The Dawn of Multi-Messenger Astronomy

G. Greco, E. Chassande-Mottin, M. Branchesi and many others

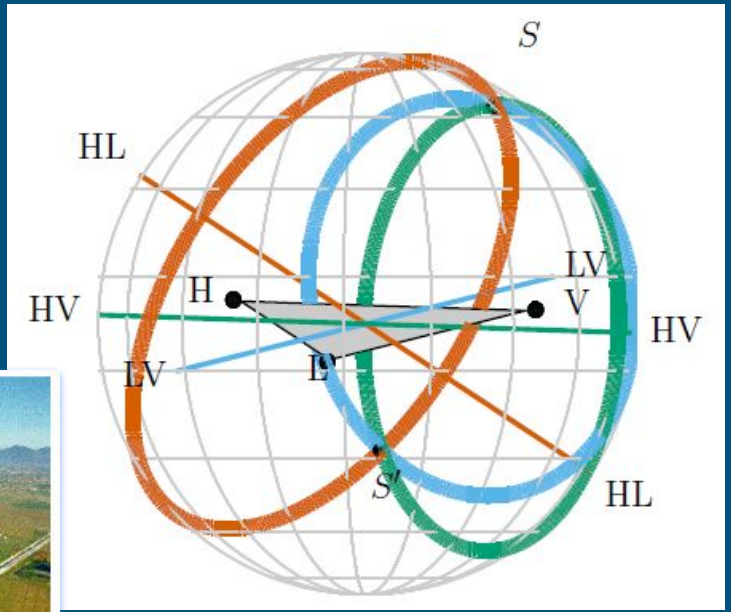
ASTERICS DADI ESFRI Forum & Training Event 2, Trieste

GW170814: A Three-Detector Observation of Gravitational Waves from a Binary Black Hole Coalescence

B. P. Abbott *et al.* (LIGO Scientific Collaboration and Virgo Collaboration)
Phys. Rev. Lett. **119**, 141101 – Published 6 October 2017

Physics See Focus story: Three-Way Detection of Gravitational Waves

- Source localization using only timing for a two-site network yields an annulus on the sky (signal amplitude, spin, and precession effects resolve this to only parts of the annulus).
- For three detectors, the time delays restrict the source to two sky regions which are mirror images with respect to the plane passing through the three sites.



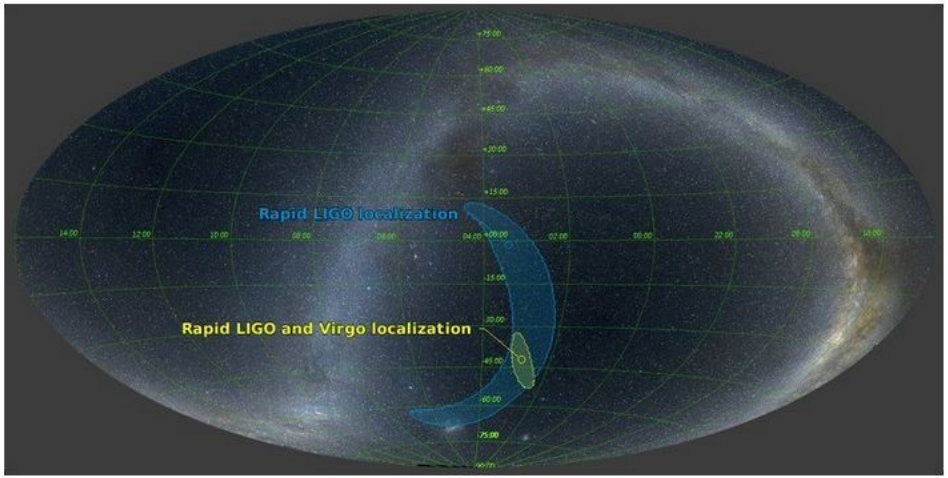
Abbott et al. 2016, Living Rev. Relativity 19, 1

The New York Times

SCIENCE

New Gravitational Wave Detection From Colliding Black Holes

By DENNIS OVERBYE SEPT. 27, 2017



The LIGO and Virgo detectors in the United States and Europe identified gravitational waves emitted by the
holes 1.8 billion light years away. The location of the black holes in the night skies is
p. LIGO/Virgo

RELATED COVERAGE

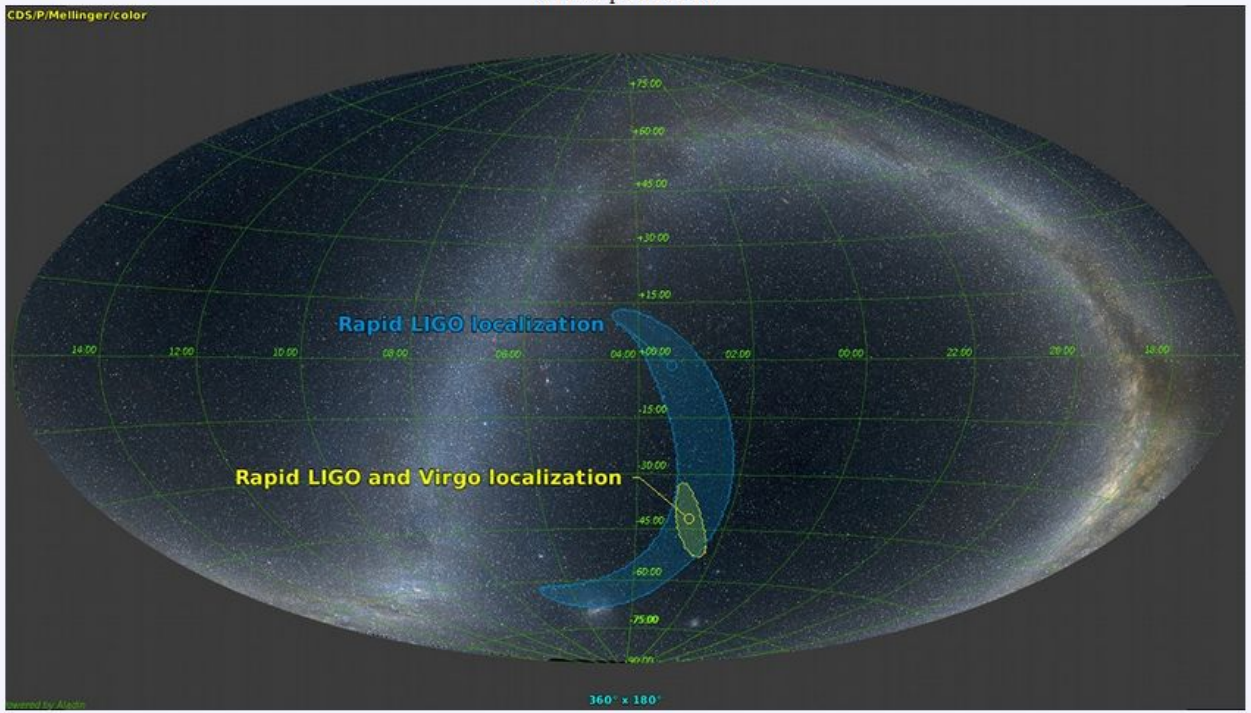
Third Gravitational Wave Detection, From Black-Hole Merger 3 Billion Light Years Away JUNE 1, 2017

