

THE GRANDMA GW FOLLOW-UP NETWORK

GLOBAL RAPID ADVANCED NETWORK DEVOTED TO THE MULTI-MESSENGER ADDICTS (ANTIER ET AL. ARXIV: 1910.11261)

David Corre

Laboratoire Accélérateur Linéaire, Orsay, France



OUTLINE

GRANDMA CONCEPT AND OVERVIEW

GRANDMA INFRASTRUCTURE: ICARE

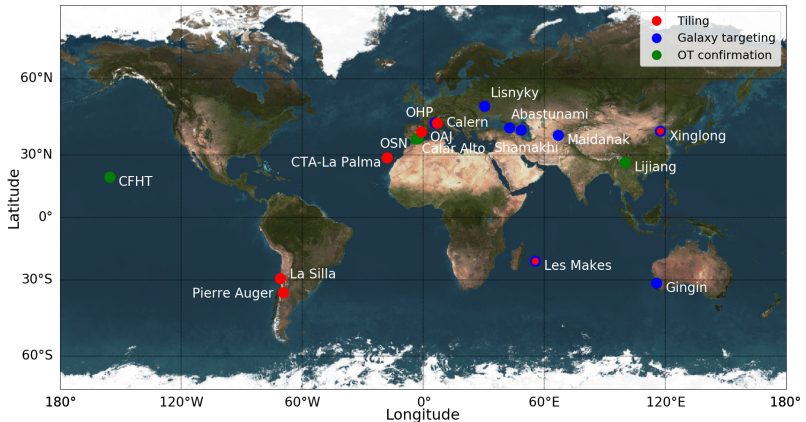
SUMMARY OF O3 FOLLOW-UP CAMPAIGN SO FAR

SUMMARY AND PERSPECTIVE

GRANDMA CONCEPT FOR GW-EM FOLLOW-UP

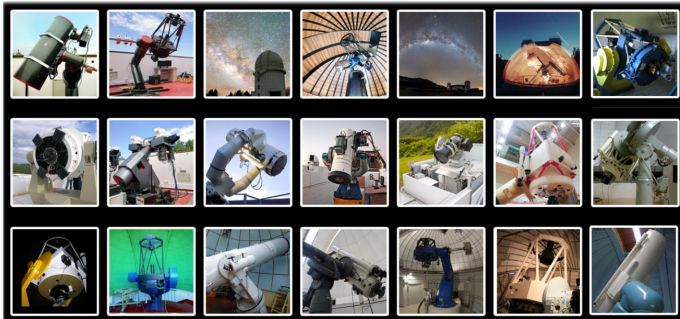
- ▶ Created in April 2018 by OCA (Nice), LAL (Orsay) and NAOJ (Beijing). P.I.: Sarah Antier.
- ▶ GWs can be anywhere → **Global coverage!**
- ▶ Discovery and follow-up network.
- ▶ Connect facilities that are not connected. Involve countries with limited resources in forefront science!
- ▶ Common infrastructure for all teams.
- ▶ Optimised observing strategy within the network: tiling + galaxy targeting.
- ▶ Citizen science project to involve amateur astronomers.

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- ▶ 23 telescopes, both robotic and "manual".
- ▶ 22 imaging, 4 spectroscopy facilities.
(img: 18-23 mag in typical observation, spec: 18-20 mag in 1h).



