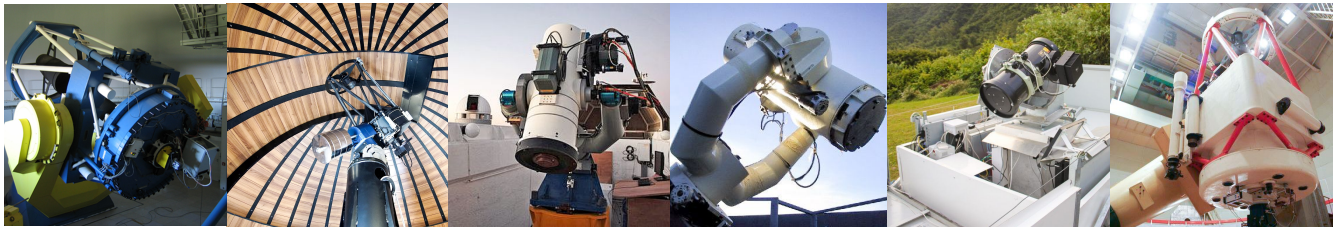
Multi-Messenger Studies with GRANDMA

P-A Duverne on the behalf of the GRANDMA collaboration



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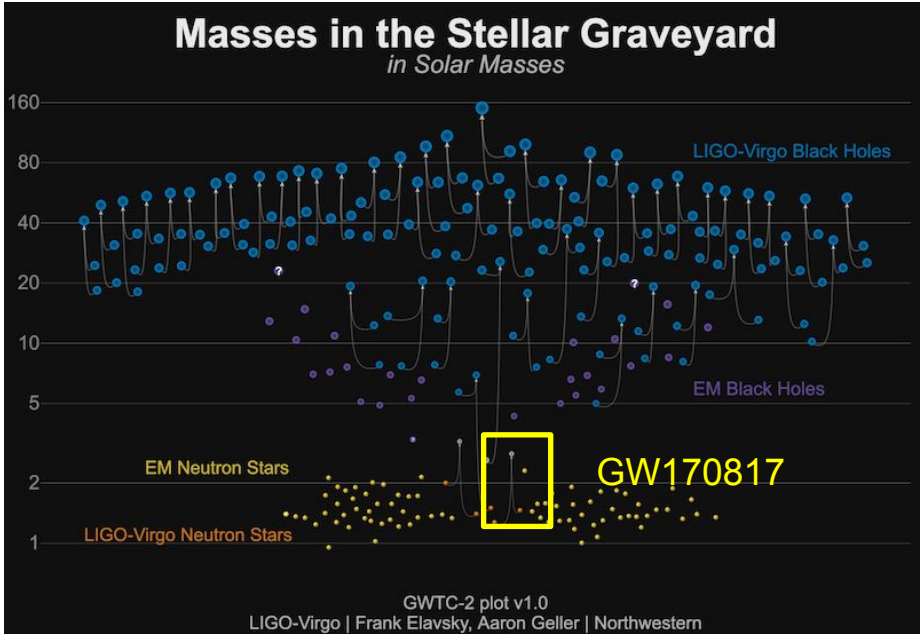
Multi-Messenger Astronomy



Gravitational waves

Initial system
Distance
Localisation > 10 deg^2

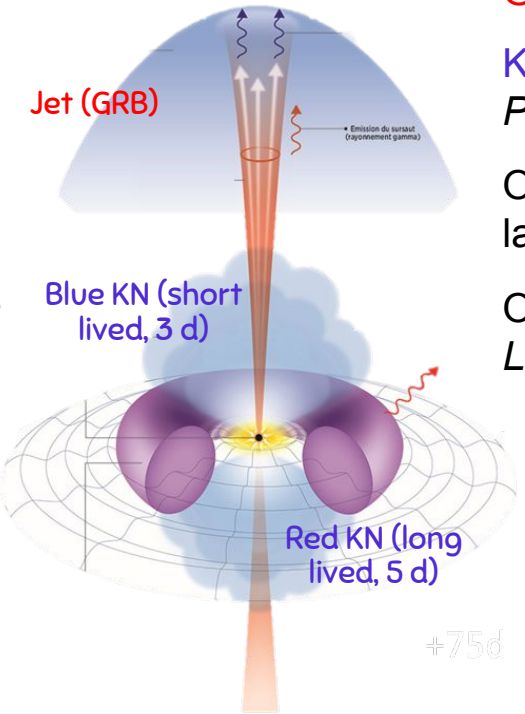
vs

EM counterpart

Ejected matter
Localisation ~ arcmin
Environment

Run O1,O2 and O3 : 50 new compact objects collisions
2 confirmed Binary neutron stars - **1 event with EM counterpart**

