GRANDMA KILONOVA-CATCHER

S. ANTIER

CNAP ATSRONOME ADJOINTE
OBSERVATOIRE DE LA CÔTE D'AZUR
IJCLAB, ORSAY

Multi-messenger studies with GWs

GW Detectors

GW Modeling

EM Instruments

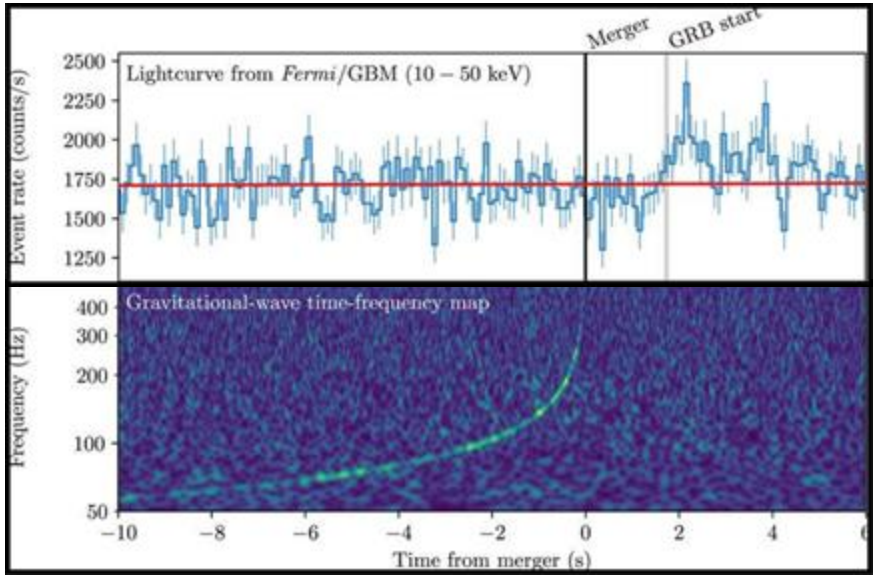
Global Astrophysical Modeling

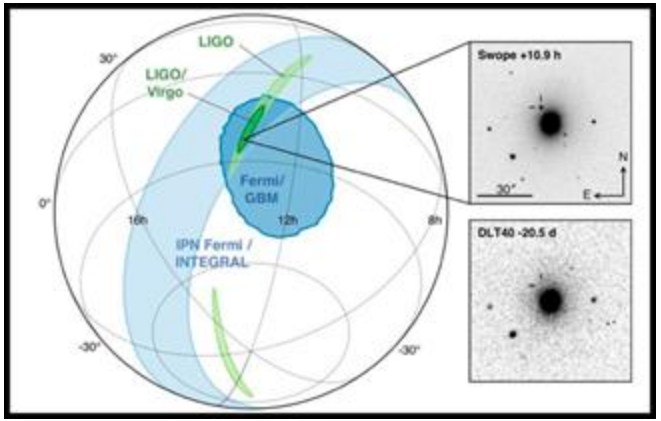
BNS, NS-BH Collisions
Core Collapse

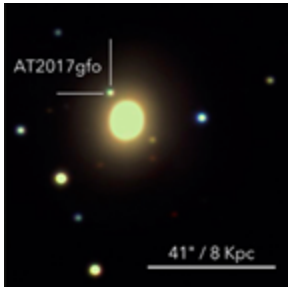
Chemical Evolution
R-process

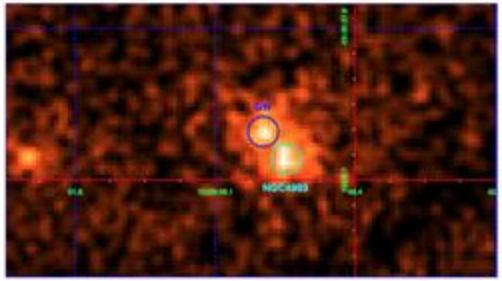
