

Exploring Time Domain Multi-Messenger Astronomy through the Virtual Observatory

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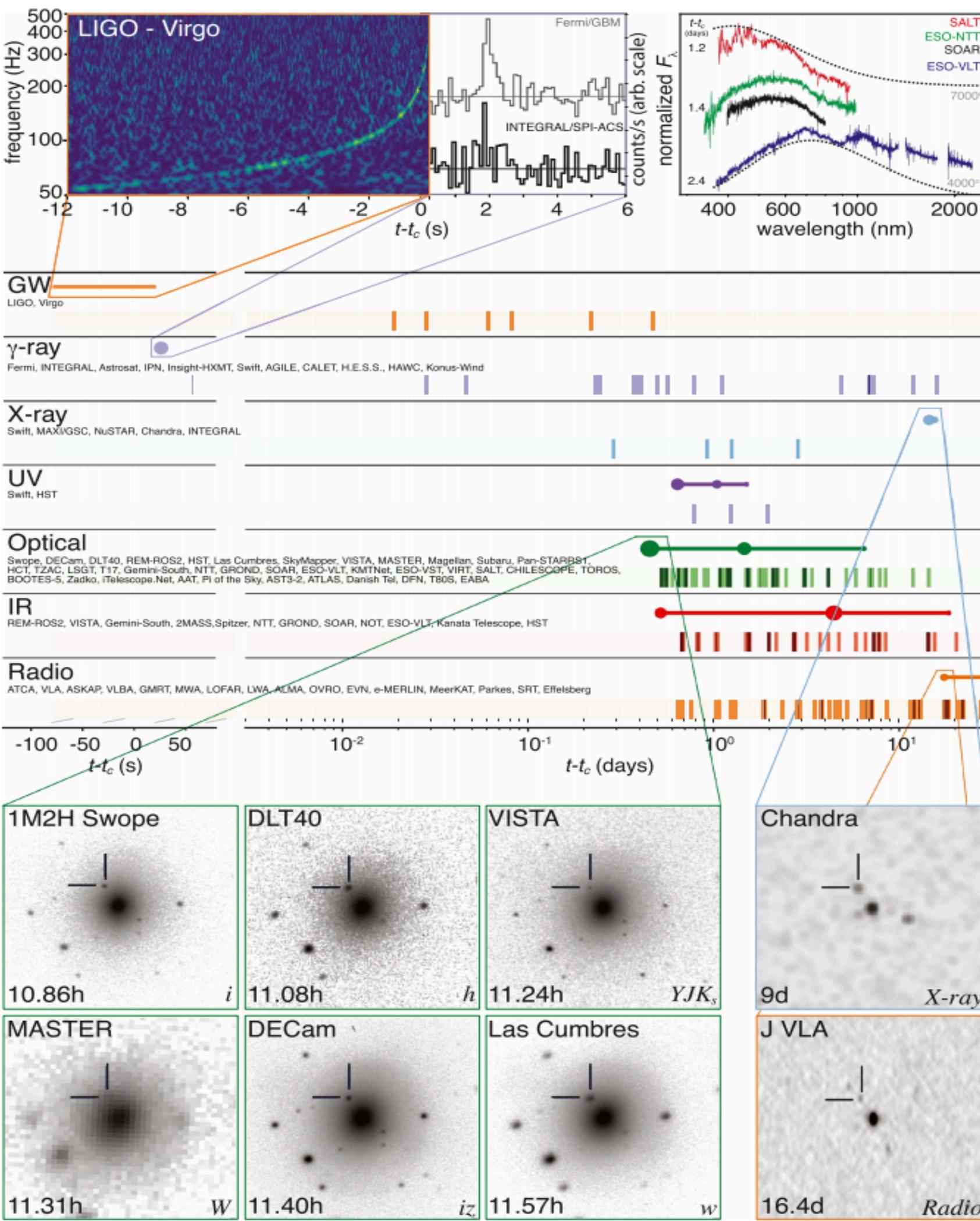


