

INTEGRAL observations of High-Energy neutrinos

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On behalf of the INTEGRAL Multi Messenger Collaboration

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INTEGRAL

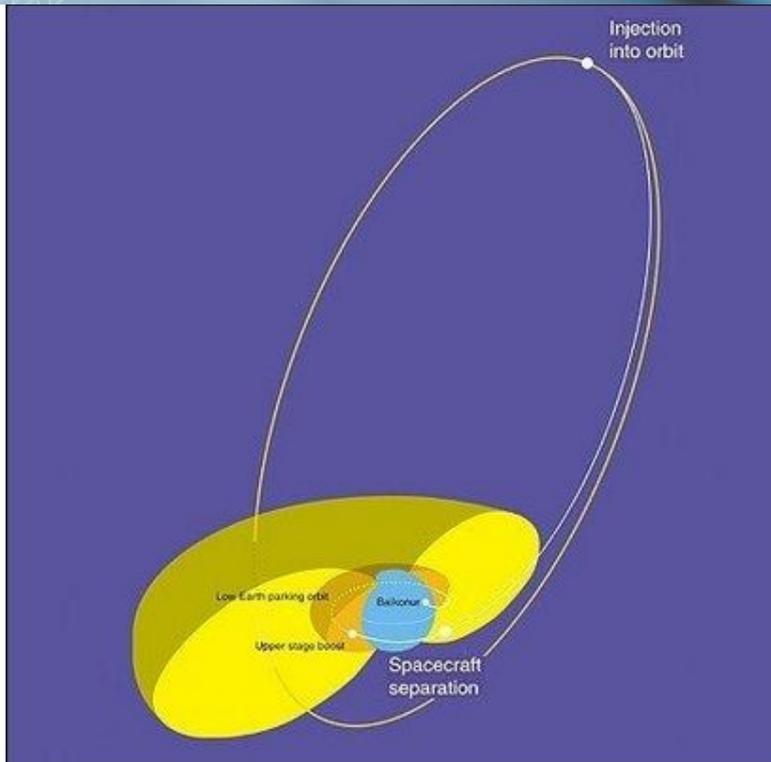
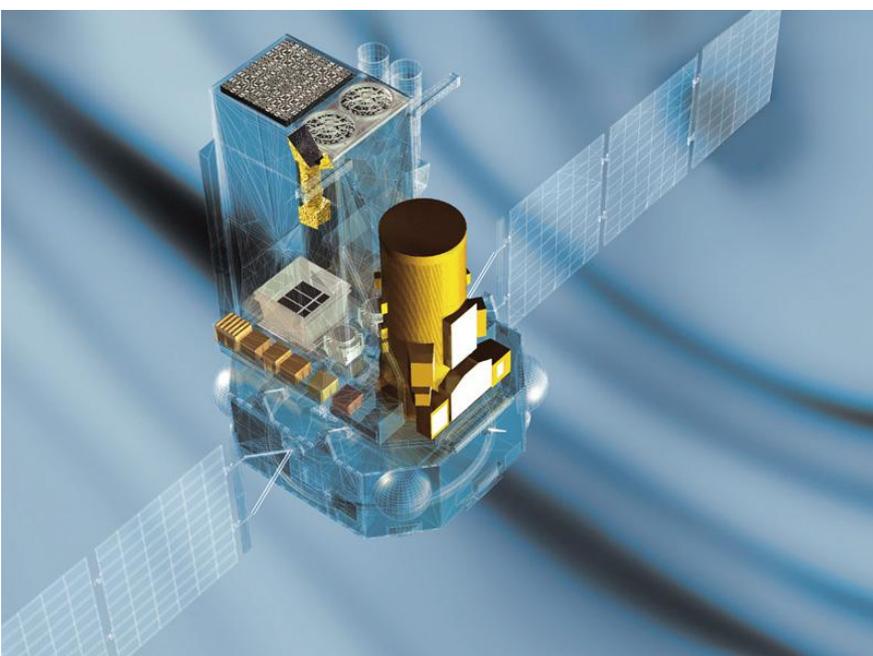
hard X-ray and soft
gamma-ray observatory

2002 - **, operations currently
approved until December 2022

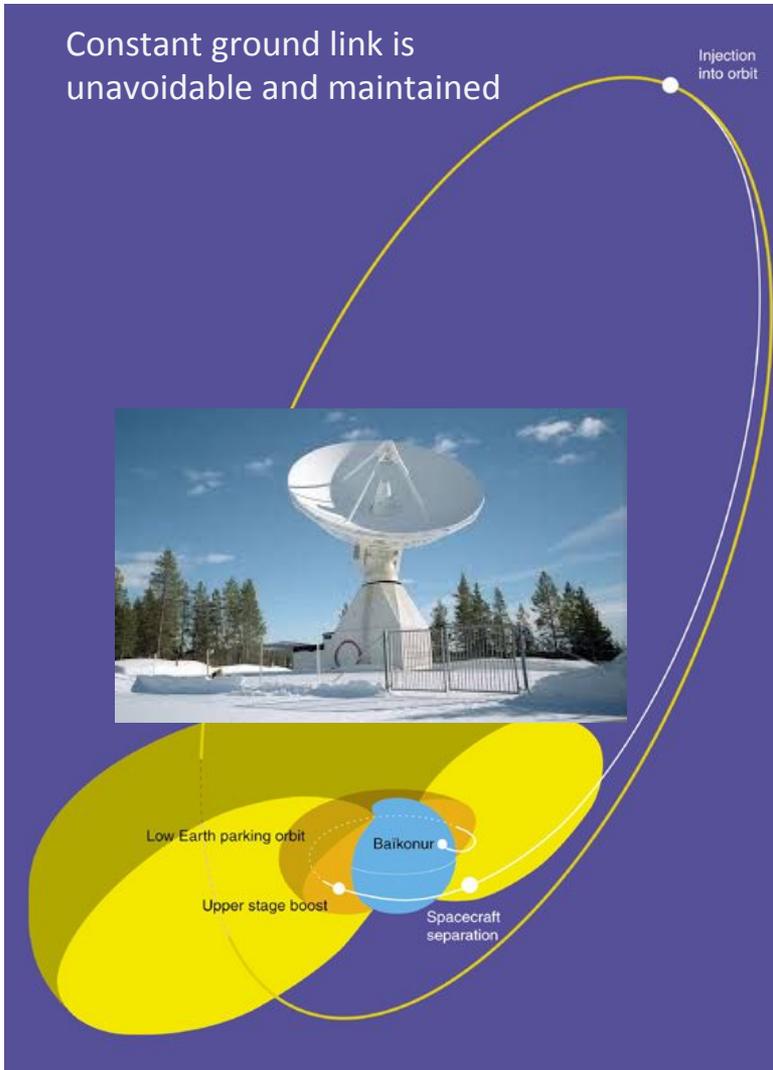
2.7 days orbit with **85% useful
observing time** above radiation
belts

