STAR CATALOGUE FACILITY

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ABSTRACT

The provision of a star catalogue is often a necessary requirement for the support of a mission. In the past the European Space Operations Centre (ESOC) has used dedicated star catalogues prepared on an individual basis to support such missions as Exosat, Hipparcos and ISO. However for future missions it is preferred to develop a central facility, which can provide the catalogues and tools to support the missions, at the same time providing a standardisation of the handling of star data across the missions.

The Star Catalogue Facility (SCF) is developed to meet this need and was designed based on the experience of recent missions and the requirements of missions planned for the first decade of the next century. It provides a database of celestial objects for the production of star catalogues to support individual missions and the tools to handle the star data.

Central to SCF is the master catalogue, which is built by combining the star data from a number of different sources: primarily the outputs from the Hipparcos mission and the Hubble Guide Star Catalogue. Mission specific catalogues are generated from the master catalogue. Each mission catalogue is tailored to the specific requirements of the particular mission, for example the restriction to include objects within a certain magnitude range. Also mission specific parameters such as a guide star classification and/or an instrumental magnitude may be added to the star record. In addition SCF provides standard for handling catalogues, such as field of view plotting, generation of density maps and generation of statistics. Within the context of the Star Catalogue Facility project, the opportunity was also taken to develop generic attitude software for the support of missions utilising star sensors

This paper describes the central features of the Star Catalogue Facility and the influence of earlier missions on the SCF design. The paper then demonstrates how SCF has been applied for the Flight Dynamics support of future missions such as XMM, Envisat, Integral and Rosetta

Key Words: Star Catalogue, attitude software

INTRODUCTION

Earlier ESA missions such as EXOSAT, HIPPARCOS, ISO and GIOTTO requiring star data (position, magnitude, proper motion etc.) for on ground operations utilised dedicated star catalogues prepared on an ad-hoc basis either within or outside ESA.

Exosat:

Around the time of preparation for the Exosat mission in the mid-seventies the requirement for a general Star Catalogue Facility was first realised. However, as development of this first star catalogue facility was in parallel with Exosat software development a catalogue to support the Exosat mission was compiled from astrometric and photometric source catalogues provided by the Centre de Donnees Stellaires (CDS) on an ad-hoc basis.

To allow for efficient access to stars in a particular area of the celestial sphere consideration has to be given as to how to organise the star catalogue data. Techniques usually involve dividing up the celestial sphere into areas, which are not necessarily equal, and indexing these areas. The structure for the Exosat star catalogue was to partition that data according to a **celestial cube** structure (RD1) and to organise the catalogue as a direct access file. The celestial cube method first partitions the sphere into 6 equal areas or **zones** defined by the projections of the faces of a cube. Each of these is then further subdivided into N*N areas, where the parameter N is referred to as the **partitioning factor**.

Hipparcos:

The Input Catalogue (INCA), together with a number of annexes, was provided to ESOC by the Hipparcos INCA consortium. From these catalogues an operational catalogue was developed according to the celestial cube structure with various mission specific parameters computed, such as the target observation times, lower and upper minimum observation times. A further off-line process ran daily to derive an ‘extended programme star file’, which contained data required for uplink to the on-board programme star file and also data required for on-ground payload monitoring software. Special programme star files were also generated to support initial calibration activities.

ISO:

For ISO a contract was placed with CDS to provide a catalogue based on the CDS databases and, when available, results from the Hipparcos data reduction. This catalogue contained certain mission specific features; such as a guide star classification scheme based on proximity to disturbing stars according to criteria derived from the properties of the ISO start tracker. This catalogue was processed to produce an operational star catalogue, again structured according to the celestial cube. An instrumental magnitude was derived and the star position propagated to an appropriate epoch. This catalogue was regenerated quarterly.

STAR CATALOGUE FACILITY DESIGN

To standardise the approach to on ground handling of star data it was decided to develop a generic Star Catalogue Facility (SCF) to support future missions.

The facility allows the generation of a master catalogue from a set of source catalogues to serve as a unique reference for generating the mission specific catalogues.

Additionally SCF provides tools for handling catalogues such as graphics and generation of density maps.

SCF also handles ephemeris data for a selected range of solar system objects.

SCF is written in FORTRAN to run on a SUN workstation environment. The man-machine interfaces (MMIs) were developed using the GUItool application from ESOC's ORATOS infrastructure. Graphics were developed using TCL/TK.