Press Statement from Dr. France A. Córdova at G7 Science Ministerial Meeting

Astronomy Picture of the Day

Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

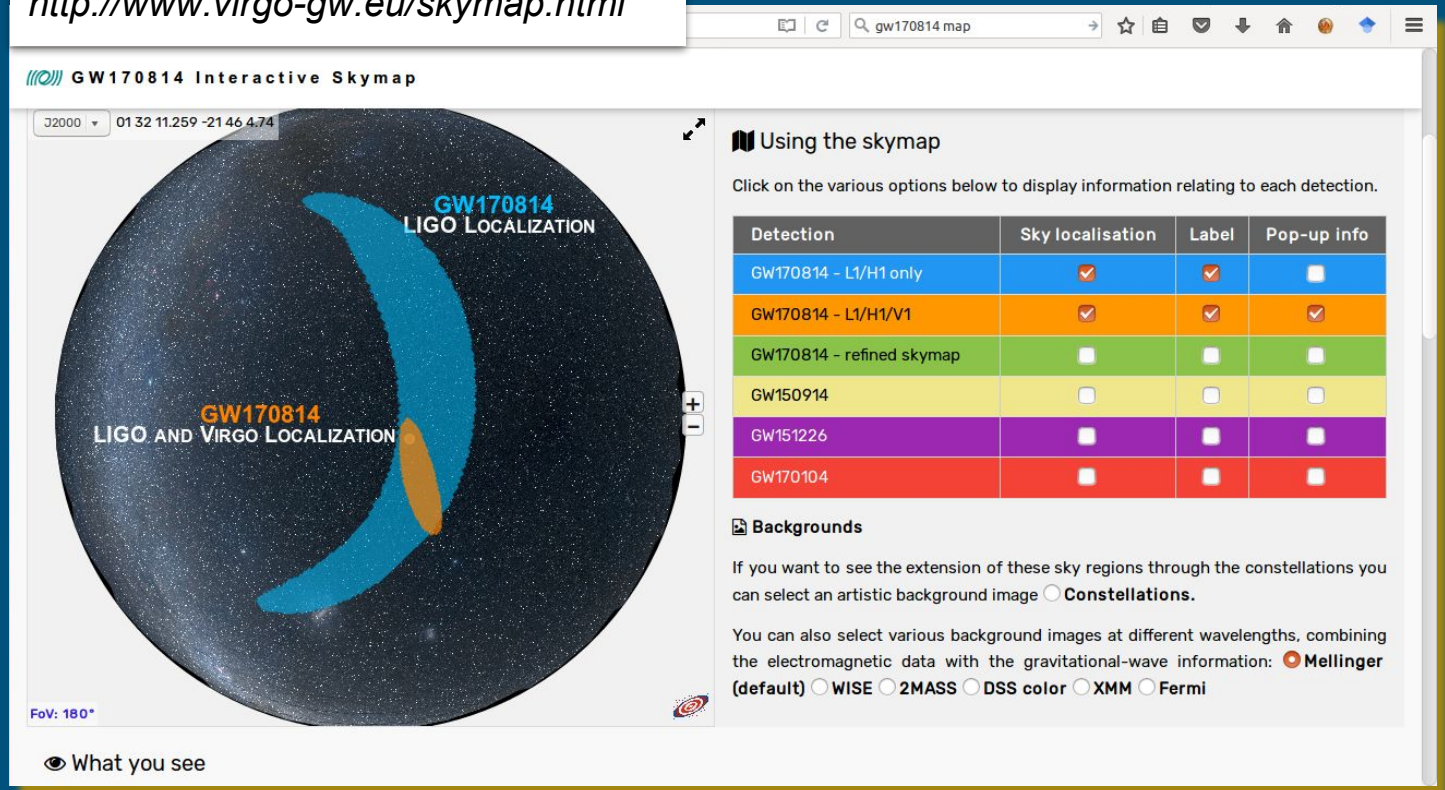
2017 September 28



LIGO-Virgo GW170814 Skymap
Illustration Credit: LIGO- Virgo Collaboration - Optical Sky Data: A. Mellinger

Welcome to the era of multimessenger astronomy with a network of advanced interferometers!

http://www.virgo-gw.eu/skymap.html



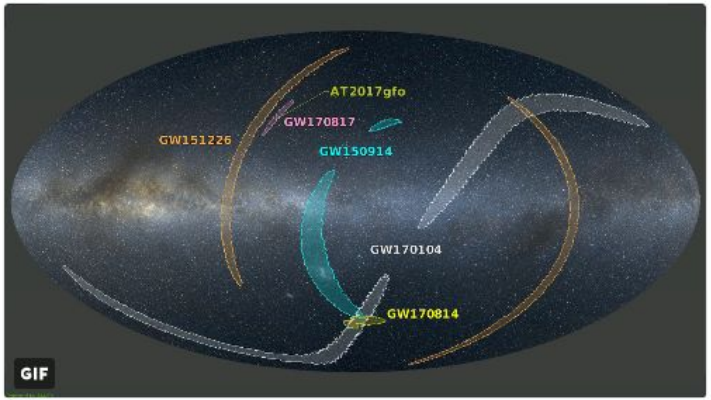
For more information, please contact the Education and Public Outreach (EPO): ***outreachteam_at_ego-gw.it***

LIGO
@LIGO

Siguiendo

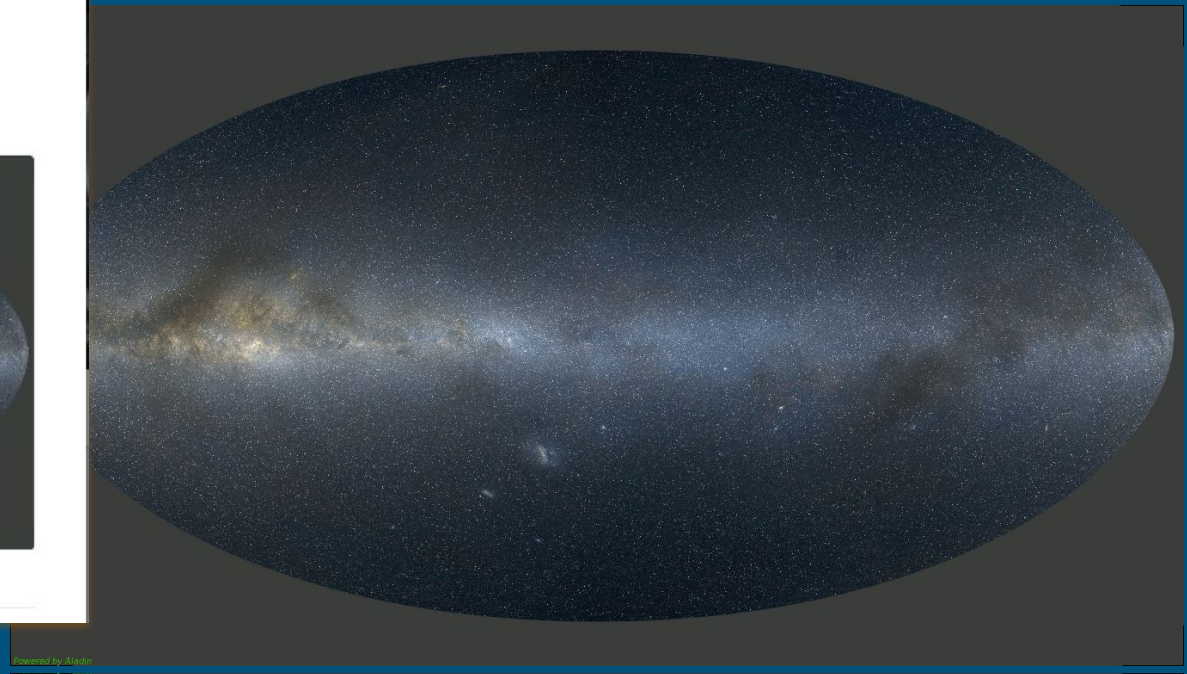
Watch how GW astronomy improves sky location of sources. @LIGO & @ego_virgo together point very well! #GW170814 #GW170817

