16. CONTENTS OF THE TYCHO CATALOGUE

An overview of the Tycho Catalogue contents is given in the first section, followed by detailed descriptions, tables and plots related to the astrometric and photometric contents, mainly derived from internal analysis of the catalogue. Comparisons with other catalogues are given in Chapter 18.

16.1. Overview of the Tycho Catalogue

This section gives a general overview of the Tycho Catalogue. A detailed description of each field of the catalogue files may be found in Volume 1, Section 2.2 and Section 2.6.

The Tycho Catalogue, and its photometric annex, referred to as the Tycho Epoch Photometry Annex, is an observational catalogue. It contains data derived exclusively from the Hipparcos satellite's star mapper observations, with the exception of certain cross-identifications.

The Tycho Catalogue provides positions and two-colour photometry (in B_T and V_T) for more than one million stars brighter than $V_T = 11.5$ mag. The median standard error is 25 mas in position and 0.10 mag in the $B_T - V_T$ colour index. These values apply at the median magnitude $V_T = 10.5$ mag for stars of median colour index $B_T - V_T \simeq 0.7$ mag. Parallaxes and proper motions were also derived, although the individual values are generally of limited significance. Table 16.1 presents the number of stars and the standard errors of the results as a function of V_T. The catalogue is more than 99 per cent complete down to $V_T \simeq 10$ mag, the incompleteness mainly occurring in dense fields.

The Tycho Catalogue contains entries for 1 058 332 stars and resolved components of multiple systems of which 1 052 031 entries (stars) were observed by Tycho and the remaining 6301 entries are those stars from the Hipparcos Catalogue and Part C of the Double and Multiple Systems Annex that were not observed by Tycho. These 6301 so-called HIP–only stars are included for the convenience of the user, but the entries are merely pointers to the Hipparcos Catalogue where the complete records must be sought. The HIP–only stars are typically stars too faint for the star mapper and components of double stars not resolved by Tycho, but also some bright stars were missed because of crowding or non-linearity of the detectors. With the HIP–only stars included, only some 120 stars from the Catalogue of Positions and Proper Motions (PPM) brighter than 9 mag are missing in the Tycho Catalogue, see Chapter 17.

Table 16.1. The table gives the number of stars in the Tycho Catalogue (TYC) and the number of Tycho catalogue stars not included in the Hipparcos Catalogue (HIP), along with the corresponding median standard errors for stars within the given intervals of V_T magnitude (the column 'All' also including entries for which V_T is not available). Systematic errors in astrometry are less than 1 mas and 1 mas/yr, although the external standard errors (the true accuracies) may be 50 per cent larger than the quoted standard errors for faint stars. In photometry, systematic errors may reach the level of the quoted standard errors for faint stars. The photometry for about 20 000 stars is considered to be uncertain, for example when the standard errors are larger than 0.3 mag.

Interval of V_T	<6.0	6–7.0	7–8.0	8–9.0	9–10.0	10–11.0	>11.0	All	<9.0
Median V_T, mag	5.38	6.63	7.62	8.62	9.61	10.58	11.19	10.47	8.33
N (TYC)	4553	9550	27750	78029	211107	515029	205934	1052031	119882
N (not in HIP)	4	55	3485	36511	182773	506720	205275	934901	40055
Median standard errors in astrometry (mas):									
Position (J1991.25)	1.8	2.6	4.0	6.7	12.9	27.2	39.2	24.6	5.6
Parallax	2.5	3.6	5.3	8.6	16.4	34.3	49.6	31.2	7.2
Proper motion/yr	2.3	3.3	5.0	8.3	16.0	33.5	48.6	30.2	7.0
Median standard errors in photometry (mag):									
B_T	0.003	0.006	0.010	0.018	0.036	0.084	0.128	0.074	0.014
V_T	0.003	0.005	0.008	0.014	0.027	0.064	0.122	0.057	0.012
$B_T - V_T$	0.005	0.008	0.014	0.024	0.049	0.117	0.200	0.104	0.019
$B - V$	0.004	0.007	0.012	0.020	0.041	0.098	0.171	0.087	0.017

The Tycho Catalogue gives a massive supplement to the Hipparcos Catalogue for the fainter stars and also an important complement for the brighter stars. The catalogue contains 40 000 stars brighter than $V_T = 9$ mag which are not in the Hipparcos Catalogue. For these stars the median precision is 7 mas in position, parallax and annual proper motion and 0.019 mag in $B_T - V_T$. Double stars with separations larger than 2 arcsec and with moderate magnitude differences could usually be resolved.

The reduced data comprise two parts. The main catalogue (the Tycho Catalogue, or TYC) contains the astrometric and summary photometric data for each star. The Tycho Epoch Photometry Annex (described in Section 16.4 and in Volume 1, Section 2.6) contains the summary photometric data for all stars, along with all the individual photometric observations for a subset of stars observed with sufficiently high signal-to-noise ratio and believed to be of particular interest. The main catalogue also provides quality indicators and flags giving warnings about stars unsuited as reference stars, flags indicating duplicity, flags stating the methods used in deriving astrometry and photometry etc. Full details are given in Volume 1, Section 2.2.

16.2. Astrometric Content

This section presents an overview of the astrometric contents of the Tycho Catalogue. Table 16.2 shows the median standard errors of position, parallax and annual proper motion for various intervals of V_T magnitude.

For stars brighter than $V_T = 5.0$ mag the positional error from Tycho is of similar quality as the Hipparcos positional error. It increases with magnitude, reaching about 60 mas

Table 16.2. Median standard errors of astrometric parameters versus magnitude: position component at the mean epoch J1991.25, parallax, and proper motion component. N is the number of stars in each interval, the 0.5 mag bins being centred on the given V_T. The standard errors for annual proper motion and parallax appear to be about 25 per cent higher than for position. The errors of position and proper motion components in right ascension and declination are respectively about 5 per cent higher and 5 per cent lower than the errors in the table. Systematic errors are less than 1 mas.

V_T mag	N	σ_{pos} mas	N	σ_{par} mas	σ_{pm} mas/yr
≤5.0	1447	1.5	1428	2.0	1.9
≤9.0	119348	5.6	118304	7.2	6.8
All	1038946	24.4	1035439	30.8	29.8
0.5	5	1.9	5	2.7	2.4
1.0	6	2.5	6	3.0	3.0
1.5	12	1.5	12	2.2	2.0
2.0	38	1.4	36	2.0	1.6
2.5	45	1.2	44	1.9	1.6
3.0	90	1.5	90	2.0	2.0
3.5	140	1.5	138	2.0	1.8
4.0	266	1.4	262	2.0	1.8
4.5	484	1.5	478	2.2	1.9
5.0	863	1.6	851	2.2	2.0
5.5	1477	1.8	1455	2.5	2.2
6.0	2564	2.0	2536	3.0	2.7
6.5	4614	2.5	4560	3.4	3.0
7.0	7798	3.0	7722	4.1	3.8
7.5	13299	3.8	13169	5.1	4.8
8.0	22591	4.8	22413	6.2	6.0
8.5	37729	6.3	37426	8.2	7.8
9.0	62478	8.7	61929	11.1	10.8
9.5	102221	12.2	100993	15.4	15.1
10.0	166009	17.8	165139	22.5	21.9
10.5	261412	26.2	261385	33.2	32.4
11.0	283126	34.7	283112	43.7	42.7
11.5	69016	41.5	69016	52.4	51.2
12.0	2499	52.5	2499	66.2	66.5
12.5	138	64.0	137	77.3	84.8
13.0	16	64.5	16	74.6	75.2
13.5	6	62.4	6	77.2	82.6
14.0	4	60.2	4	70.8	71.2

for the faintest stars, which is still very good compared to ground-based results. The density of Tycho stars on the sky is shown in Figure 16.1. Values range from 5 to 156 stars per square degree, the highest values occurring in the galactic plane and the lowest in the dust clouds in Ophiuchus. The limiting magnitude is not the same all over the sky, as shown in Figure 16.4 and 16.5. Therefore the plot in Figure 16.1 does not give a correct picture of the true distribution of all stars brighter than a given limiting magnitude. A more correct picture is given in Figure 16.2 showing only the just above

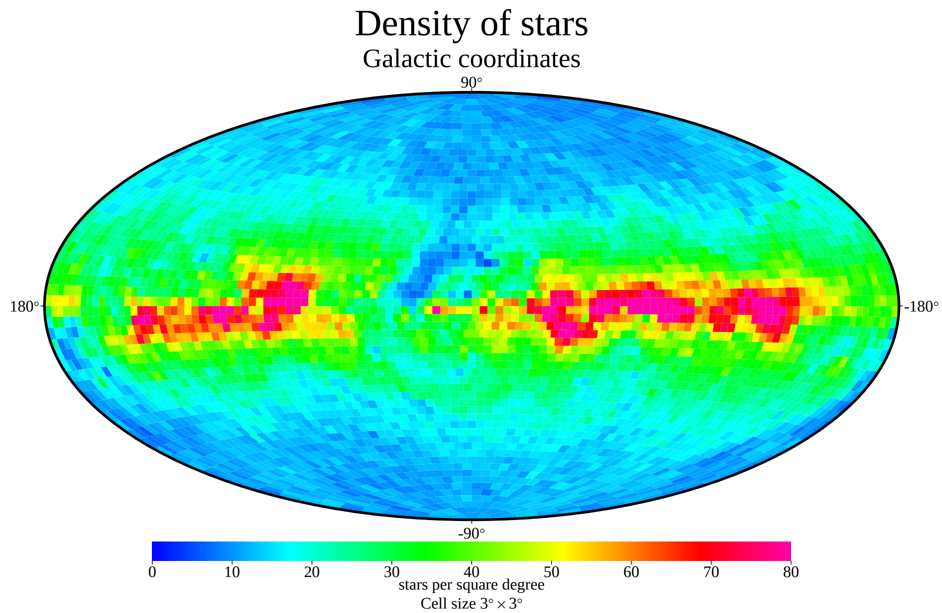

Figure 16.1. *The number of stars per square degree in galactic coordinates. The actual range of values is from 5 to 156.*

