Data challenges of the Virtual Observatory in Time Domain Astronomy

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Astronomical Data Analysis Software & Systems
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Time Domain Astronomy

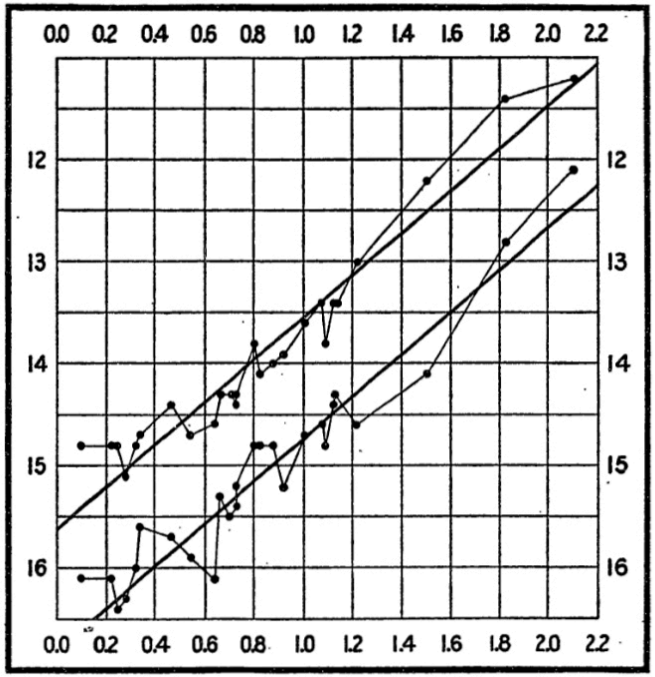
The study of variability of astronomical objects over different time-scales

- A hot topic but a new field?

Time Domain Astronomy

The study of variability of astronomical objects over different time-scales

- The Great Debate of 1920 on the **Scale of the Universe** (Curtis, Shapley)



Pickering 1912

- Observations of Cepheids showed the Universe is composed of many galaxies like our own.

The first standard candles

period-luminosity relation

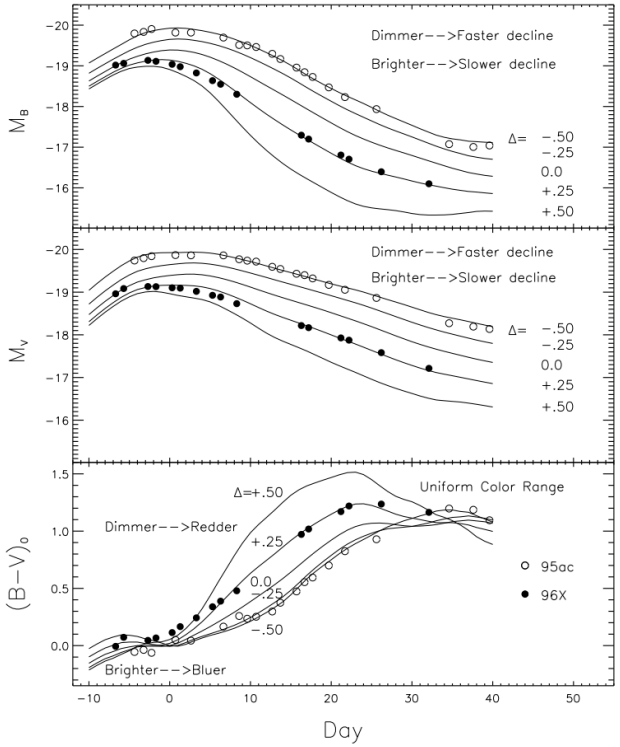
Leavitt law

➡Thanks to **Leavitt law** and the discovery of Cepheids in Andromeda

Time Domain Astronomy

The study of variability of astronomical objects over different time-scales

- The Great Debate of 1998 on the **Nature of the Universe** (Peebles, Turner)



- Observations of **SNe Ia** first direct evidence of the cosmic acceleration

Standard candles

luminosity — decay time relation

Riess et al. 1998; Perlmutter et al. 1999

Time Domain Astronomy

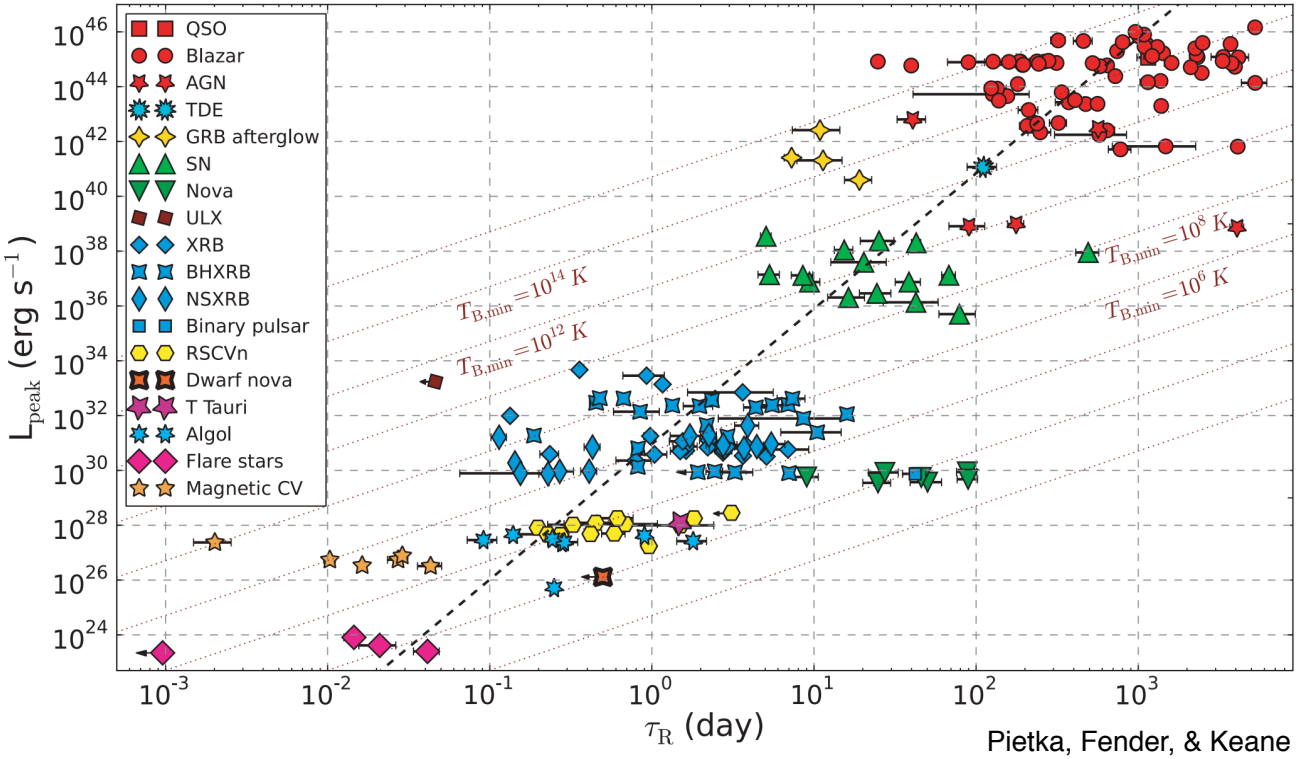
*The study of **variability** of astronomical objects over different time-scales*

- What type of variable phenomena?
  - **Periodic:** binary orbits of stars/extrasolar planets, stellar rotation, stellar pulsation…
  - **Transient:** supernovae, gamma-ray bursts, novae, X-ray bursts, transits, gravitational microlensing, flares, tidal disruption events…
  - **Stochastic:** accretion in CVs, X-ray binaries,…

Time Domain Astronomy

The study of variability of astronomical objects over different ***time-scales***

- What time-scales are we talking about?



Pietka, Fender, & Keane 2015

Time Domain Astronomy

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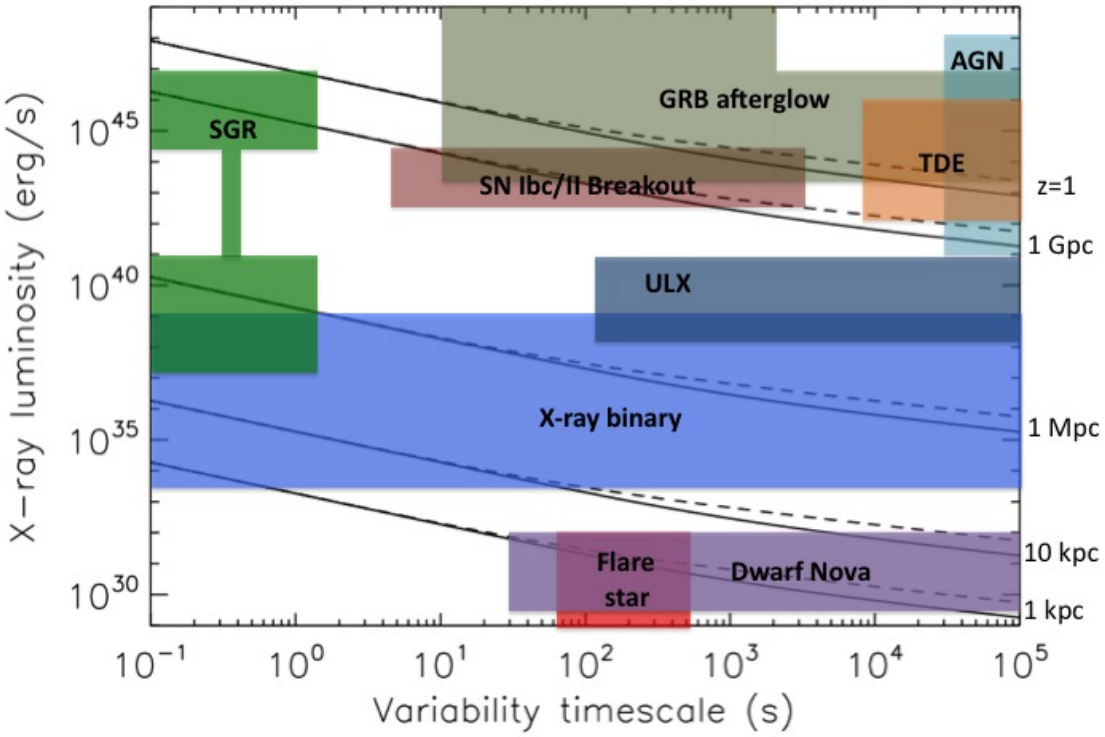

EXTraS Collaboration, De Luca, A. et al. 2016

Time Domain Astronomy

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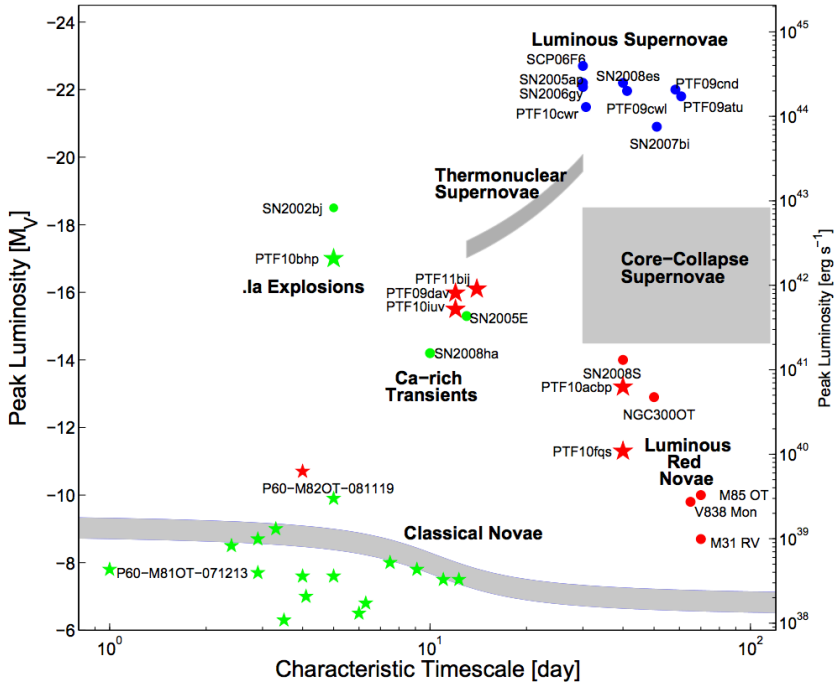
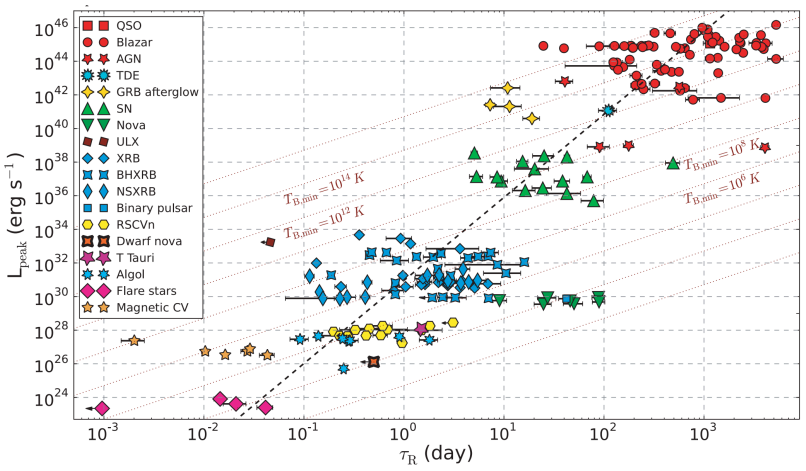


