The GRANDMA Collaboration: In Action for O4!

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Journées SF2A 2023 - Prédiction et suivi des signaux multi-messagers

Global Rapid Advanced Network Devoted to Multi-messenger Addicts

GRANDMA : Created in 2018, by IJCLab
For GW follow-up

18 countries - 23 Sites - 35 Telescopes

- Wide-fields down to 20 mag
- EM candidates ~ 23 mag in photometry
- 22 mag in spectroscopy

Allocation time on VLT/FORS2, CFHT, SOAR and SALT

GRANDMA's citizen science program :
Kilonova-Catcher

More than 130
amateur astronomers

KILONOVA CATCHER

Global Rapid Advanced Network Devoted to Multi-messenger Addicts

GRANDMA Scientific focus:

- Gravitational Waves Astrophysics
- Compact Objects and Kilonovae
- Neutrino Astrophysics

Previous **GRANDMA** Campaigns:

- Following O3 GW events (arxiv.org/abs/2004.04277)
- ZTF/Fink transients (arxiv.org/abs/2202.09766)
- Following GRBs from Swift (multiple campaigns, articles in prep.)

\+ GRB221009A (arxiv 2302.06225)

GRANDMA O4 follow-up strategy

High profile GW alerts

Blind searches focused on:

- **Candidates with at least 1 NS**
  - Expected EM counterpart
- **D_L < 200 Mpc**
  - Peak magnitude ~20-21
- **Localisation area < 200 deg^2**
  - The average coverage per alert during O3

-> Will yield a manageable number of alerts

Observation plans generated <30 min from T0, robotic telescopes (TAROT, FRAM, ASTEP) can start observing automatically

Target of Opportunity

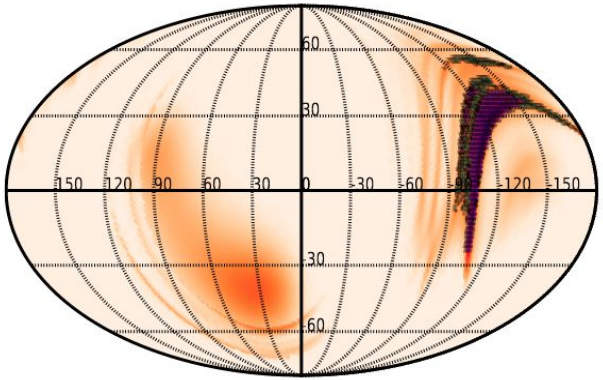
- Follow-up of promising GW source candidates (**ZTF**, GCNs, other GW counterpart candidates)
  - Selection with **ZTF-Fink**
  - Use experience from **ReadyforO4** campaigns (I) and (III)
  - Will help transient classification
- Follow-up of **Swift** alerts if GRB+GW coincidence
  - Good localization
  - Early EM info

ToO time on large telescopes for high-profile transients, e.g. CFHT

Observing Strategies

Tiling

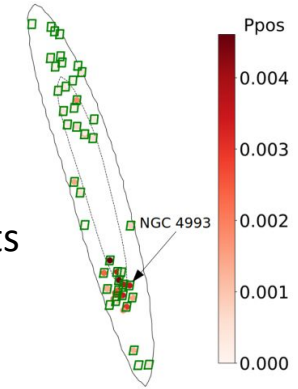
- Cover the sky localisation map of GW
- Look for new object that are related to the GW
- Best suited for large FoV (>1deg²) instruments
- Widely used by current survey (PAN-STARRS, ZTF, TAROT,...)



See 1909.01244 for the figure

Galaxy Targeting

- Observed the galaxy compatible with the spatial information provided by GW
- Galaxies classified with
  - spatial information
  - Stellar mass estimation
- MANGROVE catalog (Ducoin et al., arxiv:1911.05432)
- Best suited for small FoV instruments



GW170817 localisation and compatible galaxies 1911.05432 and 1909.01244

Process:

- **ICARE/SkyPortal** centralises alerts information
- **Gwemopt** generates observation plans
- Telescope teams are notified (Slack, email)
- Images stored on Owncloud
- **Stdpipe** and **Muphoten** process images for photometric analysis
- Results are logged and compiled on **SkyPortal**

