GRANDMA

Antier S. , Boer M., Christensen N., Cordier B., Coward D., Ducoin J~G, Gendre B., Han X.H, Khanthanakorn N., Klotz A., Jing W., Leroy N., Mao J., Turpin D., Xin L.P., Wei J.Y., Wu C., Zheng W.K.

A network of facilities dedicated to the electromagnetic follow-up of the GW-O3 candidates

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OUTLINES

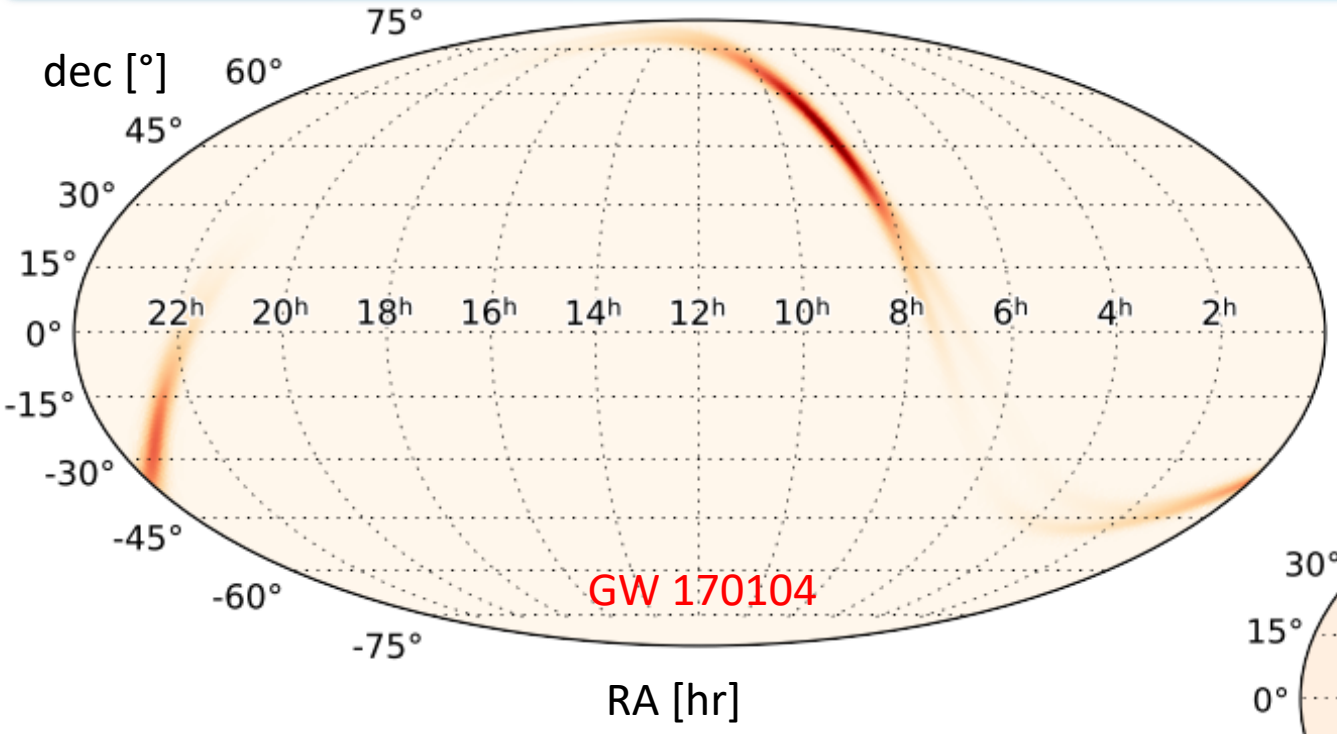
1. The EM (optical) follow-up of the GW events
2. The GRANDMA project for the GW/O3 follow-up campaign
3. Short GRB afterglow and kilonova detection with GRANDMA

I.
The EM follow-up of the GW events

Problematics

The EM follow-up of GW events

Large error boxes

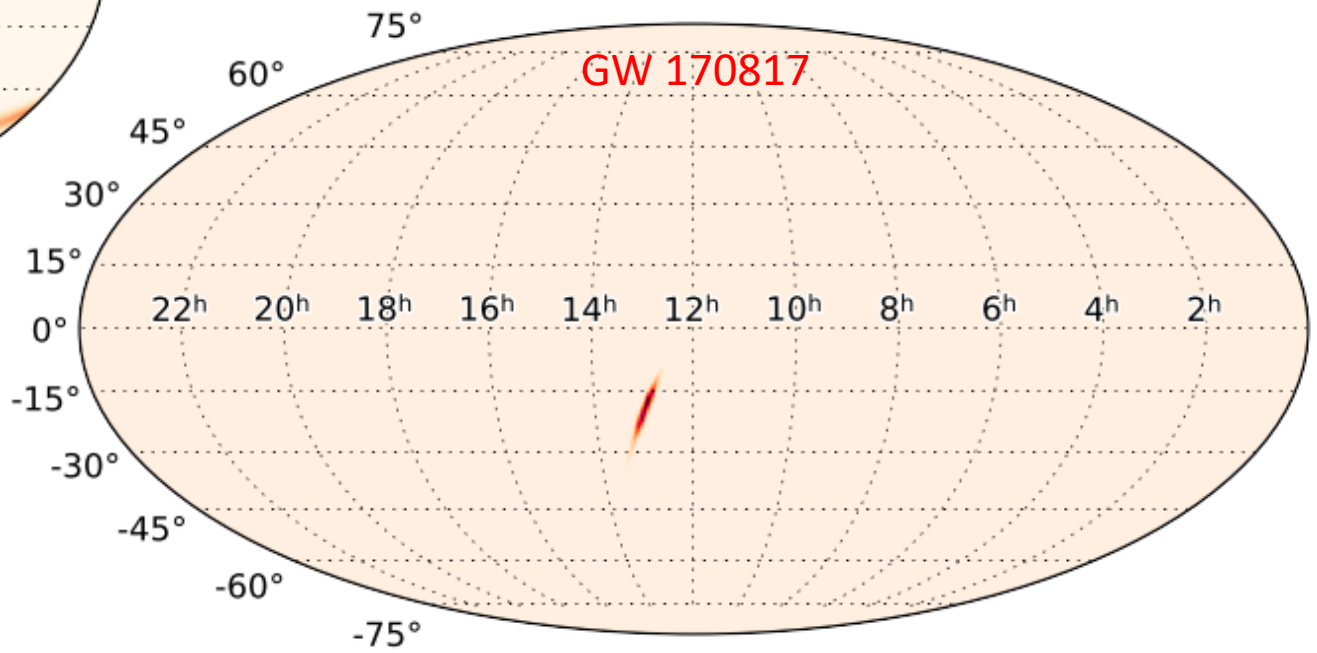


Refined position of GW 170104 -BBH-

Error box at 90% C.L : 1200 deg² (best localization)

Refined position of GW 170817A -BNS-
(GW detectors only)

Error box at 90% C.L : 28 deg² (best localization)



