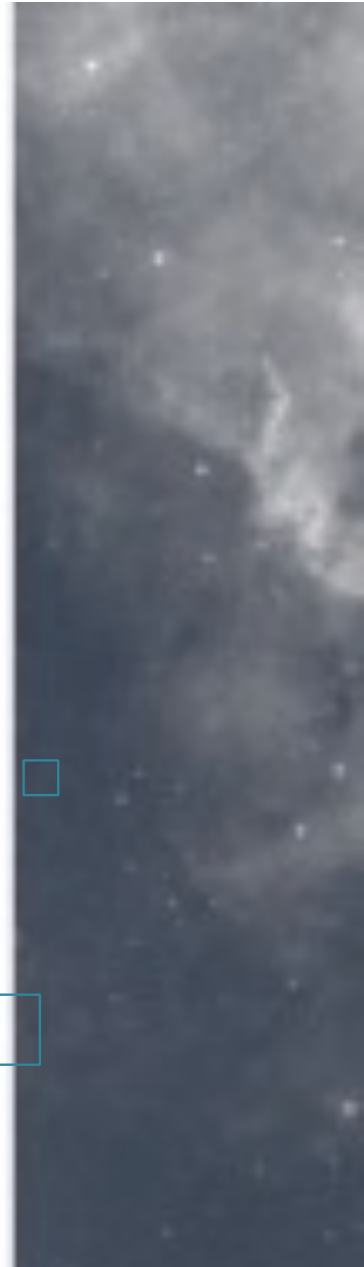


# Exploring Time Domain Multi-Messenger Astronomy through the Virtual Observatory

Ada Nebot & the CDS team

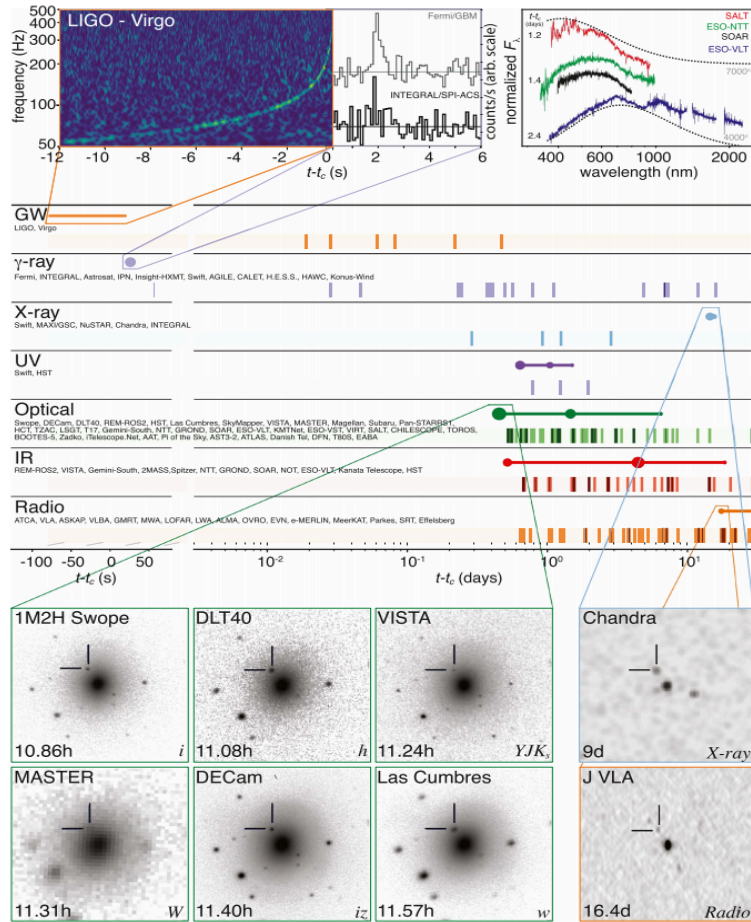
TS2020-III 26 September 2019



# Time Domain Multi-messenger Astronomy

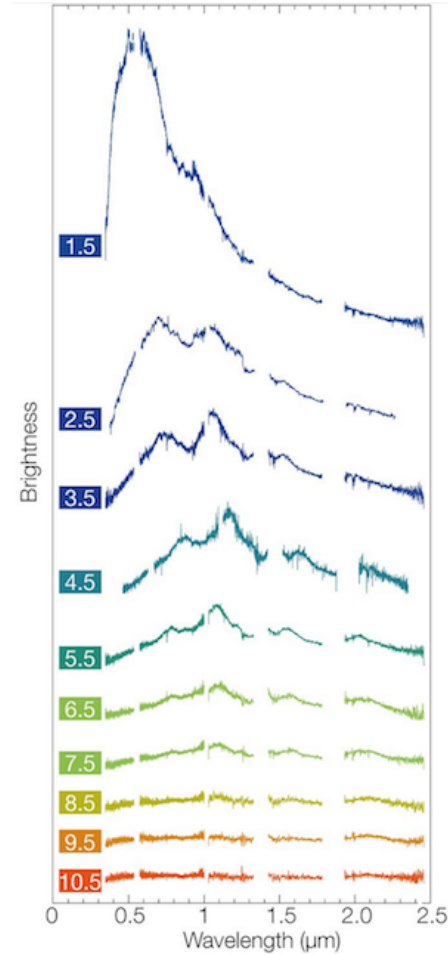
GW170817

THE ASTROPHYSICAL JOURNAL LETTERS, 848:L12 (59pp), 2017 October 20



Abbott et al. 2017

Abbott et al.



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



# □ Time Domain Astronomy Challenges/Needs

*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 (IVOA) should match user's needs  
So, what is available through the VO?**



# □ 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
- ➔ Chair & Vice-chair: A. Nebot & D. Morris
- ➔ Completely open to participation

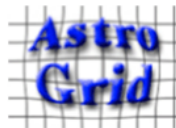
## How to join the IVOA?

