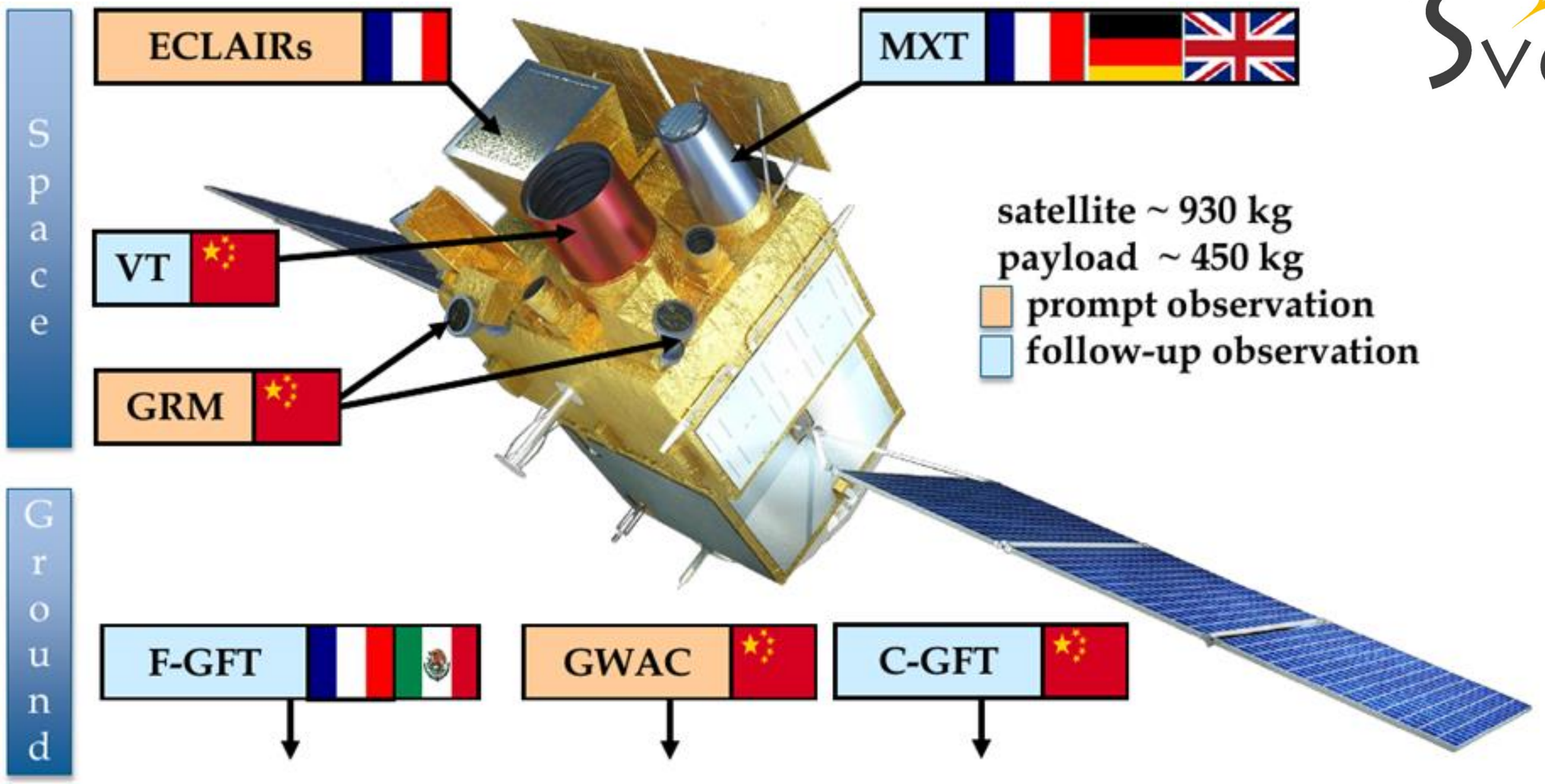
a time domain machine

B. Cordier, C. Lachaud, D. Götz & the SVOM consortium



A multi wave-length mission with space based and ground based instruments

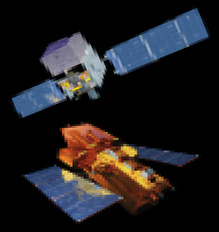
Open Questions

GRB studies

- Progenitors and central engines
- The physics of the relativistic ejecta
- Multi-messenger emission

Using GRBs as a tool for cosmology

- Spectroscopy of the line of sight
- Host galaxies
- Very distant GRBs : first stars/reionization of the intergalactic medium ?

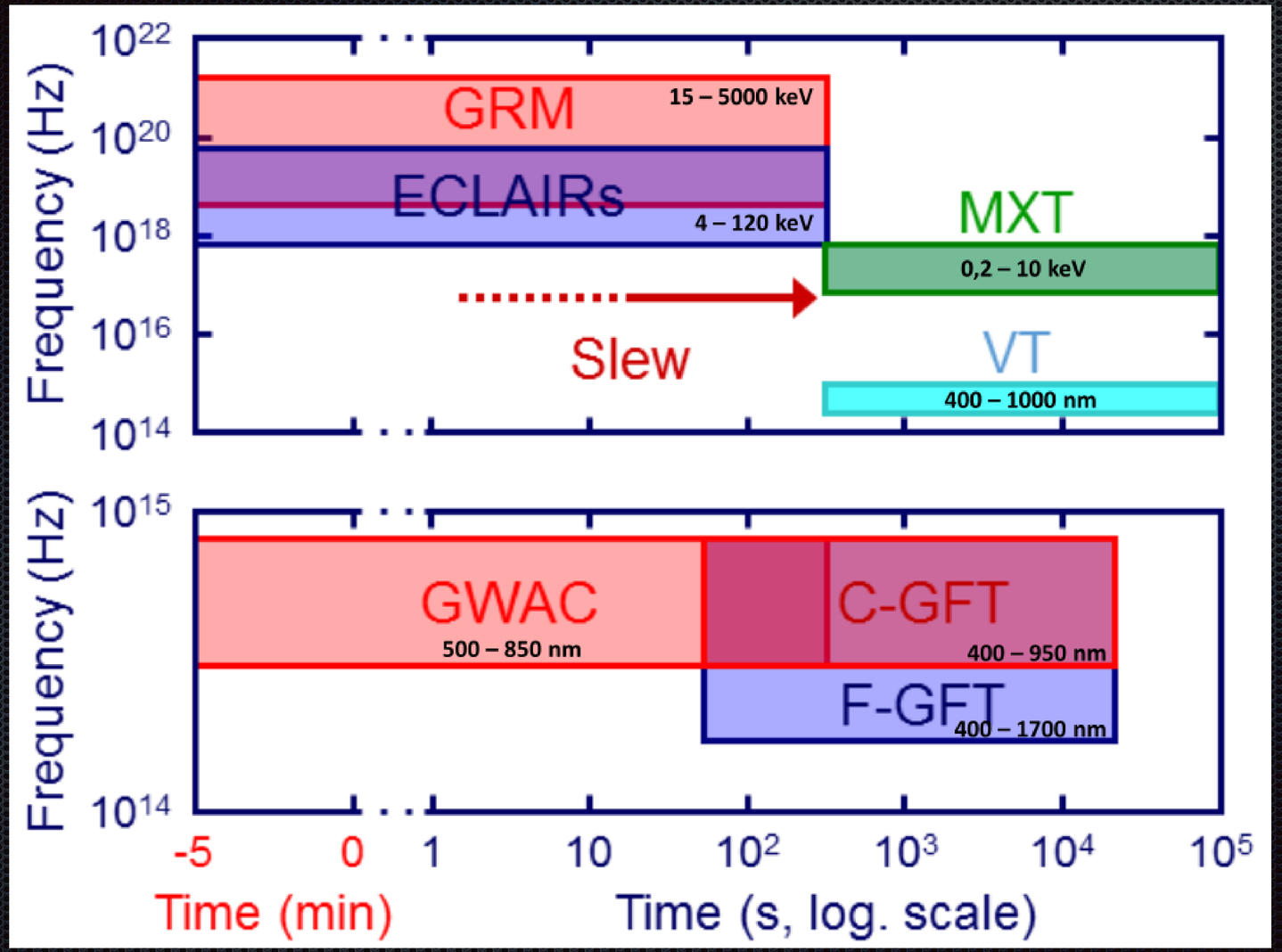


- Fermi : short GRBs and excellent coverage of the prompt emission
- Swift : study of the afterglow and measurement of the redshift

Build a homogeneous sample of GRBs
with a good time and spectral coverage
With redshift measurement

