Deliverable

H2020 COMPET-05-2015 project "Small Bodies: Near And Far (SBNAF)"

Topic: COMPET-05-2015 - Scientific exploitation of astrophysics, comets, and planetary data
Project Title: Small Bodies Near and Far (SBNAF)
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WP	**WP3: Lightcurve inversion technique**
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Lead Author	T. Santana-Ros, AO AMU, tonsan@amu.edu.pl

WP3 Lightcurve inversion technique
Objectives: To join various types of data for full physical models of benchmark asteroids. To develop the web service with a database in order to provide the models to the community.

Description of deliverable D3.1
Upgrade of GOSA service for stellar occultations

Description of deliverable

I. Introduction/background

The Gaia-Ground-based Observational Service for Asteroids (Gaia-GOSA, www.gaiagosa.eu), is a website aiming to facilitate asteroid observers in contributing to the European Space Agency *Gaia* mission by gathering lightcurves of selected targets. GOSA users can plan their observing runs by selecting the visible targets for a given date, collaborate with other observers and upload the frames obtained. The Astronomical Observatory of the Adam Mickiewicz University (AO AMU) is responsible for analyzing the data, publishing the results in the website and creating a lightcurve catalog. Once calibrated, lightcurves will be easily included in the analysis of *Gaia* data, which will allow us to enhance the determination of asteroids' physical properties.

This service was released on September 2015, and is the result of a collaboration between AO AMU and the European Space Agency (ESA Contract No. 400011266014/NL/CBi). As for now, GOSA counts with almost 50 asteroid observers, which can use the tool to plan their observations in a coordinated way. The present deliverable aims to include to GOSA information about stellar occultation (henceforth SO) predictions for selected asteroids. This way GOSA observers are now also able to plan observations of these events, which output can be greatly enhanced by coordination between observers. Observations gathered will be exploited within SBNAF project. On the basis of these observations it will be possible to determine asteroids' size, enhance the shape model (when several chords are recorded) or catalyze serendipitous discoveries (e.g. satellites, rings).

II. Introduction to Gaia-GOSA

In order to better understand the framework of this deliverable, a step-by-step usability description of the current version of Gaia-GOSA is given below.

1) Register

Users from all around the world can sign up for free to the service. The only requirement is a valid email address in order to confirm the registration process.

2) Provide instrument details and location

Once an account is created, users can edit their profile with information about their equipment (telescope's aperture and focal length, CCD characteristics) and location (longitude and latitude). These information is used by the website to generate observation plans that fits user's requirements, i.e. targets with a magnitude reachable with user's instrument and visible from its observing site.

3) Look for visible targets

The “Observation Planner” section allows users to generate a list of targets for a provided date. The Planner uses the information provided by the user (instrument and location) to constrain the list of targets to observable asteroids only. Next the program is cross-checking this list with the priority targets provided by AO AMU (including SBNAF targets). The result is a short list of asteroids for which the user can get valuable data to contribute to asteroid science.

4) Generate observation plan

Once the user selects asteroids to be observed, the service provides an observing plan which includes start and end time of observations, expected magnitude, asteroid position and other valuable comments for planning observations. It is also possible to generate a star chart, so observer can get familiar with the expected field and with the relative movement of the asteroid through the star background.

5) Submit observations

After gathering the data, users can submit their raw images to the service. AO AMU is responsible of reducing and analyzing the data, and to contact the observer for further information if required.

6) Check the results

When the lightcurve is obtained, the results are published on Gaia-GOSA's website (an example is shown in Fig.1). Users can freely share the results, i.e. using their social network profiles. Users submitting more than 10 lightcurves are receiving an official certificate with ESA and Gaia logos.

7) Additional functionalities

The service also has other functionalities that, although not being directly related to observation planning, can be attractive for the users. In “Gaia status”, asteroid transits on spacecraft's field of view are shown in real time. In this section it is also possible to check when a given asteroid will be observed by Gaia.

The website is completed with a “Guide” section, where users can find the basis of asteroids' photometric observations. There is also a Frequently Asked Questions section and a forum, where users can seek for collaboration of share their results.

