IVOA standards in a multi-messenger context: short- and long-term projects

IVOA May 2023 Interoperability Meeting

Giuseppe Greco, Mateusz Bawaj, Roberto de Pietri, Gergely Dálya, Marica Branchesi, Michele Punturo, Helios Vocca, Flavio Travasso, Maria Lisa Brozzetti, Tobia Matcovich and the CDS team

Testing and implementations

Developments from 2014 to 2023

- ASTERICS DADI ESFRI Forum & Training Event 1 – 3 & 4 December, 2015 – Trieste.
- ASTERICS DADI Technology Forum 2 – 7 & 8 March, 2016 – Edinburgh.
- DADI Meeting on Gravitational Waves – 31 May–1 June 2016 – Strasbourg.
- ASTERICS DADI ESFRI Forum & Training Event 2, 13 & 14 December, 2017 – Trieste.

IVOA: Northern Spring 2016 Interoperability Meeting

Focus session from Mark Allen

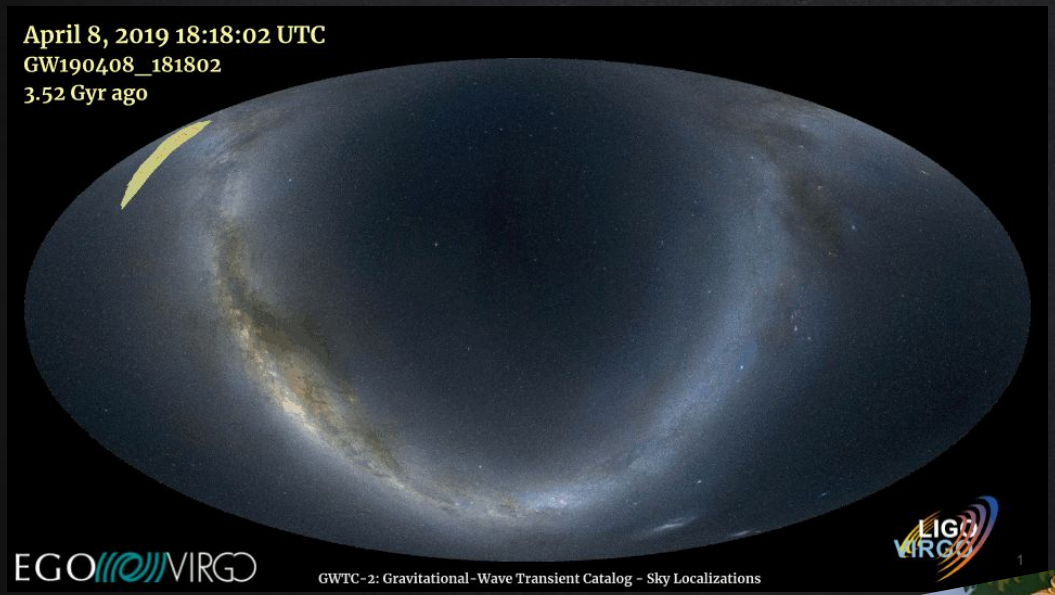
- AHEAD2020 WP12 F2F meeting 4 May, 2022 – Aquila.
- INFN–Perugia and SSDC–ASI dedicated periodic calls.
- ESCAPE to the Future 25–26 October 2022 – Brussels.
- WP4 Technology Forum 3 – 15–16 March 2022 –online
- WP4 Technology Forum 2 – 13–15 April 2021 –online
- WP4 Technology Forum 1 – 4–6 February 2020 – Strasbourg

+ Internal Virgo weeks and LVK teams calls

GWsky localizations in the IVOA ecosystem

About the Visualization tools: Aladin Lite/Desktop, ipyladin, Topcat.
about the Creation tools: MOC-WASM, Aladin Desktop, MOCPY
about the Interoperability with python: SAMP

Working with GW sky localizations (2D)



Motivations

Generally, GW sky localizations are irregularly shaped and the Multi Order Coverage (MOC) IVOA standard offers:

1) fast mapping of localization areas even if there are separated regions;
2) dedicated queries from the entire IVOA collections into that (GW) MOC;
3) accurate comparisons between any sky region encoding in a MOC:
   a) Neutrinos, GRBs localizations,
   b) EM transients field researches,
   c) references images,
4) reactive planning to coordinate electromagnetic followup.

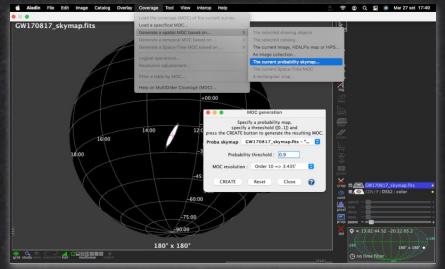
In a MOC map you can add time information performing spatial and temporal operations, simultaneously (Pierre Fernique *et al*, 2020).

