MMODA
Multi-Messenger Online Data Analysis

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département d'astronomie

ISDC

A Gallery of INTEGRAL products through the MultiMessenger Online Data Analysis

Gabriele Barni

https://www.astro.unige.ch/mmoda/gallery

University of Geneva

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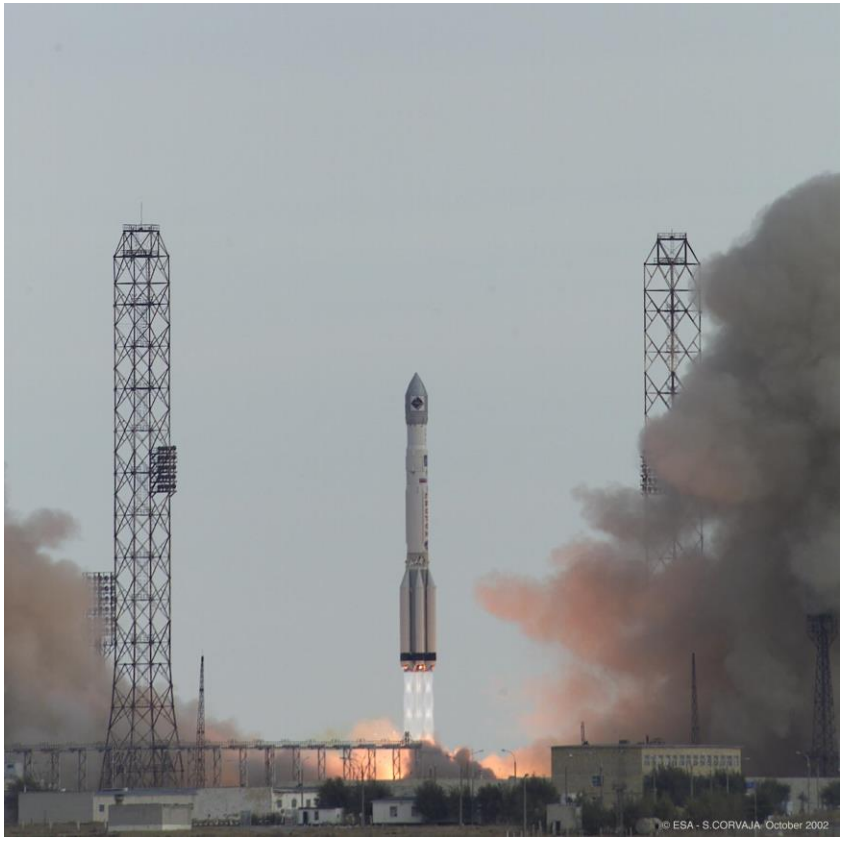
INTEGRAL Mission



- **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

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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

