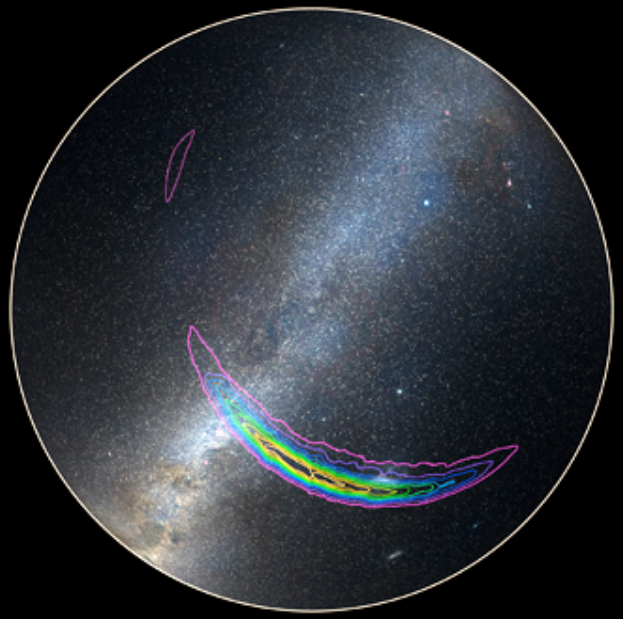
Observational Strategies

Marica Branchesi, Giuseppe Greco, Giulia Stratta
and GRAWITA team



GraWITA

O1 low-latency pipelines configuration

- **cWB: Coherent WaveBurst**

un-modeled GW bursts

Klimenko et al. 2016, Phys. Rev. D 93, 042004

- **oLIB: Omicron + LALInference**

un-modeled GW bursts

Lynch et al. 2015, LIGO-P150022

- **GSTLAL: Gstreamer + LAL**

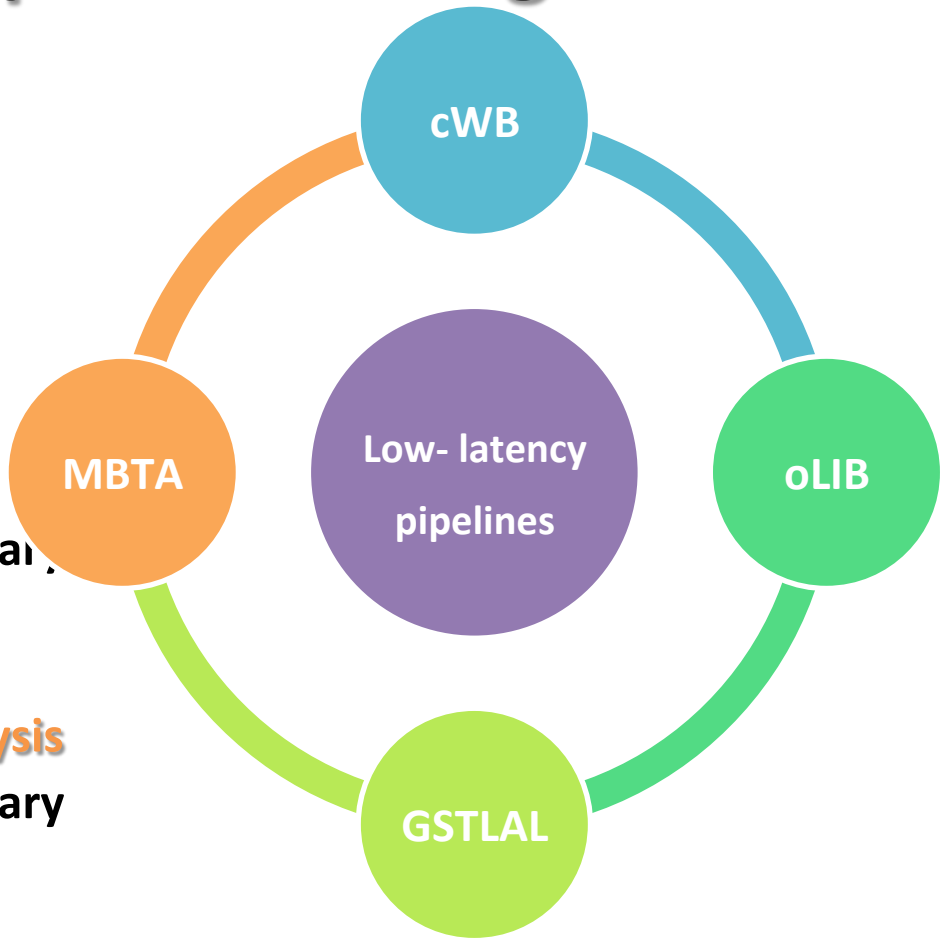
Matched-filter for compact object binary mergers

