The Gamma-Ray Burst mission

SVOM

"Towards a network of GRB-detecting nano-satellites" workshop.

Hungarian Academy of Sciences, Budapest, 2018/9/13-14

on behalf of the SVOM collaboration

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Gamma-Ray Burst science questions

GRB phenomenon	Diversity and unity of GRBs, central engine
GRB physics	Acceleration and nature of the relativistic jet
	Radiation processes, gamma-ray emission
	The early afterglow and the reverse shock
GRB progenitors	Long GRB-supernova connection
	Short GRB-merger connection
Cosmology	Cosmological lighthouses (absorption systems)
	Host galaxies
	Star formation tracer
	Re-ionization of the universe
	Cosmological parameters
Fundamental physics	Short GRBs and gravitational waves
	Origin of high-energy cosmic rays
	Lorentz invariance test

Following the way shown by the Neil Gehrels Swift observatory

Need of a <u>complete sample</u> of GRBs, with spectral and temporal coverage of the <u>prompt</u> and <u>afterglow</u> combined with a distance measurement

SVOM mission

Space-based Variable Objects monitor

- Space mission dedicated to the detection and study of Gamma Ray Bursts and their use for astrophysics and cosmology

- Cooperation between China and France
  - Space agency agreement (CNSA-CNES)
  - Mission fully founded in China and France
  - in Phase C since beginning 2017
  - Satellite: built by CAS (SECM), 950 kg, 450 kg payload
  - Launch: foreseen end 2021 with LM2C from Xichang, China
  - Orbit: LEO, ~620 km, 30° incl.
  - Operations: 3 years (+ 2 years extension)
  - Involvement of 10 French + German + UK Labs

CNSA

CAS

NAOC, Beijing	SECM, Shanghai	CEA-Irfu, Saclay	IRAP, Toulouse	LAL, Orsay
XIOPM, Xi'an	RADI, Hainan	IAP, Paris	LAM, Marseille	LUPM, Montpellier
NSSC, Beijing	CLTC, Xi'an	APC, Paris	CPPM, Marseille	MPE, Garching
IHEP, Beijing	CALT, Xichang	CNES, Toulouse	GEPI, Meudon	University of Leicester

SVOM objectives

➔ **Build complete sample of GRBs, with spectral and temporal coverage and distance measurement**

Scientific requirements of SVOM

Prompt emission:

- Trigger on all known types of GRBs (>200 in 3 years) in particular X-ray rich GRBs, high-z GRBs and under-luminous GRBs
- Provide fast and reliable (<12 arcmin) GRB positions
- Send alerts to the world-wide community (<30 s)
- Temporal variation and spectrum (from visible to MeV)

Afterglow:

- Spectrum from IR & visible to X-rays. Provide accurate (~arcsec) GRB positions
- Permit redshift measure for large fraction of triggered GRBs (~1/2)

Operate within the world-wide community:

- Benefit from new generation follow-up instruments: JWST, LSST, SKA, CTA
- Contribute to multi-messenger astronomy (GW and Neutrino telescopes)

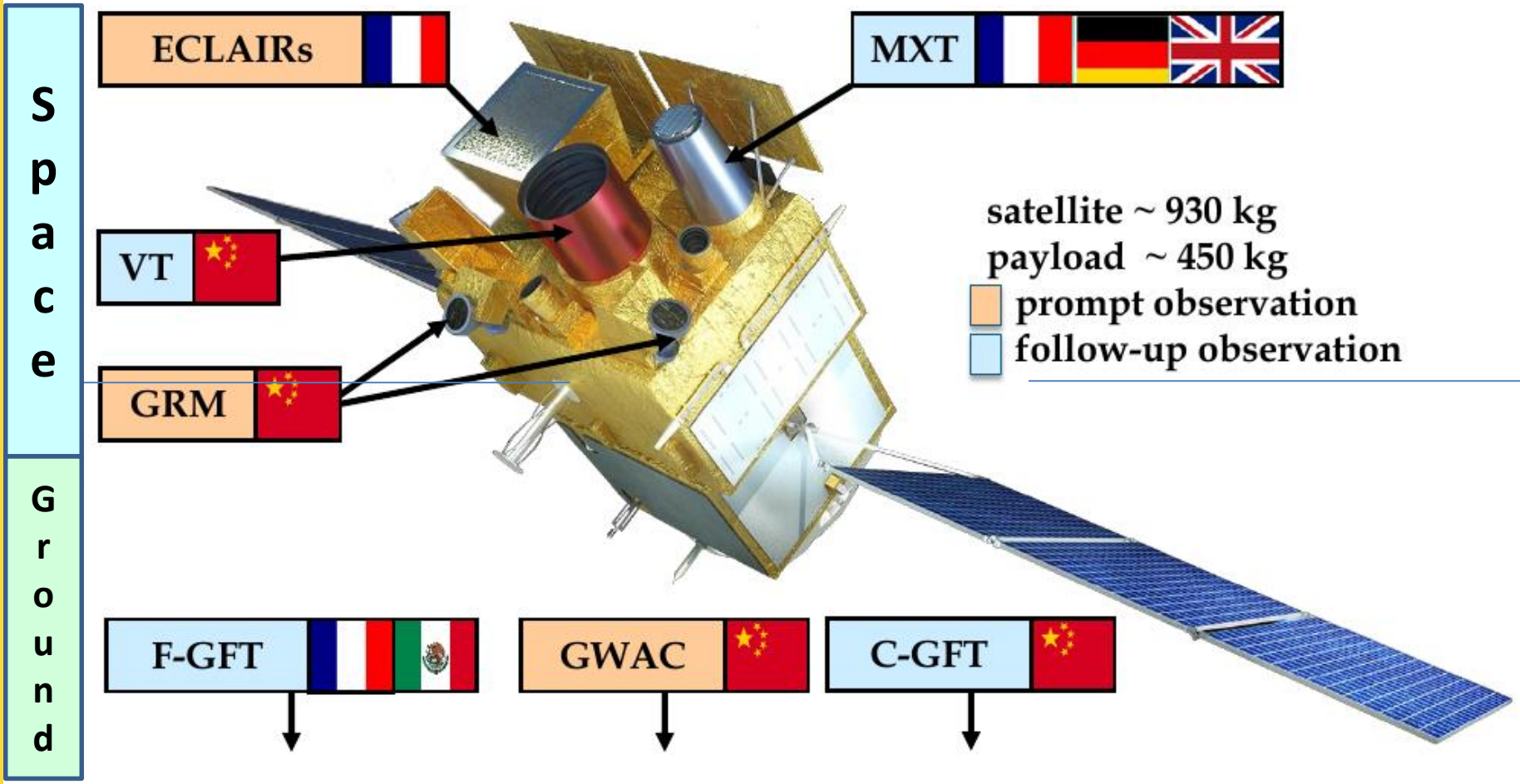
SVOM instruments

4 space instruments:

- ECLAIRs gamma-ray imager & trigger
- GRM gamma-ray monitor
- MXT X-ray focusing telescope
- VT visible band telescope

3 ground telescopes

- GWAC ground wide angle camera
- F-GFT & C-GFT: ground follow-up telescopes



ECLAIRs: hard X-ray Imager & Trigger

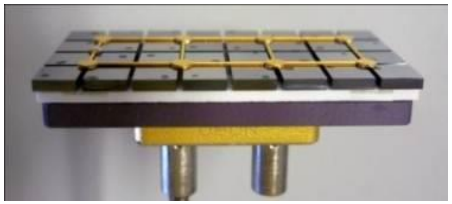
- **Allocations:** Mass ~ 90 kg, Power ~ 90 W
- **Detection plane**: 1024 cm²
  - 6400 CdTe pixels (4x4x1 mm³)
  - Energy range: 4-150 keV
- **Shield**: C/Al + Pb + Cu
  - FoV = 2 sr (total)
- **Mask**: Ta, 40% open, self supporting
  - Localisation accuracy <12'

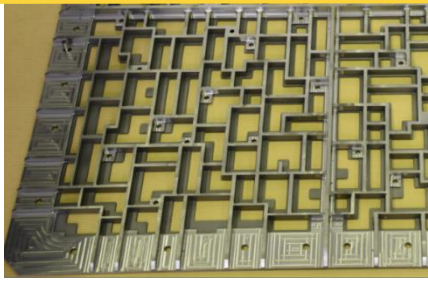
  (at detection limit, 90% C.L.)
- **Aeff** = 400 cm² @ 10-70 keV

