Archival UI, data models and formats towards the SKA

-- WP5.2 and WP5.4 activities --

AENEAS WP5

WP5 - Access and Knowledge Creation: design of the interface between ESDC and a distributed body of end users

WP5 tasks:

WP5.1: Survey of existing user interaction models for large-scale radio astronomy facilities and integration of WP5 outputs into consolidated ESDC design study

WP5.2: Recommendations for the design of user interfaces for data discovery, access, and retrieval

WP5.3: Recommendations for the design of user interfaces for data processing, reprocessing, analysis, and visualization

WP5.4: Integration with VO Interoperability Framework

WP5.5: Recommendations for the resourcing of an ESDC user interaction model

WP5.6: Recommendations for a plan of user community formation and knowledge distribution

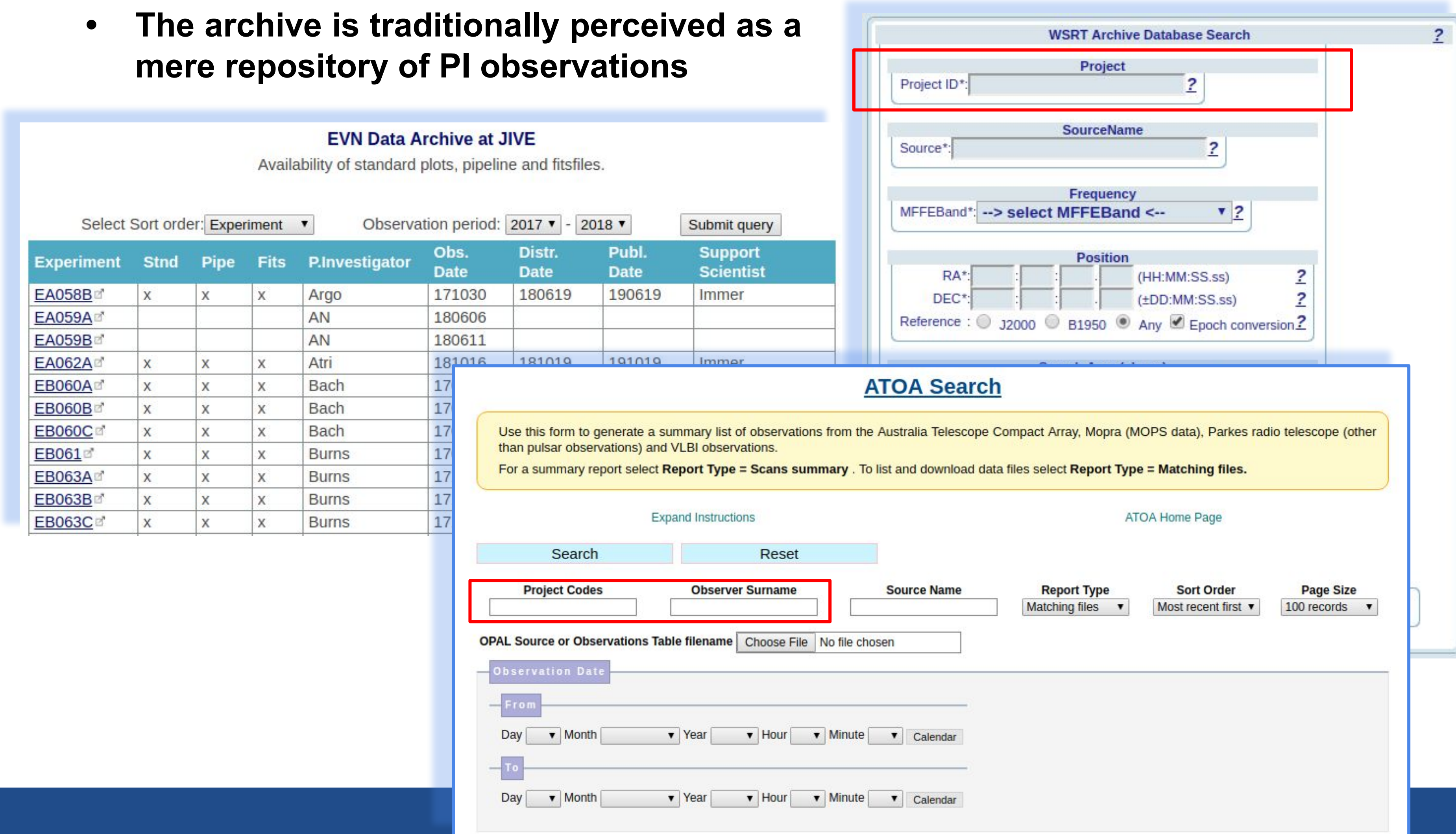
Outline

1. Evolution of radio archives and use cases
2. Survey of (radio) archival interfaces
3. SKA metadata recommendations
4. Archival UI recommendations (D5.3)
5. Data models/formats and the VO framework (D5.5)
6. Conclusions

Advanced European Network of E-infrastructures for Astronomy with the SKA

Evolution of the concept of archive

- **The archive is traditionally perceived as a mere repository of PI observations**



Evolution of the concept of archive

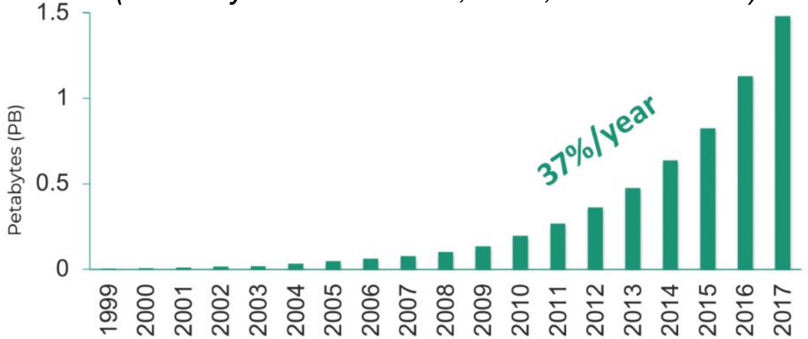
- The archive is traditionally perceived as a mere repository of PI observations
- **New telescopes (not only radio ones) already deliver huge datasets with a huge potential of re-usability and a huge potential of interoperability**

Energy, position, time, polarization, photon counts with unprecedented resolutions

A single dataset might contain several objects not covered by the primary science goal of the observation (especially true for large FoV telescopes)

The multi-wavelengths and multi-messenger astrophysics is now becoming fully applicable

(courtesy of Felix Stoehr, ESO, ADASS 2018)



Telescope	Frequency (GHz)	FoV (sqdeg)	Raw data rate (PB/yr)
MWA	0.07-0.3	2500-200	3-8
LOFAR-LBA LOFAR-HBA	0.01-0.09 0.11-0.25	1700-7	7
ASKAP	0.7-1.8	30	70
SKA-LOW	0.05-0.35	30-4	4.9×10^{6}
SKA-MID	0.35-15.3	3.3-0.012	6.2×10^{4}

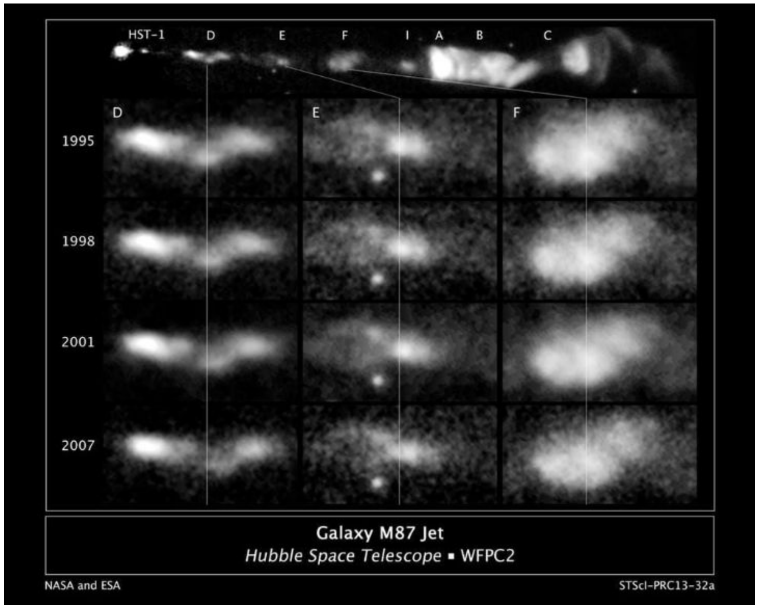
Archival publications

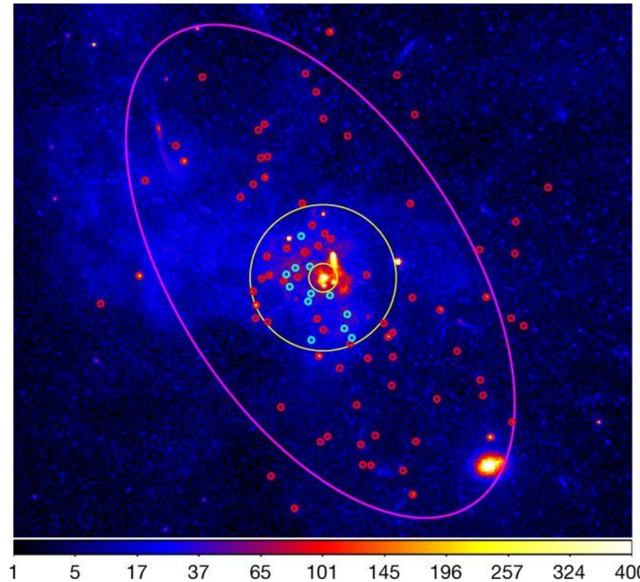
"Analysis of the productivity of mature facilities shows that publications using archival data can rapidly overtake the publications from the original proposers. [...] Nevertheless, it took over two decades for the ESA HST or the NASA telescope Spitzer, until the total archival publications outnumbered those from the original proposers" (AENEAS-D5.3, *cf.* Stoehr et al. 2009)

- Many facilities (e.g. ALMA, JIVE and e-MERLIN) have already started to offer level of services typical for PIs to archive miners as well.

- In the near future, archival publication are expected to contribute (both in terms of quantity and quality of research items) in a much more significant way to the productivity of a given facility.

