# Transient Astronomy in the EU Projects for MMA with GW: *Encoding Sky Maps*

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# Contents

# Some years in developing and testing in EGO-Virgo EU Projects

FUTURO IN RICERCA

Asterics
Astronomy ESFRI & Research Infrastructure Cluster

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

FRONTIERS

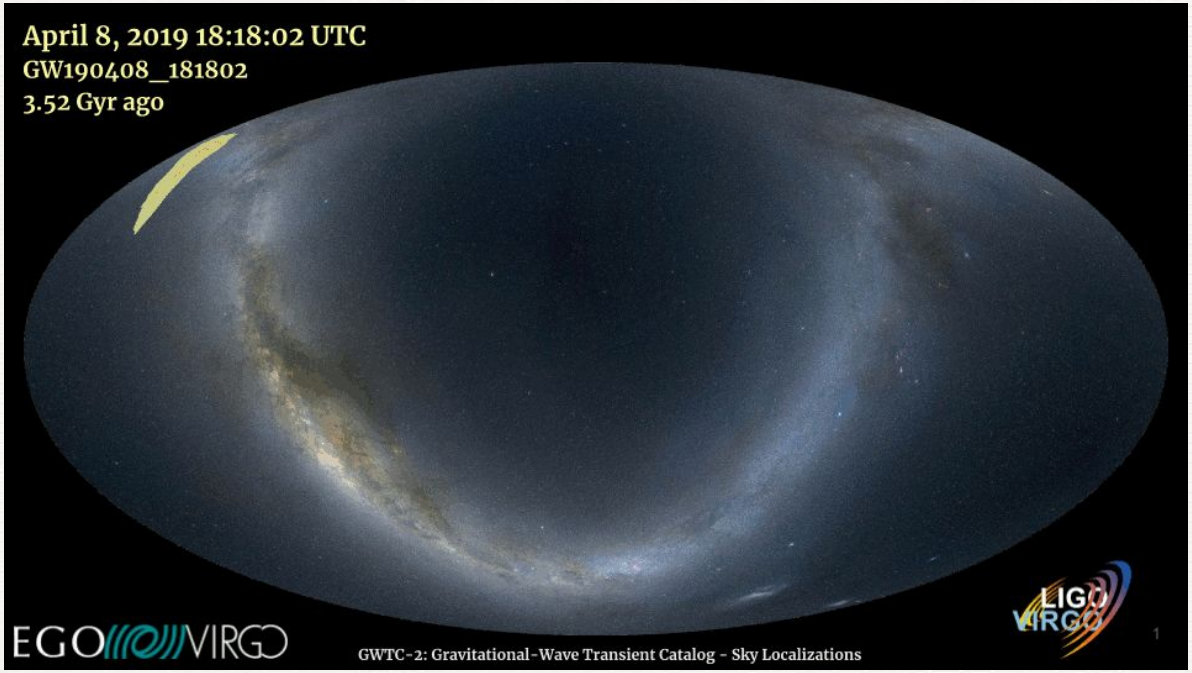
AHEAD 2020

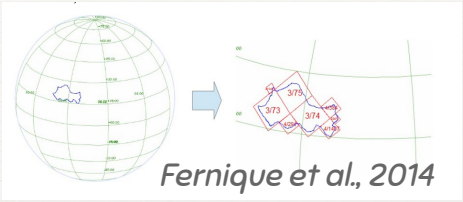
Findable Accessible Interoperable Reusable

IVOA

Strategies and implementations to connect the European Strategy Forum on Research Infrastructures (ESFRI) projects to the European Open Science Cloud (EOSC) through the Virtual Observatory (VO).

