SVOM

NEUTRON STAR ASTROPHYSICS WITH THE SVOM MISSION

Sebastien Guillot

irap
astrophysique & planétologie

on behalf on the SVOM collaboration

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

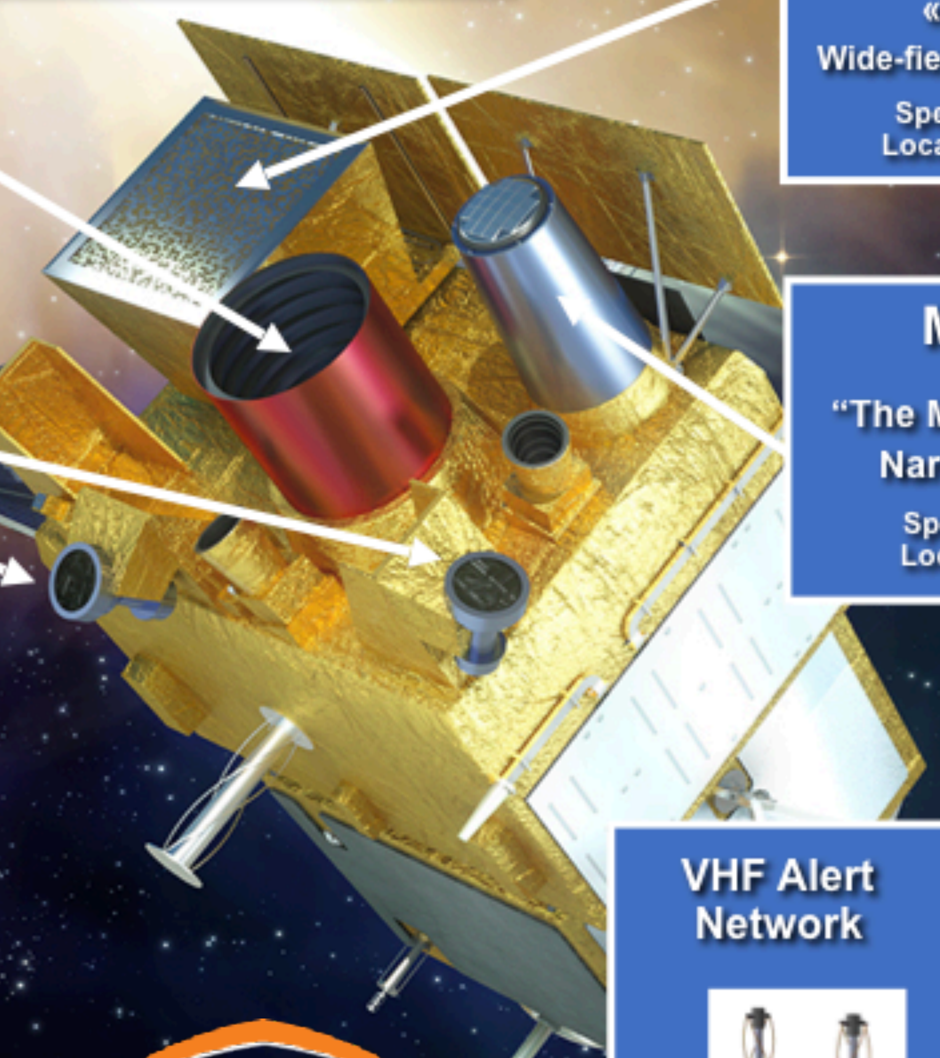
- **France (PI B. Cordier)**
  - CNES Toulouse
  - APC Paris
  - CEA Saclay
  - CPPM Marseille
  - GEPI Meudon
  - IAP Paris
  - IRAP Toulouse
  - LAL Orsay
  - LAM Marseille
  - LUPM Montpellier
  - OAS Strasbourg

- **UK** University of Leicester

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

SVOM: Space-based multi-band astronomical Variable Objects Monitor

Launch: end-2023
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
15 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

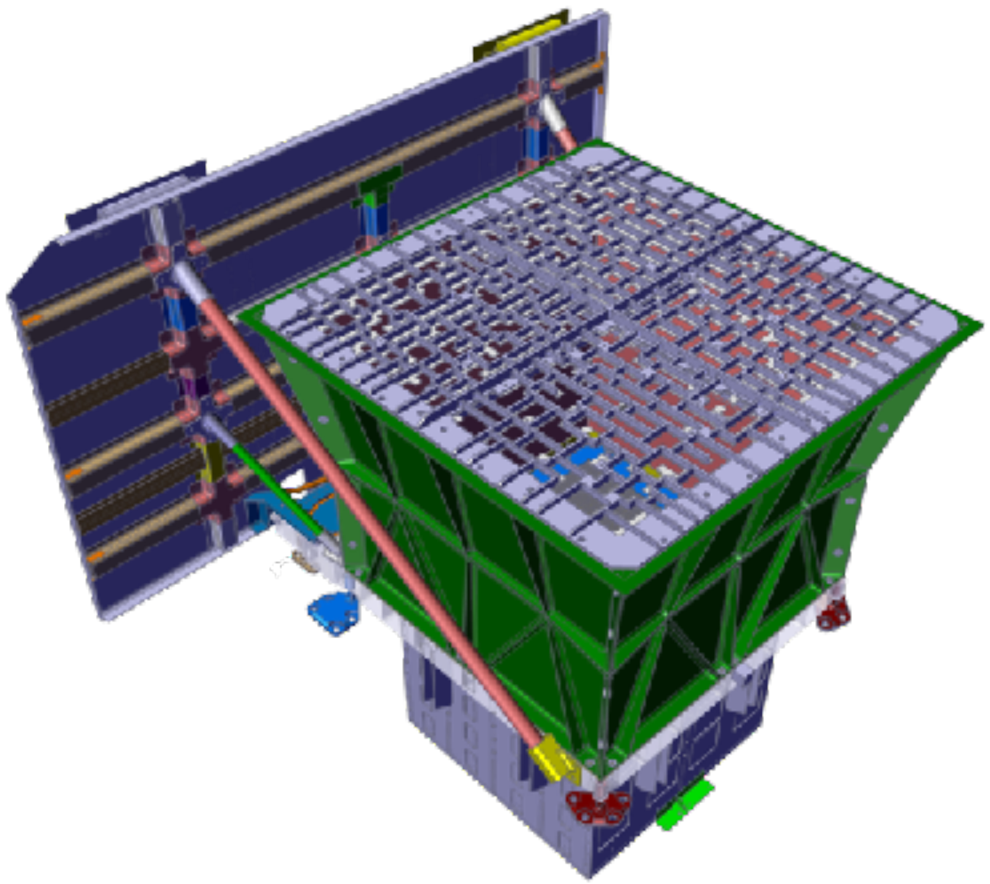
SVOM

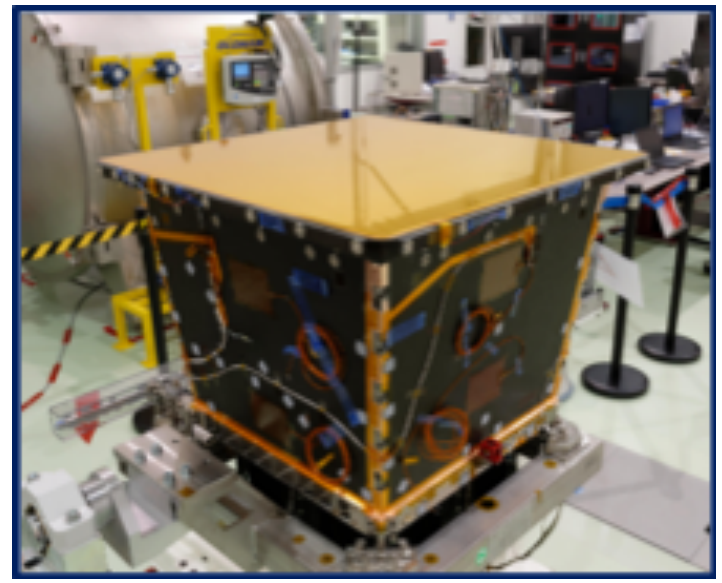
VHF Alert Network

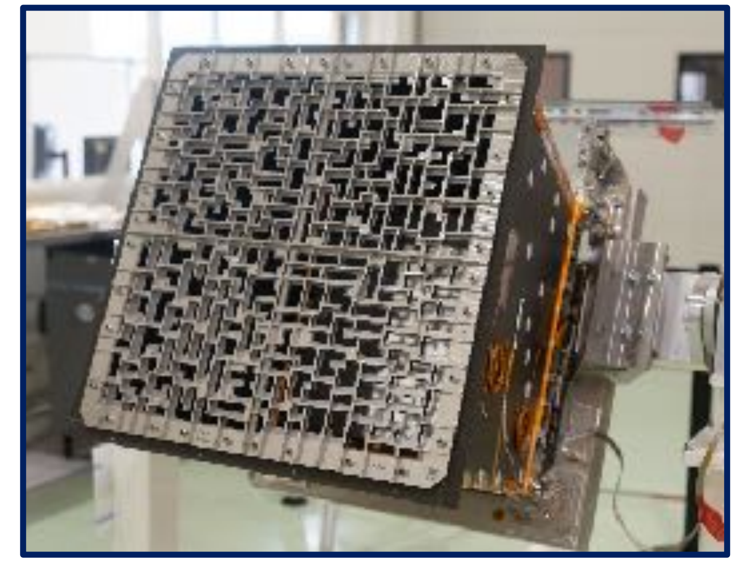
... and more !

