

Virtual Observatory and Generative Artificial Intelligence



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OBJECTIVE

The hands-on section shows how Virtual Observatory tools and standards can support multimessenger astronomy, with a focus on gravitational-wave sky localizations.

We then propose a prototype extension of the MOC (Multi Order Coverage map) standard, called **Semantic MOC**, together with simple preliminary examples that illustrate its potential in the context of **GenAI**.

VO and EM-followUP



The prompt used to generate this image is shown on the slide

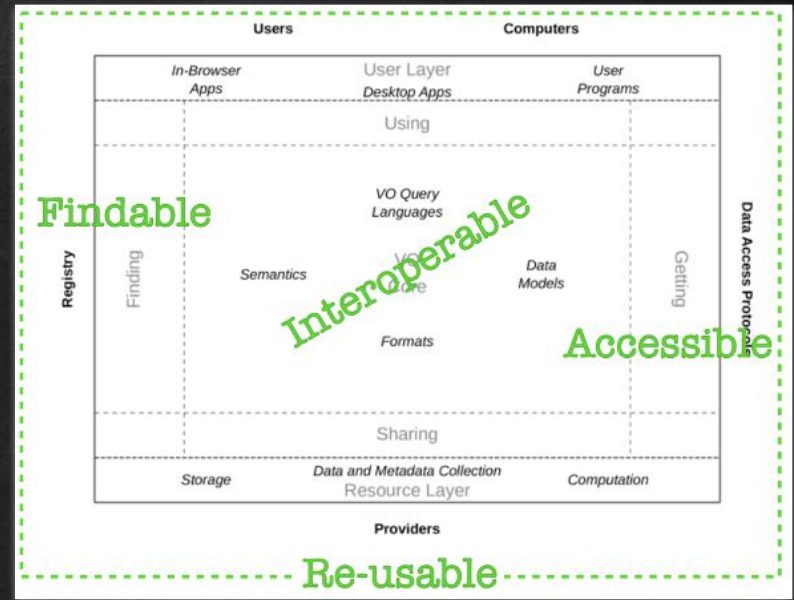
Member Organizations



- Argentine Virtual Observatory
- Armenian Virtual Observatory
- AstroGrid, United Kingdom
- Australian All-Sky Virtual Observatory
- Brazilian Virtual Observatory
- Chinese Virtual Observatory
- Canadian Virtual Observatory
- Chilean Virtual Observatory
- European Space Agency
- European Virtual Observatory
- German Astrophysical Virtual Observatory
- Japanese Virtual Observatory
- Kazakhstan Virtual Observatory
- Netherlands Virtual Observatory
- Observatoire Virtuel France
- Russian Virtual Observatory
- Square Kilometer Array Observatory
- South African Astroinformatics Alliance
- Spanish Virtual Observatory
- Italian Virtual Observatory
- Ukrainian Virtual Observatory
- US Virtual Observatory Alliance
- Virtual Observatory India

Contacts for the IVOA Member Organizations

<https://ivoa.net/>



FAIR Principles Pioneers

The Virtual Observatory (VO) aims to make astronomical datasets and resources interoperable. The IVOA defines the technical standards that enable this vision, fosters the exchange of ideas and technologies, and promotes the VO worldwide.

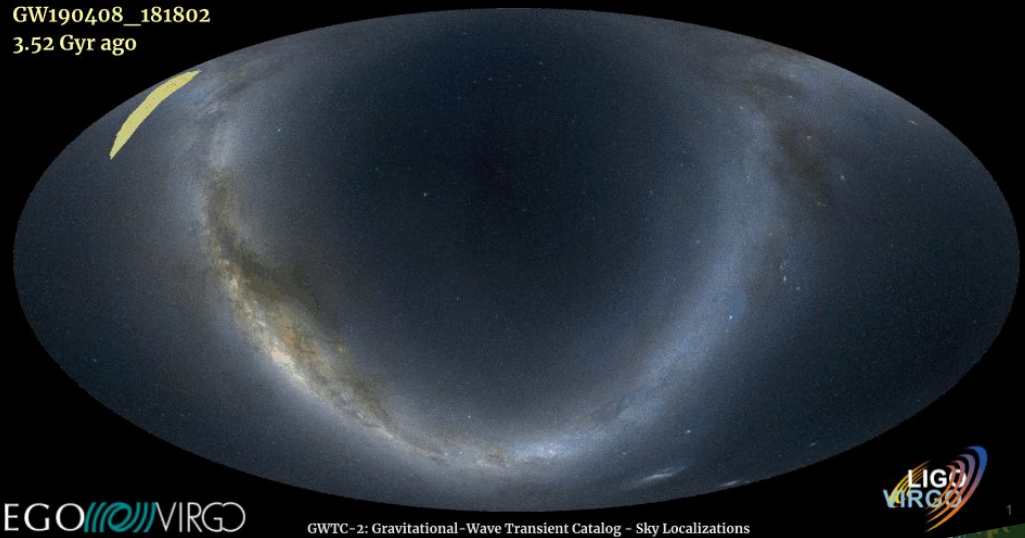
IVOA: INTERVENTIONAL VIRTUAL OBSERVATORY ALLIANCE

WORKING WITH GW SKY LOCALIZATIONS (2D)



MOTIVATIONS

April 8, 2019 18:18:02 UTC
GW190408_181802
3.52 Gyr ago



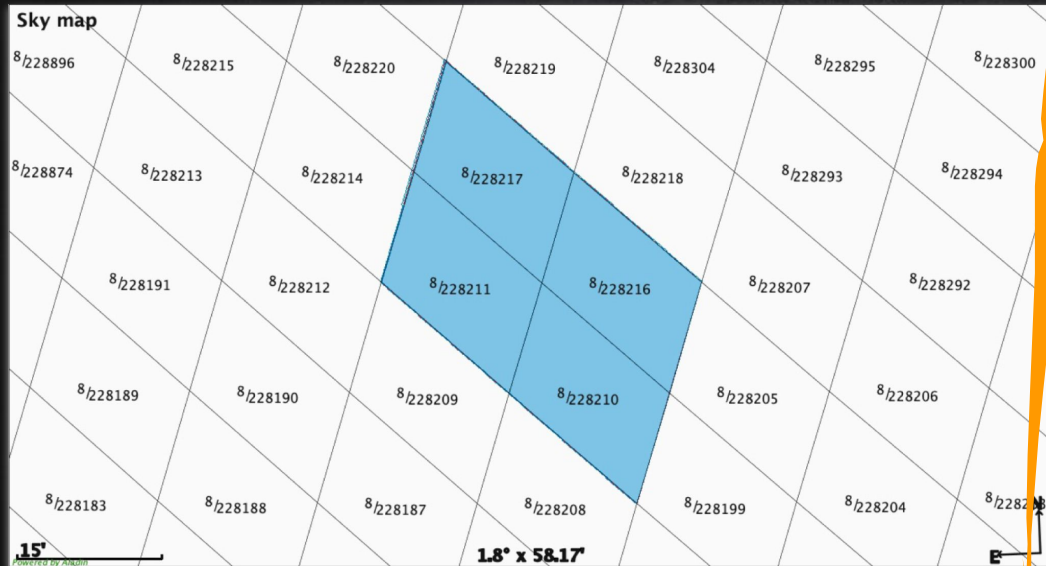
Generally, GW sky localizations are irregularly shaped and the Multi Order Coverage (MOC) IVOA standard offers:

- 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).



MOC: MULTI ORDER COVERAGE MAP



The MOC (Multi-Order Coverage) data structure is based on the HEALPix (Hierarchical Equal Area isoLatitude Pixelization) sky tessellation algorithm (*Górski et al., 2005*).

HEALPix divides the sky into curvilinear quadrilaterals, starting with twelve base pixels. Each pixel can be subdivided into four, increasing the resolution.

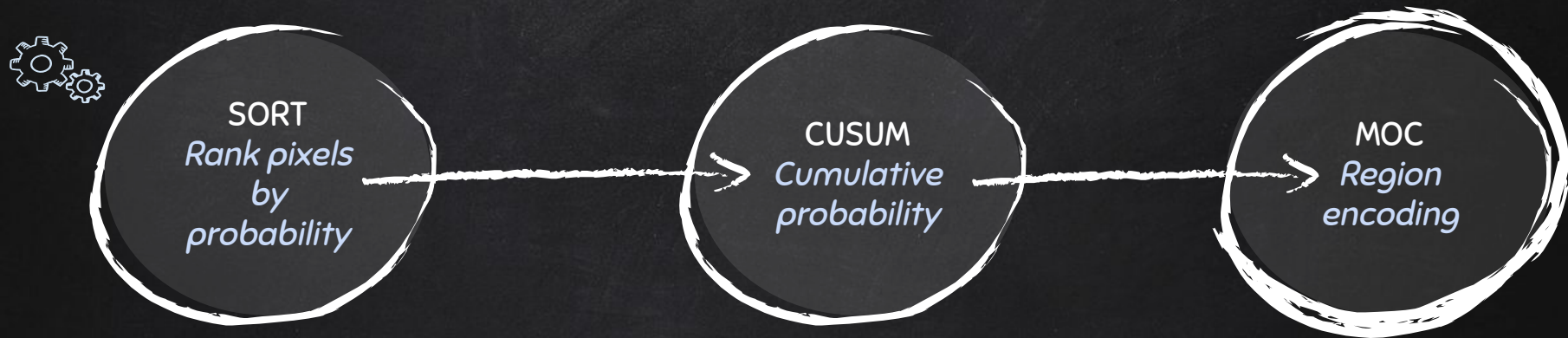
A MOC cell, which defines a unique sky region, is characterized by its hierarchy level and pixel index.

Using this hierarchical system, MOC efficiently represents complex sky regions and supports various astronomical applications (*Fernique et al, 2014*).

FITS $uniq = 4 \times (4^{order}) + npix$
Flexible Image Transport System

JSON $\{ "order" : [npix, npix, \dots], "order" : [npix, npix, \dots], \dots \}$
JavaScript Object Notation

USING MOC TO ENCODE GW SKY MAPS (2D)



CREDIBLE REGIONS MAY BE DESCRIBED AS POLYGONS ENCLOSING A SELECTED PROBABILITY LEVEL, WITH VERTICES IN RIGHT ASCENSION AND DECLINATION AND SPECIAL TERMINATORS FOR DISJOINT REGIONS.

MOC PROVIDES A MORE COMPACT REPRESENTATION, USING A FLAT LIST OF INTEGERS (FITS SERIALISATION) AND ENCODING THE HEALPIX RESOLUTION THROUGH THE MOC ORDER.ORDER PARAMETER.

[Multi Order Coverage data structure to plan multi-messenger observations](#), Greco et al., A&C 2022

Aladin Desktop

Download instructions

Description

Official

Beta

others

Aladin Desktop is the main application of the [Aladin Sky Atlas](#) suite. Developed in Java, Aladin Desktop is able to run on any configuration (Windows, Mac, Linux, etc) even on small machines (>128MB RAM). Aladin Desktop is free, distributed under [GPL3](#) licence (see [acknowledgement](#)). Download it and install it according to your operating system. Several versions are provided: the official, the beta version, etc, and also some source packages. As any Java tool, Aladin Desktop requires a [Java Virtual Machine](#) on your machine.

Official version v12.060

• Any Operating System (WebStart java installer)



Aladin.jar

- 1) [Click here](#)
- 2) Follows the instructions...

• OS specific packages

with or without Java runtime



Aladin.msi

Windows

- 1) [Download](#) the MSI installer (*)
- 2) Execute it (*)



Aladin.exe

Windows - without Java

- 1) [Download it](#) on your desktop
- 2) Launch it (*)



Aladin.deb

Linux

- 1) [Download](#) the installer
- 2) Double-click on it



Aladin.tar

Linux - without Java

- 1) [Download it](#) and untar it
- 2) Use aladin shell launcher



Aladin.dmg

Mac ARM

- 1) [Download](#) the installer (*)
- 2) Execute it (*)



Aladin.dmg

Mac - without Java

- 1) [Download it](#) and untar it
- 2) Use aladin shell launcher (*Ctrl-click + Open With + Terminal*)

Mac AMD x86

- 1) [Download](#) the installer (*)
- 2) Execute it (*)

(*) Multi-platform installer graciously generated by [Install4J](#)

(**) It may be necessary to manually authorize this execution via an exception (Windows) or by holding down the Ctrl key during launch (MacOS).

• Piece by piece:

- [Aladin.jar](#): The software
- [Aladin](#): Unix shell script launcher
- [AladinSrc.jar](#): Source package (see [GPL v3](#) licence)

Beta version v12.648 → 26/11/2025

Aladin Desktop is a Java application. To run it, you must first have the [Java Virtual Machine](#) (JVM) installed. More details are in [Aladin's download page](#).

Download the Aladin.jar from the Aladin download page. Execute it from a terminal by typing:

```
$ java -jar -Xmx3g Aladin.jar
```

The flag `-Xmx<amount of memory>` specifies the maximum memory allocation pool for a JVM. Here 3GB of memory is allocated.

Aladin Desktop: Download/Run Instructions

Command bar

Available data → 38879
● in view ● out view

Command [dropdown] Fran [dropdown] ICRS [dropdown] Projection Aitoff [dropdown]

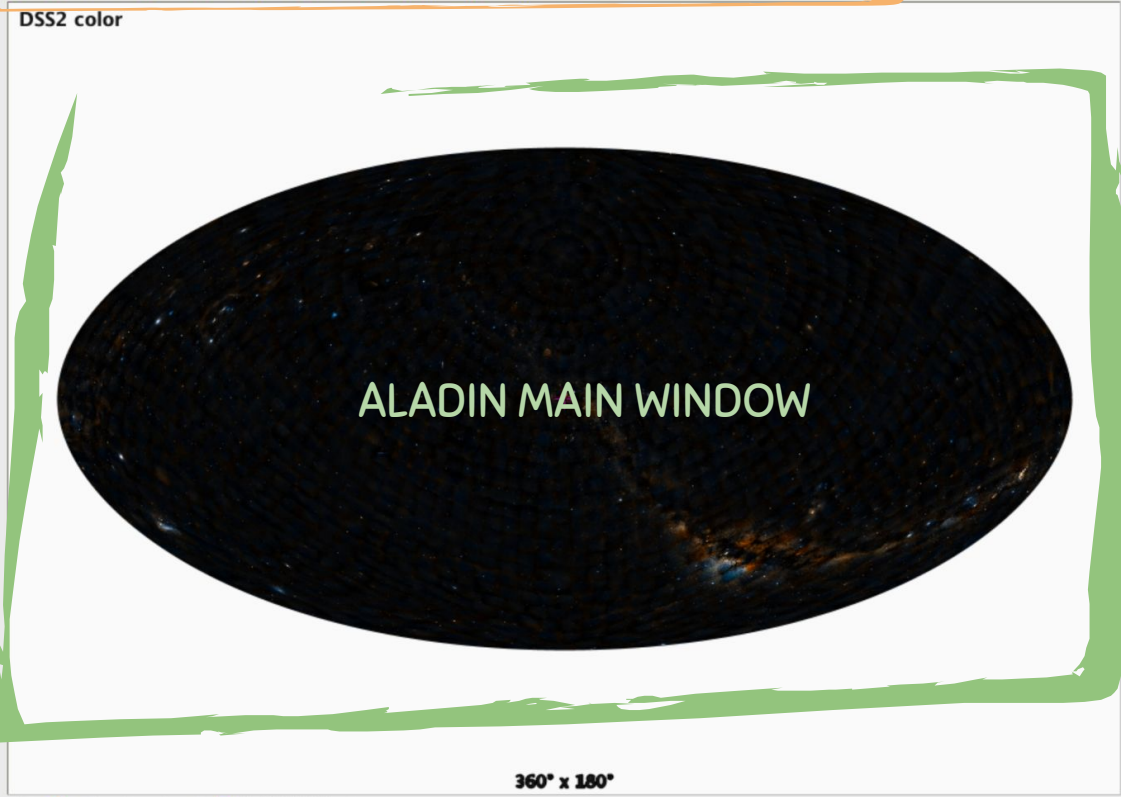
DSS PanSTARRS SDSS ZMASS WISE GALEX Gaia Simbad NED constellation +



Data Discovery tree

- Collections → 38879
 - Image → 679
 - Data base → 4
 - Catalog → 36613
 - Cube → 25
 - Ancillary → 81
 - Outreach → 10
 - Deprecated → 20
 - Others → 1447

DSS2 color



ALADIN STACK

- select
- pan
- dist
- phot
- draw
- tag
- moc
- spect
- filter
- cross
- x-y
- rgb
- assoc
- crop
- cont
- pixel
- zoom
- prop
- del

select from -- all collections ...

360° x 180°

exp. sort view scan filter grid study wink redo north hdr multiview match

CDS / P / DSS2 / color

epoch - [slider] +

size - [slider] +

dens. - [slider] +

opac. - [slider] +

zoom - [slider] +

no time tag

20 39 46.08 16 39 43.5

180 18

sky

ALADIN AND MULTI-MESSENGER APPLICATIONS

Practical Examples

GCN Circular 41414

Subject LIGO/Virgo/KAGRA S250818k: Candidates from the Zwicky Transient Facility
Event [LIGO/Virgo/KAGRA S250818k](#)
Date 2025-08-18T17:01:30Z (4 months ago)
From Robert David Stein at JSI <rdstein@umd.edu>
Via Web form

Robert Stein (JSI/UMD), Tomás Ahumada (Caltech) Mansi Kasliwal (Caltech), Theophile du Laz (Caltech), Utkarsh Pathak (IITB), Vishwajeet Swain (IITB), Anirudh Salgundi (UNC), Varun Bhalerao (IITB), Xander J. Hall (CMU) report,

On behalf of the Zwicky Transient Facility (ZTF) and Global Relay of Observatories Watching Transients Happen (GROWTH) collaborations:

We observed the localization region of the LVK trigger S250818k with the Palomar 48-inch telescope, equipped with the 47 square degree ZTF camera (Bellm et al. 2019, Graham et al. 2019). We started observations in the g- and r-band beginning at 2025-08-18 04:02 UTC, ~~approximately 2.7 hours after~~ merger. We covered 25.2% (168.3 sq deg) of the reported localization region. This estimate accounts for chip gaps. Each exposure was 300s with a typical depth of 22 mag.

The images were processed in real-time through the ZTF reduction and image subtraction pipelines at IPAC to search for potential counterparts (Masci et al. 2019). AMPEL (Nordin et al. 2019, Stein et al. 2021) was used to search the alerts database for candidates. We reject stellar sources (Tachibana and Miller 2018) and moving objects, and apply machine learning algorithms (Mahabal et al. 2019), and removing candidates with history of variability prior to the merger time.

We are left with 58 transient candidates, all lying within the 95.0% localization of the skymap. We perform additional vetting of these candidates, and identify those which appear to be hosted in galaxies at plausible redshifts for S250818k.

We highlight one of these candidates, ZTF25abjmmps/[AT2025ulz](#).

ZTF Name	IAU Name	RA (deg)	DEC (deg)	Filter	Mag	MagErr
ZTF25abjmmps	AT2025ulz	237.9757129	+30.9023146	r	21.29	0.13

ZTF25abjmmps is in an elliptical galaxy with a Legacy Survey photometric redshift of $z = 0.001 \pm 0.016$, is therefore consistent with the estimated distance to S250818k. The lower 95th percentile limit of the photoz is 0.057, and at this distance S250818k would have an absolute g-band peak magnitude of $M = -16.1$. However, the higher redshifts would be more consistent with a supernova luminosity of $M = -17$.

Forced photometry of this source reveals several detections in our data. The source appears to possibly be fading in g-band, but given the low SNR and short baseline it is difficult to constrain this.

There are also several recent non-detections, but all upper limits are shallower than the magnitude of the transient in our images. We therefore cannot confirm whether the source is young, or if it predates the merger.

LVK trigger [S250818k](#)

Candidate event reported from the ZTF team
[AT2025ulz](#)

<https://gcn.nasa.gov/circulars?query=S250818k>

Please log in to view full database contents.

