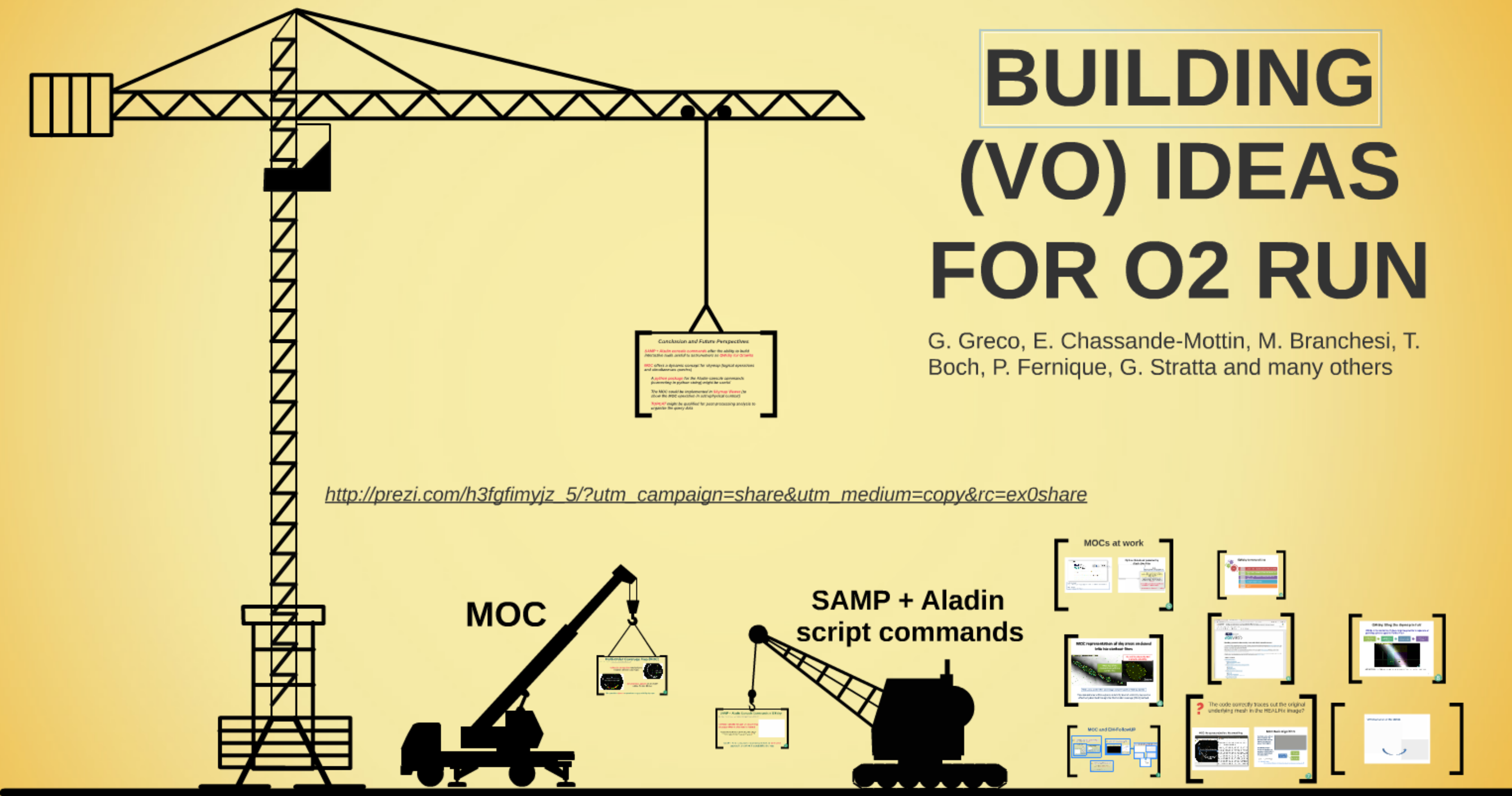
BUILDING (VO) IDEAS FOR O2 RUN

G. Greco, E. Chassande-Mottin, M. Branchesi, T. Boch, P. Fernique, G. Stratta and many others

http://prezi.com/h3fgfimyjz_5/?utm_campaign=share&utm_medium=copy&rc=ex0share



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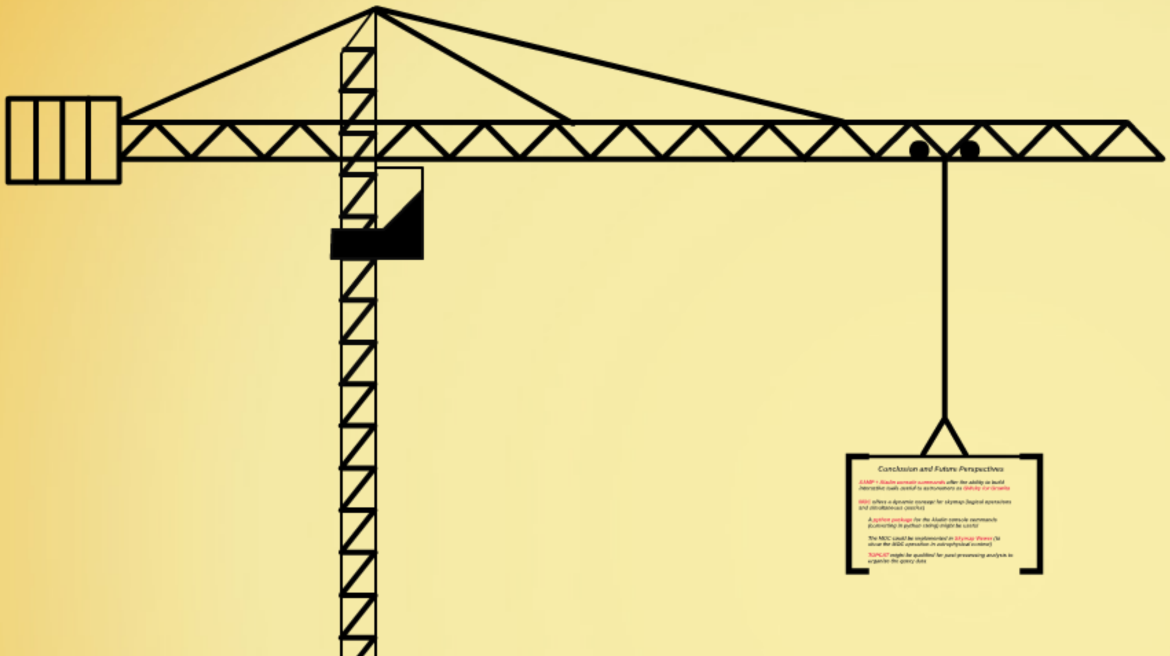

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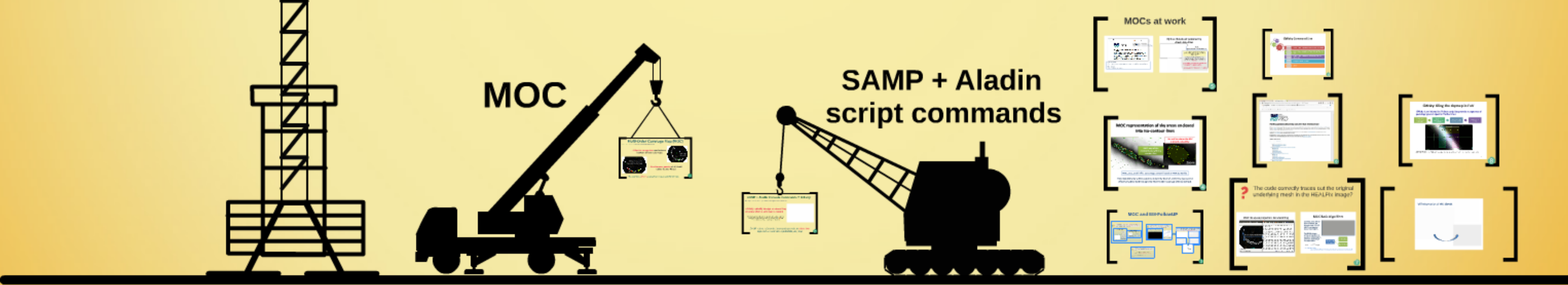
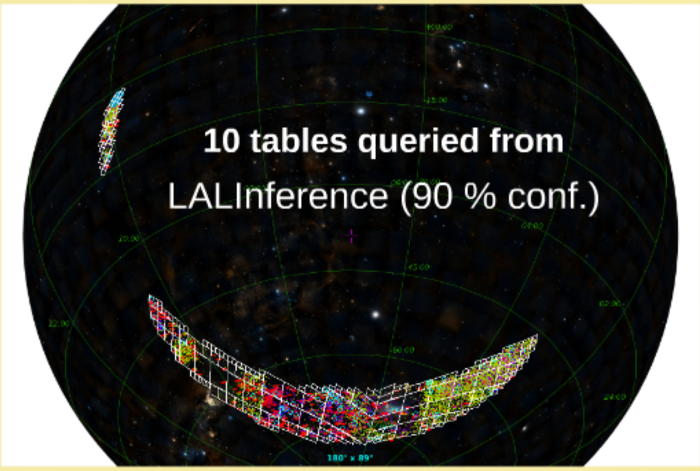


Multi-Order Coverage Map (MOC)

Fernique et al. (2015); *http://arxiv.org/pdf/1505.02937v1.pdf*

- **Effective comparison mechanisms between different sky maps**



- **Simultaneous queries of all VizieR tables (16.000 MOCs)**

MOC provides a dynamic approach to manage probability sky maps

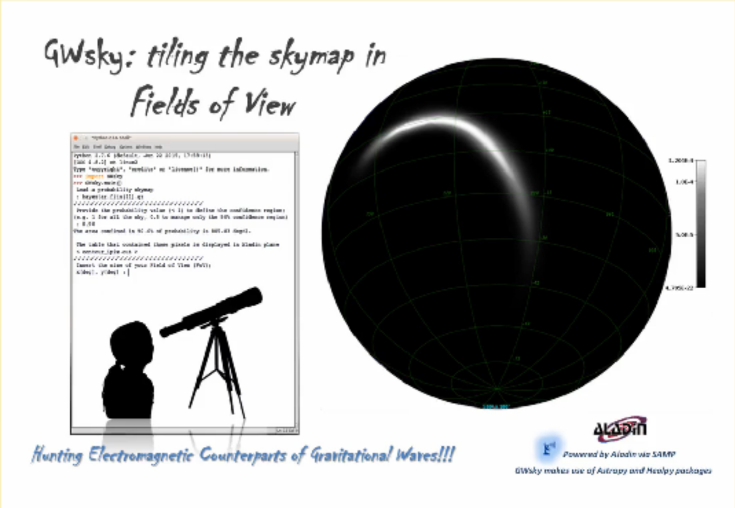
1

SAMP + Aladin Console Commands = GWsky

M.B. Taylor, T. Boch and J. Taylor *https://arxiv.org/pdf/1501.01139v1.pdf*

GWsky: quickly design an observing strategy when a sky map is issued

The sky map of a GW event - represented by white region of interest on a dark background - is tiled with multiple EM observations, each one targeting a colored tile



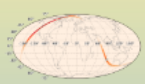
SAMP + Aladin Console Commands provide an interactive approach to work with a probability sky map

2

MOC and EM-FollowUP

The MOC method is based on the HEALPix tesselation algorithm and it is essentially a simple way to map irregular and complex sky regions into hierarchically grouped predefined cells.

