GRB 221009A
“the most powerful ever detected”

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Swiss CTA Day 2022 - 2023
2022/12/15

Disclaimer

Most of the **papers are not out yet**, the publication plans are being settled, will take some more month.

This **update** is based **exclusively on the results publicly published so far**, as well as details, interpretations, and GCNs, including our own work on INTEGRAL.

Much of the **data is strongly affected by unusual effects**, such as never before seen kind of pileup and saturation effects, so it is necessary to be cautious

This is a case study of a GRB, but GRBs should be seen as a sample, see talk of *Satoshi Fukami*

Detection timeline

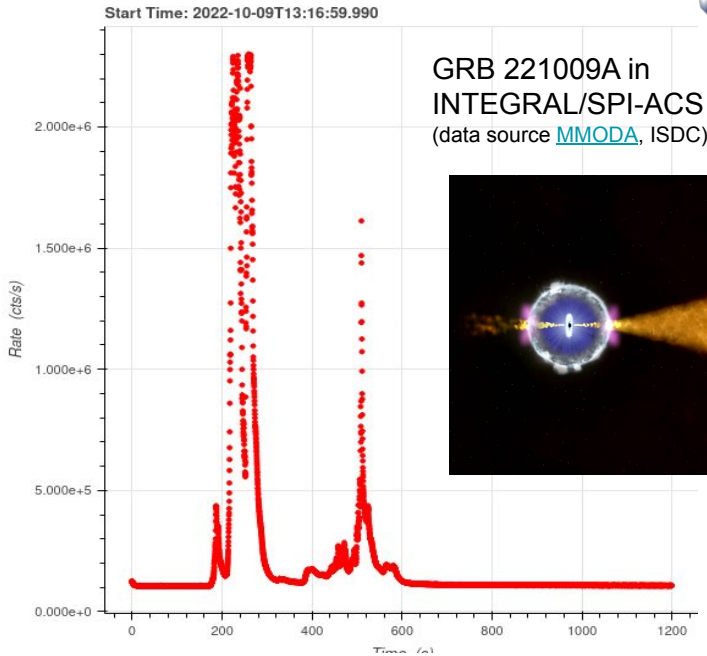
GCN circulars and notices

2022-10-09 (Sunday)

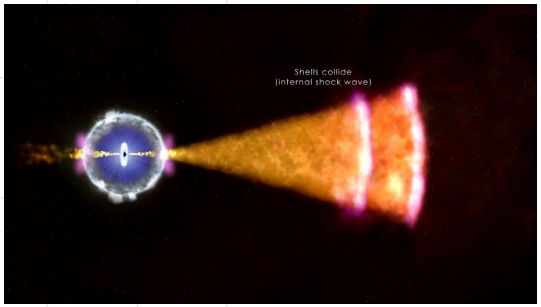
13:17:00	GRB
14:18:39	Swift/BAT trigger on afterglow
18:12:21	OT found by MASTER
20:14:47	Fermi/LAT detection
21:56:40	Fermi/GBM report

2022-10-10

14:30:00	INTEGRAL observation start, following fast ToO procedure



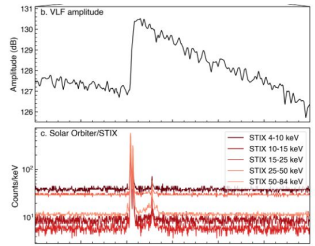
GRB 221009A in INTEGRAL/SPI-ACS
(data source MMODA, ISDC)



Like in GW170817, **potential for improvement in real-time reaction** is apparent.

