Taking the opportunity of the Gaia reference star catalogue for observing the Solar system in the past

D. Hestroffer[1], J.-E. Arlot[1], V. Lainey[1], V. Robert[1,2]

1 - IMCCE / Observatoire de Paris (OBSPM), 77 avenue Denfert-Rochereau, F-75014 Paris, France

2 - Institut Polytechnique des Sciences Avancées (IPSA), 7-9 rue Maurice Grandcoing, F-94200 Ivry-s/-Seine, France

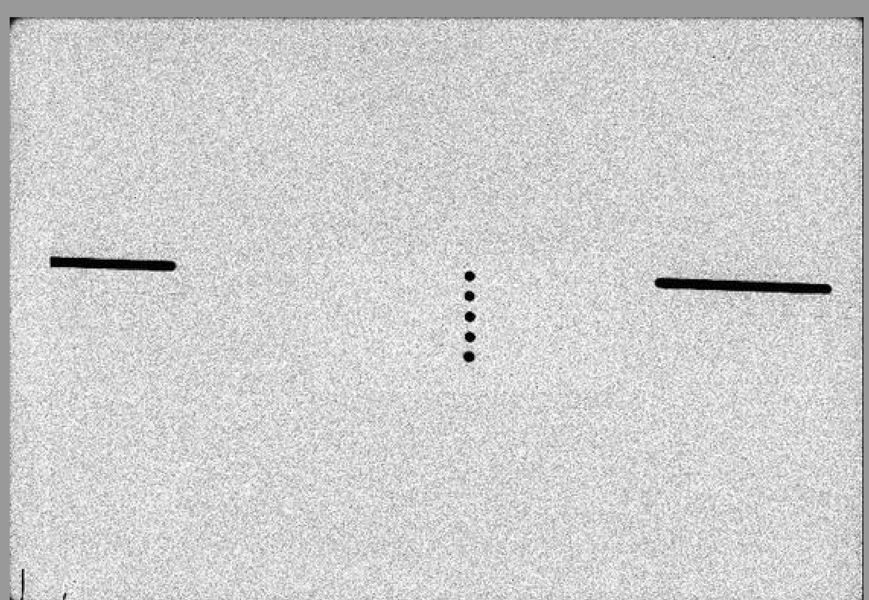
Abstract

The Gaia astrometric catalogue of reference stars will provide proper motions of stars until mag 18 with an accuracy better than 6 mas over one century. So, we may reduce all astrometric observations of Solar System objects made since the end of the XIXth century with an accuracy better than the present accuracy of the best reference star catalogues such as the UCAC2 or UCAC4. This should solve or considerably reduce the problems of biases in ephemerides because of zonal errors in the catalogues. We performed tests on photographic plates and, thanks to the use of sub-micrometric scanners, we succeeded to improve the reduction of plates made in the 1960's for planetary satellites. Even with an accuracy less than the expected one of the future Gaia catalogue, we show a systematic shift of the ephemerides during the last decades.

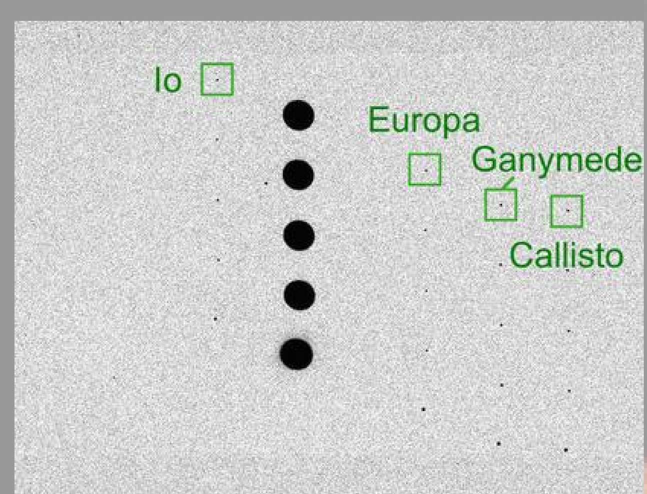
ESPaCE FP7 program and USNO photographic plates

The European Satellites PArtnership for Computing Ephemerides ESPaCE project aims 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. The main European research centers involved in space sciences and dynamics contribute by combining their expertise. Their activities are focused on the extraction and analysis of astrometric data from space measurements not yet applied to the dynamics and to combine them with ground-based astrometric data.