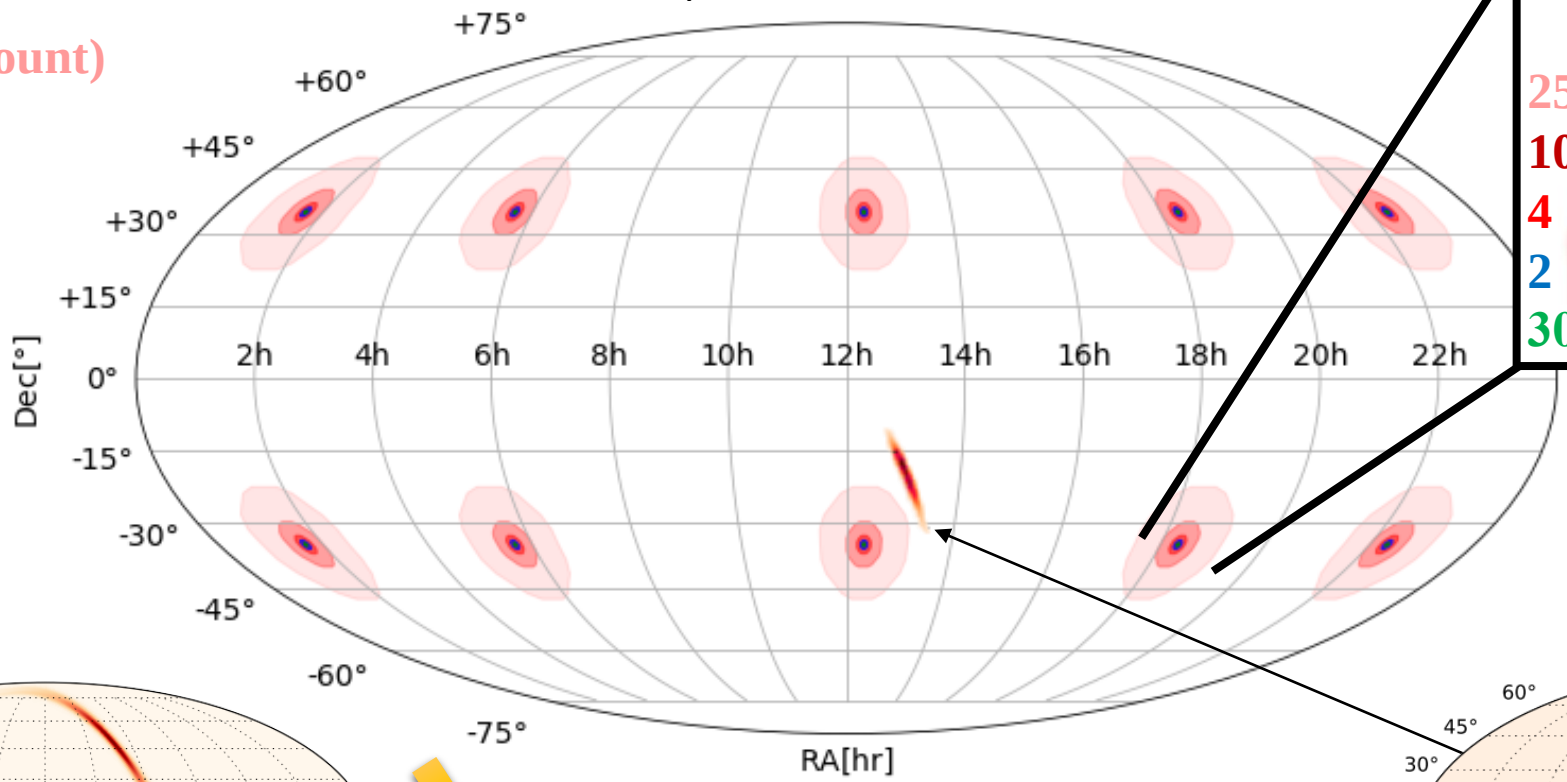
The EM follow-up of GW events

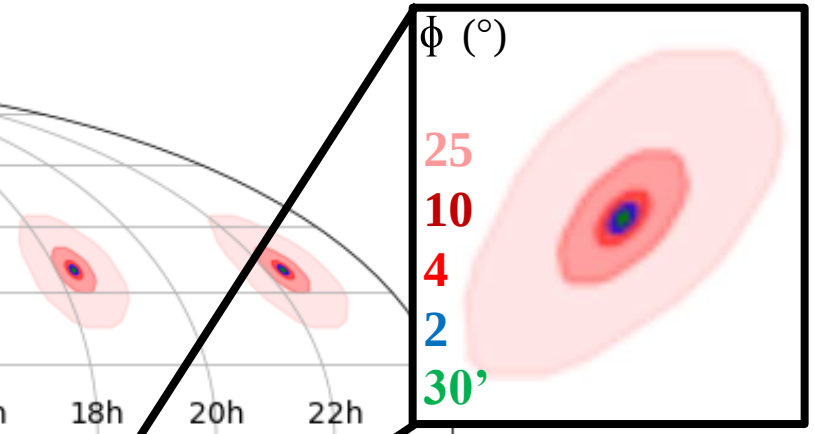
Large error boxes

Rough correspondance with FoV of

GWAC (1 mount)
LSST
TAROT
SVOM/GFT

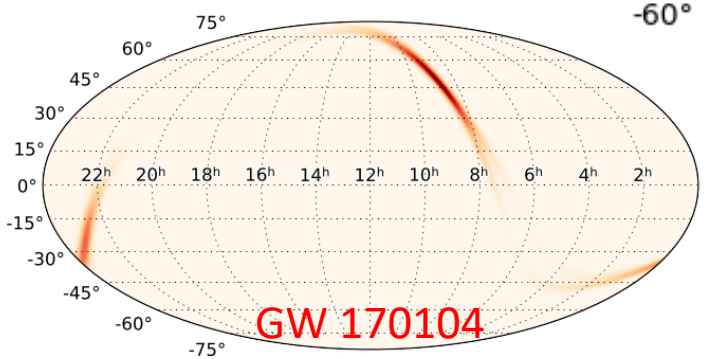
Optical Facilities FoV





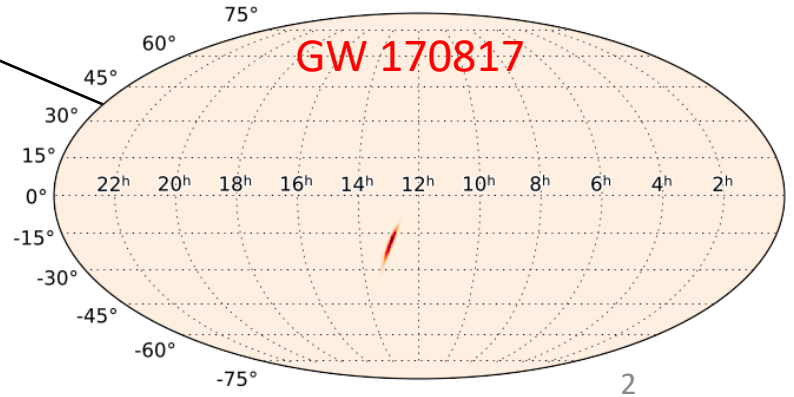
Area cov (sq degrees)

~500
~80
~12
~3
~0.2



1200 deg²

HARD to cover the whole GW error box with the FoVs of the optical telescopes

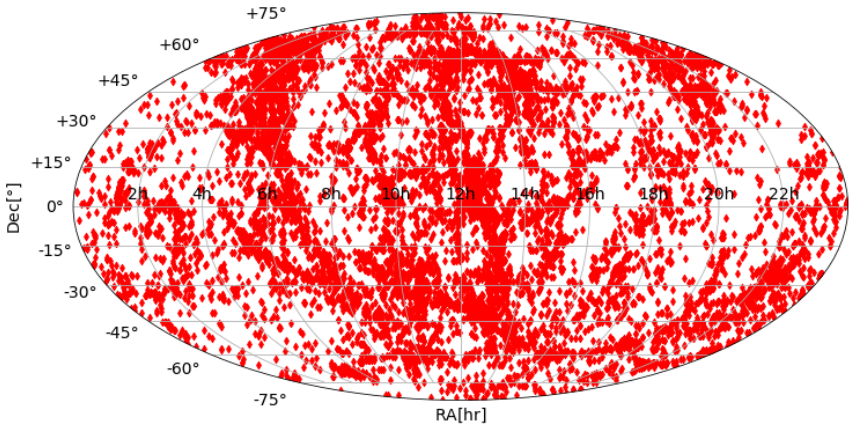


28 deg²

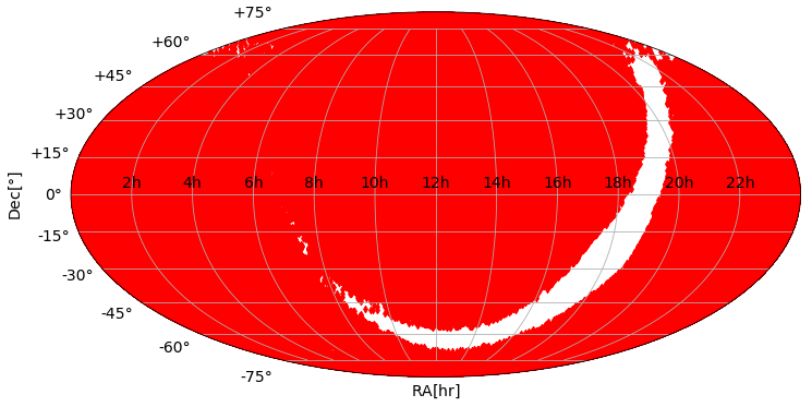
The EM follow-up of GW events

Fast response

GLADE catalog



GW170817 d = [26-48] Mpc -> 11583 gal
In 28 deg² (assuming a circle error box) : ~ 0-100 gal

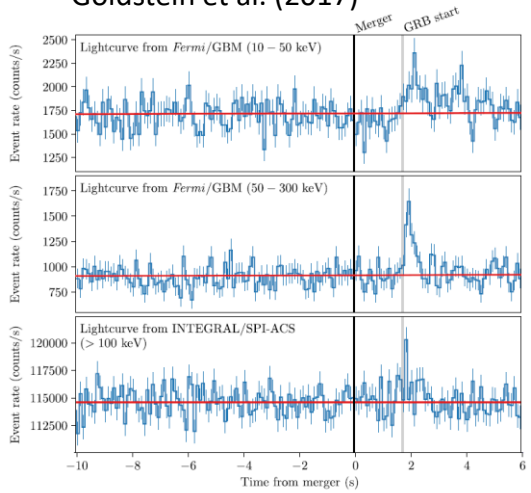


GW170104 d = [490-1330] Mpc -> 589287 gal
In 1200 deg² (assuming a circle error box) : > 10 000 gal

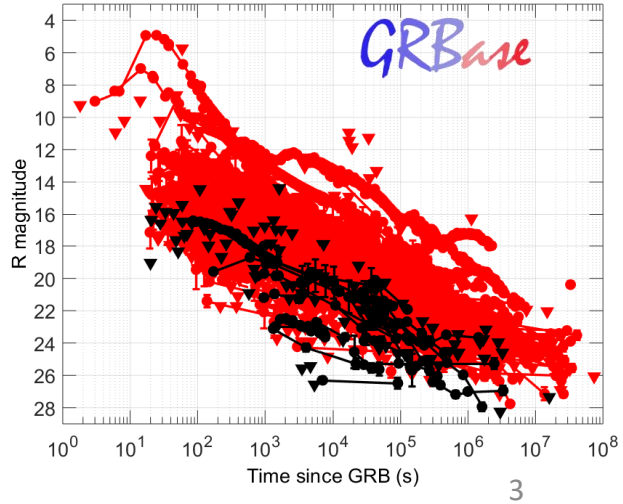
Many galaxies to target with blind or optimized search

Time is running out to catch the early EM emission of fast fading transients !!

GRB lightcurve of GRB 170817A
Goldstein et al. (2017)



Optical afterglow lightcurve of GRB from GRBase

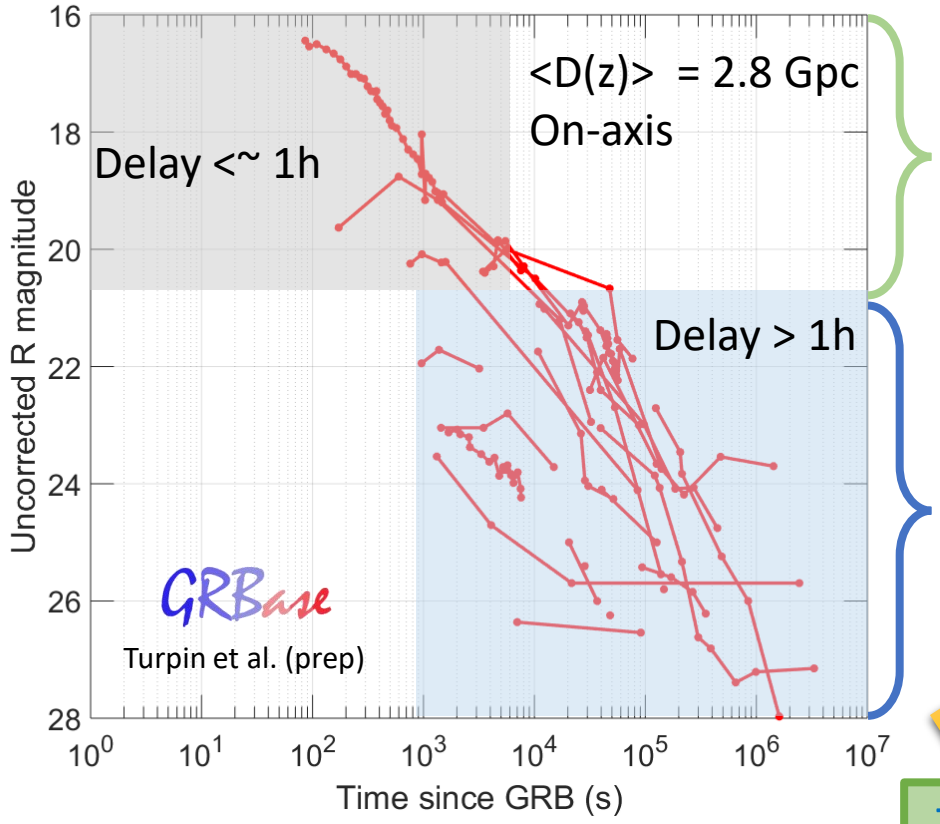


The EM follow-up of GW events

Deep photometry

SGRB Afterglows

Optical LC of 23 short* GRB (1997-2015)



