Multimessenger Astronomy in the GW group

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Univers du pôle A2C - 13/12/2024

Outline

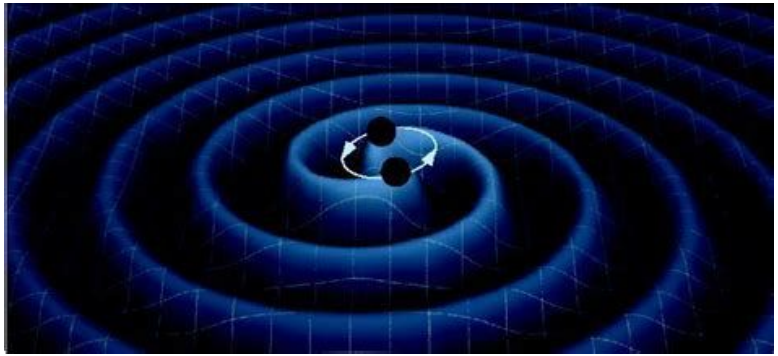
- Gravitational waves: detections and alerts
- GW Highlights from O4, LVK 4th Observing run
- Optical follow-up of O4 by the GRANDMA network
- Another multi-messenger approach: SVOM

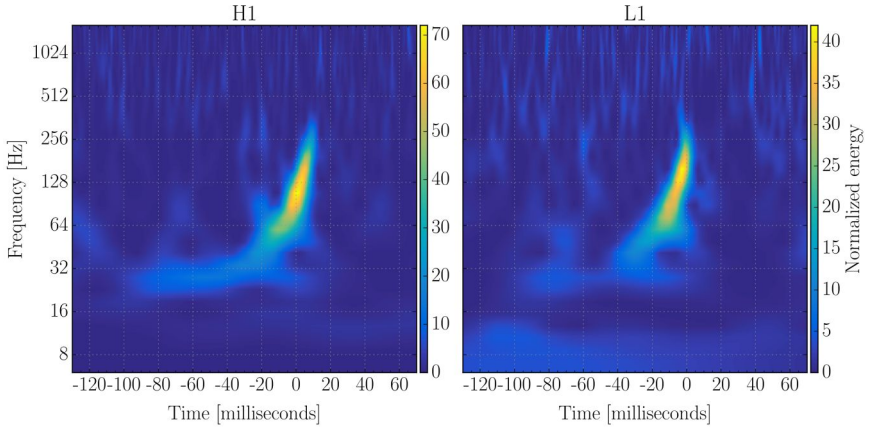
Gravitational waves *(GW)*

=> Perturbation propagating in the space-time metric

Predicted by General Relativity in 1916, first directly detected in 2015 (GW150914) in LIGO gravitational wave interferometers: black hole binary

Since then hundreds other binaries have been observed by the LVK (LIGO-Virgo-KAGRA collaboration) : black holes and neutron stars coalescence