Nuclear Physics
Dense Matter

GW170817 – GRB 170817A: MULTI-MESSENGER RAINBOW

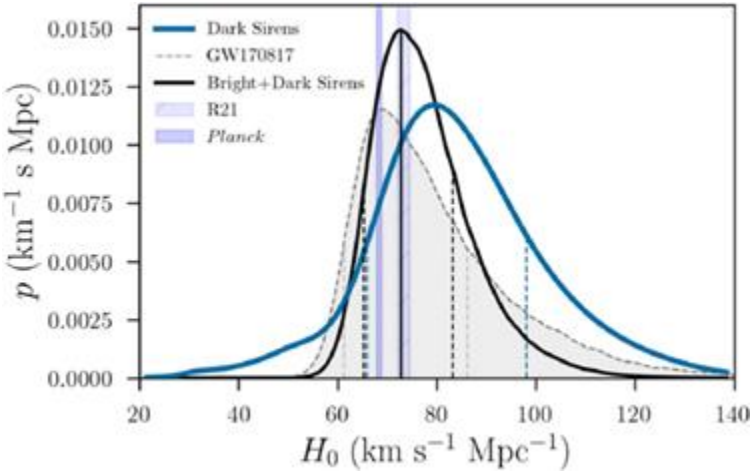




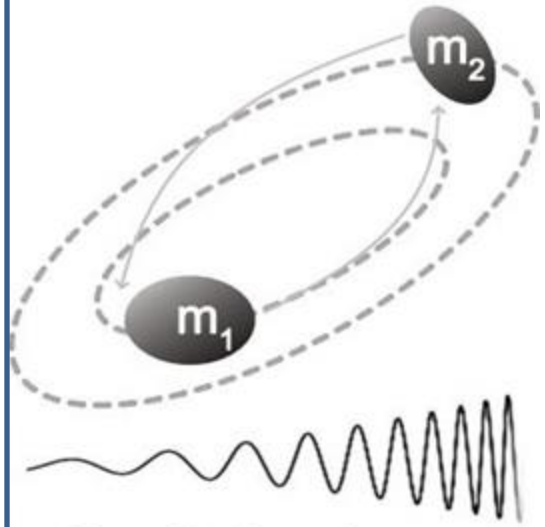




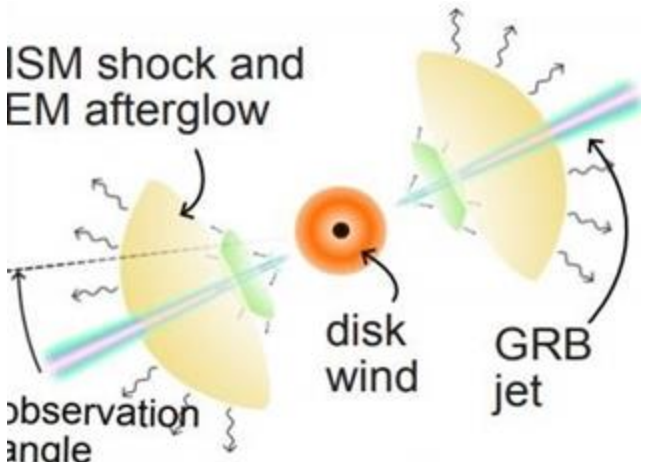
MANY IMPLICATIONS, EX: COSMOLOGY

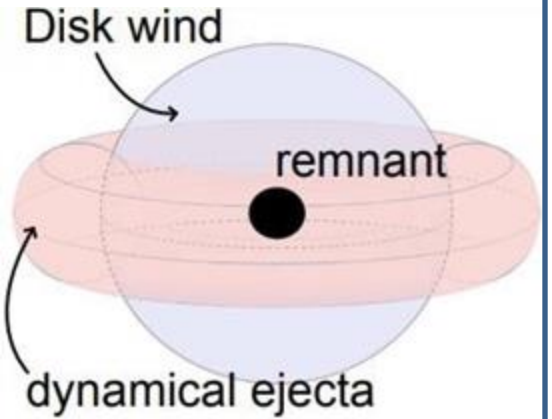


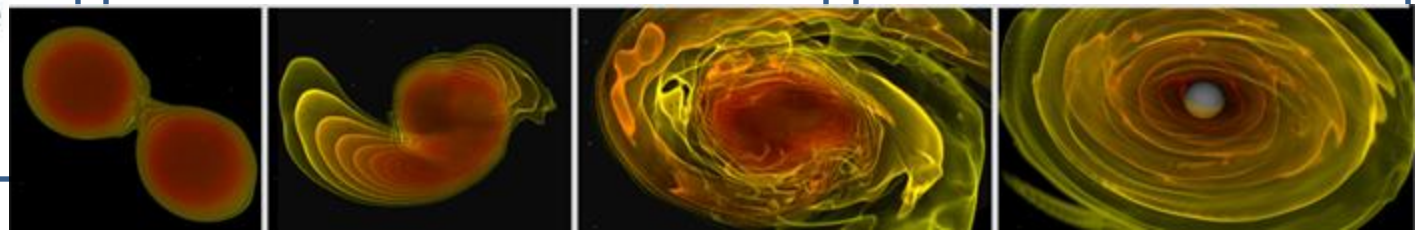
Merger Event → Gamma Ray Burst → Kilonovae



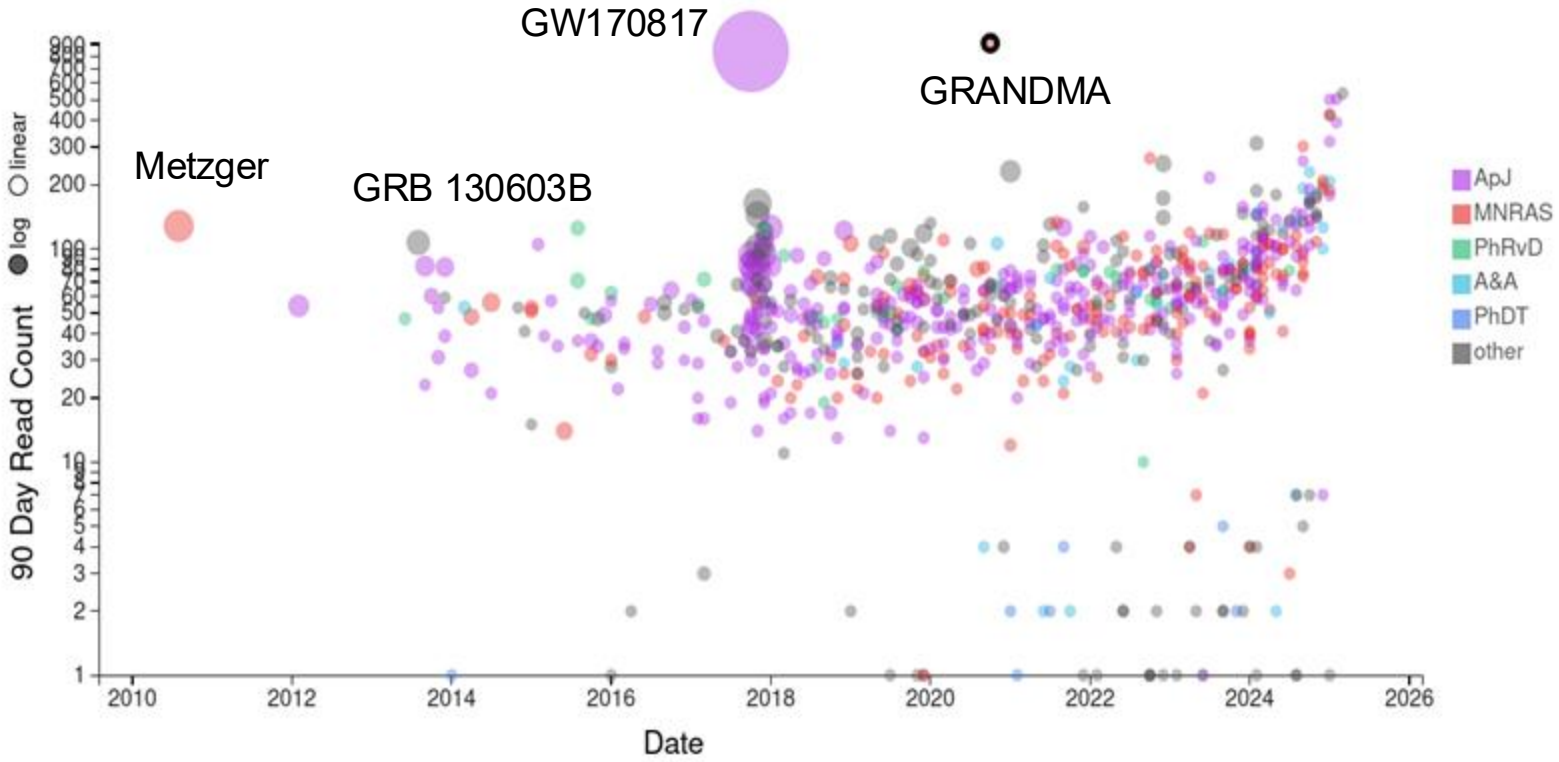
Gravitational wave "chirp"







