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

Conference **ESCAPE to the Future** | 25-26 October 2022

Royal Belgian Institute of Natural Sciences | Brussels, Belgium

25 October 2022, 13:30 - 14:25

ESCAPE VO - A European Virtual Observatory

ESCAPE VO | Virtual Observatory

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EST european solar telescope

Giuseppe Greco
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EGO VIRGO

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The Virtual Observatory in ESCAPE and EOSC

Mark Allen and François Bonnarel
CDS, Observatoire astronomique de Strasbourg
For WP4, ‘CEVO’

ESCAPE - The European Science Cluster of Astronomy & Particle Physics ESFRI Research Infrastructures has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement no. 824064.

One view of the VO from an application/portal :

Built from VO Registry

1000s All-Sky data sets

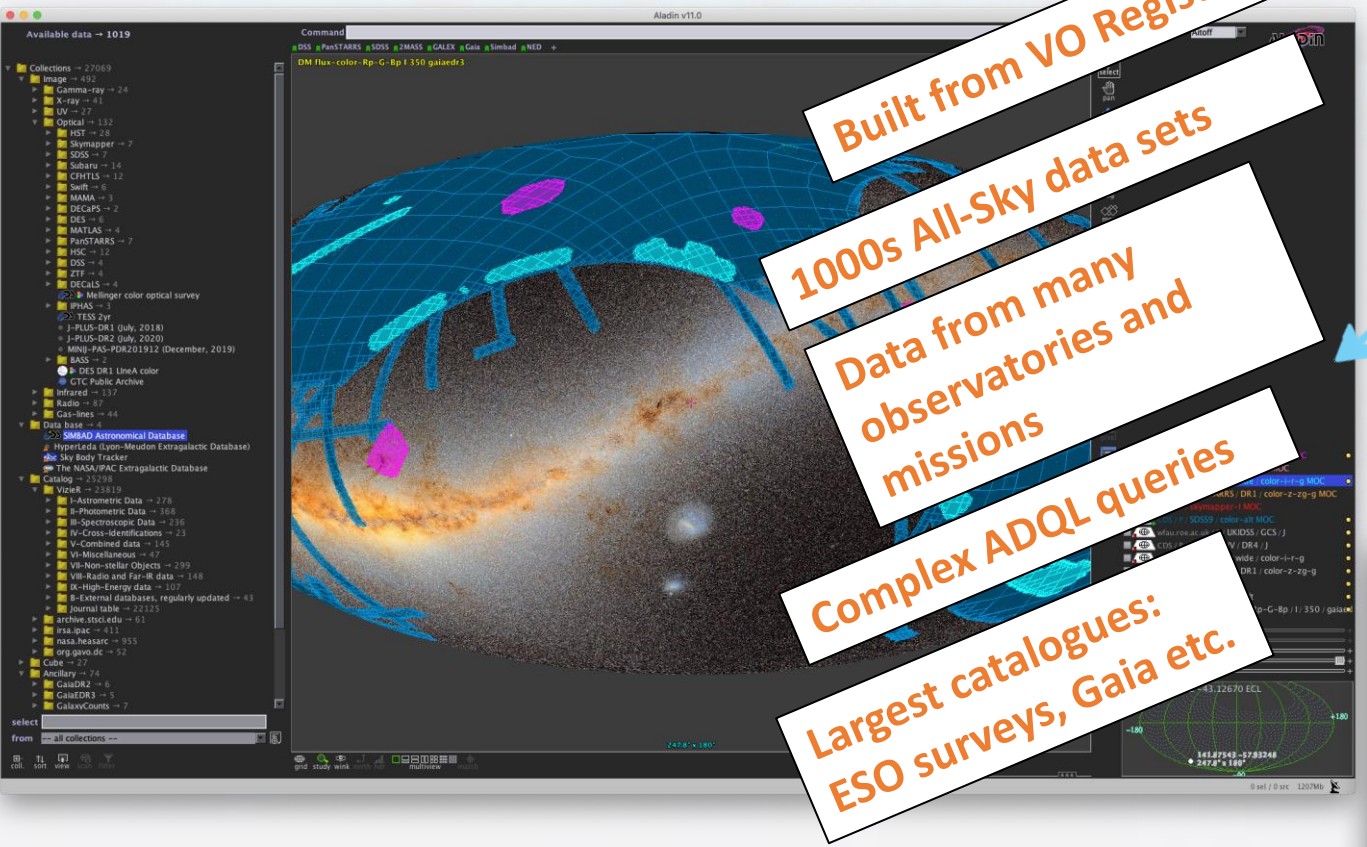
Data from many observatories and missions

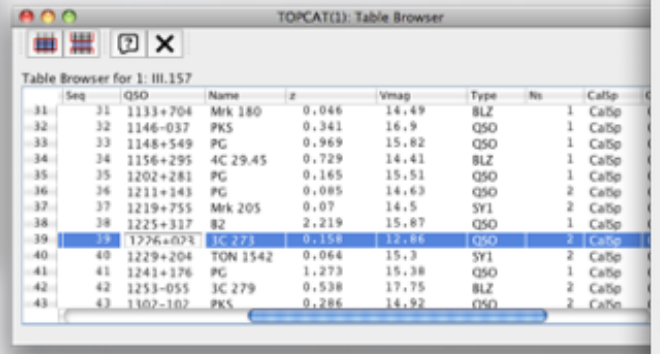
Complex ADQL queries

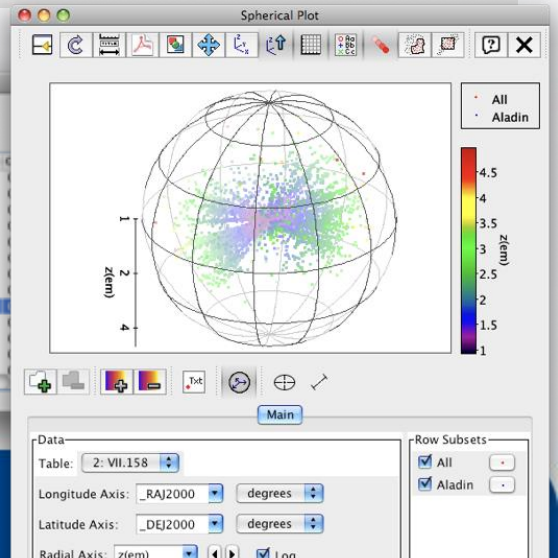
Largest catalogues: ESO surveys, Gaia etc.

Enables a *Virtual Research Environment* of interoperable tools and services based on IVOA standards:

```
In [ ]: from ipyaladin import Aladin
        a = Aladin(target='18 55 24.508 +04 29 46.72', survey='P/Mellinger/color', fov=180)
        a

In [ ]:

In [ ]: a.survey = 'P/GALEXGR6/AIS/color';a.target = 'M101';a.fov = 0.3

In [ ]: nloadTable&outputFormat=vot&filename=vizier_M101_II_328_allwise_20190322', {'color': 'red', 'onClick': 'showTable'})
```







Making data FAIR with the Virtual Observatory.

The **V**irtual **O**bservatory is:

- **An operational framework** for interoperable access to world-wide astronomical data and services.
- **A pioneer of FAIR data sharing** - **an existing global framework** – populated by major data providers (space and ground based) that is heavily used by the community.
- **Built on International Virtual Observatory Alliance (IVOA) standards**
  - *Recognised in the ESFRI roadmap (2021).*
    - *'… a global implementation of a FAIR disciplinary framework and openly avail- able data, the so-called astronomical Virtual Observatory.'*
  - *Quoted as an example in EOSC SRIA document (Feb 2021).*
- **Supported in Europe** *by* ***Euro-VO*** *(VO Partners + EC projects since ~2001).*
  - *Recognised in ASTRONET roadmap (2008, 2014, 2022).*

Successful formula: Bringing together ESFRI/RIs and VO expert partners

Astronomy ESFRIs, Research Infrastructures and associated partners

ESO

SKAO

NWO-I-ASTRON

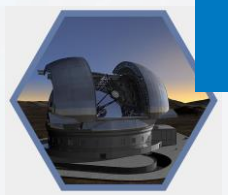
JIVE

CTAO

KIS

ORB

EGO



CNRS-OBAS

CNRS-CPPM

INAF

UEDIN

UHEI

INTA

HITS (WP3)

Partners bringing experience from European Virtual Observatory

+ many contributions from external collaborators – e.g. Europlanet

The approach:

Integration of astronomy VO data and services into the EOSC

- Interaction with EOSC projects based on experience of onboarding via EUDAT

Implementation of FAIR principles for ESFRI data through the Virtual Observatory

- ESCAPE ESFRI and RI priorities represented at the IVOA
- Community training events for *scientists* and *data producers/providers*

Adding value to trusted content in astronomy archives

- Deep learning applied to archive data sets (joint with WP3)

ESCAPE Cross-WP interaction/integration

- VO services in ESAP, VO software in OSSR, explore VO data in Data Lake, VO data/services/tools for citizen science and Test Science Projects

The results:

Integration of astronomy VO data and services into the EOSC

- Interaction with EOSC projects based on experience of onboarding via EUDAT

  ➔ *Analysis reports on VO data and service integration into EOSC*

Implementation of FAIR principles for ESFRI data through the Virtual Observatory

- ESCAPE priorities at IVOA level -- Many standards!!
- Community training events for scientists and data producers/providers:

  ➔ *2 Science with interoperable data schools*

  ➔ *European data providers Forum - Hands-on workshop for data providers*

Adding value to trusted content in astronomy archives

- Results of deep learning applied to archive data sets (joint with WP3)

  ➔ *Prototype demonstrator for value-added archive services*

ESFRI / RIs	Results for ESCAPE work toward FAIR standards and tools
ESO-ELT ESO, CNRS-ObAS, INTA, INAF,UHEI UEDIN, HITS	- Data access and visualisation standards and tools - Support of **VO standards in ESO archive** services – used as exemplary case to help others - Relevant IVOA standards updated
EGO/VIRGO EGO (INFN), CNRS-ObAS,	- Development of **MOC2.0** (approved IVOA standard) **and mocpy** - Tools / libraries integrated into GW community software - Paper published in Astronomy & Computing
SKA, JIVE, ALMA (LOFAR) JIVE, ASTRON, SKAO, ESO/ALMA, UHEI, CNRS-ObAS	- Creation and support of the **IVOA Radio Astronomy** Interest Group - New TAP services, accessible in VO tools and in the ESCAPE platform - Visualisation capabilities – transferring into SKA SRC prototyping
CTA & KM3NeT CTAO, Obs-Paris, CNRS (ObAS+CPPM) UHEI, (FAU)	- Data Provenance standards approved by IVOA - Many activities for adoption and implementation (Workshop held) - TAP services – Table Access Protocol for neutrino data - Reference paper published on a: ***Management System for Provenance Information***
EST ORB, KIS, CNRS-ObAS, INTA, UHEI	- VO metadata developed for Solar Physics - Prototype TAP services for solar data

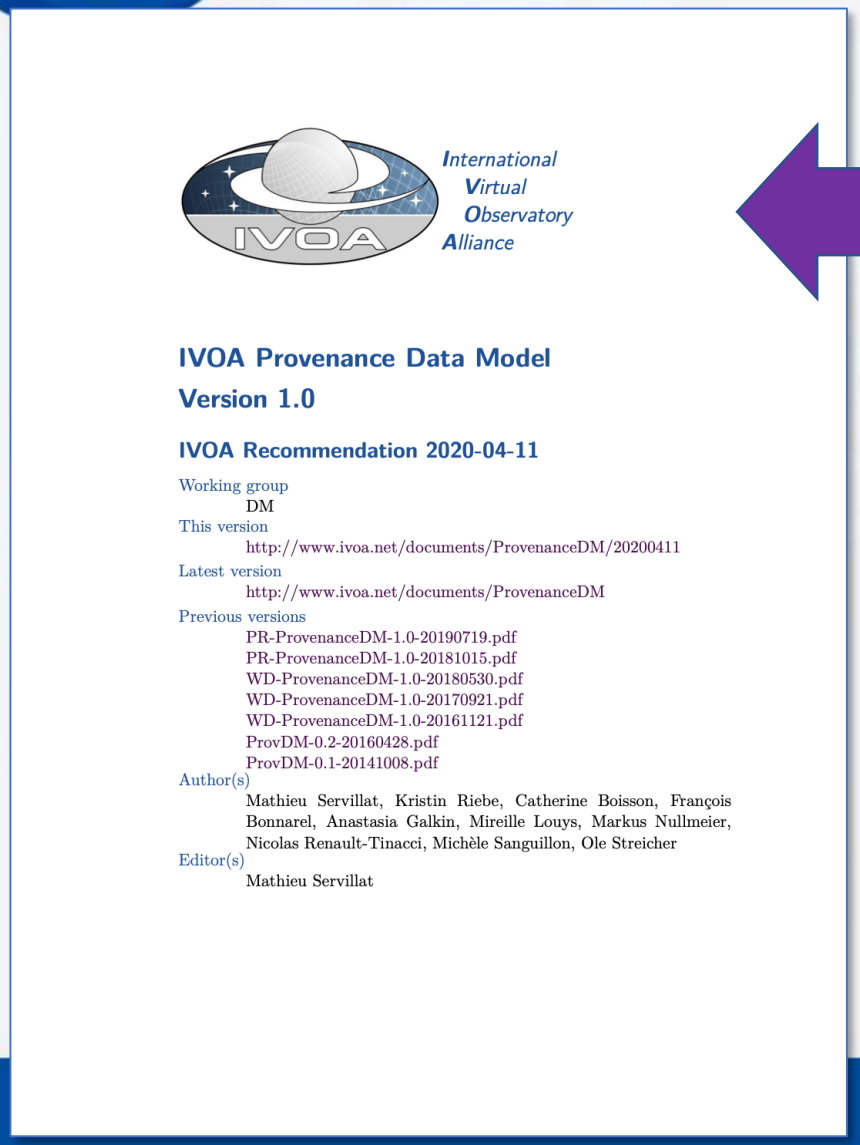
Example – 2 of the standards led/contributed to by ESCAPE partners

Provenance Data Model

Finalised and approved April 2020.