EM counterpart to GW events



Cr: La Recherche/Bruno Bourgeois

GRB : Powered by on-axis jet

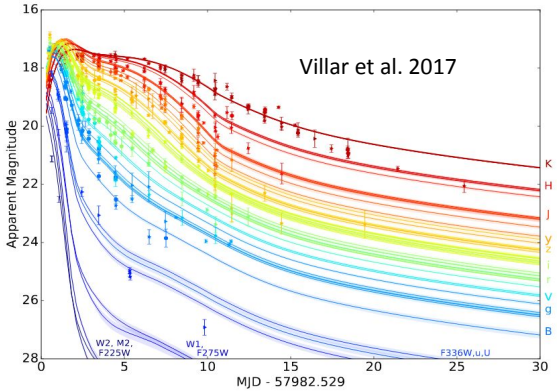
Kilonova (KN): Optical and NIR transient
Powered by r-process in neutron rich environment

Observed properties differed from mass ratio, equation of state of NS, lanthanide fraction, nature of the post-merger

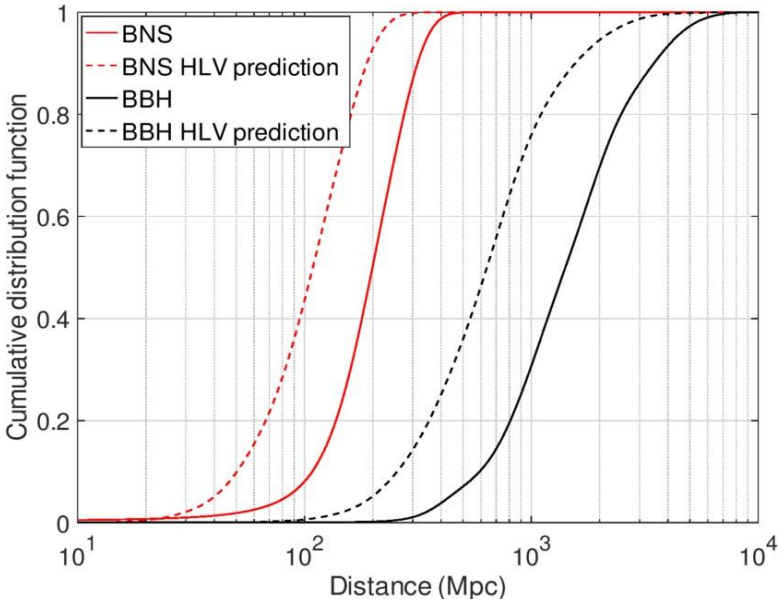
Only one clear confirmed event (AT2017gfo)
Less than 10 candidates found by Tanvir et al., Troja et al.

AT2017gfo/GW170817 properties

- 40 Mpc
- Localized in NGC4993
- Identified by LVK in 39 deg2
- *~10 Galaxy compatible*
- Absolute 16 mag in K-band mag
- Fading in 0.5 mag per day



Collecting MM sample of GW events, a real challenge



GRANDMA collab., MNRAS, 2020

Predicted rates for BNS and BHNS mergers based on O3 GW constraints:

- **1 (+10 -1)** per year in the 200 Mpc
- **10 (+52 -10)** in the 400 Mpc

GW170817 at 40 Mpc -> 1 event every ~ 12 years

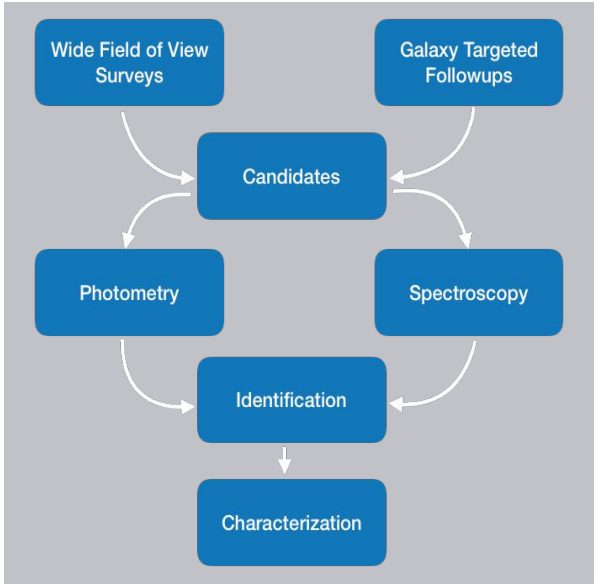
Up to **1 GW alert per day** in O4 (HLV prediction)

KN **peak magnitude > 20.5** mag for a BNS merger within **200 Mpc**

GRB: < 1 GW + GRB per year observable by Fermi

Identify and characterize KNe associated to GW events

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



Need a **Network** of **Telescopes** and **People** (EM & GW)

