See talks on the “Complementary Observations”session:
P. Evans, S. Giarratana, L. Natalucci, S. Vergani

GRB observations

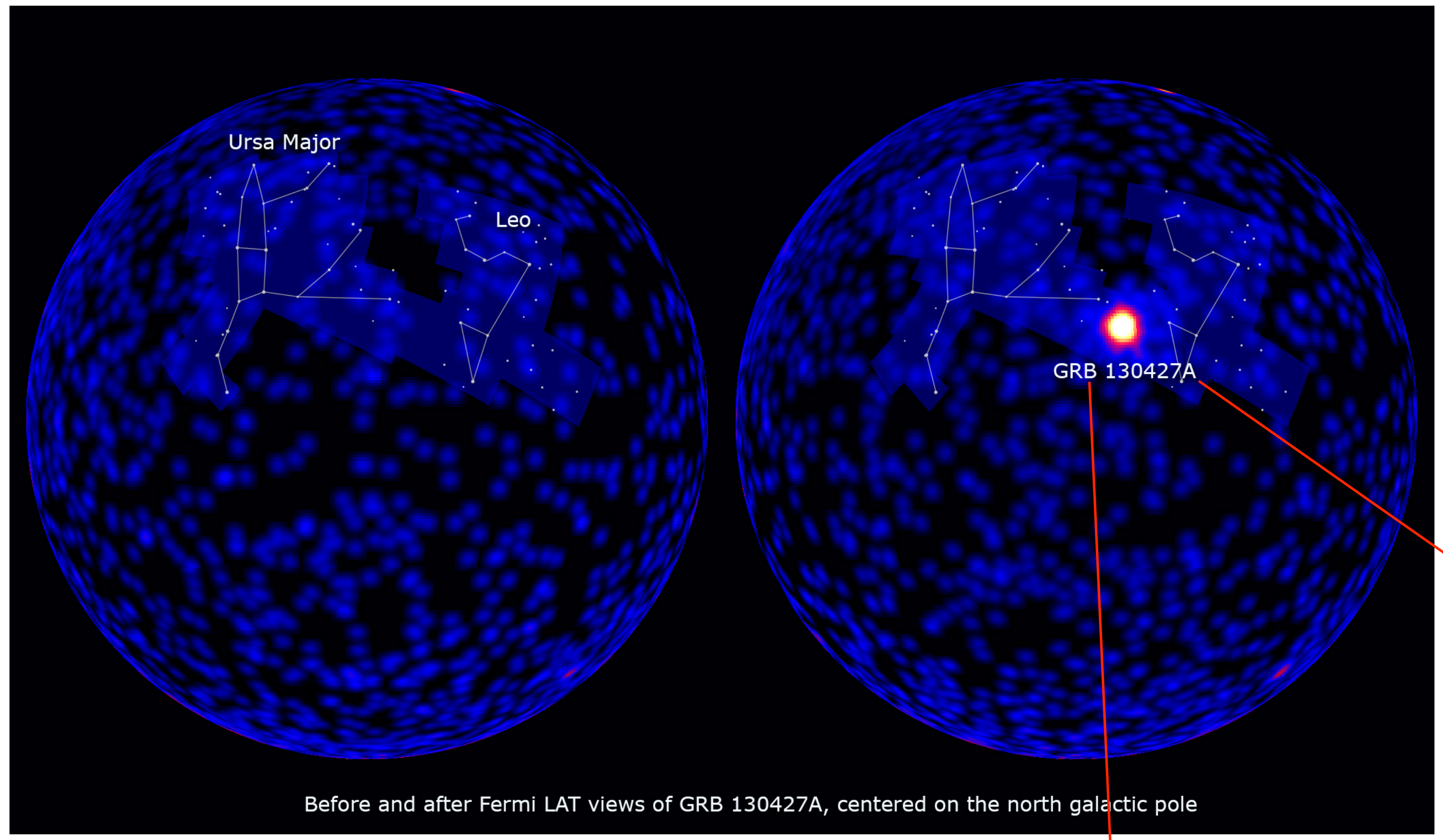
Maria Grazia Bernardini

INAF - Osservatorio Astronomico di Brera, Laboratoire Univers et Particules de Montpellier

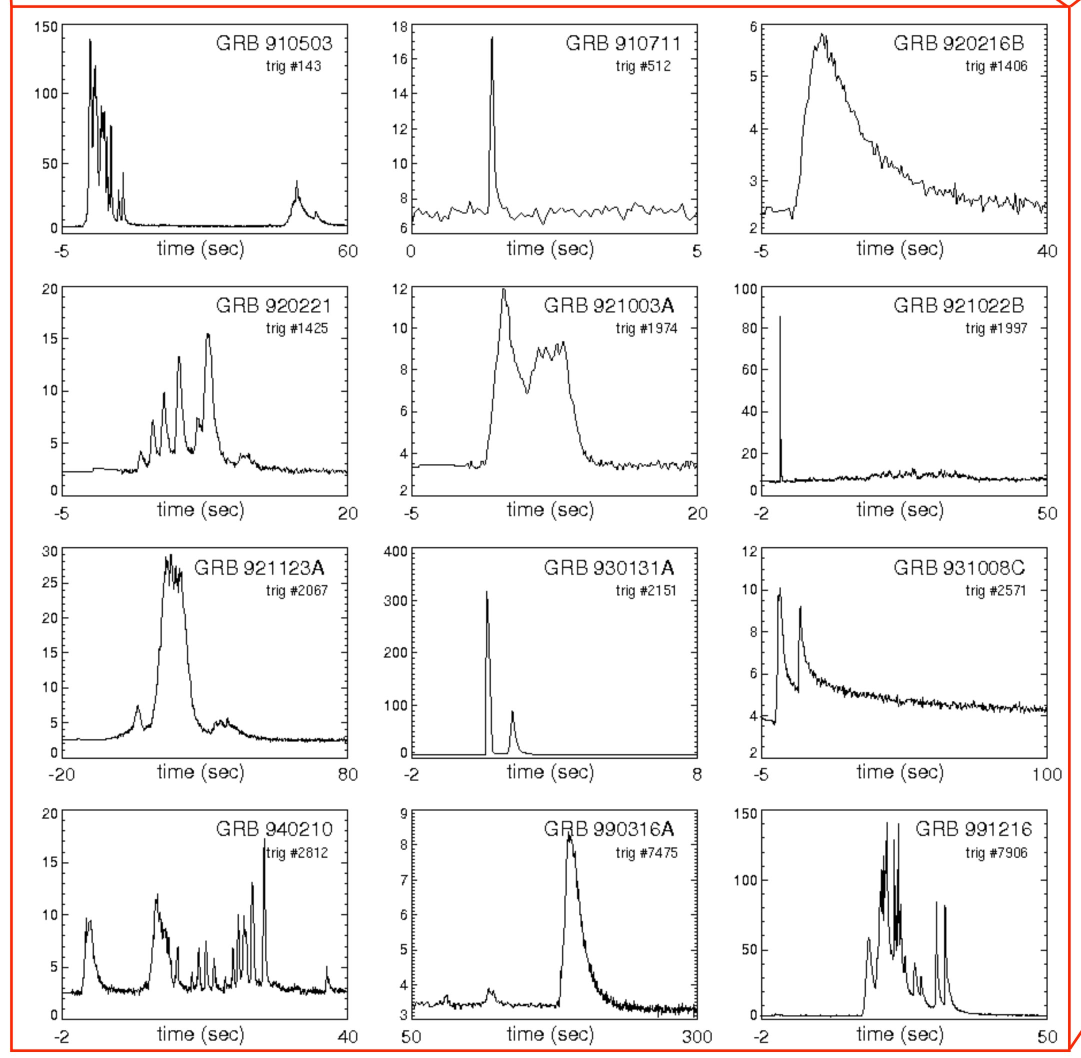
ACME
Astrophysics Centre for Multimessenger studies in Europe

Gamma-ray bursts (GRBs)

The most powerful electromagnetic sources in the Universe



PROMPT EMISSION

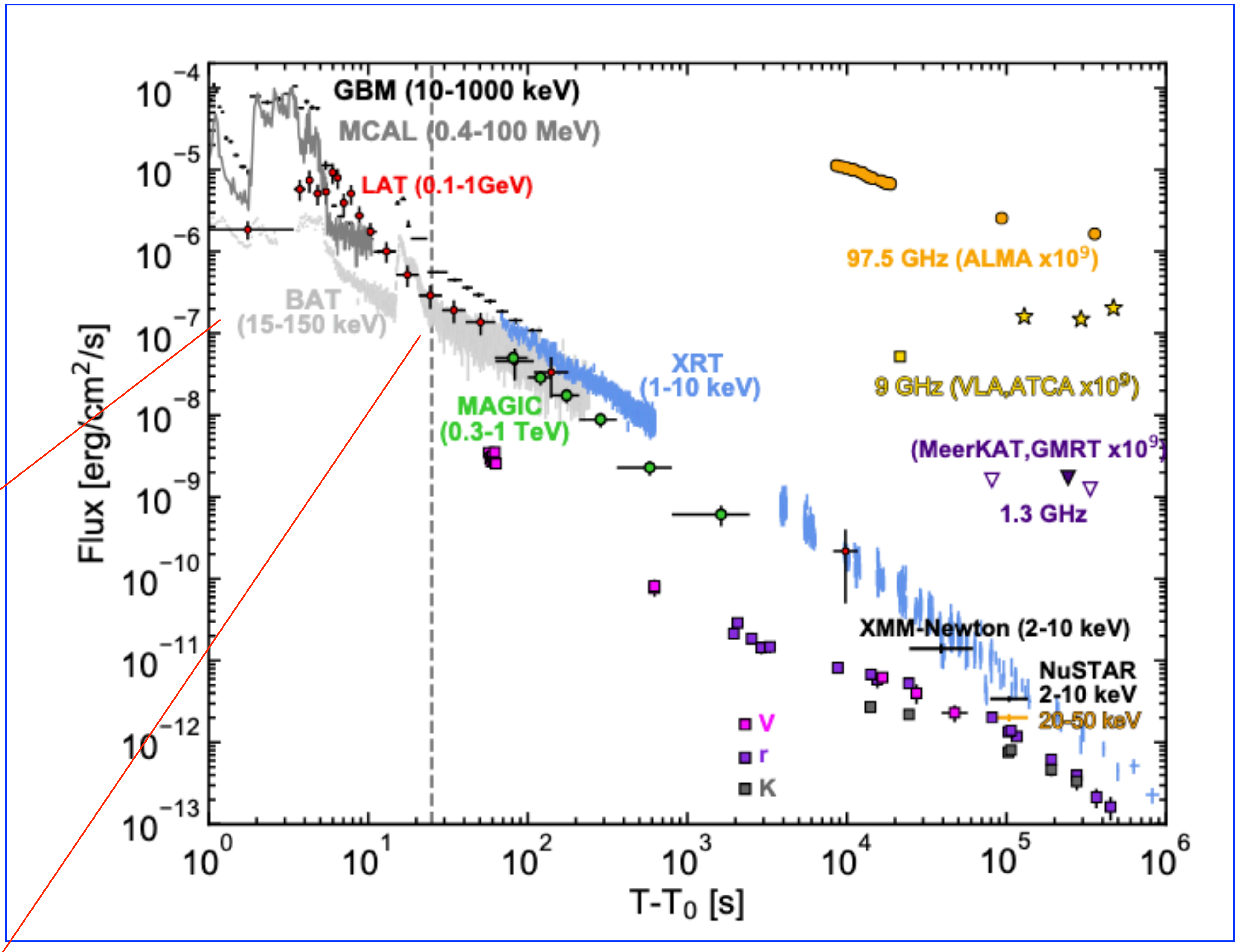


Duration: ms up to minutes

Fluence: ~10^{-7} - 10^{-3} erg cm^{-2}

Flux: ~10^{-8} - 10^{-4} erg cm^{-2} s^{-1}

Energy range: ~ keV up to ~ GeV



AFTERGLOW

Duration: hours to days

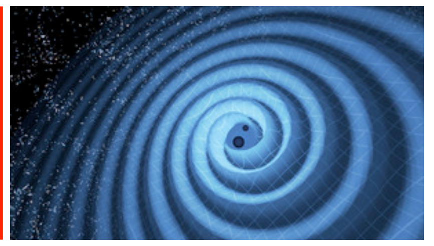
Flux: smoothly decaying

Energy range: from GeV to X-rays, UV, optical, IR, radio

Gamma-ray bursts (GRBs)

A bit of history

BIRTH OF THE MULTI-MESSENGER ASTRONOMY WITH GWs



INTEGRAL
- Short GRBs and GW

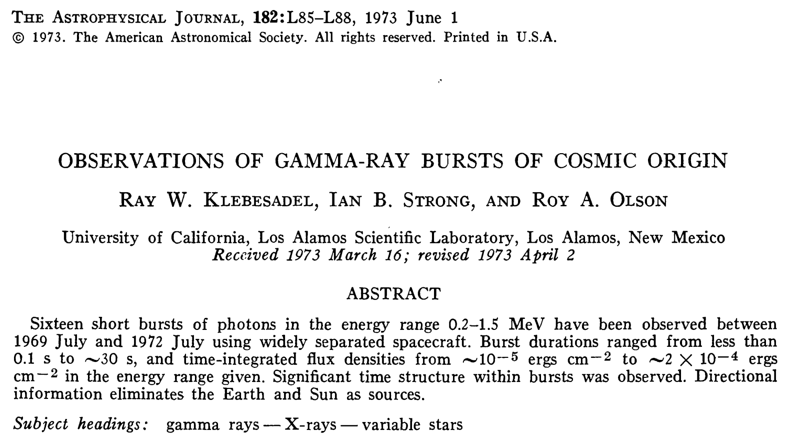
Discovery of the GRBs VHE counterpart: **MAGIC, H.E.S.S., LAAHSO**

1970 — 1980 — 1990 — 2000 — 2010 — 2020 — years

170817

Agile

Announcement of the discovery by the Vela satellites



The Astrophysical Journal, 182:L85–L88, 1973 June 1
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OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

Ray W. Klebesadel, Ian B. Strong, and Roy A. Olson

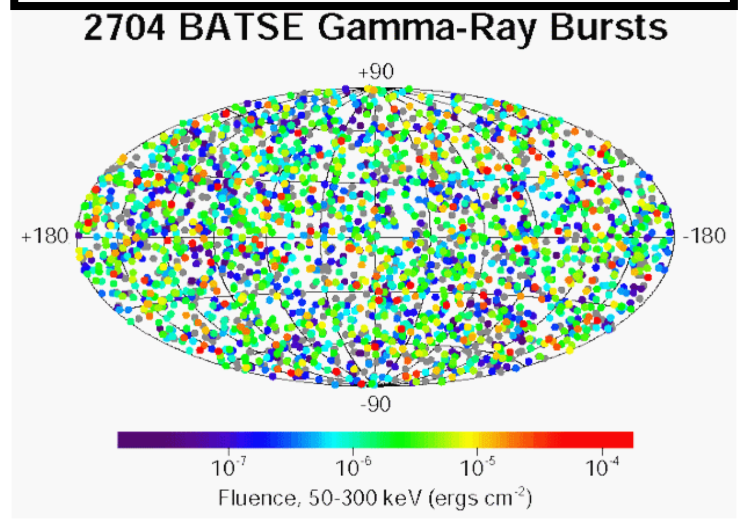
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Received 1973 March 16; revised 1973 April 2

ABSTRACT

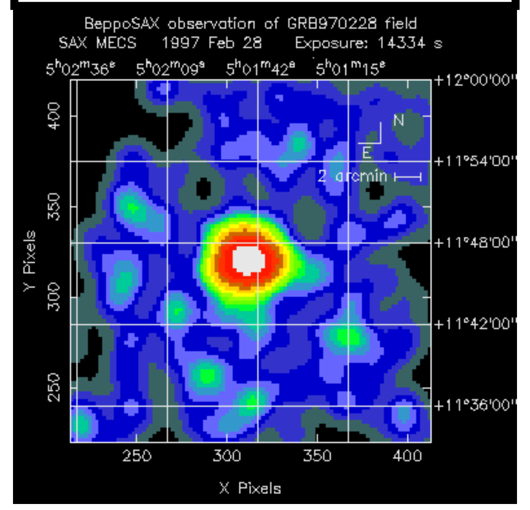
Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to ~30 s, and time-integrated flux densities from $\sim 10^{-5}$ ergs cm^{-2} to $\sim 2 \times 10^{-4}$ ergs cm^{-2} in the energy range given. Significant time structure within bursts was observed. Directional information eliminates the Earth and Sun as sources.

Subject headings: gamma rays — X-rays — variable stars

CGRO/BATSE
- Extragalactic origin
- Short and long
- Prompt emission spectrum

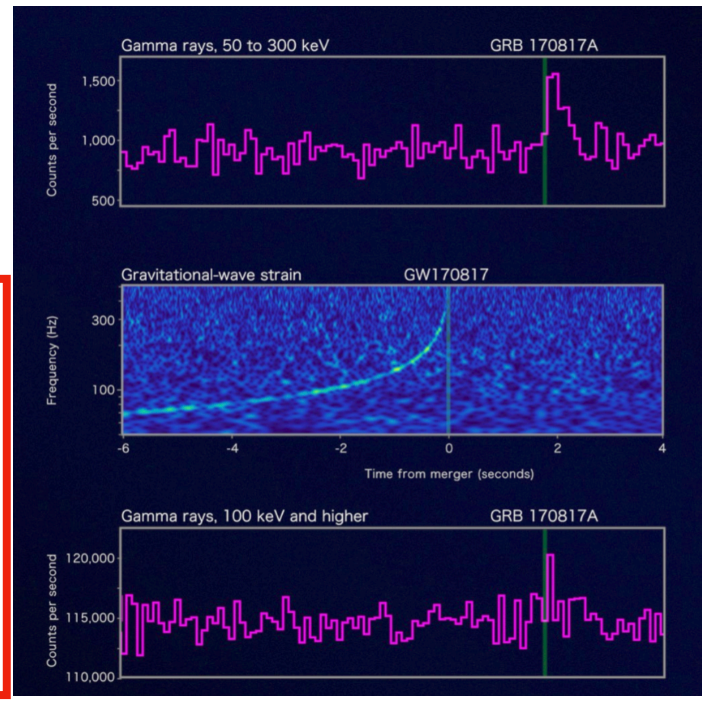


BeppoSAX
- Long GRBs afterglow and redshift
- Long GRBs and SNe

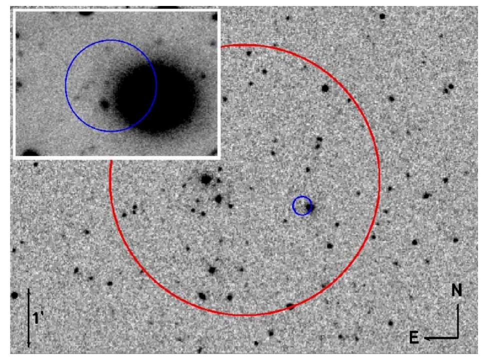


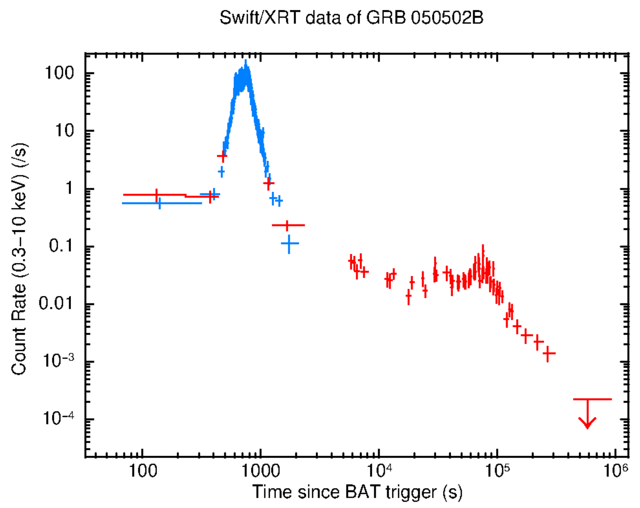
HETE II
- XRR/XRF
- Short GRB afterglow

Fermi
- Prompt emission at high-energy
- Short GRBs and GW



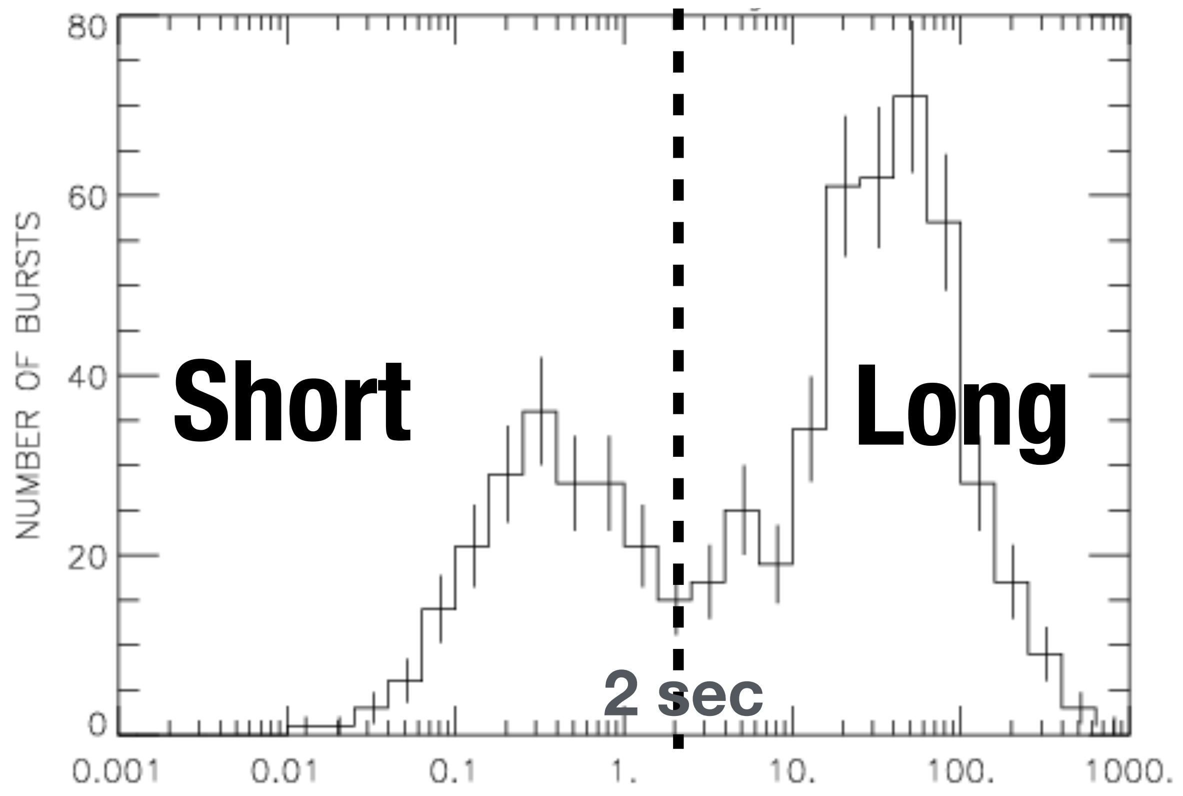
Swift
- Short GRBs afterglow and redshift (and progenitors)
- Early X-ray emission (plateaus and flares)
- UV kilonova





