Transient localization web service based on open gravitational-wave data for the multi-messenger community

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ESCAPE

AHEAD 2020

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Transient localization web service

How to ease the skymap visualisation process?

Provide just the part of the skymap userful for the observer.

Allow the user to customize the view:

- credibility level

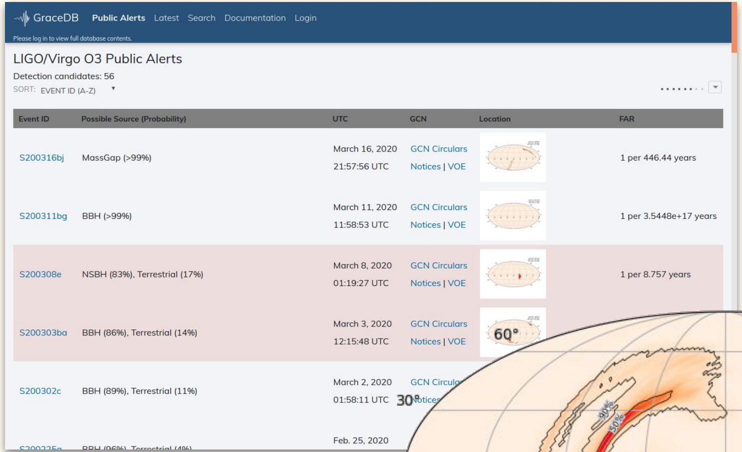
- intersection with the field of view (FOV)

It is now available through a web service.

https://virgo.pg.infn.it/maps/

Open gravitational-wave data

- from Gravitational Wave Open Science Center (GWOSC)
- maps download via GraceDB public portal


GraceDB Public Alerts Latest Search Documentation Login

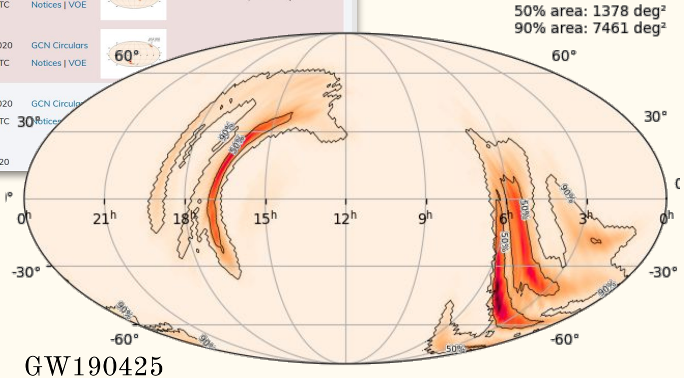
Please log in to view full database contents.

LIGO/Virgo O3 Public Alerts

Detection candidates: 56

SORT: EVENT ID (A-Z)

Event ID	Possible Source (Probability)	UTC	GCN	Location	FAR
S200316bj	MassGap (>99%)	March 16, 2020 21:57:56 UTC	GCN Circulars Notices | VOE		1 per 446.44 years
S200311bg	BBH (>99%)	March 11, 2020 11:58:53 UTC	GCN Circulars Notices | VOE		1 per 3.5448e+17 years
S200308e	NSBH (83%), Terrestrial (17%)	March 8, 2020 01:19:27 UTC	GCN Circulars Notices | VOE		1 per 8.757 years
S200303ba	BBH (86%), Terrestrial (14%)	March 3, 2020 12:15:48 UTC	GCN Circulars Notices | VOE		
S200302c	BBH (89%), Terrestrial (11%)	March 2, 2020 01:58:11 UTC	GCN Circulars Notices		
		Feb. 25, 2020			