Probability sky map



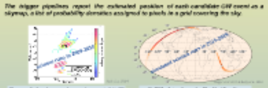
Sky localization of several hundred square degrees

Source location can be characterized by disjoint sky areas

Ring shape as a result of "triangulation" based on arrival time delay between detector sites.

We can describe complex sky region using just a list of cells based on Healpix

GW skymap: from 2009 to 2015

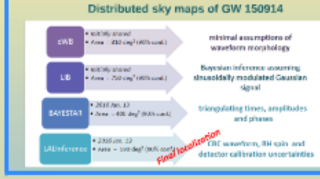


HEALPix pixelization is introduced in the Advanced LVC run.
The implementation is manageble!

The operations between the MOC maps (union, intersection, subtraction, difference) are extremely simple and fast (generally a few milliseconds) even for very complex sky regions.

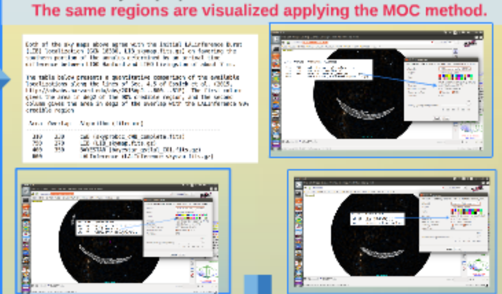
The probability skymaps are disseminated using a sequence of algorithms with increasing accuracy and computational cost.

Distributed sky maps of GW 150914



We need fast tool to compare them!

The GCN Circular (18858) shows the overlap regions between the sky maps published with the GW 150914.
The same regions are visualized applying the MOC method.



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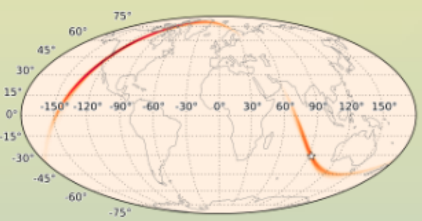

From Singer et al. 2014, The Astrophysical Journal, 795

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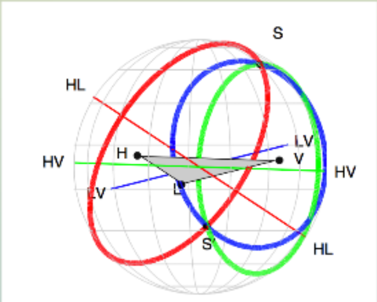

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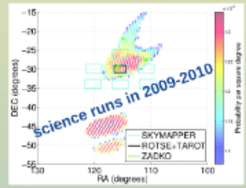
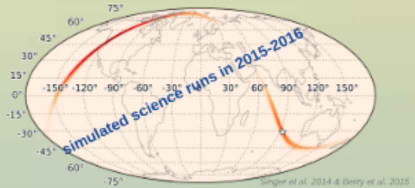


Aasi et al. 2014

The gravitational wave skymap for event G19377 which occurred on 16th September 2010. This event was later revealed to be a blind injection.



Singer et al. 2014 & Berry et al. 2015

ID 4532; data release for The First Two Years of Electromagnetic Follow-Up with Advanced LIGO and Virgo.

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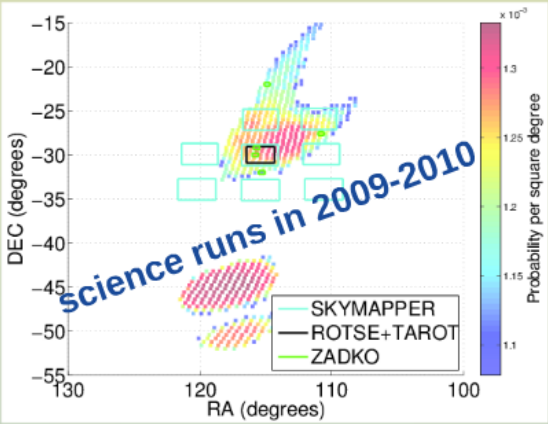

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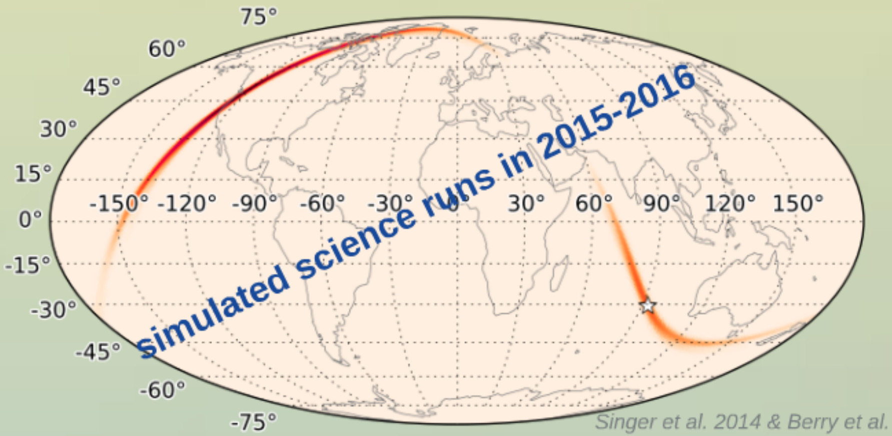

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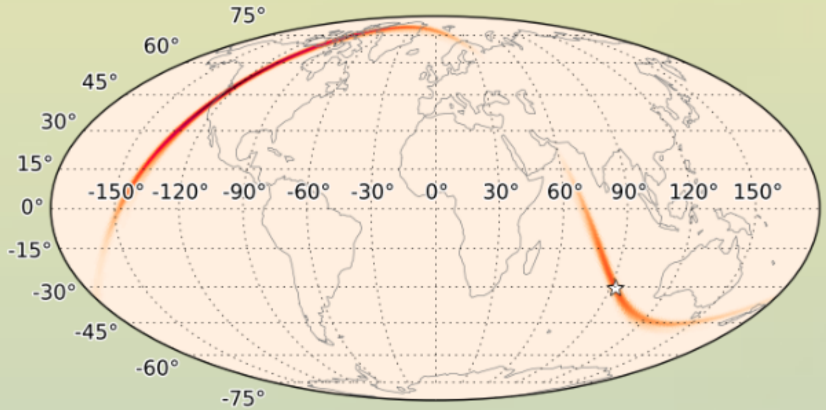

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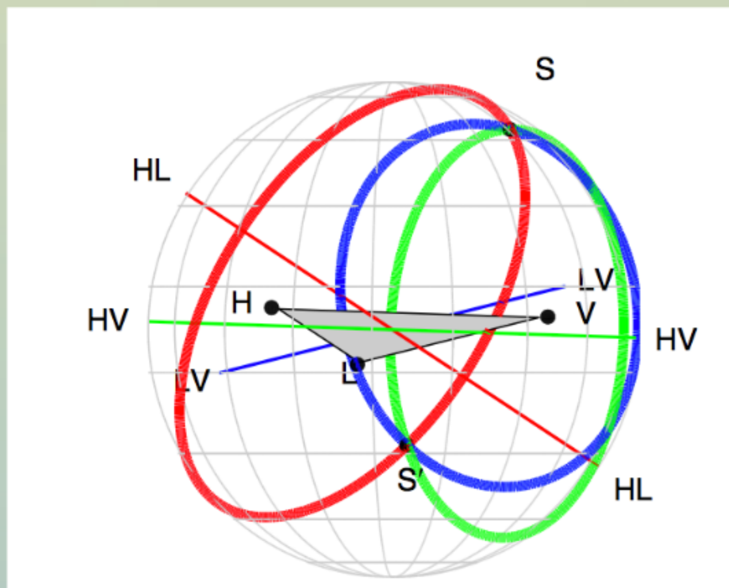

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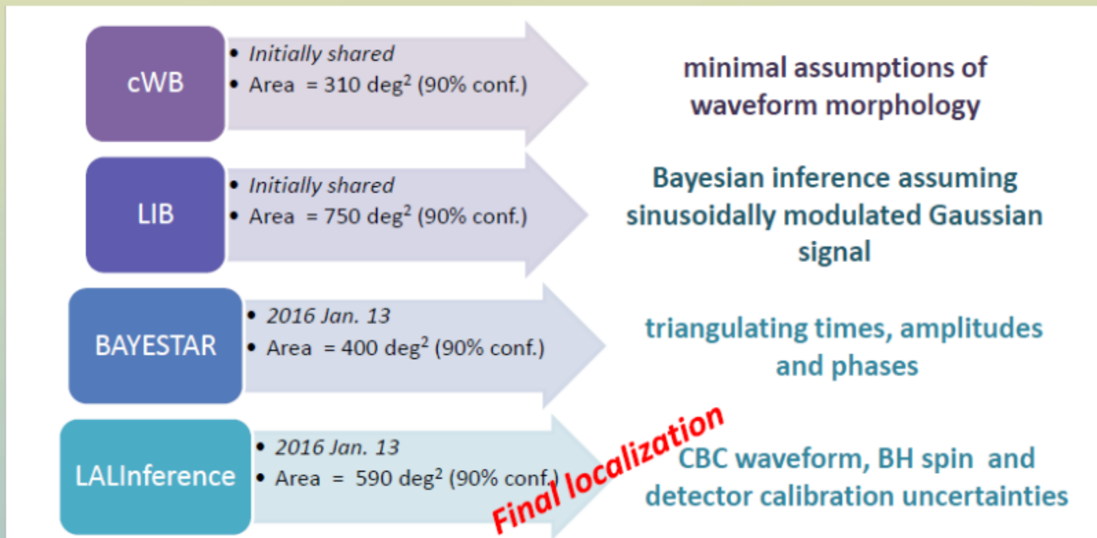

