SF2A 2019
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THE NAROO PROGRAM

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Abstract. The astrometric monitoring of Solar System objects is an important step to assess their formation and evolution. However, it is necessary to have very accurate observations over a large timespan to quantify relevant effects and thus, improve dynamical models. In this framework, observations realized with "old" astro-photographic plates provide original, valuable and essential scientific data, that most recent technological means and computing tools can fully exploit. With the New Astrometric Reduction of Old Observations (NAROO) program, we intent to measure and (re-)reduce such observations, using a new generation sub-micrometric digitizer at Paris Observatory, and Gaia-DR2 star catalog for the astrometric reduction.

Keywords: Instrumentation: miscellaneous, Astrometry & Celestial Mechanics

1 History of the program and previous results

Most of the observatories and national archives have old and useful astro-photographic observations, but only a few part was already analyzed, used to support first space reconnaissance projects and dynamical studies. We estimate that less than 30% of the total amount was effectively analyzed, and mainly with manual methods that only allowed to provide relative data.

In 2006, we started thinking that digitization of such materials could be an attractive method to get original and accurate data over a large timespan, but a high accuracy in the measurement and the reduction of those plates was absolutely necessary (Robert et al. 2011). In the framework of a first partnership, we developed methods and algorithms adapted to specific plates provided by USNO (Washington D.C., USA), using the DAMIAN digitizer of ROB (Brussels, Belgium). From a set of about 550 plates of the Jovian system, taken from 1967 to 1997, and resulting in about 2600 single observations, we have been able to produce rms residuals of 35 mas for intersatellite positions (when the original reduction provided 100 mas), and of 72 mas for equatorial positions (which were not possible to get with the original reduction). We demonstrated the value of a new astrometric analysis of old photographic plates, resulting from their accurate measurement with the DAMIAN digitizer, and we were able to extract all the important information contained in the plate data, while correcting for instrumental and spherical effects during the reduction. The new reduction provided final accurate positions which were not only more accurate than those previously derived from manual measurements, but provided new information since we obtained equatorial positions for the first time with these plates.

Since we had demonstrated that a precise digitization and a new astrometric reduction of old photographic plates could provide very accurate positions, the leaders of the European Satellites Partnership for Computing Ephemerides (ESPaCE) project chose to consider such observations as a significant task. This project aimed at strengthening the collaboration and at developing new knowledge, new technology, and products for the scientific community in the domains of the development of ephemerides and reference systems for natural satellites and spacecraft (Thuillot et al. 2013). Several European research centers involved in space sciences and dynamics were associated. From 2011 to 2013, we obtained the large photographic plate archive of the Martian satellites taken at USNO from 1967 to 1997 for remeasurement and reanalysis, and the complete set of the Saturnian satellites taken from 1974 to 1998, as well. We had significant results since we demonstrated, in particular,

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that astrometric data derived from photographic plates can compete with those of old spacecraft (Robert et al. 2015, 2016). As a last demonstration, in Fig. 1, we investigated the effect of the signal-to-noise ratio (S/N) on the precision of the Saturnian observations. Comparing the decline in precision between new and former measurements, we confirmed the high value in continuing the reduction of old observations.

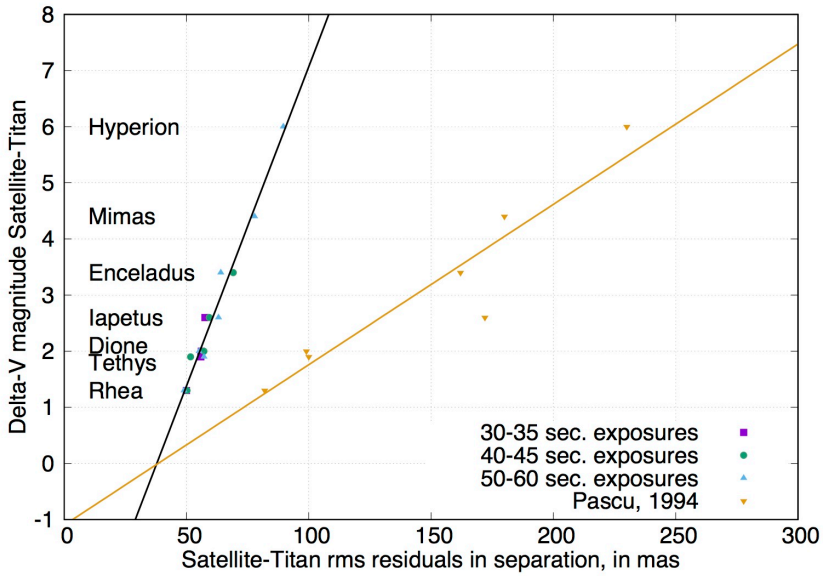

Fig. 1. rms residuals in separation from Titan as an indicator of the decline in positioning precision. Red line denotes new measurements by Robert et al. (2016). Orange line denotes former measurements made by Pascu (1994).