- **2 interoperability meetings per year**
- ➔ Next IVOA meeting in Groningen 11-13 Oct.  
following ADASS 6-10 oct.  
<https://www.adass2019.nl/ivoa/ivoa-participants/>
- ➔ Register to email lists for discussion of topics
- ➔ Asking me directly can work too [ada.nebot@asto.unistra.fr](mailto:ada.nebot@asto.unistra.fr)

# □ The VO and the IVOA

## Who is the VO?

- VO is integrated in many Astronomy data centres and archives
- Often behind the scenes...



# □ 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**



# □ Time Domain Astronomy Challenges/Needs

*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 (IVOA) should match user's needs  
So, what is available through the VO?**





# □ Time Domain Astronomy Challenges/Needs


*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)



Object Name: M81

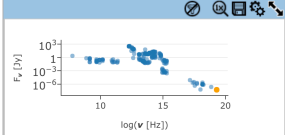
Search Options

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-SER/SERC-ER (South), Red Image

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)			
RA, Dec	RA, Dec [Deg]	Unc Semi-major, minor ["]	Unc PA [deg]
09h55m33.1730s, +69d03m55.061s	148.888221, 69.065295	1.57E-03, 3.50E-04	90
Preferred Redshift & Derived Quantities [ $H_0 = 73$ km/sec/Mpc], $\Omega_{\text{matter}} = 0.27$ , $\Omega_{\text{vacuum}} = 0.73$		Reference	
z (Helio)	V (Helio) [km/s]	V (CMB) [km/s]	Hubble Distance (CMB) [Mpc]
-0.00011 +/- 0.00001	-33.876552 +/- 3.897302	1991RC3.9.C...0000d	48 +/- 7
Classifications		Reference	
Object Type	Morphology	Activity Type	Other
G	SA(s)ab	1991RC3.9.C...0000d	Flat-Spectrum Radio Source, 2007ApJS...171...61H
Quick-look Angular & Physical Diameters		Foreground Galactic Extinction (2011ApJ)	
Passband	Diameter ["]	Reference	Diameter [kpc]
RC3 D_0 (blue)	1652.50	1991RC3.9.C...0000d	29.43
Quick-look Photometry & Luminosities (brightest flux in each spectral region)		Reference	
Spectral region	Band	Apparent mag or flux	Absolute Mag or $v_{LW}$ [W]
X-Ray	2-10 keV (BeppoSAX)	3.10E-11 +/- 0.40E-11 erg/cm <sup>2</sup> /s	2007A&A...472..705V
UV	3320 A (OAO)	8.95 +/- 0.08 mag	1982ApJ...256...1C
Visible	V	8.73 Jy	2007ApJ...655..863D
Near-IR	H_tot (2MASS LGA)	4.090 +/- 0.018 mag	2003AJ...125..525J
Far-IR	FIR (IRAS)	3.65E+12 W m <sup>-2</sup>	1988ApJS...68...91R
Radio	57.5 MHz	2.4 +/- 0.6 Jy	1990ApJ...352...301

\*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\* (HR, HR), IR (2MASS, SDSS, GALEX), B\* (Her), V\* (Ref), X (2MASS)

ICRS coord. (ep=J2000): 18 07 56.9612003141 -19 23 56.866361615 [Optical] [ 0.0479 0.0406 90 ] A 2018yCat.1345....00

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 59.649372659 -19 24 25.080719244 [ 4.5003 3.9502 90 ]

Gal coord. (ep=J2000): 010.800050877768 +00.3944248835444 [ 0.0479 0.0406 90 ]

Proper motions mas/yr: 0.787 -1.732 [0.090 0.079 90] A 2018yCat.1345....00

Parallax (mas): 0.6036 [0.0425] A 2018yCat.1345....00

Spectral type: WMS-bb C 1996MNRAS...281..1638

Fluxes (J): U 10.46 [-] C 2003yCat.2237....00, B 10.31 [-] C 2003yCat.2237....00, V 9.87 [-] C 2003yCat.2237....00, K 8.85 [0.02] D 2012yCat.1323....00, G 9.2064 [0.0066] C 2018yCat.1345....00, J 7.118 [0.018] C 2003yCat.2246....00, H 6.716 [0.021] C 2003yCat.2246....00, K 6.223 [0.024] C 2003yCat.2246....00

Identifiers (22): An access of full data is available using the icon VizieR near the identifier of the catalogue