Traducir del inglés



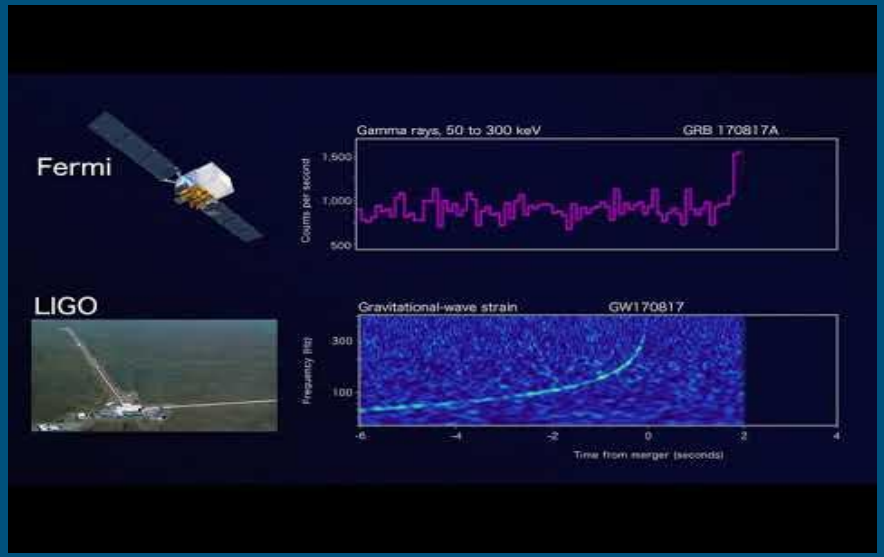
12:30 - 16 oct. 2017

Tweets	Siguiendo	Seguidores	Me gusta	Listas
3.649	165	74 K	1.095	1

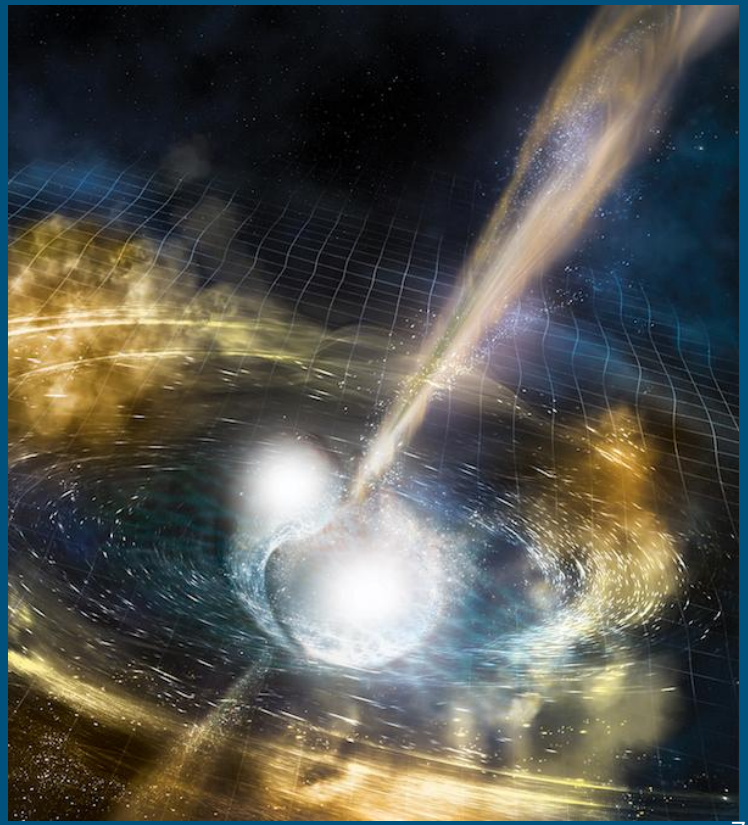


GW170817 - The first observation of gravitational-waves from a binary neutron star inspiral

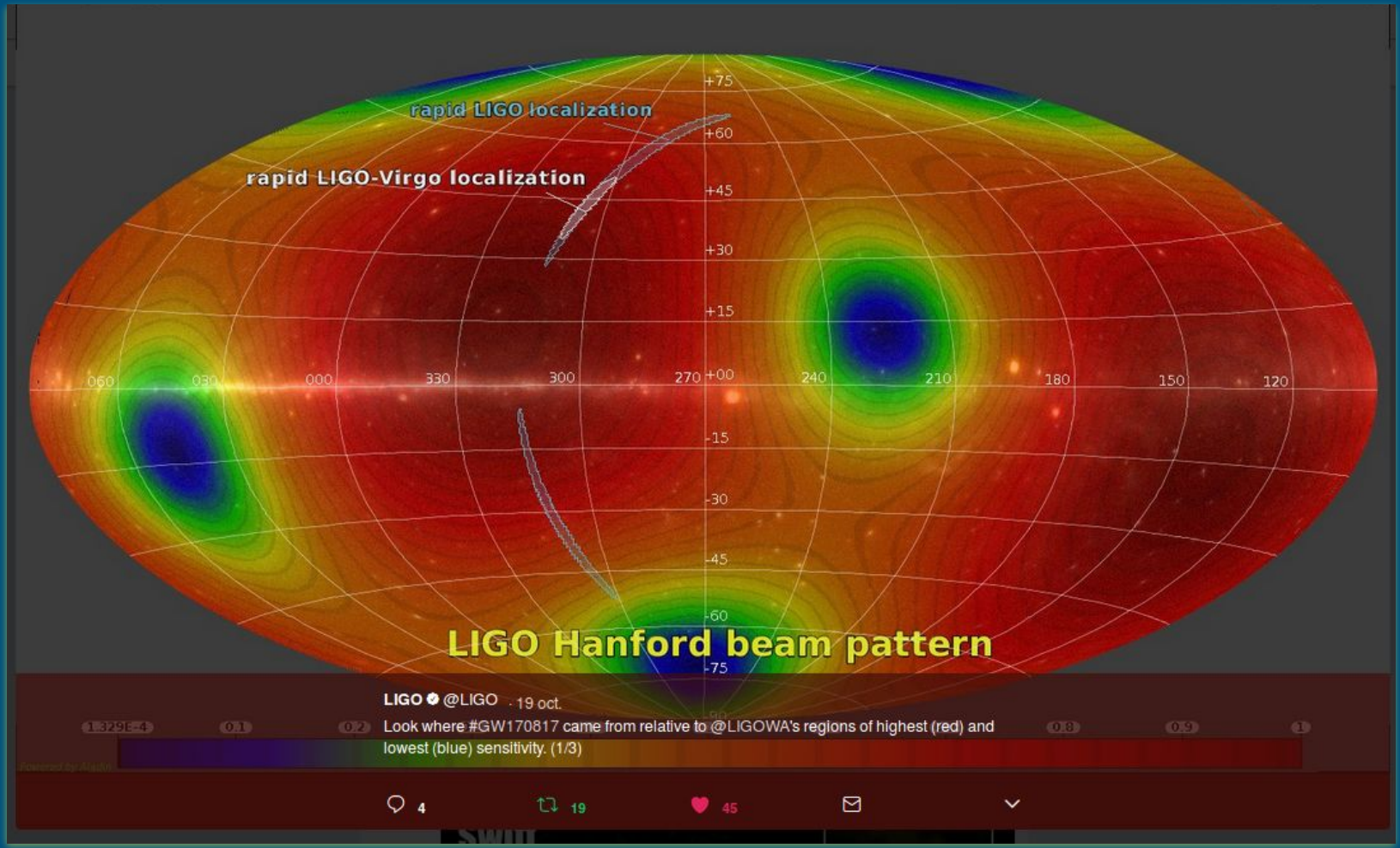
GW170817 marks a new era of multi-messenger astronomy, where the same event is observed by both gravitational waves and electromagnetic waves.