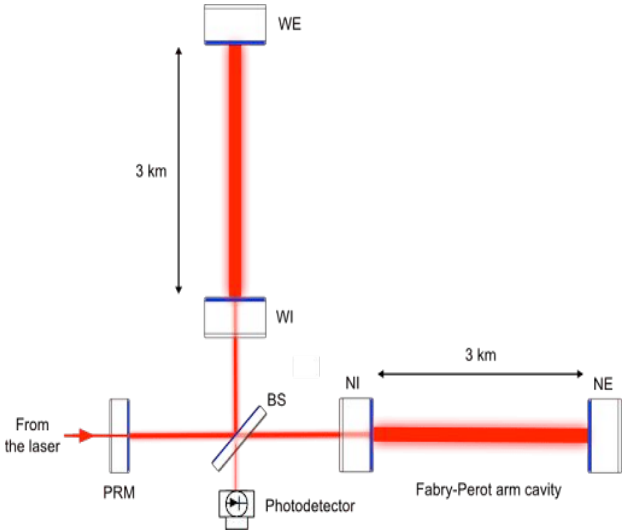


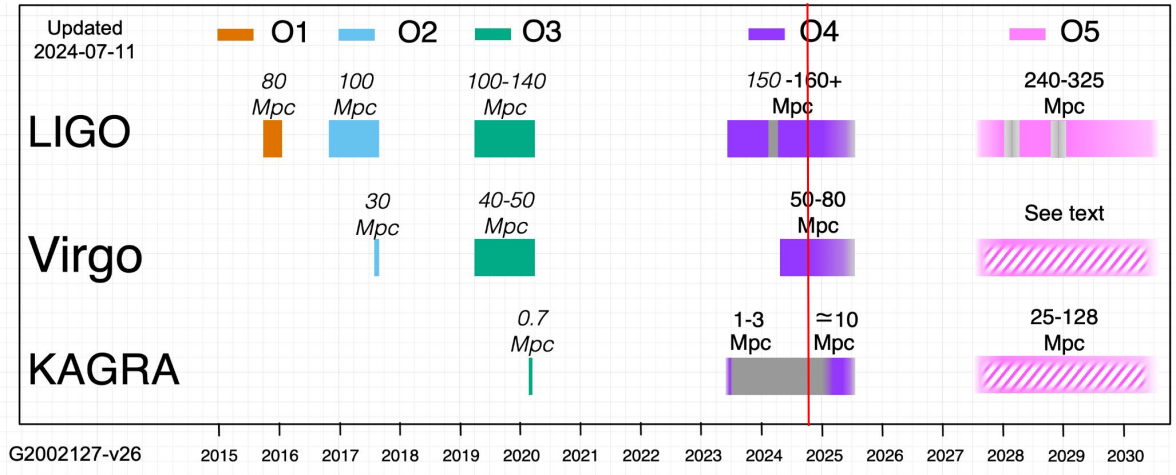


Gravitational-wave interferometric detectors

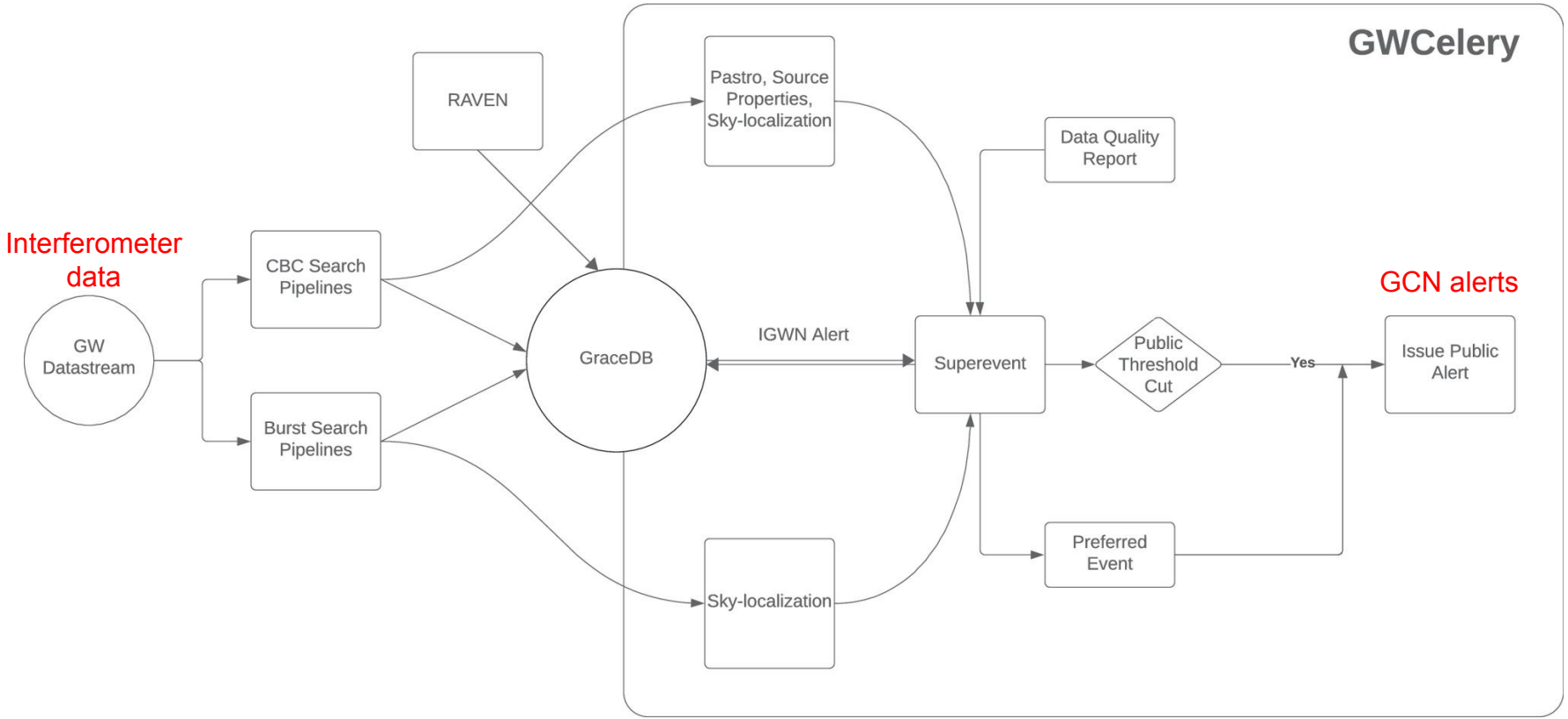
LVK network:

- **L**IGO: Hanford and Livingston (USA)
- **V**irgo in Cascina (Italy)
- **K**AGRA in Hida (Japan)





