

THE TYCHO CATALOGUE: STELLAR CONTENT

D. Egret¹, C. Fabricius²

¹Observatoire de Strasbourg, 11 rue de l'Université, 67000 Strasbourg, France

²Copenhagen University Observatory, Juliane Maries Vej 30, DK-2100 Copenhagen Ø, Denmark

ABSTRACT

The stellar content of the Tycho Catalogue (ESA 1997) is presented. It is shown that the Tycho Catalogue contains about 99.9 per cent of the stars brighter than $V = 10.0$ mag, and a large fraction of the stars in the range 10.0 to 11.5 mag. Comparisons of content are made with major reference catalogues: the Hipparcos main catalogue, the Catalogue of Positions and Proper Motions (PPM), the Guide Star Catalog (GSC) for the Hubble Space Telescope, etc. The status of missing stars is analysed, additional Tycho entries with respect to the Input Catalogue are discussed, and results of cross-matching with existing catalogues are presented.

Key words: Tycho Catalogue; Survey; Guide Star Catalog; PPM.

1. INTRODUCTION

In short, the Tycho Catalogue (ESA 1997) can be described as a survey of stars brighter than 11.0 mag. In practice, this means that the Tycho Catalogue contains about 99.9 per cent of the stars brighter than $V = 10.0$ mag, and a large fraction of the stars in the range 10.0 to 11.5 mag.

The completeness ratio drops, at the faint end, from more than 90 per cent at $V = 10.5$ mag, to roughly 65 per cent at 11.0 mag and 10 per cent at 11.5 mag (see Figure 1). Among the 120 000 stars brighter than 9.0 mag in the Catalogue of Positions and Proper Motions (PPM), about 120 are missing in the Tycho Catalogue, i.e. 0.10 per cent.

In the following the limits and characteristics of the survey are examined in more detail. We will address the following questions related to the stellar contents of the Tycho survey:

- can we be sure that all stars brighter than 10.0 are included in the Tycho Catalogue ?
- does the Tycho Catalogue include false bright stars ?
- what are the new Tycho entries ?

2. THE TYCHO SURVEY

Can we be sure that all stars brighter than 10.0 are included in the Tycho Catalogue? The answer would be much simpler if the stars were not frequently double, multiple, or variable! But setting aside the photometric variability, and the specific case of close binaries, we may investigate, by cross-comparison with other catalogues, the completeness of the Tycho Catalogue at the bright end.

2.1. Missing Bright Stars in the Tycho Catalogue

A few very bright stars, e.g. Sirius, were not observable by the star mapper. The dynamic range of the star mapper detector resulted in a non-linearity at the brightest magnitudes. In addition, some stars in very dense clusters and other dense fields could not be observed by Tycho, thus leaving the Tycho Catalogue incomplete in such regions. However, it should be noted that stars contained in the Hipparcos Catalogue and not observed by the Tycho star mapper have been added, for completeness, in the Tycho Catalogue and flagged accordingly. Because of that, one can expect to have a fairly complete catalogue at the bright end.

There are some exceptions: for instance, during the preparation of the Millennium Star Atlas (Sinnott 1997) the exercised eyes of *Sky & Telescope* experts discovered a missing star near Alcyone. Of a triangle of three stars near Alcyone, one is missing from the Tycho Catalogue: SAO 76188 (HD 23608). This star was also actually missing from the Guide Star Catalog Version 1.0 but had been introduced into the Tycho Input Catalogue (and later on into Version 1.1 of the Guide Star Catalog) from the SIMBAD or INCA databases. Although present in the Tycho Input Catalogue Revision (Halbwachs et al. 1994), this star failed to be included in the final Tycho Catalogue, due to an insufficient number of transits not affected by parasites (see Volume 4 of the Hipparcos and Tycho Catalogues, Section 7.2). The Hipparcos Catalogue does not contain the star, which would otherwise have been included as a 'HIP-only' entry.

A reasonably complete list of such bright missing stars could be derived from comparisons with ground-based catalogues. Stars in the Catalogue of Positions

