Interoperability in Multimessenger Astrophysics

1st Astro-COLIBRI Multimessenger Astrophysics Workshop

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CENTRE DE DONNÉES ASTRONOMIQUES DE STRASBOURG

IVOA

Observatoire astronomique de Strasbourg | ObAS

Index

- Interoperability, the VO and the IVOA
  - What, Who, Where, How, When?
- (Some of the) Multimessenger needs
- Does the IVOA cover those needs?
- VOEvent, status and future evolution?

Interoperability

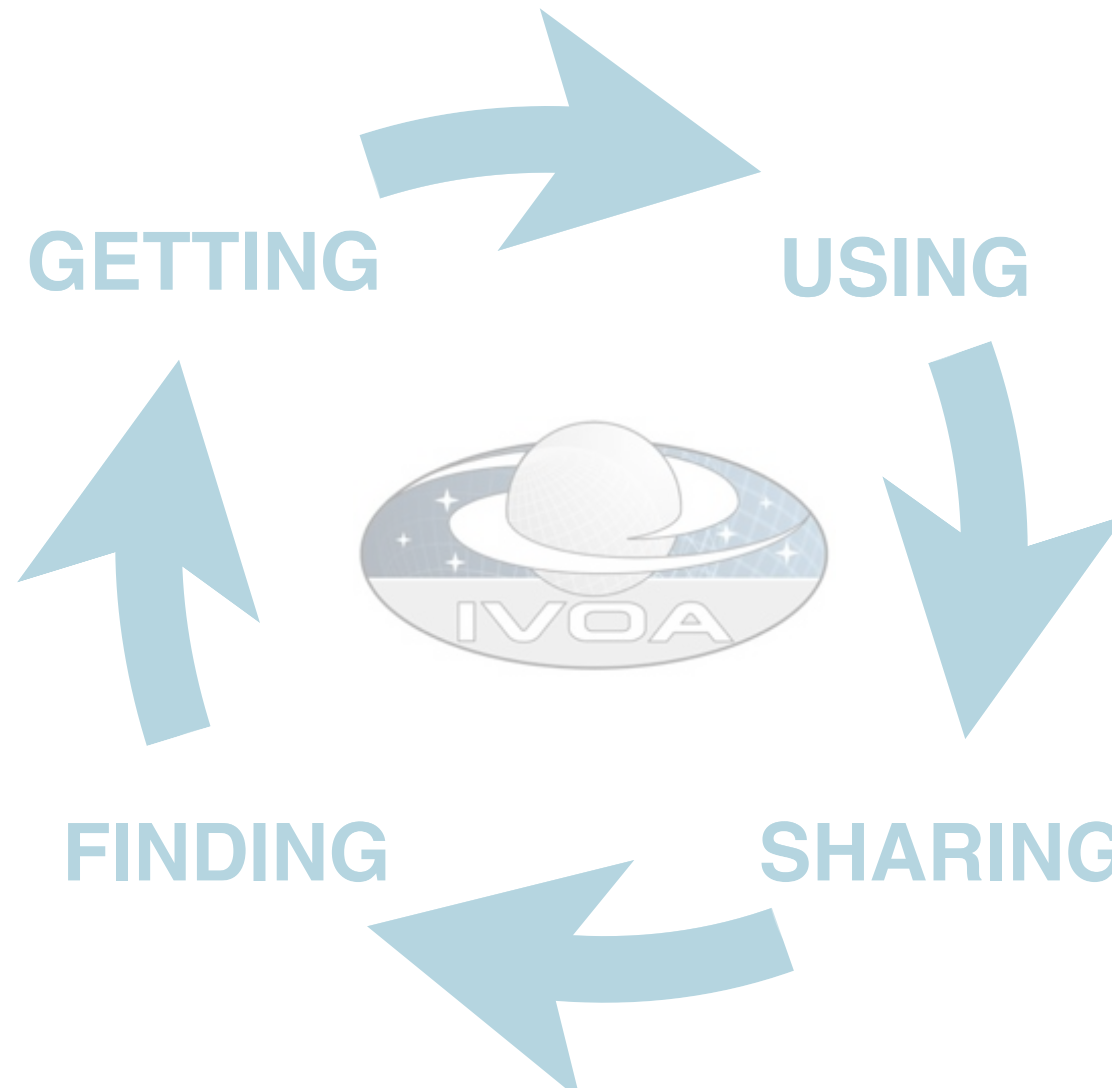
- Few definitions:
  - Interoperability:
    - “The ability of computer systems or software to exchange and make use of information.”
    - “The ability of different systems, devices, applications or products to connect and communicate in a coordinated way, without effort from the end user”
  - The Virtual Observatory: “Framework for astronomical datasets, tools, services to work together in a seamless way”

The VO and the IVOA: what?

The VO : "A multi-wavelength digital sky that can be searched, visualised and analysed in new and innovative ways"

What is the International Virtual Observatory Alliance?

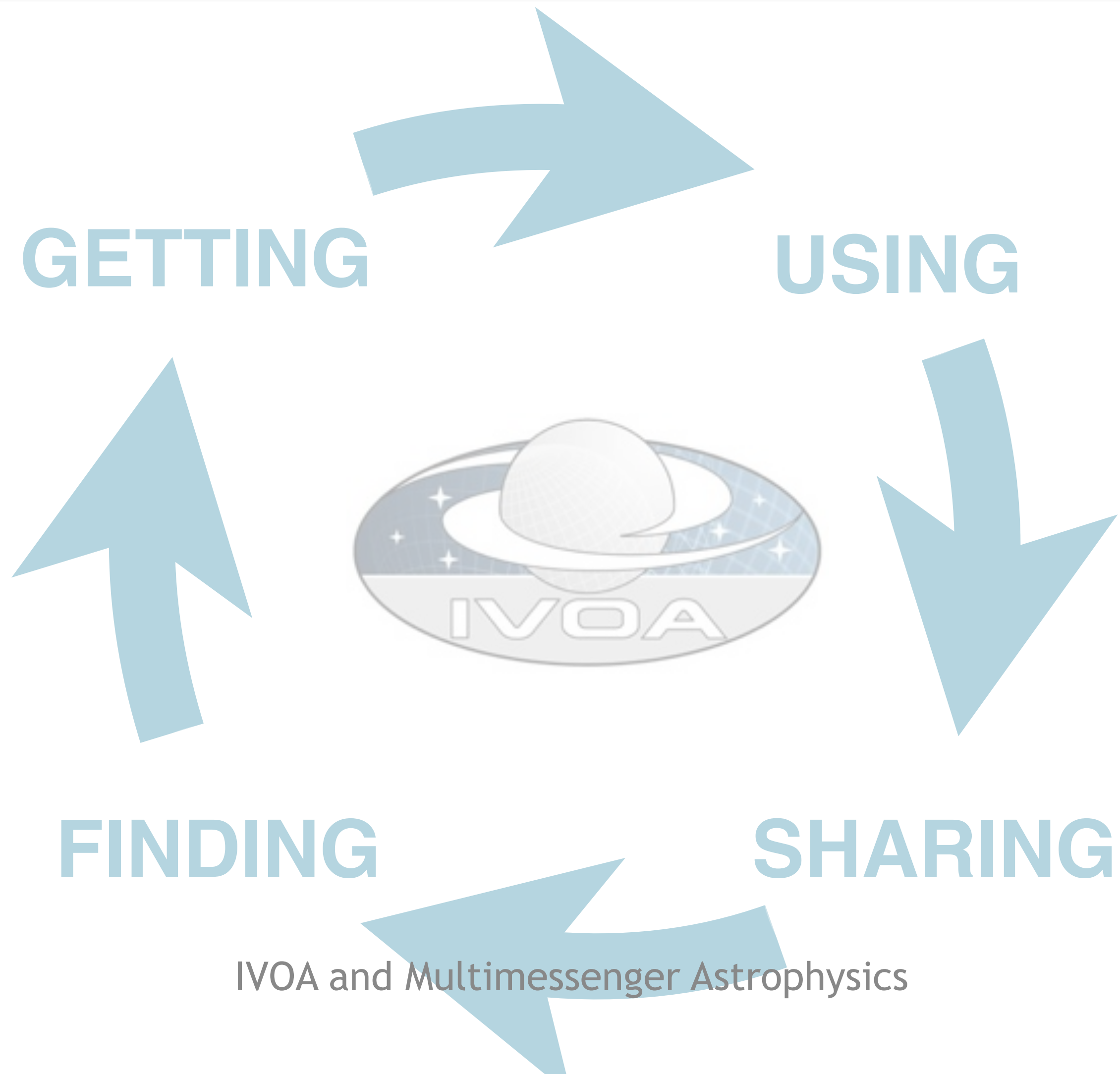
- A science driven organisation that builds the technical standards
- A place for discussing and sharing VO ideas and technology to enable science
- Promoting and publicising the VO



The VO and the IVOA: why?