Global Rapid Advanced Network Devoted to Multi-messenger Addicts

Created in 2018, by LAL – OCA

PI. S. Antier

Already a large Community

29 groups - 14 countries

75 scientists

CNRS/- APC - IAP - IJClab - OCA - IRAP – LAM - IPHC

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

Upgrades of instruments in sites (ex: Eurovision Transient Facility)

GRANDMA science program

GRANDMA is involved in several science projects :

GW Science program

- […]

Neutrino

- High Energy Neutrino alerts
- SNEWS alerts – SNe neutrinos

Orphan KNe

- Alerts by ZTF
- Prepare the LSST era

GW science program

Observations

Maximal coverage of the GW events

Maximal follow-up of events

Early and long term characterization

Kilonovae/GRB modeling

Three KN models

GRB modeling

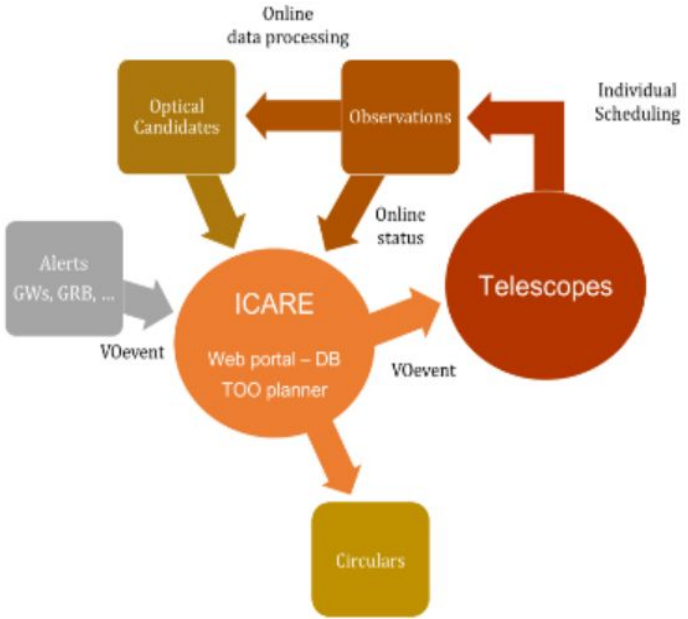
Binary Neutron star characterization

Ejecta mass

Equation of State of NS

Exotic physics

GRANDMA orchestration



6 FTE a year to run the project

All our tools are public

ICARE *Central database of GRANDMA*
In collab. GROWTH, OzGRAV, gitlab.in2p3.fr/icare/icare

MANGROVE *Galaxie catalogs* using stellar mass
Ducoin et al., 2020, MNRAS, 492, 4768

GWEMOPT : *The observation scheduler*
Coughlin, in collab. GROWTH, github.com/mcoughlin/gwemopt

STDPIPE, GMADET : *Detection of transients*
Karpov, Corre gitlab.in2p3.fr/icare/stdpipe

Astrorapid *: Transient Classifier*
Stachie et al 2020, MNRAS, 497, 1320

MUPHOTEN : *Transient photometric characterisation*
Duverne et al. - in preparation

O3 with GRANDMA

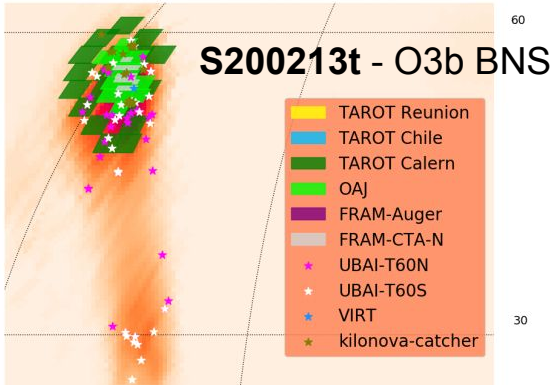
49/56 O3 alerts were followed by GRANDMA
~ 10 alerts followed by other optical groups

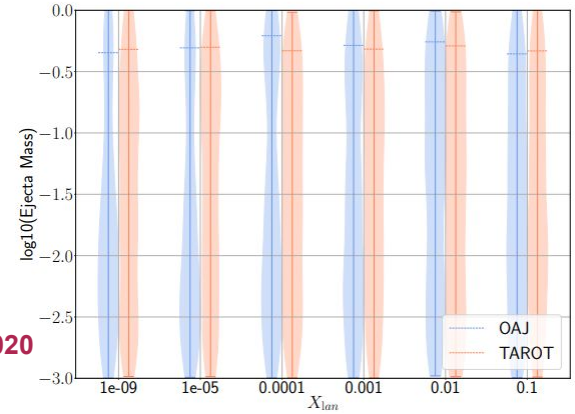
15 min for the first observation after the GW trigger
1.5 h delay for 50% of alerts