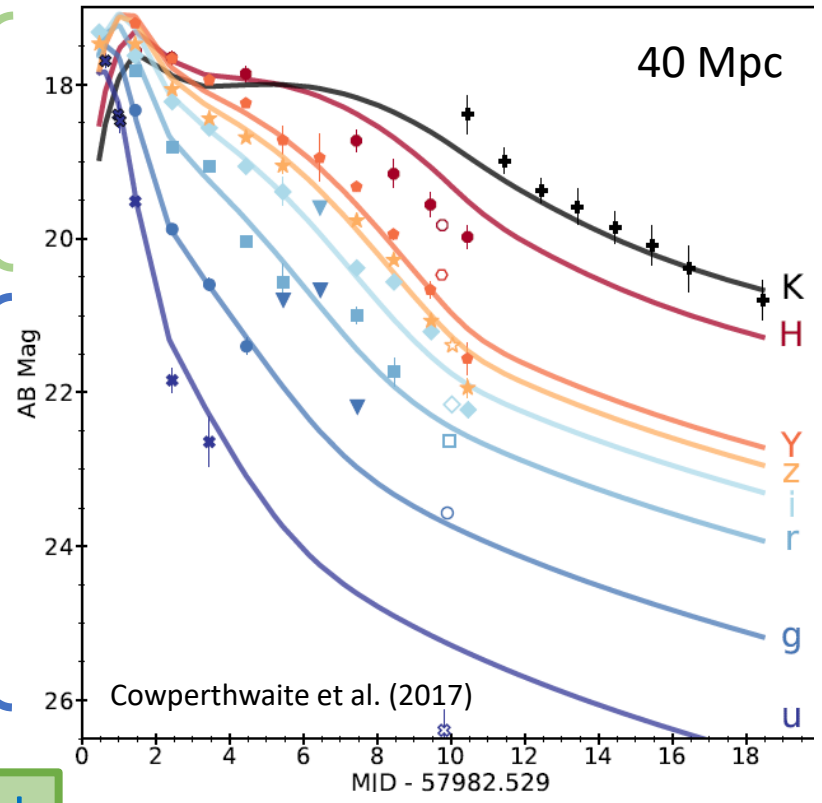
Optical emission from GW BNS + Others (BBH,BH-NS, etc…) ?

Tel <1m

Tel >1m

Kilonova emission of GW 170817

Delay >~0.5 days

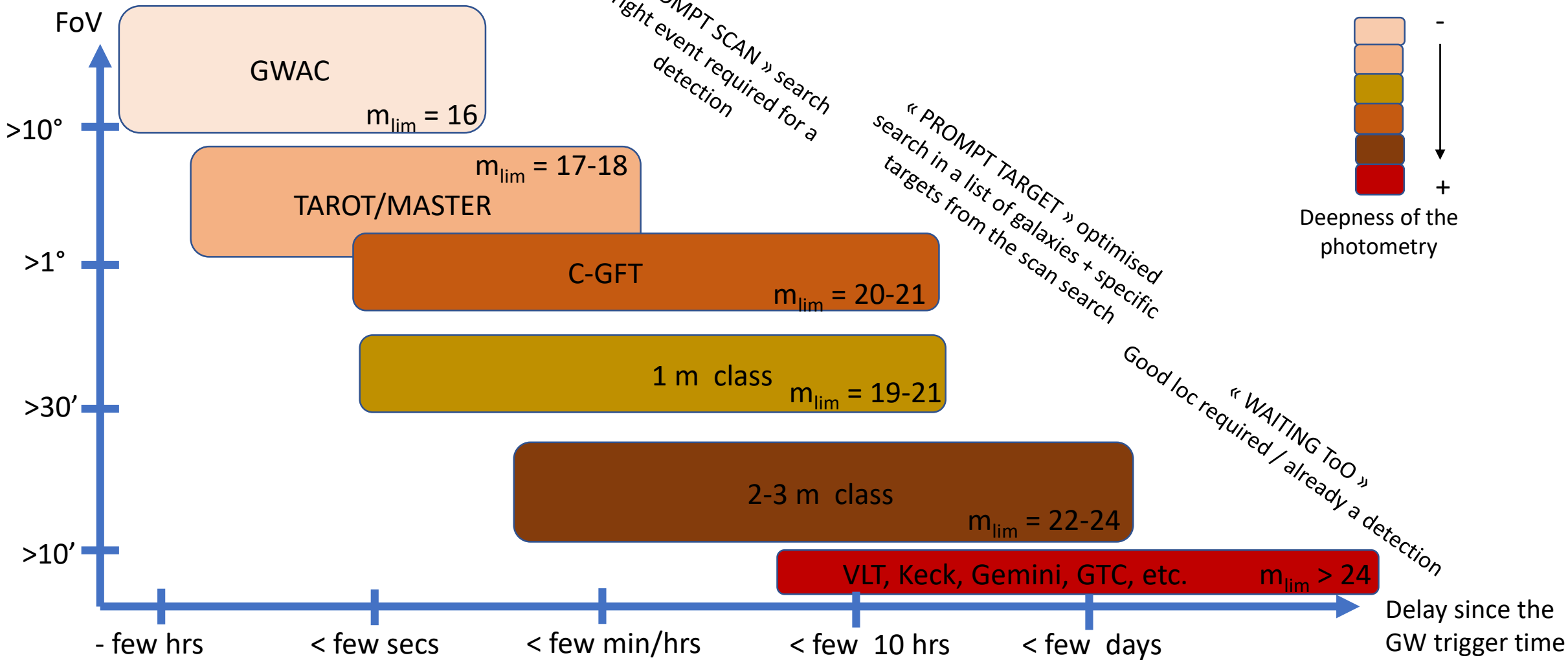


The sources are quite faint !

* Corresponding to the T_{90} definition. Some no-merger events may be classified as short GRBs here

The EM follow-up of GW events

Optimising each facility perf.



The EM follow-up of GW events

Classification of the EM candidates

Gravitational wave

Large Error boxes
~100 deg² (for O3)

EM astronomers

Large telescope FoV
>>10deg²

Many unrelated transients
+
Many fake transients

Big challenge of the incoming years for the time-domain astronomy

Powerful tools to quickly classified the transients and identify the good one
Auto-vetting, Deep Machine Learning, Likelihood algo, automatised image subtraction, etc.

The EM follow-up of GW events

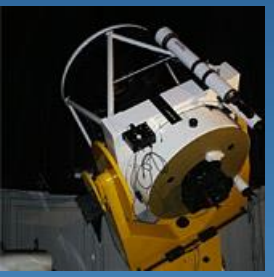
A need for a world wide network

The « Four GW commandments » for the astronomers

i. Have a large FoV
ii. Be Fast
iii. Be deep in photometry
iv. Be efficient in identifying the good EM counterpart

One telescope can not fulfill this task !

- EM (and GW) observers must be connected and share the huge observational work.
- A world wide network of telescope is needed to get the most scientific returns back from each GW/EM follow-up campaign !

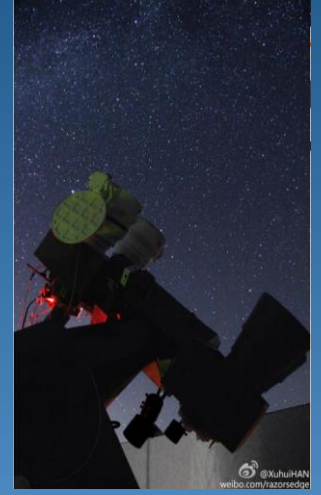


Zadko

Tarot-Calern

TAROT-Chile

TAROT-Reunion



GWAC

F60

30cm

2.16 m Xinglong

C-GFT

TNT Xinglong

2.4 m GMG

II.

GRANDMA

Global **R**apid **A**dvanced **N**etwork **D**evoted to the **M**m **A**ddicts

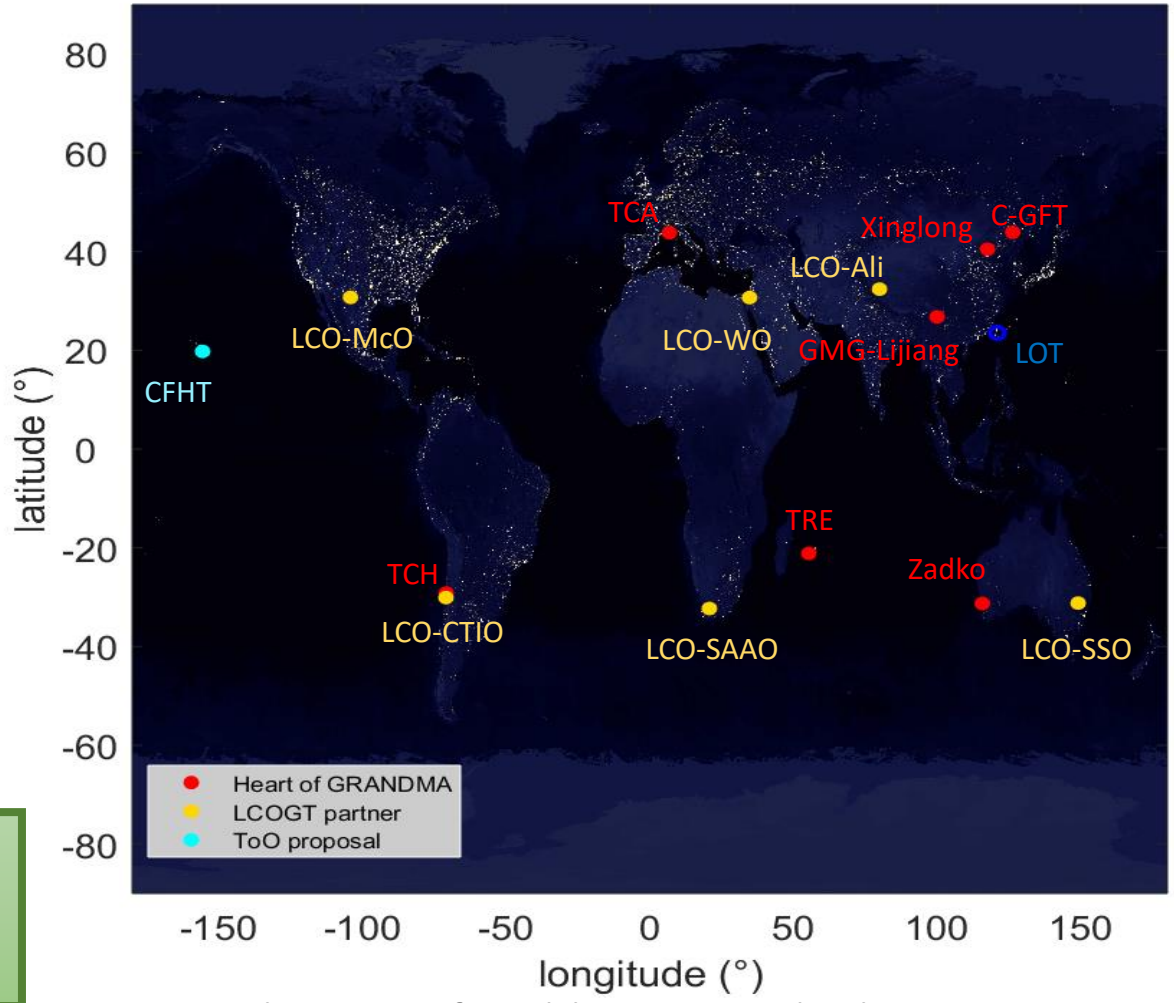
GRANDMA

The network

The fusion of the TZAC & Chinese networks of telescope

TAROT & Zadko
experience on the MM astronomy

GRB / neutrinos / GW
>200 GCNs, ~40 publications



Chinese facilities
experience on the MM astronomy

(mini-)GWAC : O2 campaign / Fermi GRB follow-up

See X.H Han's talk

TNT : GRB science
> 130 GCNs

GMG : GRB science
35 GCNs, 1 paper

A strong experience on the field of the time-domain & MM astronomy

Some Partners

GRANDMA

GW ← GRANDMA → **optical**

GRANDMA → **γ-rays**

VIRGO

Discussion on GW Sub-threshold
Contact : N. Leroy (LAL)