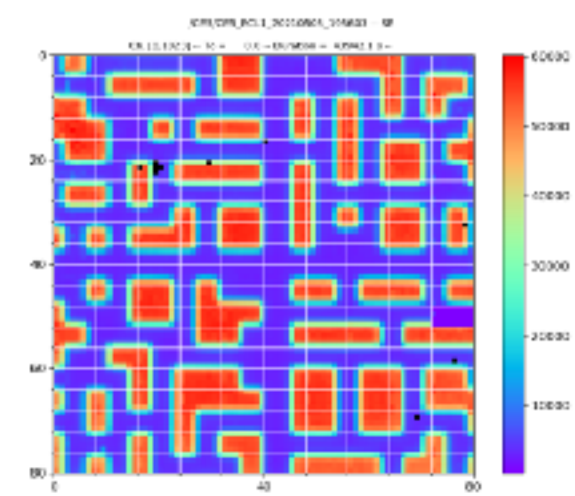
Tracking antennas

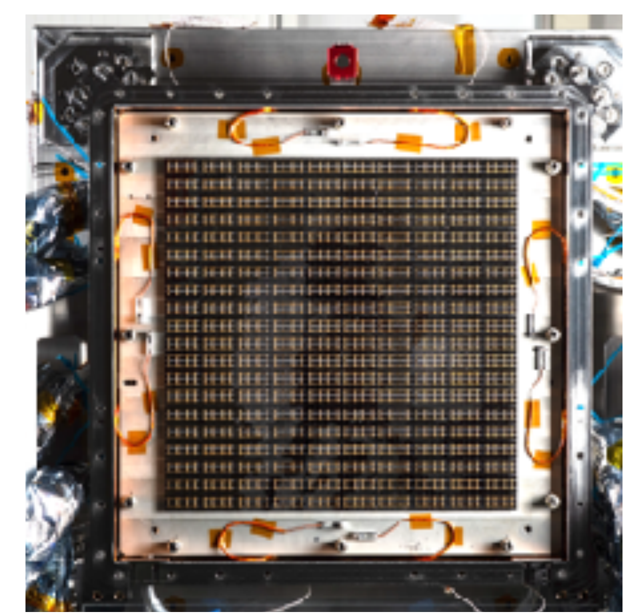
ECLAIRs – The Trigger Camera

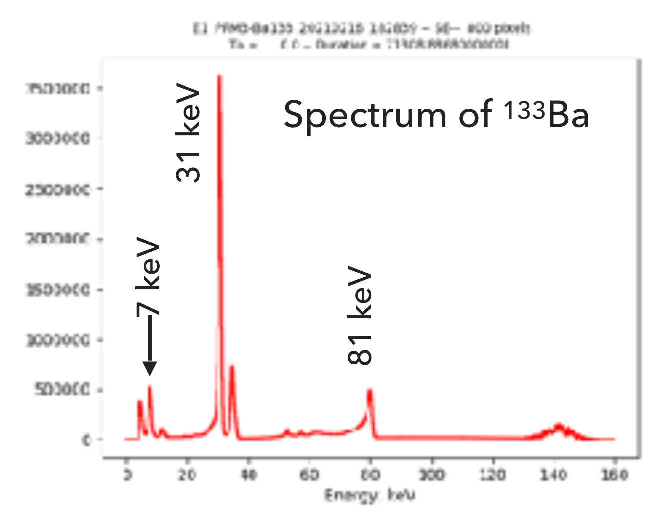










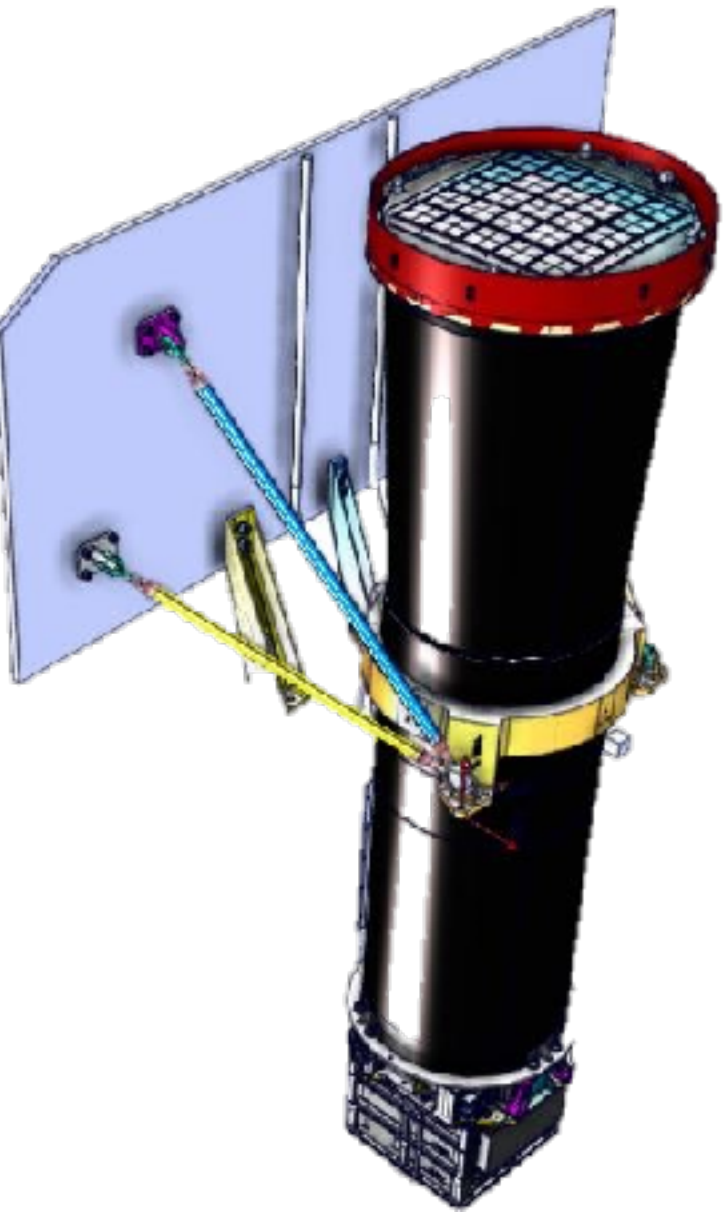


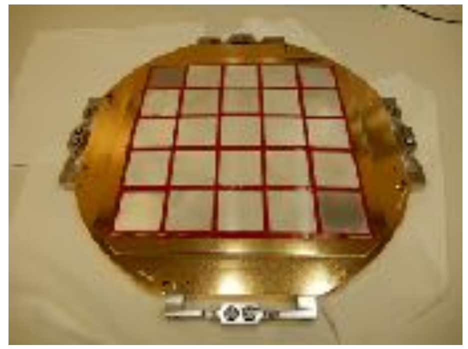
ECLAIRs (CNES, IRAP, CEA, APC)

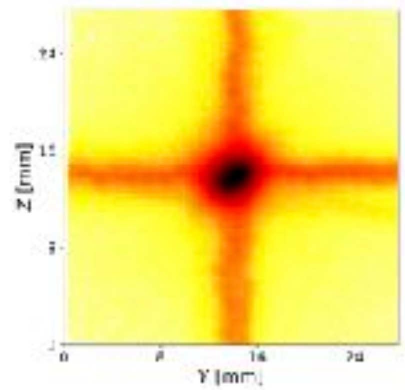
- 40% open fraction
- Detection area: **1000 cm²**
- **6400 CdTe pixels** (4x4x1 mm^3)
- **FoV: 2 sr** (zero sensitivity)
- Energy range: **4** - 150 keV
- **Localization** accuracy **<12 arcmin** for 90% of sources at detection limit
- Onboard trigger and localization: **~65 GRBs/year**