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

All data transmitted to ground in
real time and analysed for GRB
within a few seconds



Old SpaceCraft => "New" Ground Segment



Constant ground link is unavoidable and maintained

Injection into orbit



Low Earth parking orbit

Baikonur

Upper stage boost

Spacecraft separation

Ground segment receives all data and commands SC with only **0.5s** light travel time, operating as part of the spacecraft.

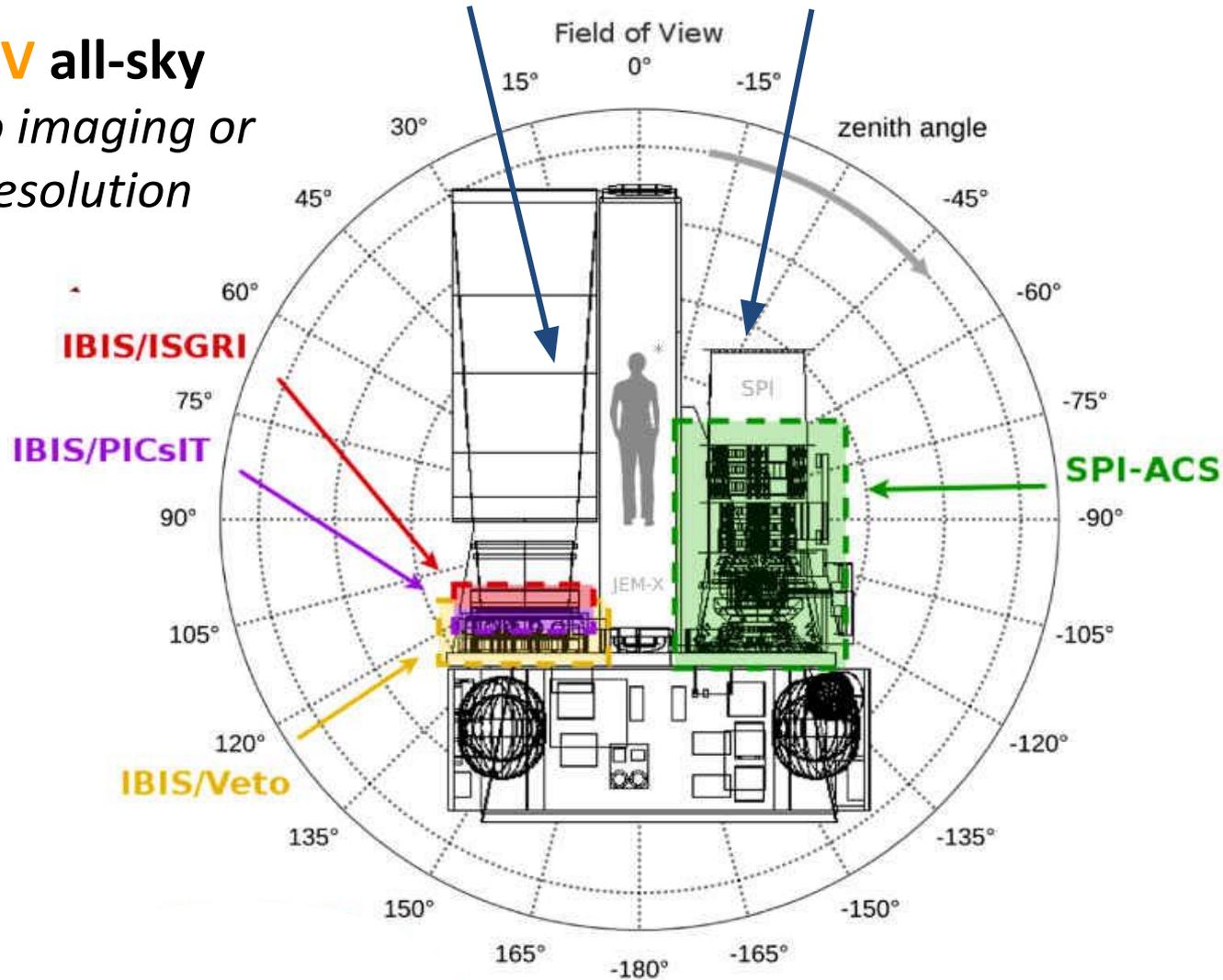
Extensible on the ground like no other spacecraft

- Old on-board CPU
- No on-board trigger
- No memory
- Limited capacity to resist problematic commanding



