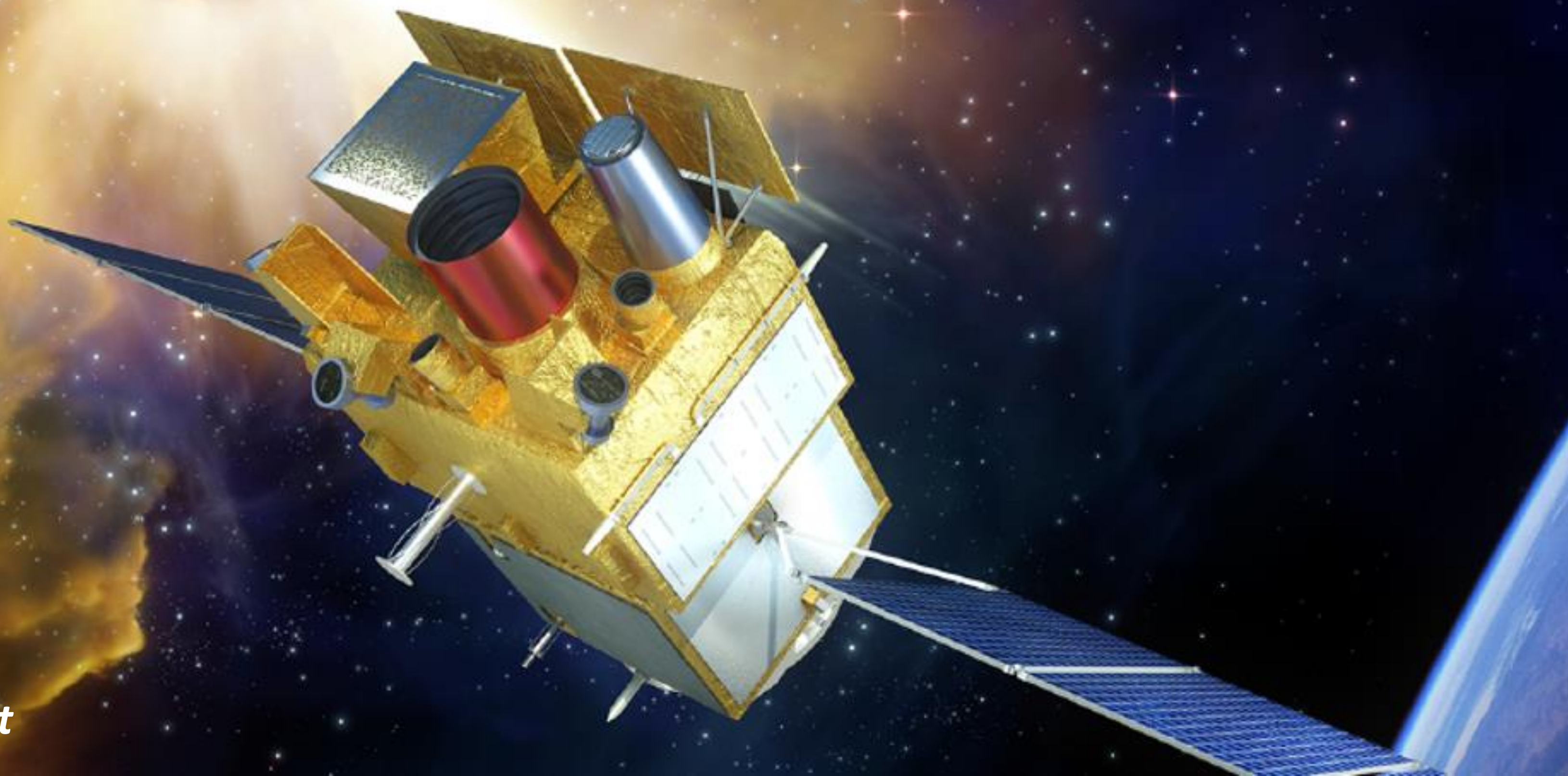
Séminaire IAP: Mardi 14 Décembre 2021

High-energy transients in the local universe seen by SVOM/ECLAIRs



B. Arcier – 3rd year PhD student

14/12/2021

Overview

I. The SVOM mission and the ECLAIRs instrument

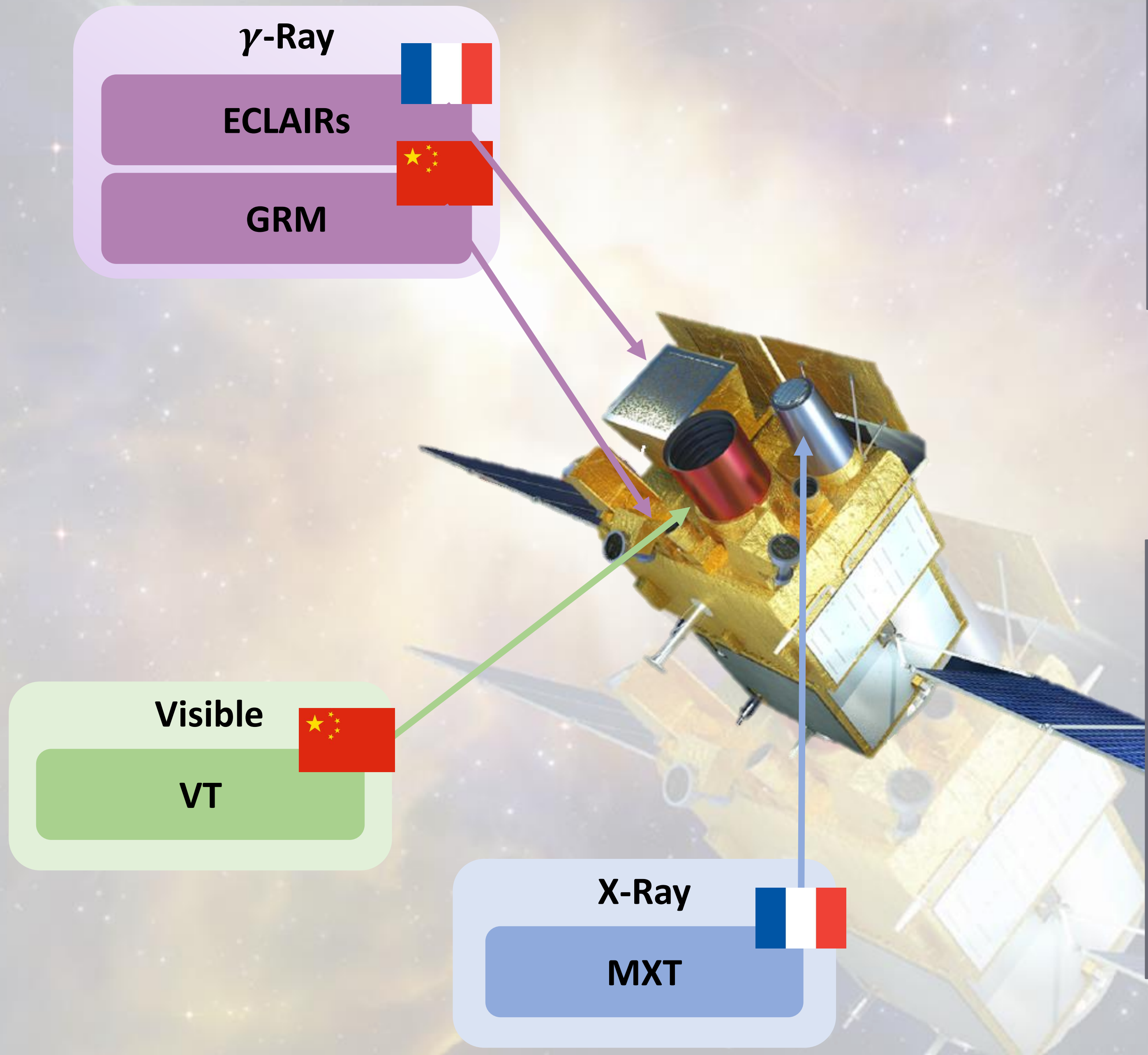
II. SVOM/ECLAIRs performances assessment via simulations

