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EXOSAT DATA ANALYSIS FACILITIES IN MILANO

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Abstract

We describe the system implemented at the Istituto di Fisica Cosmica, Milano for the analysis of X-ray data obtained with the EXOSAT satellite.

1. Introduction

The characteristics of the EXOSAT mission are described in Taylor et al. (1981). During early software development phase greater emphasis was given to the treatment of image data obtained with the EXOSAT Low Energy (LE) detectors (Garilli et al. 1985), with the main intent of interfacing with the ESO IHAP package. In the meanwhile two of the authors have been working independently to the Exosat Observatory LE Interactive Analysis system (Giommi & Chiappetti, 1985). Features of both systems have been extensively incorporated in the current implementation. A package for spectral analysis of data obtained with the EXOSAT Medium Energy (ME) detector has recently been developed in house.

The existence of noteworthy differences between X-ray data and astronomical data in other wavebands implies that data analysis packages developed for other branches of astronomy may not be used with full satisfaction for X-ray astronomy (of course also the reverse is true) :

- One point is that X-ray detectors are essentially photon counting devices (and that the number of photons is small). Hence the use of floating point images is not only unneces-

sary but misleading. Measurements are dominated by Poisson statistics: this should be taken in due account during image analysis (e.g. in a source detection program, or to optimize count rate determination). Count rate values (e.g. in spectra or in light curves) should also carry an associated uncertainty and appropriate error propagation (e.g. through background subtraction and other corrections) is vital.

One further point is the complexity of the telemetry stream, certainly true in the case of EXOSAT, where timing and spectral (or timing and image) data are generally deeply intermingled. Although the top layer of the analysis software uses general data structures like 2-d images, 1-d spectra, or time profiles, these must be generated (accumulated) from the telemetry. An automatic reduction procedure is generally not sufficient, it is instead necessary to go back often to the original telemetry through several user controlled iterations.

2. Implementation

The system currently uses the following hardware. All the telemetry filing and data accumulation is done on the IBM-compatible Fujitsu-Siemens 7.865 of SIAM - hereon IBM - under the VM/SP (CMS) operating system. Also most of the ME analysis package runs on the same machine. On the other hand the LE (image) analysis package (and the graphics for the spectral package) are implemented on the Hewlett Packard 1000 F (under RTE 6) of the Istituto di Fisica Cosmica - hereon HP. The HP is equipped with a Ramtek CDU and an HP 7550 plotter.

The languages used are Fortran 7X on the HP and VS Fortran on the IBM, both based on the Fortran 77 standard.

The software is structured in a number of (small) modules, which are generally individual programs. Although most of the modules will ever run on one only of the two machines, care has been put in ensuring some degree of compatibility in the code . The use of system specific calls is kept to a minimum, and generally done through a master scheduler program (on the HP) or directly through CMS via EXEC procedures (on the IBM).

No attempt has been made to write a common software layer for service functions (file editor, on-line help, etc.). The individual operating system utilities are used instead. E.g. the on-line help uses the CMS HELP facility (on the IBM) or makes programmatic use of the HP CMD utility.

A particular effort has also been put in the off-line documentation, in the form of an extensive Users' Guide (Chiappetti & Garilli, 1986) and of a Programmers' Reference (mainly consisting of software documentation sheets).

Each software module, corresponding to an elementary process, is invoked via a **command**, optionally followed by a parameter list (**command string**). On the HP system (modified from the Exosat Observatory original) commands are processed by the master scheduler (a few of them are actually executed within the latter, in most other cases an independent program - which generally could and often will be run on its own - is scheduled). On the IBM commands are EXEC files which interface with CMS and contain system commands or execute, when appropriate, an absolute program.

The individual modules receive and parse the command string (this is done on the HP via the RHPAR system utility, and on the IBM using the console stack). The subroutines to do this were originally developed by two of the authors for the Exosat Observatory (HP based) system; a package to emulate them on the IBM has been written later in house.

3. The interactive command syntax

Three basic levels of interactivity are available for all commands, together with their combinations.

- In the simplest mode (the beginners' mode) no command string is used. The program, invoked by name, prompts the user for all parameters needed in a straight **interactive** way. E.g.

```
ROTATE
```

- On the other hand all parameters may be passed in the **command string**, or even only some of them. Any missing parameter will be prompted interactively as above. E.g.

```
ROTATE,,IMAGE,NEWFILE,19,56,28.9,+35,3,55.,270,0,0
```

- For commands with long parameter lists, it is generally easier to write the parameters in a **command file** (which is itself passed as an argument in the command string). This is similar to the beginners' mode (actually the terminal is treated just as one kind of command file !) but the program then runs automatically with no further interaction.

