Section 2.5

Hipparcos Catalogue: Epoch Photometry Annex (and Extension)

2.5. Hipparcos Catalogue: Epoch Photometry Annex (and Extension)

The results of the detailed Hipparcos epoch photometry have been compiled into the Hipparcos Catalogue Epoch Photometry Annex, ordered by HIP number.

The epoch photometry has been used to derive the median magnitudes and related statistics given in the Hipparcos Catalogue (Fields H44–48), and also the variability characteristics summarised in the Hipparcos Catalogue (Fields H49–54) and provided in detail within the Variability Annex (Section 2.4, and Volumes 11–12).

The Hipparcos Epoch Photometry Annex consists of three header records for each object in the Hipparcos Catalogue, containing summary photometric data for the object (Table 2.5.1), followed by N transit records, one record for every star transit in the Annex (Table 2.5.2). The transit records contain the transit time (i.e. the observation epoch), followed by the calibrated Hp magnitudes and related quantities, and flags providing further observational details. Transits are presented strictly in chronological order. For resolved systems, data are provided for the combined system, or for the individual components, as specified by the component flag, Field H H2.

The mean number of transits per star is roughly 110, varying approximately in the range 30–380, depending principally on the object's ecliptic latitude. This gives a total of some 13 million transits in the Hipparcos Catalogue Epoch Photometry Annex.

Hp magnitudes contained in the Hipparcos Catalogue and in the Epoch Photometry Annex (and where appearing without further qualification) refer to $Hp_{\rm dc}$, a magnitude estimate derived from the 'dc', or unmodulated, part of the signal intensity. Magnitude estimates derived from the 'ac', or modulated, part of the signal intensity are denoted $Hp_{\rm ac}$. $Hp_{\rm ac}$, and supplementary information related to the photometric reduction, are provided for more specialist use in the Epoch Photometry Annex Extension.

Further details of the derivation of $Hp_{\rm dc}$, and the difference between $Hp_{\rm dc}$ and $Hp_{\rm ac}$, can be found in Volume 3. Median values, as tabulated in the Hipparcos Catalogue (Field H44), are referred to in this section as $\overline{Hp}$ to distinguish them from the calibrated magnitudes derived for each transit. Usually, the difference between the individual transit value, and the median value derived from all transits for a given star, is clear from the context.

Description of the Hipparcos Epoch Photometry Annex

Header Records (Table 2.5.1)

The header structure follows closely the contents of the summary photometric data presented in the main catalogue, with the corresponding data content being identical. The header is divided into three records, each of 28 bytes, for consistency with the individual transit records (see Table 2.5.2). Note that *all* transits of each star are included in the file, with those considered photometrically suspect being flagged within the relevant transit record. Values given in the header records indicate the total number of transits in the file, $N_{\rm tot}$, and the number of photometrically accepted records, $N_{\rm acc}$.

Field HH1: HIP number

Field HH2: Component flag for a double or multiple entry

This indicates whether the subsequent photometric records refer to a photocentre (*), to one of the components (A, B,..), or to combined photometry from a multiple system (–). The flag has the same value as that given in the Hipparcos Catalogue, Field H48.

Field HH3: $V - I$ colour index used for the photometric reductions

As explained under Fields H40 and H52 of the main Hipparcos Catalogue, this value of $V - I$ (typically taken from ground-based observations) may subsequently have been found to be incorrect: a systematic linear trend of the calibrated Hp magnitude with time may have arisen specifically because of such an error. $V - I$ values given in Field H40 have been updated where relevant. Field HH3 gives the value of $V - I$ used for the photometric reductions (this value is also given in the Hipparcos Catalogue, Field H75); it is not necessarily the same as given in Field H40.

Field HH4: Total number of transits in the file, $N_{\rm tot}$

$N_{\rm tot}$ gives the number of individual transits for the star following the header.

The first and last observation epochs for a given star can be accessed through the first and last transit records. Transits that are considered photometrically suspect are flagged accordingly (see Field HT4).