S250818k

Log Messages

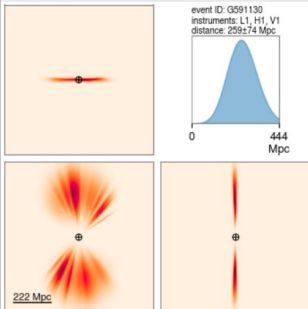
- Sky Localization
- EM Followup
- Parameter
- Estimation

Full Event Log

bayestar.mutiorder.fits,2

— Submitted by read-cvmsf-emfollow robot on August 20, 2025 04:33:40 UTC

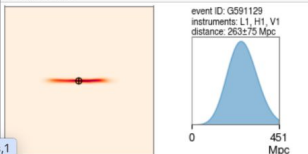
Log Image



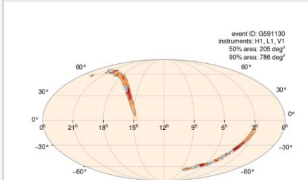
Volume rendering of bayestar.mutiorder.fits,1

— Submitted by read-cvmsf-emfollow robot on August 18, 2025 01:25:21 UTC

Log Image



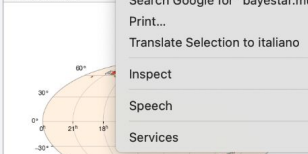
Log Image



Mollweide projection of bayestar.mutiorder.fits,1

— Submitted by read-cvmsf-emfollow robot on August 18, 2025 01:25:21 UTC

Log Image



- Open Link in New Tab
- Open Link in Split View **NEW**
- Open Link in New Window
- Open Link in Incognito Window
- Open Link as
- Save Link As...
- Copy Link Address**
- Copy
- Copy Link to Highlight
- Search Google for "bayestar.mutiorder.fits,1"
- Print...
- Translate Selection to italiano
- Inspect
- Speech
- Services

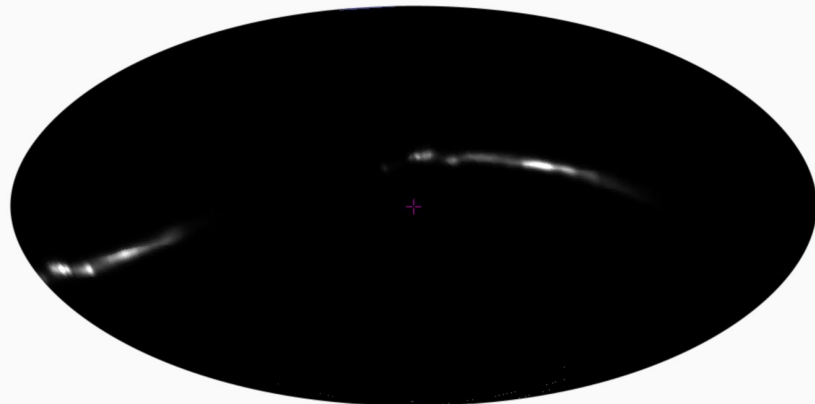
https://gracedb.ligo.org/api/superevents/S250818k/files/bayestar.mutiorder.fits,1

<https://gracedb.ligo.org/api/superevents/S250818k/files/bayestar.mutiorder.fits,1>

Command <https://gracedb.ligo.org/api/superevents/S250818k/files/bayestar.multiorder.fits,1>

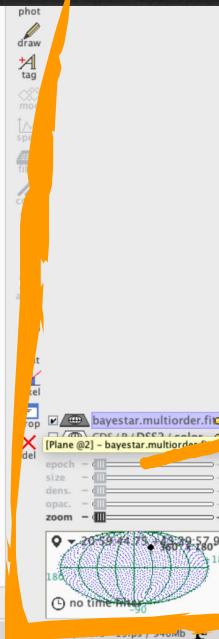
DSS2 PlanSTARRS SDSS 2MASS WISE GALEX Gaia Simbad NED constellation +

Paste the link in “Command” box and press ENTER

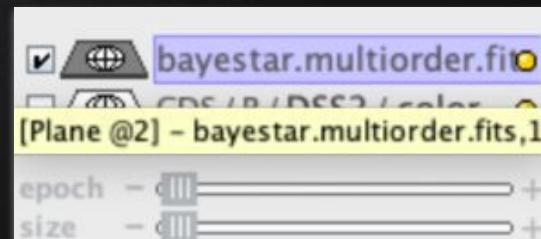


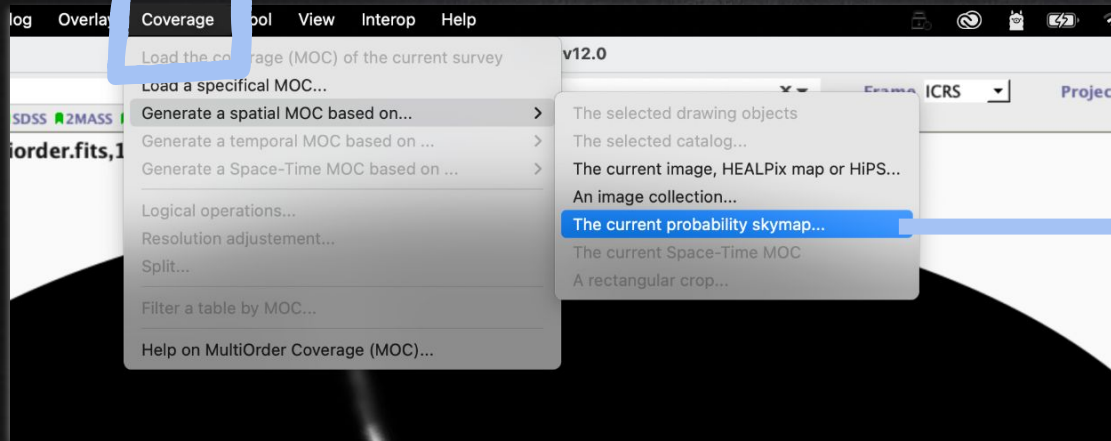
360° x 160°

[Plane @2] - bayestar.multiorder.fits,1



The sky map is loaded into the Aladin stack and shown in the main window.

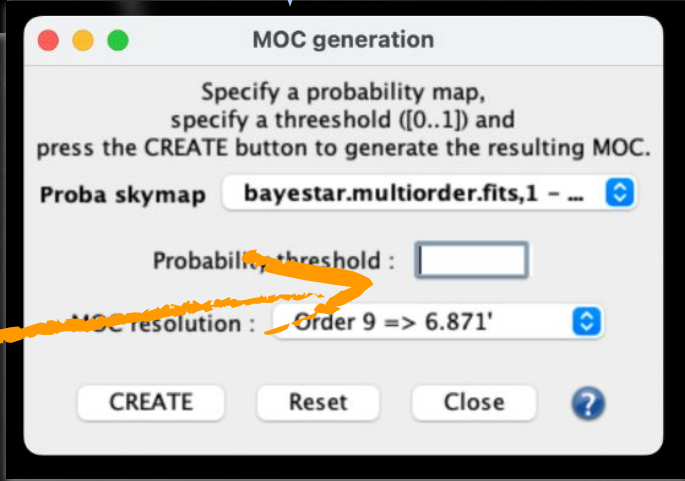


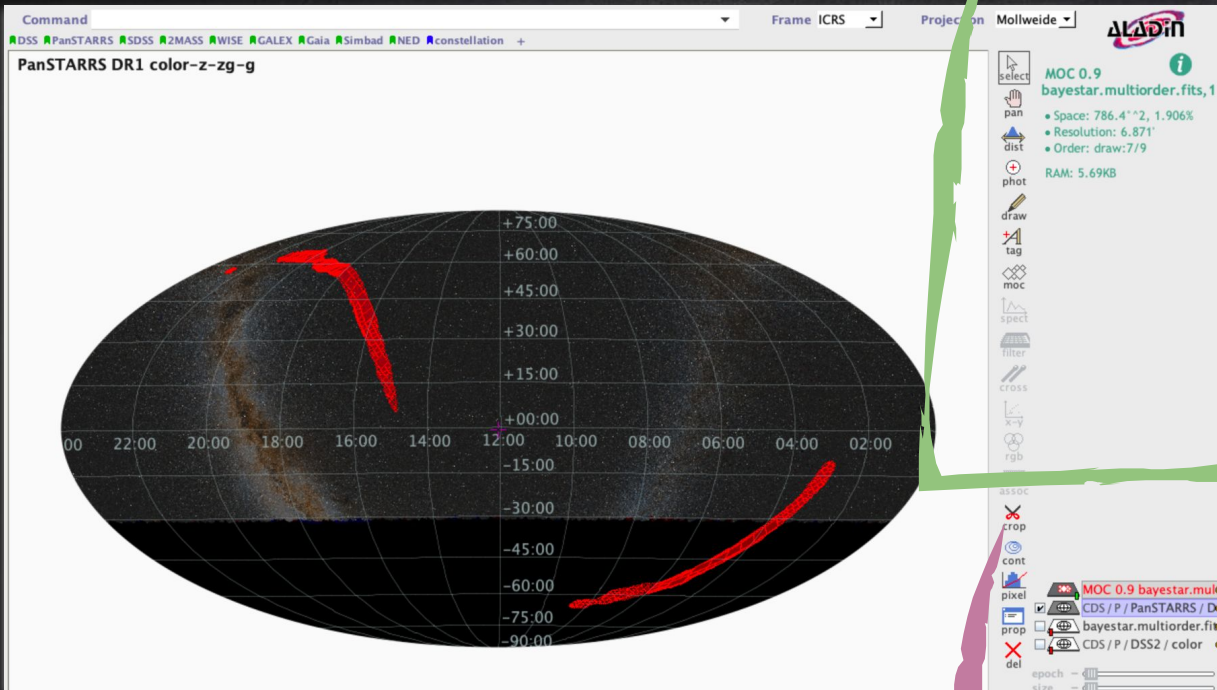


Creating GW Credible Areas

Coverage → Generate a spatial MOC based on →
The current probability skymap

In the 'Probability threshold' box, enter the probability level you want to plot.





MOC 0.9 bayestar.multiorder.fits, 1

- Space: $786.4^\circ \times 2$, 1.906%
- Resolution: $6.871'$
- Order: draw:7/9

RAM: 5.69KB

If you leave the mouse cursor on the plane **MOC 0.9 bayestar.multiorder**, at the top of the Aladin stack you can visualise the size of the area, both in square degrees and as a percentage of the whole sky.

MOC 0.9 bayestar.mu

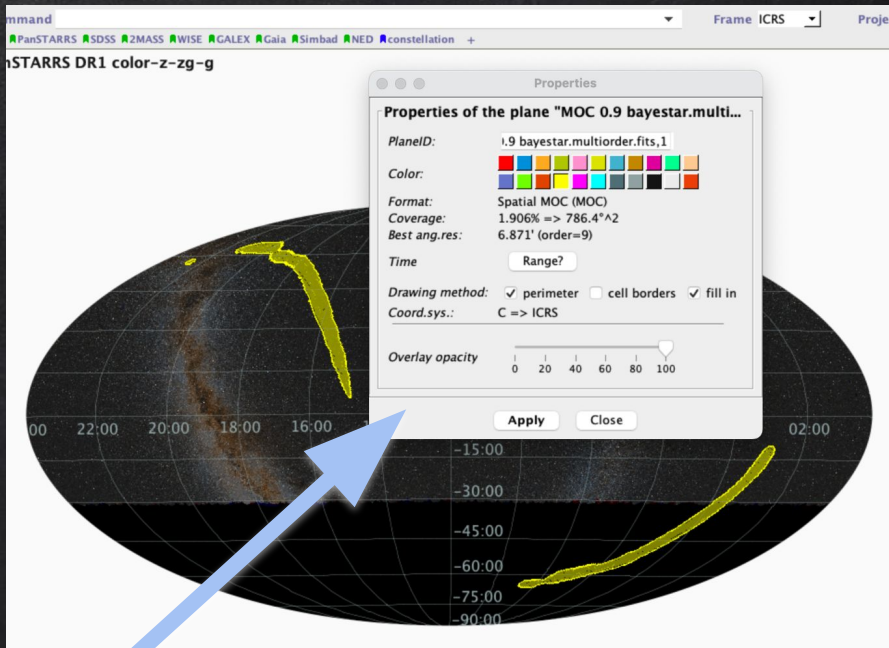
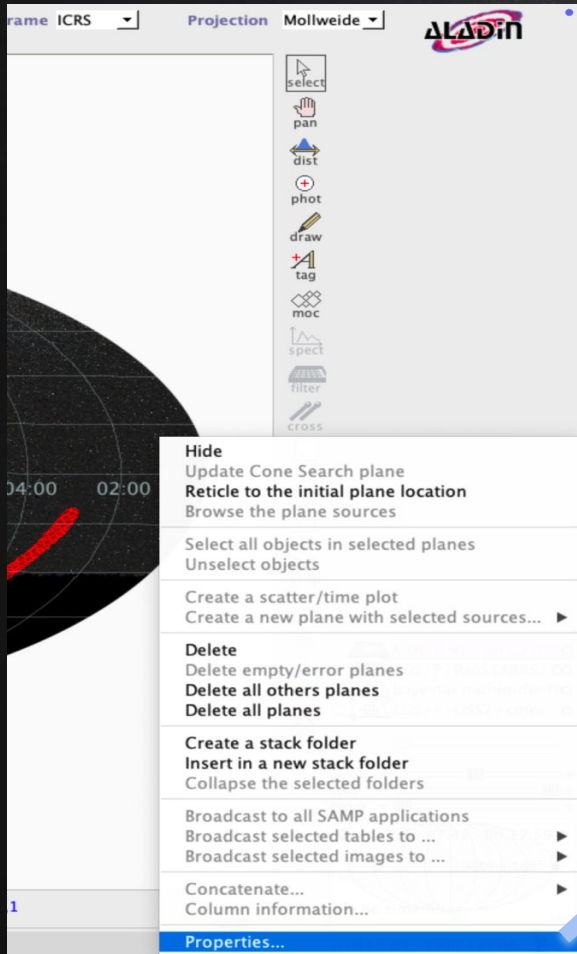
CDS / P / PanSTARRS / D

bayestar.multiorder.fi

CDS / P / DSS2 / color

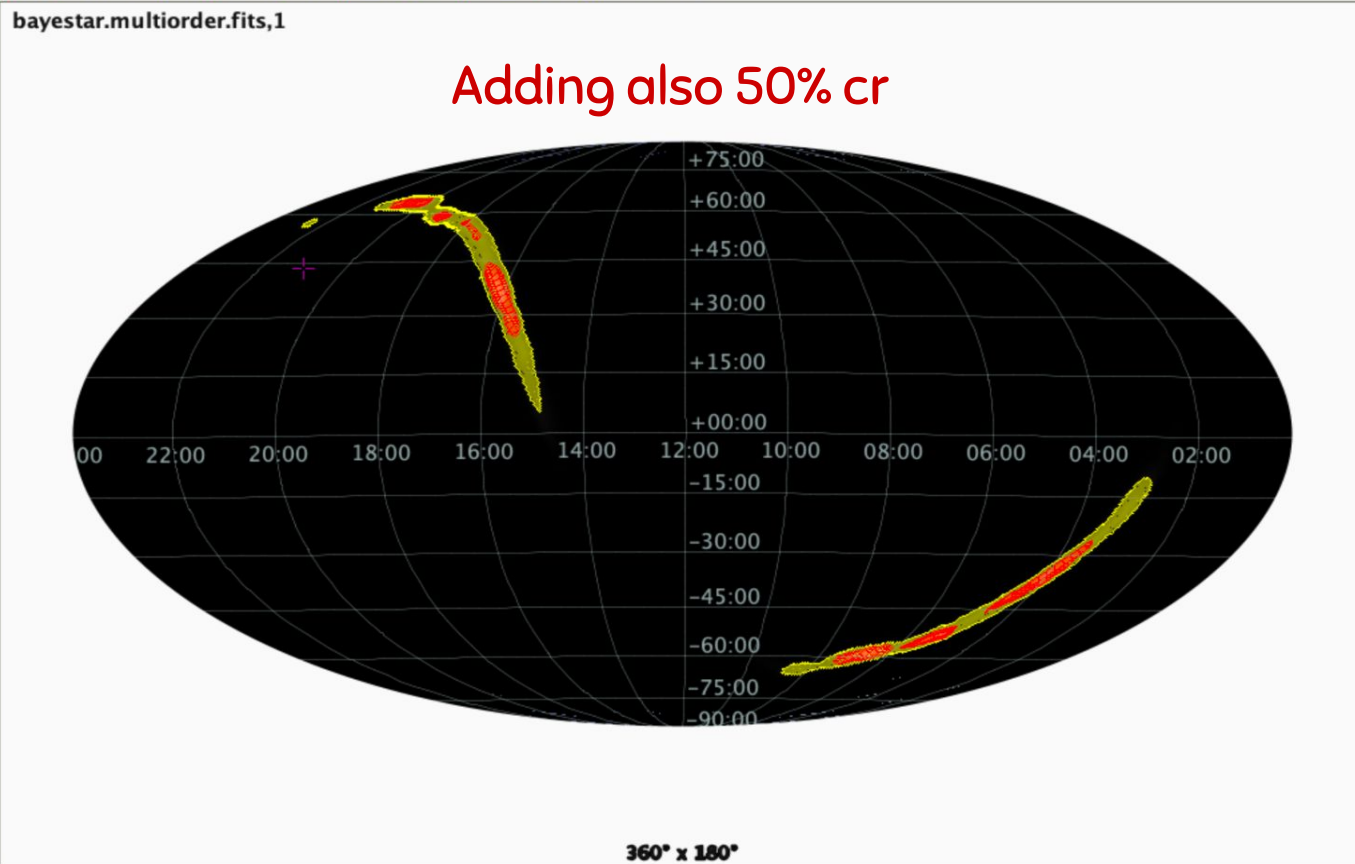
epoch - [Slider]

size - [Slider]



Right-click on the plane **MOC 0.9 bayestar.multiorder** to open the 'Properties' window and change some graphical settings.

- Collections → 3887
 - Image → 679
 - Data base → 4
 - Catalog → 3661
 - Cube → 25
 - Ancillary → 81
 - Outreach → 10
 - Deprecated → 2
 - Others → 1447



ALADiN

- select
- pan
- dist
- phot
- draw
- tag
- moc
- spect
- filter
- cross
- x-y
- rgb
- assoc
- crop
- epoch
- size
- dens.
- opac.
- zoom
- prop
- del

MOC 0.5 bayestar.mulo

MOC 0.9 bayestar.mulo

CDS / P / PanSTARRS / D

bayestar.multiorder.fits

CDS / P / DSS2 / color

epoch - [slider] +

size - [slider] +

dens. - [slider] +

opac. - [slider] +

zoom - [slider] +

12 03 07.42 -00 37 59.4

180 360 180 180

no time filter

select

from -- all...

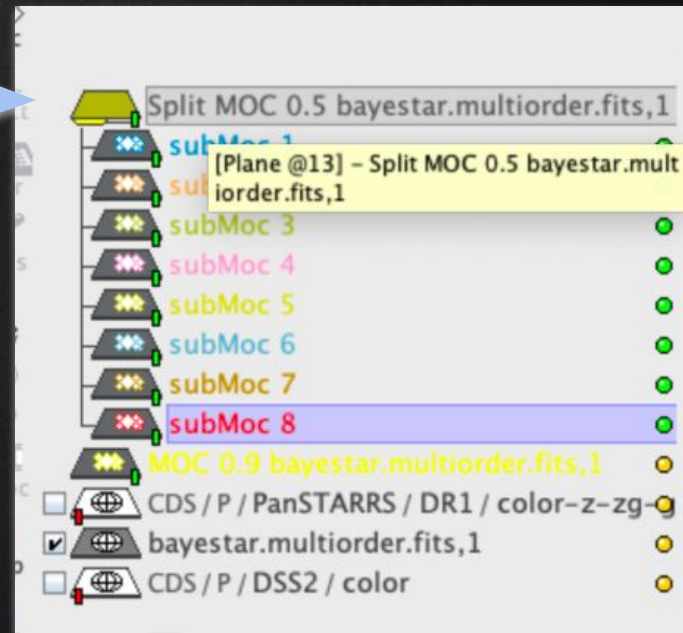
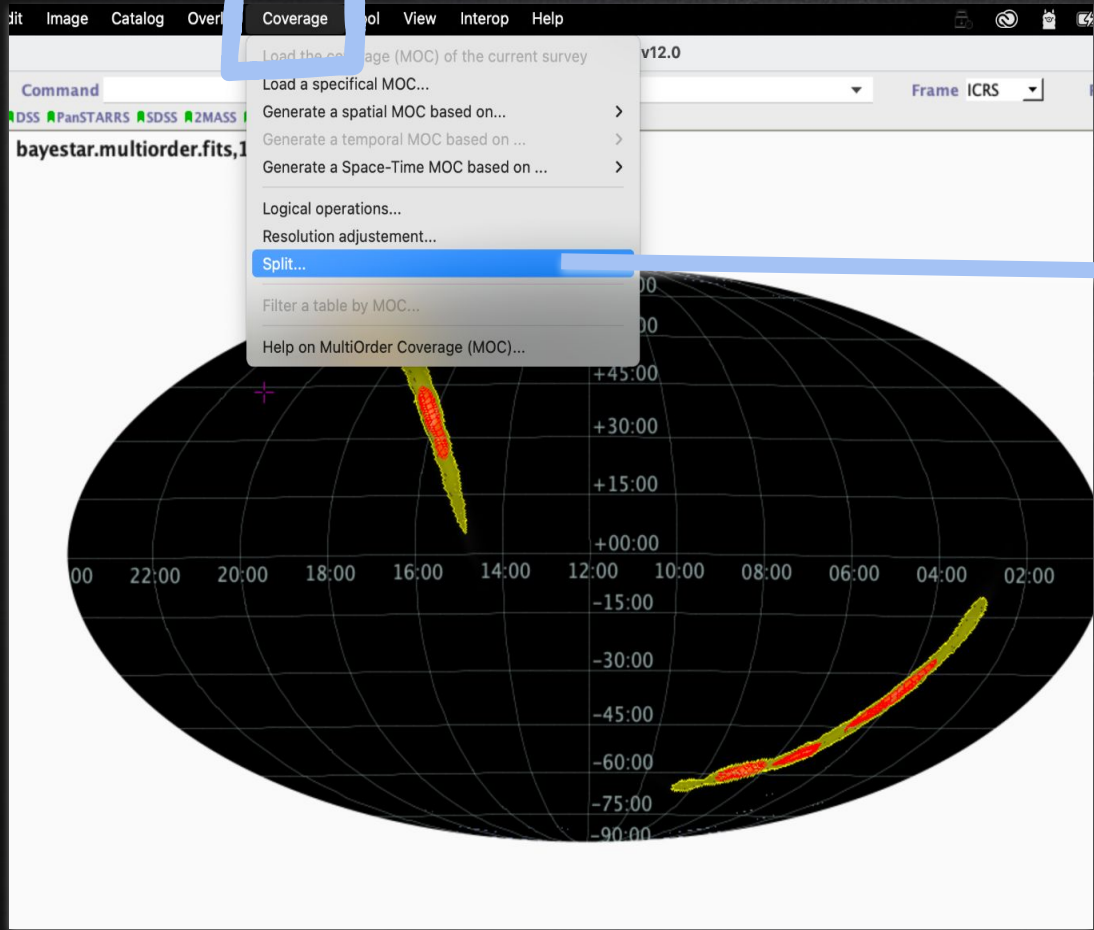
exp. sort view scan

grid study wink redo north hdr

multiview match

360° x 180°

[Plane @5] - MOC 0.5 bayestar.multiorder.fits,1



draw - graphical overlay commands:draw fct(param)

Synopsis:

draw [color] fct(param...) draw newtool[(name)] or draw newfov(xcenter,ycenter[,_name]) draw STC ... draw MOC ...