Alert system: from GW data to GCN alerts

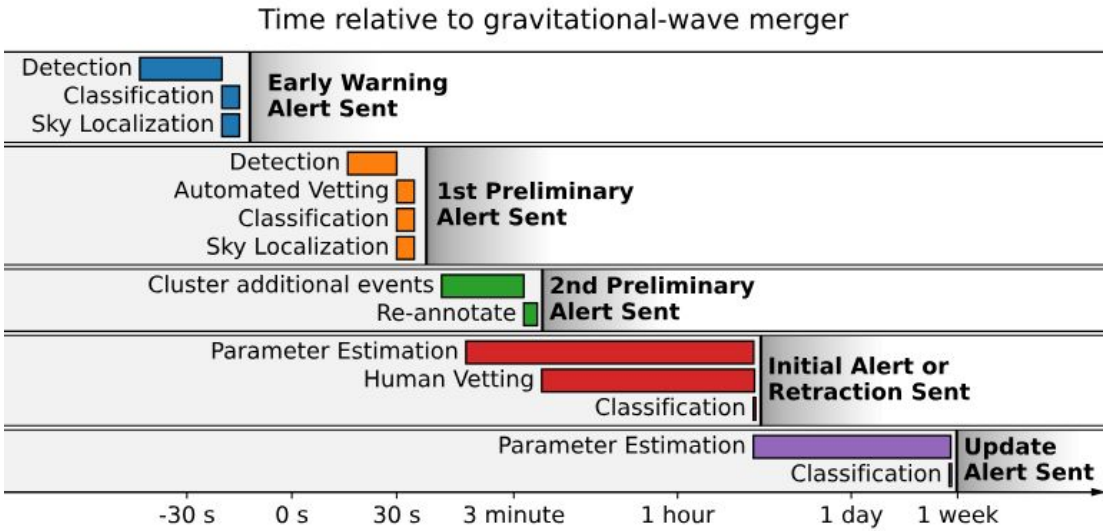


GCN: General Coordinates Network

Alert timeline

- Early warning alert if possible
- Detection and preliminary alerts
- Human Vetting and possible retractation
- Parameter estimation and updated alert

Preliminary Alert and sky localization sent in a minute after event



Possible NSBH events in O4

Alerts with p_NSBH > 10%:

- S240915b (sky localisation ~ 18 deg²)
- S240910ci (394 deg²)
- S240830gn (410 deg²)
- S240422ed (259 deg²)
- S230830b (941 deg²)
- S230731an (599 deg²)
- S230627c (82 deg²)

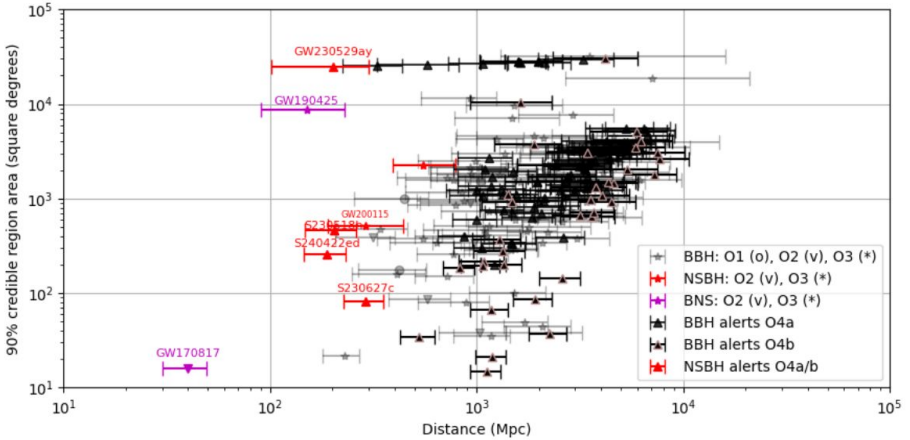


Figure 1: The most recently updated 90% credible region area versus the most recently updated luminosity distance (posterior mean distance and posterior standard deviation of distance) for all LIGO/Virgo GW events/candidates of runs O1, O2, O3, and O4 a/b (up to 24/07/2024).

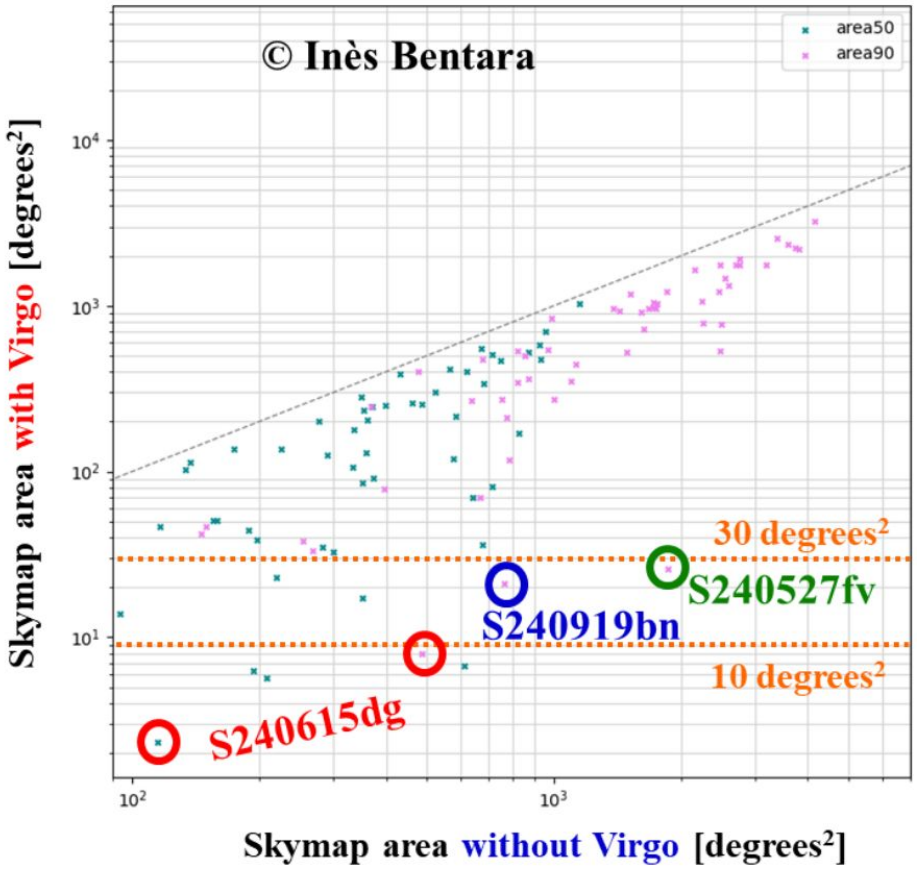
and 4 other with sky localisation > 1000 deg²

