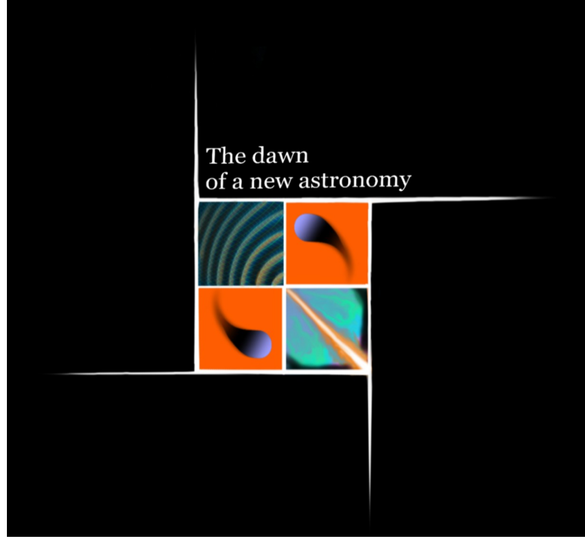
GRAN SASSO SCIENCE INSTITUTE

SCHOOL OF ADVANCED STUDIES

Scuola Universitaria Superiore



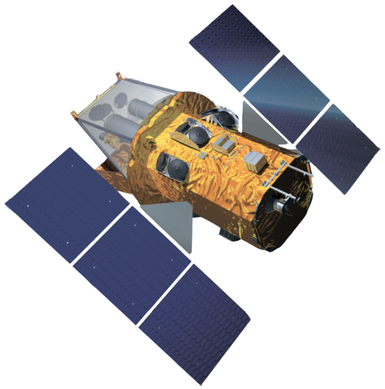
Multi-wavelength follow-up of exceptionally luminous GRBs

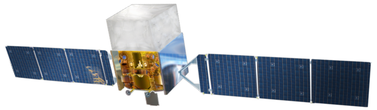
Alessio Mei, 2nd year PhD student

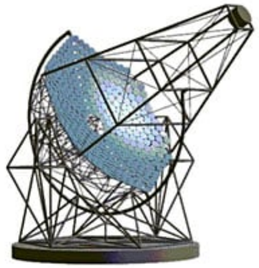
GSSI Gravity Group

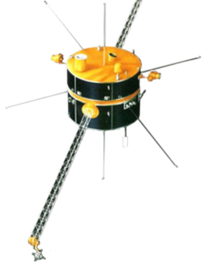
AP Science Fair

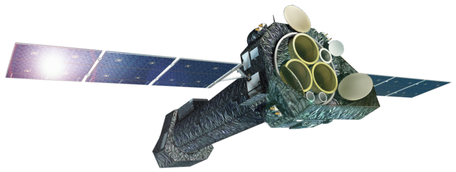
High Energy Astrophysics group











2021: A year of bright GRBs!

https://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html

Table Name and Row Count

fermigbrst:Fermi GBM Burst Catalog

Table Legend:

Display all parameters for a row

Sort by a column in order: 1,2,3 Sort by column in reverse order: 3,2,1 Current table sort

