Section 2.7

Solar System Objects

2.7. Solar System Objects

2.7.1. Hipparcos (Main Mission) Observations

The Hipparcos observing programme included careful selection of all solar system objects observable by the satellite (major planets, natural satellites and minor planets). One of the primary motivations for including these objects was to provide the necessary material for the construction of a dynamical reference frame based upon the absence of local rotation in their equations of motion. These objects are brighter than 13 mag and smaller than 1 arcsec; in addition, the planetary satellites observed had to be sufficiently far from the planet to be observable beyond the corresponding envelope of scattered light. In total, 48 asteroids were observed (among the IAU list from (1) Ceres to (704) Interamnia), and three planetary satellites (J II–Europa, S VI–Titan and S VIII–Iapetus).

Positions and proper motions in the Hipparcos and Tycho Catalogues are given within the International Celestial Reference System (ICRS), and therefore represent an extension, at optical wavelengths, of the (extragalactic) radio reference system (see Section 1.2.2). The minor planet observations have been explicitly excluded from the construction of the Hipparcos reference system. Rather, the construction of a self-consistent dynamical reference frame will be a complex, long-term project, complicated by the phase and geometrical effects mentioned below, and somewhat constrained by the relatively short observation interval. The eventual comparison of the two resulting reference frames has been considered as a problem quite distinct from the construction of the Hipparcos Catalogue, and will only be undertaken after catalogue publication.

Some specific remarks are relevant for the astrometric measurements of solar system objects. Due to the particular scanning law of the satellite, observations only occur during the 18 seconds of an object's transit in one of the telescope's fields of view; they are spread around the quadratures (when the phase angle is maximum), and are not uniformly distributed in time. Since the scanning circles always subtend angles with the ecliptic of more than 47°, Hipparcos yields in general more accurate information on the object's ecliptic latitude than on its ecliptic longitude.

Each observation corresponds to a transit of the object across the instrument main grid. Because the observations are essentially one-dimensional (namely, in the direction perpendicular to the grid slits at the epoch of observation), and because solar system objects have a large daily motion, the observed direction cannot be given in the form of conventional, two-dimensional coordinates such as right ascension and declination. Instead, the observed quantity is the abscissa v of the projected position on a reference great circle with (positive) pole P; no information is given on the object's ordinate r on this great circle, except that $|r| \lesssim 1°$ (see Figure 2.7.1). The observed position is somewhere on an arc of a great circle perpendicular to this reference great circle, where the abscissa on the reference great circle is precisely the value given by the observation.

Table 2.7.1. Object numbering for Hipparcos and Tycho.

	Name	Number
Minor planets:	(1) Ceres	1
	...	IAU Number
	(704) Interamnia	704
Satellites:	J II–Europa	901
	J III–Ganymede	902
	J IV–Callisto	903
	S VI–Titan	904
	S VIII–Iapetus	905
Major planets:	Uranus	906
	Neptune	907

The published quantities defining this arc are reckoned in the tangent plane of a particular point. This particular point, referred to as the reference point, is chosen to be as close as possible to the actual position as given by the ephemerides. The reference point thus corresponds to the observed coordinate in the scanning direction, and to the calculated coordinate in the perpendicular direction (Figure 2.7.1). In this context, references to 'place' or 'position' correspond to the arc of a circle perpendicular to the reference great circle passing through the reference point, a one-dimensional quantity referred to hereafter as the 'position locus'.

All positions are referred to the reference frame defined by the Hipparcos Catalogue. The data for one observation consist of:

(1) the astrometric coordinates (α_0, δ_0) of the reference point, i.e. the geocentric direction corrected for stellar aberration; and the direction **w** in its tangent plane, of the slit motion (i.e. the trace of the reference great circle);

(2) the mean epoch of the transit, reduced to the geocentre, and expressed on the TT time scale (see Section 1.2.3);

(3) the apparent magnitude Hp in the Hipparcos photometric system.

Object Numbering for Solar System Objects

Identification numbers used for the observation of solar system objects are specific to this section, and should not be confused with the HIP identification number of entries in the main Hipparcos Catalogue. The same solar system object number applies to objects observed either by Hipparcos or by Tycho.

The numbering of minor planets corresponds to the IAU number. For the satellites and major planets the adopted numbering code has been chosen specifically for the Hipparcos/Tycho observations, and is given in Table 2.7.1.