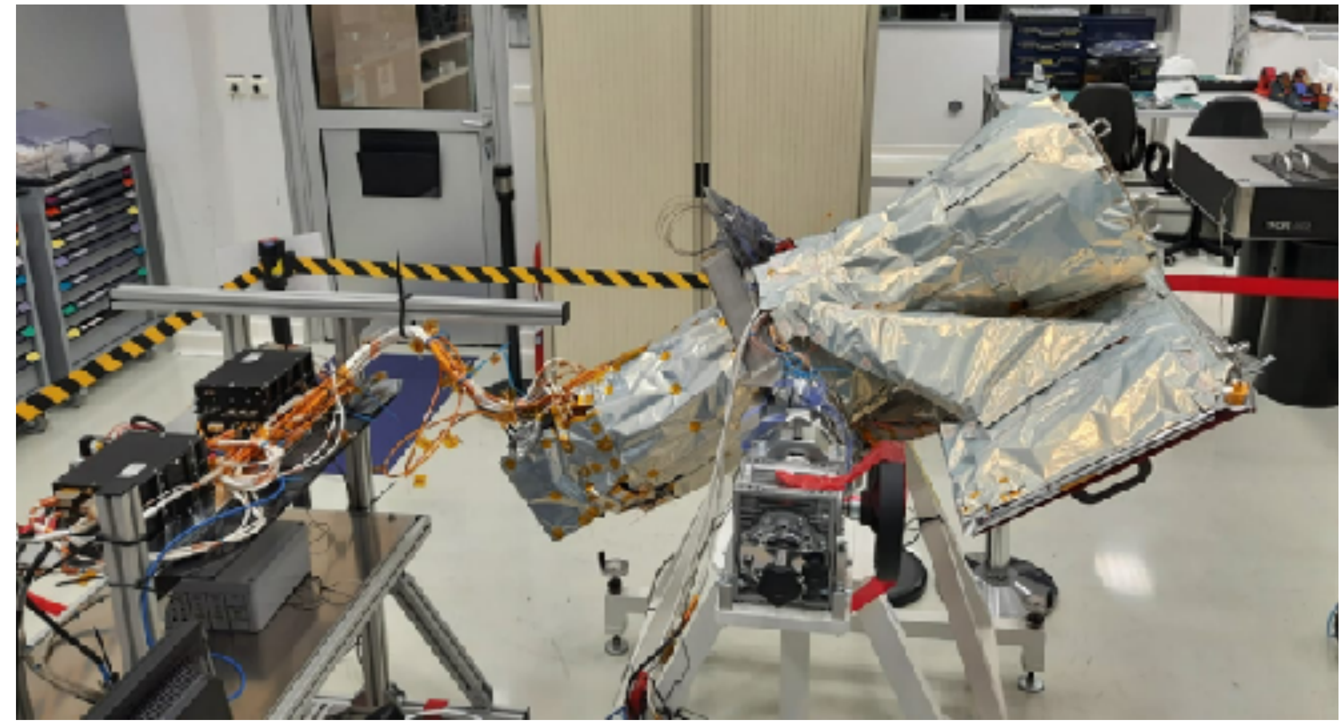
Well suited to detect GRBs with low E_{PEAK}

MXT – The Soft X-Ray Telescope







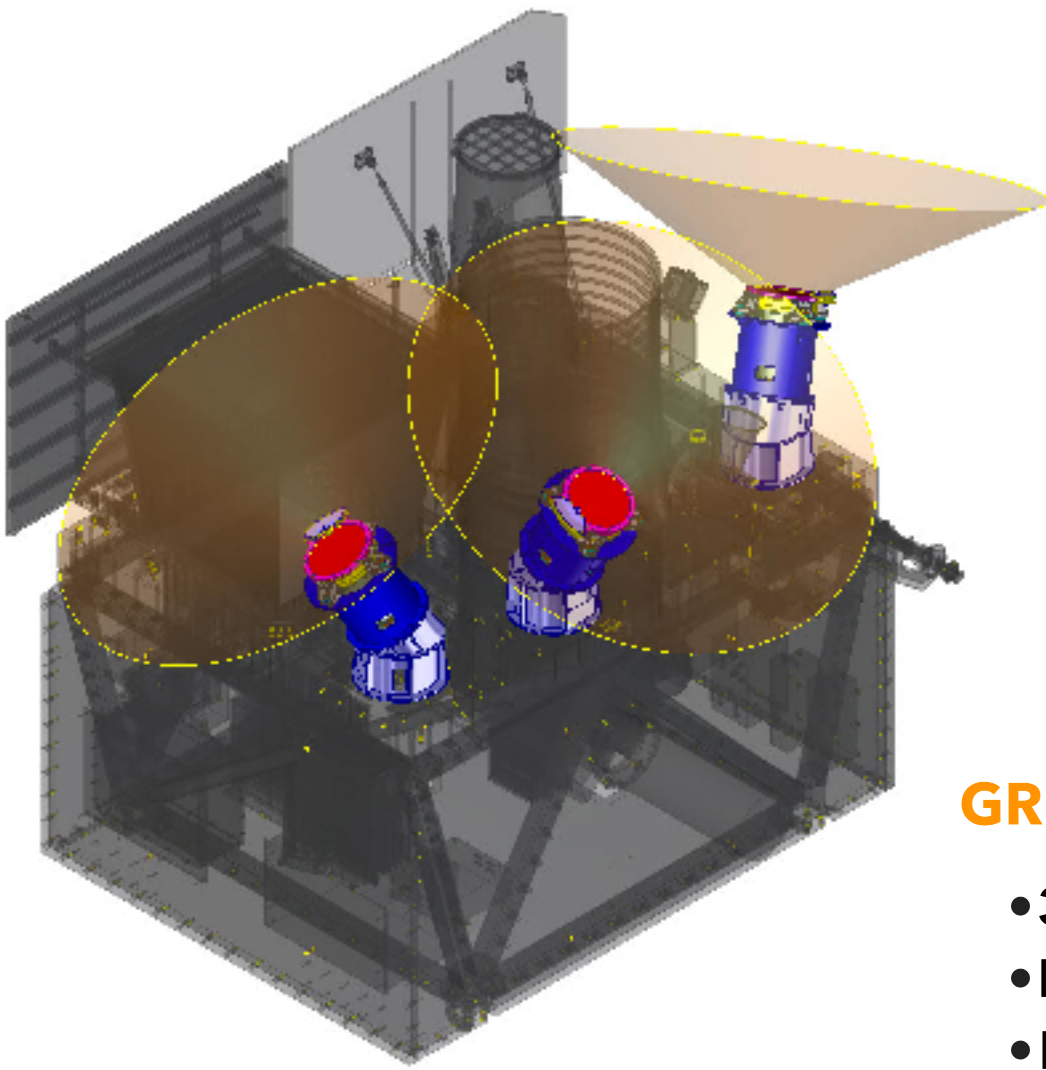


MXT Micro-channel X-ray Tel. (CNES, CEA, UL, MPE)

- **Micro-pores optics** (Photonis) with **square 40 µm 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

Innovative focusing « Lobster-Eye » X-ray optics
Will observe the X-ray afterglow promptly

GRM – GAMMA-RAY MONITOR



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: 2.6 sr per GRD**
- **Energy range: 15-5000 keV**
- Aeff = 190 cm² at peak
- Crude localization accuracy
- Expected rate: **~90 GRBs / year**

