APPENDIX A

# GLOSSARY

Some of the terms included in the Glossary of Volume 1 are repeated here, where considered appropriate. Certain additional terms more relevant for the published catalogues may also be found in the Glossary of Volume 1.

Abscissa: the angular coordinate of a star measured from an arbitrary origin on the reference great circle to the normal projection of the star on that circle. The perpendicular coordinate is known as the ordinate of the star. The collection of abscissa measurements were used to derive the astrometric parameters of each star. The individual abscissa measurements are retained as useful intermediate astrometric data on the ASCII CD-ROMs. See also great-circle reduction.

ac magnitude: the magnitude derived from measurements of the modulation amplitude of the image dissector tube signal.

Accumulated photometry: the magnitude *Hp* determined for every star as the median of the *Hp* magnitudes derived from the individual transits.

Accuracy: the uncertainty of a measured quantity, including accidental and systematic errors. The term is often used synonymously with 'external standard error' (cf. precision).

Active stars: in the FAST Consortium's great-circle reduction software, stars were divided into 'active stars' for which a rigorous least-squares solution was computed (and which, therefore, defined the geometric reference on the circle) and 'passive stars' (which were defined *a priori* or during the processing itself) which were fitted into the reference framework of the active stars. In the NDAC Consortium, the concept of active and passive stars was replaced by the procedure of re-weighting.

Astrometric binary: a physical stellar system not observed as a visual double because of its small separation and/or large magnitude difference, but evidently non-single because of the detectable non-linear proper motion of the photocentre. A large residual from a model with five astrometric parameters may also indicate that the actual motion may deviate from the assumed rectilinear motion of the centre of mass.

Astrometric parameter determination: the final step of the 'three-step' method, which allowed the calculation of astrometric parameters for any (single) star from its observed abscissae on (typically) 50 different reference great circles.

Attitude determination: the name given to the process by which the data from the satellite (the star mapper transits and the gyro data) were used to derive a description of the

three-axis attitude of the viewing directions of the payload at any instant in time. On-board, this process (referred to as real-time attitude determination) used the brighter star transit information from the star mapper to yield a three-axis attitude accurate to about 1 arcsec rms. On the ground, this was improved to some 0.1 arcsec for the direction of the spin axis, and to a few milliarcsec for the spin phase.

Attitude smoothing: as part of the iterations performed during the great-circle reductions, knowledge of the along-scan attitude of the satellite was improved by modelling the attitude evolution, between gas jet actuations, by means of splines. The improved attitude resulted in the effective connection of stars not present simultaneously within the combined field of view, in a correspondingly improved 'rigidity' of the great-circle solution, and, thus, in improved precision on the great-circle abscissae of the programme stars.

Basic angle: the fixed angle, approximately 58°, between the two viewing directions of the Hipparcos telescope. The exact value of the basic angle was determined during commissioning to a precision of about 1 arcsec, sufficient for the piloting of the image dissector tube to the transiting programme stars. During the great-circle reductions, the basic angle was determined, as part of the geometrical transformation parameters, to much better than a milliarcsec. The stability of the basic angle during the calibration period (of one reference great circle, or about 10.7 hours) was ensured by the payload thermal control.

$B_T$ magnitude: see Tycho magnitudes.

Beam-combining mirror: the first element of the Hipparcos payload optics, responsible for combining the light from the two fields of view, separated by the 'basic angle'.

Complementary field of view: during the observation of a programme star in one of the two fields of view, the region of the sky covered by the other field of view is referred to as the complementary field of view.

Corrections to origins: the angular correction applied to the arbitrary origin of each great circle to bring these origins into a consistent system (see also sphere solution).

Cramér-Rao limit (or Minimum Variance Bound): in statistical estimation a lower bound to the variance of an unbiased estimator of a parameter. The practical importance of the limit is that it is often much easier to calculate than the actual variance of a given estimator, and is independent of the choice of estimator: it is given by the negative inverse of the expected curvature (or Hessian matrix) of the log-likelihood function. The realism of the Cramér-Rao limit as an estimator of the variance of a given parameter must be investigated e.g. by Monte Carlo simulations.

dc magnitude: the magnitude derived from measurements of the zero-level of the image dissector tube signal.

