A PHOTOMETRIC CALIBRATION OF THE GUIDE STAR CATALOG

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ABSTRACT

Using the Tycho Catalogue as a photometric reference catalogue, the magnitudes of the published Guide Star Catalog 1.1 have been re-calibrated. It is possible to bring the systematic errors of the GSC well below 0.1 mag, at least for stars brighter than 11.5 mag. For each plate, an individual colour term and magnitude dependant correction was applied. Only 0.6 per cent of the plates were unfit for calibration. The systematic corrections are normally below 0.4 mag for stars of magnitude 10. The one sigma equivalent of the resulting residuals is 0.18 mag for the Palomar Quick–V plates used in the northern sky and 0.14 mag for the UKST IIIa–J plates used in the south.

Key words: photometry; Schmidt plates.

1. INTRODUCTION

In preparing the second Tycho processing, (Høg 1997), an input catalogue is being produced containing the brightest 5 or 6 million stars on the sky. One of the most important sources is the Guide Star Catalog (Lasker et al. 1992). In order to ensure a uniform limiting magnitude, it was decided to check the photometry of the Guide Star Catalog using the two-colour photometry of the Tycho Catalogue. For the original calibration of the Guide Star Catalog magnitudes, typically only 6 photometric reference stars were available on each Schmidt plate. It is therefore natural to expect that many plates can be significantly improved using a denser net of photometric reference stars.

The Tycho Catalogue provides blue and visual magnitudes, B_T and V_T, for 1 million stars brighter than 12th magnitude. Median standard errors are 0.074 mag and 0.057 mag, respectively, corresponding to the median magnitude $V_T = 10.5$ mag. Using these magnitudes, the published magnitudes of the nearly 1600 Guide Star Catalog 1.1 plates have been re-calibrated. The Tycho Catalogue provides some 100 times more reference stars per plate than the typically 6 used in the original photometric calibration.

The Guide Star Catalog was constructed to support the operation of the Hubble Space Telescope, but has found many other applications. The GSC is mainly based on a 'Palomar Quick V' survey of the northern sky and the United Kingdom Schmidt Telescope IIIa–J plates of the southern sky. A number of supplemental plates, mainly astrograph plates, were also used. See Lasker et al. (1990) for details. We will refer to the plates by the four alphanumeric characters used in the published GSC. The GSC is rather complete to 14.5 mag, i.e. several magnitudes deeper than the Tycho Catalogue. This sets a limit to what can be obtained through the present re-calibration.

2. PHOTOMETRIC CALIBRATION

Partly following the model used in the original transformation (Russell et al. 1990), the transformation between GSC and Tycho magnitudes was assumed to obey the simple relation:

$$m_{\rm GSC} + c(m_{\rm GSC}) = V_T + \alpha(B_T - V_T) \qquad (1)$$

Here, $m_{\rm GSC}$, denotes the published GSC magnitude. The colour coefficient, α, was determined for each plate, rather than for each plate–filter combination, together with a magnitude dependant correction, $c(m_{\rm GSC})$. The latter was determined by linear interpolation between 8 nodes found as the median residuals in 8 magnitude intervals, covering the range from 8 to 12 mag. The intervals are centered on 8.5, 9.5, 10.25, 10.75, 11.125, 11.375, 11.625 and 11.875 mag, i.e. with increasing density towards fainter stars. Stars brighter than 8.5 mag, on a given plate, all get the same correction and the first idea was to give the same correction to all stars fainter than 11.875 mag, but it was later decided to use the same correction for all stars fainter than 11.5 mag on a given plate.

The colour coefficient was found by trying a series of values, centered on the typical value for the given plate–filter combination, and choosing the value giving the smallest scatter of the residuals in the magnitude interval 10 to 12 mag. The typical scatter of colour coefficients, for a given plate–filter combination, is only 0.04 for the IIIa–J plates and 0.06 for the Palomar plates. It could therefore be justified to use a constant colour coefficient, but the more general approach was adopted because a handful of plates turned out to have incorrect bandpass codes in the published GSC (see Table 2).

As a result, each GSC plate is transformed to its own natural magnitude system, closely matching $V_T + \alpha(B_T - V_T)$, or, for short, $m_{\rm TYC}$.

Errors in the magnitudes depending on the position within the plate have been investigated by Morrison (1997), who finds that significant corrections are needed especially near the plate corners. These effects have not been taken into account in the present calibration.

