IMPACT OF HIPPARCOS DATA ON ASTROMETRIC REDUCTION OF SOLAR SYSTEM BODIES

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ABSTRACT

We investigated the improvement of photographic astrometric observations of solar system bodies by use of Hipparcos Catalogue stars, PPM Catalogue stars, and advanced plate reduction procedures. In the plate reductions, we first computed apparent, topocentric coordinates of the date for the reference stars, taking into account effects of refraction, aberration, precession, nutation, etc. In this way, the 6 plate constants, of our linear reduction model, need account for only the instrumental effects of scale, orientation, and zero point. This method is very accurate even if few reference stars are available on the plates. We tested our reduction methods with photographic plates of Jupiter's Galilean satellites, taken with the 26-inch refractor of the U.S. Naval Observatory. The position of Jupiter on the plates was determined from measurements of the Galilean satellites, combined with ephemerides accurate to better than 10 milliarcseconds (mas). The resulting observations were compared to DE403. Our preliminary results gave an average (O–C) of (0.014 ± 0.013) arcsec in right ascension, (−0.005 ± 0.014) arcsec in declination.

Key words: Astrometry, Galilean system.

1. INTRODUCTION

The Hipparcos Catalogue contains 118 218 entries with median astrometric precision of around 1 mas. It means that the mean sky density is, thus, less than 3 stars per square degree. So, how does one best use the possibilities of this catalogue, considering the problem of the limited number of Hipparcos stars in the field of long-focus plates.

2. ASTROMETRIC REDUCTION

The reduction process is supposed to connect to an absolute reference system one or several objects the positions of which are unknown. To do this, we have to:

1. set up the reference system by the identification and the choice of reference stars, and by the computation of their absolute positions for the date and conditions of the observations;
2. connect selected reference stars to objects by measurements on the receptor;
3. set up a model, linking the receptor and the celestial sphere.

Three types of errors arise: the errors on the positions of reference stars, the modelling errors and finally observational errors, including errors of measurements but also errors due to the conditions of observations. The contribution of each can be computed. For example, Pascu & Schmidt (1990) give:

$$e_t^2 = \frac{e_{cs}^2 + (Se_{ms})^2}{n-m} + (Se_{mo})^2$$

where n is the number of reference stars used, m, the number of constants determined in the plate solution, S, the plate scale (arcsec/mm), e_{cs}, the mean catalogue error of reference stars (arcsec), e_{ms}, the mean total observational error of the reference stars (mm), and e_{mo}, the total observational error of object (mm).

For a long focus receptor and a 3-constant model, we can make the estimations in Table 1 of the single-image external error in the position, using Hipparcos and PPM catalogue reference stars:

Table 1. Single-image external error (arcsec).

	n=4	n=8	n=10
PPM	0.271	0.123	0.104
Hipparcos	0.029	0.023	0.022

So, the interest of using the Hipparcos Catalogue is indisputable.

Nevertheless, as mentioned in the introduction, the density of the Hipparcos Catalogue cannot give us, in many cases, the possibility of using a classical reduction method requiring a large number of reference stars. In the case of long-focus plates, we did not make the choice to set up a secondary field with many stars, but we choose to develop a method using one or two reference stars if more were not available.

3. RESULTS

3.1. General Presentation

We have reduced 2 series of 33 long focus plates of the Galilean system taken, in 1967-68 with the 26-inch. refractor of the McCormick Observatory, and, in 1973-74 with the same type of instrument in the USNO, Washington DC. On these 33 plates, 21 of them have less than 3 Hipparcos stars in fields, whereas the number of stars in a linear model used to reduce long focus plates, especially in the case of images near the center, such as satellites, is at least 3. So the computation of a new reduction method is essential.

Here, we present our preliminary results concerning 10 plates of the McCormick refractor, reduced with 3 Hipparcos stars and 8 USNO plates with one Hipparcos star per plates. The total number of observations is 48.

Furthermore, the (o–c) presented here correspond to the position (α, δ) of Jupiter determined by the positions of its satellites.

3.2. Results with 3 Hipparcos Stars or More

The method, used here, is the classical technique of reduction, called the method of 'plates constants'. This technique models, by least-squares fitting, a linear law connecting the standard coordinates to the measured coordinates.

The standard coordinates are computed here using topocentric coordinates of date (algorithm of the Astronomical Almanac), corrected by atmospheric refraction (mapping function, Yan 1996).

Note that this takes into account for only the effects mainly due to the receptor.

These effects can be represented by:

- scale of the instrument;
- orientation parameters, representing rotation relative to the direction of the equator of the date;
- offsets in X and Y, due to the fact that we choose an arbitrary center of plate.

The results we obtained in Table 2 were consistent with the previous estimations: the accuracy increases by a factor 10.

Furthermore, we can conclude that the positional accuracy of the catalogue stars is no longer a limiting factor to the derived planetary position. Rather, it appears that the accuracy is now limited by observational errors, especially by approximations made for atmospheric phenomena.

Table 2. (O–C) (arcsec) of reduction with 3 Hipparcos Stars.