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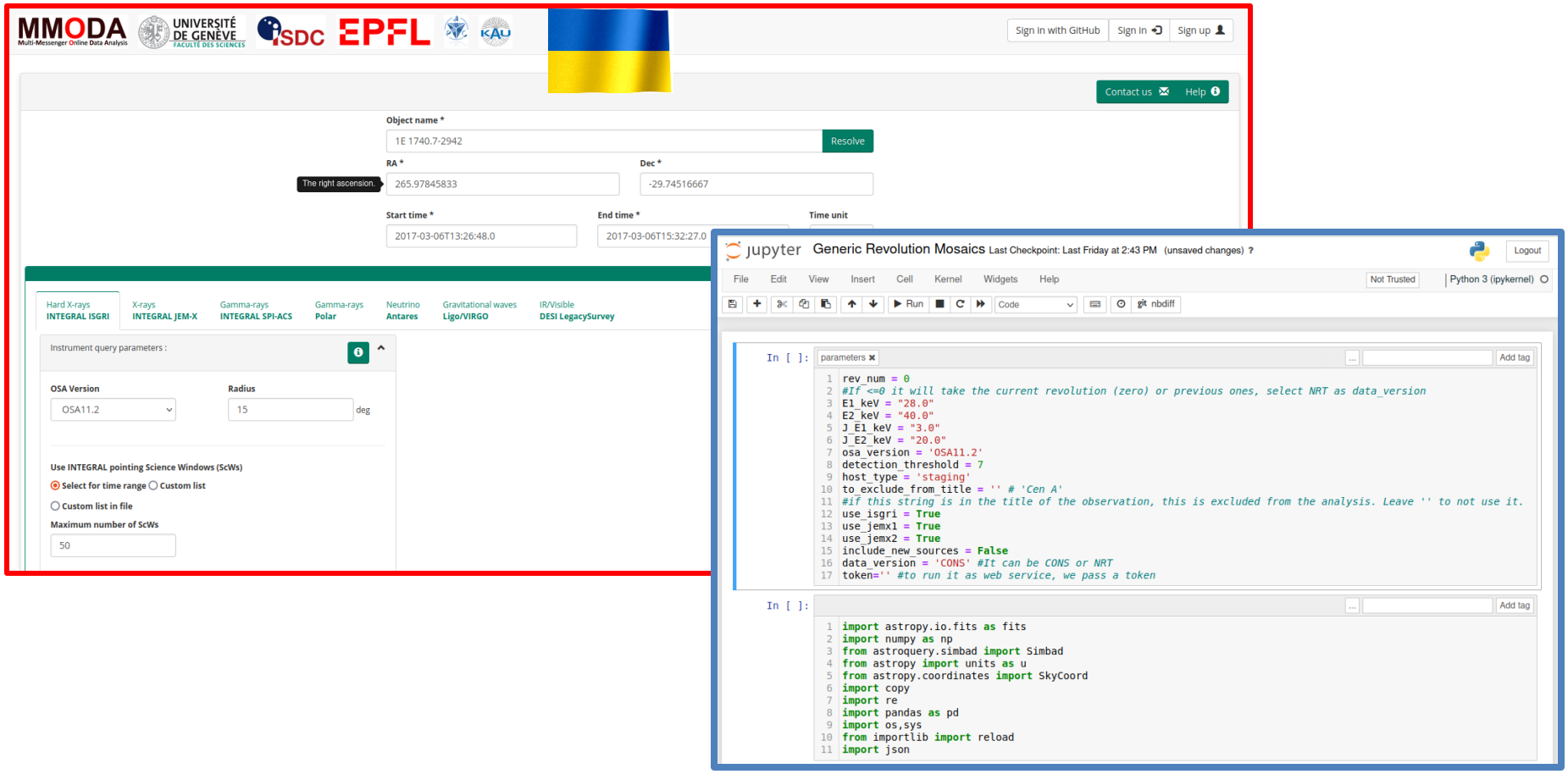
Such platform is accessible via

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



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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

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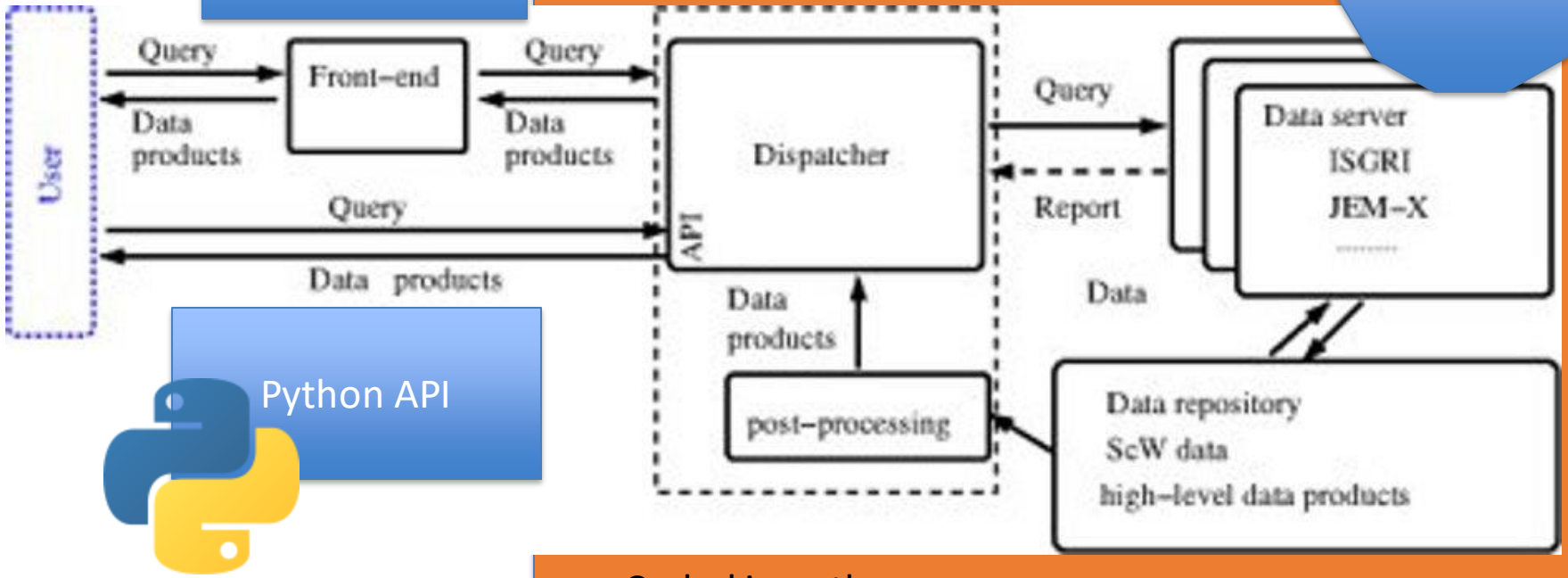
The general architecture