Dynamic smoothing: see geometric smoothing, and attitude smoothing.

Epoch photometry: the determination of the $Hp$ magnitudes (and in the case of the Tycho Catalogue, the $B_T$ and $V_T$ magnitudes) performed at every grid crossing or transit.

Field angles: spherical coordinates defined in analogy with the 'field coordinates'.

Field coordinates: direction cosines $(w, z)$ of an object in one of the two fields of view, with respect to the orthogonal unit vectors **w** and **z** (see Appendix B).

Field of view: one of the regions of sky, $0\overset{\circ}{.}9 \times 0\overset{\circ}{.}9$ in size, visible at any given instant to the Hipparcos payload. The two fields of view (preceding and following), separated by the basic angle of about 58°, were brought to a common focal surface by means of the 'beam-combining' mirror.

Field-to-grid transformation: the geometrical relationship between the coordinates of an object on the celestial sphere, as described by the 'field angles' or 'field coordinates', and the 'grid coordinates' measured at the focal surface of the telescope. The parameters of the transformation were calibrated during the great-circle reductions, over a time interval corresponding to that of a reference great circle, or about 12 hours.

Field transit: the transit of a stellar image across the field of view, often referring to the data collected for that star during this time interval.

First-look analysis: the data analysis set up by the FAST Consortium, at SRON, Utrecht, to allow a first inspection of subsets of the data within a few days of the generation of the data by the satellite.

Five-parameter model: the basic model describing the modulated image dissector tube signal in terms of a general two-harmonic trigonometric function, with five unknown parameters. The phases determined from the model fitting were used as inputs to the great-circle reductions. The term may also refer to the standard astrometric model, whereby the apparent motion of a (single, unperturbed) star is described by the five astrometric parameters.

Fully observable star: a concept defined in the context of the star observation strategy (see Volume 2) indicating that a star was within one of the fields of view throughout a given observation frame (of duration $T_4 = 2.133\ldots$ s), i.e. not in the process of entering or leaving the field. Most observed stars fell into this category (see also partially observable star).

General parameters: the set of instrumental parameters common to all abscissae determined during the sphere solution.

Geometric smoothing: the process of improving the knowledge of the satellite attitude by including a geometric model of the attitude evolution (as adopted by FAST) in contrast to an attitude model more dependent on a consideration of the dynamical motion of the satellite (referred to as dynamical smoothing).

Great circle: one revolution of the satellite, roughly corresponding to a great circle projected on the sky, corresponded to a period of approximately 2.1 hours. Data from several great circles, comprising a reference great-circle set, were reduced together as part of the great-circle reductions.

Great-circle reduction: the first step in the 'three-step' reduction method, whereby phases determined by the image dissector tube data processing were brought together (over about 5 satellite rotations or revolutions, or about 10.7 hours), to derive the along-scan abscissae of the stars, with respect to an adopted 'reference great circle' by the method of least-squares.

Grid coordinates: orthogonal rectangular coordinates in the tangent plane at the centre of the main modulating grid, expressed in linear units.

Grid period (or grid step): the period of the main modulating grid. From the great-circle reductions the mean grid period was found to be 1.207 366 arcsec, with extreme values (depending on position in the field of view) of 1.207 348 and 1.207 371 arcsec. Where only an approximate value of the grid period is relevant, the nominal pre-launch value of 1.208 arcsec is frequently used. Where a more accurate value was appropriate (for example, to correct slit errors in the sphere solution), a value of 1.2074 arcsec has been adopted.

Grid-step ambiguity: the along-scan phase measurements were made modulo one grid period (approximately 1.208 arcsec), so that stars with relatively poor *a priori* knowledge in their positions (or as a consequence of the poor instantaneous knowledge of the satellite attitude) suffered a corresponding uncertainty in the determination of their grid

coordinates. If different measurements differ within a reference great circle, this fact can be recognised in the great-circle processing and duly corrected—the effect is then referred to as a grid-step inconsistency. Once made consistent at the level of the great-circle reductions, the grid coordinate may still be incorrect by a multiple of the grid step. This problem is referred to as that of grid-step errors. Such errors do not generally affect the validity of the great-circle abscissae derivations: they are recognised and corrected during the sphere solution process, and updated values are used in iterations of the great-circle reductions to improve the attitude knowledge.

