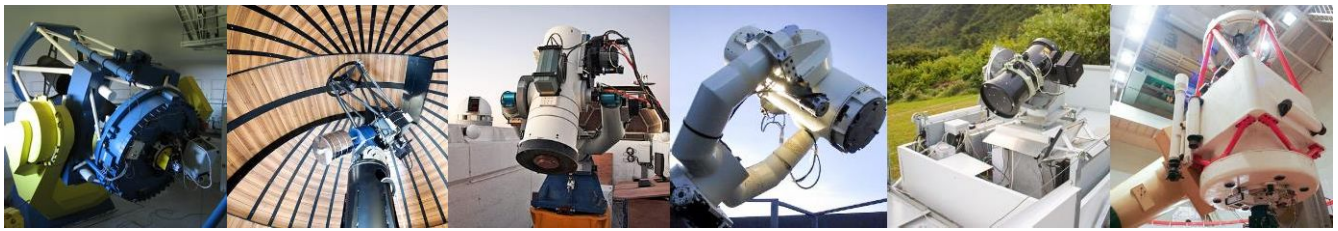
Multi-messenger astrophysics with GRANDMA

Global Advanced rapid Network Devoted to multimessenger addicts

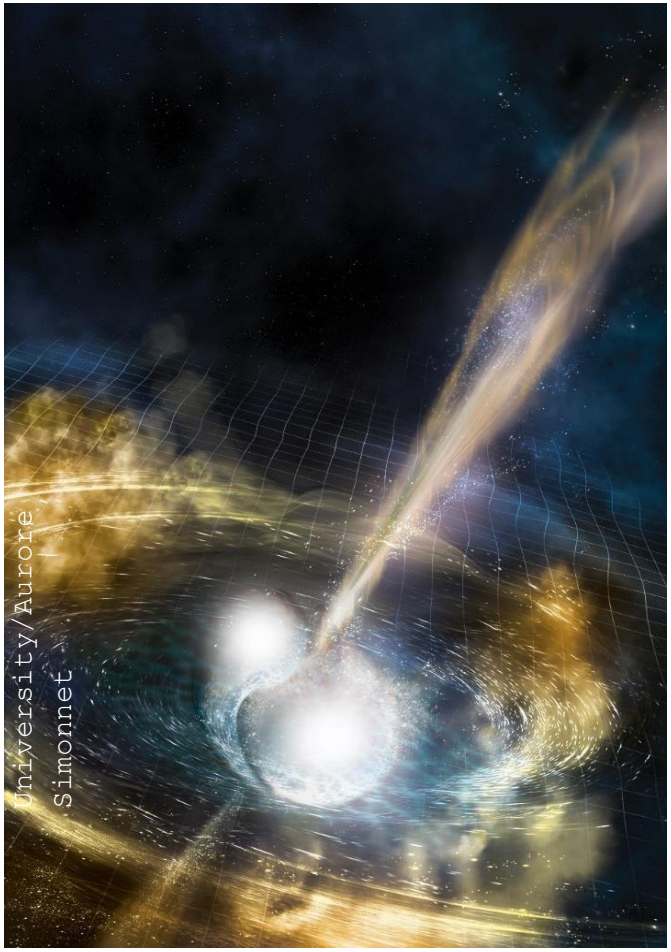
S. Antier (Observatoire de la côte d'Azur)

sarah.antier@oca.eu



Multi-messenger astrophysics of the violent universe ?

Gravitational wave astronomy



To emit GWs, a source must be compact, relativistic and asymmetric

Merger (NS-NS; NS-BH; BH-BH)

- Short GRBs, Kilonova
- Other cases ? FRB ?

Collapse of a single star

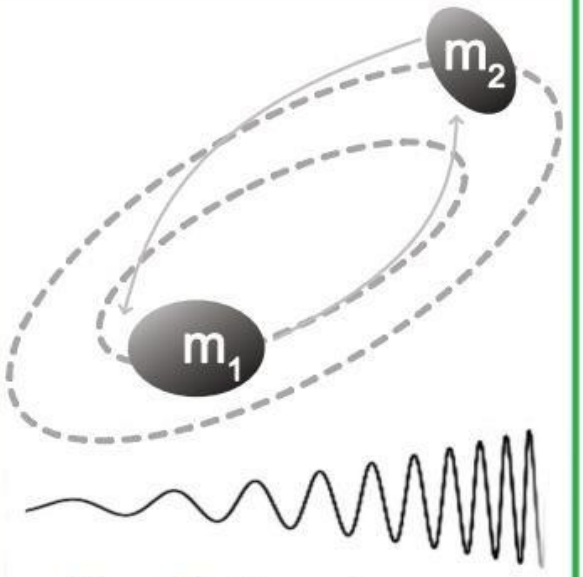
- Type Ib, Ic, II supernovae
- Long GRBs
- Intermediate cases

Neutron star instabilities

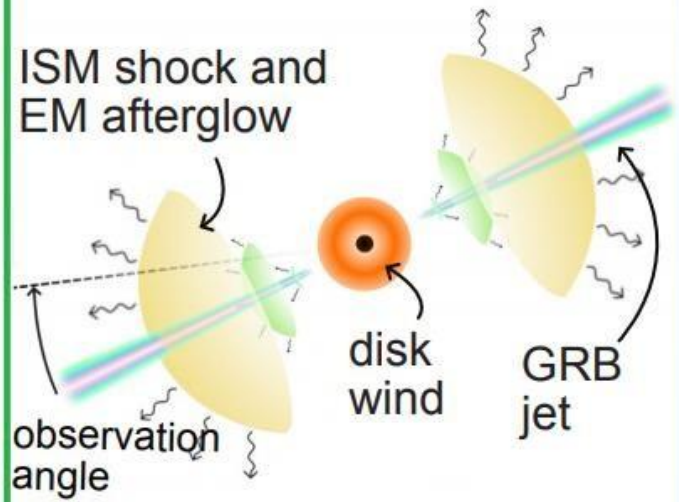
- Soft Gamma-ray repeaters
- Radio/ Gamma-ray pulsar glitches

Astrophysics

Merger Event → Gamma Ray Burst → Kilonovae

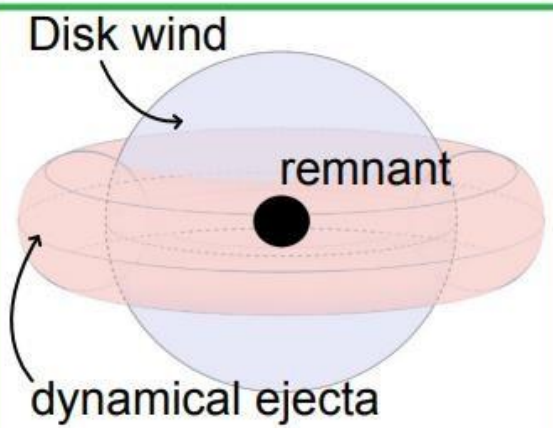


Gravitational wave "chirp"



