. Improved ephemerides can then be done by the CN and disseminated in the network.

At the end of the observing process by the Gaia-FUN-SSO network, the observed coordinates of a newly detected SSO, or improved astrometric data for known objects, will be sent to the Minor planet Center. This will be the only way to inject new SSO data issued from the network in the auxiliary database used by the Gaia data processing for subsequent identification of SSO objects. A possible channel can also be used, to send these data to the ESA Space Situational Awareness programme when the SSO will be Near-Earth Objects.

2. How to be ready for the observations

For the next months we can foresee several important actions in order to have the Gaia-FUN-SSO in a good shape for the observations on alert as soon as the Gaia probe will be operating after the launch in March 2013:

- For the Central Node:

\- some new observing sites could be get in touch in order to complete the geographical coverage of the network.

- more information are necessary for a better definition of the data format of the inputs/outputs and prepare the data useful for observing
- a wiki will be set up to facilitate the exchange of information and tools
- guidelines and recommendations will be posted on the wiki
- an online agreement document will define the reciprocal commitments
- tests and simulation of alerts will be organized

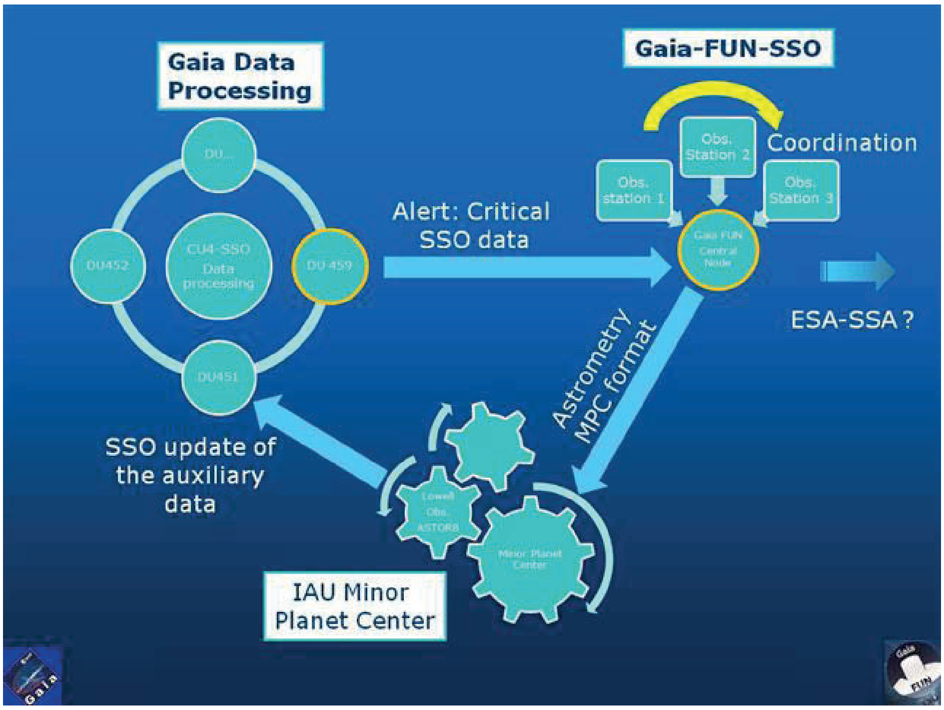


Fig. 3 – Scheme of processing of alerts on Solar System Objects

- For the Observing Sites:

- local organization must be set up for astrometric observations on alert (observers, accurate timescale in UT,…) and be ready to participate to observing tests almost one year before the launch
- OS will have to agree the reciprocal commitments and to register on the wiki in order to access the data
- OS will have to describe the site and instrument characteristics on the wiki

Conclusion

This will be probably the first time that coordinated ground-based measurement will improve, or even to secure, space astrometry measurements. In that sense, the Gaia-FUN-SSO network will be a fine opportunity to get benefit from the ground-space synergy and an important mean to improve the scientific return of the Gaia mission for the Solar System Objects science.

References

Thuillot , W., Hestroffer, D., Tanga, P.: .2011, Complementary ground-based observations for Solar System applications, EAS Publications Series 45, 2010, GAIA: At the Frontiers of Astrometry, 237-242.

The Zadko Telescope: the Australian Node of a Global Network of Fully Robotic Follow-up Telescopes

Coward, D[1], Laas-Bourez, M[1], Todd, M.[2]

[1] School of Physics, University of Western Australia, Crawley WA 6009, Australia
[2] Department of Imaging and Applied Physics, Bldg 301, Curtin University of Technology

Introduction

The Zadko Telescope (ZT) – see Coward et al. (2010), is a purpose built 1 meter, robotic telescope, located about 80 km north of Perth, Western Australia. It was designed to monitor a previously unchartered region of the "transient sky". The Zadko Telescope is the only meter class telescope capable of deep imaging between the east coast of Australia and South Africa at similar latitude. The Zadko Telescope, operated by UWA, is the Australian "node" of the TAROT robotic telescope network. As the main southern hemisphere node of the TAROT network, it enables much larger coverage of the sky for participation in frontier optical transient science projects.

The so called 'transient Universe'' consists of astronomical phenomena that vary rapidly in brightness on a time-scale of seconds to days. Transient searches with optical telescopes are designed to respond to Alerts from other detectors (which may only have relatively poor localization on the sky) and also to search for new transient sources. Transient search telescopes need to respond rapidly (to catch events before they fade away), to be very sensitive and be capable of tracking fast moving faint sources.

Fig. 1 – The 1-m f/4 Cassegrain Zadko Telescope is fully robotic and employs the same control software as the TAROT telescopes (located in France and Chile). An automated image processing pipeline produces calibrated FITS images to external users via a web-based interface.

1. Zadko Telescope Science

In addition to linking the ZT to satellite detectors, the ZT can respond robotically to Alerts sent from the Laser Interferometric Gravitational Observatory, and in the future the Square Kilometer Array radio telescope. This type of science has been termed `multi-messenger' astronomy. It utilizes different parts of the electromagnetic spectrum, in near real-time, to provide a clearer understanding of exotic phenomena that have previously eluded a complete description from observations restricted to a narrow part of the electromagnetic spectrum.

Other active science programs include the search for rare inner-Earth asteroids, Mars and Earth Trojan asteroids, main-belt asteroids and potentially hazardous asteroids. Projects that are either just commencing or in planning stage include: Alert follow-up of targets from GAIA satellite (exoplanets, NEOs, supernova, GRBs, flare stars etc.), Supernova search in nearby galaxies, Exoplanet follow-up and a survey of star forming regions in nearby galaxies.

The ZT demonstrated its science capability during a pilot program in 2009 (Coward et al. 2010) Over a period of several months, 12 new asteroids were discovered, corresponding to a discovery rate of 0.011 asteroids per square degree per hour of observing time. From 2008 Sept to 2009 Sept, 5 gamma-ray burst (GRB) afterglows were imaged with photometric magnitude estimates with the ZT. Two of them, GRBs 090205 and 090516, with respective redshifts of 4.3 and 4.1, are among the most distant optical transients imaged by an Australian telescope.

2. Zadko Telescope Robotic Imaging Capabilities

The Zadko Telescope is a fully robotic facility that is capable of autonomous operation and remote access to image data. Table 1 below shows the core-features of the telescope hardware and imager.

Table 1 – Zadko Telescope key features

GPS	31.36 deg S 115.71 deg E & Alt 50m
Primary Mirror	1 m
Mount	Equatorial Fork
Focal length	4.04 m
FOV	23.6 arcmin squared
Max slew speed	3 deg per second
CCD Camera	Andor 436 Marconi back illuminated chip
Sensitivity at 3 sigma	m=21 with 180s
Average seeing	2 – 4 arcsec (highly variable)

To coordinate the complex tasks of telescope scheduling, imaging and archiving, a centralized cluster of database servers called CADOR (Coordination et Analyse des Données des Observatoires Robotiques) see Bourez-Laas et al., (2008), Klotz et al., (2008), located in France, forms the core of the network. CADOR is undergoing upgrades to incorporate the ZT and manage scheduling and data from all three telescopes in the network.

Presently, the ZT is controlled by a local suite of independently running programs, ROS (Robotic Observatory Software) developed by our TAROT partners. The main functions of ROS are listed in Table 2 and the structure of the pipeline is shown in fig. 2:

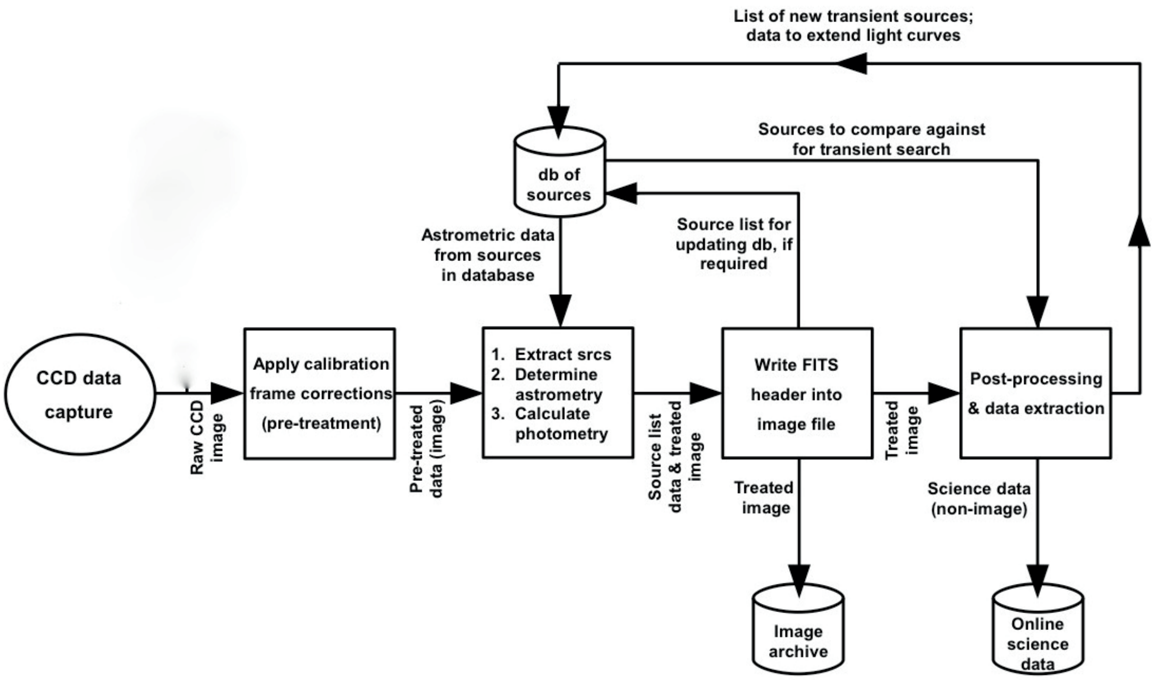


Fig. 2 – A flow diagram of the core procedures performed by the Robotic Observatory control Software (ROS) on the Zadko Telescope.

The ZT operates in Alert Mode after receipt of a high priority Alert from an external facility. In this mode, the scheduling is dynamically changed to accommodate the higher priority imaging tasks. Currently, the ZT receives Alerts from the Gamma Ray Burst Coordinated Network and the Laser Interferometric Gravitational Observatory. In the near future, it will also receive triggers from neutrino detectors and radio telescopes. When not in Alert mode, the scheduler selects those imaging tasks that are the next highest priority. After acquiring a raw image from the telescope, which is stored on local disk, a standard set of processing operations is performed on a copy of each image. Calibration frame corrections (bias, dark, and flats) are applied. The final 8-Mb calibrated images are made available for download via a webpage to authorized users, who can then perform their own image processing tasks.

3. Zadko Telescope and GAIA follow-up

The 1-m ZT has the potential to contribute to the core goals of the GAIA follow-up network. Firstly, and most importantly, it is fully robotic and uses a control system and automated image pipe-line that has been successfully employed for many years for GRB follow-up on the TAROT network. It allows for receiving automated alerts using computer socket connection, and automatic image processing for science by external users via web-page download. In the future, we plan to implement the VoEvent protocol, which may become the standard for communicating alerts between observatories.

In addition to GAIA science validation and follow-up, the ZT could participate in the GBOT (Ground Based Optical Tracking) program. GBOT will use regular scheduled optical observations of the satellite position to optimize the astrometric accuracy of GAIA observations. Such a program can be implemented on ZT as part of ROS. In Feb-Mar 2011, the ZT is participating in imaging tests of the Planck satellite and minor planets to determine the suitability for GBOT.

Conclusion

ZT has been operating as a fully robotic facility from early 2010. It core science objectives are the study of gamma ray burst afterglows and optical transients using automated alerts from other facilities and satellites. The geographic location of the ZT is important for the follow-up of a host of transients, from space-debris to cosmological gamma ray bursts. The automated control software can be adapted to respond to different types of alerts, including ones from the Swift Satellite and gravitational-wave observatories. There is excellent potential for the facility to play an important role in the follow-up of GAIA alerts, both for science validation and science follow-up of Gaia alerts. Furthermore, the ZT can potentially be used for the automated optical astrometric monitoring of GAIA for the GBOT program. In 2011, the ZT will be tested to determine its suitability for GBOT participation. In late 2011 and early 2012, the infrastructure for the facility will be upgraded to enable the above participation in GAIA related science.

References

Bourez-Laas M., et al., 2008, CADOR and TAROT: a virtual observatory, Proc. SPIE, 7019, 701918

Coward et al., 2010, The Zadko Telescope: A southern hemisphere telescope for optical transient searches, multi-messenger astronomy and education, Publications of the Astronomical Society of Australia, 27(3), 331

Klotz A., et al., 2008, Robotic Observations of the Sky with TAROT: 2004-2007*,* PASP, 120, 1298

Introduction of Astronomical Telescopes and Instruments in Yunnan Astronomical Observatory

Bai, J.M.[1,2], Liu, Z.[1,2]

[1] Yunnan Astronomical Observatory, Chinese Academy of Sciences, Kunming, Yunnan 650011, China (baijinming@ynao.ac.cn, lz@ynao.ac.cn)

[2] Key Laboratory for the Structure and Evolution of Celestial Objects, Chinese Academy of Sciences, Kunming, Yunnan 650011, China

Introduction

Gaia spacecraft will be launched in November 2012, and will survey all the sky for about 5 years, aimed at charting a three-dimensional map of our Galaxy, the Milky Way. It will provide unprecedented positional and radial velocity measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion objects in our Galaxy and throughout the Local Group, including a huge number of minor objects in our Solar System (Prusti 2011). Photometric and Spectroscopic observations of these objects observed on the average 70 times over 5 year mission will also provide a great chance to study astrophysics of stars, galaxies, AGNs, and to test general relativity and cosmology.

To achieve above scientific purposes, ground-based follow-up network for Gaia mission is necessary because of imposed date and position (Arlot 2011). The 2.4m reflector at Lijiang Observatory of Yunnan Astronomical Observatory (YNAO), Chinese Academy of Sciences, has the potential to play a important role in Gaia Follow-up Network (GAIA-FUN) in East Asia (see Fig. 1), especially for the follow-up of faint solar system objects (SSO) and Gaia itself (Thuillot 2011). The 2.4m optical telescope of YNAO and its receptors are thus presented here.

Fig. 1 – The location of Yunnan Astronomical Observatory (YNAO)

1. The Lijiang Observatory of YNAO

1.1 Location and conditions

The Lijiang Observatory of YNAO is located at $100^{o}2'$(E), $26^{o}42'$(N), about 35km from the Lijiang City, Yunnan Province, China. It is at an elevation of 3200m, about 800m higher than cities nearby. The seeing (0".9 on the average) and air transparency at Lijiang Observatory is the best among observatories in China, and on the average, there are 210 nights usable for astronomical observation each year. The sky background is B = 22.34 mag, V = 21.54 mag, and the atmospheric extinction is $K_b = 0.299$, $K_v = 0.150$.

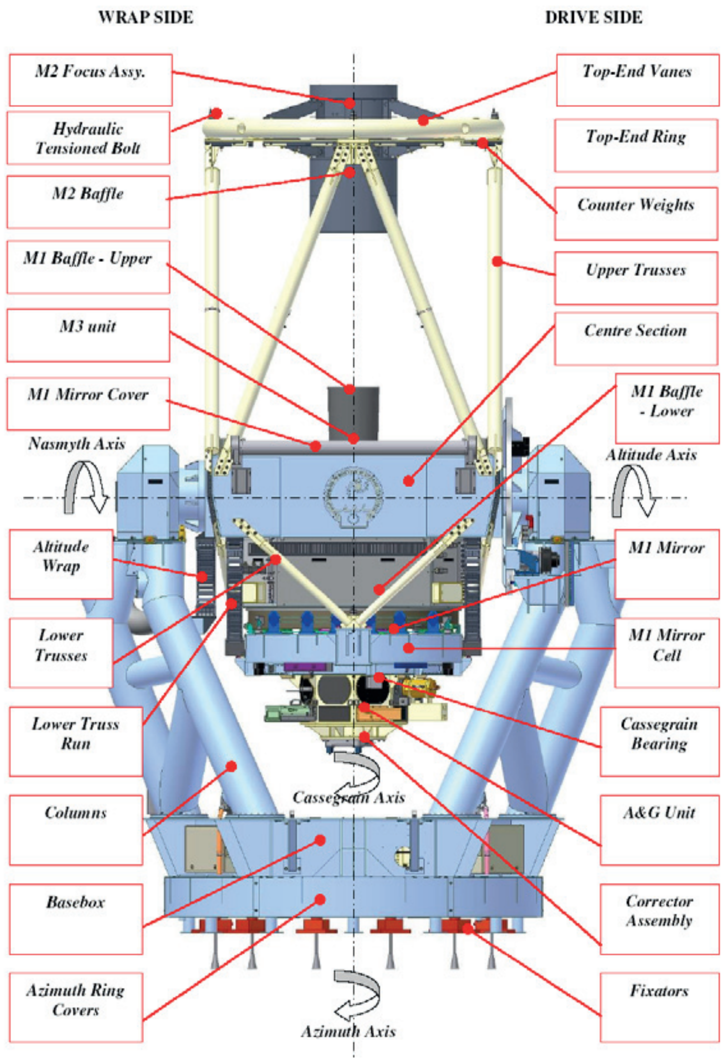


Fig. 2 – Layout of the 2.4m Telescope

1.2 The 2.4m telescope

The 2.4m optical telescope at Lijiang Observatory was made by the TTL Company, UK, and was installed at Lijiang Observatory in 2007, open to astronomers in May 2008. At present, it is the largest general-use optical telescope in East Asia. The telescope is a Ritchey-Chrétien Cassegrain optical design, on an altitude-azimuth (alt-az) mount, and designed for fully automated robotic operation (see Fig. 2). The telescope tube has Cassegrain and Nasmyth focal stations. Its focus ratio is f/8, with a focal length of 19.2m and FOV of 40′x 40′. Its image quality is <0.35″ (on axis) and <0.5″ (off axis). Its pointing accuracy is better than 2″, and tracking accuracy is better than 0.5″ /hr (close loop). The tracking speed is fast enough to follow fast moving SSO.

At the Cassegrain focal station there is an Acquisition and Guidance Unit (A&G Unit, see Fig. 2) which enables the optical beam to be passed through to a wide-field focus 40 arc minutes in diameter. In addition, the Cassegrain focal station is rotated in order to de-rotate the field rotation which results from the alt-az mount design. The A&G Unit can direct the Cassegrain beam to a straight-through port or one of four side ports using a deployable Science Fold mirror. The straight-though port has a fully illuminated field of view of diameter of 40 arc minutes. Each side port has a fully illuminated field of view of 9 arc minutes diameter.

1.3 The receptors at the 2.4m telescope

At present the 2.4m telescope is equipped with three receptors: a PI VersArray 1300B CCD camera, the Yunnan Faint Object Spectrograph and Camera (YFOSC), and the Lijiang Exoplanet Tracker (LiJET). All three receptors work at the Cassegrain focus of the telescope, and can switch to each other within a second by rotating deployable Science Fold mirror, which enables the telescope to observe efficiently ToO discovered by Gaia.

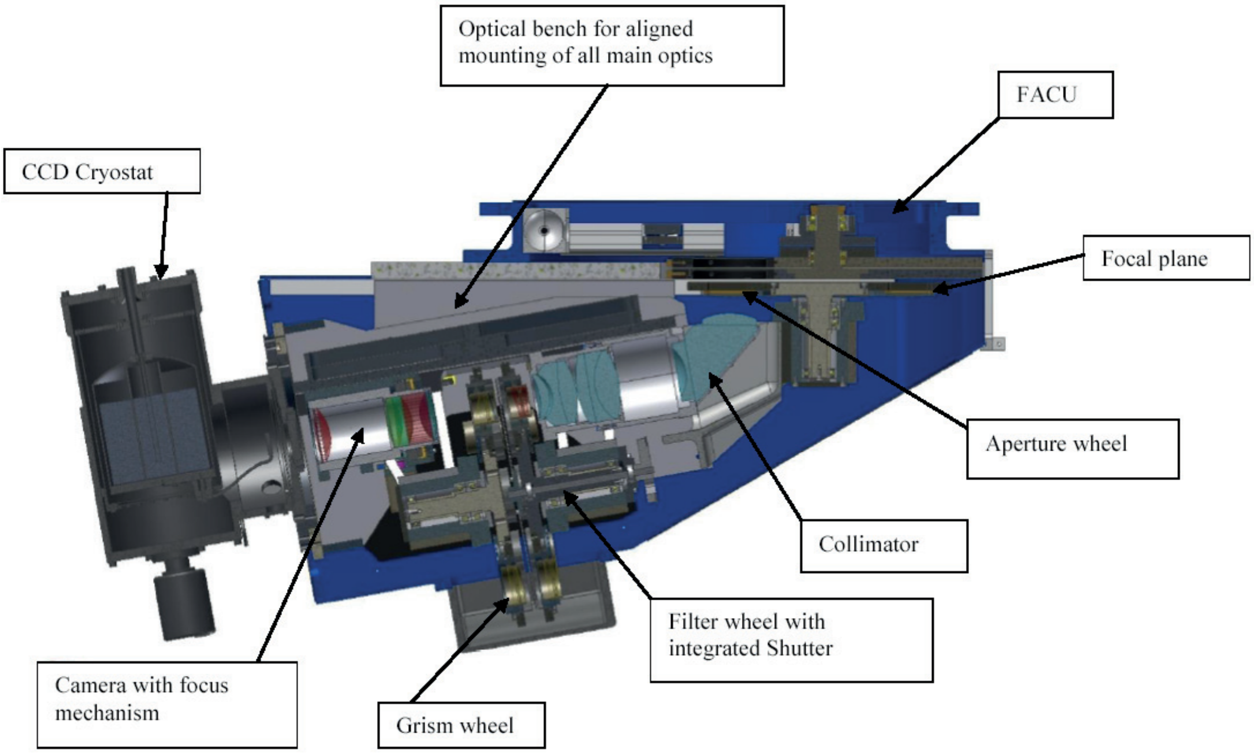


Fig. 3 – Layout of the YFOSC

The PI CCD camera can be used to do photometry and astrometry. It utilizes a back-illuminated CCD chip, with a 1340 x 1300 imaging array, 100% fill factor, and 20 x 20-micron pixels. Its dark current is negligible. The YFOSC can work as direct image camera and a low resolution spectrograph (see Fig. 3). Both receptors can be used for Gaia follow-up. Their specifications are shown in Table 1.

The LiJET is a combination of a thermally compensated monolithic Michelson interferometer and a cross-dispersed echelle spectrograph for extremely high precision Doppler measurements for nearby bright stars (e.g. 1m/s for a V=8 solar type star in 15 min exposure).

It has R=18,000 with a 72 micron slit and a simultaneous coverage of 390-694 nm. It also has a direct cross-dispersed echelle spectroscopy mode fed with 50 micron fibers. It has spectral resolution of R=27,000 and a simultaneous wavelength coverage of 390-1000 nm. As a spectrograph, LiJET can follow up stars observed by Gaia as well.

Table 1 – The specification of YFOSC and PI CCD camera

	YFOSC	PI CCD camera
CCD size	2048×2048	1300×1340
Pixel size (arcsec/pix)	0.283	0.214
Field Of View (arcmin)	9.66′×9.66′	4.8′×4.64′
Filters	Bessell U,B,V,R,I, SDSS u,g,r,i,z	Bessell U,B,V,R,I

Conclusion

YNAO has the potential to play a important role in Gaia GAIA-FUN in East Asia. The tracking accuracy and speed, the receptors of the 2.4m telescope at Lijiang Observatory of YNAO are satisfied with the demands of Gaia-FUN-SSO.

References

Arlot J.-E. : 2011, The Evolution of the network of observers, in this proceedings

Prusti T.: 2011, Gaia Status, in this proceedings

Thuillot W.: 2011, Objectives and management of Gaia-FUN-SSO network, in this proceedings

The Aosta Valley Astronomical Observatory

Carbognani, A.[1,2]

[1] Laboratoire Cassiopee - Observatoire de la Côte d'Azur, Boulevard de l'Observatoire B.P. 4229 F-06304 NICE Cedex 4, France

[2] Fondazione Clément Fillietroz-ONLUS - Osservatorio Astronomico della Regione Autonoma Valle d'Aosta e Planetario di Lignan, Loc. Lignan 39, 11020 Nus (AO), Italy

albino.carbognani@alice.it

Introduction

OAVdA stands for Astronomical Observatory of the Autonomous Region of the Aosta Valley (Italy). The centre is located in the northwestern Italian Alps, near the border with France and Switzerland (Lat: 45° 47′ 22″ N, Long: 7° 28′ 42″ E), at 1675 m above sea level in the Saint-Barthélemy Valley and is managed by the "Fondazione Clément Fillietroz", with funding from local administrations.

OAVdA was opened in 2003 as a centre for the popularization of astronomy but, since 2006, the main activity has been scientific research, as a consequence of an official cooperation agreement established with the Italian National Institute for Astrophysics (INAF). In 2009, a planetarium was built near the observatory with a 10-meter dome and 67 seats, which is currently used for educational astronomy. In the year 2009 about 15,200 people visited OAVdA and the planetarium. The staff in 2010 was made up of 12 people, including a scientific team of 5 physicists and astronomers on ESF (European Social Fund) grants and permanently residing at the observatory.

As far as observing conditions are concerned, the mean seeing allows to have a Full Width at Half Maximum of the Point Spread Function (PSF) of about 1.5-2 arcsec. Lightpollution is low because the surrounding mountains shield the site of the observatory from the lights of nearby Aosta, Turin and Milan, so the sky background is around +21.5 mag.

1. The OAVdA Building

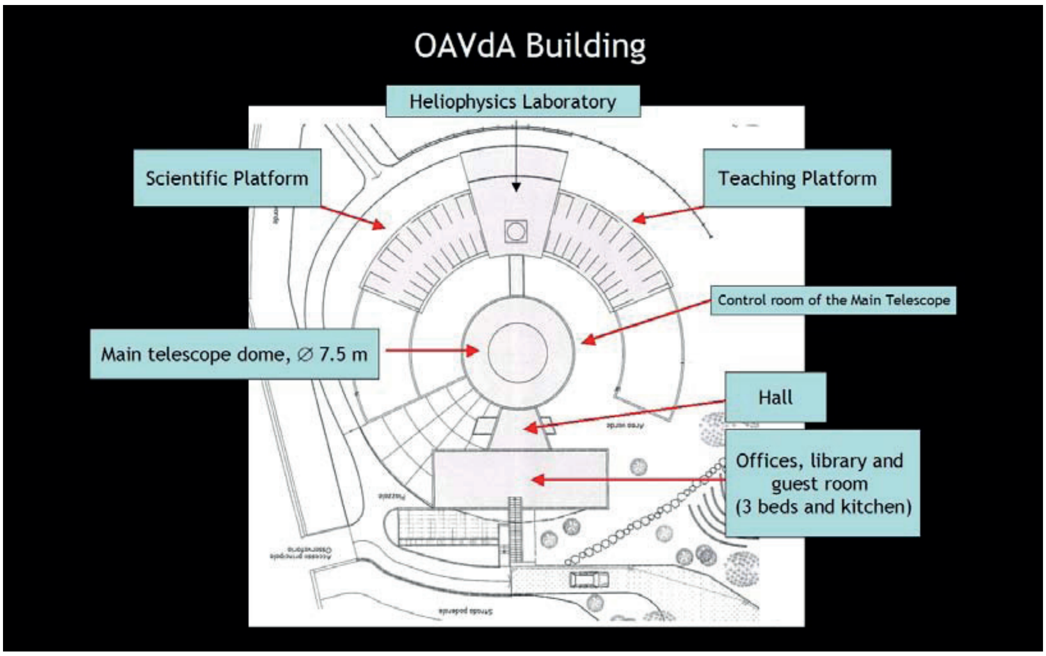


Fig. 1 – The OAVdA building. The arrows indicate the main features of the observatory.

The structure of the Observatory is shown in fig. 1. Around the dome of the Main Telescope (used for asteroids and blazar observations) are a Scientific Platform (used for extrasolar planet transit search), a Heliophysics Laboratory (for educational observations of the Sun), a Teaching Platform (meant for educational astronomy, which houses seven 250 mm f/10 Cassegrain reflectors with computerized pointing), offices, a library and a guest room.