S/W runs in Docker containers on K8s

Backend

Web interface



Python API

- Coded in python
- Specialized plugins for the different instruments and data products
- Asynchronous requests

- Deployed also on HPC cluster using containers.

Kubernetes cluster

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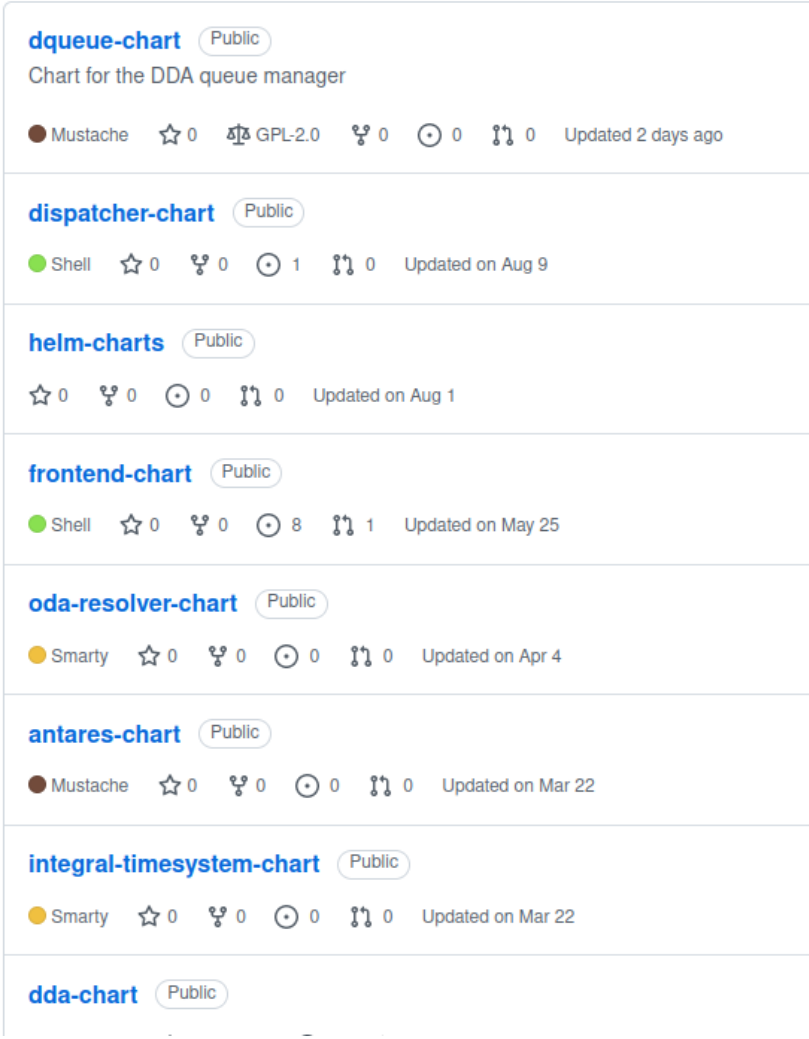
Open source and portable

- 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



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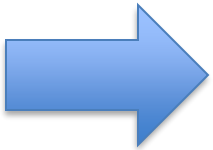
Strengths of MMODA

