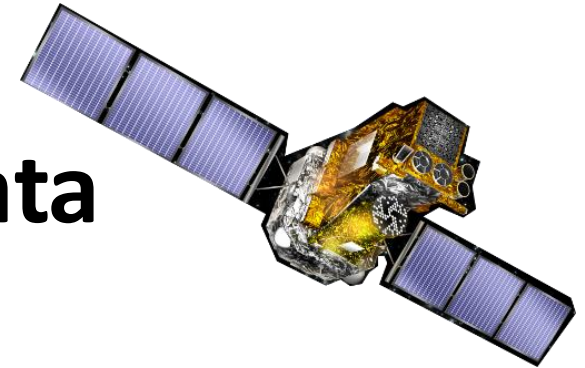


A Gallery of INTEGRAL products through the MultiMessenger Online Data Analysis



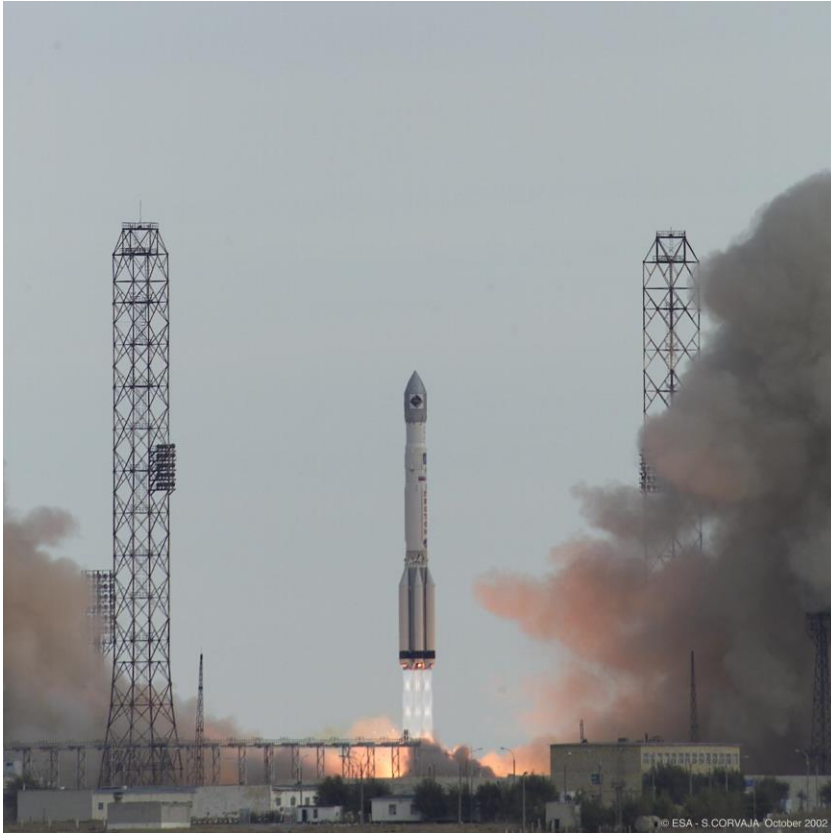
Gabriele Barni

<https://www.astro.unige.ch/mmoda/gallery>
University of Geneva





INTEGRAL Mission



- **Launched in Oct 2002**
- **Payload**
 - **IBIS/ISGRI** (X-ray/ γ -ray imaging)
 - **SPI** (X-ray/ γ -ray spectroscopy)
 - **JEM-X** (2 identical X-ray monitor)
 - **OMC** (Optical monitor)
- Nearly continuous stream of telemetry from the spacecraft to ground
- Data processed and analyzed on the fly at our facility and distributed to the community few hours after the observation - **NRT** (Near Real Time data)
- Consolidation of data few weeks after and populate our archive



Multi-Messenger Online Data Analysis

- The success of the INTEGRAL mission relies (among other assets) on the availability of easily accessible products for both **Near Real Time** and **archived** data
- Given its maturity, it is becoming more challenging to be able to perform dedicated INTEGRAL analysis
- We have developed **MMODA** for this purpose
<https://www.astro.unige.ch/mmoda>

Such platform is accessible via

- Interactive: From a browser web interface
- Code: Python API (e.g. Jupyter notebooks)