Field HH5: Number of transits considered to be photometrically accepted, $N_{\rm acc}$

Generally, transits were not considered as photometrically accepted if any of bits 3–5 or 7–8 in Field HT4 were set. However, for all entries of 'two-pointing' double systems with separation less than about 35 arcsec (irrespective of whether or not they were resolved), and for all resolved single entries with separations larger than 10 arcsec, transits with bit 4 set were also photometrically accepted.

Only photometrically accepted transits were used for the determination of the median magnitude and related statistics given in Fields H44–48 of the main catalogue, and in Fields HH6–9 of this annex. The number of Hp observations listed in Field H47 is equal to the number of photometrically accepted transits, $N_{\rm acc}$, which is typically less than the total transits given in the Epoch Photometry Annex. As explained under Field HT4, transits with bit 6 set should also, ideally, have been excluded from those accepted photometrically, although this was not done in practice. Rigorous exclusion of transits with bit 6 set would, however, not have a large effect on the resulting statistics.

Field HH6: Median magnitude in the Hipparcos photometric system, $\overline{Hp}$

This value is generally the same as that given in the Hipparcos Catalogue, Field H44. There are differences in the case of two-pointing double systems (as explained in Section 1.3): for the faint companion of a 'two-pointing' double system Field HH6 is derived from the individual transits, while Field H44 of the main Hipparcos Catalogue was obtained from observations with the detector pointing at the brighter component, using the magnitude difference determined in the double star solution. Therefore, while the difference between the two median Hp magnitudes given in Field H44 for the two components is identical to the magnitude difference ΔHp given in Field H66 of the main Hipparcos Catalogue, this is not true for the magnitude difference based on Field HH6.

Field HH7: Standard error of the median magnitude, $\sigma_{\overline{Hp}}$

Typically this value is the same as that given in the Hipparcos Catalogue, Field H45. There are differences in the case of two-pointing double systems, as explained in Section 1.3.2.

Fields HH8–9: 5th and 95th percentiles of the epoch photometry data points

Typically these values are the same as those given in the Hipparcos Catalogue, Fields H49–50. There are differences in the case of two-pointing double systems, as explained in Section 1.3.2.

Field HH10: Variability period, P (days)

The period is as given in the Variability Annex, Section 2.4, Field P11. As explained in Section 2.4, the period given in the Variability Annex is given with greater precision than that in the Hipparcos Catalogue (Field H51).

Field HH11: Reference epoch, BJD(TT)−2 440 000.0

The reference epoch gives the epoch of the first zero phase after JD(TT) 2 448 500.0. See the Variability Annex, Section 2.4, Field P13, for further details.

Field HH12: 1-letter variability type

The 1-letter variability type is that given in the Hipparcos Catalogue (Field H52) and in the Variability Annex, Section 2.4, Field P4.

Field HH13: Annex flag

This flag, identical to that given in Field H53 of the main Hipparcos Catalogue, indicates that further data are tabulated in the Variability Annex (see Section 2.4, and Volume 11).

Field HH14: Annex flag

This flag, identical to that given in Field H54 of the main Hipparcos Catalogue, indicates that (folded) light curves are included in the Variability Annex (see Section 2.4, and Volume 12).

Description of the Hipparcos Epoch Photometry Annex
Individual Transit Record (Table 2.5.2)

Field HT1: Observation epoch

This is specified in (barycentric) Julian Date, with respect to JD(TT) 2 440 000.0.

Observation epochs are given in Terrestrial Time (TT), and have been corrected for light propagation time to the solar system barycentre. They are therefore referred to as BJD(TT). Observation epochs are given with a resolution of 10^{-5} days = 0.864 s.

Field HT2: Calibrated *Hp* magnitude for this transit

Field HT3: Estimated standard error of the magnitude given in Field HT2, σ_{Hp}

Field HT4: Quality flag

If the flag is not set, then the data are considered to be photometrically reliable. If the flag is non-zero, caution must be used in interpreting the data. The various bit settings of the quality flag are given in Table 2.5.2.