- 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

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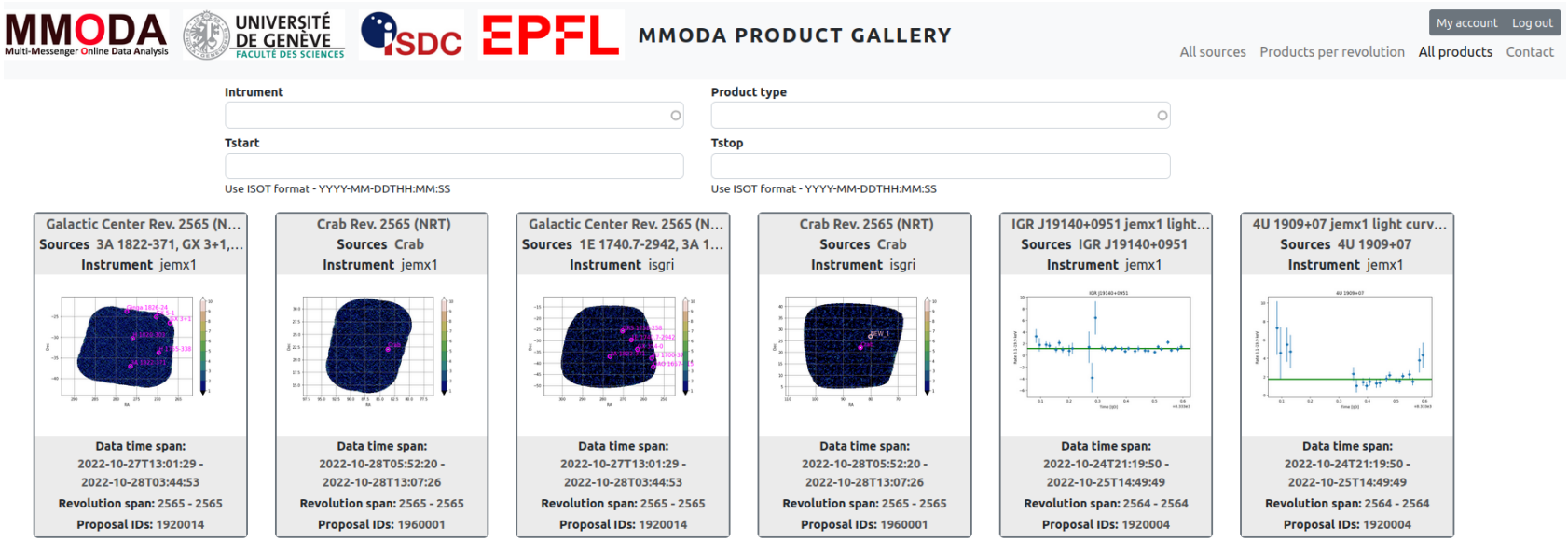
The MMODA product gallery



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

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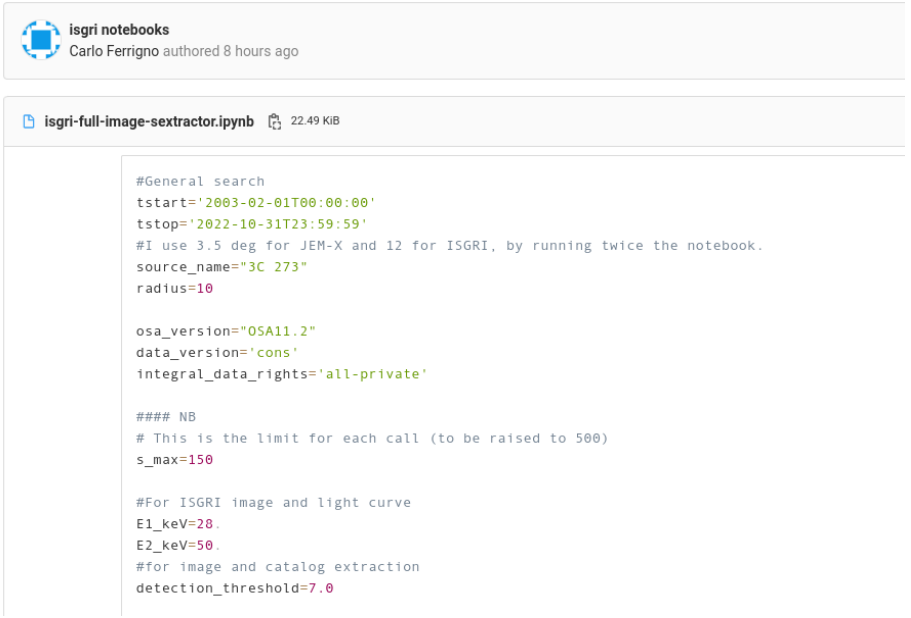
Population of the gallery

