The NAROO project

For overcoming past, current and future ephemeris errors

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Abstract

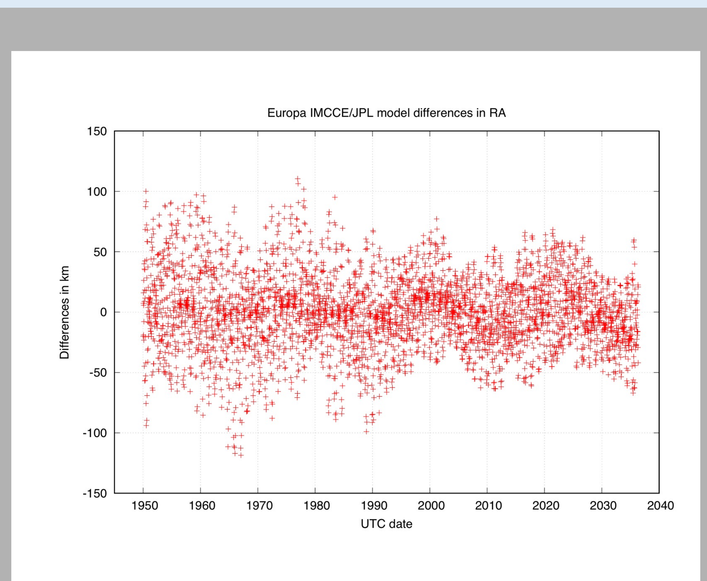
Accurate orbit determination require a large amount of observations dispatched over a large time span to allow for the best precision and extrapolation. This latter is of high importance in the context of future space missions. In practice, most orbital models of the Solar System objects are fitted to data covering typically about one century. Even if the conditions are required for precise dynamical modeling, we emphasize an important caveat : ephemerides can sometimes be significantly biased while their extrapolation quickly diverges. Even though this could be due to various reasons, we found that an important one consists in the imprecision of past observations that are introduced in the adjustments. These observations were processed a long time ago with inaccurate star catalogs and with inaccurate methods compared to recent ones. No real efforts have been attempted to reanalyze these data a new time, considering the amount of time, mean and energy required.

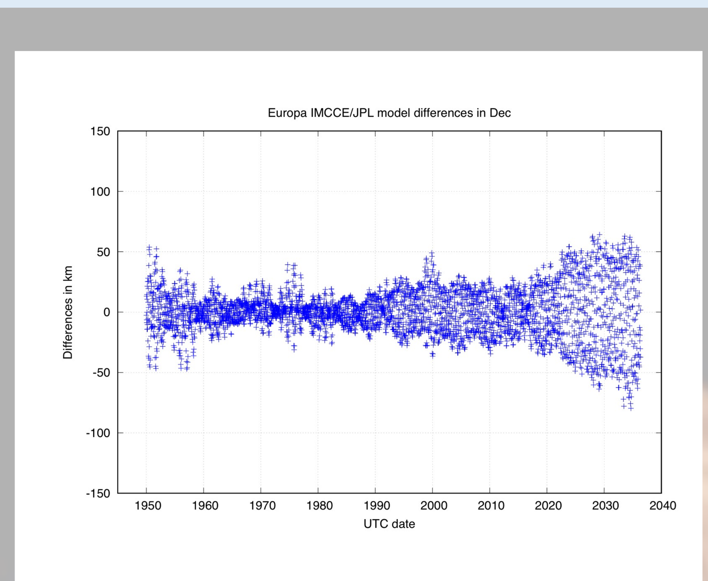
Using photographic plates of planetary satellites, we demonstrated that a new reduction of old observations can improve significantly the ephemerides. In this framework and with support of the Gaia mission, the NAROO project has been initiated at Paris Observatory with the primary aim to reprocess the old astrometric observations with the best instrumental, algorithmic and numerical techniques. We discuss the impact of the project on future planetary and satellite ephemerides.

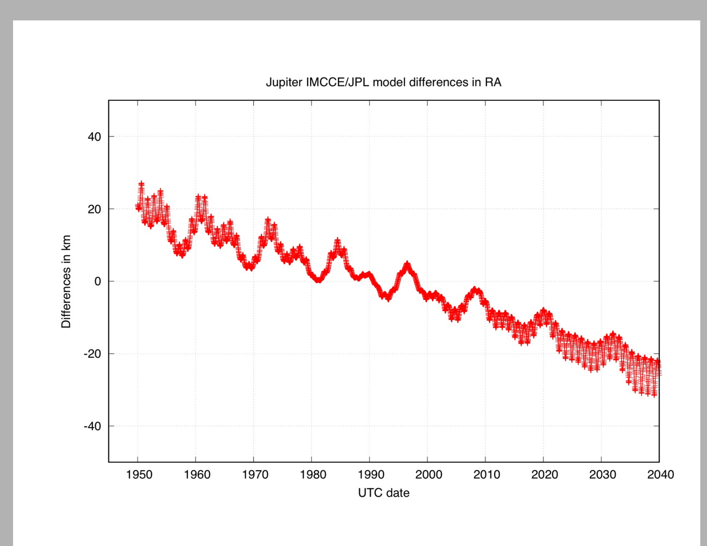
Ephemeris construction and extrapolation

