HIPPARCOS - TYCHO: PHOTOMETRY & ASTROMETRY FOR MORE THAN 500 000 STARS

M. Grewing
Astronomisches Institut
Waldhauserstrasse 64
D-7400 Tübingen
F.R.G.

E. Høg
Copenhagen University Observatory
Ostervoldgade 3
DK-1350 Copenhagen K
Denmark

ABSTRACT. The Hipparcos star mapper will be used to determine magnitudes in two colours and the positions for about 500 000 stars. The typical accuracy for the mean values is about 0.03 mag and 0.03 arcsec respectively for a star of B = 11.0 mag and B-V = 0.7 mag. The photometric system and part of the data analysis are outlined.

1. INTRODUCTION

The real-time attitude of the satellite will be monitored by a star mapper, viewing a 40 arcmin wide band of sky, ahead of the main field of view through a system of 4 vertical and 4 inclined slits (Fig. 1). The resulting on-board accuracy will be 1 arcsec rms, on-ground attitude reconstitution will later improve this value to 0.1 arcsec rms.

During the definition of the Hipparcos project it was realised that the star mapper photon records will contain extremely valuable photometric and astrometric information for hundreds of thousands of stars (see e.g. Høg et al., 1982) which will greatly enhance the scientific return from the mission. In 1981 ESA formally approved the Tycho project which aims at determining magnitudes and positions for at least 500 000 stars. The hardware changes required were the introduction of dichroic beam splitters and a pair of redundant photomultiplier tubes into the science payload (Fig. 1), and the provision to transmit all photon counts from these tubes to the ground.

In the following we outline some of the system hardware characteristics, some aspects of data extraction and the concept of the data reduction. Earlier descriptions of the Tycho project have been given by Høg (1986), and Høg (1985a).

2. HARDWARE CHARACTERISTICS

The two star mapper units, one of which is redundant, consist of two identical grid systems, symmetrically arranged on either side of the main grid as shown in Fig. 1. Each system contains 4 vertical slits and

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4 slits inclined at 45 degrees with respect to the scan direction of the satellite. The nominal configuration assumes that the leading star mapper is switched on, the trailing one being switched off.

The individual slits have a width of 0.913 arcsec. The scan velocitity of 168.75 arcsec per sec then causes a star to cross the individual slit in about 5.4 milli-sec. As the photomultiplier signal is sampled at a rate of 600 Hz in each colour, 3.2 samples are obtained in each colour during the crossing of a slit.

In choosing the dichroic beam splitter, an attempt has been made to balance the signal in the resulting two channels to minimize any adverse effects on the accuracy of the attitude determination, while separating at the same time as much as possible the central-wavelengths of the two bands. The particular choice made, together with the choice of the bialkali photocathodes, results in pass bands which resemble the B and V bands of standard photometric systems. The presently foreseen central wavelengths for the Tycho BT and VT channel are 424 nm and 524 nm respectively, whereas the corresponding values for the Johnson system are 440 nm and 548 nm (Fig. 2).

In Table 1 the expected count rates have been compiled for a star of magnitude (B+V)/2 = 9.65 mag crossing the vertical slits. The entries are for B-V = 0.0, 0.7, and 1.5. These count rates are to be compared with the expected dark count rate, including the sky, of roughly 3300 Hz.

The chosen slit geometry implies that the time it takes a star to cross an individual slit is small compared to the time needed for moving to the next slit, and this in turn is small compared to the time that elapses before the next group of four slits is encountered. This leaves room for data compression by extracting from the continuous star mapper data stream only those sections where a crossing should occur. This is described in more detail in the next section.