Kasliwal 2011

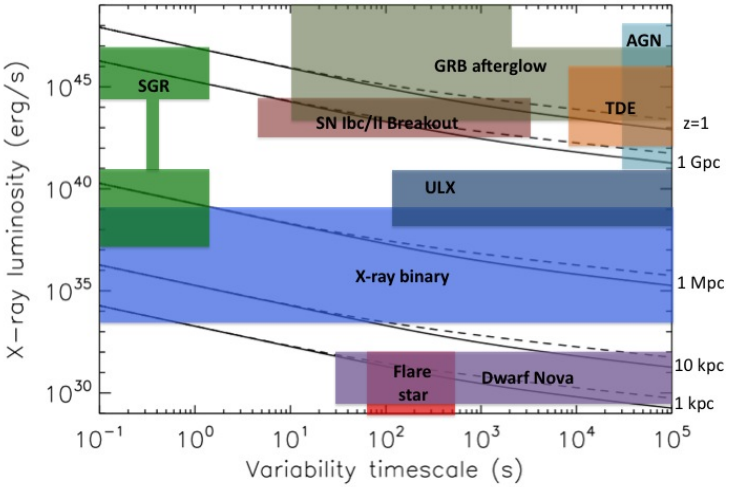
Time Domain Astronomy

The study of variability of astronomical objects over different ***time-scales***

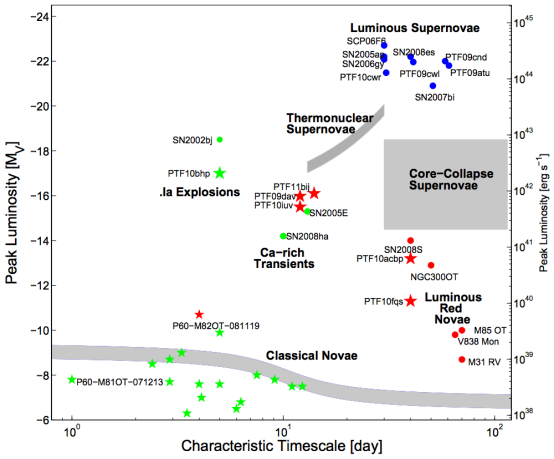
- What time-scales are we talking about?
  - ➡ Characterisation and classification of sources on the basis of their variability
  - ➡ Multi-wavelength approach is (sometimes) needed



Pietka, Fender, & Keane 2015



EXTraS Collaboration, De Luca, A. et al. 2016



Kasliwal 2011

Time Domain Astronomy

The study of variability of astronomical objects over different ***time-scales***

- What time-scales are we talking about?
  - ➡ Multi-messenger approach is (sometimes) needed

GW170817

LIGO and Virgo make first detection of gravitational waves produced by colliding neutron stars

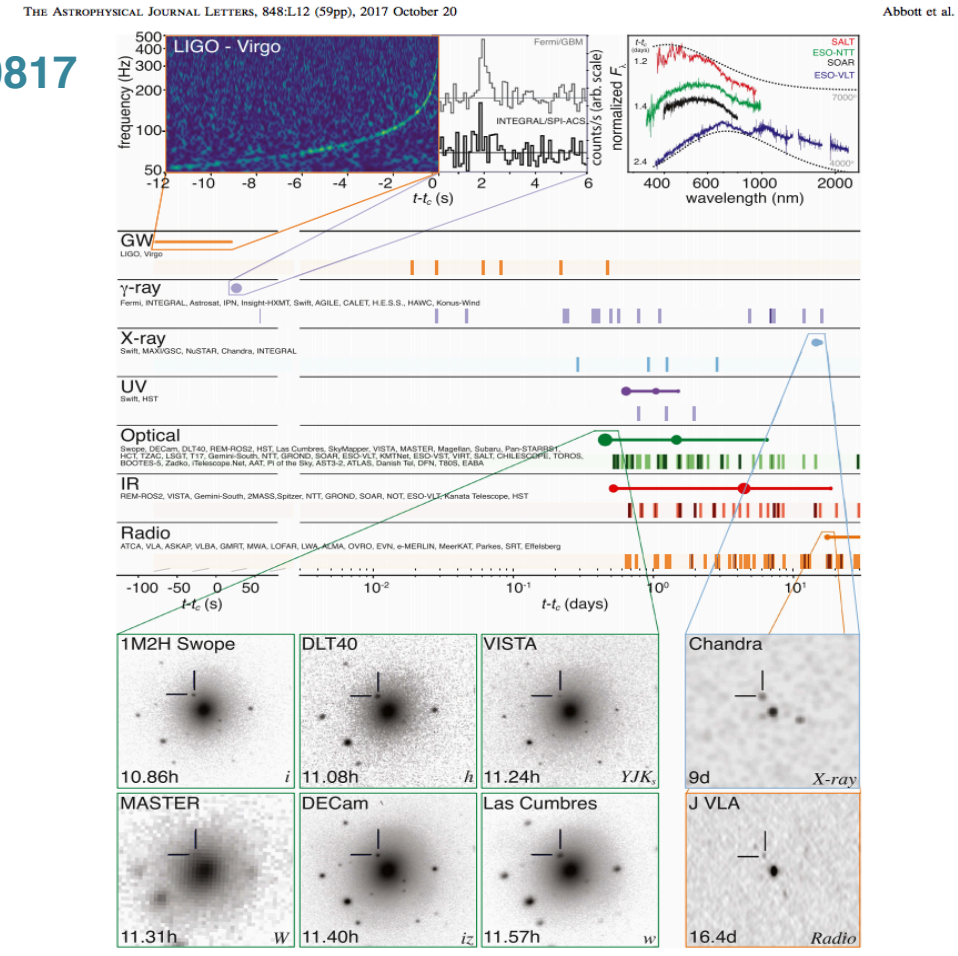
Discovery marks first cosmic event observed in both gravitational waves and light.

For the first time, scientists have directly detected gravitational waves — ripples in space-time — in addition to light from the spectacular collision of two neutron stars.

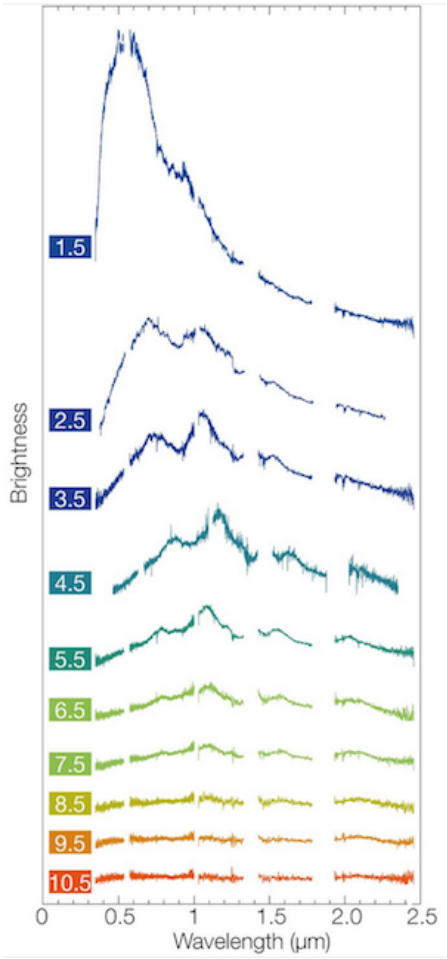
The discovery was made using the U.S.-based Laser Interferometer Gravitational-Wave Observatory (LIGO); the Europe-based Virgo detector; and some 70 ground- and space-based observatories.

Time Domain 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

The study of variability of astronomical objects over different time-scales

- Characterisation & classification of sources on the basis of their variability
- Multi-wavelength / messenger approach is (sometimes) needed
- Follow-up observations and reaction time for that can be crucial
- Visualisation & navigation thought the data
- Analysis of variance of phenomena
- Coordination is crucial - transmission of information

Time Domain Astronomy Challenges

- Classical classification
- AI, ML, DL techniques

- Cross-matching techniques
- Source identification

- Planning observations
- Transmission of information

- visualise
- coordinate

- period search methods

TD Astronomy Challenges?

TD Astronomy DATA Challenges

TD Astronomy Virtual Observatory DATA Challenges

The VO and the IVOA

What is the VO?

- Astronomical datasets, tools, services should work seamlessly together

What is the IVOA?

- An organisation that debates and agrees the technical standards that are needed to make the VO possible
- A focal point for VO aspirations, a framework for discussing and sharing VO ideas and technology
- Promoting and publicising the VO

The VO and the IVOA

Who is the IVOA?

- 6 Working Groups, 7 Interest Groups
  - ➡ There is a Time Domain Interest Group
  - ➡ Completely open to participation

How to join the IVOA?

- 2 interoperability meetings per year
  - ➡ Next meeting in Paris
  - ➡ Register to email lists for discussion of topics

http://ivoa.net/

The VO and the IVOA

Who is the VO?

- VO is integrated in many Astronomy data centres and archives
  - Often behind the scenes…
  - Huge benefits from shared software components
  - VO enables many scientific capabilities, just not possible otherwise

    ➡ All sky astronomy

The VO and the IVOA

Who is the VO for?

- **Research astronomers**
- Data Centres and Archives
- Software developers
- Educators
- …

Idea of the VO?

- In a seamless way for the user:
  - Data discovery & access
  - Visualisation & analysis
  - Through Services & tools

- **Research astronomers — Time Domain Astronomers**

Does the VO meet Time Domain Astronomers needs?

- Classical classification
- AI, ML, DL techniques

- Cross-matching techniques
- Source identification

- Planning observations
- Transmission of information

- visualise
- coordinate

- period search methods

TD Astronomy Challenges?

TD Astronomy DATA Challenges

TD Astronomy Virtual Observatory DATA Challenges

What is available through the VO?

