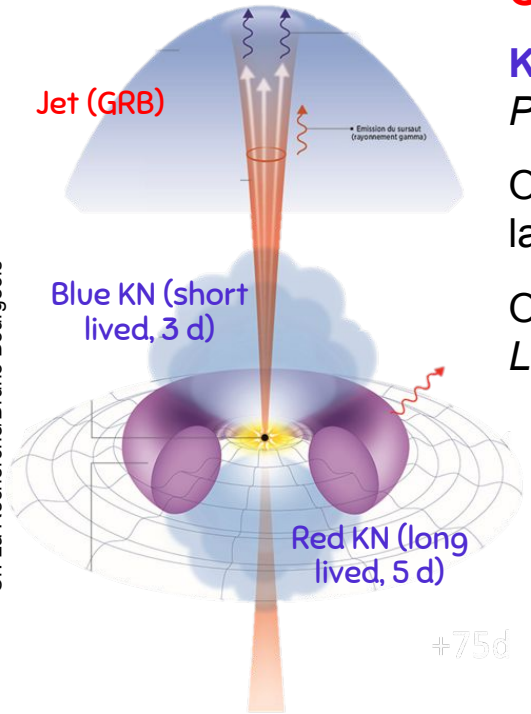
Follow-up of ZTF-FINK alerts with GRANDMA and Kilonova-Catcher

P-A Duverne on behalf of the GRANDMA and FINK collaborations

duverne@ijclab.in2p3.fr

Kilonovae



Cr: La Recherche/Bruno Bourgeois

GRB : Powered by on-axis jet

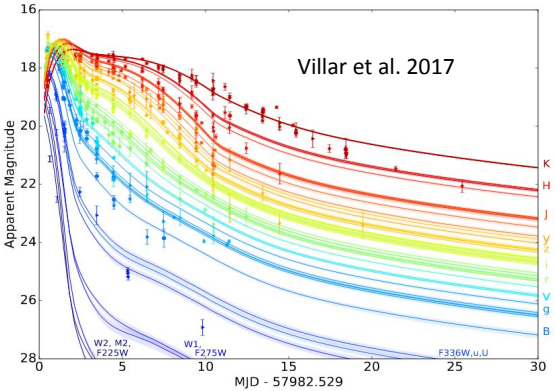
Kilonova (KN): Optical and NIR transient
Powered by r-process in neutron rich environment

Observed properties change with 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 SSS in a 39 deg2 LIGO skymap
- *~10 Galaxies compatible*
- Absolute -16 mag in K-band mag
- Fading in 0.5 mag per day



Science opportunities

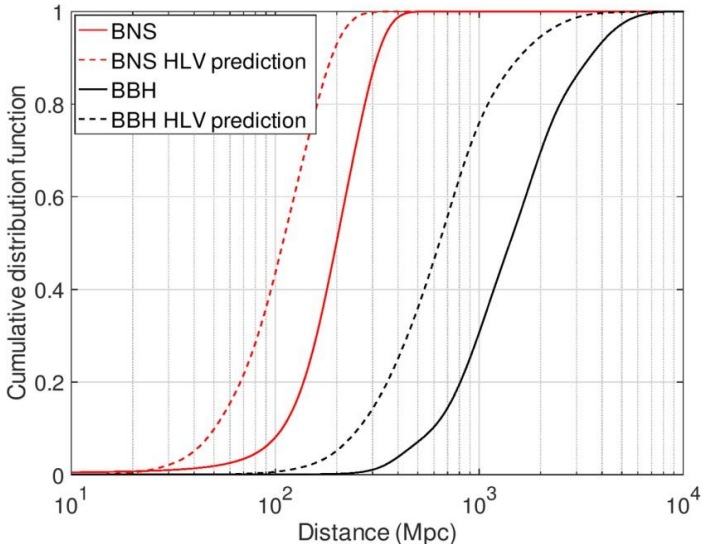
1. **Cosmology**
   - **Independent measure of H_0** (*Coughlin et al.)*

2. **Nuclear Astrophysics**
   - **r-Process** : lanthanide and actinide synthesis (*Barnes et al., Dvorkin et al.)*
   - **Dense matter:** EOS of NS (*Essick et al.)*

3. **Physics of the ejecta (post-merger)**
   - **GRB population associated to Kilonovae** : total energie,
   - **Stellar population** : Galaxy morphology of binary neutron stars mergers

Kilonovae Challenges

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



GRANDMA collab., MNRAS, 2020

- Need a **Network** of **Telescopes** and **People**
- Using only GW triggers is not enough -> **Orphan KN** discovery are necessary

