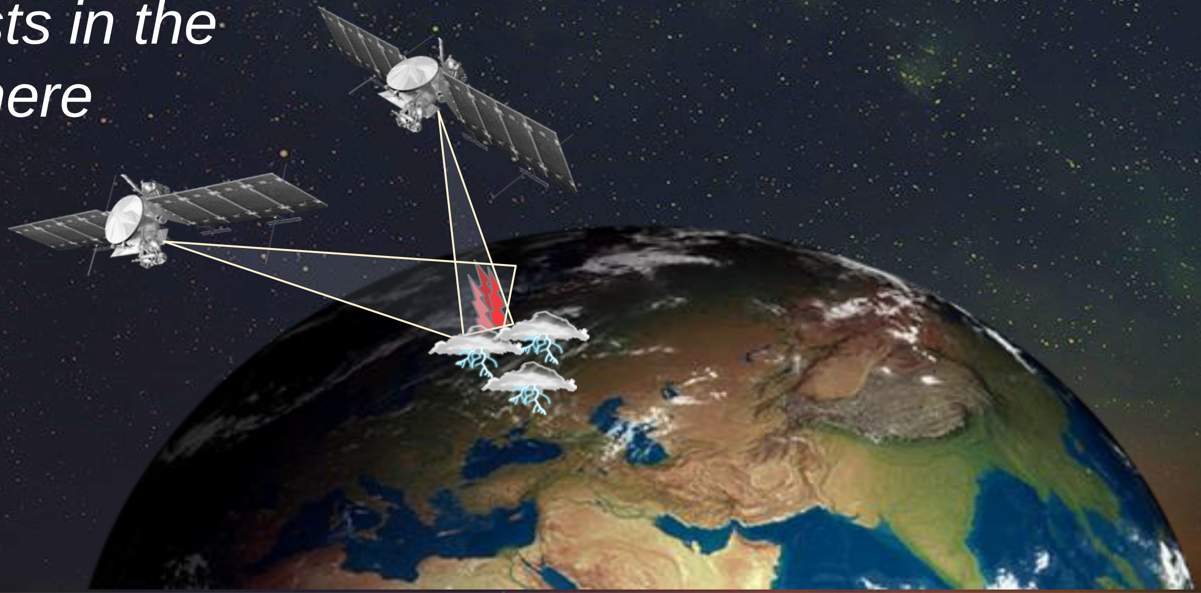
CASPER

chasing ghosts in the atmosphere



Alpbach Summer School 2022 - Team Blue


TeamBlue
SUMMER SCHOOL
ALPBACH 2022

Mission statement

The mission intends to investigate Transient Luminous Events (TLEs) and Terrestrial Gamma Flashes (TGFs).

TLEs and TGFs are plasma discharges in the lower and mid atmospheres, associated with high energy events emitting light, x-rays and gamma radiation. TLEs and TGFs are linked to high energy electrons.

The upper layer of the atmosphere is one of the least investigated areas of the atmosphere, due to the difficulty of reach. However, the TLE and TGF phenomenon has changed our understanding of the interaction between the atmosphere and the ionosphere.

Outline of the presentation

Science Case → Payload Design → Mission Design

Jonas Sinjan

- In 1989 ‘Sprites’ were first captured from ground

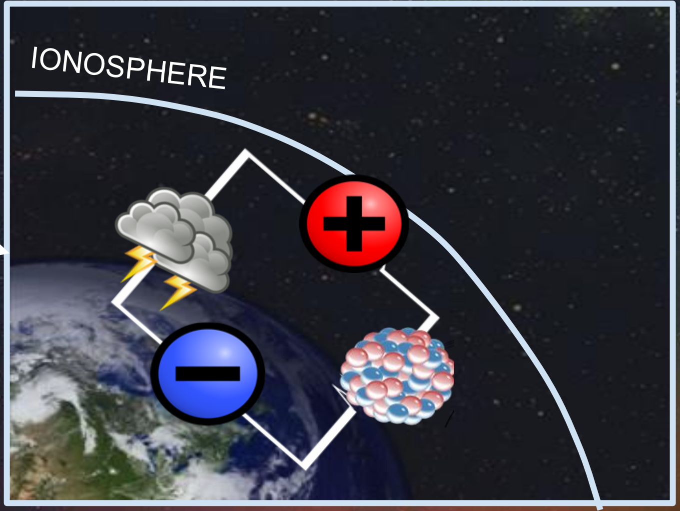
- Since 1989 many different types were detected

- Collectively called **Transient Luminous Events** (TLEs) and **Terrestrial Gamma Flashes** (TGF)

Discovery ramifications

- Revealed spontaneous transfers of energy from troposphere to the ionosphere
- Could affect chemical balance in upper atmosphere
- Could perturb population in radiation belts
- Could modify the **Global Electrical Circuit**
- New plasma physics mechanisms

[Blanc+ 2007]

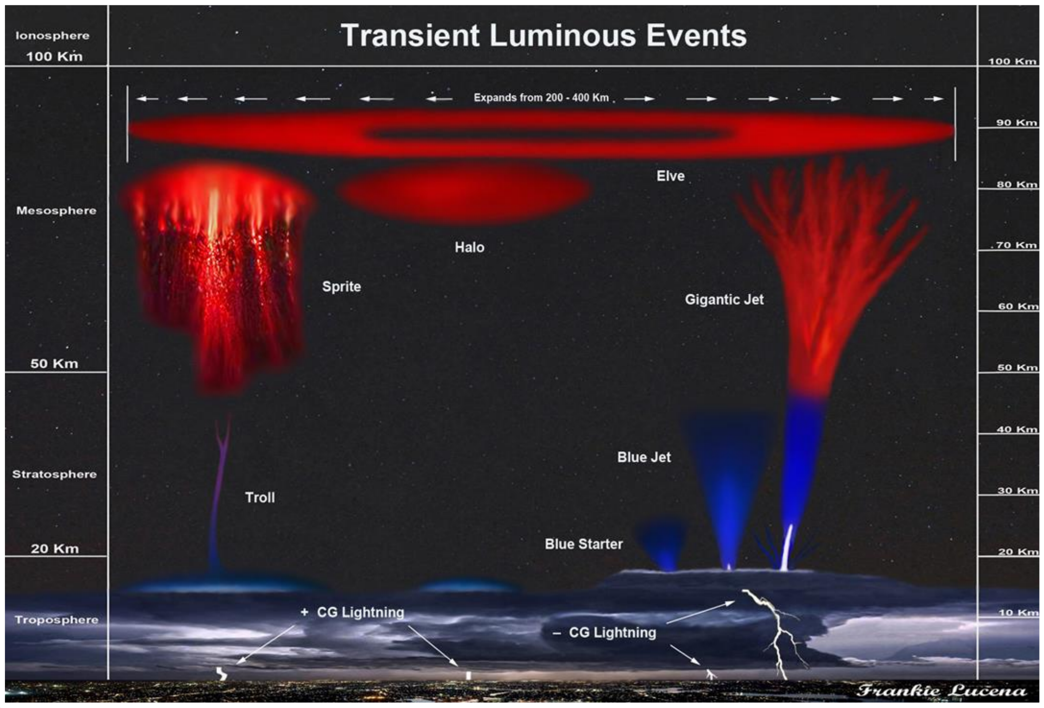


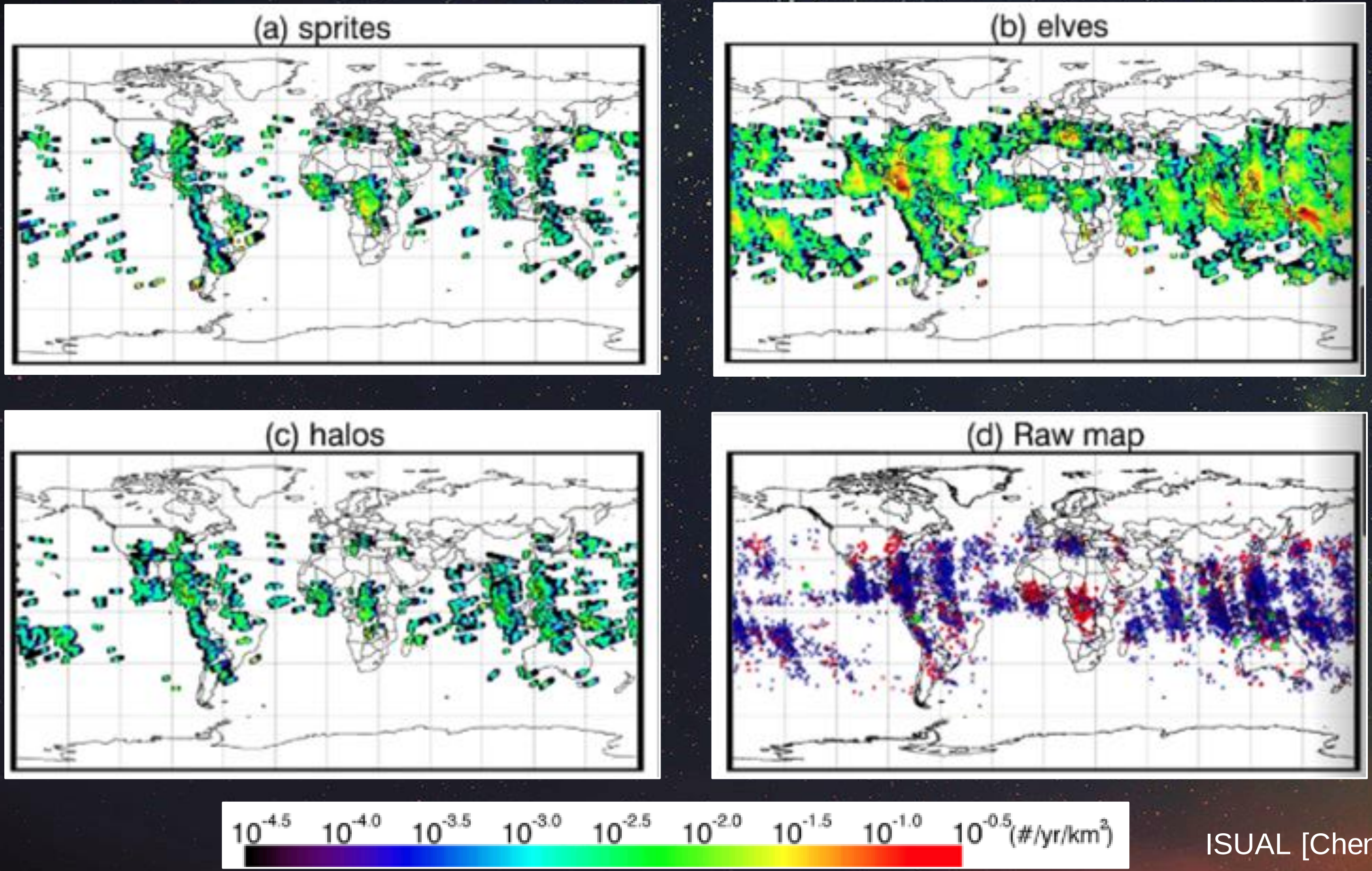
Transient Luminous Events (TLEs)

Transient Luminous Events (TLEs)

Different types of TLEs

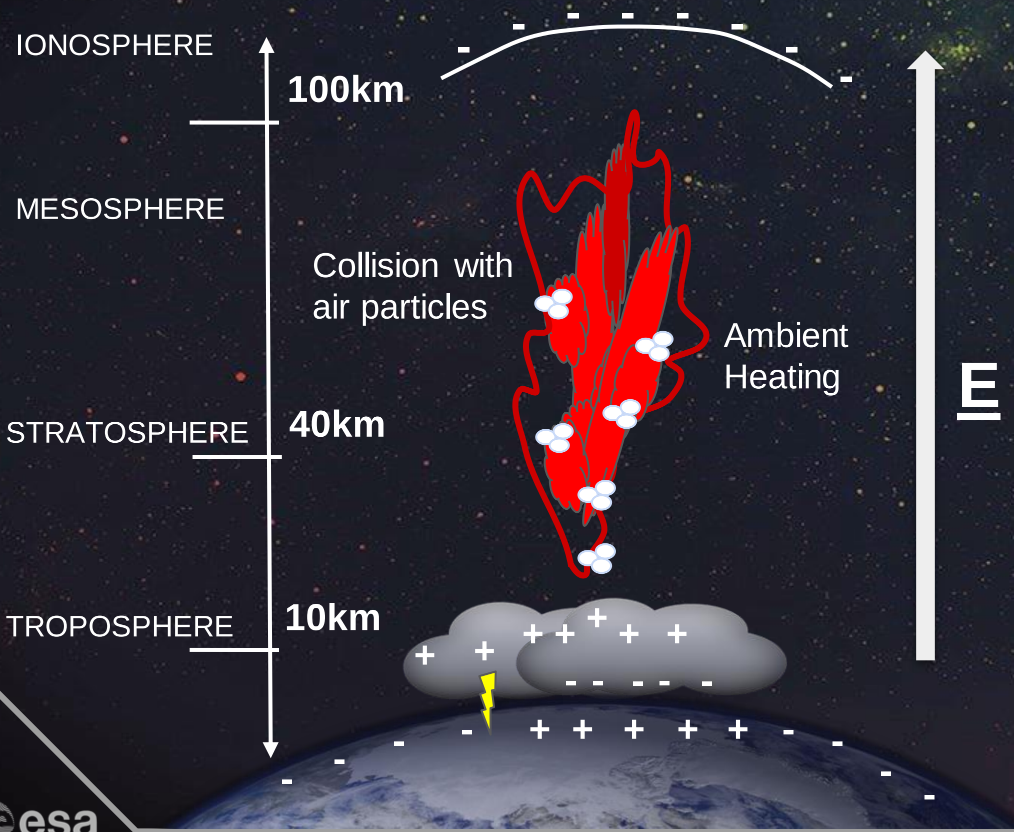
- Lifetime: < 1 - 5 ms
- Up to 500 km wide
  [Wescott+ 2001; Marshall+. 2006; Kuo+ 2013]
- Altitudes: 20 - 100 km
  [Blanc+ 2012]
- Typically seen between
  +65 and -65 deg latitude





ISUAL [Chen+2008]