2. Scientific Research Areas

The scientific research areas investigated at OAVdA are as follows:

1 – Observation of asteroids (NEOs, MBAs and Trojans), in collaboration with the Minor Planet Centre, INAF-OATo (Turin Astronomical Observatory) and DLR-German Aerospace Centre in Berlin (Mottola et al., 2010). The research work is both theoretical (Carbognani, 2010 and 2011a) and observational (Carbognani et al., 2008; Carbognani, 2008, 2010 and 2011b).

2 – Detection of small-size extrasolar planets in orbit around nearby M dwarfs using the photometric transit method. The research is conducted in cooperation with INAF-OATo and the University of Padova (Damasso et al., 2010).

3 – Monitoring of Active Galactic Nuclei (AGN) as part of the international Whole Earth Blazar Telescope (WEBT) organization in cooperation with INAF-OATo (Villata et al., 2009).

4 – Observation of Solar Corona (K-corona), on an innovative polarimeter designed for space coronagraphic study by INAF-OATo (Abbo et al., 2008).

Below, we will only briefly look at the work on extrasolar planets transit and the asteroid observations, more relevant for GAIA-FUN-SSO. The short list of selected references can give an idea of the earliest results of the scientific research.

2.1 *The Scientific Platform and the Extrasolar Planet Transit*

Since December 2008 OAVdA, in cooperation with INAF-OATo, has been actively involved in the field of extrasolar planets. A detailed feasibility study has been carried out to demonstrate that OAVdA is a well poised observing site to detect small size extrasolar planets around M dwarfs using the photometric transit method (Damasso et al., 2010). Since December 2009 a pilot study has been carried out on a small sample of nearby M dwarfs with accurate parallax measurements, mainly aimed at characterizing the photometric microvariabilty of the target stars. This study is a preliminary step toward a long-term photometric survey to search for transiting exoplanets, which will use an array of five identical f/8 Ritchey-Chretien 400mm telescopes that will be located in the Scientific Platform (fig. 1).

2.2 *Main Telescope and Control Room*

The Main Telescope is a 0.81-m f/7.8 Ritchey-Chretien reflector with a field flattener near the Cassegrain focus. The instrument is equipped with a guide telescope (a refractor with a diameter of 120 mm open to f/9) and a back illuminated 16 bit CCD camera (FLI PL 3041-1-BB, 2048 × 2048 square pixels), with a pixel size of 15 micrometers, field of view of 16.5 × 16.5 arcminutes and image scale of 0.48 arcseconds/pixel. The CCD camera is equipped with a filter wheel and a set of standard Johnson-Cousins B, V, R and I filters.

The Control Room is a separate and warmer area than the dome housing the Main Telescope. The computers controlling the pointing of the telescope and CCD imaging are located in this room. The observations are schedulable via script, so it is possible to automate the pointing of the instrument, the CCD image acquisition, the length of the pose and the filter type.

2.3 *NEAs astrometry with Main Telescope*

In July 2006, OAVdA was allotted the Minor Planet Center code B04. Around the time of the new Moon, NEAs follow-up is made of the new objects reported in the NEOCP page updated by the MPC. The typically observed NEOs have a magnitude between +19 and +20 with a sky motion of about 5 arcsec/minutes (see Fig. 2 and Fig. 3). The limiting magnitude reached on the NEOs is +20.7 with image stacking to compensate for the asteroid movement and a total exposure time of 15-20 minutes. So far, from 2006 to 2010, astrometric positions for 80 NEOs have been recorded. For the year 2010, from the Web page of "residuals statistics for observatory codes" maintained by MPC (MPC, 2010), the residues for B04 are less than an arcsecond in 98.99% of the cases. For the previous years the results are similar.

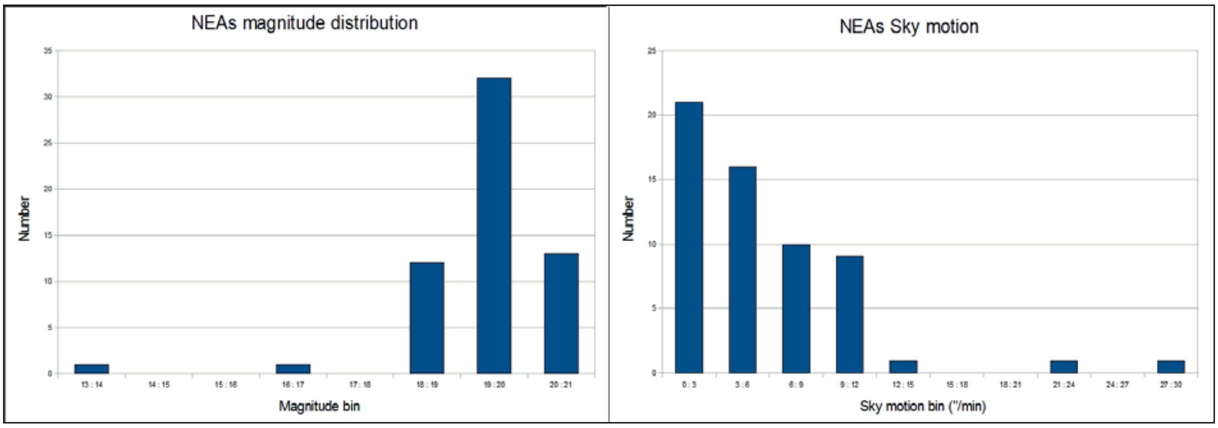


Fig. 2 – Results achieved by the NEAs follow-up. Left: NEAs magnitude distribution. Right: NEAs sky motion distribution

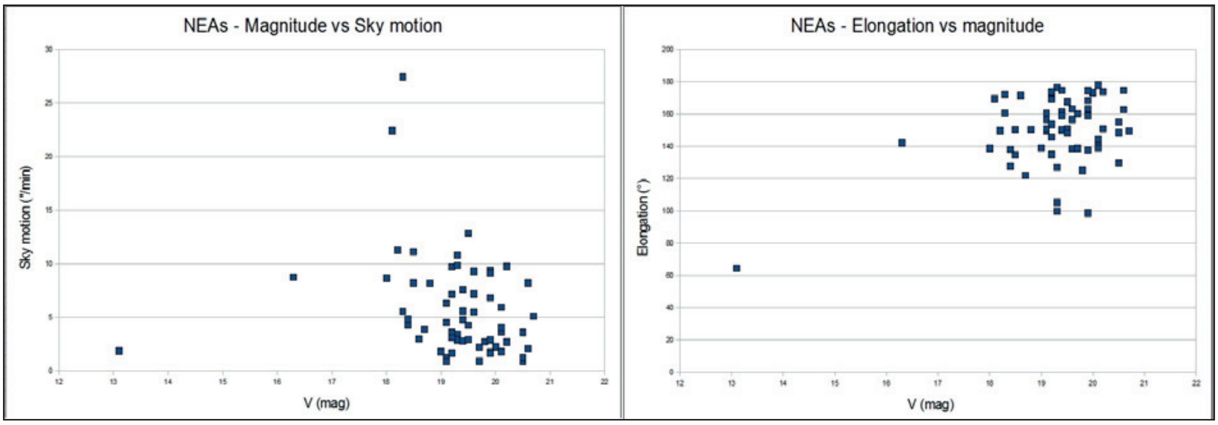


Fig. 3 – Magnitude vs sky motion (left) and elongation form Sun vs magnitude (right) for NEAs follow-up.

2.4 *Asteroids photometry with Main Telescope*

Photometric observations of Trojans, NEAs and MBAs have been made since July 2007 to determine the asteroids rotation period from lightcurve. Work on the rotation period of

Trojans has been done in collaboration with DLR (Berlin) and INAF-OATo (Mottola et al., 2010). From 2007 to the present (2010), a lightcurve for 32 NEAs and MBAs has been obtained. (Carbognani et al., 2008; Carbognani, 2008, 2010 and 2011b).

Conclusion

OAVdA is a small regional observatory in the Italian Alps, with a Main Telescope that might be suitable to join to the GAIA follow-up network (see Table 1). Reaction time from alert is about 15-30 minutes with direct telescope access and the percentage of available time for the project is estimated around 30-40% of observing time.

Table 1 – Summary of the data relevant to GAIA-FUN-SSO

Main Telescope: 0.81 m diameter, f/7.8, RC reflector.	Field of view: 16.5 × 16.5 arcminutes
Minor Planet Center Code: B04	Image scale: 0.48 arcsecond/pixel (binning 1 × 1)
Pointing accuracy: 1 arcminute	Peak quantum efficiency: 96%@750 nm
Tracking: 5 minutes exposure without autoguider	Limit Magnitude on NEOs: +20.7 with 15-20 minutes exposure
Average seeing condition: 1.5-2 arcsecond Sky background: around +21.5 mag	Available nights: about 200/365

References

Abbo L., Zangrilli L., Antonucci E., Fineschi S., Kohl J., Giordano S., Massone, G., Capobianco G., Calcidese P., Porcu F.: 2008, Investigation of the solar wind outflows and joint observations during the total solar eclipse of March 29, 2006, scientific poster, 37th COSPAR Scientific Assembly, Montréal, Canada, 13-20 luglio 2008. Symposium D, session 24, paper number D24-0038-08.

Carbognani A., Pravec P., Krugly Y. N., Pray D.P., Gajdos S., Gaftonyuk N. M., and Slyusarev I.: 2008, Lightcurve Photometry and Search for Cometary Activity of NEA 2007 PU11, Minor Planet Bulletin, 35, 61-62.

Carbognani A.: 2008, Lightcurve Photometry of NEAs 4450 Pan, (170891) 2004 TY16 2002 RC118, and 2007 VD12, Minor Planet Bulletin, 35, 109-110.

Carbognani A.: 2010, Statistical analysis of C and S Main Belt Asteroids, Icarus, 205, 497-504.

Carbognani A.: 2011a, A possible YORP effect on C and S Main Belt Asteroids, Icarus, 211, 519-527.

Carbognani A.: 2011b, Lightcurve and Periods of Eighteen NEAs and MBAs, Minor Planet Bulletin, 38, 57-63.

Damasso M., Giacobbe P., Calcidese P., Sozzetti A., Lattanzi M., Bernagozzi A., Bertolini E., Smart R.: 2010, Photometric Transit Search for Planets around Cool Stars from the Western Italian Alps: A Site Characterization Study, Publications of the Astronomical Society of the Pacific, 122, 1077-1091.

Mottola S., Di Martino M., Erikson A., Gonano M., Carbognani A., Carsenty U., Hahn G., Schober H-J., Lahulla F., Delbò M., Lagerkvist C. I.: 2010, Rotational Properties of Jupiter Trojans. I: Lightcurves of 80 Objects. Submitted to Astrophysical Journal.

MPC: 2010, Residuals Statistics for Observatory Codes, 2010 Aug. 29, *http://www.minorplanetcenter.org/iau/special/residuals.txt*

Villata M., Raiteri C. M., Gurwell M.A., Larionov V. M., et al. (including Calcidese P.): 2009, The GASP-WEBT monitoring of 3C 454.3 during the 2008 optical-to-radio and gamma-ray outburst, Astronomy and Astrophysics, 504, L9-L12.

Follow-Up Observation Plan on SSO of Purple Mountain Observatory

Zhao, H.

Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008, China
(meteorzh@pmo.ac.cn)

1. Introduction

Our planet inhabits a hazardous environment. Earth is continually bombarded by cosmic objects. Luckily for us, most are very small and cause no harm to life. Some, however, are large and cause considerable harm. Humanity has the capacity to detect and perhaps to counter an impending natural disaster. One testimony is the discovery in the late 1980s of the approximately 200-kilometer-diameter Chicxulub crater formed by an impact 65 million years ago in the Yucatan peninsula (Hildebrand 1991). The asteroid or comet that caused this crater is estimated to have been about 10 kilometers in diameter; its impact wrought global devastation, likely snuffing out species in huge numbers including dinosaurs. As another realistic testimony, the collision of comet Shoemaker-Levy 9 with Jupiter in 1994 emphasized that impacts are currently possible.

Recognizing that impacts from Near Earth Objects represent a hazard to humanity, the United States, European Union, China and other countries cooperatively organized to identify, track and study NEOs in an effort termed Spaceguard. The NEOST is constructed to undertake this mission. From October of 2006, the 1.04/1.20/1.80 m NEOST equipped with a 4096 by 4096 pixels SI CCD camera was installed completely and began regular survey operations. Due to fast optics and the high quantum efficiency (QE) of the CCD detector, the observational system can reach 22.46 mag with only 40 s exposure, which makes the sky survey with great efficiency. For example, about 22G raw image data, with respond to the sky coverage of 2700 square degree, will be produced within a good observable night, and the data will be extracted more than 2000 asteroids' positions (Zhao et al. 2008; Zhao et al. 2010; Ma et al. 2007).

The large field of view of NEOST, 1.94 degree by 1.94 degree, guarantees high efficiency of optical sky survey program, while the stable performance of NEOST observational system guarantees high accuracy of photometry and astrometry over all field of view. So NEOST is suitable for all kinds of imaging survey programs. The following two sections describe two ongoing survey program and present staged achievements.

2. Ongoing survey program I: China Ecliptic Plane Survey and China Near Earth Object Survey (CEPS & CNEOS)

As primary scientific target of NEOST, China ecliptic plane survey and china near earth object survey is the first ongoing survey program from the fall of 2006. It aims at to join George E. Brown, Jr. Near Earth Object Survey Act authorized by NASA in 2005 to detect, track, catalogue, and characterize the physical characteristics of at least 90 percent of potentially hazardous NEOs larger than 140 meters in diameter by the end of year 2020 (National Research Council 2010).

From December of 2006 to September of 2010, we carry out CEPS & CNEOS program and achieve more than 3 Tera raw image data with the sky coverage near the ecliptic plane. In the same period, our observation ranked the top-ten observational program in the World. Until September of 2010, CEPS & CNEOS program has observed 121,438 asteroids with more than

500 thousands observations, has found 933 new provisional designation asteroids, and has catalogued 97 numbering asteroids including five Jupiter Trojans, two Hildas and one Phacaea.

There are four Near Earth Asteroids (NEAs) having been found including an Apollo type NEA and three Amor type NEAs. We obtain the four NEAs' orbital elements and its uncertainties. Dynamic evolution result shows that all the four NEAs have no chance to approach the Earth within 0.05 AU during the following 200 years. A new periodical comet, P/2007 S1 found in 2009, is defined as a Jupiter-family comet. On March 10, 2010, a highly unusual rapidly moving asteroid was discovered and designated as 2010 EJ104. Connecting from the Kuiper Belt to the Main Asteroid Belt, 2010 EJ104 cannot be classified into any dynamics type and be considered as unusual object, and a study on the possible origins of 2010 EJ104 is carried out (Zhao et al. submitted to ApJ Letter).

3. Ongoing survey program II: Xuyi Schmidt Telescope Photometric Survey of the Galactic anti-center (XSTPS-Gac)

This survey program is a cooperation program between Kavli Institute for Astronomy and Astrophysics (KIAA) at Peking University (PKU) and Purple Mountain Observatory. The main scientific target is to study the structure and dynamics of Milky Way, along with its stellar populations and chemical composition. The outer parts of the Milky Way's dominant stellar component, the galactic disk, have already revealed complex structure that is poorly-understood. The Galactic anti-center survey addresses questions key to understanding how resilient galaxy disks are after gravitational interactions. XSTPS-Gac will obtain the high-quality photometric survey, which will be the most important data for analysis and target selection of LAMOST spectroscopic survey. The XSTPS-Gac will obtain three-color photometric catalogue with the coverage more than 6000 square degree near the Galactic anti-center in g'-band, r'-band and i'-band respectively.

4. Summary and outlook

CEPS & CNEOS program has produced a large amount of images of the ecliptic plane with deep to 21st magnitude. About 200 new asteroids will be discovered and designated every year. However, with the operations of PanSTARRS and future LSST (Pierfederici 2009), the competitive power of NEOST to detect asteroids will go down. So the primary scientific target should be shifted from detection to characterization. Detailed knowledge of the physical properties of the NEO population lags far behind the current rate of NEO discoveries, CNEOS will be contributed to collect information about these bodies not only to obtain a better understanding of the NEO population, but also to understand how the physical and compositional properties vary from one NEO to another. Such information is important for assessing the hazard potential of individual NEOs that may threaten Earth and the viability of proposed mitigation strategies.

XSTPS-Gac program has obtained SDSS-g', SDSS-r', and SDSS-i' band images of 6000 square degrees near Galactic anti-center. The point-source with SNR of 10 limit is achieved at or fainter than g', r', i' equal to 19 magnitude for virtually the Galactic anti-center sky. For sources' SNR at or above threshold 10, the XSTPS-Gac Point Source Catalog is highly complete and reliable. Bright source photometric accuracy is better than 0.02 mag, and astrometric uncertainty is ~ $0.10''$ relative to the ICRS. The images and catalogs of point sources will be publicly available in the near future.

A new large field of view survey program, 4 square Degree Exoplanet System Survey (4DESS) program, is in preparation. Large FOV exoplanet survey program, like TrEs (O'Donovan 2007) and WASP (Pollacco et al. 2006), can't reach deep magnitude, while deep sky survey by Hubble Space Telescope (Spergel et al. 2003) can only obtain small sky coverage. To meet half way of above mentioned type survey, 4DESS will cover a sizable sky field near the point of intersection of galactic and ecliptic planes, and obtain all the stars brighter 14 mag in i′-band with SNR greater than 100. The foreseeable results of 4DESS program will be transit observation or detection of exoplanet, a large amount of new variable stars and a large amount of asteroid lightcurves.

NEOST will also carry out the Gaia follow-up observation of solar system object. We will aim at astrometric observation of the new solar system object firstly: to obtain more position data, carry out the orbital determination, especially for fast moving NEAs and exhibiting a possible cometary activity; to carry out the impact risk assessments for NEO; to supplement the observations by Gaia of asteroids gravitational deflected during asteroid encounters. We will also observe for the physical characterizing (light curve, albedo, etc.) of the new solar system object: to carry out the light curve survey of asteroid, in order to determine the rotation period, the spin axis, and the shape of asteroid; to carry out the multi-bands observation of asteroid (esp. NEO & Jupiter Trojans), to know the period-size distribution, brightness variation distribution, etc.

We thank NEOST observation team for valuable contribution of observation. We would like to acknowledge the support of the National Natural Science Foundation of China (Grant Nos. 10503013, 11078006 and 10933004) and the Minor Planet Foundation of Purple Mountain Observatory.

References

Hildebrand A.R., Penfield G. T., et al. Geology, 1991, 19, 867-871

National Research Council, Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies. Washington, D. C., THE NATIONAL ACADEMIES PRESS, Final Report, 2010

Ma Y.H., Zhao H.B., et al. Proceedings IAU Symposium No. 236, 2007, 381-384.

O'Donovan F.T., The Publications of the Astronomical Society of the Pacific, 2007, 119, 860:1207-1207

Pierfederici F., Proceedings of Astronomical Data Analysis Software and Systems XVIII ASP Conference Series, 2009, 411, 110

Pollacco D.L., Skillen I, et al. The Publications of the Astronomical Society of the Pacific, 2006, 118, 848: 1407-1418

Spergel D.N., Kasdin J, et al. ASP Conference Proceedings, 2003, 291, 281

Zhao H.B, Yao J.S., et al. Proceedings IAU Symposium No. 248, 2008, 565-566

Zhao H.B, Acta Astronomica Sinica, 2010, 51, 3:324-325

Zhao H.B, JI J.H., et al. Discovery and Possible Origin of the Unusual Object 2010 EJ104: Asteroids from the Scattered Disk or a New Region? Submitted to ApJ Letter.

Follow-Up and Search Capabilities of Asteroids and Comets in a Location in the Southern Hemisphere

Tancredi, G.[1,2] and the OALM's Team

[1] Observatorio Astronómico Los Molinos, DICYT, Ministerio de Educación y Cultura
[2] Depto. Astronomía - Fac. Ciencias, Univ. de la República
Iguá 4225, Montevideo, 11400, URUGUAY
gonzalo@fisica.edu.uy - http://oalm.astronomia.edu.uy

Introduction

The follow-up and search capabilities of Solar System minor bodies are not evenly distributed over the world. We analyze the problem and present the activities performed at our observatory located in the Southern Hemisphere.

1. Discovery and Follow-up of asteroids and comets

1.1 The search for Near-Earth Asteroids

In the last 15 years there has been an exponential increase in the discovery rate of Near-Earth Asteroids (NEAs) as it is shown in the cumulative distribution of discoveries presented in Fig. 1a. Nevertheless, the number of large objects (diameter > 1 km) is reaching a plateau, meaning that we are close to complete the discovery of the entire population. The NEAs are classified in different groups depending on their orbital parameters: Atira, Atens, Apollo, Amor (see e.g. *http://neo.jpl.nasa.gov/neo/groups.html*). The distribution of discoveries among the groups is presented in Fig. 1b. Note that in the last years a new population of objects with orbits entire inside the Earth's orbit has been started to be discovered, the Atiras; though there are only 11 known objects of this population at present.

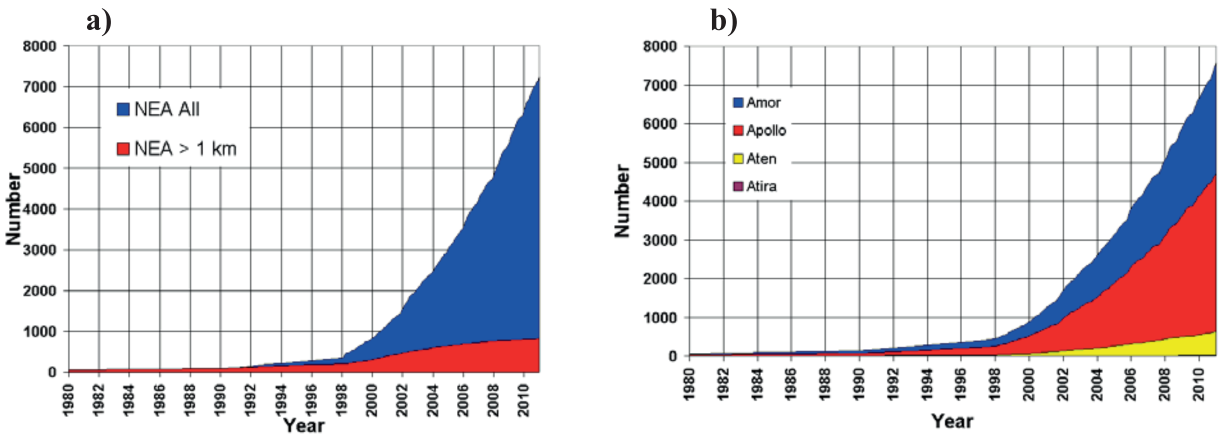


Fig. 1 – a) Discovery cumulative number of Near-Earth Asteroids.
b) Discovery cumulative number of NEAs classified in different dynamical groups.
Data compiled by Alan Chamberlin and taken from *http://neo.jpl.nasa.gov/stats/*.

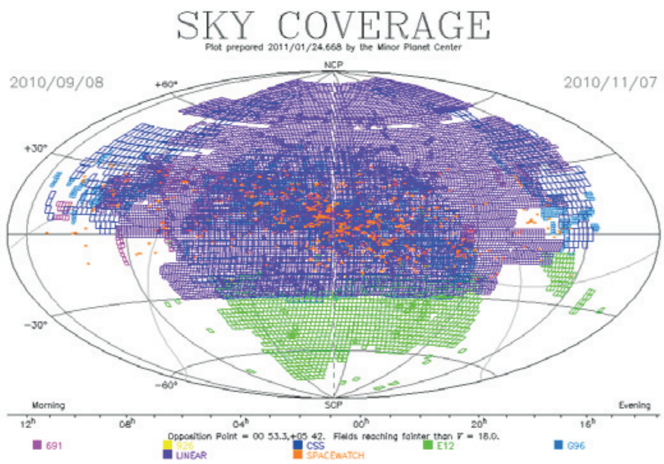


Fig. 2 – Sky coverage during the period 2010/09/08 to 2010/11/07. Plot taken from the *Minor Planet Center* webpage *http://www.minorplanetcenter.net/iau/SkyCoverage.html*.

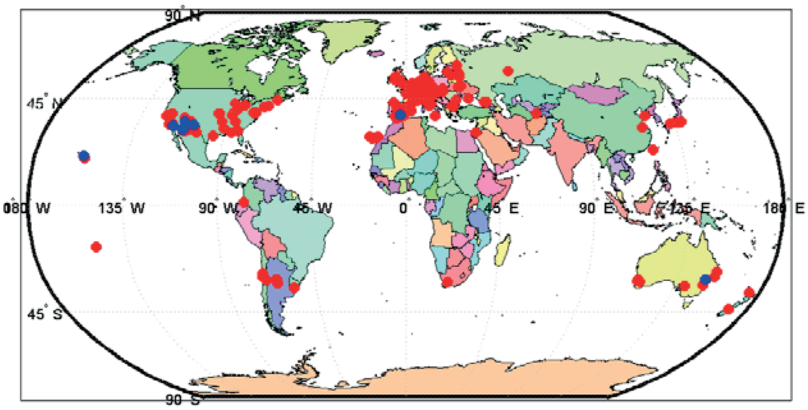
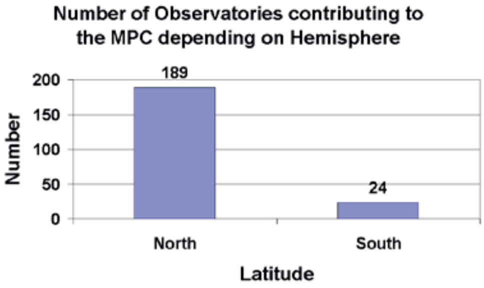


Fig. 3 – The location of follow-up and survey telescopes. The red stars correspond to observatories that have contributed more than 150 asteroid observations in the last 3 years to the *MPC*. The blue dots correspond to the survey telescopes.

This increase in the discovery rate has been possible due to the large surveys, which cover large portion of the sky every month down to magnitude V~19 or fainter. In Fig. 2 we include a plot produced by the *Minor Planet Center* with the sky coverage during two lunations in late 2010. The *LINEAR* survey covers almost the entire northern sky available (declination>-30°), while the southern sky is only partially covered by the *Siding Spring Survey*. The locations of the big surveys are presented in Fig.3 with blue dots. Note that, with the exception of *Siding Spring Survey*, all the other surveys are located in the northern hemisphere.

1.2 The follow-up of NEAs and the North-South asymmetry

As it was shown above, there is a huge asymmetry in the distribution of NEAs surveys in the world. A similar asymmetry is observed in the follow-up activities. In Fig. 3 we present the location of observatories contributing more than 150 observations to the *MPC* in the last 3 years. The same data is presented in Fig. 4 as a histogram of observatories in the northern and the southern hemisphere. Only 11% of the observatories are located in the South. Regarding the contribution of these observatories to the *MPC*, we present in Fig. 5a the number of reports classified respect to the declination of the data; while in Fig. 5b we have the number of reports classified respect to the observatory's location. Only 1/3 of the observed objects are in the southern sky (Fig. 5a), but most of the data comes from the northern observatories; since only 4% of the data are from southern observatories (Fig. 5b).



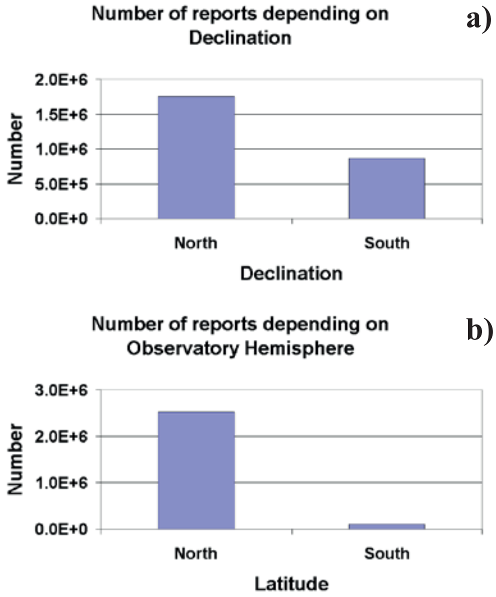
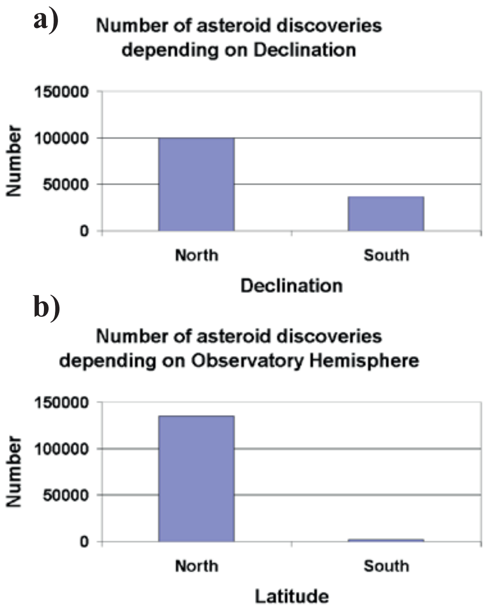


Fig. 4 – (above) Number of observatories that have contributed more than 150 asteroid observations in the last 3 years to the *MPC* classified respect the hemisphere.

Fig. 5 – (right) **a)** Number of reports classified respect to the declination of the data. **b)** Number of reports classified respect to the observatory hemisphere. Reports to the *MPC* from the period 2005 -20100 are considered. The data from big surveys are not included.