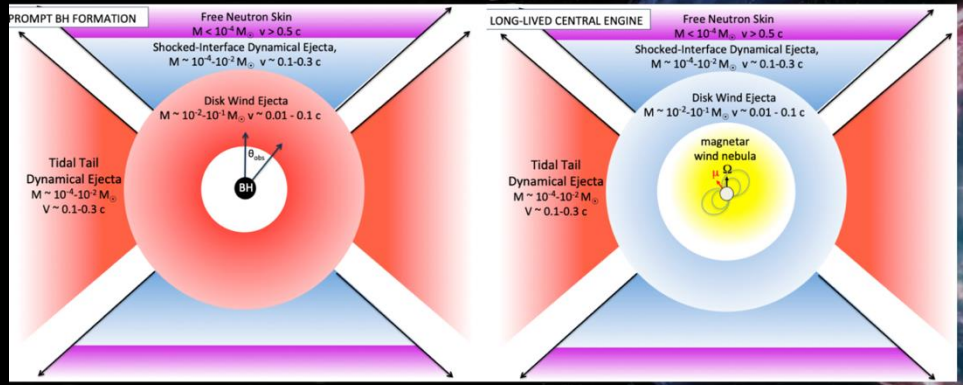
A recent Field Kilonova



(Lattimer & Schramm) 1974

Kilonova: probe of Neutron star merger environment

BNS



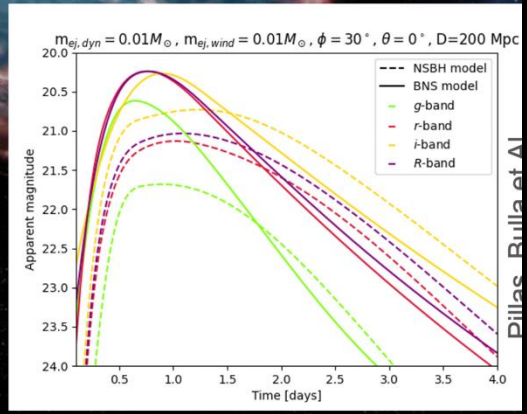
- Dynamical ejecta:
  - Equatorial (Neutron rich): High fraction of Lanthanide
  - Polar (Neutron poor): Blue kilonova
- Disc wind ejecta (equatorial, blue and red)

$$M_{ej,rem} = m_{dyn} + m_{wind}$$

NSBH

Favorable conditions:

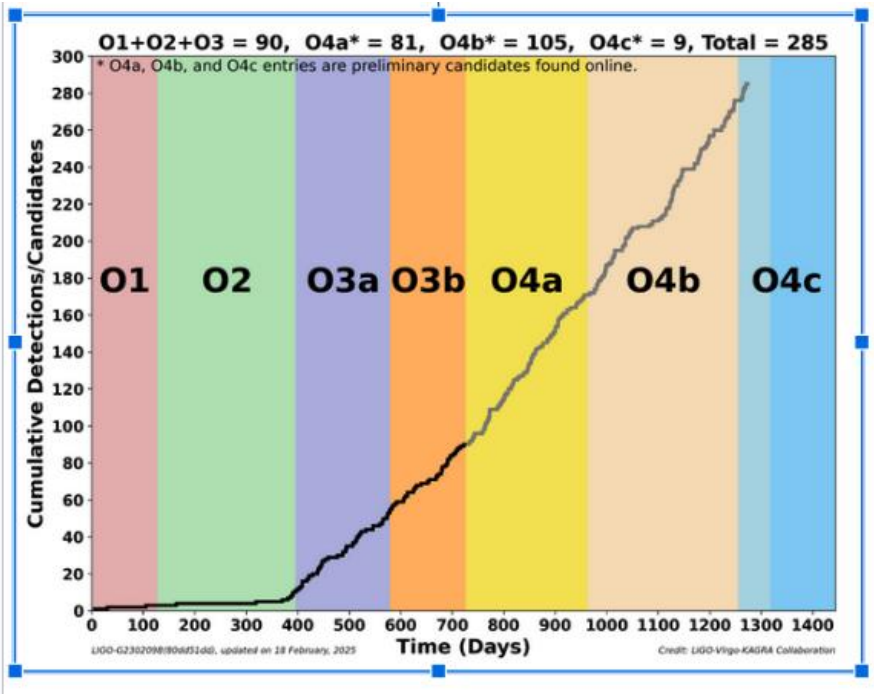
- Small mBH/mNS
- High spin BH
- Also depends on EOS