Time Domain Astronomy Challenges

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- Coordination & transmission of information

- **Characterisation & classification**
  - Big Data
  - Heterogenous Data

  ➡ Classical techniques

  ➡ **AI, ML, DL techniques**

    ➡ BoF on Monday & Session 7 & 8 on Tuesday

    ➡ IVOA Knowledge Discovery Interest Group (K.L. Polsterer & M. Graham)

Time Domain Astronomy Challenges

The study of variability of astronomical objects over different time-scales

- Characterisation and classification of sources on the basis of their variability
- **Multi-wavelength/messenger** approach is (sometimes) needed
- Follow-up observations and reaction time for that can be crucial
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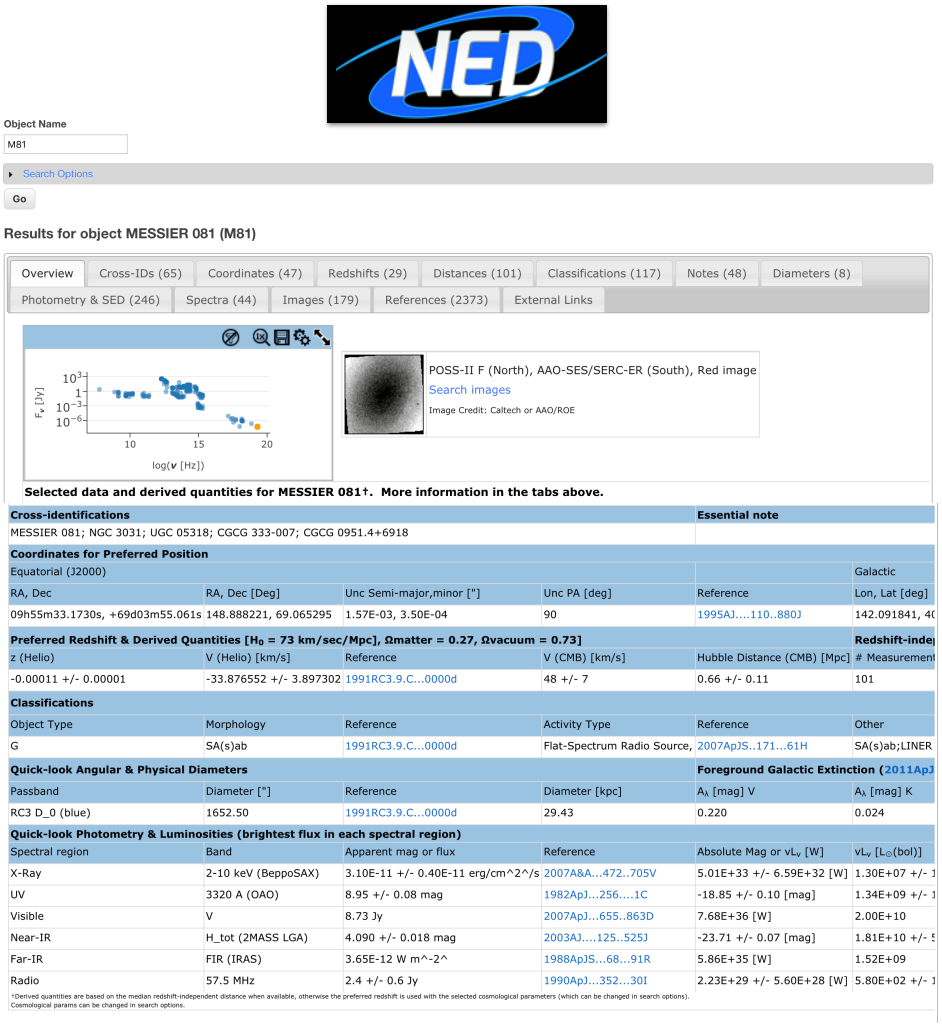
- **Multi-wavelength/messenger**
- Combining data in a coherent way from different missions covering different wavelengths
  - Big Data
  - Heterogenous Data

➡ Source identification

➡ Cross-matching techniques

Minimum information about objects



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

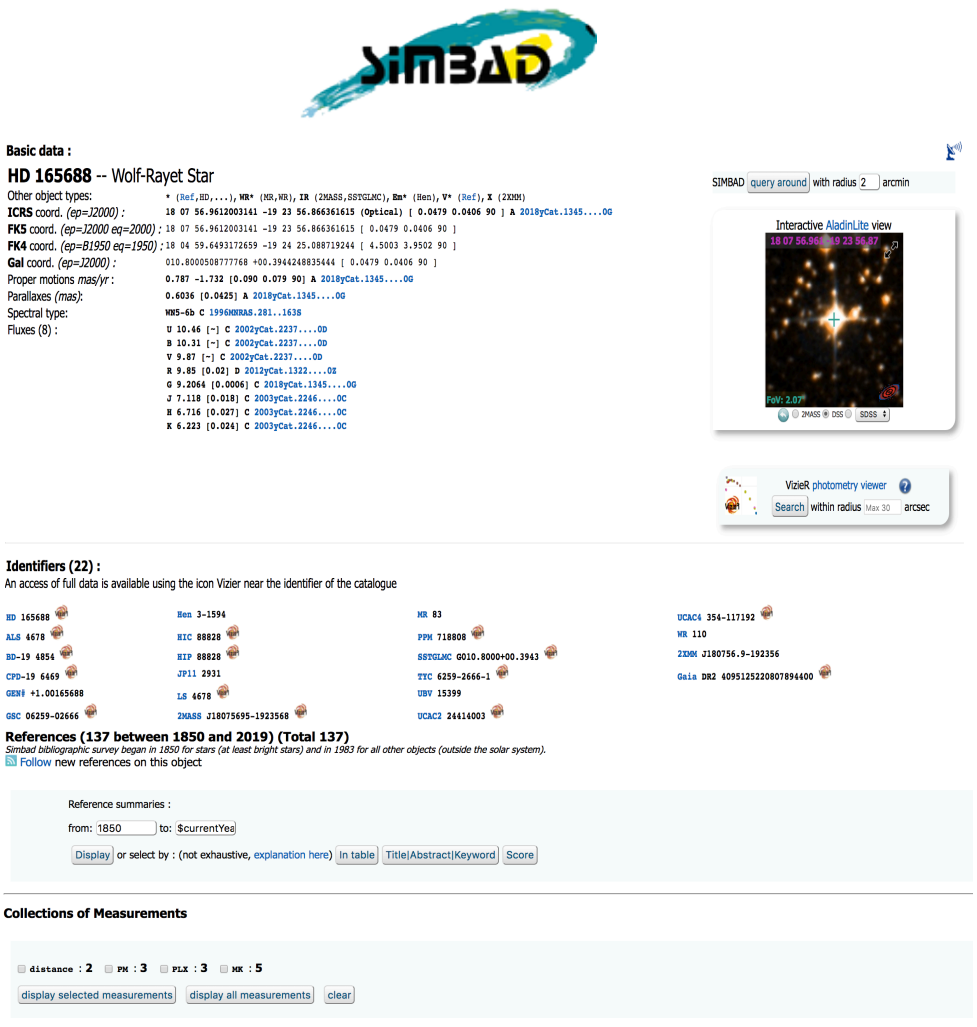
Search images

Image Credit: Caltech or AAO/ROE

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

Cross-identifications				**Essential note**	
MESSIER 081; NGC 3031; UGC 05318; CGCG 333-007; CGCG 0951.4+6918					
Coordinates for Preferred Position					
Equatorial (J2000)					Galactic
RA, Dec	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, 4(
Preferred Redshift & Derived Quantities [H_0 = 73 km/sec/Mpc], Ωmatter = 0.27, Ωvacuum = 0.73]					**Redshift-inde**
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				**Foreground Galactic Extinction (2011ApJ**	
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 νL_ν [W]	νL_ν [$L_\odot$(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
UV	3320 A (OAO)	8.95 +/- 0.08 mag	1982ApJ...256....1C	-18.85 +/- 0.10 [mag]	1.34E+09 +/- 1
Visible	V	8.73 Jy	2007ApJ...655..863D	7.68E+36 [W]	2.00E+10
Near-IR	H_tot (2MASS LGA)	4.090 +/- 0.018 mag	2003AJ....125..525J	-23.71 +/- 0.07 [mag]	1.81E+10 +/- 5
Far-IR	FIR (IRAS)	3.65E-12 W m^-2^	1988ApJS...68...91R	5.86E+35 [W]	1.52E+09
Radio	57.5 MHz	2.4 +/- 0.6 Jy	1990ApJ...352...30I	2.23E+29 +/- 5.60E+28 [W]	5.80E+02 +/- 1

†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.



Basic data :

HD 165688 -- Wolf-Rayet Star

Other object types: * (Ref,HD,...), WR* (MR,WR), IR (2MASS,SSTGLMC), Em* (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 [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 90] A 2018yCat.1345....0G

Parallaxes *(mas):* 0.6036 [0.0425] A 2018yCat.1345....0G

Spectral type: WN5-6b C 1996MNRAS.281..163S

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

SIMBAD query around with radius 2 arcmin

Interactive AladinLite view

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: $currentYea

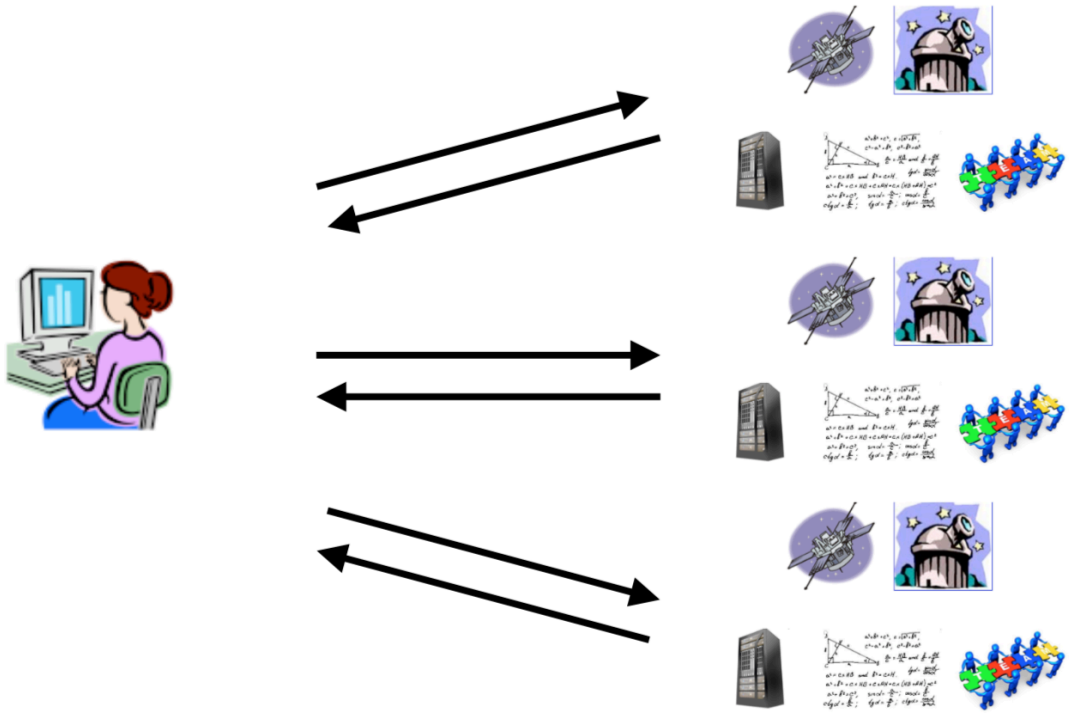
Display or select by : (not exhaustive, explanation here) In table | Title|Abstract|Keyword | Score

Collections of Measurements

distance : 2 | PM : 3 | PLX : 3 | MK : 5

display selected measurements | display all measurements | clear

Collect and combine data

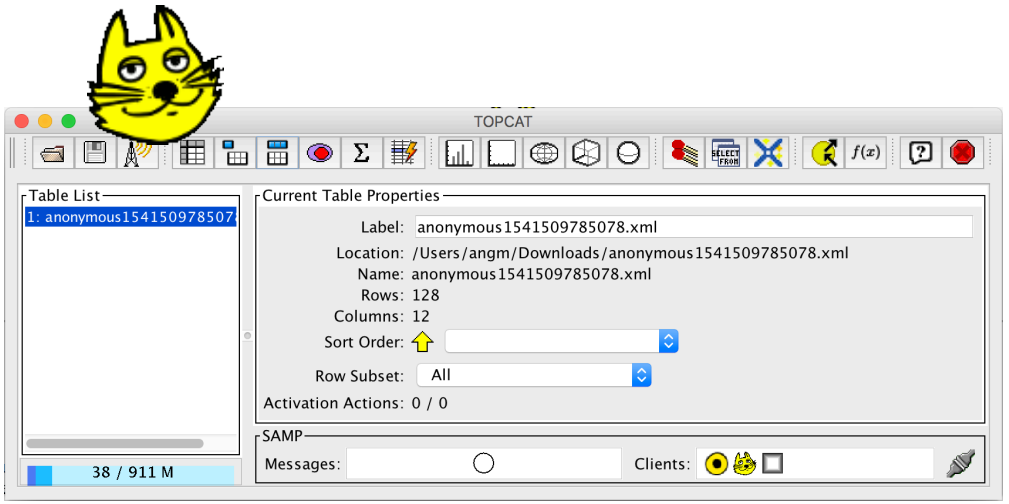


Different methods to access data on different astronomical archives

homogenize — e.g. cone-search

Cross-matching

- 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

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

Add the time as a possible information to cross-matches?

