HIPPARCOS - ACTIVITIES OF THE DATA REDUCTION CONSORTIA

L. Lindegren
Lund Observatory
Box 43
S-22100 Lund
Sweden

J. Kovalevsky
CERGA
Avenue Copernic
F-06130 Grasse
France

ABSTRACT. The complete reduction of data from the ESA astrometry satellite Hipparcos, from some 10^{12} bits of photon counts and ancillary data to a catalogue of astrometric parameters and magnitudes for the 100 000 programme stars, will be independently undertaken by two scientific consortia, NDAC and FAST. This approach is motivated by the size and complexity of the reductions and to ensure the validity of the results. The end product will be a single, agreed-upon catalogue. This paper describes briefly the principles of reduction and the organisation and status within each consortium.

1. INTRODUCTION

In the early study phases of the Hipparcos project, it became clear that the scientific activities involved in reducing the data returned by the satellite represent a very significant task, which must be regarded as an integral part of the mission. Any small piece of the raw data is by itself virtually useless, except in the context of all the other pieces. This is because the calibration and motion of the instrument can only be derived from the observations themselves. It is as if we were trying to measure stellar positions by means of a graduated arc without knowing exactly the unit of graduation, and with respect to an unknown reference point which is constantly in motion. The complexity of the reductions, and the possibility of enhancing the accuracy of the astrometric results by the application of sophisticated methods, made it desirable to have two independent groups performing the complete reductions, although the end result should be a single Hipparcos catalogue.

Two such data reduction consortia were formed in response to an Announcement of Opportunity issued by ESA. One consortium known by the acronym NDAC (Northern Data Analysis Consortium) is headed by E. Høg (Copenhagen University Observatory), the second consortium FAST (Fundamental Astronomy by Space Techniques) by J. Kovalevsky (CERGA, Grasse). The activities of the participating institutes are funded by national agencies, universities, and private foundations.

J.-P. Swings (ed.), Highlights of Astronomy, 699–706.

https://doi.org/10.1017/S1539299600007152 Published online by Cambridge University Press

2. PRINCIPLE OF REDUCTIONS

Details of the reduction processes have been published elsewhere (e.g. Kovalevsky 1984, Lindegren 1985,1986, and several papers in Bernacca 1983 and Kovalevsky 1985) and only the major steps towards the creation of the Hipparcos catalogue shall be outlined here, in order to clarify the work distribution within each consortium.

The 'raw' data supplied on magnetic tapes by ESOC (the European Space Operations Centre in Darmstadt, Germany) consist mainly of photon counts from the main detector (an image dissector tube) and the two 'star mapper' channels, sampled at 1200 Hz and 2 x 600 Hz, respectively. These record the modulation of starlight as the images of programme stars move across various grids in the focal surface (Perryman 1985). Together with ancillary data from the satellite or added at the ground station (e.g. timing information), this amounts to about 10 high-density tapes per week, which are shipped to the data reduction consortia. The main steps in the reduction are then as follows:

(A) the star mapper photon counts will be used to determine the transit times of the brighter programme stars across special slits, from which the motion of the viewing directions on the sky (the attitude) can be determined to about 0.1 arcsec. This information is needed as a first approximation to the much more accurate measurements in the main field of view. For example, the orientation of the main grid on the sky is needed to within a few tenths of an arcsec in order to relate any observation in the 0.9 x 0.9 square degree field of view to the field centre with milli-arcsec accuracy;

(B) the image dissector tube photon counts similarly determine the transit times of programme stars across the numerous equidistant slits on the main grid. However, because of the strict periodicity of this grid (as opposed to the star mapper grid), the light modulation is periodic and we determine the phase of the signal at certain instants, rather than determining transit times. The estimation of such 'grid coordinates', by means of a Maximum Likelihood algorithm, is an important step of the reductions which also entails a significant compression of the amount of data;

(C) observations collected within a time interval of 10-12 hours are confined to a strip of the sky along a great circle and only a few degrees wide, and comprising some 2000 programme stars. The next step of the reductions is to combine the many grid coordinates obtained in this interval into one-dimensional positions of the programme stars along a designated 'reference great circle'. These one-dimensional coordinates, called abscissae, are determined by a least-squares process, in which the precise motion of the field of view along the reference great circle is also estimated, together with a number of instrument parameters including the scale value and large-scale distortion of the main field, and the angular separation of the two viewing directions (the basic angle). The final astrometric accuracy depends critically on the 'rigidity' of this so-called great-circle reduction, i.e. on how well the different parts of the reference great circle are connected by direct measurement or modelisation of the motion. The rigidity is vastly improved by the use of two widely separated viewing directions, but also by the possibility to represent the motion in the quiet intervals (of the order of 10 min) between jet actuations by only a few parameters. This process is referred to as dynamical smoothing;

