The GRANDMA Analysis of GRB 221009A, the Brightest Of All Time

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See our article submitted to ApJL for the GRB special issue, arxiv 2302.06225 :
GRANDMA and HXMT Observations of GRB 221009A - the Standard-Luminosity Afterglow of a Hyper-Luminous Gamma-Ray Burst - In Gedenken an David Alexander Kann

The GRANDMA collaboration

GRANDMA stands for Global Advanced Rapid Network Devoted to Multi-messenger Addicts - grandma.ijclab.in2p3.fr

This international network is composed by GW Physicists, Observers and Astrophysicists across the world

25 telescopes - 18 countries
40 groups involved

Our main science is focusing on :

- *Gravitational waves Astrophysics*
- *Compact objects & Kilonovae*
- *Neutrino Astrophysics*

We also partner with the Kilonova Catcher citizen science program, where amateur astronomers can follow up transient sources

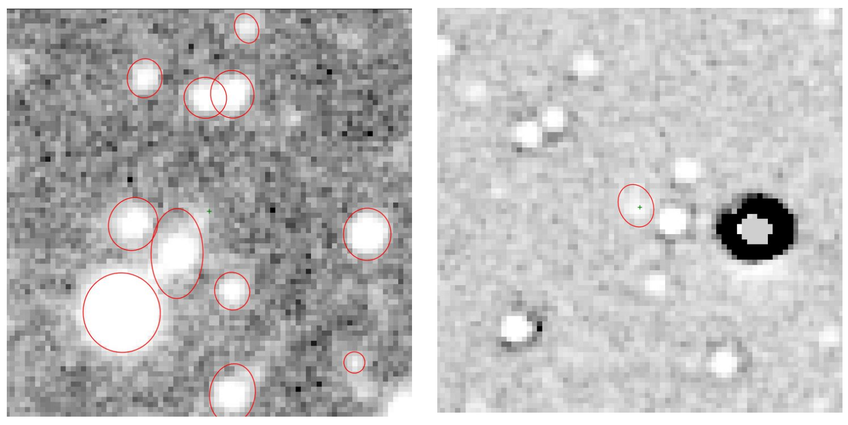
GRANDMA members followed the afterglow of GRB221009A with many instruments, leading to the analysis presented here and in the aforementioned article.
You can also have a look at *Insight-HXMT and GECAM-C observations of the brightest-of-all-time GRB 221009A* (Ann et al., 2023) for prompt studies of this GRB, in collaboration with GRANDMA

GRANDMA will next follow the GW alerts of the LVK O4 campaign

Image Analysis of GRB 221009A

We developed the MUPHOTEN pipeline for photometric analysis of the GRANDMA images. The process consists of a few steps:

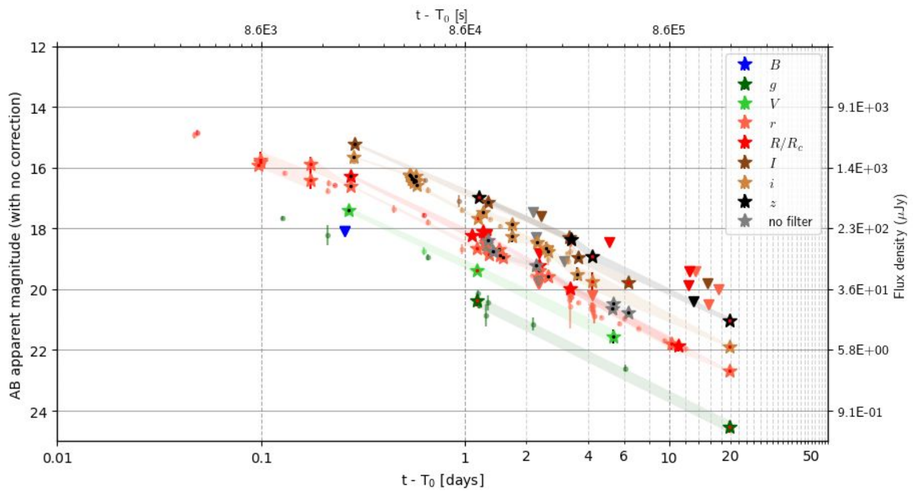
- Estimation and removal of the background noise
- Detection of sources as clusters of pixels two standard deviations above background
- Computing the appropriate aperture for each source, then measuring the flux and its uncertainty over the aperture
- Crossmatch the detected objects with reference catalogues and use the matches to calibrate the magnitudes
- Checking for self-consistency and Estimating sensitivity (magnitude upperlimits)



Observations of GRB221009A's afterglow by the Lisnyky Observatory. Left: Original image. Right: Difference image after subtracting a template image from the PanSTARRS catalogue. Apertures in red

