LEGRI SCIENCE OPERATION CENTRE AND SCIENTIFIC PROGRAM.

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ABSTRACT

The Low Energy Gamma Ray Imager (LEGRI) on board the first MINISAT mission, is a telescope with imaging capabilities working in the 20-100 KeV spectral region.
The main goal of LEGRI is to perform a galactic survey in order to observe compact objects like black hole candidates, neutron stars, pulsars and high mass X-ray binaries. By considering LEGRI sensitivity, integration times from 10^5 up to 10^6 seconds will allow to observe a total amount of ≈ 40 galactic objects. Furthermore, a few extragalactic objects (high luminosity X-ray binaries on the Magellanic Clouds and AGN) are expected to be observed.
The pointing of the instrument to the objects of interest is one of the responsibilities of the LEGRI Science Operation Centre (SOC). The LEGRI SOC is a structure which contains typical elements of a scientific operation centre as well as those of a scientific data centre.
In this paper a brief description of the LEGRI observational goals is presented together with the implementation of the different SOC tasks .

1.- LEGRI OBSERVING PROGRAMME

LEGRI is a PI class instrument and consequently target selection and observing time allocation is a LEGRI Science Team responsibility. For the definition of the LEGRI Observing Program we need to take in to account the constraints imposed by the instrument performance and operational characteristics of the MINISAT-01 platform.

First of all we need to consider that MINISAT-01 must point continuously towards the Sun, with LEGRI mounted so that is viewing direction is orthogonal with respect to the Sun-axis, so it is only possible to rotate the satellite around the Sun-axis during observations. For each orbit, only an 11° strip of sky will be observable. Another constraint on the OP definition is that the LEGRI observing schedule is shared with a second instrument on the MINISAT-01 payload – EURD – which has 1/3 of each orbit assigned (during sun eclipse), so LEGRI has only 2/3 of each orbit available to operate. Finally, we need to take into account that the MINISAT-01 will only be tracked from a single tracking station (Maspalomas in Canary Islands) having three contacts in nearly successive orbits each day, and it will only be possible to re-point LEGRI once per day.

Due to all these factors, our real observing capabilities amount to one pointing each day at a region of sky of width 11° longitude, and a useful observing time of 12 hours/day. These operational limitations do not restrict the potential capabilities of LEGRI too severely, because the minimum expected observing times for the majority of potential targets is 10*5 seconds. This implies at least 2 days of continuous observation for each field.

The last consideration concerns the very poor pointing characteristics of the MINISAT-01 platform: 3° uncertainty. This pointing error, combined with the intrinsic uncertainties in the deconvolution process, means that to provide a unique sky location of the target(s), a succession of observations is needed with the source located in different positions on the LEGRI field of view We plan to maintain the pointing within a given field for a few days such that the targets drift by 1° per day (Earth translation speed) across the field of view.

Putting everything together, the Observation Program objective will be to maintain LEGRI pointing continuously towards the Galactic Plane, and scan it regularly at a speed of 1° per day. In this way, the whole Galactic Plane will be completely scanned once every 6 months with all the bright point sources being observed for 5 x 10*5 seconds during this period. From a purely imaging point of view, and for stellar fields having more than 1 emitter, uninterrupted pointing over 11 days with the sources moving continuously across the field of view, will be sufficient to unambiguously solve the source confusion problem. Clearly it will also be possible to perform variability studies on temporal scales of less than 11 days.

This is an observational programme which is easy to implement, and in good agreement with the platform operational constraints and LEGRI imaging capabilities. Exceptions to this observing programme will consist of selective pointing to targets of opportunity, or to other interesting emitters located outside the galactic plane and sufficiently bright to be observed with LEGRI within reasonable observing times. Examples could be two or three sources within the Magellanic Clouds and possibly some AGN. Special attention will be paid to the Crab Pulsar for calibration purposes.

During the two years of MINISAT-01 nominal life-time we plan to observe the continuum of around 40 point source emitters in the 20-100 KeV energy band. The low energy resolution of LEGRI prevents us performing line observations, reducing the spectral capability to relatively wide spectral bands (one or more tens of KeV, depending on the energy). Although the individual detectors tested with laboratory electronics present very promising spectral resolution (typically 8% at 30 KeV for HgI_2), when coupled to the flight electronics and working together, their energy resolution drops by some 30 – 40%. With these limitations, LEGRI will work more like a photometer with two or three bands than a true spectrometer.

Despite the LEGRI limitation of observing continuum fluxes in wide bands a useful information concerning high energy extensions of the observed X-ray tails should be collected. For variable objects, the investigation of their variation on different temporal scales could provide valuable information about the dimensions of the emitting regions and their internal structures.

