



crab

# Exploring the X-ray Universe with ESASky

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<sup>2</sup> ESA, <sup>3</sup> AuroraTechnology for ESA <sup>4</sup> Winter Way for ESA, <sup>5</sup> RHEA for ESA

29/02/2024

- Introduction to ESASky
- High-energy data and useful functionalities in ESASky
- Demo
- Future Plans
- Summary

**Goal:** a scientific tool to facilitate data discovery and archival science

- Multi-wavelength, -mission, -messenger portal
- Access to ~100 mission metadata & data, 56,000+ catalogues, 1100+ HiPS images.
- Driven by scientific use cases and needs from the scientific community
- Exploration and Data Discovery
- Archival science and unplanned science!



# Introduction: ESASky

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  - Archival science and unplanned science!
- 
- Interface 'on top of' all ESA astronomy archives + others



**ESASky** <https://sky.esa.int>

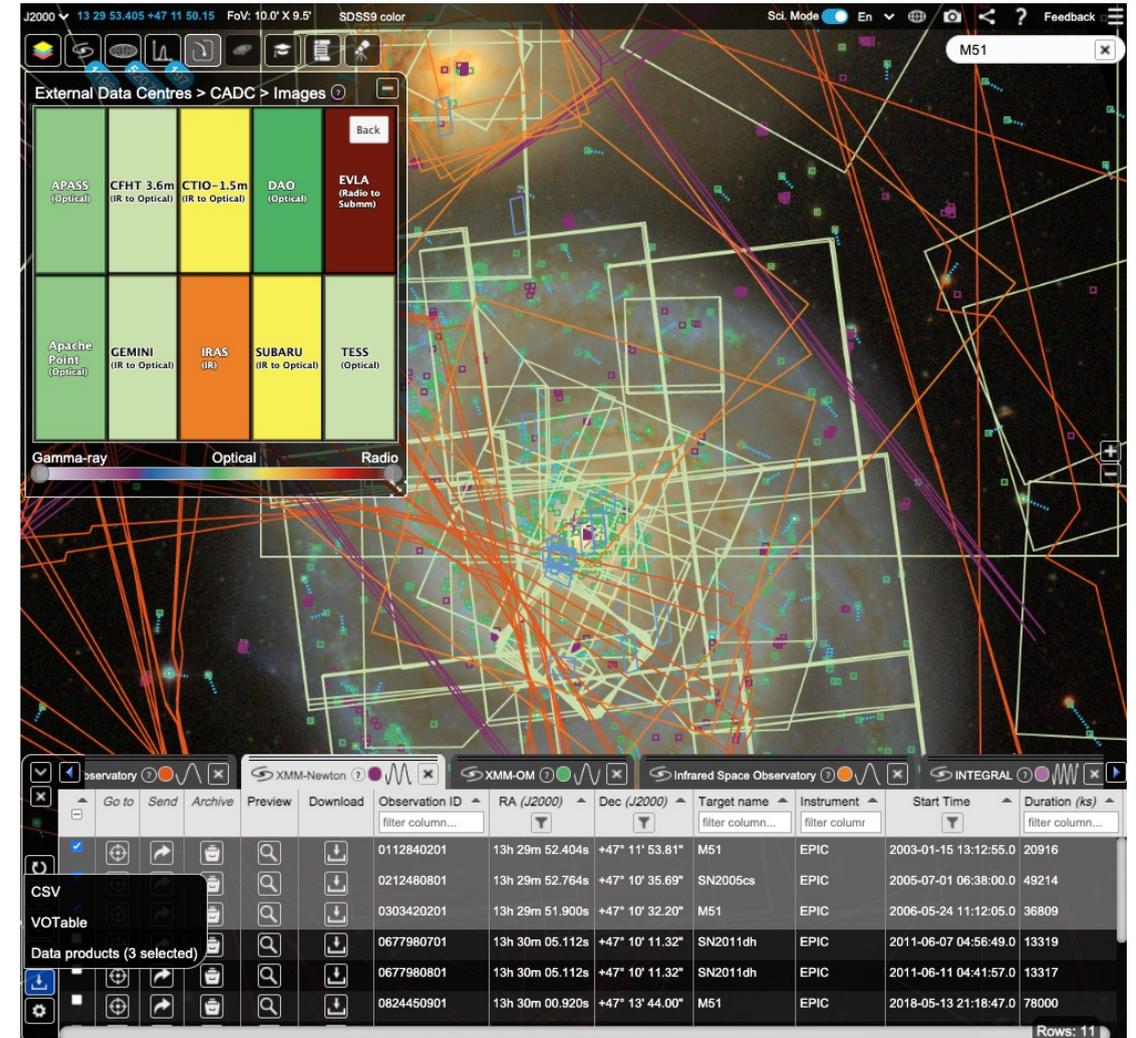


<https://youtu.be/iFFiNN1Iheg>

# How do users use ESASky for their science?

Main scientific functionalities:

- **Visual inspection** of skies (Hierarchical Progressive Surveys: HiPS), images, catalogues, footprints, probability regions, many in combination.
- **Data mining and downloading** (images, catalogues, spectra, cubes, time series, +), metadata and subsets of results tables.



The screenshot displays the ESASky web interface. At the top, it shows coordinates (J2000: 13 29 53.405 +47 11 50.15) and a field of view (FoV: 10.0' X 9.5'). The main area is a star field with various colored lines and boxes representing survey footprints. A sidebar on the left lists external data centers and their instruments, categorized by wavelength: Gamma-ray, Optical, and Radio. The table at the bottom provides a list of observations with their respective metadata.

Observation ID	RA (J2000)	Dec (J2000)	Target name	Instrument	Start Time	Duration (ks)
0112840201	13h 29m 52.404s	+47° 11' 53.81"	M51	EPIC	2003-01-15 13:12:55.0	20916
0212480801	13h 29m 52.764s	+47° 10' 35.69"	SN2005cs	EPIC	2005-07-01 06:38:00.0	49214
0303420201	13h 29m 51.900s	+47° 10' 32.20"	M51	EPIC	2006-05-24 11:12:05.0	36809
0677980701	13h 30m 05.112s	+47° 10' 11.32"	SN2011dh	EPIC	2011-06-07 04:56:49.0	13319
0677980801	13h 30m 05.112s	+47° 10' 11.32"	SN2011dh	EPIC	2011-06-11 04:41:57.0	13317
0824450901	13h 30m 00.920s	+47° 13' 44.00"	M51	EPIC	2018-05-13 21:18:47.0	78000

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- **Search for observations of solar system objects** (targeted and serendipitous; Racero+ 2022 A&A 659 38)

The screenshot displays the ESASky interface. At the top, it shows the current sky location: J2000 15 48 39.146 -17 58 01.43, FoV: 24' X 23', and AINWIS color. The main view is a sky map of Saturn with several green rectangular footprints indicating observation locations. A zoomed-in image of Saturn is shown in the bottom right, labeled 'ict901klq'. On the left, there are panels for 'SSO: Saturn (Planet)' and 'HST (UV to Near-IR)' and 'XMM-Newton (Soft X-ray)'. At the bottom, there is a table of observations.