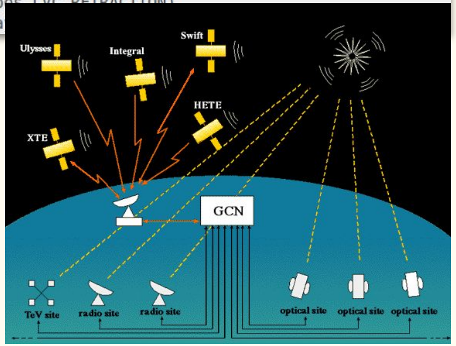


GW190425

GCN alerts

```
import gcn
import healpy as hp

# Function to call every time a GCN is received.
# Run only for notices of type
# LVC_PRELIMINARY, LVC_INITIAL, LVC_UPDATE, or LVC_RETRACTION.
@gcn.handlers.include_notice_types(
    gcn.notice_types.LVC_PRELIMINARY,
    gcn.notice_types.LVC_INITIAL,
    gcn.notice_types.LVC_UPDATE,
    gcn.notice_types.LVC_RETRACTION)
def process_gcn(pa
```



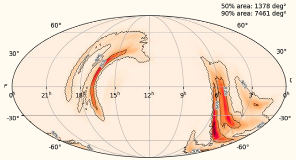
R. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), “Open data from the first and second observing runs of Advanced LIGO and Advanced Virgo”, SoftwareX 13 (2021) 100658.

https://www.gw-openscience.org/
https://gracedb.ligo.org/superevents/
https://gcn.gsfc.nasa.gov/

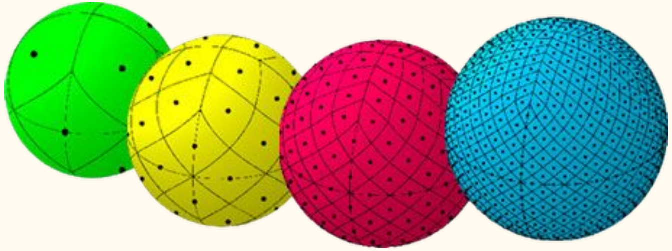
GraceDB

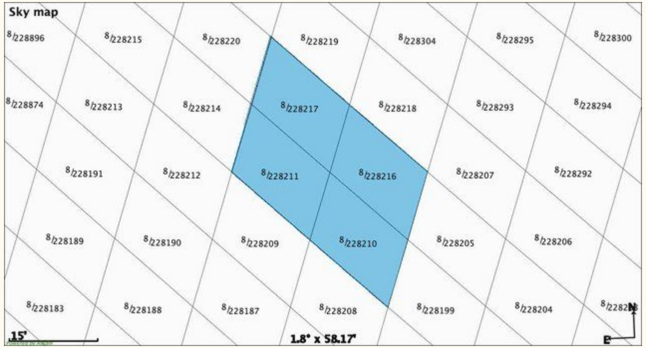
Multi-Order Coverage (MOC)

extremely efficient data format for coverage area visualization



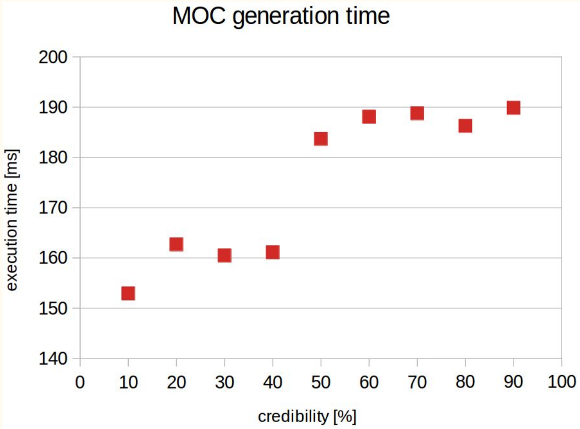
HEALPix





MOC operation computing time:

- intersection 1,6 ms
- area integration 2,7 ms



Fernique, P., et al. “MOC: Multi-Order Coverage map. Version 2.0” IVOA Working Draft 2021-03-24 https://www.ivoa.net/documents/MOC/20210324/WD-moc-2.0-20210324.pdf

International Virtual Observatory Alliance

https://ivoa.net/

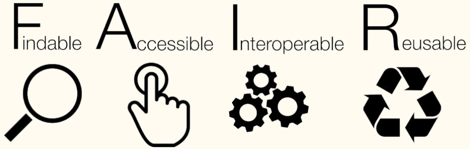
Berriman, G. Bruce, et al. “The International Virtual Observatory Alliance (IVOA) in 2020.” arXiv preprint arXiv:2012.05988 (2020).

