The SVOM mission

Bertrand Cordier
CEA

on behalf of the SVOM collaboration

16 December 2020

The SVOM consortium

- **China (PI J. Wei)** 
  - SECM Shanghai
  - Beijing Normal University
  - Central China University Wuhan
  - Guangxi University Nanning
  - IHEP Beijing
  - KIAA Peking University
  - Nanjing University
  - NAOC Beijing
  - National Astronomical Observatories
  - Purple Mountain Observatory Nanjing
  - Shanghai Astronomical Observatory
  - Tsinghua University Beijing

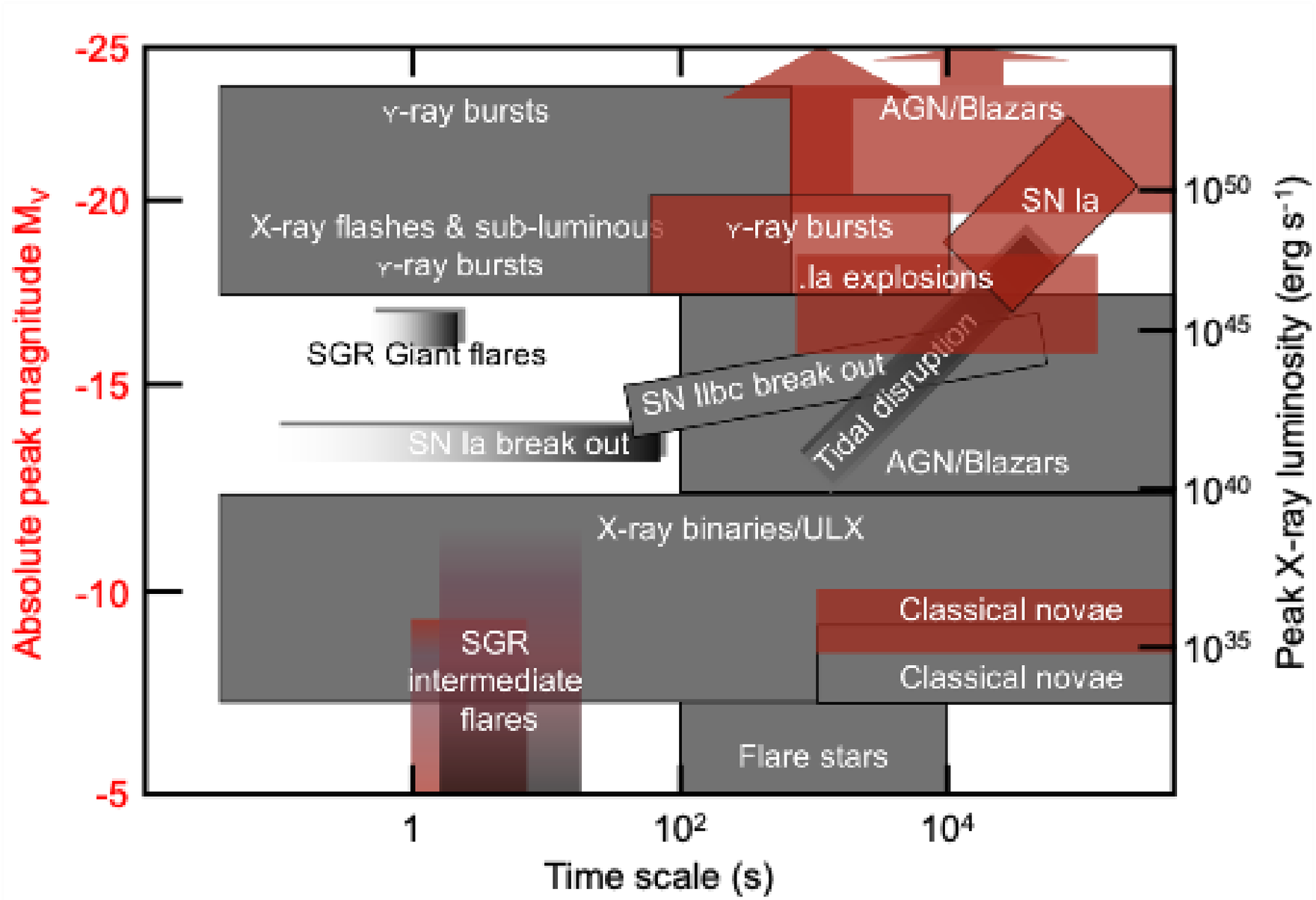
- **Mexico** UNAM Mexico 

- **France (PI B. Cordier)** 
  - CNES Toulouse
  - APC Paris
  - CEA Saclay
  - CPPM Marseille
  - GEPI Meudon
  - IAP Paris
  - IRAP Toulouse
  - LAL Orsay
  - LAM Marseille
  - LUPM Montpellier
  - OAS Strasbourg

- **UK** University of Leicester 

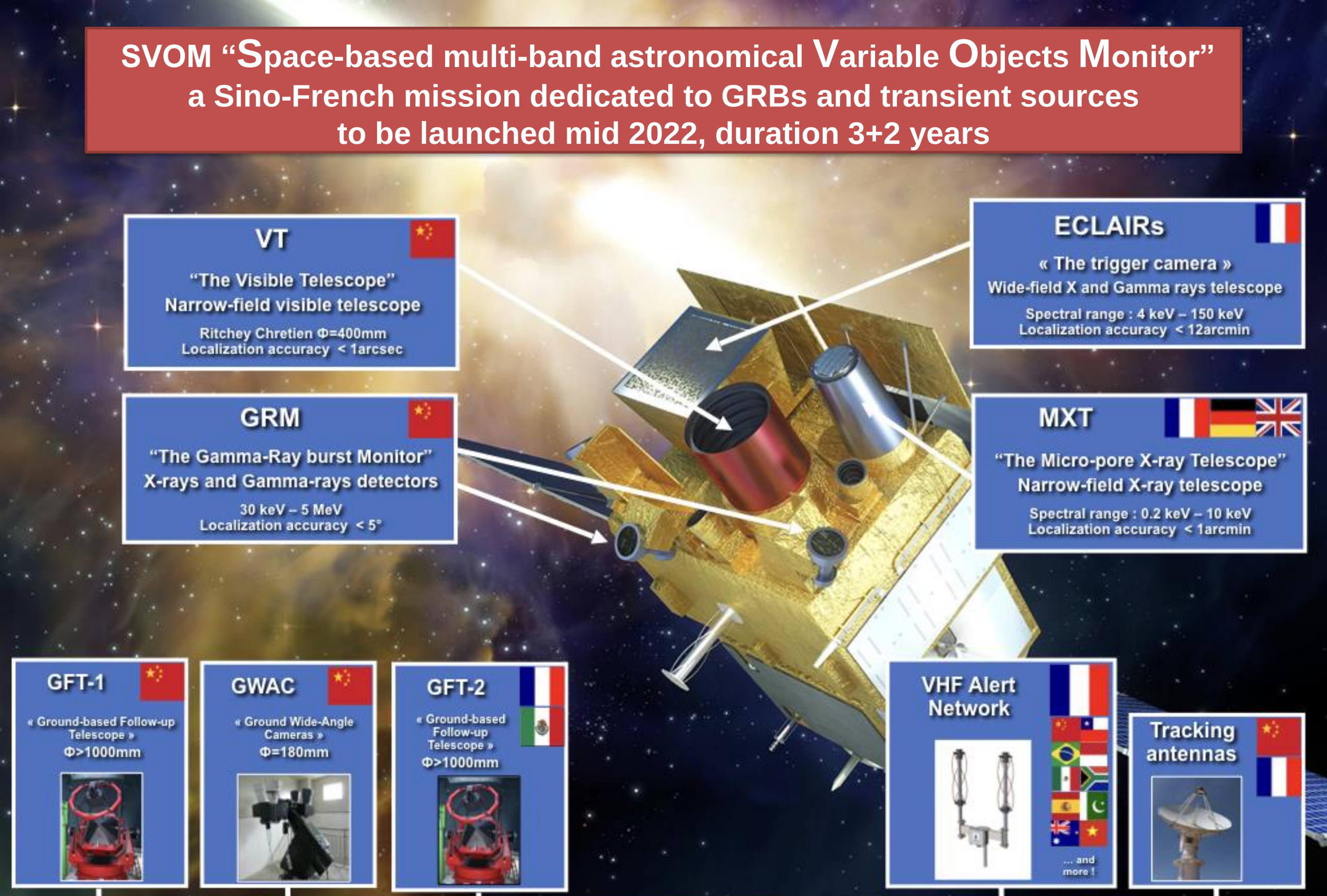
- **Germany** 
  - MPE Garching
  - IAAT Tübingen

Time-domain astronomy



- Time-domain astronomy is a priority area of research in the next decade
- Hot topics: explosive transients (GRBs, SN shock breakouts, TDE, FRB), multi-messenger astronomy (GWs, neutrinos)

SVOM "Space-based multi-band astronomical Variable Objects Monitor"
a Sino-French mission dedicated to GRBs and transient sources
to be launched mid 2022, duration 3+2 years



VT
"The Visible Telescope"
Narrow-field visible telescope
Ritchey Chretien Φ=400mm
Localization accuracy < 1arcsec

GRM
"The Gamma-Ray burst Monitor"
X-rays and Gamma-rays detectors
30 keV – 5 MeV
Localization accuracy < 5°

ECLAIRs
« The trigger camera »
Wide-field X and Gamma rays telescope
Spectral range : 4 keV – 150 keV
Localization accuracy < 12arcmin

MXT
"The Micro-pore X-ray Telescope"
Narrow-field X-ray telescope
Spectral range : 0.2 keV – 10 keV
Localization accuracy < 1arcmin

GFT-1
« Ground-based Follow-up Telescope »
Φ>1000mm

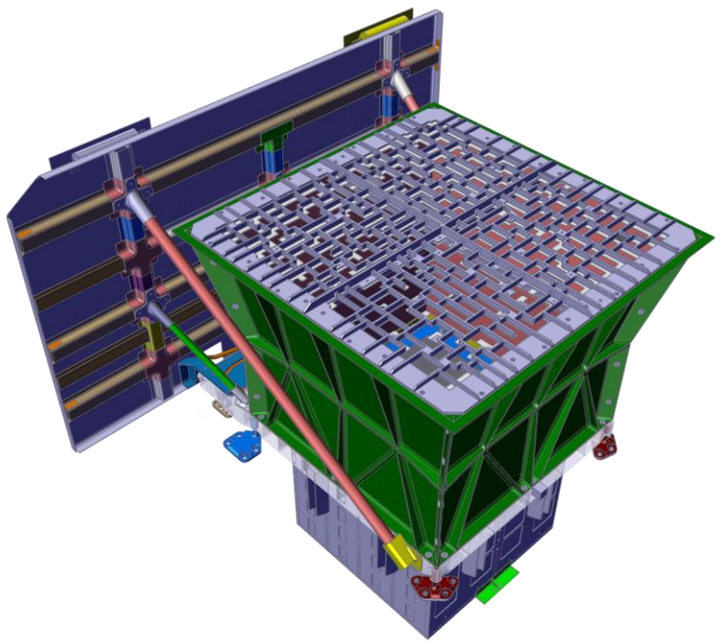
GWAC
« Ground Wide-Angle Cameras »
Φ=180mm

GFT-2
« Ground-based Follow-up Telescope »
Φ>1000mm

VHF Alert Network
... and more !

Tracking antennas

INSTRUMENTS with LARGE FIELD OF VIEW IN SPACE

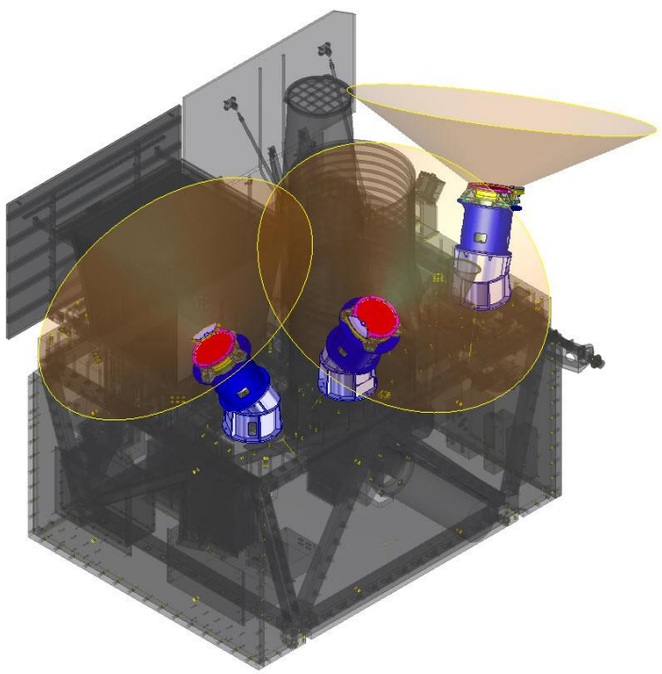


ECLAIRs (CNES, IRAP, CEA, APC)

- 40% open fraction
- Detection plane: **1024 cm²**
- 6400 CdTe pixels (4x4x1 mm³)
- FoV**: 2 sr** (zero sensitivity)
- Energy range: **4** - 150 keV
- Localization accuracy **<12 arcmin** for 90% of sources at detection limit
- Onboard trigger and localization: **~65 GRBs/year**

Will detects, localizes and characterizes HE transients. It generates alerts and slew requests:

Well adapted for the detection of lGRB with low E_{PEAK}



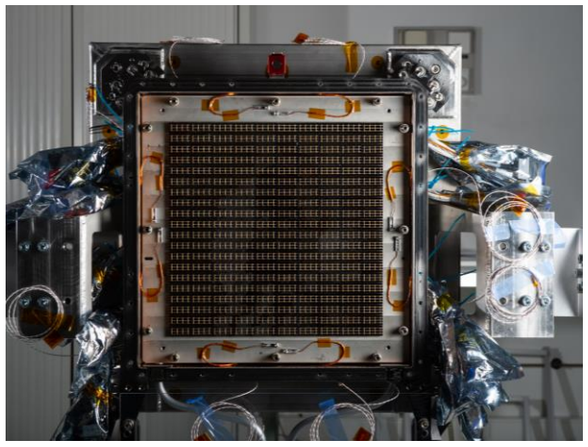
GRM Gamma-Ray Monitor (IHEP)

- **3 Gamma-Ray Detectors** (GRDs)
- NaI(Tl) (16 cm Ø, 1.5 cm thick)
- Plastic scintillator (6 mm) to monitor particle flux and reject particle events
- FOV: **5,6 sr** 3 GRDs, **1,0** intersection of 3 GRDs
- Energy range : 30-**5000** keV
- Aeff = **190 cm²** at peak
- Rough localization accuracy
- Expected rate: **~90 GRBs / year**

Will provide E_{PEAK} measurements for most ECLAIRs GRBs

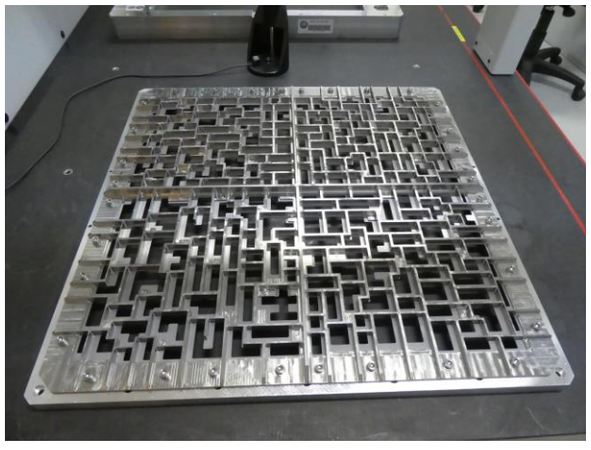
Will detect short GRBs in & out of the ECLAIRs FOV

ECLAIRS FM STATUS

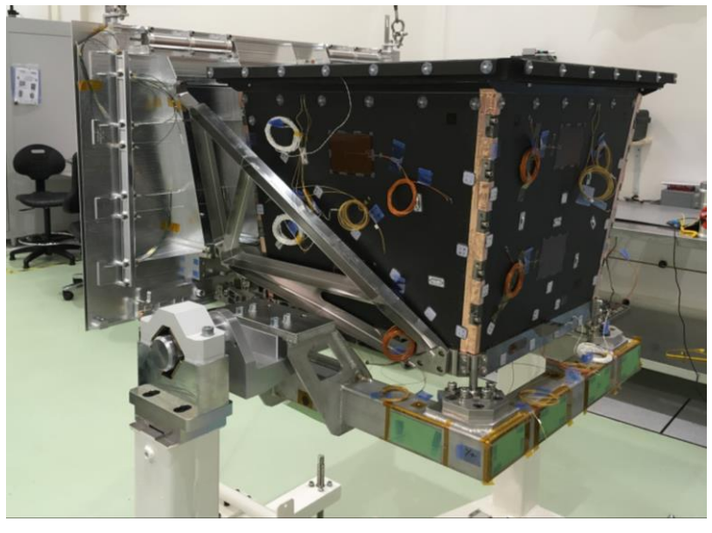


Detection plane

Onboard computer



Coded mask



Structure, mechanical & thermal

December 20, the flight models of all subsystems have been manufactured and they are being tested now, before the final integration early next year.