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

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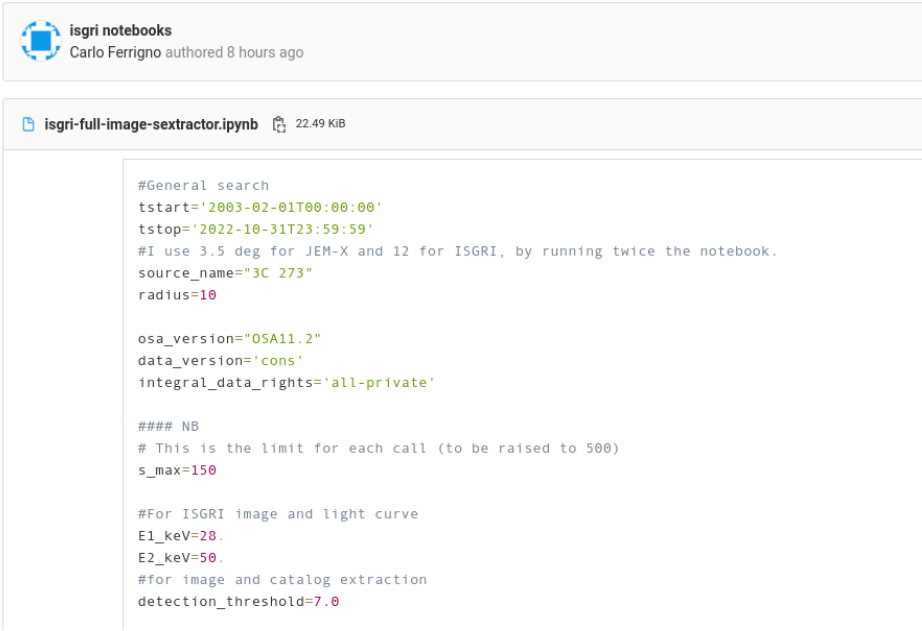
Reproducibility

- 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 !



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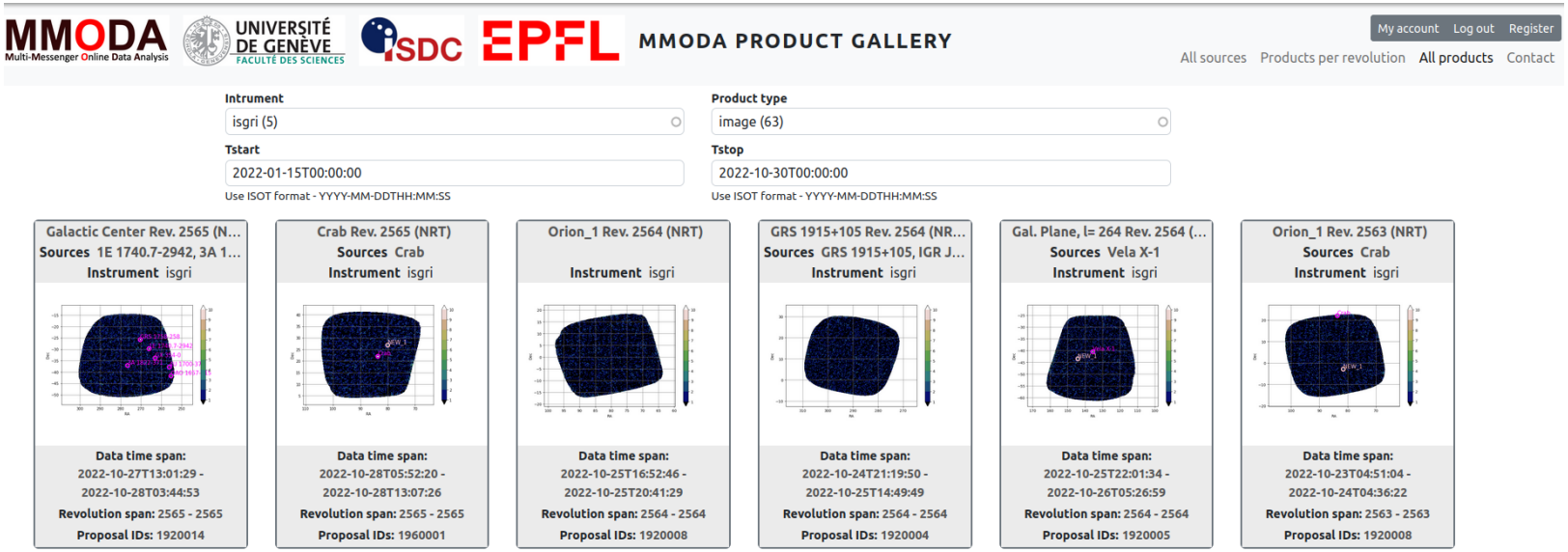
Product exploration

