

# ICARE: INTERFACE AND COMMUNICATION FOR ADDICTS OF THE RAPID FOLLOW-UP IN MULTI-MESSENGER ERA

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# MOTIVATIONS

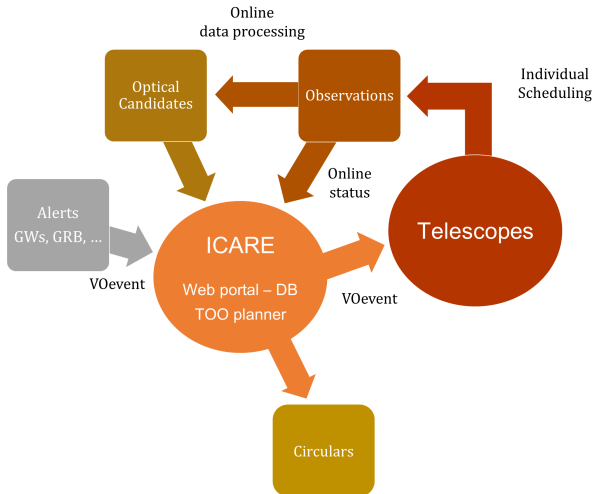
## MOTIVATIONS

- ▶ Development started <1 year ago for GRANDMA collaboration.
- ▶ Network of independent telescopes, not necessarily familiar to the transient science.

## REQUIREMENTS

- ▶ Automatic reception of MM alerts (GW, GRB, Neutrinos).
- ▶ Coordinating observations by distant and independent telescopes spread all over the world.
- ▶ Common communication protocol (IVOA based).
- ▶ Central database + web interface for real-time monitoring.
- ▶ Homogeneous photometry within a network of independent telescopes.

# INFRASTRUCTURE OVERVIEW



# ALERT RECEPTION

- ▶ Python script in charge of listening the various channels (LVC, Swift, Fermi, . . .)
- ▶ Communication protocol : VOEvent
- ▶ Specific information are extracted from the VOEvent and store in the database (Sky localisation, distance of the event, SNR, etc)

```
<Param name="GraceID" dataType="string" value="S190901ap" ucd="meta.id">
  <Description>Identifier in GraceDB</Description>
</Param>
<Param name="AlertType" dataType="string" value="Update" ucd="meta.version">
  <Description>VOEvent alert type</Description>
</Param>
<Param name="HardwareInj" dataType="int" value="0" ucd="meta.number">
  <Description>Indicates that this event is a hardware injection if 1, no if 0</Description>
</Param>
<Param name="OpenAlert" dataType="int" value="1" ucd="meta.number">
  <Description>Indicates that this event is an open alert if 1, no if 0</Description>
</Param>
<Param name="EventPage" dataType="string" value="https://gracedb.ligo.org/superevents/
S190901ap/view/" ucd="meta.ref.url">
  <Description>Web page for evolving status of this GW candidate</Description>
</Param>
<Param name="Instruments" dataType="string" value="L1,V1" ucd="meta.code">
  <Description>List of instruments used in analysis to identify this event</Description>
</Param>
<Param name="FAR" dataType="float" value="7.02720336974e-09" ucd="arith.rate;stat.falsealarm
unit="Hz">
  <Description>False alarm rate for GW candidates with this strength or greater</
Description>
</Param>
<Param name="Group" dataType="string" value="CBC" ucd="meta.code">
  <Description>Data analysis working group</Description>
</Param>
<Param name="Pipeline" dataType="string" value="gstlal" ucd="meta.code">
  <Description>Low-latency data analysis pipeline</Description>
</Param>
<Param name="Search" dataType="string" value="AllSky" ucd="meta.code">
  <Description>Specific low-latency search</Description>
</Param>
<Param type="GW_SKYMAP" name="LALInference_v2">
  <Param name="skymap.fits" dataType="string" value="https://gracedb.ligo.org/api/
superevents/S190901ap/files/LALInference_v2.fits.gz" ucd="meta.ref.url">
    <Description>Sky Map FITS</Description>
  </Param>
</Group>
<Group type="Classification">
  <Param name="BNS" dataType="float" value="0.860671959529" ucd="stat.probability">
    <Description>Probability that the source is a binary neutron star merger (both
objects lighter than 3 solar masses)</Description>
  </Param>
  <Param name="NSBH" dataType="float" value="0.0" ucd="stat.probability">
    <Description>Probability that the source is a neutron star-black hole merger (primary
heavier than 5 solar masses, secondary lighter than 3 solar masses)</Description>
```