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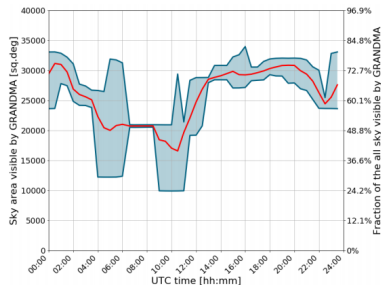
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Telescope Name	Location	Aperture (m)	FOV (deg)	Filters	3- σ limit (AB mag)	Maximum Night slot (UTC)
TAROT/TCH	La Silla Obs.	0.25	1.85×1.85	Clear, $g'r'i'$	18.0 in 60s (Clear)	06h-15h
CFHT/WIRCAM	CFH Obs.	3.6	0.35×0.35	JH	22.0 in 200s (J)	10h-16h
CFHT/MEGACAM	CFH Obs.	3.6	1.0×1.0	$g'r'i'z'$	23.0 in 200s (r')	10h-16h
Zadko	Gingin Obs.	1.00	0.17×0.12	Clear, $g'r'i'z'IC$	20.5 in 40s (Clear)	12h-22h
TNT	Xinglong Obs.	0.80	0.19×0.19	$BVR_C I_C$	19.0 in 300s (R_C)	12h-22h
Xinglong-2.16	Xinglong Obs.	2.16	0.15×0.15	$BVRI$	21.0 in 100s (R_C)	12h-22h
GMG-2.4	Lijiang Obs.	2.4	0.17×0.17	$BVRI$	22.0 in 100s (R_C)	12h-22h
UBAI/NT-60	Maidanak Obs.	0.60	0.18×0.18	$BVR_C I_C$	18.0 in 180s (R_C)	14h-00h
UBAI/ST-60	Maidanak Obs.	0.60	0.11×0.11	$BVR_C I_C$	18.0 in 180s (R_C)	14h-00h
TAROT/TRE	La Reunion	0.18	4.2×4.2	Clear	16.0 in 60s (Clear)	15h-01h
Les Males/T60	La Reunion.	0.60	0.3×0.3	Clear, BVR_C	19.0 in 180s (R_C)	15h-01h
Abastumani/T70	Abastumani Obs.	0.70	0.5×0.5	$BVR_C I_C$	18.2 in 60s (R_C)	17h-03h
Abastumani/T48	Abastumani Obs.	0.48	0.33×0.33	$UBVR_C I_C$	15.0 in 60s (R_C)	17h-03h
ShAO/T60	Shamakhly Obs.	0.60	0.28×0.28	$BVR_C I_C$	19.0 in 300s (R_C)	17h-03h
Lisnyky/AZT-8	Kyiv Obs.	0.70	0.38×0.38	$UBVR_C I_C$	20.0 in 300s (R_C)	17h-03h
TAROT/TCA	Calern Obs.	0.25	1.85×1.85	Clear, $g'r'i'$	18.0 in 60s (Clear)	20h-06h
IRIS	OHP	0.5	0.4×0.4	Clear, $u'g'r'i'z'$	18.5 in 60s (r')	20h-06h
T120	OHP	1.20	0.3×0.3	$BVRI$	20.0 in 60s (R)	20h-06h
OAJ/T80	Javalambre Obs.	0.80	1.4×1.4	r'	21.0 in 180s (r')	20h-06h
OSN/T150	Sierra Nevada Obs.	1.50	0.30×0.22	$BVR_C I_C$	21.5 in 180s (R_C)	20h-06h
CAHA/2.2m	Calar Alto Obs.	2.20	0.27×0.27	$u'g'r'i'z'$	23.7 in 100s (r')	20h-06h

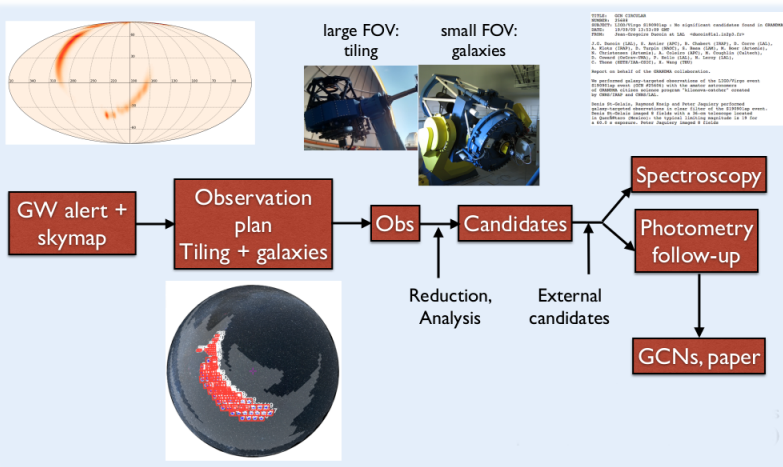
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- ▶ Covering >40% of the sky at all times
- ▶ **Constantly looking for new members!**



