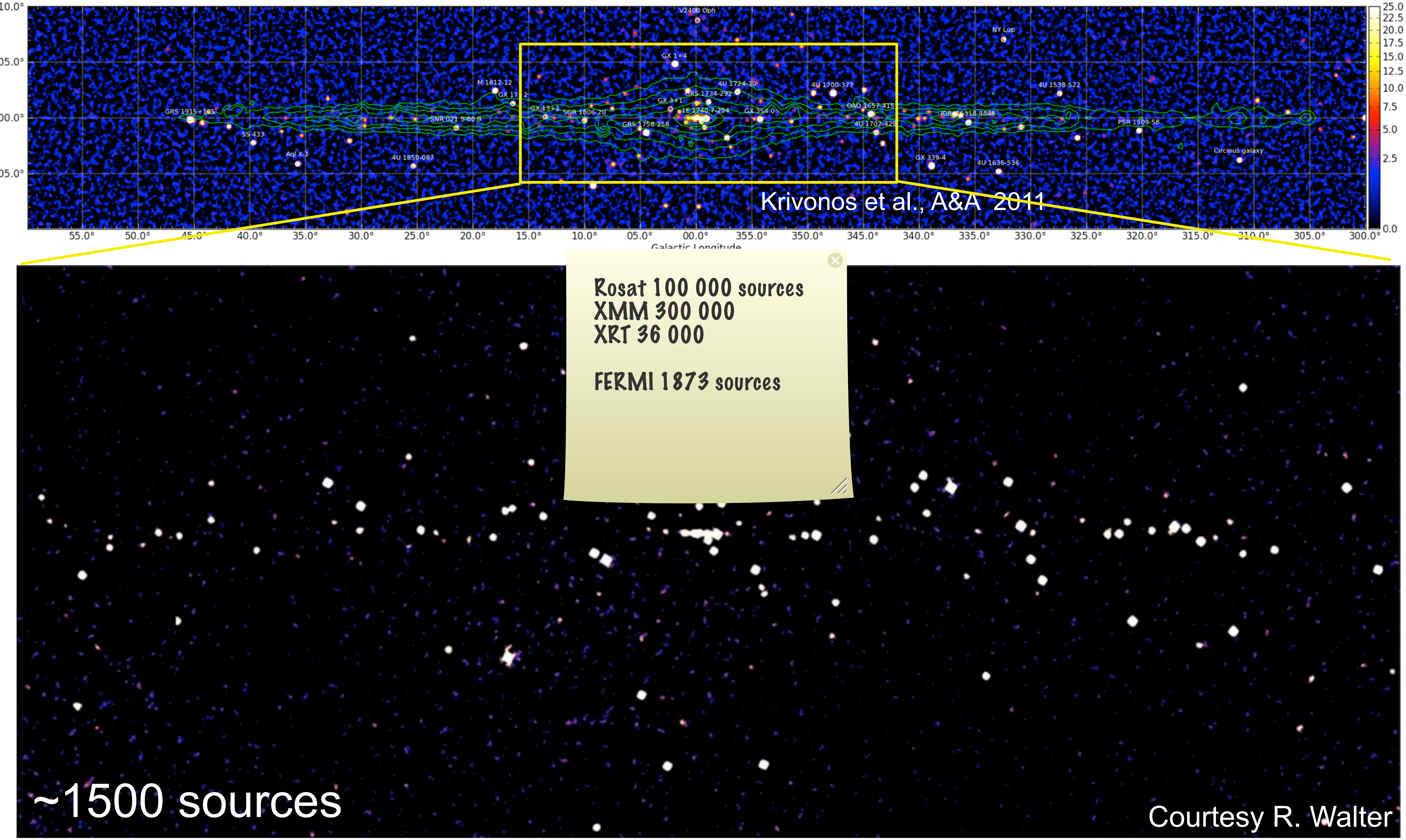
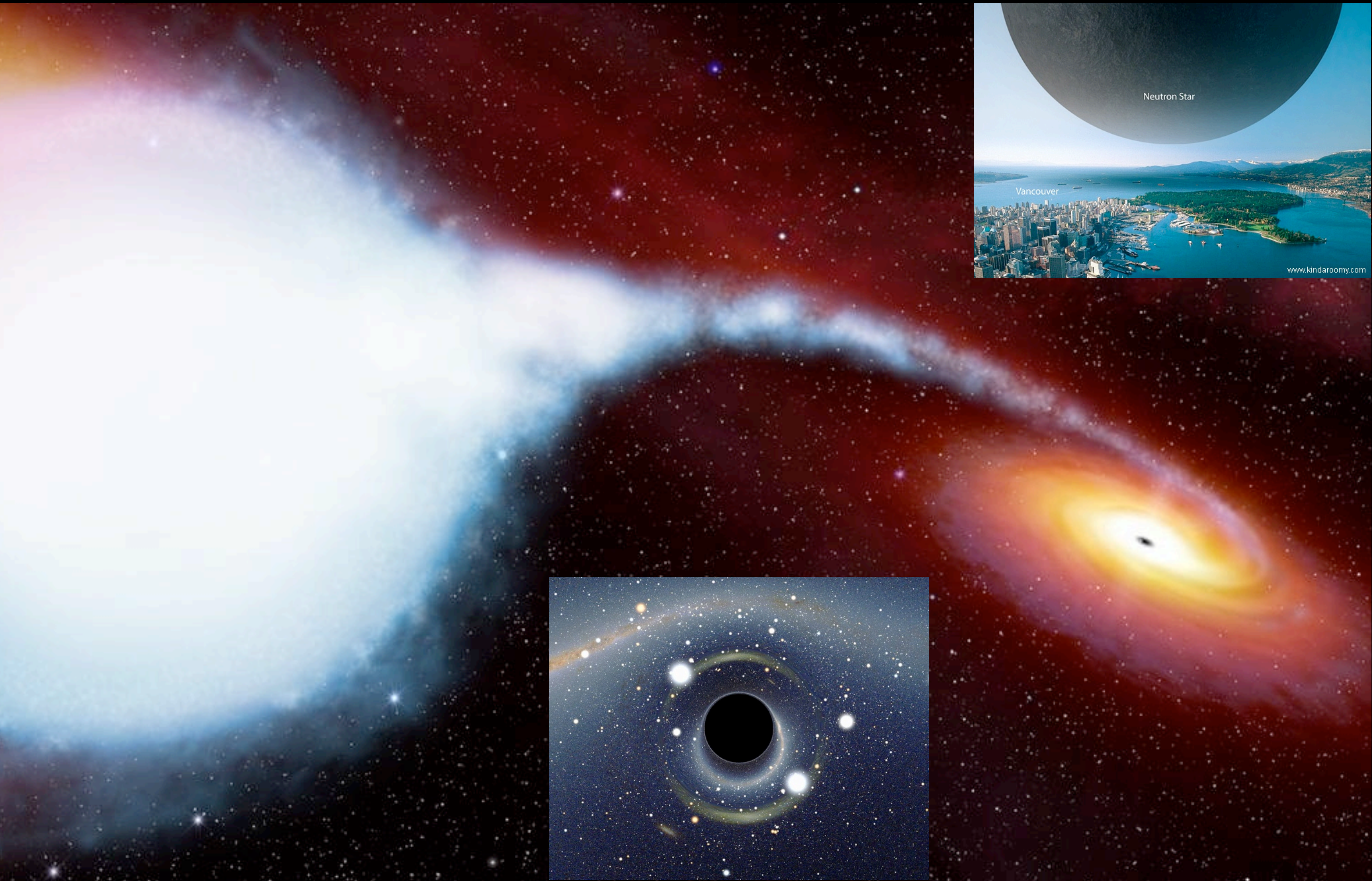
Near real time data analysis at the INTEGRAL science data centre: ten years of rewarding effort.