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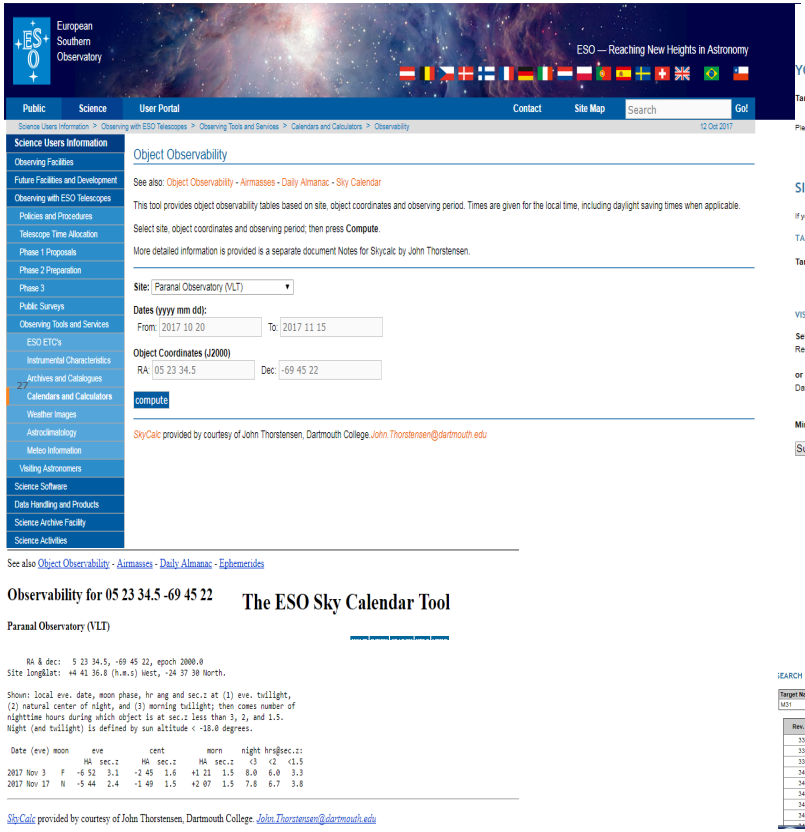
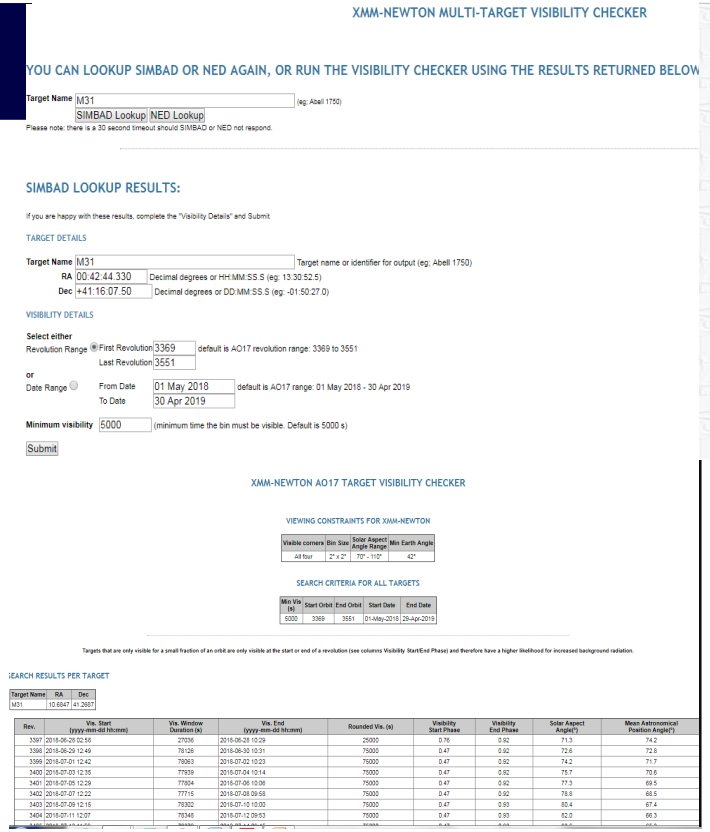
- **Follow-up observations & reaction time**
- Coordination of observations
  - Where & when?
  - Multi-national collaborations

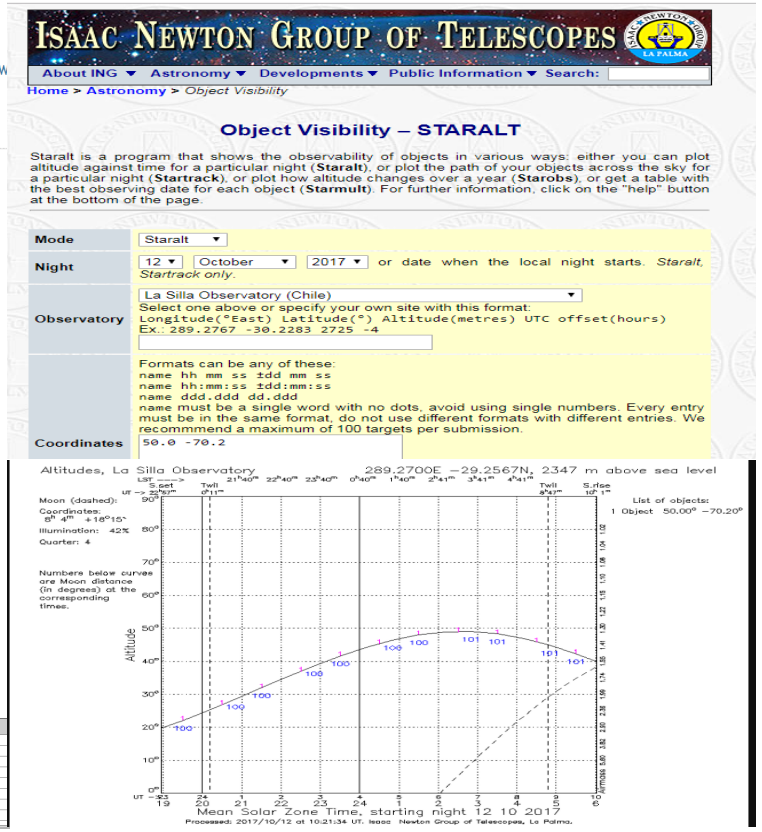
➡ Planning observations

➡ Transmission of events

Planning observations: visibility services



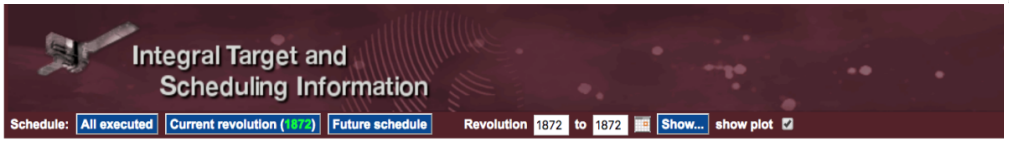




Different services have different inputs / outputs

Facilitate the work by having same inputs / outputs

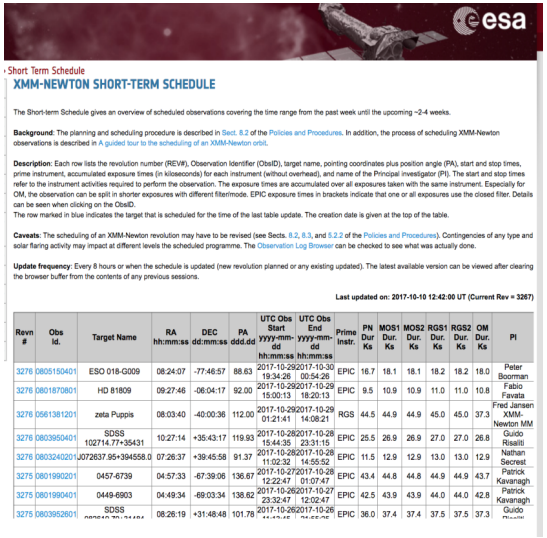
Planning observations: coordination of observations



Schedule for revolution 1872

(this list is also available in csv-format, click here to download)

Rev	Start time (UTC)	End time (UTC)	Exp. time (s)	Target	Ra (J2000)	Dec (J2000)	Pattern	PI	Proposal	Observation	Notes
1872	2017-10-10 13:29:15	2017-10-10 17:10:51	12600	Gal. Bulge region	17:45:36.00	-28:56:00.0	HEX	Erik Kuulkers	1420001	1420001 / 0022	Public
1872	2017-10-10 17:13:34	2017-10-11 07:55:55	50000	Galactic Center	17:52:11.21	-25:21:49.7	5x5 Seq	Joern Wilms	1420009	1420009 / 0011	
1872	2017-10-11 08:16:46	2017-10-11 11:58:32	12600	Galaxy (l=0, b=0)	17:42:23.76	-29:38:02.4	HEX	Rashid Sunyaev	1420021	1420021 / 0039	
1872	2017-10-11 12:26:36	2017-10-11 12:56:36	1800	Galaxy (l=0, b=-30)	20:02:16.80	-41:20:31.2	HEX	Rashid Sunyaev	1420021	1420021 / 0038	
1872	2017-10-11 13:27:21	2017-10-11 14:29:17	3600	Galaxy (l=0, b=-30)	19:59:40.80	-41:05:16.8	HEX	Rashid Sunyaev	1420021	1420021 / 0040	
1872	2017-10-11 15:00:12	2017-10-11 17:38:07	9000	Galaxy (l=0, b=-30)	19:59:40.80	-41:05:16.8	HEX	Rashid Sunyaev	1420021	1420021 / 0040	
1872	2017-10-11 18:41:00	2017-10-12 08:01:56	45000	GRS 1915+105	19:15:11.79	+10:56:45.7	5x5 Seq	Jerome Rodriguez	1420029	1420029 / 0008	
1872	2017-10-12 09:06:18	2017-10-12 12:47:54	12600	Galaxy (l=0, b=0)	17:50:46.80	-28:55:30.0	HEX	Rashid Sunyaev	1420021	1420021 / 0041	
1872	2017-10-12 13:16:06	2017-10-12 14:49:58	5400	Galaxy (l=0, b=-30)	20:07:12.96	-40:00:10.8	HEX	Rashid Sunyaev	1420021	1420021 / 0042	



The Short-term Schedule gives an overview of scheduled observations covering the time range from the past week until the upcoming ~2-4 weeks.

Background: The planning and scheduling procedure is described in Sect. 8.2 of the Policies and Procedures. In addition, the process of scheduling XMM-Newton observations is described in A guided tour to the scheduling of an XMM-Newton orbit.

Description: Each row lists the revolution number (REV#), Observation Identifier (ObsID), target name, pointing coordinates plus position angle (PA), start and stop times, prime instrument, accumulated exposure times (in kiloseconds) for each instrument (without overhead), and name of the Principal Investigator (PI). The start and stop times refer to the instrument activities required to perform the observation. The exposure times are accumulated over all exposures taken with the same instrument. Especially for OM, the observation can be split in shorter exposures with different filter/mode. EPIC exposure times in brackets indicate that one or all exposures use the closed filter. Details can be seen when clicking on the ObsID.
The row marked in blue indicates the target that is scheduled for the time of the last table update. The creation date is given at the top of the table.

Caveats: The scheduling of an XMM-Newton revolution may have to be revised (see Sects. 8.2, 8.3, and 5.2.2 of the Policies and Procedures). Contingencies of any type and solar flaring activity may impact at different levels the scheduled programme. The Observation Log Browser can be checked to see what was actually done.

Update frequency: Every 8 hours or when the schedule is updated (new revolution planned or any existing updated). The latest available version can be viewed after clearing the browser buffer from the contents of any previous sessions.

