THE REFERENCE FRAME DETERMINED FROM THE OBSERVATION OF MINOR PLANETS BY HIPPARCOS

B. MORANDO & A. BEC-BORSENBERGER

Bureau des Longitudes

77, Avenue Denfert-Rochereau

75014 Paris - France

ABSTRACT. The observation of minor planets by Hipparcos offers the opportunity to obtain high precision positions for some minor planets. About fifty minor planets are on the programme. Their ephemerides had to be improved in order to reach a precision of 1 arsec and occultations by the Earth and the Moon had to be predicted.

From the position of a minor planet on reference great circles at different times better values of the initial position and velocity will be deduced but the reduction of the observations of the minor planets have to take into account the displacement of the photocentre relative to the centre which is due to the shape, the phase effect and the scattering properties of the surface. For some very small planets considered as star like this diplacement will be small and the precise positions obtained will allow to position the dynamical reference system relative to the Hipparcos system. For the bigger minor planets the observations by Hipparcos may give informations on the shape and scattering properties of the surface.

1. List of the minor planets on the programme

The times and the number of apparitions of the minor planets in the fields of view of the Hipparcos telescope has been calculated for each minor planet. Estimations of the maximum number of possible observations have been made following different values of the predicted Hipparcos magnitude. Predicted occultations by the Earth and the Moon have been studied by the FAST data analysis consortium at Cerga, and have been taken in account to obtain the windows of observability of the minor planets. The final selection of minor planets to be observed by Hipparcos has been made after consideration of the number of transits of minor planets for the period September 1989 to March 1992, the predicted magnitudes during these transits, and a possible degradation of the transparency of the telescope optics during the mission. Presently, new parameters have been introduced in the simulation, for estimating the number of transits which can be

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obtained during successive sequences of observations from november 1989 and taking into account the increased number of predicted occultations by the Earth and the Moon due to the elliptical orbit of the satellite (Bec-Borsenberger A. 1989).

The following list gives the numbers and names of the minor planets retained after consideration of their frequency and magnitude at the time of the Hipparcos observations.

No	Name	No	Name	No	Name
1	Ceres	18	Melpomene	63	Ausonia
2	Pallas	19	Fortuna	88	Thisbe
3	Juno	20	Massalia	115	Thyra
4	Vesta	22	Kalliope	129	Antigone
5	Astraea	23	Thalia	192	Nausikaa
6	Hebe	27	Euterpe	196	Philomela
7	Iris	28	Bellona	216	Kleopatra
8	Flora	29	Amphitrite	230	Athamantis
10	Hygiea	31	Euphrosyne	349	Dembowska
11	Parthenope	37	Fides	354	Eleonora
12	Victoria	39	Laetitia	451	Patientia
13	Egeria	40	Harmonia	471	Papagena
14	Irene	42	Isis	511	Davida
15	Eunomia	44	Nysa	532	Herculina
16	Psyche	51	Nemausa	704	Interamnia

2. Improvement of the orbital elements

Because of the importance of having good ephemerides for the Hipparcos project, the improvement of the orbital elements of the Hipparcos minor planets has been realized in parallel by A. Bec-Borsenberger and J. Calaf (Bec-Borsenberger A. , Calaf J. 1989) so that there is a full and independant cross check of the two sets of improved orbital elements.

The main points of the determination of these elements by the analysis of the residuals between the observations and the ephemerides are recalled here. From initial conditions which have been taken in the ephemerides for minor planets (ITA), equatorial positions have been computed by numerical integration for each date of the available observations: those collected at the Minor Planet Center (Cincinatti) and, since 1983, about 12700 observations made specifically for the Hipparcos project (Bordeaux, Fabra, La Palma, San Fernando observatories). To reduce the residuals between the observed place and the computed place, the partial derivatives with respect to the initial conditions are computed and the system of equations of condition thus obtained has been solved by the least square method; the variations of the elements given by the solution furnished new elements. As, for the Hipparcos project, ephemerides have to be referred to the J2000 frame, the improved elements and the observations have been referred to this frame; then new improvements, including the last available observations made during 1987 and 1988, were made. Based on these ephemerides of the minor planets, a test of the Hipparcos mission over three years, from the 1st of April 1989, has been carried out at the Besancon observatory.

