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Atmosphere-Space Interactions Monitor (ASIM): State of the Art

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Abstract

Atmosphere-Space Interactions Monitor (ASIM) mission is an ESA payload which will be installed in the Columbus module of the International Space Station (ISS). ASIM is optimized to the observation and monitoring of luminescent phenomena in the upper atmosphere, the so called Transient Luminous Event (TLEs) and Terrestrial Gamma Ray Flashes (TGFs). Both TLEs and TGFs have been discovered recently (past two decades) and opened a new field of research in high energetic phenomena in the atmosphere. We will review the capabilities of ASIM and how it will help researchers to gain deeper knowledge of TGFs, TLEs, their inter-relationship and how they are linked to severe thunderstorms and the phenomena of lightning.

Keywords: space instrumentation - atmosphere physics - thunderstorms - lightning - high energy radiation.

1 Introduction

An increasing number of luminous phenomena related to lightning and severe thunderstorms have been discovered in the last decades. On the one hand, the Transient Luminous Events (TLEs) are luminous phenomena produced at the stratosphere and mesosphere. TLEs studies were pushed forward with the advent of high speed cameras (capable of several tens of frames per second, see, e.g. Franz et al. 1990). More recently, with very high speed cameras (thousands of frames per second, see for example Cummer et al. 2006) these events have been very well characterized in terms of evolution and fine structure. On the other hand Terrestrial Gamma-Ray Flashes (TGFs) are very bright high energy atmospheric emissions (x-ray and γ-ray) and were discovered by astrophysical missions in orbit. According to their appearance, TLEs are classified mainly as Blue Jets, Red Sprites or Elves. While Blue Jets and Red Sprites are directly linked to lightning and are due to air breakdown, Elves are generated by electromagnetic pulses which produce ionization at around 90 km of altitude. Elves have a typical lifetime of $\sim$1 millisecond. Red sprites are generated at the mesosphere (55-80 km) and last from a few milliseconds to tens of milliseconds. Blue jets are upward propagating jets of light from the cloud tops up to $\sim$37 km, with a velocity of $\sim$100 km/s and last for a few tens of a second. An schematic cartoon of these phenomena can be seen in Fig. 1.

With regards to TGFs, first reported detections by the BATSE team were published by Fishman et al. (1994). TGFs are bright outburst of gamma-ray radiation produced in the atmosphere and which can be seen from space-based instruments. TGFs are thought to be produced by bremsstrahlung emission from energetic runaway electrons accelerated by electric fields on top of thunderclouds. The possible connection of TGFs to electron avalanches produced by cosmic-rays in the atmosphere, or a combination of both the cosmic-ray induced electron avalanches and the electrical discharges during lightning, is also a possibility under discussion. TGFs last typically a few hundreds of microseconds and have been observed from 40 keV up to 80 MeV. For an up to date review see Dwyer et al. 2012.

Several astrophysical high energy missions, other than BATSE, have detected TGFs: RHESSI (designed to observe high energy emissions from the Sun), FERMI and AGILE (both dedicated to the observations of Gamma-Ray Bursts in the universe). FERMI team has even performed dedicated observations of the earth atmosphere and designed specific software and data analysis techniques in order to characterize the TGF emission. AGILE has been specially productive in the field of TGF detection and characterization in the 400 keV-30 MeV energy range. The AGILE team has released its own TGF catalogue available online[1] (Marisaldi et al. 2013).

This new filed of atmospheric physics has gained

[1] http://www.asdc.asi.it/mcaltgfcat

an increasing attention from atmosphere physicist and high energy astrophysicists, and is being considered seriously by space agencies as a tool to understand atmospheric phenomena related to cloud formation, severe thunderstorms and lightning, and climate changes. In the wake of this new scientific field of research, the Atmosphere-Space Interactions Monitor (ASIM) was conceived as one of the first space missions dedicated and designed specifically for the observation and analysis of TGFs and TLEs. ASIM is an ESA mission with contributions from Spain, Denmark, Norway, France, Italy and Poland.

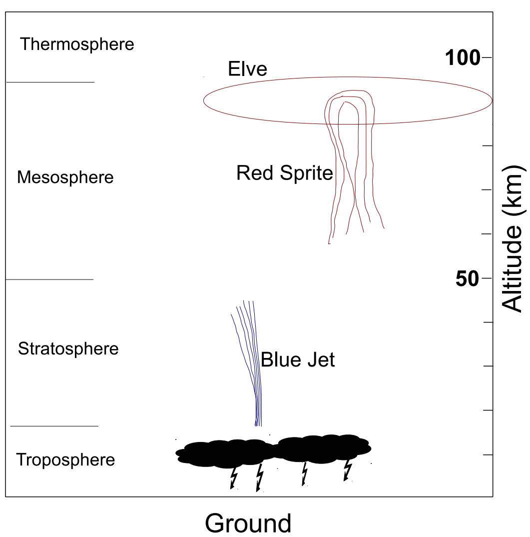

Figure 1: Schematic view of TLEs associated to the lightning phenomena.