Description

Allows one to manually add graphical overlays on views. There are several graphical functions available: .string(x,y,text) .tag(x,y[,label,dist,angle,type,ftSize]) .line(x1,y1,x2,y2,...[,txt]) .polygon(x1,y1,x2,y2,...[,txt]) .vector(x,y,w,angle) .dist(x1,y1,x2,y2) .box(x,y,dx,dy[,angle,label]) .ellipse(x,y,semiMA,semiMI,angle) .circle(x,y,r) .phot(x,y,r[,orderlmax]) .arc(x,y,r,PA,angle) .pickle(x,y,r1,r2,PA,angle) The coordinates must be expressed in the current coordinate frame. It can be image XY coordinates (use [setconf](#) frame=XY) By default, Aladin puts the new object in the last drawing plane in the stack. It is possible to create manually a new one by the "draw newtool(name)" or "drawfov(x,y,name)" commands.

Note - -The parameter separator can be the comma or the space. In case of coordinates use the colon to group the subfields or quote them -The default angle unit is degree -The color parameter is specified as colorName or rgb(n,n,n) - The tag types are: reticle, bigreticle, smallcircle, circle, bigcircle, arrow, bigarrow, nopole -DS9 region commands or STC-S regions are automatically translated in the corresponding "draw" commands (ex: STC Circle ICRS 147.6 69.9 0.4). -MOC is always created in a separated plane (ex: draw MOC 3/2-30 4/134,136)

Example:

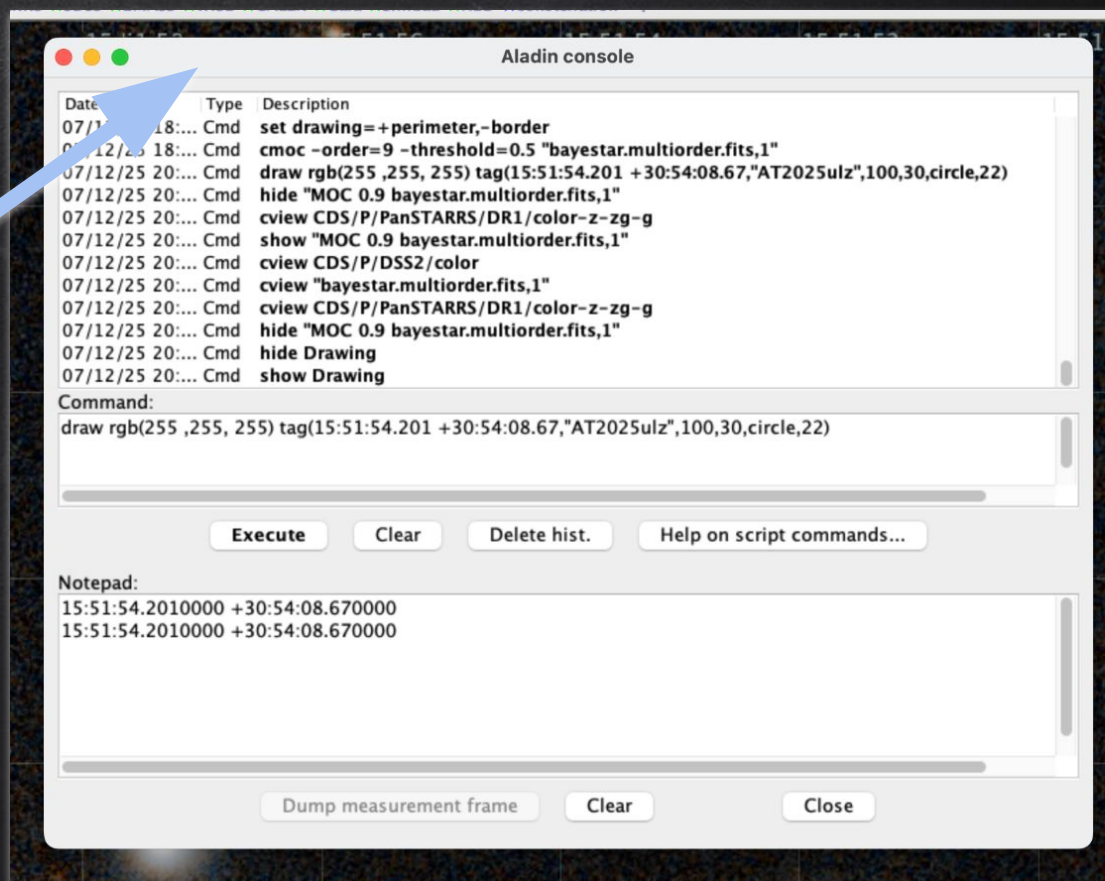
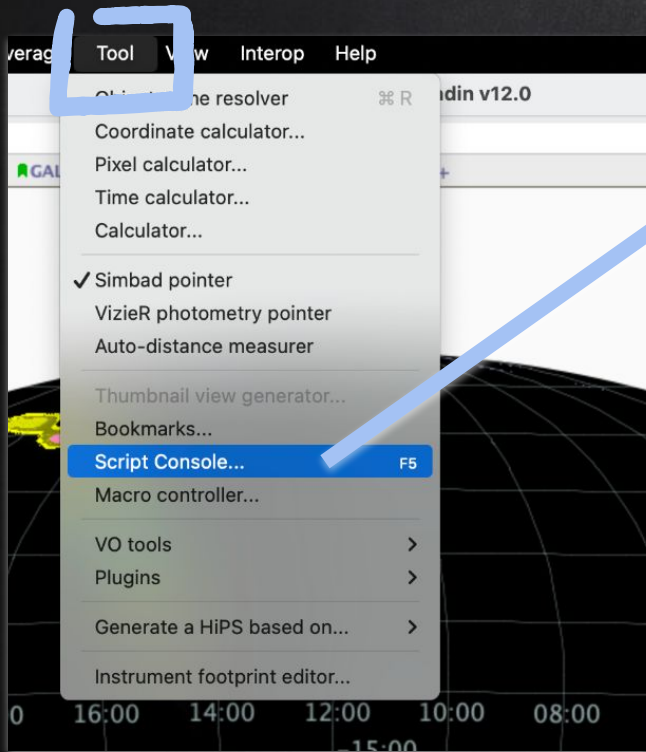
```
draw string(300,200,"my favourite galaxy")
draw rgb(100,34,89) tag(10:12:13,+2:3:4,"Big galaxy",100,30,circle,22)
draw red circle("1 2 3" "+4 5 6" 3arcmin)
```

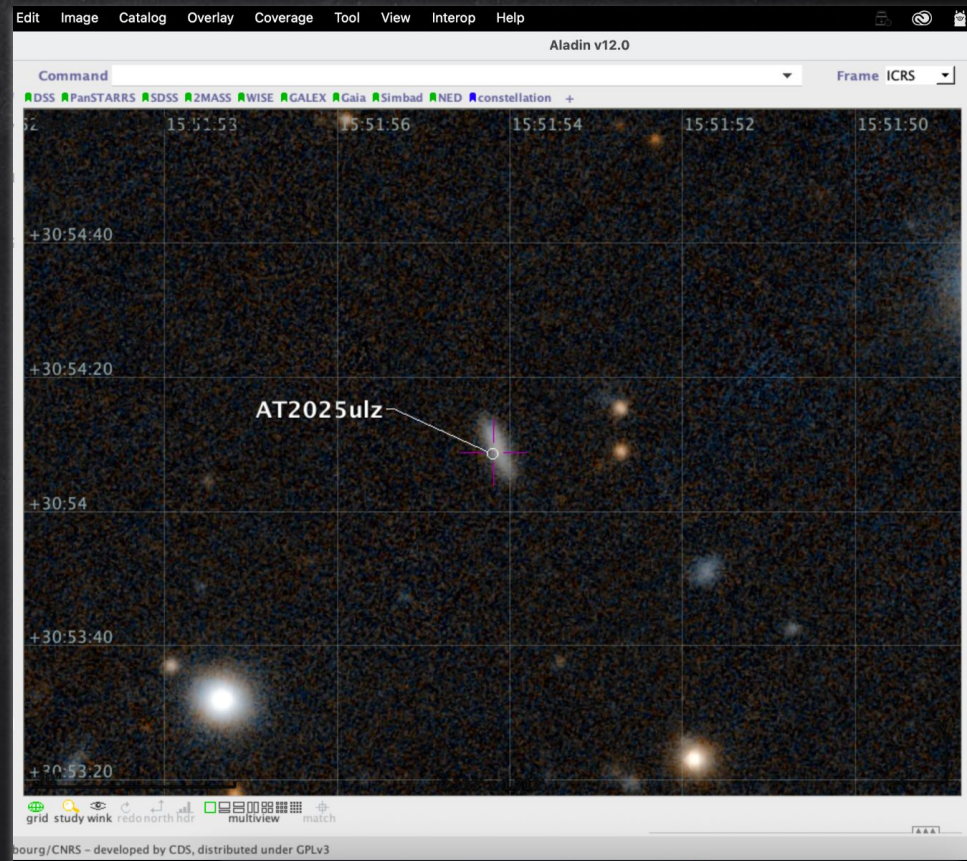
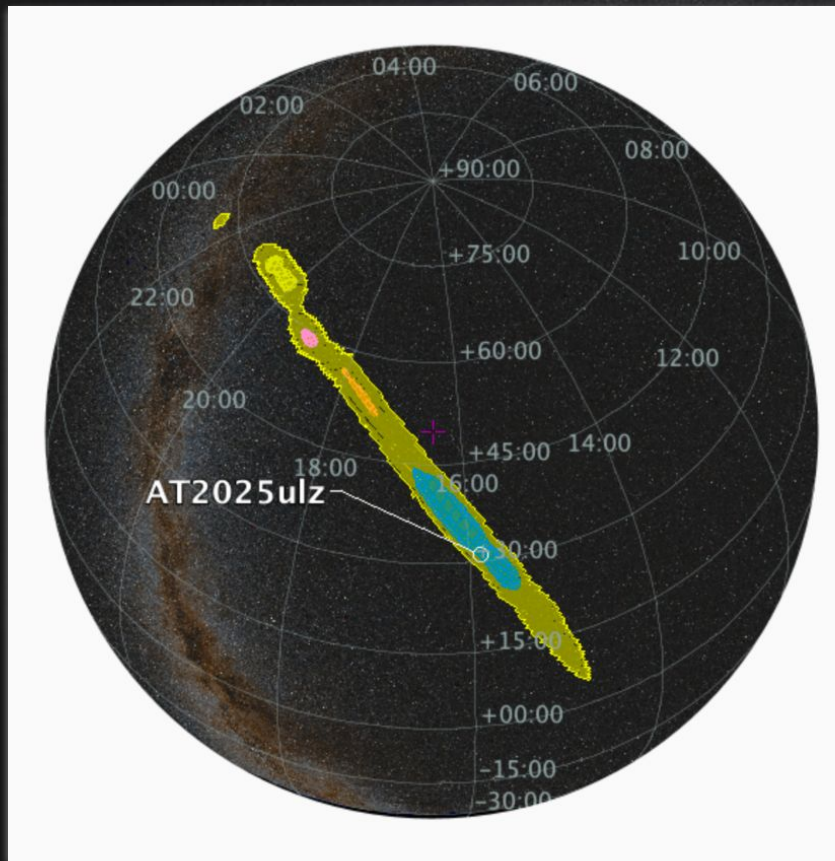
Draw the position of [AT2025ulz](#):

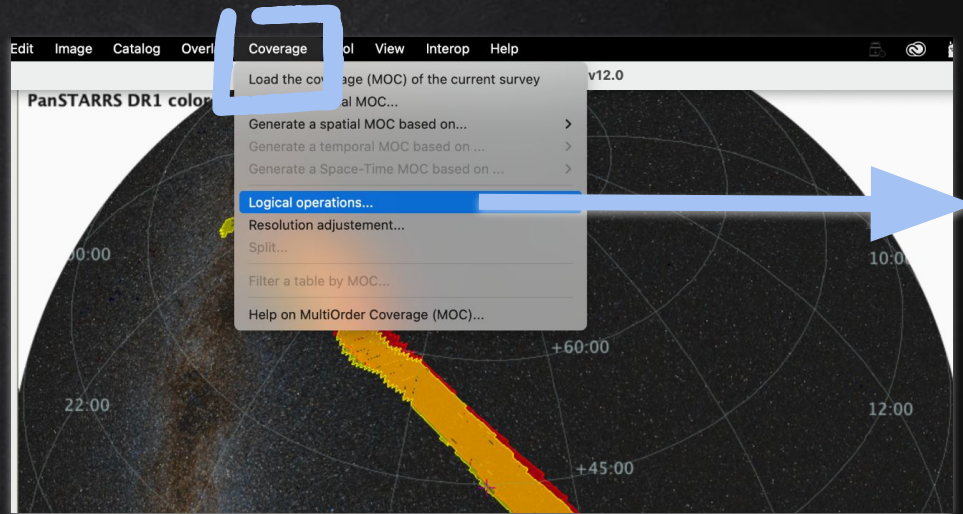
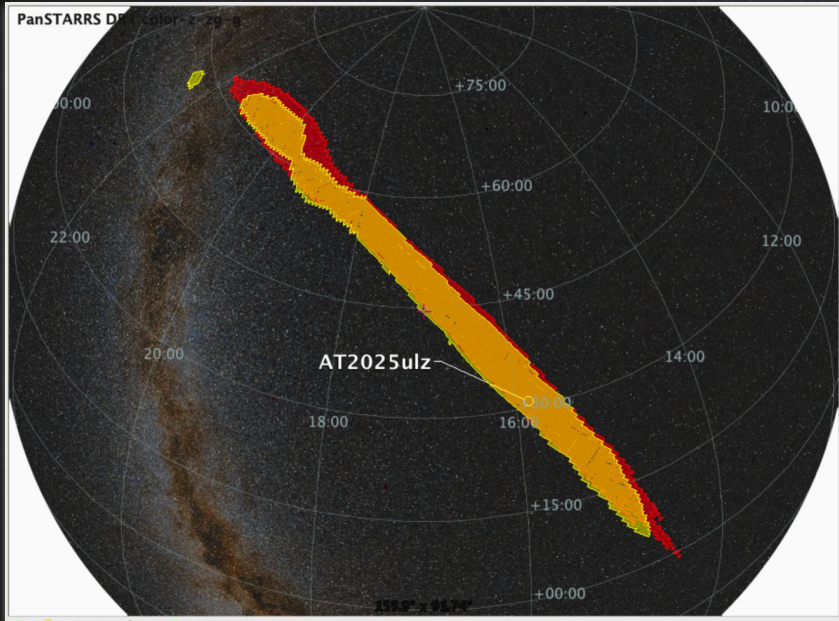
```
draw rgb(255,255,255) tag(15:51:54.201+30:54:08.67,"AT2025ulz",100,30,circle,22)
```

Aladin Script Commands:

<https://aladin.cds.unistra.fr/java/AladinScriptManual.gml#draw>







Comparison with Bilby skymaps:

<https://gracedb.ligo.org/api/superevents/S250818k/files/Bilby.offline0.multiorder.fits>

MOC operations

Specify one or two MOC planes,
choose a MOC operation and
press the CREATE button to generate the resulting MOC.

Plane

Plane

Plane

Plane

Plane

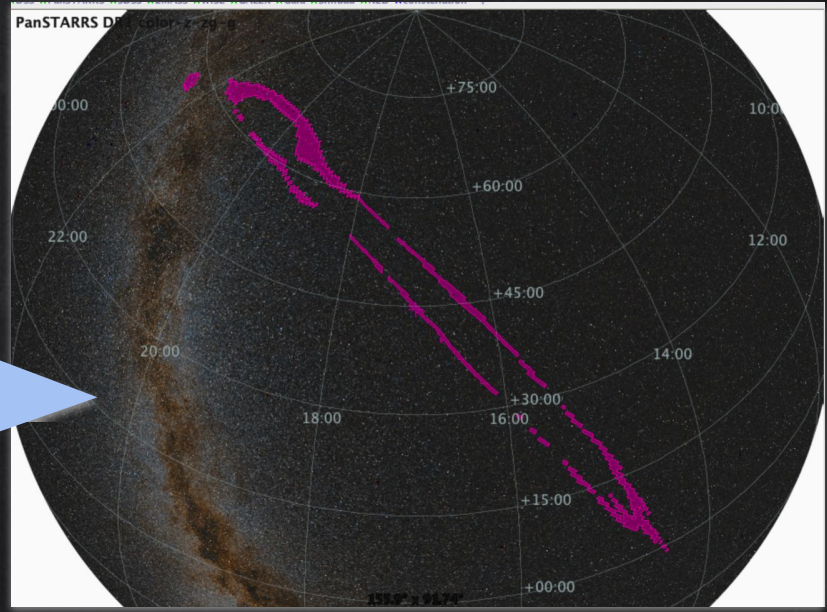
Union
 Intersection
 Subtraction
 Difference
 Complement
 Copy

Target MOC parameters

Space
 Time

Target size unlimited less than MB

if too big, reduce the resolution in: Space Time Both



Aladin v12.0


Available data → 2 / 38879
 ● in view ● out view

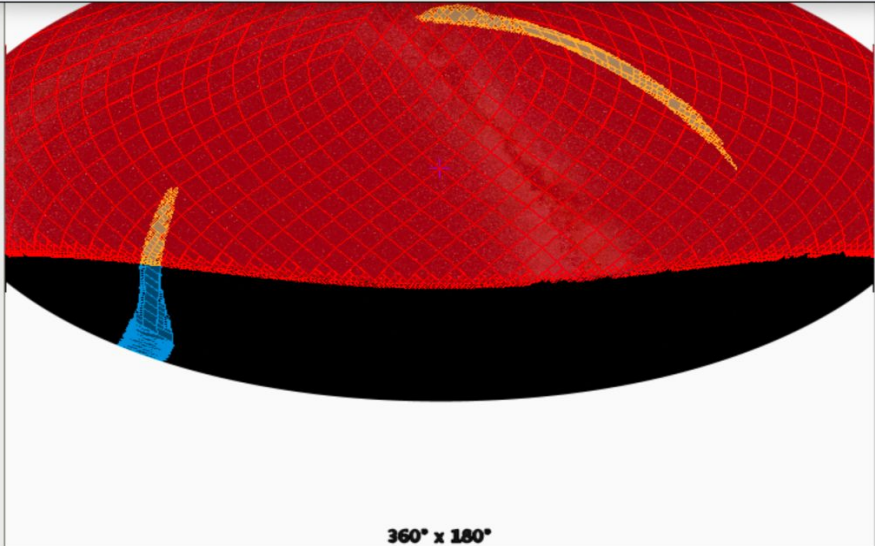
Collections → 2 / 38879
 Image → 2 / 679
 Optical → 2 / 183
 PanSTARRS → 2 / 7
 ● PanSTARRS DR1 color (i, r, g)
 ● PanSTARRS DR1 color (from ba

Command x Frame ICRS Projection Aitoff

● DSS ● PanSTARRS ● SDSS ● 2MASS ● WISE ● GALEX ● Gaia ● Simbad ● NED ● constellation +

PanSTARRS DR1 color-i-r-g

 **PanSTARRS DR1 color (i, r, g)**
 Provenance: MAST/STScI
 Coverage: 76.39% 394.3nm/760.3THz .. 843nm/355.6THz 2009-06-13 .. 2015-02-09 Res: 1.61"
 Access mode & derived prod. progressive + STMOC cov.
 CDS/P/PanSTARRS/DR1/color-i-r-g Load



360° x 180°

tag moc spect filter cross x-y rgb assoc crop epoch - size - dens. - opac. - zoom -

Int MOC 0.9 Bilby.offline0.multiorderCDS ●
 MOC 0.9 Bilby.offline0.multiorder ●
 CDS / P / PanSTARRS / DR1 / color-i-r-g ●
 Bilby.offline0.multiorder ●
 CDS / P / PanSTARRS / DR1 / color-i-r-g ●
 CDS / P / PanSTARRS / DR1 / color-z-zg ●
 CDS / P / DSS2 / color ●

epoch -
 size -
 dens. -
 opac. -
 zoom -

prop 20:59:46.06 +09:28:36.3 360° x 180°
 2009-06-13 2015-02-09


select panstarr
 from Color surveys


coll. sort view scan filter
 grid study wink redonorth hdr multiview match

ALADIN



(c) 2023 Université de Strasbourg/CNRS – developed by CDS, distributed under GPLv3 0 sel / 0 src 42fps / 919Mb

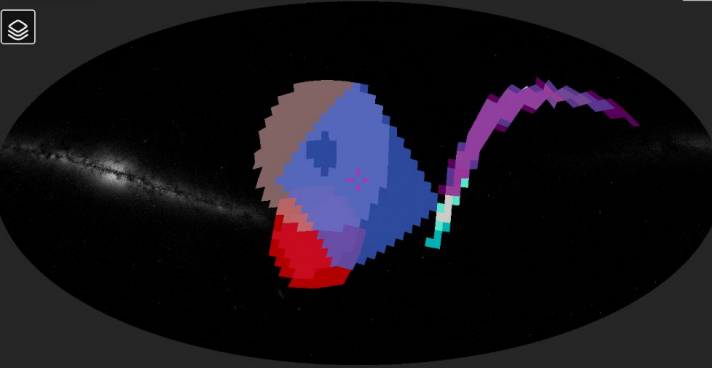
Finding reference images


The tool provides the credible areas of gravitational-wave sky localizations issued by the [LIGO-Virgo-KAGRA collaborations \(LVK\)](#). The resulting credible area is encoded with the data-structures [Multi Order Coverage map \(MOC\)](#). MOC is a Virtual Observatory standard approved by the [IVOA \(International Virtual Observatory Alliance\)](#) to manage sky coverage. Each MOC is visualized in the [Aladin Lite](#) with various background image surveys. The whole list and the image surveys are accessible by clicking the icon  manage layers located at the top left. The MOC maps are created and manipulated with the WebAssembly library [MOCWasm](#).