Last updated on: 2017-10-10 12:42:00 UT (Current Rev = 3267)

Revn #	Obs Id.	Target Name	RA hh:mm:ss	DEC dd:mm:ss	PA ddd.dd	UTC Obs Start yyyy-mm-dd hh:mm:ss	UTC Obs End yyyy-mm-dd hh:mm:ss	Prime Instr.	PN Dur Ks	MOS1 Dur. Ks	MOS2 Dur. Ks	RGS1 Dur. Ks	RGS2 Dur. Ks	OM Dur. Ks	PI
3276	0805150401	ESO 018-G009	08:24:07	-77:46:57	88.63	2017-10-29 19:34:26	2017-10-30 00:54:26	EPIC	16.7	18.1	18.1	18.2	18.2	18.0	Peter Boorman
3276	0801870801	HD 81809	09:27:46	-06:04:17	92.00	2017-10-29 15:00:13	2017-10-29 18:20:13	EPIC	9.5	10.9	10.9	11.0	11.0	10.8	Fabio Favata
3276	0561381201	zeta Puppis	08:03:40	-40:00:36	112.00	2017-10-29 01:21:41	2017-10-29 14:08:21	RGS	44.5	44.9	44.9	45.0	45.0	37.3	Fred Jansen XMM-Newton MM
3276	0803950401	SDSS 102714.77+35431	10:27:14	+35:43:17	119.93	2017-10-28 15:44:35	2017-10-28 23:31:15	EPIC	25.5	26.9	26.9	27.0	27.0	26.8	Guido Risaliti
3276	0803240201	J072637.95+394558.0	07:26:37	+39:45:58	91.37	2017-10-28 11:02:32	2017-10-28 14:55:52	EPIC	11.5	12.9	12.9	13.0	13.0	12.9	Nathan Secrest
3275	0801990201	0457-6739	04:57:33	-67:39:06	136.67	2017-10-27 12:22:47	2017-10-28 01:07:47	EPIC	43.4	44.8	44.8	44.9	44.9	43.7	Patrick Kavanagh
3275	0801990401	0449-6903	04:49:34	-69:03:34	138.62	2017-10-26 23:32:47	2017-10-27 12:02:47	EPIC	42.5	43.9	43.9	44.0	44.0	42.8	Patrick Kavanagh
3275	0803952601	SDSS	08:26:19	+31:48:48	101.78	2017-10-26	2017-10-26	EPIC	36.0	37.4	37.4	37.5	37.5	37.3	Guido

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Observing schedules

Short Range Observatory Schedule

Download

This is the confirmed schedule of NuSTAR observations. This sequence of observations has been uploaded to the spacecraft and will execute autonomously unless interrupted by a new schedule, Target of Opportunity, or instrument and spacecraft anomalies. This schedule will cover various time ranges depending on the exposure time goal of the observations, but will usually be for a period of at least one week.

The times reported here are the start and end of the on-target period (day of year UTC). The estimated exposure time takes into account Earth occultation and the SAA passage time where detector background is increased. The end time of the observation is the start of the slew to the next target. Please examine the NuSTAR As-Flown Timeline (AFT) for the log of past observations.

Table Header Explanations

obs_start	obs_end	sequenceID	Name	J2000_RA	J2000_Dec	Exp	Notes
2017:281:19:05:02	2017:283:00:30:00	90201021006	Kepler	262.671620	-21.491957	60.6	DDT
2017:283:01:11:23	2017:283:02:40:00	90311211001	Sol_17282_AR2683_POS11	195.15715	-6.38520	3.4	ToO
2017:283:02:40:32	2017:283:04:20:00	90311212001	Sol_17282_AR2683_POS12	195.21879	-6.41062	3.4	ToO
2017:283:04:20:32	2017:283:05:50:00	90311213001	Sol_17282_AR2683_POS13	195.28046	-6.43604	3.4	ToO
2017:283:06:55:11	2017:284:09:20:00	60376001002	2MASXJ19301380p3410495	292.557500	34.180500	55.3	Extragalactic Legacy Survey
2017:284:09:45:09	2017:284:20:35:00	60360008002	SDSSJ152132d21p391206d9	230.3874232	39.2007671	22.0	Extragalactic Legacy Survey
2017:284:21:10:03	2017:285:21:00:00	90301320002	NGC_6440	267.218083	-20.358944	49.5	ToO
2017:285:21:20:06	2017:286:08:20:00	30302020004	GRS_1915p105	288.79813	10.94578	21.9	(2/4) coordinated with XMM and VLT
2017:286:08:35:06	2017:286:19:30:00	60160701002	2MASXJ18560128p1538059	284.00210000	15.63200000	23.3	BAT AGN
2017:286:20:05:11	2017:287:15:05:00	60376007002	UGC06728	176.316800	79.681500	61.4	Extragalactic Legacy Survey
2017:287:15:50:11	2017:288:03:20:00	60368001002	NGC_1144	43.80083	-0.18361	22.0	
2017:288:04:05:09	2017:288:23:00:00	60301004002	ESO_103m35	279.58458	-65.4275	50.3	
2017:288:23:30:08	2017:290:05:45:00	30301026002	AX_J1841d0m0536	280.25179	-5.59625	59.7	phase constrained
2017:290:06:00:04	2017:290:17:00:00	60160607002	2E1739d1m1210	265.47600000	-12.19700000	23.5	BAT AGN
2017:290:17:15:01	2017:291:04:20:00	30363001002	GX_3p1	266.98333	-26.56361	21.8	

Long Range Observatory Schedule

Download

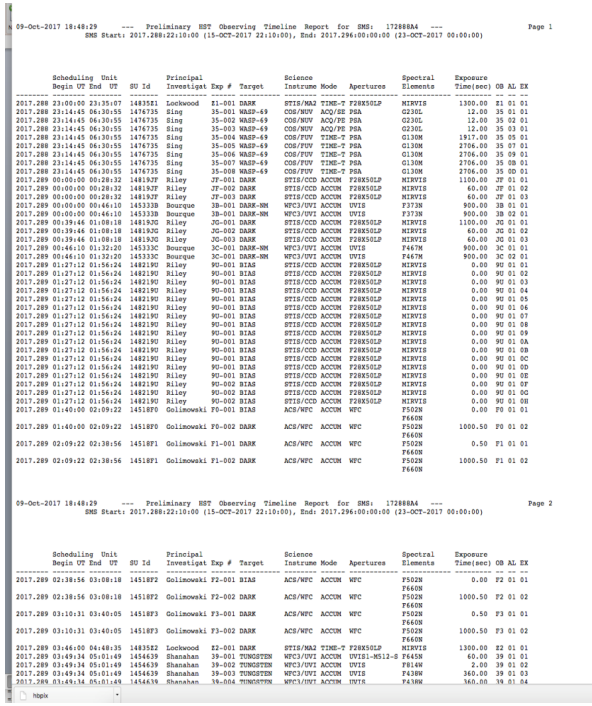
This is the latest NuSTAR long-term schedule. Observations have been sorted into one-week intervals, taking into account Sun, Moon, required exposure time, and other constraints. So the date is the Monday of the week in which the observation is scheduled to begin.

E.g. An observation with a date **2017-12-18** in this table is scheduled to have the observation ***starting*** sometime between **2017-12-18 0000Z** and **2017-12-25 0000Z**.

Currently the schedule is driven by the large number of observations coordinated with other observatories and the need to complete the NuSTAR Guest Observer programs. The exposure goal for targets allotted within one week may appear to fill more than the available NuSTAR exposure time in that week (average is 330 ks per week) but many observations start in one week and complete in the following week.

Targets of opportunity and any instrument or spacecraft anomalies may also cause the observing times of targets to shift. This long-term schedule is our present estimate of the future order of observations. Please be aware of the uncertainties.

ToO = Target of Opportunity **DDT** = Directors Discretionary Time **N03** = NuSTAR GO cycle-3 **I15** = INTEGRAL GO cycle-15
X16 = XMM-Newton GO cycle-16 **C18** = Chandra GO cycle-18 **ELS/GLS** = Extragalactic/Galactic legacy surveys



09-Oct-2017 18:48:29 --- Preliminary HST Observing Timeline Report for SMS: 17288BA4 --- Page 1
SMS Start: 2017.288:22:10:00 (15-OCT-2017 22:10:00), End: 2017.296:00:00:00 (23-OCT-2017 00:00:00)

Scheduling Unit Begin UT	End UT	SU Id	Principal Investigat	Exp #	Target	Science Instrume	Mode	Apertures	Spectral Elements	Exposure Time(sec)	OB	AL	EX
2017.288 23:00:00	23:35:07	1483SE1	Lockwood	E1-001	DARK	STIS/NUA2	TIME-T	F28X50LP	MIRVIS	1300.00	E1	01	01
2017.288 23:14:45	06:30:55	1476735	Sing	35-001	WASP-69	COS/NUV	ACQ/SE	PSA	G230L	12.00	35	01	01
2017.288 23:14:45	06:30:55	1476735	Sing	35-002	WASP-69	COS/NUV	ACQ/PE	PSA	G230L	12.00	35	02	01
2017.288 23:14:45	06:30:55	1476735	Sing	35-003	WASP-69	COS/NUV	ACQ/PE	PSA	G230L	12.00	35	03	01
2017.288 23:14:45	06:30:55	1476735	Sing	35-004	WASP-69	COS/FUV	TIME-T	PSA	G130M	1917.00	35	05	01
2017.288 23:14:45	06:30:55	1476735	Sing	35-005	WASP-69	COS/FUV	TIME-T	PSA	G130M	2706.00	35	07	01
2017.288 23:14:45	06:30:55	1476735	Sing	35-006	WASP-69	COS/FUV	TIME-T	PSA	G130M	2706.00	35	09	01
2017.288 23:14:45	06:30:55	1476735	Sing	35-007	WASP-69	COS/FUV	TIME-T	PSA	G130M	2706.00	35	0B	01
2017.288 23:14:45	06:30:55	1476735	Sing	35-008	WASP-69	COS/FUV	TIME-T	PSA	G130M	2706.00	35	0D	01
2017.289 00:00:00	00:28:32	1481YJF	Riley	JF-001	DARK	STIS/CCD	ACCUM	F28X50LP	MIRVIS	1100.00	JF	01	01
2017.289 00:00:00	00:28:32	1481YJF	Riley	JF-002	DARK	STIS/CCD	ACCUM	F28X50LP	MIRVIS	60.00	JF	01	02
2017.289 00:00:00	00:28:32	1481YJF	Riley	JF-003	DARK	STIS/CCD	ACCUM	F28X50LP	MIRVIS	60.00	JF	01	03
2017.289 00:00:00	00:46:10	145333B	Bourque	3B-001	DARK-NM	WFC3/UV1	ACCUM	UVIS	F373N	900.00	3B	02	01
2017.289 00:00:00	00:46:10	145333B	Bourque	3B-001	DARK-NM	WFC3/UV1	ACCUM	UVIS	F373N	900.00	3B	02	01
2017.289 00:39:46	01:08:18	1481YJG	Riley	JG-001	DARK	STIS/CCD	ACCUM	F28X50LP	MIRVIS	1100.00	JG	01	01
2017.289 00:39:46	01:08:18	1481YJG	Riley	JG-002	DARK	STIS/CCD	ACCUM	F28X50LP	MIRVIS	60.00	JG	01	02
2017.289 00:39:46	01:08:18	1481YJG	Riley	JG-003	DARK	STIS/CCD	ACCUM	F28X50LP	MIRVIS	60.00	JG	01	03
2017.289 00:46:10	01:32:20	145333C	Bourque	3C-001	DARK-NM	WFC3/UV1	ACCUM	UVIS	F467M	900.00	3C	01	01
2017.289 00:46:10	01:32:20	145333C	Bourque	3C-001	DARK-NM	WFC3/UV1	ACCUM	UVIS	F467M	900.00	3C	02	01
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	01
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	02
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	03
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	04
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	05
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	06
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	07
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	08
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	09
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	0A
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	0B
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	0C
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	0D
2017.289 01:27:12	01:56:24	1482190	Riley	90-001	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	0E
2017.289 01:27:12	01:56:24	1482190	Riley	90-002	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	0F
2017.289 01:27:12	01:56:24	1482190	Riley	90-002	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	0G
2017.289 01:27:12	01:56:24	1482190	Riley	90-002	BIAS	STIS/CCD	ACCUM	F28X50LP	MIRVIS	0.00	9U	01	0H
2017.289 01:40:00	02:09:22	1481BF0	Golimowski	E0-001	BIAS	ACS/WFC	ACCUM	WFC	F502N F660N	1000.50	E0	01	01
2017.289 01:40:00	02:09:22	1481BF0	Golimowski	F0-002	DARK	ACS/WFC	ACCUM	WFC	F502N F660N	1000.50	F0	01	02
2017.289 02:09:22	02:38:56	1481BF1	Golimowski	F1-001	DARK	ACS/WFC	ACCUM	WFC	F502N F660N	0.50	F1	01	01
2017.289 02:09:22	02:38:56	1481BF1	Golimowski	F1-002	DARK	ACS/WFC	ACCUM	WFC	F502N F660N	1000.50	F1	01	02