As a typical example, residuals, $m_{\rm TYC} - m_{\rm GSC}$, are shown in Figure 1 for the IIIa–J plate 049T, before and after applying the magnitude dependant correction. The colour correction has been applied to both plots. A one sigma equivalent for the residuals (based on the 16th and 84th percentiles) for stars fainter than 10 mag is 0.19 mag.

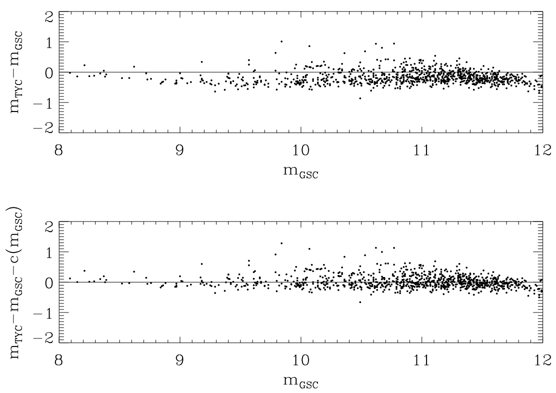

Figure 1. Residuals, $m_{\rm TYC} - m_{\rm GSC}$, for the IIIa–J plate 049T, before and after applying the magnitude dependant correction. For short, we write $m_{\rm TYC}$ instead of $V_T + \alpha\ (B_T - V_T)$.

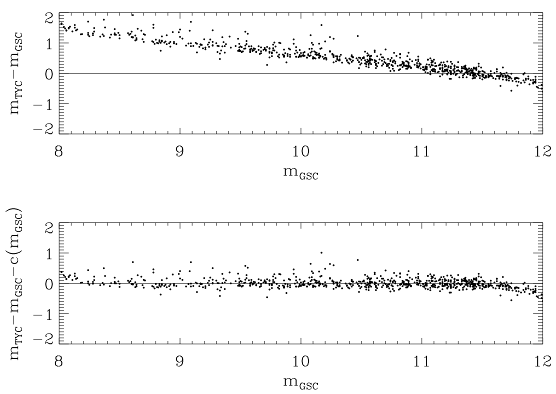

Figure 2. Residuals, $m_{\rm TYC} - m_{\rm GSC}$, for the IIIa–J plate 00OL, before and after applying the magnitude dependant correction.

A dozen plates showed a very strong magnitude dependence of the residuals. An example, plate 00OL, is shown in Figure 2. The original reduction of this plate included only three reference stars which were in the magnitude interval 11.1 to 13.8, making the calibration very uncertain.

A dozen plates showed strong inconsistencies and could only be partly calibrated. An example, plate 00CW, is shown in Figure 3. The residuals lie in two bands as if two separate sets of measurements were mixed. In the affected magnitude interval, no way was found to tell in which band a GSC star belonged without knowing the Tycho photometry. The position on the plate, e.g., seemed not to be the key. According to Lasker (1997) the explanation is probably '*lamp flicker*' in the measuring machine. The nine clearest cases are listed in Table 1.

Table 1. Nine plates affected by a serious inconsistency in a certain magnitude interval.

Plate name	Magnitude interval
0176	10.5–11
01OQ	9–9.5
00CW	9–10
0170	8–9
017D	8–9.5
0189	10–10.5
0173	8–9.5
018D	9.5–10.5
0087	8–9.5

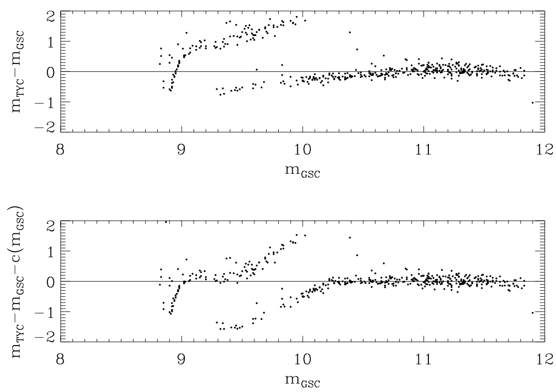

Figure 3. Residuals, $m_{\rm TYC} - m_{\rm GSC}$, for the IIIa–J plate 00CW, before and after applying the magnitude dependant correction.

Typical colour coefficients are −0.11 for Palomar plates with Wratten 12 filter, −0.04 for Palomar plates with GG495 filter and +0.44 for the UKST IIIa–J plates. Thus the Palomar plate photometry is very close to V_T and the IIIa–J plates give magnitudes close to the mean of B_T and V_T. More details are presented in Table 2.