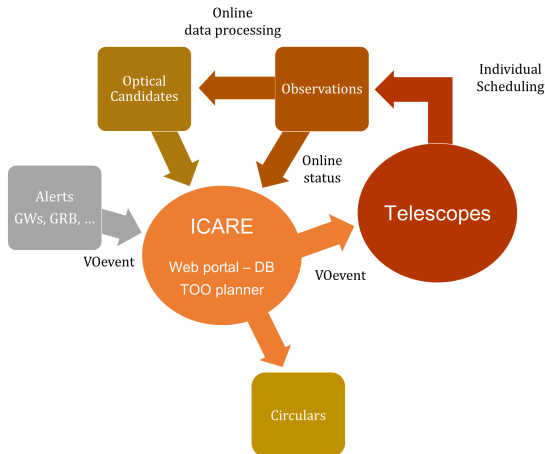
COORDINATED OBSERVATIONS



INFRASTRUCTURE REQUIREMENTS

- ▶ Infrastructure must allow to:
 - ▶ automatise MM follow-up from alert reception to the sending of **coordinated observation plans** to a network of independent telescopes, and report of observations.
 - ▶ Web portal to monitor in real-time the network follow-up.
 - ▶ Centralise information in a **single common database**.
 - ▶ Homogenise the photometry with a common detection pipeline.
- ▶ Common communication protocol (IVOA based).
- ▶ Open source.
- ▶ Adaptable to any network of telescopes.

ICARE: INTERFACE AND COMMUNICATION FOR ADDICTS OF THE RAPID FOLLOW-UP IN MULTI-MESENGER ERA (CORRE ET AL. IN PREP)

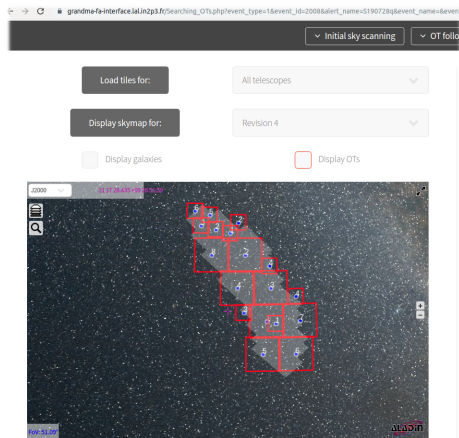


AUTOMATIC COORDINATED OBSERVATION PLANS

- ▶ Automatic scheduler for each telescope.
- ▶ Observations coordinated within the network using *gwemopt*¹.
- ▶ Tiling or galaxy targeting approach depending on telescopes FoV.
- ▶ Galaxy catalog: GLADE, Mangrove².
- ▶ Communication protocol : standardised VOEvent sent through a broker (comet).

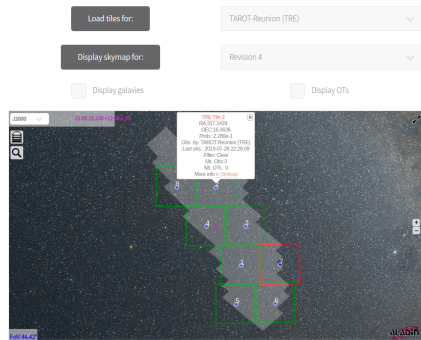
¹ <https://github.com/mcoughlin/gwemopt>

² Ducoin, Corre et al., submitted to MNRAS, <https://arxiv.org/abs/1911.05432>



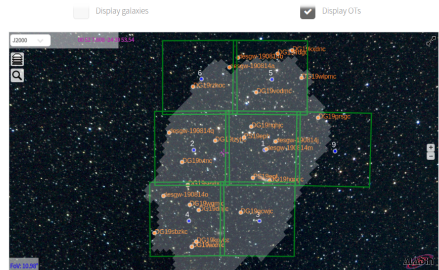
REAL TIME MONITORING OF THE FOLLOW-UP

- ▶ Visualisation of the GW skymap region using MOC and Aladin.
- ▶ Display each tile sent to the telescopes.
- ▶ Status of the observations (time, airmass, lim. mag, ...)
- ▶ Localise optical candidates, even found by other teams.
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WEB INTERFACE: OPTICAL COUNTERPART CANDIDATES

- ▶ Reported through a python API.
- ▶ Internal rating.
- ▶ Visual inspection of sub-images with respect to catalogs (PS1, Gaia) using Aladin lite.
- ▶ Multi-wavelength light curve to help for characterisation.
- ▶ OT candidate characterisation performed using machine learning on photometric light curve + spectroscopy.
- ▶ Observability in the next 24h for all network observatories.
- ▶ Send observation request to a specific telescope (VOEvent).

