19. VERIFICATION OF THE TYCHO CATALOGUE: PHOTOMETRY

This chapter discusses the photometric contents of the Tycho Catalogue and its epoch photometry annex. The systematic differences between the Tycho mean and ground-based magnitudes for 17 683 standard stars are well below 0.010 mag in the range $V_T \simeq 4.25$ to 11.0 mag, and only few stars in this sample were found to be variable or at least suspected to be so in the course of analysis of the satellite data. The method and outcome of a Tycho variability search is described in detail. Finally, the Tycho magnitudes of double stars were compared with recent ground-based observations: pairs of equal brightness reveal too bright magnitudes in the Tycho Catalogue by about 0.05 mag and this bias increases to about 0.1 mag for other pairs.

19.1. Tycho Mean Magnitudes

The majority of mean magnitudes in the Tycho Catalogue are flagged by 'M' or 'N' in Field T36 (Section 2.2, Volume 1) and are called 'fully calibrated' magnitudes. They were constructed using two different methods, namely median magnitudes for bright stars, de-censored magnitudes for faint stars, and using data from two different processing schemes, i.e. main processing and reprocessing. Photometrically, the major difference between main and reprocessing is the usage of different single-slit response functions (see Chapter 8) which is of importance only for very bright stars. The selection of the magnitudes is described in Section 11.5. A few thousand mean magnitudes in the catalogue, flagged by 'D' or 'T' in Field T36, have a different origin.

In the following, the fully calibrated Tycho mean magnitudes are checked for systematic differences between the four possible origins of the magnitudes. For this purpose, the Tycho magnitudes were compared with B_T and V_T magnitudes derived from ground-based observations for 17 683 stars, which is exactly the same standard star sample as used in Chapter 8. Figure 19.1 shows the difference for both Tycho channels between mean observed magnitudes in the Tycho Catalogue and ground-based magnitudes as a function of the ground-based magnitudes. The figure may be compared directly with Figures 8.3(a) and 8.3(b) which show the corresponding median magnitudes for the same stars, thus demonstrating the crucial correction of the de-censoring process for stars fainter than $V_T \simeq 8.0$ mag. The median difference between Tycho and ground-based magnitudes is shown with a broken line in Figure 19.1 together with the 15th and 85th percentiles of the distribution. Table 19.1 gives the corresponding median differences for both Tycho channels.

The systematic differences in V_T are below 0.005 mag for stars in the magnitude range 5.5 mag to 10.25 mag, but brighter stars seem to obtain too faint magnitudes while fainter stars may have obtained too bright magnitudes. This conclusion suffers however from the very small number of standard stars at both the bright and the faint ends of Table 19.1. Regarding the B_T channel, median differences are somewhat larger than for V_T when considering stars brighter than $B_T = 7$ mag. This is a result of the (magnitude-independent) calibration carried out in the 4.5 mag to 9 mag interval for both channels separately. The median differences are smallest for the magnitudes where the bulk of standard stars is located. The calibration limit of 9 mag affects more the distribution of standard stars in B_T than that of V_T because only 69 per cent of stars in the sample were available for the calibration of the B_T channel while 83 per cent were available for the V_T channel.

The limit of 9 mag was, however, needed in the calibration process because no de-censoring was possible during this process. It may be noted in Figure 19.1 that the scatter is larger for B_T than for V_T. This is in accordance with the larger errors given for the ground-based B_T(cat) magnitudes.

Differences between main and reprocessing calibration are below a few millimagnitudes for stars fainter than $V_T \simeq 5$ mag and therefore negligible. For the very bright stars the improved estimation in reprocessing gave better mean magnitudes, and reprocessing magnitudes were therefore preferred over those from the main processing. The actual number of stars from the reprocessing in the Tycho Catalogue is however only 51 586. The processing origin of the data is not given in the Tycho Catalogue, but may be obtained from the flags in the Tycho Epoch Photometry Annex.

Table 19.1 also shows that no systematic differences remain from the usage of median magnitudes for stars brighter than $V_T = 8.0$ mag and $B_T = 8.5$ mag and de-censored values for fainter stars. This can also be seen from the distribution of stars with magnitude in Figure 16.19. The small artefact in the figure at $B_T \simeq 10.95$ mag due to different de-censoring processings, discussed in Section 16.3, is not visible in Table 19.1.

In summary, calibration and de-censoring led to median systematic errors well below 0.01 mag in the ranges $V_T \simeq 4.25$ to 11.0 mag and $B_T \simeq 4.75$ to 11.5 mag, i.e. well down to the completeness limits. Outside these ranges too few standard stars are available to judge on the accuracy of calibration and de-censoring.

19.2. Doubtful Standard Stars

In principle, 17 683 stars were available for the Tycho photometric calibration. This number comprises an already 'cleaned' sample of the original set of stars, e.g. after removing obvious variable stars (see Section 8.3). The true numbers were only about 10 000 stars for the main processing and 13 600 for the reprocessing calibration, because only the magnitude range of 4.5 – 9.0 mag was used for the calibration processes. The complete sample of 17 683 stars was used when the results of photometric calibration (Section 8.2) and the accuracy of Tycho photometry (Section 19.1) were discussed.

Table 19.1. Median differences: Tycho Catalogue mean magnitudes minus ground-based magnitudes, as a function of the magnitude at the centre of a bin.