If only bit 0 or bit 1 is set, the data may be reliable, but no cross-check between the consortia was possible, since the data were obtained from one consortium only (the corresponding data having been rejected by the other consortium for a variety of reasons which were not precisely the same for both consortia).

Bit 2 was not used.

If any of bits 3–8 are set, the data are likely to be unreliable:

• bit 3 was set for transits observed during intervals of high background level (e.g. during certain parts of the satellite's orbit). For stars brighter than 10 mag the data may be reliable even when bit 3 is set;

• bit 4 was set when an object, either in the same or in the complementary field of view, was likely to have perturbed the resulting photometry. For some 'two-pointing doubles' (see Section 1.4) bit 4 is set for all transits, since there is a strong possibility of the photometry of each of the components being affected by the companion;

• bit 5 flags correspond to transits which the FAST Consortium flagged as suspect as a result of poor attitude reconstruction;

• bit 6 flags were assigned, as a result of a detailed investigation of outliers in the photometric data, where a cause could be identified for the perturbation. Such flagged transits typically originate from events which are generally clustered in time: thus *Hp* estimates were found to be systematically too bright near to some shutter closures (close to Earth occultations), and systematically too faint during periods of poor instrument pointing. While future investigations should suppress these flagged transits, they have been included in (and will weakly influence) the published statistical results of the Hipparcos photometry (Fields H44–47);

• bit 7 flags were assigned to identify observations acquired during (relatively short) intervals of satellite Sun pointing. It is believed that the data quality are affected by the non-nominal thermal environment of the satellite.

Transits with any of bits 1–8 set are not plotted on the folded or unfolded light curves. Transits with bit 0 set are plotted, using a different symbol.

Table 2.5.1. Hipparcos Epoch Photometry Annex: star header

Record	Field	Bytes	Format	Description
1	HH1	1– 7	I6,X	HIP number
	HH2	8– 9	A1,X	Component flag
	HH3	10–16	F6.3,X	$V - I$ (mag)
	HH4	17–20	I3,X	Total transits, $N_{\rm tot}$
	HH5	21–28	I3,5X	Accepted transits, $N_{\rm acc}$
2	HH6	1– 8	F7.4,X	Median magnitude, $\overline{Hp}$ (mag)
	HH7	9–15	F6.4,X	$\sigma_{\overline{Hp}}$ (mag)
	HH8	16–21	F5.2,X	5th percentile (max) (mag)
	HH9	22–28	F5.2,2X	95th percentile (min) (mag)
3	HH10	1–12	F11.7,X	Variability period, P (day)
	HH11	13–22	F9.4,X	Reference epoch (day)
	HH12	23–24	A1,X	Variability type
	HH13	25–26	A1,X	Annex flag (tables)
	HH14	27–28	A1,X	Annex flag (light curves)

Table 2.5.2. Hipparcos Epoch Photometry Annex: individual transit record

Field	Bytes	Format	Description
HT1	1–11	F10.5,X	BJD(TT), (barycentric) Julian Date (TT)–2 440 000.0 (days)
HT2	12–19	F7.4,X	Hp for the transit (mag)
HT3	20–25	F5.3,X	σ_{Hp} (mag)
HT4	26–28	I3	Quality flag (bit): 0 NDAC data only 1 FAST data only 2 (not used) 3 Very high background estimate (threshold 70 Hz) 4 Possible interfering object in either field of view 5 FAST quality flag set 6 Perturbed for other identified reasons 7 Observation during Sun-pointing mode 8 Significant difference between FAST and NDAC data

Note: see Section 2.11.1 for interpretation of the bit settings in Field HT4.

