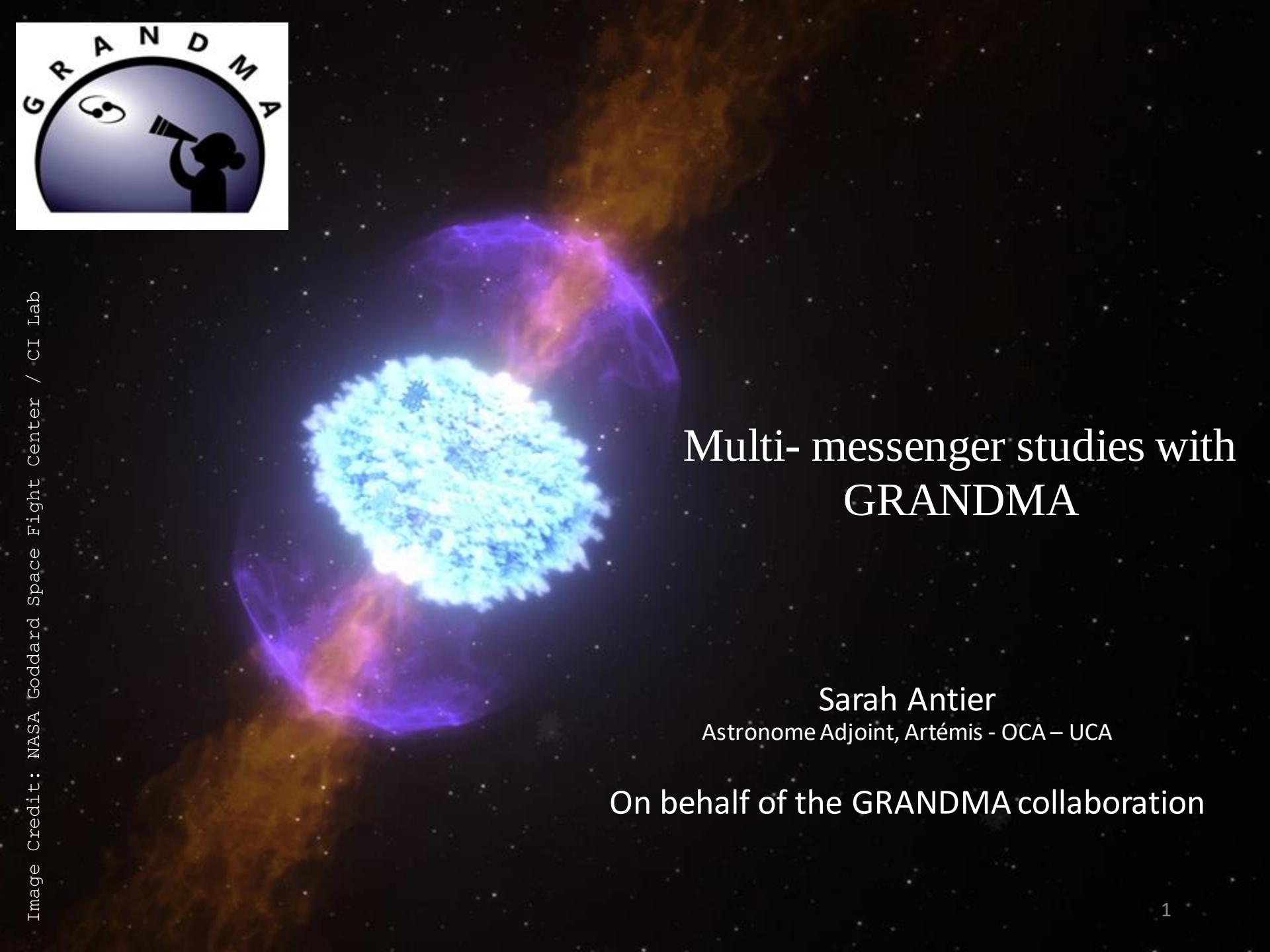


Multi- messenger studies with GRANDMA

Sarah Antier
Astronome Adjoint, Artémis - OCA – UCA

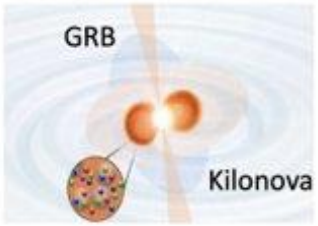
On behalf of the GRANDMA collaboration

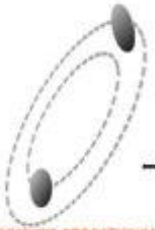
Image Credit: NASA Goddard Space Fight Center / CI Lab

Multi-Messenger Ecosystem

Global astrophysical modeling

Compact Binary Coalescences



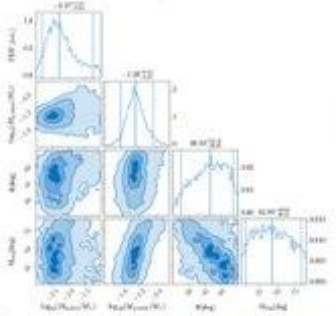


Gravitational waves

Dedicated instrumentation

Eurovision Transient Facility
Multi-wavelength facilities

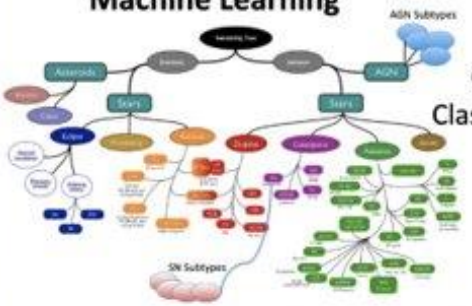
Bayesian Inference



GW-EM Joint Parameter Inference

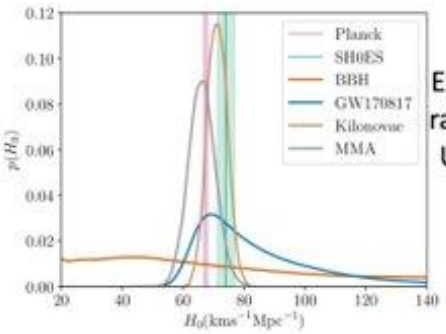
Multi-Messenger Framework

Machine Learning



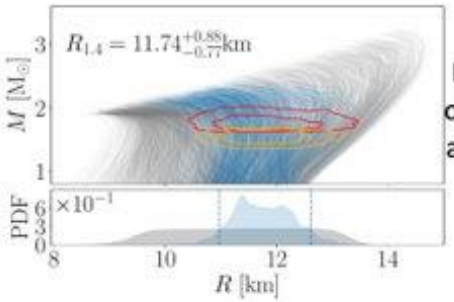
Object Classification

Cosmology



Expansion rate of the Universe

Nuclear Physics



Equation of state of a neutron star

Open data
Sharing of results

Rapid analysis tools with ML

Multi-physics expertise

GW170817

Objective

EM counterpart of GW and neutrino events
Kilonovae

Created in April, 2018

by IJCLAB – Observatoire de la côte d'azur

More than 85 scientists

PI. S.Antier (Artémis)
Co-PI. A. Klotz (IRAP)

Project manager:
T. Midavaine (Inst. Optique)

Work Packages :
- Consortium (Antier)
- Data Base (Perus)
- Follow-up (Tosta e Melo)
- Data reduction (Karpov)
- Online Infrastructure (Leroy)
- Observation plan (Coughlin)
- Citizen science (Turpin)

+30 institutes / groups

Including in Europe CNRS – Univ. Amsterdam – Univ. Louvain – Univ. Postdam – FZU – INFN - IAA

