

Exploring Time Domain Multi-Messenger Astronomy through the Virtual Observatory

Ada Nebot, M. Allen, P. Fernique, T. Boch, C. Bot, S. Derriere,
M. Baumann, K. Lutz, F. Genova

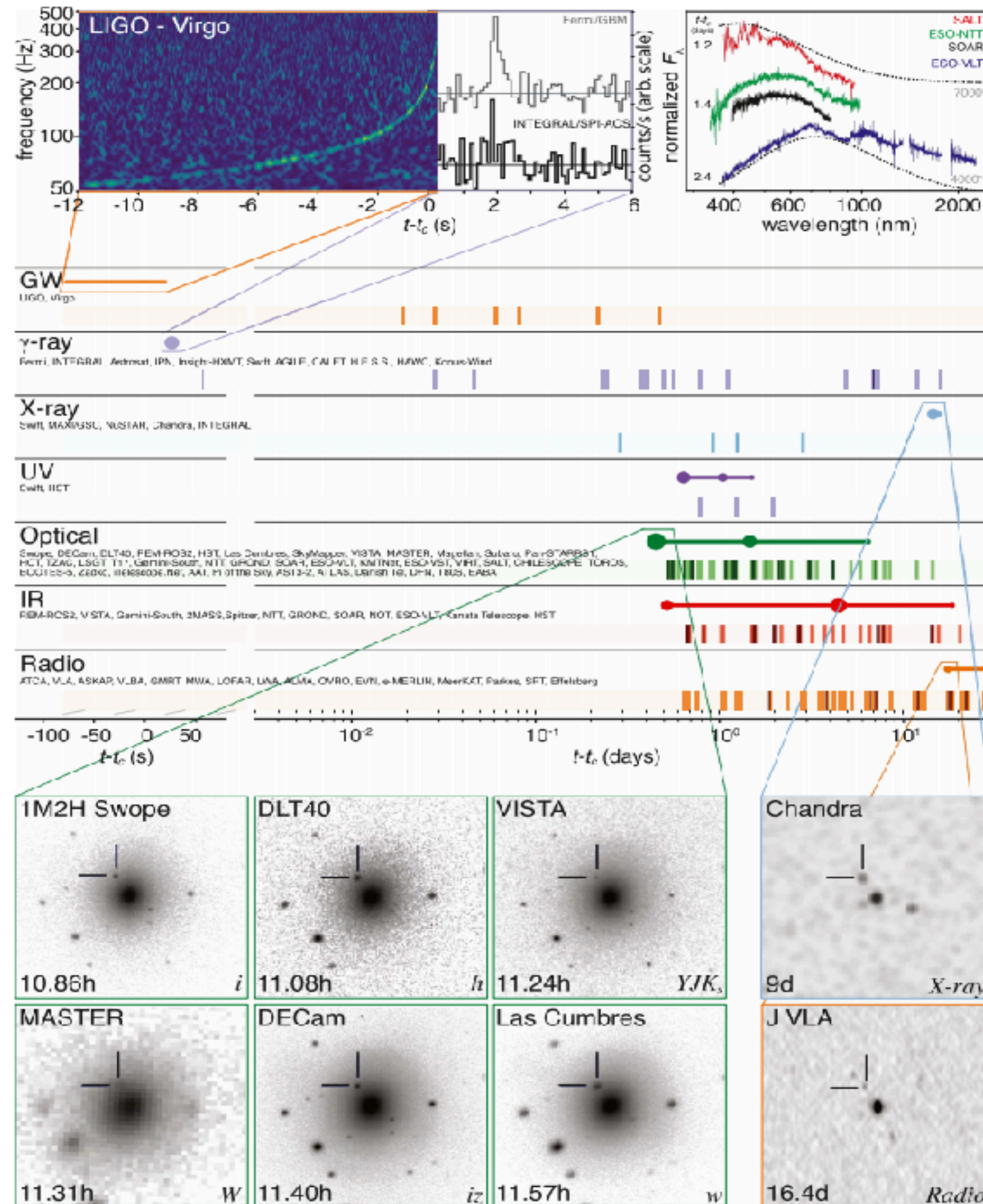


Time Domain Multi-messenger Astronomy

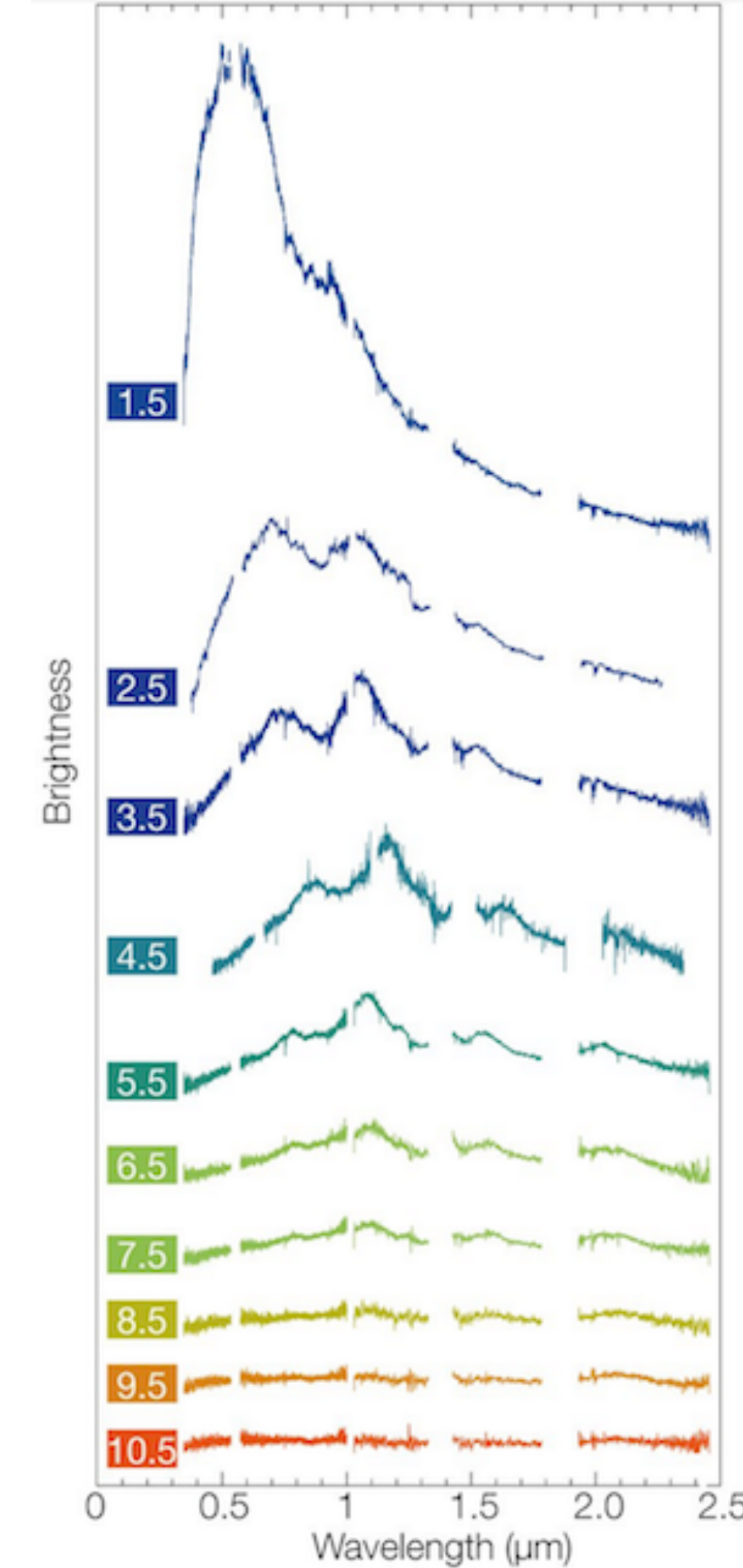
GW170817

THE ASTROPHYSICAL JOURNAL LETTERS, 848:L12 (Supp), 2017 October 20

Abbott et al.