# GW Sky Localization from LIGO-Virgo O3a Catalog




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

SORT → CUSUM → MOC

**Flatten and multi-order LVK sky map format**

# Why MOC? Presentations and Discussions

## 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.**








# Overall impact of *MOC approach*

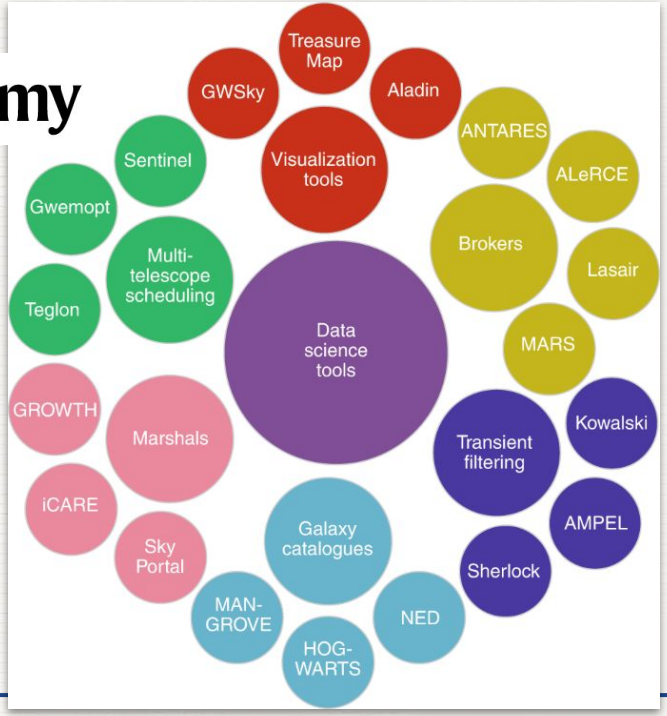
LSC LIGO Scientific Collaboration

VIRGO

**Public Alerts**

**User Guide**

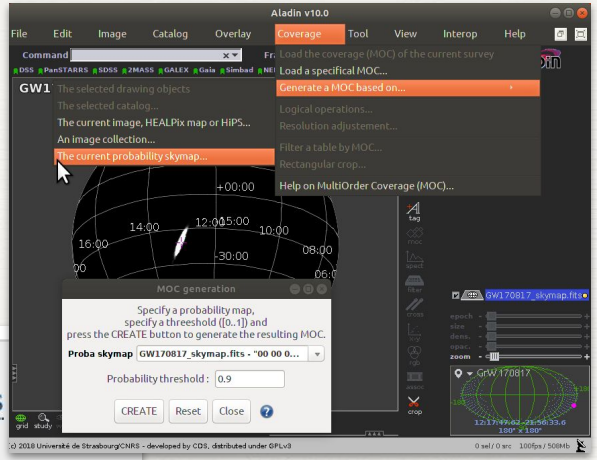
nature astronomy

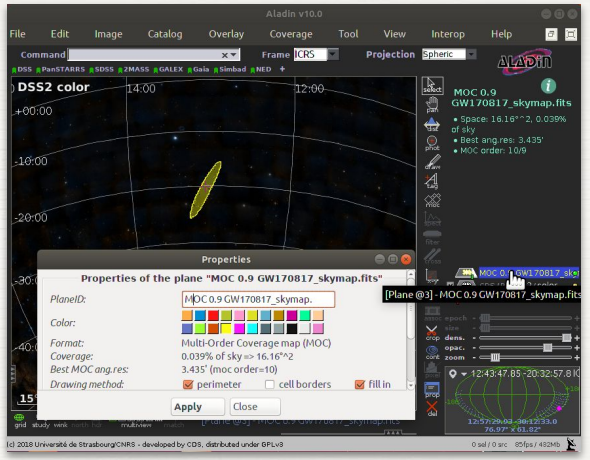



## Sky Map Visualizations and Credible Regions in Aladin

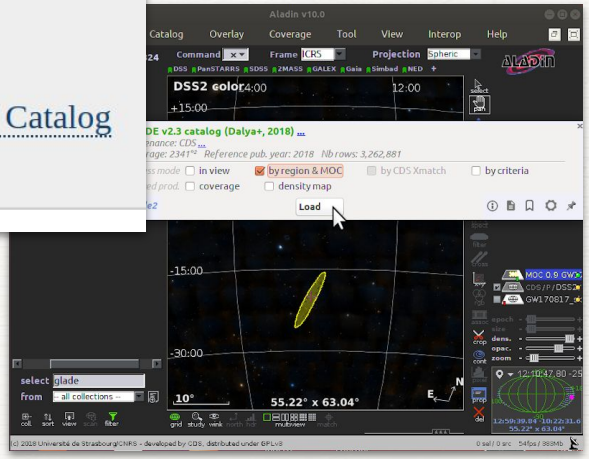
In this section, we demonstrate working with gravitational-wave sky localizations in Aladin Desktop. The following main topics are addressed.