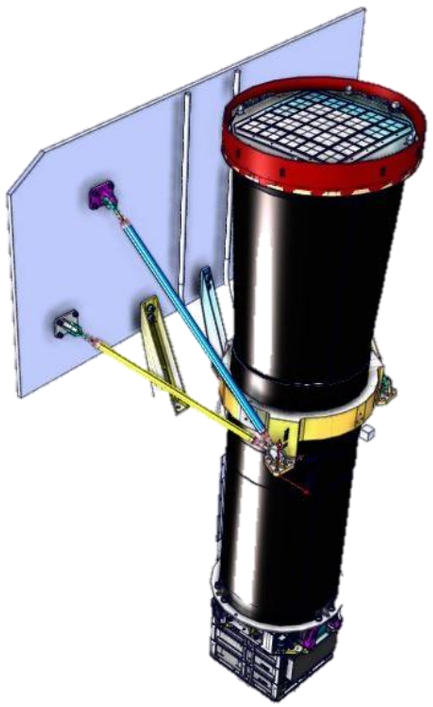
INSTRUMENTS with LARGE FIELDS of VIEW: on GROUND

Ground Wide Angle Cameras

cameras: 40
wavelength : 500-800nm
5000 deg2, mV= 16 (10s)
Self Trigger

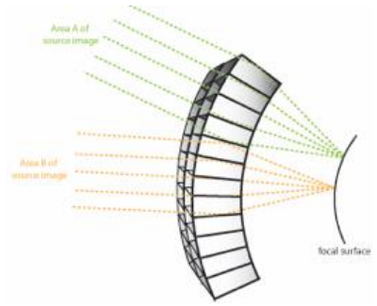
- Search for prompt visible counterparts of GRB
- Of course this instrument can be used to search for electromagnetic counterpart in the large error boxes of gravitational wave detectors

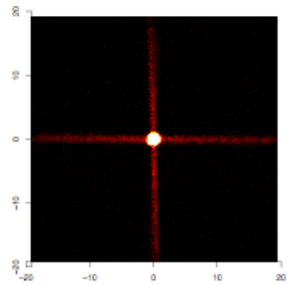
INSTRUMENTS with SMALL FIELD OF VIEW IN SPACE



MXT Micro-channel X-ray Telescope (CNES, CEA, UL, MPE)

- **Micro-pores optics** (Photonis) with **40 µm square pores** in a “Lobster Eye” conf. (UL design)
- pnCCD (MPE) based camera (CEA)
- FoV : **64x64 arcmin²**
- Focal length: 1 m
- Energy range : 0.2 – 10 keV
- Aeff = **27 cm² @ 1 keV** (central spot)
- Energy resolution: ~80 eV @ 1.5 keV
- Localization accuracy **<13 arcsec** within 5 min from trigger for 50% of GRBs (statistical error only)



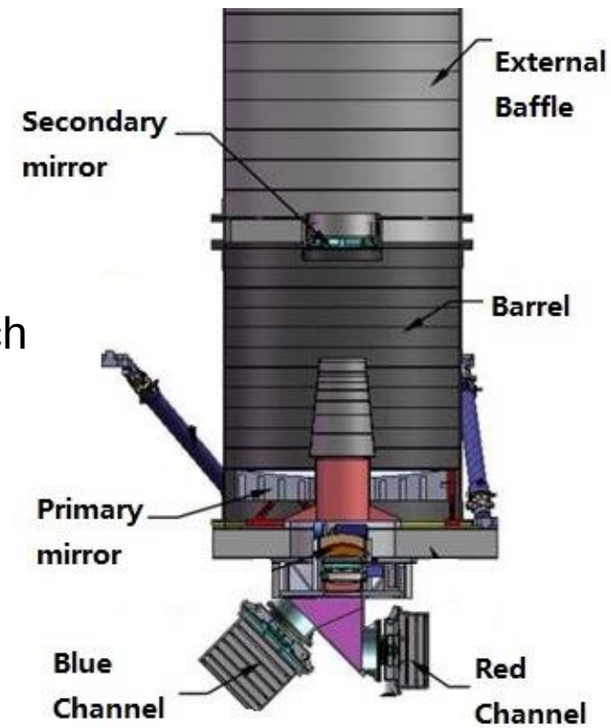


Implements innovative focussing X-ray optics based on « Lobster-Eye » design
Will reduce the ECLAIRs error box
Will be able to promptly observe the X-ray afterglow

VT Visible Telescope (XIOMP, NAOC)

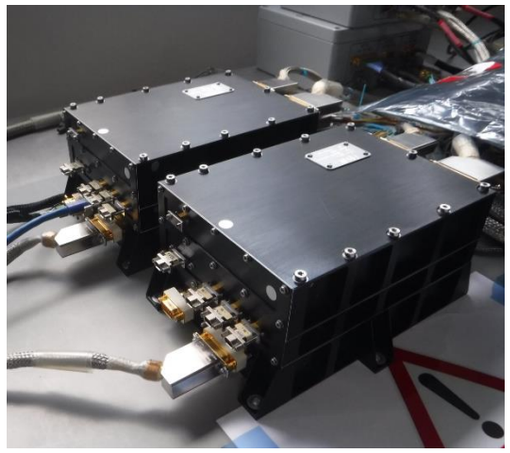
- Ritchey-Chretien telescope, 40 cm Ø, f=9
- FoV: **26x26 arcmin²**, covering ECLAIRs error box in most cases
- **2 channels: blue (400-650 nm) and red (650-1000 nm),** 2k * 2k CCD detector each
- **Sensitivity MV=23 in 300 s**
- Will detect ~80% of ECLAIRs GRBs
- Localization accuracy **<1 arcsec**

Able to detect high-redshift GRBs up to z~6.5 (sensitivity cutoff around 950 nm)
Can quickly provide redshift indicators due to the presence of two channels

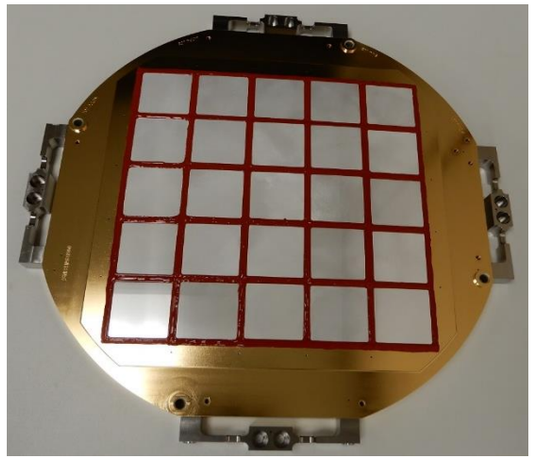


MXT FM STATUS

Detector and camera

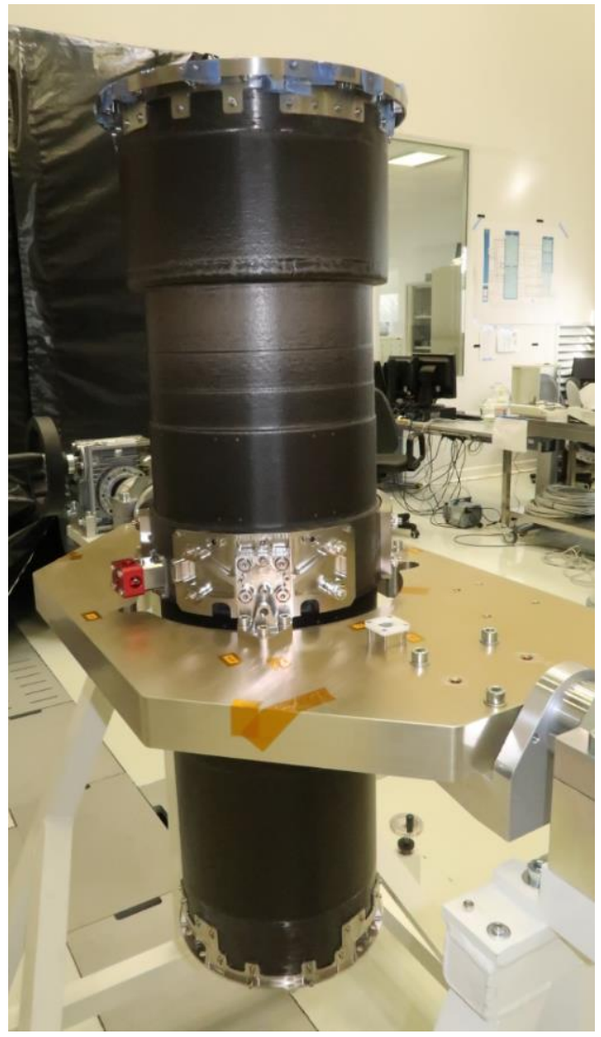


Onboard computer



Optics

Structural tube



December 20, the flight models of all subsystems have been manufactured and they are being tested now, before the final integration early next year.

INSTRUMENTS with SMALL FIELDS of VIEW: on GROUND

Grounf Follow-up Telescopes permit the fast identification and measure of early optical/NIR afterglows using the ECLAIRs positions, while the spacecraft is slewing to the source.

- C-GFTs is located at Weihai observatory (Jilin province)
- F-GFT will be located at San Pedro Martir (Mexico)

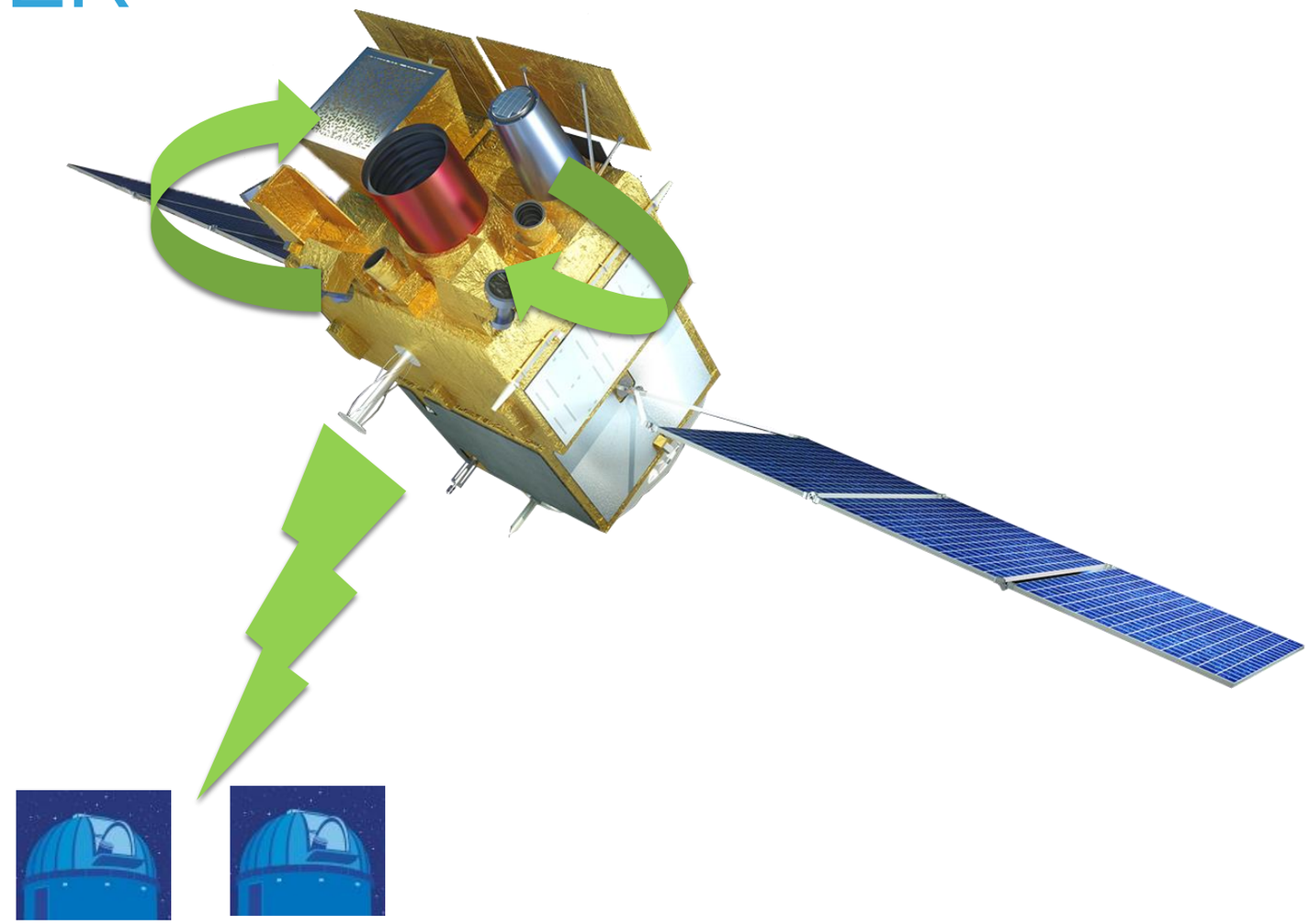
Diameter : 130 cm
FOV : 26 x 26 arcmin
400 – 1700 nm

Diameter : 120cm
FOV : 90 x 90 arcmin
400 – 900nm

Guaranteed access to the LCOGT network through NAOC (2000hr/year)

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

SVOM INSTRUMENTS COMMUNICATE WITH EACH OTHER



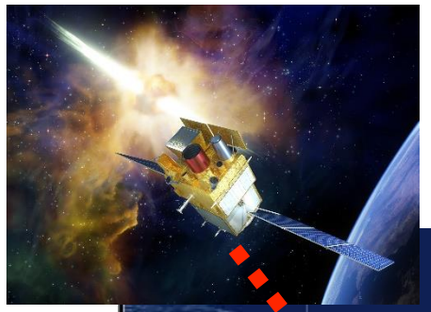
GRM -> ECLAIRs to help the detection of short GRB

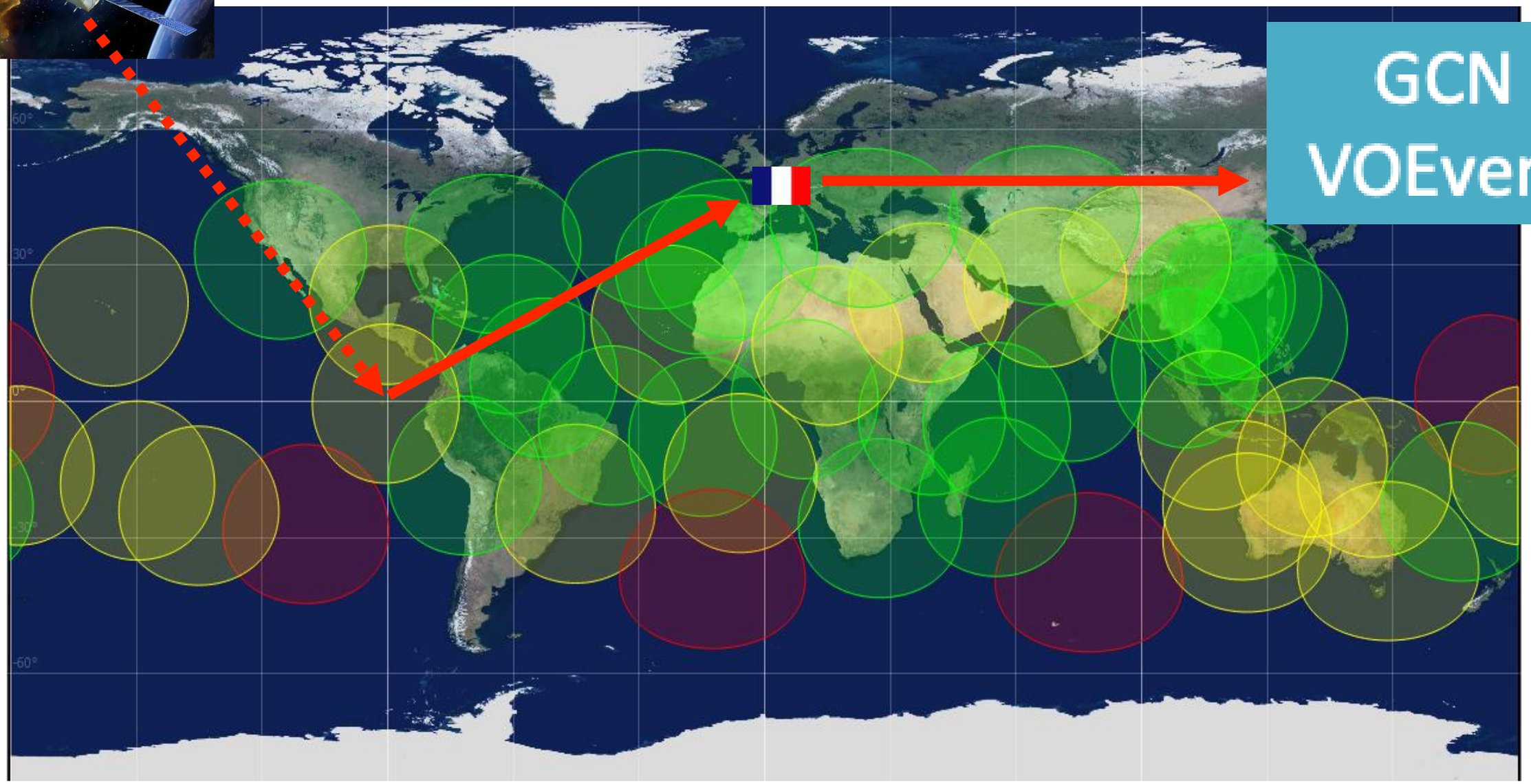
MXT-> VT to search for sources in the VT image inside the MXT error