Archival publications: impacting examples





THE ASTROPHYSICAL JOURNAL LETTERS

OPTICAL PROPER MOTION MEASUREMENTS OF THE M87 JET: NEW RESULTS FROM THE *HUBBLE SPACE TELESCOPE*

Eileen T. Meyer[1], W. B. Sparks[1], J. A. Biretta[1], Jay Anderson[1], Sangmo Tony Sohn[1], Roeland P. van der Marel[1], Colin Norman[1,2], and Masanori Nakamura[3]

Published 2013 August 22 •
The Astrophysical Journal Letters, Volume 774, Number 2

nature
International journal of science

Letter | Published: 04 April 2018

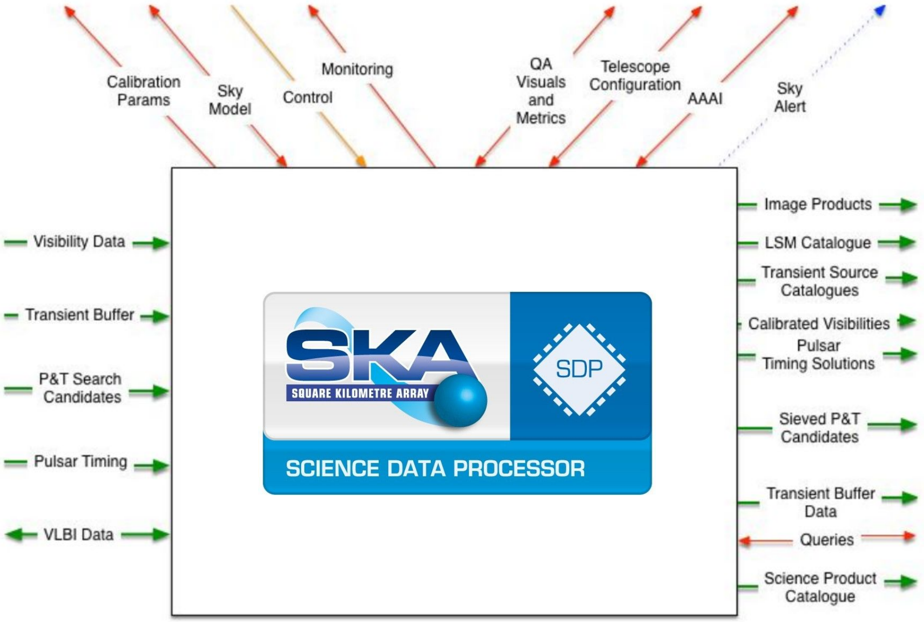
A density cusp of quiescent X-ray binaries in the central parsec of the Galaxy

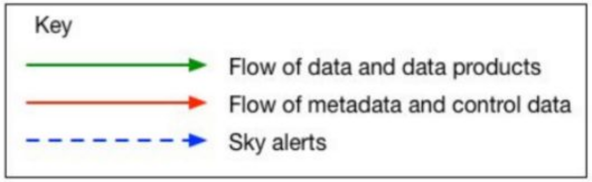
Charles J. Hailey, Kaya Mori, Franz E. Bauer, Michael E. Berkowitz, Jaesub Hong & Benjamin J. Hord

Nature **556**, 70–73 (05 April 2018) | Download Citation

Evolution of the concept of archive *(in the SKA era)*

- **Raw data cannot be preserved** for a long time and data calibration/processing strongly couples with the archival system (e.g. for SKA SDP)





Data and metadata fluxes through SDP
(*cf.* Fig.3 of SKA1 SDP High Level Overview)

Evolution of the concept of archive *(in the SKA era)*

- **Raw data cannot be preserved** for a long time and data calibration/processing strongly couples with the archival system (e.g. for SKA SDP)
- Great boost in terms of the number people interested in data (**PIs from other research fields** and **archive miners**), hence a much more variegate community, asking for **different levels** of access and **different advanced data products**.

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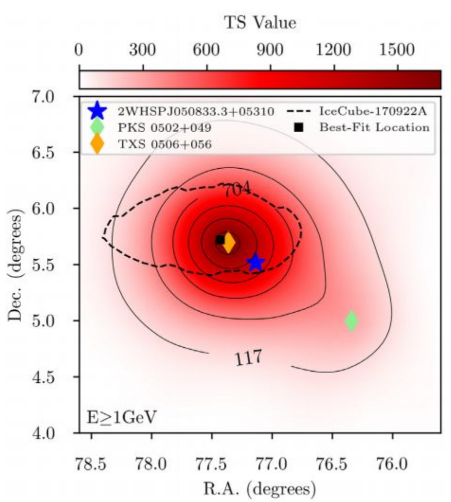
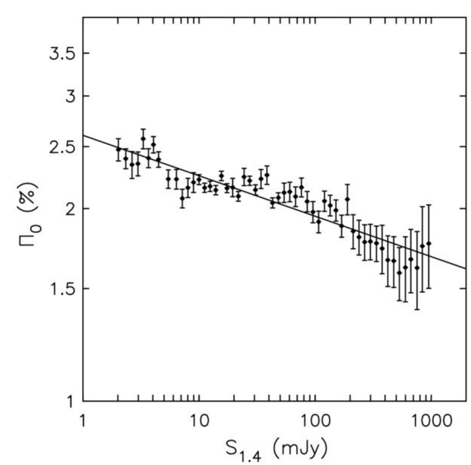
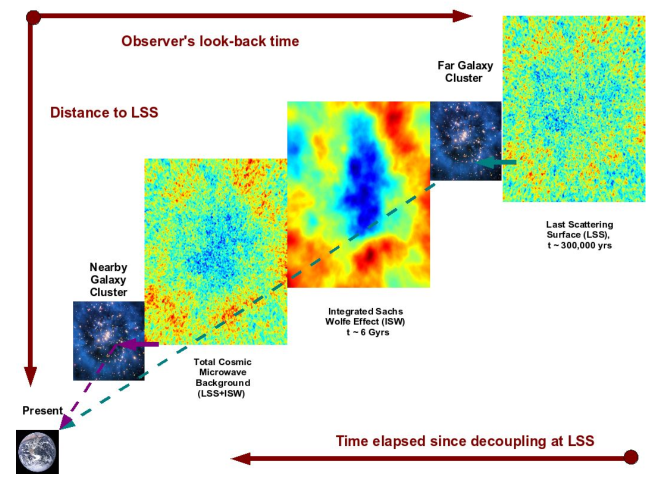
    - **correlations** between radio properties and other **multi-wavelength/multi-messenger** ones;
    - **population studies** by adopting **stacking techniques** (~millions of objects)
    - **cross-correlation** of radio objects with **completely different surveys** (e.g. the CMB, in order to constraint our cosmological model by looking at the Integrated Sachs-Wolfe effect)



(Padovani et al. 2018 , 2019)



(Stil et al. 2014)



(Hernandez-Monteagudo & Sunyaev 2009)

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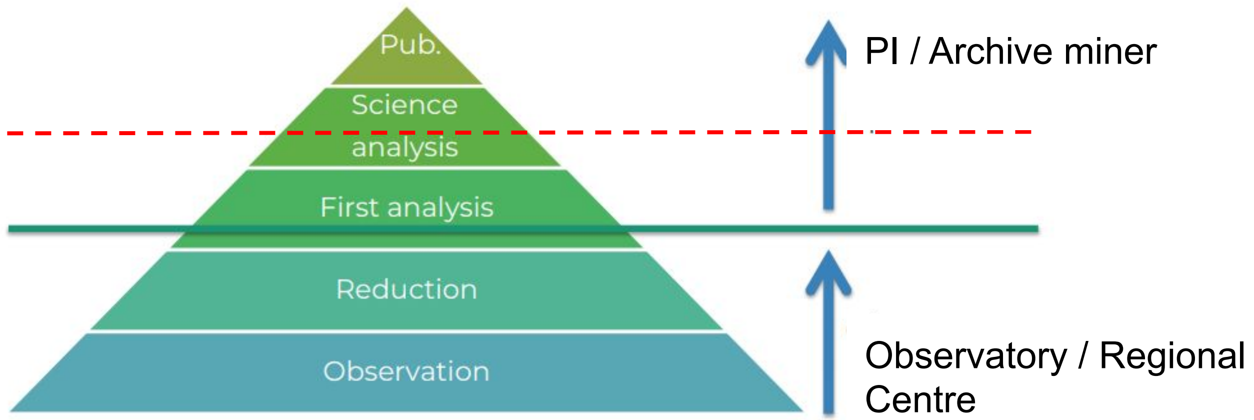
- **More responsibility** for the observatory and/or the infrastructure (e.g. Regional Centres)



Courtesy of Felix Stoehr (ESO, ADASS 2018)

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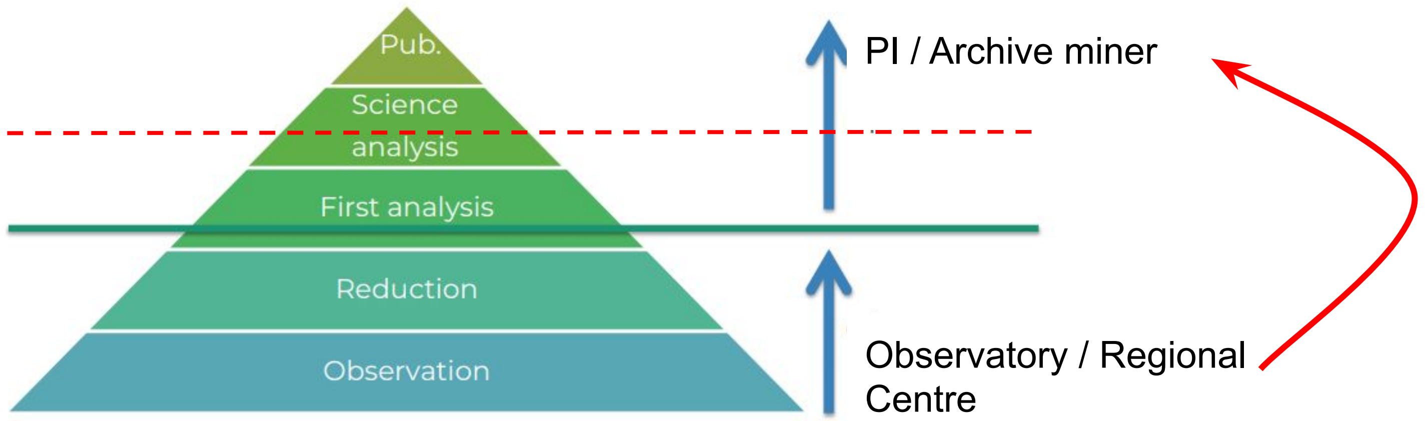
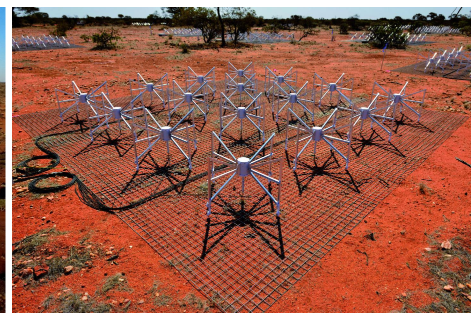


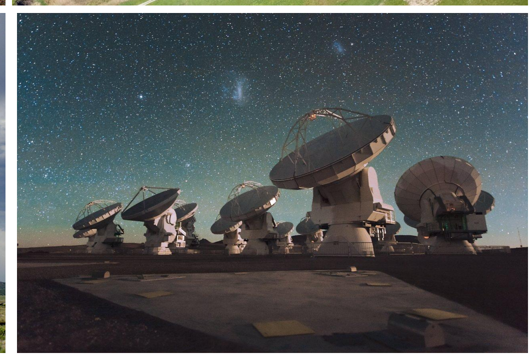
Courtesy of Felix Stoehr (ESO, ADASS 2018)

A survey of radio archives *(... and not only)*

- We focused on the most important SKA <u>*precursors*</u>: ASKAP, ***MWA***, (KAT-7 and MeerKAT)
- … and <u>*pathfinders*</u>: ***LOFAR***, EVN, (u)GMRT, e-MERLIN, ***(J)VLA***
- We also considered: WSRT, ATCA, ***VLBA (and GBT)***, ***ALMA***
- We extended the analysis to: CADC, **ESO Science Archive**, CDS, IA2