Formation mechanism



Quasi-Electrostatic (QE) Model

- Charge build up in active thunderstorm
- Electric field between thunderstorm and ionosphere
- CG lightning or intracloud discharge triggers TLE
- Ambient heating and ionisation
- Collide and excite nitrogen molecules

[Pasko+ 1997; Pasko+2006]

Issues with the TLE formation mechanism theory

- Some TLEs detected many kilometers away from thunderstorms

- Some have a large temporal delay from lightning (90 ms)
  [Matsudo et al. 2009]

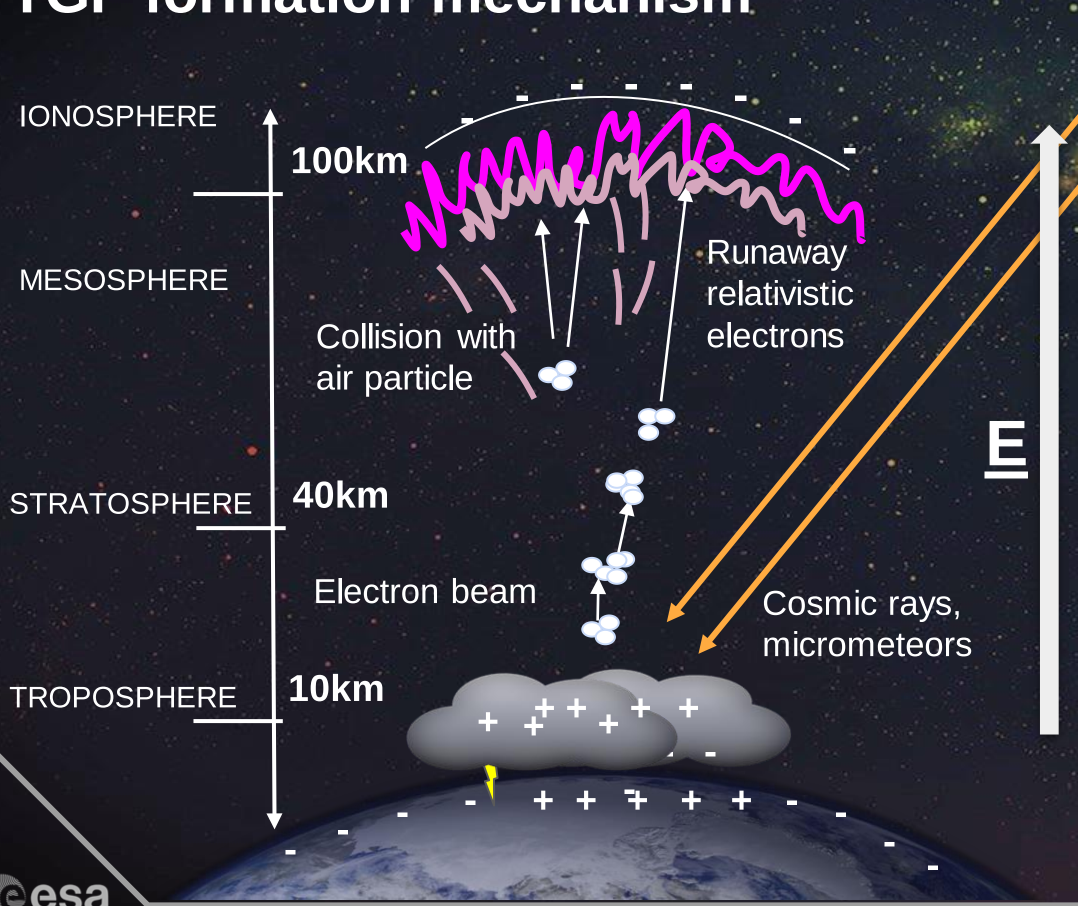
- Different types not explained
  [Blanc + 2007]

Terrestrial Gamma-Ray Flashes (TGFs)

Terrestrial gamma ray flashes

- TGFs are transient gamma-ray emissions, generated by electrons accelerated to relativistic energies in electric fields
- Energetic gamma rays with single photon energies of up to 40 MeV
- Lifetime: 10μs - 100μs
- Associated with lightning
  [Briggs+ 2010; Fishman+ 1994]
- Detected in low latitude regions like TLEs

TGF formation mechanism



- Proposed to be triggered by Cosmic Rays
- Secondary shower of electrons act as seed
- Runaway of electrons up to relativistic speeds

[Gurevich+ 1992, Roussel-Dupré+ 2005]

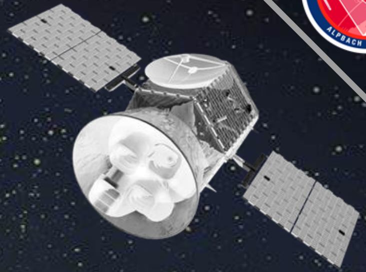
What is the comparative part of this mission?

- New fundamental plasma physics mechanisms
- Theoretical and experimental work has predicted that TLEs should be present on other planets
  [Yair+ 2009]
- Jupiter
  - The Juno mission observed 11 bright flashes with an average duration of 1.4 ms at 260 km altitude above the 1-bar-level. They have characteristics comparable to TLEs on earth
    [Giles+ 2020]
- Event comparison between earth and other planets will improve the understanding of the planetary atmospheric electrical activity

Why a space mission?

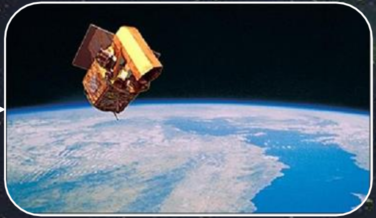
- Global mapping with large statistics
- Some types of TLEs detected over the ocean
- Range of environmental conditions (solar cycle, season, location, sea surface temperature)
- Absorption of wavelengths from the troposphere when on ground (blue wavelengths) [Chern+ 2003]
- Other options are locally (aircraft, ground, balloon, sounding rockets) and temporally restricted

Previous & complementary missions



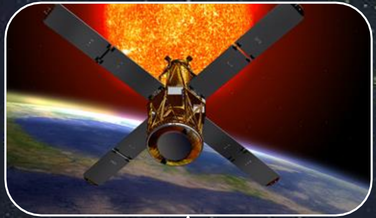
TLE

- FormoSat-2/ISUAL (2004-2015)
- SpriteSat (lost)



TGF

- RHESSI (2002-2018)
- Fermi (2008-present)
- AGILE (2007-present)

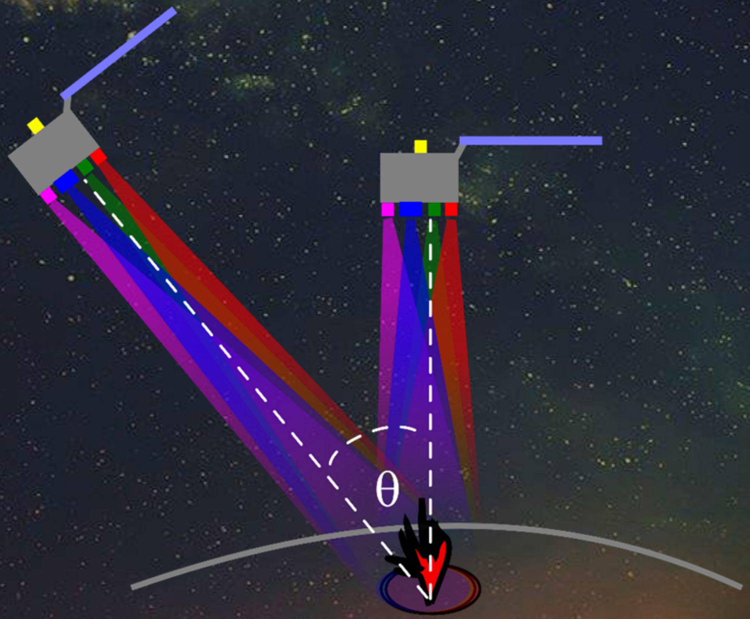


TLE & TGF

- TARANIS (lost)
- ASIM (2018-present)
- RELEC (2014-2014)

What distinguishes us from previous missions?

- CASPER is the first ever mission to observe upper atmospheric lightning in a stereo-configuration, allowing us to characterise the vertical structure of TLEs
- The mission will deliver the highest temporal optical imaging of TLEs to date from space



Complementary data

- Sea surface temperature [PO.DAAC]
- Magnetic field eg: Swarm
- Coordinated observations with ground observers [eg: Peng+ 2017]
- Solar cycle activity eg: SDO / STEREO / ACE
- Micrometeorites [Wescott+ 2001]

Expected detected events

Type	Raw Occurrence /Min	Detections/Mission Year
Elves	3.62	~1800
Halos	0.37	~180
Sprites	0.42	~230
Gigantic Jets	0.01	~5

	Detection Rate / Day	Detections/Mission Year
TGF	0.5	~180

Want 4 years observing time to collect > 20 GJ

0.09% area/min

[Hsu+2009, Chen+2008, Østgaard+2019]

Science Objectives and Requirements

Scientific objectives

- SO-1: Constrain the mechanism by which TLEs and TGFs originate and their link
  - SSO1: Characterize the spatial and temporal connection between thunderstorms, TGFs and TLEs
- SO-2: Constrain the extent to which TLEs and TGFs play a role in the interaction between the atmosphere, ionosphere and magnetosphere
  - SSO2: Quantify the energy transfer to the upper atmosphere and space
- SO-3: Identify the influence of environmental conditions
  - SSO3: Measure data over a spectrum of different environmental conditions, including but not limited to: solar cycle, sea surface temperature, geographic position

Scientific requirements

SR-1: Global Mapping of TLEs and TGFs

SR-2: Spatially resolve TLEs horizontally and vertically

SR-3: Temporally resolve TLEs and TGFs

SR-4: Measure energy spectrum of the TLEs and TGFs

SR-5: Detect electron flux from TLEs and TGFs

SR-6: Discriminate downward from upward electron fluxes

SR-7: Identify lightning events

Measurement requirements

- MR-1: Vertical structure
- MR-2: Minimum spatial resolution of 0.5 km (horizontal + vertical)
- MR-3: Minimum temporal resolution of 0.3 ms
- MR-4: Observational wavelengths required
  - SMR-1: 762 nm (mainly N_2 1P)
  - SMR-2: 777 nm (mainly O_2)
  - SMR-3: 150-280 nm (N_2 LBH UV band) [Blanc, 2010]
  - SMR-4: Gamma rays up to 10 MeV
  - SMR-5: X-rays from 20 keV
- MR-5: Upwards propagating electrons of 10 keV-10 MeV along the magnetic field lines (requires polar orbit)
- MR-6: Downwards propagating electrons of 30 keV-300 keV

Traceability matrix

Scientific objective	Scientific requirement	Measurement requirement
SSO-1	SR-1	MR-1, MR-2, MR-3, MR-4, MR-5, MR-6
	SR-2	MR-1, MR-2
	SR-3	MR-3
	SR-7	MR-4
SSO-2	SR-2	MR-1, MR-2
	SR-3	MR-3
	SR-4	MR-4
	SR-5	MR-5
SSO-3	SR-1	MR-1, MR-2, MR-3, MR-4, MR-5, MR-6
	SR-2	MR-1, MR-2
	SR-3	MR-3

Traceability SSO-1

Scientific objective	Scientific requirements	Measurement requirements
SSO-1	SR-1	MR-1, MR-2, MR-3, MR-4, MR-5, MR-6
	SR-2	MR-1, MR-2
	SR-3	MR-3
	SR-7	MR-4

Traceability SSO-1

Scientific objective	Scientific requirements	Measurement requirements
SSO-1	SR-1	MR-1, MR-2, MR-3, MR-4, MR-5, MR-6
	SR-2	MR-1, MR-2
	SR-3	MR-3
	SR-7	MR-[illegible]

Constrain the mechanisms by which TLEs and TGFs originate

Temporally resolve TLEs and TGFs

Minimum temporal resolution of 0.3 ms

Outline of the presentation

Science Case

Payload Design

Mission Design

Gwendal Henaff

System drivers

INSTRUMENTS

- Spatial + temporal resolution
- Electron flux measurement
- Emission wavelengths

ORBITAL CHARACTERISTICS

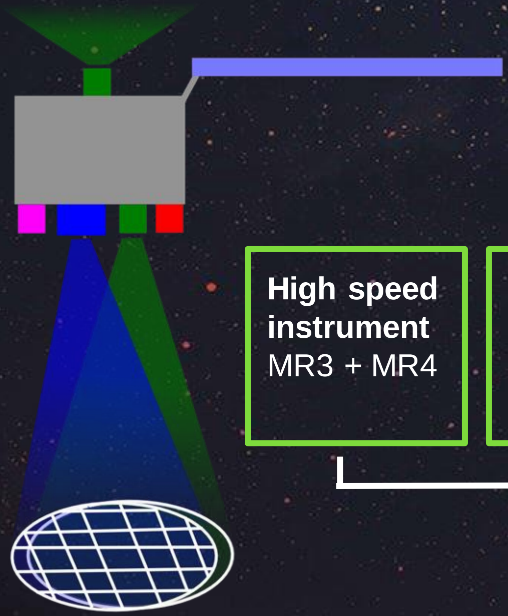
- Stereography
- Global coverage
- Electron flux measurement

MISSION DESIGN

- Data volume
- Power

On-board instrumentation

High speed (MR3) and high resolution (MR1 + MR2) needs : conflicting requirements



High speed instrument
MR3 + MR4

High speed instrument
MR3 + MR4 + MR5

High speed instrument
MR3 + MR4 + MR5

High speed instrument
MR3 + MR4 + MR6

High resolution instrument
MR2

Measurement requirements
MR1 : Vertical structure
MR2 : Horizontal + vertical spatial resolution < 0.5 Km
MR3 : temporal resolution < 0.3 ms
MR4 : Frequency observations : 762 nm, 777 nm, 200 nm, X-ray to Gamma (20 keV - 10 MeV)
MR5 : upwards electrons count between 10 keV and 10 MeV
MR6 : Downwards electrons count between 30 keV and 300 keV