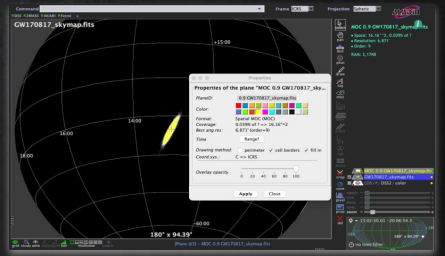
Aladin Desktop

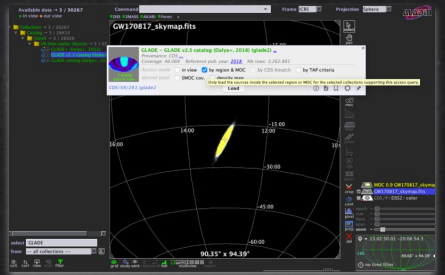
IGWN – Public Alerts User Guide

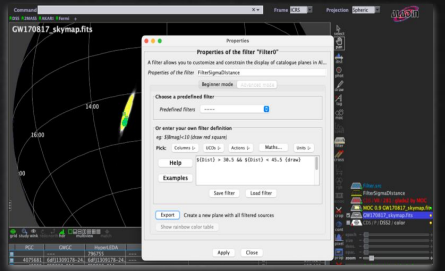
- MOC and GW Sky Localizations
- Running Aladin Desktop
- Loading a GW Sky Localization
- Building a Credible Region
- Area Within a Credible Region
- Querying and Filtering a Galaxy Catalog
- Thumbnail View Generator
- Building a Spatial and Temporal Credible Region
- Spatial and Temporal Coverage Intersections

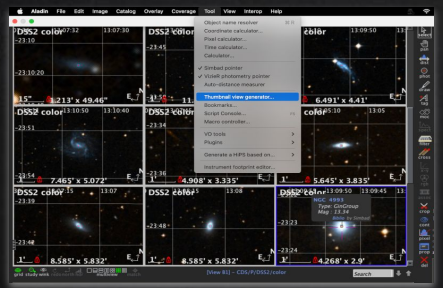
https://emfollow.docs.ligo.org/userguide/index.html

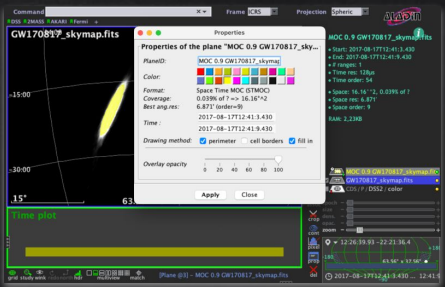


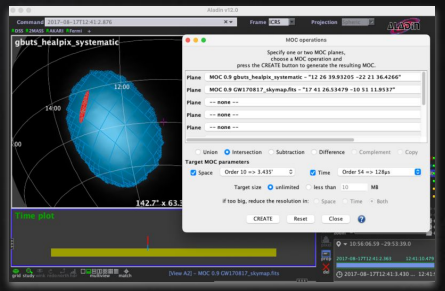








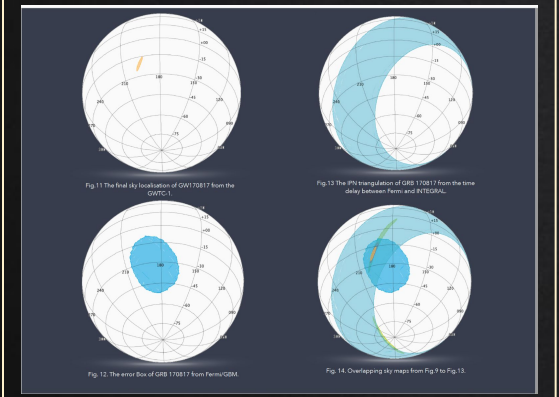




VO schools and LVK open data workshops

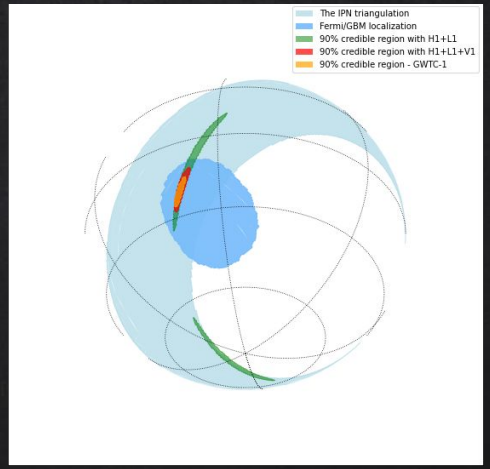
The tutorials are mainly based on use of the Aladin Desktop, mocpy, matplotlib, astropy, astroquery and ipyladin.

