Exploring Time Domain Multi-Messenger Astronomy through the Virtual Observatory

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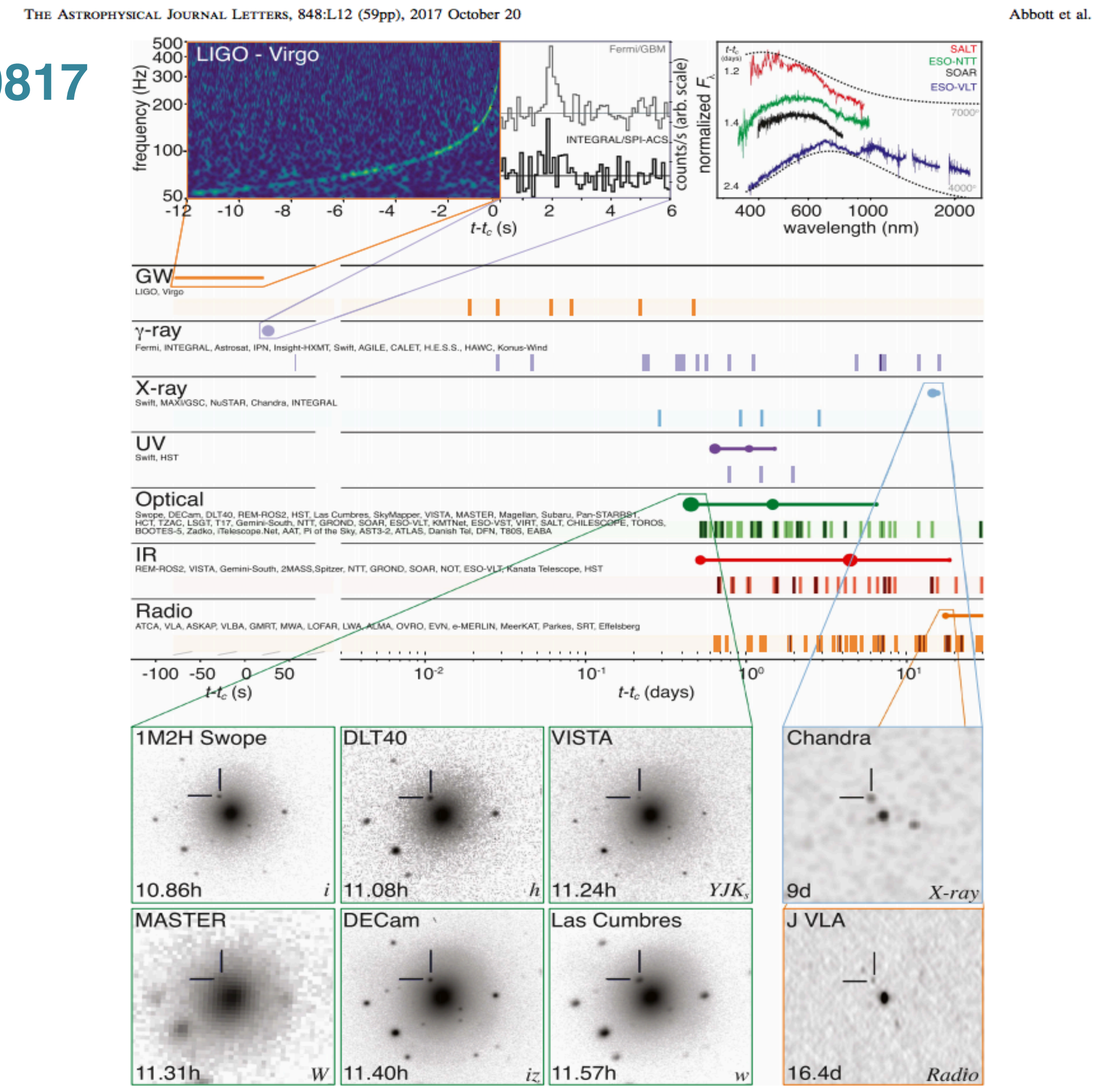
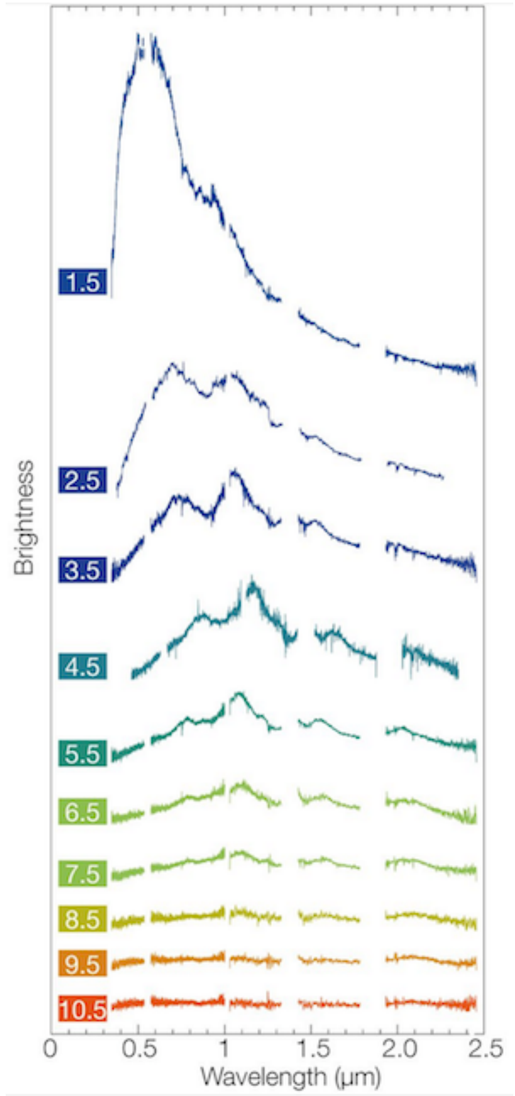
Time Domain Multi-messenger Astronomy

GW170817



Abbott et al. 2017



X-shooter spectra in the kilonova in NGC 4993 over 12 days.
Image credit: ESO/Pian et al./Smartt & ePESSTO.

