20th Annual AIAA/USU Conference on Small Satellites
General Architecture of ECLAIRs Microsatellite

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ABSTRACT : The ECLAIRs mission is part of CNES Myriade micro satellite family, and has been selected at the end of 2004 for a launch scheduled in 2009. The development of satellite reached the end of phase A in the first trimester of 2006. The scientific objective of the mission consist observing and characterizing in several wavelengths Gamma Ray burst, to localize them and to alert in real time a ground station network in order to allow ground based telescope to observe the burst's afterglows.
The payload is composed of a set of two instruments : a X-ray/g-ray camera (CXG) developed by CEA that will detect and characterize gamma bursts and a Soft X-ray camera (SXC) developed by MIT that allows to increase the precision/accuracy in gamma ray burst localization.

ECLAIRS MISSION OVERVIEW

General Context

ECLAIRs, is a space mission in universe's science program proposed by CEA (French Atom Agency). In 2005 CNES Scientific Program Committee authorized to start a feasibility study of the mission (phase A). This mission is developed in the frame of the scientific missions exploiting the MYRIADE micro-satellite product line[1]. The development of the MYRIADE product line has started in 1999 under the lead of CNES. The design of the micro-satellite line is a compromise between high performance, efficiency, robustness and cost. The architecture of the satellite is based on a platform (Figure 1) with generic functional chains (AOCS, Energy, Communication, Computer, Structure, Thermal Control), and on a decoupled payload located on the upper part of the platform structure.
The MYRIADE platform is compatible with Ariane 5 Structure for Auxiliary Payloads (ASAP) and DNEPR launch interfaces.

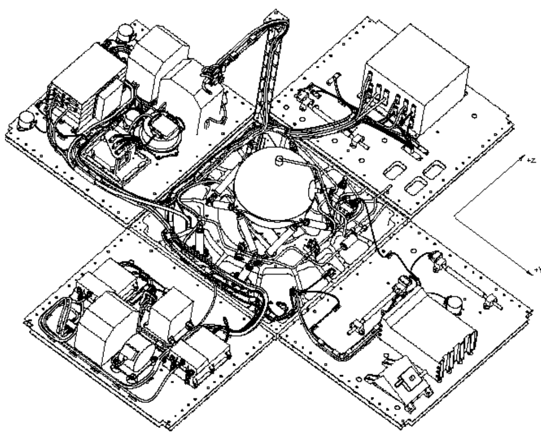

Figure 1 : Myriade plateform

The first mission using Myriade platform has been the scientific and technological satellite DEMETER[2] dedicated to the study of ionospheric electrical and magnetic disturbances in connection with a seismic activity.
DEMETER (Figure 2) has been launched in June 2004 and is still in operation.

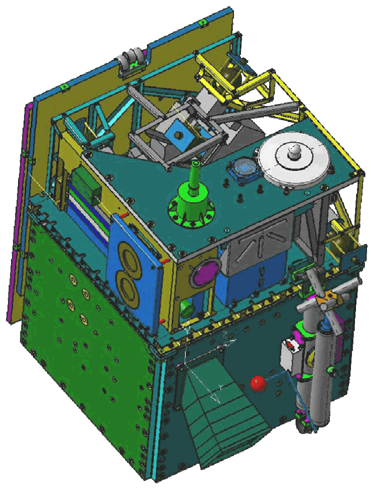

Figure 2 : DEMETER Microsatellite

DEMETER has been followed by ESSAIM and PARASOL[3] developed by ASTRIUM and launched in December 2004.
Today, 8 additional microsatellites of the Myriade family are under development by CNES or by French industries.

ECLAIRs Mission Scientific Objectives

The scientific objective of the mission[4] is the observation and characterisation of Gamma Ray Bursts in several wavelengths, to localize them and to alert in real time a ground station network in order to allow ground based telescopes to observe the burst's afterglows.
Gamma Ray Bursts (GRB) are one of more energetic events in the universe; the prompt emission has been observed for the first time in the 1967 by the and the afterglow emission in 1997 by the Beppo-Sax satellite.
They are usual events (more than 2500 have been observed since 1967) and they are randomly distributed in space (Figure 3).

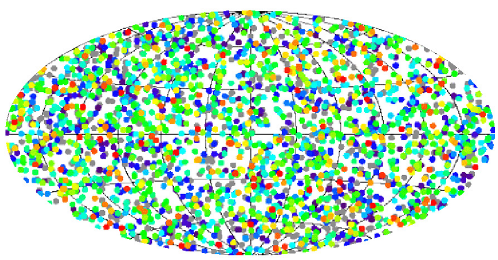

Figure 3 : γ-ray bursts distribution

GRB are characterise by a very heterogeneous behaviour : their duration could vary between few thousandths and several hundreds of seconds, their time histories are very dissimilar and their emission cover many wavelengths from visible band to hard γ-ray band.