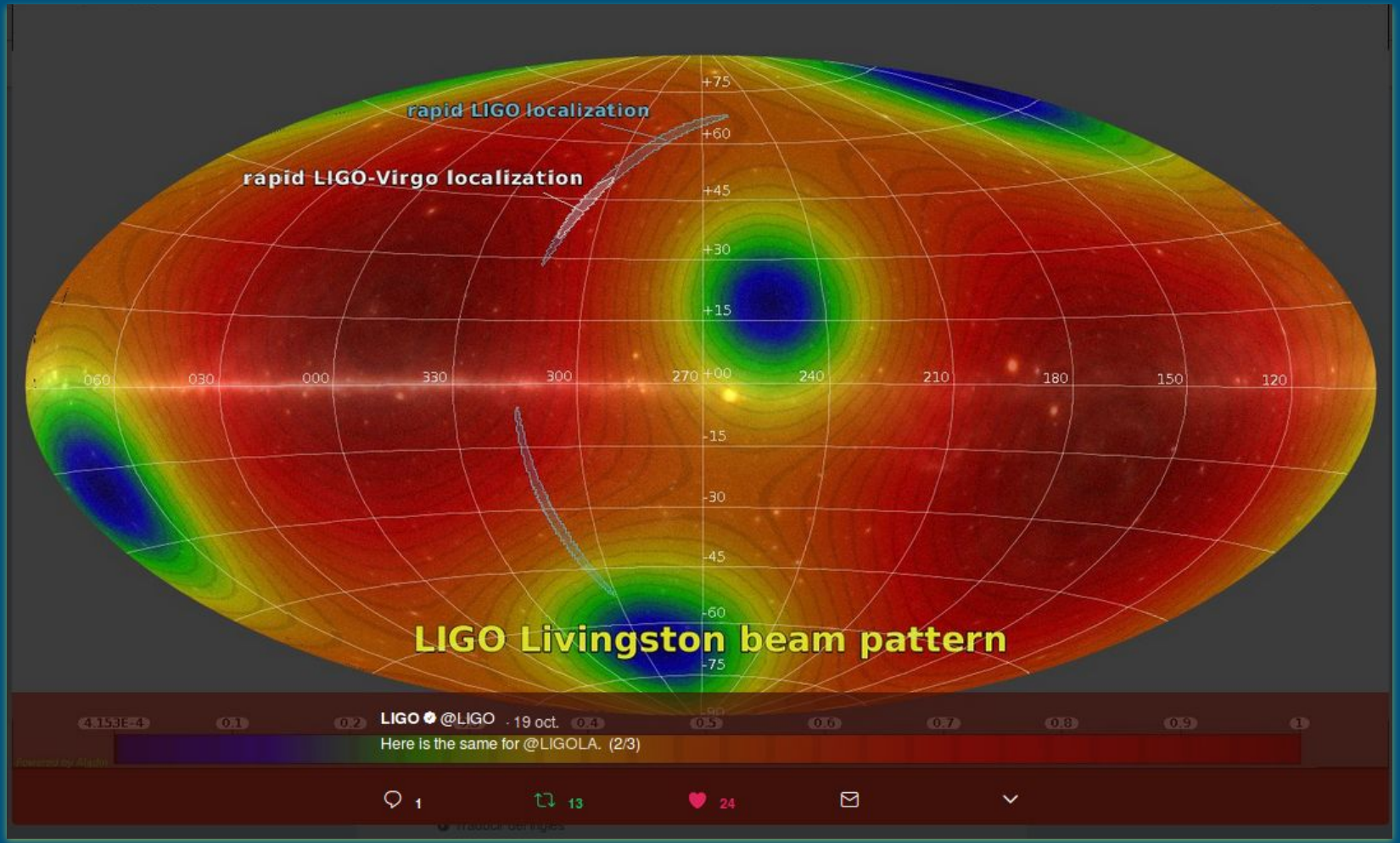
Credit: NASA GSFC & Caltech/MIT/LIGO Lab