Time Domain Astronomy Challenges

To characterise and classify sources…

- Multi-wavelength / messenger approach is (sometimes) needed
- Follow-up observations and reaction time for that can be crucial
- Visualisation & navigation thought the data
- Coordination & transmission of information

The VO should match user's needs

So, what is available through the VO?

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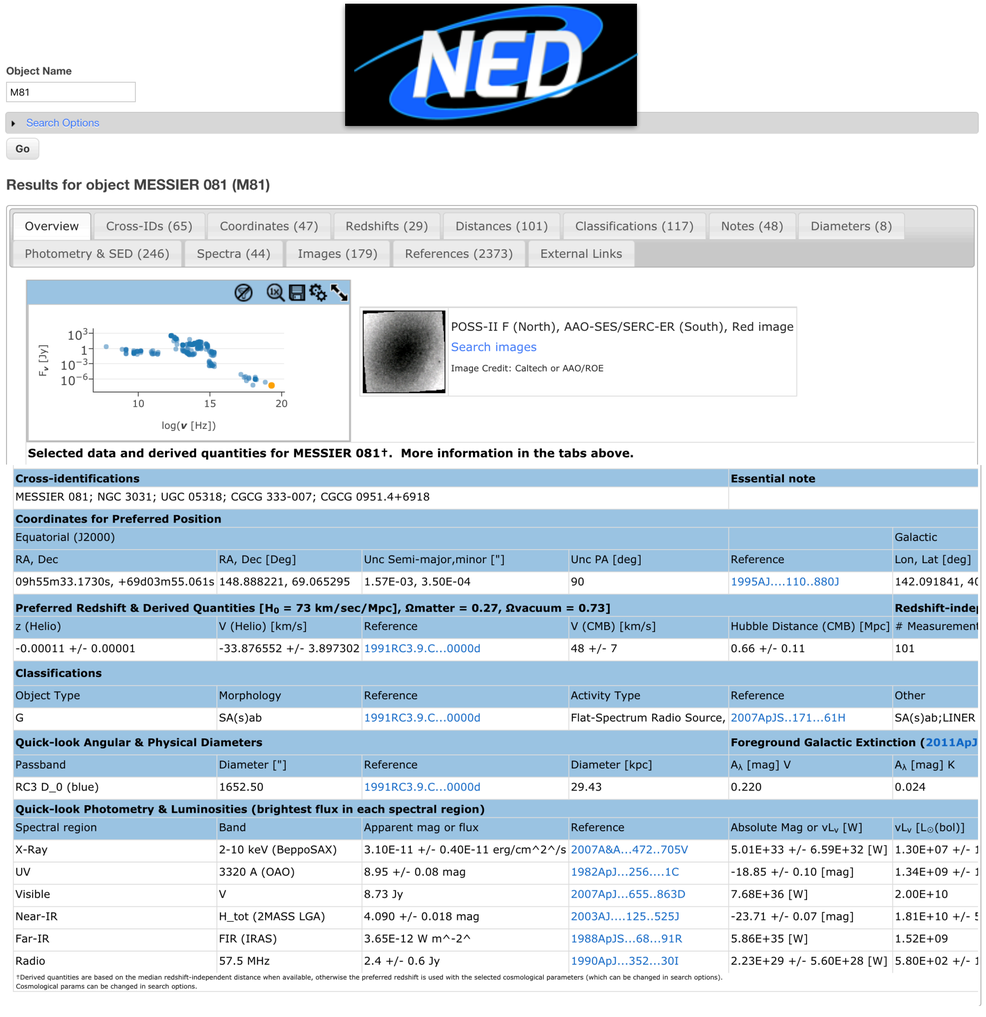
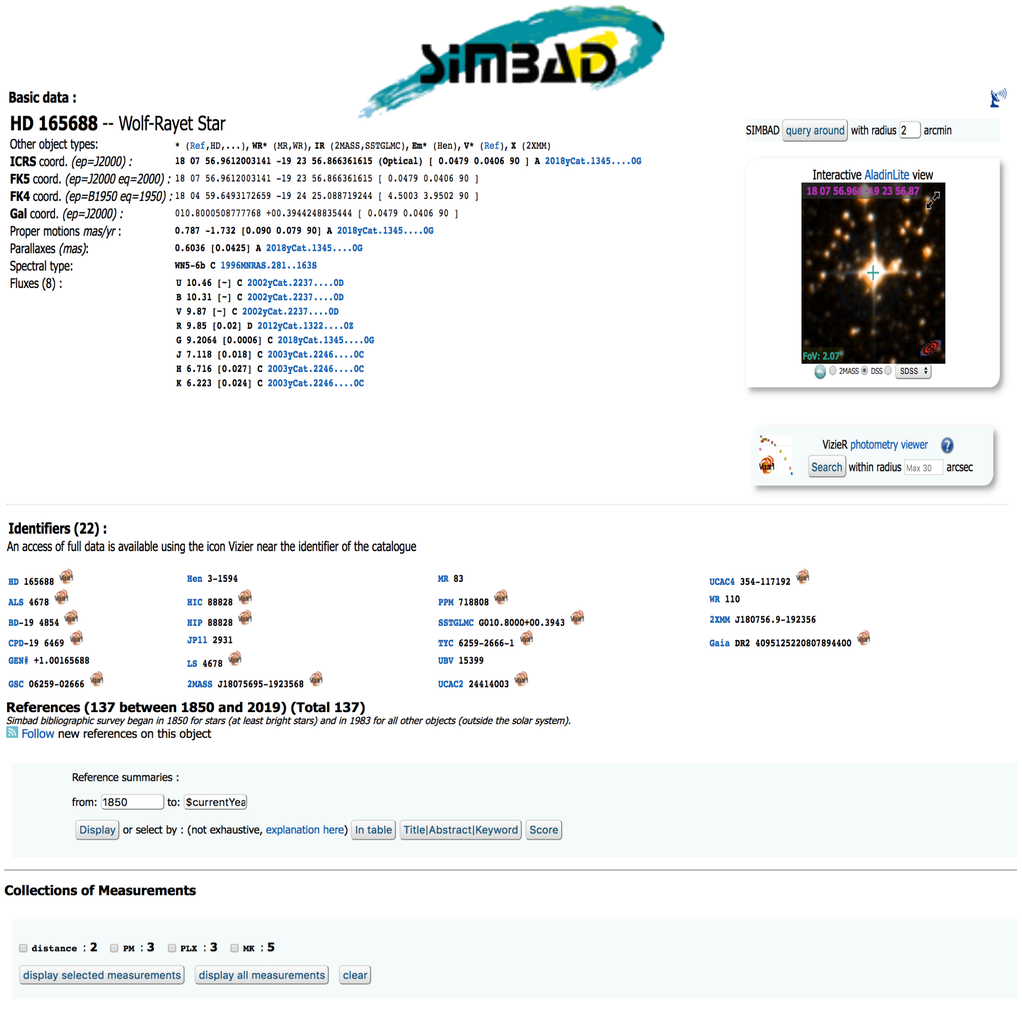
- **Multi-wavelength/messenger**
- Combining data from missions covering different wavelength ranges
  - ➡ Source identification
  - ➡ Cross-matching techniques

