Interoperable multi-messenger approach for GW sky localization and EM follow-up

practical tools and methods supported by the ESCAPE project

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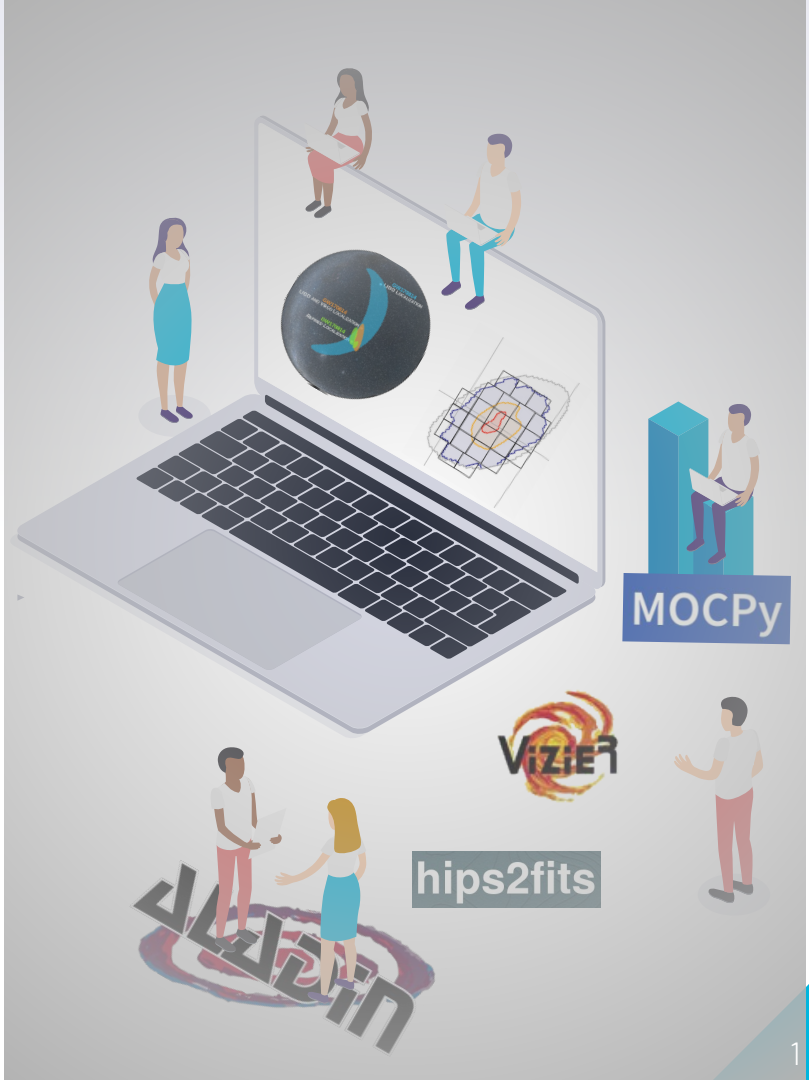
for ESCAPE/CEVO

ESA/ESO SCIOPS 2019 WORKSHOP

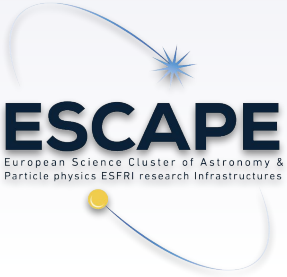
ESCAPE
European Science Cluster of Astronomy & Particle physics ESFRI research Infrastructures

EGO - Virgo



ASTERICS and ESCAPE

The inclusion of the data of the ESFRI facilities from astronomy and astroparticle physics in the VO is already well advanced thanks to the collaboration between ESFRI pathfinders and European VO teams in the ASTERICS Data Access, Discovery and Interoperability (DADI) Work Package since 2015.