Nevertheless they could be separated in two categories (Figure 4) :

- Short GRB, called also "Hard GRB" : They are characterise by a prompt emission with a life time less than 1-2 seconds; and an emission concentrated in high energy band (> 10 keV).
- Long GRB, called also "Soft GRB" : They are characterise by a prompt emission with a life time more than 10 seconds; and an emission concentrated in soft X-ray energy band (< 10 keV).

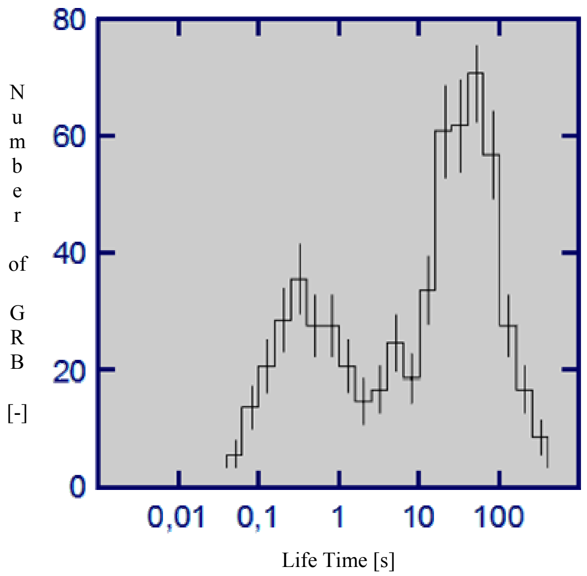

Figure 4 : GRB life time distribution

The mechanism that generates the GRB is not well known; the most plausible theory associates GRB to the death of stars (Figure 5).

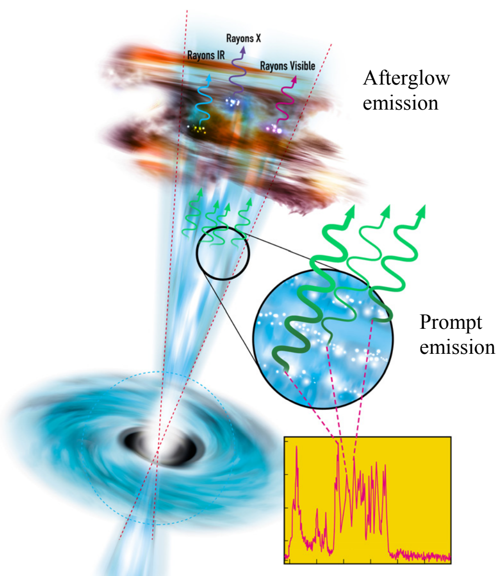

Figure 5 : origin of GRB

The end of massive star is characterised by the gravitational collapse of its core, during the collapse some matter is ejected in a particular direction.
The collisions inside the relativist wind generate the prompt emission observable in visible, X and γ bands.
The interaction between the ejected matter/prompt emission and the cosmic matter generates the afterglow emission observable in near infrared, visible and X band.

The observation of prompt emissions before, during and after the GRB in several spectral bands will help high energy physics to understand the origin of GRB.
The observation of afterglow emissions and the measurement of the redshift will allow observing the birth of the first generation of stars.

The main requirements of the ECLAIRs mission are resumed in Table 1.

To detect more than 200 GRB of any type (i.e. either short and long)
To observe these GRB before during and after the detection in the band (1-300 keV)
For 100 % of detections to localise the GRB with a precision better of 2.9 mrad in less than 10 s.
For 50 % of detections to localise the GRB with a precision better of 290 µrad in less than 10 s.
For 100% od detections to transmit to the ground the coordinate of GRB in less then 60 s.
For 20% of detections to localise the GRB with a precision better then 5 µrad and to estimate the redshift in less than 300 s.
For 75 % of cases to allows to 8m class ground telescopes the observation of the afterglow emission.

Table 1 : ECLAIRs mission requirements

The time needed for the payload development defines a launch date at the end of 2009.
This date is compatible with CNES program's strategy and allows a good recovery with the other GRB detection missions.

ECLAIRs Payload Description

The ECLAIRs payload is separated in a ground element and in a space element.

The ground element is composed of a robotic telescope called UGD.
UGD is able to observe the afterglow emission in visible (R and I band) and infrared (J and H band).
The main requirements of UGD are :

- The capability of pointing of detected GRB better than 50 µrad in less than 10 seconds.
- A mirror diameter between 1 and 1.5 m.
- A spectral observation range between 550 and 1800 nm.