Brought to community via **ESCAPE Provenance workshop** September 2020.

- **Published -** Servillat et al. – SPIE



International Virtual Observatory Alliance

IVOA Provenance Data Model
Version 1.0

IVOA Recommendation 2020-04-11

Working group
DM
This version
http://www.ivoa.net/documents/ProvenanceDM/20200411
Latest version
http://www.ivoa.net/documents/ProvenanceDM
Previous versions
PR-ProvenanceDM-1.0-20190719.pdf
PR-ProvenanceDM-1.0-20181015.pdf
WD-ProvenanceDM-1.0-20180530.pdf
WD-ProvenanceDM-1.0-20170921.pdf
WD-ProvenanceDM-1.0-20161121.pdf
ProvDM-0.2-20160428.pdf
ProvDM-0.1-20141008.pdf
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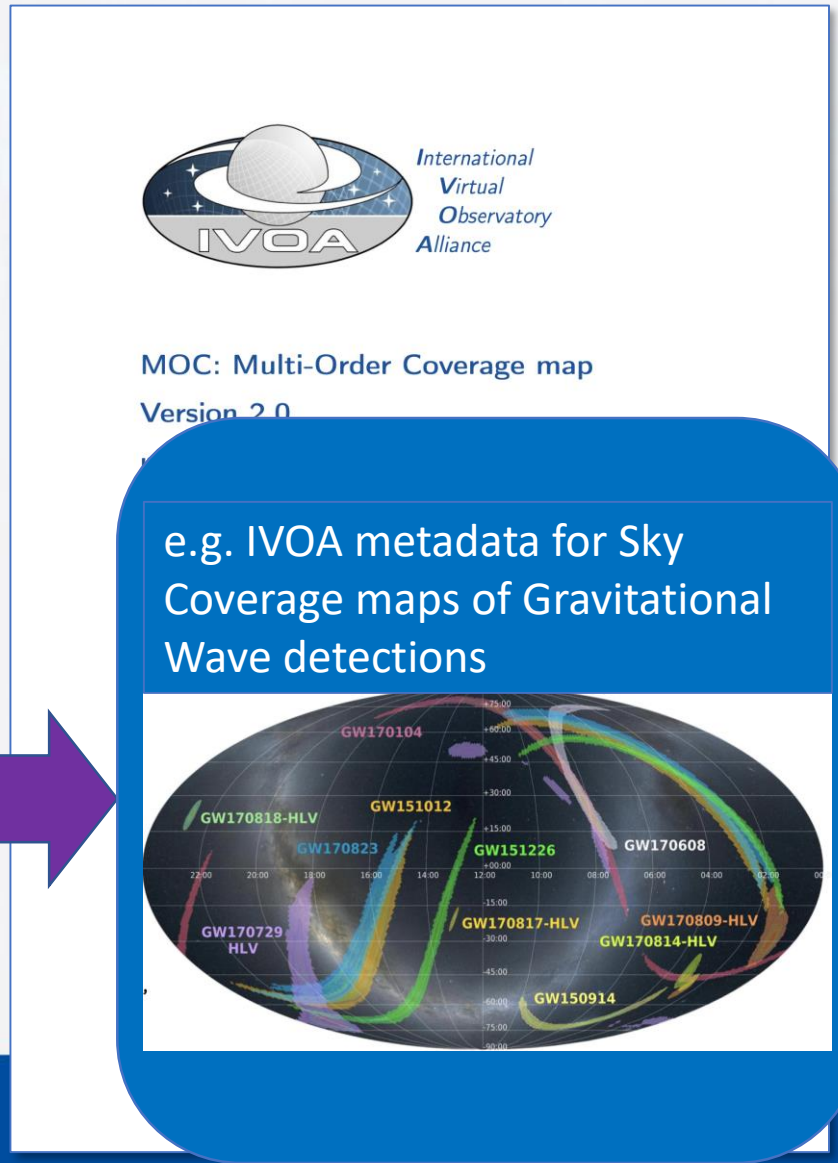
Editor(s)
Mathieu Servillat

Multi-Order Coverage 2.0

Space coverage extended with TIME coverage.
Approved in April 2022.

Driven by ESFRI/RI needs (EGO, ESO, Radio astronomy,+++).



International Virtual Observatory Alliance

MOC: Multi-Order Coverage map
Version 2.0

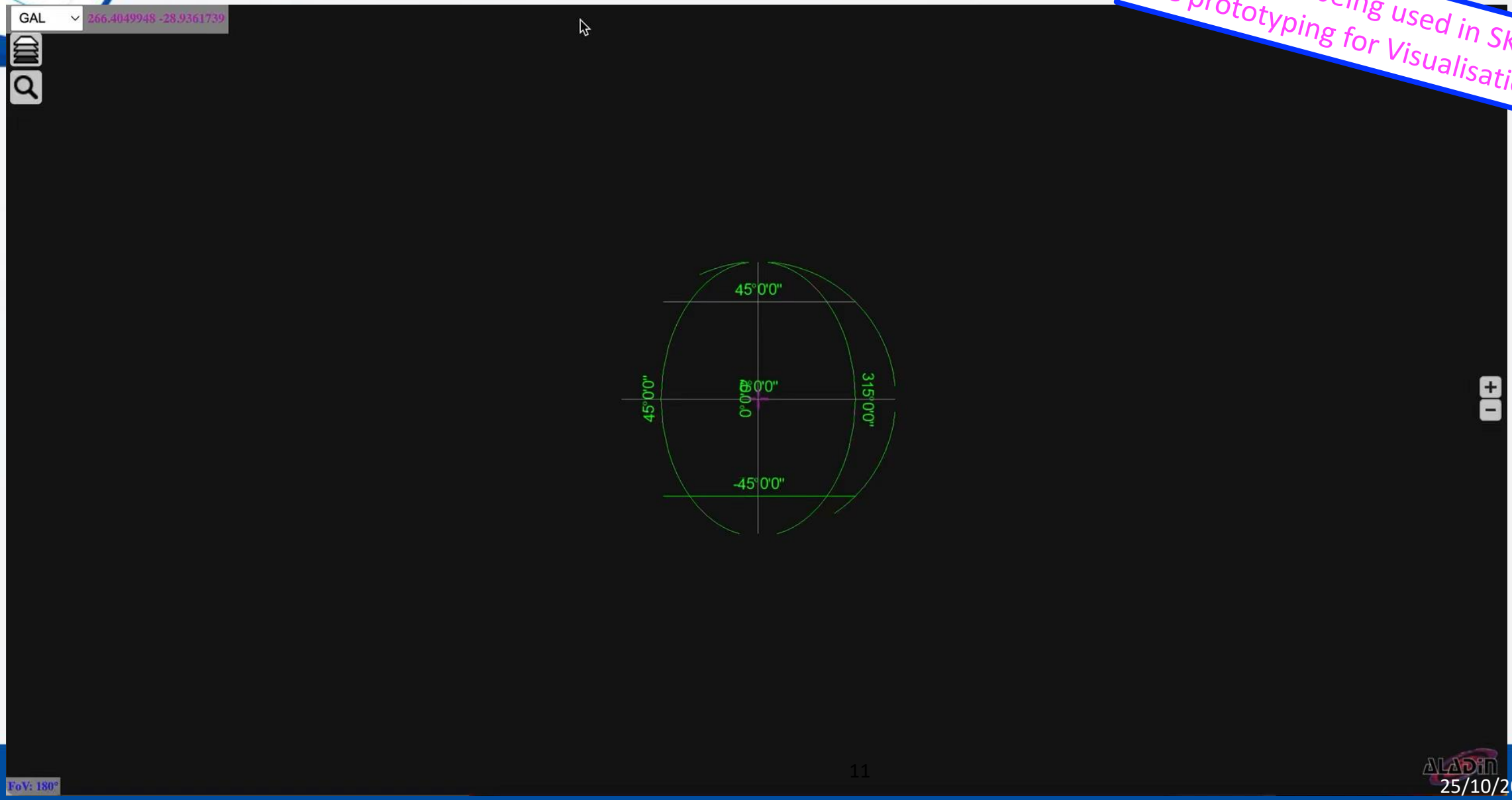
e.g. IVOA metadata for Sky Coverage maps of Gravitational Wave detections

Highlight : VO in B2FIND

- **Demonstrates 1st level of metadata compatibility**
  - Links to the actual service
  - enables feedback to EOSC

Example of MeerKAT SKA pathfinder data

ESCAPE work being used in SKA SRC prototyping for Visualisation



Today - Focus on ESCAPE-enabled interoperable services

Mark Kettenis
JIVE
A VO service for the European VLBI Network

Martino Romaniello
ESO
The VO at ESO

Giuseppe Greco
INFN - Perugia
VO interoperability for visualisation of GW sky localizations and strategies of EM follow-up

Vernoique Delouille
Royal Observatory of Belgium
ESCAPE VO Impact on the European Solar Telescope ESFRI

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The VO at ESO

Martino Romaniello (ESO)
Head, Back-end Operations Department

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ESO, The European Southern Observatory

- What we do
  - Develop ground-based **astronomical telescopes and observatories** that are not individually achievable by single Member States
  - Secure science community access to high quality data
- Founded in 1962 (60th anniversary!)
- 16 Member States; host state: Chile; strategic partner: Australia

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The ESO Science Archive as an essential component to ESO's operations

"The telescopes are operated to optimise scientific excellence, to maximise the scientific return of ESO by undertaking observations that have the potential to yield significant scientific advancements, and to exploit synergies between them as well as with other facilities. **The telescopes are operated within an end-to-end process which starts with proposal solicitation and ends with data preservation and publication […] ESO supports an open data policy**"

ESO Optical/Infrared Telescopes Science Operations Policies, 2020, Cou-1847

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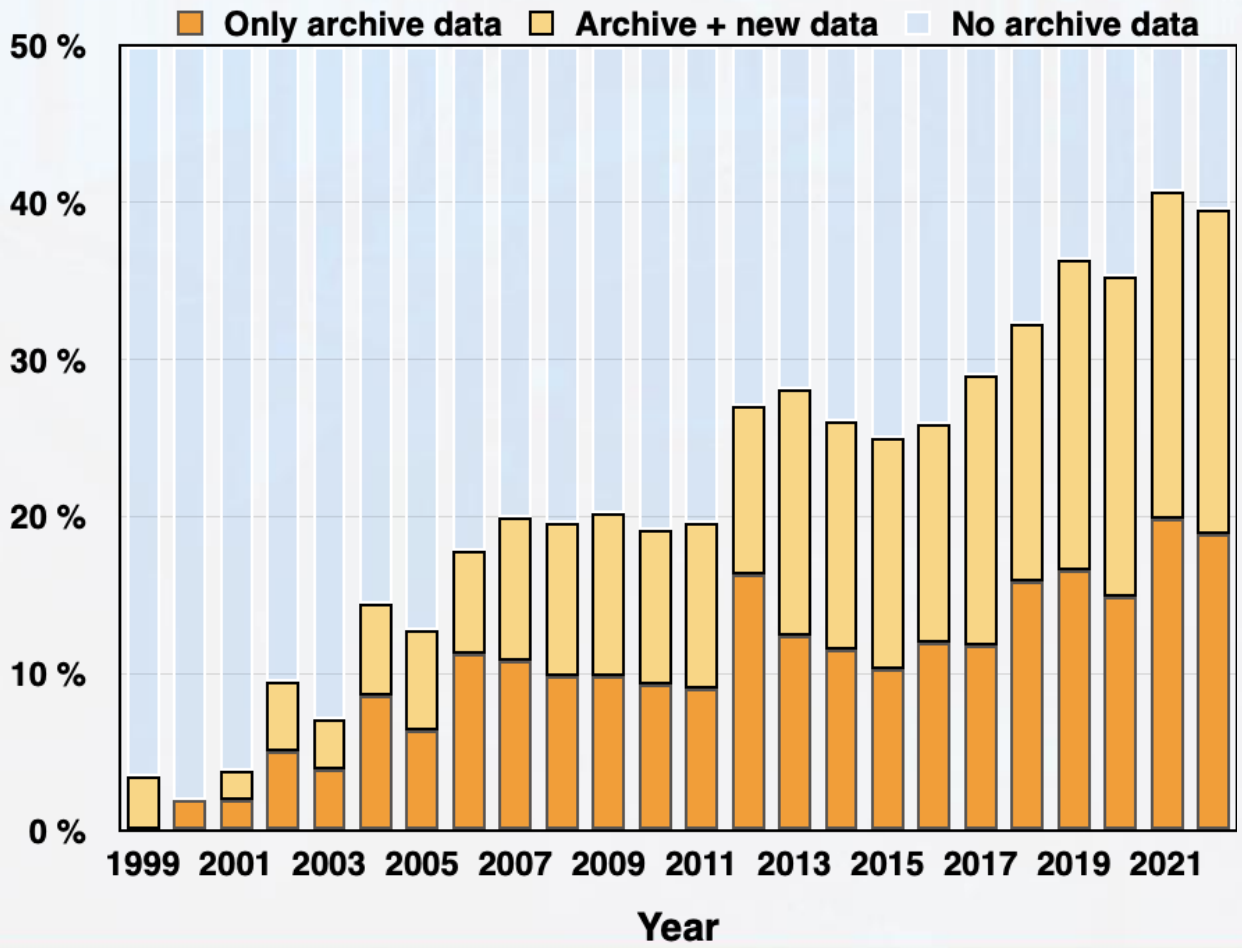
The ESO Science Archive as science machine

- About 40% of the science publications with ESO data use the archive



Source: ESO Telescope Bibliography (telbib.eso.org)

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The impact of the ESO Science Archive

- It allows to scrutinize published results: a staple of the scientific method
- It fosters a culture of cooperation and open data in Astronomy and science in general
  - Astronomy has been leading open data
- It broadens ESO's user community
  - Rather large community: ~ 60% of professional astronomers worldwide
  - One third of archive users are new to ESO
  - Larger fraction of early-career scientists than as Principal Investigators
  - Reaches out beyond the ESO Member States
  - Brings in new communities, e.g. earth atmosphere

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Data interoperability: the Virtual Observatory