Present in

18 countries

23 observatories

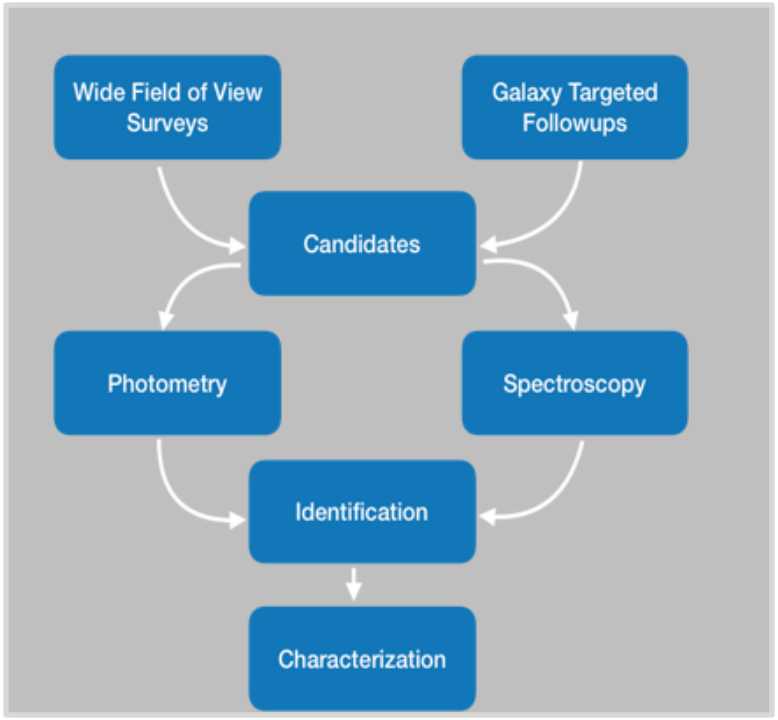
When the sun never rises

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

GRANDMA : GW program

What are the properties of cold ultra-dense matter ?
What are the properties of ejecta of GW events ?
Properties of kilonovae ? How heavy metals are produced ?
Can we use these mergers for precision cosmology?



Challenge	Solution
Short lived	Speed
Faint - Peak at 20.5 mag at 200 Mpc	Deep Observations
Rapid Color Evolution	Observation in g and r bands (adding i if possible)
Large localisation uncertainties + Many alerts to follow + Well sampled lightcurves	No duplication Coordination of Observations Choosing alerts

Identify and characterize GRBs afterglow and kilonovae associated to GW events

Network and challenges

Required a network of telescopes

--> common observation strategy
--> generic data reduction tools (spectro + photometry)
--> web central and data base

+ expertise on transient follow-up (Postigo, Klotz, Stargate, TAROT)
+ Filtering in collaboration with FINK