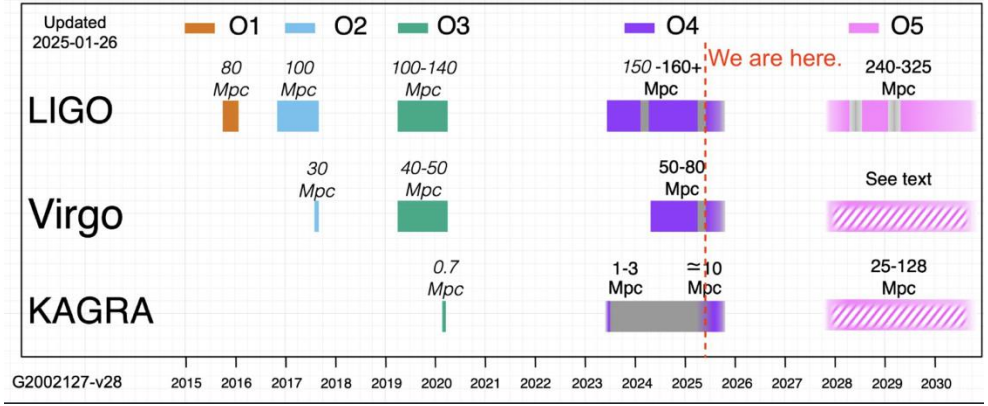


Pillas, Bulla et Al

6

O4 Gravitational wave campaign





About 2.3 triggers per week (at the public nominal threshold)

Observational challenges

GW alert

Search Area
Up to thousands of square degrees

EM Triggers

- Within few hours

Rapid brightness decay of the kilonova ~200 Mpc, magnitude 22 to reach after 22h.

What is mission « chaînon manquant »
Telescope network of small and mid-size telescopes

Kilonova identification based on photometric ev.

- Few days

Spectral and temporal characterization

- Few weeks

Deep Sky

	2015	2016-2017	2019-2020	2023	2028	> 2035
GW	2 BBHs	1 BNS – 8 BBHs LIGO-Virgo	1 alert / week	< 2 BNS/NSBH / month + KAGRA	1 BNS / week + LIGO INDIA	> 1 BNS / day Einstein Teles
EM		GW170817	+ ZTF GRANDMA	SVOM LSST ?	+ SKA CTA	+ Athena

Follow-up is hard ☺

When an alert comes

As an astronomer...

Wake up

Do you have shifters / a rota ?
Do you have automatic processing ?

Focus

Is it Important ?
Is it Urgent ?
Can I solve it myself ? Do I need a team ?

Filter

Pass or reject based on automated criteria
Read manual to understand the Process
Similar situation as before, can solve
Don't know !

GO / NO GO / ?

Is it worth it for the experts !!!
Argg

GW astronomy requires lots of observations

Everyone is looking at the same region of the search area to find the counterpart of GW events

Our proposition - Coordination

Professionals + Amateurs

Global Rapid Advanced Telescopes Devoted to Multi-messenger Addicts

GRANDMA

37 telescopes - 26 observatories - ToO time guaranteed - 40 institutes/groups - *Born in 2018 at LAL*

Coordination on multiple axis

- Observations
- Data reduction
- Interpretation

PI. S. Antier

Co-PI. P. Hello

Scientific programs of GRANDMA and Kilonova-catcher

I. Binary neutron stars - Kilonovae - GW counterparts

GRANDMA Observations of LIGO-Virgo O3 run, MNRAS, 2020, Antier

I. Relativistic jets - Gamma-ray bursts

GRANDMA and HXMT Observations of GRB 221009A, ApJ, 2023, Kann et al.

III. Vera-Rubin Fast transients

GRANDMA Observations of ZTF/Fink Transients, 2022, MNRAS, Agayeva

IV. Continuous Training with other opportunistics sources (SNIa, ...) ...

GRANDMA E-INFRASTRUCTURE: ICARE

Karpov, et al.,
Duverne et al.,

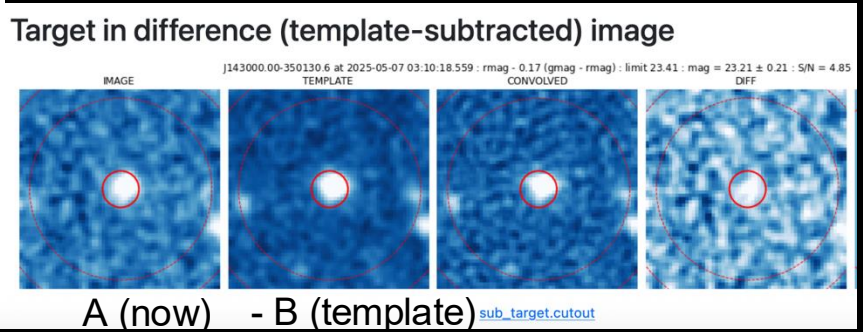
Le Montagner et al.,

- ✗ Communication with telescopes
- ✗ Central Manager

Reception of any type of alert and sender

- ✗ Time domain Web portal

Monitor of GW/GRB observations and candidates
Candidates from online pipelines
Automatic report