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 through the data
- Coordination & transmission of information

The VO should match user's needs
So, what is available through the VO?



□ Time Domain Astronomy Challenges

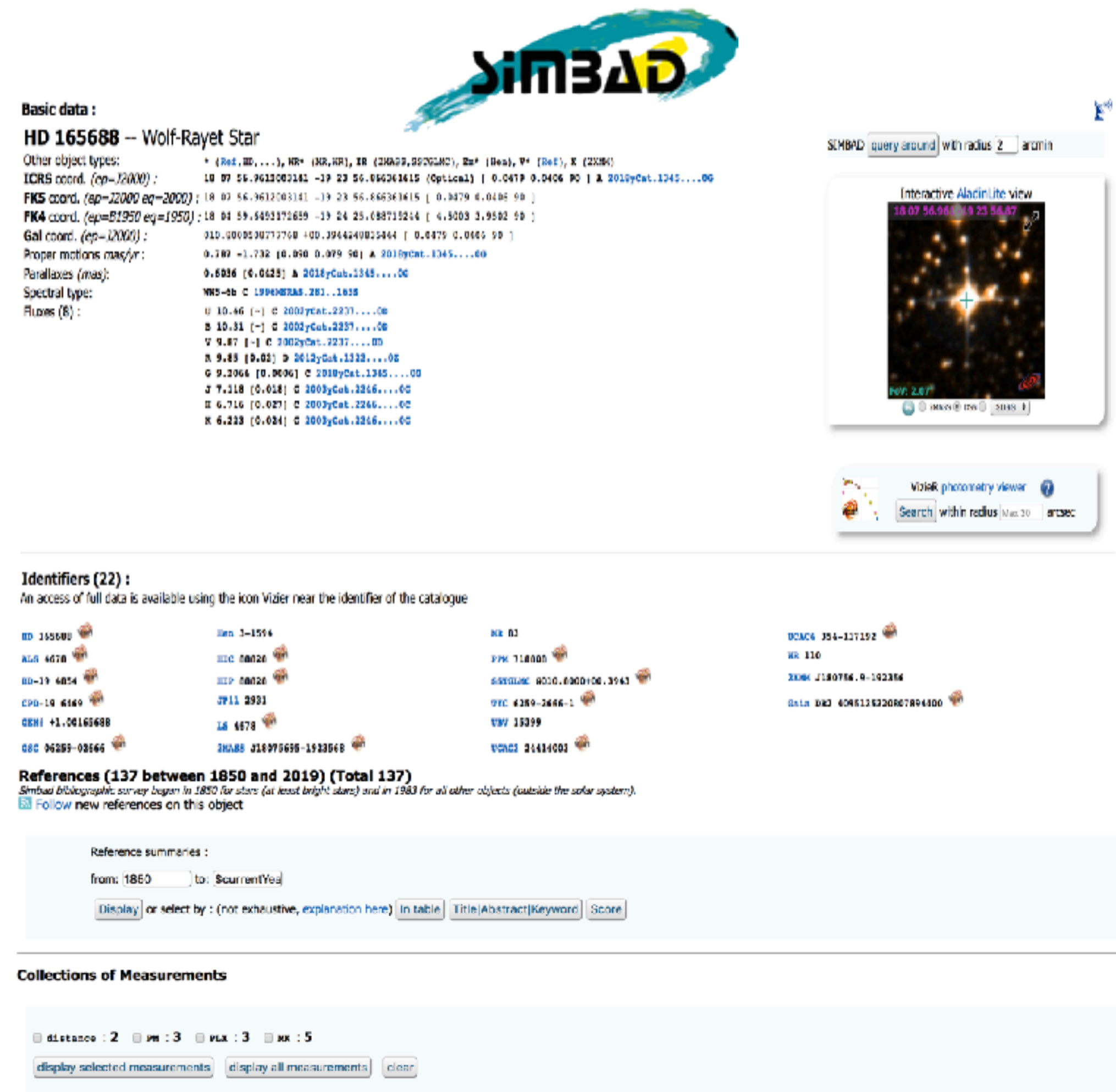
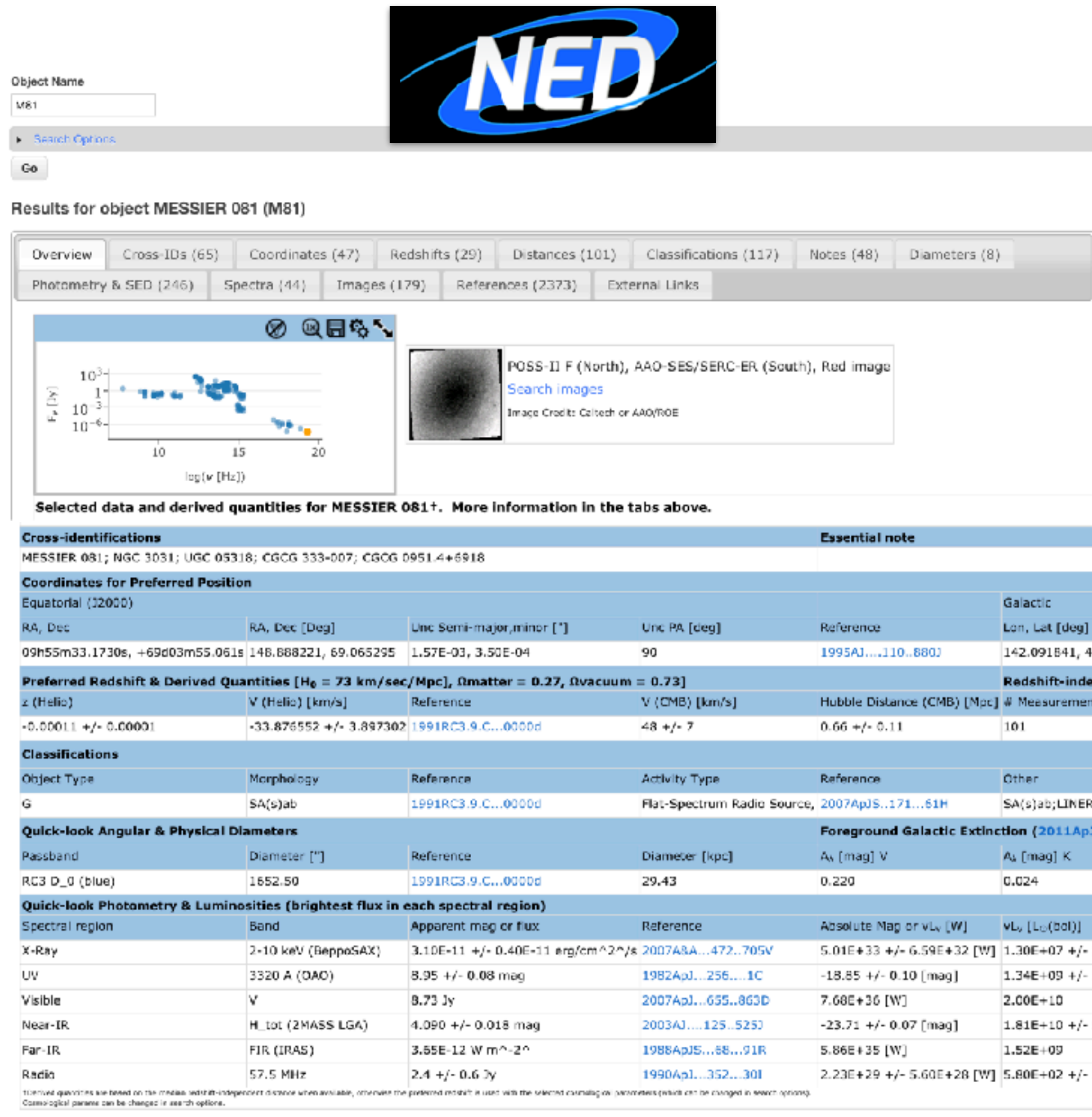
To characterise and classify sources...