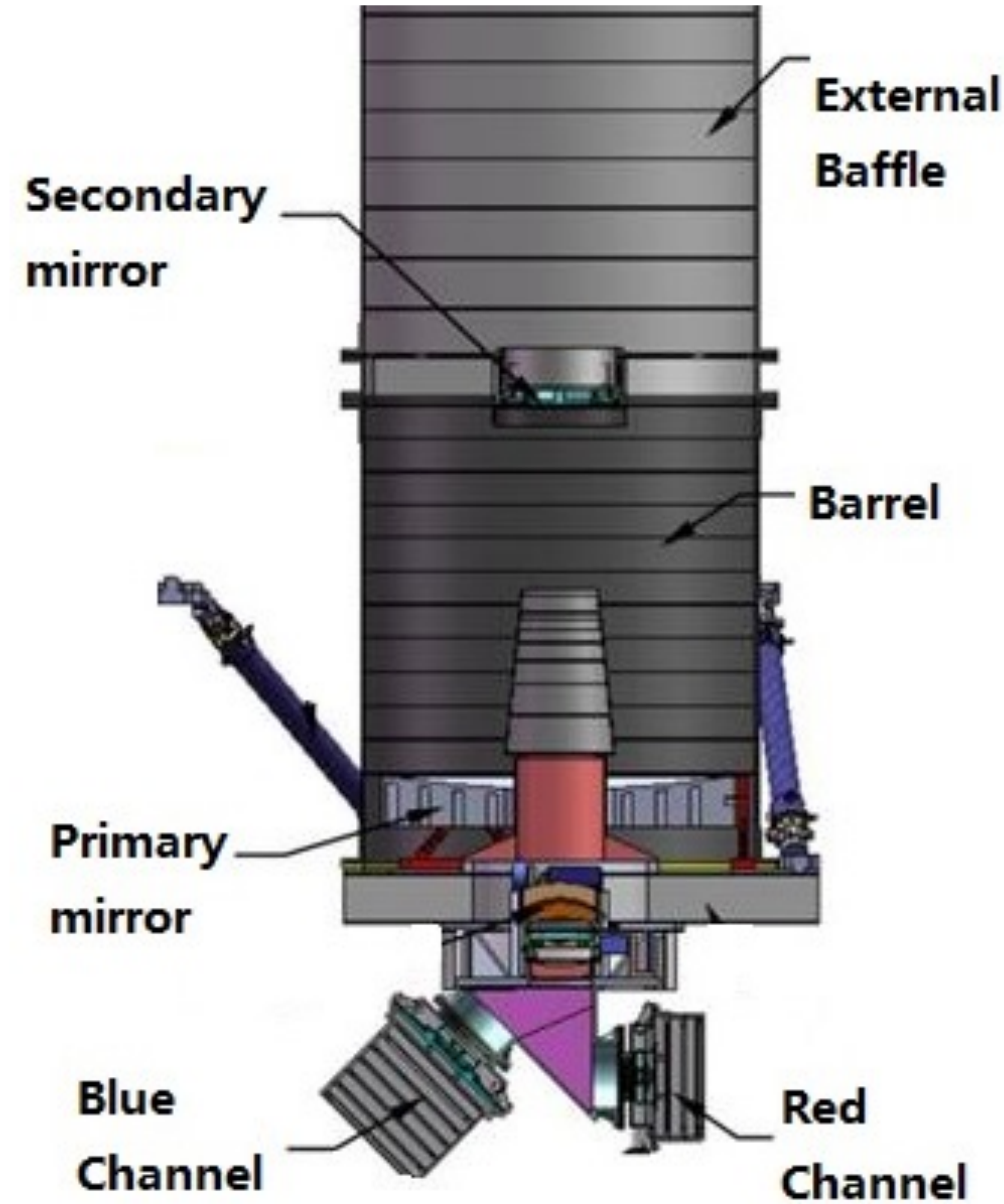
Will measure E_{PEAK} for most ECLAIRs GRBs
Will detect short & long GRBs out of the ECLAIRs FOV

VT – THE VISIBLE TELESCOPE

VT Visible Telescope (XIOMP, NAOC)

- Ritchey-Chretien telescope, 40 cm Ø, f=9
- **FoV: 26x26 arcmin²**, covering ECLAIRs error box
- **2 channels: blue (400-650 nm) and red (650-1000 nm)**, with 2k * 2k CCD detector each
- **Sensitivity M_V=22.5 in 300 s**
- Will detect ~80% of ECLAIRs GRBs
- **Localization accuracy <1 arcsec**

Able to detect high-redshift GRBs up to z~6.5, with two channels



SVOM From The Ground

GWAC Ground-based Wide Angle Camera

- **In China**: 40 cameras of 180 mm diameter
    - **total FOV ~6000 deg^2** ; limiting magnitude 16 (V, 10s)
- **In Chile**: 50 cameras of 250 mm diameter
    - **total FOV ~5000 deg^2** ; limiting magnitude 17 (V, 10s)
- Self triggering capabilities
- 12% of the ECLAIRs FOV, and full accessible sky each night

GFT Ground Follow-up Telescopes

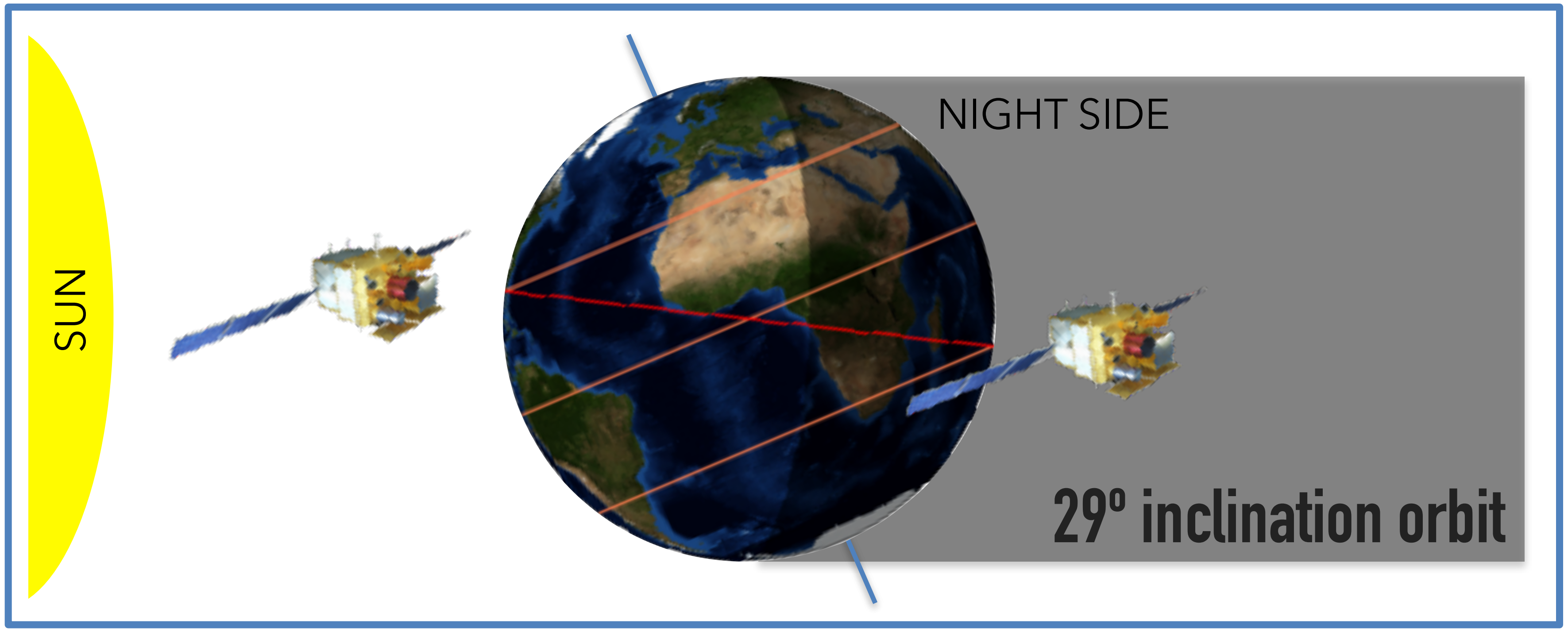
- Early optical/IR afterglows of > 75% of ECLAIRs detected GRBs
- **In China**: Chinese GFT
    - 120 cm telescope, limiting mag. 20 (r, 300 s)
    - 21x21 arcmin FOV
    - 400-900 nm
- **In Mexico**: French-Mexican GFT
    - 130 cm telescope, limiting mag. 22 (r, 300 s)
    - 26x26 arcmin FOV
    - 400-1700 nm

The SVOM Mission Strategy

Driven by

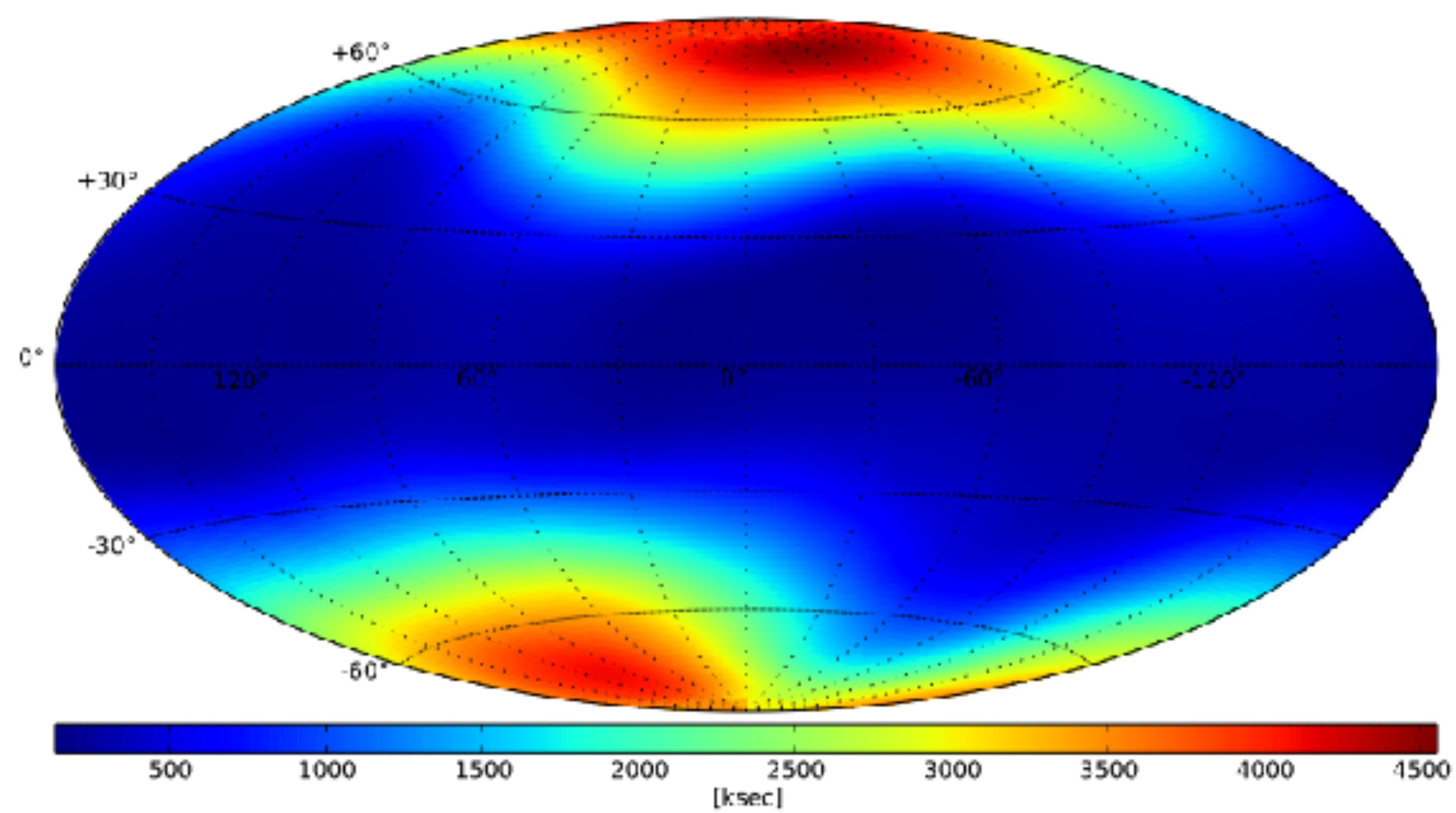
Gamma-ray Bursts and High-energy Transient