The screenshot shows the MMODA web interface. At the top, there are logos for MMODA, UNIVERSITÉ DE GENÈVE, ISDC, EPFL, and KAU, along with a Ukrainian flag. Navigation links include 'Sign in with GitHub', 'Sign in', and 'Sign up'. A 'Contact us' and 'Help' button is also present. The main search area includes fields for 'Object name *' (1E 1740.7-2942), 'RA *' (265.97845833), 'Dec *' (-29.74516667), 'Start time *' (2017-03-06T13:26:48.0), and 'End time *' (2017-03-06T15:32:27.0). Below this, there are tabs for different instruments: 'Hard X-rays INTEGRAL ISGRI', 'X-rays INTEGRAL JEM-X', 'Gamma-rays INTEGRAL SPI-ACS', 'Gamma-rays Polar', 'Neutrino Antares', 'Gravitational waves Ligo/VIRGO', and 'IR/Visible DESI LegacySurvey'. The 'Instrument query parameters' section shows 'OSA Version' set to 'OSA11.2' and 'Radius' set to '15 deg'. There are also options for 'Use INTEGRAL pointing Science Windows (ScWs)' and 'Maximum number of ScWs' set to '50'.

The screenshot shows a Jupyter notebook titled 'Generic Revolution Mosaics'. The code in the notebook is as follows:

```

In [ ]: parameters x
1 rev_num = 0
2 #If <=0 it will take the current revolution (zero) or previous ones, select NRT as data_version
3 E1 keV = "28.0"
4 E2 keV = "40.0"
5 J_E1 keV = "3.0"
6 J_E2 keV = "20.0"
7 osa_version = 'OSA11.2'
8 detection_threshold = 7
9 host_type = 'staging'
10 to exclude from title = '' # 'Cen A'
11 #if this string is in the title of the observation, this is excluded from the analysis. Leave '' to not use it.
12 use_isgri = True
13 use_jemx1 = True
14 use_jemx2 = True
15 include_new_sources = False
16 data_version = 'CONS' #It can be CONS or NRT
17 token='' #to run it as web service, we pass a token

In [ ]:
1 import astropy.io.fits as fits
2 import numpy as np
3 from astroquery.simbad import Simbad
4 from astropy import units as u
5 from astropy.coordinates import SkyCoord
6 import copy
7 import re
8 import pandas as pd
9 import os.sys
10 from importlib import reload
11 import json
    
```



Flexible implementation of workflows

Workflows are available for:

