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Proceedings of the
Workshop and colloquium held at the CIAS (Meudon)
on October 14-18, 2015

"Astrometry/photometry of Solar System objects after Gaia"

Institut de mécanique céleste et de calcul des éphémérides
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Foreword

The modeling of the dynamics of the solar system needs astrometric observations made on a large interval of time to validate the scenarios of evolution of the system and to be able to provide ephemerides extrapolable in the next future. That is why observations are made regularly for most of the objects of the solar system.

The arrival of the Gaia reference star catalogue will allow us to make astrometric reductions of observations with an increased accuracy thanks to new positions of stars and a more accurate proper motion. The challenge consists in increasing the astrometric accuracy of the reduction process. More, we should think about our campaigns of observations: due to this increased accuracy, for which objects, ground based observations will be necessary, completing space probes data? Which telescopes and targets for next astrometric observations?

The workshop held in Meudon tried to answer these questions. Plans for the future have been exposed, results on former campaigns such as Phemu15 campaign, have been provided and amateur astronomers have been asked for continuing their participation to new observing campaigns of selected objects taking into account the new possibilities offered by the Gaia reference star catalogue.

We look now forward to the arrival of the Gaia data in order to define the future works and programs of observations astrometric reductions of solar system objects.

The organizing committee: J.E. Arlot, V. Lainey, V. Robert, E. Saquet.

Acknowledgements

We would like to thanks the CIAS for welcoming us in Meudon observatory and Nicole Letourneur for her kindness during our workshop.

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All the presentations are available on ftp://ftp.imcce.fr/pub/colloquia/PHEMU-CIAS/presentations

Papers on the presentations are available below and at the Internet address:
on ftp://ftp.imcce.fr/pub/colloquia/PHEMU-CIAS/proceedings
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Astrometric reduction of old observations before and after Gaia

V. Robert

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CIAS Workshop
October 14-16, 2015

Abstract

Considering the old observations, *i.e.* astrophotographic plates and CCD that were taken before the arrival of the Gaia catalog, we discuss the astrometric process. The question is : how to increase the astrometric accuracy using the Gaia reference catalog ? To answer this, we detail the different steps of a complete astrometric method to estimate the contribution of the instrumental and physical errors in the final budget. We conclude about future works to ensure the Gaia accuracy in the astrometric reduction.

I. Introduction

Dealing with "old" observations henceforth means to consider observations that were realized before the Gaia catalog. With regard to the propagation of its reference errors and proper motions announced to be 1000 times more accurate than currents' (Robin et al. 2012), this catalog will be the best tool for positioning measurements. The question is now to re-analyze all the observations (or the major part), especially because they were reduced a long time ago with less accurate references, and most important because these observations are used to fit our satellite and planetary models. It is obvious that new accurate positions will be useful to detect and modelize new dynamical effects, or for better constraints.

Old observations are numerous worldwide. All the observatories have photographic plates (Kodak, Schmidt...) and CCDs in their archives. The amount of available observations is huge, and all systems and objects can be observed : satellites, planets, asteroids, comets... It is even more interesting that only a small part of these observations were analyzed and used for scientific purposes. Accurate methods and star catalogs were not available to decrease the positioning accuracy or to directly provide spherical positions for example, but now they are.

Making a new reduction of old observations will let us to observe in the past and for large time span, up to 100 years. The scientific goals are numerous : astrometry, celestial mechanics, dynamics ans evolving systems with time.

II. Astrometry before Gaia

In the “ideal” case, we consider observations with reference stars that are perfectly known, numerous, and homogeneously distributed around the center of field. The transformation of $(x, y)_m$ measured coordinates of objects to $(X, Y)_m$ measured tangential coordinates directly used to provide (RA, Dec) spherical coordinates, generally consists in a conventional model :

$$\begin{aligned} X_m &= ax_m + by_m + c + dx_m^2 + ey_m^2 + fx_m y_m + \zeta_{(x_m,y_m)} \\ Y_m &= a'x_m + b'y_m + c' + d'x_m^2 + e'y_m^2 + f'x_m y_m + \zeta'_{(x_m,y_m)} \end{aligned} \tag{1}$$

Using such method, all effects could be modeled by the fited $(a, b, ..., a', b', ...)$ parameters, but it does not allow any physical interpretation of the constants.

In the “real” case, the reference stars are not perfectly known (errors on positions, proper motions...), they are randomly distributed in the field and limited in number. The transformation of $(x, y)_m$ measured coordinates of objects to $(X, Y)_m$ measured tangential coordinates, now consists in a functional model (degree 1, 2, 3, orthogonal...) that could be chosen for the needs :

$$\begin{aligned} X_m &= \rho_x \cos\theta_x \times x_m - \rho_y \sin\theta_x \times y_m + \Delta_x \\ Y_m &= \rho_x \sin\theta_y \times x_m + \rho_y \cos\theta_y \times y_m + \Delta_y \end{aligned} \tag{2}$$

Using such method, all effects are not modeled by the fited parameters, but it allows physical interpretation of the constants (scale factors ρ_i, orientations θ_i, center offsets Δ_i...). Because the number of references (and corresponding internal errors) are not sufficient to perfectly calibrate the field and provide a precise astrometry, one should carefully look to correct the theoretical (RA, Dec) positions for spherical effects, and (x, y) positions for instrumental effects.

Spherical corrections include those due to the relative motion between the observer and objects (parallaxes, proper motions, radial velocity), the optical effects due to the electromagnetic signal propagation (aberrations, relativistic deflexion, atmospheric refraction), the precession and nutation effects, the local perturbations, the time conversions. All these effects could be modeled within 5-10 mas (Kaplan et al. 1989, Robert 2011).
Instrumental corrections generally include terms from the 1st to 3rd order, corresponding to the coma-magnitude effect, the tilt terms, and the distortion terms, respectively.

At the end, a more complete functional model needs more informations :

$$
\begin{aligned}
&X_m = \rho_x \cos\theta_x \times x_m - \rho_y \sin\theta_x \times y_m + \Delta_x + C_x x_m (m - m_0) + p x_m^2 \\
&+q x_m y_m + D x_m (x_m^2 + y_m^2) \\
&Y_m = \rho_x \sin\theta_y \times x_m + \rho_y \cos\theta_y \times y_m + \Delta_y + C_y y_m (m - m_0) + p x_m y_m \\
&+q y_m^2 + D y_m (x_m^2 + y_m^2)
\end{aligned}
\tag{3}
$$

We used such method to analyze USNO photographic plate series of the Martian, Jovian, and Saturnian systems (Robert et al. 2011, 2014, 2015, 2016 in progress). We demonstrated that we could calibrate the fields with a high accuracy, and we found correlations between the plate constants and the temperature that were not suspected. We demonstrated that old observations could compete with those of old spacecraft since one looks carefully for each step of the reduction process, not to decrease the accuracy.

III. Astrometry after Gaia

The current error budget is dominated by the atmospheric effects within 20-40 mas (Lindegren 1980), the extraction of the sources within 15 mas (Bertin et Arnouts 1996), and the star catalog within 15 mas (Zacharias et al. 2013).
With the Gaia catalog, this last contribution will directly fall. Hence, the atmospheric effects and extraction remain. We conclude that these first effects could not be decreased. Since observations are realized from ground, it will introduce random errors due to the air fluctuations that will always be unknown. But efforts could be done for extraction improvements. In parallel, the reduction model by itself could be improved within 5-10 mas. To do so, relativistic terms should be introduced and developments should be realized to higher orders. For example and to ensure the Gaia accuracy with the proper motion correction, the micro-arcsec is reached at the 3rd order of t.

At the end and if efforts are made for all these considerations, the overall accuracy of old ground observations could be finally limited by the atmospheric effects or 20-40 mas. For now, it seems not possible to overcome this limit.

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Digitization of astronomical plates and application

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Abstract:
This paper reports our digital research of astronomical plates. The astronomical plates are digitized with the advanced commercial scanner. And some results of the digitization are also present in this paper.

1 Introduction
Astronomy is a subject based on observations. Although the observing ability of astronomical plates hardly compare to that of CCD detector, astronomical plates as the main data carrier record more than one hundred years astronomical information. The plates are scientific heritage, which play a positive role in promoting the development of astronomy. But photographic astronomical plates are coated with light-sensitive materials, which are emulsions. They are very sensitive to the changes of temperature and humidity. With the passing of time and the change of environment, the emulsion will deteriorate gradually. In order to preserve and take full advantage of these historical data, we should to digitize plates as soon as possible.

2 Digitization of astronomical plates
The foremost problem is that the digital speed is very slow. In recent years the quickly digital technology have been developed in many countries, including using advanced commercial scanners and developing specialized scanners (Robert et al. 2011). However, the specialized scanners are very few in number and not readily available. The method of using advanced commercial scanners is simple, low-cost and effective, which has been employed by many scholars (Vicente et al. 2007). So the advanced commercial scanner EPSON 10000 XL has been used to digitize plates in our study.

This scanner has a linear CCD camera with the maximum scanning dimension of 31.0 cm by 43.7cm. Because this scanner adopts linear scanning mode, there have some instability in the scanning direction, which affect the precision of digitization. To solve this problem, we scan each plate in two orientations with the rotation by 90 degrees and only use the data in linear CCD direction to determine results.

Some marks were left in plates, which made in the observation or history measurement. So the method to digitize astronomical plates is as follows. First, preview astronomical plates at low resolution in JPEG format to store the marks as an important part of the plate archive (Tsvetkov et al. 2012). Second, remove the marks, because they could interfere with data processing. Then scan astronomical plates at high resolution in TIFF format. As previously mentioned, each plate should be scanned in two orientations with the rotation by 90 degrees. Finally, convert TIFF image to FITS image and create a complete FITS header.

3 Application

We have digitized and processed a series of astronomical plates of natural satellites observed form 1987 to 1990. We have also compared the new obtained positions of natural satellites with the IMCCE ephemeris. The comparison has shown that the new satellites positions have a consistency with the theory positions of about 100mas. And the standard deviations of these positions are almost between 100 and 250mas. Moreover, these positions are more accurate than that obtained in history (Qiao et al.1995), which is largely benefited for the new star catalogue.

4 Summary

Digitization of astronomical plate not only helps us preserve these historical data, but also allows us take full advantage of these historical data. It is a simple way to digitize astronomical plates with an advanced commercial scanner. Now with the new star catalogue, digitizing astronomical plates and processing the digitized images can improve the accuracy of the historical data. The public of GAIA catalogue will be very good for the reduction of astronomical plate.

This work was supported by the National Science Foundation of China (NSFC) (Grant Nos 11573029).

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The NAROO Project
(New Astrometric Reduction of Old Observations)

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Introduction

The astrometry of solar system objects has been performed since tears in order to accumulate data necessary for fitting the theoretical dynamical models, very sensitive to periodic terms. Data spread on a long interval of time are more efficient than precise data on a short period of time. We know that old observations and old reductions are not sufficiently precise for our present purposes: we intend, with the NAROO project, to re-reduce the old observations with modern reference star catalogues that corresponds to observe in the past with today accuracy.
For that purpose, we propose to set up a centre for sub micrometric digitizing of photographic plates and for CCD images analysis.

The context of the project

The studies of small effects in the motion of solar system objects increased the interest of old data useful for the dynamics of solar system objects and several projects for digitizing old plates arose. Even before the Gaia project, reference star catalogues (UCAC, URAT) made progresses allowing to reduced old data.
Besides the catalogue useful for the astrometric reduction, we had a progress of the technology of sub-micrometric scanners. Projects of scanning old photographic plates were studied (Brussels, St Petersburg, Shanghai, Harvard).

The past progresses of astrometry are shown in figure 1 below.

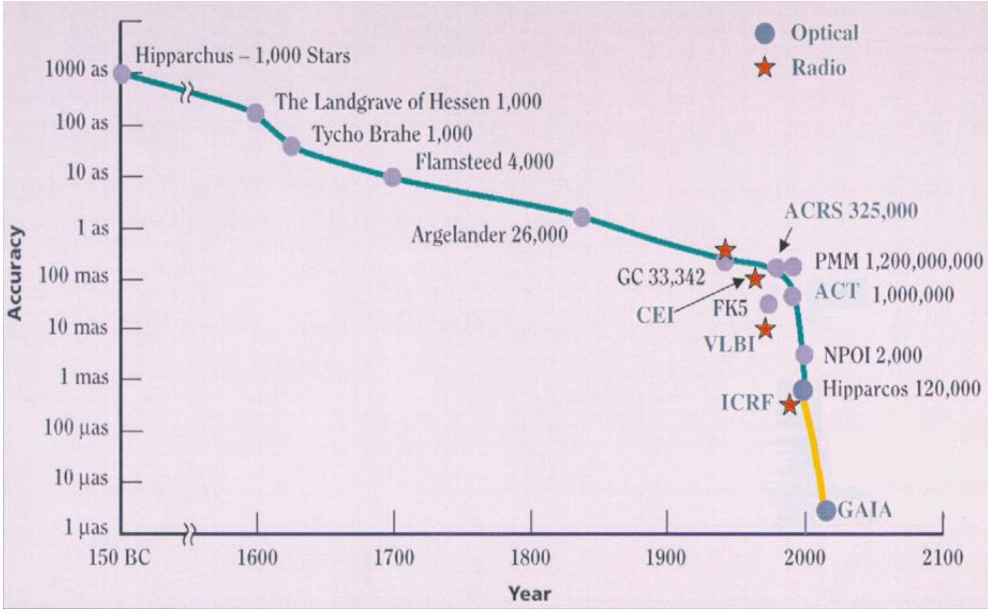


Figure 1

The future progresses of astrometry are shown in the figure 2 below through the positional accuracy of the Gaia star catalogue for the period 1890-2090 giving the accuracy for several magnitudes of the reference stars. Star proper motions of the Gaia catalogue will allow to go one century in the past.

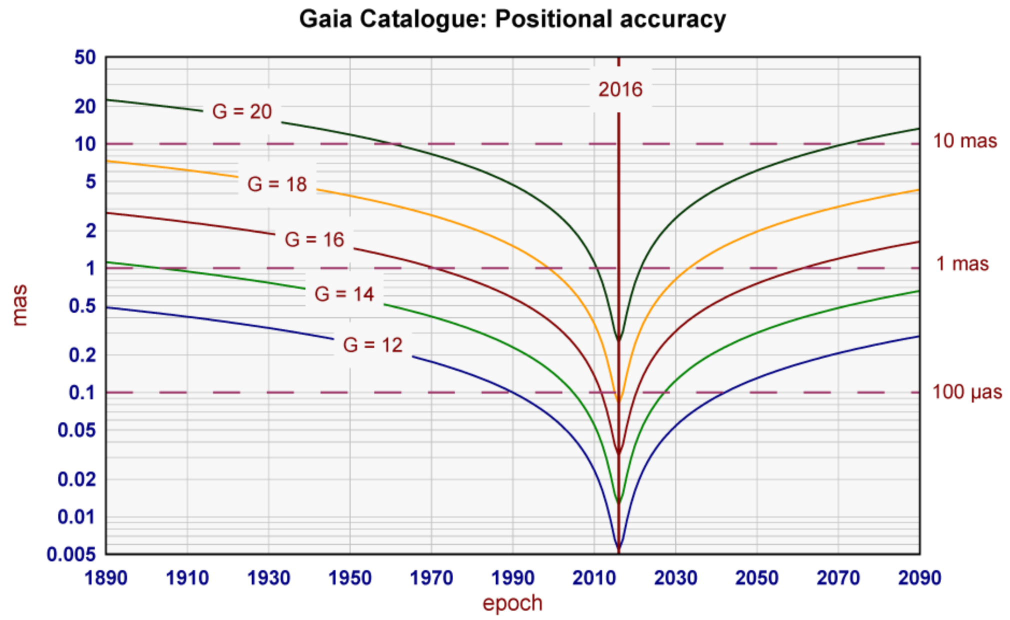
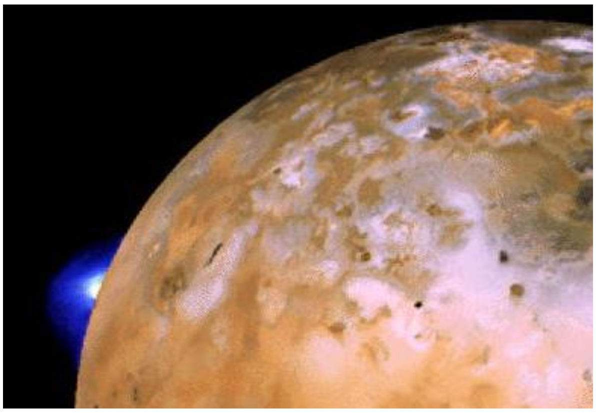


Figure 2

The NAROO project will endorse :
-the making of a new reduction of old observations for: « observing in the past »
-the creation of a centre for digitizing photographic plates and image analysis
-the data mining on CCD observations for a new astrometric reduction
-the use of a new reference catalogues such as UCAC4 and Gaia reference star catalogues for the new reduction
Our goal is mainly to emphasizing the astrometry of solar system bodies in the scope of the arrival of a new astrometry thanks to the arrival of the Gaia reference catalogue

The scientific goals

There are many scientific goals which should be fulfilled thanks to our project. First, by providing a coherent reference system for all data, the extrapolation of the ephemerides of solar system objects will become confident. More, for specific objects such as TNO and NEO, we will be able to make pre-discoveries on astrographic plates such as Schmidt plates.
By increasing the astrometric accuracy of one order of magnitude, we will be able to quantify small effects such as the dissipation of energy due to tides in the natural satellites systems: internal structure and scenarios for the formation should be validated. We would explain the thermal equilibrium of Io and the geysers on Enceladus by looking for an acceleration in the motion of the icy satellites.



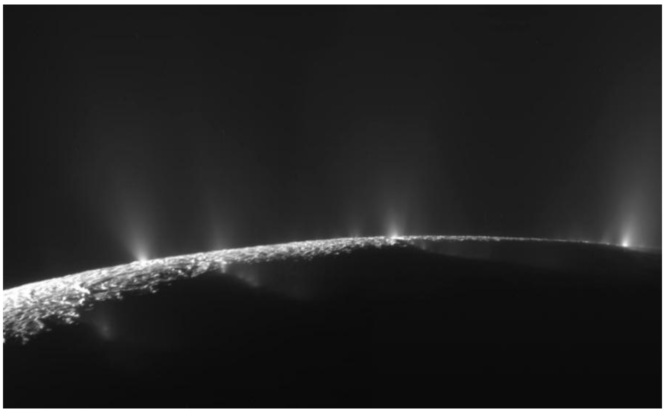


Figure 3

Volcanoes on Io and geysers on Enceladus: an explanation through the explanation of their motion

Concerning the Saturnian system, we look for old data helping to validate the scenarios of formation and evolution of the satellite system.

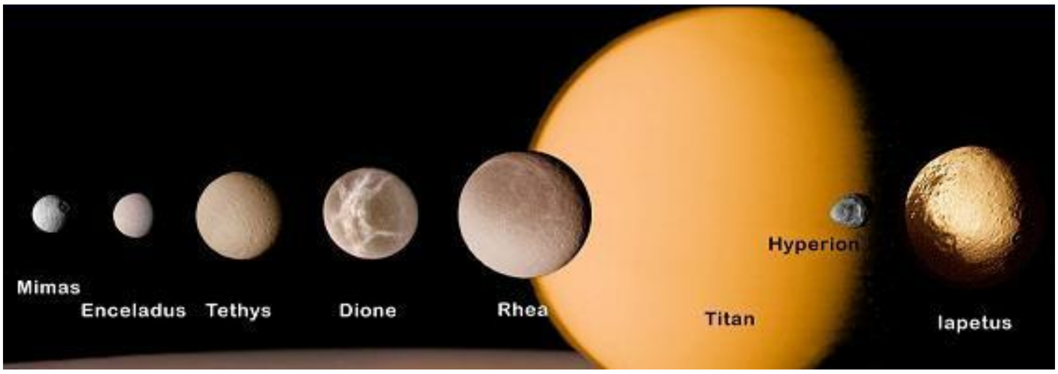


Figure 4

The Saturnian satellites

What is an « old » observation worth to be re-reduced ?

The astrometric observations of the natural planetary satellites may be found as follows:

1) on photographic plates made from1890
2) on CCD observations made from 1980
3) astrometric observations from space probes

More generally, an old observation is an observation made before the arrival of the Gaia catalogue.

Example of old plates worth to be re-reduced and scanned as tests :

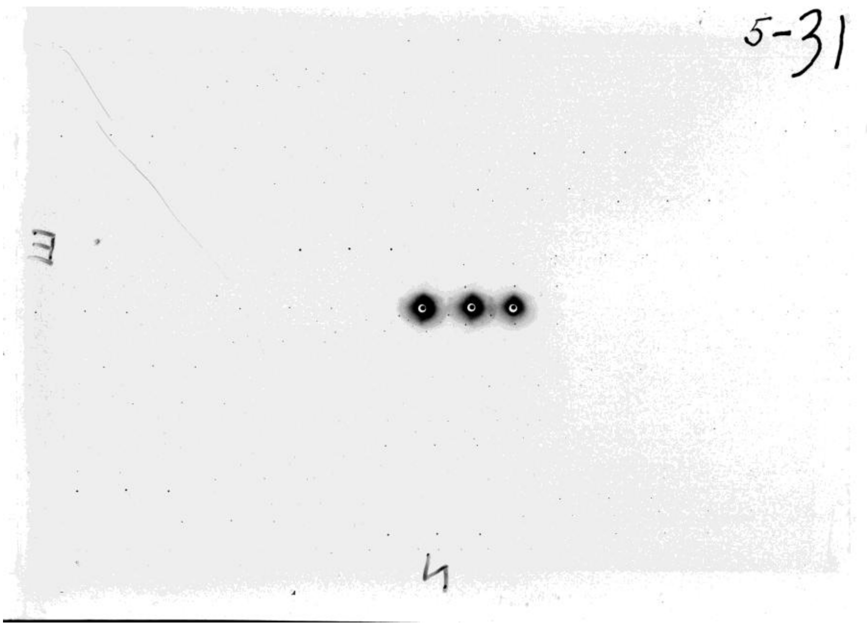


Figure 5: Three exposures of the Martian system with a detail (positive) on Phobos, Deimos near their planet. The accuracy of the reduction is the same as the accuracy of the observations by mariner made at the same time.

The competitors and precursors projects

The scanning of photographic plates is performed by several observatories with different purposes. The main projects are as follows:
MAMA - observatoire de Paris (accuracy 1000 nm)
Starscan – U.S. Naval Observatory (accuracy 500 nm)
Harvard University scanning « Historic Sky Project » (accuracy 1000 nm)
Pulkovo Fantasy digitizer (accuracy 1000 nm)
DAMIAN-Royal Observatory of Belgium (accuracy 70 nm)
Our NAROO project: a sub-micrometric scanner (accuracy 70 nm) as Damian.

	MAMA	StarScan	DAMIAN
Temps de scan	1 h	20 min	8 min
Positionnement XY	1 μm	0.1 μm	0.001 μm
Répétabilité de positionnement XY (mesurée)	1.17 μm	0.50 μm	0.07 μm

Table 1

We had collaborations with laboratories owning sub-micrometric scanners and photographic plates (USNO-Washington DC, ROB-Bruxelles, Bucharest Astronomical Institute, QMUL-London, OCA-Nice). We made an inventory of existing plates scientifically interesting and we found a large number of interesting available plates (until 200 000 plates) especially plates from refractors the focal length of which being from 3 to 20 meters or from reflectors (Schmidt plates). We made tests by scanning Galilean, Saturnian and Martian plates with ROB-DAMIAN digitizer.
We got first encouraging results with the Martian satellites astrometric positions (Table 2) the accuracy of which being the same than for Mariner data made at the same date.

	$(O-C)_{\alpha\cos\delta}$ NOE	$\sigma_{\alpha\cos\delta}$ NOE	$(O-C)_{\delta}$ NOE	σ_{δ} NOE
Mars	–1.8	56.9	–5.3	50.7
Phobos	6.0	58.3	–1.7	48.6
Deimos	4.3	41.9	–3.1	47.3

Table 2

Tables 3 and 4 provides the O-C of the Galilean satellites in mas: they allow to validate Jupiter's ephemerides and to show the biases in these ephemerides. Due to the use of the UCAC4 catalogue, the standard error is abourt 50 mas which should decrease when using the Gaia catalogue.

Table 3. Details of the (RA, Dec) (O−C) in mas according to the INPOP06 theory with DAMIAN digitizations: USNO Galilean plates of 1974.

Satellite	$\overline{(O-C)}_{\alpha\cos\delta}$ INPOP06\L2	$\sigma_{\alpha\cos\delta}$	$\overline{(O-C)}_{\delta}$ INPOP06\L2	σ_{δ}
JI	−9	54	34	68
JII	−10	56	14	70
JIII	1	63	39	72
JIV	−20	64	10	70
Average	−10	59	24	70

Table 4 . Details of the (RA, Dec.) (O—C) in mas according to the INPOP08 theory with DAMIAN digitizations: USNO Galilean plates of 1974.

Satellite	$\overline{(O-C)}_{\alpha\cos\delta}$ INPOP08\L2	$\sigma_{\alpha\cos\delta}$	$\overline{(O-C)}_{\delta}$ INPOP08\L2	σ_{δ}
JI	65	52	91	67
JII	64	55	82	77
JIII	61	73	91	69
JIV	40	76	81	71
Average	57	64	86	71

Besides photographic plates, we analyzed CCD observations made in the 1990's such as Flagstaff astrometric observations shown on figure 6.

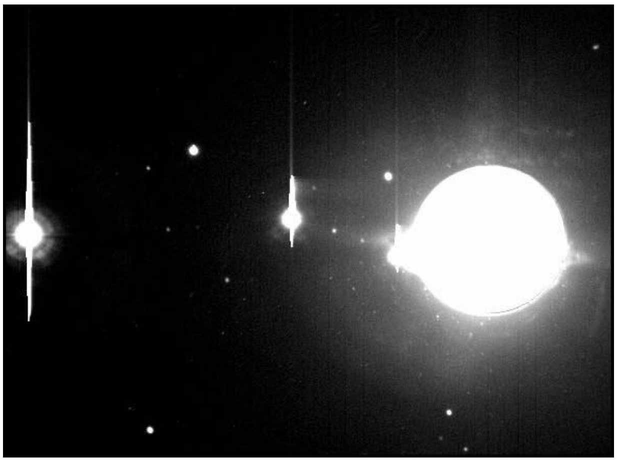
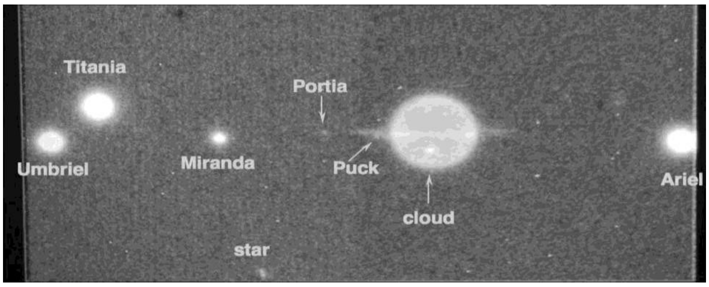


Figure 6

Small inner satellites may be referred to astrometric stars which were not catalogued at the time of the first reduction but which will be included in the Gaia catalogue. We have CCD observations of Dione, Tethys and the Lagrange L4 librators Helene and Telesto made with the Flagstaff 61-inch telescope.

Data mining in the archives of large telescopes provides interesting data.



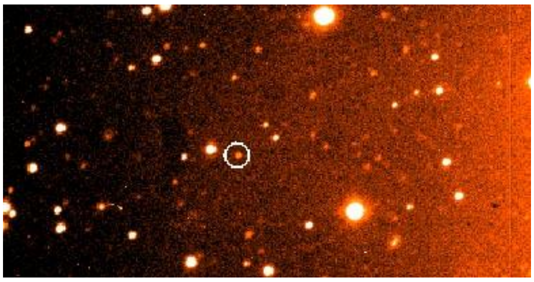


Figure 7: Uranian system at VLT at left (adaptative optics NACO)
and **Outer satellite of Uranus at right** (MegaCam CFHT)

Observations from space probes

The observations made by space probes were also reduced with the available reference star catalogues and may be re-reduced. The images contain the satellites with stars in the background and the reduction is the same than for ground based observations. With the UCAC2 or 4 catalogue, the astrometric accuracy reaches 60 mas; the Gaia reference catalogue should allow to reach an accuracy of 1 mas. In this case, many other problems should be solved such as the figure of the satellite, even the center of mass is easier to determinate than from ground-based images.

Conclusion

Because of the large number of plates available and of the need of high astrometric level of old data, we intend to continue our project of re-reducing old data. Our tests made with the UCAC catalogues let us think that the use of the Gaia catalogue will provide valuable data for the study of the dynamics of the solar system.

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Astrometric reduction of the PHEMU observations: overcome obstacles to increase the accuracy

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The main goal of natural satellite observations is to build a motion model adequate to the observations. As soon as such a model is available, one can use it for many purposes. Observations of different types provide us positional data about the satellites. Astrometric ground based observations give the topocentric angular coordinates. Observations made from space give the spacecraft centered angular coordinates.

In 2014-2015, the Sun and the Earth passed through the equatorial plane of Jupiter and therefore through the orbital planes of its main satellites. It was the equinox on Jupiter. This occurrence made mutual occultations and eclipses between the satellites possible. Experience has shown that the photometric observations of such events provide accurate astrometric data able to bring new information on the dynamics of the Galilean satellites. These observations give the differences between the topocentric angular coordinates of two satellites (case of mutual occultation) or the differences between the heliocentric angular coordinates of two satellites involved in the phenomenon (case of mutual eclipse). To derive astrometric data from photometric observations of the mutual occultations and eclipses of the Galilean satellites we develop an accurate photometric model of mutual events and we are able to apply our original method. Starting from the ephemeris satellite coordinates and using a photometric model of mutual event we generate a theoretical light curve. This theoretical light curve is fitted then to the observed one introducing correction parameters to the differences in satellite coordinates. These parameters allow us to have the true observed satellite relative positions.

The present communication focuses on photometric model of mutual occultations and eclipses of the Galilean satellites and mostly on sources of systematic errors in the astrometric results obtained. We consider a grid of elements on the visible surface of the occulted or eclipsed satellite and apply some light scattering law to the flux emitted by each element. The integration of the flux over the entire visible surface gives us the modelled light flux emitted from the satellites during the phenomenon. We adopt Hapke's light scattering law in our solution (Hapke 1981, 1984). His scattering function depends on five parameters which are constant for a given satellite and spectral band. McEwen et al. (1988) give the Hapke parameters for the rough surface of the Io satellite, whereas Domingue and Verbiscer (1997) refined the Hapke function for rough surfaces and, in particular, for the other three Galilean satellites. Given that most of the observations of the Galilean satellites were made with the V filter, or with no filter at all, we adopt the set of parameters from Domingue and Verbiscer (1997) for the 0.55 µm spectral band. During the event, almost half of the leading and half of the trailing hemisphere of each satellite were viewed from the Earth, and therefore we use the mean values for the corresponding parameters. In such a way we must take in consideration the variation of the light reflectivity of satellites with the angle of rotation anyway. We do it using some data published in Morrison and Morrison (1977), in Johnson and McCord (1970), in Prokof'eva-Mikhailovskaya et al. (2010) and in Abramenko et al. (2011).