- **Multi-wavelength/messenger** approach is (sometimes) needed
 - Follow-up observations and reaction time for that can be crucial
 - Visualisation & navigation through the data
 - Coordination & transmission of information
-
- **Multi-wavelength/messenger**
 - Combining data from missions covering different wavelength ranges
 - ➡ Source identification
 - ➡ Cross-matching techniques



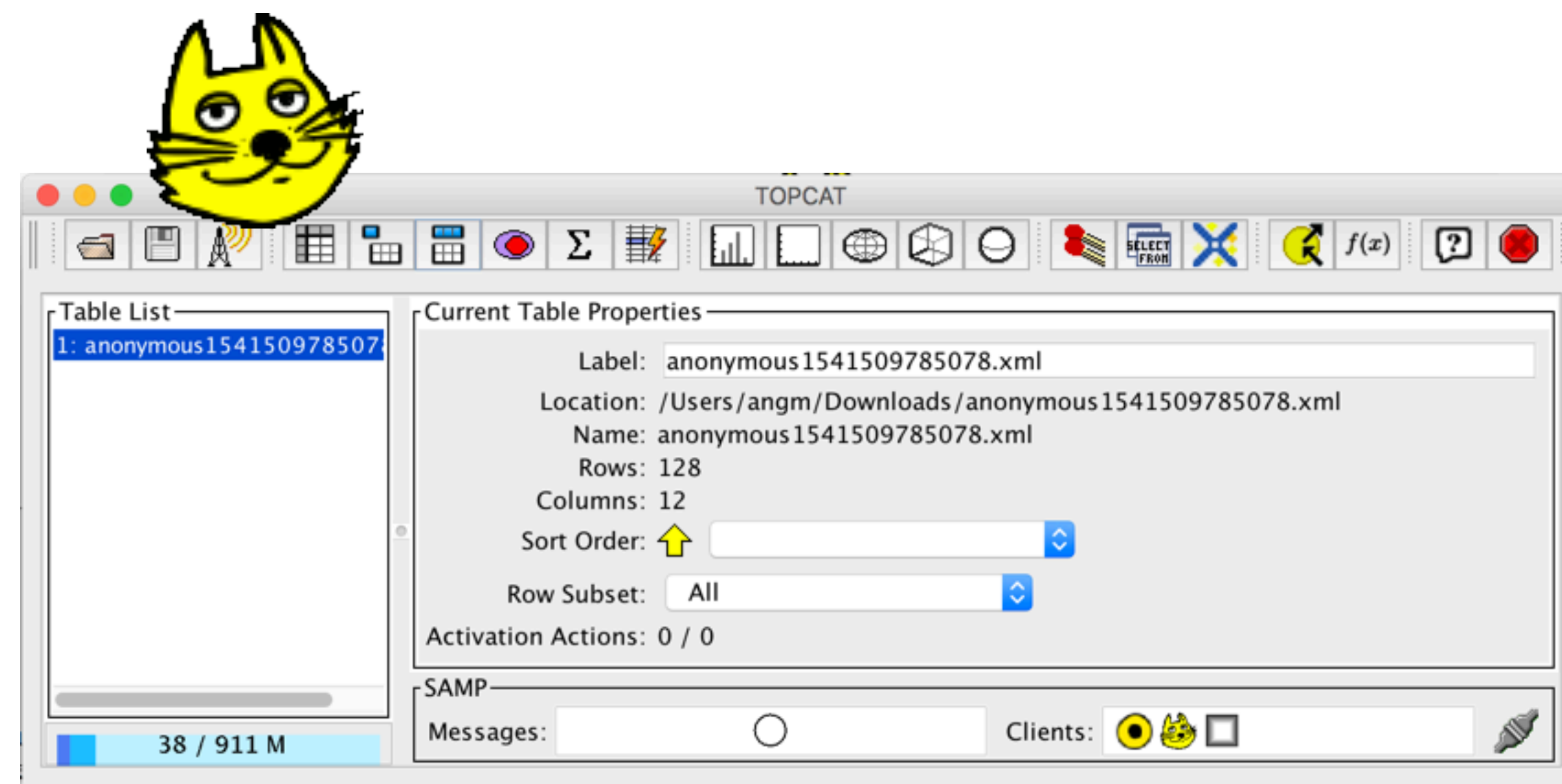
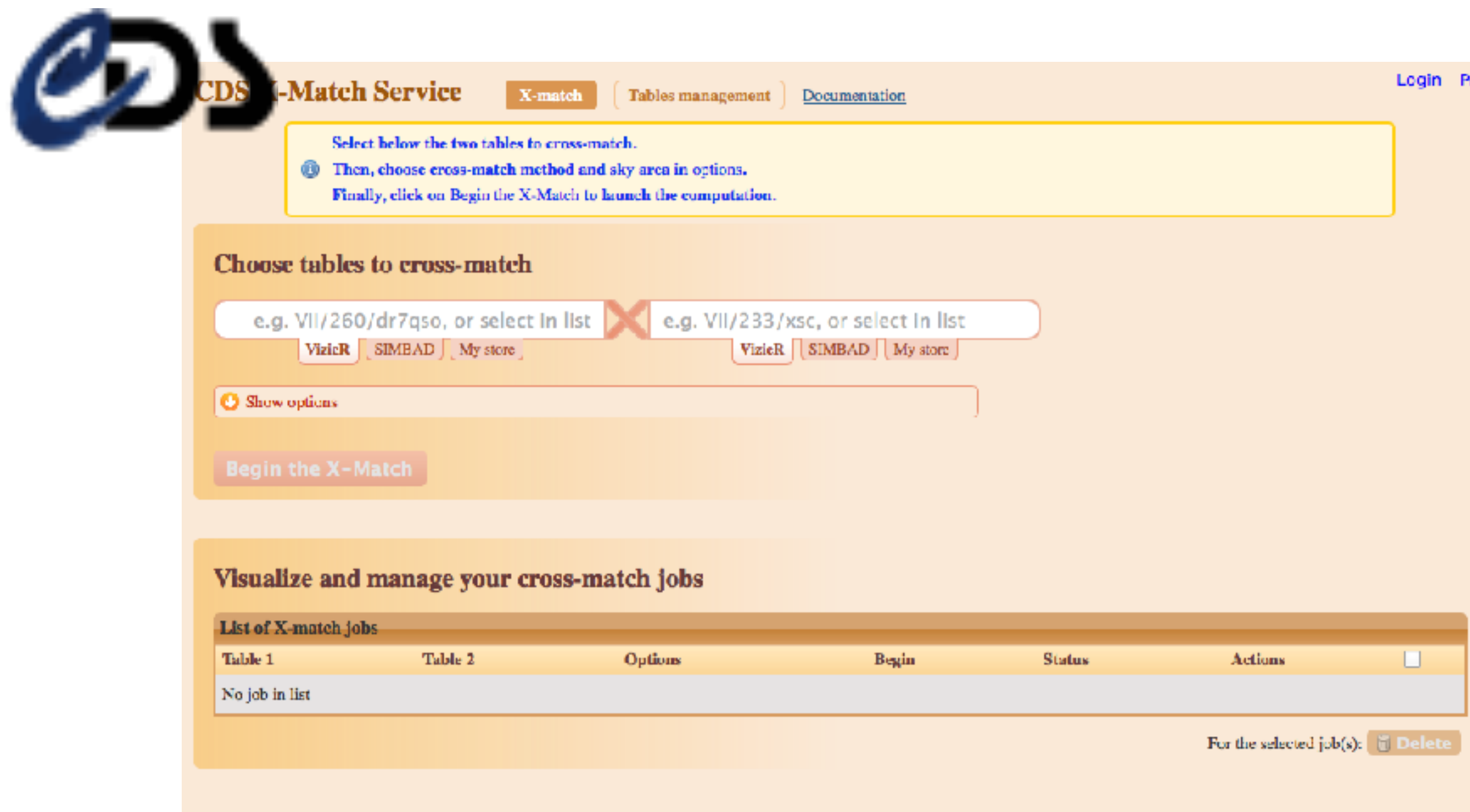
Minimum information about objects