- About 50% of the ESO science results also use data from other observatories (source: ESO Telescope Bibliography + NASA ADS)
- Exchanging data is, then, necessary to make the most out of it
- The Virtual Observatory is the de-facto standard for data interoperability in astronomy …
  - Standards, protocol, tools
- … and it needs to keep evolving to keep up with new data types, new instruments and science cases
- CEVO is instrumental in doing so
  - For ESO data itself, and for coordination of European astrophysics interests in the IVOA and EOSC

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The Virtual Observatory and the ESO Science Archive

- The ESO Science Archive heavily relies on the Virtual Observatory
  - For internal operations, e.g. internal communications
  - For user access and services

- ADQL
- Aladin Lite
- DataLink
- HiPS
- ObsCore
- SAMP
- SODA
- SSA
- STC-S (point, circle, multi-polygon)
- TAP (DALI, VOSI, UWS, UCD, UTYPE, …)
- TOPCAT
- VOTable
- pyvo
- …

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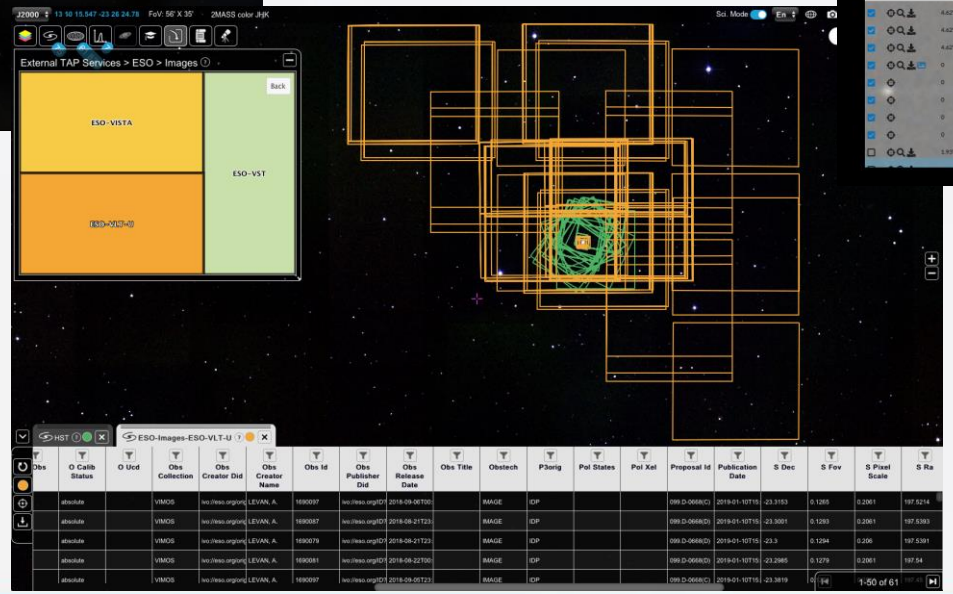
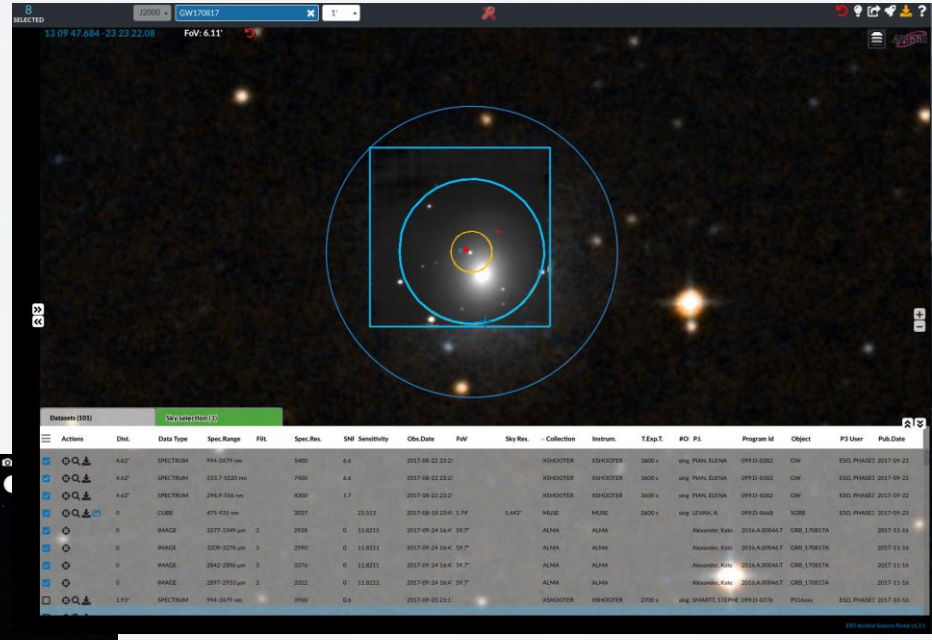
Multi-messenger, multi-wavelength view of neutron star merger GW170817

ESO + LIGO/Virgo

ESO + HST (ESASky)





ESO La Silla Paranal + ALMA

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In summary: ESO and CEVO

- The Virtual Observatory is central to the success of the ESO Science Archive
- CEVO provided crucial support to the ESO Science Archive
  - Continued support and development of tools, protocols and standards
  - Coordinated involvement and expansion of the astronomical community
  - Prototyping of new techniques to add-value to archive contents
  - Connection to the EOSC, the common framework for European Open Science
- CEVO also provided training to:
  - Early career researchers on the use of the VO and the development of EOSC
  - Other astronomy data providers for their use of the standards and tools

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An outlook to the future

- The Virtual Observatory is a very mature set of tools, protocols, standards/specifications
- It is an essential component of the ESO Science Archive … and, arguably, of all the major ones, present and future
- A key component to the success of the VO is that its components have constantly evolved with the data …
- … this needs to continue, and the ESCAPE Open Collaboration is in an ideal position to contribute coordination of European Virtual Observatory efforts in the development of EOSC, in particular for interoperability

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ESCAPE VO Impact on the European Solar Telescope ESFRI

Véronique Delouille, Royal Observatory of Belgium
Nazaret Bello Gonzalez, KIS

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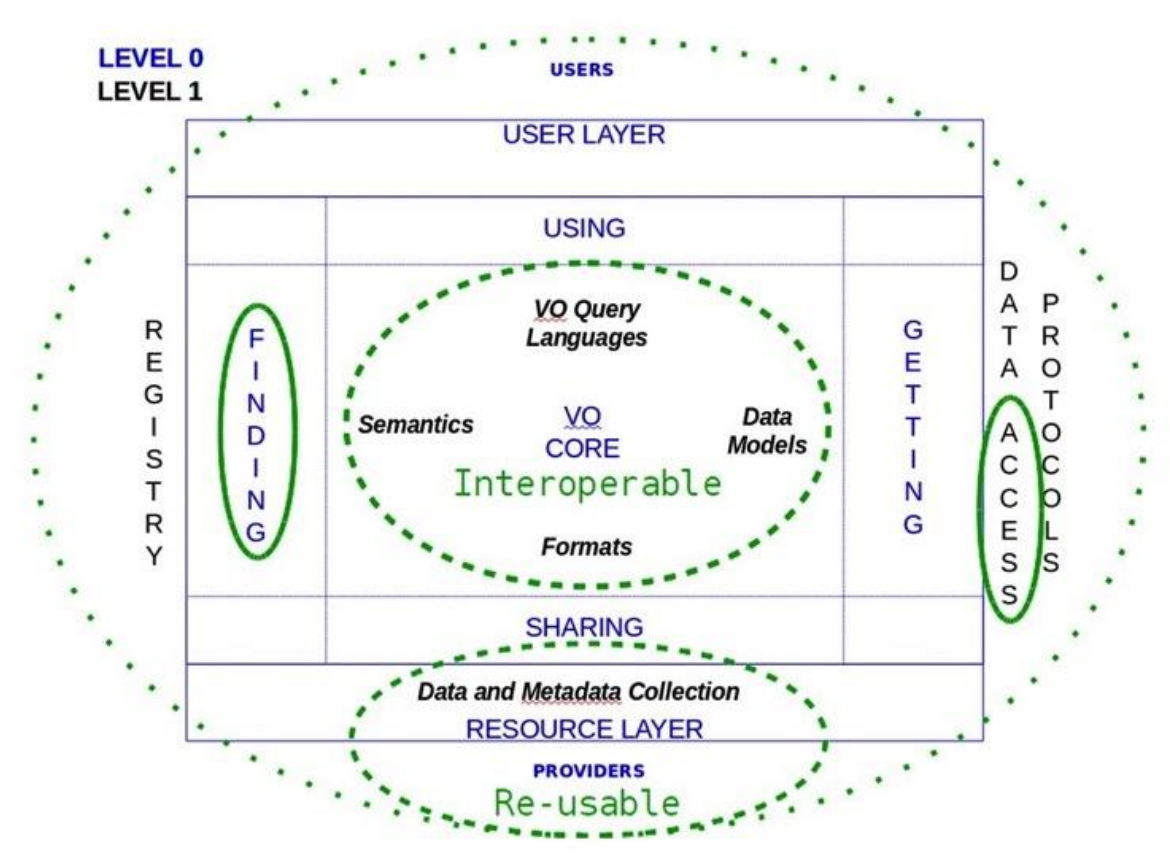
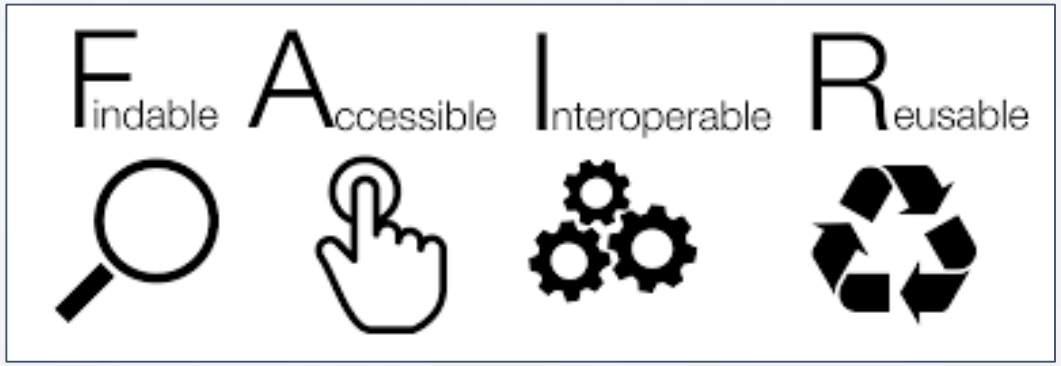
Goal of Task 4.2: Enable high level data products and archive services to be interoperable in the VO framework, so that they can connect to the EOSC through the VO





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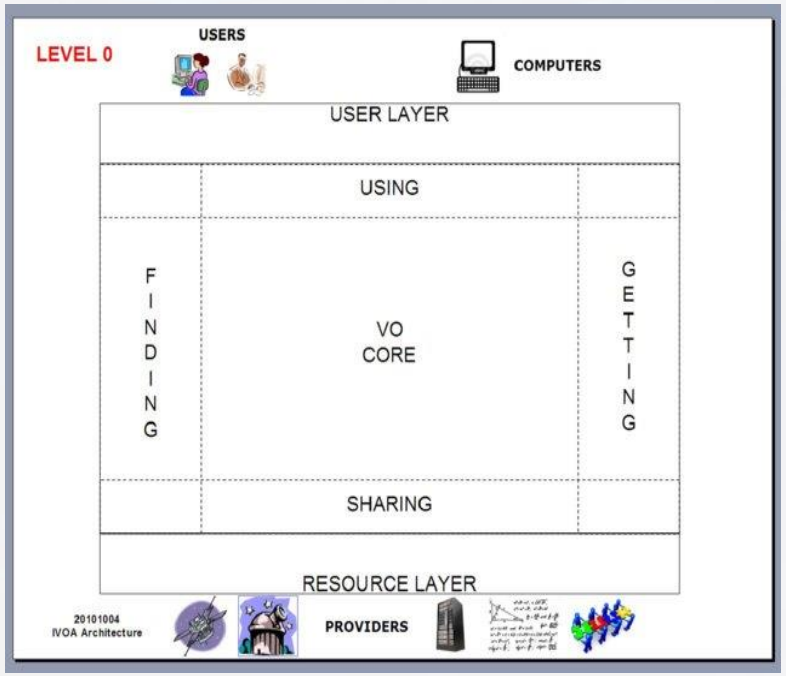
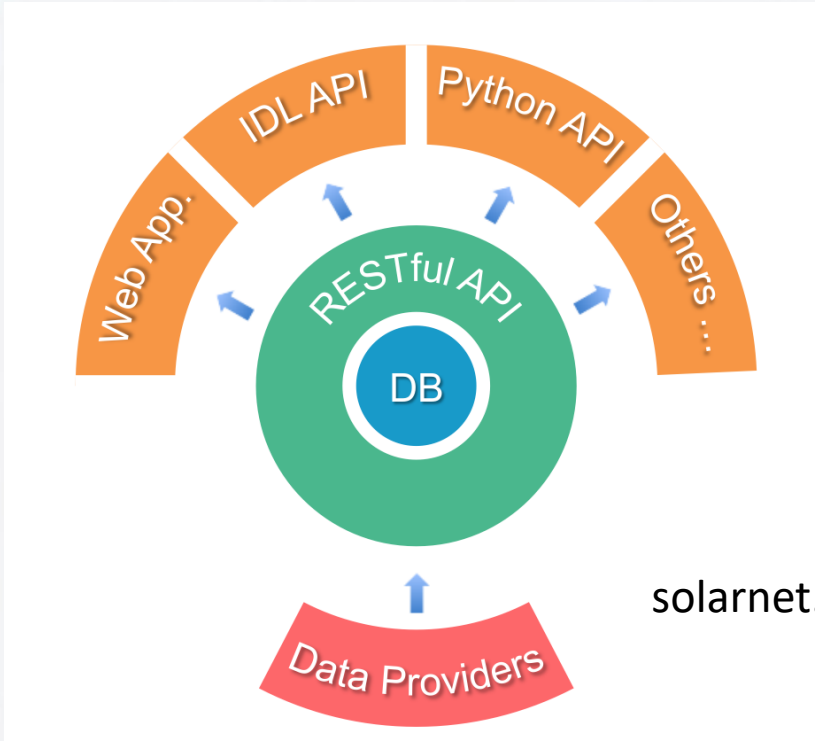
What already existed in terms of VO in solar physics?