Larger tidal deformation: brighter event

Smaller tidal deformation: fainter event



$q = m_1/m_2 = \sim 1$
Light ejecta

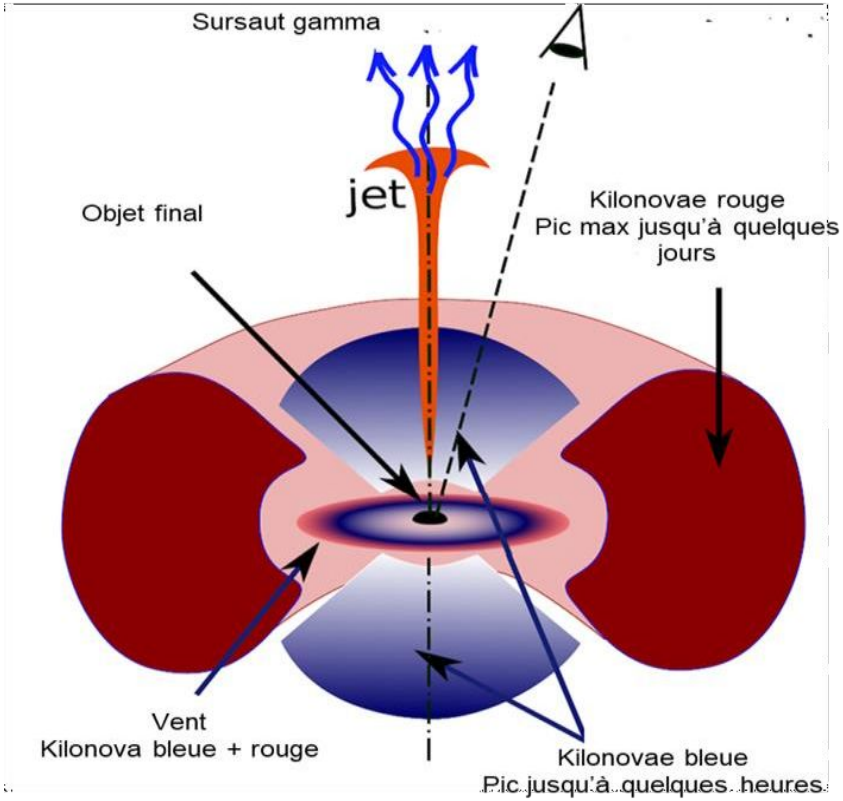
$q = m_1/m_2 = \sim 2\text{ -}3$
Heavy ejecta

$q = m_1/m_2 > 5$
no ejecta, no kilonova

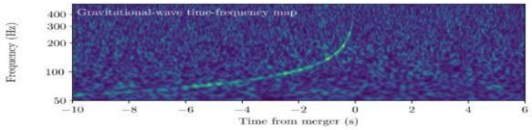
Astrophysics & Nuclear Physics

Matter behavior in extreme conditions ?

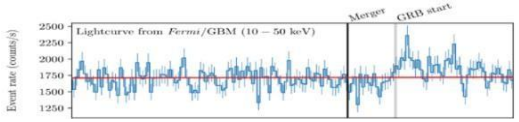
Uncertainties in the Equation of State of Utra-dense matter



GW170817

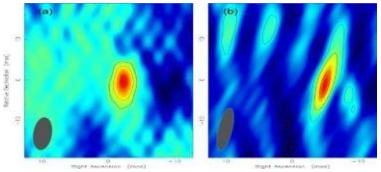


Gravitational waves



Gamma-ray Burst

Kilonova



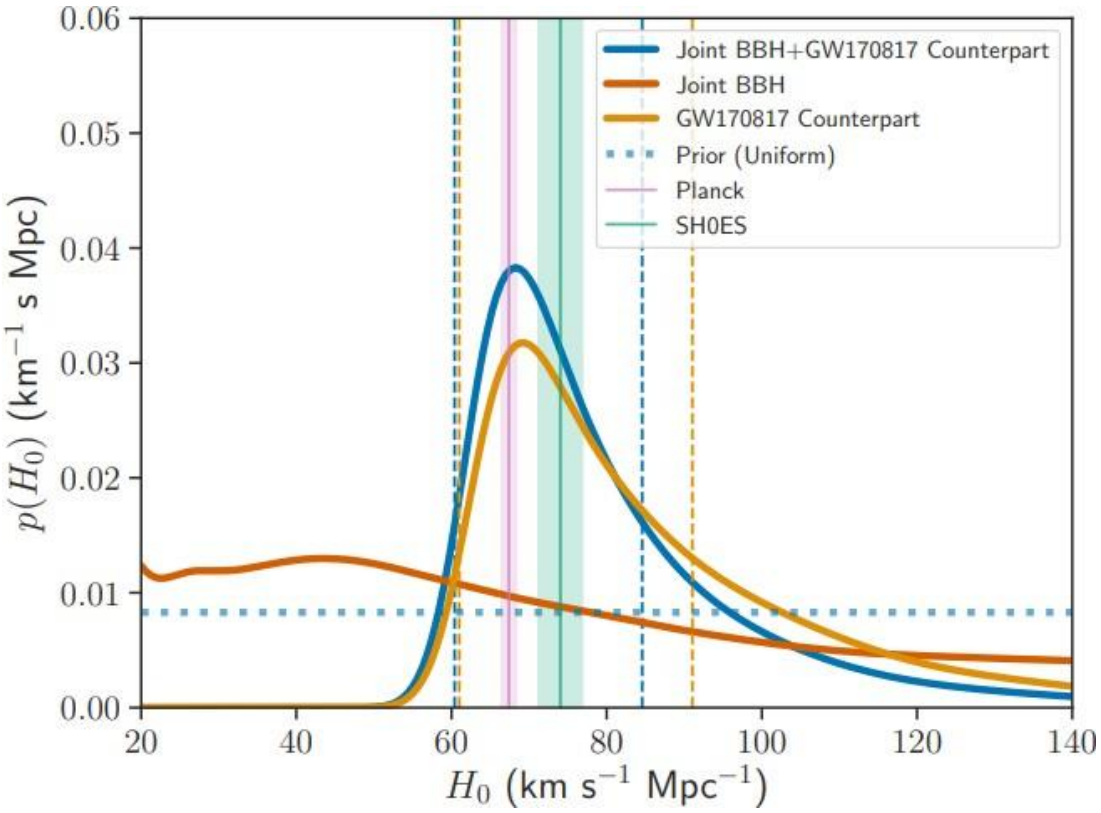
Afterglow

How are produced ejected matter in compact collision ?

Uncertainty of the central object

Mechanisms for the jet emission

Astrophysics & Cosmology
BNS – BBH as standard bright and dark sirens



A gravitational-wave measurement of the Hubble constant following the second observing run of Advanced LIGO and Virgo, O2 run, LVC

- Method 1 : GW + KN + help the degenary of the distance – inclination
- Method 2 : Statistical approchs with BBH (prob loca and catalogs)
- Method 3 : KNe as standard canddles

The GRANDMA collaboration

GW astronomy is a lot of excitement But also 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

Created in April, 2018

by IJCLAB – Observatoire de la côte d'azur

More than 70 scientists

PI.
S.Antier

37 telescopes - 26 observatories - ToO time guaranteed - 40 institutes/groups

When the sun never rises

26 observatories - ToO time guaranteed

O3b and global summary of O3: **GRANDMA Observations of Advanced LIGO's and Advanced Virgo's Third Observational Campaign** O3a and presentation of the collaboration: **The first six months of the Advanced LIGO's and Advanced Virgo's third observing run with GRANDMA**, 2020, MNRAS, 492, 3904