Clear benefits

- Growth in the scientific return of data
- Capability to discover and fuse multiple data sets
- Application of the VO in planning new observations and observing strategies



The VO and the IVOA: who?

Who is the IVOA?

- **5 Committees:** Exec, Tech Coordination, Standards & processes, Media, Science priorities
- **6 Working Groups (WG):** Applications, data access, models, grid & web services, registry, semantics
- **8 Interest Groups (IG):** **Time-domain**, radio, solar system, theory, operations, data curation, knowledge & discovery, education

Want to get involved?

- Meetings: 2 interoperability meetings per year
- Don't know where to start? Email any chair/vice-chair of a IG/WG, CSP

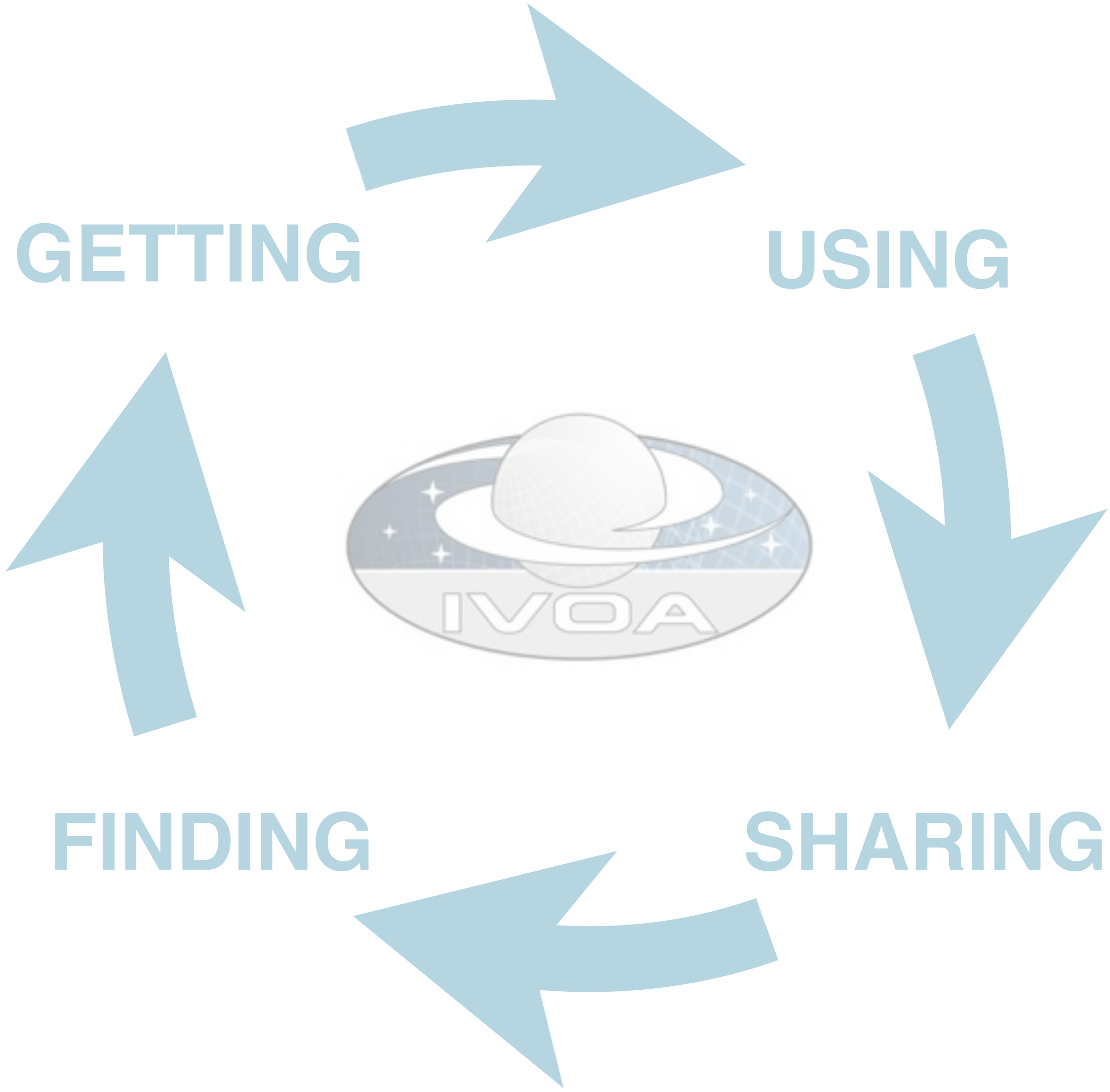
http://ivoa.net/

The VO and the IVOA: where?

Existing global framework: populated by major data providers (space and ground based) that is heavily used by the community (e.g. Gaia data access is fully VO)

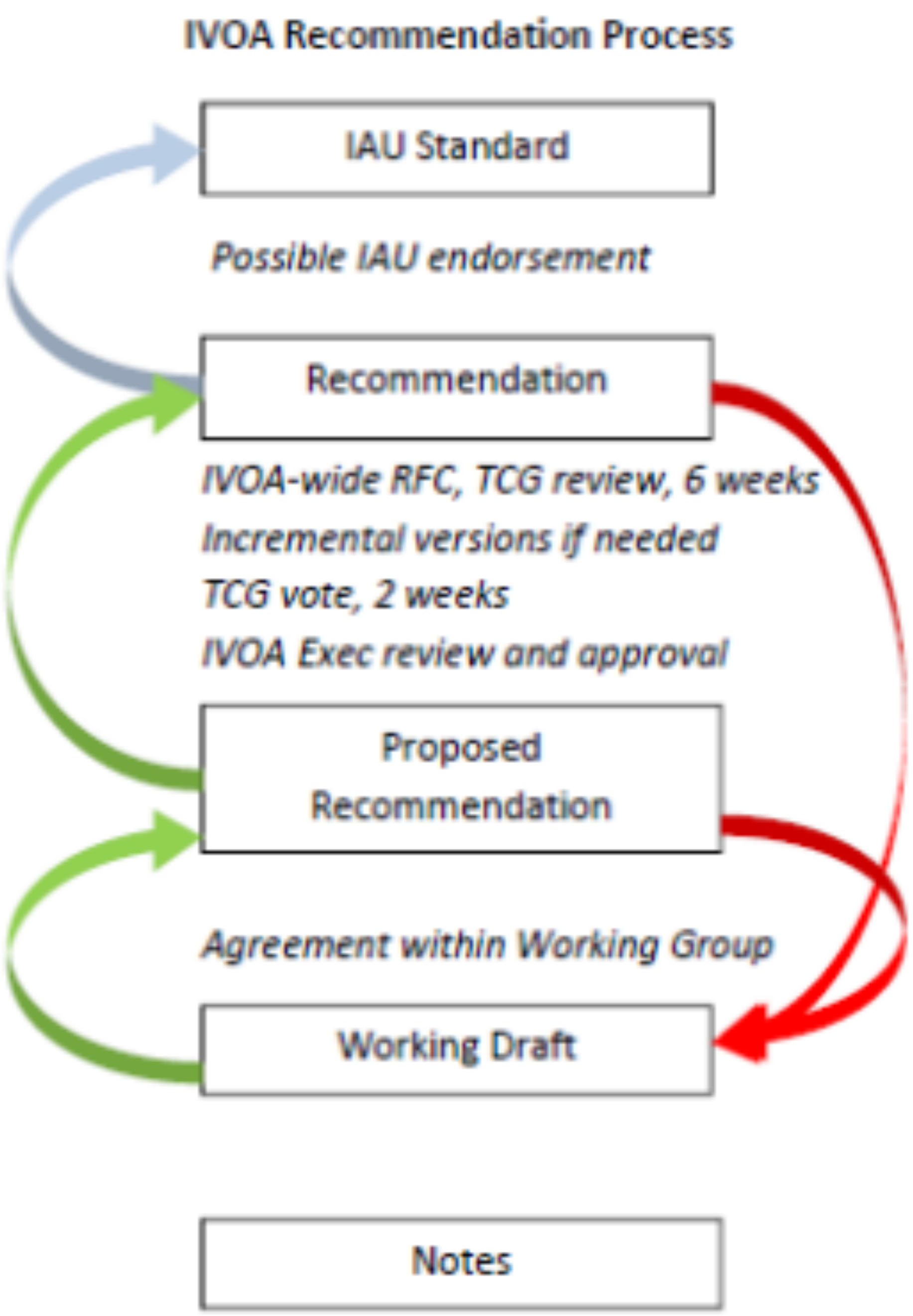
The VO and the IVOA: how?