THE POINTING STRATEGY FOR THE GRB PROGRAM

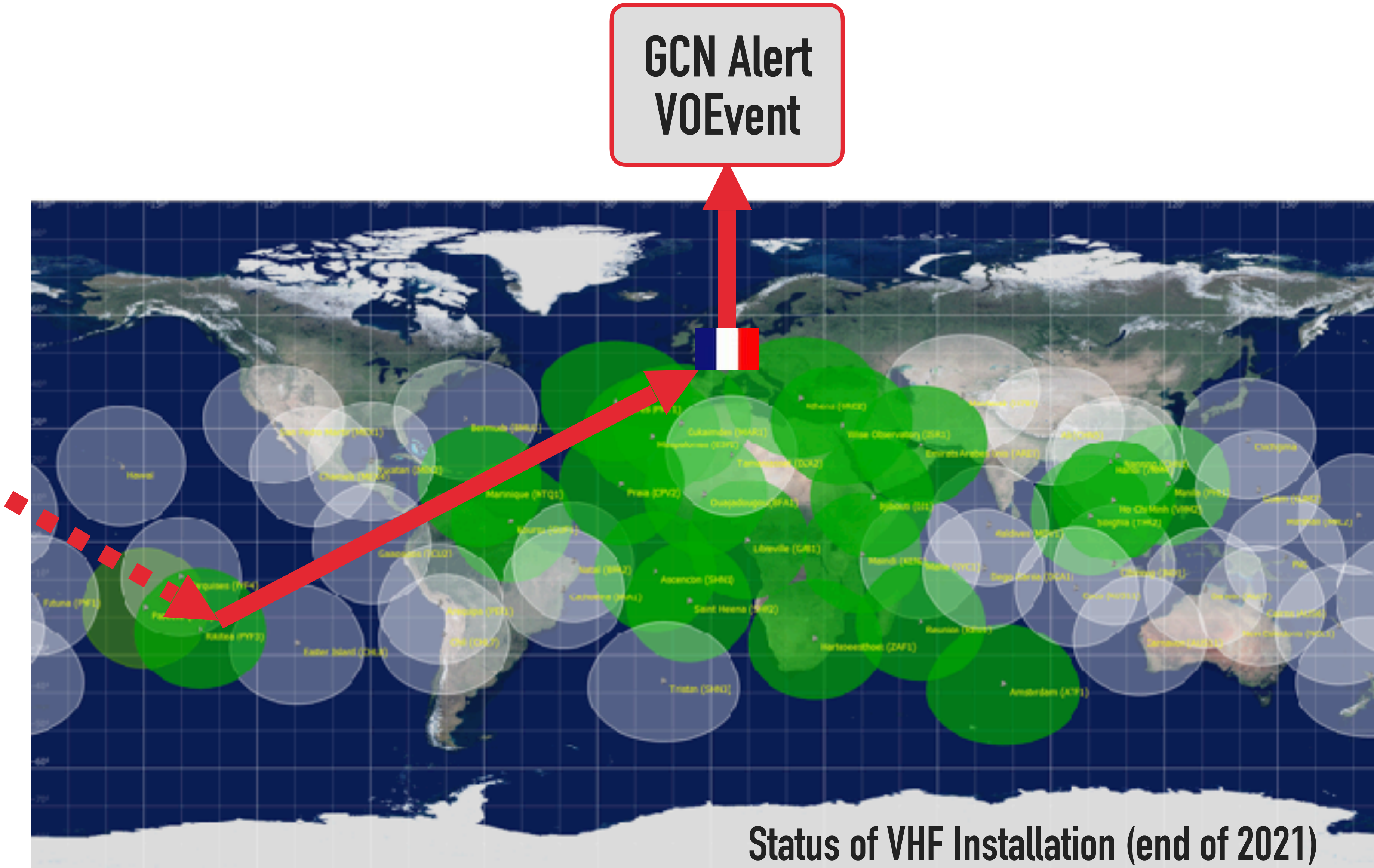


- **<u>Optimized for ground follow-up of GRB candidates</u>**
- Nearly anti-solar pointing (with Earth in FOV each orbit
- 65% duty cycle for ECLAIRs
- 50% duty cycle for MXT and VT

- Avoidance of the Galactic plane (and bright sources)
- ~ 65% GRBs per year expected
- <u>ECLAIRs annual exposure time</u> from 500 ks on the Galactic plane, and 4000 ks on the Galactic poles



SVOM Alert Downlink via VHF Network



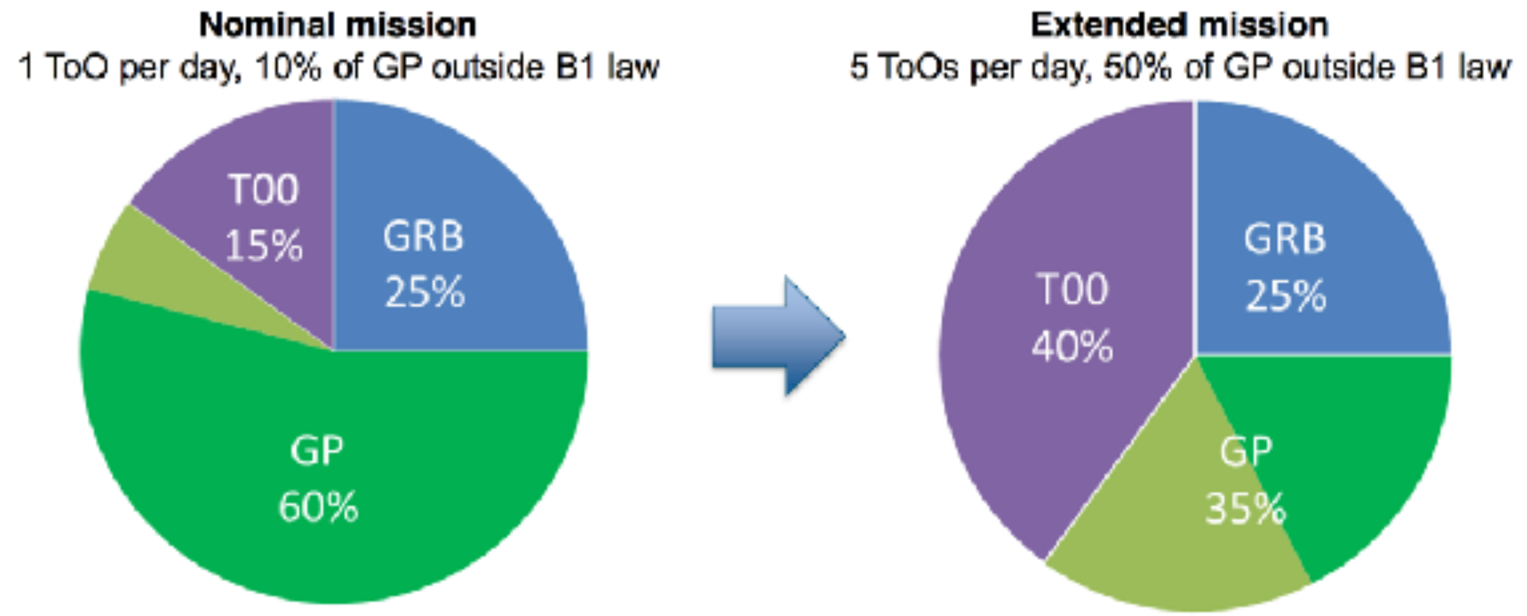
- Alerts are transmitted to a network of 40 VHF receivers on Earth
- Goal: 65% of them received within 30 s at the French Science Center
- ECLAIRs + post-slew X-ray and Visible information is also sent through the VHF link