Multi-Order Coverage

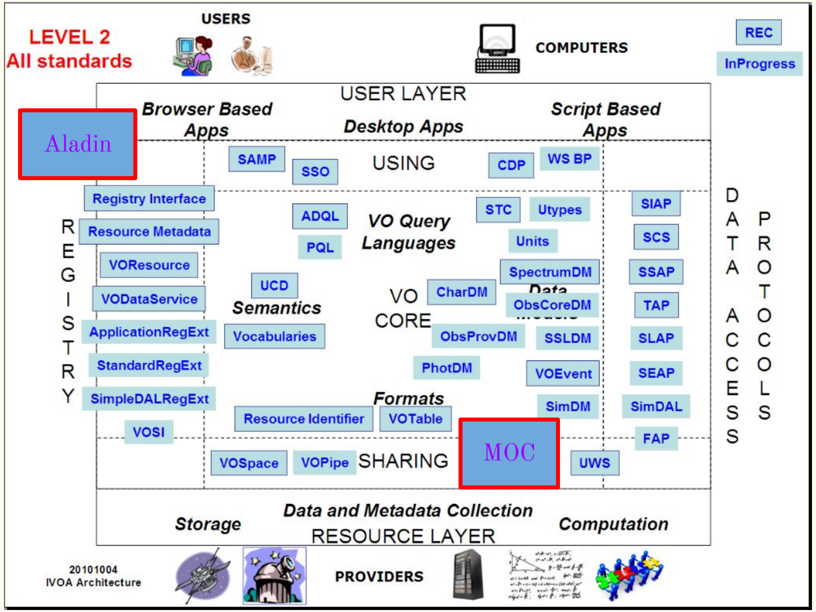
Aladin lite – interactive sky atlas allowing the user to visualize digitized astronomical images.

https://aladin.cds.unistra.fr/aladin.gml#information

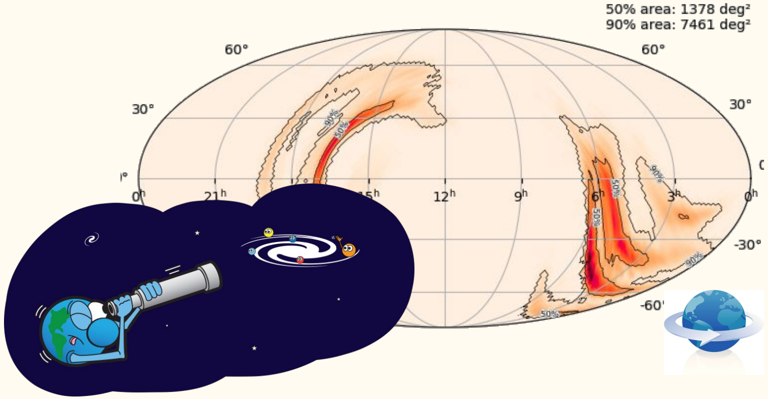
IVOA principles:



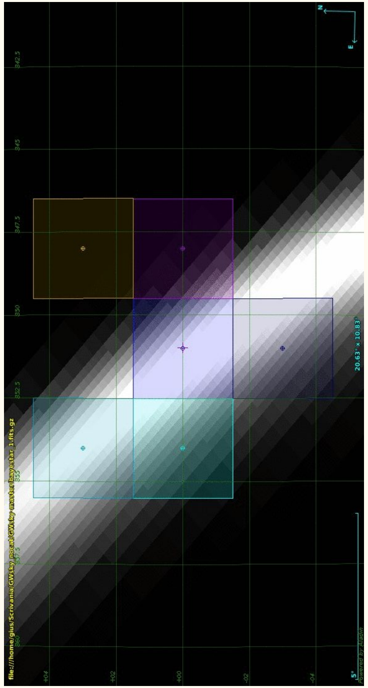
Williamson, M. D., et al. 2016, Scientific Data, 3, 160018. doi:10.1038/sdata.2016.18