Time Domain Multi-messenger Astronomy

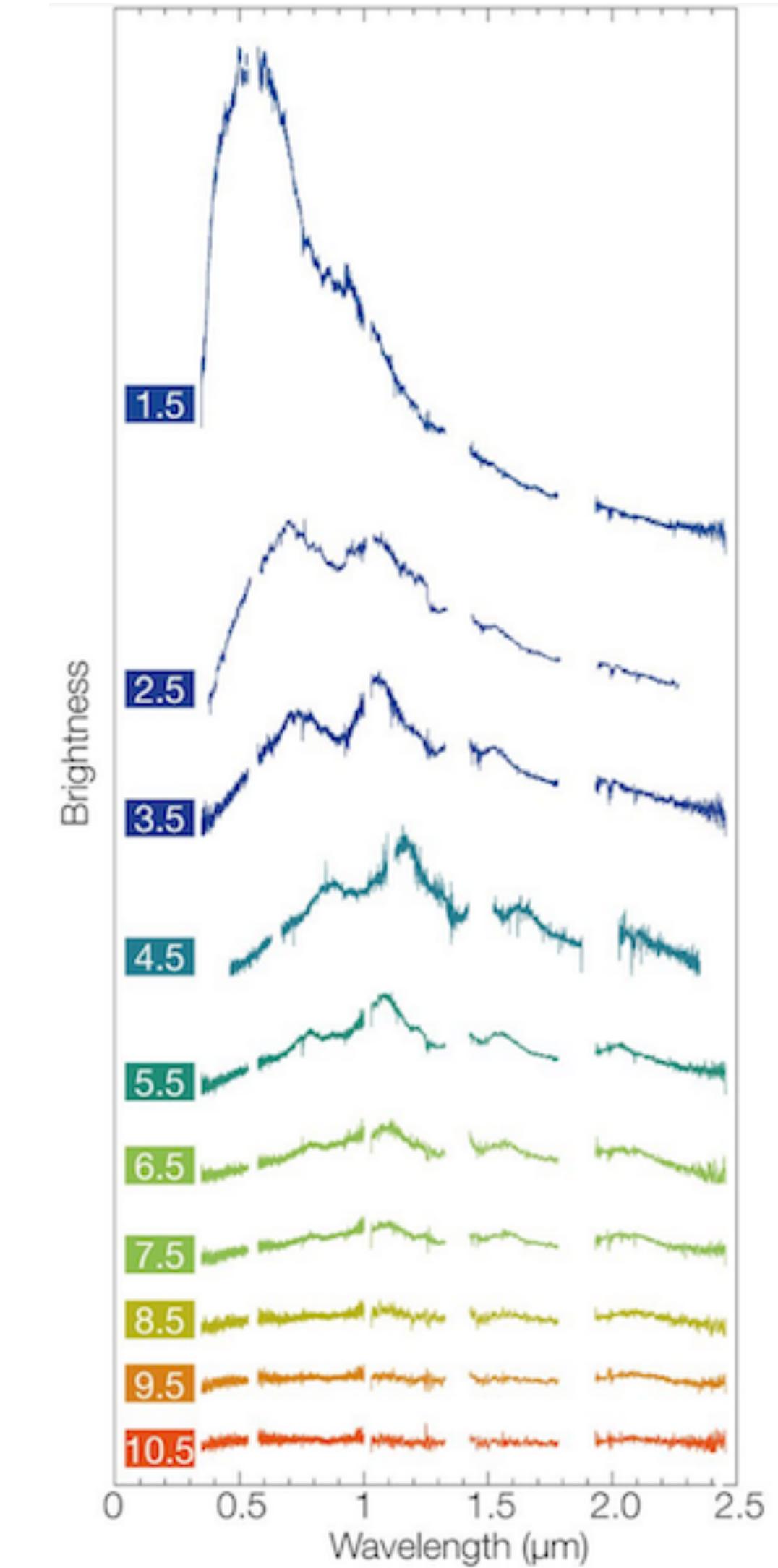
GW170817

THE ASTROPHYSICAL JOURNAL LETTERS, 848:L12 (59pp), 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 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)

NED

Object Name: M81

Search Options

Go

Results for object MESSIER 081 (M81)

Overview Cross-IDs (65) Coordinates (47) Redshifts (29) Distances (101) Classifications (117) Notes (48) Diameters (8)

Photometry & SED (246) Spectra (44) Images (179) References (2373) External Links

POSS-II F (North), AAO-SES/SERC-ER (South), Red image

Search images

Image Credit: Caltech or AAO/ROE

Selected data and derived quantities for MESSIER 081†. More information in the tabs above.

Cross-identifications

MESSIER 081; NGC 3031; UGC 05318; CGCG 333-007; CGCG 0951.4+6918

Coordinates for Preferred Position

Equatorial (J2000)	RA, Dec [Deg]	Unc Semi-major,minor ["]	Unc PA [deg]	Reference	Lon, Lat [deg]
09h55m33.1730s, +69d03m55.061s	148.888221, 69.065295	1.57E-03, 3.50E-04	90	1995AJ....110..880J	142.091841, 40.065295

Preferred Redshift & Derived Quantities [$H_0 = 73 \text{ km/sec/Mpc}$, $\Omega_{\text{matter}} = 0.27$, $\Omega_{\text{vacuum}} = 0.73$]

z (Helio)	V (Helio) [km/s]	Reference	V (CMB) [km/s]	Hubble Distance (CMB) [Mpc]	# Measurement
-0.00011 +/- 0.00001	-33.876552 +/- 3.897302	1991RC3.9.C...0000d	48 +/- 7	0.66 +/- 0.11	101