III. Detection of short high-energy transients in the local universe

IV. Are binary black hole mergers and long γ-ray bursts drawn from the same BH population?

I. The SVOM mission and the ECLAIRs instrument

Space-based multi-band astronomical
Variable Objects Monitor



Detection

ECLAIRs X-/γ-ray coded-mask camera

GRM Gamma-Ray bursts Monitor

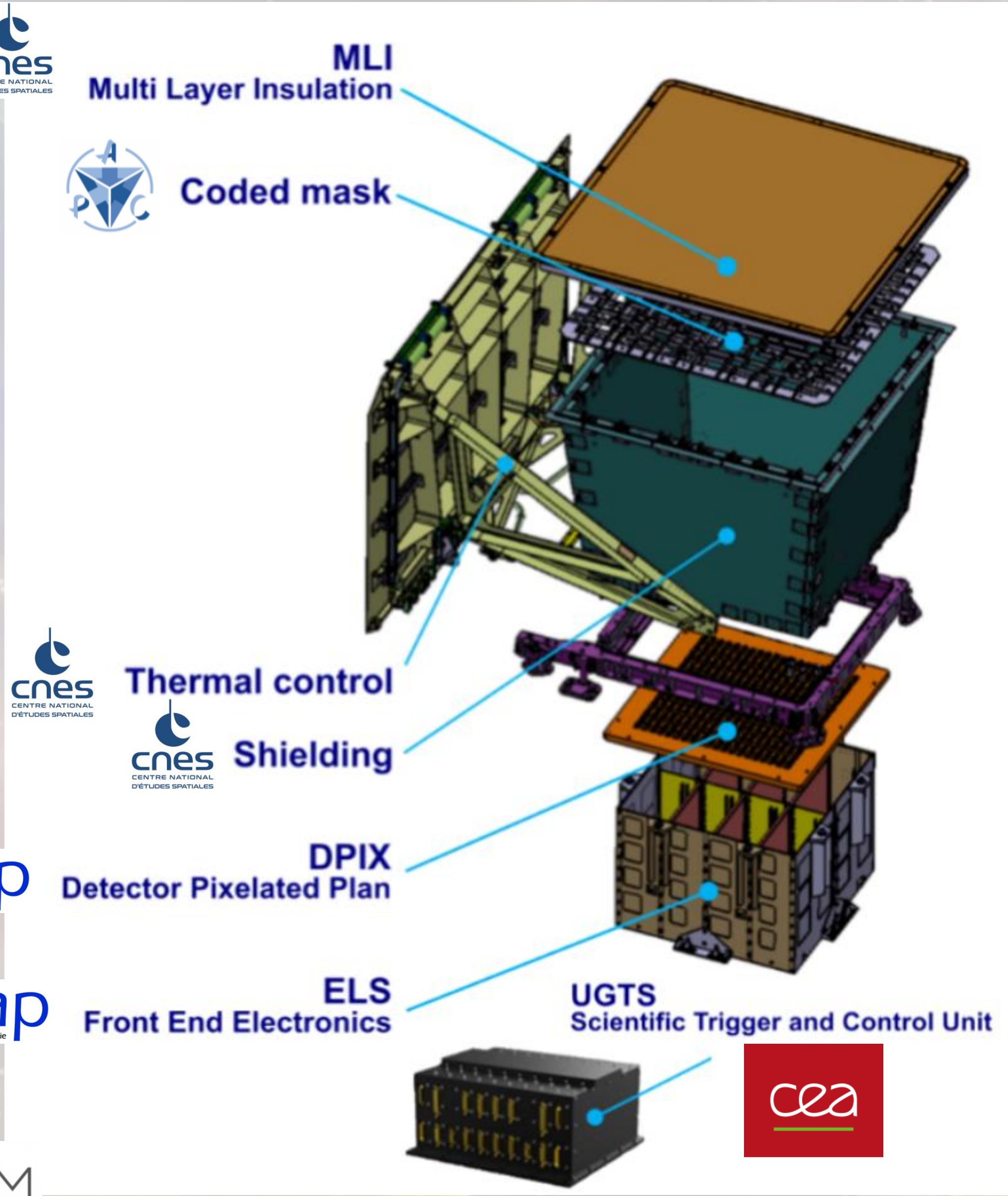
Slew of the satellite within 10 minutes

Follow-up

MXT Microchannel X-Ray Telescope

VT Visible Telescope

Ground Telescopes: Colibri, C-GFT, GWAC

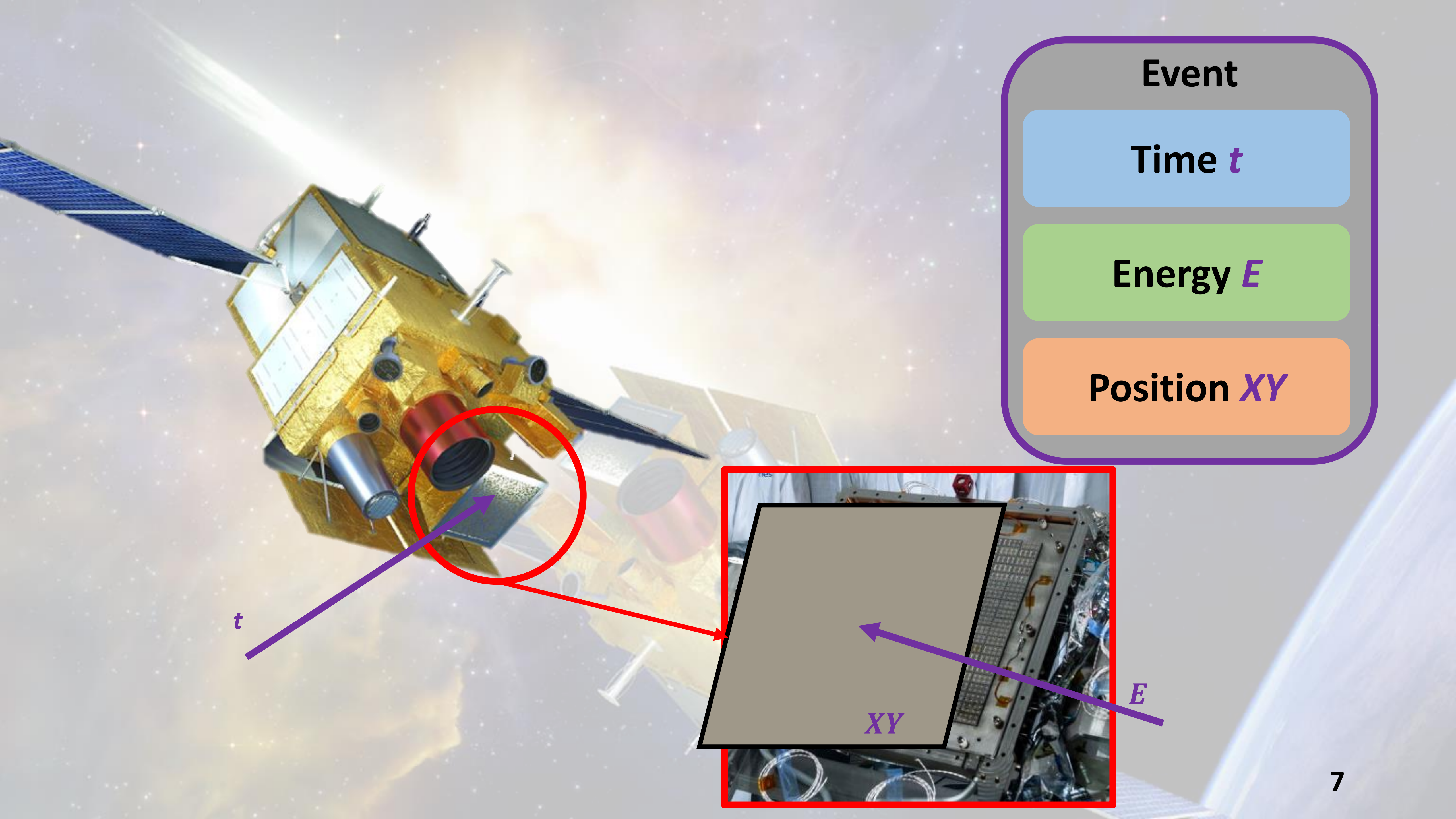


Main components of ECLAIRs
Source: Arcier et al. 2020

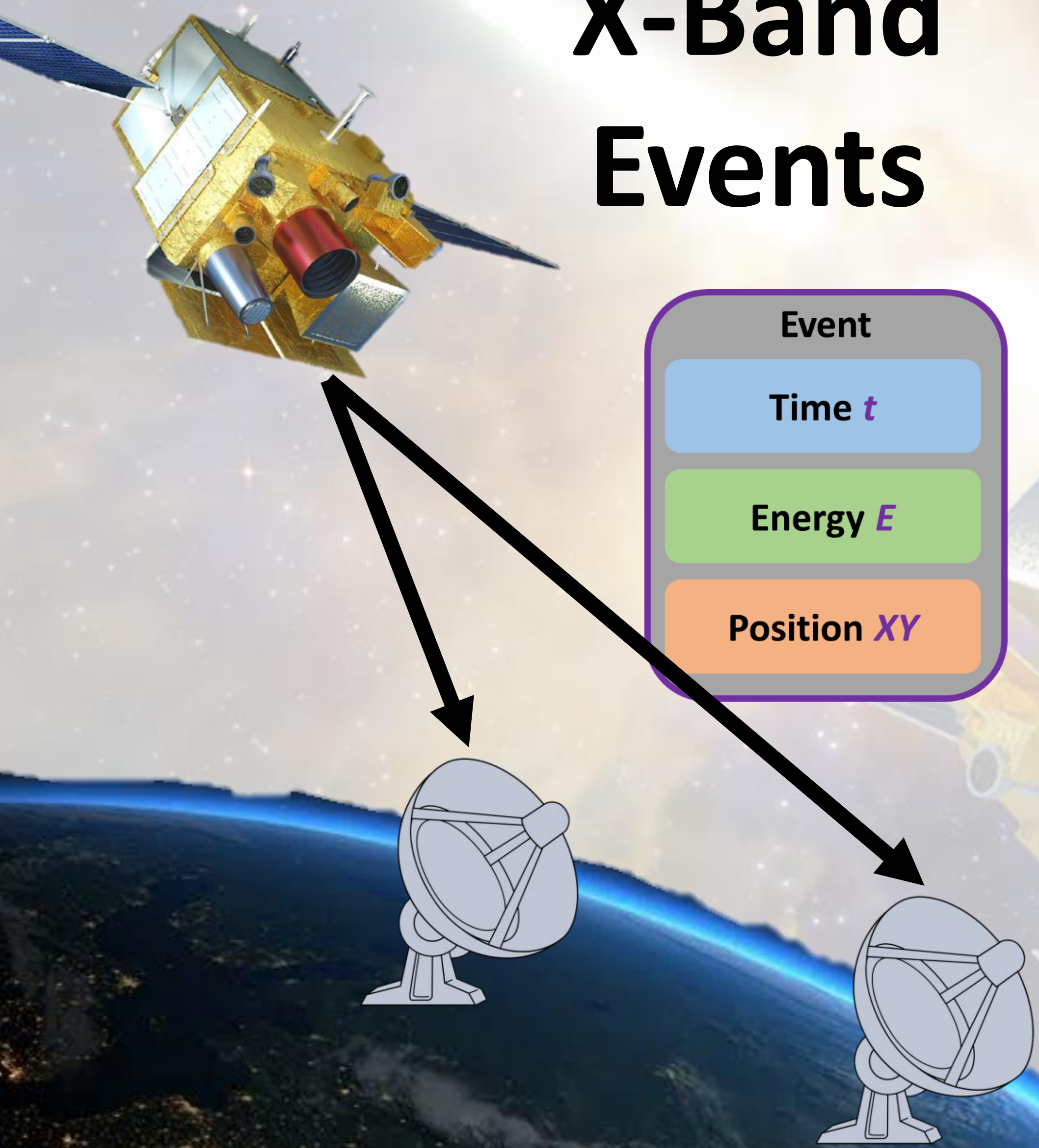
ECLAIRs

Characteristics:

- 4 – 120 keV
- $90 \times 90\ \mathrm{deg}^2$ FoV
- 6400 CdTe detectors
- $400\ cm^2$ @ $20\ keV$
- $< 1.6\ keV$ energy resolution
- 3 – 10 arcmin localisation


Event
Time t
Energy E
Position XY
t
XY
E

X-Band Events



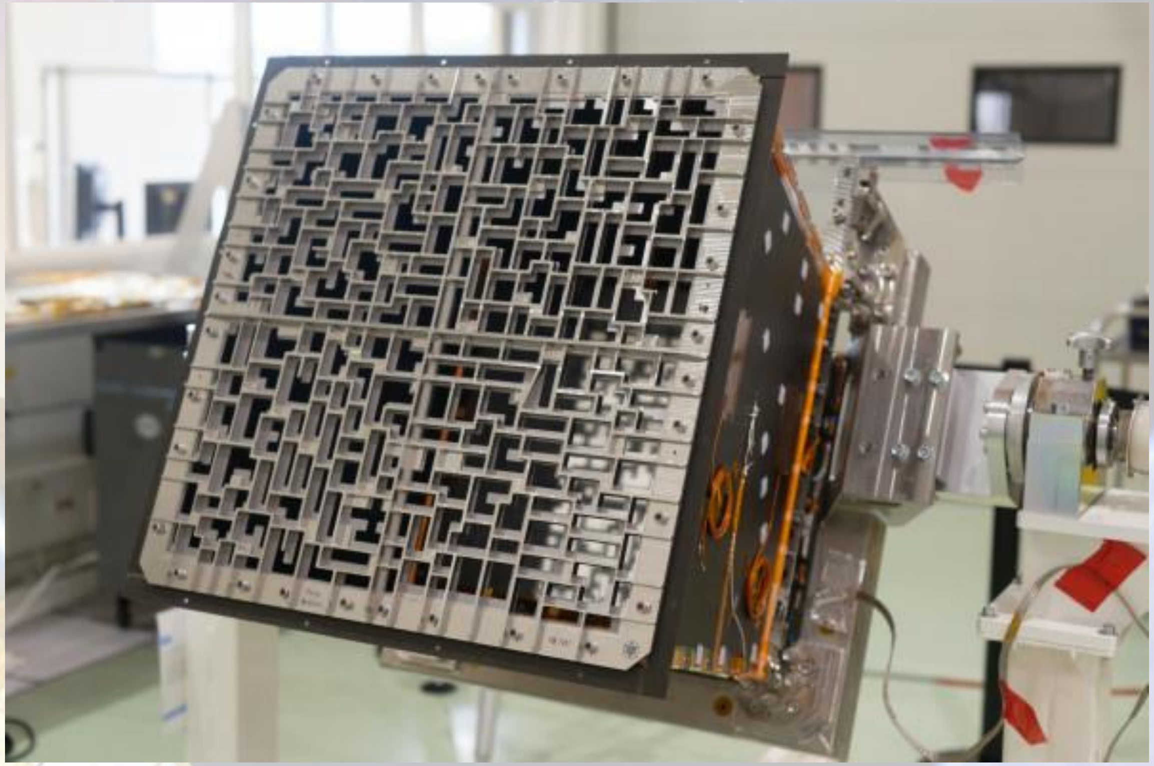
Offline Trigger

- More time to analyze the data
- More calculation power
- Data when on-board triggers are shutdown (SAA, Earth in FoV, …)
- False alert rate more important