VO schools



https://indico.in2p3.fr/event/25225/

VO participant use –cases



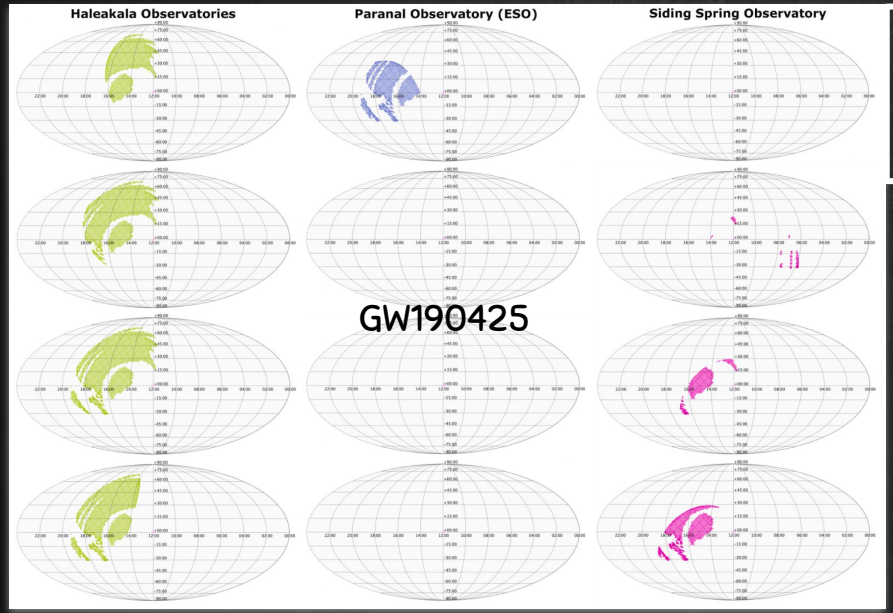
https://indico.in2p3.fr/event/25225/

LVK open data meeting

```
from ipyaladin import Aladin
from ipywidgets import Layout, Box, widgets

# Define two widgets.
left_widget = Aladin(layout=Layout(width='500px'), target='16.91000 -28.1100', fov=180)
right_widget = Aladin(layout=Layout(width='500px'), survey='P/DSS2')

# Synchronize target between two widgets.
widgets.jslink((left_widget, 'target'), (right_widget, 'target'))

# Synchronize FoV (zoom level) between widgets.
widgets.jslink((left_widget, 'fov'), (right_widget, 'fov'))

items = [left_widget, right_widget]

# Define layout.
box_layout = Layout(display='flex',
                    flex_flow='row',
                    align_items='stretch',
                    border='solid',
                    width='100%')
box = Box(children=items, layout=box_layout)
box
```

https://github.com/gw-odw/odw-2021

MOC Visibility



Demonstrations of the utility of MOCs in the preparation of observation campaigns, Greco *et al.*, A&C 2022.

Table 1. Visibility MOC areas [deg^2].

Obs Time (UTC)	Haleakalā	Paranal	SSO
2019-04-25 08:18:05.0	2567	2038	–
2019-04-25 10:18:05.0	3989	–	126
2019-04-25 12:18:05.0	4334	–	767
2019-04-25 14:18:05.0	3711	–	1500

cds-astro / tutorials

Multi Order Coverage data structure to plan multi-messenger observations

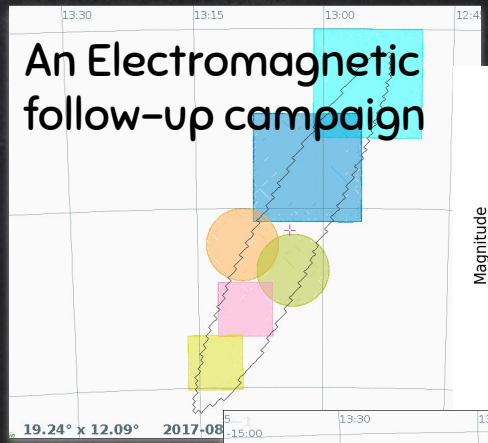
Giuseppe Greco[1], Manon Marchand[2]