- SOLARNET VO : few constraints on metadata and on ways to access the data (ftp, https)
- Limited to FITS files
- No standardization, but SOLARNET recommendation for FITS keywords





solarnet.oma.be

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How to go further ?

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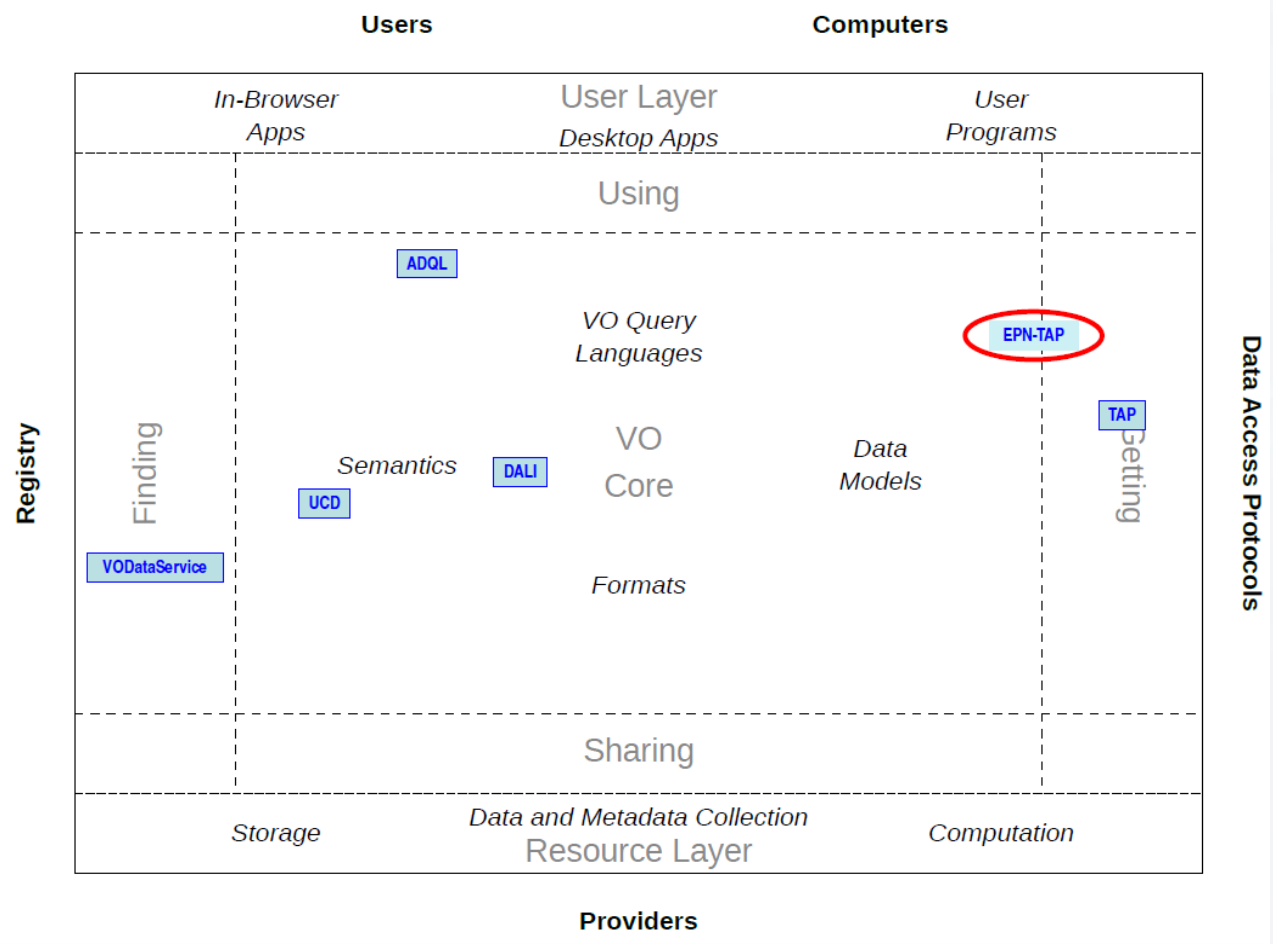
EPN-TAP extension to solar physics

- Correspondance between EPN-TAP parameters and SOLARNET FITS keywords
- Review of UCD for the needs of solar physics community
- Comparison with existing databases of solar event (HEK, HFC)
- Addition of UCD terms



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Data Access Layer for solar physics data sets

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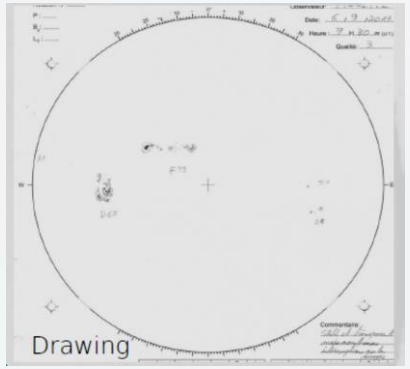
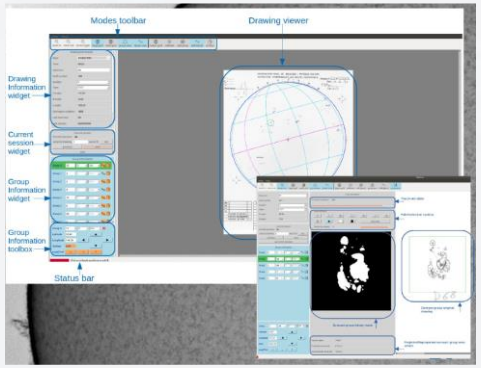
Implementation of EPN-TAP services

uset_sunspot_drawings



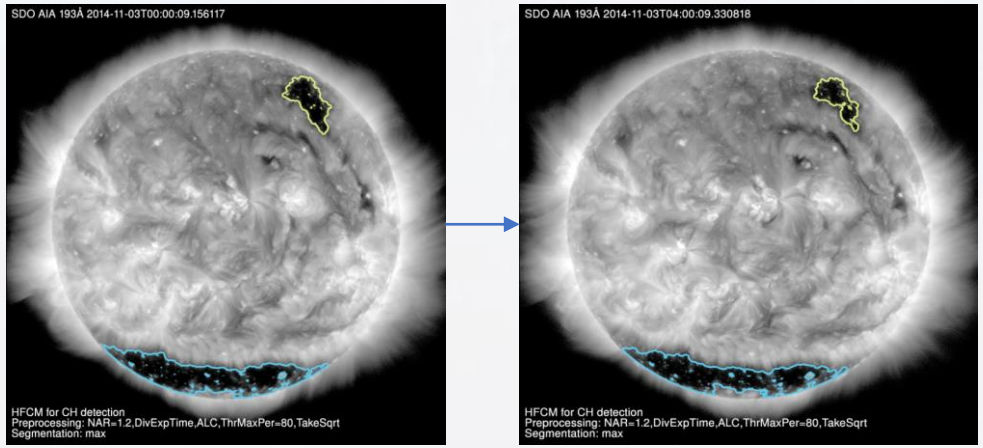
Parameters from the drawings, e.g
Total number of sunspots

uset_sunspot_groups



Individual sunspot group parameters computed from in-house software

Catalog of Coronal Holes, from EUV solar images

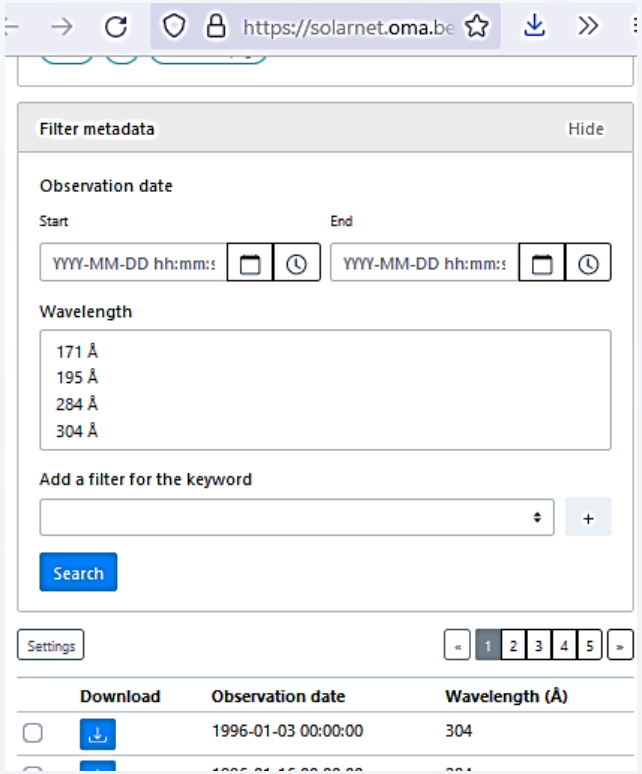


rob_spoca_ch : main table with position, area, intensity, etc,...
rob_spoca_ch_tracking : tracking table to follow a same CH over time

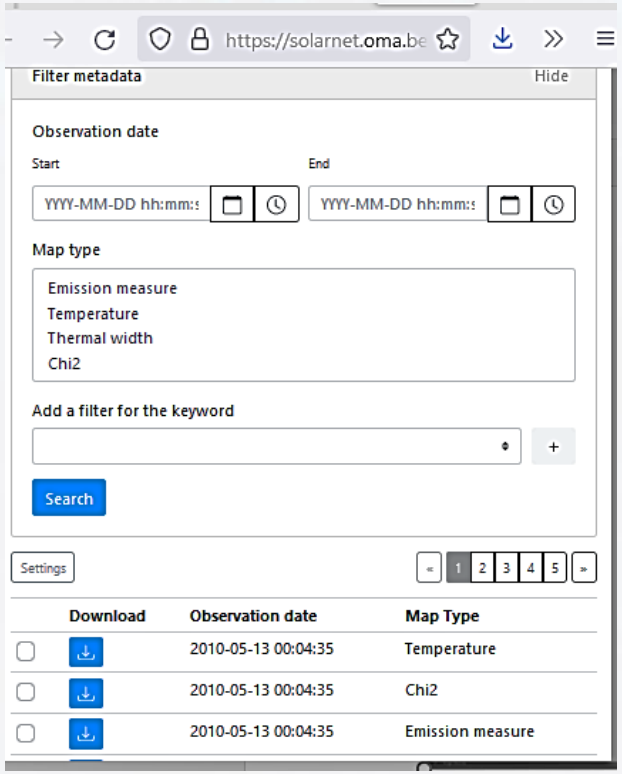
uset : EPN-TAP service exists (still need to be registered) **spoca** : data ready to be ingested in EPN-TAP