Grid-step error: see also grid-step ambiguity. In the double-star reductions, a grid-step error may occur for any (or several) stars in a system with poorly known *a priori* positions, and especially for new doubles with a large magnitude difference, the separation may be in error by one or more times 1.2 arcsec (due to differences in the scanning geometry, the unit is not exactly that of the nominal grid period).

Heliotropic angles: angles within the heliotropic reference frame in which one of the reference axes was constantly pointing towards the (nominal) Sun. This reference frame was used in the NDAC Consortium reductions (for defining the instantaneous deviation of the actual satellite attitude from that given by the nominal scanning law, and in defining the reference framework for the great-circle reductions).

Hipparcos magnitude: the magnitude, designated by *Hp*, sensed by the (broad-band) main detection system of the Hipparcos payload. The payload response was calibrated as a function of wavelength before launch, and photometric calibration was carried out throughout the mission by means of the reductions to an adopted system defined by standard stars.

*Hp*: see Hipparcos magnitude.

Housekeeping data: auxiliary data generated by the satellite, in addition to the main mission data, needed for a full exploitation of the satellite information. It included in-flight calibration data, thermal payload measurements, and instrument status.

ICRS: the International Celestial Reference System, in which the Hipparcos and Tycho Catalogue positions and proper motions are given. This is consistent with the conventional equatorial system for the mean equator and equinox of J2000, previously realised by the FK5 Catalogue (see Section 1.2.2 of Volume 1 for further details).

Inclined slits: part of the star mapper grid consisting of four $\vee$-shaped slits, and used for the determination of the transverse coordinate of star images. The apex of the inclined slits is located in the viewing plane. See also vertical slits.

Instantaneous field of view: the sensitive area of the image dissector tube (behind the modulating grid) of about 38 arcsec diameter. The image dissector tube allowed a rapid change of the mean position of the instantaneous field of view, making it possible to observe several stars in the field of view almost simultaneously.

Instantaneous scanning great circle: see viewing plane.

Intensity transfer function: the description of the relation between the measured photon-counts (in de-compressed form) and a linear intensity scale.

Julian Year: $365.25 \times 86\,400$ s (exactly).

Large-scale distortion: the component of the field-to-grid transformation (originating from the payload optics) which was calibrated during the great-circle reductions.

Longitudinal: this prefix usually signifies a quantity measured or counted in the direction of scanning (i.e. perpendicular to the slits of the main grid), as opposed to the transverse quantity (normal to the scan)—e.g. longitudinal field angle.

Main grid: the main modulating grid of 2688 parallel slits, each of width 3.13 $\mu$m, and separated by 8.2 $\mu$m, or approximately 1.208 arcsec on the sky. The grid, engraved on the spherical surface of a piece of glass matching the telescope's focal plane curvature, was built up from 168 by 46 elements (each containing 16 lines), referred to as 'scan fields'. With the scanning of the telescope, stellar images moved across the focal plane roughly perpendicular to the grid lines, resulting in a very regular modulation of the light observed from behind the grid.

Main mission/main experiment/main grid: sometimes used to refer to the Hipparcos Catalogue related aspects of the satellite or mission, in contrast to the 'star mapper' or Tycho Catalogue related aspects.

mas: milliarcsec (0.001 seconds of arc).

Medium-scale distortion: the component of the field-to-grid transformation (originating from the method by which the modulating grid was fabricated in $46 \times 168$ scan fields—see Volume 2) which was calibrated on ground, and used as input to the data reductions as a matrix of calibration points, depending on the location of the star image on the grid at the instant of observation.

Modulating grid: see main grid.

Modulation phase: the phase of the first harmonic in the five-parameter model which increased cyclically from 0 to $2\pi$ radians as the satellite rotated. The value of the modulation phase at a specific instant was derived by the process known as 'phase extraction'.