Cannon et al. 2012, ApJ, 748, 136

- **MBTA: Multi-Band Template Analysis**

Matched-filter for compact object binary mergers

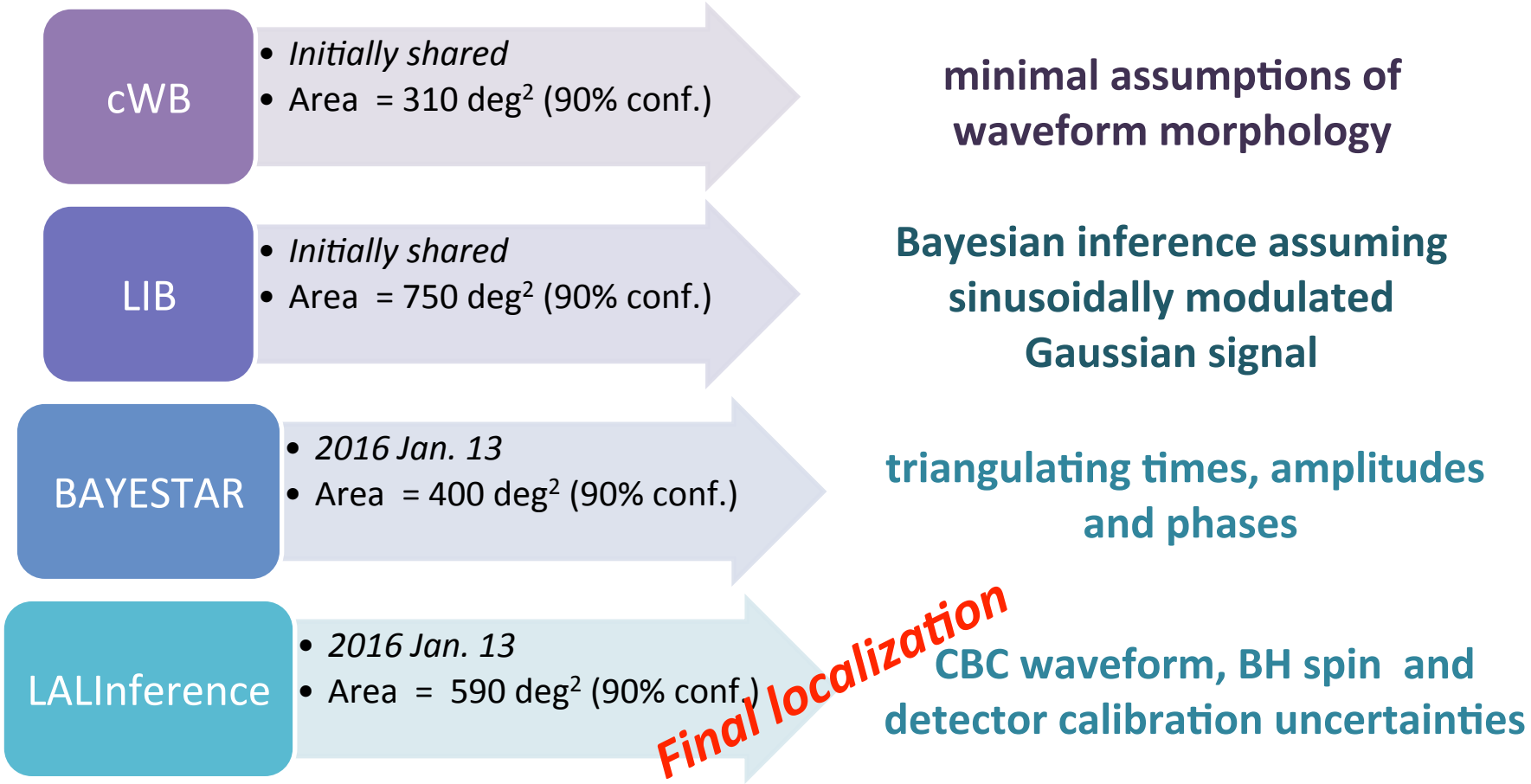
Adams et al. 2015, arXiv:1512.02864



All four detection pipelines report candidates within a few minutes of data acquisition. They continually search for transients that are coincident in the two detector within 10 ms.