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: ScurrentYear

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

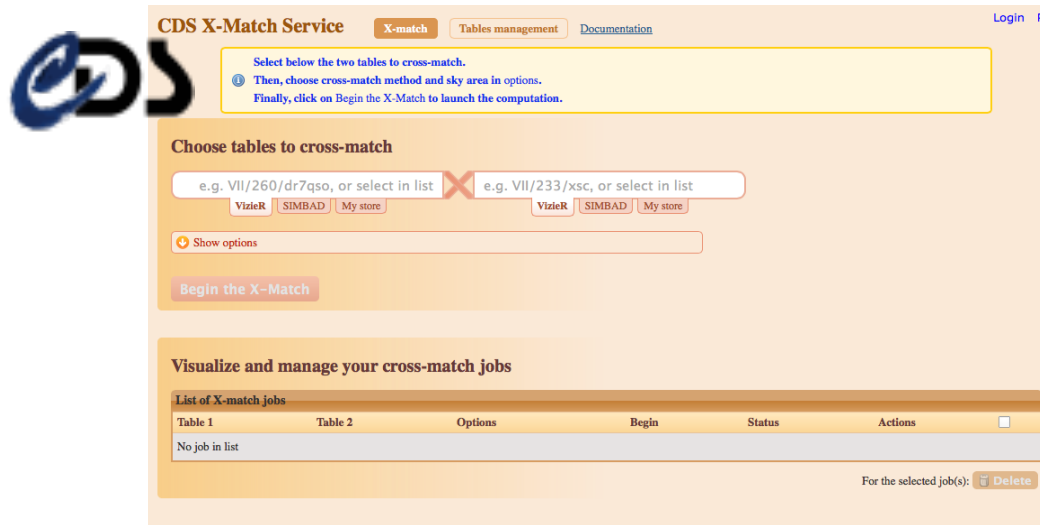
Collections of Measurements

distance: 2 | PH: 3 | PLX: 3 | HR: 5

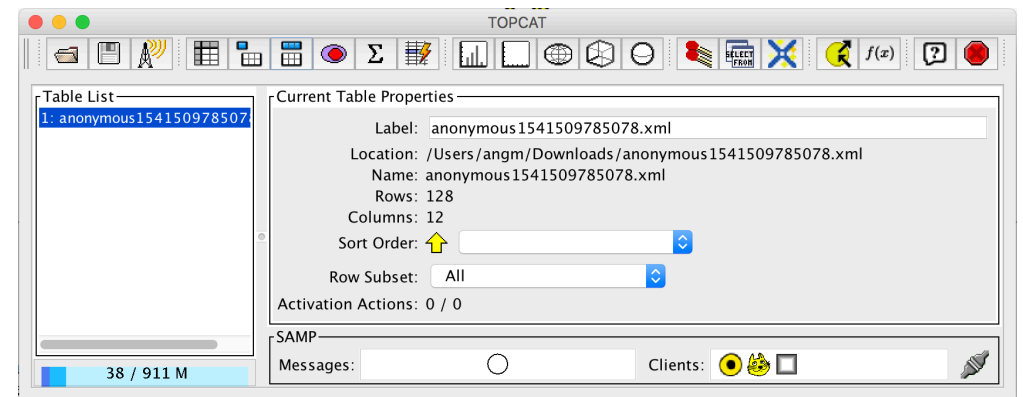
[display selected measurements] [display all measurements] [clear]

# □ Cross-matching — A key point

- CDS dev. **F. X. Pineau et al.**
- 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
- Available through TOPCAT and stilts too



The screenshot shows the CDS X-Match Service web interface. At the top, there are navigation tabs for 'X-match', 'Tables management', and 'Documentation', along with a 'Login' link. A yellow box contains instructions: 'Select below the two tables to cross-match. Then, choose cross-match method and sky area in options. Finally, click on Begin the X-Match to launch the computation.' Below this, the 'Choose tables to cross-match' section features two input fields with placeholder text 'e.g. VII/260/dr7qso, or select in list' and buttons for 'VizieR', 'SIMBAD', and 'My store'. A 'Show options' button and a 'Begin the X-Match' button are also present. The bottom section, 'Visualize and manage your cross-match jobs', includes a table with columns 'Table 1', 'Table 2', 'Options', 'Begin', 'Status', and 'Actions'. The table is currently empty, showing 'No job in list'. A 'Delete' button is visible at the bottom right of the table area.



The screenshot shows the TOPCAT software interface. The title bar reads 'TOPCAT'. The interface is divided into several panels. On the left, the 'Table List' panel shows a single table selected: '1: anonymous154150978507'. On the right, the 'Current Table Properties' panel displays the following information: Label: anonymous1541509785078.xml, Location: /Users/angm/Downloads/anonymous1541509785078.xml, Name: anonymous1541509785078.xml, Rows: 128, Columns: 12, Sort Order: (up arrow icon), and Row Subset: All. Below this, the 'Activation Actions' are shown as 0 / 0. At the bottom, the 'SAMP' panel shows 'Messages:' and 'Clients:' with various icons.





# Cross-matching

## Positional cross-match performance, radius 5''

Table 1	Table 2	Computation time	Result generation	Result size	Total time
<b>SDSS DR9</b> <i>469M rows</i>	<b>2MASS</b> <i>470M rows</i>	3 min	7 min	19 GB	10 min
<b>2MASS</b> <i>470M</i>	<b>GAIA-DR1</b> <i>1.1 billion</i>	16 min	65 min	193 GB	81 min
<b>Tycho-2</b> <i>2M</i>	<b>SIMBAD</b> <i>8M</i>	6 sec	25 sec	1 GB	35 sec
<b>List of</b> <i>40k positions</i>	<b>SIMBAD</b> <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/Needs

*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, IVOA Standard**
    - ➔ VOEvent Standard for Fast Radio Bursts FRBs, Petroff et al. 2017
    - ➔ Damien Dornic yesterday mentioned: VOEvent Standard for Neutrino ! :)
    - ➔ VOEvent Standard for other science / mission specific field?
  - ➔ **Planning observations: visibility, available telescope time 2 IVOA Standards in process**







# Planning observations: coordination of observations

**Integral Target and Scheduling Information**

Schedule: **All executed** **Current revolution (187)** **Future schedule**    Revolution **1872** to **1872**    **Show...** **show plot**

## 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	

**ESA**

**Short Term Schedule**  
**XMM-NEWTON SHORT-TERM SCHEDULE**

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 *Politics 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 (REVW), 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 CM, the observation can be split in shorter exposures with different filtermaps. EPIC exposure times in brackets indicates that one or all exposures use the closed filter. Details can be seen when clicking on the ObsID.

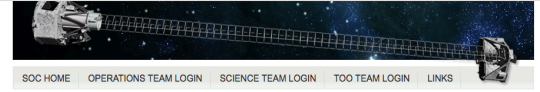
The row marked in blue indicates the target that is scheduled for the time of the last table update. The creation date is given at the top of the table.

**Caution:** The scheduling of an XMM-Newton revolution may have to be revised (see Sects. 8.1, 8.2, and 8.3 of the *Politics and Procedures*). Contingencies of any type and solar flaring activity may impact or affect the scheduled programme. The *Observation Log Browser* can be checked to see what was actually done.

