BIRKELAND CENTRE
FOR SPACE SCIENCE

ASIM - Fermi - AGILE simultaneous observation of Terrestrial Gamma-ray Flashes

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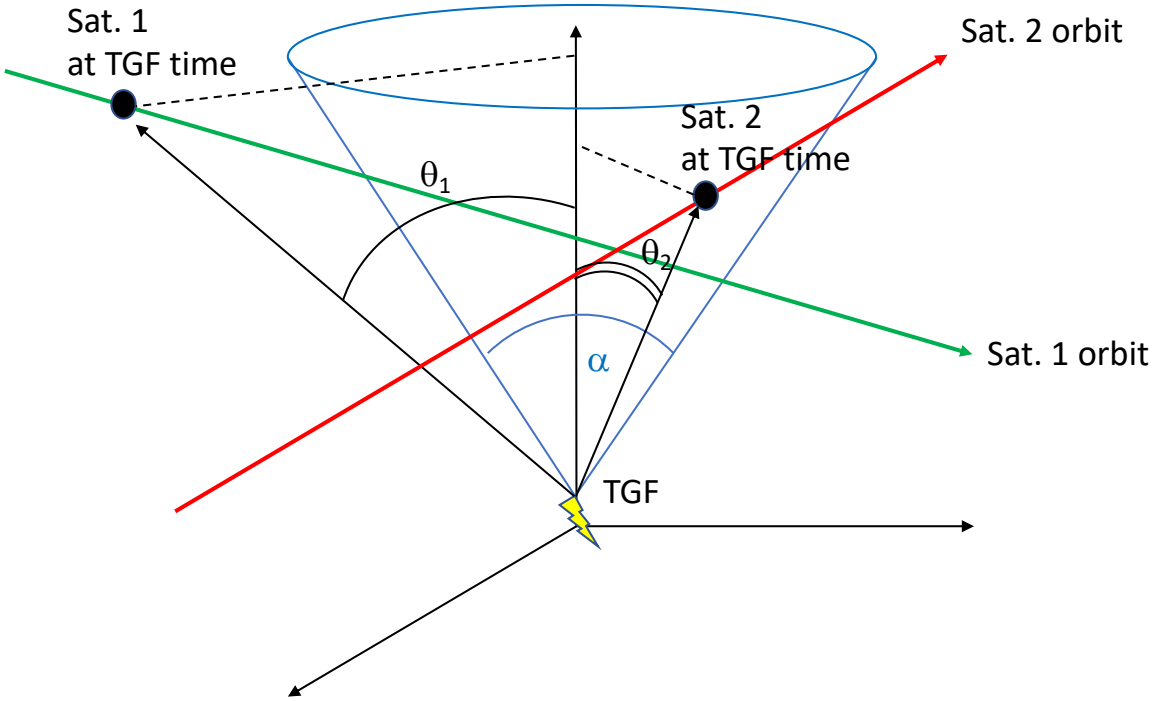
UNIS The University Centre in Svalbard

NTNU Det skapende universitet

Abstract

The Atmosphere Space Interaction Monitor (ASIM) mission onboard the International Space Station is the first mission specifically dedicated to the observation of Terrestrial Gamma-ray Flashes (TGF) and Transient Luminous Events (TLE). ASIM, together with the Fermi and AGILE satellites, are the only three currently operating missions capable to detect TGFs from space. Depending on orbital parameters, pairs of these missions periodically get closer than few hundreds kilometers, observing the same region on the Earth surface for up to several tens of seconds. This offers the unique chance to observe the same TGF from two different viewing angles. Such observations allow to probe the TGF production geometry and possibly put constraints on production models and electric field geometry at the source. Here we present four TGFs detected by ASIM and simultaneously detected by Fermi (three events) or AGILE (one event) in the period June 2018 - November 2019.