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

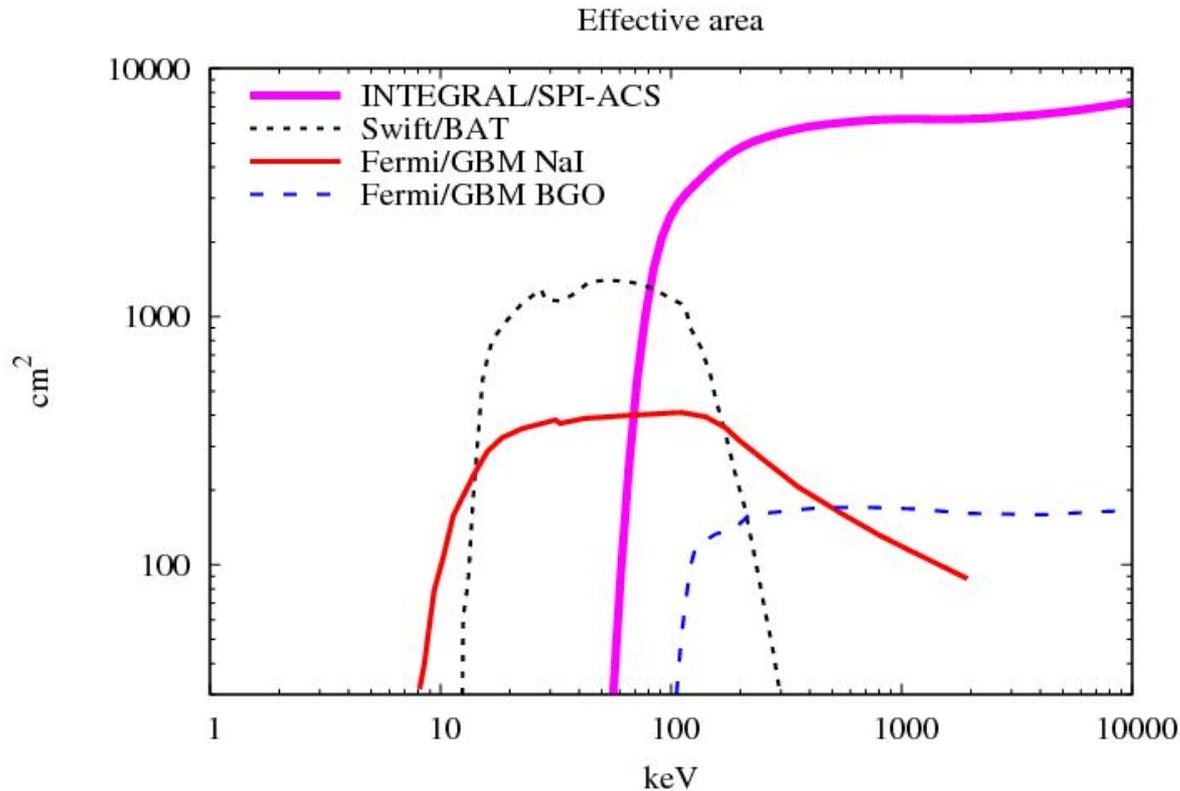
> 100 keV all-sky
almost no imaging or spectral resolution



unique > 100 keV, both FoV and all-sky

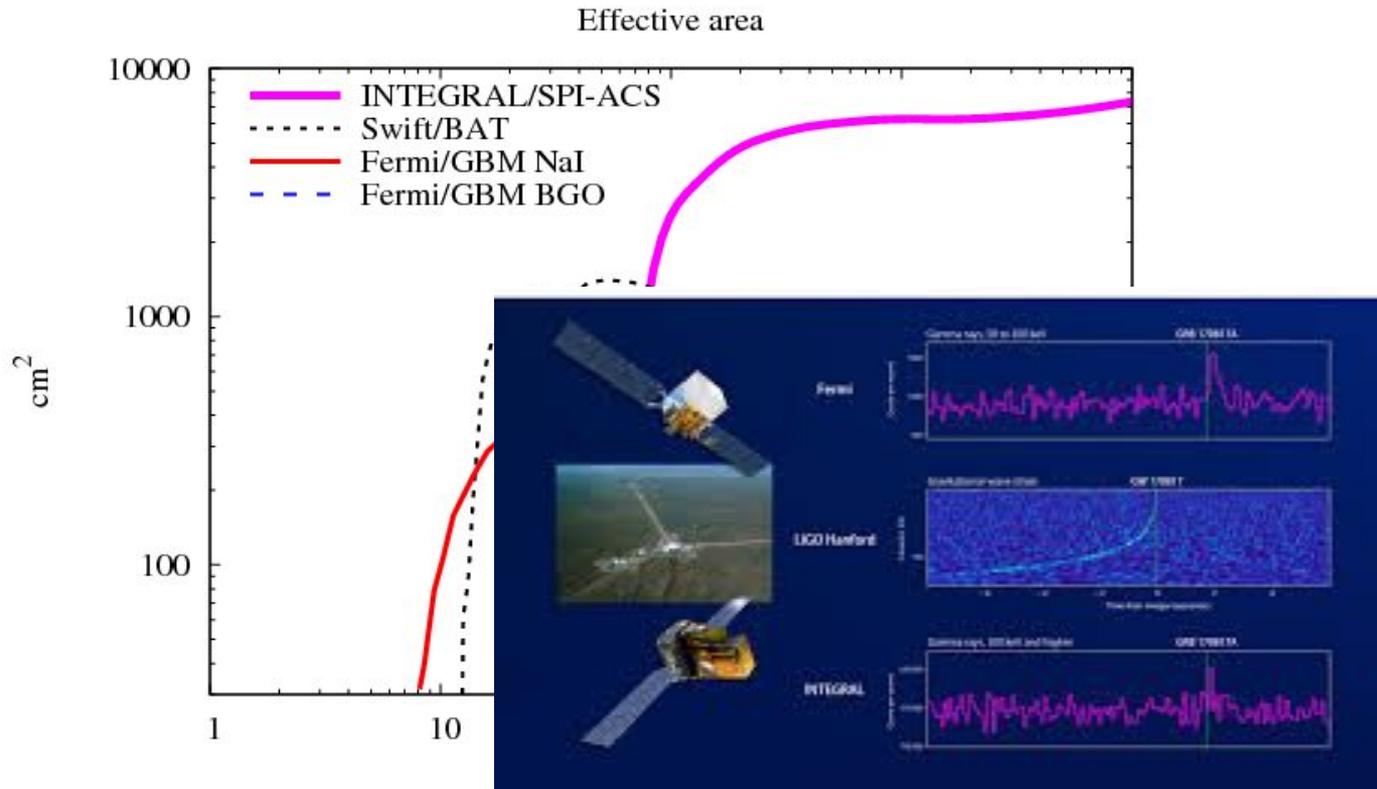
* Astronomer for scale (175 cm)
 VS+ 2017

