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The *INTEGRAL* Ground Segment

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Abstract. *INTEGRAL*, the gamma-ray observatory of the European Space Agency, was launched on October 17, 2002. Since then, nominal operations are conducted very successfully and scientific alerts and products are made available to the science community with a short delay. Here we briefly describe the 3 centers responsible for the *INTEGRAL* operations, emphasis on the system built at the *INTEGRAL* Science Data Centre and conclude on the performance of the ground segment.

1. Introduction

INTEGRAL was successfully launched by a PROTON rocket from Baikonour on October 17, 2002. During the Launch & Early Orbit Phase (LEOP) the final orbit of 72 hours was reached and most of the spacecraft platform functions commissioned. The scientific payload was then switched on, commissioned, tuned and partially calibrated within the allocated time so that routine science operations could start, as planned, in the last days of 2002.

The status and performance of the satellite (platform and payload) is good. All prime equipment is still used. The on-board resources are efficiently used providing the option to extend the mission for many years beyond the nominal mission phase of 2 years. The mission has been extended to December 2008.

The *INTEGRAL* mission is heavily used, i.e. observation proposals replying to the first announcement of opportunity, re-quested 19 times more exposure time than available. Therefore the ground segment is in charge to use *INTEGRAL* efficiently and to optimize the scientific return of the mission.

The science operations are very demanding. Due to the design of the payload, the spacecraft attitude is for example to be changed every 30 minutes, which requires a very automated ground segment. The Telemetry that is received continuously from the satellite and auxiliary data are to be processed in real time and have to be distributed within the various centers of the ground segment.

The operations of the *INTEGRAL* mission are split between 3 centers. The *INTEGRAL* Science Operation Centre (ISOC, located in ESTEC, Noordwijk, The Nederlands) derives the sequence of observations to be executed from the accepted proposals. Those sequences are converted to operational timelines by the Flight control team at the Mission Operation Center (MOC, located in ESOC, Darmstadt, Germany) and are used to control the satellite. The MOC also monitors the satellite safety and health using the TM data. TM and appropriate auxiliary data are forwarded to the INTEGRAL Science Data Centre (ISDC, located in Versoix, Switzerland). The ISDC analyze the TM on different time scales and produces and distribute science alerts and data products to the scientific community.

2. The *INTEGRAL* Mission Operation Centre

The *INTEGRAL* flight operations are conducted from the Mission Operations Centre (MOC). The two prime ground stations that ensure real time contact with the satellite 68 hrs out of the 72hrs orbit are the ESA station in Redu, Belgium, and the NASA station at Goldstone, California.

The MOC uses generic infrastructure that is provided by the European Space Operation Centre (ESOC). The routine operations are highly automated. In order to operate the satellite in the most efficient way new S/W tools have been applied for the first time: the S2K infrastructure for the monitoring and control system and the new Space Link Extension (SLE) protocol for the interface to the NASA ground stations at Goldstone.

3. The *INTEGRAL* Science Operation Centre

The main role of the *INTEGRAL* Science Operations Center, is to put together an observation program based on submitted proposals. For each revolution ISOC provides to the MOC a timeline of what targets are to be observed with which instrument settings. To put together a schedule is a complex task. Besides the proposals themselves the planning process takes into account e.g. proposal priority, target visibility and spacecraft constraints, efficiency, i.e. minimizing the times spent in slewing.

The ISOC systems supporting proposal capture, handling and scheduling are centerred around an ORACLE data base. All ISOC software is written in JAVA. The ISOC proposal generation and submission is unique. All proposers need to generate their proposals using a downloaded JAVA application. All proposals are prepared locally and when ready they can be submitted using the same application. The sending of a proposal only takes seconds of load on the ISOC system which fully supported the heavy peak load and avoided an inevitable bottle neck that always occurs before a proposal submission deadline.