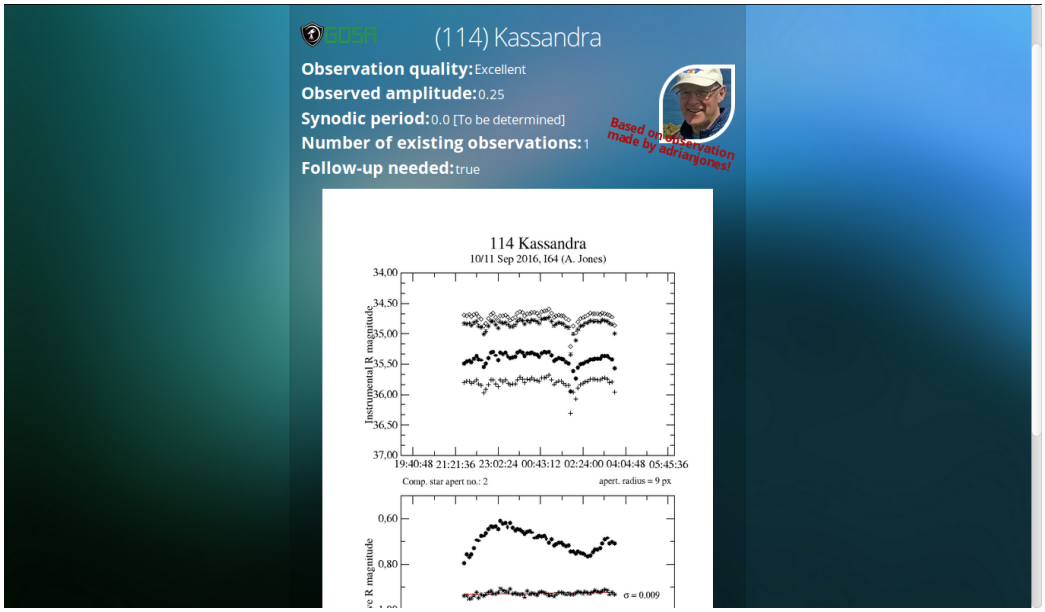


Fig.1. Example of a lightcurve obtained by a user of Gaia-GOSA

III. Stellar occultation information

A SO occurs when the light from a star is blocked by an asteroid from reaching an observer. With accurately measuring the timing of disappearance/reappearance of the star, it is possible to retrieve valuable information of the asteroid (Millis & Elliot, 1979, Millis & Dunham, 1989), e.g. its size, the existence of a satellite (Fig.2) or even discover a ring! (Braga-Ribas et al. 2014).

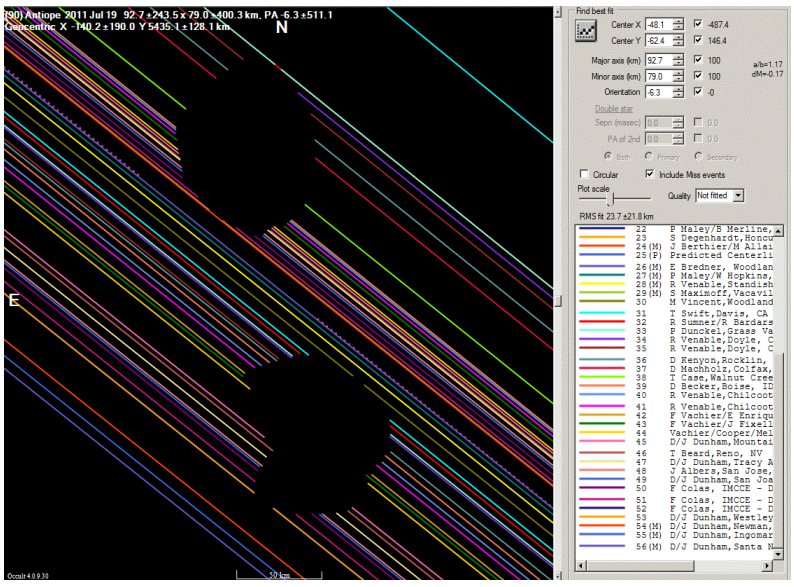


Fig.2. Chords obtained for the stellar occultation of binary asteroid 90 Antiope. Credits: Dunham / IOTA

For predicting such events, it is required to know with a high accuracy the astrometric position of the star and to have a good determination of the asteroid's orbit. The accuracy of the latter values, determines how exactly we can predict the occultation's shadowing path (see for instance Fig.3 for a path prediction).