Catalogue Data Organisation

The celestial cube method of organising star catalogues used in the earlier ESA mission had shown good performance for operational support and was therefore adopted as the standard for SCF.

For the earlier missions the structure of the celestial cube catalogue was contained within the actual catalogue file as header records. The approach adopted within SCF is to describe the structure of the celestial cube catalogue in a second file: the catalogue definition file. The definition file lists the partitioning factor along with the list of the number of stars in each zone of the cube - this allows for fast access of stars referenced by their position on the celestial sphere. The definition file also lists other general data on the catalogue such as the reference system, epoch equinox and the data fields contained within the catalogue.

Moreover the concept of a definition file is extended to allow the handling of catalogues imported from other sources. For example the definition file for an ASCII catalogue contains a description of which data is contained in the catalogue, which bytes of the input record the data occupies and the units of that data.

The definition file concept allows the handling of many catalogues by the SCF applications.

CATALOGUE DATA FIELDS

SCF defines a number of fields that may be contained in any celestial cube catalogue. Right ascension and declination are compulsory fields as is a magnitude representation. Other fields such as colour, spectral class, constellation, reference numbers, duplicity and variability are options and are included at user request.

CATALOGUE TYPES

A 4 level hierarchy of star catalogues is contained within the Star Catalogue Facility:

1. Catalogues obtained from external sources

The source catalogues considered as input to SCF include: Hipparcos catalogue, Tycho catalogue, PPM catalogues and the Hubble Guide Star Catalogue (HGSC).

Source catalogues are generally ASCII files with a fixed record format. The exception is the HGSC, which is organised as a series of FITS tables.

In order to support the requirements for the XMM optical monitor the SCF design has been extended to also include access to the USNO catalogue.

2 Master catalogue

The master catalogue of stars will contain all the stars within the Star Catalogue Facility and will be derived from one or more source catalogues. Likewise a master catalogue of extended celestial objects is constructed.

3 Mission Catalogues

These will be derived from the master catalogue and will contain a subset of the master catalogue appropriate for the particular mission and may contain mission specific fields

4 Run catalogues

Run catalogues will contain a subset of the mission catalogue valid for a limited period of time and/or containing a limited sky area.

TRANSITION BETWEEN CATALOGUE TYPES

The transitions between catalogue types are shown in Figure 1.

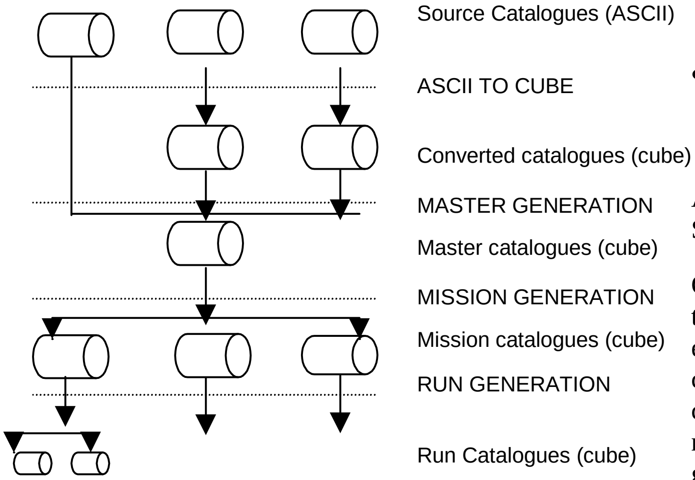

Figure 1 - Transition between catalogue types

ASCII source to Celestial Cube Format

The first step is to convert a source catalogue to the celestial cube format. As with catalogues in celestial cube format, a catalogue definition file, containing standard data such as reference system, epoch and equinox, is constructed for each source catalogue. For ASCII sources the definition file lists the data fields available by using keywords to define data types and for each data type available the units, start and end byte in the ASCII reference and default values must be listed. The standard definition file format allows reading of source catalogues through a single application.

Master Catalogue Generation

Master catalogue generation combines the cube versions of source catalogues. The sources are added one at a time, starting with the catalogues believed to be the most accurate. As each new source added SCF identifies which objects from the source catalogue are already included in the master catalogue and where appropriate the data record for such objects is expanded for each object to include new fields. All objects from the source catalogue not already included in the master catalogue are added as new records.

Mission Catalogue Generation

A mission catalogue comprises a subset of the master catalogue. At this stage additional mission specific or derived parameters may be added:

- instrumental magnitudes based either on a look-up table of instrumental magnitude offsets from visual as a function of spectral class;
- new fields constructed as numerical combinations of any other fields;
- classifications (e.g. guide star classifications) based on the logical combination of expression for field values or proximity to neighbouring objects.