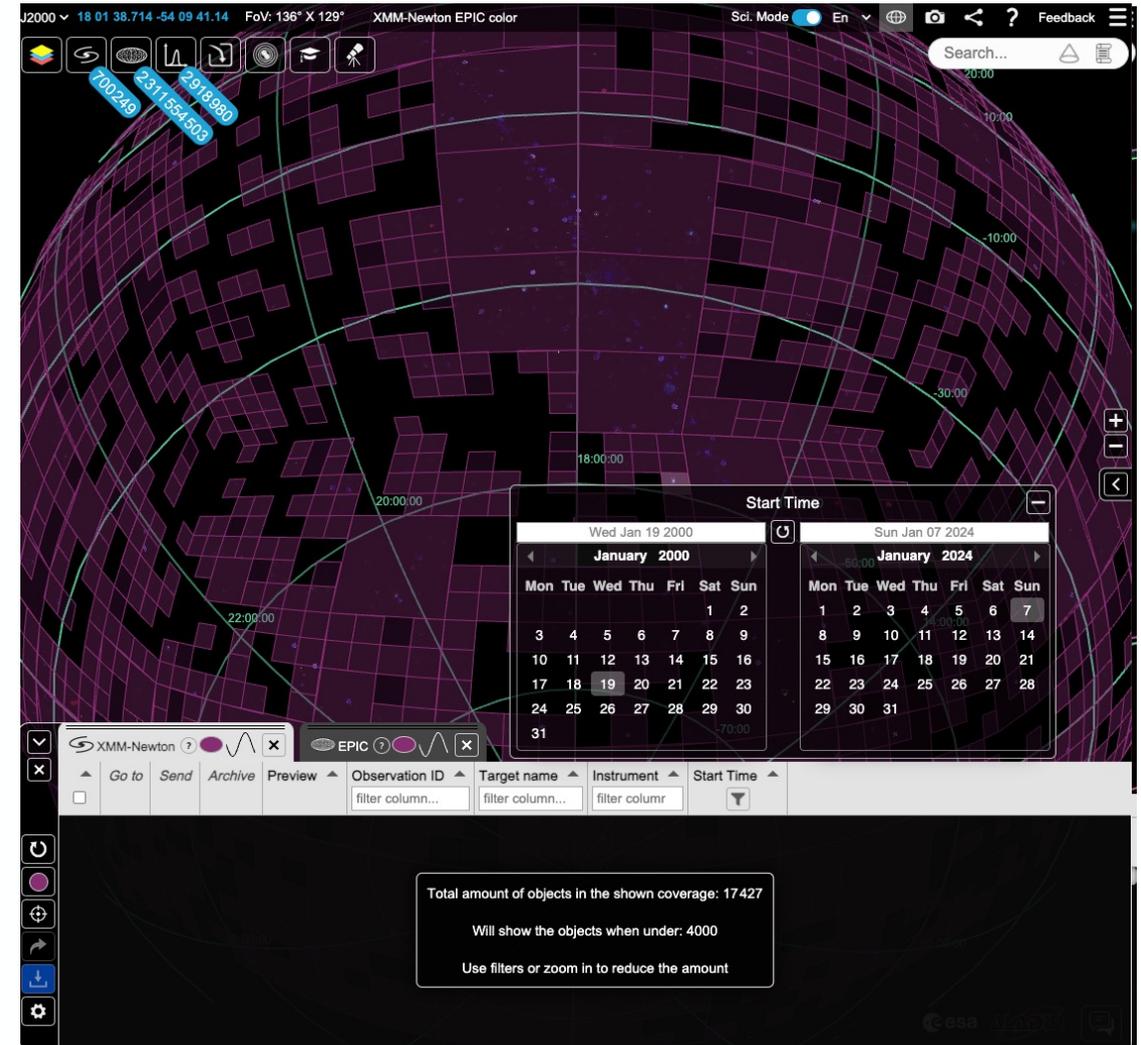
Go to	Archive	Preview	Observation ID	Target name	Instrument	Filter	Start Time	Name	RA Start (J2000)	Dec Start (J2000)
			ict901kiq	SATURN+63N-FEATURE	WFC3/UVIS	F689M	2015-06-29 22:56:01.21	Saturn	15h 48m 42.624s	-17° 51' 46.38"
			ict901kjq	SATURN+63N-FEATURE	WFC3/UVIS	F547M	2015-06-29 22:57:32.18	Saturn	15h 48m 42.609s	-17° 51' 46.37"
			ict901kkq	SATURN+63N-FEATURE	WFC3/UVIS	F410M	2015-06-29 22:58:55.19	Saturn	15h 48m 42.594s	-17° 51' 46.36"
			ict901klq	SATURN+63N-FEATURE	WFC3/UVIS	FQ727N	2015-06-29 23:01:32.21	Saturn	15h 48m 42.565s	-17° 51' 46.32"
			ict901kmq	SATURN+63N-FEATURE	WFC3/UVIS	FQ750N	2015-06-29 23:06:21.21	Saturn	15h 48m 42.507s	-17° 51' 46.21"

Rows: 1370

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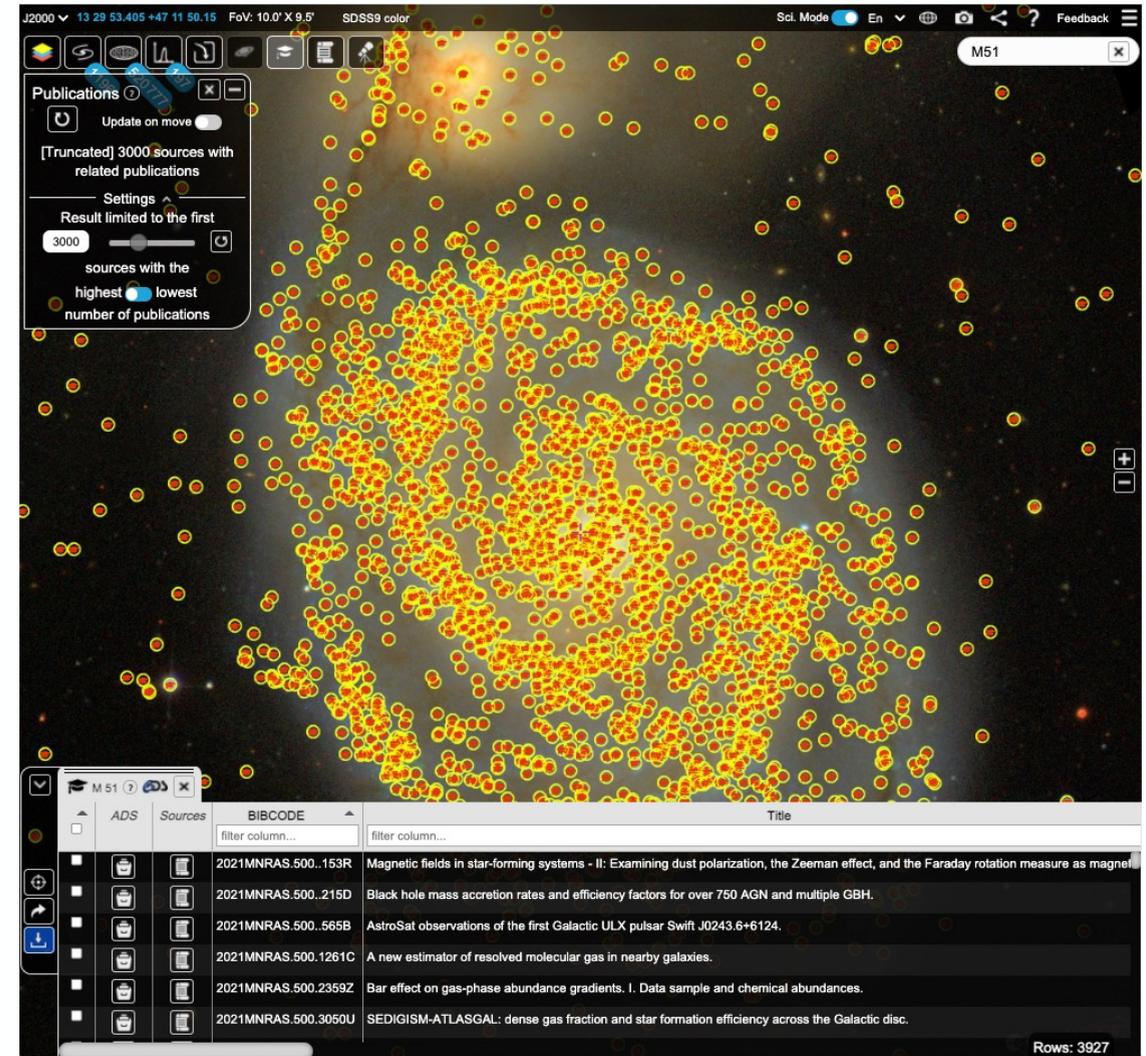
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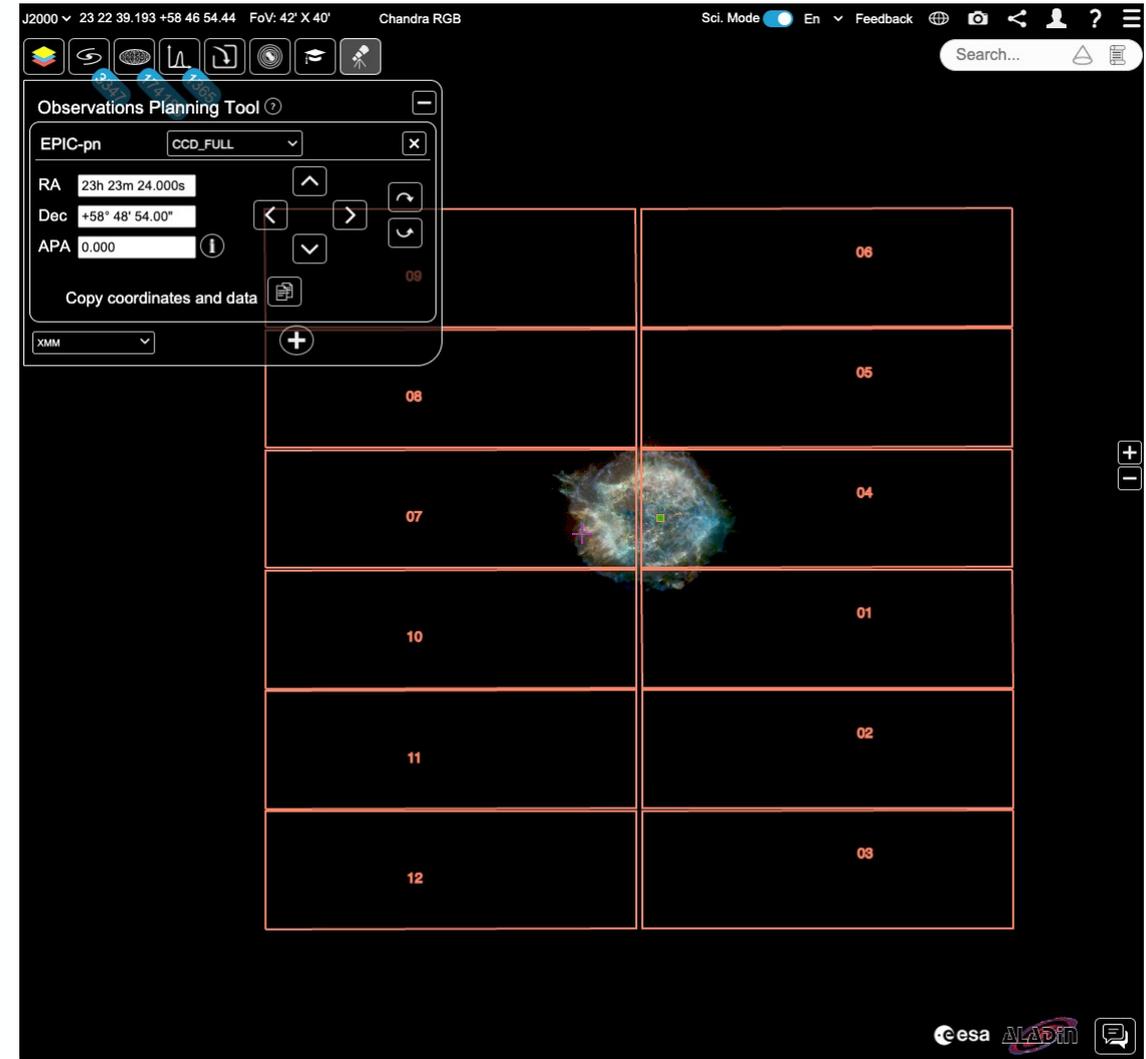
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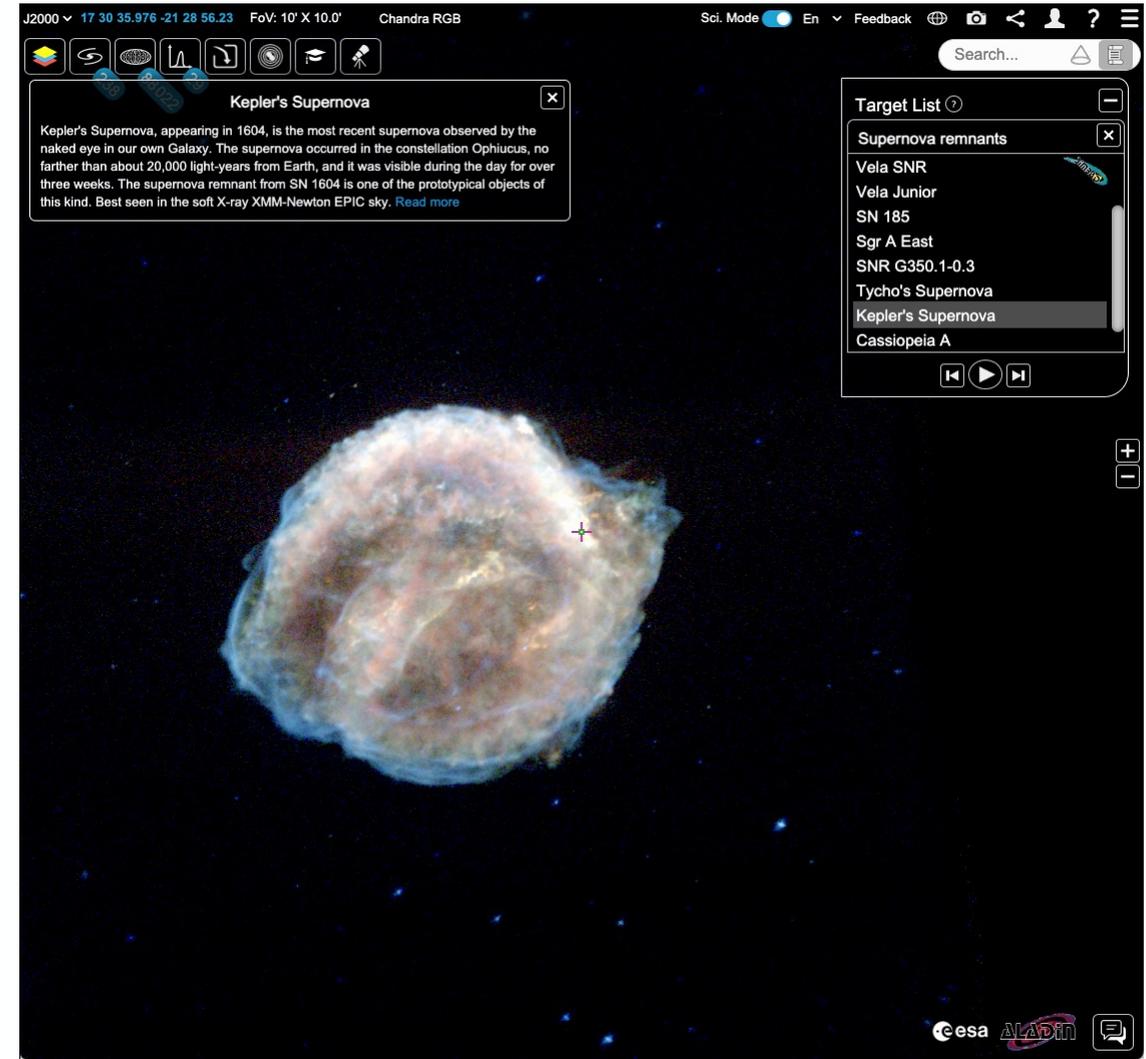
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- Upload and play through target lists.