Challenges of all-sky detection with INTEGRAL SPI-ACS



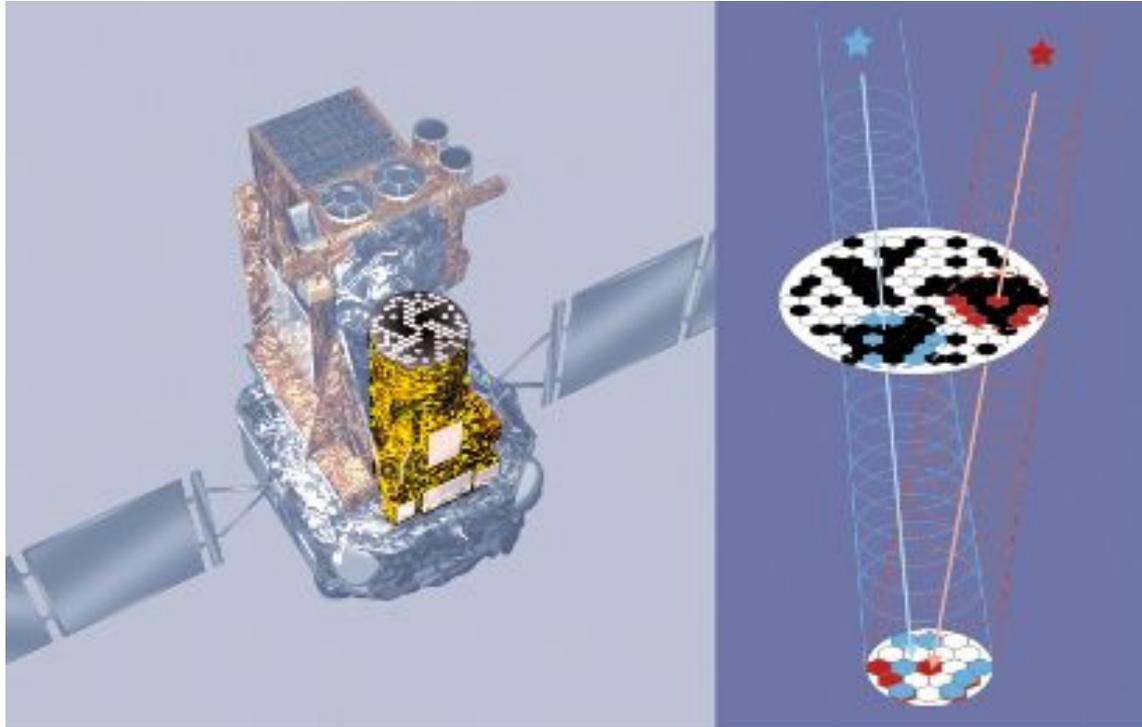
- Exceptional GRB detection capability > 100 keV, all sky
- Poor localization and spectral characterization all-sky
- We do not usually send GCN Circ with SPI-ACS GRB detections
- We **opted for interoperability**, joining observations with other missions, e.g. by **IPN multi-spacecraft gamma-ray localization**.
- Full public data available through an **online analysis, APIs**.

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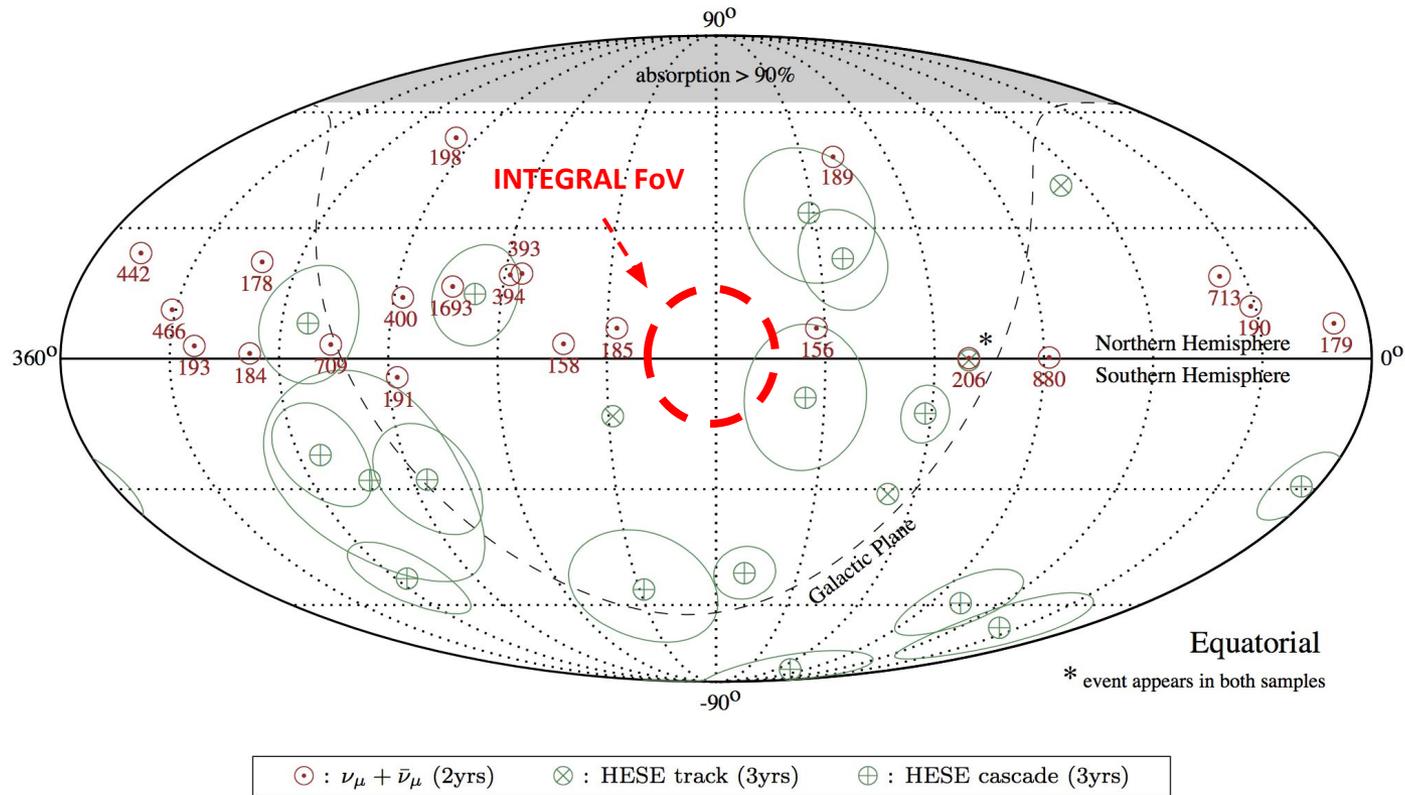
INTEGRAL Coded Masks