09-Oct-2017 18:48:29 --- Preliminary HST Observing Timeline Report for SMS: 17288BA4 --- Page 2
SMS Start: 2017.288:22:10:00 (15-OCT-2017 22:10:00), End: 2017.296:00:00:00 (23-OCT-2017 00:00:00)

Scheduling Unit Begin UT	End UT	SU Id	Principal Investigat	Exp #	Target	Science Instrume	Mode	Apertures	Spectral Elements	Exposure Time(sec)	OB	AL	EX
2017.289 02:38:56	03:08:18	1481BF2	Golimowski	F2-001	BIAS	ACS/WFC	ACCUM	WFC	F502N F660N	0.00	F2	01	01
2017.289 02:38:56	03:08:18	1481BF2	Golimowski	F2-002	DARK	ACS/WFC	ACCUM	WFC	F502N F660N	1000.50	F2	01	02
2017.289 03:10:31	03:40:05	1481BF3	Golimowski	F3-001	DARK	ACS/WFC	ACCUM	WFC	F502N F660N	0.50	F3	01	01
2017.289 03:10:31	03:40:05	1481BF3	Golimowski	F3-002	DARK	ACS/WFC	ACCUM	WFC	F502N F660N	1000.50	F3	01	02
2017.289 03:46:00	04:48:35	1483SE2	Lockwood	E2-001	DARK	STIS/NUA2	TIME-T	F28X50LP	MIRVIS	1300.00	E2	01	01
2017.289 03:49:34	05:01:49	1454639	Shanahan	39-001	TUNGSTEN	WFC3/UV1	ACCUM	UVIS1-M512-8	F645N	60.00	39	01	01
2017.289 03:49:34	05:01:49	1454639	Shanahan	39-002	TUNGSTEN	WFC3/UV1	ACCUM	UVIS	F814W	2.00	39	01	02
2017.289 03:49:34	05:01:49	1454639	Shanahan	39-003	TUNGSTEN	WFC3/UV1	ACCUM	UVIS	F438W	360.00	39	01	03
2017.289 03:49:34	05:01:49	1454639	Shanahan	39-004	TUNGSTEN	WFC3/UV1	ACCUM	UVIS	F438W	360.00	39	01	04

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

Time Domain Astronomy Challenges

The study of variability of astronomical objects over different time-scales

- Characterisation and classification of sources on the basis of their variability
- Multi-wavelength/messenger approach is (sometimes) needed
- Follow-up observations & reaction time for that can be crucial
- **Visualisation & navigation** thought the data
- Analysis of variance of phenomena
- Coordination & transmission of information

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

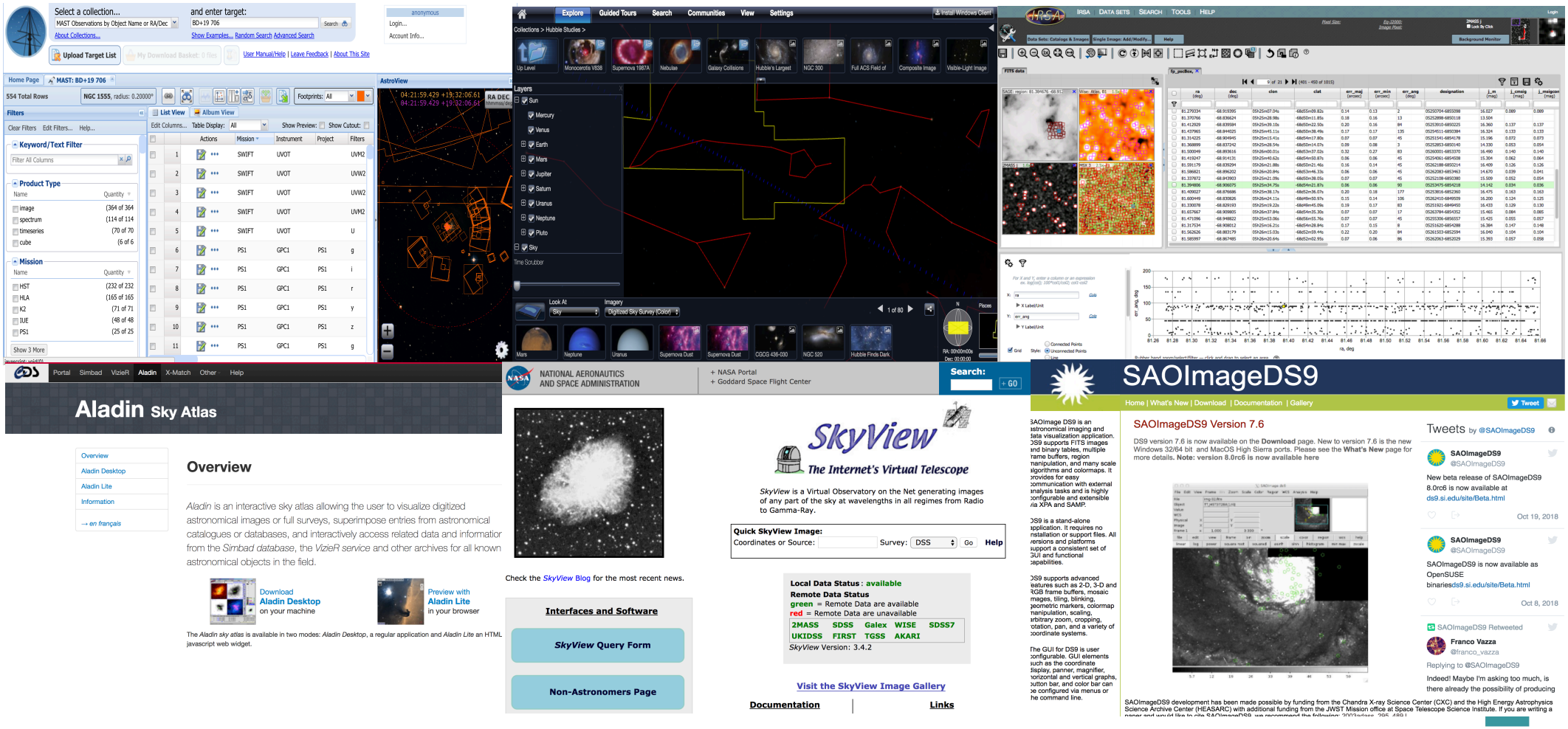
Time Domain Astronomy Challenges

The study of variability of astronomical objects over different time-scales

- Characterisation and classification of sources on the basis of their variability
- Multi-wavelength/messenger approach is (sometimes) needed
- Follow-up observations & reaction time for that can be crucial
- Visualisation & navigation
- **Analysis of variance** of phenomena
- Coordination & transmission of information

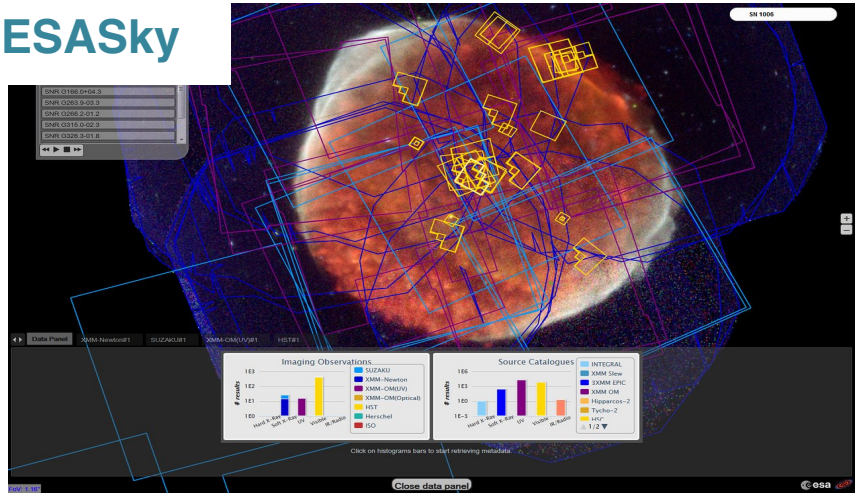
- **Analysis of variance**
  - ➡ period search methods
  - ➡ phase folding, binning, fitting…

Visualisation of the object/area of interest (Desktop / web)