On-board Instrumentation

UPVIS:
UV + 740-780nm + IR photometer
1px
300 Hz
MR3 MR4

IPG:
γ-ray scintillator
1px
300 Hz
MR3 MR4 MR5

IPXI:
γ + X-ray scintillator
1px
300 Hz
MR3 MR4 MR5

High speed trigger instruments

ROTCAM:
CMOS camera
1024 x 1024 px
762 nm, 777 nm, 200 nm
60 Hz
MR2

Low speed high resolution instrument

DELEC:
Scintillator
300Hz
pointing upwards
MR6

FLY-IP:
On-board image processing for data selection

Measurement requirements
MR1 : Vertical structure
MR2 : Horizontal + Vertical spatial resolution < 0.5 Km
MR3 : temporal resolution < 0.3 ms
MR4 : Frequency observations : 762 nm, 777 nm, 200 nm, X-ray to Gamma (20 keV - 10 MeV)
MR5 : upwards electrons count between 10 keV and 10 MeV
MR6 : downwards electrons count between 30 keV and 300 keV

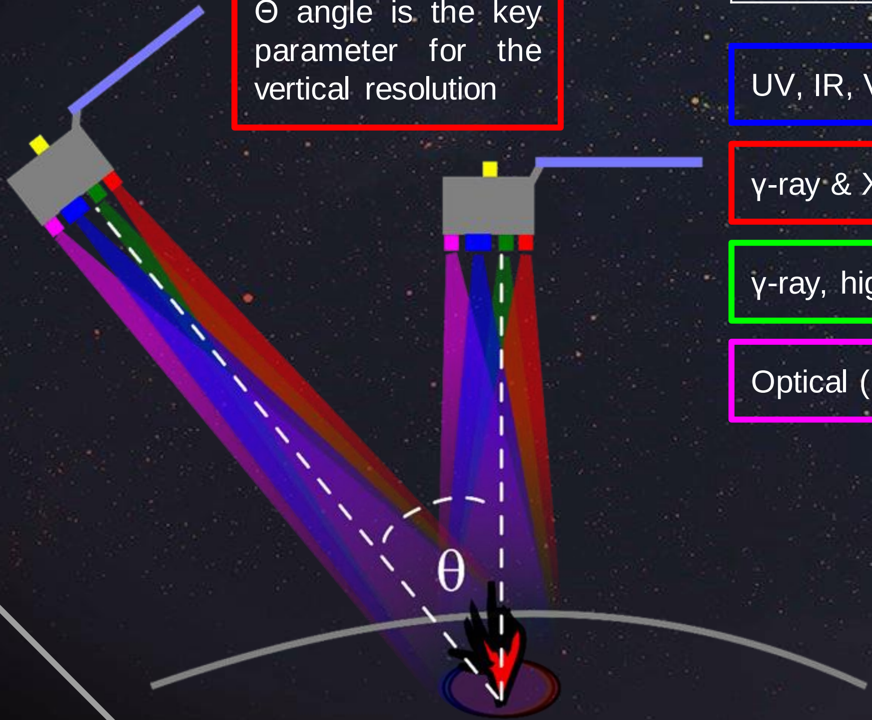
esa

Observation concept

Measurement requirements

MR1 : vertical structure
MR2 : horizontal + vertical spatial resolution 0.5km

Θ angle is the key parameter for the vertical resolution

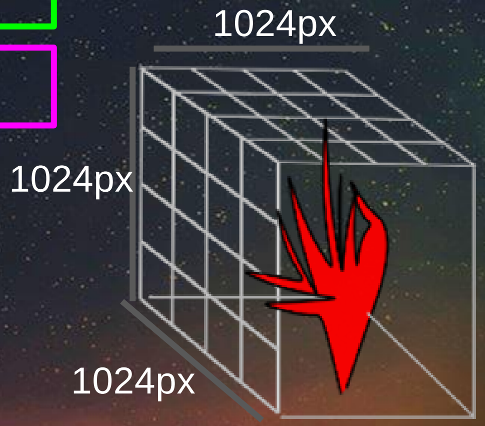


UV, IR, VIS, high res. images

γ-ray & X-ray, high rate trigger

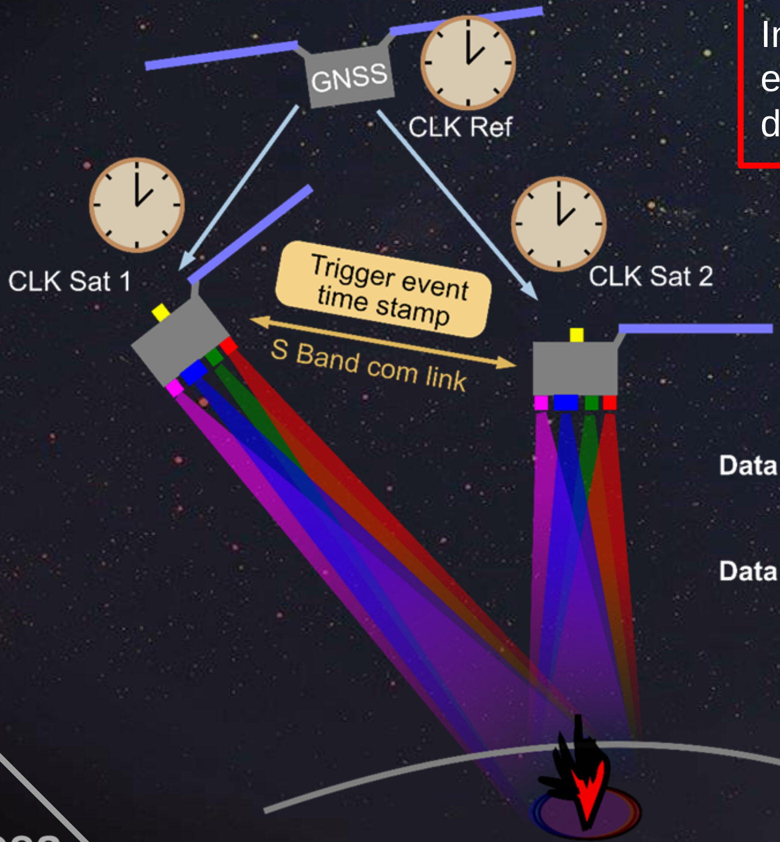
γ-ray, high rate trigger

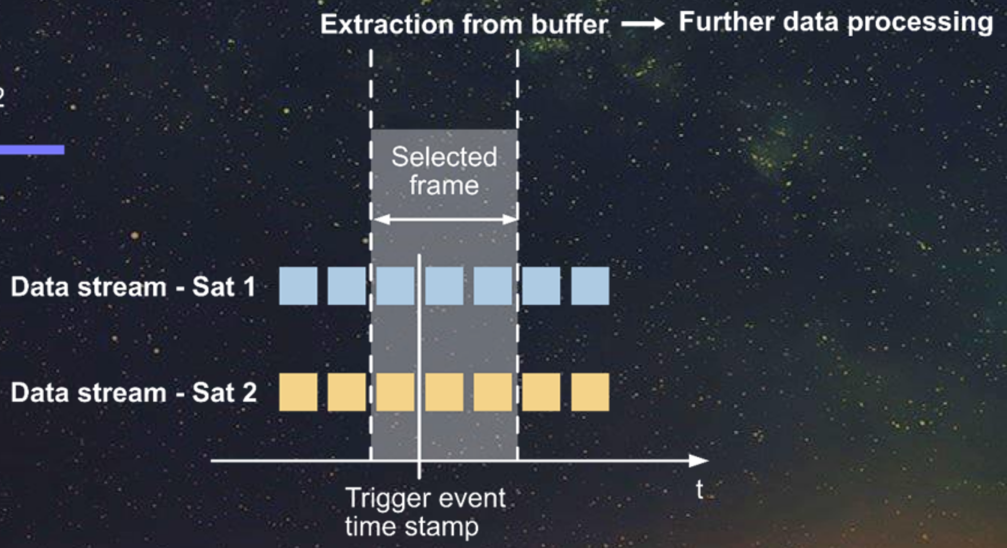
Optical (IR) / UV, high rate trigger



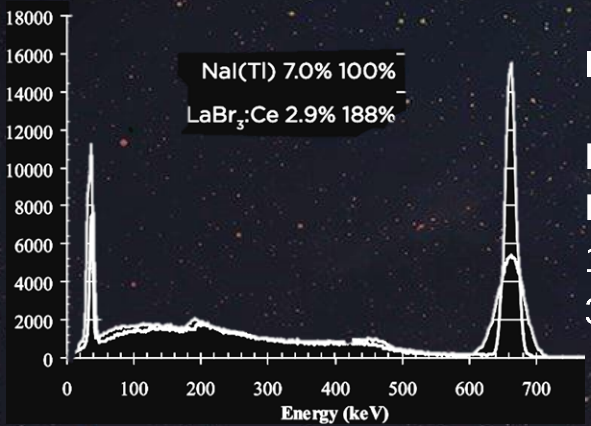
Measurement synchronization

In case of a trigger event, the trigger timestamp is exchanged between the satellites for synchronous data extraction.



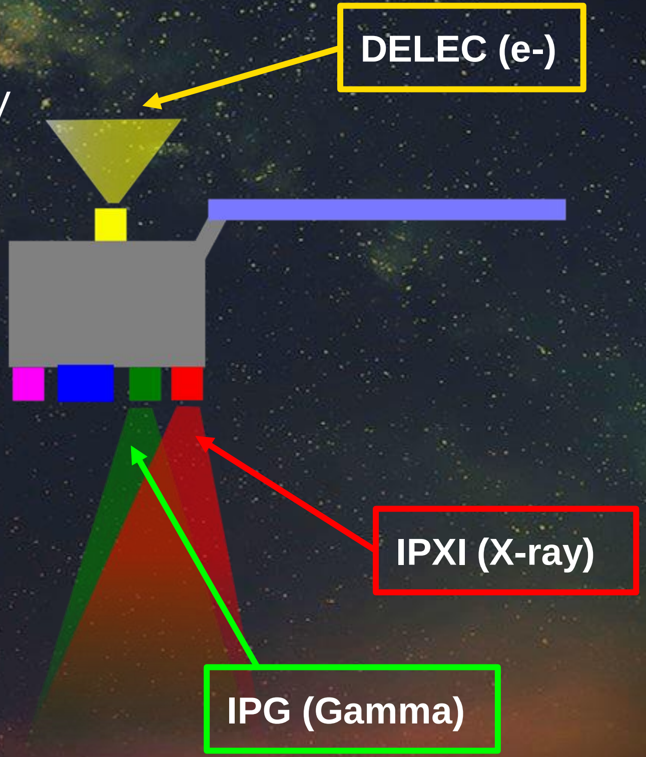


Fast trigger-X-ray, gamma, electrons



IPG / IPXI / DELEC

Photon range : 20 keV to 10 MeV
Electrons : 1 MeV to 10 MeV
1 pixel
300 Hz



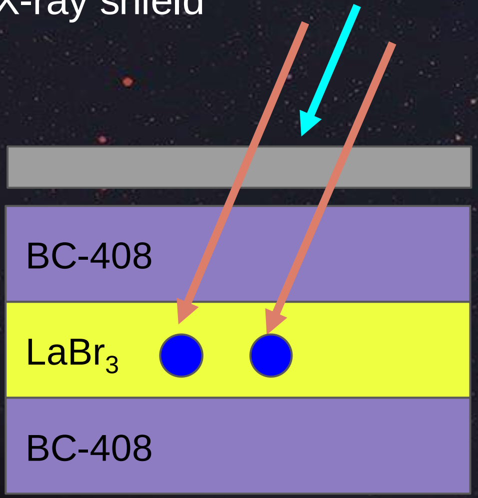
Three versions:

- DELEC : No filter, pointing upwards
- IPXI : No x-ray shield, pointing downwards
- IPG : With x-ray shield pointing downwards, gamma measurements

Fast trigger-X-ray, gamma, electrons

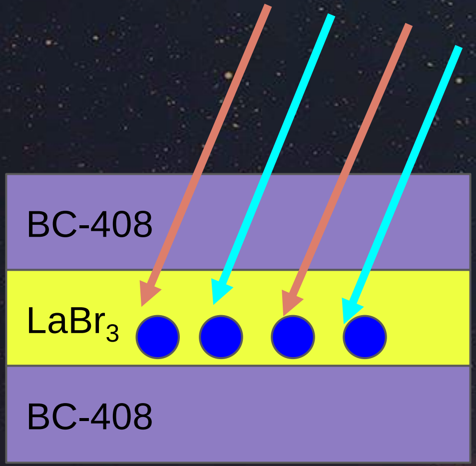
IPG
Photon range : 60 keV to 10 MeV

Gamma and X-rays with X-ray shield

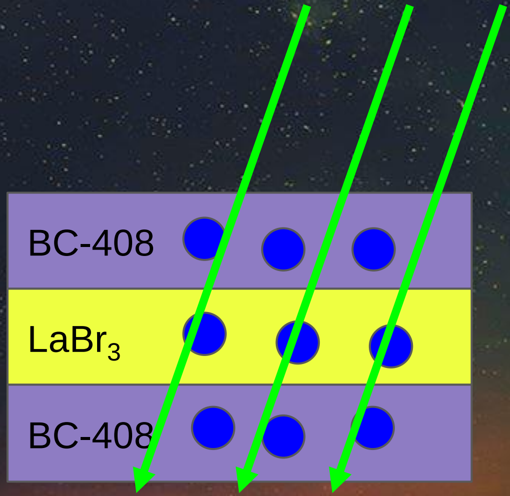


IPXI
Photon range : 20 keV to 10 MeV

Gamma and X-rays



DELEC
Electrons : 1 MeV to 10 MeV

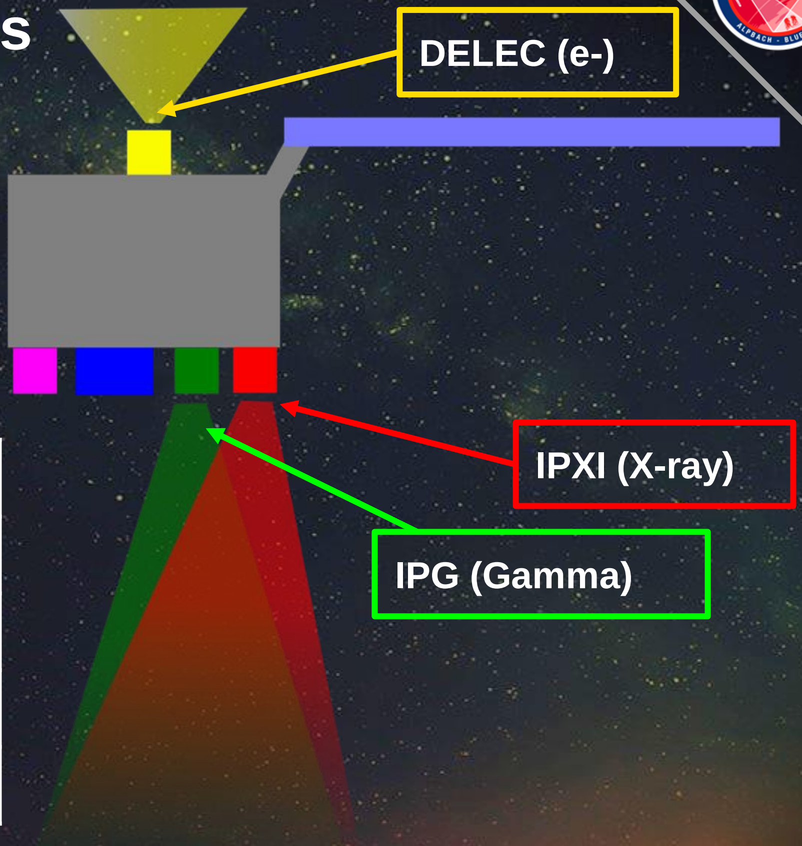


Fast trigger-X-ray, gamma, electrons

IPG / IPXI / DELEC

- Crystal scintillators
- High voltage power supply
- PMT

Readiness :	TRL 8, no flight heritage
Power :	~2W
Effective area :	~ 900 cm^2
FOV :	40°
Mass (individual) :	~500 g