First month of O4 follow-up

6 Detection candidates (+ 75 low-significance):
5 Binary Black Hole + 1 Intermediate Mass

No significant event passed our criterion for blind searches, we focused on following source candidates

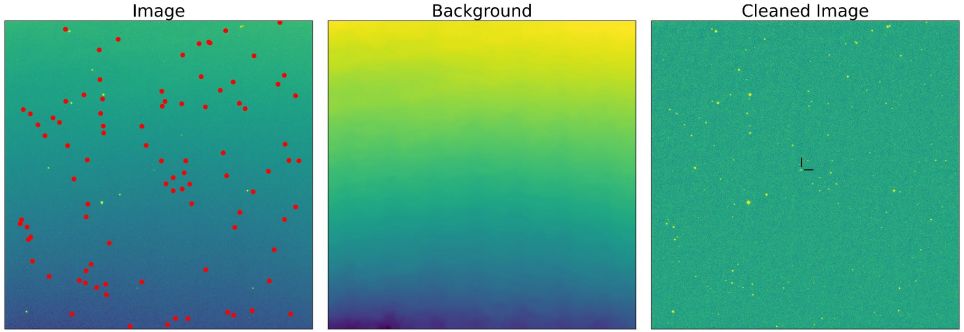
S230615az (low significance Binary Neutron Star candidate), GRANDMA followed 4 candidates from GOTO and GIT → published GCN
https://gcn.nasa.gov/circulars/34020

Plan to relax the >1 NS, <200 Mpc <200 sq. degrees criterion until Virgo joins, so that GRANDMA can continue practicing blind searches

My contributions: MUPHOTEN

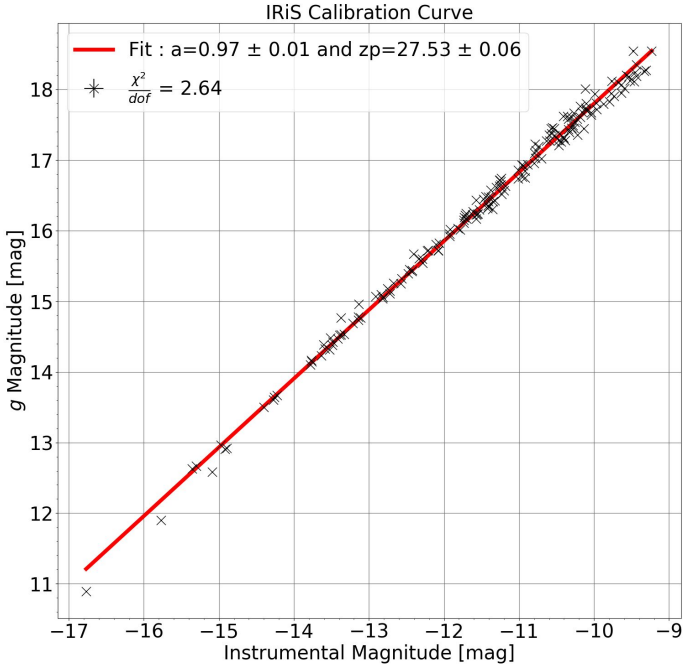
Photometric Analysis Pipeline (https://gitlab.in2p3.fr/icare/MUPHOTEN/) developed with P.A. Duverne (https://arxiv.org/abs/2201.07565)

- **Background Estimation**
  - Estimation & Subtraction
  - Define threshold for source detection
- **Photometry of the detected sources**
  - Estimation of M_{ins}
- **Crossmatch with a reference catalog**
  - Extracts M_{ref} for sources
  - Available: Pan-STARRS - SDSS - Gaia - USNO-B1