With Gaia mission, this technique has entered a golden age (Tanga & Delbo, 2007) as SO predictions are now enhanced with the high accuracy of star positions provided by Gaia. In the future, these predictions will be even better when Gaia will release its catalogue with asteroid orbits. However, shadowing path will always have an uncertainty. Therefore the probability of recording a positive event will be higher the greater the number of observers distributed along a certain area close to the predicted path.

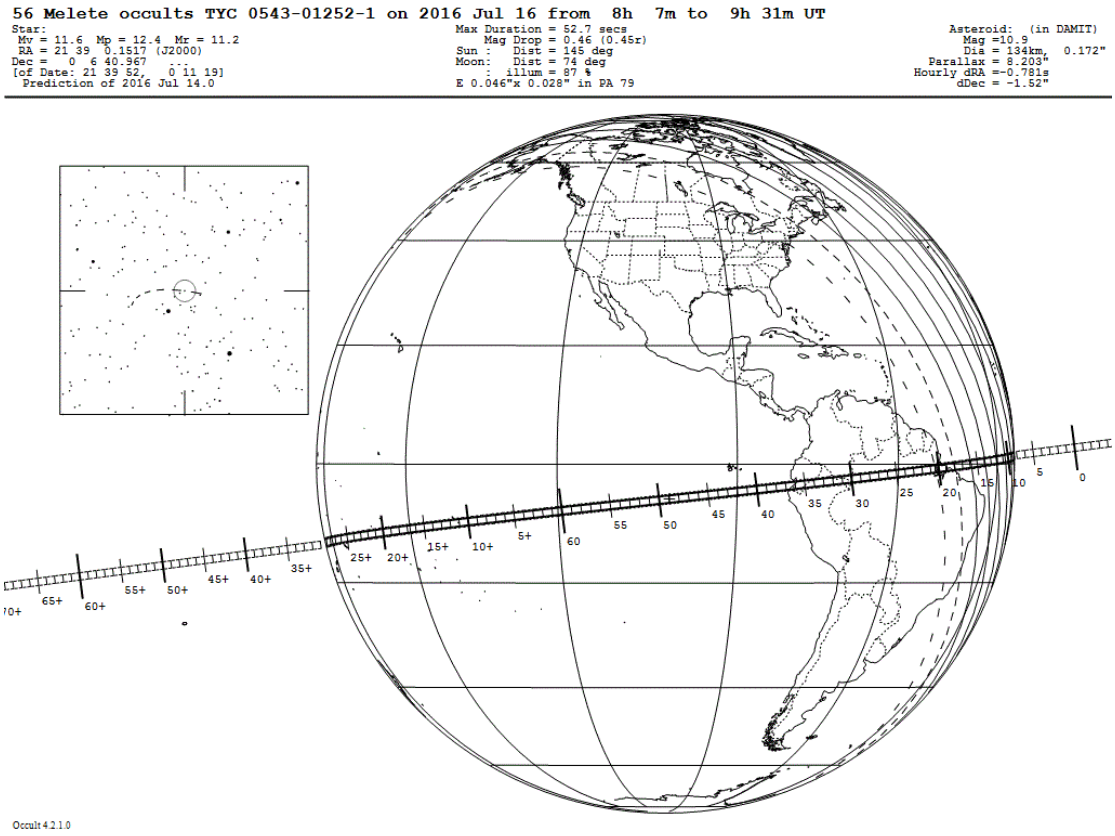


Fig.3. Example of a shadowing path prediction for a SO event. Source: www.asteroidoccultation.com.

Such predictions are regularly calculated by scientific teams (such as IAA-CSIC Granada SBNAF team) and are published in dedicated websites (e.g. http://www.asteroidoccultation.com).