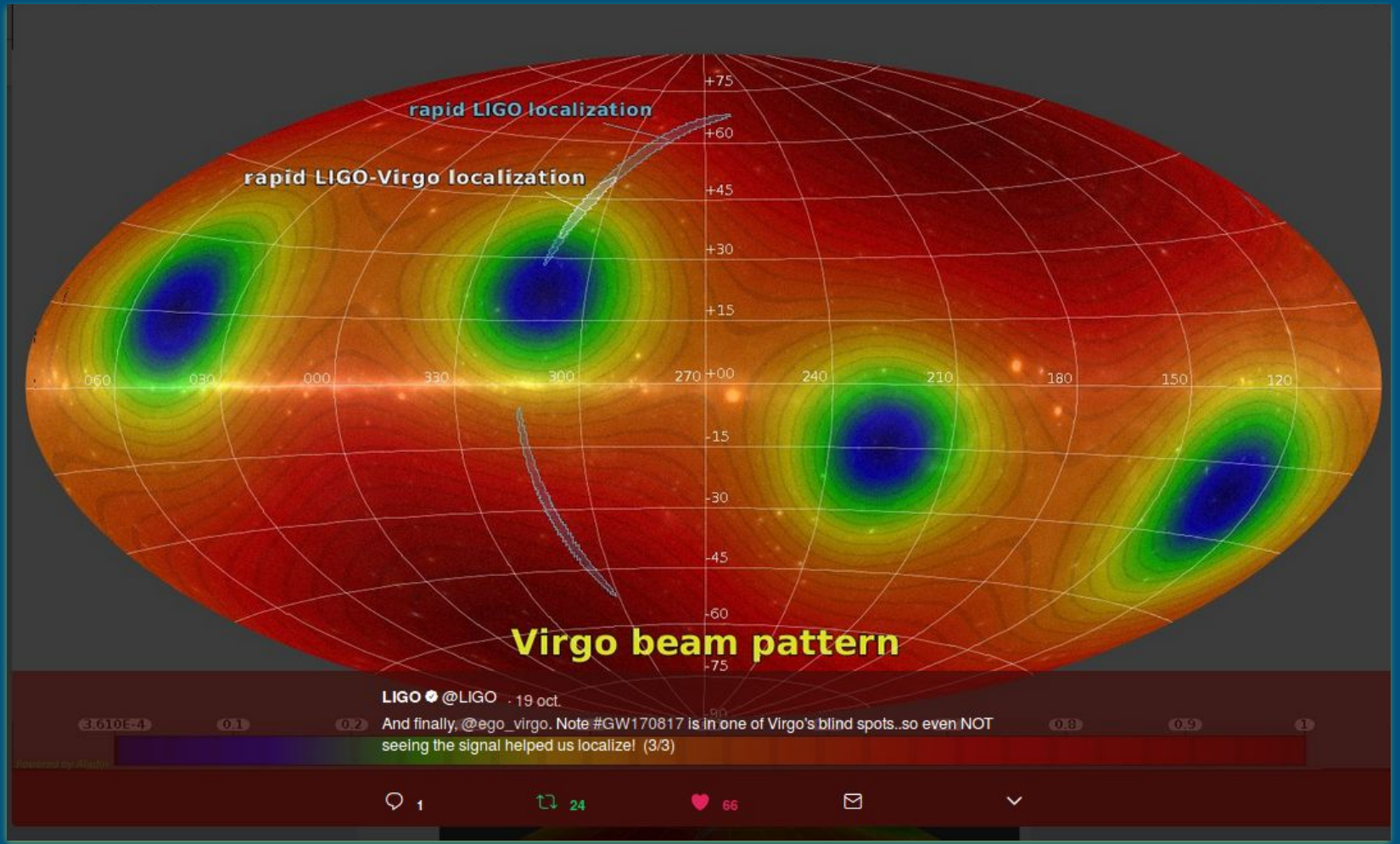


Credit: NSF/LIGO/Sonoma State University/A. Simonne

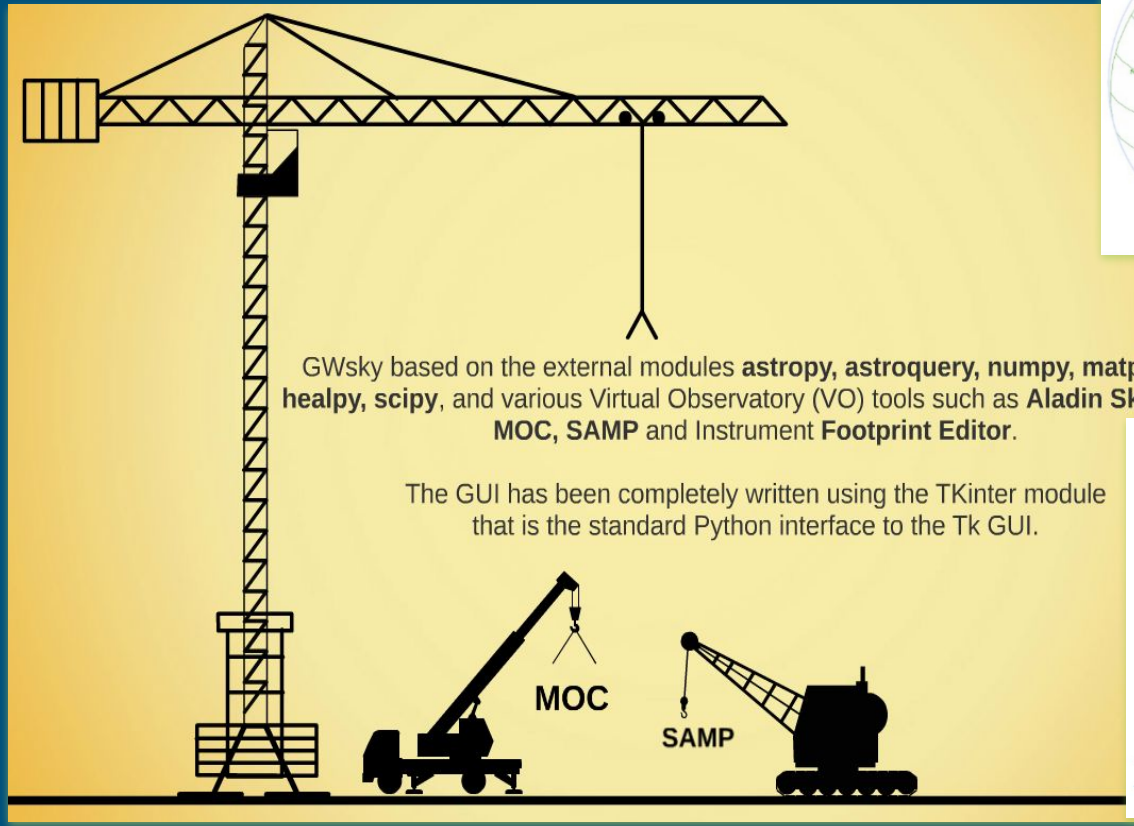


The sensitivity increases from blue to red


rapid LIGO localization
rapid LIGO-Virgo localization
+75
+60
+45
+30
+15
+00
-15
-30
-45
-60
-75
060
030
000
330
300
270
240
210
180
150
120
LIGO Livingston beam pattern
LIGO @LIGO · 19 oct.
Here is the same for @LIGOLA. (2/3)
1
13
24

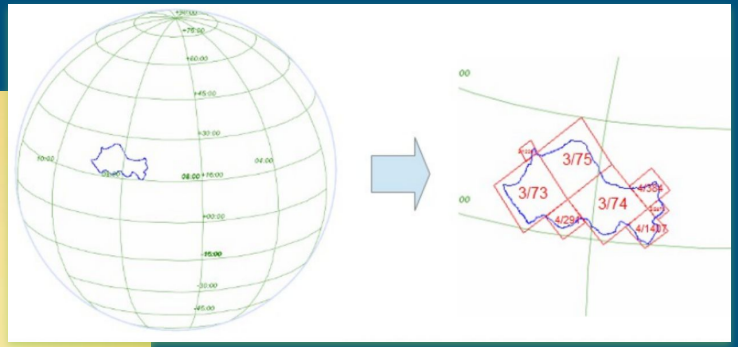

rapid LIGO localization
rapid LIGO-Virgo localization
Virgo beam pattern
LIGO @LIGO · 19 oct.
And finally, @ego_virgo. Note #GW170817 is in one of Virgo's blind spots..so even NOT seeing the signal helped us localize! (3/3)
1
24
66

GWsky: basic algorithms

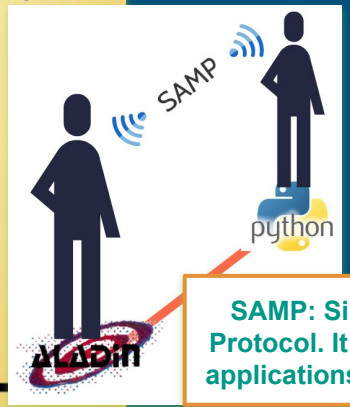


GWsky based on the external modules **astropy, astroquery, numpy, matplotlib, healpy, scipy**, and various Virtual Observatory (VO) tools such as **Aladin Sky Atlas, MOC, SAMP** and Instrument **Footprint Editor**.

The GUI has been completely written using the TKinter module that is the standard Python interface to the Tk GUI.



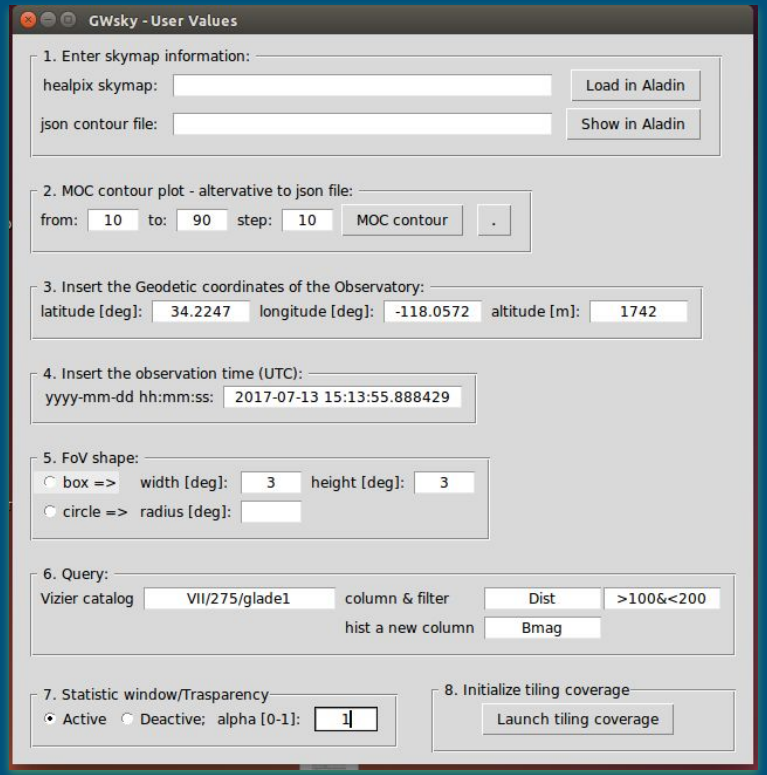
To map irregular and complex sky regions into hierarchically grouped predefined cells.
Based on the HEALPix tessellation algorithm
Gorski et. al 2005, ApJ 622, 759.



MOC, SAMP and HiPS are approved by IVOA standards.

SAMP: Simple Application Messaging Protocol. It is a protocol for astronomical applications to collaborate (DS9, TopCat).

GWsky: basic architecture



UserValues generates the initialization files getting inputs from an user.

Coverage opens a small window placed on top of the Aladin Sky Atlas.