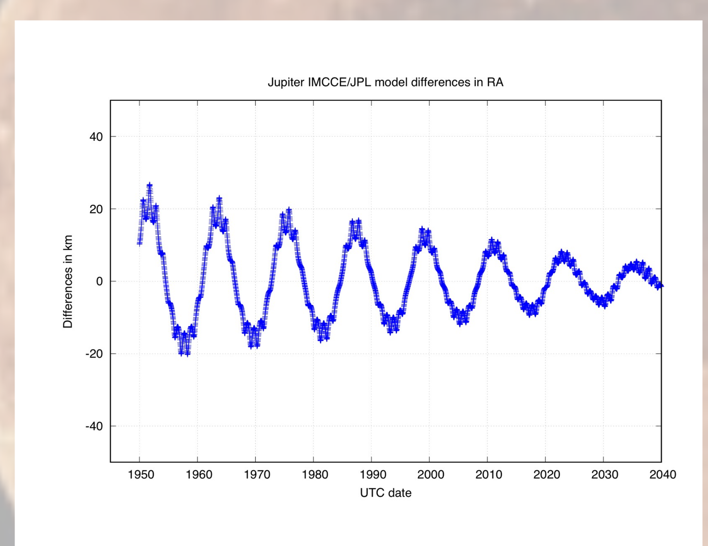
Ephemerides consist in numerical implementations of the n-body problem in the Solar System. Equations are solved considering the eight planets, the Moon, the Sun, Pluto, and a variable set of asteroids of the Main Belt. Beyond the resolution of the problem, numbers of parameters are adjusted such as the position of the Solar System barycenter, the J2 of the Sun, the asteroid masses…

The main dynamical models used for space science are different and they are distinguished by the number of bodies in question, the numerical integration method and the physical parameters to fit, and most important by the numbers of observations used for the fit and weights, hence their respective dynamics. Figures below show examples of differences in positions and extrapolations in km between JPL and IMCCE ephemerides. We here consider Europa (Lainey et al., 2011; Jacobson, 2004) and Jupiter (Fienga et al., 2014; Folkner, 2014), but note that comparisons between models for other planets and satellites would show such disparities. Differences in extrapolation span from tens of km to hundreds of km









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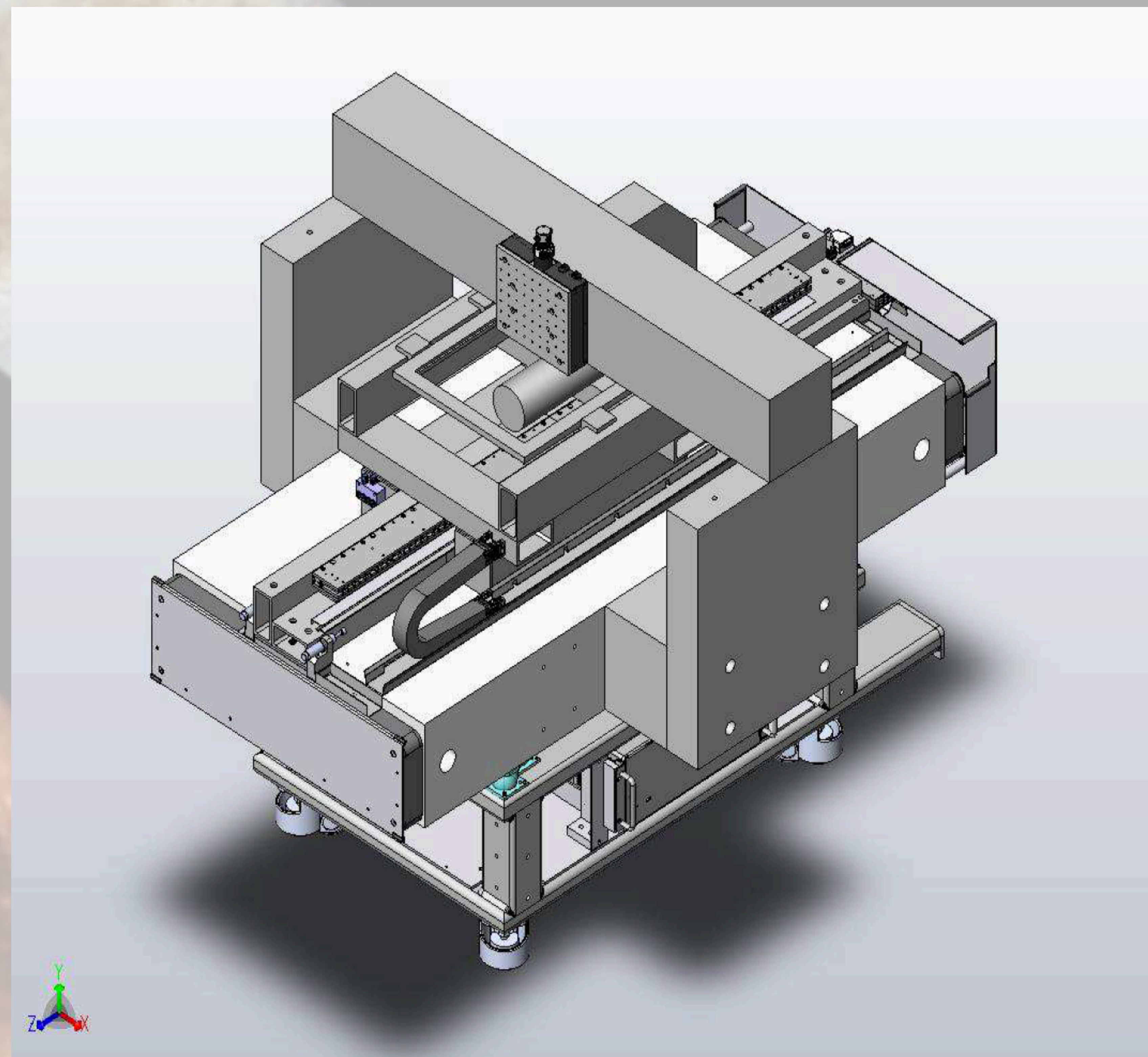
Recently, Desmars et al. (2009) have shown that astrometric data spread over a large time span were better than more accurate astrometric data spread over a short interval of time for dynamical and ephemeris purposes. The extrapolation of the ephemerides for space missions are more confident. Similarly, Arlot et al. (2012) have shown the benefit of using old observations and how new reductions and future reductions with the Gaia catalog in particular (Robin et al. 2012) will be useful. In view of this, and since we had demonstrated that a precise digitization and a new astrometric reduction of old photographic plates could provide very accurate positions (Robert, 2011; Robert et al., 2011), IMCCE decided to design and install a new sub-micrometric digitizer at the Paris Observatory.