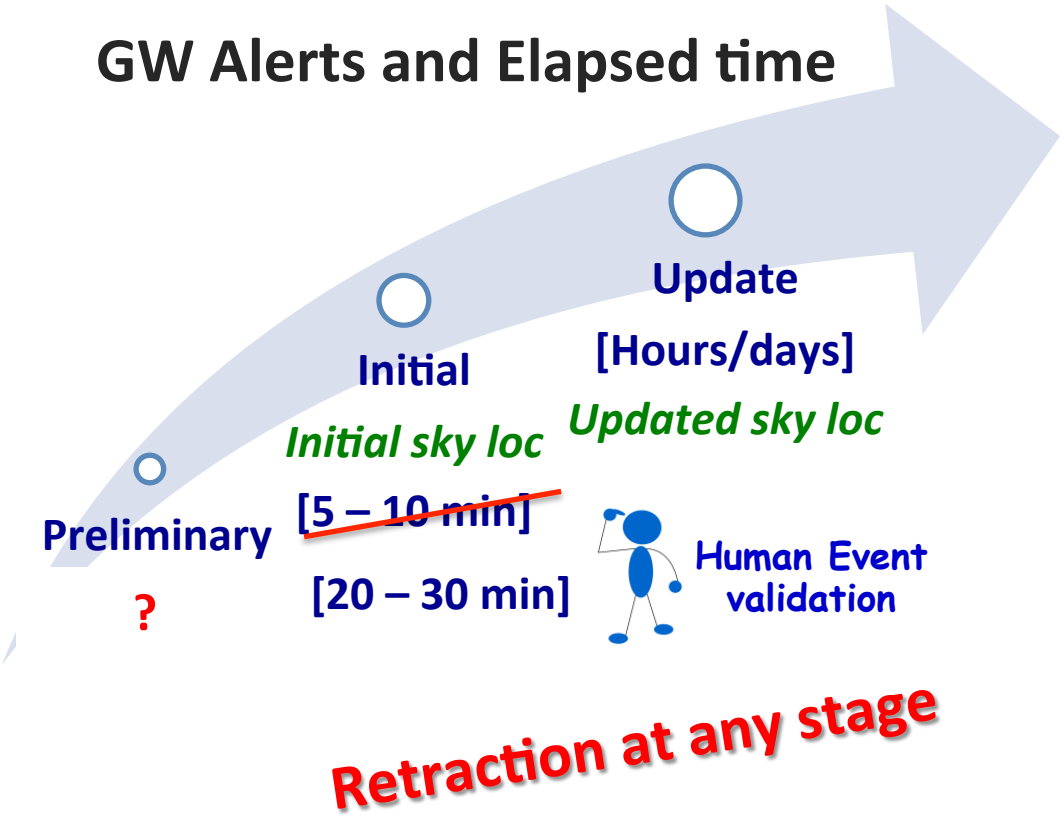
Sky Maps

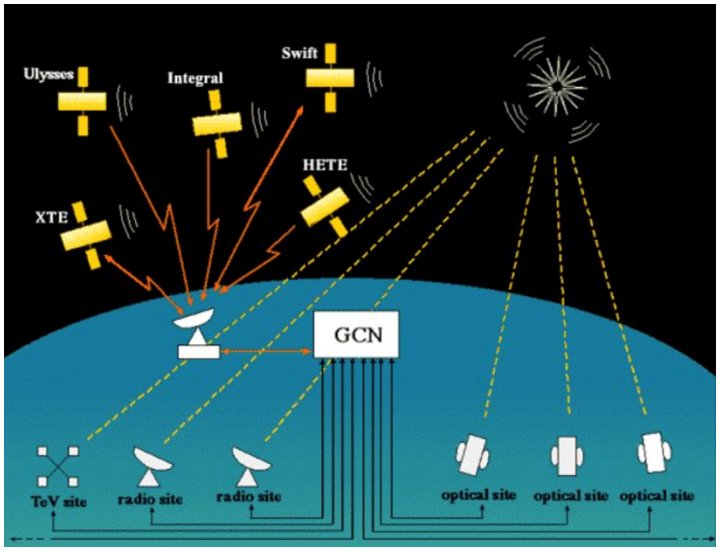
The probability skymap are disseminated using a sequence of algorithms with increasing accuracy and computational cost