# DATABASE + WEB INTERFACE + OWNCLLOUD

## DATABASE (LAL)

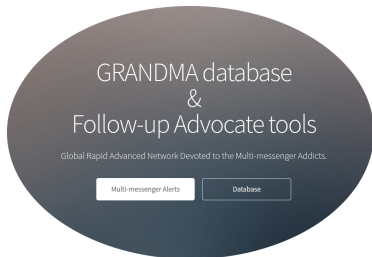
- ▶ MySQL / Apache.
- ▶ Store information regarding events, observations plans and reports, photometry, GCN circulars.

## WEB INTERFACE (LAL)

- ▶ HTML5 / PHP7 / javascript / customised CSS / Python 3 scripts.
- ▶ Real time monitoring of the follow-up.

## OWNCLOUD (LAL)

- ▶ client synchronisation between telescopes and LAL servers.
- ▶ Store obs. plans and candidates sub-images



# COMMUNICATION WITH TELESCOPES

## TOWARDS TELESCOPES

- ▶ Communication protocol : standardised VOEvent sent through a broker (comet)
- ▶ Observation plans are coordinated within the network using *gwemopt*<sup>1</sup> using either a tiling or galaxy targeting approach (see *J-G. Ducoin's talk*)

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

# COMMUNICATION WITH TELESCOPES

## TOWARDS T

- Commun broker (c
- Observat *gwemopt* *J-G. Duc*

```
</group>
<Param dataType="Int" name="Obs_req" ucd="meta.number" value="1">
  <Description>Set to 1 if observation are required, 0 to stop the observations</Description>
</Param>
<table name="Obs_plan">
  <Description>Titles for the observation plan</Description>
  <Field dataType="Int" name="Grid_id" ucd="" unit="">
    <Description>ID of the grid of FOV</Description>
  </Field>
  <Field dataType="Float" name="Ra" ucd="pos.eq.ra" unit="deg">
    <Description>The right ascension at center of fov in equatorial coordinates</Description>
  </Field>
  <Field dataType="Float" name="Dec" ucd="pos.eq.ra" unit="deg">
    <Description>The declination at center of fov in equatorial coordinates</Description>
  </Field>
  <Field dataType="Float" name="Os_grade" ucd="meta.number" unit="None">
    <Description>Gives the importance of the tile/galaxy to observe</Description>
  </Field>
  <Data>
    <TR>
      <TD>1.0</TD>
      <TD>194.9171</TD>
      <TD>-24.5454</TD>
      <TD>0.0029</TD>
    </TR>
    <TR>
      <TD>2.0</TD>
      <TD>200.884</TD>
      <TD>-24.5454</TD>
      <TD>0.0028</TD>
    </TR>
    <TR>
      <TD>3.0</TD>
      <TD>198.895</TD>
      <TD>-24.5454</TD>
      <TD>0.0027</TD>
    </TR>
    <TR>
      <TD>4.0</TD>
      <TD>196.9061</TD>
      <TD>-24.5454</TD>
      <TD>0.0027</TD>
    </TR>
    <TR>
      <TD>5.0</TD>
      <TD>192.9282</TD>
      <TD>-24.5454</TD>
      <TD>0.0026</TD>
    </TR>
    <TR>
      <TD>6.0</TD>
      <TD>199.5652</TD>
      <TD>-22.7273</TD>
      <TD>0.0023</TD>
    </TR>
  </Data>
</table>
```

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## FROM TELESCOPES

- ▶ Communication protocol : HTTP POST method + Owncloud
- ▶ Reporting:
  - ▶ Real-time observation status
  - ▶ Optical counterpart candidates photometry + sub-images