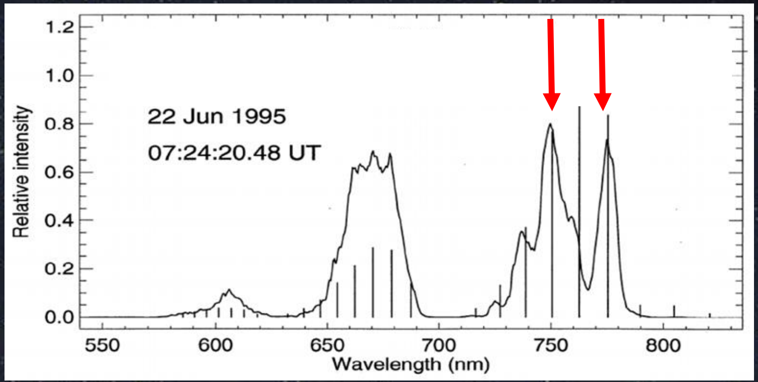
Fast trigger-UV/IR/optical

UPVIS - Optical photometer

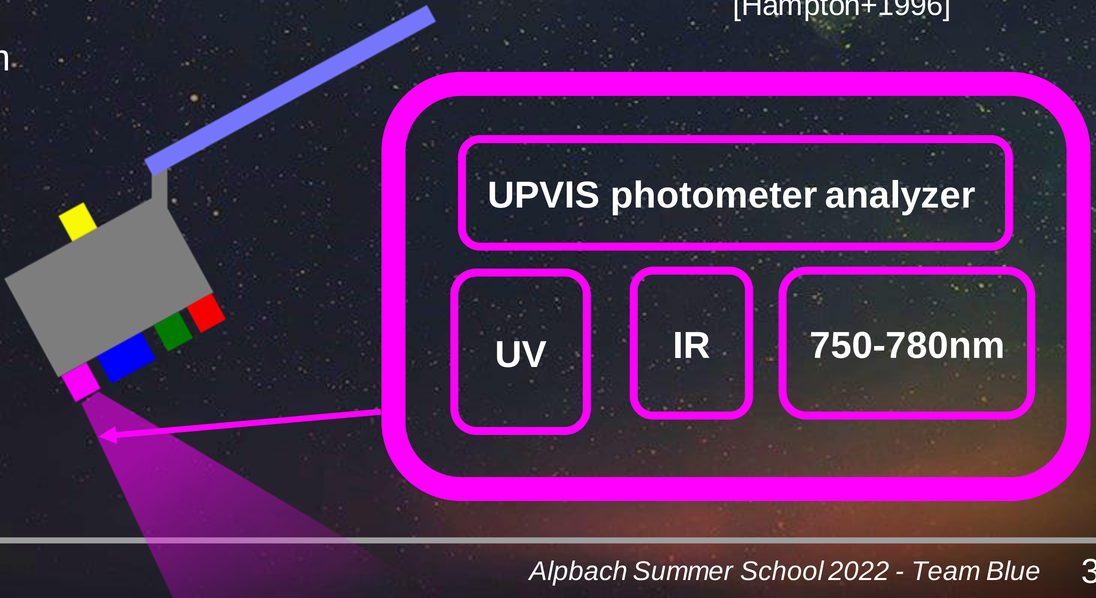
- Most intense line of the N_2 at 750 -780 nm
- 762 nm for sprite
- 777 nm for lightning
- N_2 Lyman-Birge-Hopfield (LBH) UV band system from 150 to 280 nm

Photometer analyzer

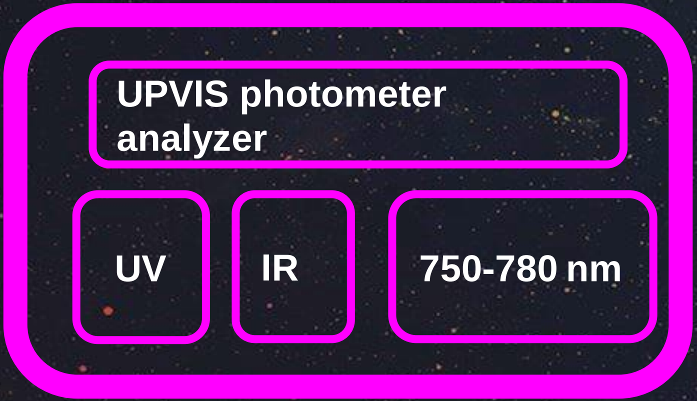
- Photomultiplier
- High voltage supply
- Acquires signals from the sensor



[Hampton+1996]

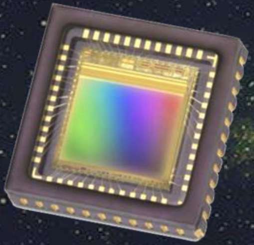


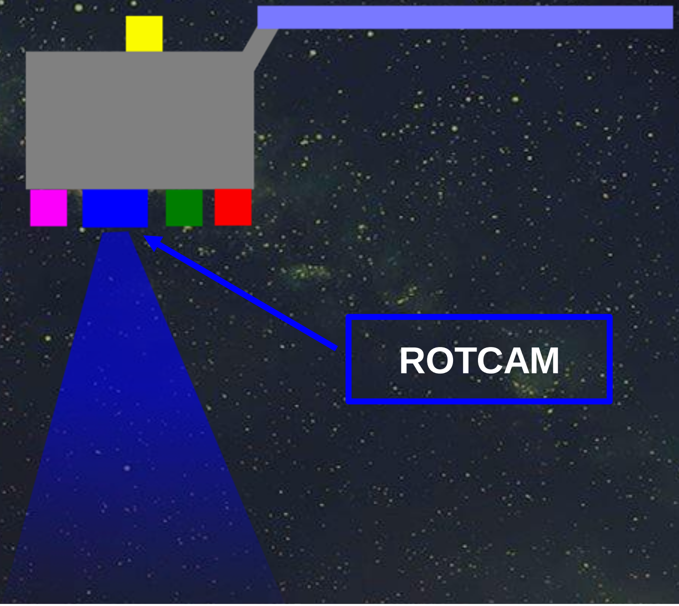
Fast trigger-UV/IR/optical



Readiness :	TRL 7, no flight heritage
Power :	<6 W
FoV :	40° (nadir) 12° (limb)
Mass :	~2.5 kg
Size:	185 x 127 x 200 mm

Imaging detectors





3 ROTCAM

- Teledyne Ruby EV76C660
  Wavelengths:
  1. Ultraviolet (193-400 nm)
  2. Visible (400-700 nm)
  3. Near Infrared (700-1000 nm)

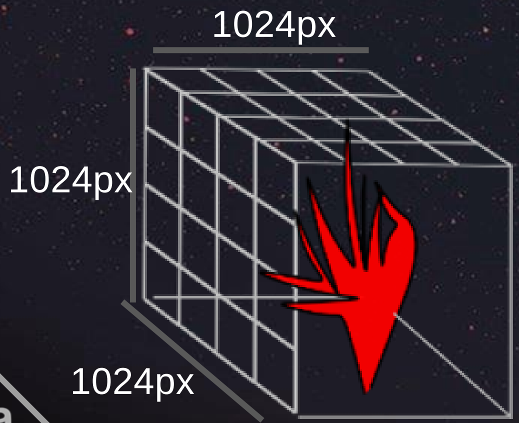
- CMOS 1280x1024 px (1.3 MP)
- Image size 1024 x 1024
- 60 fps full resolution readout
- 5.3 µm pixel size

Readiness:	TRL 6, no flight heritage
Power:	<1W
FoV:	40° (nadir) 12° (limb)

Instrument concept

ROTCAM:
3x CMOS Camera
1024x1024 px
60 Hz

Length of one TLE / TGF : 10ms - 100ms



- 15 events / day
- 150 false events / day
- 3 Mbyte per frame
- 1 Mbyte/s for the triggers
- 30 frames per event
- 2*3 cameras, 2*7 triggers

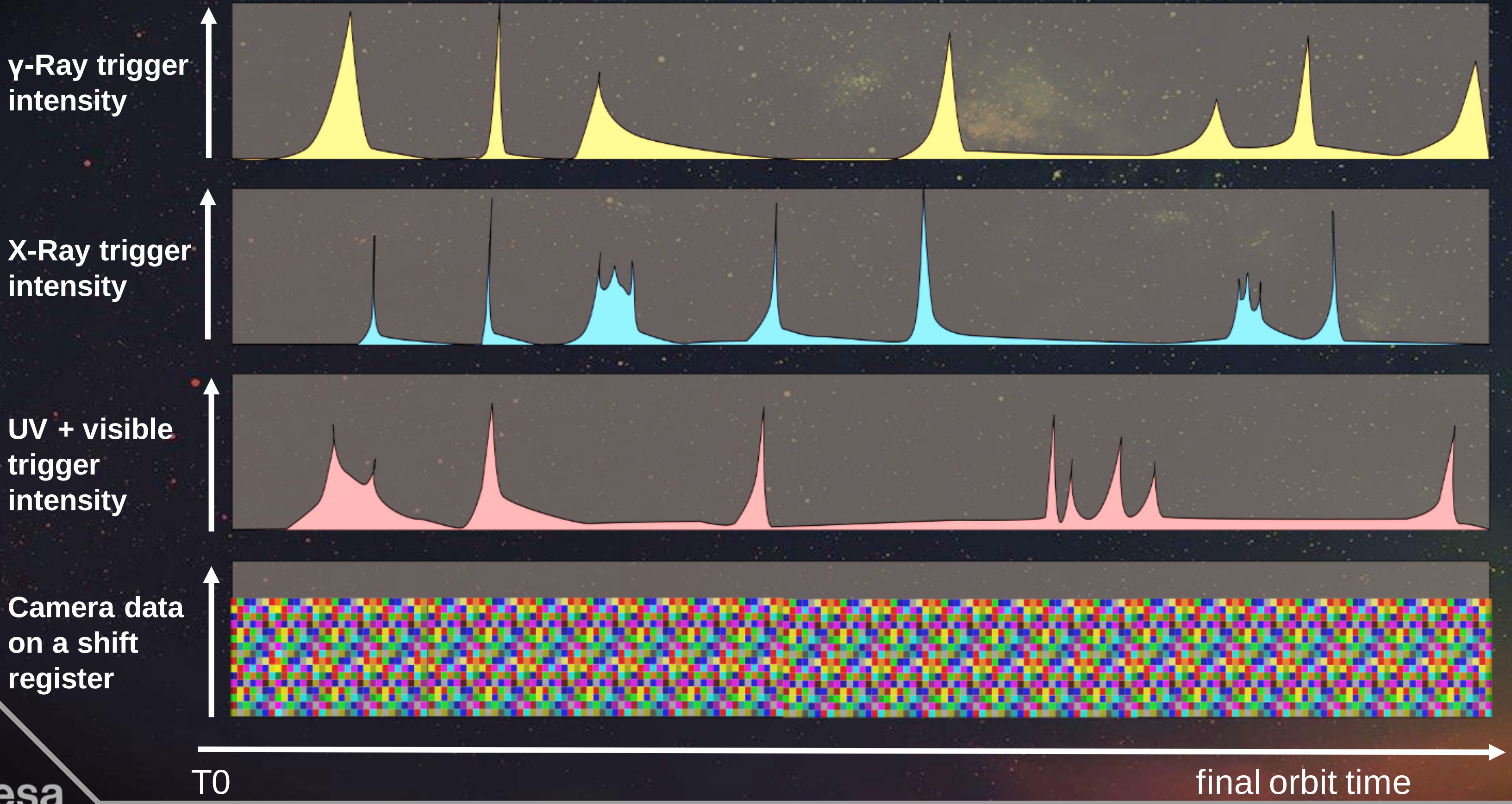
Estimated data collection per day :

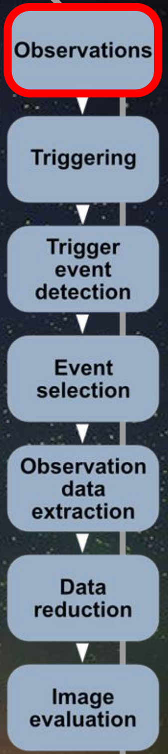
> 90 Gbytes / day for the camera data
> 5 Gbytes / day for the triggers data

