GRANDMA follow-up of LVK campaigns O3, O4 so far, perspectives

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GdR Ondes Gravitationnelles Oct 14 – 15, 2024

Plan

1. The GRANDMA collaboration, with improved tools
2. Follow-up strategy for LVK campaigns, results of O3 and O4 so far
3. Preparing analyses for the next Kilonova

Acronyms

BBH: Binary Black Hole

BNS: Binary Neutron Star

DL: Luminosity Distance

EM: Electromagnetic

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GRB: Gamma-Ray Burst

GW: Gravitational Wave

KN: Kilonova

NSBH: Neutron Star - Black Hole

ToO: Target of Opportunity

Global Rapid Advanced Network Devoted to Multi-messenger Addicts

GRANDMA : Created in 2018, by IJCLab

20 countries - 23 Sites - 35 Telescopes

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

Allocation time on CFHT, SOAR, SALT

GRANDMA's citizen science program :
Kilonova-Catcher

More than 130
amateur astronomers

KILONOVA CATCHER

French collaborators in IJCLab, APC, CEA/Irfu, CPPM, OCA, IPHC, IRAP

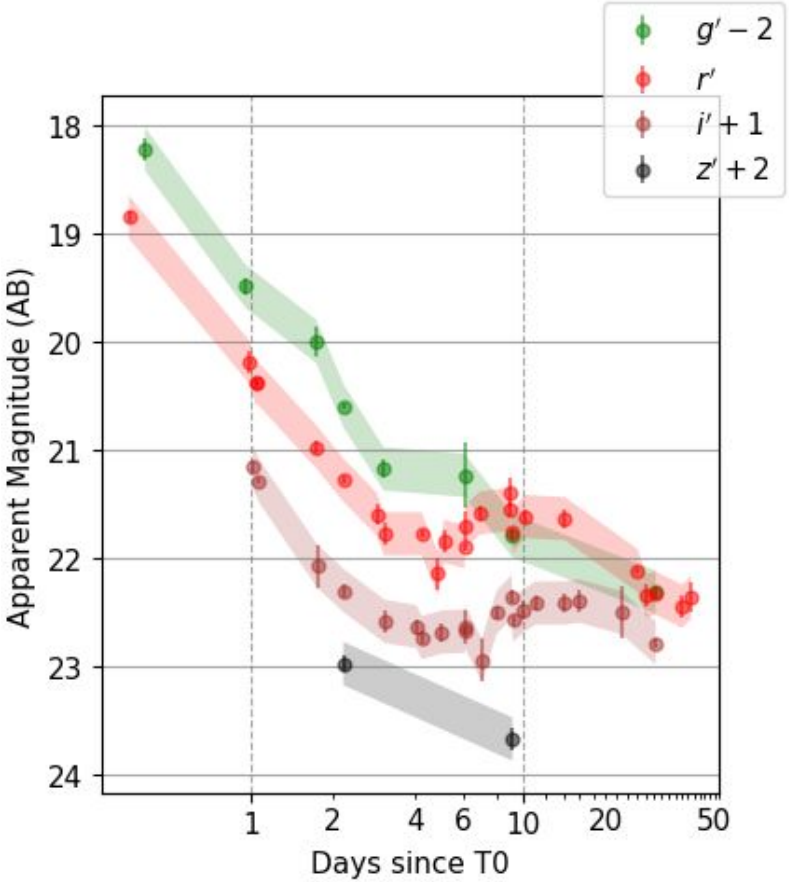
Global Rapid Advanced Network Devoted to Multi-messenger Addicts

Science Topics : Following transient sources:

- GW counterparts: Kilonovae
- GRBs (including SVOM) and high energy transients
- Neutrino-emitting transients