	B_T		V_T	
Magnitude	$N_{\rm stars}$	Median	$N_{\rm stars}$	Median
2.75	1	–	0	–
3.00	0	–	3	0.015
3.25	2	0.042	1	–
3.50	4	0.024	4	0.010
3.75	3	0.015	4	0.000
4.00	4	0.019	7	0.006
4.25	12	0.015	14	0.006
4.50	11	0.011	11	0.004
4.75	26	0.005	30	0.003
5.00	27	0.007	62	0.005
5.25	43	0.008	79	0.005
5.50	75	0.009	134	0.005
5.75	92	0.004	219	0.004
6.00	141	0.004	296	0.004
6.25	489	0.004	223	0.006
6.50	294	0.006	648	0.003
6.75	396	0.006	678	0.003
7.00	499	0.006	798	0.003
7.25	694	0.002	1041	0.003
7.50	910	0.001	1367	0.002
7.75	1113	−0.001	1724	0.002
8.00	1445	−0.002	2026	0.001
8.25	1704	−0.004	2007	0.001
8.50	1799	−0.002	1539	0.001
8.75	1836	−0.001	1135	0.000
9.00	1434	−0.002	850	0.002
9.25	997	0.000	652	−0.002
9.50	756	0.003	557	0.000
9.75	655	0.002	447	−0.003
10.00	585	−0.001	323	−0.004
10.25	511	0.001	220	−0.004
10.50	407	0.000	149	−0.006
10.75	308	−0.001	101	−0.007
11.00	207	0.000	52	0.005
11.25	174	0.003	10	−0.052
11.50	114	0.006	4	−0.140
11.75	74	0.013	2	−0.139
12.00	66	−0.009	0	–
12.25	21	−0.073	0	–
12.50	11	−0.117	0	–
12.75	9	−0.197	0	–

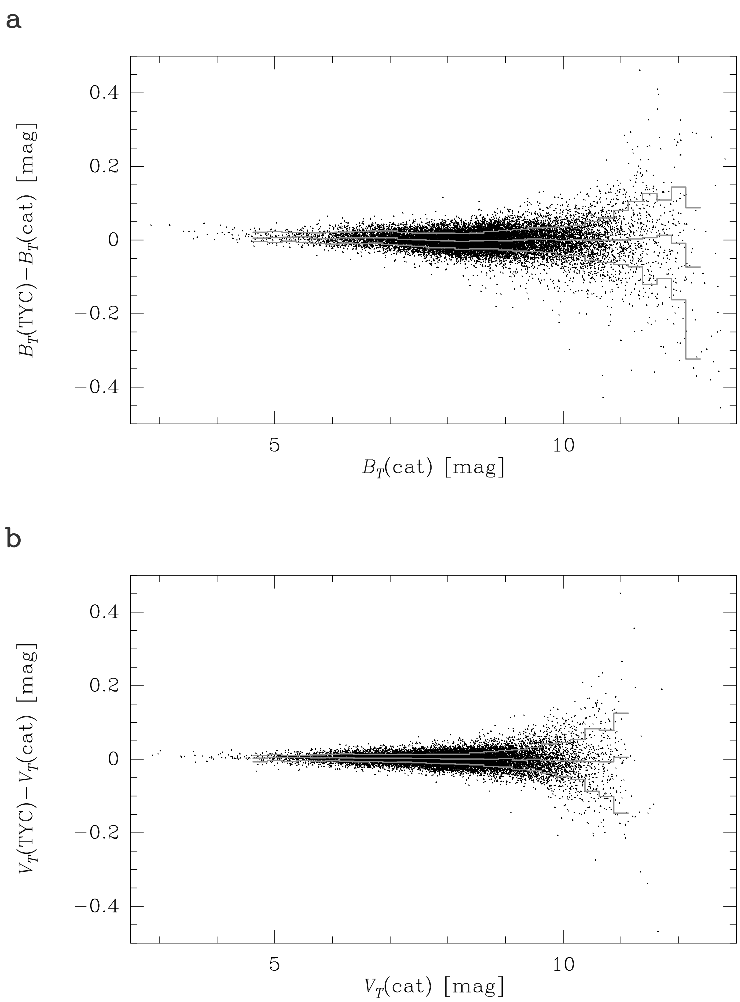


Figure 19.1. *Tycho mean magnitudes of 17 683 standard stars. Each point represents (a) a B_T magnitude or (b) a V_T magnitude for one star, namely the difference between the Tycho mean magnitude and the ground-based magnitude (B_T (cat) or V_T (cat)) versus the ground-based magnitude. The three lines give the median of this difference in 0.25 mag bins (middle) and the 15th and 85th percentiles of the distribution for a minimum of 15 stars per bin.*

The 'cleaned' sample of standard stars thus included all stars believed to be constant at the beginning of the calibration process, already based on results from a first analysis of satellite data. Nevertheless, 584 standard stars in the Tycho Epoch Photometry Annex B, including 199 stars in the Tycho Epoch Photometry Annex A, are flagged as variable or suspected in either Hipparcos, Tycho or the General Catalogue of Variable Stars (GCVS) and the New Catalogue of Suspected Variable Stars (NSV), see Section 16.4. These stars, classified in Table 19.2, are discussed below.

158 stars were found by the Tycho variability analysis described in Section 19.3. This analysis is quite sensitive even to small variations in the light curve as can be seen when studying the 11 stars also found by Hipparcos variability analysis, e.g. the star TYC 7554–1099–1. (The remaining 147 stars were probably not Hipparcos stars.)

Among the 44 stars listed as variable or suspected variable in the GCVS/NSV only 11 were confirmed by the Hipparcos data and one star by Tycho. The latter star can not

Table 19.2. Doubtful standard stars.

Total	Single stars:			Combinations:			
	GCVS/NSV	Hipparcos	Tycho	Tycho Hipparcos	GCVS/NSV Hipparcos	GCVS/NSV Tycho	All
584	44	405	158	11	11	1	0

be shown to be definitely variable, and was not found as such from Hipparcos data, but it exhibits an increased scatter in the Tycho measurements.

In conclusion, all the 584 stars are only, with some reservation, constant enough for use as standards. Not all the 158 stars found in the Tycho variability analysis are definitely variable, but they showed an increased scatter which may be due to undiscovered duplicity or other effects. They should not be used for a photometric re-calibration of Tycho data. This is also true for the stars found to be variable during Hipparcos analysis, but the variability may be on such a low level that it would not harm Tycho calibration.