High data load requires efficient on-board data processing

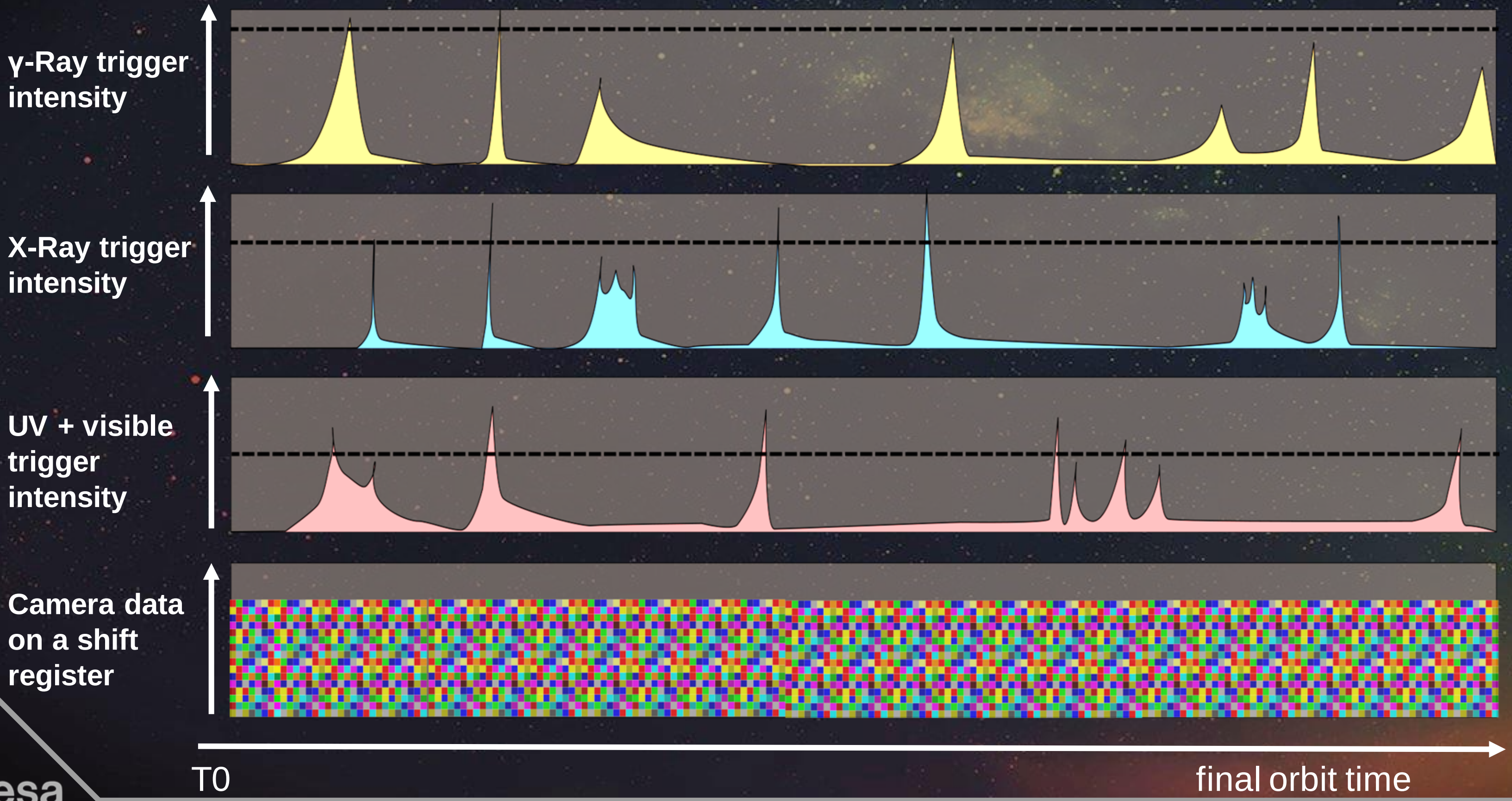
FLY-IP : FPGA encoded in-flight image processing for parametric area selection and data reduction

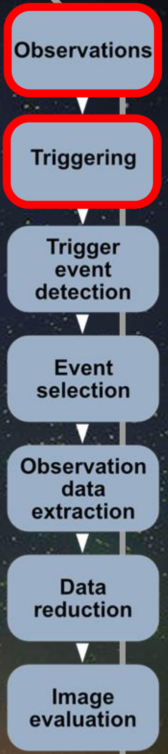
Data collection over one orbit



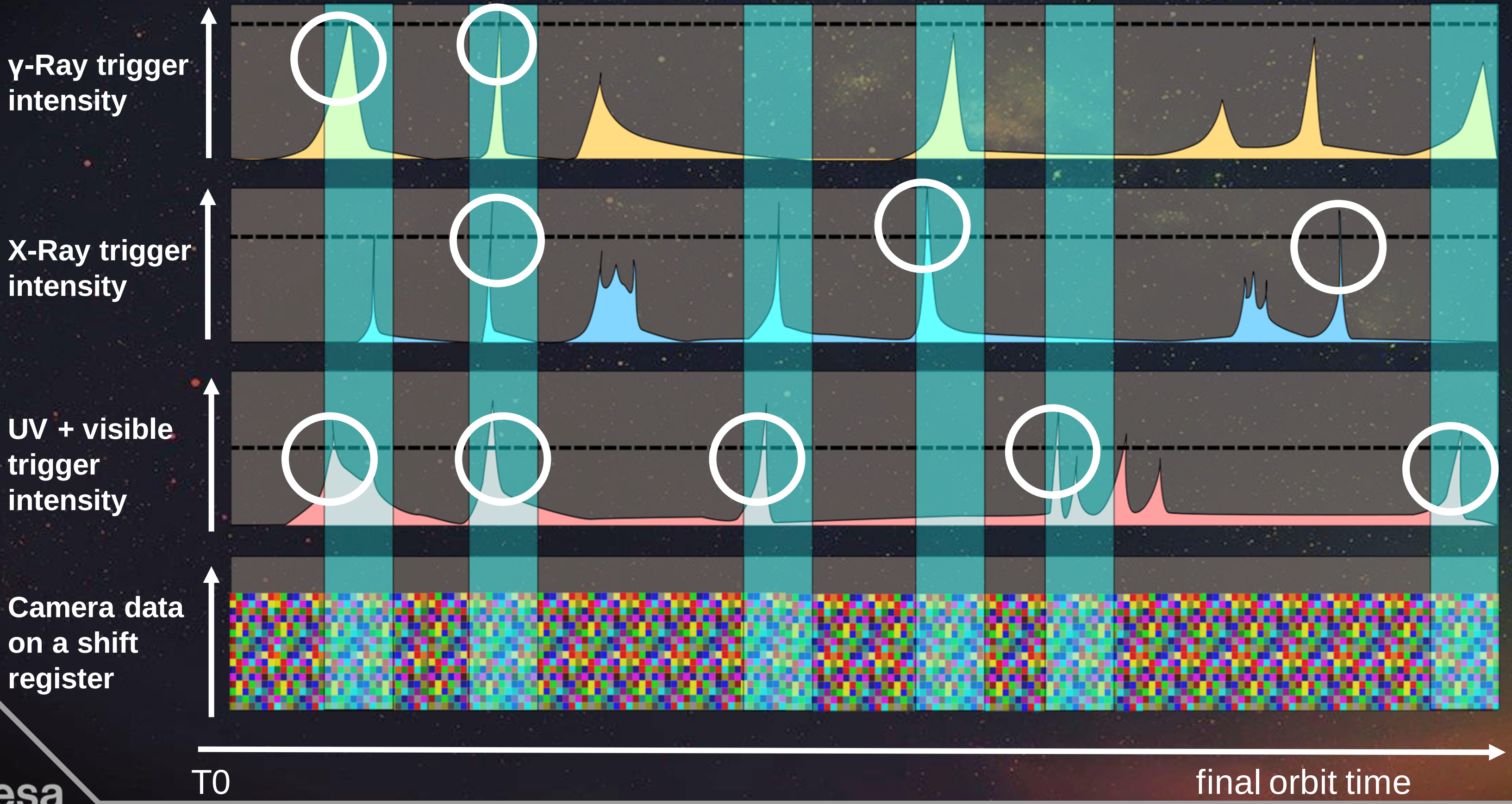


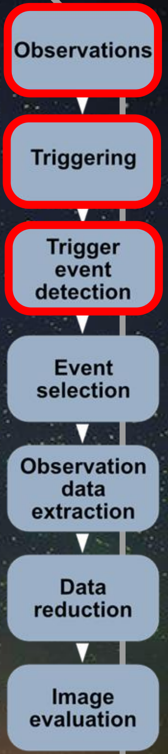
Data collection over one orbit, threshold positioning





Data collection over one orbit, detection of trigger events





Data collection over one orbit

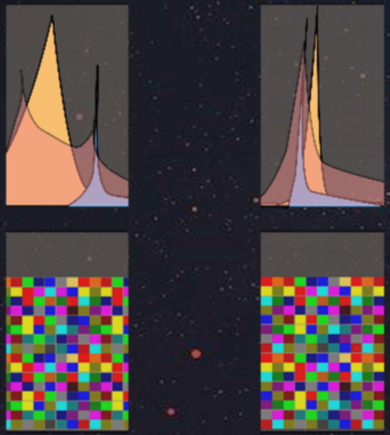
Each dataset sent to the buffer will have a length of 30 frames to cover the time gap between trigger and event

The mean time between two events is enough to write from the buffer to the hard memory

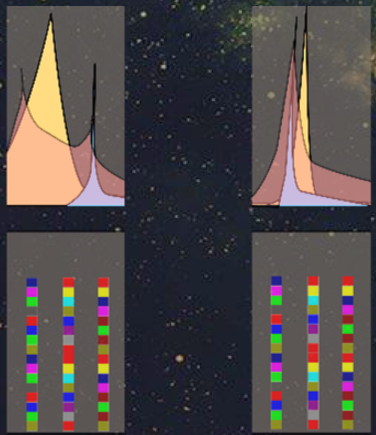
- Observations
- Triggering
- Trigger event detection
- Event selection
- Observation data extraction
- Data reduction
- Image evaluation

Data collection over one orbit

set #1 set #2



set #1 set #2



Each dataset has now a size of 30 frames of 1024x1024 pixels encoded on 3 bytes per frame:

One dataset is 30 Mbytes

An event will extend on 3 frames maximum:

first level processing reduces this data to 3 frames : 3 Mbytes

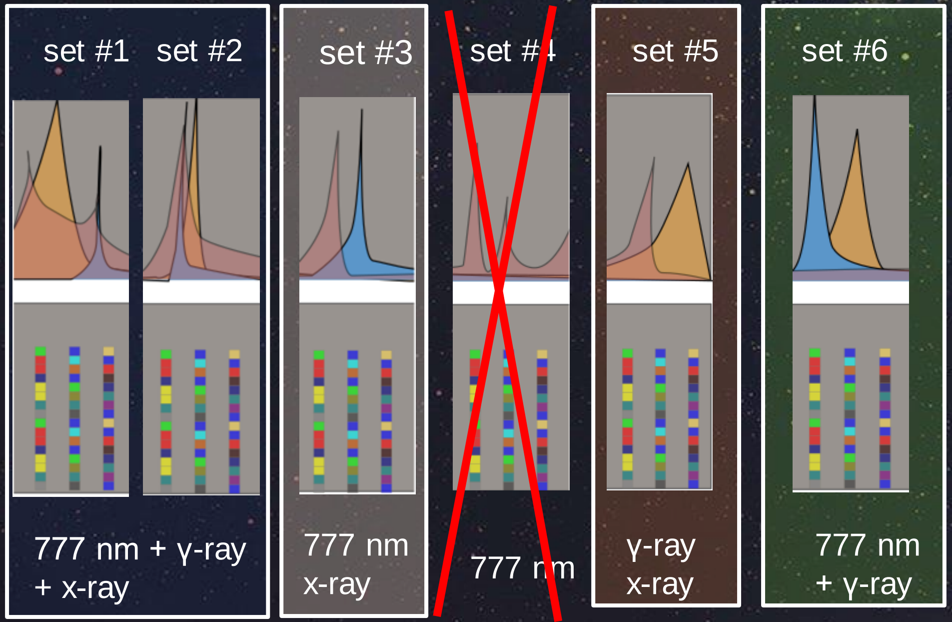
raw data sets in memory : 30 Mb each

selected data sets in memory : 3 Mb each

FPGA encoded in-flight image processing for parametric area selection and data reduction

Observations
Triggering
Trigger event detection
Event selection
Observation data extraction
Data reduction
Image evaluation

Data collection over one orbit



raw data sets in memory : 30 Mb each

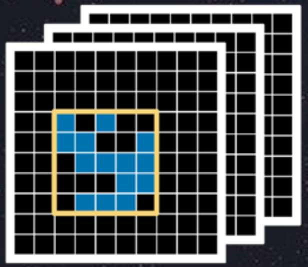
selected data sets in memory : 3 Mb each

FPGA encoded in-flight image processing for parametric area selection and data reduction

- Observations
- Triggering
- Trigger event detection
- Event selection
- Observation data extraction
- Data reduction
- Image evaluation

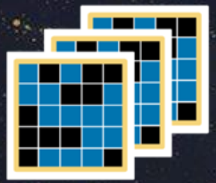
Image processing

Data reduction (onboard)



Parametric area selection

Data transfer (onboard)



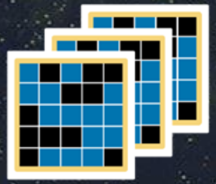
Meta data

Trigger

Collection of relevant images, meta data, trigger signals

Data downlink

Data evaluation (science center)



Meta data

Trigger

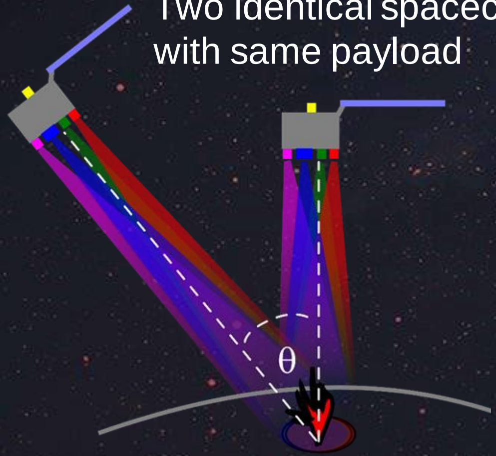
Auxiliary data

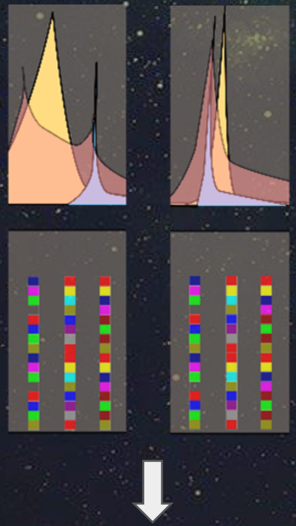
Fusion with auxiliary data from other sources and detailed data evaluation