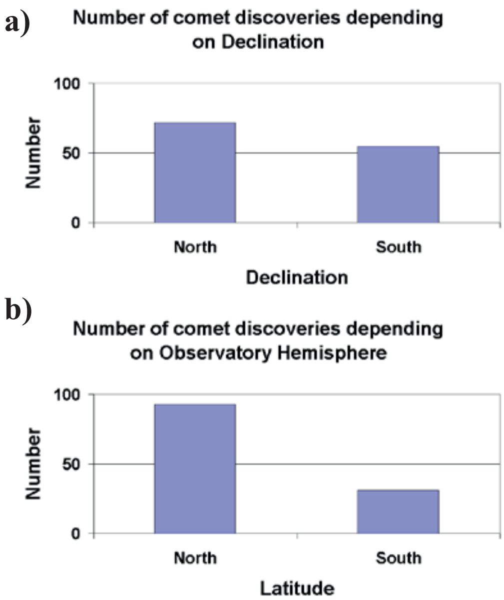


Fig. 6 – **a)** Number of asteroid discoveries classified respect to the declination. **b)** Number of asteroid discoveries classified respect to the observatory hemisphere. Discoveries made in the period 2008-2010.

Fig. 7 – **a)** Number of comet discoveries classified respect to the declination. **b)** Number of comet discoveries classified respect to the observatory hemisphere. Discoveries made in the period 2008-2010.

A similar situation is found in the distribution of asteroid discoveries as it is shown in Fig. 6: 27% of the discoveries are made in the southern sky (Fig. 6a); but the southern observatories contribute only 1% of the discoveries (Fig. 6b). Nevertheless, the asymmetry regarding the discovery of comets is not as bad: 43% of the discoveries are made in the southern sky (Fig.

7a); but the southern observatories contribute 25% of the discoveries (Fig. 7b). The decrease in the asymmetry is mainly due to the prolific activity on a single discoverer in the southern hemisphere: *Robert McNaught*.

2. Follow-up and search activities at *Observatorio Astronómico Los Molinos*, Uruguay

The *Observatorio Astronómico Los Molinos* (*OALM*) is located in Uruguay, South America. The geographical coordinates are: Latitude 34º 45' 20" S, Longitude 56º 11' 23" W , Altitude 130 m. It has the IAU code 844. OALM was inaugurated in 1994 and belongs to the Innovation, Sciences and Technology Office (*DICYT*) of the Culture and Education Ministry (*MEC*). It is also supported by the Department of Astronomy of *Universidad de la República*. It is the only professional observatory in Uruguay. Since it is located close to Montevideo, the light pollution issues are worrisome. This fact leads us to build another observing facility in the country side, the *Observatorio de Aiguá* in Maldonado (250 km from Montevideo).
The scientific activity of *OALM* is focused on Solar System Minor Bodies (i.e. comets and asteroids), being one of the few observatories dedicated to this topic in the southern hemisphere. We observe recently discovered asteroids (i.e. the confirmation task), or already discovered ones that need further observations (i.e. the astrometric follow-up). The main instruments are CCD-equipped 35 and 46cm telescopes used for astrometrical and photometrical programs. Also in the *OALM* facilities are placed other observing instruments with their respective domes that belong to amateur astronomers. Detail information about our facilities can be found in our institutional website: *http://oalm.astronomia.edu.uy*.

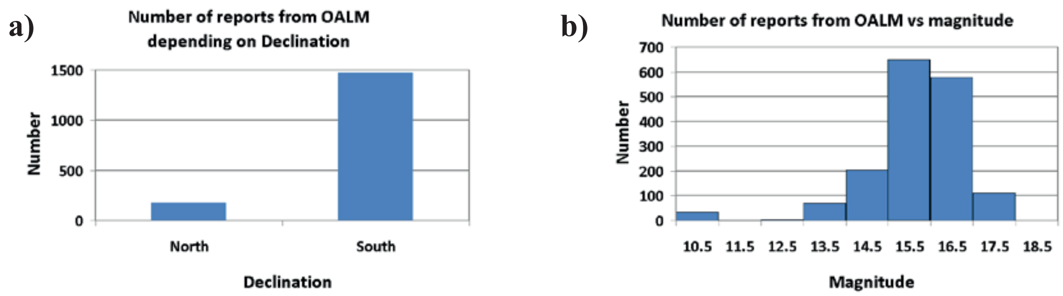


Fig. 8 – a) Number of asteroid reports to the MPC in the period 2005-2010 from *OALM* classified respect to the Declination of the data. **b)** Histogram of the distribution of the reported magnitudes.

We concentrate our follow-up observations on objects in the southern sky, as it is shown in Fig. 8a. The histogram of the distribution of reported magnitudes peaks at V~16 (Fig. 8b), but we can reach magnitudes down to 18.5, especially, after some instruments improvements, in the last year. The mean residual and standard deviation of the astrometric observations reported by *OALM* are: in right ascension μ_{RA}= -0.013”, σ_{RA} = 0.78”; in declination μ_{Dec}= -0.066”, σ_{Dec}= 0.92”, respectively.

Conclusion

The north-south asymmetry in the discovery and follow-up of asteroids is a problem that reflects the economic and scientific development of the world. An all-sky survey like *Gaia* would help to mitigate this problem. Nevertheless, much effort should be put in the follow-up activities in the southern hemisphere after the discoveries by *Gaia*.

C2PU: 1-Meter Telescopes for the GAIA-FUN

Bendjoya, Ph.[1], Abe, L[1], Rivet, J.P.[2]

[1] Laboratory H. Fizeau, Université de Nice Sophia-Antipolis, Observatoire de la Côte d'Azur, CNRS-UMR 6525, Campus Valrose 06108 Nice cedex 2 France

[2] Laboratory Cassiopée, Université de Nice Sophia-Antipolis, observatoire de la Côte d'Azur, CNRS-UMR 6202, Boulevard de l'Observatoire, B.P. 4229 F-06304 NICE Cedex 4

Presentation

C2PU stands in french for "*Centre Pédagogique Planète Univers*" (Planet and Universe Pedagogic Center). It is a project both for pedagogic and research purposes. It relies on the renewal of two 1-meter diameter telescopes. These two telescopes were earlier coupled as part of an interferometric instrument called SOIRDETE (for "*Synthèse d'Ouverture en Infra Rouge avec DEux Telescopes"*), described in Rabbia et al. 1990.

These two telescopes are located in southern France, 50 km away from the city of Nice, on the so-called "*Plateau de Calern*". The coordinates are 6° 55′ 22″ East in longitude, 43° 45′ 14″ North in latitude and 1261 m in elevation. The average number of clear nights per year is 200 and the sky background level ranges from 20.7 to 21 magnitudes per square arc-seconds.

The project is supported by the "Observatoire de la Côte d'Azur" (OCA), the University of Nice Sophia-Antipolis (UNS) and the "Collège de France" (CdF). The two Cassegrain telescopes are planned to be renewed in two phases. The first one which has begun in September 2010 involves the shaping and polishing of a 1-meter primary mirror for the East Telescope (E-Tel), out of a Zerodur® blank provided by OCA. This phase should end late 2011. During this polishing operation by D. Vernet from CdF, the refurbishing of the mechanical structure of the telescope is undertaken. In parallel, we are designing the hardware and software for the remote control of E-Tel through Internet The second phase will begin in 2012 and will concern the second 1-meter telescope, the West-telescope (W-Tel).

The E-Tel is planned to have two different focus configurations: an F/3 prime focus for wide field imaging, and a Cassegrain F/12.5 focus. Switching from one configuration to the other will only consist in plugging or unplugging an opto-mechanical module. The telescope will be driven by an automatic controller, accessible through an internet interface, to allow for remote observations. The F/3 focus will be equipped with a SBIG STX-16803 CCD camera. This will lead to a pixel scale of 0.6''/pix and a 40×40 arcmin field of view. The 20th magnitude is expected to be reachable in a 1 min exposure. This configuration will be dedicated to wide field imagery and transit photometric surveys. The F/12.5 focus will receive a SBIG ST8XME CCD camera. This will provide for a 3.8×2.5 arcmin field of view, with a pixel scale of 0.15 arcsec/pix. Magnitude 17 is expected to be reachable in 1 minute exposure. This configuration will be used for spectroscopy and/or polarimetry. The characteristics of the spectrometer and of the polarimeter are currently under discussion.

The W-Tel with its F/35 "*coudé*" focus should be available late 2012. The focal image will be delivered on an optical bench, at a fixed point, regardless of the position of the astronomical target. On this optical bench, all kind of focal instrumentation will be welcomed, such as a deformable mirror and a wave front sensor for an adaptive optic system, a differential speckle interferometer, a spectrometer of a polarimeter. With a SBIG ST8XME CCD camera, this

configuration would lead to a 1.3×1 arcmin field of view, with a pixel scale of 0.05 arcsec/pix. Magnitude 15 should be reachable in 1 minute exposure.
The observation will be performed essentially by supervised master students, but in case of alert during a non pedagogic period, dedicated staff will be reachable for an in situ observation and/or remote session assistance.

Fig. 1 – from up left to down right: a) The roadmap from Nice International Airport to "*Plateau de Calern*", b) the two C2PU domes, c) East telescope (E-Tel), d) polishing and curvature control of the 1-meter Zerodur® blank.

Table 1 – Summary of the C2PU characteristics and receptors

Instrument	1	2	3
Name	T_E_F3=GROUCHO	T_E_F12=HARPO	T_W_F35=ZEPPO
Refractor/Reflector	reflector	reflector	reflector
Focal length(m)	3	12.5	35
Diameter (m)	1	1	1
Comments	GROUCHO and/or HARPO will be remotely accessible		
Receptor			
Type/name	SBIG STX-16803	SBIG ST8XME	SBIG ST8XME
Pixel size (arcsec/pix)	0.6"/pix	0.15"/pix	0.05"/pix
Field Of View (arcmin)	40×40'	3.8×2.5'	1×3.1'
Limiting magnitude	20 in 1 minute exposure	17 in 1 minute exposure	15 in 1 minute exposure

Conclusion

C2PU will offer as soon as late 2011 an observation facility, perfectly suited for GAIA-FUN. Indeed, it will allow for both an easy follow-up of moving object through its wide field F/3 focus, and efficient physical parameters measurements through a range of focal instruments, to be fitted to the F/12.5 and F/35 focuses. The remote control through Internet and the supervised student manpower will allow for a fast reactivity and extensive time coverage.

References

Rabbia Y., Mékarnia D., Gay J. :1990 Infrared interferometry at Observatoire de la Côte d'Azur, France, in Infrared Technology XVI; Proceedings of the Meeting, San Diego, CA, July 11-13, 1990 (A92-21426 07-35). Bellingham, WA, Society of Photo-Optical Instrumentation Engineers, p. 172-182.

PRAIA – Platform for Reduction of Astronomical Images Automatically

Assafin, M.[1], Vieira Martins, R.[2,1], Camargo, J.I.B.[2],
Andrei, A.H.[2,1], Da Silva Neto, D.N.[3], Braga-Ribas, F.[4,2]

[1] UFRJ, Observatorio do Valongo, Rio de Janeiro, Brazil (massaf@astro.ufrj.br)
[2] Observatorio Nacional/MCT, Rio de Janeiro, Brazil
[3] Universidade Estadual da Zona Oeste (UEZO), Rio de Janeiro, Brazil
[4] Observatoire de Paris, LESIA, Meudon, France

Introduction

PRAIA performs high precision differential photometry and astrometry on digitized images (CCD frames, Schmidt plate surveys, etc). The package main characteristics are automation, accuracy and processing speed. Written in FORTRAN 77, it can run in scripts and interact with any visualization and analysis software. PRAIA is in cope with the ever growing amount of observational data available from private and public sources, including data mining and next generation fast telescope all sky surveys, like SDSS, Pan-STARRS and others. PRAIA was officially assigned as the astrometric supporting tool for participants in the GAIA-FUN-SSO activities and will be freely available for the astronomical community.

1. PRAIA astrometric structure

Figure 1 displays the astrometric scheme of PRAIA package. The photometric part of the platform is out of scope in this text and will not be presented here.

1.1 Information extraction, parameter configuration. Results and information archiving.

PRAIA is composed of separate independent programs. Each program runs in automatic fashion without interaction with the user. Each program has an input data file which must be filled in. Due to the high degree of development of the algorithms used in the image and data treatments, there are quite a few critical parameters which cannot be internally computed and must be furnished by the user. Most of the information in the input data files regards to input and output file names. There are also parameters indicating reduction models and other auxiliary information. In some cases, there are also other input data files that must be present in order to run a task. Usually, those regard to target and to image header information. Image header extraction furnishes critical FOV information like field size, (α,δ) central coordinates and exposure mid-instants. Other auxiliary information is also extracted, as exposure time, filters, object name, image file name. Note that PRAIA reads only FITS format images, but recognizes many FITS header “free” styles. One can always edit and change the extracted information. Target information files contain: (α,δ), JD, standard object name. PRAIA includes programs which can automatically generate target files for solar system bodies by ephemeris extraction, using web services (IMCCE/Skybot or JPL/Horizons) and NAIF/SPICE package. More than one target, with or without changing coordinates with time, can be included in a single target file.

Results are archived on two types of output files with redundancy: (α,δ), exposures mid-times, magnitudes (psf-based and from catalogue), seeing, proper motions (computed, from catalogue), number of reference stars, position errors (mean error, standard error, (O-C)s, …), (x,y), Gaussian psf parameters and errors, magnitude errors, filters, object name, fits file, etc. One file type regards to individual image output and includes information for all objects measured in the FOV. The other type refers to the list of targets and gives in one single file the results from all treated images, only for the targets identified in the FOVs. All the files are formatted and written in standard ASCII, making it very easy for the user to analyze data using their own graphic and statistic tools.

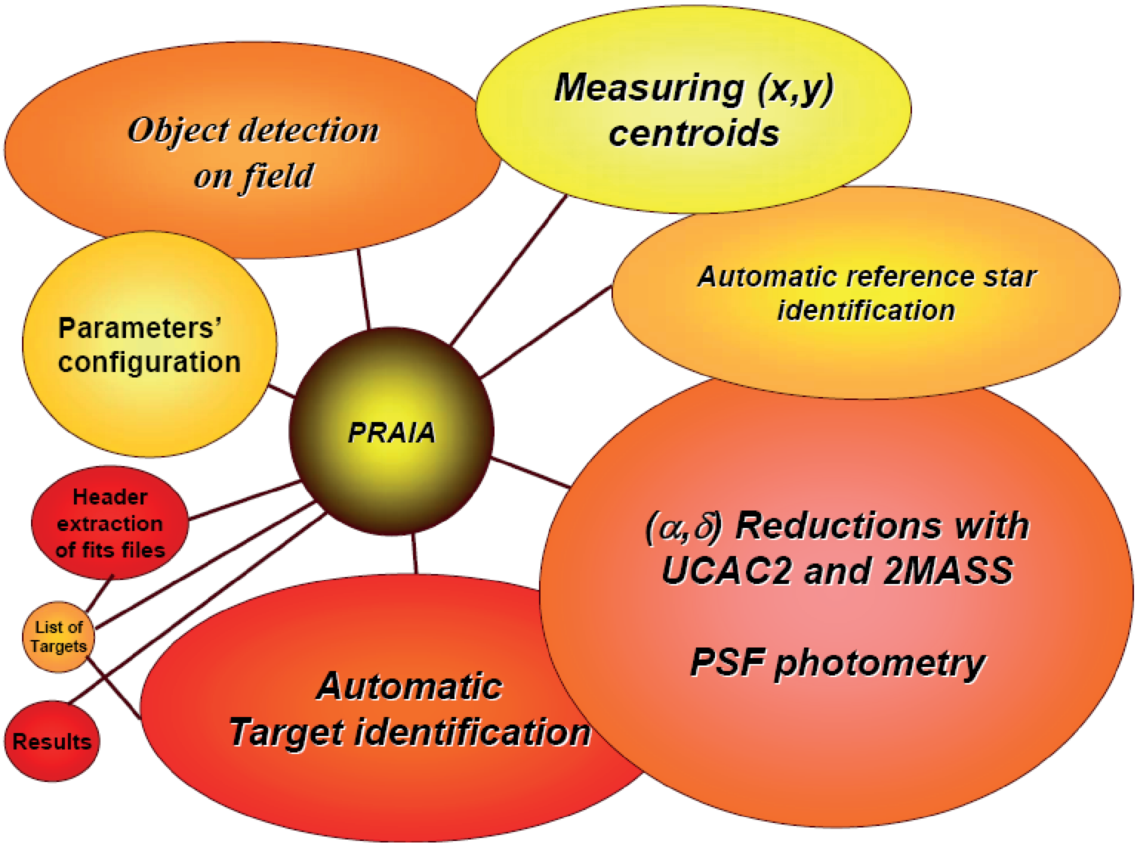


Fig. 1 – Astrometric scheme of PRAIA package.

1.2 Object detection, measuring. Automatic reference star identification. (α,δ) reduction.

Prior to object detection, the images undergo bad pixel elimination (including saturated ones) and sky background flattening (absence of previous photometric flat field corrections, vignette, Moon and sky background scattered light). Object identification is based on a local maxima spiral search algorithm. Sky background threshold and variation is evaluated from the histogram of counts. Objects above background by a given factor from the sky variation are stored and evaluated. Only pixels within 1 FWHM are computed in the iterative Gaussian fit procedure. The Gaussian psf fits furnish among other parameters (like psf magnitude) the (x,y) centroid and FWHM (seeing) of the object profile. Objects within a given FWHM range are validated and kept for astrometry. These procedures prove to be efficient against false detections by cosmic rays, spurious artificial structures and bright star image subdivisions. It is efficient for fitting saturated star images and blended objects. Field distortion pattern masks can be applied to the (x,y) measurements prior to the (α,δ) reductions. The reference star identification procedure settles the catalogue stars, the pixel scale and axis orientations automatically. Orientation, pixel scales and pairs of (x,y) and (α,δ) projected in the tangent plane are tried with 4 Constant and higher order polynomial models. The best match is then stored. This is made very fast with bright measured stars and the 2MASS catalogue, so that reference stars are recognized even with small or star-devoid FOVs. The (α,δ) reductions can be made with any chosen polynomial model (first, second, third degree plus third or fifth radial distortion terms plus magnitude and color terms) which relates (x,y) and (α,δ) coordinates in the tangent plane. Reductions are automatically performed with four different sets of reference star catalogues: UCAC2, 2MASS and two modified versions of 2MASS. The first 2MASS modified version consists of 2MASS positions corrected to the UCAC2 frame by means of polynomial-based model fits in the tangent plane in much the same way as in a normal reduction. In the second modified version, the positions are further corrected by proper motions, using the average values from faint UCAC2 stars within an area twice as large as the FOV. Based on reference stars (O-C)s, outliers are eliminated one-by-one in an iterative way, until a given (O-C) threshold is reached. For each set of reference stars, output files for individual frames and for targets are generated. Many error estimates are derived from the (x,y) Gaussian psf fits and from the (α,δ) reductions, like (x,y) Gaussian fit errors, (α,δ) mean errors and standard errors from the variance-covariance matrix. After (α,δ) reductions, proper motions are computed for each 2MASS star, using the positions in that catalogue as the other epoch. In the case of overlapping FOVs, firstly the individual frames are reduced. Then, the (α,δ)s are matched and averaged and an intermediary instrumental catalogue is generated, containing all objects from all FOVs. The positions in this intermediary catalogue are further corrected to the reference catalogue (say, the UCAC2) by means of polynomial-based model fits in the tangent plane. The resulting intermediary catalogue is then used as reference in new individual frames (α,δ) reductions. The procedure is repeated until convergence is reached in the positions of all objects. For consistency, only "fixed" objects like stars should be used in the procedure. Entries in the target list can be excluded, like solar system moving objects. Table 1 presents a sample of results which show PRAIA astrometry and data handling performance according to object type (star, quasar, solar system object), field size, reference star number, field star number, brightness and epoch.

Table 1 – PRAIA: astrometry and data handling.

Object	Tels.	PRAIA minus Target αΔcosδ Δδ (mas)		PRAIA minus Target σα σδ (mas)		No. Img	CCD Field (')	Number comptd (α,δ)s	PIV 3.2GHz Procces time	FITS data	Ep. (yrs)	Mag V	Ncat	Sα Sδ (mas)	
254 qsos	0.6m	+00	+11	42	48	3546	10x10	5626000	110.9hs	29.0GB	2000.3	15-18.5	22 U2	44	42
215 qsos	1.6m	-04	-06	50	52	2445	5x5	3997412	106hs	19GB	2000.7	15-21	21 MA	34	34
62 qsos	0.5m	+06	+14	47	52	4124	7.4x7.4	641756	8.8hs	3.5GB	2005.1	15-17.5	22 MA	39	43
Pluto	0.6m	-20	+09	60	42	1541	10x10	12577580	23.4hs	19.0GB	2004.2	14.0	79 U2	52	50
Pluto	1.6m	-20	+00	52	60	398	5x5	446.512	12hs	2.1GB	1997.9	14.0	16 MA	65	54
Triton	0.6m	+18	-135	60	63	273	10x10	31540	1.8hs	1.5GB	2006.5	13.5	17 U2	59	57
Elara	0.6m	-47	-135	29	36	89	10x10	179516	1.0hs	329MB	2006.1	17.2	17 UC	52	53
Himalia	0.6m	-112	-10	31	26	98	10x10	142768	1.0hs	319MB	2006.1	15.3	19 UC	53	54
Phoebe	0.6m	+67	-99	22	50	16	10x10	47524	0.6hs	174MB	2006.1	16.2	12 UC	55	60
Pasiphe	0.6m	+62	-43	84	68	41	10x10	56704	0.4hs	137MB	2006.1	17.6	17 UC	66	58
Iapetus	0.6m	+85	-116	91	99	40	10x10	57044	0.5hs	156MB	2006.1	10.9	10 UC	62	62
Titan	0.6m	+94	+28	132	183	15	10x10	29436	0.3hs	100MB	2006.1	8.2	5 UC	52	59
Hiperion	0.6m	+174	-74	---	---	1	10x10	5760	0.1hs	29MB	2006.1	14.2	8 UC	53	56
60 O.C.	1m Mex.	----	----	---	---	1880	6.7x6.7	1161886	10hs	4.6GB	2003.5	12-18	181 2M	72	74

Conclusion

PRAIA was officially assigned as the astrometric supporting tool for participants in the GAIA-FUN-SSO activities. No interaction is needed to run the programs of the package. PRAIA automatically identifies reference stars and targets, performs photometric and astrometric measurements, and computes positions and errors. All polynomial models, including radial distortions, magnitude and color terms are available. Default reference catalogues are the UCAC2 and the 2MASS. Others may be used, including secondary catalogues generated (or not) from former PRAIA runs. It also performs astrometry over overlapping frames, from single observations or from CCD mosaics for instance. All results - including those for pre-selected targets - plus complete observational and reduction information are archived in one or few output files with redundancy. PRAIA also allows for a fast visual inspection of the results by screen plots of graphics, tables and statistics using your preferred tools. PRAIA astrometric and photometric performance is certified by a number of publications given in the references. They are examples of high precision photometry and astrometry of CCD observations of asteroids, occultation candidate stars, TNOs, ICRF radio sources and natural satellites. The photometric precision is compatible with DAOPHOT performance to 0.001mag or better. Depending on the reference catalogue, instrument, field size and exposition, positional errors range between 30mas and 70mas and astrometric accuracy (repeatability) can be as good as 20mas to 10mas.

References

Assafin et al.: 2007, Optical astrometric positions of 59 northern ICRF radio sources, Astronomy and Astrophysics 476 (2), 989-993

Assafin et al.: 2008, Instrumental and digital coronagraphy for the observation of the Uranus satellites' upcoming mutual events, Planetary and Space Science 56 (14), 1882-1887

Assafin et al.: 2009, Observations and Analysis of Mutual Events between the Uranus Main Satellites, The Astronomical Journal 137 (4), 4046-4053

Assafin et al.: 2010, Precise predictions of stellar occultations by Pluto, Charon, Nix, and Hydra for 2008-2015, Astronomy and Astrophysics 515, A32, 01-14

Descamps, P. et al.: 2007, Figure of the double Asteroid 90 Antiope from adaptive optics and lightcurve observations, Icarus 187 (2), 482-499

Descamps, P. et al.: 2009, New insights on the binary Asteroid 121 Hermione, Icarus 203 (1), 88-101

Sicardy, B. et al.: 2006, Charon's size and an upper limit on its atmosphere from a stellar occultation, Nature 439 (7072), 52-54

Sicardy, B. et al.: 2011, Constraints on Charon's Orbital Elements from the Double Stellar Occultation of 2008 June 22, The Astronomical Journal 141 (2), A67, 01-16

Thuillot et al.: 2009, Division I / Working Group Astrometry by Small Ground-Based Telescopes, Transactions IAU 4 (27A), Reports on Astronomy 2006-2009. Edited by Karel van der Hucht. Cambridge: Cambridge University Press, 63-67

The 2-Meter Telescope of the National Astronomical Observatory Rozhen: Opportunities for GAIA-FUN-SSO

Bonev T.

Institute of Astronomy
National astronomical observatory - Rozhen
Bulgarian Academy of Sciences

Introduction

The 2 meter reflector of the National Astronomical Observatory (NAO) Rozhen offers two main modi of observations: imaging in the Ritchey-Chretien (RC) focus and spectroscopy in the Coude focus. Images can be obtained with two spatial scales: 0.25 arcsec/px or 0.89 arcsec/px. High signal-to-noise, high resolution (up to 35000) spectra are obtained with the Coudé spectrograph. Upgrades of the 2 meter telescope performed in the last years are presented: autoguiding system in 2007, recoating of the optics in 2008, installation of a new telescope control system in 2009. The performance of the 2-m telescope after these upgrades will be illustrated by a sample of observations and the capabilities for observations of Gaia follow-up of SSO will be discussed. Some of the characteristics of the telescope presented here and many more, can be found on the web-site of the National Observatory: www.nao-rozhen.org.

1. The 2-meter telescope : main modi of observations

1.1 Imaging in the Ritchey-Chretien focus

The focal length of the 2-meter telescope at the Ritchey-Chretien focus is 16 m. The optically corrected field in this focus is 1 degree^2. This relatively wide field was used extensively for large scale imaging for more than ten years after commissioning of the telescope in 1981, during the era of astronomical photographic plates. Presently a LN_2 cooled CCD camera VersArray 1300B is used, having 1340 x 1300 pixel, each of size 20 μm which yields a spatial scale of 0.25 arcsec/px. The field of view is 5.5 arcmin. Today, the smaller field of view is partially compensated with the faster detector. Following parameters describe the photometric precision of the imaging mode: in an exposure of 120 s., a star of R-magnitude 20, at seeing 1.2 arcsec has a S/N of approx. 100.

1.2 The 2-channel focal reducer

The 2-channel Focal Reducer Rozhen (FoReRo2) is mounted in the Ritchey-Chretien focus. It is a multimode instrument which allows simultaneous observations in the red and blue spectral range in following modes: broadband imaging, narrow-band imaging, long-slit spectroscopy, Fabry-Perot imaging, and imaging polarimetry. It makes the 2-meter telescope faster by changing its focal ratio from f/8 to f/2.8 and thus making the instrument an excellent device for observations of low surface brightness objects. This instrument has been developed and continuously improved during a period of more than 20 years in the Max-Planck-Institute for Aeronomy, today MPSS (Max-Planck-Institute for Solar System Research: mps.mpg.de). Description of the instrument is given by K. Jockers et al. (2000). Recent results obtained with FoReRo2 by using broadband and polarimetric images can be found in Bonev et al. (2008). Narrow-band images have been used to analyse the rotational state and emission patterns in the CN coma of comet 8P (Waniak et al. 2009). Using low-dispersion spectra, Borisov et al. (2008) derived the chemical composition and reddening of the continuum in comet 8P/Tuttle. Similar research based on low-dispersion spectra of comet C/2007 N3 Lulin was made by Borisov (2010).

An example of cometary observations obtained in the narrow-band mode of FoReRo2 is shown on Fig.1. This sequence of images illustrates the process of revealing of faint plasma structures in the near nucleus region of a comet.

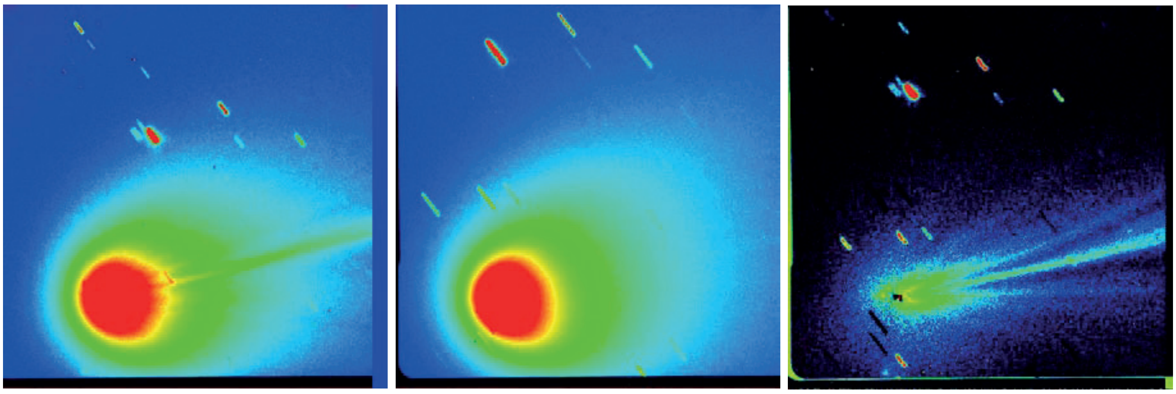


Fig. 1 – Images of comet Q4 (NEAT) obtained with the 2-channel focal reducer on May 26, 2004. Left: image obtained with a narrow –band filter centered at 616 nm (molecular lines of H2O+ and continuum). Middle: image obtained at 642 nm – a well defined continuum window in cometary spectra. Right: The difference (Left – k*Middle) removes the continuum and reveals the spatial distribution of the ions in the near nucleus region.