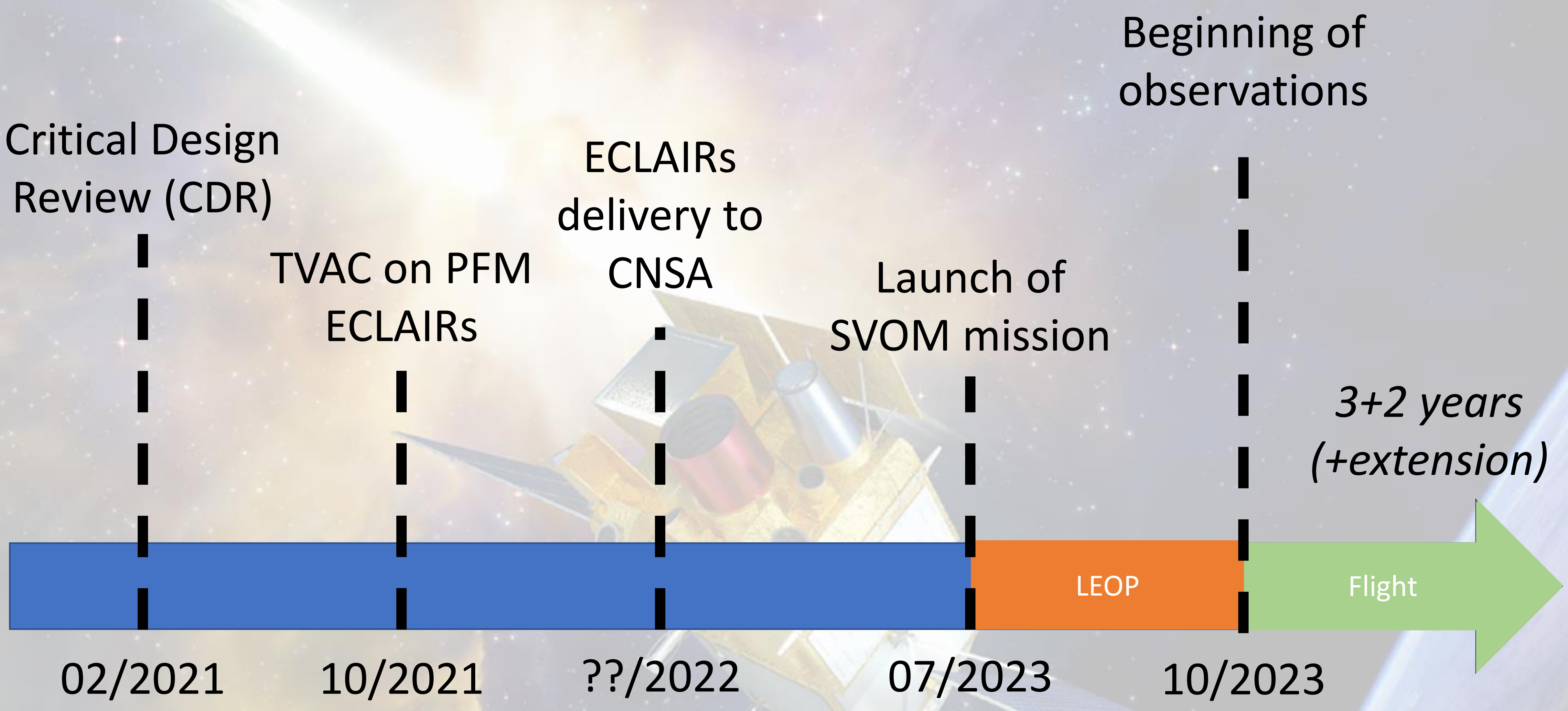
Arcier et al. in prep …

Offline Analysis

PFM ECLAIRs detection plane assembled
Source: www.svom.eu



ECLAIRs, its coded mask and shielding
Source: www.svom.eu


Critical Design Review (CDR)
TVAC on PFM ECLAIRs
ECLAIRs delivery to CNSA
Launch of SVOM mission
Beginning of observations
3+2 years (+extension)
LEOP
Flight
02/2021
10/2021
??/2022
07/2023
10/2023

II. SVOM/ECLAIRs performances assessment via simulations

Astrophysics background simulation from CNES attitude files:

PIRA

PIRA – *Mate et al. 2019*

- Generate list of simulated photons from GEANT4 photons
- Simulation of CXB, Albedo, Reflection, Particles

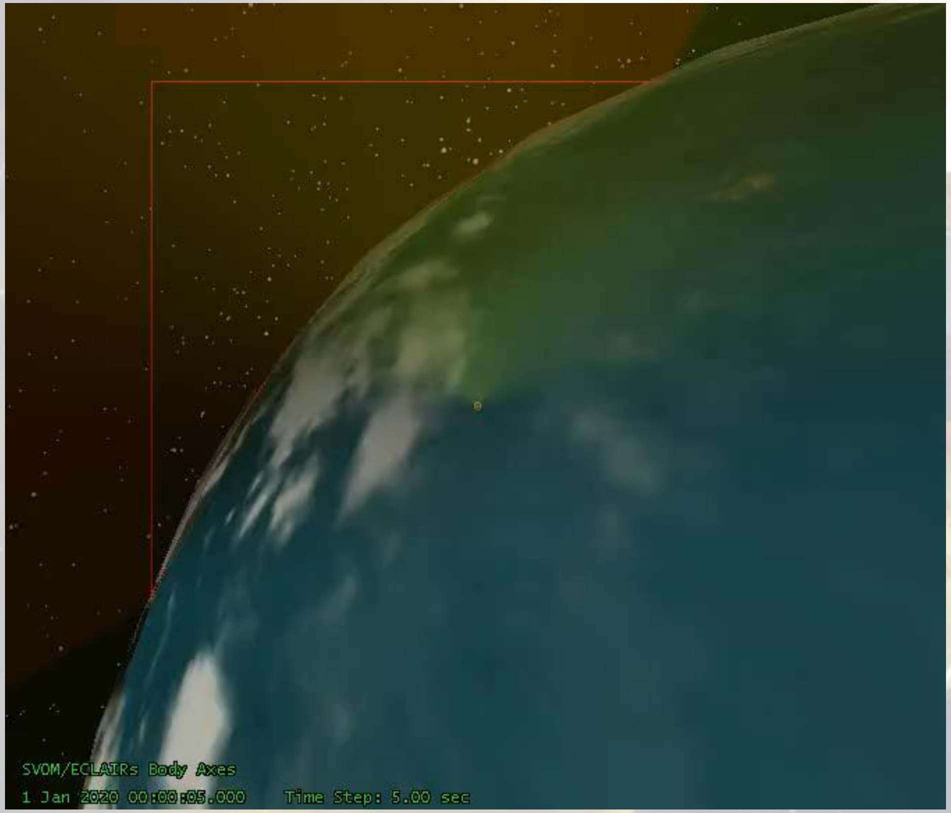
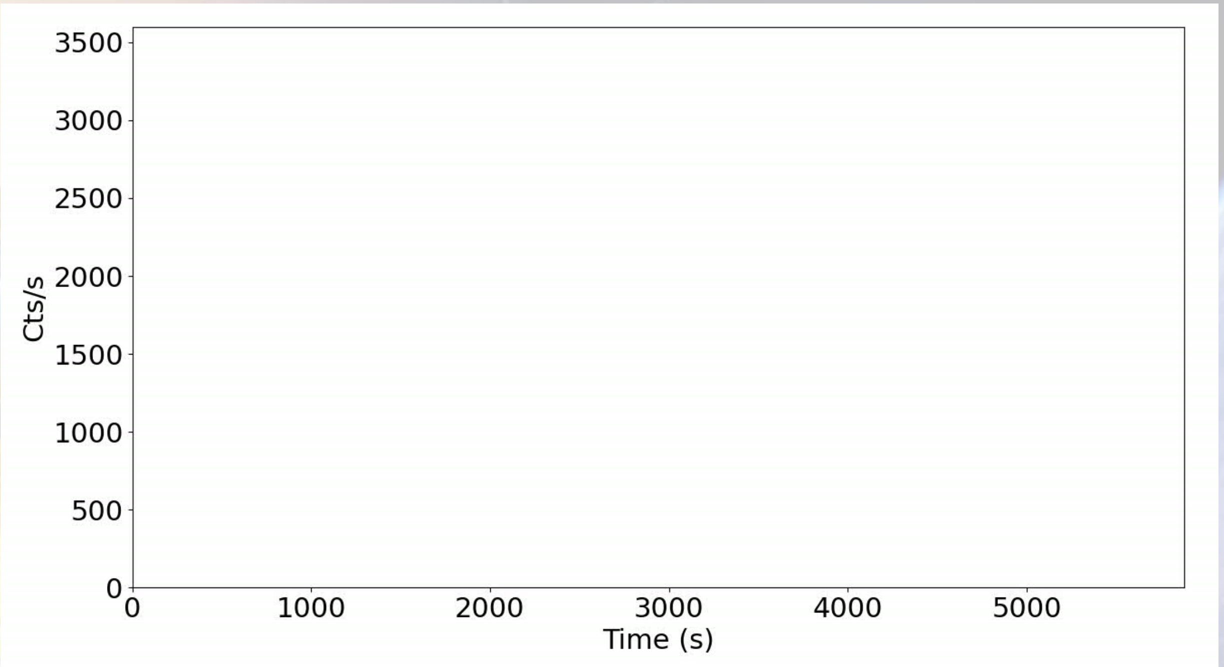


Illustration of ECLAIRs FoV for its orbits around Earth
Source: CEA, H. Triou



ECLAIRs background lightcurve synchronized with left image
Source: Mate et al. 2019

High-energy transients simulation: *grbsimulator*

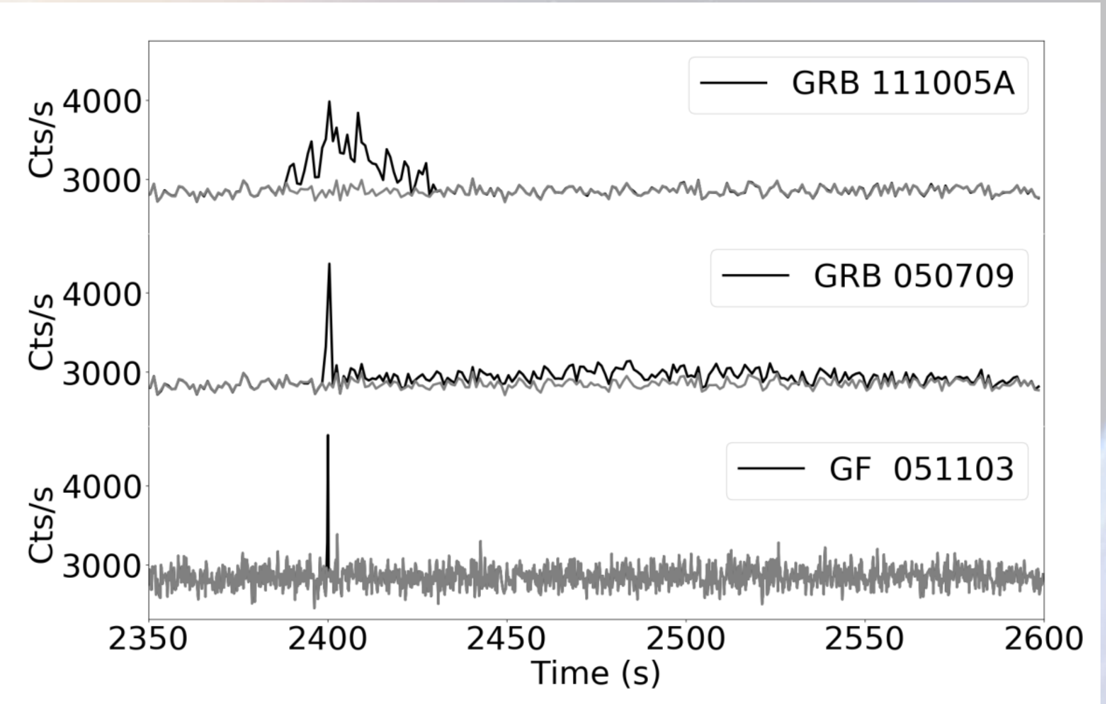
grbsimulator v5 – *S. Antier, F. Daigne, M. Bocquier, D. Corre*

- Translate lightcurve and spectrum in SVOM/ECLAIRs bands
- Generate list of simulated photons
- Can simulate at several redshifts

SPECTRUM

+

LIGHTCURVE



Example of simulated lightcurves with grbsimulator
Source: Arcier et al. 2020

Ray-tracing of photons from bkg attitude files: *ecl_data_simulator*

GRB photons

+

Sky X-Ray sources

(Dagoneau et al. 2021)