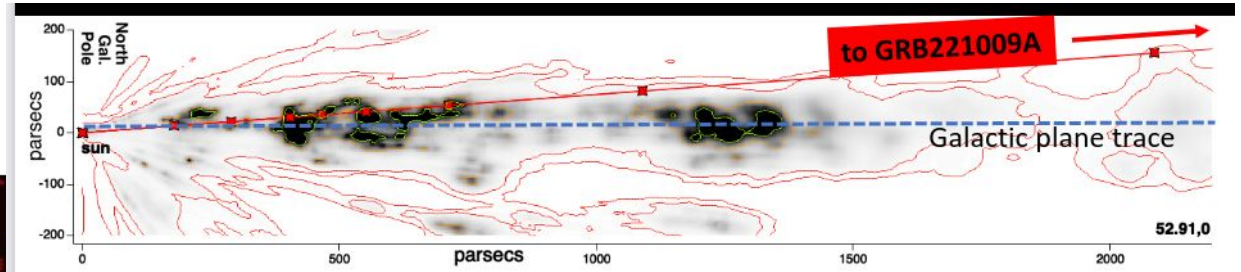
Fluence of **0.04 erg cm^2** (vs **0.0025 erg cm^2** of *GRB 130427A*) would be outrageous if it was on a "normal" or even "rather nearby" GRB distance, but still way lower than some galactic magnetar flares, reaching 50 times more: **2 erg cm^{-2}**

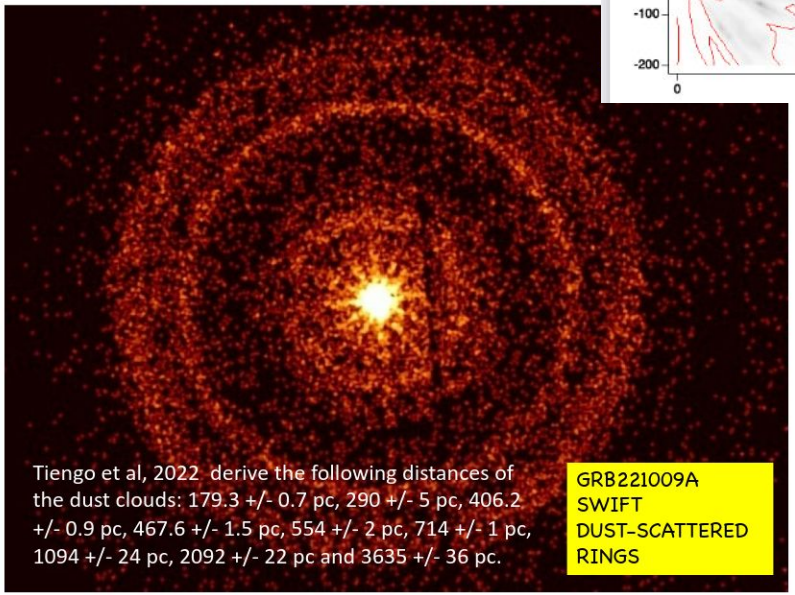
Bursts this bright have **significant ionisation effect** on **Earth magnetosphere** (implication for evolution and stability of habitable exoplanets)



Dust Scattering Halo Rings

Bright bursts have halo rings due to dust scattering, just like sun does. The brighter the better [GCN 32680]





Gaia allows to build **3D tomography of dust maps** with extinction measurements.

Local environment cosmic ray propagation in our galaxy, observed cosmic ray spectrum. Do we live in a special place? *We sort of do*.

[see more here]

Host Galaxy, Progenitor, Event rate

Redshift found spectroscopically at **z = 0.15**, X-Shooter (GCN 32648) GTC (GCN 32686) and host galaxy identified (GCN 32765)