One of the Hapke parameters w is a multiplier in all expressions for the flux. It can be seen that the dependence of the other Hapke parameters (except w) from the spectral band (Λ) is very low. It is enough to take into account only the dependence of w on the wavelength of light. It is clear also that the parameter w is proportional to the disk resolved albedo of satellite. Approximately we may admit that the parameter w is proportional to the disk integrated albedo of the satellite. During the mutual phenomena we measure the ratio of the fluxes of two satellites (except for a mutual eclipse when the flux from eclipsed satellite is measured). As it follows from the paper by Johnson and McCord (1970) spectral reflectivity of the Galilean satellites has a linear dependence with nearly the same coefficients. That is why the measured ratio of the fluxes is almost independent on the wavelength. In that issue, to derive astrometric results, we can process the photometric observations using the Hapke light scattering law with the parameters given for the band V only.

Another method of astrometric reduction the mutual event observations based on another light scattering law is recently developed by Dias-Oliveira et al. (2013). Input parameter of this method is the ratio of the albedo of the two satellites.

There are two sources of significant systematic errors in the astrometric results obtained. They do not depend on the applied light scattering law. To understand the problem let us look at a simplified model of the mutual occultation of two satellites. In this model we suggest homogeneous satellite disks. Let the occulting satellite be "number 1" and the occulted one be "number 2" as well. During the observation we measure a combined flux E from the two satellites. Let S be a normalized flux so S= 1 when the satellites are outside the occultation. During the event the satellite 2 is occulted so we have S<1. We suppose an equation

$$E = K \cdot S \,,$$

where K is some constant coefficient and $E=K$ is the flux outside the event. Let us denote p_1 , p_2 − disk integrated albedos of the first and second satellites correspondingly. Further notation are r_1 , r_2 −apparent radii of the disks. Then the flux from occulting satellite is equal to $R\, p_1\, r_1^2$ and the flux from occulted satellite is equal to $R\, p_2\, r_2^2\, k_2(d)$, where R is some coefficient, $k_2(d)$ is a share of uncovered portion of the disk of occulted satellite, d being the apparent distance between the centers of the disks on the sky. Normalized flux S can be expressed by

$$S = \frac{p_1 r_1^2 + p_2 r_2^2 k_2(d)}{p_1 r_1^2 + p_2 r_2^2} = \frac{1 + \dfrac{p_2 r_2^2 k_2(d)}{p_1 r_1^2}}{1 + \dfrac{p_2 r_2^2}{p_1 r_1^2}} \,.$$

In the no event case k_2=1. If a full occultation occurs k_2 is equal to zero and in the case of annular occultation $k_2 = (r_2^2 - r_1^2)/r_2^2$. Fig. 1 demonstrates the case of full occultation. For the time period (t_1,t_2) we have k_2=0 and

$$S = \frac{1}{1 + \dfrac{p_2 r_2^2}{p_1 r_1^2}} \,.$$

Thus, S is independent from satellite position.

It happens in the case of full occultation that for the observed flux E_{observed} we have

$$E_{observed} \neq K \frac{1}{1 + \frac{p_2 r_2^2}{p_1 r_1^2}},$$

where K is the flux outside the event. See an example in the Fig. 2. There are two possibilities. First is

$$E_{observed} = K \frac{1}{1 + \frac{p_2 r_2^2}{p_1 r_1^2}} + P,$$

where P is a parasitic background flux which was not taken in consideration. Second is

$$E_{observed} = K \frac{1}{1 + m \frac{p_2 r_2^2}{p_1 r_1^2}},$$

where m is some artificial correction to the ratio of the albedo of satellites. There remains uncertainty: what reason of two does take place. We have an equivalence

$$K \frac{1}{1 + \frac{p_2 r_2^2}{p_1 r_1^2}} + P = K \frac{1}{1 + m \frac{p_2 r_2^2}{p_1 r_1^2}},$$

Processing the observed light curve during a full or annular occultation gives us the value of P or the value of m. We have made a lot of such analysis from observations of different pairs of satellites and for almost all observations it happened that $P<0$. This allows us to assume that the parasitic background P is dominant.

If an unexpected parasitic background flux exists or the assumed albedo ratio is not correct we have the following situation for a partial occultation. In the case of parasitic background

$$E = K \frac{1 + \frac{p_2 r_2^2 k_2(d)}{p_1 r_1^2}}{1 + \frac{p_2 r_2^2}{p_1 r_1^2}} = K \frac{1 + \frac{p_2 r_2^2 k_2(d + \Delta)}{p_1 r_1^2}}{1 + \frac{p_2 r_2^2}{p_1 r_1^2}} + P.$$

or in the case when the albedo are not correct

$$E = K \frac{1 + \frac{p_2 r_2^2 k_2(d)}{p_1 r_1^2}}{1 + \frac{p_2 r_2^2}{p_1 r_1^2}} = K \frac{1 + \frac{p_2 r_2^2 k_2(d + \Delta)}{p_1 r_1^2}}{1 + m \frac{p_2 r_2^2}{p_1 r_1^2}}.$$

Thereby we are forced to introduce an astrometric error Δ . These are two circumstances when a significant astrometric error appears.

Note that the same circumstances take place in the case of mutual eclipse of satellites if the combined flux of eclipsing and eclipsed satellites together is measured. By the way, our analysis shows that systematic errors in the astrometric results (“O-C”) are three times the errors from the random error of photometry.

Thus, there are two problems: first is to detect and measure the parasitic background in photometric observations, second is to get correct disk integrated albedo of satellites. A parasitic background flux may come from following sources: sky background, telescope light scattering, photodetector disturbances. The methods applied in photometric processing of the images are intended to take into account all these effects. The fact is that these methods are not perfect.

To have a real albedo of satellite we really need to know for each satellite the disk integrated albedo as a function

$$p(\theta, \alpha, \Lambda)$$

depending on θ - the satellite rotation angle, α - the solar phase angle, Λ – the wavelength of light. The only data are available in the papers by Morrison and Morrison (1977), by Johnson and McCord (1970), by Prokof'eva-Mikhailovskaya et al. (2010) and by Abramenko et al. (2011). These data are not sufficiently precise and do not cover all the necessary ranges of the arguments θ, α, Λ .

Conclusions.

To increase the astrometric accuracy of the PHEMU observations:

- The methods of photometric processing of the PHEMU observations must be revised and corrected to exclude parasitic flux *P*.
- A large photometric observations of Galilean satellites must be made to get correctly the function $p(\theta,\alpha, \Lambda)$.

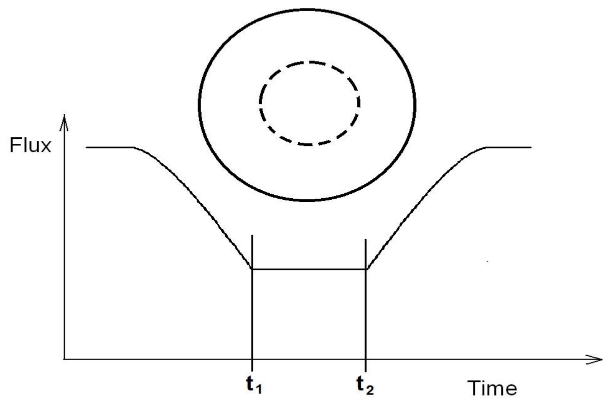

Figure 1. Case of full occultation.

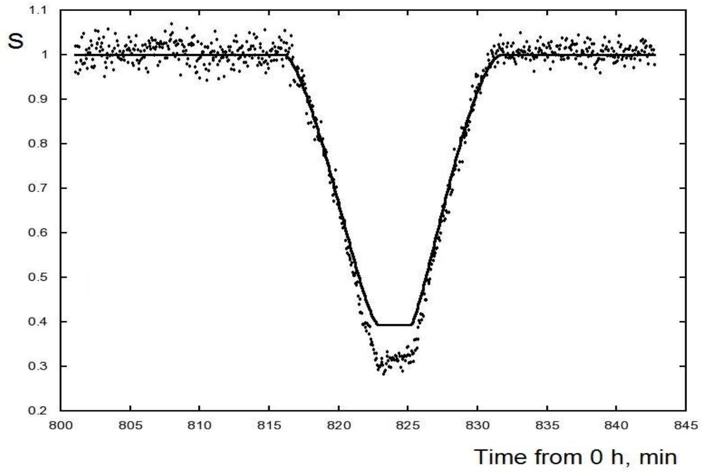

Figure 2. Occultation of Io by Callisto observed November 2, 2014 at Umatilla, Oregon, USA.

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Short time span ephemeris for Pluto

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Introduction

Pluto is the best known and studied transneptunian. Recently visited by the flyby of the New Horizons spacecraft (closest approach on July 2015), this dwarf planet shows an expanding atmosphere [1], a radius of 1187 km (±2 km) [2], and forms a binary system with Charon, the largest of its 5 known satellites. From the ground, the stellar occultation technique has played an important role on the knowledge of Pluto and its environment (see also [3], [4], [5], and [6] to mention some recent works).

Prediction of occultation events relies on the accuracy of star positions and of ephemerides of the occulting bodies. With the astrometry from the GAIA space mission (first release on mid 2016), accurate $10 < V < 20$ star positions will no longer be a problem in the near-mid future. Ephemerides of distant solar system bodies, nevertheless, will still depend on ground-based astrometry to continuously assure the accuracy of their orbits up to few years (1-3) ahead of the most recent observational data used in their determinations. Although modern planetary ephemerides for Pluto (JPL DE432[1], INPOP13c [7]) have enough accuracy to the current prediction tasks related to Pluto, it is just as well to have an independent procedure to improve Pluto's orbit and keep errors under reasonable limits when propagating its positions.

Method and Results

One of the difficulties related to orbit determination is to retrieve not only past positions of a given body but also their history, so that we can have a realistic evaluation of their quality. For Pluto, in particular, there is also the nearby presence of Charon that displaces Pluto's photocenter. In this context, positions of Pluto from almost two decades of observations, as well as a correction due to the presence of Charon, are reported and well documented by [8]. This is the only set of observational data used here.

The orbit fitting code we used, Numerical Integration of the Motion of one Asteroid (NIMA [9]), starts from an initial orbit of Pluto from the Asteroids Dynamic Site (AstDys[2]), corrected to fit these observations. One important step was to retrieve the barycenter of the Pluto system from the observed positions. The results are shown in Fig. 1. Figure 2 shows the prediction of the 29 June 2015 stellar occultation [1] obtained with this procedure.

Although a smaller difference between the paths given by both panels in Fig. 2 is desirable, the result is still competitive. It should be emphasized the weighting scheme detailed by [9] and that

1 http://naif.jpl.nasa.gov/pub/naif/generic_kernels/spk/planets/de432.pdf
2 http://hamilton.dm.unipi.it/astdys/

the historical background of the observations is of relevance to properly determine the weights. The astrometry provided by [8] can be added to new and accurate astrometric data to allow a safe propagation of Pluto's orbit in the immediate future.

Comments and conclusions

Pluto has observations since 1914 (see the MPC[3] site) and this work, by no means, discourages its use. Alternatively, it presents a way to update Pluto's orbit in a useful context to stellar occultation predictions (that is, still accurate when propagated 1-3 years ahead of the most recent observation used in the orbit determination from recent and well documented astrometric data). Also, once one has new observations of Pluto, the orbit can be promptly updated. The weighting procedure described in [9] should be taken into account and well known orbit fitting codes, like OrbFit[4], are also well-suited for this purpose.

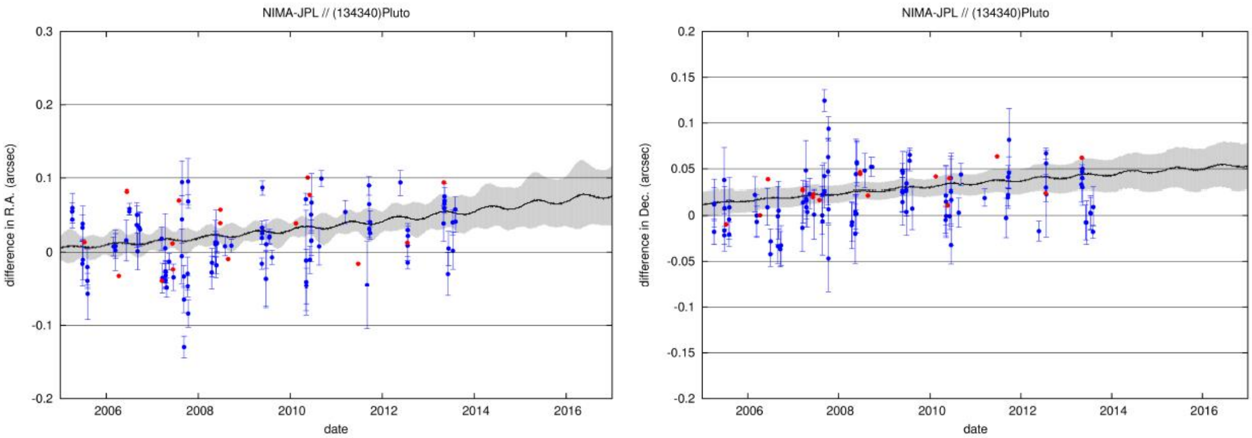

Fig. 1 Dark continuous line shows the difference in the sense NIMA minus DE432. Grey area around this line gives the 1-σ uncertainty. Blue points: positions derived from traditional astrometry (with 1-σ uncertainty error bars). Red points: positions derived from stellar occultations (error bars not seen). Only data since 2006 are shown.

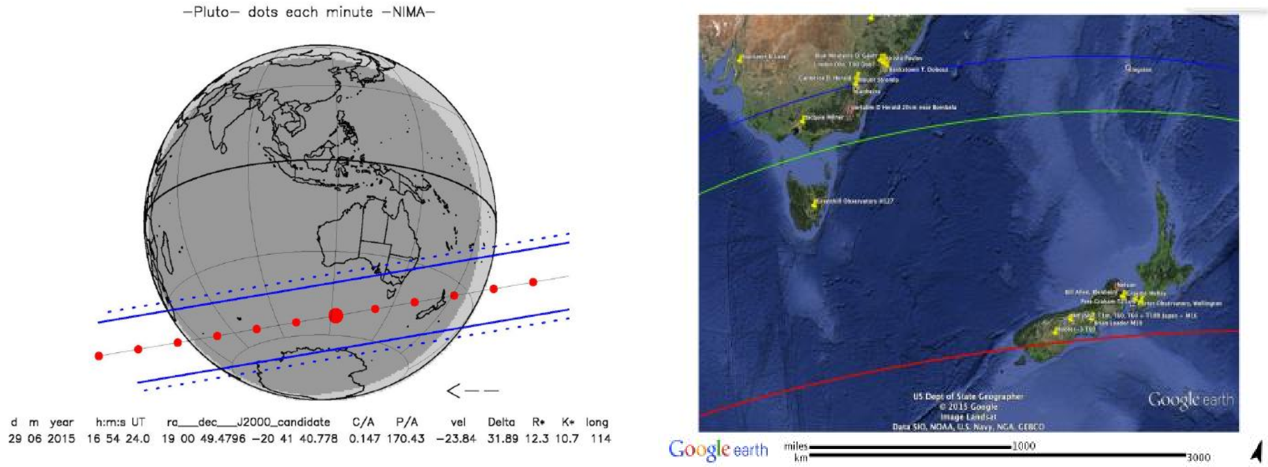

Fig. 2 Left panel: occultation map for the 29 June 2015 stellar occultation by Pluto using NIMA, as explained in the text. The continuous blue lines indicate the limits of Pluto's diameter. The dashed blue lines indicate the drop of 50% of the stellar light due to Pluto's atmosphere. The central thin line shows the center of the shadow. Right panel. Similar to the left panel, with the red continuous line showing the real path of the center of the occultation shadow as determined

3 http://www.minorplanetcenter.net/iau/mpc.html
4 http://adams.dm.unipi.it/orbfit/

after the event.

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Exploring the outer solar system with stellar occultations

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The Trans-Neptunian Objects (TNOs) orbiting beyond Neptune's contain largely unaltered material from the primordial proto-planetary disk. They also kept the memory of the early planetary migrations, and thus contains essential information on the origin and evolution of our solar system. Still, because of their remoteness, there merely appear as point sources in classical images, so that their surface properties and immediate environments are very difficult to study.

In that context, the stellar occultation technique is a very powerful tool to study TNOs, and their cousins Centaurs that orbit between Saturn and Uranus. It consists in observing the passage of those remote bodies in front of stars, revealing their shapes, atmosphere and possible presence of rings. Sub-km accuracies on sizes and nanobar-pressure sensitivities are routinely attained with this technique, at levels that are thus comparable in terms of precision to what is obtained from space missions.

In the last decade, about half a dozen remote objects have been observed with occultation, among which the Trans-Neptunian dwarf planets Pluto, Eris, Makemake, Quaoar and Varuna, Pluto's satellite Charon and the largest Centaur known to date, Chariklo. Among the noteworthy breakthroughs obtained so far, we may quote:

(1) The discovery of rings around Chariklo. This is the first time that rings are observed elsewhere than around giant planets. The presence of rings around such a small body (about 240 km in diameter) is a puzzle and shows that rings are more common than previously thought.

(2) The monitoring of Pluto's atmosphere, that revealed a continuous pressure increase in spite of a monotonic recession from the Sun, hence a gradual cooling that should freeze the atmosphere onto Pluto's surface. This paradoxical situation can probably be explained by strong seasonal effects that sublimate nitrogen ice that has been for decades in a permanent night. This study is most timely at the epoch of the NASA/*New Horizons* Pluto flyby of July 2015.

Nowadays, about half a dozen stellar occultations by TNOs can be detected yearly from the ground. The ESA/*GAIA* mission is expected to provide a greatly improved astrometric catalog release at mid-2016. This will increase the number of successful observations by at least one order of magnitude, paving the way for discoveries of new dwarf planets with an atmosphere, or more ring systems around small bodies.

Gaia and the orbit determination of faint TNOs using Public Deep Surveys - Occultation Predictions

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Abstract:
One way to know the physical properties of Trans-Neptunian objects (TNOs) is the analysis of star occultations by these objects (Sicardy et al. 2011, Ortiz et al. 2012, Braga-Rbas et al. 2013 and 2014). The prediction of a stellar occultation basically depends of comparisons of the positions of TNOs and stars (Assafin et al. 2012, Camargo et al. 2014). However with the current ephemeris of TNOs and star catalogs is not possible to do good predictions of the event. With the release of GAIA catalog the limitations with respect to the stars will be overcome.

This work consists of developing a methodology to refine the orbits of some TNOs. For this purpose, we use data released of the year 2013, by the *Dark Energy Survey* (DES – http://www.darkenergysurvey.org/).

The methodology basically consists in knowing the pointings, observation date and the observed field with the Dark Energy Camera (DECam), to identify the known solar system objects located in this field (SkyBot – http://vo.imcce/webservice/skybot/). Then retrieve the images which contain some TNO and with the positions obtained after doing astrometry (PRAiA – Assafin et al. 2010) added to the existing literature, we do a better fit of the orbits of TNOs and Centaurs (NIMA – Desmars et al. 2015) found in DECam. Finally predict stellar occultations by using an astrometric star catalog.

Astrometry and dynamics of SSOs with the Gaia satellite and the Gaia mission

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Abstract

After a successful launch of the satellite in December 2013, the Gaia missions is performing its regular operation since mid-2014. This cornerstone mission - from ESA's Horizon 2000+ programme - will provide more than the 3D census of our Milky Way with high precision parallax and other parameters for a billion of stars. Indeed, by scanning regularly the whole sky during 5 years (and possibly more), Gaia will detect and observe a large number of extragalactic objects as well as Solar System objects, mainly small bodies with roughly 350,000 asteroids observed down to magnitude 20.7; and provides valuable scientific perspectives (Tanga et al. 2014 EPSC 9, 486).

The scientific payload consists of a telescope with two 1.7x0.7m primary mirrors, open pupil astrometry and photometry in the visible, low resolution spectroscopy for deriving colors, a spectrometer, and big focal plane with 106 CCDs covering an angle of 0.6x0.6 squ. degrees. The high precision astrometry and photometry that will be regularly collected will provide a tremendous scientific harvest for the science of SBSS. There are two chains for the data reduction, short-term and long-term. The short-term chain operates on a daily basis and provides astrometry of SSOs and possible scientific alert that triggers a ground-base network of observatiories (Gaia-FUN-SSO). The long-term chain operates at about half-mission and treats all the transit data accumulated to derive global and local parameters. The astrometry precision and accuracy achieved for SSO is unprecedented with formal precision ranging from 2mas at faint end to less than 0.1 mas at the bright end. All astrometry is given in the Gaia catalogue that will be the best astrometric catalogue available and the optical counterpart of the ICRF with much higher density. Actually Gaia will yield -from its direct observations of SSOs (asteroids, comets, planetary satellites) - taxonomy, shape, sizes and spin data, improved orbital elements, results for binary asteroids, masses and densities, test of GR, links of reference frames, etc. (Hestroffer et al. 2010, LNP 790, 25) Besides, the Gaia stellar catalogue will also radically change future astrometry of small bodies, stellar occultation predictions, etc. Indeed, the use of the stellar catalogue itself for the astrometric reduction of future or past observations will improve the accuracy of the measurements by removing strong catalogue biases (Chesley et al. 2010, Icarus 210, 158). I will present the general data reduction scheme concerning the task specific to SSOs, ground-based support activities, the catalogues validation and construction, and possibly first outcomes from the mission.

Satellites and planets:which observations need theoreticians in dynamics?

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Abstract

Dynamical models for the motion including all gravitational effects and dissipation of energy are presented, as well as the observations used in the reduction. This allows to set some dynamical questions linked to planetological ones. We look after these questions especially in the Jovian and Saturnian systems. One of them is the important question of tidal effects detected from the secular acceleration. By statistical methods, we show that the accuracy of satellite ephemerides needs to have long period of observations rather than few observations of better precision.

1 Introduction

The systems of natural satellites of the planets represent small solar systems. The biggest satellites of the giant planets have a similar size as some planets of the solar system. For example, the diameter of Mercury and Mars are 4879 km and 6794 km respectively while the one of Ganymede and Titan are 5268 km and 5150 km respectively. Io (3630 km) is bigger than the Moon (3475 km). In fact almost all the main satellites are telluric worlds with sometimes icy surfaces (eg: Enceladus 512 km, Titania 1578 km). The study of their dynamics allows us to understand the formation and the evolution of these systems.

Getting accurate observations deals with ephemerides improvement, for example: spacecraft needs, prediction of star occultations by natural satellites, position of the planet through the positions of the satellites and detection of a secular acceleration in the motion of these bodies consequence of tidal effects.

More generally, we expect improvement in our knowledge of their physics, in the evolution of the corresponding system of satellites, and then in the understanding of their formation.

2 Dynamical models for the motion

There are various dynamical effects such as resonnances or important tidal effects. Generally the main perturbations are the same but the dynamical interactions do not come in the same order of magnitude and the precision of observations is different from a system to another.

For the Galilean satellites, the dynamical model has been developped by (Lainey et al, 2004a). They have benefited the experience of the construction of the theory of motion of the eight major satellites of Saturn by Vienne & Duriez (1995). The theory of motion of the Uranian system has been developped by (Lainey, 2007) using a more general sofware called NOE in order to realize ephemerides of any planetary satellites.

The physical model takes into account the planet oblateness (until degree 6), the mutual interactions, the solar perturbation and the given mean mean motions. It is constructed in a dynamically consistent way, in which the satellites are considered all together; their only parameters are explicitly the initial conditions, the masses of the satellites and the oblateness coefficients. The model can also take into account new effects such as: $C_{2,0}$ and $C_{2,2}$ of the satellites, spin-orbit resonance of satellites, tides due to the satellites on the planet, and the ones due to the planet on the satellites.

A numerical integration was performed over several thousands years. Then, a frequency analysis is used in order to build a quasi-periodic representation of the motions. Each frequency has been reconstructed as integer combinations of the fundamental ones.

The representation has a faithful accuracy of a few tens kilometers upon one century and remains definite upon more than 2000 years.

The constants of the Galilean and Saturnian theories have been fitted on a set of Earth-based observations over more than one century. Thanks to recent comparison with CCD astrometric observations, the external precision in the Saturnian system has been estimated to $0.''06$ (Vienne et al., 2001). For the Galilean satellites, very good residuals have been obtained and lead to a global accuracy of about $0.''04$ (Lainey et al., 2004b). The external precision is several tens of kilometers over one century.

For the Uranian system, only the initial conditions are fitted. 11,359 ground observations are used. The residuals for the best of them are about a thousand kilometers. The 445 spacecraft observations of 1986 are also used for which the residuals are about one hundread kilometers.

3 Dynamical questions

After a numerical integration, we have made a frequency analysis in order to build a quasi-periodic representation of the motions. This analytical or synthetical formulation offers the advantage to describe the considered system over a very long time span. Furthermore the synthetic form is fundamental to understand the dynamics of the system. At the same time, it can be used for ephemerides.

The analytical form of the solution is suitable for questions about the dynamics of the corresponding systems and gives the tools for their study.

example 1: The Galilean system

Besides the strong perturbations induced by the masses, the dynamics is controlled by the so-called Laplacian resonance between Io, Europe and Ganymede. Such a configuration involving 3 satellites is unique in the Solar System since it is of second order of masses. We have the following mean motions quasi-commensurabilities: $n_I \approx 2n_E$, $n_E \approx 2n_G$ which lead to a strict commensurability relation $n_I - 3n_E + 2n_G = 0$ with the related argument between the mean longitudes $\lambda_I - 3\lambda_E + 2\lambda_G$ which librates around π (period: 5,64 years).

However this system is characterized by great inequalitiy too: $3n_G - 7n_C \approx 0$. The quasi-commensurability 7:3 between the mean motions of the Galilean satellites Ganymede and Callisto, known as De Haerdtl inequality, has never been taken into account in previous works dealing with the dynamical history of the Galilean system. It induces long-period terms of 22 years (Noyelles & Vienne, 2004).

The main difficulty is that the masses of Galilean satellites are big enough to distinguish proper elements from velocities of nodes and pericenters. A localization of resonances related to each term of the developpement shows some overlaps (Noyelles & Vienne, 2004), which are necessarily stochastic layers. A numerical study shows that the inequality induces chaos, more particularly because of Callisto's eccentricity. Anyway, even if the orbits were nearly circular, Callisto's inclination is strong enough to induce chaos. This inclination is forced by the Sun, this means that Jupiter's obliquity is partly responsible for the chaos induced by De Haerdtl inequality.

The work on the identification of the main resonances responsible for the presence of chaos should be completed, leading to scenarios of the long term evolution. These scenarios require more accurate values for some parameters (such as the eccentricities or the dissipation rates) and more precise observations.

example 2: The Mimas-Tethys system

Another example of how the analytical representation can lead to some important dynamical questions concerns the Mimas-Tethys resonance. New terms appeared in the representation of (Vienne & Duriez, 1995) and allowed a better knowledge of the evolution of this system (Champenois & Vienne, 1999a;b).

The ancient descriptions of the dynamics of the Mimas-Tethys system were limited to the primary 2:4 mean motion resonance: the argument $\varphi = 2\lambda_M - 4\lambda_T + \Omega_M + \Omega_T$ librates, so the conjunction line oscillates, over 70 years, between $-48°$ to $+48°$ around the mean point $(\Omega_M + \Omega_T)/2$ of the **nodes** of both satellites.

Considering a non-circular orbit for Tethys (and so the longitude of the pericenter of Tethys ϖ_T), new terms appear near the resonance, which have the same frequency corresponding to $\sigma = (\Omega - 3\Omega')/2 + \varpi_T$ (with period 200 years), changing the vision of the dynamics of the Mimas-Tethys system that we had so far. Because of tidal effects due to dissipation in Saturn, the mean angular velocity of the arguments φ and σ are variables. Then, the system can enter in one or several secondary resonance. or may have behaved in a chaotic way on capture in the present ii' resonance. Then, the inclination of Mimas may have been very different. Moreover, the eccentricity of Tethys has been higher in the past (up to 0.008). The probability of capture into the present resonance, extremely depends upon the value of e', may be much higher (up to 1) than found previously.

The terms with the frequency of σ are proportional to the eccentricity $e'$of Tethys, but the value of e' is badly known (between 0 and 0.001).

example 3: Tidal effects and secular acceleration

The tidal dissipation is very difficult to quantify. It is very small but its effect is cumulative. So it is sometimes detected as a secular acceleration in the mean longitude of the closer satellites.

It is the case for Io but with a very rough precision. In 2005, Lainey & Tobie (2005) show how the tidal effects can vanish during the fit process to the observations. They also suggest an upper bound value for the dissipation rate within Io.

For the Saturnian system, the situation is worth. Dourneau (1987) and Kozai (1957) found a secular acceleration. In fact, there values are not reliable. Probably these observers have made a confusion between a eventual acceleration in the longitude of Mimas and the terms with the argument $\sigma = (\Omega_M - 3\Omega_T)/2 + \varpi_T$; they are proportional to the eccentricity of Tethys which is badly known.

4 Observations

In order to obtain reliable results, it is essential to have numerous observations of high quality. At present, we have two kinds of observations: astrometric and photometrics ones.

Astrometric observations

The direct astrometric observations have a precision limited by the instruments and the catalog of stars, of about 0.1 second of degree, which corresponds to 300 km for the satellites of Jupiter until 1200 km for the satellites of Uranus. Nevertheless, it is possible that using the UCAC2 catalog for the astrometric calibration of these observations we can arrive to astrometric precisions better than 50 mas for almost all satellites. Numerous direct astrometric observations are available specially for the satellites of Jupiter. Then, a new reduction with catalog linked to the Hipparcos or GAIA system is necessary.

Since 1990, the astrometric observations of Saturn satellites are CCD ones. The problem is that the scales of these frames were rather small. So, most often, there is no reference stars which would allow to perform a complete astrometric reduction. Vienne et al. (2001) give a reduction which uses the positions of the satellites themselves and allows to give coordinates apart from the calibration parameters (the scale factor and the rotation angle). However all the astrometric corrections have been introduced. Then, if someone wants to touch up the calibration parameters, no astrometric consideration is necessary.

Mutual events

In order to still improve the precision, observations of occultations or eclipses are organised: Indeed the precision of such observations is photometric and depends only upon the flux drop of the light during the event. At present, the precision is about 60 km, that is $0.''015$ for the satellites of Jupiter but $0.''005$ for the satellites of Uranus.

Mutual events occur when the planetocentric declination of the Sun and of the Earth become zero (at the equinox of the planet). This configuration has occured in 2003, 2009 and 2015 for Jupiter satellites, in 2007 for the Uranian satellites (every 42 years) and in 2010 for the Saturnian satellites.

Nowadays, seven observations campaigns have been performed for the Galilean satellites. Most observations have been introduced in the fit of the theories.