IV. Purpose of upgrade

There are at least two good reasons to develop tools for encouraging observers to plan and record SOs. The first one is that (as already mentioned) the greater the number of observers, the higher is the probability of obtaining a positive event. Besides, when for a given SO several positive chords are recorded, it is possible to reconstruct a crude 2D snapshot of the asteroid as seen from the observer's view and for the event time. This shape information can be combined with the 3D shape models derived from the lightcurve inversion technique. As a

result, it is then possible to scale the model (obtain the asteroid's size) and improve the shape model itself, specially if it includes large concavities.

SO observers have their own tools developed to plan their observations. One of the most popular is OccultWatcher, which is a program for Windows operating system that allows users to look up for incoming occultation events and to announce their intentions to observe them. Such tools were developed several years ago and despite some constraints, they work reasonably well. SO observers are familiar with these software and they use them to coordinate observation campaigns. For this reason, it is not realistic to expect that they will stop using their own tools and switch to Gaia-GOSA. Therefore, **the main purpose of this deliverable is to encourage new observers, which are still not part of SO community, to track these events**.

Recruiting new observers is a necessary effort in order to keep SO community active and productive. For a better preparation of this deliverable, a member of SBNAF attended the largest European meeting on SO (ESOP35, Guildford University, 19th-23rd August 2016). The large majority of attendees (from a total of 40 participants) were very experienced observers that have observed during several years. However, there is a clear lack of new (young) observers within SO community and this can put at risk our capacity of gathering observations of these events in the future. SO community largely consists of amateur observers who, on the one hand, spend a lot of time and effort on observing and improving their skills but, on the other hand, they are not worried about legacy of their meaningful work. Moreover, in this field it is of special importance to keep a close Pro-Am collaboration. Professionals (e.g. SBNAF, Gaia-DPAC CU9 WP948) can support amateurs on their planning, suggest targets of special scientific interest, and also ensure that observations are correctly archived. In sum, Pros shall guarantee that the gathered data will be exploited scientifically.

Gaia-GOSA counts with almost 50 observers which regularly provide photometric measurements of asteroids. If correctly instructed and motivated, some of them could also join SO campaigns. Thus the new content shall encourage Gaia-GOSA observers to learn the state of art of SO techniques and provide the tools and knowledge needed to observe. Gaia-GOSA is also present in social networks such as Twitter and Facebook and counts with more than 400 followers. These channels can be exploited to make SO more visible and catch the attention of new amateur observers which could otherwise ignore this fruitful and accessible observing technique.

V. Upgrade implementation

Gaia-GOSA service was build to explicitly promote photometric observations of asteroids, and thus, it is not designed to include information of other observation techniques (and in particular SO). For this reason, the following actions has been taken to reach the goal of the present deliverable:

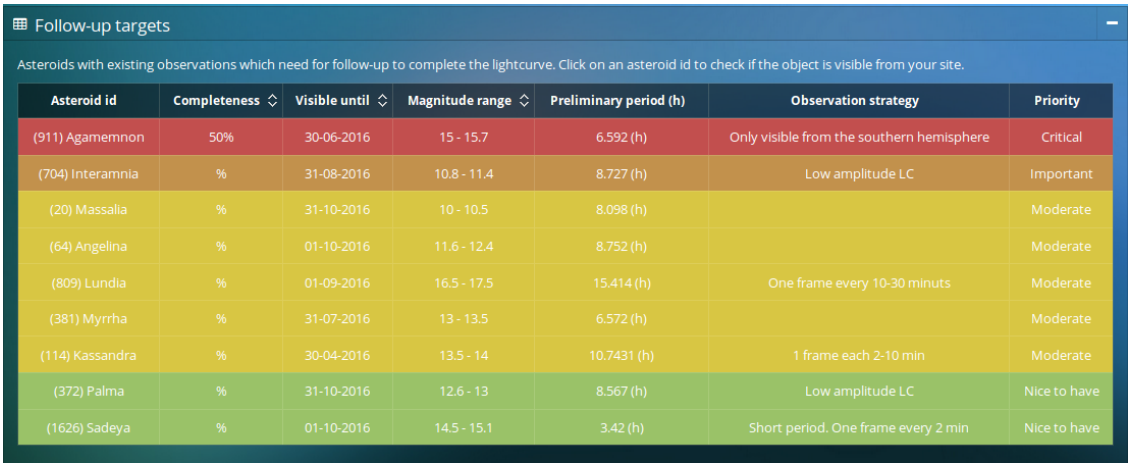
1) Upgrade of the “Follow-up asteroids” table in GOSA's home page