The space element is a micro-satellite of the Myriade family with two instruments :

- A X-γ Camera called CXG, provided by CEA, observing GRB in the band (4-300 keV).
- A X camera, called SXC, provided by MIT, observing the GRB in the band (1-12 keV).

The payload is completed by :

- a payload management unit called EGCU, under the responsibility of CNES, which stores the scientific data, surveys the payload and links the instruments to the bus. EGCU is an equipment of the Myriade product line.
- a scientific data treating unit, called UTS under the responsibility of CEA, which detects and localises the GRB using information provided by CXG and SXC.
- a real time alert system using VHF band to transmit the location of GRB to ground segment. This system is similar to the HETE2 alert system.[5]
- a High Rate Tele Measurement system using X-band to transmits the scientific data to the ground, it is based on the Myriade product line elements.

The CXG (Figure 6) is the main instrument of ECLAIRs mission.

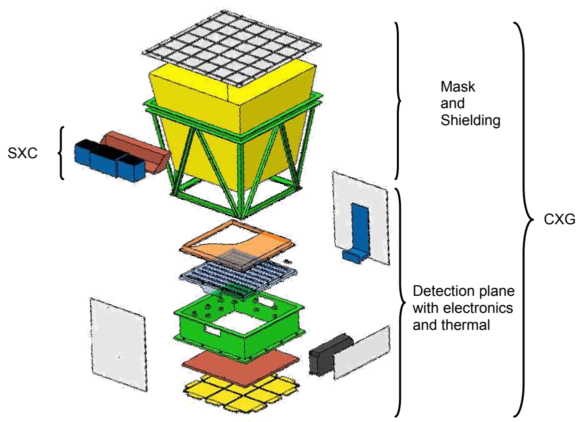

Figure 6 : CXG overview

It is based on a detection plane composed of 6400 CdTe detectors with theirs electronics.
The localisation of the GRB direction is guaranteed by a coded mask and a shielding protecting the instrument from parasite radiations.
Two structure and thermal control supports complete the CXG:

- A lower structure supports the detection plane and its electronics
- An upper structure supports the Mask, the shielding and the SXC.
- Thermal control is realised by a heat pipe array and two radiators which are cooling the

detector plane and guarantee constant thermal conditions.

The geometrical parameters of the instrument (surface and shape of detection plane, size of the mask, distance between the mask and detection plane) have been optimised in order to find the best compromise between, the Field of View (FoV) of the cameras, the sensitivity and the resolution of the detection plane. Additionally, the instrument's volume and mass were optimised to meet the requirements.
The main characteristics and requirements of CXG are resumed in Table 2.

Field of view : 89°x 89°
Detection plane surface : 420 mm x 420 mm
Mask surface : 540 mm x 540 mm
Distance Mask – Detection plane : 460 mm
Overall dimensions : 600 mm x 600 mm x 640 mm
Mass : 48 Kg
Power : .51.3 W (including thermal control)

Table 2 : CXG main requirements

The SXC cameras allow increasing the precision in the GRB localisation.
Their detection plane is composed of 4 Si CCID with 1 million of pixel each.
The coded mask in front of each CCID allows the localisation of GRB only in one direction. For this reason, the SXC camera works in pairs: one provides the X coordinate and the other one the Y coordinate.
For the ECLAIRs mission two pairs of SXC cameras are used to increase the global detection surface and improve the sensitivity.
The ECLAIRs SXC cameras are an evolution of the ones used on HETE satellite[6].
The main characteristics and requirements of the SXC are resumed in Table 3.

Field of view : 2 Sr
Detection plane surface : 50 mm x 50 mm each
Mask surface : 540 mm x 540 mm
Overall dimensions (l x w x h) : 600 x 600 x 640 mm^3
Mass : 4.5 Kg
Power : .4.5 W

Table 3 : SXC main requirements

Orbital Configuration

The choice of the orbit is the result of several compromises.
In order to reduce the perturbation due to cosmic and solar radiation, the satellite should be inside the 'protection belt' created by the Earths magnetic field.
This belt is localised between ±45° of inclination and an altitude less than 1000 km.
Taking into account the effects of the South Atlantic anomaly, the optimum area is reduced to ±20° of inclination and an altitude less than 650 km.

These orbits are not usual and it is difficult to find an opportunity of piggy back or low cost launch.

The only opportunity of a piggy back lauch clearly identified is Megha-Tropiques which's launch is scheduled for 2009 with a PSLV rocket.
The orbit has an altitude of 870 km and an inclination of 20° - values which are acceptable for the scientific needs.
Using the Myriade propulsion subsystem for lowering the orbit after the release allows decreasing the altitude to 745 km, the dead time due to the South Atlantic anomaly perturbation will be reduced from 30 % to 19%.