Scientific programs of GRANDMA and Kilonova-catcher

I. Binary neutron stars - Kilonovae - GW counterparts

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

II. Relativistic jets - Gamma-ray bursts

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

III. Vera-Rubin Fast transients

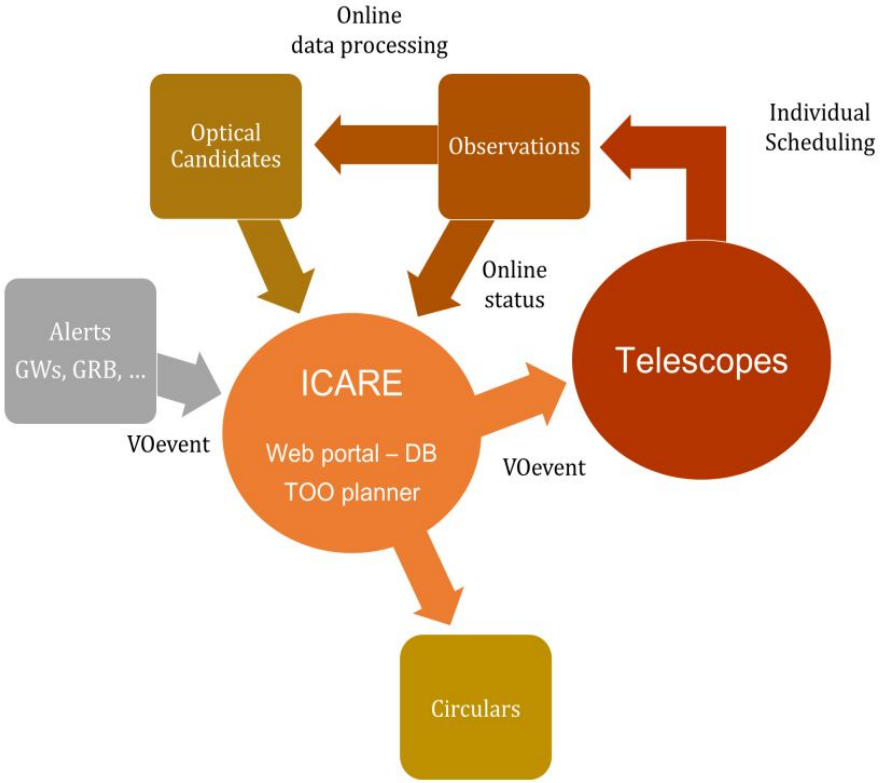
GRANDMA Observations of ZTF/Fink Transients, 2022, MNRAS, Agayeva

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

GRANDMA E-Infrastructure: ICARE

J. Peloton

https://gitlab.in2p3.fr/icare



- ✘ Communication with telescopes

Standardized specific Voevents

- ✘ Central Manager

Reception of any type of alert and sende

- ✘ Time domain Web portal

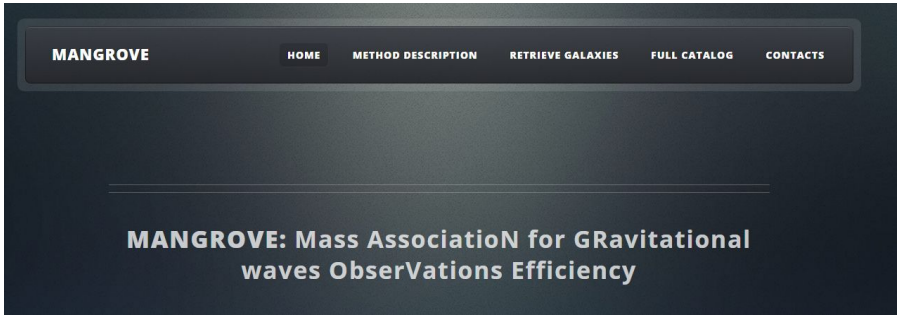
Monitor of the observations and candidates

Candidates from online pipelines

External candidates

Automatic report

- ✘ Central data base



Optimising gravitational waves follow-up using galaxies stellar mass

Ducoin et al.

Joint Scheduler

- ✘ Spatial coverage

Distribution of the tiles over the network

- ✘ Temporal resolution

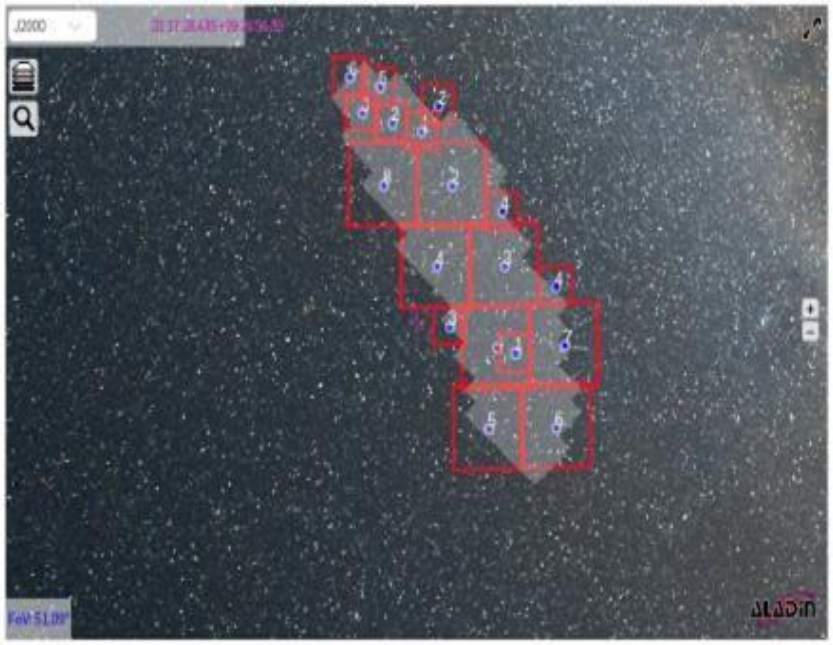
Best portion of the credible region observed several times with 1h delay minimum

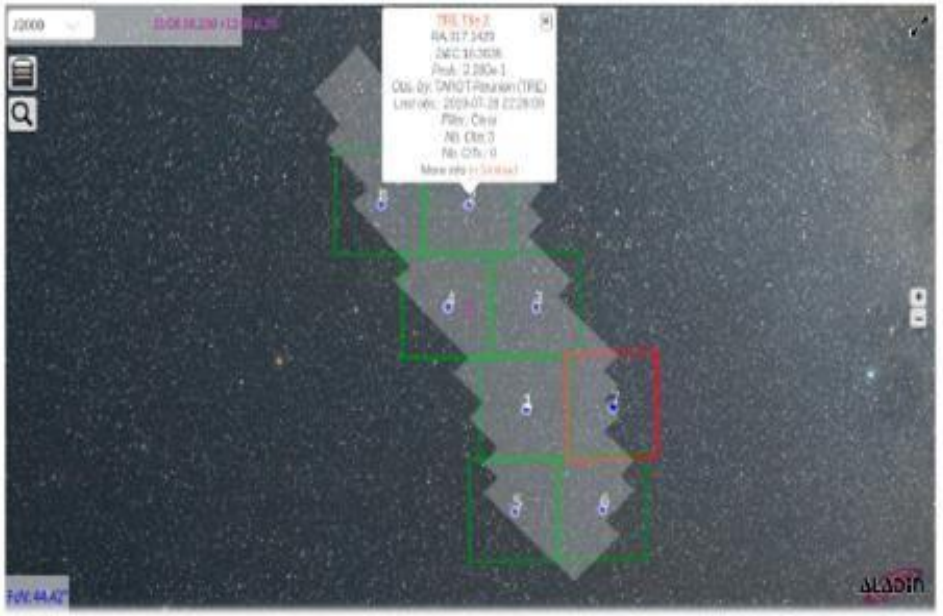
Designed for each telescope

Optimizing multitelescope observations of gravitational-wave counterparts

Michael W Coughlin ✉, Sarah Antier, David Corre, Khalid Alqassimi, Shreya Anand, Nelson Christensen, David A Coulter, Ryan J Foley, Nidhal Guessoum, Timothy M Mikulski ... Show more

Monthly Notices of the Royal Astronomical Society, Volume 489, Issue 4, November 2019, Pages 5775–5783, https://doi.org/10.1093/mnras/stz2485