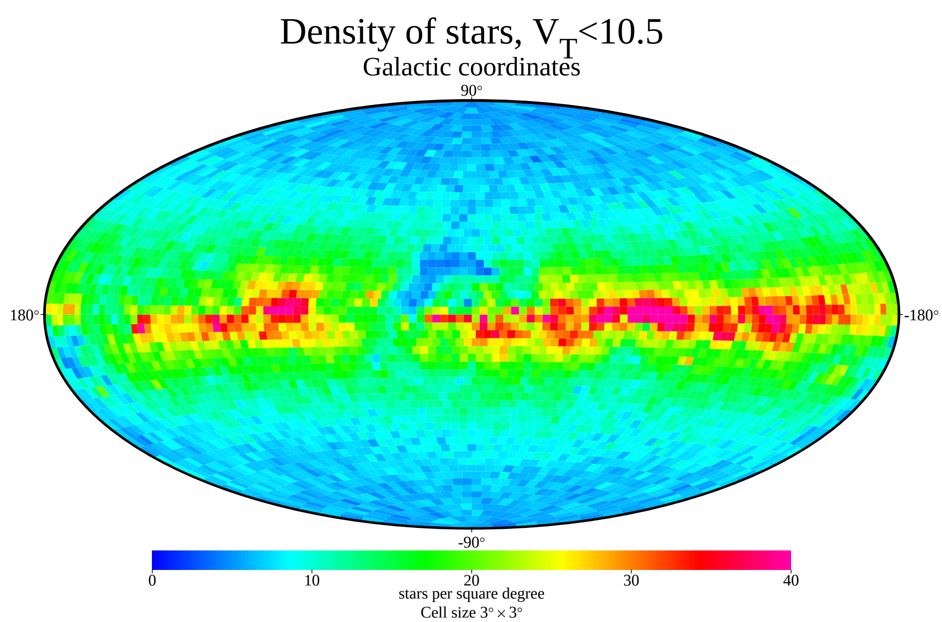

Figure 16.2. *Distribution of the brighter half of the stars. With a limit of* $V_T = 10.5$ *mag the Tycho catalogue is almost complete and the true distribution of stars brighter than this magnitude is evident. The actual range of values is from 3 to 82.*

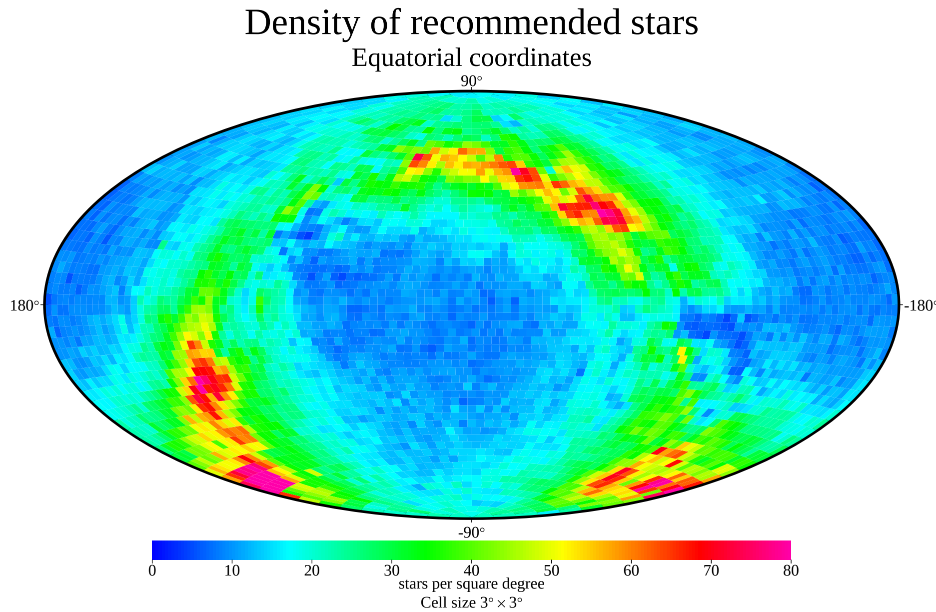

Figure 16.3. *The number of stars per square degree, recommended as astrometric reference stars, in equatorial coordinates. The actual range is from 4 to 105.*

500 000 stars with $V_T < 10.5$ mag. The irregularities caused by the scanning pattern of the satellite (see Figure 16.5) have almost disappeared.

Some stars have been flagged as unsuited as astrometric reference stars, (see Field T10 described in Volume 1, Section 2.2). The reason may be duplicity or low quality of the astrometric solution. Figure 16.3 shows the density of the recommended reference stars, values ranging from 4 to 105 stars per square degree. At high galactic latitudes the density is typically 10. Underlying the quality of the results obtained in different parts of the sky is the number of transits across the satellite's fields of view for that sky region. The sky was scanned along a great circle, the pole of which was precessing around the Sun at a constant angle of 43°. As a result, the maximum number of transits is obtained at ecliptic latitude ±47°. Figure 16.6 shows the median number of observations used in astrometry, typical values lying between 50 and 150 and the maximum as expected at ±47°. Faint stars have a high rate of non–detection and if they also have few transits they may end up with too few detections to be accepted in the astrometric reduction. This deficit of faint stars is seen in Figure 16.4, where the areas with rather few scans generally have a median magnitude half a magnitude brighter than areas with many scans.

The internal standard errors of the five astrometric parameters depend strongly on the magnitude, as already seen in Table 16.2, and also on the number of transits used. For stars of $V_T = 9.0 \pm 0.5$ mag, Figure 16.7 shows the standard errors transformed to ecliptic coordinates as a function of ecliptic latitude. The longitudinal parameters show a large contrast between the highest and lowest values. This is another result of the scanning law, because a rather large percentage of the scans at latitude ±47° are mainly measuring the longitudinal coordinate; at the ecliptic, however, scans mainly measuring latitude dominate. Scans at the poles measure an even amount of longitude and latitude making the curves meet there. Figures 16.8–16.12 show sky plots of the internal median standard errors for the five parameters. The combined effect of limiting magnitude and scanning law is clearly visible in these plots.

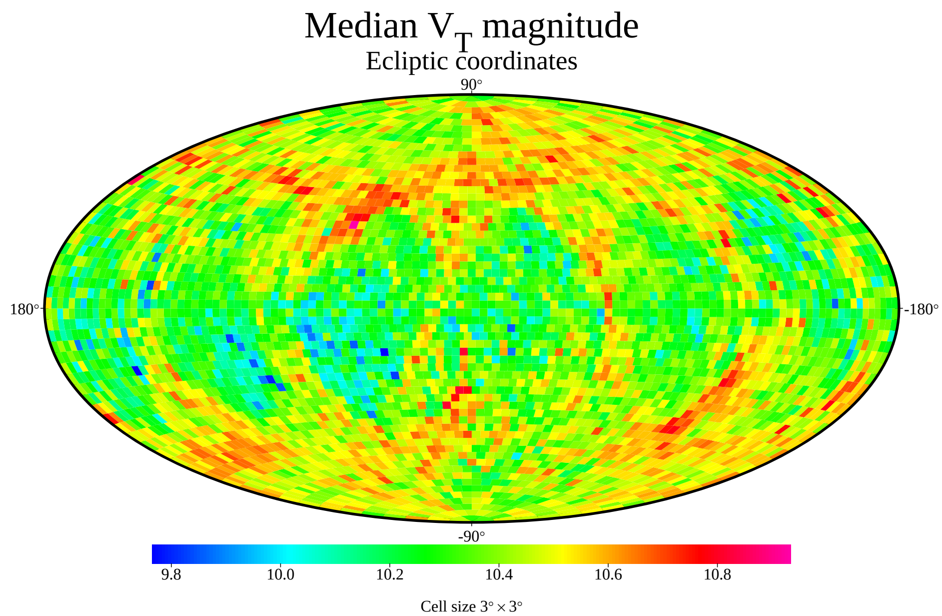

Figure 16.4. *The median V_T magnitude plotted in ecliptic coordinates.*

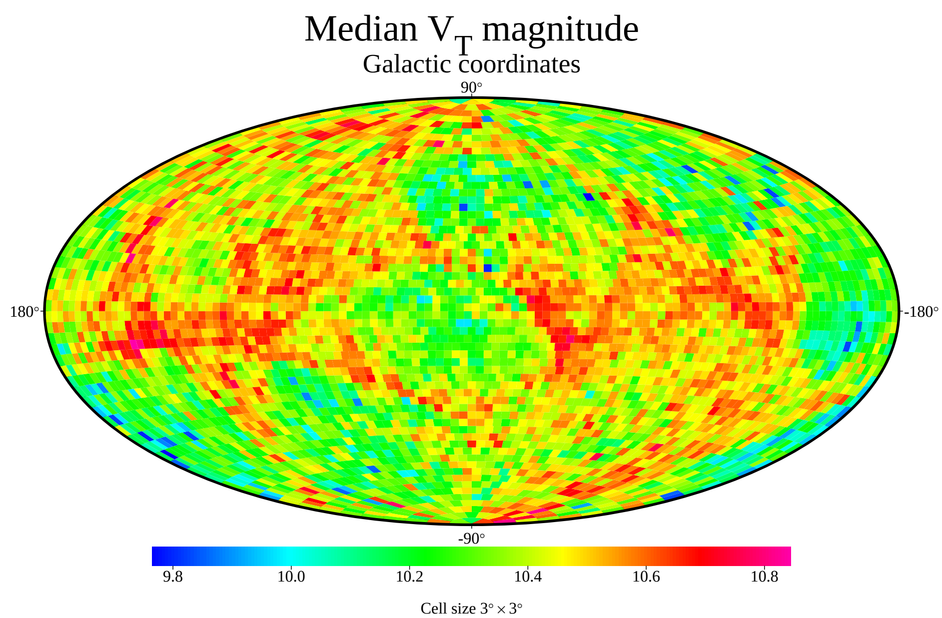

Figure 16.5. *The median V_T magnitude plotted in galactic coordinates.*

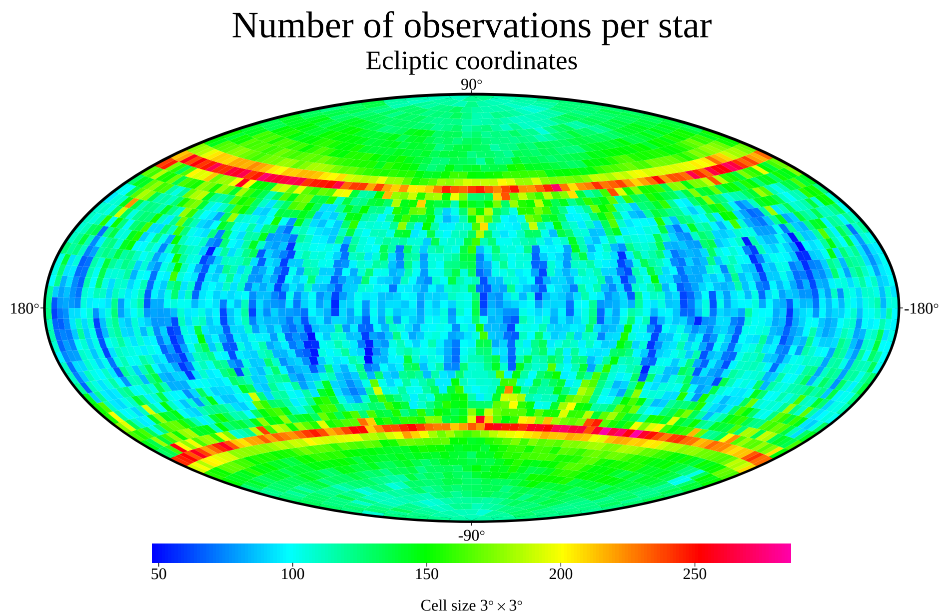

Figure 16.6. *The median number of astrometric observations. The scanning law for the satellite produces maxima at ecliptic latitude ±47°.*