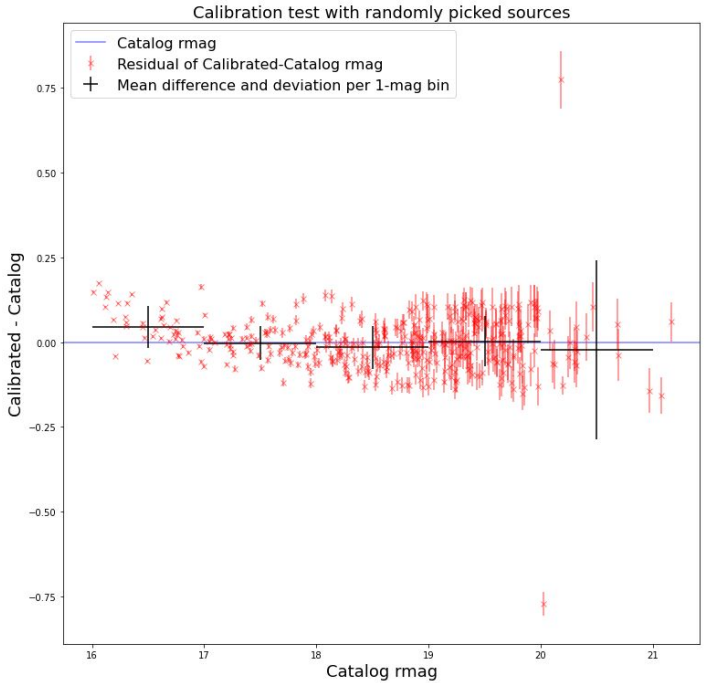
IRiS image example

- **Photometric calibration**
  - Simple linear model M_{ins} VS. M_{ref}

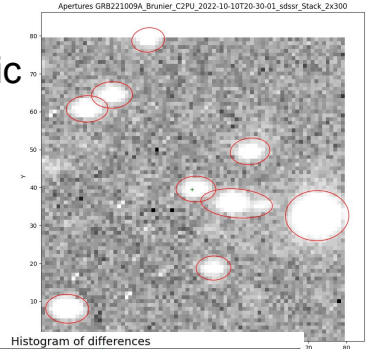


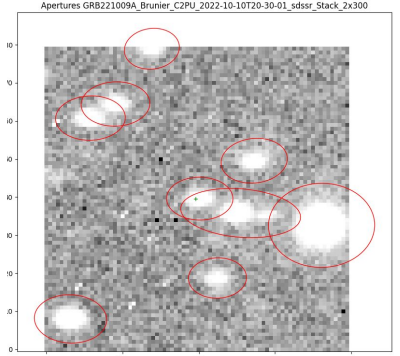
MUPHOTEN Self-consistency checks

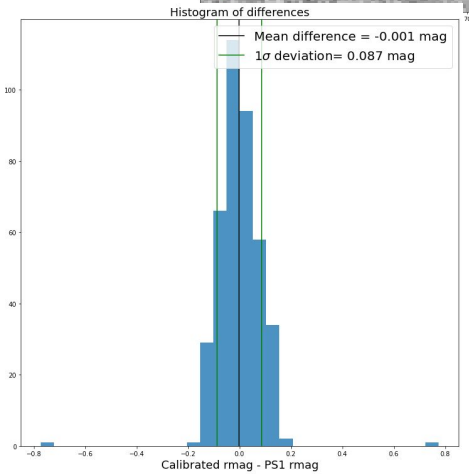
Measuring sources matched with PanSTARRS and checking that we recover catalog magnitudes

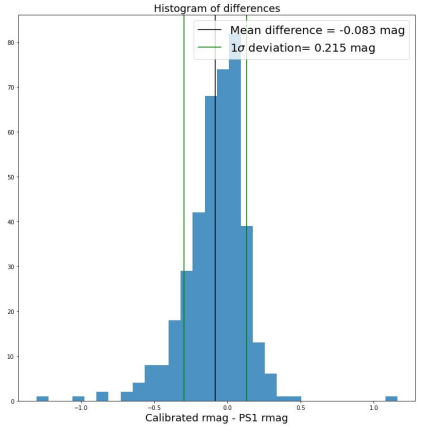


Studying the systematic uncertainties of this recovery for different configurations, e.g. choice of isophotal radius:





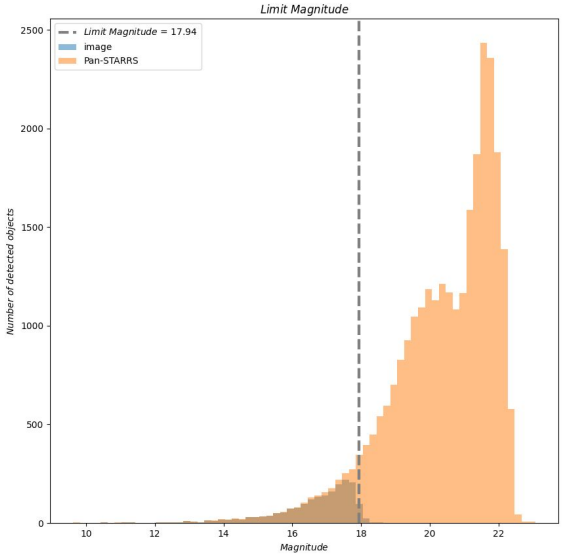




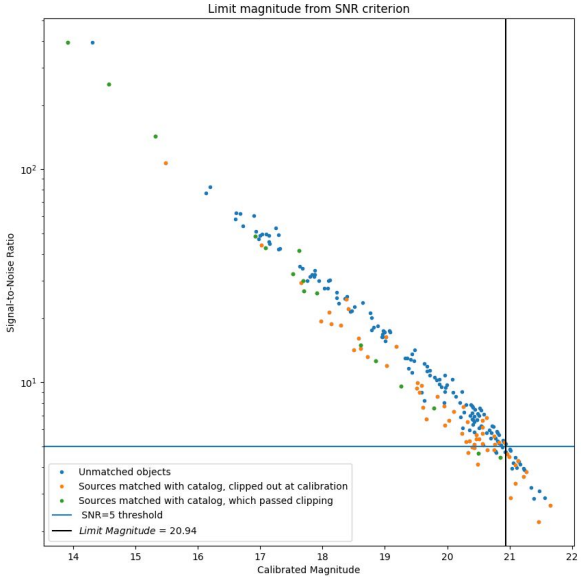
MUPHOTEN Upperlimit estimations

Different criteria can be chosen to define the limit magnitude

When < 10% of catalog objects are detected



When all detected sources have SNR < 5



When < 50% of injected fake stars are recovered

Using our calibration fit, and our point-spread function, we can simulate the signal of a star at any given magnitude

Work in progress!

Next for Muphoten:

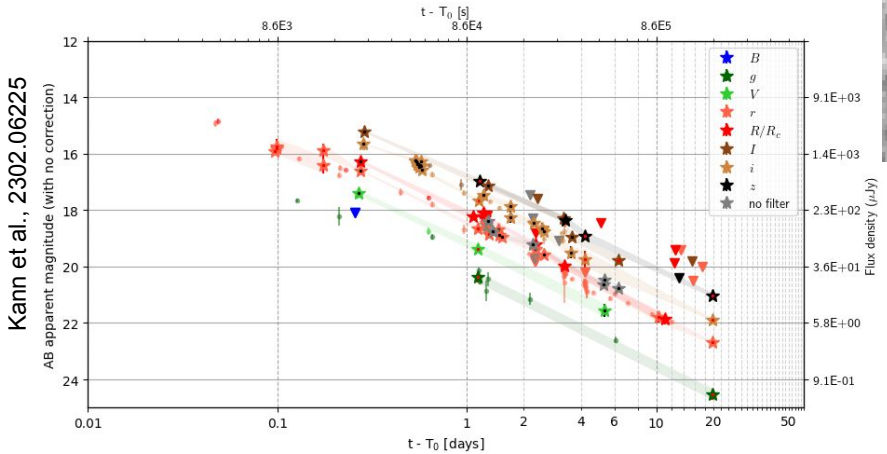
Hosting on Virtual Machine to become online service