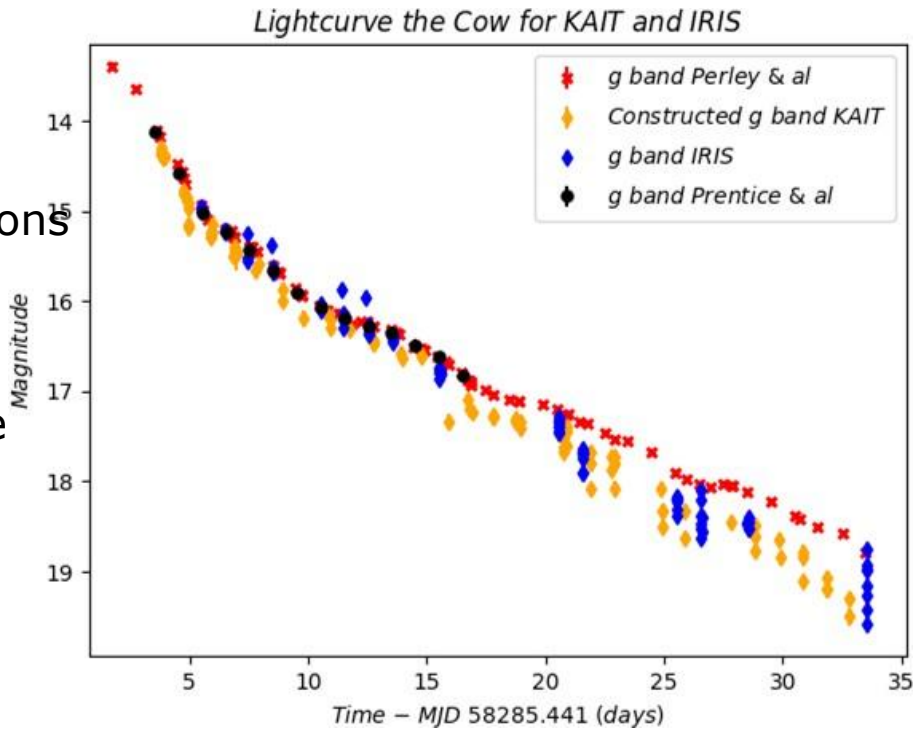




Transient characterization

P.A Duverne (IJLCLAb) et al.

- Obj. Uniformity between the observations
- Photometry pipeline able to :
  - estimate the background level
  - perform subtraction of a reference image if there is an host galaxy
  - extract the magnitude of a detected transient
- Tested on the Cow - the first transient followed by GRANDMA

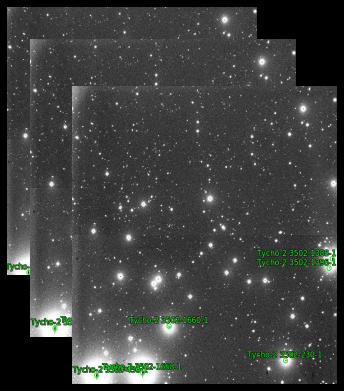


Lightcurve of the Cow for the g band of IRIS and and an equivalent of the g band for KAIT constructed by combining its B and V bands

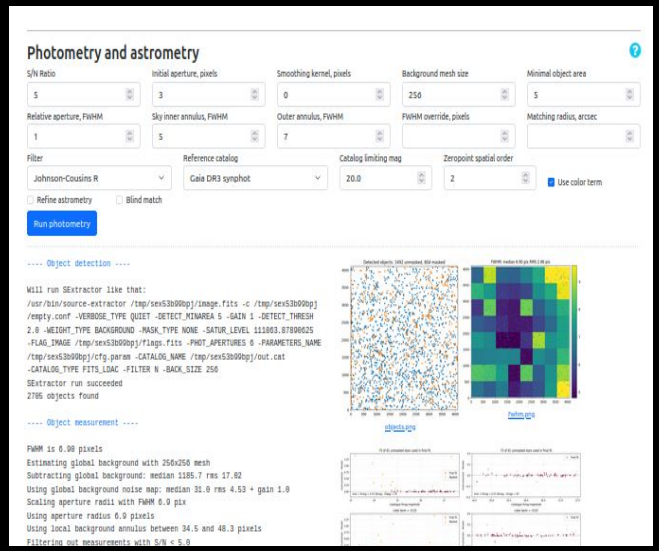
Standardisation of the optical image analysis
STDPIPE

S. Karpov (FZU)

P. Duverne(APC)

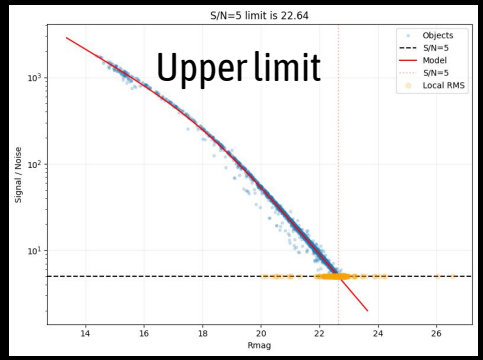


Mask



Astrometry / SCAMP
Compile images

Catalogs
Reference images
Color term ?
Aperture vs Detection



Can we agree on ?

All pre-processed images immediately public
Sloan filters for time domain
Upper limit definition
Standard exchange (via Skyportal ;))