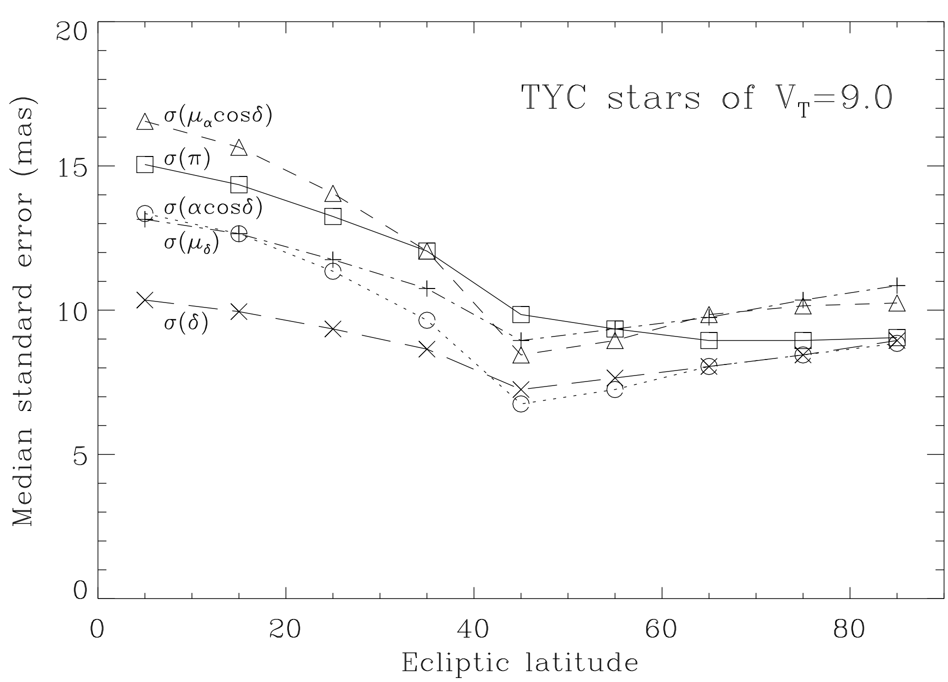

Figure 16.7. *The standard error of the astrometric parameters as a function of ecliptic latitude.*

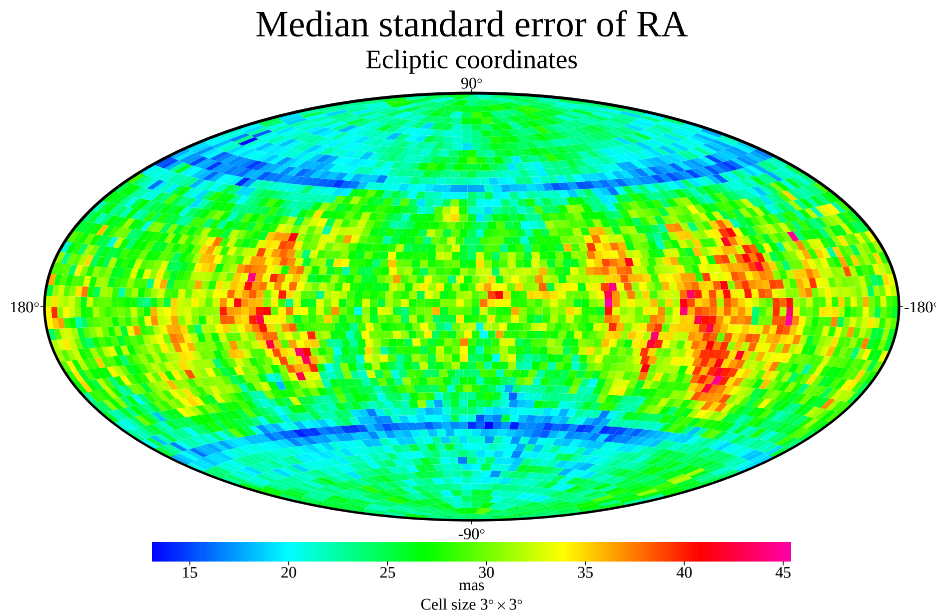

Figure 16.8. *The median standard error of right ascension (in ecliptic coordinates).*

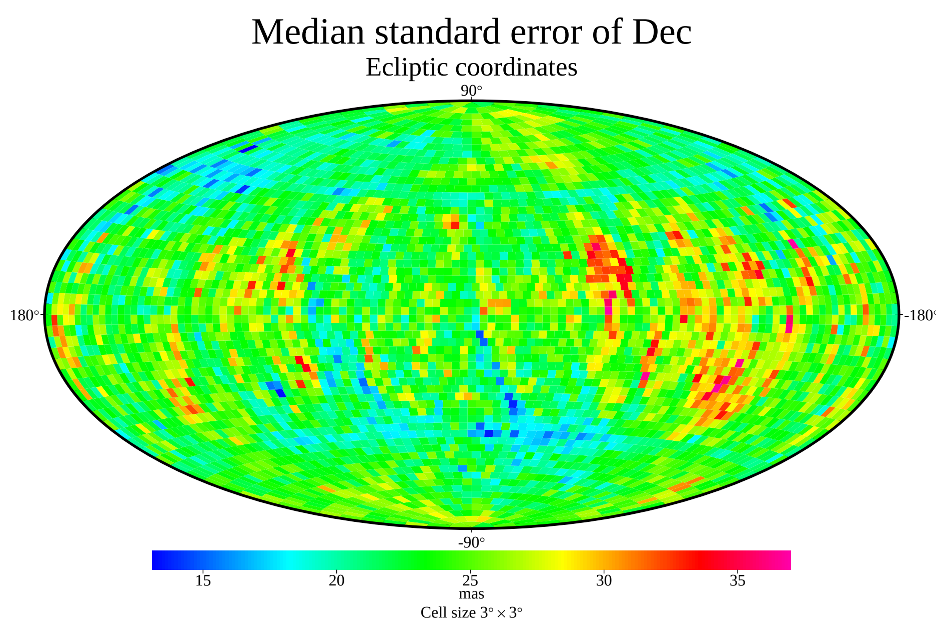

Figure 16.9. *The median standard error of declination (ecliptic coordinates).*

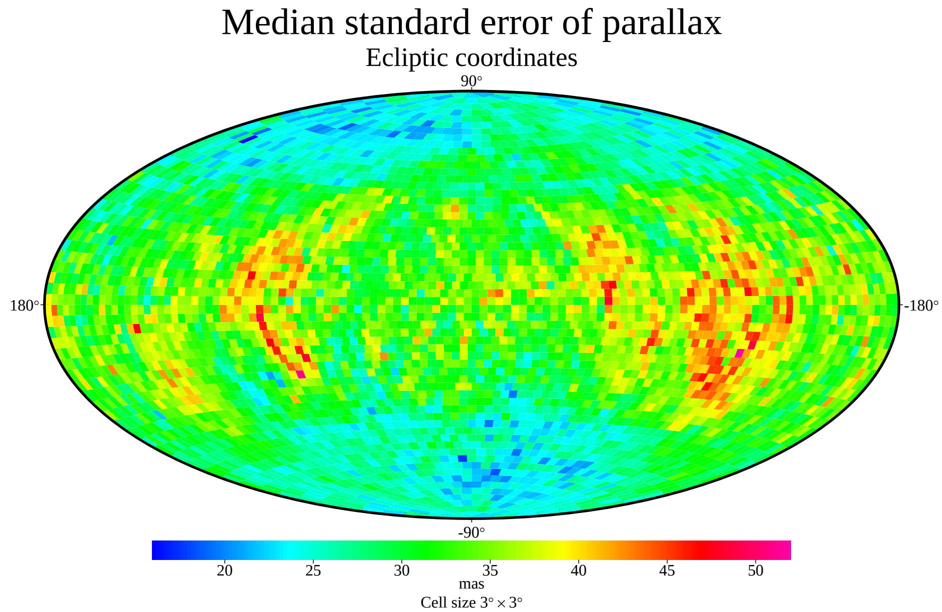

Figure 16.10. *The median standard error of the parallax (in ecliptic coordinates).*

F_s, F2 and correlation coefficients: Figure 16.13 shows F_s which is a measure of the signal-to-noise ratio, see Section 7.4. It is based on the assumption that detections within 0.7 arcsec of the mean position represent signal detections plus background detections, whereas detections between 0.7 and 1.4 arcsec represent background only. Usually images are sharp on a low rate of background detections, giving F_s values which are the square root of the number of transits used. Figure 16.13 is therefore very similar in appearance to Figure 16.6.

Figure 16.14 shows F2, the so-called goodness-of-fit parameter. The idea was to check whether the scatter of the residuals, after fitting the five parameters, corresponded to the expected scatter. If this expected scatter can be realistically computed, F2 should have a mean value of 0.0 and a standard deviation of 1.0 (see Field H30 in Section 2.1 of Volume 1). A value of 3.0 represents a rather too poor fit and −3.0 a rather too good fit. The computed values of F2 do not live up to these expectations, probably because too small a scatter was predicted for the faint stars. F2 was therefore not used in the production of the Tycho Catalogue and the values should be used with much care.

Figure 16.15 shows the distribution of the correlation coefficients for the five astrometric parameters. With the exception of panels (d) and (h), all coefficients have their maximum about 0.0 and a half-width at half maximum about 0.2. The dominance of negative values in panels (d) and (h) merely tells that the mean observational epoch is somewhat later than the catalogue epoch (J1991.25) (see Equation 1.2.6 and 1.2.8 of Volume 1).