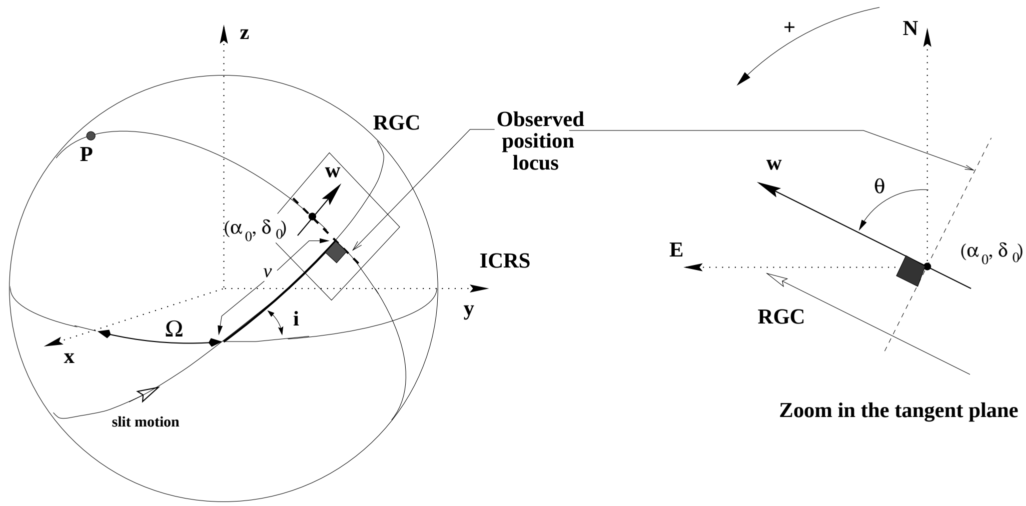

Figure 2.7.1. *One dimensional position locus for solar system objects observed by Hipparcos, on the celestial sphere (left), and on the tangent plane (right).*

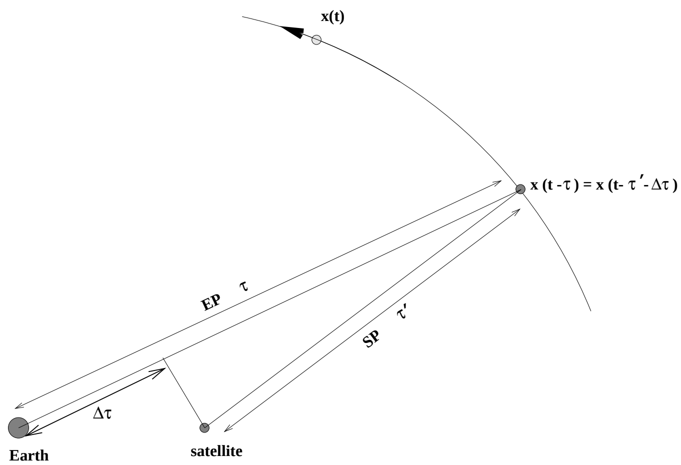

Figure 2.7.2. *Planetary aberration and the correction of light travel time.*

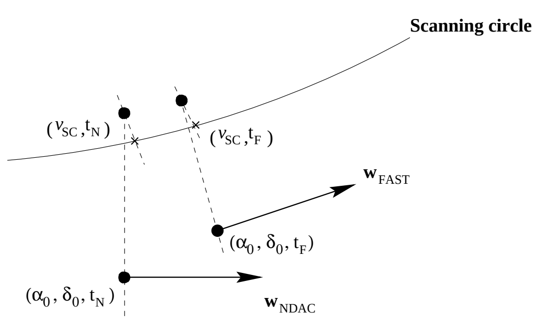

Figure 2.7.3. *FAST and NDAC observed reference points and position loci for two different* **w** *directions (or reference great circles) and for the different epochs* t_F *and* t_N*.*

2.7.2. Hipparcos Astrometry

The catalogue of minor planets and natural satellites consists of the separate FAST and NDAC consortia results. The main difference between the two reductions is in the expansion of the modulated light signal: using only the first harmonic for NDAC, but the first and second harmonics in the case of FAST. This has a negligible effect for the smallest bodies (with apparent diameters smaller than approximately 0.1 arcsec); then the positions correspond, to a first approximation, to the position of the photocentre. For the largest bodies, care must be taken in the actual definition of the observed direction. If the modulated signal is written in the form:

$$S(t) = I\ [1 + M\ \cos(\omega t + \varphi) + N\ \cos(2\,\omega t + 2\,\psi)] \qquad [2.7.1]$$

then the NDAC abscissa definition corresponds to the phase of the first harmonic $v_{\mathrm{N}} = f(\varphi)$; while the FAST abscissa definition corresponds to a weighted mean of both harmonic phases $v_{\mathrm{F}} = f(3/4\,\varphi + 1/4\,\psi)$ (where f is the application expressing the whole reduction process). For a point source the calibrated phases φ and ψ are equal so that $E(v_{\mathrm{F}} - v_{\mathrm{N}}) = 0$. For an extended source, $E(v_{\mathrm{F}} - v_{\mathrm{N}}) \sim f(1/4\,(\psi - \varphi))$ depending on the physical properties of the minor planet or satellite (such as apparent diameter, albedo contrast, and light scattering by the surface).