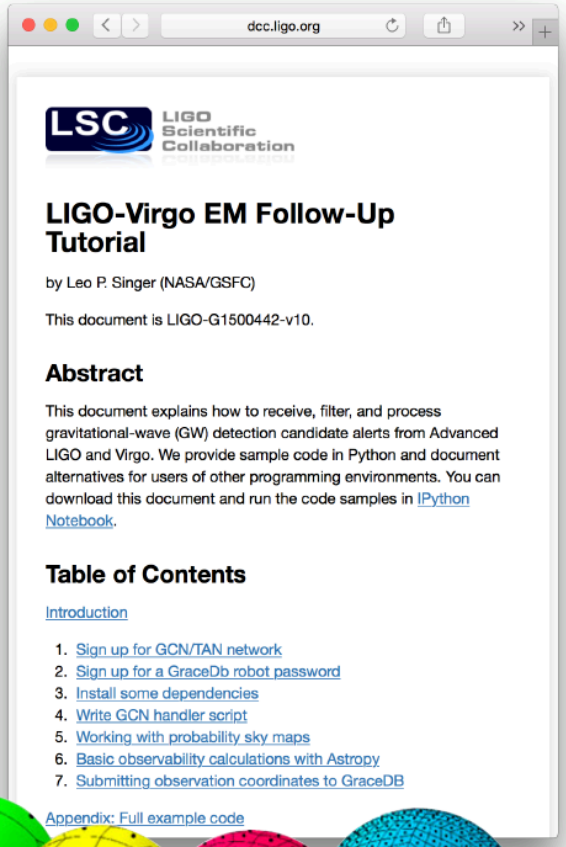
LVC GCN notices

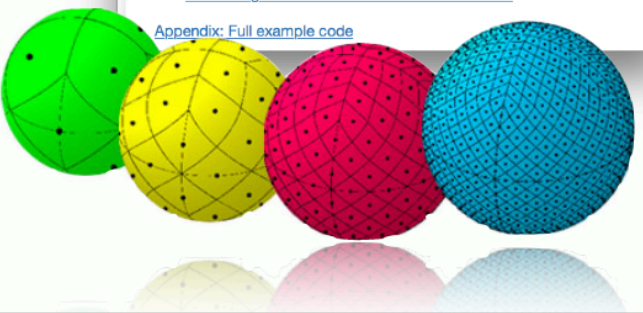
LVC GCN notices do not contain a position (RA, Dec, error radius) instead they point to an URL to a **FITS file containing a probability sky map in the HEALPix all-sky projection**

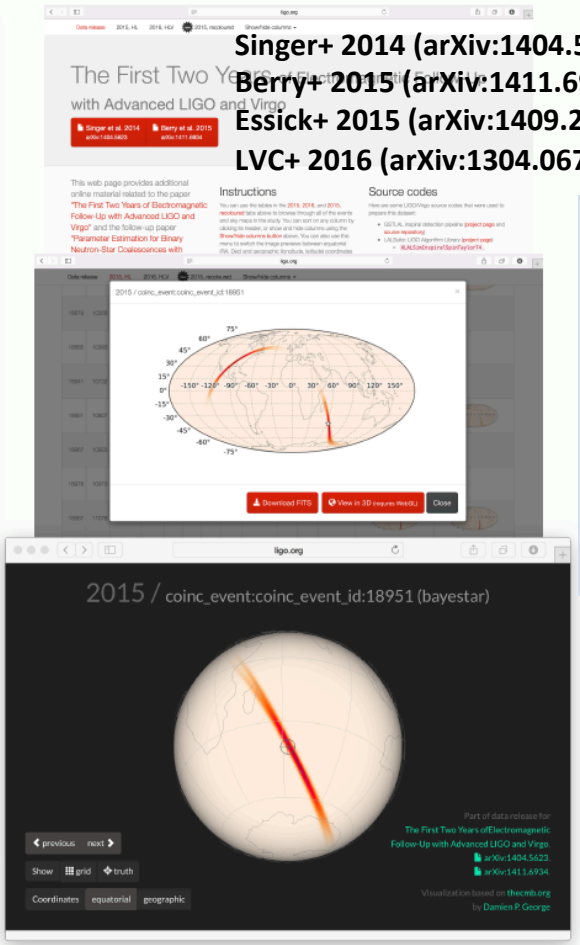




How to get started with LIGO/Virgo alerts



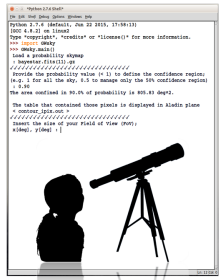


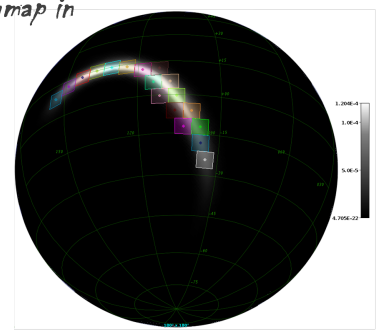


Singer+ 2014 (arXiv:1404.5623)
Berry+ 2015 (arXiv:1411.6934)
Essick+ 2015 (arXiv:1409.2435)
LVC+ 2016 (arXiv:1304.0670)