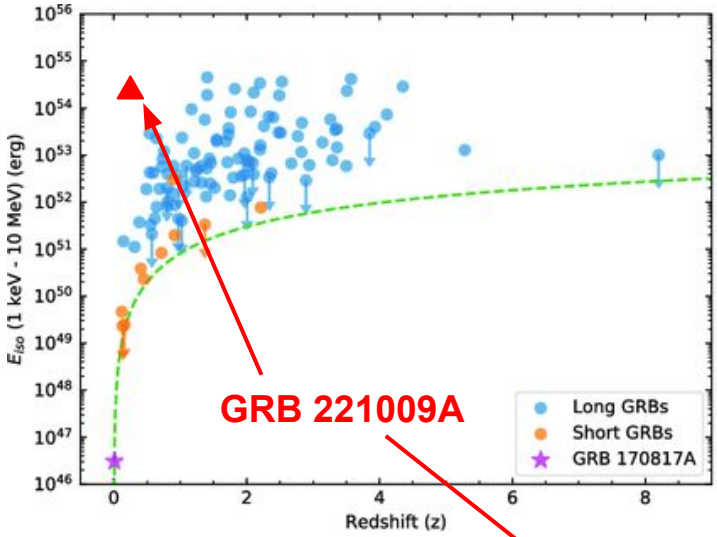
Ic-BL, “stripped core-collapse supernova” , GCN 32800, GCN 32800

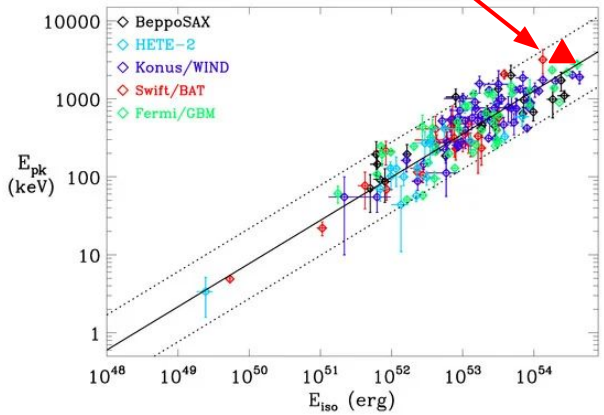
z = 0.151, 726 Mpc, E_{iso}= 2 x 10^{54} erg

Given the time-averaged peak energy of **2.5 MeV** the GRB is consistent with the Type II (collapsar origin) bursts in the Ep - Eiso diagram (Amati et al. 2002)

- With a constant GRB formation rate, we obtain 1 extremely energetic GRB per ~130 yr.
- With decreasing GRB formation rate of Palmerio & Daigne (2021), we obtain **1 extremely energetic GRB per ~520 yr**.

Depending how this is interpreted, it might have **implications for local GRB population**





Parsotan+ 2022

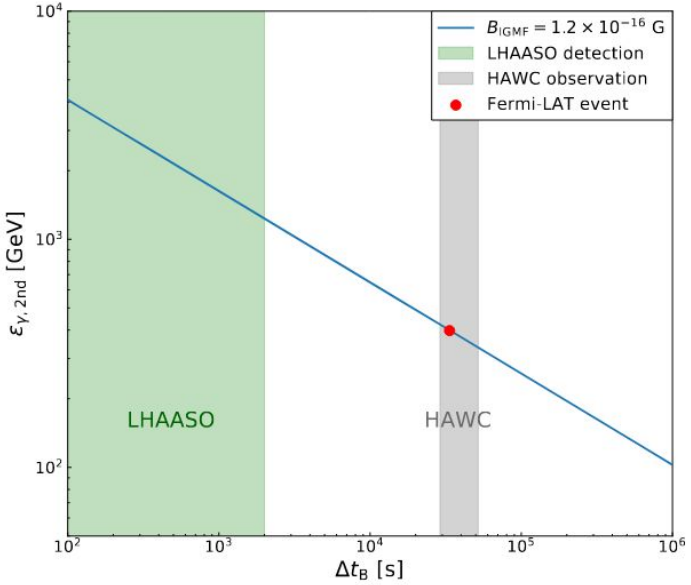
Highest energy emission

Fermi/LAT detected **400 GeV** photon arXiv:2210.13052

IACT results not available yet.