Orphan Kilonovae

- With public data from optical surveys
- Increase the kilonova sample with a larger diversity
- Refine the intrinsic population rate

Depending on the model used and the cadence chosen by LSST :

- O(10) - O(100) KNe expected during the Survey observation (Andreoni et al. 2021)

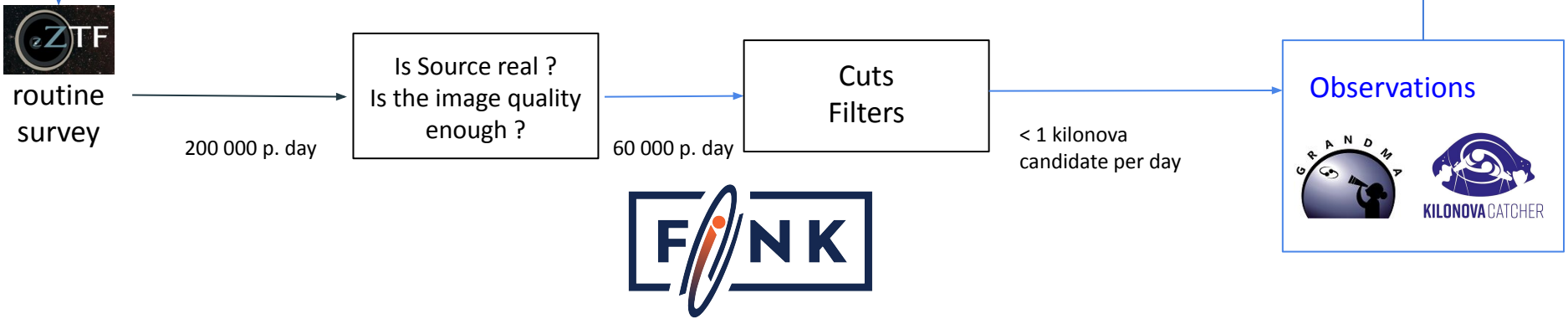
Additional Challenges

- **No** access to the merger time provided by **external triggers** (GRBs or Gws)
  - Lack of early information (photo or spectro)
- Many contaminants in optical domain (SNe, Novae, GRB afterglows, …)
- Highly telescope time consuming
- Lack of practice (only AT2017gfo so far)

Our proposition

One point per source
evr. 2 days in 2 colors

Re-injecting obs for improving the classifications



~~Where ?~~ Which ? When ?

How to deal with multiple-telescopes ?

How to deal with Galaxy contamination ?

ref. Peloton, 10.09.2021

Alerts/night	**300,000**
Data/night (alerts only)	10 GB
Depth	**20,5 mag**
Area covered	10% sky/hour
Photometric bands	**g, r**
Camera resolution	600 Mpx
Mirror size	1.2m
Field of view	**47 deg^2**

Wide field survey at Palomar observatory, California

- Used as a prototype for the LSST science
- O(1) kilonova expected for ZTF
- A lot of alerts produced every night

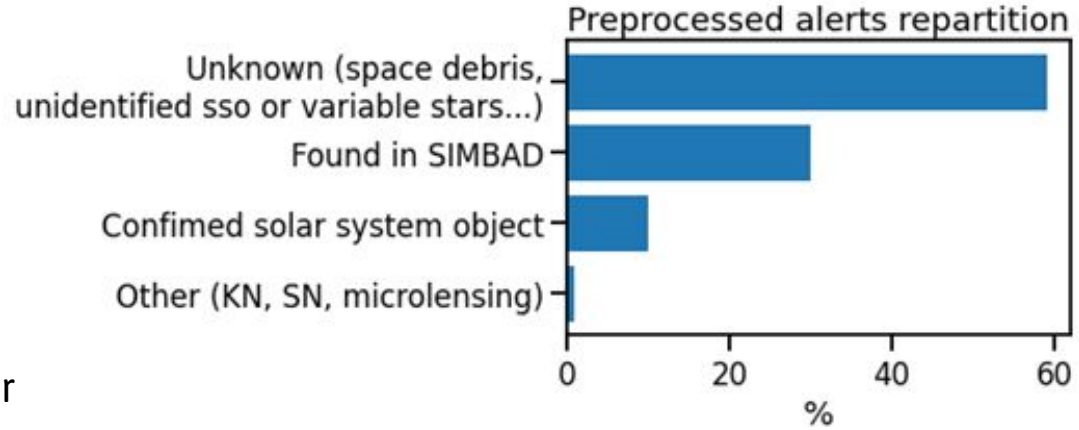
A broker : FINK

Fink : process and annotate the **ZTF** alert stream (and LSST in the future). It has been **prototyped** with **ZTF and** is designed to satisfy **LSST requirements**.
Study **Supernovae**, variable stars, microlensing, solar system, **GRB**, **Kilonovae…**

The aim of Fink-GRANDMA collaboration is to **coordinate** available resources to optimize the **search** and **identification** of **kilonova candidates**.