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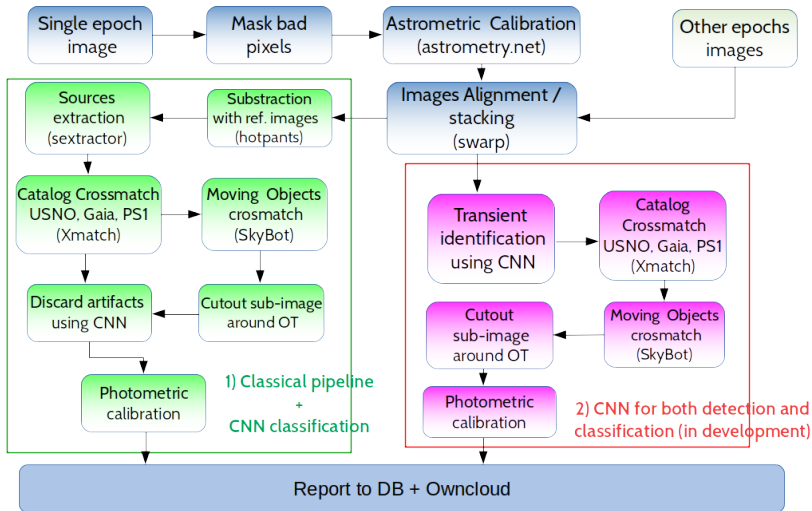
<sup>1</sup><https://github.com/mcoughlin/gwemopt>



## COMMON DETECTION PIPELINE (IN DEVELOPMENT)

- ▶ Developed in Python 3
- ▶ Detection pipeline run on telescope side to avoid data transfer and the lack of server with huge storage capacity. Configuration adapted to each telescope.
- ▶ For the machine learning development, access to GPU server at the IN2P3 Centre de Calcul at Lyon.

## COMMON DETECTION PIPELINE (IN DEVELOPMENT)



## GW FOLLOW-UP: OBSERVATION PLAN

- ▶ MOC visualisation of the GW 90 % credible region using Aladin.
- ▶ Display each tile sent to the telescopes.
- ▶ Status of the observations (time, airmass, lim. mag, ...)
- ▶ Localise optical candidates, even found by other teams.

The screenshot shows the Aladin web interface. At the top, there is a browser address bar with the URL: `grandme-fe-interface.lal.in2p3.fr/Searching_OTs.php?event_type=1&event_id=2008&alert_name=G190729&event_name=6event1`. Below the address bar, there are two dropdown menus: "Initial sky scanning" and "OT follow-up".

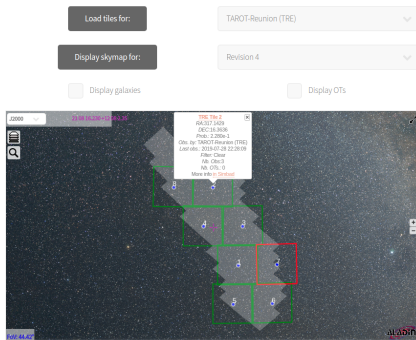
Below these are two buttons: "Load tiles for:" and "Display skymap for:". To the right of "Load tiles for:" is a dropdown menu set to "All telescopes". To the right of "Display skymap for:" is a dropdown menu set to "Revision 4".

Below the buttons are two checkboxes: "Display galaxies" (unchecked) and "Display OTs" (checked).

The main part of the screenshot is a dark sky image with a grid of red-outlined rectangular tiles overlaid on it. Each tile contains a small blue icon representing a telescope. The tiles are arranged in a roughly triangular pattern, representing the 90% credible region for a gravitational wave event. The interface includes a search icon on the left and a "Nov 31 20" timestamp in the bottom left corner.

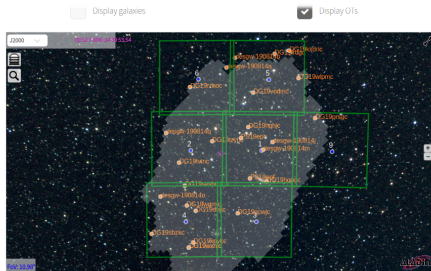
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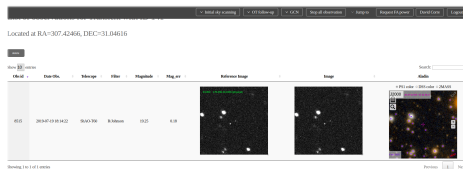
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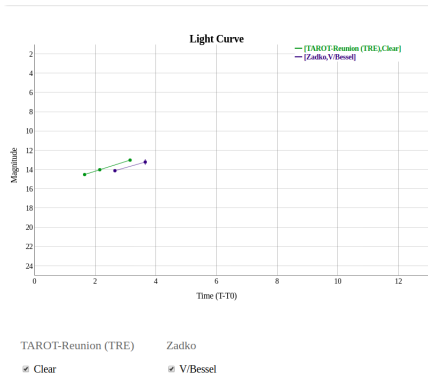
## GW FOLLOW-UP: OPTICAL COUNTERPART CANDIDATES

- ▶ Can be reported both automatically and manually.
- ▶ Internal rating.
- ▶ Visual inspection of sub-images with respect to catalogs (PS1, Gaia).
- ▶ Multi-wavelength light curve to help for characterisation.
- ▶ Observability in the next 24h for all network observatories.
- ▶ Send observation request to a specific telescope (VOEvent).