C. Ferrigno, E. Bozzo, R. Rohlfs
V. Beckmann, N. Mowlavi, T. J.-L. Courvoisier

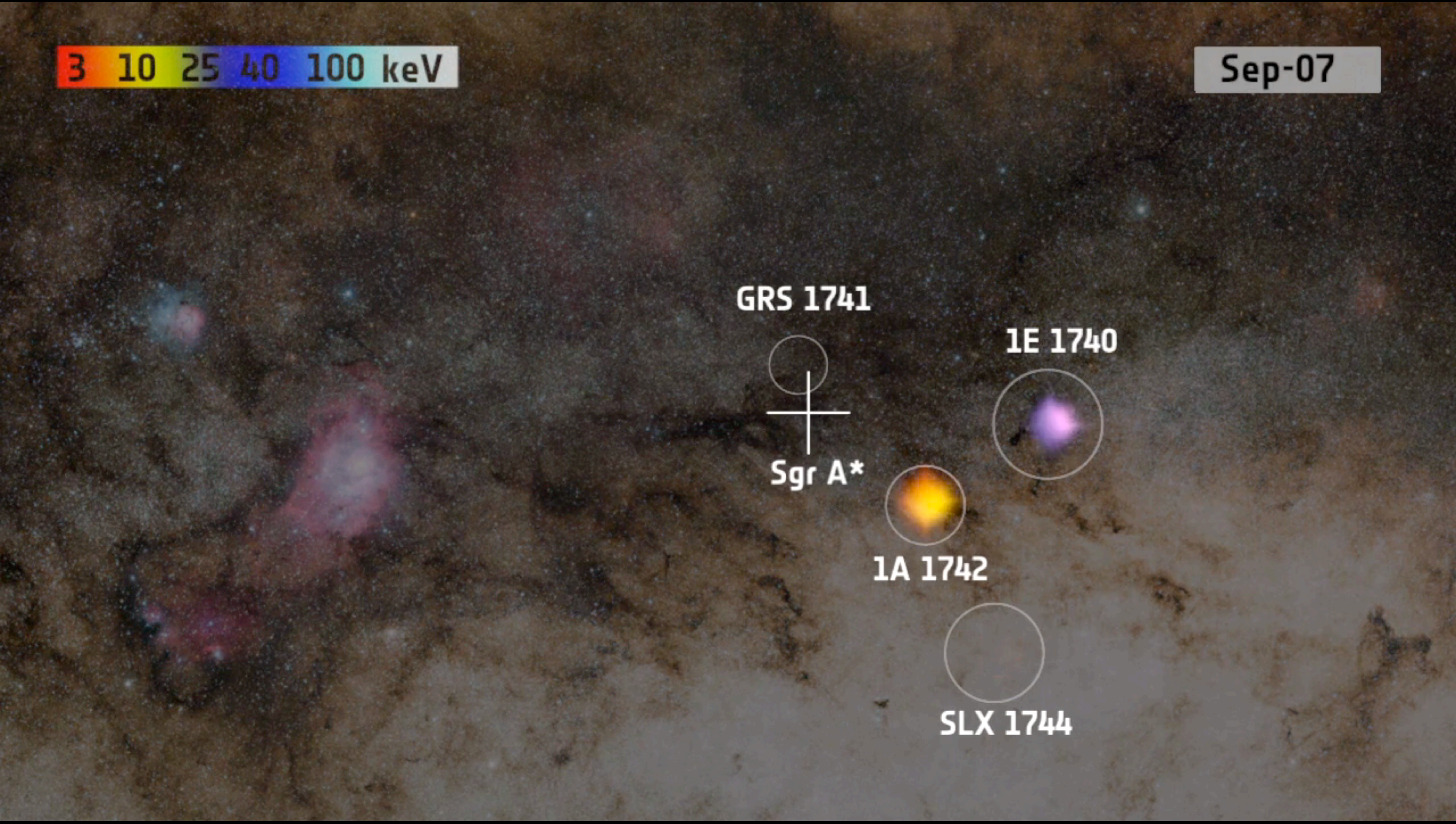
The hard X-ray sky (15-150 keV)



White dwarfs, neutron stars or black holes may accrete matter and produce enormous energy, detectable in X-rays.