5 Estimating the accuracy of satellite ephemerides using the bootstrap method

During the period of observations, the accuracy of predicted orbital positions can be estimated through comparison with observations. Outside this period, the estimation remains difficult.

In Desmars et al. (2009) one introduces a new method to estimate the accuracy of predicted positions at any time, in particular outside the observation period. It is based upon a bootstrap resampling and allows this estimation with minimal assumptions.

This new method was applied to two of the main Saturnian satellites, Mimas and Titan. The bootstrap resampling is a robust and practical method for estimating the accuracy of predicted positions.

The results of the extrapolated accuracy over two observational periods lead to these conclusions:

- The ephemeris accuracy of Mimas is better after fitting to the old observations than after fitting to the recent ones

- The old observations (73 years) cover the period of the main term of the mean longitude of Mimas (70.56 years). This is not the case with recent ones (46 years)

6 Conclusions

Despite large progess in dynamical description, specially in the model used for ephemerides, there are still some unknown dynamical parameters in the main satellites of Jupiter and Saturn. We have seen some examples for both system. Among these badly known parameters, there are the tidal effects which supply the internal dynamic and the thermical evolution of the satellites.

The distant satellites of giant planets are badly known because they have been observed very few and they were not the aim for spacecraft missions. Yet, it is important to understand also for these satellites their formation and their stability.

For accurate ephemeris, a long period of observations with average quality (0.2-0.3 arcsec) is sometimes preferable to a short period of good quality observations (0.1 arcsec). More genrally, it's important to have long period of observations (and without gap).

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Improvement of ephemerides with Gaia catalogue

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1 Introduction

The Gaia catalogue will be a dense and accurate stellar catalogue allowing a large improvement of the astrometry of the solar system objects. Due to its high accuracy, new processes of reduction would be necessary. Future and past observations from photographic plates or CCD frames could be reduced again. The precision of this new reduction would depend on the object, the telescope, the plates, and many other parameters. Nevertheless, a precision of 1 to 100 mas may be expected.

In this paper, we try to answer two main questions for ephemerides of solar system objects: What can we expect by reducing existing observations with the Gaia catalogue ; and which strategy should we adopt for new reduction ? We study three cases : the Saturnian satellites, the Near-Earth asteroids and the detection of Yarkovsky effect.

2 Gaia catalogue and the Saturnian satellites

Saturnian satellites have been observed for about 130 years. From the beginning of 20th century to the 1980s, these observations come from photographic plates with a variable astrometric precision of 0.1 to 3 arcsec. During the mission, Gaia will provide also about 50 observations for some satellites with a expected precision of 1 mas. In order to quantify the impact of those observations on the ephemerides of Saturnian satellites, we determined the precision of their ephemerides considering (i) the current set of all available observations, (ii) the same set + 50 additional observations from Gaia (with a precision of 1 mas) and (iii) the current set of observations assuming that all photographic plates could have been reduced with Gaia catalogue (with a precision of 10 mas) (see Desmars, 2009, for more details).

Figure 1 shows the precision of Mimas and Dione ephemerides we have for the various cases. Actually, 50 high accurate observations do not improve a lot the ephemeris because for those objects, we have a large set of data. Nevertheless, if we assume that all photographic plates could be reduced with the Gaia catalogue, then the orbital uncertainty of the satellites is greatly reduced.

3 The Gaia catalogue and Near Earth asteroids

Near-Earth asteroids (NEAs) have regular close approaches with Earth. Due to the uncertainty of their orbit, they sometimes present a risk of collision with Earth. With the Gaia catalogue, it will be possible to reduce future observations of those objects with a better precision. Moreover, it would be possible to reduce old observations on photographic plates or CCD frames. The precision of these observations would depend on several factors such as the date of the observation, the telescope, etc, and we can expect a precision of about 10 mas (that will be considered therafter as the precision of an observation reduced with Gaia catalogue). Obviously, the reduction of all the available observations would be long and costly. In this context, we determine what will be the improvement of the orbital uncertainty if we reduced only a part of available observations. We specifically studied the case of (99942) Apophis, discovered in 2004 and that will have a very close approach with Earth on April 2029, leading to an uncertain orbit thereafter.

Figure 2 represents the orbital uncertainty of Apophis considering (i) the current set of observations (about 6300 observations from 2004 to 2015 and 20 radar measurements), assuming that (ii) 10%, (iii) 25%, (iv) 50%,

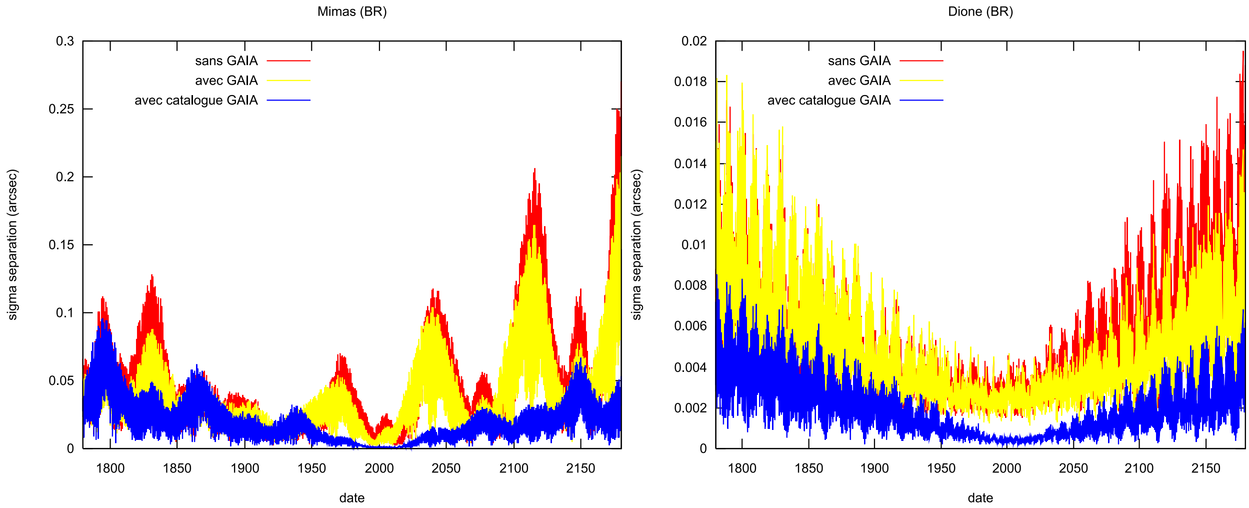

Figure 1: Ephemeris uncertainty of Mimas and Dione considering the current set of all available observations (blue), the same set + 50 additional observations from Gaia with a precision of 1 mas (yellow) and the current set of observations assuming that all photographic plates could have been reduced with Gaia catalogue with a precision of 10mas (red).

and (v) all (100%) of the observations are reduced with the Gaia catalogue (10 mas precision).

Even if only 10% of observations are reduced with the Gaia catalogue, the uncertainty is reduced by a factor of 10, and the improvement is less important when reducing a more important part of observations. It means that only a small part (10%) can be reduced to lead to a huge improvement in the orbital uncertainty. By making comparison, we determined that, in order to improve the orbital uncertainty, it should be better to reduce again the first and the last observations of the set instead of a random part of them (see Desmars et al., 2013).

Figure 3 is similar to Fig. 2 considering in that case that only two (the first and the last observations of the set), 10 (the first five and last five) and 20 observations (the first ten and the last ten) are reduced with the Gaia catalogue. Also in that cases, with only two observations newly reduced with Gaia catalogue, the orbital accuracy can be greatly improved.

4 The Gaia catalogue and the detection of Yarkovsky effect

The Yarkovsky effect is a weak non gravitational force associated with an anisotropic emission of thermal radiation. It affects mainly small NEAs (from 10cm to 10km) and modify their semimajor axis. Despite the small magnitude, the Yarkovsky effect has important effect in dynamical evolution of NEAs.

The modelling of this effect is quite complex because it depends on several parameters (size, density, spin). However, it can be modeled as a transverse force that depend on orbital elements and a drift in semimajor axis. Consequently, the drift in the semimajor axis can be fitted to the observations (with the orbital elements). For some NEAs, when the observational period is long enough (20 years) and for a diameter of hundreds meters, a reliable drift can be measured and is in the range of 10^{-3} to 10^{-4} au/My (Desmars, 2015).

As the astrometry will be improved thanks to Gaia catalogue, we determine how the measure of the drift in semimajor axis could be improved using observations reduced with the Gaia catalogue. In that context, we considered 1629 NEAs and the sets of observations used in previous section.

Figure 4 represents the observed arc versus the accuracy of the drift in semimajor axis for the 1629 NEAs considering (i) the current set of observations, (ii) that two observations, (iii) that 10 observations, and (iv) that

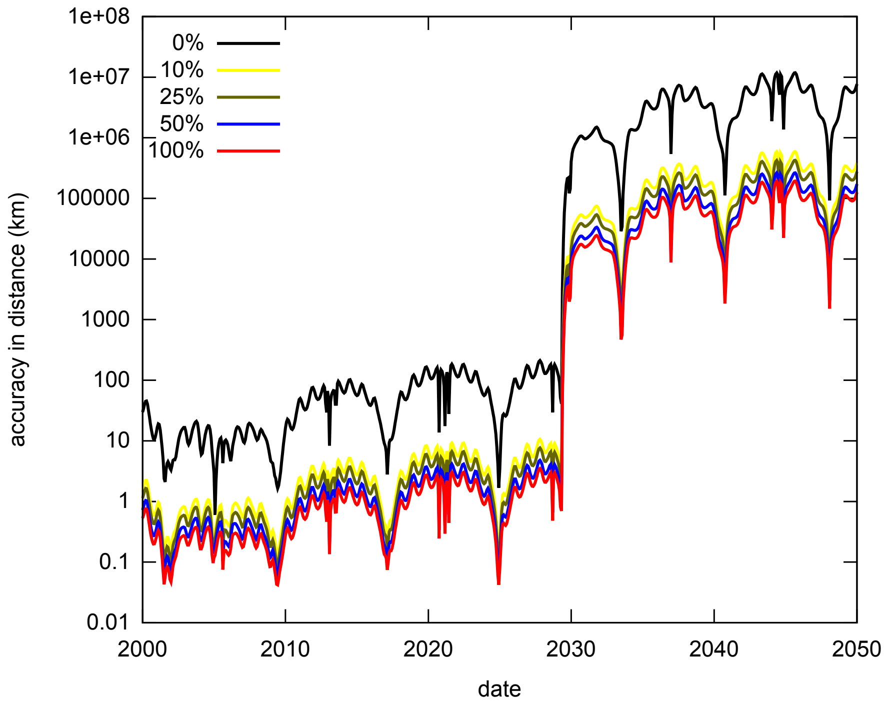

Figure 2: Accuracy in distance of the Apophis orbit considering (i) the current set of observations, and assuming that (ii) 10%, (iii) 25%, (iv) 50%, and (v) 100% of observations are reduced with Gaia catalogue (10 mas precision).

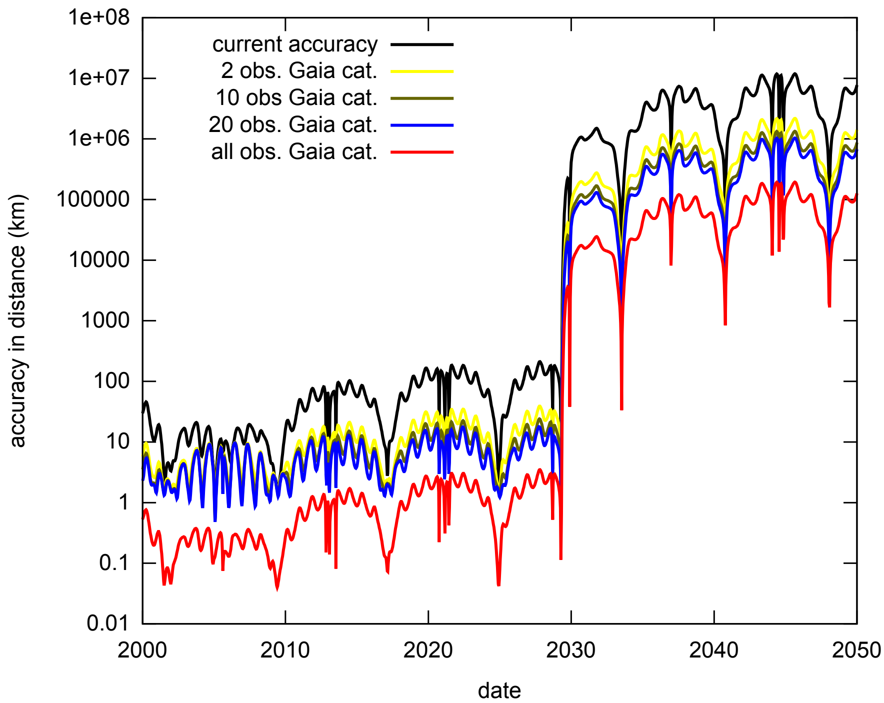

Figure 3: Accuracy in distance of the Apophis orbit considering (i) the current set of observations, and assuming that (ii) 2, (iii) 10, (iv) 20, and (v) all observations are reduced with Gaia catalogue (10 mas precision).

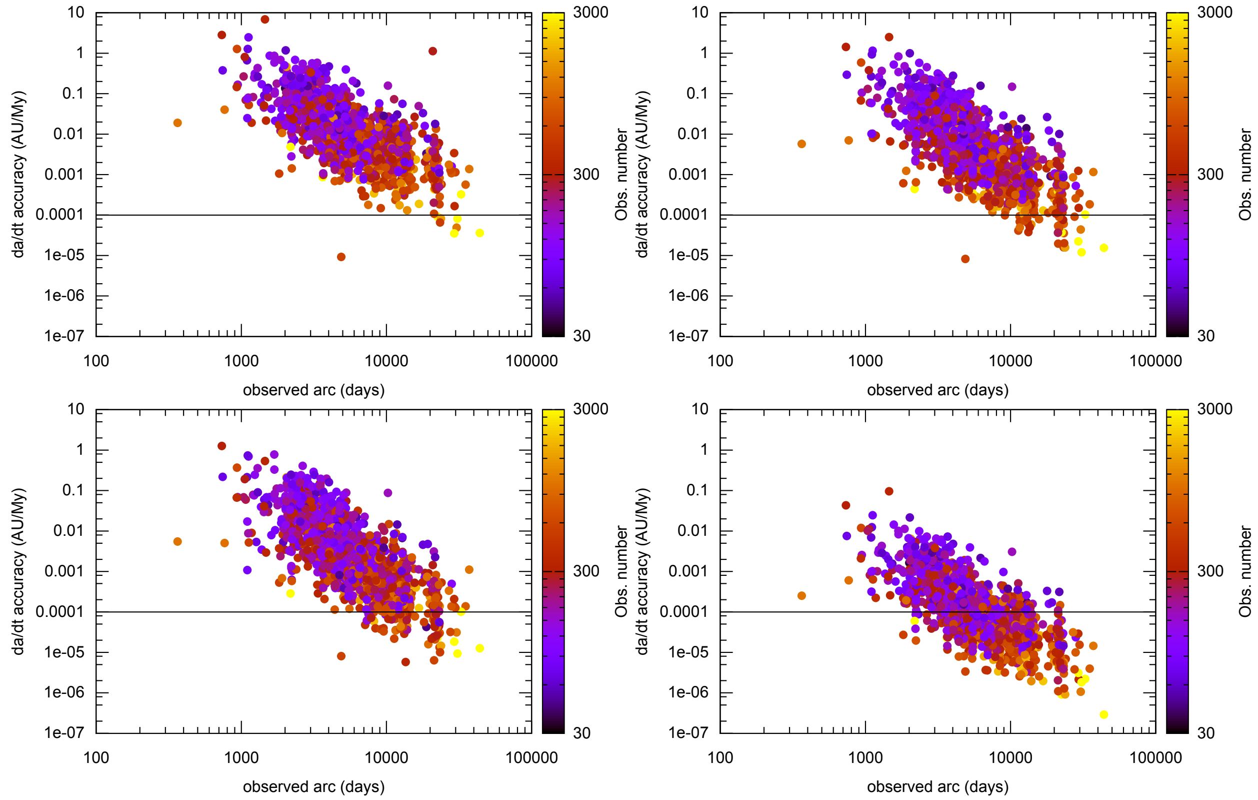

Figure 4: Observational arc, accuracy of the drift in semimajor axis and number of observations for 1629 NEAs considering (top-left) the current set of observations, (top-right) that two observations could be reduced with Gaia catalogue, (bottom-left) that 10 observations are reduced with Gaia catalogue, and (bottom-right) that all observations are reduced with the Gaia catalogue.

all observations could be reduced with Gaia catalogue. The number of observations available is indicated in colour. The limit of 10^{-4} au/My is also indicated as it represents a reliable detection. Currently, only 8 NEAs reach this level of accuracy, whereas 31 objects reach it with 2 observations reduced with Gaia catalogue, 93 NEAs with 10 observations reduced with Gaia catalogue, and 688 NEAs with all observations reduced with Gaia catalogue.

The Gaia catalogue and the reduction of a small part of the observations will allow to measure a reliable drift for a hundred of NEAs. As the drift can be related to physical parameters such as the spin, the size, the density, etc, we will be able to constrain or measure these parameters of these objects.

5 Conclusion

The Gaia stellar catalogue will be very helpful for accurate ephemeris, in particular for natural satellites and asteroids. We showed how a new reduction of some current observations by the Gaia catalogue will improve the orbital uncertainty, even with a few number of new reductions. For NEAs, the drift in semimajor axis (due to the Yarkovsky effect) would be measurable for a hundred of them leading to a better orbit determination and extrapolation and to a better evaluation of the risk of collision.

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Determination of the Masses of Planetary Satellites from Their Mutual Gravitational Perturbations

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It is clear that the GAIA project opens up new possibilities in the study of dynamics and physics of planetary satellites. It may be asked the question: could be obtained new values of the masses of satellites with (1) old observations reduced thanks to the GAIA Catalogue, (2) observations made with GAIA space telescope, (3) new ground-based observations reduced thanks to the GAIA Catalogue? On the determination of the masses of outer planetary satellites from their mutual gravitational perturbations, following papers were published: Emelyanov (2005) and Emel'yanov et al. (2007).

Let us consider some results from these papers.

- The mass of a satellite cannot be measured directly during the process of observation.
- For most of the outer satellites of the major planets, only their magnitudes could be determined from observation. Measured magnitude + hypothetical albedo = the size.
- The size + hypothetical density = mass to be estimated. The accuracy of the resulting masses estimates has been proved to be inadequate.
- Methods from celestial mechanics allow masses of satellites to be determined directly from astrometric observations.
- The possibility of such a determination depends crucially
  - on the masses of the satellites considered,
  - their mutual distances during their motion
  - the time period of observation
  - the accuracy of the observations.
- Masses of outer planetary satellites are very small. The mutual gravitational attraction of outer satellites is very weak.
- The gravitational interaction between satellites is maximal during their encounters in space. In these cases, the mean motion of the satellite changes and coordinate perturbations begin to be accumulated with time.
- The trajectories of outer satellites of the major planets are very diverse and, therefore, the possibility and accuracy of the determination of their mass can only be assessed on a case-by-case basis.
- The least-squares method not only allows the masses of the satellites to be determined, but also their errors to be estimated.
- The possibility of refining the mass is determined by the ratio of its error to the mass itself.
- Some groups of satellites with closely located orbits were analyzed.
- The most massive of these satellites for the determination of their mass were chosen.
- In the case of the Jovian satellites we chose Himalia, because it had a close encounter with Elara on July 15, 1949, when the minimum distance between the satellites was equal to 65031 km. Note that the semi-major axis of Himalia's orbit is 11486797 km. This very close encounter allowed to determine the mass of Himalia (J6) from observations. The gravitational parameter of Himalia is found to be 0.28 +/- 0.04 km^3/s^2. Compare with result obtained by Rettig, Walsh (2002) from photometric observations: the gravitational parameter of Himalia is found to be 0.45 km^3/s^2.
- At the present time, the gravitational parameter of Phoebe is assumed to be equal to 0.5534 +/- 0.0006 km^3/s^2. This value was inferred from the measurements of the gravitational field of this satellite made by the Cassini probe during its flyby near Phoebe in 2004 (Jacobson et al. 2006).
- The mass of the Saturnian satellite Phoebe can be refined if ground-based observations of the

satellites Ymir (S19), Mundilfari (S25), and Thrymr (S30) are continued until 2027.

- The accuracy of present-day observations is not sufficient to allow the determination of the masses of the other outer satellites of Jupiter, Saturn, Uranus and Neptune .
- We report the results of our analysis of the possibility of determining the masses of the other outer satellites of Jupiter, Saturn, Uranus, and Neptune from observations.
- We performed our analysis on simulated observations.
- We simulated geocentric astrometric right ascensions and declinations of satellites. On these coordinates, we then superimposed Gaussian random errors with the given dispersion.
- The least-squares method not only allows the mass of the satellite to be determined, but also its error to be estimated.
- We find this error to be proportional to the input errors of simulated observations.
- To establish the optimum sample of observations, we analyzed the determination of the mass of the Jovian satellite Himalia (J6) from simulated observations of satellites Elara (J7), Lysithea (J10), and Leda (J13), which we took as the perturbed bodies.
- To establish the optimum ratio between the observation time intervals before and after the encounter, we compute the errors of the mass of Himalia inferred from observations made during different time intervals. We test various time intervals from 40 years before the time of the satellite encounter to 40 years after the time of the encounter. We generate simulated observations with a time step of 90 days.
- The error of the mass is minimal if the time interval before the encounter is equal to the time interval after the encounter.

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Astrometric Observations from Space after Gaia – the Cassini Experience

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Abstract

The Cassini mission has been ground-breaking in many ways. However a rarely mentioned achievement has been the extensive and ongoing effort to observe the Saturnian satellites astrometrically using the Imaging Science Subsystem (ISS) of the Cassini orbiter. By end-of-mission in 2017, many thousands of observations will have been made with unprecedented precision, spanning a thirteen-year period. The future availability of the GAIA catalogue will offer a denser sky-coverage of reference stars, with greater precision by several orders of magnitude compared to existing star catalogs. However, currently, the main limitation on the precision of the Cassini observations derives from the techniques used to measure satellite positions, not the precision of the reference star catalogues. So while the potential improvements in star coverage and precision suggest that some corresponding reduction in camera pointing errors may be possible, the full benefits of GAIA will only be realized if satellite measurement techniques can themselves be improved.

1. Introduction

Imaging cameras have been included on all the major interplanetary missions of the past few decades, including, in chronological order, Mariner 9, Viking 1 and 2, Voyager 1 and 2, Galileo, Cassini, and New Horizons.

Missions up to and including Voyager employed a Vidicon system to take 'still' images using technology based on television. For missions since Galileo, CCD technology has been used.

Prior to Cassini, spacecraft astrometry has generally been performed on images not specifically designed for astrometry, with the exception of images taken for operational navigation purposes. Cassini is the first mission to include a dedicated campaign of astrometric observations, as a planned science goal of one of the imaging team members, in this case Carl Murray.

The Imaging Science Subsystem (ISS) on the Cassini orbiter consists of a narrow- and a wide-angle camera, each with a 1024x1024 pixel CCD chip, and with fields-of-view of

3.5 and 0.35 degrees respectively. The cameras are bore-sighted so that the target can be centered in the field-of-view of both cameras simultaneously, if required. For more details, see Porco et al (2004).

So far, approximately 380 000 CCD images have been recorded by the Cassini ISS experiment since the start of the mission, including around 27000 from the Jupiter flyby, with an expected total by the end of the mission in 2017 in excess of 500 000. Of the ~380 000 images so far recorded, ~272 000 used the narrow angle camera (NAC) and ~107 000 used the wide angle camera (WAC). Approximately 46 000 or ~12% have so far been designed by the Cassini group at Queen Mary University of London (QMUL).

2. Cassini Imaging and Astrometry at Queen Mary University of London and IMCCE, Paris

The principal science goals of the QMUL group using the Cassini ISS include satellite/ring formation and dynamical evolution, with particular emphasis on the morphology and dynamics of Saturn's F ring. The design and reduction of astrometric observations of the inner Saturnian satellites throughout the mission has been key to this work. These observations have also been delivered to JPL for use in their own mission-related operational navigation work.

The ~46000 images designed by the QMUL group so far, at this stage of the mission, consist of ~12000 'SATELLORB' images (26%) and ~4000 MUTUAL EVENT images (9%), both for the refinement of satellite orbits, ~1000 satellite search images designed to detect new satellites, ~15000 F ring images plus ~14000 assorted other images.

Since 2011, QMUL has embarked on a wide-ranging collaboration with the Institut de Mécanique Céleste et de Calcul des Éphémérides (IMCCE). The prinicipal aim is the study of the internal structure and dynamical evolution of the main and inner moons of the giant planets, using astrometry (Lainey et al 2015). The availability of high-precision Cassini images has been an important part of this collaboration. As a result, an ongoing program of astrometric reduction of all Cassini images suitable for astrometry (i.e. including images not specifically designed for astrometry) has so far resulted in more than 12 000 published observations (Tajeddine et al 2013, Cooper et al 2014, Cooper et al 2015, Tajeddine et al 2015).

In addition to the above, the group has been directly involved with the discovery of three new satellites of Saturn: Polydeuces (Murray et al 2005), Anthe (Cooper et al 2008) and Aegaeon (Hedman et al 2009), all based on Cassini ISS astrometry.

3. Cassini ISS Astrometric Reduction

Astrometric data reduction at QMUL has been carried out using an IDL-based software package, Caviar, originally developed by Michael Evans at QMUL in 2004. As part of the collaboration with IMCCE (see above), the Caviar software package has been re-written, incorporating a graphical user interface, and will shortly be made available publicly through the NASA/PDS website.

Data reduction consists of a camera pointing correction followed by the astrometric measurement of the centre of each target satellites in the image. Reference stars are used for the camera pointing correction, currently using the Tycho2 and UCAC4 (Zacharias et al 2013) catalogues. The GAIA catalogue will replace these, as soon as it is available. For target satellites whose images are unresolved, the centre-of-light of the imaged signal is estimated by matching to a Gaussian function. This is the same basic technique used by the software to find the positions of reference stars when correcting the camera pointing direction, and is based on the DAOPHOT method of Stetson (1987). The centre-of-figure of the satellite is then given by the measured centre-of-light after correction for the phase angle (observer-object-sun angle).

The centres-of-figure of resolved bodies are found by fitting a shape model, based on a triaxial ellipsoid projected onto the image, to the measured limb of each body in question. The centre-of-figure of the body is then given by the centre of the fitted shape model.

Imaged positions of satellites and reference stars are stored in pixel coordinates, as well as in RA and DEC, in order to allow future reprocessing using new and improved reference star catalogues, such as GAIA, without the need to re-measure the positions from the images.

4. Observing from Space

Images from Cassini and other spacecraft are designed with a particular purpose in mind, requiring imaging parameters, such as exposure length and resolution to be optimized for that specific purpose. To be useful for astrometry, imaging parameters have to balance often conflicting imaging requirements.

For example, to analyse the surface of an icy satellite, the highest possible resolution may be required. However, the number of imaged reference stars has an inverse relationship with the size of the satellite in the image: if the satellite fills too much of the field-of-view, the result may be an insufficient number of detectable reference stars, making the correction of errors in the camera pointing direction, necessary for astrometry, more difficult.

Similarly, the choice of exposure length is often a compromise between the need to exposure surface features on a bright satellite (shorter exposure) with the need to image faint reference stars for astrometry (longer exposure).

Thus images specifically designed for astrometry may require imaging parameters that are sub-optimal in terms of imaging the details of the target satellite itself. On the other hand, the suitability for astrometry of images designed for other purposes is largely a matter of whether the particular imaging parameters used have resulted in a sufficient number measurable reference stars.

For more discussion of some of these issues, see Tajeddine et al (2013).

5. Current Limitations and the Influence of Gaia

The overall precision of Cassini imaging astrometry is currently ~0.8 pixel or typically ~ 10 km at the target satellite distance (equivalent to about 1 mas from Earth). This includes a camera pointing uncertainty of ~0.1 pixel, with the remainder coming from the measurement of the centre-of-figure of the target satellite. The uncertainty in the spacecraft position is of the order of 100 metres.

The accuracy of the UCAC2 reference star catalogue is at about the 0.05 pixel level, while GAIA will be accurate to about 0.0008 pixel. Also GAIA has far greater sky coverage (~1 billion stars, compared to 48 million for UCAC2). So a reduction in camera pointing errors can be expected.

However, as indicated above, the limiting factor in the precision of Cassini ISS astrometry is currently not the camera pointing error, but the measurement of the position of the target satellite, and the overall improvement in accuracy possible with GAIA will be many orders of magnitude smaller than the current satellite position accuracy of ~0.8 pixel.

Thus, the challenge of GAIA for spacecraft imaging will be to improve the precision of satellite measurement techniques so that the potential accuracy of GAIA can be fully realized.

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The astrometric observation of planets through their natural satellites

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Introduction

The astrometric observation of planet is essential to keep the quality of their ephemerides. However, having accurate data is a challenge. The space probes provide very precise data but on a small interval of time and it is necessary to include ground based data in the sample of data used for the making of ephemerides. Unfortunately, giant planets are gaseous bodies, the observation of which is uncertain. Note that we need to observe their center of mass which is difficult to deduce from an image of a plant with a thick atmosphere. Contrarily, their natural satellites are bodies without atmosphere with a perfectly observable limb. The center of mass is easy to determine. Since the satellite are orbiting around the center of mass of the system, as the planet does, observing the satellite is observing this center of mass through the modeling of the motion of the satellite.

The problems to be solved

We have then two problems to solve:

- Making the observation of the satellite in RA and DEC
- Going from the satellite to the planet (in fact to the center of mass of the system which is orbiting around the Sun)

The first problem leads to use specific instruments. In fact, the satellites are often observed in relative positions, either relative to the planet or relative to another satellite. These observations are not useful for our purpose, we need positions which may be linked to the others in the same reference frame in RA and DEC. For imaging, we need to record reference stars which will link the observation of the satellites to the reference frame in which the motion of the planets are described.
The second problem shows that we need a very good modeling of the motion of the satellites around the planet to be able to go from the satellite to the planet. We need ephemerides of the satellites very accurate at the time of the observation, so we may build specific ephemerides for that purpose, different from ephemerides build for a long period of time. Anyway, among the satellites, we will choose those for which the motion is well known or make the average between several satellites.

Examples of observations

Photographic plates or CCD images of natural satellites are often made with long focus instruments: the field is smaller by the scale allows to separate the bright planet from its small satellites. Because of the small size of the field, very few reference stars are present and the reduction in RA and DEC is poor. The arrival of the Gaia catalogue will solve this problem thanks to the numerous faint stars of this catalogue. Figure 1 shows the field of the Galilean satellites: the field is 14 arcmin wide and very few reference stars are present. This image was made through a long focus telescope.