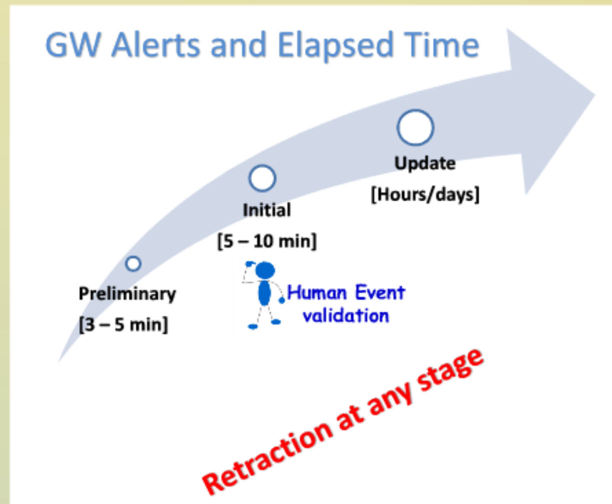

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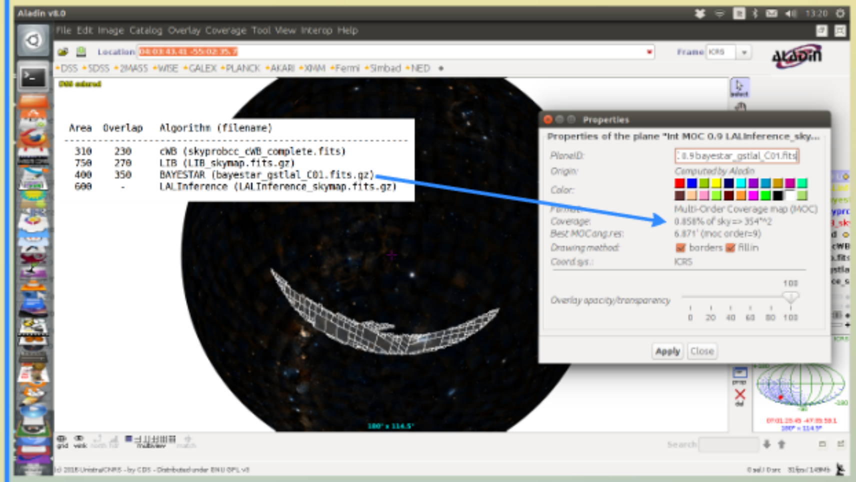
The GCN Circular (18858) shows the overlap regions between the sky maps published with the GW 150914.

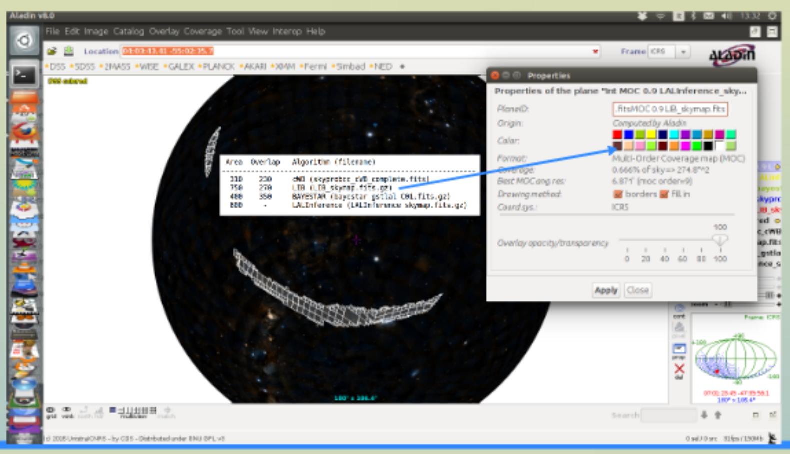
The same regions are visualized applying the MOC method.

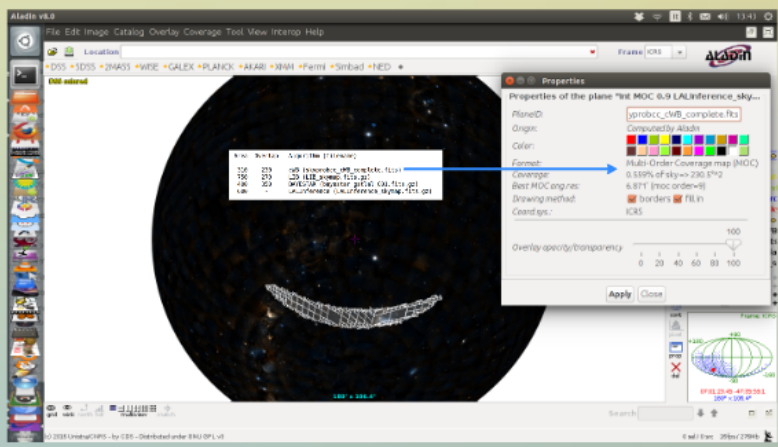
Both of the sky maps above agree with the initial LALinference Burst (LIB) localization (GCN 18330, LIB_skymap.fits.gz) on favoring the southern portion of the annulus determined by an arrival time difference between LIGO Hanford and LIGO Livingston of about 7 ms.

The table below presents a quantitative comparison of the available localizations along the lines of Sec. 4.5 of Essick et al. (2015, http://adsabs.harvard.edu/abs/2015ApJ...800...81E). The first column gives the area in deg2 of the 90% credible region, and the second column gives the area in deg2 of the overlap with the LALInference 90% credible region.

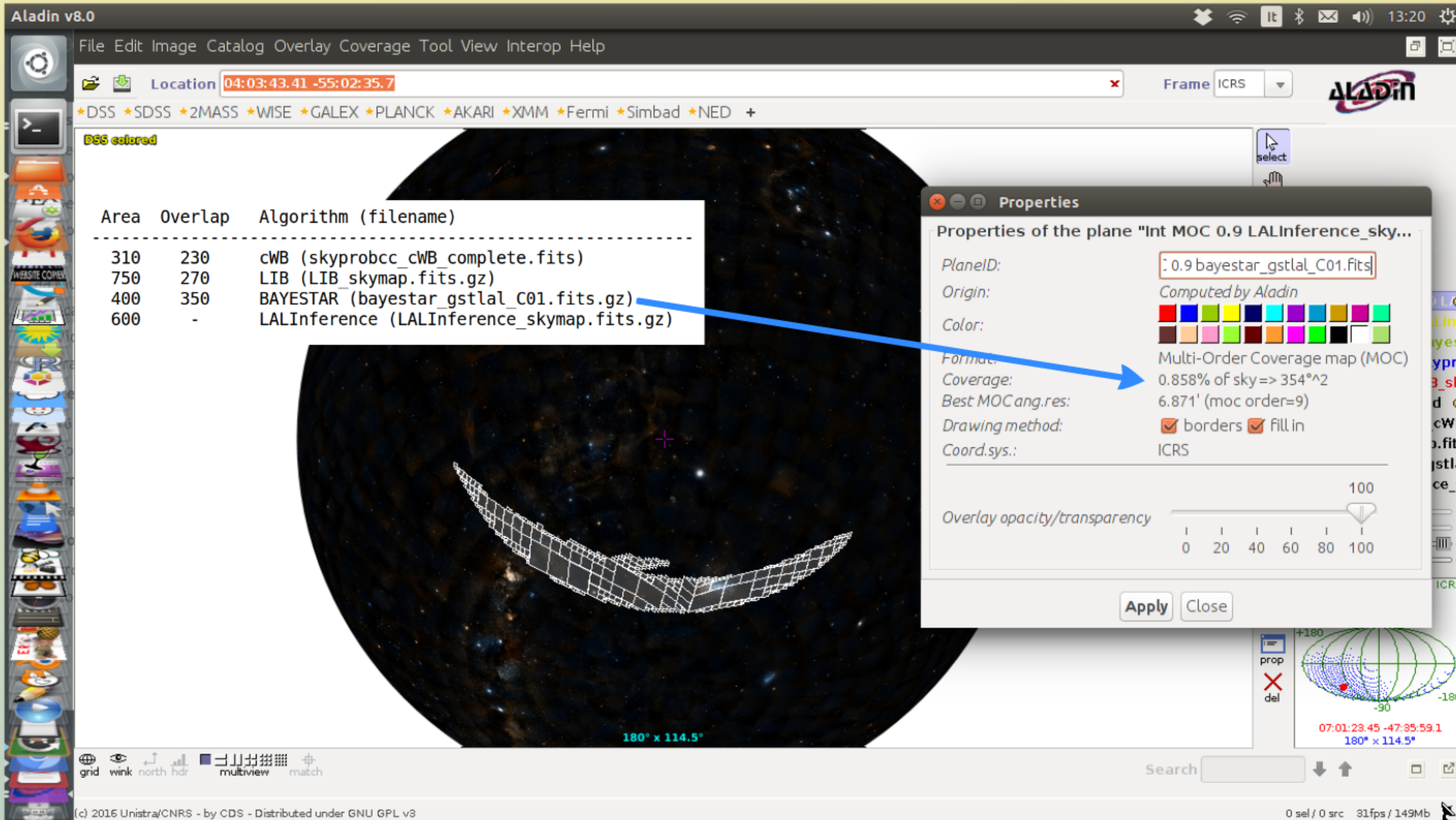
Area	Overlap	Algorithm (filename)
310	230	cWB (skyprobcc_cWB_complete.fits)
750	270	LIB (LIB_skymap.fits.gz)
400	350	BAYESTAR (bayestar_gstlal_C01.fits.gz)
600	-	LALInference (LALInference_skymap.fits.gz)