19.3. Tycho Suspected Variable Stars

Construction of the Flags T48 and T49

Two flags in the Tycho Catalogue indicate variability (T48) and duplicity (T49), see Section 2.2, Volume 1. Their construction was part of the photometry verification and is therefore described here rather than in Chapter 11.

Since duplicity may mimic variability in the Tycho measurements, the construction of the two flags could not be separated and the production of the flags was a far from straightforward procedure. The flags were derived by applying dedicated processes to results of the Tycho reduction chain. A procedure applied to the Tycho Photometric Observation Catalogue (TPOC, Section 11.4) yielded T48. The T49 flag required merged results from a procedure run on raw data and another one also applied to TPOC data. The flags were in fact the first derived quantities, constructed from preliminary versions of the Tycho Catalogue and its annex. Thus, providing a verification of the catalogue contents.

The flag in Field T50 (availability of epoch photometry) marks a selection of stars to be contained in the Tycho Epoch Photometry Annexes. A substantial part of the stars included in the Tycho Epoch Photometry Annex A consists of the stars flagged in Fields T48 and T49. This flagging was carried out as a two step procedure:

1. creation of two data bases containing all stars which are probably double or variable, respectively;
2. flagging of the stars in the Tycho Catalogue according to a well defined flag hierarchy.

The following three subsections describe the creation of the two data bases and the flag hierarchy used in flagging the star records in the Tycho Catalogue.

Variability Data Base

The search for variability was carried out relative to the Tycho photometric precision, i.e. stars were considered to be 'potentially variable' if the variance of their observations exceeded the expected variance. The variances of the observations of stars were derived from the 15th and 85th percentiles of the actual magnitude distribution for all accepted transits. The expected variance was calculated using an empirical function derived from a carefully selected three-parameter fit to the distribution of the photometric standard errors against the number of observations of all standard stars and of a sample consisting of more than 50 000 randomly selected stars. The fit has been compared with a similar distribution for a second sample consisting of more than 10 000 stars flagged as variable and more than 6000 known variable stars selected from the Hipparcos Input Catalogue and cross-identified with the Tycho Photometric Observation Catalogue entries.

The resulting adopted procedure was very robust against single outliers. The procedure was applied to all stars satisfying the condition $V_T \le 9.5$ mag and $N \ge 80$, i.e. $\simeq 384\,000$ stars from the Tycho Catalogue. For fainter stars or stars having fewer observations the method of comparing an expected variance with the actual variance would not provide reliable results, since the expected variance was very unreliable beyond these limits. The function used in the search was:

$$F_{\rm err} = 4.6 \times 1.75^m (N - 40)^{-0.71} \qquad [19.1]$$

where $F_{\rm err}$ is the expected upper limit of the standard error of the mean magnitude of a non-variable star with V_T magnitude m and with N observations. Figure 19.2 shows lines of equal magnitude in a standard error versus N plane, calculated with Equation 19.1. Lines are drawn for the magnitudes given.

This simple model obviously fails for a small number of observations ($N \le 50$ for $V_T = 6.5$ mag and $N \le 70$ for $V_T = 10$ mag). In this range the correlation between N and the standard error vanishes.

As an example of the process, consider the 140 δ Scuti stars flagged in the Hipparcos Input Catalogue, 49 of which are also flagged in the Tycho Catalogue. Only 9 of the 49 are fainter than $V_T = 8$ mag and 7 of these fainter ones have an amplitude larger than the one given in the Hipparcos Input Catalogue (some of them do not have an amplitude given). Most of the δ Scuti stars have amplitudes around 0.1 mag and an unstable period around 0.1 days, thus Tycho was expected to find only the brightest ones. Most of the δ Scuti stars not flagged in the Tycho Catalogue had too few transits or did not show any variability in the Tycho data. Similar comparisons have been carried out for variables of Algol and RR-Lyrae types. (Algol itself is not flagged as a Tycho variable because there are only few measurements during one of the minima within the satellite operation time, see Section 19.4).

Duplicity Data Base

The search for double stars has been carried out using two independent procedures:

1. flagging of suspected double stars during Tycho Input Catalogue Update production in order to extract the raw photon counts during the detection process in reprocessing. The resulting data base of raw counts has been treated by a double peak fitting algorithm (Section 14.5). The number of input stars flagged in the