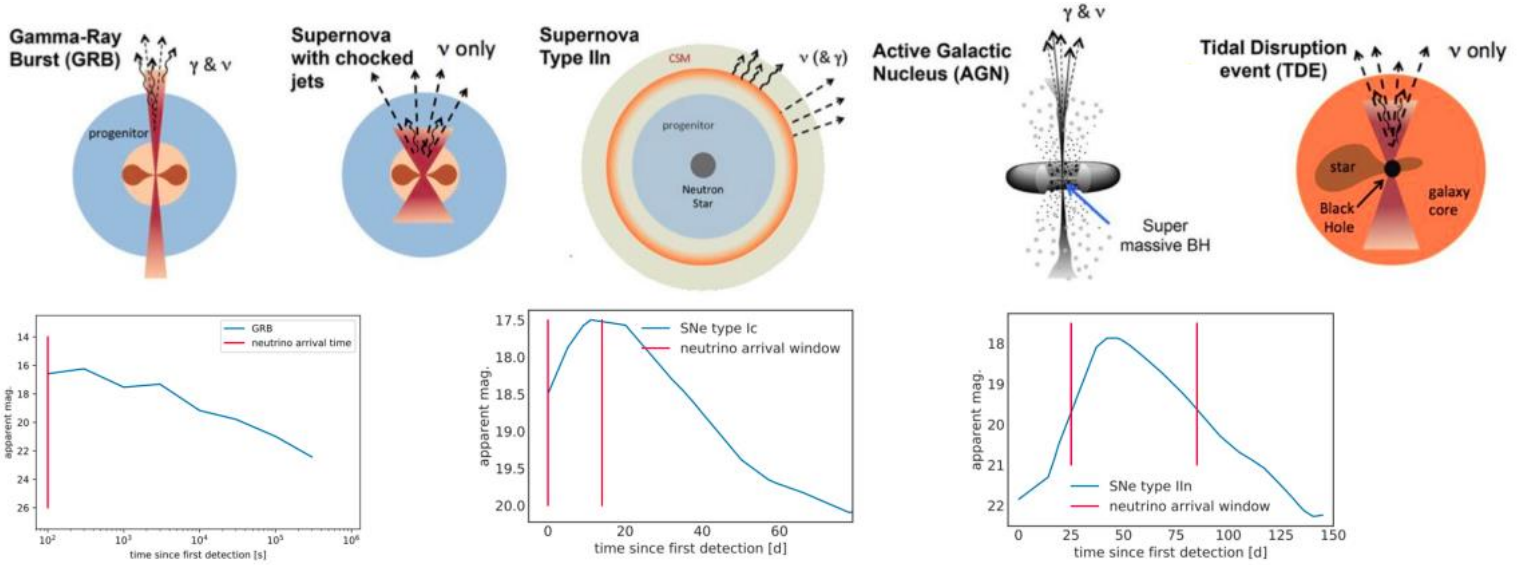
+ expertise on ejectae (GRB with SVOM France Daigne, Basa, Kilonovae with GRANDMA)

+ expertise on GW physics (Virgo members)
+ GW pipelines (GstLAL, Caudill) + **LVK low latency** (Antier)

+ expertise on nuclear physics (Tews, Khan)

GRANDMA with HEN (resp. Pradier)

What are the origin of astrophysical neutrinos ?



Short duration
GRB-like

Medium duration
SNIc, Kilonova

Long duration
SNIIn, AGN, TDE

GRANDMA follow-up strategy at early and longer term (within years)

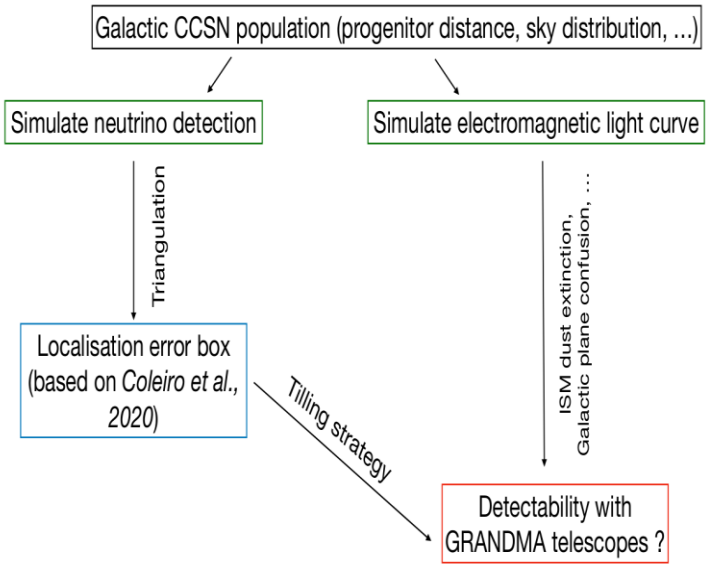
~2-3 neutrinos / month, only 30% followed by e.g. ZTF
80% by Master for counterpart identification
Medium-Long term followup needed for counterpart(s) classification+characterization

→ Require expertise on KM3Net/Ice-cube alerts (Dornic, De Wasseige) and on neutrino physics together with follow-up expertise developed for GW follow-up

GRANDMA with SNEWs (resp. Coleiro)

Mecanisms explosion of the core-collapse supernovae
Equation of state of the ultra-dense matter
Propertiesnature of the remanent (neutron star vs black hole), fundamental
Properties of neutrinos (mass hierarchy)

Work in progress (APC, Purdue University)
--> build the framework to receive SNEWS alerts and trigger follow-ups
--> Optimize the followup strategy to maximize the counterpart detection probability/rapidity



⇒Run Monte-Carlo simulations to optimize the follow-up strategy

Questions

How to prioritize observations among network ? Amateurs vs professionals ?