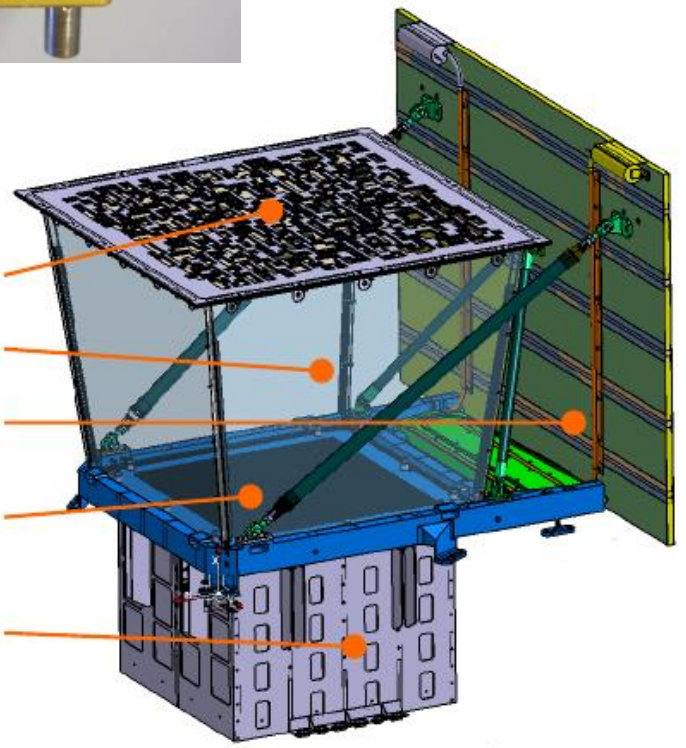
  > 200 cm² @ 6 keV
- **UGTS (control and trigger unit)**
  - All photons to ground (18 Gbit/day 6-12 h delay)
  - GRB trigger & localization software:

    alert to ground via VHF & spacecraft slew for follow-up

CNES, IRAP, CEA, APC





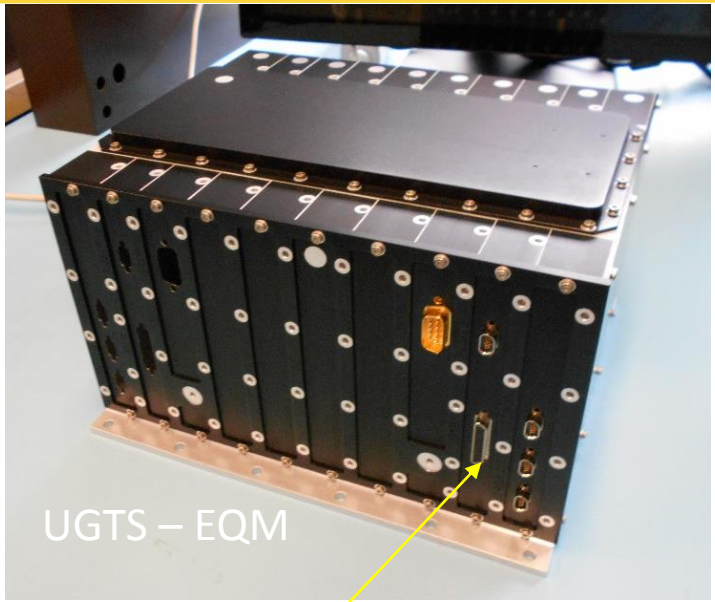


ECLAIRs UGTS: dev. in the lab

CNES, CEA

Hardware : 10 boards, cold redundant, rad tolerant
- Power supply (2+4) + I/O board (2) + CPU board (2)
- FPGA: data acquisition and pre-processing
- dual core CPU (2×50 Mflops): processing tasks

Software :
- OS : time partitioning hypervisor
- Custom scientific libraries : C++
- software compiles for on-board target and linux on-ground for performance tests

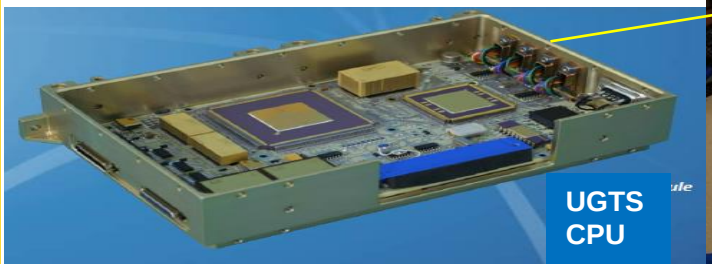


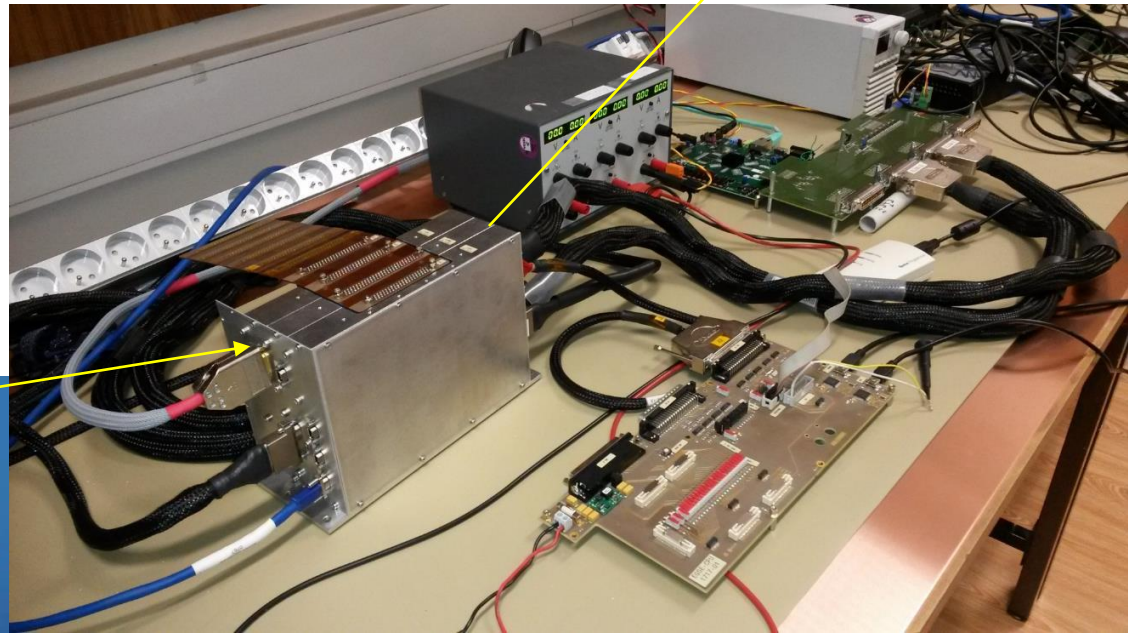
EQM model

➔ **interconnection tests with Chinese PDPU in Shanghai foreseen beginning 2019**

BBM model

➔ **representative hardware for flight software dev.**

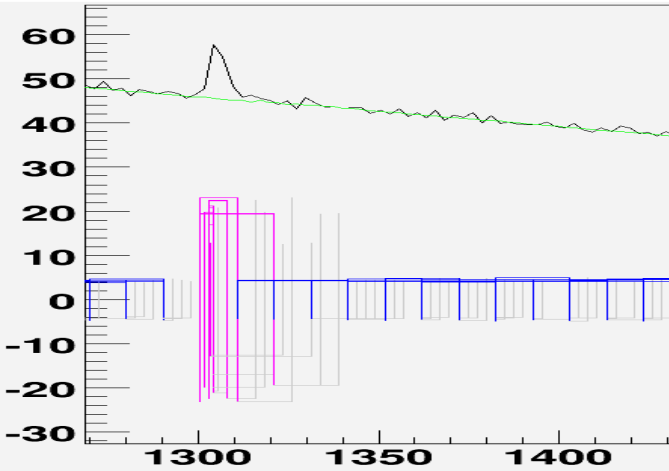




ECLAIRs UGTS: onboard Trigger

CEA

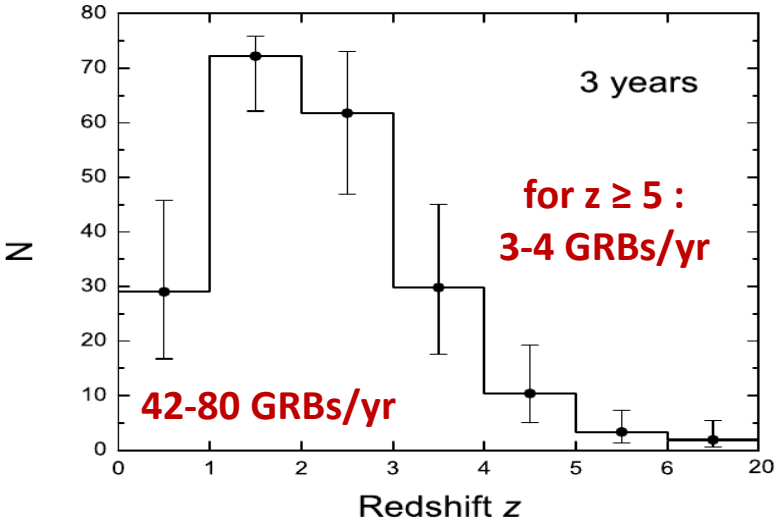
- **2 algorithms** (on 4 energy bands, 4-120 keV):
  - Count-rate trigger (10 ms to 20 s) followed by coded mask deconvolution
  - Image trigger (systematic deconv. 20 s, stack images to 20 min, known source cat.)