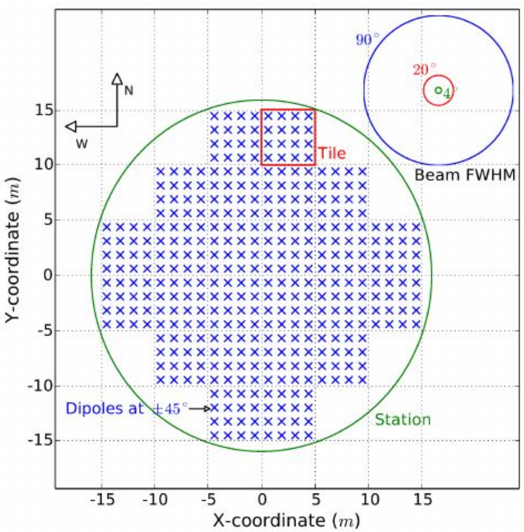



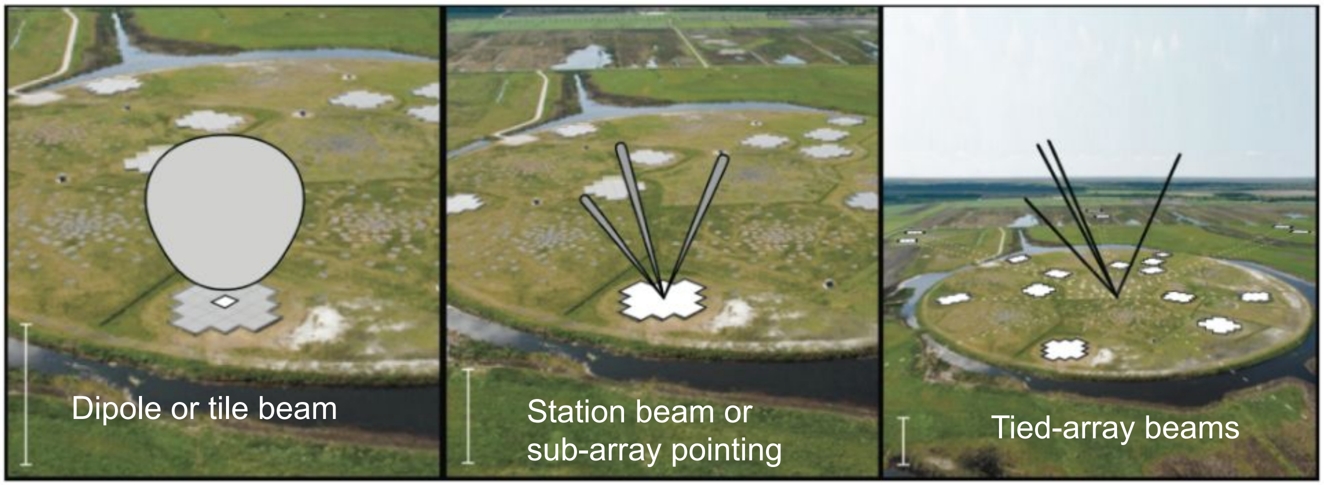




LOFAR

- The **Lo**w-**F**requency **AR**ray is operated by ASTRON and observes between 10 and 250 MHz (LBA: 10-90 MHz; HBA: 110-250 MHz)
- It consists of 24 core stations, 14 remote stations and 13 international ones *(... so far)*.
- It can collect data through three modes of acquisition:
    - interferometry, i.e. correlated visibilities
    - beam-formation *(Coherent Stokes, Incoherent Stokes, Fly's Eye)*
    - transient buffer modes
- Time/spectral resolution can be traded in order to fit with scientific goals



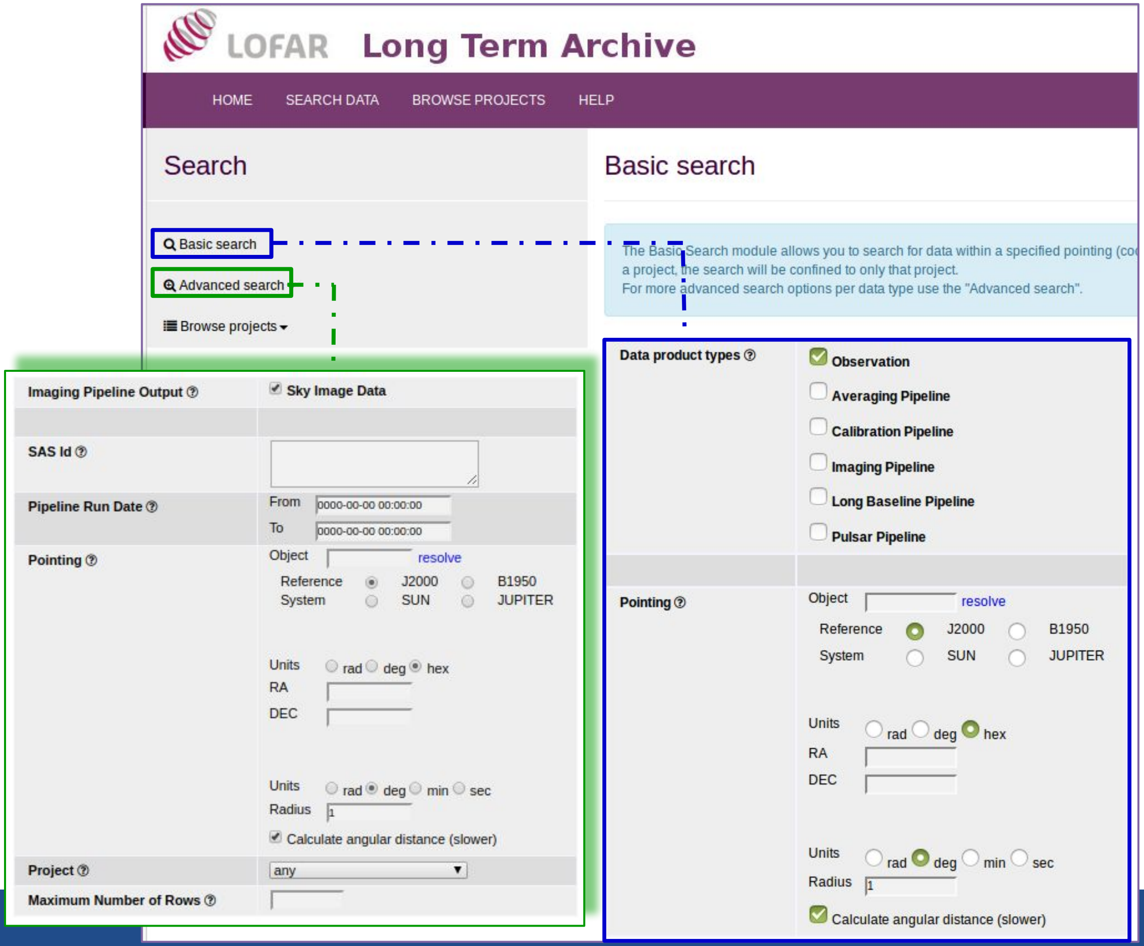


LOFAR LTA

- The LOFAR **L**ong **T**erm **A**rchive (LTA) allows metadata search without any account (you need one for downloading/staging requests)

- It can be decomposed in two sections: left panel, namely **basic search**, **advanced search** and **browse project**; the right panel displaying a dedicated search mask.

- There is also a server for **SQL queries** and a **Python interface**, as well as a **Python API** for improving user control over staging requests.

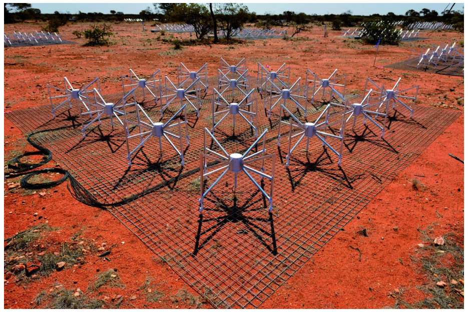


GUI of LOFAR LTA (https://lta.lofar.eu/) *(basic and advanced search are shown)*

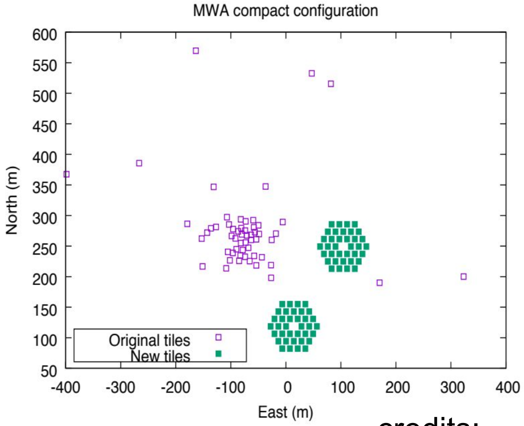
MWA

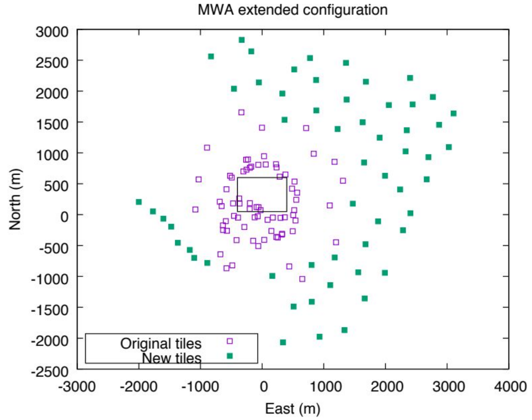
- The **M**urchison **W**idefield **A**rray is run by a consortium of **21 institutions** from Australia, New Zealand, China, Japan, Canada and USA, led by the **Curtin University**.
- It consists of 256 stations (tiles), 128 (chosen among two configurations, can be correlated at a time)

- Main features:
  - wide field of view (200-2500 sqdeg)
  - instantaneous bandwidth of 30.72MHz
  - spectral resolution of 20 kHz
  - temporal resolution of 0.5s
  - wide frequency range (70–300 MHz) with flexible tuning
  - digital design with extreme frequency and pointing agility, wide fractional bandwidths and considerable signal processing capabilities.



An MWA tile (4 x 4 dipoles)

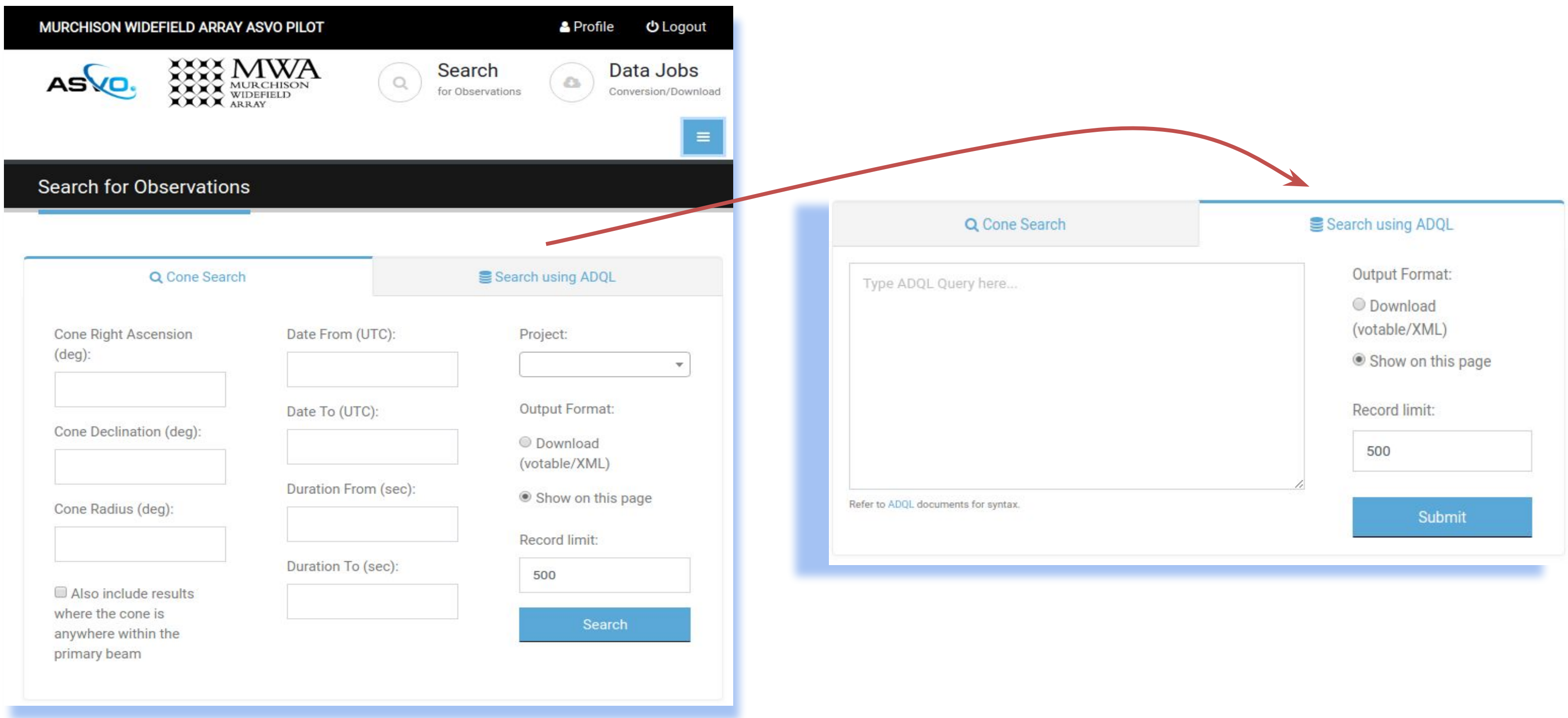




credits:

MWA Archive

- Access to the MWA Archive is granted by the **MWA All-Sky Virtual Observatory** (ASVO) data portal, through: a web dashboard, a Python API (Manta-ray-client) or a VO TAP service.
- It is requested a **registration on the ASVO portal** to use the web dashboard or there is the possibility to exploit **eduGain** (ORCID and United ID are also supported).