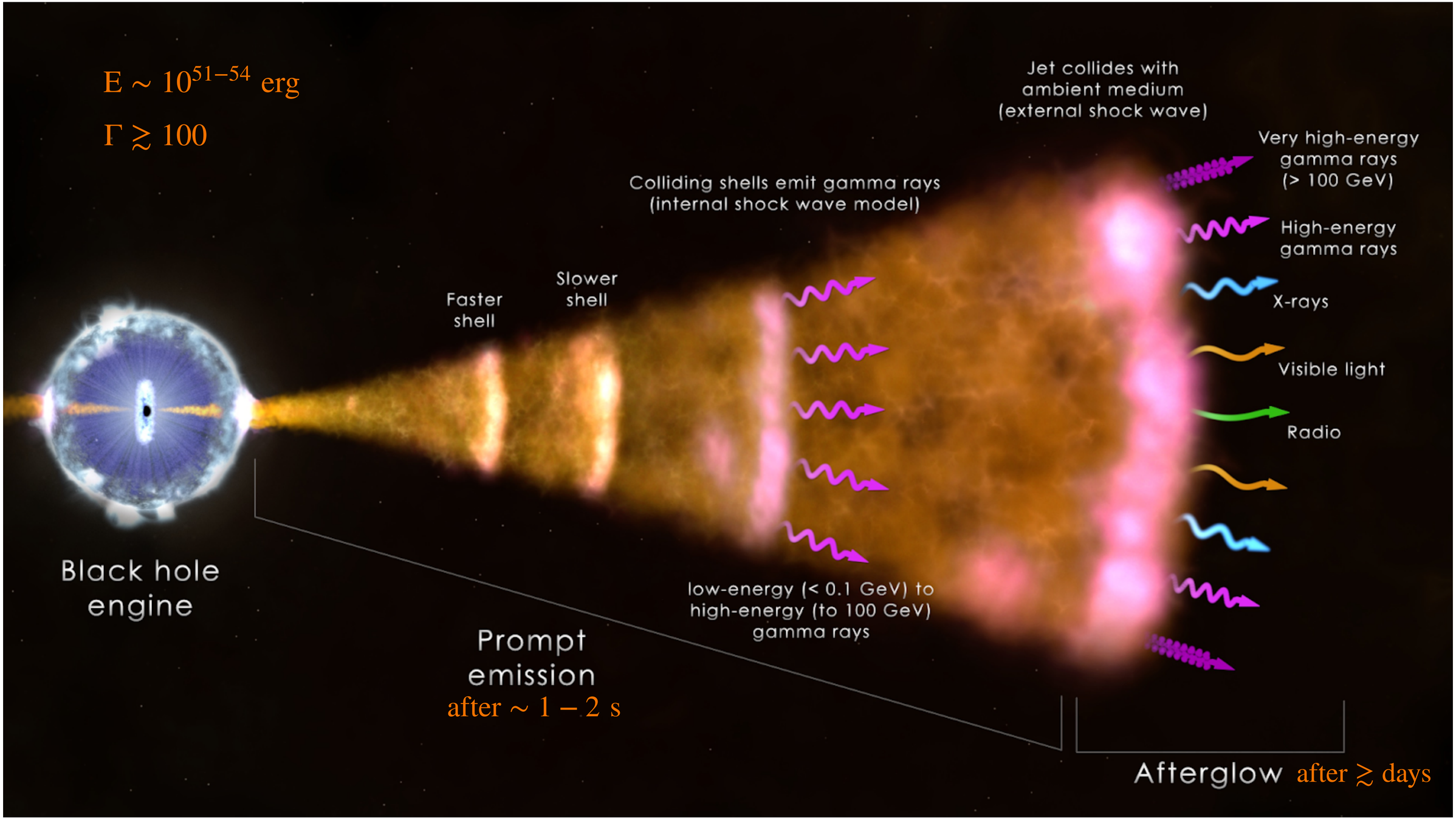
Services Links: O: Digitized Sky Survey image, R: ROSAT All-Sky Survey image, N: NED objects near coordinates, D: get list of data products, B: ADS bibliography holdings

Scroll down below query results to select Data Products and Further Actions.

Fermi GBM Burst Catalog (fermigbrst) Bulletin README

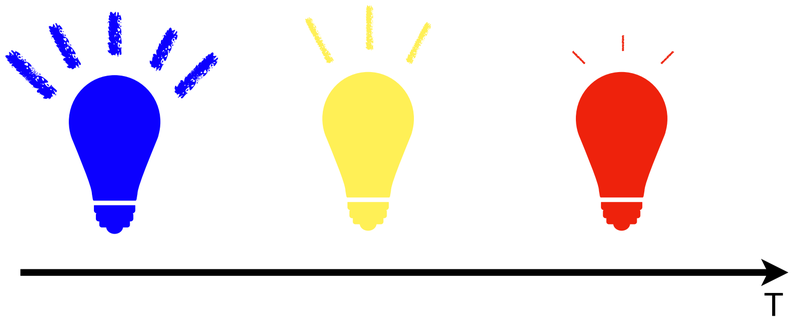
Select All	Services	name	trigger time	t90 [s]	fluence [erg/cm^2]	flux 1024 [photon/cm^2/s]
	D	GRB090626707	2009-06-26 16:58:45.464			
	D	GRB210518545	2021-05-18 13:04:09.640	6.400	2.4604e-02	374860.0000
	D	GRB130427324	2013-04-27 07:47:06.420	138.242	2.4620e-03	1051.8600
	D	GRB160625945	2016-06-25 22:40:16.275	453.385	6.4256e-04	216.8460
	D	GRB171010792	2017-10-10 19:00:50.576	107.266	6.3279e-04	120.1400
	D	GRB160821857	2016-08-21 20:34:30.039	43.009	5.2221e-04	123.0790
	D	GRB211211549	2021-12-11 13:09:59.651	34.305	5.0118e-04	324.8990
	D	GRB190114873	2019-01-14 20:57:02.626	116.354	4.4325e-04	246.8640
	D	GRB190530430	2019-05-30 10:19:08.903	18.432	3.7062e-04	160.5450
	D	GRB210619999	2021-06-19 23:59:25.604	54.785	3.0248e-04	238.6250
	D	GRB180720598	2018-07-20 14:21:39.654	48.897	2.9853e-04	124.5480

+ ...