**Update frequency:** Every 6 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 session.

Last updated on: 2017-10-10 12:42:00 UT (Current Rev = 2387)

Rev#	Obs. Id.	Target Name	RA	DEC	PA	UTC Obs Start	UTC Obs End	Prime Inst.	PN Dur. Ks	MO51 Dur. Ks	RG52 Dur. Ks	OM Dur. Ks	PI
3276	9805150401	ESO 019-G009	08:24:07	-77:46:57	86.83	2017-10-292017-10-30	19:30:28	EPIC	18.1	18.1	18.2	18.0	Peter Soames
3276	9801878001	HD 81909	09:27:46	-06:04:17	92.00	2017-10-292017-10-29	15:00:13	EPIC	9.5	10.9	11.0	11.0	Fabio Favata
3276	0561381201	zeta Puppis	08:03:40	-40:00:36	112.00	2017-10-292017-10-29	01:21:41	RGS	44.5	44.9	45.0	37.3	Prof. Jansen XMM-Newton IEM
3276	9803950401	S058	10:27:14	+36:43:17	119.93	2017-10-282017-10-28	15:44:30	EPIC	29.5	26.9	27.0	28.8	Guido Risalti
3276	9803240201	102714-77-36431	04:57:33	-67:39:06	136.67	2017-10-262017-10-27	11:02:32	EPIC	11.5	12.9	13.0	13.0	Nathan Secret
3276	9801902001	0457-6739	04:57:33	-67:39:06	136.67	2017-10-262017-10-27	12:22:47	EPIC	43.4	44.8	44.9	43.7	Patrick Kavanagh
3276	980190401	0449-6903	04:49:34	-69:03:34	138.62	2017-10-262017-10-27	23:32:47	EPIC	42.5	43.9	44.0	42.8	Patrick Kavanagh
3276	9803950201	S058	08:26:19	+31:48:48	101.78	2017-10-262017-10-26	01:07:47	EPIC	36.0	37.4	37.5	37.3	Guido Risalti



## Observing schedules

### Short Range Observatory Schedule

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 location 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	90311212001	Sol_17282_AR2683_POS12	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	2MASX193013903410495	292.55700	34.180500	55.3	Extragalactic Legacy Survey
2017:284:09:45:09	2017:284:20:35:00	60360008002	SDDS151232621p39120669	230.3874232	20.3907671	22.0	Extragalactic Legacy Survey
2017:284:21:10:03	2017:285:21:00:00	90303200002	NGC_6440	267.218083	-20.38944	49.5	Too
2017:285:21:20:06	2017:286:08:20:00	30302002004	GRS_1915p105	288.79813	10.94578	21.9	(Z/4) coordinated with XMM and VLT
2017:286:08:35:06	2017:286:19:30:00	60160701002	2MASX18560128p1538059	284.00210000	15.63200000	23.3	BAT AGN
2017:286:20:05:11	2017:287:15:05:00	60376007002	UGC08728	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	122.0	
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_11841d0m536	280.25179	-5.59625	59.7	phase constrained
2017:290:06:00:04	2017:290:17:00:00	60160670002	2E1739d1m1210	265.4760000	-12.19700000	23.5	BAT AGN
2017:290:17:15:01	2017:291:04:20:00	30363001002	GX_3p1	266.98333	-26.56361	121.6	

### Long Range Observatory Schedule

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.

09-Oct-2017 18:49:29 --- Preliminary SST Observing Timeline Report for SMS: 17289884 --- Page 1  
SMS Start: 2017.28812210:00 (15-OCT-2017 22:10:00), End: 2017.29619010:00 (23-OCT-2017 00:10:00)

Scheduling Unit	Begin UT	End UT	SO ID	Principal Investigator	Exp #	Target	Science	Instrument Mode	Apertures	Spectral Elements	Exposure Time(sec)	OB	AL
2017.288	23:00:00	23:15:07	148351	Loebwood	1	01-01 DARK	RTS/MS	TIME-T	F28X50P	NEWITS	1300.00	1	01
2017.288	23:14:45	06:10:55	1476735	Sing	35-001	WAGP-49	COB/FW	ACQ/FE	PSA	G230C	12.00	35	01
2017.288	23:14:45	06:10:55	1476735	Sing	35-002	WAGP-49	COB/FW	ACQ/FE	PSA	G230C	12.00	35	02
2017.288	23:14:45	06:10:55	1476735	Sing	35-003	WAGP-49	COB/FW	ACQ/FE	PSA	G230C	12.00	35	03
2017.288	23:14:45	06:10:55	1476735	Sing	35-004	WAGP-49	COB/FW	TIME-T	PSA	G130W	1911.00	35	04
2017.288	23:14:45	06:10:55	1476735	Sing	35-005	WAGP-49	COB/FW	TIME-T	PSA	G130W	2766.00	35	07
2017.288	23:14:45	06:10:55	1476735	Sing	35-006	WAGP-49	COB/FW	TIME-T	PSA	G130W	2766.00	35	08
2017.288	23:14:45	06:10:55	1476735	Sing	35-007	WAGP-49	COB/FW	TIME-T	PSA	G130W	2766.00	35	09
2017.288	00:00:00	00:18:32	148197F	Riley	JP-001	DARK	RTS/CCD	ACQCN	F28X50P	NEWITS	1100.00	JP	01
2017.288	00:00:00	00:18:32	148197F	Riley	JP-001	DARK	RTS/CCD	ACQCN	F28X50P	NEWITS	65.00	JP	02
2017.288	00:00:00	00:18:32	148197F	Riley	JP-001	DARK	RTS/CCD	ACQCN	F28X50P	NEWITS	60.00	JP	03
2017.288	00:00:00	00:14:10	145333B	Bourque	38-001	DARK-SM	WFC3/ON	ACQCN	UVIS	F3738	900.00	38	01
2017.288	00:00:00	00:14:10	145333B	Bourque	38-001	DARK-SM	WFC3/ON	ACQCN	UVIS	F3738	900.00	38	02
2017.288	00:39:44	01:09:18	148197G	Riley	JP-001	DARK	RTS/CCD	ACQCN	F28X50P	NEWITS	1100.00	JP	01
2017.288	00:39:44	01:09:18	148197G	Riley	JP-001	DARK	RTS/CCD	ACQCN	F28X50P	NEWITS	60.00	JP	02
2017.288	00:39:44	01:09:18	148197G	Riley	JP-001	DARK	RTS/CCD	ACQCN	F28X50P	NEWITS	60.00	JP	03
2017.288	00:44:10	01:12:20	145333C	Bourque	38-001	DARK-SM	WFC3/ON	ACQCN	UVIS	F4176	900.00	38	01
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	01
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	02
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	03
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	04
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	05
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	06
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	07
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	08
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	09
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	10
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	11
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	12
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	13
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	14
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD	ACQCN	F28X50P	NEWITS	0.00	90	15
2017.288	01:17:12	01:16:24	1482190	Riley	90-001	BIAS	RTS/CCD						