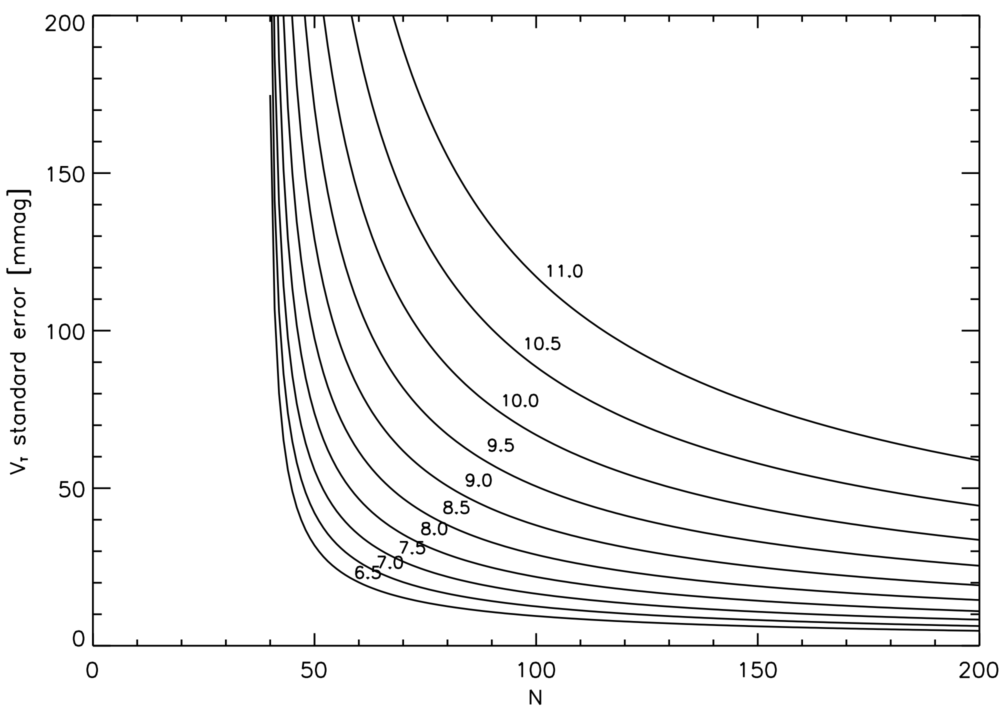


Figure 19.2. *The lines show the empirical upper limit of the standard error of the mean magnitude for non-variable stars of 10 different magnitudes in the range from V_T = 6.5 mag to V_T = 11.0 mag.*

Tycho Input Catalogue Update for this process was 22 083, collected from different sources. The method is called 'DP' hereafter;

2. the search for a correlation between the position angles of the slit and the measured magnitude for all stars brighter than $V_T = 10.5$ mag (Section 14.6). This process was carried out for almost 500 000 stars. The method is called 'Ph' hereafter.

The duplicity data base was built up using input from these two sources. An overview of the results of the two methods is given in Table 19.3.

The duplicity data base contained data of all stars from both sources. There was a non-empty overlap between the two, and the internal flagging of the data base has been carried out applying the following precedence rule:

$$\text{'D'} \Rightarrow \text{'S'} \Rightarrow \text{'Y'} \Rightarrow \text{'Z'}$$

This means, the data base flag was set to the highest indication found by either of the methods ('Z' indicates stars without an investigation of duplicity carried out).

The overlap of stars found to be 'double' or which showed some indication of duplicity in both input streams is given in Table 19.4.

Of the 22 083 stars contained in the candidate list (Section 14.3) for the DP-method, 16 194 stars did not show a significant indication of duplicity after DP-processing. 15 190 stars of this list could not be found by the Ph-method, either. On the other hand, by comparing the numbers contained in the Tables 19.3 and 19.4 it appears that about 75 per cent of the 'D' doubles found by the DP-method were also found by the Ph-method to be 'D' cases. As can be seen in the first two rows of the last column of Table 19.4

Table 19.3. Results of the two duplicity search methods. The letters are 'D' for double, 'S' for suspected double and 'Y' for having been treated, but no indication for duplicity found.

Method	D	S	Y
Double-peak (DP)	3239	2650	16194
Photometry (Ph)	7254	12672	478070

Table 19.4. Overlap between the internal flags in the duplicity data base. 'DP' is the 'double-peak' method and 'Ph' stands for the photometric method. The letters are 'D' for double, 'S' for suspected double, 'Y' for treated but no indication for duplicity found, and 'Z' not treated.

DP / Ph	D	S	Y	Z
D	2415	588	249	4002
S	296	443	536	11397
Y	183	496	1687	475704
Z	346	1122	13722	556029

many stars got a flag solely because of the Ph-method. The reasons for this are first of all that the initial selection of the candidate list treated by the DP-method was not considered to be complete; and second that the DP and the Ph-methods had different separation sensitivity. The latter reason was also the decisive factor for the selection of the precedence rule given above.

Flagging in T48 and T49

The final flagging procedure followed the fact that most of the double stars produced an apparent variability due to the long slits of the Tycho instrument. A hierarchical procedure was used to set flags T48 and T49. Any positive indication of duplicity was given precedence over an indication of variability for a given star. A description of the flagging procedure is given in Volume 1, Section 2.2.

Examples of Tycho Phase Plots

Figures 19.3–19.5 show Tycho Epoch Photometry Annex A single observations for three periodic variables. The periods used to fold the lightcurves have been derived by a periodogram method and/or by a method called epoch folding. They agree with the periods found in the literature for these stars. Figure 19.3 shows the classical Cepheid SU Cas with TYC number 4313–1573–1 and a period of 1.94967 days. Figure 19.4 shows the double mode Cepheid TU Cas (TYC 3260–1095–1). The upper panel of Figure 19.4 shows the result of folding the lightcurve with the primary period of 2.13935 days. The lower panel shows the lightcurve folded with double the primary period, showing the typical behaviour of double mode Cepheids. Figure 19.5 shows the Mira variable R Car (TYC 8945–1871–1). This star has an amplitude of more than 4.5 mag and a period of 302.098 days. This figure shows how the errors of a single Tycho observation depend on the magnitude itself. The error bars shown in the plots are the 1σ errors as given in the Tycho Epoch Photometry Annex A.