Challenges:

- massive number of alerts
- little information on the alerts
- various objects



FINK is one of the seven official LSST broker

Alerts classification

- **Quality filter** :
  - No **bad pixel** flagged in the image
  - real bogus score > 0.55
  - ~70% alerts discarded
- **ML based classification** :
  - **Light curve classifier** :
    - PC extraction of the LC via Fink simulations
    - Random forest trained on simulations
  - **Luminosity decay rate** :
    - KN are rapidly evolving : >= 0.3mag/day
    - require at least 2 days of obs in practice to get a reliable score
- **Cross match with nearby galaxies** :
  - Use **Mangrove** (Ducoin et al. 2020) to associate the near-by host
  - Use distance info to evaluate Abs mag (~-16 mag as peak for kilonovae)
  - Quasi-instantaneous : Max 6h after the alert

Filter	Number of alerts per month	NB of unique objects per month
No filter	~2,000,000	~700,000
ML based	~20	~10
Mangrove	~10	~10

Number of alerts **after quality filtering**.for 5 months
01.04.2021 to 31.08.2021
Courtesy of J.Peloton

< 0.001% of candidates remaining after the filtering of the alerts

Created in 2018, by LAL – OCA

PI. S. Antier

Already a large Community

29 groups - 15 countries

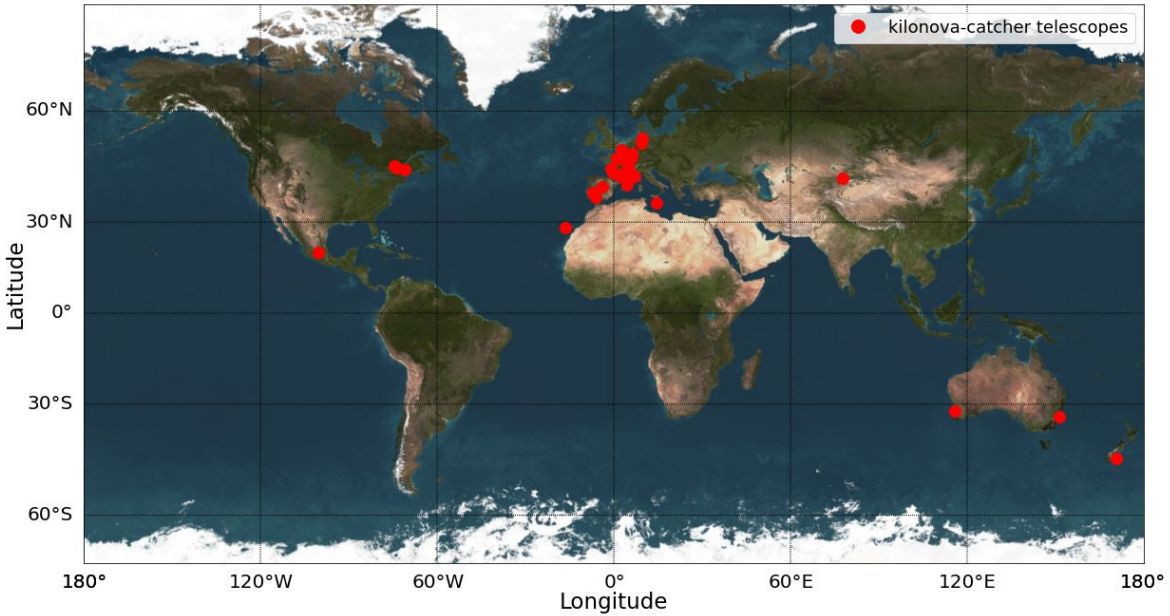
75 scientists

CNRS/- APC - IAP - IJCLab - OCA - IRAP – LAM - IPHC - CCPM

Wide-fields up to 20 mag, EM candidates ~ 23 mag in photometry (6h per semester on the CFHT in 2021)