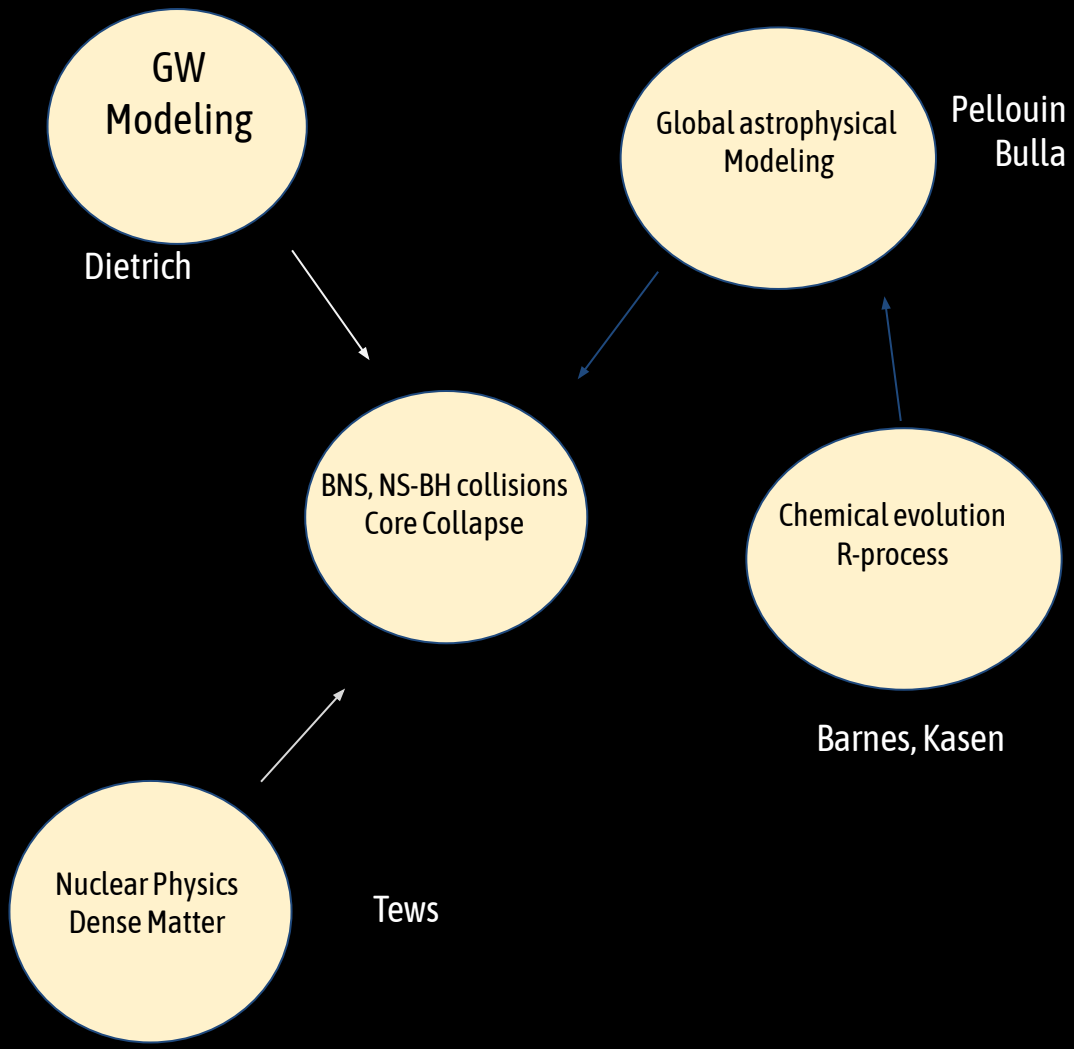
stdpipe.readthedocs.io

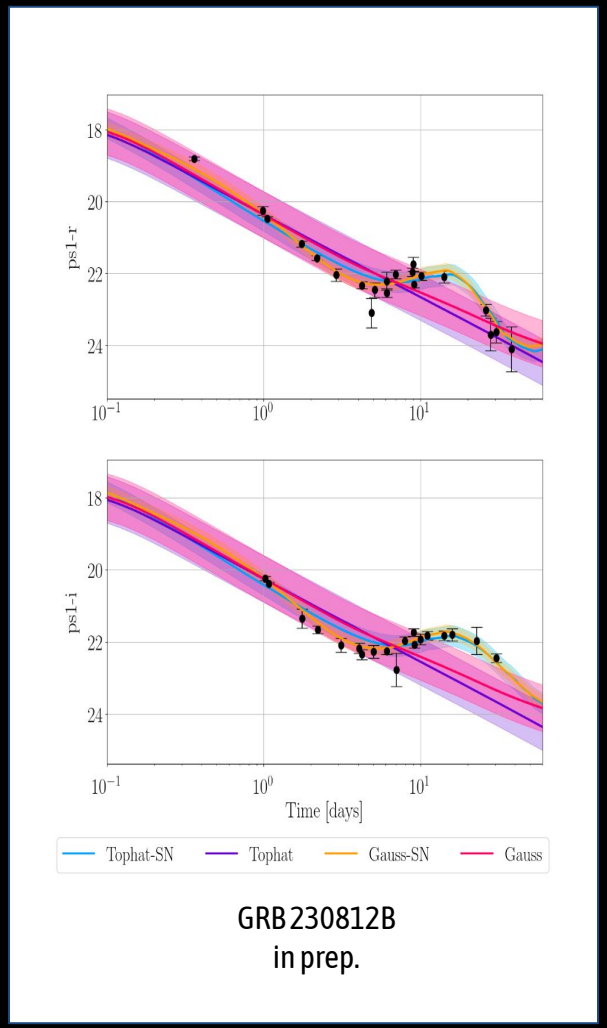
Coordination of the Bayesian inference

Nuclear Multi-messenger Astronomy (NMMA)

T. Dietrich (Potsdam)

P. Pang (Utrecht)



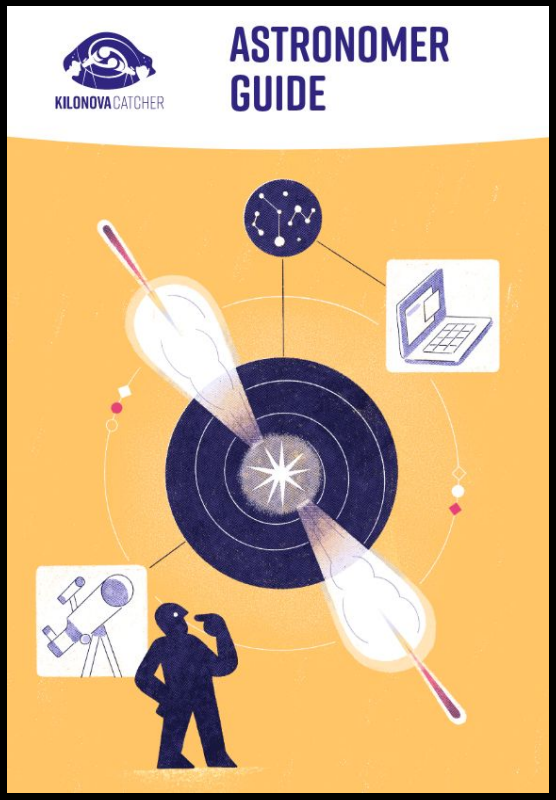


GRB 230812B
in prep.

Citizen Science

kilonovacatcher.in2p3.fr/

D. Turpin (CEA)



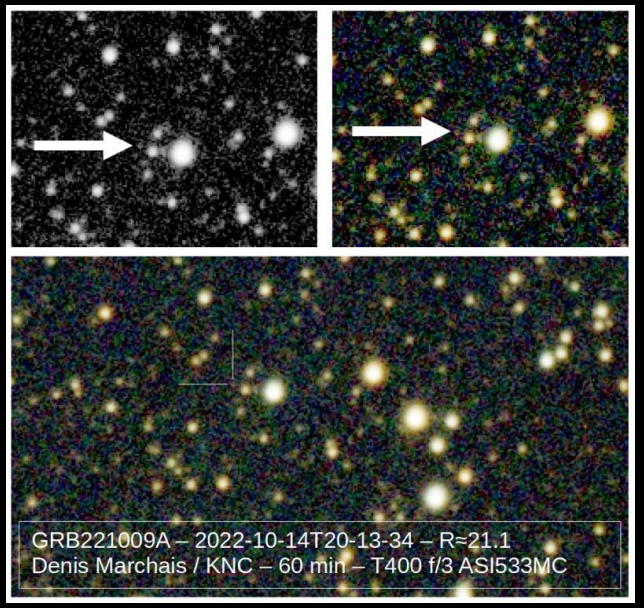
Objective:

Use Amateur astronomer observations

to support GRANDMA science

Actions:

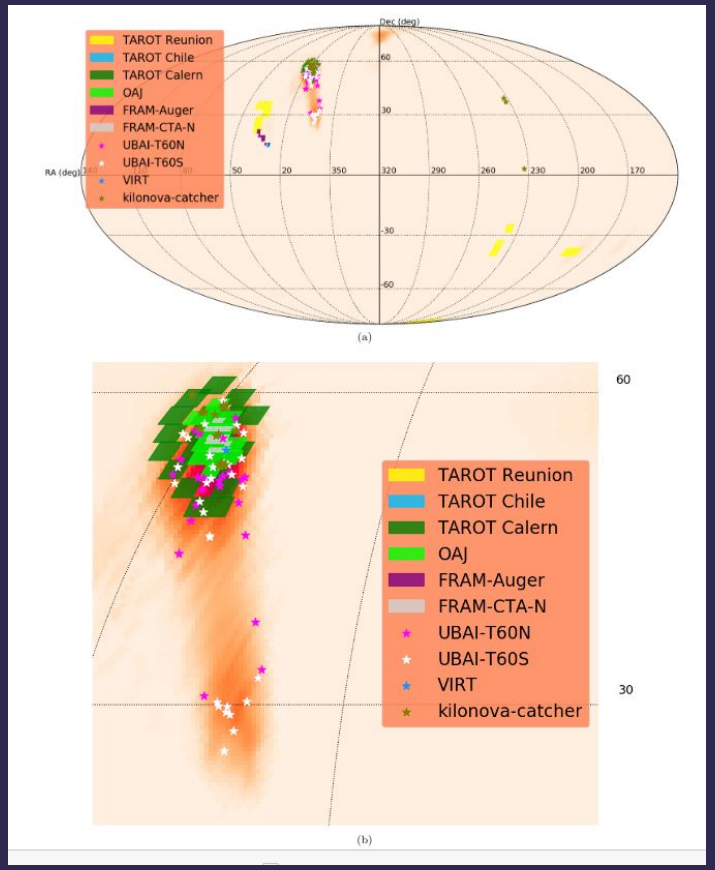
- A community of 100 members
- Access to LCO and iTel networks
- up to 21 mag apparent mag