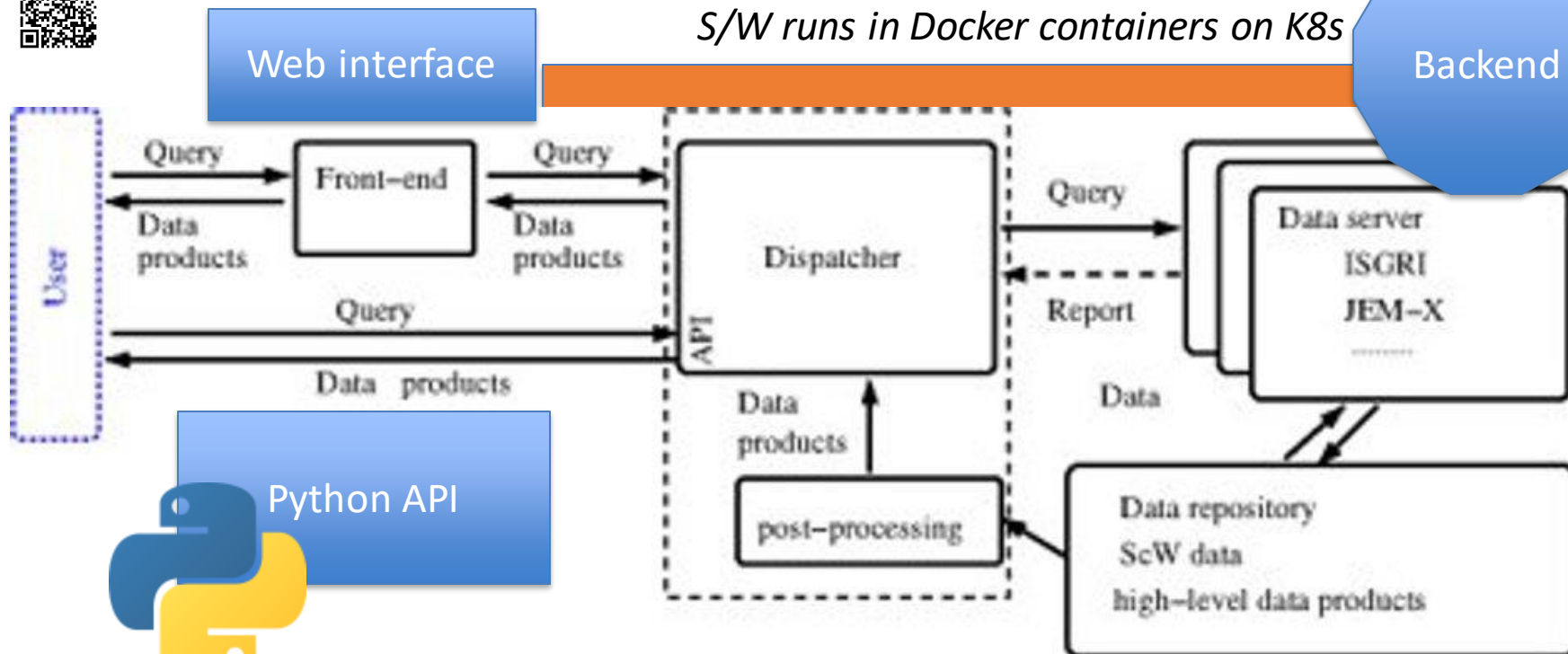
- **INTEGRAL** instruments
 - IBIS/ISGRI (images, spectra, lightcurves)
 - SPI-ACS (lightcurves)
 - JEM-X (images, spectra, lightcurves)
- Other experiments
 - Polar (light curves)
 - LIGO-Virgo (spectrograms, localizations)
 - Desi Legacy Survey (images, photometry)
 - ANTARES



The general architecture

S/W runs in Docker containers on K8s

Backend



- Coded in python
- Specialized plugins for the different instruments and data products
- Asynchronous requests
- Deployed also on HPC cluster using containers.

Kubernetes cluster



Open source and portable

- All the infrastructure is publicly available
- It can be run on any Kubernetes cluster (something that is common use nowadays)
- Public on github -> **oda-hub**
<https://github.com/oda-hub>

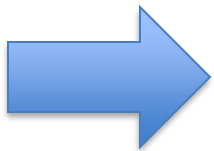
The screenshot displays a list of public repositories on GitHub, all under the 'oda-hub' organization. Each repository entry includes the repository name, a 'Public' badge, a description, a language icon, star count, license, forks, issues, and the last update date.

Repository Name	Language	Stars	License	Forks	Issues	Last Updated
dqueue-chart	Mustache	0	GPL-2.0	0	0	Updated 2 days ago
dispatcher-chart	Shell	0		1	0	Updated on Aug 9
helm-charts		0		0	0	Updated on Aug 1
frontend-chart	Shell	0		8	1	Updated on May 25
oda-resolver-chart	Smarty	0		0	0	Updated on Apr 4
antares-chart	Mustache	0		0	0	Updated on Mar 22
integral-timesystem-chart	Smarty	0		0	0	Updated on Mar 22
dda-chart						



Strengths of MMODA

- The system saves intermediate products (save energy and time!) -> second time you make the same query, results are almost instantaneous
- No s/w installation and testing required -> just an account
- Continuously updated and improved by us
- Intuitive and easy to use, with emails notifications for submission and completion
- The python api can be used to build and perform more complex analysis



Those have been used to build «standard products» used for the population of a products gallery