3. Determination of accurate positions from Hipparcos

An observation by Hipparcos gives the position of a minor planet along a given reference great circle for a given time. From a certain number of these observations the position and velocity at a given time, considered as beeing an initial time, can be determined.

On figure 1 RGC is the reference great circle at a given time and P its pole. N being the ascending node of the RGC on the the ecliptic of J2000.0, Hipparcos gives us only arc λ equal to NM", where M" is the projection on the RGC of the position M of the minor planet on the celestial sphere.

Let β be arc M"M and l and b the ecliptic coordinates of M. The two vectors :

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} \cos\beta\cos\lambda \\ \cos\beta\sin\lambda \\ \sin\beta \end{bmatrix} \quad ; \quad \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \cos b \cos l \\ \cos b \sin l \\ \sin b \end{bmatrix}$$

are such that :

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = R \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

R is a rotation matrix which can be obtained for each observation as the ecliptic coordinates L and B of the pole P of the RGC are given. If :

$$i = \pi/2 - B \qquad u = \pi/2 + L$$

then :

$$R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos i & \sin i \\ 0 & -\sin i & \cos i \end{bmatrix} . \begin{bmatrix} \cos u & \sin u & 0 \\ -\sin u & \cos u & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} \cos u & \sin u & 0 \\ -\sin u \cos i & \cos u \cos i & \sin i \\ \sin u \sin i & -\cos u \sin i & \cos i \end{bmatrix}$$

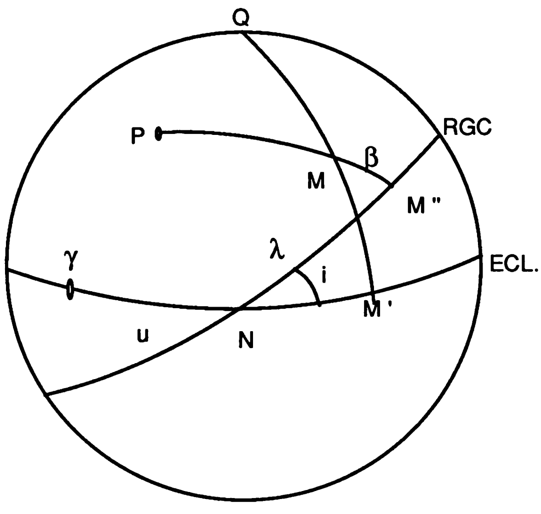

Figure 1.

The calculated coordinates x_c, y_c, z_c are functions of time t and of the initial conditions q_i (i = 1...6), the observed coordinates x_o, y_o, z_o are functions of time t and of $q_i + dq_i$, where the dq_i are corrections to he q_i

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$$x_c = x(q_i,t) \quad ; \quad x_o = x(q_i + dq_i,t)$$

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with analogous expressions for the y and z. A Taylor expansion to the first order gives :

$$x_o - x_c = \frac{\partial x}{\partial q_i} dq_i$$

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But the corresponding variations of the coordinates X, Y, Z in the RGC reference system are given by :

$$\begin{bmatrix} dX \\ dY \\ dZ \end{bmatrix} = R \cdot \begin{bmatrix} \frac{\partial x}{\partial q_i} \\ \frac{\partial y}{\partial q_i} \\ \frac{\partial z}{\partial q_i} \end{bmatrix} = \begin{bmatrix} A_i\, dq_i \\ B_i\, dq_i \\ C_i\, dq_i \end{bmatrix}$$

This gives, in terms of λ, β, $d\lambda$, $d\beta$:

$$- \sin\beta \cos\lambda\, d\beta - \cos\beta \sin\lambda\, d\lambda = A_i\, dq_i$$

$$- \sin\beta \sin\lambda\, d\beta + \cos\beta \cos\lambda\, d\lambda = B_i\, dq_i$$

$$\cos\beta\, d\beta = C_i\, dq_i$$

(The second members are, of course, summed over i.)