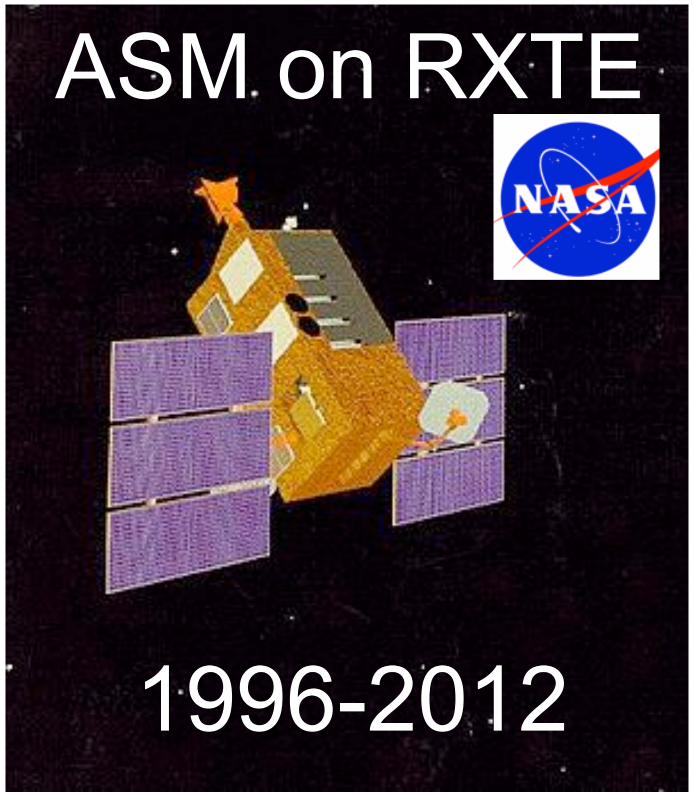


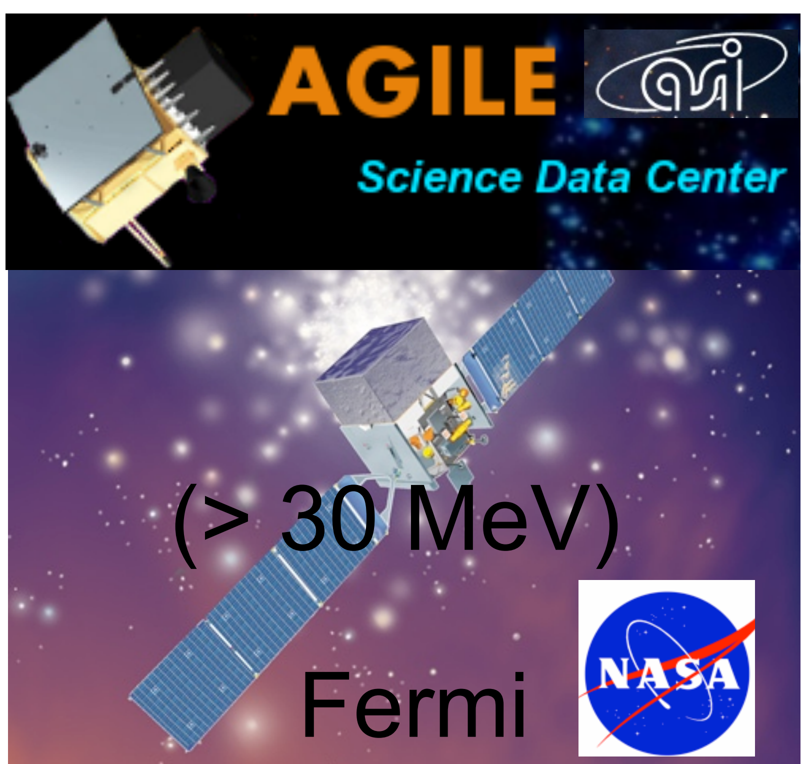
Sources are variable, phenomena unpredictable: a human expert monitoring is fundamental