The network allows for well-sampled follow-up in multiple bands

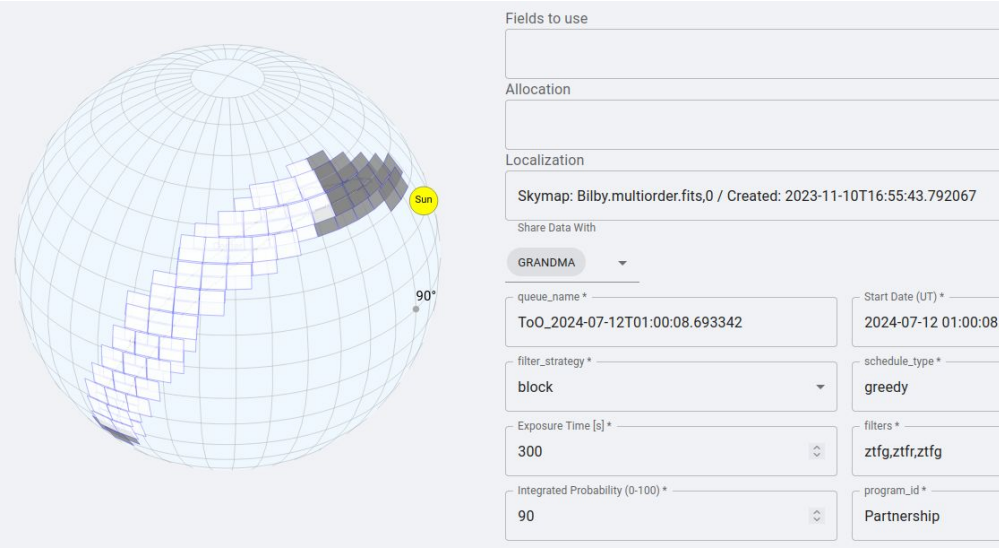
Right: GRB230812B observations (arXiv:2310.14310)