<https://gitlab.astro.unige.ch/oda/product-gallery/gallery-notebooks>



The MMODA product gallery

Instrument: Product type:
 Tstart: Tstop:
Use ISOT format - YYYY-MM-DDTHH:MM:SS

<p>Galactic Center Rev. 2565 (N... Sources 3A 1822-371, GX 3+1,... Instrument jemx1</p> <p>Data time span: 2022-10-27T13:01:29 - 2022-10-28T03:44:53 Revolution span: 2565 - 2565 Proposal IDs: 1920014</p>	<p>Crab Rev. 2565 (NRT) Sources Crab Instrument jemx1</p> <p>Data time span: 2022-10-28T05:52:20 - 2022-10-28T13:07:26 Revolution span: 2565 - 2565 Proposal IDs: 1960001</p>	<p>Galactic Center Rev. 2565 (N... Sources 1E 1740.7-2942, 3A 1... Instrument isgri</p> <p>Data time span: 2022-10-27T13:01:29 - 2022-10-28T03:44:53 Revolution span: 2565 - 2565 Proposal IDs: 1920014</p>	<p>Crab Rev. 2565 (NRT) Sources Crab Instrument isgri</p> <p>Data time span: 2022-10-28T05:52:20 - 2022-10-28T13:07:26 Revolution span: 2565 - 2565 Proposal IDs: 1960001</p>	<p>IGR J19140+0951 jemx1 light... Sources IGR J19140+0951 Instrument jemx1</p> <p>Data time span: 2022-10-24T21:19:50 - 2022-10-25T14:49:49 Revolution span: 2564 - 2564 Proposal IDs: 1920004</p>	<p>4U 1909+07 jemx1 light curv... Sources 4U 1909+07 Instrument jemx1</p> <p>Data time span: 2022-10-24T21:19:50 - 2022-10-25T14:49:49 Revolution span: 2564 - 2564 Proposal IDs: 1920004</p>
---	---	---	---	--	---

Collection of high-level products

- Products can be explored and downloaded
- IBIS/ISGRI, and JEM-X instruments currently available
- Hosted on a **Drupal**-powered website
- Dedicate RESTful-API endpoints for automatized content creation and editing



Population of the gallery

HOW

- A set of **RESTful endpoints** for writing/reading/updating to and from the gallery in a programmatic way out of the box with Drupal
- Fully exploited for the population of the gallery: a set of **python notebooks** developed to create these products (linked to each product along with the input parameters)

WHAT: we process **available daily** data:

- Produce images and detect possible sources
- We extract light curves and spectra for each detected source
- This is done per observation within the satellite revolution
- **CONS** data: after data consolidation, we update our products

```
isgri notebooks
Carlo Ferrigno authored 8 hours ago

isgri-full-image-sextractor.ipynb 22.49 KiB

#General search
tstart='2003-02-01T00:00:00'
tstop='2022-10-31T23:59:59'
#I use 3.5 deg for JEM-X and 12 for ISGRI, by running twice the notebook.
source_name="3C 273"
radius=10

osa_version="OSA11.2"
data_version='cons'
integral_data_rights='all-private'

#### NB
# This is the limit for each call (to be raised to 500)
s_max=150

#For ISGRI image and light curve
E1_keV=20.
E2_keV=50.
#for image and catalog extraction
detection_threshold=7.0
```



Reproducibility

- An account in **MMODA** to reproduce the analysis is needed
- Upload permission to the gallery is restricted, but it can be granted
- The Drupal instance is very easily deployable anywhere (even on commercial providers, Drupal is fully open-source)
- Drupal is widely used in NASA !

isgri notebooks
Carlo Ferrigno authored 8 hours ago

isgri-full-image-sextractor.ipynb 22.49 KiB

```
#General search
tstart='2003-02-01T00:00:00'
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s_max=150

#For ISGRI image and light curve
E1_keV=28.
E2_keV=50.
#for image and catalog extraction
detection_threshold=7.0
```



Product exploration

Products can be searched

- Per **instrument**: ISGRI, JEM-X1, JEM-X2, JEM-X.
- Per **type of product**: spectrum, light curve, image
- Per **observing period**: specify start and end time
- [example](#)

MMODA PRODUCT GALLERY

My account Log out Register

Instrument

Product type

Tstart

Use ISOT format - YYYY-MM-DDTHH:MM:SS

Tstop

Use ISOT format - YYYY-MM-DDTHH:MM:SS

Galactic Center Rev. 2565 (NR...)
Sources 1E 1740.7-2942, 3A 1...
Instrument isgri

Data time span:
2022-10-27T13:01:29 -
2022-10-28T03:44:53
Revolution span: 2565 - 2565
Proposal IDs: 1920014

Crab Rev. 2565 (NRT)
Sources Crab
Instrument isgri

Data time span:
2022-10-28T05:52:20 -
2022-10-28T13:07:26
Revolution span: 2565 - 2565
Proposal IDs: 1960001