Lightcurve : All the GRANDMA observations

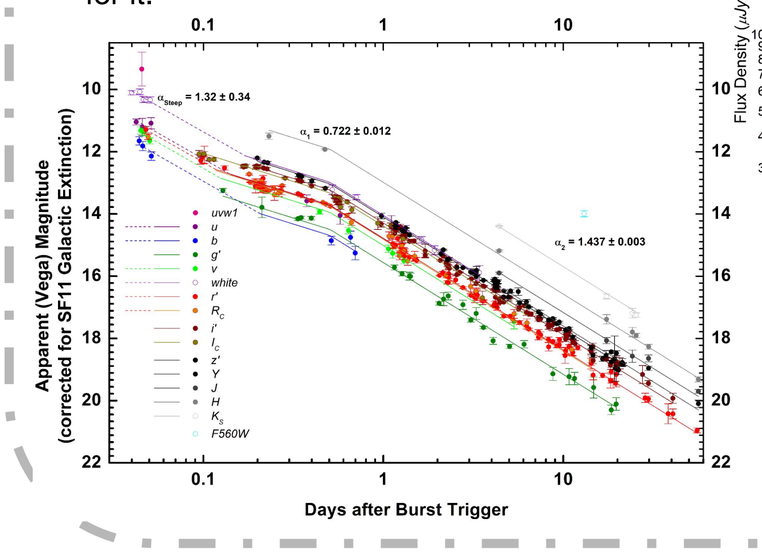
Starting with a prompt upper-limit during the GRB prompt sequence (V, 3.8 upper limit), 15 professional and 15 amateurs telescopes observed the afterglow of GRB221009A for GRANDMA, from 2h30 to 20 days post T0.

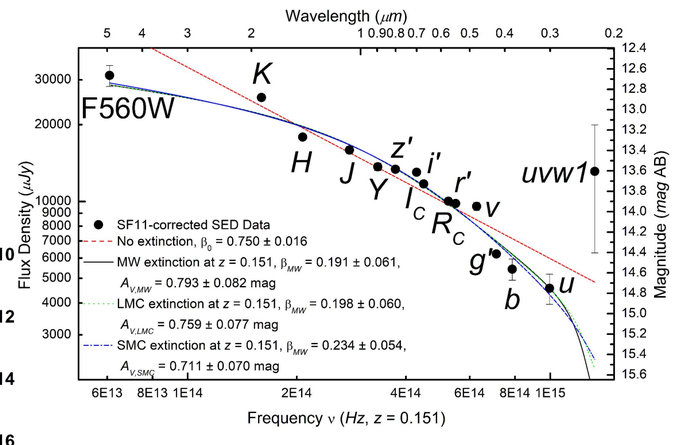


The optical afterglow of GRB 221009A (not corrected for the Galactic extinction). The selected optical GCN data we use are represented by dots and the GRANDMA data measurements and upper limits are indicated by larger stars and downward-pointing triangles. The red points within the stars indicate measurements made by professional observers, while black points represent observations made by KNC observers.

Analysis of the Spectral Energy Distribution

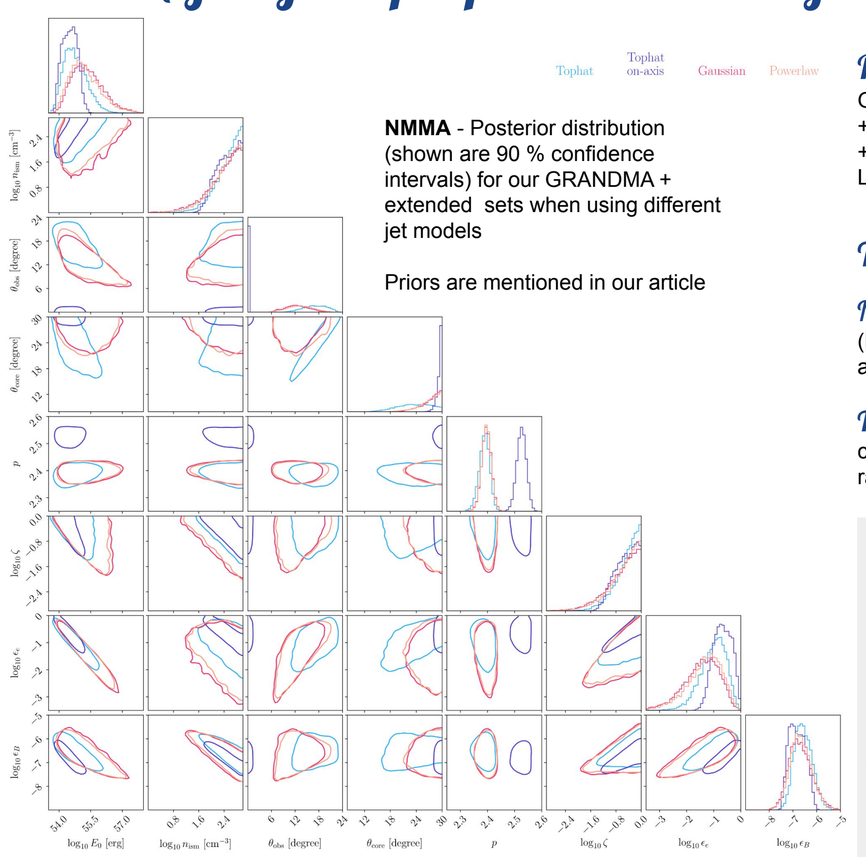
Using an empirical model $F_\nu \propto t^{-\alpha}\nu^{-\beta}$, we fit our observations to a broken power law model and study its Spectral Energy Distribution, using it to estimate Milky Way and host-galaxy extinction and later correct for it.