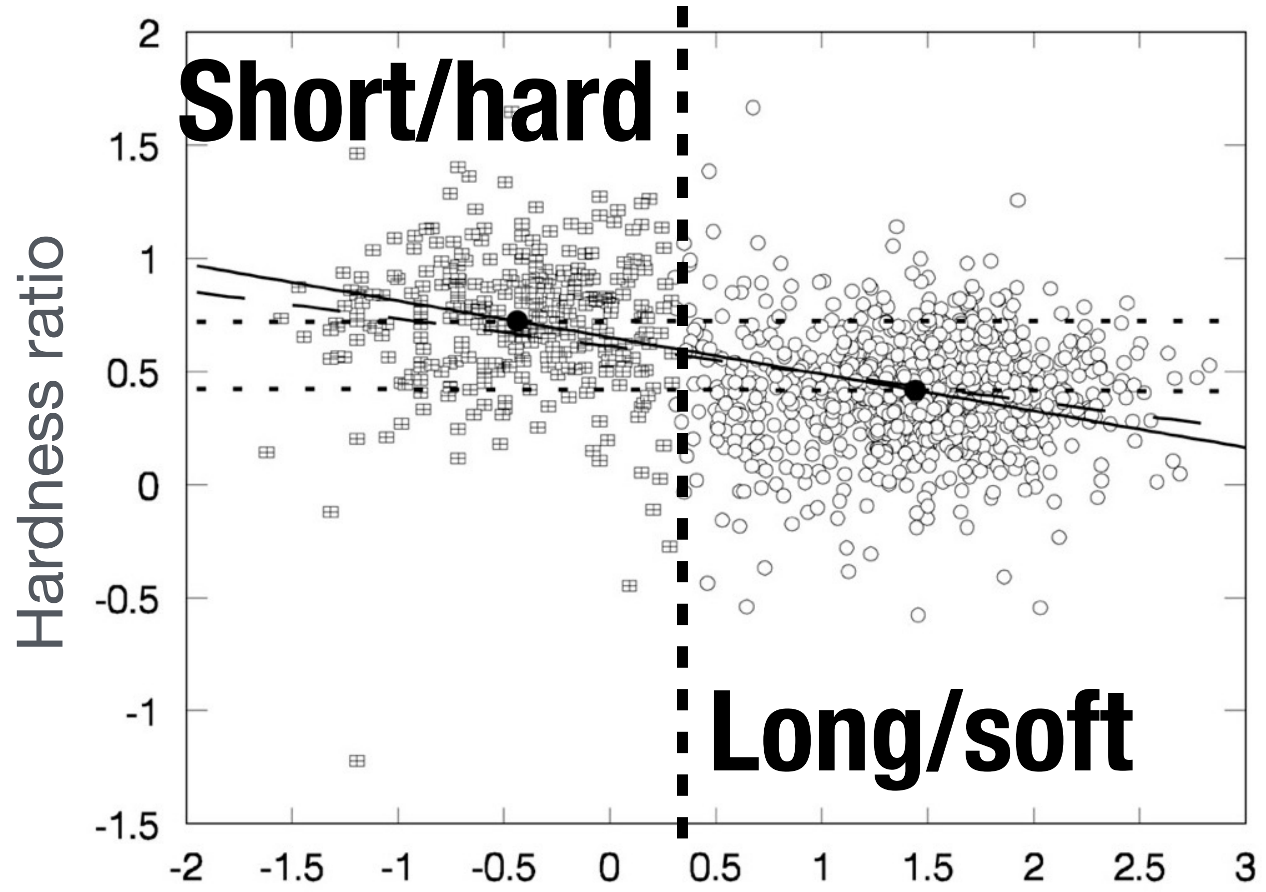
Two flavors: SGRBs and LGRBs

Distribution of prompt emission duration from BATSE catalog



Prompt emission duration

Duration vs. Hardness

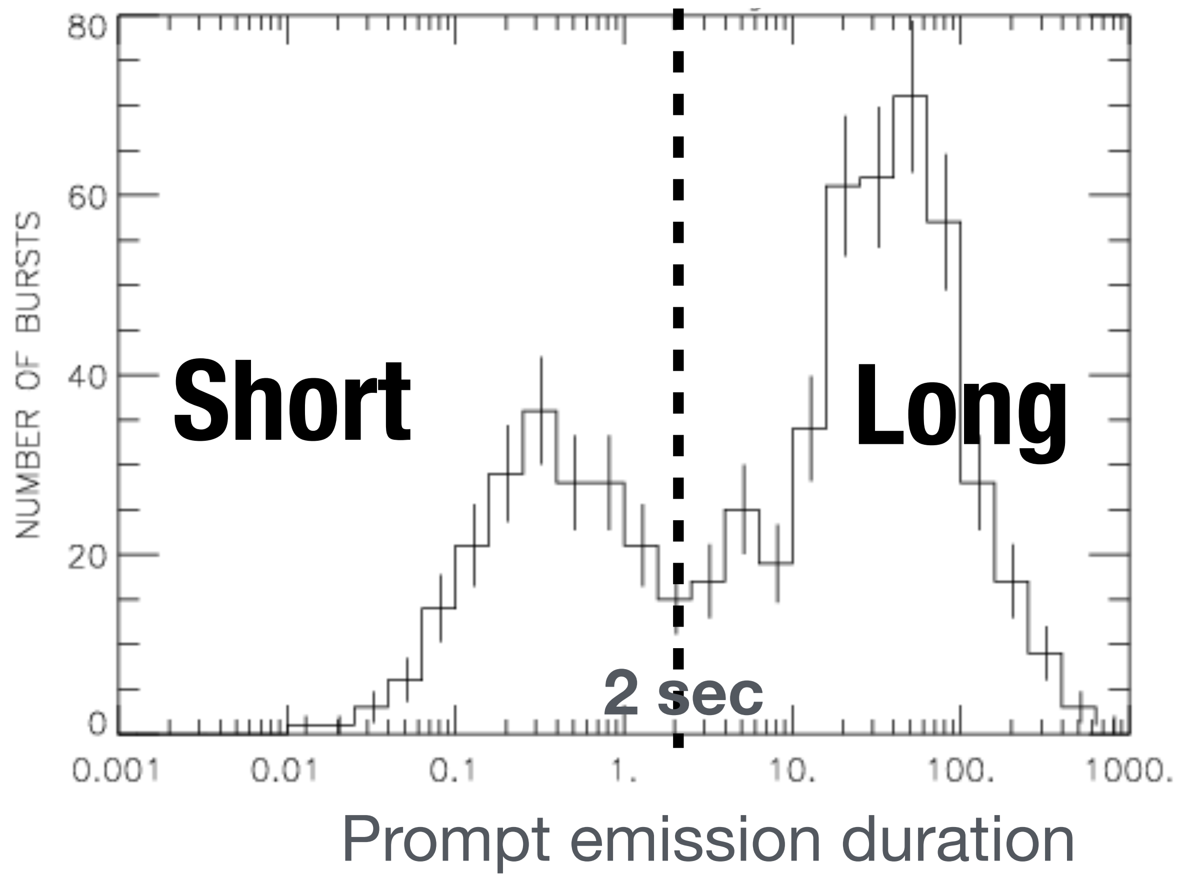


Prompt emission duration

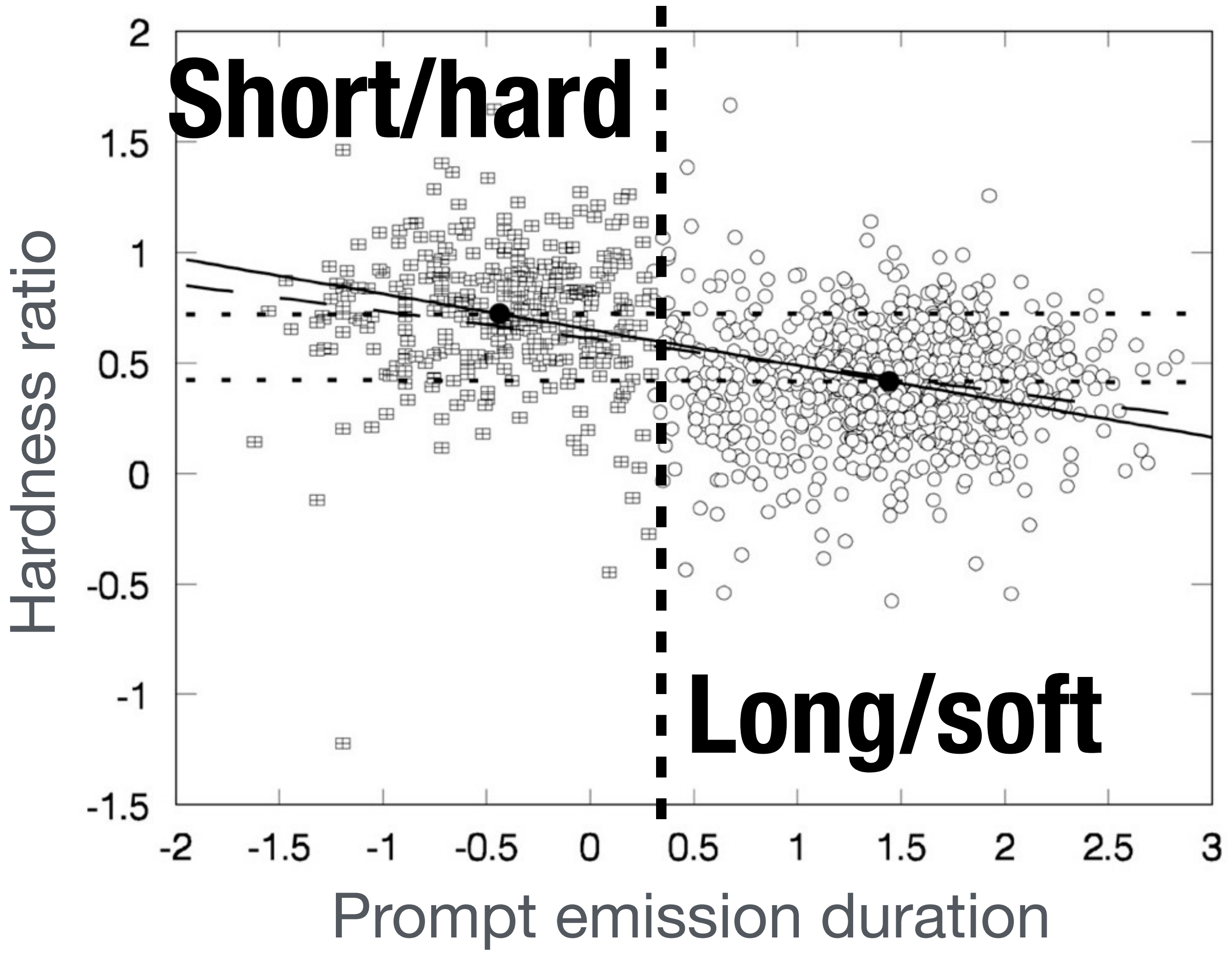
- Two types of GRBs when classified on the basis of their prompt emission duration: SGRBs (T_{90}<2 s) and LGRBs (T_{90}>2 s)
- SGRBs are spectrally harder than LGRBs

Two flavors: SGRBs and LGRBs

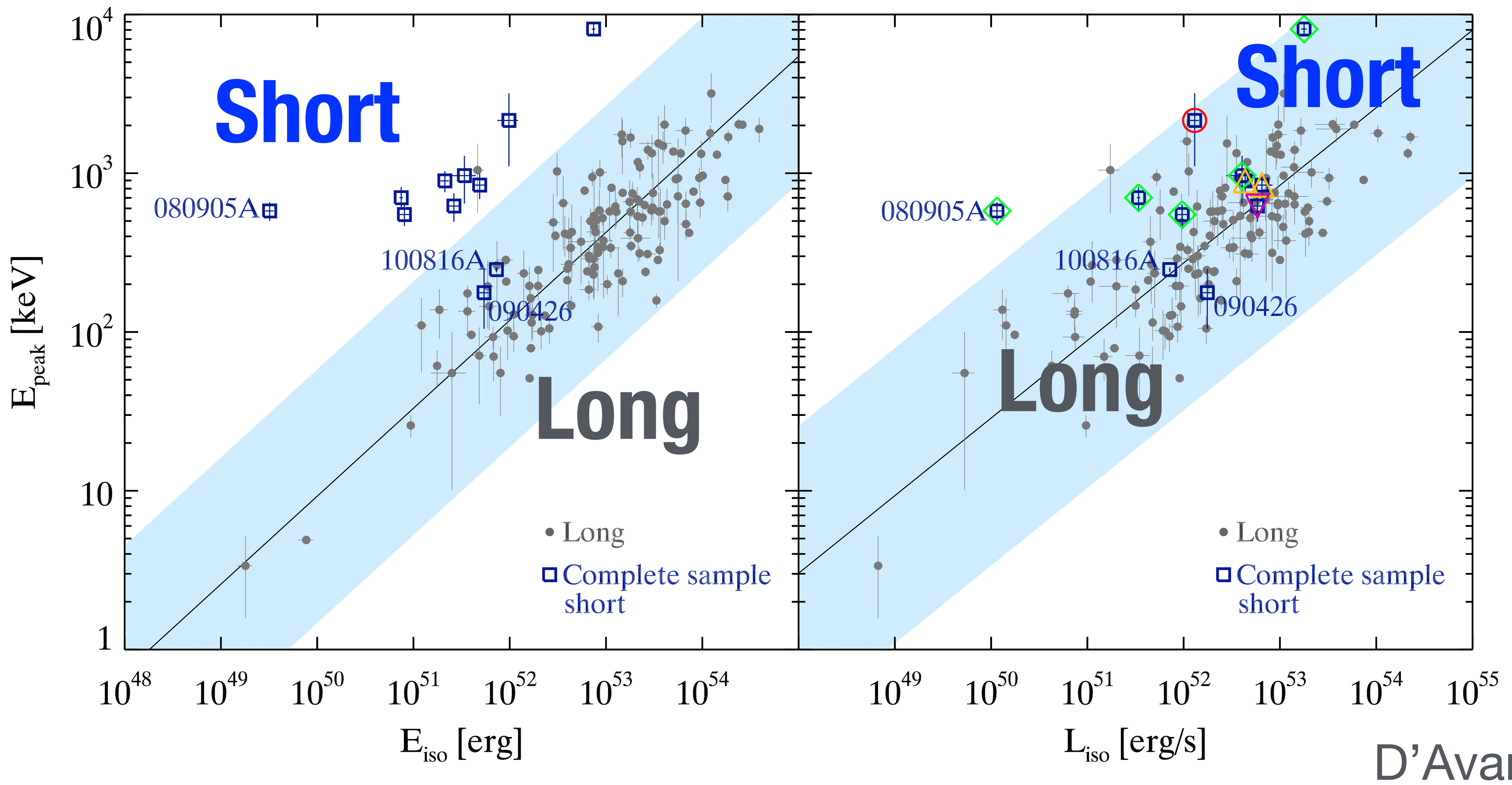
Distribution of prompt emission duration from BATSE catalog



Duration vs. Hardness



Epk-Eiso and Epk-Liso correlations



D'Avanzo+14

- Two types of GRBs when classified on the basis of their prompt emission duration: SGRBs (T_{90}<2 s) and LGRBs (T_{90}>2 s)
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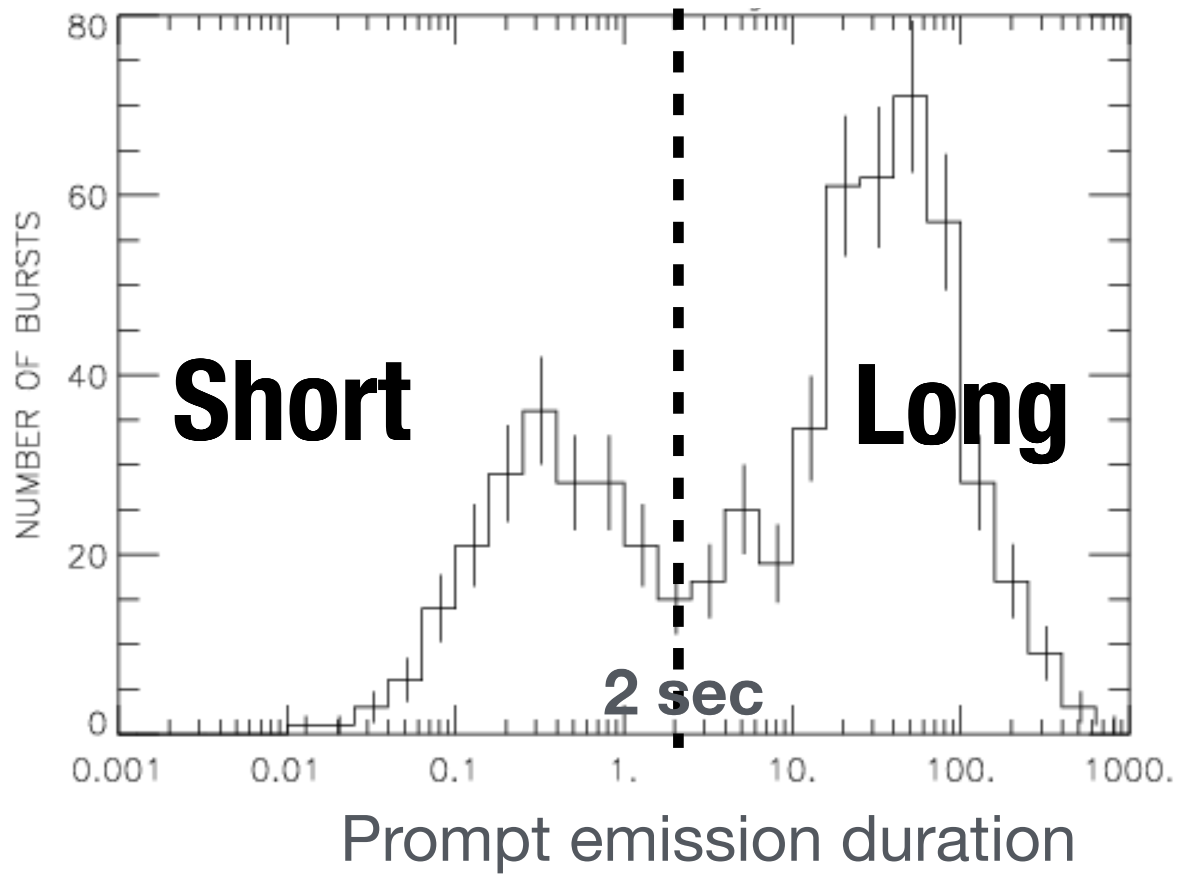
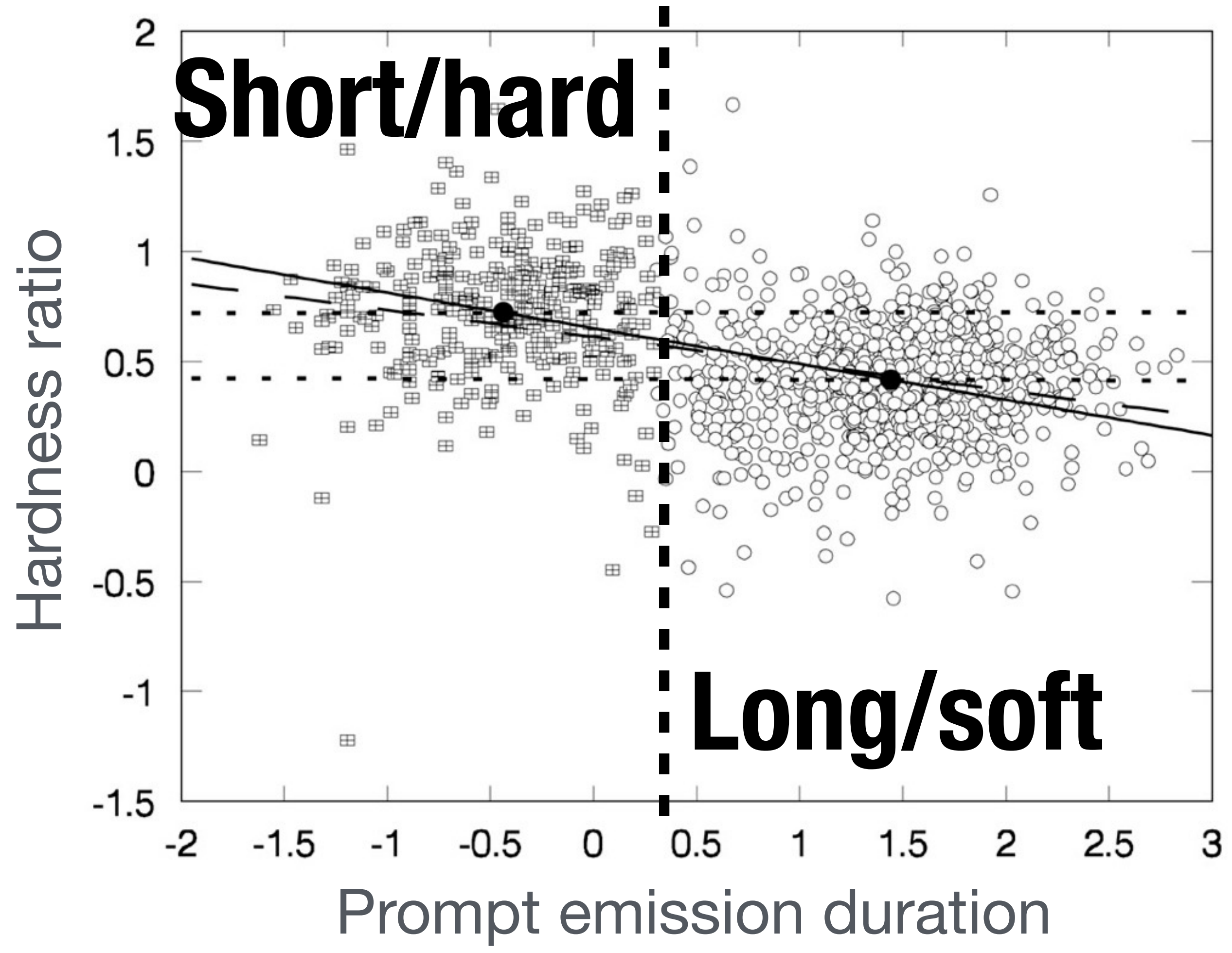
- SGRBs ~100 times less energetic than LGRBs but have similar luminosities

Two flavors: SGRBs and LGRBs

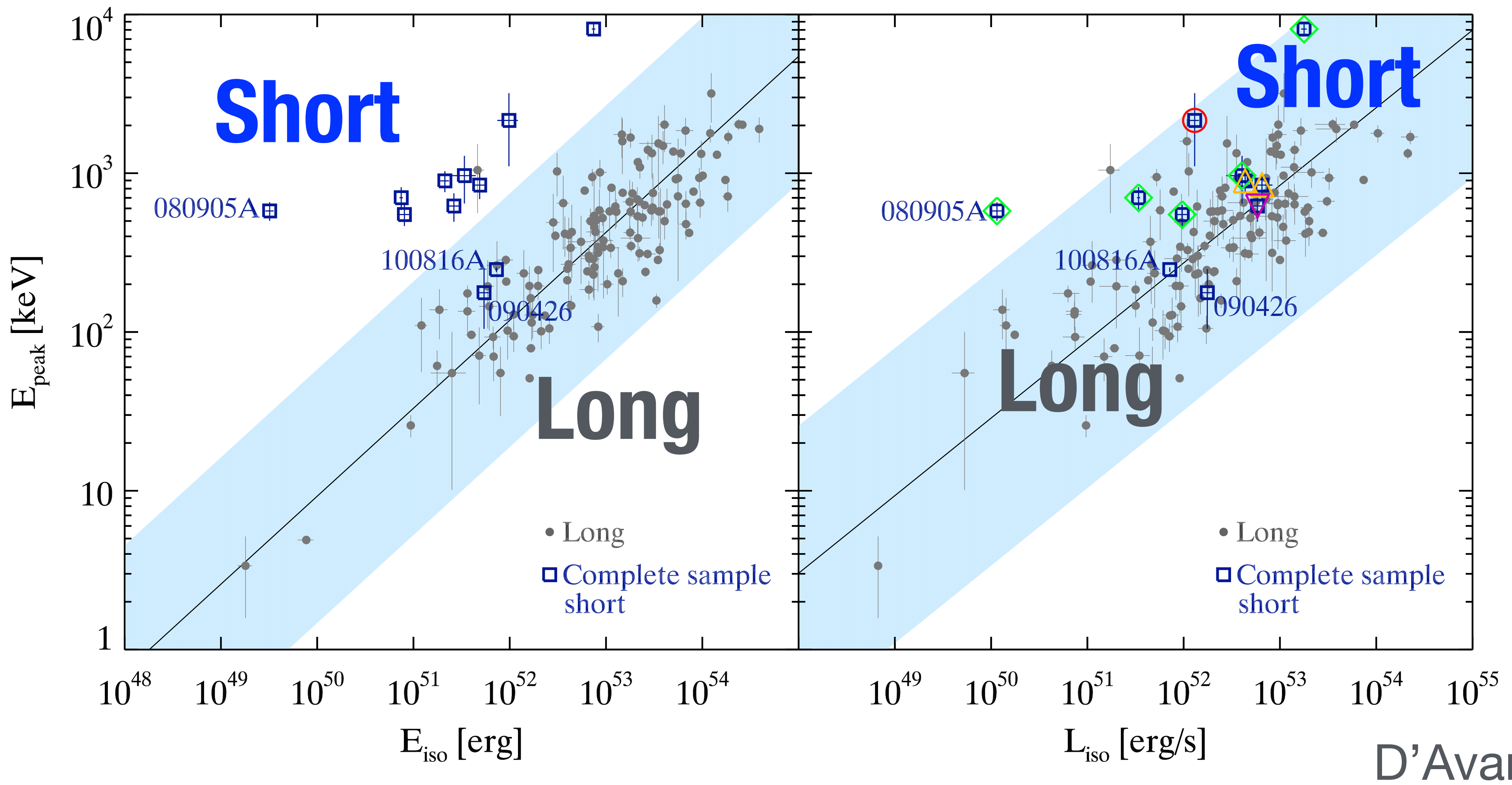
Distribution of prompt emission duration from BATSE catalog