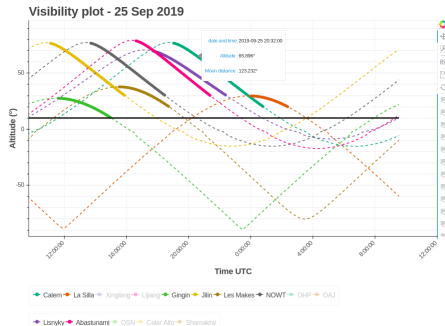
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# GW FOLLOW-UP: GCN CIRCULAR GENERATION

- ▶ Automatic GCN circular generation summarising the follow-up campaign.
- ▶ Automatic GCN circular generation for candidate follow-up. (in dev.)
- ▶ Send directly from the web portal to <https://gcn.gsfc.nasa.gov/>

The screenshot shows a web interface for generating GCN circulars. At the top, there are navigation tabs: 'Initial sky scanning', 'OT follow-up', 'GCN', 'Setup all observation', and 'Jump to'. The main heading is 'Send GCN circular summarising GRANDMA follow-up campaign'. Below this, a message reads: 'Please read carefully and correct the circular if necessary before sending the circular!'. There are two input fields: 'Display GCN and Telescope for:' and 'Revision 4'. A 'Telescope:' dropdown menu is set to 'TAROT-Reunion (TRE)', and a 'Load GCN' button is visible. The 'Title:' field contains the text: 'LIGO/Virgo S190720q : TAROT-Reunion (TRE)/GRANDMA observation report.'. The main content area displays a list of authors: 'D. Corre (LAL), S. Beradze (Illiuni), M. Coughlin (Caltech), M. Vardosanidze (Illiuni), X. Zhang (THU), M. Boer (Artemis), N. Christensen (Artemis), L. Eymar (Artemis), A. Klotz (IRAP), K. Naysena (Artemis, IRAP), S. Antier (APC), S. Basa (LAM), D. Cosard (OzGrav-UMA), J.G. Ducoin (LAL), B. Sendre (OzGrav-UMA), P. Hello (LAL), C. Lachaud (APC), N. Leroy (LAL), D. Turpin (NAOC)'. Below the author list, it states: 'Report on behalf of the TAROT network and GRANDMA collaborations.' and 'We performed tiled observations of LIGO/Virgo S190720q event with the TAROT-Reunion (TRE) telescope operating in the visible located at Les Mages astronomical observatory. The observation started on 07/20/19 20:45:51 UTC which corresponds approximately to 841 minutes after the trigger time.'

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LIGO/Virgo S190728q : TAROT-Reunion (TRE)/GRANDMA observation report.

We performed the following tiled observations :

Tstart [UTC]	TEnd [UTC]	RA [deg]	DEC [deg]	Proba [%]
2019-07-28 20:45:51	2019-07-29 01:07:43	313.954	12.273	12.5
2019-07-28 21:04:24	2019-07-29 15:52:40	318.909	4.891	4.9
2019-07-28 21:17:34	2019-07-30 17:07:57	321.429	16.364	4.4
2019-07-28 21:49:30	2019-07-29 08:29:13	315	4.091	4.9
2019-07-28 22:21:35	2019-07-28 22:28:09	317.143	16.364	22.8
2019-07-28 22:33:49	2019-07-28 22:40:17	318.139	12.273	10.4
2019-07-28 23:05:38	2019-07-29 08:54:33	314.483	8.182	26.7

TStart and TEnd refers respectively to the time of the first and last exposure for a given tile. Observations are not necessarily continuous in this interval.  
The Probability refers to the 2D spatial probability of the GW skymap enclosed in a given tile. Each tile is 4.2x4.2 degrees. These observations cover about 86% of the cumulative probability of the skymap.  
The typical limiting magnitude is 17.0 for a 60.0 s exposure.