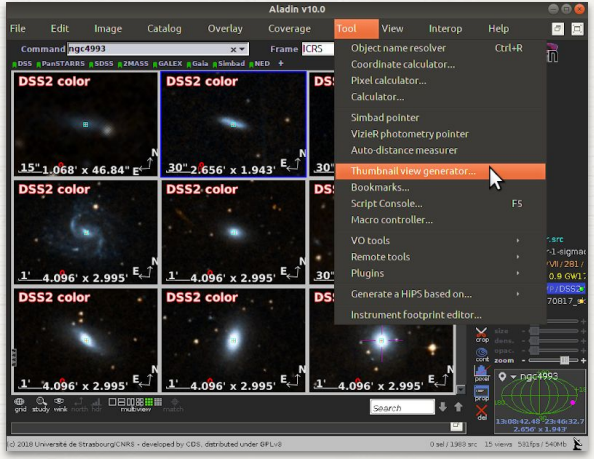
*Lessons from counterpart searches in LIGO and Virgo's third observing campaign from Michael W. Coughlin.*




- 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

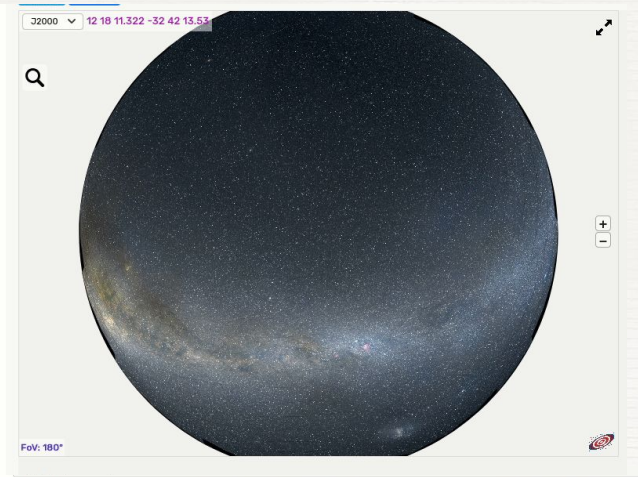


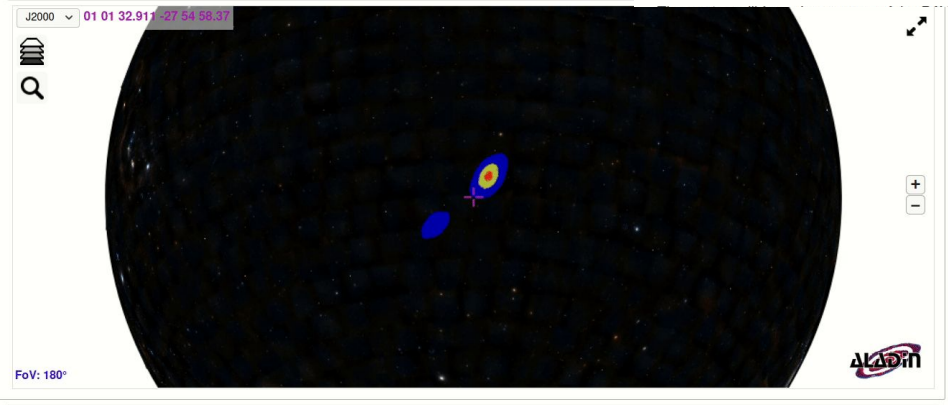

https://emfollow.docs.ligo.org/userguide/resources/aladin.html

# High degree of Interoperability

**Download and run the tutorial from https://l.infn.it/2v**








MOCpy