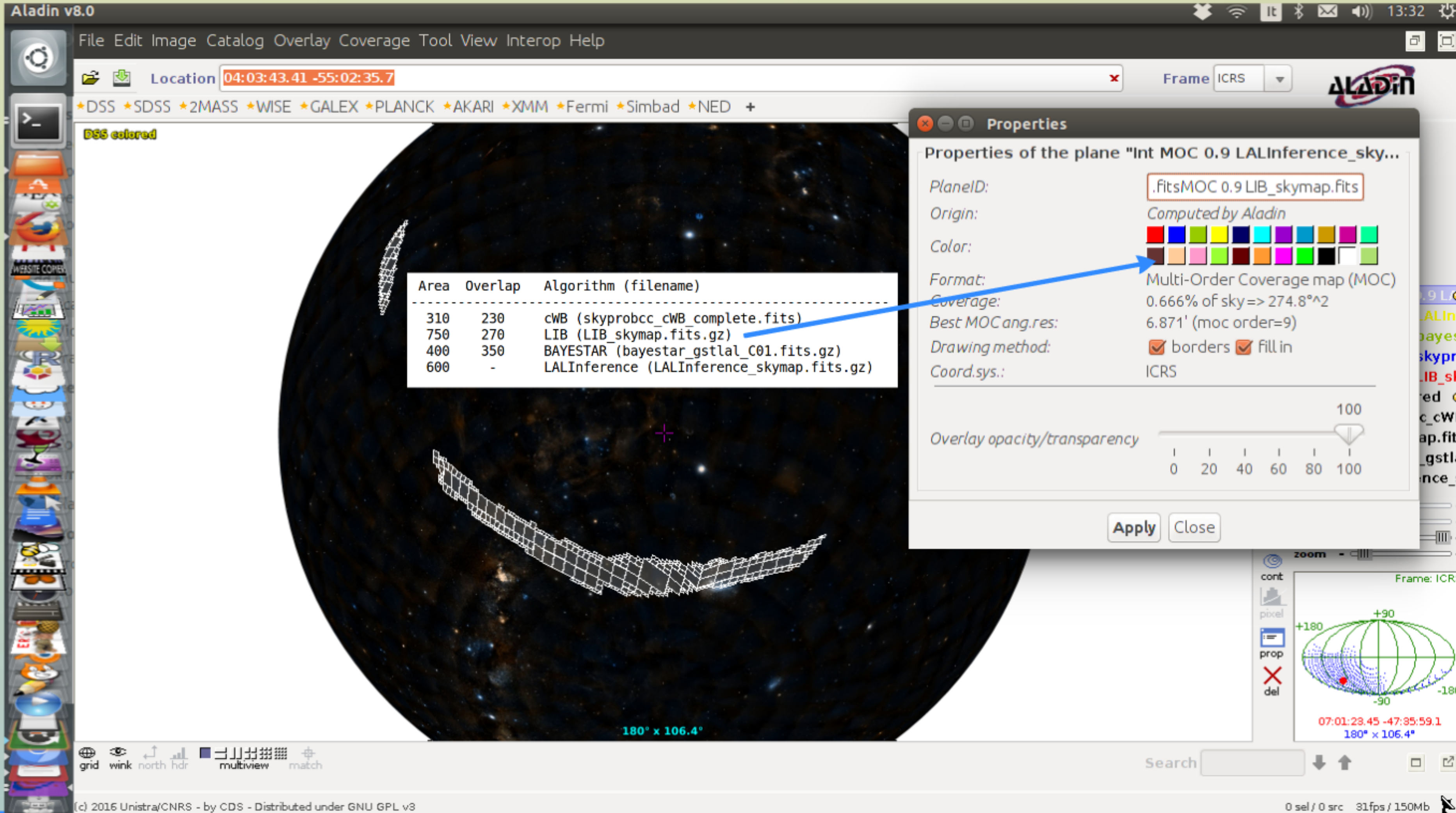




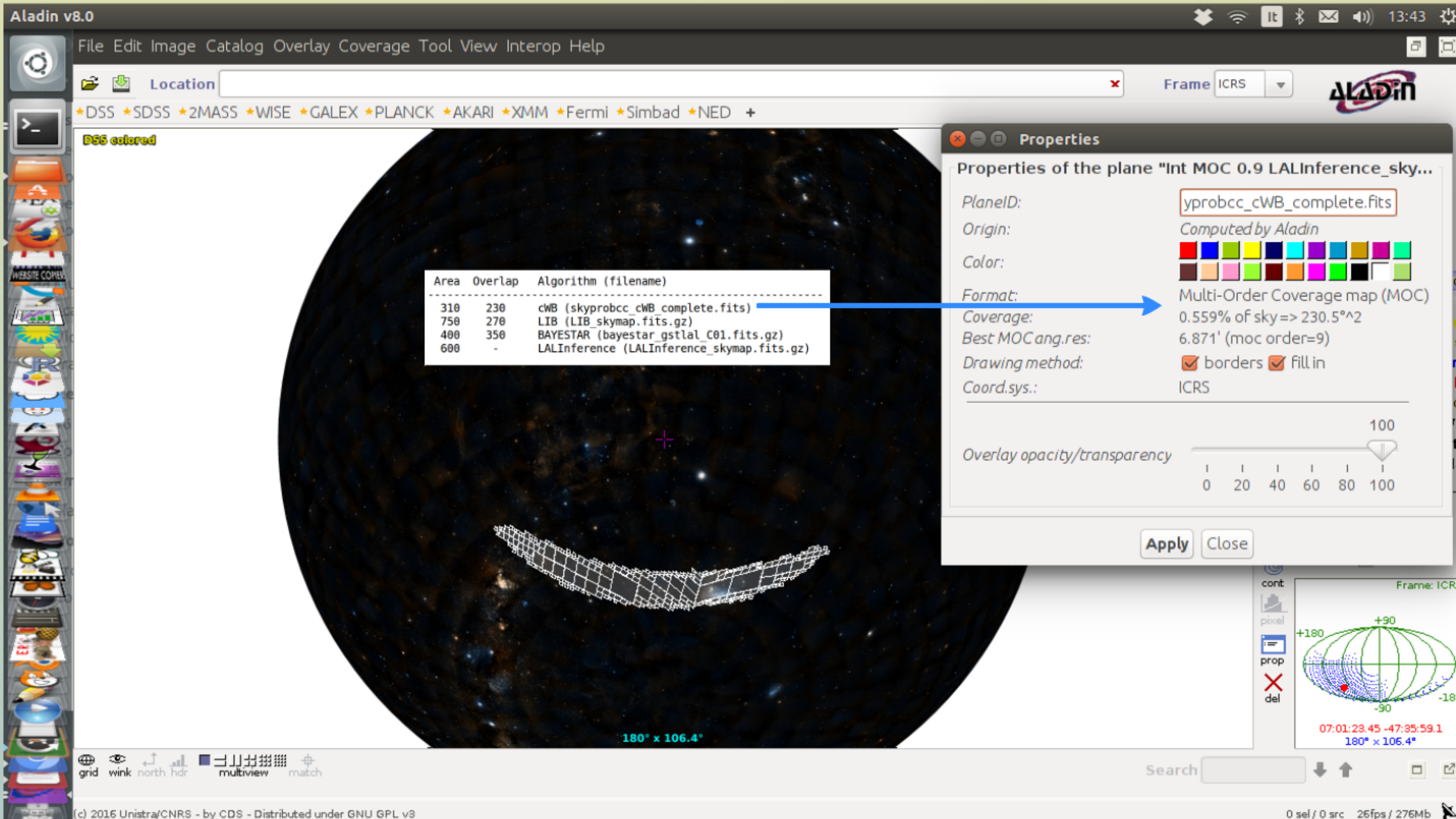
ed applying the MOC method.

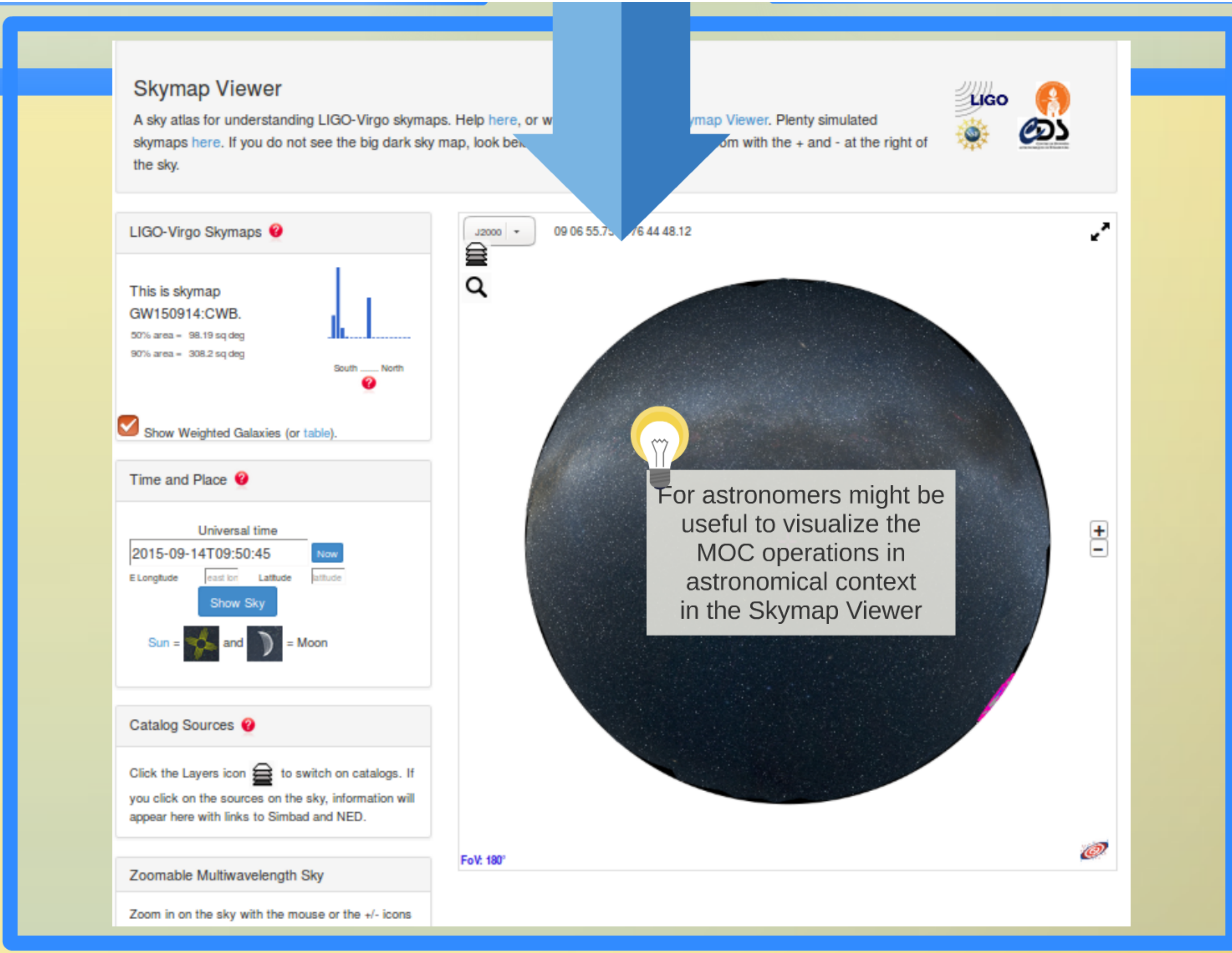


```
400     350     BAYESTAR (bayestar_gstlal_C01.fits.gz)
600      -      LALInference (LALInference_skymap.fits.gz)
```