Collaboration-wide Tools : SkyPortal

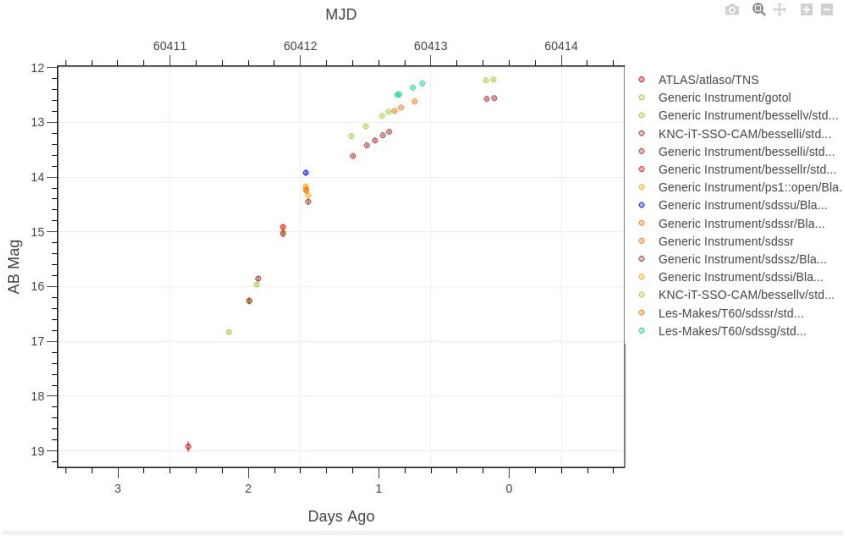
Collecting the alerts and their skymaps

→ Generating Observation Plans



Centralizing photometry data points in one table

→ Data visualization helps discussion



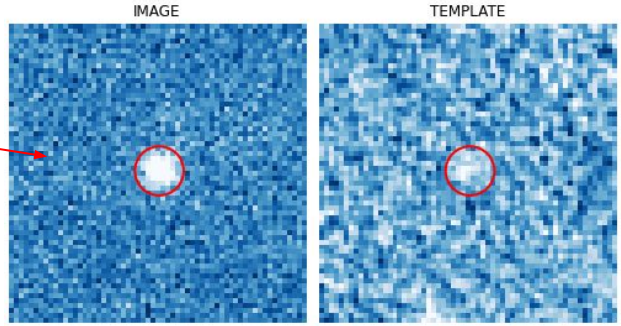
Collaboration-wide Tools : STDweb

- Standardized Photometric Analysis pipeline

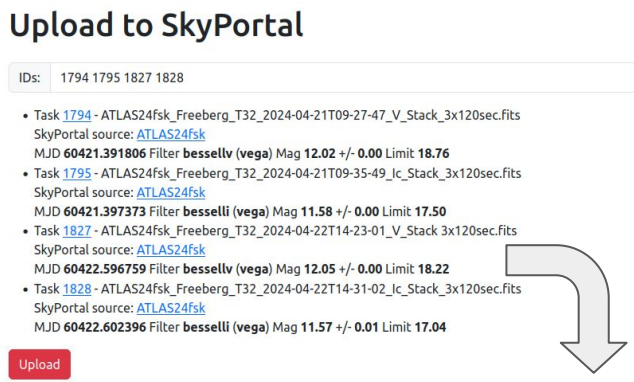
→ Calibration on catalogue

→ Transient Detection

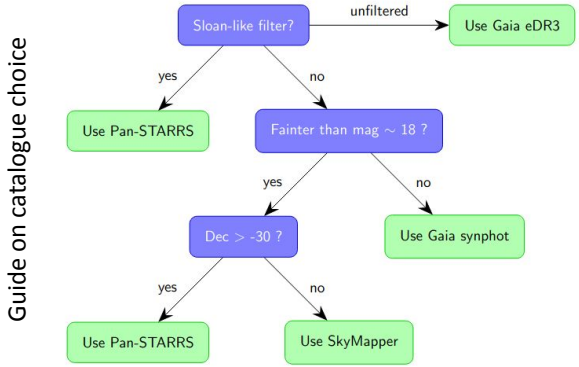
→ Upperlimit estimations



SkyPortal Integration



- Documentation Handbook



Photometry of ATLAS24fsk VEGA

id	mjd	mag	magerr	limiting_mag	filter	instrument_name
5726	60421.39180556	12.019894	0.003682	18.763007	bessellv	KNC-iT-SSO-CAM
5727	60421.39737269	11.576070	0.004947	17.497591	besselli	KNC-iT-SSO-CAM
5728	60422.59675926	12.045082	0.004253	18.221660	bessellv	KNC-iT-SSO-CAM
5729	60422.60239583	11.570798	0.005227	17.039702	besselli	KNC-iT-SSO-CAM

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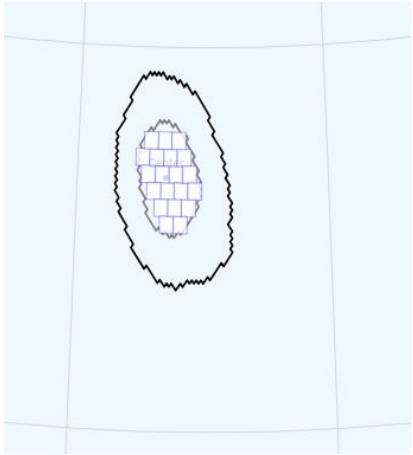
GRANDMA Follow-up Strategy

- **Blind search of the GW skymap**



Tiling

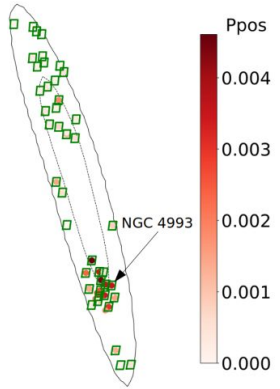
Large FoV instruments

Observation plan computed within 30 min

Galaxy Targeting

Small FoV instruments

Cross match with MANGROVE catalog
(Ducoin et al., arxiv:1911.05432)



GW170817 localisation and compatible galaxies
1911.05432 and 1909.01244

- **Target of Opportunity follow-up**

Follow-up of promising candidates: ZTF (selection with Fink), GCN counterpart candidates

O3 with GRANDMA

O3: 56 significant Detection candidates :

49/56 followed (~1 alert per week). Median start of observations 1.5h post trigger

Average ~200 deg2 covered at ~18 mag

What number of alerts were expected for O4?

		BNS	NSBH	BBH
Annual number of public alerts (log-normal merger rate uncertainty × Poisson counting uncertainty)				
O4	HKLV	36^{+49}_{-22}	6^{+11}_{-5}	260^{+330}_{-150}

https://emfollow.docs.ligo.org/userguide/capabilities.html

→ ~1 alert per day !