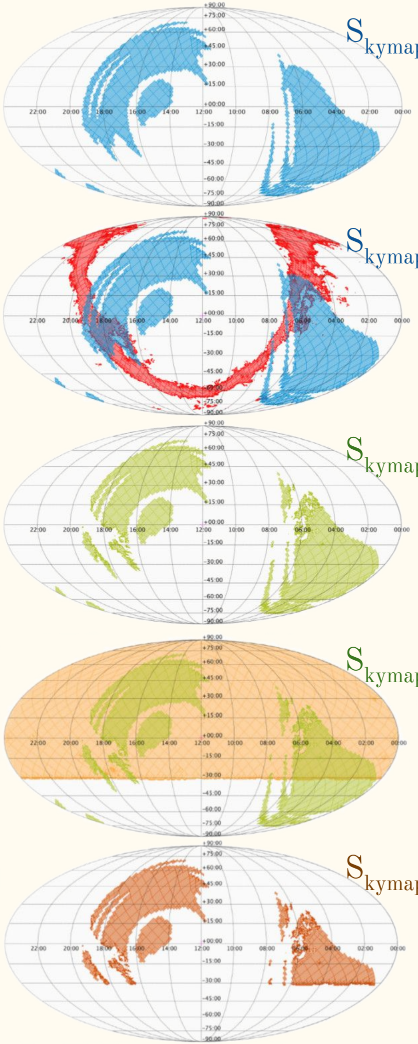


EM follow-up strategy



tiling





S_{kymap}

$S_{kymap} + D_{ust}$

$S_{kymap} \setminus D_{ust}$

$S_{kymap} \setminus D_{ust} + F_{OV}$

$S_{kymap} \setminus D_{ust} \cap F_{OV}$

Greco, G., et al. "Multi Order Coverage Data Structure to Plan Multi-Messenger Observations." Astronomy and Computing 39 (2022): 100547. doi.org:10.1016/j.ascom.2022.100547.

Multi-messenger community

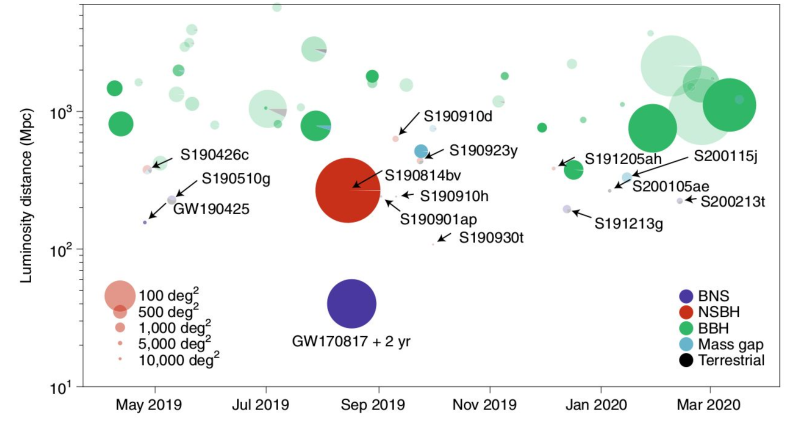


Fig. 1 | Public O3 alerts, including BNS, NSBH and binary black hole (BBH) candidates. The size of the circle is inversely proportional to the area, and so bigger circles indicate easier objects for follow-up. The transparency is related to the candidate's false-alarm rate, with a higher opacity indicating a greater significance.

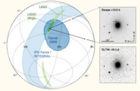
Coughlin, M.W. "Lessons from counterpart searches in LIGO and Virgo's third observing campaign." Nat Astron 4, 550–552 (2020). doi:10.1038/s41550-020-1130-3.