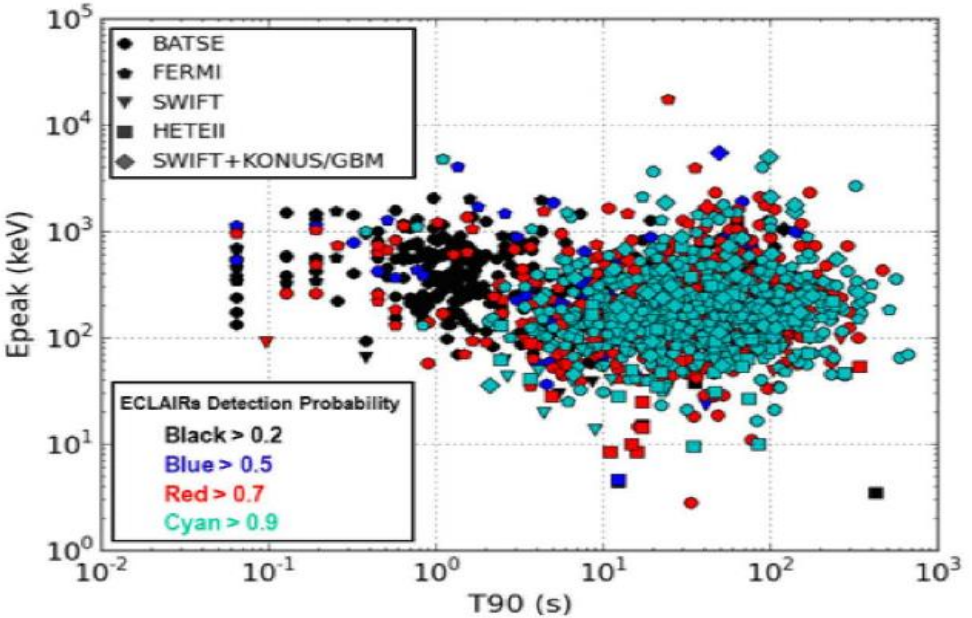
- **Trigger various GRB types**

➔ sensitive to Long, Short, Soft, X-Ray rich, Ultra-long…

- **Expected ECLAIRs rate: ~70 GRB/yr**



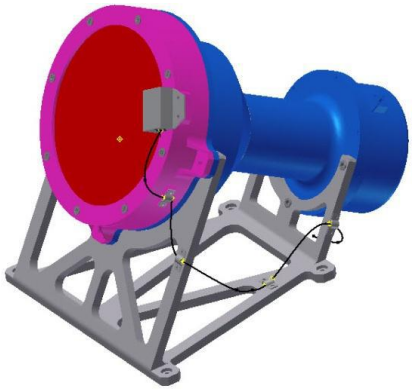
Detailed simulations of algorithm prototypes on GRB databases of previous missions (BATSE, Fermi, Swift, Hete-2)

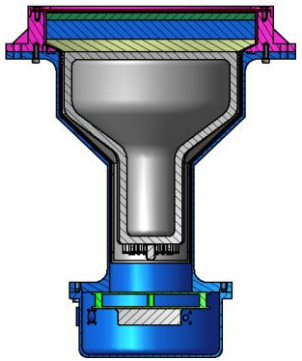


GRM: onboard Gamma-Ray Monitor

IHEP

- **3 Gamma-Ray Detectors** (GRDs)
- NaI(Tl) (16 cm Ø, 1.5 cm thick)
- Plastic scintillator (6 mm) to monitor and reject particle events
- FoV = 2 sr per GRD



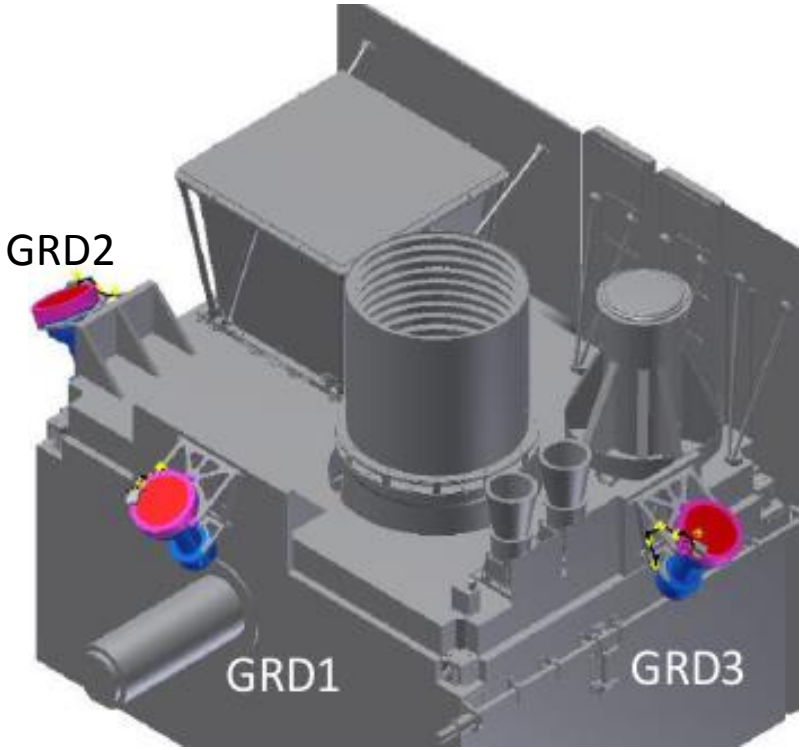


- Energy range: 15-5000 keV
- Aeff = 190 cm² @ peak
- Rough localization accuracy

- Expected GRD rate: ~90 GRB/yr

- GRM data sent to ECLAIRs

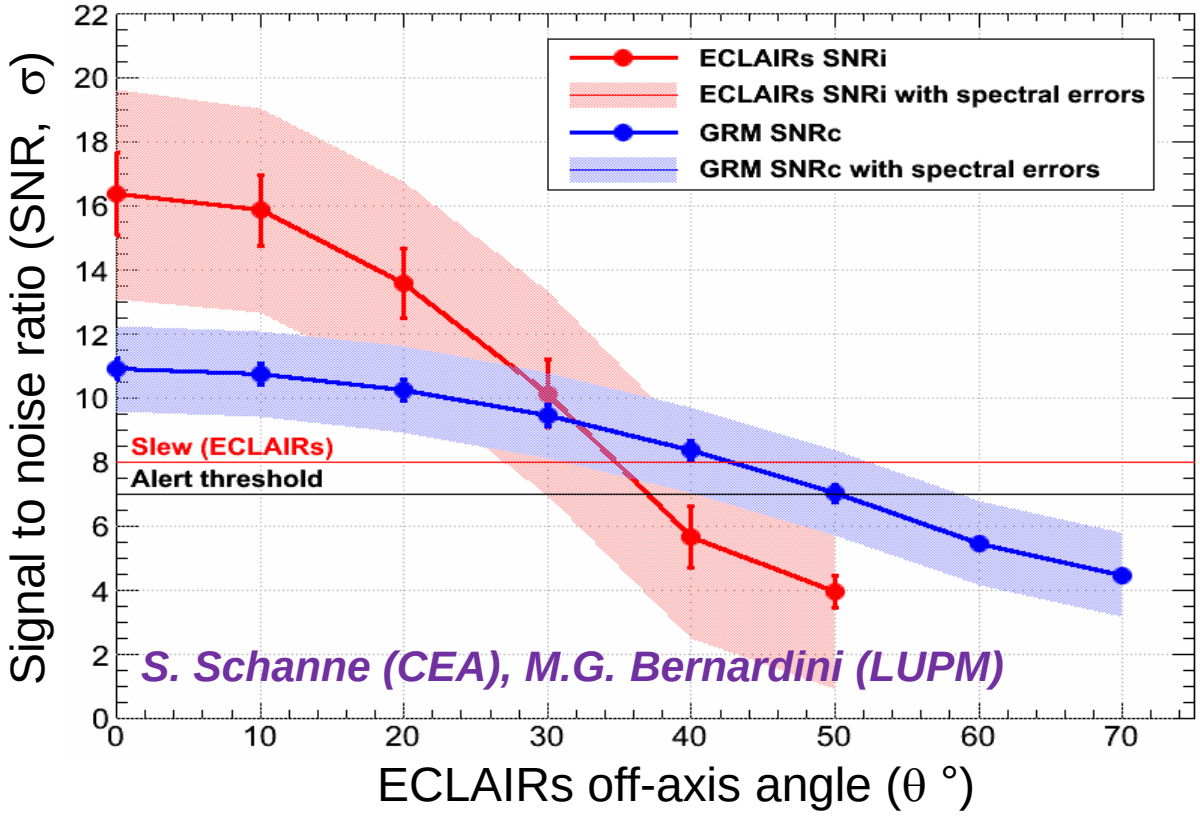
→ enhance Trigger sensitivity to short GRBs