A research of back-up solutions has not identified any reliable alternatives:

- a dedicated launch using Vega or SHTIL will be too expensive without finding any other passengers.
- Falcon 1 is not still qualified at the moment.
- DNEPR could reach an altitude of 650 km but its inclination is limited to 49°, these values present a worst solution respect to PSLV launch from the mission point of view.

The attitude of the satellite also states a compromise of scientific requirements and mission complexity.
An inertial pointing is necessary to avoid the trail of γ and X sources into the images.
Pointing the cameras perpendicular to the orbit plane should guarantee a full observation time but it will be limited to telescopes in the polar region of sky.
Earth based large telescopes are localized mainly in tropical regions so it will very difficult to observe the afterglow because the detected GRB will be localised always near to the telescope's horizon.
Pointing the cameras parallel to the orbit plane and in opposite to the sun would allow a good observability of GRB from earth but the total observation time of the satellite will be reduced as the earth will sometimes be in the field of view of the cameras.

Finally an antisolar pointing was chosen.
This attitude guarantees the possibility of observing the afterglow emission from earth and it puts the satellite in a very favourable thermal environment (only one side is exposed to solar flux).
The time lost due to the eclipses is limited to 33 % of orbital time; this value is acceptable for the mission's scientific objectives.

ECLAIRS SATELLITE ARCHITECTURE

Approach

ECLAIRs Architecture is defined by a very classical methodology. The first step was to identify, analyse and classify the constraints in term of mechanical and thermal architecture. The second step was to evaluate different architectures and to select a baseline only considering qualitative criteria. Then main budgets and performances have been studied.
It was also early considered that ECLAIRs payload must be compatible with the MYRIADE generic platform.
The choice was made to take benefit of the MYRIADE development in terms of structural concept, integration principles and MGSE, in order to minimise costs and development risks.
Nevertheless, it showed clearly from the beginning of the feasibility study that the volume and interface requirements of the ECLAIRs payload could not fit in the Myriade generic payload capabilities given in Table 4.

Overall dimensions (l x w x h) : 610 x 580 x 340 mm^3
Mass : 50 Kg
Mean Power : .50 W

Table 4 : Myriade payload main requirements

Mass and volume of the CXG overpass naturally the specifications: the use of heavy material for shielding and detector and the geometrical parameters of the telescope are necessary to observe GRB with the foreseen sensitivity and resolution.

For this reason the goal in terms of mass has been fixed to 150 kg.
This value is higher than 120 kg specified in many piggy back launcher user's manual but correspond to an actual trend of microsatellite market[7] and some deviations with respect to the specified mass have been accepted by the launcher authority in the past.
For the same reason it had been judged acceptable that the total volume of the satellite exceeds the classic envelope of 600x700x850 mm^3 specified for many launchers in order to keep the length and the width of satellite inside the allowable values.

Consequently some minor changes in the satellites structure definition should be introduced to withstand the loads due to the increase of total mass.
Also the internal accommodation of platform equipments is not frozen by Myriade legacy and it could be optimized for the frame of ECLAIRs mission.
The equipments necessary for ECLAIRs are different from those used in previous missions. The chosen orbit and attitude allow to unshipping SADM (?) but imposing to use higher momentum reaction wheels and magnetotorquers.and a double-head Star Tracker..
Considering the very high sensitivity of the payload instrument to the satellite orbit and the few identified opportunities of launch, the choice was early made to concentrate efforts to acquire the compatibility with PSLV as piggy back passenger of Megha-Tropiques.

Communications are another critical point of the mission in particularity to the real time alert system.
The satellite presents many antennas (VHF, S-band and X-band) and their accommodation was a problematic issue.

Finally the constraints of the instruments are taken into account :
CXG detection plane needs to work in a very homogenous and cold environment typically -20°C with $\Delta T < 5°C$.
SXC needs to work at -60°C and thermal distortions between the star sensor and SXCs line of sight needs to be minimized to guarantee its pointing accuracy.

Satellite mechanical and thermal architecture

ECLAIRs reference frame (Figure 7) is the same than the one of all Myriade family satellites i.e.:

- X axis is perpendicular to launcher I/F directed from the launcher to the satellite.
- Y axis is perpendicular to solar Array surface in stowed configuration directed from the Solar Array to the satellite.
- Z axis completes the coordinate system.