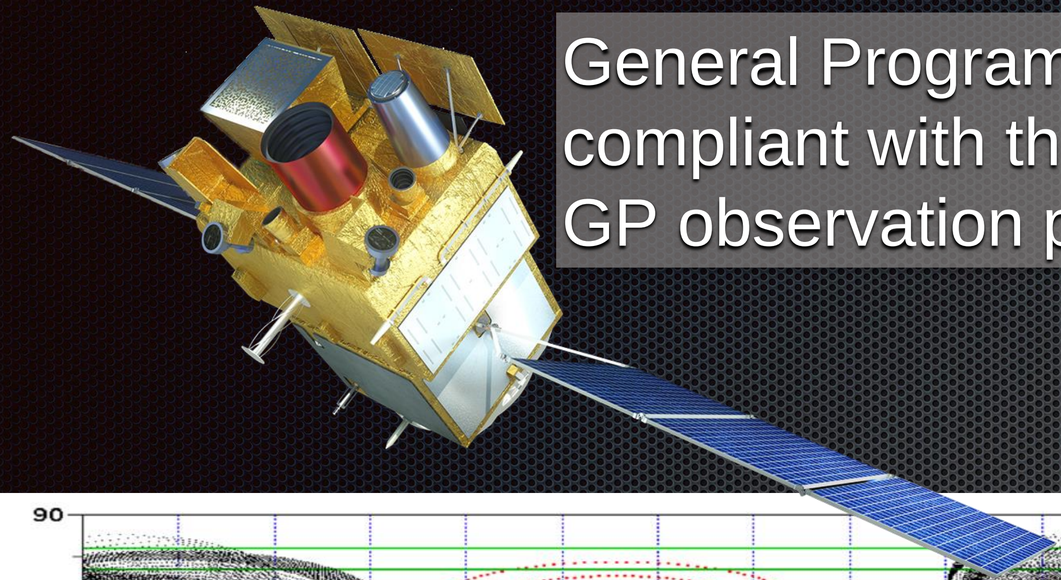
SVOM

Spectral and temporal coverage

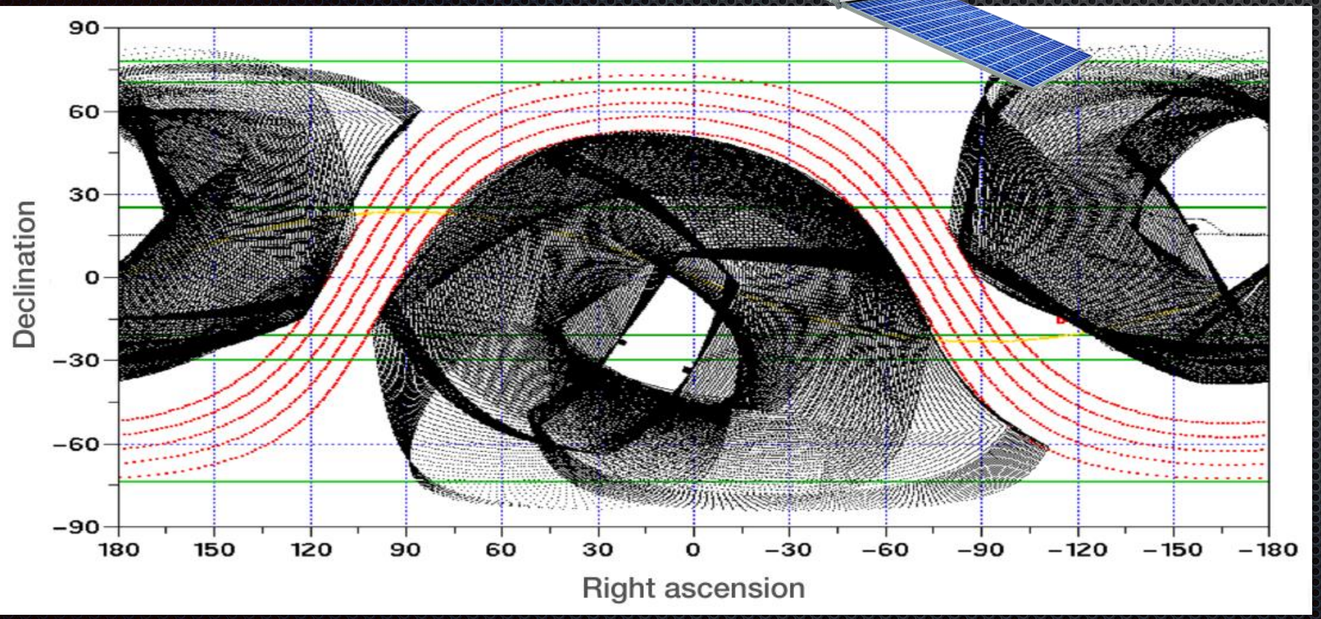


An efficient time domain machine

The SVOM observation programs (1/4)



General Program (GP) : astrophysical targets of interest mostly compliant with the B1 law (satellite attitude law).
GP observation plan is uploaded to the satellite every 2 weeks.



How to apply ?

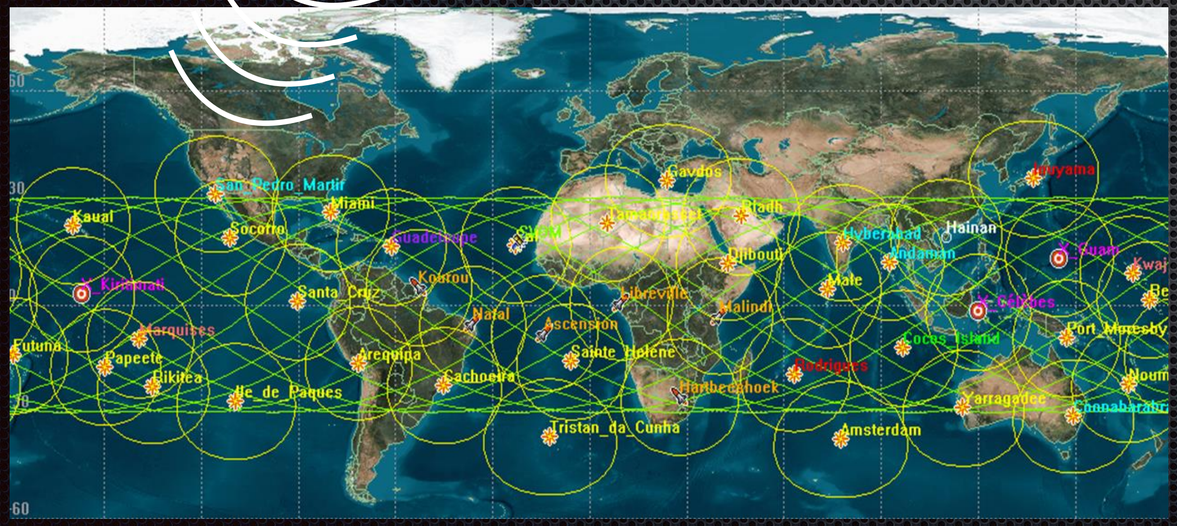
Call for observation proposals once per year. Selection by a TAC.

Example : survey of the Virgo cluster (TDEs, AGNs)

The SVOM observation programs (2/4)

Autonomous transient detection by ECLAIRs :

- known sources (repointing only if above a given threshold)
- unknown sources : GRBs (Core Program : CP) or other astrophysical transient (GP)



All transients will be notified on short time scales (<30 s for 65% of alerts) to the FSC and then to the community.

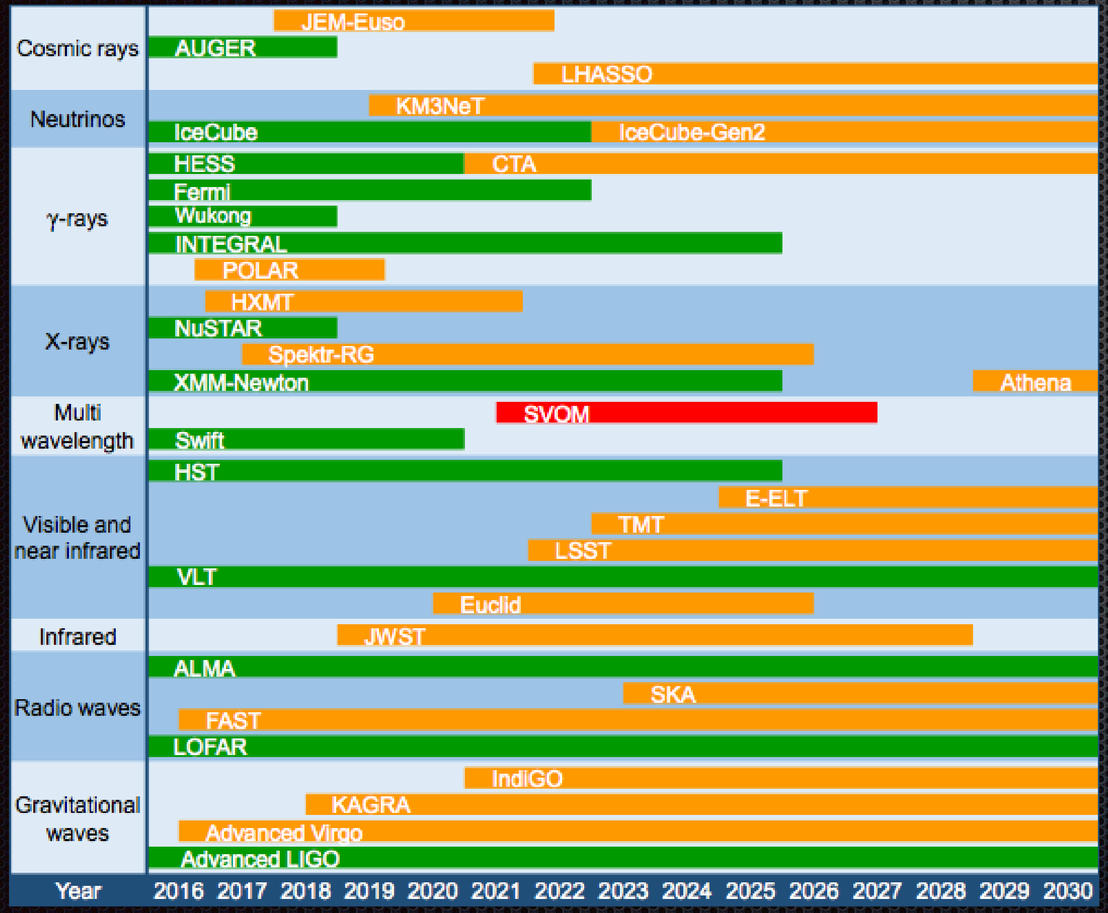
SVOM has been designed for autonomous detection, fast repointing, short timescales alerts and follow-up

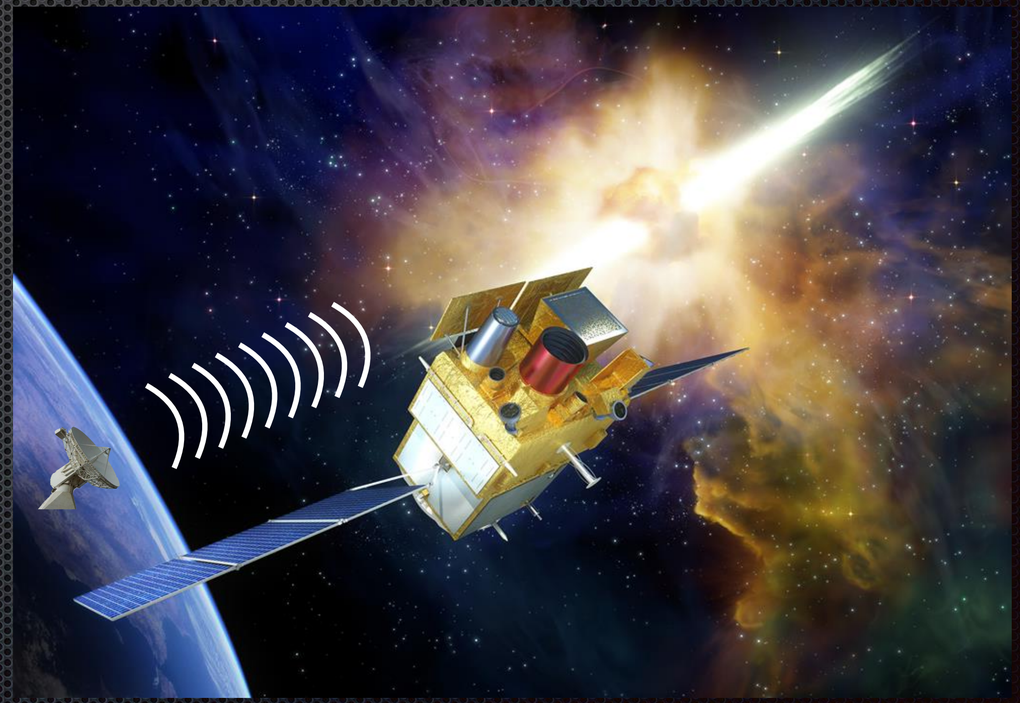
The SVOM observation programs (3/4)