Skymap Viewer


Aladin v8.0
File Edit Image Catalog Overlay Coverage Tool View Interop Help
Location
Frame ICRS
DSS SDSS 2MASS WISE GALEX PLANCK AKARI XMM Fermi Simbad NED
DSS colored
Area Overlap Algorithm (filename)
310 230 cWB (skyprobcc_cWB_complete.fits)
750 270 LIB (LIB_skymap.fits.gz)
400 350 BAYESTAR (bayestar_gstlal_C01.fits.gz)
600 - LALInference (LALInference_skymap.fits.gz)
180° x 106.4°
Properties
Properties of the plane "Int MOC 0.9 LALInference_sky...
PlaneID: yprobcc_cWB_complete.fits
Origin: Computed by Aladin
Color:
Format: Multi-Order Coverage map (MOC)
Coverage: 0.559% of sky => 230.5°^2
Best MOC ang.res: 6.871' (moc order=9)
Drawing method: borders fill in
Coord.sys.: ICRS
Overlay opacity/transparency
0 20 40 60 80 100
Apply Close
Frame: ICRS
07:01:23.45 -47:35:59.1
180° x 106.4°
grid wink north hdr multiview match
Search
(c) 2016 Unistra/CNRS - by CDS - Distributed under GNU GPL v3
0 sel / 0 src 26fps / 276Mb


Skymap Viewer
A sky atlas for understanding LIGO-Virgo skymaps. Help here, or w
ymap Viewer. Plenty simulated
skymaps here. If you do not see the big dark sky map, look be
om with the + and - at the right of
the sky.
LIGO
LIGO-Virgo Skymaps
This is skymap
GW150914:CWB.
50% area = 98.19 sq deg
90% area = 308.2 sq deg
South North
Show Weighted Galaxies (or table).
Time and Place
Universal time
2015-09-14T09:50:45
Now
E Longitude
Latitude
Show Sky
Sun = and = Moon
Catalog Sources
Click the Layers icon to switch on catalogs. If you click on the sources on the sky, information will appear here with links to Simbad and NED.
Zoomable Multiwavelength Sky
Zoom in on the sky with the mouse or the +/- icons
J2000
09 06 55.75
76 44 48.12
FoV: 180°
For astronomers might be useful to visualize the MOC operations in astronomical context in the Skymap Viewer

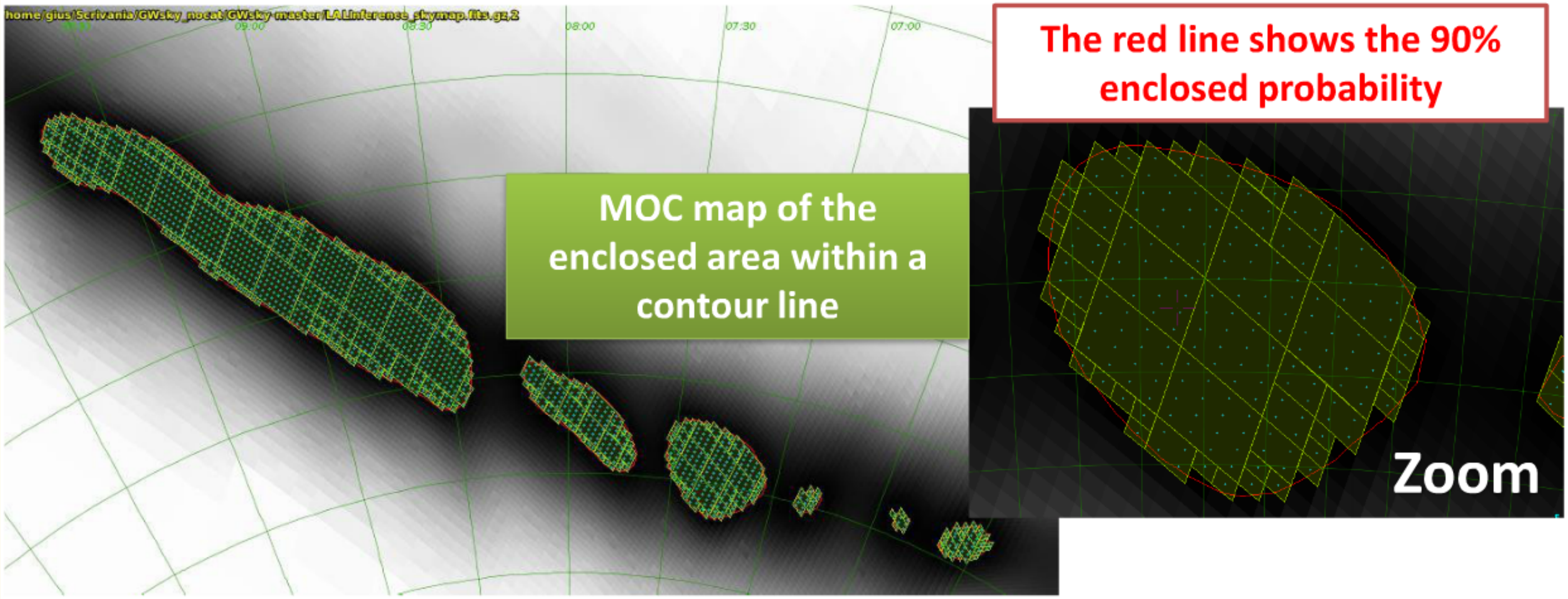
Some dataserver, such as VizieR, can be queried by MOC in order to return data (galaxy catalogs/list of images) only inside the MOC coverage.

To identify likely host galaxies of a GW event we need to collect as much information as possible

post-processing: to organize data from queries.

TOPCAT

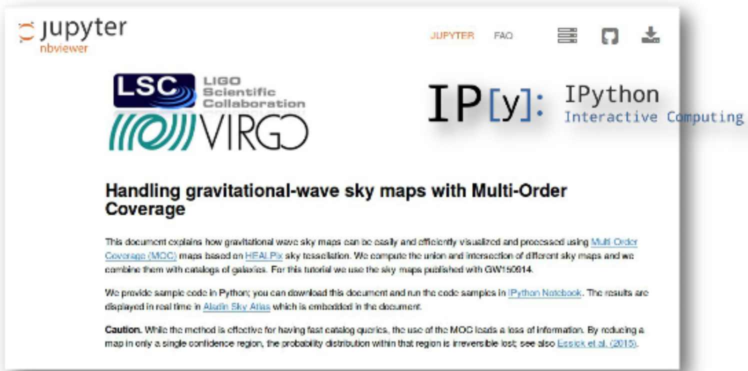
MOC representation of sky areas enclosed into iso-contour lines



MOC_area_prob(infile, percentage, output) based on MOCpy module

The enclosed area within a given probability level of a GW sky map can be effectively described through the Multi-Order Coverage (MOC) method.

MOCs at work



jupyter nbviewer   JUPYTER   FAQ

LSC LIGO Scientific Collaboration   VIRGO   IP[y]: IPython Interactive Computing

Handling gravitational-wave sky maps with Multi-Order Coverage

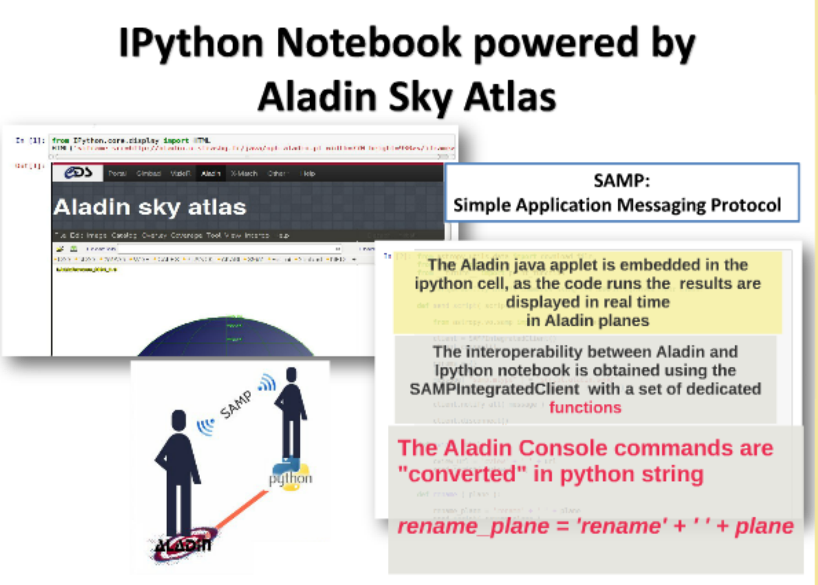
This document explains how gravitational wave sky maps can be easily and efficiently visualized and processed using Multi-Order Coverage (MOC) maps based on HEALPix sky tessellation. We compute the union and intersection of different sky maps and we combine them with catalogs of galaxies. For this tutorial we use the sky maps published with GW150914.