Classifications

Object Type	Morphology	Reference	Activity Type	Reference	Other
G	SA(s)ab	1991RC3.9.C..0000d	Flat-Spectrum Radio Source,	2007ApJS..171...61H	SA(s)ab;LINER

Quick-look Angular & Physical Diameters

Passband	Diameter ["]	Reference	Diameter [kpc]	A_λ [mag] V	A_λ [mag] K
RC3 D_0 (blue)	1652.50	1991RC3.9.C...0000d	29.43	0.220	0.024

Quick-look Photometry & Luminosities (brightest flux in each spectral region)

Spectral region	Band	Apparent mag or flux	Reference	Absolute Mag or vL_v [W]	vL_v [$L_\odot(\text{bol})$]
X-Ray	2-10 keV (BeppoSAX)	3.10E-11 +/- 0.40E-11 erg/cm^2/s	2007A&A...472..705V	5.01E+33 +/- 6.59E+32 [W]	1.30E+07 +/- 1.00E+07 [W]
UV	3320 Å (OAO)	8.95 +/- 0.08 mag	1982ApJ...256....1C	-18.85 +/- 0.10 [mag]	1.34E+09 +/- 1.00E+09 [mag]
Visible	V	8.73 Jy	2007ApJ...655..863D	7.68E+36 [W]	2.00E+10 [W]
Near-IR	H_tot (2MASS LGA)	4.090 +/- 0.018 mag	2003AJ....125..525J	-23.71 +/- 0.07 [mag]	1.81E+10 +/- 5.00E+09 [mag]
Far-IR	FIR (IRAS)	3.65E-12 W m^-2^	1988ApJS..68...91R	5.86E+35 [W]	1.52E+09 [W]
Radio	57.5 MHz	2.4 +/- 0.6 Jy	1990ApJ...352...30I	2.23E+29 +/- 5.60E+28 [W]	5.80E+02 +/- 5.00E+02 [W]

*Derived quantities are based on the median redshift-independent distance when available, otherwise the preferred redshift is used with the selected cosmological parameters (which can be changed in search options).
Cosmological params can be changed in search options.

SIMBAD

Basic data :

HD 165688 -- Wolf-Rayet Star

Other object types: * (Ref,HD,...), WR* (MR,WR), IR (2MASS,SSTGLMC), Sm* (Hen), V* (Ref), X (2XMM)
ICRS coord. (ep=J2000) : 18 07 56.9612003141 -19 23 56.866361615 (Optical) [0.0479 0.0406 90] A 2018yCat.1345....0G
FK5 coord. (ep=J2000 eq=2000) : 18 07 56.9612003141 -19 23 56.866361615 (Optical) [0.0479 0.0406 90]
FK4 coord. (ep=B1950 eq=1950) : 18 04 59.6493172659 -19 24 25.088719244 [4.5003 3.9502 90]
Gal coord. (ep=J2000) : 010.8000508777768 +00.3944248835444 [0.0479 0.0406 90]
Proper motions mas/yr: 0.787 -1.732 [0.090 0.079] A 2018yCat.1345....0G
Parallaxes (mas): 0.6036 [0.0425] A 2018yCat.1345....0G
Spectral type: NN5-6b C 1996NNRAS.281..163B
Fluxes (8) :

U 10.46 [-] C 2002yCat.2237....0D
B 10.31 [-] C 2002yCat.2237....0D
V 9.87 [-] C 2002yCat.2237....0D
R 9.85 [0.02] D 2012yCat.1322....0Z
G 9.2064 [0.0006] C 2018yCat.1345....0G
J 7.118 [0.018] C 2003yCat.2246....0C
H 6.716 [0.027] C 2003yCat.2246....0C
K 6.223 [0.024] C 2003yCat.2246....0C

Interactive AladinLite view

18 07 56.961 -19 23 56.87

FoV: 2.07°

2MASS DSS SDSS

Vizier photometry viewer

Search within radius Max 30 arcsec

Identifiers (22) :

An access of full data is available using the icon Vizier near the identifier of the catalogue

HD 165688	Hen 3-1594	MR 83	UCAC4 354-117192
ALS 4678	HIC 88828	PPM 718808	WR 110
BD-19 4854	HIP 88828	SSTGLMC G010.8000+00.3943	2XMM J180756.9-192356
CPD-19 6469	JP11 2931	TYC 6259-2666-1	Gaia DR2 4095125220807894400
GEN# +1.00165688	LS 4678	UBV 15399	
GSC 06259-02666	2MASS J18075695-1923568	UCAC2 24414003	

References (137 between 1850 and 2019) (Total 137)

Simbad bibliographic survey began in 1850 for stars (at least bright stars) and in 1983 for all other objects (outside the solar system).