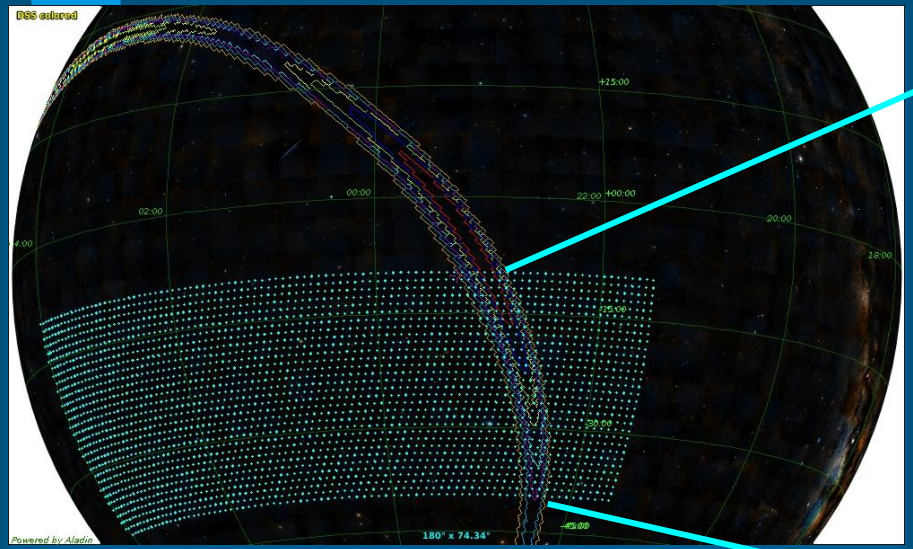
The Aladin plans are collected in specific **Folders.**

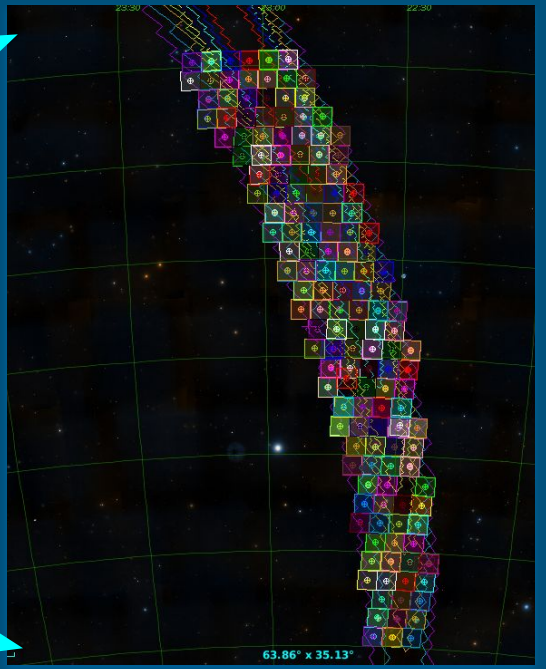
GWsky@work

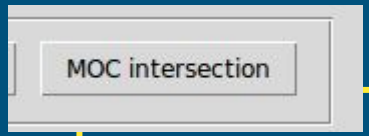
- Contour plot generation
- Skymap Tiling
- Source localization
- Observability
- Reference image

GWsky: *intersection with VST surveys*

Filtering reference images for image subtraction

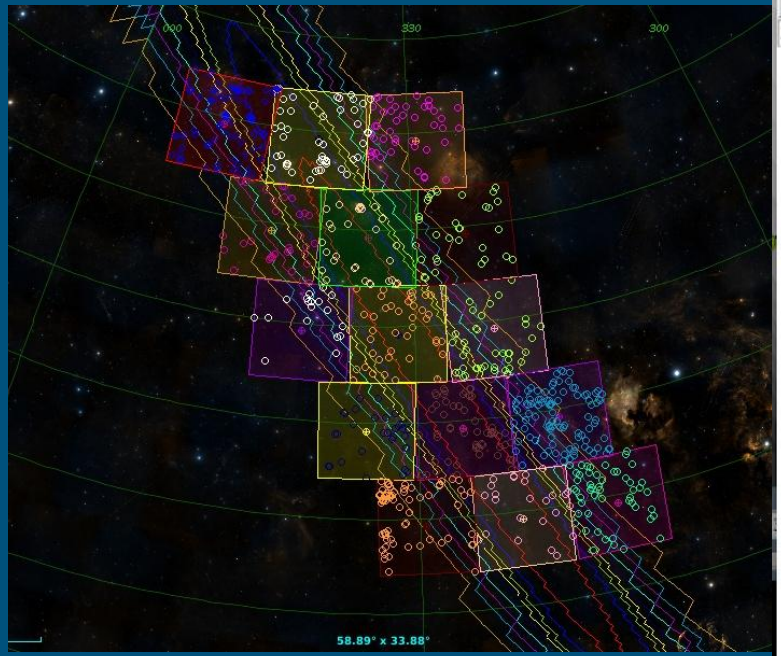




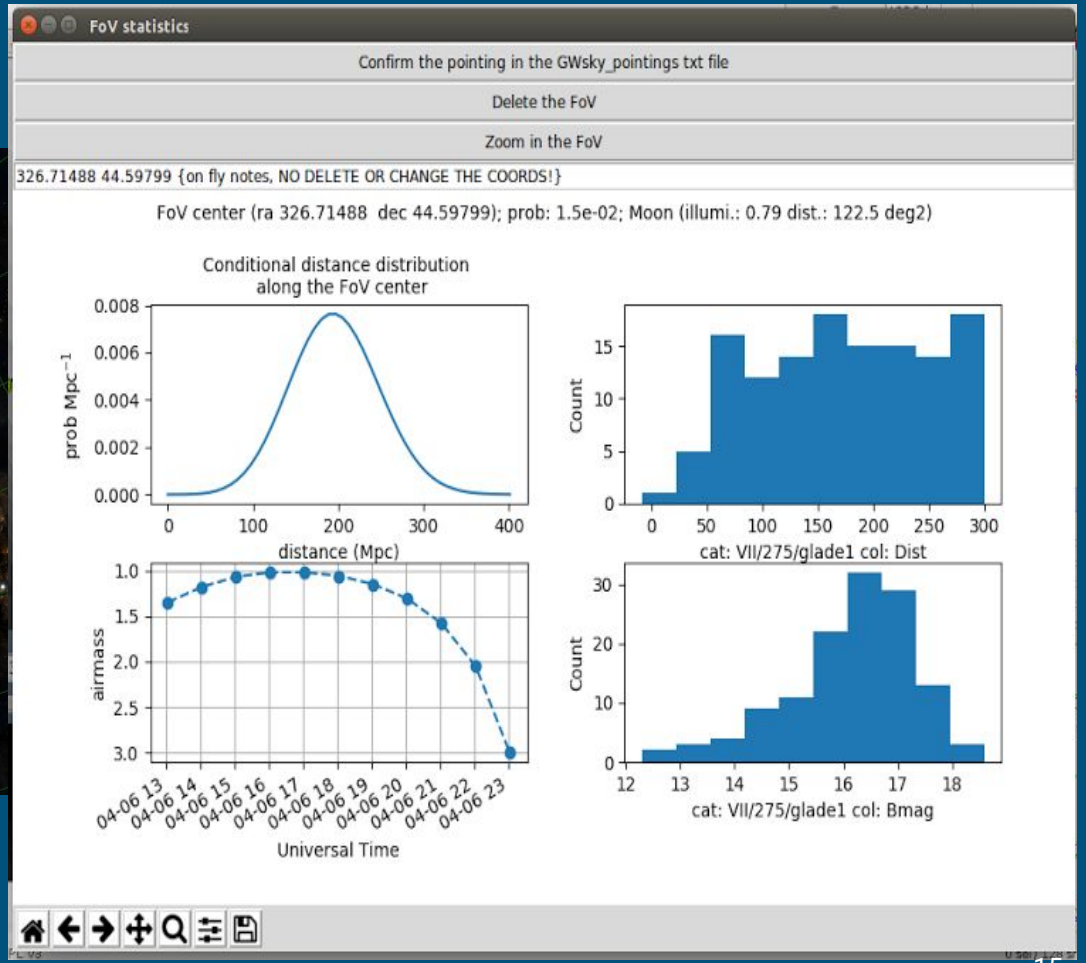


It shows the footprints of the archival VST data over the MOC contours of a probability skymap.