Duration vs. Hardness



Epk-Eiso and Epk-Liso correlations



D’Avanzo+14

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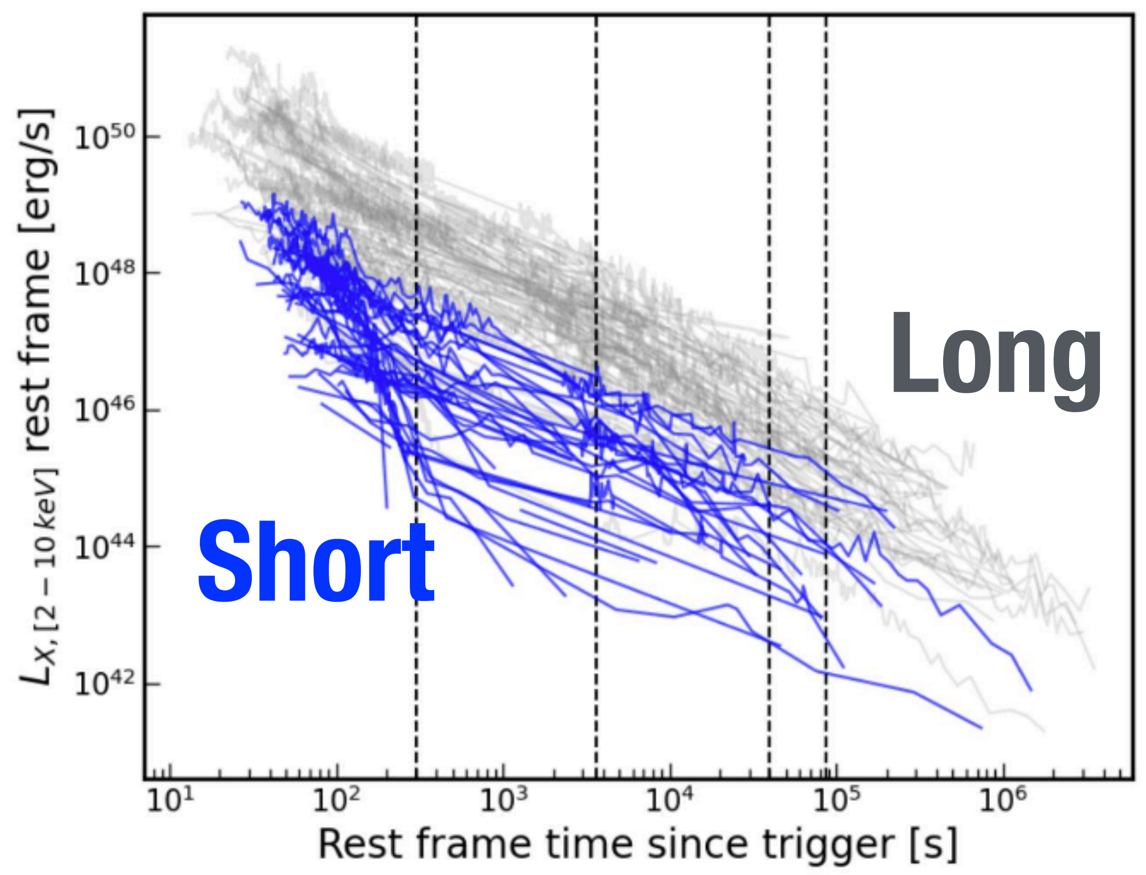
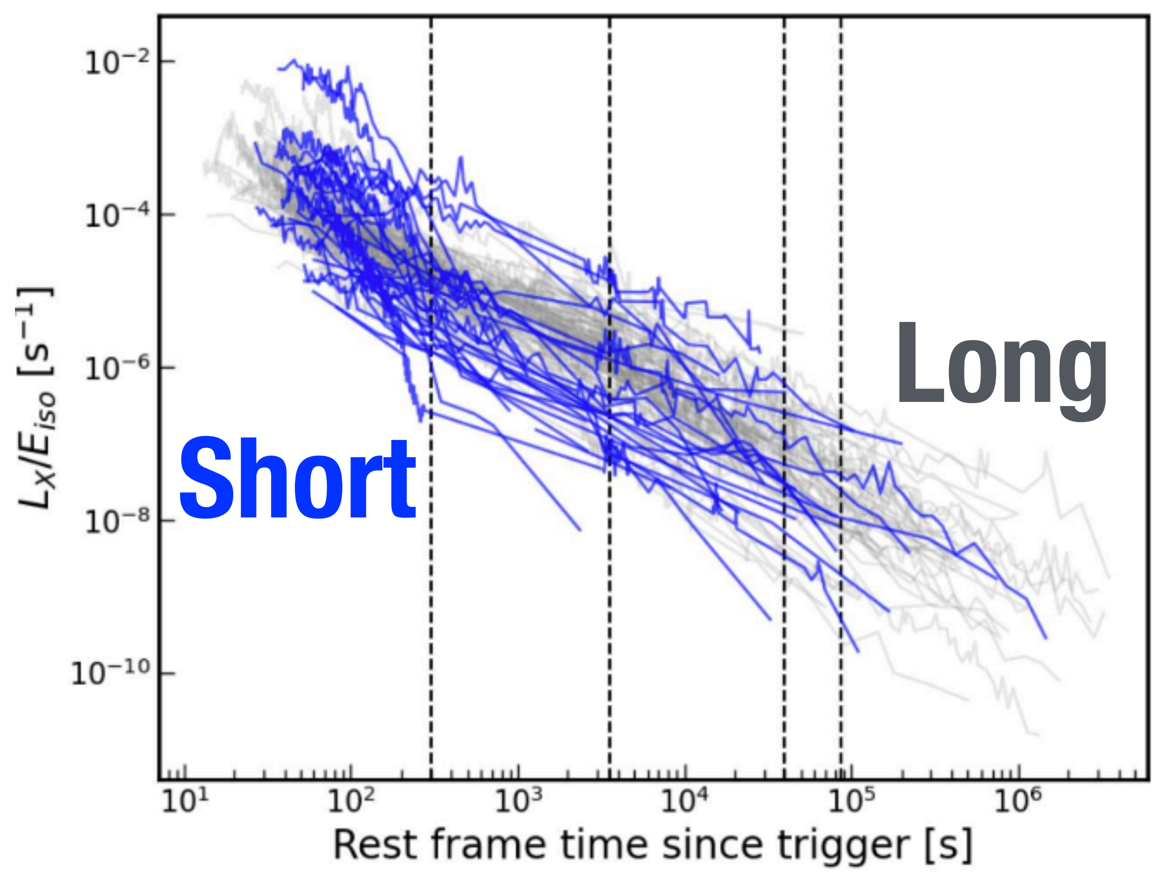
- SGRBs are spectrally harder than LGRBs
- SGRBs ~100 times less energetic than LGRBs but have similar luminosities
- SGRBs have fainter X-ray afterglow
- SGRBs and LGRBs are similar when we rescale for the total energy

X-ray luminosity in common rest frame



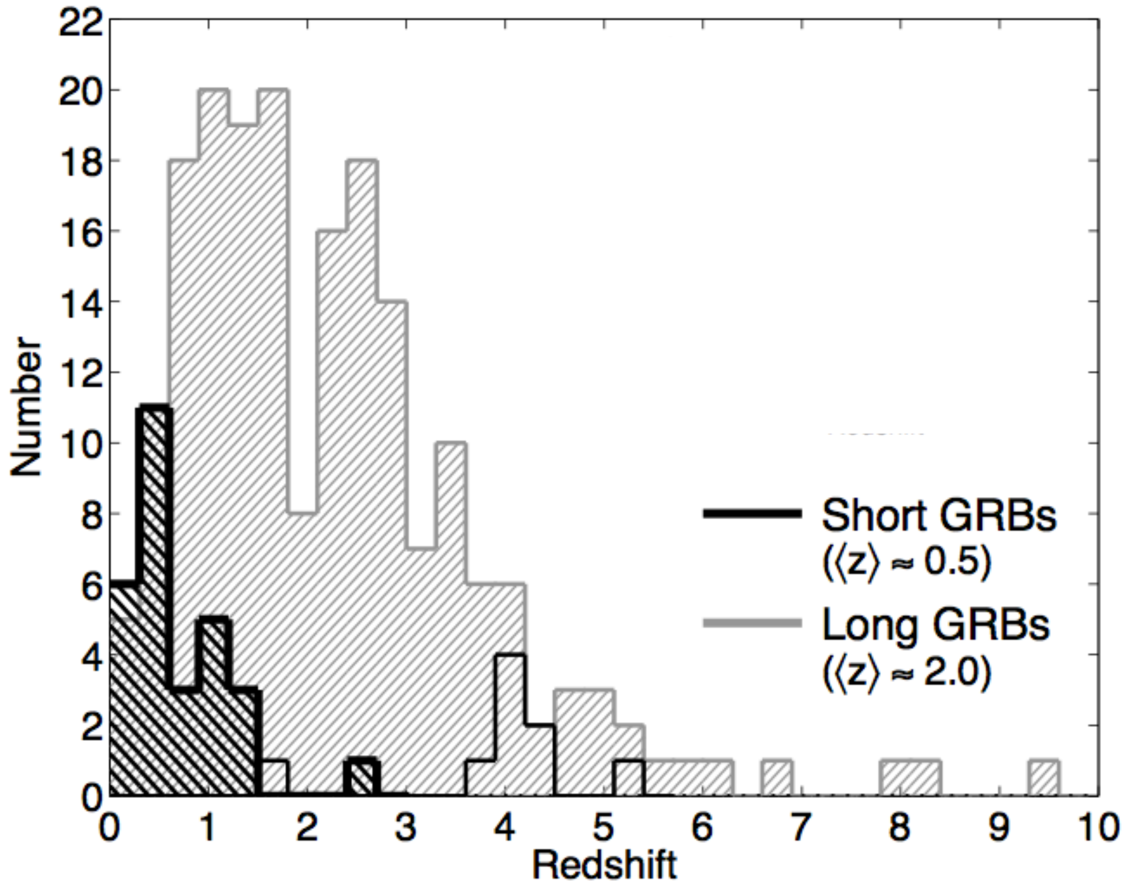
X-ray luminosity/Eiso



D’Avanzo+14, Brivio+ in prep.

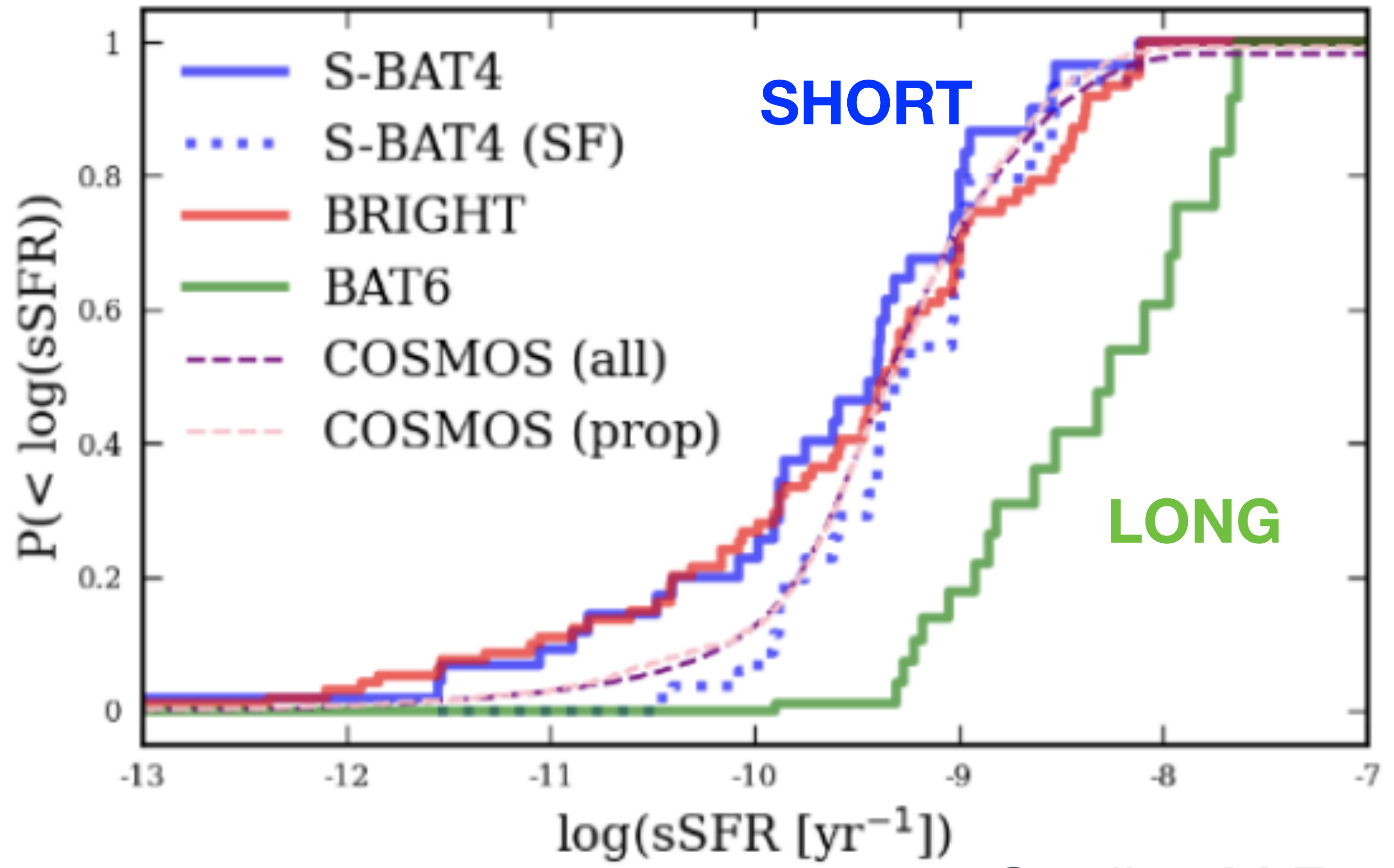
SGRBs and LGRBs: a tale of two progenitors

Redshift distribution



Berger+14

L and SGRBs sSFR compared to the COSMOS galaxies



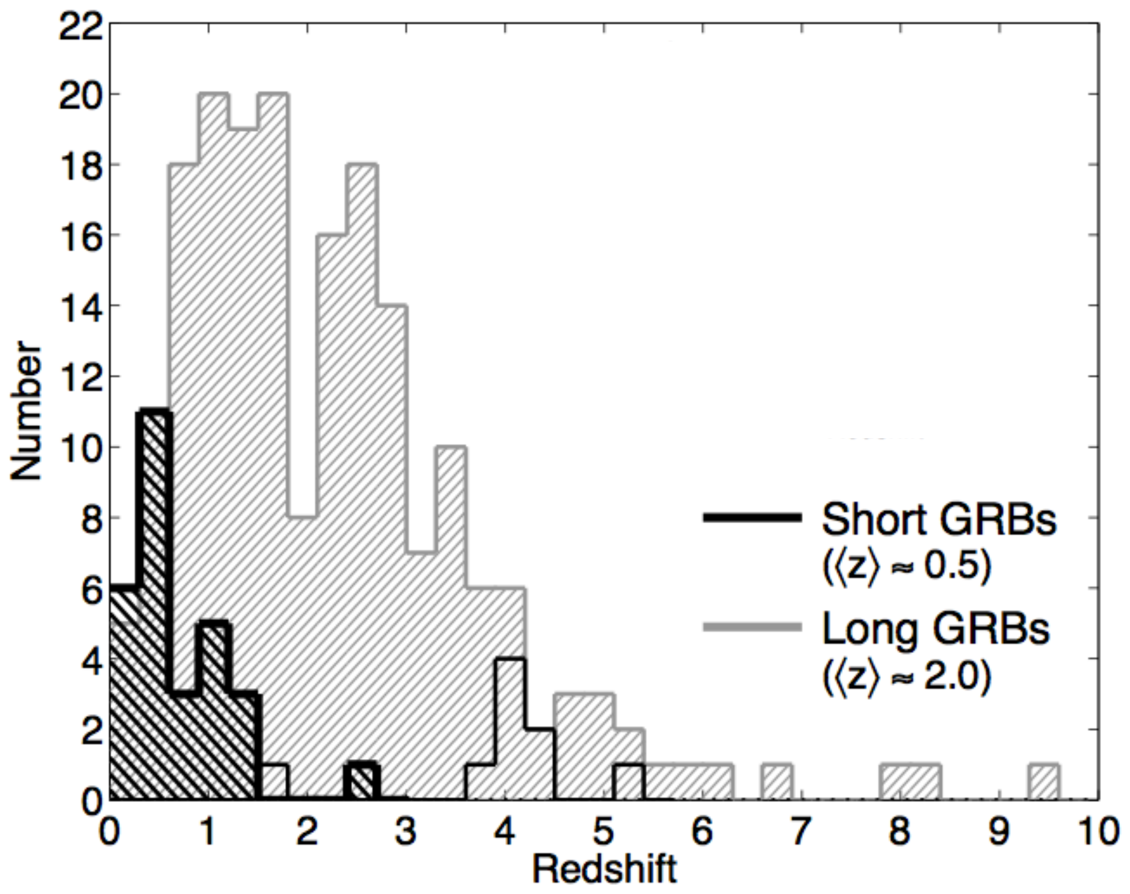
Credits: M.Ferro

- Redshift distributions significantly different
- LGRBs follow the SFR (with some caveats), while SGRBs a delayed SFR
- LGRB hosts are young, less massive and with high sSFR, while SGRBs explode in all type of galaxies
- LGRBs track the UV light of their host, while SGRBs explode with significant offset w.r.t. their host

➡ LGRBs associated to young stellar population, while SGRBs to old stellar population whose explosion site is not representative of the progenitor birth site

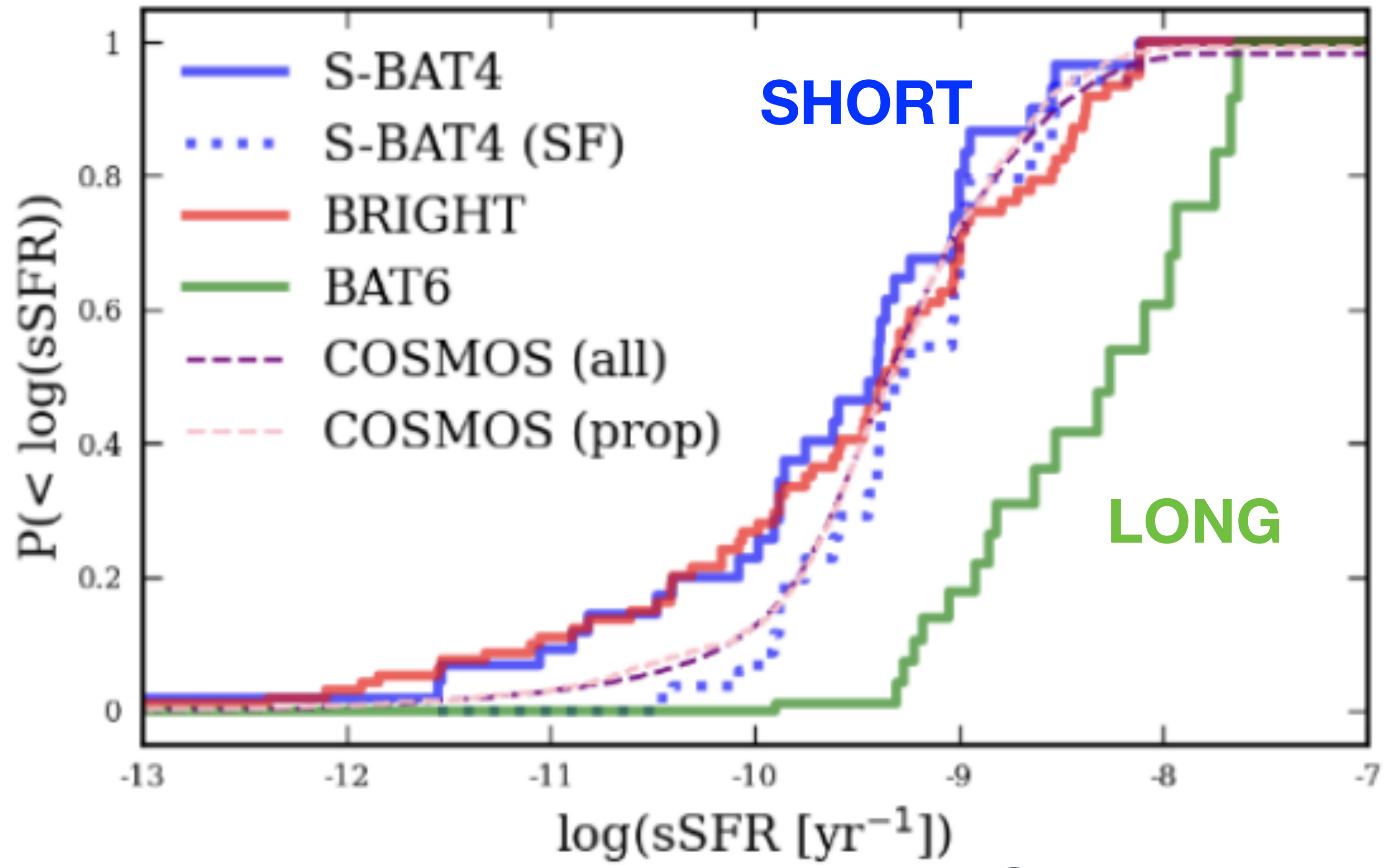
SGRBs and LGRBs: a tale of two progenitors