Minimum information about objects

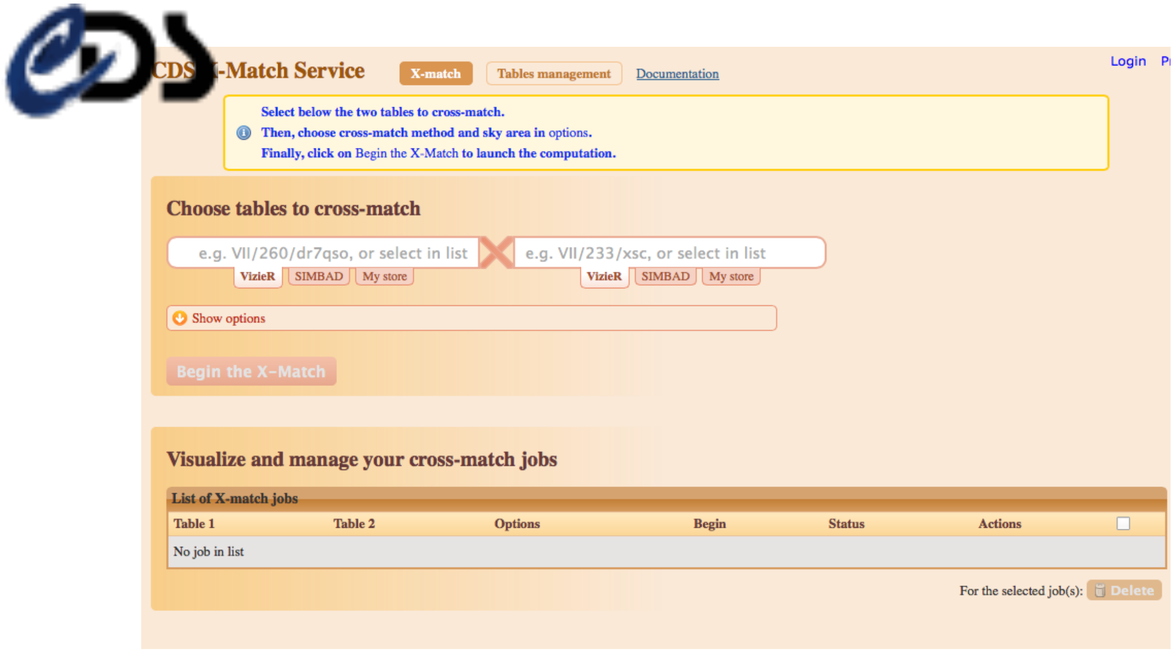
- Which objects around this area are already known and have a classification?
- Give me a minimum information about this object / list of objects (e.g. it's a Galaxy at redshift z)