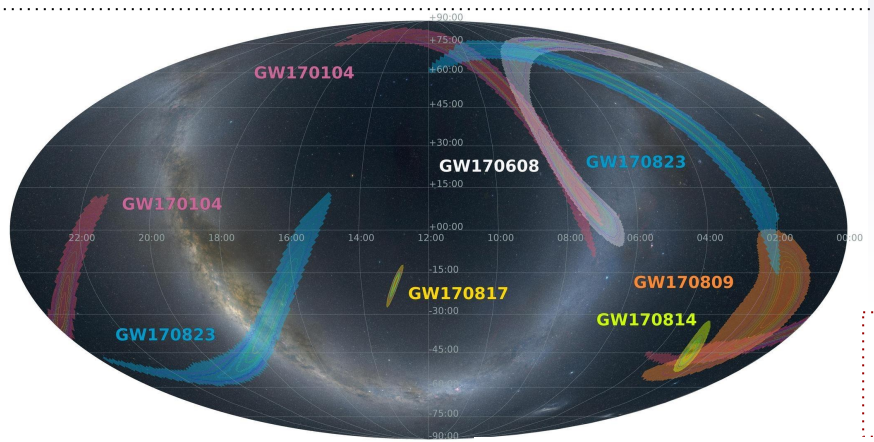
ESCAPE is a project supported by the European Commission Framework Programme Horizon 2020 Research and Innovation programme of the European Union. The ESCAPE project will address the challenges in open science and data accessibility faced by European researchers.

Work Package 4 of ESCAPE, "Connecting ESFRI (European Strategy Forum on Research Infrastructures) projects to EOSC (European Open Science Cloud) through VO framework". CEVO plans to make the seamless connection of ESFRI and other astronomy and astroparticle research infrastructures to the EOSC through the Virtual Observatory framework.

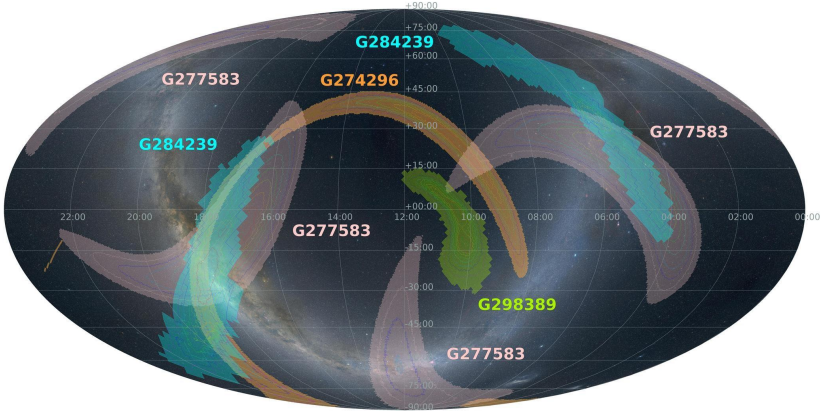
Low Latency campaign in O2

14 alerts were distributed and 6 events were declared as confident GW events.