The Hipparcos Epoch Photometry Annex Extension

As described previously, the median $\overline{Hp}$ magnitudes contained in the Hipparcos Catalogue, and the individual Hp magnitudes in the Hipparcos Epoch Photometry Annex, refer to $Hp_{\rm dc}$, a magnitude estimate derived from the unmodulated part of the signal intensity. Magnitude estimates from the modulated part of the signal intensity, denoted $Hp_{\rm ac}$, were derived as part of the photometric reductions (further details of the derivation of $Hp_{\rm dc}$, and the difference between $Hp_{\rm dc}$ and $Hp_{\rm ac}$, can be found in Volume 3).

For most users of the epoch photometry, the Hipparcos Epoch Photometry Annex will contain much if not all of the information needed. However, $Hp_{\rm ac}$, and supplementary information related to the photometric reduction, are provided for more specialist use within the Hipparcos Epoch Photometry Annex Extension.

The information contained in the Hipparcos Epoch Photometry Annex Extension is provided to allow users to verify the quality of individual photometric measurements at a particular epoch (further verification by the Hipparcos data analysis teams could have been carried out, but at the expense of delaying the publication of the results).

Such verification may fall into the following categories:

(a) verification of the overall photometric calibration with respect to photometric standard stars. As described in Volume 3, the photometric calibration was a complex process, dependent on the field of view and position in the field of view, time, magnitude, colour index, and background intensity. Recalibration would require a reordering of all transits in order of acquisition, and provision of additional geometrical information related to the viewing configuration. Since the final photometric calibration was consistent at the level of the photon noise statistics, such information has not been preserved, and such a re-calibration is essentially precluded;

(b) differences between $Hp_{\rm dc}$ and $Hp_{\rm ac}$, derived on the basis of the unmodulated and modulated components of the signal respectively, provide a sensitive indication of the presence of resolved structure within the target, i.e. whether the entry is possibly double, multiple, or extended. Since the signal amplitudes of the modulated and unmodulated components will depend on the scanning geometry, the resulting time-dependent variations may mimic variability. Specialist users may wish to verify the presence or absence of such multiplicity, and its possible effects on the inferred variability. For these reasons, $Hp_{\rm ac}$ is provided within the Hipparcos Epoch Photometry Annex Extension;

(c) although a careful calibration of the magnitudes took account of background variations (both sky, and van Allen radiation background induced), modelling of the background was performed differently by the two reduction groups. The two separate background estimates are included in the Hipparcos Epoch Photometry Annex Extension;

(d) less easy to take rigorously into account was the possible perturbing influence of one or more stars (within the instantaneous field of view of the detector's response profile) coming from the other field of view—the Hipparcos observations being acquired from two such superposed fields of view, separated by about 58° on the sky. Possibly interfering objects known from the Tycho Input Catalogue have been considered, and clearly perturbed observations have been flagged in the list of transits compiled in the Hipparcos Epoch Photometry Annex (see Field HT4). The Hipparcos Epoch Photometry Annex Extension provides sufficient information for the specialist user to verify whether an object from the other field of view (identified during the Hipparcos data reductions or not) might have perturbed a transit at any given epoch, by providing the coordinates of the other field of view at that epoch.

In summary, the general user will find most of the information needed within the Hipparcos Epoch Photometry Annex. Transits flagged already as suspect should typically be rejected from further use. Users interested in assessing whether duplicity/multiplicity might have affected the light curves may wish to investigate the values of Hp_{ac} in further detail. Those wanting to verify the nature of identified perturbing objects in the complementary field of view, or wanting to assess the effects of (faint) stars in the complementary field of view, will make use of the coordinates of the complementary field of view given in the Hipparcos Epoch Photometry Annex Extension.

In general, for double and multiple objects the median ac magnitude is higher than the median dc magnitude, since extended structure decreases the signal modulation so that the object appears fainter in the modulated signal. Also the ratio between the standard errors on the ac and dc magnitudes will be higher than for single objects. For extended objects (e.g. planetary nebulae) the ac magnitudes will be higher than the dc magnitudes, but the ratio between the standard errors will be much the same as for a single object (see Volume 3). For variable stars, the standard error of the ac magnitudes can become smaller than that of the dc magnitudes.