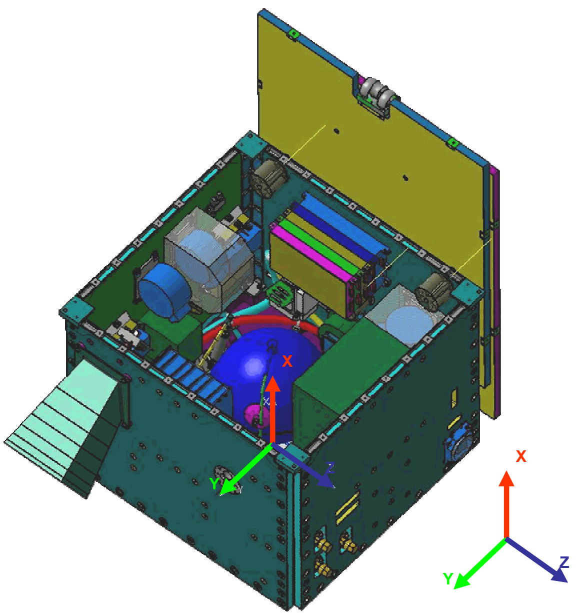

Figure 7 : Myriade reference frame

The instruments are accommodated with the line of sight directed toward +X, The Z-direction is perpendicular to the orbit plane.
These choices present several advantages:

- to limit the overpass of allocated volume essentially in X direction.
- to expose to solar flux only on the –X side.
- to guarantee a good thermal environment for ± Z walls.
- to avoid the presence of SADM after the solar array release.

The SXC is mounted on the CXG shield structure.
All the appendices needed to be accommodated by pair opposing in 180°, i.e. VHF antennas, S-Band antenna and Star Sensor heads are accommodated on the ± Z walls.
Star Tracker heads are mounted on the payload wall in order to reduce thermoelastic distrorsions between SXC and SST, to simplify the thermal control of SST and to free some volume inside the platform.
The final accommodation study results are showed in Figure 8

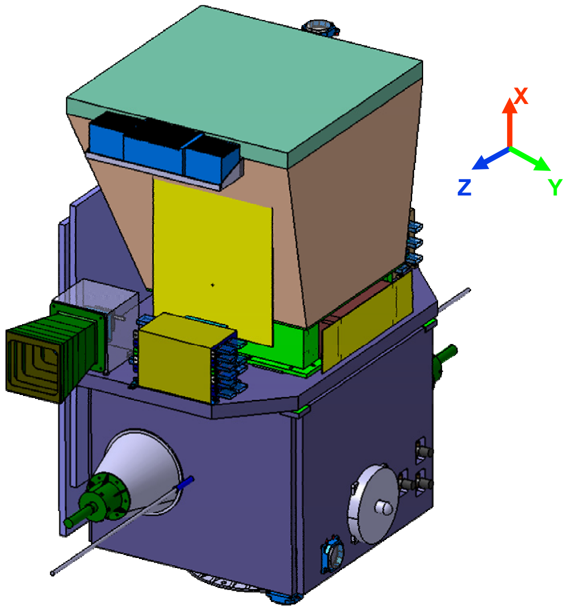

Figure 8 : ECLAIRs microsatellite architecture

Compatibility with the launcher

PSLV[8] is a 4 stages launcher which allows to orbit a main passenger, typically 1200 kg in SSPO orbit at 817 km, and up to two auxiliary passengers[9] of microsatellite class.
Main specifications for auxiliary payloads are resumed in Table 5.

Overall dimensions (l x w x h) : 600 x 700 x 850 mm^3	
Center of Gravity location	lateral < ± 5 mm longitudinal < 450 mm
Mass < 120 Kg	
Frequency	lateral : > 45 Hz longitudinal > 90 Hz
Quasi Static Loads	lateral : ± 6 g longitudinal -2.5 / +7 g

Table 5 : PSLV auxiliary PL main requirements

The accommodation of main and auxiliary passenger under the fairing is shown in Figure 9

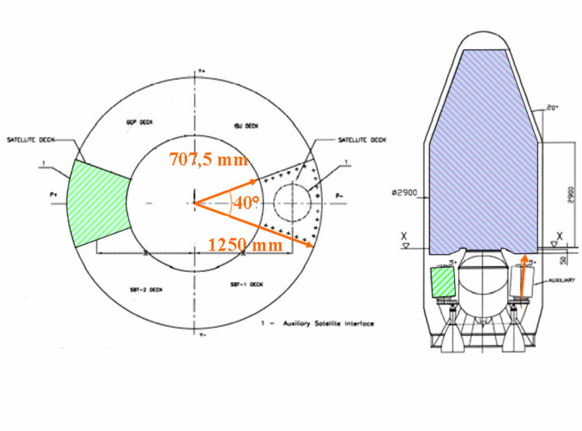

Figure 9 : payloads under PSLV fairing

ISRO has developed 3 interface adapters :
- IBL-230 for 50 kg satellites.
- IBL-298 for 120 kg satellites.
- IBL-358 for 150 kg.satellites.