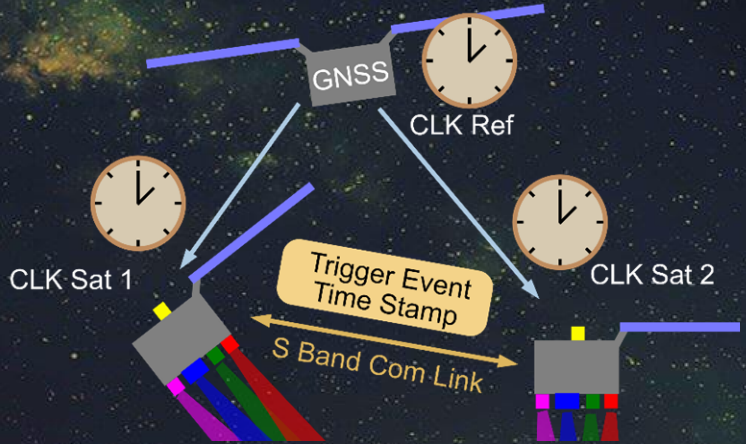
Observations
Triggering
Trigger event detection
Event selection
Observation data extraction
Data reduction
Image evaluation

Instrumentation summary

Two identical spacecraft with same payload







5 instruments :
High frequency triggers : **IPXI, IPG, UPVIS**
High spatial resolution instrument : **ROTCAM**
Down electrons sensor : **DELEC**

Standard data set :
ROTCAM frames
IPXI, IPGI, IPVIS data

Synchronized clock time and time stamps in the meta data

Outline of the presentation

Science Case

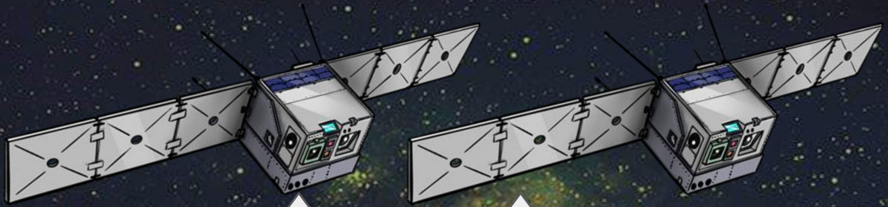
Payload Design

Mission Design

Loui Byrne

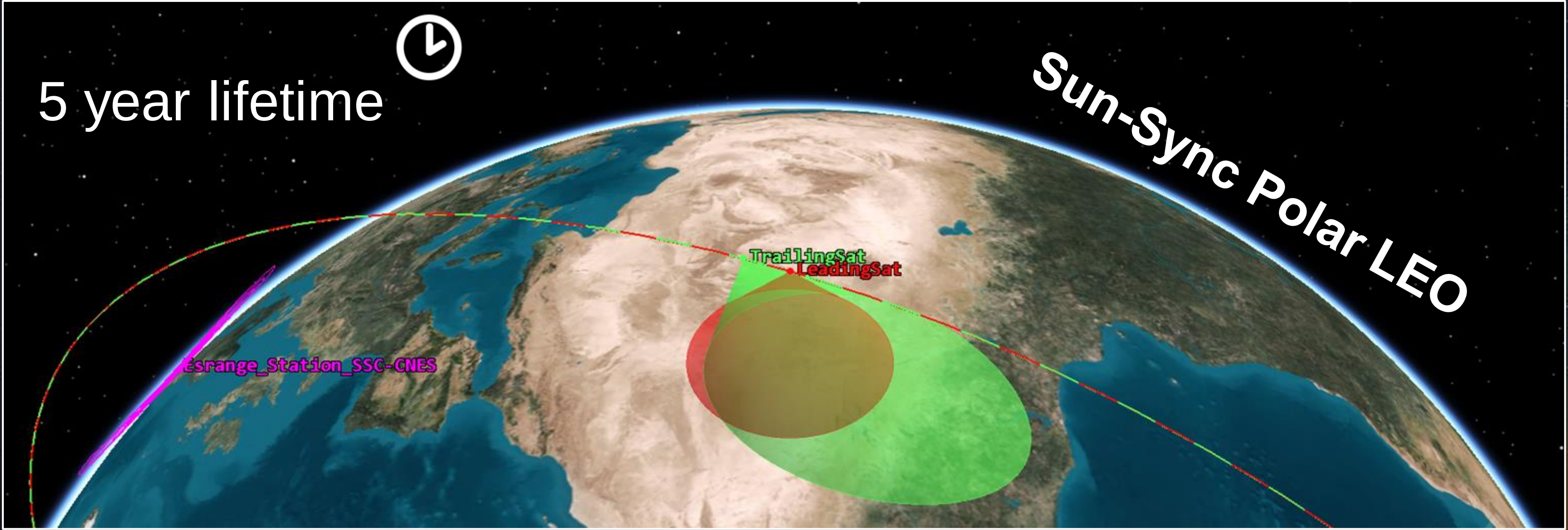
Mission overview

F-Class mission



5 Instruments each

How did we come up with this …



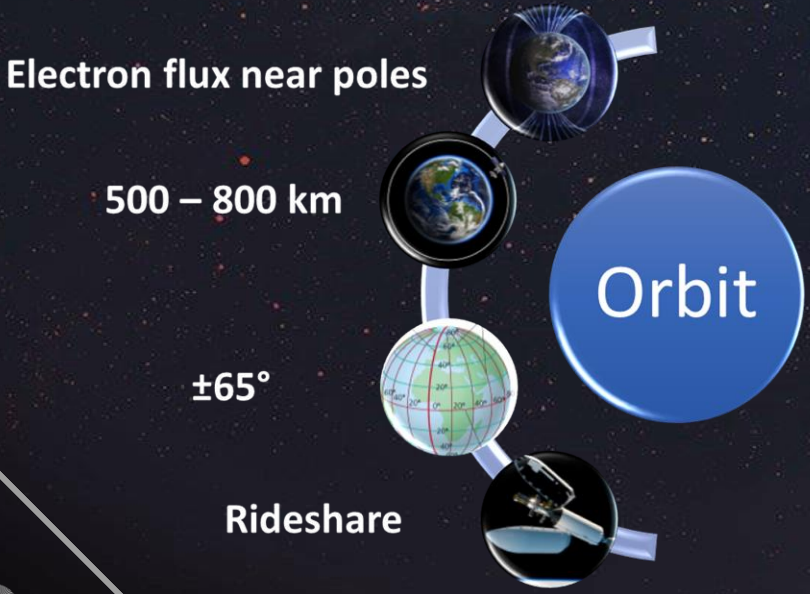
5 year lifetime

Sun-Sync Polar LEO

Mission requirements

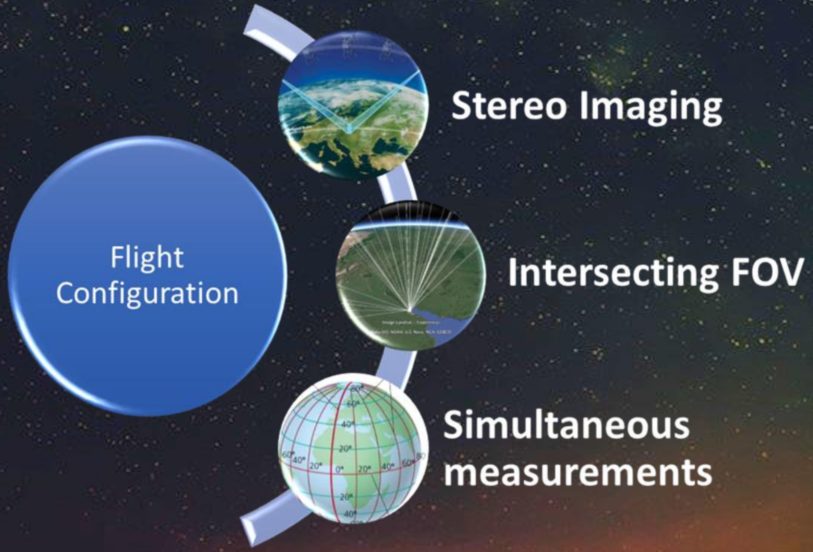
Orbit

- **SR-1:** Global Mapping
- **SR-5:** Detecting electron flux



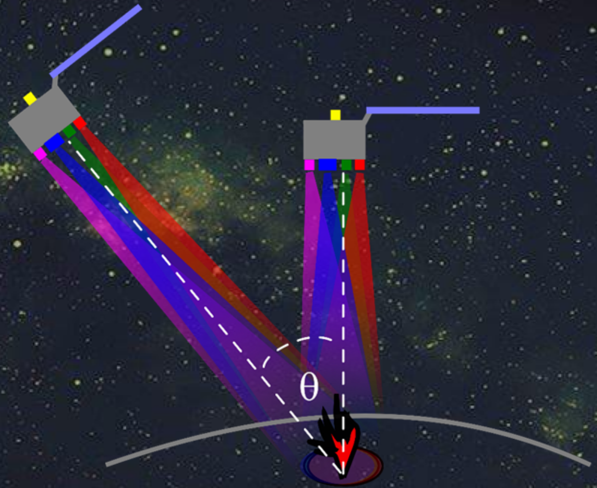
Flight configuration

- **SR-2:** Spatially resolve TLEs
- **SR-4 / SR-7:** *'Measure low intensity events'*



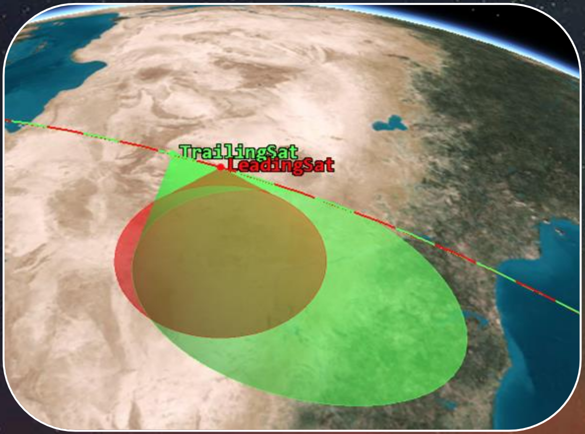
Mission profile

- Sun synchronous LEO
  - Inclination = 98°
  - RAAN rate = 9.5° / day
- Altitude = 670 km
- Ascending node time = 10:30
- 14 orbits / day
- Period = 96 mins



<u>Delta V Requirements</u>

ΔV Phase Maneuver = 75.4 m/s
ΔV Deorbit = 70 m/s
ΔV Margin = 10 m/s
Total ΔV = 155 m/s



Development phases

Phase 0
- Mission analysis and identification

Phase A
- Feasibility

Phase B
- Preliminary definition

****Alpbach Summer School***

Phase C
- Detailed definition

Phase D
- Qualification and production

Phase E
- T0
- Utilisation

Mission phases

LEOPS

- *T < 20 days*
- Vega rideshare launch
- No time demand for launch
- Orbit injection maneuvers

Commissioning

- T < 0.5 year
- Phase injection maneuvers
- Instrument health
- Instrument calibration

Scientific Operations

- T < 5 years
- Orbit maintenance maneuvers
- Main objective operations - gather and transmit data

End of Life

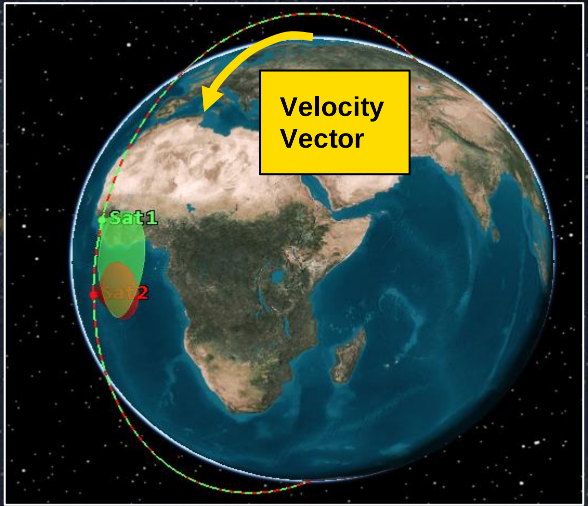
- T $\gtrsim$ 5 years
- End of nominal mission*
- End of main objective operations
- De-orbit into atmosphere

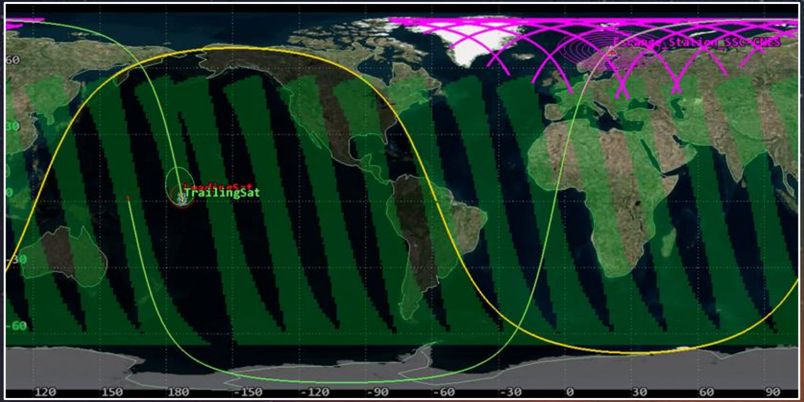
**Option for extended mission*

esa

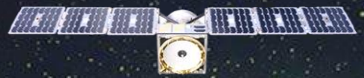
Instrument pointing & coverage

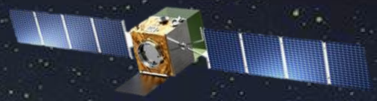
- TLE latitudes of interest = ± 65°
  - 70 min observation per orbit
- FOV cone half angle = 40° (nadir) 12° (limb)
- Phase angle = 5.25°
- Pointing accuracy requirement = 1°
- Coverage
  - 1 day: 50% of surface
  - 2 day: 80% of surface
  - 7 days: 96.5% of surface