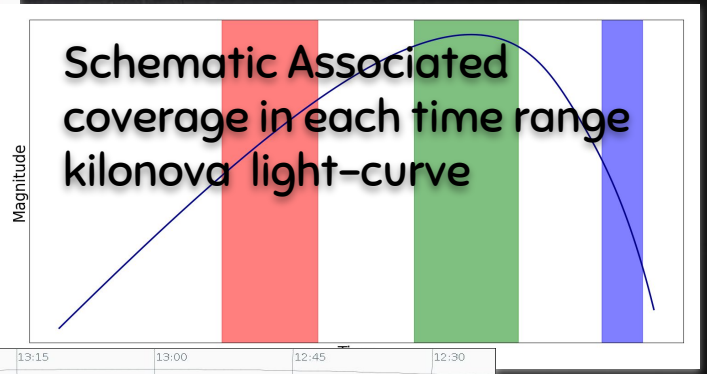
1. INFN, Sezione de Perugia, 1-06123 Perugia, Italy
2. Université de Strasbourg, CNRS, Observatoire Astronomique de Strasbourg, UMR 7550, F-67000, Strasbourg, France

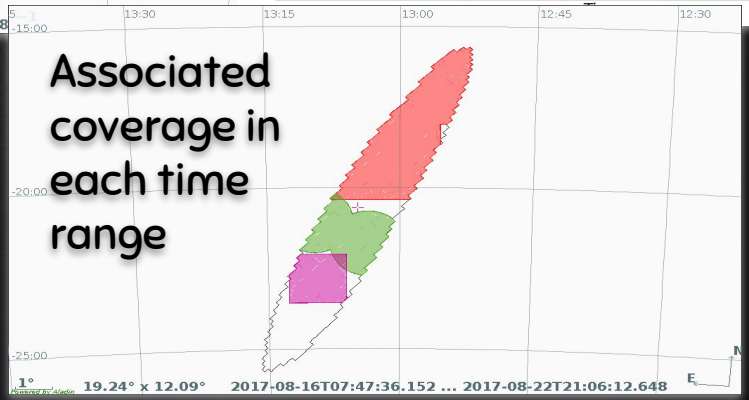
A new tutorials is revisited by Manon Marchand; many thanks!

Coordination tool for follow-up campaigns

Possible open post-doc position to the INFN-PG to develop a world-wide coordination webtool for kilonova follow-up.

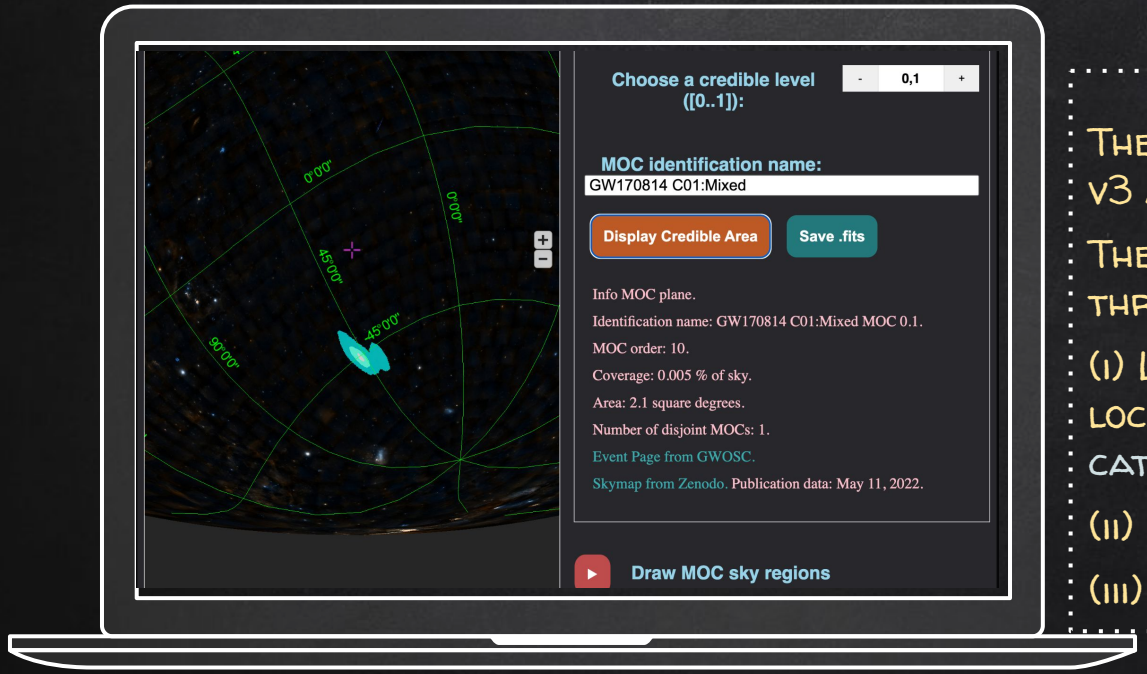






LOOKING FOWARD P. FERNIQUE'S TALK ABOUT F-MOC

Gravitational-Wave Sky Localizations: Online Calculator and Interactive Viewer of Credible Areas



The webtool is powered by Aladin Lite v3 and MOCWASM.