Fermi Gamma-ray Space Telescope

GBM Sub-threshold
Coincidence with GRANDMA OTs
Contact : N. Christensen (Artemis)

LCO

Coincident obs. + share obs strategy & results with the LCOGT network

TAROT + **collaborators**

60 cm La Reunion island + others (TBD)
contact : M.Boër /A.Klotz (Artemis/IRAP)

CFH

CFHT (Hawaii, US) ToO request
PIs : M.Boër / J.Y. Wei (Artemis/NAOC)

Lulin observatory (Taiwan)

Discussion with the LOT team (1m) : ToOs
GRANDMA contact : L.P Xin (NAOC)

Under discussion
Proposal for O3
agreed

Motivations

Build a world wide network of various facilities dedicated to the detection and the follow-up of the EM (optical) counterpart of GW/O3 candidates. Provide quick GRANDMA alerts to the scientific community as soon as an optical detection is confirmed or perform a quick follow-up of interesting optical transients (OTs) found by external teams.

Science case

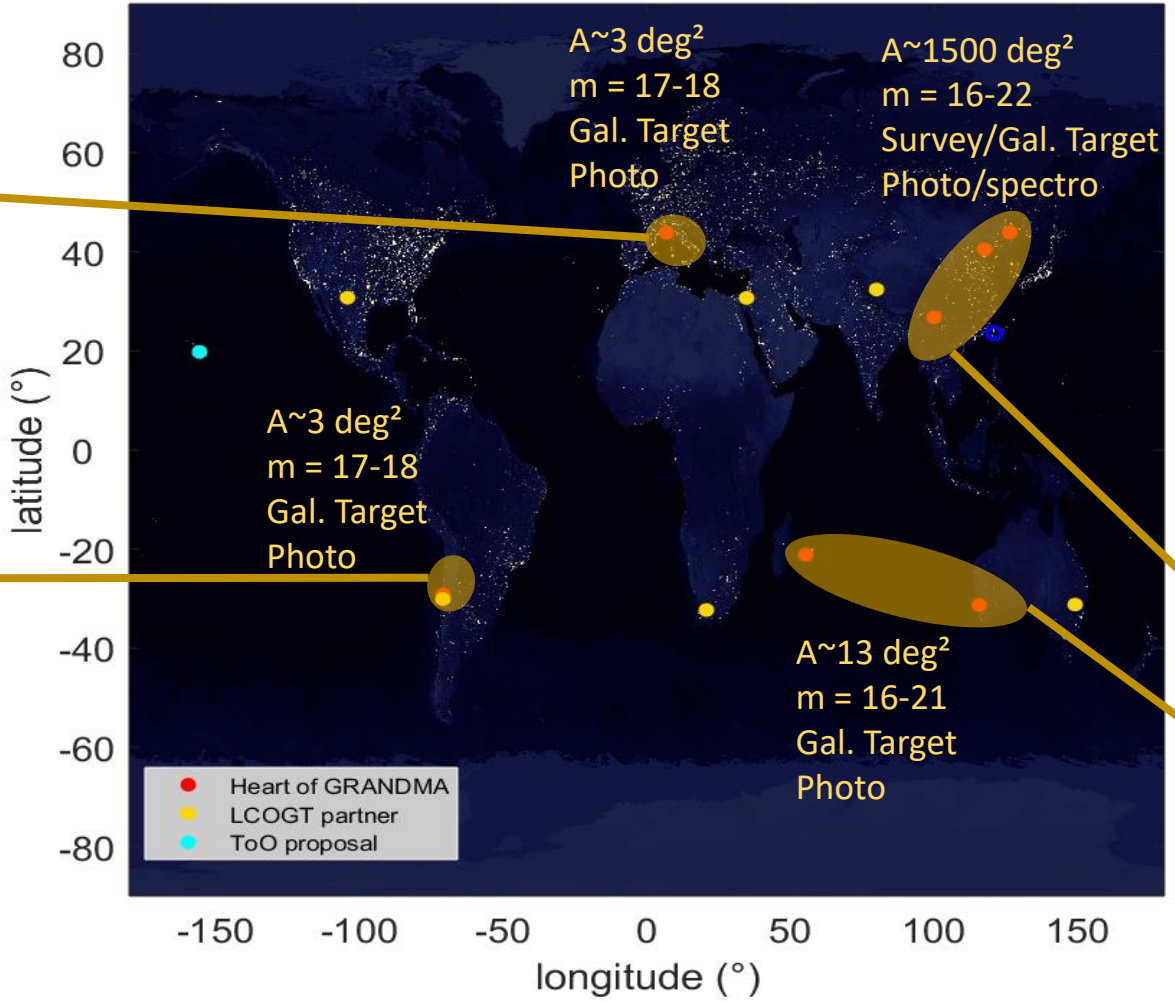
1. Detect the optical counterpart of any GW candidate : GRB (early on-axis/ late orphan) afterglow, unkown OTs, etc…
2. Perform a highly sampled « late » follow-up of the OT related to the GW candidate in different color band to identify the radiative processes and the lightcurve features.
3. Identify the source redshift and the emission/absorption spectral features thanks to spectroscopic observations.
4. Detect the early (and/or late) stage of the BNS kilonova emission (color photometry + spectroscopy if possible). Identify the nature of the ejecta and the origin of the chromatic evolution of the KN emission.

16 telescopes covering a wide field of performances

Telescope	Num.	location	Aperture (m)	FoV	filter	m_{lim} [Single/stack]	Obs.mode
GWAC	3	China	0.18	25°	Clear	16/17	Survey
30 cm	1	China	0.30	1°	Clear, BRI	16.5/17	Gal. target
F-60A/B	2	China	0.60	18’	Clear, BRI	18/19	Gal. target
TNT	1	China	0.80	12’	Clear, R	19/20	Gal. Target or ToO ?
2.16 m	1	China	2.16	~9’	BFOSC (im/spec)	22 (18.5)	ToO (pho/spectro)
C-GFT	1	China	1.20	1.5°	Clear (for O3)	19/20	Gal. target
GMG-2.4	1	China	2.40	~10’	YFOSC (im/spec)	22/24 (18)	ToO (spectro)
TAROT	3	France / Chile	0.25 x2 + 0.18	1.9° x2 + 4°	Clear, RI	17/18+ 16/17	Gal. target
CFHT	1	US	3.6	1° / 20’	gri, JH	23, 22	ToO
Zadko	1	Australia	1.00	23’	Clear, gri	20/22	Gal. target
60cm	1	France	0.6	23’	Clear, gr	18/19	Gal. target

GRANDMA

Collective performances



~40 Gal/night
Prompt answer<20s

~40 Gal/night
Prompt answer<20s

- Ensure the coverage of the both hemisphere
- Quick answer to any trigger in the sky
- Almost continuous monitoring of the GW error box
- Quasi instantaneous vetting of fake candidates and/or confirmation of valuable OTs
- Ensure the high sampling (in different filters) of the GW/OT lightcurve in case of a detection
- Ensure spectroscopic measurement

~100 Gal/night
Prompt answer<2min

~60 Gal/night
Prompt answer<30-60s

Observation strategy

OT classification and human BA check of the best candidates pre-classified → See L.P Xin's talk

Fast answer

1. GWAC/TAROT **survey mode** (if available)
2. **Galaxy targeting mode** for the available telescopes : optimisation of the number of galaxies to be observed per night
3. **Smart schedule** of obs. on other tel.

→ continuous follow-up over a duration >12h after the GW alert receipt

Late actions

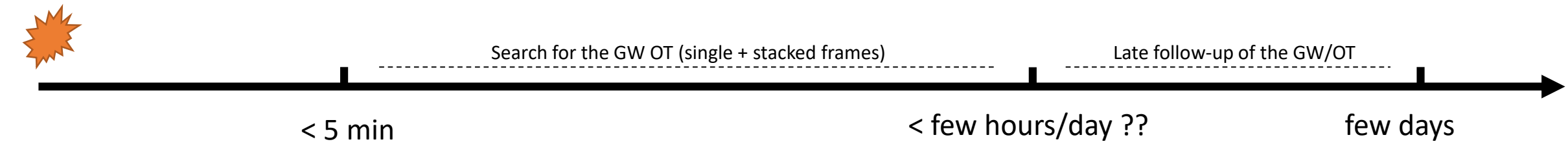
If credible OTs (internal or external) :

1. Launch ToO obs. on our largest telescope >2m
2. Pursue the photometric follow-up with our small telescope (if bright enough)
3. Spread out the OT alert to the scientific community (GCN, ATeL, mail)