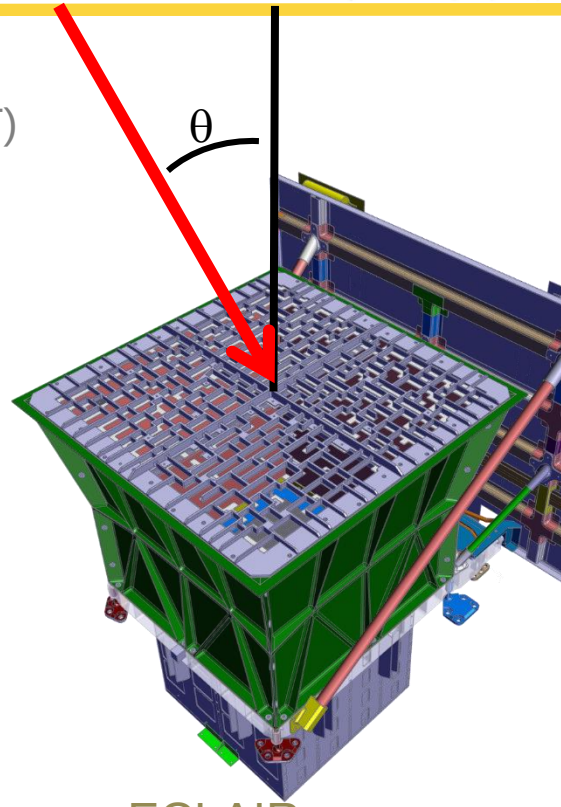


GRB 170817A in ECLAIRs & GRM

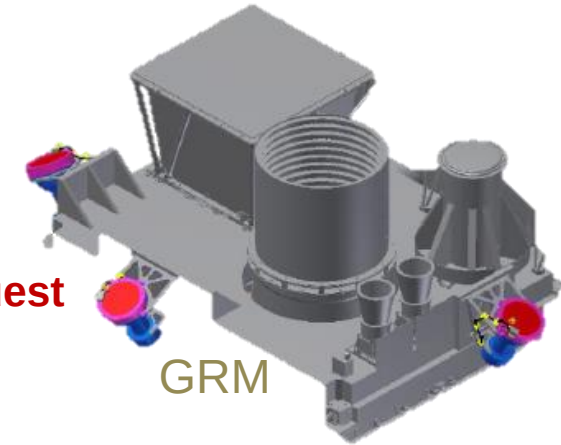
Simulation of event (counts+background)

Parameters of Fermi-GBM (public GCN 2017/8/17 10:00 GMT)





ECLAIRs



GRM

➔ **Up to 11°: detection, localization < 6 arcmin (90%)**
detectable up to 1.5 × distance (60 Mpc)

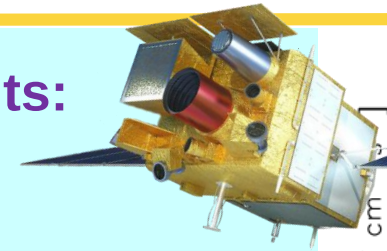
➔ **Up to 35°: ECLAIRs alert to ground (good loc.) + slew request**

➔ **Up to 50°: GRM alert to ground (crude loc.)**

GRB prompt observations by SVOM

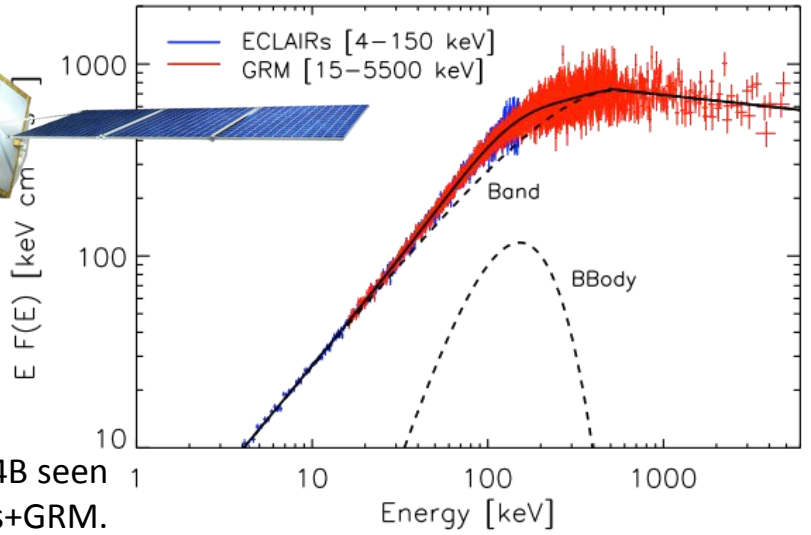
- **Space based instruments:**

ECLAIRs + GRM



- Broad-band coverage 4 keV – 5 MeV

➔ Well measured prompt gamma (Epeak, …



Multi-component spectrum of GRB100724B seen by Fermi/GBM imulated in ECLAIRs+GRM.

- **Ground-based Wide Angle Camera (GWAC)**

- dedicated to SVOM, partially operational already in 2018

- sites: Ali (China) and CTIO (Chile)

- 40 camera units, 5400 deg², following ECLAIRs FoV

- band: 0.5-0.8 µm; sensitivity: M_V=16 in 10 s

- external trigger and self-triggering

~16% of ECLAIRs-triggered GRBs observable by GWAC

MXT: onboard X-ray Telescope

CNES, CEA, UL, MPE

- Micro-pores optics (Photonis)

with square 40 µm-size pores

in a “Lobster Eye” configuration

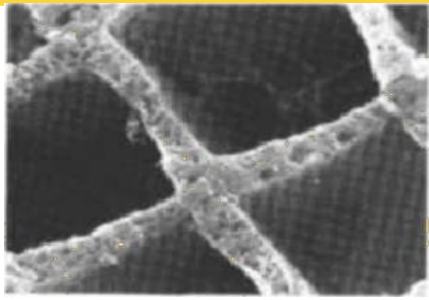
- Focal length: 1.15 m
- FoV = 57x57 arcmin²

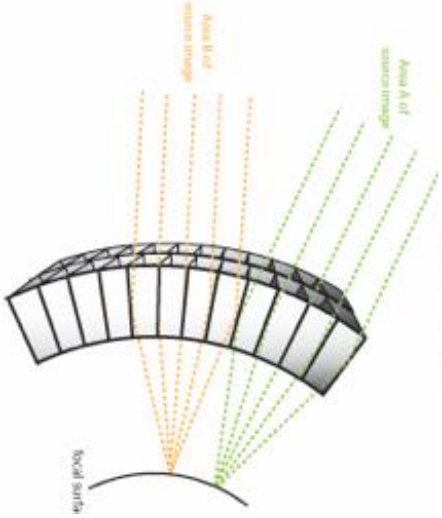
- pnCCD camera
- Energy range: 0.2-10 keV
- Aeff = 27 cm² @ 1 keV (central spot)
- Energy resolution: ~80 eV @ 1.5 keV

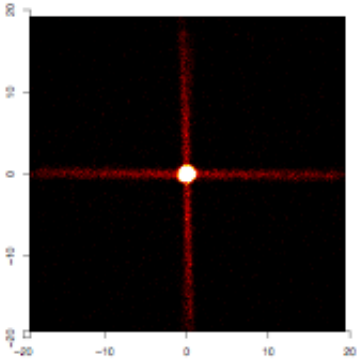
- Localization accuracy < 80 arcsec

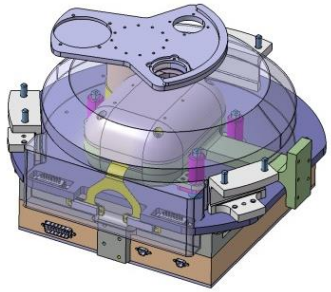
(20 arcsec for bright GRBs)