SVOM's Special Features

- **ECLAIRs + GRM + GWAC**
  - Prompt multi-wavelength coverage of transient from optical to gamma-rays
- **MXT + VT + GFT**
  - Afterglow multi-wavelength coverage of transients from optical to X-ray
  - Accurate localisations in ≤ 30 sec
  - Good coverage and sensitivity for the prompt-afterglow transition (visible and X-rays)
- **ECLAIRs 4 keV low energy threshold**
  - Ideal for high-z GRBs, and X-ray flares
- **All ECLAIRs and GRM events are sent to the ground**
  - Will permit delayed off-line trigger
  - Will allow monitoring of sources
- **Fast alerts with a world-wide network of VHF antennae**
- **Strong ToO program using Beidou short messages**

SVOM's Observing Programs

- Core Program (CP): a complete GRB sample with excellent coverage of the prompt and afterglow emission, as well as redshift measurements.
  - Diversity of GRBs
  - Physical mechanisms at work in GRBs
  - Short GRBs and the merger model
  - GRB-SN connection
  - High-z GRBs



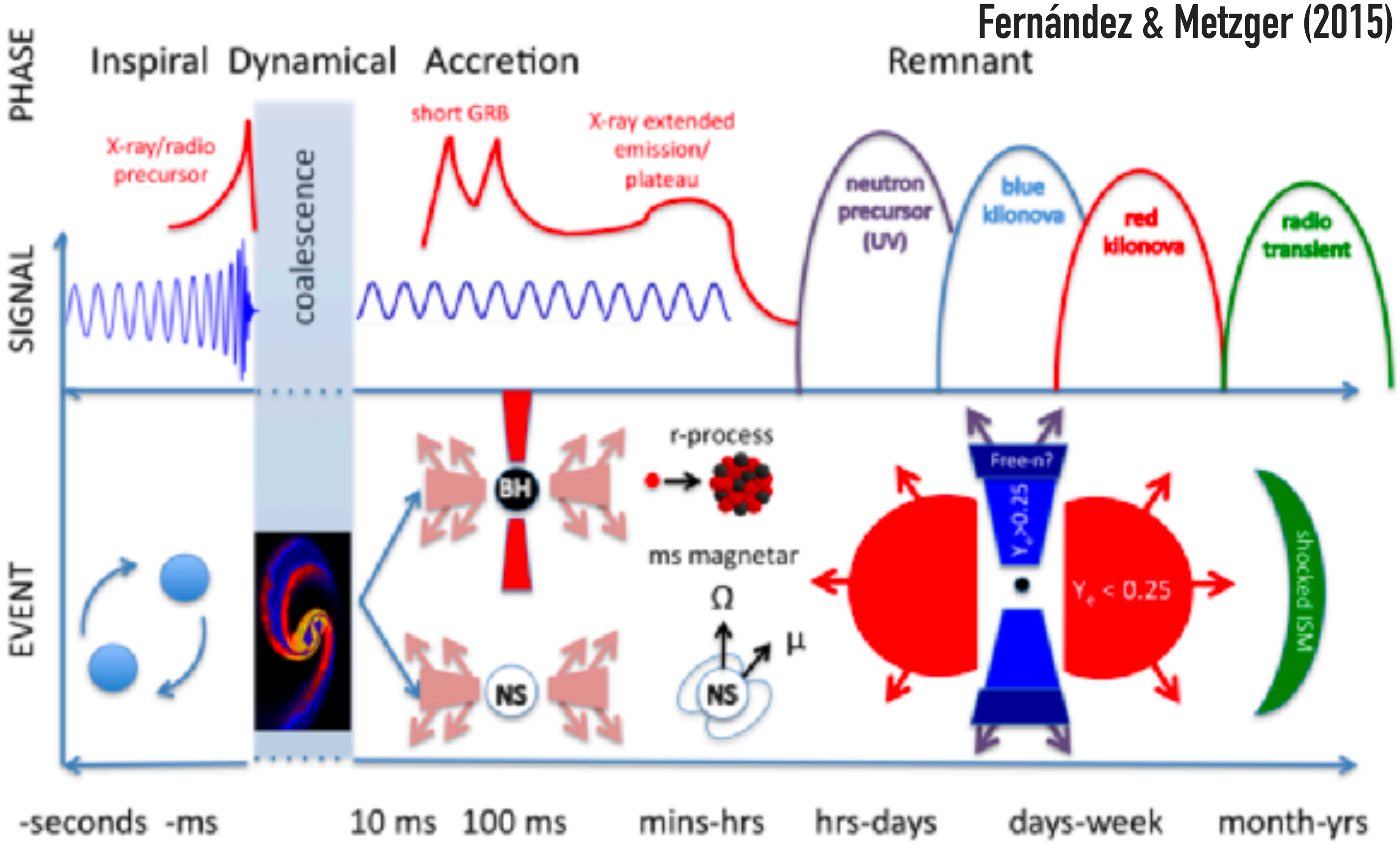
- General Program (GP) via TAC
  - Proposal with a SVOM co-I, for targets of interest mostly compliant with the satellite attitude law .
  - Low Galactic latitude sources: 10% of the time (Nominal mission) -> 50% during extended mission.

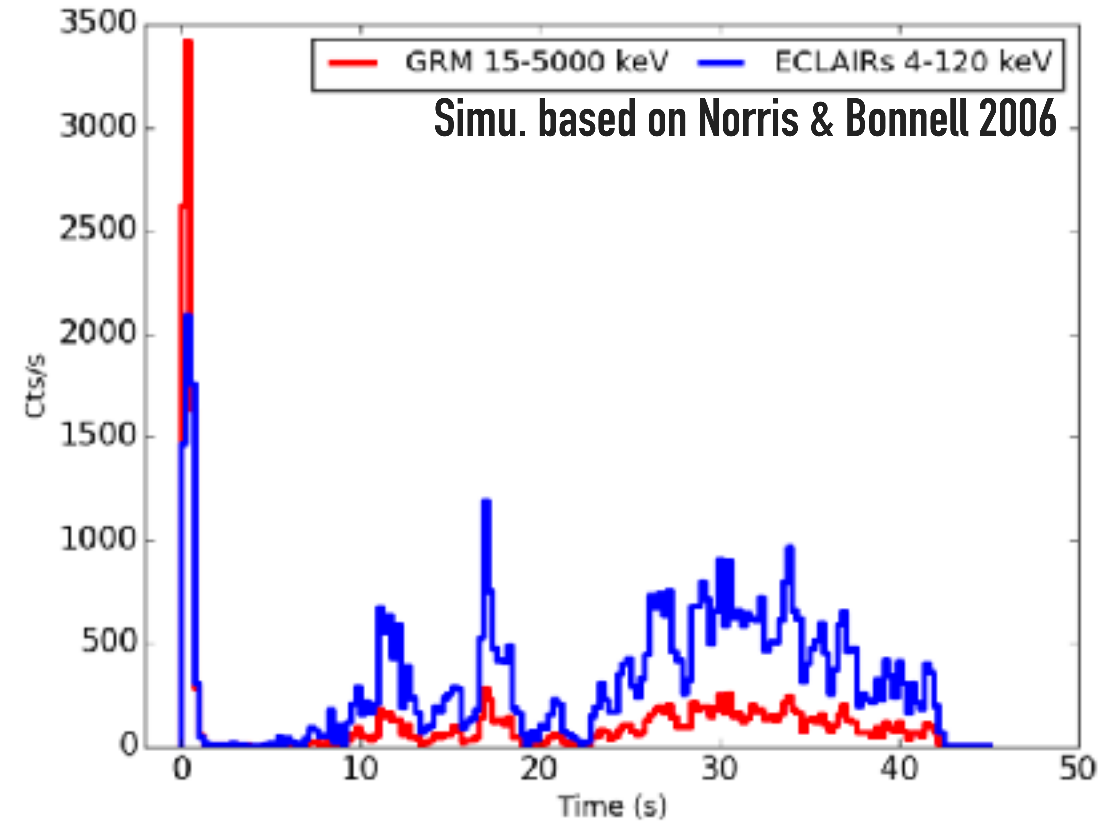
- Target of Opportunity (ToO) – initially about 1/day (will increase)
  - ToO-NOM from the ground (GRB revisit, known source flaring, new transient)
  - ToO-EX for fast ToO-NOM in case of an exceptional astrophysical event
  - ToO-MM for EM counterpart search in response to a multi-messenger alert (usually larger error box)