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**



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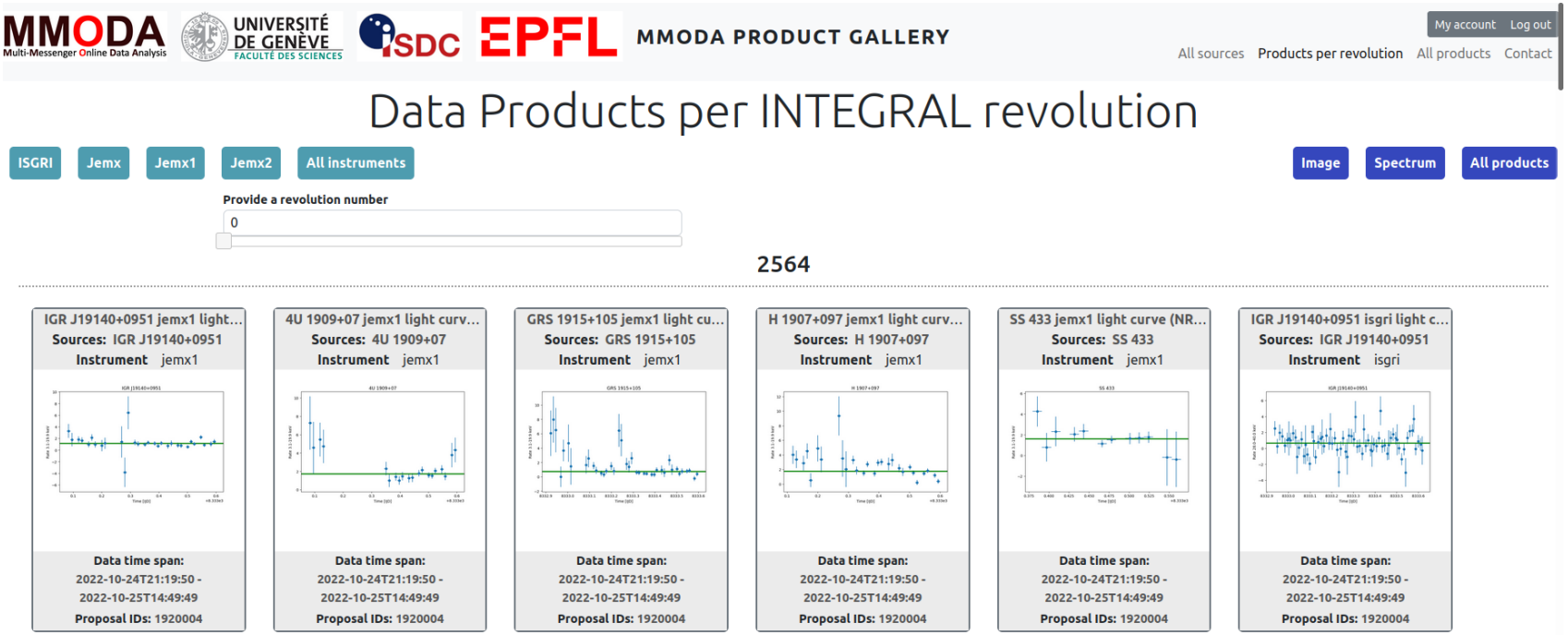
Products per revolution