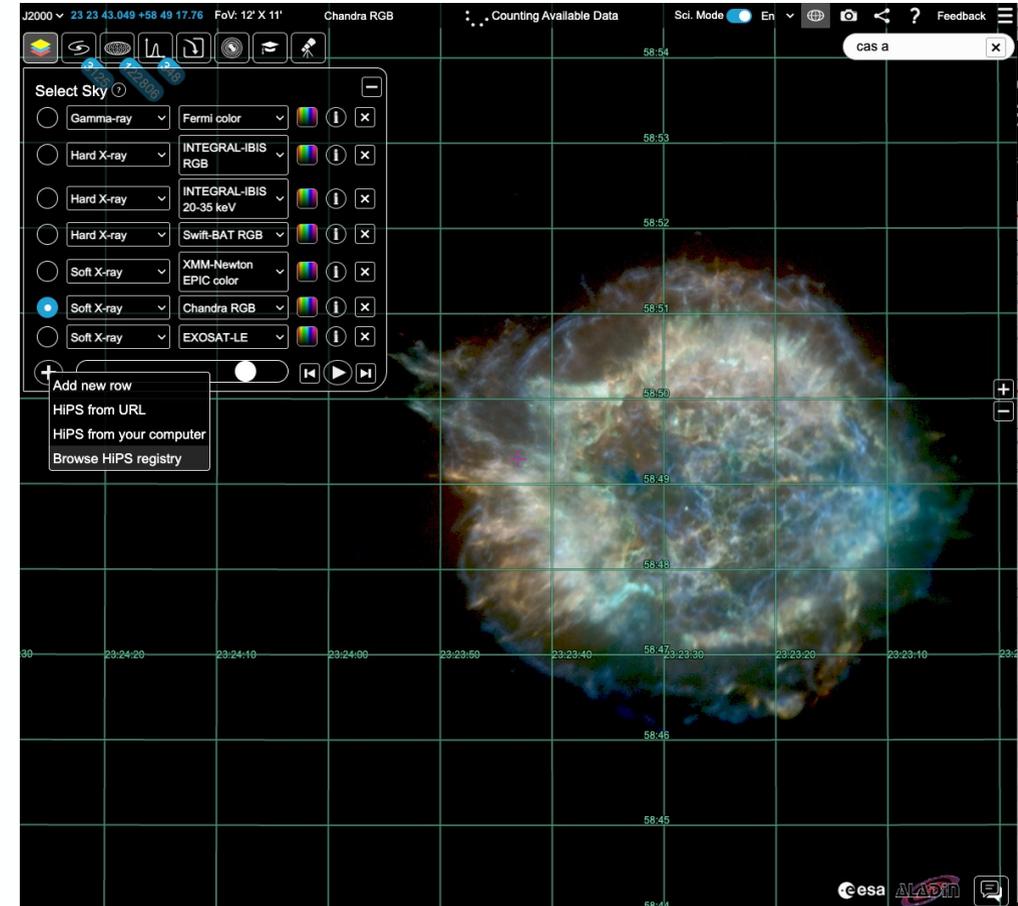


# High-energy data and functionalities

High-energy data and useful functionalities for high-energy astronomers:

## Data:

- **HiPS: Access to 12 high-energy HiPS and a further 60+ in the HiPS registry:** XMM-Newton EPIC; Chandra; SUZAKU; EXOSAT; eROSITA; INTEGRAL; Swift; Fermi plus ASCA; COMPTEL; EGRET; HGPS; Hitomi; MAXI; ROSAT.

