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XGRE: a TGF/GRB detector on the TARANIS spacecraft

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Abstract. With a launch expected in 2020, the TARANIS microsatellite, supervised by CNES, is dedicated to the study of transient radio, optical and gamma-ray phenomena observed in association with thunderstorms. On board the spacecraft, XGRE is the instrument optimized to study terrestrial gamma-ray flashes (TGF) and can detect gamma-rays from 30 keV to 10 MeV, with a very high counting capability (about a million counts per second). GEANT4 Monte Carlo simulations of TARANIS/XGRE, using a detailed mass-model cross-checked by FM calibrations, has allowed us to estimate the sensitive area of the instrument. With a spectral averaged effective area of 425 cm2, XGRE should detect about 200 TGFs per year. It will also detect short GRB and monitor bright X-ray sources, such as the Crab and Cygnus X-1.

1. Introduction

Observations of "sprites", "jets", "elves", all optical events named Transient Luminous Events (TLE), and observations of Terrestrial Flash Gamma (TGFs) have shown the existence of sudden energy transfers between the Earth's atmosphere and the space environment. Early TGF detection over active thunderstorms by the BATSE instrument aboard the CGRO satellite provided evidence of relativistic electron acceleration in the Earth's atmosphere (Fishman et al. 1994). TGFs are also monitored by the RHESSI satellite which has so far observed 10 to 20 TGFs per month (Smith et al. 2005). Associations with lightning discharges have been reported by Inan et al. (1996) and Cummer et al. (2005) from electromagnetic ground measurements. The geographic distribution of TGFs roughly corresponds to the geographical distribution of lightning on continents and also to the sprites distribution (Christian et al. 2003; Chen et al. 2005). However, many questions remain. TGF emissions are rarely detected in the southern United States where many sprites are observed on the ground (Smith et al. 2005). The origin of most TGFs may be related to lightning at the top of thunderstorms (Dwyer & Smith 2005; Williams et al. 2006). However, differences in the temporal and spectral signatures of several TGFs observed by BATSE and RHESSI have suggested the existence of higher altitude sources (Ostgaard et al. 2008).

Terrestrial Gamma-ray Flashes are the highest energy natural particle acceleration phenomena occurring on Earth.There are flashes of gamma-ray which last from 20 to 2000 microseconds. These are very energetic

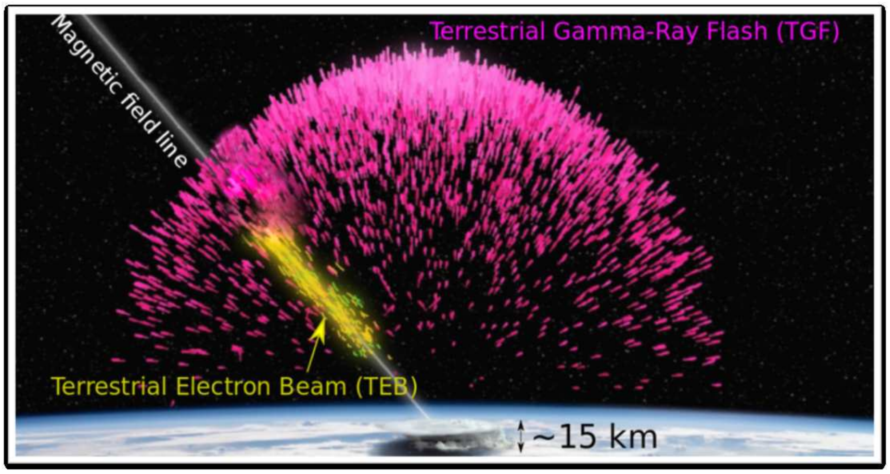

Fig. 1. Scheme of a TGF (Terrestrial Gamma-Ray Flash) and a TEB (Terrestrial Electron Beam).

events as some of them have been already detected up to 40 MeV, and most of them extend to several MeV. The TARANIS microsatellite, supervised by CNES, will carry a complete set of innovative tools that will answer the specific questions raised by the many ground campaigns and previous missions. The scientific objectives of the TARANIS mission are thus divided into three broad categories:

1. To understand the physical links between TLE, TEB and TGF, their regions of origin, and the environmental conditions (lightning activity, thermal plasma variations, etc.) that require their triggering.
2. To identify generation mechanisms for TLE, TEB and TGF.
3. To evaluate the potential effects of lightning, TLE, TGF and accelerated electron bursts on the Earth's atmosphere and radiation belts. These have potential impacts on the ozone layer (Cramer et al. 2017), on the natural production rate of isotopes (Enoto et al. 2017), and for aircrafts safety Tavani et al. (2013).