$E \sim 10^{51-54}$ erg
$\Gamma \gtrsim 100$
Jet collides with ambient medium (external shock wave)
Very high-energy gamma rays (> 100 GeV)
Colliding shells emit gamma rays (internal shock wave model)
High-energy gamma rays
Faster shell
Slower shell
X-rays
Visible light
Radio
Black hole engine
low-energy (< 0.1 GeV) to high-energy (to 100 GeV) gamma rays
Prompt emission after ~ 1 – 2 s
Afterglow after ≳ days

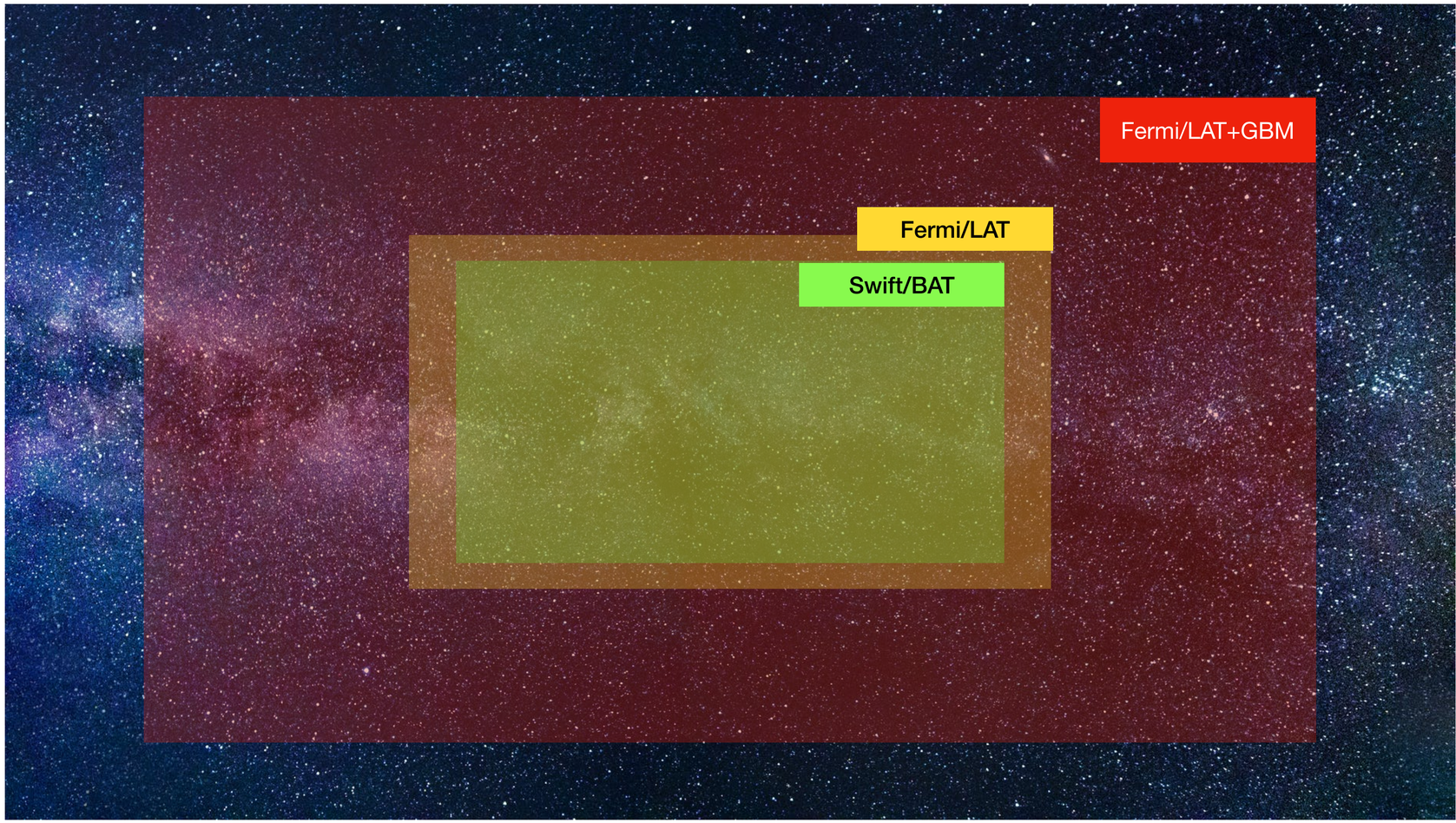
Fundamental tools for GRB astronomy

What do we observe?

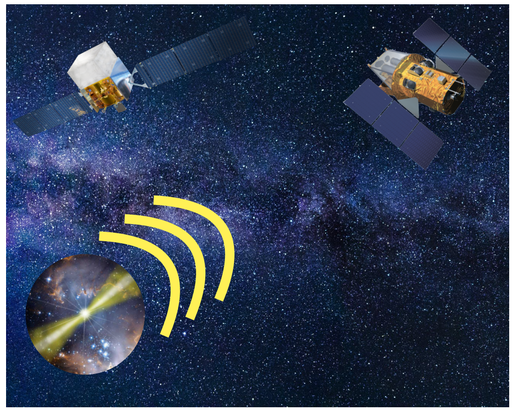


What do we need?

- Instruments with high field of view to scan large portions of the sky simultaneously (e.g. Fermi, Swift/BAT) .
- Good **angular resolution** to measure more precisely the **position** of the source in the sky.
- Fast slewing telescopes to rapidly point towards the GRB.