	α_{HIP}	α_{PPM}	δ_{HIP}	δ_{PPM}
	0.014±0.013	-0.257±0.101	-0.005±0.014	-0.366±0.058
5σ	0.030±0.012	-0.746±0.147	-0.015±0.012	-0.950±0.227

Table 3. (O–C) (arcsec) of reduction with 1 Hipparcos star and 2 PPM stars (line 1) and 1 Hipparcos star only (line 2).

stars	α_{HIP}	α_{PPM}	δ_{HIP}	δ_{PPM}
3	0.016±0.103	0.023±0.153	0.101±0.096	0.175±0.121
1	0.017±0.028	0.193±0.190	0.025±0.033	0.039±0.098

3.3. Reduction with 1 or 2 Stars

This technique is based also on the plate-constant method, but we solve only for the offsets in X and Y. This is feasible if the plates scale is accurately known and stable, and the plate orientation is determined from a star trail. Any error resulting from inaccuracies in these two quantities is minimized because the satellite system is near the center of the field.

We applied this procedure to the 24 observations made in 1973-74 with the USNO refractor:

- for observations, previously reduced, with the trail scale method (Pascu, Arlot), the center of the projection must be chosen quite accurately, by iterative process, to limit propagation of errors on the other parameters;
- for other observations, without star trail, we have to compute the orientation of the plate at the epoch of each observation. We made an initial choice for the orientation parameter and we determined the offset. If orientation is properly chosen, the χ^2 of the plate-to-plate transformation should be a minimum. We simply sample the orientation parameter population and search for the value at which χ^2 is minimized, and adopted this as the orientation parameter. This method was previously used by Guo (1993).

An offset between α and δ arises in Table 3. These results suggest an anisotropy of the scale factors in the X and Y directions.

Table 4. Scale factors for 1967 series.

(arcsec/mm)	X	Y
Computed	20.7608±0.00083	20.7616±0.00068
Theory(T=3°C)	20.7577±0.00140	20.7611±0.00130
mean theoretical value	20.7580±0.00100	20.7580±0.00100

4. CONTRIBUTION AND PROSPECTS

4.1. Anisotropy of the Scale

As explained previously, the offset between X and Y urges us to study the variations of the scale factors in X and Y. To study the scale anisotropy, we averaged the 10 plates of the McCormick refractor. These reductions were made for those plates having at least three Hipparcos stars on them.

The theoretical scale corresponds to a value determined by Gatewood (1997) from his Praesepe scale field and the study of the temperature dependence of scale by McAlister (1974).

A small systematic effect arises between scale in X and Y, however, this effect is included in error bars of these factors.

In other words, we may consider this offset in two ways:

- a real offset of scale for the Galilean system; effect that one can recognize in other data and can explain for in part by the inconsistency between optical and radar absolute positions of Jupiter;
- instrumental effects, for example differences between coefficients of expansion of the telescope versus the glass plate, or uncorrected atmospheric effects.

4.2. Prospects

So we may consider the first applications of such accuracy:

1. with the help of such results, it becomes possible to consider and to study poorly understood phenomena, such as refraction based upon a realistic atmosphere profile or relativist ephemerides and data reduction. Until now, the approximations made in such reductions were acceptable, but with the accuracy afforded with Hipparcos data, these effects can no longer be considered negligible;
2. improvement of planetary ephemerides: The ephemerides of outer planets have an accuracy of around an hundred mas. Furthermore, at the time of the adjustment of DE403 theory with observations, a systematic effect between the radar ranging data and the optical data have been observed. It is possible that positional data, obtained with Hipparcos reference stars, can help resolve this discrepancy.

In conclusion, due to its exceptional accuracy, the Hipparcos Catalogue can help us obtain planetary positions with an accuracy of an order of magnitude greater than that from classical methods. In addition, with this improved precision, we can now separate and study the instrumental and cosmic effects in plate solutions by advanced reduction methods.

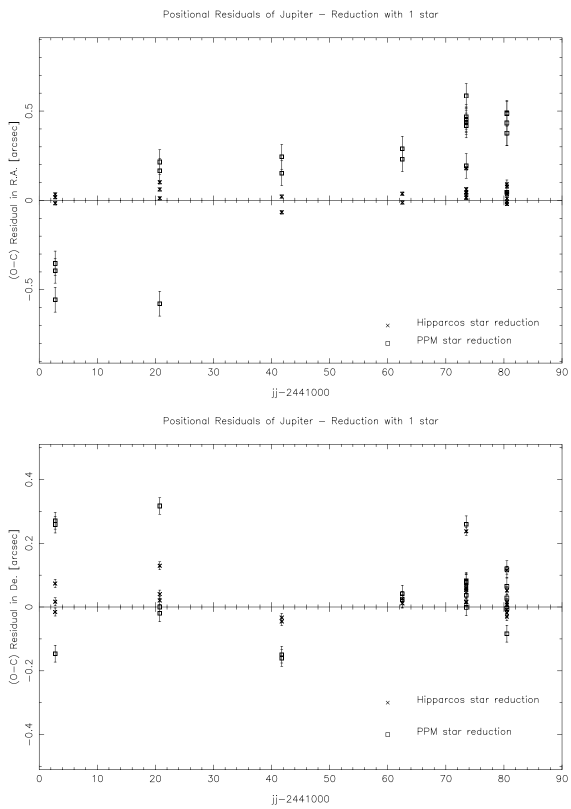

Figure 1. Positional residuals of Jupiter for 1 star reduction.

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