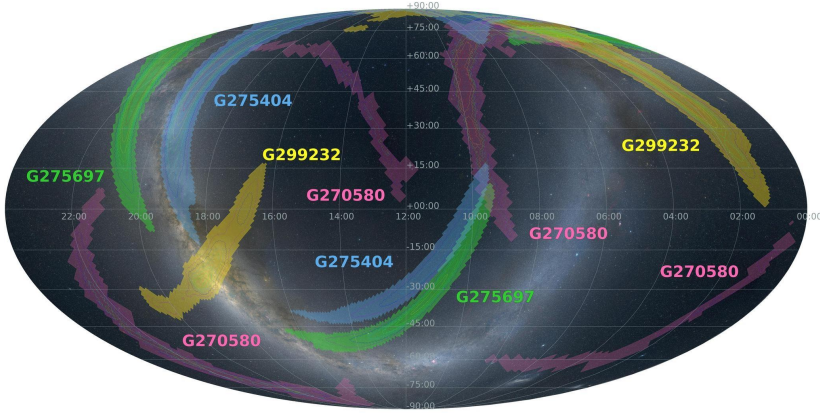
GW confident events



GW candidates



Marginally significant GW triggers



Multi Order Coverage Map

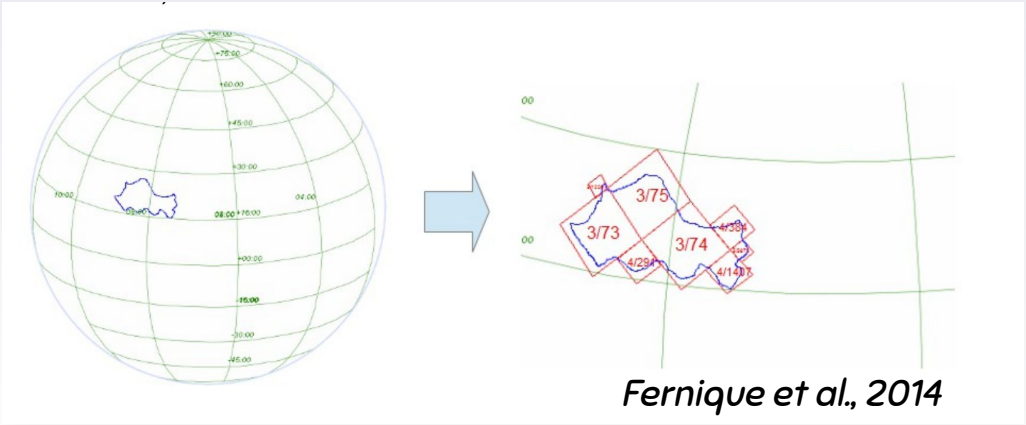
- The **MOC** data structure is based on the **HEALPix** (Hierarchical Equal Area isoLatitude Pixelation) tessellation (Gorski et. al 2005) to map irregular and complex sky regions into hierarchically grouped predefined cells.
- The operations between the MOC maps (union, intersection, subtraction, difference) are very fast even for very complex regions.
- 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.**

MOC Basic Algorithm

Each MOC cell is defined by two numbers: the hierarchy level (HEALPix *order*) and the pixel index (HEALPix *ipix*).

The NUNIQ scheme defines an algorithm for packing an (*order*, *ipix*) pair into a single integer for compactness:

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



Fernique et al., 2014

A MOC can thus be represented as a flat list of integers (in this example, 8 of them) and stored in a single-column FITS table.

GW Sky localization area is the confidence region that encloses a given percentage of the localization probability.

MMA Section

A live demo at the end of presentation

Asterics DADI Tutorial

https://www.asterics2020.eu/tutorials/overview

Fourth ASTERICS School

International Virtual Observatory school

Observatoire Astronomique de Strasbourg, France

DADI: Data Access Discovery and Interoperability

Electromagnetic follow-up of gravitational-wave events

by G. Greco giuseppe.greco@uniurb.it, E. Chassande-Mottin ecm@apc.univ-paris7.fr and M.Branchesi marica.branchesi@gmail.com and many others

1. Working with the sky localizations of GW150914, GW151226 and GW170104

The probability sky maps are produced using a sequence of algorithms with increasing accuracy and computational cost. Here, we compare three location estimates: the prompt cWB and/or the rapid BAYESTAR localizations that were initially shared with observing partners and the final localization from LALInference.

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

GW170814 is the fourth published detection of gravitational waves. As was the case with the first three published detections, the waves were generated by the coalescence of a pair of stellar-mass black holes. When we compare its position reconstruction in the Universe with the previous events, the sky localization of GW170814 is the narrowest. This new and exciting result was reached through a triple-coincident detection, coordinated by a body of more than 1,000 international scientists forming

3 VST tiling of GW170814

You are at ESO-Paranal Observatory in Chile and your team are planning to observe the LIGO and Virgo trigger G297595 (confirmed as GW170814), with the VLT Survey Telescope (VST) equipped with OMEGACAM. The observations are divided in 9 regions - 3° x 3° - centered on the following coordinates RA, Dec (ICRSd):