22 mag in spectroscopy

Kilonova-Catcher



Kilonova-Catcher current network : 70 telescopes

GRANDMA's citizen science program

Created in 2019

PI : S. Antier

Now 100 amateur astronomers

Used for the galaxy targeting strategy

Already performed some observation during O3

Currently working on the skill improvement

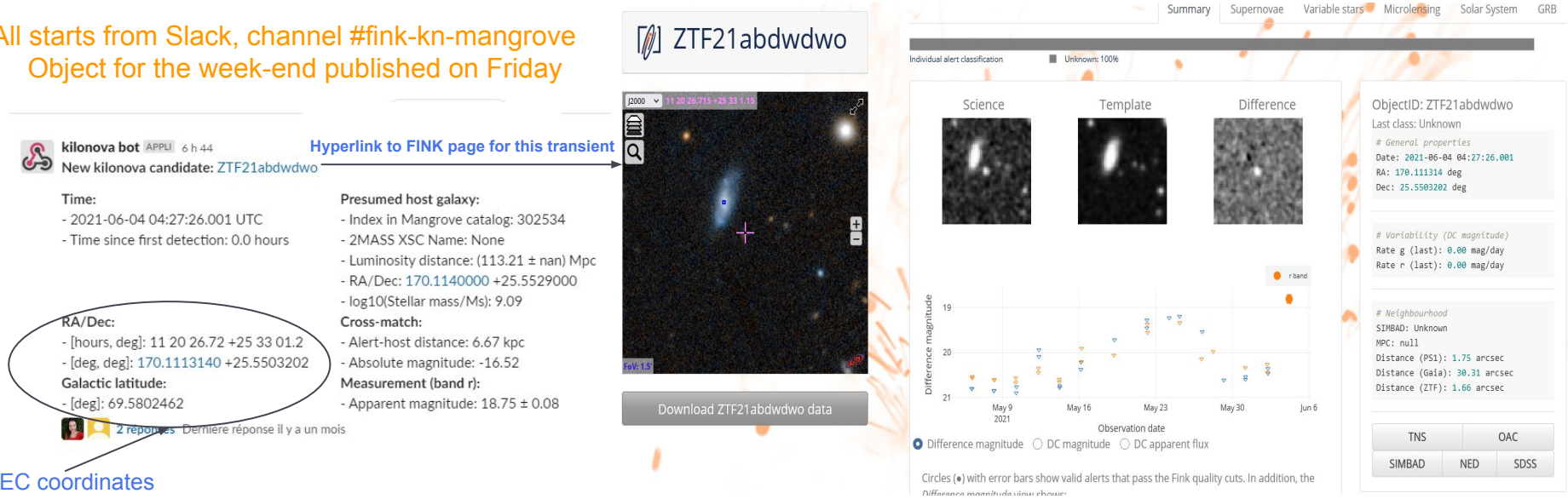
Project funded by PNHE

Ready for O4 (June - September 2021)

ReadyforO4 → Goal = be ready to (1) search for kilonovae upon alerts and (2) characterize light curve
→ train the amateurs for alerts, observation, preprocessing, uploading
→ train professionals to process our data
→ 10 alerts followed so far - ~8 observers/alerts in avg (min 4; max 12) - GRANDMA and Kilonova-Catcher

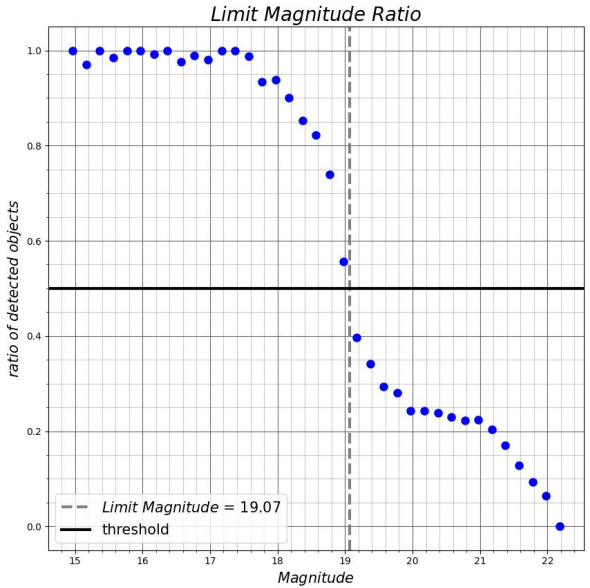
Running since 3 months now with Targets of Opportunity (ToO) extracted by the pros out of the ZTF observations for goal (2)