Asteroids which have high priority or need for follow-up observations are listed in a table located at the top of Gaia-GOSA's home page (Fig. 4). At present, this table provides the following information:

Asteroid id: Name and number of the asteroid
Completeness: Part of the lightcurve in percent that has been observed
Visible until: Date for which asteroid is no more observable from Earth
Magnitude range: Maximum and minimum expected magnitude
Preliminary period: When existing, a synodic period from previous observations is provided.
Observation strategy: Any additional comment that can be useful for planning observations
Priority: Level of priority depending on visibility and target's significance

These parameters are useful for planning photometric observations, but when planning a SO observation, additional information is required. Thus we have defined a new table which can accommodate necessities from both observing techniques.
The new table includes all the parameters of the old table and additionally also the following ones:

Technique: To be chosen between Photometry and Occultation.
Star: Name and magnitude of the star to be occulted.
Observation window: Range of time in UT of the SO event. This will also be useful for photometry in order to avoid duplicity of phase coverage.
Visibility: Regions on Earth where the event will be observable.
External link: Additional information from an external source. In the case of SO, link directs user to a map generated with OccultWatcher software where the shadow path on Earth of the event is shown.



Asteroid id	Completeness	Visible until	Magnitude range	Preliminary period (h)	Observation strategy	Priority
(911) Agamemnon	50%	30-06-2016	15 - 15.7	6.592 (h)	Only visible from the southern hemisphere	Critical
(704) Interamnia	%	31-08-2016	10.8 - 11.4	8.727 (h)	Low amplitude LC	Important
(20) Massalia	%	31-10-2016	10 - 10.5	8.098 (h)		Moderate
(64) Angelina	%	01-10-2016	11.6 - 12.4	8.752 (h)		Moderate
(809) Lundia	%	01-09-2016	16.5 - 17.5	15.414 (h)	One frame every 10-30 minuts	Moderate
(381) Myrrha	%	31-07-2016	13 - 13.5	6.572 (h)		Moderate
(114) Kassandra	%	30-04-2016	13.5 - 14	10.7431 (h)	1 frame each 2-10 min	Moderate
(372) Palma	%	31-10-2016	12.6 - 13	8.567 (h)	Low amplitude LC	Nice to have
(1626) Sadeya	%	01-10-2016	14.5 - 15.1	3.42 (h)	Short period. One frame every 2 min	Nice to have

Fig.4. View of the Follow-up target's table in the previous version of Gaia-GOSA, before implementation of the present deliverable.

The implementation of this new table will be done by the company subcontracted within Gaia-GOSA project which is responsible for service's website development and maintenance. This upgrade shall be done by the end of November 2016.

2) Upgrade of the “Guide” section to include information on how to observe stellar occultations

A basic guide for SO observers will be upgraded to Gaia-GOSA's “Guide” section, similar to the information already available in SBNAF's website (http://www.mpe.mpg.de/~tmueller/sbnaf/techniques/c_occultation.html). However, other good sources with very precise information on how to observe SOs are already available online. For this reason, we are not aiming to create an exhaustive description of the technique, but rather a basic text where a complete “newbie” can understand what a SO is, and where to find further references.

