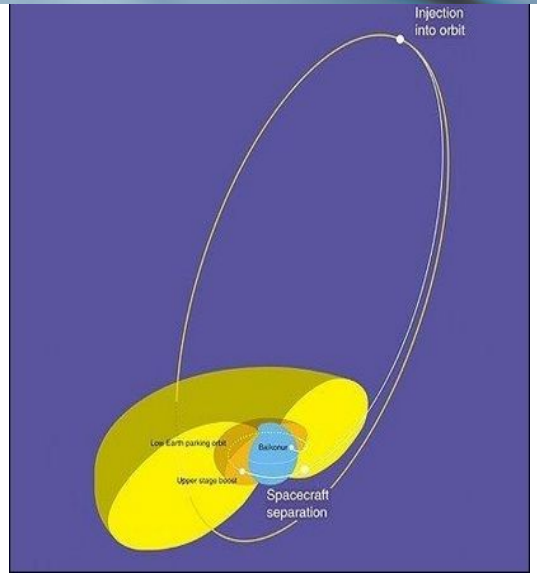
Interoperability and automation in searches for Hard X-ray counterparts of multi-messenger transients with INTEGRAL

Volodymyr SAVCHENKO

SCIOPS 2019
ESAC



INTEGRAL

hard X-ray and soft gamma-ray observatory

2002 - **, operations currently approved until December 2022

2.7 days orbit with **85% useful observing time** above radiation belts

Only **very small fraction of sky occulted by Earth**

Especially suited for serendipitous observations

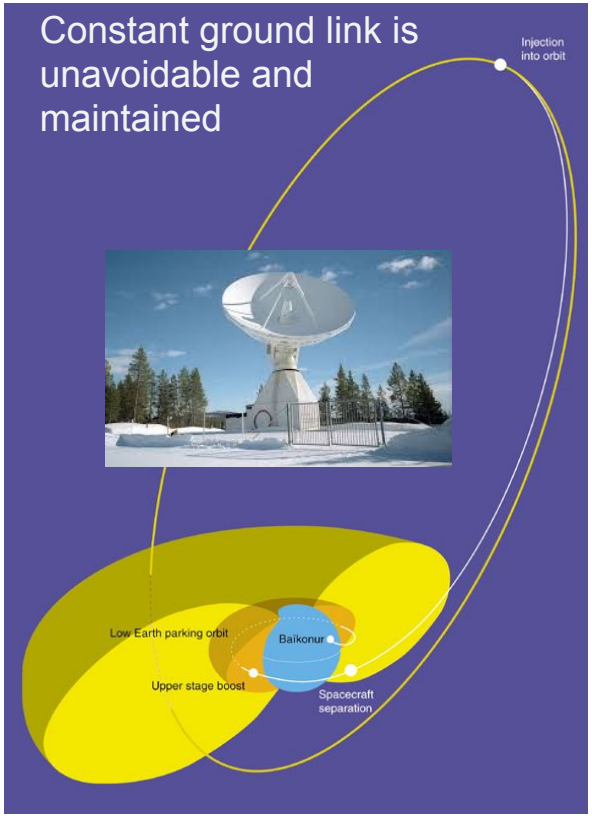
Old Spacecraft => “New” Ground Segment

Old on-board CPU

No on-board trigger

No memory

Limited capacity to resist problematic commanding

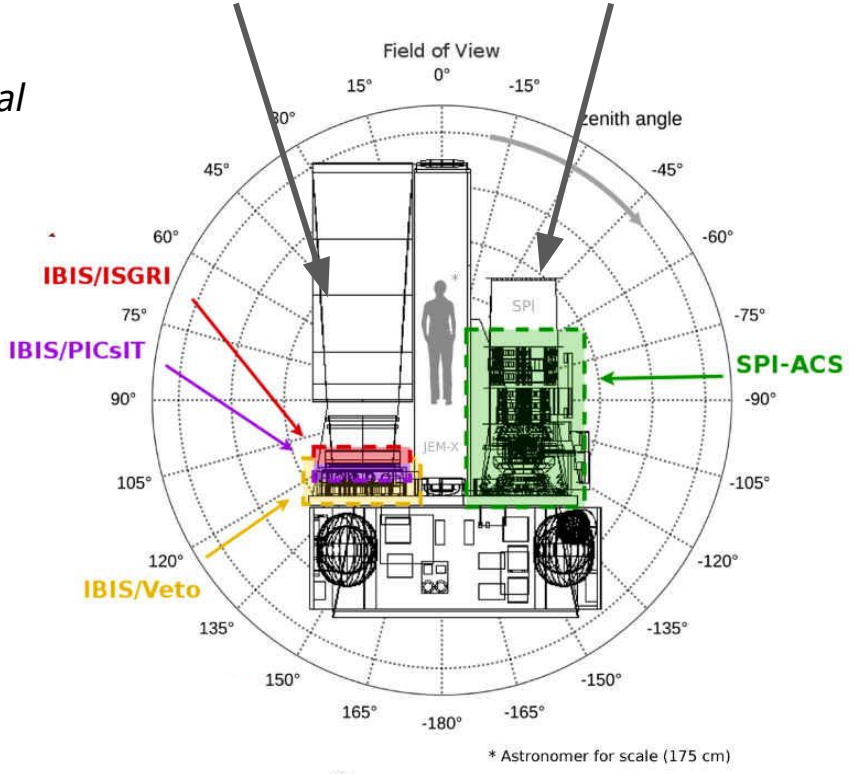


Ground segment receives **all data** and can command the spacecraft with only **0.5s** light travel time

Extensible on the ground, though automated commanding from GC is limited

3 - 8000 keV pointing field of view (from 3x3deg at 3-30 keV to 30x30deg > 25 keV)
sub-arcmin imaging, good spectral resolution