No significant BNS alert

Virgo’s importance in sky localisation

Virgo’s detection range is lower than LIGO’s interferometers

Its contribution to detections is scarce but has important impact on reducing sky localisation



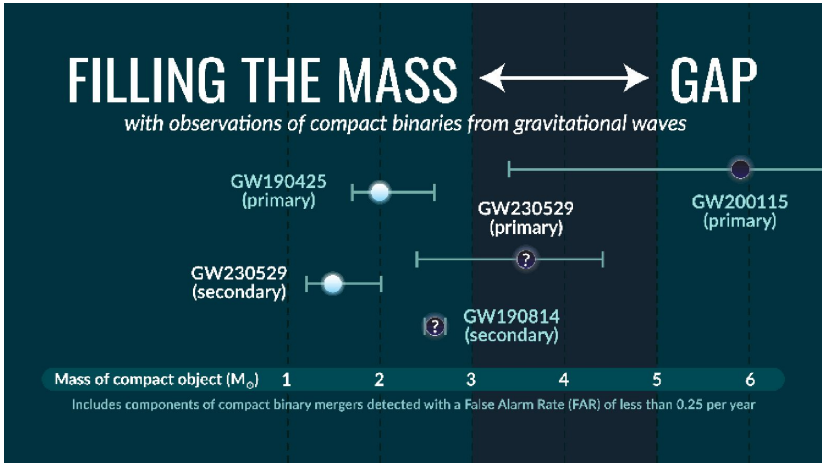
Signal focus: GW230529

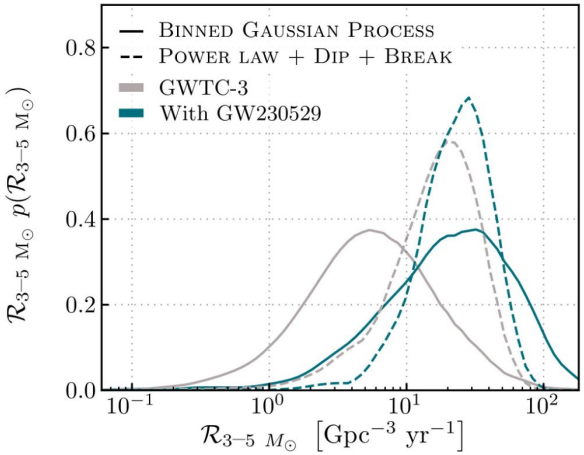
Detected by LIGO Livingston on May 29th 2023

Rare collision of a neutron star with a compact object of 2.5 to 4.5 $M_\odot$

=> Great Input for low mass merger rates!

Low masses are prone to tidal disruption, which could power a range of EM counterparts, including a kilonova => Multi-messenger prospect





Full article: https://doi.org/10.3847/2041-8213/ad5beb

A network for optical follow-up:

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

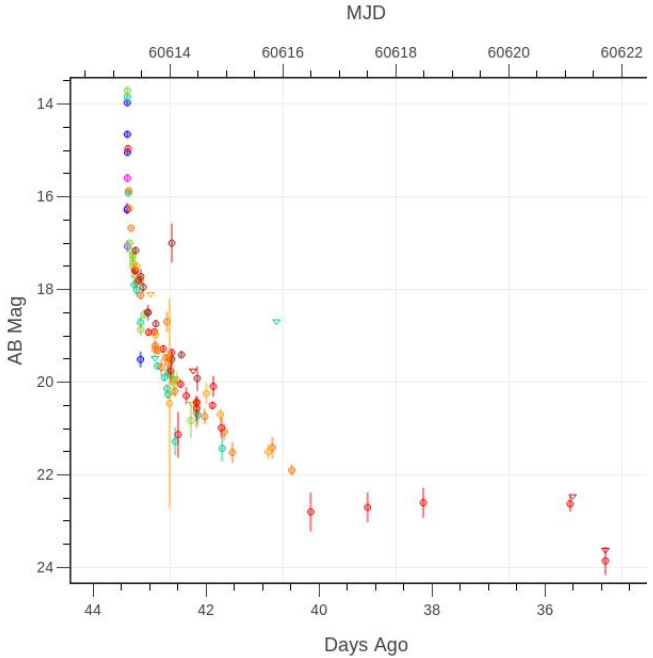
KILONOVA CATCHER

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

GRANDMA Recent Follow-up: Multiple science topics

GCNs produced in the last 6 months:

- Gravitational Wave events:
  → 3 following LIGO/Virgo/KAGRA
- Gamma-ray bursts:
  → 13 following Swift and SVOM
- X-ray transients:
  → 3 following Einstein Probe
- Neutrino events:
  → 3 following IceCube in the past year