# □ Time Domain Astronomy Challenges/Needs

*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

The collage displays three main astronomical data visualization tools:

- MAST (Multi-Mission Archive of Space Telescopes):** A web-based search interface for astronomical data. It includes a search bar, filters for keywords and mission types, and a table of search results with columns for RA, Dec, and other parameters.
- AstroViz:** A web-based visualization tool showing a star field with various overlays and toolbars for navigation and analysis.
- SAOImageDS9:** A desktop application for viewing FITS files. It includes a FITS viewer, a data table, and a plot of error vs. magnitude.

## Aladin sky Atlas

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.

## 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:  Go

Local Data Status : available  
Remote Data Status  
green = Remote Data are available  
red = Remote Data are unavailable  
2MAS J SDSS Galax WISE SDSS7  
UKIDSS FIRST TGSS AKARI  
SkyView Version: 3.4.2

Check the [SkyView Blog](#) for the most recent news.

Interfaces and Software

SkyView Query Form

Non-Astronomers Page

Visit the [SkyView Image Gallery](#)

Documentation | Links

SAOImage DS9 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 XPM and SAMPL.

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 maps, film, blinking, geometric markers, colormap manipulation, scrolling, 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, pan, magnify, horizontal and vertical graphs, status bar, and color bar can be configured via menus or the command line.

## SAOImageDS9

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

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-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

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

Oct 19, 2018

SAOImageDS9 is now available as OpenUSE binaries [ds9.si.edu/site/Beta.html](https://ds9.si.edu/site/Beta.html)

Oct 8, 2018

SAOImageDS9 Retweeted

Franco Vazza @franco\_vazza

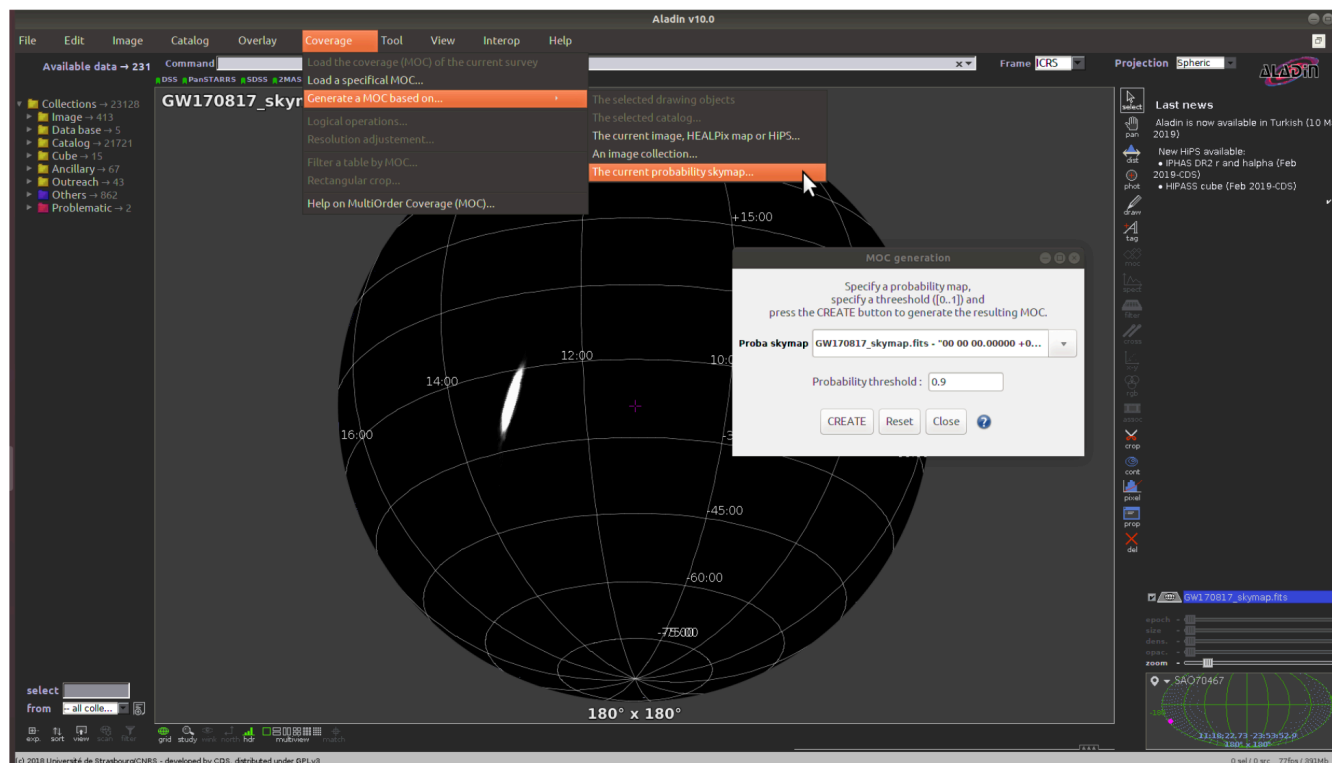
Replying to @SAOImageDS9

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 want to cite the SAOImageDS9, use the following information: DOI: 10.1006/stsci.2001.0101

# Visualisation of the sky in Aladin

- GW localisation in the sky in Aladin using **MOC IVOA standard**
- Background image can be DSS, 2MASS, WISE, XMM, Fermi,...
- We can overlay catalogues of interest, query Simbad, ... by region



➔ <https://emfollow.docs.ligo.org/userguide/tutorial/aladin.html>

# Visualisation of the sky in AladinLite

The CDS is very pleased that our Aladin and Aladin-Lite tools are being used to visualise the sky locations of GW170814, and that the images are on Astronomy Picture of the Day and the New York Times.