Pair statistics: If stars were uniformly distributed on the sky, the number of stars within some distance from a particular star should be proportional to the area within that distance, i.e. to the square of the distance for small distances. The number of stars per interval of distance is then proportional to the distance. This is also true when the density of stars on the sky is constant within small areas (1 arcmin in radius, say) although it is variable when distances of several degrees are considered. Figure 16.16 shows the distribution of distances between pairs of Tycho stars (excluding HIP–only

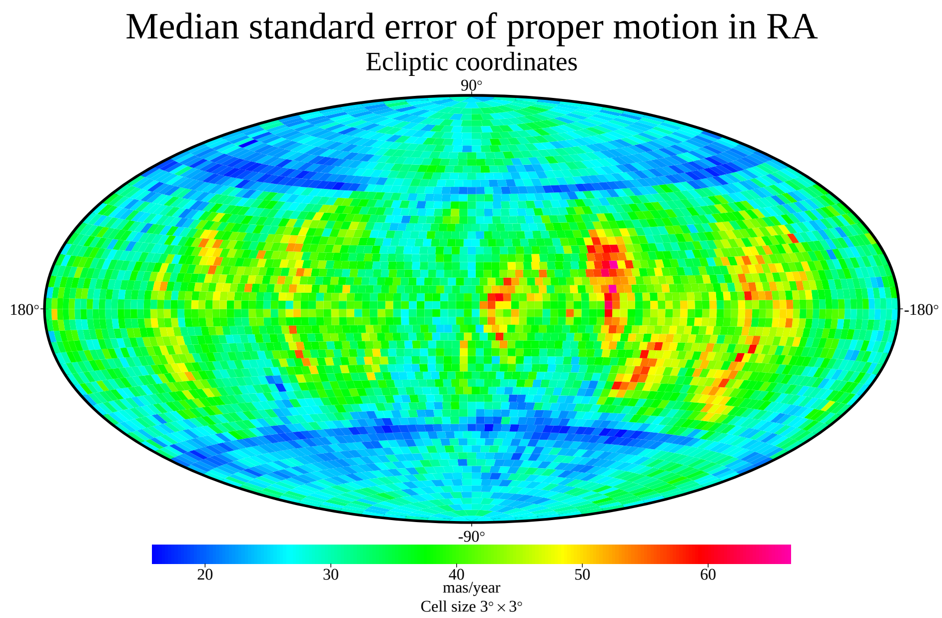

Figure 16.11. *The median standard error of annual proper motion in right ascension.*

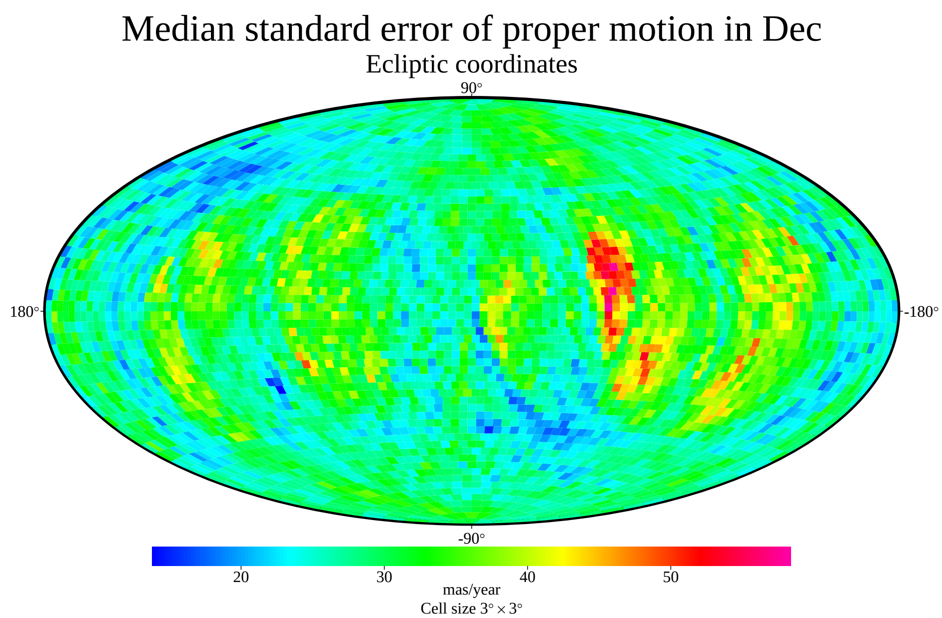

Figure 16.12. *The median standard error of annual proper motion in declination.*

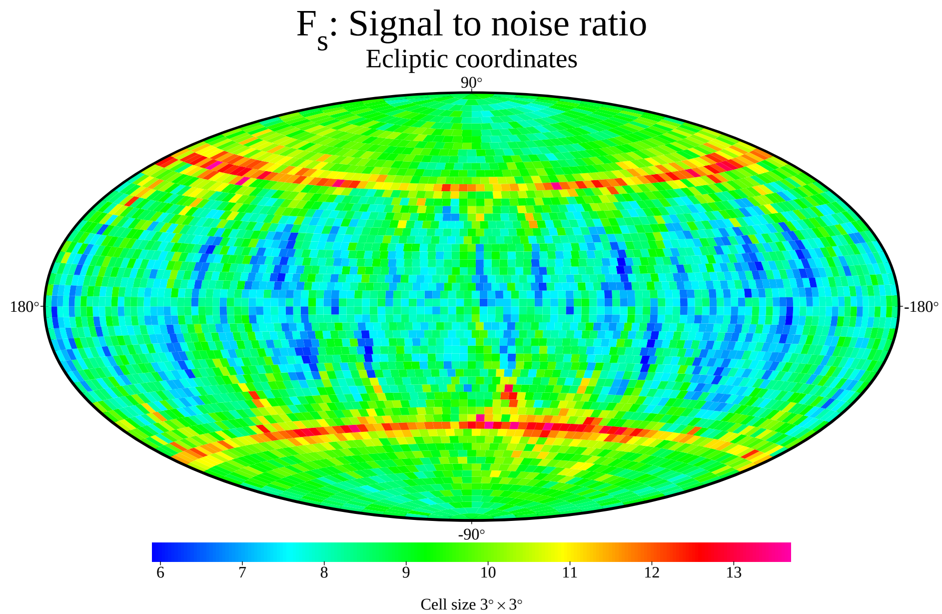

Figure 16.13. *The median value of the signal-to-noise ratio, F_S. When the rate of background detections is low, F_S is the square root of the number of astrometric observations.*

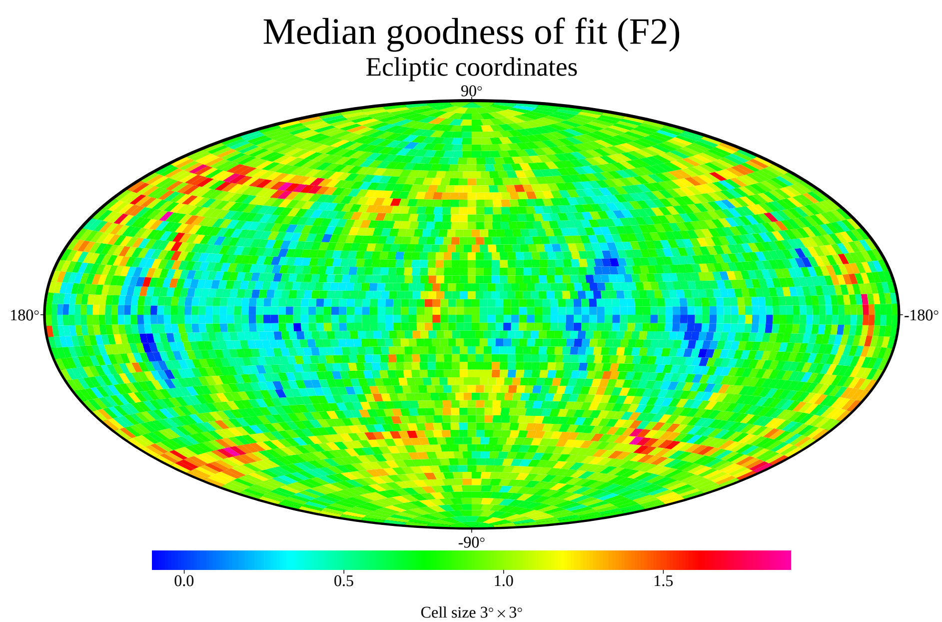

Figure 16.14. *Plot of the goodness-of-fit, F2*

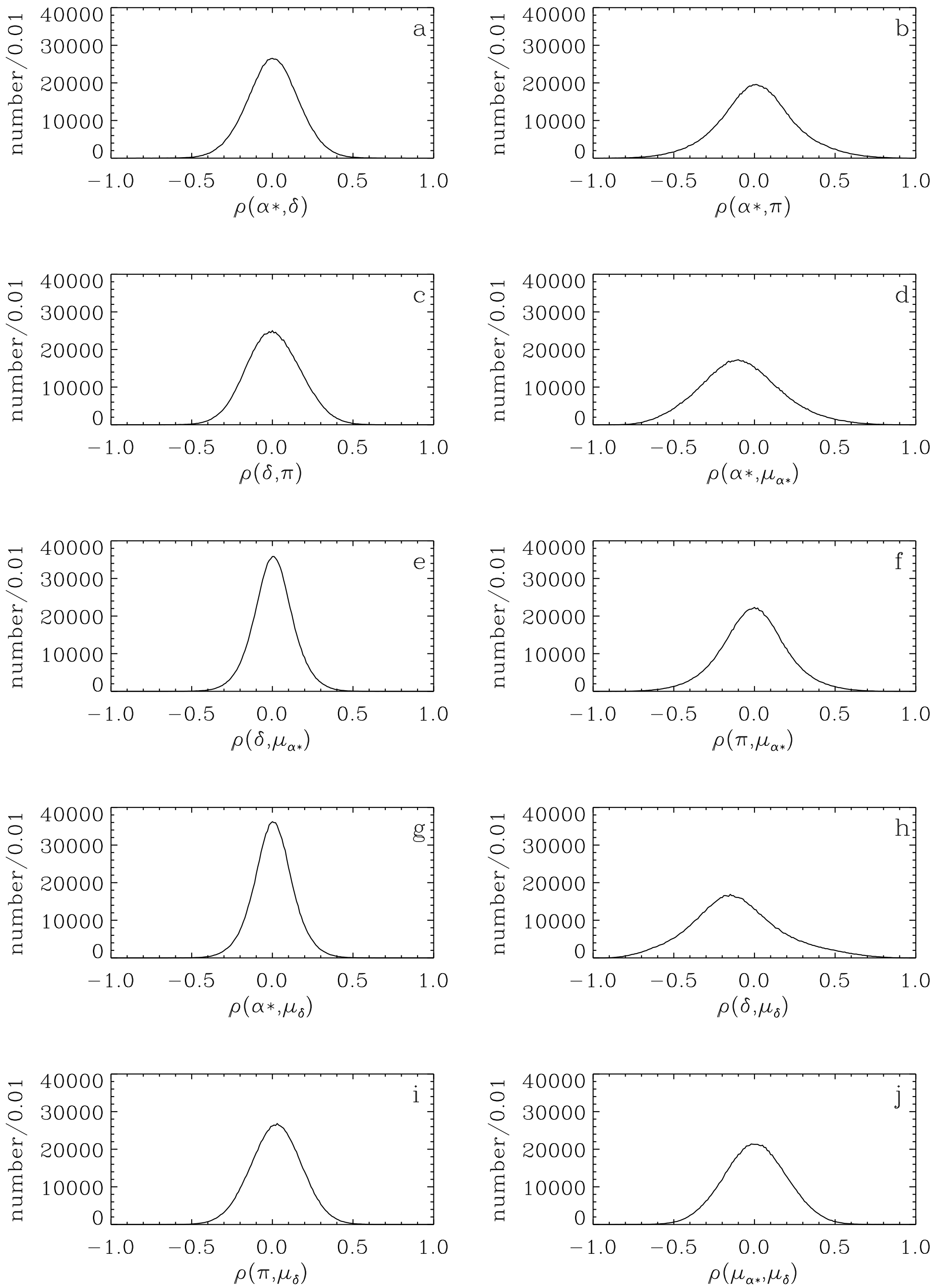

Figure 16.15. *The distribution of the correlation coefficients for the five astrometric parameters.*