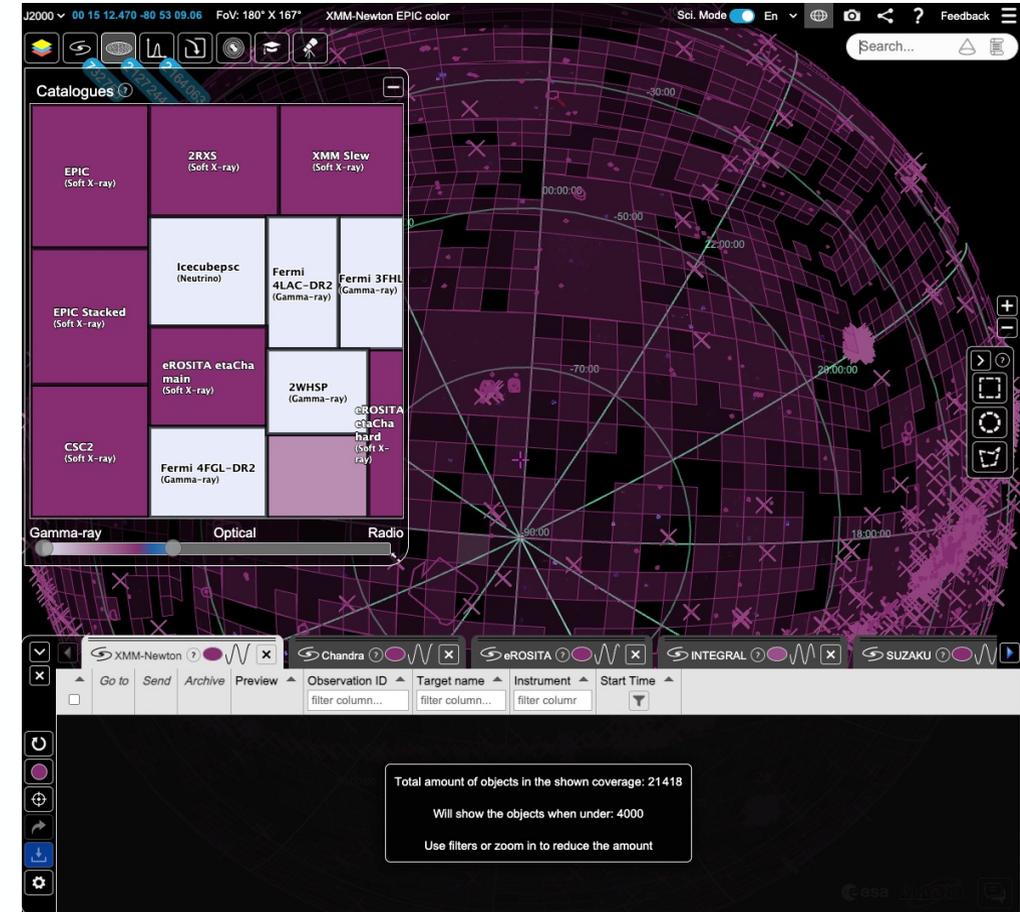


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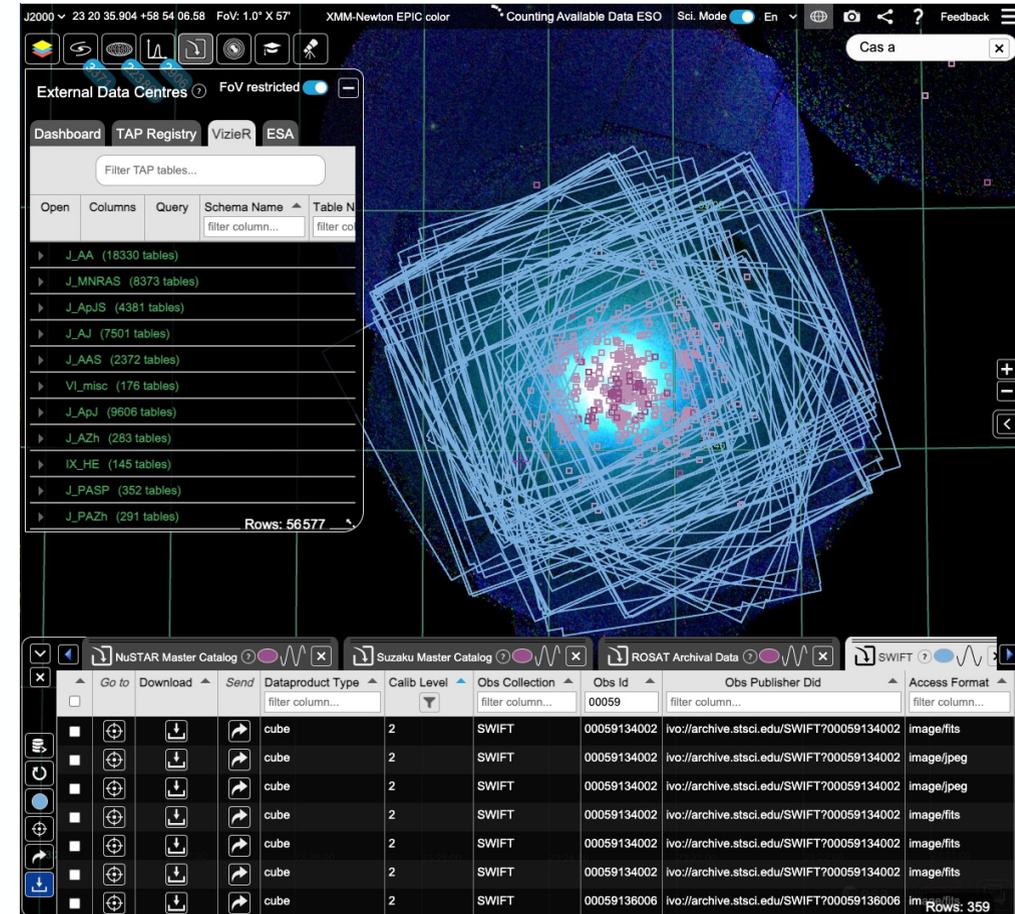


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- **High-energy catalogues:** XMM-Newton, Chandra, eROSITA, INTEGRAL, Fermi, ROSAT, IceCube and Blazars.
- **Access to high-energy data in the External Data Centres feature (TAPs):**
  - **HEASARC**, XMM-Newton, Chandra TAPs
  - ESASky legacy TAP (with EXOSAT, COS-B tables)
  - **Access to all VizieR catalogues.**



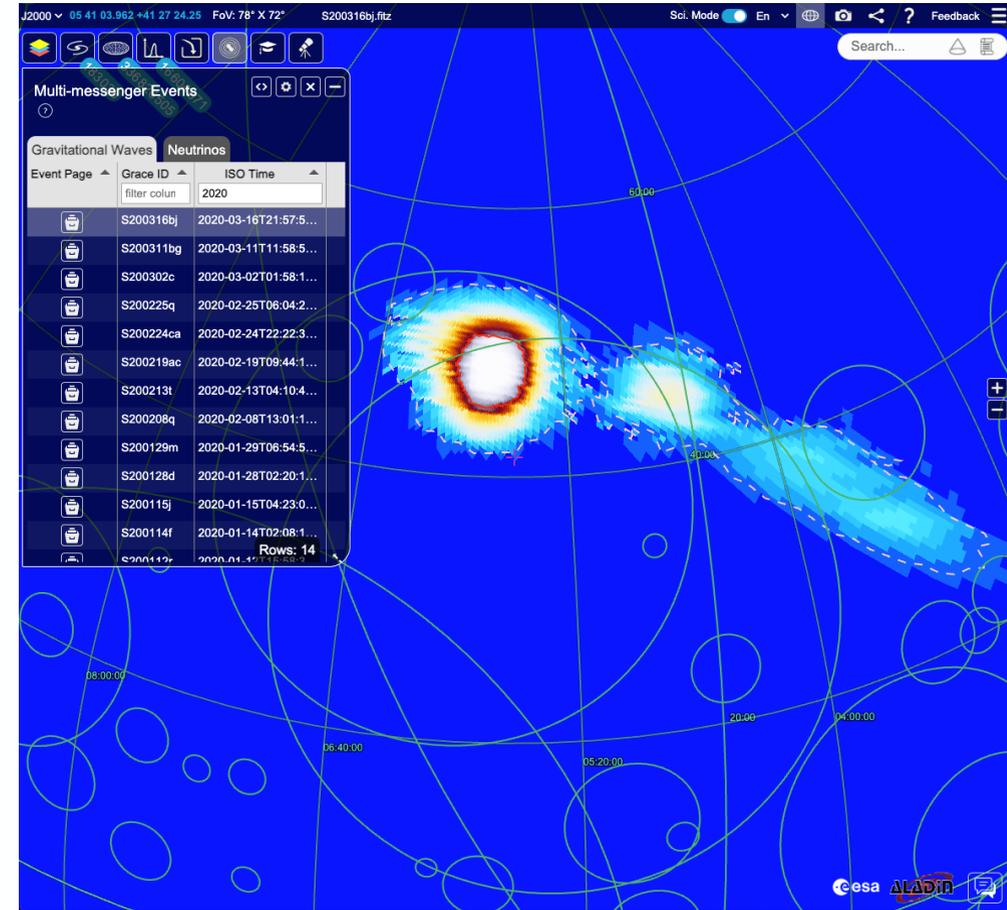
The screenshot displays the External Data Centres (TAPs) interface. The top panel shows a list of tables with columns for Open, Columns, Query, Schema Name, and Table Name. The list includes tables such as J\_AA (18330 tables), J\_MNRAS (8373 tables), J\_ApJS (4381 tables), J\_AJ (7501 tables), J\_AAS (2372 tables), VI\_misc (176 tables), J\_ApJ (9606 tables), J\_AZh (283 tables), IX\_HE (145 tables), J\_PASP (352 tables), and J\_PAZh (291 tables). The total number of rows is 56577. The bottom panel shows a table of observations with columns for Go to, Download, Send, Dataproduct Type, Calib Level, Obs Collection, Obs Id, Obs Publisher Did, and Access Format. The table lists several observations from the SWIFT mission, including observation IDs like 00059134002 and 00059136006, and their corresponding access formats like image/fits and image/jpeg. The background features a visualization of XMM-Newton EPIC data, showing a complex pattern of overlapping observation footprints in blue and cyan, with a bright central region.