In particular the FAST abscissa for larger objects does not correspond to the conventional definition of the photocentre of the body. For this reason, no merging of the solutions has been performed, for any of the minor planets, on the FAST and NDAC catalogues. For a similar reason, only astrometric data within NDAC can be given for the two satellites J II–Europa and S VI–Titan. In fact, the FAST astrometric reduction procedure is unsuitable for objects with an apparent diameter larger than roughly 0.7 arcsec, i.e. when the second harmonic amplitude is too small. Table 2.7.2 summarises the data obtained by the Hipparcos (main mission) observations. In general, both FAST and NDAC observed abscissae are provided for each transit (a few transits do not appear in both consortia results). The corresponding position loci are perpendicular to two different **w** directions, the latter being close to the actual scanning motion (see Figure 2.7.3). The corresponding epochs are also different.

The various steps of the reduction procedure took into account effects down to the order of one milliarcsec. The observations are referred to the geocentre; they are corrected for stellar aberration (due to the satellite's barycentric velocity $\mathbf{v}$, and expanded to second order in $|\mathbf{v}|/c$), and general relativistic light deflection (due to the Sun's spherical gravitational field). Conversely, effects not modeled with the observing precision are discarded, in particular no attempt has been made to account for phase, shape, or albedo corrections. In general the observed minor planets are small (with an apparent diameter of less than 0.1 arcsec); in such cases the systematic photocentre offset between the observed centre of light and the centre of gravity may be smaller than the measurement noise, but still of the order of a few milliarcsec.

As stated previously, a single mean coordinate is given for the mid-time of each 18 s transit across the main field of view. For this reduction the movement of the object along the **w** direction was assumed to be linear in time and with a known velocity. One resulting normal point corresponds to the median (FAST) or a weighted mean (NDAC) of typically eight single measurements, so that the corresponding error distribution will not follow a normal distribution but rather a Student's t-like distribution. Some transits were discarded during one or other of the consortia's great circle data reductions, and also during the transit reductions. The latter correspond essentially to measurements corrupted by parasitic light (for example due to the parent planet in the case of planetary satellites, or veiling-glare by a star) and/or a badly centered instantaneous field of view.

The treatment of grid-step ambiguities for minor planets or natural satellites also differs from that applied in the case of stars. The basic measurement of the modulation phases φ and ψ in Equation 2.7.1, when translated to a one-dimensional geometrical coordinate, only gives the fraction of the grid period (1.2074 arcsec) counted from the centre of the nearest slit; to this must be added the coordinate of this nearest slit, which is assumed to be the nearest to the calculated ephemeris position of the object. The validity of the resulting position locus can only be verified in comparison with the improved ephemerides obtained after incorporating the Hipparcos observations. In this process, it may occasionally be necessary to correct the abscissae by ± 1.2074 in the scanning direction. As a rule, abscissae differing from the calculated abscissa by more than 0.801 arcsec in modulus were corrected by one grid period. This correction was only necessary for a very small number of observations. The data for minor planet (27) Euterpe are more troublesome. After rejection of suspicious transits, sometimes no satisfactory solution was found for the treatment of grid-step correction, so only the data uncorrected for possible grid-step errors are given. This means that some of the transits may be suspicious, or erroneous by one grid period (the transits concerned are in the time window $8200.5 < t - 2\,440\,000.0 < 8380.5$).

The published quantities defining the arc of a great circle of the observed positions are:

(a) the reference point (α_0, δ_0) of this arc such that its abscissa on the reference great circle is the observed one, and its (unobserved) ordinate on this great circle is taken from the ephemerides ($v = v^{\mathrm{obs}}$; $r = r^{\mathrm{calc}}$). The reference point is generally within ~ 1 arcsec of the true position;

(b) the position angle θ between the direction $\mathbf{w}$ of the slit motion and north (see Figure 2.7.1). The $\mathbf{w}$ axis is also oriented in the sense of increasing abscissae v, with the position angle θ reckoned positive from north through east;

(c) the standard error in the $\mathbf{w}$ direction, $\sigma_{v*} = \sigma_v \cos r^{\mathrm{calc}}$. There is no astrometric measurement, and thus no similar quantity, along the perpendicular direction ($\theta \pm \pi/2$).