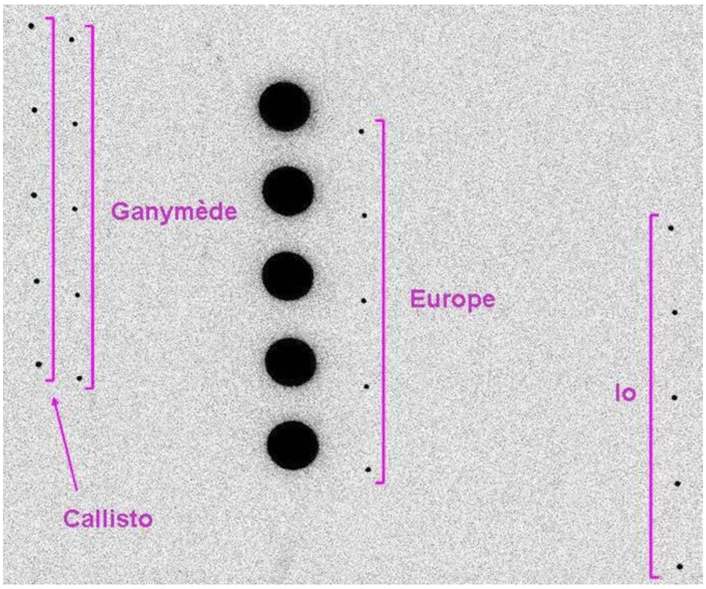

Figure 1: 5 exposures on a photographic plate: the Galileans are easy to measure contrarily to the planet. Stars are very rare in the field

Astrometric observation of bright objects may be made through meridian transit circles. These observations were first a timing of the time of transit which is transformed into a RA and DEC thanks to the Sidereal Time and the elevation measured on the instrument. At the present time, CCD have been set at the focus of the meridian transit circles and objects and stars xxxdéfilentxxx on the target allowing to rebuild a long strip showing a large number of reference stars. RA and DEC are directly determined through an astrometric reduction. Figure 2 shows the last two meridian transit circles still observing.

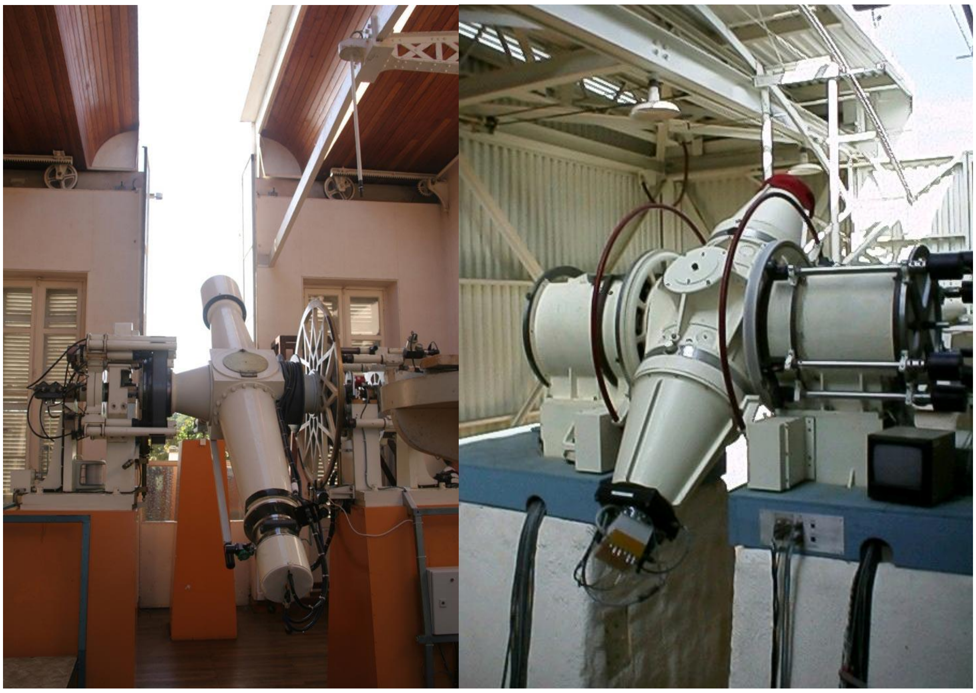

Figure 2: left the meridian transit circle in Flagstaff and right the one at Bordeaux observatory.

Results for planets through satellites

What is the quality of such observations? Let us analyze a set of data: astrometric observations extracted from photographic plates never used for planet purpose.

	DE405		DE421		INPOP06		INPOP10	
	J-1	J-4	J-1	J-4	J-1	J-4	J-1	J-4
1967-1979	23	18	-3	-6	-6	-9	2	-3
1980-1989	14	10	0	-5	-6	-10	6	1
1990-1998	-11	-5	-9	-3	-15	-10	-5	1

Table 1: comparison of Jupiter ephemerides through the observation of its satellites

In table 1, we present the O-C residuals in RA and DEC for two Galilean satellites depending on several different planetary ephemerides for photographic plates. The rms of the residuals is 60 mas and the O-C residuals are quite small with up to date ephemerides and very similar for both satellites. This similarity for two different satellites shows that the method is not biased by the ephemerides of the satellites.

Conclusion

Other examples may be taken with other planetary satellite systems. For the Saturnian moons, the ephemerides of the different satellites are of different accuracy because of the samples of observations very different: Mimas is much more difficult to observed than the other satellites and Titan is very bright, often observed but difficult to reduce. The Uranian moons have similar ephemerides except Miranda very faint and less observed. Many old observations of the natural satellites have never been used for planetary purpose but may be reduced at the present time, especially when the new reference catalogue Gaia will be available.

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WHAT COULD BE AMATEUR ASTRONOMER CONTRIBUTIONS TO POST GAIA PRO-AM COLLABORATIONS ?

REVIEW OF THE SET UP RANGE OF AMATEUR EQUIPMENTS, HOW TO UPDATE IT ? PROBLEMS ENCOUNTERED BY THE AMATEURS

ASTROMETRY/PHOTOMETRY OF SOLAR SYSTEM OBJECTS AFTER THE GAIA PROJECT WORKSHOP

MEUDON OBSERVATORY 14-16 OCT 2015

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KEYWORDS: amateur astronomer, pro-am collaboration, instrument setup

ABSTRACT:

Amateur astronomers contribute from the beginning to advanced research in astronomy. Solar System Objects (SSO) are still an intensive field of pro am collaborations. In the coming years of GAIA data release, what could be the new perspective of amateur activities? What is the range of amateur equipments? How could it be updated for this perspective? How could we support them to mitigate the problems and limitations they encountered?

1. INTRODUCTION

This is the proceeding attached to the presentation made at the workshop, thanks to refer to the PDF of the PPT I used during the lecture to get access to all the illustrations developed here. The paper gathered inputs from Club Eclipse members and from other association members we are networked with :

- Bernard Christophe
- Olivier Dechambre
- Christian Drillaud
- Thomas Flatres (SAR)
- Thierry Legault
- Michel Ory (MOSS)
- David Romeuf (Observatoire de Pommier)
- Cesar Valencia
- Jean-Marie Vugnon

2. AMATEUR ASTRONOMER TOPICS

Through a 2 years periodicity AFA (Association Francaise d'Astronomie) helds Les Rencontres du Ciel et de l'Espace [1] in Paris. Several sessions are dedicated to the various fields of research from amateur observations. I used to consolidate these inputs and other publications from the astronomical community in a table [2]. to be able to deliver an up dated review of all topics. Appendix 1 at the end of this paper shows an extract of the file. The lattest issue is currently available on the Club Eclipse Web Site [3]. Here is the table released just after the end of the workshop in Novembre 2015. Each line refers to a topic, with the related 5 amateur activity profiles :

- Discover Objects
- Follow Objects
- Contribute to event campaigns
- Perform Metrology
  - Astrometry
  - Photometry
  - Polarimetry
  - Spectroscopy
  - Vs time
- Exploit Data Base

A colour code allows identifying the activity for the beginner in blue, for the amateur equipped with a 8 inches class telescope in green, with a 20 inches or more telescope in yellow and the challenging topics requiring thousand hours or more in red.

We may prepare a new table issue to forecast the impact of the GAIA outputs.

Appendix 2 Shows the lines related to SSO with the focal points and organisations coordinating the respective topics.

End of 2014 a dedicated issue of Ciel et Espace reviewing the main topics in few pages was released [4].

3. AMATEUR MEASUREMENT LIMITS AND ACCURACIES

We may sum up the measurement limits and accuracies usually performed by amateurs.

3.1. Astrometry

Astrometric measurement on asteroids delivered to the MPC was checked once a year by Oleg Bykov from Pulkovo Observatory.
He gave me the feedback of O-C measurements I performed on the TJMS Buthiers [5] a 60cm F/3.4 with 9µm pitch camera. He gave me O-C 0,2 arcsec on asteroid around V16. Even with seeing induced angular resolution limited in the range of 1 to 3 arc sec, a nice SNR allows you to achieve an angular resolution 10 times sharper. In addition, a PSF larger than 2 pixels with a good SNR allows you to get an astrometric accuracy around 1/10 pixel. A mean value from several measurements reach O-C 0.1 to 0;08 arcsec from Oleg assessment. A key point is the catalogue and the software used to perform the astrometric reductions. On appendix 3 is a review of the star catalogues used in the past. Today latest UCAC catalogues are currently used in J2000. An open question was how long we will keep the J2000 frame ? For high resolution and accuracy astrometric reduction software performed the catalogue translation for the current epoch with the star velocity integration, refraction and aberration induced drift are then to be implemented to get the relative position of SSO for the current epoch. Then you perform the translation to the J2000 equinox.

3.2. Photometry

Photometric measurements could be done up to magnitude 19 with a 60cm class telescope rather easily in 60s long exposure. Therefore deeper detection are achievable in adding several exposures or better in performing longer exposure time if mount, tracking and background sky brightness meet the waited accuracies. The SNR will give the photometry accuracy. A 0,01 relative accuracy could be achieved thanks to an accurate methodology. A 0,001 routine accuracy is a real challenge. Turbulence, PSF random variation from exposure to exposure and on bright source background contamination could bring additional limitations on the effective SNR and magnitude measurement accuracy compare to the theoretical Poisson law limitation. Of course here I consider only relative magnitude measurement. Ref catalogue and spectral bands could bring from an observer to another one discrepancies in the measurements. Software improvement could brings improve capabilities in the future. Aperture photometry is currently used in algorithm image processing. We may wonder if fitted PSF filtering could be used to reach such improvement.

3.3. Timing events

Video cameras with DCF77 was first used to get 10ms accuracy in recording events like Phemu and asteroidal star occultations. Thanks to the use of PPS form GPS and drift-scan mode in CCD camera, 1ms accuracy has been achieved 10 years ago thanks to pioneered work made with Audine setup and eventaude device. Today 10µs accuracy could be achieved from the GPS PPS with device like the time box. In fact 100µs is currently achievable due to software limitation. Does sharper time accuracy is a real need in astronomy ? Whatever, we showed during WETO workshops, an effective qualification of complete acquisition chain is still mandatory to control any timing bias induced by latencies and rms jitter. In addition PPS, NMEA code and software writing time stamping may induce a # 1,0000s time shift !

3.4. GAIA catalogues

Therefore it could be interesting to foresee the benefits in amateur measurements bring by the GAIA catalogues. It is necessary to prepare a 10GB and 100GB version of the catalogues to allow a nomad use. It will be necessary to update these shorten catalogue may be once a year. Therefore GAIA1 catalogue scheduled for summer 2016 with 100000 stars will be the first issue of such shorten ref catalogue [6].
An open question is do we keep data reduction in the J2000 frame. Up to when J2000 will be used. Do we foresee to move to J2025 or J2050 in the future? From the discussion it is agreed that J2000 epoch could be used till for several years. The accurate used algorithm does not induced bias in astrometric reductions. We may dream of a time ref source in the sky like a Pulsar or a beacon on a geostationary satellite to share an optical time ref in the sky to test and control acquisition setups.

4. GAIA OUTPUT

The 1 billion objects GAIA catalogue will issue unusual objects from cinematic, photometry variation or spectral signatures, ambiguities from multiple object signature fusion. These may feed an uncommon object list to be checked. This list could be 1 million objects long if we assume 1/1000 of the GAIA catalogue list is uncommon or ambiguous. Amateur astronomer task force could be helpful to solve these candidates and select them for deeper analysis for professional means. A web site to manage this activity gathering GAIA, amateur and professional in a collaborative team.

5. Updating amateur setup

During the 15 last years Asian industrial manufacturing of telescopes reduced the market prices. Affordable refracting telescope up to 150mm diameter Achromat (700€) or event Apochromat (1700€) are available with F/8 or even F/5 numerical aperture. For larger aperture, Newton telescope 200mm class (700€) up to 300mm diameter (2500€) on equatorial mounts are available. For larger aperture Ritchey Chretien telescopes are entering in mass production from 300mm aperture (3400€) up to 500mm (14000€). F/2 F/3 class setup was also introduced on the market using the primary focus of Newton, Schmidt Cassegrain or Ritchey Chretien integrating a camera with a correcting lens instead of the secondary mirror. For larger telescopes more and more amateur societies are proposing 60cm and above class telescopes for amateur missions or ProAm collaborations. In France I found today 27 telescopes.

The most productive telescope amateur set-up for astrometric measurements and SSO discoveries is the Claudine Rinner and Michel Ory MOSS Observatory [7].

6. CONCLUSIONS

To conclude I would like to share several ideas or actions arising from this presentation, the workshop and from discussions during the workshop for amateur involvement.

- Amateur silver halide picture archives on SSO are meaningful for new astrometric reduction. Even grandfather pictures from beginning of the XXth century could be gathered for data reduction.
- Light diffusion level in the optic and sky background during occultation are variable during the events on bright sources (Phemu) inducing photometric bias
- Softwares [8, 9, 10, 11] for photometric reduction of recordings (occultation, eclipse, variable, transit,...) could be improved. Variable PSF induce the noise level of the data. We are far from photon noise limitation.
- Jupiter satellite photometry vs rotation and phase angle has to be measured. Referenced measurements show discrepancies. B, G, R, I, Methane bands measurements are wished.
- On asteroid astrometry priorities.on potentially hazardous objects (PHA).
- The successfull recordings of Phemu events on small Jupiter satellites (Amalthe and Thebe) with 60cm class telescope motivate the preparation of dedicated campaign on these satellites for the next Phemu period.
- For the above campaign a network of 60cm telescope with a preferred optomecanical set up (planetary coronagraph) with a planet occulter, mask to reduce optical diffusion an filters are to be proposed on each telescope.
- Does GAIA catalog may allow the prediction ground track of bright star occultations from earth grazing asteroids ?
- New generation of low noise CMOS arrays embedded in cooled cameras brings new capability and sensitivity allowing the reduction of exposure time. Small pixel pitch allows the use of short focal length and high aperture optics to reach more quickly the sky background induced noise.
- Low cost microbolometers may open new infrared windows to amateur : see picture 6
- GPS based devices [12, 13] allow 1ms time stamping accuracies on the recordings.

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5. TJMS Planete Sciences

6. GAIA1 first catalogue to be published summer 2016 : 100000 stars up to 1mas and 14mas/yr accy

7. http://www.moss-observatory.org/index.php

8. PRISM 10

9. Limovie

10. IRIS

11 MUNIWIN

12. TIMEBOX

13. EVENTAUDE

.

Appendix 1

Objets	Découverte	Suivi	Evenement	Métrologie	Astromètrie	Photomètrie	Polarisation	Spectroscop	Rés Tempor	Exploitation	Point Focal France
Unités	**Mag min**				**arcsec**	**Précision**	**Taux de Pol**	**P Résolution**	**seconde**	**sur Internet**	
Météorites		Fripon									Brigitte Zanda
Météores	-4	Vigie Ciel	Fragmentatio	Orbite, Impac	60				1		Karl Antier
Essaims d'étoiles filantes	1	Orbite	Sursaut	ZHR Radian	240				60		J. Vaubaillon
Cratères d'impact terrestre										Google Earth	David Baratoux
Aurores Boréales											
Night Glow											
Sprite											
Rayons Cosmiques											
Lune			TLP	Occultation Rasante			0.1	10	0.1	Moon zoo	
Impacts sur la Lune			flash								Sylvain Bouley Uranoscope
Lumière Cendrée								10			Luc Arnold
Lumière Zodiacale										Stardust	
Planètes		Météorologie	Tempête, Occultation					100	1		SAF commission des planètes
Venus		UV ou PIR									Christophe Pellier
Mars										planet four	
Jupiter			Impact								Marc Delcroix
Saturne											
Uranus, Neptune			Tempete								Marc Delcroix
Satellites de Planètes	21		Occultation	Phemu	0.04	0.1			1		Jean-Eudes Arlot, Bruno Sicar
Astéroïdes (orbites)	19	Position	Occultation		0.2	0.1			0.1	http://www.asteroi	Jerome Berthier
Astéroïdes (objets)		CdR	Occultation			0.05		10	0.1	Asteroids@home	Benoit Carry, Eric Frappa
Satellites d'astéroïdes	CdR ou Occu	CdR	Occultation			0.01			0.1		Raoul Behrend
Géocroiseurs AAA	19			Orbite, Impact				10	0.1	orbit@home	Mirel Birlan
Objets Trans Neptuniens	20		Occultation	Myosotis	0.2	0.2		10	10		Bruno Sicardy
Objets de la bande de Kuiper								10			Francoise Roque
Comètes	14		Sursaut, Fragmentation		0.2	0.2		100	1	Soho	Commission Comètes SAF
Comete 67P Tchouri			CdR								
Soleil Taches		Nbre Wolf					0.05	1000	0.1	Soho	Didier Favre
Soleil Protubérances			Eruption, Eclipse				0.05	1000	0.1	Solar stormwatch	Franck Vessière
Soleil Couronne			Eclipse Totale								
Etoiles										DASCH	
Etoiles à record				Mouvement p	0.1	0.1		10	10000		CDS
Jumelles du Soleil	9										
Etoiles Doubles	11				0.1	0.1		10	100000		David Valls Gabaud
Binaires Spectroscopiques								1000			Daniel Bonneau
Binaires à éclipses	10	CdL				0.1	0.1		1000		Laurent Corp
Etoiles Variables	10	CdL				0.1			100	aavso.org/vsx	Dominique Proust
Céphéides											
RR Lyrae	14	GRRS				0.1		10000	8000		Jean-Francois Le Borgne
Delta Scuti						0.1					
Etoiles Be, Eruptives	7		Sursaut			0.1		1000	10000		Valérie Desnoux
Etoiles OB actives											Christian Buil
Etoiles Cataclismiques											Etienne Morelle
Etoiles Symbiotiques											Francois Teyssier
Nouvelles classes variables						0.001			100		Denis Gilet
Pulsars	10					0.1			0.01	einstein@home	Fabrice Mottez
Trous Noirs Galactiques											
Disques Stellaires										diskdetective.org	
Planétes Extra Solaire		Vitesse radia	Transit			0.01		10000	10	planethunters.org	Alexandre Santerne
Super-Terres										Kepler	Jean-Philippe Beaulieu
Satellites de Planètes Extra Solaire						0.01			10		Jean Schneider, David Kipping
Vie extraterrestre										seti@home	
Novae de la Voie Lactée	10					0.05			10000		
Super Novae Voie Lactée	0										
Remanents de SN					1		0.1	1000	100000		Agnés Acker
Nébuleuses Planétaires	16			étoile centrale			0.1	600		Digital Sky Survey	Agnés Acker, pascal.le.du
Nebuleuse de Wolf-Rayet											Agnés Acker
Nébuleuses								1000			
Bulles cosmiques										Milky way project	
Amas d'étoiles et asterism	9					0.01		10		Milky way project	Jose Peña Institut d'Astronomi
Amas Globulaires											
Voie Lactée										MilkyWay@Home	
Galaxies naines											
Galaxie d'Andromède	Novae									PHAT	
Novae galaxies voisines											
Amas d'etoiles galaxies voisines										http://www.projectstardate.org/	
Galaxies	green peas	Classification								Galaxy zoo	
Galaxies à noyaux actifs											
Micro Quasars											Katherine Blundell
Quasars	15		Sursaut			0.1		10	10000		Jean Schneider
Supernovae	14 - 21		Discontinuité			0.1		10	10000	http://tarot.obs-hp.	Emmanuel Conseil
Gamma Ray Burst	18	contrepartie optique				0.1			10000		CESR, Alain Klotz
Trous Noirs Super-Massifs											
Amas de Galaxies											
Filaments extragalactiques											David Valls Gabaud
Lentilles Gravitationnelles										space_warps	
Autres Objets											
Matière Noire											David Martinez-Delgado Max F
Energie noire											
Cosmologie						0.1		10		cosmology@home	SAF Commission Cosmologie
										www..zooniverse.org	
Code Couleurs Sujets Coll Amateurs-Pro			Facile		Exigeant		Difficile		Challenge	boinc.berkeley.edu	
V2.5 Novembre 2015 Thierry Midavaine Club Eclipse										scistarter.com	
Pour tous complements et corrections adresser un mail à		thierrymidavaine@sfr.fr									Thierry Midavaine
Publications de reference	Hors-Série 22 Ciel et Espace		Guide Pratique de la Science Participative en Astronom				Collectif				
							Olivier Mousis	http://arxiv.org/pdf/1305.3647v1.pdf/			
								www.afanet.fr/sciences-participatives-afa.pdf/			

Table 1: of the Amateur Astronomer topics

Appendix 2

Objets	Découverte	Suivi	Evenement	Métrologie	Astrométrie	Photométrie	Polarisation	Spectroscop	Rés Tempor	Exploitation	Point Focal France	Organisation	site web	e mail	Conférence	
Unités	Mag min				arcsec	Précision	Taux de Pol	P Résolution	seconde	sur Internet			astro-proam.com			
Météorites		Fripon									Brigitte Zanda	Fripon				
Météores	-4	Vigie Ciel	Fragmentatio	Orbite, Impac	60				1		Karl Antier	REFORME	www.boam.fr	reformemeteor.net	International Meteor Confer	
Essaims d'étoiles filantes	1	Orbite	Sursaut	ZHR Radian	240				60		J. Vaubaillon	IMO	www.imo.net		International Meteor Confer	
Cratères d'impact terrestre										Google Earth	David Baratoux					
Aurores Boréales													www.spaceweather.com			
Night Glow																
Sprite																
Rayons Cosmiques																
Lune			TLP	Occultation Rasante			0.1	10	0.1	Moon zoo		ALPO, IOTA	users.aber.ac/atc/tlp/tlp.htm			
Impacts sur la Lune			flash								Sylvain Bouley Uranoscope	IMCCE	http://uranoscope.free.fr			
Lumière Cendrée								10			Luc Arnold					
Lumière Zodiacale										Stardust						
Planètes		Météorologie	Tempête, Occultation					100	1		SAF commission des planètes	ALPO	www.astrosurf.com/planetessaf/		European Planetary Scienc	
Venus		UV ou PIR									Christophe Pellier	SAF				
Mars										planet four						
Jupiter			Impact								Marc Delcroix	SAF		delcroix.marc@free.fr		
Saturne																
Uranus, Neptune			Tempete								Marc Delcroix	SAF		delcroix.marc@free.fr		
Satellites de Planètes	21		Occultation	Phemu	0.04	0.1			1		Jean-Eudes Arlot, Bruno Sicar	IMCCE	www.imcce.fr/phemu09			
Astéroïdes (orbites)	19	Position	Occultation		0.2	0.1			0.1	http://www.asteroid	Jerome Berthier	MPC	www.minorplanetcenter.net/iau/	mpc@cfa.harvard.edu		http://m1p.fr/s
Astéroïdes (objets)		CdR	Occultation			0.05		10	0.1	Asteroids@home	Benoit Carry, Eric Frappa	EAON, IOTA,	www.euraster.fr		ESOP	
Satellites d'astéroïdes	CdR ou Occu	CdR	Occultation			0.01			0.1		Raoul Behrend	CdR-CdL	http://obswww.unige.ch/-behrend/page_cou.html			
Géocroiseurs AAA	19			Orbite, Impact				10	0.1	orbit@home	Mirel Birlan	EURONEAR	http://www.minorplanetcenter.org/iau/NEO/TheNEOPage.html			
Objets Trans Neptuniens	20		Occultation	Myosotis	0.2	0.2		10	10		Bruno Sicardy	MPC				
Objets de la bande de Kuiper								10			Francoise Roque					
Comètes	14		Sursaut, Fragmentation		0.2	0.2		100	1	Soho	Commission Comètes SAF	CBAT	www.cfa.harvard.edu/iau/mpc.html	cbatiau@eps.harvard.edu		
Comete 67P Tchouri			CdR													
Soleil Taches		Nbre Wolf					0.05	1000	0.1	Soho	Didier Favre	GEFOS	http://solardatabase.free.fr		liste astrosoleil	
Soleil Protubérances			Eruption, Eclipse				0.05	1000	0.1	Solar stormwatch	Franck Vessière	Observateurs	www.climso.fr			
Soleil Couronne			Eclipse Totale										http://rosetta.jpl.nasa.gov/rosetta-ground-based-campaign			

Table 2: Lines related to Solar System Object

Appendix 3

Catalogue	Année	MagLim	Nbre d'étoiles	Précision	Taille du fichier Remarques
Hipparque	-200		700	30'	
Ptolémée	150		1022	10'	
Tycho Brahe				2'	
Hevelius	1690			1'	
Flamsteed	1725			15as	
La Caille				4as	
John Bird Jesse Ramsden				1as	
D. Gill J. Kapteys			450 000	1as	
Bessel	1818		36		36 étoiles fondamentales
Plaque photo				0,13as	
Henry Draper					
SAO	ref 1950		250 000		Précision 1,5 as à ne plus utiliser
FK4	1963		1 535		Précision 0,1 as
FK5	1986		1 535		Nouvelle équinoxe, constante précession, mvt propre
FK5 extended	1988		3 000		Précision 0,08 as
FK6	2000		4150		Wielen R. et al Part I 1999, Part III 2000
BSC		7	9 096		Les étoiles les plus brillantes
Hipparcos	1993	13	117 955		Précision 0,001 as
Hipparcos 2	2007				van Leeuwen F.
Tycho 1			118 218		Précision 0,03 as
Tycho 2	2000		2 539 913		Hog E.
GSC		13 et 16	15millions	216MO	précision 1,5 as ancien, inclus dans Prism6
GSC ACT				291MO	Plus recent, inclus dans Prism7
GSC 2.3					
AC2000					
AGK2					
USNO SA1		20 reg espacées	55millions	1CD	
USNO SA2					idem SA1 en plus précis
USNO A1		20 B R	550millions	10CD	
USNO A2		20 B R			idem A1 en plus précis préférables aux GSC
USNO-B1.0		21	1045913669	80GO	accessible en ligne préférable aux USNO-AX
UCAC 1					petit domaine du ciel Sud, Obsolète
UCAC 2		de 7,5 à 16 R	48millions		-90° +50°, magnitude entre B et R, obsolète
UCAC 3	2009	mag 8 à 16 V		8GO+ (2DVD)	1% de bug, obsolète
UCAC 4	2013	mag 8 à 16.3 v-r	113 780 093	8GO (2DVD)	20mas, photométrie 2MASS, APASS en B, V, g, r, i
Nomad v1				environ 100GO	des anomalies sur les magnitudes
PPM			380 000		précision 0,3 as
PPMX	2008		18 088 919		Roser S.
PPMXL	2010	mag 20 V	910 468 710	4DVD 37GB zip	combine USNO-B1.0 & 2MASS précision 0.3as
/Vizier					
CCMC 14					
CMC15					
2MASS	1999	infrarouge			
DENIS		infrarouge			
URAT		18	20mas		USNO Robotic Astrometric Telescope
URAT1	2015	3-18.5 R	228millions	10 – 30 mas 18GB	VizieR Hemisphere Nord à –15° 2013.5 5mas/yr CDS
URAT2	2016				
GAIA 1	2016		100000		1-2 mas de précision 14–134mas/yr
GAIA 2	2018		10^9 objets		Précision 7 µas
GAIA	2020		10^9 objets		

Table 3 : Astrometric catalogue review

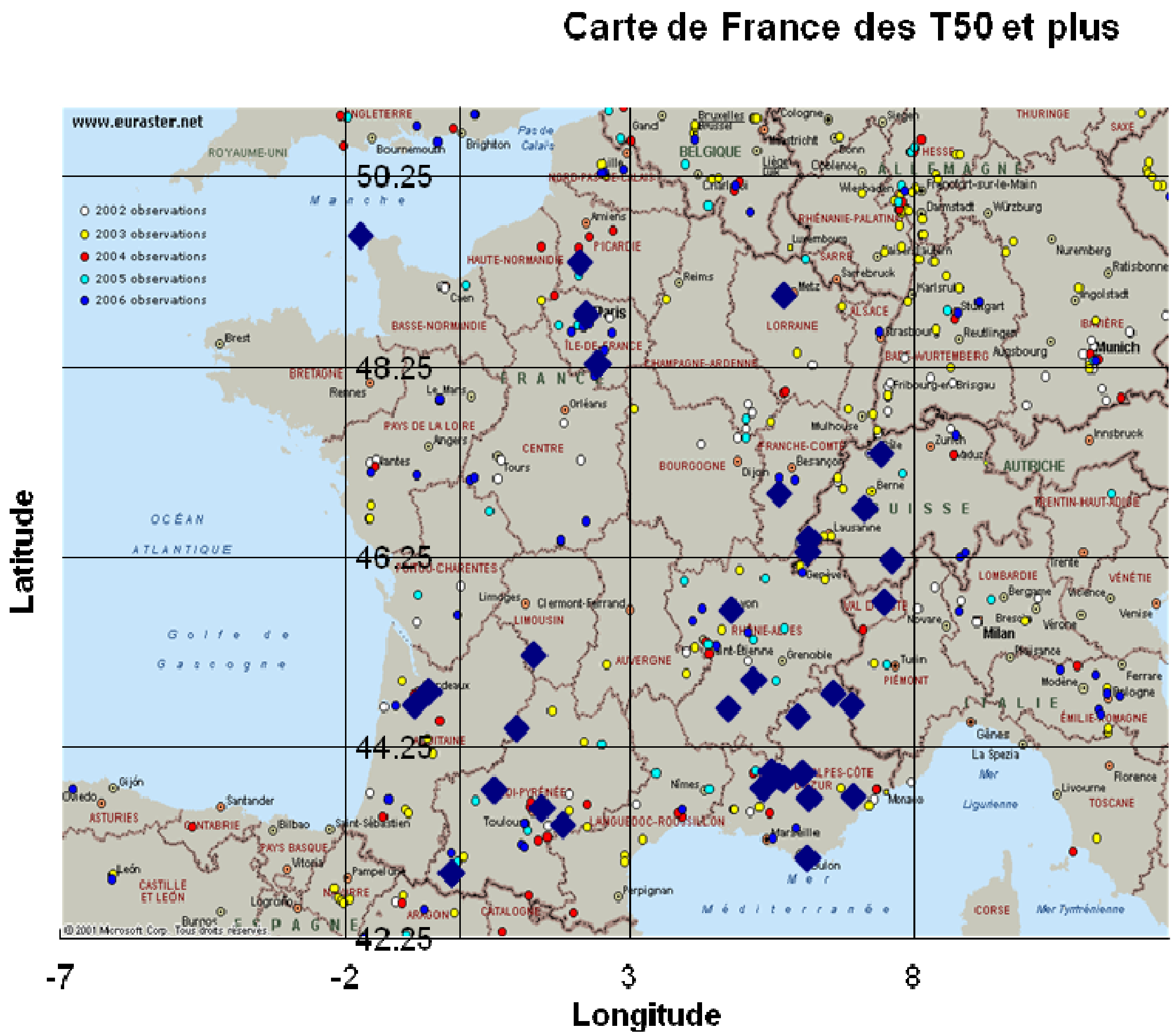

Table 4 : Above 50cm class telescopes in France (Blue Losange) on the Eric Frappa map on occultation observer network