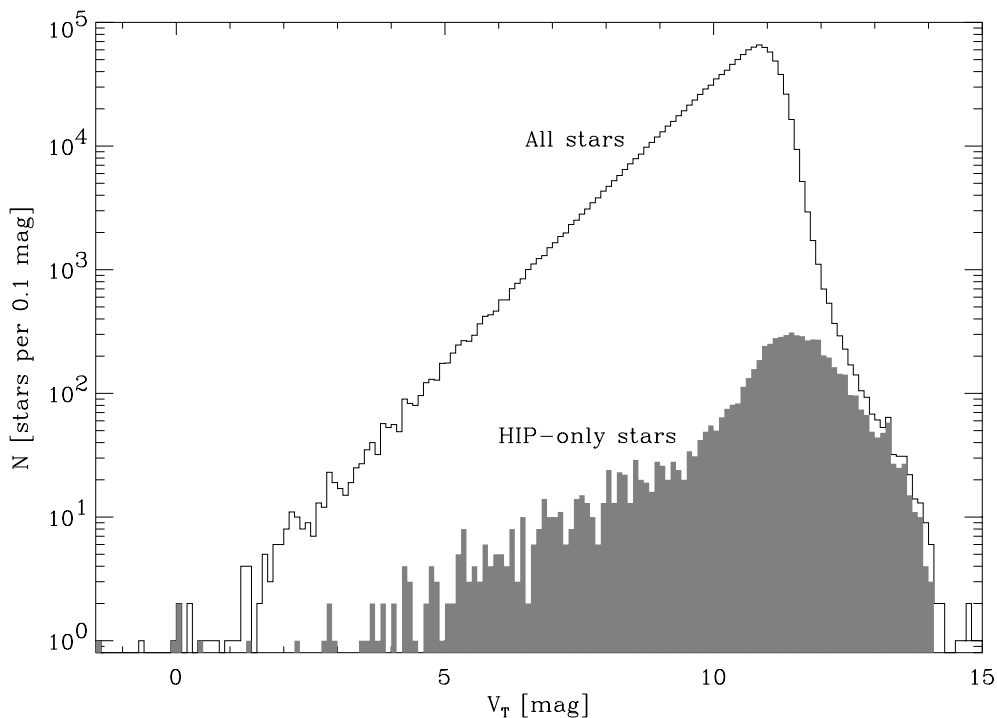


Figure 1. Histogram of TYC and HIP-only stars as a function of the V_T magnitude. For 1 per cent of the stars another magnitude had to be used.

and Proper Motions (PPM; Röser & Bastian 1991), including the Bright Star Supplement, of magnitude 9.0 or brighter were sought in the Tycho Catalogue.

Among a total of 143 490 stars, no corresponding Tycho Catalogue star was found within 3.0 arcsec in 137 cases. A closer examination showed that at least 117 stars are not in the Tycho Catalogue. These stars are listed in Volume 4, Chapter 17 (ESA 1997).

The 20 remaining cases are not actually missing stars in the Tycho Catalogue, but rather inconsistencies between the catalogues (see detailed discussion in Chapter 17).

From this brief analysis, we can conclude that among the stars of the Catalogue of Positions and Proper Motions brighter than 9 mag, only 117 are missing in the Tycho Catalogue, providing a completeness ratio of about 99.9 per cent. We expect this completeness ratio to be fairly constant up to magnitude 10.0, although complete and accurate reference catalogues are lacking in this magnitude range.

2.2. Bright Stars from the Tycho Input Catalogue not Confirmed in the Final Catalogue

We have checked the status of stars brighter than 9.0, present in the Hubble Space Telescope Guide Star Catalog (GSC; Lasker et al. 1990), and therefore in the Tycho Input Catalogue (TIC; Egret et al. 1992), but which are not in the final Tycho Catalogue. There are 2028 such stars in the northern sky

($V < 9.0$ mag), i.e. 1.5 per cent of the Tycho Input Catalogue in this magnitude range. There are 4635 such stars in the southern sky ($B \leq 9.0$ mag; no V available). As explained below, most of these ‘stars’ are false Guide Star Catalog entries. Such stars have been sought in two sample areas of 6° radius, one in the South and one in the North, using the Centre de Données astronomiques databases: Simbad and Aladin (Genova et al. 1996, Egret et al. 1997).

In the South, from a test on 31 objects, we estimate that 70 per cent are galaxies or nebulae and 30 per cent are redundancies. For the galaxies and nebulae the ‘stellar’ magnitude given by the Guide Star Catalog was too bright because these are extended objects. The redundancies occur when the same bright star appears on two plates with a position difference slightly too large for automatic identification.

In the North, from a test on 15 objects, 50 per cent are redundancies, 25 per cent are galaxies/nebulae or false stars, most often flagged in the Guide Star Catalog with ‘nonstar’ class and 25 per cent are double systems. For these systems the median position given by the Guide Star Catalog has not been confirmed by Tycho. Therefore the Tycho Catalogue obtained ‘new’ entries, carrying a new identification number.

All these features of the Guide Star Catalog were already known, and some of them have been corrected in later versions of the Guide Star Catalog. Comparison with the Tycho Catalogue provides useful tools for a systematic search of such defects in the Guide Star Catalog.