(D) the final step of the main astrometric reductions is to combine the different abscissae for a given programme star, obtained on some 20-50 reference great circles spread over the 2.5-year mission, in a least-squares solution of its astrometric parameters, giving the parallax and the components of the position and proper motion. The main difficulty here is that the abscissae origin of each reference great circle is quite arbitrary, and has to be put on a consistent global system by means of a process known as the sphere reconstitution.

Several of the steps described above must be iterated, using successively more accurate versions of the working catalogue, before a satisfactory solution is reached. To determine the attitude to 0.1 arcsec, for instance, will require star positions which are better than those given in the Input Catalogue. Preliminary reduction of the first 6-12 months of observation will be used, among other methods, for such improvement.

Apart from the main line of astrometric reductions, there are several more processes going in parallel or being performed after the main reductions. One such task is to extract the photometric information from the detector signals. Double and multiple stars require particular attention at all stages of the reductions in order to preserve information on these objects and prevent them from disturbing the results on other stars. A small number of minor planets will furthermore be observed and will require special treatment.

3. ACTIVITIES OF THE NORTHERN DATA ANALYSIS CONSORTIUM, NDAC

The routine reductions will be shared between two sites: at the Royal Greenwich Observatory (RGO), using a DEC VAX-11/750 computer, and the Danish Space Research Institute (DSRI), using a Hewlett-Packard HP 9000 system. Exchange of data, mainly of partially reduced data from RGO to DSRI, will take place on a weekly basis, and the main sequence of processing is as follows (Fig. 1).

Tapes with 'raw' data are received at RGO and the different types of data separated and copied onto disc files. The processing then progresses in three stages. A preliminary attitude reconstitution (A) is first performed, using the star mapper photon counts and gyro signals as input. At the same time, improved magnitudes and colours are deduced for programme stars observed with the star mapper.

In the second stage, the preliminary attitude allows the computation of the frequency of light modulation by the main grid so that the image dissector tube photon counts can be analysed and the Fourier coefficients estimated (B). Using several hours of data at a time, the systematic phase shift and modulation ratio (second to first harmonic) are calibrated as functions of position in the field; this so-called OTF calibration will lead to improved phase estimates ('location estimator') and permits to single out disturbed observations