ECLAIRs , MXT and VT -> GWAC and GFTs to indicate the coordinates of te GRB

GRM-> GWAC to indicate the time slice of the trigger

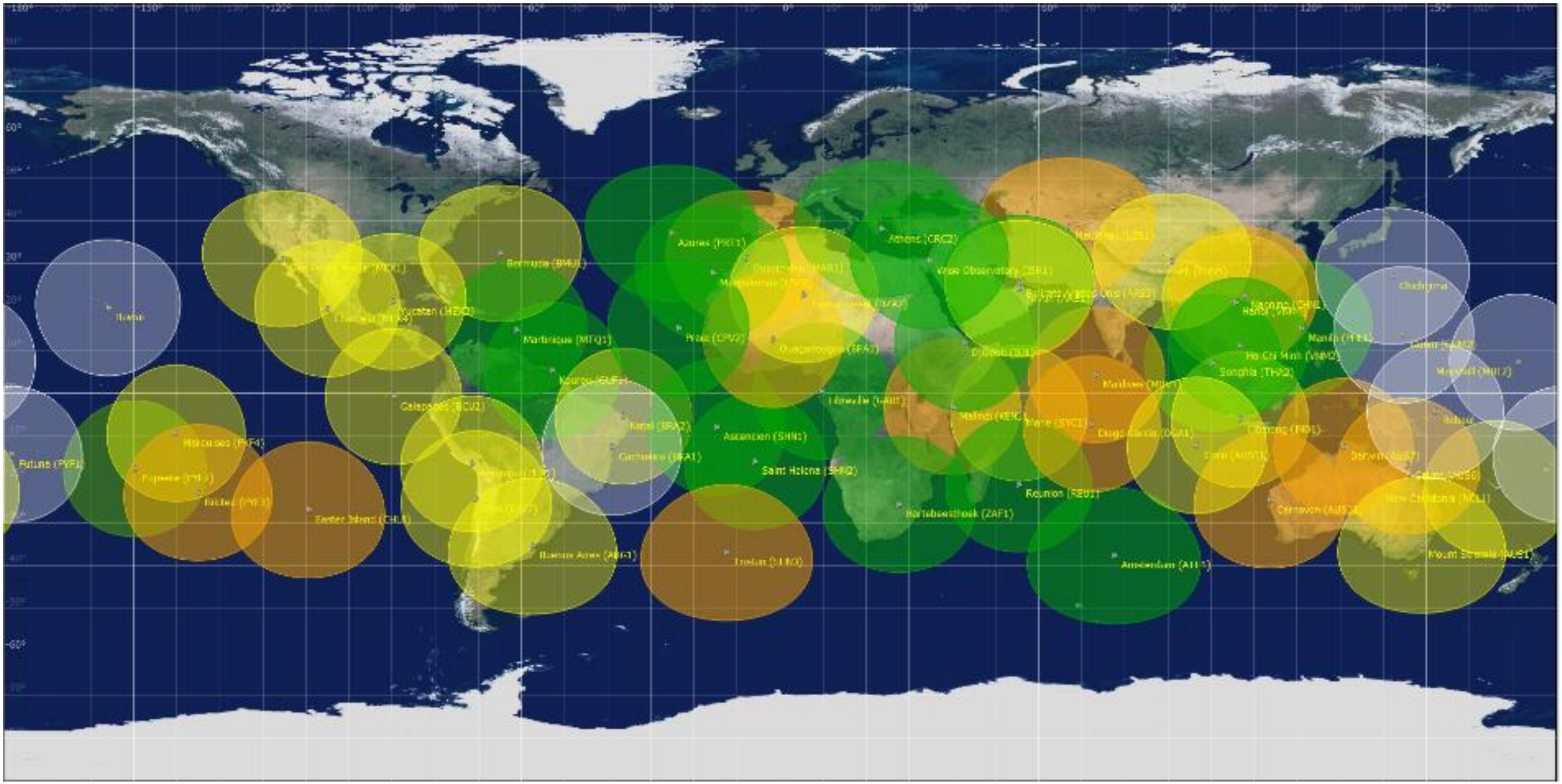
SVOM alert system





- Alerts are transmitted to a network of ~40 VHF receivers on Earth
- Goal: 65% of the alerts received within 30 s at the French Science Center

Le déploiement - suite



Station Installée

Station sur place/en transit

Accords de principes

Discussions engagées

NB : cercles de visibilité théoriques à EL=10°

Florilèges des stations installées









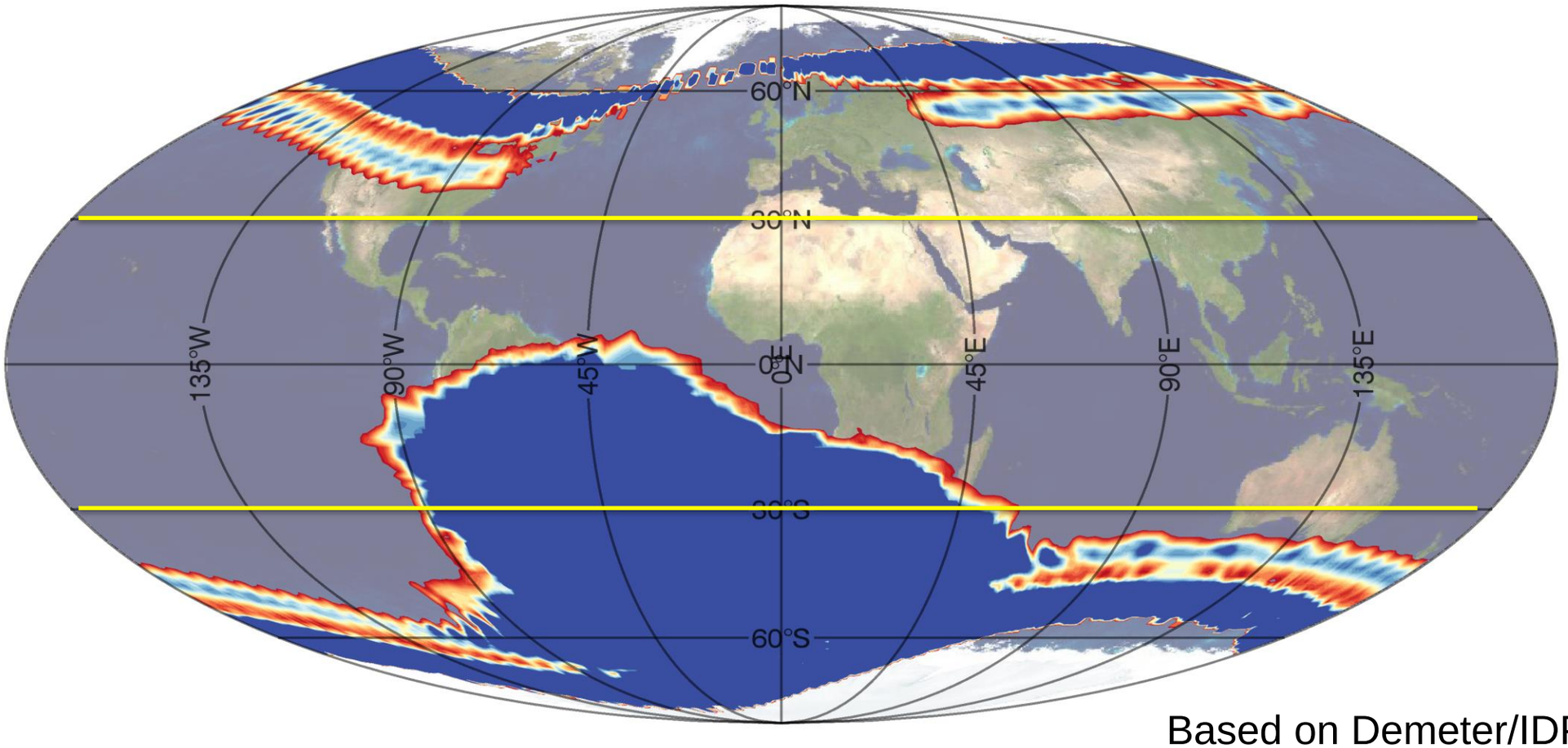








The SVOM orbit

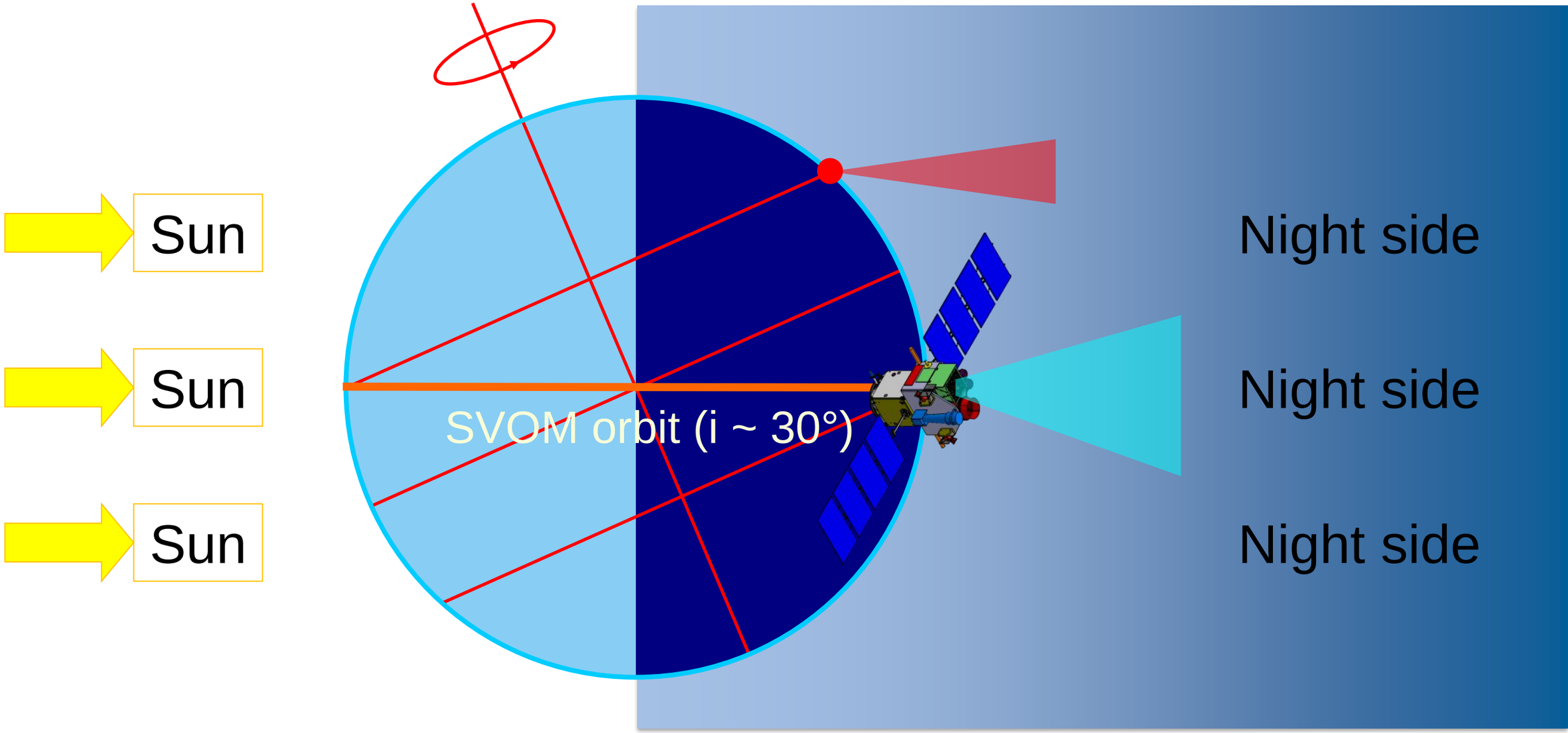


Based on Demeter/IDP electron flux

LEO altitude 625 km, with an inclination of 30°, launched by a LM-2C from Xichang

→ the satellite passes though the South Atlantic Anomaly
→ induces a dead time of (13-17)%

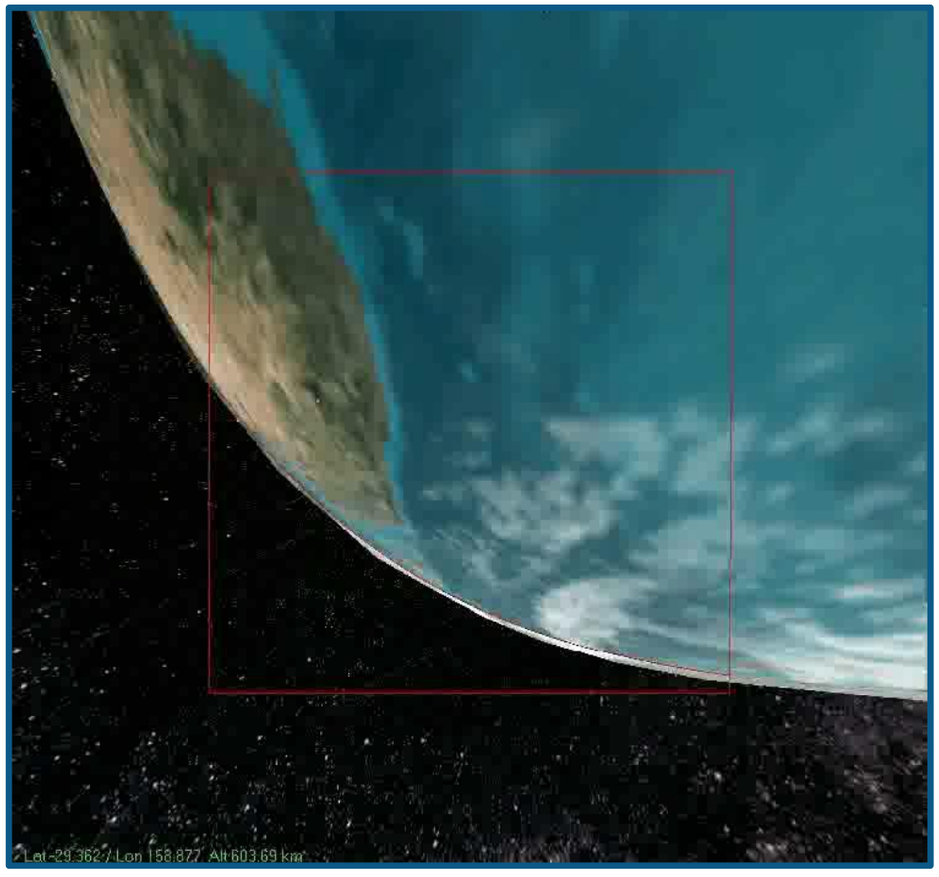
The SVOM attitude law



To detect GRB on the night side → attitude law : roughly antisolar

The SVOM attitude law

Low Earth Orbit + roughly antisolar attitude law



Consequence : at each orbit the Earth occults the instruments FOV

- ECLAIRS duty cycle 65%
- VT duty cycle 50%
- MXT duty cycle 50%

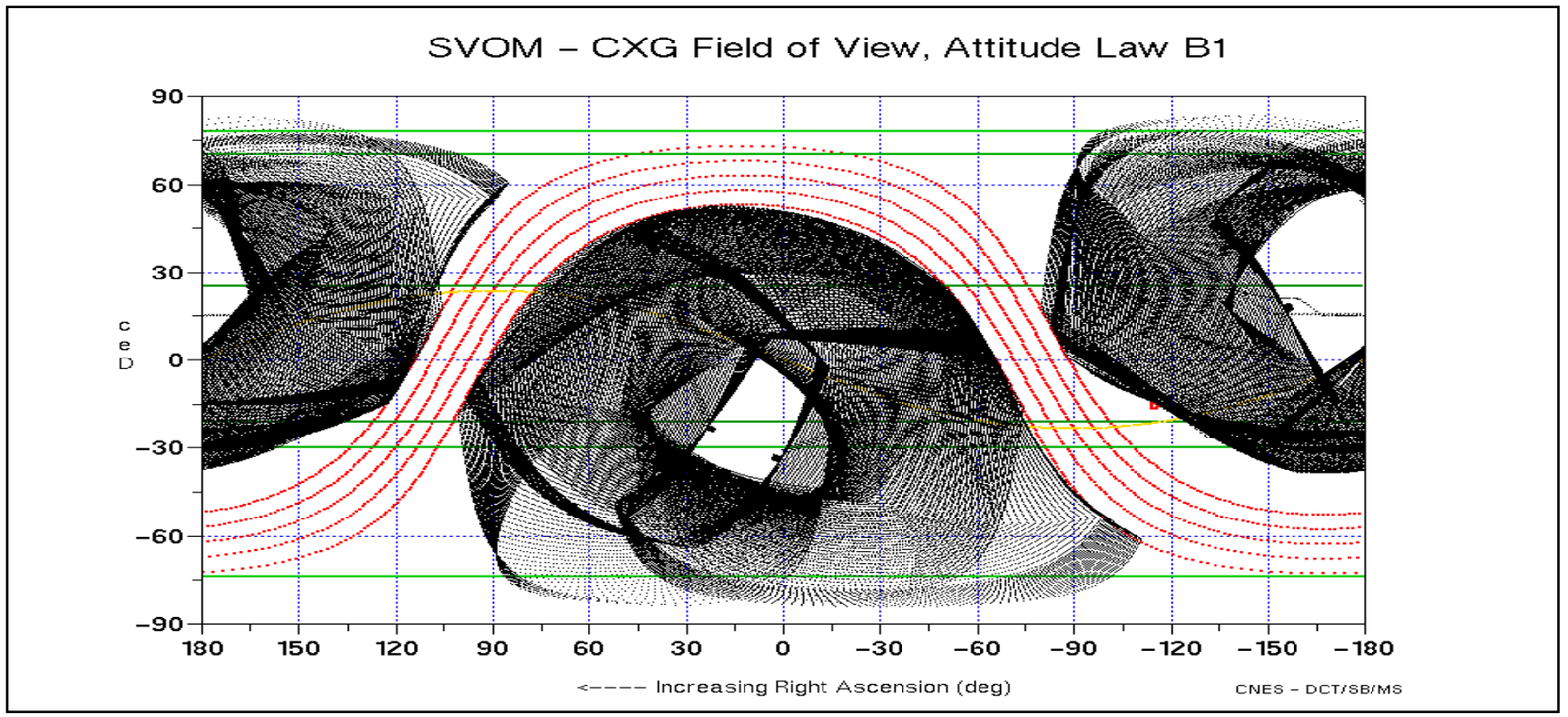
Optimization of the SVOM attitude law

To favor the GRB detection by ECLAIRs
- avoidance of the the Sco X1source (outsite of the ECLAIRs FOV)
- avoidance of the Galactic Plane (+/- 10° for the ECLAIRs FOV)