Major results:

- Observations of dozens of host galaxy candidates during O3
- GRB231009A / GRB230812B afterglow
- ZTF classification of fast transients

I. Binary neutron stars - Kilonovae - GW counterparts
Follow-up strategies and results



THE OBSERVATION STRATEGY TO ADOPT

1. **Make successive observation sequences with a «blue»** (UBV/ug) **and a «red»** (RI/riz) **filter.** Ex: one 300s exposure with a B filter and one 300s exposure with a Rc filter
2. **Expose as long as it is needed** to detect the kilonova in a given field (the expected apparent magnitude will be communicated to you) at least in the red filter
3. **Observe several sky regions of your observation plan** by order of probability that your images contain the gravitational-wave event
4. **Send your calibrated images** (Dark and Flat correction, astrometrically solved if possible) as soon as possible using the Kilonova-Catcher web application
5. **Think about making revisits** of sky regions you previously observed hours ago or on promising transient sources flagged by GRANDMA

O4 observational camp.

LIGO/Virgo/KAGRA S230627c
About 20 fields with multiple galaxies in the field

and

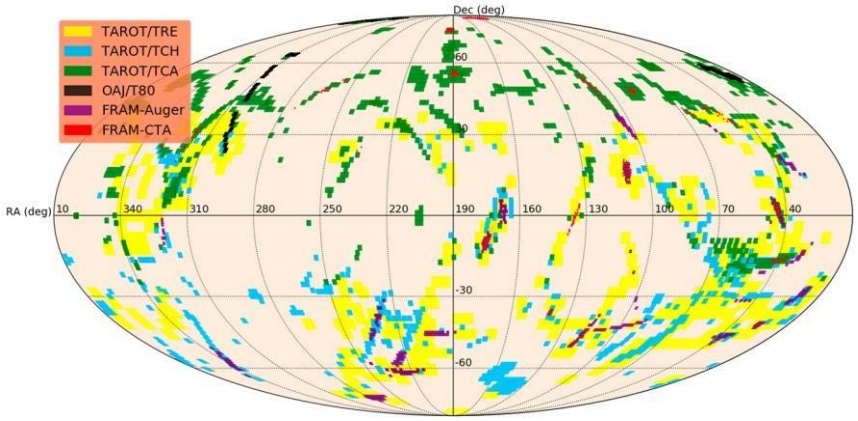
Follow-up of source counterpart-candidates (e.g GOTO23hn, ...)

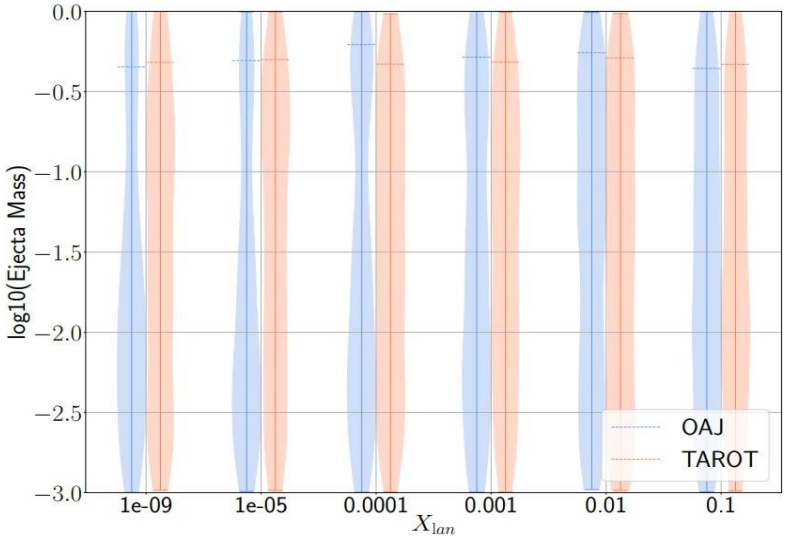
No confirmed sources

S200213t, BNS candidate but rejected in offline, Antier for GRANDMA, O3 summary, MNRAS 2020

I. Binary neutron stars - Kilonovae - GW counterparts
Follow-up strategies and results

All O3 observations done by GRANDMA wide field of view teles.





87% of O3 alerts follow-up by GRANDMA

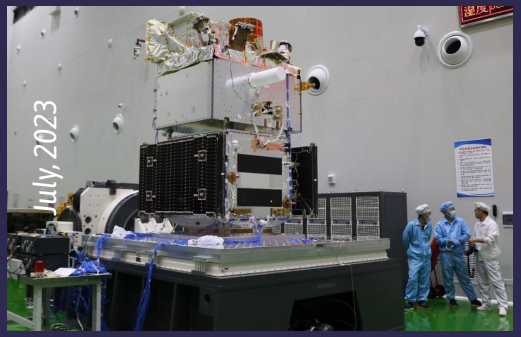
49/56 alerts for O3a

90 minutes delay between first Obs and GW trigger for 50% of the alerts
Minimal delay 15 min (5 min for LVC, 5 min GWEMOPT, 5 min telescope operation)

Coverage in average per alert 200 deg2 at 18 mag
In case of interesting candidates, we can trigger OAJ and CFHT for 100 deg2 with upper limit 22 mag

Constraints on the ejecta mass in terms of lanthanide fractions Xlan for the BNS candidate S200213t based on the OAJ and TAROT observations.

II. Relativistic jets - Gamma-ray bursts in partnership with



Kilonova-catcher will participate to GRB-SVOM follow-up (based on best effort) for the first hours

- *Find visible counterpart if not provided*
- *Follow-up of bright sources*

Versatile Satellite (Gamma, X-rays, Visible)
Launch Spring 2024
60 GRBs per year

Public alerts *within 30 s*
up to 5 ToOs per day with < 3h delay

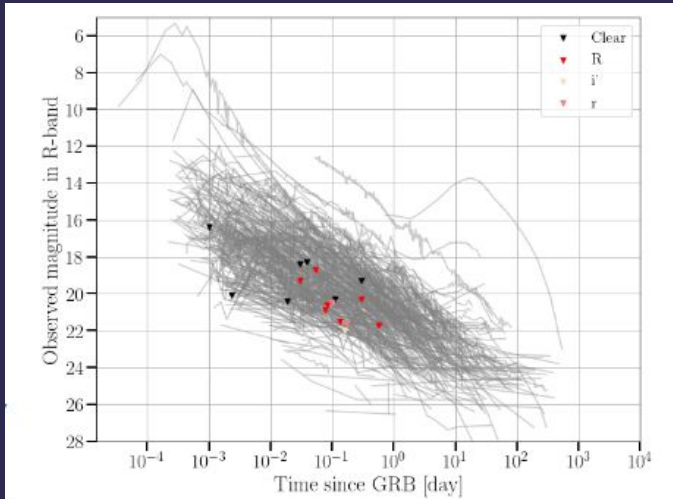
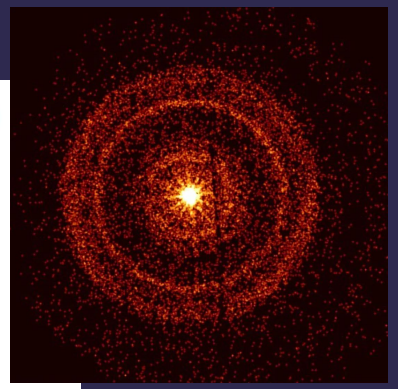


Fig. 5. Selected achieved upper limits of observation performed during the campaign (gathered in Table B.2) compared to a sample of observed afterglow lightcurve in R band.