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2.- LEGRI SENSITIVITY

The low flux levels of the celestial γ-ray sources and the high radiation environment encountered by gamma-ray telescopes on board satellites cause the measurements performed by these instruments to be background dominated. In this sense, how to reduce the background noise in order to achieve the high values of resolution and sensitivity required in present missions, constitutes the main problem of Astronomical research in the γ-ray domain.

The sensitivity evaluation of a satellite-borne γ-ray telescope is a complex problem due to the wide range of background sources that may affect the measurements. Among all the background noise sources, proton interactions within the detector and surrounding materials by means of "spallation" reactions have demonstrated to be one of the most important [1-5]. The high energy of trapped and cosmic protons allows to generate a large amount of unstable fragments of the target nuclei whose decay, often delayed, produces a very important fraction of events that cannot be distinguished from the "real" events.

Here, the background component due to protons has been calculated in two steps: first the calculation of the proton-induced radioactivity has been performed by means of the GEANT/GCALOR [6] simulation package (compared before with experimental results showing a good agreement [7,8]) and then, the background due to the emission of the unstable isotopes has been estimated by using the GEANT-3 Montecarlo simulation code [9].

In order to obtain the proton-induced unstable isotopes the GEANT/GCALOR package has been used in each material involved in LEGRI except the mask. The simulation has been performed by using protons of:

- 150 MeV, that represents the mean energy of proton flux in the range 100-500 MeV which is dominated by trapped protons (5.6 p s^{-1} s^{-1} cm^{-2} sr^{-1} averaged over a day) due to the pass of LEGRI orbit through the South Atlantic Anomaly (SAA)
- 1.0 GeV corresponding to the weighted mean energy of protons in the range 0.5-3.0 GeV with a flux of 0.5 p s^{-1} s^{-1} cm^{-2} sr^{-1}
- an energy distribution (αE^{-2}) in the range 3.0-8.0 GeV with 0.1 p s^{-1} s^{-1} cm^{-2} sr^{-1}

Protons with energies below 100 MeV have not been considered here since spallation reactions are negligible in this range [10].

After having obtained the proton-induced unstable isotopes, the radioactivity spectra due to their decay has been calculated at a different moments of the mission. The prompt contribution of the trapped protons has not been included since LEGRI will not be operational during the transit through the SAA.

Finally, the background spectra have been calculated by using the radioactivity spectra, the efficiency of the 10x10 detector array and LEGRI geometry by means of the GEANT-3 simulation code.

The estimated spectrum of the proton-induced background 1 year after the launch (averaged over a day) can be seen in Figure 1 together with that due to the cosmic diffuse gamma-rays separated into the shield leakage and aperture components. A comparison between these components shows clearly that the dominant contribution comes from the proton-induced background

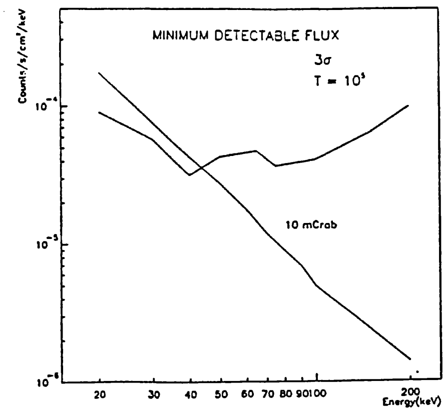

Fig.1. LEGRI background noise spectrum generated by the decay of spallation products induced by protons (one year after launch and averaged over a day) and cosmic diffuse γ-ray flux through the shield (leakage) and aperture.

Once obtained the proton-induced background noise, the on axis continuum sensitivity of LEGRI telescope has been estimated by means of the next expression [11]:

$$F_{min} = \frac{n_\sigma}{\varepsilon A T \Delta E (1-\theta)^2}\left(n_\sigma(1+\theta) + \sqrt{n^2_\sigma(1+\theta)^2 + 4BAT\Delta E(1-\theta)^2}\right)$$

where:

F_{min} : minimum detectable flux (phs^{-1}cm^{-2}KeV^{-1})
B: background (countss^{-1}cm^{-2}KeV^{-1}) (proton-induced + cosmic diffuse γ-ray flux contribution)
n_σ : statistical significance in standard deviations
A: detector area
T: observation period
ΔE: bandwidth (assumed to be E)
ε: gamma-ray total detection efficiency
θ: mask leakage

The calculations of the sensitivity have been performed by assuming n_σ= 3, T = 10^5 s (typical duration of LEGRI observations) and the background B equal to the sum of both proton-induced and cosmic diffuse γ-ray flux components. This sensitivity is shown in Figure 1 in comparison with the Crab emission (10 mCrab). It can be seen that the estimated sensitivity of LEGRI, around 7.5 mCrab at 30 KeV, will allow to observe a significant fraction of the well-known hard X-ray and soft γ-ray celestial sources.