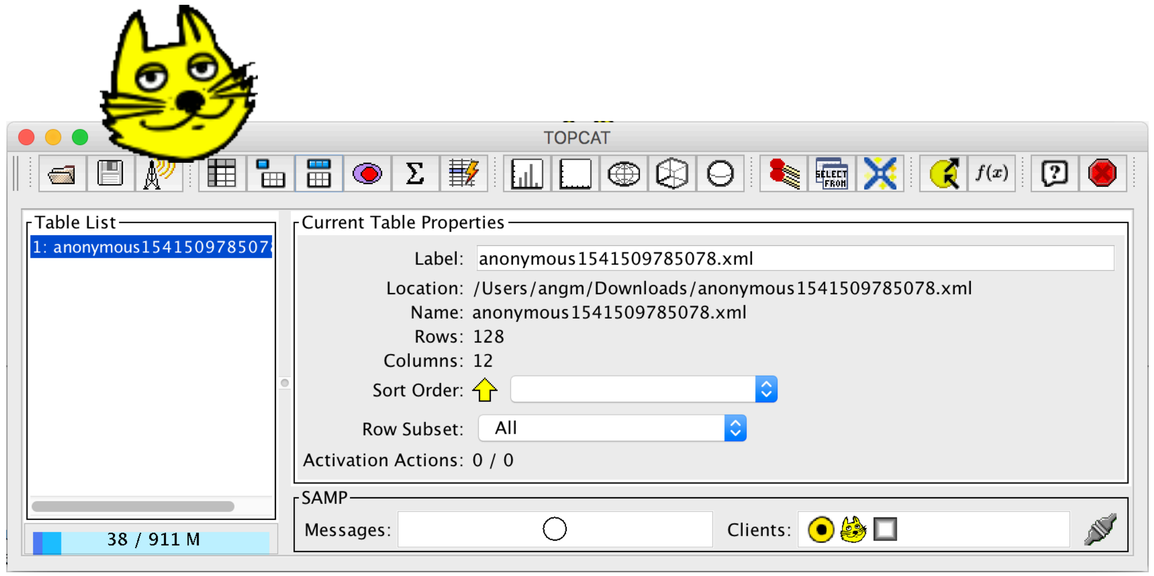




Cross-matching — A key point

- Positional cross-correlation of sources in 2 tables (VizieR tables, simbad, user uploaded lists)
- Result in different formats (VOTable, CSV or ASCII)
- Programatic access too (http API)
- New developments for a multi-catalogue cross-match





Cross-matching

Positional cross-match performance, radius 5”

Table 1	Table 2	Computation time	Result generation	Result size	Total time
SDSS DR9 *469M rows*	**2MASS** *470M rows*	3 min	7 min	19 GB	10 min
2MASS *470M*	**GAIA-DR1** *1.1 billion*	16 min	65 min	193 GB	81 min
Tycho-2 *2M*	**SIMBAD** *8M*	6 sec	25 sec	1 GB	35 sec
List of *40k positions*	**SIMBAD** *8M*	1 second	4 seconds	10 MB	5 sec

Under dev.: add the time as a possible information to cross-matches

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- Visualisation & navigation thought the data
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- **Follow-up observations**
  - ➡ **Transmission of events: VOEvent**, more on Friday
  - ➡ **Planning observations: visibility, available telescope time** (see next talk by E. Kuulkers)

Time Domain Astronomy Challenges

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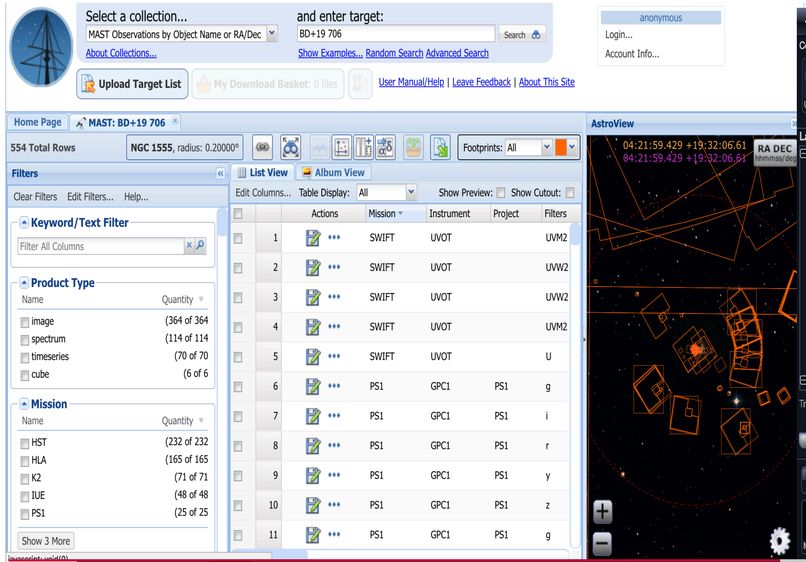
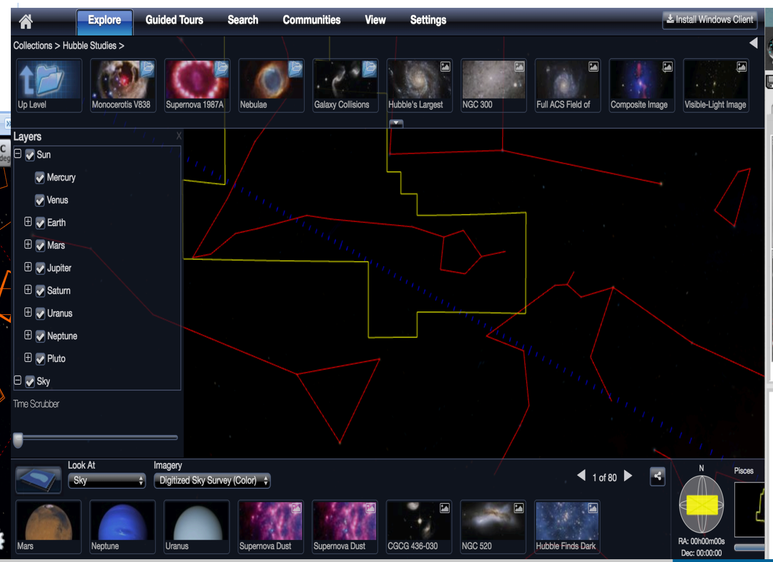
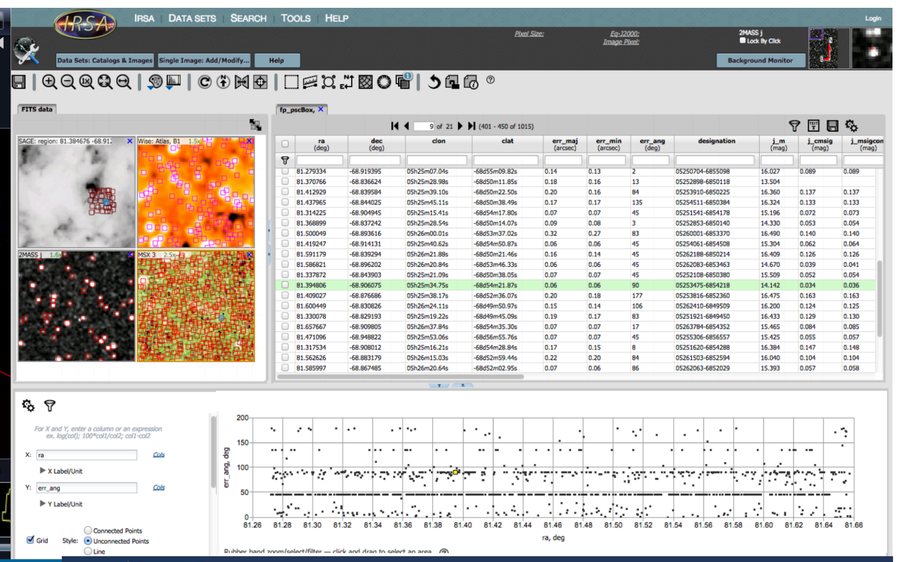
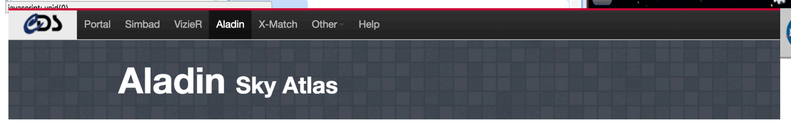
- **Visualisation & navigation**
  - ➡ sequences of images, spectra, photometry, positions, … and all interoperable
  - ➡ tools