We want better localization precision

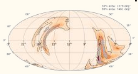
It must be done by improving the detectors but it is not only about the localization precision [deg^2]

Let us consider four cases:

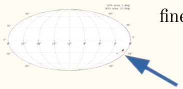
GW170817 ~30 Mpc 30 deg^2	**GW190425** ~160 Mpc 10 000 deg^2	**S190814** ~276 Mpc 23 deg^2	**ET prediction**[2] <200 Mpc 100 deg^2
283 Mpc^3	$1\cdot10^7$ Mpc^3	$6\cdot10^4$ Mpc^3	$8\cdot10^4$ Mpc^3



historical discovery



way too big



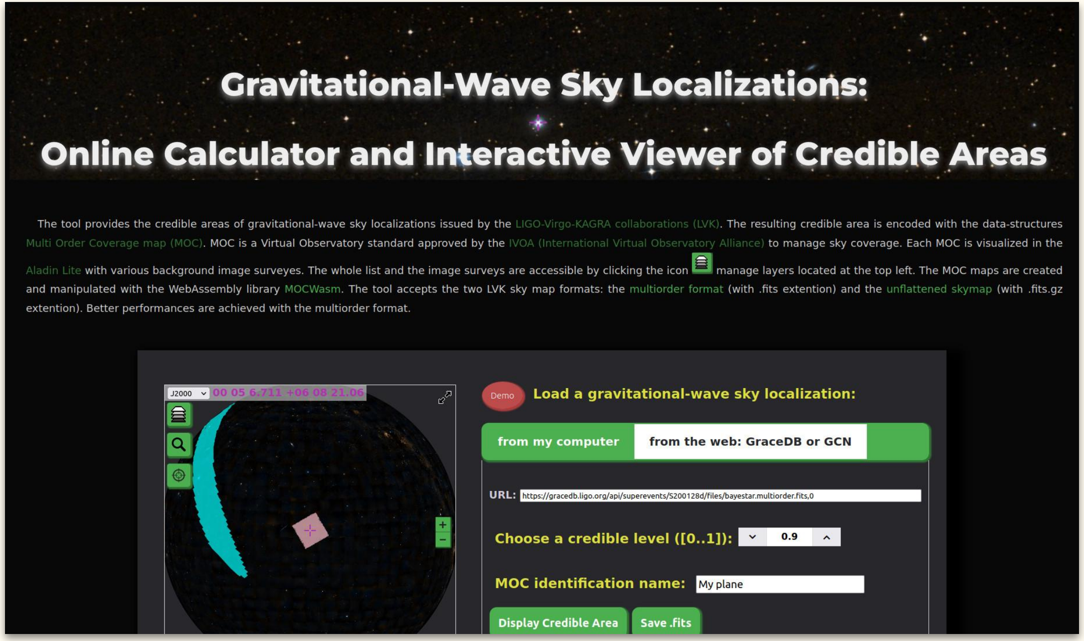
is this area fine?

* all skymap coverages are at the credibility level of 90%

Transient localization web service

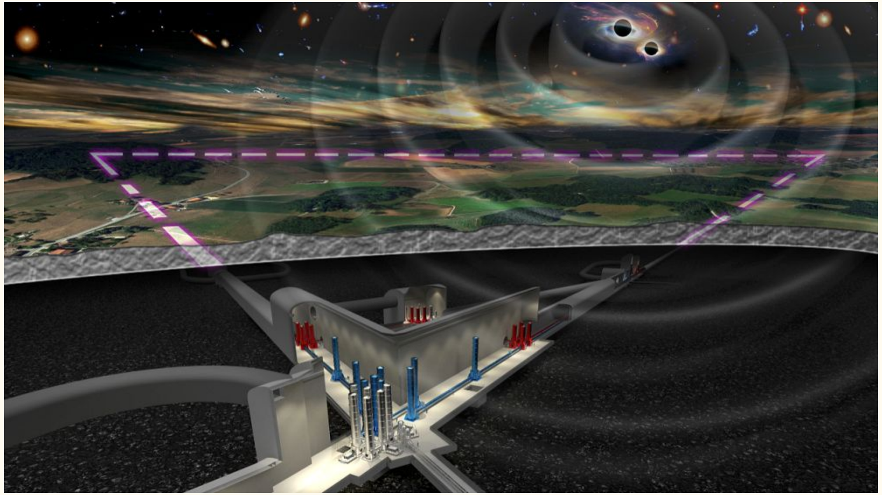
Web interface https://virgo.pg.infn.it/maps/

- input form in HTML/javascript
- download FITS file
- calculation engine MOC-wasm
- visualisation in Aladin lite plugin



For tiling support & outreach

Technological advantages & future challenges

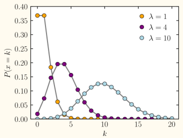


Maggiore, M, et al. "Science Case for the Einstein Telescope." Journal of Cosmology and Astroparticle Physics 2020, no. 03 (2020): 050–050. doi:10.1088/1475-7516/2020/03/050.