2 The ASIM Mission

ASIM was conceived as a monitoring mission with imaging and spectroscopic capabilities, with the goal to locate TGFs and TLEs and provide empirical data which will help to understand the nature of these emissions and the possible links between them. Although TLEs are known to be related to lightning in severe thunderstorms, the relationship of TGFs with both of them is up to now only an hypothesis. There is some evidence that points to the relationship between TGFs and lightning, but a clear understanding is still lacking (Oostgaard 2013).

ASIM will be located at the nadir looking Columbus External Payload Facility (CEPF) on the Columbus module of the International Space Station. ASIM will continuously monitor the earth atmosphere from an ISS altitude of around 400 km. At a global scale, there are approximately 40 lightning flashes per second, as estimated from data taken by the Optical Transient Detector (OTD, Christian et al. 1996) and Lightning Imaging Sensor (LIS, Christian et al. 1999), and they are related to changes in the chemistry of the NO_x molecules in the atmosphere (very determinant for the Ozone generation) and are thought of being of great interest for climate change studies (see for example Reeve and Toumi 2006, and Price and Rind 2012). For this reason, the observation and monitoring of lightning and related phenomenology has become of great interest for the scientific community. ASIM will also address this questions and provide for the first time strictly simultaneous optical and high energy data of the phenomenology related to severe thunderstorms.

ASIM science goals will focus on understanding the physics behind TLEs and TGFs, get a deeper knowledge on how they are related to lightening, and understand their impact on atmospheric processes and possible links to climate determining factors. Other science related to high-altitude cloud formation, cloud electrification, NOx production, meteors, auroras, etc. will also be in the scope of the mission.

3 The ASIM Instruments

The ASIM payload will consist of two main instruments, the Modular X and Gamma-ray Sensor (MXGS) and the Modular Multi-spectral Imaging Array (MMIA). Fig. 2 shows the location of the instruments on the CEPA (Columbus External Payload Adapter) which will be attached to the Columbus nadir CEPF.

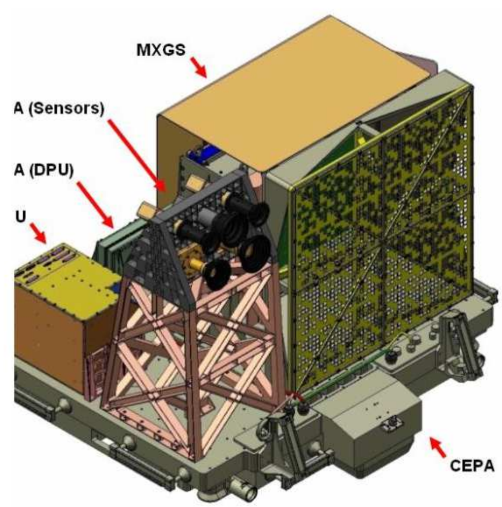

Figure 2: Schematic view of the MXGS and MMIA instruments in the CEPA.

MXGS is a coded mask imaging instrument with two detector layers: one with imaging capabilities (LED, Low Energy Detector), operating in the 15−400 keV energy range, and a second layer (HED, High Energy Detector) sensitive to higher energy photons (200 keV−20 MeV), but without imaging capabilities. The optimal energy resolution (10% at 60 keV for the LED and 15% at 662 keV for the HED), the good angular location accuracy (0.7° for point sources and 2° for diffuse sources), and a time resolution bellow 5μs, make from MXGS an ideal instrument to locate TGFs and characterize their emission in terms of duration, shape of the light-curve and their spectral behavior. MXGS will have a field of view of 80°×80°, which at zero response becomes 147°×147°, i.e., the size of the earth disc as seen from the ISS. Table 1 summarizes the MXGS capabilities and in Fig. 3 a MXGS model is depicted.

Table 1: Summary of MXGS capabilities.

	LED	HED
Collecting Area	1024 cm^2	900 cm^2
Energy Range	15−400 keV	200 keV−20 MeV
Energy Resolution	10% at 60 keV	15% at 662 keV
Time Resolution	≤5 μs	≤5 μs
Location Accuracy (degrees)	0.7 (point src.) 2 (diffuse)	
FOV	80°×80° †	

†147°×147° at zero response

MXGS may be the very first instrument locating TGFs with an error circle of ∼15 km radius, solving for the first time the ambiguities in the TGF association with lightning activity. MXGS will also be capable to observe for the very first time the TGF spectra in a very wide energy range, from 15 keV up to 20 MeV. MXGS is also the very first coded mask imaging instrument specially designed to observe high energy atmospheric phenomena.