Figure 4 shows the median magnitude dependant corrections for northern sky Palomar plates (Wratten 12 filter) and for the UKST IIIa–J plates of the southern sky. It is not at all clear what corrections are needed for stars fainter than 11th or 12th magnitude. The

Table 2. Typical results for each bandpass used in the GSC giving the median colour coefficient, the median of an estimate of the standard deviation for the residuals and the number of plates involved. Five plates appeared to have an incorrect bandpass code.

Code	Band	Plate–Filter	α	σ_m	$N_{\rm pl}$	Comments
0	J	IIIaJ+GG395	0.44	0.14	801	plate 034O is V
1	V	IIaD+W12	−0.11	0.18	568	
3	B	photoelectric				not re-calibrated
4	V	photoelectric				not re-calibrated
6	V	IIaD+GG495	−0.04	0.18	139	
8	E	103aE+red plexi	−0.29	0.11	1	
10	V	IIaD+GG495+yellow OG	−0.21	0.11	15	
11	J	103aO+blue OG	0.57	0.10	44	plates 06G5, 06GB and 06G4 are V
12	J	103aO+blue OG	0.59	0.10	12	plate 06G3 is V
13	V	103aG+GG495+yellow OG	0.02	0.12	5	
14	V	103aG+GG495+yellow OG	0.05	0.14	1	
16	V	IIIaJ+GG495	0.09	0.11	1	
18	J	IIIaJ+GG385	0.48	0.12	6	

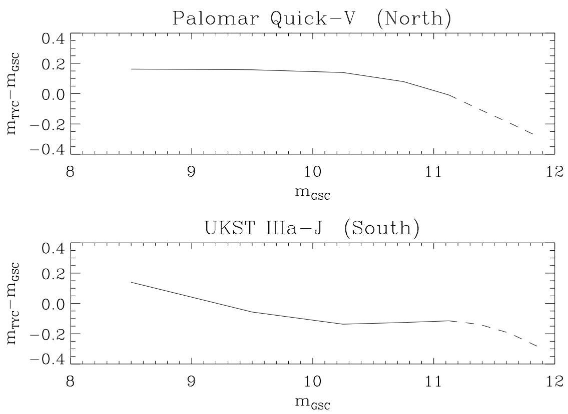

Figure 4. Median corrections to the GSC magnitudes for Palomar and UKST plates. Beyond magnitude 11 the corrections are uncertain because of possible errors in the Tycho magnitudes.

typical corrections would yield unrealistic values if extrapolated to 15th magnitude. There are several reasons to be cautious:

- Tycho photometry is not verified to better than a few tenths at the faint end – see Table 19.1 in Volume 4 of the printed catalogue (ESA 1997);
- the original calibration of the GSC plates used mainly faint reference stars, making large corrections to faint GSC magnitudes unlikely;
- direct comparison between GSC V–magnitudes, i.e. from Palomar plates, and V–magnitudes from Carlsberg Meridian Catalogue No 9 (1997) show only a small magnitude dependence in the magnitude interval 8 to 14 (see Figure 5). Colour effects could not be investigated in this comparison, but may be important.

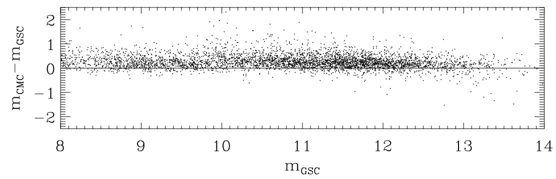

Figure 5. A direct comparison between V–like magnitudes from GSC and from Carlsberg Meridian Catalogue No 9 for 4300 stars.

A simple and not too unrealistic solution is to apply the same correction for all stars fainter than 11.5 mag on a given plate.

3. CONCLUSIONS

Although the reliability of the Tycho photometry is not verified for V_T fainter than 11 mag, several interesting results have been obtained.

Magnitude dependant systematic errors between −1 and +1 mag were removed. For 10 per cent of the plates, the correction was above 0.4 mag at magnitude 10.

The one sigma equivalent of the resulting residuals is 0.18 mag for the Palomar Quick–V plates used in the northern sky and 0.14 mag for the UKST IIIa–J plates used the south.

A dozen plates show systematic errors with very strong dependence on magnitude.

Less than a dozen plates showed strong inconsistencies and could only be partly calibrated.

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