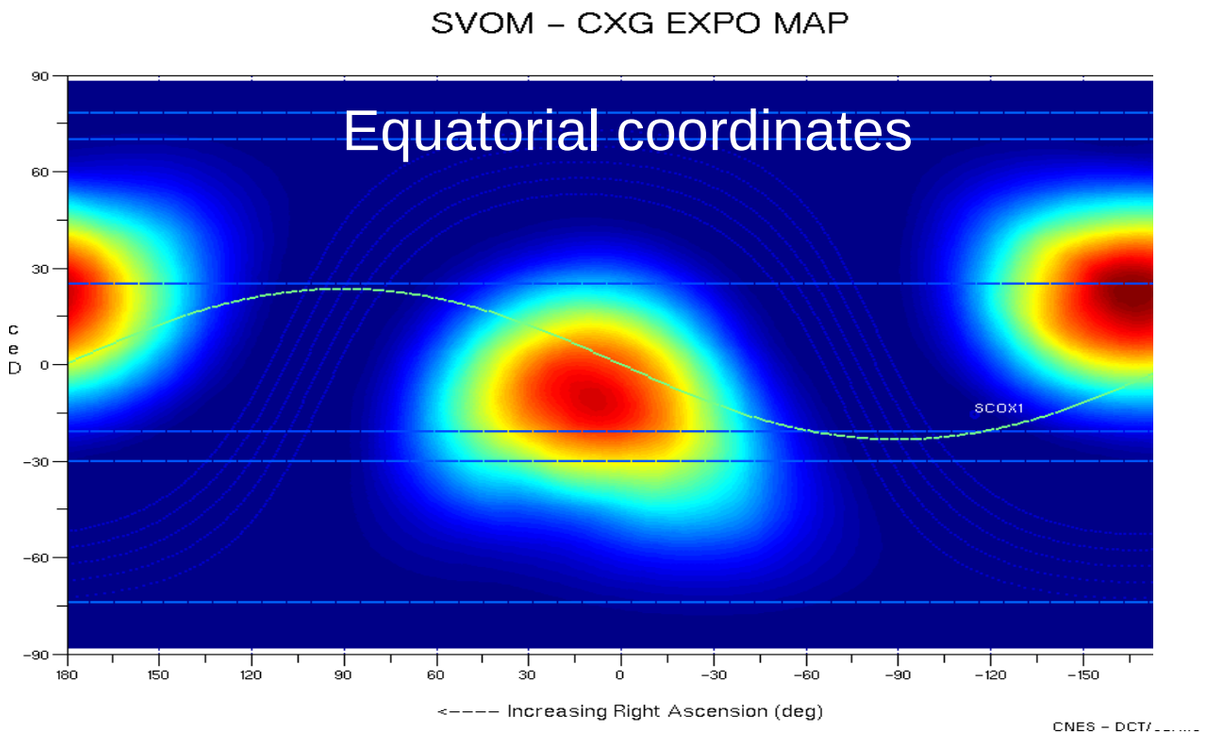
To favor the redshift measurement on ground.
- avoidance of the Galactic Plane (+/- 10° for the ECLAIRs FOV)
- → to favor the sky area observable from both Hawaii, Chile and the Canary
- → SVOM points to areas near the equator (declination $\delta=0$)

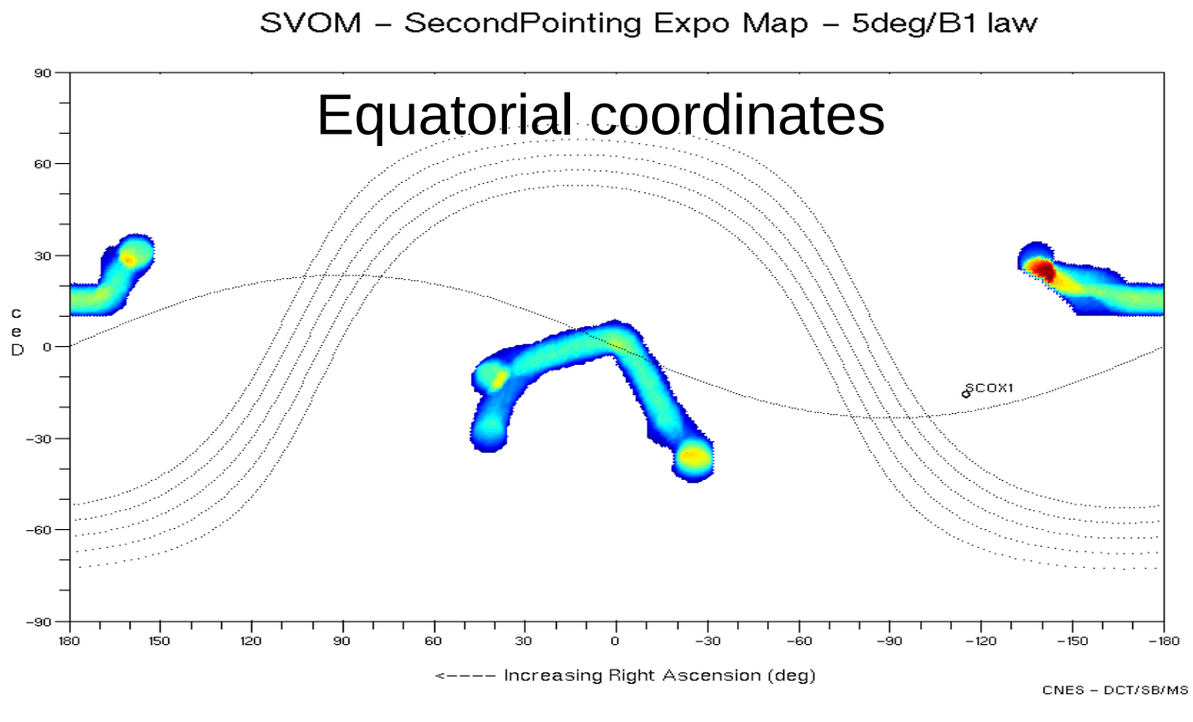
To maintain a cold face for the satellite
Offset of 45° with respect to the antisolar direction

Tolerance of 5° with respect to the nominal pointing

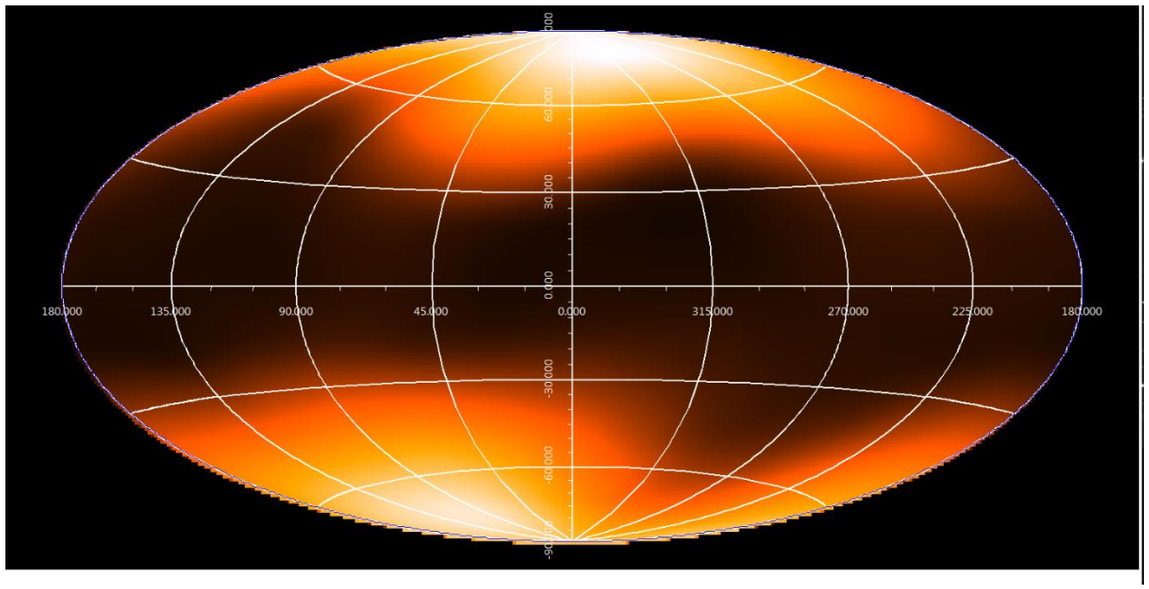


The SVOM attitude law: consequences on the exposure map
1 year scenario

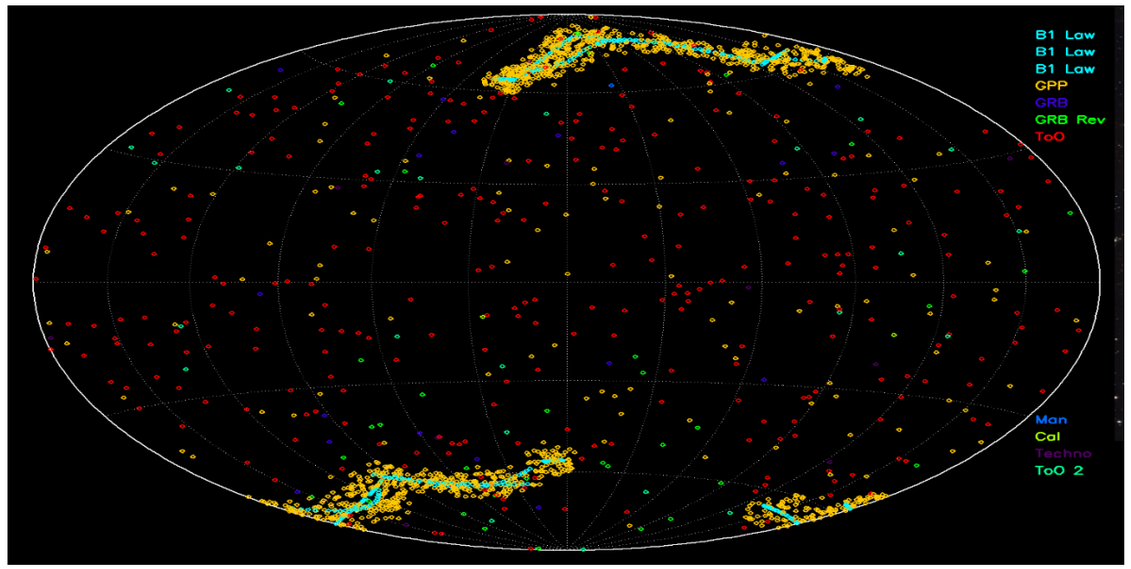




Galactic coordinates



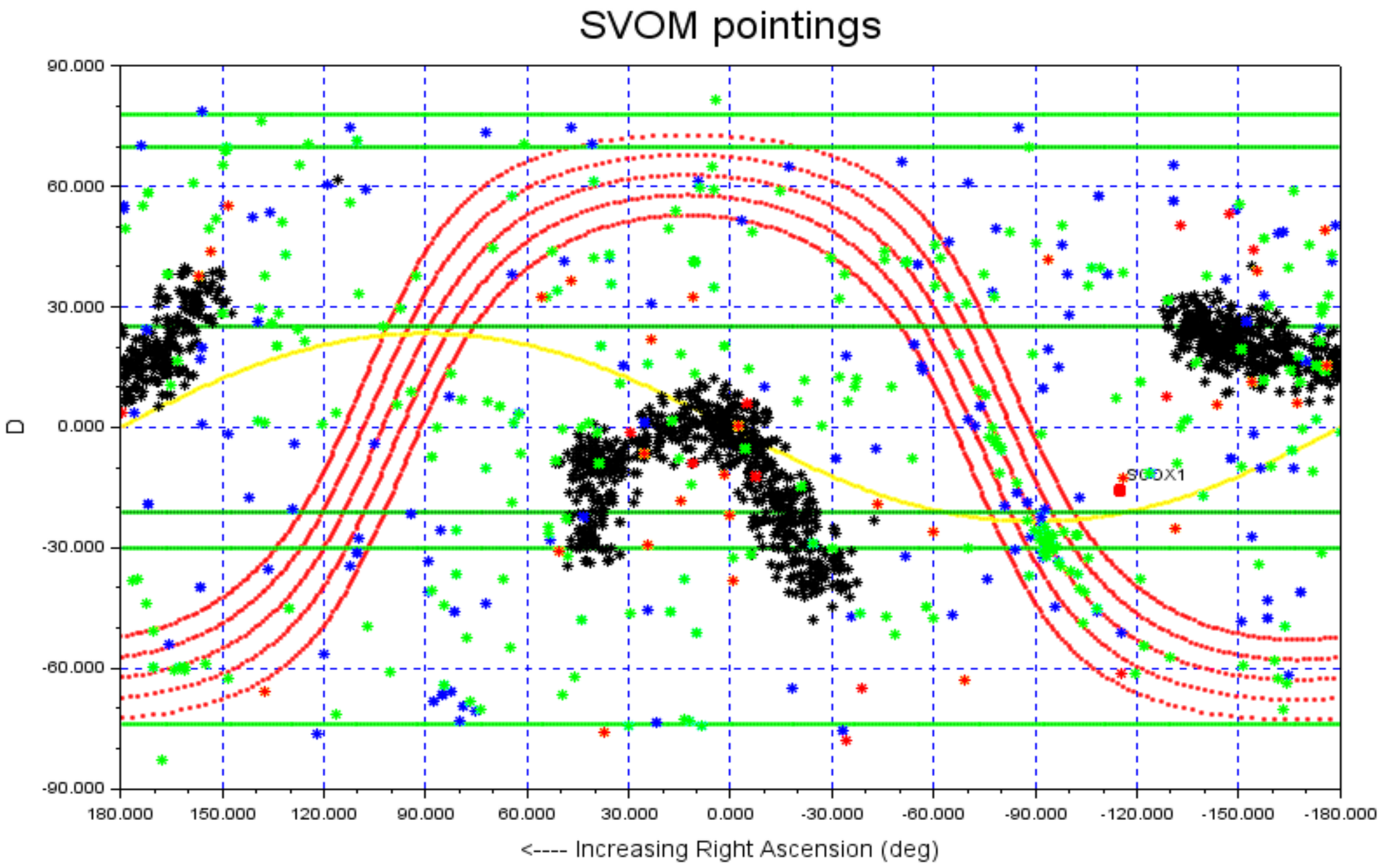
Galactic coordinates



Wide field instruments : ECLAIRS, GRM,

Narrow field instruments : MXT, VT

One Year of observation



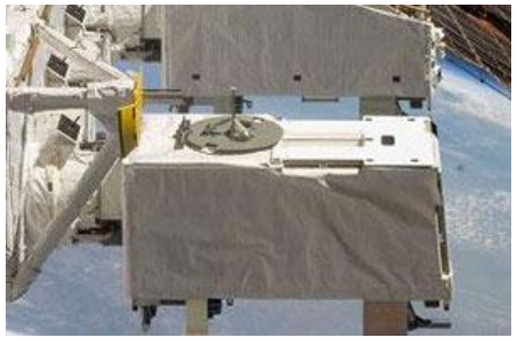
The satellite's attitude law
Blue and black dot : nominal attitude law and General program pointings
Green dot ToO pointings
Red dot GRB pointings

Disturbance : presence of X-ray sources in the field of view of the trigger

Construction of a catalogue (1793 sources) :

- *MAXI*/GSC (2-20 keV) *(standard online products)*
- *Swift*/BAT (14-195 keV) (*Oh et al., 2018*)
- Mainly X-ray binaries.

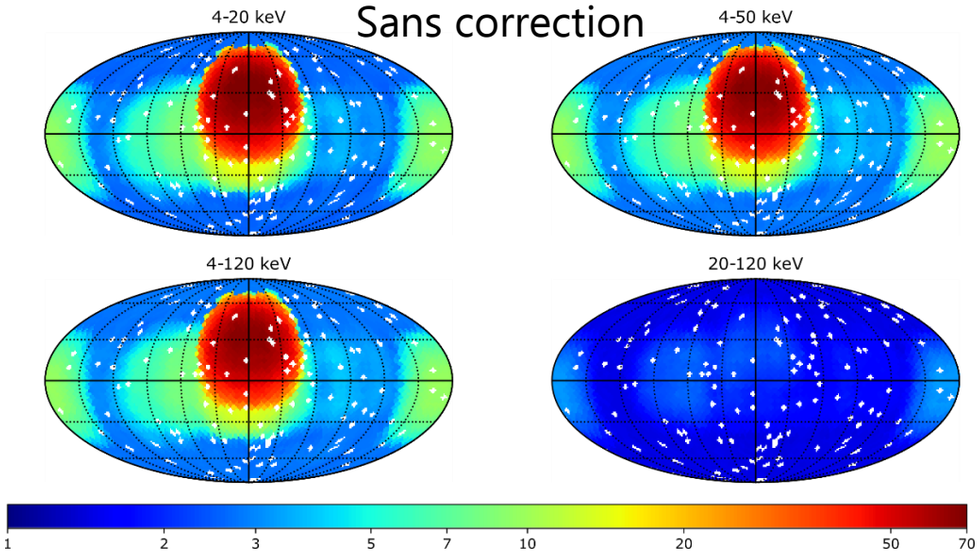
MAXI (ISS)



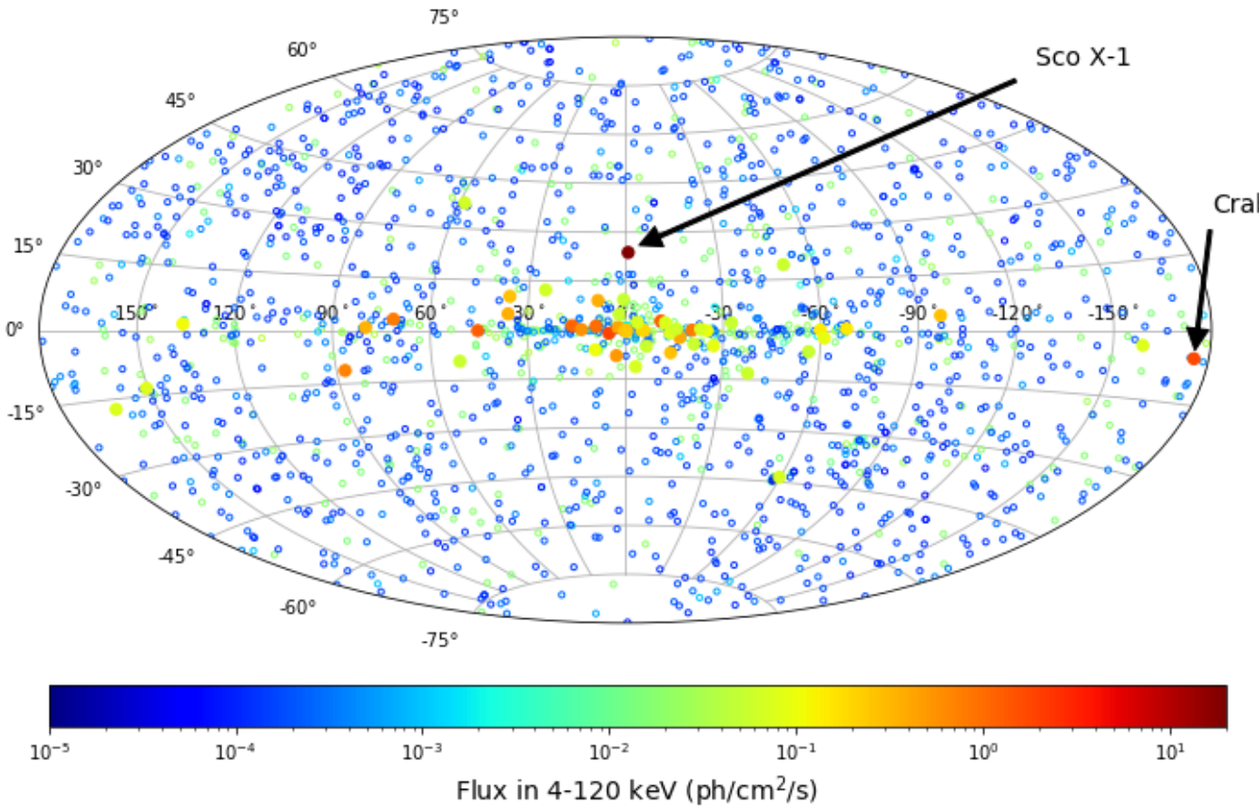
Studies of the impact of sources :

- Génération de spectres (loi de puissance simple ou brisée) à partir de flux moyens.
- Simulation des sources dans le champ de vue.