Tosta e Melo & Ducoin for GRANDMA, A&A, 2023

Ready for O4 campaign, ,8 weeks of GRB follow-up



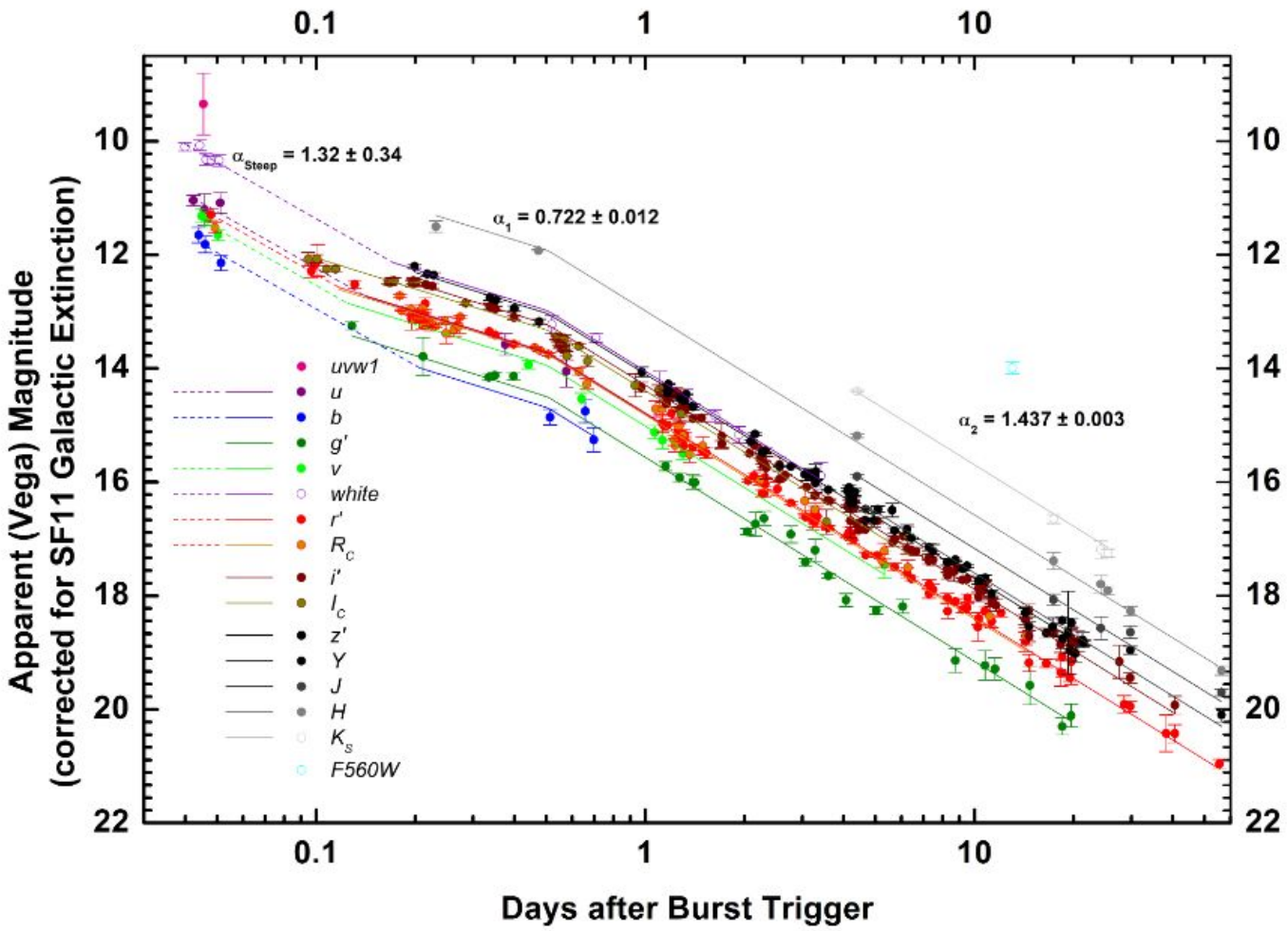


Figure 11. UVOIR light curve of GRB 221009A **(see section "Empirical light curve analysis)**. The magnitudes, expressed in the Vega system, are corrected for the SF11 galactic extinction. The break slope is at $\sim$ 0.6 d post GRB trigger time between α_1 and α_2.

KILONOVA CATCHER

II. Relativistic jets - Gamma-ray bursts - More science

- GRANDMA and HXMT Observations of GRB 221009A -- the Standard-Luminosity Afterglow of a Hyper-Luminous Gamma-Ray Burst
  A big thank you to : E. Broens, H-B. Eggenstein, M. Freeberg, R. Kneip, A. Lekic, B. Delaveau, E. Durand, S. Leonini, D. Marchais, R. Ménard, F. Romanov, M. Serrau, S. Vanaverbeke, G. Parent, E. Maris, F. Bayard, O. Aguerre and M. Richmond (hope I forgot no one...)

- Ready for O4 II: GRANDMA Observations of Swift-BAT GRBs during Spring 2022 (to be submitted very soon to MNRAS)
  A big thank you to : O. Aguerre-Chariol, E. Broens, M. Freeberg, R. Kneip, D. Marchais, A. Oksanen, A. Popowicz, M. Serrau, J-P Vignes, F. Kugel, A. Klotz

- GRANDMA and partners follow-up of GRB230812B (to be submitted this month)
  A big thank you to : M. Odeh, S. Leonini, M.Serrau, J. Nicolas, M. Freeberg, L. Rousselot

KILONOVA CATCHER

III. Vera-Rubin Fast transients in partnership with

J. Peloton (IJCLAB)

Follow-up of fast transients with GRANDMA (< 20.5 mag in r-band)
e.g orphan GRBs, Kilonova, emerging SN..