> 100 keV all-sky
almost no imaging or spectral resolution

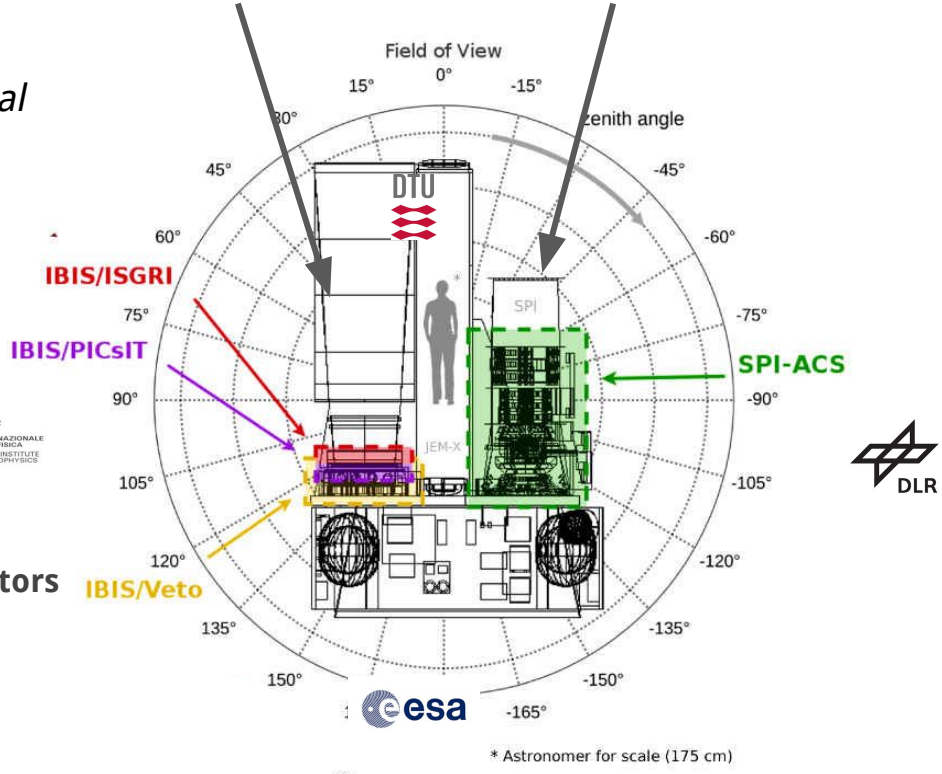


unique 100 keV - 10 MeV, both FoV and all-sky

VS+ 2017

3 - 8000 keV pointing field of view (from 3x3deg at 3-30 keV to 30x30deg > 25 keV)
sub-arcmin imaging, good spectral resolution

> 100 keV all-sky
almost no imaging or spectral resolution



Best results can be achieved by **combining all INTEGRAL detectors**

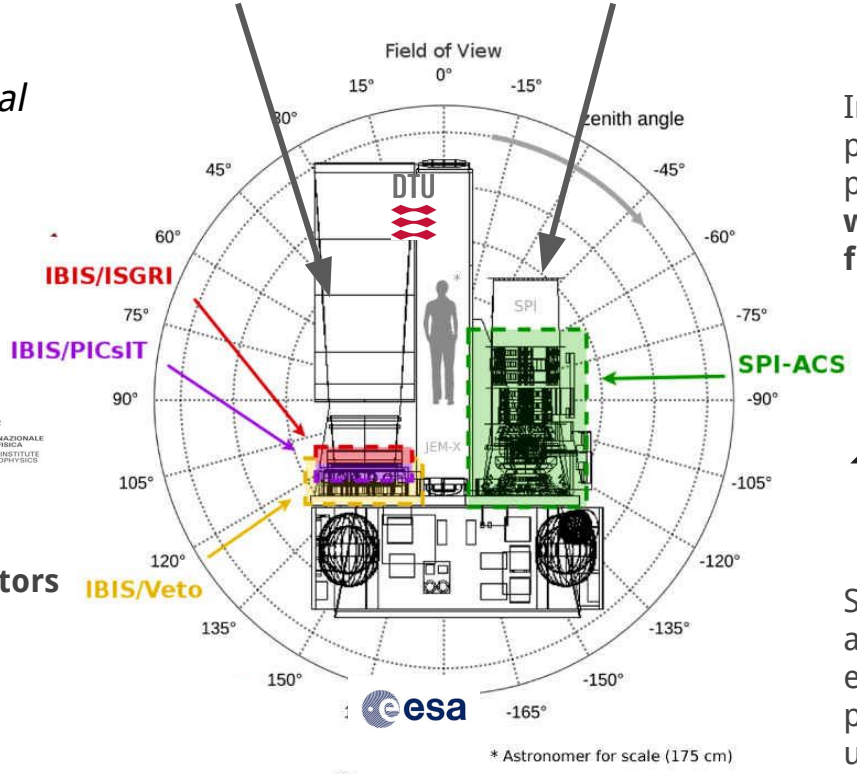
But they are built by different countries, **challenging internal interoperability**

unique 100 keV - 10 MeV, both FoV and all-sky

VS+ 2017

3 - 8000 keV pointing field of view (from 3x3deg at 3-30 keV to 30x30deg > 25 keV)
sub-arcmin imaging, good spectral resolution

> 100 keV all-sky
almost no imaging or spectral resolution



Best results can be achieved by **combining all INTEGRAL detectors**

But they are built by different countries, **challenging internal interoperability**

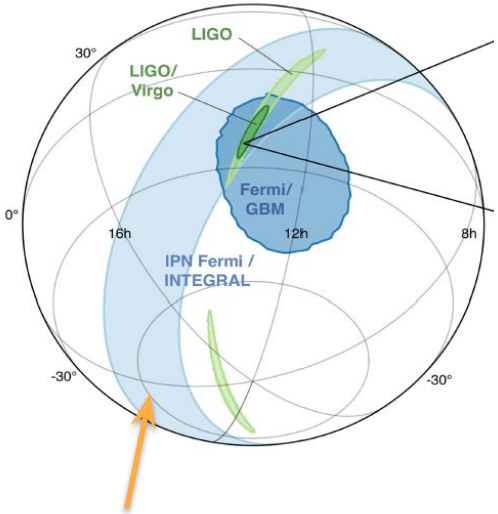
In addition, INTEGRAL was not primarily built as a GRB detector, and provides best results by **combining with spectral, timing information from other missions**