The functionalities are grouped into three main categories:

(i) Load a gravitational-wave sky localization from my device, GraceDB, catalogs and alerts,

(ii) Draw MOC sky regions,

(iii) Sky operations.

- https://virgo.pg.infn.it/maps/
- https://zenodo.org/record/6805866#.ZFHEHuxBxUI

We request that the UTC time scale in the ST-MOC also be supported in order to minimize potential user issues.

Working with GW sky localizations (3D)

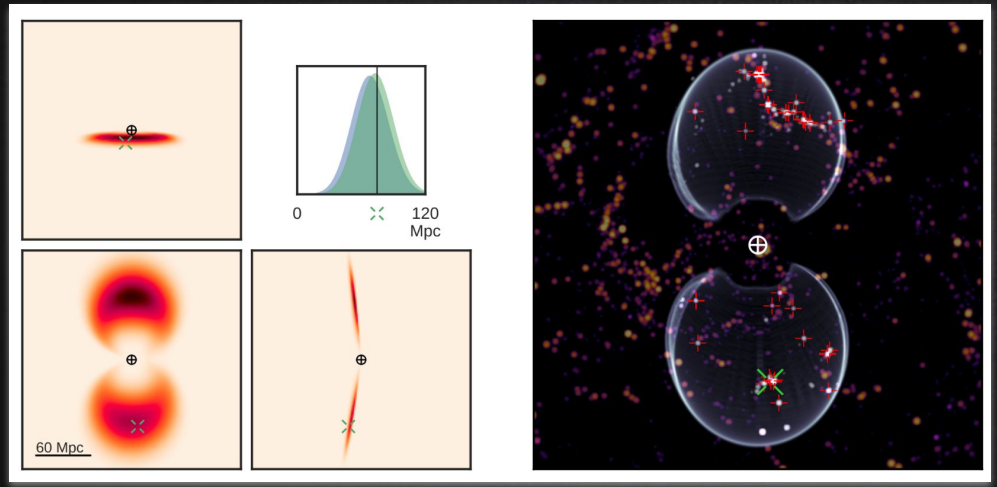


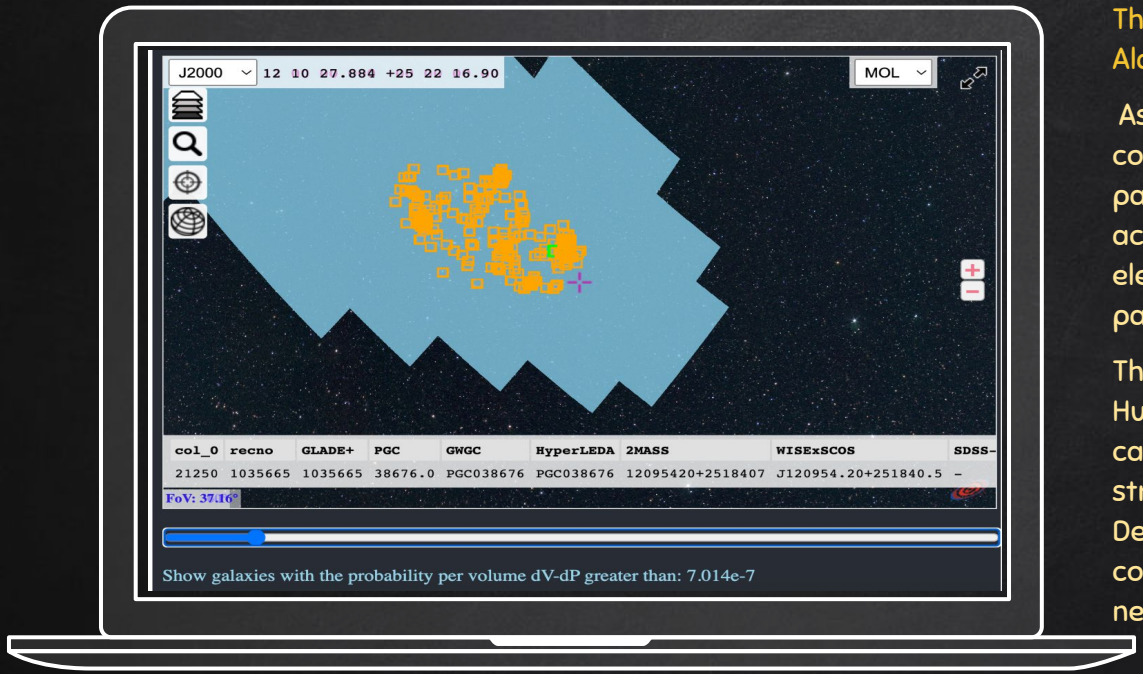
Fig. 2 from GOING THE DISTANCE: MAPPING HOST GALAXIES OF LIGO AND VIRGO SOURCES IN THREE DIMENSIONS USING LOCAL COSMOGRAPHY AND TARGETED FOLLOW-UP; Leo P. Singer et al 2016 ApJL 829 L15