During the discussion with ISRO it appeared that IBL-358 is not available anymore and it has been replaced by IBL-298 with an extended capability to carry up to 150 kg.

The allocated volume specifications were widely exceeded; in order to find the optimum satellite architecture and accommodation (with minimized encroachments within the launcher) a CAD study has been conducted. By this way some solutions could be excluded very early and only the best one has been submitted to ISRO for their approval.
Nevertheless some iterations were necessary (Figure 10) before finding the final configuration.

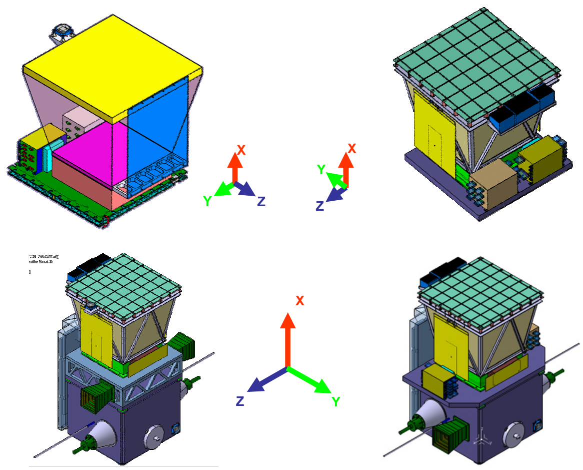

Figure 10 : Payload accommodation evolution

In order to limit the encroachment within the fairing (Figure 11) the CXG geometry has been modified by introducing a misalignment of 10° between the mask and detection plan; this change is acceptable for the

scientific point because of its limited impact on the FoV (loss of 1°).
The payload panel has been enlarged in Z direction to accommodate the payload electronic boxes (UTS and EGCU).
Solar Array standard pyronuts have been changed with low shock pyronuts not needing a bolt catcher.
This modification allows a reduction of the satellite volume in Y direction.

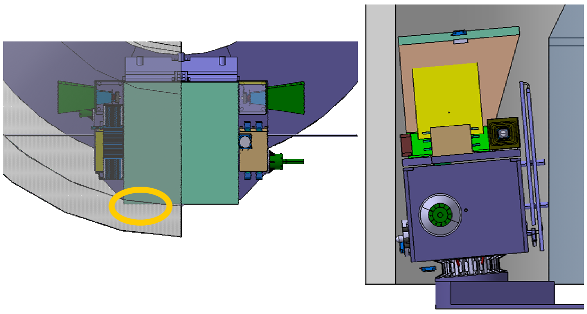

Figure 11 : ECLAIRs under PSLV fairing

Finally the satellite presents a negative margin of 20 mm between the CXG corner and the fairing dynamic volume which has been considered acceptable by the launch provider.
Nevertheless, the margin between the Solar Array and the PS4 Tank is very tight and a problem could occur during the satellite release.
The compatibility study should be completed by separation analysis.

Structural concept

ECLAIRs structural concept is directly derived from the MYRIADE platform (Figure 12). The structure is composed of five rectangular sandwich panels made of Aluminum skins with a honeycomb core and one lower base plate made of machined Aluminum-Alloy.
Lateral panels are supported by four L-spar structures and can be opened for satellite integration.

Figure 12 : MYRIADE platform structure

Equipments are mainly fixed on the lateral panels with inserts (Figure 13).
The lower plate accommodates the launcher interface adapter and propulsion subsystem.
The upper plate supports the payload instruments. It's design can be adapted (thickness, material, insert location) to the payload needs.