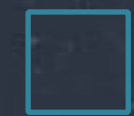
- ➡ Which objects around this area are already known and have a classification?
- ➡ Give me a minimum information about this object / list of objects (e.g. it's a Galaxy at redshift z)



□ 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 <i>469M rows</i>	2MASS <i>470M rows</i>	3 min	7 min	19 GB	10 min
2MASS <i>470M</i>	GAIA-DR1 <i>1.1 billion</i>	16 min	65 min	193 GB	81 min
Tycho-2 <i>2M</i>	SIMBAD <i>8M</i>	6 sec	25 sec	1 GB	35 sec
List of <i>40k positions</i>	SIMBAD <i>8M</i>	1 second	4 seconds	10 MB	5 sec

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



□ Time Domain Astronomy Challenges

To characterise and classify sources...

- Multi-wavelength/messenger approach is (sometimes) needed
 - **Follow-up observations** & reaction time for that can be crucial
 - Visualisation & navigation through the data
 - Coordination & transmission of information
-
- **Follow-up observations**
 - ➡ **Transmission of events: VOEvent**, more on Friday
 - ➡ **Planning observations: visibility, available telescope time** (see next talk by E. Kuulkers)



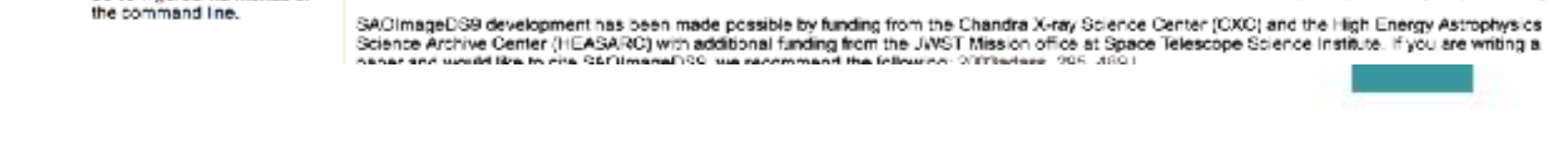
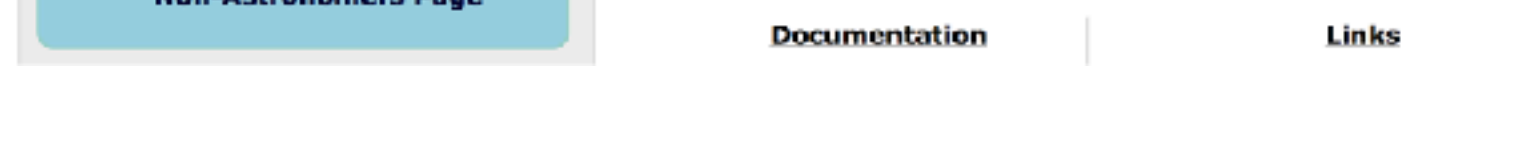
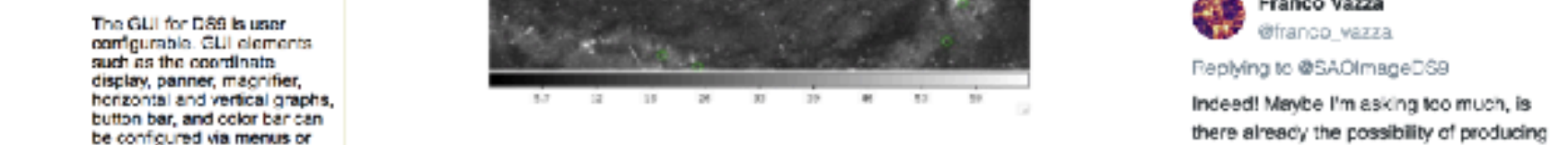
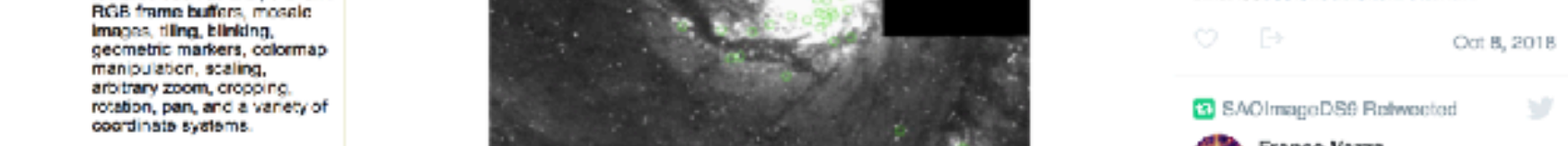
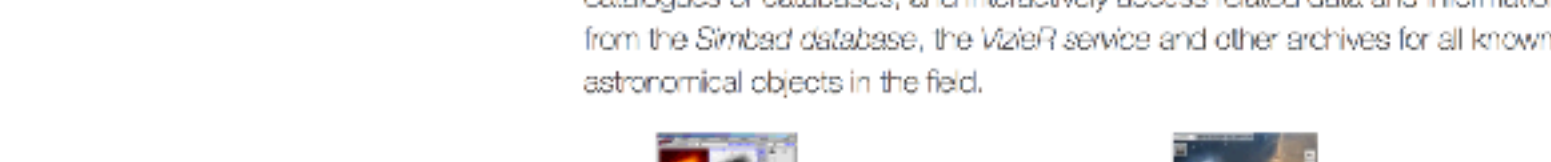
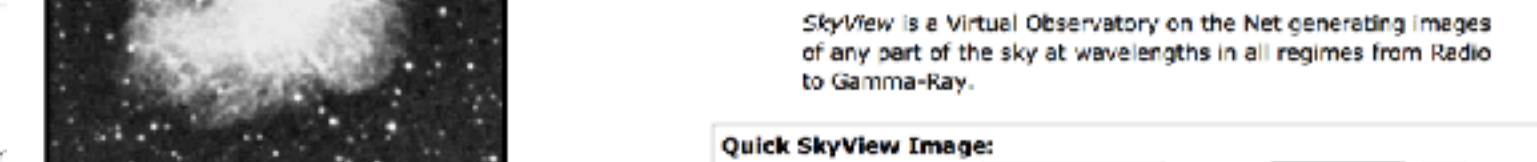