GRB astronomy in a nutshell



High FOV Gamma-ray instruments are triggered by GRB prompt emission

Trigger and position

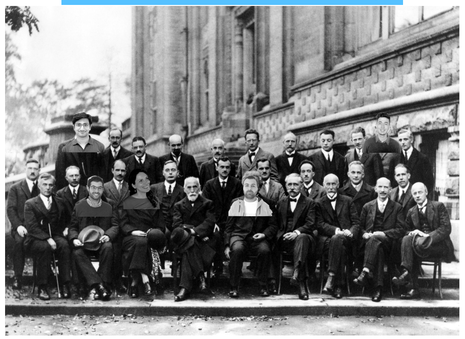
Gamma-Ray Coordinates Network

- **Location of GRBs** and
- other transients (**Notices**)
- Reports of **follow-up**
- **observations** (**Circulars**)

GCN

Automatic pipelines

Scientific community



Follow-up

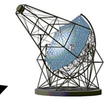
VHE

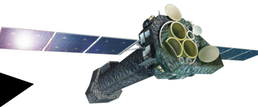
X-rays

Optical

Radio

γ – rays

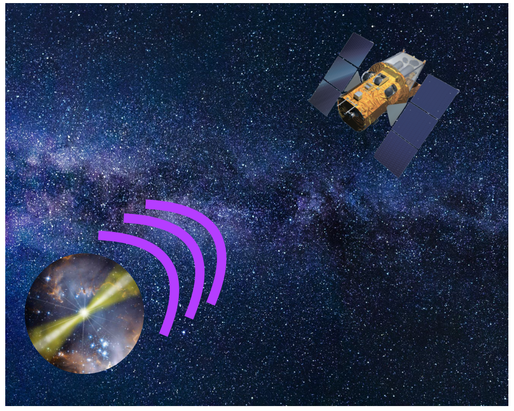




Fast-slewing instruments

~100 s

~20 s

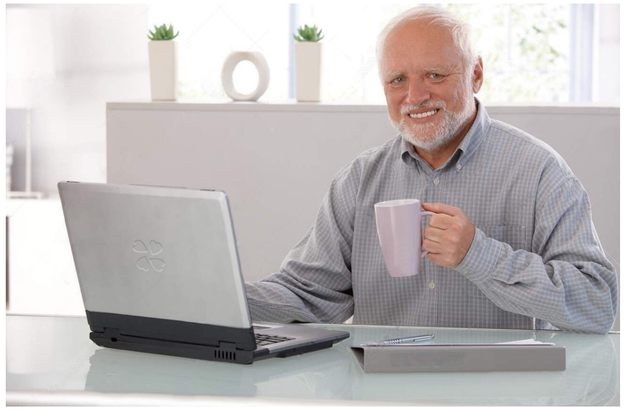


Space-based

Ground-based

Our Routine

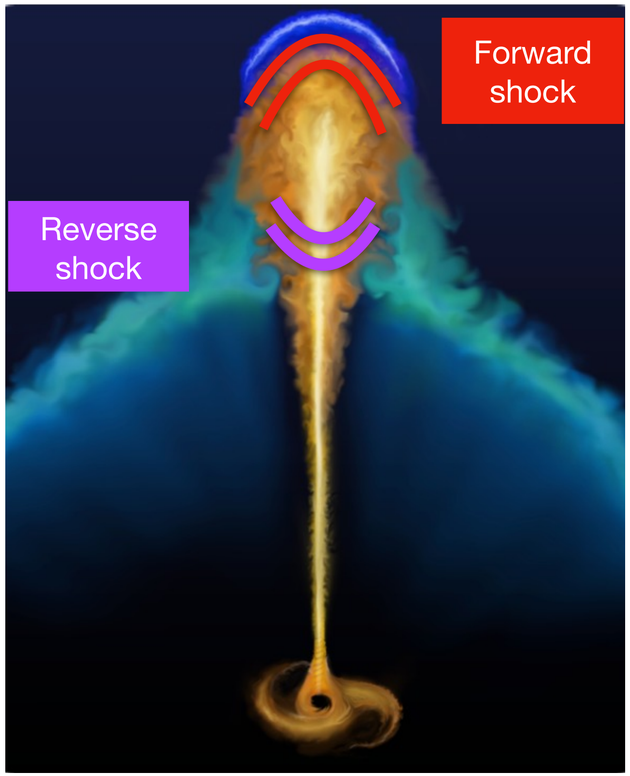
GCN Circulars	Inbox	GRB 220210A: Insight-HXMT/HE detection - TITLE: GCN CIRCULAR NUMBER: 31583 SUBJE
GCN Circulars	Inbox	GRB 220211A: Swift/BAT-GUANO detection outside the coded FOV (short) - TITLE: GCN CIR
GCN Circulars	Inbox	GRB 220210A: 1.5m OSN optical upper limit - TITLE: GCN CIRCULAR NUMBER: 31581 SUBJ
GCN Circulars	Inbox	GRB 220210A: Fermi GBM detection - TITLE: GCN CIRCULAR NUMBER: 31580 SUBJECT: GF
GCN Circulars	Inbox	Fermi GRB 220211B: Global MASTER-Net observations report - TITLE: GCN CIRCULAR NUM
GCN Circulars	Inbox	GRB 220211B: Fermi GBM Final Real-time Localization - TITLE: GCN CIRCULAR NUMBER: 3
GCN Circulars	Inbox	GRB 220209A: Fermi-LAT detection - TITLE: GCN CIRCULAR NUMBER: 31577 SUBJECT: GRI
GCN Circulars	Inbox	GRB 220210A: Fermi-LAT detection - TITLE: GCN CIRCULAR NUMBER: 31576 SUBJECT: GRI
GCN Circulars	Inbox	GRB 220210A: AGILE detection - TITLE: GCN CIRCULAR NUMBER: 31575 SUBJECT: GRB 22
GCN Circulars	Inbox	GRB 220210A: BOOTES-5/JGT optical afterglow candidate discarded - TITLE: GCN CIRCULA
GCN Circulars	Inbox	GRB 220210A: BOOTES-5/JGT optical afterglow candidate - TITLE: GCN CIRCULAR NUMBE
GCN Circulars	Inbox	GRB 220210A: Swift/BAT-GUANO localization - TITLE: GCN CIRCULAR NUMBER: 31572 SUB
GCN Circulars	Inbox	Fermi GRB 220211A: Global MASTER-Net observations report - TITLE: GCN CIRCULAR NUM
GCN Circulars	Inbox	GRB 220211A: Fermi GBM Final Real-time Localization - TITLE: GCN CIRCULAR NUMBER: 3
GCN Circulars	Inbox	Fermi GRB 220210A: Global MASTER-Net observations report - TITLE: GCN CIRCULAR NUM
GCN Circulars	Inbox	GRB 220210A: Fermi GBM Final Real-time Localization - TITLE: GCN CIRCULAR NUMBER: 3
GCN Circulars	Inbox	GRB 210919A: Maidanak optical observations - TITLE: GCN CIRCULAR NUMBER: 31567 SUI



