Figure 1. The principal operational interfaces between ESOC and the science teams within the Hipparcos mission.

The programme star file was generated using an input catalogue provided by the Input Catalogue (INCA) consortium. This catalogue contained the programme stars to be observed by the main instrument supplemented by all stars brighter than magnitude 9, which were not otherwise included. Provisional results of the main catalogue processing were periodically fed back to the Hipparcos operations in the form of a more accurate input catalogue. The input catalogue was also used by the ground-based attitude determination system, which was used after every perigee to independently derive the spacecraft

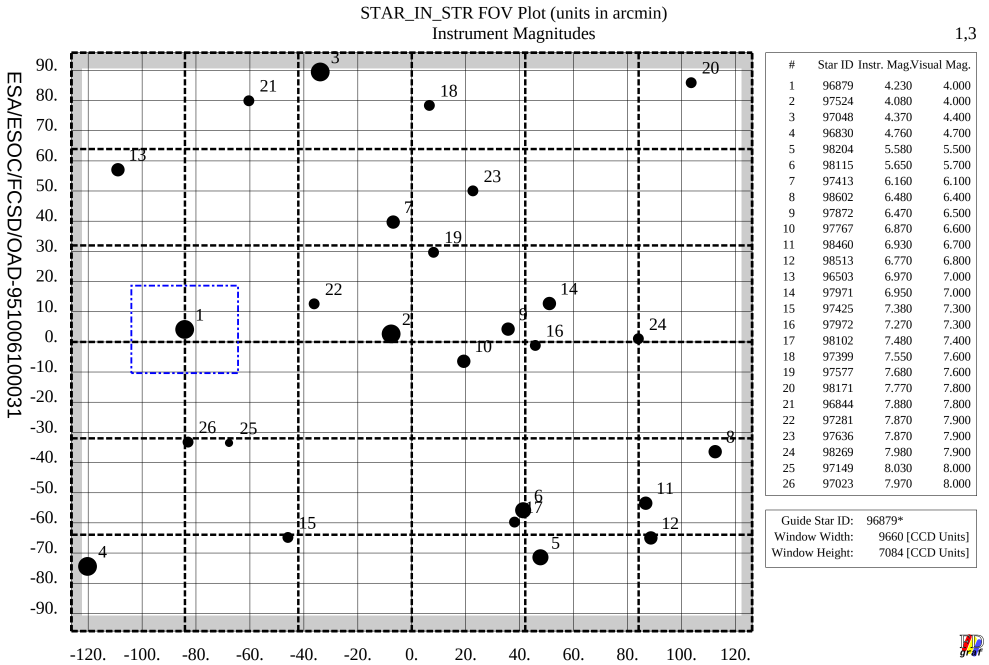

Figure 2. A typical star tracker field of view taken from the ISO mission. The restricted search window can be seen in the left half of the field of view. The XMM and INTEGRAL missions will make use of a similar star tracker design.

attitude and (if necessary) correct the real-time attitude knowledge. The benefits to the mission of this early feedback were:

- the reduction of star catalogue position and magnitude errors to a level much lower than the intrinsic real-time attitude determination accuracy;
- improvement in real-time attitude determination stability, contributing to a lower probability that ground intervention was required after perigee;
- greater reliability and speed of ground real-time attitude determination operations.

3. ISO

Hipparcos was constantly rotating and relied on a star mapper for inertial attitude determination. ESA's Infra-red Space Observatory (ISO), launched in 1995 and still in operation, maintains inertial attitude control during scientific observations to an accuracy of 1–2 arcsec, using a combination of fine Sun sensor (viewing perpendicular to the telescope optical axis) and star tracker (viewing parallel to the optical axis). The star tracker has a 3 × 4 degree field of view (see Figure 2) and locks on one guide star which is pre-selected from ground. For each observation, the target attitude and inertial guide star vector are uplinked. Once the requested attitude is reached, the on-board system computes the guide star position in the star tracker field of view. The star tracker searches for a star at that position within a search window, the size of which is prescribed from ground and restricted to avoid the possibility of accidentally locking on a neighbouring star of similar brightness. Assuming the star is successfully identified, the spacecraft attitude is controlled to put the guide star at the centre of the search window.