Fits to SED after correcting it for SF11 (Schlafly, 2011) foreground extinction and shifting it to z = 0.151. The favored scenario is that of a host galaxy with an extinction profile similar to the Small Magellanic Cloud

Afterglow properties with Bayesian Inference



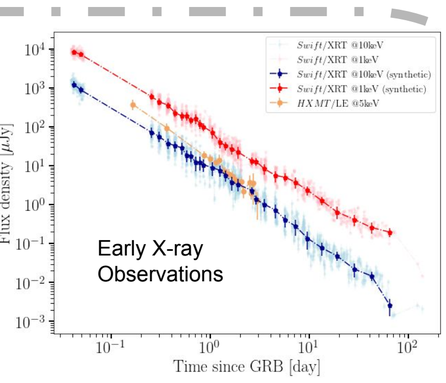
Isotropic energy, ISM density, Observation angle, Core opening angle, Electron distribution index, Fraction of accelerated electrons, Energy fractions in electrons and magnetic fields

NMMA - Posterior distribution (shown are 90 % confidence intervals) for our GRANDMA + extended sets when using different jet models

Priors are mentioned in our article

Data sets

GRANDMA + UVOT for UV/O/IR
+ HXMT-LE + XRT for X-rays
++ Extended (Williams, Shrestha, Laskar, Levan, O'Connor - 2023)



Two independent methods

Nuclear physics and Multi-Messenger Astronomy framework NMMA (Dietrich & Pang 2022) with afterglowpy - We also investigate the possibility of an SN connected to the GRB with nugent-hyper model

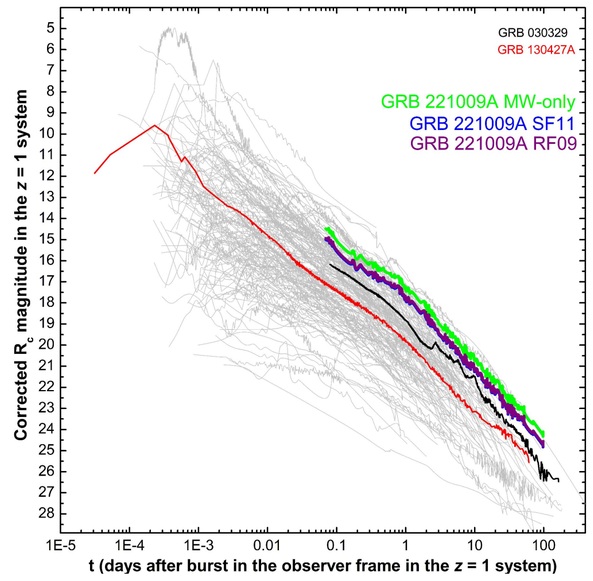
The afterglow model from Pellouin & Daigne (2023) which model and compute both synchrotron radiation and the Synchrotron Self-Compton (SSC) radiation.

Conclusions

Fitting the afterglow lightcurve with a standard model (synchrotron radiation at the forward shock of a relativistic top-hat jet propagating through a constant density medium) ***only result in a moderate reproduction of the observed data.***
Taking into account a different jet structure, synchrotron self-Compton emission, or underlying supernova does not help to disentangle the tension. Further analysis will require going beyond the most standard GRB afterglow model.

How extraordinary is the GRB221009A afterglow ?

Not intrinsically extraordinarily bright compared to the global data set despite its extreme energetics



GRB 221009A afterglow (corrected for Galactic extinction using SF11 (Schlafly & Finkbeiner 2011) and RF09 (Rowles & Froebrich, 2009) methods) in context of a large sample of GRB afterglows. All of them have been shifted to z=1 taking the individual spectral slopes beta and cosmological k-correction into account.