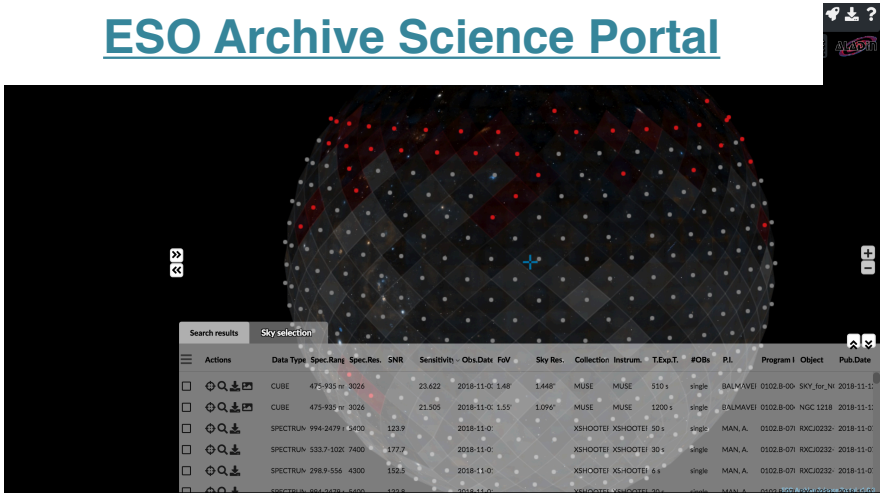


Aladin Lite implementations

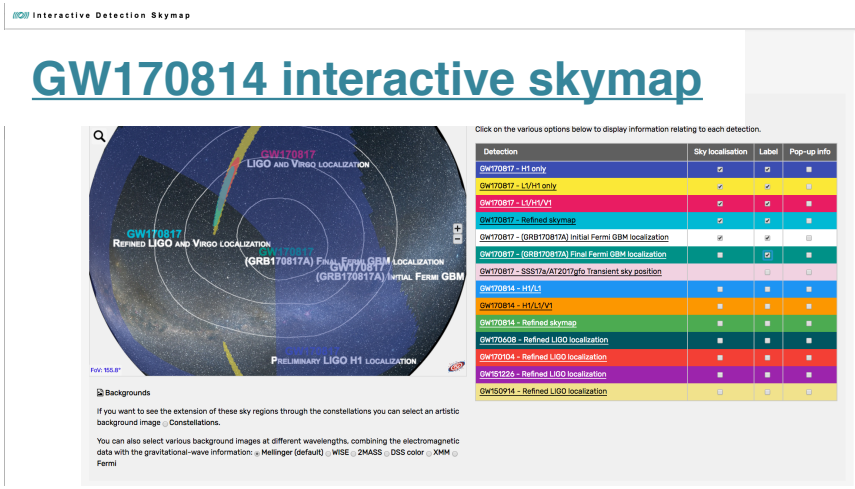
ESASky



ESO Archive Science Portal



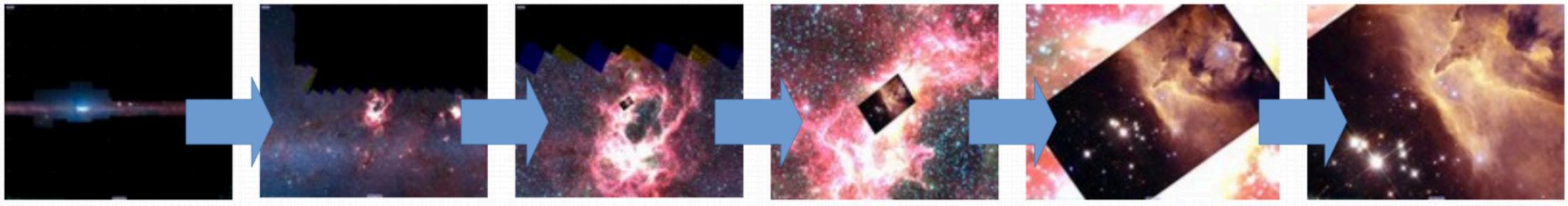
GW170814 interactive skymap



- ESO Archive Science Portal
- ESA Sky allows for discovery and access of data observed by ESA space missions
- ALMA Science Archive
- GW170814 interactive skymap displays the localisation on the sky of the gravitational wave event jointly detected by LIGO and Virgo observatories, and announced in September 2017.
- HEASARC Xamin system for discovery and data retrieval
- Skymap Viewer shows probability contours for gravitational wave events from LIGO/Virgo
- JVO Portal v2
- Gamma Sky, a portal to gamma-ray sky (developed by C. Deil and A. Voruganti)
- SETI uses Aladin Lite to display targets currently observed (development by J. Richards)
- J-PLUS DR1, a portal to access data of the First Data Release of the Javalambre-Photometric Local Universe Survey (J-PLUS)
- CEFCA images navigator and images tours
- ARCHES Walker, an Outreach tool showcasing astronomical objects in different wavelengths (ARCHES project)
- MOPRA Radio Telescope Pointing and Status
- JUDO2 (JAXA Universe Data Oriented)
- Akari explore tool
- CASSIS atlas of Spitzer Infrared Spectra
- GLIMPSE 360
- CADE (*Centre d'Analyse de Données Etendues*) uses Aladin Lite to provide previews of the HEALPix maps they publish (Example for CGPS data)
- ADS All-Sky Survey makes use of Aladin Lite to display heatmaps of SIMBAD objects cited in the literature.

Hierarchical visualisation of images and catalogues

- HiPS — Hierarchical approach to data
- The more we zoom the more detail we get



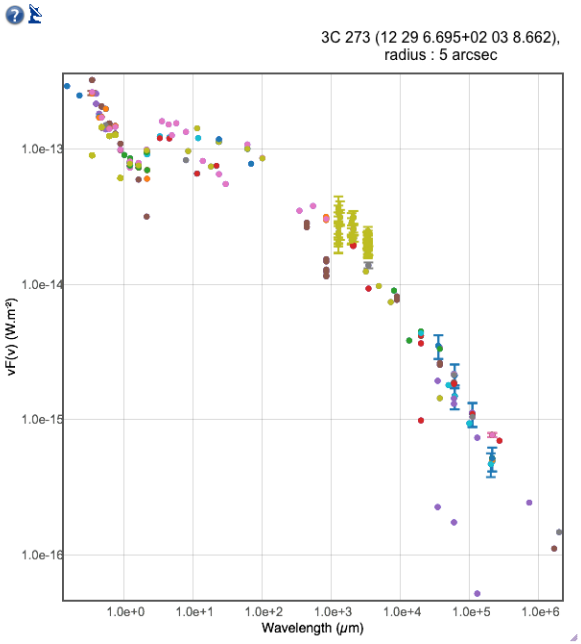
Something similar for *time* and treat light-curves in a lite way?

Hierarchical approach to light-curves?

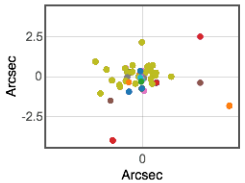
Visualisation of photometric data: photometric viewer

Target 3C 273
Radius (in arcsec) 5
submit

settings share



Mouse position:
Wavelength :
1.46e+1 μm
Frequency :
2.05e+4 GHz
Energy :
8.49e-2 eV
Flux density or F(ν) :
2.13e+0 Jy
νF(ν) :
4.38e-13 W.m^{-2}
F(λ) :
3.00e-11 erg.s^{-1}.cm^{-2}.μm^{-1}



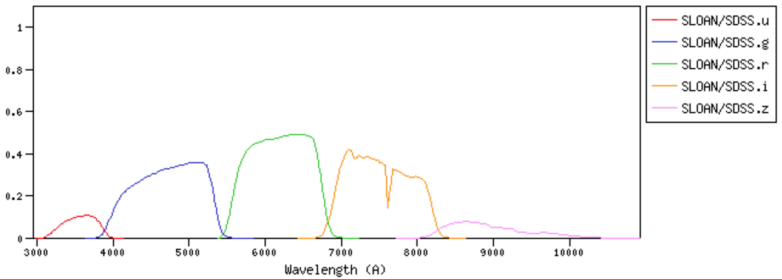
Center (R.A.+Dec.):
12 29 6.695+02 03 8.662
reset zoom

2MASS	AAO	AKARI	Astrosat	BOK	CAHA	CFHT	COBE	CTIO	DENIS	Euclid	GAIA	GALEX	GCPD	Gemin
Generic	Geneva	GTC	Herschel	Hipparcos	HST	IAC80	ING	INT	IRAS	ISO	IUE	JWST	Keck	Kepler
KPNO	LasCumbres	LaSilla	LBT	LCO	LICK	Liverpool	LSST	McD	Misc	MKO	MMT	MSX	NIRT	NOAO
NOT	OAF	OAJ	OSN	P200	Palomar	PAN-STARRS	Paranal	SAO	Scorpio	SkyMapper	**SLOAN**	SOFIA	Special	Spitze
STELLA	Subaru	Swift	TCS	TD1	TESS	TJO	TNG	TNO	TYCHO	UKIRT	VATT	WFIRST	WHT	WISE
WIYN														

SLOAN filters:

Filter ID	λ_{mean}	λ_{eff}	λ_{min}	λ_{max}	W_{eff}	ZP (Jy)	Obs. Facility	Instrument	Description
SLOAN/SDSS.u	3561.8	3594.9	3048	4028	558.4	1568.5	SLOAN		SDSS u
SLOAN/SDSS.g	4718.9	4640.4	3783	5549	1158.4	3965.9	SLOAN		SDSS g
SLOAN/SDSS.r	6185.2	6122.3	5415	6989	1111.2	3162.0	SLOAN		SDSS r
SLOAN/SDSS.i	7499.7	7439.5	6689	8389	1044.6	2602.0	SLOAN		SDSS i
SLOAN/SDSS.z	8961.5	8897.1	7960	10833	1124.6	2244.7	SLOAN		SDSS z