“Summer” GRB 210619B: Reverse shock!

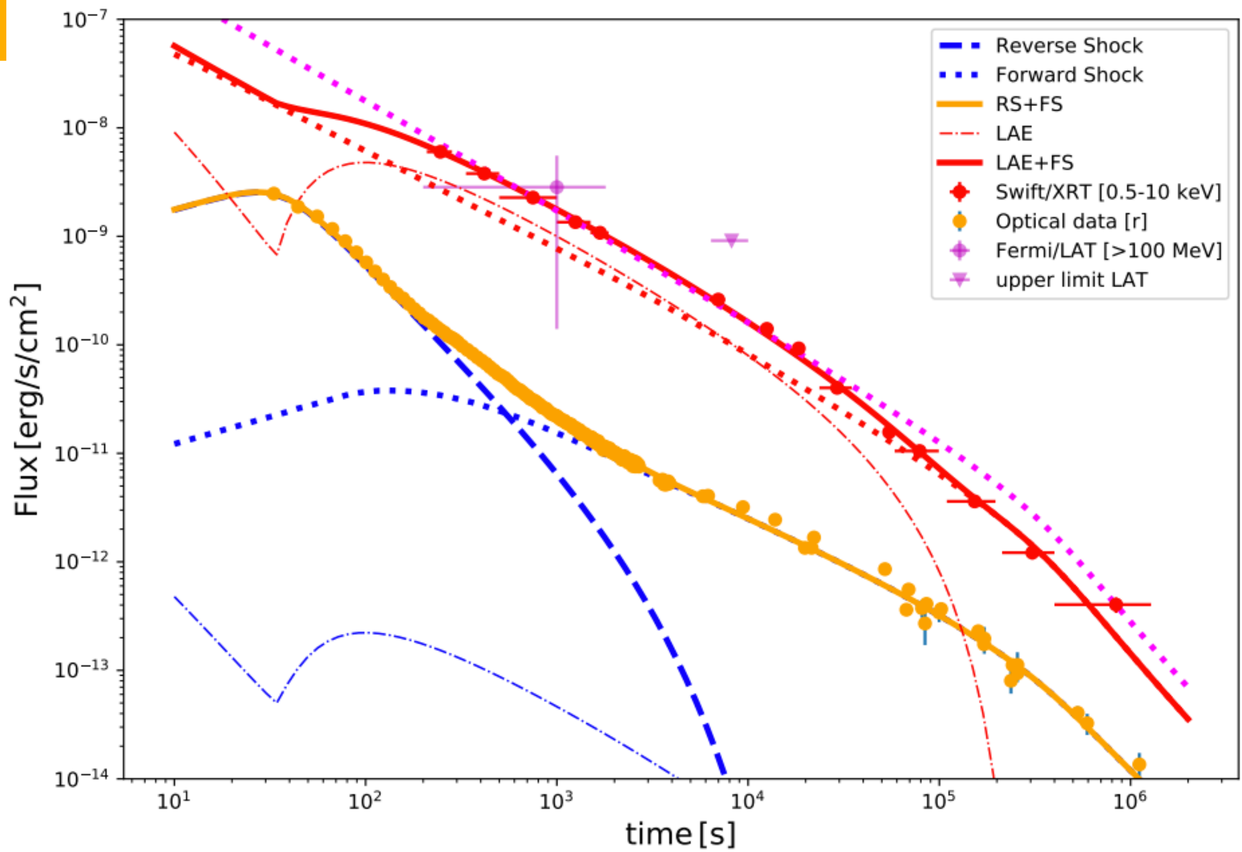
- One of the **brightest** and most **energetic** GRB ever observed !