There are two reasons for retaining possibly perturbed transits in the Hipparcos Epoch Photometry Annex and its Extension. First, the criteria used for flagging has been rather severe, and there will be cases where the disturbance, for many applications, is not too serious. Second, it is in principle possible to correct for perturbations from the complementary field of view when the separation from the centre of the instantaneous field of view is small (a few arcsec). Such corrections have not been made for the published data, since the available magnitudes and colours of the disturbing objects were often very uncertain.

Description of the Epoch Photometry Annex Extension

Header Records (Table 2.5.3)

The Extension file is organised exactly in parallel with the Annex file, but with records of 44 byte length. The Extension consists of three header records for each object in the Hipparcos Catalogue (as for the Annex file, facilitating the synchronous reading of the both files, see Table 2.5.3), followed by N transit records (Table 2.5.4). The transit records in the Extension are for the same epochs as the individual transit records in the Annex. The first header record of the Extension is a copy of the first header record of the Annex. The second record contains the median $\overline{Hp}_{\rm ac}$ and $\sigma_{\overline{Hp}_{\rm ac}}$, i.e. analogous to the Annex header, but containing the Hp magnitudes derived from the modulated signal (i.e. $Hp_{\rm ac}$ instead of $Hp_{\rm dc}$). It also contains parameters derived from $\overline{Hp}_{\rm dc}$ and $\overline{Hp}_{\rm ac}$ providing indirect information on the likelihood of data being disturbed by duplicity or background objects.

Field HHE1: HIP number (as Field HH1)

Field HHE2: The component flag for a double or multiple entry

This is the same as given in the Hipparcos Catalogue (Field H48) and in Field HH2. However the photometric data in the Annex Extension always refer to the combined system, with no correction for duplicity or for the attenuation profile of the detector.

Field HHE3: $V - I$ colour index (as Field HH3)

Field HHE4: Total number of transits in the file $N_{\rm tot}$ (as Field HH4)

Field HHE5: Number of photometrically accepted transits, $N_{\rm acc}$ (as Field HH5)

Field HHE6: Median magnitude for the modulated signal component, $\overline{Hp}_{\rm ac}$

Field HHE7: Standard error of the median $\overline{Hp}_{\rm ac}$ magnitude, $\sigma_{\overline{Hp}_{\rm ac}}$

Fields HHE8: $\overline{Hp}_{\rm dc} - \overline{Hp}_{\rm ac}$ (the difference between Fields HH6 and HHE6)

Fields HHE9: Ratio of the standard errors on the medians, $\log_{10}(\sigma_{\overline{Hp}_{\rm ac}} / \sigma_{\overline{Hp}_{\rm dc}})$

This is a good approximation to the ratio between the standard deviations in $Hp_{\rm ac}$ and $Hp_{\rm dc}$, since $N_{\rm acc}$ is the same for both parameters.

Field HHE10: Coincidence pointer offset

This is used in combination with a coincidence index in the transit record (Field HTE8) to determine possibly perturbing objects in the complementary field of view.

Field HHE11: Double star correction

The correction applied to the epoch photometry and summary data to account for the effect of a companion, calculated as part of the double star processing (see Section 1.3.2).

Description of the Epoch Photometry Annex Extension
Individual Transit Record (Table 2.5.4)

Field HTE1: $Hp_{\rm ac}$ magnitude for this transit

$Hp_{\rm ac}$ is given to three decimals, compared with four decimals for $Hp_{\rm dc}$, reflecting the larger error on the magnitude derived from the modulated signal component. The epoch of the transit is precisely that given for the corresponding transit in the Hipparcos Epoch Photometry Annex.

Field HTE2: Estimated standard error of the magnitude given in Field HTE1, $\sigma_{Hp_{\rm ac}}$

Field HTE3: Background determined by the FAST Consortium, b_F, in Hz

The field is blank if no data from this consortium were available for this transit.

Field HTE4: Background determined by the NDAC Consortium, b_N, in Hz

The field is blank if no data from this consortium were available for this transit.