End of the follow-up campaign

Offline analysis of all the images

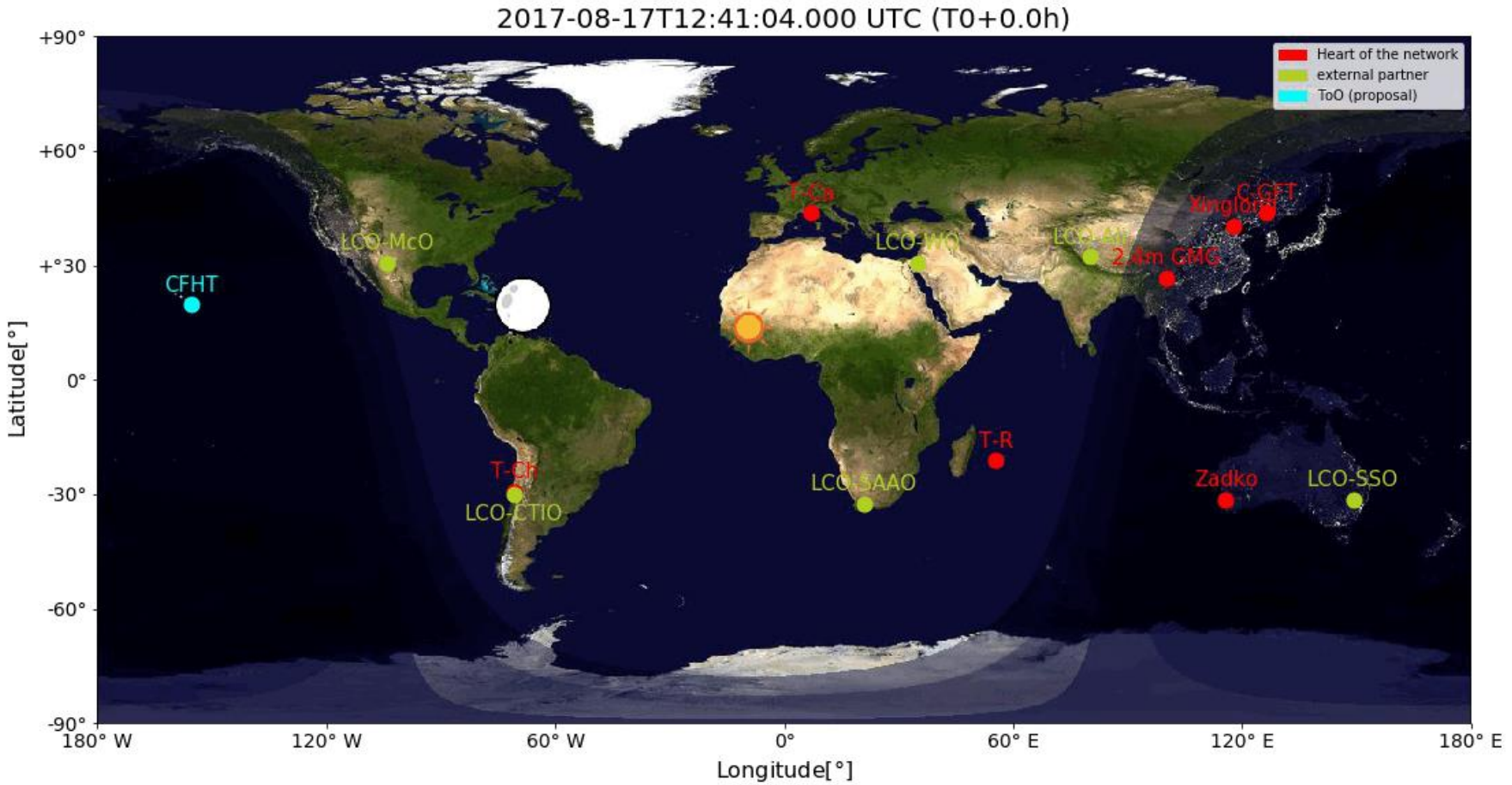
Internal report of our obs. results



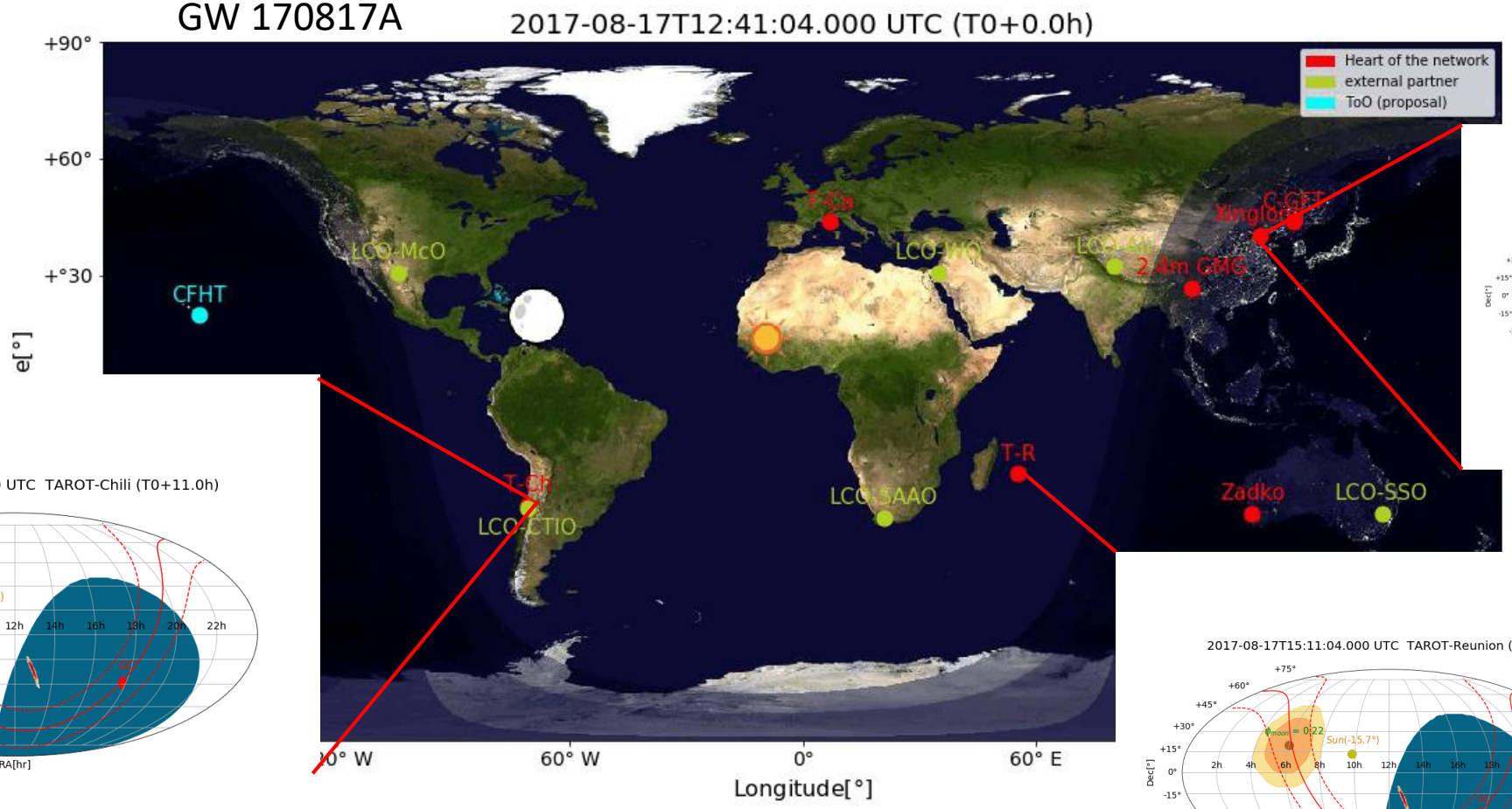
1. Availability of each telescope and visibility of the trigger position

GW 170817A

From T0 -> T0+24h

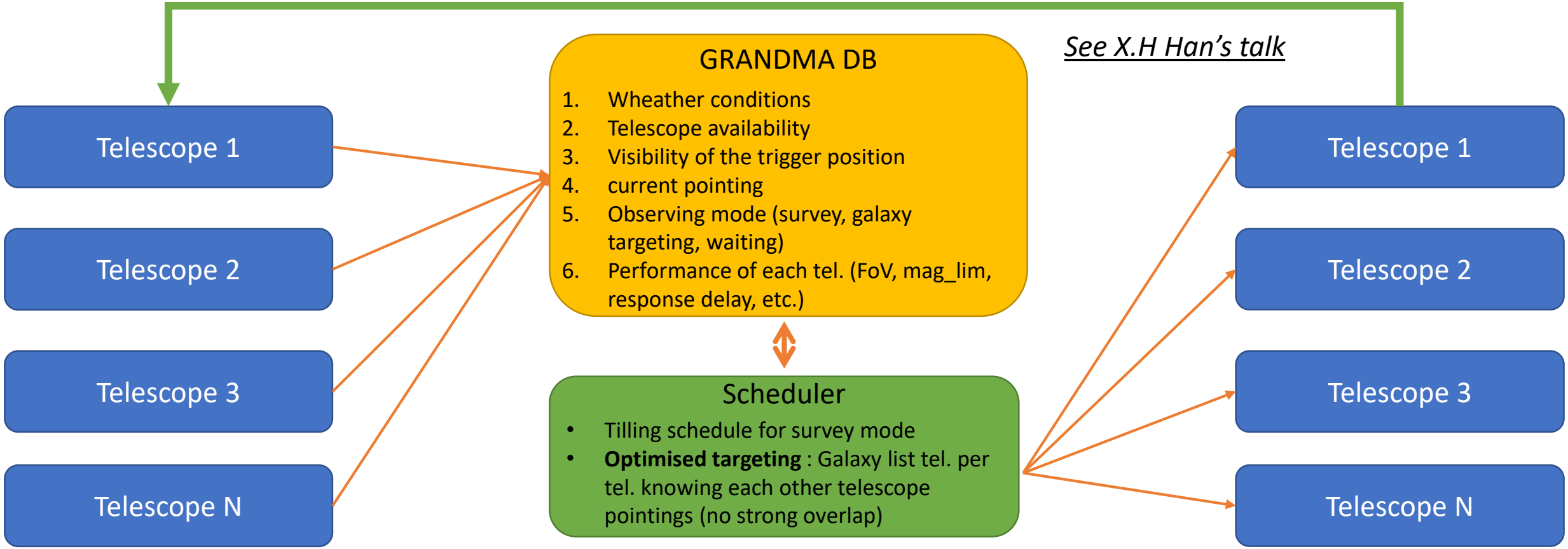


1. Availability of each telescope and visibility of the trigger position



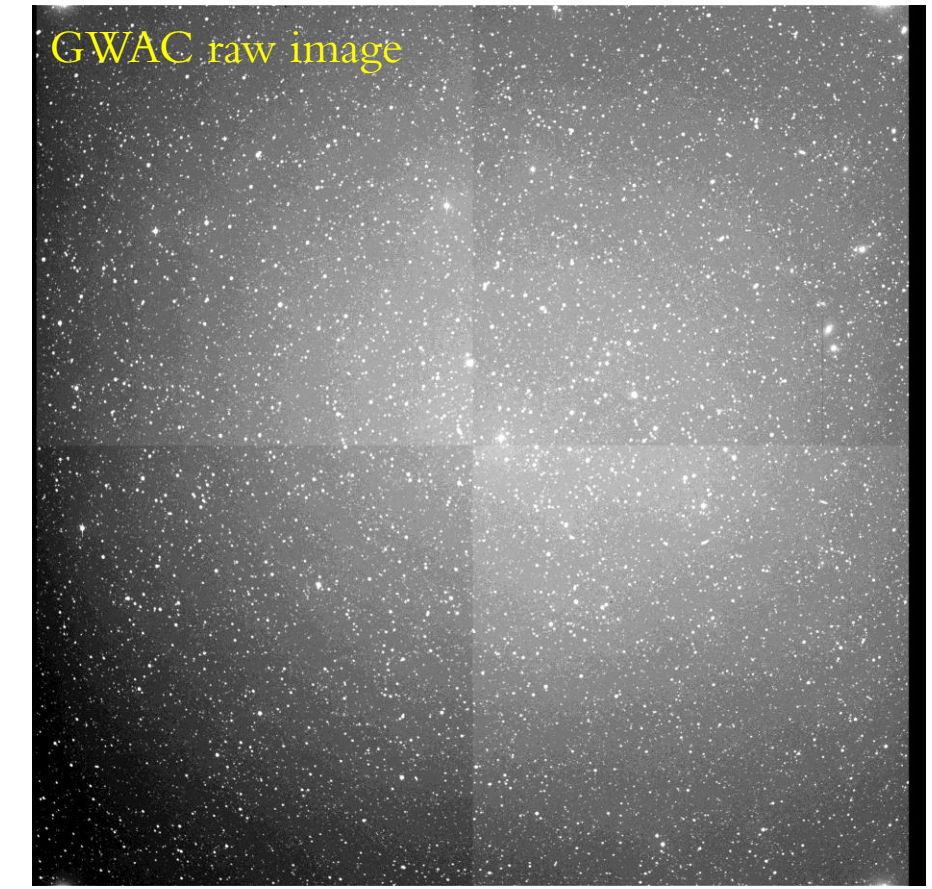
Organisation of the observations

2. A smart and dynamic schedule of the observations



OT detection & classification

Large FoV = large number of OTs / image
(more than few hundreds / night with GWAC)