Example of GRANDMA follow-up: **GRB221009A**

Observations

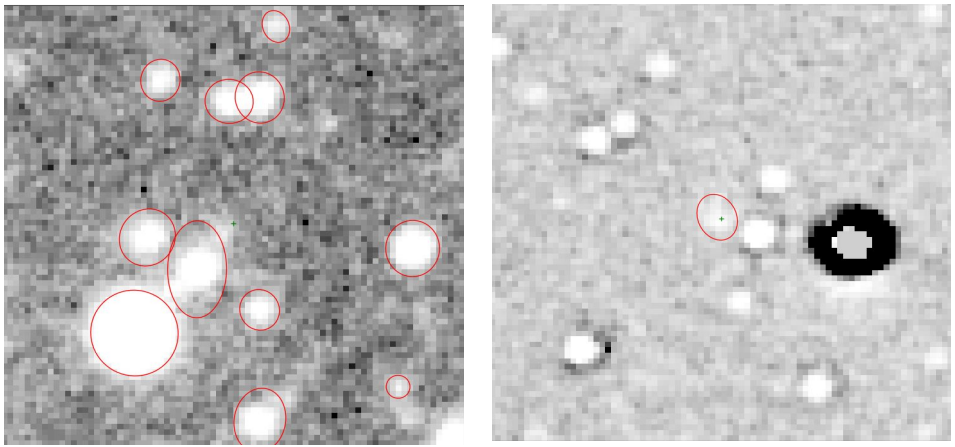
- **Multi-band** image dataset
- 15 GRANDMA telescopes-> **80 images**
- 15 KNC observers -> **250 images**
- 2h30 to 20 days after T0

Image reduction -> Lightcurves



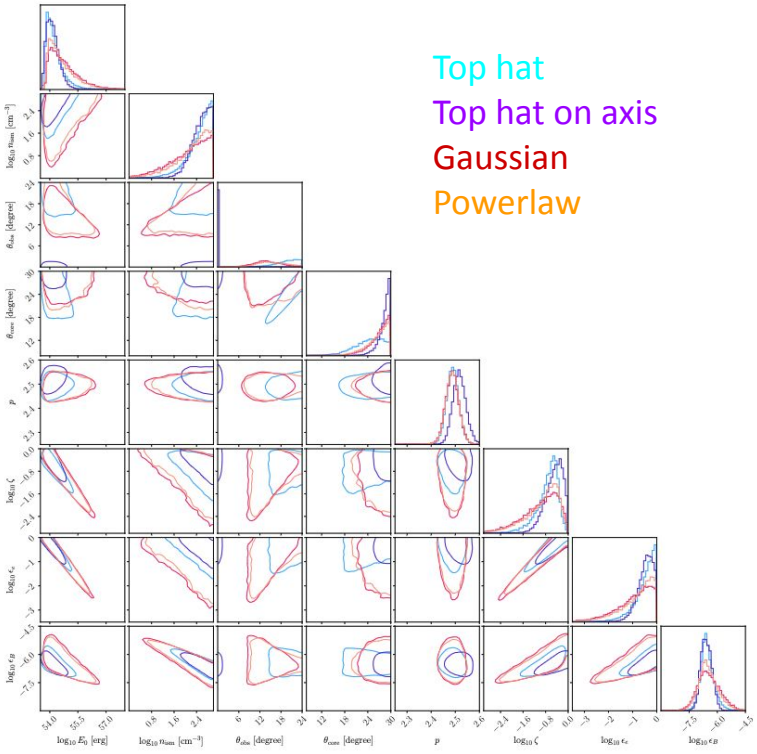
Kann et al., 2302.06225

MUPHOTEN Analysis:



Observations of GRB221009A's afterglow by the Lisnyky Observatory. Left: Original image. Right: Difference image after subtracting PanSTARRS

GRB221009A 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

Data analysis

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

Analysis with two independent methods

- NMMA (Dietrich et al 2020)
- Pellouin & Daigne 2023

The standard afterglow models only result in a moderate reproduction of the observed data.

All our results in :

David Alexander Kann et al.

arxiv 2302.06225

Conclusion

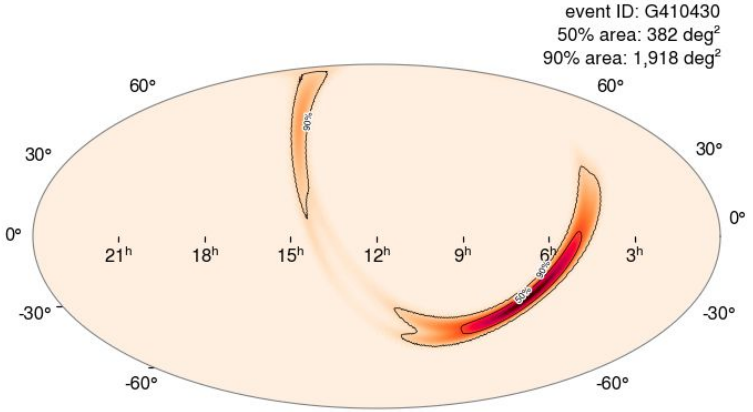
First month of O4, limited by having only LIGO

Localisation too wide for blind search

GRANDMA is active in following up counterpart candidates from GCNs
Hoping for coincident GRB

Virgo should join in 2-3 months and help providing better localization

GRANDMA is ready for O4 !