Through the development and adoption of common standards scientifically driven, as an international community effort where astronomers and software engineers are involved



IVOA development process of standards

- Build IVOA standards to match users needs:
  - Find and report the community needs
  - Find and report gaps in the existing standards
  - Propose new ways to fill the gaps
  - Implement & validate
  - Standardise when consensus is reached



OK, but where do I start?

- A good starting point to newcomers to the IVOA: **the architecture document**

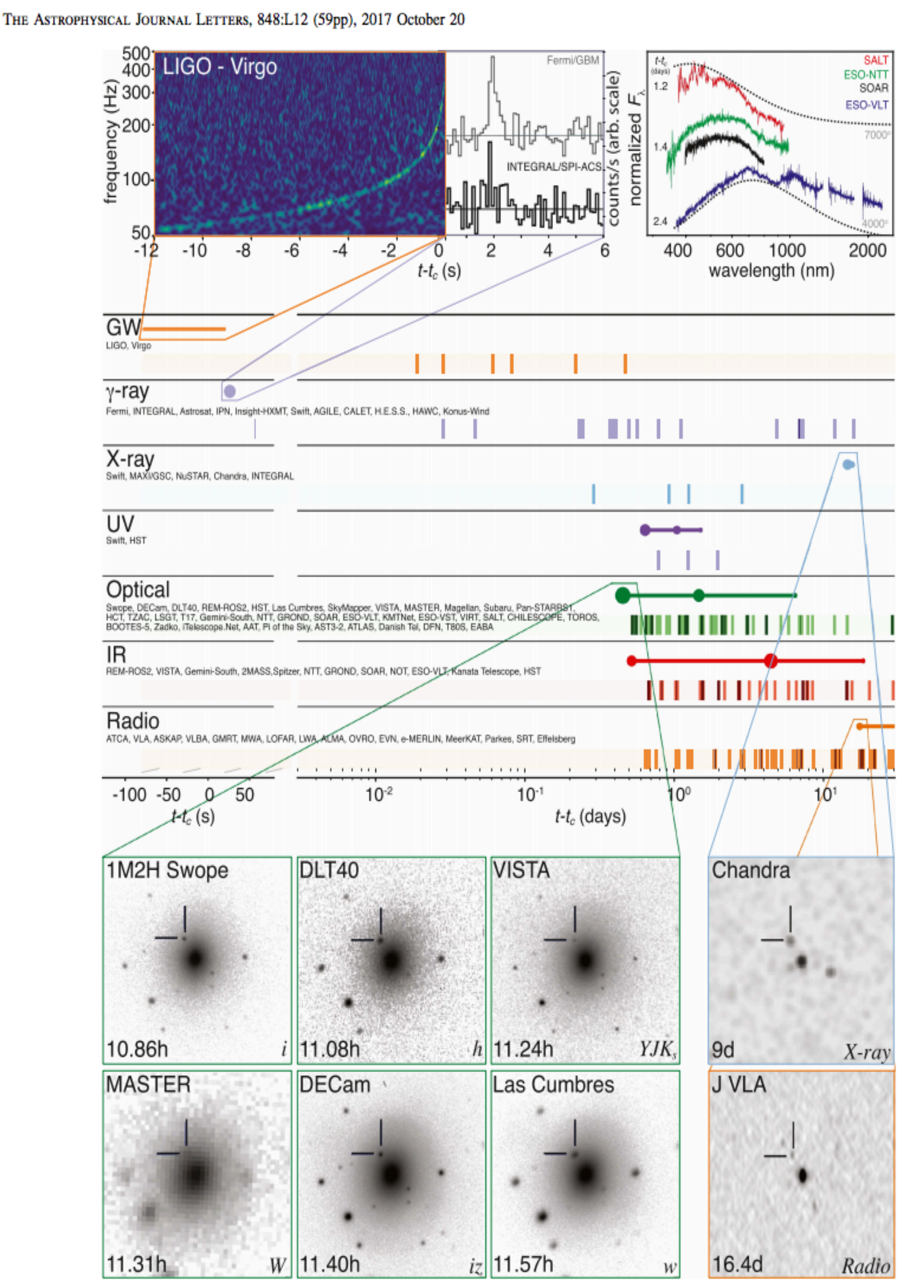
  https://www.ivoa.net/documents/IVOAArchitecture/20211101/index.html

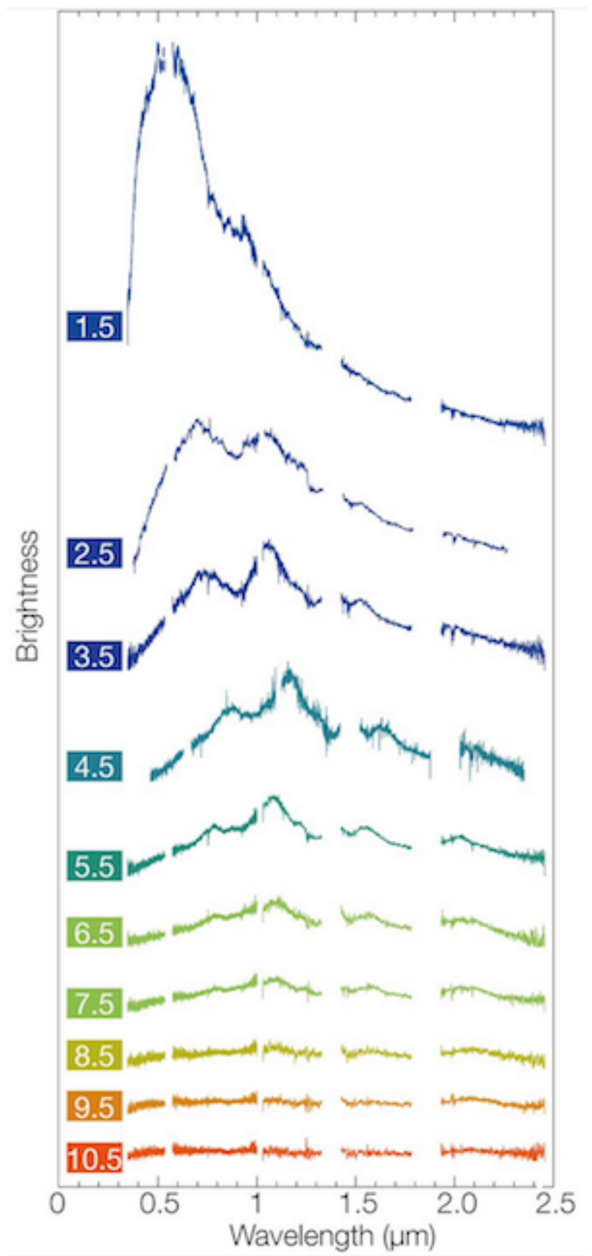
Things to keep in mind:

- The IVOA will not answer your scientific questions nor will it ask the questions for you
- The IVOA provides you with common formats and common ways of describing and accessing the data which when adopted will ease your work

Let's see it with an example

Multi-messenger needs?