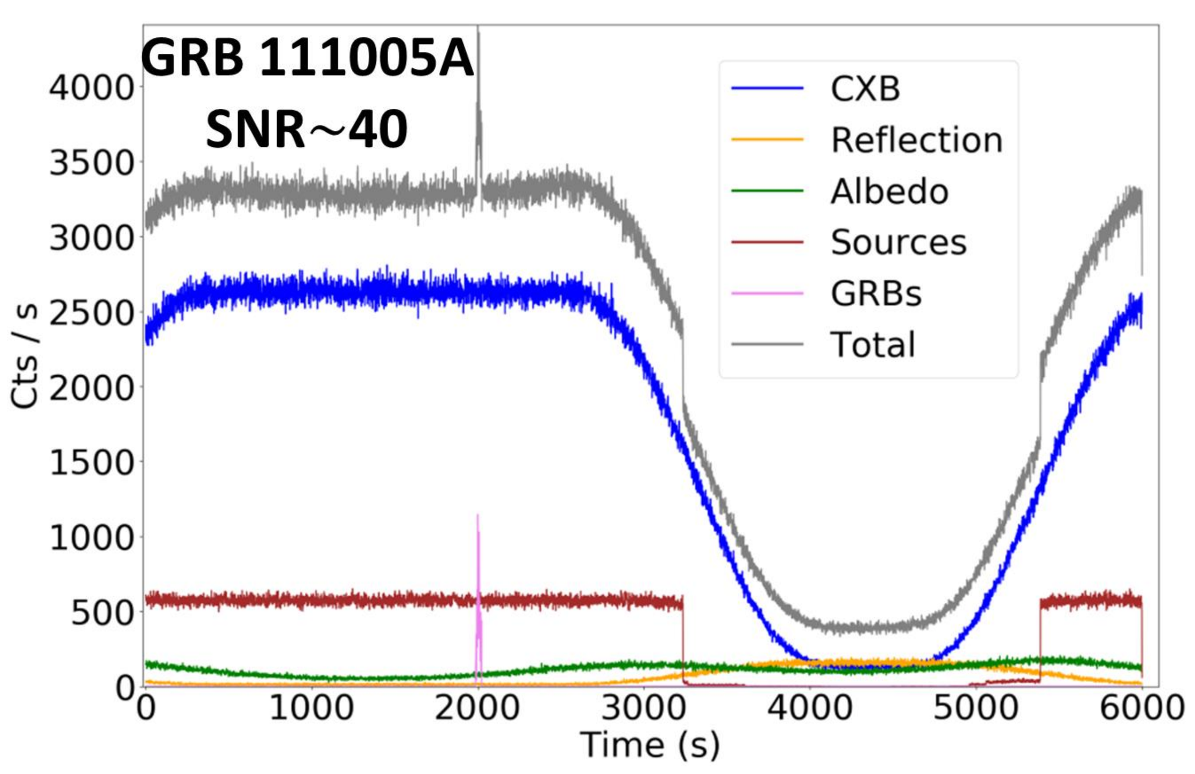
+

Background

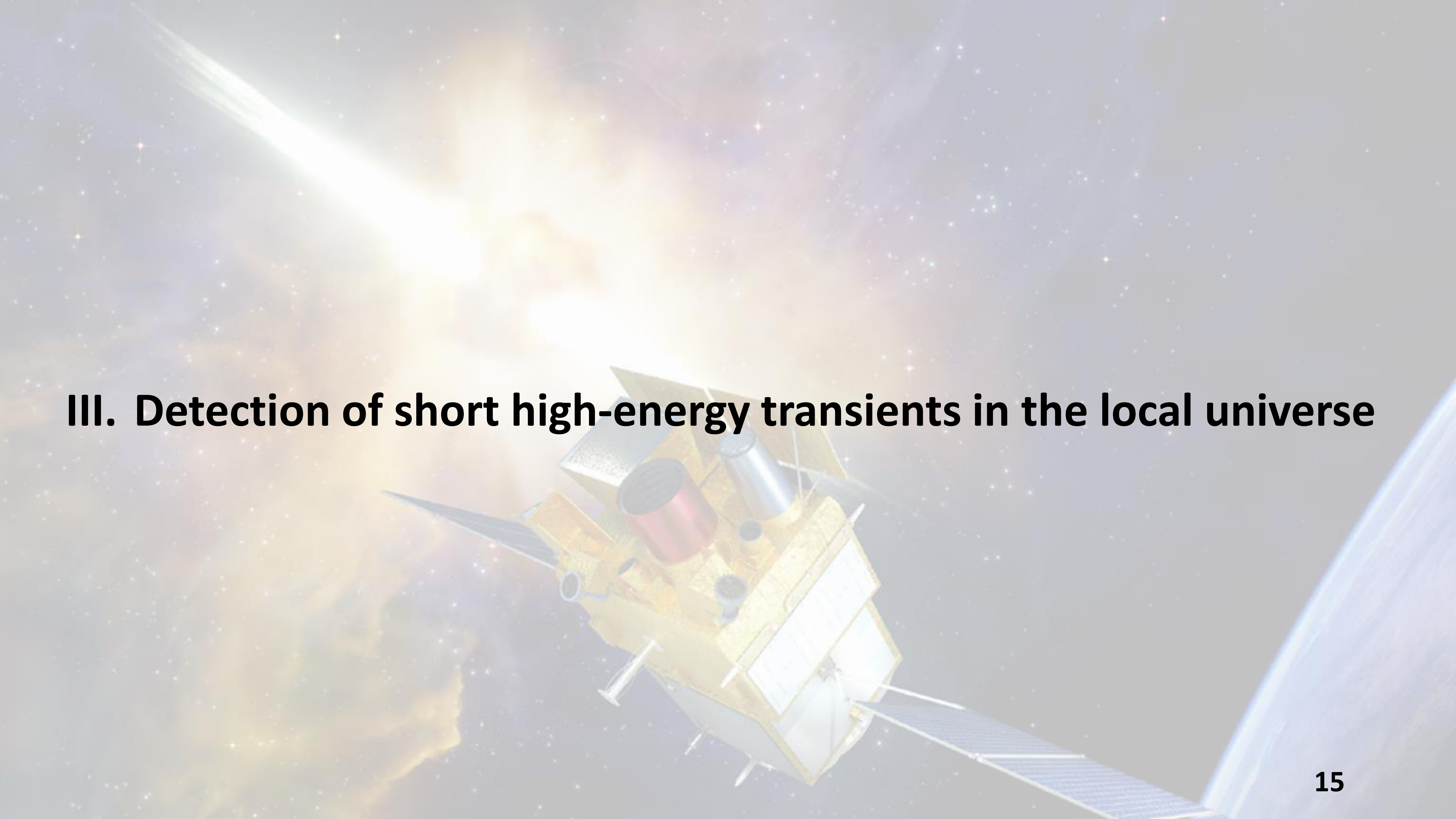
(PIRA)

ecl_data_simulator – *S. Mate*

- Gather all photons with ray-tracing from the orbit attitude information
- Add X-ray catalog sources from Dagoneau et al. 2021



Example of simulated orbit with a GRB on top of an orbit with the Crabe rising
Source: Arcier et al. 2020



III. Detection of short high-energy transients in the local universe

Arcier et al. 2020, published in December 2020 in *Astrophysics and Space Science*

Astrophys Space Sci (2020) 365:185
https://doi.org/10.1007/s10509-020-03898-z

ORIGINAL ARTICLE

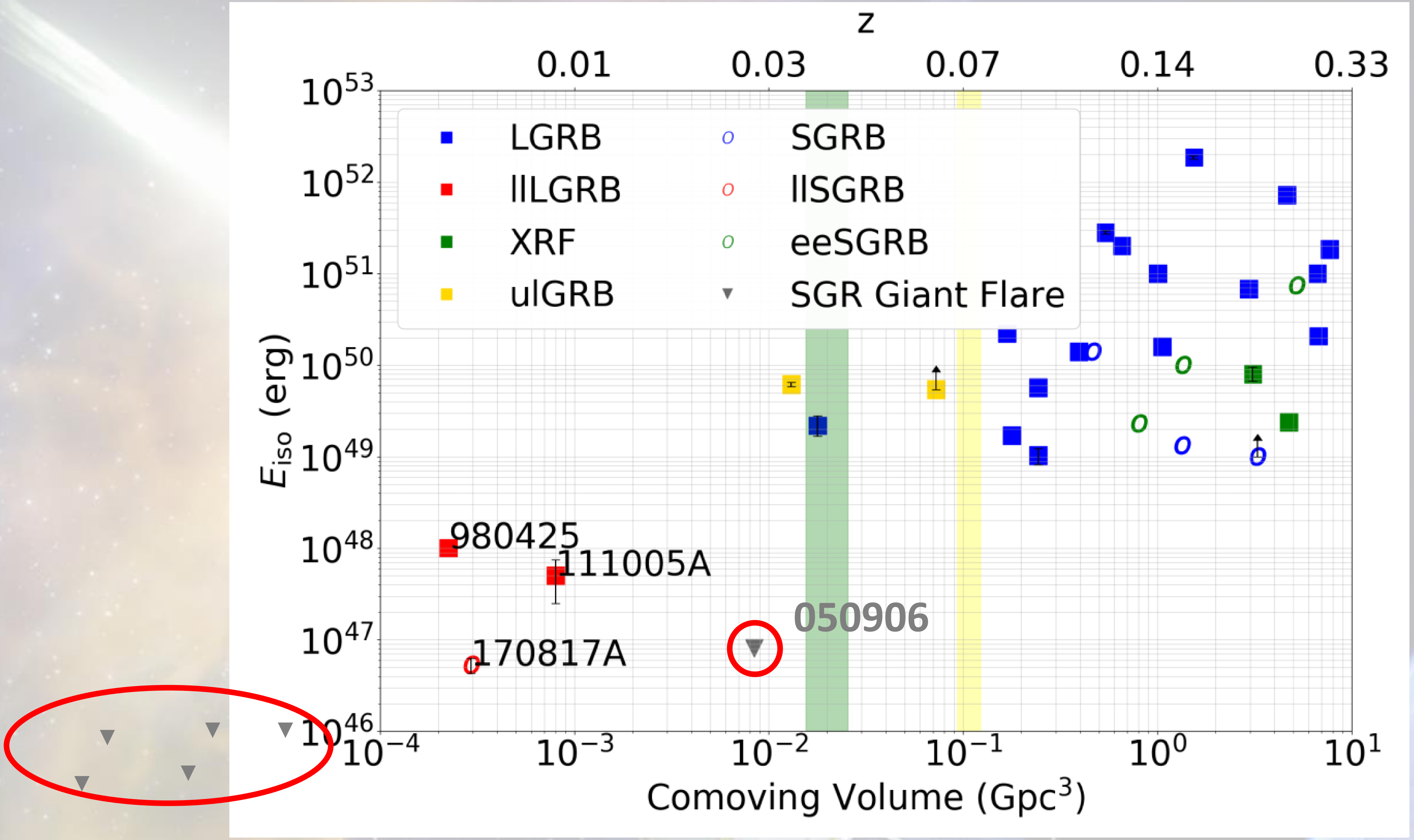
Check for updates

Detection of short high-energy transients in the local universe with SVOM/ECLAIRs

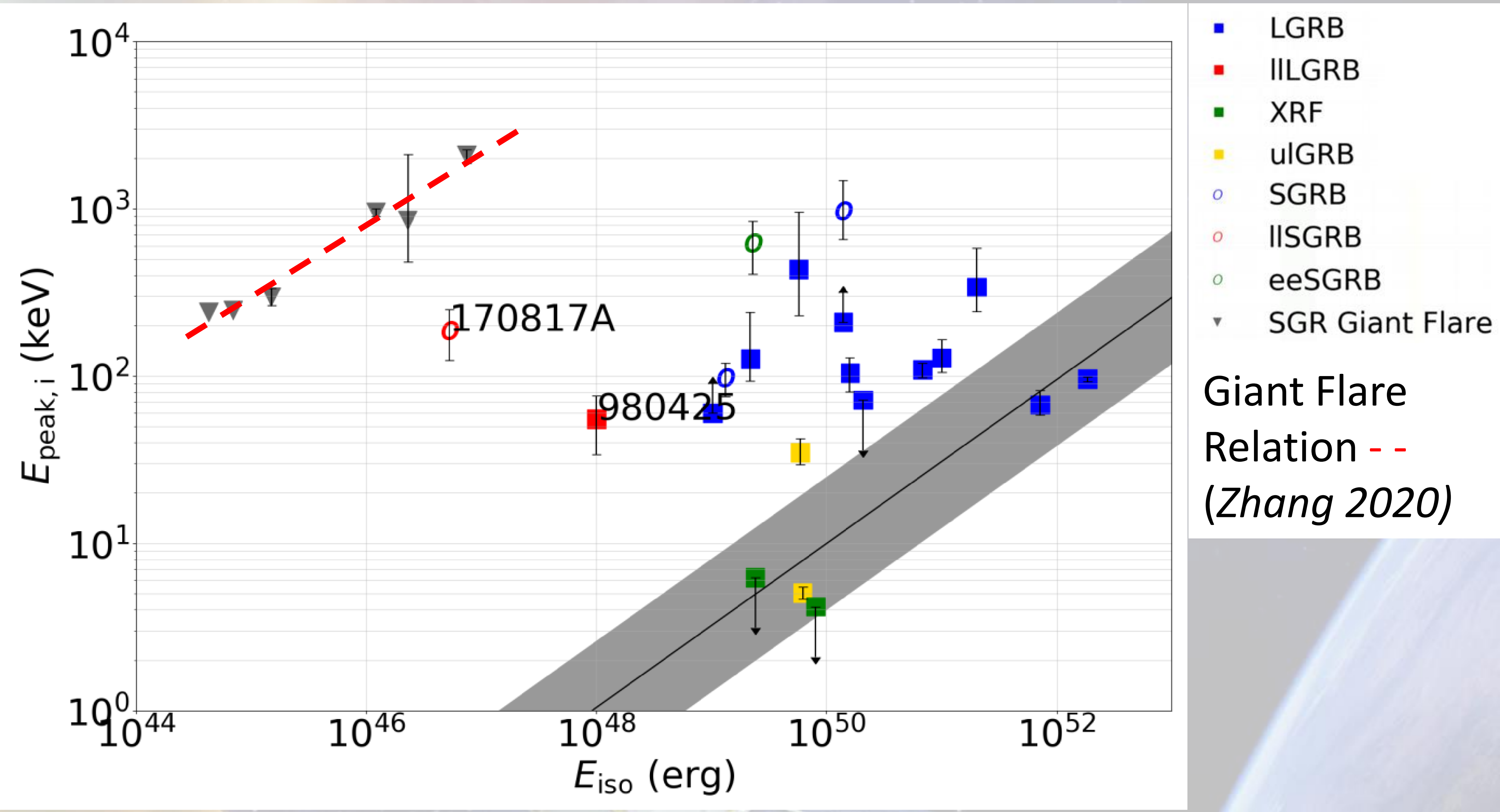
B. Arcier[1] · J.L. Atteia[1] · O. Godet[1] · S. Mate[1] · S. Guillot[1] · N. Dagoneau[2] · J. Rodriguez[2] · D. Gotz[2] · S. Schanne[2] · M.G. Bernardini[3,4]