The New Astrometric Reduction of Old Observations NAROO project aims at digitizing and analyzing with high accuracy old selected observations of planets, satellites, asteroids and comets, covering about of one century. These observations are available in most of the observatories and national archives, and most of them were never used to provide positionning data. Only subsets were used to fit first ephemerides, but they were manually reduced with non accurate reference catalogs. Even if their precision was sufficient for the needs at these epochs, it now results in significant biases and divergences that we should eliminate.

In some words, the NAROO instrumentation consist in:

- Air-bearing XY table suited for mounting glass plates up to 350mm wide
- Granite base of 1900mm x 1400mm
- 2D CMOS camera mounted on a telecentric 1:1 objective, attached to the Z axis
- Air-conditioned clean room at 20°C±0.1°C, 50%RH±10%RH



Design of the NAROO sub-micrometric digitizer, © Newport-Microcontrol.

First results and discussion

Using a previous built sub-micrometric digitizer at the Royal Observatory of Belgium, we digitized first sets of astrophotographic plates to develop new softwares, try out the new methods of analysis and to estimate the accuracy of the measurements. We analyzed full series of the Martian, Jovian and Saturnian systems spanning 30 years from the 1960's each. Our results put into light new informations on tidal accelerations in particular. Most important, we reached a positionning accuracy that was never achieved with such materials, two to four times better than previous measurements. Some significant conclusions:

- The Martian ephemerides are biased by 3 km (Robert et al., 2015)
- The Jovian ephemerides are biased by 70 km (Robert, 2011; Robert et al., 2011)
- The Saturnian ephemerides are biased by 31 km (Robert et al., 2016 forthcoming)

Moreover, we demonstrated that astrometric data derived from photographic plates could compete with those of old spacecraft but more numerous spread on a longer interval of time, and with much more Gaussian error.

Processing unused old observations with accurate star catalogs and methods will provide new informations and refine the model definitions. More important, it appears necessary to reprocess the « historical » astrometric observations used for the ephemeris adjustments to correct for systematic errors that remains for years now. Part of these observations are important in the sets, it deals in particular with all transit circle observations and those reduced with biased star catalogs. We estimate that the contribution of these data is up to 40% of the positions used.

Conclusion

We demonstrated the high interest to analyze old photographic plates, thanks to the new technologies. Astrometric data extracted from such materials could now compete in terms of accuracy with those of old spacecraft.

The NAROO project aims at digitizing several thousands of photographic plates for astrometry and thus dynamics purposes. Moreover, the Gaia astrometric catalog of reference stars will provide proper motions of sources up to mag 18 with an accuracy better than 6 mas over one century. We look forward its arrival which will be a revolution in Solar System astrometry: reductions of old observations will yield increase accuracy by eliminating errors due to "old" reference star catalogs. We will be able to observe in the past with today accuracy, that is essential for fast moving objects of the Solar System.

We have started to establish contacts to improve the dynamics of the planetary systems with old data in the framework of the FP7 ESPaCE program. We are now followed by various observatories and institutions worldwide to help in that purpose. By the end, we should eliminate all systematic errors in ephemerides to propose tools for space science related to all objects of the Solar System.

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