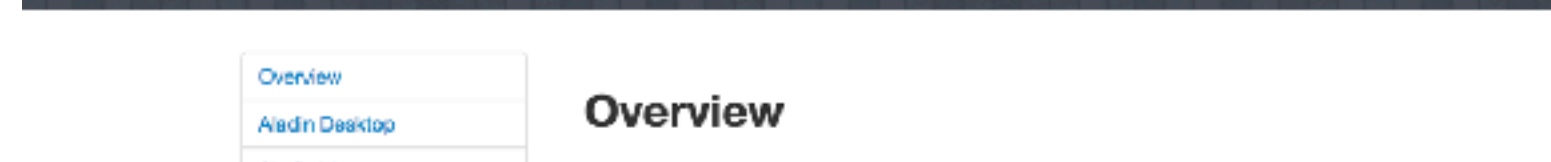
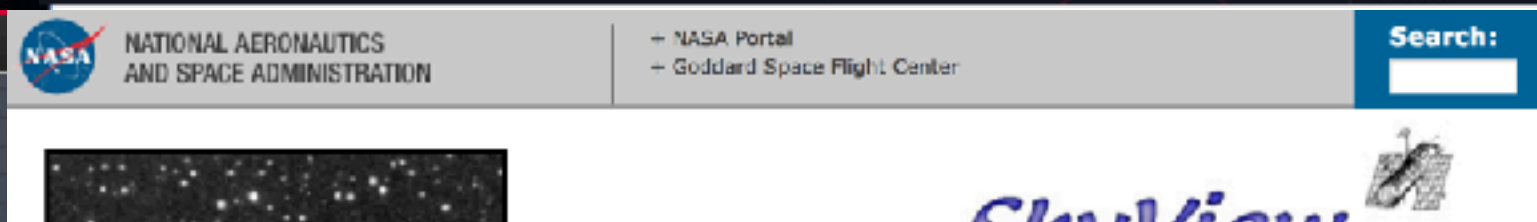
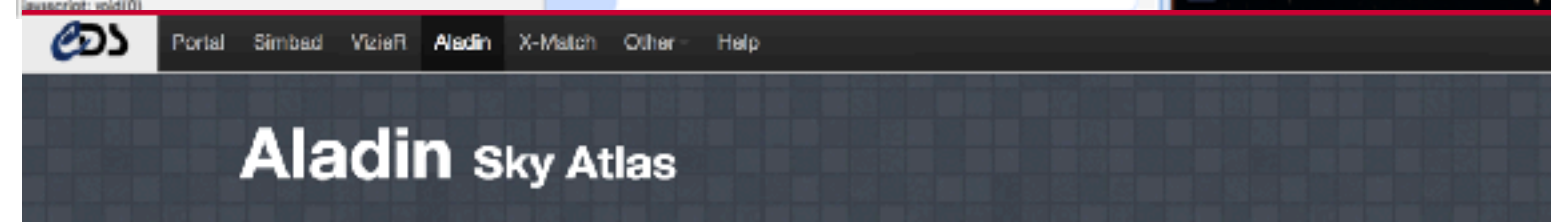