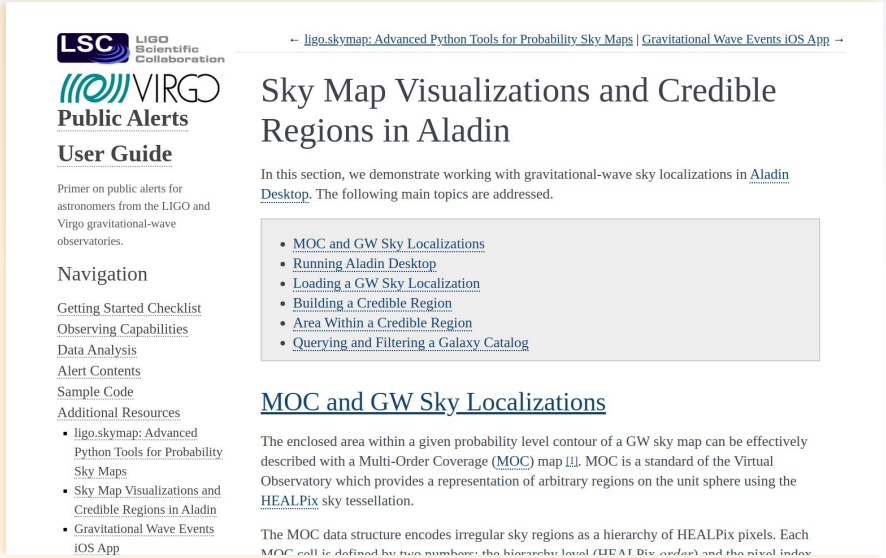
4. GW 170817: sky localizations of the *golden binary*

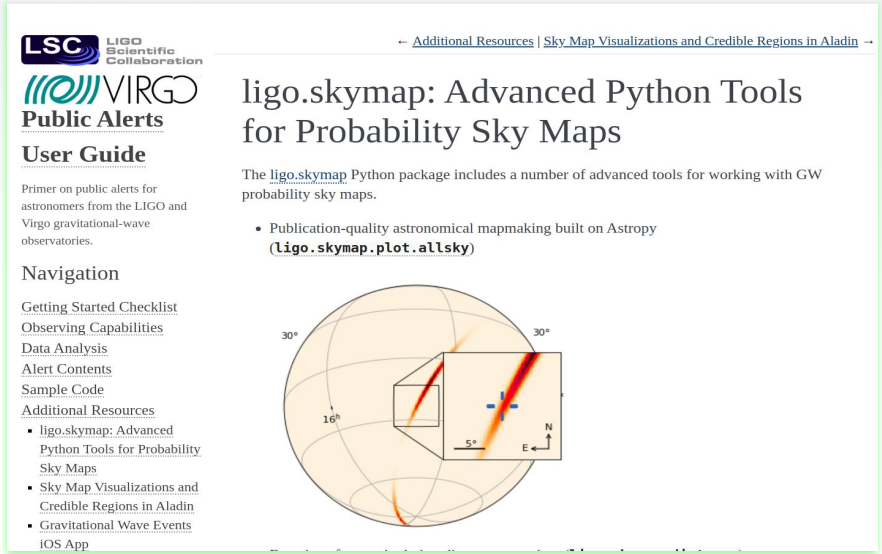
Fig.7 shows the localization of the gravitational-wave, gamma-ray, and optical signals. The left panel shows a projection of the 90% credible regions from LIGO (light green), LIGO-Virgo (dark green), triangulation from the time delay between Fermi and INTEGRAL (light blue), and Fermi GBM (dark blue). The inset shows the location of the apparent host galaxy NGC 4993 in the Swope optical discovery image at 10.9 hours after the merger (top right) and the DLT40 pre-discovery image from 20.5 days prior to merger (bottom right).

5 Verrecchia et al., in preparation: An AGILE Science Case: using MOC within AGILE procedure

An AGILE Science Case of interface between L-V GW skymap with AGILE data to look for gamma-ray counterpart to GW event.

LIGO and Virgo User Guide





- *ligo.skymap* mainly developed by Leo Singer.
- We discussed a merge request to create credible regions using the MOC data structure for interoperability. MOCpy module will be used.