Redshift distribution



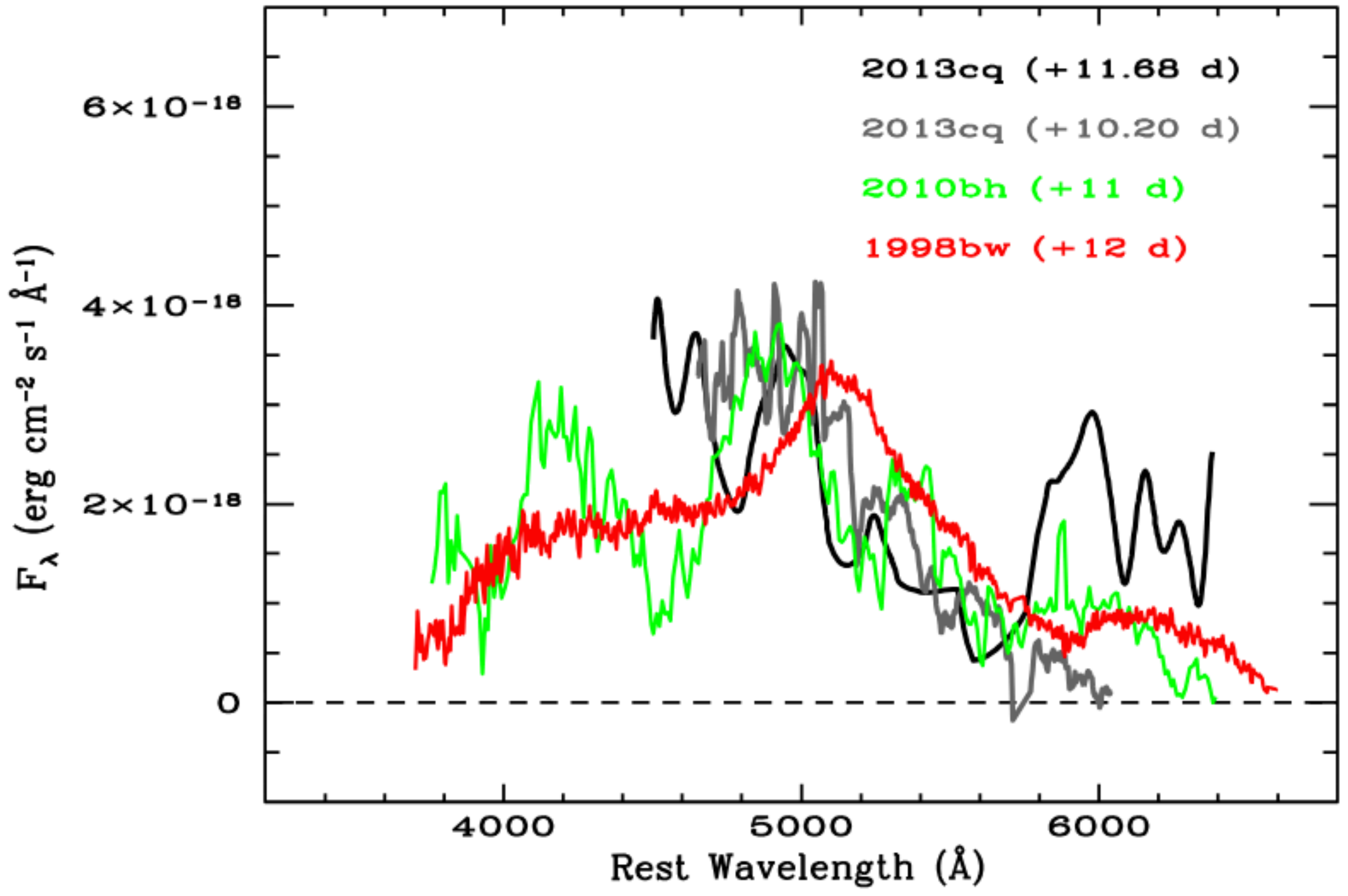
Berger+14

L and SGRBs sSFR compared to the COSMOS galaxies



Credits: M.Ferro

Spectra of SNe associated to LGRBs



Melandri+14

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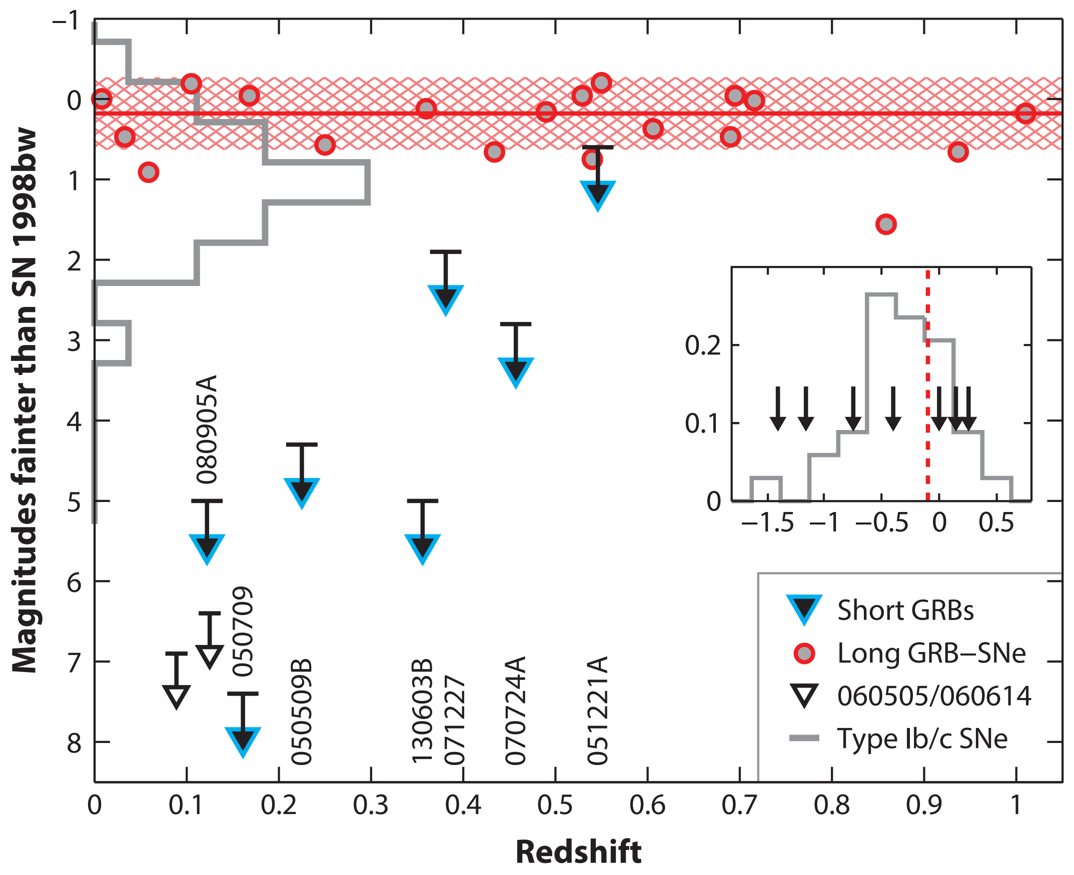
➡ **LGRBs associated to young stellar population, while SGRBs to old stellar population whose explosion site is not representative of the progenitor birth site**

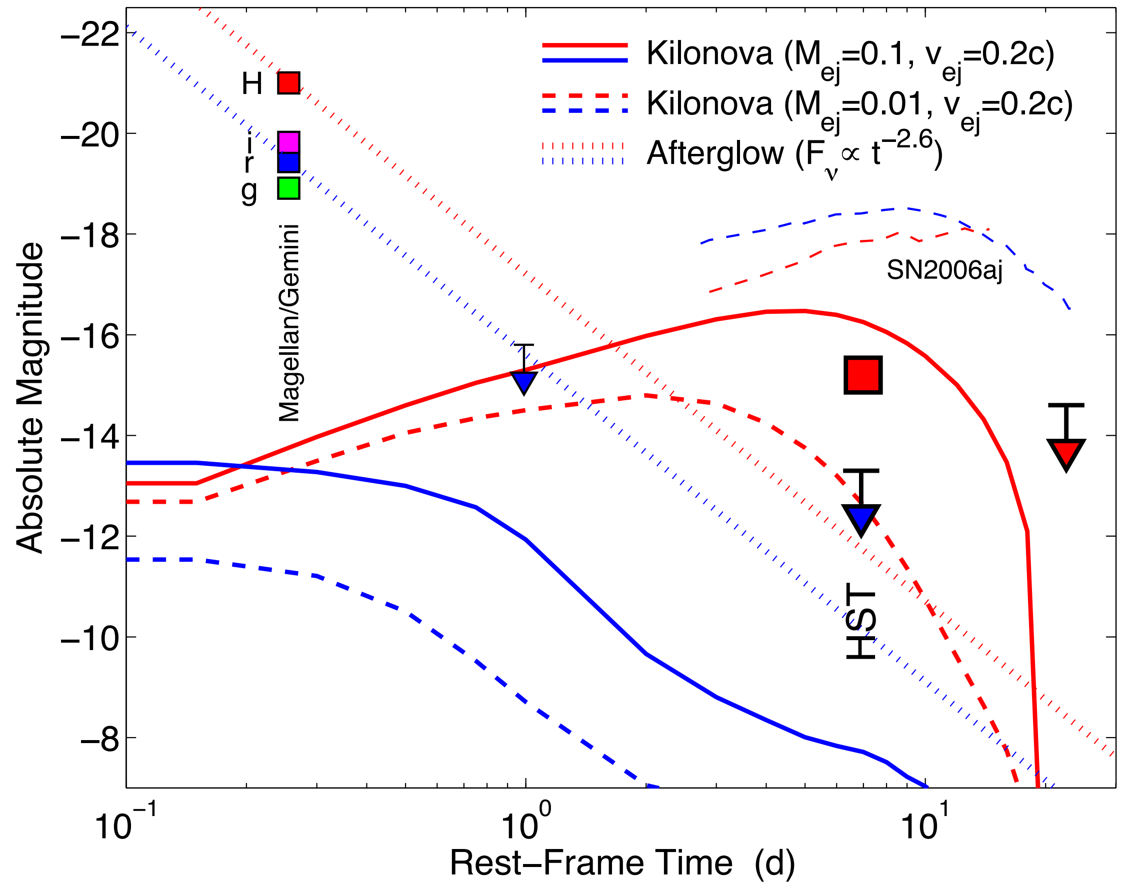
- **SNe associated to LGRBs** <- spectroscopically confirmed
- **KNe associated to SGRBs** <- chromatic excesses in SGRB afterglows

Limits of the SN mag in SGRBs compared to typical LGRB SNe



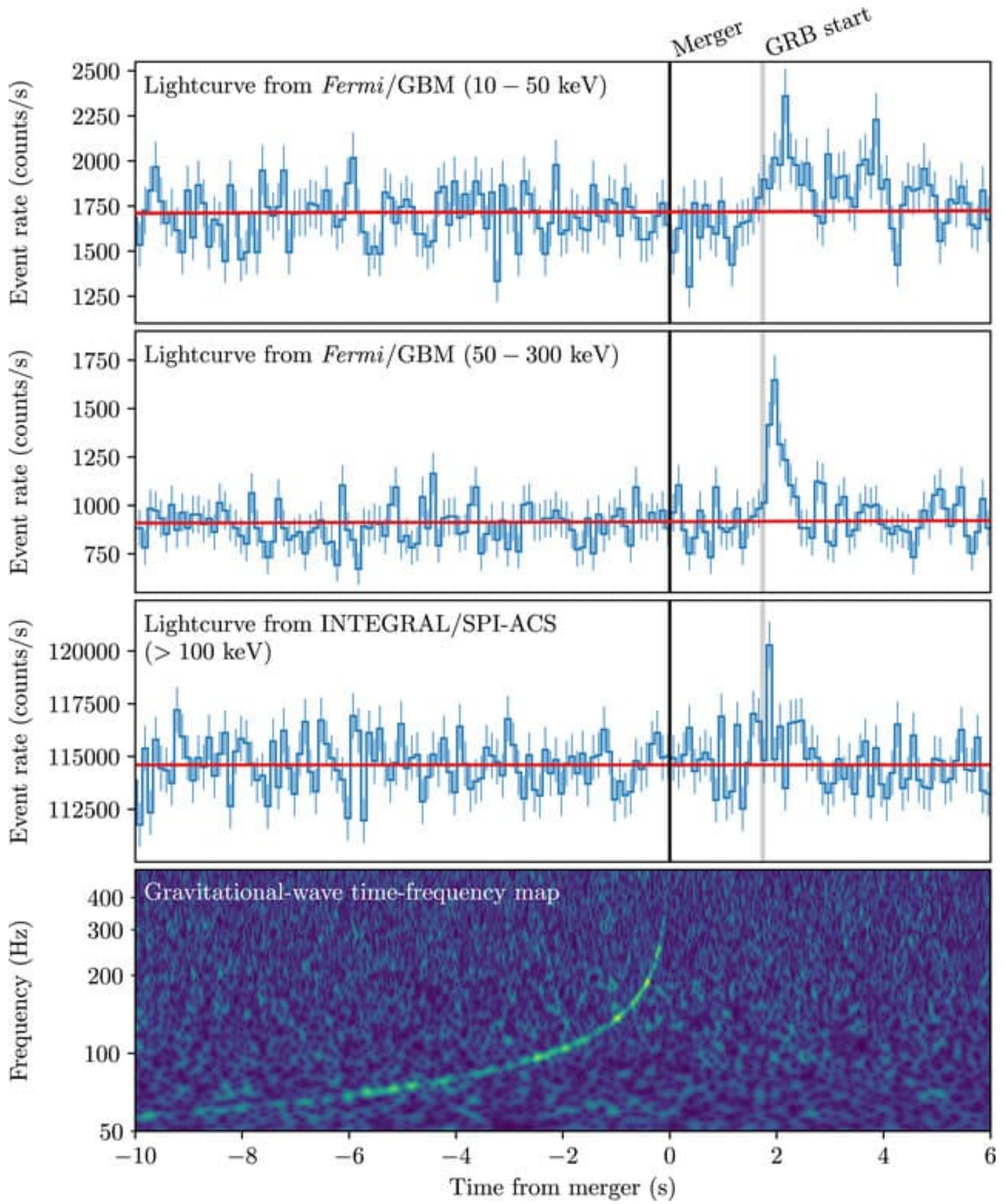
Berger14

KN excess in the afterglow of GRB 130603B



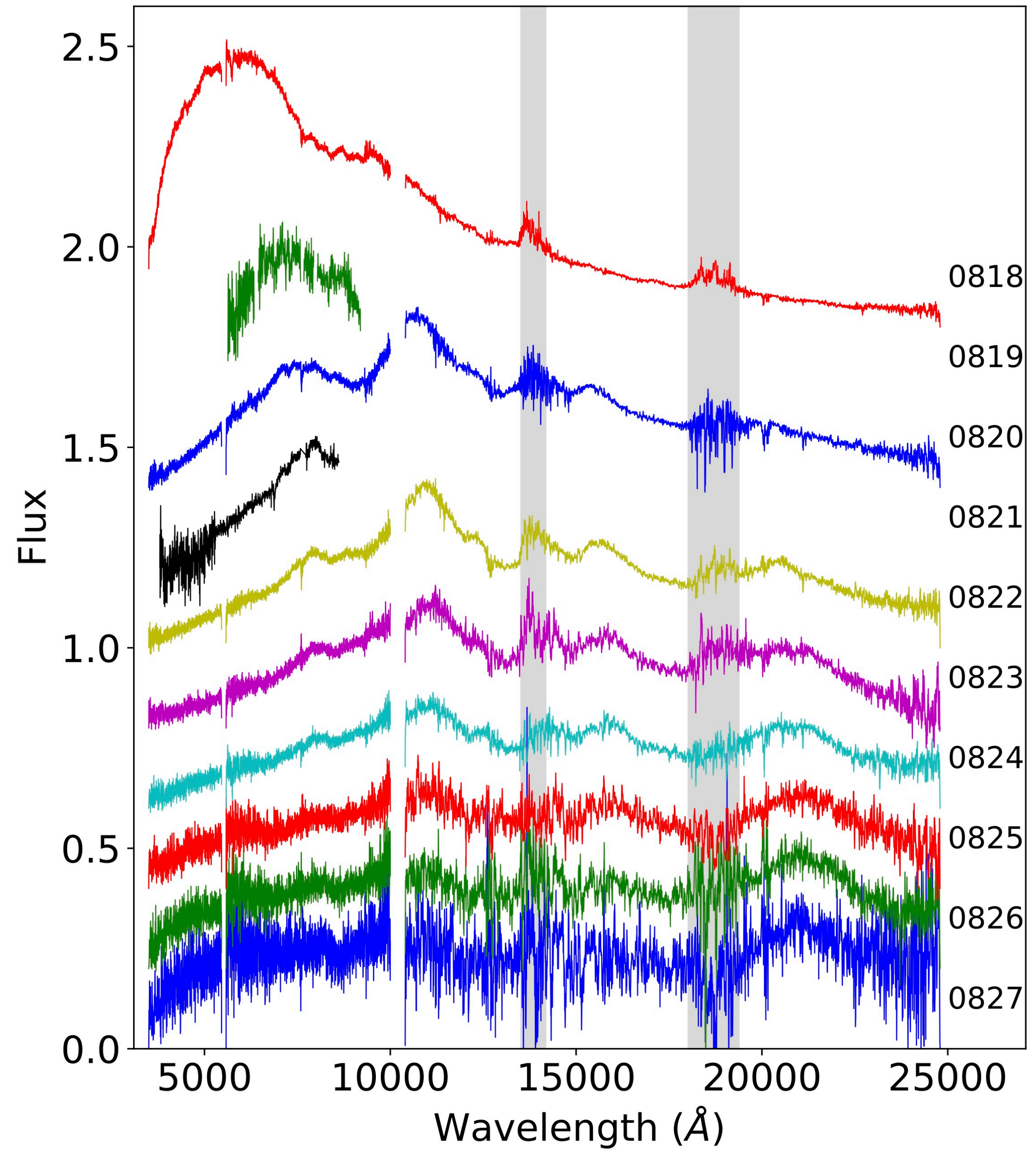
Berger+13

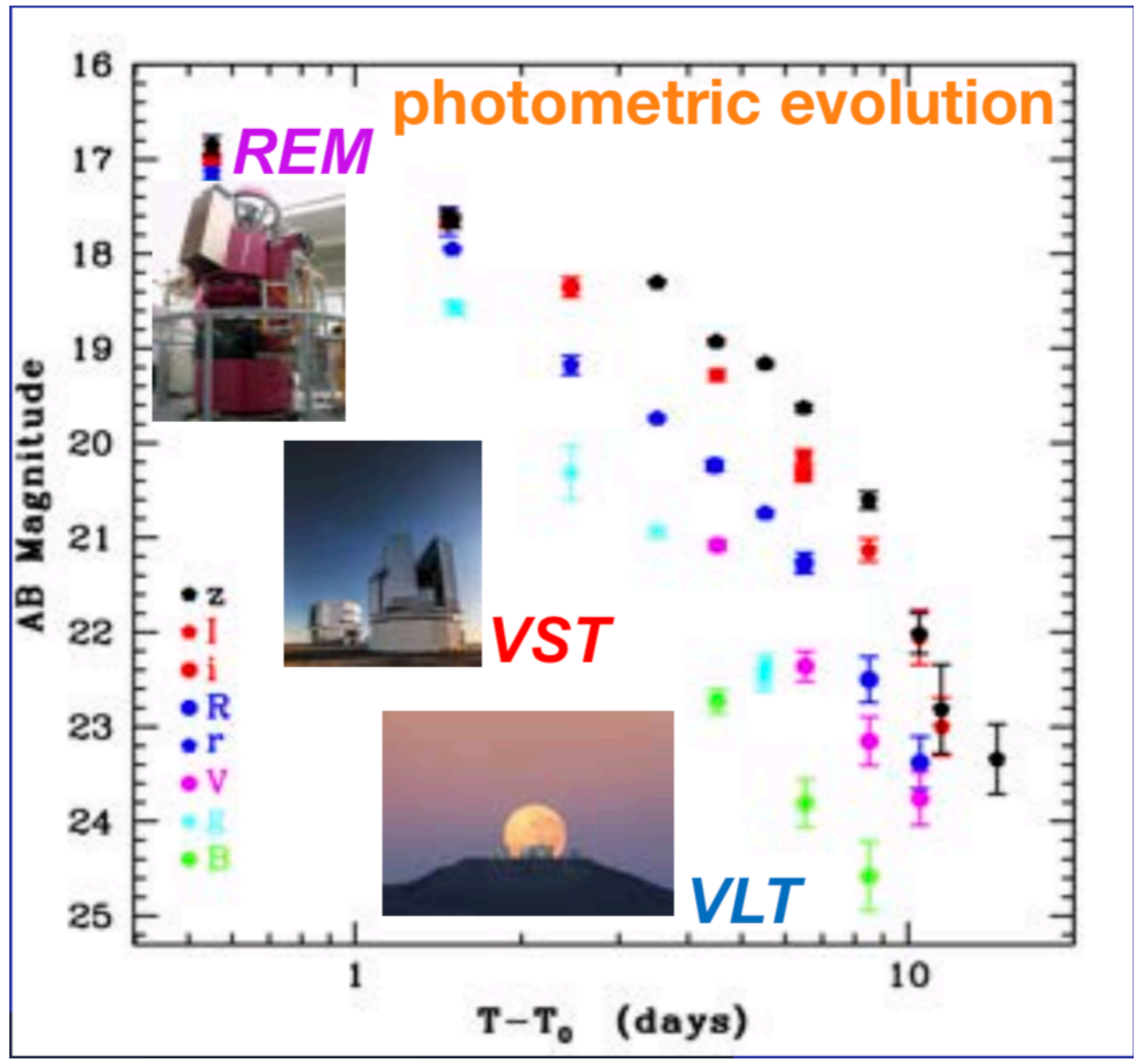
GW 170817/GRB 170817A/AT2017gfo: the smoking gun of SGRB progenitors



Abbott+17; Goldstein+17; Savchenko+17

AT2017gfo spectral sequence and light curve



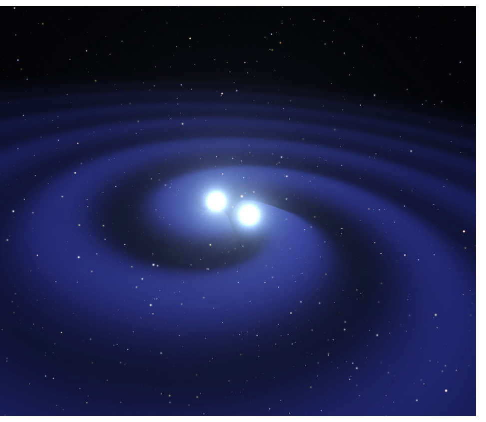


Pian, D'Avanzo+2017

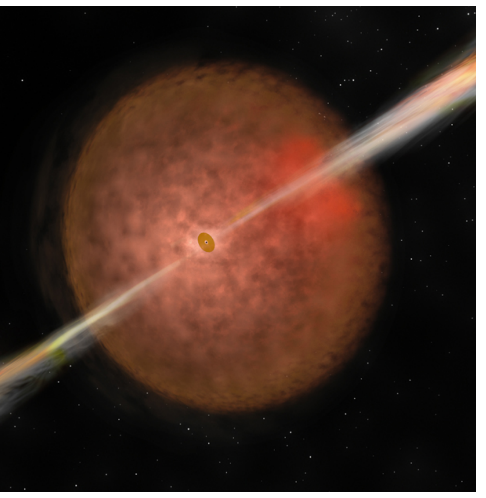
First direct observation of a **SGRB** (GRB170817A) associated to a GW event originated by a **BNS merger** (GW 170817) and to the first spectroscopically identified **KN** (AT2017gfo)

BIRTH OF THE MULTI-MESSENGER ASTRONOMY WITH GWs

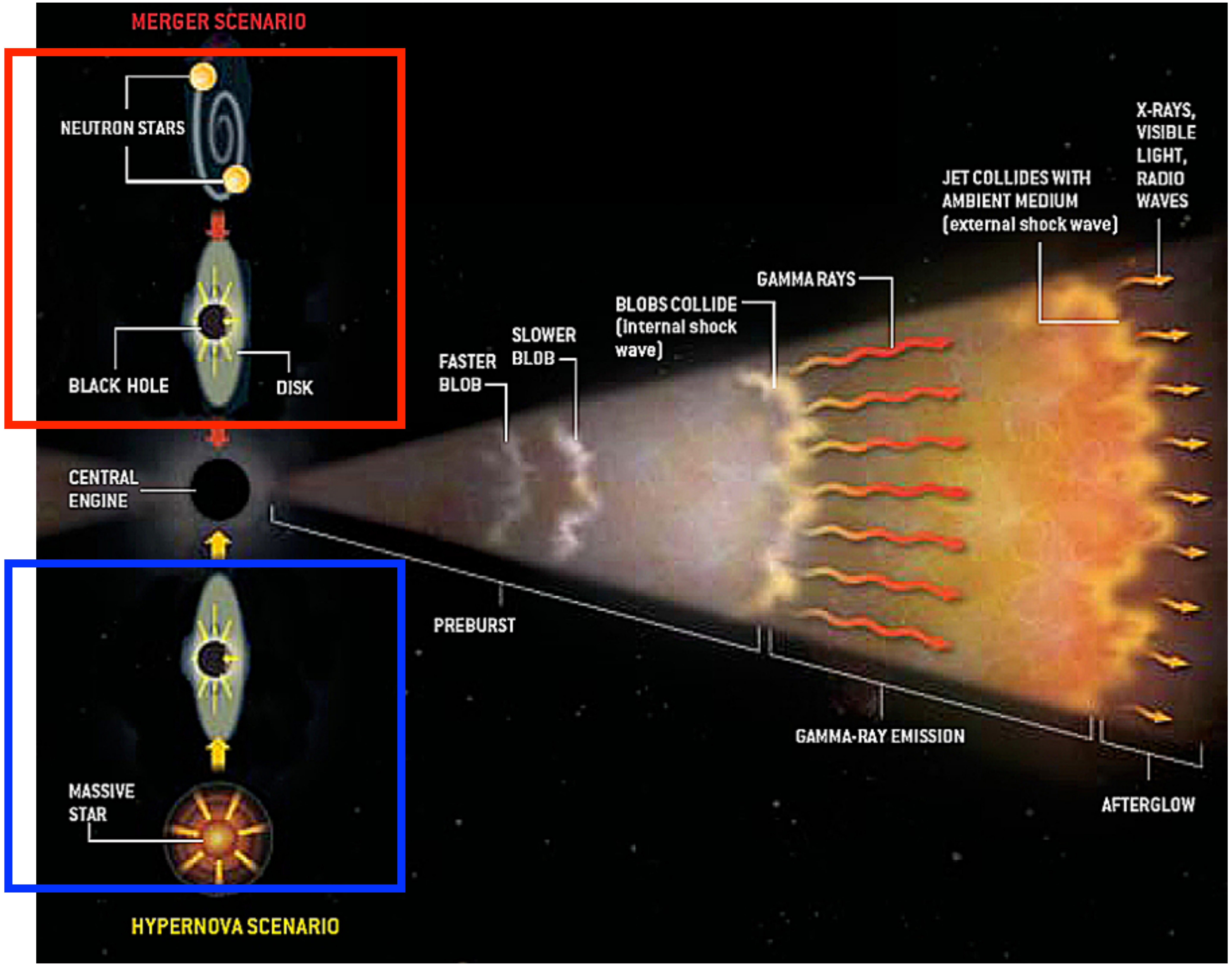
Gamma-ray bursts: the current paradigm



Short: merging of compact objects with a NS



Long: core collapse of massive stars

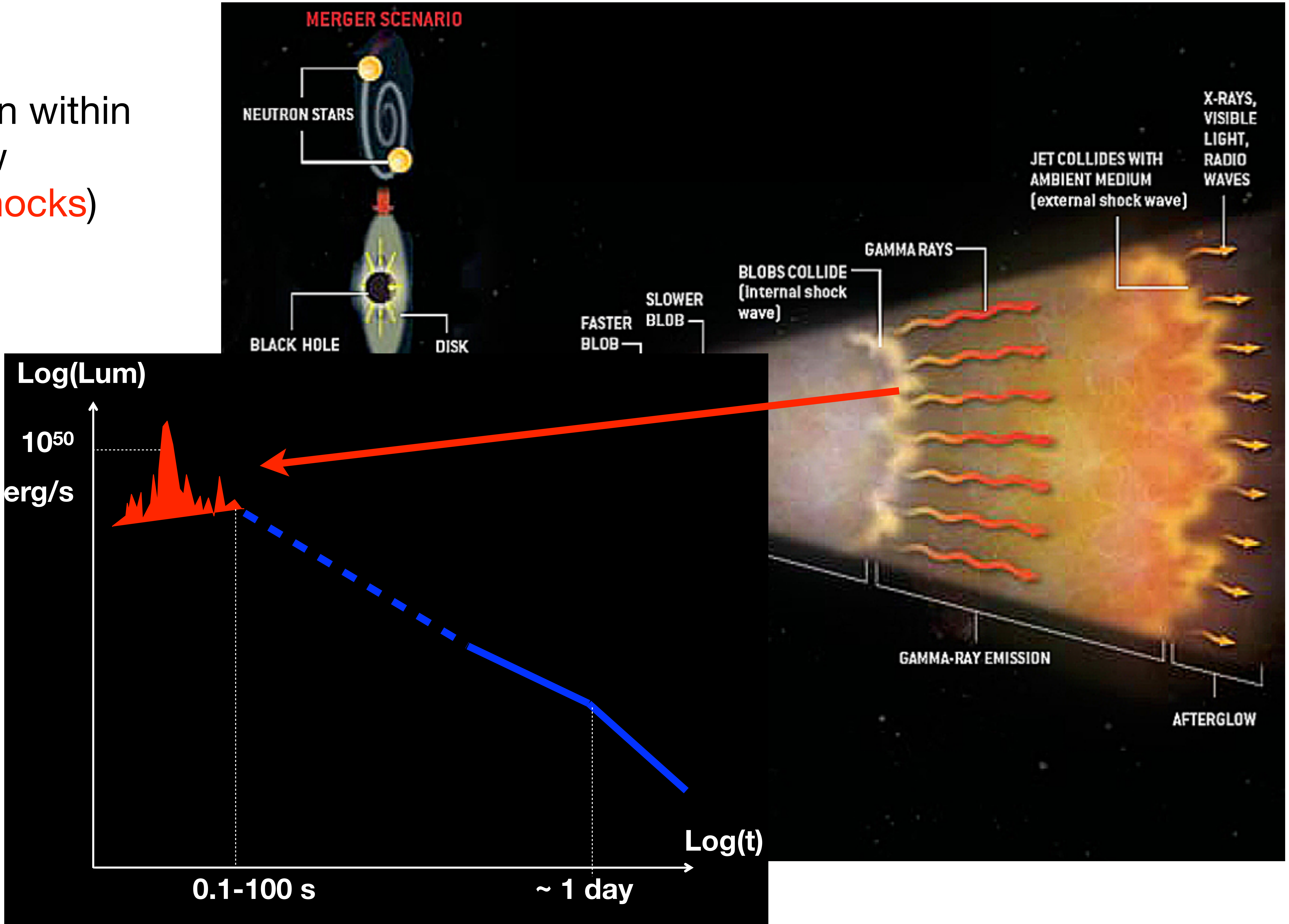


➡ Central engine + ultra relativistic outflow “jet"