Motivations

For CBC events, 3D sky localization maps are released (Singer et al. 2016). A dedicated functionality in *ligo.skymap* is provided to crossmatch in 3D the event's HEALPix map with a galaxy catalogue. The HiPS catalog and Aladin Lite offer:

1) optimized management of large catalogues;
2) customized interactive filtering to select galaxies (K- or B- absolute magnitudes, probability density *etc.*)
3) Online archive for realtime and post-processing analysis

GLADEnet



The Progressive Web App is powered by HiPs catalogs and Aladin Lite v3.

As GLADE+ is a vast collection of various catalogs, its completeness can vary significantly between different parts of the sky. Knowing the completeness of the catalog accurately is crucial for the synergetic work of electromagnetic follow-up and inferring cosmological parameters.

These results can be mainly used (*i*) to estimate the Hubble constant with dark standard sirens when the catalog approach is applied and (*ii*) to set up EM follow-up strategies: galaxy targets *vs.* wide-field observations. Dedicated surveys can also be performed to improve the completeness of the 3D sky localizations by uploading new data to the Virtual Observatory servers.

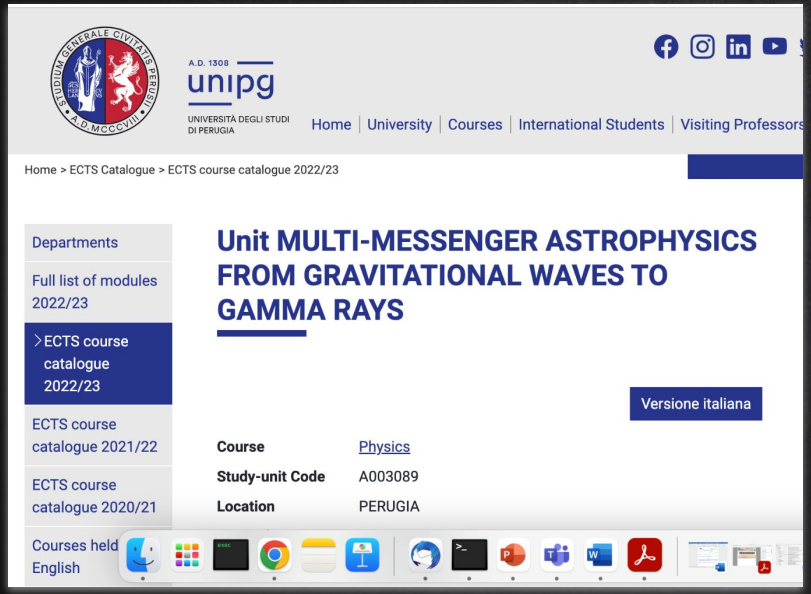
https://virgo.pg.infn.it/gladenet/catalogs/

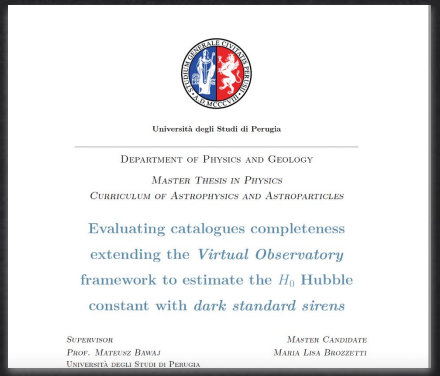
PhD thesis of Maria Lisa Brozzetti in collaboration with Gergely Dálya

In supporting GLADEnet, a hackathon on HiPS catalogue can be useful.

Aladin Lite;
filtering ST-MOC with a dedicated slider bar

IVOA in an academic environment: lectures and thesis




Università degli Studi di Perugia

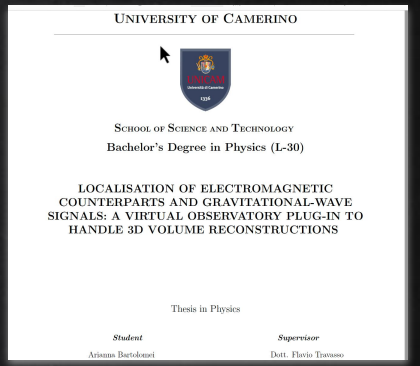
Department of Physics and Geology

Master Thesis in Physics
Curriculum of Astrophysics and Astroparticles

Evaluating catalogues completeness extending the *Virtual Observatory* framework to estimate the H_0 Hubble constant with *dark standard sirens*