~1 BNS or NSBH /week

O4a with GRANDMA

Criteria for blind search: - BNS or NSBH (expecting EM counterpart)

- 90% skymap <200deg2 - DL < 200 Mpc (Kilonova peak mag ~20-21)

81 significant detections : Only 1 passed the criteria

S230627c (NSBH): Targeted galaxy observations (T0+ 0.69 to 0.84 days) + ToO on ZTF candidates (T0+0.44 d)

→ Only upperlimits, can be compared against peak of ~1/4 of the NSBH scenarios

Only ToO of candidates for other O4a events: S230529ay (NSBH), S230615az (low-significance BNS), S230627c (low-significance BBH with IceCube track)

O4b with GRANDMA

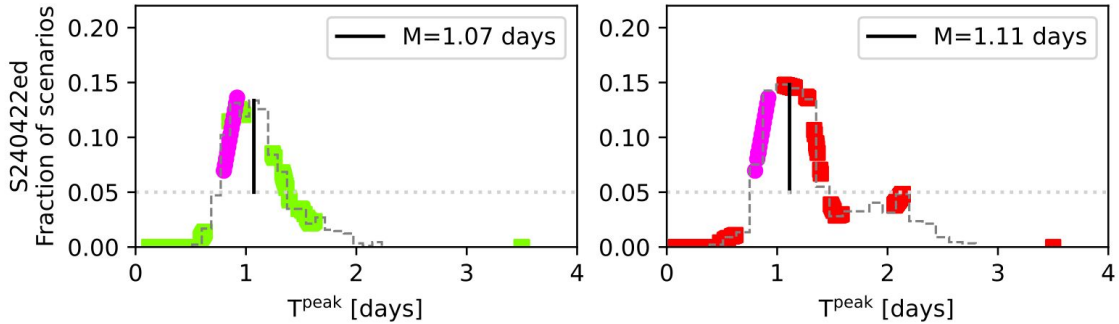
Criteria for blind search: - BNS or NSBH or **BBH either <200 deg2 or <200 Mpc**

- 90% skymap <~200deg2 - DL < ~200 Mpc

68 significant detections : - Some well localised BBH (240527fv, 240615dg, 240920dw) → Tiled observations: only upperlimits

Only 1 NSBH, S240422ed: Tiled observations (T0+0.1 to 0.3 days) +Targeted galaxy observations (T0+ 0.5 to 0.9 d) + ToO on GCN candidates (T0+ 2 to 4 d)

→ Only upperlimits, but constraints ~1/4 of the NSBH scenarios (Marion Pillas talk Pillas et al., in prep.)



23% peak during GRANDMA obs in g-band

21% in r-band

Ready for the next BNS?

- Tools for network coordination and image analysis are operational

- Tiling and galaxy targeting observations are working

→ GRANDMA is ready to observe the next BNS

However, are we prepared to extract information out of the next Kilonova?

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Kilonova Parameter Estimation

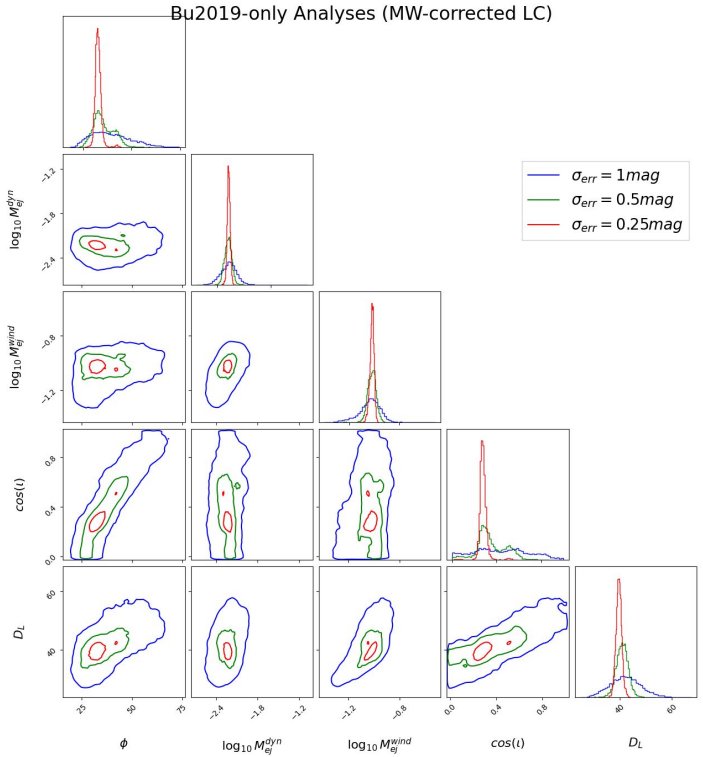
We use the NMMA framework (arXiv:2205.08513) for Bayesian Analysis with Monte Carlo ‘nested sampling’