Gamma-ray bursts: the current paradigm

PROMPT EMISSION

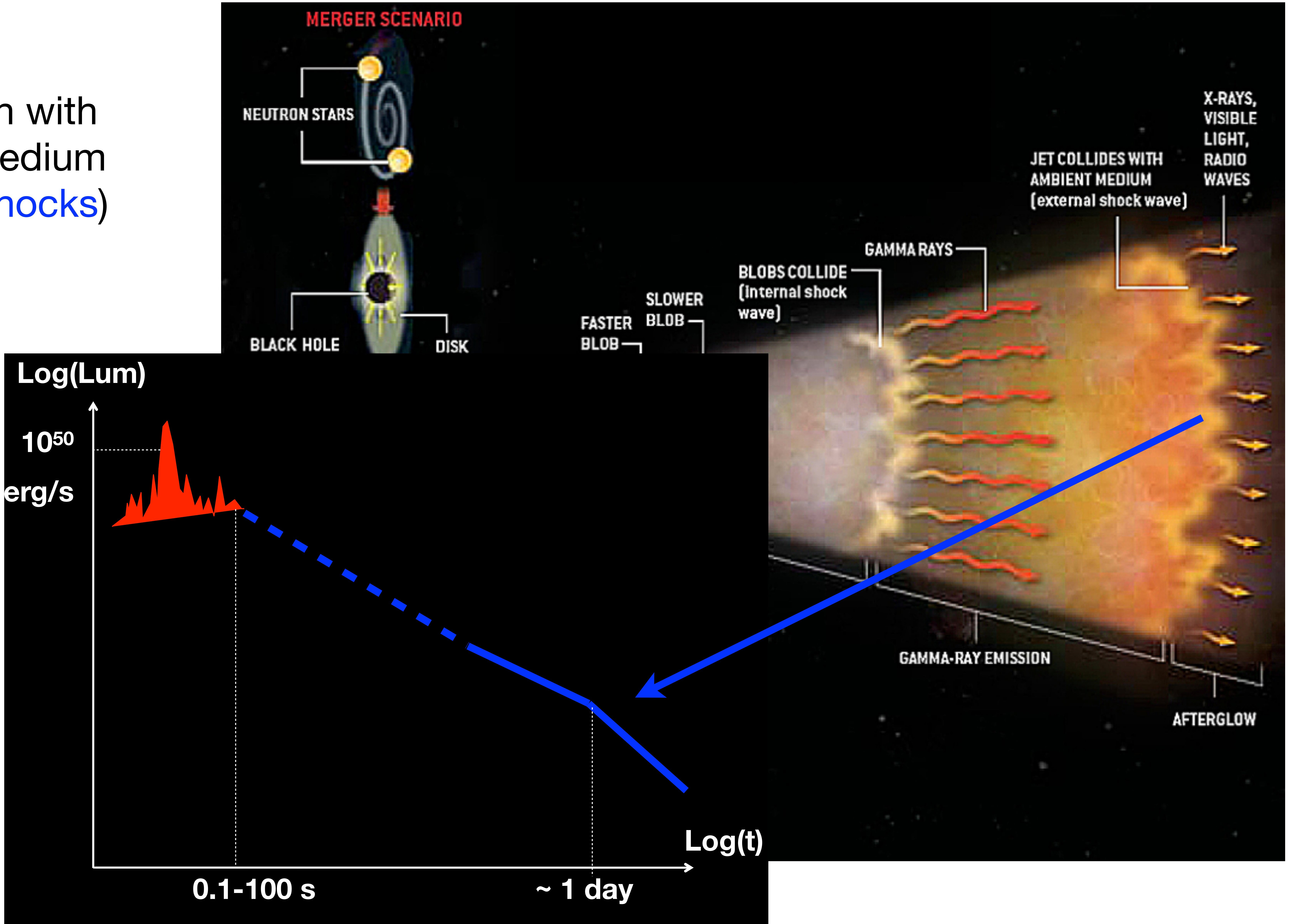
➡dissipation within the outflow (internal shocks)



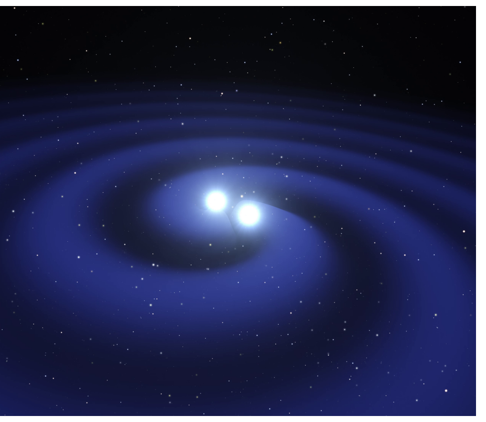
Gamma-ray bursts: the current paradigm

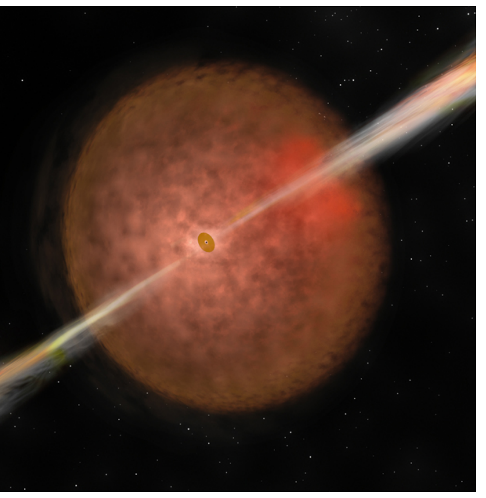
AFTERGLOW

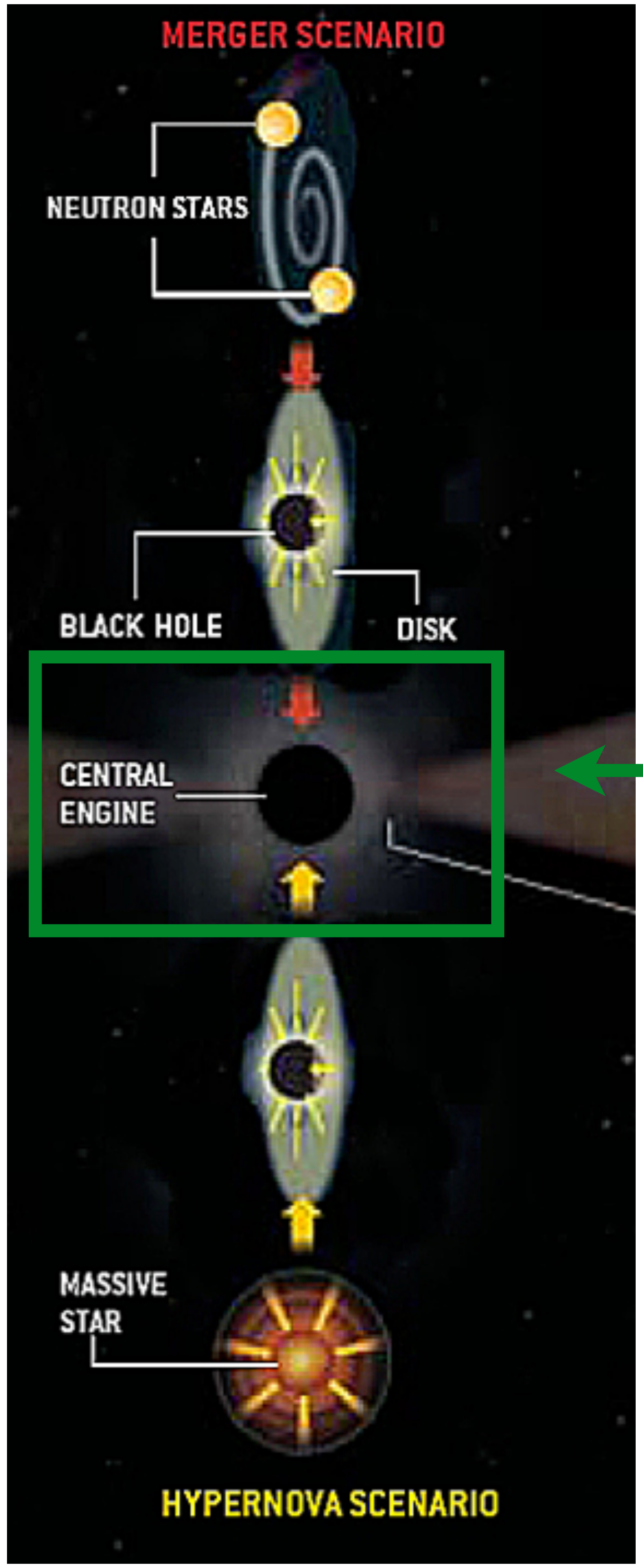
➡Interaction with ambient medium (external shocks)



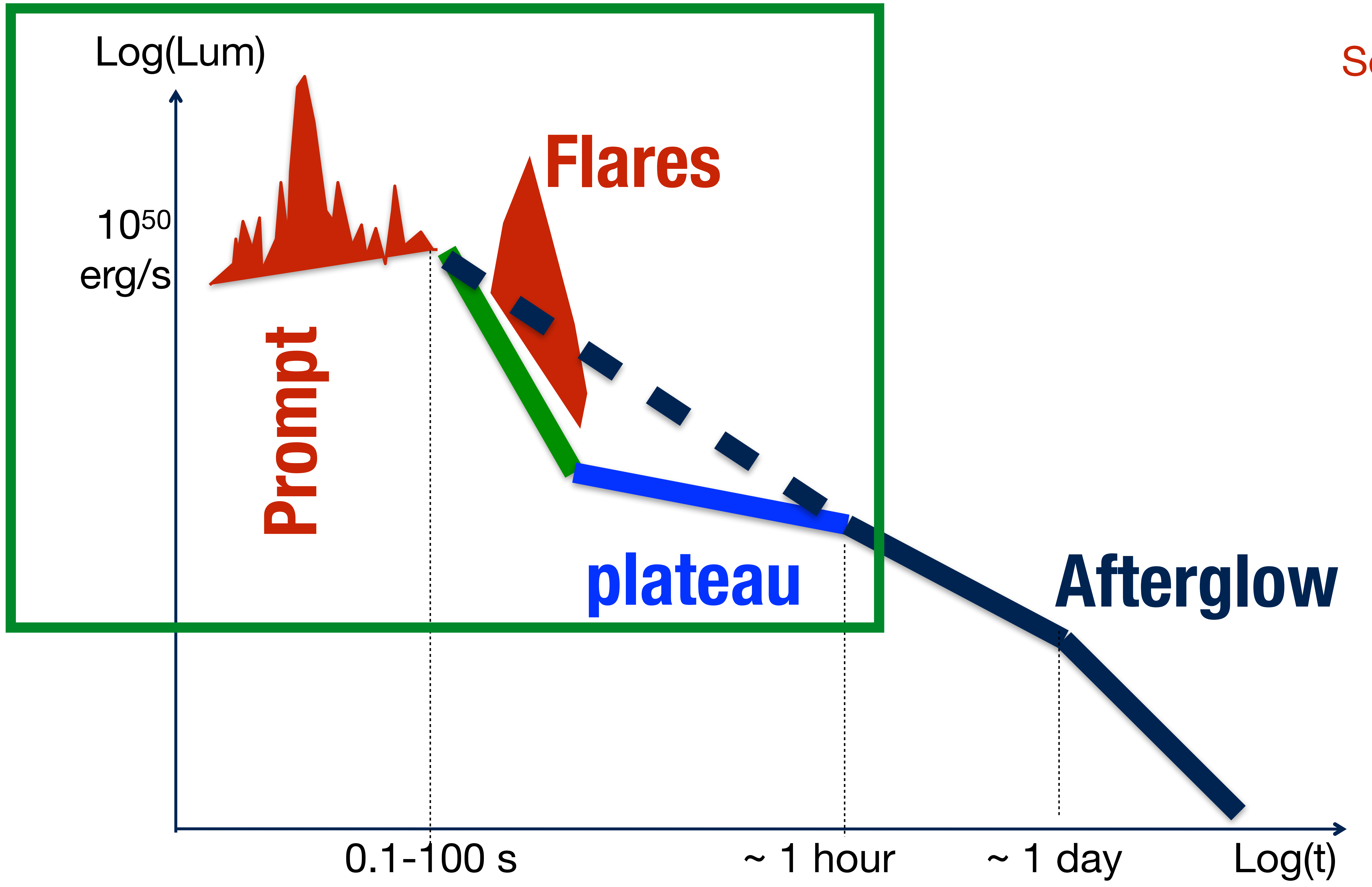
Gamma-ray bursts: the current paradigm







X-ray emission of GRBs

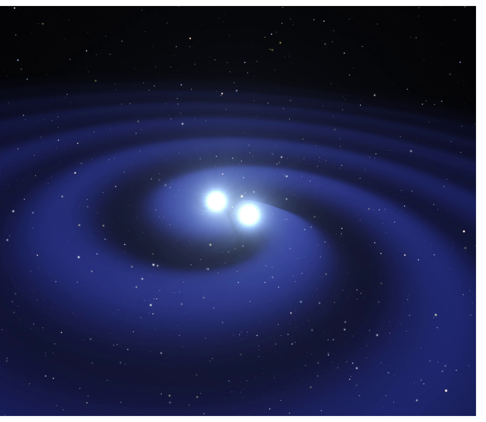


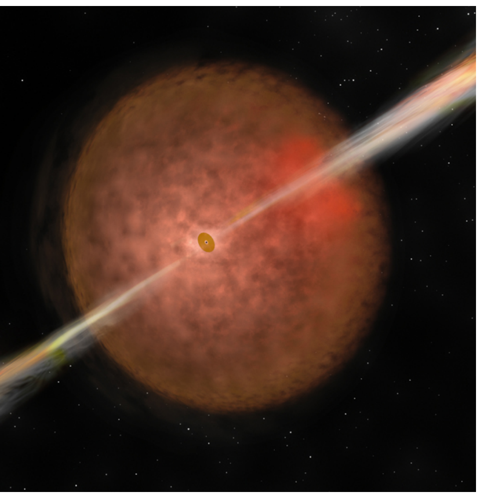
See C. Plasse's talk

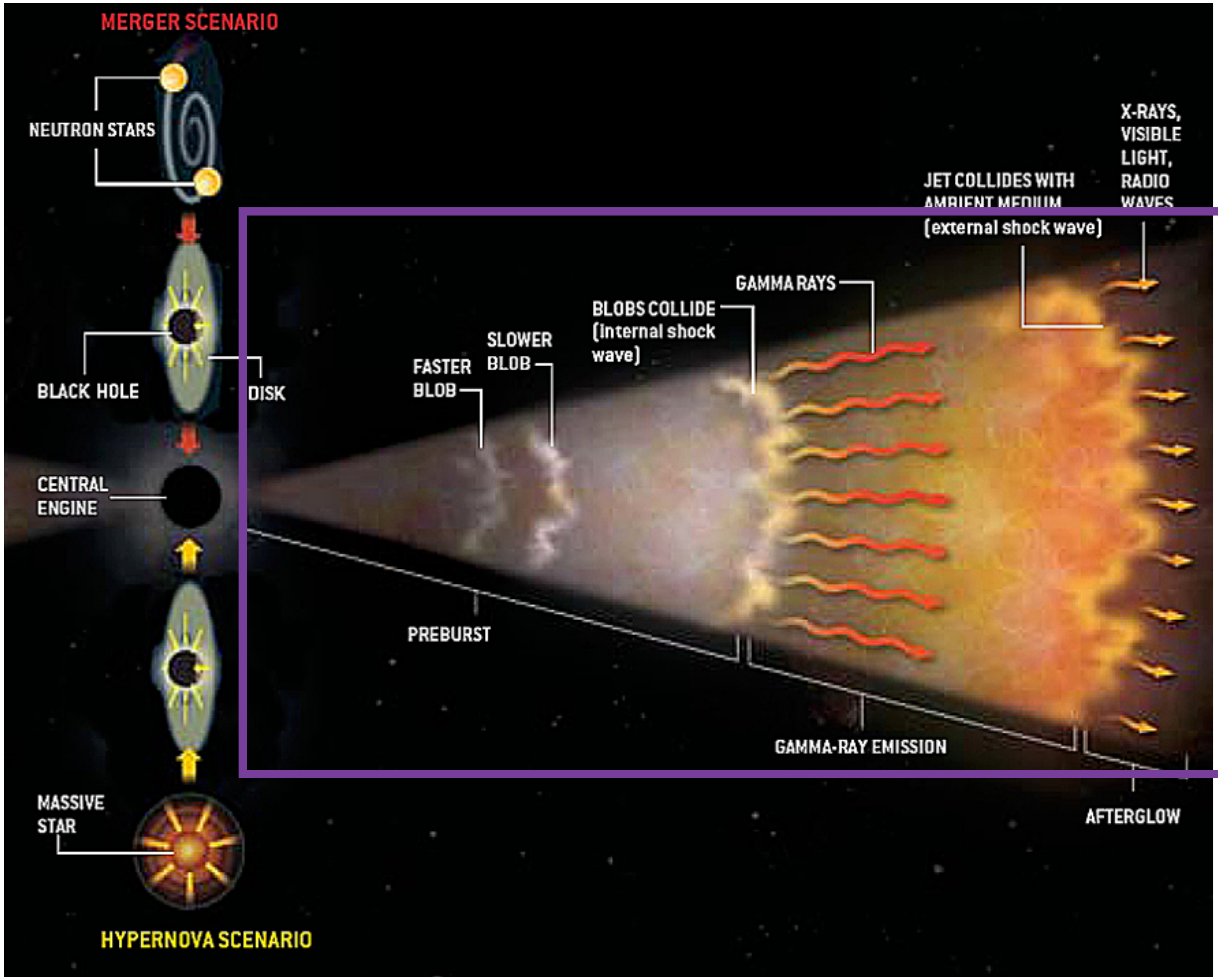
Magnetars are competing with **BHs** as source of GRB power

Usov 1992, Duncan & Thompson 1992, Dai & Lu 1998, Zhang & Meszaros 2001, Metzger et al. 2011, ….