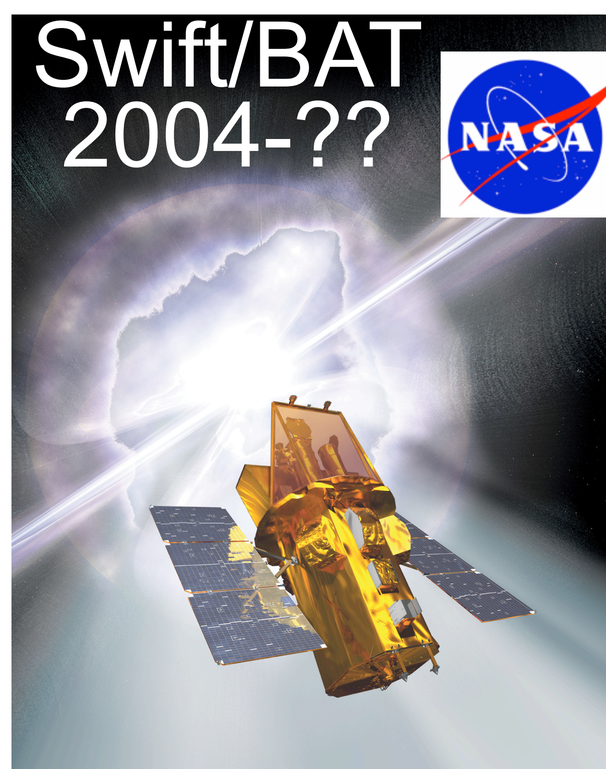


Trigger study of important transient sources.

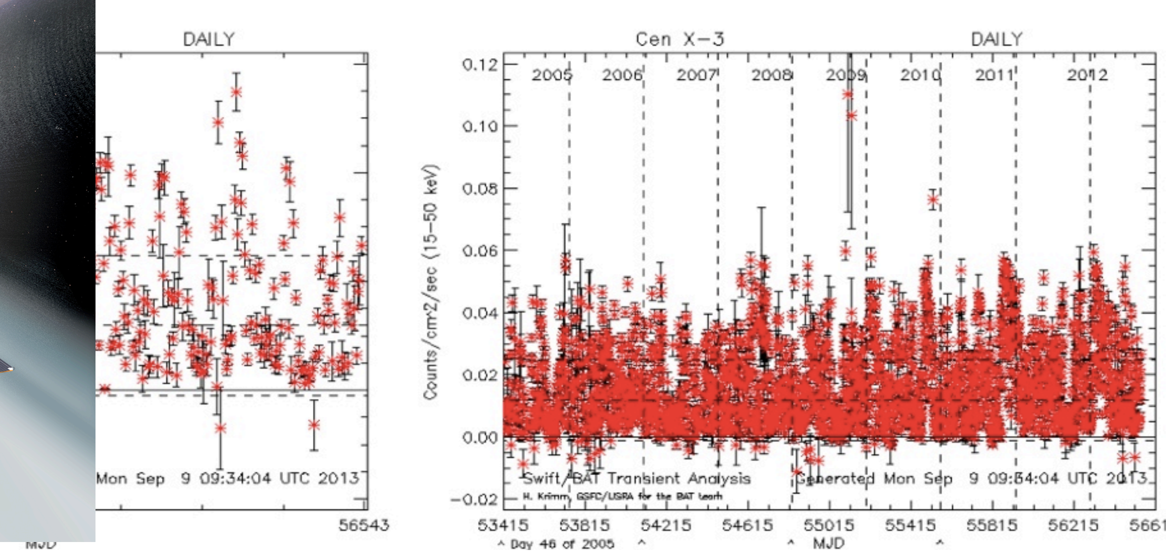
High-energy facilities with monitoring capabilities