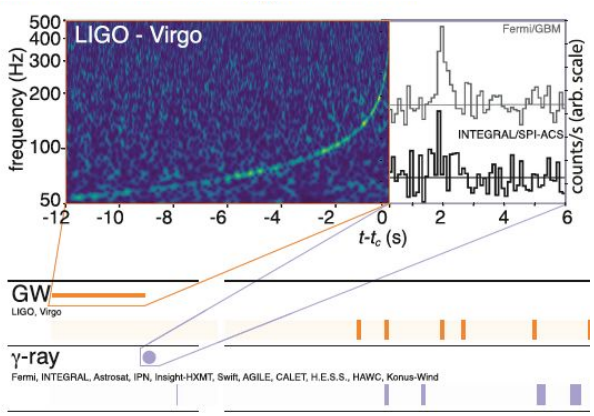
Since INTEGRAL-only GRB detections are rarely useful on their own, it was elected to **provide API to access** public data, instead of sending uninformative GCNs.

unique 100 keV - 10 MeV, both FoV and all-sky

VS+ 2017

GW 170817: to best advise the follow up





LIGO and Fermi trigger at T_0+14s (GCN Notice/VOEvent)

Final Fermi location at T0+44m

INTEGRAL data was analysed at T_0+1h, and produced a GCN Circular

Triangulation (IPN: INTEGRAL + Fermi) was computed at T_0+6h

Fermi + INTEGRAL Triangulation
unique multi-mission approach

Learned further needs:

- latency to access INTEGRAL data was not optimal (**fixed**)
- Fermi/GBM could make faster reliable localizations (**fixed**)
- Multi-instrument INTEGRAL analysis (IBIS, SPI, etc) requires combination of specialist expertise (**partially addressed**) - intra-mission interoperability
- Combing multi-mission expertise, e.g. for triangulation, is even harder (**very partially addressed**) - intra-mission interoperability

Automation and Interoperability relies on standards

Building automation which expresses researcher capacity in reusable code costs effort.

Sharing effort requires communication languages, **standards**

Automation and Interoperability relies on standards

Building automation which expresses researcher capacity in reusable code costs effort.

Sharing effort requires communication languages, **standards**

Standards for messages, facts, exist, allow to exchange data

- **Structured (well-defined but diverse)**: GCN/Notices, VOEvent, Kafka (e.g. ANTARES/ZTF/LSST), TNS
- **Free-text (poorly defined standards)**: GCN/Circulars, ATels, arXiv, zenodo

Automation and Interoperability relies on standards

Building automation which expresses researcher capacity in reusable code costs effort.

Sharing effort requires communication languages, **standards**

Standards for messages, facts, exist:

- **Structured (well-defined but diverse)**: GCN/Notices, VOEvent, Kafka (e.g. ANTARES/ZTF/LSST), TNS
- **Free-text (poorly defined standards)**: GCN/Circulars, ATels, arXiv, zenodo

But not for **transformations of methods (workflows) scientific data analysis and modelling**

Automation and Interoperability relies on standards

Building automation which expresses researcher capacity in reusable code costs effort.

Sharing effort requires communication languages, **standards**

Standards for messages, facts, exist:

- **Structured (well-defined but diverse)**: GCN/Notices, VOEvent, Kafka (e.g. ANTARES/ZTF/LSST), TNS
- **Free-text (poorly defined standards)**: GCN/Circulars, ATels, arXiv, zenodo

But not for **transformations of methods (workflows) scientific data analysis and modelling**

Example:

1. INTEGRAL, Fermi data is distributed in FITS tables and IPN SSV, Fermi data is in FITS images and tables
2. Input trigger is in VOEvent, healpix
3. Likely targets in TAP
4. Planning information in REST
5. **Methods to converge the formats, perform the analysis, and format the output: not very findable, accessible, and described**

Automation and Interoperability relies on standards

Building automation which expresses researcher capacity in reusable code costs effort.

Sharing effort requires communication languages, **standards**

Standards for messages, facts, exist:

- **Structured (well-defined but diverse)**: GCN/Notices, VOEvent, Kafka (e.g. ANTARES/ZTF/LSST), TNS
- **Free-text (poorly defined standards)**: GCN/Circulars, ATels, arXiv, zenodo

But not for **transformations of methods (workflows) scientific data analysis and modelling**

Especially needed when software is contributed, exchanged, integrated, automatically used

But what kind of standard? Imposing? Very general?

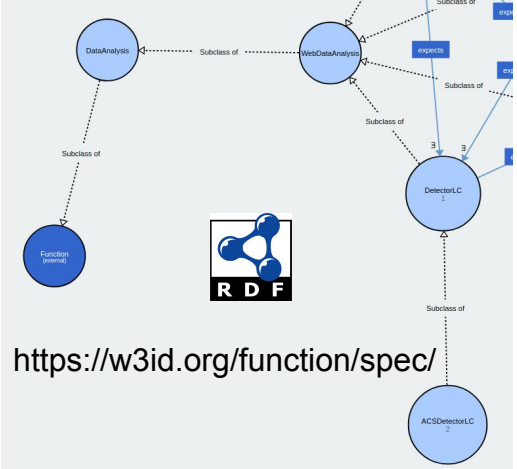
Example:

1. INTEGRAL, Fermi data is distributed in FITS tables and IPN SSV, Fermi data is in FITS images and tables
2. Input trigger is in VOEvent, healpix
3. Likely targets in TAP
4. Planning information in REST
5. **Methods to converge the formats, perform the analysis, and format the output: not very findable, accessible, and described**

Interoperability relies on standards

The **workflow standard** can be build from **existing standards for data** (e.g. http://www.ivoa.net/rdf/)**, independently of origin, to set:**

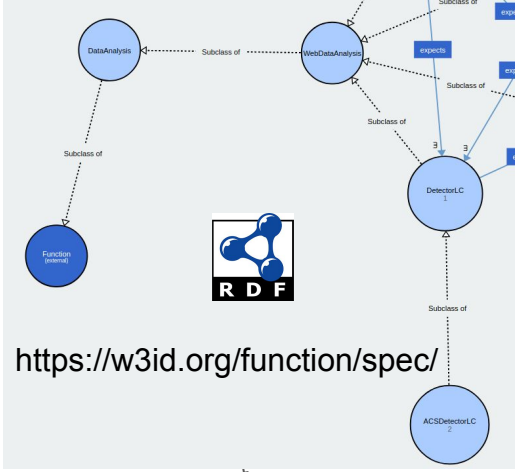
- Input, output data types/standards
- Execution rules
- Content keywords (e.g. statistical methods, binning, etc)