- Code, tutorials and more to use LVC GCN, FITS and HEALPIx at https://gw-astronomy.org/wiki/LV_EM/TechInfo
- Tools: Astropy, Healpy, PyGCN, **GWsky and MOC**

GWsky: tiling the skymap in Fields of View

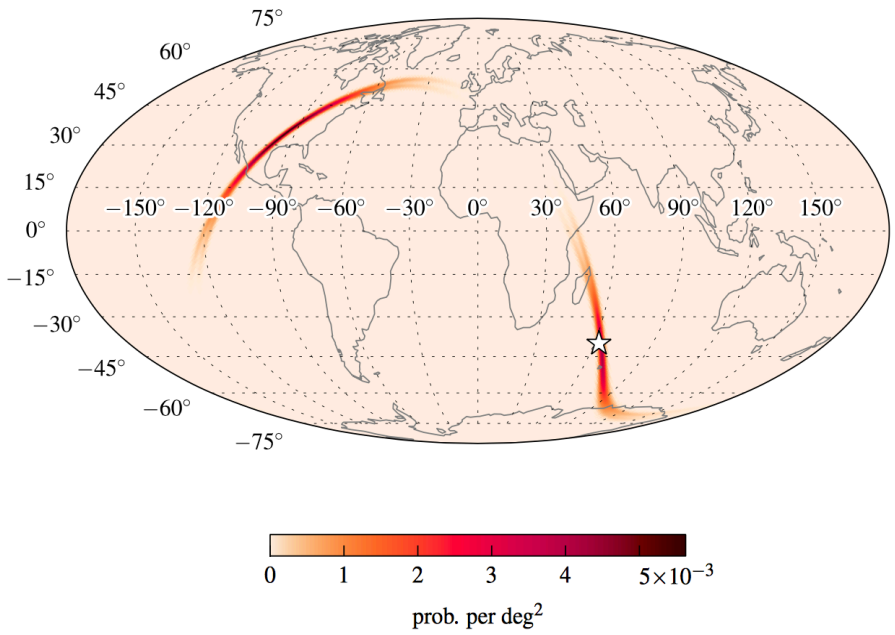


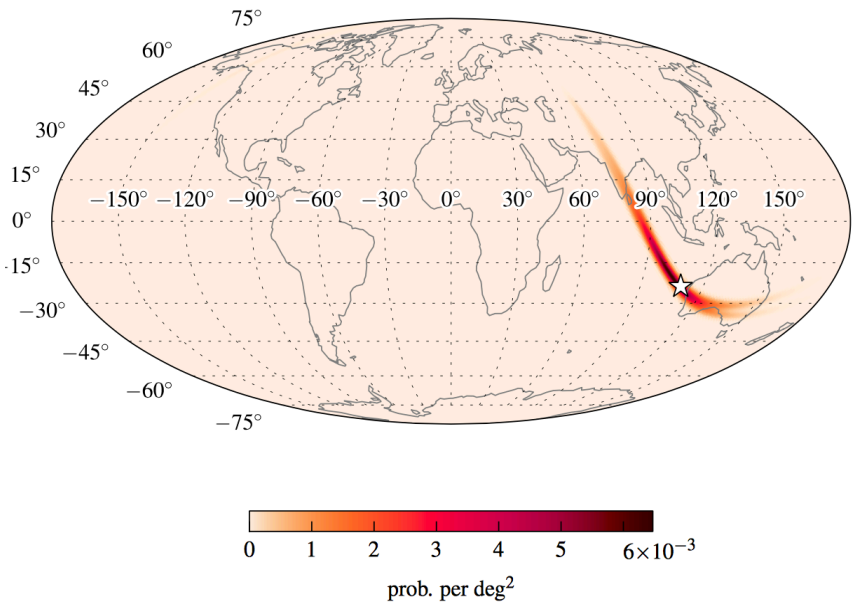


Hunting Electromagnetic Counterparts of Gravitational Waves!!!