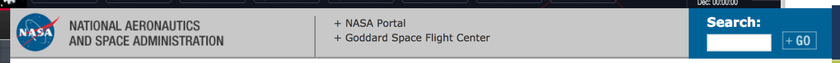
Visualisation of the sky











- Overview
- Aladin Desktop
- Aladin Lite
- Information
- → *en français*

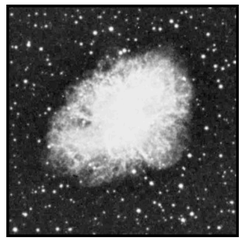
Overview

Aladin is an interactive sky atlas allowing the user to visualize digitized astronomical images or full surveys, superimpose entries from astronomical catalogues or databases, and interactively access related data and information from the *Simbad database*, the *VizieR service* and other archives for all known astronomical objects in the field.

Download
Aladin Desktop
on your machine

Preview with
Aladin Lite
in your browser

The *Aladin sky atlas* is available in two modes: *Aladin Desktop*, a regular application and *Aladin Lite* an HTML javascript web widget.



Check the *SkyView* Blog for the most recent news.

Interfaces and Software

***SkyView* Query Form**

Non-Astronomers Page

SkyView is a Virtual Observatory on the Net generating images of any part of the sky at wavelengths in all regimes from Radio to Gamma-Ray.

Quick SkyView Image:
Coordinates or Source: Survey: DSS Go **Help**

Local Data Status : available
Remote Data Status
green = Remote Data are available
red = Remote Data are unavailable

2MASS	SDSS	Galex	WISE	SDSS7
UKIDSS	FIRST	TGSS	AKARI	

SkyView Version: 3.4.2

Visit the SkyView Image Gallery

Documentation | **Links**

SAOImageDS9 is an astronomical imaging and data visualization application. DS9 supports FITS images and binary tables, multiple frame buffers, region manipulation, and many scale algorithms and colormaps. It provides for easy communication with external analysis tasks and is highly configurable and extensible via XPA and SAMP.

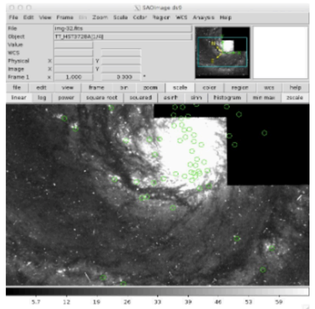
DS9 is a stand-alone application. It requires no installation or support files. All versions and platforms support a consistent set of GUI and functional capabilities.

DS9 supports advanced features such as 2-D, 3-D and RGB frame buffers, mosaic images, tiling, blinking, geometric markers, colormap manipulation, scaling, arbitrary zoom, cropping, rotation, pan, and a variety of coordinate systems.

The GUI for DS9 is user configurable. GUI elements such as the coordinate display, panner, magnifier, horizontal and vertical graphs, button bar, and color bar can be configured via menus or the command line.