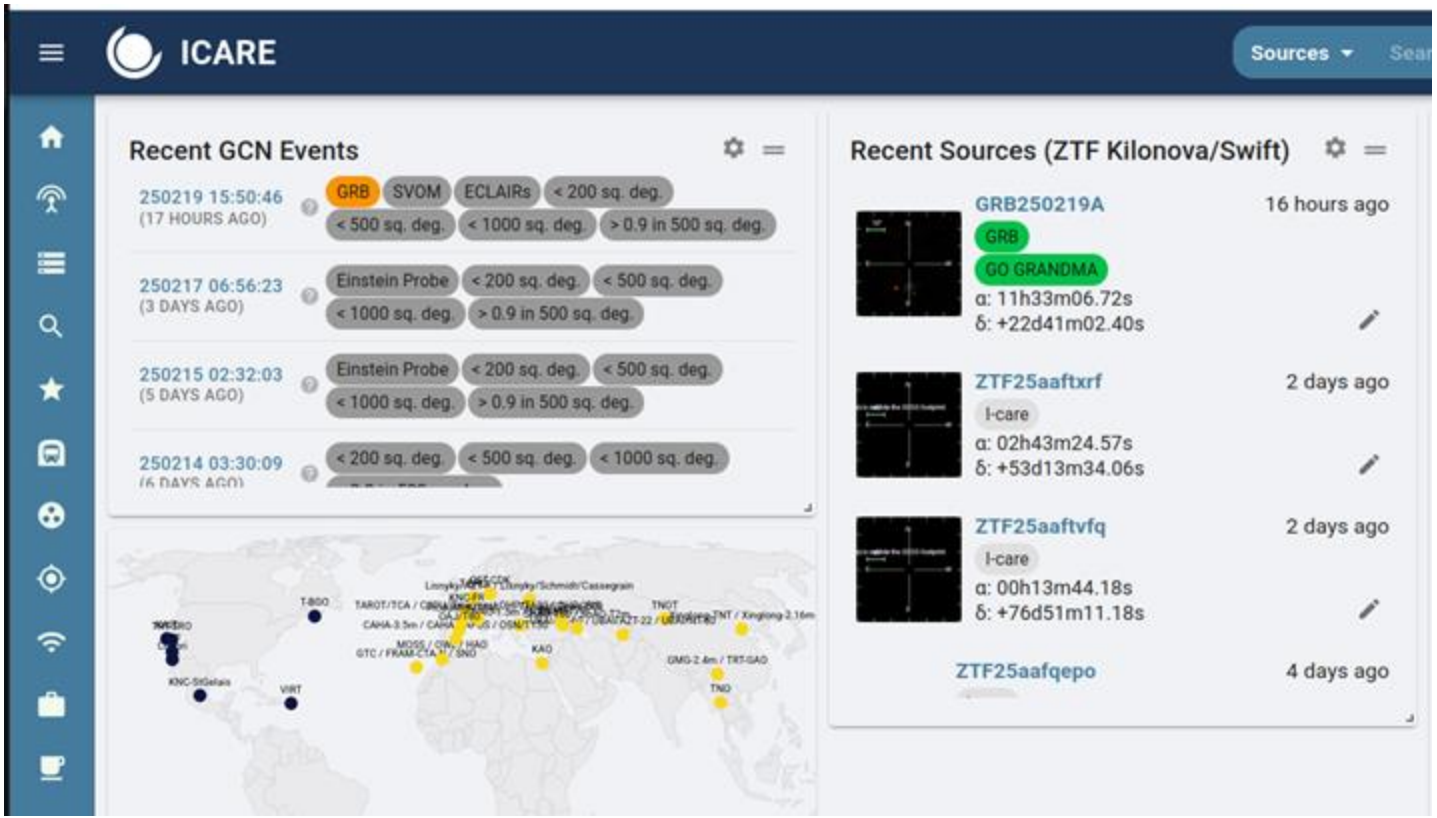
Science Portal: Skyportal the Key Tool for time domain

Open to Europe in 2027 via ACME

Receive alerts
Scheduling
Annotation
Scanning candidates
Basic analysis

Hosted at IJCLAB

C. Douzet



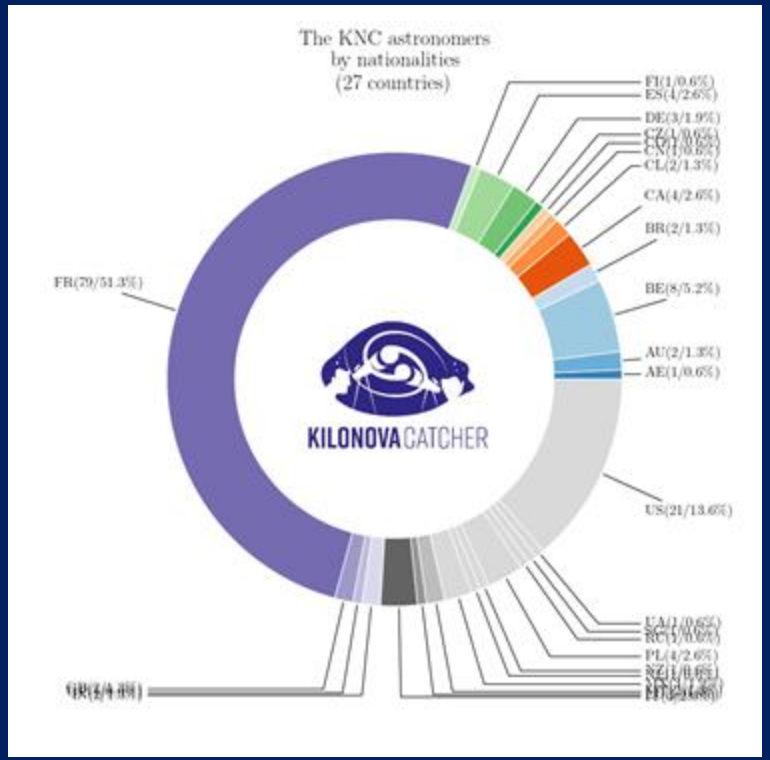
KILONOVA CATCHER

kilonovacatcher.in2p3.fr

by IJCLAB

SF2A citizen price 2025 !!