Follow new references on this object

Reference summaries :

from: 1850 to: \$currentYear

Display or select by : (not exhaustive, explanation here) In table Title|Abstract|Keyword Score

Collections of Measurements

distance : 2 pm : 3 plx : 3 mk : 5

display selected measurements display all measurements clear

□ 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)
- Programmatic access too (http API)
- New developments for a multi-catalogue cross-match

The screenshot shows the CDS X-Match Service web interface. At the top, there's a logo and navigation links for 'X-match', 'Tables management', and 'Documentation'. Below that, instructions say: 'Select below the two tables to cross-match.', 'Then, choose cross-match method and sky area in options.', and 'Finally, click on Begin the X-Match to launch the computation.' The main section is titled 'Choose tables to cross-match' with fields for 'Table 1' and 'Table 2' (both set to 'VizieR') and a 'Show options' button. A large red 'Begin the X-Match' button is prominent. At the bottom, there's a 'List of X-match jobs' table with one row: 'Table 1' (No job in list), 'Table 2' (No job in list), 'Options' (dropdown), 'Begin' (button), 'Status' (empty), and 'Actions' (checkbox). A note says 'For the selected job(s):' followed by a 'Delete' button.

The screenshot shows the TOPCAT software interface. It features a toolbar at the top with various icons, a yellow cat icon in the center, and a status bar at the bottom showing '38 / 911 M'. The main window is divided into several sections: 'Table List' (containing '1: anonymous1541509785078'), 'Current Table Properties' (Label: 'anonymous1541509785078.xml', Location: '/Users/angm/Downloads/anonymous1541509785078.xml', Name: 'anonymous1541509785078.xml', Rows: 128, Columns: 12, Sort Order: up, Row Subset: All, Activation Actions: 0 / 0), 'SAMP' (Messages: empty, Clients: empty), and a 'TOPCAT' tab bar at the bottom.



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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 - **Follow-up observations** & reaction time for that can be crucial
 - Visualisation & navigation thought 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

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 - **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

Aladin Sky Atlas

Select a collection...
and enter target:
BD+19 706
Search

anonymous
Login...
Account Info...

Up Level Monocerotis V838 Supernova 1987A Nebulae Galaxy Collisions Hubble's Largest NGC 300 Full ACS Field of Composite Image Visible-Light Image

554 Total Rows NGC 1555, radius: 0.20000°

Filters
Clear Filters Edit Filters... Help...
Keyword/Text Filter
Filter All Columns
Product Type
Name Quantity
image (364 of 364)
spectrum (114 of 114)
timeseries (70 of 70)
cube (6 of 6)
Mission
Name Quantity
HST (232 of 232)
HLA (165 of 165)
K2 (71 of 71)
TUE (48 of 48)
PS1 (25 of 25)
Show 3 More

AstroView
04:21:59.429 +19:32:06.61 RA DEC hhmmss/deg
Footprints: All

Layers
Sun Mercury Venus Earth Mars Jupiter Saturn Uranus Neptune Pluto Sky

Table View
Edit Columns... Table Display: All Show Preview: Show Cutout:
Actions Mission Instrument Project Filters