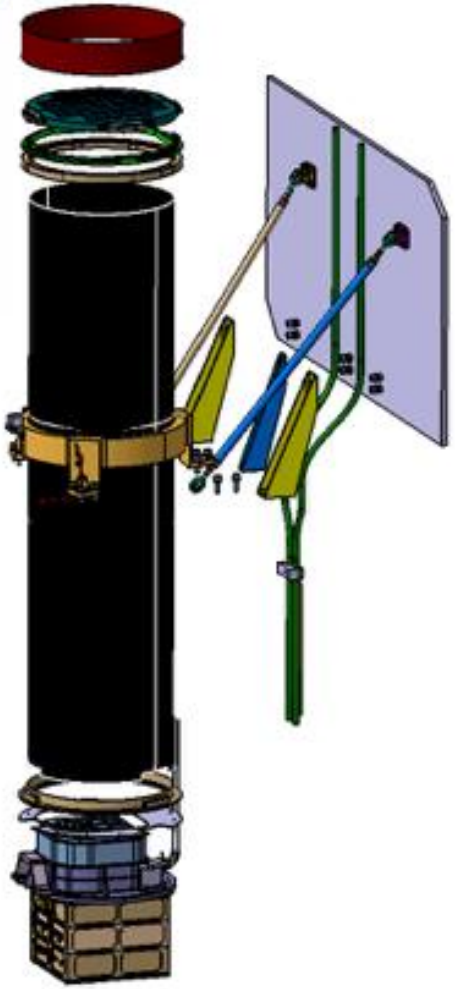
within 5 min (for 50% of GRBs)







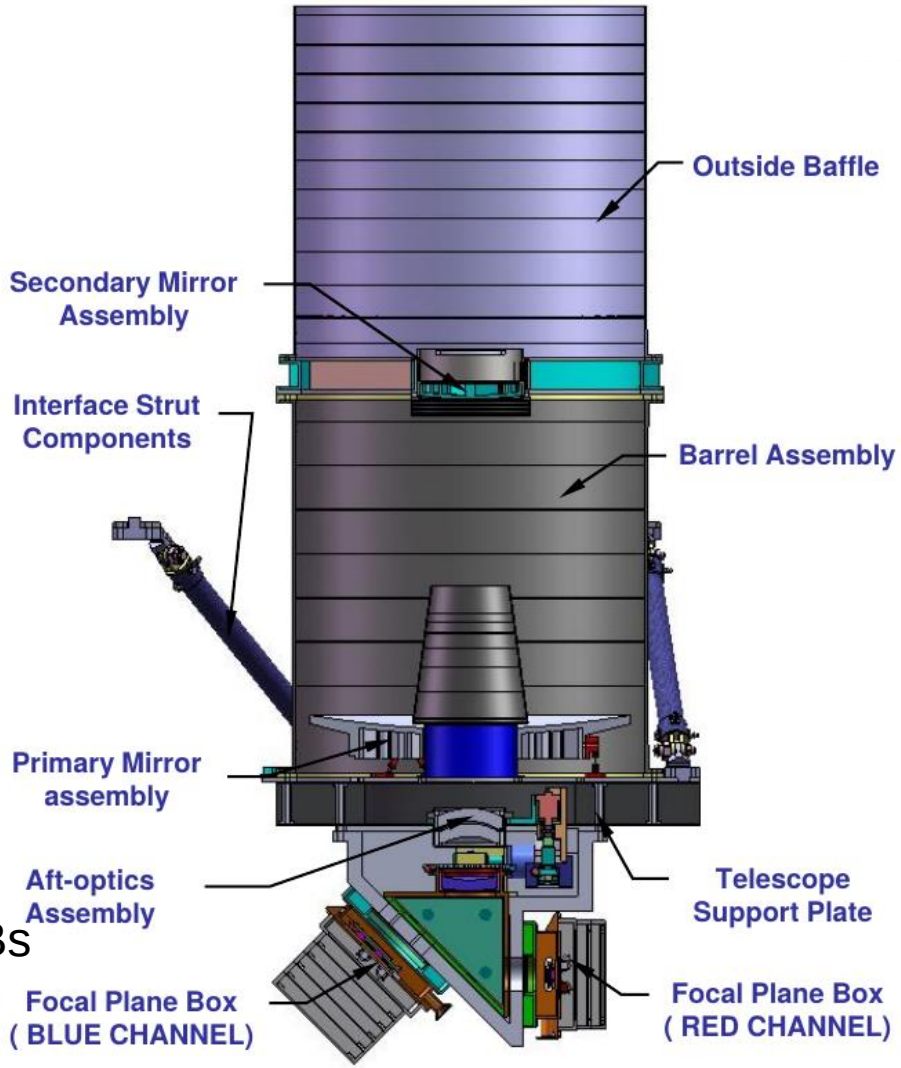


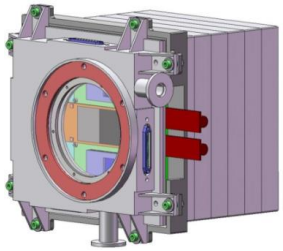


VT: onboard Visible Telescope

- Ritchey-Chretien telescope
- Ø=40 cm, f=9
- FoV = 26x26 arcmin² covering ECLAIRs localization error box
- Focal length: 3.6 m
- 2 channels: blue (400-650 nm) and red (650-1000 nm)
- Each channel: 2k x 2k CCD detector (13.5 μm pixels)
- Sensitivity M_V=22.5 in 300 s
- Expect to detect ~80% of ECLAIRs GRBs
- Localization accuracy <1”

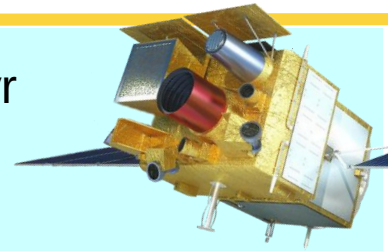
NAOC, XIOPM





GRB afterglow observations by SVOM

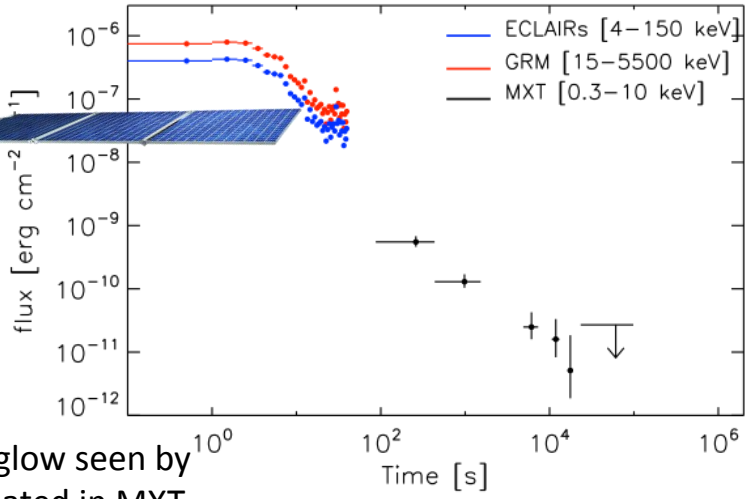
Spacecraft slew: 36-72 GRB/yr



- **Space-based follow-up:**

MXT X-ray afterglow for 90% of slewed GRBs

VT Visible/nIR afterglow + photometric redshift



GRB 091020 afterglow seen by Swift/XRT simulated in MXT.

- **Ground Follow-up Telescopes (GFTs)**
  - **Chinese Ground Follow-up Telescope (C-GFT)**
    - Robotic 1.2 m telescope, Weihai observatory (Jinlin province)
    - FoV = 90x90 arcmin², 400-900 nm
  - **French Ground Follow-up Telescope (F-GFT)**
    - Robotic 1.3 m telescope, San Pedro Martir (Mexico)
    - FoV = 26x26 arcmin²
    - Multi-band photometry (400-1700 nm, 3 simultaneous bands)
  - **Contribution to LCOGT network** (12×1m + 2×2m tel.)