Trying to maximise the likelihood:

observed magnitude model predicted magnitude

$$= \prod_{ij} \frac{1}{\sqrt{2\pi((\sigma_i^j)^2 + (\sigma_{\rm sys})^2)}} \exp\left(-\frac{1}{2}\frac{\left(m_i^j - m_i^{j,\rm est}(\vec{\theta})\right)^2}{(\sigma_i^j)^2 + (\sigma_{\rm sys})^2}\right)$$

observed magnitude error model error margin

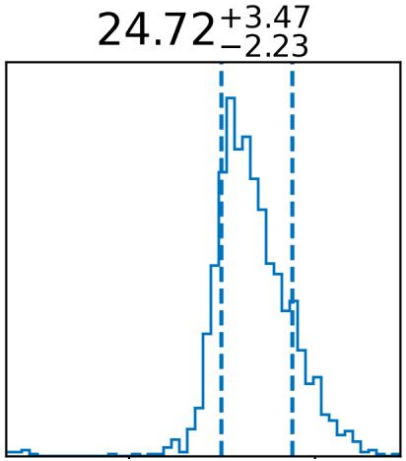


Posterior distributions, varying the error margin

Tensions in KN models

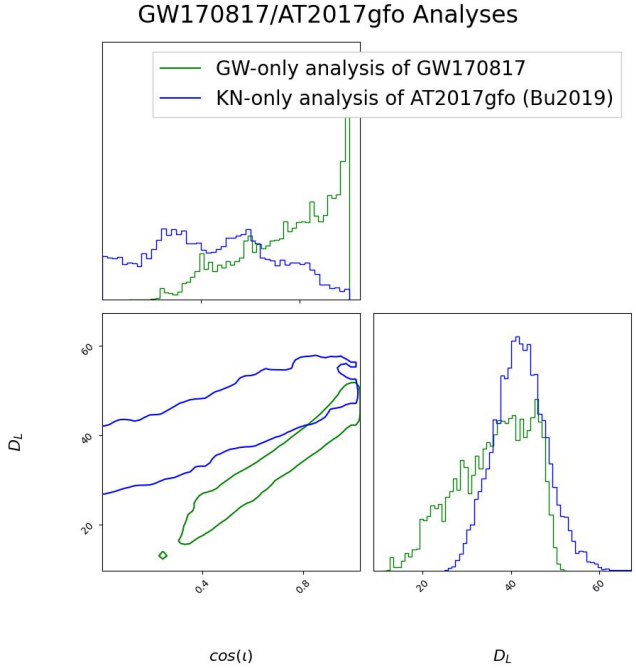
Problems with recovering the GW170817 distance (40-42 Mpc) with KN models

The Kasen2017 model underestimates distance:



Distance [Mpc] posterior for Ka2017 analysis of 170817

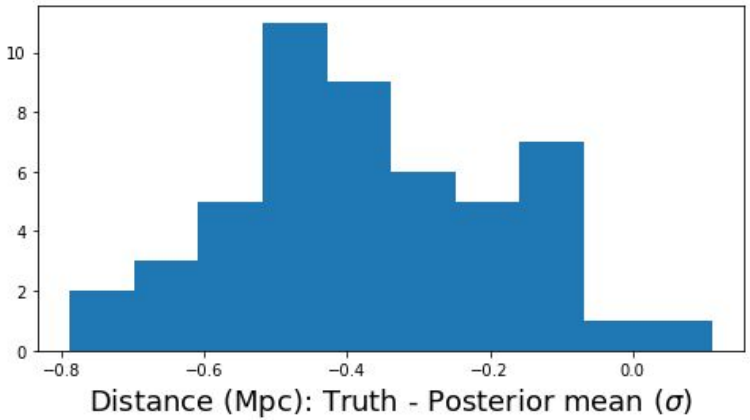
The Bulla2019 model find distances systematically large:

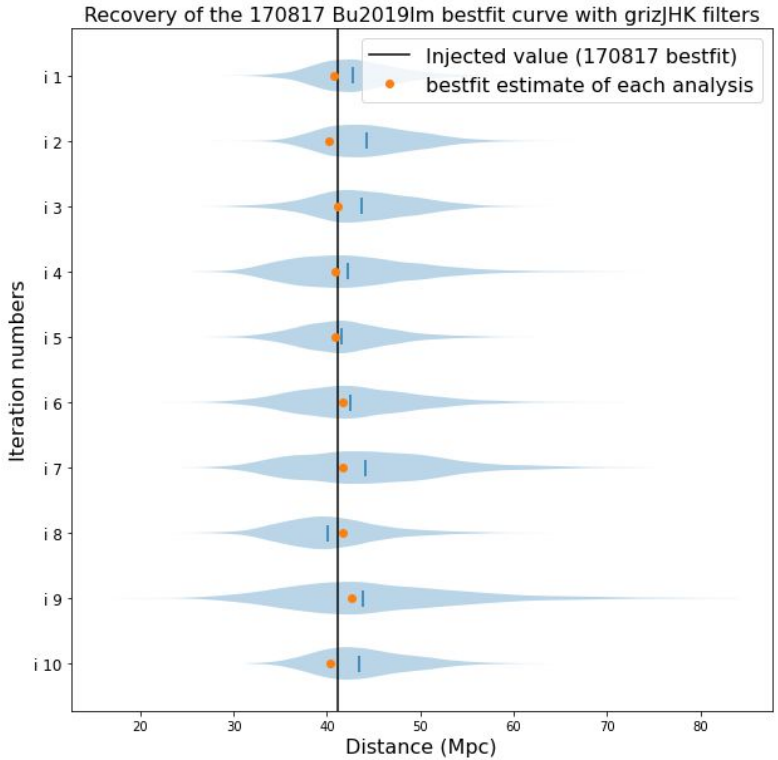


Potential variability

Possible selection bias from observation sparseness

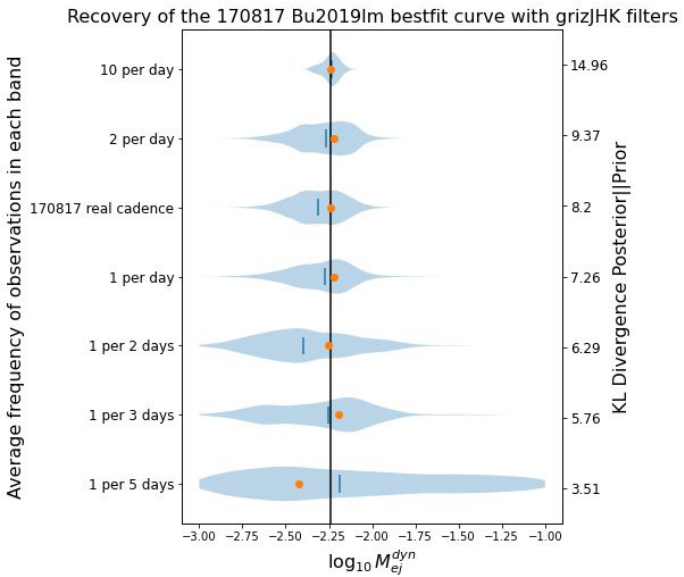
Given a model with set parameter combination →Generate lightcurves randomly sampled in time (average 1 obs/day)→Try to recover input