Our large FoV telescope

GWAC (25°x25°), TAROT-Reunion (4°x4°), TAROT-Calern & La Silla (1.9°x1.9°), C-GFT (1.5°x1.5°)

See L.P Xin's talk

OT detection (automatised)

1. Standard filters (cross catalog matching, MP check, hot pixels, etc..)
2. OT search : Blind + galaxy in the field
3. Differential imaging : residual analysis
4. Cross check with other instrument images
5. Machine Learning algorithm

OT identification (semi-automatised)

1. Likelihood analysis with known template (SN, KN, GRB afterglow, etc.)
2. Confirmation by other telescopes
3. Human-eye check (BA of GRANDMA)

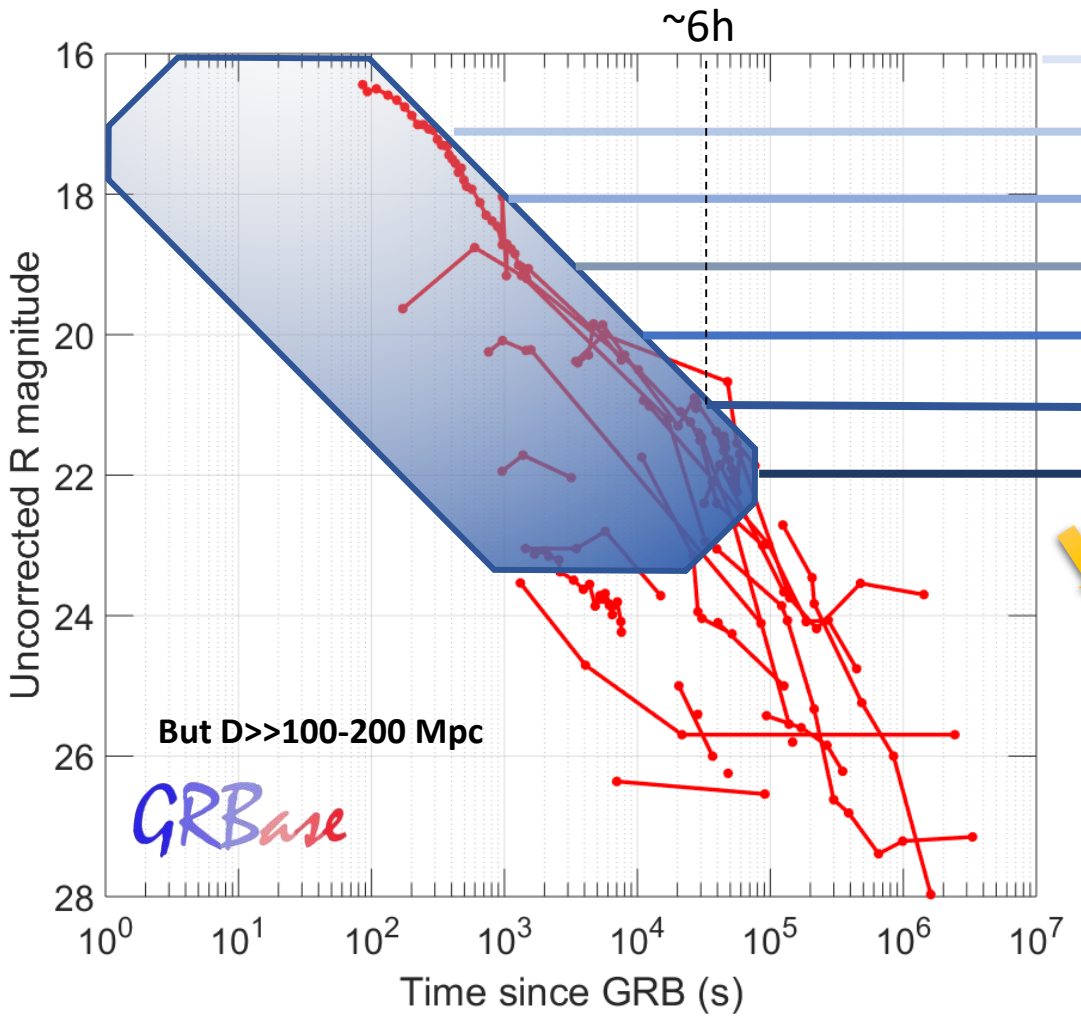
III.

Short GRB afterglow and kilonova detection with GRANDMA

Short GRB afterglow emission & the kilonova of GW170817

SGRB & kilonova detection with GRANDMA

short GRB afterglow



GWAC, T-Reunion single frame

GWAC, T-Reunion stacking / T-Calern & Chili + 30cm Xinglong single frame

T-Calern & Chili + 30cm Xinglong stacking / 60 cm Xinglong+Reunion single frame

60 cm Xinglong+Reunion stacking

1m class single frame (Zadko, LCOGT, C-GFT)

1m class stacking / 2m class single frame

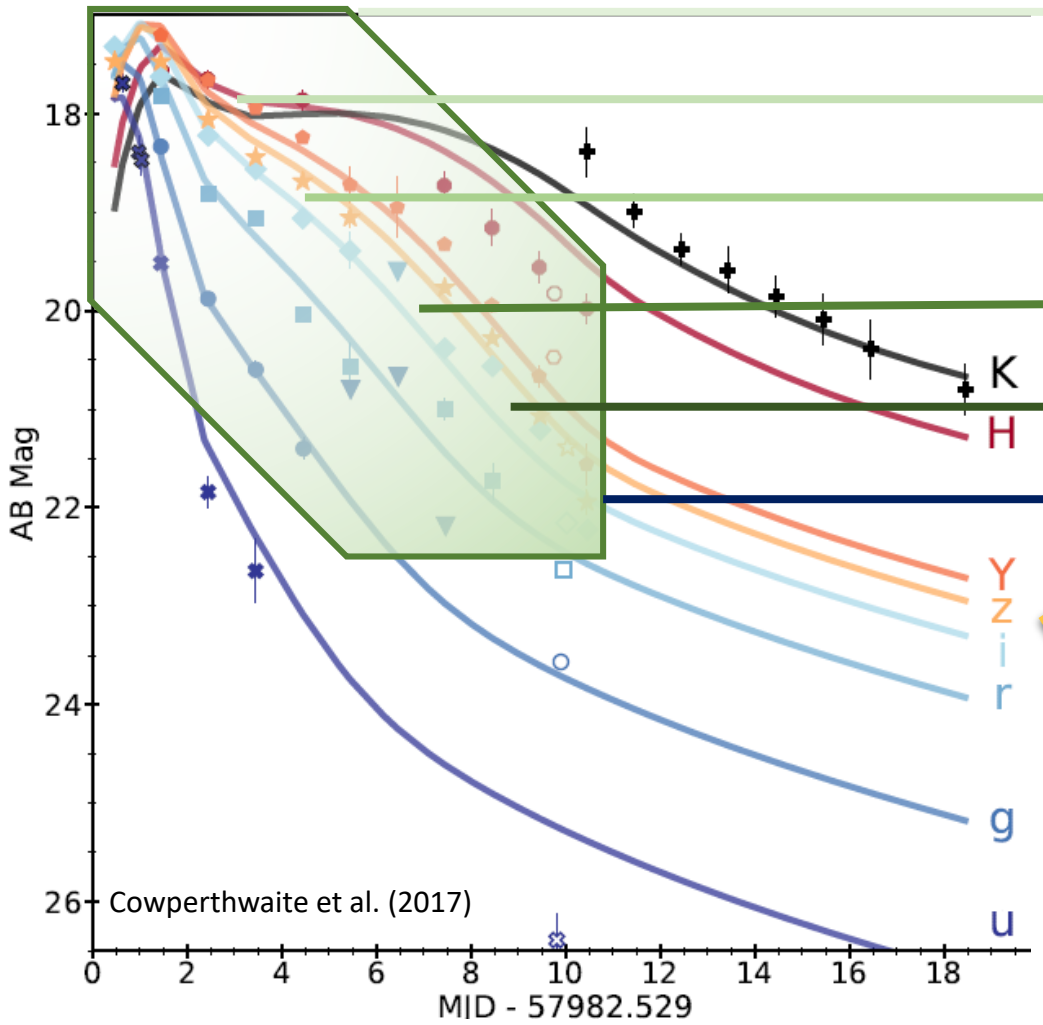
2m class stacking / 3m class single frame (CFHT)

Up to R~21, a GRANDMA discovery is possible for a maximum delay wrt the SGRB trigger time not more than ~ 6 hours* BUT actually even with larger delays if the GRB (on-axis) is within the expected GW horizon distances (~100Mpc)

*** BUT for a short GRB at <z>~0.5**

SGRB & kilonova detection

The case of GW 170817 (40Mpc)



GWAC, T-Reunion stacking / T-Calern & Chili + 30cm Xinglong single frame

T-Calern & Chili + 30cm Xinglong stacking / 60 cm Xinglong+Reunion single frame

60 cm Xinglong+Reunion stacking

1m class single frame (Zadko, C-GFT)