- Large excess in the optical band detected after ~ 30 s from the burst, simultaneously with prompt emission



Credits: S. Ronchini

Oganesyan, … ,Ronchini, Banerjee, Branchesi + 2021, under review Nature Astronomy

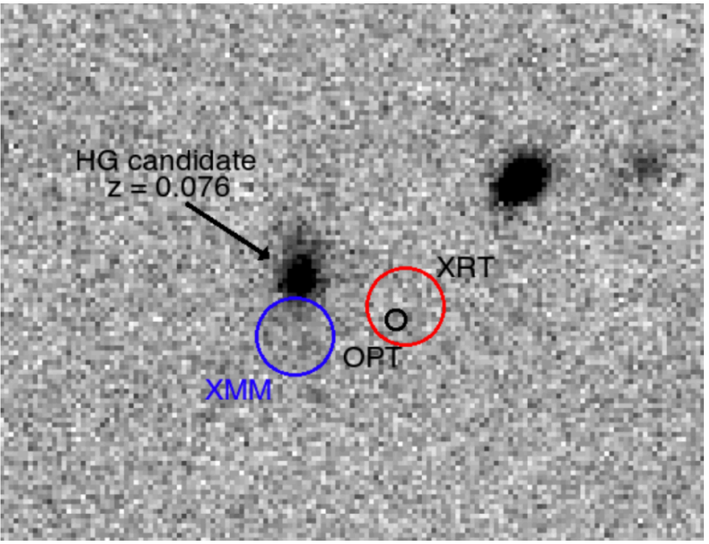


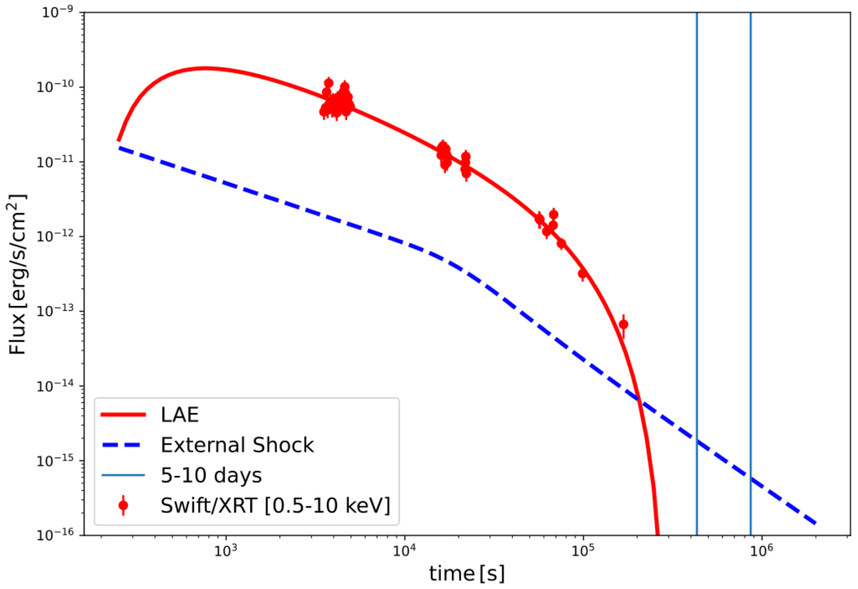
Interaction between **jet** and **circum-burst material** creates two shocks with ~ **same energy**: **forward** through ISM and **reverse** through the jet

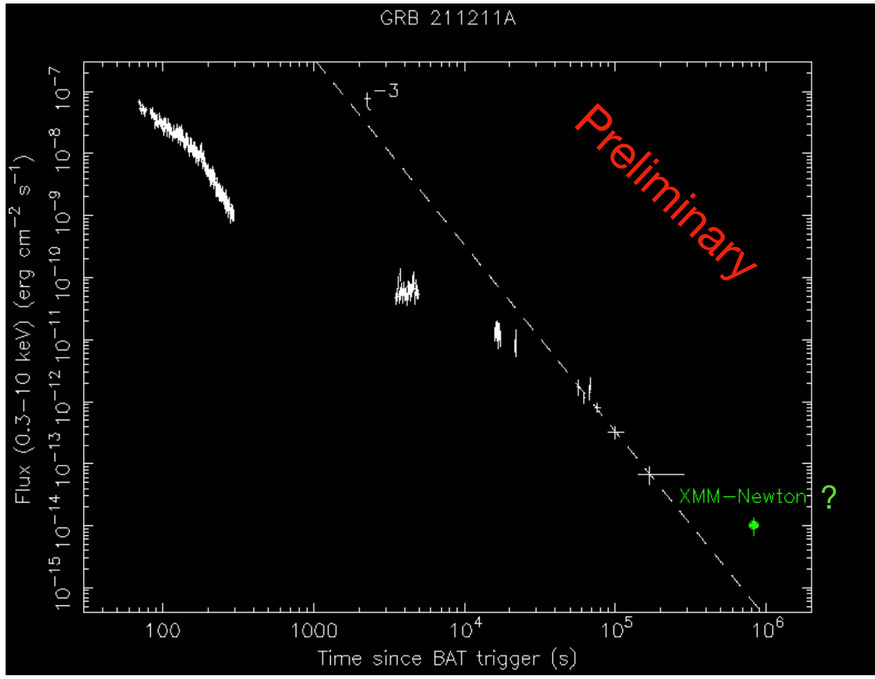
Jet material is hotter and more dense w.r.t. ISM, producing an emission which lasts less and with less energetic photons (optical band)

“Xmas” GRB 211211A: Short or Long?