Using SOLARNET as a TAP client

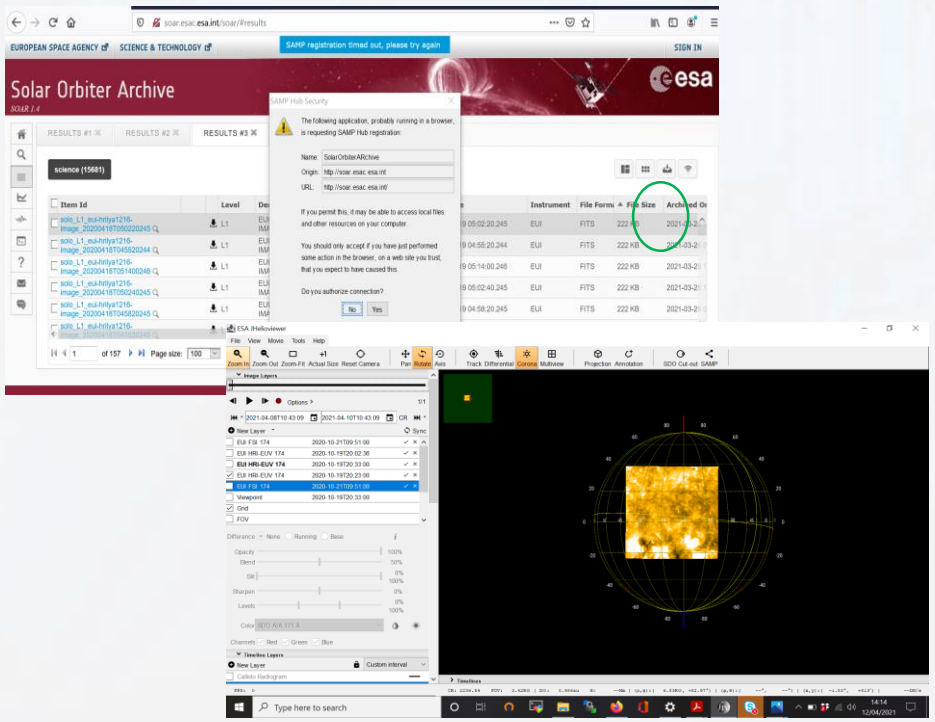
MEDOC – EIT Synoptic maps



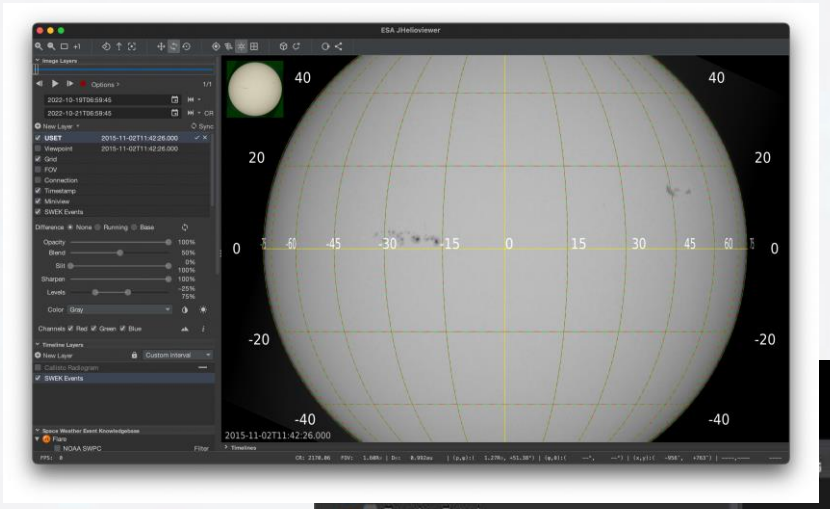
MEDOC – GAIA-DEM maps



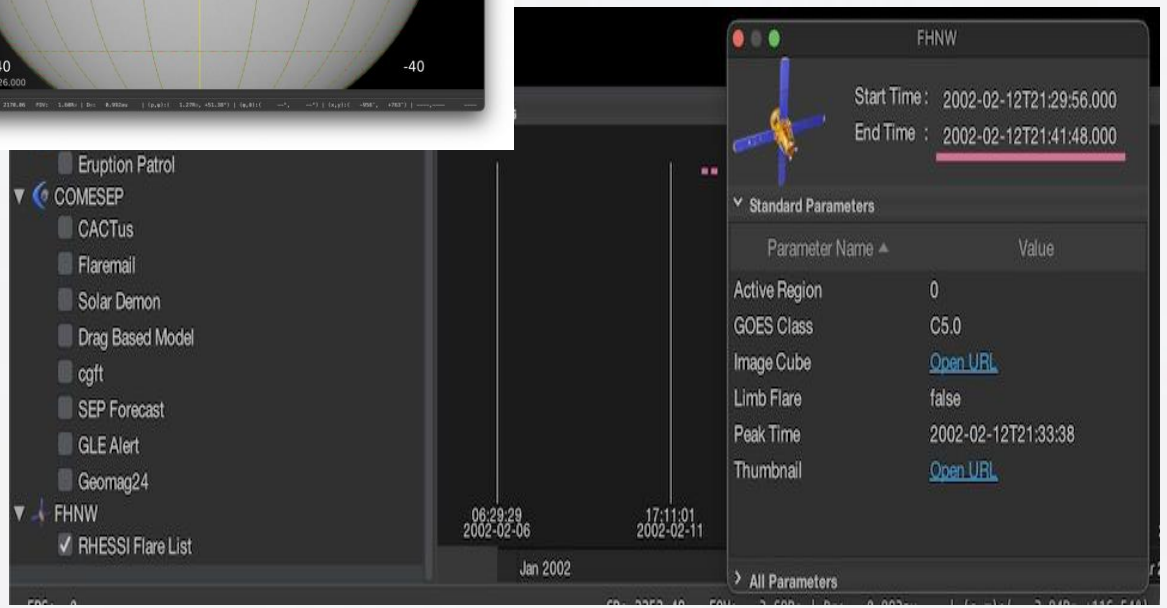
Interoperability with solar visualization tool JHelioviewer



TAP archive of ESA imported via SAMP protocol



USET images imported from SOLARNET



RHESSI Flare list imported from EPN-TAP

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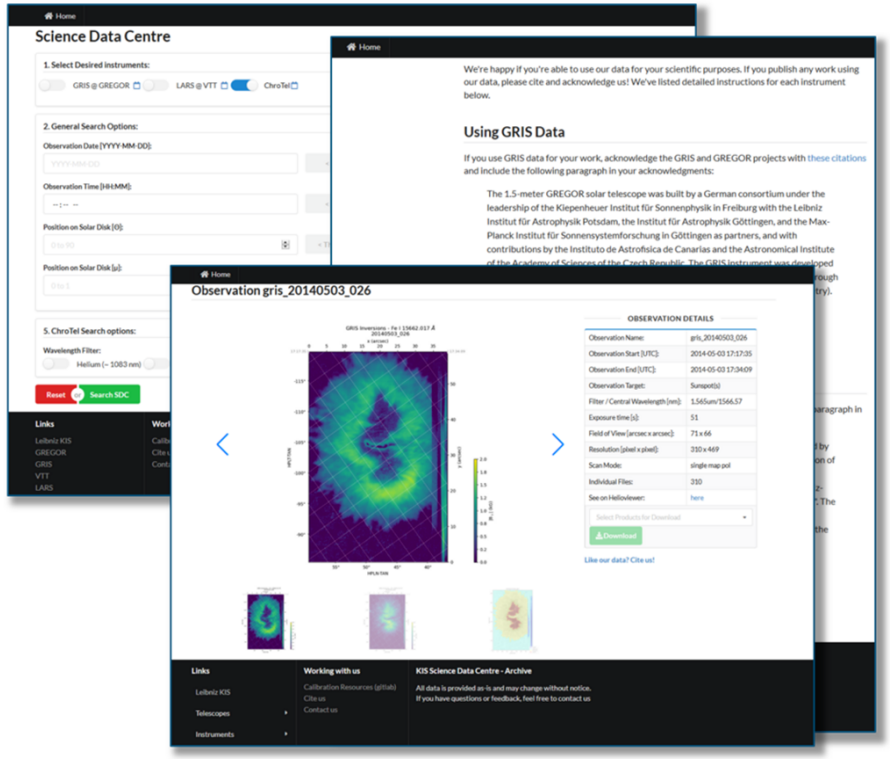
KIS/ EST in ESCAPE WP4

Thanks to ESCAPE WP4, KIS/EST has achieved the following goals:

- Curation of highly-inhomogeneous datasets of high-res ground-based spectro-polarimetric solar data starting from 2014
- Creation of an instrument-independent importing framework
- Proper archiving of the data archive.sdc.leibniz-kis.de
- Implementation of IVOA standards



EPN-TAP publishing of ground-based solar data in the Astronomical VO planned for Nov 2022 in collaboration with M. Demleitner, GAVO (Heildeberg)

This has been a pioneering endeavour within the ground-based high-resolution solar community

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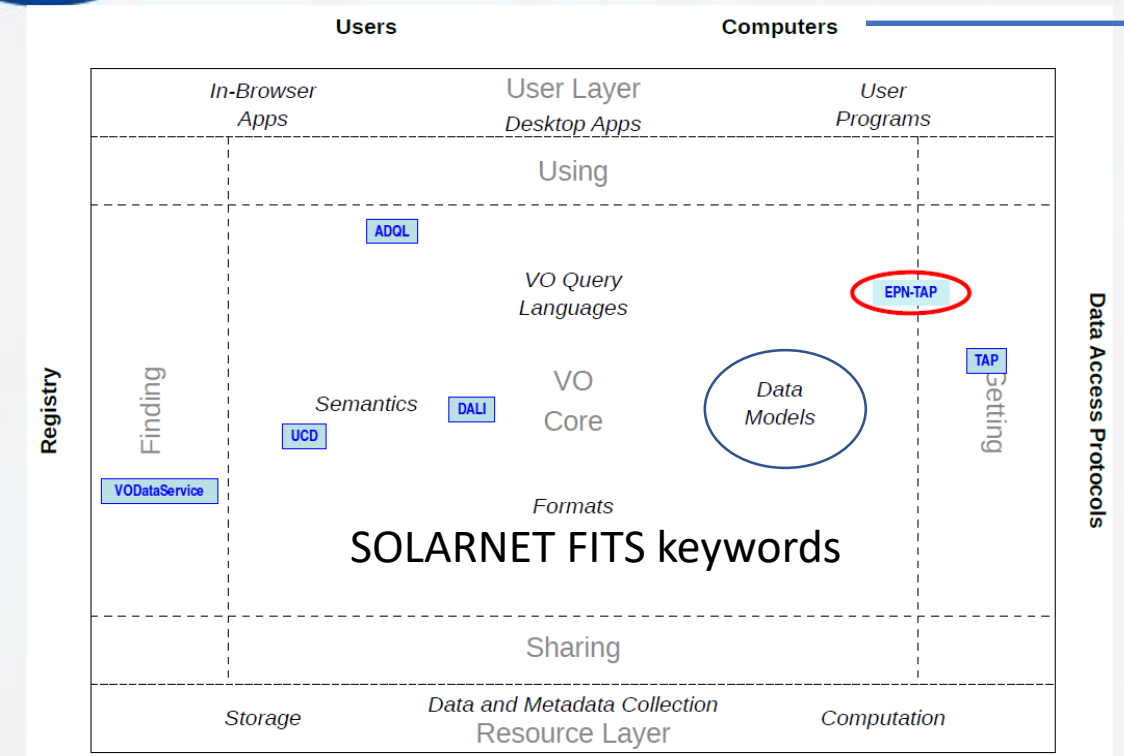
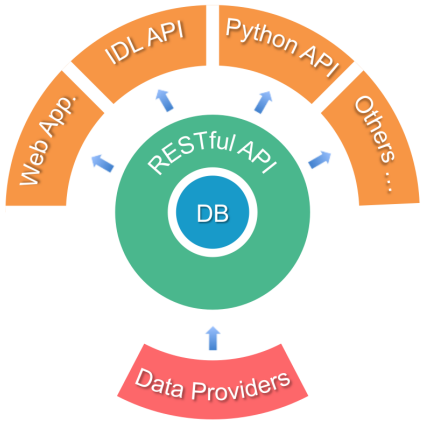
Summary CEVO/EST
… and the future

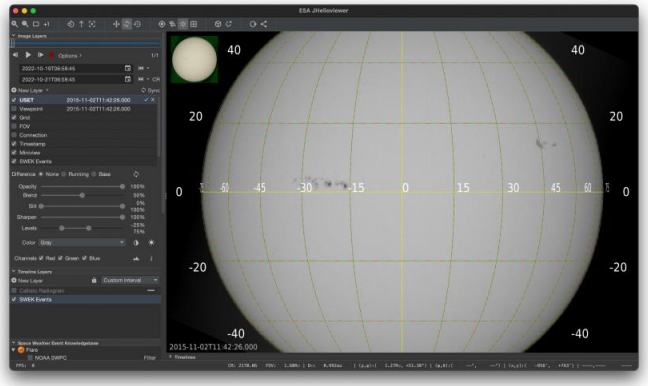


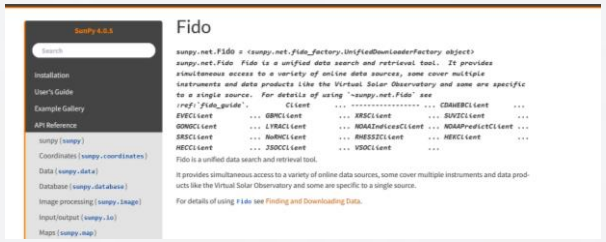
Providers : ground based telescopes (high resolution, synoptic observations)

Dedicated VO



Visualization tool





Python access (pyVo, ‘fido’ search function, etc...)

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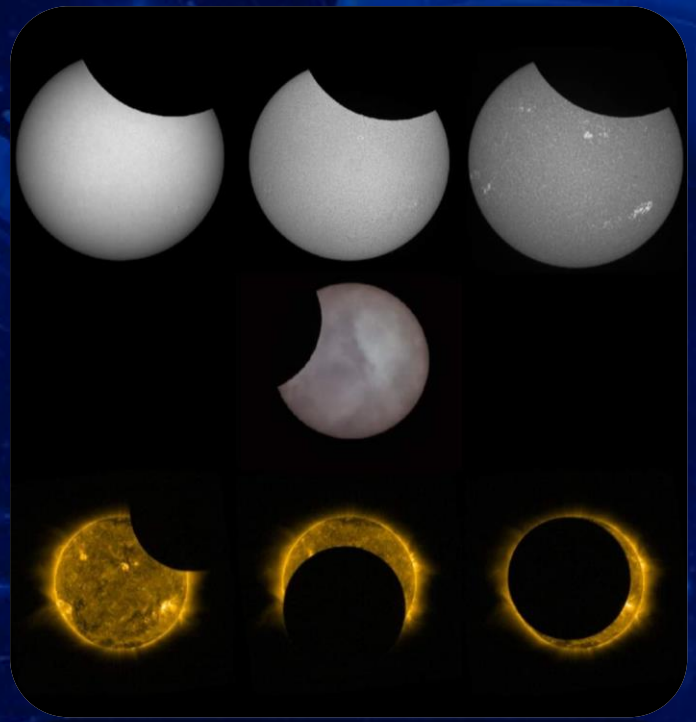
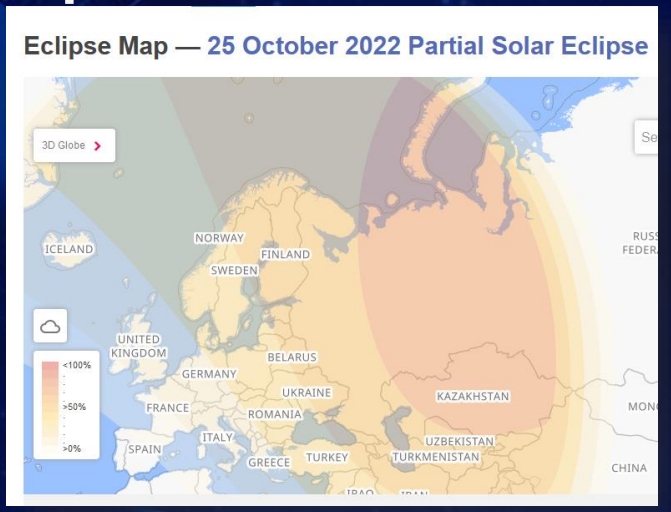


And enjoy the solar eclipse !