matplotlib

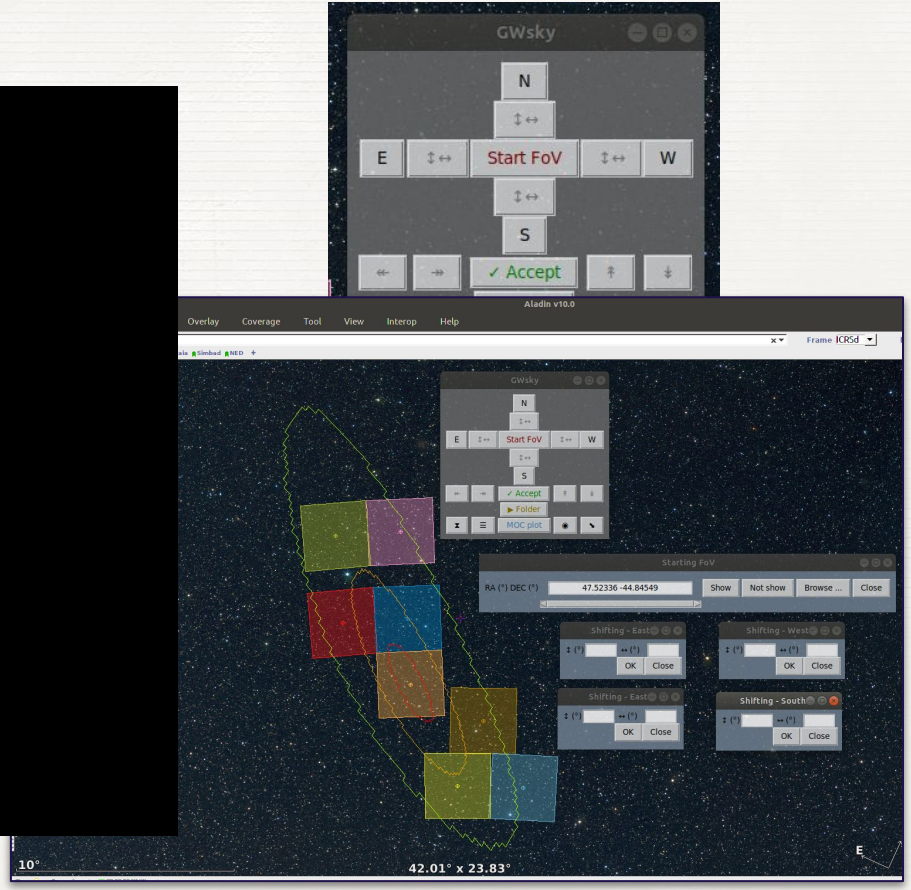
ipyaladin

ligo.skymap

jupyter

*and more...*

# GWsky: Interactive Tiling based on SAMP



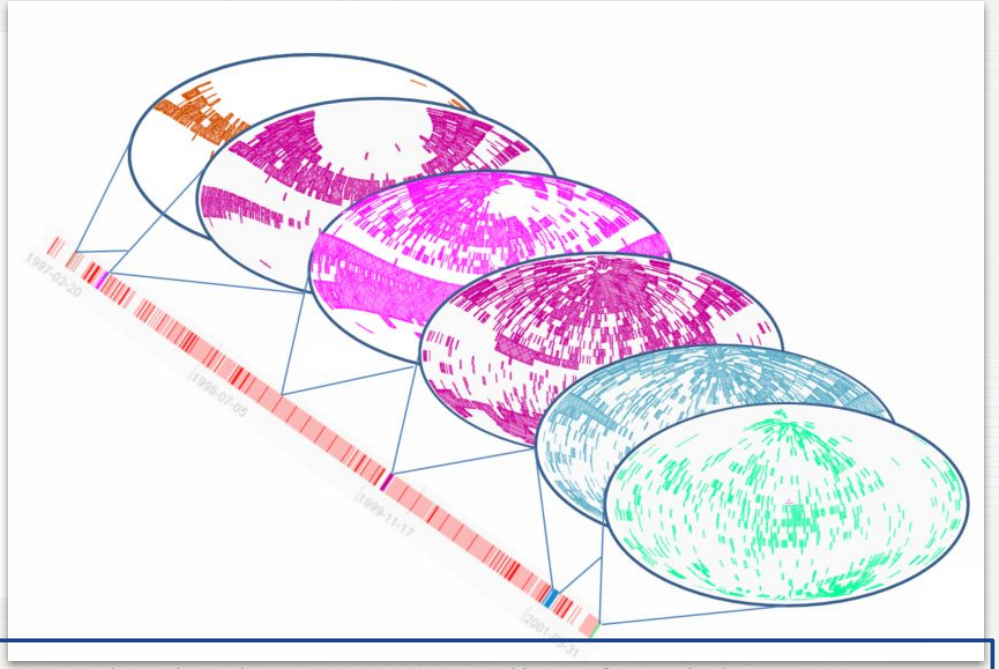
# Spatial and Temporal MOC: ST-MOC

International Virtual Observatory Alliance

MOC: Multi-Order Coverage map

Version 2.0

IVOA Working Draft 2020-10-30



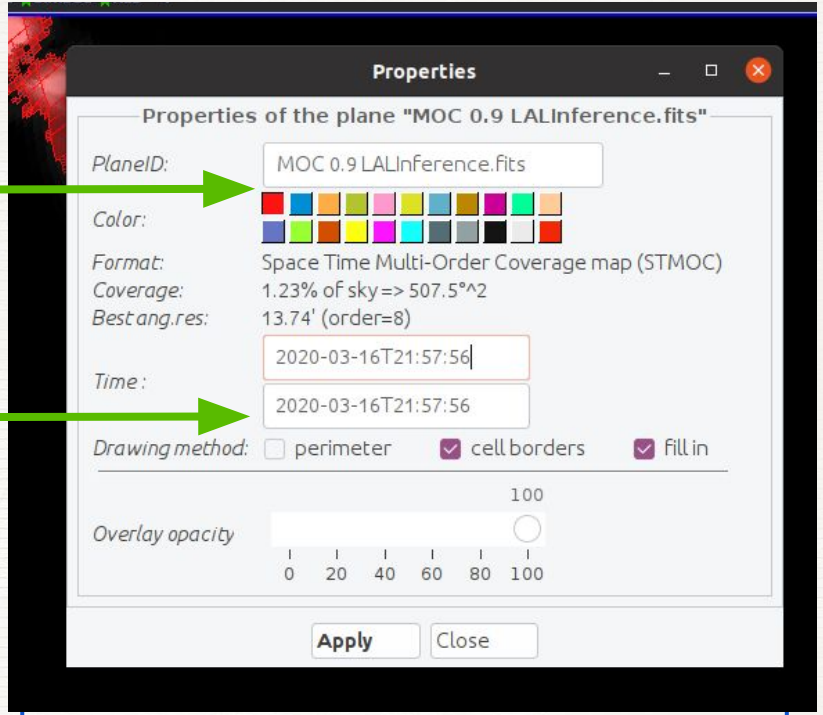