THE SCIENCE

GRBs and NS–NS Mergers

Fernández & Metzger (2015)

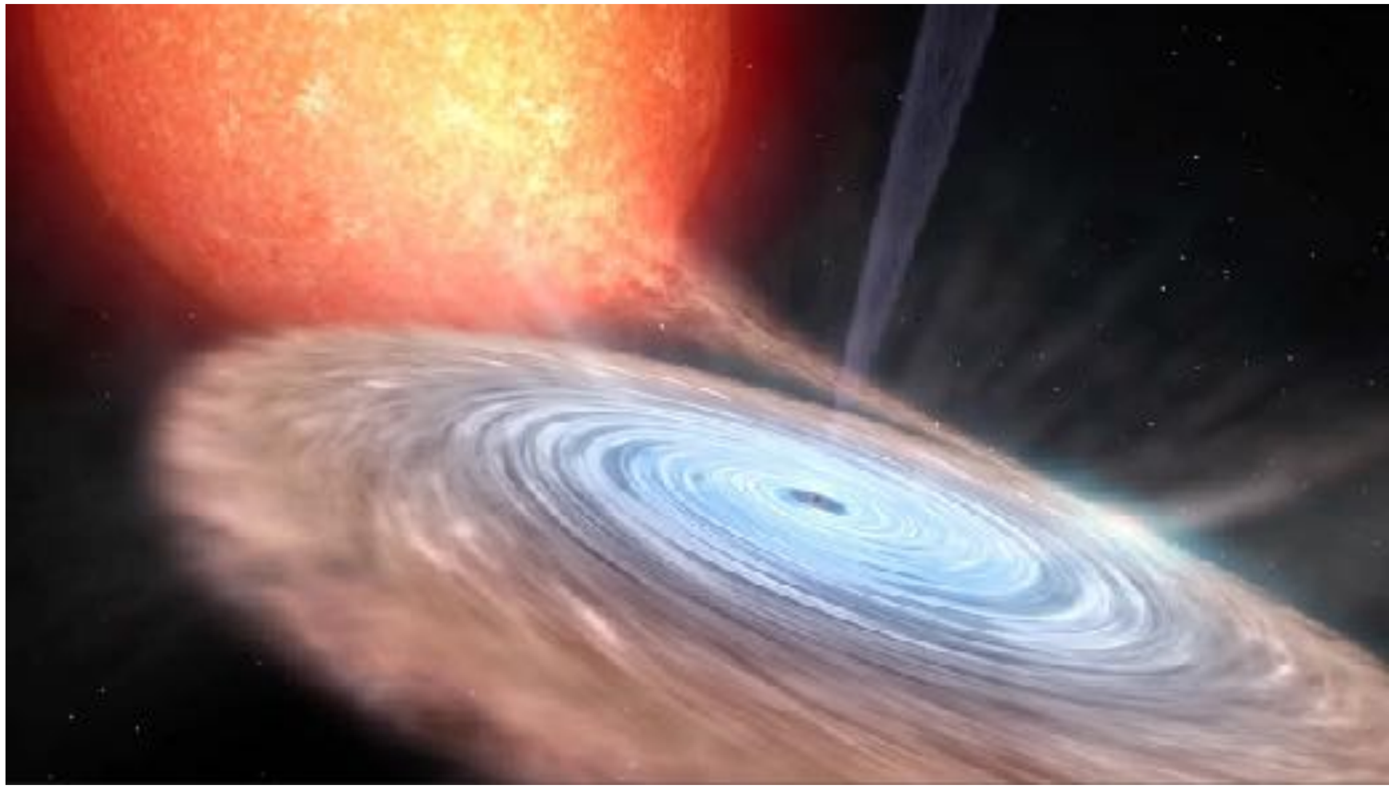




- For upcoming runs of GW interferometers, SVOM will help:
  - Rapidly localise EM counterparts to ~arcsec precision.
  - Characterise the prompt emission
- Joint GW-EM measurements provide:
  - better sensitivity,
  - more diagnostics on the binary (precursor),
  - the evolutionary context,
  - info on the equation of state,
  - (and even constraints on Cosmology and speed of GWs)

ACCRETION AND X-RAY BINARIES

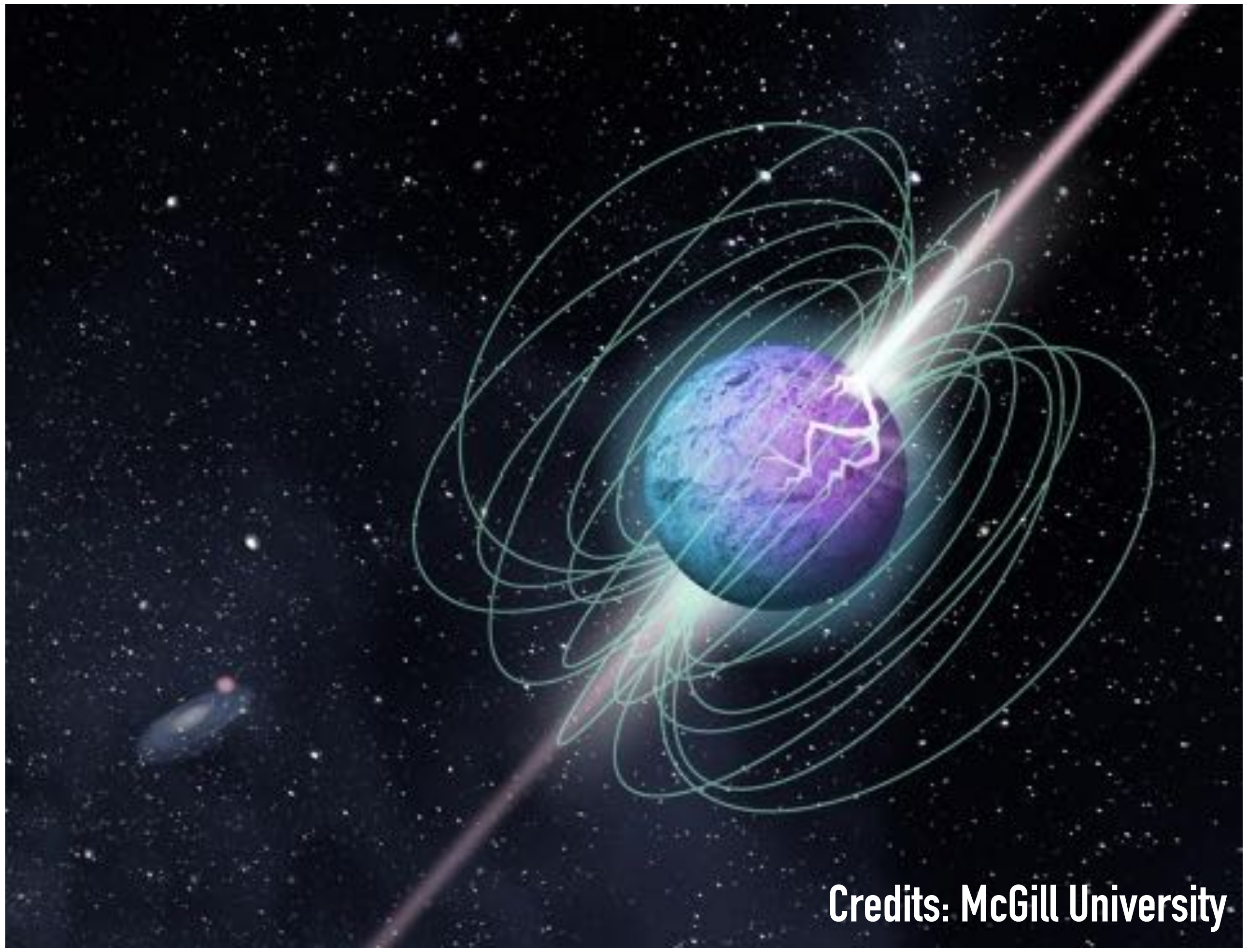
- Physics of accretion
- Physics of ejection
- Reflection on disks



- SVOM will help with:
  - Regular monitoring of known sources (Galactic binaries, ULXs):
    - down to 50 mCrab in one orbit with ECLAIRs
    - down to 10^{-12} erg/s/cm^2 in one orbit with MXT
  - Identify and localise new X-ray binaries and send alerts rapidly
  - Observe X-ray binaries via ToO program
  - Observe bright sources: ECLAIRs high throughput permits observing sources of ~Crab with ~5% dead-time

MAGNETARS

- Origin of magnetar activity
- Emission mechanisms



- SVOM will help with:
  - The identification of new magnetars via their bursts activity
  - The detection of Soft Gamma Repeaters
  - The detection and the rapid follow-up of fainter magnetars
  - Exploring the link between FRBs and magnetars.