Field HTE5: Field of view index

This takes the value:
0 : for observations made in the following field of view;
1 : for observations made in the preceding field of view.

Field HTE6–7: Right ascension and declination of the complementary field of view

The measurement principle of Hipparcos involved the superposition of two fields of view, separated by approximately 58° on the sky. The photometric (and astrometric) measurements were affected if objects of sufficient brightness from the complementary field of view were superposed on the target field of view. To permit further consideration of the possibility that photometry at a given observation epoch was perturbed due to the geometrical configuration at that epoch, the equatorial coordinates of the complementary field of view are provided. Resulting contaminating objects already identified from the Tycho Input Catalogue are included in a corresponding 'coincidence file', see Field HTE8. The complimentary field of view coordinates were only retained by the NDAC Consortium, and thus if no NDAC data are available these two fields are blank.

Field HTE8: Coincidence index

The 'coincidence file' contains about 100 000 entries, and provides information on identified objects in the other field of view (details of the file are given in Table 2.5.5). Transits are indicated as 'perturbed by an identified object in the other field of view' (as found in the Tycho Input Catalogue) by a non-zero value of the 'coincidence index' given in the transit record. More than one object may have been identified in the 'other field of view'. When added to the 'coincidence pointer offset' given in the header, the 'coincidence index' provides a pointer to the first of these identified objects. Subsequent objects may follow, as indicated by a 'pointer terminator'. This will be set to 1 if the last entry related to the relevant transit has been found. It will be set to 0 if the next entry is also related to the same transit. In the majority of cases, however, only one entry will be found for a transit, thus the 'pointer terminator' will usually be 1.

Table 2.5.3. Hipparcos Epoch Photometry Annex Extension: star header

Record	Field	Bytes	Format	Description
1	HHE1	1– 7	I6,X	HIP number
	HHE2	8– 9	A1,X	Component flag
	HHE3	10–16	F6.3,X	$V - I$ (mag)
	HHE4	17–20	I3,X	Total transits, $N_{\rm tot}$
	HHE5	21–23	I3	Accepted transits, $N_{\rm acc}$
		24–44	21X	
2	HHE6	1– 8	F7.4,X	Median magnitude, $\overline{Hp}_{\rm ac}$ (mag)
	HHE7	9–15	F6.4,X	$\sigma_{\overline{Hp}_{\rm ac}}$ (mag)
	HHE8	16–22	F6.3,X	$\overline{Hp}_{\rm dc} - \overline{Hp}_{\rm ac}$ (mag)
	HHE9	23–28	F6.3	$\log_{10}(\sigma_{\overline{Hp}_{\rm ac}} / \sigma_{\overline{Hp}_{\rm dc}})$
		29–44	16X	
3	HHE10	1– 7	I6,X	Coincidence pointer offset
	HHE11	8–14	F7.4	Double star correction (mag)
		15–44	30X	

Table 2.5.4. Hipparcos Epoch Photometry Annex Extension: individual transit record

Field	Bytes	Format	Description
HTE1	1– 7	F6.3,X	$Hp_{\rm ac}$ for the transit (mag)
HTE2	8–13	F5.3,X	$\sigma_{Hp_{\rm ac}}$ (mag)
HTE3	14–17	I3,X	Background, b_F (Hz)
HTE4	18–21	I3,X	Background, b_N (Hz)
HTE5	22–23	I1,X	Field of view index
HTE6	24–32	F8.4,X	RA of other field of view (degrees)
HTE7	33–41	F8.4,X	Dec of other field of view (degrees)
HTE8	42–44	I2,X	Coincidence index

Table 2.5.5. Hipparcos Epoch Photometry Annex Extension: coincidence file

Field	Bytes	Format	Description
HCE1	1– 5	F4.1,X	Distance from IFOV centre (arcsec)
HCE2	6–10	F4.1,X	Magnitude (mag)
HCE3	11–15	F4.1,X	Colour index, if known (mag)
HCE4	16	I1	Coincidence terminator flag