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25-26 October 2022
Brussels, Belgium

VO interoperability for visualisation of gravitational-wave sky localisations and strategies of EM follow-up

Giuseppe Greco - INFN Perugia
Mateusz Bawaj, Roberto de Pietri, Marica Branchesi,
Flavio Travasso, Michele Punturo, Helios Vocca and CDS team

EGO VIRGO

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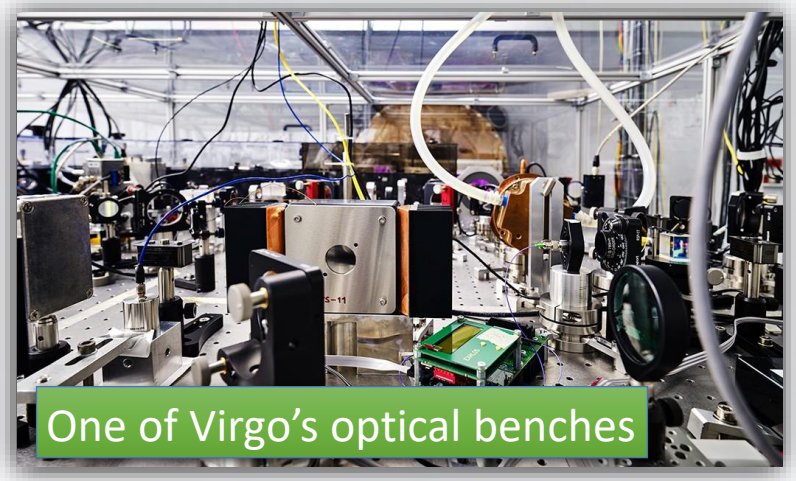
The Virgo interferometer

Aerial view of EGO and Virgo

One of the 3 km long tunnels



One of Virgo's optical benches

One of Virgo's mirrors

The Virgo Collaboration works as a community on the building, development and operation of the Virgo gravitational-wave detector, hosted by the European Gravitational Observatory (EGO) at Cascina, near Pisa, Italy. The Virgo Collaboration works together with the scientists of the LIGO Scientific Collaboration and of the KAGRA Collaboration to form the **LIGO-Virgo-KAGRA (LVK) Collaboration -** *https://www.virgo-gw.eu/about/scientific-collaboration/.*

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The dawn of Multi-Messenger and Gravitational-Wave Astronomy

- GW150914: first gravitational wave detection, BH-BH merger.
- BH-BH binaries exist, and coalesce within a Hubble time at a detectable rate.
- The observation of tens of BH-BH coalescences has revealed a previously unknown population of stellar-mass BHs, much heavier than those detected through the observation of X-ray binaries.
- GW170817: first NS-NS merger, birth of the multi-messenger with GW.
- Neutron star tidal deformability and equation of state constraints.
- Solved the long-stating problem of the origin (at least some) short GRBs.
- The observations of the associated kilonova revealed that NS-NS mergers are a major formation site of the heaviest elements through r- process nucleosynthesis.
- GW200105 and GW200115: Gravitational Waves from Two Neutron Star–Black Hole Coalescences.
- Speed of GWs is the same as the speed of light to about a part in 10:15.
- The first measurement of the Hubble constant with GWs.
- The tail of the waveform of the first observed event, GW150914, showed oscillations consistent with the prediction from General Relativity.
- Several possible deviations from GR (graviton mass, post-Newtonian coefficients, extra polarizations, etc.) could be tested and bounded.
- ....

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MOC (Multi Order Coverage) in action

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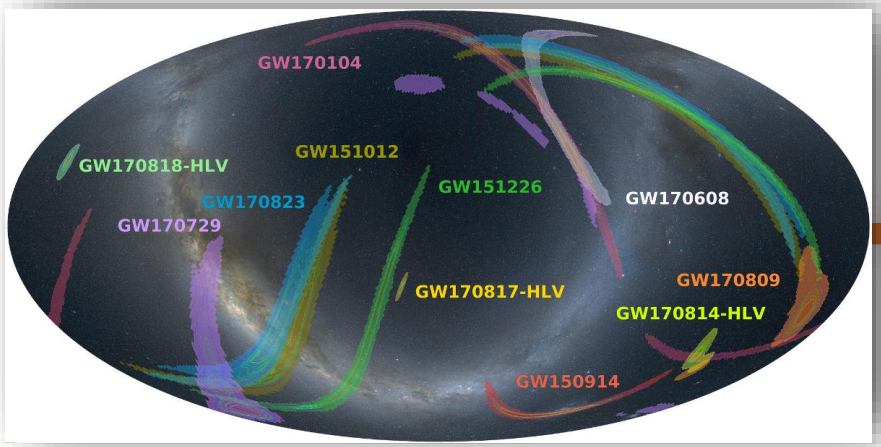
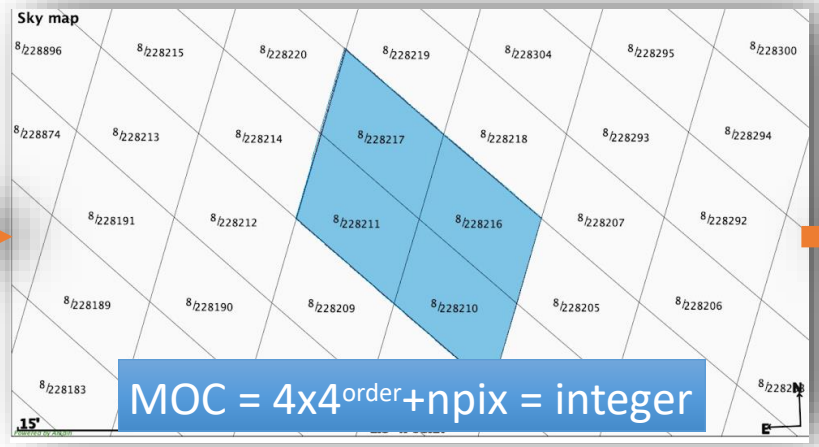
MOC VO Standard to encode GW sky localisations





- We demonstrate that these irregularly shaped and complex sky localisations can be encoded as MOC maps, and how they can be used in visualisation tools, and processed (filtered, combined) and also their utility for access to Virtual Observatory services which can be queried ‘by MOC’ for data within the region of interest. The use of MOC maps allows a high level of interoperability to support observing schedule plans.

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Aladin Desktop in action

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LIGO-VIRGO-KAGRA Public Alert User Guide

Added new sections dedicated to the MOC 2.0

LIGO Scientific Collaboration

VIRGO

Public Alerts User Guide

Primer on public alerts for astronomers from the LIGO and Virgo gravitational-wave observatories.

Navigation

Getting Started Checklist
Observing Capabilities
Data Analysis
Alert Contents
Sample Code

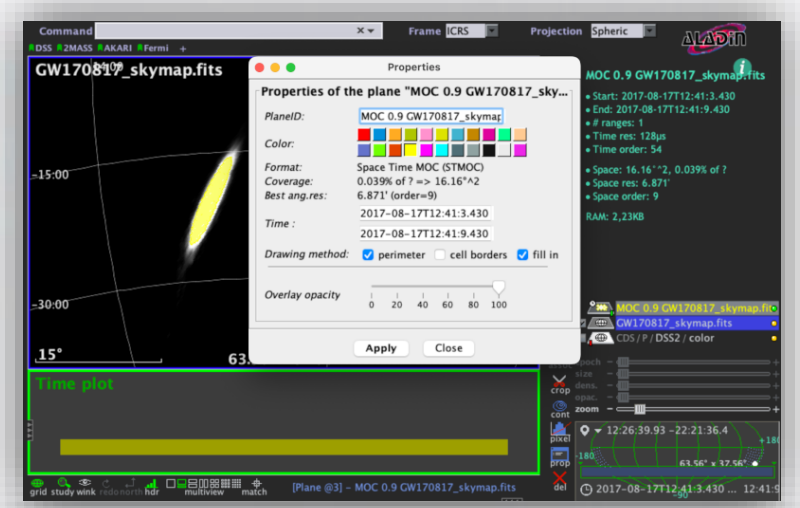
← ligo.skymap: Advanced Python Tools for Probability Sky Maps | Mobile Apps →

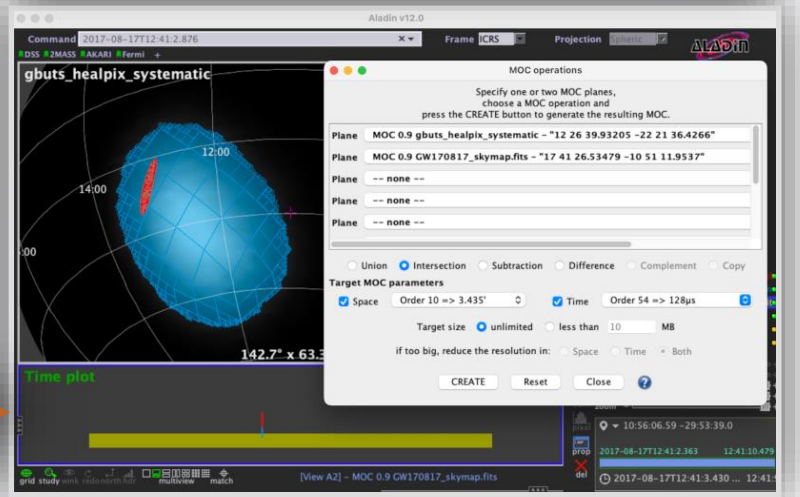
Sky Map Visualizations and Credible Regions in Aladin

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

- 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

- Building a Spatial and Temporal Credible Region
- Spatial and Temporal Coverage Intersections





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Aladin Lite “meets” MOCWasm

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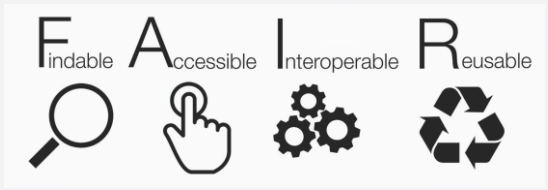
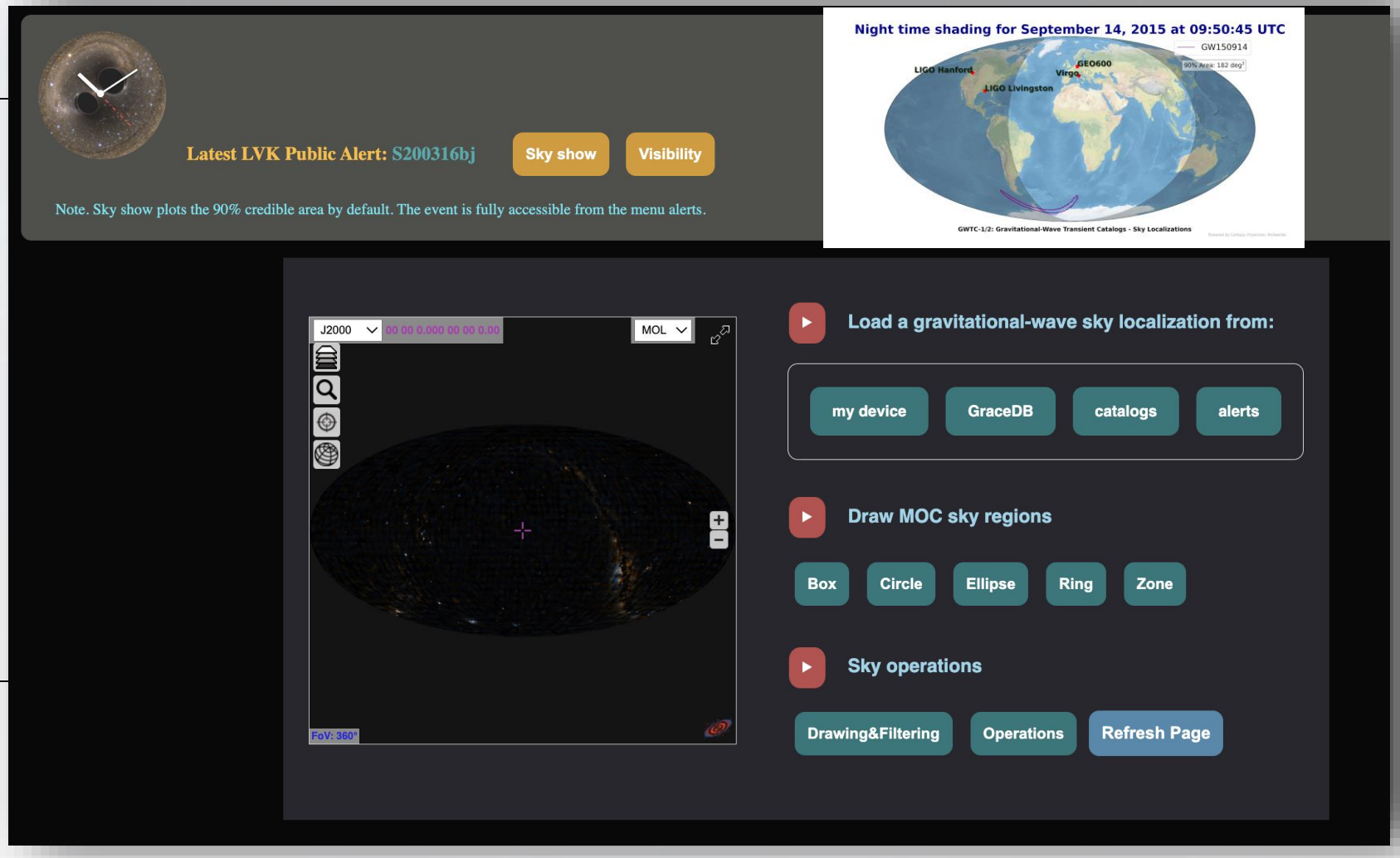
Online Calculator and Interactive Viewer of Credible Areas

- The webtool organizes all the skymaps released by the LVK collaborations both in low latency and catalog publications.
- Users can locate EM transients and perform dedicated operations.