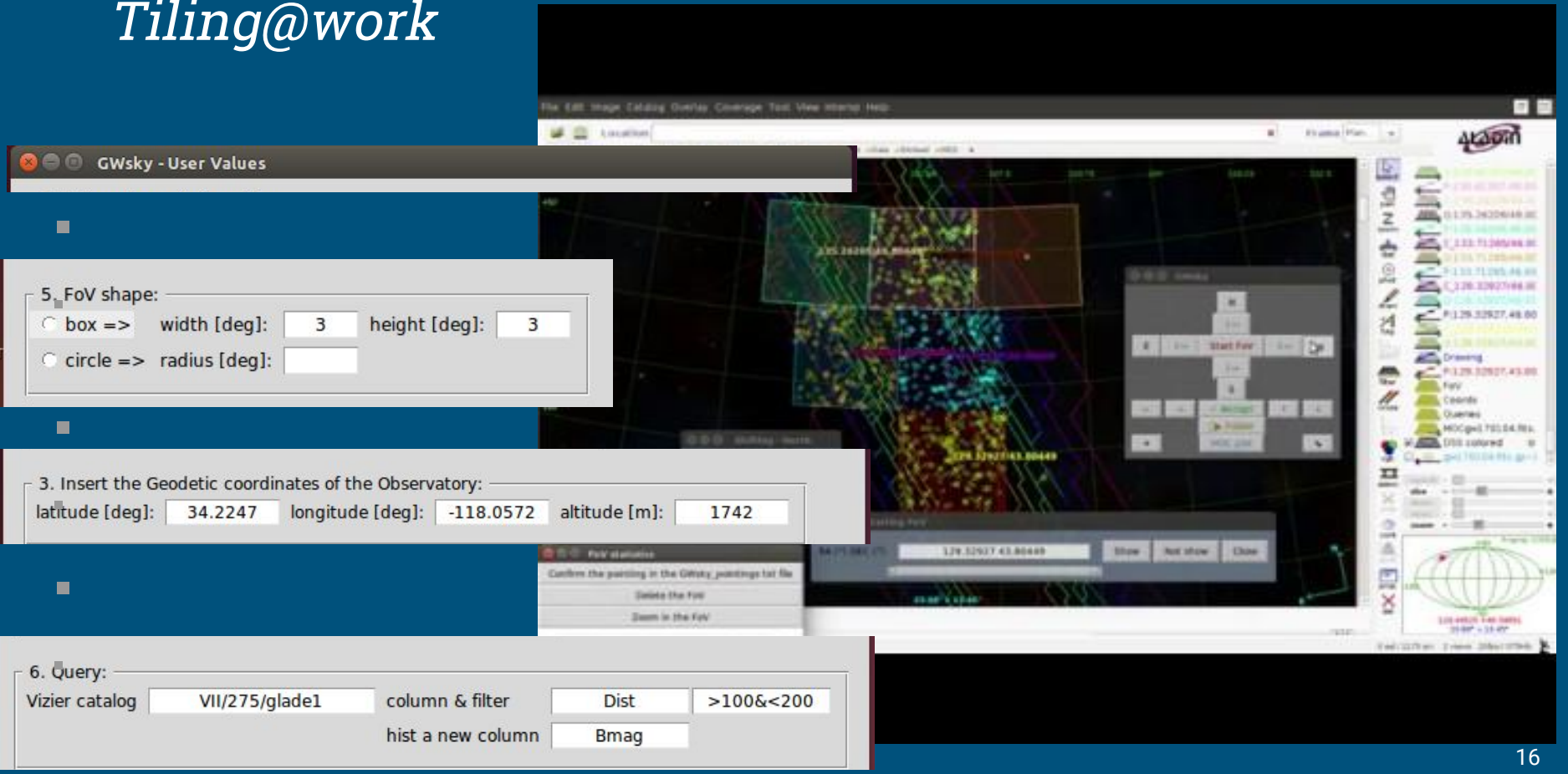
GWsky: *tiling*



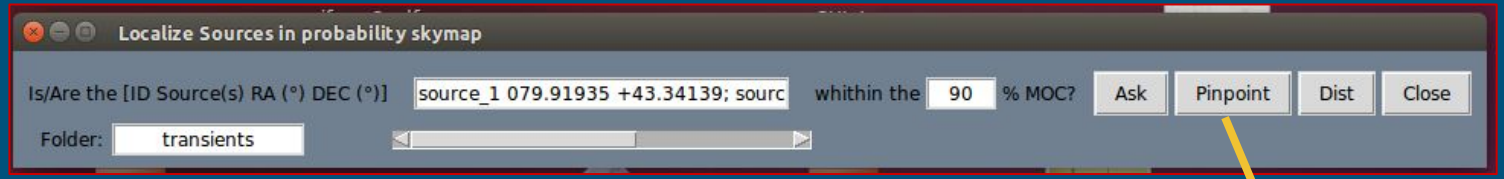
Each Field of View is accompanied by descriptive statistics to manage the sequence of pointings.



Tiling@work

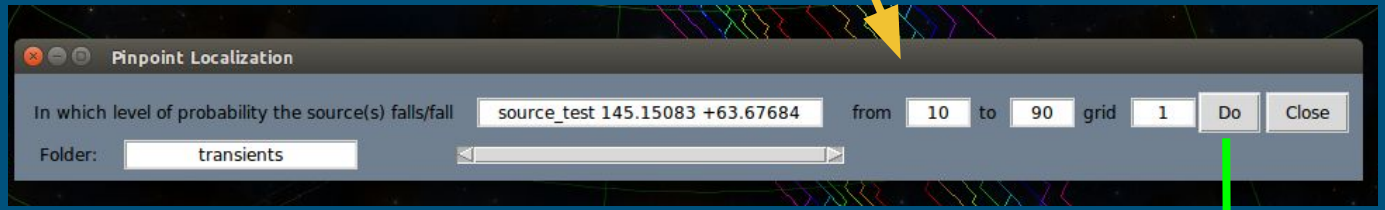

GWsky - User Values
5. FoV shape:
box =>
width [deg]:
3
height [deg]:
3
circle =>
radius [deg]:
3. Insert the Geodetic coordinates of the Observatory:
latitude [deg]:
34.2247
longitude [deg]:
-118.0572
altitude [m]:
1742
6. Query:
Vizier catalog
VII/275/glade1
column & filter
Dist
>100&<200
hist a new column
Bmag

Determining in which level of probability the source falls

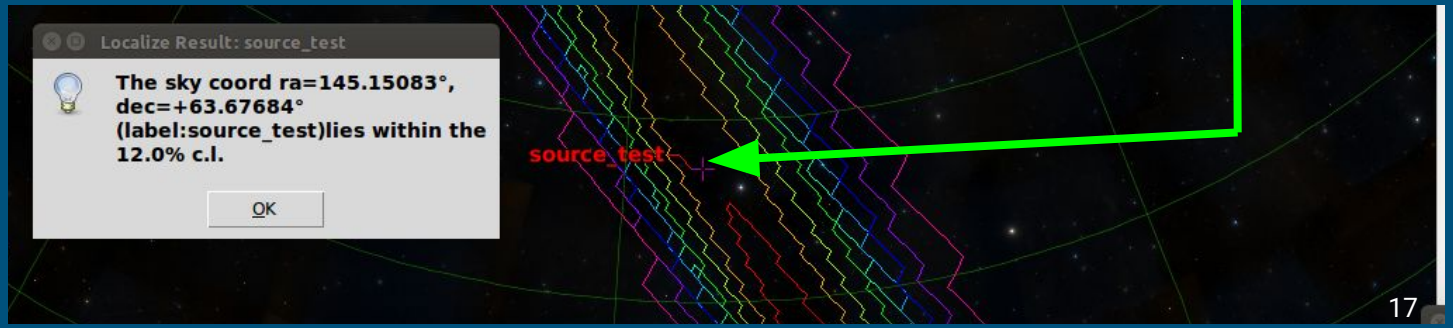


LocalizeSource *is designed to determine in which level of probability a source is localized.*

The localization accuracy *is improved with increasing the resolution (grid label).*