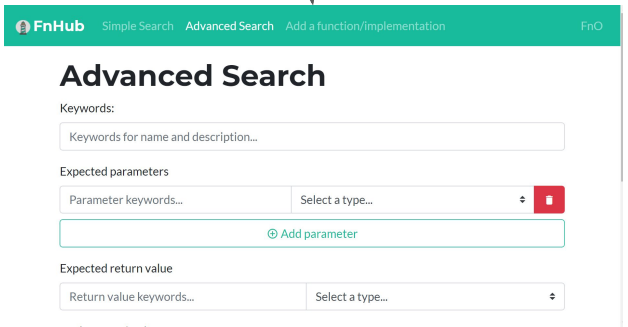
Interoperability relies on standards

The **workflow standard** can be build from **existing standards for data** (e.g. http://www.ivoa.net/rdf/)**, independently of origin, to set:**

- Input, output data types/standards
- Execution rules
- Content keywords (e.g. statistical methods, binning, etc)



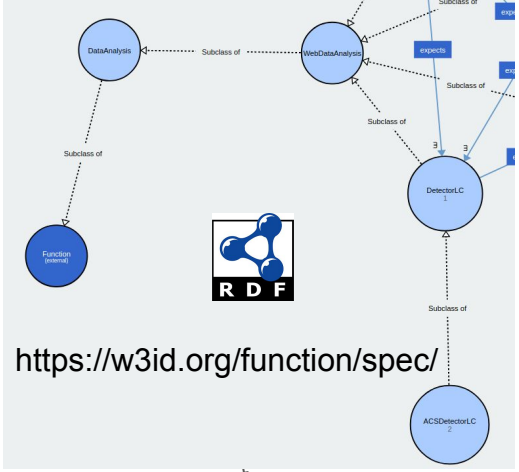
- Notebook or library in a **GitLab/GitHub repository**
- Package in a **traditional repository** (e.g. pypi/pip)
- Container on dockerhub
- Live, (OpenAPI) **remote service** (**private workflows**): **view, close-the-data analysis**



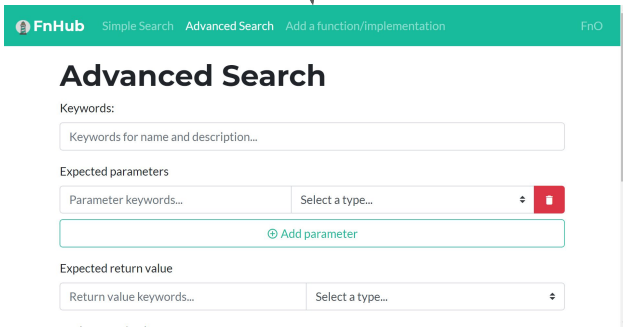
Interoperability relies on standards

The **workflow standard** can be build from **existing standards for data** (e.g. http://www.ivoa.net/rdf/), **independently of origin, to set:**

- Input, output data types/standards
- Execution rules
- Content keywords (e.g. statistical methods, binning, etc)



- Notebook or library in a **GitLab/GitHub repository**
- Package in a **traditional repository** (e.g. pypi/pip)
- Container on dockerhub
- Live, (OpenAPI) **remote service** (**private workflows**): **view, close-the-data analysis**



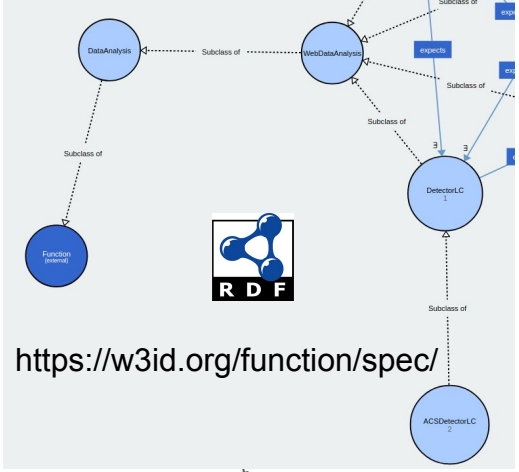
FTP links to Data files => TAP

libraries, codes => workflows

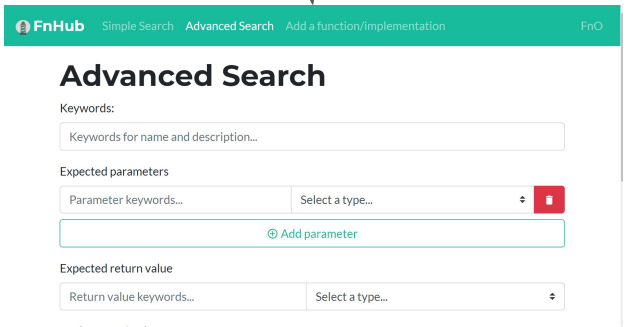
Interoperability relies on standards

The **workflow standard** can be build from **existing standards for data** (e.g. http://www.ivoa.net/rdf/), **independently of origin, to set:**

- Input, output data types/standards
- Execution rules
- Content keywords (e.g. statistical methods, binning, etc)



- Notebook or library in a **GitLab/GitHub repository**
- Package in a **traditional repository** (e.g. pypi/pip)
- Container on dockerhub
- Live, (OpenAPI) **remote service** (**private workflows**): **view, close-the-data analysis**



FTP links to Data files => TAP

libraries, codes => workflows

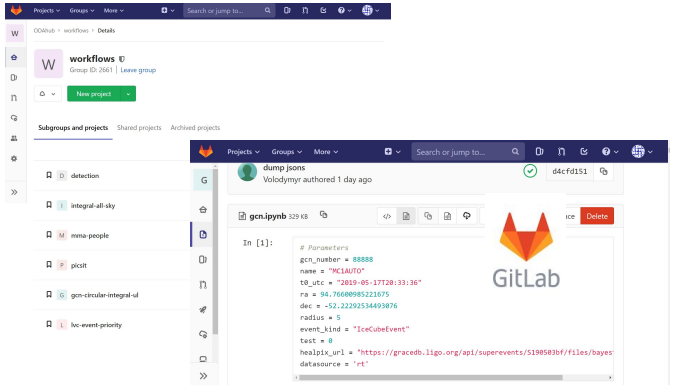
This description allows to **associate workflows to data and scientific context and execute them,** a variant of a “live” distributed appstore

“Standard” INTEGRAL transient analysis: end to end

Research, development environment lets **experts develop standardized, test, and integrate:**