ROTATE,CFILE

where the command file CFILE contains for instance :

IMAGE	The input image file name
NEWFILE	The output image file name
19,56,28.9	The center RA of the output image
+35,3,55.0	The center declination
270,0,0	The roll angle of the output image

It is also possible to combine use of a command file and a command string (advanced users' mode). The command file may contain default values or standard setups, and the command string only the parameters to be overridden. E.g.

ROTATE,DEFAULT,IMAGE,NEWFILE

(where the command file DEFAULT contains all blanks) will rotate IMAGE into NEWFILE using the standard defaults (same centre and roll angle as input image).

Finally it is possible, using a special character in the command file, to cause a parameter to be read from the terminal even when using command file **and** command string. This is useful to customize a standard setup, without having to retype (with the risk of errors) the whole string.

All the above modes, combined with the possibility of executing **batch macros** (i.e. files containing sequences of complete commands, including other macros), makes the system both simple to use and friendly for the beginner, and very effective to test complex procedures interactively and then execute them repetitively in batch mode.

4. Available functions

All functions related to telemetry data reside on the IBM (where a larger disk space is available). The functions common to all EXOSAT experiments include : filing telemetry tapes (FOTs) to disk, listing the observation directories, accessing Housekeeping (HK) telemetry data - including accumulation of HK time profiles - , saving reduced data to tape (for backup or transfer to the HP when needed).

We term data **accumulation** the process of extracting **reduced data** (images, spectra, etc.) in a standard (experiment-independent) format from telemetry data. The relevant functions are : accumulating LE images and sum signal histograms, accumulating ME spectra and light curves, accumulating HK time profiles and attitude error profiles (deblur files).

A number of the LE analysis functions (on the HP) are experiment independent (they include image display with different thresholding, smoothing, rebinning, contouring, image rotation, operations on images etc.). Additional modules are available for the management of the Ramtek CDU (colour tables, etc.), tape input/output and ancillary tasks (spool file control, image header handling, etc.). In other modules the experiment specific part (e.g. the instrument Point Spread Function or effective area) is generally well isolated and could be replaced : this is the case of the modules for source detection, PSF generation, source statistics (count rate determination), spectral analysis of multi-filter observations and pixel to celestial coordinate conversion.

The same criterion of experiment-independence holds for the ME spectral analysis package. Actually the only experiment-dependent functions are the generation of the detector response matrix and the calculation of dead time correction coefficients from HK data. All other data reduction (algebra on spectra and light curves, dead time correction, display, rebinning in time and energy, truncation and "editing" of spectra) and data analysis (chi-square spectral fitting, production of chi-square grids, convolution of spectral forms) modules actually constitute a general-purpose X-ray spectral analysis package.

5. Data file structure

The inspiring criteria in the definition of the layout of the data files have been: they should appear natural, be simple to use, and as portable as possible, even when all that causes a slight loss in efficiency.

The types and layout of data files have been defined according to a criterion of simplicity. The following main types of reduced data are produced and used by our system: images, spectral files (actually a time sequence of one or more spectra), light curves (including HK time profiles), response matrices. In addition a few more types are used by dedicated modules, like sum signal histograms, attitude time profiles, time windows and channel masks for spectra.

For portability's sake, whenever possible or sensible, all values are in standard 16-bit integer binary format. In the header records a few 32-bit integers are allowed. On the other hand, for simplicity, floating point binary format is used when dealing with count rates (spectra and light curves). However, when 32-bit integers or reals are used in conjunction with 16-bit integers, care has been given to a neat alignment of the fields in the record.A general purpose layout (formatted) is used to transfer floating point data between different machines (e.g. for graphics) and for small ancillary files (time windows, etc.).

All data files incorporate one or more header records, containing information on the target and on the file characteristics.

Images represent the more natural data structure : they are stored on disk in binary integer format, one row per record, with as many data records as rows in the image. A single data record is enough for sum signal histograms. Time windows or channel mask files (used to rebin a spectrum) are free-format files, which can be handled by the system editor. Spectral files have a more complex structure: they are sequences of couples of records (one for the count rate vs channel, and the other for the associated error), each one with its own epoch and exposure; channel boundary records terminate the sequence. A similar complexity is present for light curve files (mainly for reasons related with dead time correction). Response matrix files include all elements (efficiency, resolution, acceptances, escape fractions, geometric factors, area etc.) necessary for a convolution in a (floating point) array: there is one row for each channel, and as many columns as points on an arbitrary energy grid.

References

Chiappetti L. and Garilli B., 1986, The IFCTR Exosat Analysis System. Users' Handbook. Rapporto Interno IFCTR N.1/86

Garilli B., Mussio P. and Rampini A., 1985, Data Analysis in Astronomy (Erice, 1984)

Giommi P. and Chiappetti L., 1985, The LE Interactive Analysis System Users' Guide. Exosat Observatory Internal Report.

Taylor B.G., Andresen R.D., Peacock A. and Zobl R., 1981, Space Sci. Rev., 30, 479