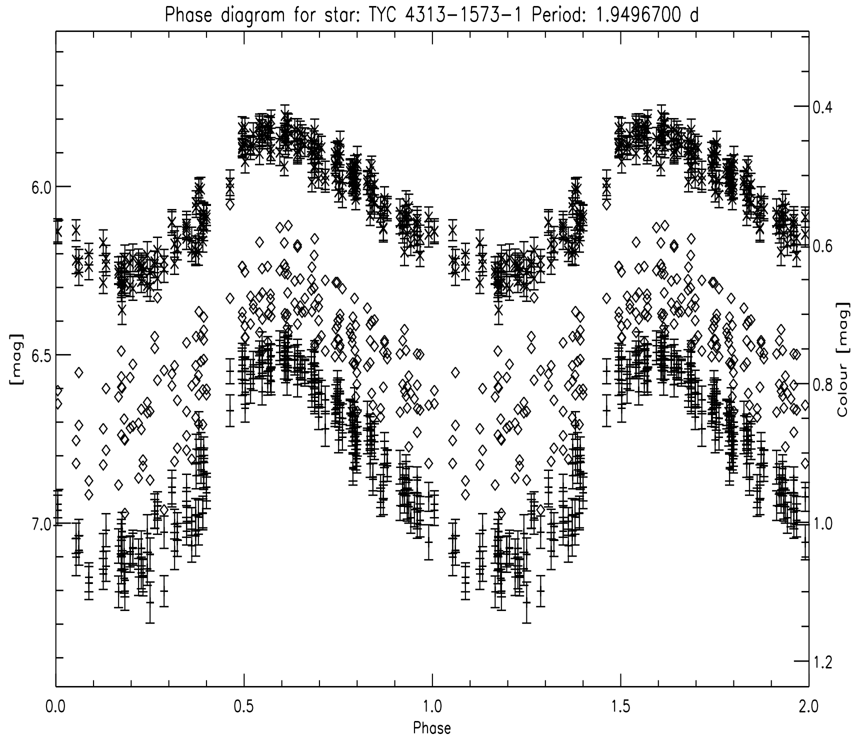


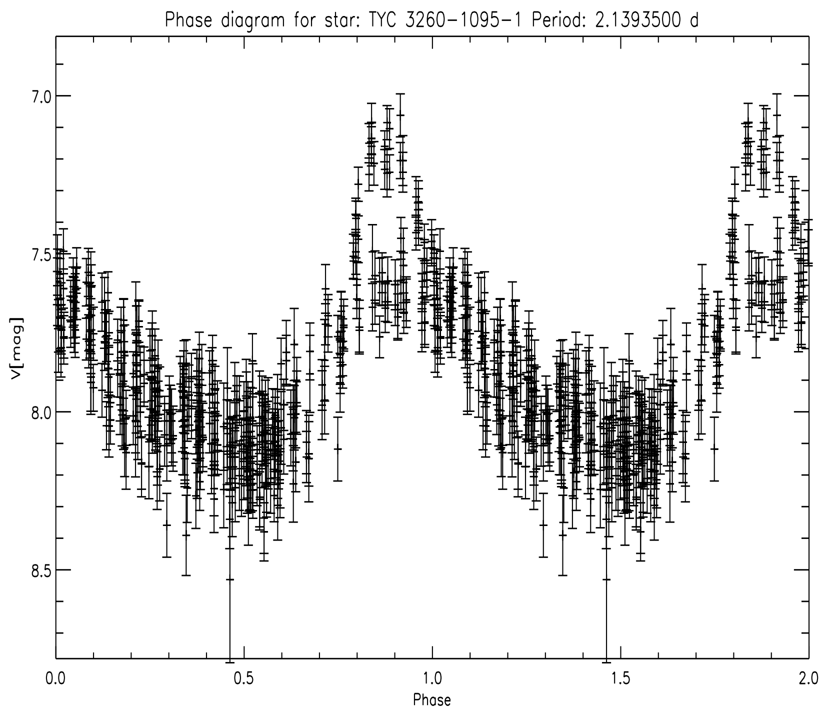
Figure 19.3. *The phase diagram of the classical Cepheid SU Cas. The V_T observations are drawn with '×' markers and error bars (upper curve). The $B_T - V_T$ points are drawn with diamonds. For clarity no error bars are given for the colour. The B_T observations are drawn with + markers and their error bars. The magnitude axis is given at the left, the colour axis at the right.*

19.4. Comparison of Tycho and Hipparcos Epoch Photometry for Algol

Algol is a well-known bright eclipsing star contained in the Hipparcos Photometry Annex and in both Tycho Epoch Photometry Annexes as HIP 14576 and TYC 2851–2168–1. Due to its eclipses this star provides a suitable target to check the time scales of both Photometry Annexes. This section also compares the photometry in the different catalogues.

Mean and Single Transit Magnitudes

Algol was rather regularly and accurately observed by both the Tycho and Hipparcos instruments during the mission, providing a fair number of nearly simultaneous photometric estimations. Fortunately, both instruments observed a deep eclipse around JD 2 448 308.14, when the brightness had dropped by more than 1 mag (see Figure 19.6, upper panel for the observed V_T magnitudes). With a colour index of almost zero ($B_T - V_T = -0.005 \pm 0.005$ mag) differences between Hp and B_T or V_T are small. Mean values from the Hipparcos Catalogue and the Tycho Catalogue are: $Hp = 2.0970 \pm 0.0020$ mag and $B_T = 2.100 \pm 0.003$ mag, $V_T = 2.105 \pm 0.004$ mag. The good agreement between both catalogues demonstrates the good photometry available