At a given Time range we obtain the corresponding Spatial coverage.

# GW credible regions in Space and in Time

In ***PlaneID*** a credible region is selected.

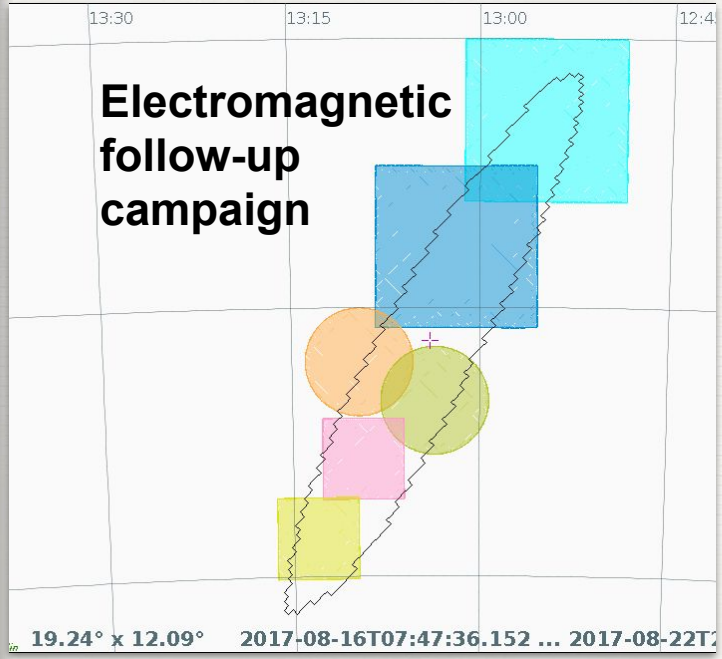
In ***Time*** the merger time is added.

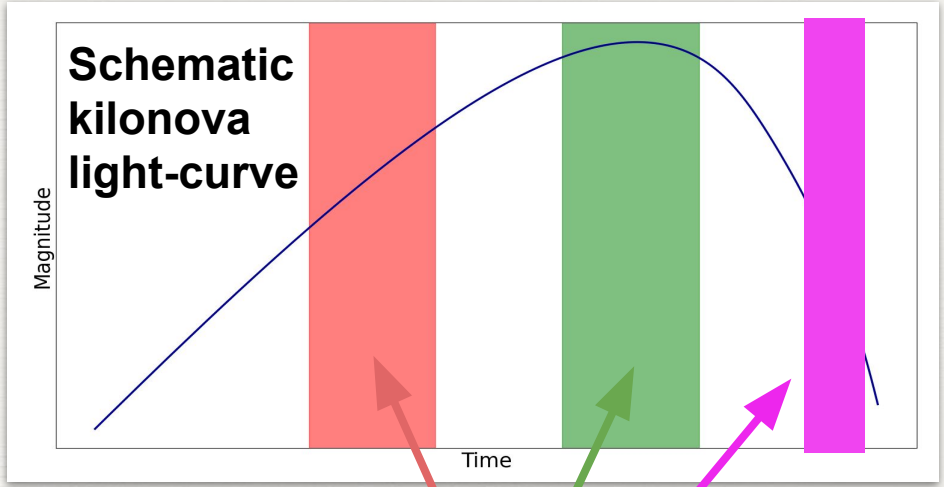
To search for any electromegnetic emissions before or after the compact binary coalescence, the time values can be modified accordingly producing a new ST–MOC.