Hipparcos only yields values for $d\lambda$, elimination of $d\beta$ between the first two equations gives the fundamental equation of the problem :

$$\boxed{\cos\beta\, d\lambda = \left(B_i \cos\lambda - A_i \sin\lambda\right) dq_i}$$

Many such equations for a given planet can be combined and solved for the dq_i by the least square method. The combination of many such positions will give the position of the dynamical reference system relative to the Hipparcos system (Söderhjelm S. , Lindegren L. 1982).

4. Displacement of the photocentre

The ephemerides give the position of the centre of the minor planet but the observations give the position of the photocentre. The situation is explained on figure 2.

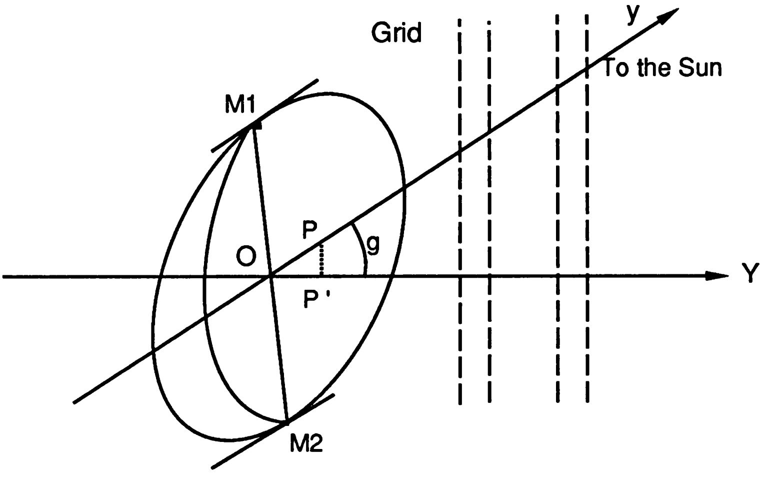

Figure 2.

This figure shows the focal plane of the Hipparcos telescope. Axis OY is perpendicular to the grid slits, Oy is directed towards the Sun. Assuming the minor planet to be a three axes ellipsoid, its image in the focal plane is an ellipse centered at O and the terminator is a half ellipse also centered at O and tangent to the first ellipse at M_1 and M_2. Hipparcos measures the abcissa along OY of the projection P'on OY of the photocentre P.

This peculiarity, which makes the observation of minor planets different from the observation of stars, has been studied by both reduction consortia, NDAC (Lindegren L. 1986) and FAST (Morando B. 1985, 1986). The position of P at any time may be calculated (Morando B. 1985) but depends strongly on the scattering properties of the surface of the minor planet. It is shown, for instance, that for a uniformly lit

Ceres the displacement of the photocentre is 0.004 arcsec for a phase angle of 20° but it is 0.02 arcsec if Lambert'law is true (Morando B. 1986). Unfortunately there are only few cases where shape-albedo models are known. However 17 of the minor planets on the programme are small enough to be considered as star like so that their positions will reach the nominal precision (Morando B. , Lindegren L. 1989).

5. Conclusion

Launched on the 9th of August 1989 Hipparcos could not be put on a geostationnary orbit so that the nominal mission will not be fulfilled. This means, as far as minor planets are concerned, that less observations will be made because occultations by the Earth and eclipses of the Sun as seen from the satellite will be more numerous than expected. Yet it is hoped that a good coverage made of observations to a few hundred arcseconds will be obtained.

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Discussion

MORRISON: Regarding the problem of the accurate calculation of the phase effect due to the scattering law, I presume that you are aware of the series of papers based on photometric results obtained with the CAMC?

MORANDO: Of course, I forgot to mention that we have a lot of information on the physical properties of the minor planets on the programme. In some cases they may be insufficient owing to the high precision of the observations by HIPPARCOS.

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