INTEGRAL detectors use coded mask technology, similar to Swift/BAT and SVOM/ECLAIR, but in **3 keV - 10 MeV** energy range

Yielding large **30 x 30 deg FoV**, but high background

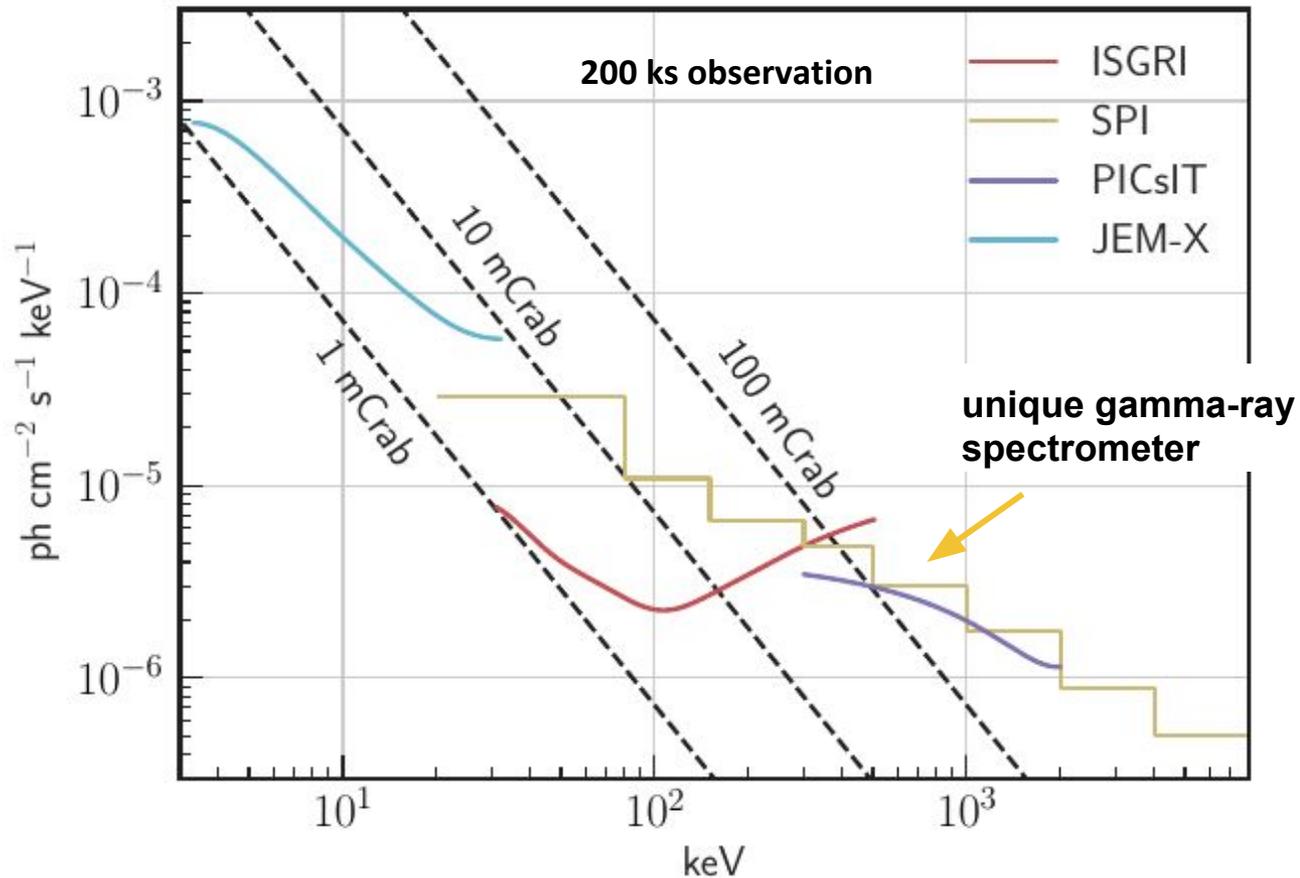
INTEGRAL FoV matches neutrino localization uncertainty



