GRBs and Transient Astronomy with SVOM and LSST

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on behalf of the SVOM consortium

LSST and SVOM

LSST : Time Domain Astronomy
Starts operations in 2021

SVOM : hard X-ray transients
Launched in 2021

After 2020, French astronomers will be involved in two major projects for the study of the variable sky at different wavelengths.

We must start thinking how to best use the synergy between these two projects

Outline

- Presentation of SVOM

- GRBs afterglows with LSST
  - On-axis afterglows
  - Orphan afterglows

- Perspectives

Warning: *this talk presents some very preliminary ideas, which will deserve additional work with the new start of SVOM*

The SVOM mission

- SVOM is a GRB mission designed for GRB ***detection, alert*** & ***follow-up***
  - Hard X-ray survey:
    - Sky activity and arcminute source positions over ~10% of the sky (ECLAIRs)
    - Sky activity and degree source positions over ~30% of the sky (GRM)
  - X-ray and visible follow-up from space (MXT & VT -- R_{lim}≈24)
  - Visible and NIR follow-up from the ground (GWAC & GFTs -- R_{lim}≈22, J_{lim}≈20)
  - Fast alert transmission
  - <1 day ToO capability

Astrophysics with GRBs

- GRBs permit various studies:
  - The physics of stellar explosions
  - The physics of relativistic jets
  - The death of massive stars and the birth of stellar mass black holes

  - The composition and physical state of distant galaxies
  - The evolution of the IGM and the epoch of reionization
  - The cosmological parameters (standard candles)

  - GRBs are potential sources of GWs, neutrinos and CRs...

  - They can test some predictions of fundamental physics (Lorentz invariance…)

- ***Addressing these questions require complex observing strategies due to the diversity of GRBs and the dynamic range of timescales and luminosities***

The detection of GRBs

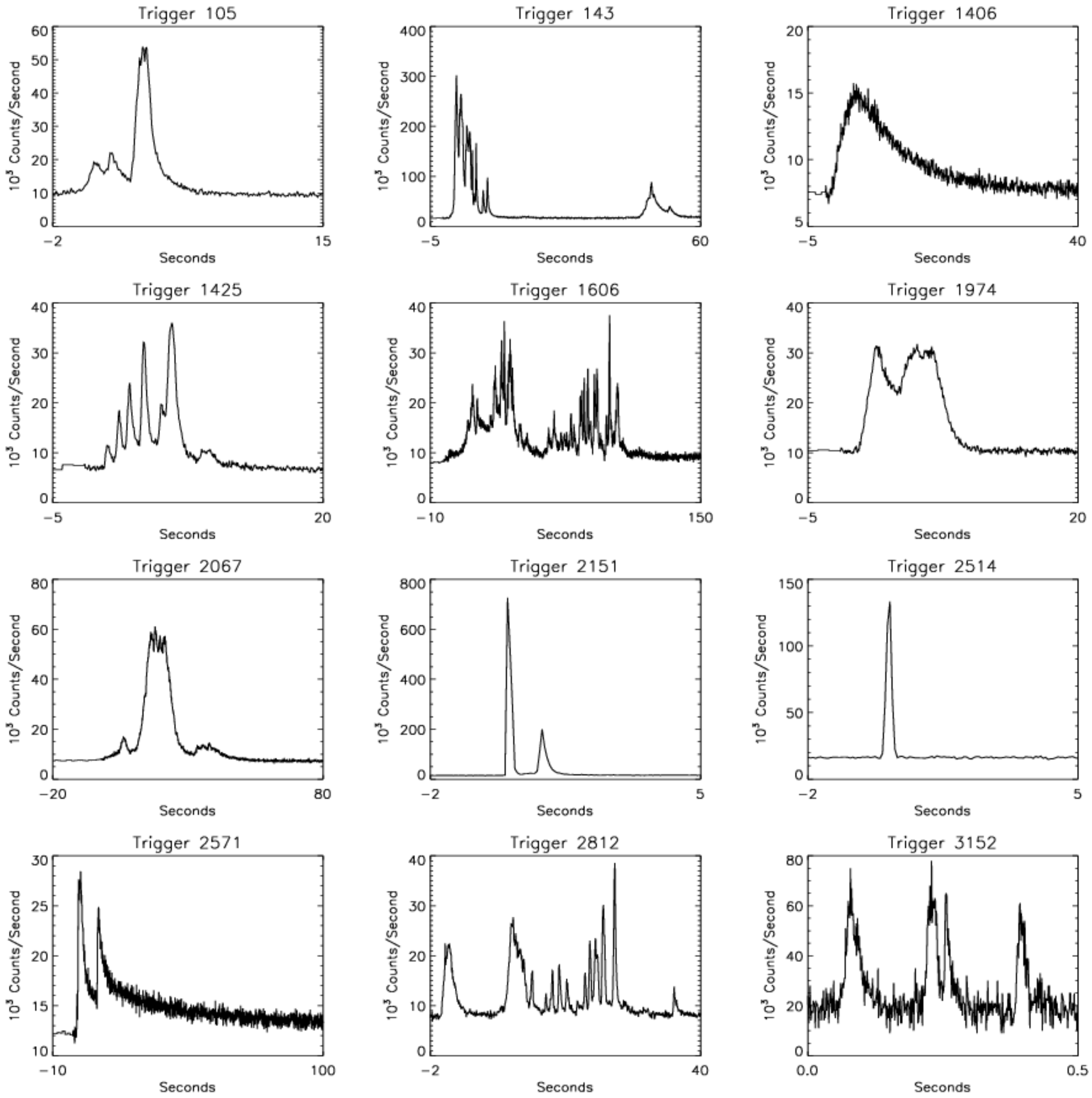
- All GRBs known to date have been detected from space in X-rays or γ -rays (GRB energetics).

- All distances have been measured on the ground.

==> GRBs require an excellent synergy between space and ground.

- The direct detection of GRB afterglows in visible from the ground is still awaited
  – We tried with Megacam at the CFHT without success (Malacrino et al. 2007)
  – *The LSST may detect a few dozen untriggered GRB afterglows per year*