- Multi-wavelength / messenger approach is needed - different data types
- Follow-up observations and reaction time for that can be crucial - alerts
- Analysis, Visualisation & navigation through the data
- Coordination & transmission of information

The IVOA should match user's needs

Some selected standards

1. **VOTable** the format for tabular data for allowing interoperability (coosys, timesys, ucd, utype, VOunits, datalink).
2. **HiPS** more than a format for images - tailored for large data volumes
3. Search for data:
    - **Cone search** — spatial + temporal search
    - **MOC** — spatial and temporal indexing for large data volumes and more complex areas in the sky
    - **TAP + ADQL** — Table Access Protocol & astronomical data query language
    - **ObsCore & ObsTAP** — description of observations
4. Planning of observations:
    - **ObjVisSAP** — visibility of object to plan observations
    - **ObsLocTAP** — facilitate coordination of observations
    - Facilities / observatory list (under dev.)
5. Alerts: **VOEvents**
6. **… many more! SLAP, SIAP, SSA, Provenance, SAMP… each tailored to specific use cases**

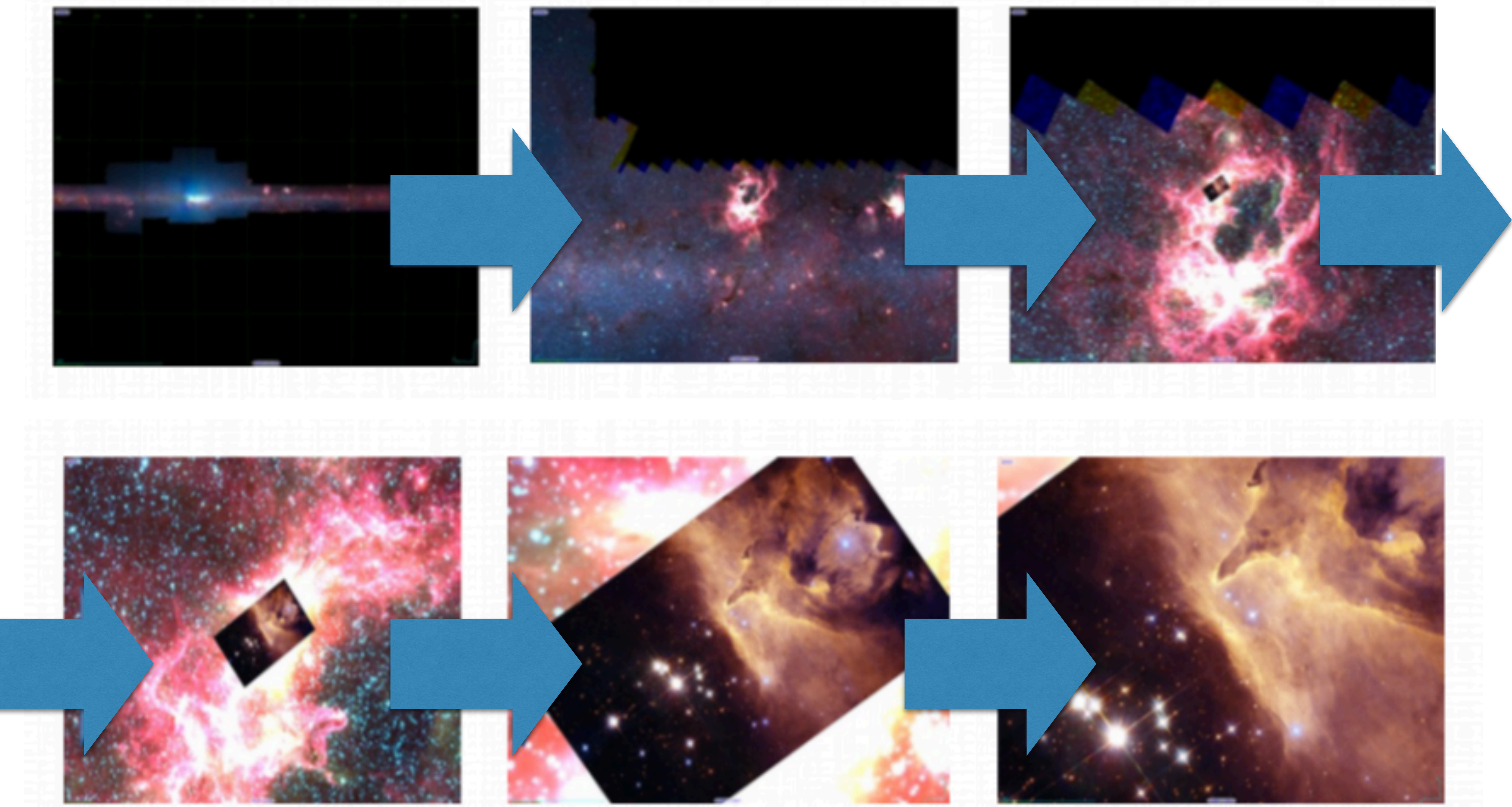
VOTable: format for tabular data

Standardisation of coordinate system annotation (time and space), UCD, utypes, VOUnits, datalink

- **COOSYS** ("ICRS", “eq_FK5”,…)
- **TIMESYS** (scale: TT, TAI, …, refposition: barycenter,… timeorigin: JD, MJD,…)
- **Unified Content Descriptor** (**UCD**): controlled vocabulary for describing astronomical data quantities - related to the nature of the values
- **UTypes:** relationship between the columns and the data model components
- **VOUnits:** units expressed as a simplified text label (e.g. m.s-2 instead of m s^{-2})
- **Datalink**: links to other associated data

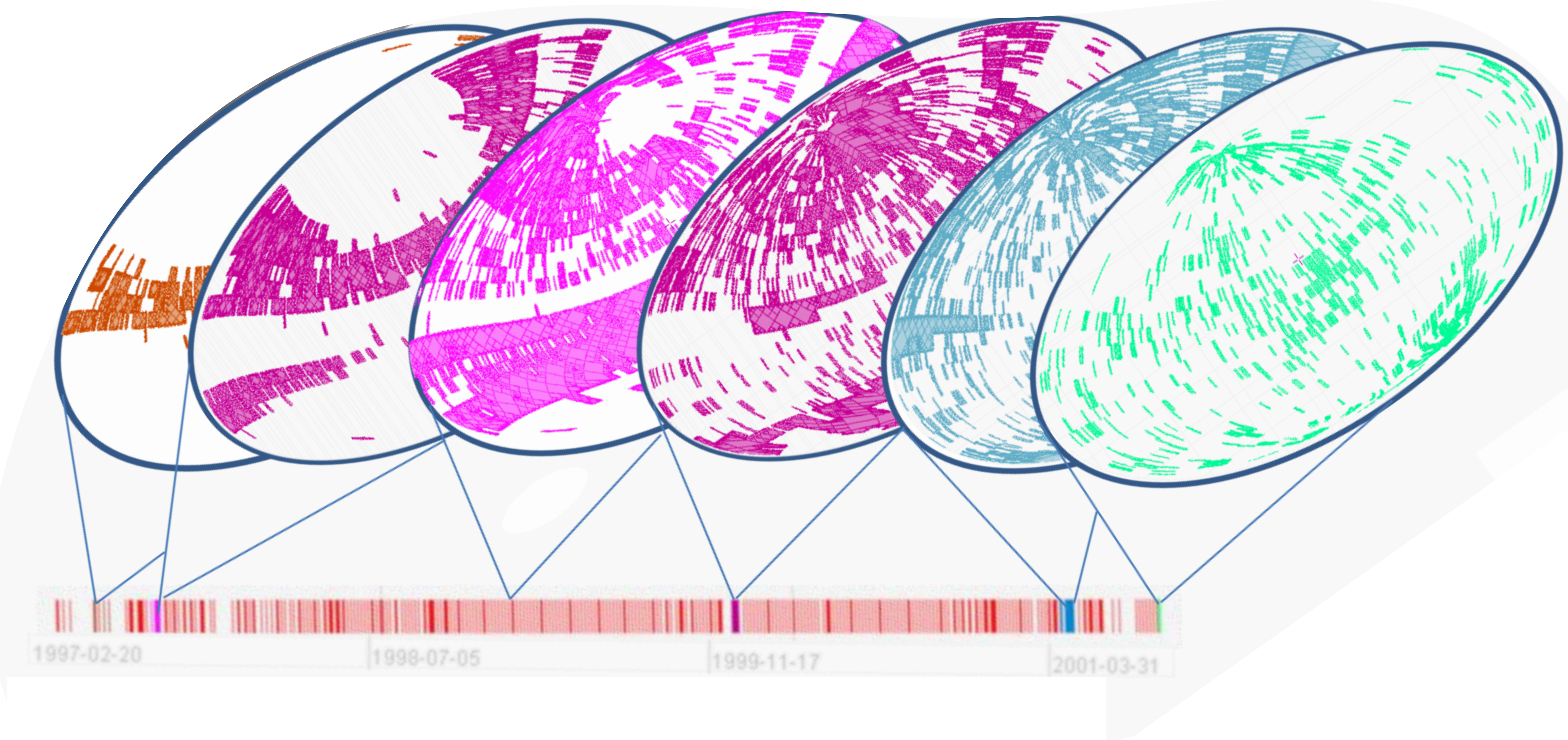
HiPS: Hierarchical image Progressive Survey