Powered by Aladin via SAMP
GWsky makes use of Astropy and Healpy packages

- GW sky localizations: wide regions of the sky (tens to hundreds of sq. degrees)
- Difficult shape, annulus, may be split into patches





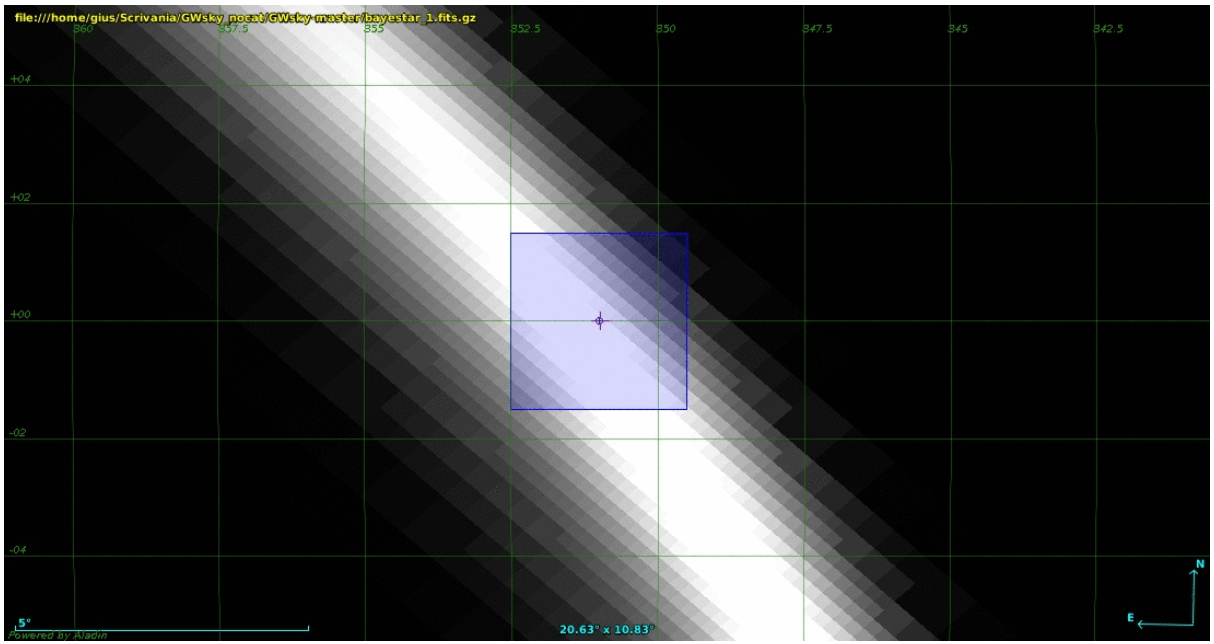
Examples of BAYESTAR localizations of GW detection using only the two LIGO detectors **Singer et al 2014, *ApJ*, 795**
Singer & Price 2016, *Phys. Rev. D*, 93

How to point the wide-FoV telescopes?

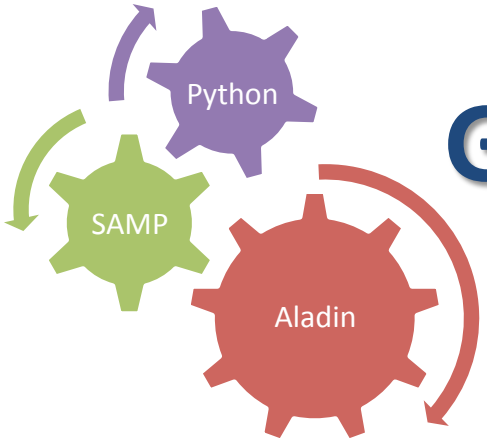
GWsky: tiling the skymap in FoV

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

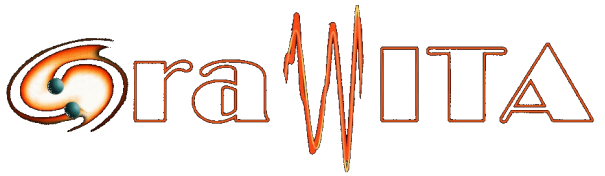
I runs a new sequence without drawing the *input* FoV