MWA Archive

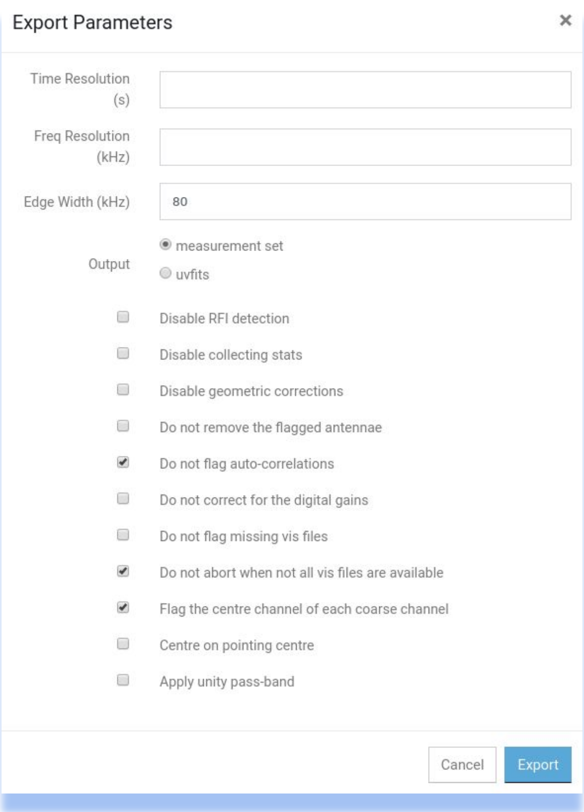
- The Data Export Tool allows to perform some **pre-calibration tasks** and **data format conversions**

Show 10 entries Search: Export Conversion | Export Visibility | Select all | Select none

Showing 1 to 10 of 500 entries Previous 1 2 3 4 5 … 50 Next

ID	Url	Name	Project ID	Description	Creator	Size (bytes)	RA (deg)	Dec (deg)	FOV (deg)	Start time (UTC)	End Time (UTC)	Duration (s)	Lower Freq (MHz)	Upper Freq (MHz)
1197895384	1197895384	PicA_121	G0040	Follow up observations of UV Ceti	msok	61143160320	77.771	-42.834	46	2017-12-21 12:42:47.980	2017-12-21 12:44:47.990	120	140	169
1197898024	1197898024	PicA_121	G0040	Follow up observations of UV Ceti	msok	60463990080	78.683	-44.937	43	2017-12-21 13:26:48.019	2017-12-21 13:28:48.028	120	140	169
1197898328	1197898328	PicA_69	G0044	EoR SKA Fields	msok	66585516480	79.953	-44.935	77	2017-12-21 13:31:51.974	2017-12-21 13:33:51.984	120	73	102
1197898448	1197898448	PicA_93	G0044	EoR SKA Fields	msok	63589570560	80.455	-44.934	56	2017-12-21 13:33:51.984	2017-12-21 13:35:51.993	120	104	133
1197898568	1197898568	PicA_121	G0044	EoR SKA Fields	msok	61616298240	80.956	-44.933	43	2017-12-21 13:35:51.993	2017-12-21 13:37:52.003	120	140	169
1197898688	1197898688	PicA_145	G0044	EoR SKA Fields	msok	62462001600	81.457	-44.932	36	2017-12-21 13:37:52.003	2017-12-21 13:39:52.012	120	170	200
1197898808	1197898808	PicA_169	G0044	EoR SKA Fields	msok	60803925120	81.959	-44.931	31	2017-12-21 13:39:52.012	2017-12-21 13:41:52.022	120	201	230
1197909168	1197909168	PicA_69	G0044	EoR SKA Fields	msok	67093363565	74.99	-46.407	74	2017-12-21 16:32:31.977	2017-12-21 16:34:31.987	120	73	102
1197909288	1197909288	PicA_93	G0044	EoR SKA Fields	msok	64060514007	75.492	-46.406	54	2017-12-21 16:34:31.987	2017-12-21 16:36:31.996	120	104	133
1197909408	1197909408	PicA_121	G0044	EoR SKA Fields	msok	62151460544	75.993	-46.405	42	2017-12-21 16:36:31.996	2017-12-21 16:38:32.006	120	140	169

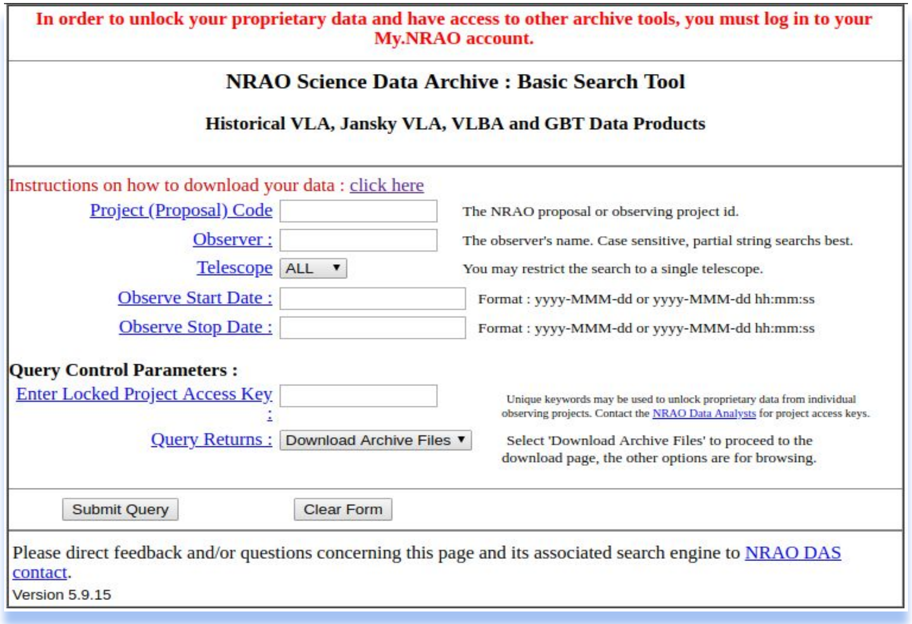
An example of web returned results for a cone search of 10 arcsec around the core of Pictor A



The Export Conversion web interface for selected MWA data

The new NRAO portal

- The traditional **NRAO Data Archive System** (now called NRAO Legacy Archive) used to be the unified data archive for (J)VLA, VLBA and GBT data, and it **is going to be completely replaced.**



In order to unlock your proprietary data and have access to other archive tools, you must log in to your My.NRAO account.

NRAO Science Data Archive : Basic Search Tool

Historical VLA, Jansky VLA, VLBA and GBT Data Products

Instructions on how to download your data : click here

Project (Proposal) Code — The NRAO proposal or observing project id.

Observer : — The observer's name. Case sensitive, partial string searchs best.

Telescope ALL — You may restrict the search to a single telescope.

Observe Start Date : — Format : yyyy-MMM-dd or yyyy-MMM-dd hh:mm:ss

Observe Stop Date : — Format : yyyy-MMM-dd or yyyy-MMM-dd hh:mm:ss

Query Control Parameters :

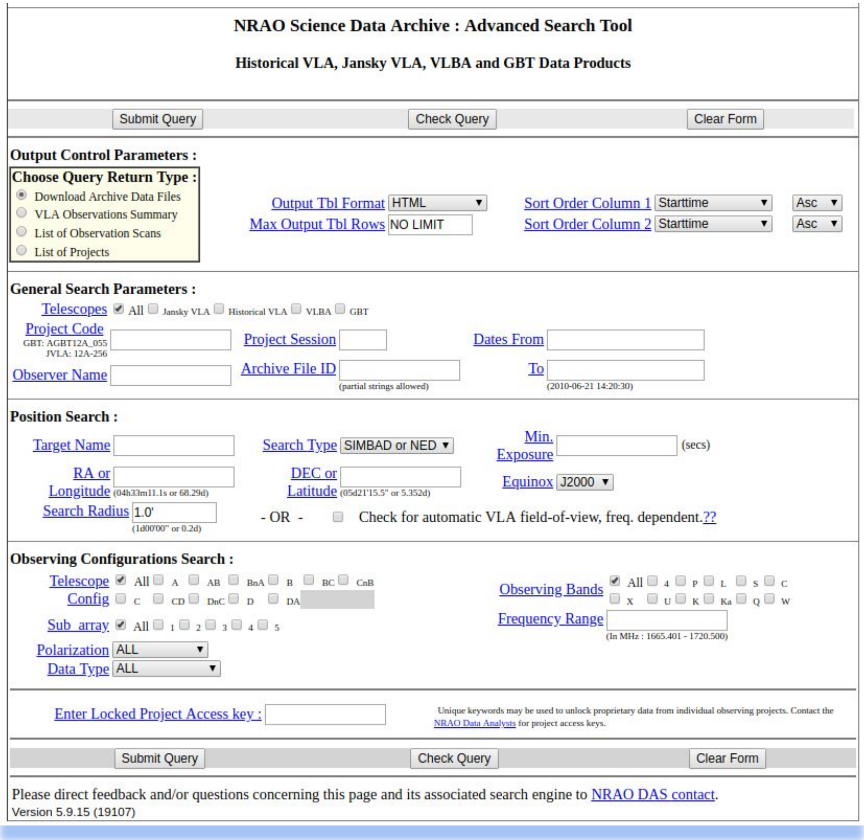
Enter Locked Project Access Key : — Unique keywords may be used to unlock proprietary data from individual observing projects. Contact the NRAO Data Analysts for project access keys.

Query Returns : Download Archive Files — Select 'Download Archive Files' to proceed to the download page, the other options are for browsing.

Submit Query | Clear Form

Please direct feedback and/or questions concerning this page and its associated search engine to NRAO DAS contact.