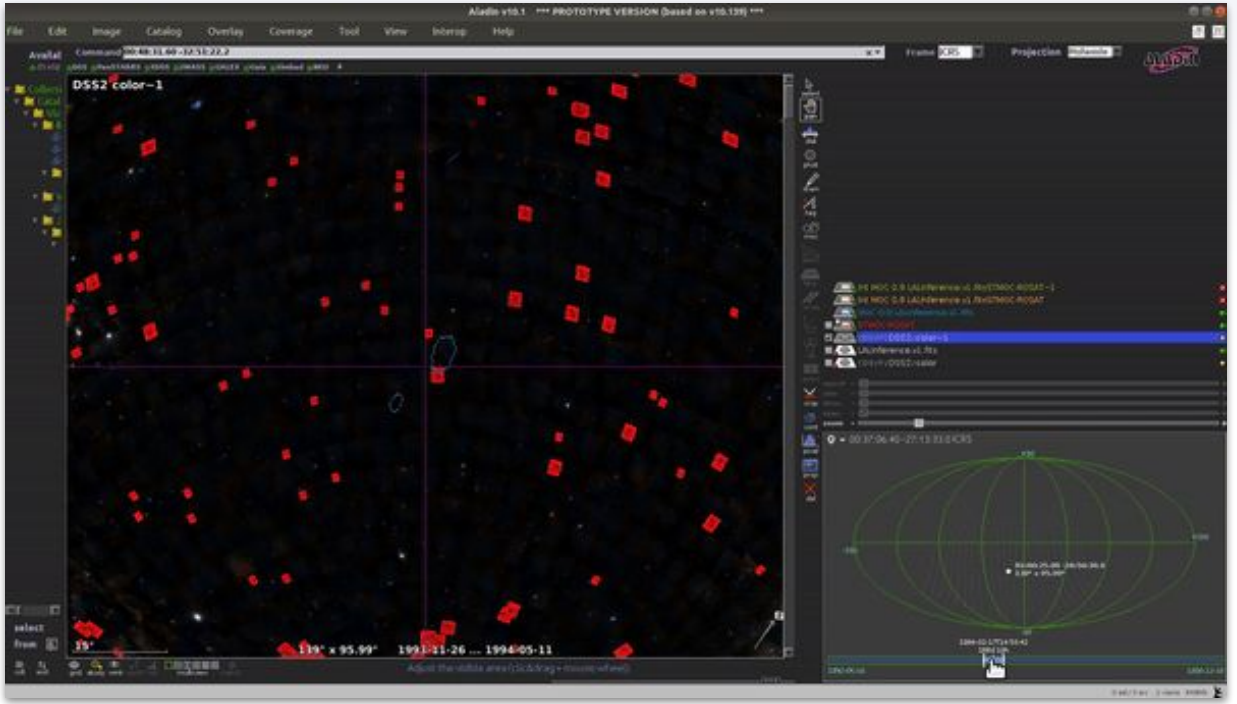
SpaceTime MOC

http://www.ivoa.net/documents/stmoc/20190515/NOTE-stmoc-1.0-20190515.pdf

SpaceTime of GW sky localizations

The next Aladin releases will provide the GW credible regions in the space-time MOC data format.

- FIltering EM candidates according with the trigger time reported in the image header.
- Space-time intersection with the existing surveys.



TimeSpace MOC to have simultaneously space and time coverage.

In progress

HIPS2FITS

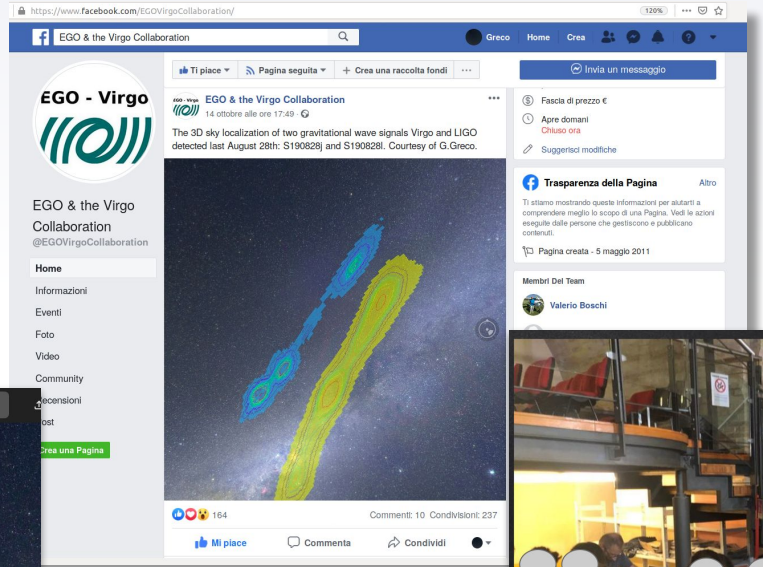
- https://alasky.u-strasbg.fr/hips-image-services/hips2fits