Galactic 


128.448792 -14.7928179


MOL  





356.8° × 180.0° 

- ▼ Info MOC coverage (My device)
- ▼ Info MOC coverage (GraceDB)
- ▼ Info MOC coverage (Catalogs)

 Info MOC coverage

 Identification name: GW200225_060421 C01:SEOBNRv4PHM MOC 0.95

 MOC order: 9

 Coverage: 1.007% of sky

Load a gravitational-wave sky localization from:

My device	GraceDB	Catalogs
Alerts	Login	Close

1. Insert a valid URL from GraceDB: ✕
2. MOC identification name (optional):
3. Choose a credible level and press the button:

-

0,9

+
Display Credible Area

Draw MOC sky regions:

Box	Circle	Ellipse
Ring	Zone	Close

GWsky: <https://virgo.pg.infn.it/maps/>

Spatial and Temporal MOC: ST-MOC

International Virtual Observatory
Alliance

IVOA Documents



MOC: Multi-Order Coverage map
Version 2.0

IVOA Recommendation 27 July 2022

Interest/Working Group:

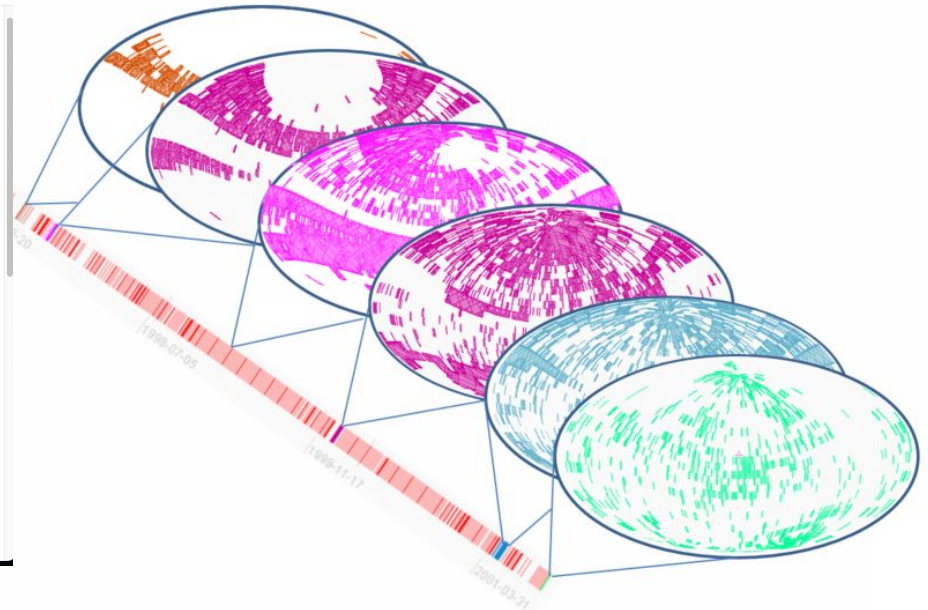
<http://www.ivoa.net/twiki/bin/view/IVOA/IvoaApplications>

Author(s):

Pierre Fernique (CDS), Ada Nebot (CDS), Daniel Durand (CADC), Matthieu Baumann (CDS), Thomas Boch (CDS), Giuseppe Greco (EGO-Virgo), Tom Donaldson (STScI/NASA), Francois-Xavier Pineau (CDS), Mark Taylor (University of Bristol), Wil O'Mullane (Vera C. Rubin Observatory), Martin Reinecke (Max Planck), Sébastien Derrière (CDS)

Editor(s):

Pierre Fernique, Ada Nebot, Daniel Durand



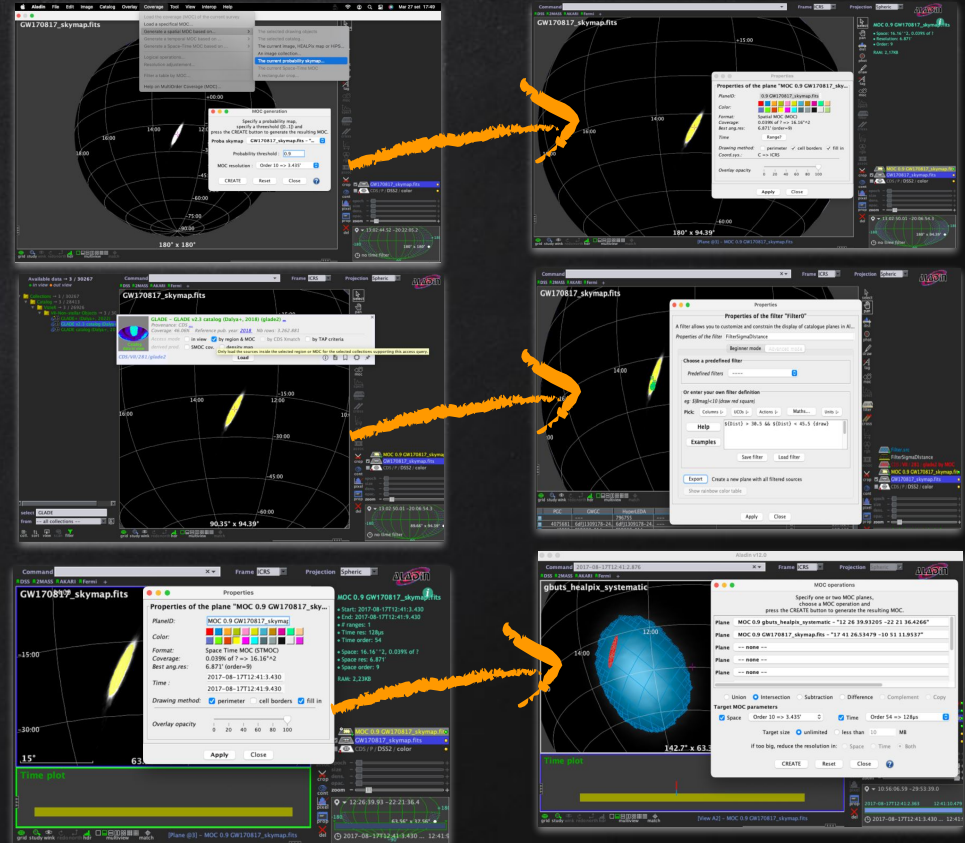
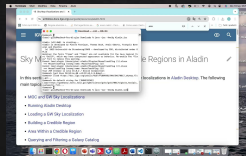
At a given Time range we obtain the corresponding Spatial coverage.

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>
- https://indico.in2p3.fr/event/25225/sessions/15780/attachments/69008/98807/MMA-Aladin-vr2_compressed.pdf
- Video Tutorial



Gravitational Waves

Superevent

Enter an event name from the O3 or O4 runs (e.g. S251112cm).

e.g. S251112cm

Credible level

From 0 (most likely) to 1 (least likely)

0.2

Search for matching alerts

Information

Enter a superevent name on the left (check O3 or O4 runs if you are unsure), and enter a credible level in the resulting credible level map vary inversely with probability density: the most probable pixel is assigned level 0.0, and the least likely pixel is assigned the credible level 1.0.

The alerts falling into the sky map are shown in the table, with the following columns:

- **diaObjectId**: LSST object ID.
- **SIMBAD**: Crossmatch tag according to SIMBAD, at the time of the match.
- **Number of measurements**: Number of available measurements, at the time of the match.
- **Delay**: Time delay in days between the GW trigger time t_0 and the first alert emission time (firstAlertTime).

Note that only alerts that started varying within the time boundaries

$$[t_0 - 1 \text{ day}, t_0 + 6 \text{ days}]$$

are considered, where t_0 is the GW trigger time. Finally we provide a visualisation of the alerts on the sky map, along with a Multi-Ordered Coverage (MOC) of the GW event.

* At the start of the LSST stream, firstDiaSourceMjall is populated by the project, and all alerts regardless their first emission time are considered.



VERA C. RUBIN
OBSERVATORY



Multi Order Coverage data structure to plan multi-messenger observations

Giuseppe Greco, Michele Punturo, Mark Allen, Ada Nebot, Pierre Fernique, Matthieu Baumann, François-Xavier Pineau, Thomas Boch, Sébastien Derriere, Marica Branchesi, Mateusz Bawaj, Helios Vocca



<https://lsst.fink-portal.org/gw>

Ready to run the tutorial in Colab!

Accessing and using astronomical data from Python: a series of Jupyter notebooks tutorials

This website contains the Jupyter-notebook tutorials hosted by the Strasbourg Astronomical Data center CDS.

All tutorials here illustrate how astronomers can search, find, and access data they need from archives across the world. We offer a focus on archives compliant with Virtual Observatory (VO) protocols and standards, as defined by the International Virtual Observatory Alliance (IVOA).

Some tutorials hosted here are based on [EURO-VO tutorials](#) and were translated into python tutorials. The original version usually has the same or a similar name.

List of tutorials

The tutorials come in a recommended order ranging from basic usage to more advanced examples.

- [Introduction to the CDS services](#)
- [First steps with Multi-Order Coverage data structure](#)
- [The Simple Spectral Access Protocol to explore Abel 1656](#)
- [Combining the CDS services to study gamma-ray and high energy spectral bands](#)
- [Cross matching catalogs to discover potential brown dwarfs](#)
- [Advanced usage of MOCs](#)
- [Planning multi-messenger observations rapidly with MOCs](#)

Multi Order Coverage data structure to plan multi-messenger observations

Giuseppe Greco¹, Manon Marchand²

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

This notebook is a tutorial associated to the article [Multi Order Coverage data structure to plan multi-messenger observations](#).

We will first explore Multi-Order Coverage (MOC) data structure manipulation, then we will see how astropal and Space-Time Multi Order Coverage (STMOC) can be combined. The final step is a concrete example illustrating how STMOCs can be build in a few seconds to plan observations from three ground observatories of the full sky localisation produced after detection of a gravitational wave.

Loading a GW Sky Localization

MULTI ORDER COVERAGE DATA STRUCTURE TO PLAN MULTI-MESSENGER OBSERVATIONS

Loading a GW Sky Localization

0:04 / 10:40

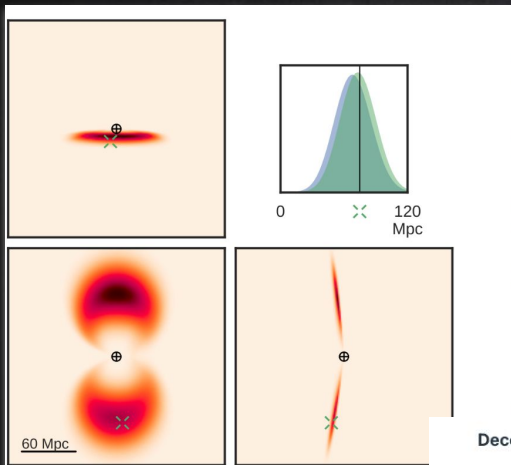
https://virgo.pg.infn.it/multimedia/tuto_A_C_mid.mp4

Tutorials from [Multi Order Coverage data structure to plan multi-messenger observations](#) – Greco et al., 2022

GLADENET: WORKING WITH GW SKY LOCALIZATIONS (3D)

For Compact Binary Coalescence events, 3D sky localization maps are released (Singer et al. 2016).

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



Next in September(?)



A prototype standard to enable GenAI

Toward Agentic Alert

From MOC Sky Maps to AI-Enhanced Analysis

- IVOA MOC standards provides an efficient way to describe complex sky regions.
- IVOA MOC is especially suited to GW sky localizations.
- IVOA MOC supports data discovery and sky-map operations.

The next step is to bring AI into this framework.

- The goal is to extend the data structure without losing existing uses.
- New layers can be added gradually: RAG, semantic search, agents, and vision models.



After showing how MOCs can support EM follow-up activities, we now ask a broader question: how can they be adapted for GenAI?

Encapsulating textual contents into a MOC data structure for advanced applications

Giuseppe Greco^a ✉, Thomas Boch^b, Pierre Fernique^b, Manon Marchand^b,
Mark Allen^b, Francois-Xavier Pineau^b, Matthieu Baumann^b, Marco Molinaro^c,
Roberto De Pietri^{d e}, Marica Branchesi^{f g}, Steven Schramm^{h i}, Gergely Dályai^j,
Elahe Khalouei^k, Barbara Patricelli^l, Giulia Stratta^m

ENABLING BASIC:

- SEMANTIC SEARCH
- RETRIEVAL-AUGMENTED GENERATION
- AGENTIC WORKFLOW
- VISION MODEL ANALYSIS

- <https://www.sciencedirect.com/science/article/pii/S2213133725000873>
 - <https://arxiv.org/abs/2510.12213>

TEXTUAL MOCs

WHERE, WHEN AND WHAT

Prototype extension of the MOC standard: beyond spatial and temporal components, a textual *What* dimension to explicitly describe the content of a given sky region.

Snippet 1: JSON structure of a Space MOC

```
{
  "ordern": [npixi | where npixi uniquely defined integers],
  // ... continue for other orders ...
}
```

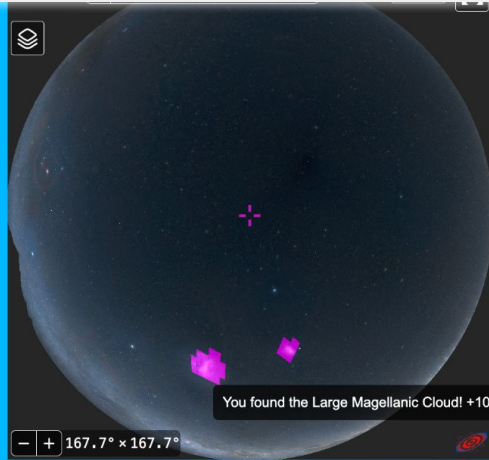
In the JSON serialization of MOCs, an additional key has been introduced that allows to add textual content.

Snippet 2: JSON structure of a Textual MOC with text, metadata, and cell annotations

```
{
  "ordern": [npixi | where npixi uniquely defined integers],
  // ... continue for other orders ...
  "text": "Your textual description here",
  "metadata": {
    "key1": "value1",
    "key2": "value2",
    // ... continue metadata entries ...
  },
  "annotated_cells": {
    "ordern": {
      "npixi": "annotationi",
      // ... continue for other pixels ...
    }
  }
  // ... continue for other orders ...
}
```

Textual MOC applications: EDU Game

An interactive game using Textual MOCs within Aladin Lite helps users locate the Large Magellanic Cloud (LMC). The magenta-colored MOC marks the position of the LMC, and informational popups provide feedback as the user interacts with the map. Auditory cues enhance the user experience by signaling correct or incorrect selections.

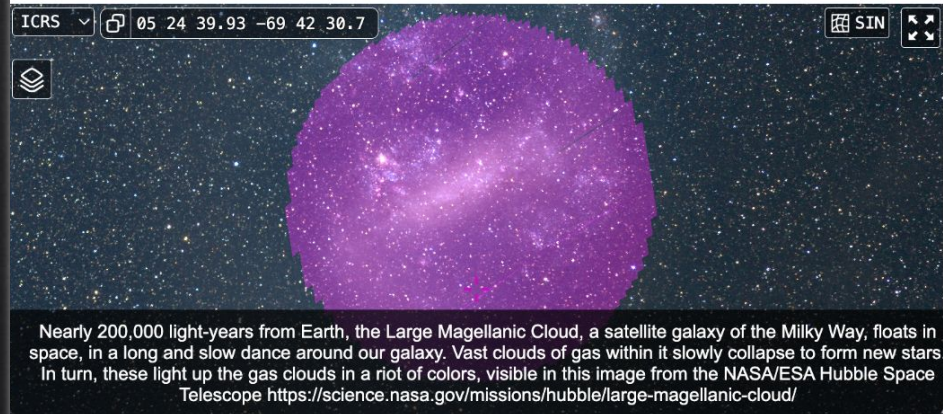


Start Game

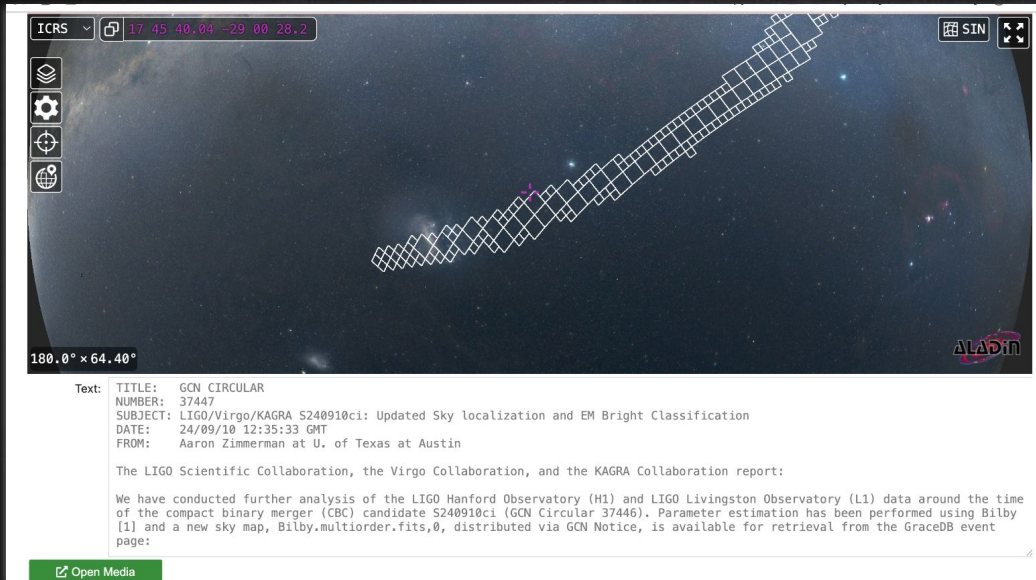
Congratulations! You found the Large Magellanic Cloud!

Textual MOC Application with Aladin Lite

This application demonstrates a simple example of using Textual MOCs in an interactive page powered by Aladin Lite. Hovering over the magenta-colored MOC will open a popup at the bottom displaying the information contained in the textual MOC. A button allows you to enable sounds that will be played when the cursor enters or exits the region defined by the MOC.



TEXTUAL MOC APPLICATIONS: ENCAPSULATING GCN CIRC.



ICRS 17 45:40.04 -29 00 28.2 SIN

180.0° × 64.40°

ALADIN

Text: TITLE: GCN CIRCULAR
NUMBER: 37447
SUBJECT: LIGO/Virgo/KAGRA S240910ci: Updated Sky localization and EM Bright Classification
DATE: 24/09/10 12:35:33 GMT
FROM: Aaron Zimmerman at U. of Texas at Austin

The LIGO Scientific Collaboration, the Virgo Collaboration, and the KAGRA Collaboration report:

We have conducted further analysis of the LIGO Hanford Observatory (H1) and LIGO Livingston Observatory (L1) data around the time of the compact binary merger (CBC) candidate S240910ci (GCN Circular 37446). Parameter estimation has been performed using Bilby [1] and a new sky map, Bilby.multiorder.fits,0, distributed via GCN Notice, is available for retrieval from the GraceDB event page:

Open Media

This use case shows how to display the 90% credible region of a gravitational-wave sky localization alongside LVK alerts via the General Coordinates Network (GCN). GCN Circulars are accessed in text or JSON format.

Building on the method by Greco et al. (2022b), we enhance sky maps with Textual MOCs, linking each sky region with its related GCN Circular(s).

Other astronomical platforms can be utilized for the creation of Textual MOCs, such as the General Coordinates Network (GCN)10, the Transient Name Server (TNS) (Gal-Yam, 2021), the Astrophysical Multimessenger Observatory Network (AMON) (Ayala Solares et al., 2020) and follow-up pointings in the Gravitational Wave Treasure Map (Wyatt et al., 2020).