The position locus and epoch of observation are both corrected to the geocentre. The astrometric direction corresponds to the position of the object at time $t - \tau$, where t is the published epoch of observation and τ the light time delay to the geocentre.

The epoch at the Hipparcos satellite can be calculated by $t' = t - \Delta\tau$ where the difference $\Delta\tau \equiv \tau' - \tau$ is provided as additional data (see Figure 2.7.2). Since the latter is a small quantity when compared to the time resolution of the basic measurement, no use of a special relativistic formalism has been made; this time offset is then calculated as:

$$\Delta\tau \equiv \tau' - \tau = \frac{EP - SP}{c} \qquad [2.7.2]$$

where EP and SP are respectively the geocentric and satellitocentric distances of the planet apparent position, and c the velocity of light.

When comparing the published coordinates with independent two dimensional equatorial coordinates (α^c, δ^c)—which may be either calculated or observed—the strictly one-dimensional nature of the Hipparcos observations must be taken into account, since the published direction (α_0, δ_0) effectively constrains the position in only this single dimension (see Figure 2.7.1). Thus, for comparison with the observed positions, the residuals (i.e. the differential equatorial coordinates):

$$\begin{pmatrix} \Delta\alpha* \\ \Delta\delta \end{pmatrix} = \begin{pmatrix} (\alpha_0 - \alpha^c) \cos\delta_0 \\ \delta_0 - \delta^c \end{pmatrix} \tag{2.7.3}$$

should be projected onto the great circle:

$$\begin{pmatrix} \Delta v* \\ \Delta r \end{pmatrix} \sim \begin{pmatrix} \sin\theta & \cos\theta \\ -\cos\theta & \sin\theta \end{pmatrix} \begin{pmatrix} \Delta\alpha* \\ \Delta\delta \end{pmatrix} \tag{2.7.4}$$

from which only the single equation of condition:

$$\Delta v* = v^{\mathrm{obs}} - v^{\mathrm{calc}} \sim (\sin\theta \quad \cos\theta)\ \mathbf{M}\,\Delta\mathbf{x}^{\mathbf{c}} \tag{2.7.5}$$

is retained, instead of the usual system of two equations:

$$\begin{pmatrix} \Delta\alpha* \\ \Delta\delta \end{pmatrix} \sim \mathbf{M}\,\Delta\mathbf{x}^{\mathbf{c}} \tag{2.7.6}$$

where $\mathbf{M}$ is the matrix yielding the differential equatorial coordinates from the variation in orbital elements $\Delta\mathbf{x}^{\mathbf{c}}$; and where small terms due to the projection from the celestial sphere to the tangent plane are neglected.

2.7.3. Hipparcos Photometry

The published photometric data is the result of a single data reduction consortium (the FAST Consortium) and is restricted to minor planets only. The reduction of the data was similar to that adopted for double stars. Two different estimations of the apparent magnitude (Hp_{dc} and Hp_{ac}) are given for each transit in the Hipparcos photometric system Hp (see Section 1.3 and Section 2.5). The correction to the geocentre of the epoch of observation is irrelevant for the photometry and, in contrast with the astrometric data, is not applied.

The magnitude estimator Hp_{dc}, derived from the integrated light, corresponds to the 'true' magnitude; while the estimator Hp_{ac}, derived from the two harmonics of the modulated part of the light, is biased and of lower accuracy. Although the difference between these two estimations depends on the scanning direction, shape, albedo contrast, and light scattering on the surface of the object, it depends mostly on the object's apparent diameter. Moreover $\Delta Hp = Hp_{\mathrm{ac}} - Hp_{\mathrm{dc}} > 0$ and in a first approximation $\Delta Hp(\varrho, \alpha) = a\varrho^2 + o(\varrho^4) + o(\alpha)$, where a is a scalar, ϱ the apparent diameter and α the solar phase angle. For the smallest asteroids, the difference between these two determinations is however smaller than the measurement noise.

Due to the rather random observation epochs of the objects, the data rarely yield magnitudes over a rotation period, nor representative light curves. They can nevertheless be used for deriving absolute magnitudes (accurate to about 0.03 mag) over a large range of phase angles and rotational phase. Some aspect data are also provided for convenience: these are the Sun-asteroid and satellite-asteroid distances, and the solar phase angle.

Due to the perturbation by the planet, which contributed significantly to the background scattered light, no photometry is provided for the planetary satellites.