The amateur network



- ~ 5% provided photometric results
- ~ 10% can reach 21 mag in r-band
- ~ 50% provided images once
- ~ 100 accounts

Since 2019, +700 images uploaded and 70% science valid (for 30 alerts)

We have provided sloan filters g, r, i, z to 6 amateur astronomers

Summary of the coverage from 0 to 6 days post T0

Filter	0 - 1 day % c.r	0 - 1 day upper	1 - 2 day % c.r	1 - 2 day upper	2 - 6 day % c.r	2 - 6 day upper	Instruments
S230518h							
600 - 1000 nm	25%	16	25%	16	25%	16	TESS
R	21%	21.6	18%	21.6	-	-	GECKO
o-band	44%	17.9	-	-	25%	18.8	ATLAS
c-band	-	-	25%	19.5	47%	19.5	ATLAS
GW230529							
L-band	10%	19.7	2%	19.4	2%	19.2	GOTO
g-band	16%	20.6	-	-	-	-	ZTF
r-band	12%	20.6	-	-	-	-	ZTF
i-band	5%	20.1	-	-	-	-	ZTF
o-band	2%	17.8	4%	18.9	23%	17.6	ATLAS
S230627c							
L-band	45%	19.1	84%	19.0	23%	19.1	GOTO
g-band	88%	21	-	-	-	-	ZTF
R-band	4%	18.5	2%	20.7	2%	20.7	GRANDMA - GECKO
r-band	88%	21	-	-	-	-	ZTF
o-band	-	-	18%	18.6	17%	18.0	ATLAS
S240422ed							
g-band	53%	19.5	83%	19.7	<1%	22.5	GRANDMA, ZTF
L-band	96%	19.1	96%	19.6	94%	20.1	GOTO
G-band	19%	19.5	-	-	-	-	CSS/SAGUARO
R-band	69 %	16.7	67%	21.6	22%	21.3	GRANDMA - GECKO
o-band	99%	18.9	7%	18.7	99 %	18.6	ATLAS
z-band	75%	22.6	81%	22.4	71%	23.0	DECam
J-band	16%	16.5	-	-	-	-	WINTER