2.3. False Bright Entries

Does the Tycho Catalogue include false Bright Stars?

There are 59 TYC entries, among the 14000 with $V_T < 7.0$ mag, for which there is no HIP identifier in the catalogue: could they be ‘false stars’?

A study of these individual cases showed that:

- for one star the Hipparcos Catalogue cross-identification was omitted in the Tycho Catalogue because of missing Hipparcos astrometry;
- 23 entries are components of a double or multiple system: the Hipparcos Catalogue number was assigned to (one of) the other component(s) of the system, but not to this one;
- 4 stars are (according to the Simbad and INCA databases) fainter than the formal survey limit, and accordingly were not included in the Hipparcos Catalogue;
- 30 stars, slightly brighter than the limit of the survey, were not, for various reasons, selected in the Hipparcos Input Catalogue;
- 1 false star, with appropriate flagging, including field T40 astrometric quality, $Q = 9$ (Høg 1997), was found at 26 arcsec from a very bright star and at the exact location of a much fainter Tycho Input Catalogue entry.

In a second step, stars in the range 7.0 to 8.0 mag were also considered, and those absent from both Hipparcos and HD Catalogues were investigated. As HD is expected to be complete to at least 8.0 mag, this criterion was used to look for potentially false stars in the Tycho Catalogue for this magnitude range. There are 76 such entries in the Tycho Catalogue:

- 42 had a PPM or other identification. Their magnitude in Simbad is compatible with V_T : thus there is confidence that they are real stars. The fact that the HD number is missing can be generally explained by a multiple system or by a failed cross-identification in case of PPM/Simbad discrepancy;
- 34 remaining stars were searched in the Guide Star Catalog, in the Simbad database, and on the digitized sky, with Aladin:
 - 9 have a faint Guide Star Catalog magnitude (in the range 11–12 mag) while $V_T \simeq 8 - 9$ mag. They have an astrometric quality $Q = 9$; they are most probably false stars, generally generated by transits from a nearby bright star. Aladin confirms their faint Guide Star Catalog magnitude;
 - 2 are typical wide companions, real components of double systems, but not recorded in the HD Catalogue;

- a problem occurred with a double system, where the Tycho Catalogue contains three entries at a place where there is actually, on the sky, a double system with a bright star ($V = 7.5$ mag) and a fainter one ($V = 11.2$ mag). Tycho reduction did not perform well here: if the quality flag T40 is neglected two bright stars are found, while only one is actually there. If the quality flag is taken into account, only the faint entry remains;
- the remaining entries are confirmed stars, not recorded in HD for various reasons.

In conclusion, bright Tycho entries, provided they are flagged with an astrometric quality better than 9, proved to be of very high reliability.

2.4. TYC Completeness at the Faint End

Figure 1 gives an histogram of all stars in the Tycho Catalogue as a function of V_T magnitude. For 1 per cent of the stars another magnitude was used because no V_T was available.

The approximately linear slope, in logarithmic scale, indicates that the completeness ratio stays constant until $V_T = 10.0$ to 10.5 mag.

From the comparison with bright PPM stars we have found a completeness ratio of 99.9 per cent at $V_T = 9$ mag. After $V_T = 10$ mag, the number of HIP-only stars begins to rise more steeply and we might expect a decline in the completeness ratio to begin there. Extrapolating the distribution in Figure 1, the completeness ratio is estimated to be at least 90 per cent at $V_T = 10.5$ mag, 65 per cent at 11 mag and 10 per cent at 11.5 mag.

In order to avoid a bias in the $B_T - V_T$ colour index (see Volume 4, Chapter 16, ESA 1997), it is recommended to select stars on the basis of the T magnitude, which may be derived with the approximate formula: $T = (B_T + V_T)/2$.

The completeness ratios are then 90 per cent at $T = 10.8$ mag, 65 per cent at $T = 11.5$ mag and 10 per cent at $T = 11.8$ mag.

The Tycho Catalogue includes, on the distribution tail, stars as faint as $V = 12.0$ mag. The analysis of a statistical sample (with V_T in the range 11.0–12.1 mag) confirmed that these are appropriate entries in the Tycho Catalogue. There are a few thousand stars in the Tycho Catalogue fainter than 12.0 mag, but these magnitudes are quite uncertain. Projects of an extended catalogue resulting from a second Tycho processing are presented by Høg (1997), in this volume.

2.5. Additional Tycho Catalogue Entries

From the whole Tycho Catalogue 1584 entries carry a new Guide Star Catalog number, not present in the original GSC or Tycho Input Catalogue; they are

mainly Tycho serendipity entries and wide companions (Halbwachs et al. 1992).

