

THE NAROO DIGITIZATION CENTER

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ABSTRACT. The study of transient events or motion of stars and solar system bodies uses old data in order to modelize the evolution of the studied object. In all models strongly depending on time, data from the past are of great interest. Unfortunately, old data are, most of time, of a poor accuracy, the references used at the time of the reduction being not confident. The arrival of the new reference star Gaia was the opportunity of a new reduction of old data allowing observation in the past with today accuracy. However, a new reduction means that we have digitized images of the old observations which were made for most of them on photographic plates from 1890 to 1980. For such a purpose, we started the NAROO project joining digitization and reduction of old plates. A new sub-micrometric scanner has been built in Meudon observatory and we are now starting the scientific program.

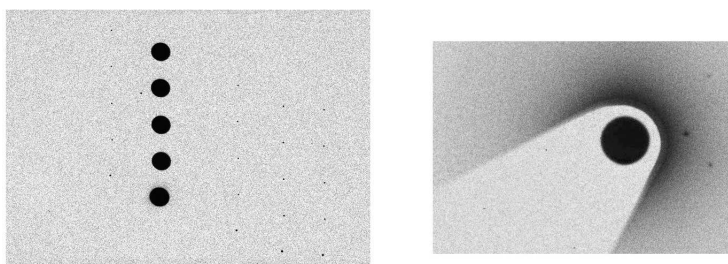


Figure 1: Examples of plates for Solar system dynamics studies: left, the Jupiter system (5 exposures) showing the bright planet and the faint satellites; right, the planet Mars and its two faint satellites Phobos and Deimos. The bright light from Mars is decreased thanks to a metallic filter.

1. PRESENTATION OF THE PROJECT

The old observations of the bodies of the solar system are of great interest: they make possible to better evaluate the dynamics and physical evolution of these bodies. To build the dynamical models of the solar system, observations are necessary to adjust the constants of the motions. For this purpose, observation sampling must be sufficiently extensive to determine the small effects that accumulate over time but are difficult to detect on close observations. Thus, the astrometric observations published at the end of the nineteenth century are still useful and used for the current models. Unfortunately, these old observations did not benefit from accurate star catalogs for their reduction, and this biased these data. It appeared to us that a new reduction with recent catalogs could improve their accuracy. For this, it was necessary to find the original observation as the photographic plates. A new measurement based on a sub-micrometric digitization of these plates and an advanced image processing could then be used in a new reduction using the latest catalogs of reference stars. The GAIA catalog whose proper motions will allow to go up to the late nineteenth century justified our approach allowing to observe in the past with today accuracy. A work of inventory and backup of the available plates, of selection of the best old observations and

the building of a sub-micrometric scanner for the digitization of the photographic plates allowed our project to start. Besides the study of astrometry and dynamics in the solar system, our digitizing device may be useful for other purposes such as photometry, spectroscopy of transient objects the evolution of which with time being essential to understand. These works will require specific calibrations but will benefit from photographic plates allowing to extend their database towards past.

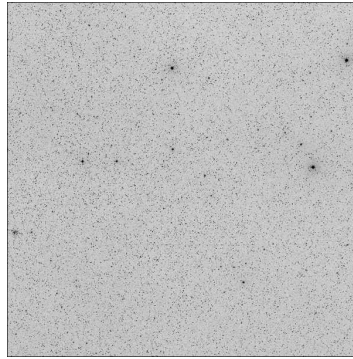


Figure 2: A Schmidt plate may contain thousands objects with a lot of small bodies of the Solar system. Prediscoveries of objects unknown at the time of the observation are possible adding observations from the past for the understanding of the dynamics of their motion.

2. OLD OBSERVATIONS

Old observations compared with new ones allow to detect, measure and model the evolution of the objects. For example, the solar system objects are moving and the modelization of their motion benefit of observations spread on a large interval of time. All the periodic terms and perturbations are better described and taken into account. More, some suspected effects such as dissipation due to tides and cumulative on a long interval of time may be out into evidence (cf. Figure ??). Even with accurate data made on a too short interval of time, such as space data, may not detect such effects.