# High-energy data and functionalities

High-energy data and useful functionalities for high-energy astronomers:

## Multi-messenger Data:

- Access to Gravitational Wave events and probability maps: LIGO-Virgo-KAGRA collaboration
- Access to IceCube Neutrino events



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## Multi-messenger Data:

- Access to Gravitational Wave events and probability maps: LIGO-Virgo-KAGRA collaboration
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## Functionalities:

- Wavelength slider in treemaps (observations, catalogues and External Data Centres).
- XMM-Newton EPIC-pn footprint in planning tool.
- Publications feature.

The screenshot displays the XMM-Newton EPIC color interface. At the top, it shows the date J2000, coordinates 15 03 48.168 -42 03 04.92, and field of view (FoV) 1.0° X 56°. The main window features an 'Observations Planning Tool' with fields for RA (15h 02m 55.502s), Dec (-41° 55' 31.92"), and APA (18.000). Below these fields is a 'Copy coordinates and data' button. The background shows a color-coded astronomical image with a red grid overlay and yellow circles. At the bottom, a table lists publications related to the current observation.

NAME Lupus SN	BIBCODE	Title
2023MNRAS.518.2574B		New ASKAP radio supernova remnants and candidates in the Large Magellanic Cloud.
2023ApJS...265...52W		The Long-term Monitoring Results of Insight-HXMT in the First 4 yr Galactic Plane Scanning Survey.
2023ApJ...946...44G		Rapid Expansion of the Young Type Ia Supernova Remnant 0519-69.0: More Evidence for a Circumstellar Shell.
2023ApJ...947...90R		A Possible Surviving Companion of the SN Ia in the Galactic SNR G272.2-3.2.
2023A&A...672A..57P		The X-ray synchrotron rims in Cassiopeia A narrow with energy.
2023A&A...672A.194R		Study of the effect of turbulent interstellar medium on the morphology of young supernova remnants.
2023A&A...672A.195D		Radio and infrared study of the supernova remnant candidate HESS J1912+101.

Rows: 1323

<https://youtu.be/ny2Zu2RUIpk>

# Other ways to access data in ESASky



pyESASky  
Jupyter widget

Astroquery module:  
astroquery.esasky

Table Access Protocol  
(TAP) access

The notebook shows examples of what a scientist may typically want to do within a Jupyter notebook using pyESASky, e.g.:

- Download and inspect data from ESASky (images, spectra, catalogues, ...)
- Cross-match catalogues available through ESASky
- Upload your own data to ESASky, e.g.:
  - Cross-matched tables
  - Wider catalogues (astroquery tables)
  - User provided tables
  - Footprints
  - WUP
- Interact with ESASky Functionalities:

```
[41]: # Import the required python modules:
from pyesasky import ESASkyWidget
from pyesasky import Catalogue
from pyesasky import CatalogueDescriptor
from pyesasky import GridFrame
from pyesasky import Informat
from pyesasky import FootprintSet
from pyesasky import FootprintDescriptor
from pyesasky import MetadataDescriptor
from pyesasky import MetadataType
import pandas as pd

[42]: # Instantiate the pyESASky instance
esasky = ESASkyWidget()

All of the functions are now documented. Use the IPython ? magic to read about the function. Use tab to complete function names etc:

[43]: # Load the pyESASky instance
esasky
```

### ESASky Queries (astroquery.esasky)

#### Getting started

This is a python interface for querying the ESASky web service. This supports querying an object as well as querying a region around the target. For region queries, the region dimensions may be specified as a radius. The queries may be further constrained by specifying a choice of catalogs, missions, or spectra. Documentation on the ESASky web service can be found here.

#### Get the available catalog names

If you know the names of all the available catalogs you can use `list_catalogs()`:

```
>>> from astroquery.esasky import ESASky
>>> catalog_list = ESASky.list_catalogs()
>>> print(catalog_list)
['LAMOST', 'ALLIANCE', 'AKARI-IRC-SC', 'TwoMass', 'INTEGRAL',
'CHANDRA-SC2', 'XMM-EPIC-STACK', 'XMM-EPIC', 'XMM-OM', 'XMM-SLEW',
'Tycho-2', 'Gaia-EDR3', 'Hipparcos-2', 'HSC', 'Herschel-HPPSC-070',
'Herschel-HPPSC-100', 'Herschel-HPPSC-160', 'Herschel-HPPSC-250',
'Herschel-HPPSC-350', 'Herschel-HPPSC-500', 'Planck-PRISM',
'Planck-PRISM-DR1', 'Planck-PRISM-DR2', 'Planck-PRISM-DR3',
'Planck-PRISM-DR4']
```

#### Get the available maps mission names

If you know the names of all the available maps missions you can use `list_maps()`:

```
>>> maps_list = ESASky.list_maps()
>>> print(maps_list)
['INTEGRAL', 'XMM', 'Chandra', 'Suzaku', 'XMM-OM-OPTICAL',
'XMM-OM-UV', 'BST-UV', 'BST-OPTICAL', 'BST-IR', 'ISO-IR',
'Herschel', 'AKARI', 'Spitzer', 'ALMA']
```

#### Get the available maps mission names

If you know the names of all the available spectra you can use `list_spectra()`:

```
>>> spectra_list = ESASky.list_spectra()
>>> print(spectra_list)
['XMM-SWIFOT', 'Chandra', 'IRIS', 'BST-UV',
'BST-OPTICAL', 'BST-IR', 'ISO-IR', 'Herschel', 'LAMOST']
```

#### Query an object

There are three query objects methods in this module `query_object_catalogs()`, `query_object_maps()`, and `query_object_spectra()`, which all work in almost the same way.

For catalogs, the query returns a maximum of 10000 sources per mission by default. However, this can be modified by the `row_limit` parameter. You can set the parameter to -1, which will result in the maximum number of sources (currently 100 000). To account for observation errors, this method will search for any sources within 5 arcsec from the object.

For instance to query an object around M51 in the Hubble catalog:

```
>>> from astroquery.esasky import ESASky
>>> result = ESASky.query_object_catalogs('M51', 'HSC')

Note that the catalog may also be specified as a list. So the above query may also be written as:
```

```
>>> result = ESASky.query_object_catalogs(['M51'], ['HSC', 'XMM-OM'])
```

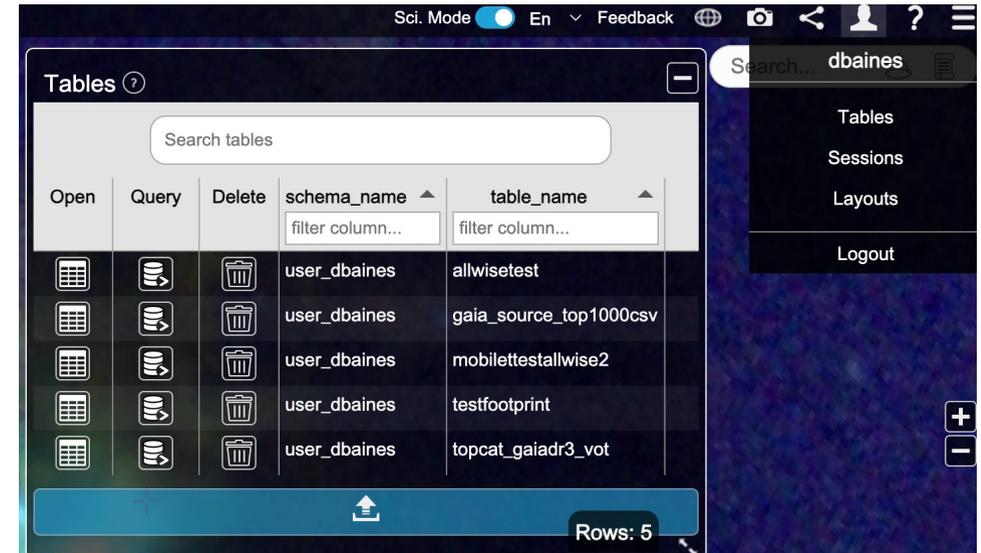
The screenshot shows the TAP interface with a table list on the left and a 'Current Table Properties' window on the right. The table is 'TAP\_4\_tycho2.tdsc\_catalogue' with 38 rows and 3 columns. Below it, a 'Table Access Protocol (TAP) Query' window shows a metadata table with columns for Name, Descrip, Or, Type, Unit, Indexed, and Schema. The metadata table lists various astronomical parameters and their units.