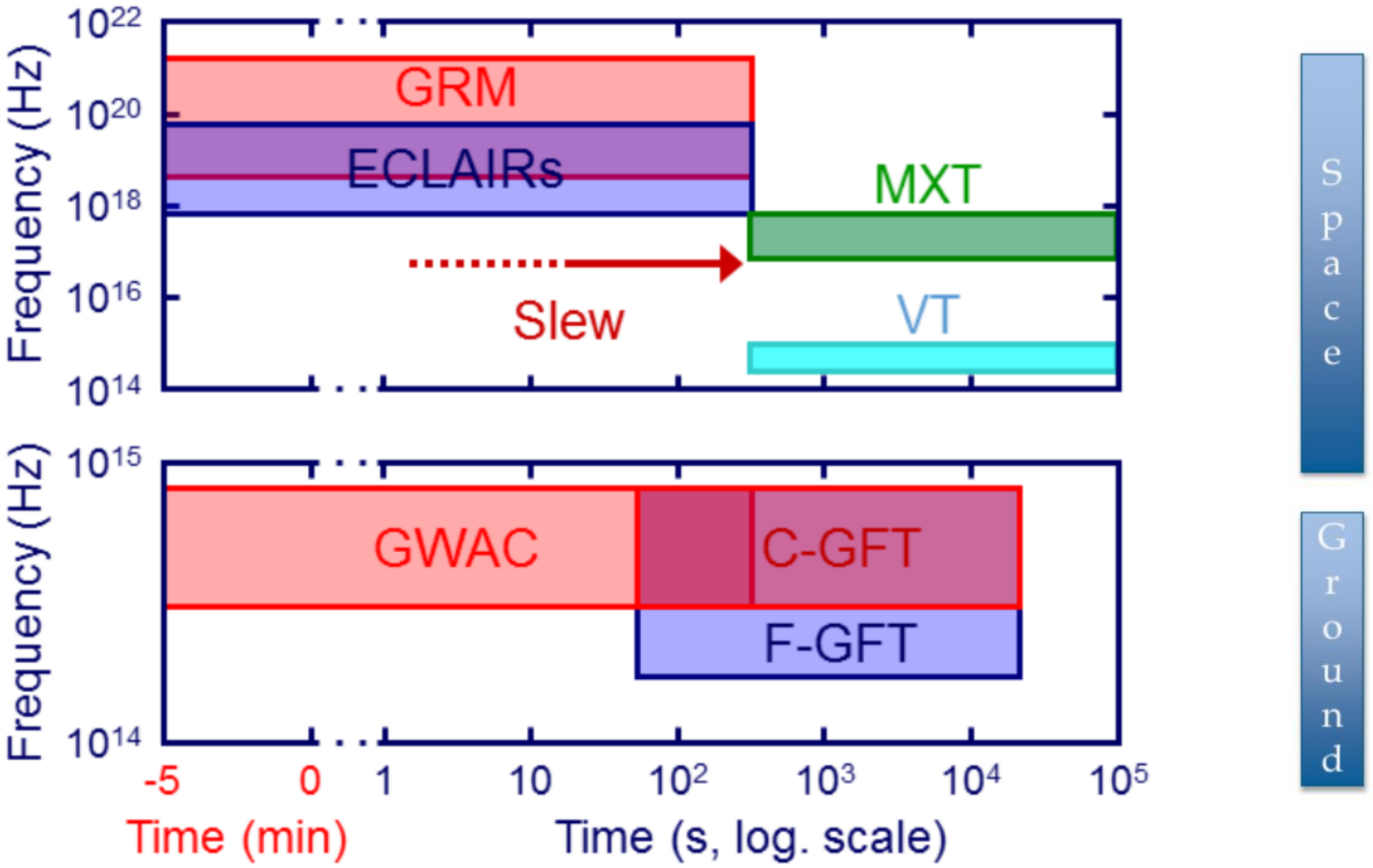
Standard deviation of sky images SNR (20 min).



Map in galactic coordinates of the catalogue sources



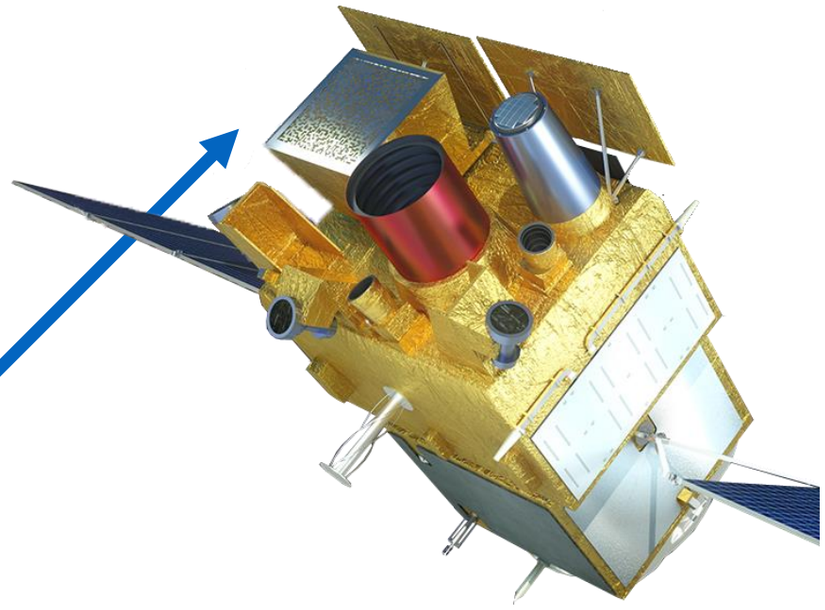
A powerful time domain machine



- Trigger and locate (hard) X-ray transients
- Multi-wavelength follow-up
- Alerts and localization distributed in real-time => **follow-up from other facilities**

Illustration on the core program :GRBs

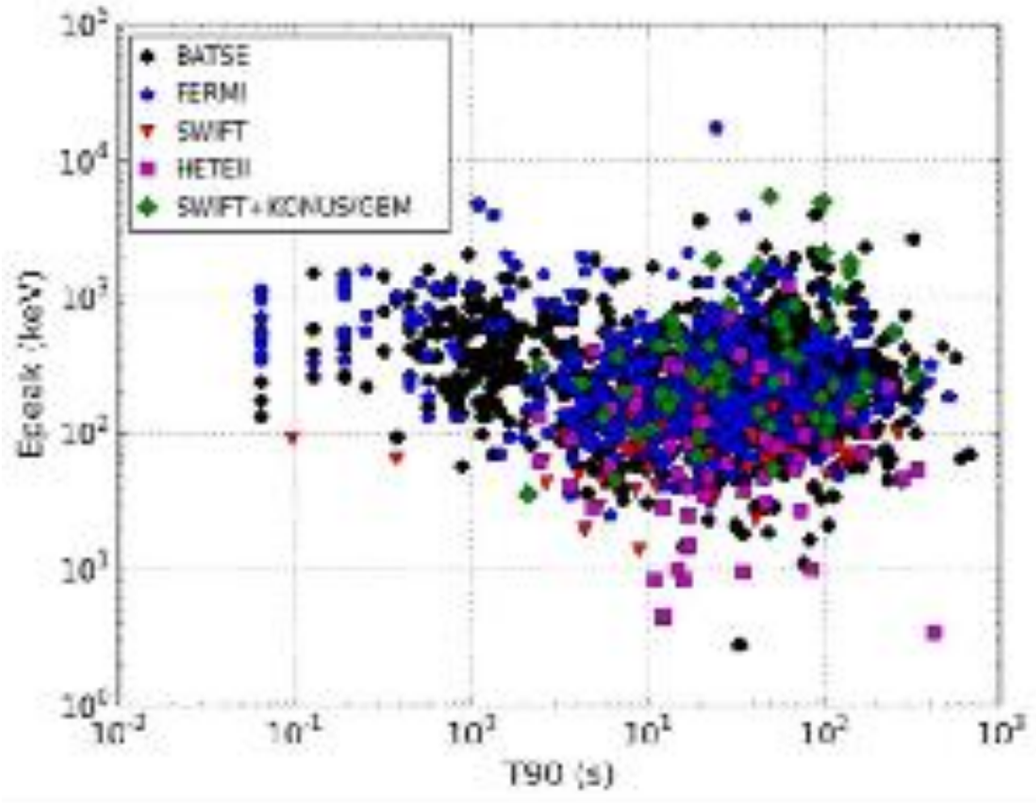
The GRB detection



ECLAIRs

- 4-150 keV
- ~ 2 sr
- Loc. < 12’
- 42-80 GRBs/yr

Detection probability by ECLAIRs

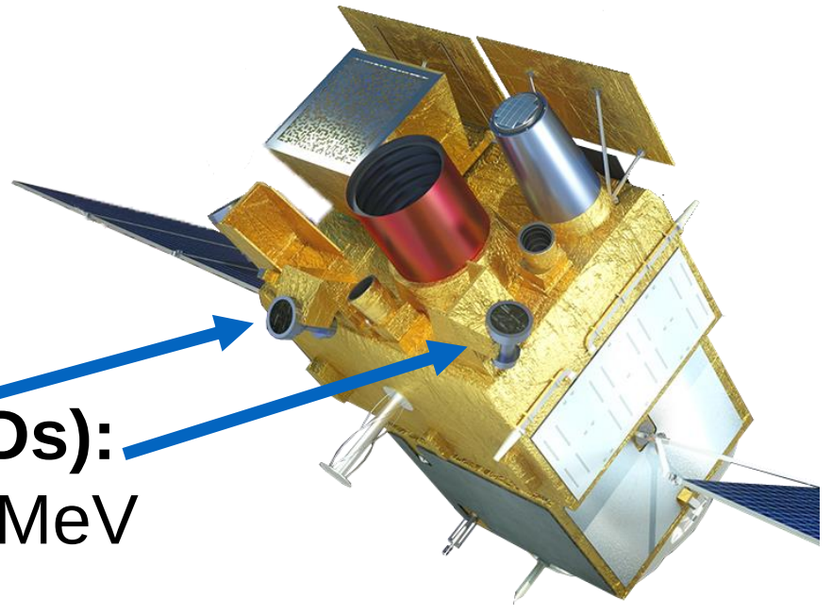


(simulations by S. Antier; Wei, Cordier et al., arXiv:1610.06892)

ECLAIRs is sensitive to all classes of GRBs:

- Classical long GRBs
- Soft GRBs (XRR, XRF)
- Short GRBs (but with a moderate efficiency)

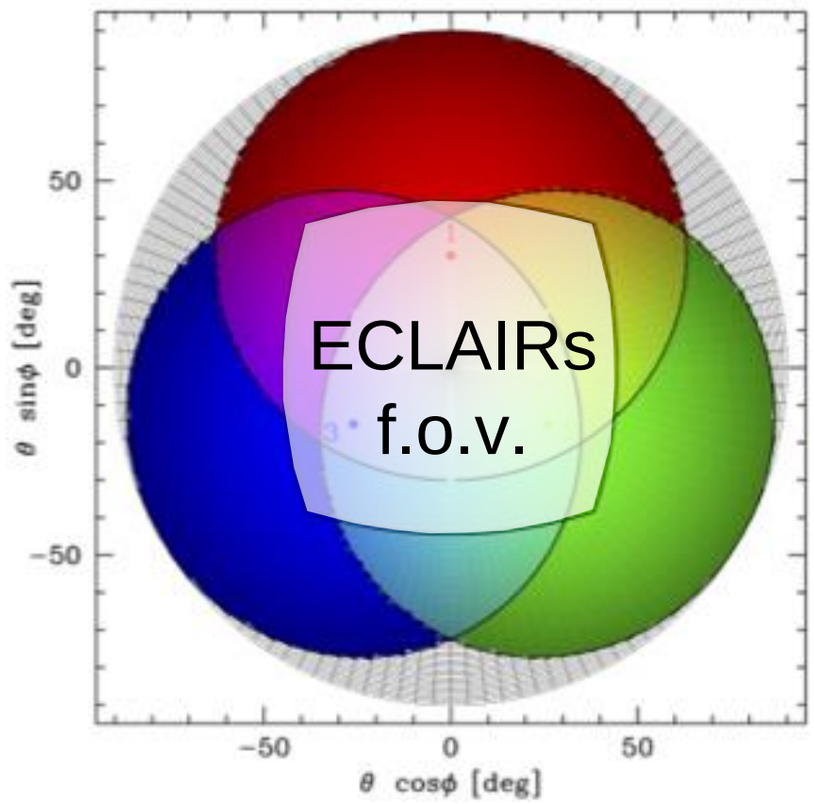
The GRB detection



GRM (3 GRDs):

- 15 keV - 5 MeV
- ~ 5.6 sr
- Loc. ~5-10 deg
- ~90 GRBs/yr

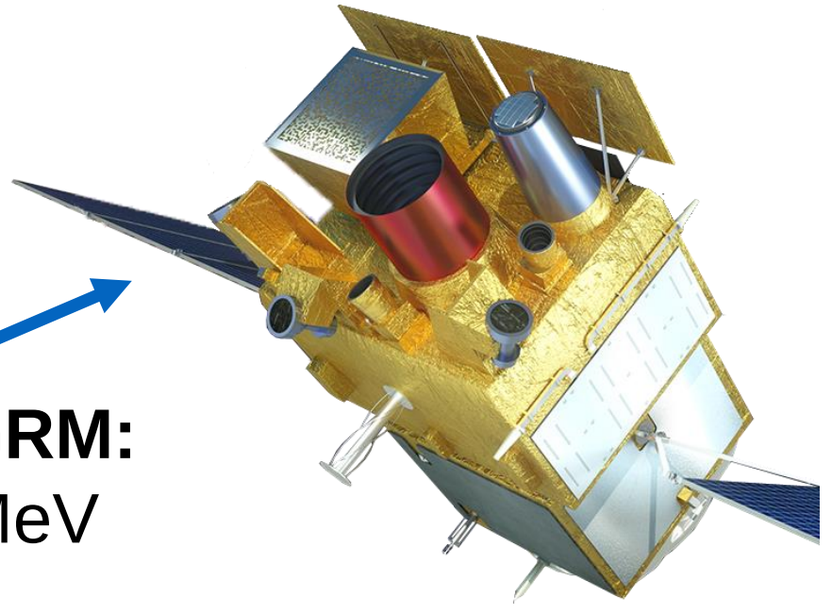
GRM field of view



GRM has a larger field of view than ECLAIRs

ECLAIRs sensitivity to short GRBs can be improved by combining ECLAIRs+GRM

The GRB prompt emission

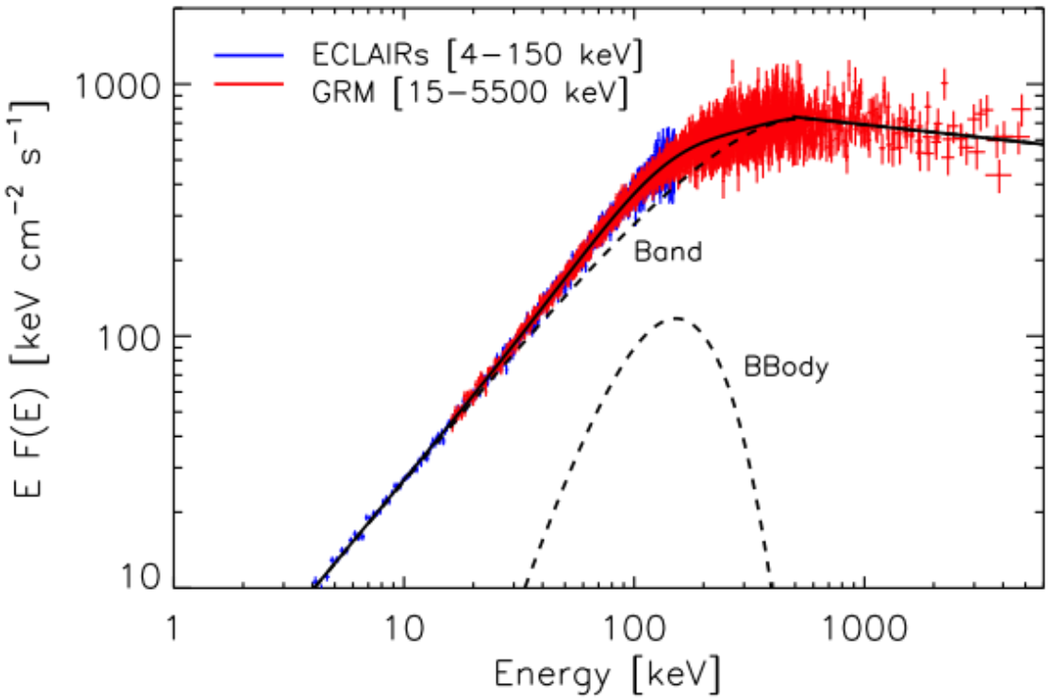


ECLAIRs+GRM:
- 4 keV - 5 MeV

+

GWAC:
- 5000 deg^2
- 500-800 nm
- m_{lim} ~ 16-17 (10s exposure)
- Prompt visible emission in ~16% cases

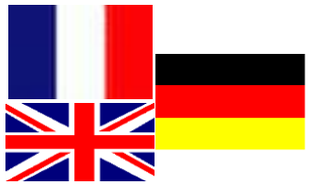
Multi-component spectrum of the Fermi burst GRB 100724B simulated in ECLAIRs+GRM.