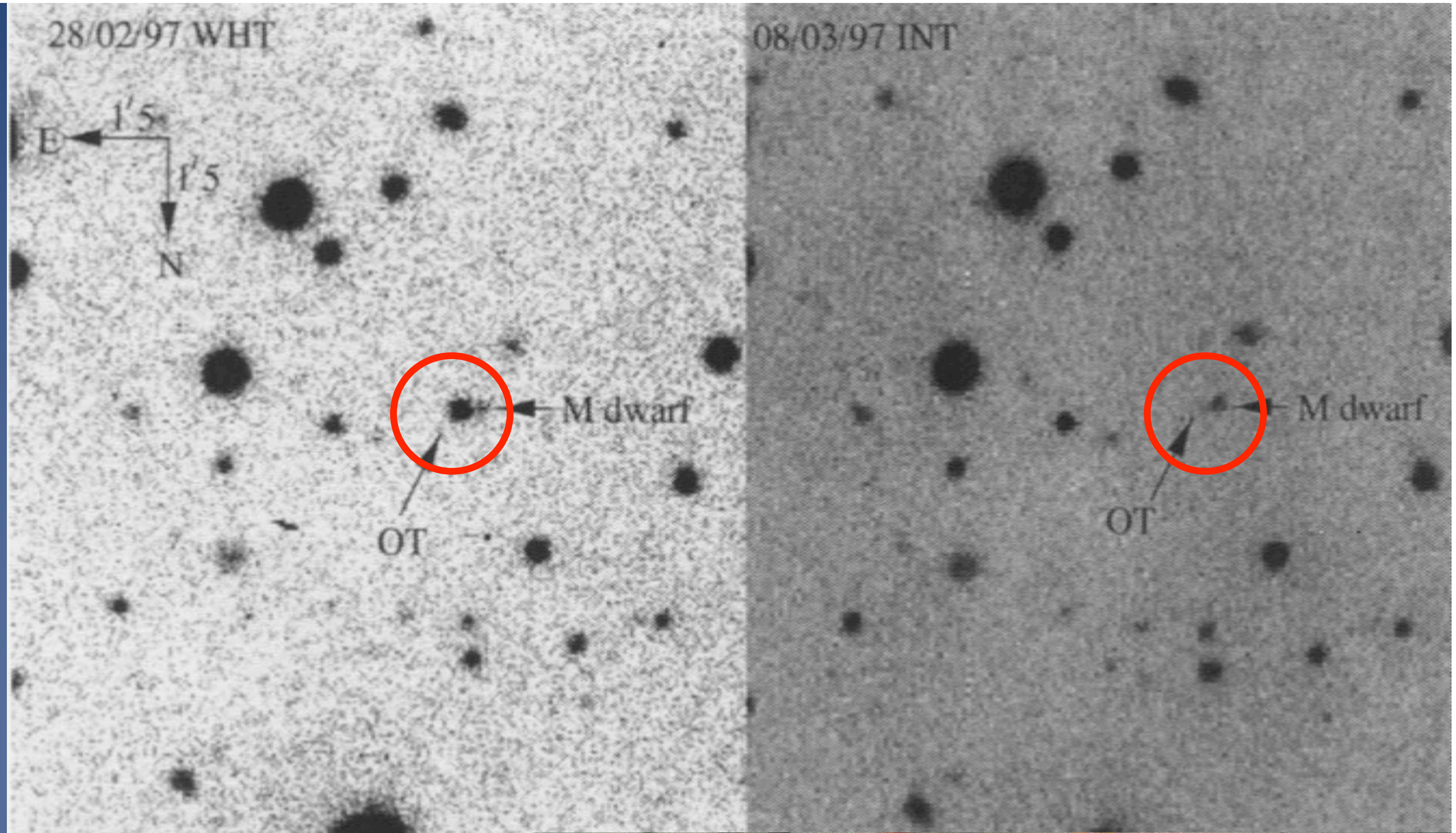
GRB hard X-ray light-curves



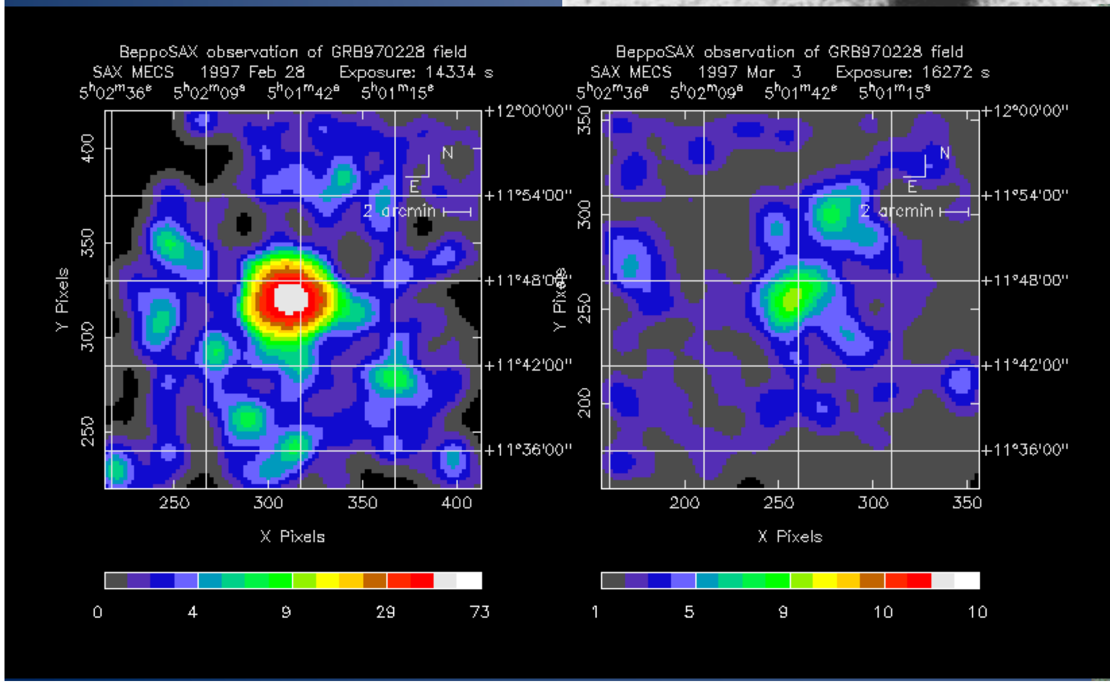
GRB 970228:

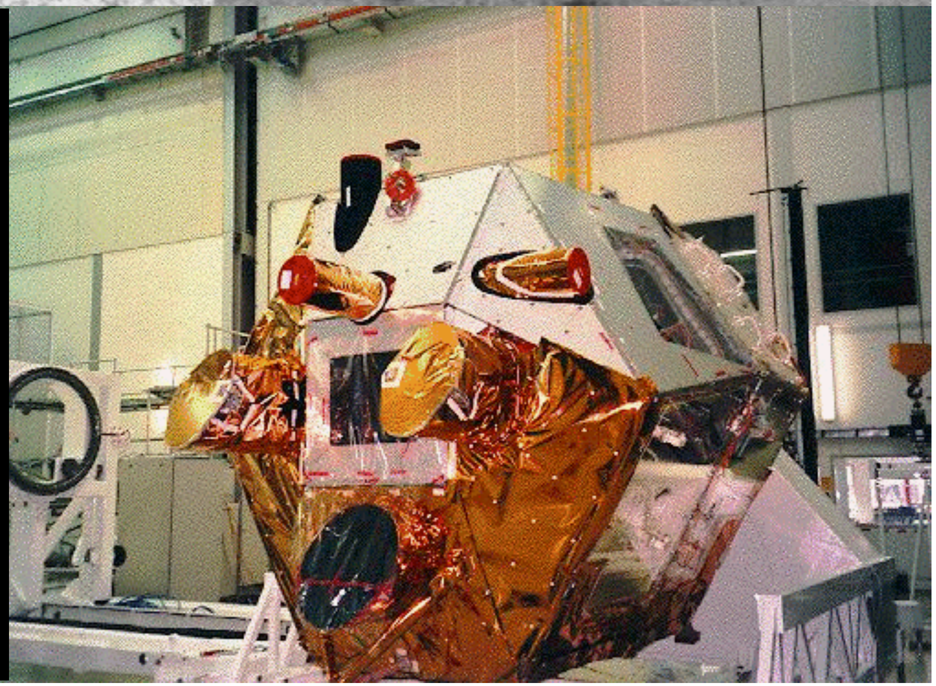
the discovery of GRB afterglows

Visible →



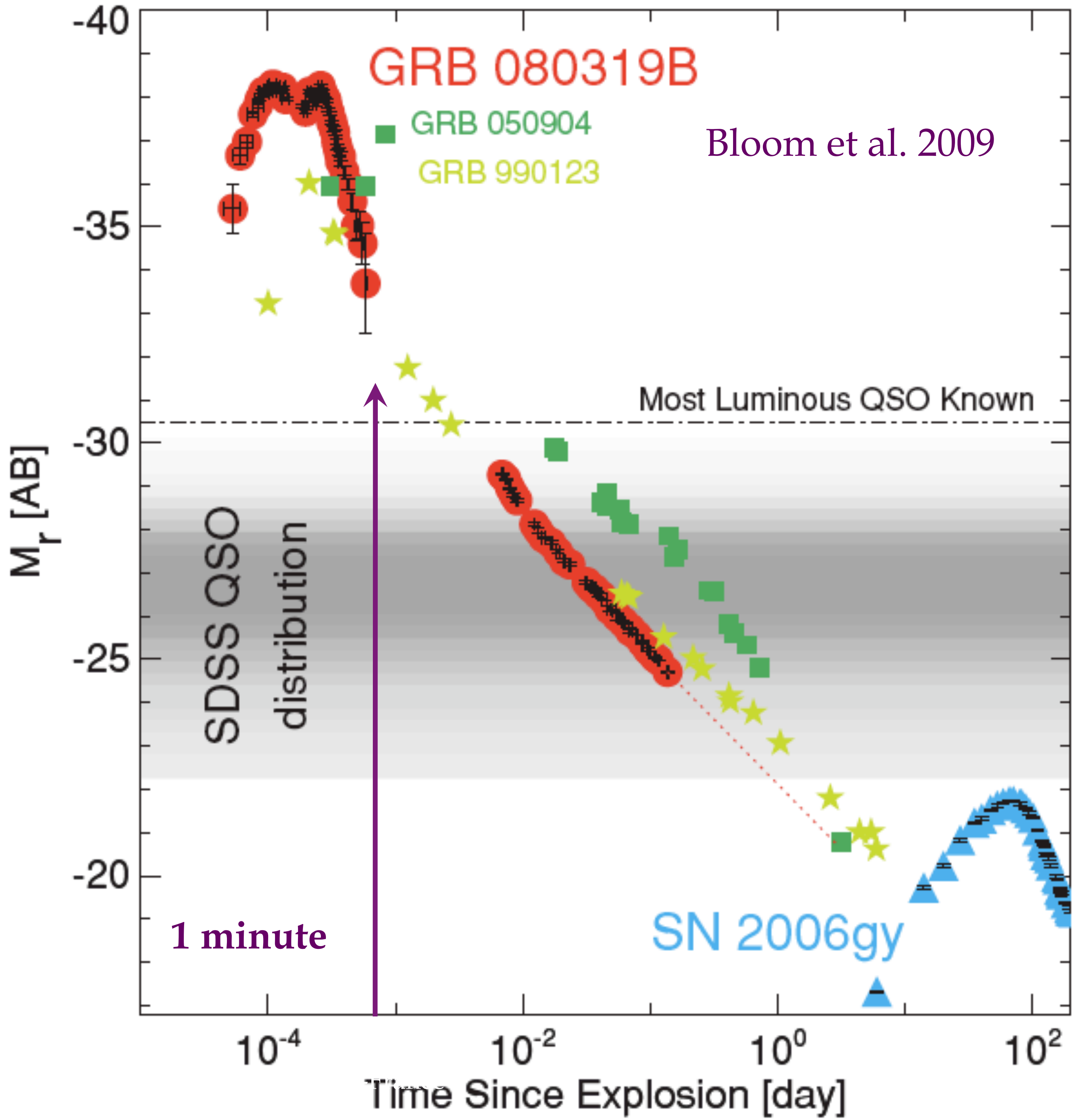
X-rays

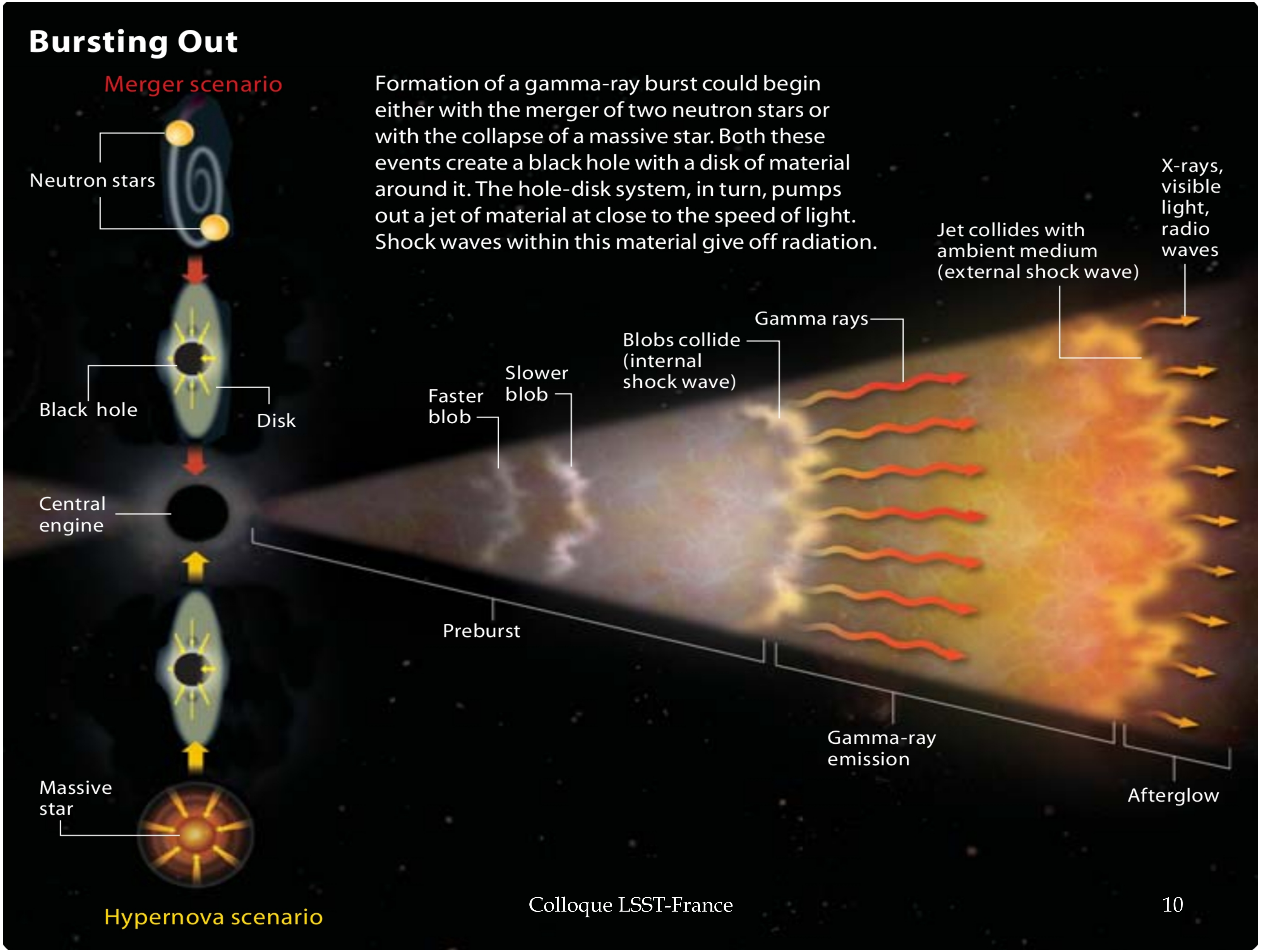




GRB 080319:

Optical light-curve of a very bright GRB



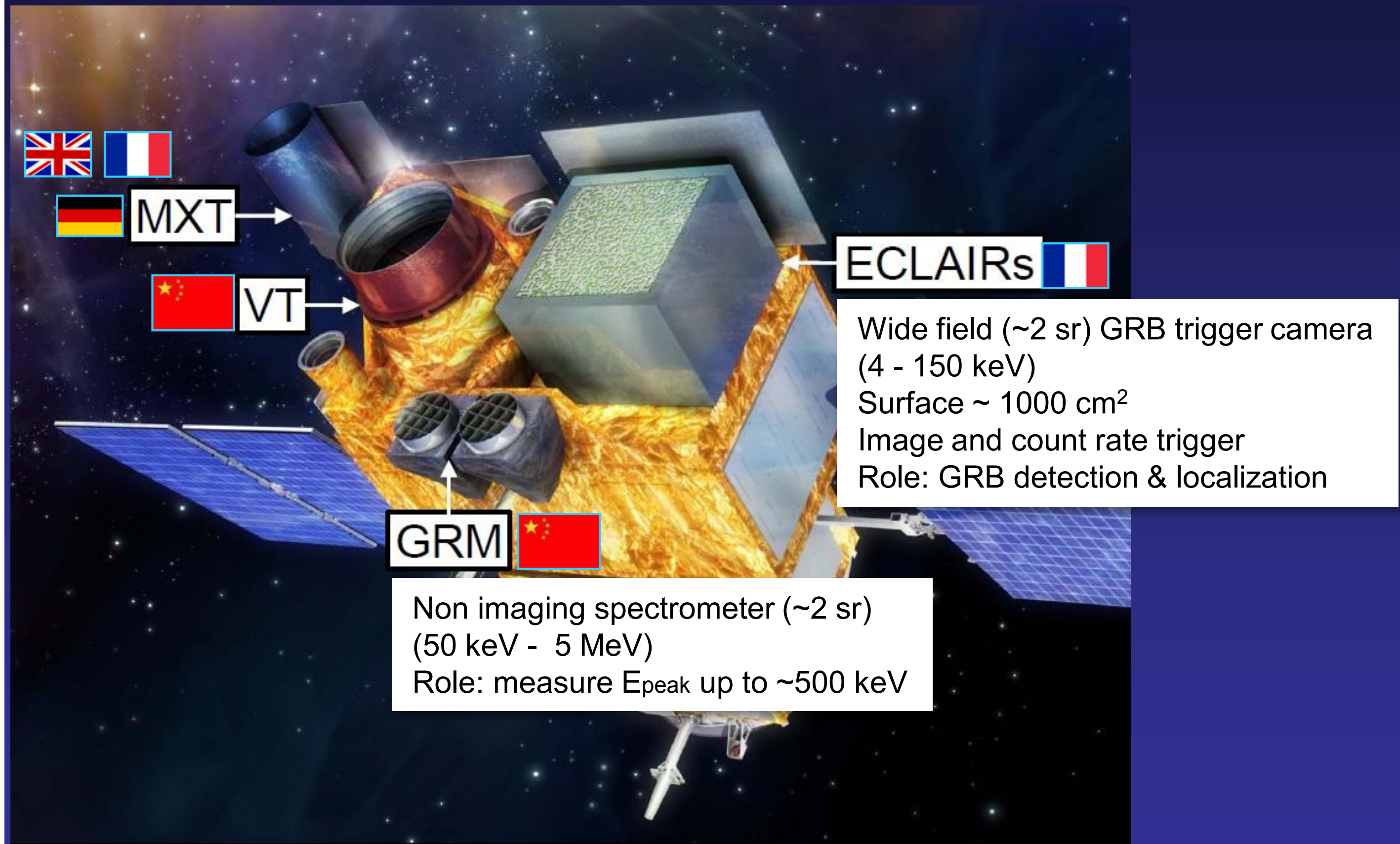


Bursting Out
Merger scenario
Formation of a gamma-ray burst could begin either with the merger of two neutron stars or with the collapse of a massive star. Both these events create a black hole with a disk of material around it. The hole-disk system, in turn, pumps out a jet of material at close to the speed of light. Shock waves within this material give off radiation.
Neutron stars
Black hole
Disk
Central engine
Massive star
Hypernova scenario
Faster blob
Slower blob
Blobs collide (internal shock wave)
Gamma rays
Jet collides with ambient medium (external shock wave)
X-rays, visible light, radio waves
Preburst
Gamma-ray emission
Afterglow

SVOM science payload

a combination of a multi-wavelength space payload

Space payload

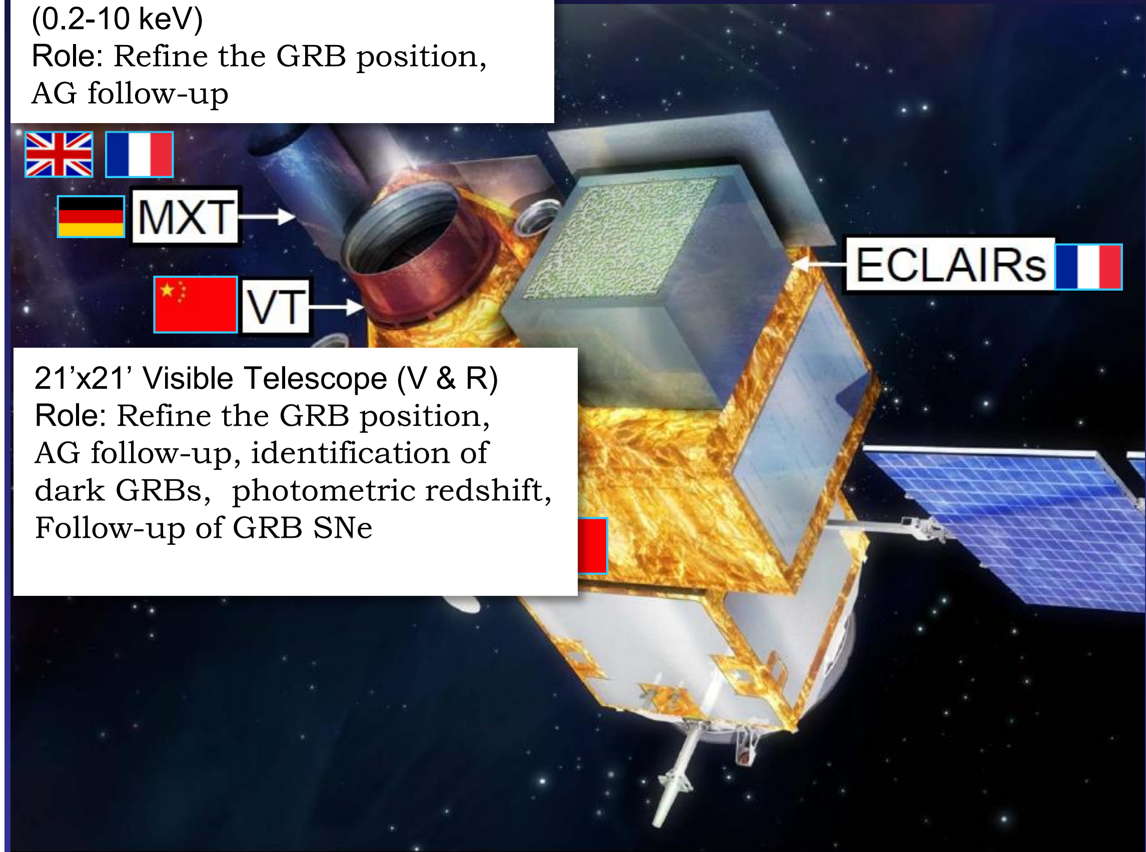


SVOM science payload

a combination of a multi-wavelength space payload

payload

64'x64' 1 m length X-ray Telescope (0.2-10 keV)
Role: Refine the GRB position, AG follow-up