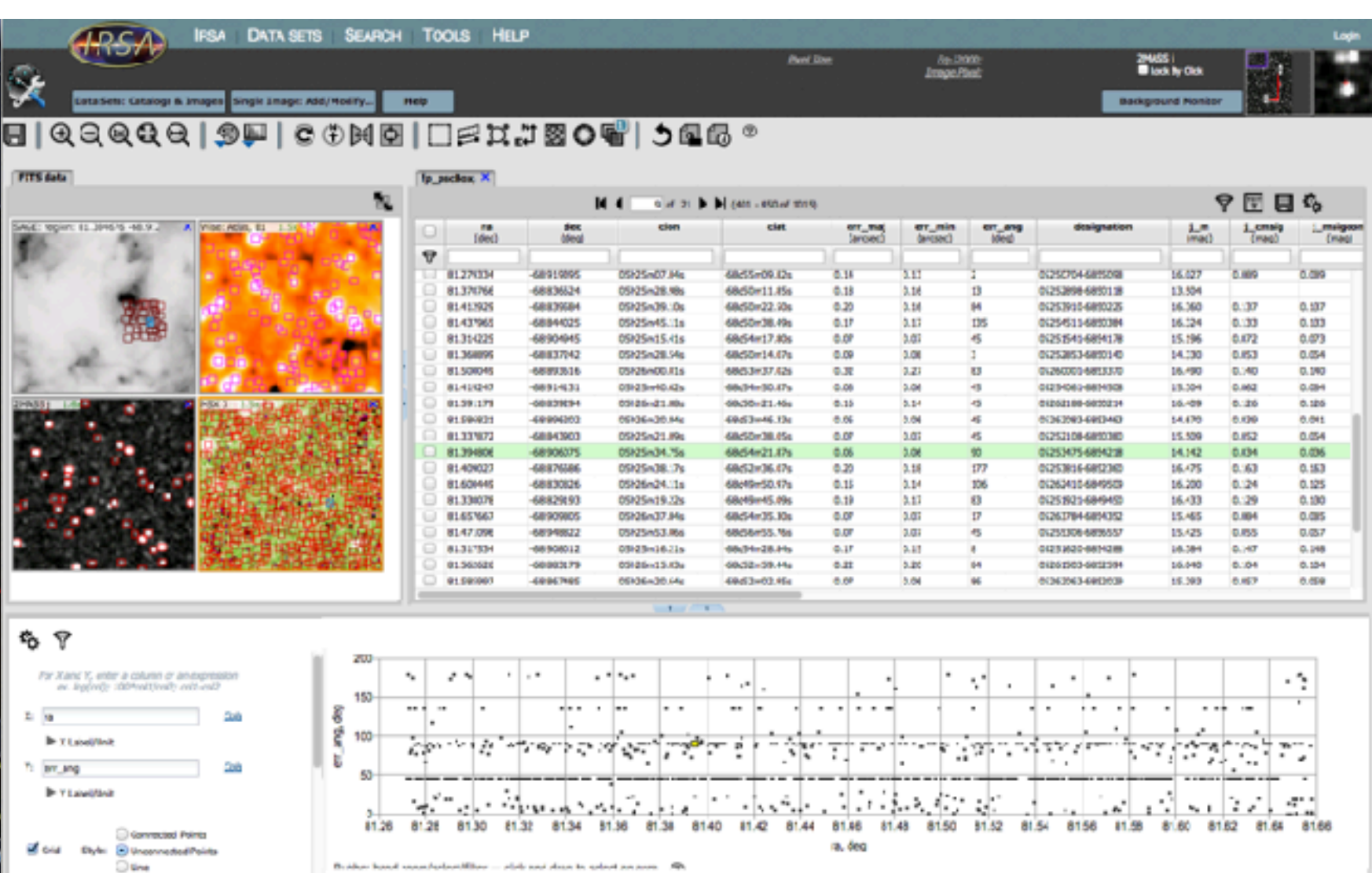
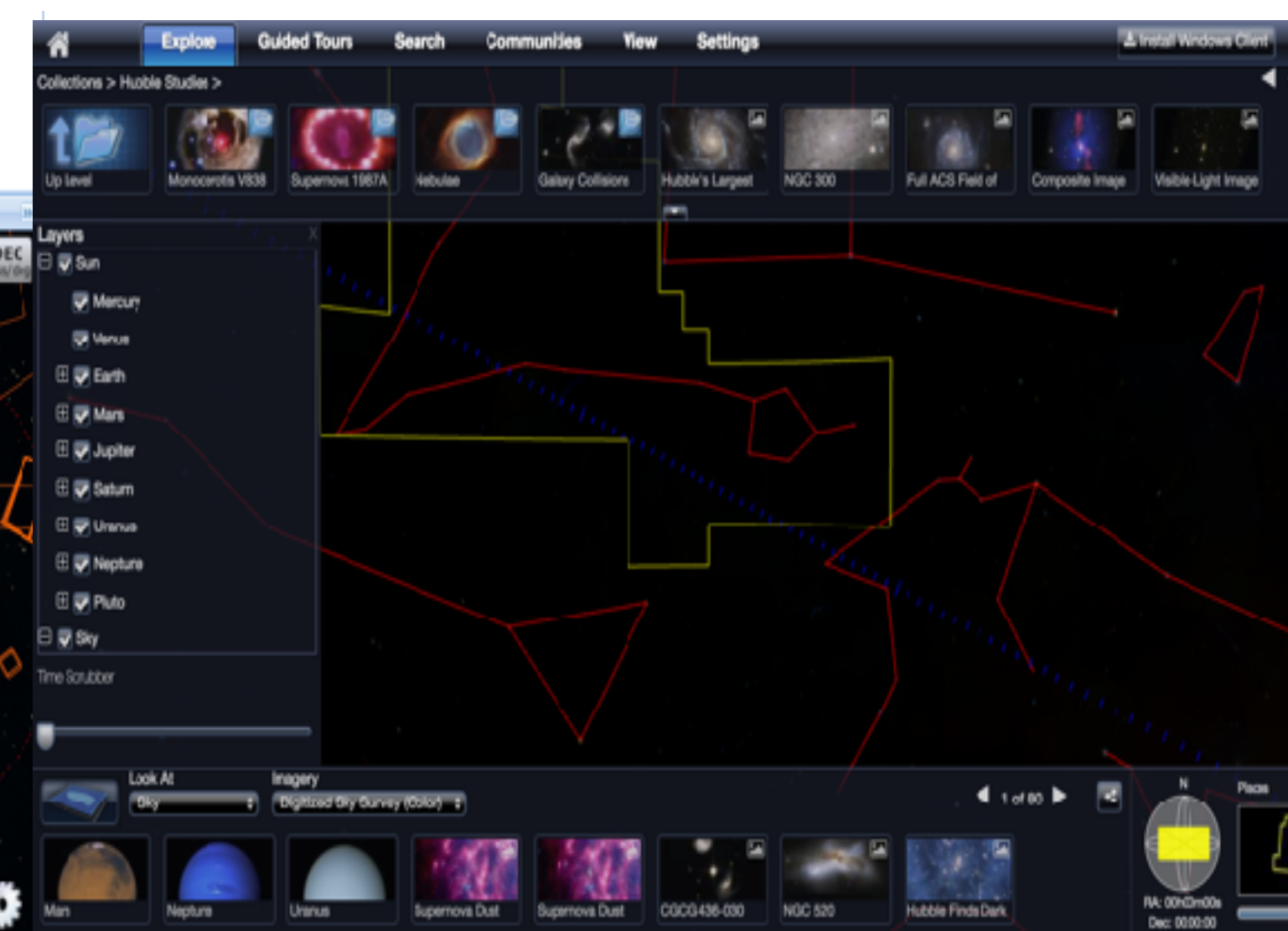
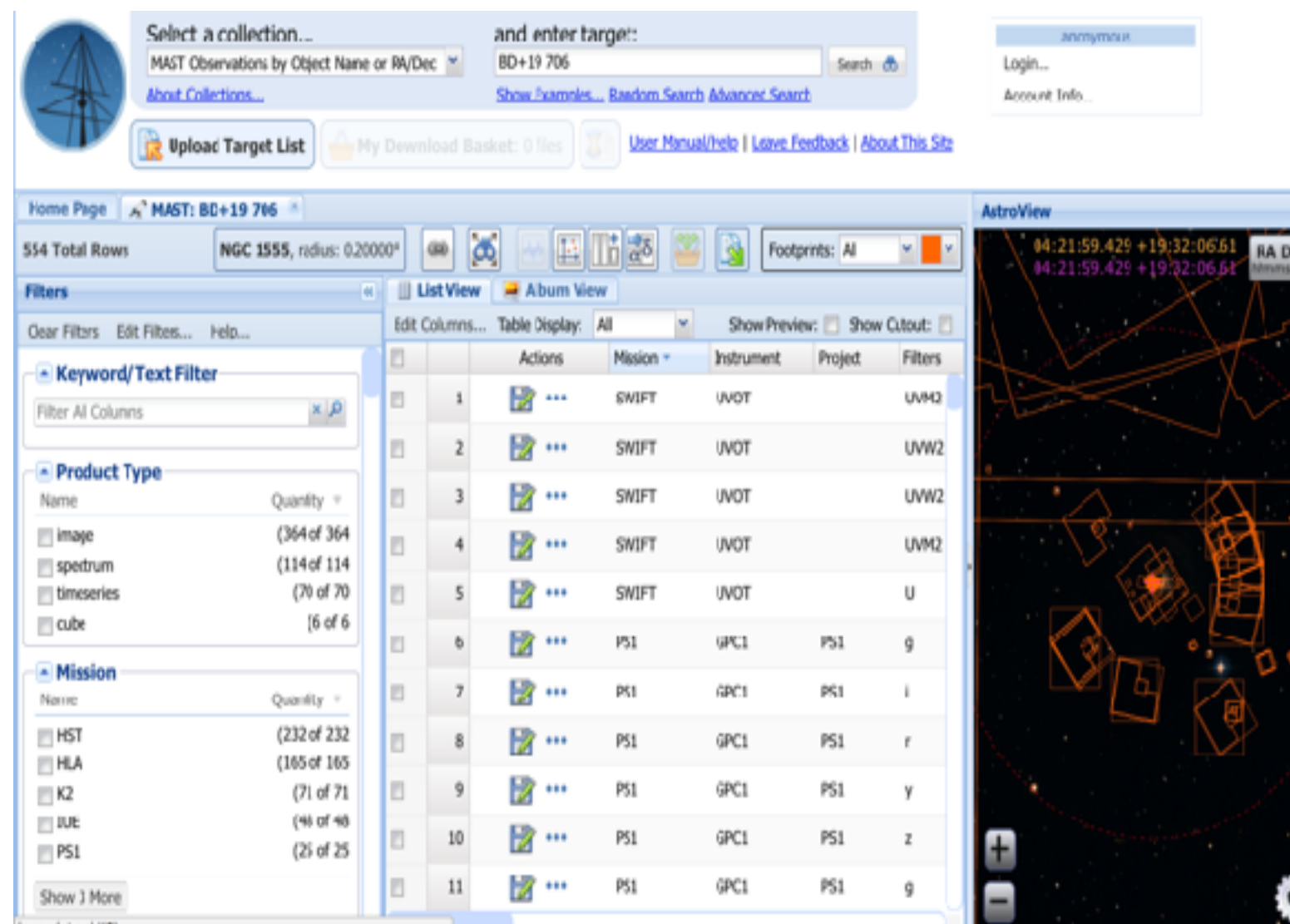
□ Time Domain Astronomy Challenges