LHASSO observed GRB 221009A with more than **5000 VHE photons up to around 18 TeV** GCN 32677

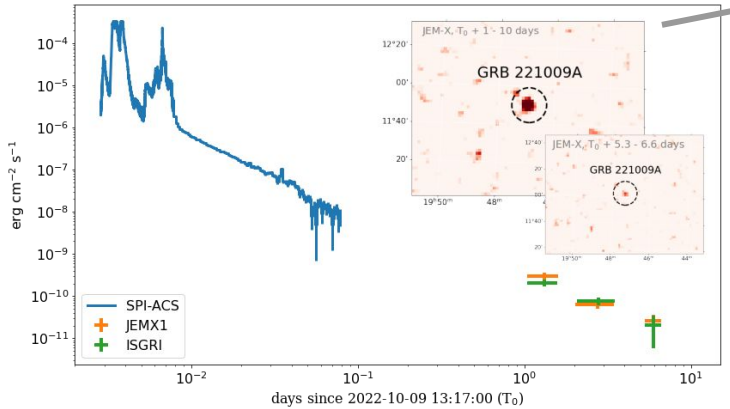
Report of 18 TeV photon by LHASSO triggered **numerous speculations**, since EBL absorption suppresses photons at this energy by . It is also claimed that **standard physics can explain it**, especially considering energy resolution arXiv:2210.10778. It is also possible this photon belongs to a background source.

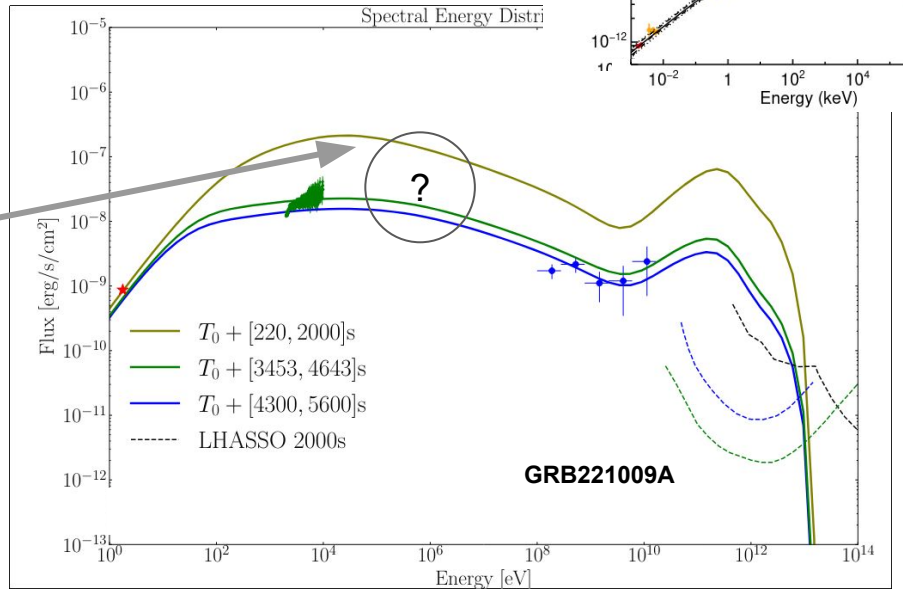


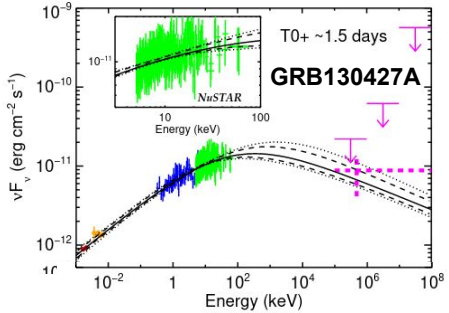
Gamma-Ray Afterglow

Phenomenology similar to **GRB 121107A**, **GRB 130427A**

Can be uniquely probed by **NuSTAR** (3-79 keV) and **INTEGRAL** (till few 100 keV)