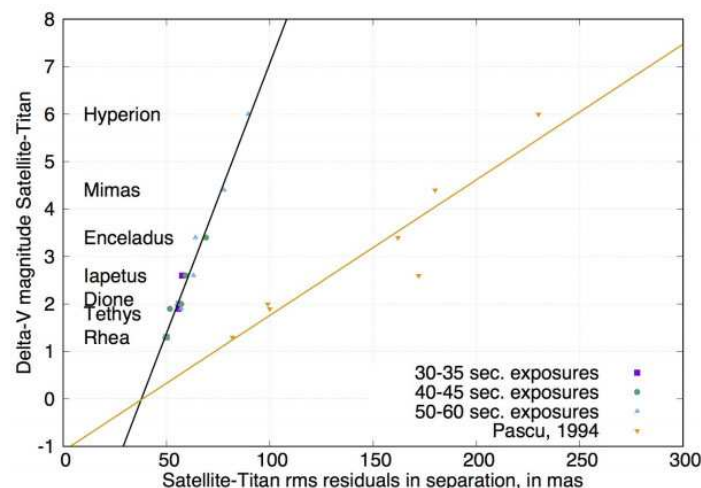


Figure 3: Comparison between old classical reduction showing a worst accuracy compared with the new one for Saturnian satellites.

Old observations are still available since published at the time of their making. However, they

were reduced using old reference catalogues not enough accurate for today purposes. A new reduction of these old observations using the Gaia reference star catalogue will allow to get the old data with today accuracy. We then are able to observe in the past. For such a reduction, a digitizing of the photographic plates is necessary in order to be able to analyze the original image with modern tools. Note that the proper motions of the Gaia stars have an accuracy of one mas one century ago that is sufficient for our purpose.

3. PREVIOUS TESTS WITH BELGIAN DIGITIZER

Thanks to a similar device in Belgium, we were able to demonstrate the validity of our project of digitizing photographic plates. We made a new reduction, using new astrometric catalogs that provided final accurate positions. We applied this to the Galilean satellites and their astrometric positions were not only more accurate than those previously derived from manual measurements, but provided new information due to the star link reduction: we obtained equatorial RA and Dec positions of the Galileans, allowing us to deduce positions of Jupiter indirectly through accurate ephemerides of the Galilean satellites. Finally, we compared these astrometric positions of Jupiter to the best current ephemerides of the planet. Depending on the ephemeris, we obtained residuals between a few tens of mas, to better than 100 mas. We also demonstrate the interest of a new reduction based on a sub-micrometric digitization comparing old and recent reduction of the positions of the satellites of Saturn (cf. Figure ??).

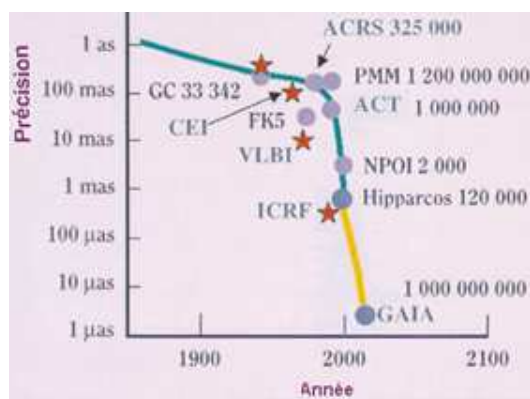


Figure 4: Progresses of astrometric accuracy of reference star catalogues. All the old observations still used nowadays were reduced with 100 mas accuracy catalogues making necessary a new reduction with the Gaia reference catalogue.

4. SCIENCE WITH NAROO

4.1 Astrometry in the Gaia era

In the context of long-term dynamic studies, the old observations are all the more interesting because they are indispensable for the modeling of transient events or observable periodic behavior. Also, the first objective of the NAROO project is to achieve a new astrometric reduction of old observations (astro-photographic plates and CCD) using the last release of the Gaia-DR reference catalog to ensure the best measurement accuracy. The Figure ?? shows the positioning accuracy of the Gaia reference stars versus time. An important result: the stars present on the oldest plates, typically a century old, will have an astrometric precision of 1 mas, allowing the same reduction as for today observations. More, all observations will now be in the same reference frame.