Table 2.7.2. Solar system objects observed by the Hipparcos main mission. Apparent magnitudes are from the FAST Consortium only. Astrometry results have been derived from the separate FAST and NDAC reductions.

	Name	Photometry	Astrometry
Minor planets:	(1) Ceres	FAST	FAST + NDAC
	...	FAST	FAST + NDAC
	(704) Interamnia	FAST	FAST + NDAC
Satellites:	J II–Europa	–	NDAC
	S VI–Titan	–	NDAC
	S VIII–Iapetus	–	FAST + NDAC

Table 2.7.3. Solar system objects observed by Tycho. The star mapper observations yield astrometry for the objects listed, and photometry for the smallest objects only.

	Name	Photometry	Astrometry
Minor planets:	(1) Ceres	√	√
	(2) Pallas	√	√
	(4) Vesta	√	√
	(6) Hebe	√	√
	(7) Iris	√	√
Satellites:	J III–Ganymede	–	√
	J IV–Callisto	–	√
	S VI–Titan	√	√
Major planets:	Uranus	–	√
	Neptune	–	√

Table 2.7.4. Number of observations for Hipparcos and Tycho.

Hipparcos			
N	Astrometry		Photometry
	NDAC	FAST	FAST
1	72	65	65
2	66	63	63
3	67	61	60
4	55	58	58
5	89	81	81
6	100	95	91
7	73	71	69
8	58	56	56
9	43	40	40
10	62	51	51
11	83	68	68
12	24	24	24
13	37	34	34
14	51	45	45
15	96	84	83
16	56	49	49
18	110	100	100
19	30	30	30
20	62	62	61
22	67	63	63
23	69	66	66
27	38	35	35
28	35	34	33
29	85	75	74
30	47	48	48
31	17	14	14
37	40	33	32
39	123	114	112
40	107	103	103
42	53	51	51
44	53	53	53
51	15	15	14
63	15	12	12
88	36	36	36
115	31	33	33
129	46	41	40
192	33	32	32
196	18	14	14
216	22	21	21
230	33	35	35
324	74	73	73
349	108	94	92
354	103	98	98
451	31	29	29
471	114	112	112
511	62	64	64
532	41	40	40
704	87	82	82
901	64	0	0
904	38	0	0
905	5	8	0

Tycho		
N	Astrometry	Photometry
1	43	43
2	31	31
4	40	40
6	12	12
7	24	24
902	16	0
903	13	0
904	19	19
906	51	0
907	42	0

2.7.4. Tycho Observations

The data gathered by the star mapper yield valuable results for some of the minor planets, satellites and planets, as given in Table 2.7.3. The main differences between the Tycho and Hipparcos results are that Tycho provides: (a) photometry in the B_T and V_T bands; (b) more conventional two-dimensional astrometry; (c) astrometry for larger angular diameter objects. The theory of Tycho astrometric reduction of solar system objects is given in Volume 4.

Photometry can only be provided for objects smaller than the width of the modulating slit, i.e. 0.91 arcsec; while astrometry can be obtained for larger objects up to approximately 5 arcsec. For the smallest objects both photometric and astrometric data can be obtained (see Table 2.7.3); for major planets, the Tycho observations only provide astrometric information.

No attempt has been made to account for phase, shape, or albedo corrections. The published Tycho astrometric position corresponds to the photocentre for objects smaller than the slit width, where the photocentre is the 'centre of gravity of light'.

The astrometric position of the single slit group crossing corresponds to the projection of the slit group on the sky at the time of transit determined by the Tycho detection algorithm (see Volume 4).

For the largest natural satellites and for the major planets, it is assumed that (1) the time offset between the two slit group crossings is small enough and (2) the distribution of light is sufficiently symmetric, so that the published position corresponds, to a first approximation, to the photocentre. Additional data are provided to enable the user to reconstruct the slit geometry during the observation if a more comprehensive treatment is undertaken.

Each observation corresponds to a transit, on both vertical and inclined slits, across the star mapper for one of the fields of view. One (mean) position is constructed assuming that the ephemeris is sufficiently accurate to yield the true planet motion during the short interval $t_2 - t_1$, where t_1 and t_2 are the times of transit across the inclined and vertical slit respectively (see Figure 2.7.4). The position (α, δ) given in equatorial coordinates corresponds to the intersection of the fiducial slits at O_2' at the time of transit t_2, i.e. when the inclined slit has been translated by an amount corresponding to the calculated displacement $\overrightarrow{c_1 c_2}$.