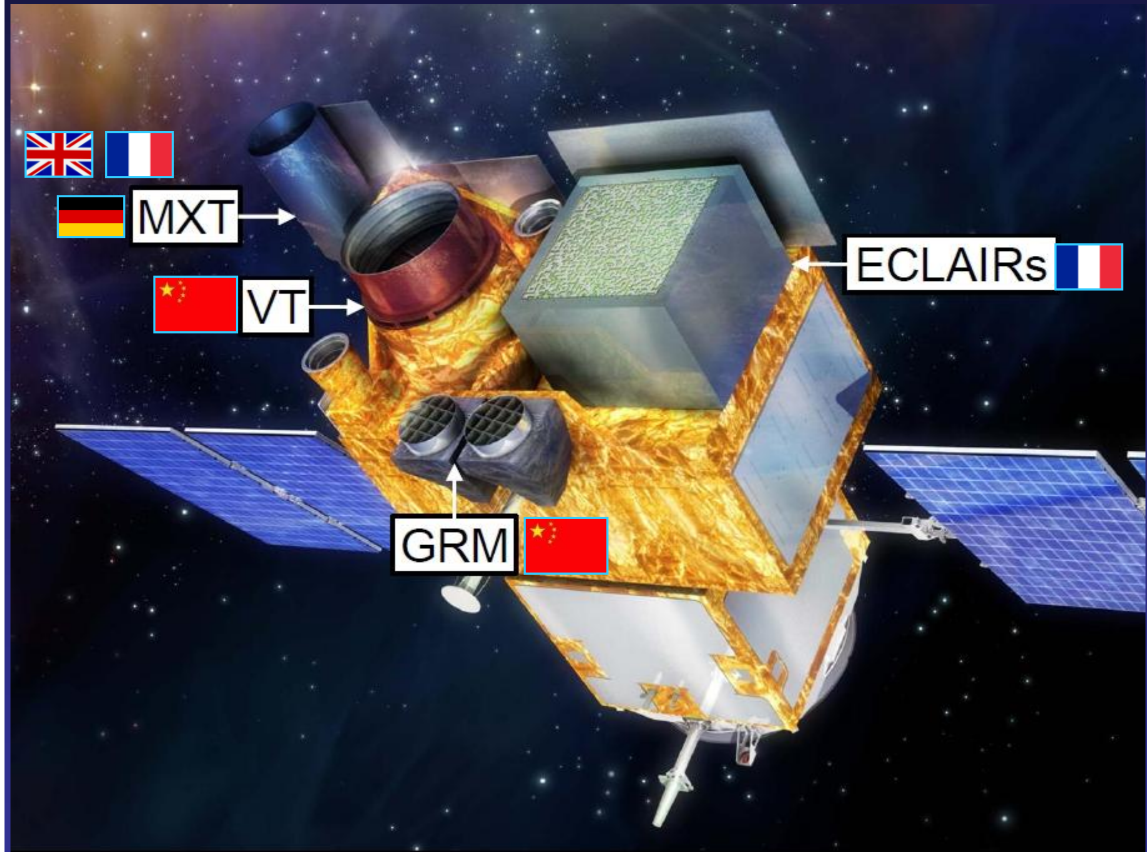


21'x21' Visible Telescope (V & R)
Role: Refine the GRB position, AG follow-up, identification of dark GRBs, photometric redshift, Follow-up of GRB SNe

SVOM science payload

a combination of a multi-wavelength space payload
with a dedicated ground NIR/optical instruments

Space payload



Ground segment

GWAC

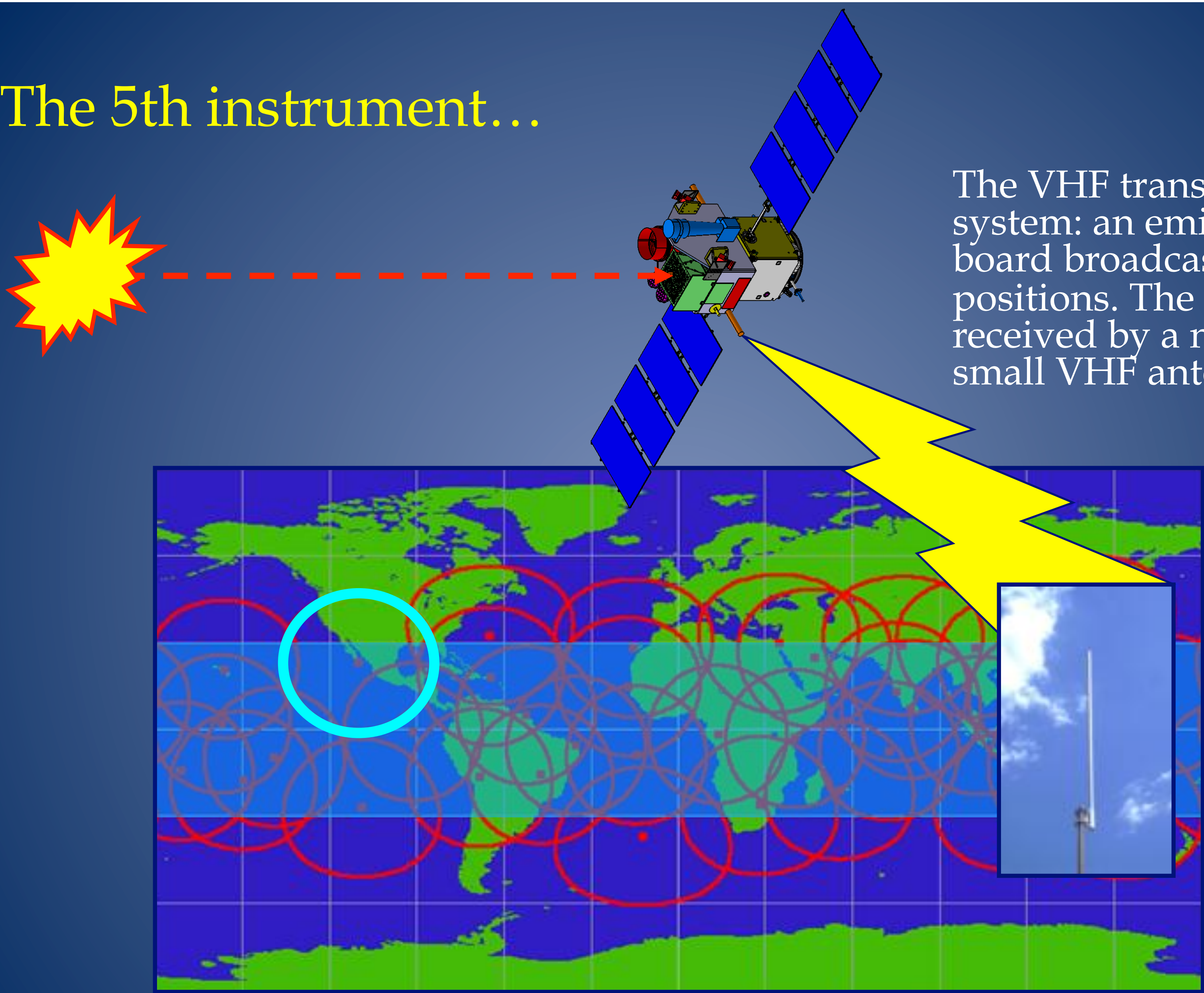
Ground Wide (~2 sr) Angle Camera (V band)
Role: study of the prompt optical emission

GFT-1

GFT-2

Ground follow-up telescope
(BVRI – J & H)
Role: Identification & localisation of AG using ECLAIRs positions, localisation of dark GRBs, follow-up of the early AG in NIR/optical, Spectral distribution of the early AG, measure the prompt optical emission of long GRBs

The 5th instrument…

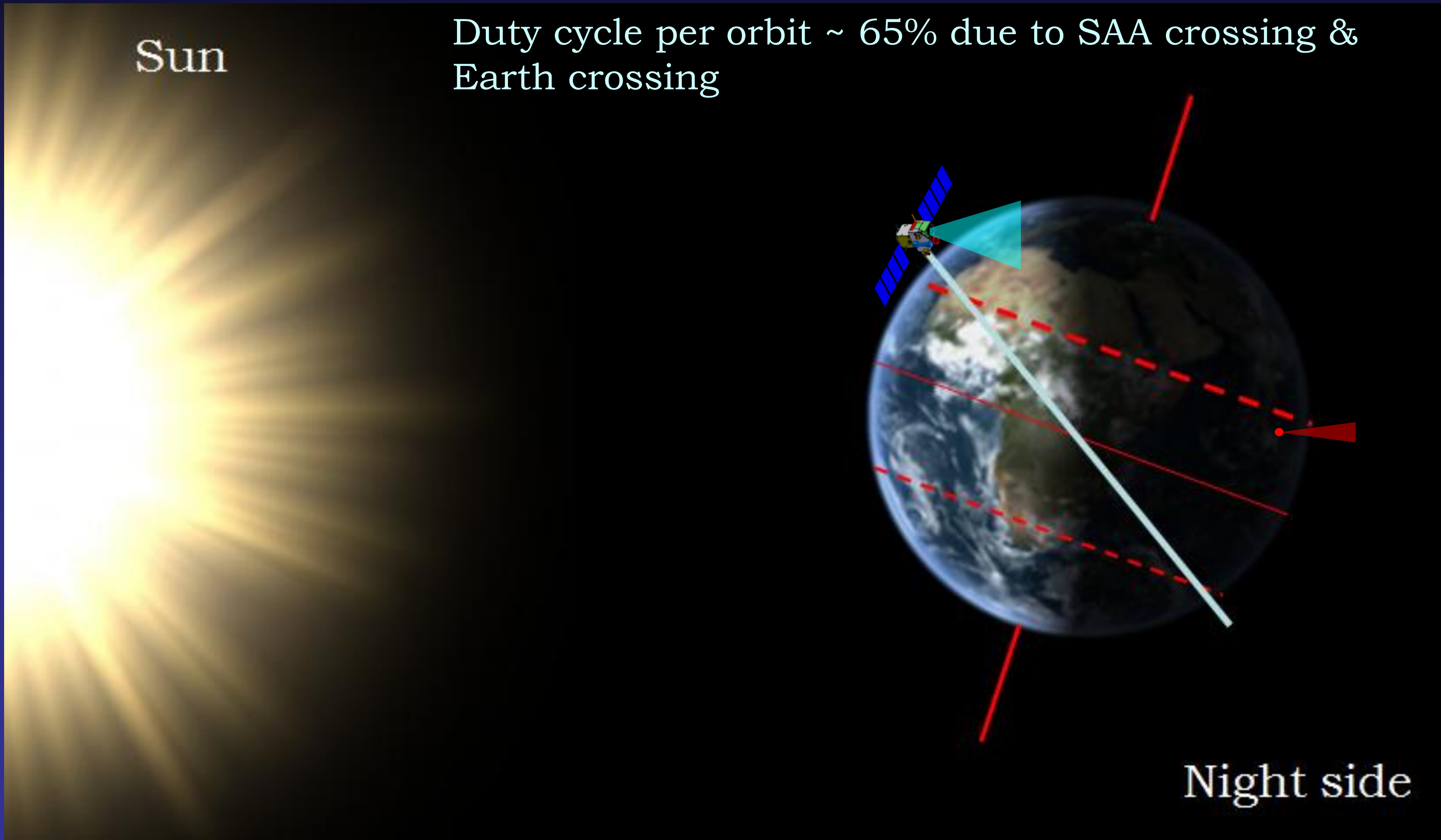


The VHF transmission system: an emitter on-board broadcasts GRB positions. The signal is received by a network of small VHF antennas