TEXTUAL MOC ENRICHED BY MOCSEVER

```
import tempfile
from astroquery.mocserver import MOCServer

# Retrieving the MOC of a specific dataset: CDS/P/Euclid/Q1/color
moc_from_mocserver = MOCServer.find_datasets(meta_data="ID=CDS/P/Euclid/Q1/color", return_moc=True)

# Inspecting metadata - obs_description
metadata = MOCServer.find_datasets(meta_data="ID=CDS/P/Euclid/Q1/color")
obs_description = metadata["obs_description"][0]

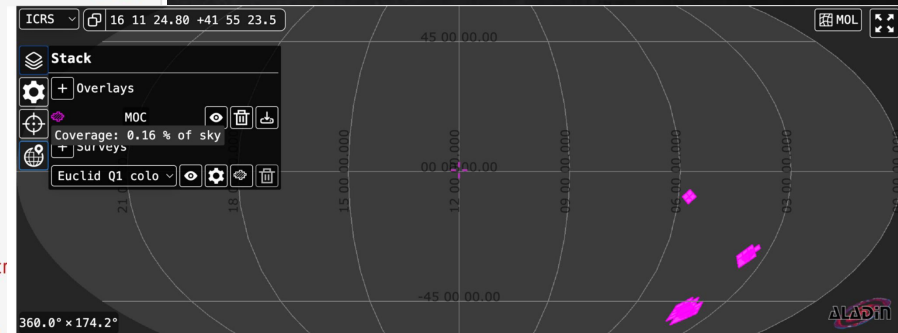
# obs_description = obs_description.replace(" ", "~65 deg^2")

# Initialize TextualMOC class with the created MOC
textual_moc = TextualMOC(moc_from_mocserver)

# Multimedia link
multimedia_url = 'https://esdcdoi.esac.esa.int/doi/html/data/astronomy/euclid/eqrq1.htm'

# Create a temporary file and write the obs_description to it
with tempfile.NamedTemporaryFile(delete=False, mode='w', suffix='.txt',) as temp_file:
    temp_file.write(obs_description)
    temp_file_name = temp_file.name # Get the temporary file name

# Adding text and multimedia using the temporary file name
textual_moc.add_text_media_image(temp_file_name, multimedia_url )
```



Text: The Euclid Q1 data release encompasses ≈ 65 deg² and contains the VIS and NIR data of one pass on each of the three Euclid deep fields (EDF-North, EDF-South, and EDF-Fornax), as well as data on Lynds Dark Nebula LBN1641 in the Orion star-formation region. The release aims to showcase the scientific potential of Euclid data, help the community prepare for the upcoming DR1, and support early science projects spanning topics from cosmology to the Solar System. In the 3 Euclid deep fields, this HiPS has been produced using bands NISP.H, NISP.Y and VIS for creating the color, and VIS for the luminance. In the Orion star-formation region, this HiPS has been produced combining infrared bands NISP.H, NISP.J and NISP.Y.

MOCserver enables textual MOCs enriched with high-quality metadata curated by archival experts.

PROPOSE A NEW SCIENTIFIC USE CASE WHERE A TEXTUAL MOC WOULD BE USEFUL

DEVELOP IT!



VA platform

The platform allows users to request assistance on any of the topics related to the expertise of the different centres. The users can register on the platform, create a ticket, and interact directly with experts there. The platform can be accessed through the following link:

Ask an expert

YOU CAN OPEN A TICKET IF YOU WOULD LIKE TO CONTINUE
THE DISCUSSION OFFLINE

<https://www.acme-astro.eu/centres-of-expertise/>

What else is needed to make textual MOCs usable with generative AI models?

SEMANTIC MOC

FROM WHAT IT IS TO WHAT IT MEANS

Textual MOCs are converted into semantic embeddings, which are compact numerical representations that encapsulate the meaning of the text within a multidimensional geometric space.

Snippet 3: JSON structure of a Semantic MOC with text transformed into semantic embeddings.

```
{
  "order_n": [npix_i | where npix_i, uniquely defined integers],
  // ... continue for other orders ...
  "text": "Your textual description here",
  "metadata": {
    "key1": "value1",
    "key2": "value2",
    // ... continue metadata entries ...
  },
  "annotated_cells": {
    "order_n": {
      "npix_i": "annotation,"
      // ... continue for other pixels ...
    }
    // ... continue for other orders ...
  }
  "embedding": [text vectorization],
  "embedding_model": "selected embedding model"
  "image": "https://alaskv.cds.unistra.fr/...".
}
```



The “embedding” field contains the numerical vector representation of the text, generated through a chosen text vectorization technique, encoding the semantic meaning in a compact form suitable for computational analysis. The “model” entry specifies the embedding model used to generate the vector representation.

Ready for GenAI workflow to query space and semantic simultaneously!

Tokenizer

Learn about language model tokenization

OpenAI's large language models process text using **tokens**, which are common sequences of characters found in a set of text. The models learn to understand the statistical relationships between these tokens, and excel at producing the next token in a sequence of tokens.

[Learn more.](#)

You can use the tool below to understand how a piece of text might be tokenized by a language model, and the total count of tokens in that piece of text.

GPT-5.x & O1/3

GPT-4 & GPT-3.5 (legacy)

GPT-3 (legacy)

Enter some text

Clear

Show example

Tokens

Characters

0

0

DATA

Points: 10000 | Dimension: 200

5 tensors found

Word2Vec 10K

Label by

word

Color by

No color map

Edit by

word

Tag selection as

Load

Publish

Download

Label

Sphereize data

Checkpoint: Demo datasets

Metadata: oss_data/word2vec_10000_200d_labels.tsv

UMAP

T-SNE

PCA

CUSTOM

X

Component #1

Y

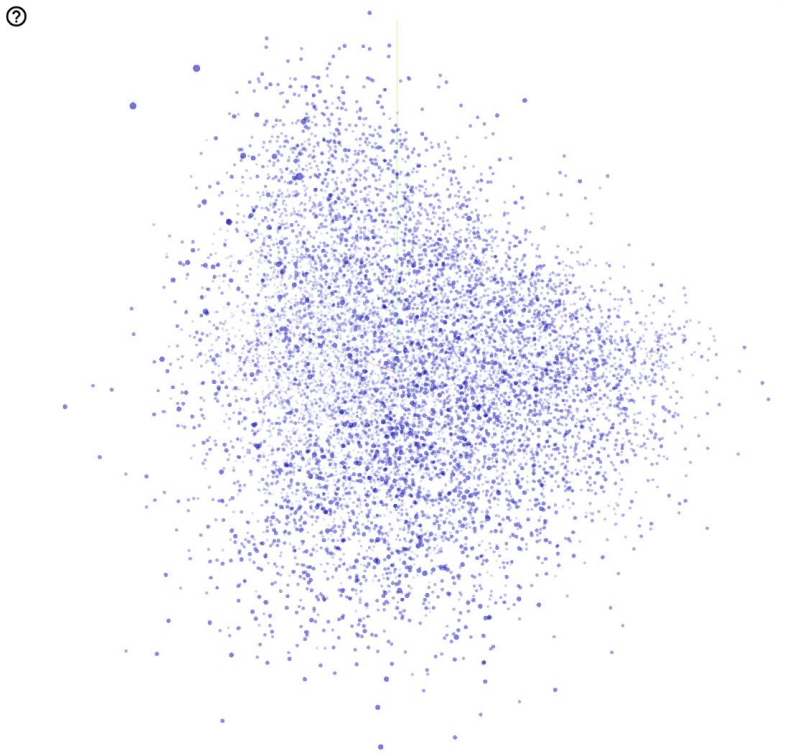
Component #2

Z

Component #3

PCA is approximate.

Total variance described: 8.5%.



Show All Data

Isolate selection

Clear selection

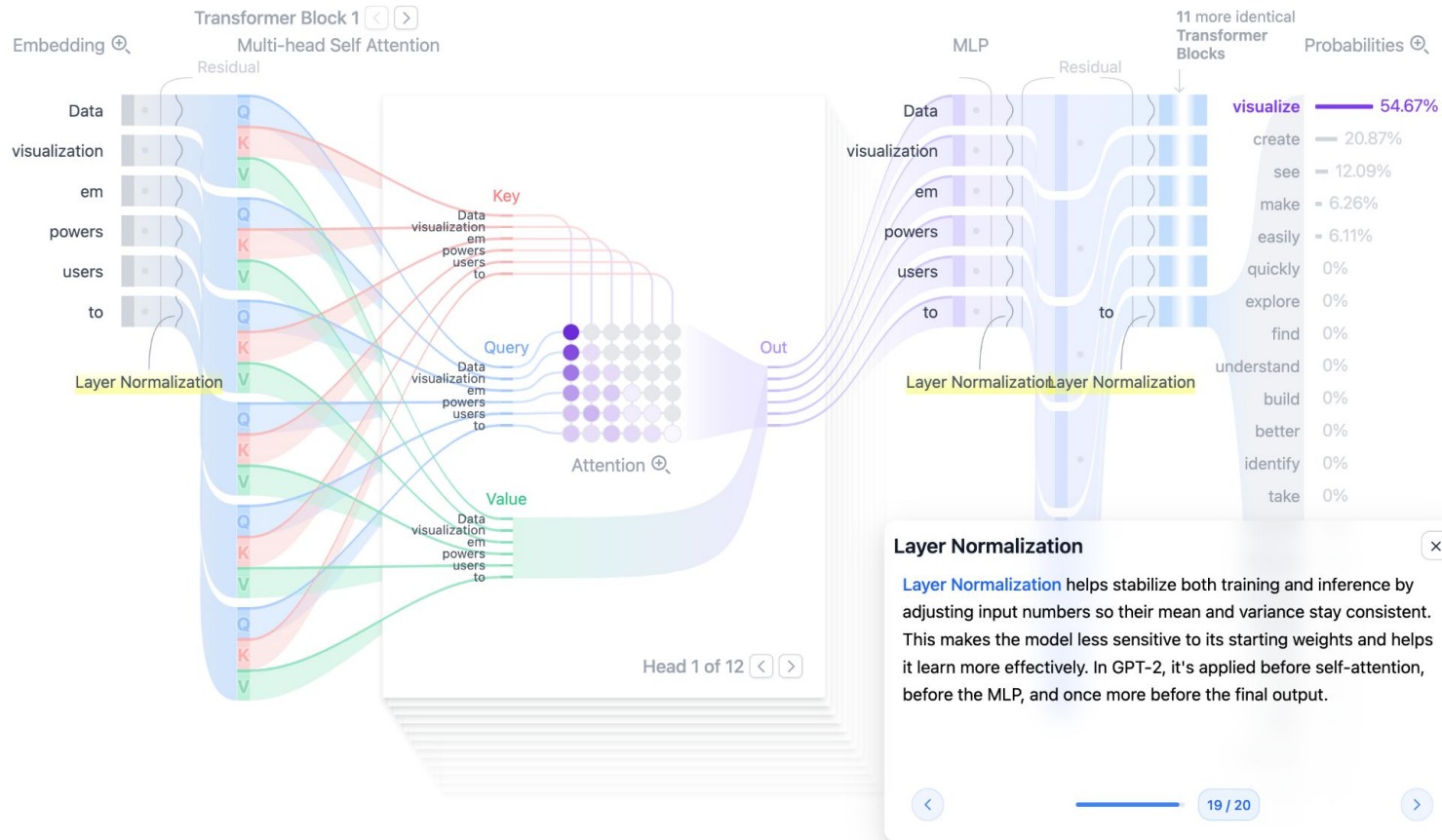
Search

by

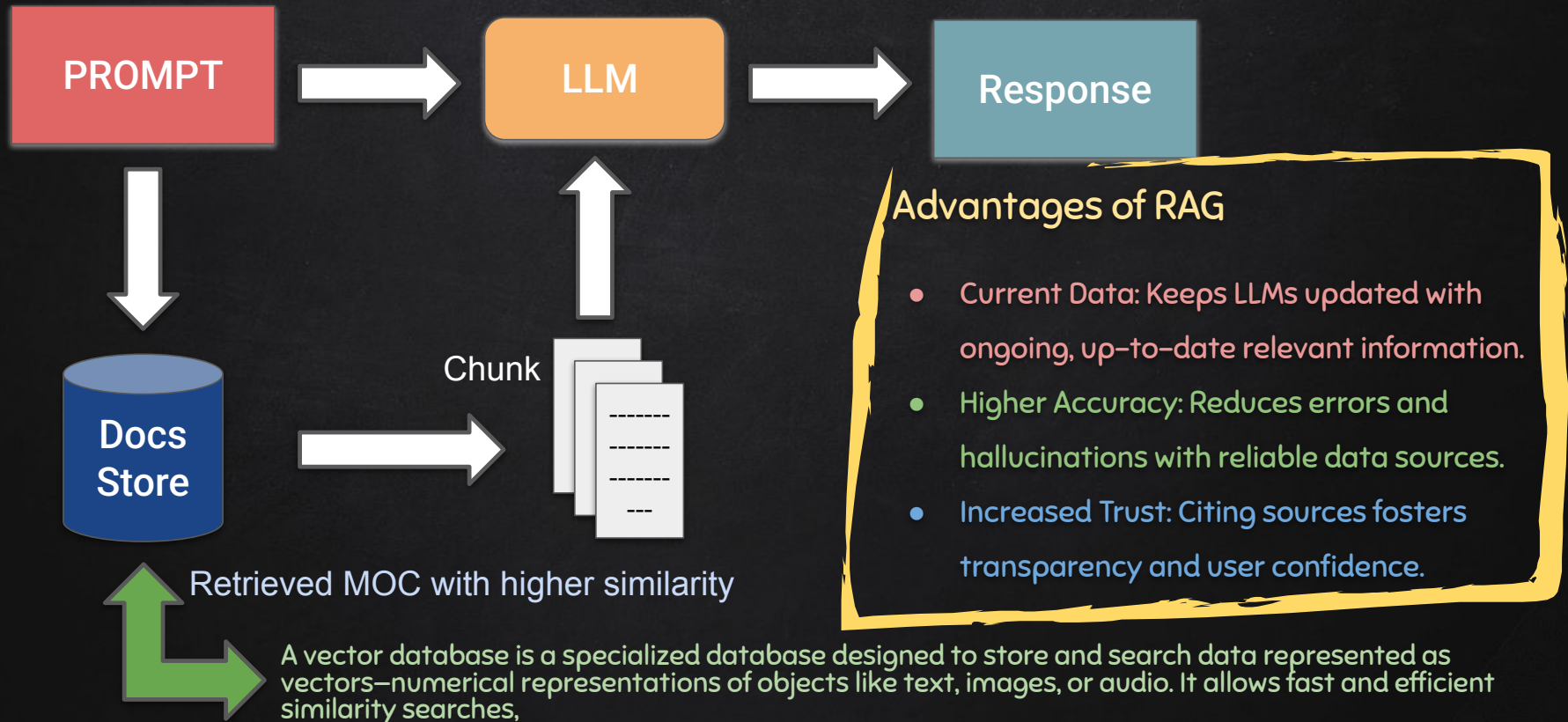
word

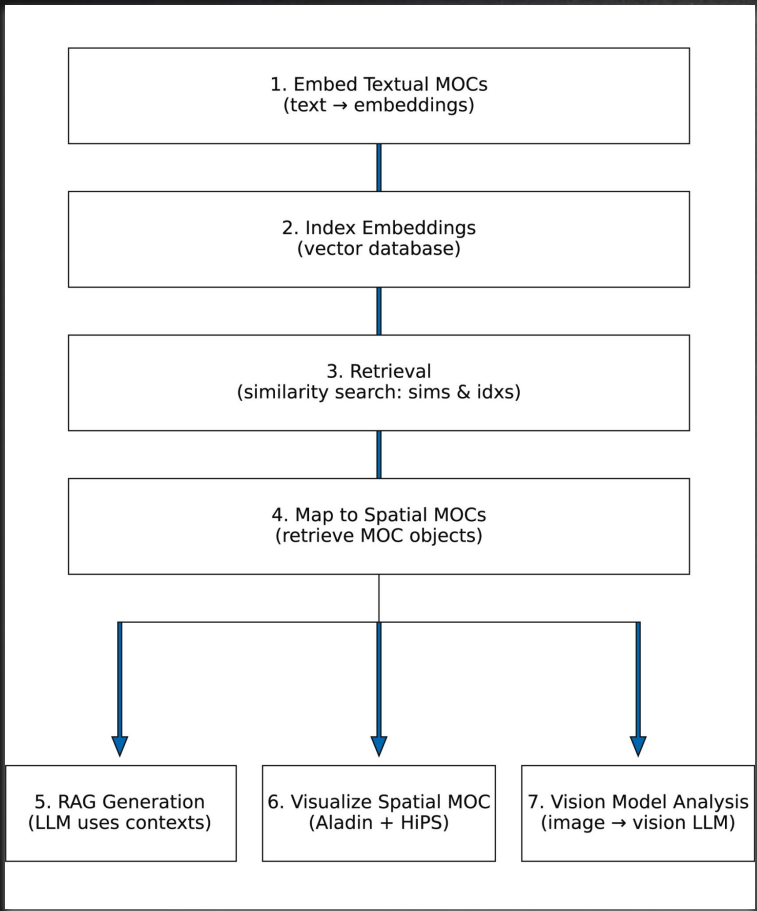
BOOKMARKS (0)





Retrieval Augmented Generation (RAG)





Snippet 3: JSON structure of a Semantic MOC with text transformed into semantic embeddings.

```

{
  "order_n": [npix, | where npix, uniquely defined integers],
  // ... continue for other orders ...
  "text": "Your textual description here",
  "metadata": {
    "key1": "value1",
    "key2": "value2",
    // ... continue metadata entries ...
  },
  "annotated_cells": {
    "order_n": {
      "npix": "annotation",
      // ... continue for other pixels ...
    }
    // ... continue for other orders ...
  },
  "embedding": [text vectorization],
  "embedding_model": "selected_embedding_model",
  "image": "https://alasky.cds.unistra.fr/../../../../",
}
  
```

The key "image" links to an astronomical image. In this scenario, the hips2fits server is used to retrieve astronomical images via direct URL parsing



Retrieve spatial, semantic, and visual data in a unified operation.



PORTAL



SIRIUS



VIZIER



ALADIN



XIMATCH

OTHERS ▾

HELP ?

HiPS2FITS

Fast generation of FITS images cutouts from HiPS datasets

The HiPS2FITS service enables generation of FITS images cutouts of arbitrary size and resolution from a given HiPS.

This means you can easily generate **FITS cutouts** (as well as JPEG) from **popular image surveys** (DSS2, SDSS, PanSTARRS, 2MASS, GALEX, ALLWISE, etc) for your favorite **set of objects or coordinates**.

The [form below](#) will let you test the service. For intensive use, exhaustive description of the options and parameters, have a look at the [HiPS2FITS cutout API](#).

Try it now!

Use the form above to use the service

By parameters **By WCS**

HiPS survey

Dimension × pixels

Target
Enter equatorial coordinates or object name.
Examples of valid targets:

- Orion nebula
- Messier 82
- 12 01 53.170 -18 52 37.92
- 05h23m34.601s -69d45m22.0s
- 83.6287 +22.0147

<https://alasky.cds.unistra.fr/hips-image-services/hips2fits>

TEXTUAL MOC IN THE GENAI ECOSYSTEM

EXPLORING INTEGRATION OPPORTUNITIES
AND POTENTIAL IMPACT

```

matched = chunk_texts[idx]
full = moc.moc_data.get('text', '')
print(f" Rank {len(results)}: {title} ({fn}) - sim: {sim:.4f}")
print(f"   └─ MATCHED CHUNK ({len(matched.split())} words): \"{matched[:120]}...\"")
print(f"   └─ FULL DOCUMENT ({len(full.split())} words): \"{full[:150]}...\"")
print()
if len(results) >= 3: break
print(f"{len(results)} result(s)")

```

Query: 'Identify the host galaxy of the gravitational-wave event GW170817 in the provided sample and make a short summary about properties and identification of GRB'

```

=====

Rank 1: NGC4993 (NGC4993.json) - sim: 0.7507
└─ MATCHED CHUNK (67 words): "The elliptical galaxy NGC 4993, about 130 million light-years from Earth, viewed with the VIMOS instrument on the Europe..."
└─ FULL DOCUMENT (161 words): "The elliptical galaxy NGC 4993, about 130 million light-years from Earth, viewed with the VIMOS instrument on the European Southern Observatory's Very..."

Rank 2: M87 (M87.json) - sim: 0.6747
└─ MATCHED CHUNK (99 words): "The elliptical galaxy M87 is the home of several trillion stars, a supermassive black hole and a family of roughly 15,000..."
└─ FULL DOCUMENT (99 words): "The elliptical galaxy M87 is the home of several trillion stars, a supermassive black hole and a family of roughly 15,000 globular star clusters. For c..."

Rank 3: Arp273 (Arp273.json) - sim: 0.6468
└─ MATCHED CHUNK (109 words): "The galaxies' twisted and distorted appearance is due to mutual gravitational tides as the pair engage in close encounters..."
└─ FULL DOCUMENT (129 words): "The galaxies' twisted and distorted appearance is due to mutual gravitational tides as the pair engage in close encounters. Cataloged as Arp 273 (also..."

```

3 result(s)

Step 3: Generate an answer with RAG

The **full documents** (not chunks) are passed to the LLM as context. Below you can see exactly what the LLM receives: system prompt, user prompt with context, and the response.

=====

SYSTEM PROMPT

=====

You are an astrophysics assistant. Answer using ONLY the provided documents. Cite sources inline with [Doc n]. If the documents do not contain enough information, reply exactly: I don't know.