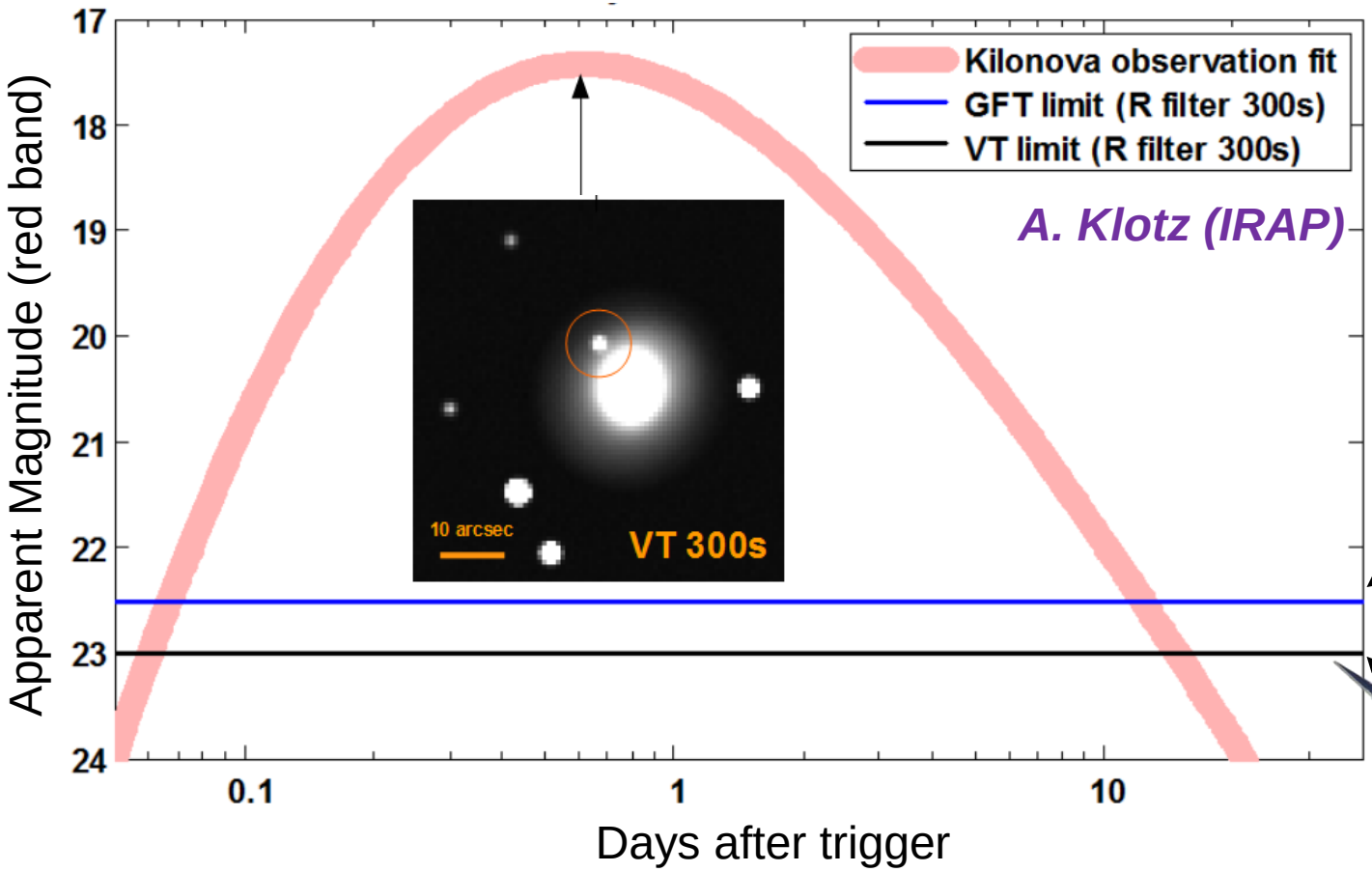
~75% of ECLAIRs-triggered GRBs immediately visible by one ground telescope (GFTs+LCOGT)

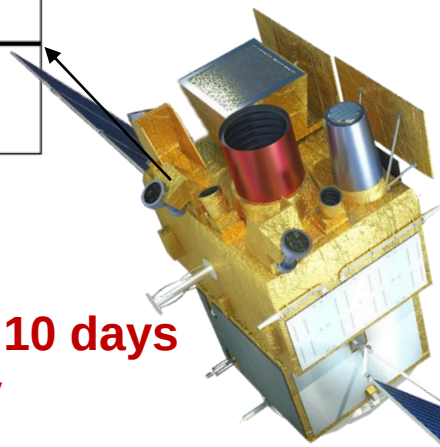
➔ Very large telescopes for redshift determination

GRB 170817A in VT & GFT

Simulation of the event (counts+background)

Parameters of the kilonova in NGC 4993

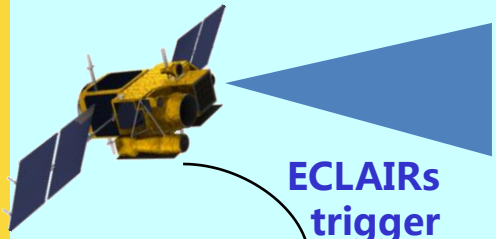




➔ **VT and GFT can observe the kilonova from beginning to 10 days**

➔ **In case of no ECLAIRs detection: SVOM ToO within 1 day**

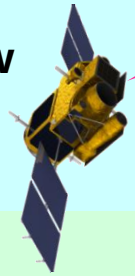
SVOM GRB observation scenario



ECLAIRs trigger

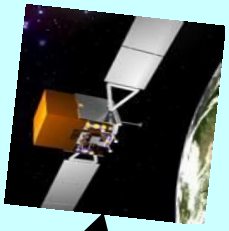
Auto slew

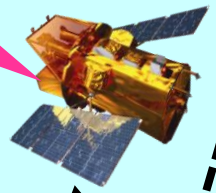
T0 GRB trigger



T0+5min
VT,MXT
observation
14 orbits
(~1 dy)

GRB





On board

On Ground

VHF network

F SC

T0+30s

Inside SVOM

Outside SVOM

Other SC mission center

T0+1min

C SC

GCN & VO event

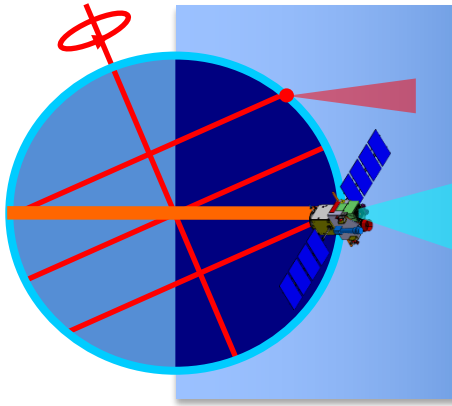
GRB coordination distribute

Other telescopes

SVOM pointing strategy

For optimal ground follow-up to determine redshift :

- favor sky observable from Hawaii, Chile and Canary Islands
- satellite attitude roughly antisolar towards the night

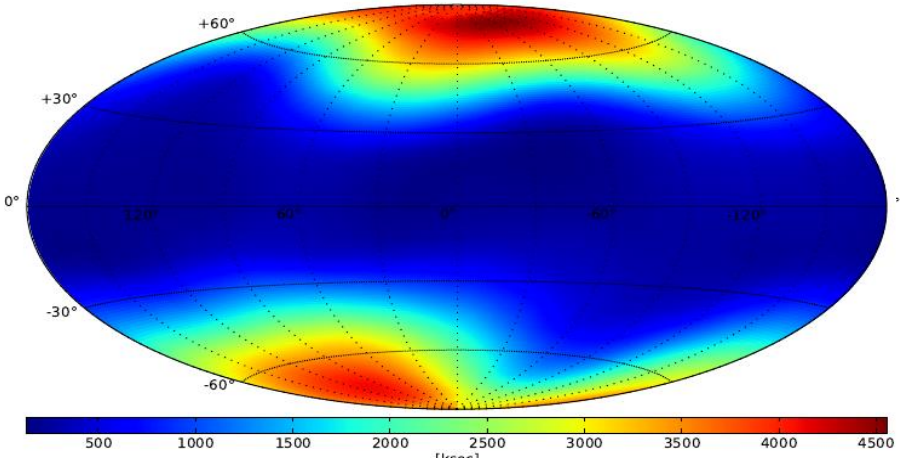


To maintain satellite radiators cold :

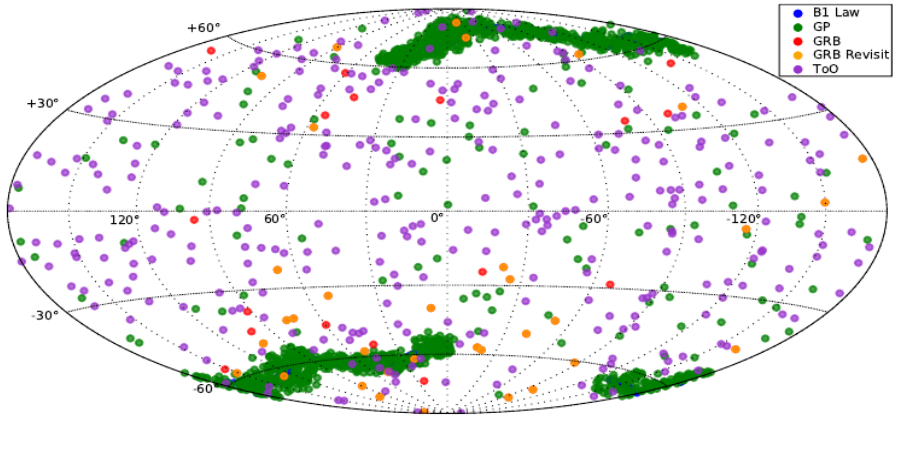
- satellite attitude antisolar within 45°