- data reduction (close to data)
- GRB spectral models (linked to literature)
- statistical methods (as portable as possible)
- visibility planning tools (remote ESAC service)

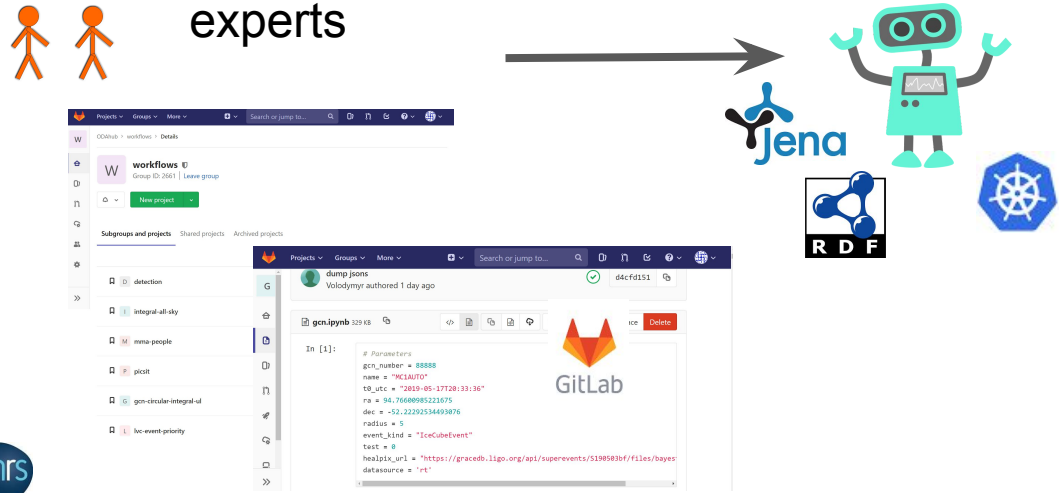
experts



“Standard” INTEGRAL transient analysis: end to end

Research, development environment lets **experts develop standardized, test, and integrate:**

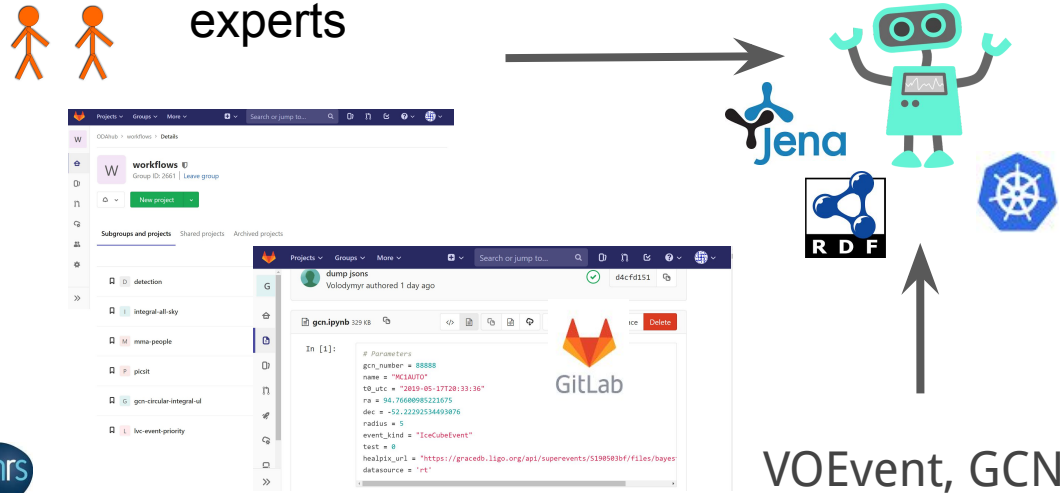
- data reduction (close to data)
- GRB spectral models (linked to literature)
- statistical methods (as portable as possible)
- visibility planning tools (remote ESAC service)



“Standard” INTEGRAL transient analysis: end to end

Research, development environment lets **experts develop standardized, test, and integrate:**

- data reduction (close to data)
- GRB spectral models (linked to literature)
- statistical methods (as portable as possible)
- visibility planning tools (remote ESAC service)



VOEvent, GCN,
ATel, Kafka, etc

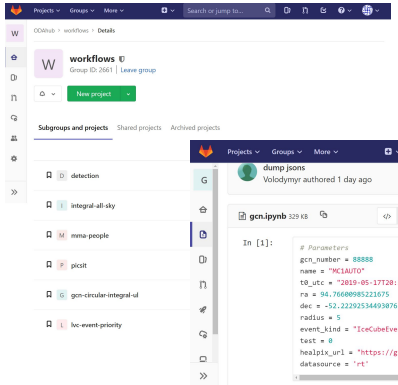
“Standard” INTEGRAL transient analysis: end to end

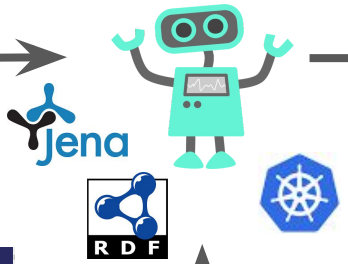
Research, development environment lets **experts develop standardized, test, and integrate:**

- data reduction (close to data)
- GRB spectral models (linked to literature)
- statistical methods (as portable as possible)
- visibility planning tools (remote ESAC service)

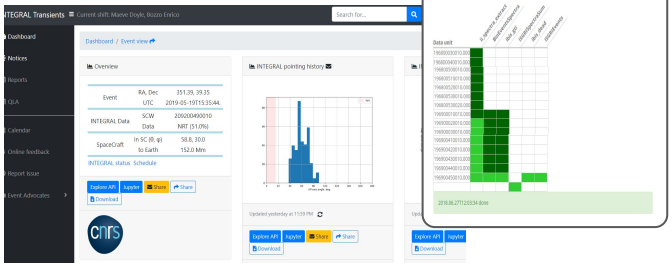
- **Find combinations** of data, adapters, statistical methods, publishers, planners
- **suggest follow-up**
- **distribute** standard results with public data, uploads to zenodo sandbox.

experts





Shift (24/7)