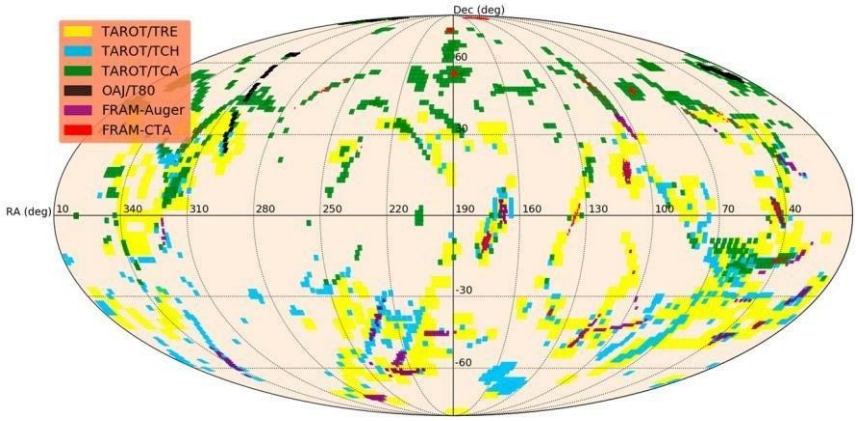
Distribution of massive stars + Galactic plane as a prior to constrain the source localization

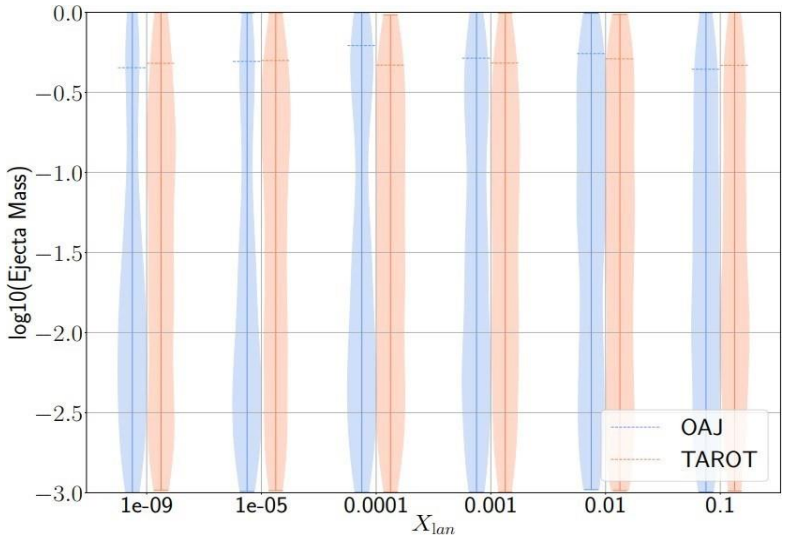
How to maximize the chance of detecting the shock breakout ?

Galactic CCSN may saturate GRANDMA CCD detectors. How to deal with this possible issue ?

GRANDMA GW O3 observations

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)