SVOM orbit

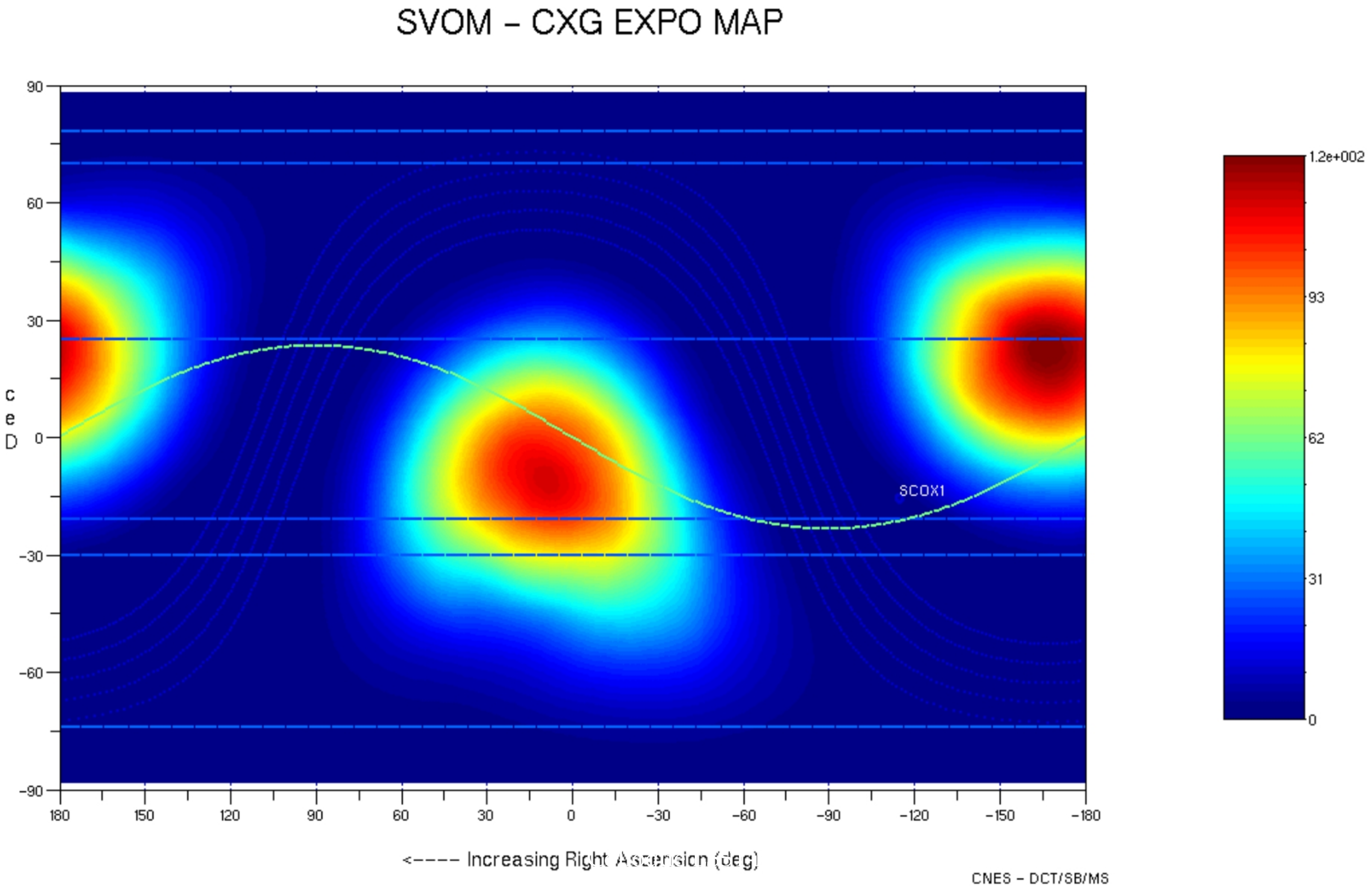
Orbit: LEO (625-650 km) with an inclination of ~30° & Anti-Sun pointing

Avoidance of the Galactic Centre as well as the brightest X-ray sources

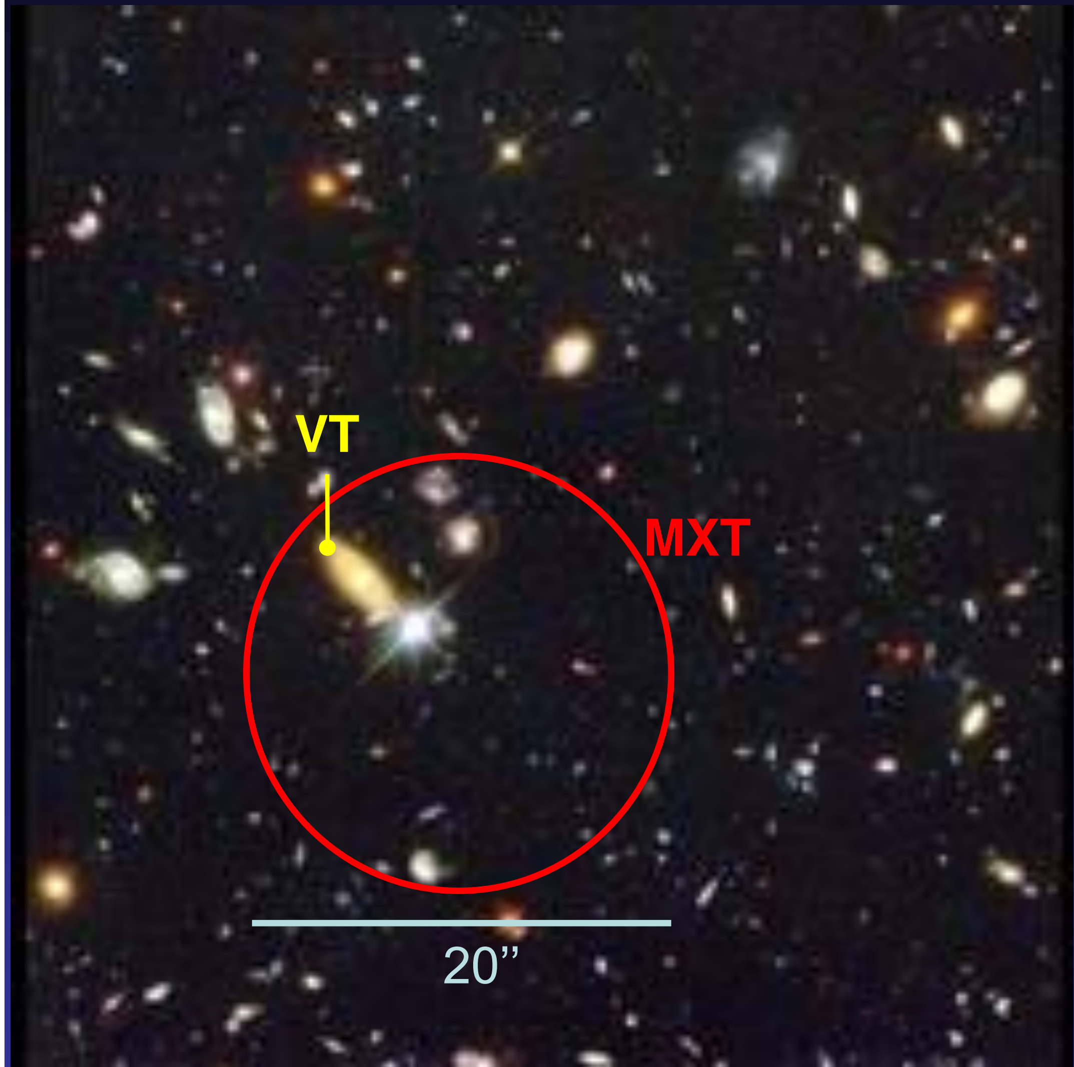


Most of the GRBs (up to 75-80%) detected by SVOM to be well above the horizon of large ground based telescopes all located at tropical latitudes

The pointing strategy of SVOM

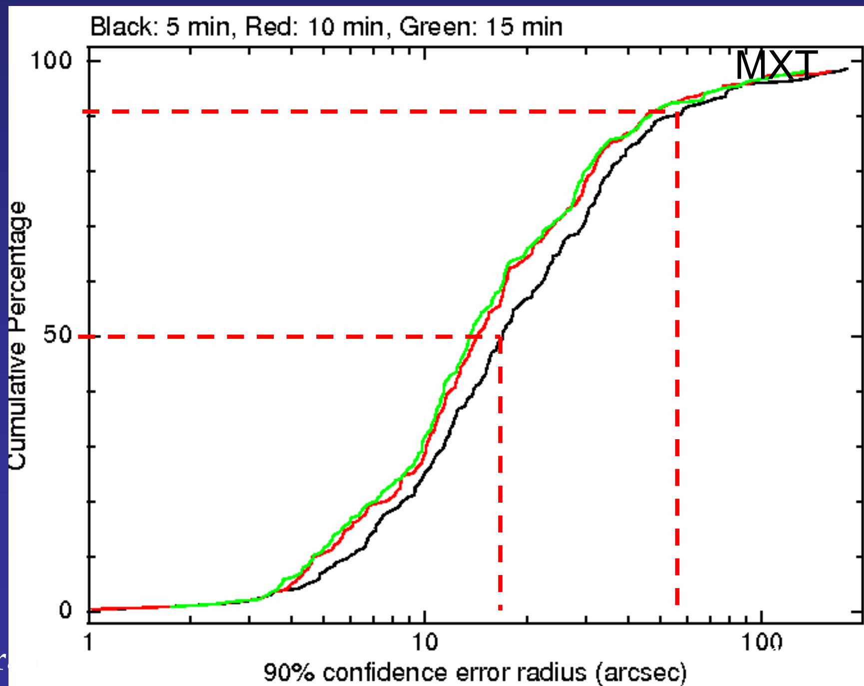


GRB localisation budget



Required loc. Accuracy (90% c.l.)	
ECLAIRs	< 12 arcmin
MXT*	< 17'' for 50% of loc. sources < 53'' for 90% of loc. sources
VT	< 1 arcsec

* Assuming an obs. start time at T_0 + 5 min



SVOM status

- The mission is undergoing a new start, with a launch planned in 2021
- France provides a significant hardware contribution: the γ-ray imager (ECLAIRs), the X-ray telescope (MXT) and the VHF alert network.
- China provides the launch and the satellite, with the γ-ray spectrometer (GRM) and the Visible Telescope (VT)
- The instruments are currently under development
- SVOM will detect ~80 GRB/yr, which are adequately located for fast follow-up from the ground

GRB studies with *LSST*

Basic GRB statistics

- ~1000 GRB/yr all sky
- Beaming implies that GRBs are 10^2-10^3 time more frequent than the observed rate → prediction of the existence of ***orphan afterglows***
- LSST will permit the detection of GRBs from their optical emission, with a reasonable rate for the first time → ***untriggered afterglows***
- At present, there is a single untriggered afterglow candidate: PTF11agg (Cenko et al. 2013)
- We discuss the detection of on-axis GRB afterglows and off-axis GRB afterglows ("orphan afterglows")
  - ***"Untriggered afterglows are not all orphans"***

GRB statistics – corrected for beaming

- For long GRBs, the beaming angle is estimated to be few degrees, we see one GRB out of several hundred.
- The jets of short GRBs could be more open (10°-30°), and we may see one short GRBs out of several ten.