The interest for a new analysis and reduction.- The Figure ?? show the interest of a new reduction of old observations. The figure proposes a comparison two reductions: the one made by

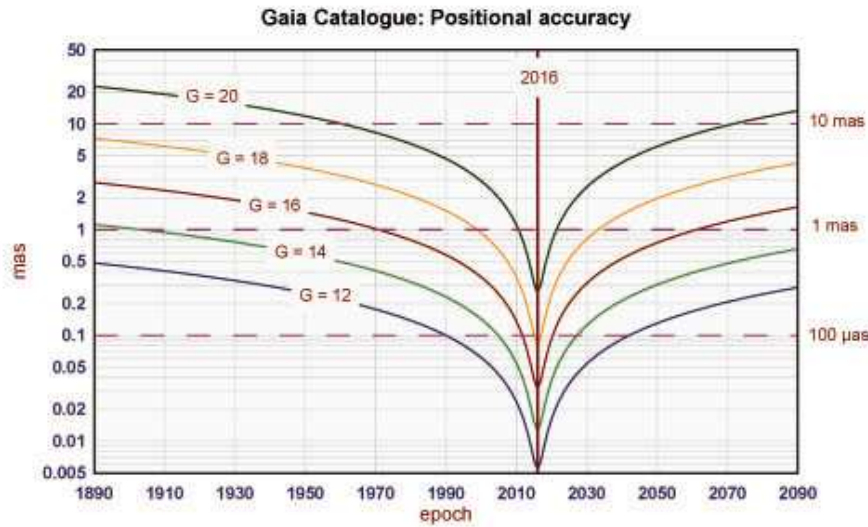


Figure 5: The accuracy of Gaia reference stars versus time (c) F. Mignard. Most of stars on old plates have a magnitude smaller than 15 having a positional accuracy better than one mas one century ago.

D. Pascu (1994), and the one made by V. Robert et al. (2016) after digitization. The plots RMS vs ΔV magnitude show the decreasing trend of the accuracy in positioning the satellites having different magnitudes. The new analysis led to an increase of the accuracy.



Figure 6: The sub-micrometric scanner in Meudon Observatory.

4.2 Solar system dynamics

Asteroids and comets.- Old observations of comets and asteroids had a very poor astrometric accuracy because of the reference star catalogues used at that time. A new astrometric reduction after digitization will be very useful putting all data in the same reference frame with the same accuracy. The main goals are : - analysis of Schmidt plates which contains a large number of objects still unknown (cf. Figure ??) - pre-discoveries of TNO, comets and Near Earth objects NEA/NEO; - increasing the time interval of the observations made and used in the theoretical

models being then able to detect and quantify the non-gravitational and/or cumulative effects.

The natural satellites of planets.- The interest of increasing the time interval for which we have observations, is to allow in particular the quantification of the effects of tides. These effects, due to energy transfers between satellite and planet, lead to orbital accelerations or decelerations (cf. Figure ??). These movement variations generate cumulative effects that become easily detectable over a century of observations. The old photographic plates are therefore essential for this research.

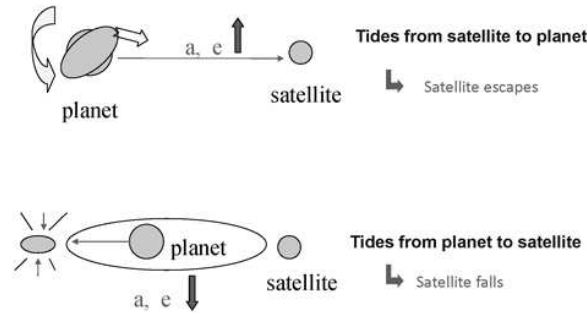


Figure 7: Influence of tides on satellite motion: satellites have an acceleration in their motion which is detectable and measurable through observations made during a long interval of time since the effects are cumulative with time.

Planets.- Planets are objects that are difficult to observe directly, especially because of their apparent brightness that disturbs images. Planetary dynamical models are adjusted on astrometric positions derived from those of natural satellites. We have shown that old observations, unfortunately inaccurate and used in the adjustments, could introduce biases in the results (V. Robert et al., 2015, 2016). A new reduction of old photographic plates is therefore essential to correct those already used, to complete and improve the existing models, to allow a better estimation of the internal structure.