=====

USER PROMPT (444 words, showing first 600 chars)

=====

Question:

Identify the host galaxy of the gravitational-wave event GW170817 in the provided sample and make a short summary about properties and identification of GRB

Documents:

[Doc 1] (title=NGC4993, similarity=0.751)

The elliptical galaxy NGC 4993, about 130 million light-years from Earth, viewed with the VIMOS instrument on the European Southern Observatory's Very Large Telescope in Chile. After the almost simultaneous detection of gravitational waves by the LIGO/Virgo collaboration, GW170817, and of a gamma-ray burst by ESA's INTEGRAL and NASA's Fermi satellites, GRB170817, a large ... [2811 total chars]

=====

LLM RESPONSE

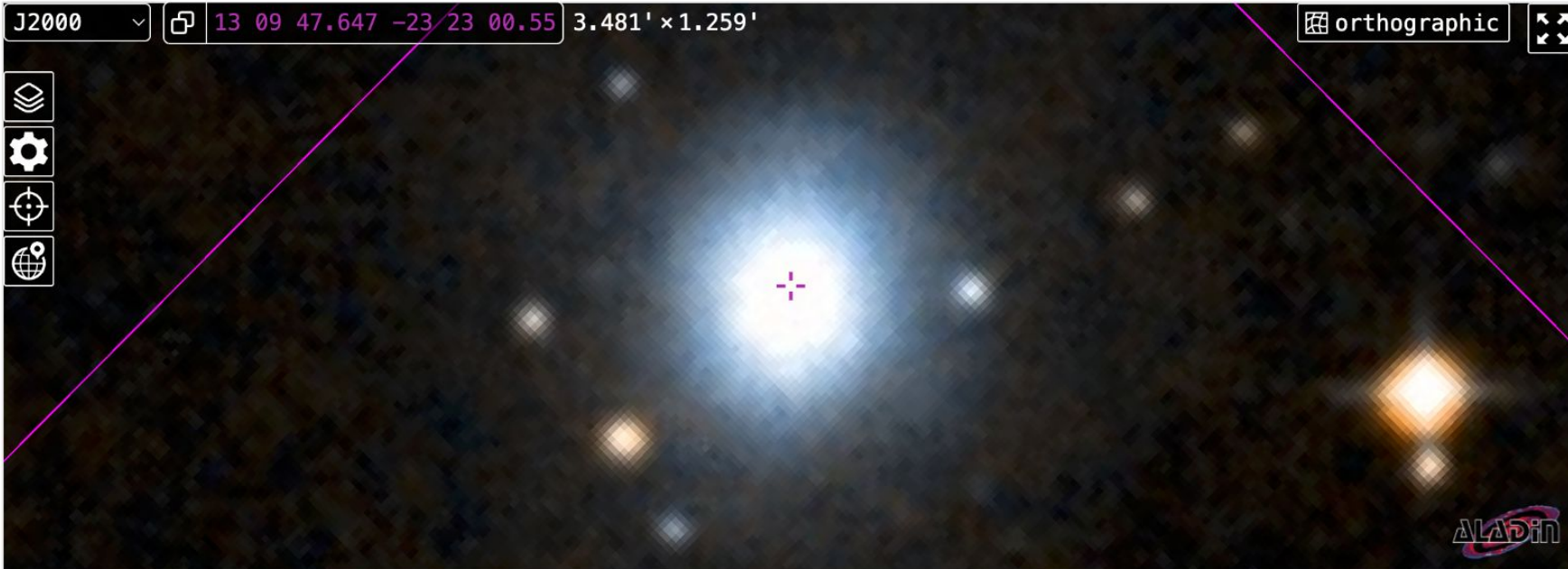
=====

The host galaxy of the gravitational-wave event GW170817 is NGC4993 [Doc 1]. This galaxy, about 130 million light-years from Earth, was confirmed as the source of the gravitational waves and the gamma-ray burst (GRB170817) when a visible light counterpart, AT2017gfo, was spotted near its core. The collision of two neutron stars in this galaxy resulted in a kilonova [Doc 1].

USED: 1

Step 4: Visualize the MOCs cited by the LLM

We parse the [Doc n] citations from the LLM response and display **only the MOCs it actually used** in ipyaladin. This closes the loop: query → retrieval → generation → spatial visualization of the answer.



■ NGC4993 | sim=0.7507

The elliptical galaxy NGC 4993, about 130 million light-years from Earth, viewed with the VIMOS instrument on the European Southern Observatory's Very Large Telescope in Chile. After the almost simulta...

Image: <https://alasky.cds.unistra.fr/hips-image-services/hips2fits?hips=CDS%2FP%2FDSS2%...>

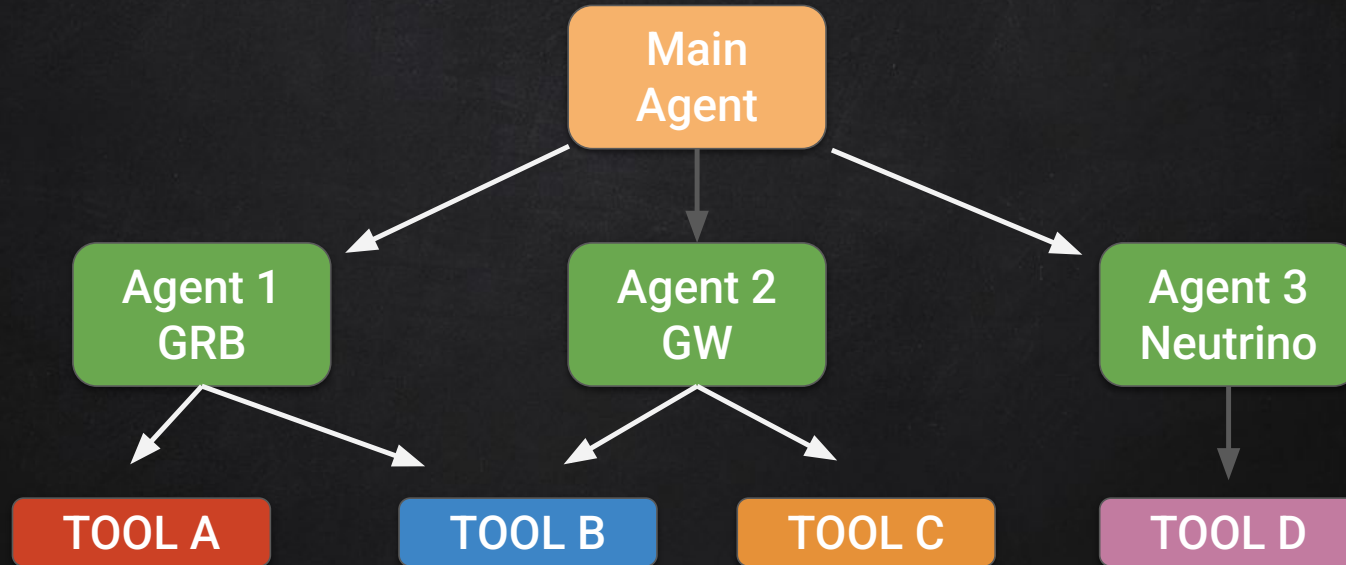
=====

Galaxy: NGC4993 | sim=0.7507
VISION: Elliptical: 85%

Note: The verification of the validity of the multimodels is beyond the scope of this work, which solely illustrates how IVOA standards and tools can be used in the multimodal generative AI systems. In any case, it provides a useful starting point for evaluating their behavior in controlled astronomical environments.

TOWARDS AI (SKYMAP) AGENTIC APPLICATIONS

Semantic MOCs provide a **Structured Data Formats**, making them well-suited for developing multi agent-based applications. These can be integrated into various multi-messenger activities enabling the evaluation of coincident events and the autonomous generation of alerts.



Tools based on mocpy for making MOC Operations

Textual MOC and LangGraph/LangChain

Positioning Textual MOC as a core element of an agent state

Graphs

At its core, LangGraph models agent workflows as graphs. You define the behavior of your agents using three key components:

1. **State**: A shared data structure that represents the current snapshot of your application. It can be any data type, but is typically defined using a shared state schema.
2. **Nodes**: Functions that encode the logic of your agents. They receive the current state as input, perform some computation or side-effect, and return an updated state.
3. **Edges**: Functions that determine which **Node** to execute next based on the current state. They can be conditional branches or fixed transitions.

By composing **Nodes** and **Edges**, you can create complex, looping workflows that evolve the state over time. The real power, though, comes from how LangGraph manages that state.

Textual MOC represents the agent state, unifying spatial coverage, text, metadata, and annotations in a single structured object.

Spatial nodes and edges can be built with the MOC/VO ecosystem, using tools such as `mocpy`, `astro`, and `astroquery` for coverage, coordinates, and region-based operations.

The textual layer can be handled by LLMs and enriched with curated IVOA metadata and vocabularies.

In this way, a shared state can orchestrate both spatial and textual agent behaviors, enabling hybrid retrieval and RAG workflows that combine embeddings with spatial filtering and contextual reasoning.

Textual MOC and LangGraph/LangChain

Positioning Textual MOC as a core element of an agent state

```
agent = create_agent(  
    model=llm,  
    tools=[  
        append_text_to_textual_moc,  
        update_multimedia_url,  
        update_image_url,  
        annotate_textual_moc_cell,  
        update_textual_moc_metadata,  
        save_textual_moc_to_file,  
        merge_textual_moc_from_local_file,  
        get_current_textual_moc_sky_fraction,  
    ],  
    system_prompt=SYSTEM_PROMPT,  
    state_schema=TextualMOCAgentState,  
    checkpointer=checkpointer,  
    middleware=[continue_on_tool_error],  
    name="textual_moc_first_agent",  
)
```

Tool	Description
<code>annotate_textual_moc_cell</code>	Adds a textual annotation to an existing HEALPix cell.
<code>append_text_to_textual_moc</code>	Appends new content to the <code>text</code> field of the current <code>TextualMOC</code> .
<code>get_current_textual_moc_sky_fraction</code>	Returns the sky fraction of the current <code>TextualMOC</code> spatial coverage, together with the corresponding sky area in steradians and square degrees.
<code>merge_textual_moc_from_local_file</code>	Loads a local <code>TextualMOC</code> and merges it with the current one, combining spatial coverage and textual content.
<code>save_textual_moc_to_file</code>	Saves the current <code>TextualMOC</code> state to a local file.
<code>update_image_url</code>	Updates the <code>image</code> field without changing any other part of the <code>TextualMOC</code> .
<code>update_multimedia_url</code>	Updates the <code>multimedia</code> field while preserving the rest of the <code>TextualMOC</code> .
<code>update_textual_moc_metadata</code>	Updates the <code>author</code> and <code>date</code> metadata fields.

Building an agent and agent tools

```
SYSTEM_PROMPT = """
```

```
You are an assistant that modifies an astronomical Textual MOC (Multi-Order Coverage) map.
```

```
Operational instructions:
```

- Use tools whenever the user request requires modifying, annotating, merging, intersecting, or saving the Textual MOC, and whenever a suitable tool-based execution over free-text explanations whenever the requested action is actually executable with the available tools.
- Do not invent missing data under any circumstances: never create orders, pixels, cells, file paths, parameters, metadata values, URLs, or any other data that does not actually exist in the current Textual MOC.
- Modify or annotate only data that actually exist in the current Textual MOC.
- When the user asks to save, use the dedicated save tool, if available.
- If a request requires multiple operations, use all valid ones.
- If one tool fails, do not stop the entire request, continue with the remaining valid tool calls.
- If one requested item does not exist, report the missing item as failed, without treating it as a global fatal error.
- Never simulate executions that cannot actually be performed with the available tools.
- Never claim that an action was completed unless it was actually completed by a tool or clearly scheduled through the corresponding tool.
- If the user asks to load a Textual MOC from a local file and merge it with the current one, use the dedicated tool. A bare uploaded filename is not sufficient.
- If the user asks for an operation that matches an available tool, call the tool instead of only describing what should be done.
- If no valid tool exists for a requested action, explicitly say so and explain that the action cannot be executed because of the current tool capabilities.
- In such cases, also state which kind of tool would be needed to complete the request, if that can be determined from the request.
- If the user asks for the sky fraction or sky area of the current Textual MOC, use the dedicated tool.
- If a tool would be required but one or more mandatory parameters are missing, do not invent them.
- In that case, explain precisely:
 - 1) which tool would be needed,
 - 2) which required parameters are missing,
 - 3) why the action cannot be executed without them.
- If only part of the request is actionable, execute the actionable part with tools and clearly report the remaining part as not executable.
- Do not perform unsupported transformations implicitly. If there is no tool for a requested transformation, say that explicitly.
- Base every action on the current Textual MOC state and on the actual capabilities of the available tools.

```
Final answer requirements:
```

- Always separate clearly:
 - 1) successful updates
 - 2) failed or non-executable updates, with the reason
- Be explicit about partial success whenever only some sub-tasks were completed.

```
"""
```

System Prompt under testing

Viewer Textual MOC

The screenshot shows the ALADIN viewer interface. At the top left, there is a dropdown menu for 'ICRS' and a search bar containing the coordinates '13 09 47.69 -23 23 02.3'. To the right of the search bar are icons for 'SIN' and a zoom-in/out symbol. On the left side, there is a vertical toolbar with icons for layers, settings, zoom, and a globe. The main area displays a star field with a large, semi-transparent purple circular field of view (MOC) overlaid. At the bottom left, there is a zoom control showing '35.34' x 12.69''. The 'ALADIN' logo is visible in the bottom right corner of the viewer area.

Text: The elliptical galaxy NGC 4993, about 130 million light-years from Earth, viewed with the VIMOS instrument on the European Southern Observatory's Very Large Telescope in Chile. After the almost simultaneous detection of gravitational waves by the LIGO/Virgo collaboration, GW170817, and of a gamma-ray burst by ESA's INTEGRAL and NASA's Fermi satellites, GRB170817, a large number of ground and space telescopes started searching for the source in the sky. About half a day later, scientists at various optical observatories spotted something new near the core of galaxy NGC 4993: this was the visible light counterpart to the gravitational waves and the gamma-ray burst, confirming that they originated from the collision of two neutron stars. The result of such a cosmic clash is a kilonova: the neutron-rich material released in the merger is impacting its surroundings, forging a wealth of heavy elements in the process. The kilonova can be seen just above and slightly to the left of the centre of the galaxy, AT2017gfo.

[Open Media](#)

Initial Viewer Setup: The agent's state updates will be displayed here interactively.

```
state = ask_agent("""
Add the following text: The spectral series evolves rapidly, showing sub-hour variations
at early times and indicating the early presence of strontium, consistent with theory.

Also add a new image link: https://www.ligo.caltech.edu/page/press-release-gw170817
and a new multimedia link: https://www.media.inaf.it/2018/11/15/cosa-e-successo-alla-kilonova-gw170817/

Update the author to Giuseppe Greco.

Also annotate the cell with order=10 and pixel=60400.

Remove the term 'NGC 4993' from the text."""
)
```

Just a Raw Prompt for Testing the Agent...



You:

Add the following text: The spectral series evolves rapidly, showing sub-hour variations at early times and indicating the early presence of strontium, consistent with theory.

Also add a new image link: <https://www.ligo.caltech.edu/page/press-release-gw170817>

and a new multimedia link: <https://www.media.inaf.it/2018/11/15/cosa-e-successo-alla-kilonova-gw170817/>

Update the author to Giuseppe Greco.

Also annotate the cell with order=10 and pixel=60400.

Remove the term 'NGC 4993' from the text.

🔧 TOOL → append_text_to_textual_moc({'new_text': 'The spectral series evolves rapidly, showing sub-hour variations at early times and indicating the early presence of strontium, consistent with theory.'})

🔧 TOOL → update_image_url({'image_url': 'https://www.ligo.caltech.edu/page/press-release-gw170817'})

🔧 TOOL → update_multimedia_url({'multimedia_url': 'https://www.media.inaf.it/2018/11/15/cosa-e-successo-alla-kilonova-gw170817/'})

🔧 TOOL → update_textual_moc_metadata({'author': 'Giuseppe Greco'})

🔧 TOOL → annotate_textual_moc_cell({'order': 10, 'pixel': 60400, 'note': 'Annotation added by user request'})

✅ Tool result: Text added correctly to the Textual MOC.

✅ Tool result: image field updated to: <https://www.ligo.caltech.edu/page/press-release-gw170817>

✅ Tool result: Metadata updated: author='Giuseppe Greco'.

✅ Tool result: multimedia field updated to: <https://www.media.inaf.it/2018/11/15/cosa-e-successo-alla-kilonova-gw170817/>

✅ Tool result: Annotation not applied: the combination order=10 e pixel=60400 does not exist in the Textual MOC.

👤 Agente: 1) ****Successful updates****:

- Text appended: "The spectral series evolves rapidly..."

- Image URL updated to: [`https://www.ligo.caltech.edu/page/press-release-gw170817`](https://www.ligo.caltech.edu/page/press-release-gw170817)

- Multimedia URL updated to: [`https://www.media.inaf.it/2018/11/15/cosa-e-successo-alla-kilonova-gw170817/`](https://www.media.inaf.it/2018/11/15/cosa-e-successo-alla-kilonova-gw170817/)

- Author updated to: [`Giuseppe Greco`](#)

2) ****Failed or non-executable updates****:

- ****Annotation for order=10, pixel=60400****: Failed because the cell does not exist in the current Textual MOC.

- ****Removing 'NGC 4993' from text****: Not executable. No tool exists to modify or edit existing text in the ``text`` field of the Textual MOC.

C. The available tool (``append_text_to_textual_moc``) only supports adding text, not removing or replacing existing content.

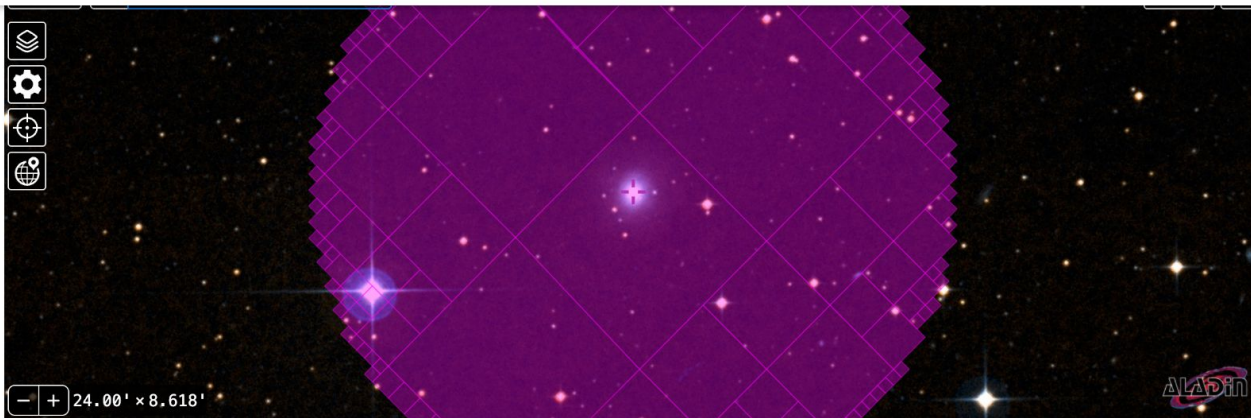
Do you confirm the state update?

✓ Update state

✗ Cancel

✅ State updated.

```
# Since this is the first render, there is no previous snapshot to compare with.
#render_textual_moc_state
render_textual_moc_state(
    current_snapshot=copy.deepcopy(INITIAL_STATE["textual_moc"]),
    previous_snapshot=None,
    show_full_json=False,
)
```



Text: The elliptical galaxy NGC 4993, about 130 million light-years from Earth, viewed with the VIMOS instrument on the European Southern Observatory's Very Large Telescope in Chile. After the almost simultaneous detection of gravitational waves by the LIGO/Virgo collaboration, GW170817, and of a gamma-ray burst by ESA's INTEGRAL and NASA's Fermi satellites, GRB170817, a large number of ground and space telescopes started searching for the source in the sky. About half a day later, scientists at various observatories spotted something new near the core of galaxy NGC 4993: this was the visible light counterpart to the gravitational waves and the gamma-ray burst, confirming that they originated from the collision of two neutron stars. The result of such a cosmic clash is a kilonova: the neutron-rich material released in the merger is impacting its surroundings, forging a wealth of heavy elements in the process. The kilonova can be seen just above and slightly to the left of the centre of the galaxy, AT2017gfo. The spectral series evolves rapidly, showing sub-hour variations at early times and indicating the early presence of strontium, consistent with theory.



[Open Media](#)

Overlay legend — magenta: current coverage; yellow: annotated cells; green: added cells; red: removed cells.

Changed field: multimedia**Before**

<https://sci.esa.int/web/integral/-/59671-new-source-in-galaxy-ngc-4993>

After

<https://www.media.inaf.it/2018/11/15/cosa-e-successo-alla-kilonova-gw170817/>

Changed field: image**Before**

https://alasky.cds.unistra.fr/hips-image-services/hips2fits?hips=CD5%2F%2FDSS2%2Fcolor&width=1200&height=900&fov=0.04&projection=SING&coordsys=icrs&rotation_angle=0.0&object=NGC%204993&format=jpg

After

<https://www.ligo.caltech.edu/page/press-release-gw170817>

Changed field: author**Before**

None

After

Giuseppe Greco

Changed field: date**Before**

None

After

2026-04-01

Changed field: last_text_update**Before**

None

After

2026-04-01 09:27:57

Human-in-the-loop for validating agent updates

stuale

Previous text

DIFF

Previous text

Updated text

about 130 million light-years from Earth, viewed with the VIMOS instrument of the European Southern Observatory's Very Large Telescope in Chile. After the almost simultaneous detection of gravitational waves by the LIGO/Virgo collaboration, GW170817, and of a gamma-ray burst by ESA's INTEGRAL and NASA's Fermi satellites, GRB170817, a large number of ground and space telescopes started searching for the source in the sky. About half a day later, scientists at various optical observatories spotted something new near the core of galaxy NGC 4993: this was the visible light counterpart to the gravitational waves and the gamma-ray burst, confirming that they originated from the collision of two neutron stars. The result of such a cosmic clash is a kilonova: the new type of transient is impacting its surroundings, forging a wealth of heavy elements in the process. The kilonova can be seen just above and slightly to the left of the centre of the galaxy, AT2017gfo.

f	1	The elliptical galaxy NGC 4993, about 130 million light-years from Earth, viewed with the VIMOS instrument on the European Southern Observatory's Very Large Telescope in Chile. After the almost simultaneous detection of gravitational waves by the LIGO/Virgo collaboration, GW170817, and of a gamma-ray burst by ESA's INTEGRAL and NASA's Fermi satellites, GRB170817, a large number of ground and space telescopes started searching for the source in the sky. About half a day later, scientists at various optical observatories spotted something new near the core of galaxy NGC 4993: this was the visible light counterpart to the gravitational waves and the gamma-ray burst, confirming that they originated from the collision of two neutron stars. The result of such a cosmic clash is a kilonova: the new type of transient is impacting its surroundings, forging a wealth of heavy elements in the process. The kilonova can be seen just above and slightly to the left of the centre of the galaxy, AT2017gfo.
t	2	The spectral series evolves rapidly, showing sub-hour variations at early times and indicating the early presence of strontium, consistent with theory.