[www.virgo-gw.eu/skymap.html](http://www.virgo-gw.eu/skymap.html)

[apod.nasa.gov/apod/astropix.html](http://apod.nasa.gov/apod/astropix.html)

[www.nytimes.com/2017/09/27/science/black-holes-collision-ligo-virgo.html](http://www.nytimes.com/2017/09/27/science/black-holes-collision-ligo-virgo.html)



J2000 05 47 27.462 -00 14 38.73

**GW170814**  
LIGO AND VIRGO LOCALIZATION

**GW170814**  
REFINED LOCALIZATION

FoV: 171.62°

### Using the skymap

Click on the various options below to display information relating to each detection.

Detection	Sky localisation	Label	Pop-up info
GW170814 - L1/H1 only	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
GW170814 - L1/H1/V1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
GW170814 - refined skymap	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
GW150914	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
GW151226	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
GW170104	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### Backgrounds

If you want to see the extension of these sky regions through the constellations you can select an artistic background image  **Constellations**.

You can also select various background images at different wavelengths, combining the electromagnetic data with the gravitational-wave information:  **Mellinger (default)**  WISE  2MASS  DSS color  XMM  Fermi

# □ Visualisation of the sky in AladinLite

## Tutorial on usage of VO tools for EM follow-up of GWs



JUPYTER

FAQ



### Fourth ASTERICS School

International Virtual Observatory school

[Observatoire Astronomique de Strasbourg, France](#)

## Electromagnetic follow-up of gravitational-wave events

by G. Greco [giuseppe.greco@uniurb.it](mailto:giuseppe.greco@uniurb.it), E. Chassande-Mottin [ecm@apc.univ-paris7.fr](mailto:ecm@apc.univ-paris7.fr) and M. Branchesi [marica.branchesi@gmail.com](mailto:marica.branchesi@gmail.com) and many others

The tutorial focuses on some basic strategies for working with gravitational-wave sky localization maps in the context of electromagnetic follow-up activities. Here we propose the usage of [Aladin](#), [TOPCAT](#) and [GWsky](#). The following main topics are addressed.

1. Gravitational-Wave sky localization map: visualization and tiling
2. Access to existing catalogs using the Multi-Order Coverage map (MOC)
3. Planning for EM follow-up observations

# Visualisation of the sky in AladinLite



## User Guide

Primer on public alerts for astronomers from the LIGO and Virgo gravitational-wave observatories.

## Navigation

[Getting Started Checklist](#)

[Observing Capabilities](#)

[Data Analysis](#)

[Alert Contents](#)

[Sample Code](#)

- [Prerequisites](#)
- [Receiving GCNs](#)
- [Working with Sky Maps](#)
- [Multi-Order Sky Maps \(For Advanced Users\)](#)

[← Additional Tools](#) | [Change Log](#) →

## Sky Map Visualizations and Credible Regions in Aladin

In this section, we demonstrate working with gravitational-wave sky localizations in [Aladin Desktop](#). The following main topics are addressed.

- [MOC and GW Sky Localizations](#)
- [Running Aladin Desktop](#)
- [Loading a GW Sky Localization](#)
- [Building a Credible Region](#)
- [Area Within a Credible Region](#)

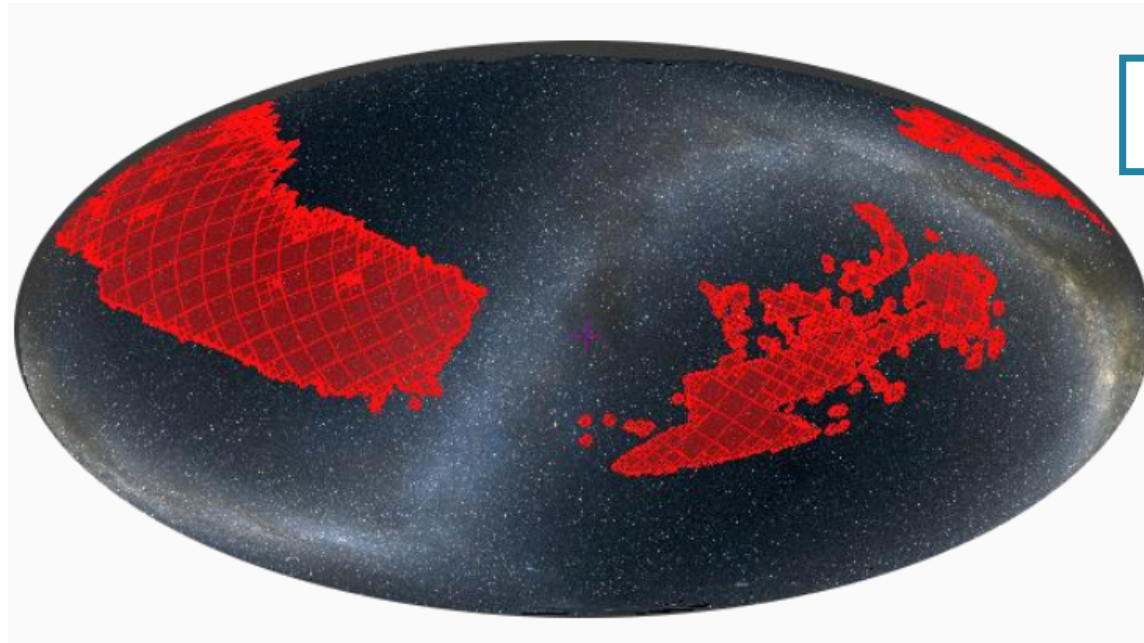
### MOC and GW Sky Localizations

The enclosed area within a given probability level contour of a GW sky map can be effectively described with a Multi-Order Coverage ([MOC](#)) map [1]. MOC is a standard of the Virtual Observatory which provides a representation of arbitrary regions on the unit sphere using the [HEALPix](#) sky tessellation.