Motivation



- Population studies suggest that TGF sources emit over a broad angle of about 30 – 40 deg half aperture (Hazelton et al., GRL 2009)
- However direct measurements of emission cones for single observations do not exist
- Observing the same TGF from two different viewing angles can provide the first direct constraints on emission geometry

Instruments and datasets

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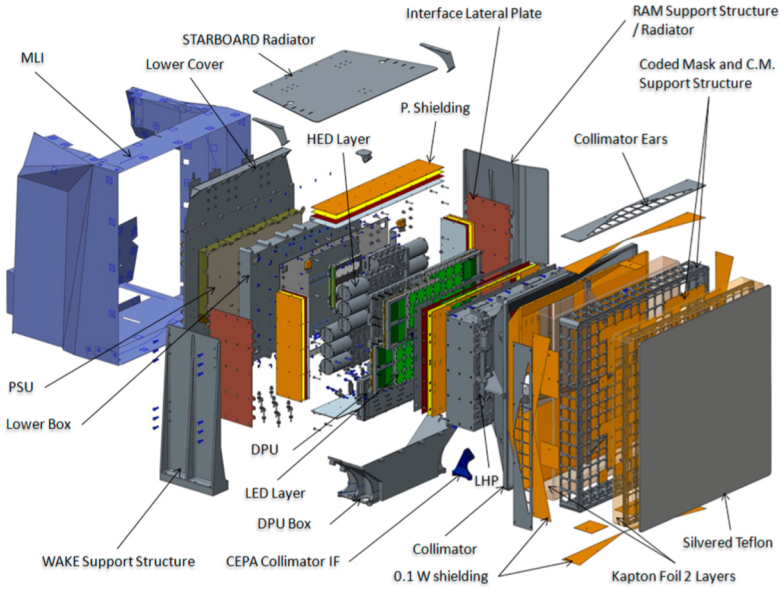
- ASIM is a mission of the European Space Agency (ESA) installed on the external facility of the Columbus module of the International Space Station (ISS), in nominal operations since June 2018
- ASIM is the first mission specifically dedicated to the observation of TGFs and Transient Luminous Events (TLEs) (Neubert et al., Sp.Sci. Rev. 2019)

Key features:

- Simultaneous optical (MMIA) and X-gamma-ray (MXGS) instruments
- MXGS consists in a pixelated Low Energy Detector (LED) (15 – 400 keV) and a High-Energy Detector (HED) (0.2 – 40 MeV) (Østgaard et al., Sp. Sci. Rev. 2019)
- A coded-mask system on top of LED allows for the first time direct imaging of TGFs in hard-X rays with <10 km source location accuracy
- MXGS and MMIA are triggered by an onboard logic



Instruments and datasets

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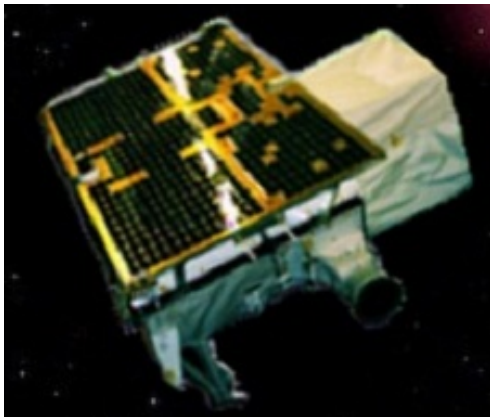
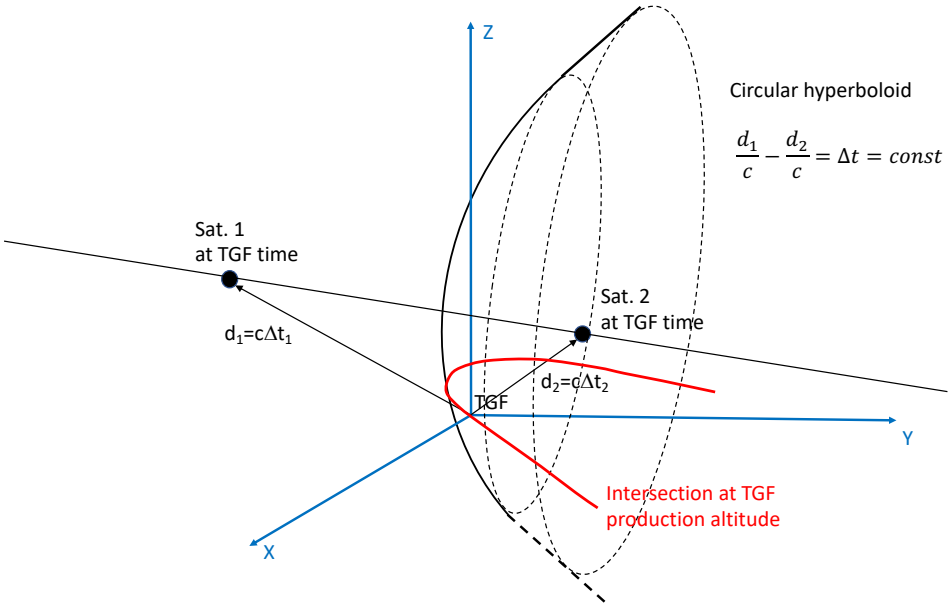
- **Fermi** is a NASA satellite dedicated to gamma-ray astrophysics in operations since 2008
- The **Gamma-ray Burst Monitor (GBM)** onboard Fermi is a segmented scintillation detector (12 x NaI + 2 x BGO) designed for Gamma-ray Burst (GRB) detection, but also highly sensitive to TGFs (Roberts et al., JGR 2017)
- GBM data are collected continuously, a TGF detection algorithm is run on ground (Briggs et al., JGR 2013)