Gamma-ray bursts: the current paradigm







ultra relativistic outflow

“jet”: Composition and structure

See C. Pellouin’s talk

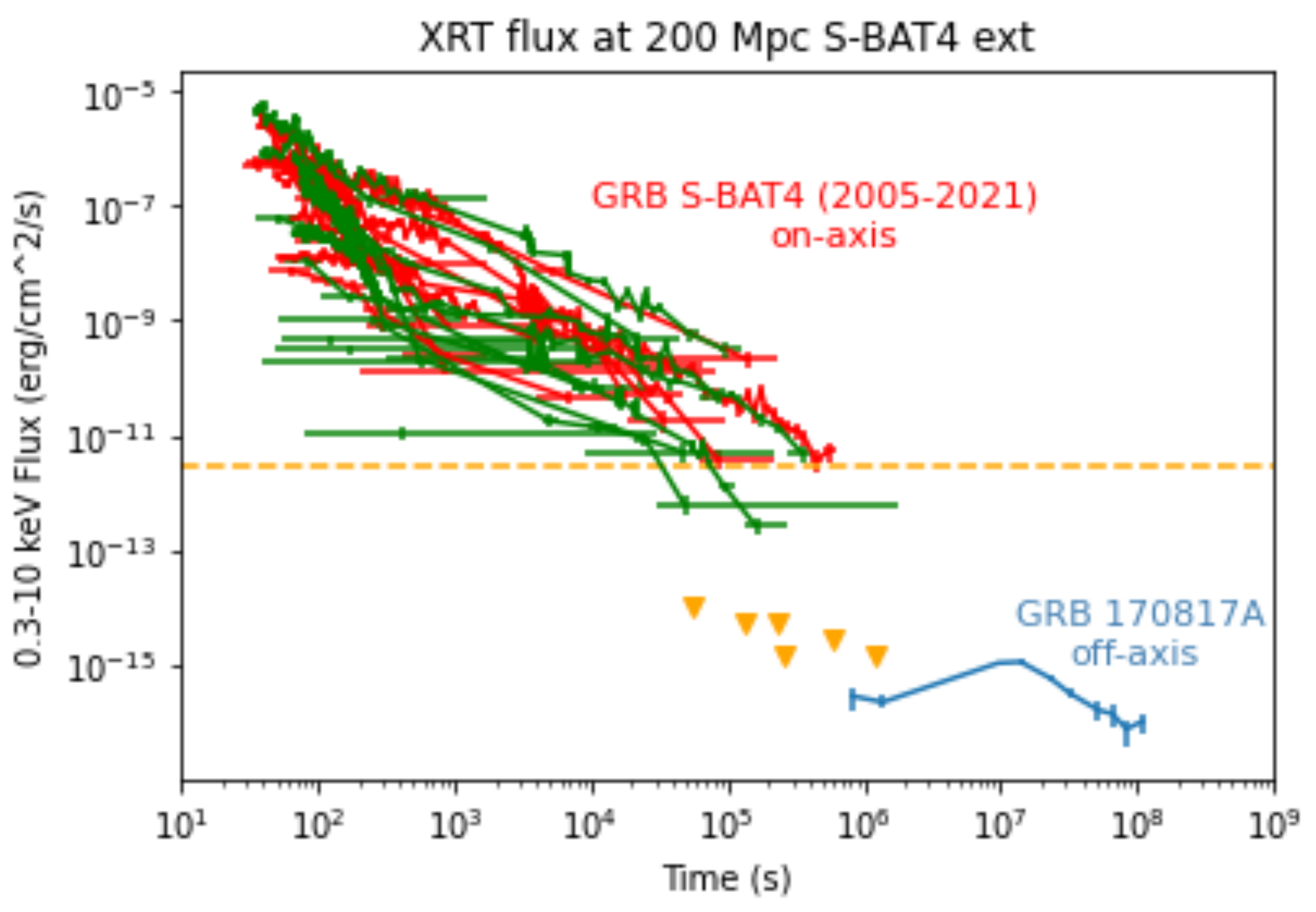
GRB 170817A: the first direct observation of the jet structure

- X-ray and radio emission non detected until 9 days and peaking at ~100 days Alexander+17,18; D'Avanzo+18; Dobie+18; Fong+19; Haggard+17; Hallinan+17; Hajela+19; Margutti+17,18; Mooley+18a,b; Reasmi+18; Ruan+18; Troja+18a,b,19,20; Piro+19 and many many others

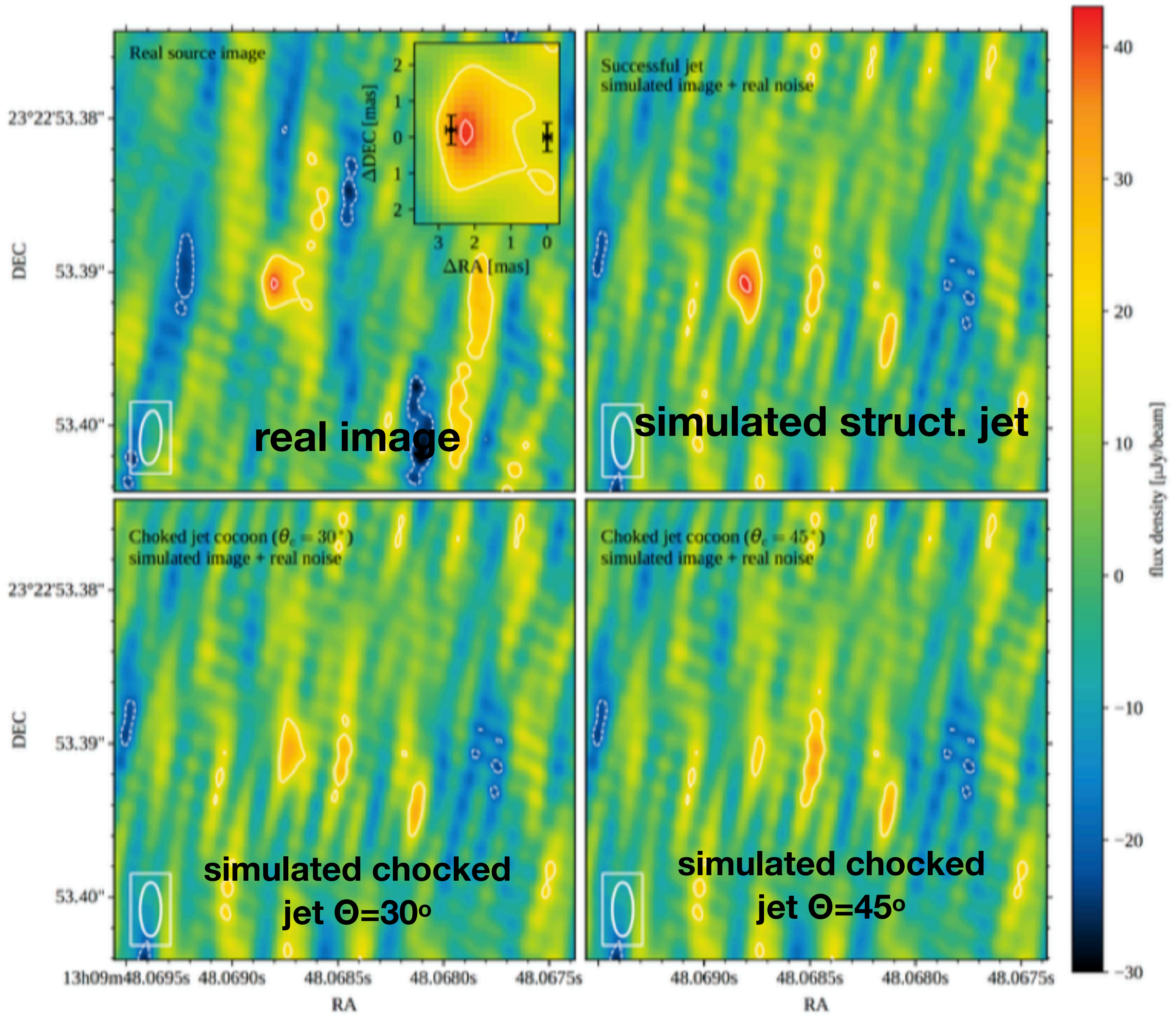
➡**First GRB seen off-axis**

- Evidence of proper motion and measure of the source size with **VLBI** Ghirlanda+19, Mooley+18

➡**Final proof of the structured jet scenario**



Credit: M. Dinatolo



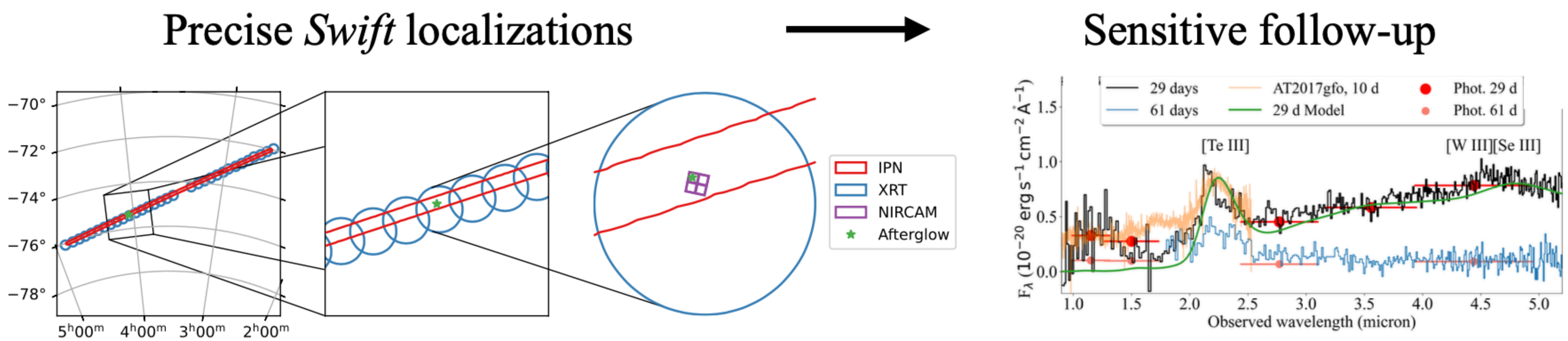
Ghirlanda, Salafia+19

Structured jet: relativistic core with $\theta_{jet} < 5$ deg and $\theta_{view} \sim 20$ deg

See S. Giarratana's talk

Key-points in GRB observations

- Triggering facilities to **discover and localize GRBs** + **rapid public dissemination of the alerts**
  - ➡ Need to **pinpoint GRB locations** to spot counterparts at other wavelengths and also the associated SNe-KNe
  - ➡ Need to catch the afterglow when it is still bright for **spectroscopic measurement of the redshift**
  - ➡ Need to monitor GRBs at **all wavelengths** (from GeV to radio) **with different facilities**



From precise Swift/XRT localization to sensitive follow-up: the example of GRB 230307A; from 2025 Swift Senior Review, Levan et al. (2024)

- Publicly accessible data and GRB information

ALL LESSONS LEARNED FROM 20 YEARS OF SWIFT

https://www.swift.ac.uk/

Key-points in GRB observations

- Large samples (~1700 GRBs from Swift) enable statistical studies of GRB properties
  - ➡ Need for **redshift measurements** to study the physical properties
  - ➡ Need to build samples that are **representative of the population of GRBs** that we want to study

Complete (flux-limited) samples of events, with favorable observing conditions for ground-based observations (redshift determination)

BAT6 sample

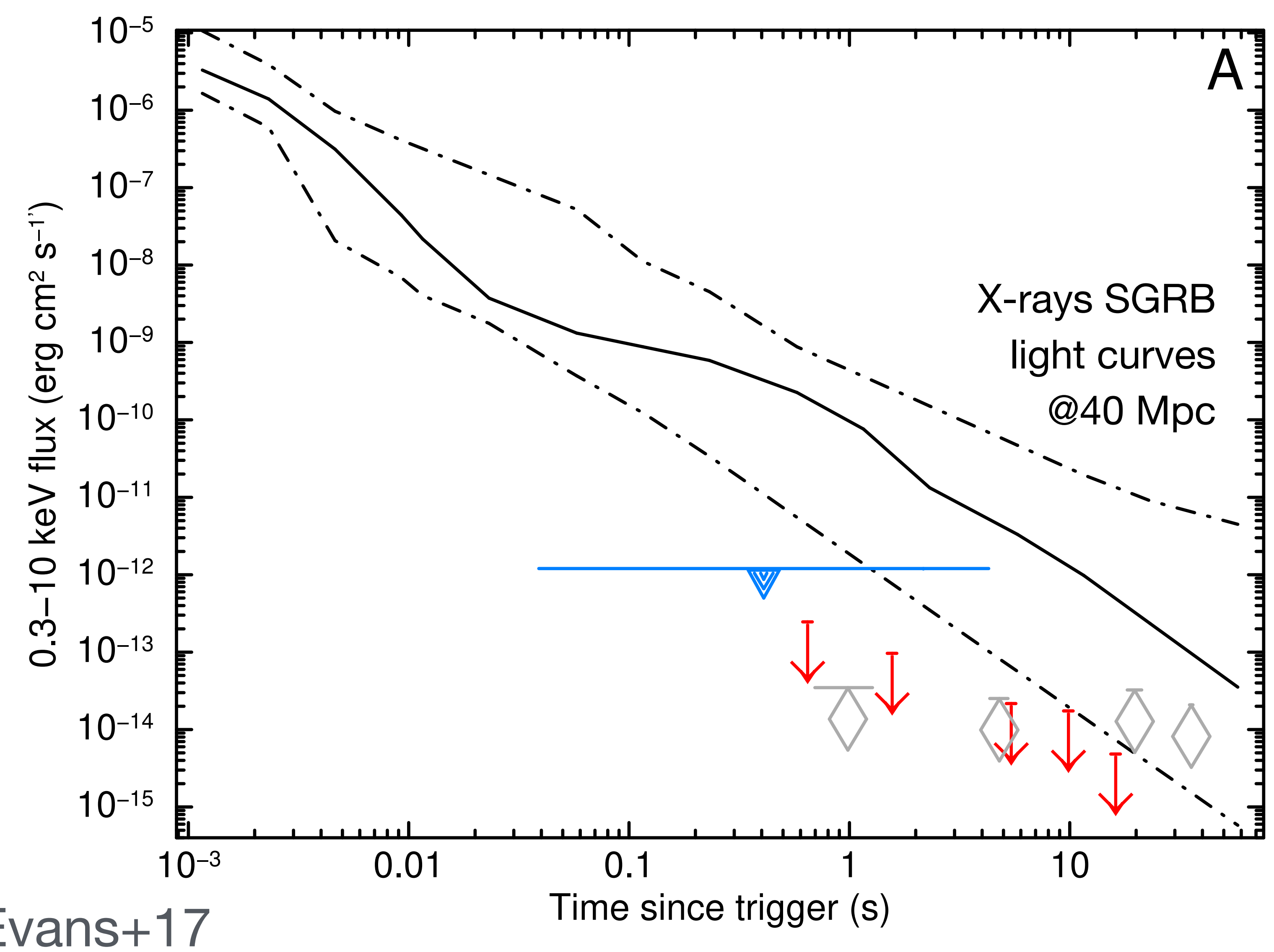
Salvaterra+12

- 124 long GRB
- peak flux > 2.6 photons/s/cm^2
- ~85% with redshift (wrt 40% whole Swift sample)

SBAT4 sample

D'Avanzo+14

- 27 short GRB
- peak flux > 3.5 photons/s/cm^2
- ~60% with redshift (wrt 25% whole Swift sample)



Evans+17

Comparison bw XRT limits on GRB170817A with the SBAT4 sample

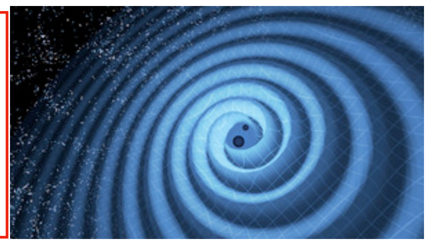
- ➡ luminosity function and redshift distribution
- ➡ prompt/afterglow emission rest-frame properties
- ➡ GRB environments
- ➡ host galaxy properties
- ➡ simulations and predictions for high-z and GW (rates)

GRB observations: present and future status

EINSTEIN TELESCOPE

THESEUS

BIRTH OF THE MULTI-MESSENGER ASTRONOMY WITH GWs



2010 — 170817 — 2020 — 2024 — 2030 — 2040 — years

Swift

Fermi

Einstein Probe

- CAS with ESA and MPE
- 2 X-ray telescopes on board
  - Large FoV lobster-eye optics (WXT)
  - Sensitive X-ray telescope (FXT)

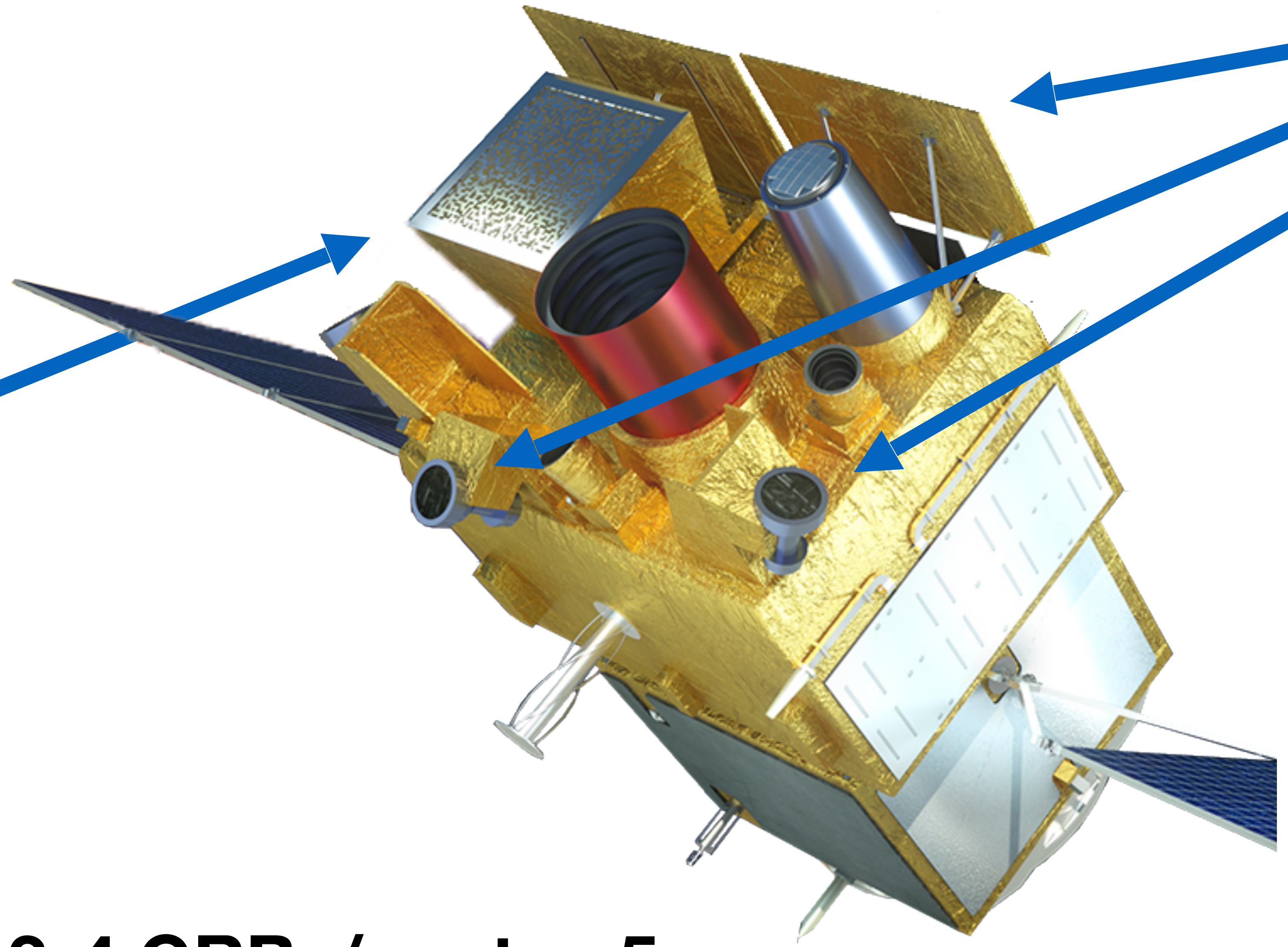
➡Monitor the X-ray sky and discover cosmic variable objects and transient phenomena shining in X-rays

SVOM

- CAS and CNES
- 4 instruments on-board
  - Large FoV: hard X-rays coded mask (ECLAIRs) + gamma-ray monitor (GRM)
  - Narrow FoV: lobster-eye X-ray telescope (MXT) + optical telescope (VT)
- Ground segment of 2 dedicated robotic telescopes and 1 optical monitor

➡Discovery and multi-wavelength follow-up of GRBs and other transients, high fraction of redshift expected

SVOM observations: prompt emission



GRM (3 GRDs):

- **15 keV - 5 MeV**
- Fov ~ 5.6 sr
- Loc. ~5-10 deg (3 GRDs)
- ~90 GRBs/yr

ECLAIRs:

- **4-120 keV**
- Fov ~ 2 sr
- **Loc. < 12’**
- **42-80 GRBs/yr, including 3-4 GRBs/yr at z>5**

+

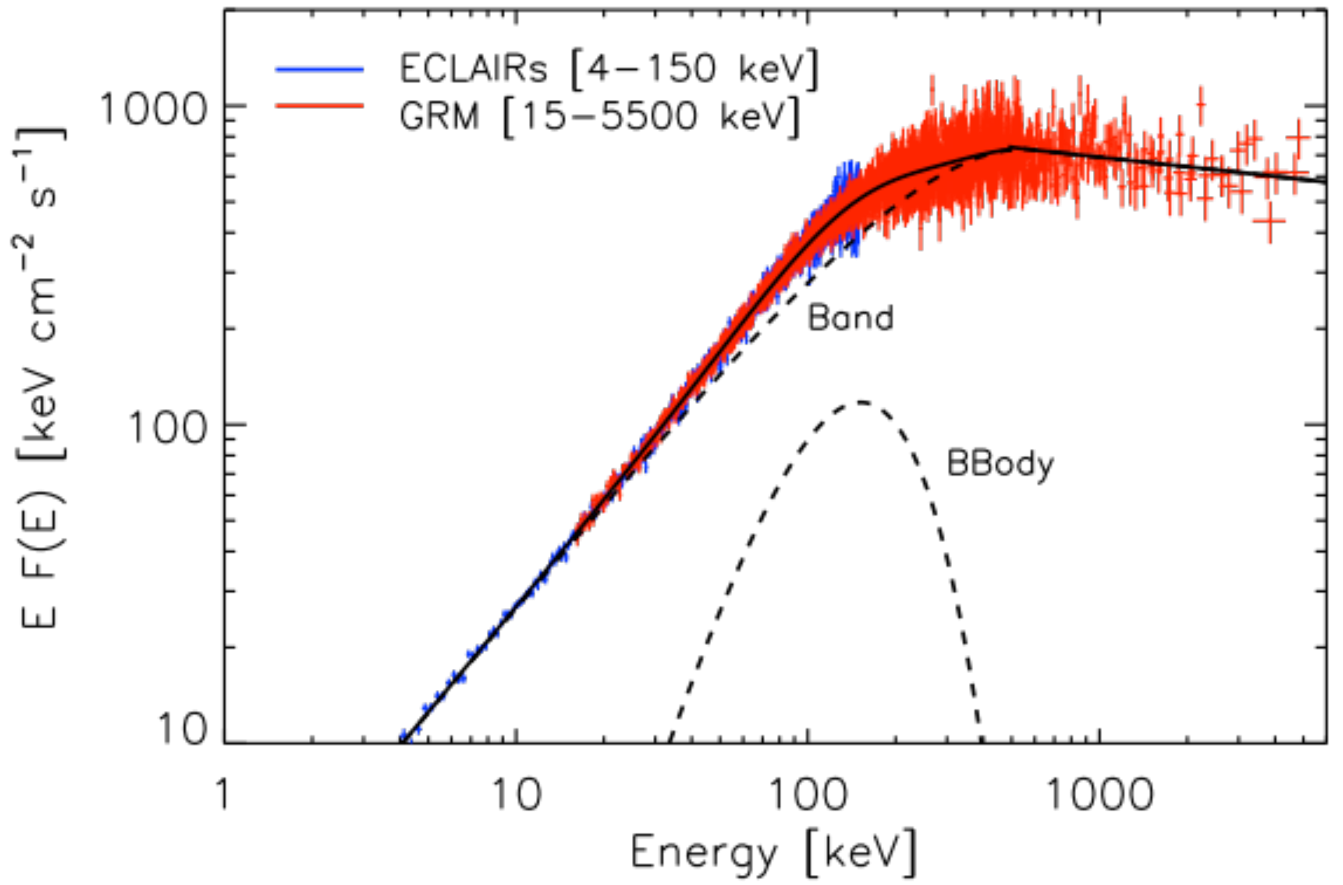
GWAC:

- 2x5400 deg^2 (half of ECLAIRs fov)
- 500-800 nm
- m_{lim} ~ 16-17 (10s exposure)

- ECLAIRs sensitive to **all classes of long GRBs**
- **Sensitivity to short GRBs improved** by combining ECLAIRs+GRM

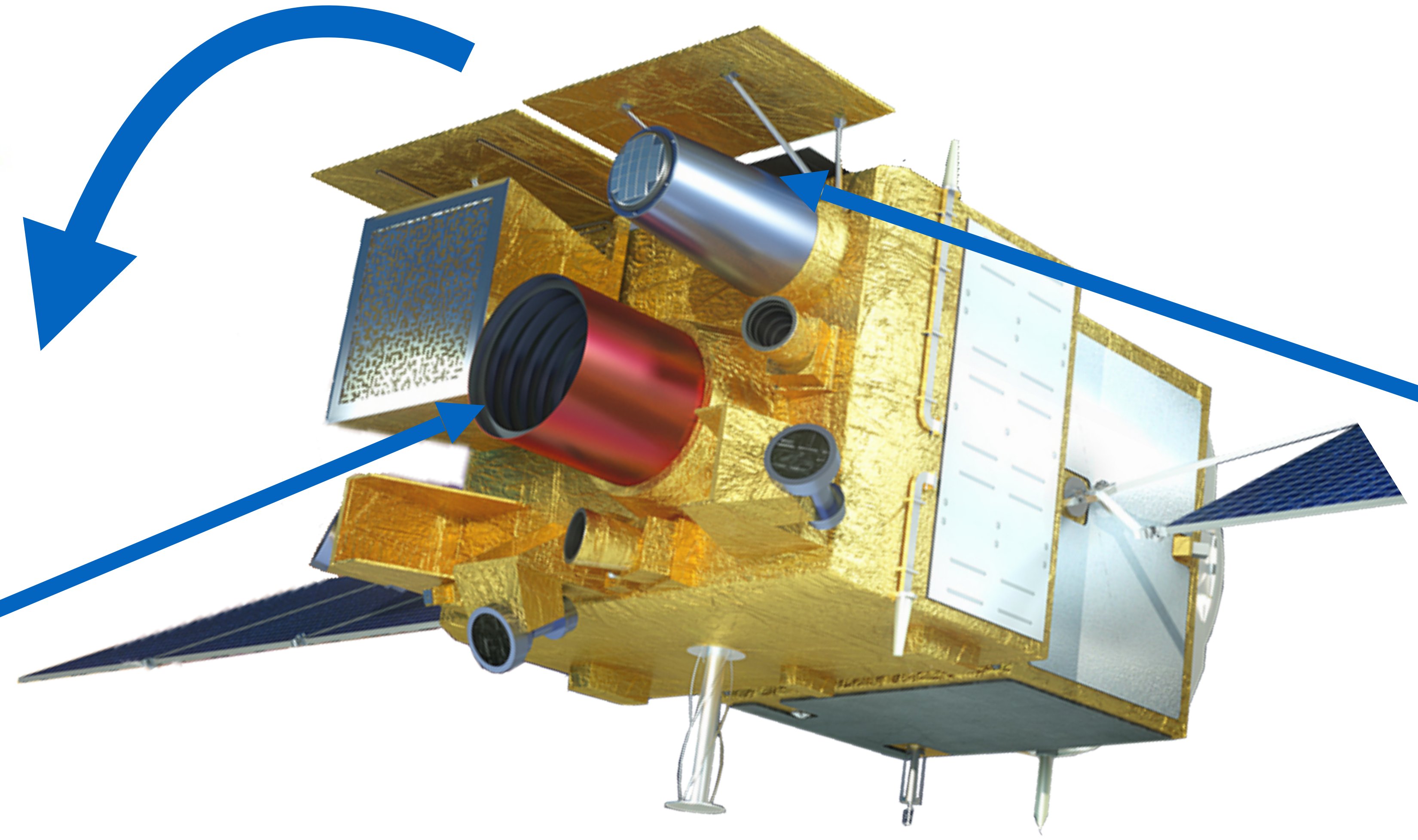
- ECLAIRs+GRM measure the **prompt spectrum over 3 decades in energy**
- GWAC will add a constraint on the **associated prompt optical emission** in a good fraction of cases (16%).