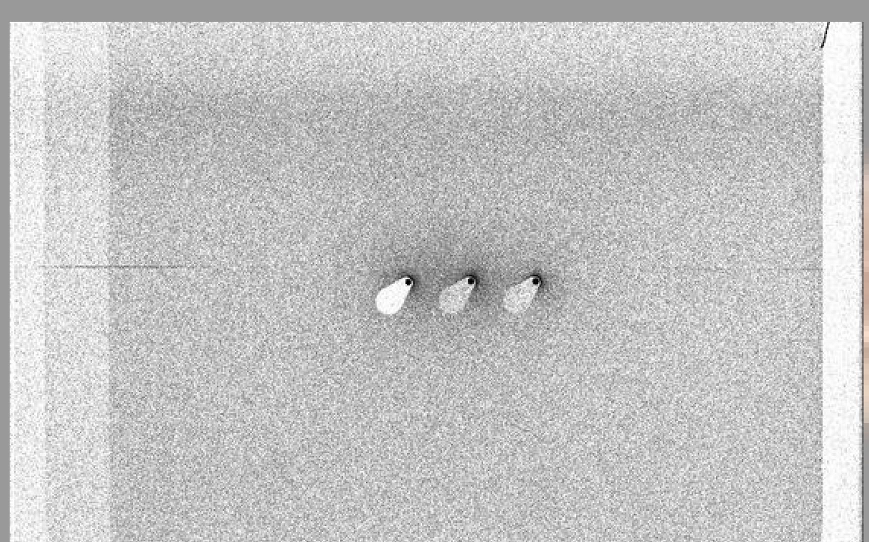
We focus here on a subset of a few hundred photographic plates of the Galilean and Martian satellites, taken with the USNO 61-inch reflector (37' field) and the USNO 26-inch refractor (57' field) by D. Pascu (1977, 1979 & 1994) from 1967 to 1998. Each plate contains several exposures shifted on the Dec axis for the Galileans and on the RA axis for the Martians. All these photographic plates were recently digitized with the new generation ROB digitizer (Robert et al., 2011, 2014).