- <http://sky.esa.int/esasky-tap/tap>
- <http://esaskylegacy.esac.esa.int/esasky-legacy-sl-tap/tap>

Additional scientific use cases that you can't perform in the main interface.

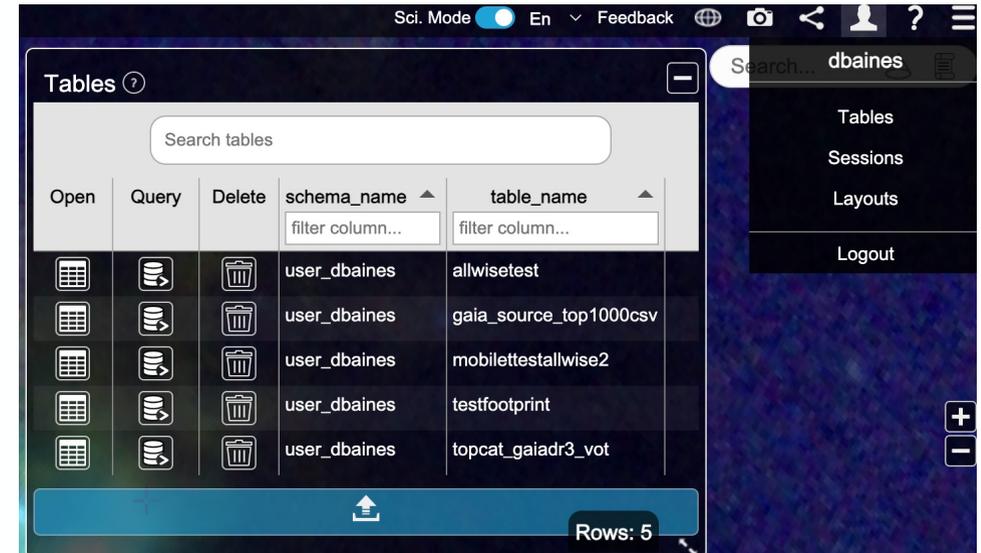
# ESASky (near)-future plans

- **User area** (released last week!): Upload your own tables, save your session, customise the ESASky layout, quotas per user currently 1 GB (more can be requested).
  - Future updates: upload your own images, sharing.



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- **User area** (released last week!): Upload your own tables, save your session, customise the ESASky layout, quotas per user currently 1 GB (more can be requested).
  - Future updates: upload your own images, sharing.
- Access to **eROSITA DR1** data
- Extending the multi-messenger feature to include more types of events (e.g. **GRBs** etc.) reported in NASA GCN.
- Access to **Euclid Early Release Observations**.
- Updating to **AladinLite v3** -> fits image visualisation.
- **Time-series data visualization** functionality.
- And more! (catalogue updates, access to EPIC light curves, HILIGT, ...).



# Collaboration is key!



External Data Centres

Dashboard TAP Registry Vizier ESA

CADC ESO MAST HEASARC ASTRON

Gamma-ray Optical Radio

Observation ID	RA (J2000)	Dec (J2000)	Target name	Instrument
w1dg5v01p	15h 03m 12.398s	-41° 59' 07.06"	HI-LAT	WFPC/WFC
w1dg5v02t	15h 03m 12.398s	-41° 59' 07.06"	HI-LAT	WFPC/WFC
w1dg5v03t	15h 03m 12.398s	-41° 59' 07.06"	HI-LAT	WFPC/WFC



# Collaboration is key!



International Virtual Observatory Alliance



Standards: HiPS

TAP

MOC

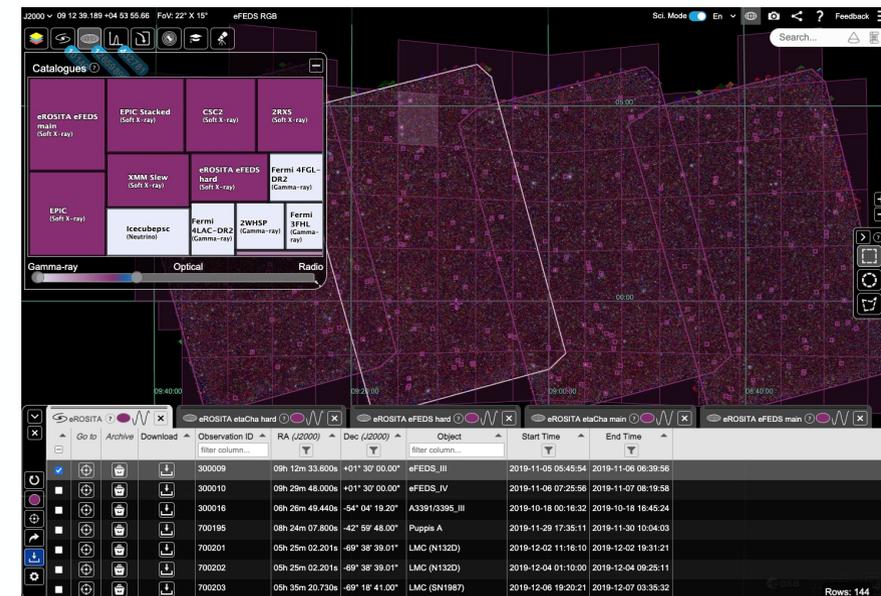
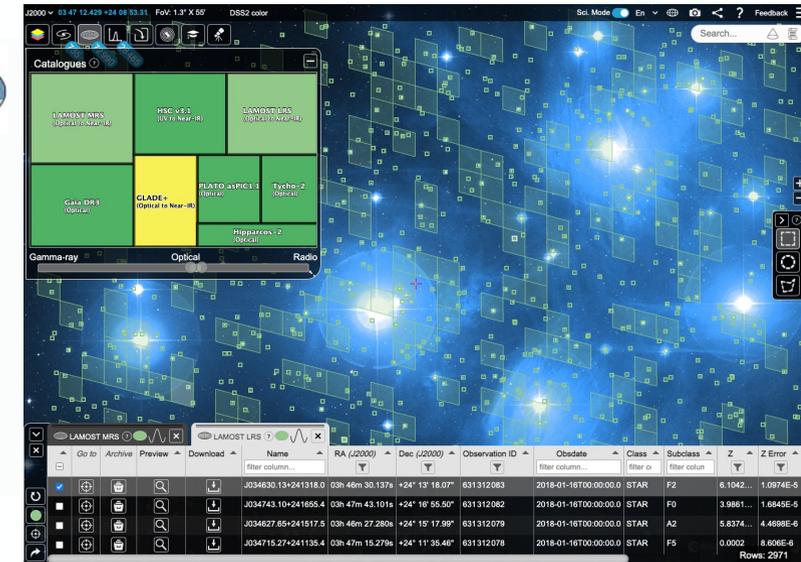
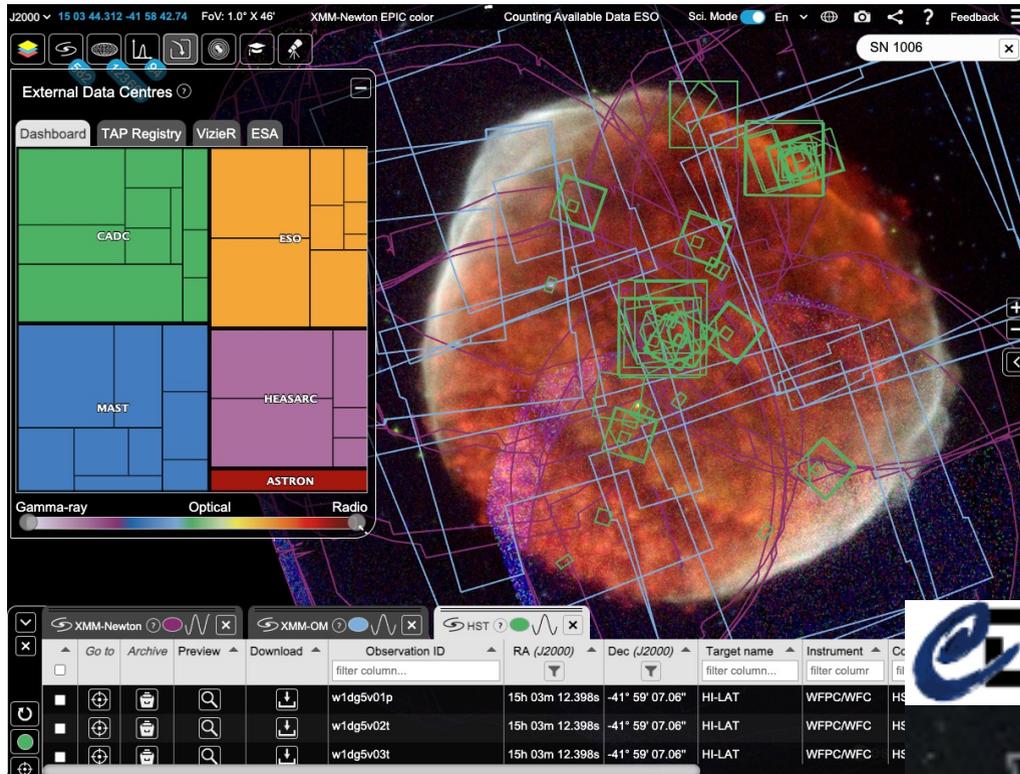
Datalink