1.3 The coude-spectrograph

The resolving power of the coude-spectrograph is going up to 35000. The spectrograph is used predominantly for high dispersion spectroscopy of stars: symbiotic, cataclysmic, chemically peculiar, different kinds of binaries, etc. Only occasionally spectra of solar system objects are obtained, for example spectra of comets which are bright enough and allow resolving the rotational lines in their vibrational emission bands. One recent example (the resolved rotational lines of CN at 387 nm in the spectrum of comet C/2009 R1 (McNaught)) can be seen on the web-site of the National observatory: www.nao-rozhen.org, in the rubric "Observations".

2. Recent upgrades of the 2-meter telescope

2.1 Autoguiding system

The autoguiding system of the Rozhen 2-meter telescope was designed in 2006. It uses the image of a star outside of the observed field of view. The system consists of an optomechanical module, detector, controller, relays-module and a PC. The detector is a Peltier cooled CCD SONY ICX 204. which is operated with the open source code uClinux. The user interface is a program running under Windows XP and communicating with the detector via TCP/IP. The opto-mechanical part is mounted at the offset module of the telescope which allows selecting a proper star for the guiding process. The position of the selected star in the focal plane is calculated by a dedicated software. With a guide star of magnitude about 12, under mediocre seeing conditions (about 3 *arcsec*), the integration time needed for reliable derivation of the star's center of weight is about 15 seconds. With the commissioning of the autoguider the quality of the images obtained in the RC-focus of the 2-m telescope was substantially increased, especially in the cases of fainter objects and correspondingly longer exposures. Details of the autoguiding system are described in Bonev et al. (2006).

2.1 Re-coating of the optics

The main mirror of the 2-meter telescope and the first plane mirror deflecting the light to the coude-spectrograph were re-coated in 2008. The comparison of observations obtained before and after the re-coating shows an increase of the performance of the telescope by a factor of two.

2.1 New control system

In 2009 the more than 30 years old control system of the telescope was replaced by a new one. The new system is based on Siemens industry controllers. All the drives, sensors, user interface, etc. are replaced with state-of-the art technologycal solutions, which is a guarantee for high reliability of the new system. Incorporation of the TPOINT model takes account for the various kinds of errors: misalignment of the polar axis, non-perpendicularity of the hour and declination axes, bending of the tube, and many more. The very first results showed an enormous improvement of the telescope pointing accuracy after application of the TPOINT model, as can be seen on fig. 2.

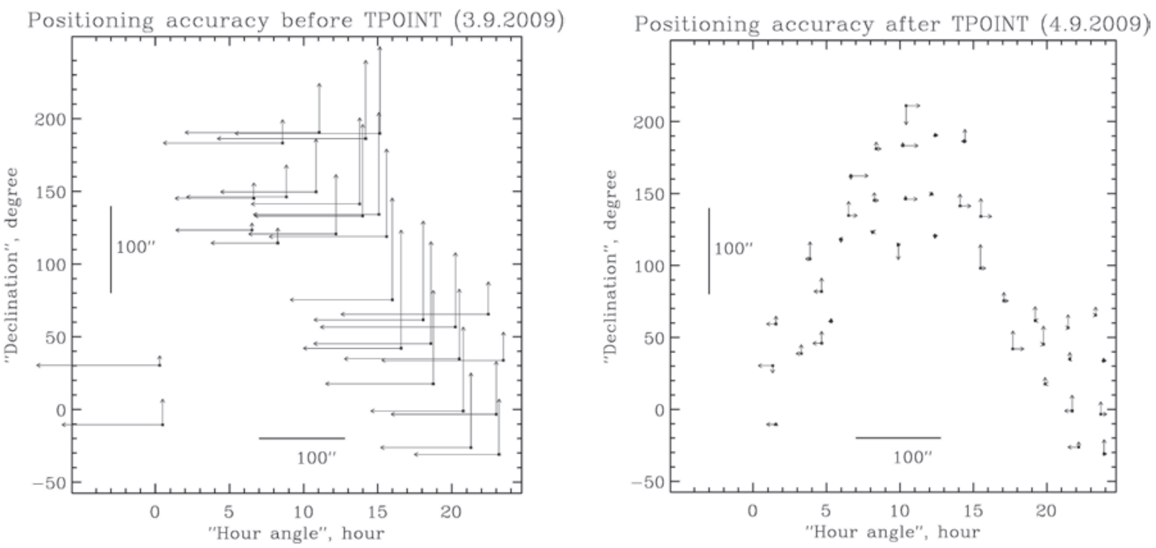


Fig. 2 – Left: pointing of the 2-meter telescope before application of the TPOINT model. Right: Pointing of the telescope after application of the model feeded with measured pointing errors of only 28 stars.

Conclusion

The 2-meter telescope of the National astronomical observatory can be an effective member of GAIA-FUN-SSO. It can be used for: photometry, astrometry, broad-band and narrow-band imaging of extended objects (comets), and polarimetric imaging of asteroids and comets. The telescope is equipped for observations useful for determination of the physical state and chemical composition of solar system objects, but it can be effectively used also for astrometric measurements of Solar system objects discovered by Gaia. The author thanks for a grant provided by the organizers of the GAIA-FUN-SSO workshop allowing him to present these data at the meeting. Partial support for participation at the workshop was provided by the National Science Fund in Bulgaria under contract DO 02-85.

References

Bonev, T., Lukarski, H., Parov, I., Neykov, S., Marinkov, V., and Yaramov, K. : 2006 , Autoguiding system for the 2-m RCC telescope of the Rozhen National Astronomical Observatory, Bulgarian Astronomical Journal 8, 201-208

Bonev, T., Boehnhardt H., and Borisov G.: 2008, Broadband imaging and narrowband polarimetry of comet 73P/Schwassmann-Wachmann 3, components B and C, on 3, 4, 8, and 9 May 2006, Astronomy & Astrophysics 480, 277-287

Borisov, G. , Waniak, W., Bonev, T., Czart, K., and Drahus, M.: 2008, Low dispersion spectroscopy of the comet 8P/Tuttle, Bulgarian Astronomical Journal 10, 59-66

Borisov, G.B.: 2010, Observations of the Comet C/2007 N3 (Lulin) during its Closest Approach to the Earth, Publications de l'Observatoire Astronomique de Beograd 90, 19-23

Jockers, K., Credner, T., Bonev, T., Kiselev, V. N., Korsun, P., Kulyk,I., Rosenbush, V., Andrienko, A., Karpov, N., Sergeev, A., Tarady, V.: 2000. Exploration of the solar system with the Two-Channel Focal Reducer at the 2m-RCC telescope of Pik Terskol, Observatory. Kinematika i Fizika Nebesnykh Tel Supplement 3, 13–18

Waniak, W., Borisov, G., Drahus, M., Bonev, T., Czart K., Kueppers, M.: 2009, Rotation of the Nucleus, Gas Kinematics and Emission Pattern of Comet 8P/Tuttle: Preliminary Results from Optical Imaging of the CN Coma, Earth Moon Planet 105, 327–342

Analysis of Astrometry and Photometry Observations of Asteroids at the RTT150

Ivantsov, A.[1], Gumerov, R.[2], Khamitov, I.[3], Aslan, Z.[4], Thuillot, W.[5], Pinigin, G.[1], Hestroffer, D.[5], Mouret, S.[6]

[1] Nikolaev Astronomical Observatory, 1 Observatorna St., 54030 Mykolaiv, UKRAINE
[2] Kazan State University, 18 Kremlevskaya St., 420008 Kazan, RUSSIAN FEDERATION
[3] TÜBITAK National Observatory, Akdeniz Üniversitesi Yerleşkesi, 07058 Antalya, TURKEY
[4] İstanbul Kültür Üniversitesi, 34156 Bakirköy, İstanbul, TURKEY
[5] IMCCE, Observatoire de Paris, 77 Av. Denfert-Rochereau, 75014 Paris, FRANCE
[6] Lohrmann-Observatorium, Technische Universität Dresden, 01062 Dresden, GERMANY

Introduction

The space astrometric mission Gaia, a cornerstone of the European Space Agency, will be launched in 2012 with the objective to make a 3D precise map of our Galaxy. The Gaia will furnish positions, distances and motions of a billion stars with unprecedented precision. Beside stars, the Gaia will observe asteroids with unprecedented precision from 0.5 to 3 mas, allowing the extremely fine orbit determinations (Tanga et al., 2008). This precision has great significance for the determination of small effects influencing the dynamics (relativistic, gravitational, non-gravitational, etc.) of Solar system bodies. The determination of masses of a hundred asteroids with a relative precision better than 50% is expected in 5 years of Gaia operation (Mouret et al, 2007).

Considering the time length of the Gaia mission, there will be encounters between asteroids occurring either at the beginning or the end of the mission, so the maximum of deflection angle pertained to the perturbation maximum will not be observed. The precision of mass determinations based solely on the Gaia observations will deteriorate in such cases (Hestroffer et al., 2008). A possible way out consists of acquiring ground-based observations of high accuracy of selected asteroids and organizing a dedicated network (Thuillot, 2005). The RTT150 telescope is one of the professional telescopes, which has already shown its possibilities for researching orbital dynamics of asteroids (Aslan et al., 2006).

1. Astrometrical Results

The original list of Institut de Mécanique Céleste et de Calcul des Éphémérides (IMCCE) for astrometry measurements of asteroids consists of 279 perturbed asteroids to be observed during 2008-2010. If astrometrical accuracy of their positions is high enough, then they can be used for complementary science with the Gaia results, thus improving determination of masses for 27 asteroids, including Ceres and Vesta. The idea consists of recovering the orbits of the perturbed asteroids through accurate astrometrical ground-based observations spanned in time before the Gaia launch.

There are two difficulties in accomplishing this task: limited visibility of selected asteroids caused by changing their configuration with respect to the Sun and Earth, as the three year period is comparable to the synodic periods of main belt asteroids, and the limited allocated time for astrometrical observations of asteroids at the professional telescopes, allowing both aperture for imaging faint asteroids, appropriate field of view and scale for making astrometrical measurements at the accuracy level of 0.1″ with contemporary astrometric catalogues.

The selection of asteroids for observations at the RTT150 telescope was made of those perturbed asteroids which can make possible of mass determination for as many as possible asteroids, and those ones perturbed by Ceres and Vesta, which have observed effect greater than 50 mas. The first group consisted of 48 asteroids and the second made up of 22 ones, 70 perturbed asteroids in total. There was calculated visibility for each selected asteroid for the time period of 2008-2010, consisted of apparent visual magnitude, zenith distance at the meridian, solar elongation. The final observational programme was made of those asteroids, whose visibilities were limited by magnitude less than 18, zenith distance at the meridian less than 70°, solar elongation greater than 90° for attaining the best achievable conditions for astrometrical observations.

In the given allocated time of 3 years, there were observed 45 perturbed asteroids at the RTT150, making up a catalogue of 2437 astrometry positions. The astrometric reduction was made with the UCAC2 and UCAC3 catalogues. For making analysis of astrometrical observations of asteroids, there were calculated mean differences *(O–C)* for each series of observations using the HORIZONS system. The resulting distribution is given in Figure 1.

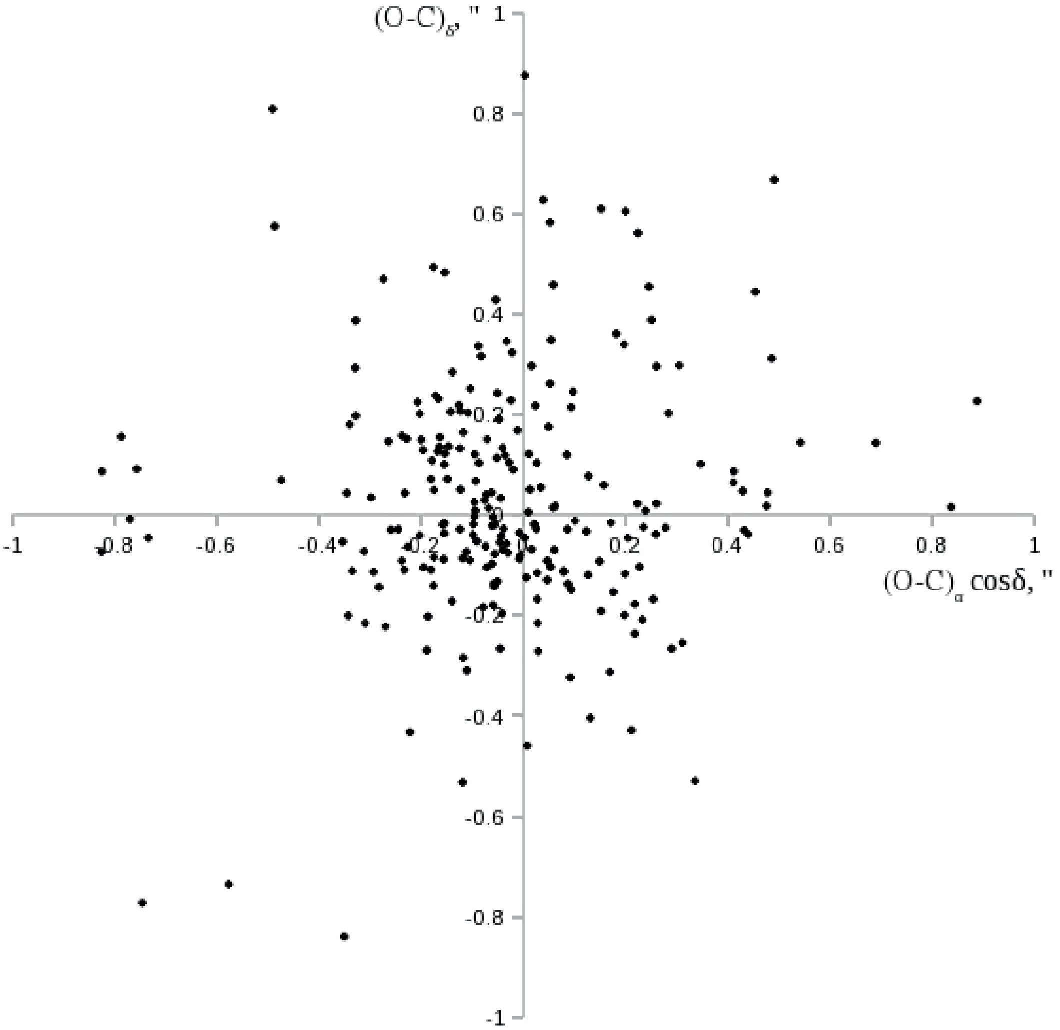


Fig. 1 – Distribution of *(O–C)* in position measurements of asteroids

Certainly, several points may belong to the measurements of one asteroid though in different nights.

The weighted errors of a single measurement are 0.16″ in right ascension and 0.13″ in declination. The standard error was calculated as a standard deviation of a single position from the mean one in the series of observation positions in one night. The weights for individual dispersions were assigned proportional to the number of positions in respective series.

Considering the above listed values of errors, the length of series greater than ten positions, one can expect to find significant discrepancies in *(O–C)* at the level 0.1″, assuming a normal distribution. As one can easily discover in Figure 1, the majority of *(O–C)* in both right ascension and declination described here has great “Student's ratio”, and thus, the associated positions can be used for improving orbital elements of observed asteroids even now.

2. Photometrical Results

The differential photometry was made for all images where the reference stars of SDSS7 catalogue were present. The stellar magnitudes of SDSS7 were transformed to the BVR Johnson-Cousins-Bessel system using the adopted equations. Thus, there were photometrically reduced 1842 images. The weighted errors are 0.14 mag in B-band, 0.09 mag in V-band, 0.14 mag in R-band, which are greater than the best errors about 0.01 mag of the respective transformations, given by R. Lupton, on the site of SDSS Data Release 7 (http://www.sdss.org/dr7/algorithms/sdssUBVRITransform.html).

The light curve of one of the observed asteroids (35107) 1991 VH belonging to Apollo group is given below, Figure 2. The photometrical data represents observations made on June 28, 2008. The light curve shows changes of brightness with the period of variability about 0.1 day and amplitude about 0.2 mag. The error bars indicate standard errors, resulting from the signal-to-noise registered.

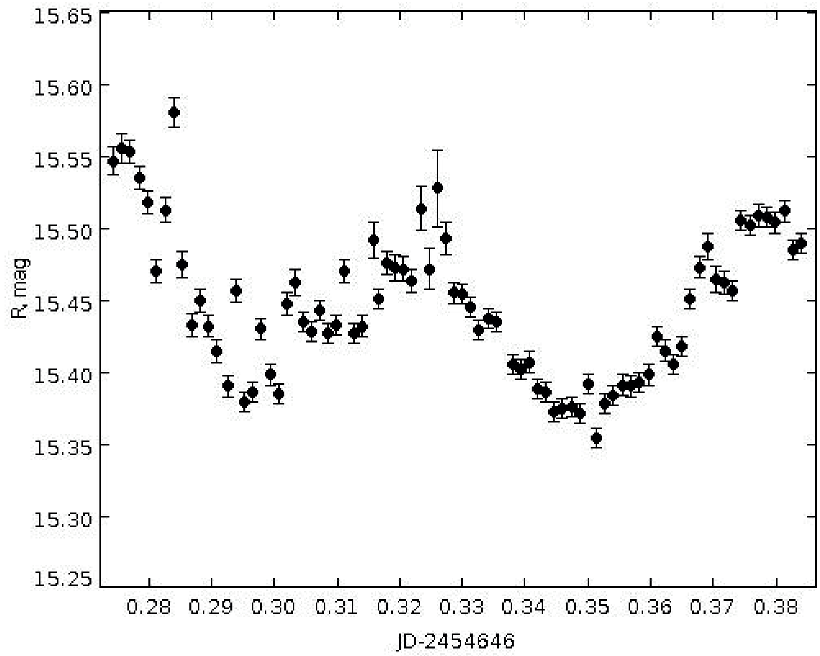


Fig. 2 – Light curve of asteroid (35107) 1991 VH

Conclusion

The telescope RTT150 is used for observations of perturbed asteroids under the observational programme made of the IMCCE list. There were observed 45 asteroids in 3 years run. The allocated time is a principal factor which limits the number of observed asteroids.

The achieved position precision is 0.16″ in right ascension and 0.13″ in declination and is limited by small effects of atmosphere and optics. There are possibilities to reduce precision less than 0.1″.

There was made differential photometrical reduction for 1842 images (82% of positions) in the BVR Johnson-Cousins-Bessel system. The weighted errors are 0.14 mag in B-band, 0.09 mag in V-band, 0.14 mag in R-band.

Acknowledgements

A.I. and G.P. express their gratitude to the Organizing Committee for the partial support of their stay during the Gaia-FUN-SSO Workshop. R.G. is partially supported by Russian Foundation for Basic Research, grant 11-02-00262-a.

References

Aslan Z., Gumerov R., Hudkova L., Ivantsov A., Khamitov I., Nemtinov A., Pinigin G. and Zelikov S.: 2006, Observational Programs and First Results of Selected Asteroid Observations at RTT150 within International Cooperation, Roman. Astron. J. Suppl. 16, 11–31

Hestroffer D., Thuillot W., Mouret S., Colas F., Tanga P., Mignard F., Delbò M., and Carry B.: 2008, Ground-based observations of solar system bodies in complement to Gaia, Proc. Ann. Meet. Fr. Soc. Astron & Astroph. (SF2A-2008), 21

Mouret S., Hestroffer D., and Mignard F.: 2008, Asteroid mass determination with the Gaia mission. A simulation of the expected precisions, P&SS 56, 1819-1822

Tanga P., Hestroffer D., Delbò M., Frouard J., Mouret S., and Thuillot W.: 2008, Gaia, an unprecedented observatory for Solar System dynamics, P&SS 56, 1812-1818

Thuillot W.: 2005, A Ground-Based Network of Observers for Gaia Follow-Up, Proc. Symp. “The Three-Dimensional Universe with Gaia” (ESA SP-576), 317

Observation of NEOs Having High Apparent Rates with Mobitel Telescope

Shulga, O.[1], Kozyryev, Y.[1], Sybiryakova, Y.[1]

[1] Research Institute "Nikolaev Astronomical observatory" (RI NAO), Ukraine, Nikolaev

Introduction

When NEO approaching to the Earth close then 0.05 AU its apparent rate begin increasing and magnitude begin decreasing rapidly by hyperbolic low. These dependences are shown on figures 1, 2, by the example of the two NEO observed in RI NAO. When small NEO close to the Earth it is observable for the small telescopes, but after going away it may become unobservable for the most of telescopes. Observations of NEO on short distances are valuable for the orbit determination. Increasing of NEO's apparent rate causes limitation of exposure time in case if telescope observe in star tracking mode. So the telescope's limited magnitude can't be reached. Not all telescopes are able to track NEO with two axles. Frames obtained while NEO tracking contain stretched images of stars. Stretched stars images and telescope movement with two axles while exposure time cause accuracy decreasing. An original combined observation method is used in RI NAO for observation of NEOs having apparent rate >10″/min without any telescope mechanical tracking. There are two telescopes in RI AO that can observe NEOs, fast moving near the Earth at distances 0.0002 ÷ 0.05 AU.

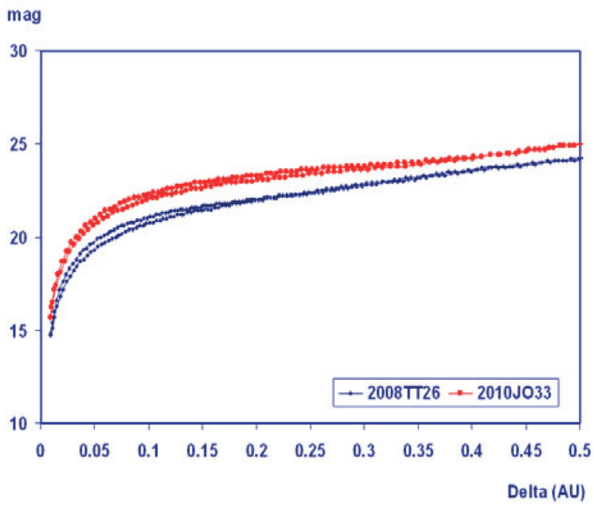


Fig. 1 – Magnitude decreasing from delta

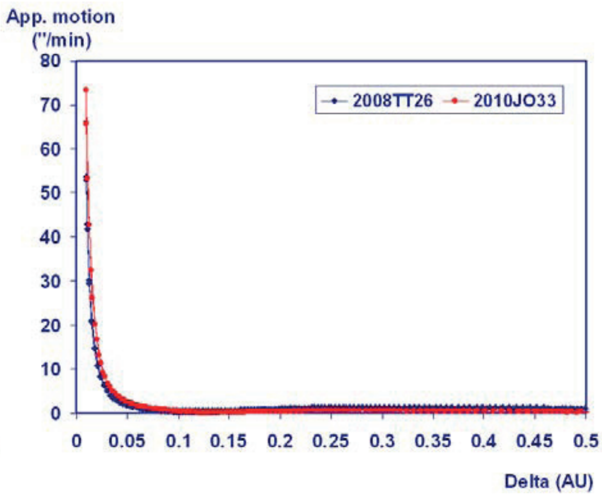


Fig. 2 – Apparent rate increasing

1. Original Combined Observation Method (COM)

The original Combined Observation Method (COM) is used for observation of objects having high apparent rates on stare telescope. COM use a filed de-rotator, a short TDI imaging technique and additional stars frames. COM is cost-effective for observations of Earth-orbit satellites on all orbit types and NEOs, fast moving near the Earth at distances 0.0002 ÷ 0.05 AU. The main advantage of COM is that astrometric accuracy and limiting magnitude do not depend on object apparent rate.

1.1 Short TDI imaging technique

The time delay integration mode (TDI) with a field de-rotators are used on all telescopes of RI NAO. The field de-rotator aligns CCD columns with object motion direction. This permit TDI imaging of objects with arbitrary motion direction (e.g. stars with the altazimuth mount type). In usual way of TDI imaging the object continue accumulating while passing through all of the field of view (FOV). This full exposure time can be excessive because of two big FOV size and nonlinearity of object trajectory (e.g. stars on big declination). A special "short" TDI imaging technique can be used to specify smaller exposure type. The short TDI imaging technique combines two processes:

1) TDI readout, during a specified exposure time;
2) Fast readout of all CCD matrix, like after stare integration.

The specified exposure time can be set from 0 to full TDI imaging exposure time. The usable height of obtained frame changes correspondently from the CCD matrix size to 0.

1.2 Additional stars frames

The frame imaged with the short TDI technique in synchronization with object sky speed looks like to be imaged while telescope object tracking. The TDI frame obtained on a fixed telescope is free of any mechanical motion irregularity. The images of stars are starched and their brightness became lower with object apparent rate increasing. To avoid the problem of starched stars image processing the additional frames with point like images of stars are used with different way of imaging. In case when the object sky motions direction close to the stars sky motion direction the short TDI imaging, synchronized with stars sky speed, is used. In other case stare integration imaging with very short exposure time is used.

Telescope is pointed to object's position on the sky with some advance and stays unmovable while imaging of a frame sequence: leading stars frame, object frame, following stars frame. Astrometry reduction of such frame sequence has some addition. The coefficients of the polynoms, calculated from the leading and following stars frames, are interpolated to the object frame.

2. Telescopes

FRT Telescope (D=30 cm, FOV 84'x84', 1.65"/pix) is a stationary telescope having equatorial mount. Mobitel Telescope (D=50 cm, FOV 42'x42', 0.83" /pix) is a compact telescope having azimuth mounting installed on trailer carriage. Both telescopes equipped with CCD camera Alta U9000 (3056×3056 12μ) and field de-rotator. Limiting magnitude (including NOEs having high apparent rates): Mobitel – 18 mag, FRT – 17 mag. Figures 3, 4 shows view of the telescopes. Both telescopes are located in the center of Nikolaev city at altitude 80 m, in conditions of light pollution. Mobitel Telescope was designed on the trailer carriage and it has an opportunity to be moved away from the city to a mountain region.

Fig. 3 – FRT Telescope

Fig. 4 – Mobitel Telescope

3. NEOs observation results

Observations of NEOs having high apparent rate are carried out in RI NAO since 2008. Residuals (O-C) were calculated with the JPL Solar System Dynamics ephemerides. Observation results for two telescopes are given in Tables 1, 2.

Table 1 – NEOs observed on FRT telescope

Object	App. rate ("/min)		Size (km)	Mag	Delta (AU)	Frames	Mean residuals O-C (")		RMS errors (")	
	α	δ					α	δ	α	δ
2005RC34	6.5	21.1	0.4-0.8	14.4	0.037	179	-0.11	-0.12	0.42	0.32
2008TT26	28.8	-36.0	0.05-0.12	14.7	0.010	75	0.04	0.01	0.41	0.23
2008SV11	15.0	-19.4	0.6-1.4	12.8	0.045	22	-0.25	-0.18	0.27	0.15
2005YU55	-61.2	21.5	0.1-0.3	15.3	0.016	29	0.03	-0.10	0.23	0.26
2010JO33	68.3	4.6	0.03-0.06	15.9	0.009	29	0.10	-0.20	0.38	0.26

Table 2 – NEOs observed on Mobitel telescope

Object	App. rate ("/min)		Size (km)	Mag	Delta (AU)	Frames	Mean residuals O-C (")		RMS errors (")	
	α	δ					α	δ	α	δ
1997GL3	2.0	9.5	~ 0.20	15.7	0.094	53	-0.13	0.14	0.19	0.18
1997GL3	2.9	12.6	~ 0.20	15.5	0.082	43	-0.07	0.21	0.11	0.10
1997GL3	4.3	17.0	~ 0.20	15.2	0.069	30	0.07	0.16	0.12	0.10
2000GC2	-3.6	3.4	1.0-2.3	17.7	0.438	7	-0.10	0.10	0.20	0.20
2000GC2	-3.7	3.3	1.0-2.3	17.7	0.438	26	-0.16	0.08	0.19	0.15
2005GE59	4.9	-0.5	0.7-1.6	17.4	0.270	14	-0.20	0.22	0.16	0.25
2005GE59	5.2	-0. 7	0.7-1.6	17.4	0.262	6	-0.14	0.11	0.27	0.42
2003UV11	-138	-13.5	0.4-0.8	12.0	0.014	16	0.88	0.34	0.38	0.17
2007VC138	7.3	-9.3	0.4-0.8	16.7	0.121	23	0.08	-0.50	0.25	0.18
2010VZ139	-44.4	-10.3	0.1-0.2	17.5	0.021	10	0.20	-0.42	0.16	0.19

Distributions of residuals (O-C) for FRT and Mobitel telescopes are shown on figures 5, 6. These observations results not been sent to Minor Planet Center, so they not affected JPL ephemerides. The residuals (O-C) probably will be smaller after taking into account of these observations results.