Obs Astro Val d'	Meudon	Centre de Recherche astronomique de lyon			OHAM	Les Makes	OBP Baronn	Saint-Caprai	Bauduen	OHP	OCA Calern	CLE1HM	Mars
			SAL	SAPToulouse		AGORA	e-scop sarl		OAB Observatoire Astronor		C2PU	SAT	CAM
			513			181	B10				910		
oui	non	non	non	non			en cours						
						55°410	E5,5°		6°17E				4°20'07"
						-21.198	44,4N		43°73N				45°00'25"
1600						1000	820						1080m
	Cassegrain	Cassegrain				Ritchey Chretien							Ritchey Chreti
0.8	0.6	1	0.6	0.83	0.8	0.62	0.82	0.94	0.62	1.52	1	0.66	0.6
5					6.4		3.28		2.046				5E-10
									Paracorr				
									40				
						4.771	6.56		Barlow X2				
						f/3			Nasmith f/D20				
oui							1						
					1.8								
									60				
HiSIS39						ST 11000M							Apogee
KAF1001E						KAI 11002M							
1024 x 1024						4008x2672							
						9							
						657x495 7.4µm							
						C14			Lunette de 120mm			Dobson406	LX200 12"
					1								
téléphone	demande												
		non											
							16		14				
indisponible fin 2005			vendredi soir				Véhicule		Voiture				
							14						
250							50/pers						
					700 pour 4 - 5 personnes								
2000/10j									250				
						200							
www.oavda.it		http://www-obs.ui	www.astrosurf.co	www.saptoulouse.net/			www.obs-bp.com		http://www.observatoire-astronomique-de-bauduen.com				www.clubastro
	dominique.proust@obspm.fr		sal@astrosurf.co	sap@saptoulouse.net		obs.astronomique@wanadoo.fr			olivier.planchon29@orange.fr				
Saint Barthélémy	Loc. Lignan					18 rue Georges Bizet			Quartier les vallons				
3911020		69561	69230	31500		97421			83630				0
Nus		Saint Genis Lava	Saint Genis Lava	Toulouse		Les Makes, la Rivière			Bauduen			Tahiti	Mars
3.90166E+11			674422629			262378683			06 76 05 96 36				
			Bernard Reynaud										
			bernard.reynaud@free.fr										

Table 5B : 60cm class telescopes in France or closed to France

Observatoires 60cm et sup	Unité	T60 OMP	Château Renarc	TJMS Buthiers	Cotes de Meuse	Sirene	Plateau du Mou	Ludiver	Col de la Lebe	Belesta	La ferme des ét	OHP St Michel	OHP St Michel	FXBagnoux
Associations		AT60	Astroqueyras	Planète Sciences		Sirene	Centre d'Astronomie		Club astro nature	Adagio	A Ciel Ouvert	CNRS	CNRS	
Station UAI n°			615	199	216					A05				
Station de nuit		non	non	oui	non	non	oui	oui	oui	non	oui	non	non	non
Long	° ' "	00°09'32"	6°54'24"E	2°26'16.9"		05°29'13"E	5° 43' 17" E	1°39' O			00°48E	E 5°43'54 "	E 5°43'54 "	
Lat	° ' "	42°56'12"	44°41'52"	48°17'30.4"		44°00'00"	43° 54' 22" N	49°37' N			43°54	N 43°52'36"	N 43°52'36"	
Alt	m	2861m	2931	92		1100	560	180		250	180	600 m	601 m	
Instrument		Newton	Cassegrain	Newton-Cassegra	Newton	Coudé	Newton	Newton	Newton	Newton	Newton			Newton
Diamètre Pupille	m	0.6	0.62	0.59	0.83	0.635	0.583	0.6	0.6	0.82	0.62	0.8	1.2	0.6
Focale	m	2.13	9	2.013	3	13	2.2	2.83	2.1	3.1	2.4	12		2.28
Correcteur de champ		oui	non				non							
Champ utilisable	arcmin													
Focale combinaison 2	m	2.01 Wynne 3pou	2	4.8		non		4.5		13.9				
Focale combinaison 3	m		7.5	9.6				9.6						
GoTo		non	oui	oui	oui	oui	oui	oui	NON	oui	oui	non		
seeing moyen	arcsec	2	1.5	3				3						
Pose max (dérive<seeing)	s	600		60	5	visuel uniquemen		60						
Caméra CCD		STL6303E	U16M	STL11000	Apogee	non	Platinum	MX916, synonym	Audine	ST8e	ST6	ANDOR		AP47
CCD		KAF6303E	KAF 16803		AP47-10 ?		KAF402ME		KAF 400			Marconi ccd aminci 42-40		Marconi 47-10
Pixels		3072x2048	4096x4096	4008x2672	1024x1024		768x512	512 x 512	768x512		378x242	2048x2048 13.5 pixels champs 7'		1024x1024
pas pixel	µm	9	9	9										
Autres cameras		Ethernaude 1603	HiSIS22	Ethernaude 1600										
Cam Video		Watec 120N	Mitron	DMK										
Spectro		Lihres III	Musicos		non	non	oui (Barège)	non				LORIS en cours de réalisation		
Autre instrument		Lunette de 120	RC500	coro H 100mm		T406 sur ZX10 et	ST7, webcam	webcam		correcteur Wynne	WEBCAM ET AF	Filtres UBVRI		HiSIS44
Accés par Internet														
Missionnaires														
Demande de mission		écrit 3mois avant	écrit en février	télephone	téléphone	téléphone / e-mai	téléphone/e-mail	tél + courrier		téléphone	Tél/mail/courrier			
Comité des programmes		oui	oui	non	non	non	non	non		non	oui	oui		
Membre		individuel	club et individuel	club ou indiv		non nécessaire	oui	non			individuels et clubs			
Autonome si Agrément		oui	oui ou chaperon /	oui	non	oui	non	non			non	oui		
Nbre de personnes max		4	6	15	8	1 à 40	10	9	12	6	15			20
Accueil mineurs		non	non	oui	oui	oui	oui	oui mais accompagnés d'adultes			oui accompagnés			
durée min de mission	nuits	6	7 en été, 1 en hiv	1	1	1	1	1			1	1		
Coûts														
accés		téléphérique	piste, ski l'hivers	RER		véhicule	véhicule	véhicule			Véhicule			
Age minimum	ans	18	18	0										
adhesion	€	25	25	50/Club			10	aucune			non			
Instrument/nuit	€			125	150	70/pers maxi	142.5	150	27/pers	152	150 / nuit (animat	40		500CHF
Instrument/semaine	€	15/pers	compris	775		nous consulter	non	non			nous consulter			
Hébergement	€/pers/nu	22	compris	12	30	tous types d'hébe	Pension C. 30,50	non, gîtes à 10 mn		non	possible sur plac	Oui, supplément	Centre d'Astronomie	
Forfait une semaine	€/pers/semaine		175				non				de 10 à 44 /p			
Repas	€	12.5	cuisine sur place	12	#NOM?	cuisine équipée à	11.5	non			de 12 à 19 / repa	Oui, supplément		
Nombre de nuit/an		100	100	100										
Pour les Contacter														
Site web			www.astroqueyra	www.planete-scie	http://assoc.wana	www.obs-sirene.c	www.centre-astro	www.ludiver.com	http://astroval.fre	adagio@astrosur	www.fermedeset	http://www.obs-h	http://www.obs-h	http://www.ofxb.c
e-mail		castets.martine@wanadoo.fr			observatoire.t83@	sirene@obs-siren	contact@centre-a	ludiver@lahague.com						info@ofxb.ch
Adresse		Pic du Midi	Mairie de Saint-V	Base Régionale d	8 place de Verdu	ZL.12 - D.34	Centre d'Astronor	1700 rue de la Lil	Canv	BP8	Au Moulin du Roy			
code postal		65000	5350	77760	55210	84400	4870	50460	1260	31450	32500			3961
ville		Bagnères de Big	Saint-Véran	Buthiers	Viéville-sous-les (	Lagarde-d'Apt	Saint Michel l'Ob	Tonneville	Charancin	Labastide-Beauvo	Fleurance			Saint Luc
telephone			671068923	169027610	329895864	490750417	492766969	233781380	479876731	561818866	562060976			41274755808
Thierry Midavaine 19/06/10														
thierrymidavaine@sfr.fr	Contact pour les mises à jour													

Table 5A : 60cm class telescopes in France or closed to France

Picture 6 : Moon total eclipse recorded in the 3 – 5 µm IR thermal band

Imaging the natural planetary satellites

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Introduction

Astrometric observations of the natural satellites are extensively made for dynamical and planetological studies but each satellite is a specific case: its size, its brightness, the closeness of a bright planet or not will need different types of observation. More, natural satellites are not punctual targets and the center of mass is not well defined; albedo variations, phase defect and reflection/diffusion of light law are not well known. Mutual event observations have shown these photometric problems which should be solved also for direct imaging.

Mars	Magnitudes at opposition	Maximum elongation
M-1 Phobos		
M-2 Deimos		

Jupiter	Magnitudes at opposition	Maximum elongation
J-1 Io	5.0	2' 27"
J-2 Europa	5.3	3' 54"
J-3 Ganymede	4.6	6' 13"
J-4 Callisto	5.6	10' 56"

Saturn	Magnitudes at opposition	Maximum elongation
S-1 Mimas	12.9	32"
S-2 Enceladus	11.7	41"
S-3 Tethys	10.3	51"
S-4 Dione	10.4	65"
S-5 Rhea	9.7	90"
S-6 Titan	8.3	209"
S-7 Hyperion	14.2	254"

Uranus	Magnitudes at opposition	Maximum elongation
U-1 Ariel	14.4	15"
U-2 Umbriel	15.3	21"
U-3 Titania	13.9	35"
U-4 Oberon	14.2	47"
U-5 Miranda	16.5	10"

Table 1: magnitudes and elongations for the main planetary satellites

The distance to the planet

The apparent distance of a satellite to its primary is quite important. For a small apparent distance, the contrast will decrease the signal/noise ratio. Table 1 shows the magnitude and the elongation for the main planetary satellites. Farther is the plant, smaller is the apparent distance but similar is the brightness contrast between satellites and planet.

The phase defect and the albedo

Figure 1 shows what we see from the Earth. For most of the planetary satellite, the phase angle is small but sufficiently large to induce biases in the measured positions. More, the surface is not uniform and the center of light does not correspond to the center of figure (and no more to the center of mass which is our target).

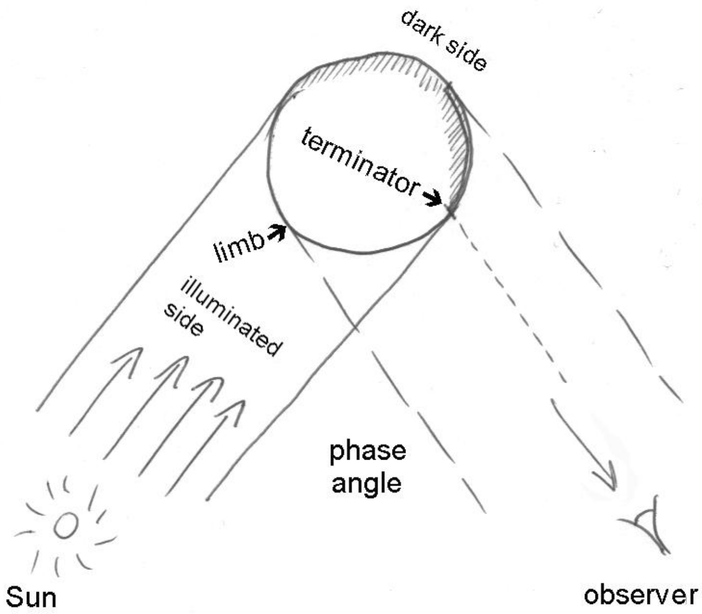

Figure 1 : a solar system object and an observer

Examples of observations

Let us examine the different case of observation.

1)° The Martian satellites
The figure 2 below shows that it is necessary to put a mask on the bright planet and that a specific treatment of the image is needed to have measurable satellites. It is difficult to measure the position of the satellite referred to the planet but it is possible with a density in place of an opaque mask as shown on figure 2.

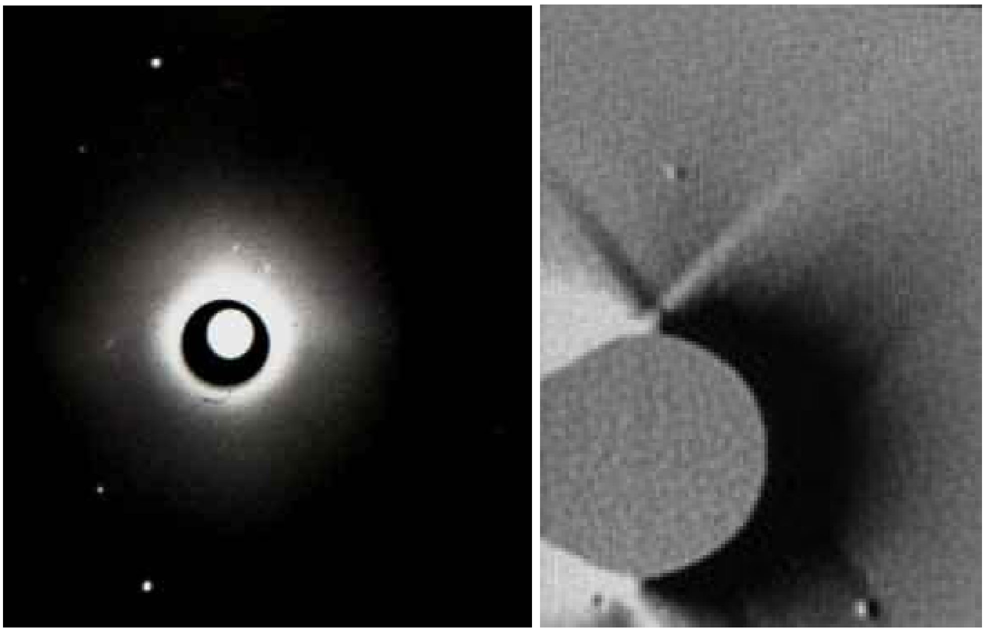

Figure 2 : left : photographic plate with a density on the planet and right, a CCD image with an opaque mask

2) The inner satellites of Jupiter

In that case, the magnitude difference and the closeness of the planet make the observations difficult. Even the Galileans are too bright to be used as a reference.

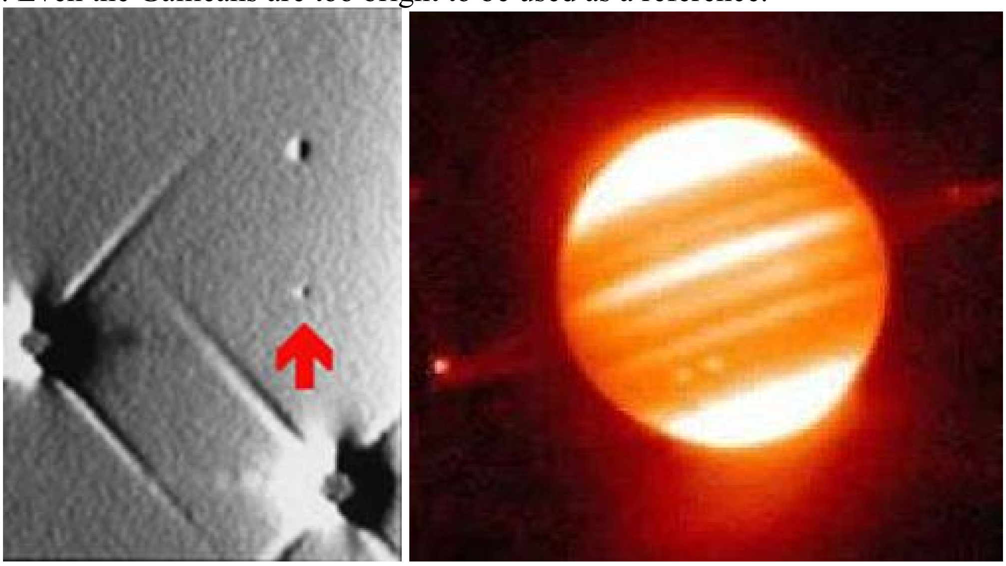

Figure 3: CCD image of Thebe: the bright objects are the Galilean satellites. At right, a infra red image showing at left Amalthea above the ring. The planet is darkened thanks to the filter K in the methane band.

3) The inner satellites of Saturn

The problem is quite different from the inner satellites of Jupiter. Saturn has a bright ring and the infra red wavelengths are not useful to eliminate the brightness of the ring. Only a mask may darken the planet. For the ring, it is better to wait for the equinox on Saturn. The Earth is in the plane of the ring which disappear and makes the inner satellites observable. Figure 4 shows an image of Saturn and its satellites during the transit of the Earth in the ring plane.

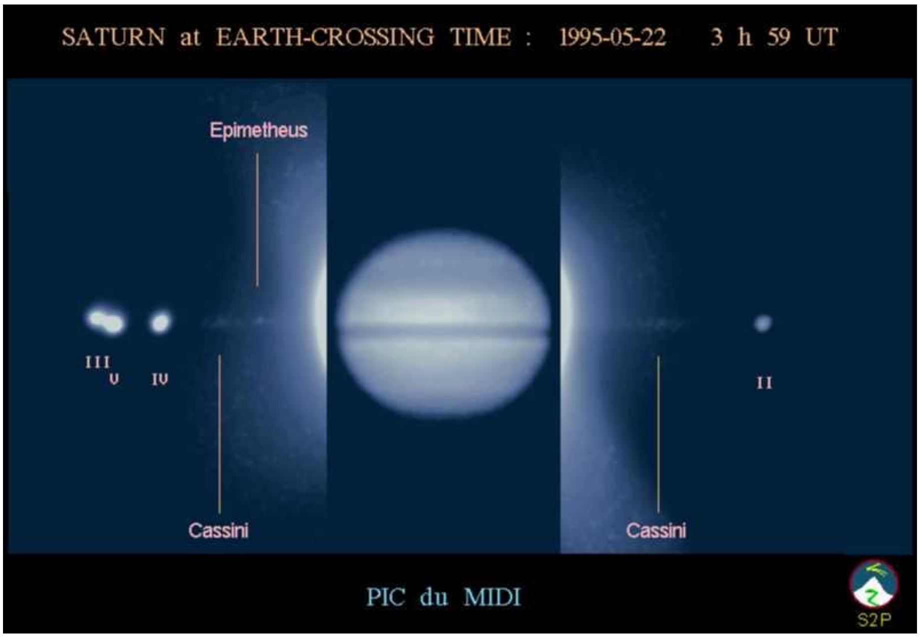

Figure 4: small inner satellites of Saturn observable when the ring disappear at the Saturnian equinox

4) The Galilean satellites

These objects, the magnitude of which being from 4 to 5, are too bright. If we wish to have stars on the same image, the satellites are saturated. The solution is to stack images in order to avoid the saturation and to have a sufficient signal/noise ration fir the stars.

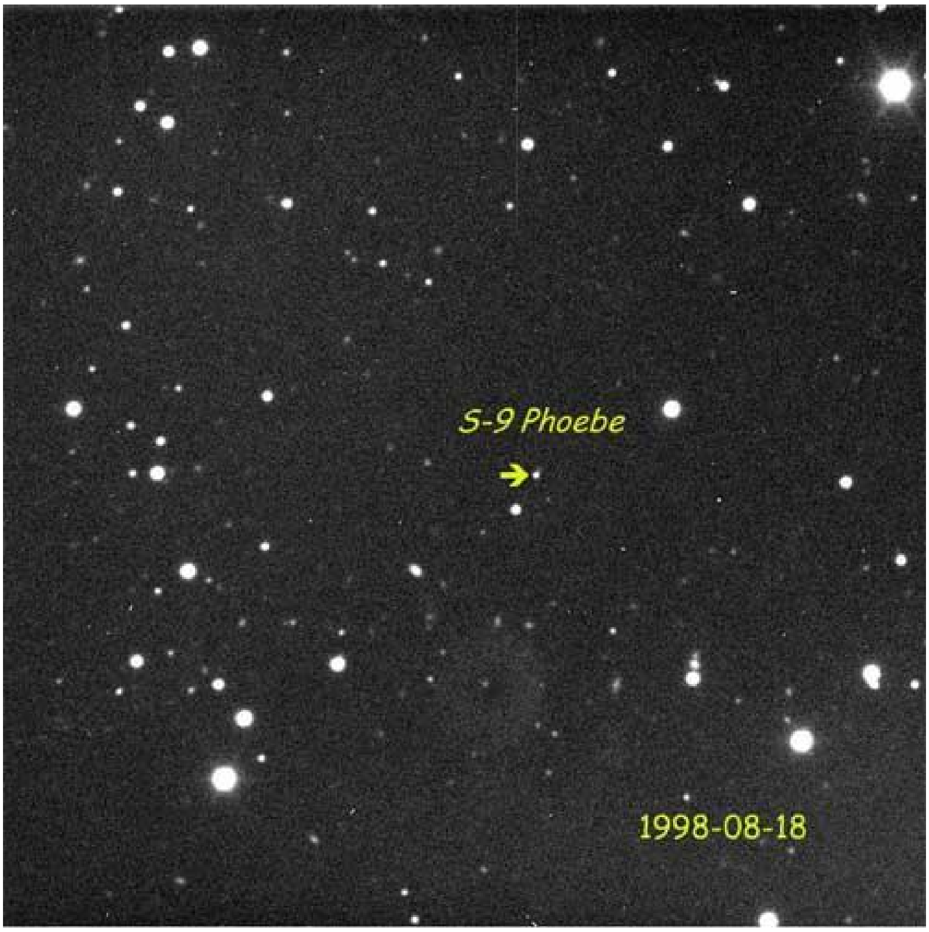

Figure 5: a 12x12 arcmin field containing an irregular satellite of Saturn, Phoebe

5) The irregular satellites of the giant planets
The giant planet have many irregular satellites far from the planet. Their magnitude are similar to stars and they may be observed in rich fields making easy the astrometric reduction. The image are classical astrographic plates as shown by figure 5. Many reference stars are available for the reduction.

6) The satellites of Uranus and Neptune
Since these planets are far from the Earth, all the satellites, except the irregular, are close to the primary. Long focus observations are necessary and infra red CCD are preferable, darkening the atmosphere of the planets. The reduction are often difficult because, with long focus telescopes, the field is small with very few reference stars. This problem will be solved thanks to the arrival of the Gaia reference catalogue. Figure 6 shows the Uranian system in visible wavelength: the planet is bright and the inner satellites are not observable. Even Miranda is difficult to see. However, these observations are easy to make and the main satellites are easily measurable.

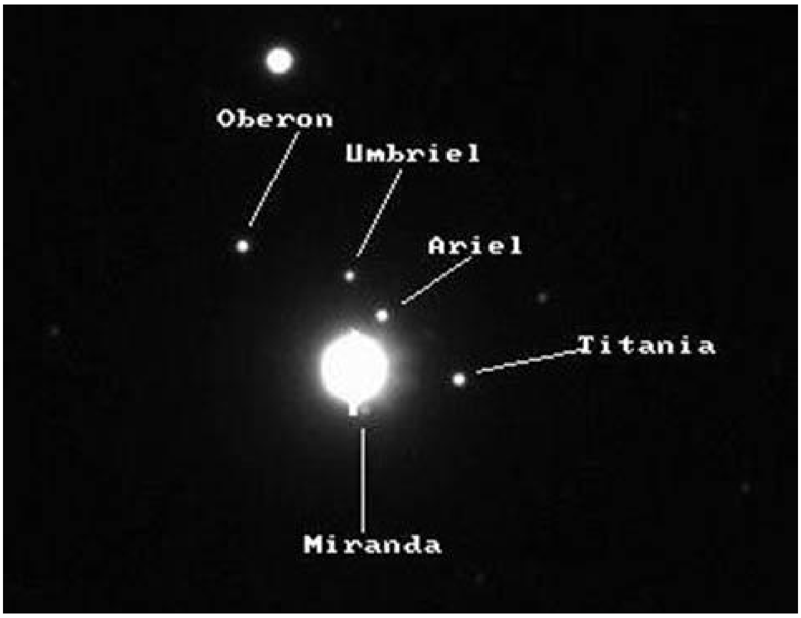

Figure 6: the Uranian system observed in Brazil: Miranda is difficult to see and the stars are not numerous

The K band at 2.2 micrometers allows to darken the planet in the absorption methane band. Figure 7 shows an image made at that wavelength. The planet is very dark compared to the satellites. Even the small Miranda is well observable.

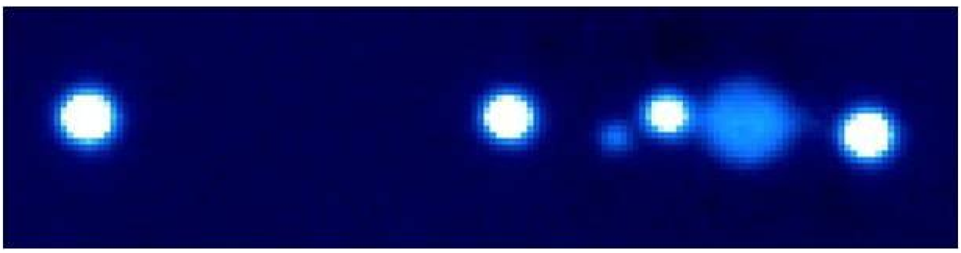

Figure 7: the Uranian system at 2.2 micrometers on the ESO NTT telescope. It is possible to see the Uranian ring at the right of the planet.

However, the small inner satellites are not observable. For that purpose, the K' band will be used associated with the VLT. Figure 8 shows an image where Puck appears near the ring and Portia at the left of Uranus. The main satellites are very bright but not saturated and may be used for the astrometric reduction since stars are very rare in this 20 arcsec field.

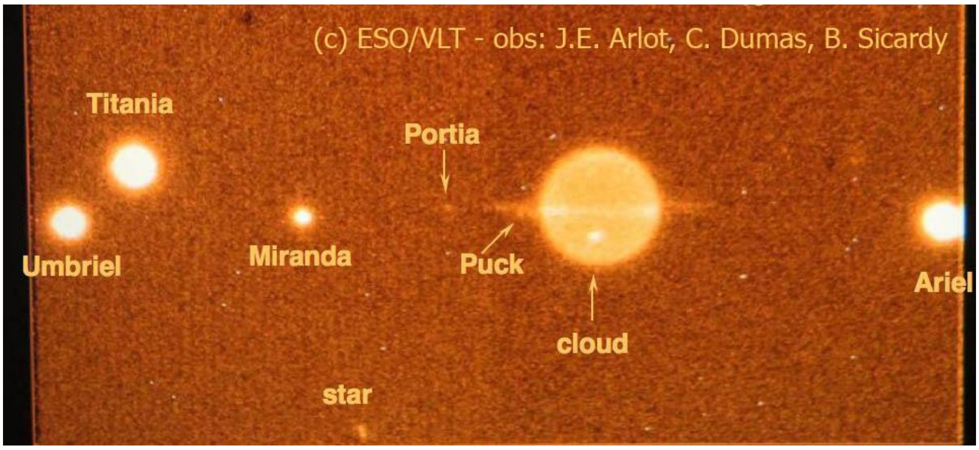

Figure 8: the Uranian system observed using the NACO camera on the UT4-VLT ESO telescope.

Neptune has a bright satellite Triton which must be observed near the elongation to be measurable.

7) Pluto's satellites

The classical ground-based images do not show all the satellites. Even Charon is difficult to separate from Pluto, its elongation being onlyone arcsec! All observations are using the VLT with adaptive optics or the HST.

8) The observations from space probes

The observations made by space probes in the vicinity of the planetary satellite systems are the best data to be used for astrometric purpose. The observations are similar to the ground-based ones: the satellites with reference stars in the background for the reduction as seen of figure 9.

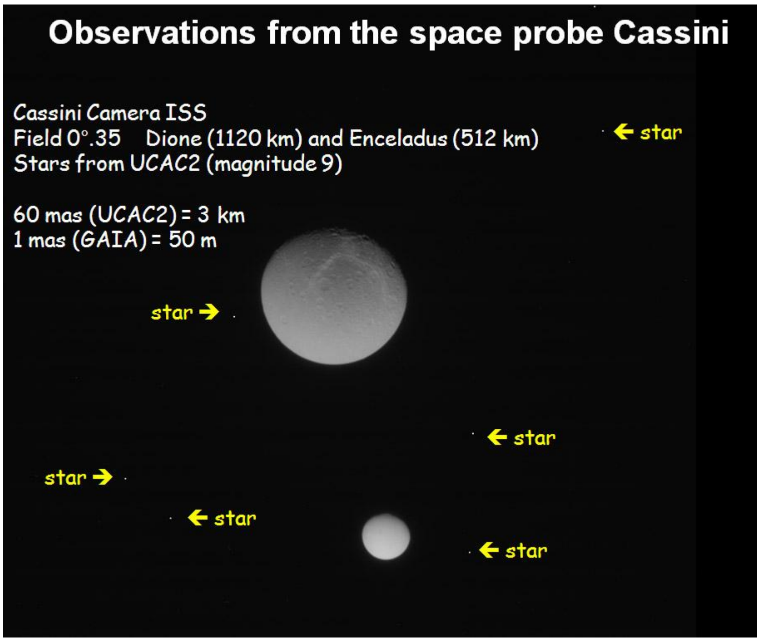

Figure 9: Dione and Enceladus as seen by Cassini. Reference stars (the very small white points) are sufficiently numerous. The only problem is to know the position of the probe.

Conclusion

Natural planetary satellites are worth being observed as often as possible due to their fast motions. Each satellite has an optimal density of observations in order to fit the theoretical model and to determine the precise amplitude of periodic terms in the motion. As we have seen above, each satellite family has a specific way to be observed. Specific observational campaigns have to be made and adapted to each type of satellite from the inner faint satellites drowned in the scattered light of the planet needing masks or infra red targets to the far faint satellites needing large telescopes. The reduction has to be prepared by the recording of reference catalogue stars which will depend greatly on the nature of receptors and telescopes used. However, these interesting objects that are natural satellites are worth being the goal of extensive permanent observational campaigns.

Discussion and conclusions

The following notes were taken during the discussion session.

Introduction

During the workshop, we asked several questions and you will find below discussion, comments and conclusions.