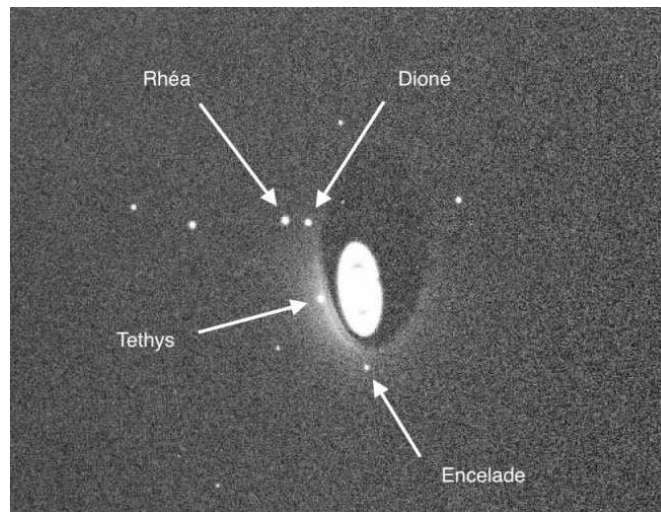


Figure 8: The first light from NAROO: the digitization of a plate of the Saturnian system.

5. THE DIGITIZING DEVICE

The astronomical plates and the quality of the results require a digitizing machine of a particular

precision because of the importance of the relative positions of the measured objects (Robert et al. 2011). Our project is based on the installation at the Paris observatory of such an instrument that we acquired and which was built in France by Newport-Microcontrol (cf. Figure ??). Note that the significant resistance to time of photographic plates has been demonstrated (Hendriks 1983). Admittedly, "ideal" archiving conditions are recommended, but emulsions and supports can remain intact and therefore usable as long as they do not undergo rapid temperature variations or extreme humidity conditions. The machine has a granite base on which an XY table rests on an air cushion. The plate holders can support plates up to 350 mm side. The position of the XY table is determined by Heidenhein encoders. Stability and repeatability are on the order of 50 nanometers. The XY table is powered by two frictionless linear motors that avoid zero problems and has progressive accelerations optimized to avoid vibrations. The XY table is completed by an optical system composed of a 1: 1 telecentric objective and an illumination system, both specially dimensioned by the Observatory's Instrumental Pole in order to accommodate, on the Z axis, a Andor SCMOS camera.

6. CONCLUSION

The reduction of old photographic plates has been tested first with the UCAC2 reference star catalogue. It was not possible to analyse data older than those of 1980s but the arrival of the Gaia reference star catalogue allows to go further in the past. Even one century ago, the astrometric accuracy will reach one mas. Our project of a new reduction of old plates is now running and is able to digitize and reduce any photographic plate in good shape (cf. the first light of our scanner on Figure ??). One may have more information on the NAROO web site at naroo.imcce.fr

7. REFERENCES

- Hendricks, J. S.; Booth, T. E., 1985, "MCNP Variance Reduction Overview", Monte-Carlo Methods and Applications in Neutronics, Photonics, and Statistical Physics. Proceedings of the Joint Los Alamos National Laboratory - Commissariat à l'Energie Atomique Meeting, held at Cadarache Castle, Provence, France, April 22-26, 1985. Lecture Notes in Physics 240, edited by R. Alcouffe, R. Dautray, A. Forster, G. Ledonois, and B. Mercier. Springer-Verlag, Berlin, 1985., p. 83, doi: 10.1007/BFb00490371.
- Pascu, D., 1994, "An appraisal of the USNO program for photographic astrometry of bright planetary satellites", Galactic and Solar System Optical Astrometry, Proceedings of the Royal Greenwich Observatory and the Institute of Astronomy Workshop, held in Cambridge, June 21-24, 1993. Edited by L.V. Morrison and G.F. Gilmore. Cambridge: Cambridge University Press, 1994., p. 304
- Robert, V.; de Cuyper, J. -P.; Arlot, J. -E.; de Decker, G.; Guibert, J.; Lainey, V.; Pascu, D.; Winter, L.; Zacharias, N., 2011, "A new astrometric reduction of photographic plates using the DAMIAN digitizer: improving the dynamics of the Jovian system", MNRAS 415, pp. 701–708.
- Robert, V.; Lainey, V.; Pascu, D.; Pasewaldt, A.; Arlot, J. -E.; De Cuyper, J. -P.; Dehant, V.; Thuillot, W., 2015, "A new astrometric measurement and reduction of USNO photographic observations of Phobos and Deimos: 1967-1997", A&A 582, pp. 36–43.
- Robert, V.; Pascu, D.; Lainey, V.; Arlot, J. -E.; De Cuyper, J. -P.; Dehant, V.; Thuillot, W., 2016, "New astrometric measurement and reduction of USNO photographic observations of the main Saturnian satellites: 1974-1998", A&A 596, pp. 37–46.