HiPS : Hierarchical Progressive Surveys

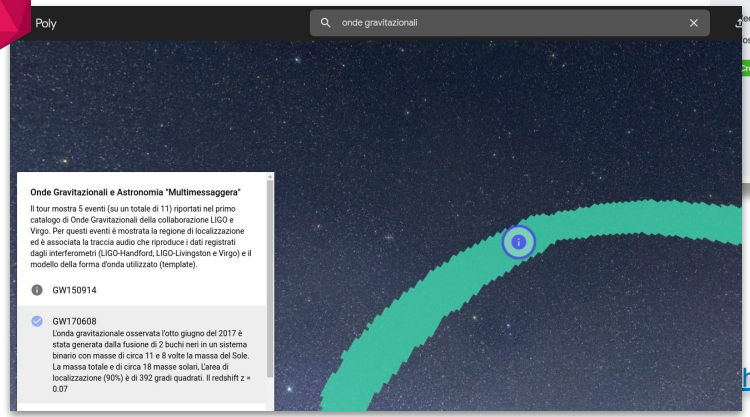
Hierarchical scheme for the description, storage and access of sky survey data. The system is based on hierarchical tiling of sky regions at finer and finer spatial resolution which facilitates a progressive view of a survey, and supports multi-resolution zooming and panning. HiPS uses the HEALPix tessellation of the sky as the basis for the scheme.

HIPS2FITS: Educational

- The hips2fits service enables generation of FITS (JPEG) images cutouts of arbitrary size and resolution from a given HiPS.
- IVOA Interop, Groningen, Apps 2 (Boch et al., 2019)