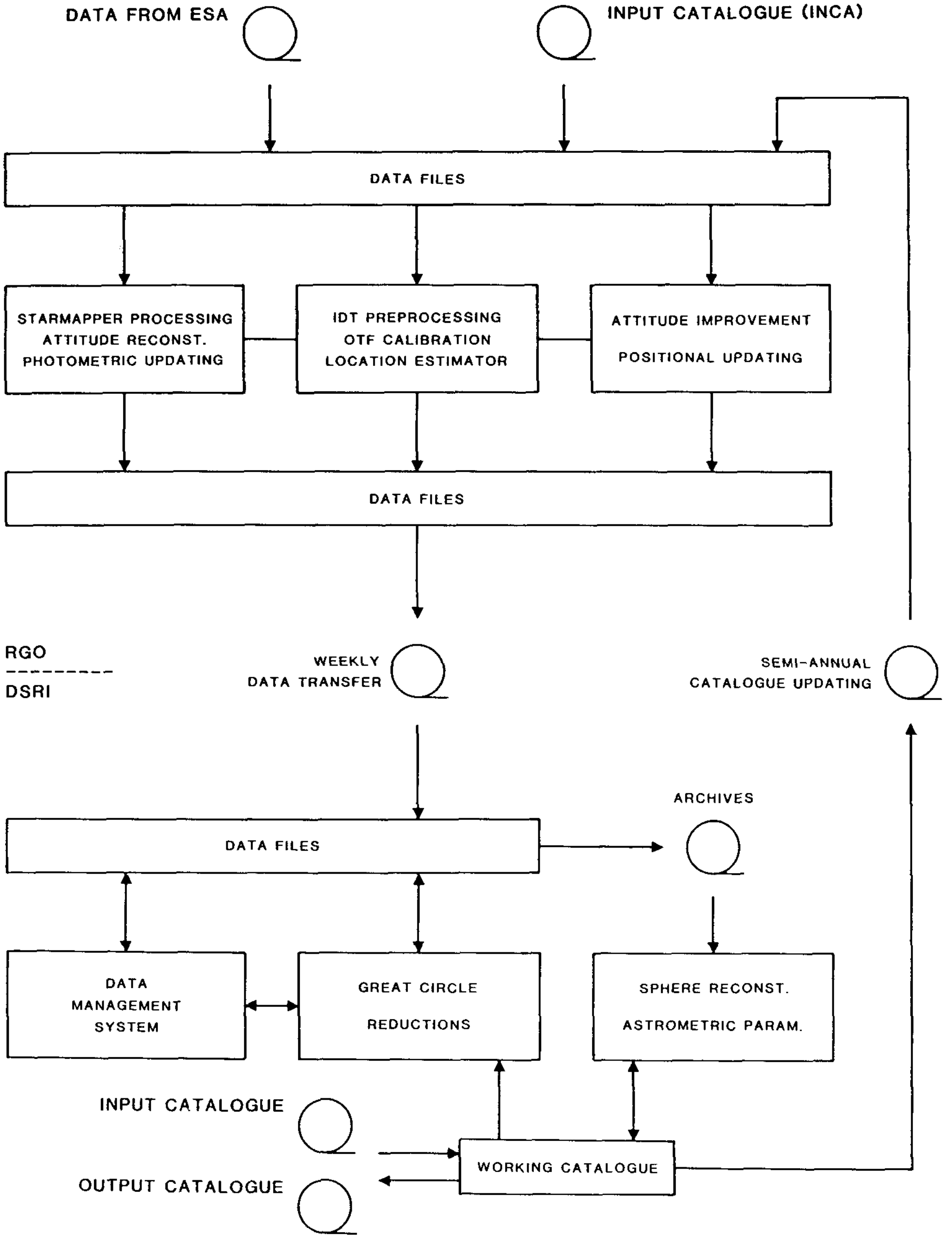

Figure 1. Organisation of the main sequence of Hipparcos data reductions by the NDAC Consortium. Note the division of work between RGO (Royal Greenwich Observatory) and DSRI (Danish Space Research Institute). The treatment of minor planets, double stars, and photometry in the main field is not explicitly indicated in this figure.

(e.g. of double stars).

The third stage improves the attitude estimate in the scanning direction by incorporating corrections to the modulation frequency as observed with the image dissector tube. Residuals of the star mapper transits with respect to this improved attitude are used to update positions in the working star catalogue.

Tapes with attitude and phase estimates and catalogue updates are sent to DSRI, where the different types of data are again separated and copied to disc files. The great-circle reduction (C) is performed and the results stored on magnetic tape.

At certain milestones of the mission, in particular after 6, 12, 18 and 30 months of observation, all abscissae available at the time will be combined in a reconstitution of the sphere and redetermination of the astrometric parameters of all programme stars (D). The improved star catalogues resulting from this process are fed back to RGO for the benefit of the attitude reconstitution.

It is estimated that the attitude reconstitution and great-circle reductions of the whole first year will have to be iterated with the updated catalogue produced at that time.

The software development is shared between the U.K. and Scandinavian institutes according to the division of the actual reductions. Algorithms for preprocessing of star mapper and main detector photon counts have been developed at Mullard Space Science Laboratory (A.M. Cruise, N. Elton) and installed at RGO during 1985.

The attitude reconstitution, OTF calibration and location estimator were developed at RGO (F. van Leeuwen, C.A. Murray, Margaret Penston). The coordination of this software and its final implementation at RGO will be the responsibility of F. van Leeuwen.

Development of the great-circle reduction is near completion at Copenhagen University Observatory (C. Petersen) and a working version of the sphere reconstitution and determination of astrometric parameters has been successfully tested at Lund Observatory (L. Lindegren, S. Soderhjelm). Both packages will be installed at DSRI in 1986, after which a full system test of the routine reductions will take place at RGO and DSRI. On the subsystem level, individual processes are tested with input data simulated especially for each purpose. For the system test it is essential, however, to carry the same data set through the whole reduction chain, up to and including the great-circle reduction. This data set should be created in as nearly as possible the same format as the real satellite data, and for this purpose NDAC will partly depend on data exchanges with FAST and ESA.