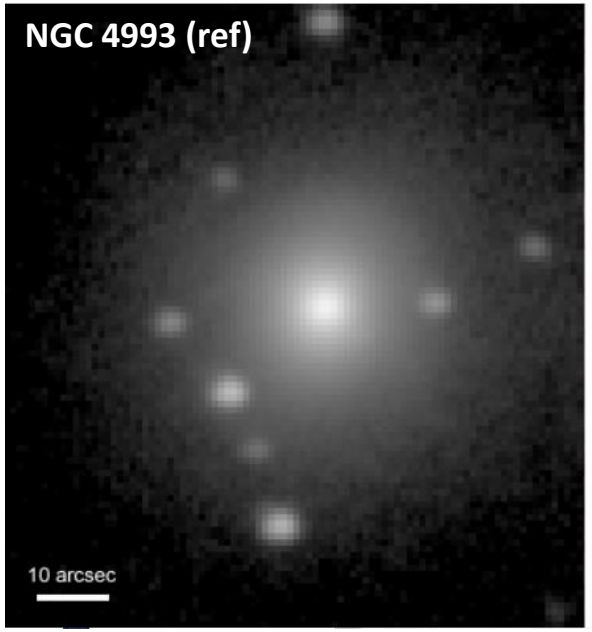
1m class stacking

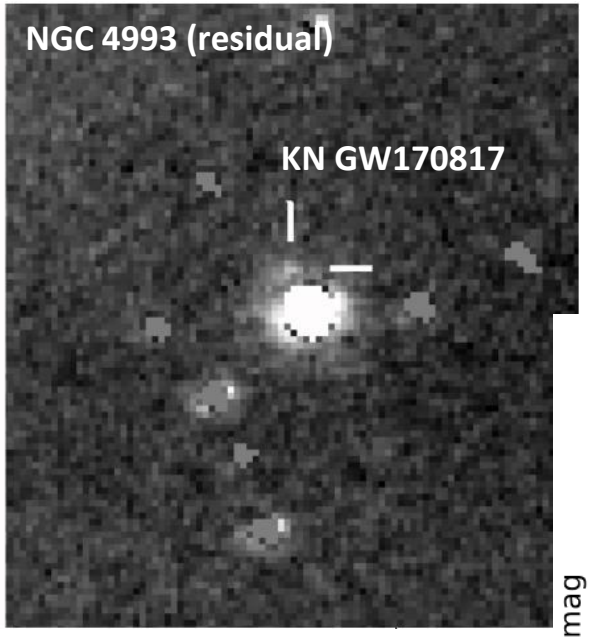
2m class single / 3m class single frame (CFHT, griJH)

The kilonova of GW170817 would have been detectable by almost all our instruments from 0.45 to ~10 days after the GW /GRB trigger time

SGRB & kilonova detection

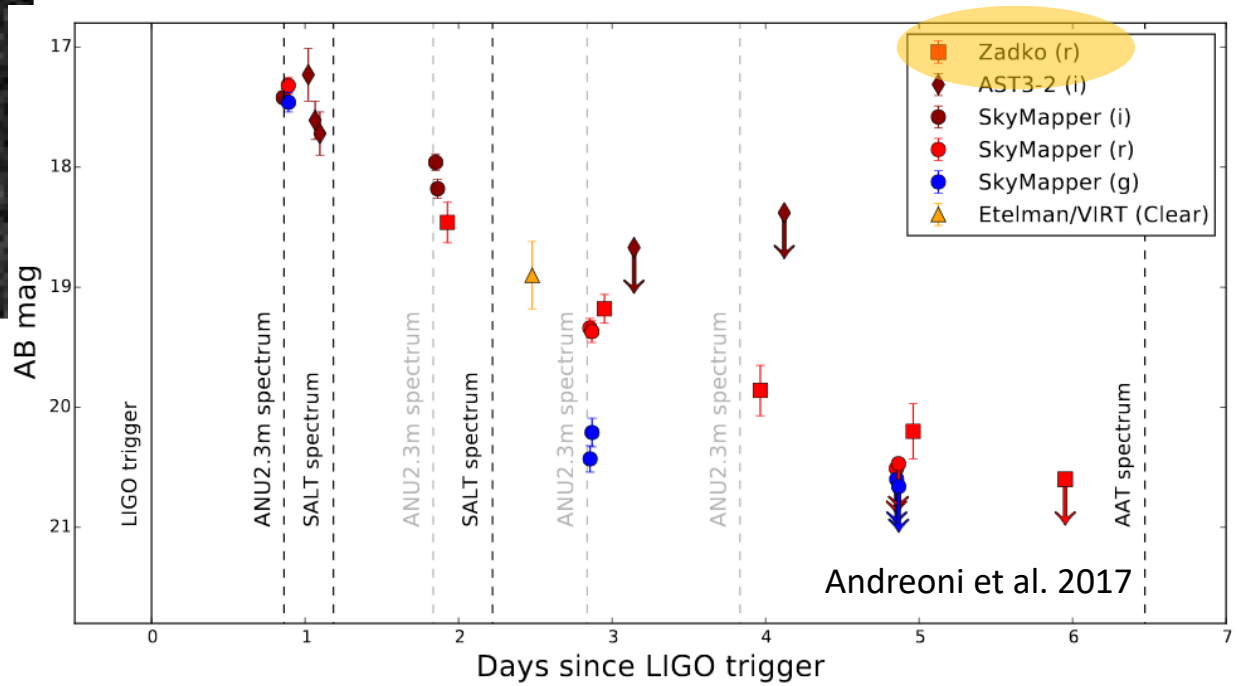
The case of GW 170817 (Zadko)





Zadko residual image of the GW170817 kilonova

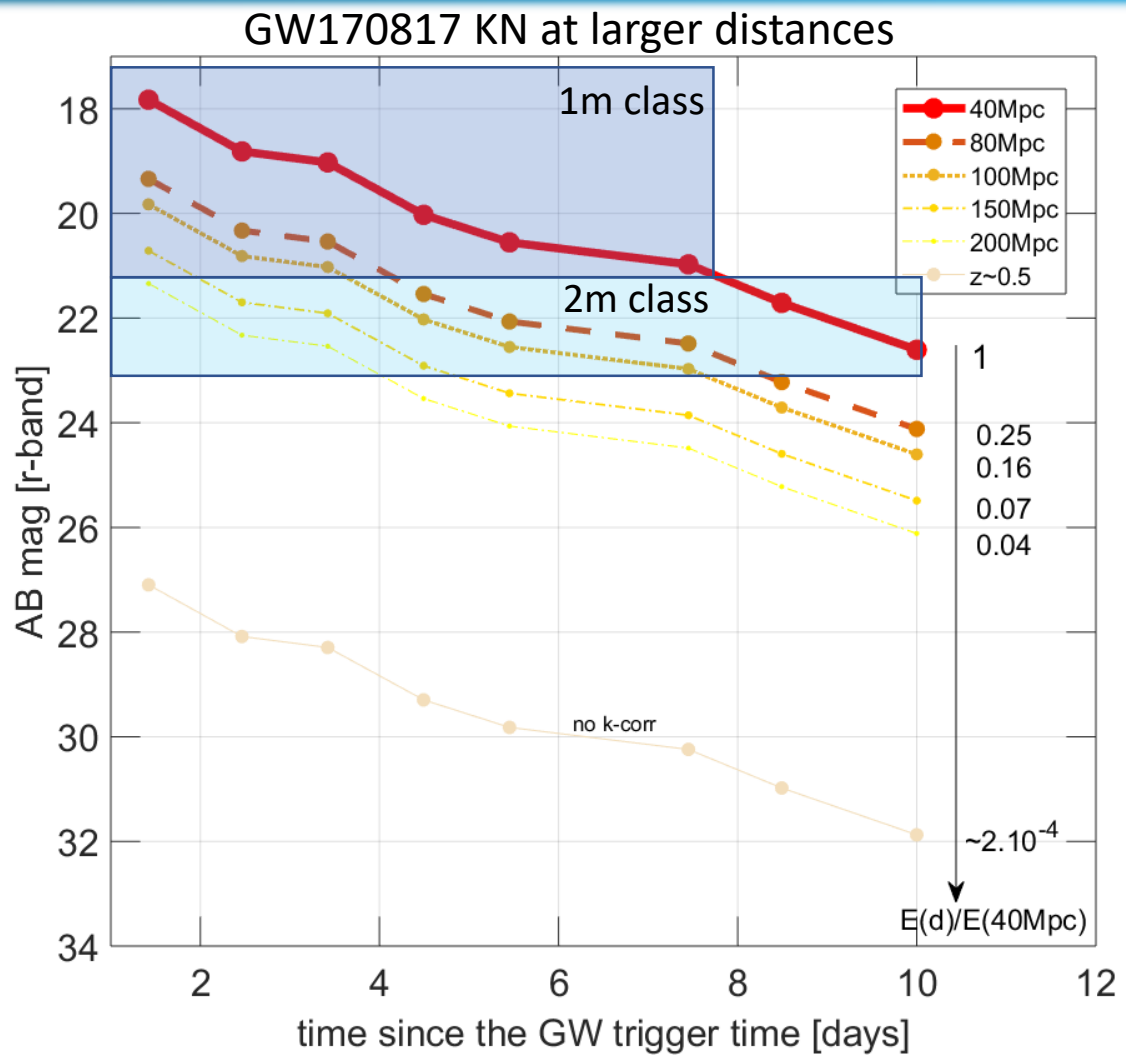
Optical light curve obtained by some Australian facilities



The Zadko telescope catched the optical counterpart of the GW170817 kilonova up to 5 days after the GW trigger time down to r = 20.2

SGRB & kilonova detection

and at larger distances…



Just by a distance effect, a GW170817-like kilonova is hard to catch with 1m class telescopes for D>100-150 Mpc (in r-band)

At D = 100Mpc, the KN signature could be still detectable (by 1m tel) within $T\text{-}T_{GW}$ < 2-3 days

General Conclusions

WE MUST BE READY TO FACE THE GW/O3 RUN CHALLENGES !

GRANDMA

- 16 telescopes + external partners for O3
- Wide variety of perf. : FoV [10' – 25°], fast response to a GW trigger <few secs/mins, photo/spectro, m_{lim} [16-23], Survey/Gal.target/ToO, continuous monitoring of the both sky hemisphere
- Powerful tools to manage the network + make the online OT classification + broadcast the results
- Public OT alerts will be released and we will follow-up OTs found by other teams