Choosing a BUS



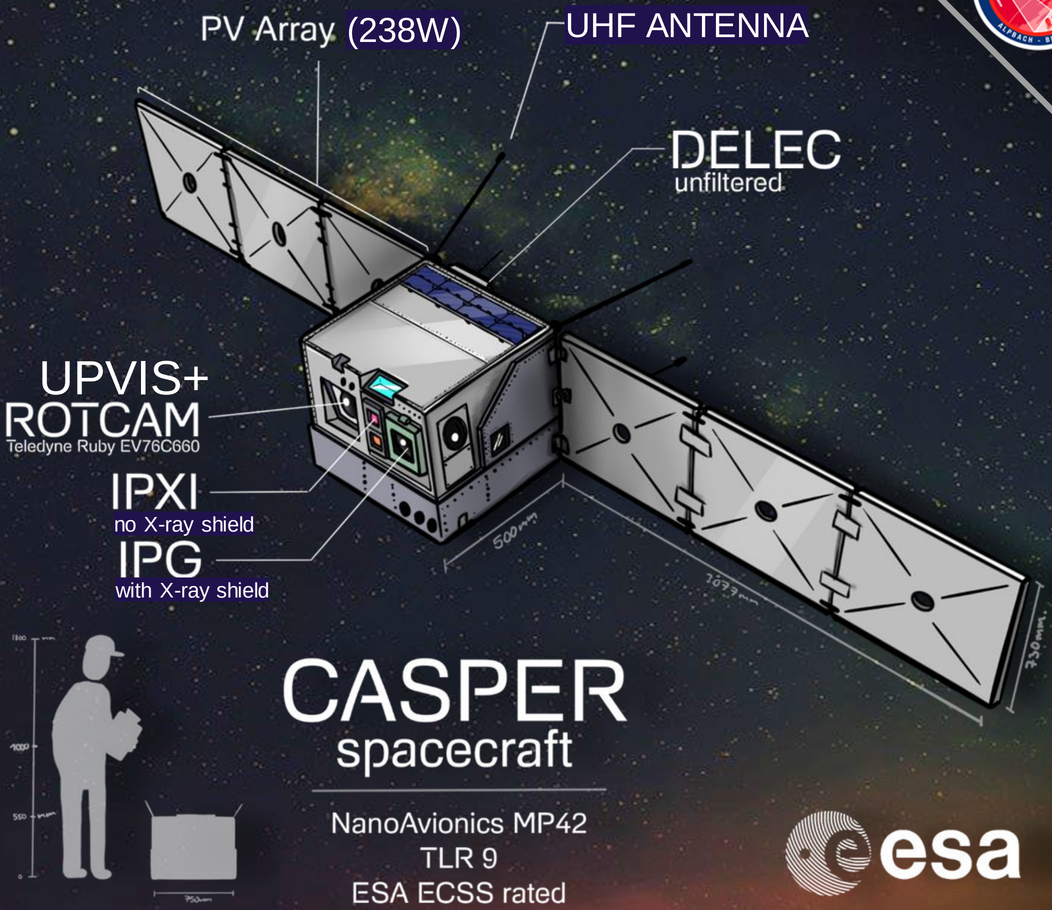


Subsystem	Mission Requirements	NanoAvionics MP42	Reorbit Gluon	Proprietary w/ Integration Partner
Pointing Accuracy	1°	0.05°	0.02°	> *1°*
ΔV	155 m/s	170 m/s	225 m/s	> *140 m/s*
TX Rate	100 MB/s	500 MB/s	500 MB/s	> *100 MB/s*
Power	140 W	237 W	100 W	> *140 W*
Lifetime	5 Yrs.	6 Yrs.	3 Yrs.	> *5 Yrs.*
Battery	80 Wh	300 Wh	-	> *80 Wh*
Cost (M €)	**€ € €**	**€ €**	**€ €**	**€ € € €**

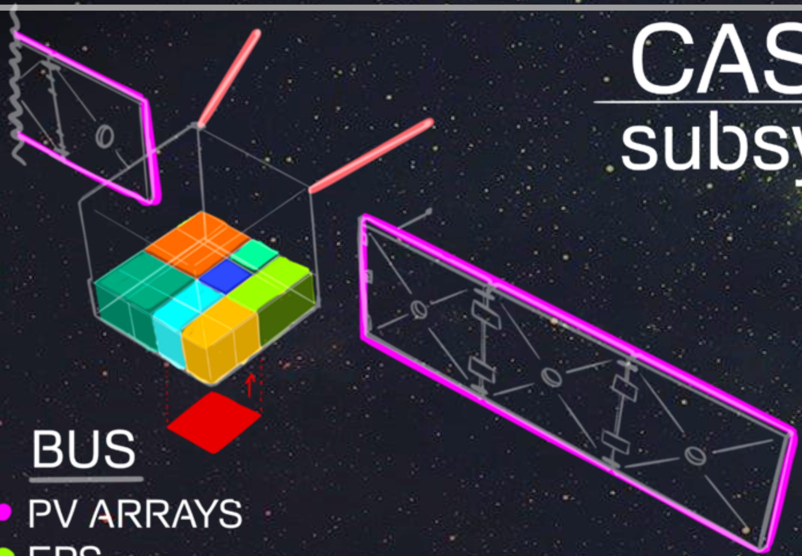
esa

Spacecraft design

- Bus choice: NanoAvionics MP42
  - TLR 9
  - Integration partner
- Specs:
  - Volume: 500 x 500 x 700 mm
  - X-band TX: 500 Mb/s
  - Solar arrays: 238 W
  - Bus mass: 45kg
  - Monoprop thruster: 1N
  - Magnetorquer + 4 reaction whls.
  - ΔV: 170 m/s

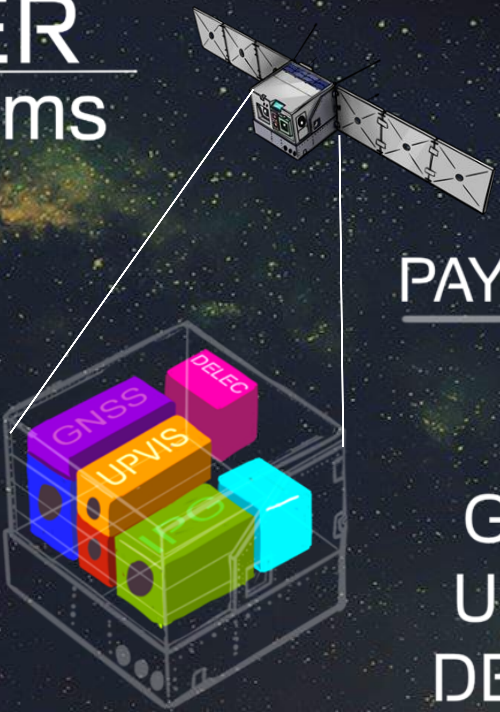


CASPER subsystems



BUS

- PV ARRAYS
- EPS
- X-BAND RADIO
- ADCS (MGT + RW)
- OBC
- PAYLOAD CONTROLLER
- UHF TELEMETRY ANTENNA
- UHF RADIO
- ADN PROPELLANT
- X-BAND PATCH ANTENNA



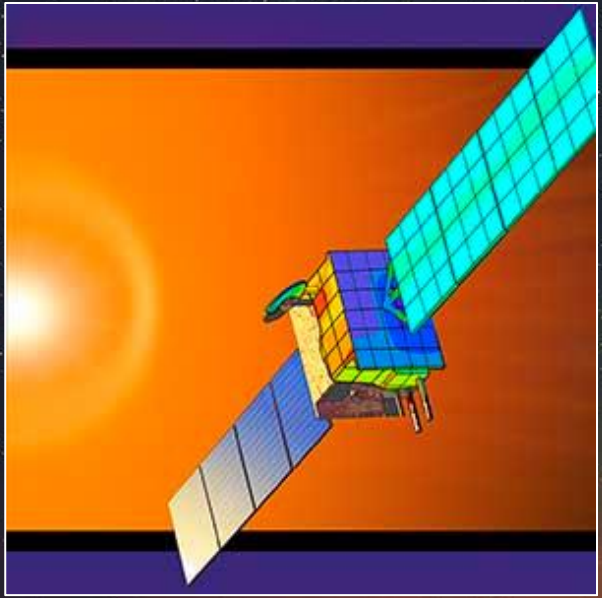
PAYLOAD

- IPG
- IPXI
- GNSS
- UPVIS
- DELEC
- ROTCAM
- STORAGE

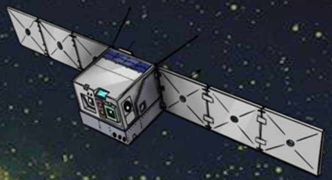
Thermal control

- Hot case: Burst mode
  - Power dissipation 30 W
- Cold case: Standby mode
  - Power dissipation 8.5W
- Satellite bus configurable w/ 50W radiator
- Heaters needed for camera
  - Operating temp 25℃

Heat source	Hot Case	Cold Case
Electronics (W)	30	8.5
IR earth (W/m^2)	258	216
Albedo (W/m^2)	466.62	0
Sun (W/m^2)	1368	0



Product tree with allocated functions



- **Satellite**
  - **Payload**
    - Si Scintillator
    - Crystal Scintillator
    - Plastic Photodiode FUV
    - Si Photodiode NUV
    - Camera
  - **GNCS**
    - Propulsion System
      - Phase Separation Control
    - Attitude Control
      - Pointing
  - **COMMS**
    - X-band TX Data Downlink
    - S-band Command RX
  - **DHS**
    - Process Data
    - Apply ML Algorithm
  - **Power System**
    - Solar Arrays
    - Power Distribution
    - Battery
  - **OBC**
    - Conduct Operations
    - Coordinate Subsystems
  - **TCS**
    - Thermal Control
  - **Structure**
    - Mechanical Load
    - Instrument Packaging
    - Launcher Interface

Operational modes

Mode 1: Standby mode

South pole pass

****South Atlantic Anomaly***

- Function 1.1 Data processing
  - Scientific Instruments: OFF
  - Image compression

Mode 2: Reduced operations

Day pass

- Function 2.1 - Scientific observation
  - 2x Scintillators (electron flux):ON
  - 2x Photodiodes: ON
  - Camera OFF

Mode 3: Data link mode

Esrange pass

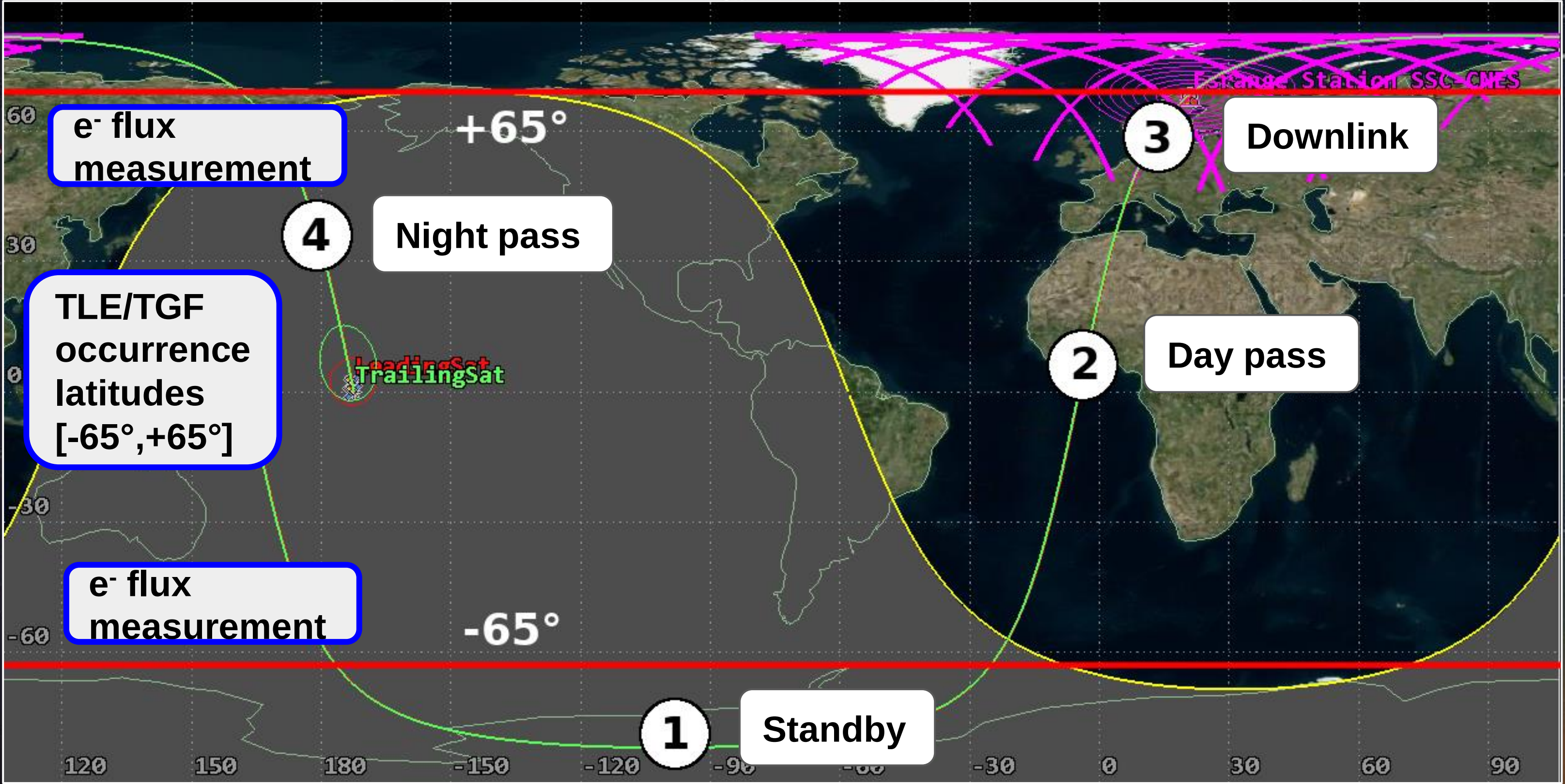
- Function 3.1 - Rx & TX data transmission
  - Scientific instruments: OFF
  - X-band: ON (TX downlink)