Version 5.9.15



NRAO Science Data Archive : Advanced Search Tool

Historical VLA, Jansky VLA, VLBA and GBT Data Products

Submit Query | Check Query | Clear Form

Output Control Parameters :

Choose Query Return Type : Download Archive Data Files; VLA Observations Summary; List of Observation Scans; List of Projects

Output Tbl Format HTML; Max Output Tbl Rows NO LIMIT; Sort Order Column 1 Starttime Asc; Sort Order Column 2 Starttime Asc

General Search Parameters :

Telescopes: All, Jansky VLA, Historical VLA, VLBA, GBT

Project Code (GBT: AGBT12A_055, JVLA: 12A-256); Project Session; Dates From; Observer Name; Archive File ID (partial strings allowed); To (2010-06-21 14:20:30)

Position Search :

Target Name; Search Type SIMBAD or NED; Min. Exposure (secs)

RA or Longitude (04h33m11.1s or 68.29d); DEC or Latitude (05d21'15.5" or 5.352d); Equinox J2000

Search Radius 1.0' (1d00'00" or 0.2d) - OR - Check for automatic VLA field-of-view, freq. dependent. ??

Observing Configurations Search :

Telescope Config: All, A, AB, BnA, B, BC, CnB, C, CD, DnC, D, DA

Observing Bands: All, 4, P, L, S, C, X, U, K, Ka, Q, W

Sub_array: All, 1, 2, 3, 4, 5

Frequency Range (In MHz : 1665.401 - 1720.500)

Polarization ALL; Data Type ALL

Enter Locked Project Access key : — Unique keywords may be used to unlock proprietary data from individual observing projects. Contact the NRAO Data Analysts for project access keys.

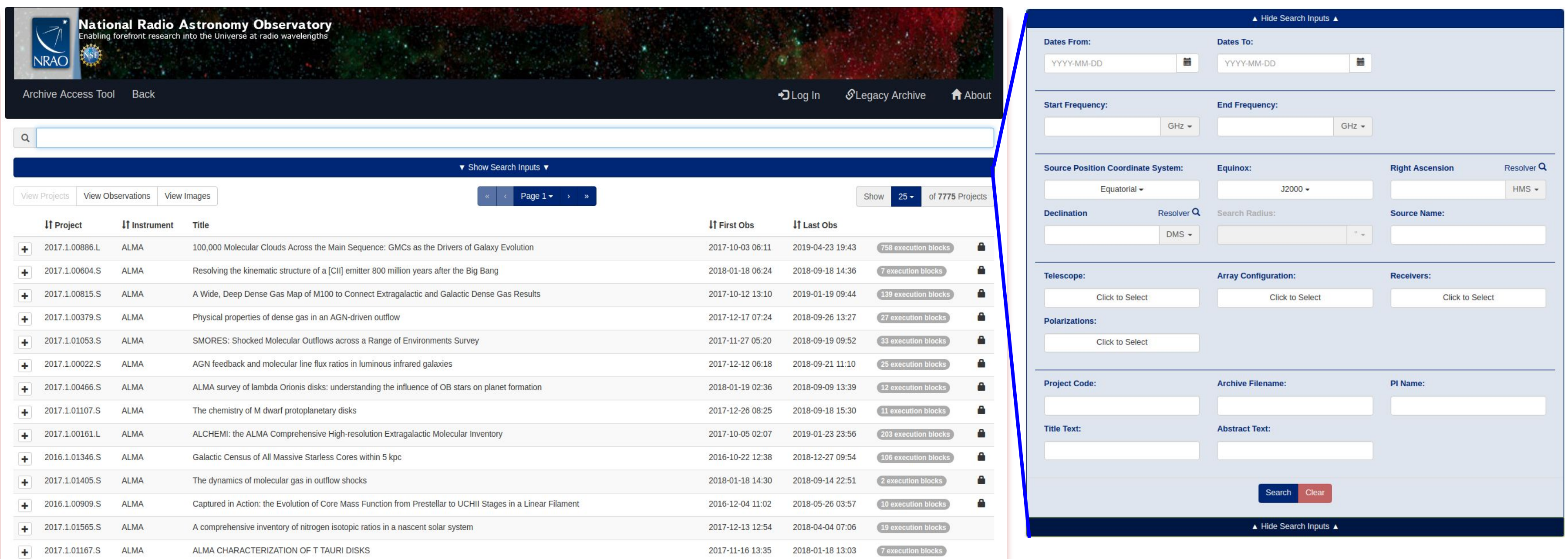
Submit Query | Check Query | Clear Form

Please direct feedback and/or questions concerning this page and its associated search engine to NRAO DAS contact.

Version 5.9.15 (19107)

The new NRAO portal

- The new [NRAO Science Data Archive]() is still under development but has been already publicly released: also ALMA data are being ingested.
- Major features: **more responsive**, **interactive and significantly cleaner** with respect to its predecessor
- Access to raw observations and images via a new **Archive Access Tool (AAT)** and to processing via the Pipeline Processing Interface (PPI)



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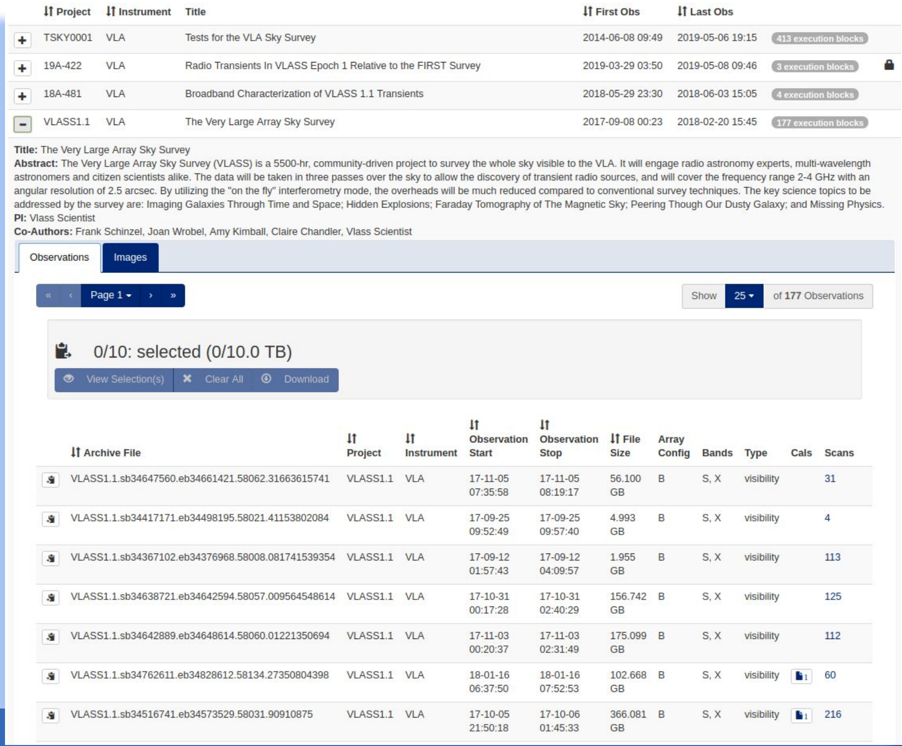
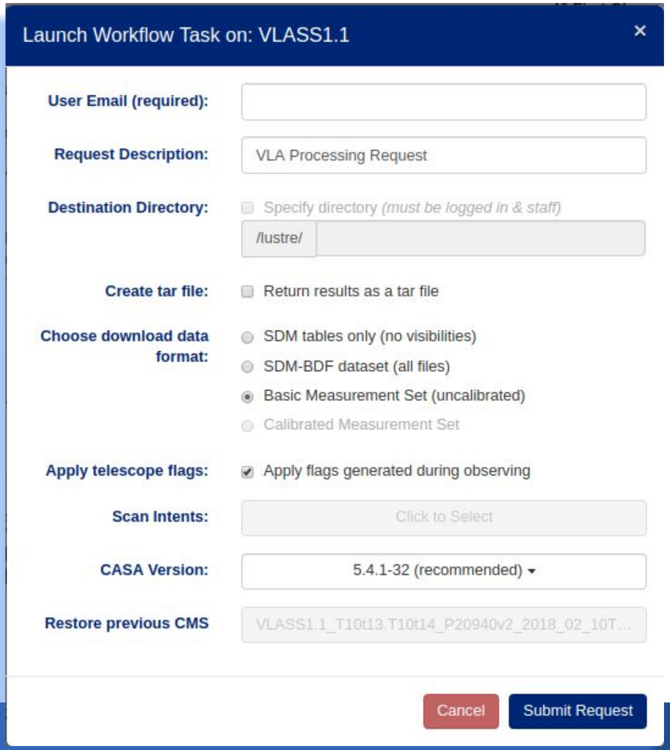
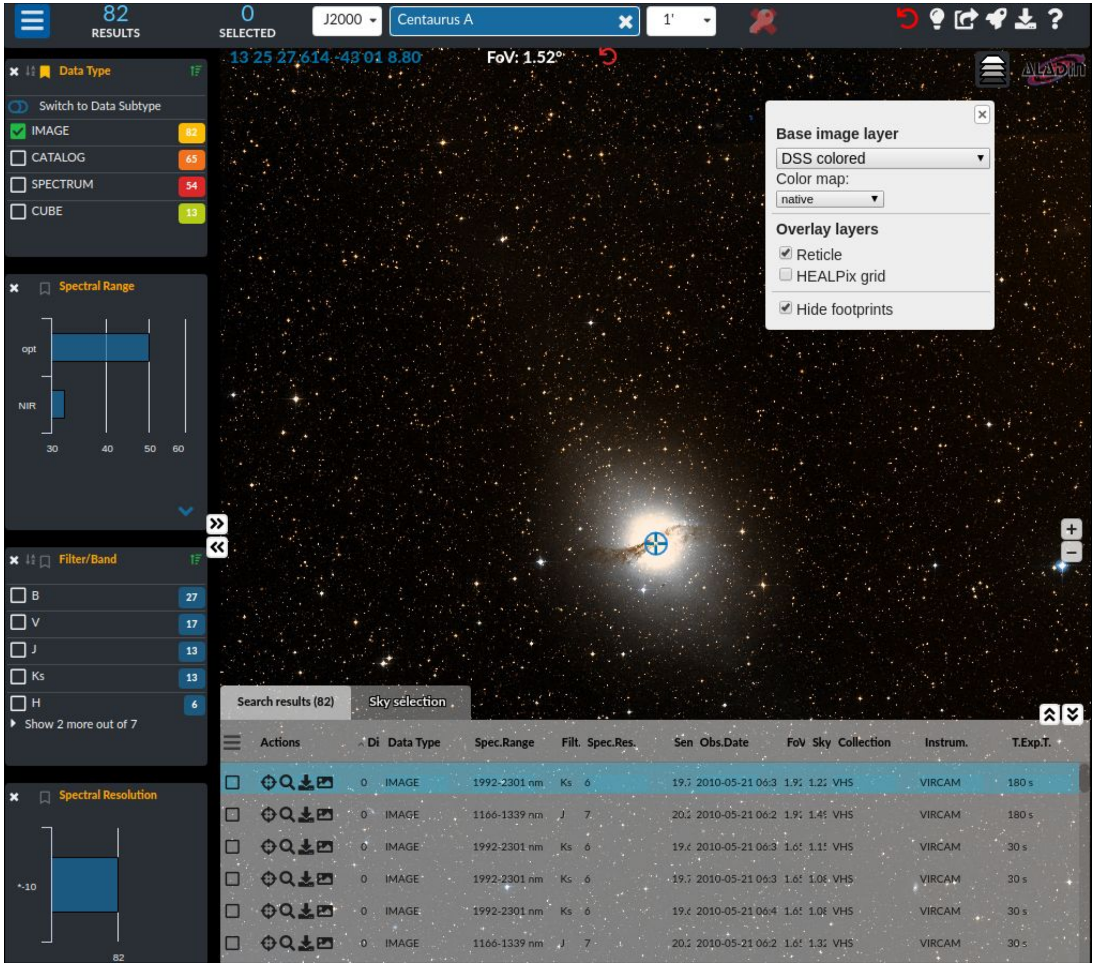




The ESO portal



The [ESO Science Archive]() contains data from ESO telescopes operated by *La Silla Paranal Observatory* and, in addition, raw UKIDSS/WFCAM data gathered by the *United Kingdom InfraRed Telescope* (UKIRT) facility in Hawaii.