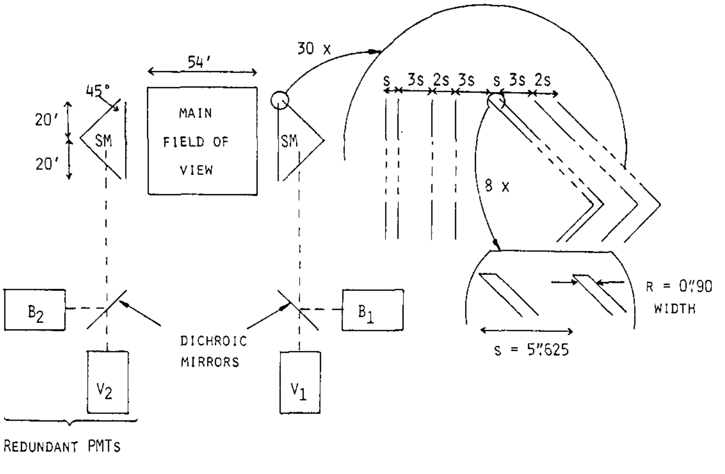

Figure 1. Schematic illustration of the Tycho slit systems

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3. SINGLE GROUP CROSSINGS

In what follows we shall consider the passage of a star over a group of 4 slits, either the vertical or the inclined ones. We shall further assume that we can predict the time of the crossing with an accuracy of 1 arcsec (or about 6 milli-sec of time) from the knowledge of the Hipparcos scanning law and a Tycho Input Catalogue. The use of an input catalogue reduces the scope of the data reduction task since we confine the data extraction and analysis work to a fraction of the entire star mapper data stream.

This will be true even if the Tycho Input Catalogue will contain as many as 2 million entries. This catalogue, distinct from the Input Catalogue for the main mission, will be constructed by merging data from the Space Telescope Guide Star Catalogue and from the Strasbourg Stellar Data Centre. Further details are given by Russell (1985).

As shown in Fig. 1, the spacing of the slits within each group is non-periodic. This choice minimises the effects of noise and of other stars in the fields. In a first reduction step this signal is folded with a numerical filter with 4 peaks corresponding to the 4 slits. The output from this filter will contain a main lobe with 6 side lobes on each side, each side lobe being 4 times smaller than the main lobe. The analysis has been studied theoretically and by simulations by Yoshizawa et al. (1985). The main lobe will be detected if it exceeds a given threshold of signal-to-noise ratio. The amplitude of the main lobe scales with the magnitude of the star. The time of the lobe is related to the clock system and, hence, contains the astrometric information since the satellite attitude is known at any one instant.

Such an individual measurement or detection will, however, normally not be counted as a final target detection. Instead, advantage will be taken of the fact that a star is viewed repeatedly, firstly during successive scans, and secondly several months later, depending on its location in the sky and the actual Hipparcos scanning law. This is

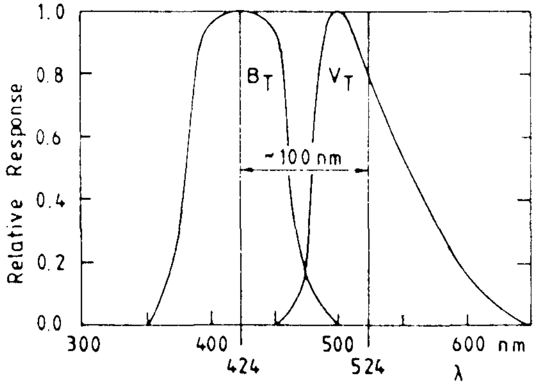

Figure 2. The relative spectral response of Tycho

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discussed in more detail in the next section.

4. THE IDENTIFICATION PROCESS

Initially, the knowledge of where a star will actually cross the slit pattern is limited. Therefore, allowance will be made for a 12 x 12 square arcsec field on the sky, centred on the Tycho Input Catalogue position, in which the actual crossing ought to happen. Suppose each group of slits is represented by a centre line. Then the orientation and position of this line within the 12 x 12 square arcsec field will be well known from the transit time. The location of the star along the line will not, however, be known at this stage.

As the sky is being scanned, repeated observations of the same target, which will generally occur under different angles, will all produce lines as shown in Fig. 3. Under ideal circumstances all these lines would meet in one location which corresponds to the position of the star in the sky. In reality, however, displacements will occur and, more seriously, lines arising from false detections will be present which can, in principle, be recognised from the fact that they are randomly distributed across the field.

A numerical method has been designed by Høg (1985b), called numerical mapping, which allows to determine in an automated way where several lines meet, and what the probability is that this represents a true detection of a star and not a chance coincidence due to false detections. It is considered at present that this method will allow the correct identification of one or more stars in the 12 x 12 square arcsec

Table 1. Photometric Characteristics of Tycho.