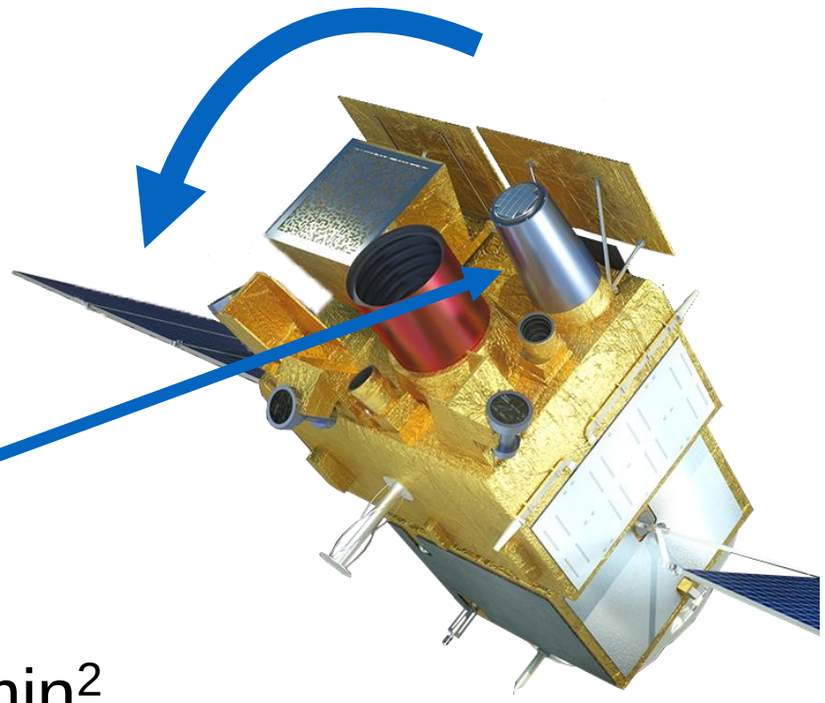


(Bernardini et al., 2017)

- ECLAIRs+GRM can measure the prompt spectrum over 3 decades in energy
- GWAC will add a constraint on the associated prompt optical emission in a good fraction of cases.

The GRB follow-up



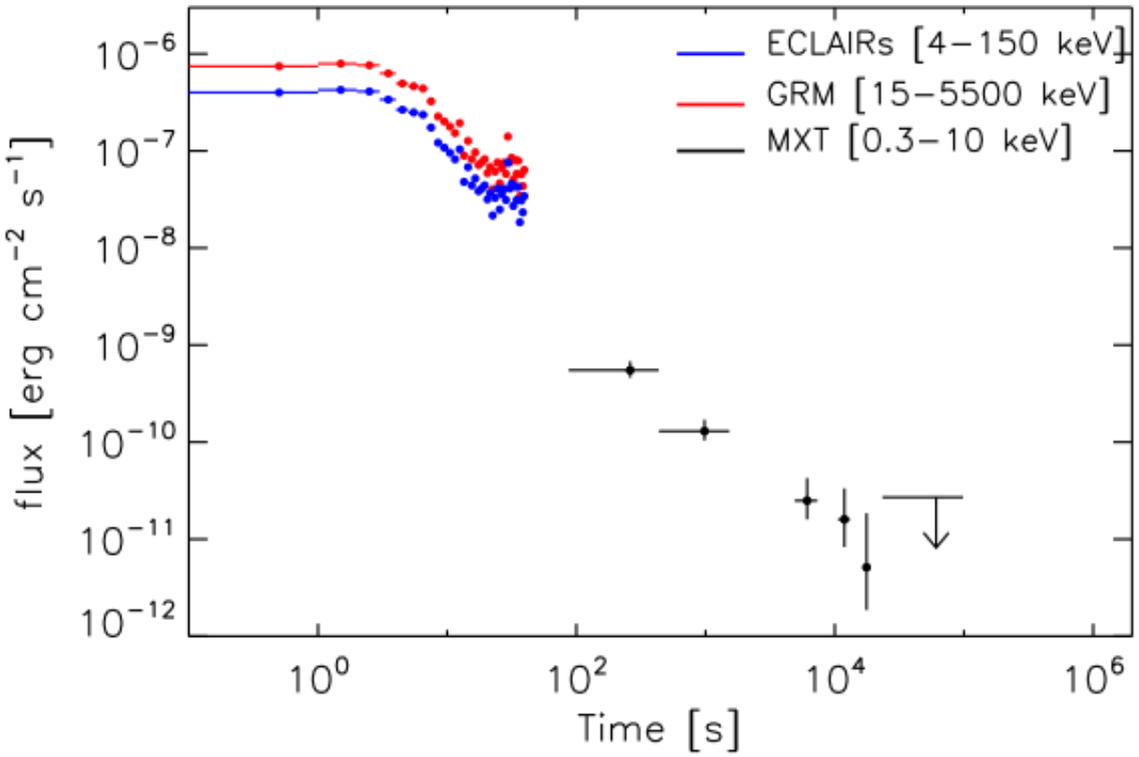


MXT:

- 0.2-10 keV
- 64x64 arcmin^2
- Loc. <13”

slew request: 36-72 GRB/yr

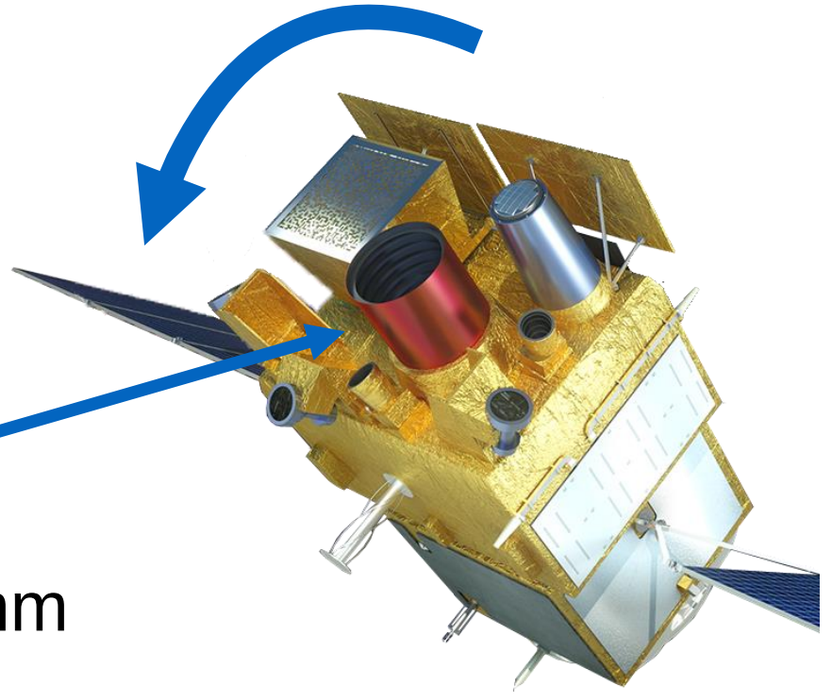
The X-ray afterglow of the Swift GRB 091020 simulated in MXT



(Wei, Cordier et al., arXiv:1610.06892)

- MXT can detect and localize the X-ray afterglow in >90% of GRBs after a slew

The GRB follow-up



VT:
- 400-1000 nm
- Loc. <1”

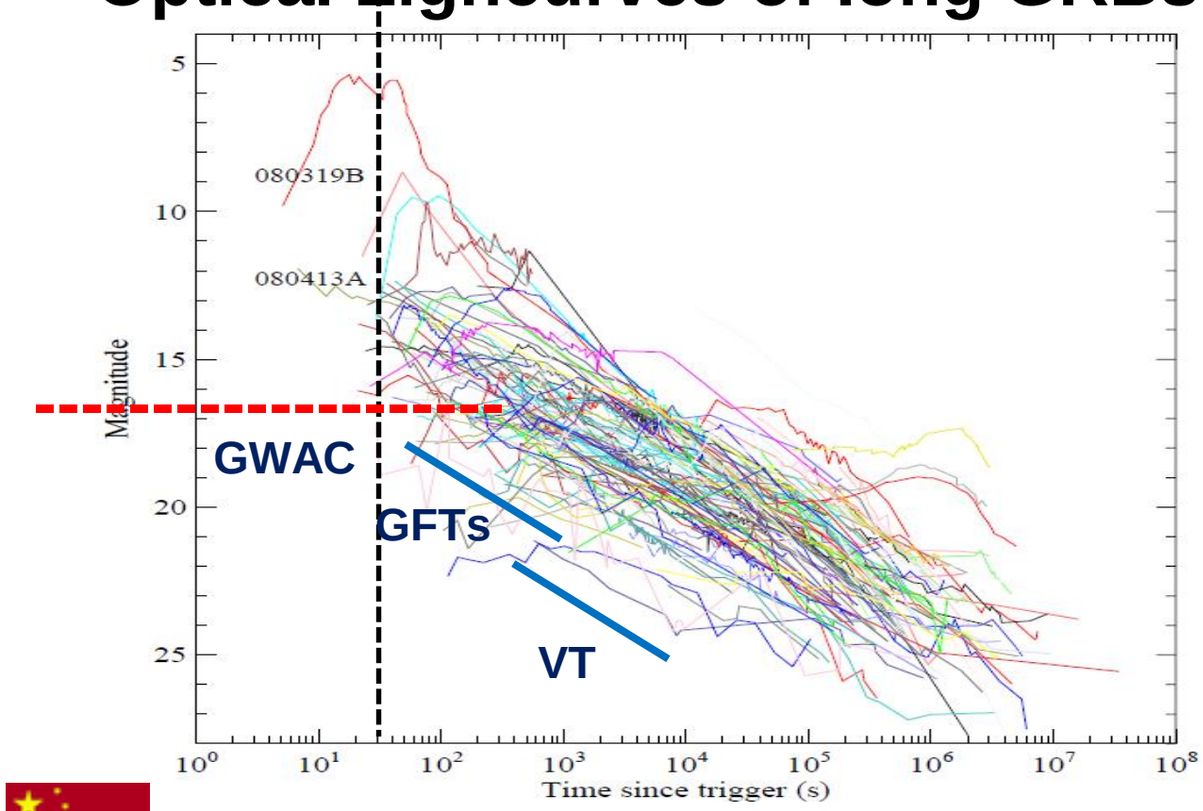
+

GWAC:
- 2x5000 deg^2
- 500-800 nm

F-GFT:
- 1.3 m
- 400-1700 nm

C-GFT:
- 1.2 m
- 400-950 nm

Optical Lighcurves of long GRBs



(Wang et al., 2013)

- VT + ground segment will detect, localize and characterize the V-NIR afterglows (lightcurve+photo-z)
- Early observation by large telescopes are favored by pointing strategy
- Redshift measurement is expected in ~2/3 of cases

The SVOM GRB sample

A unique sample of **30-40 GRB/yr** with:

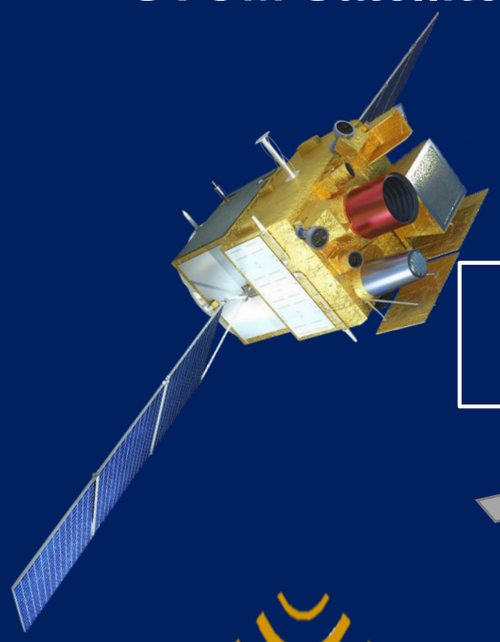
- **prompt emission** over 3 decades (+ optical flux/limit: 16%)
- X-ray and V/NIR **afterglow**
- **redshift**

	Swift	**Fermi**	**SVOM**
Prompt	Poor	Excellent 8 keV -100 GeV	**Very Good** **4 keV - 5 MeV**
Afterglow	Excellent	> 100 MeV for LAT GRBs	**Excellent**
Redshift	~1/3	Low fraction	**~2/3**

- **Physical mechanisms at work in GRBs**
  - Nature of GRB progenitors and central engines
  - Acceleration & composition of the relativistic ejecta
- **Diversity of GRBs: event continuum following the collapse of a massive star**
  - Low-luminosity GRBs / X-ray rich GRBs / X-ray Flashes and their afterglow
  - GRB/SN connection
- **Short GRBs and the merger model**
  - GW association

Operational Scenario for GRB detection

SVOM Satellite

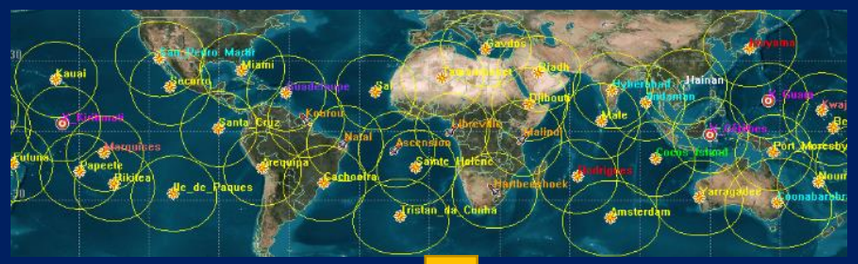


ECLAIRs detects a new gamma-ray burst

Automatic slew and observation start

VHF Band

X & S Band



Tracking antennas

SVOM users

Large Ground Telescopes

VHF alert data

Science and HK data

Alert data processing by French Science Center

Science data processing by French and Chinese Science Centers

… Now that this whole system is in place, SVOM is a powerful time domaine machine

SVOM Satellite

Object detected by other observatories (Space or Ground)

SVOM users

Slew and observation start

X Band

S Band

Tracking antennas

Tracking antennas

Science data

Telecommands

Observation requests (ToO)

Science data processing by French and Chinese Science Centers

Chinese Control Center

Preparation of satellite TC plan by Mission Center

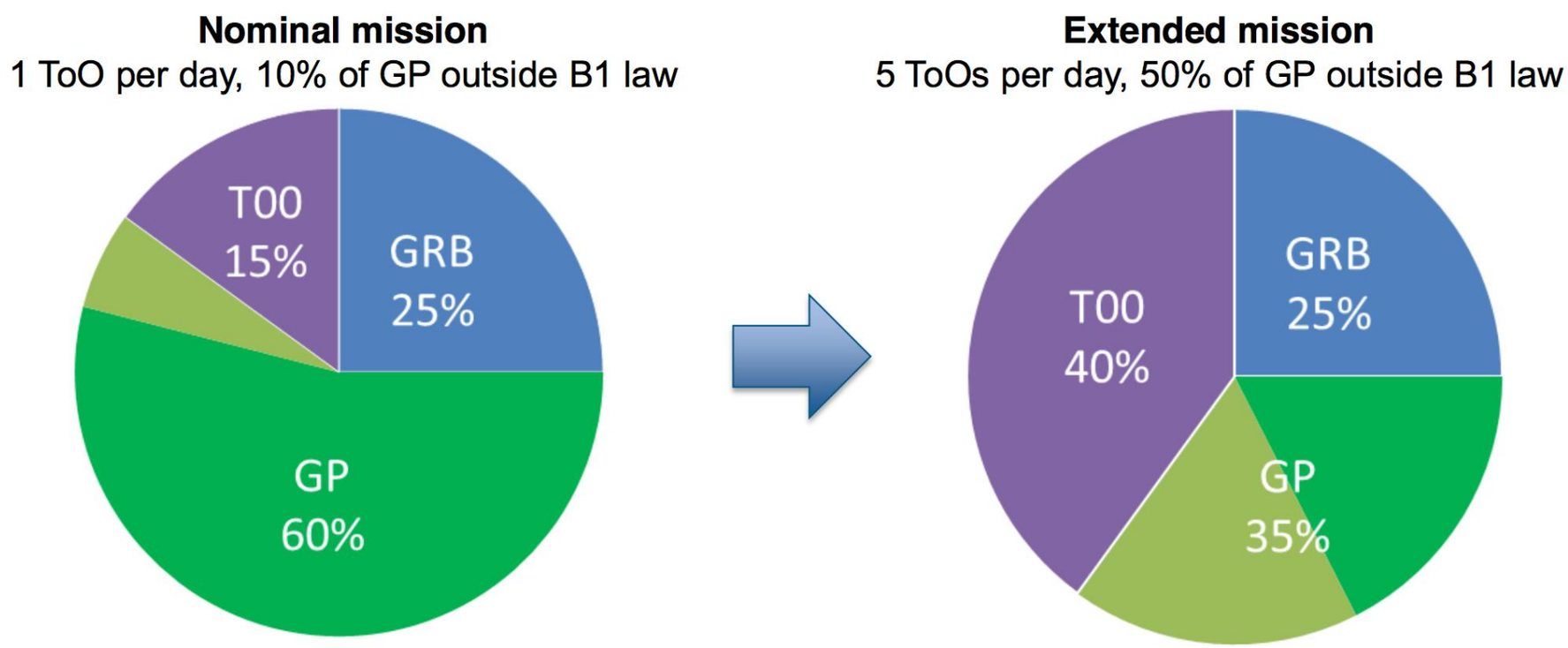
SVOM as an open observatory

The general program (GP)

- Observation proposals being awarded by a TAC (a SVOM co-I needs to be part of your proposal) for astrophysical targets of interest mostly compliant with the satellite attitude law

Target of Opportunity (ToO) programs

- **ToO-NOM** is the nominal ToO which covers the basic needs for efficient transient follow-up alerts sent from the ground to the satellite (GRB revisit, known source flaring, new transient)
- **ToO-EX** is the exceptional ToO which covers the needs for a fast ToO-NOM in case of an exceptional astrophysical event we want to observe rapidly.
- **ToO-MM** is the ToO-EX dedicated to EM counterpart search in response to a multi-messenger alert. What differs from the ToO-NOM and ToO-EX is the unknown position of the source within a large error box…



The SVOM ToO programs

WORLD

Only accessible by the SVOM CO-Is

ToO-Multi-Messenger

- 1/week
- Allocated time: 1-14 orbits (1 day)
- Max latency: 12h (S-Band) / <4h (Beidou)
- Instruments: MXT, VT + grd seg.