2 The NAROO centre

With the arrival of the Gaia-DR2 catalog (Lindegren et al. 2018), we are now allowed to analyze until the oldest photographic plates (close to 1890) without degrading the astrometric precision, due to errors on reference star positions and/or proper motions. Thus, in 2013, we have started creating a digitization centre*., at Paris Observatory, dedicated to the analysis of old astro-photographic plates for scientific purposes, and we are now almost to "open".

2.1 Hardware

Fig. 2 shows the NAROO digitizer as on 2019 April. The machine consists of a granite based Newport-Microcontrol air-bearing XY positioning table suited for mounting glass plates up to 350-mm wide. The complete set measures 1.90m x 1.29m x 1.60m, for about of 2 tons weight.

The optical unit consists of a Neo 5.5, 16 bit sCMOS Camera from Andor, mounted on a VS-TCM1-130/S telecentric 1:1 objective. This system is attached to the Z-axis above the XY table. The 2D sCMOS Camera provides images with 2560 x 2160 pixels of 6.5 μm x 6.5μm. The photographic images are illuminated from below with suitable very bright Light Emitting Diode's, controlled by a high precision DC power supply. The complete optical system was designed at Paris Observatory to avoid any distortion effects. The position of the XY table is read by Heidenhain encoders. The linearity and orthogonality of the (X, Y) axes were calibrated by Newport-Microcontrol using a laser interferometer. The local XY table positioning stability (how closely the

*https://bibnum.explore.univ-psl.fr/s/naroo/page/accueil

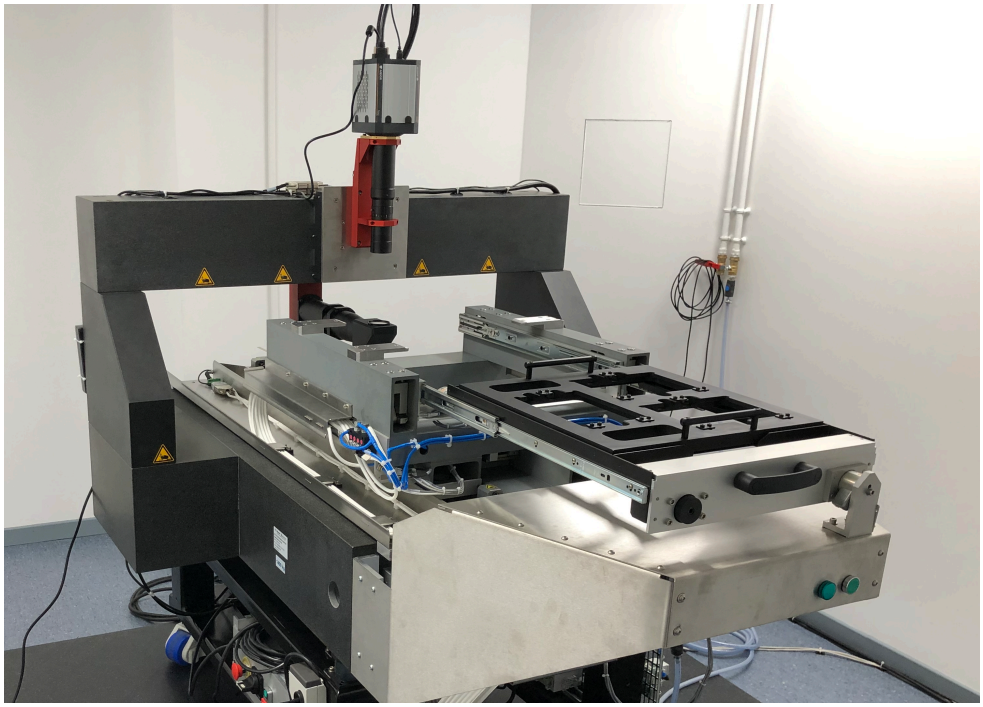

Fig. 2. The NAROO digitizer, Paris Observatory.

table can fix a position) was measured by the manufacturer at ±0.010 μm. With real data, we measured the stability at ±0.025 μm. In order to reach and maintain a high geometric and radiometric accuracy, the digitizer is placed in an air-conditioned clean room, at a temperature of 20 Celsius degrees ±0.1 Celsius degrees, and a relative humidity of 50 per cent RH ±5 per cent RH. Fig. 3 shows the "First light" of the NAROO machine: the Saturnian system on a 1975 USNO photographic plate, taken on 2019 April.