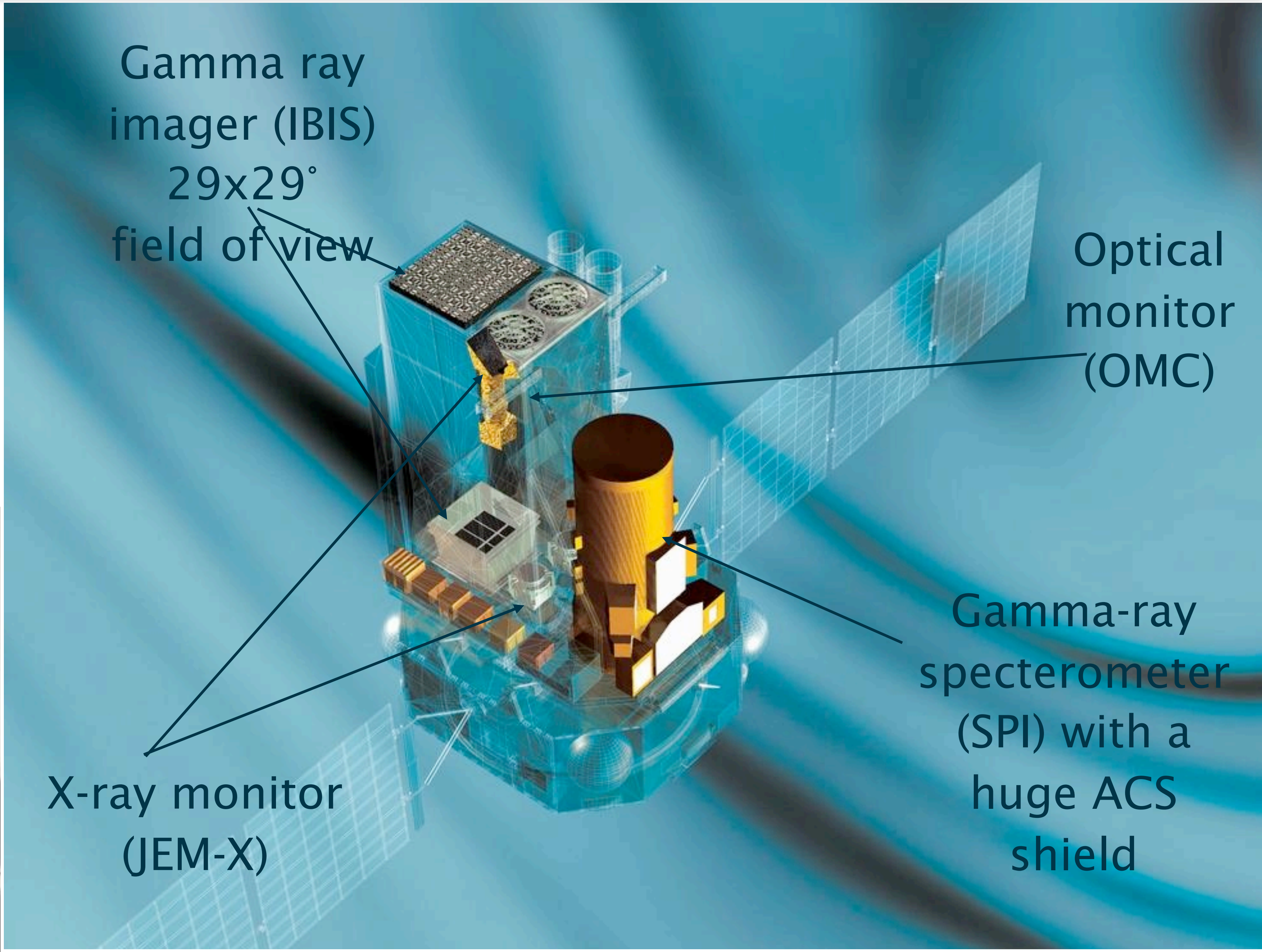


Scaled Map Transient Analysis for Cen X-3



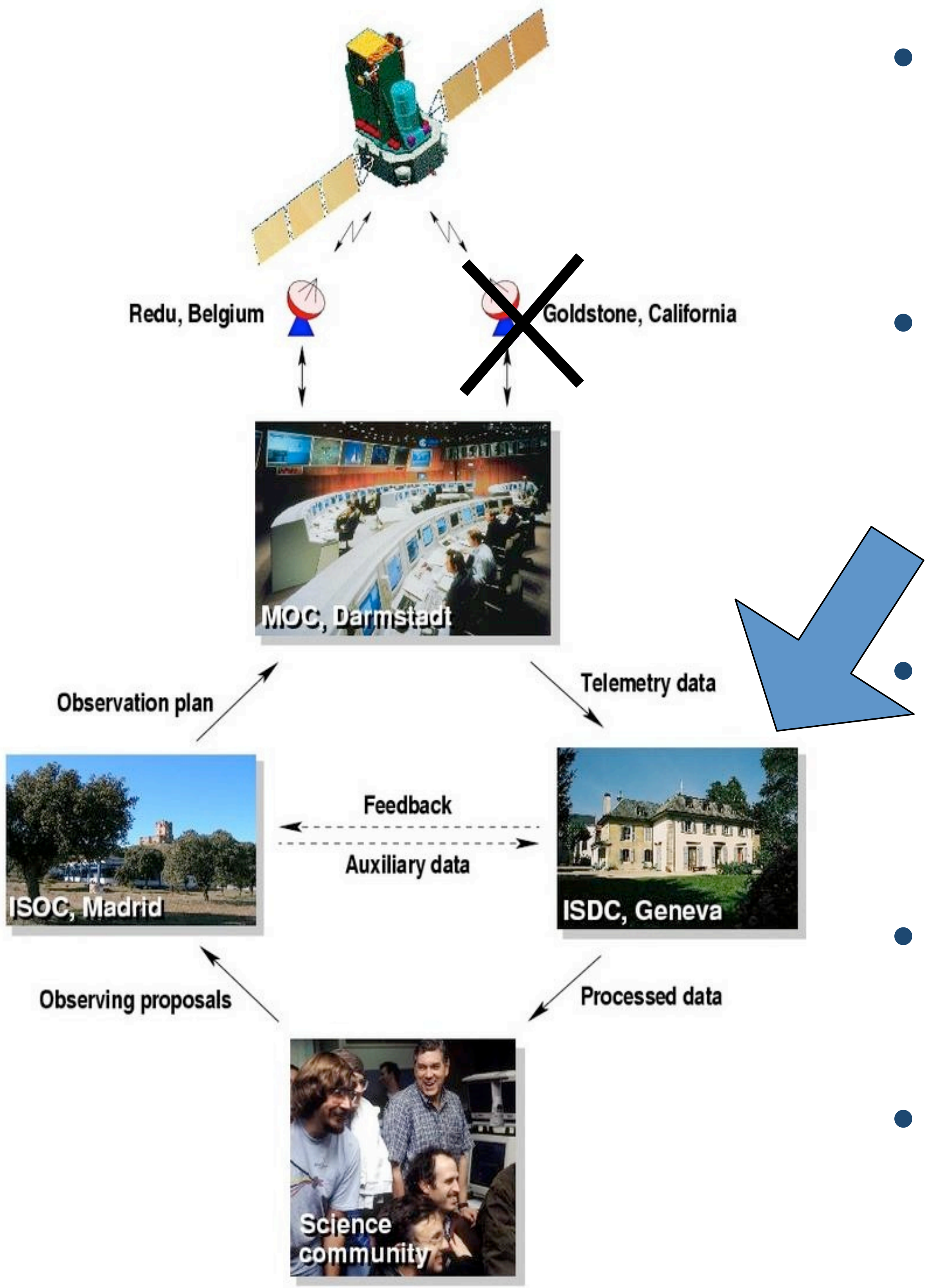
INTErnational
Gamma-Ray
Astrophysics
Laboratory:

INTEGRAL
(2002-??)



Unique coverage from
3 keV to 30 MeV

INTEGRAL data flow



- INTEGRAL controlled at the ESA Mission Operation Center in Darmstadt
- The ISDC located in Switzerland processes the INTEGRAL telemetry stream in Near Real Time (~1GByte/day, 7d/7 24h/24)
- Data are made immediately available on a FTP server as soon as they are decoded
- A team ensures that the automatic processing works 24/7
- Consolidated data are distributed and archived later

A long story

1994 ESA AO for INTEGRAL
- Geneva-led ISDC consortium

1995 Start of set-up

1996 User requirements
- Ended by User requirement review (ESA led)

1997 Software requirements
- Ended by software requirements review (ISDC+ESA)

1998 System architecture
- Ended by architecture review (led by ISDC)

1999-2000 Coding
- Data reception/preprocessing/correction pipeline
- Binning/imaging/spectral and lightcurve extraction pipeline
- Data archive organization