Simulation of the multi-component spectrum of GRB 100724B



Bernardini+17

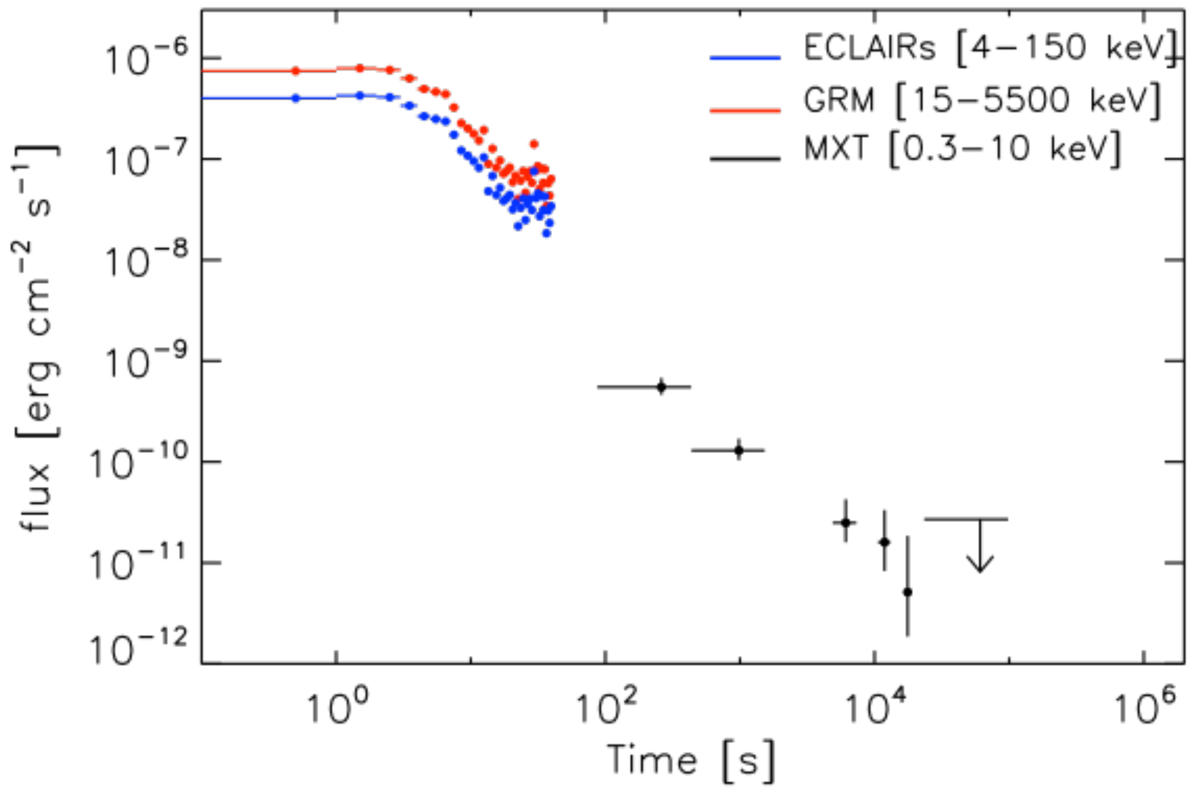
SVOM observations: prompt emission



MXT:

- 0.2-10 keV
- 64x64 arcmin^2
- **Loc. <13"** within 5 min after the trigger for 50% of GRBs
- slew request: **~72 GRB/yr**

Simulation of GRB 091020



Wei, Cordier et al., arXiv:1610.06892

VT:

- 400-1000 nm
- Loc. <1"

+

GWAC:

- 2x5400 deg^2
- 500-800 nm

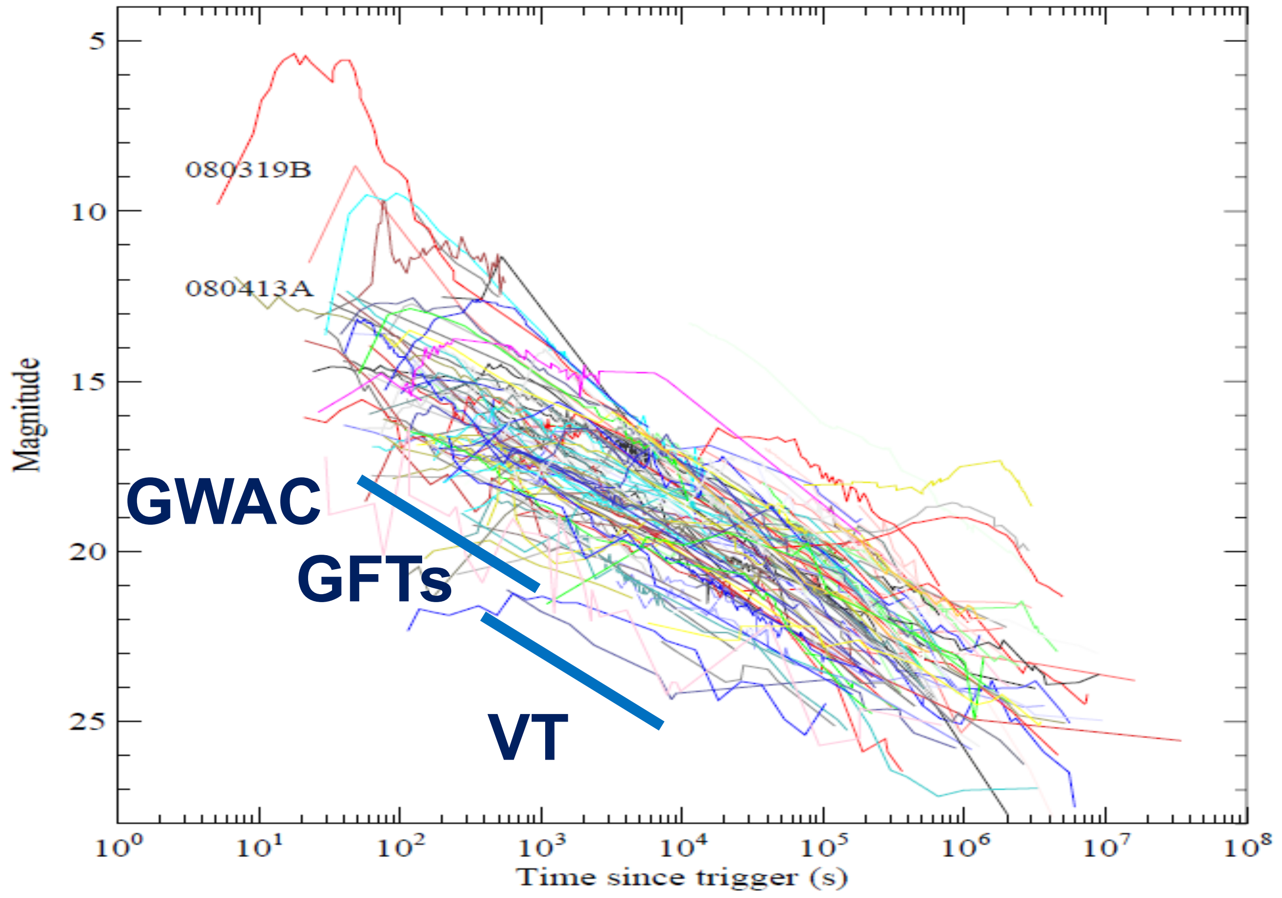
F-GFT (Colibrì):

- 1.3 m
- 400-1700 nm

C-GFT:

- 1.2 m
- 400-950 nm

Optical Light curves of long GRBs



Wang+13

- MXT can **detect and localize the X-ray afterglow** in >90% of GRBs after a slew
- VT + ground segment will **detect, localize and characterize the visible-NIR afterglow**

The SVOM GRB sample

	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**

A unique sample of **30-40 GRB/yr** with:
- **prompt emission** over 3 decades
- X-ray and V/NIR **afterglow**
- **redshift**

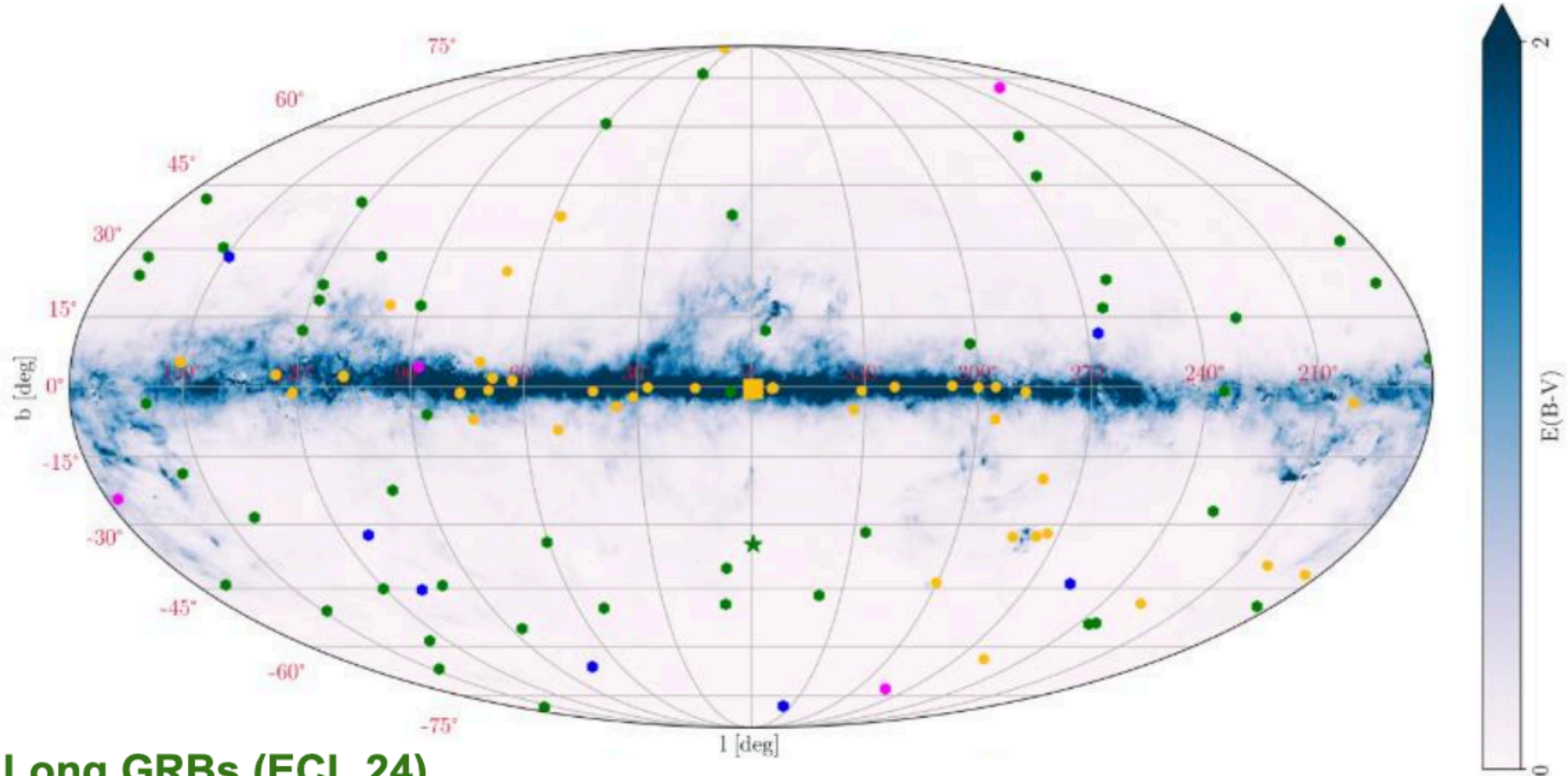
- **Physical mechanisms at work in GRBs**
  - Nature of GRB progenitors and central engines
  - Acceleration & composition of the relativistic ejecta
- **Diversity of GRBs: event continuum following the collapse of a massive star**
  - Low-luminosity GRBs / X-ray rich GRBs / X-ray Flashes and their afterglow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

The current SVOM GRB sample

199 astrophysical alerts (updated March 21, 2025)

- **99 Gamma-Ray Bursts** (87 GRM, 30 ECLAIRs of which 18 ECLAIRs+GRM)
- **100 Catalogued sources** (7 GRM, 95 ECLAIRs of which 2 ECLAIRs+GRM)

18 GRBs with redshift (ECL 10)!!!!



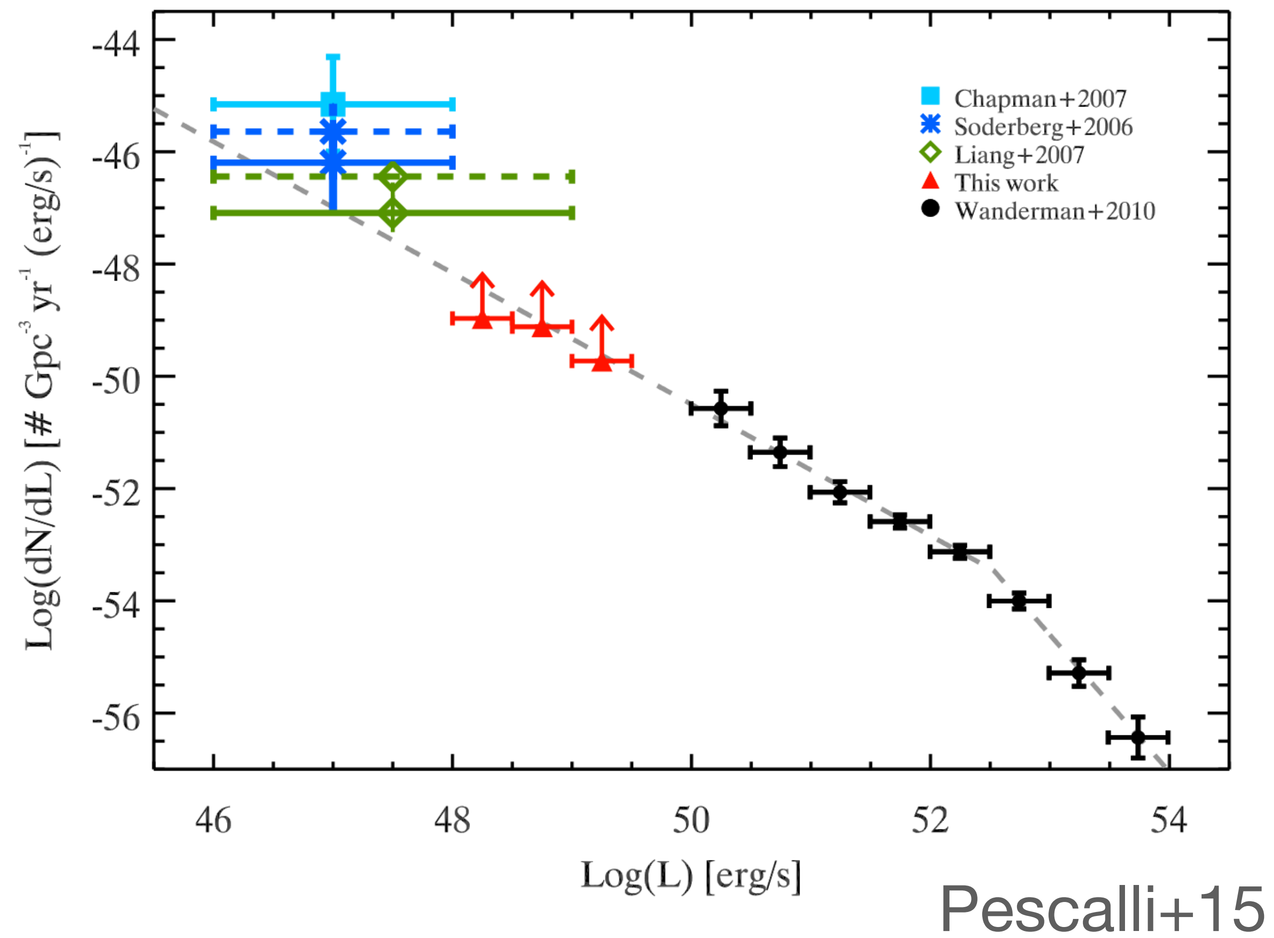
- **80 Long GRBs (ECL 24)**
- **15 Short GRBs (ECL1)**
- **4 X-ray Rich GRBs (ECL 4)**
- **100 alerts related to catalogued X-ray sources (essentially in the galactic plane)**

Credit: B. Cordier

Open questions in GRB science: progenitors, central engine and jet structure

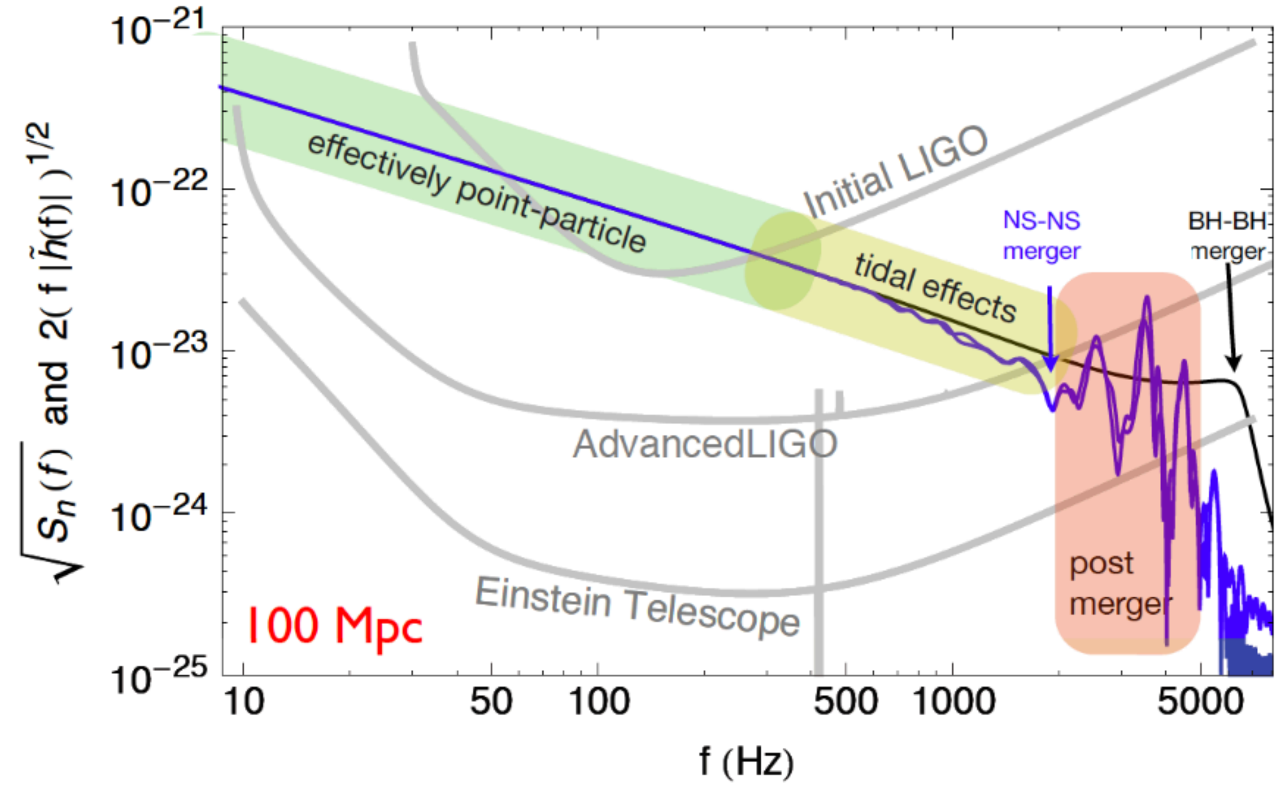
- **Long/short dichotomy** recently challenged by observations of long GRBs from BNS mergers (e.g. GRB 230307A - long with KN discovered by JWST, Levan+23)
- **Poorly explored families of GRB**, as XRR, XRF, low-luminosity, ultra-long -> GRBs in a more **general scenario of explosive events**, possible clues on secret ingredients needed to produce a GRB See M. Bugli's talk
- Long-lasting post-merger signals are the best direct detection to distinguish between the formation of a magnetar or a BH (e.g. Giacomazzo & Perna 2012, 2013; Dall'Osso et al., 2015). Hard to get it any time soon, but **good prospects with 3rd generation of detectors, as the ET**
- Our current understanding of the **jet structure** is essentially based on one event (GRB170817A): need for improvement in our capability to recognize **orphan afterglows in optical (from ZTF to Rubin) and radio (SKA) surveys** to get direct look to the jet structure and consequently of true rates for both short and long GRBs See M. Masson's talk