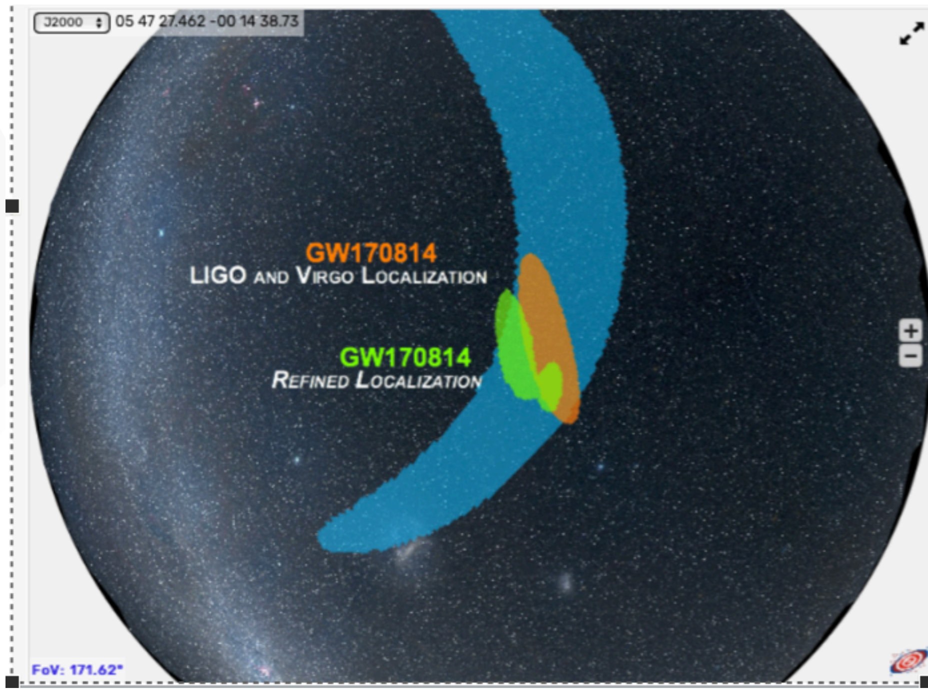
- A hierarchical scheme for the description, storage and access of sky survey data (the more you zoom-in the more the details)



Search: know where & when

- **Cone search** extension to add a time interval for search in catalogs
- **MOC** : allows to search by temporal+spatial coverage of surveys for the more complicated areas (Simple definition: Associated coverage at a given time)

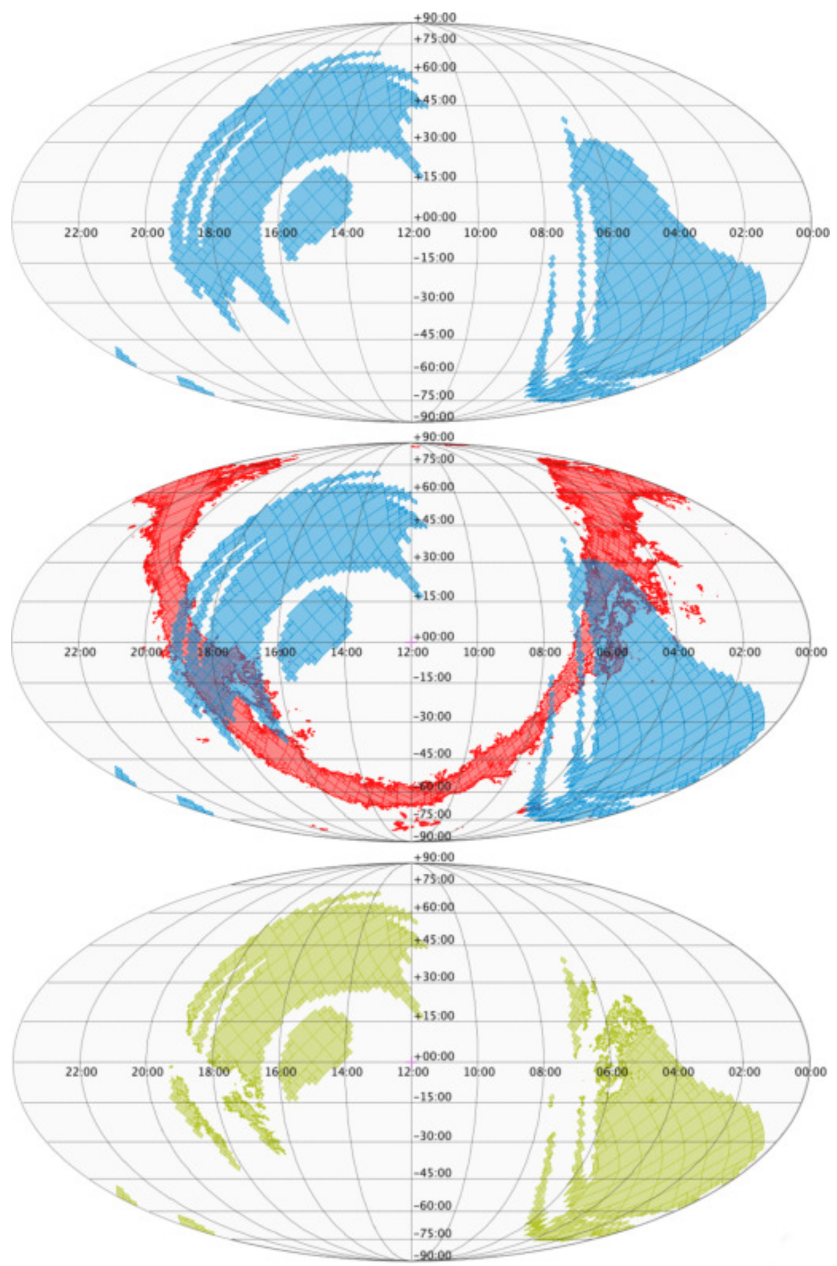




MOC: Multi-order coverage map

Multi Order Coverage data structure to plan multi-messenger observations

G. Greco, et al. 2022A&C....3900547G



Allows to quickly compute intersections between different surveys

Top: Gravitational-wave sky localisation of GW190425 – 90% credible region

Middle: A selected high Galactic dust extinction region is overlaid. The range of pixel values was set from 0.5 up to the highest value.

Bottom: The resulting sky map defined by the gravitational-wave sky localisation with the dust absorption fields subtracted.