VOEvent, GCN,
ATel, Kafka, etc

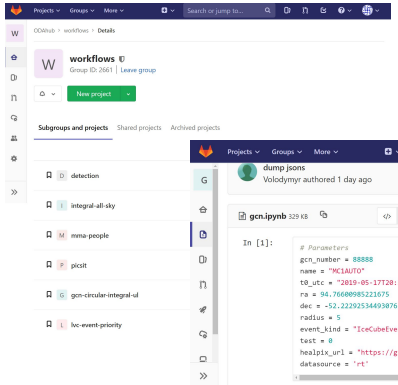
“Standard” INTEGRAL transient analysis: end to end

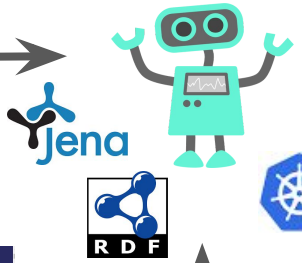
Research, development environment lets experts develop standardized, test, and integrate:

- data reduction (close to data)
- GRB spectral models (linked to literature)
- statistical methods (as portable as possible)
- visibility planning tools (remote ESAC service)

- **Find combinations** of data, adapters, statistical methods, publishers, planners
- **suggest follow-up**
- **distribute** standard results with public data, uploads to zenodo sandbox.

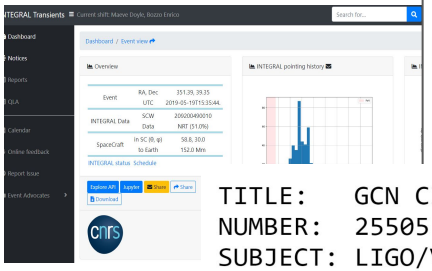
experts

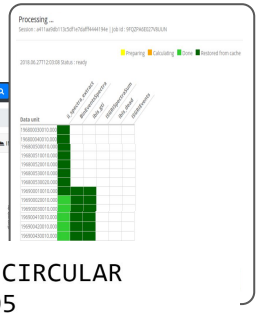




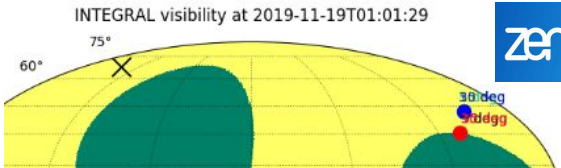
VOEvent, GCN, ATel, Kafka, etc

Shift (24/7)

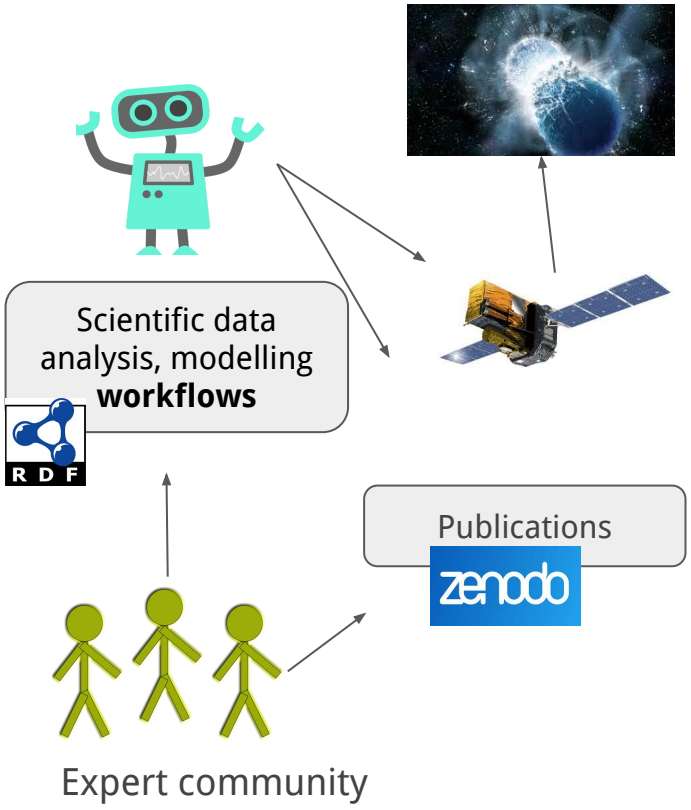




TITLE: GCN CIRCULAR
NUMBER: 25505
SUBJECT: LIGO/Virgo S190828l:
in INTEGRAL SPI-ACS prompt ob
DATE: 19/08/28 08:59:07 GM

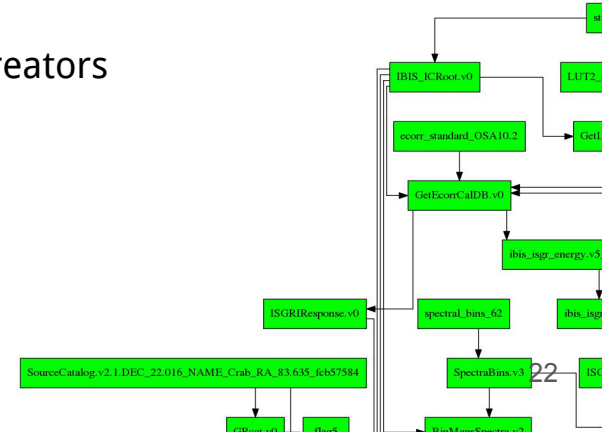


Workflow standards let researchers build the system



- Workflow standards foster understandable, usable **publishing** of **Findable Accessible Interoperable Reusable** methods
- Workflows can offert **adapters for data formats**
- Deriving **data, result provenance**
  - explain data
  - trace history
  - credit and blame creators

Provenance RDF PROV-O



Ongoing

How to expand:

- Standard (e.g. https://w3id.org/function/spec/)
- Tools to implement standards (workflows that act on workflow standards)
- An exchange hub (e.g. public SPARQL endpoint)

Intercalibration test kit: instrument support in ops

Ongoing development (aligned with **IACHEC and DataLabs**) is a **intercalibration “test kit”** platform allowing to build workflows for **verifying expectations** for instruments, **linking**:

- Data reduction of different missions
- Astrophysical Source models
- Statistical methods