ra (deg)	dec (deg)	clon	clat	err_mag (arcsec)	err_min (arcsec)	err_max (arcsec)	designation	J_m (mag)	J_maxmag (mag)	J_minmag (mag)
81.279734	-68.919395	09:25m07.04s	-68d55m09.82s	0.14	0.13	2	05250704-6855098	16.027	0.089	0.089
81.370766	-68.836624	09:25m26.98s	-68d52m11.95s	0.18	0.16	13	05252098-6852118	13.504		
81.412929	-68.839584	09:25m39.10s	-68d52m22.50s	0.20	0.16	84	05253110-6852026	16.360	0.137	0.137
81.437965	-68.944025	09:25m45.11s	-68d53m38.49s	0.17	0.17	135	05254511-6853394	16.324	0.133	0.133
81.514225	-68.904945	09:25m15.41s	-68d54m17.80s	0.07	0.07	45	05251541-6854178	15.196	0.072	0.073
81.368899	-68.837242	09:25m28.54s	-68d53m40.07s	0.09	0.08	3	05252653-6853404	14.330	0.053	0.054
81.500049	-68.893616	09:26m00.01s	-68d53m37.02s	0.32	0.27	83	0526001-6853370	16.490	0.140	0.140
81.429131	-68.954062s	-68d54m50.87s	0.06	0.06	45	05254961-6854508	15.304	0.062	0.064	
81.591179	-68.839294	09:26m21.88s	-68d52m21.46s	0.16	0.14	45	05262188-6852024	16.409	0.126	0.126
81.596821	-68.896202	09:26m20.94s	-68d53m46.33s	0.06	0.06	45	05262083-6853463	14.670	0.039	0.041
81.337872	-68.843903	09:25m21.09s	-68d53m38.05s	0.07	0.07	45	05252108-6853380	15.509	0.052	0.054
81.394806	-68.906075	09:25m34.75s	-68d54m21.87s	0.06	0.06	90	05253475-6854218	14.142	0.034	0.036
81.409027	-68.876686	09:25m38.17s	-68d52m36.07s	0.20	0.18	177	05253116-6852360	16.475	0.163	0.163
81.600049	-68.830826	09:26m24.11s	-68d49m50.97s	0.15	0.14	106	0526210-6849059	16.200	0.124	0.125
81.330078	-68.829193	09:25m19.22s	-68d49m45.09s	0.19	0.17	83	05251921-6849450	16.433	0.129	0.130
81.657667	-68.909805	09:26m37.84s	-68d54m35.30s	0.07	0.07	17	05263784-6854352	15.465	0.084	0.085
81.471096	-68.948822	09:25m53.06s	-68d56m55.76s	0.07	0.07	45	05255206-6855557	15.425	0.055	0.057
81.317534	-68.908012	09:25m16.21s	-68d54m28.84s	0.17	0.15	8	05251620-6854288	16.384	0.147	0.148
81.562626	-68.881379	09:26m15.03s	-68d52m59.44s	0.22	0.20	84	0526103-6852594	16.040	0.104	0.104
81.585997	-68.867485	09:26m20.64s	-68d52m02.95s	0.07	0.06	86	05262063-6852029	15.393	0.057	0.058

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Search: + GO

SAOImageDS9

Home | What's New | Download | Documentation | Gallery

SkyView The Internet's Virtual Telescope

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

Interfaces and Software
SkyView Query Form
Non-Astronomers Page

Visit the SkyView Image Gallery

Documentation

Links

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

SAOImageDS9

New beta release of SAOImageDS9 8.0rc6 is now available at [ds9.si.edu/site/Beta.html](#)

Oct 19, 2018

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

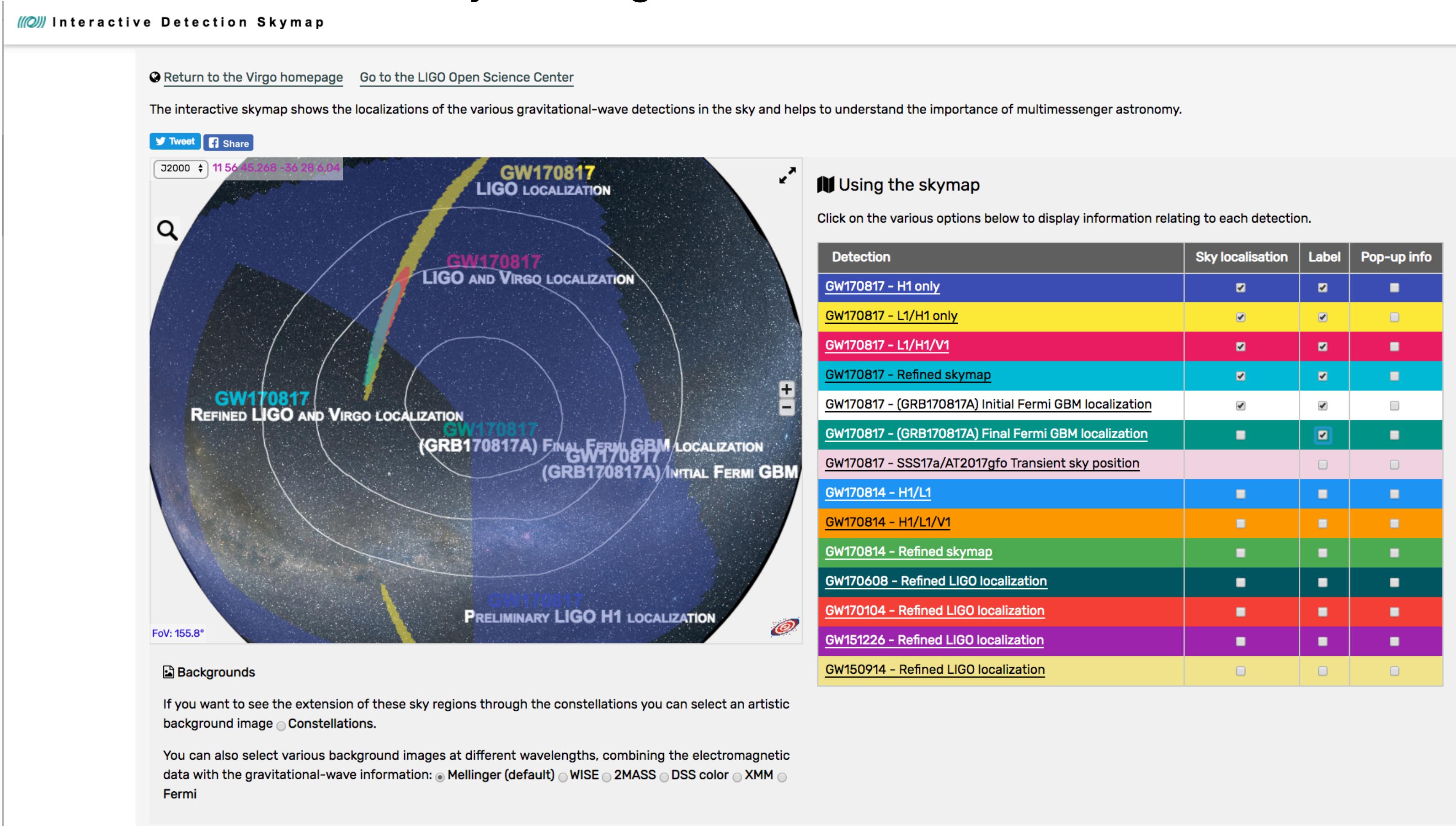
Indeed! Maybe I'm asking too much, is there already the possibility of producing