All starts from Slack, channel #fink-kn-mangrove
Object for the week-end published on Friday

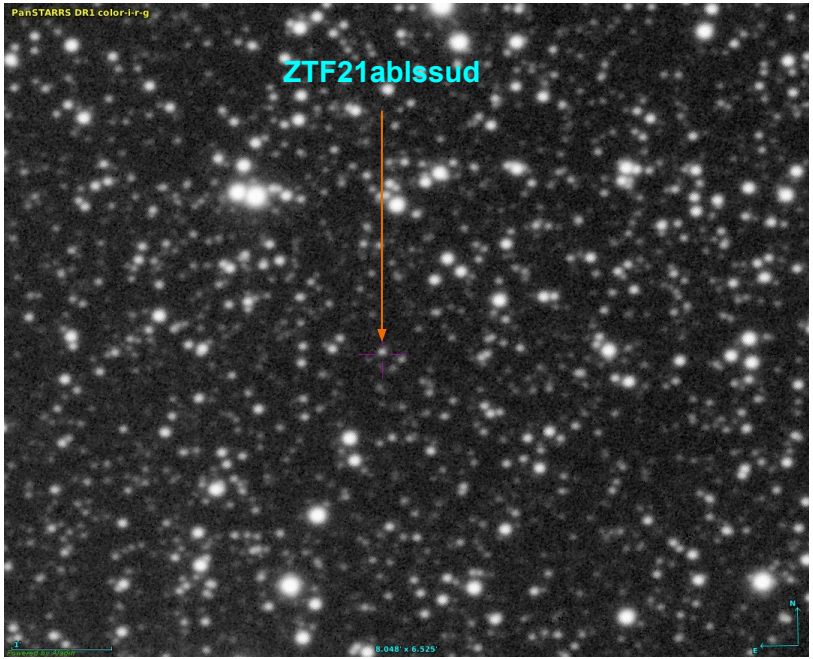


Example : ZTF21ablssud

- Detection : 2021-06-04 04:27:26.001
- 147 images by 11 pro and amateurs astronomers
- 9 different bands : g, r, i, B, V, R, I, L and Clear



limit magnitude = 19.1 ± 0.2 mag



ZTF21abdwdwo by D. Boutigny (R band)

Ra = 289.1551294 deg
Dec = 24.409455 deg

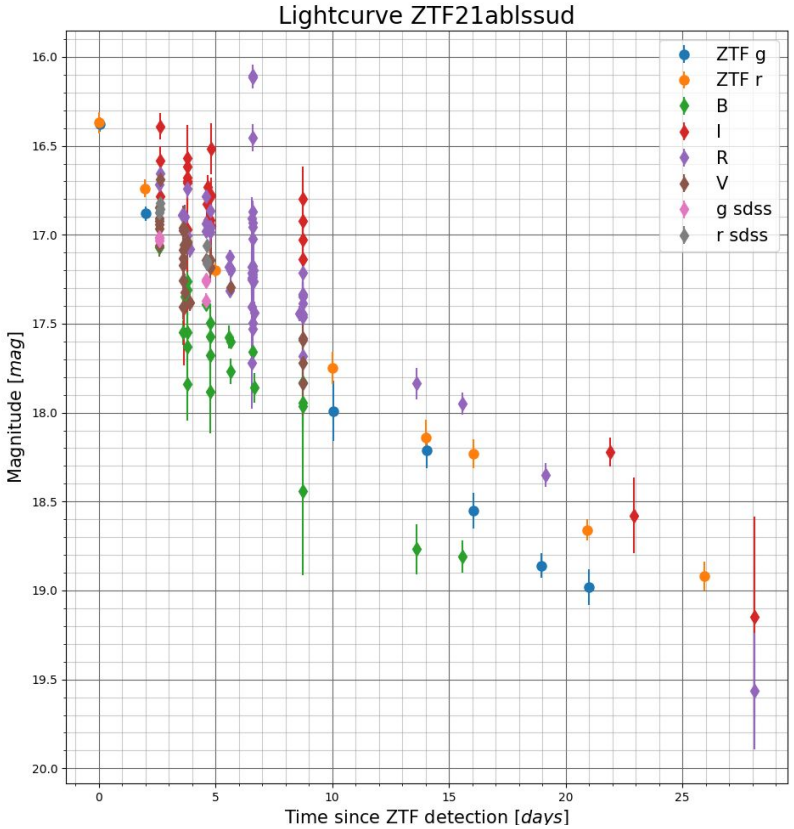
Image reduction

std_pipeline (WP leader : **S. Karpov**):