The Instrumental Context

- The golden age of transient astrophysics …
  - VHE γ-rays: CTA, HAWC, LHAASO
  - Transient HE sky: INTEGRAL, Swift, Fermi, GECAM, SVOM, POLAR-2, Einstein Probe
  - X-rays: eROSITA
  - Visible: Pan-STARRS – ZTF - Vera Rubin Observatory
  - Radio: SKA precursors & FRB detectors

- … and multi-messenger astrophysics
  - GWs: LIGO – VIRGO – KAGRA
  - Neutrinos: KM3NeT – ICECUBE

- The important points are:
  - improved coordination between instruments and flexibility of the observing strategy
  - High-energy missions must account for the diversity of HE sources
    - energies
    - time scales
    - variability
  - Some events are rare or faint, requiring deep all-sky surveys (e.g. GW170817)

- Observing GRBs, AGNs, TDEs, Galactic HE sources and GW transient sources, SVOM will be a major observatory for the study of Neutron stars and Black Holes and their astrophysical impact.
- With its unique combination of space and ground facilities, it is expected to become a key player in the fields of High-Energy Astrophysics, Time Domain Astronomy and Multi-Messenger Astrophysics. These domains are expected to develop very rapidly thanks to a new generation of powerful observatories:
  - Vera Rubin Observatory – Pan-STARRS – ZTF
  - GW detectors
  - SKA precursors & FRB detectors
  - Large neutrino observatories
  - CTA

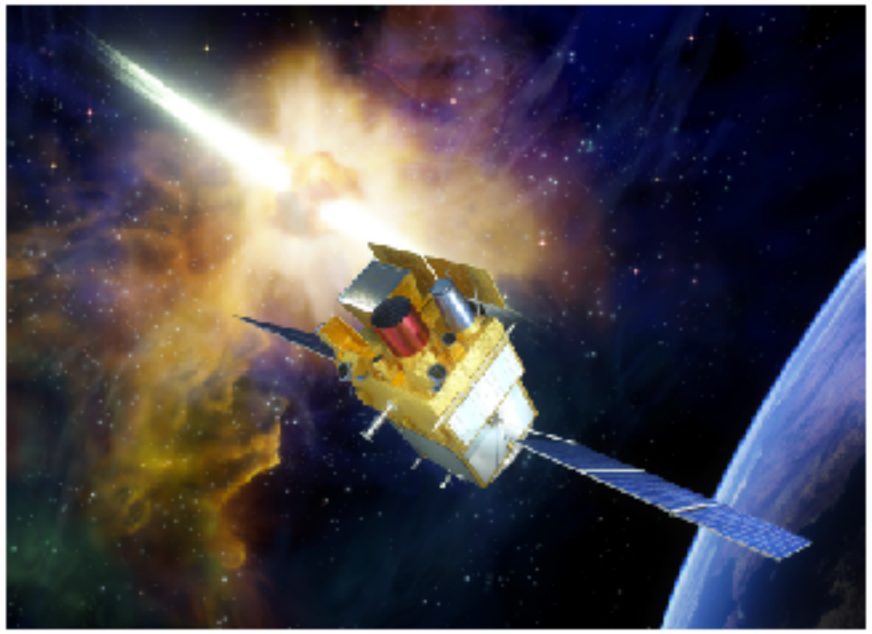
-- Launch late 2023 --

The Deep and Transient Universe:
New Challenges and Opportunities

Scientific prospects of the *SVOM* mission

J. Wei, B. Cordier, et al.
(Version of 05-10-2016, for full list of contributors see overleaf)

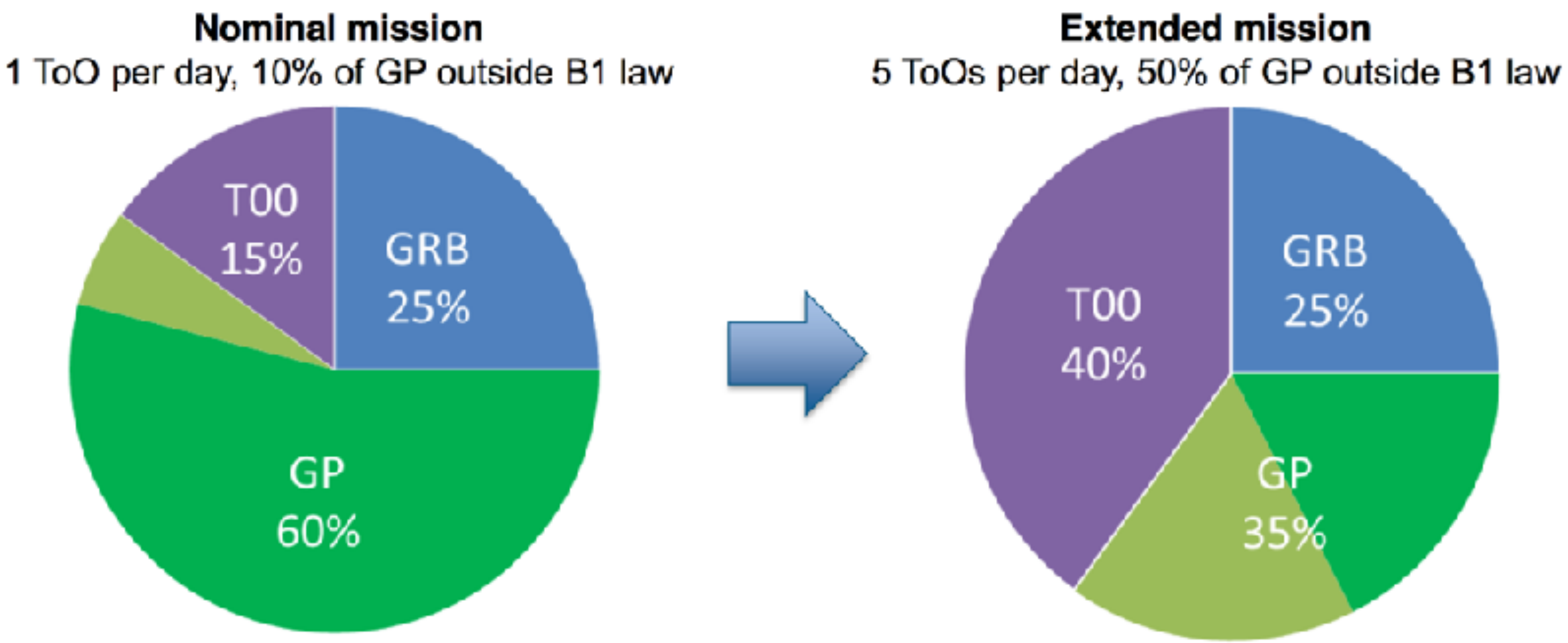
arXiv:1610.06892v1 [astro-ph.IM] 21 Oct 2016



FOR MORE INFORMATION
SVOM white paper: arXiv:1610.06892
SVOM Website: http://www.svom.fr/en/

EXTRA SLIDES

SVOM AS AN OPEN OBSERVATORY



ToO	Approval	From accep-tance/ trigger	GRB inter-ruption	Frequency	Duration
ToO-NOM	PI	<48h	Yes	MAX 1/day => 5/day	1 orbit
ToO-EX	PI	<12h	No	MAX 1/month	1-14 orbits

- High-energy astrophysics addresses major questions:
  - Stellar explosions
  - Relativistic jets in GRBs and AGNs: composition, acceleration and dissipation processes, geometry, impact of the central engine…
  - Physics of accretion / ejection around compact objects
  - Origin of magnetar activity
  - Role of jets in VHE cosmic rays production
  - Using GRBs for cosmography
  - Test of Lorentz Invariance
  - GRB-SN connection
  - Origin of ultra-long GRBs
  - BH astrophysics: demography, birth places, masses & spins?
  - Hosts of BNS mergers
  - The IGM at high redshift (with high-z GRBs)
  - Pop III & star formation at high-z, Pop III & first BHs
  - GRB beaming
  - …

- Multi-messenger astrophysics opens a new window on several topics:
  - Origin of heavy elements: role of BNS, study at the production site, galaxy enrichment
  - BH+NS binaries: demography, origin, merger remnant
  - Physics of mergers
  - BBH demography & merger rates
  - BH masses: Why BHs seen by LVC in binaries are so massive, compared with accreting BHs in our galaxy?
  - What are the masses of the BHs in GRBs?
  - EM emission from BBH mergers?
  - …

- A large diversity of sources offer complementary views on these topics:
  - Gamma-ray bursts of all types: long, short, ultra-long, X-Ray Flashes
  - Mergers of compact objects
  - Soft Gamma Repeaters
  - Relativistic Tidal Disruption Events
  - Active Galactic Nuclei
  - Galactic HE transients (accreting binaries)
  - (Terrestrial Gamma-ray Flashes)
  - (Fast Radio Bursts)