Transient/event detected by other facilities

Target of Opportunity program

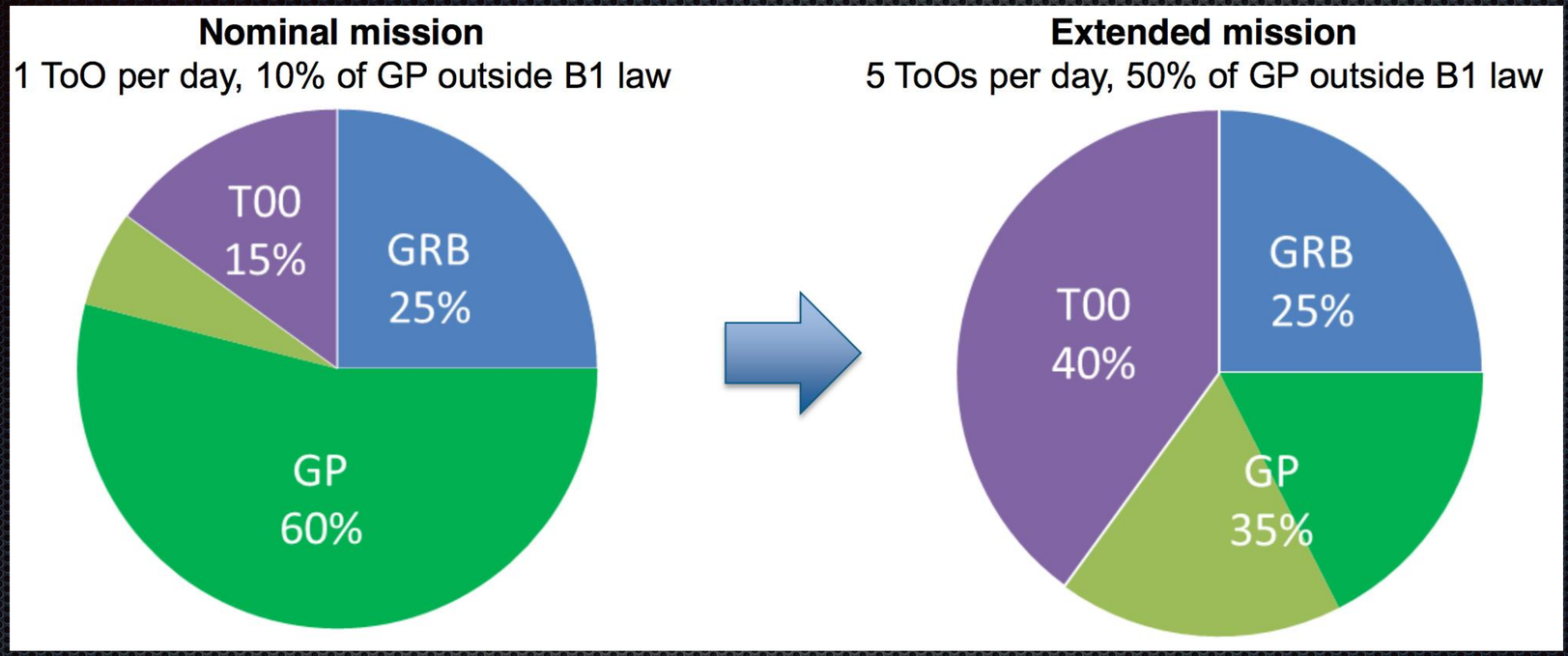
=> send commands to the satellite to trigger observations from the ground





Complex operations at system level

The SVOM observation programs (4/4)

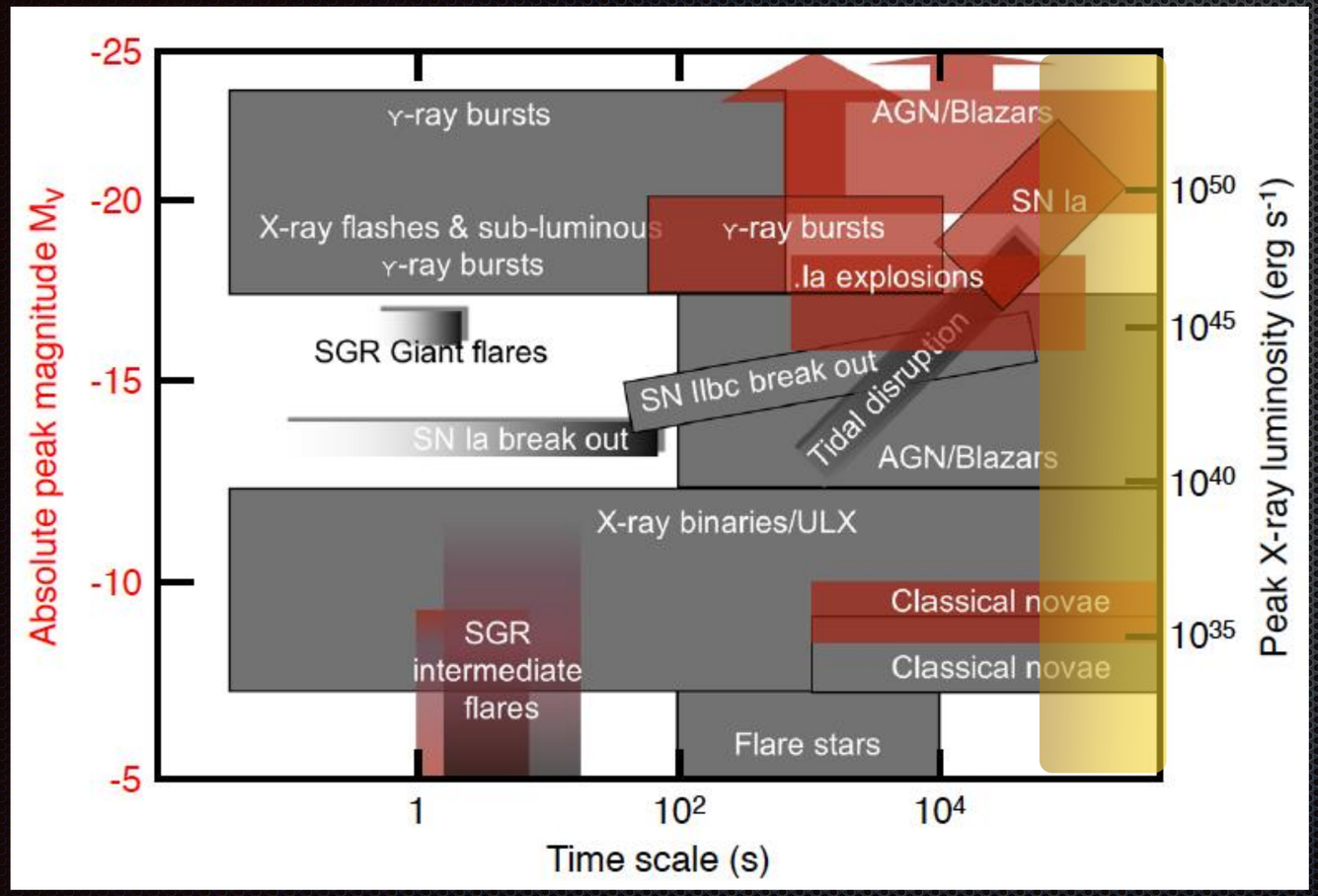


From 1 ToO/day to as much as 5 ToOs/day druing the extended mission.

GP reduced but more tolerance to escape the B1 law (galactic plane avoidance).

Target of Opportunity program: ToO-NOM

ToO-NOM is the *nominal* ToO which covers the basic needs for efficient transient follow-up.



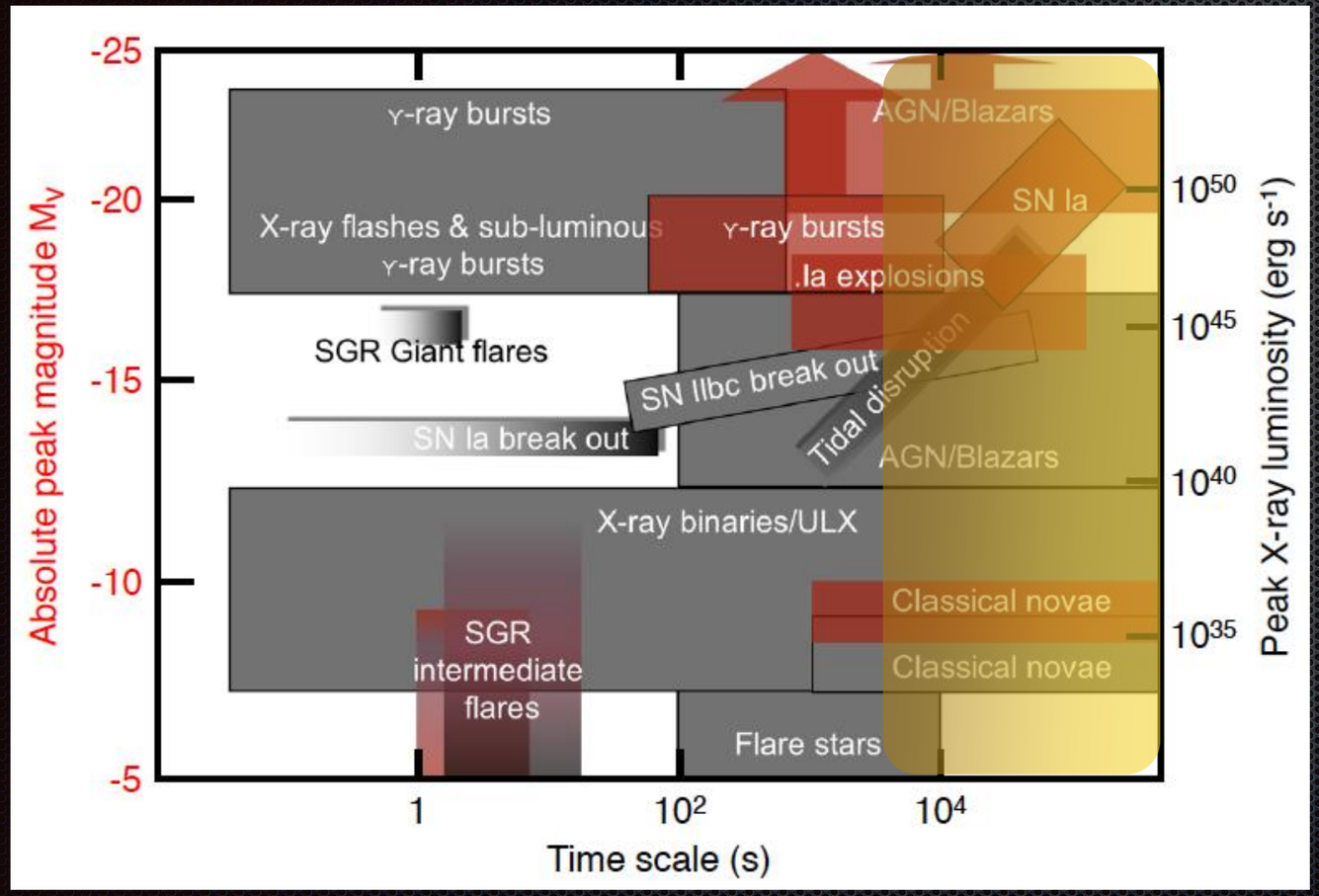
Scientific target :

- GRB revisits (CP; user : BA)
- Observations of a pre-approved GP ToO target (AGN,…)
- New transient

Main characteristics :
Frequency : 1/day
Standard delay : < 48h
Duration : 1 orbit (or more)