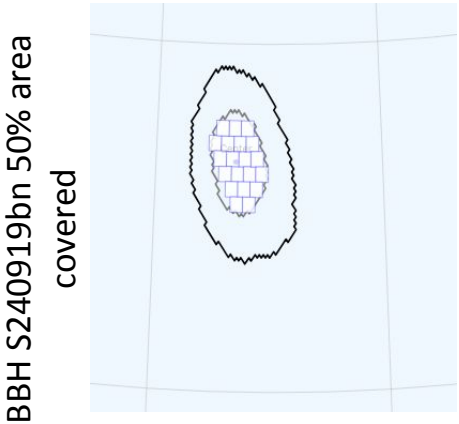


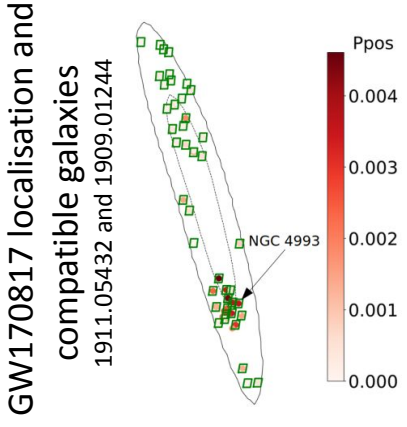
Ex: Swift GRB241030A

In average, GRANDMA outputs one GCN per week

GRANDMA GW Follow-up

- Blind search of the GW skymap





Tiling

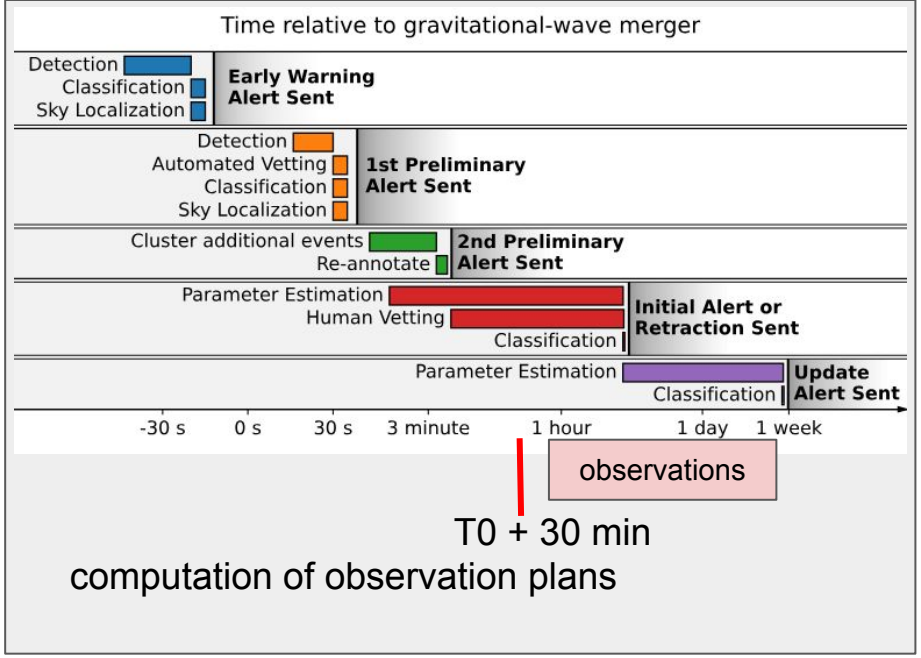
Galaxy Targeting

Large FoV instruments

Small FoV instruments

Cross match with MANGROVE catalog

(Ducoin et al., arxiv:1911.05432)



- Target of Opportunity follow-up

Follow-up of promising candidates:

ZTF survey (selection with Fink)

GCN counterpart candidates

O4a with GRANDMA

Criteria for blind search: - Main category 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
(NSBH S230627c: Targeted galaxy observations → Only upperlimits)

Rate smaller than initial predictions of ~1 BNS or NSBH per week

		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}

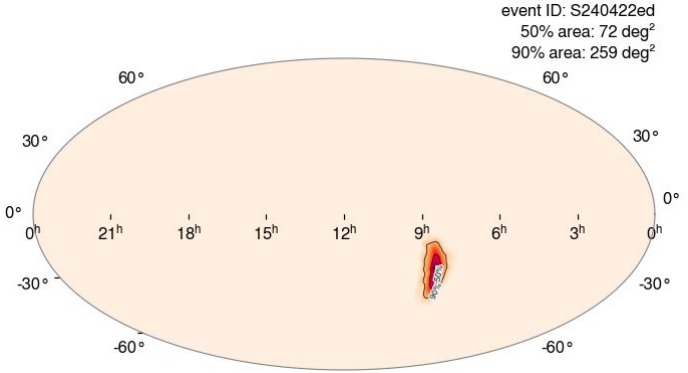
https://emfollow.docs.ligo.org/userguide/capabilities.html