1. Publication of proceedings ?

Participants agree to the publication of proceedings and to post the presentation on the web site of the workshop. Proceedings will be published as “Scientific notes of IMCCE” without reviewing but will be included and reachable through the ADS server.

2. How to increase the astrometric reduction when using the Gaia reference catalogue?

The best present accuracy of astrometric observations of solar system objects is around 50 mas. This limit is mainly due to the accuracy of the reference star catalogues. Since the observations made in a relative reference frame may have an accuracy around 30 mas, it appears that this accuracy could be improved in the future, especially using the Gaia reference star catalogue. The one mas accuracy is a goal for the future and may be obtained by correcting:

- The distorsion due to the optics and to the geometry of the detector
- The differential refraction using new models of refraction
- The magnitude and color effects
- The determination of the centroid of the images which may be moved by the phase effect, the albedo of the surface of the object and the variation of absorption during a long exposure (the center of light being moved to the moment of minimum absorption)

New softwares should be built for the astrometric reduction.

3. For which past observations should we make a new reduction with the Gaia catalogue?

The Gaia catalogue will allow to make new reductions of old observations with a theoretical accuracy of one mas for observations made starting at the end of the XIXth century. Observing in the past with today accuracy will be a dream for astronomers looking for cumulative effects observable in observations made on a long interval of time. However, the large number of old observations, still available (photographic plates) with all metadata is too large to be re-reduced within an acceptable interval of time. So that specific scientific goals have to be defined first. As examples, we may propose:

- Objects for which a cumulative effect is easy to be quantified
- Observations for dynamical studies avoiding gaps in the sample data
- Measuring the Yarkovsky drift on selected asteroids (selected families)
- Selected PHA and pre-discoveries through a specific search in photographic plate archives defined by their RA and DEC (Schmidt plates) where pre-discoveries of objects are suspected

4. How to increase the accuracy of the mutual events to challenge astrometric imaging with Gaia?

The main problem encountered during the reduction of the mutual event is the photometric calibration. Depending on the position of the satellite around Jupiter, the albedo is different and varies with the jovicentric longitude. This albedo depends also on the wavelength so that observations should be made: all satellites at several jovicentric longitude in the main wavelengths used for observing the mutual events. This leads to the following program:

- Observing the satellites for photometric survey in V, R, I, Methane
- Asking amateurs to include this survey in their program
- Developing new softwares for photometric reduction

5. Improvements for occultations and Phemu observations

How the star occultation observations will benefit from the Gaia project?

For star occultation, we need a good reference star catalogue and a good ephemeris of the occulting object. This is very important to be sure to be able to observe the event. The zone of visibility is very sensitive to the accuracy of both star catalogue and object ephemeris. So that the Gaia catalogue will help for:

- Having stars better known
- Having “Gaia” asteroid ephemerides better known at least a few years after Gaia

Then new types of occultations involving fainter asteroids will be possible with more well-known fainter stars. A large number of predictions will be possible so that we will need a scientific choice between this large number of predictions. The participation of amateurs could increase with bright stars for high time resolution possibly occulted by faint asteroids

Will mutual events of natural satellites reduction improved thanks to Gaia?

No, possible improvement only from ground based photometry since ,most of time, bright satellites not observed by Gaia (Galileans, Titan) are involved.

Will mutual events reduction be helpful for extra-solar planet transits reduction ?
Not really: softwares for Phemu or occultation reductions could be used for extra solar planet transit reduction but the reverse may be possible

6. Ground based observations useful after Gaia

Which objects are still worth to be observed since Gaia will observe most of solar system objects? What are the priority?

We must take into account the scientific interest: the accumulation of ground-based observations was necessary before Gaia but may be not useful now for all solar system objects.
First, the objects which will not be observed by Gaia remain the main goal. Then, fast objects observed by Gaia must be observed during and after the end of the Gaia mission. The Gaia observations of these objects (no more than 50 during the 5-yrear mission) are not sufficient. Slow objects will have ephemerides from Gaia easily extrapolable for several years before

needing new observations. Among the objects not observed by Gaia will be planets and bright satellites the observations of which being essential for the knowledge of solar system dynamics.

How to complete Gaia observations for large bright objects (planets, large satellites)?

It will be necessary to organize new observational campaigns. The arrival of a high precision reference star catalogue will allow classical astrometric observations of high accuracy. Maybe the Phemu observations, which are the most precise at the present time, will be superseded by classical astrometry. However, the reduction procedures should be revisited and improved taking into account small effects at mas level.

How to complete space probes observations?

Thanks to the Gaia star catalogue, classical observations will have a better astrometric accuracy and it will be easier to complete gaps in the observations between space missions with a smaller number of observations.

What will be the usefulness of the Gaia reference star catalogue for old observations, i.e. observations made before the arrival of the Gaia catalogue?

Besides the reduction of newly made observations with the Gaia catalogue, we may wonder if the Gaia catalogue will help improving the old data. These old data have a poor accuracy for several reasons but the main one is that the old catalogues have a few number of stars known with a small accuracy. More, the reference frames were all different all along the decades until today. This is the main reason for the bad quality of solar system ephemerides when extrapolating far in the future of in the past. However, the old observations are necessary to fit the dynamical models because of the short periodic terms of fast objects.

How to correct old observations?

Several ways may be used. First, the observations are still available (mainly as photographic plates or CCD images) with all the needed metadata. Then, a new reduction is possible using the Gaia catalogue which will provide more stars than the old catalogues used for the reduction of old observations and proper motions of stars with an accuracy of one mas one century ago. This is sufficient for our purpose. The scanning of old photographic plates will allow to make pre-discoveries of comets, asteroids, outer satellites not yet known at the time of the old observations enlarging the sample of data for dynamical purpose.
If old observations are not available, corrections may be made if knowing which stars have been used and which star catalogue.

7. Available useful telescopes for future observations

At Pic du Midi

1m-telescope offers possibilities for observing solar system objects: objects until mag 22 are observed at the present time with an accuracy of 50 mas. Objects with mag>24 are not observable.
Among the fast objects needing observations: the Martian satellites does not need ground-based observations since space probes are still in the vicinity of Mars, observations of the

Inner Jovians, Uranians and Neptunians are needed because not enough observations will be provided by Gaia (if so), NEO and comets are needed. For inner satellites, we have to improve the coronographic and filtering system

T60 telescope has a field of 30' and observes objects until mag 19

What next telescope generation shall be used for solar system astrometry (ELT, LSST, JWST, ALMA, ...)?

The need for new observations may concern faint satellites discovered by space probes and not yet observable from ground-based observatories. Larger telescopes may help to enlarge the sample of data for a better modeling of their dynamics. However, it is very difficult to get observing time on large telescopes for solar system objects. At the present time, we have difficulties for observing on the VLT even it is the lonely telescope to get the faintest satellites near the primary thanks to adaptive optics. More, some outer satellites of the giant planets which have been discovered recently have never been observed and they are now lost, the ephemerides being not able to provide their positions. The survey of satellites in order to maintain the ephemerides is not a sufficient reason to get observing time. If a space mission was planned toward these objects, maybe it will be possible to get time.

If getting observing time is difficult, we may make some data mining on archives of observations of the planets themselves: most of time, the faint inner satellites are visible on the images when made with adaptive optics.

Prospective on future telescopes and proposals

We have to remind us that we may obtain observing time on large telescopes through an association with other programs (we get observing time on the VLT for the Uranian satellites by gathering astrometric, photometric and planetologic observations). The proposals should be carefully prepared with fast results to be published just after the observations.

8. The participation of amateur astronomers to future campaigns

The arrival of the Gaia catalogue will change many things. Numerous low precision observations were useful in the past in order to avoid gaps in the samples of data. With observations more precise, the samples of data should be different. However, since solar system objects are easily observable with small telescopes , the participation of amateur astronomers should be useful if the observing procedure is modified: the Gaia catalogue should be used and some extract of the Gaia catalogues should be made in order to make the reduction more easy. Stars until magnitude 20 on all sky are not necessary for small telescopes observing from a given site.

Mutual events and star occultations may be continued. Mutual events reductions may be improved if more photometric surveys are performed: photometric observations of the Galileans are wanted in the B, V, R, I and methane bands at several phase angles for different longitudes in the orbit.

It appears that it would be interesting to organize a “WETA” for astrometry to build interesting programs (such as close approaches of natural planetary satellites), to ensure the reduction procedures and to make a list of amateur observatories ready to participate to astrometric programs.

9. Defining the new astrometric observational programs

What should be the astrometric observational program in the next ten years ? Will dynamical studies be able to help defining the astrometric observational programs of the next years?
The photometric observation of the Galilean satellites should be useful either for mutual events reduction and for astrometric measurements since the phase effect is not negligeable for these objects (remember that Ganymede has a one arcsec diameter. Old observations could be corrected thanks to a better knowledge of their surface photometry.
The new observing program should take into account specific needs for dynamical purpose: we have to select the objects worth to be extensively observed. Objects such as NEO, TNO, comets might be included in observational campaigns. The analysis of the observations of the solar system objects by Gaia will help us to identify our future targets.

40 years of observation of the mutual phenomena

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Introduction

The astrometric observations of solar system objects are commonly measurements of angular positions of bodies on the celestial sphere in a given reference frame. Astronomers saw very early that celestial bodies were often involved in phenomena such as eclipses of the Sun or of the Moon, or of the Galilean satellites. Such phenomena correspond to specific positions of the involved bodies in space. 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 it appears that the observation of phenomena are more accurate than direct astrometric observations.

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.

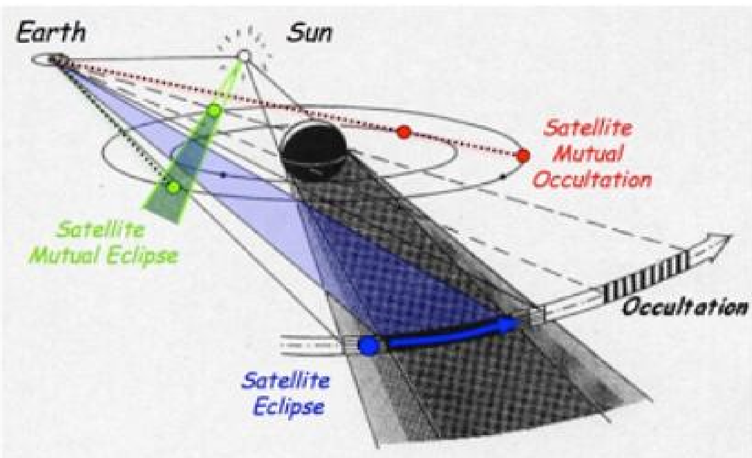

Fig. 1 : The principle of the phenomena of the Galilean satellites of Jupiter

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.

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. Since the Galilean satellites are bright, the recording of the events was easy: it needed a fast photometric receptor associated to a telescope the aperture of which being not too small but the increased sensitivity of the receivers allowed to use smaller telescopes. An occultation or an eclipse was only a few minutes long and is not time consumer. 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 to observe 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.

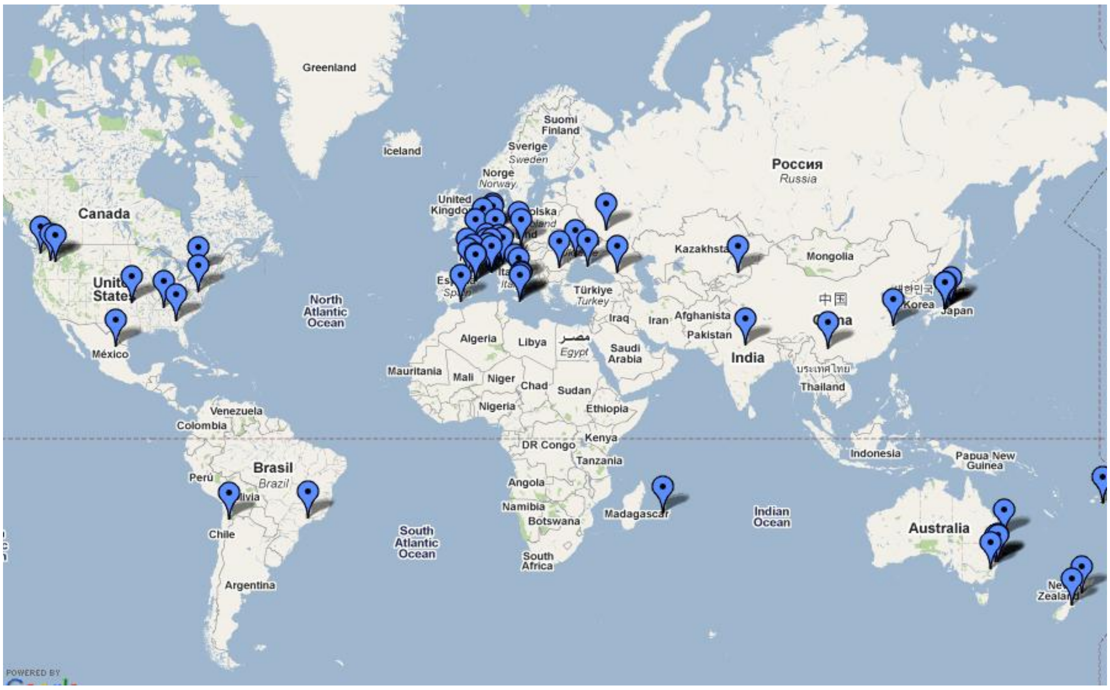

Figure 2: The present PHEMU network of observers

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).

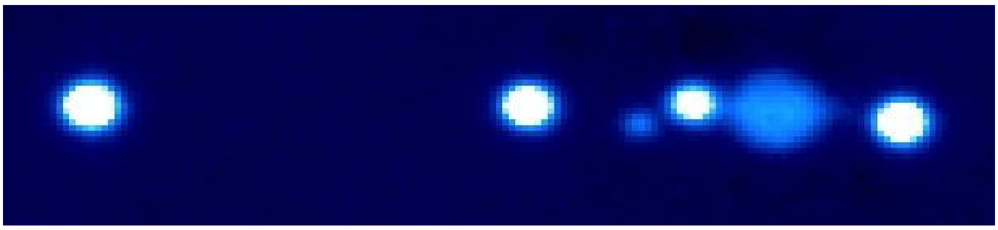

Figure 3: The Uranian satellites as seen with the NTT in the K'-band.
The planet Uranus is darker than the satellites (except the small Miranda)

4. The results of fourty 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 decorrelate 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).

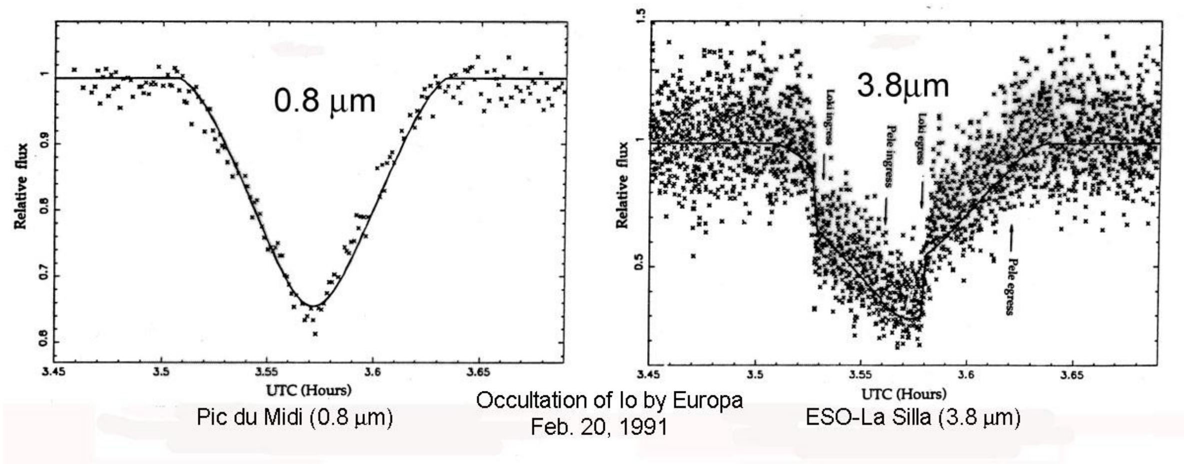

Figure 4: Occultation of Io by Europa:
the occultation of the hot spots are visible on the light curve at right

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 40 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. 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.

5. Providing astrometric data

After making the recording of the images of the phenomenon, we have to build the photometric light curve: since we need only relative photometry, the observation of a reference object (another satellite in the field) allows to eliminate the effect of light clouds or twilight appearing during an event as shown in figure 5.

Table 2 : Observations made since the beginning of the campaigns

	Number of observations	Number of sites of observation	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
2015				
Saturn				
1980	14	6	13	213
1995	66	16	43	182
2009	26	15	17	131
Uranus				
2007	52	19	36	193

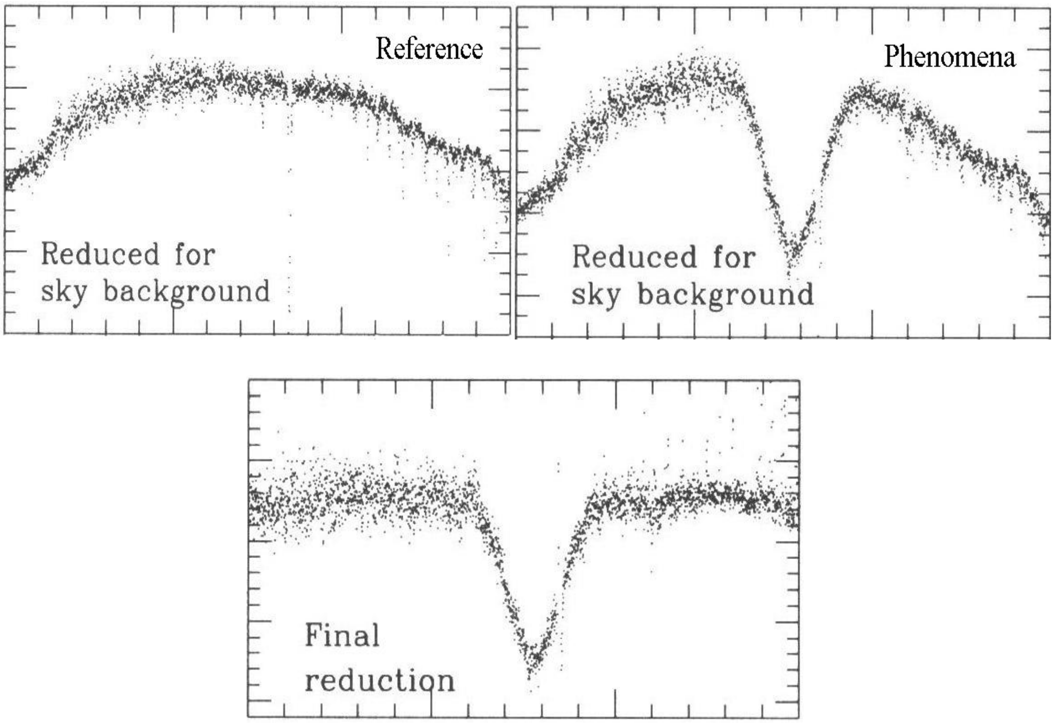

Figure 5: after eliminating the sky background, the signal may be polluted by light clouds. They are eliminated thanks to a reference constant object recorded during the event

From the final light curve, we have to extract the astrometric information, i.e. the relative position of the involved satellites in the phenomenon. For that purpose, we have to model the photometric flux at any time as a function of the relative position of the satellites and also as a function of parameters such a the reflectivity of the surfaces, the phase angle. Figure 6 shows that we have one relationship for every light point allowing to go from the photometry to the astrometry as it was explained in Emelyanov and Gilbert (2006).

Then, each mutual event will provide a relative position of the two involved satellites. In some cases, we can provide only the position angle or the separation between the two satellites due to specific events or to the lack of information.

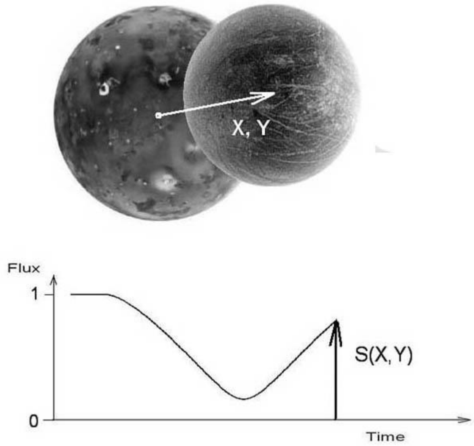

Figure 6: the building of the function S(X,Y), X, Y being the relative astrometric position of the two satellites during an occultation

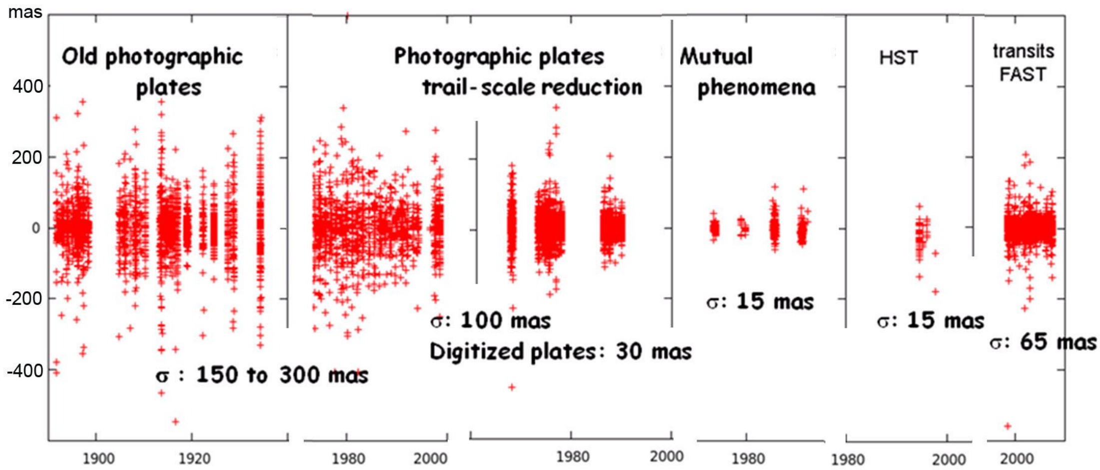

Figure 7

Conclusion

The observation of the mutual events of the natural planetary satellites have brought near 2000 astrometric observations of the satellites spread on 40 years using the opportunity of the event occurrences. Their accuracy is at the level of the best observations such as those by HST. Figure 7 shows the comparison between the difference types of observation.

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Observations of Galilean satellites close approach - astrometric results

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Abstract:
The ground-based astrometry of natural satellites is not an easy task. Usual CCD astrometry delivers positions with errors in the 50 mas to 150 mas range only (Peng et al. 2012, Camargo et al. 2014, Gomes-Junior et al. 2015). But, at least this can be done whenever the satellite is visible. The satellite apparent distances from mutual phenomena, on the other hand, have much smaller errors (Arlot et al. 2014, Dias-Oliveira et al. 2013). However, this method can only be applied during the equinox of the planets.

As an alternative to mutual phenomena, we developed a new, simple method that can provide highly accurate astrometric data for natural satellites at any epoch. We call this method mutual approximations. The method is applied when any two satellites pass close by each other in the apparent sky plane – but without occultations. The fundamental parameter is the central instant t0 of the passage when the typically short apparent distances between the satellites reach a minimum. For determining t0, we model the relative motion between the satellites. For short apparent distances, we find that the variation of the square of the distance can be accurately described at the mas level by a polynomial curve in time of arbitrary power n. We benefit of the typical short distances in mutual approximations (less than 85”) in a similar fashion as for the differential photometry in a small FOV (field of view). The astrometric accuracy resulting from measurements in a very small FOV is known as precision premium, and is responsible for the success of the mutual approximations.

We applied the method for the Galilean moons. All observations were made at the OPD observatory with the 0.6 m Zeiss telescope with a narrow-band filter centered at 889 nm with width of 15 nm which attenuated Jupiter’s scattered light. We obtained central instants for 14 mutual approximations observed in 2014-2015. We determined t0 with an average precision of 3.42 mas (10.43 km). For comparison, we also applied the method for the images before and after 5 occultations in the 2009 (Dias-Oliveira et al. 2013, Arlot et al. 2014) mutual phenomena campaign and for 22 occultations in the 2014-2015 campaign. The comparisons of t0 determined by our method with the results from mutual phenomena show an agreement by less than 1-sigma error in t0, typically less than 10 mas. This places mutual approximations in high stand with mutual phenomena. Due to its simplicity and to the advantages of covering as many approximations as possible at all times, this new method is particularly suitable for observations by small telescopes, especially from the amateur community.

PHEMU 2015 - Brazilian campaign - preliminary results

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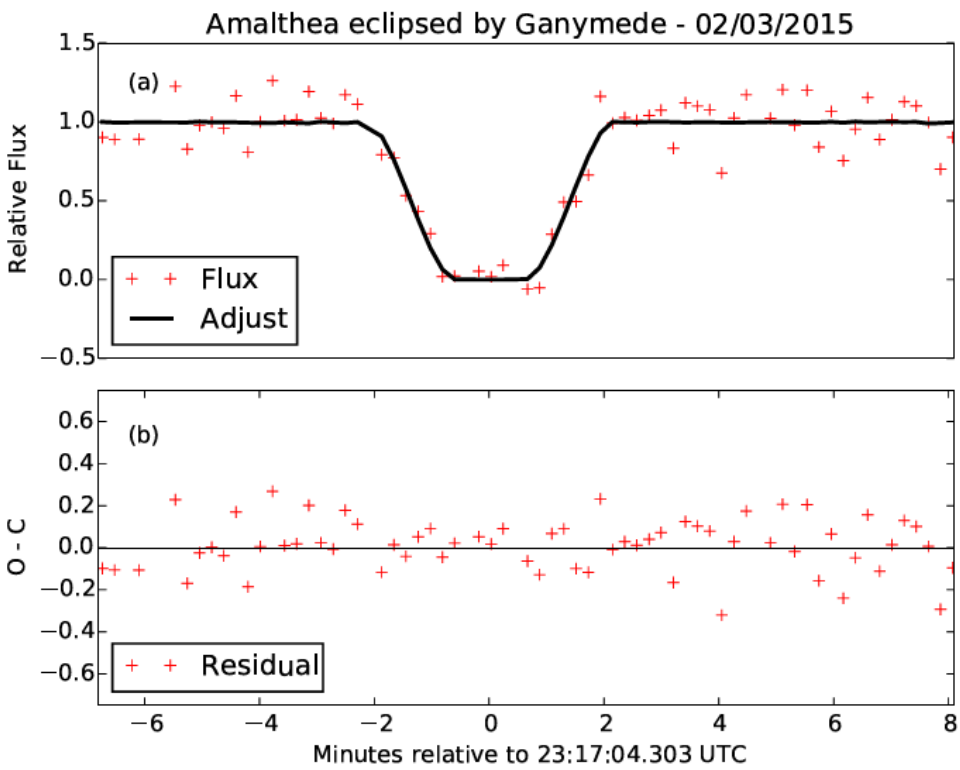
Abstract:

The precise knowledge of the Galilean satellites' position provides important information in the study of very weak disturbing forces, such as the tidal effect. However, the usual CCD astrometry of these bodies is not easy to be done with the necessary accuracy. The usual CCD astrometry of a single satellite position has a typical error of 150 mas, and it can be done at any time that the planet is visible to the observer. The mutual events, on the other hand, have uncertainties below 10 mas (Arlot et al. 2014, Dias-Oliveira et al. 2013), however it can only be done during the equinox of the planet, for Jupiter this occurs every six years. In the years of 2014 and 2015 Jupiter was once again in its equinox. A campaign was organized by our group to observe these mutual phenomena in collaboration with more than six others Brazilian's Institutes. We reduced 47 light curves and determined relative positions with an average precision of 8 *mas*. In all observations we use a narrow band methane filter centered in 889 *nm* with a width of 15 *nm*.

An eclipse of Amalthea by Ganymede was observed and a preliminary light curve is presented below



Astrometry of the main satellites of Uranus

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Introduction

Astrometry of Uranus, as for the outer planets, is difficult. The planet is very bright as compared to the reference stars and also presents phase effects (maximum about 48 mas), so that the positions of the satellites are used to access the position of the central body. In addition, [1] clearly indicates that its orbit improvement in the future relies on reprocessing of historical observations. Since space probes may not be sent to the Uranian system before 2030, ground-based observations are certainly on the spot.

With the release of the astrometry from the GAIA space mission (mid 2016), this reprocessing is expected to highly contribute to more detailed models of the motion of the satellites and, as a consequence, to the ephemeris of Uranus.

Methods and Results

Positions of the main satellites of Uranus, from 18 years of observations, were determined by [2]. A digital coronography procedure [3] was applied to attenuate the effect of the scattered light from the central body. Positions were obtained with the software PRAIA [4], having the

Overall offsets, all satellites.

Satellite	$\Delta\alpha*$ (mas)	$\Delta\delta$	$\sigma_{\alpha}*$ (mas)	σ_{δ}	# positions
Miranda	–22	–8	96	60	584
Ariel	–30	–21	65	40	1710
Umbriel	–28	–27	62	48	1987
Titania	–25	–35	59	48	2588
Oberon	–35	–26	56	42	2928

UCAC4 [5] as reference for astrometry. Tables 1 and 2 summarize the resulting astrometry.

Table 1 Satellite name; mean offsets in right ascension and declination in the sense observation minus ephemeris; standard deviation of the offsets; number of positions used to derive offsets and standard deviations. Ephemeris positions for the satellites are DE432+ura111[1]. The asterisk indicates multiplication by cos(DEC).

[1]http://naif.jpl.nasa.gov/pub/naif/generic_kernels/spk/

Overall residuals with respect to Oberon.

Satellite	[$\Delta\alpha*$] (mas)	[$\Delta\delta$]	$\sigma_{\alpha}*$ (mas)	σ_{δ}	# positions
Miranda	–2	7	69	54	584
Ariel	4	1	31	28	1710
Umbriel	3	–6	33	30	1987
Titania	5	–6	31	30	2588

Table 2 Satellite name; mean difference in the sense satellite offset minus Oberon offset; standard deviations of the offsets; number of positions used to derive offsets and standard deviations.

A comparison between the offsets from Tables 1 and 2 shows that the orbits of the satellites around Uranus are better known than the orbit of Uranus around the Sun. One can expect that the offsets from Table 1, exception made to Miranda, give a correction to the orbit of Uranus. In addition, noting that the standard deviations in Table 2 (reflecting mostly the internal precision of the measurements) are smaller than those in Table 1 (reflecting mostly the reference catalogue), we can conclude that it is thoroughly worthwhile to reprocess the observational data from [2] with a better catalogue.

Comments and conclusions

Gaia will provide unprecedented astrometric accuracy (sub-milliarcsecond to V~20, microarcsecond level to V~15) to more than 1 billion stars, along with photometry. This will also allow a better calibration of image deformation as well as taking color effects into consideration to all reference stars. The larger number of reference stars that will be found in the CCD frames will make results less susceptible to the presence of occasional bad measurements. The virtual absence of catalogue systematic errors should greatly improve the reliability of the uncertainties as well as consistently relate positions that are degrees away one from the other, as it is the case for moving objects when observed for many years.