4. The *INTEGRAL* Science Data Centre

The *INTEGRAL* Science Data Center receives the telemetry, broadcasts gamma-ray burst alerts in real-time, monitors the status of the scientific instruments, searches for new and transient sources within some hours of the observation, performs a standard analysis of the data, archives 2 TB of compressed data per year and distributes them to the scientific community with analysis software.

The ISDC is provided to the mission by the scientific community through a consortium led by the Geneva Observatory. The ISDC staff increased from 2 in 1995 to about 40 people at launch. The software and hardware systems were built and integrated locally following the ESA quality standards. A large fraction of the analysis software was developed by the teams providing the scientific instruments.

Several key design decisions were made early in the ISDC project:

- Use only FITS as data format (most data files are compressed);
- Keep all data on-line on hard disks;
- Control all interfaces using IRAF parameter files and the data format of every FITS extension through CFITSIO template files.
- Build each analysis step with a standalone executable (FTOOL concept);
- Customize a public domain and modern environment (CERN's ROOT) to develop analysis scripts and applications (Rohlfs et al, this volume);
- Use OPUS developed at the STSCI to control the processing flow (Beck et al, this volume);
- Use a single and solid operating system for operations (SUN/Solaris) but port the analysis software on Linux as well;
- Use HEASARC's W3Browse as archive interface and distribute all data through the internet (Meharga et al, this volume)

The *INTEGRAL* data model and implementation has been developed to allow performing scientific analysis with thousands of different datasets without the need for a DBMS. As *INTEGRAL* spend a considerable fraction of the time dithering around the target that is being observed, about a hundred pointings or slews are performed every day and a new dataset is created for each of them. Those datasets could be grouped in an arbitrary way for scientific analysis. The FITS grouping convention has been extensively used (O'Neel et al, this volume) to build observation datasets and various indexing tables in the data themselves.

Several key applications have been developed:

- A library of tools to receive and broadcast CCSDS telemetry and to wrap it to FITS format.
- A real-time multi-threaded system made of several concurrent and communicating processes to extract the relevant information from the telemetry, search for gamma-ray bursts using various algorithms in the data of the different instruments, filters the triggers and broadcast gamma-ray burst alerts over the internet.
- An application to decomute the telemetry and store the complete information in FITS format. The decomutation is data driven (by the SCOS 2000 database) for the decoding of the housekeeping telemetry and code driven for the scientific telemetry (Morisset et al, this volume).
- Several pipelines have been written to handle data sets derived from the telemetry as well as auxiliary files.
- A set of portable graphical user interface to browse, display and perform simple analysis of the data and of the results of the scientific quick-look analysis (Lerusse et al, this volume).
- A set of analysis scripts (including user interface, Beck et al, this volume) including the scientific software modules written by the instrument teams. Those scripts are used with standard parameters for automated analysis and are also distributed to the scientific community for offline analysis.
- An archive, indexing and distribution system used to ingest, store and distribute on line all *INTEGRAL* data (Meharga et al, this volume).

In addition a number of tools have also been developed to manage software deliveries, configuration and automatic testing (Beck et al 2004). The software was built as much as possible mission independent and several parts are currently being reused for the Planck mission (Tuerler et al, this volume).

5. Conclusions

The performance of the ground segment meet the mission requirements based on the expectation of the scientific community.

- The planning overhead have been minimized such that more than 96% of the available time is used for scientific observations.
- Replanning (e.g. in case of a TOO observation) were scheduled in less than one revolution. The AO-1 observation program will be completed within the first year of operation, as planned.
- The accuracy of the mission auxiliary data necessary for science analysis mission exceed the performance requirements.
- Gamma-ray bursts alerts are broadcasted on the internet within 30 seconds. 13 new gamma-ray sources have been detected in the galaxy and announced often within one day, which generated about 60 IAU circulars or astronomical telegrams.
- Real time data have been made available to observers within 3 hours. First public data have been made available in the archive 2 months after the end of the performance-verification (PV) phase. First data resulting from the standard analysis together with analysis software were distributed to observers 3 months after the end of the PV phase.