An example of guide star classification possible using SCF is given below:

One classification value could be given to stars brighter than magnitude 6 with no neighbouring stars or extended objects within 200 arcseconds, if this condition is not satisfied a second classification value could be given to stars brighter than magnitude 7 with no neighbours within 300 arcseconds and so on. Such a guide star classification is typically used in observatory missions such as XMM, where the accuracy of a scientific observation is limited by the accuracy of tracking on a guide star.

The subset of stars to be taken from the master catalogue to include in a mission catalogue is defined similarly to guide star classifications, typically stars in a particular magnitude range are included.

A second method of constructing a celestial cube mission catalogue is allowed for - this is when a mission specific source catalogue is provided complete with mission specific parameters. In this case the cube mission catalogue is constructed directly from the ASCII source using the standard SCF application.

Run catalogue generation

A further reduction of stars may be made to include those valid for a particular epoch, by limiting to a specific region of the celestial sphere or ignoring stars close to solar system objects (SSOs) at a particular time. Typically a run catalogue may contain those stars expected to be viewed during a single orbit of an earth observation satellite such as ENVISAT.

Cube to ASCII

A further transition is possible from any cube catalogue to an ASCII file. The ASCII file may contain all or a subset of the source stars defined in an analogous manner to the inclusion of stars in a mission catalogue.

The user may select all or some of the fields for output and define the field length and units.

In fact the ASCII file is produced with a corresponding catalogue definition file and may be further handled by SCF as a catalogue.

OTHER SCF UTILITIES

Catalogue verification

Catalogue verification compares any two celestial cube catalogues, identifying common objects and identifying inconsistencies between the two catalogues. It is typically used to compare an imported mission catalogue with a master catalogue. Tables comparing the positions and magnitude of common stars are prepared and differences larger than predefined tolerances identified.

Statistics

SCF allows the generation of statistics based on the values of one or more fields within the catalogue. The specification for generating a statistic follows the format for generation of mission specific parameters. Any generated statistic may be plotted as a density map.