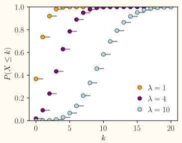
ET detection frequency forecast:

- average alert rate ~1,8 event/min
- alerts number should rarely exceed 6 events/min
- given the very early alerts, we can assume $\gg$10 updates per event
- users: there are ~50 active groups performing multi-messenger counterpart search
- how many updates per event we can expect?

We should expect up to: 32 updates/min
(assuming 10 updates per event)

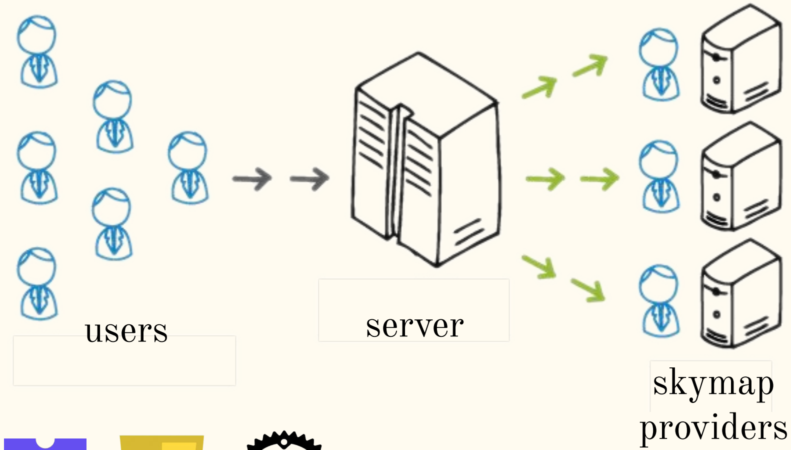


We should expect up to: 250 updates/min
(assuming 100 updates per event)



Technological advantages & future challenges

HTML + JavaScript
+WebAssembly



Computation throughput

Single core server performance:

- HEALPix to MOC conversion: 5,7 operations/s
- MOC intersection: 625 operations/s
- MOC area calculation: 370 operations/s

web server is not a bottleneck

Support

AHEAD2020 – (Integrated Activities in the High Energy Astrophysics Domain) is an ongoing project approved in the framework of the European Horizon 2020 program (Research Infrastructures for High Energy Astrophysics)

ESCAPE – addresses the critical questions of open science and long term reuse of data for science and for innovation, many European scientific facilities have combined forces to make their data and software interoperable and open

MOSAICO – contributes to theoretical studies and development on the topic of multi-messenger astronomy in the view of the next generation detectors

References

1. R. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), "Open data from the first and second observing runs of Advanced LIGO and Advanced Virgo", SoftwareX 13 (2021) 100658.
2. Fernique, P., et al. "MOC: Multi-Order Coverage map. Version 2.0" IVOA Working Draft 2021-03-24 https://www.ivoa.net/documents/MOC/20210324/WD-moc-2.0-20210324.pdf
3. Berriman, G. Bruce, et al. "The International Virtual Observatory Alliance (IVOA) in 2020." arXiv preprint arXiv:2012.05988 (2020).
4. Williamson, M. D., et al. 2016, Scientific Data, 3, 160018. doi:10.1038/sdata.2016.18
5. Greco, G., et al. "Multi Order Coverage Data Structure to Plan Multi-Messenger Observations." Astronomy and Computing 39 (2022): 100547. doi.org:10.1016/j.ascom.2022.100547.
6. Maggiore, M, et al. "Science Case for the Einstein Telescope." Journal of Cosmology and Astroparticle Physics 2020, no. 03 (2020): 050–050. doi:10.1088/1475-7516/2020/03/050.
7. Coughlin, M.W. "Lessons from counterpart searches in LIGO and Virgo's third observing campaign." Nat Astron 4, 550–552 (2020). doi:10.1038/s41550-020-1130-3.