Orion_1 Rev. 2564 (NRT)
Instrument isgri

Data time span:
2022-10-25T16:52:46 -
2022-10-25T20:41:29
Revolution span: 2564 - 2564
Proposal IDs: 1920008

GRS 1915+105 Rev. 2564 (NR...)
Sources GRS 1915+105, IGR J...
Instrument isgri

Data time span:
2022-10-24T21:19:50 -
2022-10-25T14:49:49
Revolution span: 2564 - 2564
Proposal IDs: 1920004

Gal. Plane, l= 264 Rev. 2564 (...)
Sources Vela X-1
Instrument isgri

Data time span:
2022-10-25T22:01:34 -
2022-10-26T05:26:59
Revolution span: 2564 - 2564
Proposal IDs: 1920005

Orion_1 Rev. 2563 (NRT)
Sources Crab
Instrument isgri

Data time span:
2022-10-23T04:51:04 -
2022-10-24T04:36:22
Revolution span: 2563 - 2563
Proposal IDs: 1920008



Products per revolution

Data are processed per observation within the satellite revolution



Products are easily searchable per satellite revolution

[example](#)

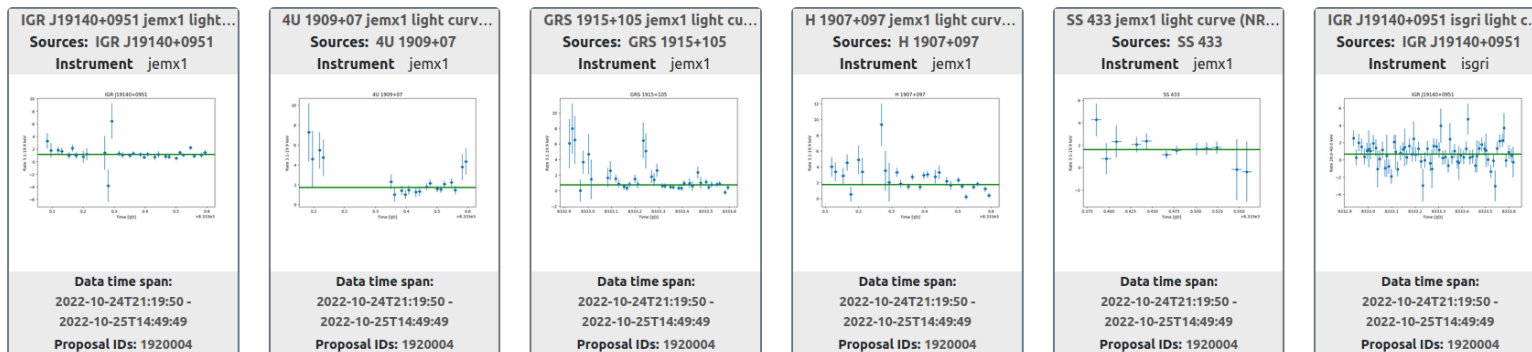
Data Products per INTEGRAL revolution

ISGRI | Jemx | Jemx1 | Jemx2 | All instruments

Image | Spectrum | All products

Provide a revolution number

2564





Sources

Every source that is detected by ISGRI or JEM-X within at least a single observation appears in the Gallery



Sources can be searched based on their name(s) as well as per class e.g. all LowMassXBin

[example](#)

Source name Source type

Search within the list of available sources also with alternative names

<u>Source</u> [▲]	<u>RA</u>	<u>DEC</u>	<u>Source type</u>	<u>Online catalog</u>
1A 0535+262	84.727400	26.315800	HighMassXBin	🔗
1A 1742-294	266.522000	-29.514800	LowMassXBin	🔗
1A 1743-288	266.761000	-28.883000	LowMassXBin	🔗
1E 1145.1-6141	176.869000	-61.953700	HighMassXBin	🔗
1F 1740.7-2942	265.978000	-29.745200	LowMassXBin	🔗



Long term products: light curves, mosaics, spectra spanning a long duration observation

Special highlights products e.g. light curves for outbursts, cumulated spectra

Per-revolution products: for each observation in each satellite revolution

[example](#)