SAOImageDS9 Version 7.6

DS9 version 7.6 is now available on the **Download** page. New to version 7.6 is the new Windows 32/64 bit and MacOS High Sierra ports. Please see the **What's New** page for more details. **Note: version 8.0rc6 is now available here**



Tweets by @SAOImageDS9

SAOImageDS9 @SAOImageDS9
New beta release of SAOImageDS9 8.0rc6 is now available at ds9.si.edu/site/Beta.html
Oct 19, 2018

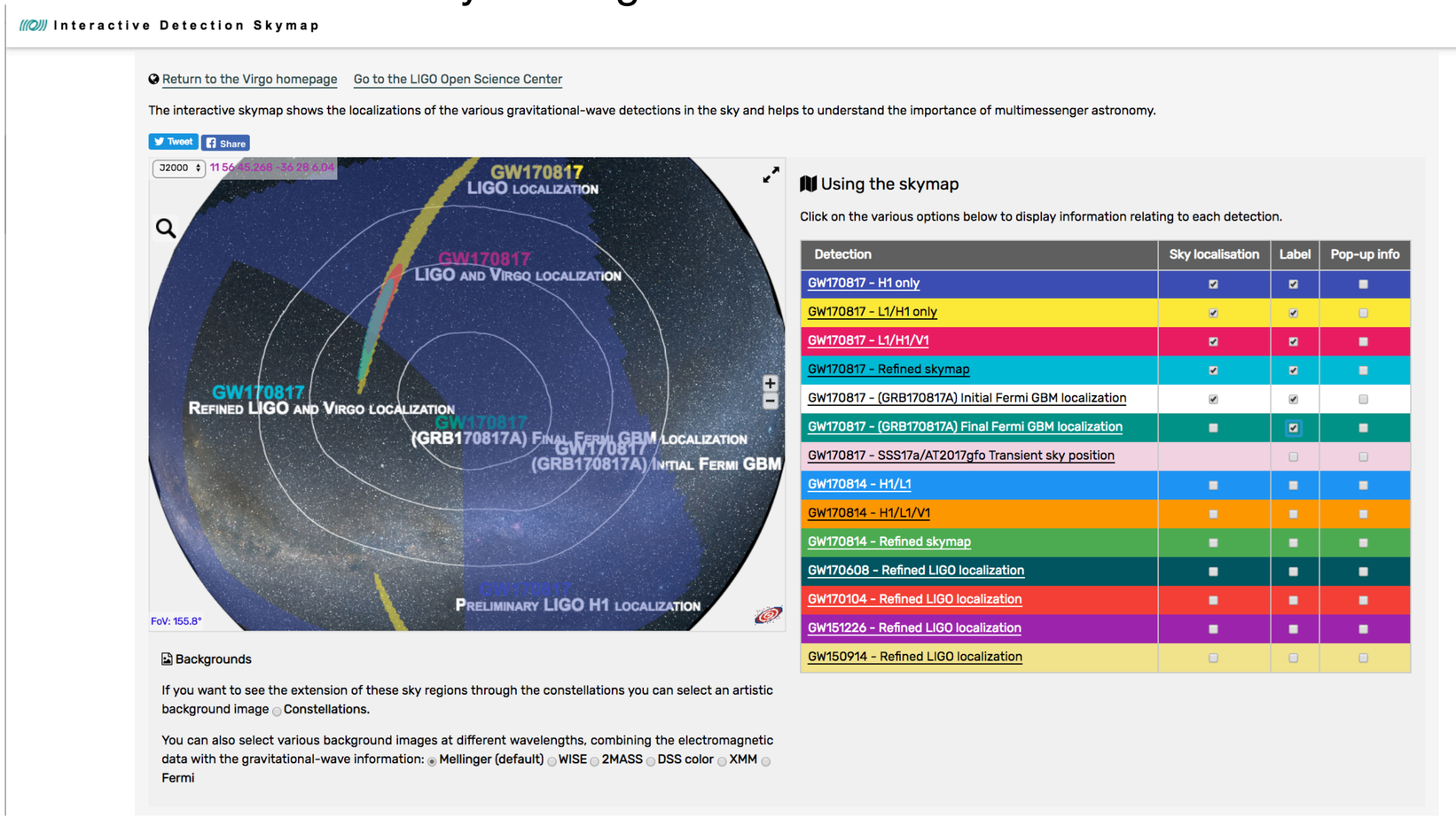
SAOImageDS9 @SAOImageDS9
SAOImageDS9 is now available as OpenSUSE binaries ds9.si.edu/site/Beta.html
Oct 8, 2018

SAOImageDS9 Retweeted
Franco Vazza @franco_vazza
Replying to @SAOImageDS9
Indeed! Maybe I'm asking too much, is there already the possibility of producing

SAOImageDS9 development has been made possible by funding from the Chandra X-ray Science Center (CXC) and the High Energy Astrophysics Science Archive Center (HEASARC) with additional funding from the JWST Mission office at Space Telescope Science Institute. If you are writing a