Data are processed per observation within the satellite revolution

Products are easily searchable per satellite revolution

[example]



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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

Source	RA	DEC	Source type	Online catalog
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	
1E 1740.7-2942	265.978000	-29.745200	LowMassXBin	

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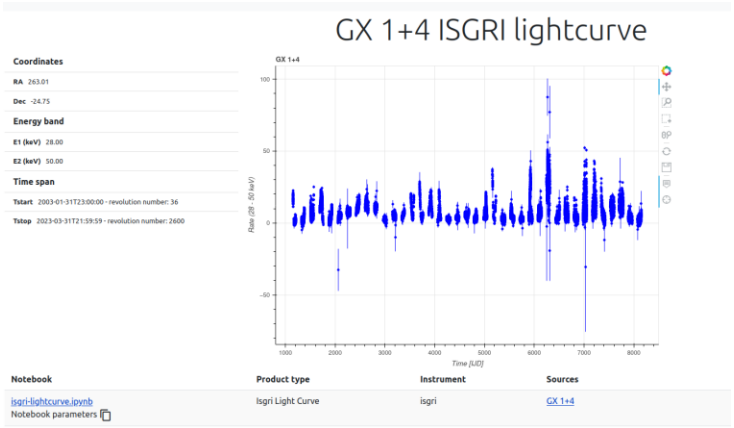
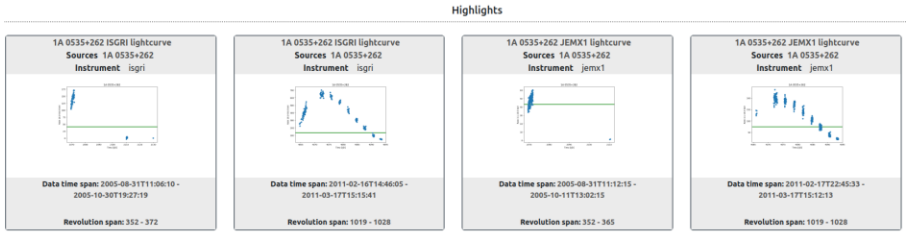
Source products

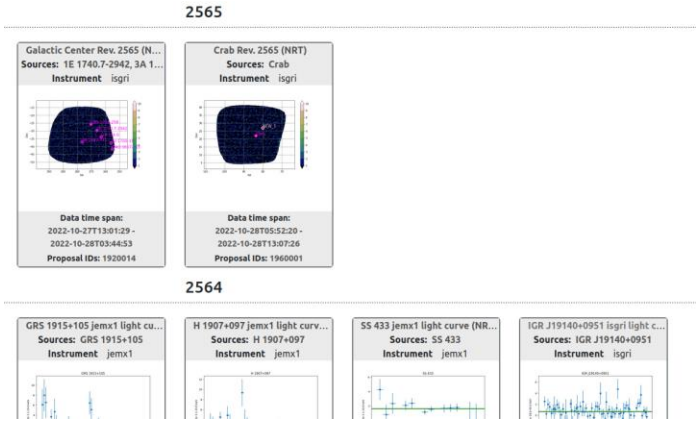
Long term products: light curves, mosaics, spectra spanning a long duration observation



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



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



[example]

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Image products visualization

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

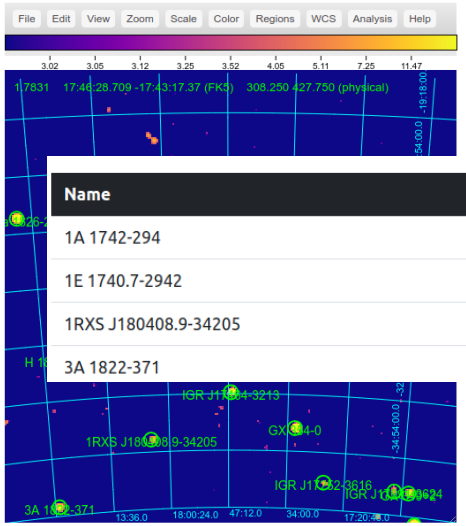
The **detected sources** are listed, with their flux in a table along with other information (eg coordinates)

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]