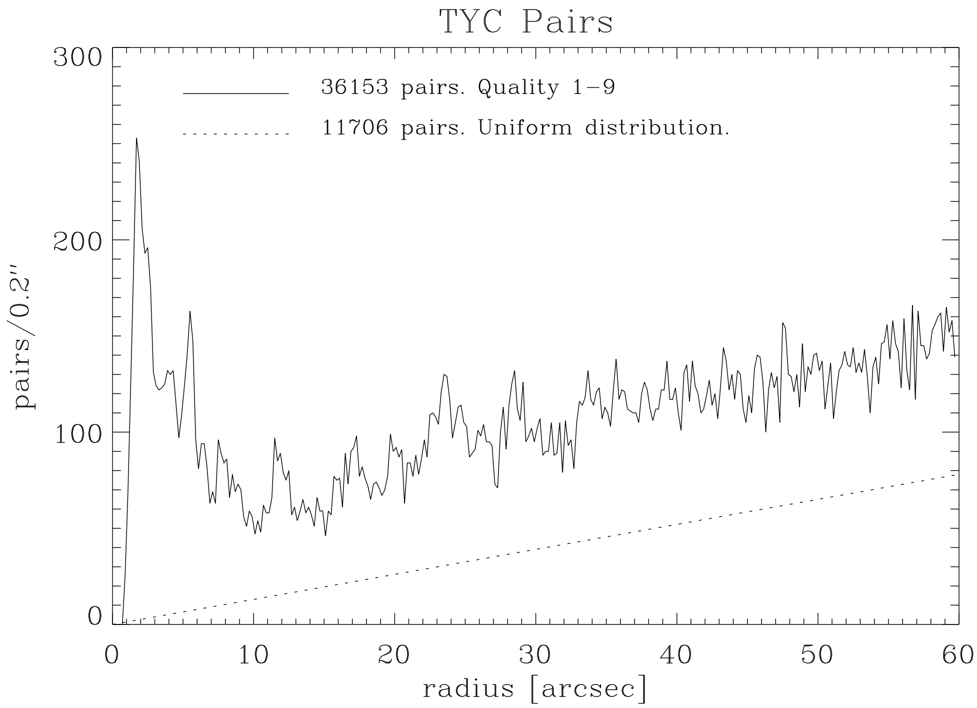

Figure 16.16. *Distribution of distances between all pairs of Tycho Catalogue stars. For comparison the distribution for a uniformly populated sky is also given. The peaks at 5.6, 11.3, 17, 23, 29 and 34 arcsec are due to side lobes.*

stars). Resolved double stars produce a peak at 2 arcsec separation. There are, however, other peaks of a less innocent nature, i.e. the peaks at 5.6, 11.3, 17, 23, 29 and 34 arcsec. These distances correspond to the side lobes of the response function of the slits, as discussed in Section 4.3. A star may give rise to false detections at these distances or make true detections brighter when another star is crossing the slit system at the same time.

It is estimated from Figure 16.16 that a few hundred stars that are either false or actually too faint for Tycho detection, have found their way into the final catalogue, due to side lobes. For the same reason, the brightness of the double star components was overestimated as explained in Section 19.5. The question of false stars is discussed further in Chapter 17.

Parallaxes: The individual parallaxes in the Tycho Catalogue are generally of low significance. Figure 16.17(a) shows the distribution of measured parallaxes. The negative wing contains 44 per cent of the stars. The overall median value is 4.0 mas, see Figure 16.18 which shows the median parallax across the sky. Figure 16.17(b) shows the distribution of the parallax divided by its standard error. Because the true parallaxes are generally much smaller than the error, we would expect an almost normal distribution. The dashed curve is a Gaussian distribution centred at 0.2 and with a standard deviation of 1.33. This suggests that the internal standard error should be increased some 30 per cent to produce the external standard error. The external errors of the Tycho Catalogue are discussed further in Chapter 18.

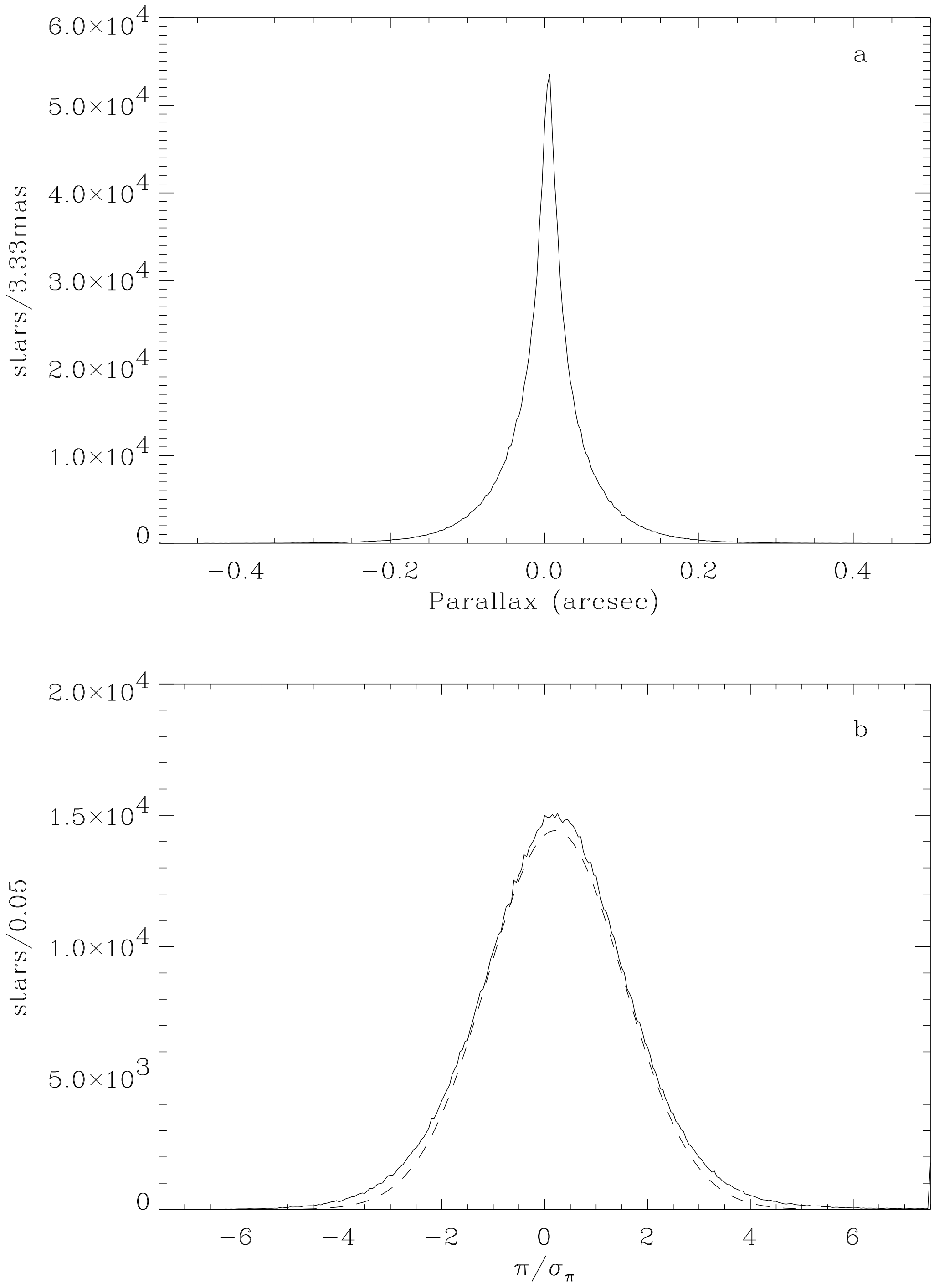

Figure 16.17. *Distribution of parallaxes and their significance. The dashed curve is a Gaussian fit with standard deviation 1.3.*

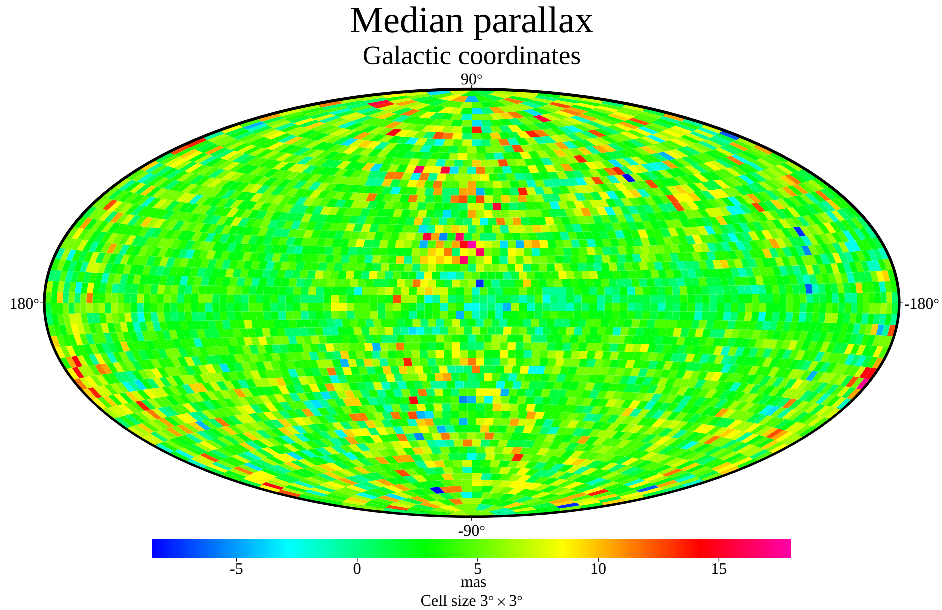

Figure 16.18. *The median parallax. The overall median is 4 mas. Towards the Hyades ($l = 180°, b = -20°$) and the dust clouds in Ophiuchus ($l = 0°, b = 20°$) the median parallax is much higher.*

16.3. Photometric Content

The Tycho Catalogue contains photometric data for both the southern and the northern sky obtained with a single instrument. The two colour bands B_T and V_T define a new independent system providing mean magnitudes for 1 047 132 stars. An additional 4647 stars obtained photometric values from a special treatment in the astrometric reductions, e.g. the double stars (see Section 14.4).