the INTEGRAL Field of View (FoV) about **30 x 30 deg** depends on instrument

localization accuracy depends on source S/N, from 15 arcmin to 10 arcsec

INTEGRAL FoV matches neutrino localization uncertainty

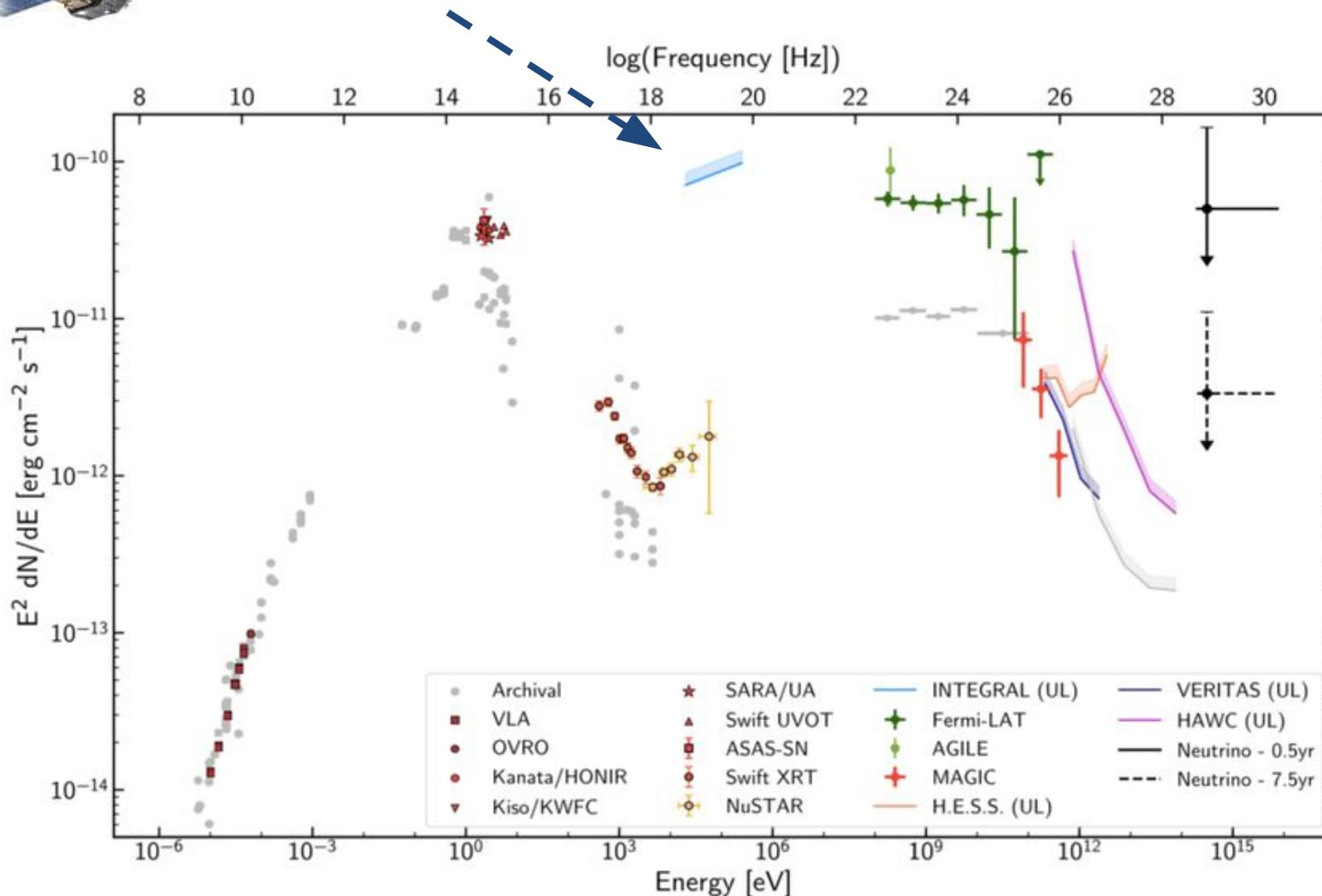


Reaches sensitivity of $\sim 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ in 25-80 keV in a typical 2-day observation