Target of Opportunity program: ToO-EX

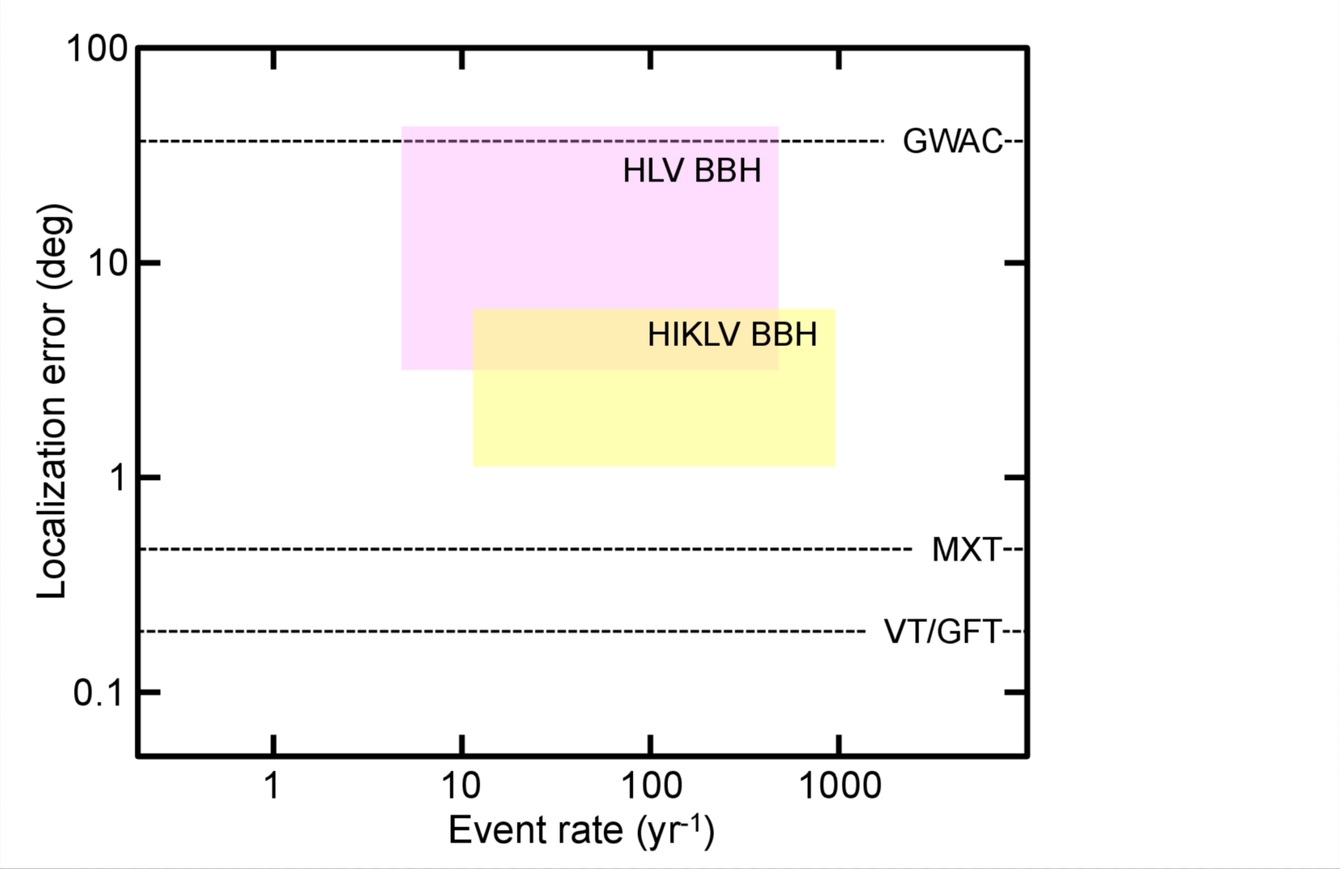
ToO-EX is an *exceptional* ToO which covers the needs for a rapidly implemented ToO in case of a peculiar astrophysical event.

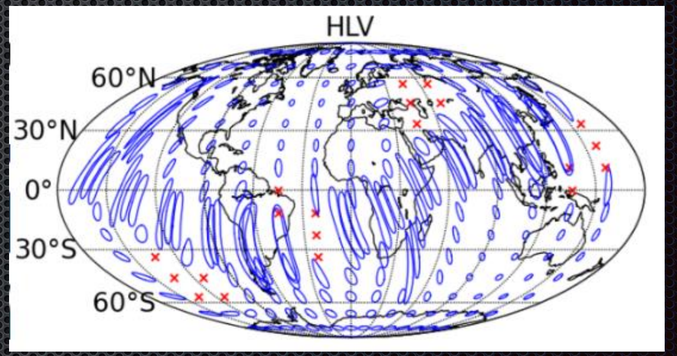


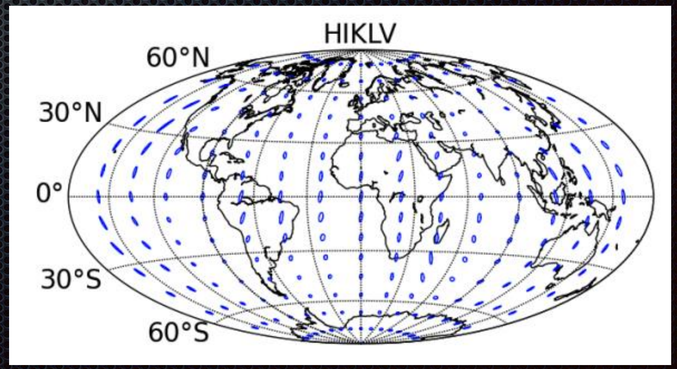
Main characteristics :
Frequency : 1/month
Standard delay : < 12h
Duration : 7-14 orbits

Target of Opportunity program: ToO-MM

ToO-MM is a ToO dedicated to the search of an EM in response to a multi-messenger alert (GW, neutrino,…). What distinguishes a ToO-MM from a ToO-EX is the unknown position of the source within a large error box…







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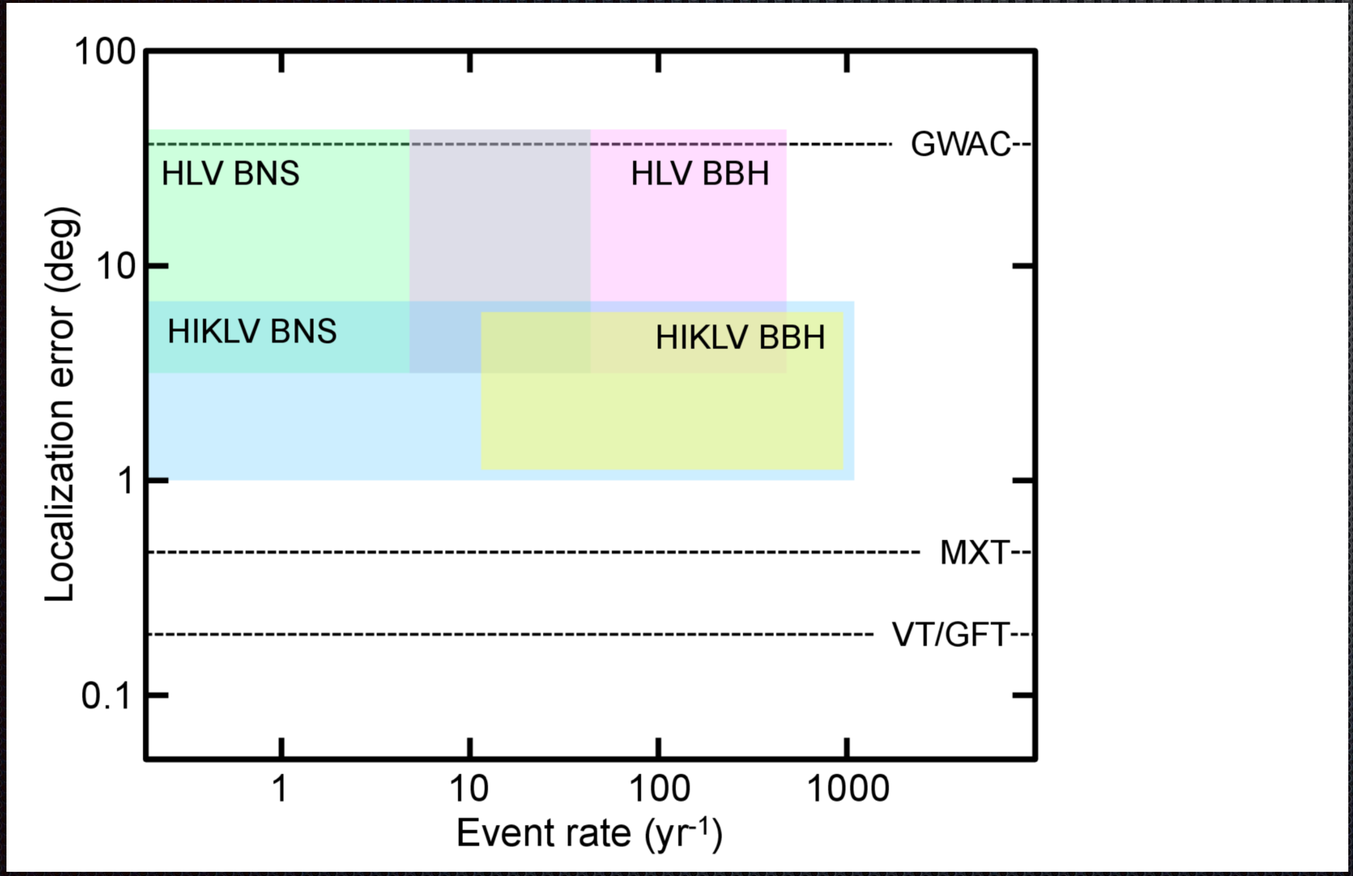