GW FOLLOW-UP: GCN CIRCULAR GENERATION

- ▶ Help the shifters to make the results rapidly available to the community.
- ▶ Automatic GCN circular generation summarising the follow-up campaign, and OT candidates.
- ▶ Send directly from the web portal to <https://gcn.gsfc.nasa.gov/>

Send GCN circular summarising GRANDMA follow-up campaign

Please read carefully and correct the circular if necessary before sending the circular!

Display GCN and Telescope for

Revision 1

Select telescopes for generating GCN.

(Only telescopes that have reported observations are displayed)

Tiling strategy:

☒ TAROT-Calern (TCA)
 ☐ TAROT-Chil (TCH)
 ☒ TAROT-Reunion (TRE)
 ☒ FZU-Auger
 ☐ FZU-CTA-N

Prepare GCN

Galaxy targeting strategy:

Prepare GCN

Title:

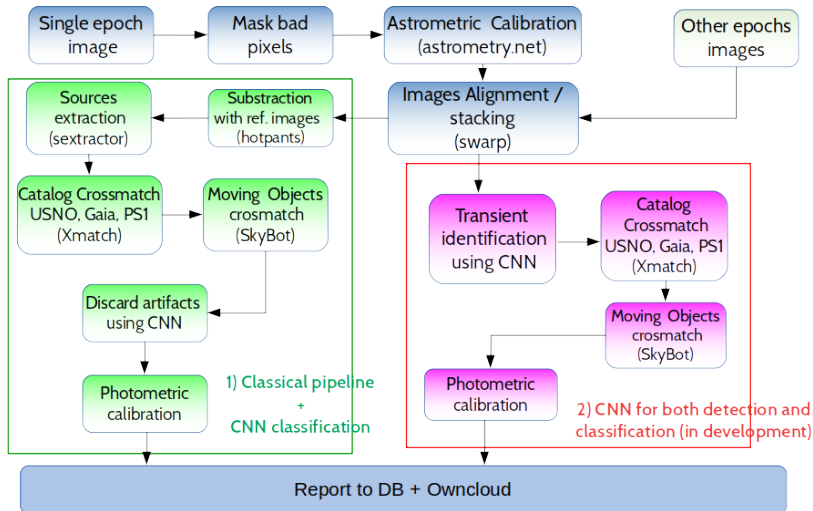
L150/Virgo S191109d : TAROT-Calern (TCA) - FZU-Auger - TAROT-Reunion (TRE) / GRANDMA observation report.

D. Corre (LAL), N. Christensen (Artemis), M. Coughlin (Caltech), W. Lin (THU), C. Stachis (Artemis), M. Boer (Artemis), L. Eymar (Artemis), S. Karpov (FZU), A. Klotz (IRAP), M. Masek (FZU), K. Nayana (Artemis, IRAP), S. Ancier (APC), A. Coleiro (APC), D. Coward (OZGrav-IMa), J.-G. Duciin (LAL), B. Gendre (OZGrav-IMa), P. Hello (LAL), D. A. Kann (HETH/IAA-CSIC), N. Kochiashvili (Ilium), C. Lachaud (APC), N. Leroy (LAL), C. Thone (HETH/IAA-CSIC), D. Turpin (MAGC), X. Wang (THU)

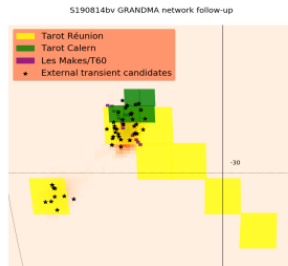
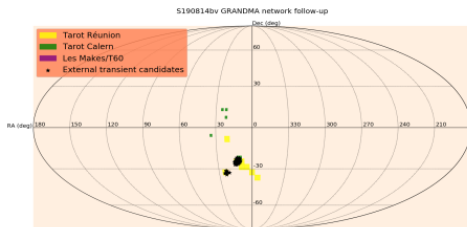
Report on behalf of the FZU-Auger, TAROT-Calern (TCA), TAROT-Reunion (TRE) and GRANDMA collaborations.

We performed tiled observations of L150/Virgo S191109d event with the

COMMON DETECTION PIPELINE (IN DEVELOPMENT)



EXAMPLE OF FOLLOW-UP FOR S190814BV



- ▶ NSBH (99%), $D_{lum} = 267 \pm 54$ Mpc, 90% error box: 23 deg².
- ▶ Observations: 31min after trigger, total: 18h.
- ▶ 162 deg², 91% of latest skymap covered. (large initial skymap)
- ▶ No counterpart found to 19mag.