Out of these 1584 entries, 260 are ‘HIP-only stars’ and are not considered in the following.

The quality distribution for the remaining 1324 ‘new’ entries is given in Table 1.

Table 1. The quality distribution of ‘new Tycho Catalogue entries’. This is field T40 of the Tycho Catalogue (see, in this volume, Høg (1997), Table 2).

Quality	Number
1	8
2	41
3	349
4	627
5	14
6	12
7	112
8	161

A random sample of 30 stars was also analyzed. Of these, 13 (43 per cent) are rather bright stars for which the position has been substantially revised, so that the former Guide Star Catalog number could not be kept, at least through the automatic procedure. Some high proper motion stars may also fall into this category. A further 14 (47 per cent) are components of double systems for which the Guide Star Catalog gives the position of the photocentre, while the Tycho Catalogue gives the position of (at least one of) the individual components. The remaining 3 (10 per cent) are ‘serendipity’ or ‘wide companion’ entries. It has already been shown by Egret et al. (1992) why the Guide Star Catalog missed such entries (confusion with spikes or halos of bright stars, etc.).

3. CROSS-IDENTIFICATIONS

The Tycho Catalogue gives cross-identifications to the Hipparcos Catalogue (HIP), the Catalogue of Positions and Proper Motions (PPM), the HD Catalogue (Cannon & Pickering 1918-1924), the Durchmusterung (DM) Catalogues (partly) and it flags stars from the General Catalogue of Variable Stars (GCVS; Kholopov et al. 1988) and the New Catalogue of Suspected Variable Stars (NSV; Kukarkin et al. 1982).

Except for the Hipparcos Catalogue and the Catalogue of Positions and Proper Motions, these catalogues are of poor astrometric quality. For a catalogue the size of the Tycho Catalogue, it is therefore not always possible to provide fully correct and consistent identifications. Even for the Hipparcos Catalogue and the Catalogue of Positions and Proper Motions there were many non-trivial cases. Therefore, absence of a cross-identification may not necessarily imply that the star is not in the corresponding catalogue.

The Hipparcos Catalogue also provides (in the machine readable version) references to the HD and DM Catalogues, and the critical user of the Tycho Catalogue may take advantage of this in order to detect possible mis-identifications for Hipparcos stars in the Tycho Catalogue. It is also advisable to check the notes of the Hipparcos Catalogue. These notes may give corrections to the identifications of some stars in the Hipparcos Input Catalogue, and such stars are likely also to have a wrong identification or a wrong flag in the Tycho Catalogue.

4. CONCLUSION

The analysis of the stellar contents of the Tycho Catalogue presented here, shows that the Tycho Catalogue presents unique characteristics making it the first reference survey of the one million brightest stars in the sky. The catalogue will, for this reason, be a very important tool for supporting cross-identification with other catalogues, surveys or wide-field images obtained from ground- or space-based telescopes, in the optical as well as in other wavelength ranges.

ACKNOWLEDGMENTS

Help of A. Balland and A. Piskunov in the preparation of this contribution is gratefully acknowledged.

REFERENCES

- Cannon, A.J., Pickering, E.C., 1918-1924, Henry Draper Catalogue, Harv. Ann. 91-100
- Egret, D., Didelon, P., McLean, B.J., Russell, J.L., Turon, C., 1992, A&A, 258, 217
- Egret, D., Ochsenein, F., Genova, F., 1997, ESA SP-402, this volume
- ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200
- Genova, F., Bartlett, J. G., Bienaymé, O., et al. 1996, Vistas in Astronomy, 40, 429
- Halbwachs, J.L., Bässgen, G., Bastian, U., et al. 1994, A&A, 281, L25
- Halbwachs, J.-L., Høg, E., Bastian, U., Hansen, P.C., Schwekendiek, P. 1992, A&A, 258, 193
- Høg, E. 1997, ESA SP-402, this volume
- Kholopov, P.N., et al. 1988, General Catalogue of Variable Stars, 4th Edition, Volumes I-III
- Kukarkin, B.V., et al. 1982, New Catalogue of Suspected Variable Stars, Moscow ‘Nauka’ Publish. Office
- Lasker, B.M., Sturch, C.R., McLean, B.J., et al. 1990, AJ, 99, 2019
- Röser, S., Bastian, U., 1991, PPM Star Catalogue, Volumes I and II, Astronomisches Rechen-Institut, Heidelberg
- Sinnott, R. W., 1997, ESA SP-402, this volume