Supervisor
Prof. Mateusz Bawaj
Università degli Studi di Perugia

Master Candidate
Maria Lisa Brozzetti


University of Camerino

School of Science and Technology

Bachelor's Degree in Physics (L-30)

LOCALISATION OF ELECTROMAGNETIC COUNTERPARTS AND GRAVITATIONAL-WAVE SIGNALS: A VIRTUAL OBSERVATORY PLUG-IN TO HANDLE 3D VOLUME RECONSTRUCTIONS

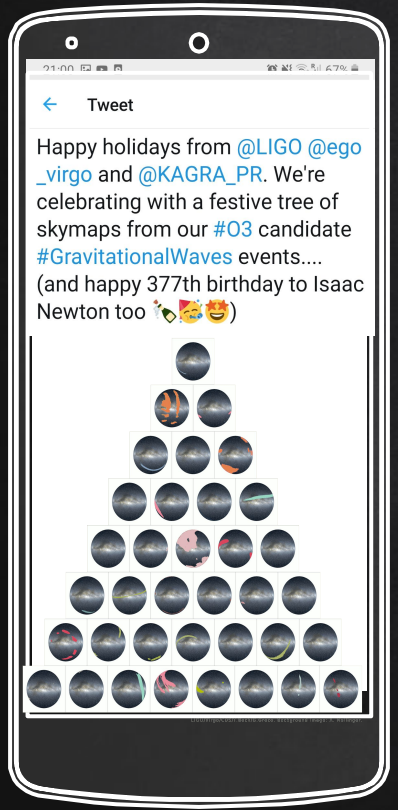
Thesis in Physics

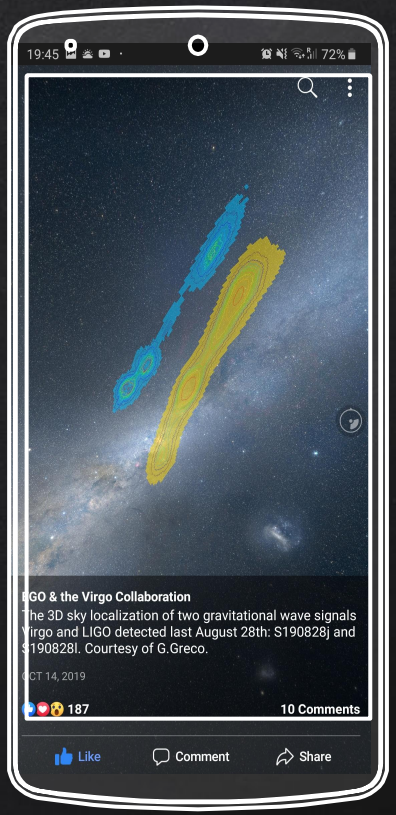
Student
Arianna Bartolomei

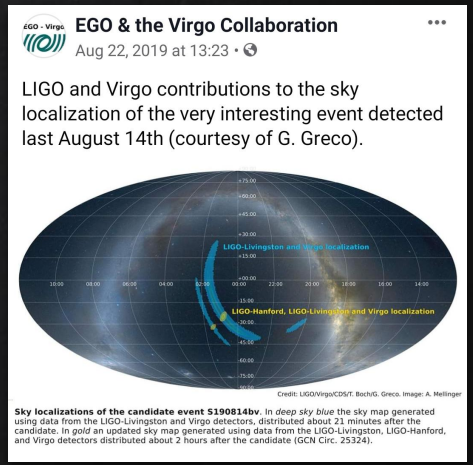
Supervisor
Dott. Flavio Travasso

At the University of Perugia is active an astrophysics multimessaggera class with a dedicated laboratory to the IVOA tools and standards. Some works have been presented at the ADASS meetings.

Outreach (Hips2fits)