Visualisation of the sky

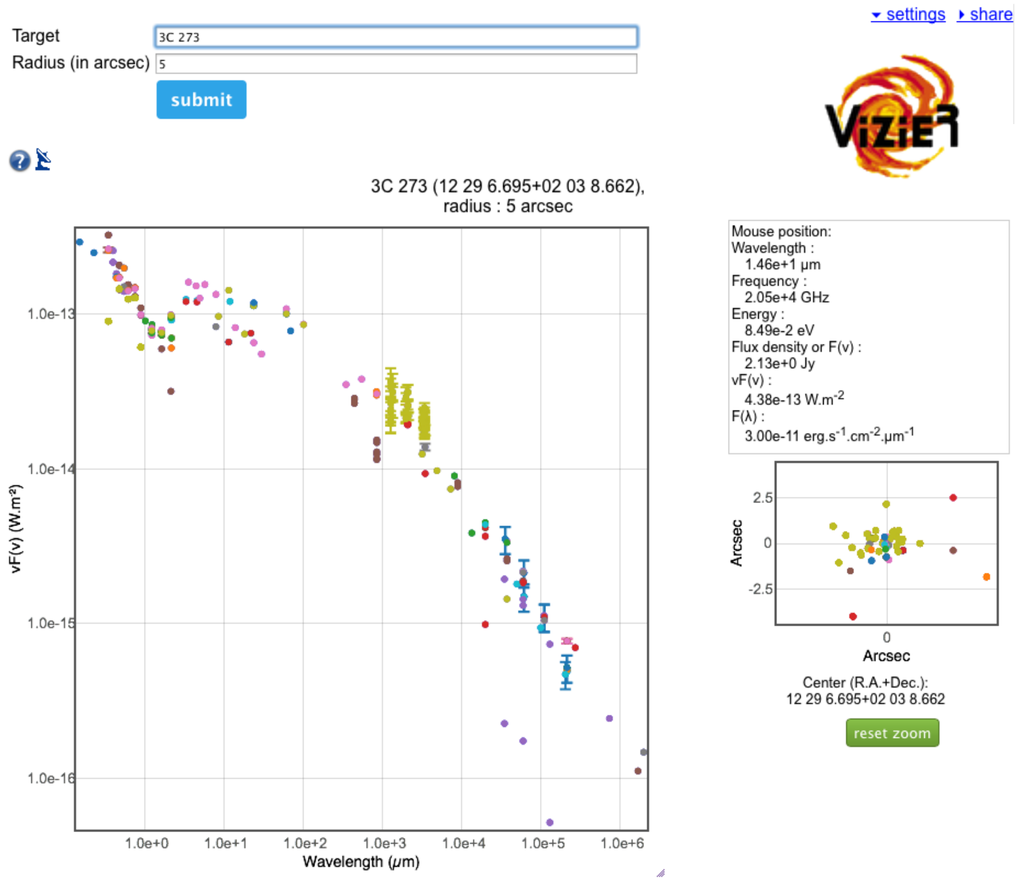
- Aladinlite implementation for GW localisation in the sky
- Background image can be DSS, 2MASS, WISE, XMM, Fermi,…
- We can overlay catalogues of interest



- (see talk by G. Greco)

Visualisation of photometry

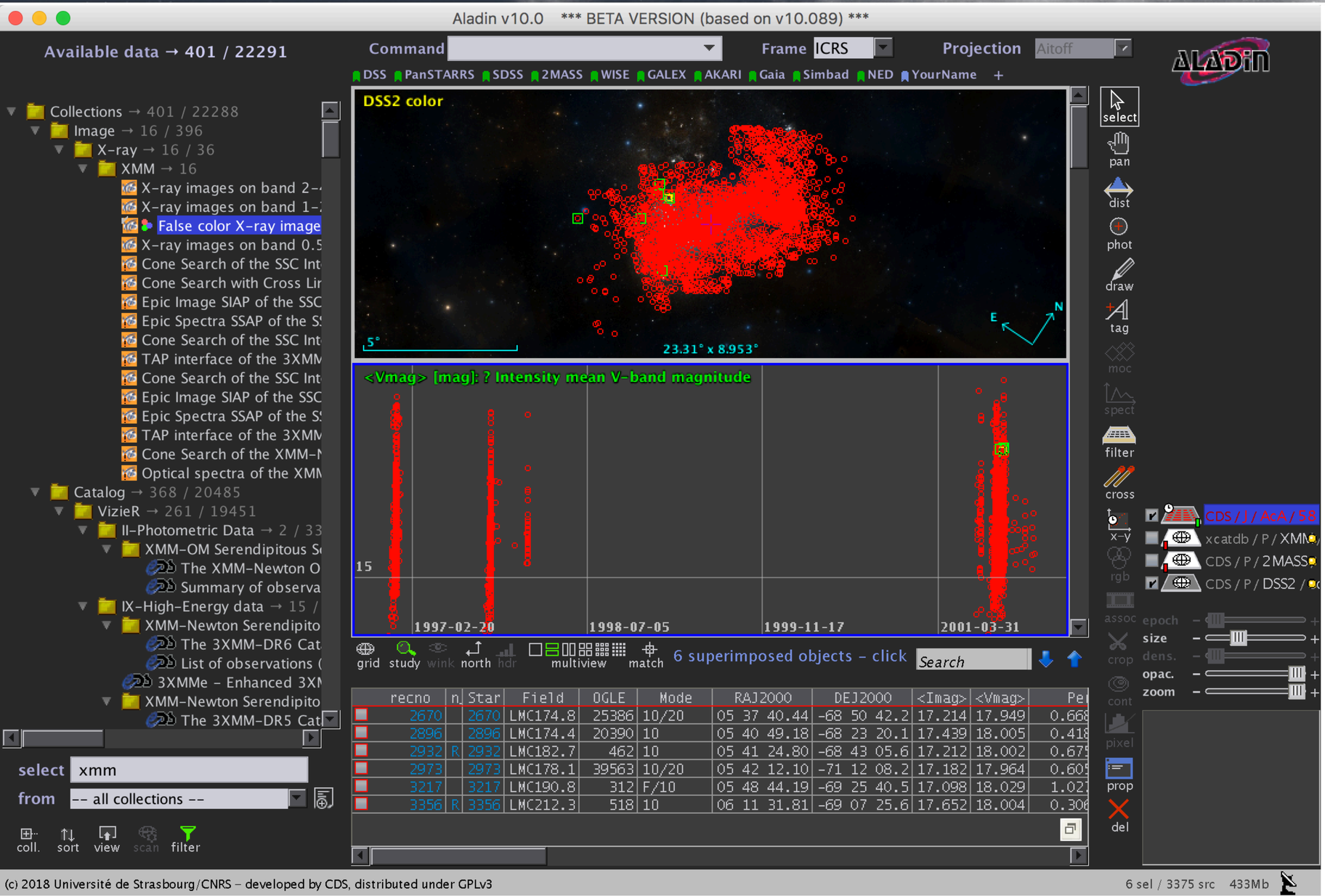
- Search all the photometry available around a position in the sky
- Plot photometry against wavelength