Nominal scanning law: see scanning law.

Observational frame: the basic time unit of 32/15 s, also referred to as $T_4$, used to fit the photon counts to the five-parameter model.

Off-line tasks: a collective name given to those reduction tasks which strictly did not fall within the main (three-step) reduction chain: the photometric reductions, the double star and minor planet treatment, simulations and instrument modelling, calibrations and first-look activities, and the link to the quasi-inertial reference systems.

On-ground attitude determination: see attitude determination.

Optical transfer function: the description of the modulation coefficients and the phase differences between the first and second harmonics in the modulated signal for the main grid, as a function of field of view, position in the field of view, and star colour.

Orbital period (of the Hipparcos satellite): the interval between perigee passages. In its geostationary transfer orbit, the orbital period of the Hipparcos satellite was approximately 10.7 hours.

Ordinate: the angular distance of a star from the reference great circle, reckoned positive towards the great-circle pole. See also abscissa.

Parallax: the Hipparcos and Tycho Catalogues provide the annual parallax, $\pi$, from which the coordinate distance is $(\sin \pi)^{-1}$ astronomical units, or with sufficient approximation, $\pi^{-1}$ parsec if $\pi$ is expressed in arcsec. The parallax determinations are trigonometric, absolute (in the sense that the parallax determination of a given star is not dependent upon either the parallaxes, or assumptions concerning the parallaxes, of other stars—including stars close by on the sky), and independent of any previous distance determinations. Analyses place a limit on the global parallax zero-point offset of less than 0.1 milliarcsec, and give confidence that the published standard errors are a reliable indication of their true external errors.

Partially observable star: a concept defined in the context of the star observation strategy (see Volume 2) indicating that a star was in the process of entering or leaving the

field during a given observation frame (of duration $T_4 = 2.133\ldots$ s). Bright partially observable stars were included in the star observations in order to improve the attitude determination during the observation frame.

Passive star: see active star.

Phase extraction: the derivation of phases from analysis of the image dissector tube data, by fitting of the experimental data to the three- or five-parameter signal model.

Position: the Hipparcos and Tycho Catalogues provide the barycentric coordinate direction, specified as right ascension, $\alpha$, and declination, $\delta$.

Precision: the uncertainty of a measured quantity due to accidental errors. The term 'precision' is often used synonymously with 'internal (or formal) standard error' as derived e.g. from a least-squares solution (cf. accuracy).

Primary grid: the main modulating grid of 2688 parallel slits, separated by 8.2$\mu$m, or 1.2074 arcsec on the sky, located at the focal surface of the combined field of view of the telescope, on which the main Hipparcos measurements were based.

Primary reference star: a star selected to be included in the sphere solution due to its appropriate properties (bright, single, etc.). These stars (which numbered around 40 000) defined the relative origins of the 2000 or so reference great circles generated throughout the mission. The secondary reference stars were subsequently fitted into the resulting reference system.

Programme star: one of the stars (approximately 120 000) contained in the Hipparcos Input Catalogue, and observed by the main detector. The observing programme was defined before launch and remained essentially fixed for the entire mission duration.

Proper motion: the Hipparcos and Tycho Catalogues provide the rate of change of the barycentric coordinate direction expressed as proper motion components $\mu_{\alpha *} = \mu_\alpha \cos\delta$ and $\mu_\delta$, in angular measure per unit time (milliarcsec per Julian year).

Real-time attitude determination: see attitude determination.

Reference great circle: a reference plane chosen to correspond to the mean scanning motion of the satellite during several hours, and signifying also the collection of observations during this time-interval. In practice the maximum duration of observations constituting the reference great circle was limited by the satellite's orbital period, corresponding to about 5 great-circle scans, or about 10.67 hours—typical lengths of the reference great circles were somewhat shorter. Star abscissae were projected onto the reference great circle (through a knowledge of the three-axis attitude of the satellite) and solved for during the great-circle reductions.

Scan field: elements of the mosaic in which the main grid and star mapper grids were manufactured. The main grid consisted of $46 \times 168$ scan fields, and the star mapper grids of 102 scan fields on either side of the main grid (68 for the chevron slits and 34 for the vertical slits). See also medium-scale distortion.