Together with the position the standard errors $\sigma_{\alpha *} = \sigma_{\alpha \cos\delta}$, σ_δ and the correlation coefficient $\rho^{\delta}_{\alpha *}$ are given, where small additional error contributions due to the projection on the focal plane are neglected (Figure 2.7.5). The orientation and size of the error ellipse defined by the covariance matrix of the observed equatorial coordinates, as well as the non-zero correlation coefficient, are related to the spatial direction of the slits and to the standard deviations σ_1, σ_2 of the slit abscissae measured along the direction of the slit motion during each observation. The cartesian equation of the ellipse is in the (E, N) frame (see Figure 2.7.5):

$$\frac{(\Delta\alpha *)^2}{\sigma^2_{\alpha *}} + \frac{(\Delta\delta)^2}{\sigma^2_{\delta}} - \frac{2\,\rho^{\delta}_{\alpha *}\,\Delta\alpha *\,\Delta\delta}{\sigma_{\alpha *}\,\sigma_\delta} = 1 - (\rho^{\delta}_{\alpha *})^2 \qquad [2.7.7]$$

The transit epoch, measured at the satellite, is given in Julian date in the TT time scale. In contrast to the astrometric catalogue of the Hipparcos solar system objects

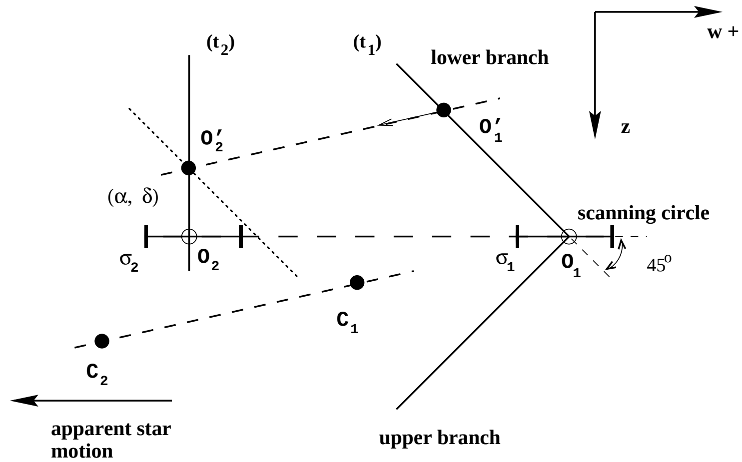

Figure 2.7.4. *A projection on the sky showing how a two-dimensional position of a solar system object is constructed within Tycho. C_1 and C_2 are the calculated positions at times t_1 and t_2. O_1 and O_2 are the observed slits abscissae with error bars σ_1 and σ_2. The published position corresponds to O_2', i.e. the intersection of the vertical slit at t_2 with the translated inclined slit.*

(Figure 2.7.2), the light-time delay between the satellite and the geocentre is neglected. Thus the position is not corrected for light-time delay, nor is it referred to the geocentre. The position corresponds in first approximation to the astrometric direction, given in equatorial coordinates in the ICRS system (see Section 2.7.1). The apparent magnitudes B_T and V_T are in the Tycho photometric system (see Section 1.3.3).

The Tycho observation principle is to detect transits near the predicted slit crossing time (within a few arcsec on the sky). Some observations were corrupted by the presence, in one of the fields of view, of a parasitic object, i.e. a star near the predicted position. Such observations had to be filtered and rejected. Rejection criteria were based on the observed V_T magnitude, on a comparison between the observed with respect to the calculated position, and on its standard error. Certain ambiguous cases still remain, however, and in these cases the different possible transits are published. These cases are specifically flagged since only one of the published transits can be correct.

Additional information concerning the observations for each transit is also given. These are the standard errors σ_1 and σ_2 (see Figure 2.7.4) related to the observed positions, along the direction **w**, of the inclined and vertical slits. The position angle θ of the direction **w** normal to the vertical slits, and the branch of the inclined slits on which the transit occurred (+1 for the upper and −1 for the lower) are also given (see Figure 2.7.6).

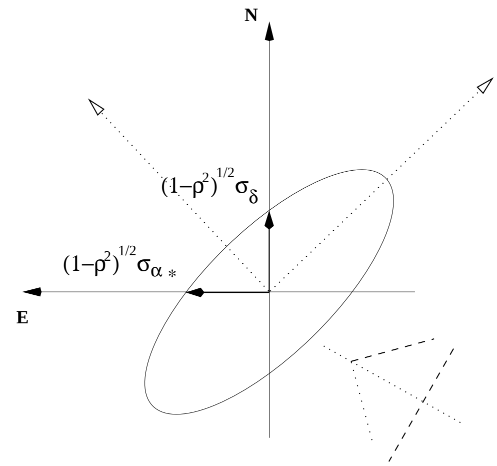

Figure 2.7.5. Standard errors for Tycho astrometry. In general the published standard errors of the equatorial coordinates do not correspond to the principal components of the ellipse. The published equatorial coordinates are thus correlated. The slit system is shown together with the error ellipse for a realistic observation ($\sigma_1 = 2\,\sigma_2$) and a transit in the upper part of the inclined slit.