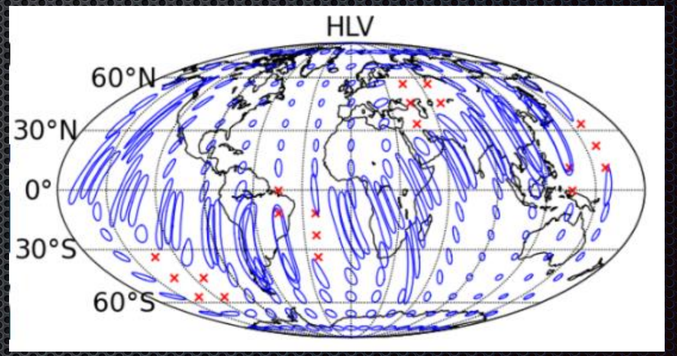

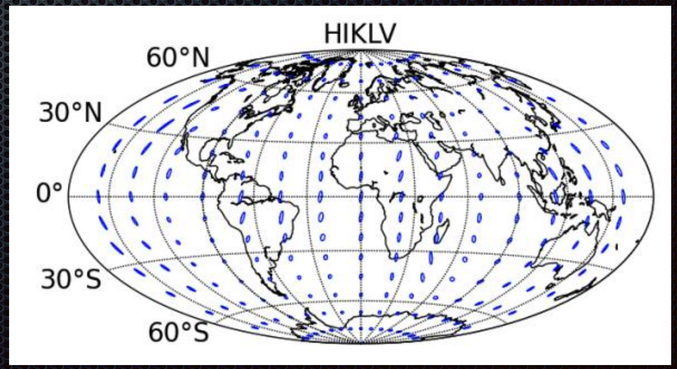

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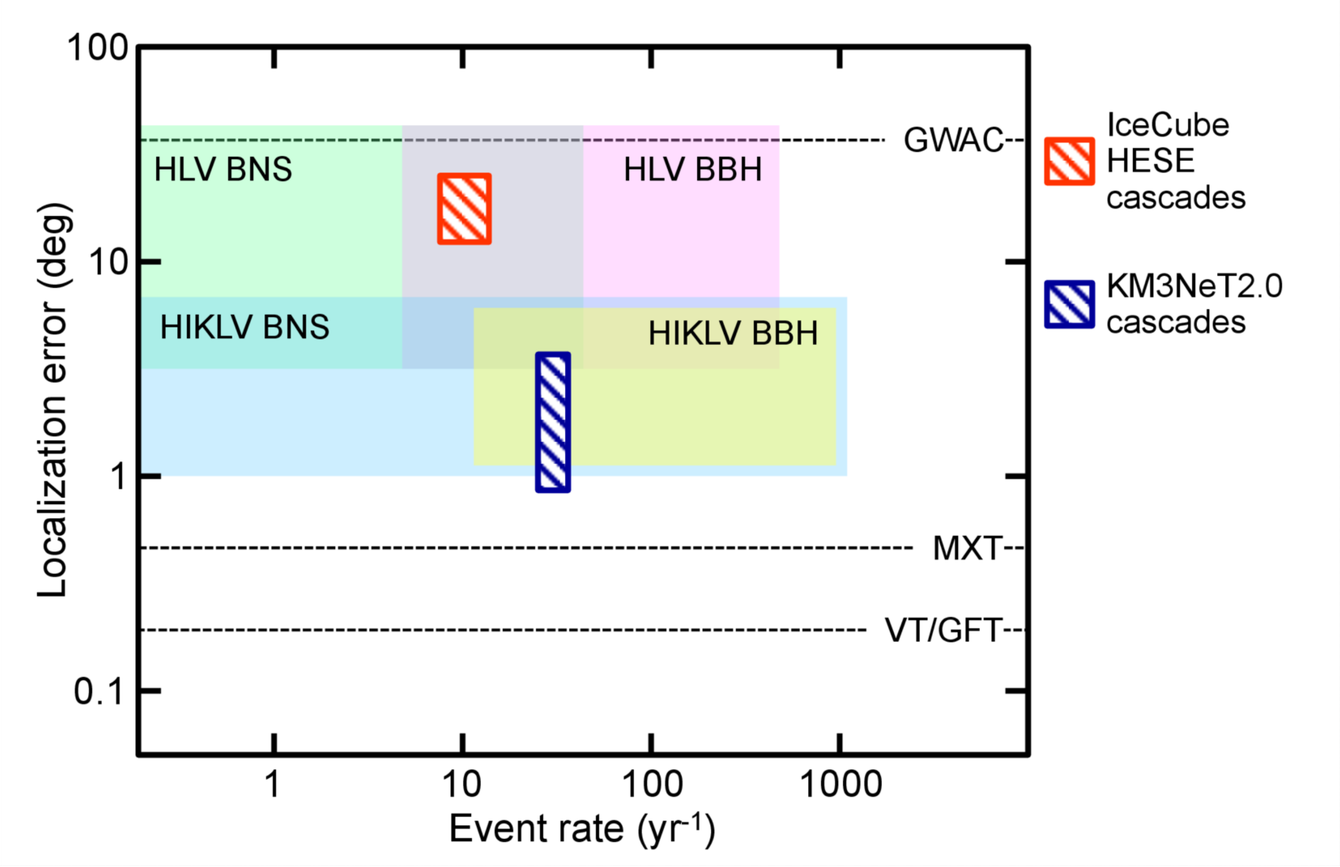
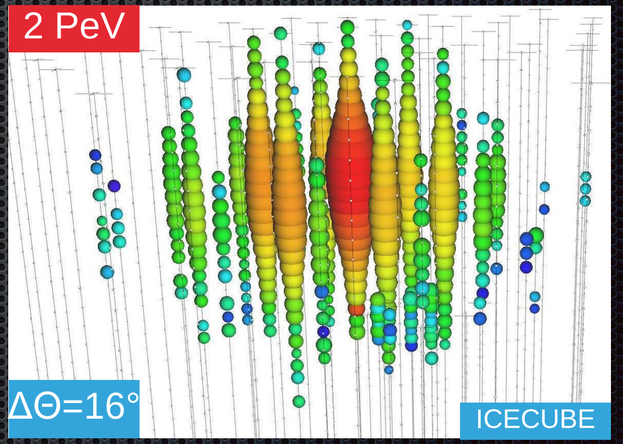
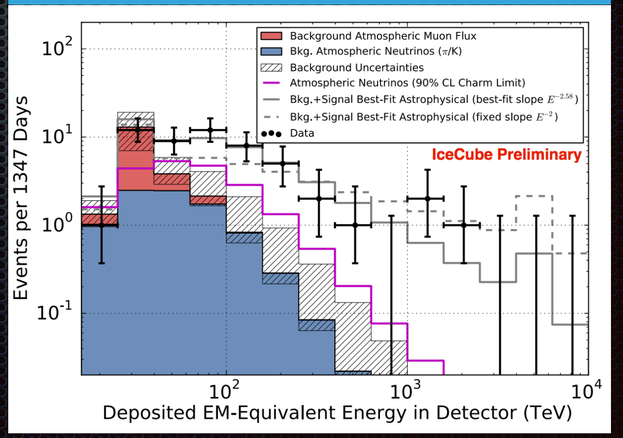




4-YEARS ICECUBE (2010-2013). 53 HESE. E>60TEV



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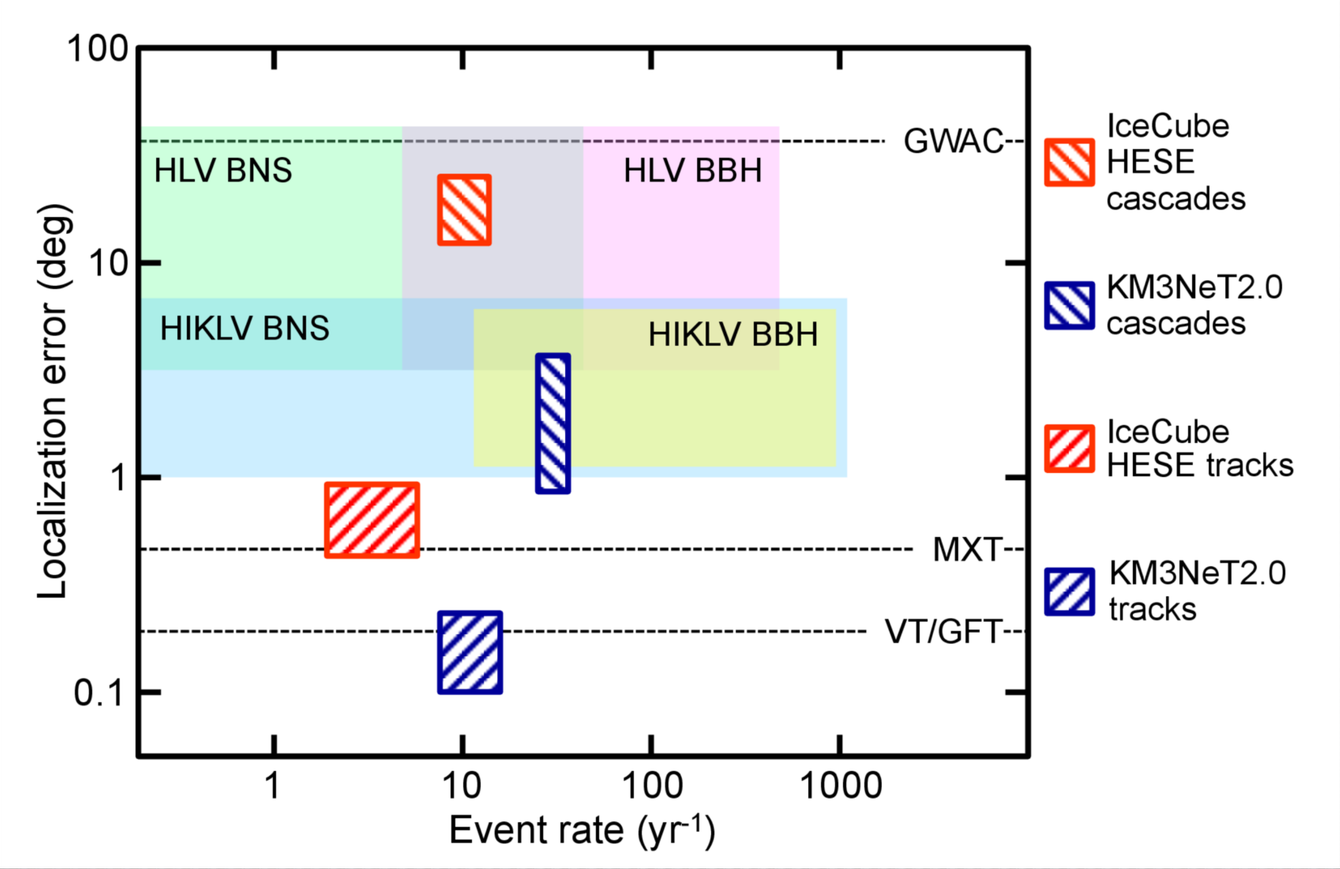

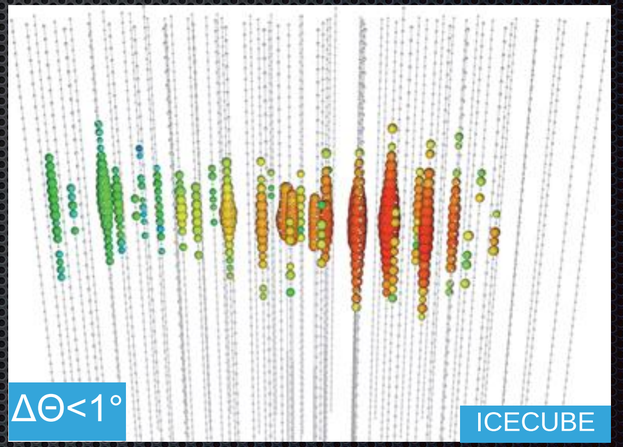

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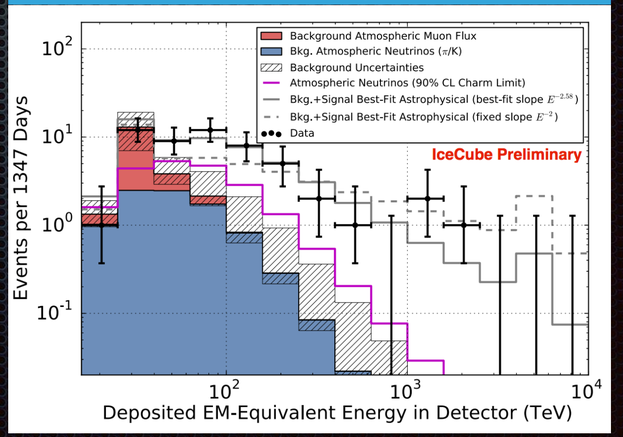