O4b with GRANDMA

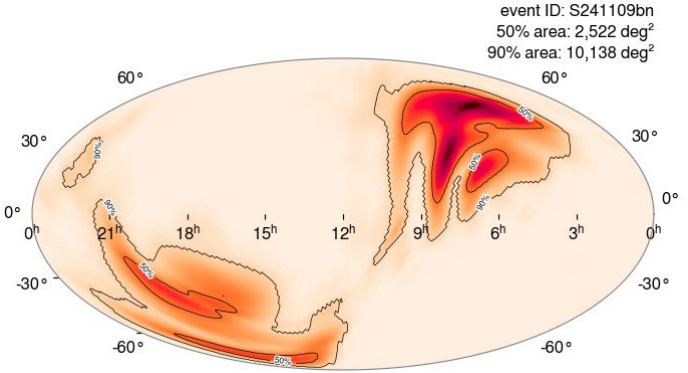
Criteria for blind search: - BNS or NSBH or **BBH**

- 90% skymap <~200deg2 ~~AND~~ **OR** DL < ~200 Mpc

89 significant detections : - Some well localised BBH (S240527fv, S240615dg, S240920dw, S241127aj) → Tiled observations: only upperlimits



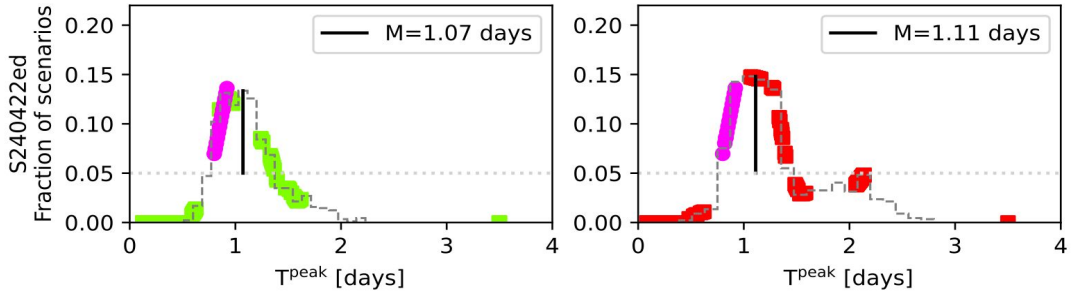
low-significance NSBH S240422ed
Tiled +Targeted galaxy observations



NSBH S241109bn
Area too large to follow-up

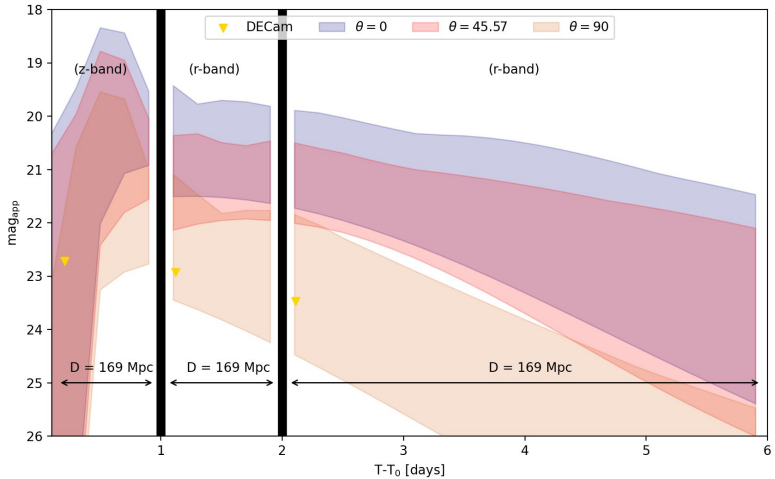
Extracting Kilonova Information

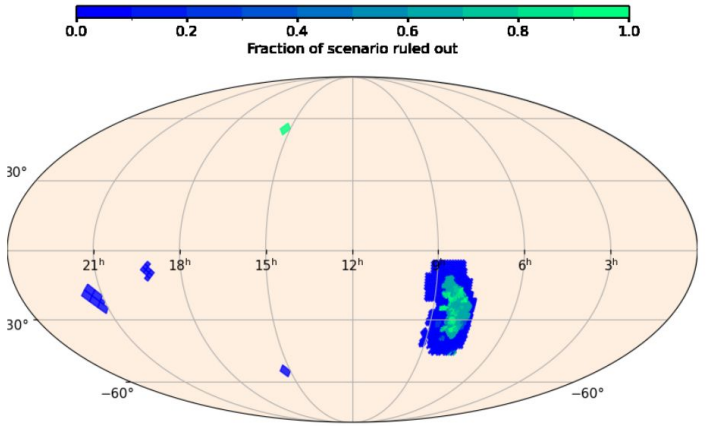
Observing around expected peak time of NSBH Kilonova scenarios



23% peak during GRANDMA obs in g-band 21% in r-band

Pillas et al., in prep.