Figure 2 - SCF Density Map

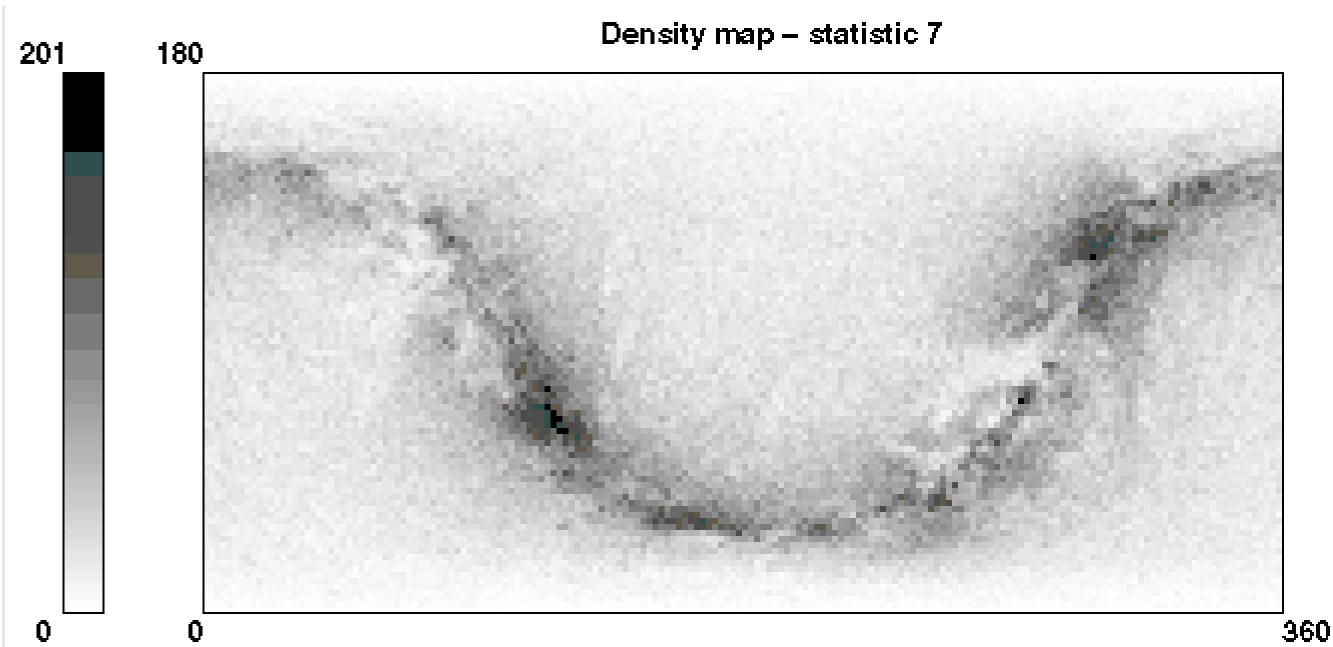

Figure 2 shows a density map for stars between magnitude 10 and 12 from a master catalogue built from the Hipparcos and Tycho catalogues. The galactic plane is clearly visible.

Groups of statistics may be displayed as a histogram. Figure 3 shows a histogram generated from the same catalogue indicating stars in various magnitude ranges

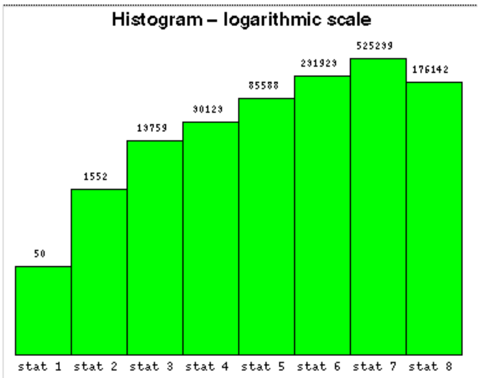

Figure 3 - SCF Histogram

Graphics

The SCF graphics tool allows the user to plot a field of view containing stars, extended celestial objects and solar system objects, taking its input from any celestial cube star catalogue, any celestial cube catalogue of extended objects and a master set of SSO ephemeris. Instrument fields of view may also be plotted..

A suite of subroutines is provided to allow a user to build their own plots tailoring the layout to the needs of specific missions.

A sample plot is shown in Figure 45. In addition to stars, extended objects and solar system objects in a star tracker field of view, the plot shows objects retrieved from telemetry, star tracker blemish an instrument field of view within the star tracker field of view and a raster pattern. The guide star is also identified.

The graphics allow zoom features, the measurement of distance between any two points on the graph and the pop up display of object data on any selected object, an example of which is shown in Figure 4.

GENERIC ATTITUDE SOFTWARE (GAS)

The generic attitude support (GAS) software provides a library of subroutines for use in attitude applications, which make use of star data. The GAS subroutines are derived from applications developed to support earlier ESA missions, such as HIPPARCOS and ISO and are developed to be fully consistent with the ORATOS infrastructure.

For spacecraft where the attitude evolves slowly due to controlled rotation rates a star transit time predictor is developed. Spacecraft of this type include Hipparcos and Envisat. The software is also applicable to 3-axis stabilised spacecraft following closed/open slew between targets (e.g. XMM and Integral)

For three axis stabilised spacecraft the GAS software provides subroutines for star pattern matching, attitude determination and guide star selection. Spacecraft of this type include ISO, XMM and Integral.

The GAS subroutines extend the functionality of the Star Catalogue Facility to provide a reusable library of routines for the development of attitude monitoring and command generation systems to support ESA missions or specific phases of ESA missions

CONCLUSIONS

The first Star Catalogue Facility developed for ESOC was not used for the Exosat mission because of the parallel development of the Exosat software. The next mission, Hipparcos, benefited from the availability of the INCA catalogue for the support of that mission and therefore had no need for a generic facility. The facility was ported from ICL 4/72,to Honeywell Bull,to IBM and finally archived on SUN.

The design for the new Star Catalogue Facility therefore attempted to account for the requirements of anticipated future mission and at the same time built on the experience gained in the operations of the earlier missions. The design was such that the facility can be included in the context of the ORATOS infrastructure for ESOC Flight Dynamics.

The result of this approach was the development of a facility which is both usable by ESOC missions and which is actually being employed to support the preparation of the ground control systems.