New folder ***List of transients*** ***selected c.l.***

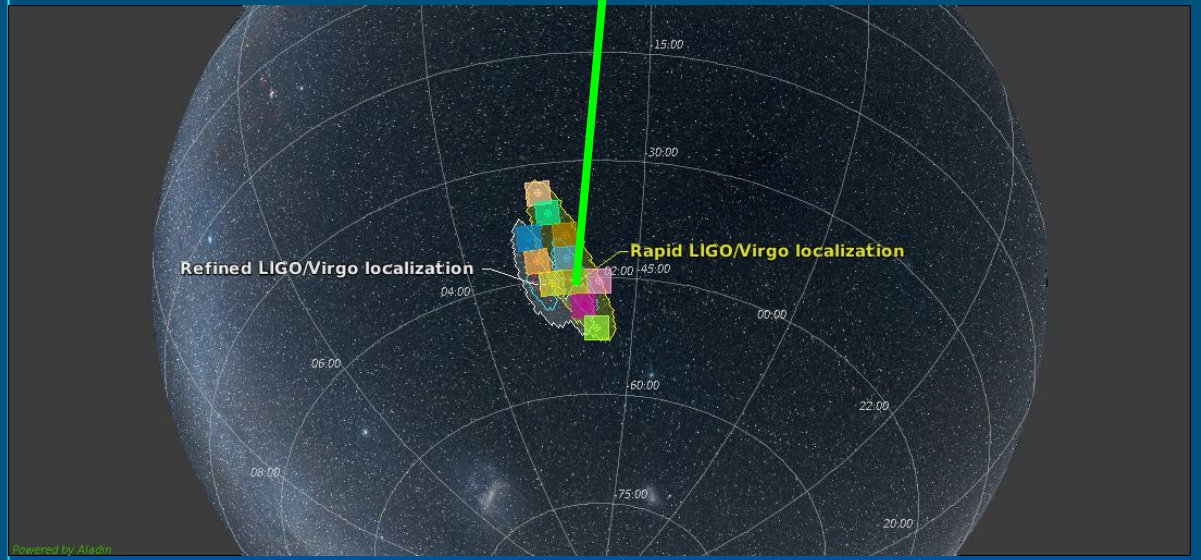


Future developments (I)

From FoV footprints to MOC

A function to convert a XML FoV in a MOC

- **fast computation of the integrated probability even in overlapping observations**



The pointing sequence is taken from GCN 21498 and GRAWITA paper in preparation

Future developments (II)

sampjs application

GWsky on line

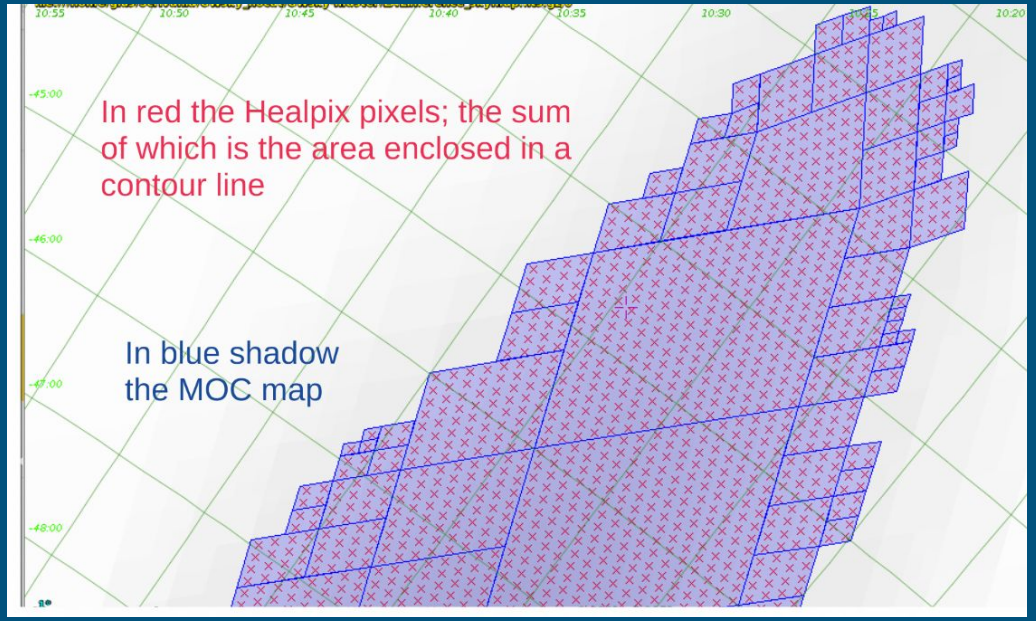
- **A dedicated web page to communicate with a local Aladin/TOPCAT application incorporating the main features of GWsky.**

- *sampjs is a small JavaScript library for using the SAMP Web Profile from within web pages - http://astrojs.github.io/sampjs/*

Main developers: S. Zorba, L. Rei and G. Greco

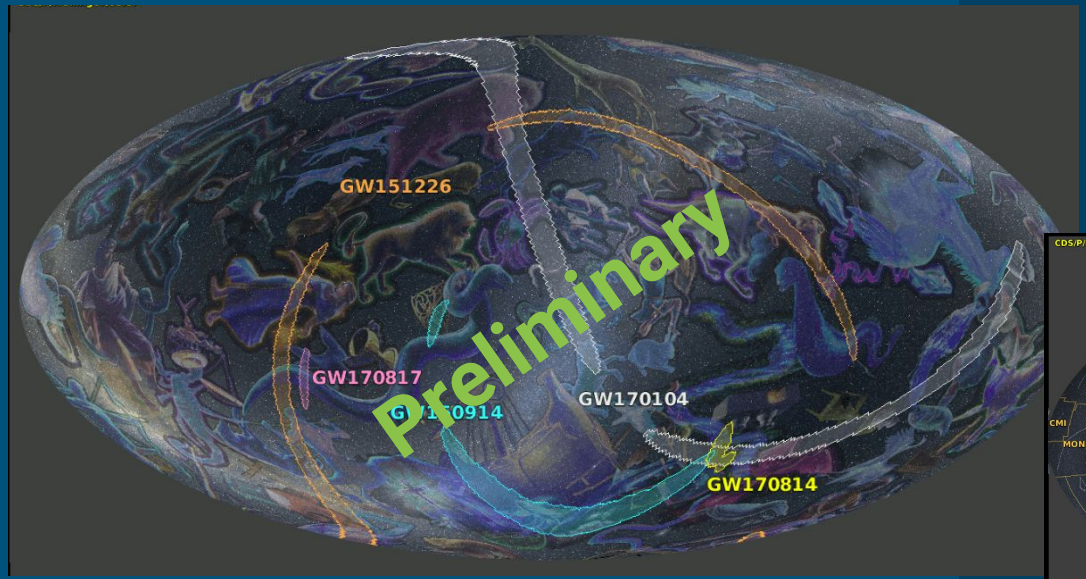
ISSUE

I. **The actual resolution of a sky localization map is too large (NSIDE=2048) for running the MOC in a normal pc!**
   A. **You need to sort the values in order to scan the higher elements. If your memory cannot contain all your values, the sort can not be done easily and the time of computation explodes.**

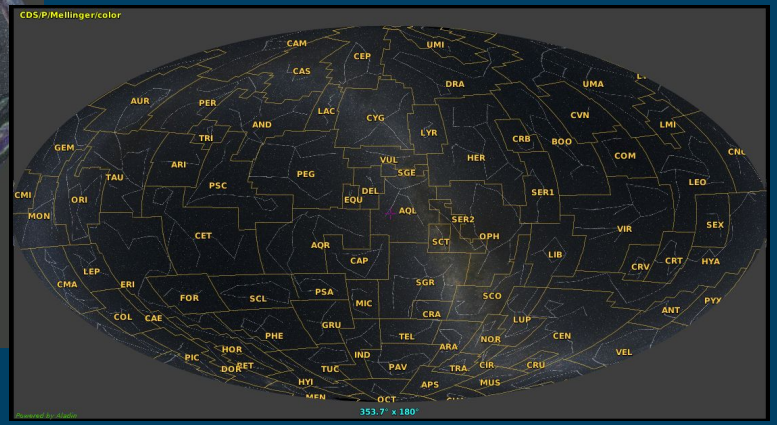


Need to develop a new algorithm!

An interactive game: which constellations a GW skymap crosses?



- Users should choose from a set of constellations which are crossed by a selected skymap.
- Using Aladin Lite and EXELEARNING application.
- Extraction of the boundary constellation as MOC/polygon plane to show interactively the answer.



Thanks