To characterise and classify sources...

- Multi-wavelength/messenger approach is (sometimes) needed
 - Follow-up observations & reaction time for that can be crucial
 - **Visualisation & navigation** thought the data
 - Coordination & transmission of information
-
- **Visualisation & navigation**
 - ➡ sequences of images, spectra, photometry, positions, ... and all interoperable
 - ➡ tools



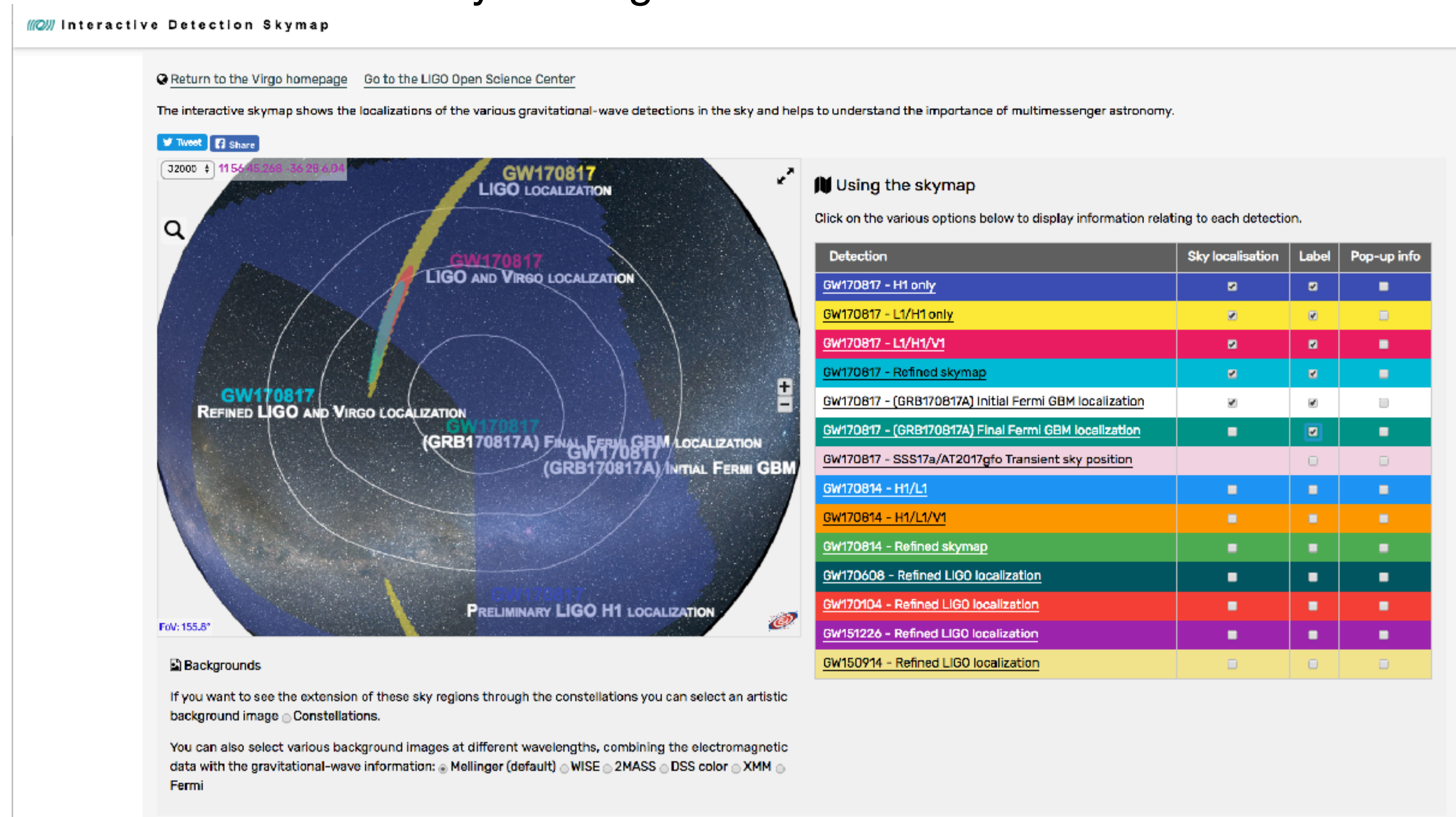
Visualisation of the sky





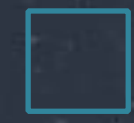
Visualisation of the sky

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



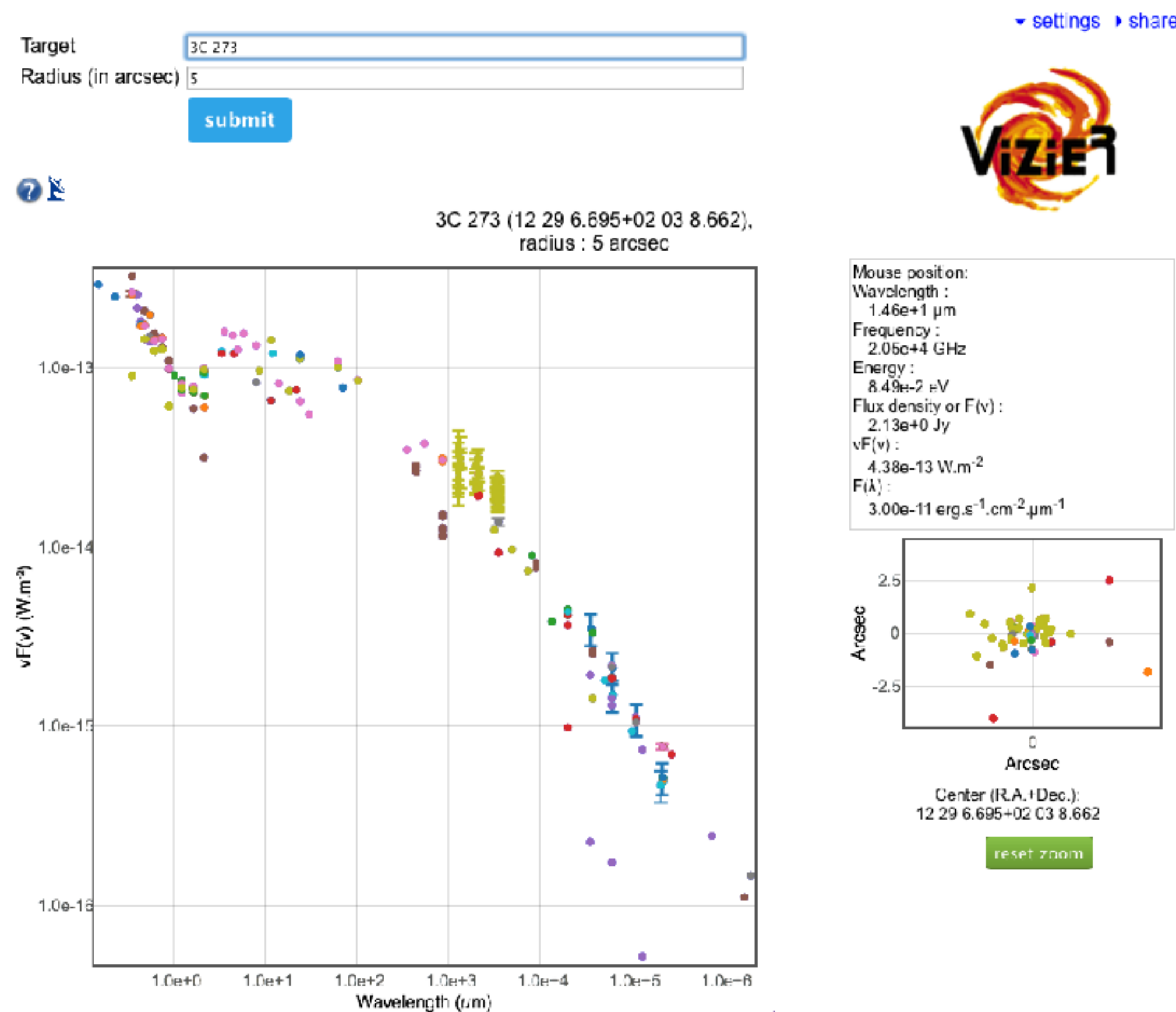
➡ (see talk by G. Greco)