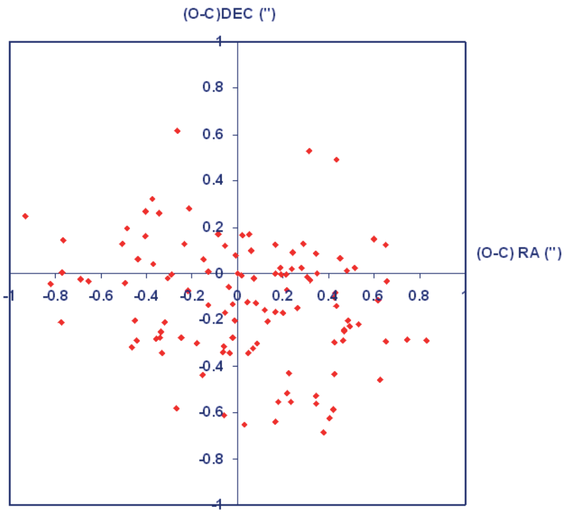


Fig. 5 – FRT residuals (O-C) (≤16 mag)

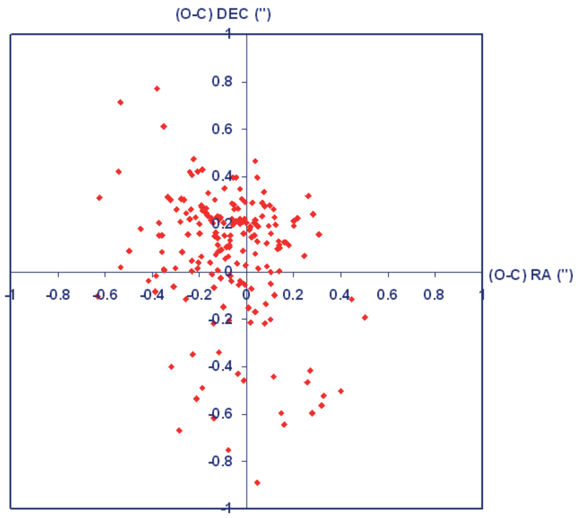


Fig. 6 – Mobitel residuals (O-C) (≤ 18 mag)

Conclusion

The original Combined Observation Method permits to create low-cost means for observation of Earth-orbit satellites on all orbit types and fast NEOs.

Despite the small diameters FRT and Mobile telescopes can observe NEOs which are hard for observation due to high apparent rate. Position accuracy (relatively to JPL ephemerides): FRT 0.25" – 0.55"; Mobitel 0.15" – 0.35".

Contribution of FRT and Mobitel telescopes to Gaia-FUN can be observations of just discovered NEOs, moving toward to the Earth at distances 0.0002 ÷ 0.05 AU. Limited magnitude of Mobitel telescope is 18 at present location in the center of Nikolaev city. Mobile telescope has a potential to be moved to a better astroclimate.

Observations of Asteroids in International Scientific Optical Network

Krugly Yu.N.[1], Molotov I.E.[2], Agapov V.M.[2], Elenin L.[2], Gaftonyuk N.M.[3], Kouprianov V.V.[4], Minikulov N.H.[5], Gulyamov M.I.[5], Abdulloev S.[5], Donchev Z.[6], Ivanova V.[6], Sergeev A.V.[1], Burkhonov O.A.[7], Ehgamberdiev Sh.A.[7], Rumyantsev V.V.[3], Inasaridze R.Ya.[8], Ivashchenko Yu.N.[8], Satovskiy B.[10], Cappelletti C.[11], Baransky A.[12], Dorokhov N.I.[13]

[1] Institute of Astronomy, Kharkiv National University, Sumska str. 35, Kharkiv, Ukraine;
[2] Keldysh Institute of Applied Mathematics, RAS, Miusskaya sq. 4, Moscow 125047, Russia;
[3] Crimean Astrophysical Observatory, Crimea, Ukraine;
[4] Pulkovo Observatory, RAS, Pulkovskoje Ave. 65-1, St. Petersburg 196140, Russia;
[5] Institute of Astrophysics, Dushanbe, Tajikistan;
[6] Institute of Astronomy, Sofia, Bulgaria;
[7] Ulugh Beg Astronomical Institute, Uzbek Academy of Sciences, Astronomicheskaya 33, T ashkent 100052, Uzbekistan;
[8] Abastumani Observatory, Georgia;
[9] Andrushivka Observatory, Zhitomir region, Ukraine;
[10] Astrotel, Moscow, Russia;
[11] Gruppo di Astrodinamica dell'Universita degli Studi "La Sapienza", Roma, Italy;
[12] Astronomical Observatory, Kiev Shevchenko National University, Kiev, Ukraine;
[13] Astronomical Observatory, Odessa National University, Odessa, Ukraine.

Introduction

The International Scientific Optical Network (ISON) was established in 2004 to carry out regular monitoring of the population of artificial objects at high altitude orbits (mainly GEO). Now the network joins 23 observatories in 10 countries, which are located at different longitudes and latitudes of the globe (Molotov et al., 2009).

Since 2006 the photometric observations of asteroids has been started in frame of ISON to increase the network scientific output. The main targets of these observations are near-Earth asteroids (NEAs) as hazardous objects pose a threat for the Earth civilization. The observations are aimed to investigate physical properties of the asteroids and astrometric positions. The network is also involved into projects on searching binary asteroids, support of asteroid radar research and investigation of the YORP effect. In last two years the project was also directed to be involved in follow-up and discovery asteroids and comets, especially NEAs in frame of the Asteroid Hazard problem.

Capabilities of our network to obtain astrometry and photometric data can be used in frame of the project GAIA for doing observations of newly discovered asteroids and comets.

1. ISON Project

1.1 The Aims of the ISON Project

- Monitoring of man-made space debris (primarily high-geostationary orbits, high-elliptical, circular type of GLONASS and GPS) by means of carrying out astrometric and photometric observations of orbiting objects (i.e. the study of their orbital and physical properties), prediction long-term evolution of this state, taking into account various factors, identify the sources of formation of small debris, identifying objects of

potential sources of risk to the functioning for operational spacecrafts. This is the main task.
- Tracking of NEAs: to do the discovery, refinement of orbital parameters and to study their physical properties.
- A gamma-ray burst optical “afterglow” observations.

1.2 Telescopes in the network

More than 25 wide-field telescopes were made and installed at different observatories of the network. The diameters are from 12.5 up to 50 cm, with field of view on several degrees.

The old telescopes with diameters from 60 cm up to 2.6 m have been modernized and using in the network. Most of these telescopes have been equipped with modern CCD-cameras, mainly manufactured by firm Finger Lakes Instrument (FLI) in USA.

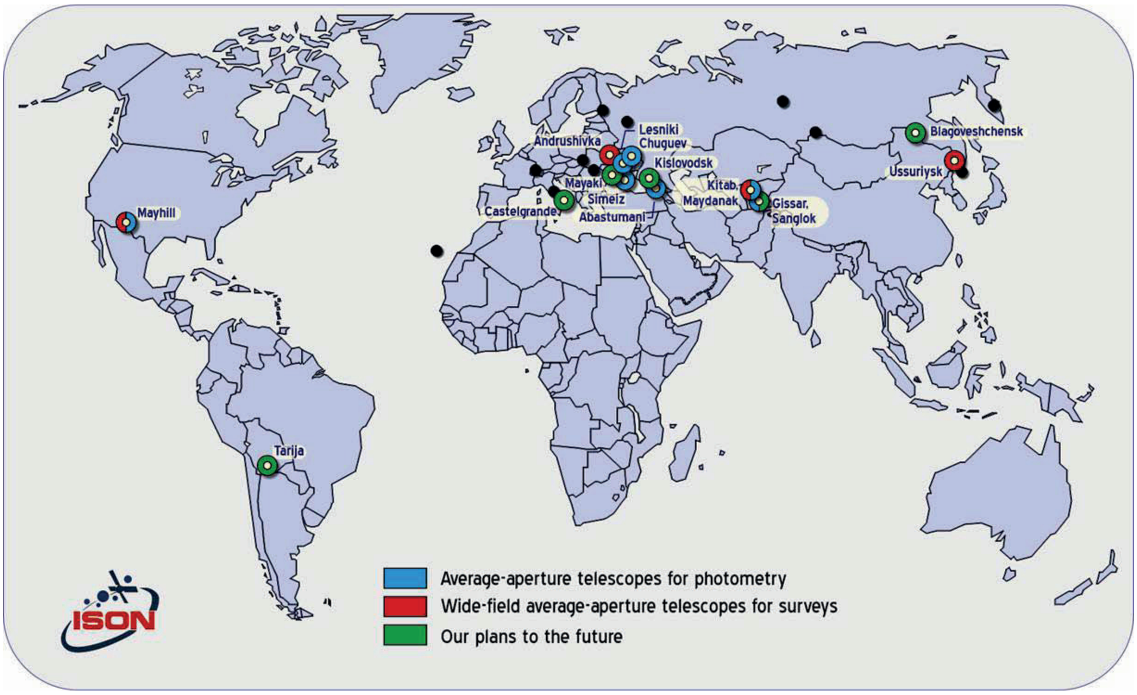


Fig. 1 – Map of observatories in the network involved in asteroid’s observations. Tree colors show telescopes involved in photometry and searching NEAs, and also future plans of the ISON.

2. Kharkiv Program: CCD Observations of Near-Earth Asteroids

CCD observations of NEAs were started at the Chuguev Observing Station of the Kharkiv National University in frame of cooperation with the Institute for Planetary Exploration (DLR, Berlin). The joint project aimed at solving the Asteroid Hazard problem was started. It was the first European initiative in this direction: establishing European Near-Earth Asteroid Observatory (EUNEASO). The 0.7-m telescope was equipped with CCD camera and began carrying out photometry and astrometry of NEAs in 1995. Since 1996 the Program is carried out jointly with the Crimean Astrophysical Observatory (CrAO). The 1-m telescope with CCD camera is used at Simeiz Observatory (Department of CrAO).

Main aims of the Program are to obtain physical parameters of NEAs by photometry: rotation properties, surface properties, diameters, and shape models, and to do follow-up astrometry and photometry of newly discovered NEAs (Krugly et al., 2002).

Up to 2005 in frame of the Program it has been observed more than 100 NEAs and obtained in result:

- more than 500 lightcurves
- rotational periods for 60 (45 for the first time)
- absolute magnitudes for 60
- binary asteroids observations (6)
- constrained photometric models (6)

3. Asteroid observations in frame of ISON

3.1 Asteroid Photometry

Since 2006 the Asteroid Group at the Institute of Astronomy of the Kharkiv National University cooperates with ISON. Now several ISON's observatories are involved in asteroid photometry (see Fig. 1). The process of creating a subnet for photometry is in progress. This subnet includes 2.6-m telescope of CrAO (Nauchnyi, Crimea, Ukraine), 2-m telescope of the Rozhen Observatory (Bulgaria), 1.5-m and 60-cm telescopes of the Maidanak Observatory (Uzbekistan), 1-m telescope o Simeiz Observatory (Crimea, Ukraine), 70-cm telescope of Chuguev Observatory (Ukraine), 70-cm telescope of Gissar Observatory (Tajikistan), 70-cm telescope of the Kiev Comet Station (Ukraine), 1.25-m and 70-cm telescopes of Abastumani Observatory (Georgia).

The main directions of the photometric researches:

- Physical properties of the NEAs
- Observations of newly discovered NEAs and Potentially Hazardous Asteroids (PHAs)
- Searching for binary asteroids and determining parameters of the binary systems
- Support in optics of asteroid's radar observations
- Investigation of the Yarkovsky-O'Keeffe-Radzievskii-Paddack effect (YORP effect) – the effect's influence on rotations of asteroids

3.3 Subset of ISON for NEA Searching

Since 2010 in frame of ISON the asteroid's surveys have been started in two sites:

- Andrushivka Observatory: 60-cm telescope (field 1°, upgraded in April 2010);
- ISON New Mexico Observatory: 46-cm telescope (1.65°, worked since July 2010).

Also the surveys are planned to start at the Kitab Observatory: 40 cm telescope (2.3°, February 2011), and at the Ussurijsk Observatory: 50 cm telescope (1.8°, February 2011).

In results of the first months observations at the ISON New Mexico Observatory: about 3000 sq. degrees of the sky were surveyed, thousands asteroids were measured, hundreds asteroids were rediscovered, and tens of the main-belt asteroids, two Mars-crossers, and one NEA (2010 RN80) were discovered. Statistic of the asteroid astrometric observations at the Andrushivka and the ISON New Mexico observatories is included in Table 1.

Table 1 –Statistic of observed and discovered asteroids within ISON surveys

ISON-NM (H15)	Number of measurements	Measured objects	Discovered objects	Observing nights
August	**7 777**	1 861	7	19
September	9 502	2 232	6	16
October- November	25 545	5 943	81	59

TOTAL:	**42 824**	**10 036**	**94**	**94**
Andrushivka (A50)	**Number of measurements**	**Measured objects**	**Discovered objects**	**Observing nights**
August	*1 167*	367	2	10
September	*3 768*	1 196	3	9
October- November	6 643	1 997	14	14
TOTAL:	**11 578**	**3 560**	**19**	**33**

4. Conclusion

Directions of ISON improvements and outlook:

- Since 2010 the ISON participates in the Roscosmos' project "Automated System for Prediction and Warning on the Dangerous Situations in the Near-Earth Space". A few more observatories will be established and several telescopes installed.

- Formation of two new subsets for NEA observations – for searching observations and photometry.

- Establishing a few more observation facilities in Western/South Hemisphere. In 2010 ISON's expeditions visited Argentina, Bolivia, Brazil, Mexico, Venezuela, and Mongolia, and have a plan to visit Chile and South Africa.

- Modernization of old telescopes (with an aperture from 60-cm up to 2.6 m) and/or their equipping with CCD cameras.

We hope to be involved in the Gaia Follow-Up Network for observations of Solar System Object and to make a contribution to the study of the Solar system bodies within this project.

References

Krugly Yu.N., Belskaya I.N., Shevchenko V.G., at al.: 2002, CCD Photometry of Near-Earth asteroids in 1996-1999, Icarus 158, 294-304.

Molotov I.E., Agapov V.M., Kouprianov V.V., et al. : 2009, International Scientific Optical Network, Izvestia of Pulkovo Observatory 6, No.1, 231-248.

Science Alerts with Gaia

Mignard, F.

Univ. Nice-Sophia Antipolis, CNRS Laboratoire Cassiopée, Observatoire de la Côte d'Azur, Le Mont Gros, BP 4229, 06304, Nice, France

Introduction

Gaia is before all a survey mission designed to observe the sky in a continuous manner. The sky coverage results from the spin of the satellite over a period of 6h, combined with a much slower motion of the spin axis, allowing after six months complete sky coverage. The CCD counts are stored on-board and sent to the ground station every day during the visibility period of the spacecraft by the ground antenna. The satellite design has been optimized for a survey mission, with ground treatment and not for an immediate access to the data, let alone to some scientifically immediately usable information. The processing comprises several more or less independent pipelines, each involving some sort of global processing requiring the accumulation of a substantial amount of data over several weeks or months. However, it remains possible to carry out a quick, but crude in regard of the accuracy achievable on a longer term, analysis of the data stream arriving on the ground to detect transient phenomena, like photometric burst or fast motion of solar system objects. This dedicated processing, largely distinct from the general processing, and the associated validation systems put in place, is referred to as *Science Alerts* within the DPAC community.

1. The Gaia Science Alerts

1.1. Constraints set by the Gaia observing principle

Compared to the baseline observing principle of Gaia, the distinguished feature of the Science Alerts mode is the need of a short reaction time. To understand this constraint it is useful to delve into the timeline between the data acquisition and the earliest availability of alerts information.

In its survey mode, Gaia observed continuously with an internal detection system allowing achieving astrometric and photometric observations for every sufficiently point-like source brighter than V~ 20. The spectroscopic survey does not go fainter than V ~ 15-17, according to the stellar type, being more efficient in the redder part of the spectrum. Gaia is not a pointing mission with adjustable integration time to the source brightness and it is operated with a well defined and fixed scanning law. Upon receiving the raw data collected on-board a quick initial and simplified treatment can be done within 24h, using the best current knowledge of the instrument parameters and solving for the satellite attitude with 1D astrometry. The Alert system will work only on the basis of this short timescale processing, ending with a selection of alert events.

1.2. Definition of a Gaia Science Alert

In a very generic way, one can define a Gaia Science Alert (GSA) ad **a piece of science data that would have little or no value without quick ground-based follow up**. Typically a transient photometric event evidenced in the Gaia data, or a fast-moving solar system object without known orbit. In both cases, something scientifically interesting is spotted, but there is no possibility to monitor the event further with the spacecraft. The only way to possibly benefit from this observation will be to set off quickly additional observations from the ground to sample the time-varying phenomena.

This definition implies several general features attached to a Gaia Science Alert:

- an alert must be produced by the near-real time processing
- an alert is released to the science community by the Gaia scientists
- it needs a quick ground-based monitoring
- astrometry, photometry and possibly spectroscopy could be the source of a Gaia Alert
- immediate follow-up needs the participation of the astronomical community
- alerts will be intermingled with false alerts, whatever the quality of the Gaia validation system.

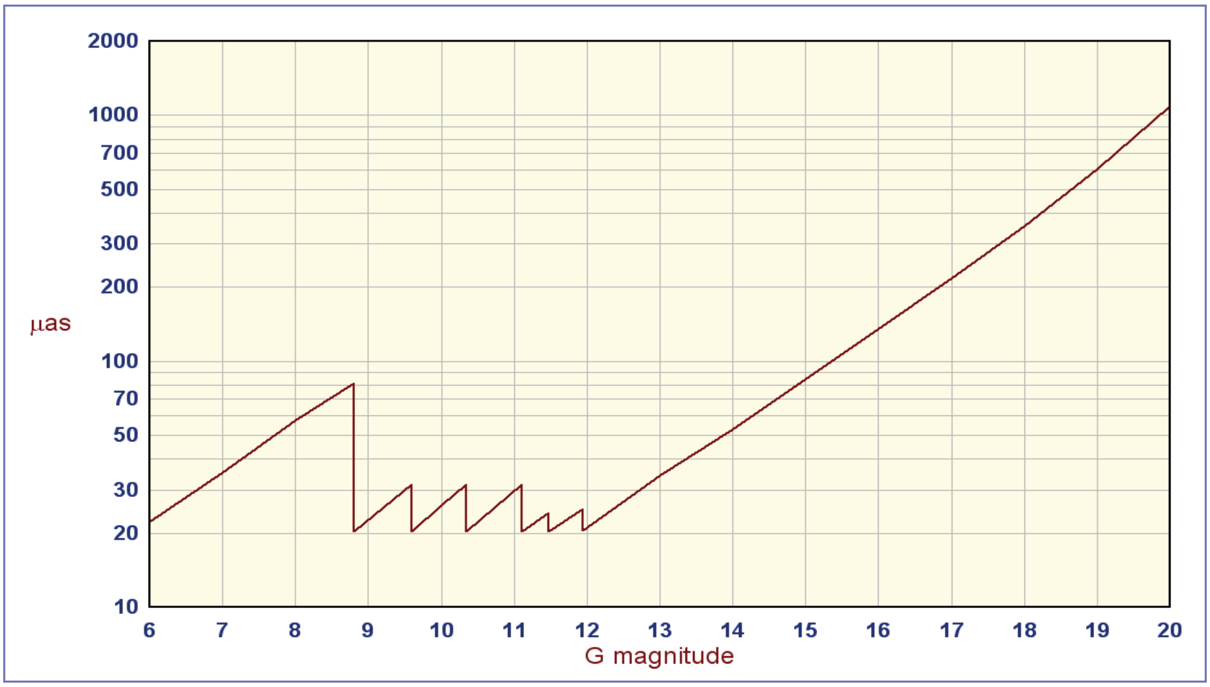


Fig. 1 – Astrometric accuracy expected over one transit of a point-like source. This is 1D accuracy along the scan direction.

2. The Astrometric and Photometric Science Alerts

2.1. Astrometric alerts

The only valid alerts of this kind will come from the observation of fast moving solar system object, typically NEO moving with angular velocity above 50 mas per second. Over a transit of 40s on a Gaia FOV, this translates into a shift of several pixels in the scanning direction and should be easily seen in the data. The local astrometric accuracy at this level is shown in Fig. 1, where the saw-tooth shape near the bright end follows from the handling of the CCD saturation. Most of the alerts, if not all, will come out with rather faint objects, fainter than V~ 18, giving a small field astrometric accuracy slightly better than one mas.

With the current calibration and the available attitude reconstruction done in nearly real-time, the position on the sky should be obtained with a 50 to 100 mas accuracy, in apparent direction as seen from Gaia. This is sufficient to match the observations to precomputed positions of all the already catalogued minor bodies and decide whether a genuine new object has been detected.

Correcting for the contribution of Gaia velocity to aberration won't be a problem, but without knowing the actual distance of the object, there is no accurate way to compute the light-time. For the same reason, the geocentric direction cannot be estimated without an assumption on the true position of the source. The shift at the time the object has been observed could be as large as one degree for a NEO at a distance less than one AU. On top of that, there will be the displacement between the observation by Gaia and the trigger of the alert, at least one day, meaning another degree shift.

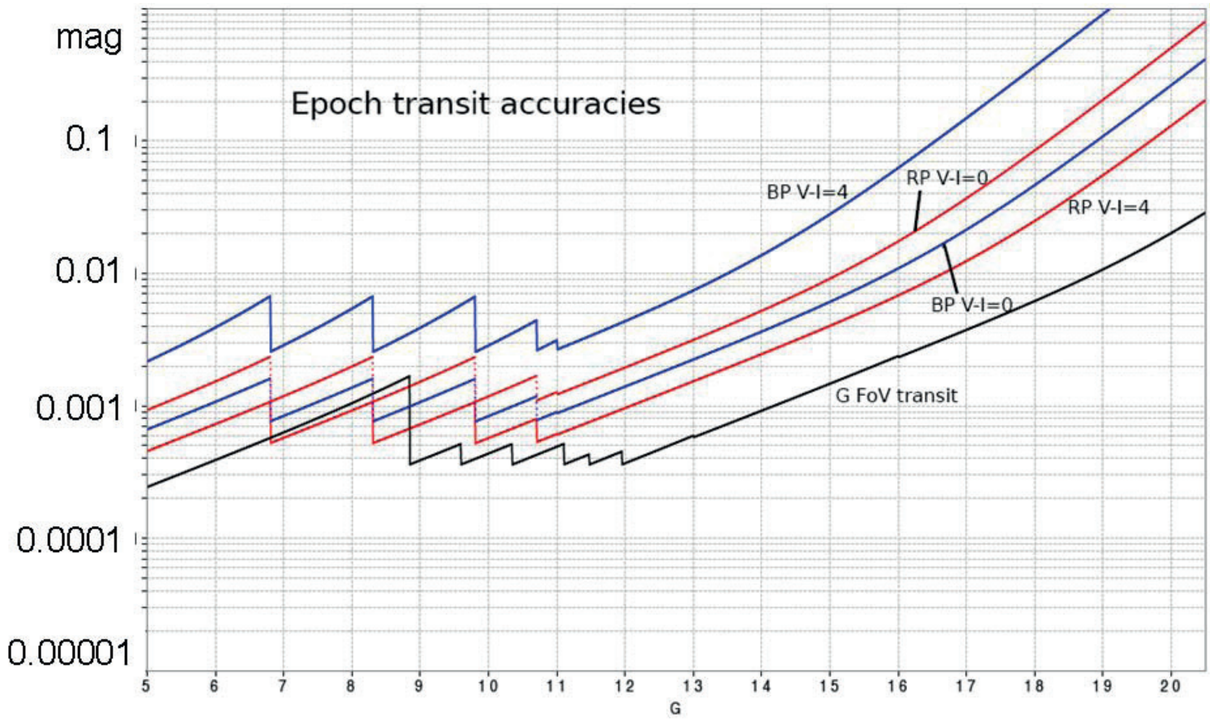


Fig. 2 – Photometric accuracy expected over one transit with the Gaia photometers. The G-band refers to the full light measurement on the astrometric CCDs.
(Fig: Courtesy of D.W. Evans)

2.2. Photometric Alerts

Photometric alerts are triggered by anomalous and unaccounted change in the light flux received from the observed sources, including that coming from new sources. The main photometric information comes from the Gaia astrometric CCDs in broad light, referred to as the G-band or equivalently the G magnitude. Another source is based on a low resolution spectrophotometer delivering two integrated magnitude in the blue and red bands. Alert will be based only on the G-band data, which is the most accurate, as illustrated in Fig. 2. The data received for the initial processing are uncalibrated and must enter first into a photometric pipeline to remove the instrumental effects and compute a magnitude in a well and stable photometric system.

Anomaly detection with an "old source" will rely on the history of that source, ideally incorporating both Gaia observations collected so far and historic ground-based data. Within a single processing batch of data we will investigate the most current observed transits (usually one or two) for each object by comparing them to the available historic measurements. The vast majority of the photometric changes will not trigger an alert to the community, but will have to be classified to eliminate all the known sources of variability, before one reach sufficient certainty that there is something worth to look at from the ground. The filtering will have to find the right balance to maintain the level of false alerts at an acceptable level and a period of internal validation will be necessary to set the various filters.

3. Basic time-line for the alerts

Compared to the baseline observing principle of Gaia, the distinguished feature of the Science Alerts mode is the need of a short reaction time. To understand this constraint it is useful to delve into the timeline between the data acquisition and the earliest availability of alerts information. The top-level description is shown in Fig. 3, sketching out the raw data flow within one operational day. An operational day starts at the end of the visibility period, when the data are acquired and no longer transmitted in real time to the ground and ends about 24h later, when the data stored during this day have been transmitted. The visibility period lasts on the average eight hours (longer in summer, shorter in winter as the declination of L2 is just the opposite of that of the sun), with the baseline of using a single ground station. When the transmission starts, there is about 16h of observations stored on board on the solid state memory to be downlinked during the next eight hours, together with the observations performed during this period.

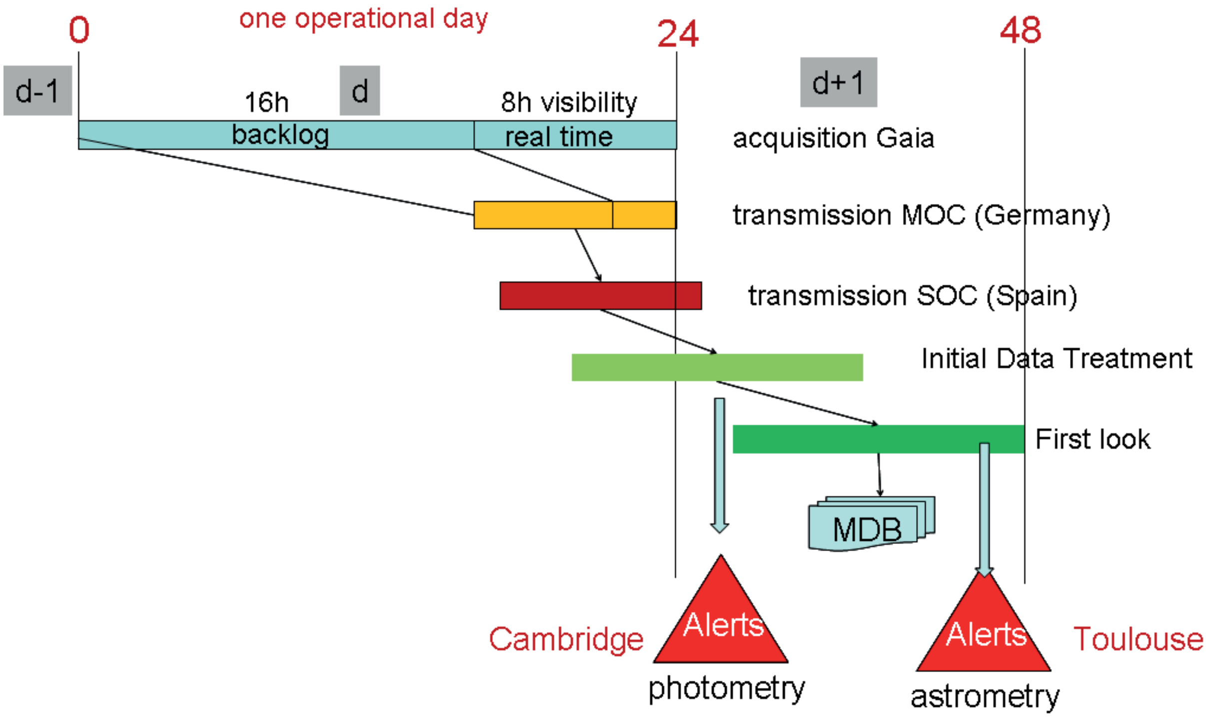


Fig. 3 – Short timescale data flow from the on-board acquisition to the alert production. The Initial Data Treatment processes the elementary images with local centroiding and photometry, while the First Look delivers the first astrometric solution.

Data are received by the ESA Mission Operation Centre (MOC) and then sent to the Science Operation Centre (SOC) near Madrid. They are in the form of telemetry packets in binary form and must be decompressed and rearranged to enter the DPAC first step of the processing. This Initial Data Treatment will isolate the CCD counts of each source detected on board and produce the raw image parameters (centroid of images, flux and background) and compute a first on-ground attitude, starting from the crude on-board star tracking. Observations will be cross-matched with the current best Gaia star list, to pair the observation to a source. This will fail for solar system objects at this stage, as the identifying tool is too heavy to be used during this phase (there are too many stars compared to planets to be effective). Normally, the unpaired observations should be essentially solar system objects, but there will be many exceptions to the rule.