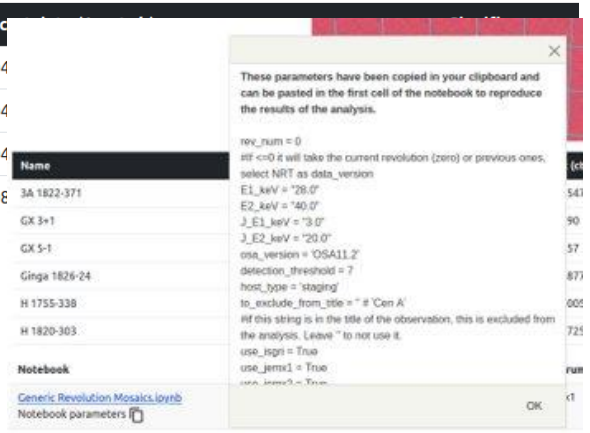
GX 1+4



Attachments

- /mmoda/gallery/sites/default/files/544515_image_GX_1p4_isgri_mosaic_clean_significance28_50.fits.gz
- /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

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	0.08



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Spectrum and Light-Curve products visualization

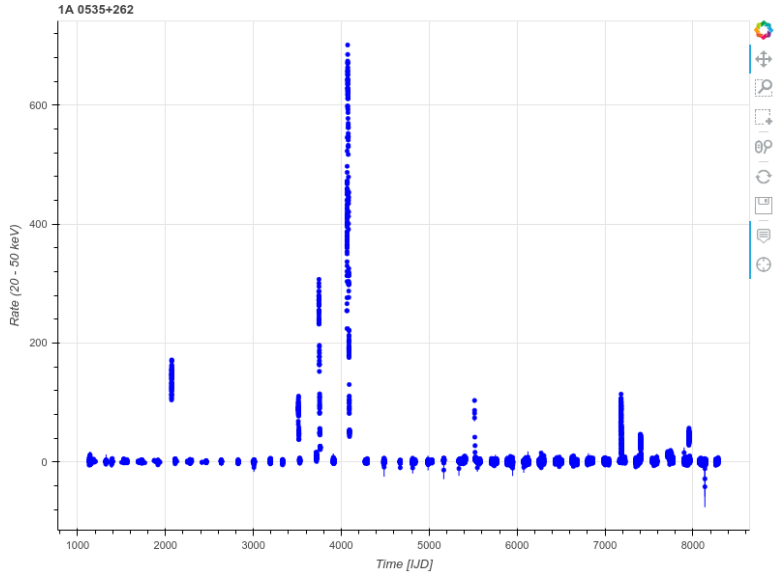
Interactive visualization using the **bokeh** library for each spectrum/light curve

Fits files and region file are attached and can be downloaded

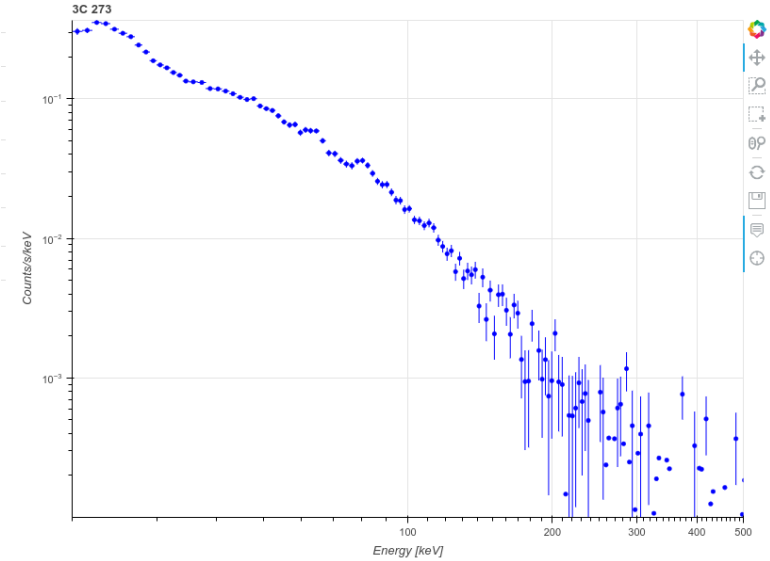
Link to the **notebook** that generated the product is also available, along with the input parameters

example, **example**

1A 0535+262 ISGRI lightcurve



3C 273 ISGRI spectrum



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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 !***

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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 !