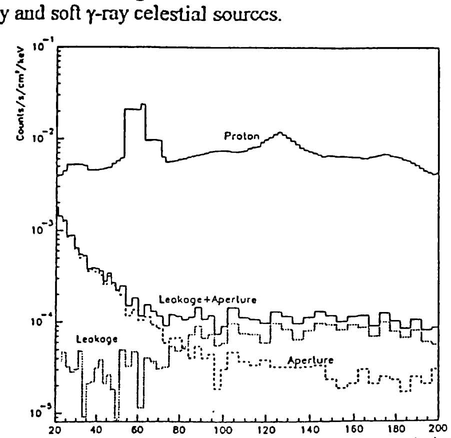

Fig.2. LEGRI sensitivity taking into account the background due to both cosmic diffuse γ-rays and trapped and cosmic protons.

3.- SCIENCE OPERATION CENTER (SOC)

The Science Operation Centre is the single contact point between the LEGRI collaboration and the MINISAT-01 "Centro de Operaciones Cientificas" (COC) located at Villafranca del Castillo (Madrid). The main SOC tasks will be the implementation of the Observing Plan decided by the LEGRI Science Team and the reception of the data files provided by the COC. The raw data will be stored and pre-processed at the SOC, which will establish the basic calibration files and deliver the data to the different scientific working groups defined within the collaboration. The SOC in collaboration with RAL, will also process the LEGRI Star Sensor data to obtain the fine pointing of the instrument. Historical archiving activities are also SOC responsibility.

3.1.- The SOC Interfaces

The LEGRI SOC has interfaces with the MINISAT-01 COC, the LEGRI Science Working Groups, the LEGRI Science Team. (See Figure 3)

The COC - SOC Interface

The Science Operation Centre (COC) of MINISAT-01 is the interface between the instruments and the Mission Control Centre at INTA main site. Its main tasks are to receive the telemetry data from the MCC, create the data files for each instrument and build the instrument configuration commands for uploading to the satellite.

The information that the COC will provide to the LEGRI SOC will be:

- Raw science data produced by LEGRI. These will include the detector, star sensor ,and house-keeping data.
- A selection of satellite data: spacecraft and instrument health status; attitude, orbit and timing information; orbital predictions, time allocation and command history.

From its side, the LEGRI SOC will provide to COC:

- The observing programme. This will consist of a global programme which will detail the main scientific targets in the long term, and the short term observing plan (weekly) which will contain the detailed command sequences to be up-linked to the satellite.
- Fine pointing correction requests to ensure proper centring of the observed sources.
- Pointing to Targets of Opportunity (TOO).

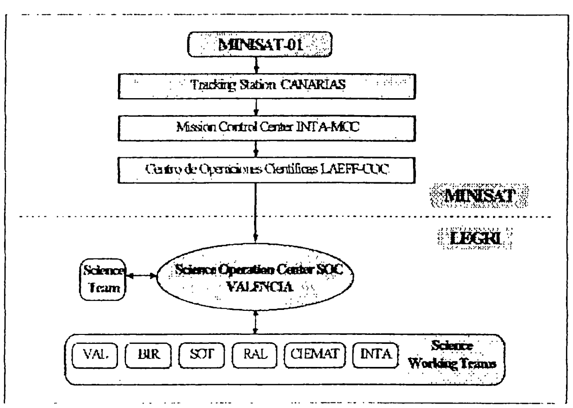

Fig.3. SOC Interfaces

The SOC - Science Team (ST) Interface

The Science Team is made up of a Principal Investigator and a Co-Investigator from each participating institution, i.e. 6 in total. Their responsibility is the definition of the Observing Program and the provision of observation requests to the SOC. Orbital predictions, observing capabilities (including observing time available for LEGRI) and information about possible Targets of Opportunity found after the imaging process will be provided to the ST.

The SOC - Science Working Groups (SWG) Interface

Investigators from the different institutes of the LEGRI Consortium will form SWG to analyse the data and produce scientific outputs. The SOC will provide the raw data, processed images, pointing reconstruction data and all the relevant information requested by the SWG. The SWG will provide to SOC the software and calibration improvements and the final processed images for the historical archive.

3.2.- Tasks and Responsibilities

Due to the innovative character of the mission, the LEGRI SOC has a mixed structure. It contains the typical elements from a Science Operation Centre and a Science Data Centre. These elements are (see Fig.4):

- Reception of the raw data and the other relevant information from the COC via an Internet link, and their archive for safety. The expected amount of raw data for archival is about 10 MByte/day.