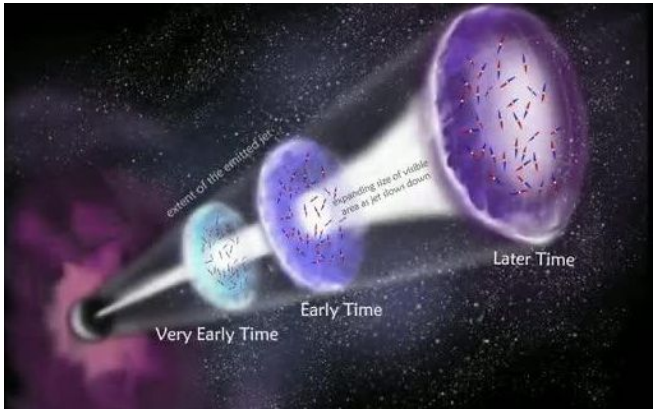
Favors stellar-wind-dominated environment
arXiv:2210.10673

I-PoM, materials

Note growing convergence with **blazar** modelling: broadband observations and physical models

Polarization

This is a rare case when **polarization** measurements are possible across different wavelength and epochs. Although not simultaneous, they are connected.



Afterglow:

X-ray, Polarization degree (PD) **< 11.1%** GCN 32754 (see also an excellent talk about first results from IXPE)

Optical 2 sigma upper limit of **< 5.1%** percent on the polarization degree GCN 32995

Radio *pending, exists*

Prompt:

Gamma-Ray can be characterized by INTEGRAL/IBIS, at 70 deg off-axis the signal is attenuated but one of the strongest, *analysis pending*

Polarization introduces two new dimensions: **direction**, and **system coherence scale**

Hadrons in the jet, Neutrino, UHECR, Gravitational Waves

There should be **hadrons** in the GRB jet: it is hard to ensure there are none.

The best individual constraint on neutrino energy fraction: **<0.2%** of prompt energy in **800 GeV - 1 PeV neutrino** GCN 32665 arXiv:2210.14116, arXiv:2210.15625

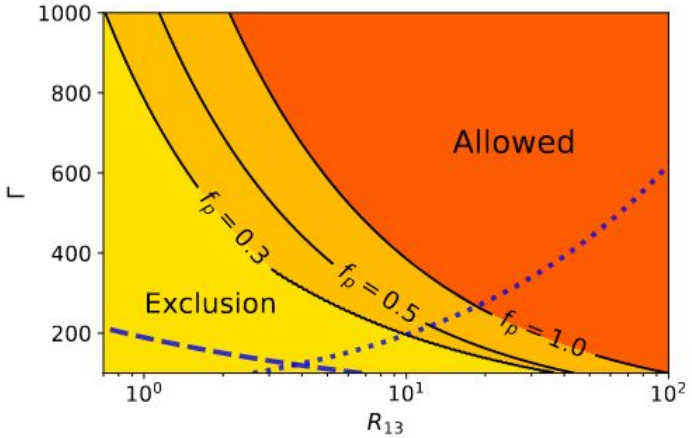
IceCube neutrino non-detection indicates that GRB 221009A likely has a **large bulk Lorentz factor**, which is expected.

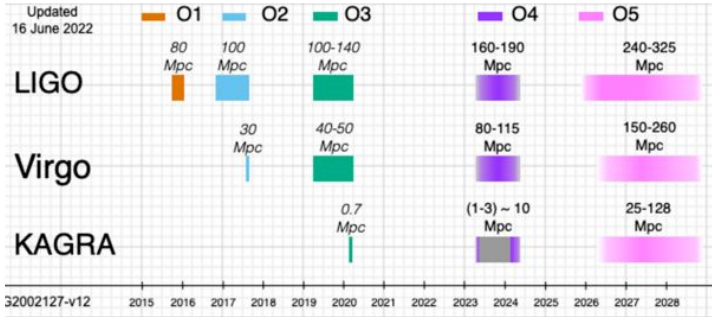
However. single burst limits are comparable to those from **stacking analysis**

Still, GRBs like this can be the origin of Ultra-High-Energy Cosmic Rays, arXiv:2210.14243