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 paper and would like to cite SAOImageDS9, we recommend the following: 2003ds9; 2004_A&A_



Visualisation of the sky

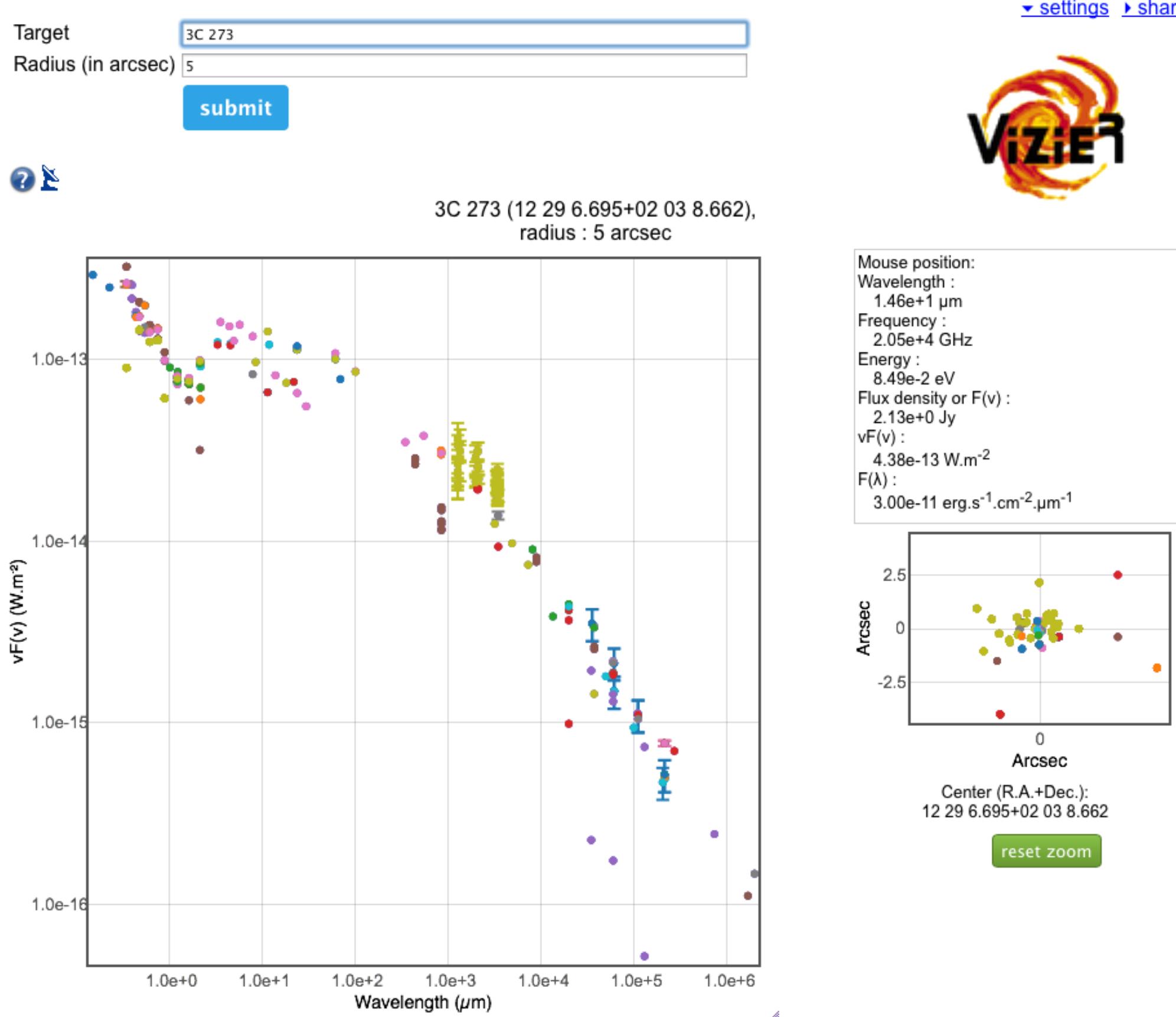
- ➡ Aladinlite implementation for GW localisation in the sky
- ➡ Background image can be DSS, 2MASS, WISE, XMM, Fermi,...
- ➡ We can overlay catalogues of interest