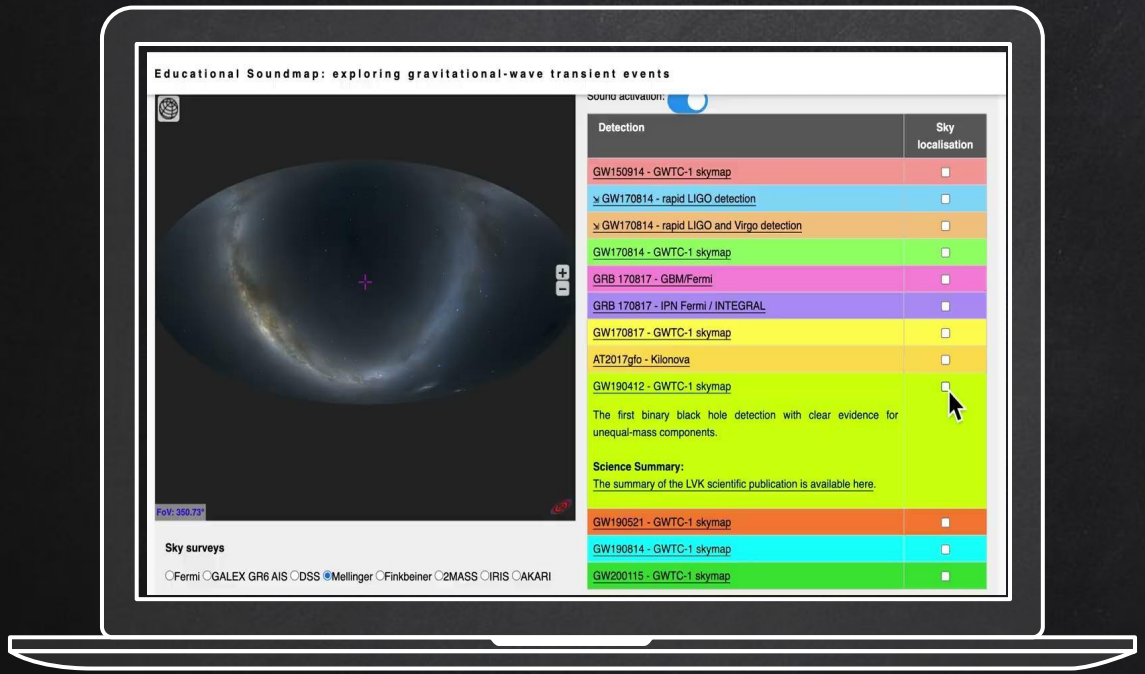






Click on the Figures to direct to the original post

Soundmaps



A specific chord is played when the cursor enter or leave the MOC region. When the cursor is inside the MOC, an audio files will start in less one second.

The binary merger events that LIGO and Virgo have detected are in the audio band. They can be converted to sound (.wav) files, so that you can hear them.

Soundmaps is intended for educational purposes.

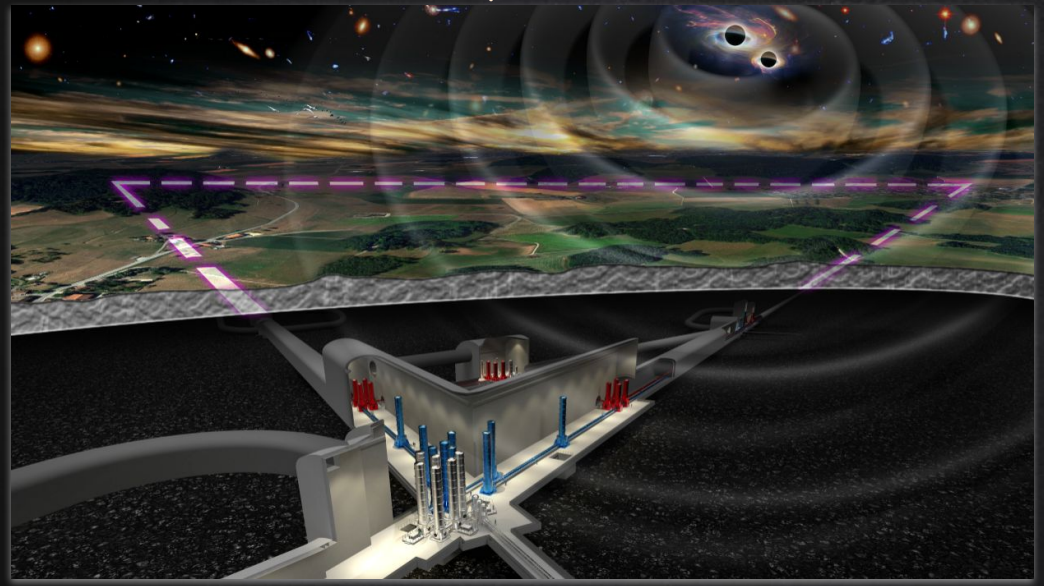
https://gwosc.org/audio/

It will be online soon!

A BIG thank to the CDS team;
about 1 e-mail per day!
(including weekend!)

Einstein Telescope observatory

In ESFRI roadmap



A sky localization is produced when a new event is detected. The initial map will incorporate every new updates with an automatic re-filtering of candidate transient events and GRB/Neutrino localizations.

All sky information of that event will be nested in a Matryo*sky* system from the early warning alerts to the final skymap catalogs.

Sketches to manage GW alerts in the ET era with about 1 million of black holes mergers and thousands of neutron star coalescences in binary systems per year.