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The international astrometric network for astrodynamic studies of asteroids: asteroid mass determination and physical properties of PHAs

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Introduction

Using classical differential observations and contemporary catalogs (e.g. UCAC4, PPMXL) one can expect to have random errors in astrometric measurements of 60 mas level even at the small ground-based telescopes if the instrumental systematic errors are decreased [Stone 2000]. These high-accurate astrometric measurements allow us to study orbital peculiarities and, indirectly, the physical properties of the asteroids that result in significant deviations from nominal orbits. The asteroid being a small Solar system body can have complex motion which is gravitationally perturbed by the massive bodies, especially during the close encounters with the planets and other asteroids, and influenced by non-gravitational effects, like Yarkovsky, YORP, Solar pressure, etc. The latter effects depend on the physical and geometric properties of the surfaces and the mass of the individual asteroid, so that the motion of each asteroid is tied inseparably to its physical properties and to the external forces acting on it.

While some physical and spin properties of the asteroids can be determined from the photometric observations, it is expected that the combined orbital and spin modeling of the asteroid motion as well as of some of its physical properties should benefit long term orbit predictions. Potentially hazardous asteroids (PHAs) constitute a special subclass of the near-Earth asteroid (NEA) population that exhibits a higher potential for impacting the Earth compared to other asteroids. Thus, PHAs in particular require accurate orbital modeling.

Masses of asteroids are generally poorly known. Out of the more than 700 000 known asteroids only 154 have their masses determined by dynamical method with different accuracies [Carry 2012]. The Gaia mission is expected to give accurate astrometry of the asteroids, so that the masses of more than 100 asteroids will be either determined or substantially improved [Mouret 2007]. The short life-time of the mission, however, limits the number of the observable close encounters between asteroids. Additional highly-accurate ground-based measurements, especially performed close to the end of the Gaia mission, have the potential to substantially contribute to the missions scientific goals.

Linking astrometric research provides numerous possibilities to both increase the number of measurements and share reduction experience. Sharing expertise is, furthermore, extremely important to achieve high instrumental accuracies at numerous meter-class telescopes. While the best present day astrometric measurements are considered to be limited by catalog uncertainties, future astrometric re-reduction of the past measurements using the Gaia astrometric catalog should be limited by the random errors of the instruments and atmospheric seeing. This assumption is only reasonable if the systematic errors of the instruments are studied and eliminated. Also, the stability of the astrometric properties of ground-based telescopes will have to be investigated properly. This will hopefully result in a regular astrometric calibration of the ground-based telescopes.

Instrumentation & requirements to observations

Apart from the reference stars' individual contributions to the global astrometric measurement error budget, there are timing, «imaging» and reduction errors which can be used to group the sources of other errors. The timing error corresponds to the error in accurate time recording of the observational epochs of observation. So-called «imaging» errors group imaging-related factors, such as the focal distance, image SNR, FWHM, length of trailing, profile overlapping, etc. Reduction errors are usually associated with some simplifications that were assumed in the reduction calculations.

The proposed astrometric research network unites teams of the researchers from different countries, see Tabl. 1.

Table 1. The teams of the astrometric research network

Team Status	Country	IAU Observatory Code	Telescopes
Active	Turkey	A84	D=1m, D=1.5m
Active	Ukraine	585	D=0.7m
Active	Russia	B18	D=0.6m, D=2m
Candidate	France	511	D=1.2m
Candidate	France	586	D=1.05m
Candidate	Israel	97	D=1m
Candidate	Serbia	C89	D=0.6m
Candidate	Austria	562	D=1.5m
Candidate	Bulgaria	71	D=2m
Candidate	China	O44	D=2.4m

In addition to a regular astrometric calibration routine, we consider the following requirements to set a uniform standard for observations of asteroids:

1) signal-to-noise-ratio (SNR) > 20 for asteroid images;
2) limiting the trailing of asteroid images to one FWHM;
3) making observations at zenith distances less than 70 deg.;
4) observations have to be performed in standard photometric bands;

5) monitoring of actual meteorologic parameters with the required accuracies: pressure, 0.3 mm Hg, temperature, 0.1C, relative humidity, 12% [Stone 1996];

6) recording exposure times with an accuracy below 0.1 s;

7) atmospheric extinction measurements, in case photometry is additionally required.

The listed above constraints should allow for a modeling of atmospheric refraction to the accuracy of 50 mas, substantially decreasing imaging errors due to the motion of asteroids, and atmospheric effects, etc.

Test observations & express analysis

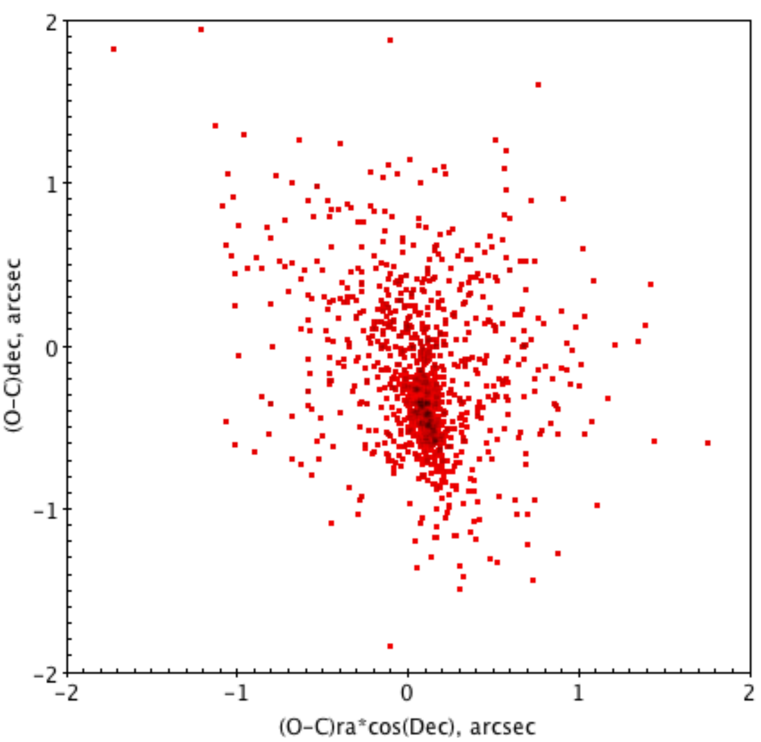
During the summer of 2015 first observations of three numbered PHAs: 66391, 85989 and 163899 were performed at the TUBITAK National Observatory (A84) and the Kyiv Comet Station (585), see Table 2.

Table 2. Statistics of the observations of PHAs made within the astrometric research network in 2015.

PHAs \ IAU Observatory Code	A84, D=1m	585, D=0.7m
66391	155 obs/ 4 nights	
85989	65 obs/ 2 nights	1829 obs/ 5 nights
163899	4 obs/ 1 night	

The preliminary reduction by the Ukrainian team was made for 1666 observations of PHA (85989) at the Kyiv Comet Station (585). The measurements made were reduced with the UCAC4 catalog. For each measurement, residuals *(O-C)* were calculated using DE431 and the orbital solution JPL#288, based on 2385 observations; the RMS of the orbital solution was 0.35″.

Fig. 1. Joint distribution of differences of *(O-C)* for the measurements of PHA (85989) at the Kyiv Comet Station (585).



We found the following basic statistics for *(O-C)* residuals:

$$\overline{(O-C)_\alpha \cos\delta} = +0.07'', \quad \sigma_\alpha \cos\delta = 0.39''$$
$$\overline{(O-C)_\delta} = -0.11'', \qquad \sigma_\delta = 0.49''$$

The visible correlation between *(O-C)* differences given on Fig. 1 above suggests errors in either timing or orbital mean anomaly. The differences between the modes of the distributions in both right ascension and declination are also visible which indicate significant asymmetries of the distributions resulted in non-Gaussian distributions. At present, the probable explanation for the scatter is due to the errors in timing and instrumental systematic errors. We expect a significant improvement of the accuracy after the astrometric calibration routine is applied.

Conclusions

The motion of small bodies of the Solar system is influenced by many forces and effects which depend not only on perturbations from external bodies and the relative distances to them, but also on the physical properties of the studied bodies themselves. Potentially hazardous asteroids can have complex motion which can change due to each close encounter with the Earth, the Moon and other planets. Highly-accurate ground-based observations can contribute to the future determination of asteroid masses through Gaia mission astrometry. As a result, the complex motion of small bodies can be studied by combining astrometric/radar and photometric observations which should give a deeper insight on the accurate future orbital prognosis and evolution.

The astrometric research network described in this contribution results in a group of observatory sites considerably spread in longitude. Among other advantages, the dependency on local weather conditions is severely decreased. Furthermore, we expect that the quality of the astrometric observations will increase due to the sharing of experience between partners.

A high quality of astrometric and/or photometric measurements should be guaranteed by setting quality standards for observations (SNR limits, minimum trailing, monitoring meteorologic parameters with the required accuracy, standard photometry bands, etc.). Furthermore, the astrometric calibration of the field of view and accurate timing are considered a necessity. Efforts such as the one presented in this contribution are required to live up to the new standard in astrometry that is set by the Gaia mission in the near future. The partners of the astrometric network are certain that their collaboration will considerably improve the overall quality of minor planet astrometry and our understanding of the physics of potentially hazardous asteroids.

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Campaign of PHEMU 2014-2015
Participation of Astronomical Society of Tunisia (S.A.T)

Sofien KAMOUN[1], Hanadi ETTROUDI[1]

1. Astronomical Society of Tunisia

Presentation of SAT

- Scientific Tunisian non-profit Association founded in June 1990
- Tunisian Amateur astronomers with several scientific backgrounds(mathematics, physics, biology, medicine, engineering ......)
- An average of 30 events organized per year
- Astronomy courses in secondary education in 1992
- Ephemeris calculation and publication in Arabic since 2005 on the site:www.sat.tn

Used Equipement

- Schmidt Cassegrain telescope-,203mm diameter ,F / D = 10,Altazimuth mount ,motorized with a GPS module
- Camera ZWO 120MM, often equipped with a red filter No. 25A.
- Laptop
- 7Ah rechargeable battery capacity (approximately 2.5 hours of autonomy)
- Photometry with IRIS software
- Estimation of the polynomial of the observed curve by EXCEL

Observation choices

- Some phenomena were excluded :
    - Slow phenomena (battery)
    - Taking place during twilight (holding that the sky brightness reduction was not controlled)
- For close enough phenomena of Jovian disk, Jupiter was out of camera range to limit its effect on the photometric reduction (methane filter was not available)
- All observations were made in the city of Tunis (logistics of SAT).

Difficulties

- Weather conditions between December 2014 and April 2015 were special with increased cloud coverage rates about 220%
- The Noise on the films was high (with short integration time (often 0,02sec) to avoid saturation of satellites ?: sensitive camera)
- We have not opted for the defocusing of the picture because we also wanted to use pictures from these phenomena.
- The clock synchronization with the UTC scale was difficult (GPS accuracy was around 1sec, by comparing it to the speaking clock), average error of 0,3sec
- The photometric reduction required a lot of time (an average of 7 hours and around 20000-40000 measures)

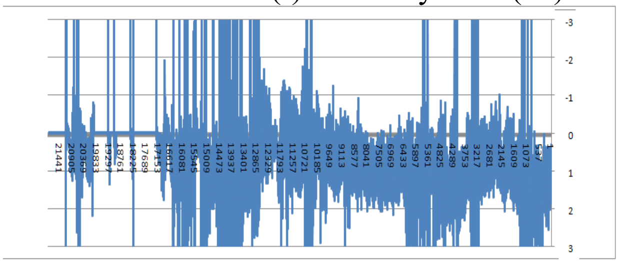
RESULTS:

- Only 9 Phemus were observed
- completely (7)
- partially (2)

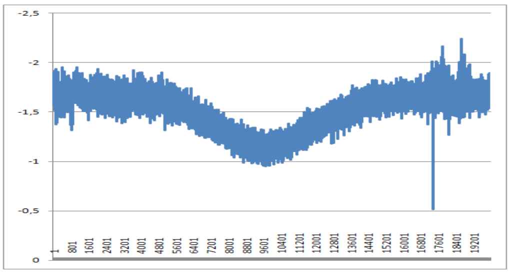
- Often atmospheric turbulence was important with interruption **of a few seconds in measures when there is passage of some clouds.**

1. ***Phemu of Dec 6th 2014: 3O1***

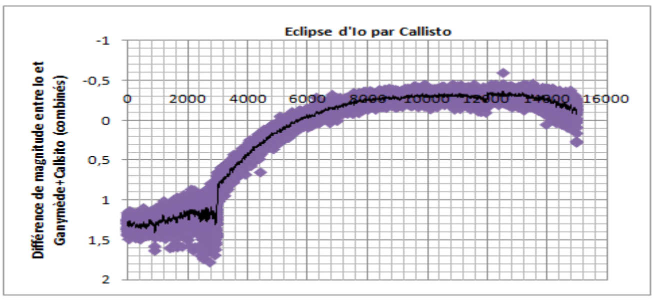
- The worst observation
- Low height relative to the horizon (10-12 °)
- Cloudy (cumulus +++)
- Comparing the combined flow of Io (I) and Ganymède (III) relative to Europe (II).



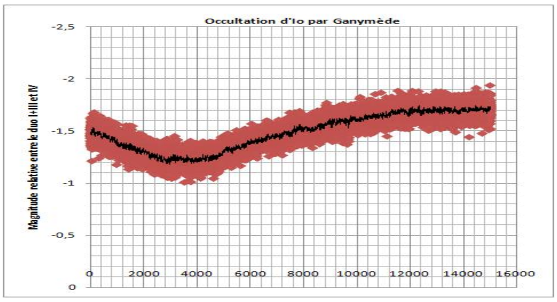
2. ***Phemu of dec 21st 2014 : 3O1***
   - Clear sky, moderate turbulence
   - Comparing the combined flow of I + III vs IV
   - D = 0.45 mag (25A filter)
   - Maximum phenomenon at1h 11mn 25.47 UTC dry (relative spatial uncertainty of 17km between I and III)



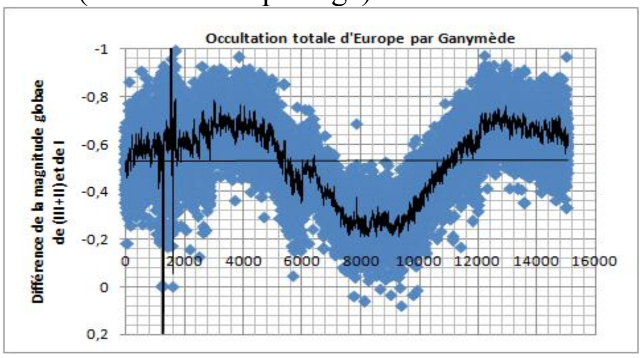
3. ***Phemu of dec 21st 2014 : 4E1***
   - Clear sky, moderate turbulence
   - Partially observed phenomenon (electrical problem in monitoring of the telescope)
   - Comparing the flow of I vs IV
   - Oscillation phenomenon before a steep climb (secondary diffraction du to a brilliant area of Io ????) in 3h25mn 10.05 sec
   - D = 1.72 mag
   - It seems that this rise occurred 57 sec ago before the predicted time (uncertainty about the position of Callisto? Photocenter of Io shifted due to a volcanic eruption?)



4. ***Phemu of dec 21^st^ 2014: 3O1***
    - Clear skies, moderate turbulence
    - Partially observed phenomenon (Bug PC with restart)
    - Comparing the flow of I + III vs IV
    - asymmetric phenomenon
    - Moment of maximum at 4h17mn 21,80sec
    - D = 0.50 mag

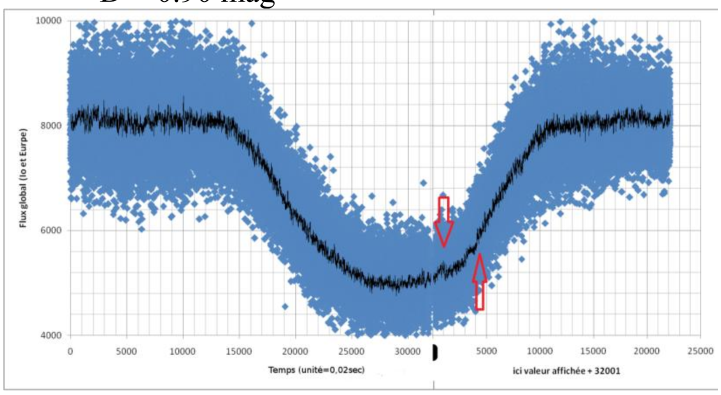


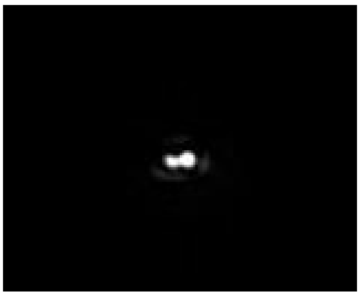
5. ***Phemu Jan 19th 2015 : 3O2***
    - Slightly cloudy sky, slightly turbulent
    - Comparing the combined flow of I + III vs IV
    - D = 0.42 mag (25A filter)
    - Maximum of phenomenon 2h 33mn 50.65 UTC dry (relative spatial uncertainty 3km between II and III)
    - Slit on the curve (du to a cloud passage)



6. ***Phemu Feb 7th 2015 : 2O1 then 2^{E}1***

- Clear skies, moderate turbulence
- Comparing the flow of I + II vs II (before and after the event
- Two overlapping curves (?)
- D = 0.90 mag

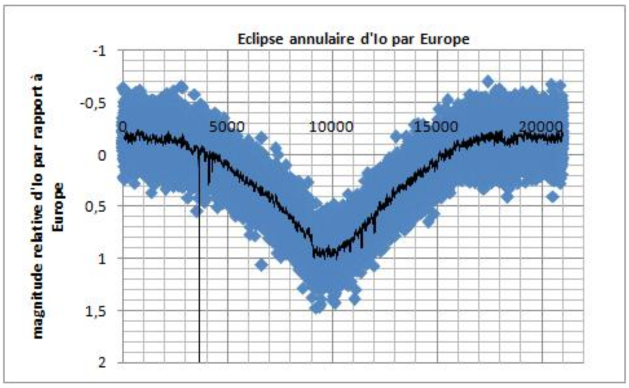




7. ***Phemu March 4th 2015 : 2 E 1***

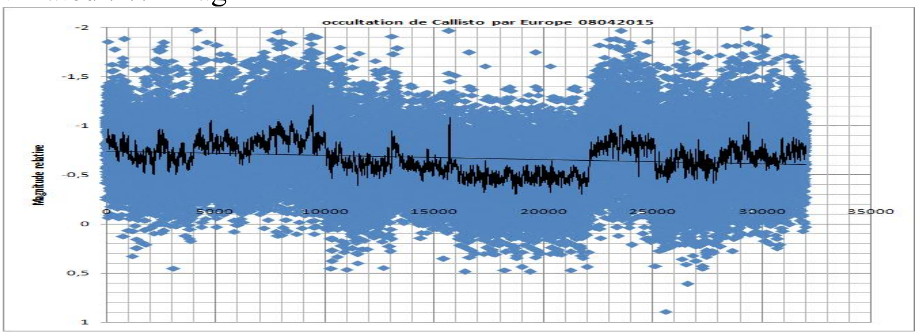
- Mostly cloudy, very turbulent
- Comparing the flow of I vs II

- Abrupt change before the maximum of the phenomenon
- D = 1.14 mag



8. ***Phemu April 8th 2015: 2 O4***

- Mostly cloudy, very turbulent
- Phenomenon observed near the Jovian disk
- Comparing the combined flow of II + IV vs II before and after the event
- D estimated : 0.2 mag



9. ***Phemu of may 8th 2015: 1 E 2:***

- last observed Phemu
- Mostly cloudy with a few passing clouds, medium to very turbulent
- Comparing the flow of I vs II
- asymmetric phenomenon

Improvements to be made to th future compaign PHEMU 2021:

- Best time synchronization
- Timestamp option on the sequences of the capture software
- Using mitigating filters
- Longer integration time
- Using a telescope F/D ratio greater with larger diameter limiting the attenuation of light.
- Automation of the observations

Future Projects of SAT:

In the short and medium term:

- Estimation of the apparent diameter of Aldebaran (Occultations from 2015 to 2017)
- Spectrographic Atlas for bright stars for amateurs
- Spectrographic Atlas for stars near the Sun.
- Estimation of the distance between Mercury and Earth during transit of May 9, 2016.

Long-term

- All-Sky Network in Tunisia
- Astronomical Observatory in south of Tunisia

PHEMU 2015 observational campaign in the Astronomical Institute of the Romanian Academy

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Abstract:

In the following we present CCD photometry of mutual phenomena of the Galilean satellites during the 2014-2015 campaign . The observations were recorded using the Astronomical Institute if the Romanian Academy T0.5m facility, as part of the international PHEMU 2015 campaign. The paper presents data for nine PHEMU events, namely five mutual occultations and four eclipses.

Introduction

The Astronomical Institute of the Romanian Academy participated actively in PHEMU 1991 (Oprescu et al. 1992), 1997 (Vass 1999; Vass & Serbanescu 1999; Dumitrescu et al. 1999) and 2003 (Arlot et al. 2005) campaigns, with the astronomical observatories from Bucharest and Cluj Napoca. This time we present solely observations made from Bucharest Observatory (Long 1^h 44^m 23^s,115 E, Lat 44° 24’ 50” N).

Usually the mutual phenomena between satellites occurs when the observed planetary system of one external planet of our Solar System is in the vicinity of its equinox. The equinox is the imaginary point defined by the intersection between the ecliptic and planet's equator. Thus, observational campaigns were recorded since the '70s for the Galilean satellites of Jupiter, for the Saturnian system of satellites (Arlot et al. 1996), and for the Uranian system of satellites (Arlot et al. 2013, Birlan et al. 2008).

Observations and results

Observations were carried out using a 0.5 meter Cassegrain telescope, installed in 1964, the main instrument of the observatory, in Bucharest. The 0.5 m primary mirror has a 7,500 mm focal lenght and f/D=15. The CCD camera used is a commercial SBIG STL11000M, with a CCD of 4008 x 2745 pixels, and square 9 microns pitch. For a fast image acquisition, a 2x2 pixels binning procedure was used, allowing us a 2004 x 1336 pixel image with a sampling of 0.5 arcsec/pixel.

A typical unfiltered CCD image taken during our PHEMU campaign contains the planet and the satellites. The planet is usually saturated but great care has been taken (by varying exposure time) not to saturate the satellites. The exposure times were between 0.1 and 1 second, depending on sky transparency and the airmass of each observed evennt. Due to the short integration time, the individual images do not present any background star.

Time synchronizing of images were performed using the protocol SNTP embeded into the tool Dimension 4. The configuration was made such as the synchronization was made each second.

Photometry was performed using Maxim DL 5, for every image taken during the observation session. The aperture used for the photometric tool had a diameter 3 times the FWHM for eclipses. In the case of an occultation the aperture of photometric data had a diameter which included both satellites. Table 1 presents the results of our observational campaign.

Table 1: Nine mutual events observed using T0.5m in Bucharest. Satellites involved into the phenomenon(occ = occultation, ecl=eclipse, J1=Io, J2=Europe, J3=Ganymede, J4=Callisto), the beginning and the end of the observation interval, the exposure time, measured and the reference satellites, as well as the altitude of the observations are presented.

No	PHEMU	UT Start YYYY-MM-DDThh:mm:ss	UT End YYYY-MM-DDThh:mm:ss	Exp. time [s]	Measured satellite	Reference Satellite	Jupiter Altitude [°]
1	J3 occ J1	2014-12-22T01:07:06.000	2014-12-22T02:44:50.000	0.5	J3 and J1	J2	60
2	J3 ecl J1	2015-02-02T18:15:44.414	2015-02-02T18:40:04.803	0.5	J3 and J1	J2	29
3	J3 occ J1	2015-02-02T18:15:44.414	2015-02-02T18:40:04.803	0.5	J3 and J1	J2	29
4	J3 occ J1	2015-02-16T23:03:23.000	2015-02-16T23:37:31.000	0.1	J3 and J1	J2	56
5	J3 ecl J1	2015-02-16T23:38:09.000	2015-02-17T00:03:09.000	0.1	J1	J2	52
6	J4 occ J2	2015-02-26T19:52:54.000	2015-02-26T20:41:47.000	0.1	J4 and J2	J3	62
7	J1 occ J2	2015-02-26T22:14:12.000	2015-02-26T22:27:06.000	0.1	J1 and J2	J3	58
8	J4 ecl J2	2015-02-26T22:40:35.000	2015-02-26T22:59:40.000	0.1	J2	J3	55
9	J1ecl J2	2015-03-23T18:40:58.000	2015-03-23T18:53:07.000	0.1	J2	J3	65

Few of these observations recorded in Bucharest are presented in Figure 1.

Conclusion

We have observed nine PHEMU event namely five occultations and four eclipses. Among them, four phenomena are involving the satellites J3 and J1, one involving J3 and J2, two are involving J1 and J2 and one involving J4 and J2.

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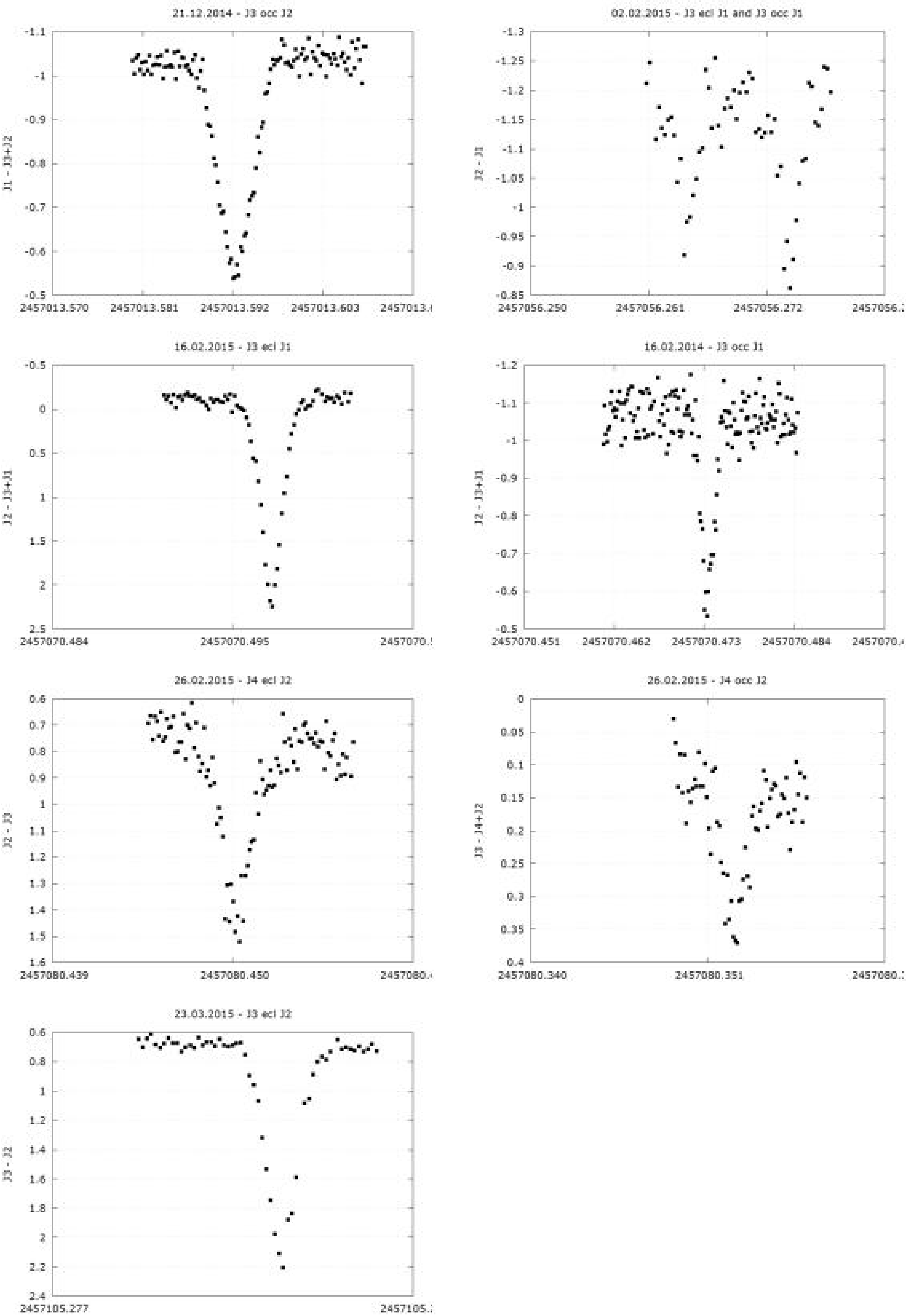

Figure 1. Few examples of mutual phenomena observed using T0.5m form Bucharest, Astronomical Institute of the Romanian Academy.

Visual observations of mutual eclipses of Galileian satellites with small telescopes under city lights

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Abstract

The nodes of the orbits of the satellites of Jupiter each 6 years are aligned with the axis Sun-Jupiter and mutual eclipses and occultations (PHEMU) occur in series, and their observations help to improve the ephemerides, influenced -on the long period- by many bodies interactions, relativistic corrections and internal mass distributions. The visual observations made in Rome with tabletop telescopes of Ganymede eclipsed on 20 and 27 Feb and Europa eclipsed on 26 February and 8 May 2015 are presented with their 10s accuracies in time, and 0.1 magnitudes in photometry, with a scale "brighter than", "equal to", "dimmer than" relative to uneclipsed satellites. The visual appearance of these eclipses introduce potentially many students to science data production for solar system astrometry. The paper is structured in 1. Introduction to the mutual phenomena as geometrical consequence of orbital momentum conservations. 2. Visual observations with 3" telescopes and lack of scotopic vision under city lights. 3. The results of 20, 26 and 27 Feb and 8 May eclipses with relative photometry 4. The determination of the accuracies on the time of center of the eclipse and on its magnitude with the Argelander method. 5. Discussion and conclusions on the utility of visual data for science and didactic purposes.

1. Introduction: the mutual eclipses of Jupiter's satellites

When the line of sight Sun-Jupiter includes the nodes of the equatorial plane of Jupiter and of the orbits of its satellites, the mutual phenomena occur: it happens each 6 years and their observations contribute to the definition of orbital parameters (the theory of the grand satellites of Jupiter, the internal distribution of their masses [1]), and to the physical parameters of the satellites, like the albedo and the transient atmosphere (e.g. The ejecta from the volcanoes of Io) when present [2, 3]. The eclipses between satellites are better observable than the superpositions (occultations) between them; the angular resolution of the telescope does not allow a significant accuracy in the determination of the superposition, while an eclipse with Jupiter not in opposition is well visible even with small telescopes as it is shown in the following.