ADQL

ObsCore

SAMP



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International Virtual Observatory Alliance



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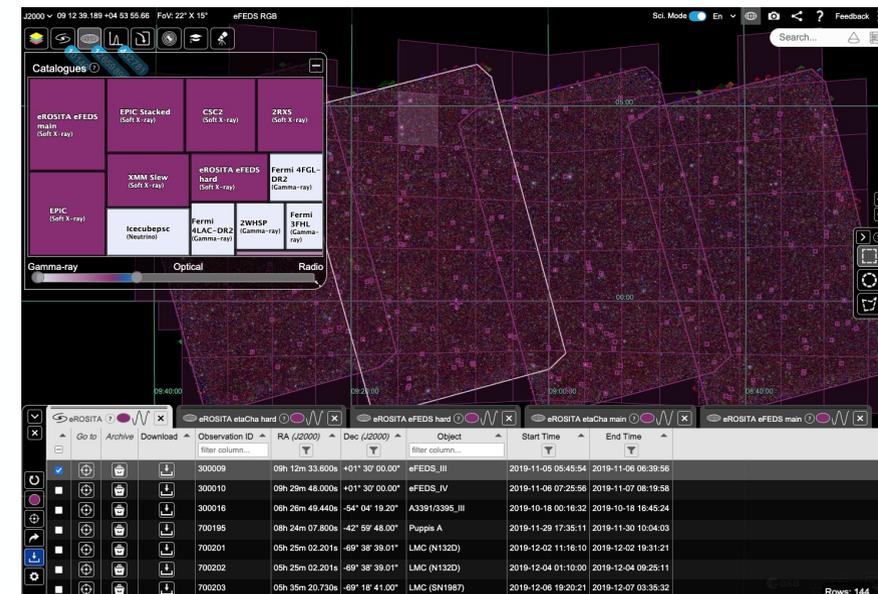
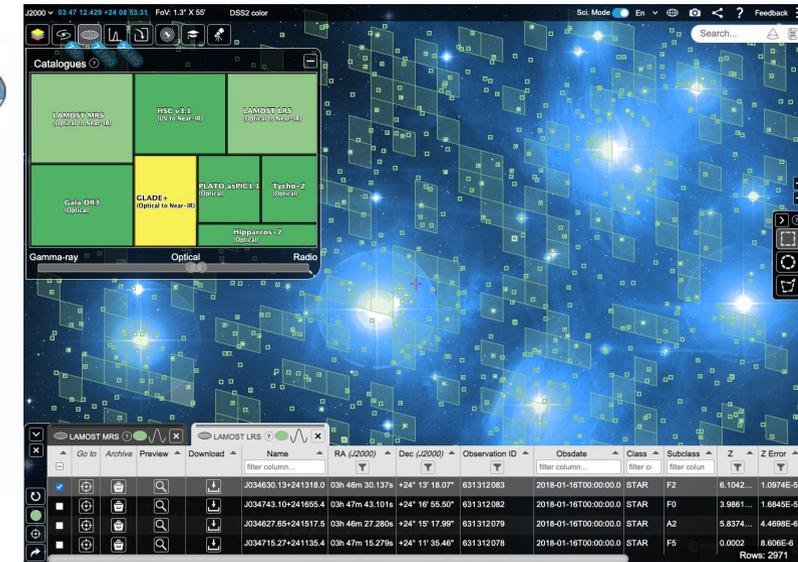
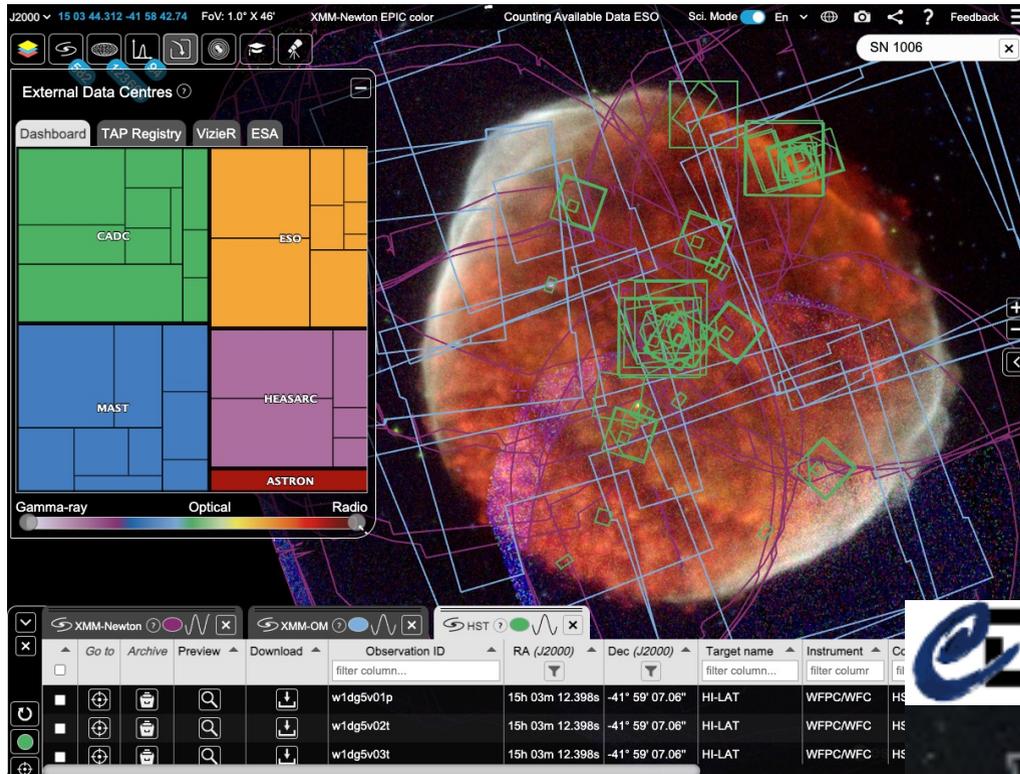
Datalink