- **AGILE** is an ASI (Italian Space Agency) satellite dedicated to gamma-ray astrophysics in operations since 2007
- The **Mini-Calorimeter (MCAL)** is a segmented scintillation detector (30 x CsI(Tl)) designed for GRB detection, but also highly sensitive to TGFs (Marisaldi et al., JGR 2015; Lindanger et al., JGR 2020; Maiorana et al., 2020)
- MCAL data are collected upon trigger on various time scales, the most relevant one for TGF science is 300μs

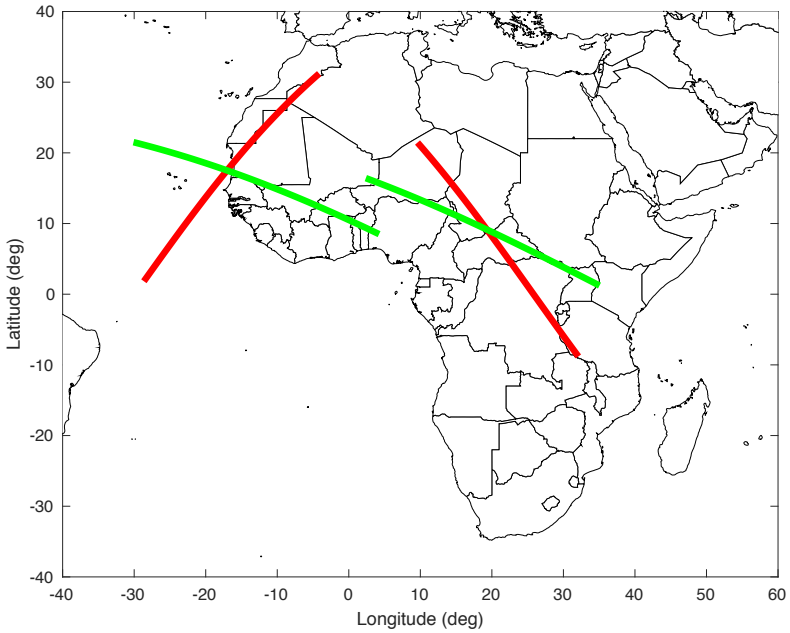
Methodology



- When the same event is detected at two different positions, the difference in arrival times determines the surface of a circular hyperboloid as possible source locations
- Intersecting this hyperboloid with the Earth geoid, assuming an appropriate production altitude, reduces the locus of possible sources to a curve