- Pre-processing of the raw data: which consist of telemetry packets of 1024 bytes comprising science data, Star Sensor data and house-keeping.

- Processing of the house-keeping data for instrument health monitoring and to detect unusual observing conditions. Out-of-range parameters will generate alerts to COC within 24 hours of the observations.

- Implementation of the software and procedures for the Star Sensor data analysis and provision of the pointing reconstruction.

- Definition and execution of the ground and in-flight calibration procedures, development of the calibration software and maintenance of the calibration files.

- Definition of imaging reconstruction software and quick-look processing of the science data. This process is near real-time, because the turnaround time must be less than 24h. This information is useful to test if the objectives of the mission are being achieved, and for any necessary fine pointing corrections. It also could give the opportunity to detect TOO (Gamma ray bursts, novae outbursts...), so that the necessary modifications to the Observing Plan can be made to observe them.

- Implementation of the Observing Plan by building the detailed configuration command sequences.

- Provision of useful data and general information to the SWG to carry out the analysis of the data.

- Maintenance and management of the LEGRI data base.

- LEGRI historical archive.

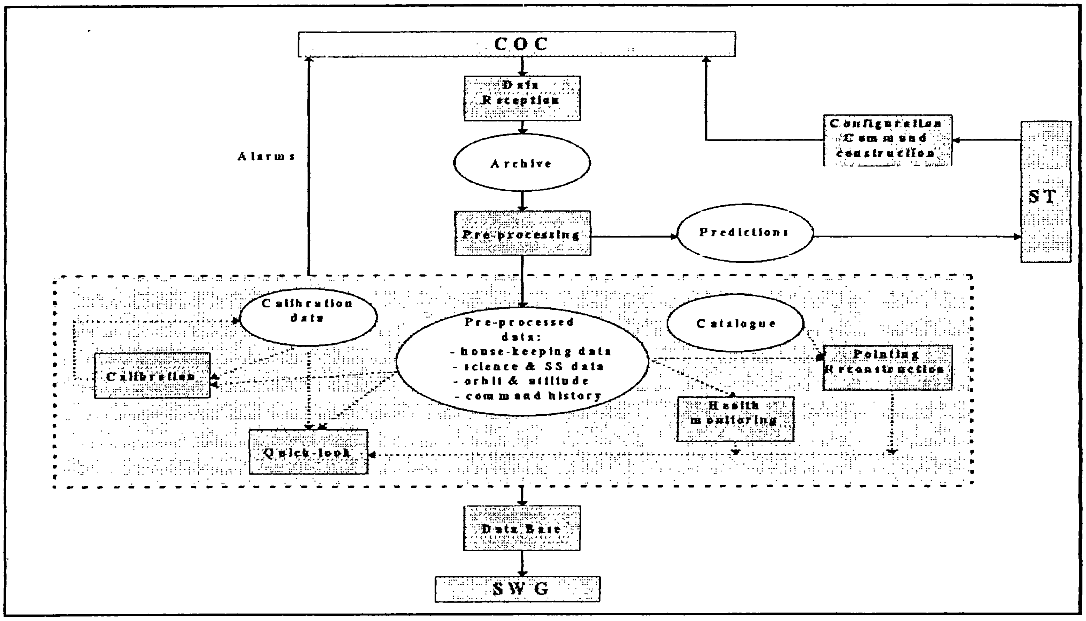

Fig. 4. SOC Flow Diagram

3.3.- SOC Architecture

The main requirements that must be accomplished by the SOC are security, capability, flexibility, accessibility. To achieve these requirements the hardware components selected are:

- Two workstations (WS) SUN Sparc 20 (a master and a slave) each with 64 MB of memory, 1 GB of internal disk, 8.4 GB multi-disk pack, a 20" colour monitor.
- A local link between the two WS.
- An Ethernet connection and access to the Internet to establish normal data exchange.
- A high speed modem as alternative link to the usual COC link.
- 1 GB Magneto-Optic disk (M-O disk) to receive daily incremental backups.
- An uninterrupted Power Supply with capacity of two hours of autonomy.

Other useful I/O components are also available such as a laser printer, a CD-ROM and a 150MB magnetic tape.

The machines run under the Solaris 2.4 operating system and have several useful standard astronomical packets installed (e.g. DIPSO, IRAF, STARLINK etc.) for data analysis. The codes developed at the SOC have been implemented in a modular way so that improvements can easily be made. Access to the data will be through a Web database which will be designed with security permissions built in.

The LEGRI SOC is located at the University of Valencia in a new laboratory facility build for INTEGRAL and LEGRI projects.

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