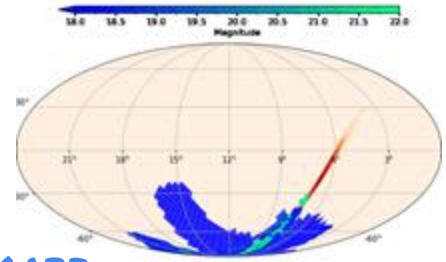
\+ Meerlich, BlackGEM, Magellan

Pillas, Antier et al., PRD, 2025

M. Pillas

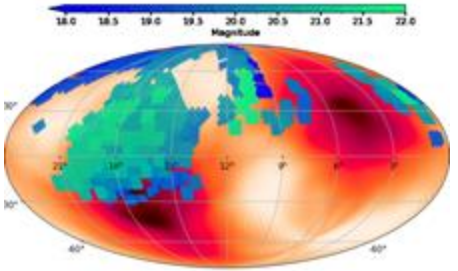
S230518h

81% cr. coverage
from 14.5 to 23.3 mag upper limit



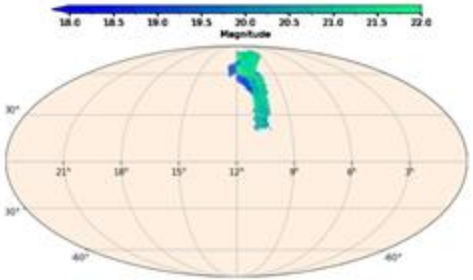
GW230529

37% cr. coverage
from 13.2 to 21.7 mag upper limit



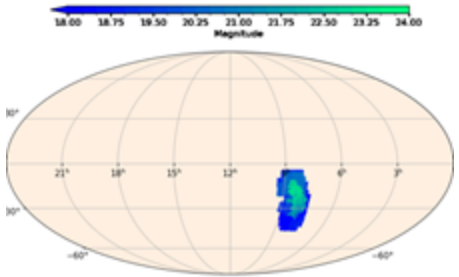
S230627c

96% cr. coverage
from 16.3 to 21.3 mag upper limit



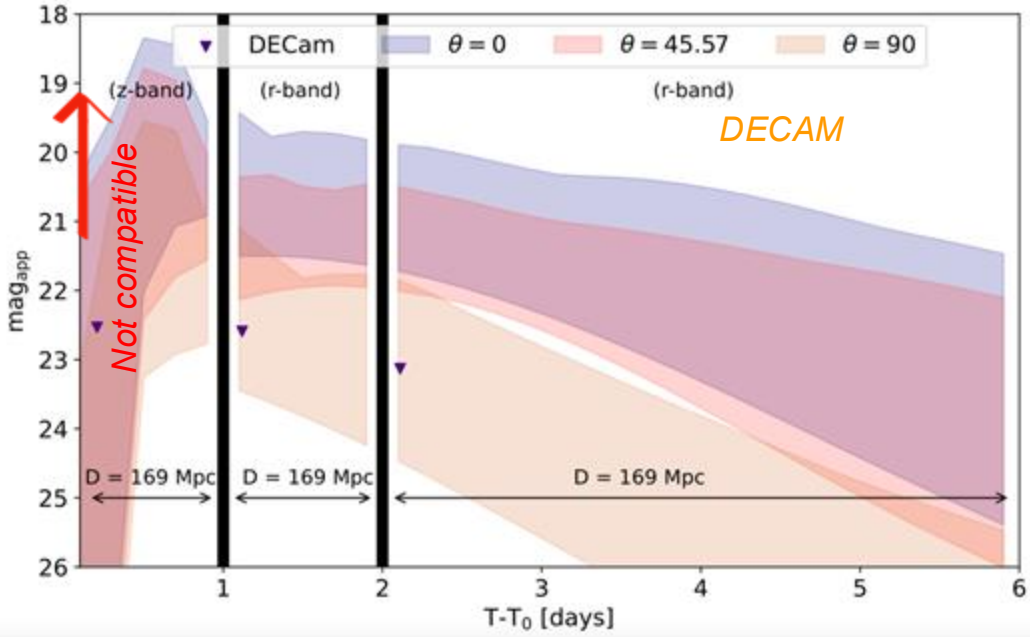
S240422ed

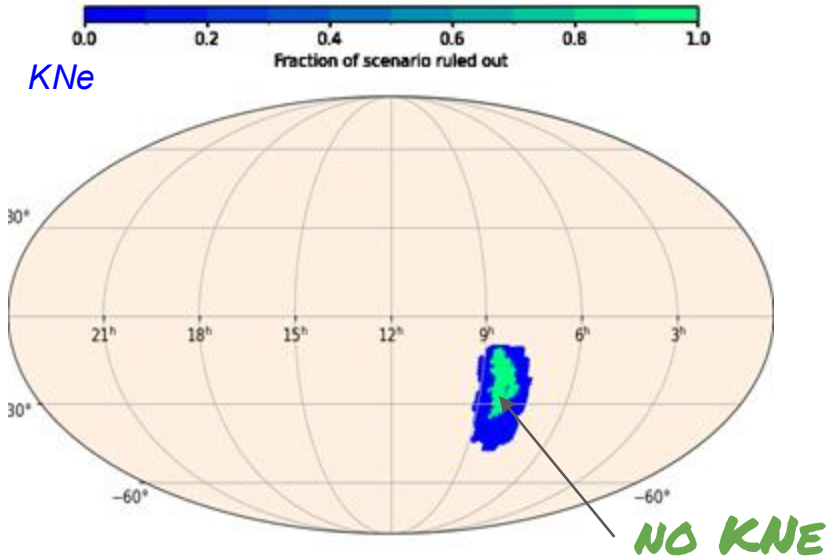
> 99% cr. coverage
from 14.1 to 23.5 mag upper limit



GW Astronomy / Results: S240422ed

One mocked KN (ArnandBulla) projected at distance and T0 from S240422ed





Observations taken one day after S240422ed ruled out Totally KNe signal in sky coverage of 180 deg² from NS-BH mergers

Pillas, Antier et al., PRD, 2025

GRB 221009A _ THE MOST ENERGETIC GRB

GRANDMA and HXMT Observations of GRB 221009A: The Standard Luminosity Afterglow of a Hyperluminous Gamma-Ray Burst-In Gedenken an David Alexander Kann, Apj, ApJL, 948, L12, 2023

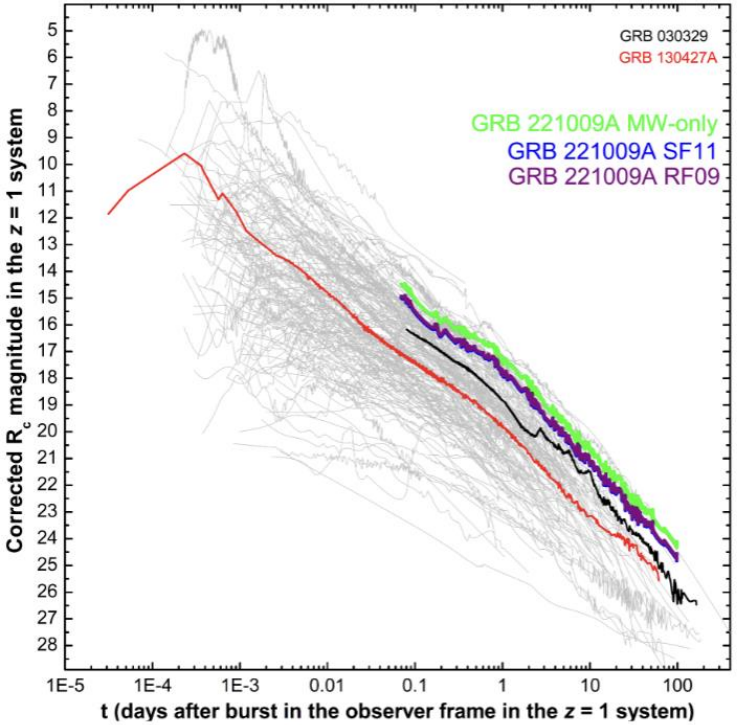
Dataset: GRANDMA (Optical)
X-ray - HXMT-LE+XRT data used for analysis

Extinction studies from both Milky Way and along the line of sight

Synchrotron radiation from forward external shock **fits observations moderately well**

Afterglow not extremely bright

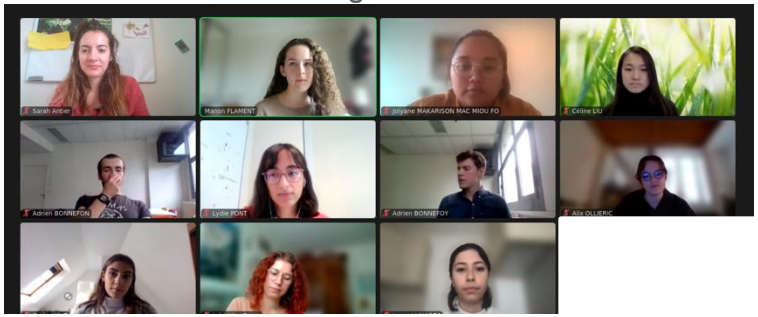
Questions: Uniform CSM ? Wind-like profile ?
Structure of the jet ?
Efficiency of the magnetic field to power the synchrotron radiation efficiency ?



INCLUSION AND DIVERSITY

The inclusion of diversity requires effort, but the fruits of this endeavor are well worth the investment.

