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The ECLAIRs micro-satellite mission for gamma-ray burst multi-wavelength observations

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Abstract

Gamma-ray bursts (GRB)—at least those with a duration longer than a few seconds—are the most energetic events in the Universe and occur at cosmological distances. The ECLAIRs micro-satellite, to be launched in 2009, will provide multi-wavelength observations of GRB, to study their astrophysics and to use them as cosmological probes. Furthermore, in 2009 ECLAIRs is expected to be the only space-borne instrument capable of providing a GRB trigger in near real-time with sufficient localization accuracy for GRB follow-up observations with the powerful ground-based spectroscopic telescopes available by then.

A "Phase A study" of the ECLAIRs project has recently been launched by the French Space Agency CNES, aiming at a detailed mission design and selection for flight in 2006. The ECLAIRs mission is based on a CNES micro-satellite of the "Myriade" family and dedicated ground-based optical telescopes. The satellite payload combines a 2 sr field-of-view coded aperture mask gamma-camera using 6400 CdTe pixels for GRB detection and localization with 10 arcmin precision in the 4–50 keV energy band, together with a soft X-ray camera for onboard position refinement to 1 arcmin. The ground-based optical robotic telescopes will detect the GRB prompt/early afterglow emission and localize the event to arcsec accuracy, for spectroscopic follow-up observations.

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1. Introduction

Gamma-ray bursts (GRB) are detected by space-borne gamma-ray telescopes as an important count-rate increase during a short period of time. These phenomena were discovered in the 1960s, however, their origin remained mysterious for a long time. Only in the 1990s, thanks to the BATSE detector onboard the NASA CGRO satellite, it was possible to get a first indication that those events were of cosmological origin. BATSE [1] showed that GRB are distributed uniformly on the sky, furthermore that about 80% of all GRB last less than one minute, and that there is a distinct class of short-duration GRB which last less than a few seconds. The real breakthrough in understanding GRB occurred in 1997 in the era of the Beppo-SAX

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satellite with the discovery of X-ray [2], optical [3], and radio [4] GRB afterglows, allowing the detection of the host galaxies and the measurement of their redshift. Those observations showed that (at least long-duration) GRB are events related to explosions of massive stars, taking place at cosmological distances. In the most commonly accepted model, the gamma-rays of a GRB are produced by internal shocks taking place in a collimated jet of particles produced during the event and directed close to the line of sight of the observer, while the afterglow results from the interaction of the jet with the surrounding medium; however, alternative models exist. The energy radiated in gamma-rays by a GRB amounts to $>10^{51}$ erg (while the energy released by a typical supernova is about 10^{49} erg), thus GRB are the most energetic explosions known to take place in the Universe since the Big Bang.

Future studies of GRB will allow to better constrain the physical GRB models by understanding the physical processes involved in those extreme events. Of particular interests are the mechanisms capable of producing the high gamma-ray flux, the origin of the prompt emission in X-rays and the visible band, and the formation of the afterglow. Additionally, the study of GRB offers important perspectives for the progress of cosmology. Due to their high intrinsic luminosity, GRB allow to probe the Universe at very high redshifts, the properties of the host galaxy and the intergalactic medium on the line of sight being imprinted in the spectrum of the GRB afterglow. The star formation rate at high z can be studied using GRB related to massive star explosions, and it could even become possible to detect the first generation of stars, responsible for the re-ionization of the Universe after the Big Band.

After its launch foreseen in 2009, the micro-satellite mission ECLAIRs (for "*flash of lightning*" in French) will detect about 100 GRB per year, observe them simultaneously in the visible and the X/γ-ray domain, and will contribute to the rich field of research which emerged from GRB observations.

2. ECLAIRs mission concept

2.1. GRB detection and observation strategy

The GRB observation strategy is based on multi-wavelength observations, which follow three steps: (i) detection of the GRB using wide field-of-view space-borne gamma-ray telescopes; near-real-time localization of the event on the sky with a few arc-minutes accuracy; (ii) observation of the prompt/early afterglow emission with robotic telescopes which point their field-of-view quickly onto the space-given error-box within tens of seconds after the event; localization with arc-seconds accuracy; (iii) spectroscopic observations of the GRB afterglow with large ground based telescopes and large space-borne X-ray telescopes.

This observation scheme is at work presently with HETE-2 [5], INTEGRAL [6] and Swift [7] (among others) in orbit, followed by event localization with small robotic telescope like REM [8] and TAROT [9] and spectroscopic studies after hours e.g. at the VLT (European Southern Observatory, Chile) and others. Faster spectroscopy of GRB afterglows, within minutes after the event, in the visible and near-infrared band is the goal of X-shooter [10], a second generation instrument to be installed in 2008 at one of the 8.2 m telescopes of the VLT. However, if not in 2008, then early in the next decade, all the space-borne GRB triggers available today will cease to function.

At this point, ECLAIRs will be the future mission capable of providing frequent and fast GRB triggers with a good localization accuracy for ground-based GRB follow-up observations. Furthermore, ECLAIRs will be operational simultaneously with GLAST [11]. For GRB observed with both satellites, a very large spectral coverage will, therefore, be available: from 1 keV by ECLAIRs up to 30 MeV by the GLAST Burst Monitor (GBM) and a few hundreds of GeV by the GLAST Large Area Telescope (LAT).

2.2. The ECLAIRs system

The ECLAIRs system is composed of a micro-satellite and a dedicated ground segment. The ECLAIRs micro-satellite (Fig. 1) is of the successful Myriade family, developed by the French space agency CNES, from which up to now 6 are in orbit, DEMETER launched in June 2004 being the first one. In 2009, ECLAIRs could be launched as a passenger of the French–Indian Megha-Tropiques mission by an Indian PLSV launcher and injected into a circular low-Earth orbit below the Earth radiation belts (altitude 860 km, 20° inclination). The altitude will then be lowered to 670 km in order to reduce the influence on the detectors of the charged particles trapped in the South Atlantic Anomaly of the Earth magnetic field. The total mass of the ECLAIRs satellite is about 150 kg, including a payload mass of 65 kg.

The payload module comprises a gamma camera (CXG, *Caméra X et Gamma*), detecting photons of energy between 4 keV and >300 keV. With its imaging capability between 4 and 50 keV, this camera is the prime instrument used for GRB detection and localization on the sky (with 10 arcmin accuracy). As a second instrument on-board, the *Soft X-ray Camera* (SXC) provides photon detection between 1 and 10 keV and a refined localization capability (with 1 arcmin accuracy) in a Vernier mode, i.e. using the error box provided by the CXG in order to further refine the position determination. This refined position will allow *prompt* ground-based searches of high redshifted GRB by large telescopes equipped with infra-red imagers whose field-of-view is <3 arcmin.

The ground segment of ECLAIRs is composed of the communication network and robotic telescopes in the visible and near infra-red band (UDV, *Unité de Détection dans le Visible*) dedicated to the mission. In low-Earth orbit, the satellite has no permanent high bandwidth