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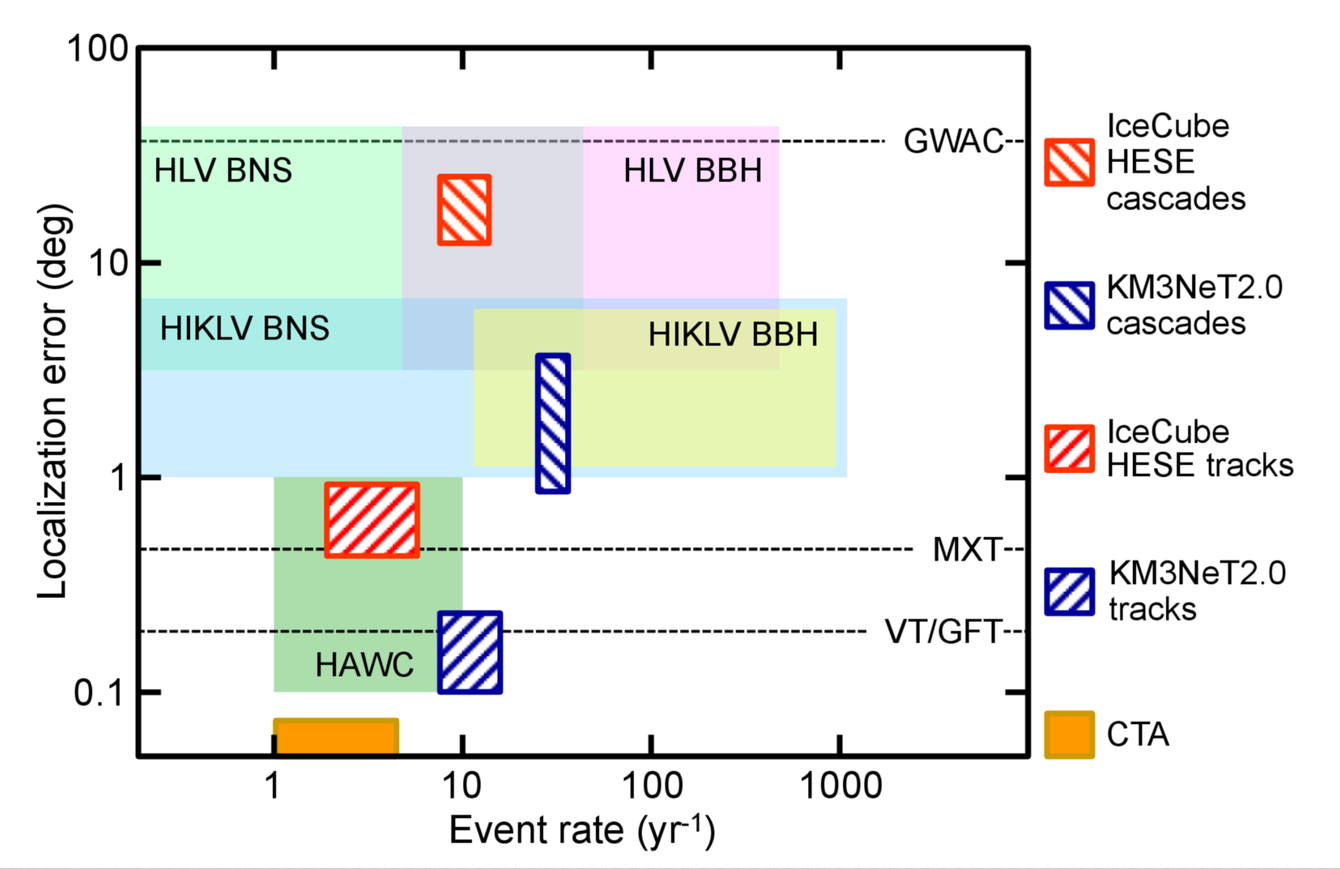
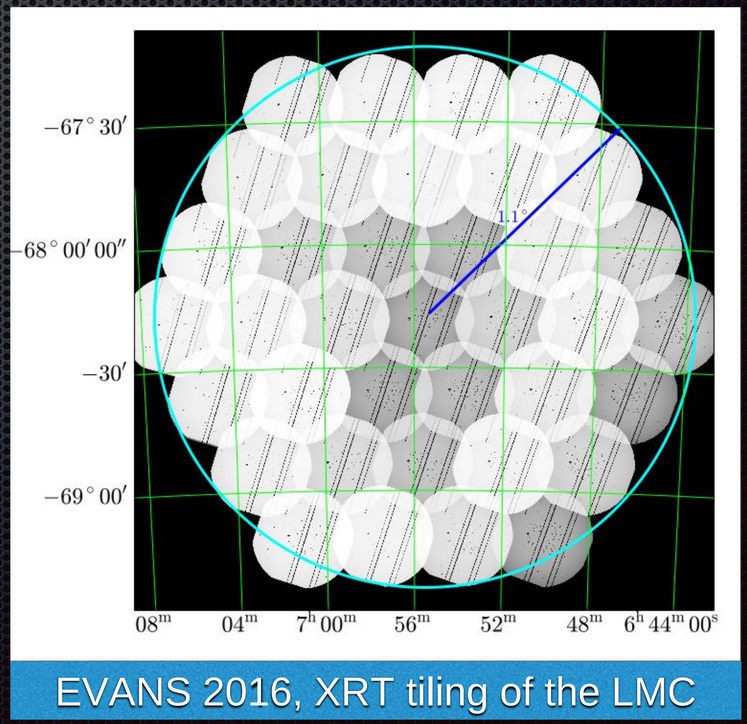


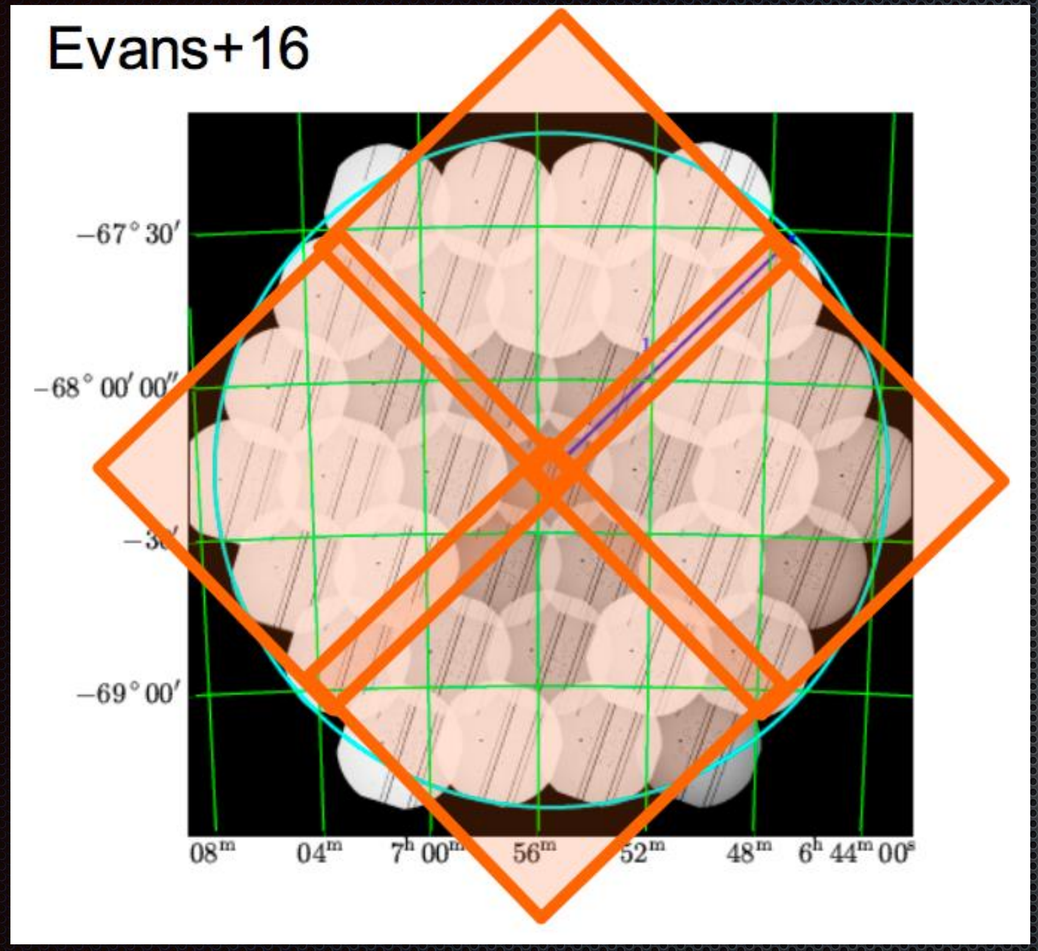
Even if MXT has a larger FOV than XRT, tiling is required.



EVANS 2016, XRT tiling of the LMC

MXT vs. XRT comparison

XRT observation of the LMC (Evans+16) following GW150914 : 4 deg²



The effective area of XRT is roughly 4 times smaller than the one of MXT
(130 cm² vs. 30cm² on-axis @1.5keV)

To cover the LMC (4 deg²)

XRT : 37 tiles of ~50 s each (i.e. 1831 s of observing time without the slew, which typically takes 1min)

MXT : 4 tiles of 500s (2ks of exposure)

MXT recovers a √10 factor in sensitivity

XRT slightly better than MXT (35%), but MXT is very competitive !

ToO-MM

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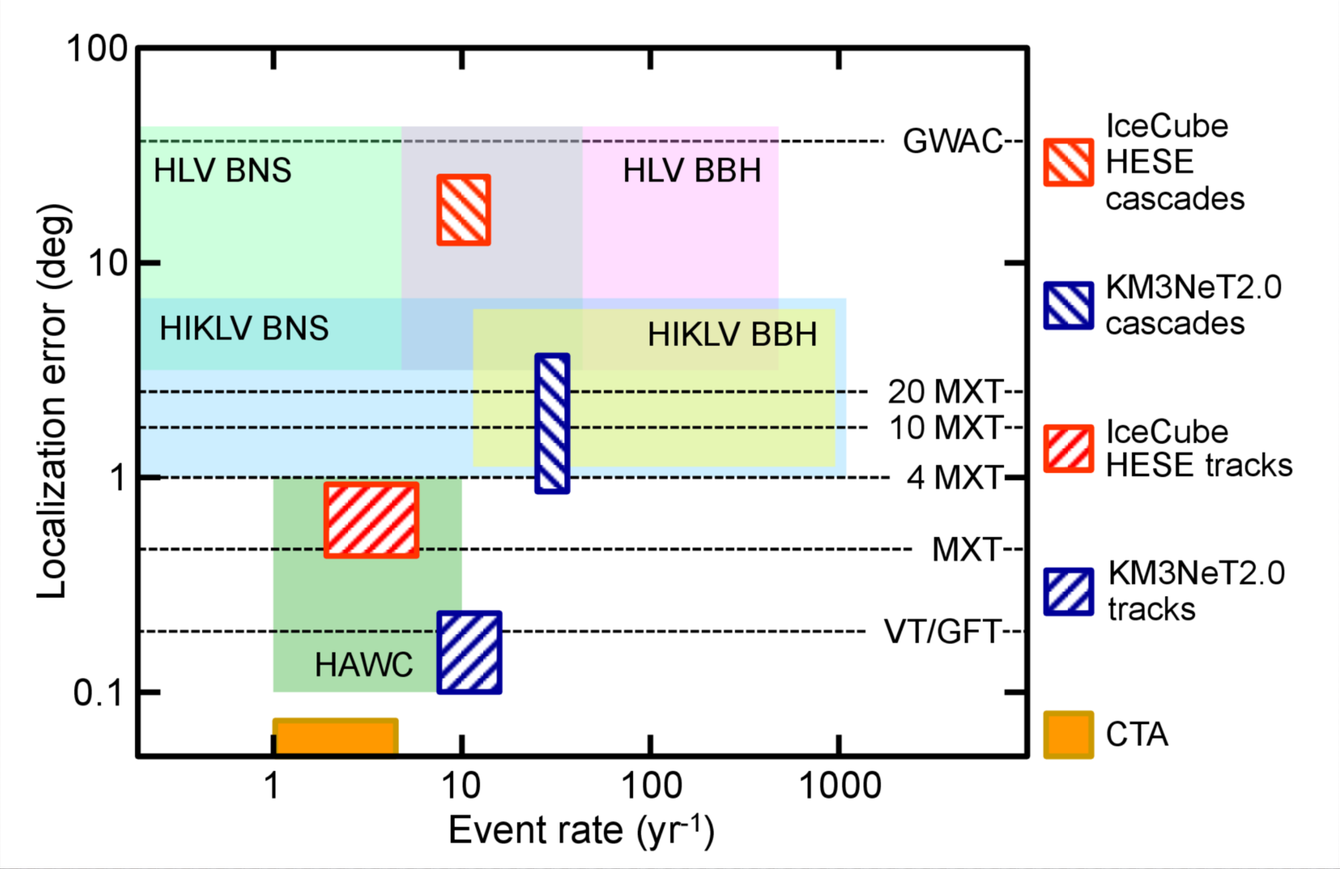