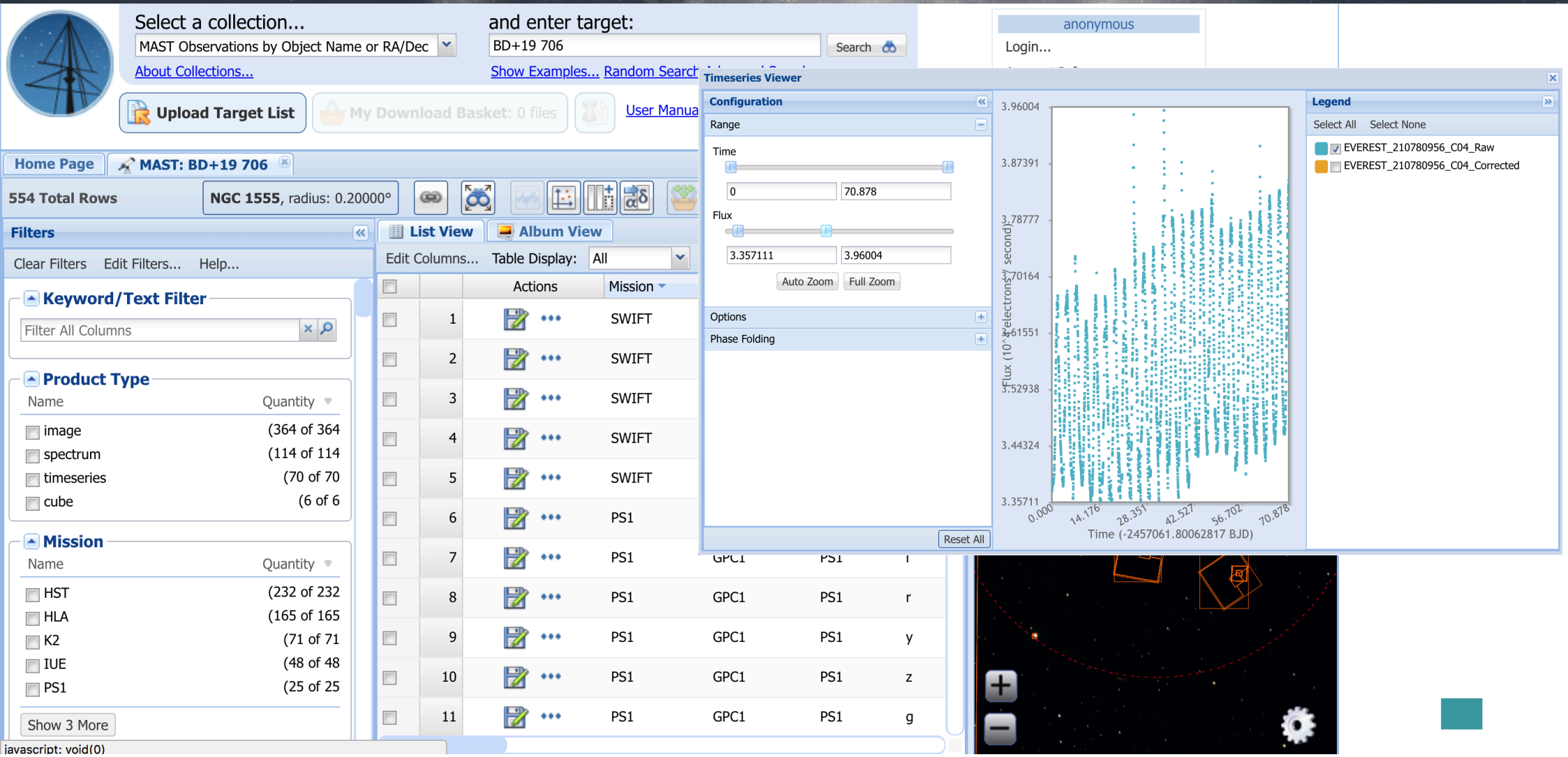
Filter Plots



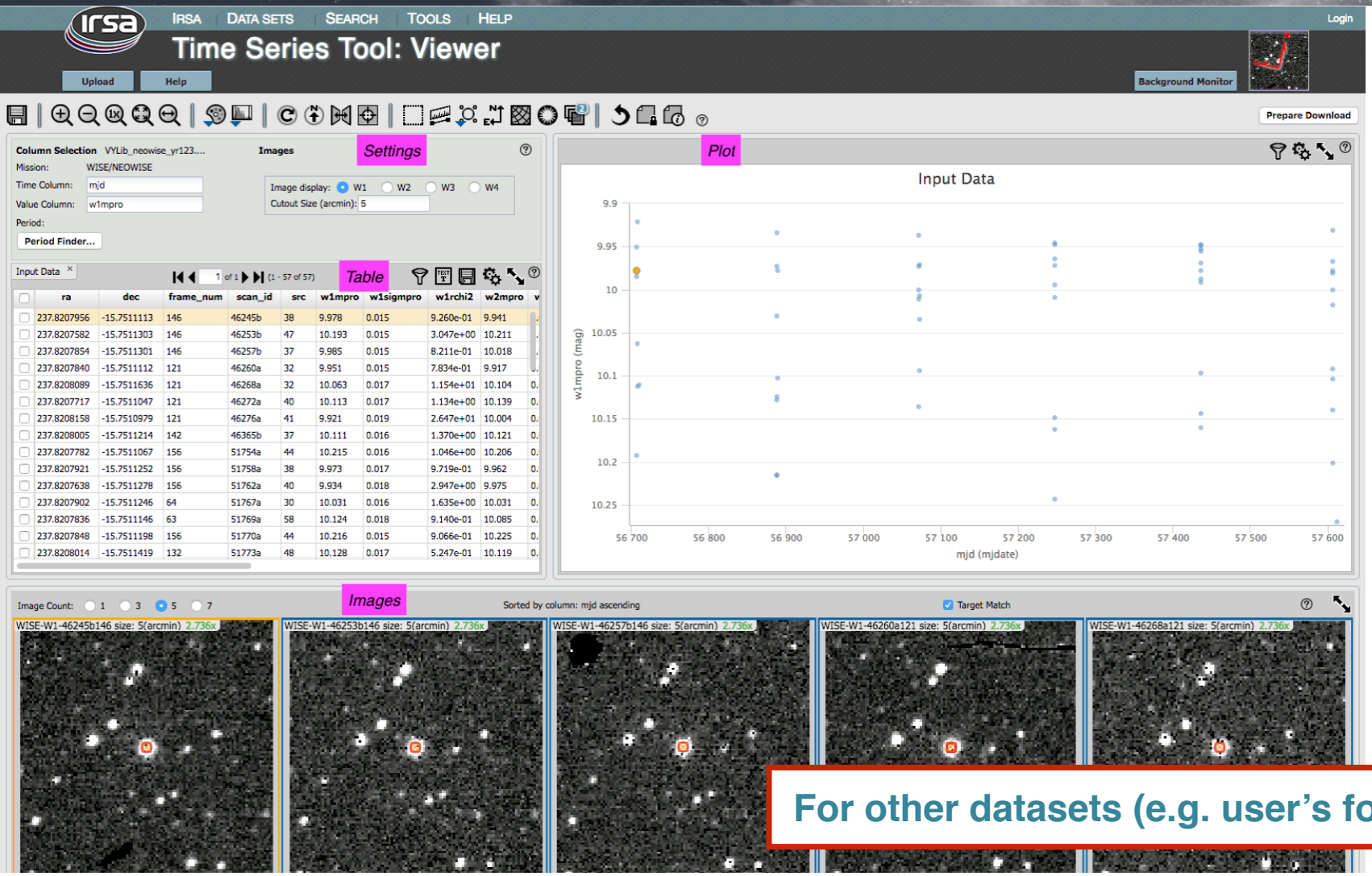
Implement something similar for time — A time (series) viewer

Need to annotate time properly

Time Series visualisation tools



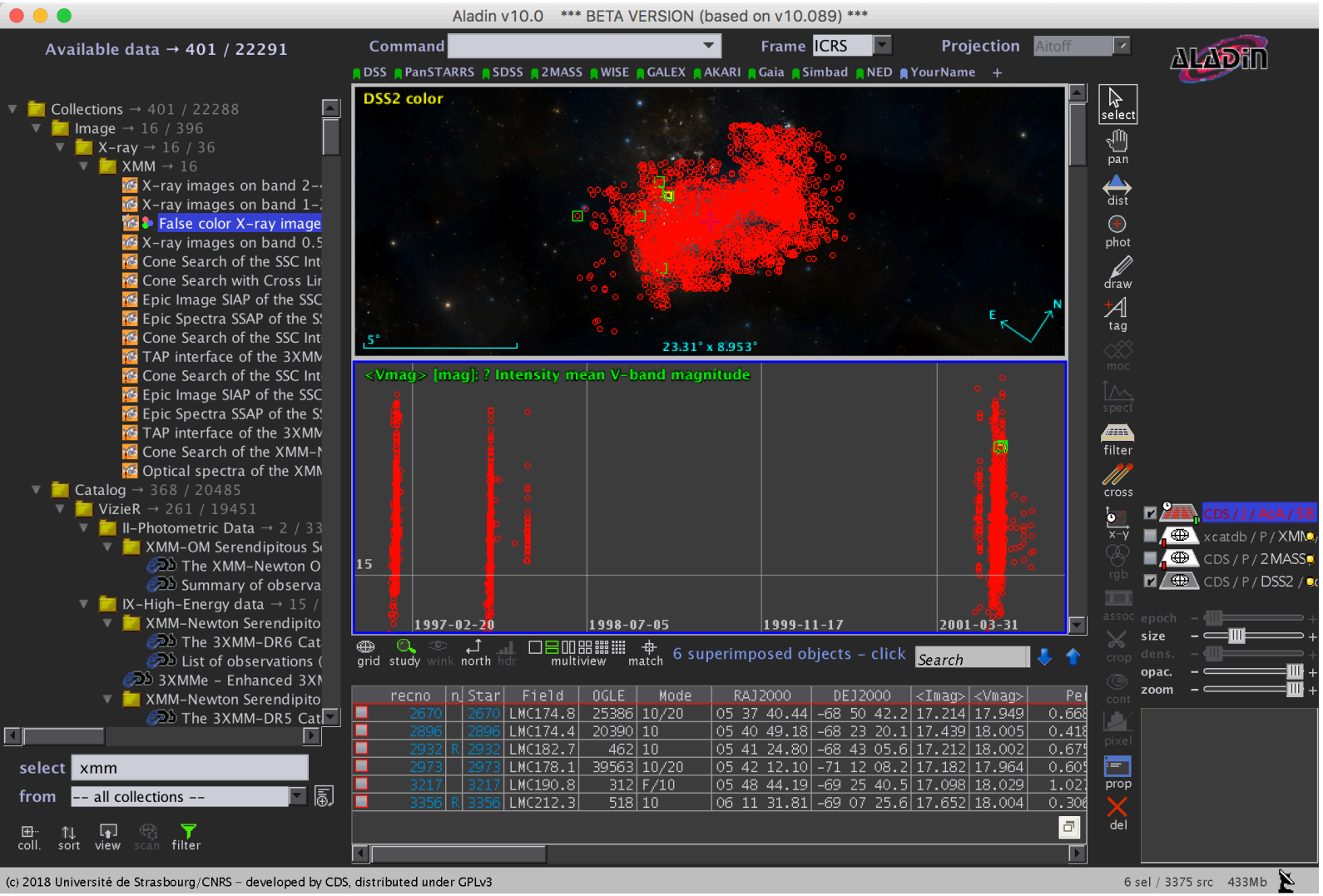
Time Series visualisation tool - Firefly



- ➡ **Measurements as a function of time**
- ➡ **Simultaneously visualize single-epoch images,**
- ➡ **Find the period of variability.**
- ➡ **Works for data coming from WISE/NEOWISE and PTF**

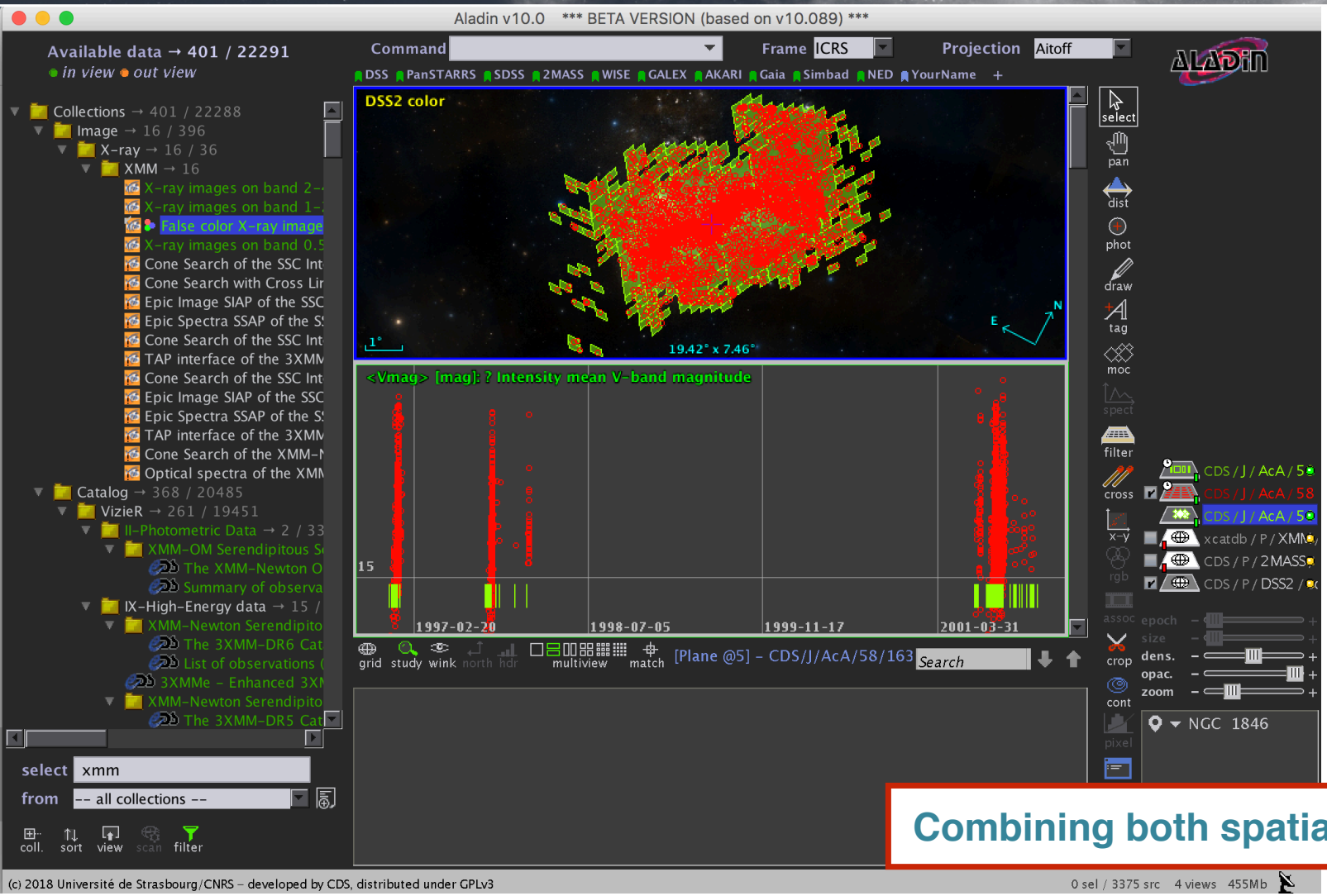
For other datasets (e.g. user's follow-up observations)

Time Series view (Aladin)



- For all catalogues available through Aladin + users
- Measurements as a function of time
- Simultaneously visualize the catalogue positions in the sky
- Background image can be any available through Aladin + users

Time Series view (Aladin)



- Coverage of a survey in space: MOC
- Coverage of a survey in time: TMOC
- Simple operations such as union, intersections,…

Combining both spatial and temporal coverages

Time Domain Astronomy Challenges

The study of variability of astronomical objects over different time-scales

- Characterisation and classification of sources on the basis of their variability
- Multi-wavelength/messenger approach is (sometimes) needed
- Follow-up observations & reaction time for that can be crucial
- Visualisation & navigation
- Analysis of variance of phenomena
- **Coordination & transmission** of information

- **Coordination & transmission**
  - ➡ collect what was observed, when, in which wavelength
  - ➡ alerts, emails, webpages, references,…

➡ **Communication and sharing in time domain multi-messenger astronomy is needed**
- ➡ **If this is a must then lets get together and do it together as a community**
- ➡ **This is exactly the vision of the VO (my point of view)**

What are the Time Domain challenges in the VO

- Display measurements as a function of time
- Simultaneously visualize single-epoch images
- Combine it with other data (description of time)
- Find the period of variability
- Combine spatial and temporal coverages
- Coordination and transmission of information

- The principle of the VO and the IVOA is to help the user to share information
- Using standards is very helpful and it works (all astronomers use it even if they don't know it!)
- It is not one tool to govern them all
- We work in international collaborations and everyone can join

Useful links

- IVOA: http://ivoa.net/
- Time Domain Interest Group:
  http://wiki.ivoa.net/twiki/bin/view/IVOA/IvoaVOEvent
- List of available VO applications and VO-compliant Tools & Services for astronomers:
  http://ivoa.net/astronomers/applications.html
- IRSA Time Series viewer
  https://irsa.ipac.caltech.edu/irsaviewer/timeseries
- More tutorials on VO services & tools:
  http://www.euro-vo.org/?q=science/scientific-tutorials