SUMMARY OF O3A FOLLOW-UP: GLOBAL EFFORT

	GW alert rate	Telescopes involved	Time available	Delay	Nom. sensitivity GW Follow-up	Nom. sensitivity counterpart Follow-up	Spectroscopy	Other-wave length
GRANDMA	27	23 in 17 sites	unlimited	~ minutes	17 – 21 (c,r)	~23	~ 19 mag	gamma
GROWTH	8	~60 in 19 sites	few hours per alerts	~ hours	20.5 (g, r) ~22 (r, z)	~23	~ 22 mag	gamma radio
MASTER	31	14 in 7 sites	unlimited	~ minutes	~ 19 (c)	~20	no	–
GRAWITA	~8	~10 in 3 sites	few hours per alert Asiago unlimited	~ hours	16 – 22 (r)	~23	~ 22 mag collab. ENGRAVE	radio
GOTO	~5	2 in 2 sites	few hours per alerts	~ dozen of minutes	~20 (l)	~21	–	–
SVOM	11	7 in 3 sites	unlimited	~ hours	16 – 18 (c,r)	~21	~ 19 mag	Future
PS1 – Atlas	~7	2 in 1 site	few hours per alerts	~ hours	~19.5 (o) ~ 21 mag (i)	~22	collab. ENGRAVE	–

- ▶ 22 GCNs on 18 different events.
- ▶ **The first six months of the Advanced LIGO's and Advanced Virgo's third observing run with GRANDMA.** *Antier et al., MNRAS, 2019*

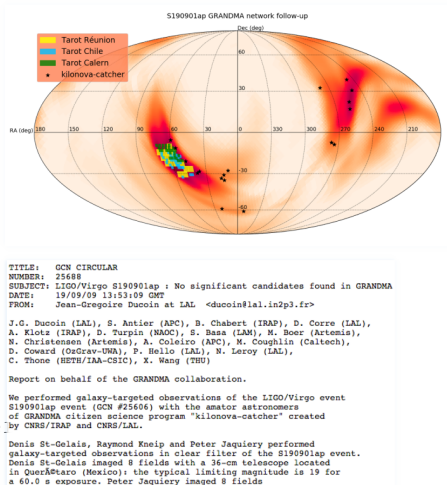
CITIZEN SCIENCE PROGRAM

- ▶ More than 40 (amateurs) participants spread all over the world.
- ▶ 15-30cm telescopes.
- ▶ Observations for S190814bv and S190901ap analysis by GRANDMA.
- ▶ GCN on S190101ap.
- ▶ <https://grandma-kilonovacatcher.lal.in2p3.fr>



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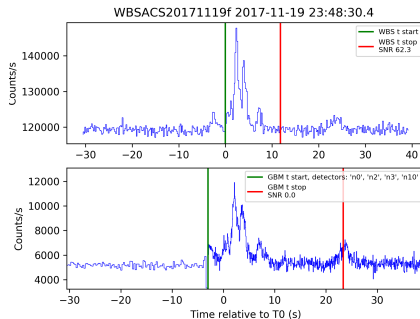
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SUMMARY AND PERSPECTIVES

OPTICAL NETWORK BUT NOT ONLY... GRB SEARCHES

- ▶ Fermi/GBM, INTEGRAL/SPI-ACS daily data
- ▶ Offline detection of GBM and SPI-ACS gamma-ray transients with wild binary segmentation³
- ▶ Prospectives to include spatial data analysis tools into the ICARE platform to create synergies between space and ground systems



³ Antier, Barynova et al., submitted to MNRAS, <https://arxiv.org/abs/1909.10002>

SUMMARY AND PERSPECTIVES

SUMMARY

- ▶ GRANDMA is a truly global network for GW-EM follow-up (and continuously getting expanded).
- ▶ Inclusion of many groups from countries not involved in follow-up.
- ▶ End to end infrastructure → attractive for new telescopes.
- ▶ Infrastructure in active development. Open source release soon (<https://gitlab.in2p3.fr/icare/icare>)

PERSPECTIVE

- ▶ Neutrinos and GRB follow-up. (MoU with ANTARES, KM3NET)
- ▶ Between O3 and O4: kilonovae search based on GRB alert and optical surveys.