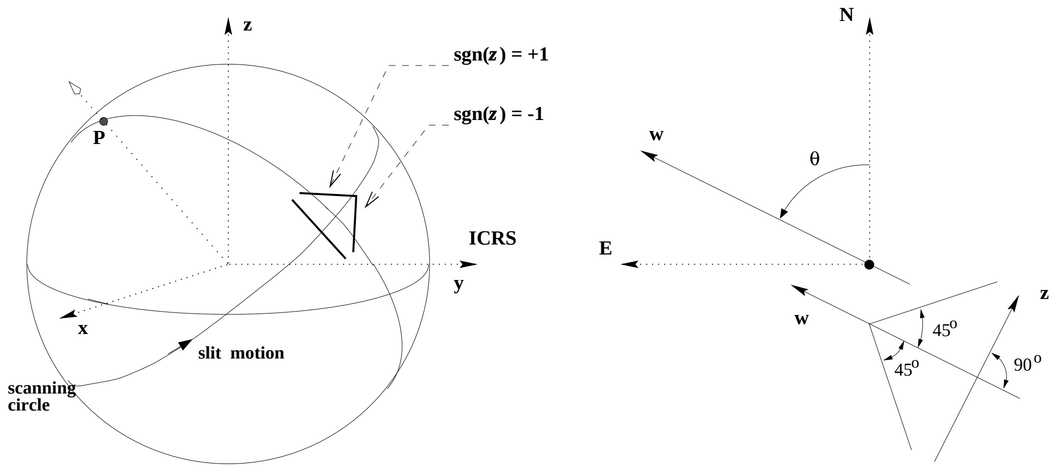

Figure 2.7.6. Additional information on the slit orientation, on the celestial sphere (left) and in the tangent plane (right). The slit coordinate direction **w** is given by the position angle θ, from which the directions of the vertical and inclined slits can be reconstructed. The figure in the tangent plane shows the slit coordinate system (**w**, **z**).

2.7.5. Hipparcos Solar System Objects: Astrometric Catalogue

Field SHA1: Object number

See Table 2.7.1.

Fields SHA2–3: Right ascension and declination of the reference point, (α_0, δ_0)

The reference coordinates are referred to ICRS.

Field SHA4: Measurement epoch, corrected to the geocentre

The measurement epoch is specified in Julian Date with respect to JD(TT) 2 440 000.0 . It is the mean epoch, given with an accuracy of 0.01 s, corrected to the geocentre as described in Section 2.7.2.

Field SHA5: Additional data: light time delay

This gives the applied light time delay in the geocentric direction of the observed object, between the satellite and the geocentre (see Figure 2.7.1), in seconds of TT.

Field SHA6: Position angle θ of the slit coordinate direction $\mathbf{w}$

The position angle is referred to the north, reckoned positive from north through east.

Field SHA7: Estimated standard error, $\sigma_{v*} = \sigma_v \cos r^{\text{calc}}$

This provides the standard error of the abscissa v along the direction $\mathbf{w}$, in milliarcsec, as described in Section 2.7.2.

Field SHA8: Consortium origin flag

If the transit corresponds to an NDAC record the flag is 1; if it corresponds to a FAST record the flag is 2.

2.7.6. Hipparcos Solar System Objects: Photometric Catalogue

Within the catalogue of solar system objects observed by the Hipparcos main mission, photometry is given only for asteroids.

Field SHP1: Object number

See Table 2.7.1.

Field SHP2: Measurement epoch

The measurement epoch is specified in Julian Date with respect to JD(TT) 2 440 000.0 . In contrast with the Hipparcos astrometric epoch for solar system objects (Field SHA4), the measurement epoch is not corrected to the geocentre (i.e. the light-time delay between the satellite and the geocentre is neglected).

Fields SHP3–4: Magnitude and standard error from unmodulated signal

The magnitude, $Hp_{\rm dc}$, and standard error, $\sigma_{Hp_{\rm dc}}$, are given in the Hipparcos photometric system Hp, as estimated from the unmodulated part of the light signal.

Fields SHP5–6: Magnitude and standard error from modulated signal

The magnitude, $Hp_{\rm ac}$, and standard error, $\sigma_{Hp_{\rm ac}}$, are given in the Hipparcos photometric system Hp, as estimated from the modulated part of the light signal.