2.2 Scientific objectives

The NAROO centre is mainly dedicated for science purposes, not for archiving or saving. That's why we have started discussing with different members of the community, in order to develop a team which would be able to estimate all the capacities of the machine for their topics, and use it for their research. Since astro-photographic plates were used for different purposes, we first separated the categories with plates dedicated to Astrometry, those dedicated to Spectrometry, and those dedicated to Photometry.

With astrometric plates, we intend to: improve ephemerides of Solar System objects by the addition of numerous high-precise positions in database, estimate long-term dissipation and secular phenomena since dynamical models will be refine over large time span, make pre-discoveries of small bodies (NEOs, PHAs,n TNOs, comets) since such objects could have been observed with very old plates before their official detection, work on the Yarkovsky effect, work on General Relativity.

With spectrometric plates, we intend to digitize old spectra of variable stars, and Be stars in particular to complete the database before the 90's.

With photometric plates, we intend to: complete the database of body surfaces to create and/or refine object albedo maps, to pay particular attention to the Sun by analyzing its long-term evolution regarding to sunspots and magnetic field.

3 Conclusions

We have demonstrated the value of a new astrometric analysis of old photographic plates, resulting from their accurate measurement with new generation digitizers. The new reduction, using new astrometric catalogs, provides final accurate positions satellites that are not only more accurate than those previously derived from

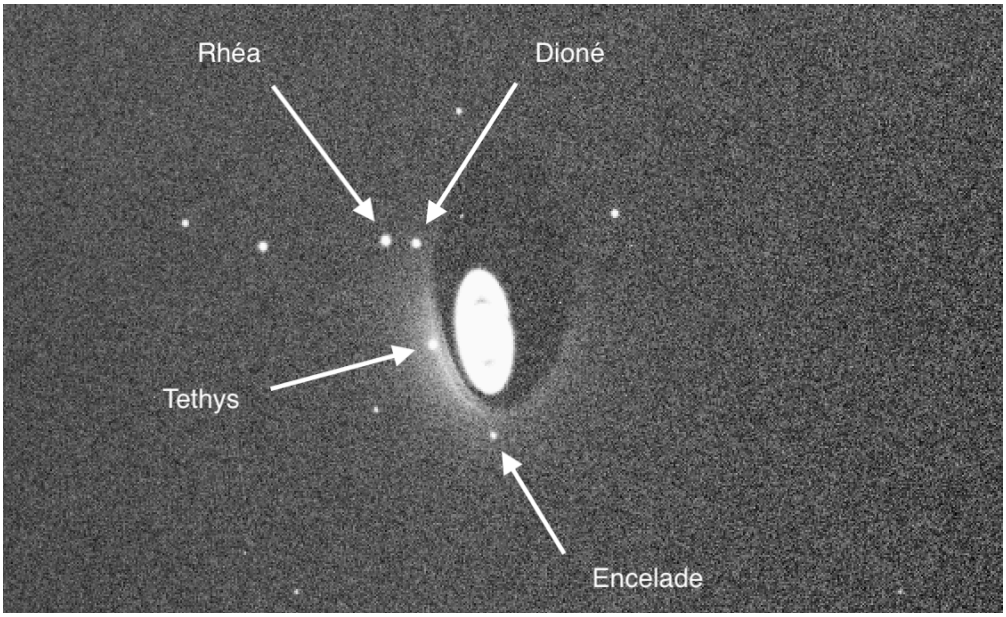

Fig. 3. NAROO First light - April 2019 - 1975 USNO plate.

manual measurements, but provides new information since we obtain equatorial positions for the first time with these plates.

With the NAROO program, we open a centre dedicated for science purposes in various fields of research. We are now realizing the last calibration tests before our new generation digitizer will be fully operational and automized. A first call for digitization time will be published by the beginning of 2020, since the centre will be open to researchers involved in astro-photographic plate analysis.

This work was supported by the Programme National GRAM of CNRS/INSU with INP and IN2P3 co-funded by CNES, by IMCCE - Paris Observatory, IPSA, DIM-ACAV, FP7 ESPaCE, and PSL Research University.

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