Received: 4 November 2020 / Accepted: 2 December 2020 / Published online: 14 December 2020

Local sample: 41 objects with z < 0.3		
24 Long GRBs	10 Short GRBs	7 SGR Giant-Flares
17 LGRBs 3 ulGRBs 2 XRFs 2 llLGRBs	7 SGRBs 2 eeSGRBs 1 llSGRBs	



Isotropic energy distribution for local short high-energy transients
Source: Arcier et al. 2020



Giant Flare Relation - - (*Zhang 2020*)

Amati relation (Amati et al. 2006) for local short high-energy transients
Source: Arcier et al. 2020

Detection of transients from the event files: *count_trigger*

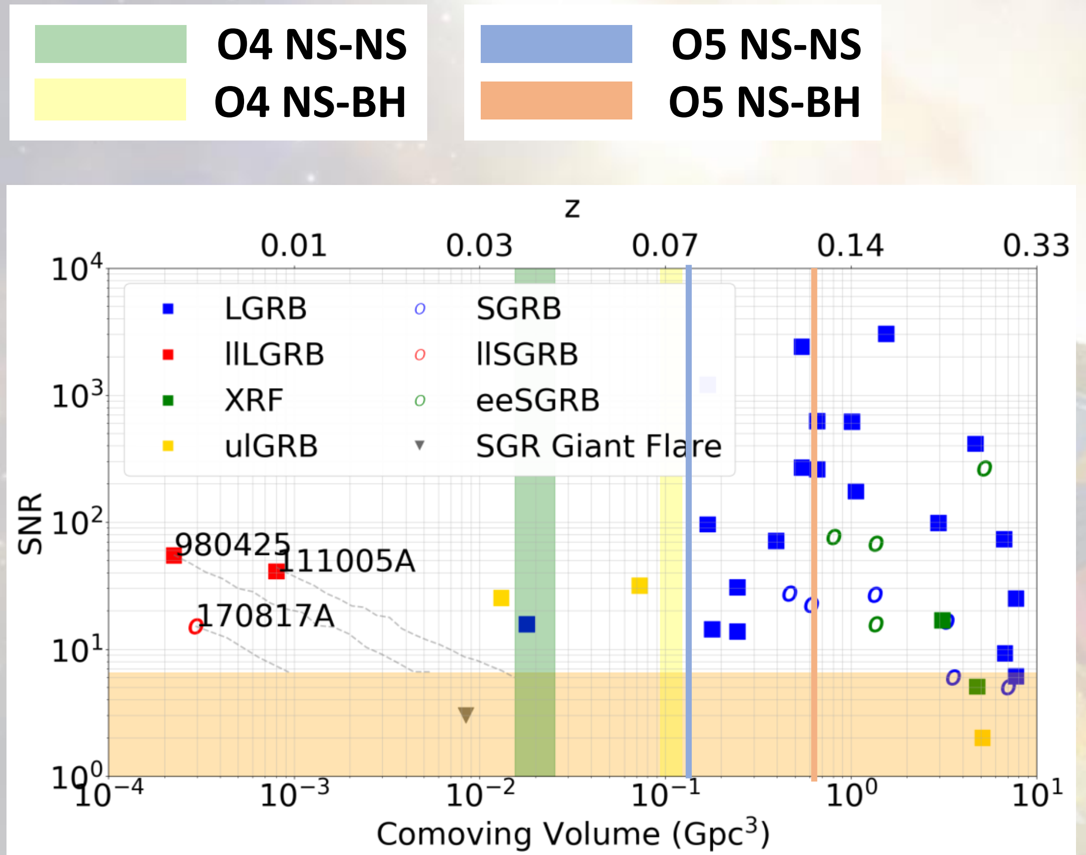
count_trigger – *ECLAIRs*

- Calculate the count SNR (count trigger) and the resulting image SNR

ECLAIRs input Events → **Count Trigger** → **Count SNR / Image SNR** → **Detected ?**

35 / 41 GRBs will be detectable !

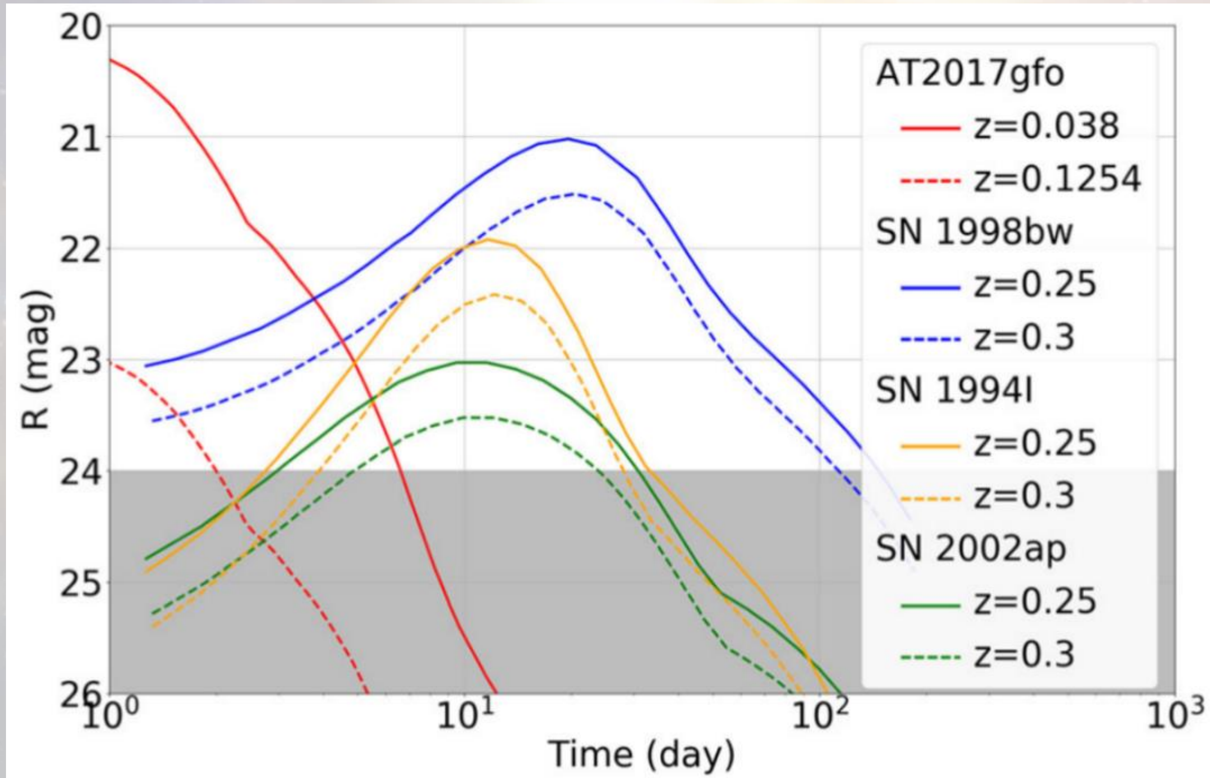
Multi-messenger astronomy with LIGO/Virgo:



Expected on-axis count SNR of ECLAIRs for local short high-energy transients
Source: Arcier et al. 2020

- GRB 111005A (SN-less supernova) and possibility to detect or not GW counterparts (ECLAIRs)
- 170817A detectable up to O4 NS-NS (ECLAIRs + GRM) + SVOM ground telescopes
- Off-axis, limited by gamma-ray telescopes. On-axis, limited by GWs detectors (ECLAIRs + GRM) → O5 will be sensitive up to first sGRBs detected

Using the VT, GWAC, C-GFT and COLIBRI for a dedicated follow-up of long & short GRBs



Estimation of the VT SN/KN detection horizon
Source: Arcier et al. 2020

- Systematic follow-up of the long GRBs with SVOM instruments
- Possibility to get observations with the VT

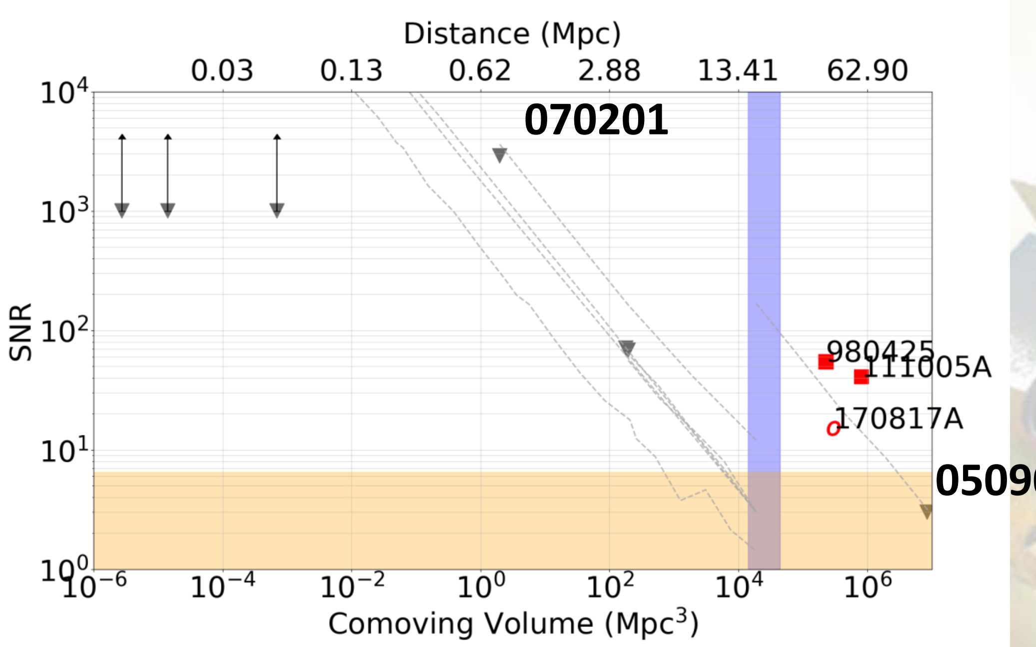
Detection of SGR-Giant Flares in the Virgo cluster

M31 – IC328:

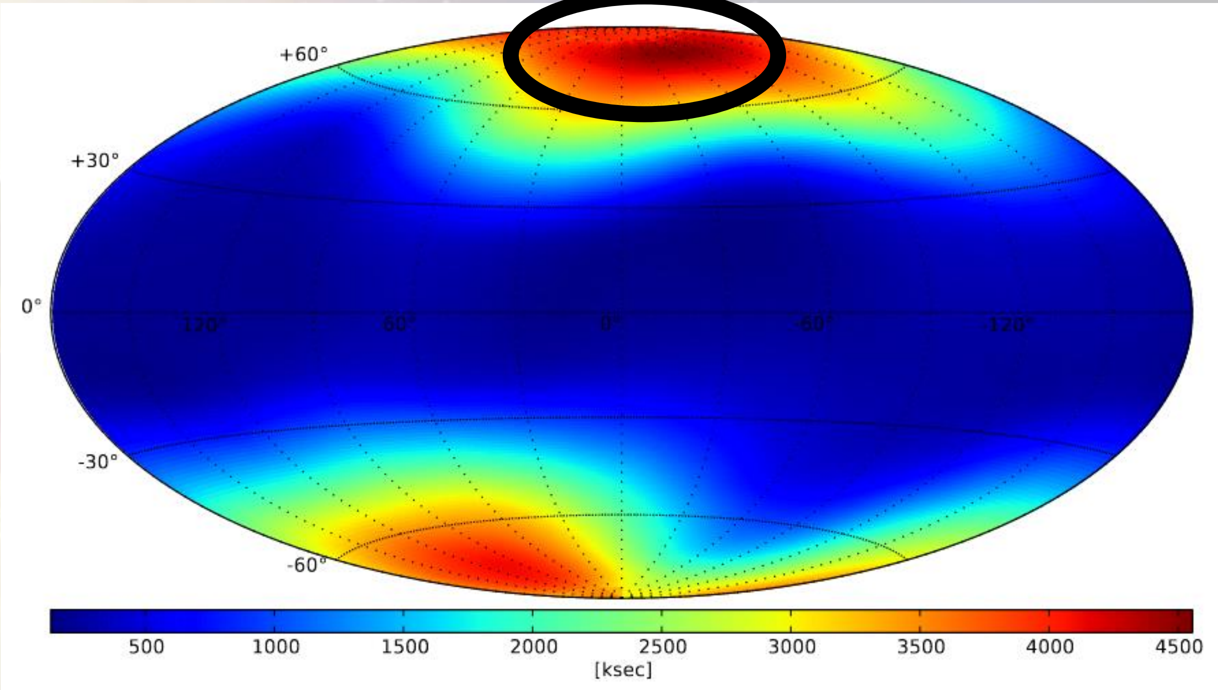
SFR $\sim 0.7\ M_{\odot}\ yr^{-1}$

Virgo Cluster:

SFR $\sim 50\ - 100\ M_{\odot}\ yr^{-1}$



SNR evolution for SGR Giant Flares.
Blue band is the Virgo cluster localization
Source: Arcier et al. 2020



Sky Exposure in galactic coordinates for the ECLAIRs pointing strategy following the B1 attitude law
Source: Wei et al. 2016

IV. Are binary black hole mergers and long γ-ray bursts drawn from the same BH population?

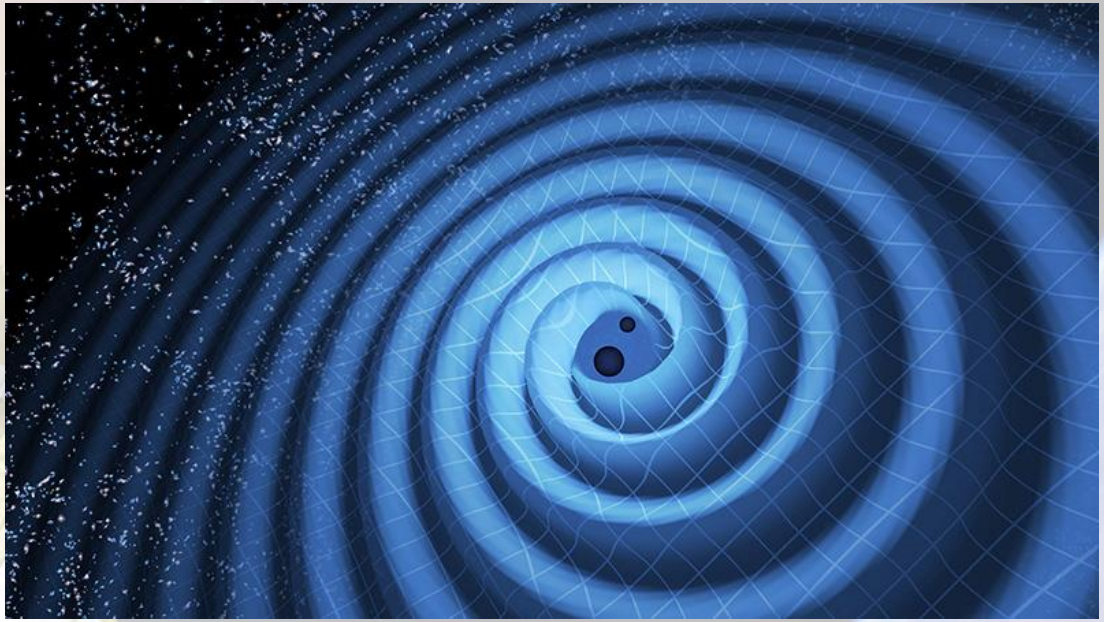
Binary Black-Holes mergers observed by advanced LIGO and advanced VIRGO:

O1, O2, O3a&b runs:
GWTC-1, GWTC-2, GWTC-2.1 & GWTC-3

Characterization of population possible !

74 BBH mergers with:

- Redshift z
- SNR
- Masses m_1 and m_2 and M_{f}



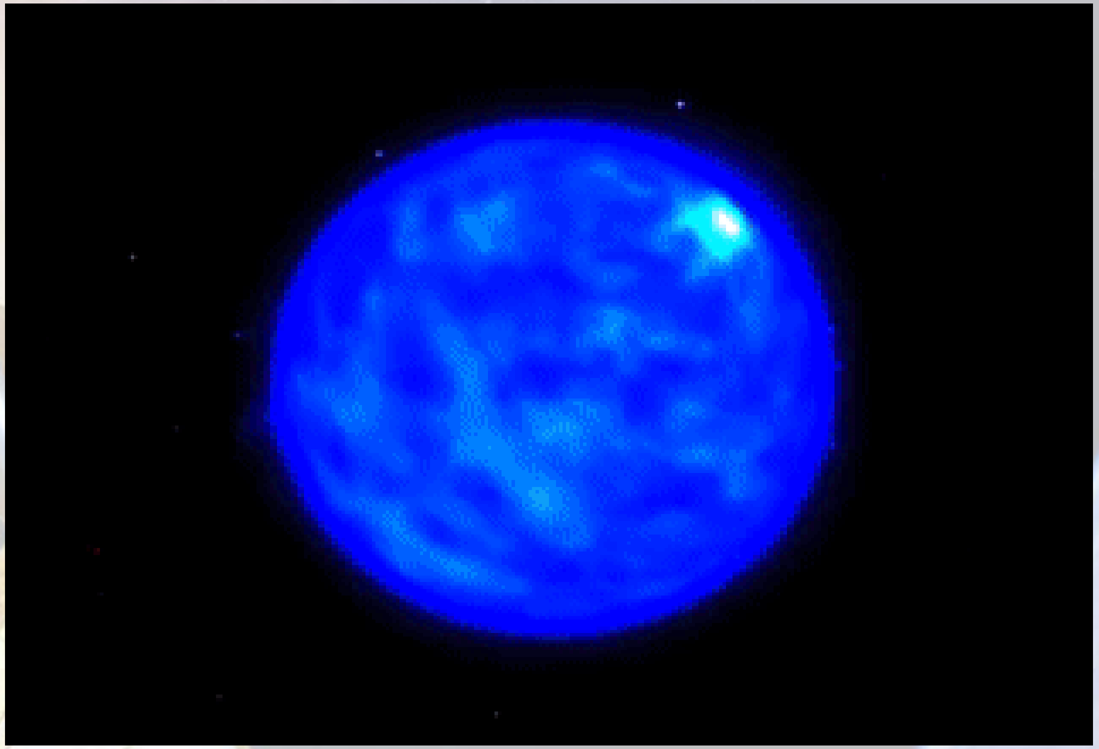
Binary Black Hole merger
Source: LVC

Long Gamma-Ray Bursts originate from collapsars

Common mechanism of formation:

- Massive stars evolve in binarity
- Low metallicity
- Rotational speed

The population might be linked ?



Collapsar artistic view
Source: INAF

Long Gamma-Ray Bursts
Density Rate

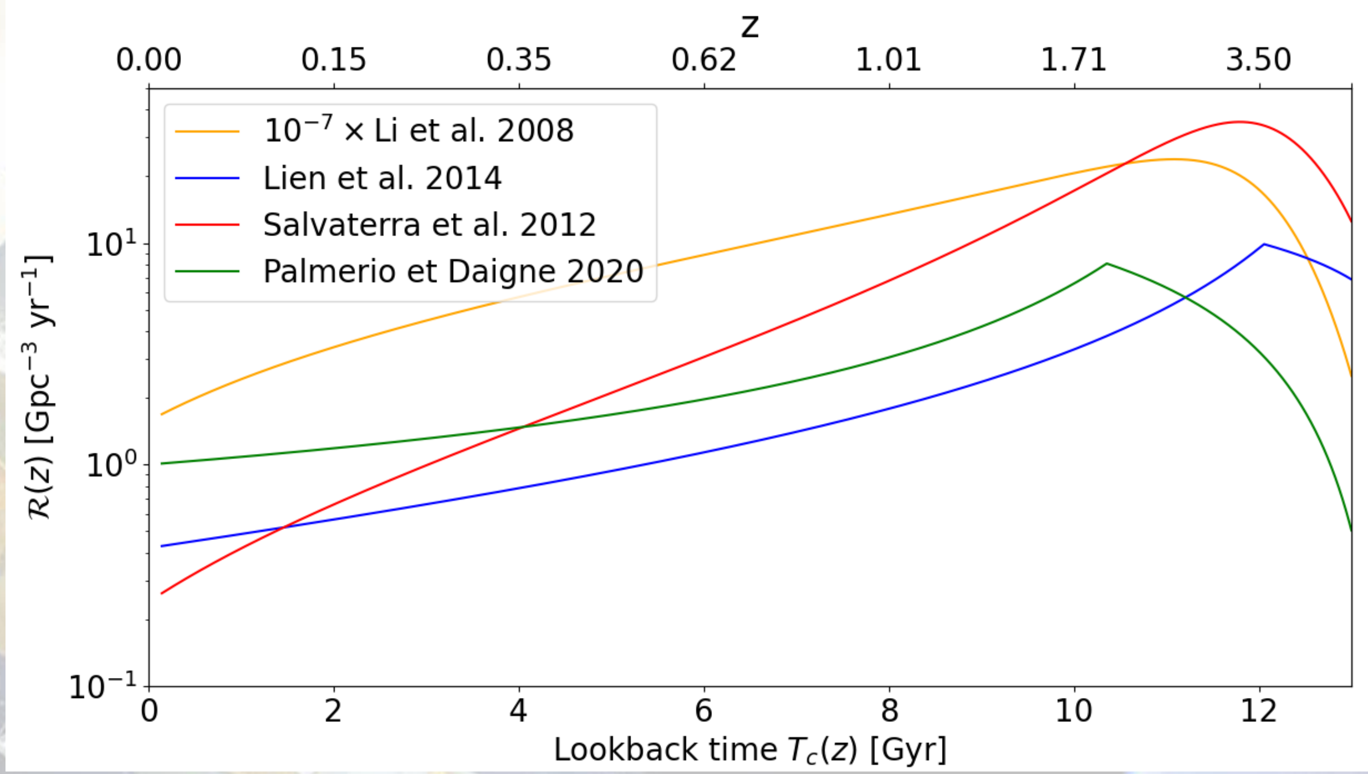
(based on Swift/BAT & Fermi/GBM observations):

GRB population models:

- *Palmerio et Daigne 2020*
- *Lien et al. 2014*
- *Salvaterra et al. 2012*

SFH models:

- *Li et al. 2008*



Density rate evolution for GRB and SFH models
Source: Arcier et Atteia 2021

Delayed models to get a $\rho(z_0)$:

$$\rho(z_0) \propto \int_{z_0}^{\infty} \mathcal{R}_{\mathrm{GRB}}(z)\, f(T_c(z) - T_c(z_0))\, \frac{\mathrm{d}T_c}{\mathrm{d}z}\, \mathrm{d}z$$

- Log-Normal

$$f(\tau) = \frac{1}{\tau\sigma_{\mathrm{t}}\sqrt{2\pi}} \exp\left(-\frac{\ln(\tau/t_{\mathrm{d}})^2}{2\sigma_{\mathrm{t}}^2}\right)$$