7 Nov 2022

Source products

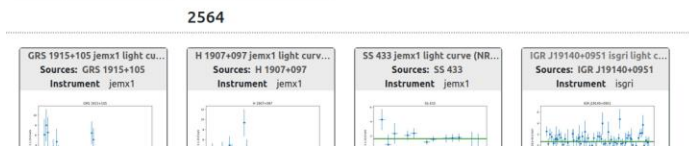
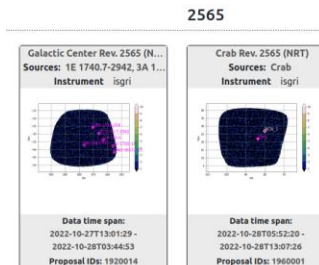
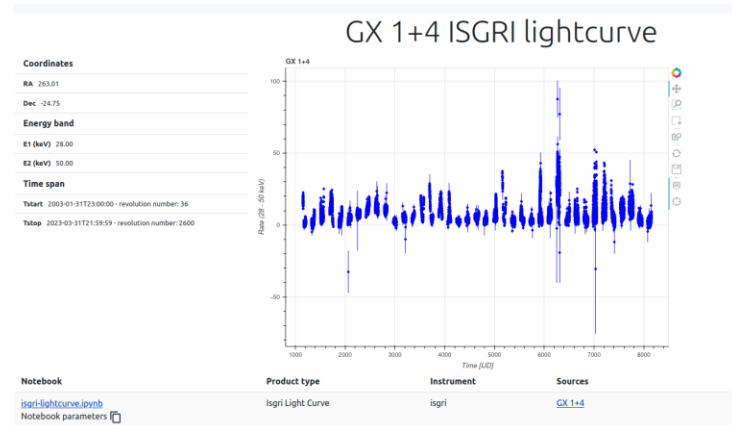




Image products visualization

Each image is displayed with **js9**, a web version of ds9 that allows interactive experience (zooming, contrast, scale)

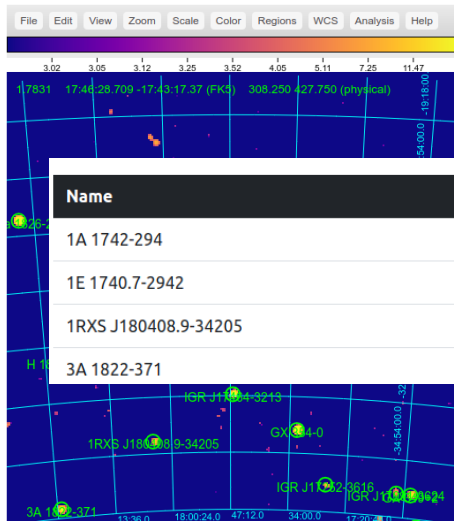
The **detected sources** are listed, with their flux in a table along with other information (eg coordinates)

Link to the **notebook** that generated the product is also available, along with the input parameters -> analysis is fully reproducible -> FAIR and open data !

Fits files and region file are attached and can be downloaded

example

GX 1+4



Attachments

- [/mmoda/gallery/sites/default/files/544515_image_GX_1p4_isgri_mosaic_clean_significance28_50.fits.gz](https://mmoda/gallery/sites/default/files/544515_image_GX_1p4_isgri_mosaic_clean_significance28_50.fits.gz)
- [/mmoda/gallery/sites/default/files/544515_image_GX_1p4_isgri_mosaic.fits.gz](https://mmoda/gallery/sites/default/files/544515_image_GX_1p4_isgri_mosaic.fits.gz)
- [/mmoda/gallery/sites/default/files/544515_image_GX_1p4_isgri_mosaic_clean_significance28_50.reg](https://mmoda/gallery/sites/default/files/544515_image_GX_1p4_isgri_mosaic_clean_significance28_50.reg)

Name	RA	Dec	Flux (cts/s)	Unc
1A 1742-294	266.5175	-29.5056	0.527	0.04
1E 1740.7-2942	265.9830	-29.7426	4.288	0.04
1RXS J180408.9-34205	271.0364	-34.3336	0.745	0.04
3A 1822-371	276.3868	-37.0936	2.555	0.06