Current uses of the star catalogue facility include in support of ESA missions include:

- XMM/ Integralmission catalogue
- Special catalogue for planning observations of the XMM Optical Monitor instrument
- Validation of the Envisat star catalogue
- XMM/Integral Flight Dynamics software
- Rosetta requirements analysis

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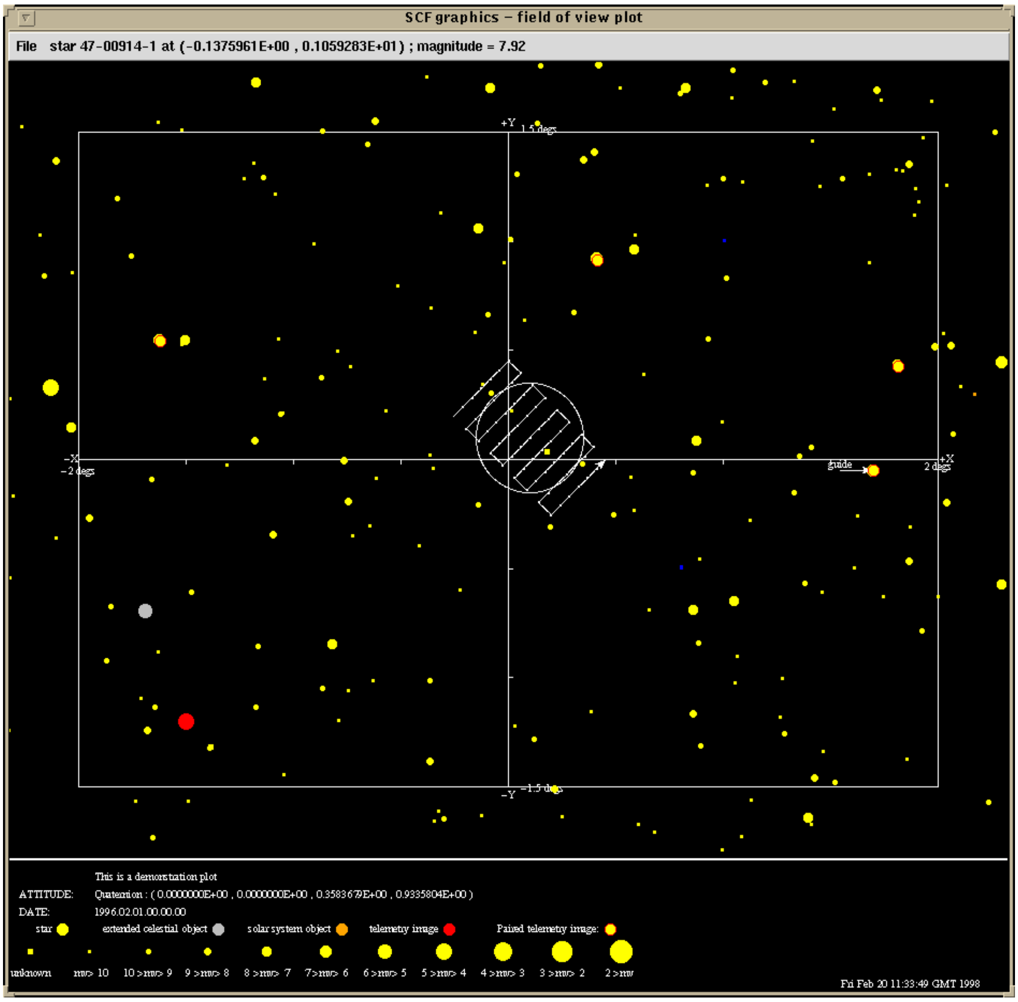

Figure 4 - Typical SCF graphics display with pop-up

SCF graphics – star data

Right Ascension	41.8624039	degrees
Declination	1.0592834	degrees
Position Error	1	arcsecs * 0.01
V magnitude	7.92	magnitudes
V magnitude error	0.02	magnitudes
Magnitude variability flag	F	
Multiple system flag	F	
Combined system flag	F	
Proper Motion Right Ascension	-20	milliarcsecs/yr
Proper Motion Declination	25	milliarcsecs/yr
Proper Motion error	13	milliarcsecs/yr
Parallax	29	milliarcseconds
Hipparcos number	13026	
GSC number	0047-00914-1	
PPM number	145900	
HD number	17397	
Mean magnitude variability	0.08	magnitudes
Minimum/brightest magnitude	8.08	magnitudes
B-V colour	0.53	magnitudes
B-V colour error	0.02	magnitudes
Bt magnitude	8.56	magnitudes
Bt magnitude error	0.02	magnitudes
Vt magnitude	7.98	magnitudes
Vt magnitude error	0.02	magnitudes
local coordinates	(-0.137596 , 1.05928)	