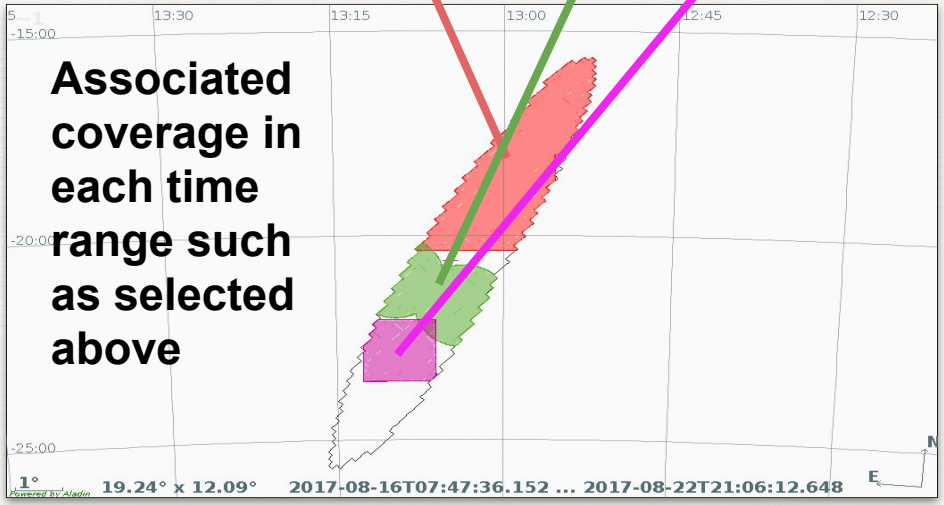



Generation of a ST–MOC from a gravitational-wave sky localization using Aladin Desktop (beta version).

# ST-MOC application: EM-followUP



ADASS XXX

# Search for Spatial and Temporal Coincidence Between LAT/Fermi Exposure Maps and GW Sky Localizations

**The poster describes a practical method to search for spatial and temporal coincidence of the LAT/Fermi coverage over a gravitational-wave sky localization. The method returns the overlap region between the two sky areas within a proper time window selected by the user. This approach offers a prompt setting of the observational strategies for searching potential electromagnetic candidates as well as a fast cross-matching between the LAT and the LIGO, Virgo and KAGRA databases for dedicated post-processing analysis.**
**The tasks are performed using the encoded standard method named Multi Order Coverage Map and visualized in the Aladin Desktop.**

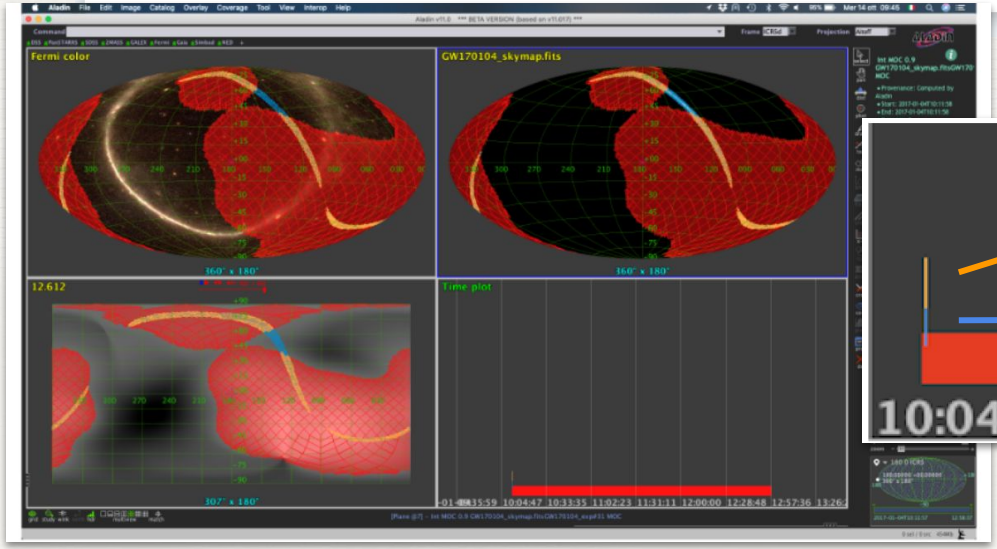
**Theme** – Multi-Messenger Astronomy

**Speaker**

Alessandra Berretta

**From the FTP**
P4-252.pdf | P4-252.LT.mp4

Video Tutorial



# Is TS-MOC eligible for MMA with ET?

1. Long-term support
2. IVOA Document and Standard
3. Interoperable data structure
4. Generate ST-MOC from VizieR and VO providers
5. Aladin Tree by Space & Time
6. Possible Extension - distance?