Mode 4: Full operations

Night pass

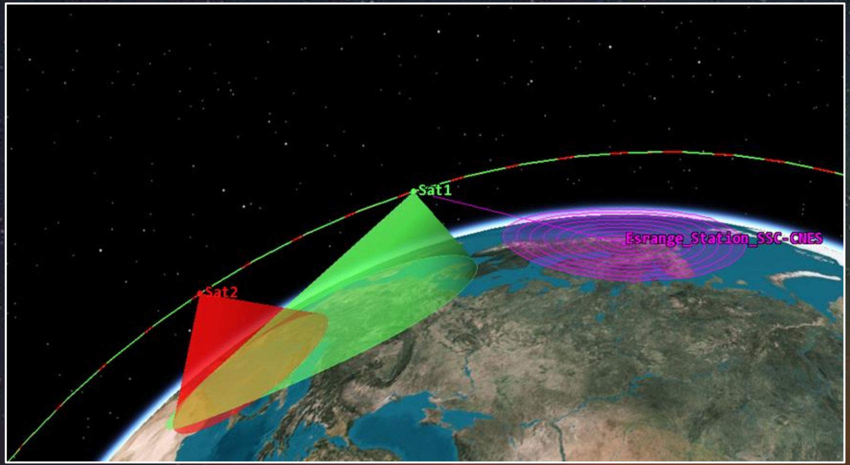
- Function 4.1 - Scientific observation
  - 2x Scintillators (electron flux):ON
  - 2x Photodiodes: ON
  - Camera: ON

Operational modes



Ground station

- Esrange Station - Kiruna, Sweden
    - High latitude maximises access time
- 12 ground passes / 24 hrs
- X-band downlink: 500 Mb/s
    - Data generated: 90 GB per day
        - TX time required: 1500 seconds
    - Access time: 8000 seconds / 24 hrs
    - 19% of access time
- 300 TB on ground storage

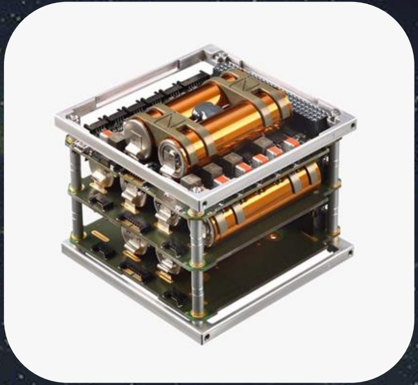


Power budget

Subsystem	Margin	Mode 1: Standby (W)	Mode 2: Day Pass (W)	Mode 3: Downlink (W)	Mode 4: Night Pass (W)	Mode 4.1: Burst (W)
Payload	10%	-	28	-	5	28
Thermal Control	5%	10	10	10	10	10
C&DH	5%	5	5	5	5	5
Communication	5%	2	2	8	2	2
ADCS	5%	-	30.5	30.5	30.5	30.5
Propulsion	5%	-	-	-	8	-
Other	5%	-	-	-	-	25
Subtotal		17	45	54	61	101
Margin		20%	20%	20%	20%	20%
Total		20	54	64	73	121

Power sizing

- Max power draw: 121 W
- PV Array: 238W
  - TLR 9
- Battery: 300 Wh
  - Day side charging rate: 184 W
  - Charging time per orbit: 48 mins
  - Charge per orbit: **147 Wh** ✔
- Beginning of life (BOL) efficiency: 30%
- End of Life (EOL) efficiency: 16%



Mass budget

- 3 sensor camera TRL 6
- Scintillators TRL 8

Payload Mass			
Instrument	**Mass (Kg)**	**% Margin**	**Mass + Margin (Kg)**
Si-photodiode far UV	5	5%	5.3
SI-photodiode near UV	5	5%	5.3
Crystal scintillator	5	5%	5.3
Plastic scintillator	5	5%	5.3
Camera	12	10%	13.8
Total Payload Mass	**33**	**-**	**35**

Spacecraft Mass				
Subsystem	**% of Dry mass**	**Mass (Kg)**	**% Margin**	**Mass+ margin (Kg)**
Payload	31%	35	0%	35
Structure	27%	30	5%	32
Thermal Control	2%	2	5%	2
Power (inc. S/A)	21%	24	5%	25
Communications	2%	2	5%	2
On Board Computer	5%	6	5%	6
Attitude Control	6%	7	5%	7
Propulsion	3%	3	5%	4
Other	3%	3	5%	4
Dry Mass	**100%**	**112**	-	**116**
System Margin	**20%**	**23**	-	139
Propellant	2%	6	20%	7
Total Wet Mass	-	**141**	-	**146**

Space mission engineering, the new SMAD. Hawthorne, CA, Microcosm Press. (2011)

Cost budget

- Science Ops: €12M
  - Team of scientists processing data on ground
- Rideshare = ¼ cost per s/c
- Comercial BUS = ½ proprietary bus costs

Contribution per ESA member state citizen: **€0.31**

	1x Spacecraft	2x Spacecraft
Spacecraft elements	**Million €**	**Million €**
Structure	1.5	3
Thermal Control	0.9	1.8
ADCS	1.2	2.4
Electrical power supply	2	4
Propulsion (reaction control)	0.8	1.6
Telemetry Tracking and Command	1	2
Command and data handling	1.2	2.4
Payload	2	4
Installation assembly and test	2	4
Engineering, software	10	12
Mission Segment SubTotal	**23**	**38**
Program management	10	10
Mission operation	10	10
Science operation	12	12
Data Storage	0.6	0.6
Industrial cost	15	30
Shared Launch	10	20
Initial cost	**80**	**120**
Margin	20%	20%
Total cost	**96**	**143**

Data distribution and postprocessing

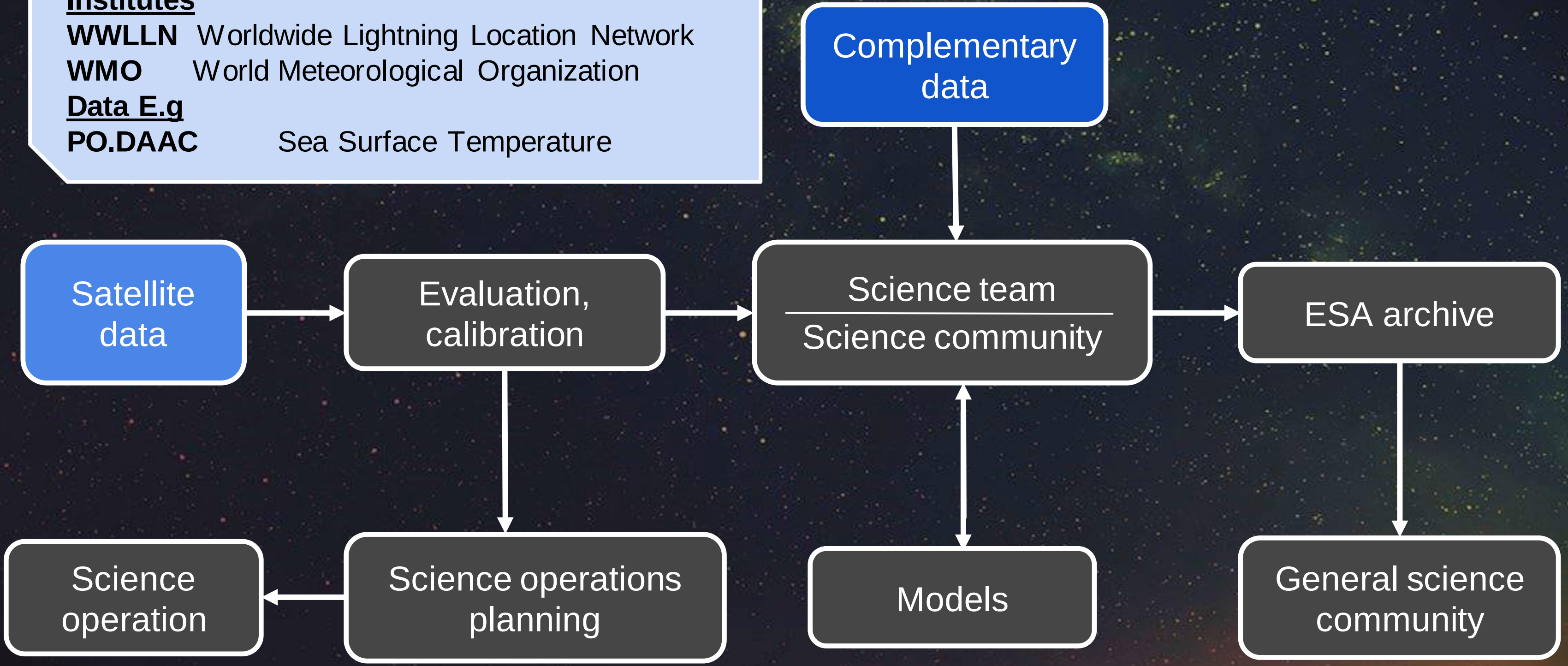
Institutes

WWLLN Worldwide Lightning Location Network

WMO World Meteorological Organization

Data E.g

PO.DAAC Sea Surface Temperature

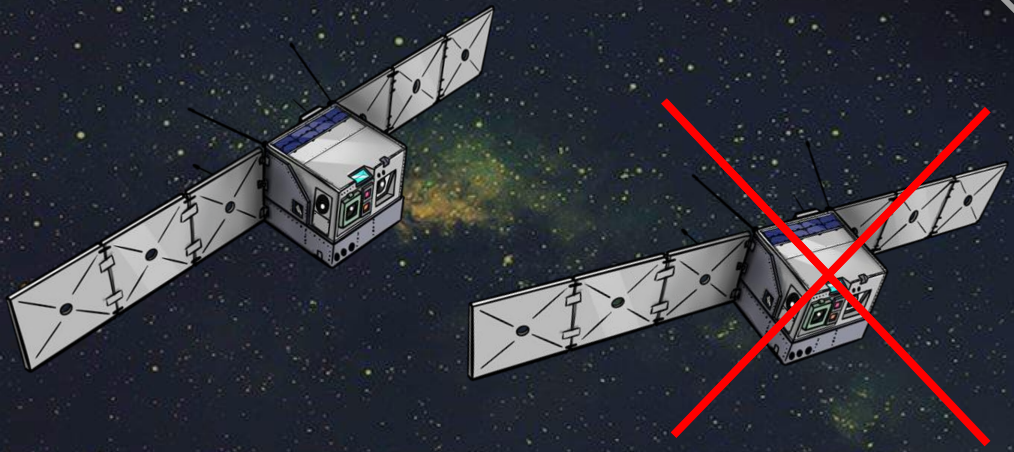


Risk assessment

- Subsystems
  - TRL 9
  - Off the shelf
- Instruments
  - Camera: TRL 6
  - Instruments: TRL 8
    - Passed pre-flight testing
    - No flight heritage
    - Development time risk

- Common LEO orbit risks inc.
  - Launch failure
  - System or component damage (space debris)

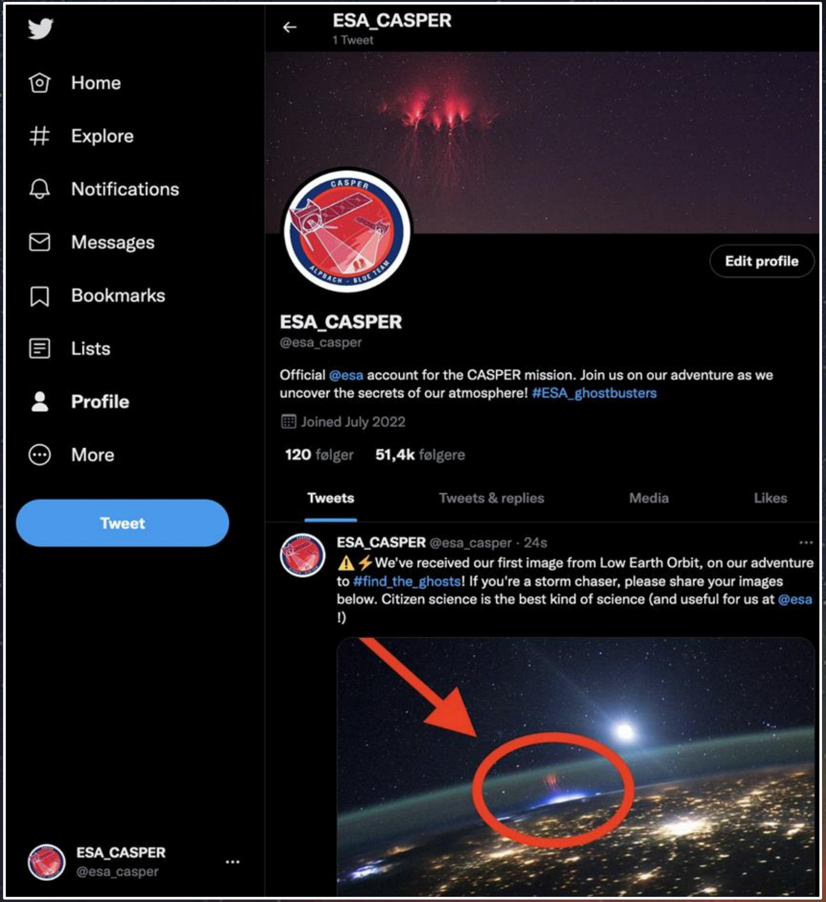
Descoping options



- Best Case: Reduce from 3 to 1 camera sensor(s)
  - Lose spectral comparison data
- Worst Case: Reduce from 2 to 1 satellite(s)
  - Loss of stereo imaging
  - No backup instruments

Outreach - social media

- Social media
  - Emphasis on citizen science.
- TLEs interesting to public.
- Coordination w/ ground based observations
  - e.g. *Storm Chasers* community.
- Success with earlier social media campaigns (ex: Rosetta mission)



Contributions

We recognised the need to understand special Plasma processes called TLEs and TGFs.

Created CASPER to:

- Spatially and temporally resolve them
- Measure the energy spectrum of these events
- Detect their triggering process
- Build an understanding of them

Any questions?

ALPBACH