Scanning law: the three-axis attitude of the satellite, determining where the two fields of view of the satellite were directed, at any instant of time. The nominal scanning law is a deterministic scanning motion which defined the required satellite attitude. By comparing the target and actual attitude on-board, by means of the star mapper transits, corrections to the actual attitude were effected by means of regular (roughly every 400 s) three-axis gas jet actuations, which brought the attitude back to its target one. In this way, deviations between the actual and nominal scanning law were kept to within about 10 arcmin throughout the mission.

Secondary reference star: see primary reference star.

Set solution: an alternative name given to the great-circle reduction process.

Small-scale distortion: the component of the field-to-grid transformation (originating from the method by which the modulating grid was fabricated—see Volume 2) which was uncalibrated on the ground, and uncorrected in orbit (see also large- and medium-scale distortion). Typically, the small-scale distortion resulted in a negligible degradation on the phase measurements.

Solar system objects: the 48 minor planets and three natural satellites observed in the Hipparcos programme.

Sphere solution: the second step of the 'three-step method', which combined the great-circle data for a number of reference stars and determined the 'great-circle zero-points'. These zero-points defined the interconnection between the reference great-circle reference systems leading to the global Hipparcos reference system.

Star mapper: the detection chain (including aperiodic vertical and inclined grids, relay optics and detectors) located on each side of the main grid (two were provided for redundancy reasons). The prime purpose of the star mapper was to provide three-axis (hence, the inclined slits) attitude information to the satellite, in real-time, on the basis of the time of transits of some 40 000 bright reference stars distributed over the sphere. It was also used for the Tycho experiment, and included, for this reason, two photometric channels ($B_T$ and $V_T$), each sampled by their own photomultiplier tube detectors. In contrast to the detector used for the main field of view, the star mapper detectors sampled the entire signal generated simultaneously by star transits over the entire star mapper grid.

Star mapper grid: the arrangement of four vertical and four inclined grids, arranged aperiodically at one side of the main grid, used for the satellite real-time attitude determination and the Tycho measurements.

Star observing strategy: the on-board algorithm which determined the cycle of star observations on the main grid, on the basis of the satellite attitude, and the information contained in the programme star file.

Telemetry format: $32/3 = 10.66\ldots$ s = 5 observation frames (= 256 telemetry frames).

Telemetry frame: 1/256 of a telemetry format (= 25 star mapper samples = 50 image dissector tube samples = 1/24s).

Three-parameter model: a constrained form of the image dissector tube signal model, involving only three unknown quantities (as compared with the more general five-parameter model) and which was valid for single stars.

Three-step method: the break-down of the (directly) intractably large Hipparcos reduction problem (to estimate simultaneously more than 600 000 astrometric parameters along with large numbers of additional satellite attitude unknowns and time-dependent geometrical calibration terms) in three partial steps. The first step is the 'great-circle reduction', the second step the 'sphere solution' and the last step the 'astrometric parameter determination'.

Transverse: a prefix used for quantities measured in a direction normal to the scan (i.e. along the slits of the main grid), as opposed to the longitudinal (along-scan) direction—e.g. transverse field angle.

Tycho magnitudes ($B_T, V_T$): the magnitude system defined by the Tycho instrument, in reasonable correspondence with the usual Johnson $B$ and $V$ magnitude system. Transformation equations between the various systems are provided.

Veiling glare: phase perturbations on the measurements of programme stars on the main grid in the presence of nearby bright stars, from either field of view, caused by the profile of the image dissector tube response.

Vertical slits: part of the star mapper grid consisting of four slits perpendicular to the scanning motion of the satellite, used for the determination of the along-scan attitude angle. See also inclined slits and attitude determination.

Viewing directions: the two directions in space towards which the telescope pointed at a given time. The directions refer, more precisely, to the centres of the two fields of view (preceding and following): the angles between them is known as the basic angle.

Viewing plane: the plane containing the two viewing directions. Its intersection with the celestial sphere is known as the viewing great circle or instantaneous scanning great circle.

$V_T$: see Tycho magnitudes.