TXS 0506+056 flare

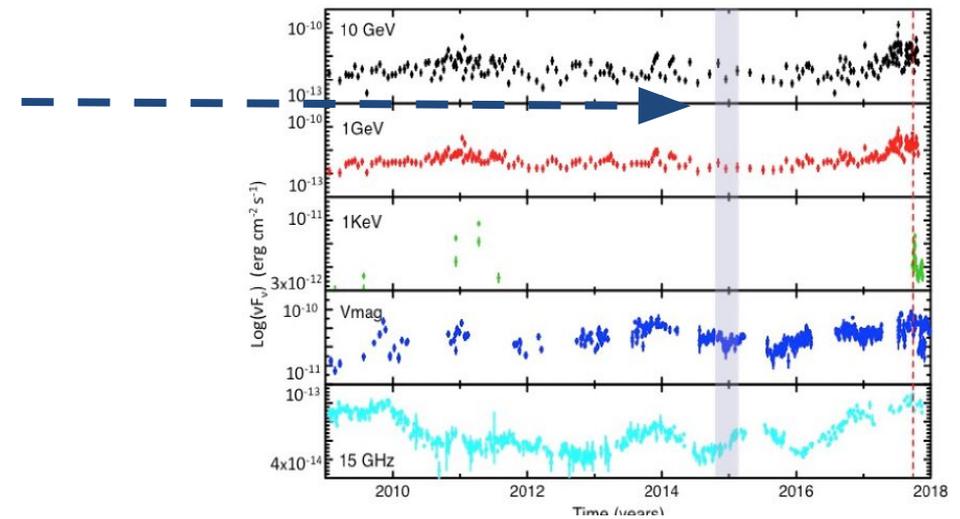
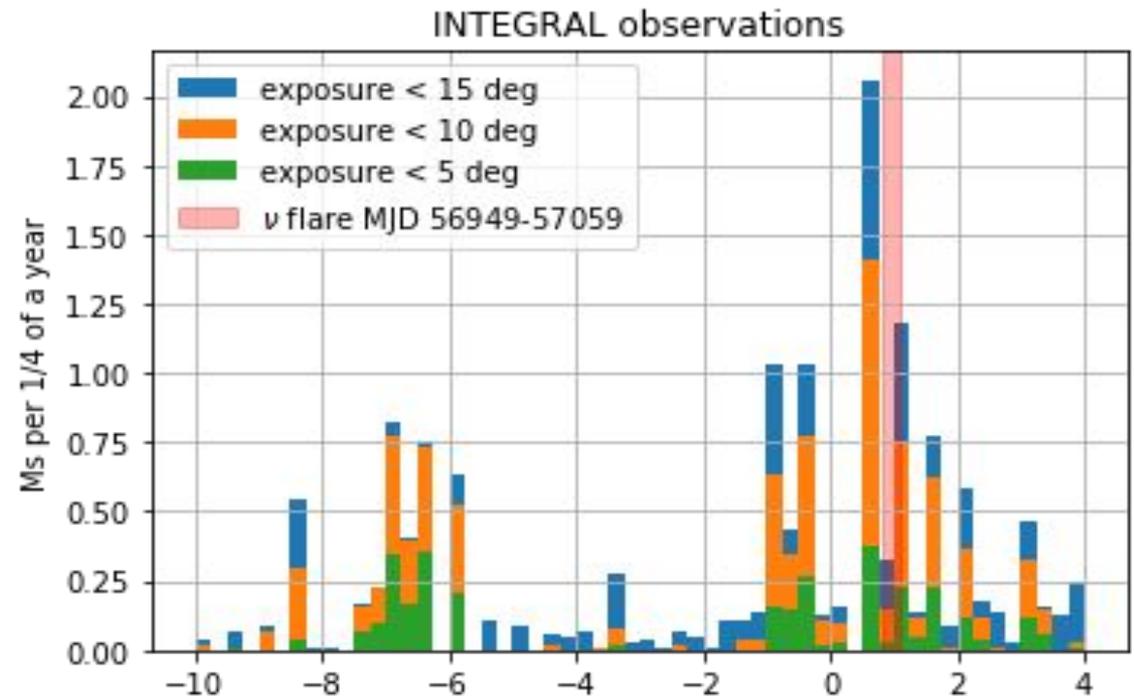
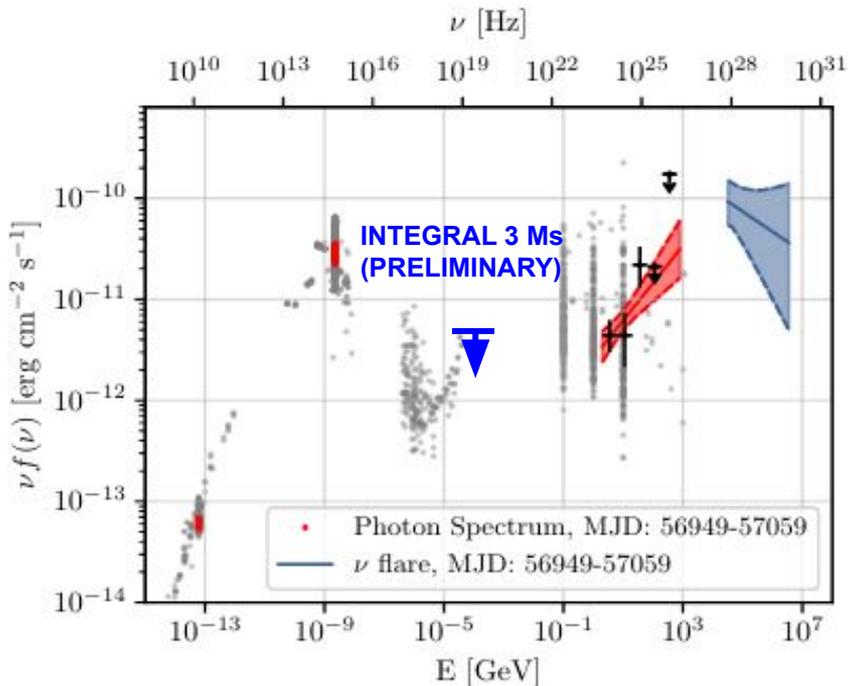


INTEGRAL serendipitous (by chance, not dedicated) observation



TXS 0506+056 2015 flare

INTEGRAL has also observed location of TXS 0506+056 around the time of the 2015 flare, setting an upper limit comparable to average flux, **excluding any coincident hard X-ray flare**



plot from Padovani+ 2018

Other observations

With 17 years of archival data, rather large FoV, a lot of historic neutrino events were well observed. The upper limits are set, interpretation is pending.

It would help to have a recent catalog of past neutrino events to perform a comprehensive study.

In real-time, we perform automated analysis, and pay attention to schedule follow-ups (for which we have a dedicated program).

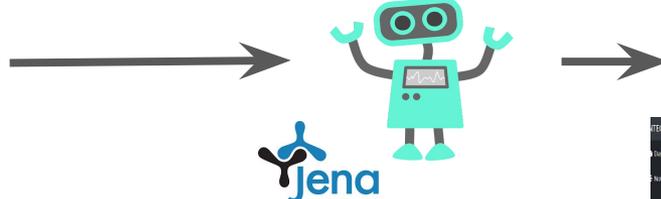
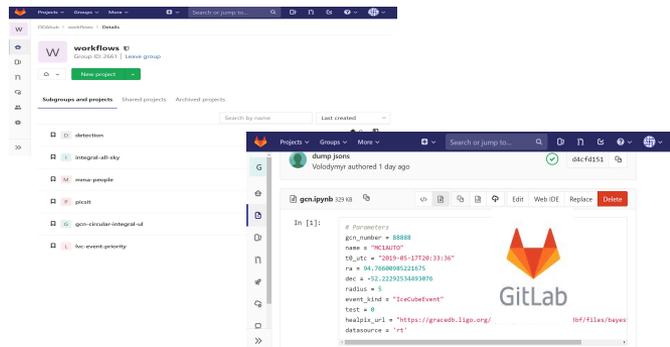
“Standard” INTEGRAL transient analysis: end to end

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

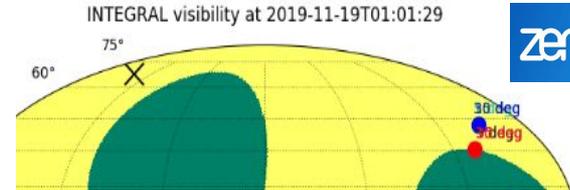


Shift (24/7)

The image is a screenshot of the 'INTEGRAL Transients' dashboard. It features a sidebar with navigation options like 'Dashboard', 'Alert view', 'Overview', 'Event', 'INTEGRAL Data', 'Swiftcraft', and 'INTEGRAL Status Schedule'. The main content area shows a table of event details and several charts, including a histogram of event counts.