It consists of three interfaces: the *Raw Data* query form, the *Science Portal* the *Programmatic and Tools* access

SKA Metadata recommendations
(Elisabetta Liuzzo et al.)

- Metadata can provide information about many aspects of data: e.g. purpose, time and date of creation, creator or author, location,file size, data quality, type of measured quantities, provenance…
- They can be classified according different criteria, e.g. in: descriptive, structural, administrative and accessibility metadata
- They can be stored internally or externally to the data structure, in human-readable or binary form
- Metadata standards can be organized into four general types (e.g. Elings & Waibel 2007):
  1. Metadata element sets or schema, sometimes called *data structure standards*
  2. Controlled vocabularies and name authorities, sometimes called *data value standards*
  3. *Data content standards* (guidelines for inputting data into metadata elements).
  4. *Data exchange standards* (specifications for encoding data)

Metadata in astronomical standards

The document provides description, tools, examples (as well as eventual extensions) for:

- **AVM - Astronomy Visualization Metadata**
- **FITS - Flexible Image Transport System**
- **International Virtual Observatory Alliance Recommendations**
- **Standard for Documentation of Astronomical Catalogues**
- **SPASE Data Model (**An information model for describing the elements of the heliophysics data environment**)**

The mostly used metadata standards in radioastronomy for images is the FITS. However, looking at the existing facilities :

- additional keywords are frequently included without clear definitions
- important info is still missing (e.g. rms, dynamic range)
- keywords could change depending on when/how the images are produced

This non-homogeneous metadata content prevents a full scientific exploitation of the science archives

SKA Metadata recommendations

Given the surveyed cases, e.g. LOFAR, MWA and ASKAP:

- Two different types of metadata could be identified
  - **internal metadata** which come along with the data in the image header keywords
  - **external metadata** which are stored elsewhere (e.g. plots of calibrated measurement sets to get trust in the data, external metadata coming from the PI advance products).

and metadata must:

- **Summarize in the most complete way the data content and production processes** (from proposing and observing to calibrating and imaging steps). This implies that metadata could be produced in different locations (SDP, ESDCs, etc)
- Contain sufficient **provenance information** to permit the replication of the published results
- Have the **sufficient attribution** to guarantee that organizations and individuals are given due credit;
- Be produced according **well defined standards** to ensure compatibility with the other astronomical images.

Recommendations for the SKA Archive

(D5.3 - Design recommendations #1)

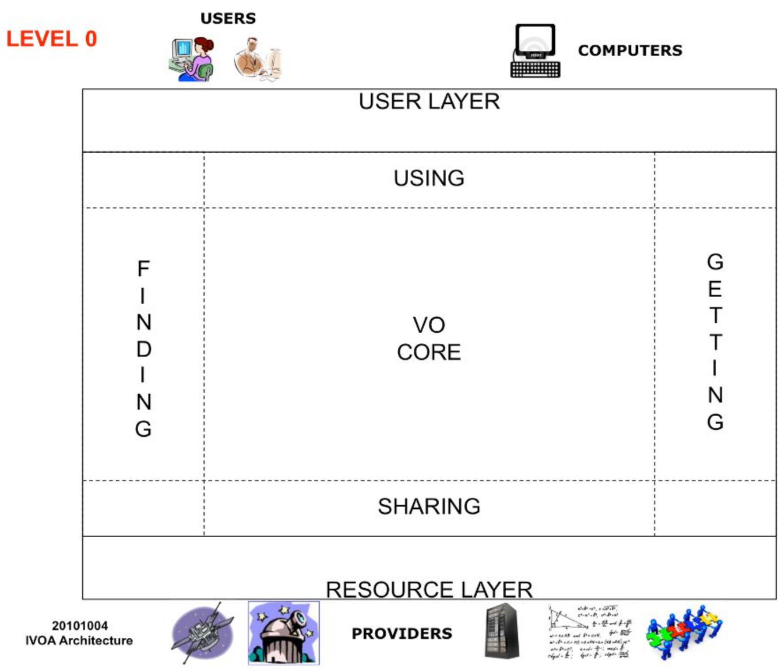
The **SKA Science Archive** will contain not only **observatory products** but also **metadata**, **advanced data products** and **codes** needed to generate the latter.

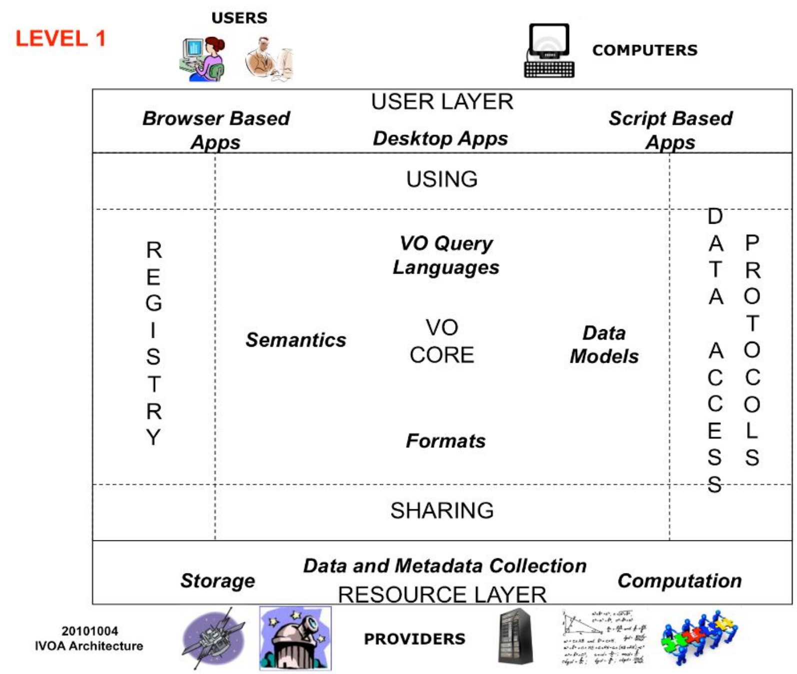
- We recommend a **multi-mask archival interface** (e.g. a basic search for observatory products and associated metadata, a dedicated or advanced mask for each product type
- **Observatory products, advanced products and codes** should be **clearly linked**
- **Proposal metadata** should be accessible
- The **query interface** should be **well documented**, with **different levels of access** (from a simple keyword-based GUI to programmatic/via tools)
- **Query refinement**, e.g. in terms of sensitivity and quality metrics, as well as lower resolution previews
- **VLBI archives** should be **homogenized** for SKA products
- **Data cutout services** and, more generally, exploitation of **VO technologies**
- The archive should be accessible through a **common gateway** to any user in the world, **managed at SRC level**, but on a **shared effort over the international partnership**

The IVOA architecture

The International Virtual Observatory Alliance (IVOA) is an organisation that debates and agrees on the technical standards that are needed to make the **Virtual Observatory** (VO) possible.

The VO is the vision that astronomical datasets and other resources should work as a seamless whole.



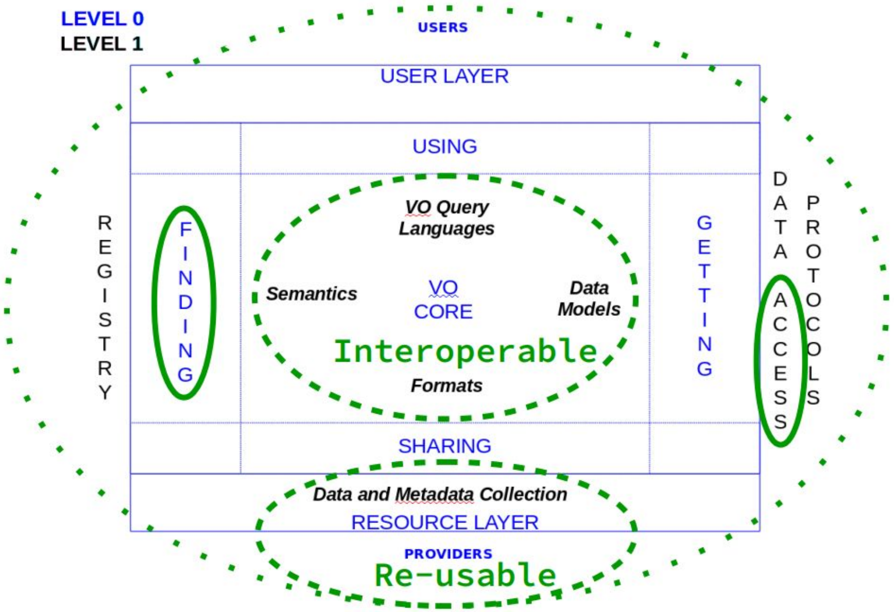


The IVOA architecture - FAIR mapping

The International Virtual Observatory Alliance (IVOA) is an organisation that debates and agrees on the technical standards that are needed to make the Virtual Observatory (VO) possible.

The VO is the vision that astronomical datasets and other resources should work as a seamless whole.

FAIR—**F**indable, **A**ccessible, **I**nteroperable, **R**eusable (Wilkinson *et al.* 2016).



(Courtesy of Marco Molinaro)

Data models for radio data

(D5.5 - Applicability of VO framework)

Content	Name	IVOA status, year	Comments	Importance
Space–Time coordinates	STC 1.33	REC 2007 version 2 in 2019 work in progress	Describes coordinates structure and frame metadata for all axes	High
Physical axis description and properties	Characterisation 1.13	REC 2008	It represents how data values span along all physical axes (spatial, spectral, temporal, flux, . . .), and defines the following properties for each axis: the coverage of an observation, the resolution information, the sampling and the accuracy. Partially used in other data models (Obscore, TimeSeries, etc..)	High
Spectral Line Transitions	Simple spectral lines 1.0	REC 2010 version 2 in progress (2019)	Describes the spectral lines in relationships with chemical species, energy levels, etc.	Low
1D Spectrum	IVOA Spectrum v1.1	REC 2011	Full representation of spectra including data and metadata.	Low
Observation DataSet Core data model (All data products)	ObsCore v1.1	REC 2017	Description of datasets made of identification, curation details, characterisation and access information. Highly useful in context of dataset discovery.	Very high

Content	Name	IVOA status, year	Comments	Importance
Photometric calibration	Phot v1.0	REC 2012	Description of photometric systems, filters, calibration information. Mainly useful for photometric data.	Low
DataSet datamodel	Dataset metadata 1.0	WD 2019 (ongoing work)	Full description of dataset metadata apart from characterisation and data. Extends identification and curation from ObsCore.	Medium
N-D dataset, cubes complex observations, sparse data	Cube 1.0	WD 2019 (ongoing work)	Describe the data structure and content of any kind of multidimensional datasets, whatever the dimension and the spanning along axes ; regular or sparse	Potentially high
Time Series	Time- Series data model	WD 2019 (ongoing work)	A derivation of Cube data model with a specialized time Axis. Valid for light curves, velocity variation curves, or Time Series of images, spectra, etc...	Medium
Provenance metadata	Provenance Data Model	PR 2019 (work close to completion)	This data model allows to trace the history of the transformation of data or signal through observation and data processing. Allows to access to progenitors	High

Data formats for radio data

- IVOA sets standards, hence data models and does not recommend data formats
- Data formats are TBD (both SDP and advanced ones) and exhaustive data models for most of the envisioned products are still lacking (e.g. calibrated visibilities, beam-formed data, RM synthesis cubes)
- Data models and formats are correlated, e.g. the format(s) should be flexible enough to address exhaustively data models.
- We critically analyse FITS (and related formats), (A)SDM/MS and HDF5
- A number of lessons learned from FITS (cf. Thomas et al. 2015) and data challenges already set (e.g. by LOFAR):