To ensure consensus on source and “standard candle” properties

Provide a reference, living report, reference for instrument status

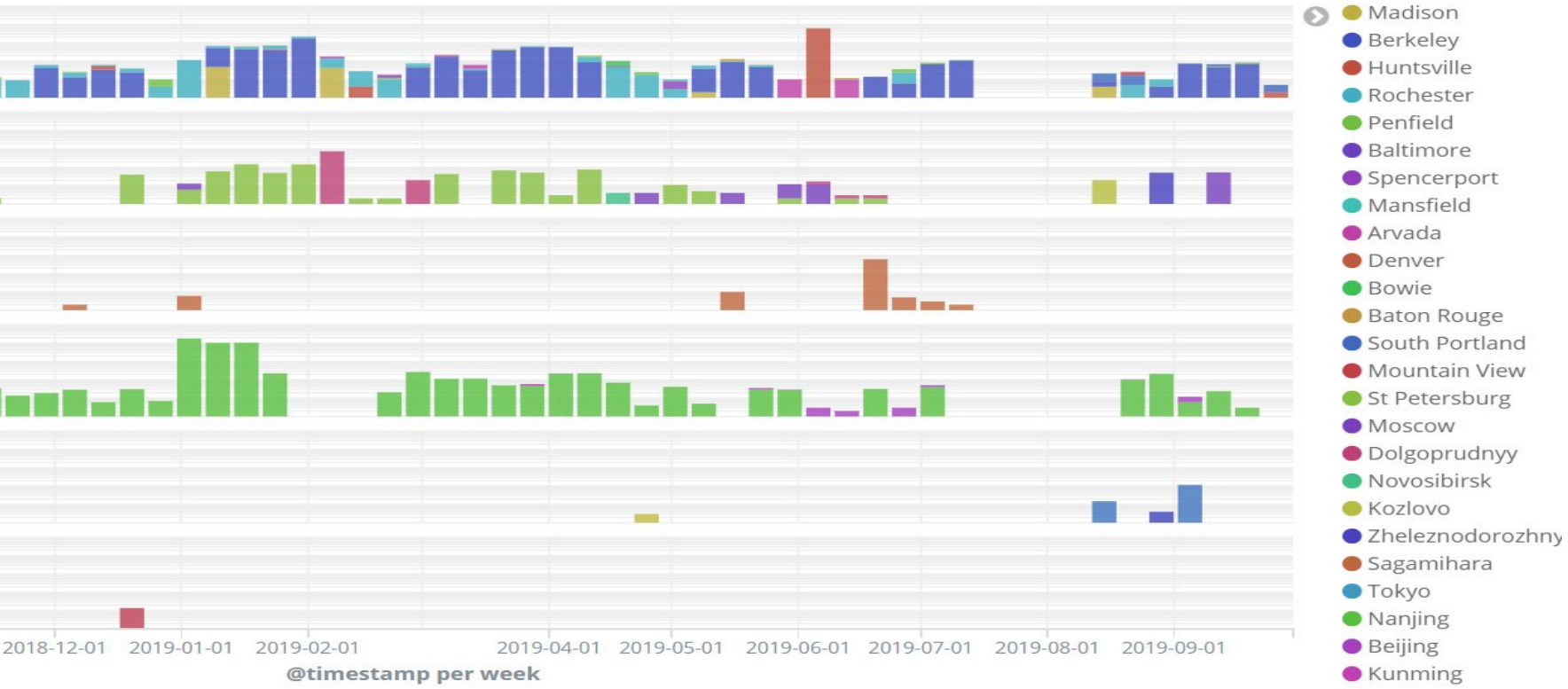
SUMMARY

- **INTEGRAL has unique capabilities for multi-messenger prompt observations** at least for O3 and O4, but fases **Unique challenges** of **inter-instrument interoperability**, and the best results (triangulations) can be derived in **interoperability with other projects**: LIGO/Virgo, Fermi, Konus-Wind, etc
- **Need to adopt expert contributions in consistent rapid reaction system require standards for scientific data analysis workflows,** and an environment reducing the development efforts
- **Workflow standards** allow to build a distributed smart **"live" semantic software and service discovery hub**, with many ways of contributing, many ways to access.
- Libraries/codes to workflows could be similar to transition from various HTML/CSV/FITS tables to TAP
- **ESA's DataLabs**, could be a perfect basis, **assuming suitable metadata for workflows**
- Workflows allow to **create adapters between data formats** and interfaces and naturally create data **provenance**, **tracking data rights and credits** for data and calibrations, ensuring **reproducibility**
- The approach has been fully implemented in a prototype **INTEGRAL "standard" transient analysis**
- Growing development is an **inter-calibration platform** allowing to build **"test kit"** for **verifying expectations for instrument** (and sky)
- Path to **living publications**: define paper as a workflow, publish, compile paper from data!

EXTRA SLIDES

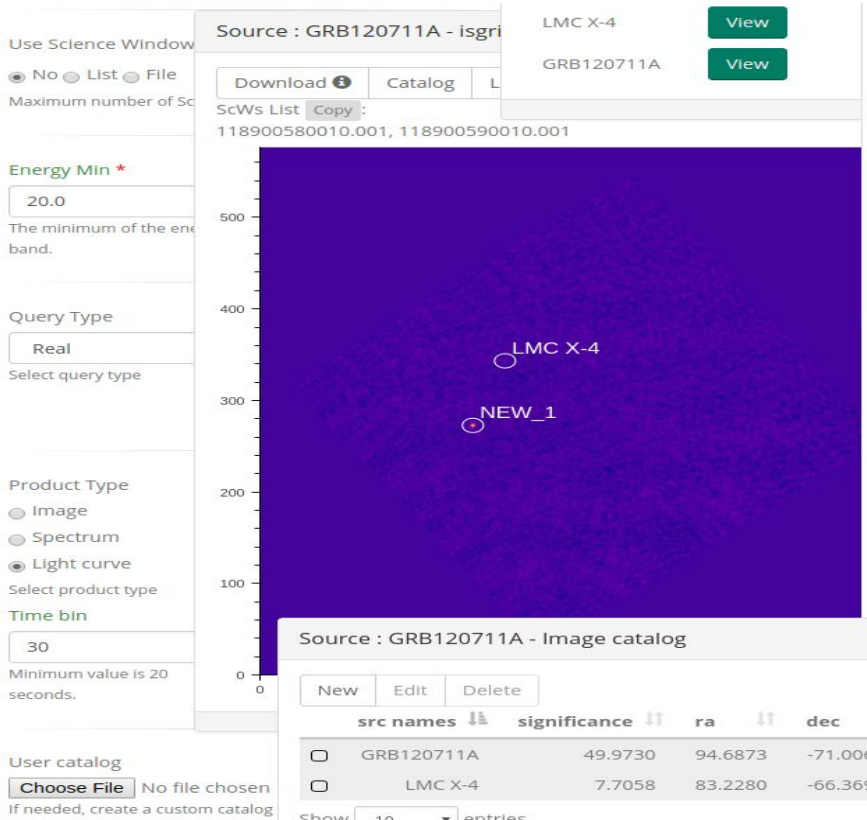
What is the ODA research and dev environment