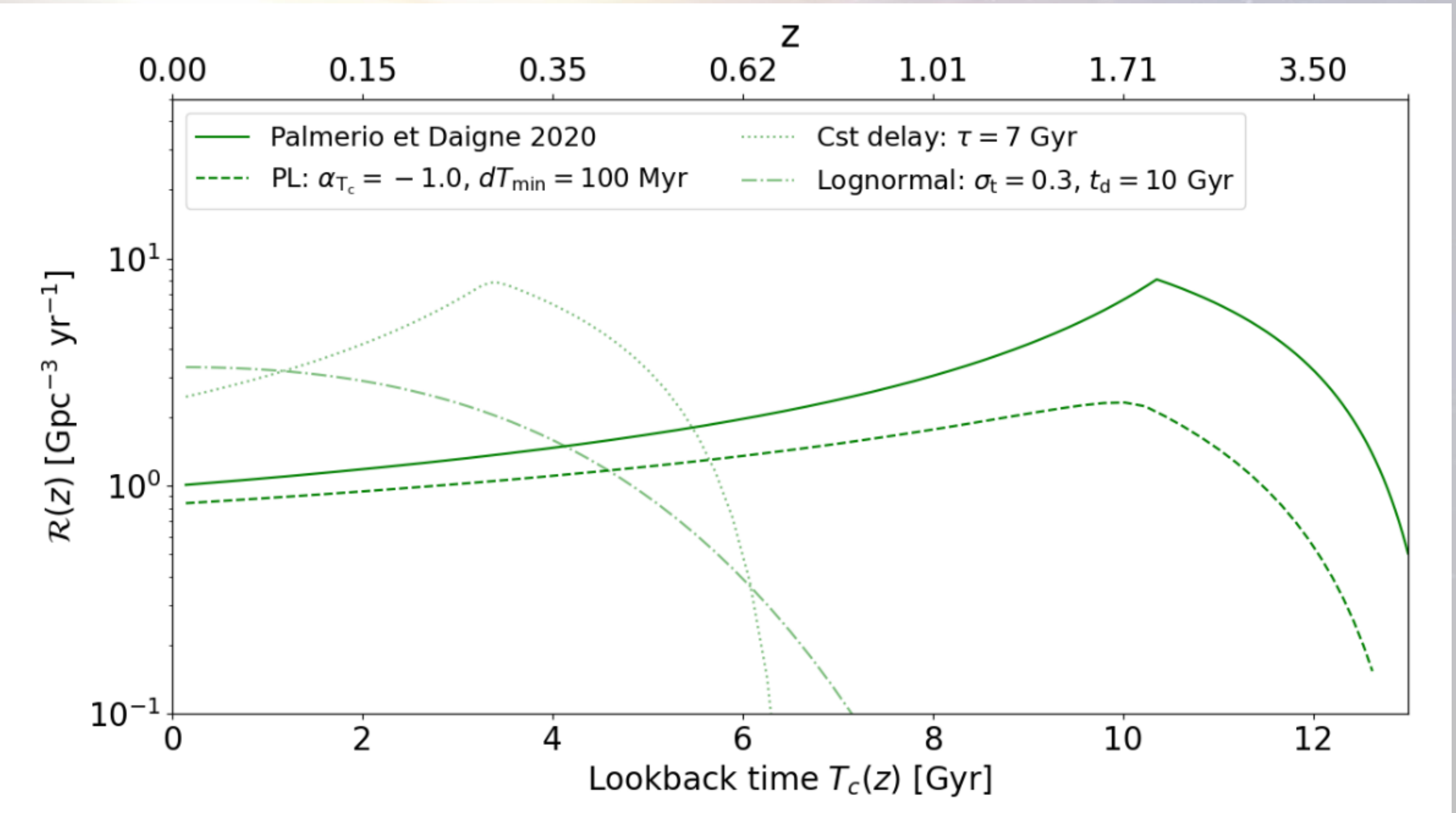
- Power-law

$$f(\tau) = \begin{cases} 0 & \tau \leq dT_{\min} \\ \tau^{\alpha} & \tau > dT_{\min} \end{cases}$$

- Cst Delay

29 models in total !

Delayed models to get a $\rho(z_0)$:

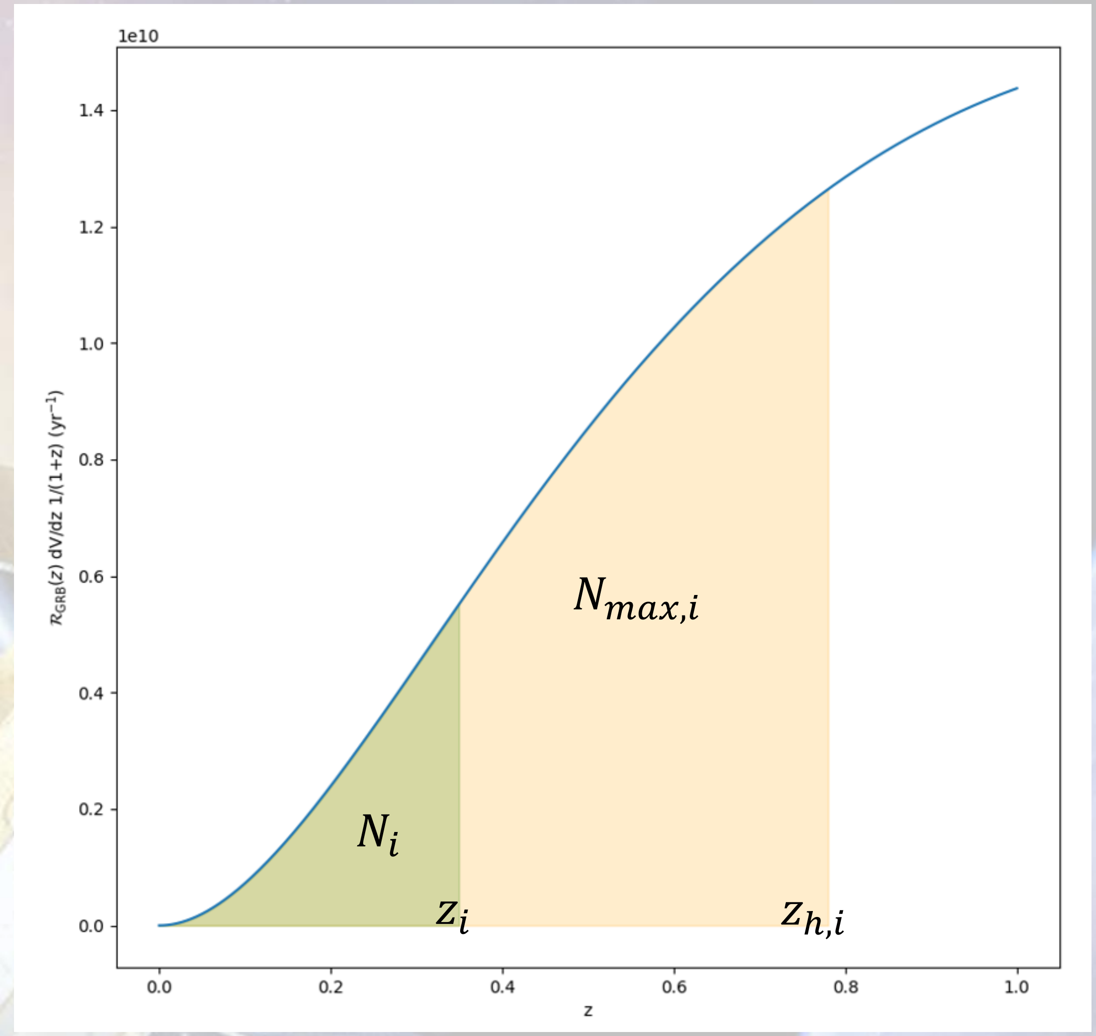


Density rate evolution for delayed GRB and SFH models
Source: Arcier et Atteia 2021

METHOD: The $N/N_{\mathbf{max}}$ test

$$\mathrm{N_i} = \int_0^{z_i} \rho(z) \, \frac{\mathrm{d}V(z)}{\mathrm{d}z} \, \frac{1}{1+z} \, \mathrm{d}z$$

Selection effects mitigated
→ testing the observed objects against there own detection limit



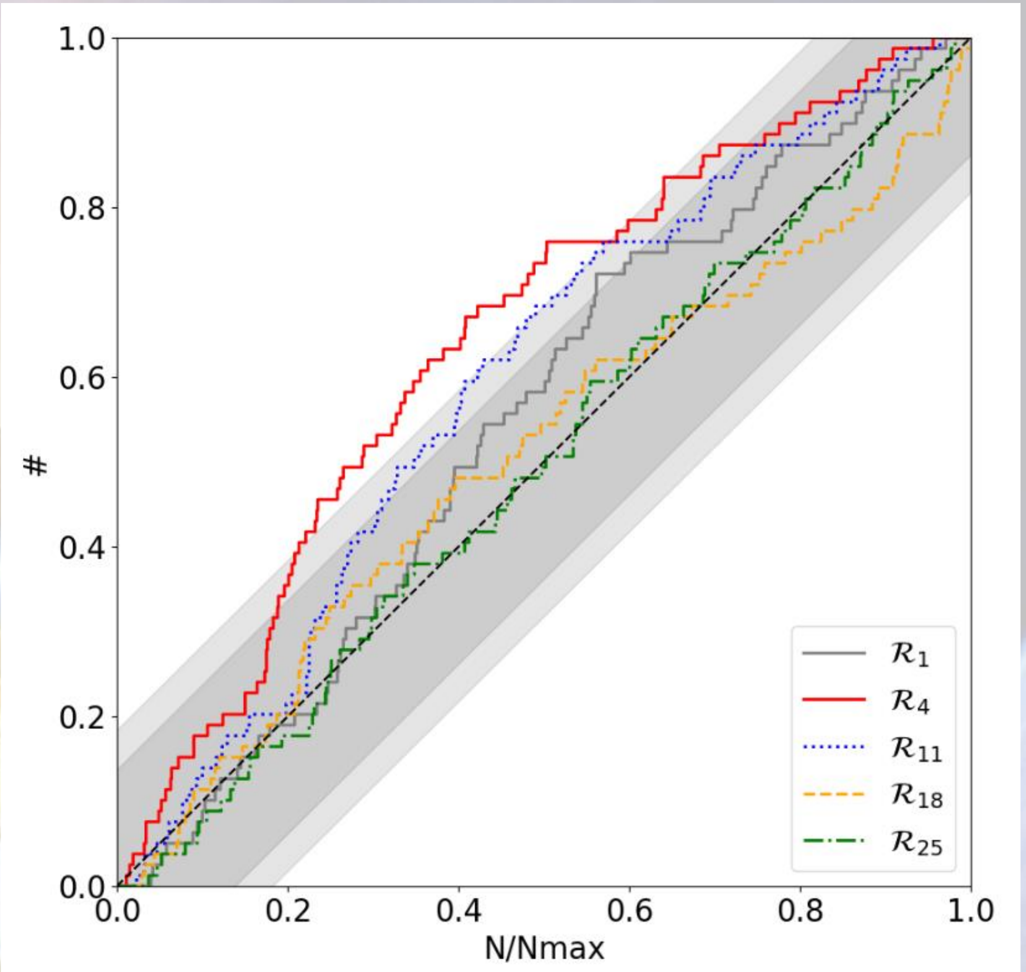
METHOD:
N/N_{max} test using $\rho(z)$

for i in 74 BBHs mergers:

- Compute horizon redshift $z_{\mathrm{h,i}}$
- Compute N_{i} and $N_{\mathrm{max,i}}$ using a model

With N/N_{max} distribution:

- Perform a KS-test vs $\mathcal{U}(0,1)$
- Reject based on p-value (1% - 10%)



Cumulative distribution for different tested models
Source: Arcier et Atteia 2021

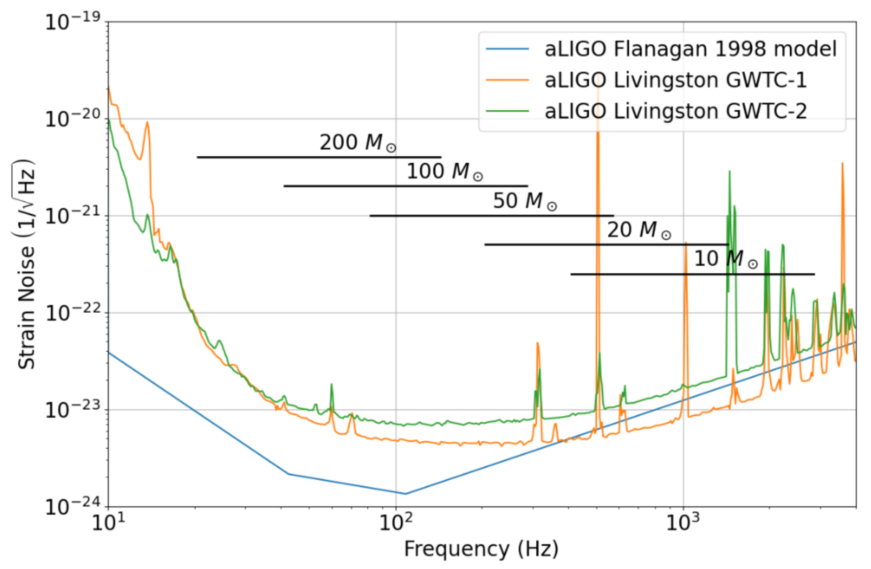
METHOD: Computation of $z_{\mathbf{h,i}}$

LALSimulation

m_1, m_2, z with IMRPhenomD

$$\mathrm{SNR}_{\mathrm{Ch21}} = \sqrt{4\int_{f_{\min}}^{f_{\max}} \frac{|h^{+}(f)|^2}{S_h(f)}\mathrm{d}f}$$