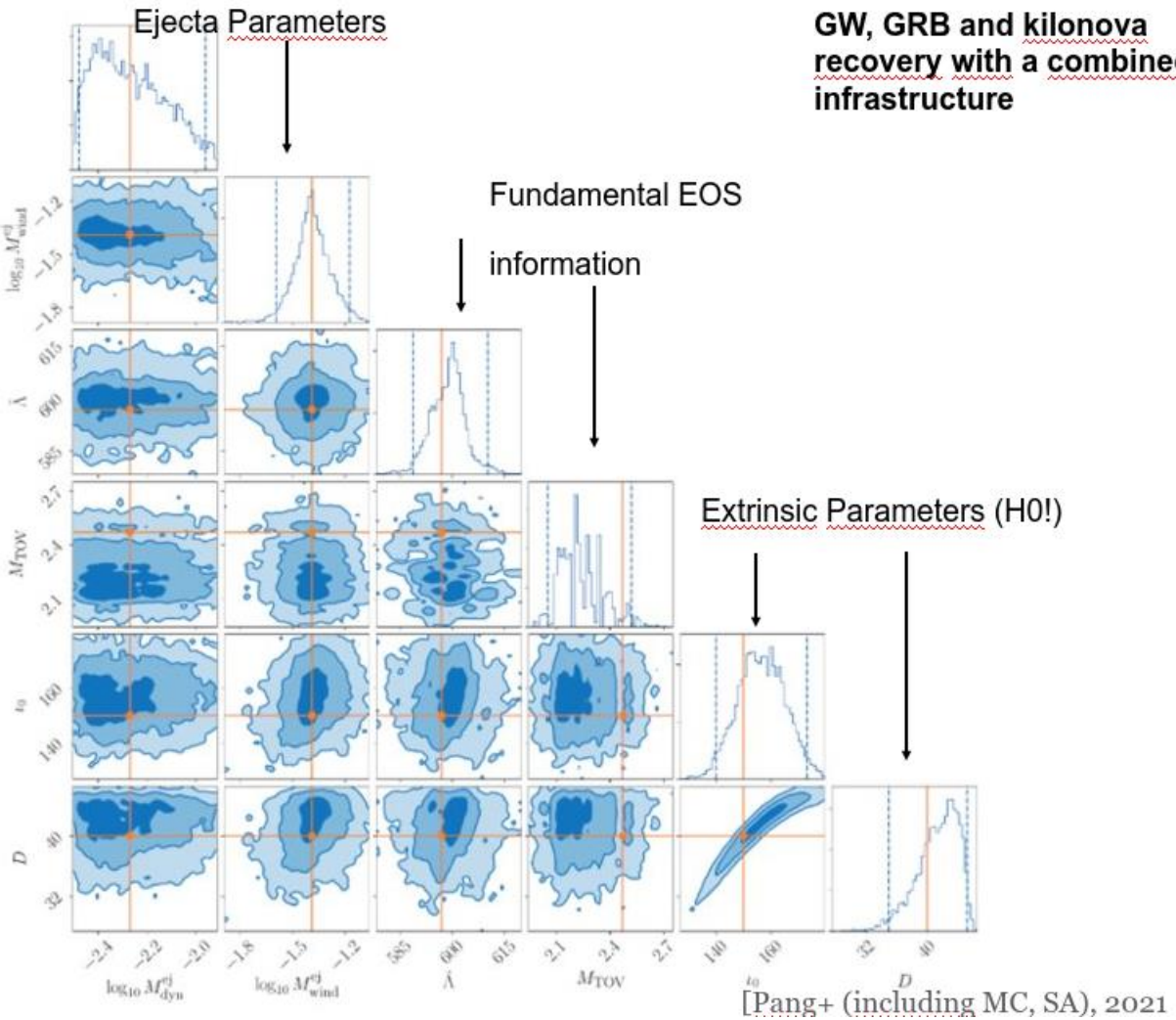
Coverage in average per alert 200 deg2 at 18 mag

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.

NMMA: Fully Bayesian Joint-Inference Pipeline GW events

Resp. T. Dietrich (Postdam) with P. Pang, G. Raajimakers (Amsterdam, Nikhef)

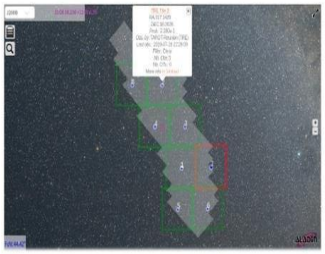


[Pang+ (including MC, SA), 2021

Raaijmakers, G., 2021

Analysis tools for the MM community
Initiated / Supported by GRANDMA

Multi-plan observations



Ingest Vo – Kafka streams

Generic photometric data reduction
- MUPHOTEN
- STDPIPE

MM Web platform
- ICARE
- Skyportal (see Coughlin)

Aladin react develop.