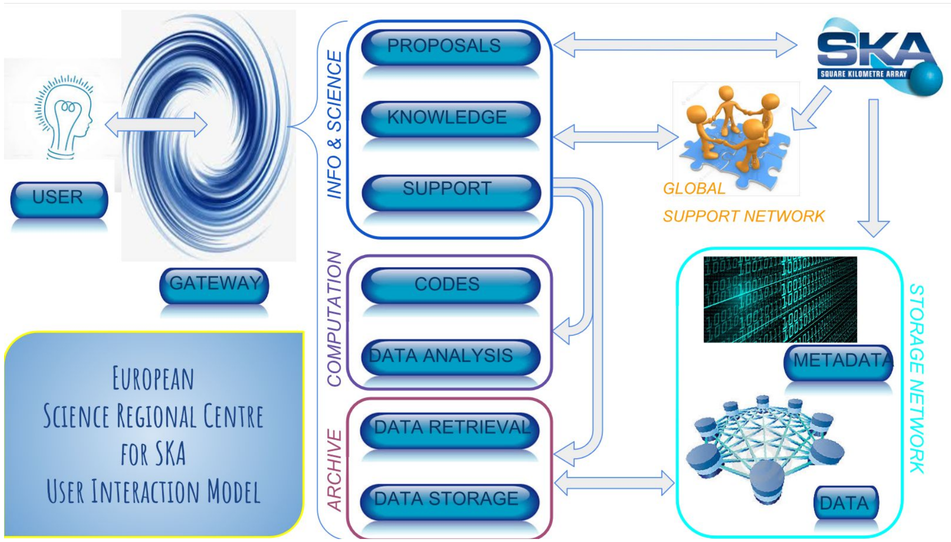
L1. A format should be versioned and suitable for data curation
L2. It should be self-describing
L3. It should not limit expression of desired data models
L4. It should support parallelization
L5. It should support streaming features with multiple data representation
L6. It should be fine for storage and processing at the same time
L7. It should allow portioning
L8. Conventions are not standards

Conclusions

The SKA is a **strategic research infrastructure** which poses challenges at different levels:

- **the boundary** between the SKAO and the SKA Data Center
- **huge amounts of data** which require unprecedented computational power (distributed resources needed) processed up to science-ready products, and the need **of interoperating** these with different wavelengths/messengers datasets
- define **different roles** and find **human resources** for such efforts

The WP5 provided a **user interaction model** for the European SKA Data Centre (ESDC) articulated in **European SKA Regional Centre (ESRC) nodes**



courtesy of Marcella Massardi
- AENEAS WP5 leader -

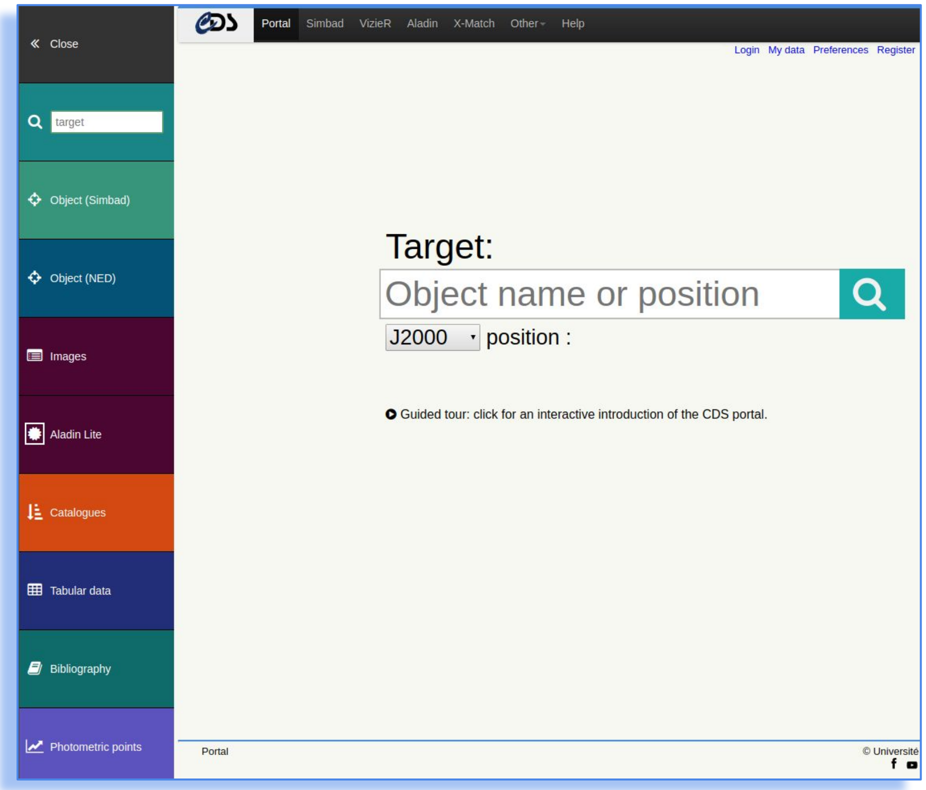
Further info:
M. Massardi's talk

Extra-slides

1. **More examples of data portals/archival UI**

Advanced European Network of E-infrastructures
for Astronomy with the SKA

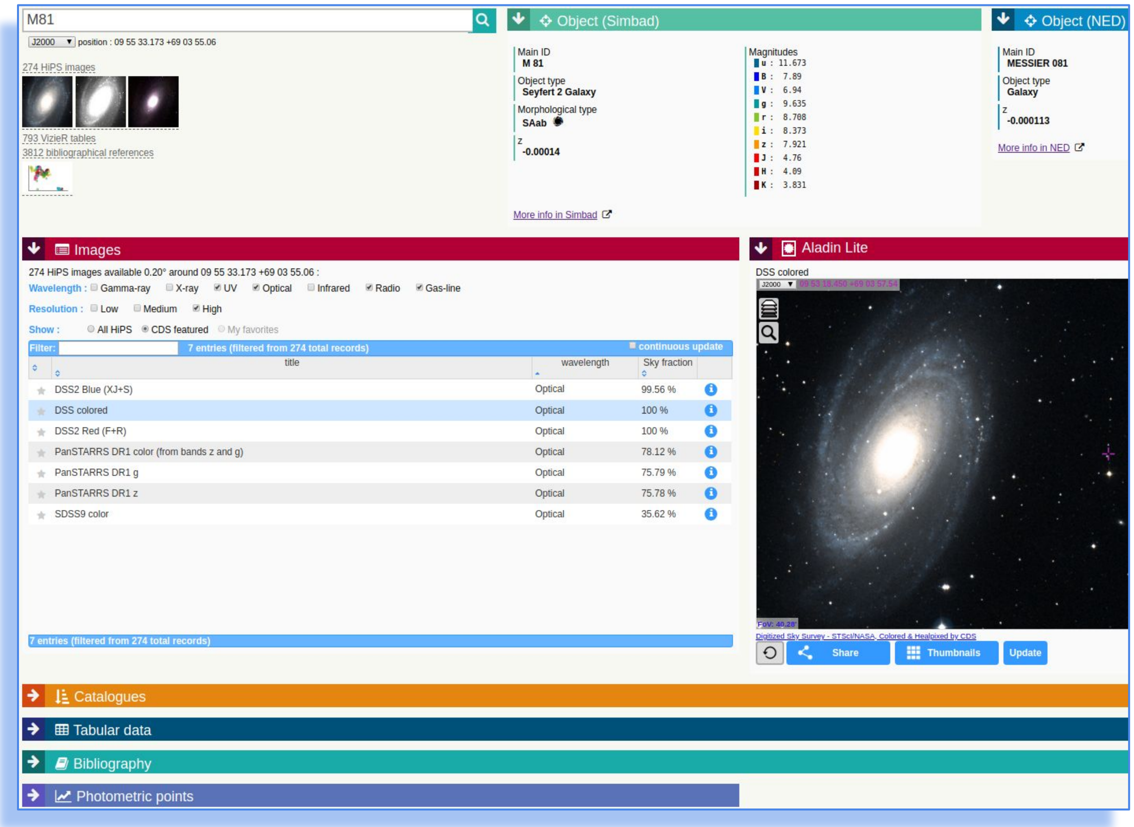
The CDS portal



The Observatory of Strasbourg hosts the **Strasbourg Astronomical Data Centre** (CDS), an important hub for the international astronomical community (at large).

The CDS portal displays a simple and easy-to-use interface and serves as a gateway to reach all the tools and services provided by the centre (e.g. Simbad, VizieR, X-match and Aladin).