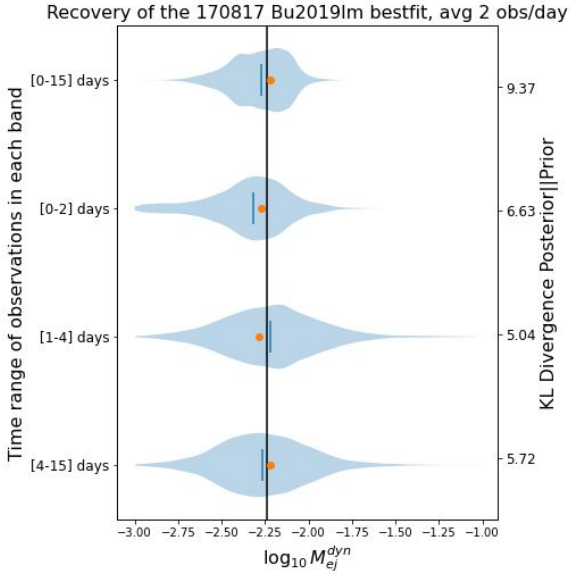


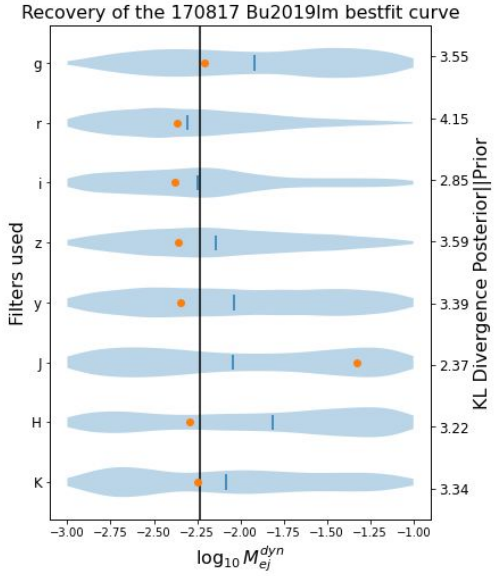


Studying precision of estimations

Quantifying posterior tightness (~quantity of gained information)







Impact of observation cadence of observation time window of choice of filters

→ **Trying to find the observation strategy that maximizes information gain**

Conclusion

- Tools for network coordination and image analysis are operational
- Tiling and galaxy targeting observations have been performed in O3 and O4, starting within a few hours from GW trigger
- We obtain upperlimits that are constraining NSBH scenarios
- We are benchmarking the KN parameter estimation tools and models, and wish to improve observation strategies to optimize information

Thank you for listening! Any questions?

GRANDMA follow-up of LVK campaigns O3, O4 so far, perspectives

Thank you for listening !

Any questions ?

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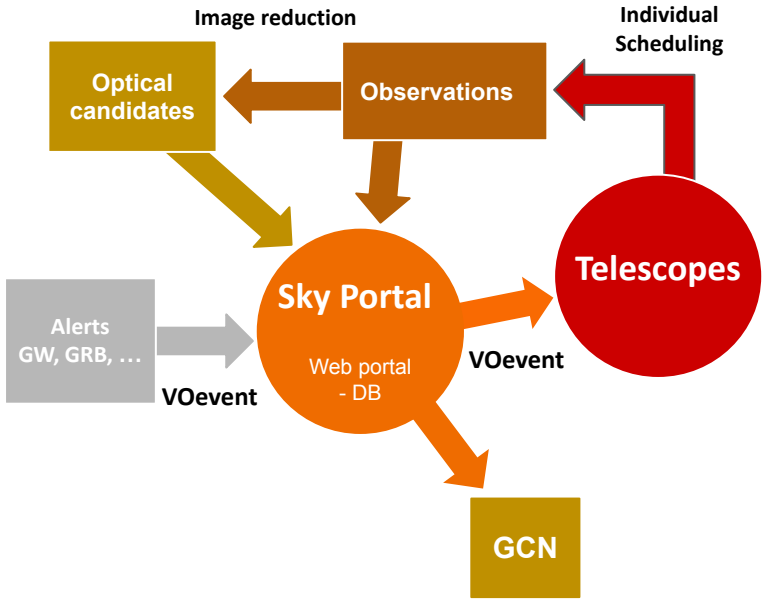
GRANDMA orchestration