The structure of this basic guide is described below:

1) Technique description and results

2) Equipment needed

3) Predictions

4) Methodology

5) Examples

6) Reporting observations

Moreover, a selection of external resources will be provided:

General information and community

International Occultation Timing Association (IOTA)
http://occultations.org

Asteroidal Occultation Observers in European (Euraster)
http://www.euraster.net

Drift Scan imaging (for those using CCD cameras)
http://www.driftscan.com/

Predictions and planners

Occultwatcher
http://www.occultwatcher.net/

WinOccult
http://www.lunar-occultations.com/iota/occult4.htm

Tools and photometry

Tangra3 (photometric and astrometric video observations)
http://www.hristopavlov.net/Tangra3/

Limovie (light measurement tool for video recordings)
http://astro-limovie.info/

Reporting results

Plannocult mailing list
http://vps.vvs.be/mailman/listinfo/planoccult

3) Use of the "News" section and social networks to call for observations of particularly interesting targets

Regular information about SO campaigns will be published in the "News" section and shared through Gaia-GOSA's social network profiles. The main goal is to increase technique's visibility and to recruit observers for particular interesting observation campaigns (e.g. asteroids included in SBNAF target's list).

A first announcement of these intentions has been already published (Fig. 5) and can be found at http://www.gaiagosa.eu/news/all

Fig.5. Announcement of the integration of stellar occultation predictions in the Gaia-GOSA website.

4) Include posts in GOSA's regional forums to call for observations from users located in an area close to the shadowing path

SO predictions of selected SBNAF targets will be included in Gaia-GOSA's forum. In particular, we will make use of the regional forums, which are divided by continents. As shadowing paths are only visible in a certain part of the Earth, each prediction will be included in the corresponding forum.

Predictions for the last trimester of 2016 have been already posted and are available in the following links:

Europe: http://www.gaiagosa.eu/forum/topic/8/28
North America: http://www.gaiagosa.eu/forum/topic/9/30
South America: http://www.gaiagosa.eu/forum/topic/10/33
Asia: http://www.gaiagosa.eu/forum/topic/11/29
Africa: http://www.gaiagosa.eu/forum/topic/12/32
Australia: http://www.gaiagosa.eu/forum/topic/13/31

5) Predictions

Predictions included in the points above have been generated using existing public tools such as OccultWatcher (in the case of main belt asteroids) and with in-home tools developed by IAA-CSIC (in the case of TNOs). While the former are publicly available, **the latter requires of fine analysis which cannot be done with regular public tools**. Thus publishing predictions for TNOs in Gaia-GOSA's website can make the difference as compared to other sources, which might attract observers to check the service.

VI. Open points/future developments

SO community is a well established group of amateur observers that have been collaborating for several years. These observers usually coordinate using their own tools, although some of these might be outdated (observations are mainly submitted through an email list called Plannoccult). It is very difficult to predict their reaction to a new source of information which has been developed externally. However, we will gather their feedback and future developments should try to adapt to their necessities.

On the other hand, we have detected that outreach is required to ensure the engagement of new generations of observers. For this reason, future work can be addressed to publishing information about SO in non-scientific journals (i.e. astronomy outreach journals, such as Sky & Telescope, Amateur Astronomy Magazine, etc). Contacting astronomy associations can be also a good way to enhance the awareness of this technique. Actually, we have started an informal collaboration with the British Astronomical Association (BAA), which has included the participation in Gaia-GOSA's project as one of its highest priorities.

As stated above, SO technique is entering a new golden age with the data releases coming from Gaia. Our ability of predicting such events is now better than ever before, and will still improve after Gaia's release of asteroid orbits (planned 2019). However, as time goes by, SO predictions will regress again due to proper motion of stars. Therefore this is a good reason to put our efforts on enhancing the exploitation of this technique on the following years.

Finally, predictions for TNOs generated by IAA-CSIC are only including those regions (Spain and Argentina) in which we have telescope time available to observe these events. In the future, depending on the feedback received from Gaia-GOSA, it could be possible to expand these predictions to other regions where observers could guarantee the ability of tracking SO of TNOs.

VII. References

- Braga-Ribas, F. et al., “A ring system detected around the Centaur (10199) Chariklo”, Nature, 508, 72-75 (2014)
- Millis & Dunham, “Precise measurement of asteroid sizes and shapes from occultations”, Asteroids II, A90-27001 10-91, 1989
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