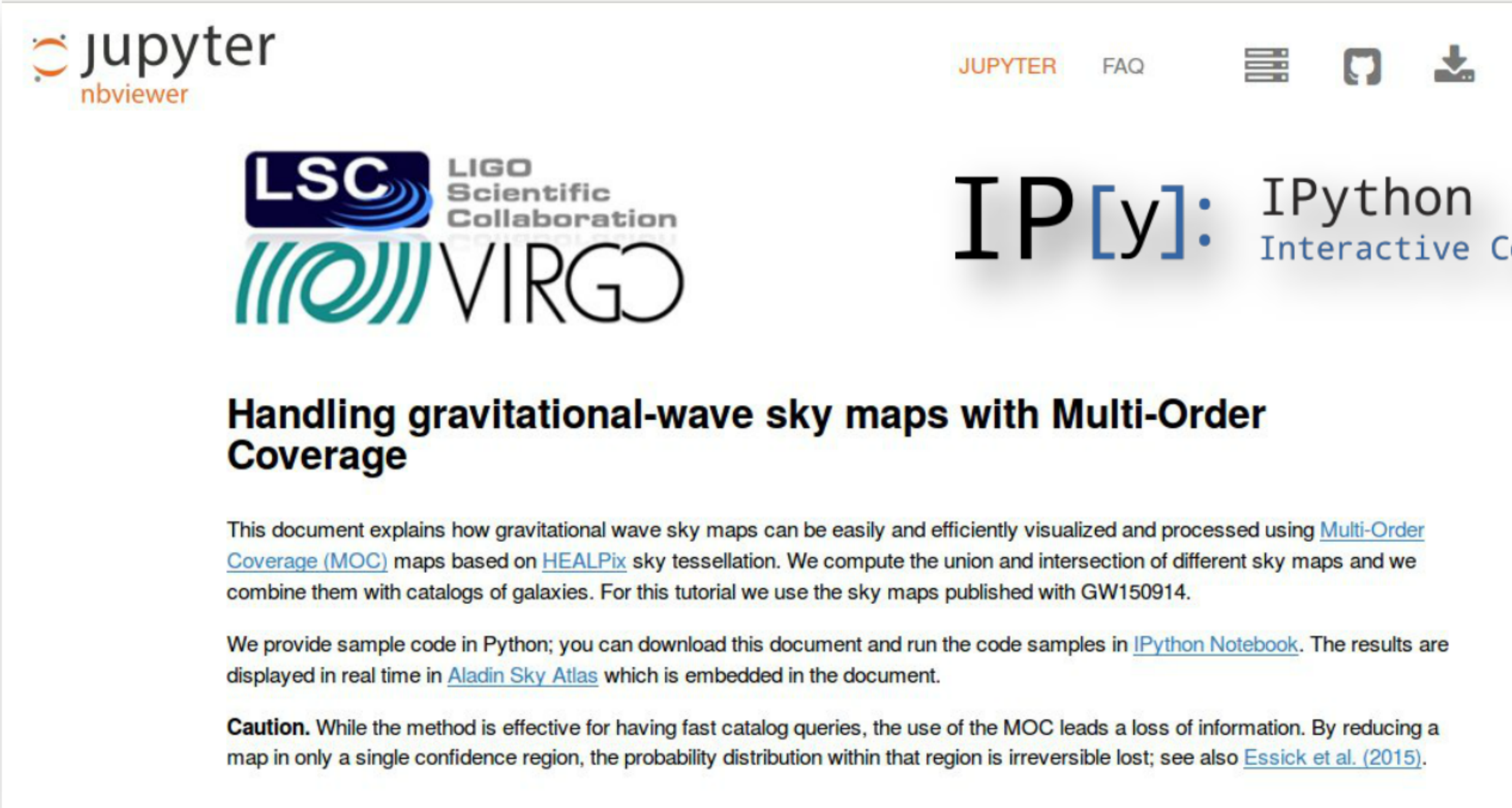
We provide sample code in Python; you can download this document and run the code samples in IPython Notebook. The results are displayed in real time in Aladin Sky Atlas which is embedded in the document.

Caution. While the method is effective for having fast catalog queries, the use of the MOC leads a loss of information. By reducing a map in only a single confidence region, the probability distribution within that region is irreversible lost; see also Essick et al. (2015).

Ipython tutorial:
http://nbviewer.jupyter.org/gist/ggreco77/5fc0cc2777f9edd446b459459db830e9

Video Tutorial:
https://vimeo.com/167173587





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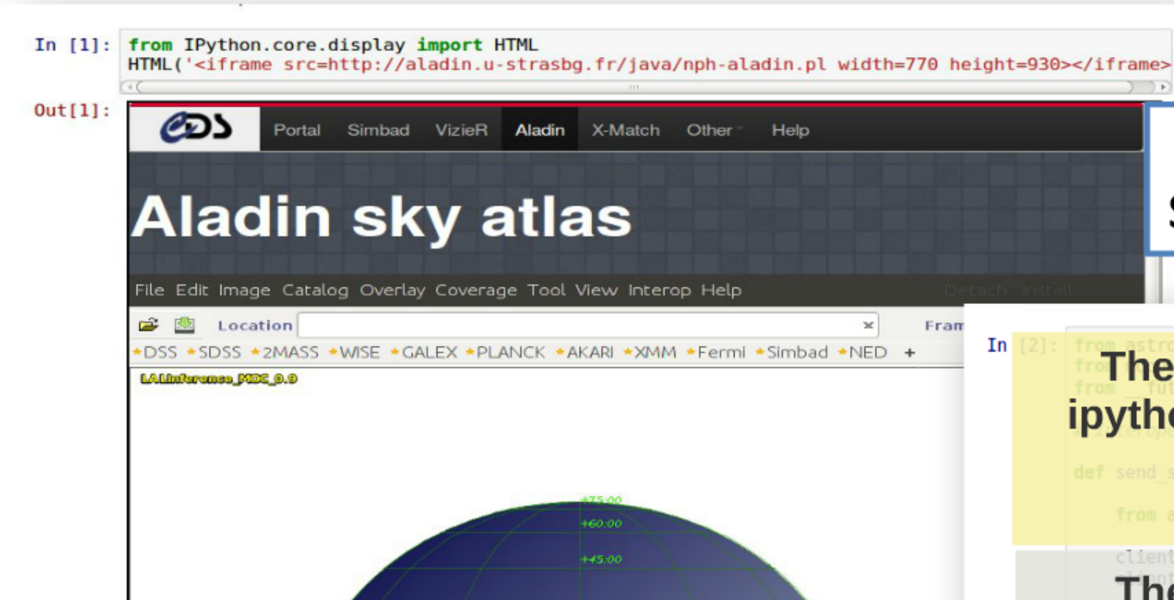
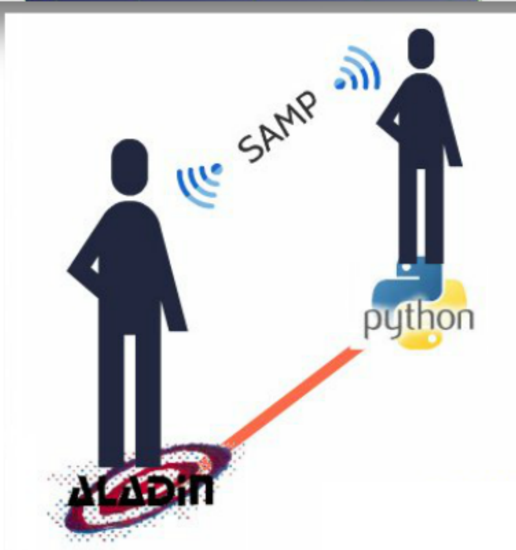
Video Tutorial:

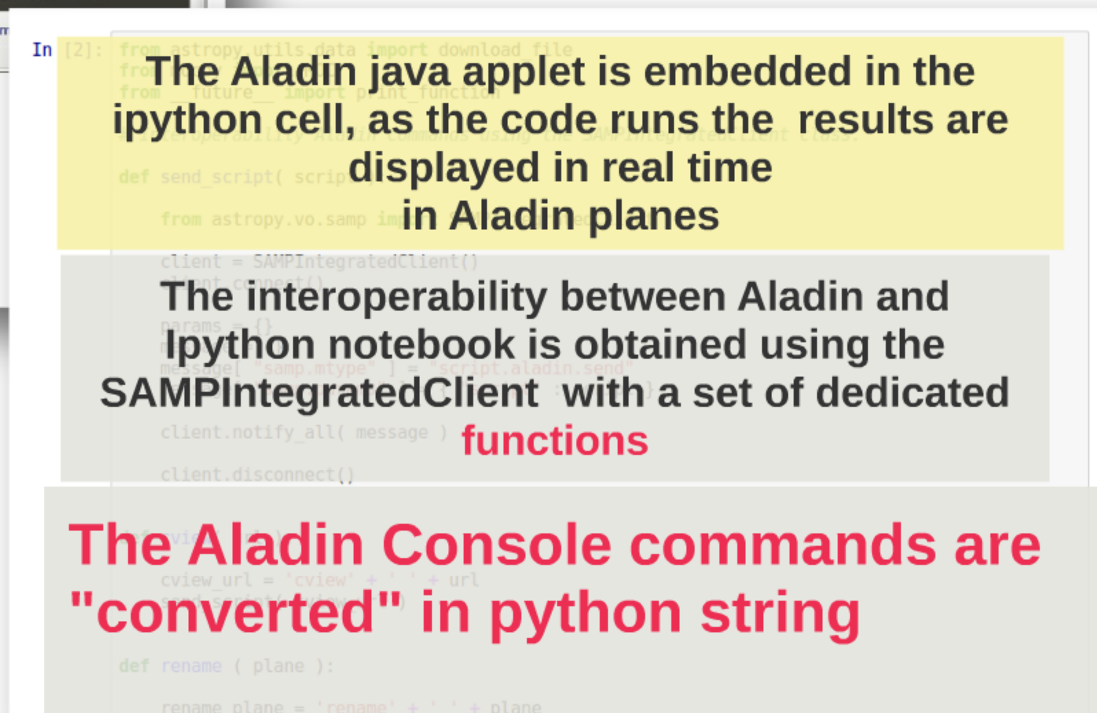
https://vimeo.com/167173587

IPython Notebook powered by Aladin Sky Atlas



SAMP:
Simple Application Messaging Protocol





The Aladin java applet is embedded in the ipython cell, as the code runs the results are displayed in real time in Aladin planes

The interoperability between Aladin and Ipython notebook is obtained using the SAMPIntegratedClient with a set of dedicated functions