2. The TARANIS/XGRE instrument

The TARANIS spacecraft will be placed in 2020 in a sun-synchronous orbit at 600 – 700 km altitude. It will carry several experiments which will allow very fast optical imaging of lightnings, measurement of electric and magnetic fields, detection of electron beams and measurement of gamma-ray photons. The payload consists of the following experiences:

1. MCP: two cameras and four optical photometers to follow-up lightning optical emission.
2. XGRE: three electron and gamma-rays detectors.
3. IDEE: two CdTe-based low energy electron detectors.
4. IME-BF: an antenna to measure the thunderstorms electric field at low frequency; it includes an ion probe (SI) to determine local thermal plasma fluctuations.
5. IME-HF: an antenna to measure the thunderstorms electric field at high frequency.
6. IMM: magnetometers to measure the local magnetic field.

XGRE, developed at the APC laboratory in Paris, can detect electrons between 1 MeV and 10 MeV, and gamma-rays between 30 keV and 10 MeV. Its excellent temporal resolution and instrumental dead time ($<$ 350 nanoseconds) allows it to measure fast and brilliant events like TGF. XGRE has also the ability to discriminate photons from charged particles.

XGRE is composed of three identical sensors, each sensor being composed of four de-

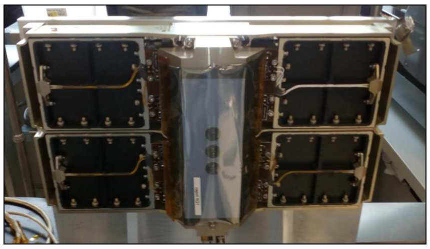

Fig. 2. The TARANIS/XGRE sensor, with its four detection units. The High Voltage sub-system is in the middle of the sensor, under its protective hood.

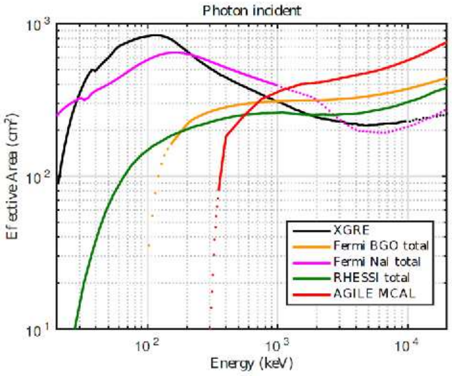

Fig. 3. XGRE effective area compared to other gamma-ray experiments (RHESSI, Fermi/GBM and AGILE/MCAL).

tection units (see Figure 2). A detection unit is the assembly of a LaBr3 crystal (for gamma-ray detection) surrounded by two plastic scintillators (for electrons). The whole system is readout by two multi-anodes 4*x*4 pixels photomultipliers. The top and bottom anode ranks read the plastic scintillators whereas the crystal is seen by the two ranks of middle anodes. Currently, XGRE is in phase D, the flight models being delivered to CNES in April 2019.

XGRE is optimized for the observation of Terrestrial Gamma-ray Flashes but it has also a $\approx$ 3.7 sr field of view toward the sky, which enable it to detect short Gamma-Ray Bursts (GRB) and bright sources, such as the Crab nebula and pulsar and Cygnus X-1. It will have also the capacity to measure Solar flares spectra.

2.1. Calibration

We made in 2018 full calibration campaigns of the three FM sensors at APC and LESIA (Meudon), checking their behaviors against high voltage and temperature. In Fall 2019, we will complete these campaigns by a full calibration on the satellite, to determine the effect of the shadowing by the satellite structure. After this campaign, the satellite will be made ready for its transportation to Kourou (French Guyana), where it should be launched between March and May 2020.

3. XGRE performance determination and comparison with other missions

3.1. Simulations

We made full GEANT 4 simulations of the XGRE sensors. These simulations were checked by comparison with calibrations at each stage of the Flight Models construction. With this mass model, we have computed the total XGRE effective area, given in Figure 3. We have also computed the effective area of Fermi GBM and Agile/MCAL for comparison. Taking into account a TGF standard spectrum, the average effective area becomes 425 cm^2 (Sarria et al. 2017). TARANIS will have a nadir pointing, so the effective area toward the sky will be highly dependent on celestial sources inclination. The maximal area, in this case, is around 200 cm^2 at 100 keV for sources perpendicular to the nadir.

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