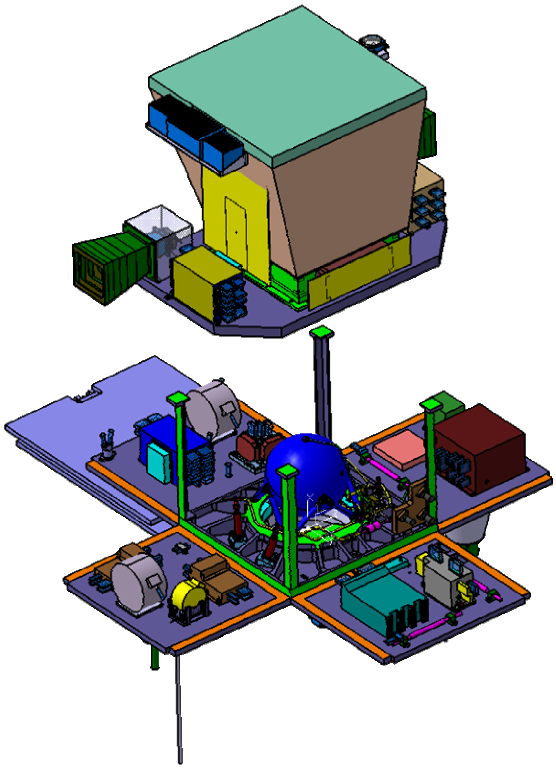

Figure 13 : Equipments accommodation

With the proposed internal equipments accommodation, the free volume inside the platform is enough to permit the replacement of the standard Myriade hydrazine tank by a bigger one.
The increase of the hydrazine mass allows lowering the orbit down to 650 km after orbit insertion by the launcher at 817km.
The feasibility of this solution should be validated by studying the impact of the modifications introduced in the piping, tank mechanical supports and thermal control.

The satellite total mass is 153.758 Kg (the global payload mass is 74.615 kg and the platform mass is 79.143 kg) the value overpasses ISRO commitment of 150 kg.
Platform subsystem masses are derived from existing Myriade functional chains; so no increases are expected except for the structure mass.
For this reason the value of structural mass include margins taking into account the potential reinforcement.
The satellite centering does not meet the launcher requirements, non conformity are limited to less than 3 mm for lateral centering and 10 mm for axial

centering. These values primary depend on the mass and the volume of the CXG.
The lateral centering (in Y and Z direction) could be adjusted using equilibration masses, vertical centering would be better using extended tank but these solutions will increase the global mass of satellite.
Due to uncertainty of payload definition it has been judged premature at this phase of development to optimize the satellite design in order to meet MCI requirement.

The first eigenfrequencies of ECLAIRs could be estimated from MCI budget using the stiffness of the Myriade platform.

- First axial mode $f_x \approx$ 119.7 Hz
- First Y lateral mode $f_y \approx$ 38.0 Hz
- First Z lateral mode $f_z \approx$ 35.0 Hz

The used method has been validated on the existing Myriade based satellites and gives acceptable results for the feasibility study needs.
The lateral frequencies do not meet the specification and some modification in structure design need to be introduced; typically stiffening the interface plate.

Thermal concept

Myriade thermal design is based on the decoupling of payload and plateform.
The orbit and attitude of the satellite limits the solar flux only to the –X wall due to reduced surfaces-sun exposition; the other walls see deep space and earth, so receive IR flux only.

This configuration gives to the satellite good long term stability as shown in Table 6.

Wall	mean T_{shrink} over 30 day
-X	-5 / -36 °C
+X	-59 / -84 °C
-Y	-39 / -84 °C
+Y	-63 / -85 °C
-Z	-72 / -92 °C
+Z	-71 / -92 °C

Table 6 : Long term thermal stability

Nevertheless, each wall is submitted to earth IR flux with a great variability during one orbit (the view factor varies between 0 and 0.83).
Consequently, it would be very hard to guarantee to the payload short term stability better than the natural one because of the high variation of external flux in one orbit (Table 7).

Wall	External flux during one orbit
-X	60 / 320 W/m^2
+X	0 / 180 W/m^2
-Y	10 / 260 W/m^2
+Y	0 / 210 W/m^2
-Z	10 / 170 W/m^2
+Z	10 / 170 W/m^2

Table 7 : Short term thermal stability

The thermal control of CXG is a critical point in instrument development.
Thermal requirements of the detection plane are not easy to meet and the high thermal dissipation of the CdTe detector implies a more complex thermal control.
CXG is equipped with two symmetric radiators directly linked to detection plane by an array of heat pipes. This is to reduce the thermal gradient of the detection plane; the power supply unit of CXG is thermal isolated from the detection plane with its own thermal control to reduce external perturbation on detector plane.
External fluxes on the ±Z walls are in opposition of phase and for this reason CXG radiators are accommodated on these walls.

SXC is accommodate on +Z side to take advantage of the coldest thermal environment.

Preliminary thermal studies made at instrument level show the conformity of the thermal design of CXG with instrument specifications.
Thermal gradient inside the detection plane is less than 5°C. Temperatures of the detector vary from -46 °C to -24°C without active thermal control, 11 W are necessary to keep the detector temperature at -20°C.
The thermal gradient between lower structure and mask is less than 3°C; consequently thermoelastic distortions are limited and SXC pointing accuracy requirement should be respected.

Satellite RF performances.

An electromagnetic model of the satellite (Figure 14) has been conducted to study the radiation diagram of the foreseen antennas. Computed antenna radiation diagrams (Figure 15) have been used to validate telemetry balance efficiency of the VHF alert solution.