The CDS portal



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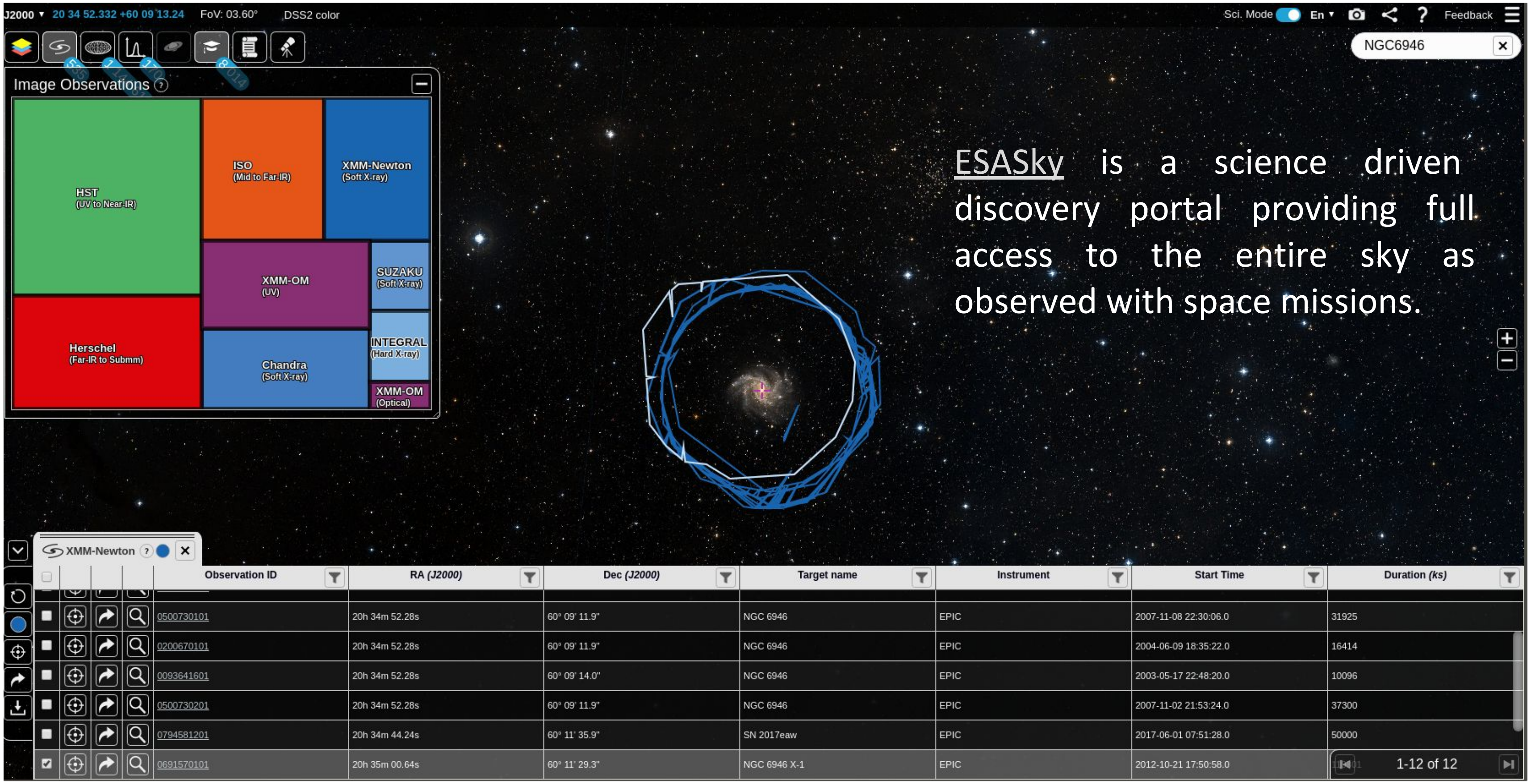
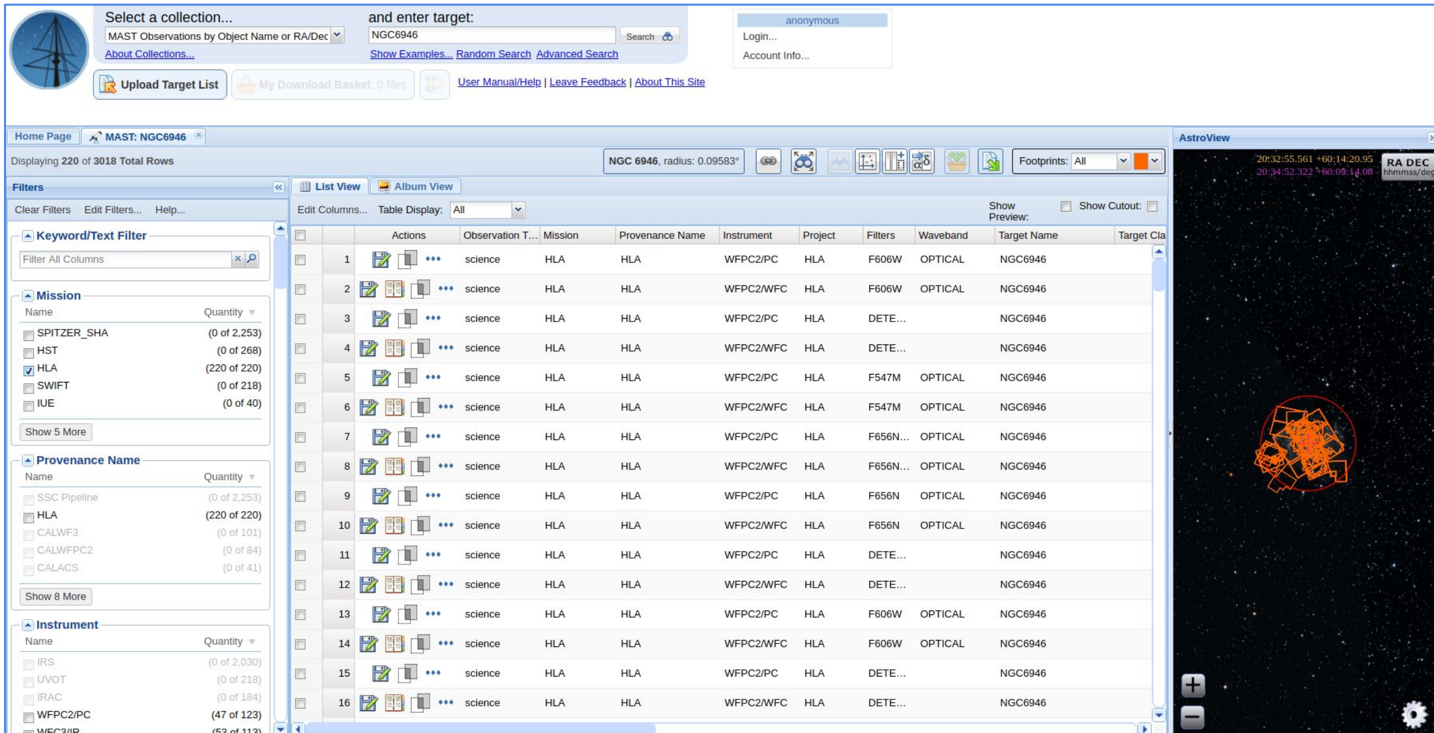
A few more examples… ESASky



ESASky is a science driven discovery portal providing full access to the entire sky as observed with space missions.

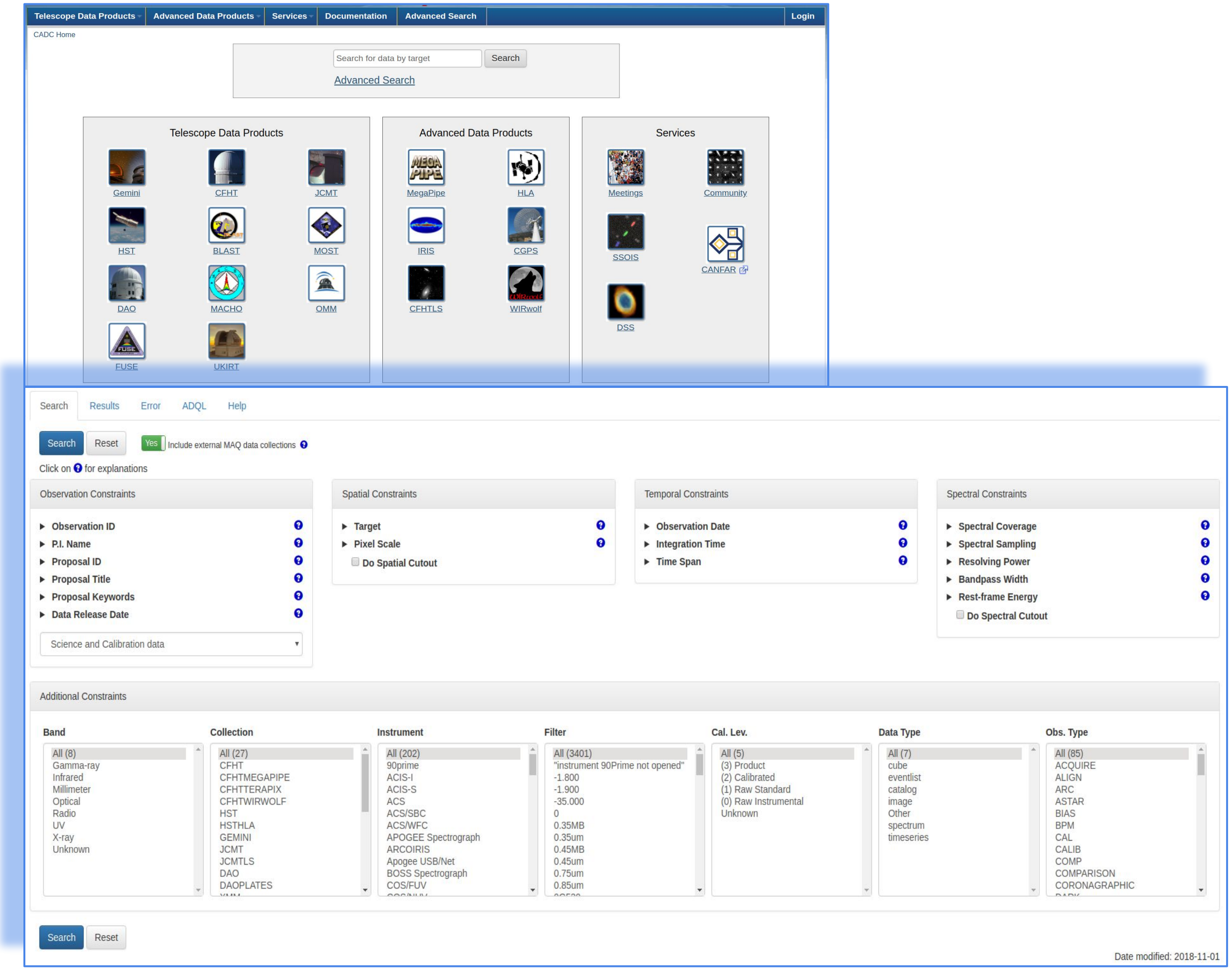
A few more examples… MAST



The Mikulski Archive for Space Telescopes (MAST) is a NASA funded project located at the Space Telescope Science Institute (STScI).

Available data collections: millions of observations and catalogues from both space- and ground-based telescopes.

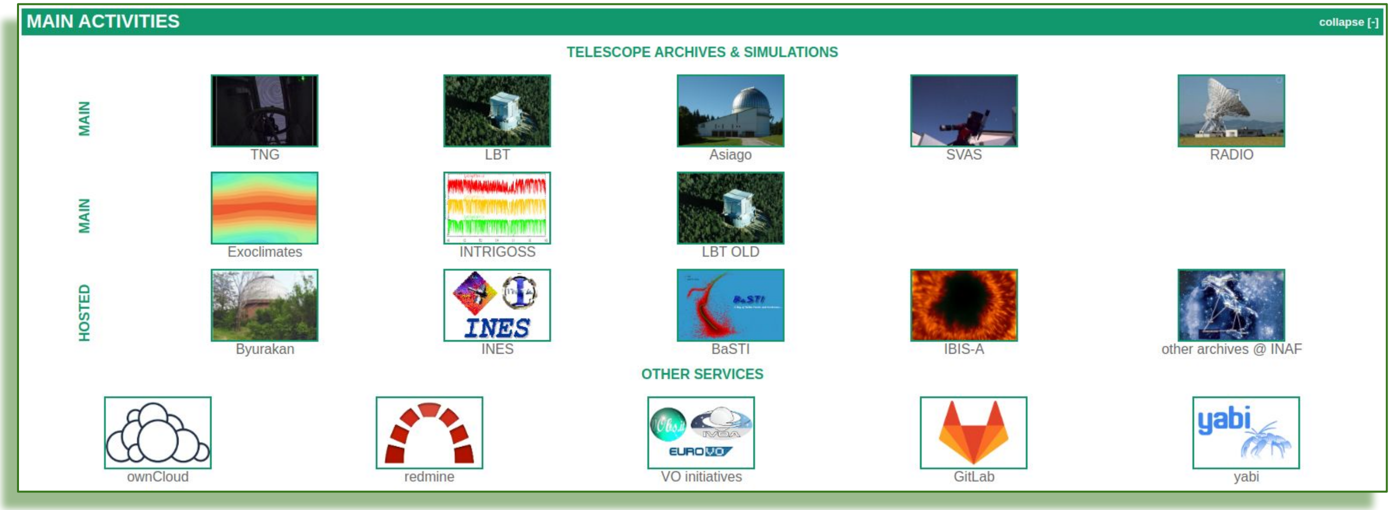
A few more examples… CADC



The [Canadian Astronomy Data Centre] (CADC) was established in 1986 by the *National Research Council* of Canada (NRC).

CADC provides *Archive-as-a-Service* (AaaS) to several Telescopes with storage and search capacity for various data collections. Also users, e.g. PIs can store their data products and are supported in creating the sufficient set of metadata to describe them.

A few more examples… IA2



Further info:
C. Knapic &
U. Becciani's talk

The Italian Center for Astronomical Archive (IA2) is an Italian astrophysical research e-infrastructure based at the Observatory of Trieste.

IA2 manage archives of the Italian facilities: Telescopio Nazionale Galileo (TNG), Asiago Observatory, Italian radio telescopes and Italian VLBI.

IA2 also hosts archives of: the Large Binocular Telescope (LBT, Arizona), the Byurakan Observatory (Armenia), the Interferometric BIdimensional Spectrometer (IBIS, at the Dunn Solar Telescope in New Mexico).