The Aladin Console commands are "converted" in python string

rename_plane = 'rename' + ' ' + plane


Home
Handling gravitation...
localhost:8889/notebooks/Handling gravitational-wave skymaps with Multi-Order Co
Search
jupyter Handling gravitational-wave skymaps with Multi-Order Coverage Last Checkpoint: 2 minutes ago (autosaved)
File Edit View Insert Cell Kernel Help
Python 2
Code
CellToolbar
LSC LIGO Scientific Collaboration
VIRGO
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Table of Contents
Forewords about GW150914
1. Installation and initialization
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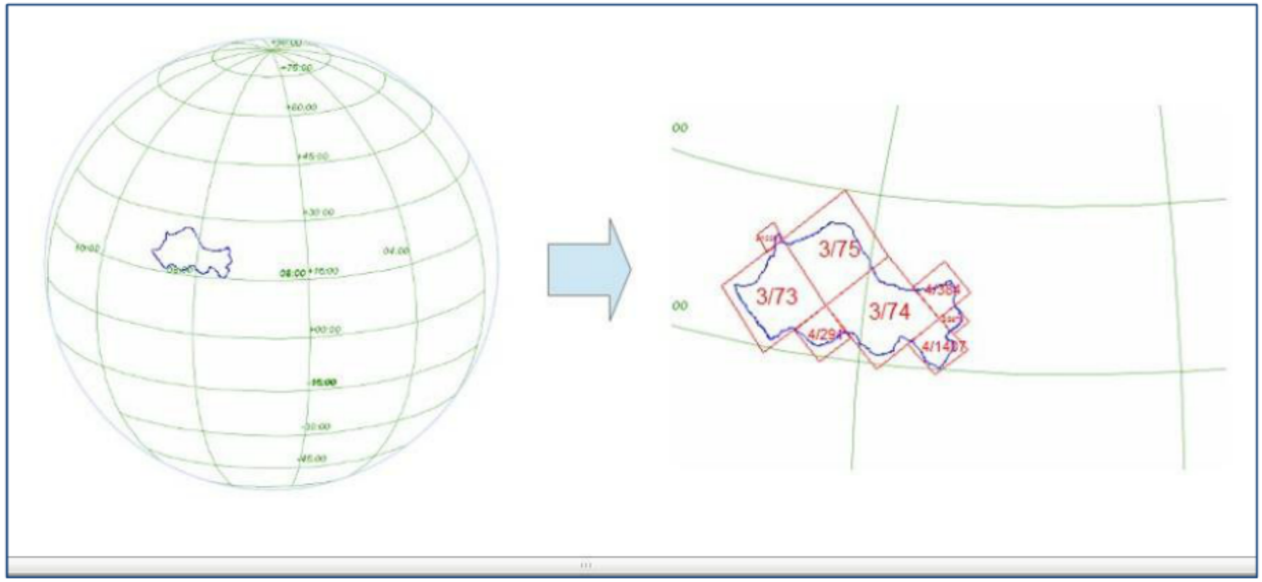
B. Python packages
2. Multiscale meshes of gravitational-wave sky maps using MOC
A. cWB sky map
B. LIB sky map
C. BAYESTAR sky map
D. LALInference sky map
3. Handling and combining multiple sky maps
A. cWB ∪ LIB
B. cWB ∩ LIB
C. BAYESTAR ∪ LALInference
D. (cWB ∪ LIB) ∩ (BAYESTAR ∪ LALInference)
4. Query Catalogs from MOCs
A. Query a single catalog

6

MOC Basic Algorithm

Each MOC cell is defined by two numbers: the hierarchy level (HEALPIX ORDER) and the pixel index (HEALPIX NPIX).



The NUNIQ scheme defines an algorithm for packing an (ORDER, NPIX) pair into a single integer for compactness:

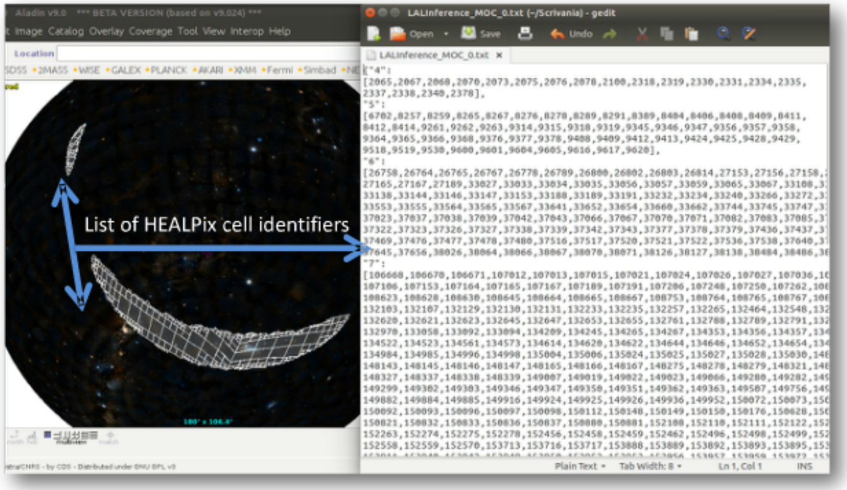
$$uniq = 4 \times 4^{order} + npix$$

Fernique et al. 2014

http://ivoa.net/documents/MOC/20140602/REC-MOC-1.0-20140602.pdf

? The code correctly traces out the original underlying mesh in the HEALPix image?

MOC: No space projection, No smoothing



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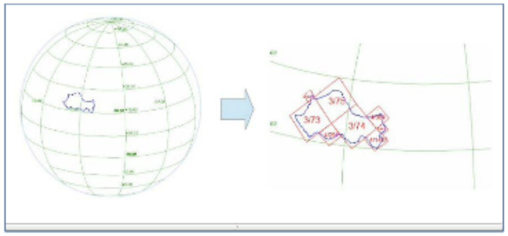

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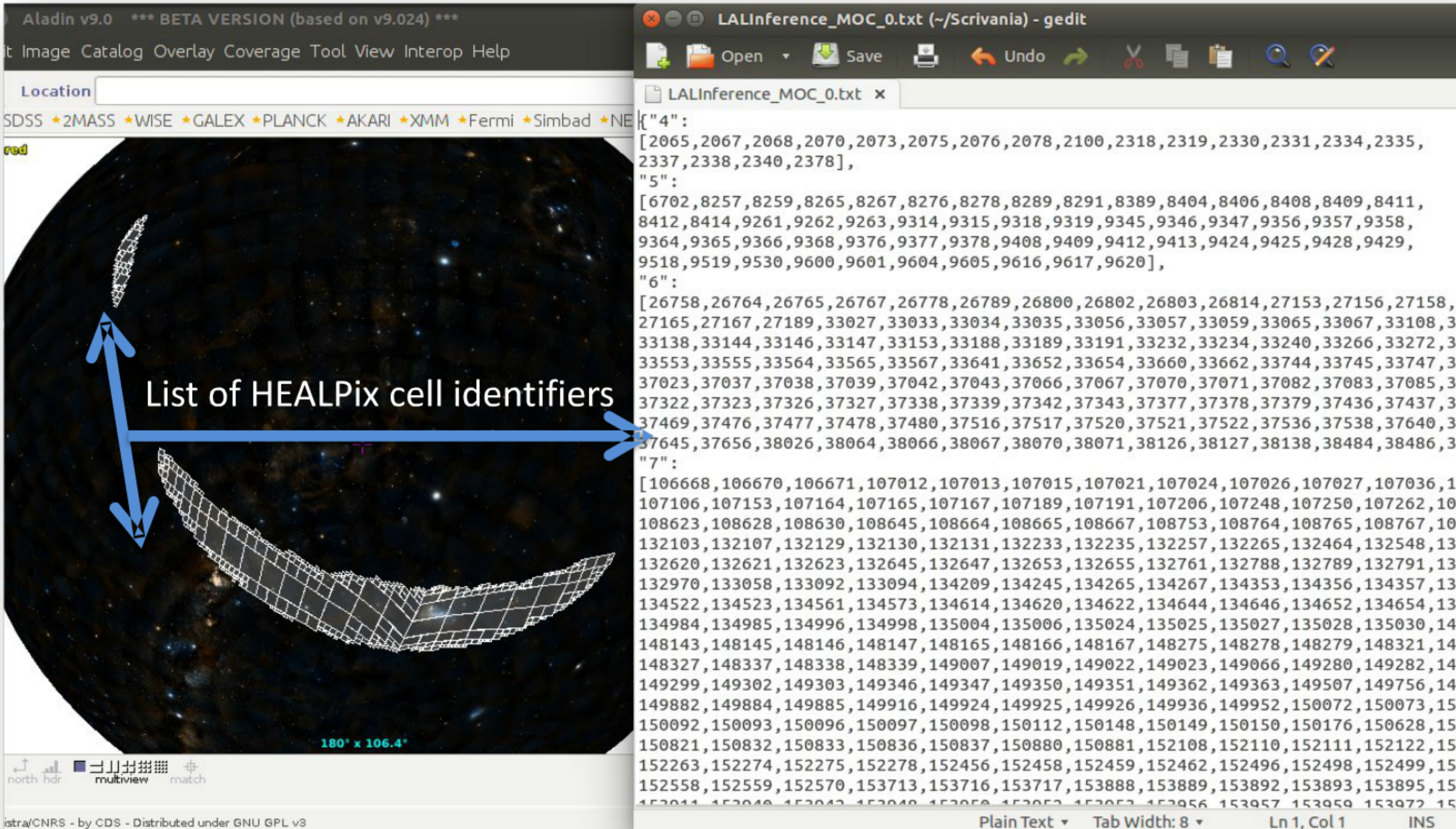
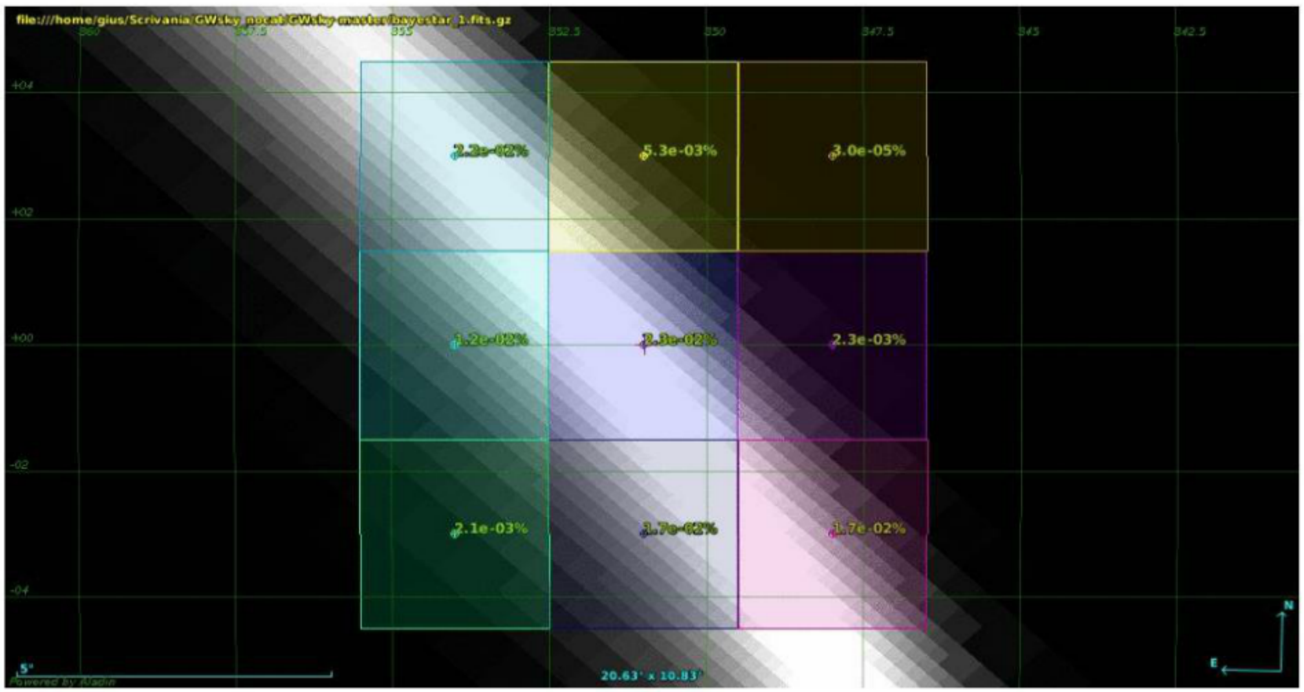