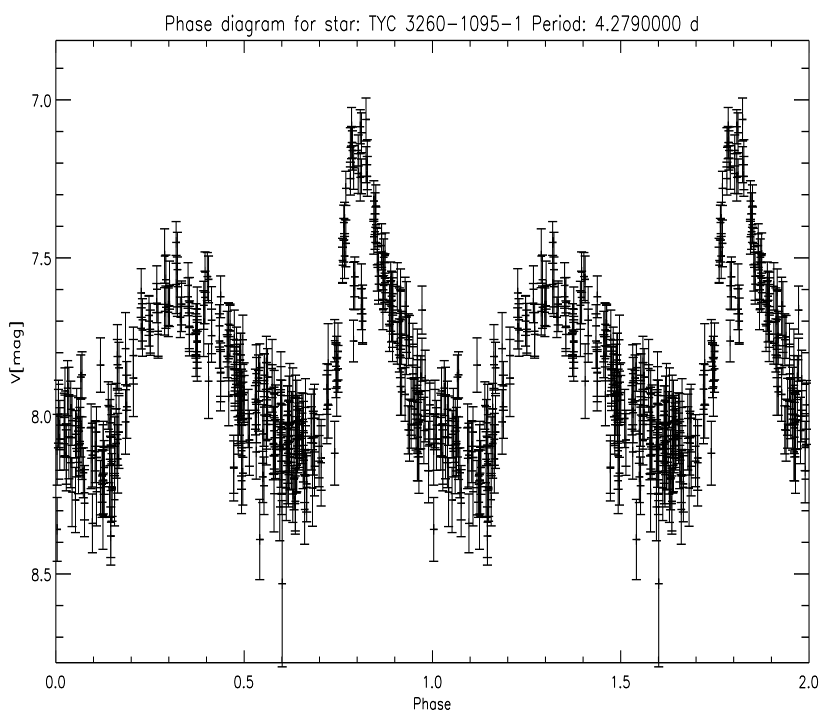


Figure 19.4. *Phase diagrams for the double mode Cepheid TU Cas. The upper diagram shows the primary period of 2.13935 days, the lower diagram is folded with twice the primary period and shows the variable amplitude of most of the secondary mode peaks.*

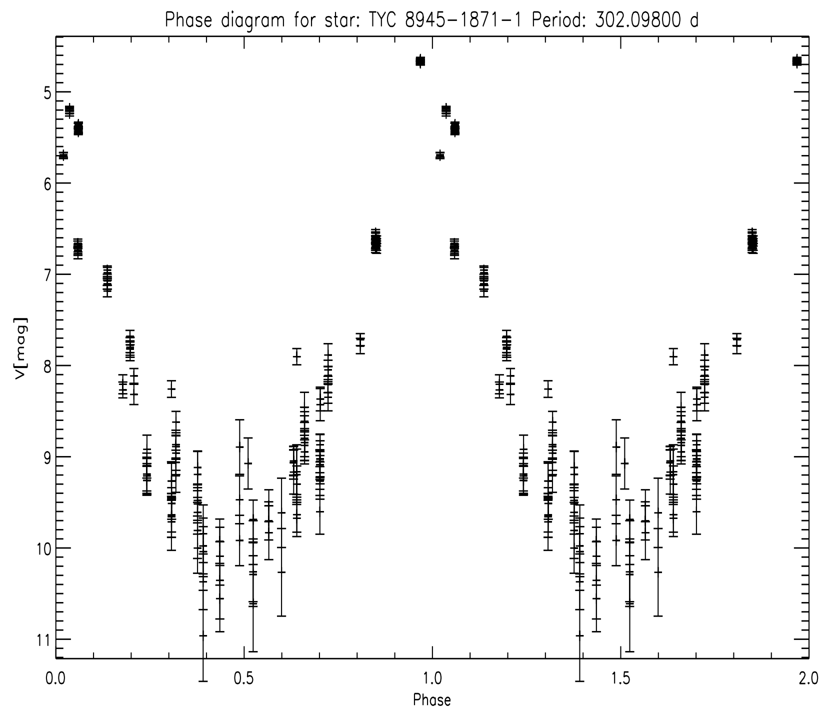


Figure 19.5. *Phase diagram of the Mira type star R Car showing the increase of the errors of the Tycho single observations with magnitude.*

when Tycho median magnitudes were derived from reprocessing data (i.e. using an estimation in the wings of the signal for very bright stars).

The differences $Hp - B_T$ and $Hp - V_T$ in observed magnitudes at the moments of quasi-simultaneous observations are shown in the two lower panels of Figure 19.6. A set of observations are called quasi-simultaneous if they were obtained during one passage across a field of view of the telescope in both the Hipparcos and Tycho experiment, i.e. within about 20 s of time. A star was first observed on the inclined slits of the star mapper, then on the vertical slits and finally on the main grid, according to the geometry of the instrument and the rotation of the satellite. The number of quasi-simultaneous observations can therefore be up to 3.

For clarity, no error bars for the Tycho magnitudes are shown in Figure 19.6. The typical values of the formal errors are about 0.01 mag in B_T and 0.009 mag in V_T, while the Hp magnitudes were measured with a much smaller formal error of approximately 0.003 mag. The scatter of the differences is 2 to 3 times larger than the expected standard error of the Tycho magnitudes. On the other hand, the scatter computed from the percentiles given in Tycho Epoch Photometry Annex is 0.02 mag for B_T and 0.03 mag for V_T. Both facts indicate that the formal errors given for the magnitudes of single transits in Tycho Epoch Photometry Annex (the photon noise and the parameter error, see Equation 8.4) do not include all error sources which may have been significant for the brightest stars. One important error source is the count rate compression during data transfer from the satellite to the ground (see Section 8.1). For a star as bright as Algol this could have introduced an additional error of up to 0.01 mag. Another error source for very bright stars was the limited knowledge of the scan velocity of the satellite.