S230609u initial skymap

Thank you for your attention!

Thomas Hussenot-Desenonges, IJCLab

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Backup slides

Thomas Hussenot-Desenonges, IJCLab

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O3 with GRANDMA

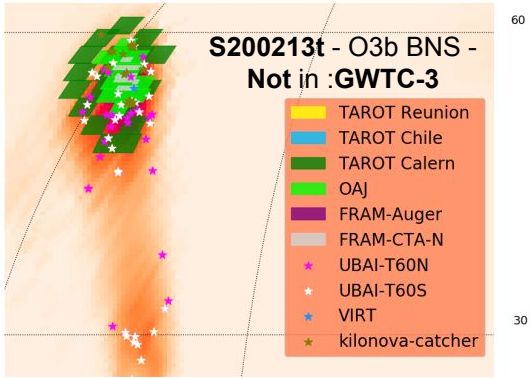
49/56 O3 alerts were followed by GRANDMA
~ 10 alerts followed by other optical groups

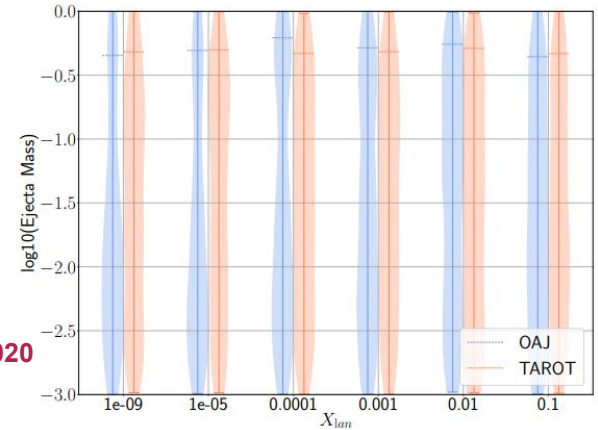
15 min for the first observation after the GW trigger
1.5 h delay for 50% of alerts

~ **200 deg^2** covered in each alert at 18 mag
11 alerts covered above 90% c.r

ToO observations from other collaborations
Participation of **amateur astronomers**

No EM GW counterpart found
Upper limits on ejecta properties





O3b and global summary of O3: **GRANDMA Observations of O3 Observational Campaign, MNRAS, 2020**
O3a and presentation of the collaboration: **The first six months of O3 with GRANDMA, MNRAS, 2020**

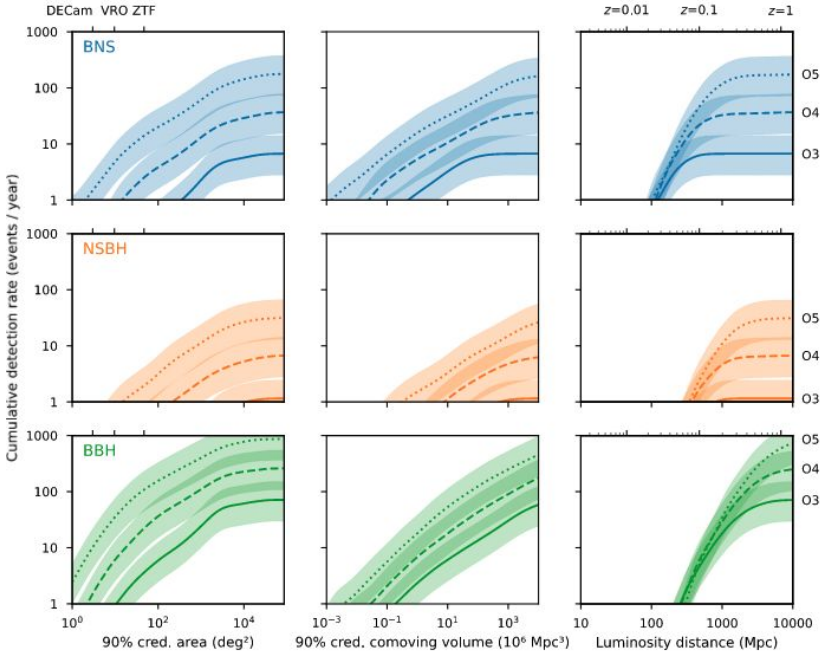
Collecting MM sample of GW events, a real challenge