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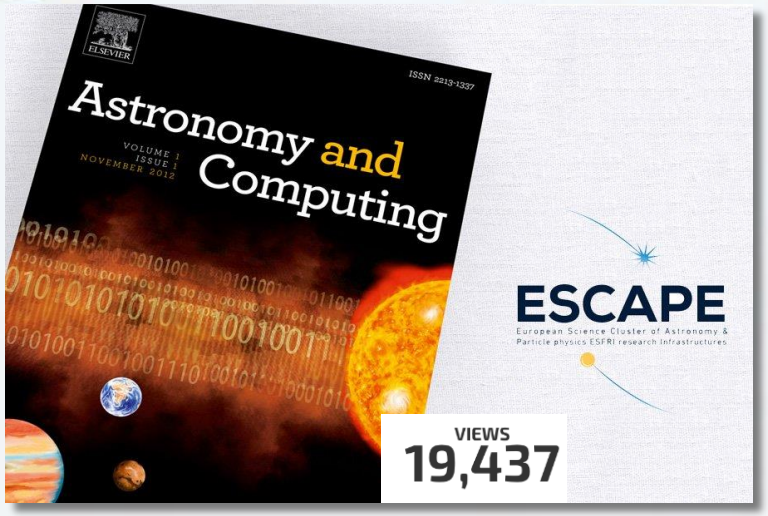
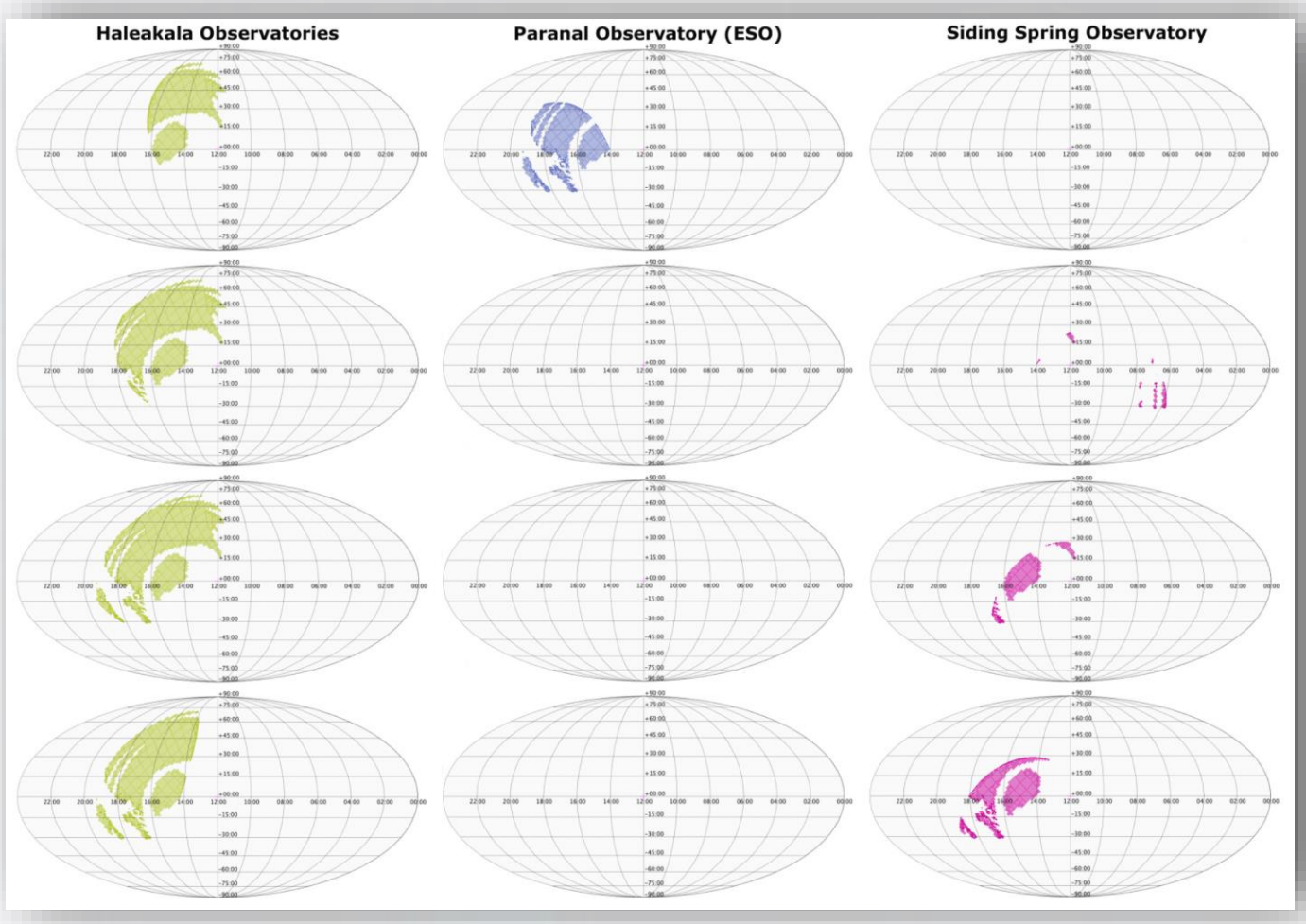
Multi Order Coverage data structure to plan multi-messenger observations





- Visibility MOC maps of a gravitational-wave sky localisation.

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Educational and outreach

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Universities, training schools, festivals and disseminations

- VO ESCAPE schools.
- LVK Open data workshop.
- Learning activities at the University of Perugia.
- Bachelor's and master's degree theses at the Camerino and Perugia Universities presented to ADASS2021/2022 conferences.
- PhD thesis (UniPG): Evaluation of catalogues completeness by extending the Virtual Observatory framework to estimate the H0 Hubble constant with dark standard sirens.
- Dissemination material for outreach, news and press releases.
- Science Festivals.

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Einstein Telescope: third-generation gravitational-wave observatory

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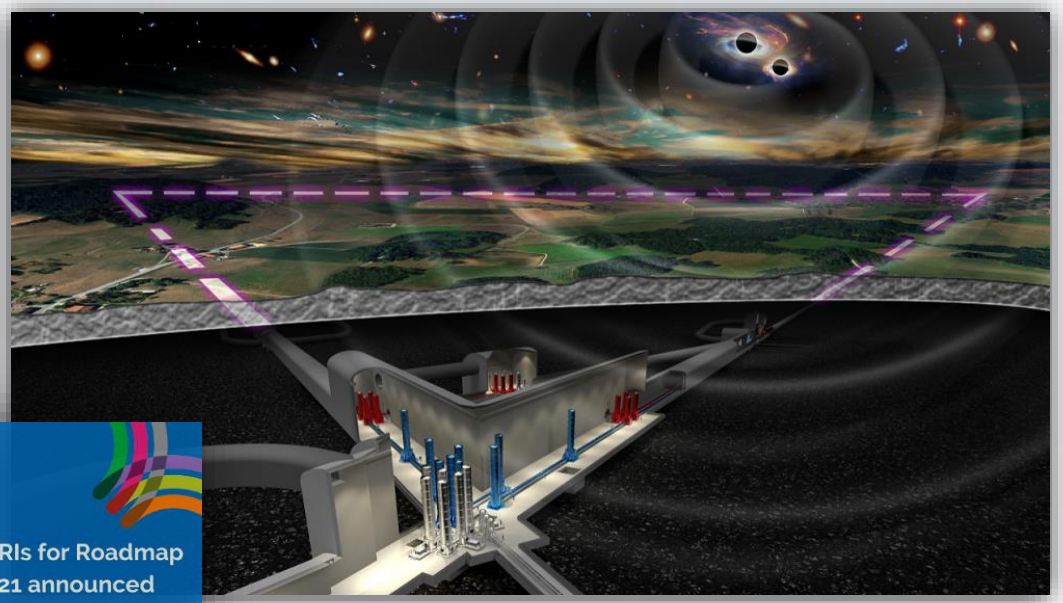
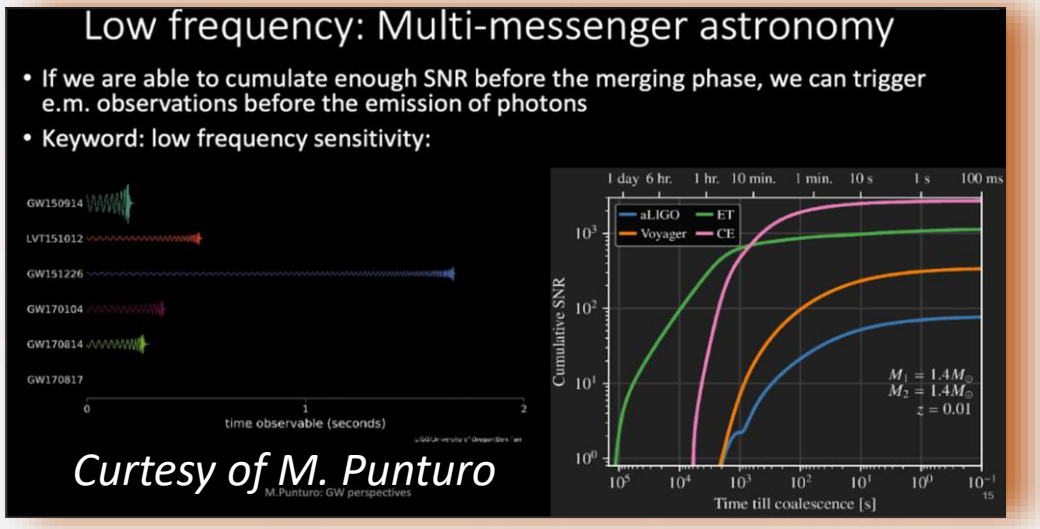
Einstein Telescope approved for ESFRI Roadmap 2021

Looking ahead

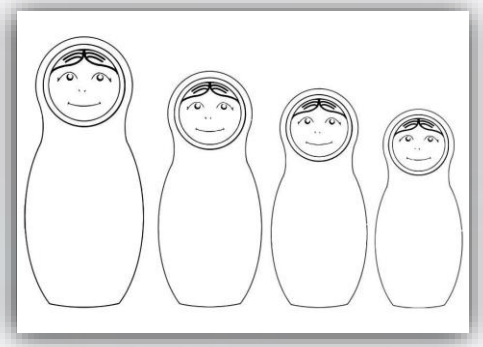


ET - **E**instein **T**elescope, the first and most advanced third-generation gravitational-wave observatory, with unprecedented sensitivity that will put Europe at the forefront of the Gravitation Waves research

https://www.esfri.eu/latest-esfri-news/new-ris-roadmap-2021.



MatryoSKY



A Nested skymap system

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JIVE

A VO service for the European VLBI Network

Mark Kettenis, Software Project Scientist
Joint Institute for VLBI ERIC

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EVN & JIVE

- European VLBI Network (EVN)
  - Very Long Baseline Interferometry
  - High-resolition radio astronomy
  - Europe and beyond!
- Joint Institute for VLBI ERIC
  - operates the EVN correlator
  - provides support to EVN users
  - hosts the EVN Data Archive

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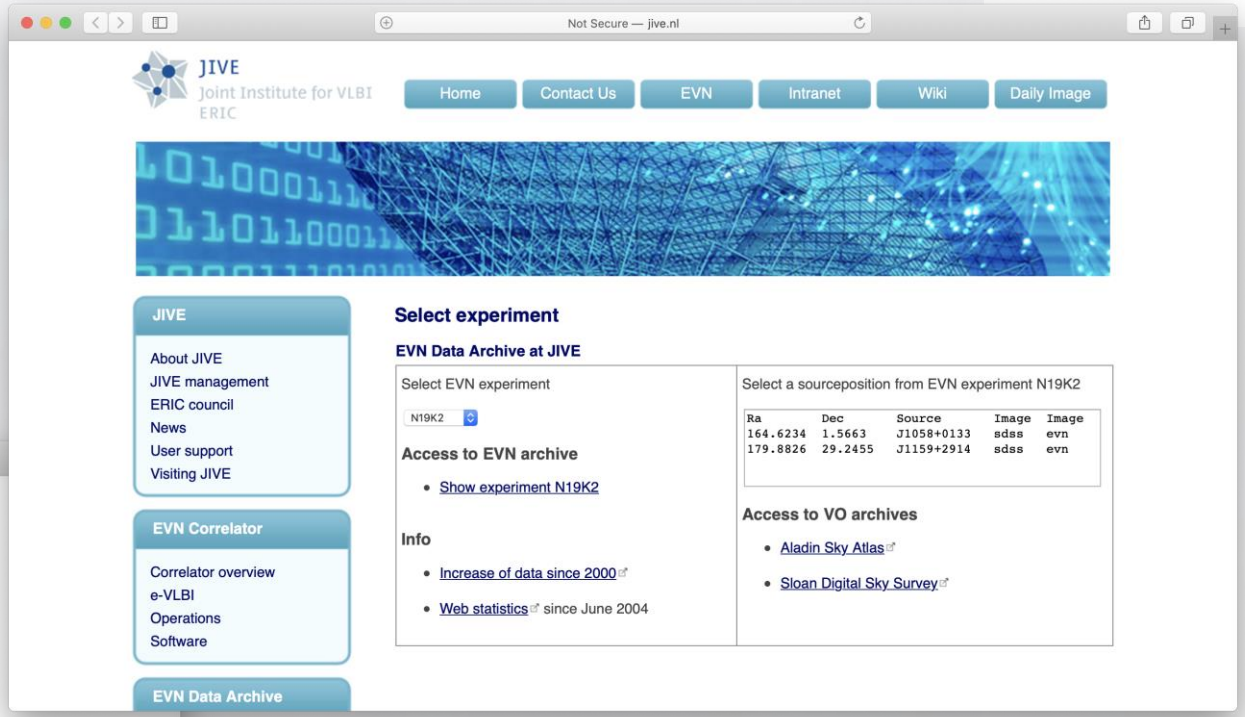
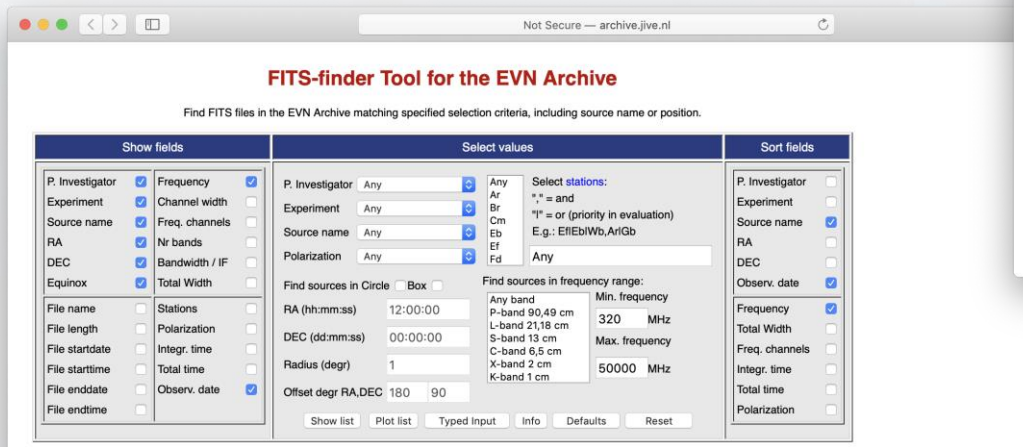
EVN Data Archive

- Searchable archive of most EVN observations since 1998
- Most data is public
- Users complain search is slow!