- Detection pipeline
- Photometry pipeline
- Design using KN images

MUPHOTEN (WP leader : **PA. Duverne**):

- Photometry pipeline
- Designed using GRANDMA images



Future for GRANDMA-FINK

Short Term :

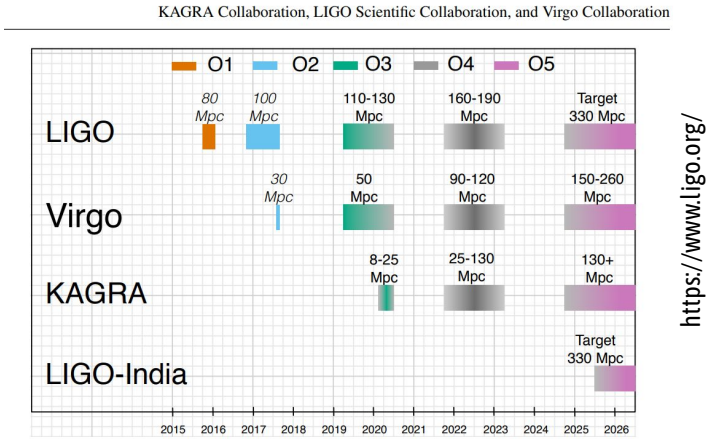
- Continue training for O4
- Follow-up the most promising KN Kilonova candidates
- Improve Fink classification

Medium term :

- Follow up the O4 alerts

Long term :

- Follow-up LSST most promising alerts
- O5 GW alerts



https://www.ligo.org/

Alerts/night	$1 * 10^7$
Data/night (alerts only)	1TB
Depth	25 mag
Area covered	30% sky/day
Photometric bands	u, g, r, i, z, y
Camera resolution	3200 Mpx
Mirror size	8.4 m
Field of view	3.5 deg^2

LSST Characteristics

Courtesy of J.Vlieghe

References

Andreoni et al. : https://arxiv.org/pdf/2106.06820.pdf

Villard et al. : https://arxiv.org/pdf/1710.11576.pdf

Tanvir et al. : https://arxiv.org/abs/1710.05455

Troja et al. : https://www.nature.com/articles/s41467-018-06558-7

Coughlin et al. : https://www.nature.com/articles/s41467-020-17998-5

Barnes et al. : https://arxiv.org/abs/2010.11182

Dvorkin et al. : https://arxiv.org/abs/2010.00625

Essick et al. : https://journals.aps.org/prd/abstract/10.1103/PhysRevD.101.123007

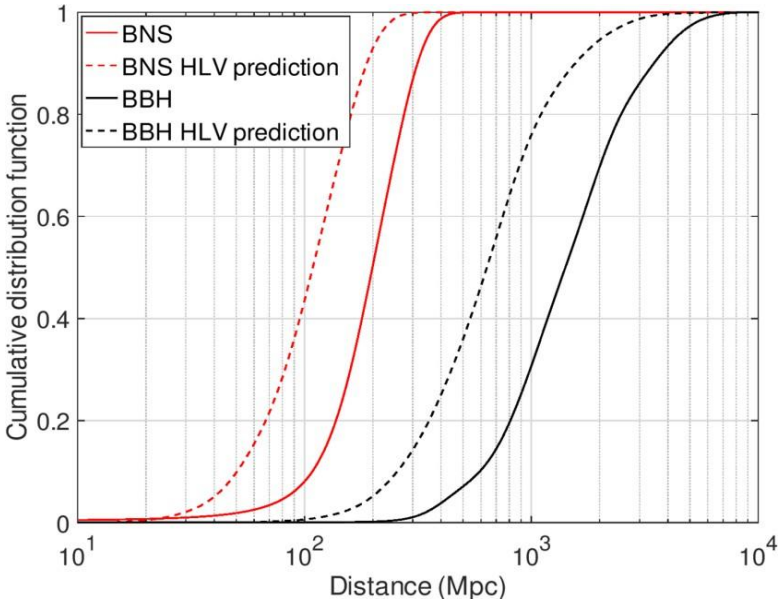
GRANDMA papers : https://arxiv.org/abs/1910.11261 & https://arxiv.org/abs/2004.04277

ZTF papers : https://arxiv.org/abs/1902.01932 & https://arxiv.org/abs/2102.11304

LSST Science book : https://arxiv.org/abs/0912.0201

Ready for O4 Tutorial for astronomers : https://www.youtube.com/watch?v=7VajPXBNvmA

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