Table 16.3 summarizes median standard errors for all stars with B_T or V_T values in the Tycho Catalogue including the approximate magnitudes obtained during astrometric processing. The $\sigma_{B_T-V_T}$ depends on magnitude, but also on the colour itself. Values for $\sigma_{B_T-V_T}$ as a function of V_T and $B_T - V_T$ are given for non-variable stars in Table 16.5, i.e. for photometric standard stars.

The approximate magnitudes for about 4600 stars, mainly from the astrometry processing, were only given a simple calibration. For the remaining part of this section, only stars with fully calibrated magnitudes are discussed, i.e. the 1 050 000 stars with median or de-censored magnitudes derived from single transits calibrated in the B_T and V_T system as described in Chapter 8. The distribution of the fully calibrated magnitudes is shown in Figure 16.19. Technically, these magnitudes are for the stars in the Tycho Catalogue defined by Field T36 (Section 2.2, Volume 1) equal to 'M' or 'N', indicating that the magnitude is a median magnitude ('M') for bright stars ($B_T < 8.5$ mag and $V_T < 8.0$ mag) or a de-censored magnitude ('N'). While median magnitude determination took into account only the detected observations, the de-censoring process also accounted for the non-detections (this is described in detail in Chapter 9). Table 16.4 gives some important numbers for fully calibrated stars.

Table 16.3. Median standard error of mean magnitude and colour index versus magnitude. N is the number of stars in each interval, the 0.5 mag bins being centred on the given V_T. σ_{B_T} is given as a function of B_T, while σ_{V_T} and $\sigma_{B_T-V_T}$ are given as functions of V_T. Systematic errors are much smaller, except for the faintest stars.

B_T mag	N	σ_{B_T} mag	V_T mag	N	σ_{V_T} mag	V_T mag	N	$\sigma_{B_T-V_T}$ mag
≤5.0	919	0.003	≤5.0	1455	0.003	≤5.0	1451	0.003
≤9.0	58763	0.009	≤9.0	119878	0.012	≤9.0	119748	0.016
All	1050525	0.073	All	1051923	0.057	All	1049579	0.087
0.5	4	0.012	0.5	5	0.010	0.5	5	0.014
1.0	4	0.012	1.0	6	0.010	1.0	6	0.014
1.5	15	0.007	1.5	12	0.007	1.5	12	0.010
2.0	19	0.004	2.0	38	0.004	2.0	36	0.004
2.5	38	0.003	2.5	47	0.003	2.5	47	0.004
3.0	57	0.003	3.0	90	0.002	3.0	90	0.003
3.5	79	0.003	3.5	143	0.002	3.5	142	0.003
4.0	183	0.003	4.0	268	0.002	4.0	268	0.003
4.5	298	0.003	4.5	484	0.003	4.5	484	0.003
5.0	521	0.003	5.0	871	0.003	5.0	870	0.004
5.5	919	0.003	5.5	1490	0.003	5.5	1489	0.004
6.0	1416	0.003	6.0	2582	0.004	6.0	2578	0.005
6.5	2435	0.004	6.5	4647	0.005	6.5	4644	0.007
7.0	4092	0.005	7.0	7861	0.006	7.0	7857	0.009
7.5	6722	0.007	7.5	13381	0.008	7.5	13375	0.011
8.0	11146	0.009	8.0	22691	0.010	8.0	22681	0.014
8.5	17801	0.011	8.5	37864	0.013	8.5	37800	0.019
9.0	29686	0.014	9.0	62629	0.018	9.0	62558	0.027
9.5	47949	0.019	9.5	102441	0.026	9.5	102313	0.039
10.0	75708	0.026	10.0	166222	0.038	10.0	165927	0.058
10.5	120981	0.039	10.5	261852	0.060	10.5	261142	0.091
11.0	184604	0.058	11.0	286408	0.095	11.0	285919	0.137
11.5	273399	0.092	11.5	74953	0.151	11.5	74758	0.205
12.0	212866	0.145	12.0	4357	0.308	12.0	4227	0.440
12.5	53225	0.232	12.5	458	0.602	12.5	334	1.039
13.0	5455	0.401	13.0	78	0.900	13.0	17	1.879
13.5	682	0.680	13.5	25	1.601	13.5	0	–
14.0	144	1.042	14.0	12	1.887	14.0	0	–
14.5	61	1.495	14.5	4	2.412	14.5	0	–
15.0	16	1.881	15.0	4	2.670	15.0	0	–

Despite the different origin of magnitudes (using median and de-censored values) there are no discontinuities in the catalogue at V_T = 8 mag or at B_T = 8.5 mag. This results from the fact that bright stars had no censored observations. The difference between median and de-censored magnitudes is less than 0.005 mag at this magnitude and therefore below the calibration uncertainty. An artifact of different de-censoring processing schemes is however noticeable for the B_T channel in Figure 16.19: at B_T = 10.95 mag the distribution in this Tycho channel has a not quite uniform slope; this is however only

Table 16.4. Numbers for fully calibrated stars.

	number of stars
B_T and V_T given	1047132
only V_T given	173
only B_T given	79
median magnitudes	29524
de-censored magnitudes	1017860

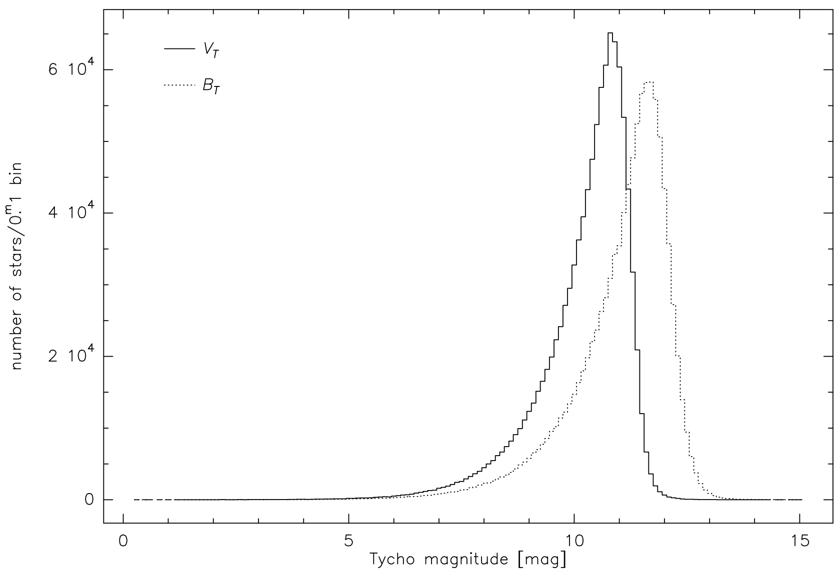

Figure 16.19. *Distribution of all stars with at least one fully calibrated Tycho magnitude binned to 0.100 mag.*

a minor effect. Thus, the B_T and V_T magnitudes can be treated as uniform entities and are simply referred to as mean magnitudes in the following sections.

Using these mean magnitudes, the colour-magnitude diagram in Figure 16.20 was constructed for all stars in the Tycho Catalogue with B_T and V_T magnitudes. Clearly visible is the completeness and the detection limit for a given Tycho colour. The large errors for very faint and very red stars (see Tables 16.3 and 16.5) are clearly visible. A remarkable feature of this diagram is the concentration of the stars in four vertical bands of constant colour. This is not an artifact, but reflects intrinsic structure of the Hertzsprung-Russell diagram, i.e. of the stellar population within a few hundred parsec.

Photometric precision over the whole sky: The standard error in V_T, depending on position in the sky, is shown in Figure 16.21 for all stars (upper panel) and in three magnitude ranges. Shown in a logarithmic colour-scale is the average σ_{V_T} as a function of the equatorial coordinates. The lowest average errors are achieved about 45° above and below the ecliptic plane. Stars located in these bands obtained the most observations due to the scanning law, as discussed in Section 16.2. As shown below, the number of observations is the main parameter for the precision of the mean magnitude. The effect of the scanning law is clearly seen in all but the faintest magnitude range with a low number of stars. Clearly visible with an increased average σ_{V_T} in all magnitude ranges is the Galactic centre region (α, δ: 266°, −29°) and the region near η Carinae (α, δ:

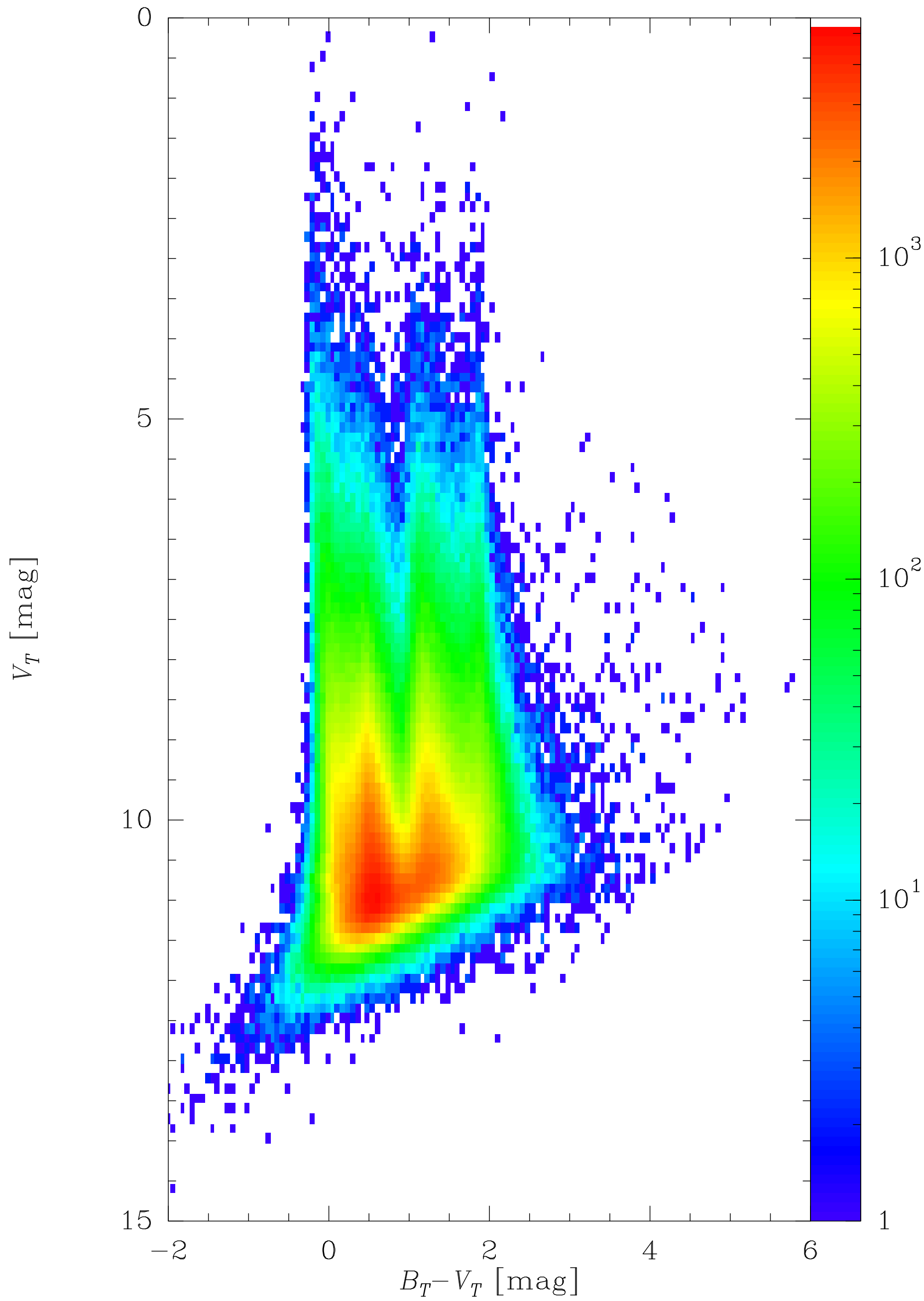

Figure 16.20. *Colour magnitude diagram for all stars with B_T and V_T magnitudes. The logarithmic colour scale shows the number of stars in bins of 0.0625 mag in $B_T - V_T$ and 0.125 mag in V_T.*

Table 16.5. $\sigma_{B_T-V_T}$ for three colour ranges as a function of V_T derived for non-variable stars with N_{photom} from 80 to 160 photometrically valid transits. *n* is the number of stars.

$B_T - V_T$		[−0.2,0.2]		[0.5,0.9]		[1.4,2.0]
V_T [mag]	n	$\sigma_{B_T-V_T}$ [millimag]	n	$\sigma_{B_T-V_T}$ [millimag]	n	$\sigma_{B_T-V_T}$ [millimag]
5	95	3	24	4	20	5
6	411	5	133	6	208	8
7	952	8	722	10	255	13
8	1217	13	2522	15	224	22
9	600	21	1258	27	153	43
10	86	44	552	54	100	120
11	17	90	73	121	36	263

160°, −60°). Higher than average errors in dense regions can be understood from the fact that many more parasite transits (i.e. transits with magnitude estimates disturbed by other stars) had to be rejected in de-censoring.

Non-variable Stars: Precision of Mean Magnitudes in the Tycho Catalogue

The following paragraphs discuss the precision of magnitudes given in the Tycho Catalogue for non-variable stars (i.e. the 17 863 photometric standard stars described in Chapter 8), allowing an estimation of the overall precision as a function of several parameters in the Tycho observations for definitively constant stars.

Precision depending on the number of observations: A crucial parameter for the precision of a magnitude is the number of observations used to derive the B_T or V_T magnitude. Given in the Tycho Catalogue is the number of photometrically valid transits, N_{photom} (Field T43, Section 2.2 of Volume 1) which is also used to show the corresponding dependency of σ_{V_T} for two magnitude ranges in Figure 16.22. It should be noted that N_{photom} counts the number of detections in the case of a median, i.e. for the bright stars in Figure 16.22, but the sum of detections and non-detections in the case of a de-censored magnitude. In addition to this, a different background limit was applied in the de-censoring analysis and observations affected by parasites were rejected. For this reason and because other selection criteria were adopted in the astrometric reduction, N_{photom} cannot easily be compared with N_{astrom} which gives the number of transits retained in the astrometric adjustment (Field T29), see Figure 16.6.

Precision depending on colour: Besides the number of photometrically valid transits, another important parameter for the achieved precision of $B_T - V_T$ at a given magnitude is the colour of the star. Table 16.5 gives $\sigma_{B_T-V_T}$ for three different colour ranges as a function of V_T. The highest values occur for red stars, because the photon noise is larger in the B_T channel at a given V_T for large $B_T - V_T$.

Colour of Stars on the Sky

Figure 16.23 shows the median Johnson $B - V$ on the sky for Tycho stars. With a limiting magnitude of $V_T = 11$ mag, the stars must generally be assumed to be within some 100–250 pc and the plot shows many features of the Galactic vicinity. About

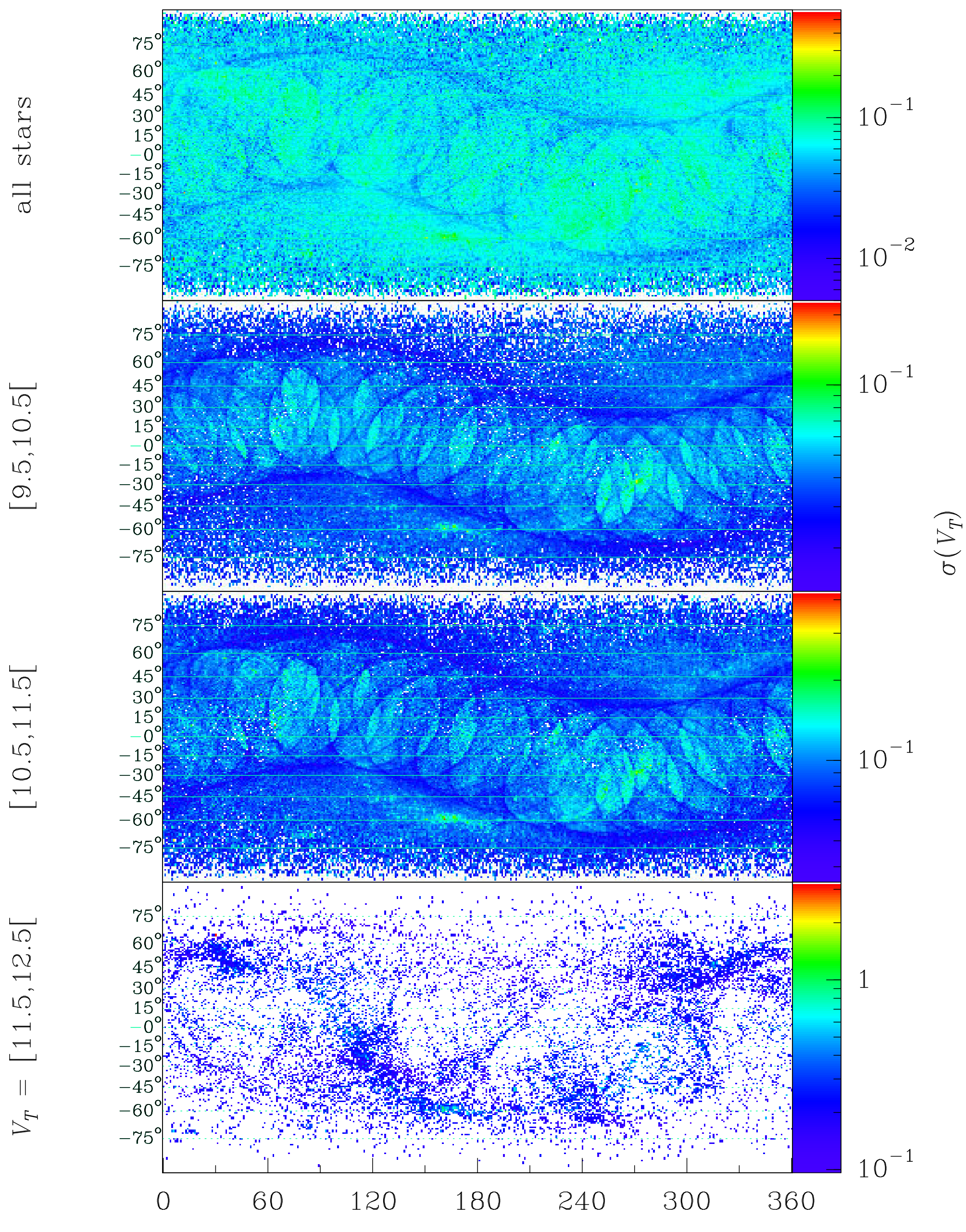

Figure 16.21. *Average errors σ_{V_T} as a function of equatorial coordinates for all stars (upper panel) and stars in three V_T magnitudes ranges, from top to bottom: V_T = 9.5 to 10.5 mag (338 227 stars), 10.5 to 11.5 mag (490 549 stars) and 11.5 to 12.5 mag (20 167 stars). The logarithmic colour scale shows the average σ_{V_T} with a resolution of 1 degree in right ascension.*

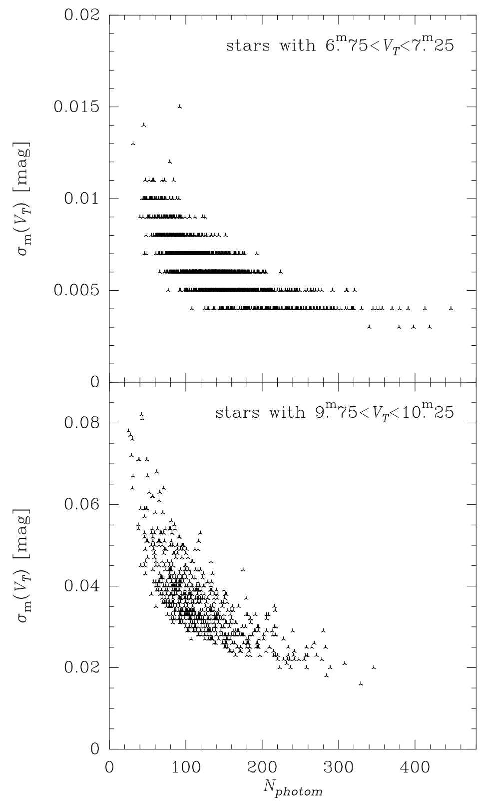

Figure 16.22. *The error of the Tycho V_T magnitudes as a function of the number of observations $N_{\rm photom}$ given in the Tycho Catalogue for non-variable stars in two magnitude ranges (upper) 6.75 to 7.25 mag (1668 stars) and (lower) 9.75 to 10.25 mag (669 stars).*

30° from the Galactic centre the dust complexes in Ophiuchus and Scorpius cause red giants or strongly reddened stars to dominate. In general, early types are in the majority, mainly because the catalogue is magnitude limited, causing the upper part of the Hertzsprung-Russell diagram to be over-represented. This is especially clear in the third quadrant of longitude ($l \in [180°, 270°]$) where the picture is less affected by interstellar absorption.