➡ (see talk by G. Greco)

□ Visualisation of photometry

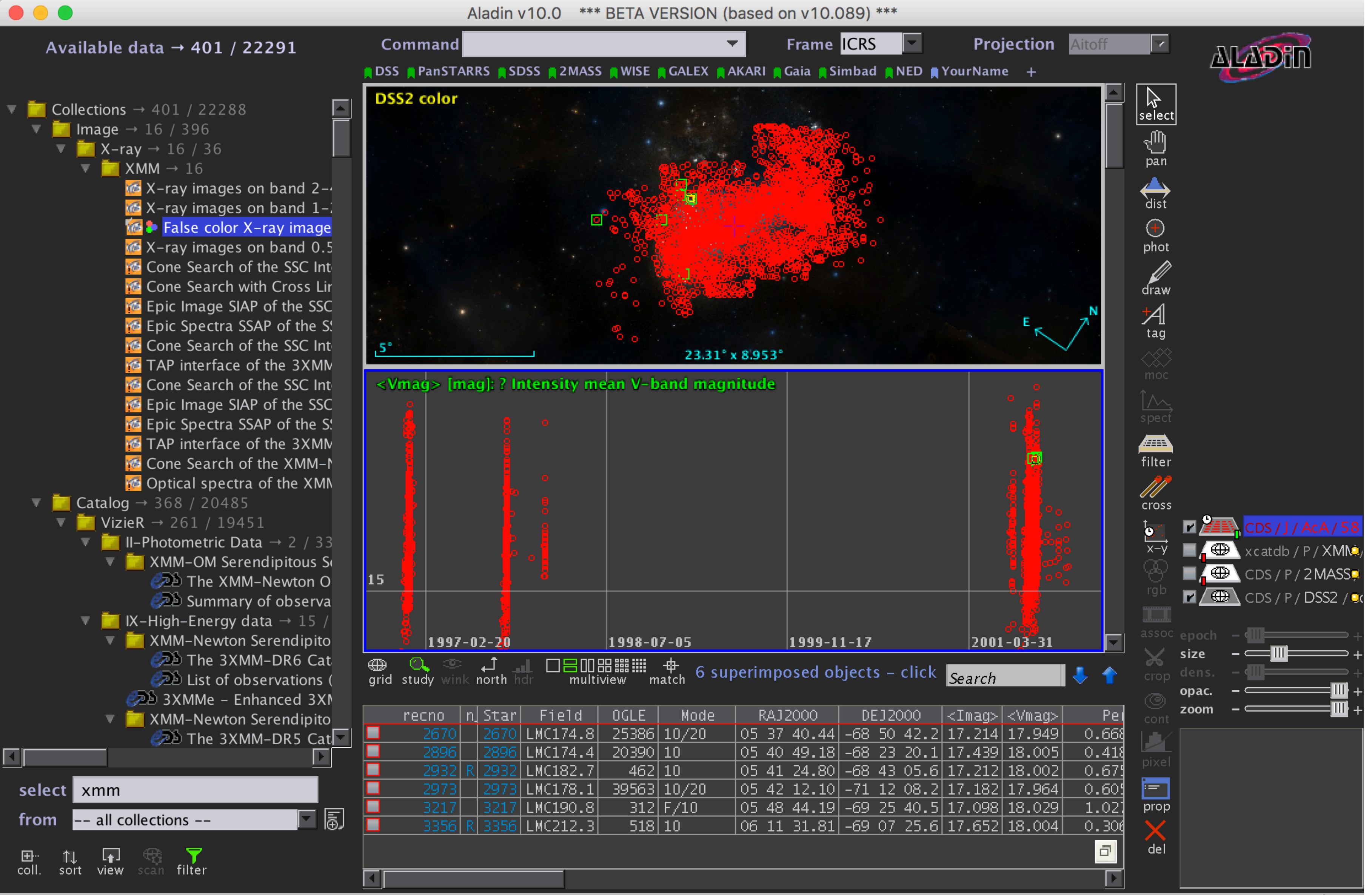
- Search all the photometry available around a position in the sky
- Plot photometry against wavelength