GWsky: tiling the skymap in FoV

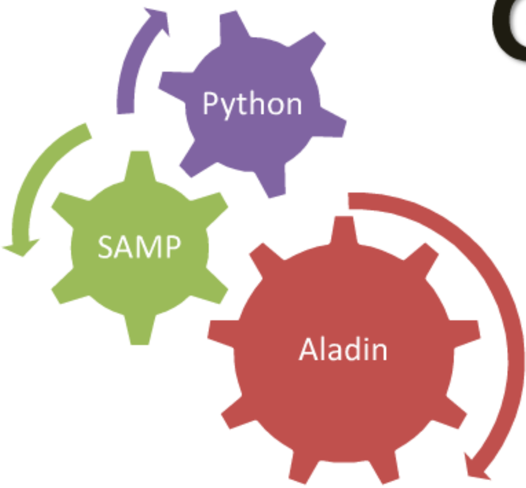
GWsky is an interactive Python script to generate a sequence of pointings given a specific Field of View

Cardinal and Intercardinal direction → Integrated probability inside each FoV → airmass in step of hour for each FoV → FoV query to catalogs

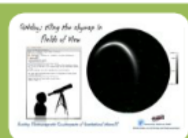


USER OPTION: the FoVs can be overlaid or separated from their default positions

GWsky Command Line




C runs a new sequence *changing* the FoV center

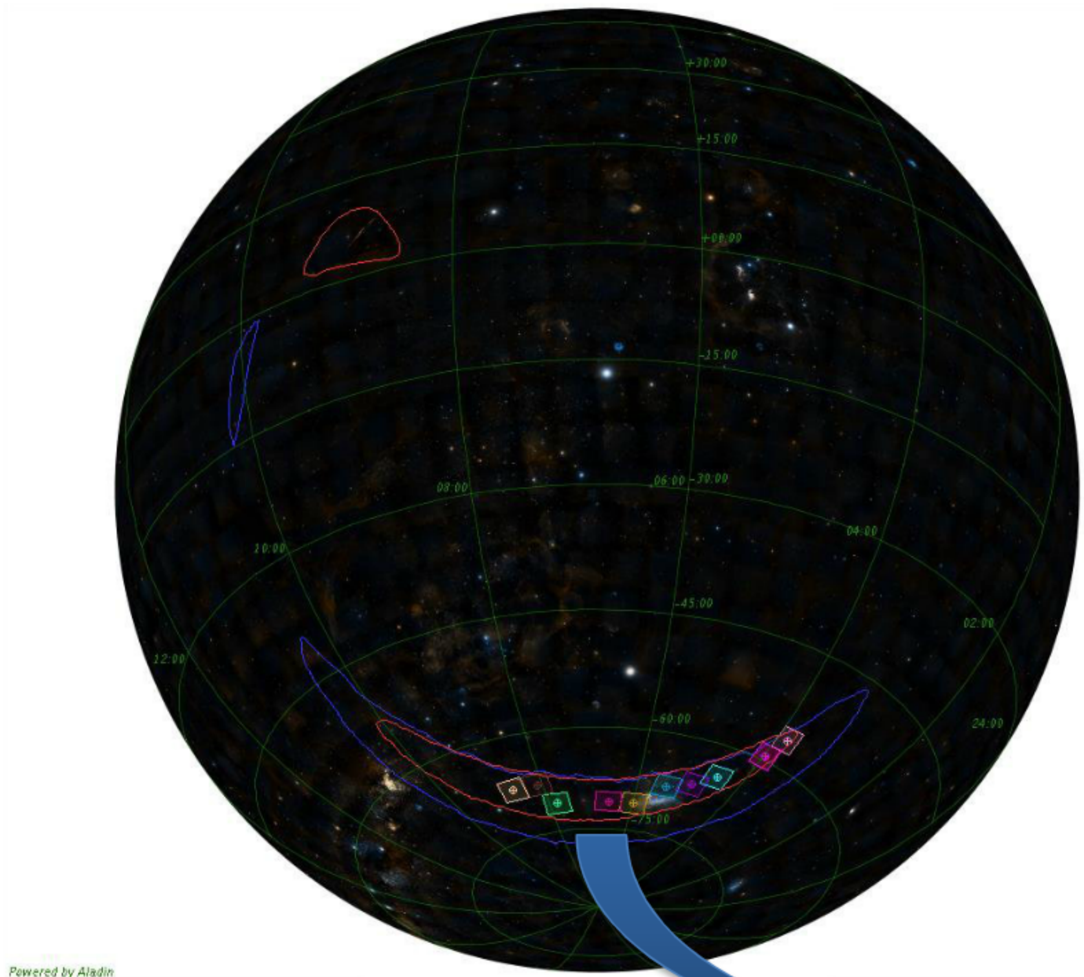

I runs a new sequence without drawing the *input* FoV

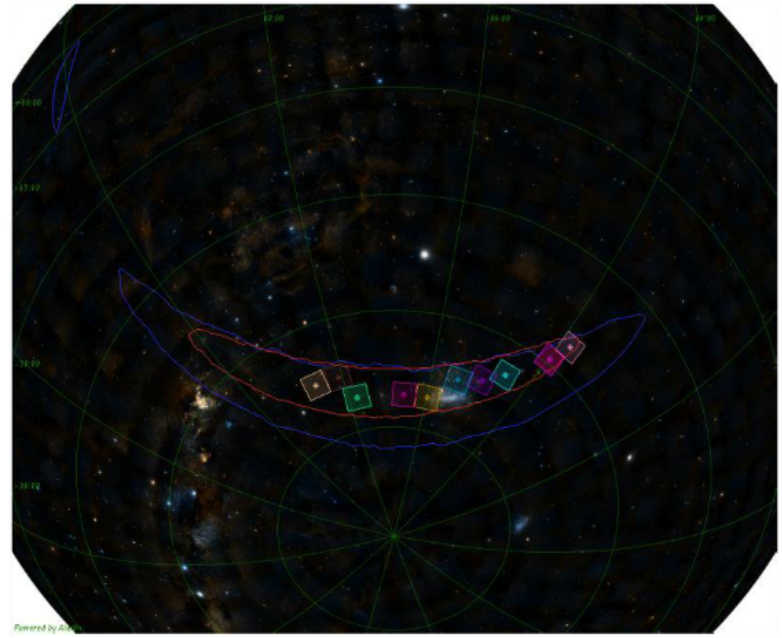

L runs a new sequence starting from the *last* drawn FoV

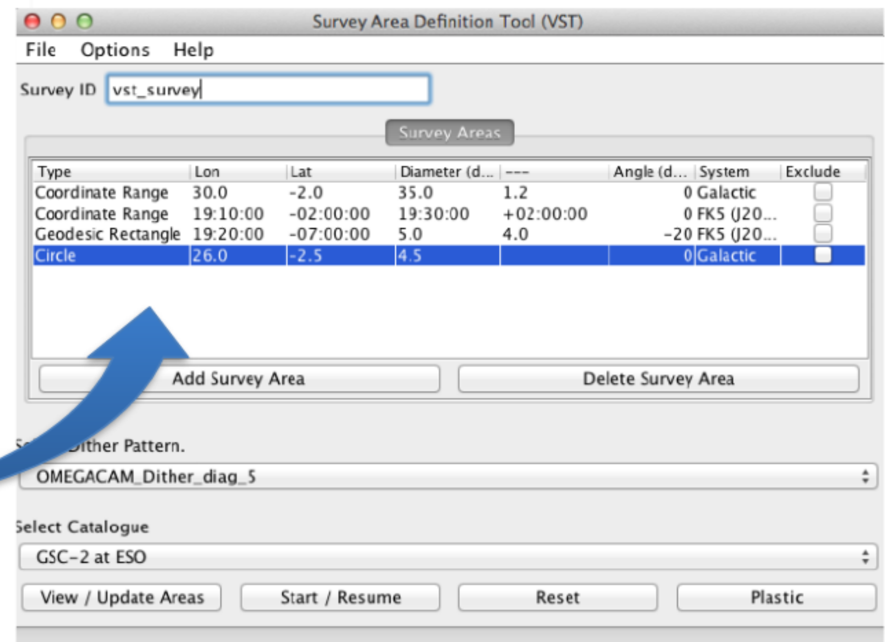

R *repeats* the last action


Q *quit*

VST Observation of GW 150914







GraWITA

Conclusion and Future Perspectives

SAMP + Aladin console commands** offer the ability to build interactive tools useful to astronomers as **GWsky for Grawita

***MOC** offers a dynamic concept for skymap (logical operations and simultaneous queries)*

A python package for the Aladin console commands (converting in python string) might be useful

The MOC could be implemented in Skymap Viewer (to show the MOC operation in astrophysical context)

TOPCAT might be qualified for post-processing analysis to organize the query data