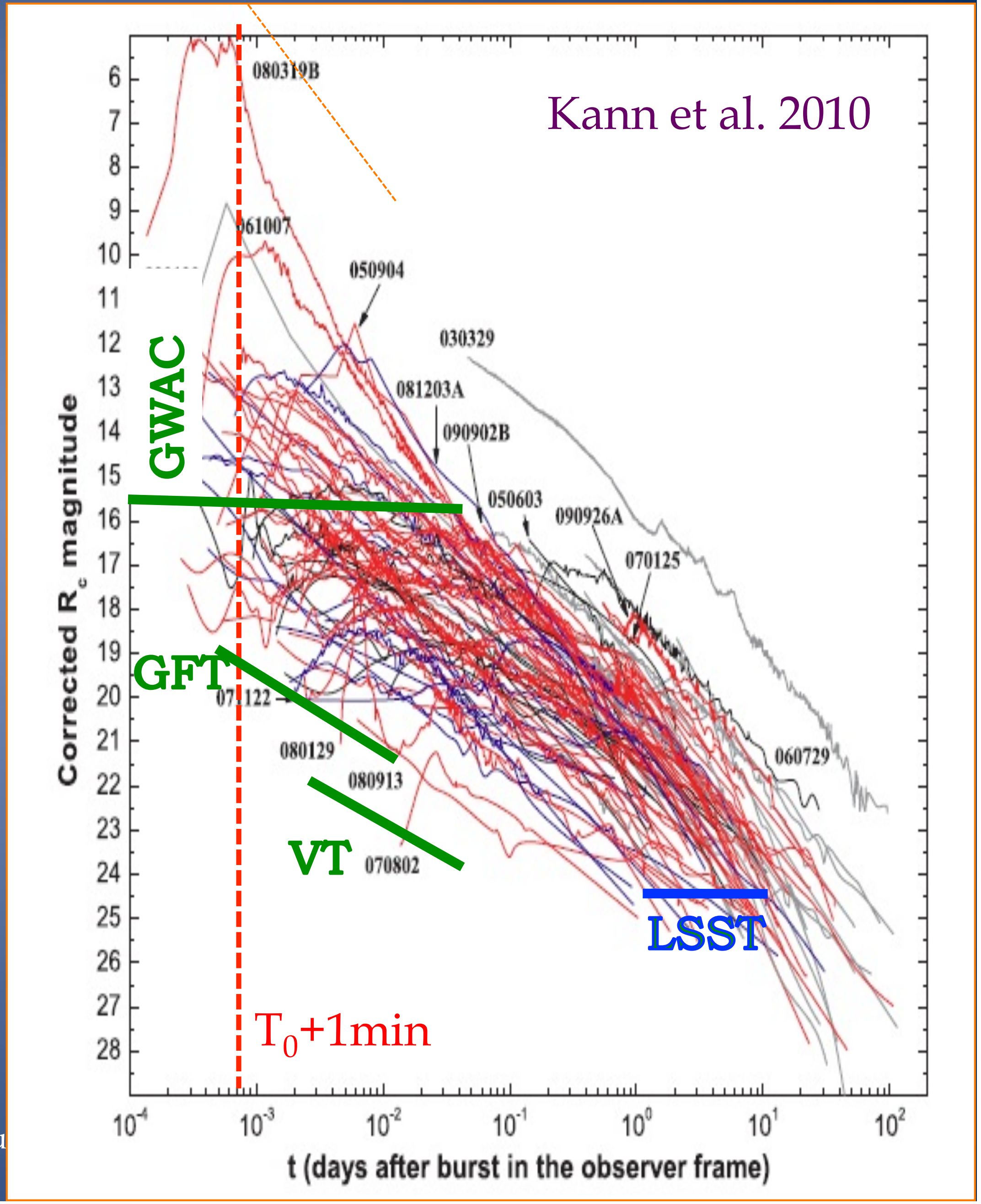
- The energy budget is strongly reduced
  - Long GRBs: $E_\gamma \approx 10^{51\text{-}52}$ erg
  - Short GRBs: $E_\gamma \approx 10^{48\text{-}49}$ erg

- The space density of GRBs is increased
  - Long GRBs: 100-1000/Gpc^3/yr – few % of the rate of SN Ibc (~9000/Gpc^3/yr)
  - Short GRBs: 100-1000/Gpc^3/yr – comparable to the rate of NS-NS mergers

- In the near future the detection of *orphan afterglows* may lead to more precise estimates

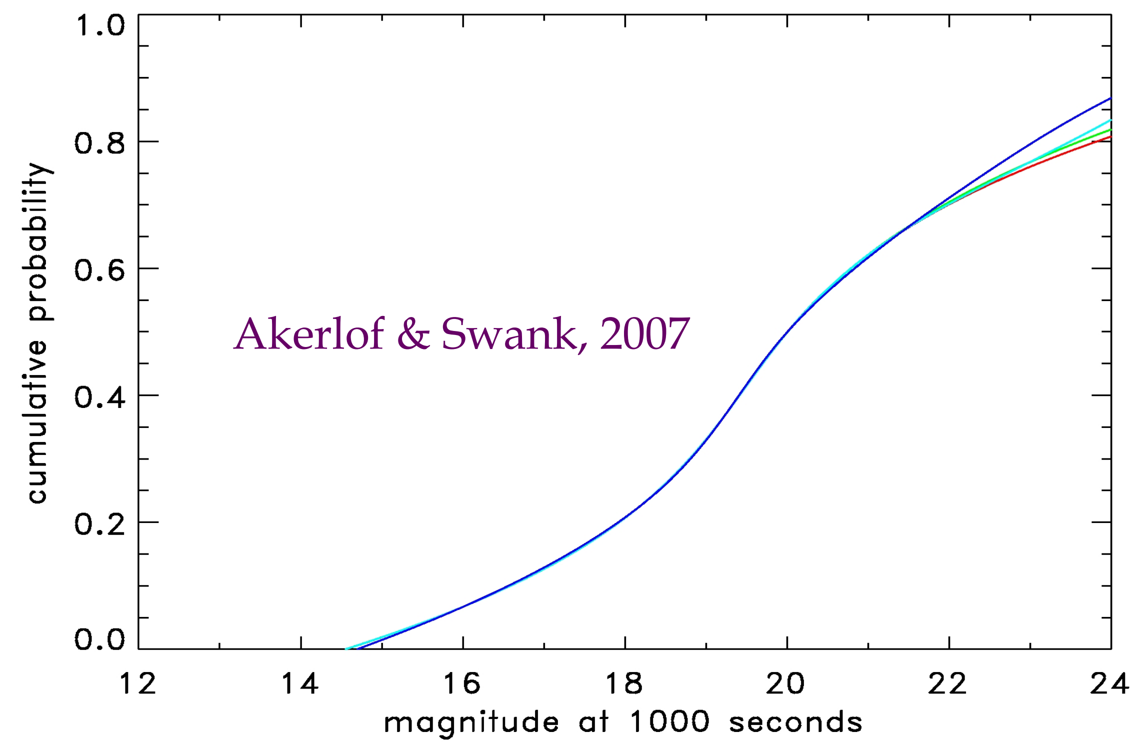
Detecting GRB afterglows with LSST

- LSST will arrive on the spot 1-4 days after the GRB. The afterglow will typically be visible in 1 to 3 « visits »
- Don't use LSST for the follow-up of well localized GRBs!
- GRB afterglows will be difficult to recognize if we don't know that there was a burst (with the prompt high energy emission)
- *Orphan afterglows* will be even more difficult to recognize