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SAMP



Dedicated Python astroquery module to ESASky and pyESASky Jupyter widget

# Credits: a long and growing list of contributors!



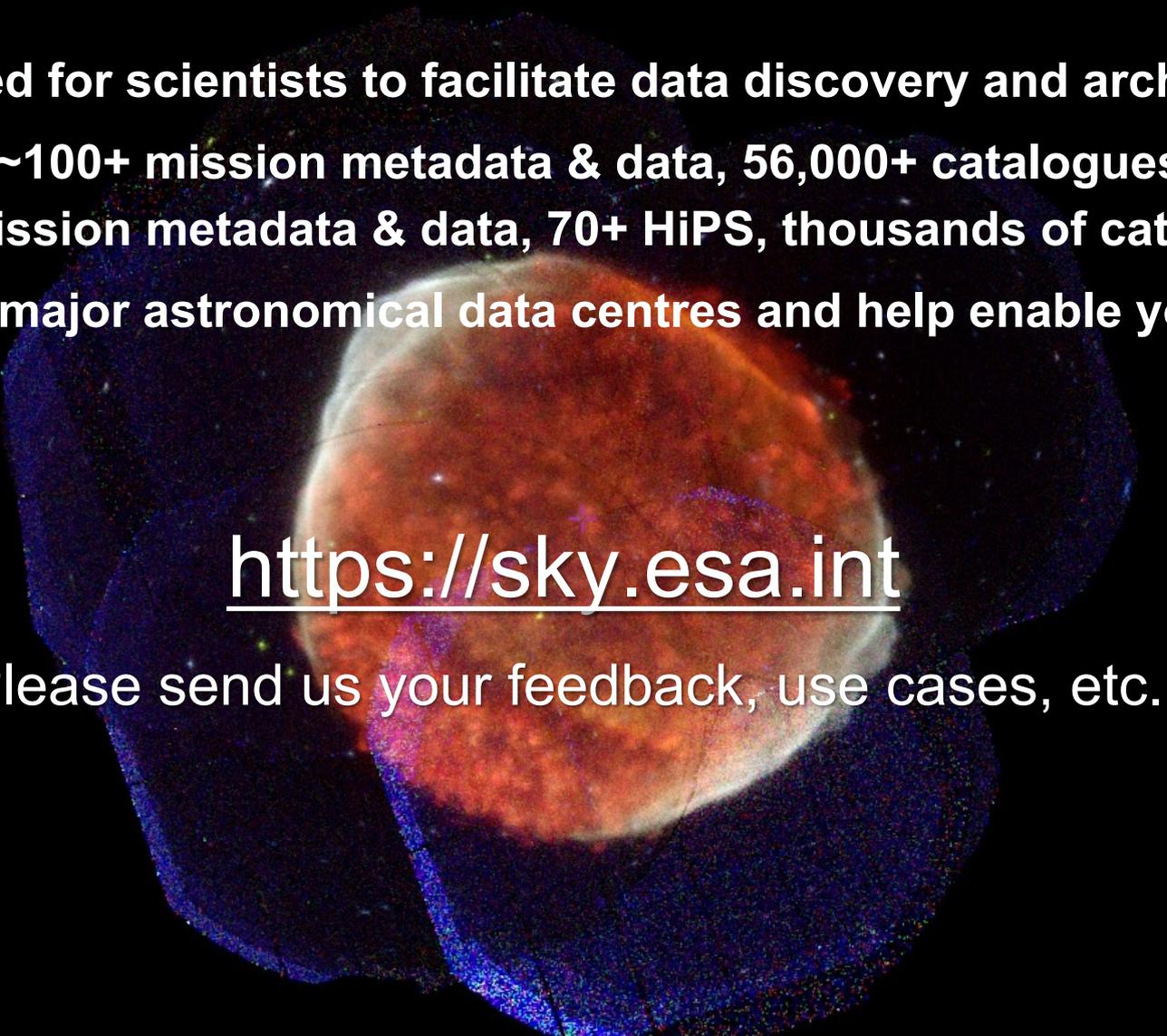
- **Former ESASky team members:** Belén López Martí, Andy Pollock, Michael Rosa, Fabrizio Giordano, Elena Racero, Mattias Wångblad +more
- **CDS:** Pierre Fernique, Thomas Boch, Mark Allen, Anaïs Oberto, Matthieu Baumann, Caroline Bot.
- **XMM-Newton Science Operations Centre:** Pedro Rodríguez, Elena Jiménez-Bailón, Maria Santos-Lleo, Matthias Ehle and Norbert Schartel
- **INTEGRAL Science Operations Centre:** Guillaume Belanger, Erik Kuulkers, Peter Kretschmar, Jari Kajava.
- **Planck Science Office:** Marcos López-Caniego, Xavier Dupac and Jan Tauber.
- **Gaia Science Operations Centre:** Jos De Bruijne, Jorgo Bakker, Hector Canovas and Timo Prusti.
- **Herschel Science Centre:** Pedro García Lario, Eva Verdugo, Ivan Valtchanov, Miguel Sánchez-Portal, Pilar Esquej and Göran Pilbratt
- **ESAC Science and Operations IT Unit:** Alejandro Lorca, Roberto Prieto, Ruben Álvarez +team.
- **Centre for Astrobiology (CAB), ESAC:** Enrique Solano, Carlos Rodrigo. • **Euclid Science Centre:** Bruno Altieri, John Hoar and René Laureijs.
- **ASTRON:** Yan Grange, Mattia Mancini, Nico Vermaas • **HST:** Antonella Nota, Chris Evans, Paule Sonnentrucker and Jonas Haase (HST/ESO).
- **JWST:** Anthony Marston, Marco Sirianni, Sarah Kendrew, Tim Rawle and Macarena García-Marín.
- **Hubble/Webb outreach team:** Bethany Downer, Mahdi Zamani, Javier Enciso • **MAST/STScI:** Tom Donaldson • **HEASARC:** Tess Jaffe
- **Canadian Astronomy Data Centre (CADC):** Daniel Durand, Brian Major, JJ Kavelaars, Patrick Dowler, Séverin Gaudet
- **ESO:** Alberto Micol, Felix Stoehr • **Johns Hopkins University:** Tamás Budavári • **CHEOPS:** Kate Isaak
- **ISAS, JAXA:** Ken Ebisawa • **Jet Propulsion Laboratory, Caltech:** Krzysztof Górski • **LIGO Scientific Collaboration:** Chris North
- **Chandra, NASA:** Pepi Fabbiano, Janet Evans, Raffaele D'Abrusco, Yulie Zografou and Arnold Rots • **OCA, Nice:** Benoit Carry.
- **IMCCE, Paris:** Jérôme Berthier and Jonathan Normand (Solar system ephemeris and name resolver). • **Smithsonian/NASA ADS:** Alberto Accomazzi, Michael J. Kurtz, Sergi Blanco-Cuaresma • **China-VO/CAS:** Chenzhou Cui, Shanshan Li, Dongwei Fan, Hanxi Yang
- **eROSITA:** Andrea Merloni, Jonas Haase, Mara Salvato, Jeremy Sanders, Susanne Friedrich • **Spitzer, IRSA:** Steve Groom, Vandana Desai, Harry Teplitz. • **IceCube Neutrino Observatory:** Marcos Santander, Claudio Kopper, Michael Larson, Juan Antonio Aguilar

- 
- ESASky is developed for scientists to facilitate data discovery and archival science.
  - Provides access to ~100+ mission metadata & data, 56,000+ catalogues, 1100+ HiPS.  
High-energy: 30+ mission metadata & data, 70+ HiPS, thousands of catalogues.
  - Vision: to link to all major astronomical data centres and help enable your science!



# Many thanks!

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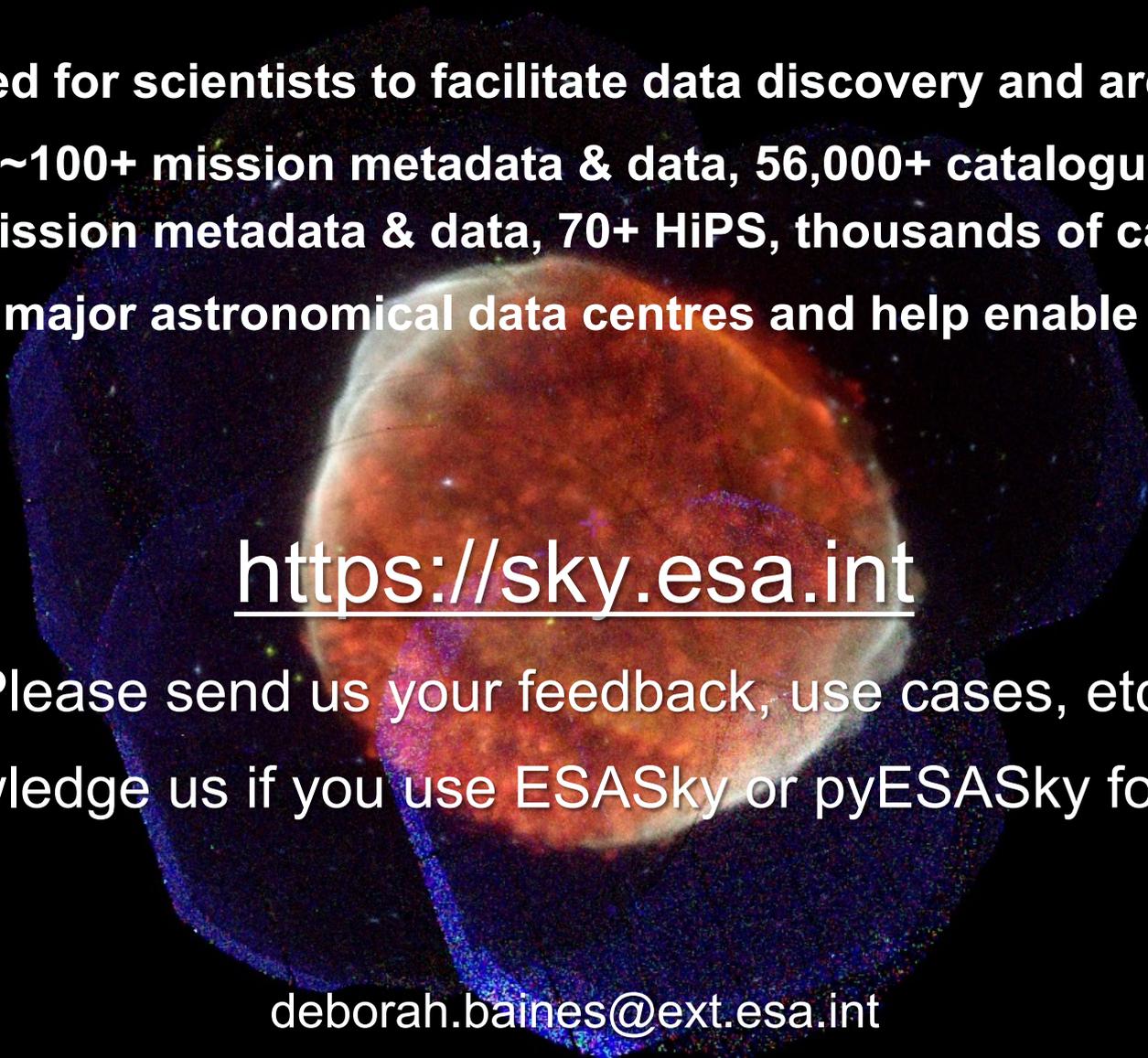
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Please acknowledge us if you use ESASky or pyESASky for your science!

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- ESASky: <https://sky.esa.int>
- How to use ESASky, videos and links to help pages: <https://www.cosmos.esa.int/web/esdc/esasky-how-to>
- pyESASky: <https://www.cosmos.esa.int/web/esdc/pyESASky>
- pyESASky notebooks: <https://github.com/esdc-esac-esa-int/pyesasky/tree/master/samples>
- astroquery.esasky: <https://www.cosmos.esa.int/web/esdc/esasky-astroquery-module>
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