Can be computed for the planning of the observations

Library Mocpy a python package affiliated to astropy

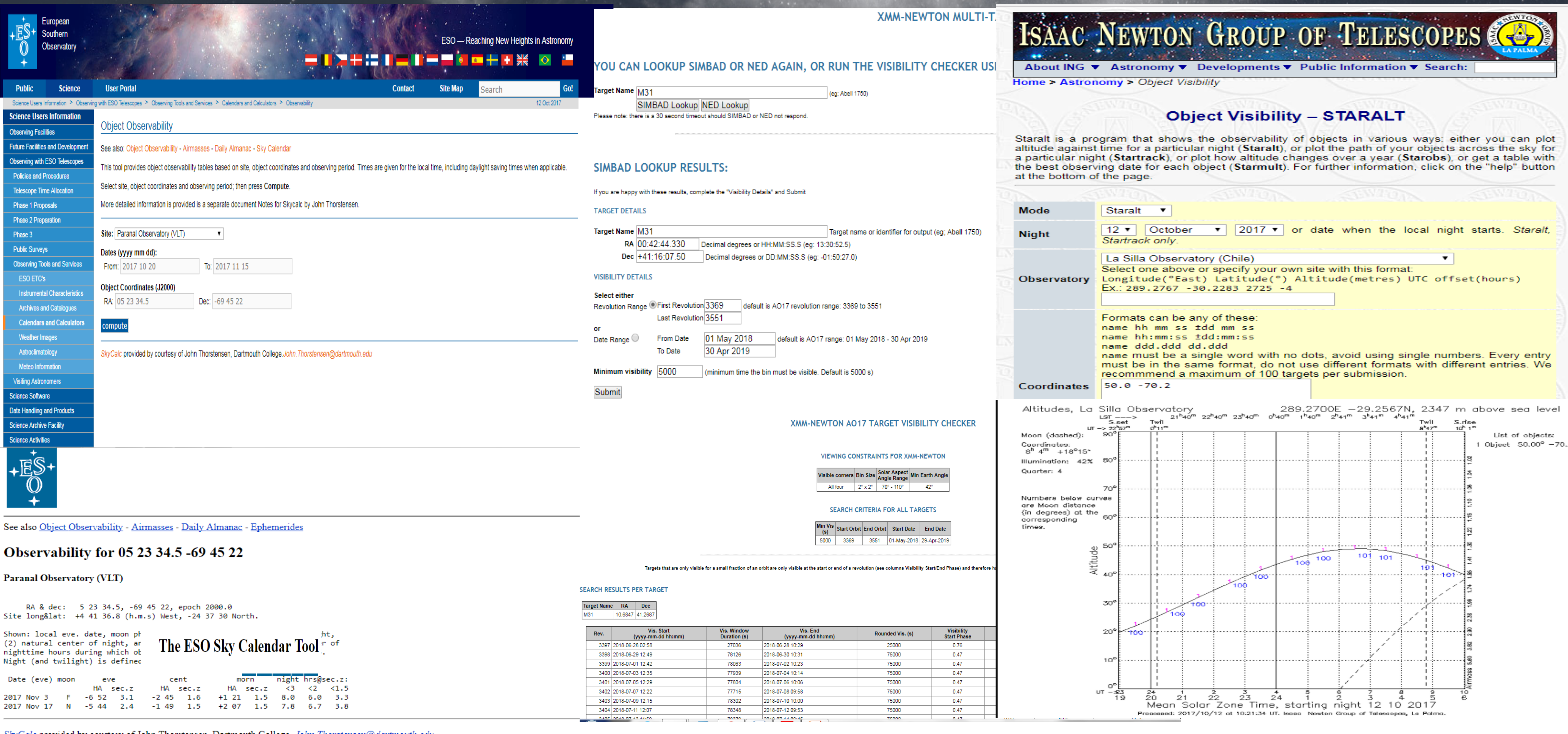
TAP & ADQL

- **Table Access Protocol (TAP)** - defines a service protocol for accessing general table data, including astronomical catalogs as well as general database tables. Access is provided for both database and table metadata as well as for actual table data.

- **Astronomical Data Query Language (ADQL)** Based on Structured Query Language (SQL) with special restrictions and extensions in order to support generic and astronomy specific operations

```
SELECT DISTANCE(
  POINT('ICRS', 266.41683, -29.00781),
  POINT('ICRS', ra, dec)) AS dist, *
FROM gaiaedr3.gaia_source
WHERE 1=CONTAINS(
  POINT('ICRS', 266.41683, -29.00781),
  CIRCLE('ICRS',ra, dec, 0.08333333))
ORDER BY dist ASC
```

Visibility of an object



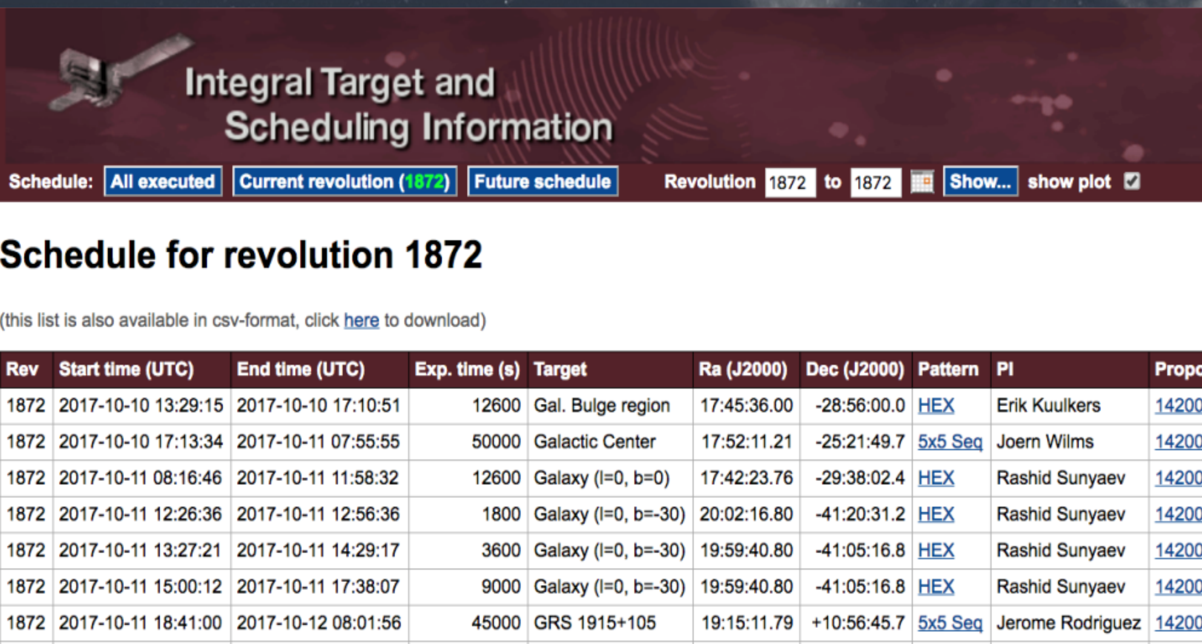
Different services have different inputs / outputs

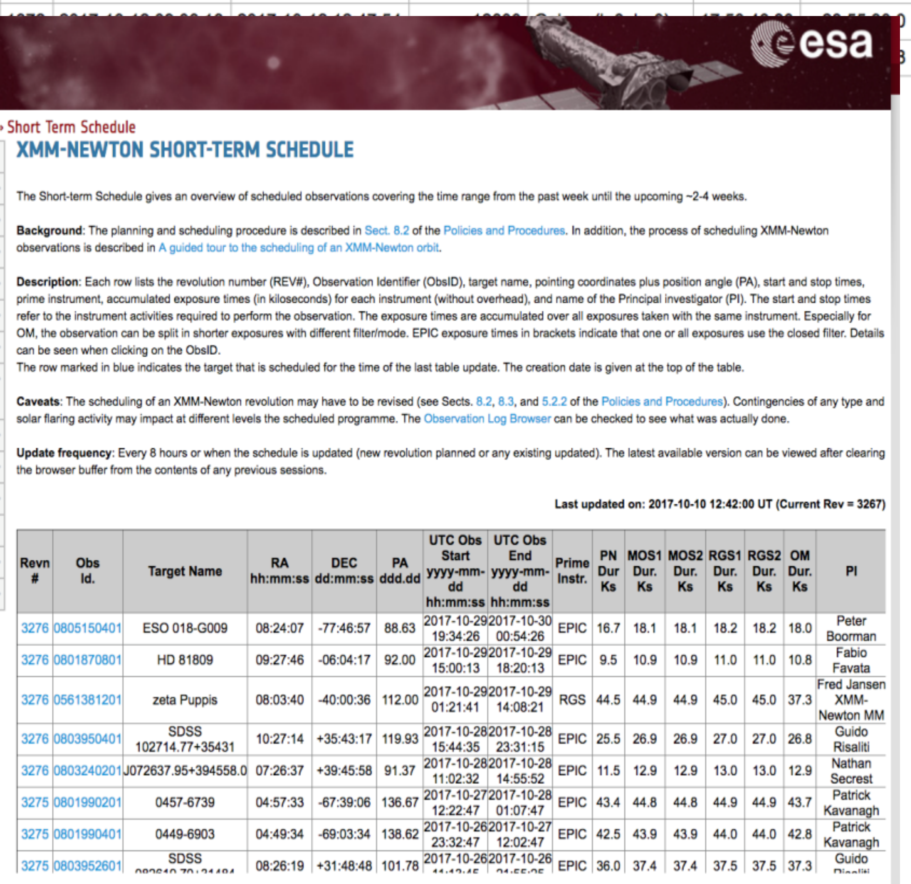
Facilitate the work by having some level of standardised input / output