API with LSST brokers

Kilonova filtering for optical surveys

Galaxy catalogs

Data Science Tools
CS+GRANDMA
Treasure Map
GWSky
Aladin
Visualization Tools
ANTARES
ALeRCE
Brokers
FINK
Lasair
MARS
sentinel
gwemopt
Multi Telescope Scheduling
tegloon
M4OPT
GROWTH
iCARE
Marshals
SkyPortal
MANGROVE
HOGWARTS
Galaxy Catalogs
NED
Transient Filtering
sherlock
Kowalski
AMPEL

Funded by individual initiatives but no funding from European programs

All our tools are public used by GRANDMA and other collaborations

GRANDMA Citizen science: Kilonova-catcher

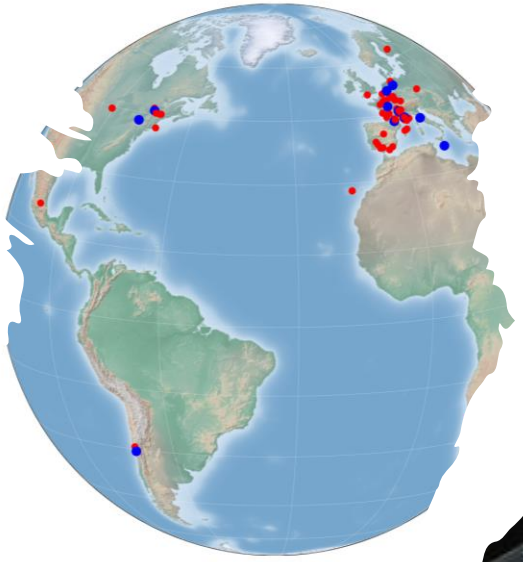
http://kilonovacatcher.in2p3.fr/ Université de Paris

Resp. D. Turpin (CEA)

- More than 130 participants telescope s from 15 cm - 60 cm

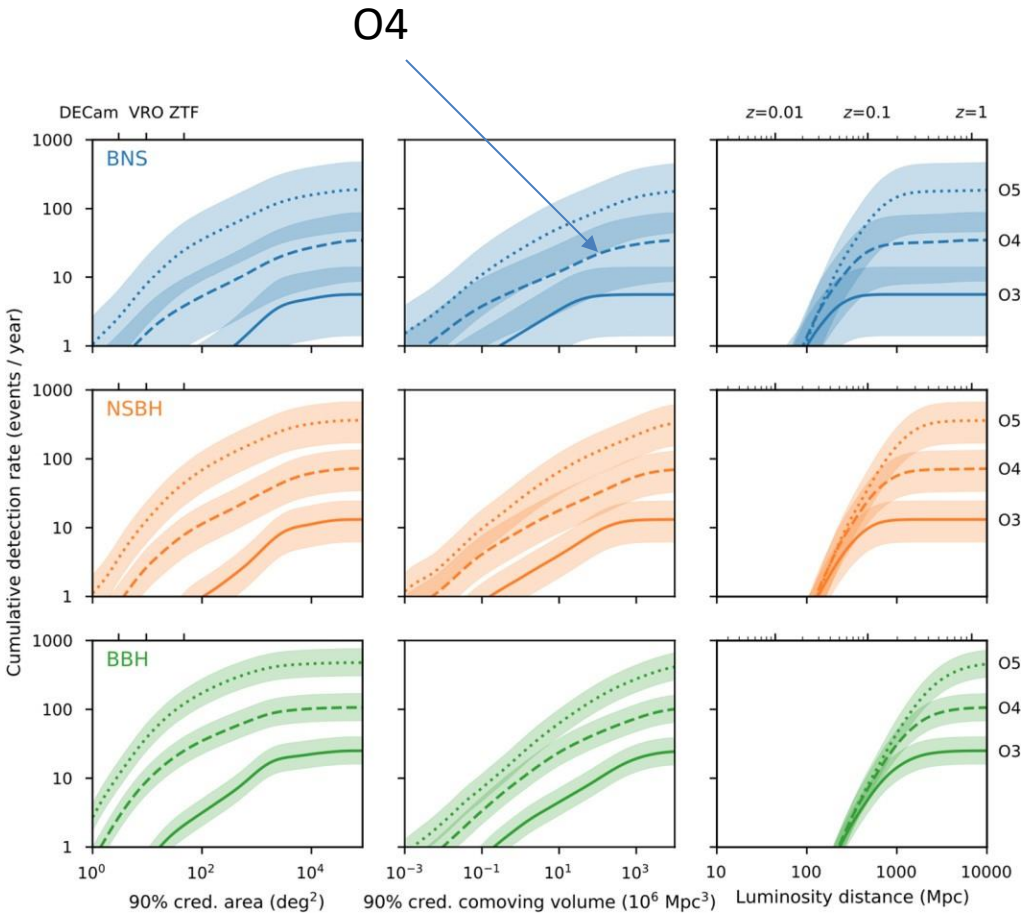
- Observations made for NS-BH and BNS candidates 100 galaxies observed