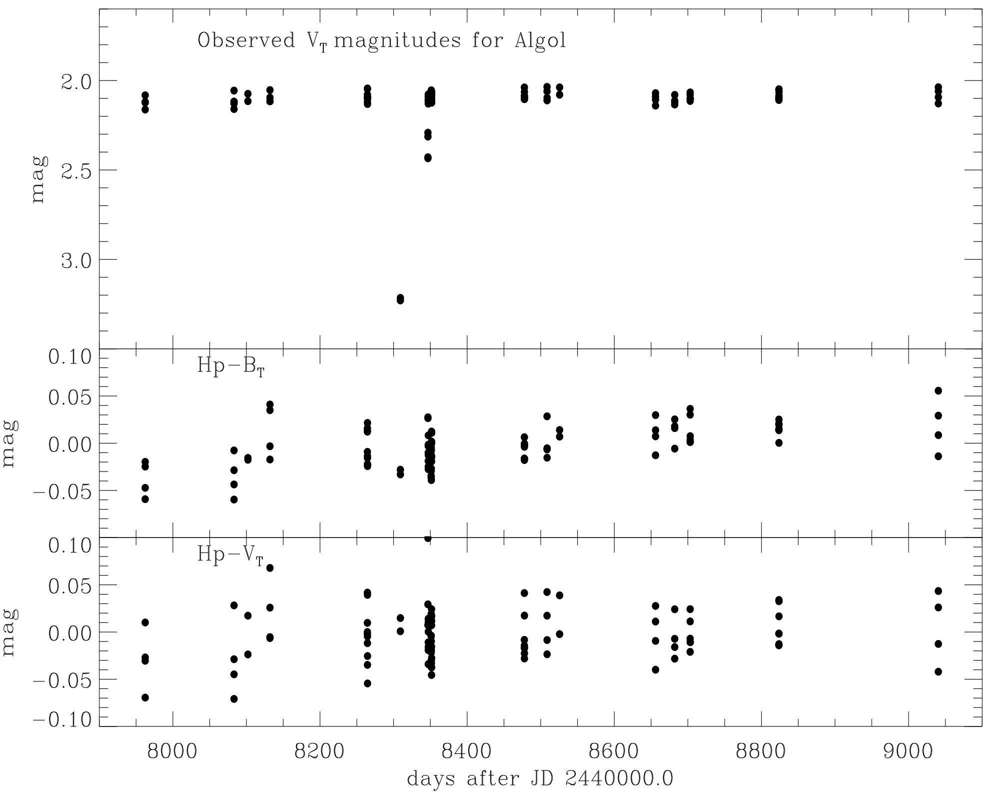


Figure 19.6. *V_T magnitudes of Algol, observed by Tycho, and the differences in magnitudes for quasi-simultaneous observations in the Tycho and Hipparcos Epoch Photometry Annexes.*

This had no consequences for fainter stars but it affected the estimation of the signal amplitudes in the wings of the signal during reprocessing.

Timing Quantities

Timing quantities in the Tycho and Hipparcos Epoch Photometry Annexes have the same basic source, namely the counts of the on-board clock. In view of the completely independent and quite complicated data flows and reduction processes through which this primary timing and other subsidiary data have passed, it is useful to compare the times of quasi-simultaneous observations of Algol in the two annexes. Figure 19.7 shows the z-coordinates, as recorded in the Tycho Epoch Photometry Annex, versus the difference in barycentric Julian Date for quasi-simultaneous observations. As expected, the diamonds, representing observations on the vertical slits, are concentrated around a vertical line at about −11 s, since they are hardly z-dependent. The gap of 11 s corresponds to the time needed for a star to move the distance of 30 arcmin between the vertical slits of the star mapper and the centre of the main grid, at a nominal velocity of 165 arcsec s^{-1}. At the same time, the filled circles clearly trace out the chevron geometry of the inclined slits. The scatter along the time axis of about 1 s is chiefly due to two circumstances: first, the timing of Hipparcos observations is not exactly centered on the middle of the main grid; and second, the timing quantities are rounded to 10^{-5} days = 0.864 s in both annexes.

From this comparison it can be concluded that timing quantities are consistent in the two Epoch Photometry Annexes for this star. Given the fact that the Tycho data analysis

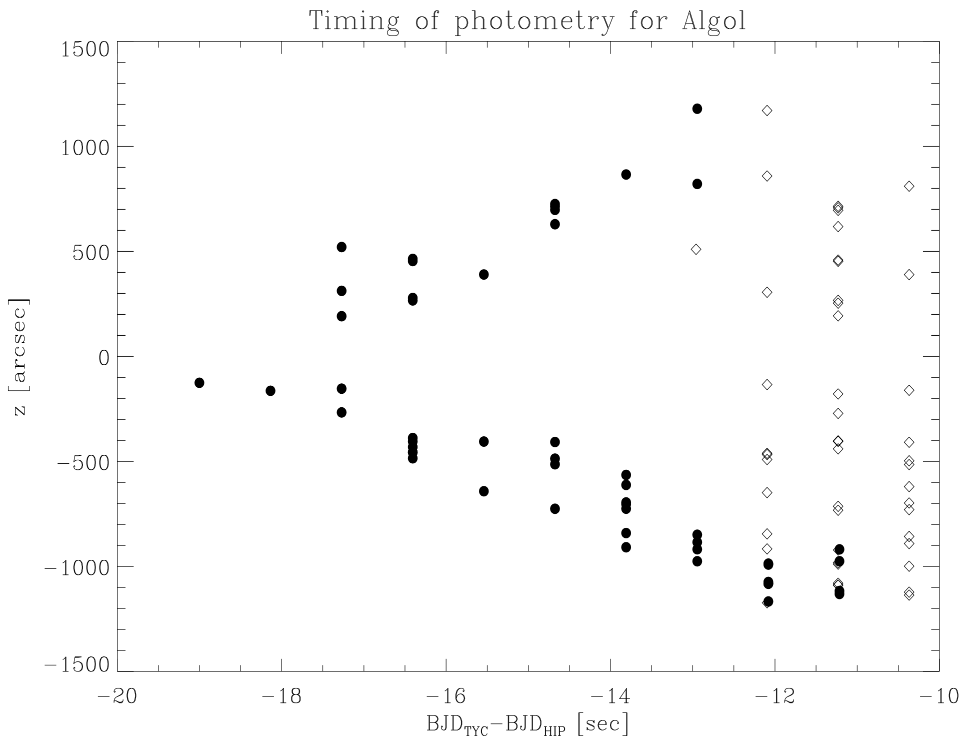


Figure 19.7. *z-coordinates of individual crossings of Algol, as recorded in the Tycho Epoch Photometry Annex, versus the difference in time of observation on the star mapper and on the main grid. Diamonds mark transits over the vertical slits, circles over the chevron slits.*

was not optimized to provide optimum photometry for very bright objects, Tycho yields very good mean magnitudes in the case of Algol (uncertainties for the brightest standard stars may be larger, especially for B_T, see Figure 19.1). However, the formal errors given in the Tycho Epoch Photometry Annex for magnitude estimations of single transits do not include all error sources. These additional errors are important for the bright stars only.