For best GRB detection performance :

- keep Sco X-1 and Galactic Plane outside the ECLAIRs FoV



ECLAIRs sky exposure
(4.5 Ms towards Galactic poles in 1 yr)

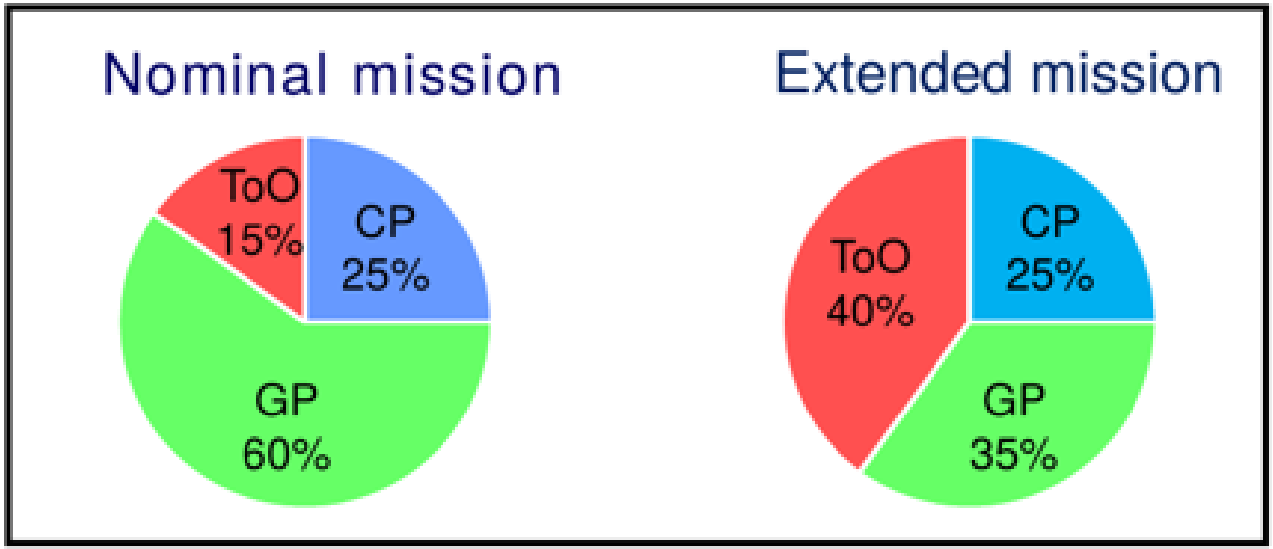


MXT and VT pointings
(in 1 yr nominal mission)

Scientific programs of SVOM

- **Core Program (CP)** : follow-up GRB triggers of ECLAIRs
- **General Program (GP)** : AGN, ULX, TDE, Galactic sources (CV, XRB, pulsars, magnetars, TGF), background studies (CXB), etc
- **Targets of Opportunity (ToO)**, 1 / day: follow-up external triggers: multi-wavelength (SKA, LSST, CTA, HAWC) or multi-messenger (GW, neutrino)

Observing time allocation



Extended mission (after 3 first years)

- ToO rate increased (up to 5/day)
- GP time outside the "B1 law" increased (10% → 50%)

Scientific programs of SVOM

- **Core Program (CP)** : follow-up GRB triggers of ECLAIRs
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- **Targets of Opportunity (ToO)**, 1 / day: follow-up external triggers: multi-wavelength (SKA, LSST, CTA, HAWC) or multi-messenger (GW, neutrino)

Data policy:

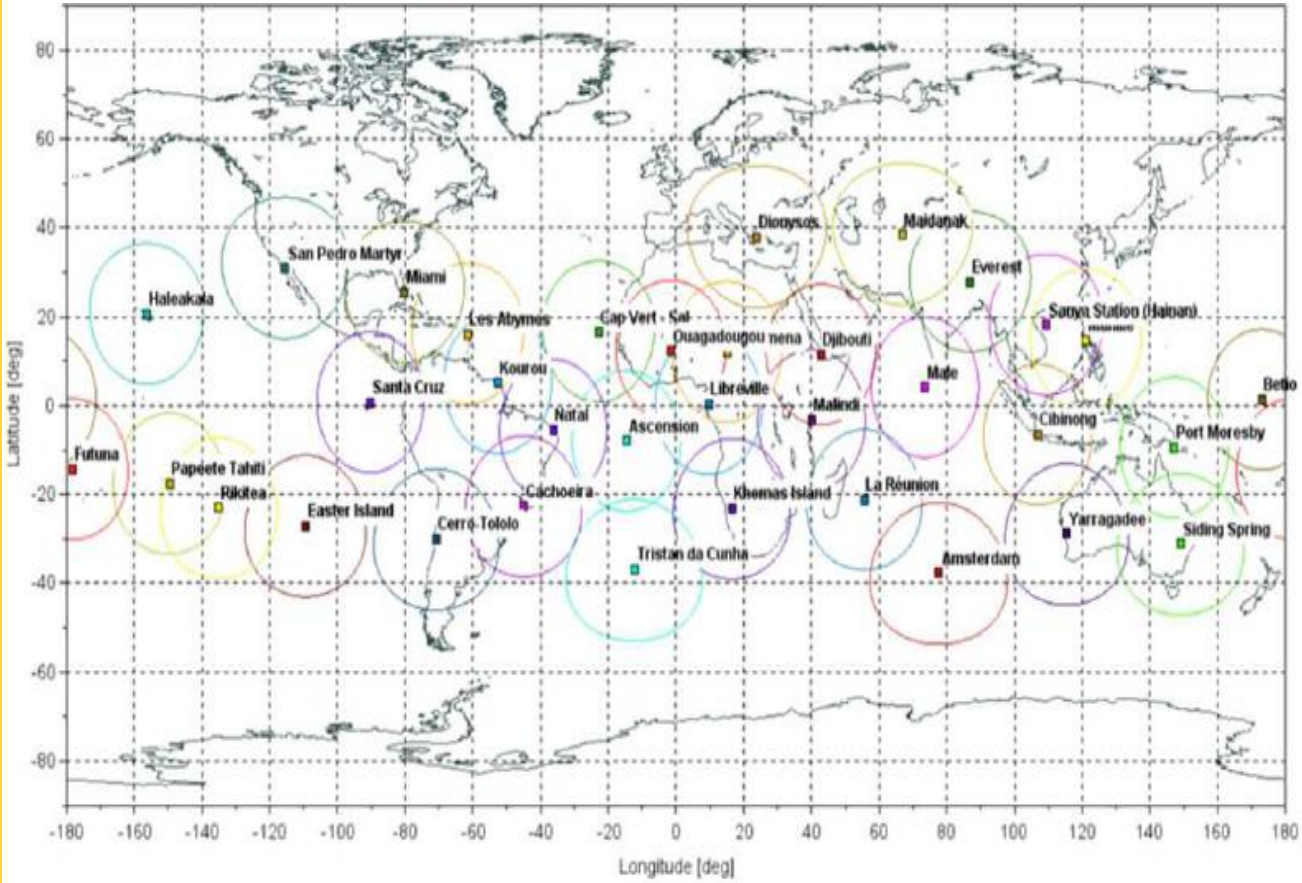
- **Core Program** Most scientific products generated by the Burst Advocate are public as soon as they are available. All scientific products are public 6 months after data observation
- **General Program** All data products are distributed to the responsible Co-I. Proprietary period: 1 year, after which the data products are public
- **Targets of Opportunity** SVOM ToO: same policy as Core Program
  -MoU ToO: policy follows the agreement of MoU
  -Other ToO: data public as soon as available

Two points related to this workshop

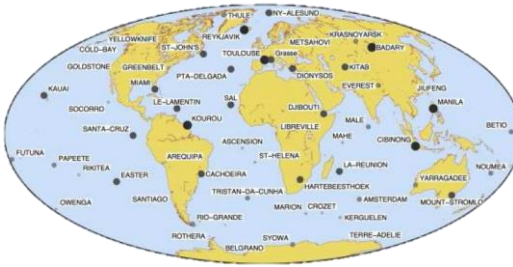
SVOM VHF network

- SVOM on-board VHF emitter to VHF receivers on Earth.
- Low data rate: 300 bits/s
- Alerts transmitted over internet to CEA Saclay (France) within 30 sec (in 65% of cases)