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

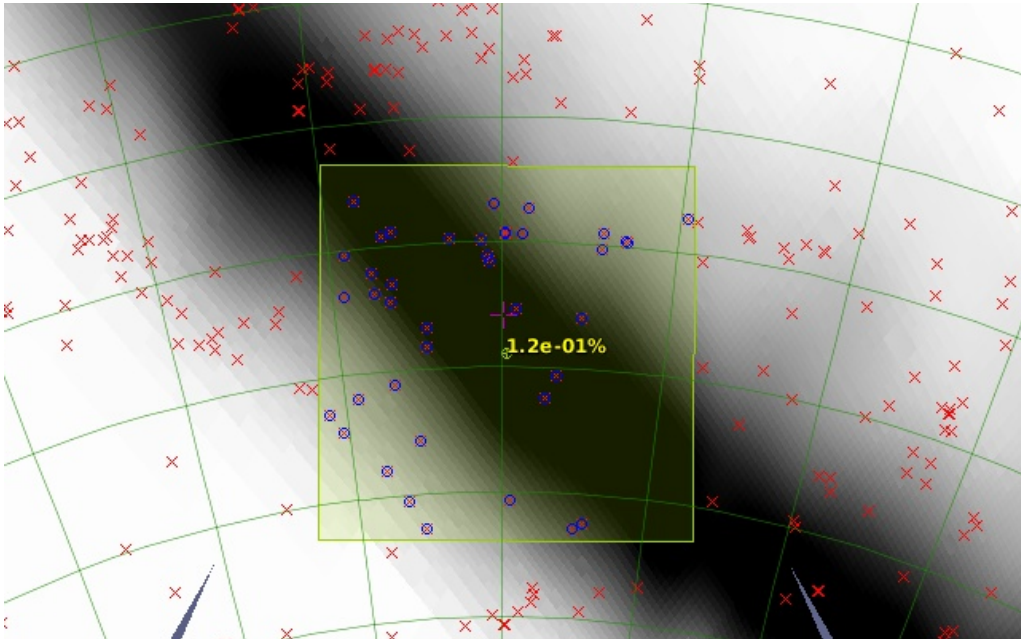
R *repeats* the last action

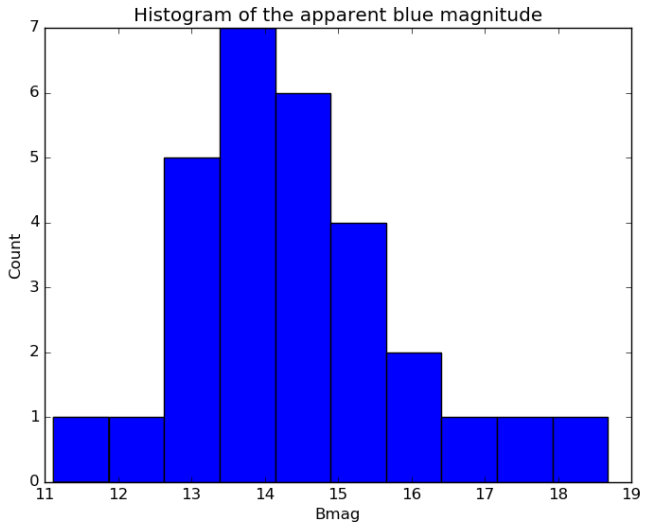
Q *quit*

Web-interface under development by the Urbino University Informatic students



FoV query to catalog: an example



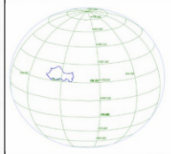


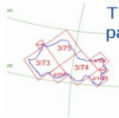
Descriptive statistic is plotted for each FoV

This can be useful to determine the integration time of each image or to avoid bright galaxies or stars

MOC: *Multi-Order Coverage*

- The MOC method is based on the HEALPix tessellation algorithm and it is essentially a simple way to map irregular and complex sky regions into hierarchically grouped predefined cells.
- The operations between MOC maps (union, intersection, subtraction, difference, complement) are extremelly simple and fast (generally a few milliseconds) even for very complex sky regions.
- In addition, same data servers, such as VizieR, can be "queried by MOC" in order to return data (catalog sources/list of images) only inside the MOC coverage.



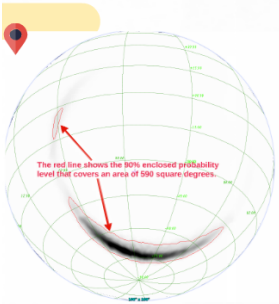


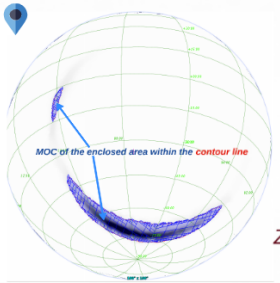
Each MOC cell is defined by two numbers: the hierarchy level (HEALPIX ORDER) and the pixel index (HEALPIX NPIX).
The NUNIQ scheme defines an algorithm for packing an (ORDER, NPIX) pair into a single integer for compactness:

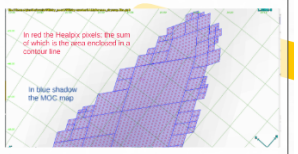
*uniq = 4 * (4**order) + npix*

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

MOC map of the enclosed area within a given probability level







Zoom

LALInference skymap of GW 150914

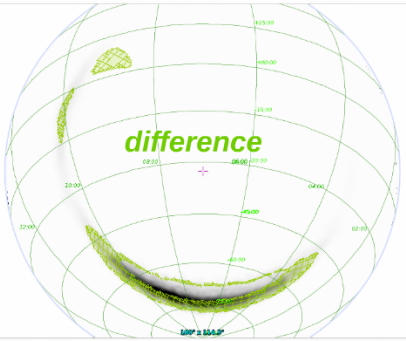
The enclosed area within a given probability level of a GW skymap can be effectively described through the Multi-Order Coverage (MOC) method.

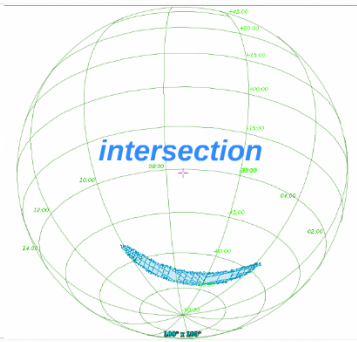
Why using MOC?

MOC operation: Union, Intersection, Subtraction, Difference

Example

Difference and intersection between the cWB and LALInf skymaps of GW 150914.



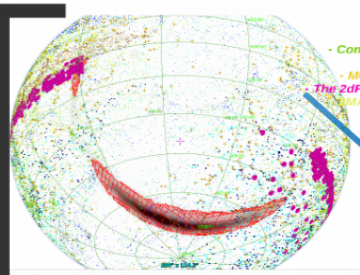


Why using MOC?

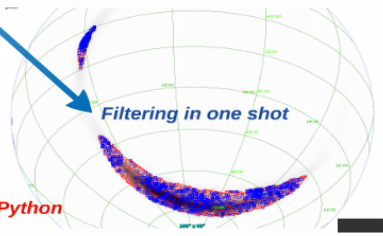
FIltering by MOC the CDS Catalogues in few ms

Example

We filter the objects inside the 90% area of credible level of the LALInference skymap of GW 150914

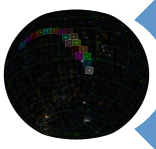


- Gravitational Wave Galaxy Catalogue (White+ 2011)
- Compact Binary Coalescence Galaxy Catalog (Kopparapu+, 2008)
- Rich Clusters of Galaxies (Abell+ 1989)
- MCXC Meta-Catalogue X-ray galaxy Clusters (Piffaretti+, 2011)
- The 2dF Galaxy Redshift Survey 100k Data Release (2dFGRS Team, 2001)
- 2MASS-selected Flat Galaxy Catalog (2MFGC) (Mitronova+, 2004)
- Galaxy groups and clusters from SDSS (Berlind+, 2006)

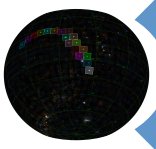


Using Aladin GUI or mocpy module in Python

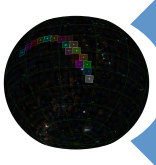
In Progress



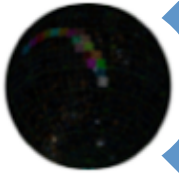
Weight the pointings using galaxy priors, reference images, GW candidate distance



Multi-order Coverage (MOC) map for rapid skymap counts, to compare different skymaps and to rapidly filter galaxy and transients catalogs.



Manage 3D skymap (volume probability distribution) Singer et al. 2016 arXiv:1603.07333



Expected magnitude for the different models taking into account distance and time delay from the GW time

Galaxy priors to identify the likely host galaxies

Next LIGO and Virgo observations run

- The current MoUs will end in June 2017
- **Open release of high-confidence events (FAR < 1 per 100 yr):** after 4 published GW significant events, *O3 open release?*
- Current FAR threshold to send alert: FAR < 1/month
  For FAR higher than 1 per 100 yr MoU regime?

Alert contents:

- Distance for CBC and burst (with emitted E_{GW} assumption), system-type flag, mass?
- 3D skymaps?
- Latency for initial and updates

Under discussion among LVC

Astronomers suggestions?