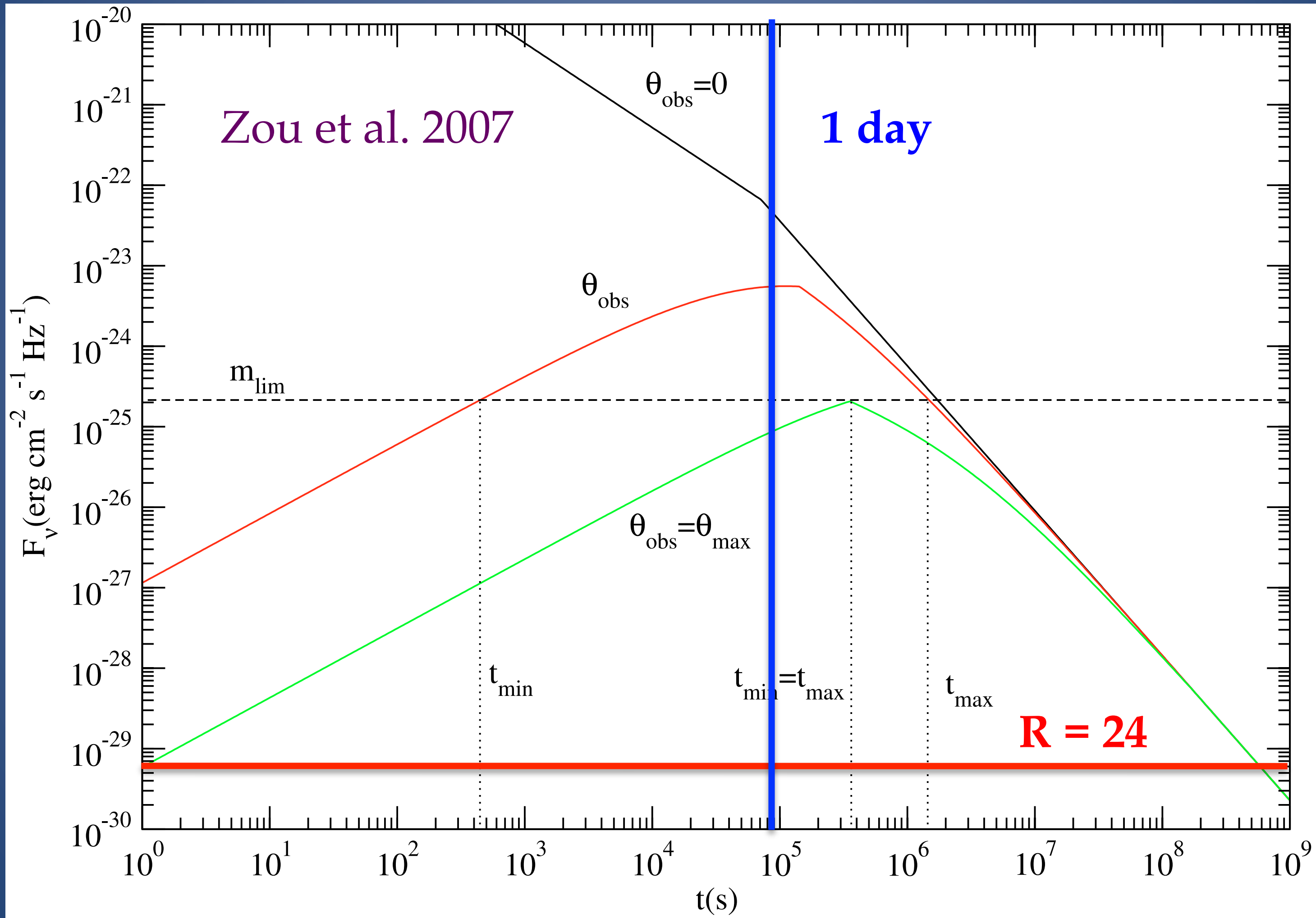


Detecting GRB afterglows with LSST

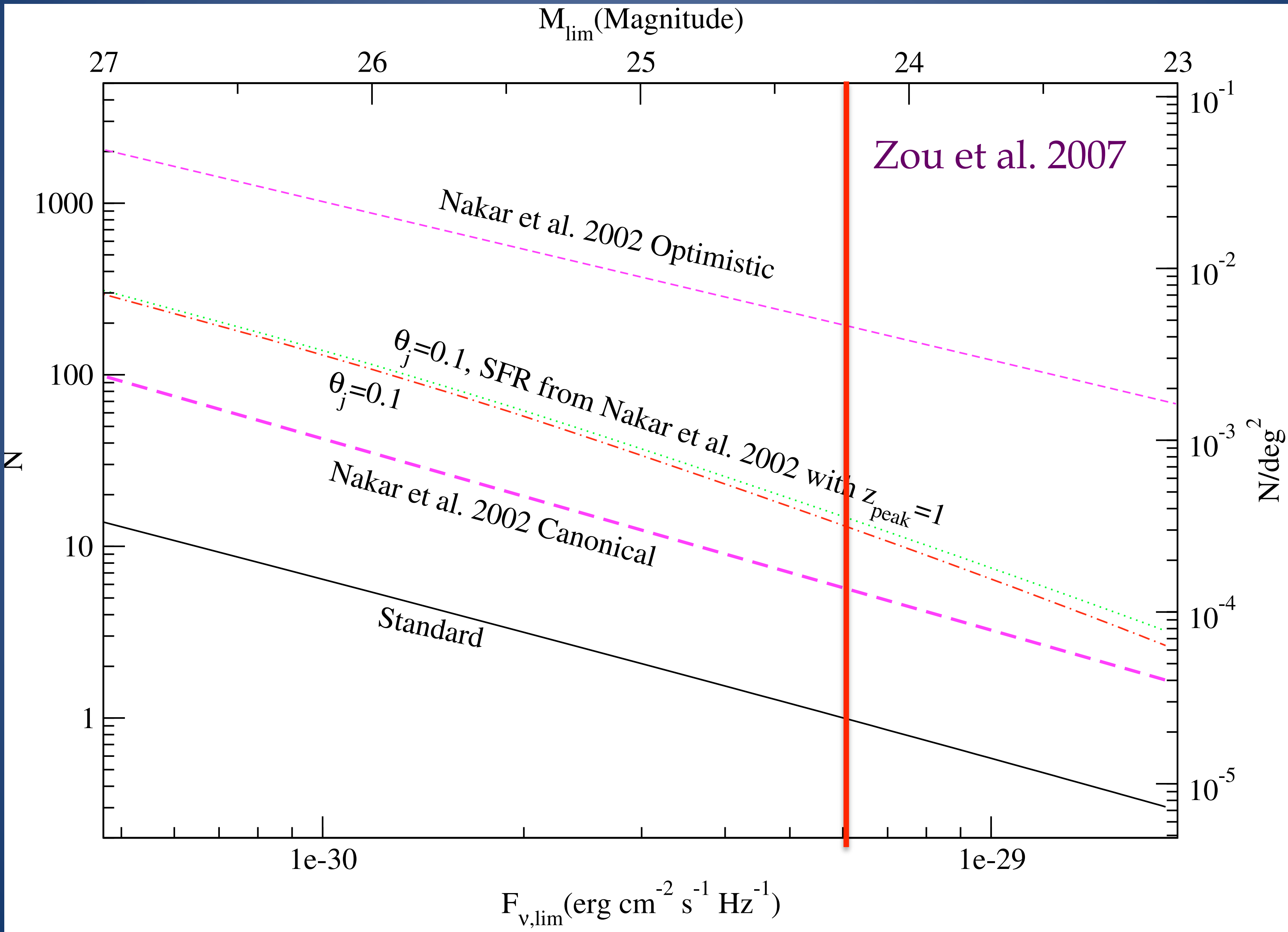
- Some difficulties:
  - LSST will not detect dark GRBs
  - The afterglows of short GRBs may also be too faint after 1-2 days (TBC)