These parameters have been copied in your clipboard and can be pasted in the first cell of the notebook to reproduce the results of the analysis.

```

rev_num = 0
# If <=0 it will take the current revolution (zero) or previous ones,
select NRT as data_version
E1_keV = "28.0"
E2_keV = "40.0"
J_E1_keV = "3.0"
J_E2_keV = "20.0"
osn_version = 'OSA11.2'
detection_threshold = 7
host_type = 'staging'
to_exclude_from_title = " # 'Cen A'"
# If this string is in the title of the observation, this is excluded from
the analysis. Leave "" to not use it.
use_isgr = True
use_jem1 = True
use_jem3 = True
                    
```

Notebook

[Generic Revolution Mosaics.ipynb](#)

Notebook parameters



Spectrum and Light-Curve products visualization

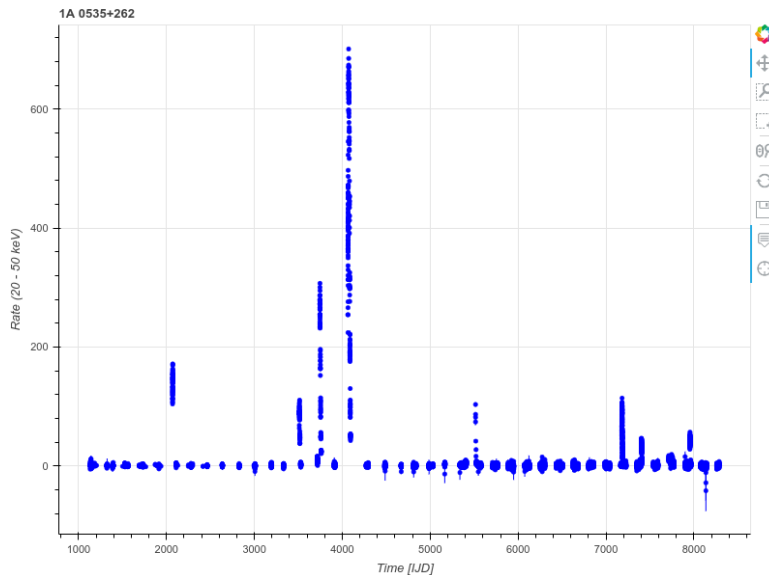
Interactive visualization using the **bokeh** library for each spectrum/light curve

Fits files and region file are attached and can be downloaded

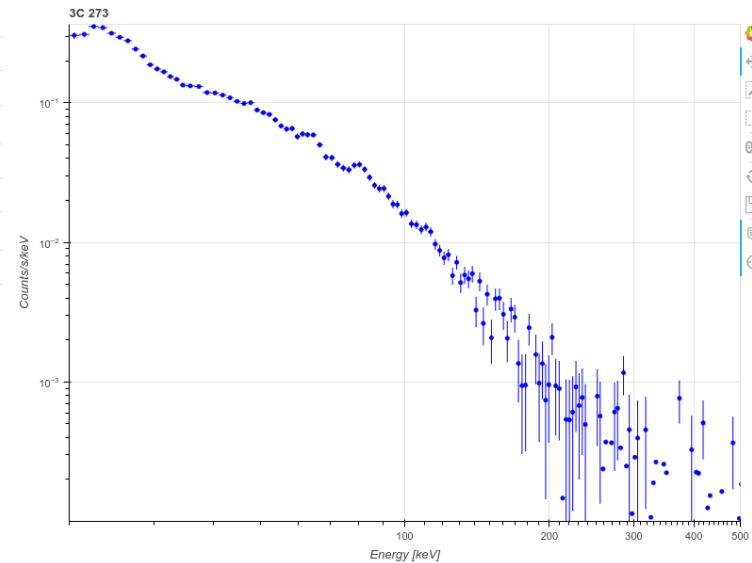
Link to the **notebook** that generated the product is also available, along with the input parameters

[example](#), [example](#)

1A 0535+262 ISGRI lightcurve



3C 273 ISGRI spectrum





Future developments

- We will extract images, spectra and light curve for each observation in each satellite revolution
- Populating the gallery will require ~6 months for standard revolution products
- For some sources, we plan to extract "highlights" and long-term products
- ***We rely on the INTEGRAL community for ideas, suggestions, and collaboration !***



Conclusions

- We build a Gallery of products upon the MMODA framework to present easily and quickly accessible INTEGRAL products
- We run several workflows to access mission-long products by source
- A great potential for legacy that could complement the efforts by ESA, or be adapted
- FAIR data and open-source technology that could be exploited by other partners for legacy and ported anywhere !