ToO-EXceptional

- 1/month
- Allocated time: 7-14 orbits (1 day)
- Max latency: 12h (S-band) / <4h (Beidou)
- Instruments: MXT, VT + grd seg.

+

Accessible to everybody

ToO-NOMinal

- 1/day
- Allocated time: 1 orbit (~45 min)
- Typical latency: 24-48h
- Instruments: MXT, VT + grd seg.

a % of sci. products public

all sci. products public

The Transient Universe & the SVOM ToO programs

SVOM Core ToO-NOM

ToO-NOM

ToO-NOM

ToO-NOM/EX

Gamma-ray Burst

AGN/Blazars

Supernovae

Neutron star giant flare

A large diversity of sources, distances, time scales physics and luminosities

FRB

ToO-NOM/EX

Unexpected

Since 2015

ToO-MM

Since 1980

Theoretically predicted

Flaring stars

ToO-NOM/EX

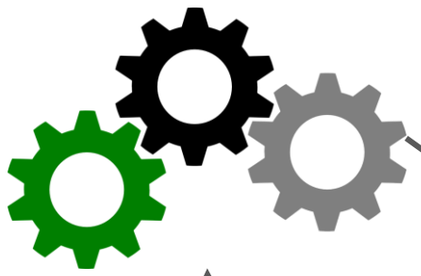
ToO-NOM

SVOM ToO infrastructure

What we have in mind...

Alert channels / Alert processing / Alert filtering

New generation of Brokers to handle 10^6 alerts/night !
(dev. triggered by the Vera Rubin LSST transient prog.)



FINK

Lasair

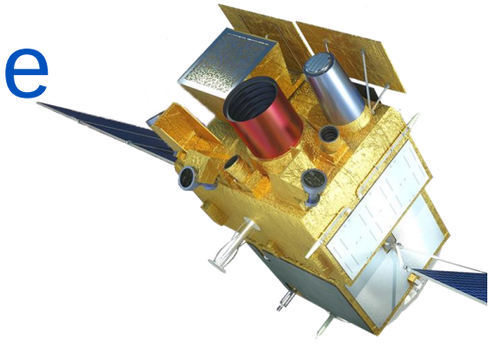
SVOM

SVOM ToO manager

Only **ONE FILTERED** alert stream for SVOM

Including -II alerts

CONCLUSION, beginning of next decade



- SVOM is mini-satellite class mision (< 1000kg)
- SVOM will provide ~80 GRB/yr.
- SVOM will study the GRBs in a wide spectral band (from Gamma-ray to IR)
- We aim to measure the redshift for >50% of the SVOM GRBs
- SVOM will operate in the era of advanced GW detectors, providing the opportunity to search correlations between GW and GRBs
- SVOM GRBs will benefit from follow-up with a new generation of astronomical instruments: JWST, SKA, CTA, LSST, ZTF.
- SVOM (ground and space instruments) will be able to follow chosen transient sources detected by the new generation of wide-field observatory ZTF-II and LSST

NAOC, Beijing

IHEP, Beijing

XIOPM, Xi'an

SECM, Shanghai

CEA-Irfu, Saclay

IRAP, Toulouse

APC, Paris

IAP, Paris

LAM, Marseille

Obs Strasbourg

LPAG Grenoble

LUPM Montpellier

LAL Orsay

GEPI Meudon

LPC2E Orléans

University of Leicester

MPE, Garching

CNES, Toulouse

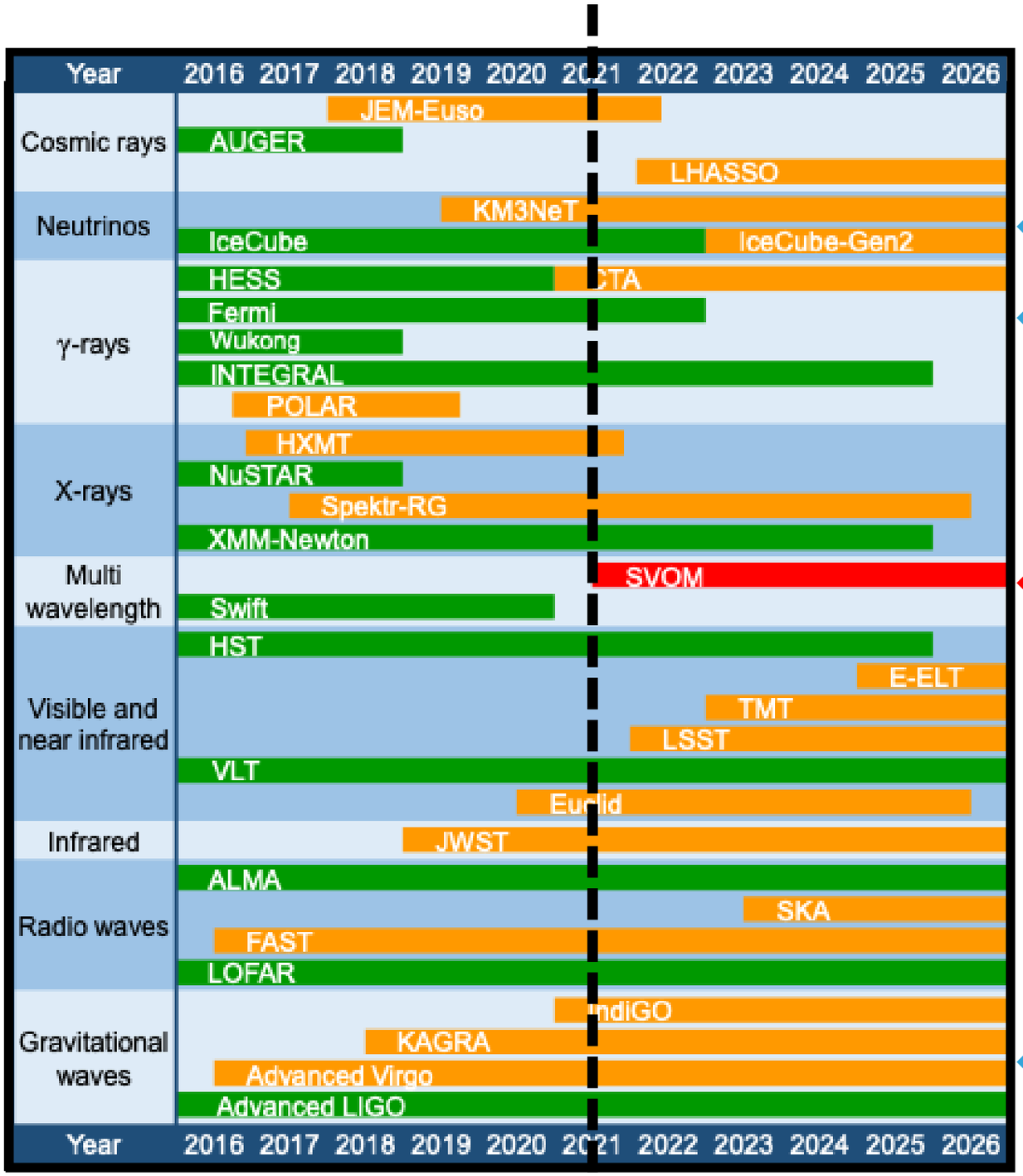
GO SVOM !

launch mid 2022

Multi-messenger Target of Opportunity

with

Multi-messenger Astronomy panorama after 2021



HE ν

HE γ

SVOM

GW

- LV at design sensitivity + new interferometers (KAGRA, LI)
- New HE neutrino detectors with better sensitivity (KM3Net, IceCube-2)

→**SVOM will play a key role in MM Astronomy**

SVOM reaction to a MM trigger

ECLAIRs/GRM Large fov, independent trigger or search in the fov

MXT/VT Slew following the alert **ToO-MM** (max 1/week)

Tiling strategy if the error box is larger than 1 deg^2

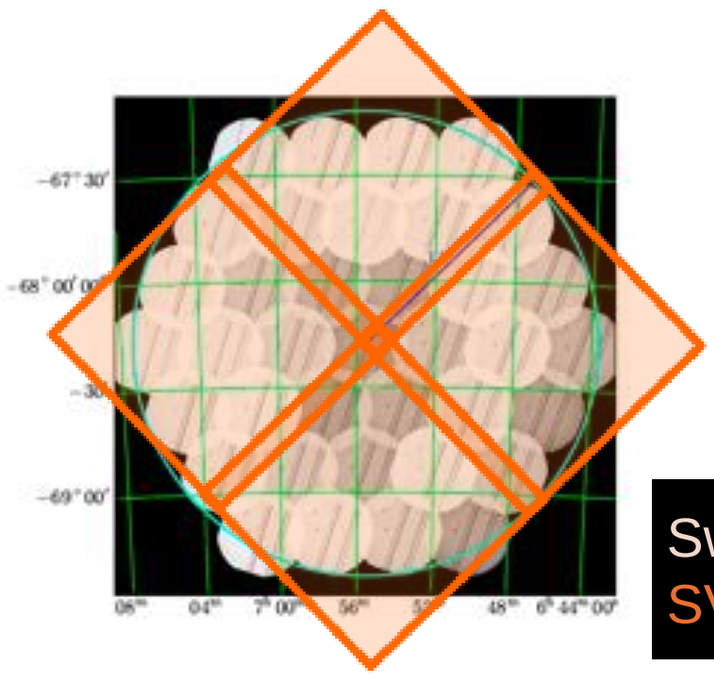
GWAC Rapid automatic response

Large fov, wide field search for counterpart

C-GFT/F-GFT Rapid response

Need accurate localization, photometric follow-up

MXT vs. XRT tiling



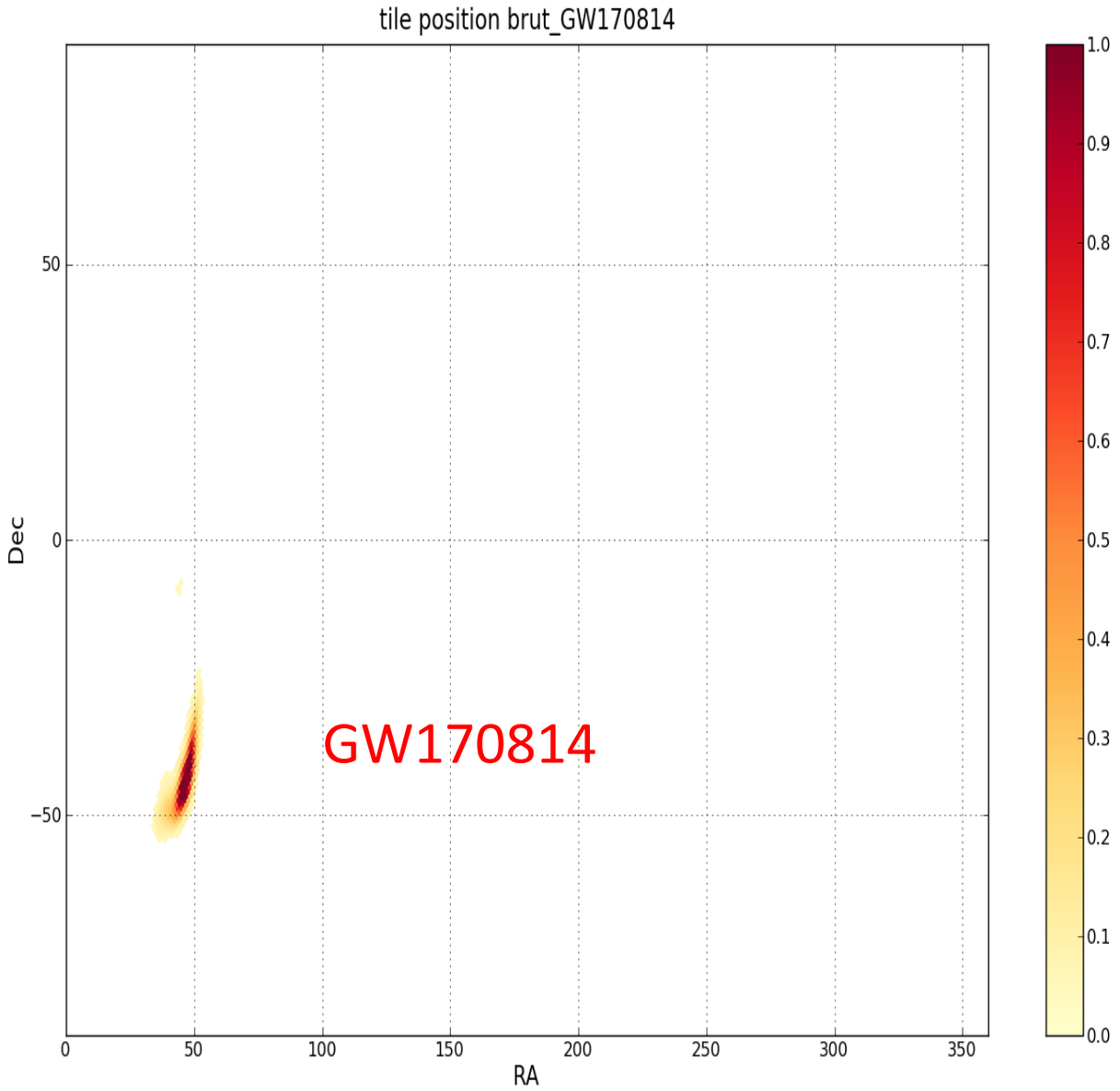
Swift/XRT f.o.v
SVOM/MXT f.o.v

Typical scenario: 5 tiles/orbit
– 15 orbits (~ 1 day)

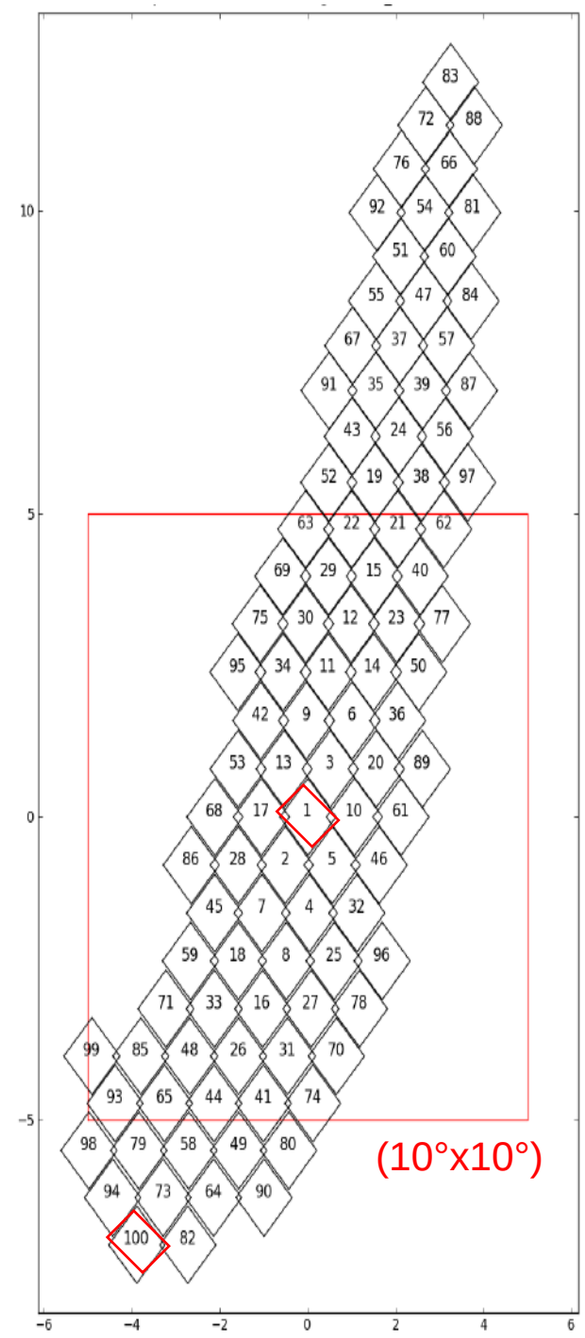
ToO Multi-Messenger : Tiles sequencing simulations