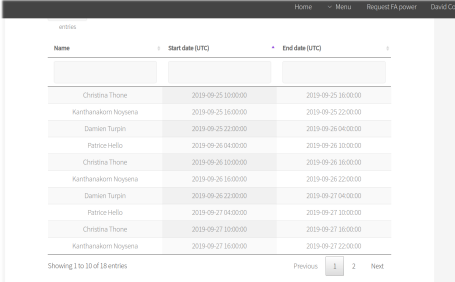
# GW FOLLOW-UP: SHIFT SYSTEM

- ▶ ICARE includes a shift system.
- ▶ Special actions only feasible by the shifter on duty.
- ▶ Logbook to communicate between shifters.

The screenshot displays a web interface for the ICARE shift system. At the top, a navigation bar includes links for Home, Menu, Request FA power, and David Corre. The main content is divided into two columns. The left column, titled 'Current FA : Christina Thone', features a green circular icon with a white mountain peak. Below the icon, a paragraph explains that users can correct their shift attribution in the list below. Two dark grey buttons are provided: 'Change current shift for me today' and 'Change next shift for me today'. The right column, titled 'Request the FA power', features a red circular icon with a white lightning bolt. A paragraph explains that users can request FA power in a hurry, even if they are not the current FA, and that this is for emergencies. A red button labeled 'I have the FA Power' is positioned below the text. At the bottom of this column, it says 'By the power of Geydali'.

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The screenshot shows a web interface for the ICARE shift system. At the top, there are navigation links: Home, Menu, Request FA power, and David Cor. Below the navigation is a table with the following columns: Name, Start date (UTC), and End date (UTC). The table contains 10 rows of shift assignments, alternating between three shifters: Christina Thone, Karthanskom Noysena, and Damien Turpin. The shifts are scheduled in 24-hour blocks. At the bottom of the table, there is a pagination control showing 'Showing 1 to 10 of 18 entries' and buttons for 'Previous', '1', '2', and 'Next'.

Name	Start date (UTC)	End date (UTC)
Christina Thone	2019-09-25 10:00:00	2019-09-25 16:00:00
Karthanskom Noysena	2019-09-25 16:00:00	2019-09-25 22:00:00
Damien Turpin	2019-09-25 22:00:00	2019-09-26 04:00:00
Patrice Hello	2019-09-26 04:00:00	2019-09-26 10:00:00
Christina Thone	2019-09-26 10:00:00	2019-09-26 16:00:00
Karthanskom Noysena	2019-09-26 16:00:00	2019-09-26 22:00:00
Damien Turpin	2019-09-26 22:00:00	2019-09-27 04:00:00
Patrice Hello	2019-09-27 04:00:00	2019-09-27 10:00:00
Christina Thone	2019-09-27 10:00:00	2019-09-27 16:00:00
Karthanskom Noysena	2019-09-27 16:00:00	2019-09-27 22:00:00

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OT follow-up GCN Stop all observation Jump to Request FA power David Corre Logout

TAROT-Reurion (TRE)

Revision 1

Display OTs

Logbook

Show 5 Search:

entries

Date	Comments
2019-09-23 22:01:16	There are report of no counterpart candidate from AGILE, ANTARES, and HAWC (see GCN). No significant identification matches the GW event. Tiles were sent to TCA, TCH, and TRE. TRE images are being analyzed through TAROT's transient search pipeline.
2019-09-23 13:35:47	Daylight for all possible tiling observations. Too far for galaxy targeting. We'll wait a bit and see what comes out of this alert.
2019-09-23 13:26:22	There is no GRBs alert since the last was GRB190921A at 16:45:55 UT on 21 Sep 2019, probably it is too far to detect.

Showing 6 to 8 of 8 entries Previous 1 2 Next

## SUMMARY

- ▶ ICARE infrastructure allows 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 common database.
  - ▶ Homogenise the photometry with a common detection pipeline.
- ▶ In operation for GRANDMA → continuous active development.
- ▶ End to end infrastructure → attractive for new telescopes.
- ▶ Adaptable to any network of telescopes. (Alert reception, obs. plan production and delivery are also used for SVOM).

## SUMMARY

- ▶ All the codes will be **open source** and available soon at:  
<https://gitlab.in2p3.fr/icare/icare>