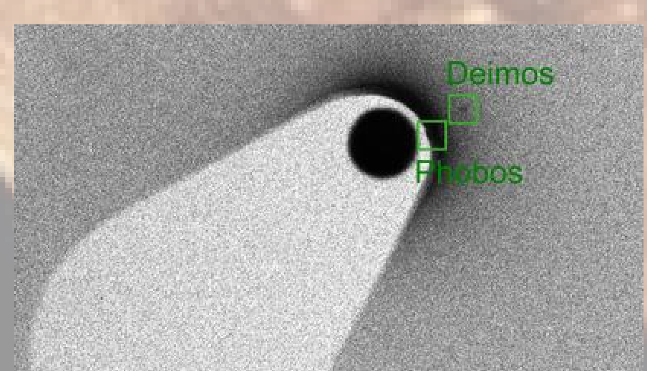
The USNO Galilean plate n°24014



Center of the USNO Galilean plate n°24014



The USNO Martian plate n°11001



Center of the USNO Martian plate n°11001

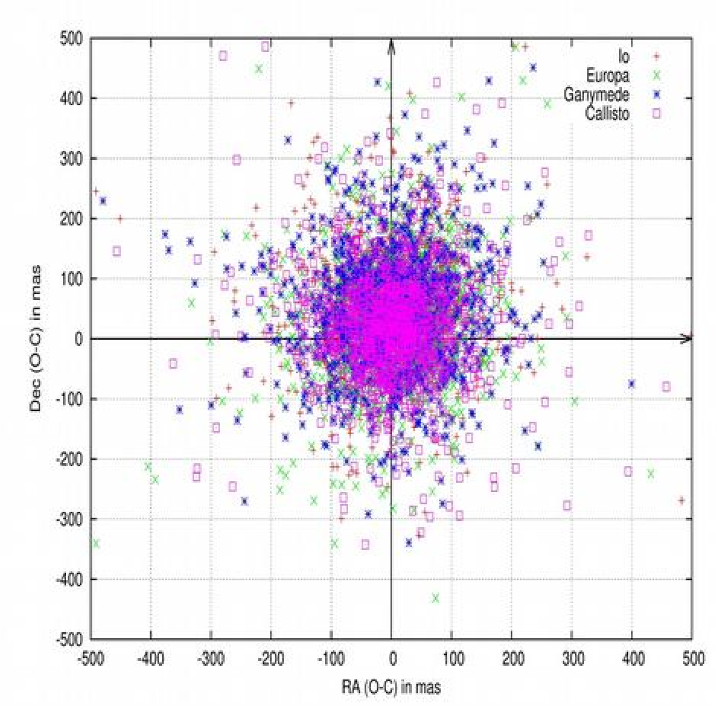
Analysis and astrometric reduction

The positions of the images of the planet, satellites and stars are extracted by means of a specific process including the use of the Source Extractor software (Bertin et al., 1996) and an IDL ellipse and limb fitting. The objects assumed to be present in the field are identified from existing catalogs to select only real astrometric sources. This process defines areas on the images in which the objects have to be found (Robert, 2011). All the available stars (depending on the catalog used) are identified and more, those that are not detected by eye. The obtained positions are finally corrected for the optical distortion introduced by the objective/camera unit during the digitization and for the instrumental coma-magnitude effect.

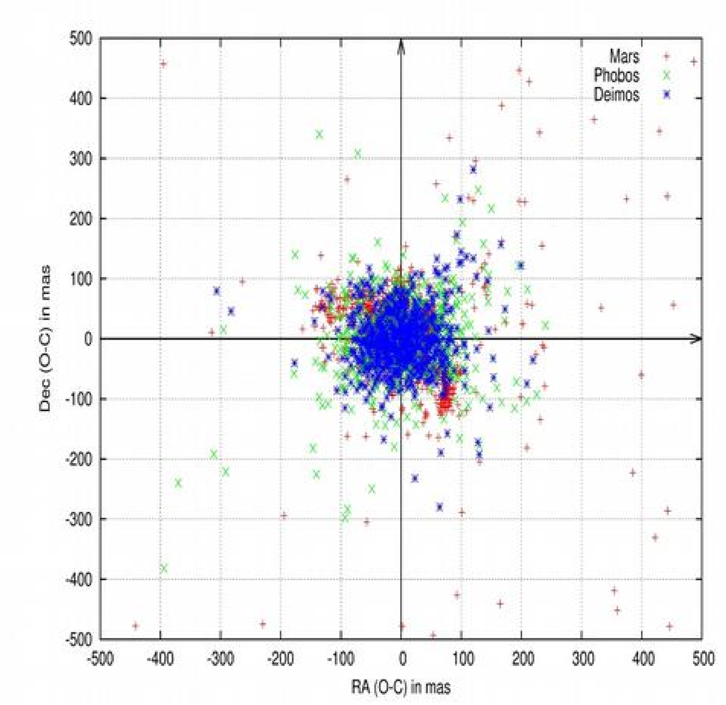
Astrometric (RA,Dec) results of the satellites and the planets are determined in an ICRS geocentric frame to be easily compared with the most recent satellite and planetary ephemerides.

Because of the few number of available stars, the astrometric reduction is quite different from a common astrometric process: the positions are calculated after correcting for instrumental and spherical effects that take into account the parallax and aberration effects and the total atmospheric refraction. (RA,Dec) positions are deduced from tangential apparent coordinates; only 4 parameters modeling the scale, orientation and center of field are fitted for a minimum of 2 reference stars. The contribution of each effect is separated.

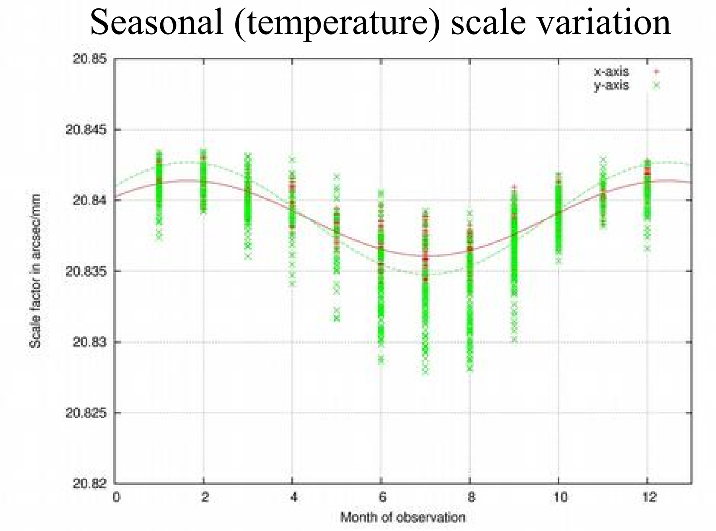
The Galilean satellites



The Martian satellites



Seasonal (temperature) scale variation



Sub-micrometric ROB digitizer

Astrometric results

The (O-C)s are for observations of Io, Europa, Ganymede and Callisto first, and for Mars, Phobos and Deimos following. Positions are deduced from the measurements.