Under dev.: A time (series) viewer

- **Plot photometry against time**

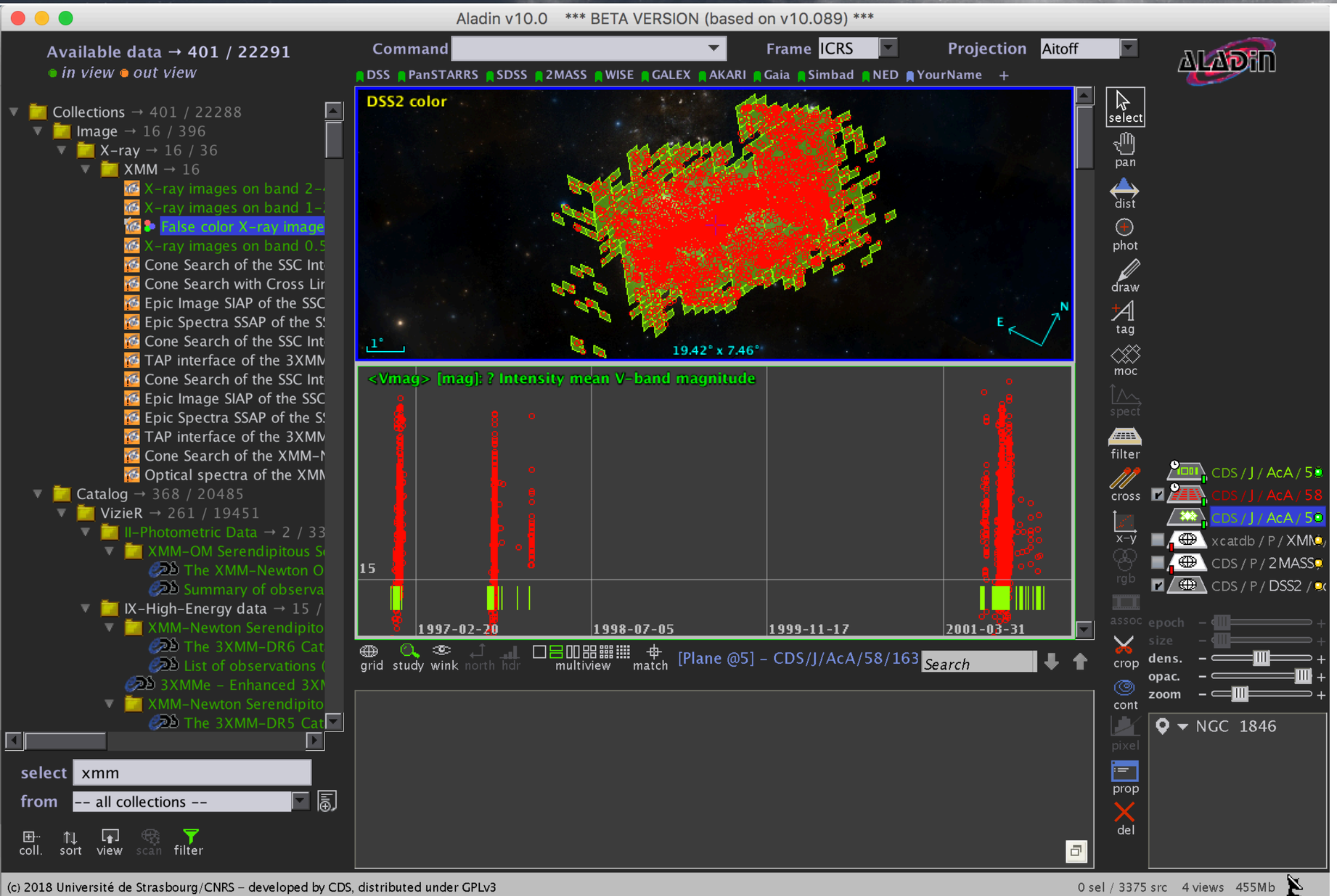
Time Series view (Aladin beta)



- For all catalogues available through Aladin (VizieR, Simbad,…)+ users
- Plot position in the sky
- Background image can be any available through Aladin + users

- **Under dev.:**
- **Measurements as a function of time**
- **Simultaneously visualise the catalogue positions in the sky**

Time Series view (Aladin beta)



- Coverage of a survey in space: MOC

Under dev.:

- **Temporal coverage of a survey: TMOC**
- **Simple operations such as union, intersections, filter a catalogue by temporal coverage, …**

Under dev.: combine both spatial and temporal coverages

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- **Coordination & transmission**
  - ➡ collect what was observed, when, in which wavelength, …
  - ➡ alerts, emails, webpages, references,…
  - ➡ See today’s and tomorrow’s afternoon sessions

Summary

- To enable access, discovery and interoperability the VO is based on standards
- The Time Domain standards needed for time domain multi-messenger astronomy are:
  - ➡ Existing (e.g. VOEvent)
  - ➡ or under development:
    - Definition of the minimum metadata for time
    - Temporal coverage (T-MOC), space + time coverage
    - Quick light-curve viewer
    - Visibility & Observation locator — see next talk ;)