19.5. Tycho Photometry of Double Stars

The Tycho photometry in double or multiple systems was checked by comparison with two sets of ground-based measurements: the first set consisted of differences of magnitudes between the components, and the second set of absolute photometry.

The difference of V magnitudes between the components was measured by the European Network managed by Edouard Oblak (Oblak *et al.* 1992 and Lampens *et al.* 1997) for several hundred double stars from the Hipparcos programme. These data were obtained from CCD observations performed at various sites (La Palma, La Silla and Saint-Michel de Provence), and some measurements were delivered in advance of publication. Furthermore, a list of Tycho double stars was prepared with the following criteria: separations closer than 20 arcsec; pair belonging to the Hipparcos catalogue;

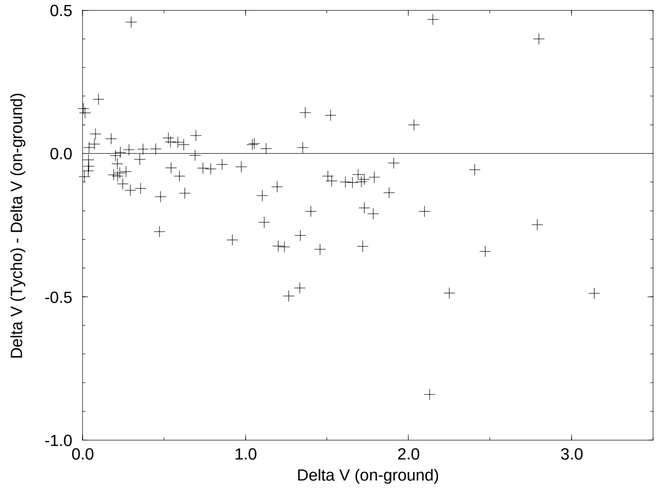


Figure 19.8. *The bias of ΔV derived from Tycho photometry.*

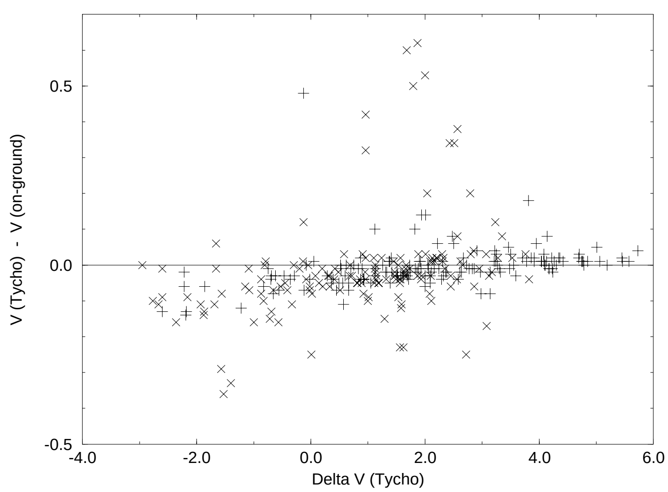


Figure 19.9. *The bias of the Tycho magnitudes for double star components, related to the difference of magnitudes between the components. The negative ΔV refer to secondary components, and the positive ones to primary components. The magnitudes derived from the median of Tycho individual measurements are represented by '+', and the magnitudes calculated by de-censoring are indicated by '$\times$'.*

no variability found in Hipparcos photometry; and fully calibrated Tycho mean magnitudes (i.e. median or de-censored magnitudes). The Tycho V_T and B_T magnitudes of these stars were transformed into Johnson V magnitudes, and the differences between the components, ΔV, were derived.

A cross-matching between the ground-based programme and the list of Tycho double stars provided 84 pairs. The offsets between the Tycho results and the ground-based measurements are plotted in Figure 19.8 as a function of the ground-based ΔV. It appears from this figure that the ΔV from Tycho are in agreement with the ground-based measurements when they are less than about 1 mag. For ΔV between 1 and 2 mag, the Tycho photometry underestimates ΔV. The bias could be about 0.1 mag. A bias in the double star photometry is not surprising because the Tycho Catalogue contains an excess of double stars due to the side lobes of the companion (see Section 16.2).

In order to confirm this feature, ground-based measurements of the V magnitudes were taken from the Hipparcos catalogue for some components of double stars. Only pairs closer than 20 arcsec, with Tycho photometry coming from the median or from de-censoring were considered. The stars classified as variable on the basis of the Hipparcos observations were discarded. A sample of 310 components was thus obtained, including 154 stars with V magnitudes derived from median V_T, B_T, and 156 stars with V magnitudes coming from de-censored B_T, V_T. The differences between the V magnitudes obtained from Tycho and the ground-based measurements are plotted in Figure 19.9 as a function of ΔV. The ΔV is defined as $\Delta V = V_2 - V_1$, where the index '1' refers to the component considered, and '2' to the other one.

It appears that the Tycho magnitudes are too bright when ΔV is small. For ΔV between –3 and +3 mag, the true magnitude of a double star component is about:

$$V_{1,\ \mathrm{corrected}} = V_{1,\ \mathrm{measured}} + 0.05 - \frac{0.1}{6}\Delta V \qquad [19.2]$$

This formula may be applied to all the stars of the Tycho catalogue having a companion closer than the width of the star mapper slit group, i.e. 34 arcsec. However, it is only an average correction, since the exact one must depend also on the separation of the components (see Section 16.2). The bias of ΔV found in Figure 19.8 is thus explained.

In conclusion, the Tycho magnitudes of double stars were compared to two different samples of ground-based measurements. It was found that the magnitudes of the stars were slightly biased, due to the contribution of the luminosity of the companions. The corrected magnitudes may be derived from Equation 19.2.

V. Großmann, A. Wicenec, V.V. Makarov, J.-L. Halbwachs