Apart from the main astrometric reductions described above, there are several less critical processes, which are not yet in a very advanced stage. These include detection and reduction of double stars for which algorithmic experiments are going on at Lund Observatory, and the treatment of minor planets, photometry, and the manipulation and comparison of catalogues.

4. ACTIVITIES OF THE FAST CONSORTIUM

The general organisation of the reduction of Hipparcos data by the FAST Consortium is presented in Fig. 2. The main reduction chain will be implemented on the CNES computer in Toulouse and will include the following subsystems:

(i) the 'Reception and Preparation' subsystem that will receive the data from ESA, and check and prepare the internal files to be used later in the reduction. It also prepares all reference data, such as apparent positions of stars or data for correcting the 'veiling glare' using the Input Catalogue;

(ii) the 'mass treatment' (corresponding to steps A,B,C above) includes the treatment of all photon counts on the main grid and on the star mapper grid (F. Donati, Torino), the determination of the attitude from the star mapper (also F. Donati), its improvement from the reduction on the reference great circle and the determination of the abscissae (D. van Daalen, Delft);

(iii) the combination of data obtained on a large number of reference great circles will then be performed (step D above). This step is being prepared in Bologna (I. Galligani) and in Heidelberg (H. Walter).

When the data have been treated once, an iteration will be prepared and performed, using the best available star catalogue and attitude data rather than the Input Catalogue and the on-board attitude.

A data management and control system, consisting of FORTRAN statements and system procedures, will be prepared by the team at CNES (Centre National d'Etudes Spatiales) under the leadership of J.-L. Pieplu (Toulouse). It will ensure the management of all input, output and intermediary files of these processors and control the development of the computations.

At present all the theoretical studies leading to the adoption of the algorithms have been performed. Their results were published mainly in the proceedings of two workshops organised by the consortium (Bernacca 1983, Kovalevsky 1985). The mock-up programs used to verify the quality of the algorithms are also finished and several processors or chains are now being implemented in their final optimised and robust form.

There are also a number of off-line processors interacting with the main reduction chain and providing some necessary data or complementing the computations. A 'first-look' task will be to process a single reference great circle every week on a very short time-scale. This will be done at the Space Research Institute of Utrecht (H. Schrijver) and will also provide a first approximation of the various calibrations. Improved calibrations, principally for the iterations, will be obtained as a special task using more complete input data. In parallel, the double star treatment (W. Delaney, Bari) will determine whenever possible the elements of double and multiple stars and link the grid modulation to the actual position of the double star components. All these tasks are still in their study phase.

The astrometric parameters determination of all stars and their discussion together with the construction of the final catalogue will be the responsibility of the Astronomisches Rechen-Institut in Heidelberg.