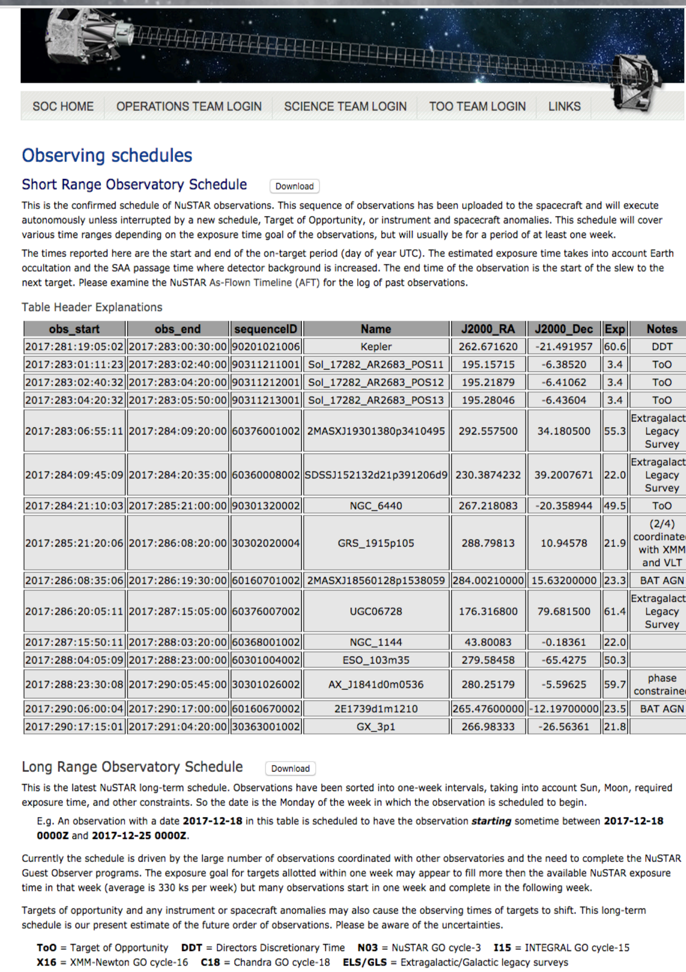
Object Visibility Simple Access Protocol, Aitor Ibarra, Richard Saxton, Jesús Salgado et al. 2020

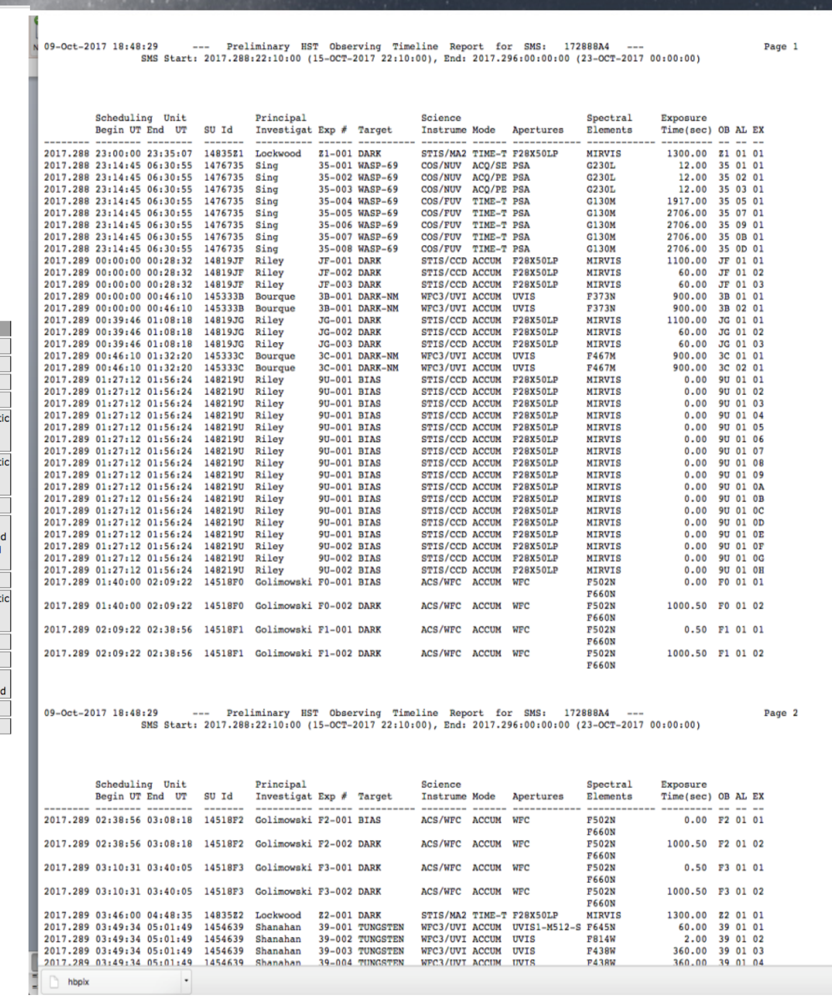
http://www.ivoa.net/documents/ObjVisSAP/index.html

Coordination of observations









What object has been (or will be) observed when and in which wavelength?

Observation Locator Table Access Protocol, Aitor Ibarra, Jesús Salgado et al. 2021
http://www.ivoa.net/documents/ObsLocTAP/

Publishing your data in the VO

Do you have data and you would like to publish it?

https://wiki.ivoa.net/twiki/bin/view/IVOA/PublishingInTheVO

Depending of your needs and your technical experience, there are several ways to publish you data into the VO:

- if you have very little technical expertise, you might want to contact your national VO projects who might already have the infrastructure to host your data and make it available to the VO. See the list of national VO projects and the selection of open data centers offering publication as a service
- if you would like to find your VO services in client applications, please publish your service in a VO Registry.
- if you have some technical expertise but don't want to spend time to development, you might want to use directly some existing VO Publishing toolkits.
- if you prefer VO interfaces to your data yourself, you might find some useful VO software tools and libraries. A good start would be to determine what type of data you want to publish (images, catalogues, spectra, ...). Reading through the IVOA Architecture document might also be useful before going into the more details of the specific IVOA standards that you might need to use

Access data in the VO

There are different ways to access the VO, eg via Aladin, Topcat, python

Page Contents

PyVO
- Introduction
- Installation
  - Source Installation
- Requirements
- Getting started
  - Data Access
  - Registry search
- Using **pyvo**

PyVO

Introduction

This is the documentation for PyVO, an affiliated package for the astropy package.

PyVO lets you find and retrieve astronomical data available from archives that support standard IVOA virtual observatory service protocols.

- Table Access Protocol (TAP) – accessing source catalogs using sql-ish queries.
- Simple Image Access (SIA) – finding images in an archive.
- Simple Spectral Access (SSA) – finding spectra in an archive.
- Simple Cone Search (SCS) – for positional searching a source catalog or an observation log.
- Simple Line Access (SLAP) – finding data about spectral lines, including their rest frequencies.

Note

If you need to access data which is not available via the Virtual Observatory standards, try the astropy affiliated package astroquery (and, of course, ask the data providers to do the right thing and use the proper standards for their publication).