Visualisation of photometry

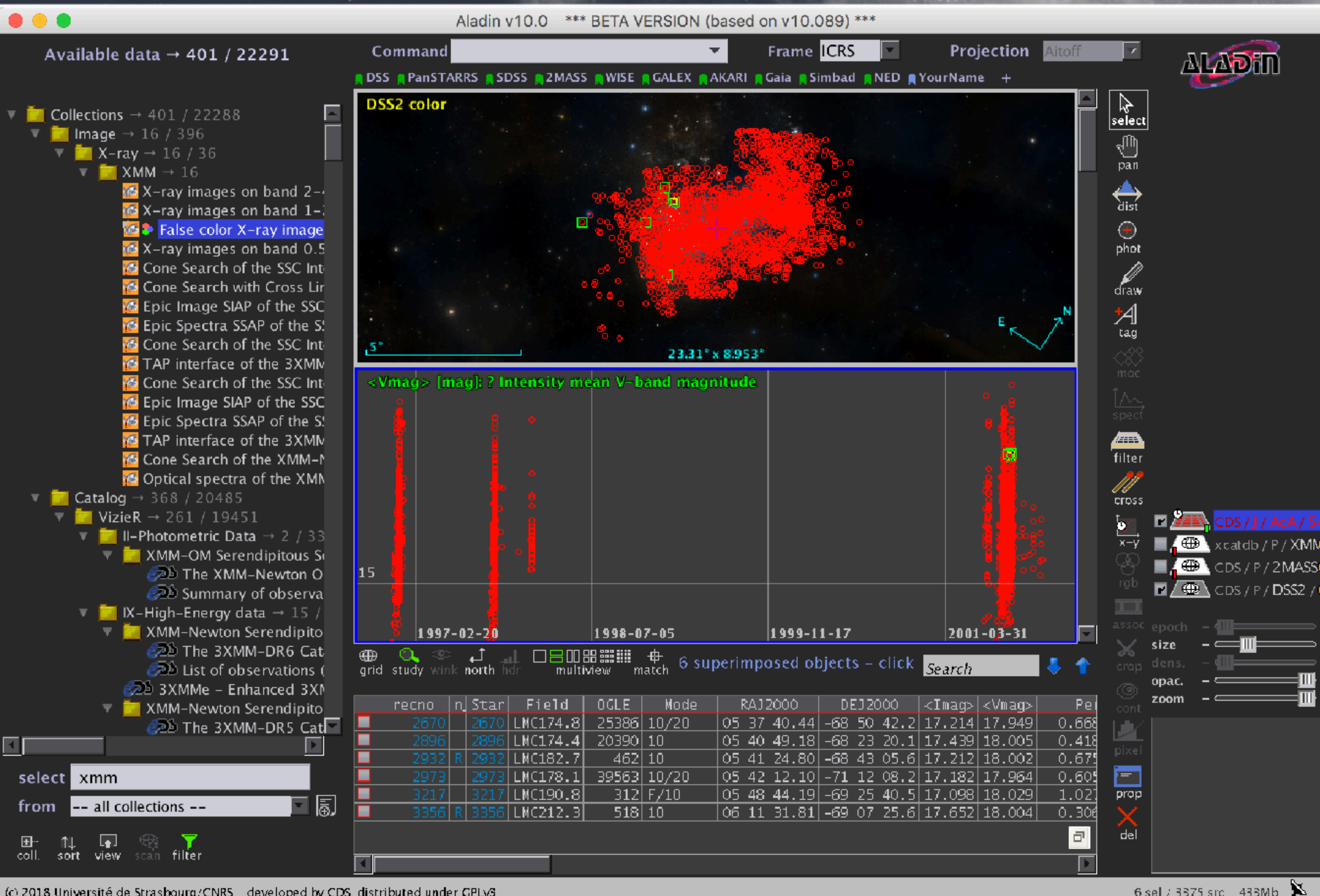
- ➡ Search all the photometry available around a position in the sky
- ➡ Plot photometry against wavelength



Under dev.: A time (series) viewer
➡ Plot photometry against time



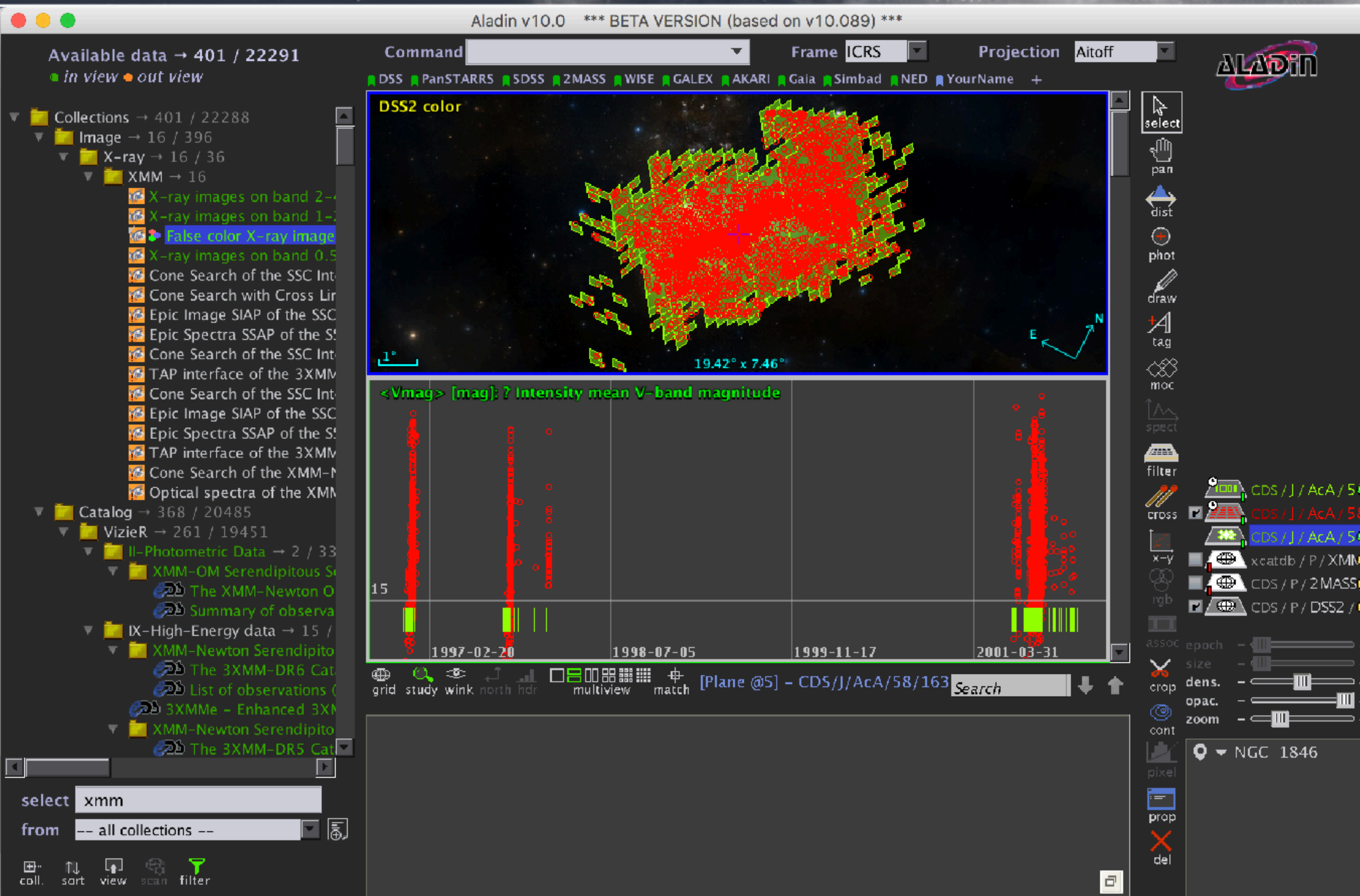
Time Series view (Aladin beta)



- 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: TMOG

→ Simple operations such as union, intersections, filter a catalogue by temporal coverage, ...

Under dev.: combine both spatial and temporal coverages

□ Time Domain Astronomy Challenges

To characterise and classify sources...

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