Luminosity function of LGRBs



Pescalli+15

Post-merger signal compared to. 2 and 3 gen. Interferometers sensitivity



Maggiore+20

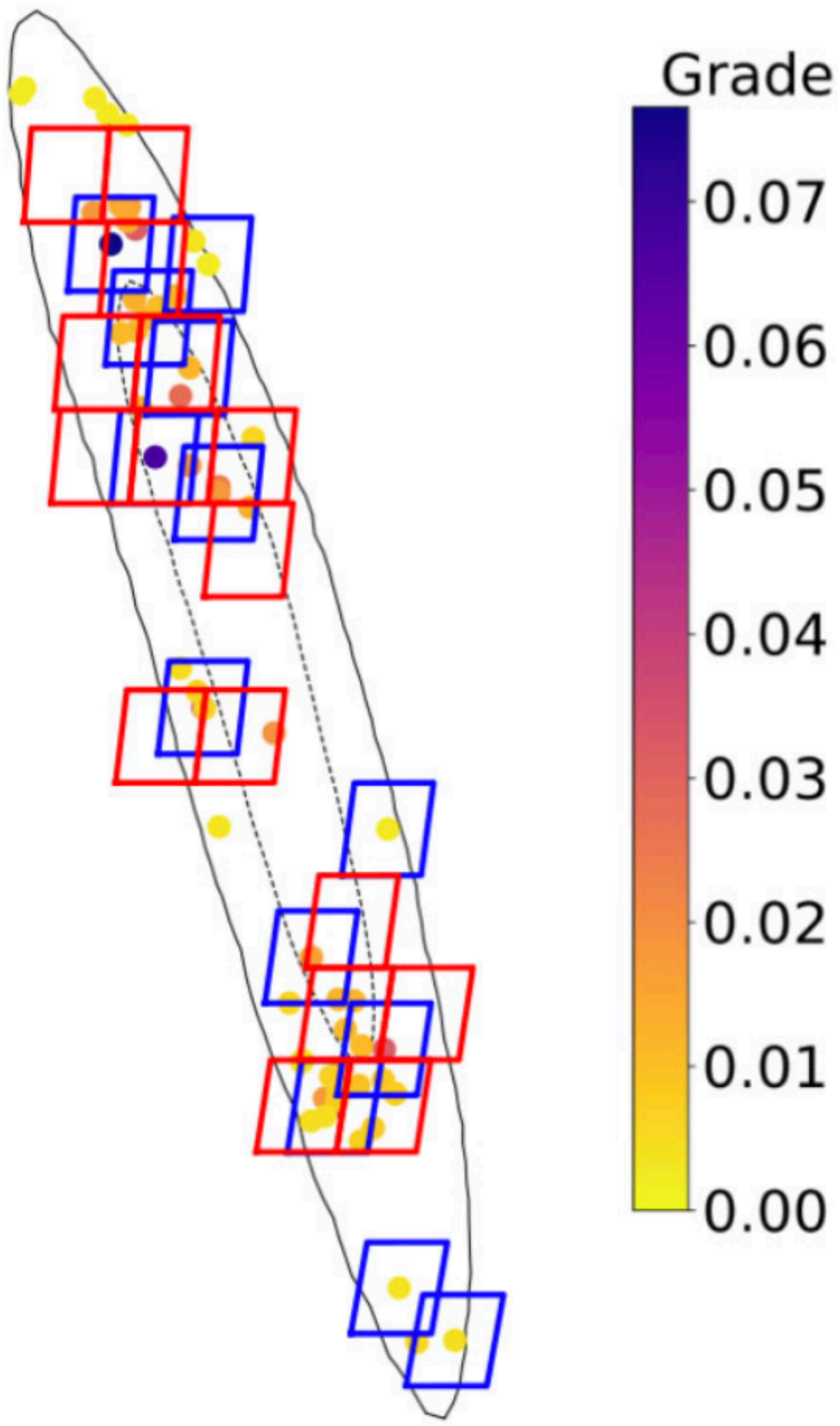
EINSTEIN TELESCOPE

2020 — 2030 — 2040 — years

Swift, Fermi, SVOM, EP

THESEUS

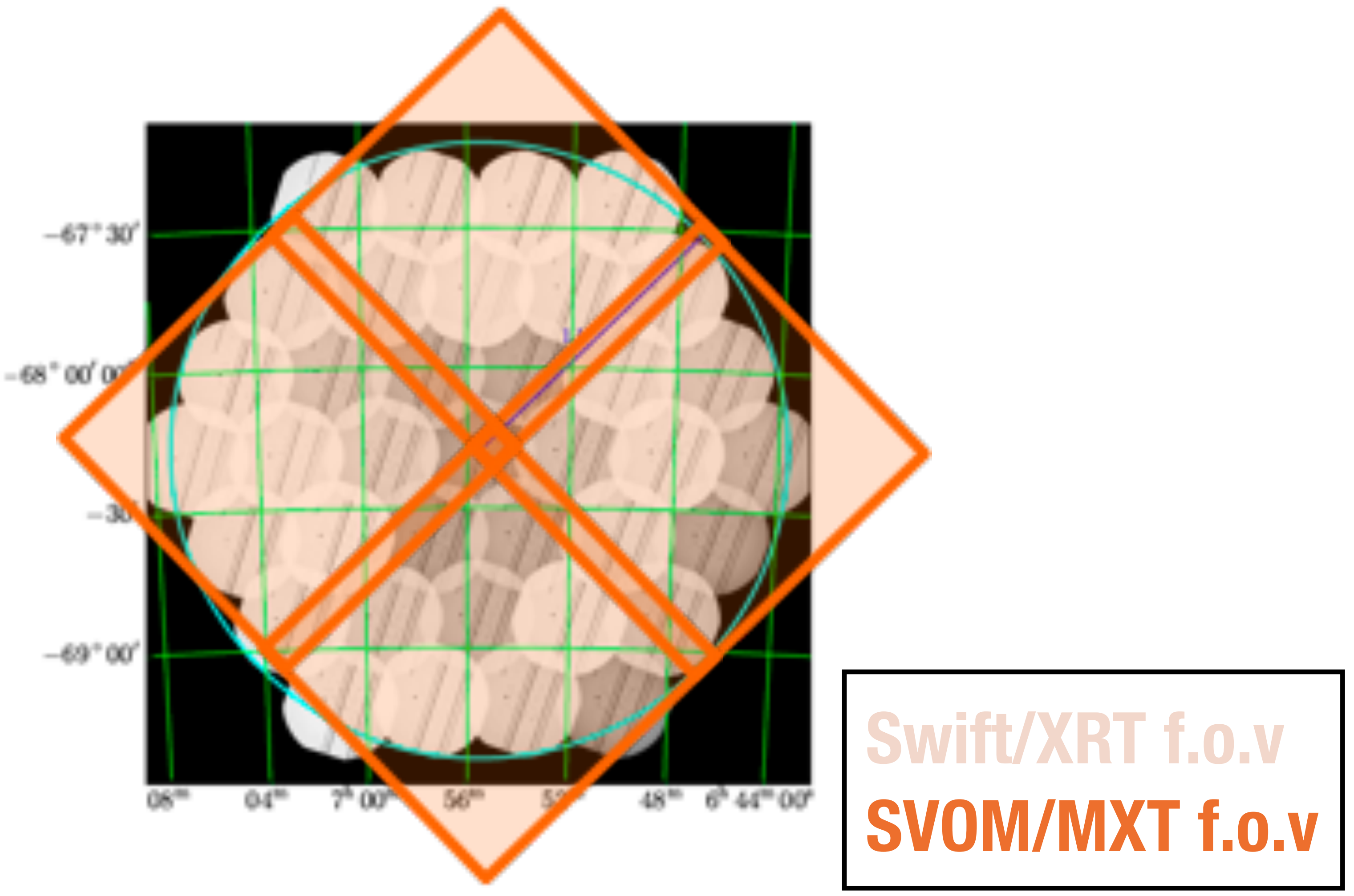
Multi-messenger astronomy with SVOM



Ducoin et al., 2020, 2023

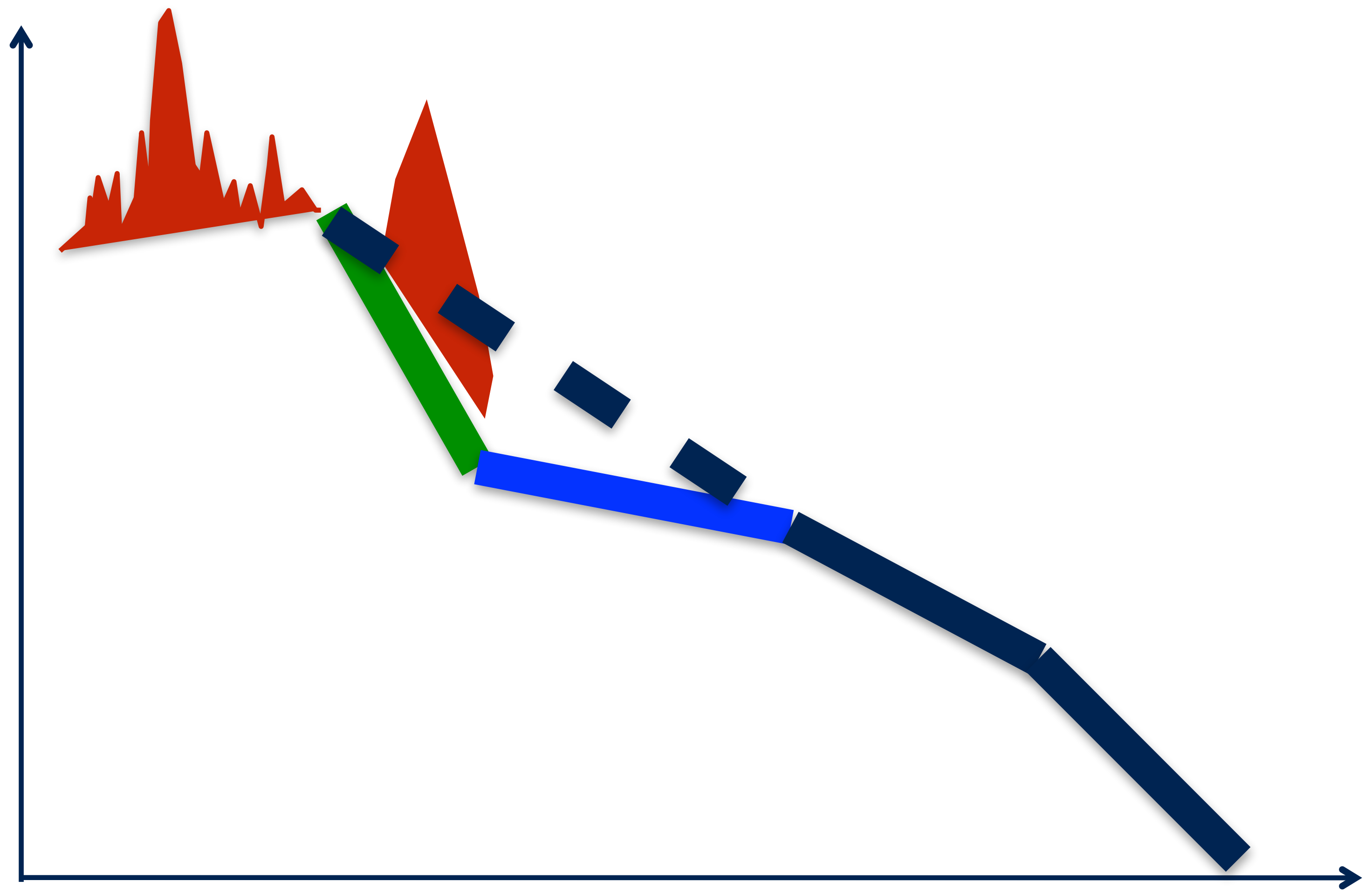
- **Ideal scenario: detection of the sGRB**
  - ➡ **ECLAIRs/GRM:** large fov, independent trigger or offline search
- **Likely scenario: external alert received**
  - ➡ **MXT/VT:** slew after the alert **ToO-MM**
  - ➡ **Galaxy tiling** strategy if the error box is larger than 1 deg^2

MXT vs. XRT tiling

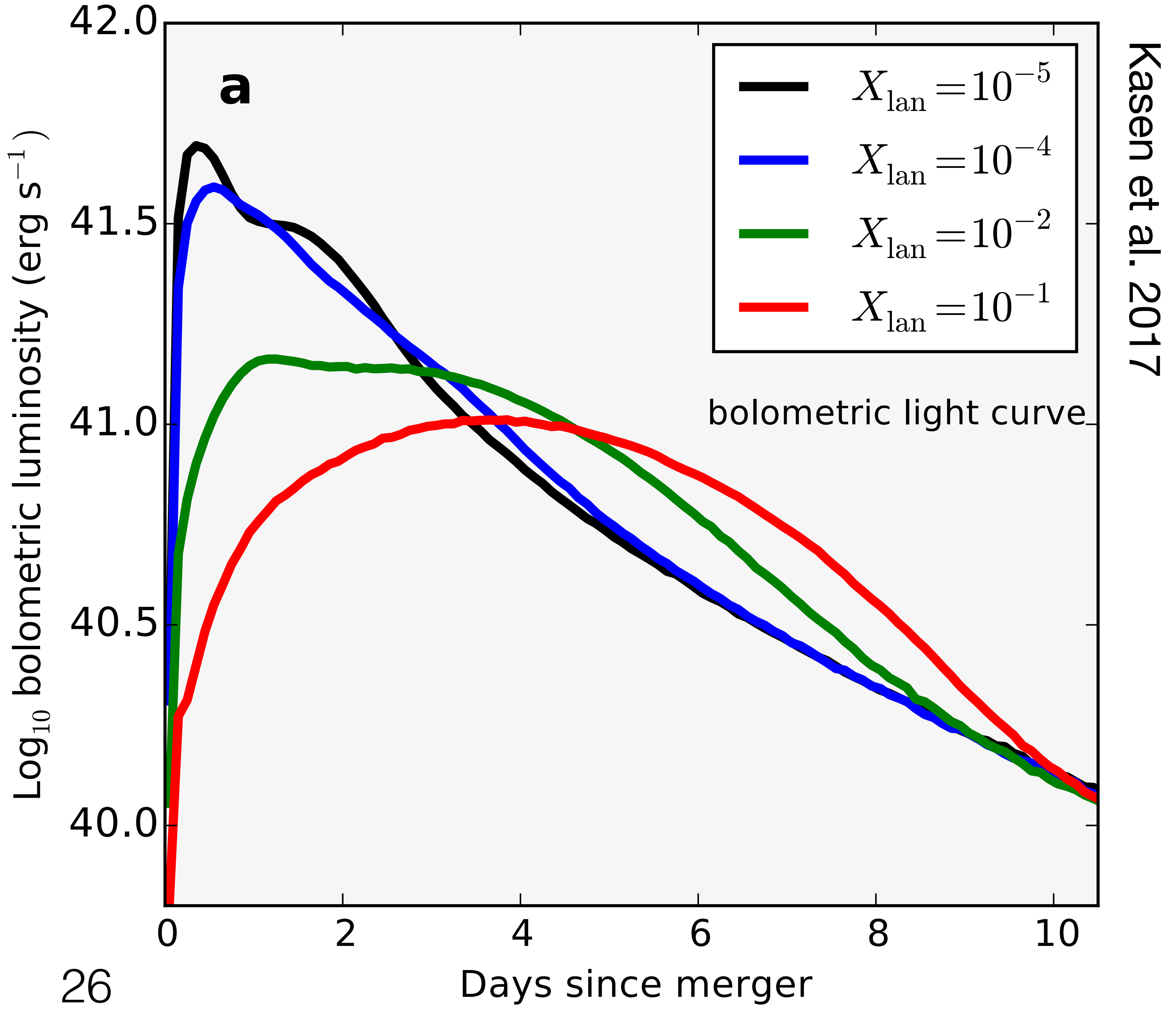


Observational imprints of the magnetar

- The GRB emission



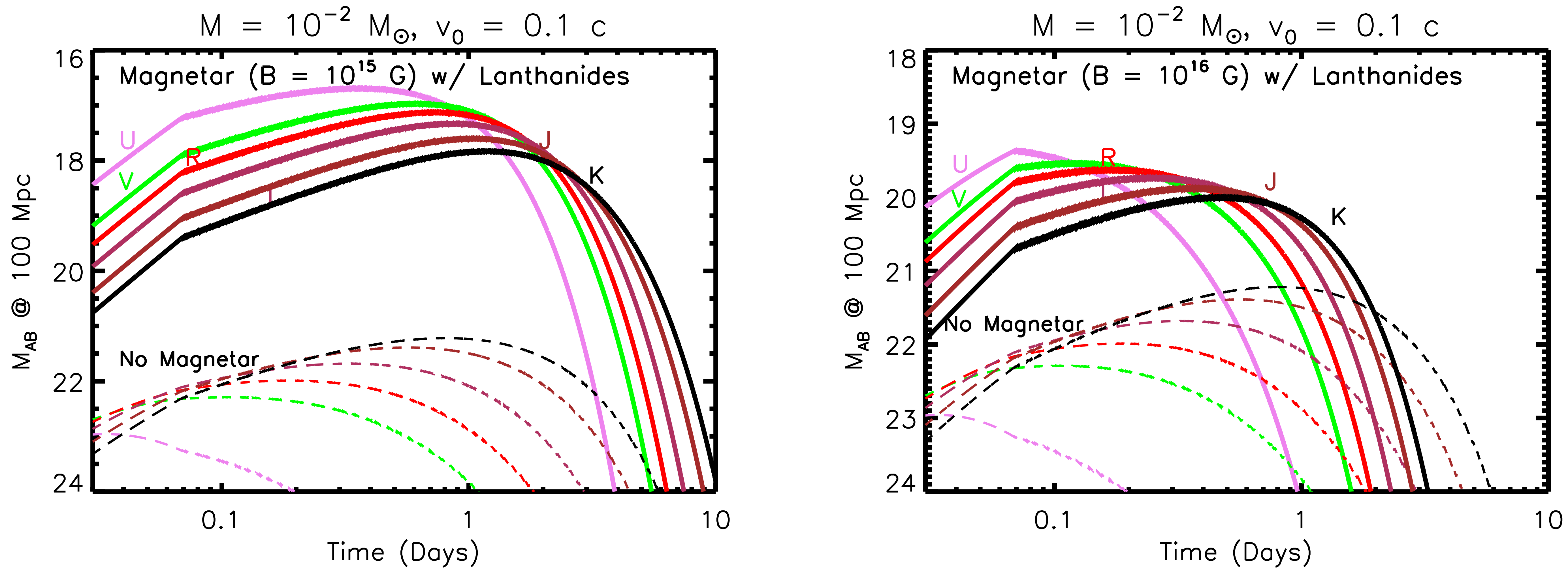
- The kilonova emission associated to SGRBs



Observational imprints of the magnetar

- The GRB emission:
  - X-ray plateau
  - Extended emission in SGRBs
  - Pre- and post-cursors in the prompt emission

- **The kilonova emission associated to SGRBs**

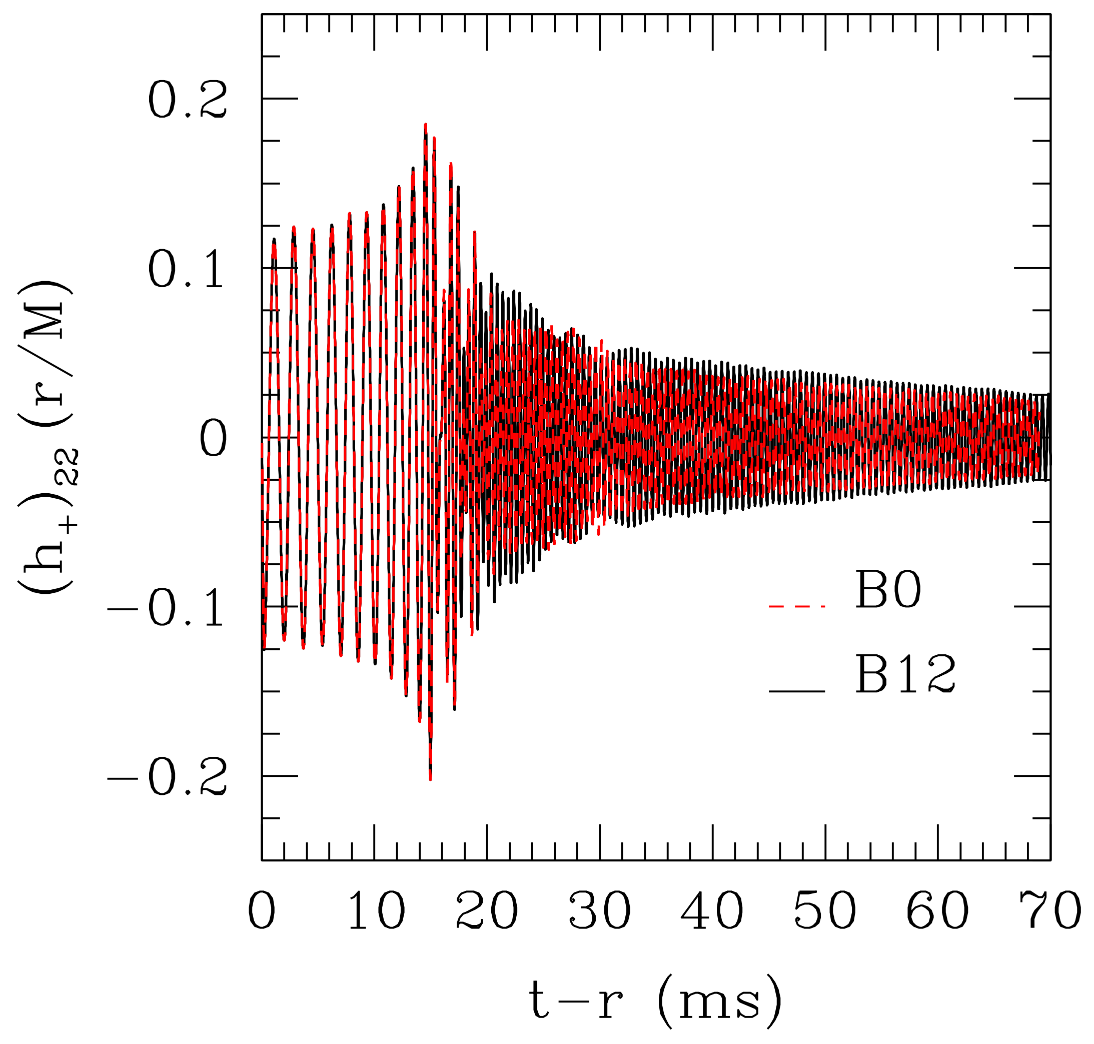


Metzger 2019

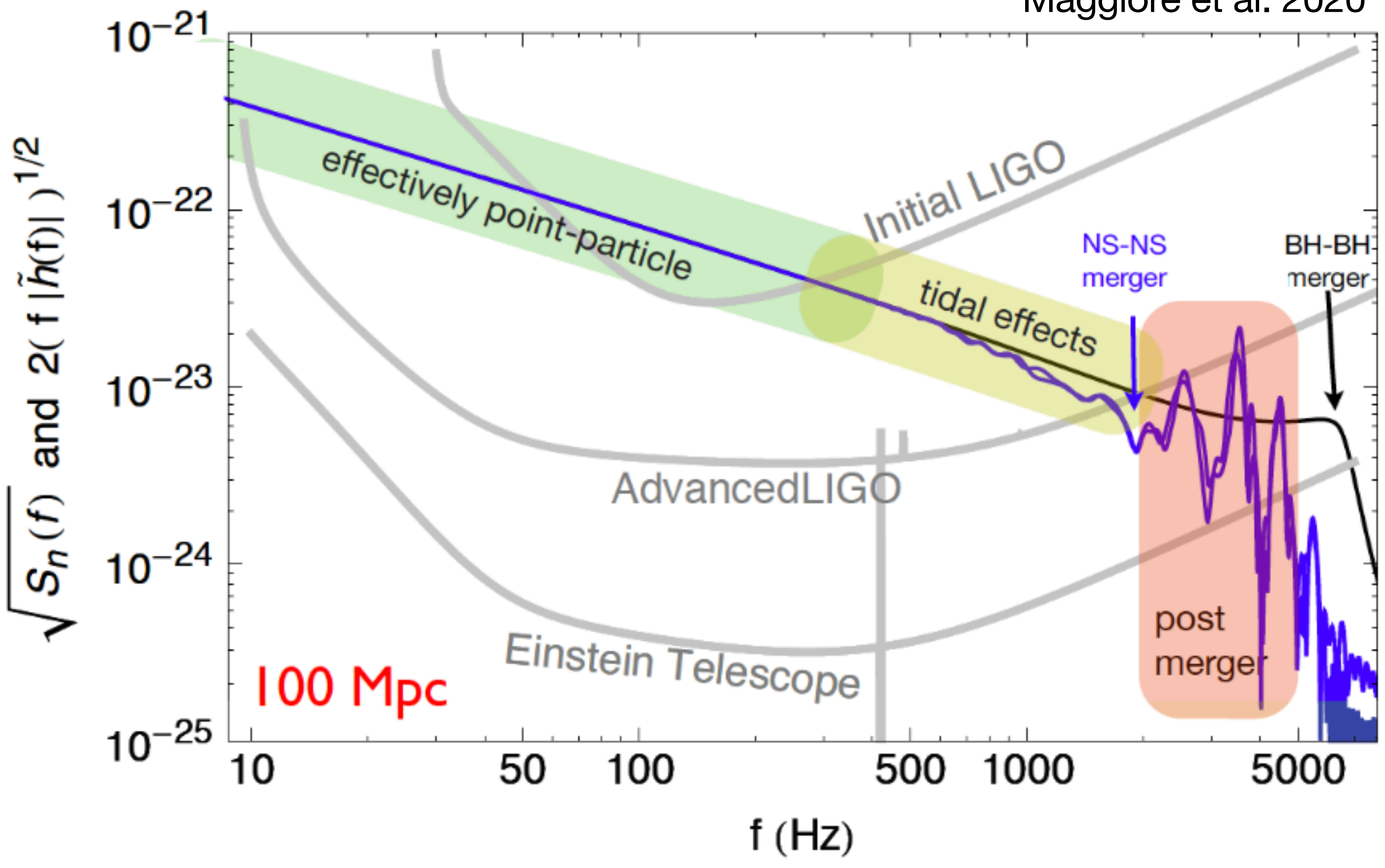
Direct detection of GWs from the magnetar

- Long-lasting post-merger signals are the best direct detection to distinguish between the formation of a magnetar or a BH (e.g. Giacomazzo & Perna 2012, 2013; Dall'Osso et al., 2015)
- Searches in the LIGO/Virgo data for short and intermediate duration signals in GW 170817/ GRB 170817A not conclusive (Abbott et al. 2017, 2019; Van Putten & Della Valle 2018)
- Hard to get it any time soon, but **good prospects with 3rd generation of detectors, as the ET** (Maggiore et al. 2020)

Giacomazzo & Perna 2013



Maggiore et al. 2020



The future after Swift

- What happens after Swift, SVOM and EP? Possibly **THESEUS** (see L. Amati’s talk), but we risk to have a long gap. Cubesats might be an easy and “light" way to provide triggers (see e.g. HERMES)
- With the third generation interferometers (ET, CE), in 20 years were might have one GW signal for each short GRB. But who will observe those short GRBs?

How to cover the long gap? How to maintain the field alive?

Need to rethink how we do science in the field

- Take advantage of the big facilities and on the large number of transients that will be discovered. But how to classify transients (SOXS, see S. Campana’s talk)?
- For a panchromatic view of transients, need to combine different facilities
- Need for public data and alerts (both lesson learnt from Swift)
- Need to develop need approaches to treat data (machine learning?)