On-ground attitude determination is possible using the on-board mapping function, which determines the position and brightness of all stars above a defined magnitude threshold in the star tracker field of view. The map is then compared with the ground based star catalogue using star pattern matching techniques to determine the attitude.

The ISO mission benefited after launch from an improved Guide and Calibration Star Catalogue provided by the Centre de Données Stellaires in Strasbourg and derived in part from the Tycho Catalogue results. The principal benefits were:

- greater reliability in acquiring the correct guide star due to greater photometric accuracy. During the initial stages of the mission there were many instances of stars being more than 0.3 magnitudes fainter than predicted from the ISO guide star catalogue, resulting in a failure to acquire the guide star;

Figure 3. The hierarchy of catalogues produced by the star catalogue facility.

will record any large inconsistencies. Inconsistency checks are made on completeness, reference number, position, brightness, spectral class. As well as making cross comparisons, each individual source catalogue will be limit checked for suspect data. The master catalogue will contain at least the following data:

- position (Equatorial J2000.0)
- position accuracy
- parallax
- proper motion and accuracy
- magnitude (B, V, I and U)
- variability
- spectral type
- multiple system information
- source catalogue reference numbers
- angular extent if object is extended

The mission catalogues should contain significantly fewer stars than the master catalogue, making them more efficient for use with operational software. Typically mission catalogues may only contain stars with a limited magnitude range, dependent on the sensitivity of on-board sensors. Classification of stars for mission specific purposes may also be included at this level (e.g. stars may be graded according to a combination of brightness and positional accuracy for possible selection as star tracker guide stars).

Instrumental magnitudes will be computed for mission catalogues based on either a mission specific table of values for particular stars, a mission specific table of instrumental magnitude offsets from visual magnitude as a function of spectral class, or a combination of both.

The epoch for star positions must also be specified for a mission catalogue, although this may not necessarily be the default J2000 epoch.

A 'run catalogue' will be a subset of a mission catalogue which is valid for a specified time period, restricted in sky coverage and/or further restricted in magnitude range. Restrictions in sky coverage are limited to either a cone around a specified direction or a band following a great or small circle on the celestial sphere. Moreover since the band may be restricted in azimuth (i.e. not a complete revolution), run catalogues for rectangular fields of view (e.g. for the XMM star tracker) may be considered as a restricted band.

The star catalogue facility also supports the following functions:

- manual catalogue updating: Star measurements in orbit from a particular instrument may reveal weaknesses in star data from either the master or mission catalogues. Stars will not be physically added or deleted from the catalogues (this may only be done by a redelivery of a new source catalogue). However, a suspect star may be flagged to disable it from inclusion in mission catalogues;
- additional routines for performing geometrical calculations: annual parallax, aberration and proper motion corrections, angular distance between two stars, angles of a spherical triangle based on three stars;
- solar system ephemerides: including derived magnitudes;
- catalogue verification: cross-verification of any externally provided mission catalogue against the master catalogue;
- star pattern recognition and attitude determination: mission independent algorithms for:
  - a 3-axis stabilised spacecraft using a star and sun sensor
  - a spinning spacecraft with star slits and a known spin axis
- visualisation of fields of view: circular or rectangular;
- statistics reports.

6. CONCLUSIONS

The Hipparcos and Tycho Catalogues are clearly of great benefit not only to the astronomical community, but also to the space sector as a whole. They provide an exceptionally valuable addition to the range of source catalogues, from which star catalogues for on-board attitude and navigation control systems can be used. As such, they help to ensure greater accuracy and safety in many future missions with consequent benefits to a far wider scientific and engineering community.

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