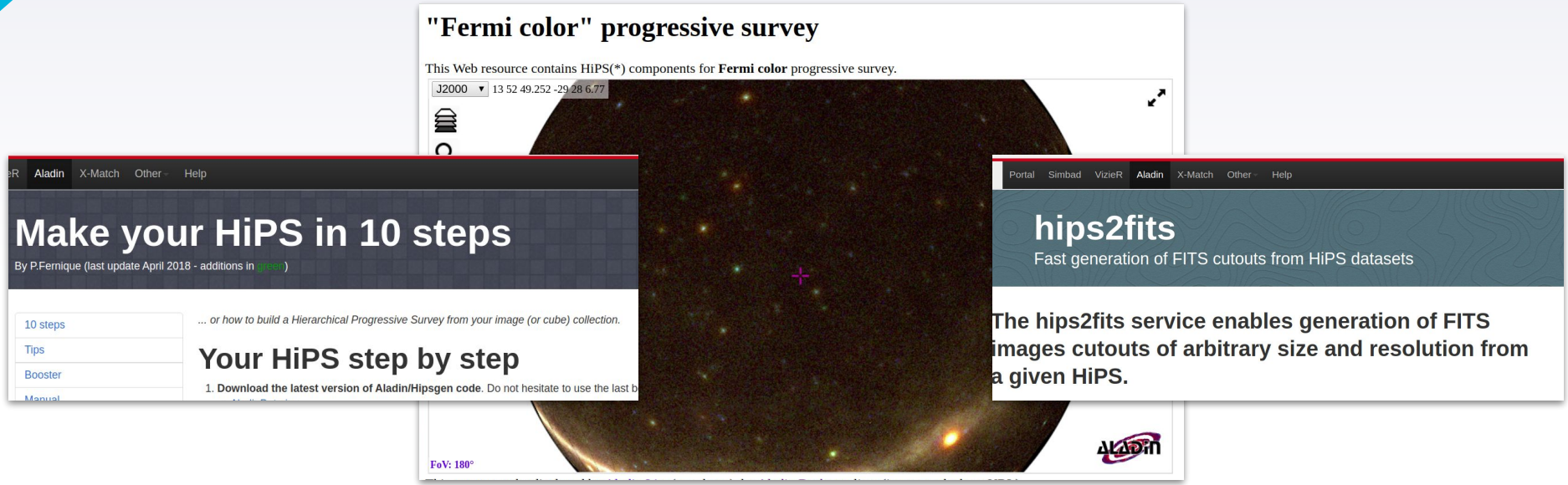
Panoramic images in Facebook



Virtual Reality tour

https://poly.google.com/view/0Jipqrriskm

HIPS2FITS: sharing MMA data



If your HiPS is publicly available through HTTP (ie no access restriction, no password), it will be reachable by the hips2fits service and anyone with the HiPS URL will be able to generate FITS cutouts extracted from this HiPS.

In progress

The approach could be useful for a fast data sharing. The user can get from the hips2fits only specific section of the image for analysis.

Accessibility

Aladin Lite for inclusive education

GW sky Sonification Project

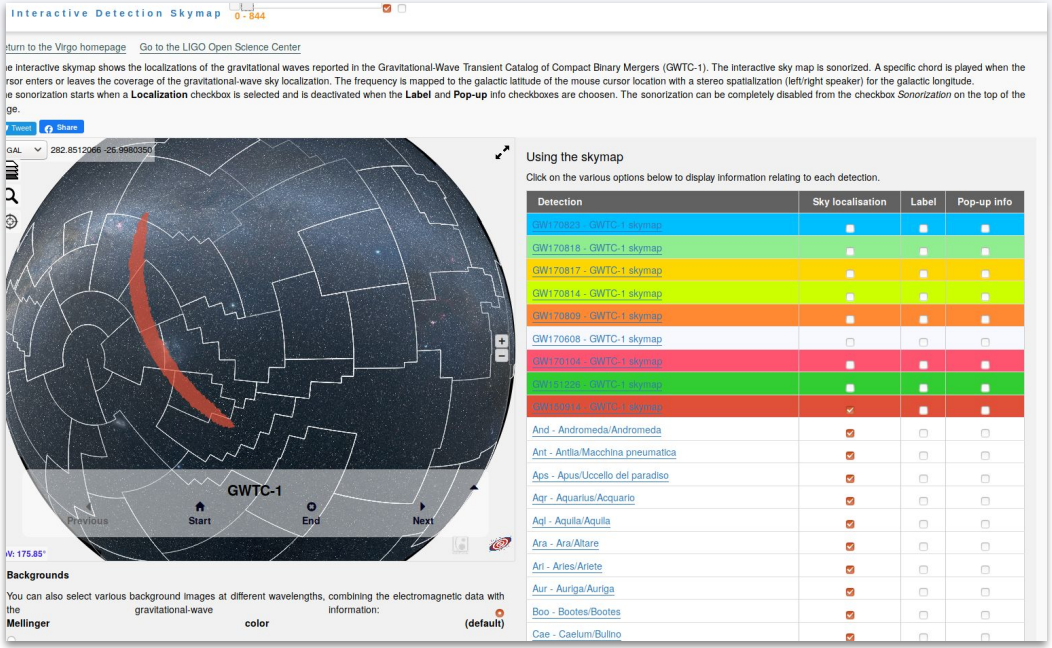
The frequency is mapped to the galactic latitude of the mouse cursor location with a stereo spatialization (left/right speaker) for the galactic longitude.

A specific chord is played when the cursor enters or leaves the coverage of the sky localization.

An audio file is added to explain the nature of each event and the main properties.

The constellations as well as the GW sky localizations are sonorized with a chord and a mp3 file description.

An automatic tour is added using the Aladin Lite Plugin developed by Tamara Civera.



Under tests in the Virgo/EGO events

In progress

Conclusion

- **Five years** in testing and implementation to support the GW credible region in MOC data format
- Supporting in the VO (Virtual Observatory) and LVC (LIGO and Virgo Collaboration) schools and tutorials
- Outreach and EPO (Facebook photospheres, VR tours, Google Poly)
- Space-time MOC implementation for GW MOC region - in progress
- Hips2fits as a new approach for sharing data in MMA - under testing

THANKS!

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