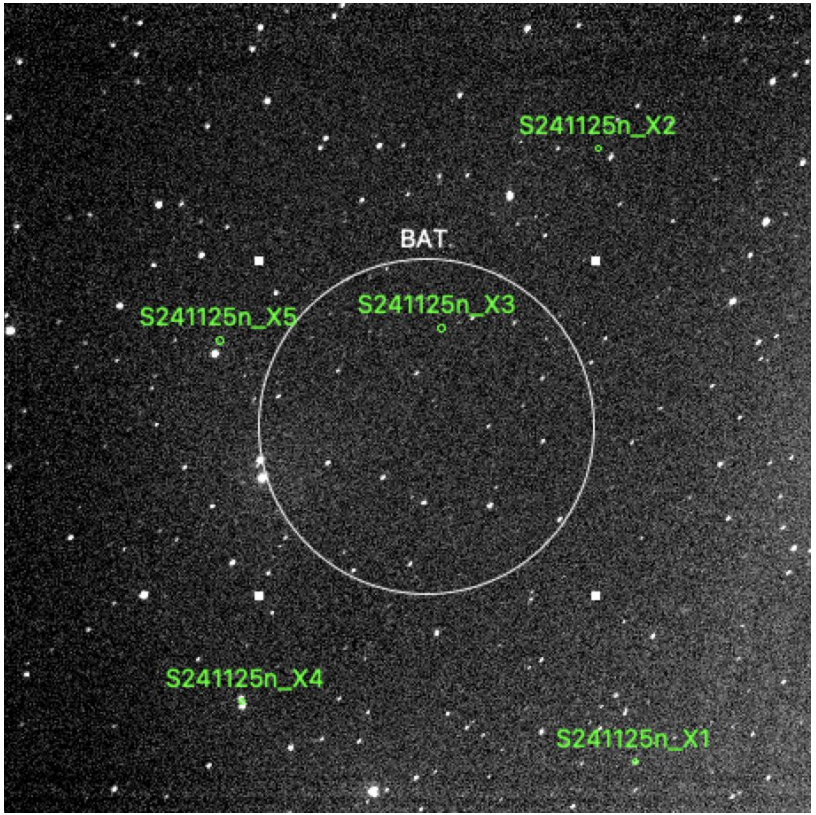
Modeled scenarios brighter than non-detections ? → Ruled out parameters

S241125n: BBH associated with low-significance GRB ?

Swift/BAT targeted search found low-significance GRB in the BBH skymap

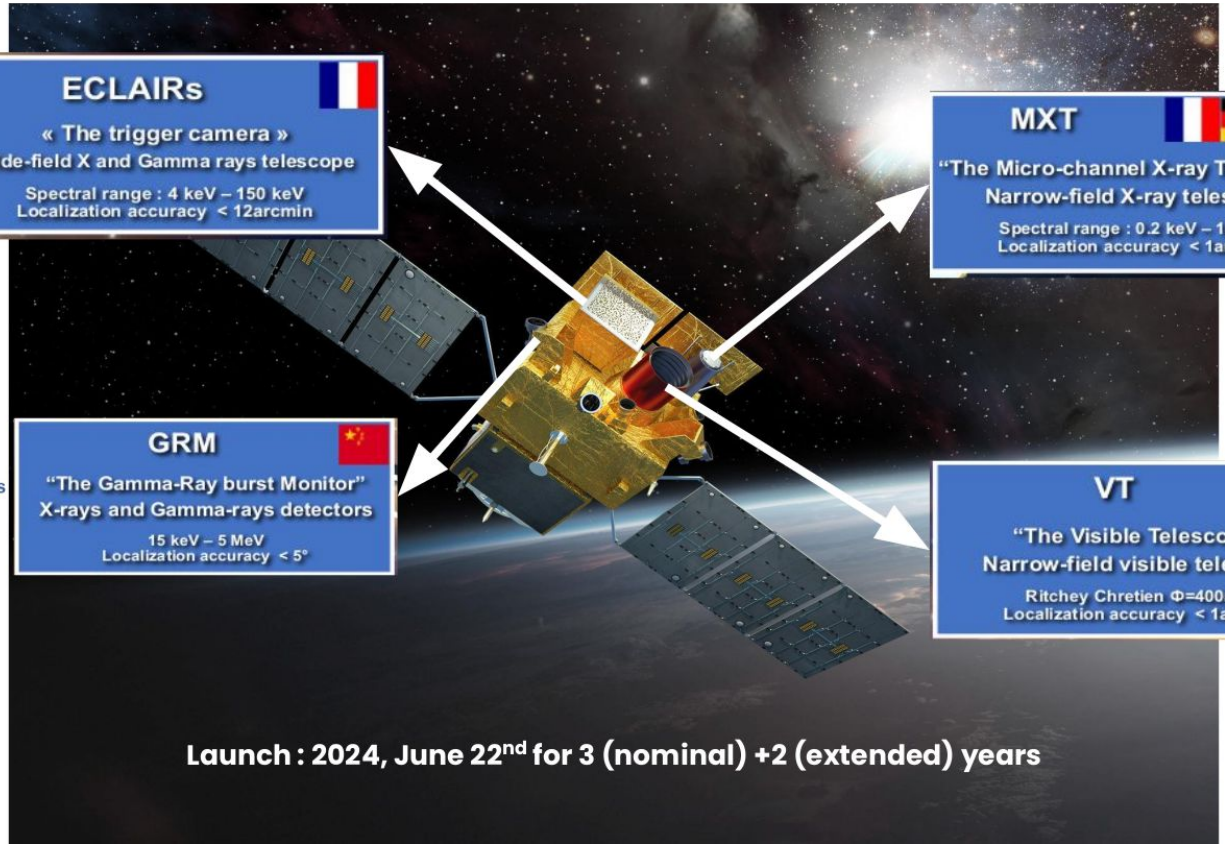
GRANDMA follow-up
→No optical detection in the 5 arcmin uncertainty region around the BAT position