~ **200 deg^2** covered in each alert at 18 mag
11 alerts covered above 90% c.r

ToO observations with 2-m spectro in China, CFHT
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**

My contribution: MUPHOTEN

SN2018cow – A Fast Blue Optical Transient

Data from GRANDMA telescopes : IRiS, KAIT, TCH

Data from collaborators: KEPD, LT (publicly available data)

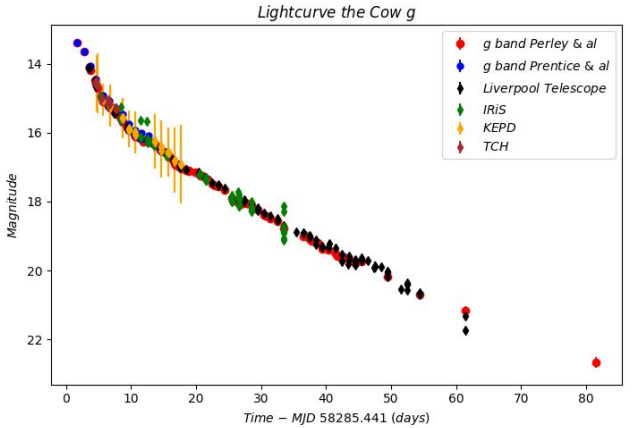
Analysis with **M**Ulti-band **PHO**tometry Tool for **TE**lescope **N**etwork

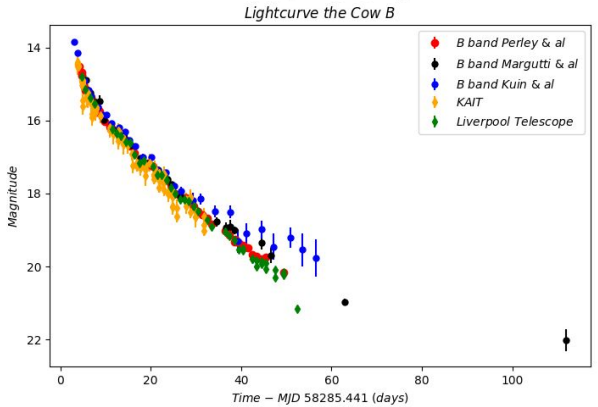
630 images analysed in ~2h

Provides :

- Background Estimation
- Photometry
- Host galaxy Subtraction
- Vetoes for poor quality images

Results consistent with Perley et al., 2018, Margutti et al., Kuin et al. and Prentice et al.





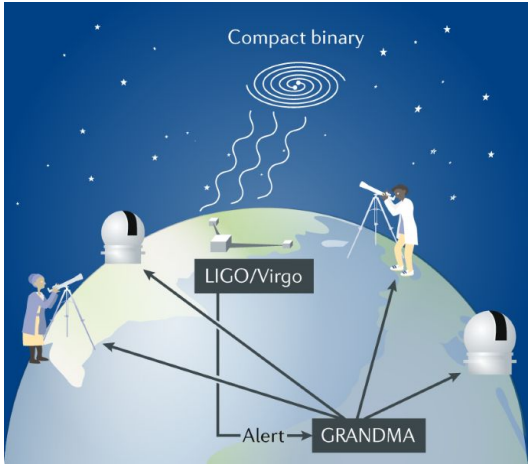
The future MM era is bright !

In the PAST

O1-O3 campaign

Astrophysics
Nuclear physics
General Relativity

In the future: O4 and beyond



Kilonova will have a **major role** in Multi-Messenger Astronomy
Observations extremely challenging

We propose **GRANDMA**, as a solution for GW events observations,

as a bond between Physicists and Astrophysicists communities

Come and join us!

Grandma@lal.in2p3.fr
Seminars visible at GRANDMA-youtube channel

BACKUP

Slides

Some research topics linked to KNe

1. **Cosmology**
   - **Independent measure of H_0** (*Dietrich et al.)*
2. **Nuclear Astrophysics**
   - **r-Process** : lanthanide and actinide synthesis (*Barnes et al., Dvorkin et al.)*
   - **Dense matter EOS of NS** : well MM sample + numerical simulation (*Essick et al.)*
3. **High Energy Astrophysics**
   - **GRB population associated to GW** : GW observation favors off-axis jet
   - **Stellar population** : Galaxy morphology
4. **GW Sources**
   - **GW progenitor** : KN color evolution to discriminate NS-BH
   - **Post-merger object** : Discriminate between NS & BH remnant