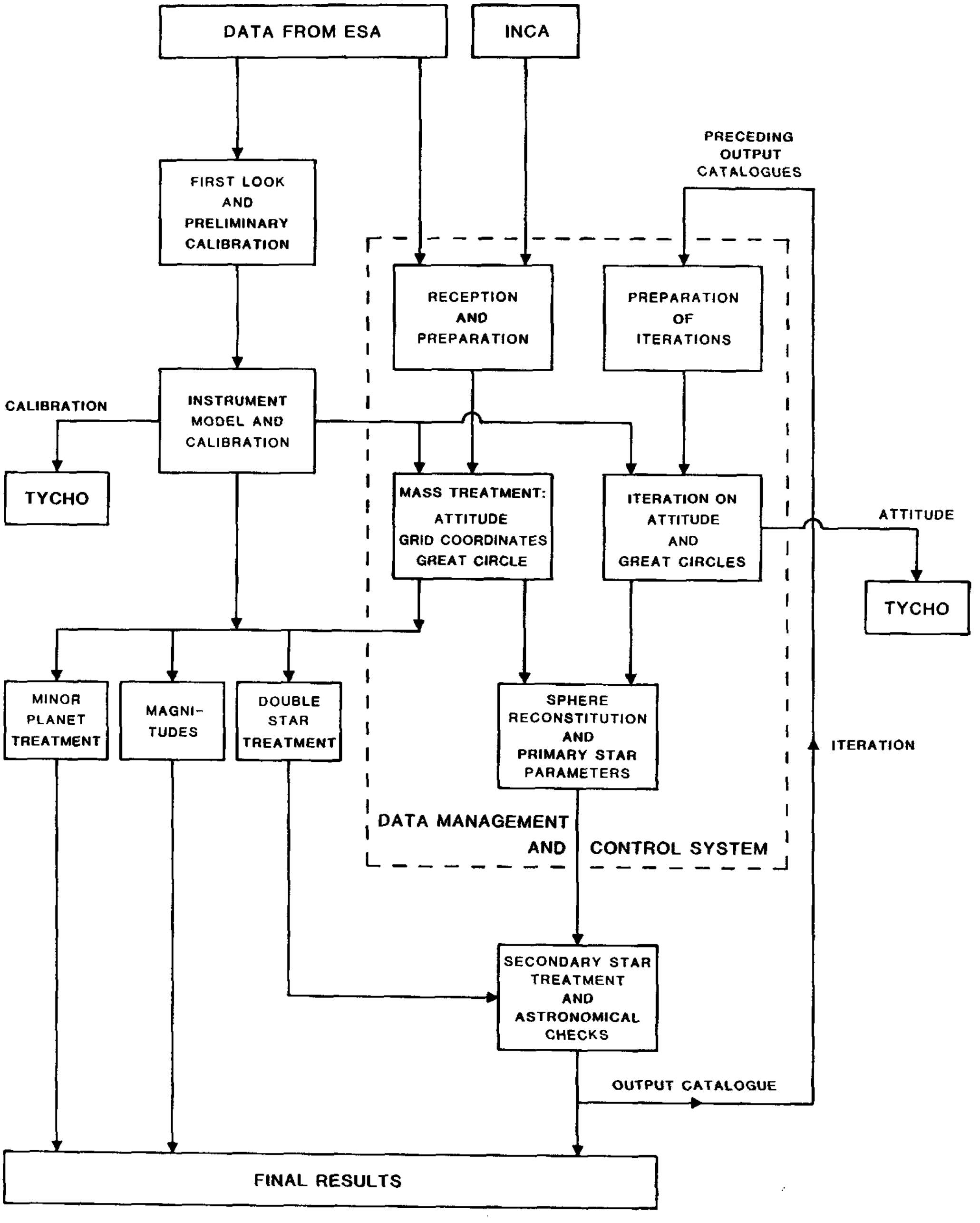

Figure 2. Organisation of the main sequence of Hipparcos data reductions by the FAST Consortium. Key: INCA = Input Catalogue, TYCHO = data output to the Tycho Data Analysis Consortium.

It involves direct action of astronomers, especially in the case of multiple stars, doubtful stars, strongly variable stars, etc. The software for this task is almost fully implemented.

Two other off-line tasks are presently being prepared. They are the treatment of minor planet data (B. Morando, Bureau des Longitudes) and computation of magnitudes for all stars (F. Mignard, CERGA). The algorithms for these tasks are presently being studied.

Another very important activity of FAST is the production of simulated data. A realistic model of the instrument has been made and used to simulate photon counts with all identified perturbations. This task was performed in CERGA under the leadership of M. Froeschlé and is now able to provide main grid and star mapper photon counts for any length of time. In addition, grid coordinates (the entry data to the great-circle reduction) are now also produced by the simulation program. It is expected that in 1986 it will provide the data under the exact form in which ESA will furnish it to the consortia. These simulated data are made available to NDAC under an exchange agreement passed last year.

FAST and NDAC will both provide accurate attitude data as well as certain calibration data to the TDAC consortium as a contribution to the reduction of Tycho observations (Grewing & Høg 1985).

REFERENCES

Bernacca, P.L. (ed.), 1983. 'The FAST Thinkshop', Asiago, Univ. of Padova.

Grewing, M. & Høg, E., 1986. This Volume.

Kovalevsky, J., 1984. Space Science Reviews 39, 1.

Kovalevsky, J. (ed.), 1985. 'The Second FAST Thinkshop', Marseille, Laboratoire d'Astronomie Spatiale.

Lindegren, L., 1985. 'Hipparcos - The Scientific Aspects of the Input Catalogue Preparation', (Turon, C. & Perryman., M.A.C., eds), ESA SP-234, 31.

Lindegren, L., 1986. In 'Astrometric Techniques', IAU Symp. No. 109 (Eichhorn, H., ed.).

Perryman, M.A.C., 1986. This Volume.

https://doi.org/10.1017/S1539299600007152 Published online by Cambridge University Press