Credits: P. D’avanzo







Long duration (~30 s) and possibly associated with a very close galaxy (z ~ 0.076)

Long GRB from star **collapse**!

If it is so close, where is the Supernova?

Long GRB but in a **more distant galaxy**
-> SN not visible

BNS merger + possible kilonova in the nearby galaxy (z ~ 0.076)
-> Short GRB with extended emission

LC for $t < 10^5$ s is not compatible with standard external shock model, in accordance with alternative models e.g. high latitude emission from a structured jet

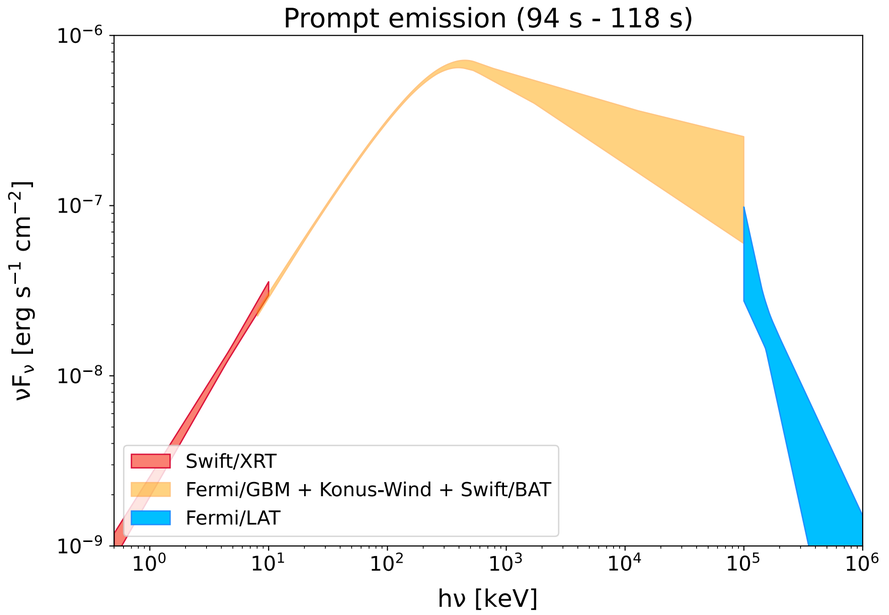
X-ray afterglow excess detected at very late time by our XMM-Newton observation resembles the **standard flux drop** from external shock

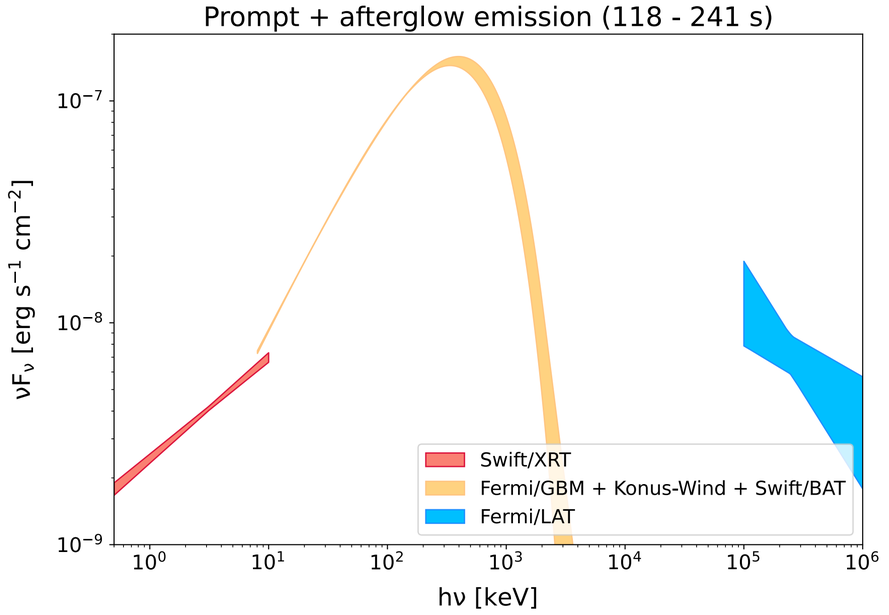
“New Year” GRB 220101A: Benchmark for relativistic physics

- Very distant (z = 4.62) and energetic ($E_{iso} \simeq 3 \cdot 10^{54}$ erg) source, high spectral coverage (from soft X-rays to ~ GeV, but also optical and radio detection)