Horizon redshift computation
Source: Chen et al. 2021



Strain noise from LIGO
Source: Arcier et Atteia 2021

METHOD: Computation of $z_{\mathbf{h,i}}$

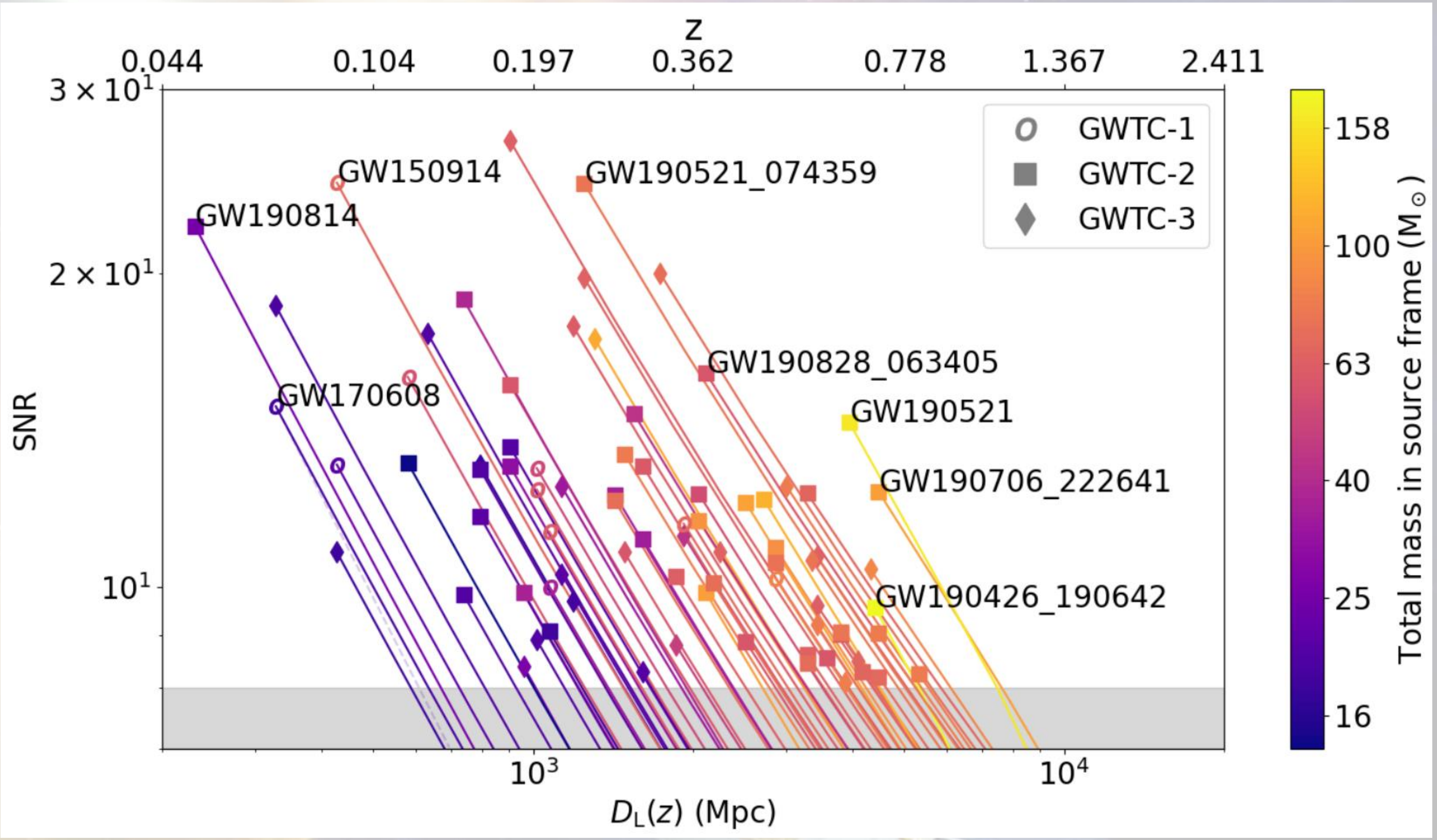
Orientation of the BBH merger + sky localization → Antennae pattern

$$\mathrm{SNR}_{\mathrm{Ch21}} = \sqrt{4 \int_{f_{\mathrm{min}}}^{f_{\mathrm{max}}} \frac{|h^{+}(f)|^2}{S_h(f)} \mathrm{d}f}$$

MAXIMUM redshift possible ≠ Horizon redshift for a given antennae pattern

$$\mathrm{SNR}(z, m_1, m_2) = \frac{\mathrm{SNR}_{\mathrm{Ch21}}(z, m_1, m_2)}{\mathrm{SNR}_{\mathrm{Ch21}}(z_0, m_1, m_2)} \times \mathrm{SNR}_0$$

METHOD: Computation of $z_{\mathbf{h,i}}$



Evolution of the expected SNR for the 74 BBH mergers

Source: Arcier et Atteia 2021

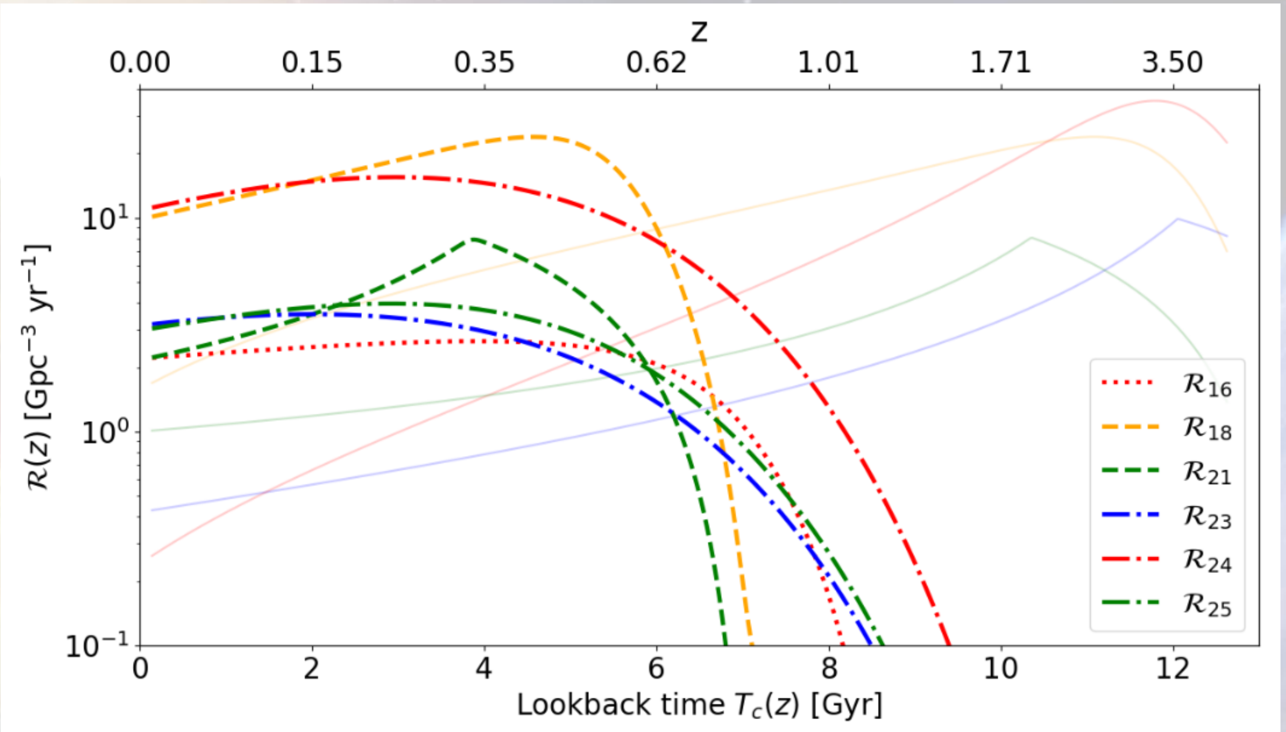
RESULTS

7 favored **GRB** models (p-value > 10%)

8 marginally accepted **GRB** models (1% < p-value < 10%)

- Without delay → not-favored
- Minimum delay ~ 6 Gyr
- Dearth of BBHs mergers after $z \sim 1$?

To be taken with a grain of salt
→ hypothesis made

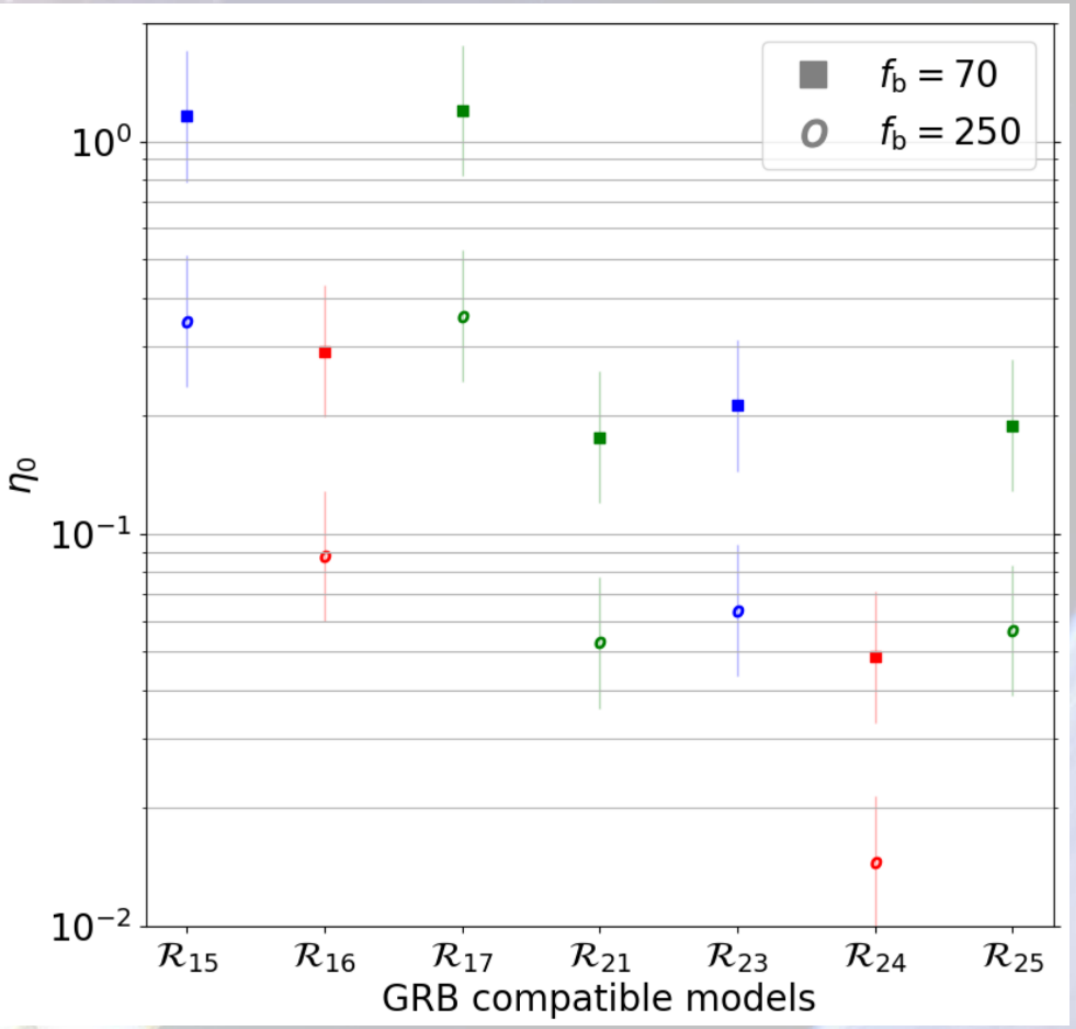


Density rate evolution for accepted models
Source: Arcier et Atteia 2021

RESULTS

7 favored **GRB** models (p-value > 10%)

- $\rho(z = 0.2) = 19 - 41 \text{ Gpc}^{-3}\text{yr}^{-1}$ from GWTC-3
- η_0 is the ratio of BHs created during long GRBs that will eventually merge into a BBH
- $\eta_0 \sim 10\%$
- Assuming here all BBHs are LGRBs descendants, maybe only a fraction



Fraction of long GRBs with BBH mergers descendants, for two beaming factors f_b
Source: Arcier et Atteia 2021

ASTROPHYSICAL DISCUSSION

Are BBH mergers and LGRBs from the same BH parent population?

- Favored models have delay $\sim 5 - 6$ Gyr between formation and merger → A bit higher than simulations
- Lack of BBHs mergers after $z \sim 0.6$ → Stochastic background analysis (*Callister et al. 2020*)
- Maybe only a subsample ? High χ_{eff} ? Given mass range ? Same for GRBs with XRFs, uLGRBs, low-luminosity GRBs

ASTROPHYSICAL DISCUSSION

Consequences on the GRB phenomenology

- Similar mechanism for BBHs mergers and LGRBs formation: binarity
- Precessing BHs and GRB jets, with imprint on prompt emission and/or afterglow (*Fargion & Grossi 2006, Huang & Liu 2021*)
- Environment for first GRB: massive star occultation, possible occultation of the jet, afterglow in very dense environment (*Zou et al. 2021*)

→ ***SVOM*** (*Wei et al. 2016, Arcier et al. 2020*)

THANK YOU ! QUESTIONS ?