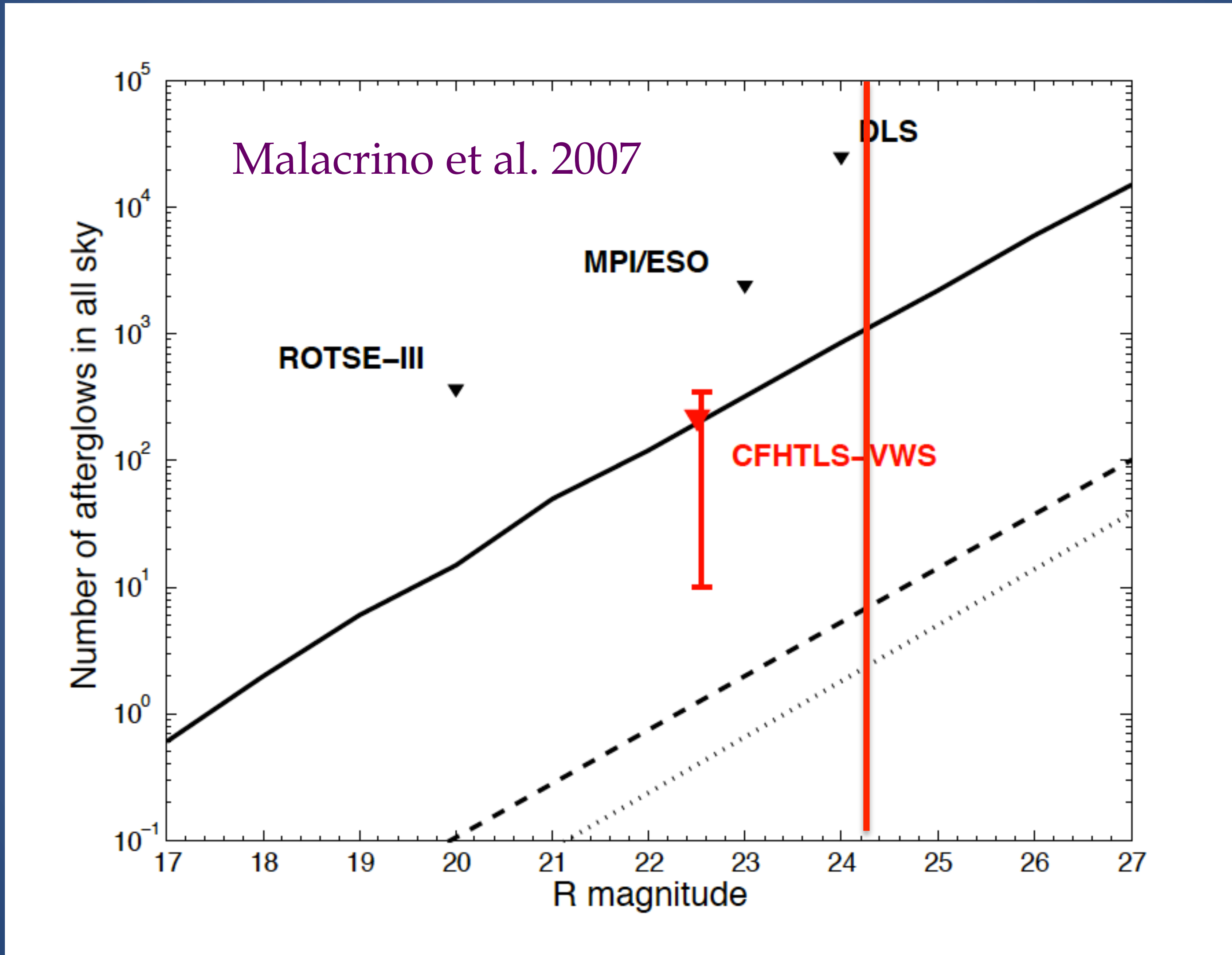
Orphan afterglows…



The expected rate of orphan afterglows

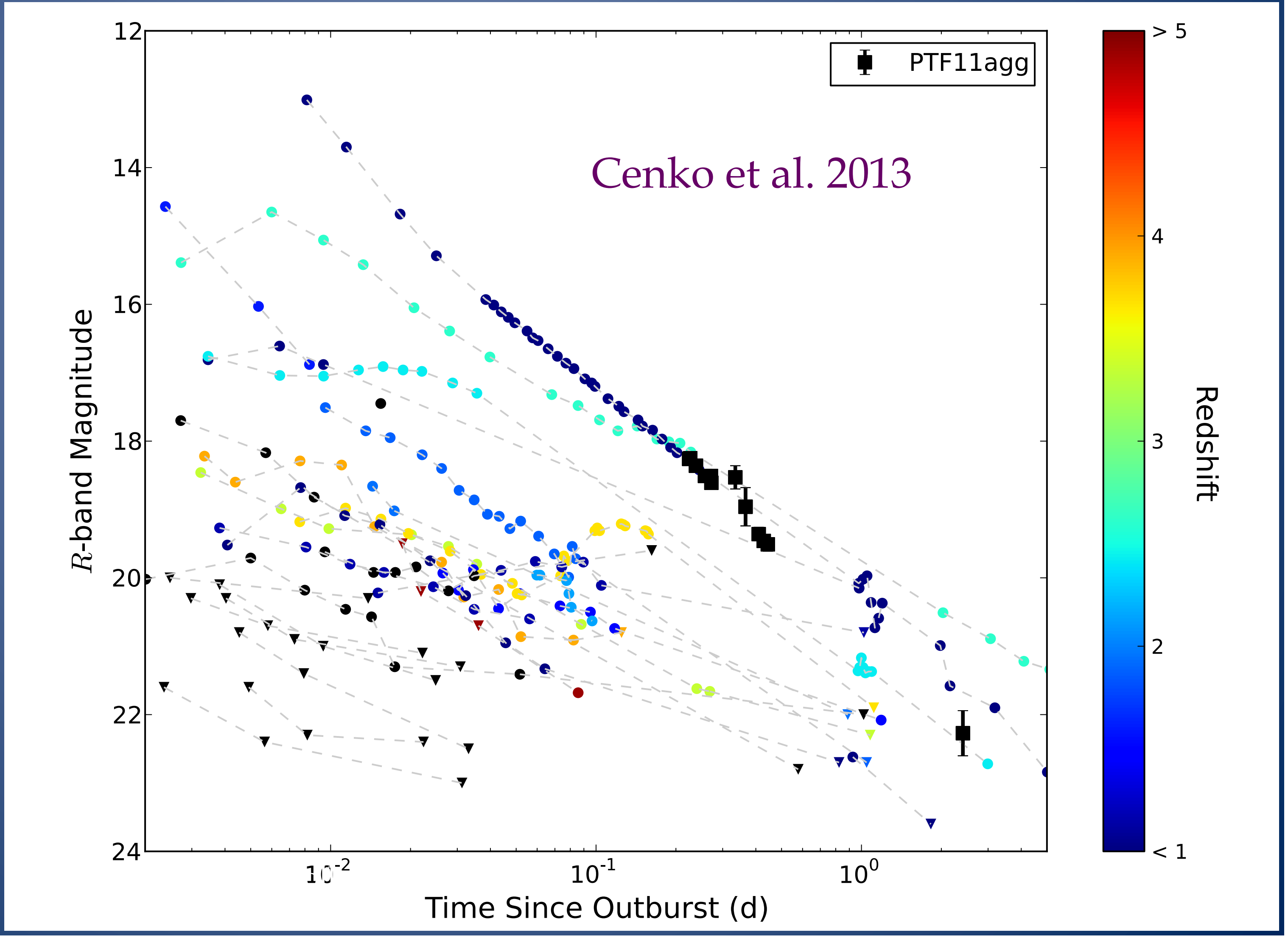


Some constraints



PTF11agg, The first "untriggered" GRB afterglow?

- Cenko et al. 2013: « Discovery of a Cosmological, Relativistic Outburst via its Rapidly Fading Optical Emission »



Perspectives for GRBs

- In the next decade LSST may detect a few tens of GRBs/yr, with selection effects quite different from GRB detectors in space: LSST will open a new window for GRB studies.
- GRBs detected with LSST and SVOM (or another GRB satellite) will be crucial to calibrate LSST-only GRBs.

- Many questions exist, that require detailed simulations:
  - Which type of GRBs afterglows will be detected with LSST?
  - What are the brightness and redshift distributions of GRB afterglows that will be detected with LSST?
  - How can we recognize GRB afterglows in LSST?
  - How can we recognize orphan GRB afterglows in LSST?
  - How many GRBs/yr will be detected with SVOM and LSST simultaneously
  - …

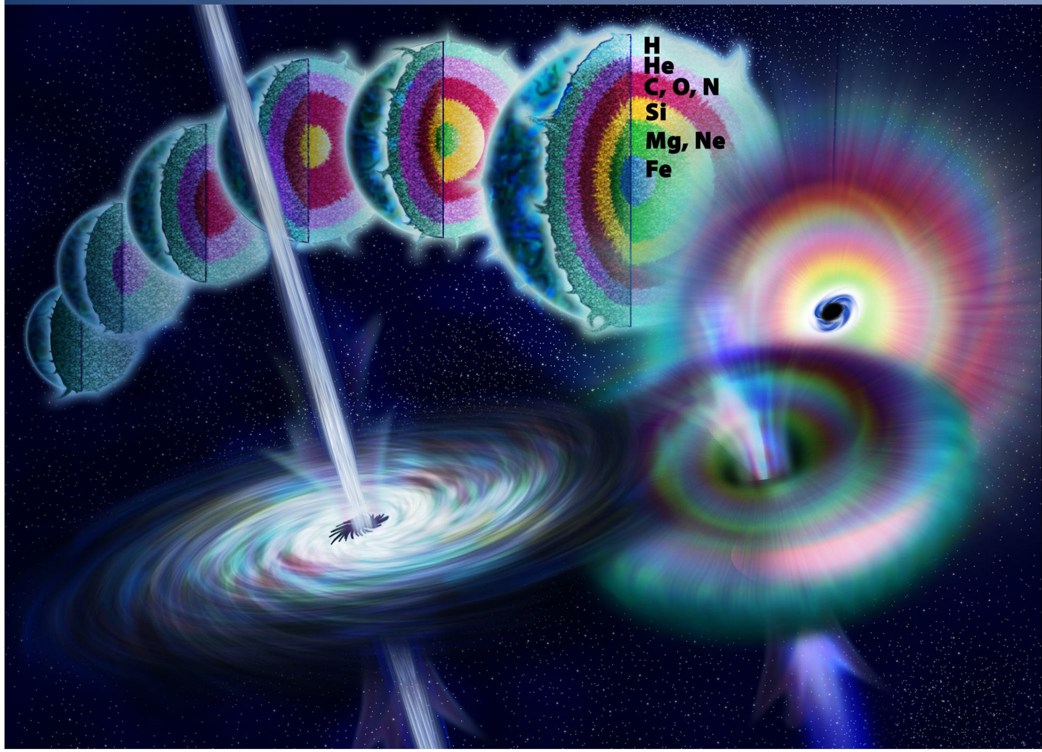
More perspectives

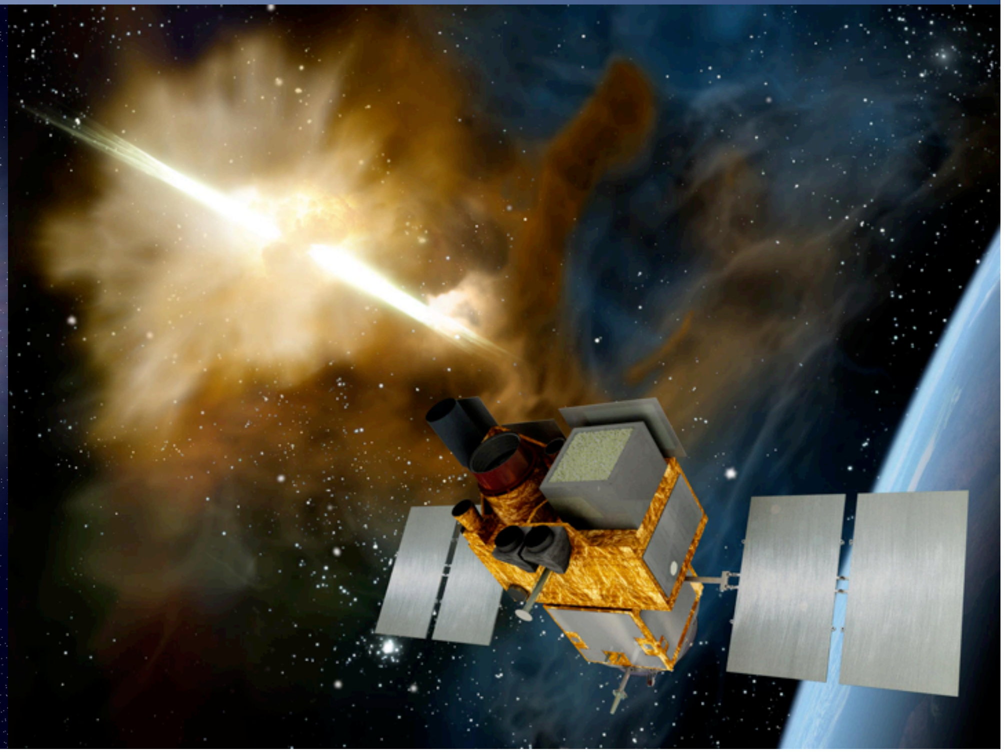
- SVOM-ECLAIRs will observe all types of hard X-ray transients, not only GRBs. Many of them will be of interest for LSST: AGN activity, X-ray binaries, SN shock breakout…

- We are witnessing some specialization of Astronomy: Survey Astronomy (e.g. LSST) and Alert Astronomy (e.g. SVOM) have different constraints but they are fully complementary:
  - Surveys require fast follow-up
  - Alerts require accurate catalogs

- Need to have few French co-Is of SVOM involved in the LSST consortium?

The end





Parameters of GWAC

- Cameras： 72 – 2 sites
- Mounts: 18
- Diameter： 180 mm
- Focal Length： 213 mm
- Wavelength： 450—900 nm
- Total FoV： 9000 sq.deg
- Limiting Mag (V)： 16.5（5σ,10s)

Prompt optical emission detection down to $M_V \sim 16.5$ (10 s exposure)

Two Ground-based Follow-up Telescopes

- The prime goal of the 2 GFTs is the early identification of GRB afterglows from the ECLAIRs positions

  – GFT-1 is the chinese GFT at Xinglong observatory (TNT / EST)
  – GFT-2 is the French-Mexican GFT at OAN-SPM

- Instrumentation of GFT-2 (2 channels)
  – 1 visible camera 4k x 4k
  – 1 NIR camera 2k x 2k H2RG
  – *1 medium resolution spectrograph (TBC)*

- GRB objectives of GFT-2:
  – Localization of SVOM GRBs, including dark GRBs
  – Observation of the early afterglow in visible/NIR
  – SED of the early afterglow
  – Study of the prompt visible emission of long GRBs