# □ Visualisation of sky coverages

- Coverage maps based on MOC IVOA standard are created from positions
  - ➔ We know where but we don't know when!
  - ➔ Need to add the time dimension



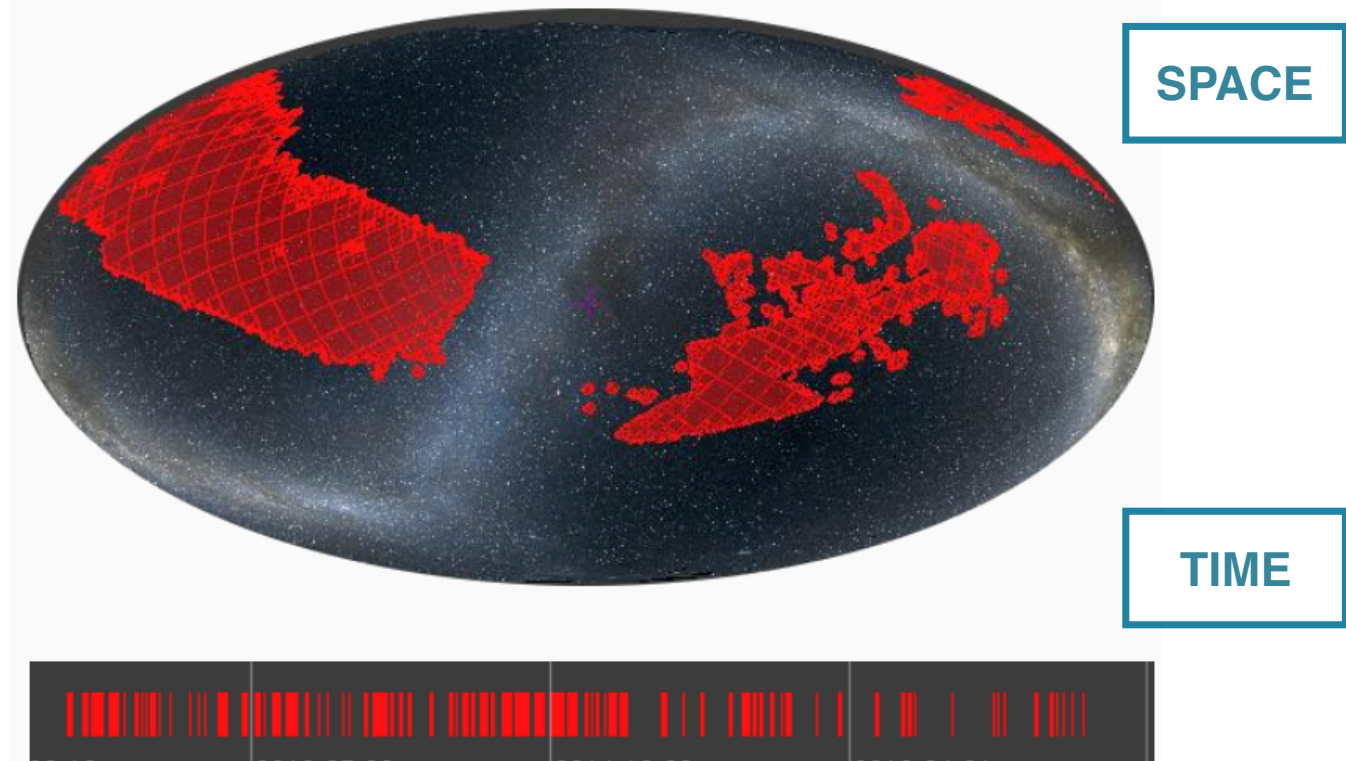
SPACE COVERAGE



# □ ST-MOC: Connecting space and time coverages

- The STMOC = Space Time MultiOrder Coverage
- Merge together both dimensions in a unique MOC in order to have simultaneously space and time coverage

2 years of CDS&Co R&D  
driven by the IVOA Time  
Domain Interest Group



➔ [https://wiki.ivoa.net/twiki/bin/view/IVOA/IvoaVOEvent#Time\\_Series\\_Data](https://wiki.ivoa.net/twiki/bin/view/IVOA/IvoaVOEvent#Time_Series_Data)



# ST-MOC: Connecting space and time coverages

The screenshot displays the Aladin v10.1 software interface, a professional sky atlas. The main window shows a 2MASS color image of a galaxy, with a mouse cursor pointing at a specific location. The interface includes a menu bar (File, Edit, View, Window, Help), a status bar (Aladin v10.1, BETA VERSION), and a toolbar with various icons for navigation and data manipulation. On the left, a list of available data sources is shown, with '2MASS color J (1.23um), H (1.66um), K (2.16um)' selected. On the right, a sidebar contains a 'Welcome to Aladin' message and a list of tools (select, pan, dist, phot, draw, tag, moc, spect, filter, cross, x-y, rgb, epoch, size, dens., crop, opac., zoom, cont, pixel, prop, del). The bottom status bar indicates '0 sel / 0 src 2 views 459Mb'.