Gravitational Waves from SNe are unlikely, as it needs to happen closer, ~10 Mpc. **LIGO/Virgo/KAGRA** were not operating and **GEO600** not sensitive (GCN 32877)

Constraints from neutrino non-detection





Orphan afterglows

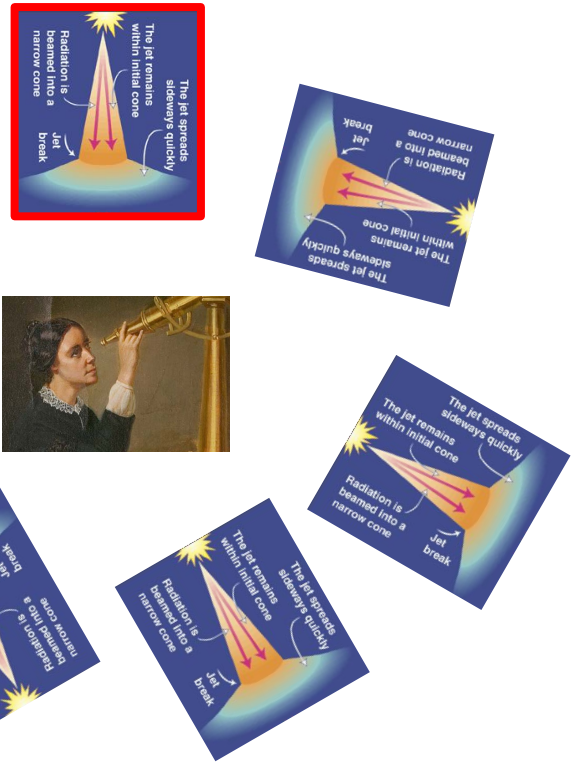
Jet break at 1 day indicates **jet half-opening angle ~ 3.5 deg** and a **beaming-corrected energy** for the GRB of ~ **6 x 10^{51} erg**, GCN 32755

- **Twins of GRB 221009A** at the same distance **occur every 2 month**, just not point towards us
- Equally frequent as **GRB 221009A (i.e. very rare but possible)** happen at **50 Mpc** off-axis

How do they look like? GRB 221009A gives some insight. After jet break, the emission is seen from broader angles, and the remnant may even approach isotropic

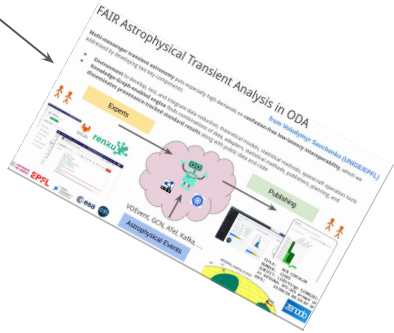
Neutron star merger GW170817 was formally such an “orphan afterglow and was found despite expectation many. GRB 221009A at 50 Mpc is not too far from Gravitational wave reach.

GRB 221009A



Lessons so far

Exploratory **low-chance high-gain proposals are valuable** (like it was with GW), prepare for unexpected: partly because expectations are uncertain, partly because rare events do happen (think about 3 sigma). INTEGRAL was prepared enough, but need to **minimize cost by developing analysis infrastructure, added-value brokers**



Real-time reaction and analysis infrastructure **still can be improved** for most observatories, despite efforts. Hopefully becomes better in LVK Run O4 (the coming April)

“**Nearby ordinary monster**” GRB 130427A (as Nature 2013 paper called it) was outmatched, and the title applies here as well. The most powerful does not mean the most informative. Likely, this was an **“ordinarily bright“ but very nearby** event, allowing **relatively faint parts** to be studied in detail and extrapolated: such as broad-band gamma-ray afterglow.

3.5 deg jet opening implies 50 Mpc distance to a source **like GRB 221009A but off-axis** (or once every 2 month at GRB). **These “monsters” are hiding there, how do they look like?**