		Tycho BT	Tycho VT	Johnson B	Johnson V
λ eff	(nm)	424	524	440	548
FWHM	(nm)	82	77	96	90
Separation	(nm)	100		108	
Background	(Hz)	3318	3400		
Count rate for stars, for the given star colours:					
B-V = 0.0	(Hz)	3629	2236		
B-V = 0.7	(Hz)	2364	2463		
B-V = 1.5	(Hz)	1500	3018		

Note: The table gives the nominal specified count rates for a star of (B+V)/2 = 9.65 when it is centred on a vertical slit. The count rates are smaller on the inclined slits than on the vertical slits by about 18 per cent in BT and about 28 per cent in VT. The flight photomultiplier tubes have recently been selected and they give about 30 per cent more counts than assumed in the Table.

field maps with a high reliability for the 500 000 brightest stars in the sky on the basis of 6 months of observations. If this expectation is confirmed by further simulations, one would not only have an efficient tool for identifying stars but also a powerful means to improve on the positions given in the Tycho Input Catalogue and to recognize areas without any detectable star. This would be of immediate practical importance as it would significantly reduce the amount of data to be handled and computer hours to be spent since future searches could be confined to smaller and to fewer areas than the 2 million or so that we start with, i.e. smaller fractions of the overall star mapper data stream have to be handled.

5. FURTHER PROCESSING STEPS

Subsequent to the identification process the data flow will run in parallel through the astrometric and the photometric reduction.

The photometric reduction uses the signal amplitudes in the estimation process after background correction and relates them to stellar magnitudes BT and VT through a system of transformation equations. The coefficients for this transformation will be determined throughout the mission by solving the set of colour equations for the subset of calibration stars (roughly 10 000 non-variable stars distributed uniformly across the sky) for which accurate Geneva photometry is available. This procedure will account for small sensitivity variations as a function of field coordinate, as well as for time-dependent effects that occur on

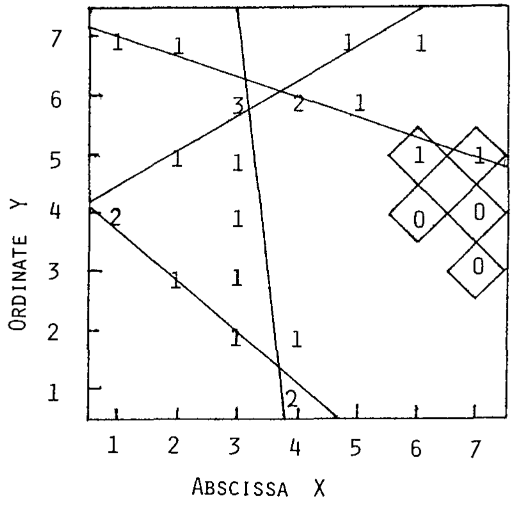

Figure 3. A numerical map as used in the Tycho identification process. The use of the numerical map is explained in the text.

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time-scales longer than about 24 hours. The resulting magnitudes will be collected in the Tycho Photometric Catalogue for later merging with the outcome of the astrometric reduction.

The astrometric reduction is partially tied in with the data reduction for the Hipparcos main mission. Firstly, the initial calibration of the star mapper geometry will be performed by FAST and NDAC taking a possible non-linearity and large-scale geometric distortion of the star mapper slits into account. Later on this calibration will be refined during the astrometric reduction of the Tycho data. Secondly, while the real-time knowledge of the attitude is sufficient for a provisional astrometric analysis of the Tycho data, the final analysis will have to rely on the improved satellite attitude determination that both FAST and NDAC will generate for their own data analysis work and that TDAC will receive and compare.

The astrometric information proper is contained in the transit time for an individual slit group. This is a one-dimensional measure of the star position in the direction perpendicular to the slit, once the attitude group crossings per star will be observed, with a number of different slit orientations on the sky. From these the five astrometric parameters, including the covariance matrix, will be derived for each star with an expected accuracy of 0.03 arcsec for positions, annual proper motions and parallaxes. These data will be compiled in the Tycho Astrometric Catalogue and later be merged into the Tycho general catalogue which should be available to the community roughly three years after the end of the satellite mission.

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