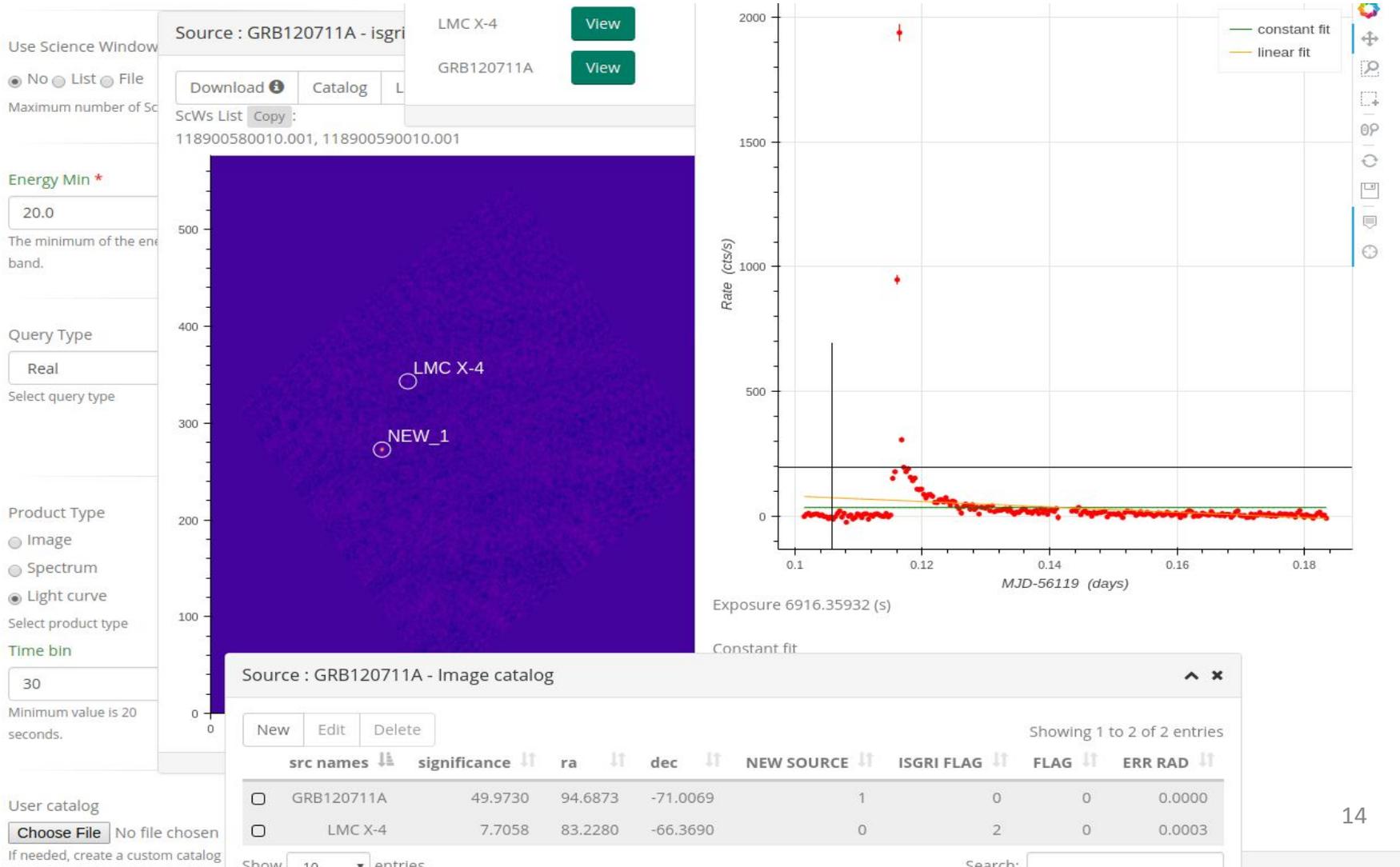
TITLE: GCN CIRCULAR
 NUMBER: 25914
 SUBJECT: IceCube-191001A: No counterj
 DATE: 19/10/01 23:23:15 GMT
 FROM: Maeve Doyle at U College Dul

VOEvent, GCN, ATel, Kafka, etc



Public Online Analysis for INTEGRAL

To facilitate exploitation of the INTEGRAL data, we made a public online analysis, frontend and API (Neronov+ 2020) <https://www.astro.unige.ch/cdci/astrooda/>, https://github.com/cdcihub/oda_api_benchmark/



Conclusions and INTEGRAL future

INTEGRAL unique capabilities for multi-messenger prompt observations and follow-up

1. For **prompt gamma-ray counterparts**: 85% duty cycle, stable background, highly competitive **all-sky** sensitivity, down to 10^{-7} erg cm⁻² s⁻¹ (75 - 2000 keV) in 1 second with complementary role of every instrument
2. serendipitous and 30 x 30 deg FoV observing in 3 keV - 10 MeV down to 10^{-11} erg cm⁻² s⁻¹ in 100 ks

Fast pipeline processing and efficient team organized for organizing expert contributions in a rapid reaction system.

INTEGRAL will operate at least until the end of 2021, likely longer, and will continue providing unique contributions to multi-messenger follow-ups