O4 Predicted rate for BNS and BHNS mergers based on O3 (see LIGO userguide) :

- **36** (+49 -22) **per year**（**BNS**）
- **6** (+11 -5) **per year**（**NSBH**）

Up to **1 GW alert per day** in O4 (HLV prediction)

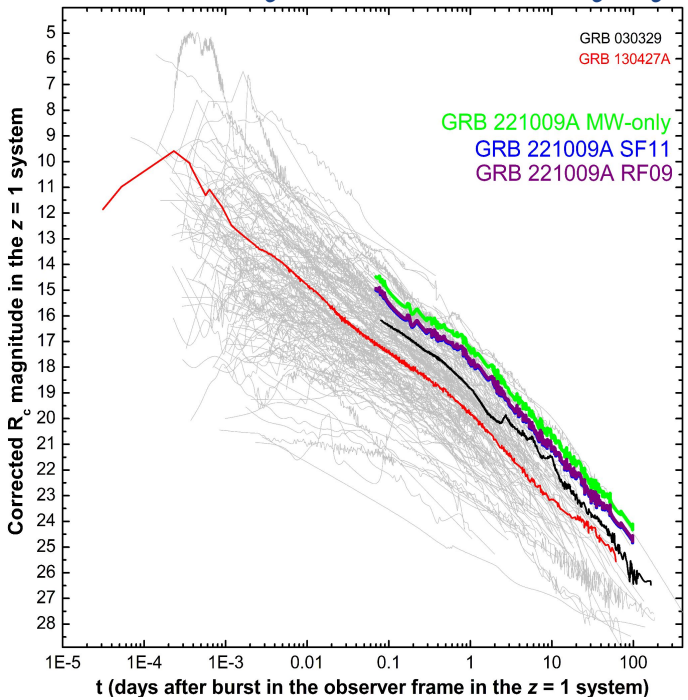
KN **peak magnitude > 20.5** mag for a BNS merger within **200 Mpc**
GW170817 at 40 Mpc -> Rare event



Petrov et al. - 2108.07277

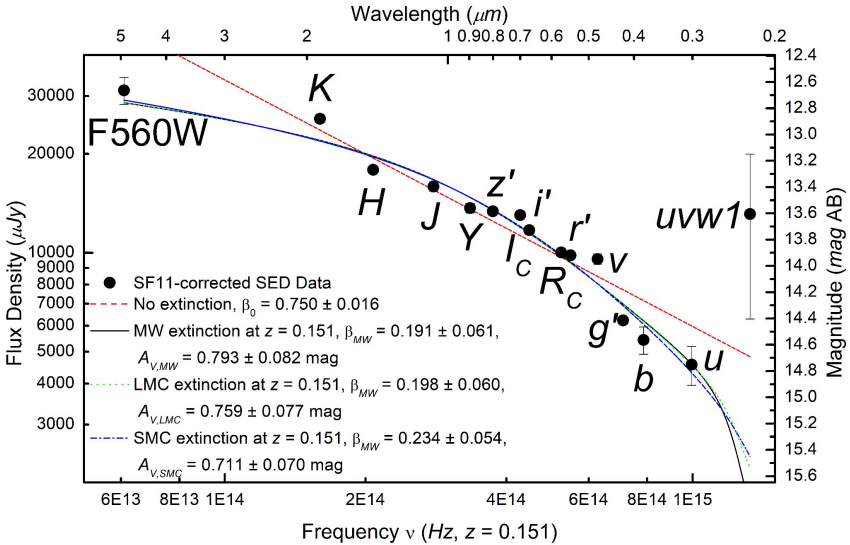
GRB221009A

How extraordinary is the GRB221009A afterglow ?



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

Extinction correction



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