- But is it findable?
  - Registered with re3data.org

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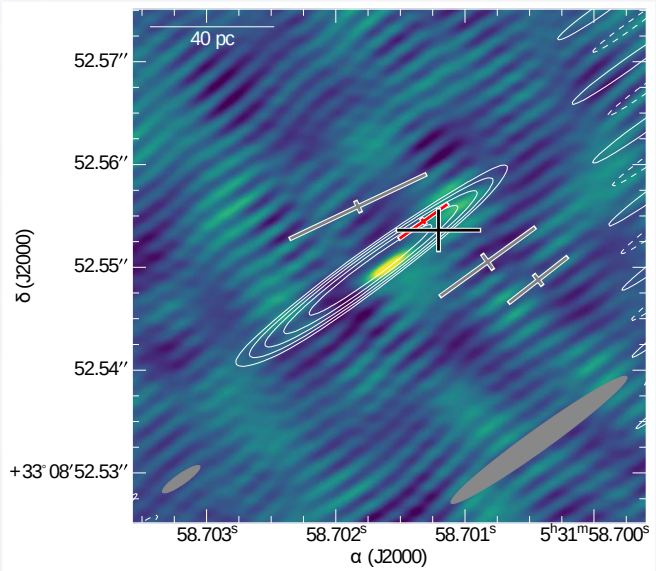
VO protocol use cases

- Access to historic data for high-resolution follow-up
  - Gravitational Wave events
  - Gamma Ray Bursts
  - Fast Radio Bursts

  (EOSC Future: The Extreme Universe and Gravitational Waves)

- Standardized access to archival data for science platform
  - JupyterLab environment (talk by Aard Keimpema)



EVN localization of FRB 121102
B. Marcote *et al* 2017 *ApJL* **834** L8

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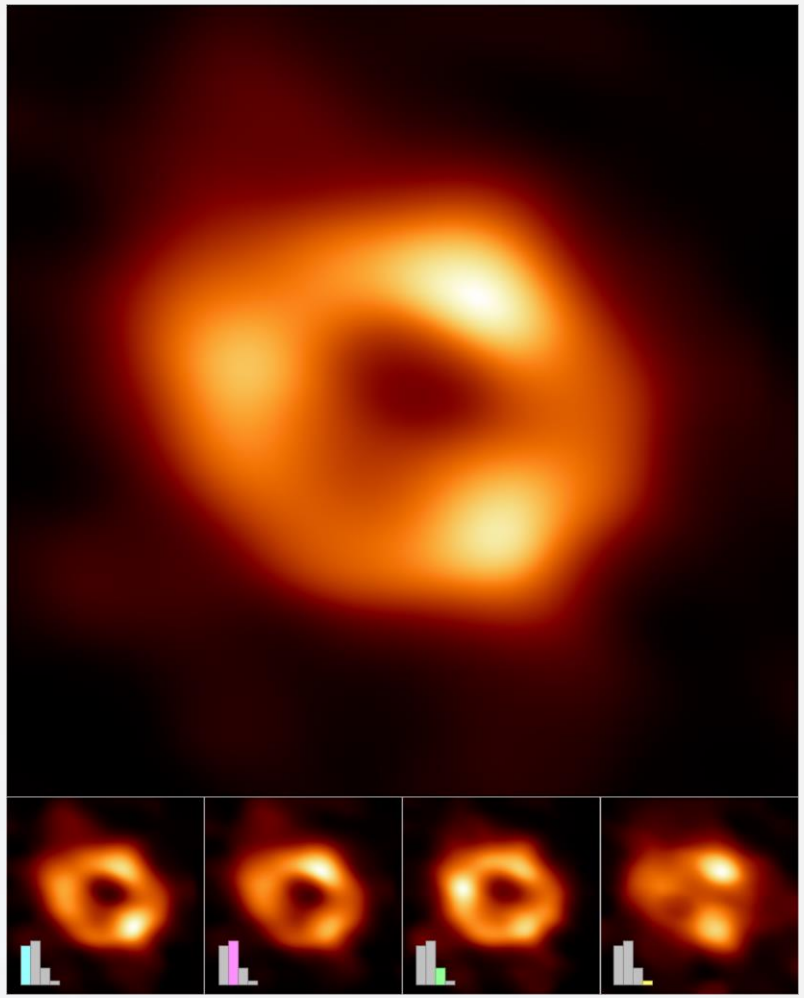
VLBI data is different

- Visibility data; not images!
  - Requires further processing to make images
  - Algorithms & parameters depend on science goals
- Observation properties not well defined:
  - Footprint depends on desired sensitivity
  - Potential gaps in spectral coverage
- Multiple sources per data set
  - Calibrators are essential for imaging targets

Discussion with ESCAPE CEVO partners and IVOA Radio IG were essential to get metadata right!



Credit: EHT Collaboration

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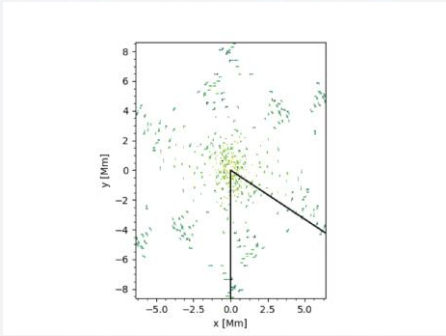
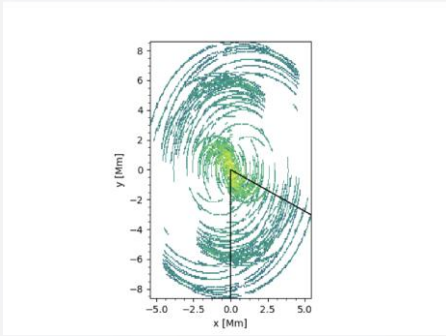
IVOA

- JIVE participates in the IVOA Radio Interest Group
  - Contributed to Implementation Note
    - Descriving JIVE use-case and implementation
    - https://www.ivoa.net/documents/Notes/RadioVOImp/index.html
  - Contributes to Radio Obscore Extension
    - Characterization of UV (visibility) coverage
      - excentricity and filling factor
    - Frequency vs. Wavelength
    - https://github.com/ivoa/ObsCoreExtensionForVisibilityData





ESCAPE CEVO was instrumental in getting the IVOA Radio IG going!

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VO Protocols used in our service

- ObsTAP (Table Access Protocol serving ObsCore metadata)
  - Provides metadata describing observations
- DataLink
  - Used to link together dataset components
  - Used to link to calibration information
  - Will be used to add preview images and diagnostic plots

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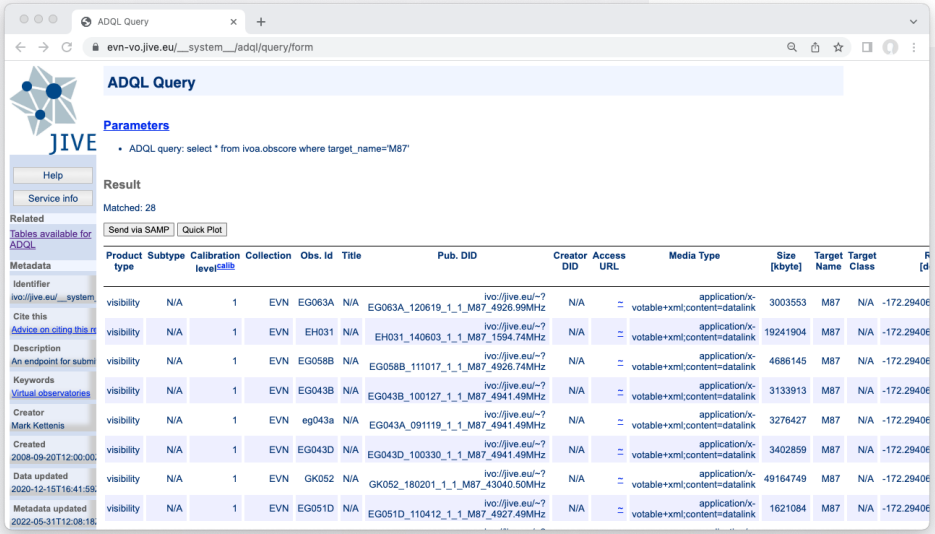
Implementation of the service

- Based on DaCHs
  - Customized resource description
- Custom software for ingest (fitscrawler)
  - Extracts metadata from FITS-IDI files
  - Written in Python
  - Open Source: https://github.com/jive-vlbi/evn-vo (BSD 3-clause)
- Runs on top of existing archive
  - Datalink URLs point to existing server



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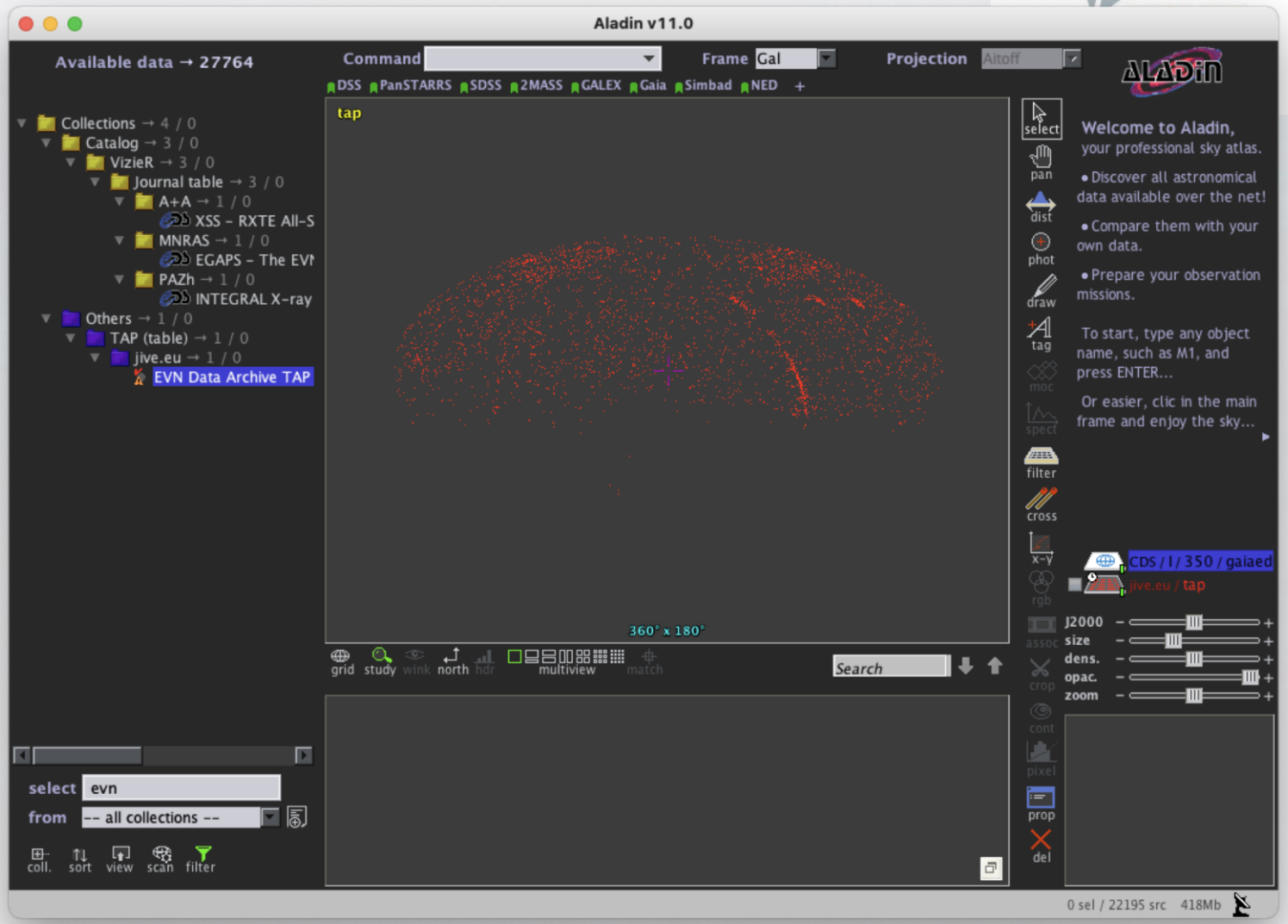
Registering the service

- DaCHS conveniently implements a registry
- Registering that registry makes published services findable
- EVN Data Archive shows up in Aladin



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Conclusions

- The EVN Data Archive is now much more **F**indable
  - DOIs will be available soon!
  - TAP service is fast
- VO protocols already used to implement other services
  - Science platform
- Help from ESCAPE CEVO and IVOA Radio IG was essential for getting metadata right
- Help from Markus Demleitner (GAVO/Universität Heidelberg) really useful to get DaCHS running (ESCAPE CEVO workshops)
- Further improvements planned!

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Future perspectives

Mark Allen and François Bonnarel

CDS, Observatoire astronomique de Strasbourg

For WP4, ‘CEVO’

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Future outlook of VO in ESCAPE and EOSC

Integration of astronomy VO data and services into the EOSC

- Next big step is to use evaluate/use the new *'enhanced EOSC Resource Catalogue'* for on-boarding of 'data sources'

FAIR principles for data through the Virtual Observatory

- ESCAPE has built capacity within ESFRI/RIs to become actors in defining the standards.
  Future : Implementation / Coordination / Innovation / Scaling up
- Continue networked approach – Standards, Data, tools/services, Training

Integration in platforms, virtual research environments

- Within ESCAPE, but also beyond: space agencies and major observatories and data centres
- Coordination of European efforts necessary to continue global impact

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Thanks!