IVOA Northern Fall Interop - MOC 2.0 Status and Discussion; P. Fernique et al. 2020

# ET Expected Detection Rate

ET will explore the universe with gravitational waves up to cosmological distances with an expected detection rate of order $10^5$–$10^6$ black holes and $7 \times 10^4$ neutron stars mergers per year (Maggiore et al., 2020).

**How TS-MOC can be used to organize the HUGE ET data release?**

# Real Time Data Access and Continue Queries/Intersections

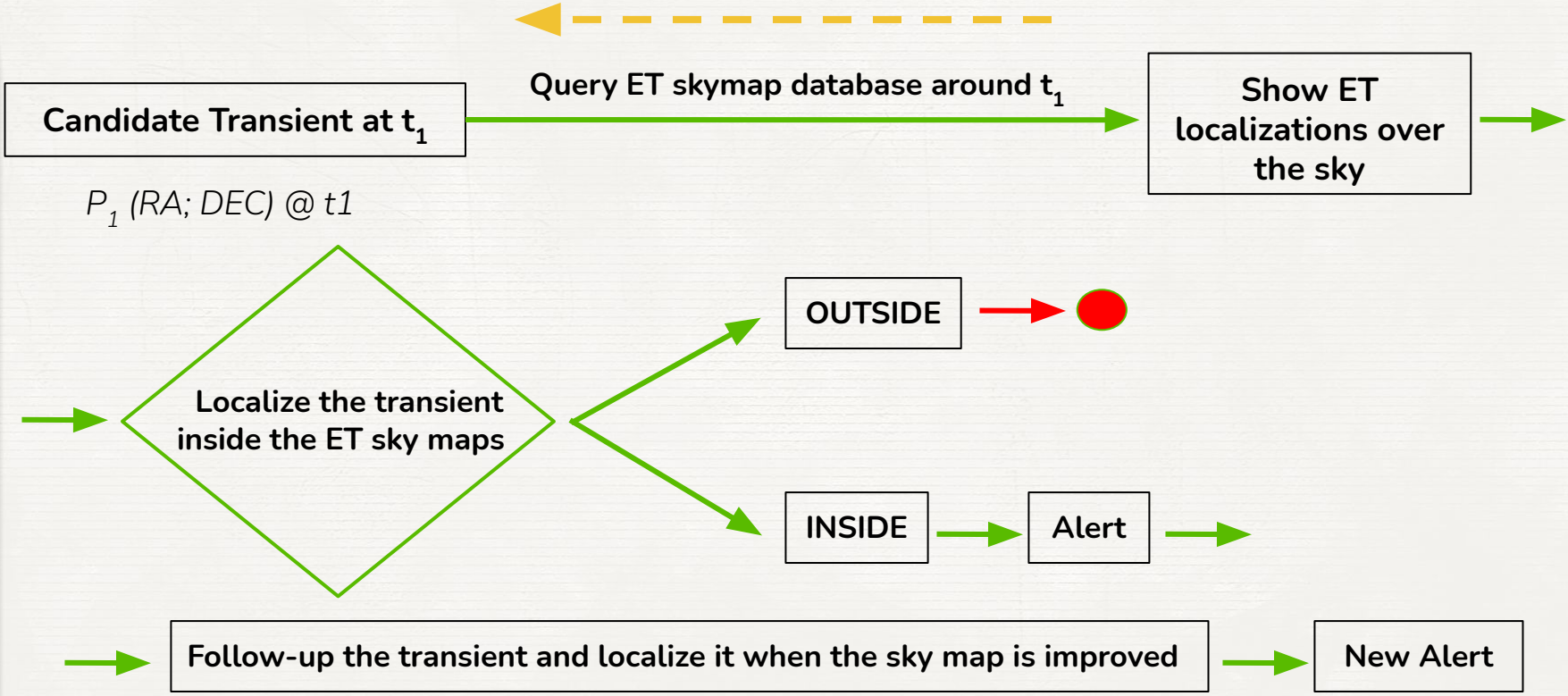
## 1 TS-MOC Queries

Fast and real time data access could be provided by encoding the ET sky localizations into ST–MOC and query them from a specific time range. Transients can be ranked based on the position inside the credible regions.