- Observations on 12 Fink-KN-SN candidates
--> 30 amateurs participated in the ReadyforO4 campaign (April – September 2021) - 1000 obs.

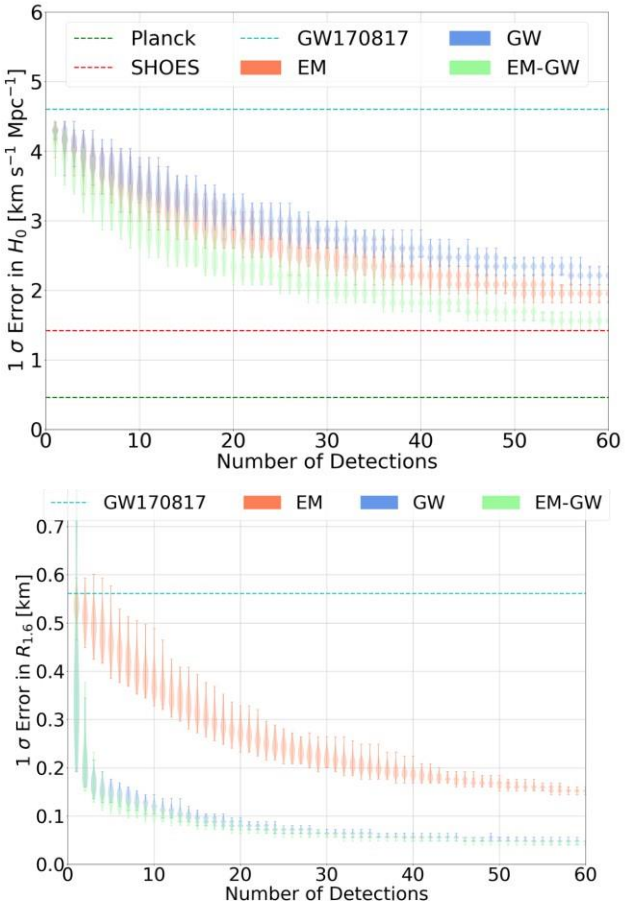


Participation to ZTF/LSST - LIGO-Virgo – SNEWs – KM3NET – IceCube and SVOM alerts

O4 observational campaign: Rate and Prospects



Petrov, Singer, et al., APJ 2022: Updated observing scenarios based on O3



Coughlin, SA et al., in preparation: Prospects for H0 and EOS based on updates

Thank you !

Grandma: a network to coordinate them all,
Multi-messenger astrophysics and the GRANDMAgeneration,
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,