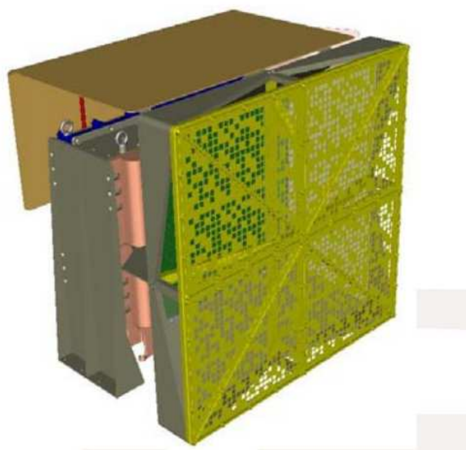

Figure 3: Schematic view of the MXGS instrument.

MMIA will consist of 3 photometers and two imaging cameras. The 3 photometers are working in the wavelengths 337 nm, 180−230 nm, 777.4 nm, and the cameras are optimized to work at 337 nm and 777.4 nm, covering altogether from the near UV up to the near IR. The time resolution is 83 ms for the cameras and 0.01−0.1 s for the photometers. The cameras will have an spatial resolution between 0.4 and 0.5 km and both the photometers and the cameras have the same field of view, namely, 61.4°. MMIA will provide invaluable data on the optical emission (as opposed to the high energy emission) from severe thunderstorms. Table 2 summarizes the capabilities of MMIA and in Fig. 4 a model of the instrument is depicted.

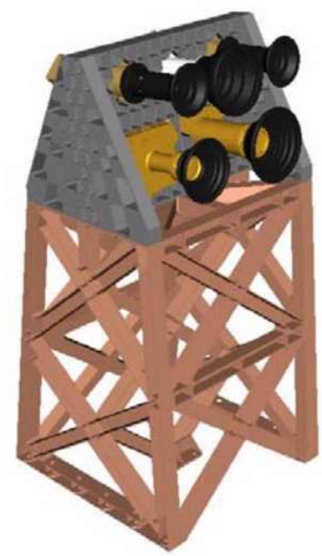

Figure 4: Schematic view of the MMIA instrument.

Table 2: Summary of MMIA capabilities.

	Cameras	Photometers
FOV (NAdir)	61.4°	61.4°
Num. of pixels	1024×1024	−−
Pixel resolution (Nadir) (km)	0.4−0.5	−−
Time Resolution (ms)	83	0.01−0.1
Spectral bands (center/width) (nm)	337/5 777.4/5	337/5 777.5/≤5 205/50

MXGS and MMIA will both work together in their triggering mode, and will be able to send their triggering information to each other. Fig. 5 depicts a schematic view of the instruments capabilities and their interconnected cross-triggering system. They will offer the first strictly simultaneous observation of luminous emissions associated to thunderstorm activity.

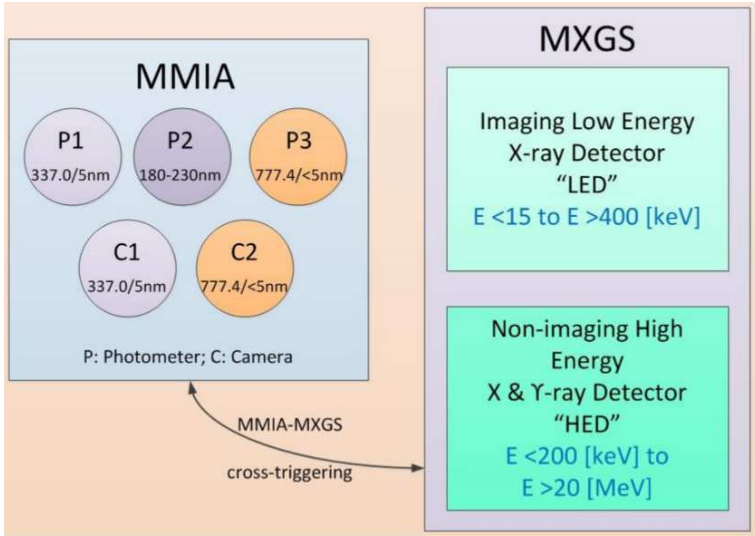

Figure 5: Schematic view of the MMIA and MXGS configurations, depicting the instruments capabilities and the interconnected cross-triggering.

4 Mission Status

ASIM mission was approved by ESA during 2005. Now (2013) the Critical Design Review (CDR) is on going and the manufacturing is expected to start along 2013. The Flight model should be ready by the end of 2014 and the launch of the mission is expected by mid-2015. The nominal operational life of the mission is 2 years, with possible extensions.

5 Conclusions

ASIM will help the scientific community to solve some of the problems related to TLE and TGF formation, a quite recent new filed of atmospheric physics which has been also called High Energy Atmosphere Physics (see Dwyer et al. 2012). The capabilities of its instruments and the wavelength coverage will allow the location TGFs with high accuracy and disentangle their links to TLEs, thunderstorms and lightning.

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