## 2 Multiple Sky Region Intersections

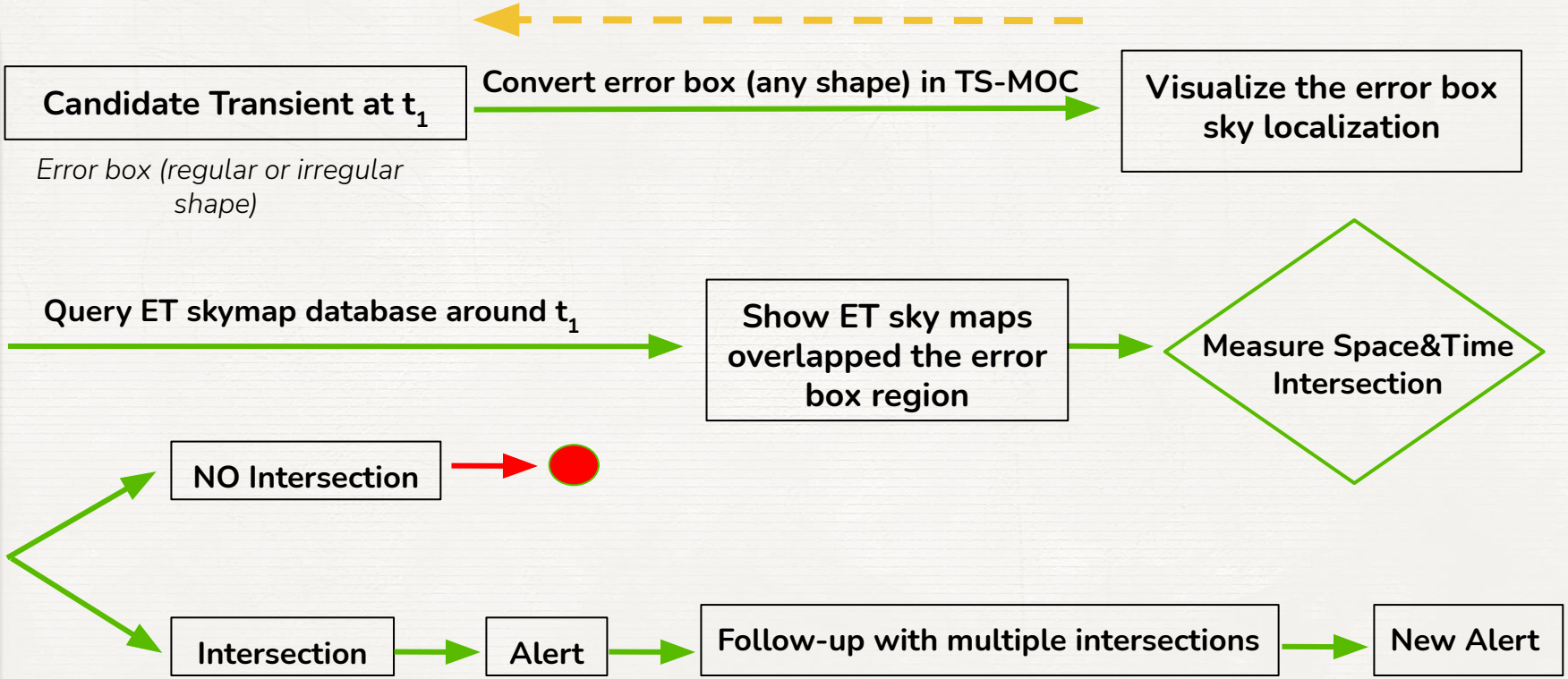
Electromagnetic/neutrino surveys will explore in real time the ET sky localizations through multiple spatial and temporal intersections to probe any electromagnetic/neutrino signals temporally and spatially connected to the inspiral, merger or ring-down phases.

# Independent Transient Classification
## ITC-1 - *for well localized transients*



# Independent Transient Classification

## ITC-2 - *for transients localized in an error box*



# Conclusions

**Feasibility studies are ongoing**

- Focusing on the last IVOA standard proposal TS-MOC.
- Real time transient classification (ITC-1/ITC-2).
- Plan interoperability with the existing facilities in the ET era.
- Simulations with theoretical predictions (detection rate and sky map size).
- New EU proposals in supporting technical approaches for ET MMA.

**Please, join the study (if you are interested) writing at**
giuseppe.greco@pg.infn.it; marica.branchesi@gssi.it

# Thanks