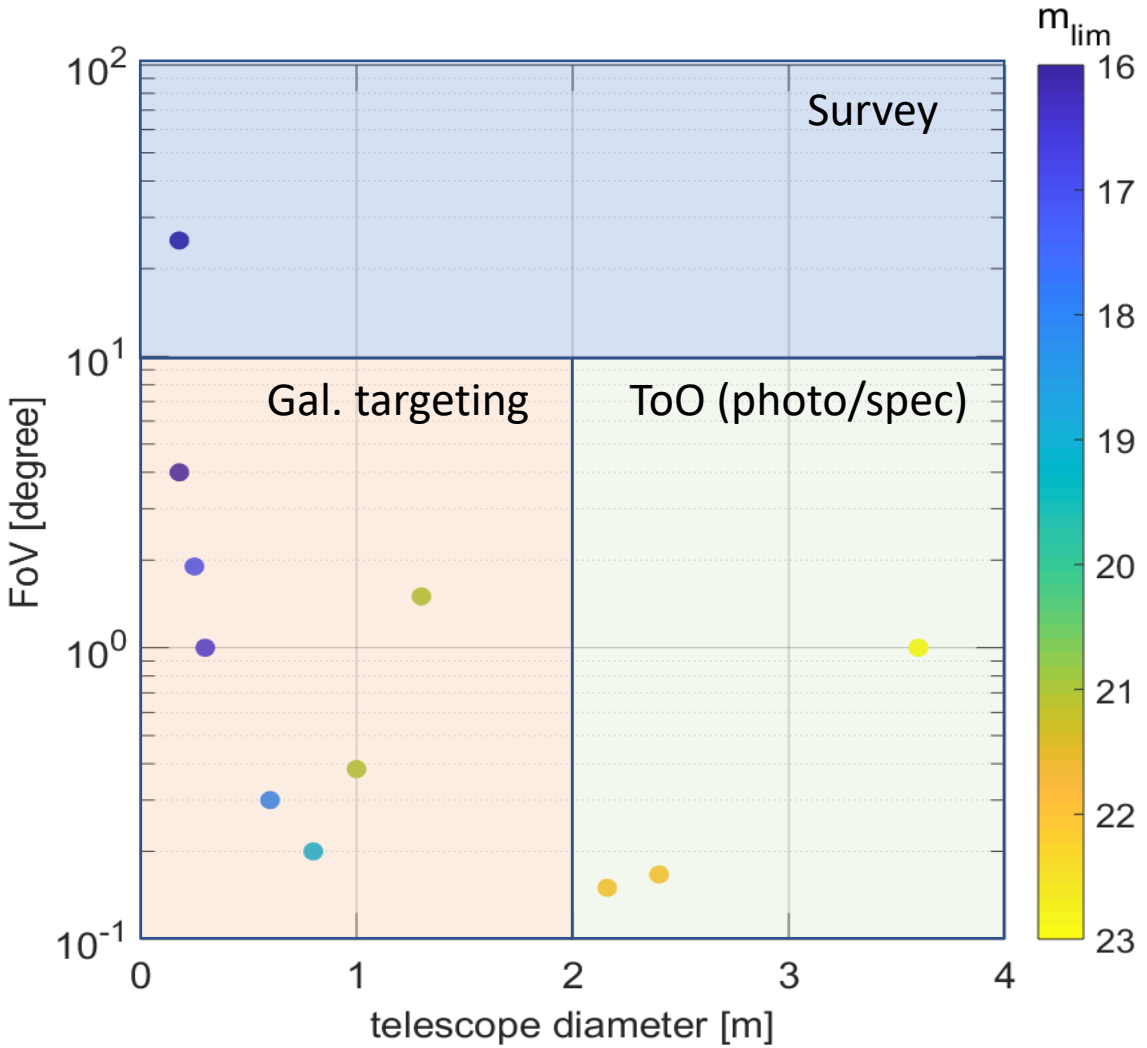
GRANDMA science

- Early detection of an « on-axis » BNS/SGRB afterglow if $T-T_0 < 6h$* / delayed emission of orphan afterglows
- Early detection of a BNS kilonova-like (GW170817) up to 100-150 Mpc within $T-T_0 < 2$ days (otherwise at 40Mpc detectable up to 10 days post GW trigger time)
- Color photometry + spectro of the SGRB afterglow and/or the KN
- Distance/redshift measurements
- Other unpredictable detections from BBHs and BNs too

* but at cosmological distance <z> = 0.5

Back-up

Individual performances



Survey mode

m_{lim} = [16-17]

Gal. target mode

m_{lim} = [16-21 -> 22]

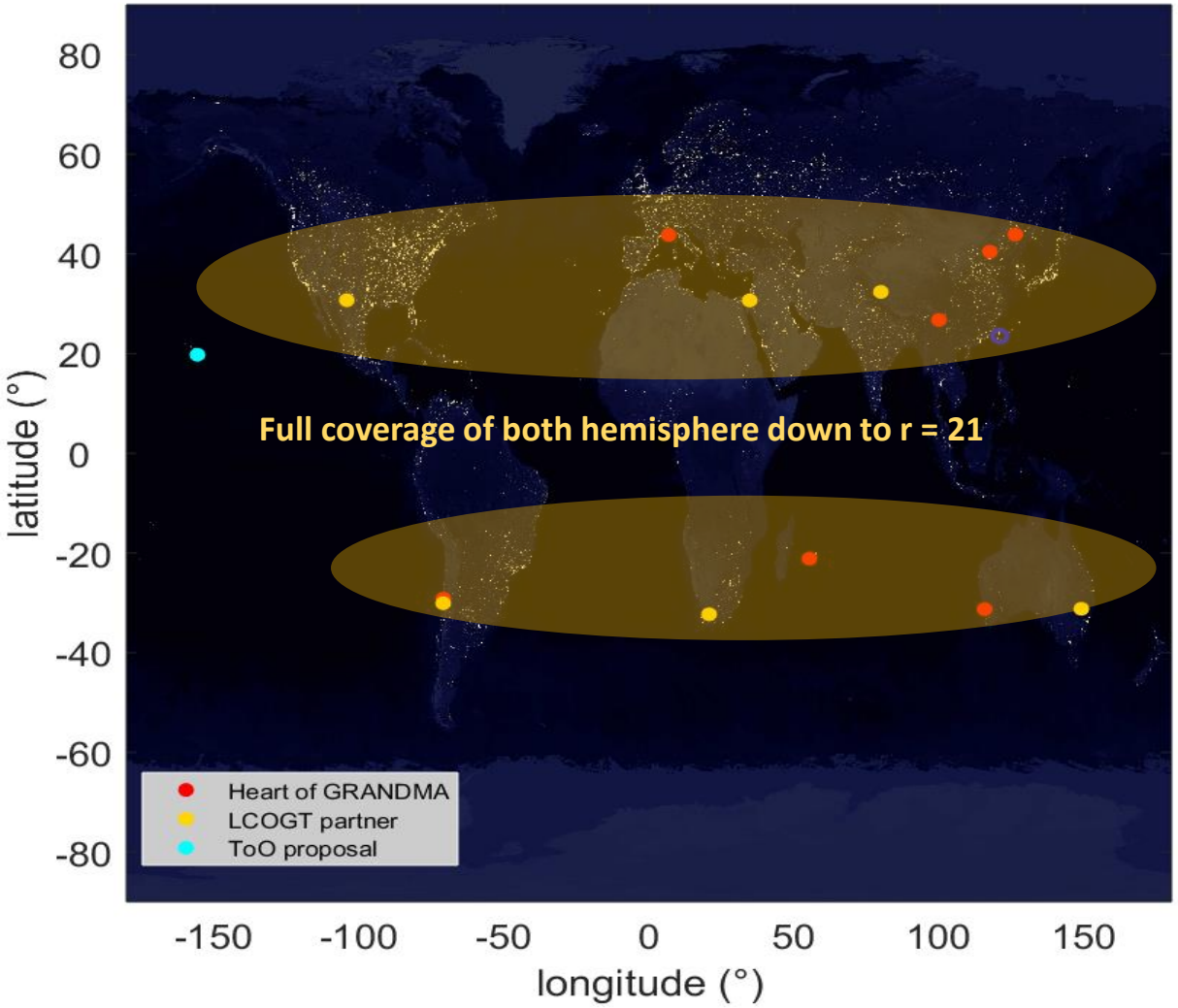
ToO mode

m_{lim} = [22-24] photo

m_{lim} ~ 18-19 spectro

GRANDMA

Collective performances with external partners



GRANDMA + LCOGT

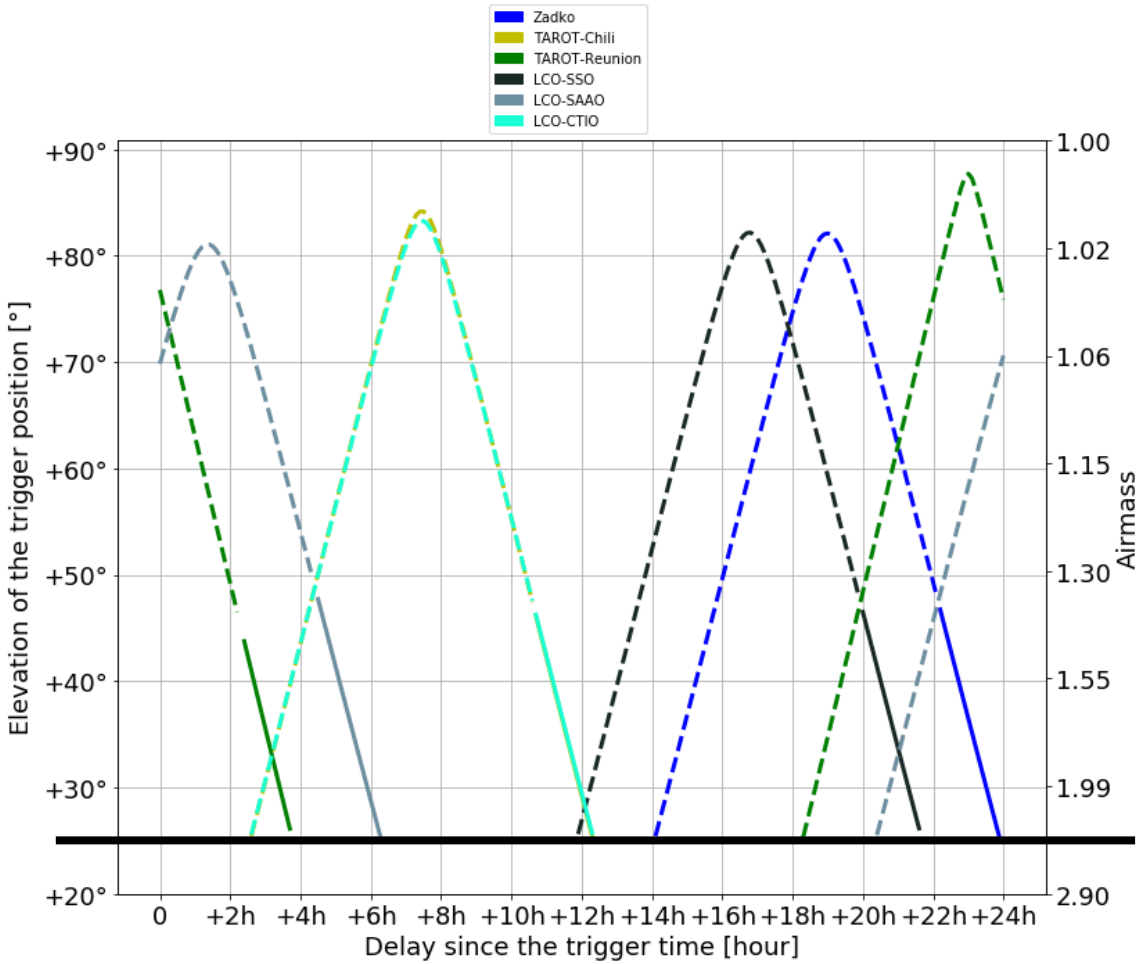
- Ensure the full coverage of the both hemisphere and so are able to have a quick answer to any trigger in the sky
- Continuous monitoring of the GW error box
- Quasi instantaneous vetting of fake candidates and/or confirmation of valuable OTs
- Ensure the high sampling of the GW/OT lightcurve in case of a detection
- Ensure spectroscopic measurement at almost any time for several candidates

1. Availability of each telescope and visibility of the trigger position

GW 170817A
Date : 12:41:04.000
Galaxy target : NGC 4993

Night time

Day time or HA<5hr



Same tools used in the LCOGT system

$Elev_{min}$ = 25°