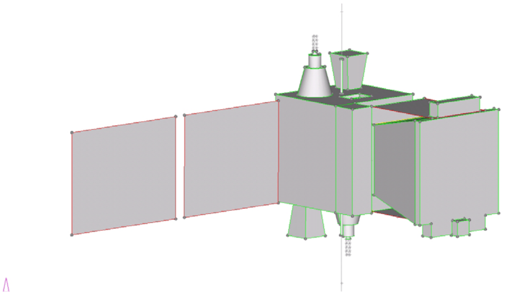

Figure 14 : Satellite EM model

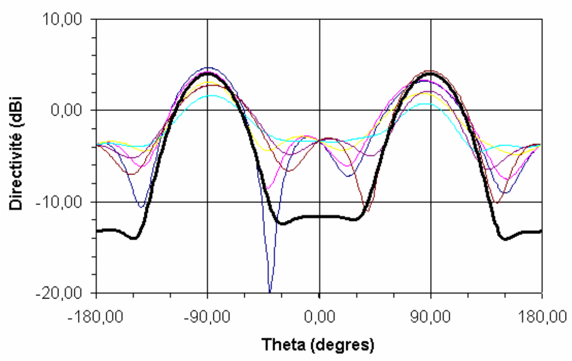

Figure 15 : VHF antennas radiation diagrams

Analysis have shown a good global coverage (Figure 16) pending the extension to 30 stations of the original HETE VHF ground station network.

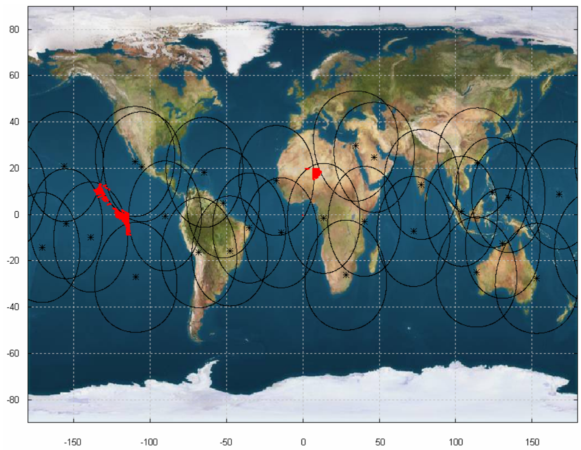

Figure 16 : VHF network covering

The probability of transmit the alert in less than 60 seconds is 99.996 %

Conclusion

The ECLAIRS Phase A review has been hold at CNES on first trimester of 2006. Both technical feasibility and programmatic aspects have been delt with during this review. CNES management concluded that the ECLAIRS technical file is of good quality and maturity, but, there is a will to extend the mission and the payload performances inducing the need to change the current microsatellite bus for a bigger platform.

Therefore it has been decided to redirect the ECLAIRs project and to perform a new phase A study with the new configuration.

Acknowledgments

Authors would like to thanks :
J.Paul, B.Cordier, F.Ardellier, H. Triou from CEA.
P.Mandrou, R.Pons from CESR.
S.Basa from LAM.
J.Gayrard, V.Dubourg, N.Fonseca, O. Alvarez from CNES.

References

[1] B.Tatry, M.A.Clair.
« Small satellite CNES programme. Mission flown and in preparation, leasson learnt, success condition »
20th AIAA/USU conference on small satellite

[2] T. Cussac, F.Buisson, M. Parrot
« The DEMETER program : Mission and satellite description – Early in flight results »
IAC-04-IAA.4.11.2.04

[3] P.Lier, M.Bach
« PARASOL a micro satellite in the A-Train for Earth atmospheric observations » IAC-05-B5.4.03 IAF2005

[4] Shanne and other
« The ECLAIRs μ-satellite for multi-wavelength studies of gamma-ray burst prompt emission »
IEEE Trans.Nucl.Sci. 52 (2005) 2778-2785

[5] HETE Burst Alert Stations
http://space.mit.edu/HETE/sgs.html

[6] R. Vanderspek, J. Villaseñor, J. Doty, J.G. Jernigan, A. Levine, G. Monnelly, and G.R. Ricker.
« GRB observations with the HETE soft X-ray Cameras »
Astron. Astrophys. Suppl. Ser. 138

[7] S.Chatoire, A.Accettura
« ASAP and future concepts », SSC05-X-4
19th AIAA/USU conference on small satellite

[8] PSLV User's Manual
VSSC :PSLV :PM :65:87:04 Iss.04 Dec. 99

[9] PSLV Auxiliary payload User's Manual
VSSC :PSLV :PR :PM :176/99 Iss.01 Dec. 99