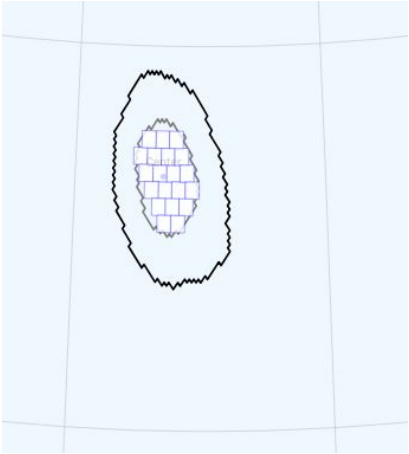
- Listening to **external alerts**: **GW**, GRB, SNe
- GRANDMA operates with a central DB **SkyPortal**
- **Individual observation plans** to GRANDMA instruments (GWEMOPT)
- 2 observation strategies : **Galaxy targeting** & **Tiling**
- Homogeneous data reduction (**STDweb**)
- Distribution of the low latency analysis via **GCN** circulars
- Off-line analysis + Modelisation (NMMA)



Observing Strategies

Tiling

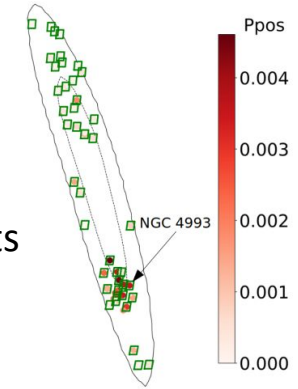
- Cover the sky localisation map of GW
- Look for new object that are related to the GW
- Best suited for large FoV (>1deg²) instruments
- Widely used by current survey (PAN-STARRS, ZTF, TAROT,...)



BBH S240919bn 50% area covered

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
- **Stdweb** : our online service to process images for photometric analysis
- Results are logged and compiled on **SkyPortal**

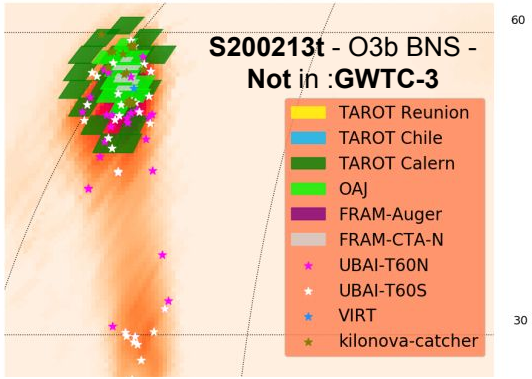
O3 with GRANDMA

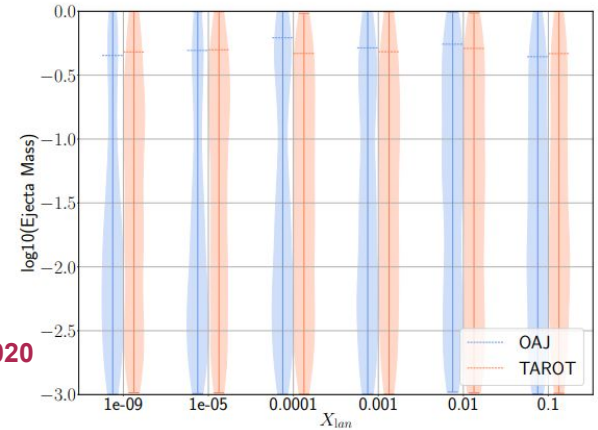
49/56 O3 alerts were followed by GRANDMA
~ 10 alerts followed by other optical groups

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**

O4 with GRANDMA

O4a: 81 significant Detection candidates :

No significant event passed our criterion for blind searches (Only LIGO meant large skymaps), we focused on following source candidates

S230529ay: NSBH ~200Mpc Observed upperlimits on ZTF candidate

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

S230627c: MassGap+BBH, One of few events with 90% area <200 deg2, GRANDMA made blind search with targeted galaxies + followed 2 ZTF candidates

KILONOVA CATCHER

Alert rate: comparison with expectations

Observed (4 month)

Event type	Announced monthly rate	Observed monthly rate
NSBH	0.08-1.4	0.5
BBH	9-49	11.75
BNS	1-7	0

1. The observed rates of NSBH & BBH are in good agreement with the expectation
2. No BNS so far! Actually consistent with the current LIGO BNS range ~160Mpc < 180Mpc (expected at the beginning of O4)