👉 You: annotate the cell in the current textual moc with order=10; pixel=6373777, 'Gal'

🔧 TOOL → annotate_textual_moc_cell({'note': 'Gal', 'order': 10, 'pixel': 6373777})

✅ Tool result: Annotation added to the cell with 10, pixel 6373777.

👤 Agente: 1) **Successful updates**:

- Annotation added to cell: `order=10`, `pixel=6373777` with note: "Gal"

2) **Failed or non-executable updates**:

- None. All requested actions were successfully executed.

Do you confirm the state update?

✓ Update state

✗ Cancel

✓ State updated.

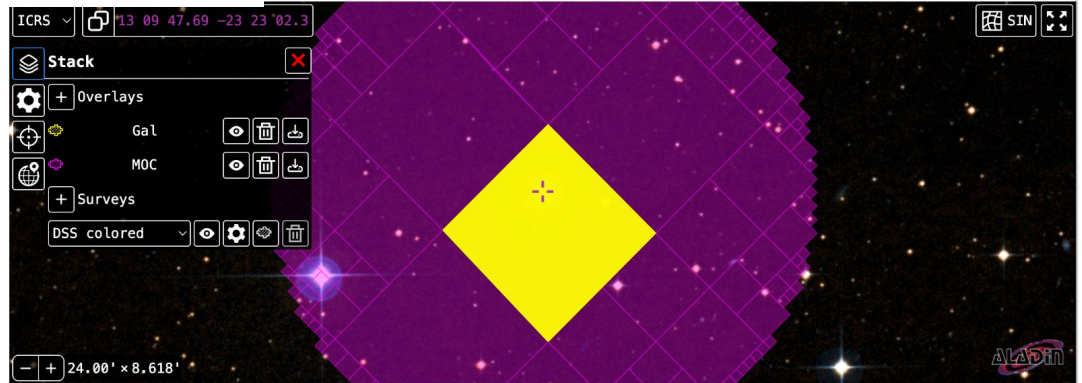
Changed field: `annotated_cells`

Before
None

After

```
{
  "10": {
    "6373777": "Gal"
  }
}
```

Human-in-the-loop for validating agent updates



Text: The elliptical galaxy NGC 4993, about 130 million light-years from Earth, viewed with the VIMOS instrument on the European Southern Observatory's Very Large Telescope in Chile. After the almost simultaneous detection of gravitational waves by the LIGO/Virgo collaboration, GW170817, and of a gamma-ray burst by ESA's INTEGRAL and NASA's Fermi satellites, GRB170817, a large number of ground and space telescopes started searching for the source in the sky. About half a day later, scientists at various optical observatories spotted something new near the core of galaxy NGC 4993: this was the visible light counterpart to the gravitational waves and the gamma-ray burst, confirming that they originated from the collision of two neutron stars. The result of such a cosmic clash is a kilonova: the neutron-rich material released in the merger is impacting its surroundings, forging a wealth of heavy elements in the process. The kilonova can be seen just above and slightly to the left of the centre of the galaxy, AT2017gfo. The spectral series evolves rapidly, showing sub-hour variations at early times and indicating the early presence of strontium, consistent with theory.

Open Media

👤 You: mesure the area of the current textual MOC

🔧 TOOL → `get_current_textual_moc_sky_fraction({})`

✅ Tool result: {

"sky_fraction": 7.981434464454651e-07,

"area_deg2": 0.032925780667692715

}

👤 Agente: The area of the current Textual MOC is **`**0.0329`** square degrees**`**`** (area_deg2).

For context, the corresponding sky fraction (proportion of the entire sky covered) is **`**7.98 × 10-7**`** (sky_fraction). This indicates a very small region of the sky is covered by this MOC.

No further actions are needed unless you request additional modifications or analyses.

4]: {'messages': [HumanMessage(content='mesure the area of the current textual MOC', additional_kwargs={}, response_metadata={}, id='cc43

No HITL – Measure only the MOC area using mocpy methods.

Tool provided by mocpy

👤 You: Load the local TextualMOC file M82.json and merge it with the current one.

🔧 TOOL → merge_textual_moc_from_local_file({'input_file_path': 'M82.json'})

✅ Tool result: Merge scheduled from local file: M82.json. Spatial coverage and textual content will be merged.

🔧 TOOL → merge_textual_moc_from_local_file({'input_file_path': 'M82.json'})

✅ Tool result: Merge already scheduled from local file: M82.json. The same merge patch will not be added twice.

🔧 TOOL → merge_textual_moc_from_local_file({'input_file_path': 'M82.json'})

✅ Tool result: Merge already scheduled from local file: M82.json. The same merge patch will not be added twice.

🤖 Agente: The merge operation from file `M82.json` has already been scheduled and cannot be repeated with the same input. The system explicitly states that "the same merge patch will not be added twice." No further action is possible with the current tool unless a different file or additional parameters are provided.

<final_answer>

1) **Successful updates**: None (the merge was already scheduled).

2) **Failed/non-executable updates**: Merging `M82.json` again is not allowed by the tool. Reason: The system explicitly prevents reapplying the same merge patch.

</final_answer>

Do you confirm the state update?

✓ Update state

✗ Cancel

✅ State updated.

```
[14]: {'status': 'waiting_human_approval',
      'thread_id': 'textual-moc-ngc4993-thread-1',
      'candidate_state': {'messages': [HumanMessage(content='Load the local TextualMOC file M82.json and merge it with the current one.', additional_kwarg=
      al_kwarg={}, response_metadata={}, id='2a9728d9-9ab8-477c-afd9-130af1a2d9e3'),
      ATMessage(content='', additional_kwarg={}, response_metadata={'model': 'gwen3:14b', 'created_at': '2026-04-01T10:19:06.058189Z', 'done':
```

Union text and area

ICRS 13 14 20.82 +17 47 32.8

Stack

Overlays

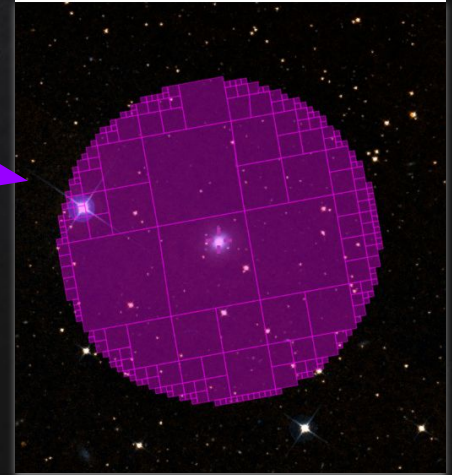
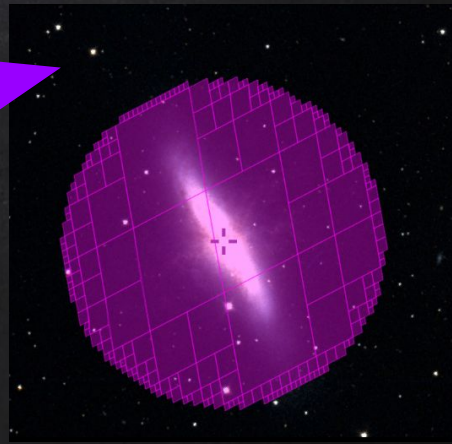
added_cells

MOC

Surveys

DSS colored

180.0° × 64.63°



Text:
 Optical observations spotted something new near the core of galaxy NGC 4991 that is a probable light counterpart to the gravitational waves and the gamma-ray burst, confirming that they originated from the collision of two neutron stars. The result of such a cosmic clash is a kilonova: the neutron-rich material released in the merger is impacting its surroundings, forging a wealth of heavy elements in the process. The kilonova can be seen just above and slightly to the left of the core of the galaxy, AT2017gfo.

Located 12 million light-years away, M82 appears high in the northern spring sky in the direction of the constellation Ursa Major, the Great Bear. It is also called the 'Cigar Galaxy' because of the elongated elliptical shape produced by the tilt of its starry disk relative to our line of sight. As shown in this mosaic image, M82 is a magnificent starburst galaxy. Throughout its central region young stars are being born ten times faster than they are inside in our Milky Way Galaxy. These numerous hot new stars not only emit radiation but also charged particles that form the so-called stellar wind. Stellar winds streaming from these stars combine to form a galactic 'superwind'.

Open Media

Overlay legend — magenta: current coverage; yellow: annotated cells; green: added cells; red: removed cells.

Union text and area

👤 You: measure the area of the current textual MOC

🔧 TOOL → `get_current_textual_moc_sky_fraction({})`

✅ Tool result: {
 "sky_fraction": 1.5997017423311872e-06,
 "area_deg2": 0.06599243398701696
}

👤 Agente: The area of the current Textual MOC is now **0.0660 square degrees** (area_deg2), which is approximately double the previous measurement.

The corresponding sky fraction is **1.60×10^{-6}** , reflecting the increased coverage after merging with 'M82.json'.

No further actions are needed unless you request additional modifications or analyses.

```
[16]: {'messages': [HumanMessage(content='measure the area of the current textual MOC', additional_kwargs={}, response_metadata={}, id='cc4360ad-745e-4759-adaf-348970f5bacb'),  
  AIMessage(content='', additional_kwargs={}, response_metadata={'model': 'qwen3:14b', 'created_at': '2026-04-01T10:53:53.171943Z', 'done': True, 'done_reason': 'stop', 'total duration': 44603038284, 'load duration': 335913794, 'prompt eval count': 1456, 'prompt eval duration': 278
```

Measuring the area in deg^2

👉 You: Save the current textual MOC in 'test_bologna.json'

🔧 TOOL → save_textual_moc_to_file({'output_file_path': 'test_bologna.json'})

✅ Tool result: Salvataggio schedulato in: test_bologna.json

👤 Agente: The current Textual MOC has been scheduled for saving to the file `test_bologna.json`. The operation will persist the current state (including coverage, annotations, metadata, and media links) to the specified JSON file. No further actions are needed unless you request additional modifications.

Do you confirm the state update?

✓ Update state

✗ Cancel

```
{'status': 'waiting_human_approval',
 'thread_id': 'textual-moc-ngc4993-thread-1',
 'candidate_state': {'messages': [HumanMessage(content='measure the area of the current textual MOC', additional_kwargs={}, response_metadata=
 {}, id='cc4360ad-745e-4759-adaf-348970f5bacb'),
  AIMessage(content='', additional_kwargs={}, response_metadata={'model': 'qwen3:14b', 'created_at': '2026-04-01T10:53:53.171943Z', 'done':
 True, 'done_reason': 'stop', 'total_duration': 44603038284, 'load_duration': 335913794, 'prompt_eval_count': 1456, 'prompt_eval_duration': 27
 80441423, 'eval_count': 122, 'eval_duration': 41387163807, 'logprobs': None, 'model_name': 'qwen3:14b', 'model_provider': 'ollama'}, name='te
  xtual_moc_first_agent', id='lc_run--019d48ac-f850-7632-8ada-2bf2f3250c0b-0', tool_calls=[{'name': 'get_current_textual_moc_sky_fraction', 'ar
  gs': {}, 'id': '0f89abb1-a3a7-47da-932f-1215726660f3', 'type': 'tool_call'}], invalid_tool_calls=[], usage_metadata={'input_tokens': 1456, 'o
  utput_tokens': 122, 'total_tokens': 1578}),
  ToolMessage(content='{\\n "sky_fraction": 7.981434464454651e-07,\\n "area_deg2": 0.032925780667692715\\n}', name='get_current_textual_moc_s
  ky_fraction', id='192b51f1-6b0a-4d95-80fe-d72961431406', tool_call_id='0f89abb1-a3a7-47da-932f-1215726660f3'),
  AIMessage(content='The area of the current Textual MOC is **0.0329 square degrees** (area_deg2). \\n\\nFor context, the corresponding sky fr
  action (proportion of the entire sky covered) is **7.98 x 10^-7** (sky_fraction). This indicates a very small region of the sky is covered by
  this MOC. \\n\\nNo further actions are needed unless you request additional modifications or analyses.', additional_kwargs={}, response_metadat
  a={'model': 'qwen3:14b', 'created_at': '2026-04-01T10:56:01.541141Z', 'done': True, 'done_reason': 'stop', 'total_duration': 128212521526, 'l
```

TUTORIALS AND HANDS-ON SECTION

Building and Handling Textual MOCs

The notebook is associated with the paper [Encapsulating Textual Contents into a MOC data structure for Advanced Applications](#); Greco et al., 2026 - [arXiv:2510.12213v1](#); [Astronomy and Computing Volume 54, January 2026](#).

The notebook outlines the basic functionalities of a new approach that integrates textual descriptions directly into the JSON representation of MOC, enabling simultaneous semantic and spatial operations. After demonstrating some basic applications and its potential use for educational gamification, we will later showcase its applicative capabilities in generative AI (GenAI).

What is a MOC?

A **Multi-Order Coverage map (MOC)** is an [IVOA standard](#) that describes arbitrary sky regions using the [HEALPix](#) tessellation. MOCs map regions on the sky into hierarchically grouped predefined cells, enabling fast spatial operations such as intersection, union, and filtering. They are widely used in astronomy to represent the spatial footprint of surveys and catalogs. For more details, see the [MOCpy documentation](#) and the [IVOA MOC standard](#).

Tutorials

1. [tuto1_TextualMOC](#) — basic application to build a Textual MOC
2. [AladinGame](#) — using Textual MOC for EDU game in Aladin Lite
3. [tuto2_SemanticMOC](#) — Creating Semantic MOC for application in Generative AI systems

These notebook explores embedding-based semantic search, Retrieval-Augmented Generation (RAG), vision model analysis, and agentic workflows applied to Multi-Order Coverage maps enriched with textual and semantic content.

Semantic MOCs: From Textual Content to GenAI Applications

This is the **second tutorial** in the TextualMOC series. While [Tutorial 1](#) introduced the basics of creating and handling Textual MOCs, this notebook explores the **semantic dimension** — transforming textual content into vector embeddings for Generative AI (GenAI) applications.

The notebook is associated with the paper [Encapsulating Textual Contents into a MOC data structure for Advanced Applications](#); Greco et al., 2026.

What you will learn

1. **Key concepts** — embeddings, semantic search, RAG
2. **Semantic MOCs** — generating and managing embeddings
3. **Galaxy collection** — building Textual MOCs using SIMBAD and hips2fits
4. **RAO pipeline** — chunked retrieval → LLM → ipyaladin → vision model
5. **Interactive explorer** — chunk size, embedding model, query formulation
6. **Latent space visualization** — PCA projection of Semantic MOCs
7. **Agentic workflow** — semantic search → MOC union → LLM summary → new Textual MOC

Modules

```
pip install mocpy matplotlib astropy ipyaladin==0.3.0 ipywidgets requests beautifulsoup4 pandas astroquery cdshealpix
pip install langchain-community langchain-ollama scikit-learn ipykernel
python -m ipykernel install --user --name claude --display-name "Python (claude)"
```

Ollama models

```
ollama pull nomic-embed-text && ollama pull mxbai-embed-large && ollama pull snowflake-arctic-embed
ollama pull mistral && ollama pull gemma3:4b
```

Background: Embeddings and Semantic Search

What is an embedding?

An embedding is a numerical representation of text as a list of numbers — a **vector**. For example, "M87 is a giant elliptical galaxy" might become [0.12, -0.45, 0.30, ...].

How to Build an Agent with TextualMOC

This is the **third tutorial** in the TextualMOC series.

While [Tutorial 1](#) introduced the basics of creating and handling Textual MOCs, the [Tutorial 2](#) the **semantic dimension** — transforming textual content into vector embeddings for Generative AI (GenAI) applications; Here, we explore how to build an agent using the [LangGraph](#) and [LangChain](#) frameworks.

The notebook is associated with the paper [Encapsulating Textual Contents into a MOC data structure for Advanced Applications](#); Greco et al., 2026.

LLM Configuration

The LLM we will use is `qwen3:14b`, which can be installed locally with `Ollama`.

```
ollama pull qwen3:14b
```

```
[ ]: ## 1)Setup
#conda create -n acme_tuto_vo_genai python=3.12 -y
#conda activate acme_tuto_vo_genai
#python -m pip install --upgrade pip setuptools wheel
#python -m pip install \
# mocpy==0.20.0 \
# matplotlib==3.10.8 \
# numpy==2.4.3 \
```

Ideas for Gen AI architecture

Dual-Store Architecture with Deterministic UUID

SEMANTIC MOC

JSON → MOC spatial + text + metadata



MOCSET

Spatial Index

HEALPix Multi-Order Coverage

Query by sky position (RA, Dec)

FITS binary storage

Key: moc_id (int)



moc_id → UUID5



WEAVIATE

Vector Store

Semantic search (embeddings)

Text, multimedia, image metadata

Near-text vector query

Key: UUID5 (moc_id)

KEY CHALLENGES OF MULTI-MESSENGER ASTRONOMY

High Alert Volume: Massive number of GW triggers during inspiral and mergers requires scalable computing and real-time event management.

Dynamic Databases: Efficiently track and update a large number of transient candidates for prompt dissemination to the astronomy community.

Automated Prioritization: Events should be ranked automatically based on parameter estimation accuracy and scientific relevance.

EM Alert Listening Capability: ET should be able to receive and process alerts from electromagnetic, neutrino and high-energy gamma-ray observatories to identify spatial-temporal coincidences.

Signal Overlapping: Superimposed signals require innovative detection methods and integrated spatial-temporal analysis strategies.

Managing Large Custom Catalogs: Handling dedicated, massive catalogs to support counterpart searches.

Interoperability & FAIR Principles: Success depends on open standards enabling data sharing across diverse infrastructures.

Global Coordination & Standardization: Collaboration between observatories is essential to define protocols and support cross-domain integration.

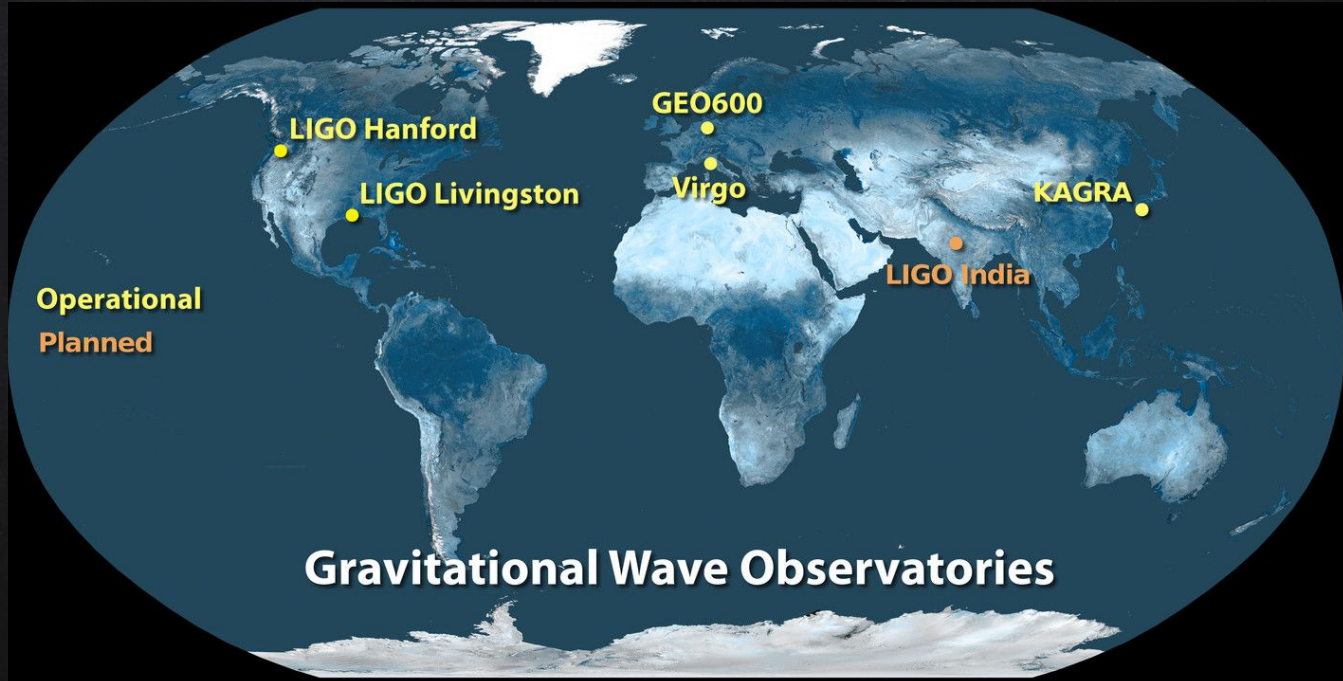
TO MAKE ALL THIS HAPPEN!