- First example of ToO-MM request : scenario « focused »

GW170814

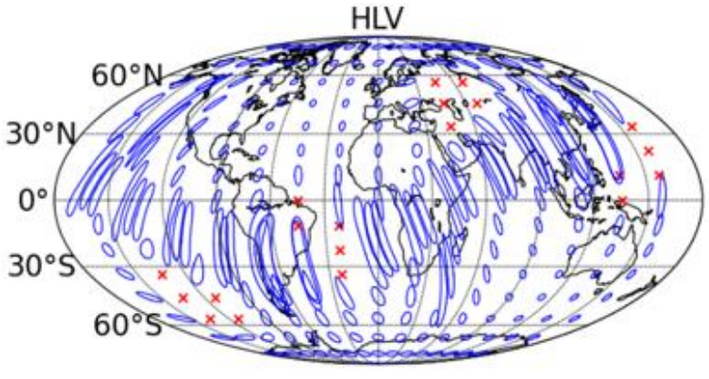


Scenario	170814 GW
Nb. tiles	230
RA min (°)	34.4
RA max (°)	53.4
Dec min (°)	-54.3
Dec max (°)	-7.8
LH total (%)	90.0
LH 75 (%)	66.0

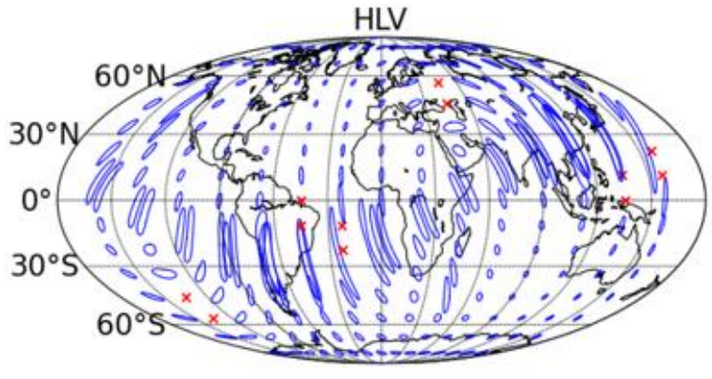


First 100 tiles

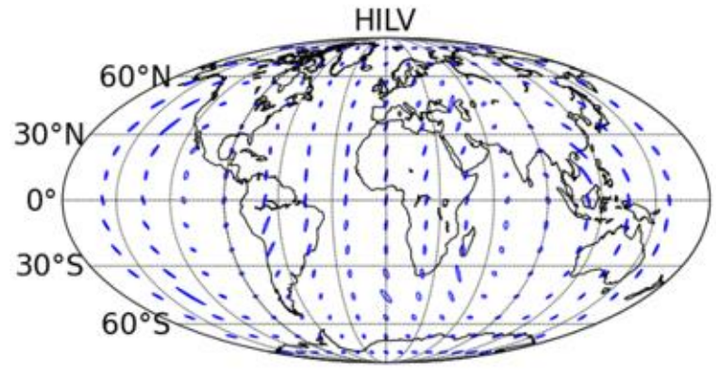
SVOM is already operating!



2017



2019



2022

Error box ≥100 deg^2 → ≤10 deg^2

GWAC — O2: Mini GWAC; O3: GWAC (m_{lim} 12 → 16)

GFTs

GRM, ECLAIRs
MXT, VT

O1: 1 GW alert followed, 1 GCN issued

O2: 8 GW alerts followed, 8 GCNs issued

O3: 9 GW alerts followed, 7 GCNs issued

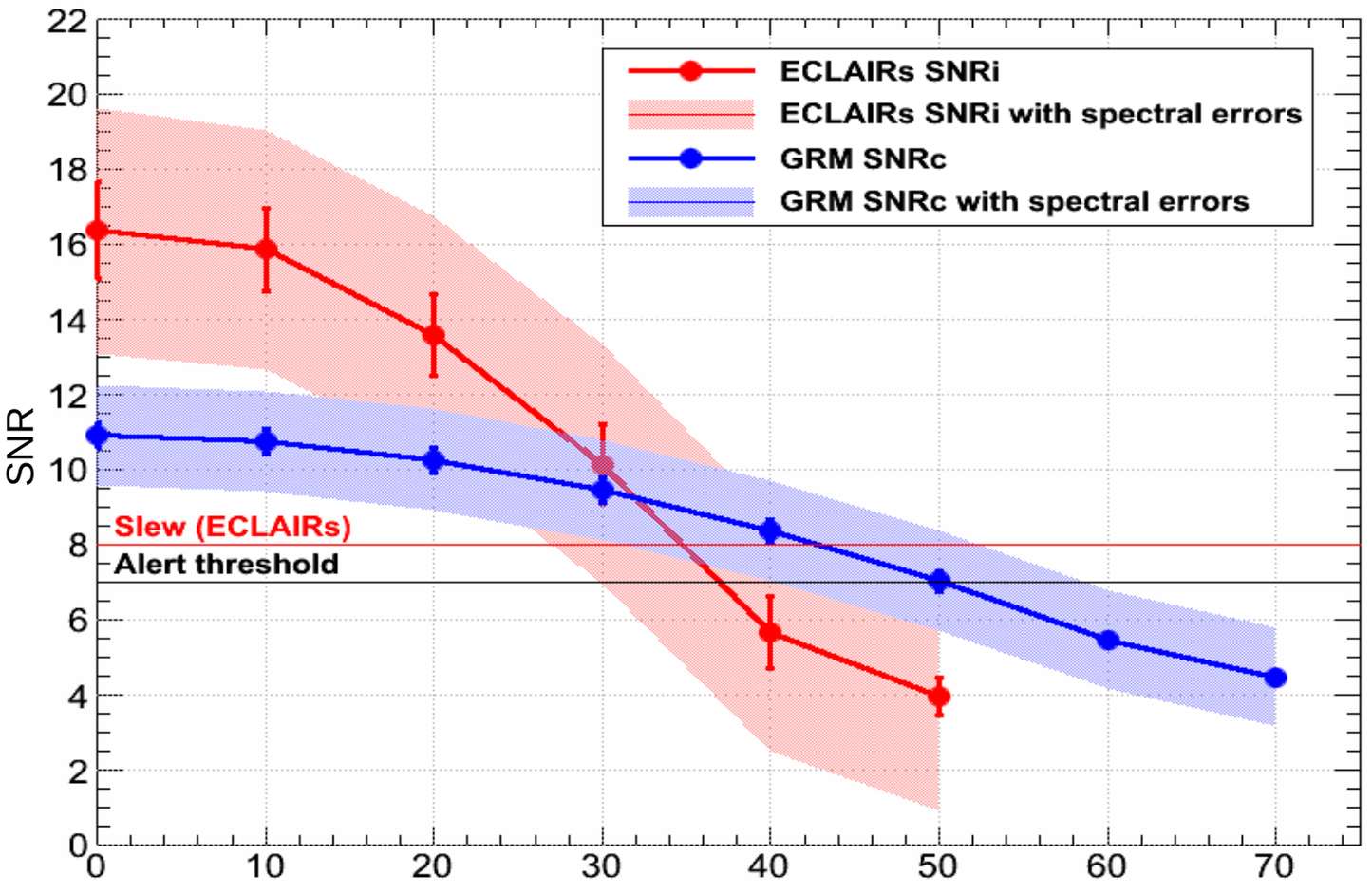
Mini GWAC

GWAC+30 and 60 cm telescopes

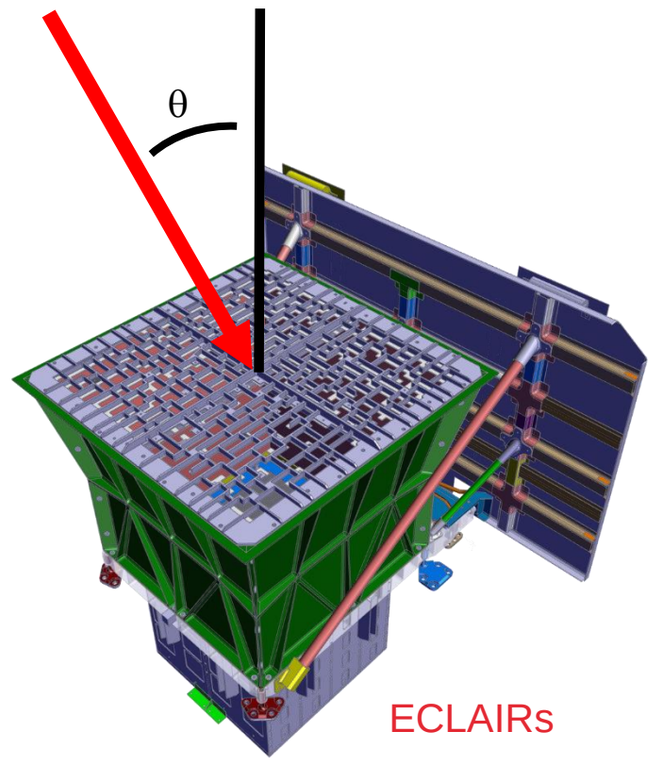
(Credit D.Turpin, see also D.Turpin et al., 2019)

GW 170817 / GRB 170817A

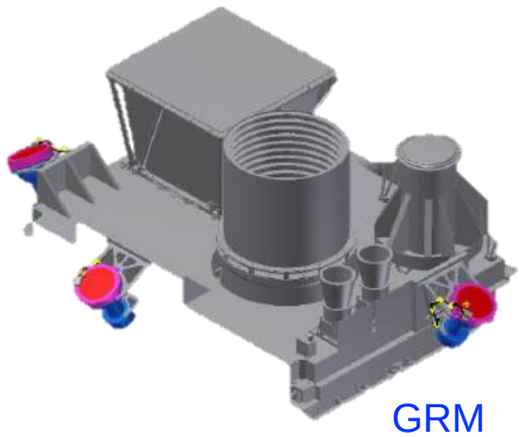
Simulation of the prompt emission of GRB170817A



(Simulations by S.Schanne, MG.Bernardini and F.Piron)



ECLAIRs

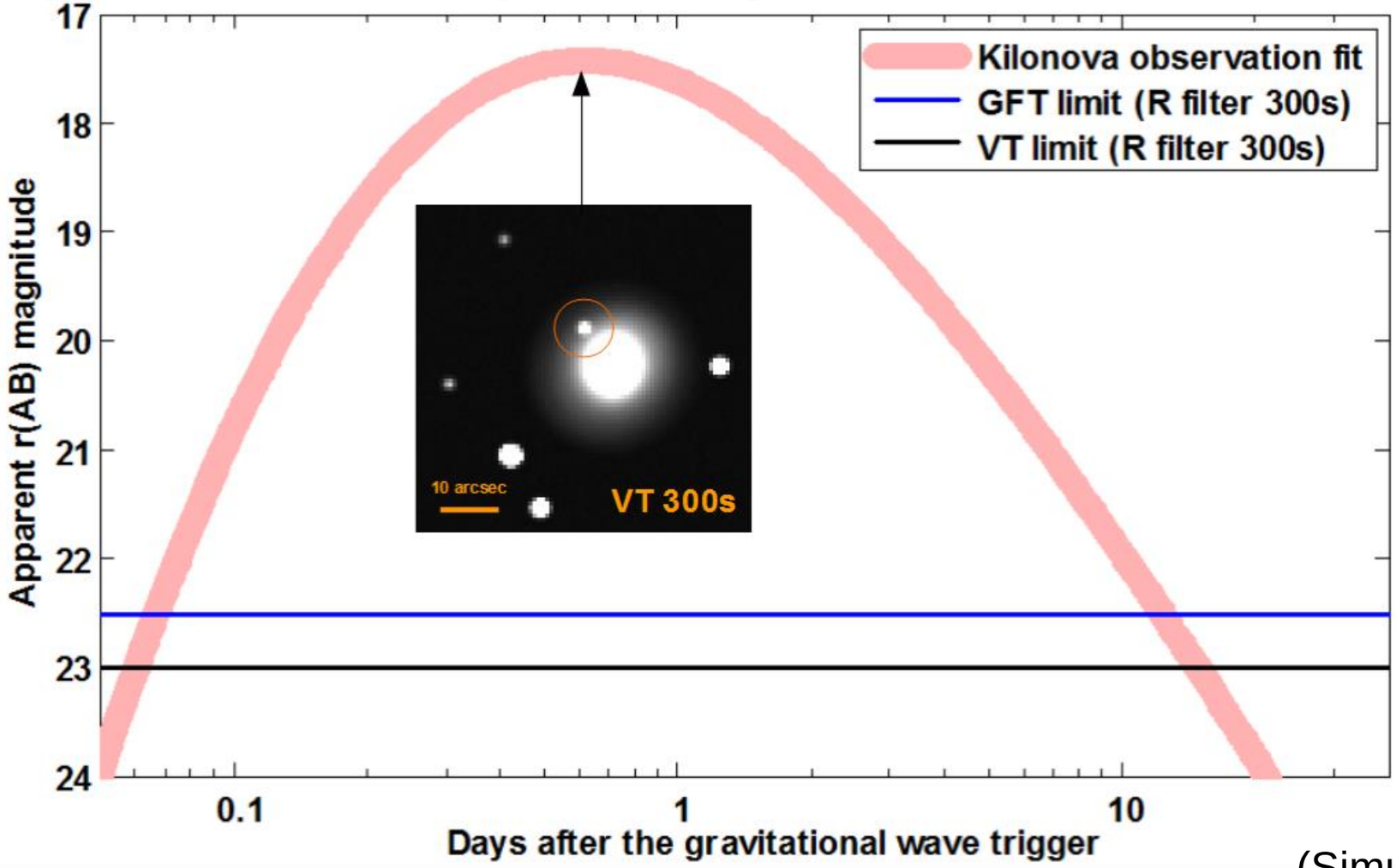


GRM

- Up to **35° off axis**: ECLAIRs triggers + alert is sent to the ground + slew is requested
- Up to **50° off-axis**: GRM triggers + alert is sent to the ground (with rough localization)

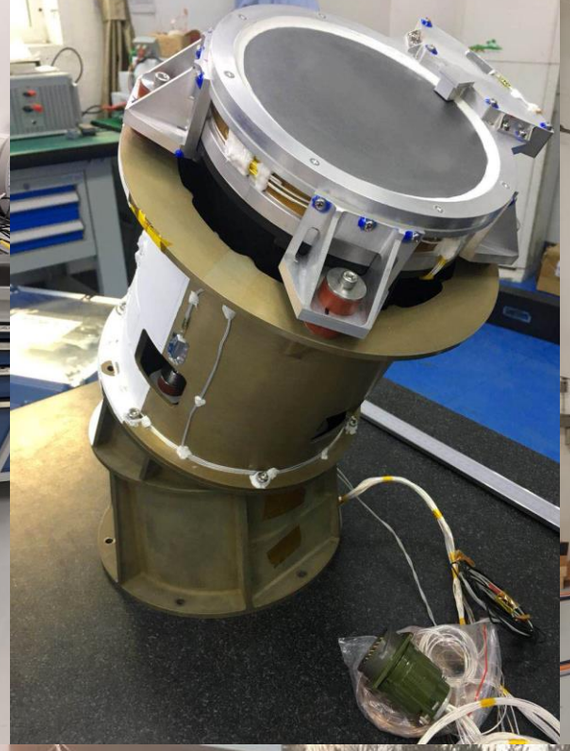
And the associated kilonova

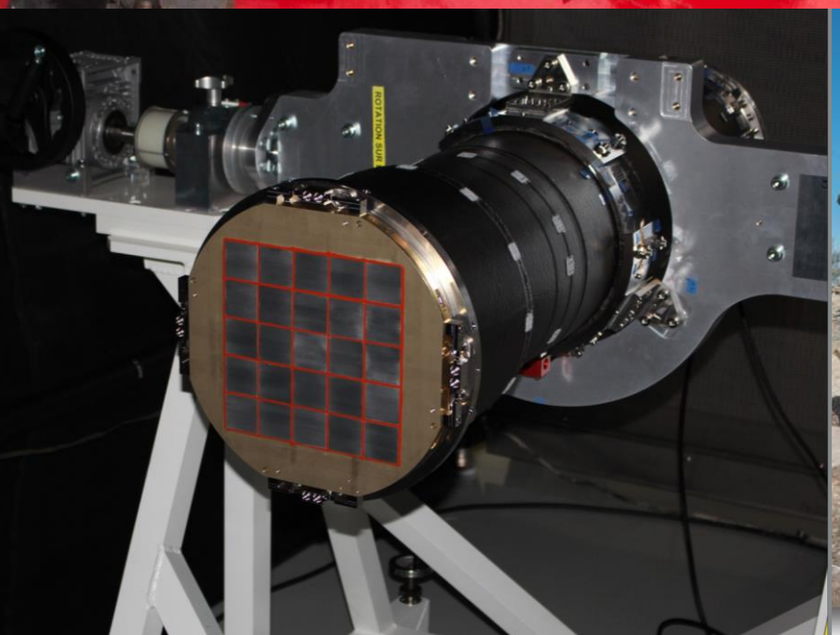
Simulation of the kilonova AT2017gfo as seen by VT in 300 s at peak magnitude



(Simulations by A.Klötz)

- VT and GFTs have the capacity to detect the kilonova since T0+2h and follow it during 10 days





Everything will be ready for mid 2022
Stay tuned!!

Data policy

- **Core Program:**
  - Scientific products generated under the supervision of the Burst Advocate are public **as soon as they are available**
  - All the scientific products are public **six month** after the data production
- **General Program:**
  - All the SVOM data products will be distributed to the Responsible Co-I
  - After **one year of proprietary period**, the data products will be public
- **ToOs:**
  - **ToO-MM**: the policy same as Core Program
  - **ToO-Nom and ToO-Ex**: the data are immediately public