2. Visual observations with small telescopes under city lights

A tabletop telescope of 3" is larger than the first galileian telescope [4] used in the discovery of the Jupiter's satellites. But the conditions of the urban skies are nowadays much worse than in 1610 and the scotopic vision of our eyes cannot often take place. This reduces the limiting magnitude for visual observations at these telescopes at $m_v=7\div7.5$, not only because the sky is bright, but also because the eye uses only the cones as detectors. So a mutual eclipse between the satellites of Jupiter can easily be a temporary disparition of the eclipsed one if observed with a small telescope. The eclipsed satellite can experience a magnitude drop from 0.1 mag to some magnitudes (about 1 in the case of Europa's eclipse of 8 May 2015). For the smaller magnitude drops the method of Argelander can take advantage of the uneclipsed satellites: their visual magnitudes when Jupiter is at mean opposition are **I**, Io, 4.8; **II**, Europa, 5.2; **III**, Ganymede, 4.5; and **IV**, Callisto, 5.5 [5]. For larger magnitudes drops the arbitrary scale A>B, A=B and A<B is better than trying to evaluate the drop, due to the rapidity of the phenomenon (usually about 5 minutes) and the difficulty to find opportune reference stars.

3. Observations from Rome

The events and their ephemerides were fournished by IOTA/ES [6] section and BAA [7] through the Planoccult mailing list. The observation of superpositions and eclipses in 2015 has been made with 3 different telescopes: a refractor of 3" at 30x, a Newton of 3" at 20x – 58x and a Schmidt-Cassegrain of 8" at 81x, all without tracking motor. The superpositions have been observed: they do not issue a sharp timing. Only with the larger telescope of 8" the difference in magnitude between

the satellites was evident, either because of the larger limiting magnitude, either due to the longer focal lenght which determines a large separation between the satellites and Jupiter.
The eclipses observed have been on 20, 26, 27 february 2015 and 8 may 2015 two of Ganymede, the brightest, and two of Europa, the third one in order of luminosity.
On 20 February Ganymede was closer to Jupiter than Io and its brightness changed as in the table:

Observations 20 February 2015	IMCCE ephemerides	BAA ephemerides
00:34:55 UT G>I 00:36:35 UT G=I 00:38:00 UT G<I 00:39:00 UT G<I 00:40:00 UT G<1 00:41:54 UT G=I 00:42:30 UT G>I 00:43:00 UT G>I 00:43:25 UT G>I	Begin : 00h 34min 55s UT End : 00h 43min 25s UT center of the eclipse 00h 38 min 10 s Duration: 8 min 30 s Delta mag = 0.835 mag	Begin 00h 36 min 45 s End 00h 41 min 43 s center of the eclipse 00h 39 min 14 s Total duration: 4 min 58 s Duration of the annular phase: 2 m 44 s Delta mag = 0.62 mag

Ganymede went dimmer than Io for 2 minutes, and the center of the eclipse estimated is around 00:39:05 UT+/-10s, in better agreement with BAA ephemerides, as well as the duration of the phase from G<I to G=I was 2 min 54 s.

On 26 of February the first satellite next to Jupiter was Europa and it was eclipsed by Callisto; observed with the SC 8". Ganymedes shined the brighter and external. Callisto appeared equal to Io.

Observations 26 February 2015	IMCCE ephemerides	BAA ephemerides
22:46:50 UT E starts to dim 22:48:19 E is dim 22:49:50 E is dimmest 22:51:57 E is recovering 22:52:21 E as the beginning	Not available	Not available

The eclipse at maximum was around 22:49:50 UT.

On 27 of February Io eclipses Ganymedes: observations with Refractor 3" at 30x.

Observations 27 February 2015	IMCCE ephemerides	BAA ephemerides
03:32:58 UT G no brightest... 03:34:00-10 UT G<I 03:34:40 UT G>=C 03:34:56 G almost = Io 03:34:15 G= Io; G > Callisto 03:35:20-30 G<Io; G= Callisto 03:36:20-45 G<Io; G=C 03:37:20 G>C; G<I 03:38:00-48 G=I 03:39:45-55 G>Io start brighter 03:40:10 G>Io more bright	Begin : 03h 31min s UT End : 03h 40min 40s UT center of the eclipse 00h 35 min 50 s Duration: 8 min 30 s Delta mag = 0. mag	Begin 03h 33 min 06 s End 03h 38 min 54 s center of the eclipse 03h 36 min 00 s Total duration: 5 min 48 s Duration of the annular phase: 3 m 14 s Delta mag = 0.69 mag

The eclipses was shallower than 20 February's one, the center was observed around 03:36:00+/-10s. Europa appeared to be the fainter object, but it was closer to Jupiter. The luminosities of Io and Ganymedes were correctly evaluated brighter than Europa and Callisto with the 3" telescopes.

On May 8 Europa was eclipsed by Io and observed from indoor with a Newton 3" f=350 mm at 58x.

Observations 8 May 2015	IMCCE ephemerides	BAA ephemerides
21:21:20 UT E is fainter	Begin : 21h 21min 26s UT	Begin 21h 22 min 35 s UT

21:22:11 E is more faint 21:23:14 E is much more faint 21:23:45 E almost disappeared 21:24:24 E at deepest 21:24:40 E starts to recover 21:25:48 E brightening 21:26:18 E brightness restored	End : 21h 26min 53s UT center of the eclipse 21h 24 min 10 s Duration: 5 min 27 s Delta mag = 0.57 mag	End 21h 25 min 39 s UT center of the eclipse 21h 24 min 09 s UT Total duration: 3 min 04 s Duration of the annular phase: 0 m 56 s Delta mag = 0.88 mag

Europa already appeared as the faintest satellite, but in the maximum eclipse it almost disappeared at 21:24:20 UT +/-10s a timing in agreement with both ephemerides. A larger Delta Mag than the ephemerides is estimated by the observations because Europa disappeared at the center eclipse [8].

4. Accuracy of timing and photometry

The timing has been taken using UTC synchronized audio-records [8], the same method used for occultations [9] or solar eclipses. The phrases are timed to the nearest second, but since the records do not contain sharp events the general accuracy is whitin ±15÷20 s. The average between symmetrical events (like the first G=I and the second G=I) help to find the center of the eclipse; with two independent determinations of the center of the eclipse we have estimated the error on its determination of ±10 s.

The photometry of the satellites of Jupiter is within ±0.1 magnitudes, since the difference in luminosity between Ganymede, Io, Europa and Callisto has been always noticed, even when their order is not known before. The data in the tables have not been converted into magnitudes, because in the case of deep eclipses the complete disappearance of the eclipsed satellite made impossible the estimate. The method of Argelander can be used only with large magnification >50x and large opening >3"for eclipses of Ganymede, which experience gradual dimmings down to the luminosity of Callistus. For Europa at the minimum of the eclipse its luminosity was much fainter than the others, making unaccurate the estimate. For the eclipses of the satellite Io the Argelander method could work too, since other two satellites are dimmer than it.

5. Discussion and conclusions

Among the mutual events between Galileian satellites, with small telescopes, no tracking and urban city lights, the eclipses give the possibility to determine visually the center of the eclipse within ±10 seconds and to check the predicted amount of Delta Magnitudes within 0.1 mag.

The ephemerides published by IOTA/ES (IMCCE) and BAA have been used as comparison to our observations: in the 8 May eclipse of Europa the Delta Magnitude seem to be larger than IMCCE and BAA, as well as the center of the 20 February eclipse of Ganymede was more in agreement with BAA ephemerides, within the errorbars evaluated. A video of such events would allow accuracies down to ±0.1 s, but our visual observations can be successfully made with simple instruments by young students and they are interesting introductory experiences for astrometry in the solar system, included the use of UTC synchronized audio-records [8].

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ABSTRACT

The TimeBox is a device designed to date a PC/Server time and digital video recordings with the Coordinated Universal Time (UTC). The TimeBox was primarily designed for precise timing of astronomic phenomena, but it can be used for other applications that require precise timing with an absolute time reference (UTC).

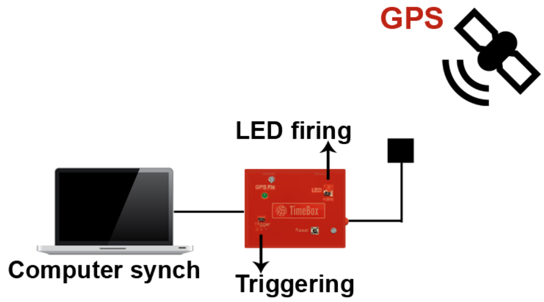
INTRODUCTION

Timing of astronomical occultations and other astronomical phenomena need to be done in an absolute time scale in order to pull and compare recordings done by different observers around the world. The timescale chosen is the Coordinated Universal Time (UTC) that is the primary time standard regulating clocks and time (McCarthy *et al.* 2009). Stellar occultation is a proven method used to determine the size, form and position of asteroids, and the topology and obits of satellites as well (Trahan *et al.* 2014); also stellar occultations are used to improve astrometry of star positions, to produce precise TNOs ephemeris (Assafin *et al.* 2012), to provide information of the atmospheric pressure of TNOs and planets (Dias-Oliveira *et al.* 2015), and recently, to discover the presence of rings on minor planets of the outer solar system (Braga-Ribas *et al.* 2014).

Scientist and amateurs use a timing system that stamps the UTC time in every frame of an analogic video recording (IOTA-VTI and Watec cameras). This system was validated by the international occultation timing community (IOTA) for years and used by hundreds of observers for more than ten years.

Almost all current video recorders devices are digital, including those possessing the most sensitive and low noise CCD, EMCCD and CMOS image sensors. CMOS image sensors are digital as the sensor produces a digital output compared to the analogic one produced by the CCD sensors. Last generation CMOS image sensors possess sensitivity and noise levels comparable to those of the best CCD sensors, without its major inconveniences (low frame rate and high cost of production). The evolution of CMOS image sensor capabilities will likely replace the CCD sensors thus favoring the development of highly sensitive/low noise digital video devices in the near future.

Up to now, no portative and precise solution was proposed for UTC timing using digital video cameras. The TimeBox was designed in order to allow precise timing of astronomical phenomena using digital video devices.



SUMMARY

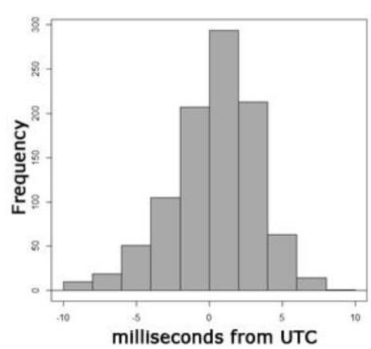
The TimeBox recovers the UTC time from GPS satellites and synchronize your measures/PC in three different ways; these modes are controlled with a fully graphical interphase using the TimeBox proprietary software:

1. **LED firing** (<1µSec UTC). Use the timeBOX LED firing mode to insert the UTC time on any video recording. This mode allows inserting the UTC time directly in the video stream by firing a LED at each UTC-second. The TimeBox possess a BNC port to allow the user to connect their cable with a LED and a resistor easing the time insertion at any step of the recording video chain.

   The TimeBox LED firing is very precise (<1µSec, measured at the SYRTE CNRS, Observatoire de Paris Atomic Clock), the length of the LED pulse can be controlled (1-100mSec), you can disable the firing of the 59th second of each minute to facilitate the data extraction and analysis, and in the same time this mode allows the precise synchronization of the internal PC clock.

2. **Computer Synchronization** (±2mSec UTC). This mode allows the synchronization of the internal PC-clock on Windows-based systems (Windows XP SP3 and later) with the UTC time. The TimeBox Computer Synchronization mode allows to precisely timing any astronomical phenomena by dating the acquired frames with the UTC-synchronized PC time.

   Technical control: TimeBox (Computer Mode). Software: Genika Astro / Trigger AiryLab (http://www.airylab.com). Camera: Basler 640-100gm at 200 fps and 50uSec exposition at 200 fps (Gigabit Ethernet). Description: The PC time was continuously synchronized (UTC time). Genika saved and dated the firing of each PPS LED. The difference between the PC-time and the start of the PPS LED pulse was measured (n= 977, milliseconds) and the results analyzed using R Statistical Software.



Values inside 95% Interval of Confidence (2xSTD): -4 ≥ 0.8485 ≤ 5

Camera Jitter at 200 fps = 5 milliseconds

The TimeBox Computer Synchronization mode is precise (± 2 milliseconds UTC) as the serial latency and transmission delay between the TimeBox and the computer are estimated and corrected by a proprietary algorithm included in the TimeBox Software. Also, the TimeBox Computer Synchronization mode can be used to measure the PC time drift compared to the UTC time by creating a log containing the PC-time and the received UTC-time. The TimeBox Computer Synchronization mode can work either in One-click (one time) synchronization of the PC clock or continuously synchronizing your PC clock.

3. **Trigger/Intervalometer** (< 10 µSec UTC, *Optional* for TimeBox BASIC with Trigger Plus, and TimeBox PRO). Use the timeBOX to trigger UTC-phased frames of selected CCD/CMOS cameras possessing an external I/O port for trigger firing. Using this mode the TimeBox is able to trigger the camera directly by emitting a series of logic square UTC-timed pulses (6v/9v/11v) through a BNC port at different frequencies (0.1-1 Hz and 7-60 Hz). In this mode, the TimeBox is also able to synchronize the internal PC-clock to ease data reduction and produces a log containing the list and precise UTC-time of each pulse up to the microsecond.

Benchtest: Watec 910HX/GPS inserter (analogic) vs Raptor KITE EMCCD/Genika/TimeBox Trigger mode (digital).

Results: The general average is +0.2 millisecond. The extremes are -42 ms (i4) and 32 ms (e4), the order of the duration of a video image.

No systematic difference between the two time frames is detected (up to 6msec at 95% confidence).

Jean Lecacheux (LESIA, Observatoire de Paris) and François Colas (IMCCE, Observatoire de Paris).

La Blaque FRANCE, 10 juin 2015.

Evénement 1ère série		tK-tW (ms)	Evénement 2ème série		tK-tW (ms)
i1	:	+3	I1	:	+7
e1	:	-2	E1	:	+4
i2	:	[-27]	I2	:	+6
e2	:	+8	E2	:	+4
i3	:	-10	I3	:	-27
e3	:	-14	E3	:	+7
i4	:	+32	I4	:	-7
e4	:	-42	E4	:	+15
i5	:	+23	I5	:	+7
e5	:	+5	E5	:	+14
			I6	:	+11
			E6	:	+13
			I7	:	+6
			E7	:	-22
			I8	:	-39
			E8	:	+14
			I9	:	-6
			E9	:	-5
			I10	:	-16
			E10	:	+9
			I11	:	-8
			E11	:	+25
			I12	:	-10
			E12	:	0

Results: Artificial occultation Benchmark test for WATEC/VTI vs. TimeBox/Genika/Raptor

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High-resolution imaging of the mutual occultations and eclipses of Jupiter moons during the winter 2014/2015

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1. Introduction

The planet Jupiter is among the favourites of many amateur astronomers. Due to its large diameter even with a small telescopes many details can be detected on its surface such as the dark North and South Equatorial Belts and the Great Red Spot. In addition, it is interesting to observe the perpetual dance of the four large satellites Io, Europa, Ganymede and Callisto. Also exciting are the transits of the satellites and their shadows over the globe of Jupiter. These phenomena make the Jovian system one of the most fascinating objects in the Solar System. But that's not all. Jupiter rotates around the Sun in nearly 12 years. Every 5.93 years, there occur phenomena of particular interest, viz. the occultations and eclipses of the big Jovian satellites by each other . These phenomena only occur when the Earth and the Sun pass through the equatorial plane of Jupiter and its moons. This was the case in the period 2014/2015 when the Jovicentric declination of the Sun and the Earth was less than plus or minus 1 degree. The occultations and eclipses taking place during one of the passages through the Jovian equatorial plane is rather unfavourable for us living in The Netherlands, because then Jupiter is low above the horizon in the constellation Capricorn and Sagitarius. At the other passage from our position Jupiter rises high in the sky and moves through Leo and Cancer. That was the case in the winter period of 2014/2015

2. Procedures

For the observation of the mutual phenomena in the period 2014/2015 we decided to combine our results. Willem Kivits used a C14 and has a 20 inch Newtonian telescope, whereas John Sussenbach used a C14 Schmidt-Cassegrain telescope. To give more insight into our approach a detailed description of the procedures for processing the images is given.

As for the cameras for planetary photography, we have used a QHY5LII camera as well as a DMK618mono camera. To record satellite phenomena we have used 600 nm (red) and a 685 nm (infrared) pass filters.

For processing of the recorded movies we have employed the programs Autostackert 2! (http://www.autostakkert.com author Emil Kraaikamp) and Registax 6.1 (http://www.astronomie.be/registax author Cor Berrevoets). When processing the AVI or SER files the best results are obtained when the objects are well centered. Therefore, the recorded movies were first processed using the PIPP program (https://sites.google.com/site/astropipp). This program selects the best images, centers the object and creates a new AVI of well-centered images. These new AVI's make it easier for the stacking software (Autostackkert2 or Registax 6.1) to select and position the best frames.

In order to improve the quality of the images various options exist. In general, the exposure time was 1 minute and the frames in each AVI were processed as described above. When a mutual phenomenon took 10 minutes, 10 AVI's were collected leading to10 individual final results. The quality of these images can be improved by combining each final image with the two flanking end plates. In this way the average of final images 1,2 and 3 is obtained, then 2, 3 and 4, etc .. This procedure can lead to a considerable improvement, but it is only possible if the images do not differ too much from each other in timing.

Another method to improve the recording of surface details during occultations and eclipses of Jupiter moons is as follows. Because the moons do not show rotation during recording, one can capture tens of thousands of frames shortly before or after an occultation or eclipse. Processing of these frames results in a very detailed image. These "master frames" are then carefully combined with the pictures of the eclipse or occultation. It is a laborious process, but the end result is often worthwhile (Fig. 1).

Figure 1 Examples of the selection of the best frames. The bottom row shows examples of single raw frames. Note the presence of a considerable noise. After a slight blur procedure we hand selected the best figurines. (Top left).. Next, the top 100 images are combined (top middle). Finally, for this image 35 or 50% may be combined with a master frame (top right).

3. **Results**

Occultations

The first category of mutual events that can be distinguished are the mutual occultations of the Galilean satellites. A typical example is the partial occultation of Io by Europa on 7 January 2015.

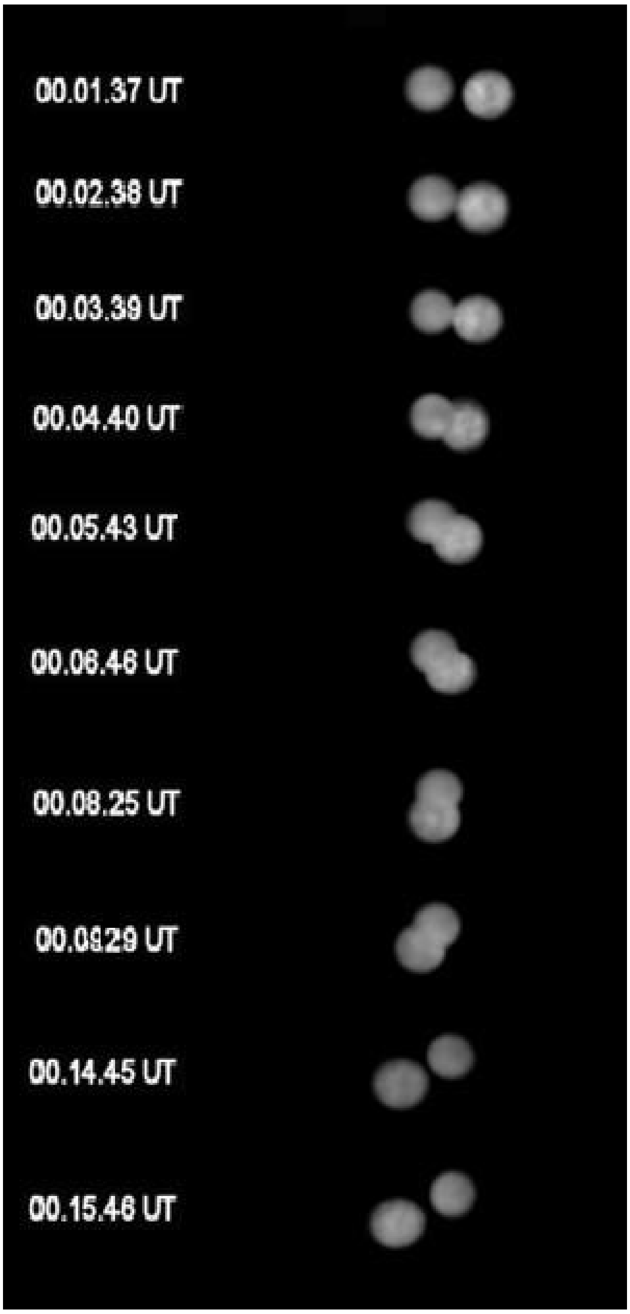

Figure 2: Partial occultation of Io by Europa 7 January 2015 .

On 7 January 7 2015 a partial occultation of Io by Europa took place. The weather conditions were very unfavourable. The seeing was very mediocre, but the most disturbing were the clouds during the occultation. The first 7 minutes were undisturbed, but after that the satellites were only seen occasionally, due to scattered patches of clouds. This had a deteriorating effect on the quality of the images. A photo report of this occultation is shown in Fig. 2. The images were obtained by stacking the best 100 frames and followed by processing with Photoshop. The noise level was reduced and subsequently the contrast was optimized. Master frames were obtained by processing the AVI's from the first 7 minutes of the observation session, when the occultation was not yet started. The raw stacks of the occultation were mixed for 35% with these master frames. The master frames of Io and Europe show some distinct details. They very well demonstrate that with the current telescopes and cameras rather detailed images can be obtained even from the Netherlands.

Simultaneous occultations and eclipses

An example of such an event took place on 12 February 2015 when Io eclipsed and occulted Ganymede. The opposition of Jupiter in 2015 took place on 6 February 19.00 UT. In the period around the opposition date it is possible that an occultation and an eclipse take place in the same night.. A good example of such an event is shown in Fig.3. It started with a partial occultation of Ganymede by Io. At 21.25 UT the maximal occultation took place.

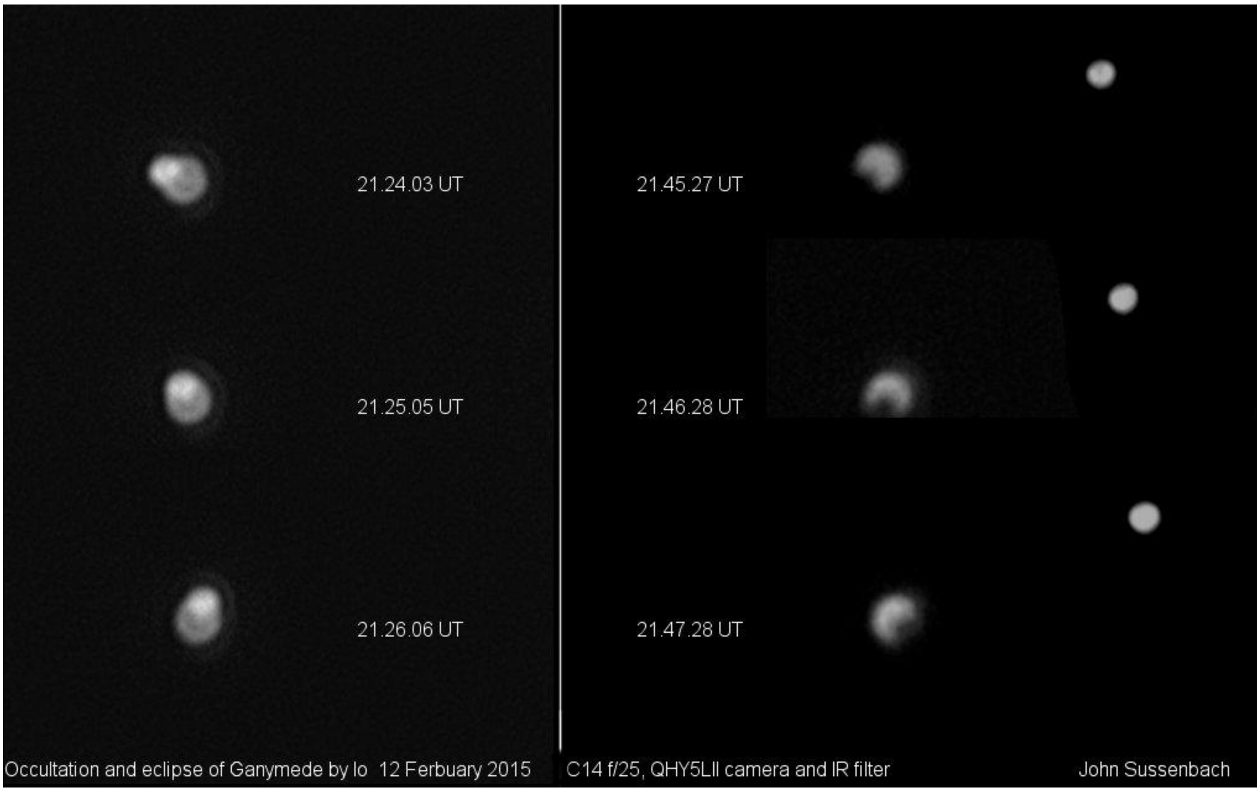

Figure 3: Io occults and eclipses Ganymede 12 February 2015

Interestingly, about 15 min after the end of the occultation the shadow of Io reached Ganymede.. The maximum eclipse was reached at 21. 46.28 UT. Note that the shadow shows an umbra as well as a penumbra.

Eclipses

A good example of such a type of events occurred on 25 November 2015, when a partial eclipse of Callisto by Ganymede took place. SER movies were recorded using exposure times of 1 minute at a frame rate of about 35 frames per second. The resulting files were processed as previously described. The 100 best frames were stacked and slightly sharpened with Photoshop CS. Subsequently, the contrast was increased.

In the Procedures section on optimization of images we have already described how using master frames the quality of the final images can be improved . For each time point the best 100 hand selected frames were stacked. Subsequently, the images were combined with 50% of a master frame. The final image is shown in Fig. 4. It shows clearly that the use of the master frames has very little effect on the pattern of the details, but the signal/noise ratio has improved considerably. Interestingly, in this series the expected penumbra is hardly noticeable.. Apparently, it is so dark in intensity, that under the conditions the penumbra can hardly be distinguished from the umbra. There are a remarkable number of details visible on the small disk of Callisto, which is only about 1.5" in size. The frames show a good reproducibility of the different details. This event was chosen to demonstrate the virtues of hand selection.

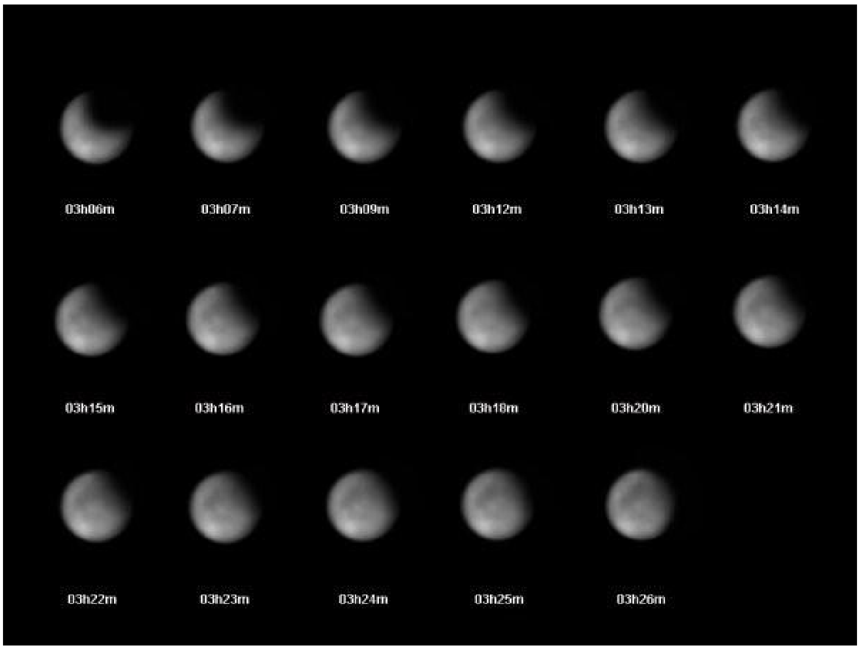

Figure 4: Progress of the eclipse using 50% master frames.
Date November 25, 2014 (JS and WK)

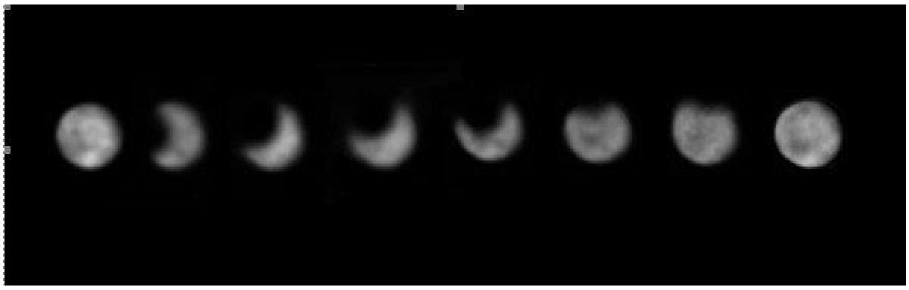

Figure 5: Partial eclipse of Ganymede by Callisto on November 25, 2014 (WK))

Another representation of the eclipse of November 25, 2014 is shown in Fig.5. Willem started his recording a bit earlier so that a larger portion of the eclipse was recorded. The orientation is different in Fig. 4 because of azimuthal mount used by WK. Note the bright spot (Osiris region) to the South Pole; that is here located at 6 o'çlock, whereas in Fig 4 it is located at about 8 o'clock.

Discussion

Imaging en processing of mutual events

The examples presented in this paper clearly indicate that with middle-sized telescopes mutual events in the Jovian system can be recorded quite well with high resolution. It is clear that the weather conditions play a paramount role in observing details on the Jovian moons. The simultaneous recording with more than one telescopes, as described in this article, leads to better results.

It is our experience that automatic processing of images of the Jovian satellites using the programs Registax 6.1 or Autostackert2! is often not satisfactory and will certainly not yield the utmost of the recordings. Due to the small size of the objects these programs have problems discriminating between background noise and the structural information of the satellites involved. Therefore proper selection based on image quality is often not satisfactory with these programs and yields mediocre final results, which leads to a poor final image In this communication we demonstrate that hand selection leads eventually to a more detailed and sharper image. It is of course a tedious and time–consuming procedure, but it is certainly worth the effort.

Structural details on Jovian satellites

We have demonstrated that with medium-sized telescopes, several detailed surface features can be visualized, in particular on Ganymede and Io. It is interesting to compare albedo differences in our images and the maps provided by NASA/JPL. Using the WinJUPOS program we produced an animation of Ganymede on 1 January 2015 (Fig 6). Several similarities can be detected, although there are also differences. It should be realized that the JPL image is based on a mosaic of partial images and that the two images were obtained at different wave lengths. We estimate that details are visible in the order of 0.1 arcsecond.

Figure 6. Details on Ganymede on 1 January 2015 (left). A WinJUPOS simulation using images of the Solar System Simulator is shown at the right side.

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