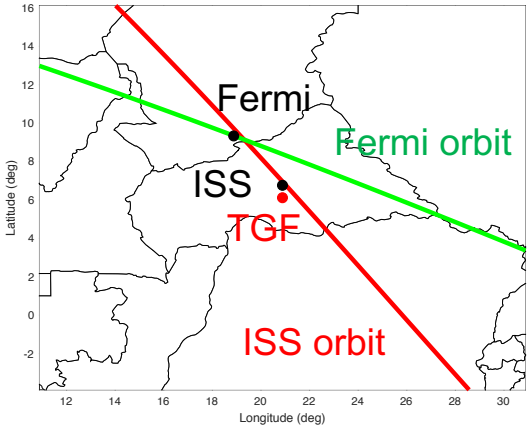
- Since time and position measurements have finite accuracy, this curve is rather a stipe, whose width is driven by the experimental uncertainties
- The most relevant uncertainty in this method is the absolute timing accuracy of the two satellites
- A candidate source, for example a lightning localized by the World Wide Lightning Location Network (WWLLN), must lie on this stripe, within the experimental errors

Methodology



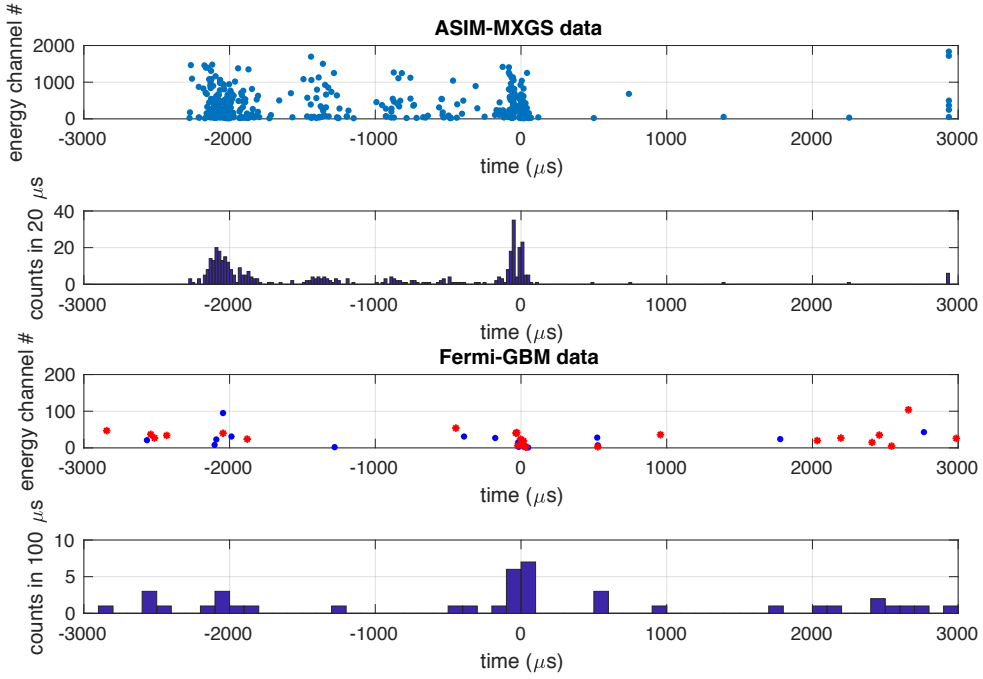
- We searched for ASIM TGFs with Fermi or AGILE within 1600 km radial distance from ASIM sub-satellite point
- We use WWLLN or Vaisala strokes to search for TGF source candidates
- Four TGFs were detected by two satellites: three by ASIM + Fermi, and one by ASIM + AGILE

RESULTS: TGF on 21-06-2018 16:00:52



- TGF observed above the Central African Republic, north of the Congo Basin
- Source tracked to a WWLLN match
- LED and MMIA data not available (daytime)
- Large difference in radial distance from source to satellites: optimal geometry to constrain emission cone

ASIM – FERMI light curves corrected for light propagation time from source



- Large difference in count statistics
- Multipeak structure evident in ASIM data only
- HED last peak appears double because of instrumental effects under very high flux condition

- This event is already presented in Østgaard et al., (2019) First 10 Months of TGF Observations by ASIM, JGR Atmospheres