Main characteristics :
Frequency : 1/month
Standard delay : < 12h
Duration : 7-14 orbits
Max : 3 tiles/orbit

MXT photons transmitted through the VHF network for an immediate analysis on the ground

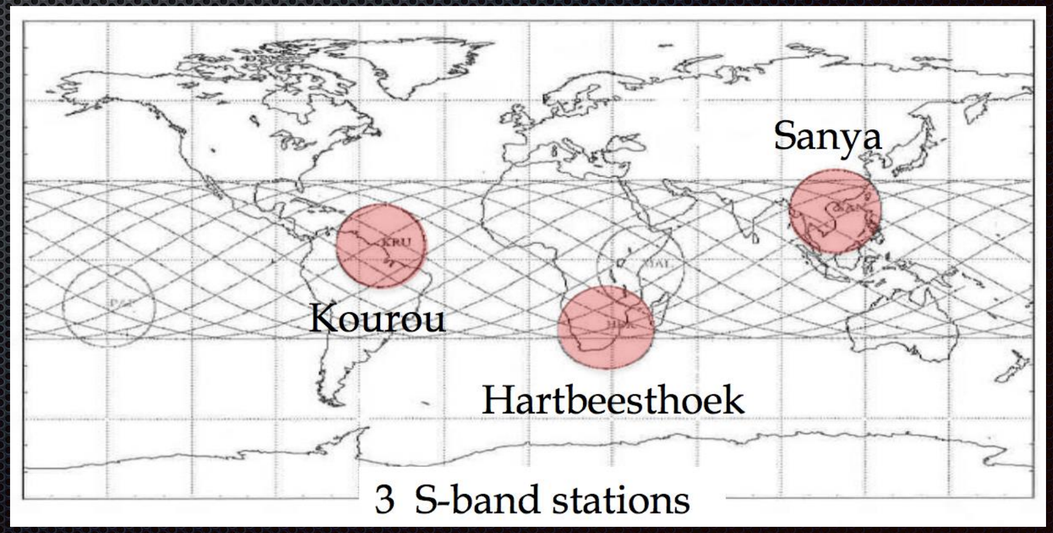
Why delays ?

Here is what happens when a ToO is performed :

1) ToO validation and selection by PIs and ToO scientists.

2) OCG (Operation and Control Group) will check that the ToO can be performed given the constraints related to satellite health.
The OCG meets once per day (5d/7).
For ToO-EX or ToO-MM a special OCG meeting is requested (24h/24).

3) The new Work Plan is sent to the CCC (Chinese Control Center) to build the Telecommands and upload them to the satellite using the S-band antennas available in Sanya (for ToO-EX and ToO-MM, the CNES provides the antennas in Kourou and Hartbeesthoek)

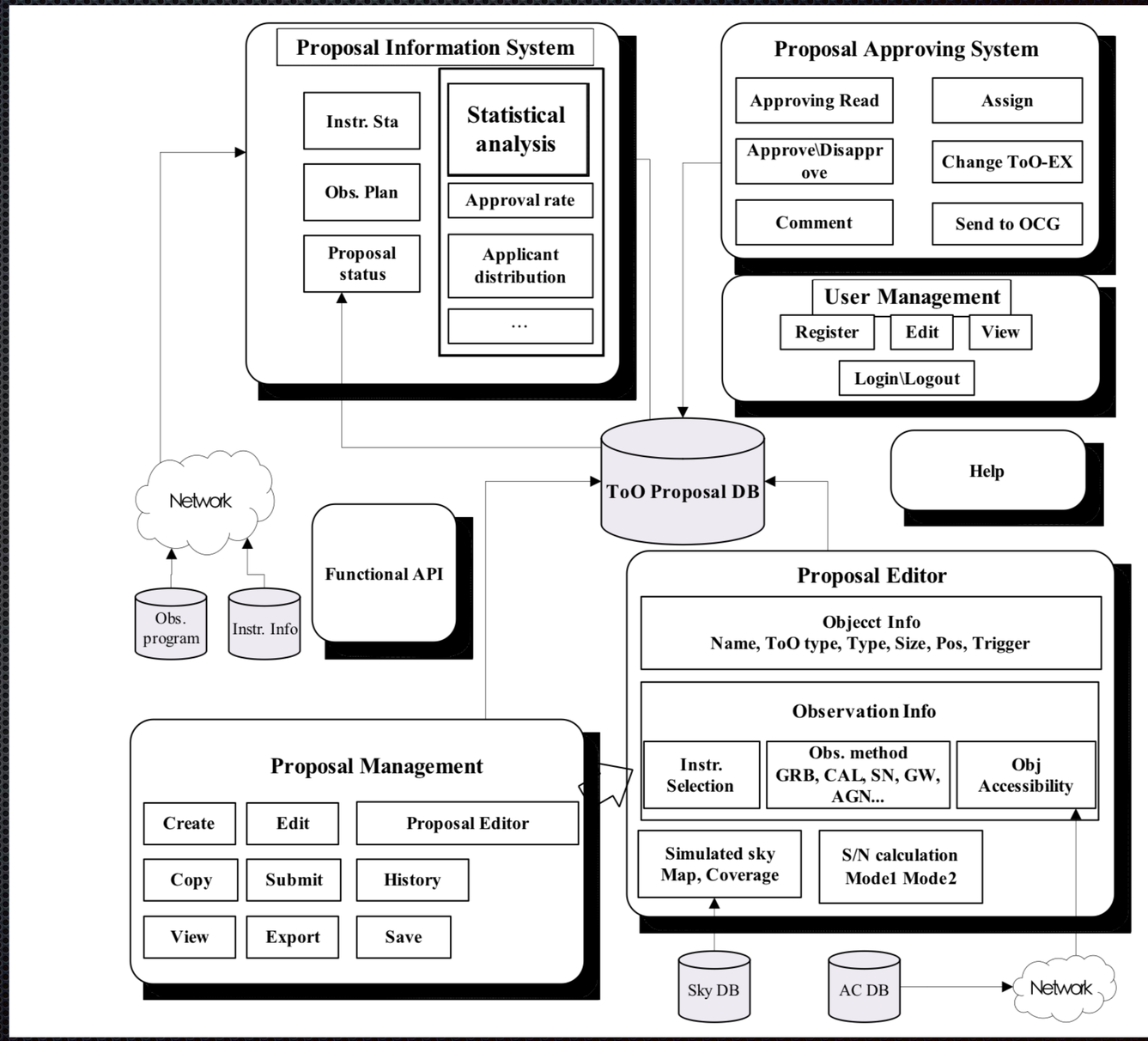


User support for ToO requests

ToO proposal support :

- Proposal preparation
  - Feasibility
  - Observation strategy
  - Instrument health
- Approval
- Progress monitoring
- Data acquiring

External interfaces :
External accessibility server
Satellite and instrument status server
Observation status database
User interface
APIs for ToO-MM



Conclusion

The importance of the ToO program has been pointed to us by Neil Gehrels (thank you !).

In 2015, we introduced the ToO program in the mission requirements and modified the sytem requirements in accordance

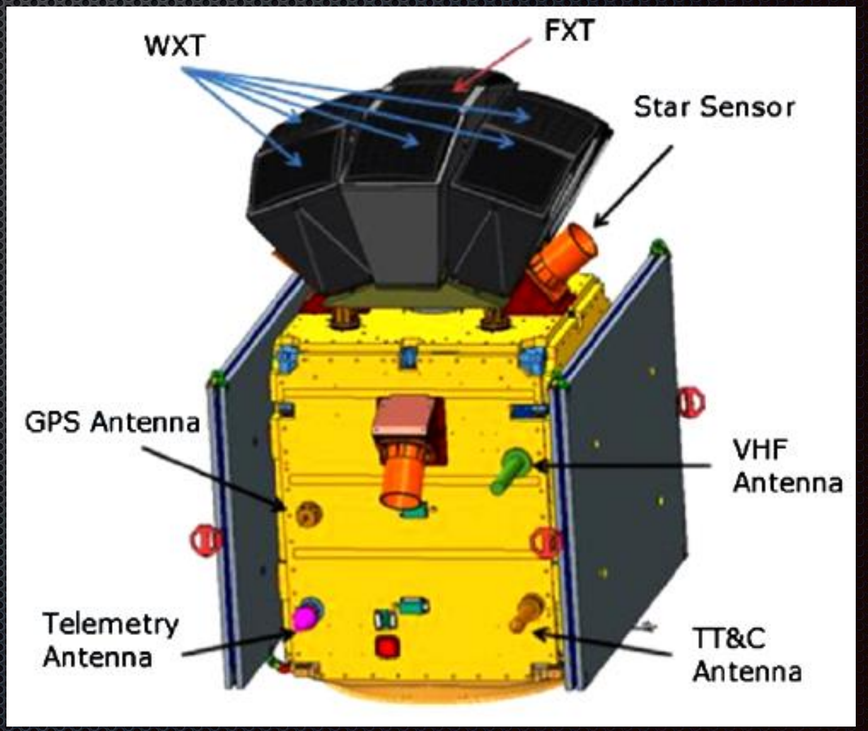
Now, with the time domain and multi-messenger astronomy in strong developments, SVOM is ready to play an important role in the future…

Beyond SVOM: Einstein Probe

An CAS project, lead by Weimin Yuan (NAOC Beijing)
Phase A study completed. Under evaluation for approval. Launch date 2025 (?)

- **WXT :** a set of eight sensitive lobster-eye telescopes observing in 0.3 - 5 keV band, total FOV of 60°x60° with source location accuracy < 1-2'. Scanning the complete night sky (anti-solar pointing) every three orbits.