- Presence of **pair-production cutoff** within the **Fermi/LAT** energy band

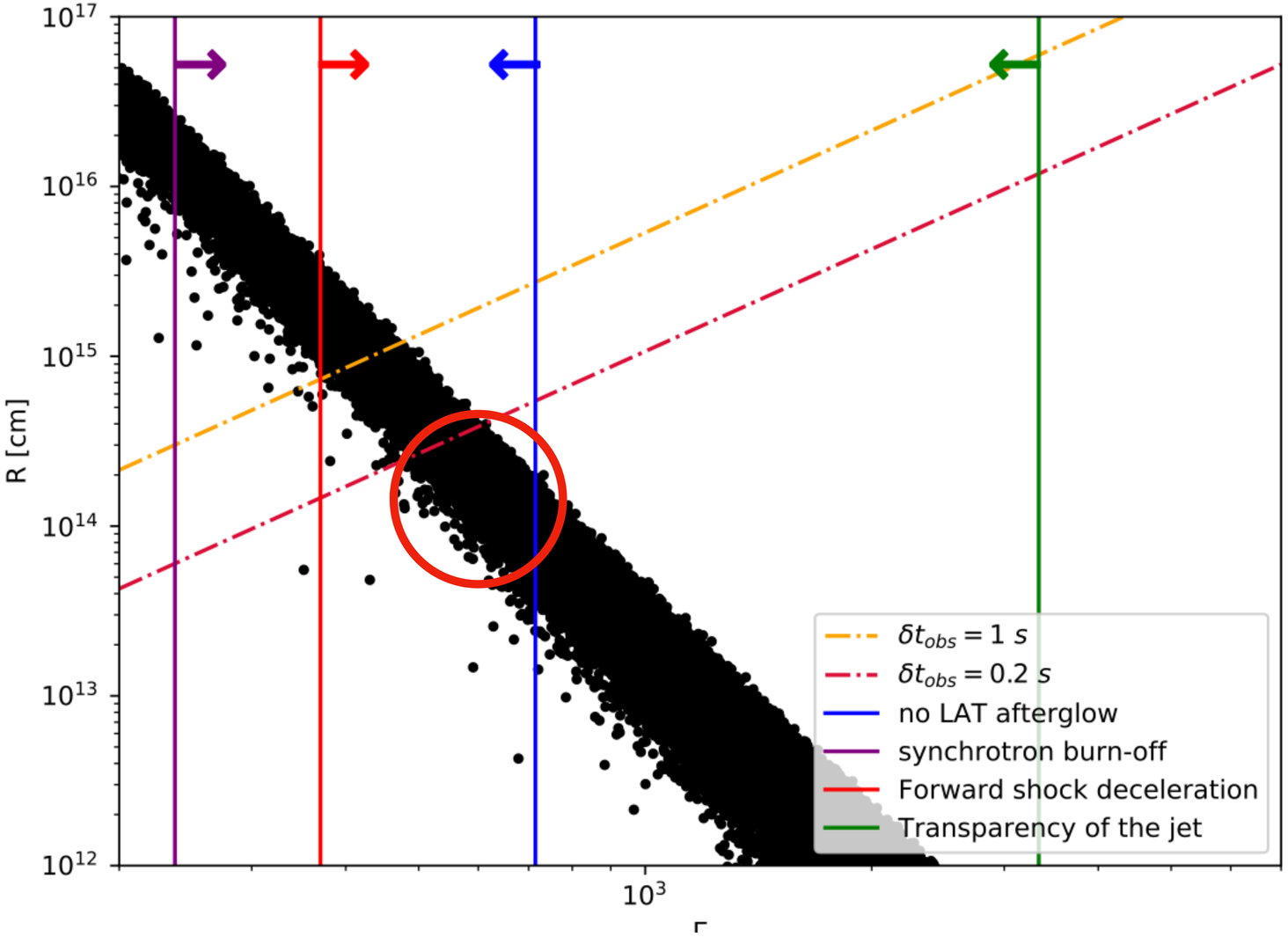
- Excess at higher and lower energies for $t \gtrsim 120$ s consistent with onset of afterglow emission





Mei, Oganesyan, … ,Banerjee, Branchesi+ 2022, article in prep.

Protons are cooling



The analysis in prompt and afterglow emission allowed to constrain theoretical parameter such as bulk Lorentz factor and radius of the emitting region!

This allows us to **discriminate** among the n**umerous emission models** in GRB physics

Dimension consistent with emission from cooling protons through synchrotron radiation, magnetic reconnection and sub-photospheric emission are excluded!

My take-home messages

- GRB physics is far to be fully understood

- Multi-Messenger astrophysics can be the answer!

What is the origin of prompt emission?

What is the dimension of the source?

What is the source???

O4 run is coming! (Dec. 2022)

A lot of observational and theoretical work to do: Neutrinos? UHECRs?

3G GW detectors will further enhance our understanding in sGRBs!

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- And last… **Be aware…**

GRBs KNOW WHEN YOU ARE ON HOLIDAY!