Swift-XRT proposed 5 X-ray sources, EP-FXT a few more. → No clear optical candidates within the localization regions of these sources



Observation by FRAM-CTA-N

An multi-messenger satellite:
Space-based multi-band astronomical Variable Object Monitor



cea irfu

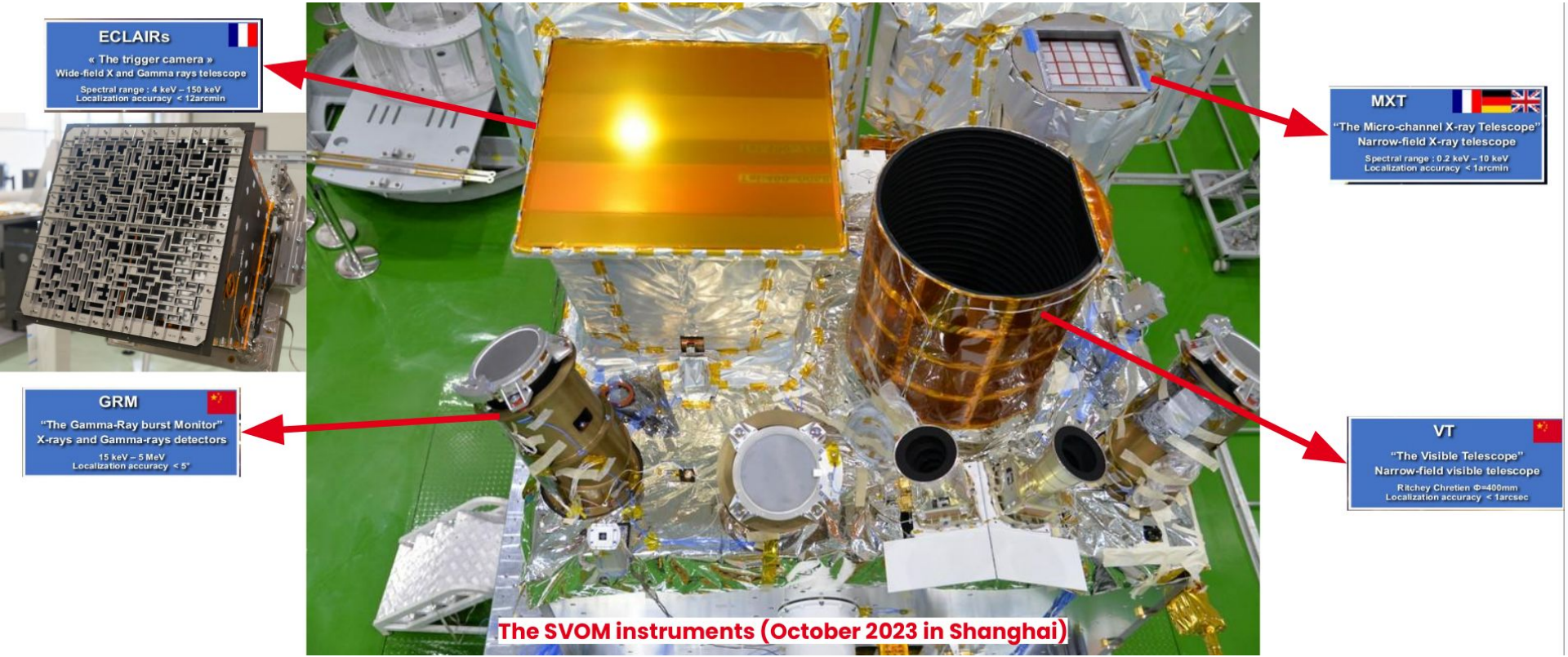
irap astrophysique & planétologie

Institute of High Energy Physics
Chinese Academy of Sciences

cea irfu

NAOC

SVOM instruments

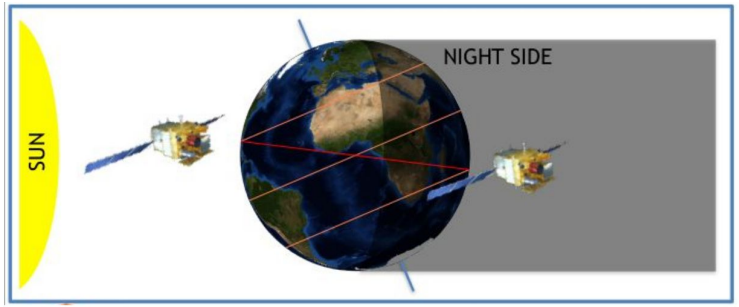


SVOM : the first 6 months

Since the launch, the SVOM collaboration published in GCN circulars:

- 57 GRM triggers
- 16 ECLAIR triggers
- 3 MXT observations
- 17 VT observations

About 20 transients with multi-instrument detections, using automatic slewing to the trigger localizations



Anti-solar pointing → Synergy with Ground-based Follow-up Telescopes (GFT)

A dozen events followed in low latency by SVOM-C-GFT

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Thank you !

Any questions ?

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Backup slides