- **FXT :** a central focussing 1°x1° X-ray telescope (either MPO or Wolter-I mirrors) with an 80 cm^2 effective area to follow-up of the detected transients



- LEO (< 30°, ~600 km)
- Rapid slewing (SVOM) bus
- Prompt downlink (SVOM VHF)

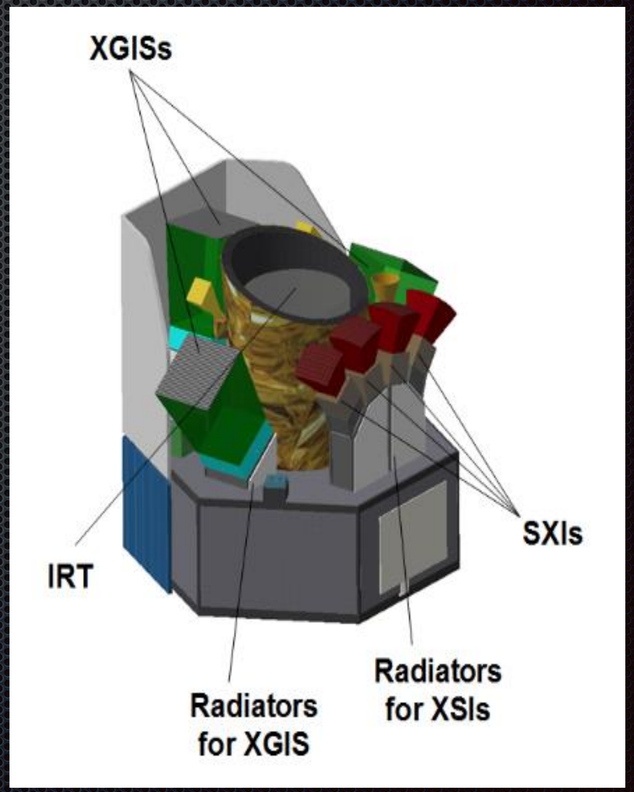
Beyond SVOM: *THESEUS*

An M5 project, lead by L. Amati (INAF Bologna)
Passed the ESA technical / programmatic review (13 projects, 3 astro)
Final selection (science) by the end of the year; launch date 2029-2030

- **Soft X-ray Imager (SXI):** a set of four sensitive lobster-eye telescopes observing in 0.3 - 5 keV band, total FOV of ~1 sr with source location accuracy < 1-2'; **UK lead**

- **X-Gamma rays Imaging Spectrometer (XGIS):** 3 coded-mask X-gamma ray cameras using bars of Silicon diodes coupled with CsI crystal scintillators observing in 2 keV – 10 MeV band, a FOV of ~1sr, overlapping the SXI, with ~5' source location accuracy;. **Italy lead**

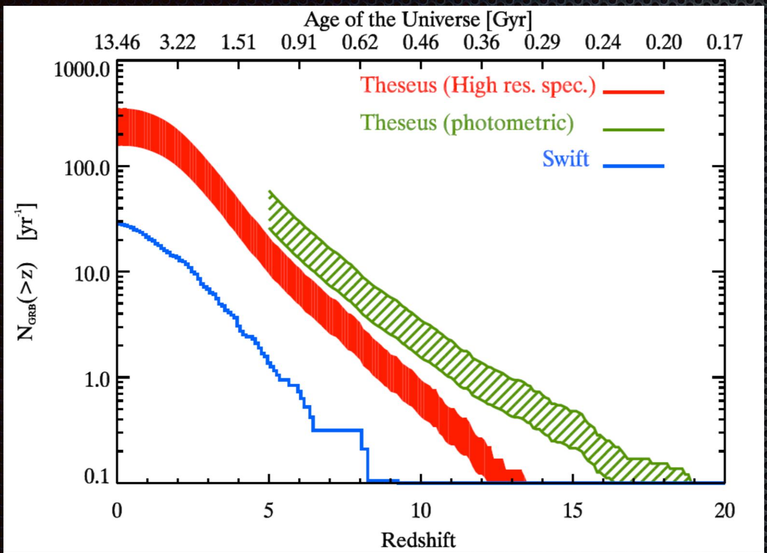
- **InfraRed Telescope (IRT):** a 0.7m class IR telescope observing in the 0.7 – 1.8 μm band, providing a 10'x10' FOV, with both imaging and moderate resolution spectroscopy capabilities; **France lead (CEA, LAM, IRAP, GEPI, …?)**



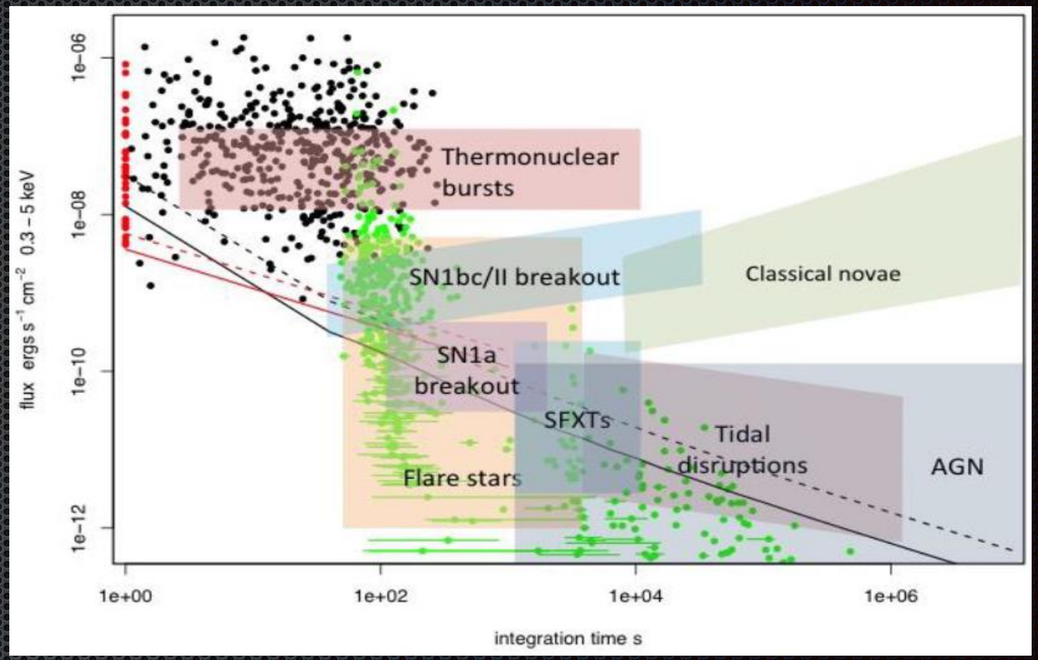
- LEO (< 5°, ~600 km)
- Rapid slewing bus
- Prompt downlink

THESEUS: the final transient machine

THESEUS GRB#/yr	All	z > 5	z > 8	z > 10
Detections	387 - 870	25 – 60	4 – 10	2 - 4
Photometric z		25 – 60	4 – 10	2 - 4
Spectroscopic z	156 - 350	10 - 20	1 - 3	0.5 - 1



Transient type	SXI Rate
GW sources	0.03-33 yr^{-1}
Magnetars	40 day^{-1}
SN shock breakout	4 yr^{-1}
TDE	50 yr^{-1}
AGN+Blazars	350 day^{-1}
Thermonuclear bursts	35 day^{-1}
Novae	250 yr^{-1}
Dwarf novae	30 day^{-1}
SFXTs	1000 yr^{-1}
Stellar flares	400 yr^{-1}
Stellar super flares	200 yr^{-1}



http://www.isdc.unige.ch/theseus/

SVOM: Multi-wavelength mission devoted to the transient sky

- Main characteristics: **coherence** between space and ground instruments for a **rapid follow-up** of gamma-ray transients
- In operation from 2022 to 2027+
- Implication of french laboratories: CEA-Irfu, IRAP, LAM, OAS, GEPI, IAP, APC, LUPM, CPPM, LAL

	Instrument 1	Band sensitivity (Gamma/X-ray …)	Description of the instruments
Space	ECLAIRs	Hard X-ray	Coded mask telescope (1024 cm2 CdTe) , FOV 2 Sr
	GRM	Gamma-ray	Nal Scintillating crystal + PM detectors, FOV >2 Sr
	VT	Visible	40cm telescope, FOV 26 arcmin2, lim mag 22,5 /300s exp
	MXT	X-ray	Lobster Eye optic, FOV 1 deg2
Ground	GWACs	Visible	36 camera units, covering 5200 deg2, lim mag:16 /10s exp
	GFTs + LCOGT	Visible + IR (F-GFT)	F-GFT diameter 1.3 m, 400-1700 nm

Mission for time-domain astronomy

- Target transients sources (ex GRBs): GRBs, SGRs, X-ray binaries, AGNs, TDEs, supernovae,TGF
- Expected scientific return :
  - prompt emission in gamma-rays, hard X-rays and visible of transient events
  - afterglow emission in X-rays, visible, IR
- Expected advances in X-ray flashes, ultra-long GRBs…

SVOM: Alerts

- All transients detected on board will be notified within minutes
- GRB rate: 55 GRBs/year with good localization
  +35 GRBs/year with poor localization
- Almost real time for arcmin GRB localization
- Arcsec GRB localization within tens of minutes in some cases

Alert types	New transient (short and long GRB, XRF) Known transient sources flaring { Quicklook Analysis (<48h delay) }	High energy transient sources
Trigger Characteristics	Onboard, delay ~30 s	Onboard, delay ~30 s
Min Rate (/year)	46 GRBs	90 GRBs
Max (/year)	82 GRBs	90 GRBs
Confidence Level	High	Crude position
Actions	Autonomous slew of the satellite Alert sent to the ground immediately	Alert sent to the ground immediately

SVOM:ToO

- 1 ToO-NOM / day (extended: 5 ToO-NOM / day)
- 1 ToO-EX/month
- 1 ToO-MM/

External ToO	ToO-NOM; ToO-EX; ToO-MM
Frequency + Delay	ToO-NOM : 1/day - < 48h ToO-EX : 1/month - < 12h ToO-MM : 1/month - < 12h
Duration	ToO-NOM : Typ. 1 orbit (45 min us.time) ToO-EX : < 14 orbits (1 day/630 min us. time) ToO-MM : < 14 orbits (1 day/630 min us. time)
Specific features	ToO-MM : Tiles : up to 3 tiles/orbit (max : 42 sq.deg./ToO-MM) MXT photons sent through VHF for immediate analysis

SVOM : Alerts and open data

	ECLAIRS	MXT	GRM	VT
Alert distribution policy	Public	Public	Public	Public
Alert Distribution System	SVOM VHF + FSC	SVOM VHF + FSC	SVOM VHF + FSC	SVOM VHF + FSC
Standard Delay	30 s - 1 min	~ 10 mins	30s - 1min	~10 min
Localisation Error Box	< 14'	< 30"	> 5°	< 2 arcsec
Type of Alert	VO + GCN	VO + GCN	VO + GCN	VO + GCN
Informations of the Alert	Position, Lightcurve, Spectrum	Position, Lightcurve, Spectrum	Lightcurve, Spectrum, Position ?	Finding charts + subimages

GWACs and GFTs : In case of ToO only followed by these ground instruments, the acdata policy has not yet been decided

SVOM: TRANSIENT SKY IN 2020

What do you expect for the follow-up of your events in 2020? (challenges/opportunities)

The prompt and early follow-up should be performed by our own instruments. The spectroscopy and the deep photometry will be organized by a dedicated group

Suggestions/advices for the other communities to optimise the follow-up of your triggers/ external triggers

For the space segment with only 1 ToO-NOM per day, we will need to perform a strong selection, on which scientific criteria, with which tools? Example: how to manage the LSST level of alerts?