Photometric data will be available first, since they do not require an attitude solution and are readily available in the form of uncalibrated fluxes. They are sent to the DPAC photometric data centre at Cambridge as soon they are available from the initial processing, in near real time. The astrometric data are available some time after when an attitude solution has been computed and are sent to the CNES computing centre in Toulouse where they enter a dedicated pipeline for the processing of solar system objects.

Astrometric Observations at the Konkoly Observatory: Prospects for Gaia Solar System Follow-Up

Kiss, L.L., Sárneczky, K.

Konkoly Observatory of the Hungarian Academy of Sciences
Budapest, Hungary
kiss@konkoly.hu

Introduction

The Konkoly Observatory of the Hungarian Academy of Sciences is the largest astronomical research institute in Hungary, with about 40 staff member scientists. The observatory, located in Budapest (Hungary), was founded in 1871 as the private observatory of Miklós Konkoly Thege. Together with the Heliophysical Observatory in Debrecen, it forms the main astrophysical institute of the Hungarian Academy of Sciences. Research includes observations with our 0.5-1 m class optical telescopes in Budapest and at the Piszkéstető Mountain Station, theoretical works and involvement in space projects. Konkoly Observatory issues the bulletin series Communications of the Konkoly Observatory, and edits the Information Bulletin on Variable Stars of the International Astronomical Union.

The actively studied research areas include:

- variable stars: stellar pulsations, asteroseismology (ground based, CoRoT, Kepler), stellar activity, eclipsing binaries;
- interstellar matter, star formation;
- small bodies in the Solar System (ground based astrometry, comets with HST/Spitzer, trans-Neptunian objects with Herschel);
- exoplanets;
- gamma-ray bursts.

Recently, we have started an extensive modernisation of the telescopes at the Piszkéstető Station, including upgrading the CCD imaging capabilities, the telescope control systems and installing a new, fully robotic 0.4m RC telescope for remote-controlled and autonomous CCD imaging. Here we briefly overview our current involvement in the Gaia preparations, the relevant information on the available instrumentation for the proposed Gaia Solar System follow-up work and some of the achievements in astrometry.

1. Current participation in the Gaia program

The Konkoly Gaia team, led by Dr. László Szabados, has been involved in the following projects:

- *DPAC Ground Based Observations for Gaia:* CU7 Specific Object Studies Working Group (Cepheids & RR Lyrae stars, secular evolution); Gaia Science Alerts Working Group.

- *Gaia Research for European Astronomy Training (GREAT):* Gaia Alerts, Distance Scales, Stellar Variability, Binaries & Multiple Systems.

These works have been funded by ESA and the Hungarian Space Office, through the PECS programme. However, the Solar System and Gaia have not yet been connected at the Konkoly and our intention is the change this situation.

2. Telescopes and instruments

The Piszkéstető Mountain Station is located approximately 80 kms from the capital city of Budapest, at 956 m above the sea level. Yearly we have about 150-180 useful nights, half of which are photometric for at least half of the dark time. The median seeing is between 2" and 3". For over 36 years there have been three telescopes mounted at Piszkéstető:

1. 0.5m Cassegrain-type telescope, equipped with a photoelectric photometer. This telescope was the main workhorse for observing bright variable stars.

2. 0.6m 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 (M. Lovas and collaborators).

3. 1m Ritchey-Chrétien-Coudé telescope, used for photoelectric and CCD photometry.

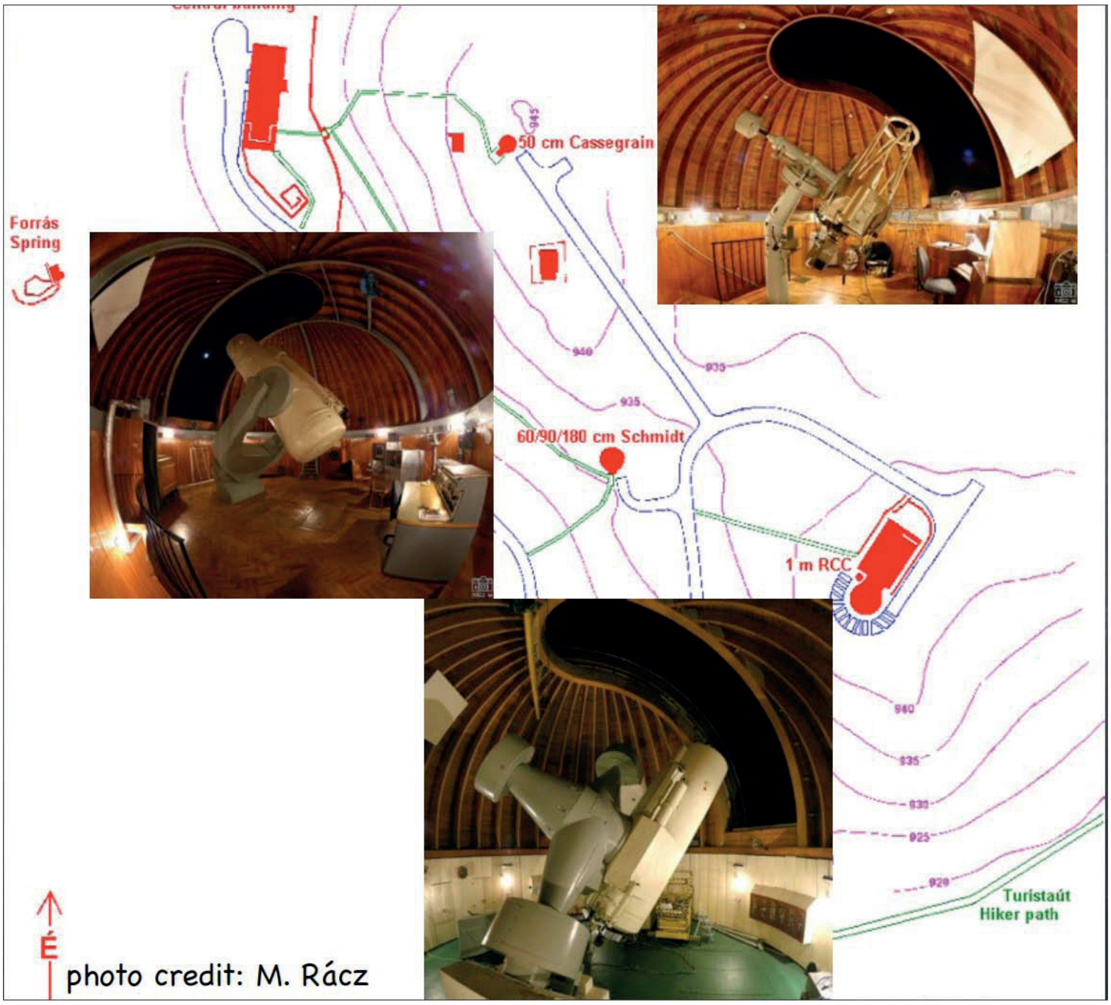


Fig. 1 – The three Zeiss-telescopes at the Piszkéstető Station

All of these telescopes 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 that are partly interchangeable between the 0.5m Cassegrain and the 1m RCC.

Almost four decades after completing the 1m RCC, in 2010 we installed a new remote-controlled 0.4m RC telescope. The main program on this small telescope consists of CCD photometric follow-up of known transiting exoplanets but we also envisage possible uses in Solar System studies.

3. Astrometric results

The most effective astrometric instrument is the 60/90/180cm Schmidt telescope that was equipped with a Photometrics 1.5k x 1k CCD between 1996 and 2010. In 2010, this camera was replaced by an Apogee Alta U16 4k x 4k CCD, which captured a 1.2 x 1.2 deg 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 (see Fig. 2).

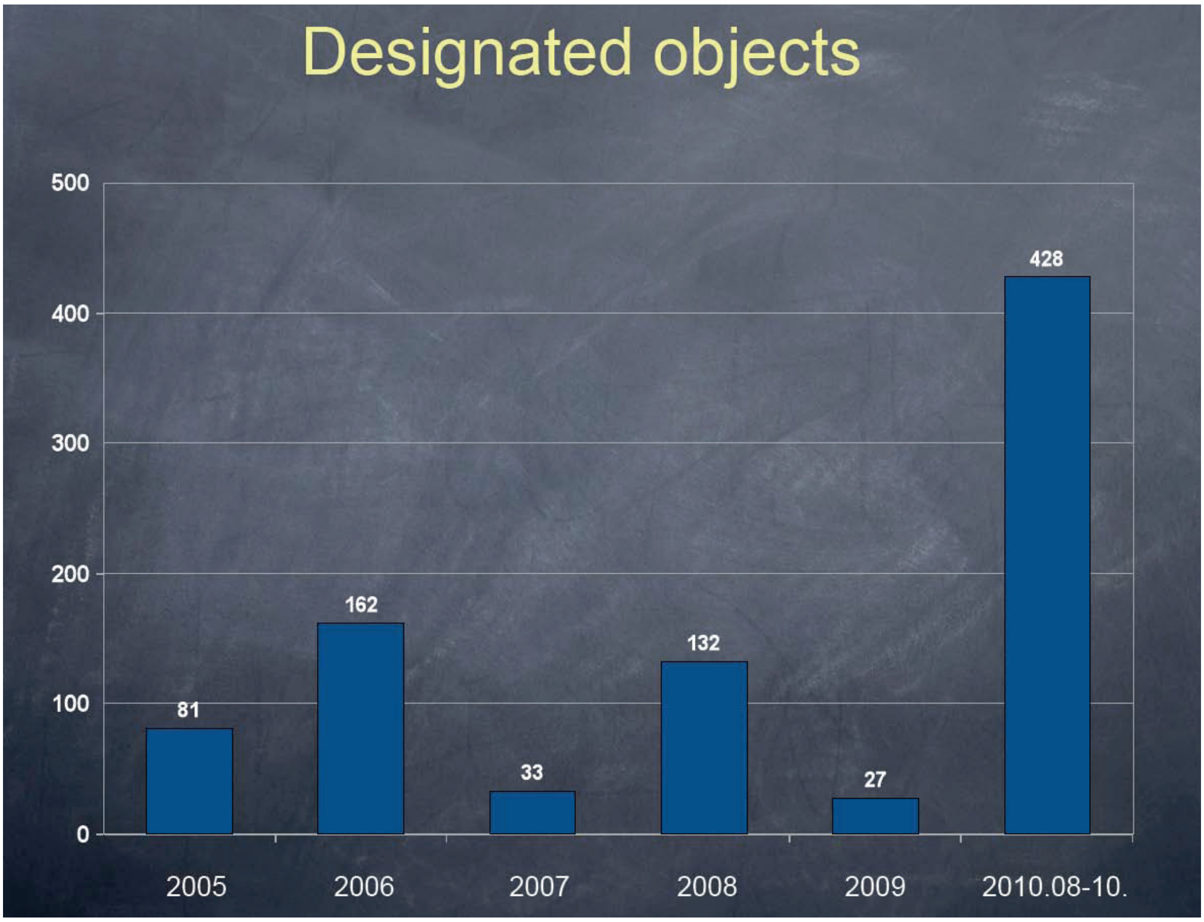


Fig. 2 – The total number of MPC-designated minor planets, discovered by K. Sárneczky and collaborators using the 0.6m Schmidt telescope. The last column shows the jump in survey efficiency that has been caused by the new CCD.

There has been a very successful astrometric program since 1998, led by K. Sárneczky. The observations, reported under the Minor Planet Center observatory code 461, were originally aimed the MPC unusual minor planets and NEO confirmations. Later, this has been extended by observations of Centaurs and distant cometary activity, while follow-up astrometry of the newly discovered minor asteroids was always important to avoid lost minor planets. The results of this work have been published in over 300 Minor Planet Electronic Circulars (MPECs), about 70 IAU Circulars (IAUCs) and 5 Central Bureau Electronic Telegrams (CBETs). 19th to 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.

Summary

The Piszkéstető Station is located at the western edge of a sparsely covered geographic longitude, with the closest telescopes resembling our Schmidt in aperture and field of view located in the middle of Asia. Hence we could provide crucial coverage when fast reaction to Gaia alerts will be of paramount importance.

We have an excellent track record in astrometry. Despite the fact that there was no dedicated telescope time for minor planet observations, our program has discovered many hundreds of new minor planets and detected thousands of known ones. We have all the necessary expertise and experience for obtaining accurate ground based astrometry of fast moving objects.

Moreover, recently finished and planned new upgrades in instrumentation make the site very suitable to provide astrometric support to Gaia. Most importantly, both the 0.6m Schmidt and the 1m RCC telescopes will be upgraded to remote-controlled instruments, meaning that the reaction time to rapid alerts will be sufficiently short.

Finally, there is also strong willingness to join the efforts. Providing valuable ground based support for cutting edge space projects is one of the golden ways to keep small national astronomical facilities in the most vibrant fields of research, an opportunity that has to be taken seriously in all circumstances.

Acknowledgements

LLK gratefully acknowledges financial support from the European Space Agency (ESA) and the Hungarian Space Office with the PECS programme (contract No. 98090). 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.

Astrometric and Photometric Observations of Solar System Bodies with Telescopes of Pulkovo Observatory

Devyatkin, A.V., Vereshchagina, I.A., Sokov, E.N., Gorshanov, D.L., Romas, E.S., Aleshkina, E.J., Slesarenko, V.J., Karashevich, S.V., Bechteva, A.S., Naumov, K.N., Kouprianov, V.V., Zinoviev, S.V., Ivanov, A.V.

Pulkovo Observatory, Russia, Saint-Petersburg, Pulkovskoye chaussee 65

Introduction

The Laboratory of Observational Astrometry of the Central (Pulkovo) Observatory of RAS makes observations of minor bodies of Solar System, such as Near Earth Objects (NEOs), Main belt asteroids, binary and multiple asteroids, comets, natural satellites of Jupiter and Saturn. Also observations of exoplanets, variable stars and search for gamma ray bursts afterglows are made. The observations are carried out with MTM-500M telescope, placed on Mount Astronomical Station of Pulkovo observatory (Northern Caucasus), and ZA-320M mirror astrograph of Pulkovo observatory.

In the Laboratory, investigations are carried on among the following topics: improvement of asteroid and comet orbits; photometry of minor bodies and their physical parameters definition; modeling of binary and multiple asteroids and their lightcurves; astrometry and physical parameters definition of the satellites of Jupiter and Saturn; observations of exoplanet transits.

1. Telescopes

MTM-500M telescope (Maksutov reflector, $D = 500$ mm, $F = 4100$ mm) is located in the Mount Astronomical station of Pulkovo Observatory at Northern Caucasus ($\lambda = 42° 40'$, $\varphi = 43° 44'$, $h = 2070$ m). It is equipped with SBIG ST-L 1001E CCD camera (1024×1024 pix., 24×24 µm, pixel size = 1.19 arcsec/pix, *BVRI* filters, field of view ≈ 21' × 21', limiting magnitude - 21^m).

ZA-320M telescope (Cassegrein reflector, $D = 320$ mm, $F = 3200$ mm) is located in the Pulkovo Observatory at Saint-Petersburg ($\lambda = 30° 19'$, $\varphi = 59° 46'$, $h = 75$ m). It is equipped with FLI IMG 1001E CCD camera (1024×1024 pix., 24×24 µm, pixel size = 1.54 arcsec/pix, *BVRI* filters, field of view ≈ 28' × 28', limiting magnitude – 18.5^m).

2. Research of Near Earth Objects and binary and multiple asteroids

2.1 Discovering

With MTM-500M telescope, 4 asteroids (2010 UP67, 2010 XA15, 2010 XL46, 2010 XM46) were discovered, 1 comet (P/2004 F3 = P/2010 V2 = 246P/NEAT, 20.5^m) and 3 asteroids (2004 TR356, 2008 EG30, 2008 FM60) were rediscovered.

2.2 Research and observations of 2008 TC3 asteroid impacted to the Earth in 7 October 2008

On October 6, 2008, at 6h 39m UTC in the Mount Lemmon Observatory in Arizona, Richard Kowalski discovered a small asteroid approaching Earth. The first calculations of its orbit showed that the asteroid would fall to Earth 19 hours after its discovery, presumably in northern Sudan (Jenniskens et al., 2009). 26 observatories all over the world made more than 800 observations of the asteroid, which was named 2008 TC3. A one third of them were made with the mirror astrograph ZA-320M at the Pulkovo observatory. Based on the analysis of observations, physical parameters of the asteroid were assessed (Aleshkina et al, 2011). The estimates of the absolute magnitude of the asteroid M = 30.6 ± 0.4^m, its size 4.8 ± 0.8 meters, and weight 131 ±5 ton were obtained. The frequency analysis of each observational series using three methods has showed that a total period of 48.6 ± 0.6 sec with the amplitude of 0.27 ± 0.08^m presents in all series. The trajectory of the asteroid was simulated (Fig. 1).

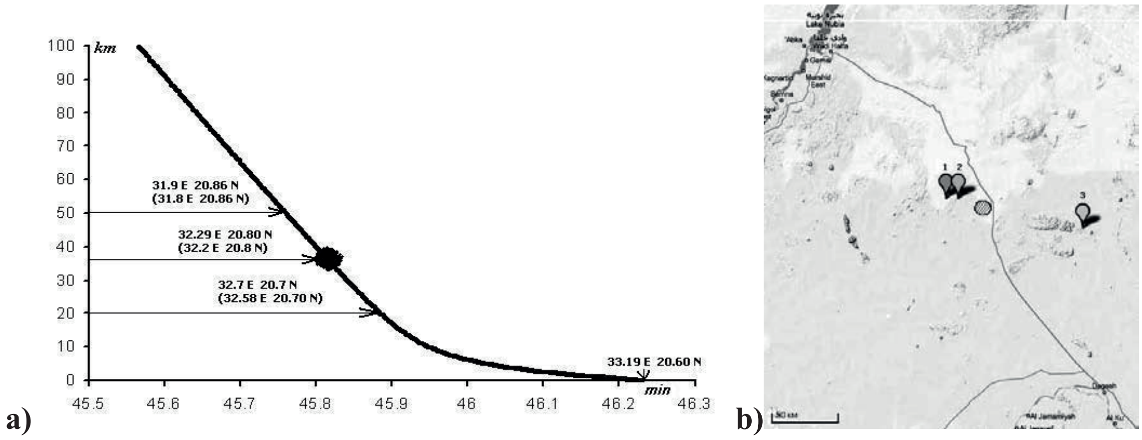


Fig. 1 – a) Estimated descent trajectory of the asteroid 2008 TC3 to the Earth. The vertical axis represents the altitude in kilometers. The horizontal axis represents the moments of time in minutes from 2 h UTC of October 7, 2008. The explosion site at the altitude of 37 km and geographic coordinates (latitude and longitude) of the asteroid at the altitudes of 50, 37, and 20 km are indicated. For comparison, the corresponding coordinate values, recorded by meteorological satellites, are given in parentheses. The coordinates of the probable asteroid impact point in the absence of the explosion are also designated; **b)** Map of the asteroid 2008 TC3 impact area. 1 is the site of the asteroid explosion at the altitude of 37 km according to the meteorological satellite observation, 2 is the location of the asteroid at the altitude of 37 km for the model trajectory, 3 is the location of the asteroid at the altitude of 0 km for the model trajectories assuming that the explosion had not happened. The shaded circle is the impact area of asteroid fragments.

2.3 Research of binary 2006 VV2 asteroid

For this asteroid, the color indices, the absolute magnitude and its possible taxonomy class A were determined on the basis of our observations (Vereshchagina et al, 2009). Based on these results, the density of the system was estimated (2.71 ± 0.04 g/cm^3). Using this value, estimates of the components masses were obtained (Table 1). Evaluation of the main component shape of the asteroid was determined, the position of the pole of rotation was defined and the period of axial rotation was specified (Table 2). Figure 1 shows the obtained shape of the main component in three different viewpoints.

Table 1 – Estimates of the components masses of the 2006 VV2 asteroid in assumption that its density is 2.71 ± 0.04 g/cm^3 (classes A, Q, V).

	Mass, kg
Main component	$8.275 \times 10^{12} \pm 0.122 \times 10^{12}$
Satellite	$1.77 \times 10^{11} \pm 0.03 \times 10^{11}$
System mass	$8.45 \times 10^{12} \pm 0.13 \times 10^{12}$

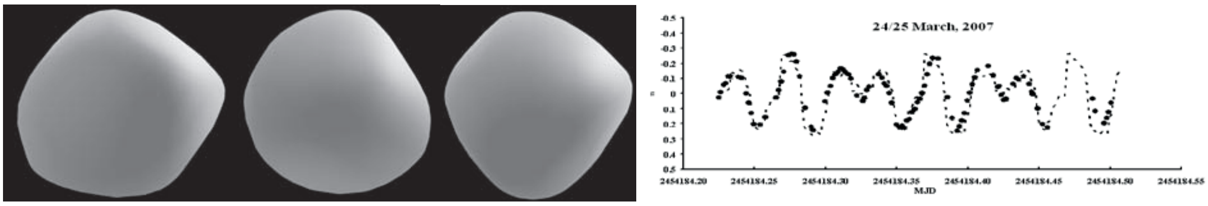


Fig. 2 – The shape of the main component of the 2006 VV2 asteroid shown in the three different viewpoints (left), and observed lightcurves of 2006 VV2 asteroid (black circles) in comparison with the model lightcurve (right).

Table 2 – Estimates of the ecliptic coordinates of the pole, the rotation period and the dimensions of the main component of the 2006 VV2 asteroid.

β, °	**λ, °**	***P*, h**
37 ± 2	29 ± 3	2.410541 ± 0.000003
Dimensions *a* × *b* × *c*, km	0.92 × 0.89 × 0.89 ± 0.05	

Table 3 – Elements of stable orbit of 2006 VV2 asteroid. Also estimates of orbital parameters taken from IAU Circular 8826, 2007 are presented.

	Semimajor axis *a*, km	**Eccentricity, *e***	**Inclination, *i*, °**	**Period *P*, h**
IAU Circular 8826, 2007	≥ 1.5	-	-	~ 5
Our results	1.9 ± 0.2	0.10 ± 0.06	0.0 ± 0.002	6.1 ± 0.2

The obtained shape and estimates of the masses allow determining the possible stable orbit of its satellite. It is the closest orbit to the data of radar observations (Table 3).

2.4 Research of 2009 WZ104 asteroid

The 2009 WZ104 asteroid was attributed as potentially hazardous near Earth asteroid. The minimal orbit intersection distance is 0.0304 a.e. The observations were made in the framework of NEOs investigation program. The following research-work were made for this asteroid: getting astrometric and photometric (in *BVRI* bands) series of observations, improving the asteroid orbit on the base of the observational data, determining its taxonomic class and absolute magnitude, investigating the dynamics of its rotation, estimating its physical parameters. The asteroid was attributed to Aten group.

2.5 Research of triple main belt 45 Eugenia asteroid

For this asteroid, shape of its main component has been refined. Direct image of the main component obtained with the Keck II telescope, the previous shape of main component (Marchis et al, 2006) and the new shape obtained in this work are shown in Fig. 3. One can see that the shape obtained in this work is in better agreement with observations than the previous one.

Fig. 3 – Left panel: The shape of the main component of the 45 Eugenia asteroid at three different viewpoints obtained in this work. **Central panel:** direct imaging of the main component of the 45 Eugenia asteroid, obtained with telescope with adaptive optics. **Right panel:** shape of the main component, obtained in [Marchis et al, 2006] (a) and shape of the main component obtained in this work (b).

Elements of the asteroid satellites stable orbits were found. For second satellite, the possible range of stable orbits begin since $a_2 = 1.65 \cdot a_1 = 1930$ km, where $a_1 = 1170$ km. Our model shows that the axis of rotation of the main component is in forced precession associated with the perturbation by the satellites, with an angle of 10 degrees and a period of 66 days. This fact explains the existing uncertainty in the inclination of main component rotation axis to the ecliptic (Marchis et al, 2006).

2.7 Research of binary main belt 762 Pulcova asteroid

For this asteroid, shape of its main component and the pole position of its rotation ($\beta = 71 \pm 3°$, $\lambda = 53 \pm 2°$) were identified using our observations. The resulting shape at three different viewpoints and the comparison of this shape with a direct image of an asteroid obtained with Keck II telescope (Merlin et al, 2000) is shows in Figure 4.

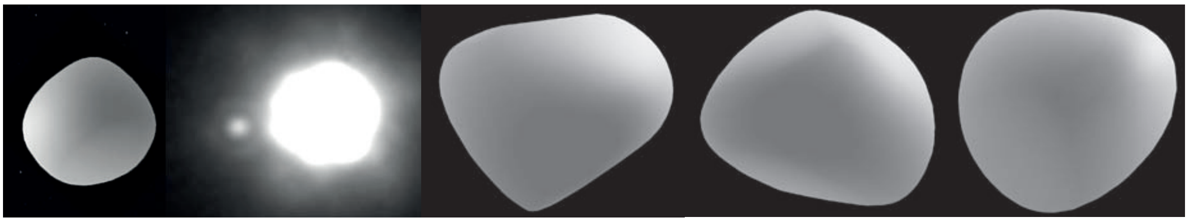


Fig. 4 – The shape of the main component of 762 Pulcova asteroid, obtained in this work, in three different viewpoints (left) and the shape of the main component of 762 Pulcova asteroid, obtained in this work, compared with a direct image of an asteroid obtained using a Keck II telescope with adaptive optics (right).

2.6 Research of binary main belt 90 Antiope asteroid

For this asteroid, light variations with a period of 0.54 years and an amplitude up to 2^m were discovered. These changes in brightness are due to the changes in phase angle and it deal with the features of the reflective properties of their surfaces (Vereshchagina et al, 2008). It was defined that a model lightcurve obtained using the Lumme-Bowell reflection law with the asymmetry factor $g = -0.8$ gives the best agreement with the observations. Also an estimation of slope-parameter for this asteroid was obtained ($G = 0.046 \pm 0.023$).

3. Mutual phenomena of satellites of Jupiter and Saturn

Since 1995, Pulkovo observatory participates in international campaign of observations of the mutual phenomena of satellites of Jupiter and Saturn. The Laboratory of observational astrometry had got data by the automated telescopes: ZA-320M — during 2002-2003; ZA-320M and MTM-500M — during 2008-2009. All observations were sent to IMCCE for further analysis. During the campaign PHEMU09 was carried out 25% of all observations made with Russian telescopes.

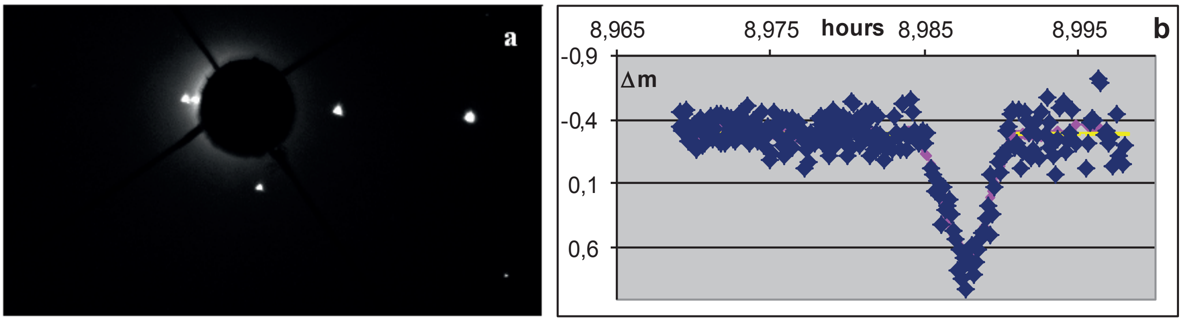


Fig. 5 – a) A frame of mutual phenomena with the use “planetary coronograph”; **b)** Graph of the mutual event Jup 1 Ecl 2.

4. Extra-solar planets

Our observations of extrasolar transit planets were started in the mid of 2010 and will be continued. During this time there were made a few observations of transits of extrasolar planets with telescopes MTM-500M and ZA-320M.

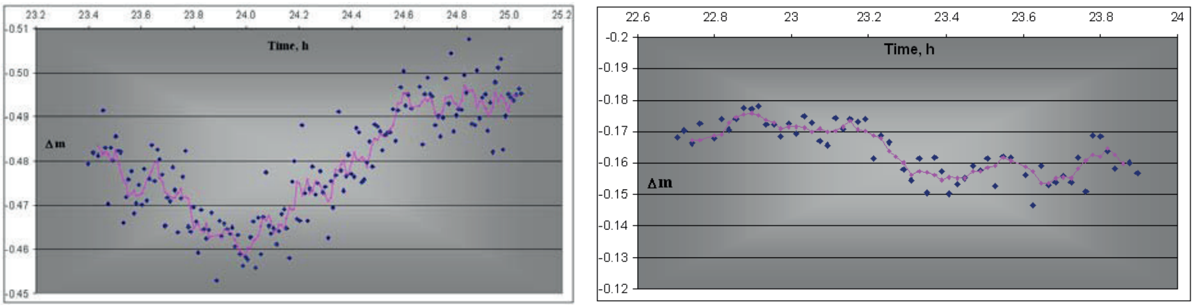


Fig. 6 – Lightcurves of the transiting exoplanets: TrES-3b (2010-07-30) observed with MTM-500M telescope (left) and WASP-12b (2010-10-12) – with ZA-320M telescope (right).