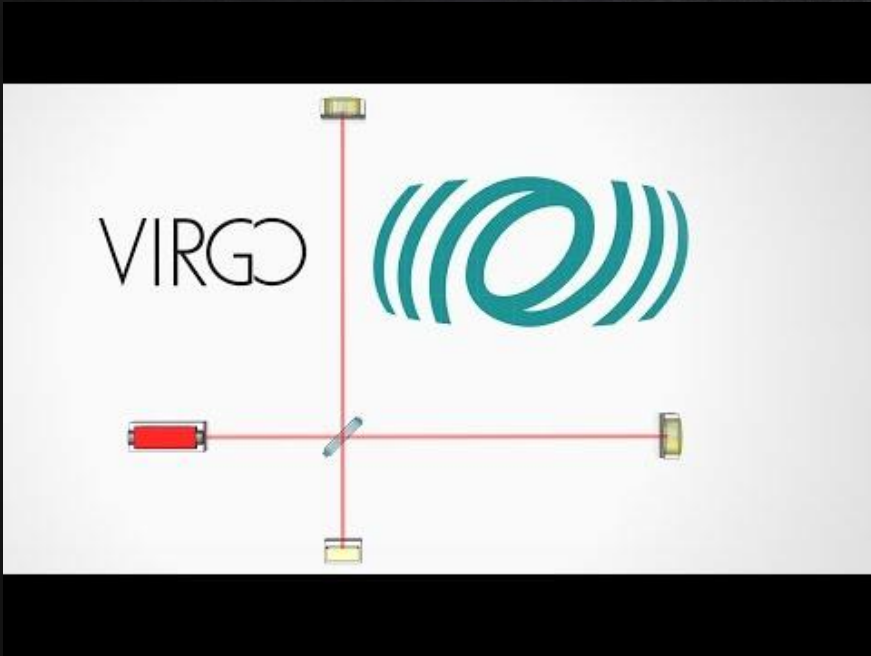


Astrophysical Context: a short introduction

The prompt used to generate this image is shown on the slide

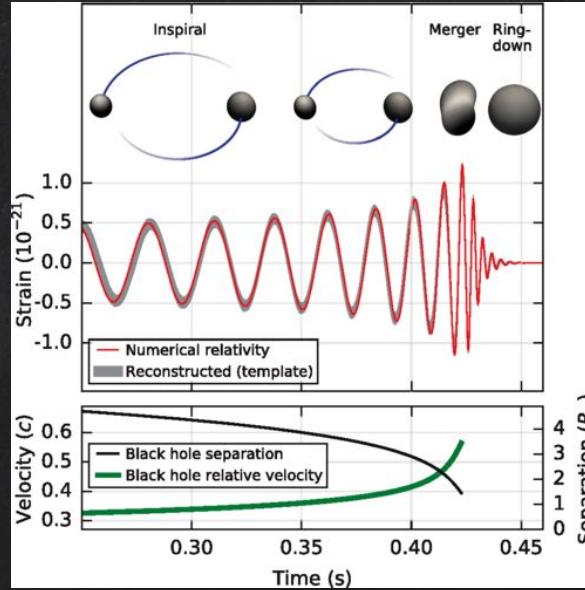
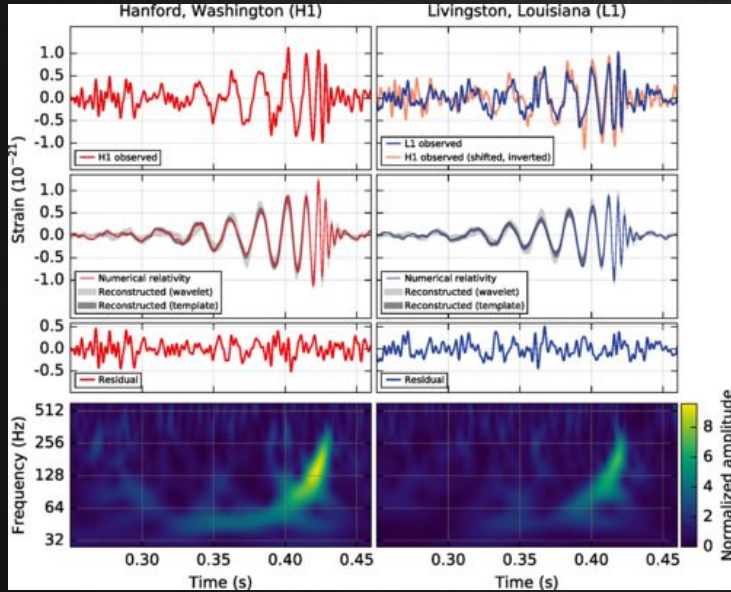
THE 2ND GENERATION GW DETECTOR NETWORK





HOW INTERFEROMETERS WORK AND The Virgo Horizon

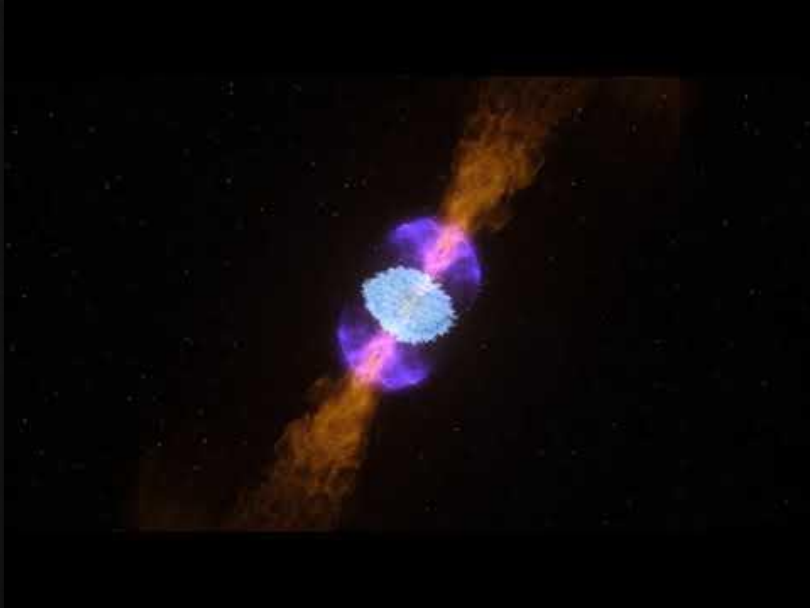
GW150914: THE BIRTH OF THE GW ASTRONOMY



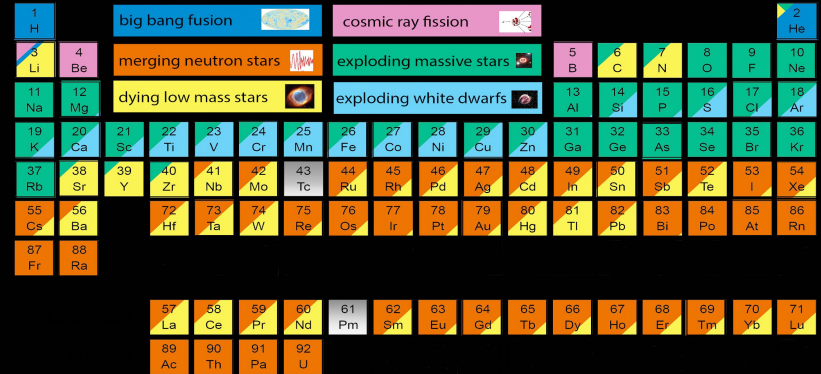
This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration) Phys. Rev. Lett. 116, 061102 – Published 11 February 2016



The Origin of the Solar System Elements



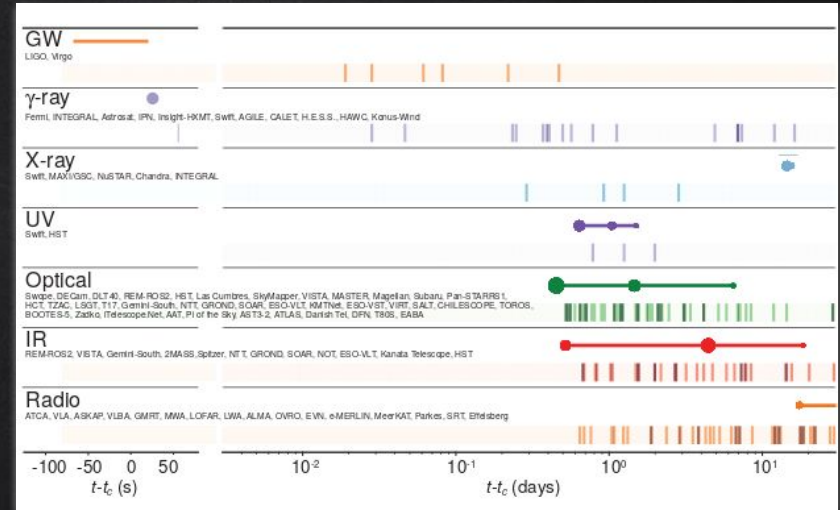
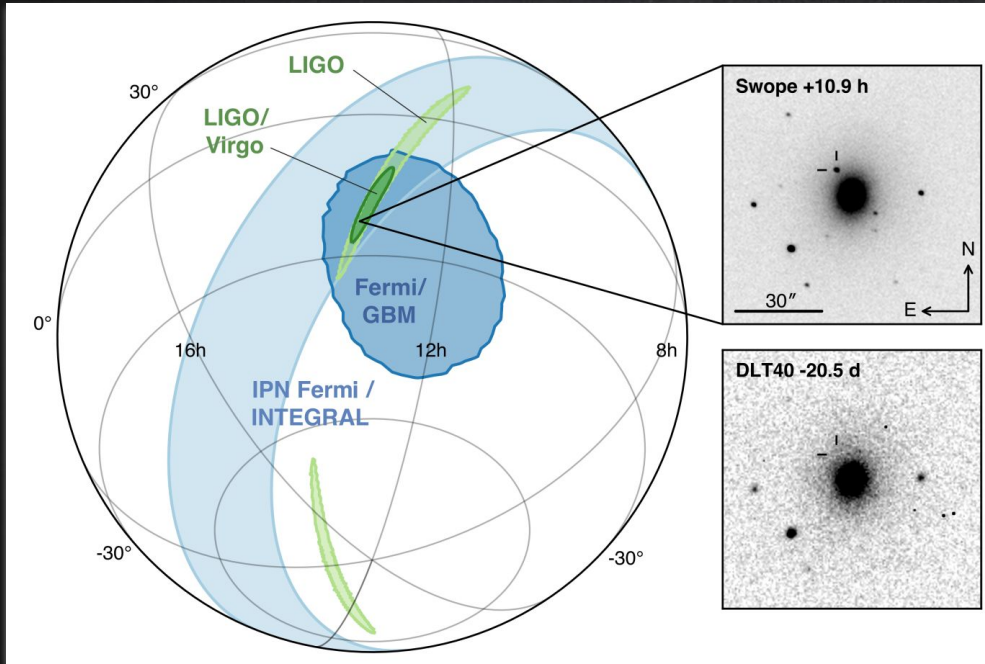
Graphic created by Jennifer Johnson

Astronomical Image Credits:
ESA/NASA/AASNova

THE FACTORY OF HEAVY ELEMENTS

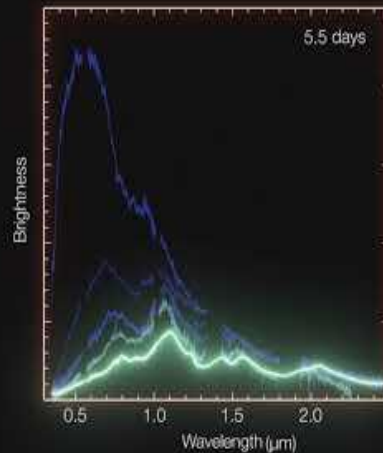
GW170817: THE BIRTH OF MULTIMESSENGER ASTRONOMY WITH GW!

EM FOLLOW-UPS OF GW170817



Multi-messenger Observations of a Binary Neutron Star Merger; B. P. Abbott et al 2017 ApJL 848 L12

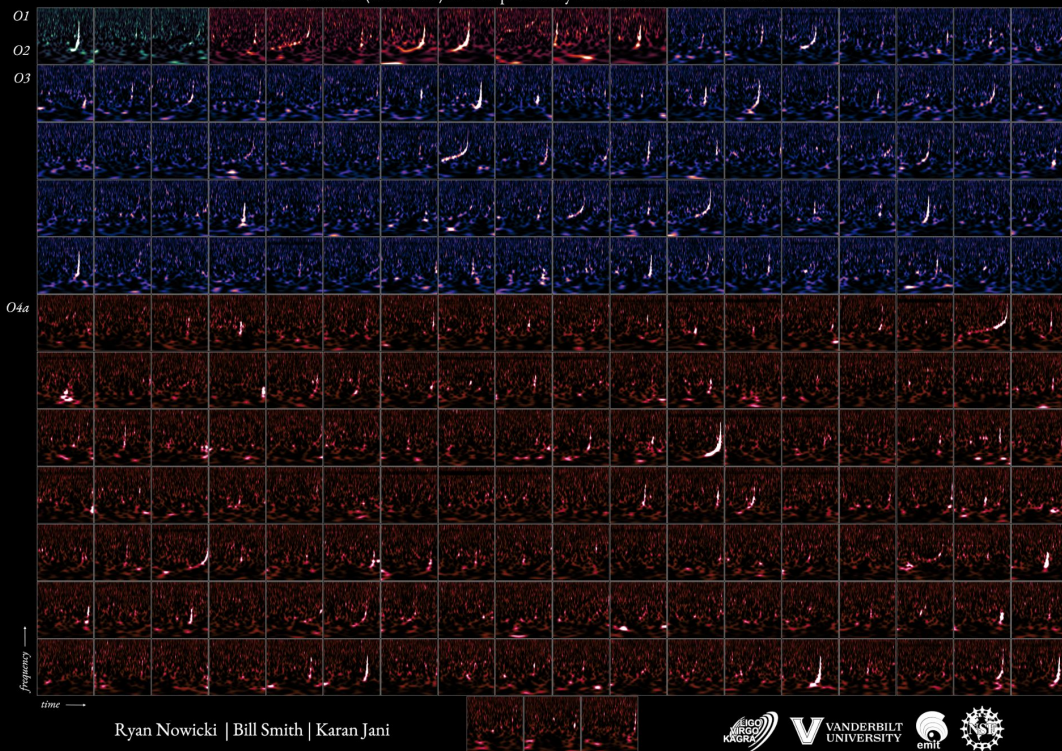
Operating the Very Large Telescope



THIS ANIMATION IS BASED ON A SERIES OF SPECTRA OF THE KILONOVA IN NGC 4993 OBSERVED BY THE X-SHOOTER INSTRUMENT ON ESO'S VERY LARGE TELESCOPE IN CHILE. THEY COVER A PERIOD OF 12 DAYS AFTER THE INITIAL EXPLOSION ON 17 AUGUST 2017. THE KILONOVA IS VERY BLUE INITIALLY BUT THEN BRIGHTENS IN THE RED AND FADES.

Gravitational-Wave Transient Catalog

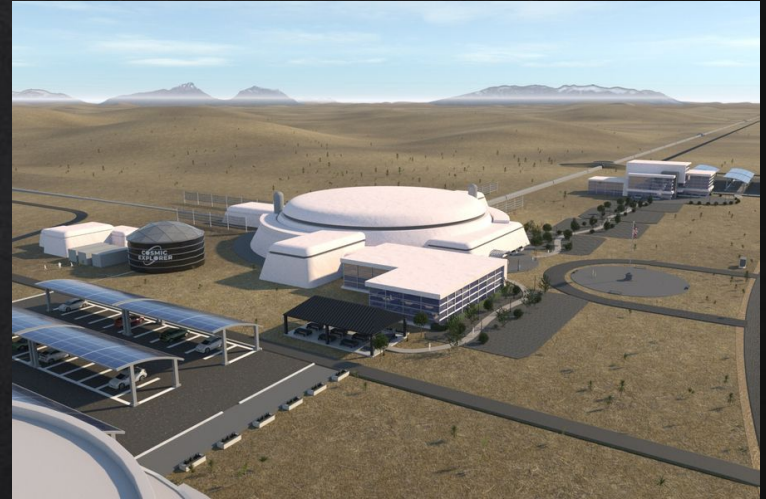
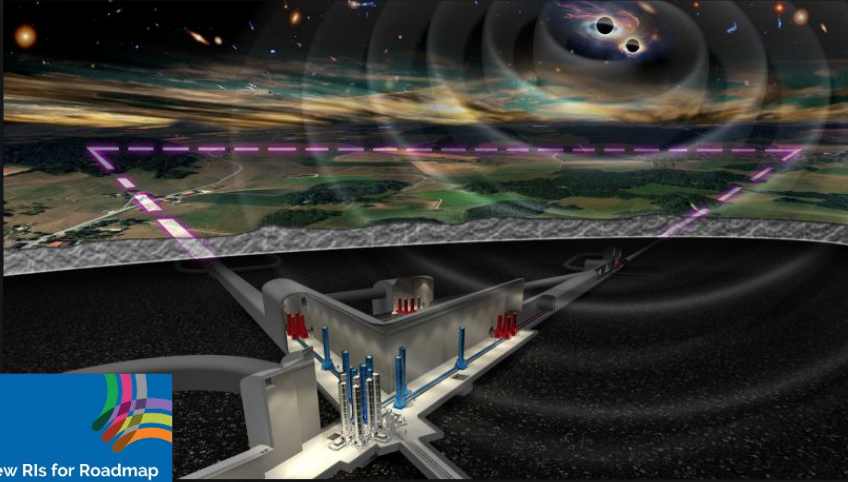
10 Years of Detections (2015-2024) of Compact Binary Coalescences with Black Holes and Neutron Stars



The catalog reveals an even broader diversity of gravitational-wave sources: **the most massive black hole binary ever detected**, **the most asymmetric black hole binary observed so far**, a system in which both black holes have exceptionally high spins, and two black hole–neutron star binaries.

GRAVITATIONAL-WAVE TRANSIENT CATALOGUE-4.0

3TH INTERFEROMETER GENERATIONS

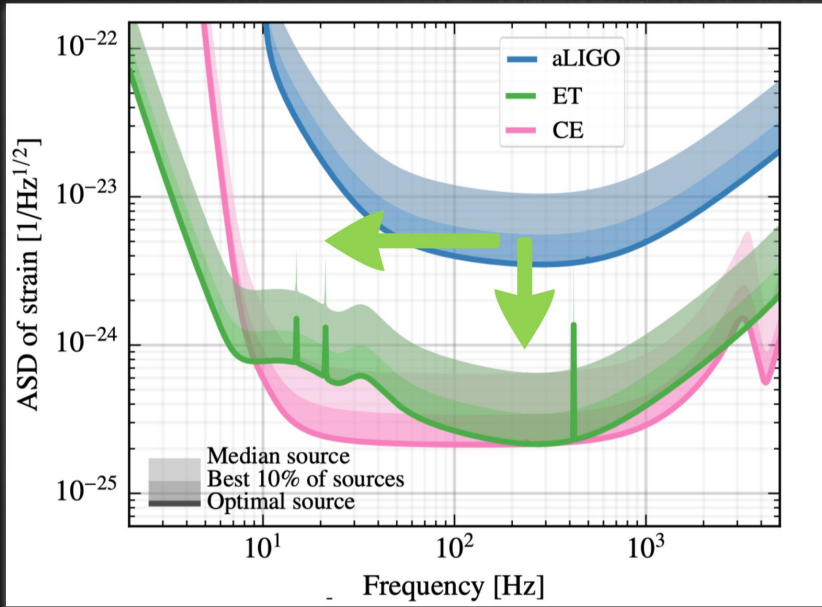



New RIs for Roadmap
2021 announced

Science Report on Research Infrastructures
ROADMAP 2021

Einstein telescope and Cosmic Explorer – Artistic Impressions

ET DESIGN SENSITIVITY



ET will improve the sensitivity by an order of magnitude with respect to the design sensitivity of Advanced Virgo and Advanced LIGO and extend the observation band towards lower frequencies.

- Primordial black holes
- Dark matter
- Effect on GW emission around compact objects.
- Exotic objects.
- Cosmology
- High precision tests of General Relativity
- Physics near BH horizon.
- Stochastic background
- Black holes origin and evolution.
- Multimessenger: nucleosynthesis, physics of jets, role of neutrinos
-

A few tens of alerts per hour
Pre-merger alerts

PROMPT FOR GETTING IMAGE SIMILAR TO THE COVER PAGE

Ultra-detailed scientific digital illustration of astronomical observatories under a star-filled night sky.

Foreground: a mountain ridge with multiple observatory domes and radio telescope dishes in silhouette, softly illuminated by twilight on the horizon, realistic perspective, no people.

Sky: deep space filled with dense stars, nebulae, and a prominent spiral galaxy on the right, realistic astrophotography style, dark blue and purple tones.

Across the sky: multiple floating translucent mosaics made of small square tiles resembling hierarchical sky coverage maps, arranged in irregular disconnected patches at different scales and resolutions, softly glowing in cyan, violet, teal, and gold.

Center: a luminous spherical network of interconnected nodes and lines representing an artificial intelligence system, glowing gently like a constellation.

Around the central sphere: several circular icons symbolizing different types of information (search, communication, database, documents, images, knowledge), each connected to the central network with thin glowing lines, forming a balanced radial composition.

Atmosphere: elegant, calm, scientific, cinematic lighting, high contrast, ultra-clean composition, no text, no UI elements, no robots, no hands.

Wide panoramic format, suitable for a keynote presentation background.

THANKS!