16.4. The Tycho Epoch Photometry Annex

The Tycho Epoch Photometry Annex (TEPA) contains individual transit data of selected stars and is divided into two parts. The smaller part, TEPA A, is delivered on CD-ROM as an ASCII file and comprises transits for 34 446 stars while the larger data base, TEPA B, contains transit data for 481 553 stars (including all TEPA A stars) and is made available through the Centre de Données astronomiques de Strasbourg. While TEPA A is formed by several peculiar groups of stars (and 5165 photometric standard stars for comparison) TEPA B gives mainly the 480 000 brightest stars. The exact criteria used to select stars for the Tycho Epoch Photometry Annex can be found in Volume 1, Section 2.6. Table 16.6 shows some statistics of stars and transits. The categories of stars do not, however, correspond strictly to the selection criteria but to the flags in the header record given for each star in the Tycho Epoch Photometry Annex (see

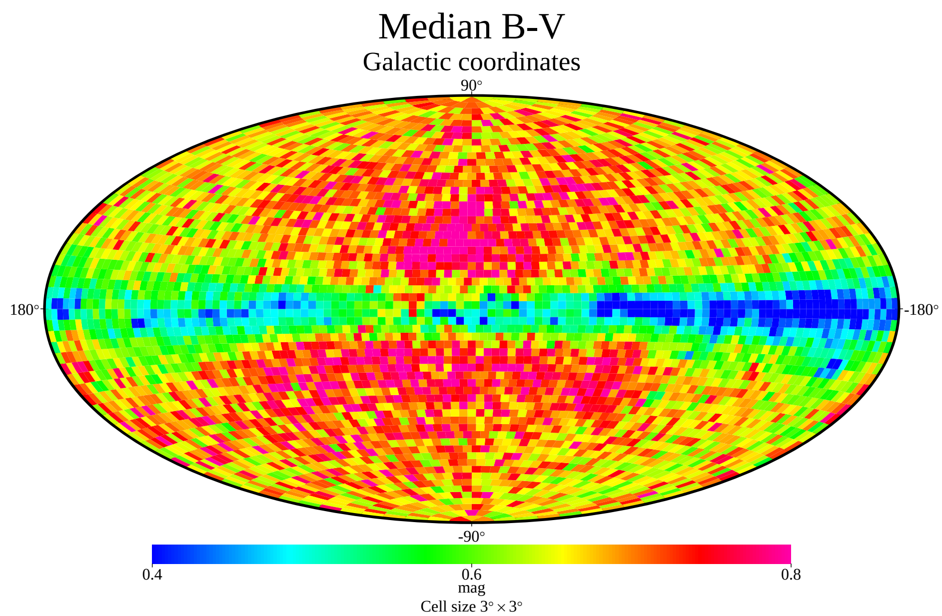

Figure 16.23. *The median $B - V$ in galactic coordinates: several features of the Galaxy are evident.*

Table 16.6. Contents of the Tycho Epoch Photometry Annex (TEPA)

	flag-bit	TEPA A	TEPA B
Number of stars:			
total		34 446	481 553
standard stars	TH16-1	5 165	13 707
standard stars (subset)	TH16-0	2 591	7 285
reprocessing reduction	TH16-2	3 405	50 358
approximate magnitudes	TH15-0	1 570	3 234
(suspected) variables:			
from GCVS, NSV	TH15-1	6 689	6 690
from Tycho	TH15-2	15 825	105 518
from Hipparcos	TH15-5	3 286	11 138
close pairs	TH15-3	4 135	16 117
doubles	TH15-4	9 093	31 381
Number of transits:			
total		6 760 543	83 196 972
empty		807 691	9 352 207
B_{det} given		658 635	7 248 080
V_{det} given		443 803	3 468 639

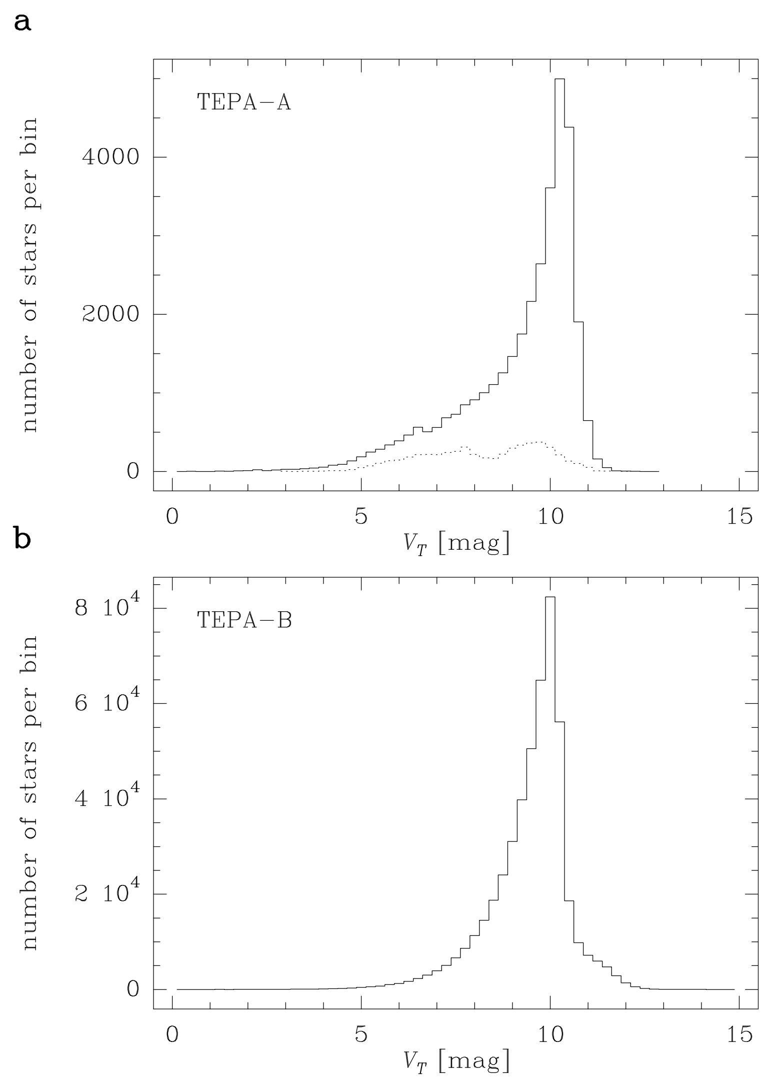

Figure 16.24. *Distribution of all stars in (a) the Tycho Epoch Photometry Annex A and (b) the Tycho Epoch Photometry Annex B, binned to 0.25 mag. The dashed line in (a) shows the number of standard stars (see Table 16.6).*

Table 2.6.1 in Volume 1 for a description of the star header record), i.e. to information given in Fields TH15 and TH16.

More specifically, the rows in Table 16.6 are described as follows:

- standard stars: gives the number of stars which were assumed constant at the beginning of the calibration process. The number given refers to Field TH16 (flag 1) marking standard stars for photometric calibration in reprocessing. After processing and variability analysis, 584 of these stars in the Tycho Epoch Photometry Annex B and 199 in Annex A were found to be flagged as variable or suspected variable in the General Catalogue of Variable Stars/New Catalogue of Suspected Variable Stars (GCVS/NSV) or from Hipparcos or Tycho variability analysis (see Section 19.2 for further discussion);

- standard stars (subset): gives only those stars used during main processing. This star sample is fully included within the sample of standard stars for reprocessing. The reason that the number of standard stars was lower for main processing is merely technical (and due to the transit data available for calibration). Therefore, the larger sample of stars marked by Field TH16 (flag 1) should be used if the Tycho Epoch Photometry Annex is searched for standard stars;
- reprocessing reduction: states that the transits for this star and the photometric quantities given in the Tycho Catalogue originate from the reprocessing data stream using reprocessing calibration (Section 11.4). This does not necessarily mean, however, that astrometric values were derived using reprocessing data (see Section 11.2);
- approximate magnitudes: means that the star did not obtain its photometric values from fully calibrated transit data, but from a dedicated treatment in the astrometric reductions applied, e.g. to double stars. Magnitudes of these stars were not derived using de-censoring and are systematically too bright (by up to 1 mag for a star of 11 mag);
- about 11–12 per cent of all transits in the Tycho Epoch Photometry Annex are found to be empty, i.e. the star was not detected in the added photon counts of the B_T and V_T channels. The detection limits $B_{\rm det}$ and $V_{\rm det}$ which are given in the Tycho Epoch Photometry Annex instead of B_T and V_T for empty transits were calculated assuming a signal-to-noise ratio of 1.5. When the star was detected in one channel, however, the detection limit given for the other channel was computed assuming a signal-to-noise ratio of 2.5. The entries '$B_{\rm det}$ given' and '$V_{\rm det}$ given' give the number of transits for the latter case.

The magnitudes of stars in the Tycho Epoch Photometry Annex A range from V_T = –0.6 mag to 12.7 mag as can be seen from Figure 16.24 (and up to 15 mag in Annex B) with Canopus (TYC 8534–2277–1) being the brightest star included. The mean V_T magnitudes and the percentiles given in the star header are strictly the same as those in the Tycho Catalogue with the exception that percentiles in the Tycho Catalogue are replaced by blanks when fainter than 15.0 mag. Values for B_T percentiles and the number of measured transits for each channel are only given in the Tycho Epoch Photometry Annex.

Number of Transits and Transit Selection

The mean number of transits given per star is 197 in the Tycho Epoch Photometry Annex A and 173 in Annex B. The minimum number is 28 and the maximum is 611. Only 'valid' transits are included, which might be either detections or non-detections. The number of measurements per star is given in the header record for both the B_T and the V_T channel. This number decreases for fainter stars. Non-detections may however also occur for bright stars (the 6 per cent 'spurious non-detections' discussed in Section 2.2 of Volume 1). The detection limits given for B_T and V_T are then meaningless. A 'valid' transit may even be a transit which was never used in photometry because of the criteria imposed during de-censoring or median computations.

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