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



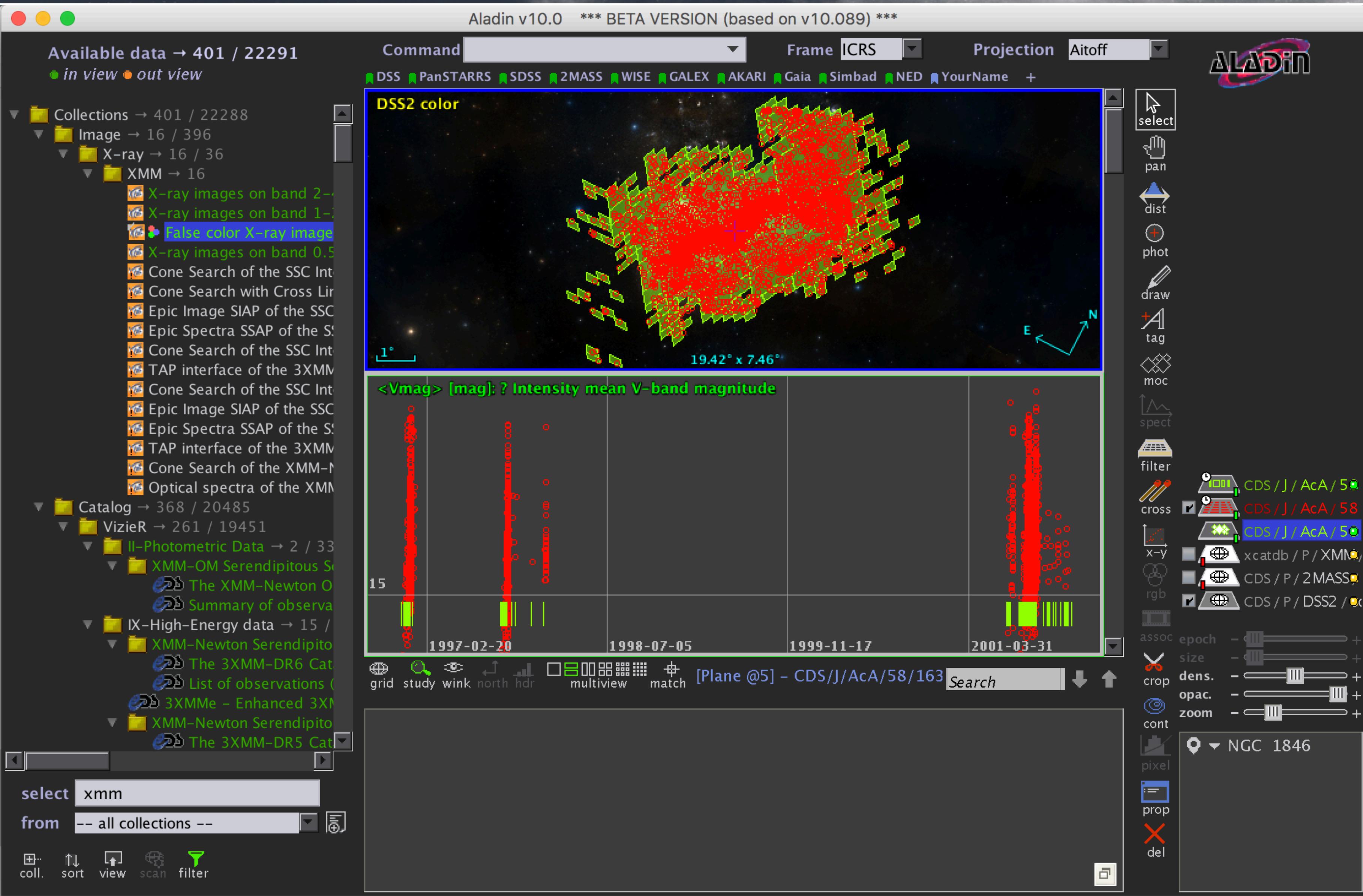
Time Series view (Aladin beta)



- 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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- 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 ;)