VHF network under satellite orbit (a=620 km, i=30°)
→ up to 45 stations deployed by CNES
→ based on existing CNES networks (DORIS, REGINA)
+ specific partners from scientific laboratories



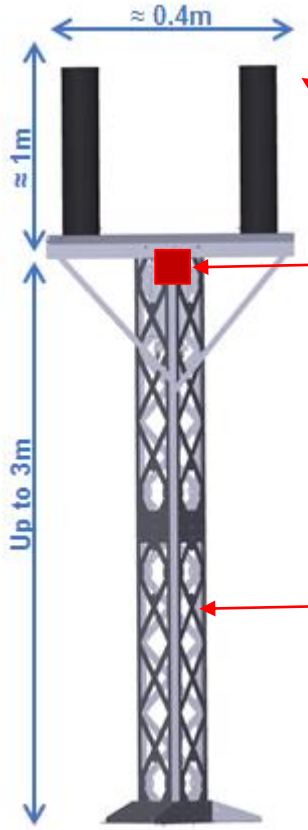
DORIS network



REGINA network

Existing Geodesy networks of CNES: for monitoring of Earth stations drifts and satellite trajectories

SVOM VHF station kit



Quadrifilar helix antennas (LHCP & RHCP) at 137-138 MHz

Processing module inside waterproof case

- transceiver (AD9361):
  digitization + filtering
- FPGA/CPU (Zynq) :
  demodulation + communications

Fully dismountable and adjustable mast

"Power over Ethernet" injector near Internet access point

We would be glad to discuss with you:

→ to join SVOM by hosting a VHF station (if you can provide a suitable site)

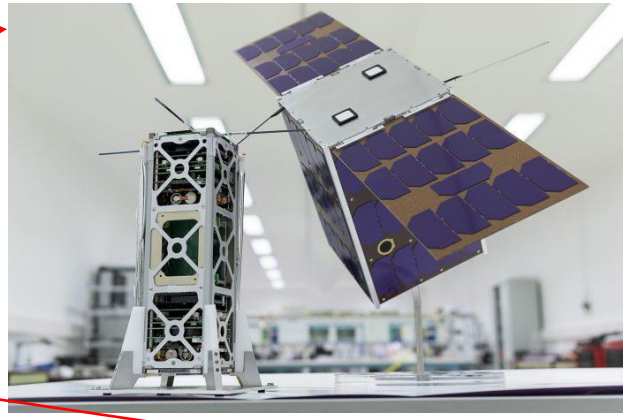
→ to use the VHF network for alerts from your nanosatellite (if you can accommodate a VHF emitter onboard)

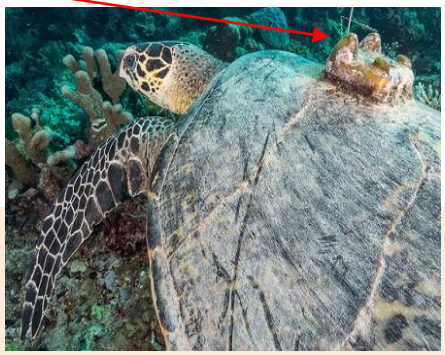
Family of nano-satellites in France

Development of French nano-satellite family
- cooperation CNES/Nexeya
- kicked-off in may 2017
- Nexeya : platform development
- production facilities in Toulouse

Characteristics:
- modular (3U to 27U)
- weight < 50 kg
- multi-mission, adaptable
- Industrial, reliable

First demonstrator: “ANGELS”
(Argos NEO Generic Economic Light Satellites)
- prototype of a new Argos constellation
- Argos: environment study & protection, location and data collection, satellites + >20 000 Earth bound emitters, e.g. > 8000 animals tracked.
- Platform by Nexeya: 3U format
- Payload by CNES and TAS: Argos NEO instrument
- Launch foreseen in 2019





CNES is currently opening a call for proposals on nano-satellites (to be evaluated in 2019).
We would like to hand-in a proposal for a GRB nano-satellite and/or take part in a constellation.

Conclusions

Concluding words on SVOM

SVOM designed to study the diversity of GRBs and get a complete sample, good spectral and temporal coverage of the prompt and afterglow, optimized follow-up strategy to get redshift of a large GRB fraction (~50%)

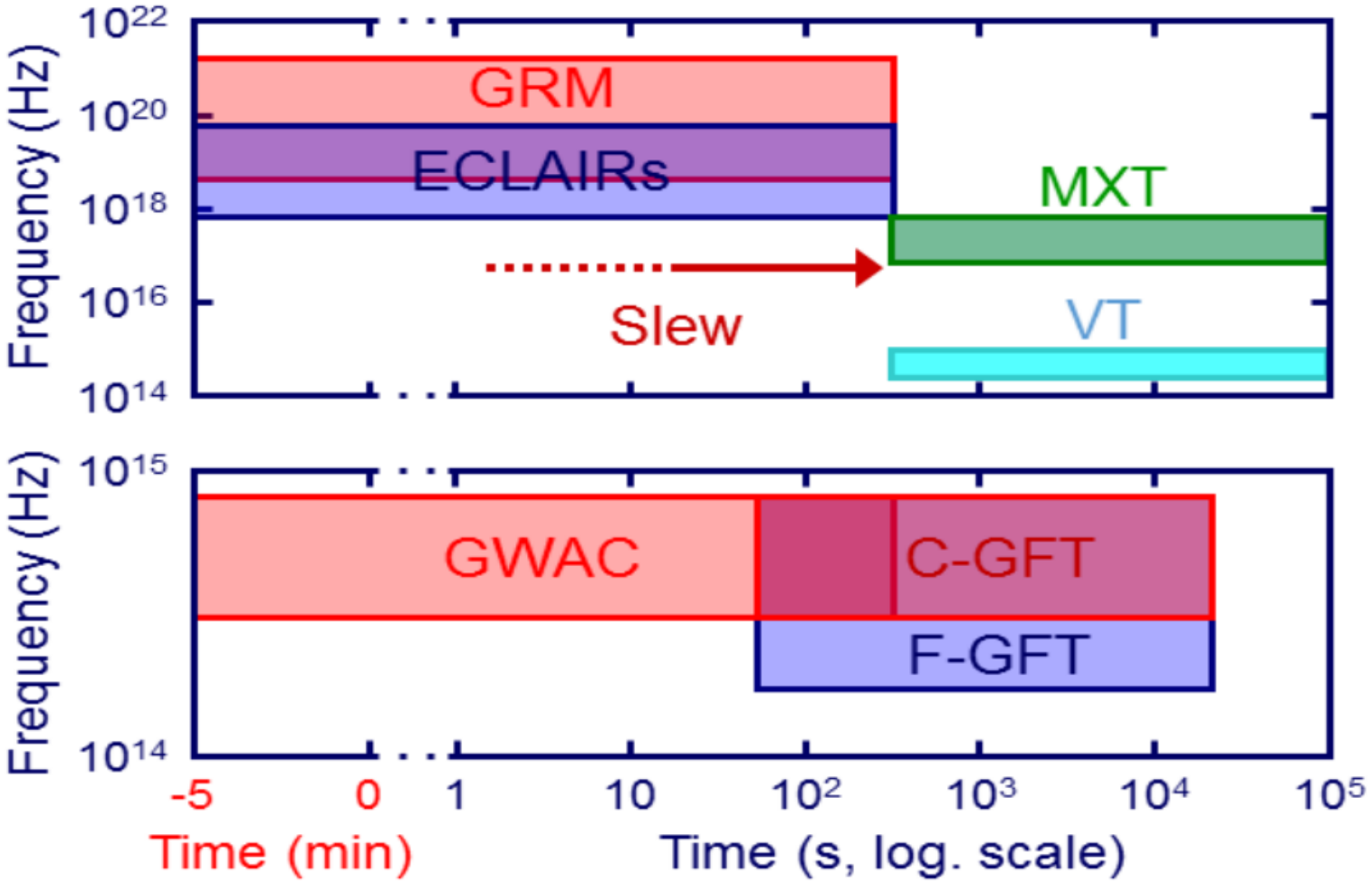
SVOM observation plan and instruments (space+ground-based) suited to detect high redshift GRBs

SVOM is prepared for multi-messenger era: ToO follow-up of GW and neutrino alerts

More information: "*The Deep and Transient Universe in the SVOM Era: new Challenges and Opportunities,* ***Scientific prospects of the SVOM mission***", J. Wei, B. Cordier et al., arXiv:1610.06892

Thank you !

Temporal & spectral GRB coverage



Space

Ground