Fields SHP7–9: Additional aspect data provided for convenience

The distances Sun-asteroid d and satellite-asteroid Δ are given in AU, the solar phase angle α (the angle between the Sun and the satellite as viewed from the asteroid) is given in degrees.

2.7.7. Tycho Solar System Objects: Astrometric/Photometric Catalogue

Field ST1: Object number

See Table 2.7.1.

Field ST2: Measurement epoch

The measurement epoch is specified in Julian Date with respect to JD(TT) 2 440 000.0 . In contrast with the Hipparcos astrometric epoch for solar system objects (Field SHA4), the measurement epoch is not corrected to the geocentre (i.e. the light-time delay between the satellite and the geocentre is neglected).

Fields ST3–4: Equatorial coordinates (α, δ) in degrees in the ICRS system

Fields ST5–6: Magnitudes in the Tycho system B_T and V_T

Field ST7 Multiple transit flag

If the flag is 1, then only one crossing of the field of view has been detected or retained. If the flag is $n > 1$, generally $n = 2$, then n candidate observed transits have been retained for that particular predicted observation (Fields ST1, ST2, ST7, ST11 and ST12 being identical in those cases).

Fields ST8–10: Standard errors $\sigma_{\alpha*} = \sigma_\alpha \cos\delta$, σ_δ given in milliarcsec, and correlation coefficient $\rho^{\delta}_{\alpha*}$ (see Section 1.2.7)

Fields ST11: Additional data: position angle θ of the slit coordinate direction **w**

Field ST12: Additional data: inclined slit flag, sgn(z)

The flag is +1 if the transit occurred in the upper branch of the inclined slits and −1 if it occurred in the lower half.

Fields ST13–14: Additional data: standard errors of the slit position along the direction **w**, σ_1 and σ_2 for the inclined and vertical slits respectively, given in milliarcsec

Table 2.7.5. Hipparcos solar system objects: astrometric catalogue

Field	Bytes	Format	Description
SHA1	1–4	I3,X	Object number
SHA2	5–16	F11.7,X	Reference point RA α_0 (degrees)
SHA3	17–28	F11.7,X	Reference point Dec δ_0 (degrees)
SHA4	29–42	F13.7,X	Measurement epoch, JD(TT) − 2 440 000.0 (days)
SHA5	43–48	F5.2,X	Light time delay satellite–geocentre $\Delta\tau$ (seconds)
SHA6	49–56	F7.3,X	Position angle θ (degrees)
SHA7	57–63	F6.2,X	σ_{v*} (mas)
SHA8	64	I1	NDAC (1) or FAST (2) flag

Table 2.7.6. Hipparcos solar system objects: photometric catalogue

Field	Bytes	Format	Description
SHP1	1–4	I3,X	Object number
SHP2	5–16	F11.5,X	Measurement epoch, JD(TT) − 2 440 000.0 (days)
SHP3	17–24	F7.4,X	$Hp_{\rm dc}$ (mag)
SHP4	25–31	F6.4,X	$\sigma_{Hp_{\rm dc}}$
SHP5	32–39	F7.4,X	$Hp_{\rm ac}$ (mag)
SHP6	40–46	F6.4,X	$\sigma_{Hp_{\rm ac}}$
SHP7	47–52	F5.3,X	Distance Sun-asteroid d (AU)
SHP8	53–58	F5.3,X	Distance satellite-asteroid Δ (AU)
SHP9	59–63	F5.2	Solar phase angle α (degrees)

Table 2.7.7. Tycho solar system objects: astrometric and photometric catalogue

Field	Bytes	Format	Description
ST1	1–4	I3,X	Object number
ST2	5–18	F13.7,X	Measurement epoch, JD(TT) − 2 440 000.0 (days)
ST3	19–30	F11.7,X	α (degrees)
ST4	31–42	F11.7,X	δ (degrees)
ST5	43–48	F5.2,X	B_T (mag)
ST6	49–54	F5.2,X	V_T (mag)
ST7	55–56	I1,X	Transit flag
ST8	57–62	F5.1,X	$\sigma_{\alpha*}$ (mas)
ST9	63–68	F5.1,X	σ_δ (mas)
ST10	69–74	F5.2,X	$\rho_{\alpha*}^{\delta}$
ST11	75–81	F6.2,X	Position angle θ (degrees)
ST12	82–84	I2,X	$\mathrm{sgn}(z)$
ST13	85–90	F5.1,X	σ_1 (mas)
ST14	91–95	F5.1	σ_2 (mas)