Conclusions

With the MTM-500M and ZA-320M telescopes its carried out observations of large number of the Minor Solar System bodies and other objects. These telescopes can participate in Gaia-FUN-SSO Network (Gaia follow-up network for the Solar System Objects).

References

Aleshkina E.Y., Kupriyanov V.V., Devyatkin A.V., Vereshchagina I.A., Slesarenko V.Yu., L’vov V.N., Tsekmeyster S.D.: 2011, Astrometric and Photometric Studies of the Asteroid 2008 TC3, Solar System Research, 45 (1), 34–42.

Jenniskens P., Shaddad M.H., Numan D. Elsir S. et al.: 2009, The impact and recovery of asteroid 2008 TC3, Nature, 458, 485-488.

Marchis F., Kaasalainen M., Hom E. et al.: 2006, Shape, size and multiplicity of main-belt asteroids, Icarus, 185 (1), 39-63.

Merlin W.J., Close L.M., Dumas C., Shelton J.C.: 2000, Discovery of Companions to Asteroids 762 Pulcova and 90 Antiope by Direct Imaging, Bulletin of the American Astronomical Society, 32, 10-17.

Vereshchagina I.A., Gorshanov D.L., Devyatkin A.V., Papushev P.G.: 2009, Some specific features of light curves of (39) Laetitia, (87) Sylvia, (90) Antiope and 2006 VV2 asteroids, Solar System Research, 43(4), 291-300.

Modern Observations of Solar Systems Bodies on 65 cm Pulkovo's Refractor

Shakht, N.A., Kiselev, A.A., Bykov, O.P., Grosheva, E.A., Izmailov, I.S., Kiyaeva, O.V., L'vov, V.N., Romanenko, L.G., Tsekmejster, S.D.

The Central (Pulkovo) Astronomical Observatory of Russian Academy of Sciences (Pulkovskoje shosse 65, St-Petersburg, Russia)

Introduction

Photographic observations of Solar system bodies started at Pulkovo since the end of XIX century. CCD-observations have been carried out with 65cm Zeiss refractor at Pulkovo since 1995. In 2007 the telescope was equipped with the CCD camera FLI Pro Line 09000 (field of view is 12×12 arcmin). In this paper we report about CCD observations of Solar system bodies with a 65-cm refractor at present. The accuracy estimations of observed positions and the used methods of detrmination of preliminary orbits are presented.

1. The observations, image processing and accuracy estimation

The coordinates of the observatory are 59°46′18.22″ N and 30°19′33.79″ E, its code is 084. The main technical parameters of refractor are as follows: diameter of objective D = 65 cm, focal distance of 10 413 mm gives the scale 19.80 arcsec/mm in the focal plane. The CCD chip is an array of 3056 × 3056 pixels where each pixel size is 12 μ or 0.24 arcsec. CCD images measurements have been carried out with the IZMCCD software package, see, Izmailov et al, (1998), Izmailov, (2005). To obtain the satellites equatorial coordinates we used the method by Turner for astrometric reduction along with the UCAC2 catalog, see Zacharias et al. (2004) as a reference one. The limit of magnitude of reference stars is about 19^{m}. The inner accuracy of astrometric reduction is determining by errors of reference stars coordinates and precision of measurements. RMS of obtained positions are 0.066 and 0.055 arcsec for tangential coordinates X and Y in average.

The estimation of external accuracy is made on a dispersion of differences observed coordinates and ephemerides. Ephemerides of major planet satellites have been given by a website "Natural Satellites Ephemeride Server MULTI-SAT" (Emel'yanov, Arlot, 2008). The theoretical positions of asteroids and minor planets are provided by "Asteroids Dynamic Site" (http://hamilton.dm.unipi.it/astdys/). The accuracy estimations for some solar system bodies observed with 65-cm refractor are presented at Table 1, where $\varepsilon = \sigma / \sqrt{N}$ and σ is standard deviation in arcsec. Residuals "O –C" for saturnian satellites had been obtained by comparison observed positions with the theoretical ones accordingly by TASS 1.7 theory (Vienne, Duriez , 1995).

2. Orbit determination

One of important aims of ground-based support for Gaia is to observe newly detected bodies of Solar system and obtain its preliminary orbits using ground-based observations. For determination of orbits two methods are applied.

Table 1 – Average residuals "O–C" and its errors.

Object	(O-C) $_{\alpha}$ cosδ	ε_{α}	(O-C)$_{\delta}$	ε_{δ}	σ_{α}	σ_{δ}
Titan (S6)	-0.010	0.025	-0.036	0.023	0.053	0.049
Hyperion (S7)	-0.057	0.027	-0.112	0.038	0.056	0.073
Iapetus (S8)	0.071	0.020	-0.007	0.022	0.040	0.045
221 Eos	-0.020	0.014	-0.120	0.016	0.032	0.035
742 Edisona	0.078	0.013	-0.047	0.012	0.028	0.027
1903 Adzhimushkaj	0.008	0.013	-0.151	0.016	0.029	0.034

1. We use the modification of Laplace method that resembles the Danjon scheme. It assumes the successive iterations where along with orbital elements the (O-C)α and (O-C)δ values also get polynomial representation. So the values of the first two derivatives become more reliable, and then obtained values of elements represent the observations at the level of their accuracy.

2. The Apparent Motion Parameters (AMP) method is directed to orbit determination from observations on a short arc. Method had been developed at Pulkovo in the beginning of 1970th (Kiselev, Bykov at al., 1970) in connection with visual and photographic observations of the Earth artificial satellites started in 1957 in the USSR. We used the AMP method of orbit determinations for following objects: artificial satellites, asteroids, double stars and stars rotating around black hole in the centre of our Galaxy. (See a short description in Shakht, Kiselev, 2008). The basic equations of this method for asteroid orbit are:

$$\mathbf{r} = r\,\mathbf{R} = g\,\mathbf{G} + d\,\mathbf{D}$$

$$\dot{\mathbf{r}} = v\,\mathbf{V} = v_{\oplus}\mathbf{V}_{\oplus} + \dot{d}\,\mathbf{D} + \mu\, d\,\mathbf{T}$$

where $r\,\mathbf{R}$, $g\,\mathbf{G}$ – heliocentric radius-vectors of asteroid and the Earth, $d\,\mathbf{D}$ - geocentric vector of the asteroid, d – geocentric distance to the asteroid, μ - apparent angular velocity of asteroid on celestial sphere, $v_{\oplus}$, $V_{\oplus}$ – velocity of asteroid with respect to the Earth, $\dot{d}\,\mathrm{D}$ – radial velocity of asteroid, $\mu\, d\,\mathbf{T}$ – transversal velocity of asteroid.

These methods were applied to orbits determination for selected asteroids of Pulkovo program and also for data of http://minorplanetcenter.org/iau/mpc.html. In some cases we had the possibility to estimate the orbital elements. As an example in the table 2 we give orbital elements of asteroid 221 Eos and comparison with data of Bowell, http://lowell.edu/pub/elgb.

On the fig. 1 an apparent track of the asteroid Eos 221 is present. It is calculated by EPOS program for the interval of time 10.04.2008–20.07.2008 in the area of sky: $11^{h}\,46^{m}$ – $12^{h}\,27^{m}$ in RA and 05° 38'–12° 54' in Dec. The red dots correspond to the short arc: 10.04. 2008 – 10.05. 2008 used for orbit's calculation. The results of orbit determination from the Pulkovo observations for asteroid 221 Eos are shown in the Table 2.

3. Pulkovo EPOS software package

The above mentioned methods of processing have been incorporated to the Pulkovo EPOS software package. EPOS (Ephemeris Program for Objects of the Solar system) is the effective application for study and ephemeris support of observations of the Solar system objects.

Table 2 – The orbital elements of 221 Eos.

Orbital elements	Laplace method	AMP method	Bowell,s data
ω°	195.992	195.673	195.083
Ω°	141.946	141.936	141.923
i°	10.891	10.888	10.88
e	0.104	0.104	0.105
a [a.e]	3.010	3.010	3.014

σ_{RA}, σ_{Dec} - the mean square deviations of one position corresponding for Laplace and AMP methods are following: σ_{RA} = 0"044; σ_{Dec} = 0".028 and σ_{RA} = 0".051; σ_{Dec} = 0".037.

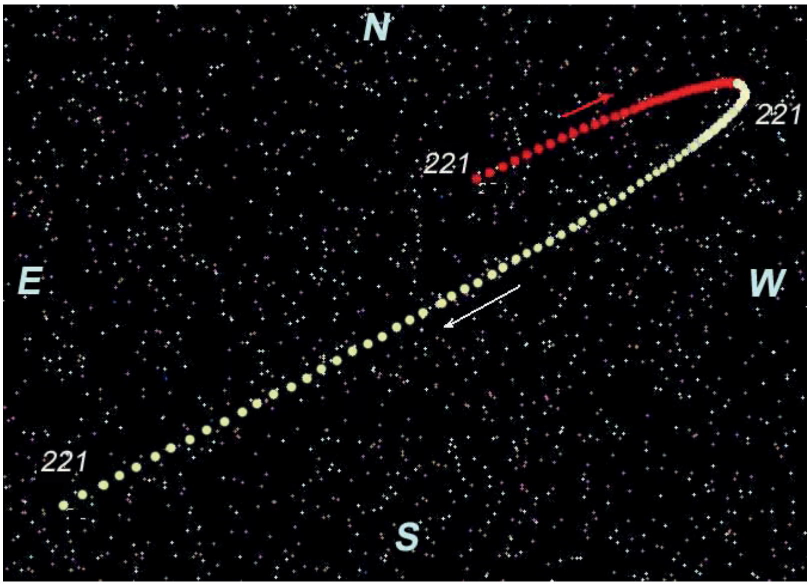


Fig. 1 – Apparent track of asteroid 221 Eos.

The orbital elements of asteroids and comets as well as the observatories coordinates obtained via Internet are used by EPOS. The application's work is also based on the data of modern numerical ephemerides of the Sun, Moon and planets (DE200/LE200, DE405/LE405, DE406/LE406) and star catalogs (Hipparcos, Tycho-2, USNO, UCAC2, etc.) that are distributed by the publishers. EPOS is intended for use under OS Windows. It has bilingual interface (English and Russian) and includes the following basic components:

1. This main program imports the observatories data and controls the use of various numerical ephemerides.
2. The "Catalogs of objects" program stores in the internal database the orbital elements and other parameters of the minor bodies of the Solar system (now more than 500000 asteroids and near 3000 comets).
3. The "Ephemerides" program calculates the ephemerides of various type and accuracy taking into account the perturbations from all planets and some asteroids.
4. The "O-C" program compares observed coordinates and velocities with the calculated ones and calculates the observational accuracy.
5. By the "Frame" program one can obtain the list of objects visible within specified sky area the specified moment.
6. The "Tracks" program visualizes the path of apparent motion of an object on the star background. One can search for apparent approaches of the Solar system objects to the stars and find the "loops" where the direction of the object's apparent motion radically changes.

7. The "Orbits" program visualizes the perturbed space motion of many objects and groups of objects along with their heliocentric orbits.
8. By the program "Hazardous Objects" one can get the current list of PHA – potentially hazardous objects for the Earth and other planets.
9. The "What to Observe" program generates the list of objects observable at the specified place in the specified night.

EPOS was used in research of the dynamical structures of the Solar system, in preparation and analysis of Pulkovo observations of asteroids and comets, for observations of transneptunian objects with the Russian 6-meter telescope (BTA), in the accuracy analysis of asteroid observations of many world observatories and in other tasks. The program has been developed by authors of this article V. L'vov and S.Tsekmejster and it may be requested in the Internet site: **EPOS.** One can find more details at:http://neopage.pochta.ru/eng/esupp/main.html.

Conclusions

In connection with Gaia-FUN Workshop we have decided to check up readiness of our instrument for observations of Solar system bodies. We wished to show that our 65 cm refractor continues traditional observations of planets, their satellites and asteroids by means of new technique. Our instrument is modernized, automated, equipped by software for processing. We have tested some programs of orbit determination and comparison of obtained elements with the catalog's ones. We have investigated the motion of selected asteroids and in some cases estimated their orbits using only a short arc.

Acknowledgments

We thank the Organizing Committee of Workshop Gaia-FUN-SSO and the Board of Pulkovo observatory for the given possibility to take part in the Conference in Paris 29.11-01.12. 2010.

References

Izmailov, I. S., 2005, Izmccd, <http://izmccd.puldb.ru/index2.htm>.

Izmailov, I. S., Kiselev, A. A., Kiseleva, T. P., Khrutskaya, E. V. Astronomy Letters, 1998, Vol. 24, 5, 665-672.

Zacharias, N., Urban, S. E., Zacharias, M. I. et al. The Second US Naval Observatory CCD Astrograph Catalog (UCAC2) // A.J., 2004, v. 127, 3043-3059.

Emel'yanov N. V., Arlot J.-E. The natural satellites ephemerides facility MULTI-SAT. Astronomy and Astrophysics. 2008. v. 487. P. 759–765.

Kiselev A. A., Bykov O. P., 1992, Proc of Meeting " Asteroid Danger ", (in Russian) St-Petersburg, p.107-110.

Shakht N. A.,.Kiselev A. A, 2008, Planetary Space Sci, 2478, v.56, 14, 1903- 1907.

Vienne A. , Duriez L. TASS1.6: Ephemerides of the major Saturnian satellites, A&A, 1995, v. 297, 588.

E. Bowell, 2010.09.21, <http://lowell.edu/pub/elgb>.

Status of a Latin American Contribution to the Follow-Up of the Gaia Space Mission

Teixeira, R.[1], Krone-Martins, A.[1], Milone, A.[2], Mallamaci, C.[3], López, C.[3], Calderon, J.H.[4], Bustos Fierro, I.H.[4], Fidêncio, M.[1], Muiños, J.L.[5], Idiart, T.E.P.[1], Horvath, J.E.[1]

[1] Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, Brazil
[2] Instituto Nacional de Pesquisas Espaciais, São José dos Campos, Brazil
[3] Observatorio Astronómico Félix de Aguilar, Universidade Nacional de San Juan, Argentina
[4] Observatorio Astronómico, Universidade Nacional de Córdoba, Argentina
[5] Real Insituto y Observatorio de la Armada, San Fernando, Spain

Introduction

The follow-up of the Gaia mission from ground-based observation is a very important task to the astronomical community. The number of transient events to be detected by the Gaia satellite which must be followed from Earth is huge and among them we shall find about one hundred thousand asteroids.

In this contribution, we just present an update about a possible participation to the Gaia follow-up from some Argentine and Brazilian colleagues.

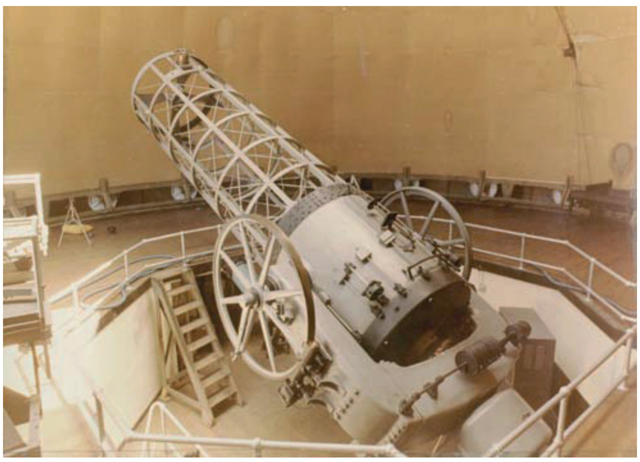
In 2004, we started contacts by mail, with Argentina, Chile, Venezuela, Bolívia and Brazil, in order to have an idea about the availability of manpower and equipped and available telescopes.

By 2006, we had formed a group that answered, somewhat enthusiastically, from Argentina, Bolivia and Brazil (Teixeira et al. 2008). Unfortunately, at this moment, for various reasons, this group has dispersed.

Now, we re-started the contacts and again we have responses from Argentina and Brazil, but up to this moment we are still waiting for responses from Tarija, in Bolivia.

Available telescopes

From Córdoba we received an enthusiastic response, confirming their interest to collaborate with this follow-up. Their 1.5m telescope (Teixeira et al. 2008) will be operational in some months. This telescope seems to have interesting characteristics for the Gaia follow-up concerning its size and detection system. Also, in some months they will upgrade their CCD camera.



Still from Argentina we received responses from San Juan and, somewhat from Pepe Muiños, who is the responsible for the CCD meridian circle installed in the el Leoncito Observatory. In el Leoncito they have a 0.5m double astrograph, which is well equipped and available, but perhaps due to its size, it is not so appropriate for what we need. They also have a CCD meridian circle which is not appropriate to the follow-up (Teixeira et al 2008).

Regarding Brazil, at the Valinhos Observatory, we have a MEADE telescope with a diameter of 0.4m, well equipped but unfortunately too small and so, probably inappropriate for the Gaia follow-up. We also have a well-equipped 0.3m Celestron telescope. This telescope is completely operated by Internet, 2 nights by week by schools. In this case, surely it is too much small. We also have a CCD meridian circle equivalent to that of El Leoncito. In São José dos Campos, we have another automated 0.3m Celestron telescope that is used to attend schools via Internet control.

Still in Brazil, at the main Brazilian Observatory, in Brazópolis, we have two very well equipped telescopes, a 1.6m and a 0.6m diameter. These instruments are not completely available for the follow-up, but they can be used in the "target of opportunity" mode. I believe that the time allocation in the 0.6m telescope for the follow up targets can be discussed, as this telescope tends to become less requested.

General considerations

To conclude, we can emphasize the following points about the Latin American contribution for the Gaia follow up:

1- The manpower will not be a big problem, since the human potential seems to be relatively large. The problem in this case, assuming we have a group, is to keep the group mobilized;
2- It seems that to have access to equipped telescopes is relatively straightforward, the CCDs are now very affordable and as we saw the most of the telescopes are already more or less equipped. In this case, the biggest problem might concern the size of the readily available instruments.

Given this scenario, we should think about having two dedicated stations to the follow-up, one in each hemisphere. Of course, these stations do not dispense the various initiatives around the world, but they could be a place of concentrate work with adequately equipped and completely dedicated instruments. In this case, for example, we could even consider the use of some of the closed telescopes at ESO-La Silla.

References

Teixeira R., Krone-Martins A., Milone A. Et al., 2008, *Contribution to the ground-based follow-up of the Gaia space mission*, P&SS, 56, 1828-1831.

Astrometry Correction for Chromatic Refraction

Ivantsov, A.

Nikolaev Astronomical Observatory, 1 Observatorna St., 54030 Mykolaiv, UKRAINE

Introduction

Since the index of refraction of air depends on wavelength, light from a star will be refracted into a spectrum as it passes through the Earth's atmosphere. The direction of the refraction is toward the zenith, with blue light refracted more than red. Consequently, stars of different spectral types will experience differing degrees of atmospheric refraction, which is referred to "chromatic" or "colour" refraction (CR). As far as the amount of refraction increases with the zenith distance, so does CR. As a result, CR will be a source of systematic error, if it is neglected.

Until very recently, catalogs of stellar positions have not been corrected for CR, since it was considered unimportant with respect to other sources of error in these catalogs. This situation has radically changed with the release of the Hipparcos and Tycho-2 stellar catalogs. If the goal for positional accuracy is less than 100 mas and include observations taken at moderate to large zenith distances, corrections for CR might be needed in the astrometric reductions.

1. Short Review of Monochromatic Refraction

In a pure sense, atmospheric refraction should be calculated theoretically by tracing the path of light through the Earth's atmosphere, wherein the refraction will be just the difference in the directions of the light before it enters the atmosphere and as seen at the telescope. In order to make this tracing, detailed knowledge of the atmospheric temperature, pressure, and water vapor is needed along this path. This aerological data can be obtained from radiosonde, radar, and lidar measurements on a nightly basis. Because of the high costs involved, it was considered impractical decades years ago. However the situation changed: one can easily get access to the numerical mesoscale weather modeling, e.g. http://www.wrf-model.org, and use it for your own predictions, even if you have not recorded necessary data at the particular observing site.

Alternately, a model for the atmosphere can be assumed, and the aerological data assumed from it. The US Standard Atmosphere (1976) is often chosen. Also, refraction can be determined in a very straightforward manner, requiring only knowledge of the meteorological conditions (ambient temperature, atmospheric pressure, and water vapor) recorded at the observing site with each observation. Besides being very simple (only analytic expressions are used) and fast, this approach is also very accurate for zenith distances under 75°.

2. Practical Considerations

The Association Internationale de Géodesie (http://www.iugg.org) has recommended new equations for the precise calculation of the continuum component of phase refractive and group indices of air. They cover a wide range of wavelength from 300 nm to 1690 nm and atmospheric conditions at least –40° to +100°C, 80 to 120 kPa, and 0 to 100% relative humidity that are relevant to both laboratory measurements and surveying. There are experimental limits to the determination of phase refractive index with a limit uncertainty about 10^{-8}, such as 0.01°C for measuring temperature, 3 Pa for pressure, 0.4% for relative humidity, 100 ppm for CO_2 content (Ciddor, 1996 & Ciddor, 2002).

For astrometry in a small field, i.e. differential reductions made with reference objects in the field, these accuracies can be much worse. For accuracies of 10 mas or less in a 5° field in declination, the required accuracies are only 0.5°C and 1 mm Hg in pressure, the correction for water vapor can be ignored altogether (Stone, 1996).

The previously discussed refraction $R(\lambda)$ is only for monochromatic light of wavelength λ. As the first approximation for the refraction, the effective wavelength of a passband could be determined and then used to compute the refraction. Unfortunately, the effective wavelength for a given passband is not constant, but rather a variable that depends on the nature of the incoming light.

As discussed in (Stone, 1996), a better method for computing CR consists of calculating a mean refraction R_m by weighting the individual selective refractions $R(\lambda)$ with the apparent stellar flux at wavelength λ and averaging across the passband. The mean refraction is given then by

$$R_m = \frac{\int_0^\infty S(\lambda)E(\lambda)A(\lambda)L(\lambda)F(\lambda)D(\lambda)R(\lambda)d\lambda}{\int_0^\infty S(\lambda)E(\lambda)A(\lambda)L(\lambda)F(\lambda)D(\lambda)d\lambda}$$

where $S(\lambda)$ is the spectral energy distribution for the star being observed; $E(\lambda)$ is the transmittance of interstellar dust along the line of site; $A(\lambda)$ is the transmission of the atmosphere at the airmass being observed; $L(\lambda)$ is the transmittance of the telescope optics; $F(\lambda)$ is the filter transmission; $D(\lambda)$ is the quantum efficiency of the detector being used; and $R(\lambda)$ is the selective refraction discussed above.

For simplicity, a blackbody function could be used for the spectral energy function $S(\lambda)$; however, this can be a poor assumption, if prominent spectral features are present within the passband. These features can reduce or increase the amount of refraction, depending on their prominence and placement within the passband. E.g., a narrow passband centered on about 500 nm will be strongly affected by TiO absorption when observing an M0 star. It would be better to use the spectral energy distribution of the star being observed. If the true distribution is not known, which is usually the case, then a distribution can be chosen that matches the spectral type of the star. Tabulations of spectral energy are given for all spectral types by different authors (Pickles, 1998). The functions $E(\lambda)$ and $A(\lambda)$ can be approximated from the tabular data in (Cox, 2000).

For many stars, neither the spectral type nor the color excess are known from spectroscopy. If multiband photometry is available, then a spectral type and color excess can be inferred. If only a color index is known, then a crude spectral type can be determined. A new opportunity arisen with the availability of 2MASS infrared magnitudes, where you can infer an approximate spectral class. When there is neither spectral nor photometric data available, which is often the case, an assumed spectral type and color excess can be adopted, e.g. a spectral type K0 and a color excess of E(B–V) = 0.3 mag. These are working assumptions, bearing in mind the refraction for these stars can be later corrected, should these parameters eventually become known. The relative displacement of star of different classes caused by CR can be assessed from Table 1, according to (Stone, 1996).

Table 1 – Chromatic refraction in mas at a zenith distance of 45°

Passbands / Spectral types	O	B	A	F	G	K	M
U	101	36	–29	0	8	–4	–42
B	88	58	12	0	–28	–100	–115
V	26	17	12	0	–8	–35	–42
R	22	18	12	0	–6	–21	–35
I	6	5	2	0	–1	–4	–6

The bluer a passband center is, the more pronounced the color refraction will be. This is to be expected considering the selective nature of atmospheric refraction. Furthermore, color refraction is a quasilinear function that decreases with later spectral type.

Conclusion

The present review shows contemporary possibilities for calculating chromatic refraction. The chromatic refraction can be computed easily if the meteorological conditions are known at the time of observations and taken near the telescope. It is wavelength dependent and should be calculated for each telescope, if the astrometric accuracy better than 100 mas is required.

References

Ciddor P.E.: 1996, Refractive index of air: new equations for the visible and near infrared, Appl. Opt. 35, 1566-1573

Ciddor P.E.: 2002, Refractive index of air: 3. The roles of CO_2, H_2O, and refractivity virials, Appl. Opt. 41, 2292-2298

Cox A.N.: 2000, Allen's Astrophysical Quantities, Springer-Verlag, New York, Inc.

Pickles A.J.: 1998, A Stellar Spectral Flux Library: 1150-25000 Å, PASP 110, 863-878

Stone R.C.: 1996, An Accurate Method for Computing Atmospheric Refraction, PASP 108, 1051-1058

Astrometry of Asteroids with Normal Astrograph of Pulkovo Observatory: from Digitized Plates to Modern CCD-Observations

Khrutskaya, E.V., Khovritchev, M.Yu., Berezhnoy, A.A., Kalinin, S.I., Shakht, N.A.

Central Astronomical Observatory of RAS, Russia, 196140, Saint-Petersburg, Pulkovskoye chaussee 65/1

Introduction

Long series of astrometric observations of asteroids have been obtained with Pulkovo Normal Astrograph (1949-2010). Observations of selected asteroids were begun since 1949. Photographic observations were performed before 2005. Only CCD observations are carried out with the Normal Astrograph since 2005. At present the observational program includes near 300 asteroids: 14 selected asteroids for analysis of linking of reference systems, double asteroids, NEOs, asteroids of families of Eos and Hygiea. All results are available via our database (http://www.puldb.ru). Digitization and new reduction of old photographic plates has been performing since 2010.

1. CCD observations of asteroids.

Astrometric observations of asteroids are significant part of investigations that are performed with the Pulkovo Normal Astrograph (D/F=0.33m/3.5m, CCD camera: S2C, FOV = 18x16 arcmin, pixel size 900x900 mas). The results of CCD observations of last 5 years contain tens thousands of separate positions of asteroids.

2.1 Observations and data reduction.

Lorentz profile was used to approximate stellar and asteroids' images. Data within 40-pixels aperture centered at the photocenter of the image of appropriate object was used to calculate PSF parameters. Astrometric calibrations were performed with UCAC3 data. Reference stars are within 10 to 14.5 mag to exclude faint end of the UCAC3 (due to possible systematic errors). Analysis of systematic residuals of pixels coordinates allowed us to calculate corrections depended on x, y and magnitude.

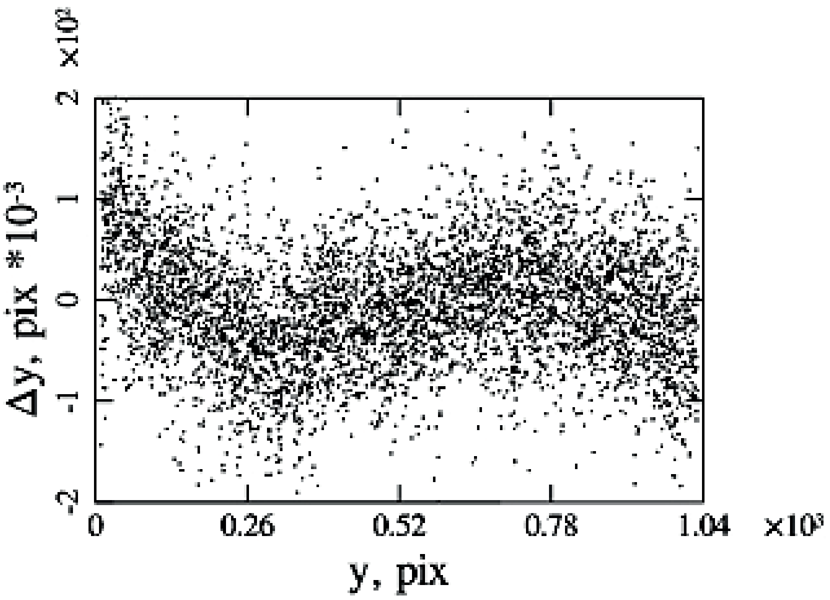


Fig.1 – Example of residuals of the pixels coordinates as function of y.

2.2. Program of CCD observations of asteroids and results.

- Observations of 14 selected asteroids (NN 1, 2, 3, 4, 6, 7, 11, 18, 25, 39, 40, 389, 532, 704). The main goal is investigation of the link between ICRF and dynamical reference frame based on ephemeris. Combination of the results of these observations with data obtained from digitized photographic plates with images of the same asteroids may be used to analyze differences between future GAIA reference frame and ephemeris.
- Investigation of known and possible double asteroids. It allow us to calculate their masses and other dynamical parameters. Observations of possible double asteroids of families of Eos and Hygiea are performed to investigate a possible link between duplicity and families.
- Observations of close approaches and occultations of asteroids with stars from HIPPARCOS and Tycho2. The astrometric parameters of these events give us information to improve the ephemeris, to investigate the link between reference frames.