RESULTS: TGF on 05-09-2018 01:51:11

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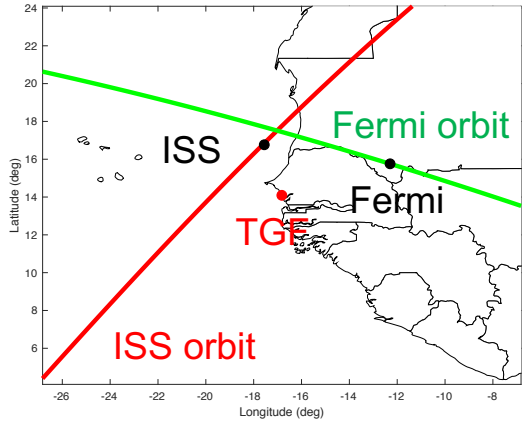
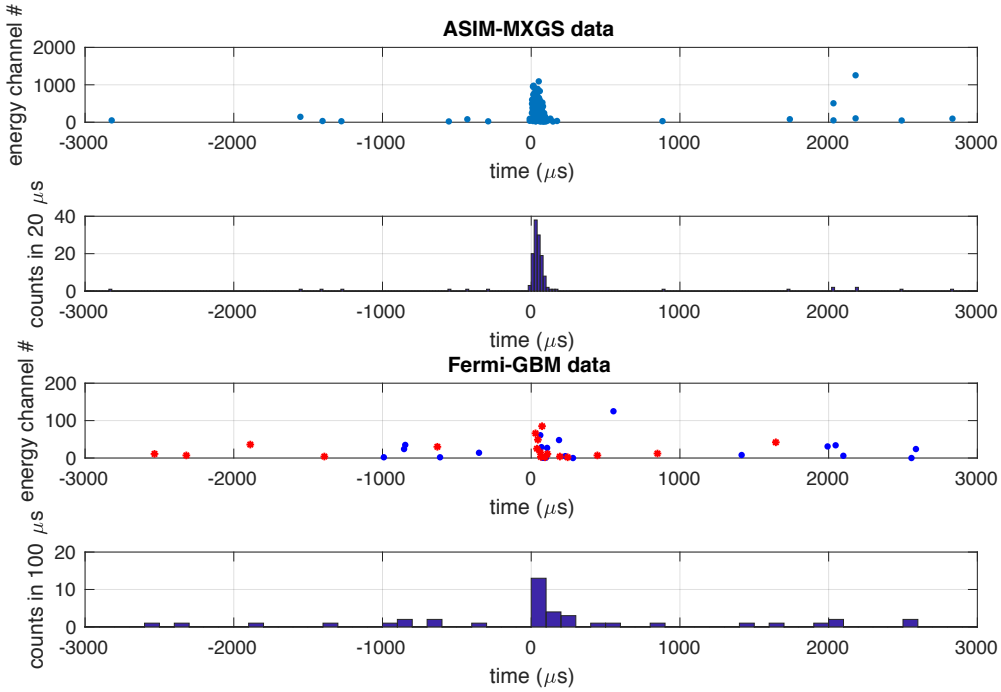


- TGF observed above the coasts of Senegal
- Source obtained also by MXGS imaging using LED data
- ASIM absolute timing with 20μs accuracy using two TLEs with WWLLN association observed by MMIA photometers 0.6s before TGF

ASIM – FERMI light curves corrected for light propagation time from source



Discussion

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- We performed GEANT4 based Monte Carlo simulations of a TGF RREA spectrum produced at different altitudes (9 to 19 km) and with a Gaussian angular distribution of initial photons with different sigma (10, 20, 30, 40 deg). Source is zenith directed.
- Photons are propagated through the atmosphere and recorded at satellite altitudes corresponding to ISS, Fermi and AGILE, for different radial distances with respect to source.
- Photon spectra at satellite altitude are passed through the ASIM mass model to estimate the ASIM effective area given the specific spectral shape and incoming direction.
- The observed fluences (photons/cm2) for the two spacecrafts are compared with various production models and geometries
- **Preliminary results suggest that observations are compatible with wide beam production geometries (sigma > 30 deg) and high production altitudes (15 km)**
- **Narrow beam geometries or low production altitudes are inconsistent with observations**
- **A publication is in preparation**