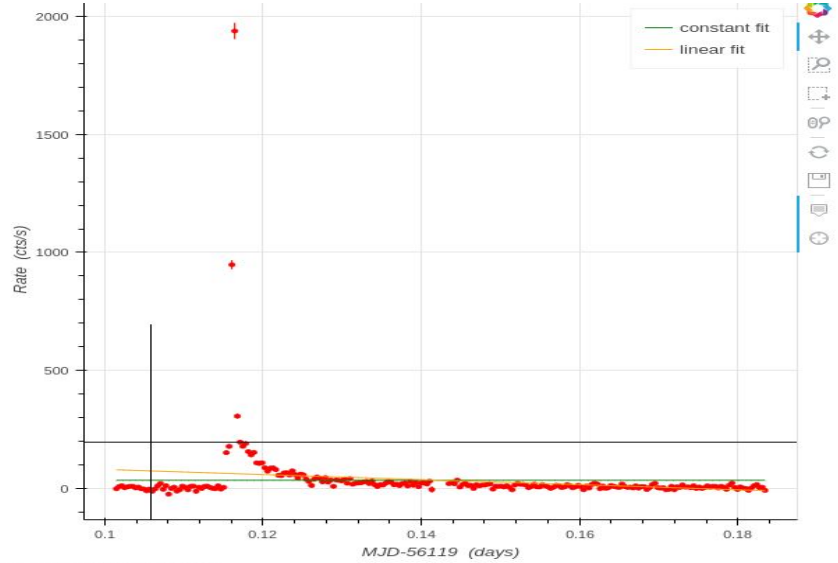
- Packages: nb2w, … oda client
- frontends
- Validate explore methods locally
- Gitlab (to store code)
- Containers to keep software portable
- CWL to define execution, input injection
- REANA runner
- Kubernetes
- slurm

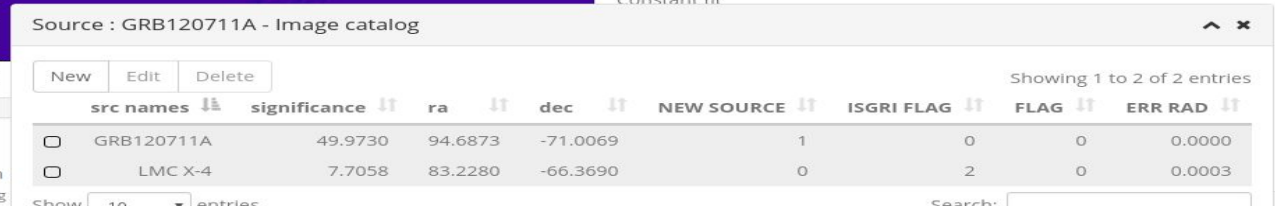

Madison
Berkeley
Huntsville
Rochester
Penfield
Baltimore
Spencerport
Mansfield
Arvada
Denver
Bowie
Baton Rouge
South Portland
Mountain View
St Petersburg
Moscow
Dolgoprudnyy
Novosibirsk
Kozlovo
Zheleznodorozhny
Sagamihara
Tokyo
Nanjing
Beijing
Kunming
2018-12-01
2019-01-01
2019-02-01
2019-04-01
2019-05-01
2019-06-01
2019-07-01
2019-08-01
2019-09-01
@timestamp per week

GRBs in the IBIS field of view

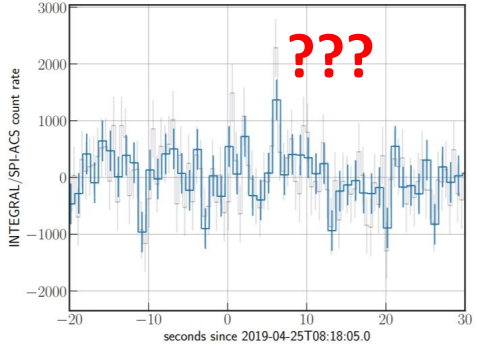
about 6 times per year, we detect a GRB in the Imager field of view and we can provide immediate localisation at 3 arcmin plus spectra



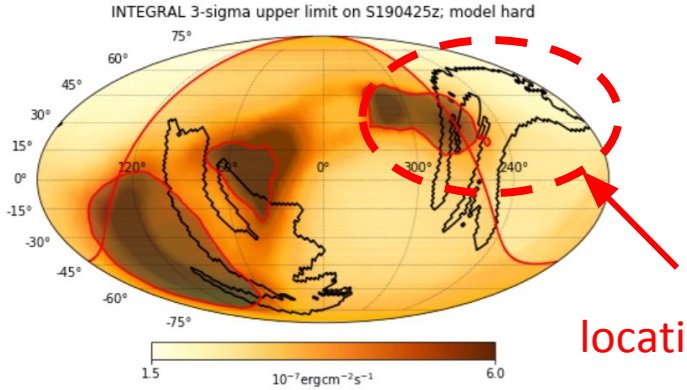




GW 190425z: a BNS merger 150 Mpc



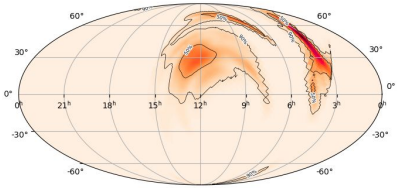
Martin-Carillo et al 2019, Savchenko et al 2019, Minaev et al 2019: discussed a weak, poorly associated possible counterpart in SPI-ACS

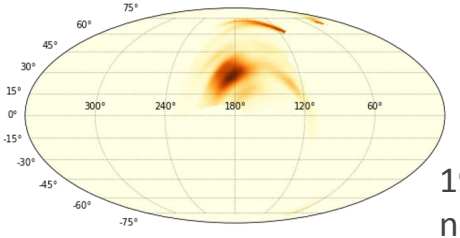


location, if real

Fermi GBM-190816: subthreshold GRB-GW candidate

Initial





19/08/20 INTEGRAL non-detection constraint

19/08/24
Updated map