Available data → 23238 / 23241

Command 19:57:21.69 +31:04:44.0 Frame ICRS Projection Aitoff

2MASS color

ay → 37  
→ 27  
ical → 90  
ared → 124  
VISTA → 12  
UltraVista → 6  
2MASS → 8  
2MASS6X → 4  
2MASS J (1.23um)  
2MASS H (1.66um)  
2MASS color J (1.23um), H (1.66um), K (2.16um)  
2MASS K (2.16um)  
DIRBE → 30  
UKIRT-WFCAM → 1  
WISE → 13  
Spitzer → 9  
HST → 6  
ISO → 2  
IRIS → 9  
AKARI-FIS → 9  
HERSCHEL → 16  
APEX → 2  
JPS-PR1 850um  
lio → 71  
r-lines → 45  
ase → 5  
j → 21721  
→ 16  
ystem → 103  
y → 67  
ch → 44  
→ 863  
matic → 2

select  
from -- all collections --

coll. sort view scan filter

grid study wink north hdr multiview match

360° x 180°

0 sel / 0 src 2 views 459Mb

ALADIN

Welcome to Aladin,  
your professional sky atlas.

- Discover all astronomical data available over the net!
- Compare them with your own data.
- Prepare your observation missions.

To start, type any object name, such as M1, and press ENTER...

Or easier, clic in the main frame and enjoy the sky...

2MASS-ST MOC  
CDS / P / 2MASS / col

epoch  
size  
dens.  
crop  
opac.  
zoom  
cont  
163418:40:49.44946  
pixel  
prop  
del

SPACE

TIME





# □ ST-MOC: Connecting space and time coverages

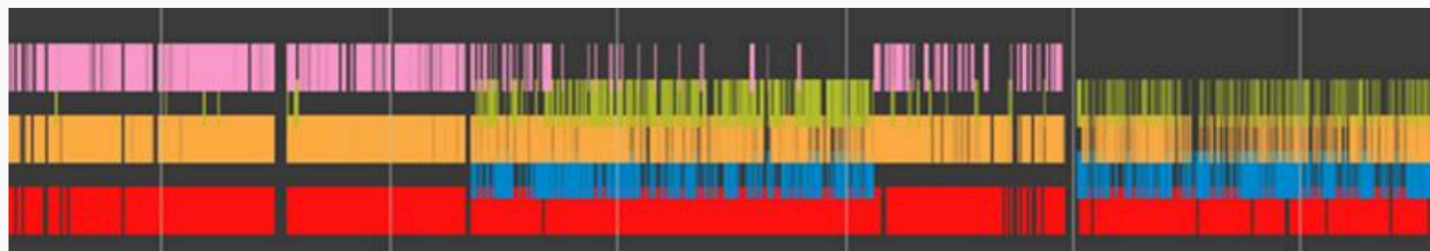
- **Possibility of extremely fast**

- ➔ computations (generate from catalog, images, regions)

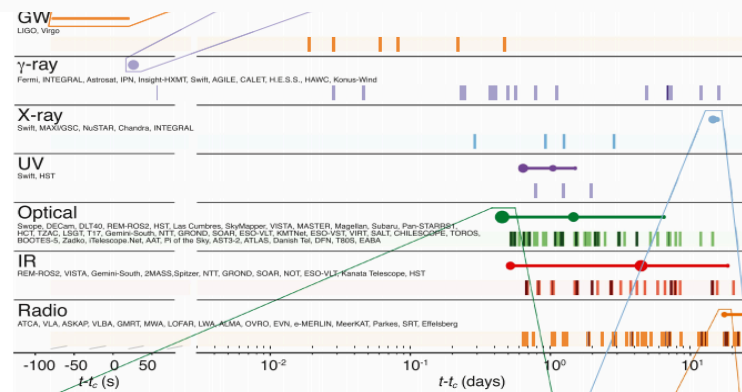
The only thing you need is a list of positions and times, spatial and temporal resolution)

- ➔ operations (unions, intersections,...)

E.g. Have these two telescopes observed the same sky region within this interval of time?



Does it remind you of anything in particular?



# □ ST-MOC: Connecting space and time coverages

- **Example use:**

- What is the 2MASS mission coverage in space & time ?
- Are there common observations in space and time for XMM and Chandra missions ?
- Which observations are available for this Gravitational Wavelength probability area detected at this epoch ?
- What are the LSST alerts in this sky region and in this interval of time?



# □ ST-MOC: Find where and when

- **IVOA Note with technical details (Durand, Fernique, Nebot et al 2018)**
- Precomputed for 150 catalogues in Vizier (and more to come!)  
<http://alasky.u-strasbg.fr/footprints/STMOC/>
- Precompute for solar system body ephemerides
- Available in MOCPy
- Jupyter Notebook showing examples

**What next? Try it!!**

➔ **Where can I find more info ? @ IVOA**

[https://wiki.ivoa.net/twiki/bin/view/IVOA/IvoaVOEvent#Time\\_Series\\_Data](https://wiki.ivoa.net/twiki/bin/view/IVOA/IvoaVOEvent#Time_Series_Data)



# □ Visualisation of data: search, find and retrieve

**KEY POINT: IVOA Standardisation of time annotation**

Time Scale: UTC, TT, TAI, TCB,...

Format: JD, MJD, ISO, truncated ISO,...

Offset: e.g. JD-XXX (e.g. Gaia...)

Reference position: Topocentre, Geocentre, Barycentre,... (light-travel correction)

**TIMESYS element in VOTables (Demleitner, M., Nebot, A., Bonnarel, et al. 2018)**



# □ Time Domain Astronomy Challenges/Needs

*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/will be observed, when, in which wavelength, ...
    - ➡ alerts, emails, webpages, references,...
    - ➡ A multi-messenger platform ?





# 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, TAP, VOTable, MOC, HiPS...)
  - ➔ or under development:
    - ▶ Definition of the minimum metadata for time (TIMESYS in VOTables)
    - ▶ Space + time coverage (STMOC)
    - ▶ Visibility & Observation locator (ObjVisSAP & ObsLocTAP)