Several thousands of asteroids' positions were obtained. Internal standard errors of equatorial coordinates are near 25 mas. Appropriate external accuracy from (O-C) analysis is 35 mas.

2. Digitization of photographic plates with Microtek flatbed scanner and a new reduction.

Pulkovo observatory has over 2500 old photographic plates with 18 selected asteroids observed between 1949 and 2004. Regular digitization of these plates using Microtek flatbed scanner started in May 2010.

2.1 Technical characteristics of the scanner

- optical resolution: 3200 dpi
- number of bits per pixel (grayscale mode): 16
- maximum size of scanned plates: 200x250 mm
- time needed to scan one 160x160 mm plate: ~5 min.
- sensor: one-dimensional CCD sensor.
- interface: USB 2.0

The main cause of systematic errors of such inexpensive flatbed scanners is imperfection of their design.

2.2 Basic types of flatbed scanner systematic errors

- variation of pixel width in different parts of the CCD sensor (results in $\Delta x(x)$ error).
- curvature of the CCD sensor (results in $\Delta y(x)$ error).
- curvature of the guide, along which the CCD sensor is moved (results in $\Delta x(y)$ error).
- variation of the speed of CCD sensor movement along the guide (results in $\Delta y(y)$ error).
- non-orthogonality of scanner's axes.

The positive feature of our calibration and reduction technique is that it allows us to obtain the sum of these errors instead of separate analysis of the errors of various types.

2.3 Calibration technique

It was assumed that systematic error can be decomposed into two independent parts: constant and variable. Variable part is much less than the constant. Constant part of systematic error is determined once in several months. Variable part is determined individually for every measured plate.

2.4 Constant part of systematic error

We divide the scan area (i.e. scanner's glass) on an imaginary grid containing M rows and M columns. The gist of the calibration method is determination of systematic errors of the scanner for each square of the grid.

Let (ξ, η) are the true coordinates of some star, and (x, y) - measured coordinates $e_x(x,y)$ and $e_y(x,y)$ - unknown corrections which represent systematic errors in different squares of the grid.

$$\xi = x + \mathbf{FW}(m)$$
$$\eta = y + \mathbf{GW}(m) \quad (1)$$

F is the vector of $e_x(x,y)$ corrections, **G** is the vector of $e_y(x,y)$ corrections, m is the number of the square which contains that star: m = [x/w] + [y/w]*M + 1, where [ ] denotes integer part of number. **W** is the vector representing position of that star in the imaginary grid, components of vector **W** are: W(i) = 1, if i=m, W(i) = 0, if i $\neq$ m.

Vectors **F** and **G** are common for all stars and all plates. Their components are calculated during calibration and are invariable up to the next calibration.

Plate for calibrating was scanned in four positions: north up, right, down, left. And for each of these provisions plate was scanned still 5 times with a shift to the right and turn to any angle. Thus, to determine the required corrections 20 scans of one plate should be obtained (the number of scans can be increased).

For determination of the unknown corrections we used photographic plates with high density star fields (e.g. with Pleiads).

Estimates of the parameters of connection (α - rotation angle, S_x - shift along X axis, S_y - shift along Y axis) are obtained for each pair of the scans. Errors in the determination of these parameters lie in the ranges: for S_x, S_y - ± 0.008-0.040 micron, for α - ± 0."1 ÷ 1".

Systematic corrections (components of F, G) are determined using the parameters of connection between pairs of scans and taking into account in equation (1) of the common system of conditional equations which formed over all the stars of all pairs of scans by the method of least squares.

2.5 An estimate of the residual systematic error of scanner.

The degree of exclusion of systematic errors of the scanner after the introduction of calibration corrections can be estimated from Fig.2 (a,b)

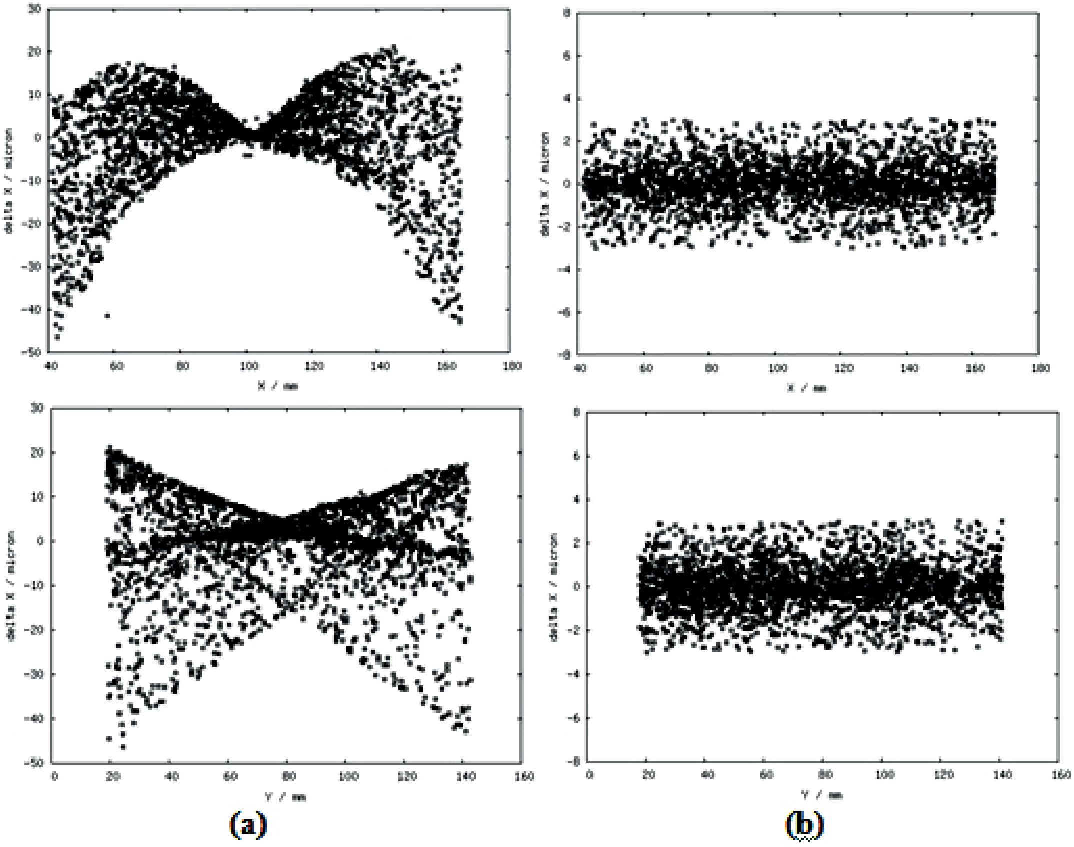


Fig. 2 – Star shifts along X and Y axes *before* systematic error correction **(a)** and after systematic error correction **(b).** Comparison of two scans of plate D469, 1820 stars, plate were rotated by 180^{o}.

2.6 Measurement of photographic plates. Determination of the X, Y of stellar objects.

Each measured plate is scanned in four positions with rotation by 90 degree (to reduce random errors and exclusion the variable part of systematic error). Measurements were performed using following algorithm:

- exclusion of non- stellar objects
- separation of exposures relevant to each object averaging coordinates for these exposures
- sorting of object lists in four scans
- exclusion of stars measured with low precision
- taking into account of systematic corrections in the measured coordinates (X,Y)
- averaging the coordinates of stars obtained at four times the scanning plate.

2.7 Astrometric reduction of digitized plates. Estimates of accuracy.

The average error of measured coordinates of stars to one plate is 50 to 65 mas. The method of six constant was used for reduction. Error unit of weight ($E_x(1)$,$E_y(1)$) is 120 to 180 mas. UCAC3 used as a reference catalog. In 2008-2009, 174 Pulkovo plates were digitized with high precision DAMIAN scanner (Royal Observatory of Belgium). An opportunity to estimate the influence of internal accuracy of measuring device on accuracy of astrometric reduction is appeared (Table 1).

Table 1 – The estimates for the accuracy of reduction (E_x (1), E_y (1)) and standard errors values (O-C) for the reference stars on the plates digitized by Microtek and DAMIAN scanners. Units: mas

Microtek ScanMaker i900 scanner					DAMIAN scanner			
N pl.	E_x(1)	E_y(1)	$\varepsilon(O\text{-}C)_\alpha \cos\delta$	$\varepsilon(O\text{-}C)_\delta$	E_x(1)	E_y(1)	$\varepsilon(O\text{-}C)_\alpha \cos\delta$	$\varepsilon(O\text{-}C)_\delta$
4955	179.7	209.3	19	20	131.6	149.4	15	16
4959	161.5	210.0	19	23	130.2	141.5	14	19
5188	113.9	173.7	19	17	79.3	100.8	14	16
5217	90.4	155.3	26	25	145.6	160.8	16	20
5849	173.4	201.7	22	21	145.6	160.8	16	20
10635	136.2	103.5	16	17	163.8	128.1	14	14
11432	124.5	136.6	17	15	78.9	102.8	14	14
11778	112.7	157.5	20	21	94.2	107.2	18	15
12828	86.8	112.8	13	13	86.5	105.4	12	10
12912	153.6	132.6	13	15	74.6	93.1	13	13
12198	122.5	103.4	15	17	100.2	100.5	16	14
mean	**132.3**	**154.2**	**18**	**18**	**112.0**	**122.7**	**15**	**16**

The accuracy of the reduction obtained with flatbed scanner and scanner DAMIAN makes possible to assume that the accuracy of the final result to a great extend depend on factors associated with quality of the images stellar objects (the atmosphere, the lens of the telescope, type of emulsion of photographic plates) under the of precision of the measurements of the order of 1-1.5 microns and above. Moreover, a significant part of the error of the results of reduction depends on systematic and random errors of the stellar positions of used reference catalogue (mainly on the errors of proper motions of stars).

At this stage the material digitized by the scanners Microtek and DAMIAN, was not corrected for the errors of coma, the magnitude and color equations and distortion.

On the whole, the work has shown the possibility of using inexpensive flatbed scanners to address a number of astronomical problems requiring long time series of observations. The proposed calibration method and the method of obtaining of the measured coordinates can be used for any scanner with similar specifications as features of Microtek scanner.

The authors express their gratitude to Dr. J-P De Cuyper and Dr. G. De Decker for the opportunity to digitize the Pulkovo photographic plates by high-precision DAMIAN scanner at the Belgian Royal Observatory and for help in digitizing plates. We also thank Dr. K. Grigoriev, who has scanned a significant part of our plates. Work was supported by RFBR N 09-02-00419.

Opportunities for Follow-Up Observations of Solar System Objects with 50/70 cm Schmidt Telescope of National Astronomical Observatory Rozhen, Bulgaria

Kostov A.

Institute of Astronomy with NAO, BAS, Bulgaria,
akostov@astro.bas.bg

Introduction

The 50/70 cm Schmidt telescope is one of the four telescopes in National Astronomical Observatory, Rozhen. The Observatory is situated in the Rozhen area of Rhodopes Mountain, at an altitude of 1750 m and away from big cities. Due to good location of observatory and high altitude light pollution is minimized and there is sufficient number of clear observational nights per year. Observations are obtained every clear dark night, for exceptional events moon nights are used, also. Telescopes schedules are allocated for 6 months ahead and the scientific teams know their dates of observations in advance. Nevertheless, changes of observational schedules (especially for small telescopes) and observations of targets of opportunity are common practice in the observatory. In addition the scientific team is experienced, with skills and background in observations of Solar system objects.

1. The Telescope

The Schmidt telescope is a classical Schmidt system with small modifications. The system has following optical parameters:

- Diameter of spherical mirror – 70 cm
- Diameter of corrector plate – 50 cm
- Focal length – 172 cm
- Focal ratio – F/3.44

Unlike the classical Schmidt system we don't use Piazzi-Smyth lens. The effects of not conversion of spherical focal surface to flat focal surface are significant for large fields of view (FOV). 20 years ago, when the telescope was used with photographic plates and the FOV was 5 x 5 degree, analysis has shown that the coefficient of distortion is

$$c = -\,0.102857\times10^{-6}.$$

A few years ago ST8 CCD camera with FOV of 27.5 x 18.4 arcmin was used as detector. At that time another analysis of systematic errors due to spherical focal surface was performed. The radial dependence of the residuals between measured and catalogue positions of stars and the dependence of the residuals caused by the differential refraction were studied (Kostov et al., 2006). All results from this study show that no significant systematic errors can be identified in the small FOV. The last analysis of the optical system of Schmidt telescope was performed this year with a new detector, commissioned in 2009. The new camera is FLI PL 16803, it comprises 4096 x 409 pixels of size 9x9 micrometer, yielding a scale of 1.08 arcsec/px, and a FOV of 73.7 x 73.7 arcmin (1.2 x 1.2 degree). This is almost 3 times less than the FOV with photographic plates, but about 3 times greater compared to ST8 CCD. The astrometric reduction in the inner part (< 1500 px from the center) is not influenced by distortions (Markishki, 2010). If standards outside from this region are used corrections should be used by introducing quadratic terms in the astrometric reduction procedures.

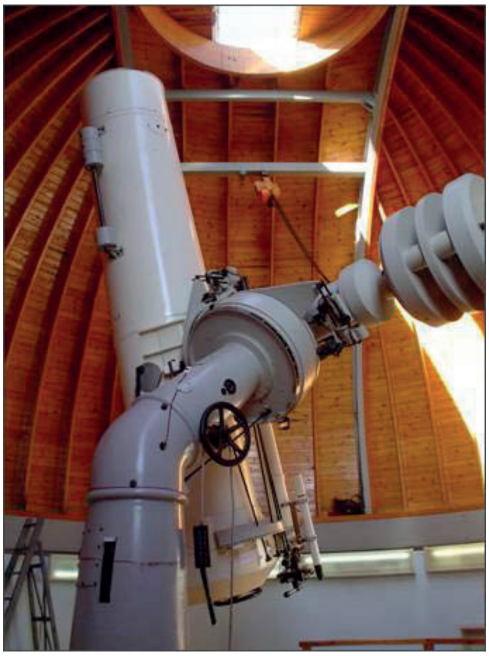


Fig. 1 – The 50/70 cm Schmidt Telescope of National Astronomical Observatory Rozhen.

2. Equipment

The detector is CCD camera FLI PL 16803. Parameters of these CCD are as follows:

- 4096 x 4096 pixels, 9 micrometer square, FOV 73.7 x 73.7 arcmin
- QE up to 50% between 470 and 650 nanometer (peak QE = 62% at 570 nm)
- Readout Noise – ~ 9 e- RMS

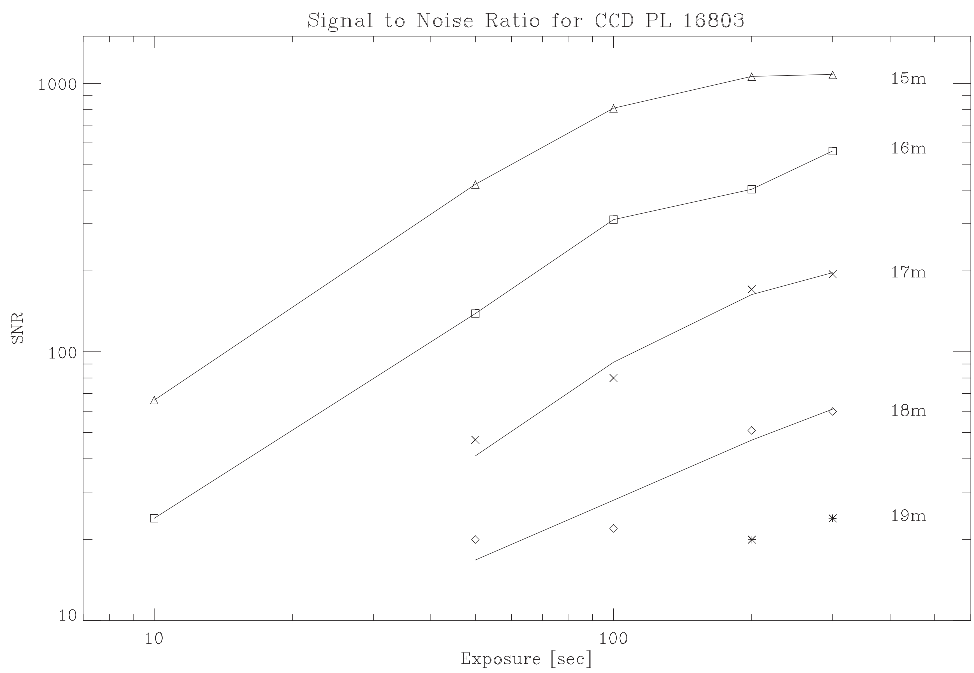


Fig. 2 – The Signal-to-noise ratio for is CCD camera FLI PL 16803.

Fig. 2 shows measurements of signal-to-noise ratio (SNR) of the CCD camera. For stars brighter than 16m the SNR is sufficient for astrometric measurements even in 10 sec expositions. Limiting star magnitudes up to 18m can be reached with exposures greater than 50 sec. UBVRI Bessel filter system is used for the observations. In addition we have opportunity to use narrowband filter set for detailed observations of comets.

3. Data Reduction

For astrometry and photometry we use **USNO-2.0 Catalog of Astrometric Standards**. The typical positional error of this catalogue is ~0.25 arcsec, and the photometric precision is ~0.25 mag. Usually we identify hundreds of standard stars in one image of the Schmidt telescope. The large number of standard stars identified in the FOV compensates for the relatively low accuracy of the **USNO-2.0 Catalog.**

The basic reduction steps are dark field (DF) subtraction and flat field (FF) division. In addition a special filtering procedure is used to remove the cosmic rays events. The parameters of flat fields and dark frames of the CCD were studied by Kostov (in press). The results show that darks are stable during the time of observation and their levels are low, giving us chance to observe faint objects. Table 1 presents quantitative analysis of the influence of these basic reduction steps on the final statistical parameters of the images. As we can see after the basic reductions, especially after subtraction of the dark currents, the photometry and astrometry results are slightly improved. Subtraction of electronic noise and the cosmic ray extraction led to better results due to increase of the number of stars used for photometry. The stars for astrometry fulfill less conditions than photometry ones, and therefore they are 3 times more. Opposite to photometry, the DF subtraction slightly decreases the number of stars used in astrometry, but thereby, separates only the stars with better-defined positions which improves the astrometry solution.

Table 1 – Comparison between parameters of raw and reduced images.

	raw	-DF	-DF, /FF
Photometry			
Standard Deviation of sky [ADU]	21.38	21.39	20.77
Photometry Zero point [mag]	5.411	5.305	5.311
Accuracy of photometry Zero point [mag]	0.141	0.109	0.109
Accuracy of instrumental magnitudes [mag]	0.0211	0.0208	0.0207
Number of used stars	399	597	597
Astrometry			
Number of used stars	1706	1641	1643
RMS positional errors [arcsec]	0.51	0.49	0.48

Measurements at different elevations are affected by atmospheric refraction and extinction. Both are functions of colours of stars. The influence of these factors is shown in table 2. The results summarized here were derived from the stars found in two images obtained at different heights in B and R filters. All identified stars were divided in 3 intervals corresponding to their colour, keeping in mind that B-R of the Sun is equal to 1.17:

Table 2 – Accuracy of astrometry depending on type of used stars and elevation.

Elevation	Filter	Type of stars	All	Blue	Solar	Red
19 degree	**R**	Number of used stars	1629	947	285	335
		σ-position [arcsec]	0.48	0.45	0.51	0.55
	B	Number of used stars	597	448	118	81
		σ-position [arcsec]	0.55	0.59	0.60	0.56
42 degree	**R**	Number of used stars	719	326	81	301
		σ-position [arcsec]	0.57	0.52	0.59	0.61
	B	Number of used stars	390	258	66	81
		σ-position [arcsec]	0.59	0.58	0.60	0.65

(B - R < 1.0 = Blue stars); (1.0 < B - R < 1.3 = Solar type stars); (B - R > 1.3 = Red stars).

No significant dependence between the astrometry precision and the colour of the stars could be measured, neither dependence on the elevation is seen. The reason for this negative result is that the stars mostly disturbed by the atmosphere are removed by several filters included in the preprocessing steps performed before the astrometric solution itself. Therefore the main factor affecting accuracy of astrometry is the number of used stars.

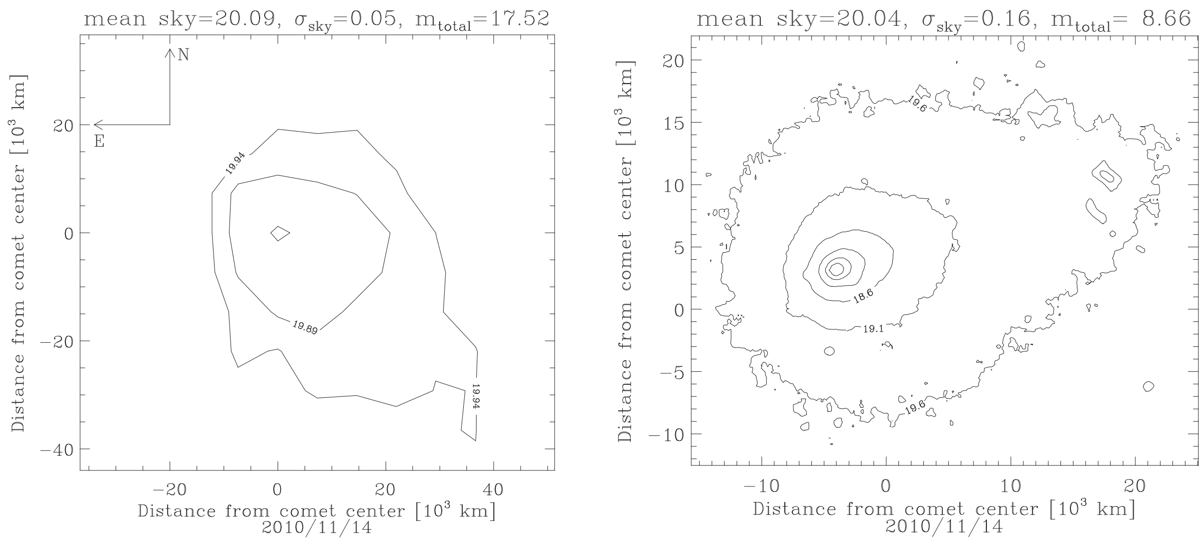


Fig. 3 – Surface brightness maps of two comets.

Other Solar system objects often observed with the Schmidt telescope are comets. In Fig. 3 two comet surface brightness maps are shown representing recent observations. The numbers at the contours have dimension of mag/arcsec^2. In the left plot is comet C2005L3 (McNaught). This faint comet, observed here at heliocentric distance of 9 AU, has been object of observations with the Schmidt telescope for the last 4 years. For comparison a brighter comet, 103P/Hartley 2, is shown in the right panel.

Conclusion

Due to the flexible schedule of observations, the presence of skilled observers and existing traditions in observations of Solar system objects the Schmidt telescope at NAO Rozhen can efficiently be used for follow-up observations of GAIA discoveries of small bodies.

This work was supported by the GAIA-FUN-SSO team and by contract with FNI DO 02-85.

References

Kostov, A. et al., 2006, "Astrometry and photometry of small bodies at the National Astronomical Observatory, Rozhen, Bulgaria", proc. conf. "Enlargement of collaboration in ground-based astronomical research in SEE countries.", Nikolaev, Ukraine, 25-28 September

Markishki, P., 2010, "Tests of the optical system of the 50/70cm Schmidt telescope in Rozhen NAO", BlgAJ, Supplement Issues, 2010,1

Kostov A., et al., in press, "Parameters of Dark currents and Flat Fields of CCD PL 16803", BlgAJ

10 years of the IAU Efforts for Capitalizing the Ground-Based Astrometry

Stavinschi, M.[1], Thuillot, W.[2]

[1] Astronomical Institute of the Romanian Academy, Romania
[2] Institut de Mécanique Céleste et Calcul des Ephémérides, Paris Observatory, France
http://www.imcce.fr/astrom/

Introduction

In 2000 a new IAU working group was founded (IAU GA, Manchester): Future Development of Ground-Based Astrometry (FDGBA). It was revised in 2003 during the IAU GA in Sydney. A new one replaced it in 2006 (IAU GA, Prague): Astrometry by Small Ground-Based Telescopes (ASGBT). It was renewed for other three years during the IAU GA in Rio de Janeiro.

The main aim of the working groups followed the Newsletter No. 1 of the IAU Commission 8, which says:

The post-Hipparcos era has brought an element of uncertainty as to the goals and future programs for all of ground-based astrometry

The purpose of the WGs was *"to update and maintain information on astrometric programmes and activities carried out by small telescopes, to diffuse news through these pages and e-mails, to facilitate the collaborations and to help for the coordination of the activities, when possible, in astrometry from ground-based telescopes"*

1. Main objectives of the WGs

The main objectives of the WGs are:

- to identify programs that could be made on instruments that are either insufficiently used or working on projects that have no significant value for the present day astrometry.
- to make assessment of the whole situation including available instrumentation
- these instruments can be used as they are or with not too expensive modifications to teach students in astronomy how to use telescopes and, in the same time, to contribute in a significant way to astronomy.
- to update and maintain information on astrometric programmes and activities carried out by small telescopes,
- to facilitate the collaborations and to help for the coordination of the activities, when possible, in astrometry from ground-based telescopes.
- to teach the astrometric theory and practice to the next generation

The IAU WG ASGBT encourages astrometric measurements of positions for dynamics, fundamental astronomy or astrophysics, but also photometric observations of events for determination of size and shape, determination of the parameters of rotation can pay benefit from these instruments. This is possible e.g. thanks to observations of mutual events of the natural satellites, stellar occultations, mutual events of binary asteroids.

In this context, the encouraged cooperative projects are:

- Mutual phenomena of natural satellites (PHEMU - PHESAT) & binary asteroids
- Ground-based monitoring of astrometric binaries (GMAB)
- Dedicated astrometric network for the follow-up of Gaia (http://www.rssd.esa.int/index.php?project=Gaia)
- Astrometry of Radiosources optical counterparts for ICRF sources positionning
- Astrometry of natural satellites for their ephemerides
- Prediction of stellar occultations by specific objects, last minute astrometry (TNOs, Pluto…).

2. Limitations of the space astrometry missions

Astrometry by small ground-based telescope remains very useful in complement to space astrometry, since there are limitations of the space missions:

• **not flexibl**e: observations are either constrained by a scanning law (Gaia) or by overall programming (SIM or HST);
• **not designed for monitorin**g: it is not possible to get long sequences of observation of a single body;
• **limited lifetim**e: many astronomical features must be observed either indefinitely or at least a longer time;
• **often need preliminary data:** for instance, ephemerides or prediction of magnitudes of irregular variables
• **they are risky.**

3. Astrometric activities in complement to Gaia

Gaia will get benefit from a dedicated network for observations on alert and follow-up. Several observations can be made with small telescopes (e.g. determination of some asteroidal masses, the improvement of orbital models of neglected natural satellites.)

The work of the actual surveys and the advent of new large and fast surveys (e.g. Pan-Starrs, LSST) which store huge amounts of data reinforces the need to have follow-up observations, in particular for the study of the Near-Earth objects and the improvement of their orbits.

A Follow-up program for Gaia relates mainly to the astrometric aspect for solar system objects and intends to call for astrometrists to join a dedicated network to carry out these observations.

Context and problems

To ensure the maximum efficiency of the observations of detection by Gaia, it is needed to organize observations "on alert" to check and follow-up from the ground. Several means make it possible to organize these observations, in particular the diffusion of alarms by Internet on mailing lists (e.g. Minor Planet Mailing List) or the maintenance of an official page of targets. Whichever means used, even if they reach a great number of potential observers, would not ensure that good reactivity to alarms would occur. The constitution of a formalized network of dedicated observers appears necessary.

Constraints

It will be necessary to have a possibility of access to the telescopes "on alert" by a local observer. The process of observation of Gaia will allow that alarm to be given approximately 48 hours after the detection of an uncatalogued target. It will be necessary to have sensitive enough CCD cameras to detect objects as faint as magnitude 20, and pixel sizes corresponding to less than 1″ on the sky. During the mission, if a preliminary catalogue from GAIA is available, smaller fields could be usable. It will be desirable that certain sites are of sufficient quality (high altitude) to reach observations with small solar elongation. Gaia will detect objects with a solar elongation down to 45°.

Conclusion

A follow-up program will be necessary to ensure the objects (of stellar, galactic and extra-galactic objects; objects of the solar system and numerous new objects) are not lost and to improve their ephemerides. Organizing a network requires time and different steps have to be done. The IAU WG *Astrometry by small ground based telescopes* encourage observers interested in this network, and particularly astrometric observers, to join the network now to help follow-up Gaia.

References

Thuillot W, Arlot J.-E., Stavinschi M., Birlan M.: 2004, *Ground-based astrometry at the time of the GAIA mission,* Astrometry with Small Telescopes, 22 - 23 October 2004, Bucharest, Romania, Rom. Astron. J. 15 (2005), Suppl.

Thuillot W., Stavinschi M., Assafin M, and the IAU Division 1 WG ASGBT, 2007, *Astrometry by small ground-based telescopes,* IAU Symposium 248, Shanghai, China

IAU division 1 WG "Astrometry by small ground-based telescopes", http://www.imcce.fr/astrom/astrom.html

Author's Index