Lots of tutorials on how to access data

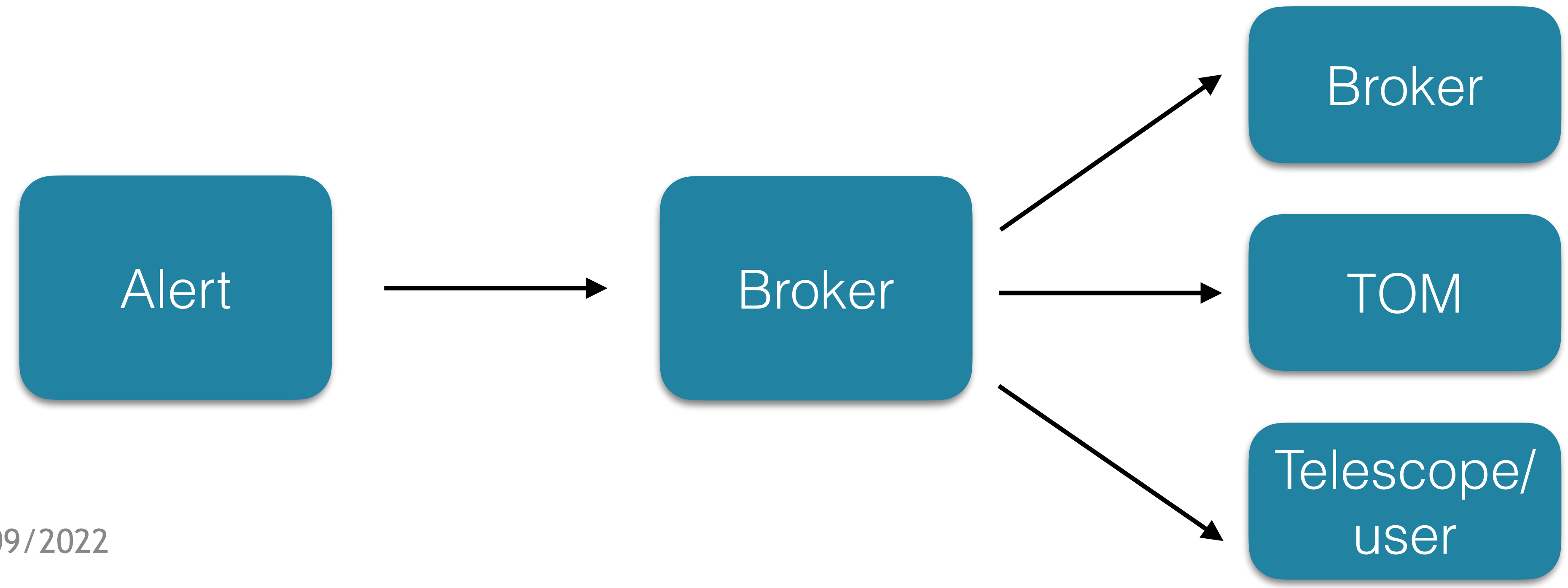
https://nasa-navo.github.io/navo-workshop/

https://github.com/cds-astro/tutorials

https://github.com/cds-astro/mocpy/tree/master/notebooks

Alerts

1. VOEvent (REC):
    - Content: a core data model for alerts
        - Who, What, WhereWhen, Why, and How
        - Defined by the community (e.g. FRB)
    - A format: a serialization of that data model (xml)
2. VTP - VOEvent Transport protocol (REC):
    - a communication protocol for publishing, and subscribing to alerts



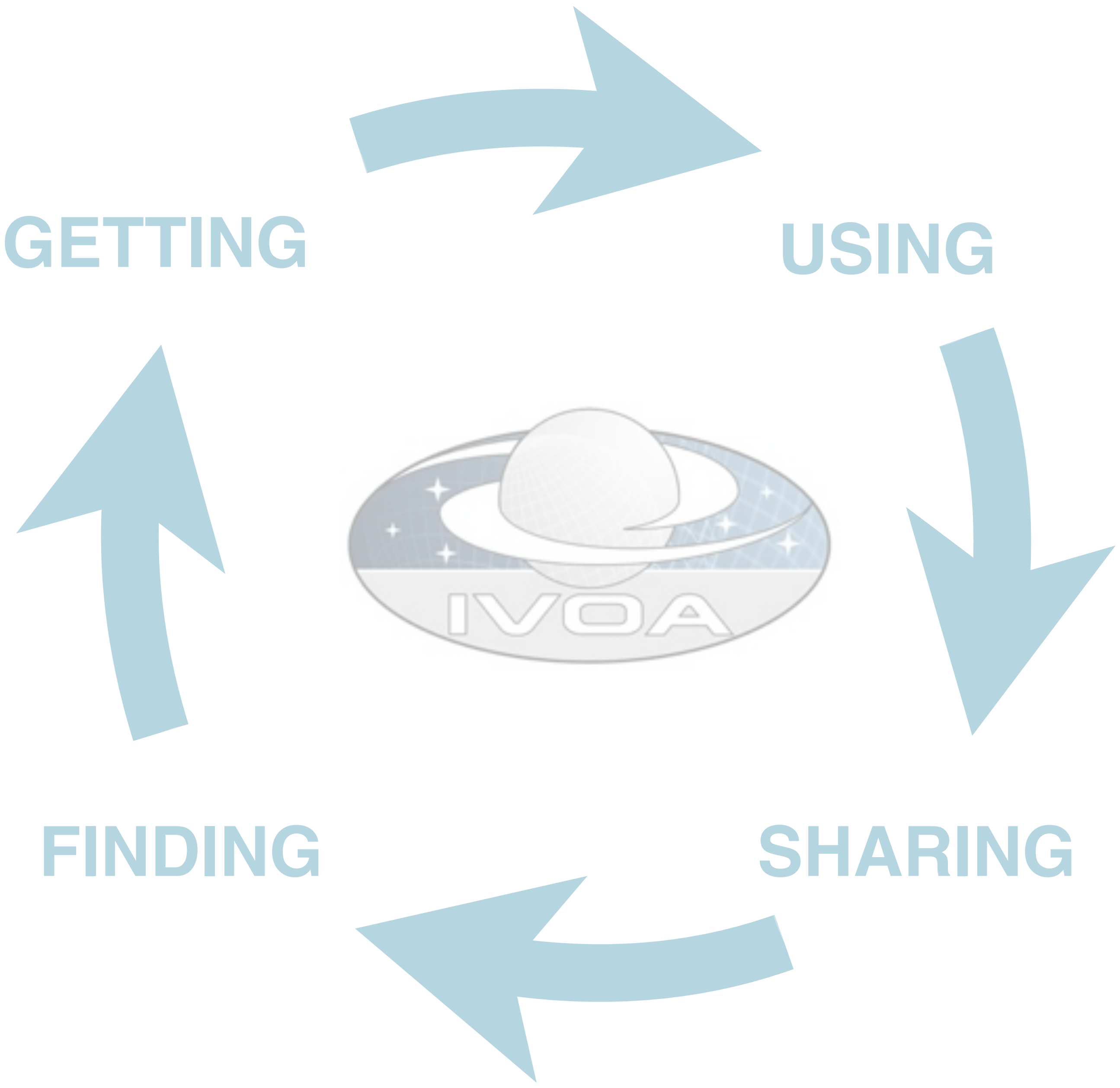
VOEvent: Sky Event Reporting Metadata

- **"Defines the content and meaning of a standard information packet for representing, transmitting, publishing and archiving information about a transient celestial event, with the implication that timely follow-up is of interest"**
  - **Who**: Identification of scientifically responsible Author
  - **What**: Event Characterization modeled by the Author
  - **WhereWhen**: Space-Time Coordinates of the event
  - **How**: Instrument Configuration
  - **Why**: Initial Scientific Assessment
  - **Citations**: Follow-up Observations
  - **Description**: Human Oriented Content
  - **Reference**: External Content

Open questions

- Are the existing standards enough or do we need changes / new developments?
- In the context of alerts:
  - VOEvent : model (content) + serialization (format)
  - VTP : transport protocol works for low rates (10 Hz) doesn't scale well for very high rates (>10^3Hz)
- Is this still what the community needs?
- New technologies and serialisations are used, in particular GCN adopting and moving towards Kafka / Avro (ZTF, Rubin, LVK,…)
- What is the impact on the existing VOEvent infrastructure & community?
- How to find who distributes alerts in the VO land? Register in the registry? Or the community knows where to find alerts?
- **Is there a need to standardize event types (Who, What, WhereWhen, Why, and How) — the core model?**
  - Extending the work on FRBs to cover other Types?
    - If so, smaller working groups within transient sub-fields develop a proposed standard to be iterated upon within the wider user base. Once a standard is developed, it can be submitted to the IVOA and published as an IVOA Note.
  - How do we store information in a way that it can be easily extracted and interpreted later? What types of queries do people want to perform on archived VOEvents? How do we make VOEvent streams findable

Thanks!



Some useful links

- https://www.ivoa.net
- Docs : https://www.ivoa.net/documents/
- GitHub : https://github.com/ivoa
- Mailing list : https://www.ivoa.net/members/index.html
- Architecture: https://www.ivoa.net/documents/IVOAArchitecture/20211101/index.html
- Slack: https://join.slack.com/t/ivoa/shared_invite/zt-17kd0v93b-b32~KReWd1T96gDyYFDLPQ