GRANDMA undergrad crew



BE INCLUSIVE, KEEP OUR DIVERSITY IDENTITY
BUILDING NEW INSTRUMENTS, TOOLS
IMPROVING MODELING

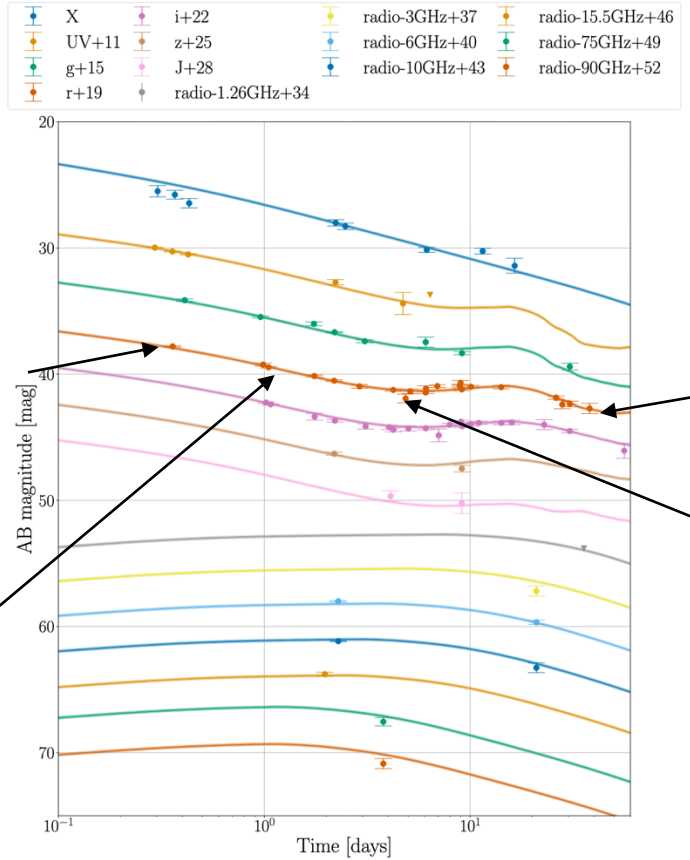
S. Brunier
Amateur
On C2PU-1m, FR
~22 mag

kilonovacatcher.in2p3.fr

KILONOVACATCHER

DIVERSITY …

GRB 230812B
Hussenot et al., 2023, MNRAS



Automatic Telescopes

Last Obs 4m or more

Pro – 1 – 2 m telescope

Amateurs

T. Hussenot

GRB 230812B
Hussenot et al., 2023, submitted MNRAS

Figure 7. Best-fit light curves of the Power-law+SN model. Datapoints are reported in the observer frame.

TOWARD LSST – GET GRANDMA READY

- Filtering the LSST stream (in partnership with Fink and Boom)
- Telescope Ressources in south hemisphere
- Dedicated follow-up strategies
- Automatisation of the data analysis
- Enrichment filtering with LSST + GRANDMA
- Scientific interpretation

ROLE OF IA

Host of the infrastructures

LAB founder

MM tools
Schuling
Science portal
Data Analysis

Kilonovae

Multi-messenger analysis

LSST follow-up

Connection to OSUPS projects
SVOM / Euclid

How to find the EM counterpart ?

GO NO GO

Follow-Up Decision Making

Multi-band Follow-up

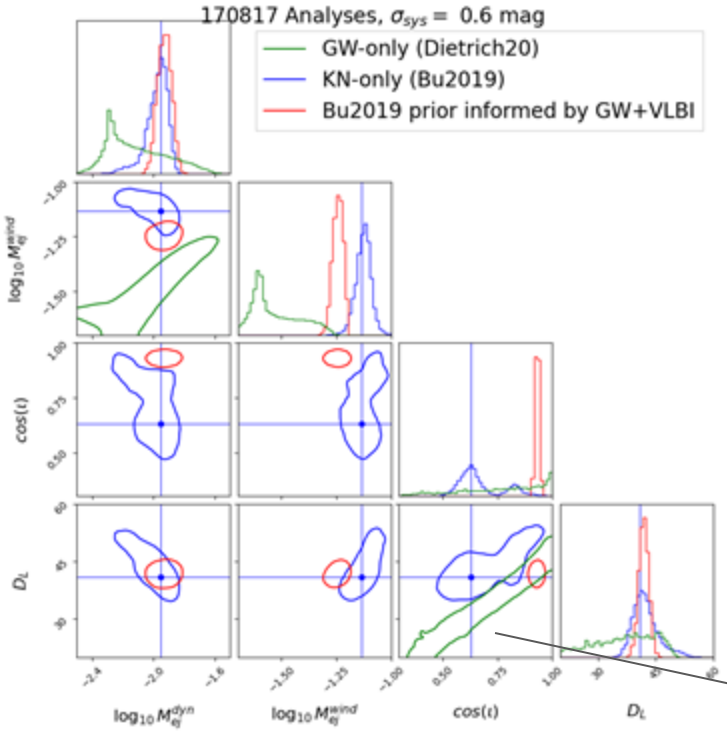
Discovery

Online Characterization

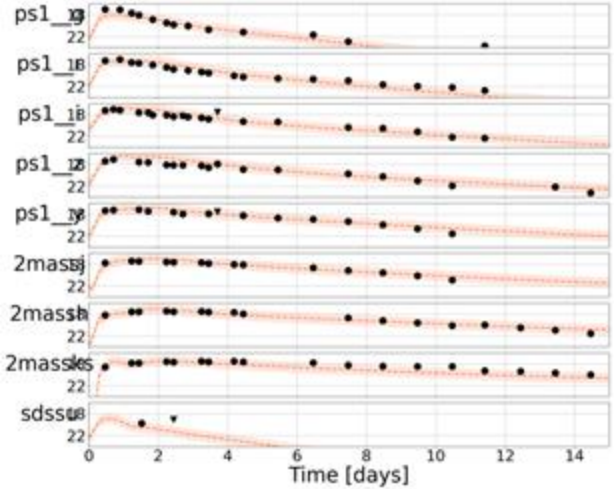
....

event properties Extraction

AT2017gfo, Not well explained by previous-gen models



(Hussenot et al., 2024)



Bulla19 only approximates the AT2017gfo lightcurve up to a 0.4 mag error margin

Other models struggle too : Breschi 2021 best fit implies distance >50 Mpc, too large

Discrepancies between separate GW-only and KN-only analyses

The Bulla 2019 model best-fit is not within incidence angle and distance constraints

New Astronomy with gravitational waves

Transient astronomy - *A race with time*

Faint and not well-known sources - Only one event found in 2017 !

Poor localizations - needle in a haystack problem

Giving a “View” to the “sound” of the Universe

BNS and NS-BH GW events for O4 a and b