The two first Figures show details of the (RA,Dec) (O-C)s according to the INPOP10 (Fienga et al., 2010) planetary ephemeris and IMCCE (Lainey et al., 2007, 2009) satellite ephemerides. The next Figure shows the contribution of the temperature on the scale variation, while the last picture shows the sub-micrometric ROB digitizer used for the digitization. Tables compare the averages of the Galilean and Martian (RA,Dec) (O-C)s and rms residuals respectively, in mas, according to the INPOP08 (Fienga et al., 2008), INPOP10, DE421 and DE430 (Folkner et al., 2008, 2014)) planetary ephemerides.

Galilean observations	$\overline{(O-C)}_{\alpha\cos\delta}$	$\bar{\sigma}_{\alpha\cos\delta}$	$\overline{(O-C)}_{\delta}$	$\bar{\sigma}_{\delta}$
INPOP08	42,7	74,3	47,9	94,9
INPOP10	3,1	69,7	34,7	76,4
DE421	-1,3	70,1	39,0	77,6
DE430	-1,8	70,0	37,7	78,0

Martian observations	$\overline{(O-C)}_{\alpha\cos\delta}$	$\bar{\sigma}_{\alpha\cos\delta}$	$\overline{(O-C)}_{\delta}$	$\bar{\sigma}_{\delta}$
INPOP08	2,3	59,8	2,6	57,8
INPOP10	3,2	59,8	2,8	57,8
DE421	2,3	59,7	2,7	57,8
DE430	2,6	59,7	2,7	57,8

Conclusion

We demonstrated the high interest to continue the analysis of old photographic plates such as USNO's. Thanks to the new technologies, we were able to provide astrometric data with a high accuracy after applying the necessary corrections.

We now provide an accuracy about of 70 mas (~210 km) for (RA,Dec) positions of the planet Jupiter and its moons. We also provide an accuracy about of 60 mas (~18 km) for (RA,Dec) positions of the planet Mars and its satellites. Note that the previous accuracy was about of 200 mas and only for relative positions. More important, these results indicate that we now can reach an accuracy better than that of CCD observations (Colas et al., 1991) and as good as the old spacecraft measurements of the Martian system for example. These results encourage us to continue the analysis of old photograhic plates. The steps after will be to reduce other relevant old photographic plates such as Yale Southern Station Saturnian observations, and to continue the effort in reducing old observations. Same, old CCD observations could be re-reduced in the same scope, increasing the accuracy of these data.

In order to fullfill our program, we start the NAROO project (New Astrometric Reduction of Old Observations) of the IMCCE / Paris Observatory. A new sub-micrometric scanner will be st-up at Paris observatory, able to digitize several thousands plates for astrometry purpose.

We look forward to the arrival of the Gaia reference star catalogue which will be a revolution in Solar system astrometry: reductions of old observations will yield increased accuracy by eliminating errors caused by old reference star catalogues. We will be able to observe in the past with today accuracy, that is essential for fast moving objects of the Solar system

References

Bertin E. et al., 1996, A&AS, 117, 393
Colas et al., 1991, A&A, 252, 402
Fienga A. et al., 2008, A&A, 477, 315
Fienga A. et al., 2010, IMCCE Memorandum
Folkner W.M. et al., 2008, JPL Memorandum
Folkner W.M. et al., 2014, IPN Progress Report
Lainey V. et al., 2007, A&A, 465, 1075
Lainey V. et al., 2009, Nature, 459, 957
Pascu D., 1977, University of Arizona Press, 63
Pascu D., 1979, in Natural and Artificial Satellite Motion, University of Texas Press, 17
Pascu D., 1994, in Galactic and Solar System Optical Astrometry, Cambridge University Press, 304
Robert V. et al., 2011, MNRAS, 415, 701
Robert V., 2011, PhD thesis of the Paris Observatory
Robert V., 2014, A&A accepted publication

JSR, Pulkovo, Russia, 2014

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2012-2013) under grant agreement n°263466.