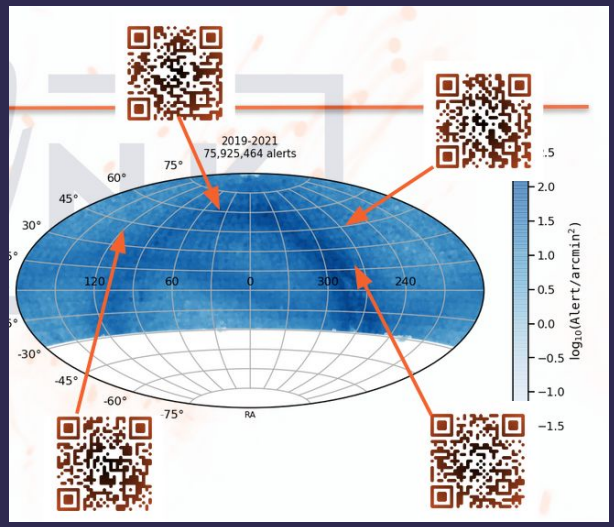
Complementary observations with Vera

Two channels following in Fink : Kilonovae and fast Transients

Open to work with others brokers ;)

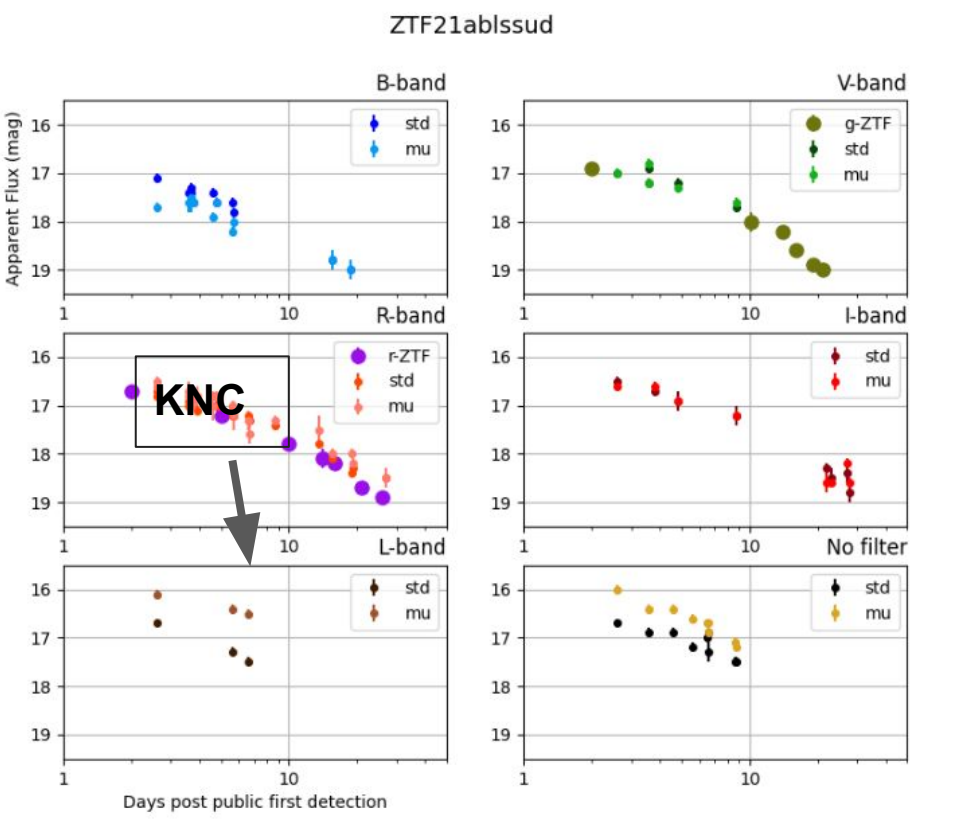
Fink is an alert broker for transient & variable science galactic to extragalactic
Users focus on the science, Fink provides tools

Since 2019: 201 million alerts received of ZTF, 136 million processed https://fink-broker.org



KILONOVA CATCHER

III. Vera-Rubin Fast transients

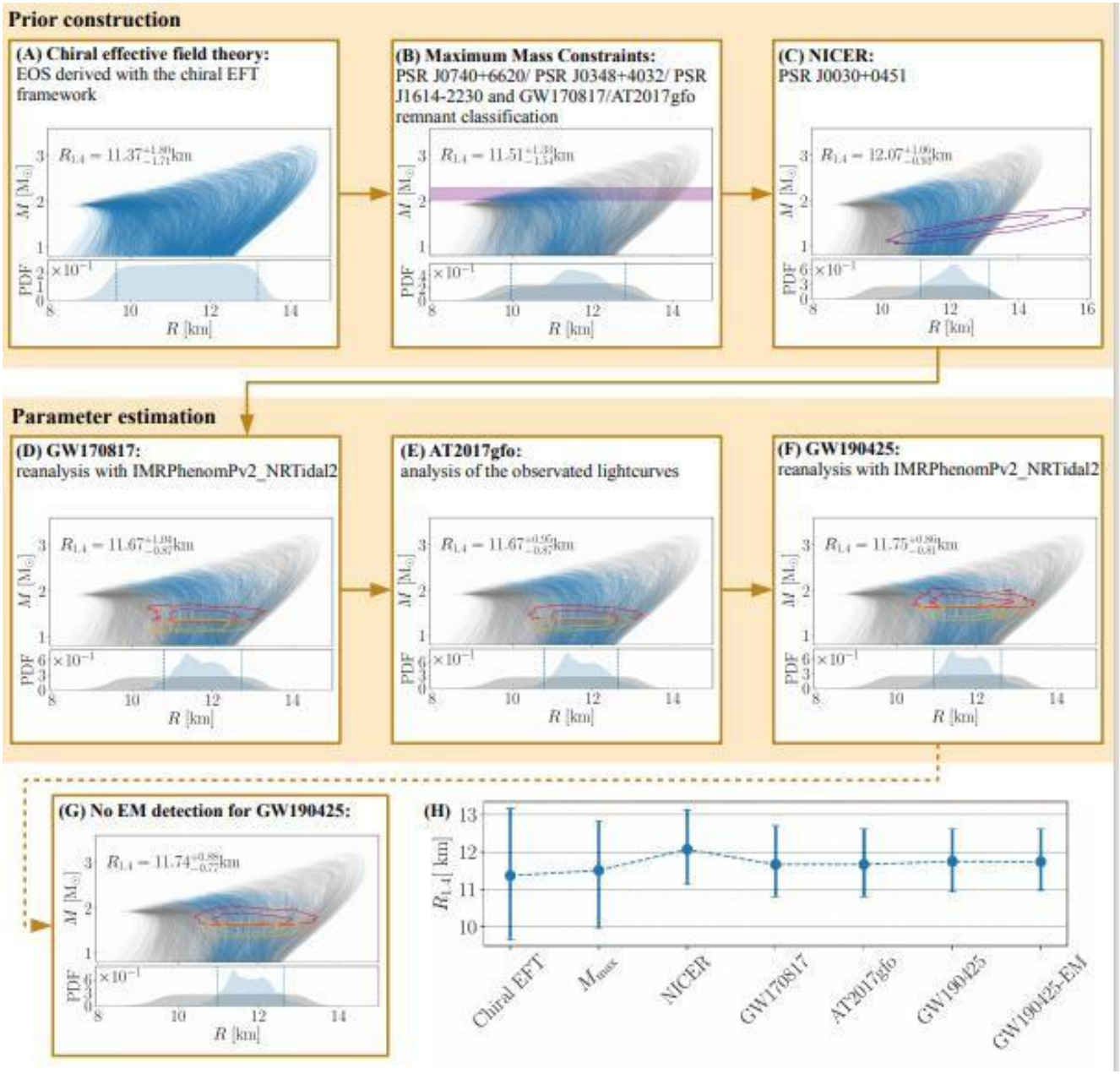


ZTF21abissud, CV

6 follow-up with amateurs over the kilonova-channel of FINK.

GRANDMA Observations of ZTF/Fink Transients during Summer 2021, Aivazyan, 2021, MNRAS

EOS of ultra-dense



Dietrich T et al., New Constraints on the Supranuclear Equation of State and the Hubble Constant from Nuclear

Thank you !

Grandma: a network to coordinate them all,
Multi-messenger astrophysics and the GRANDMA generation,
GRANDMA Observations of Advanced LIGO's and Advanced Virgo's Third Observational Campaign,
The first six months of the Advanced LIGO's and Advanced Virgo's third observing run with GRANDMA,