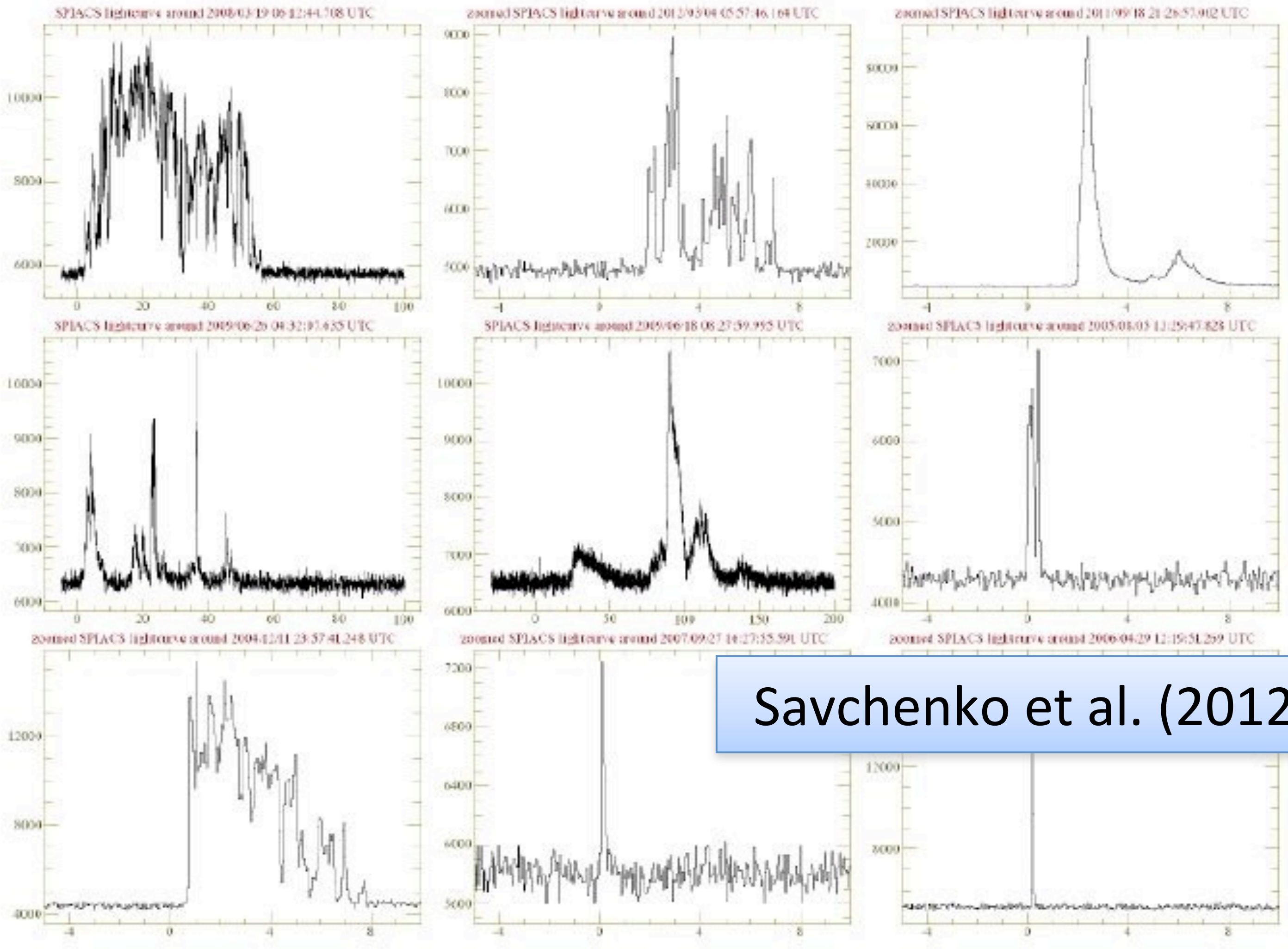
2001 Consolidation
- Organization of off-line analysis
- Calibration handling
- Scientific performances
- Ground segment tests

2002+ Launch; start of operations
- Near real time data monitoring
- Processing and dissemination of data
- Data archive management
- Software releases 1.0 – 10.0
- User support
- High-level data from other missions

See R. Rohlf's and R. Walter's presentations

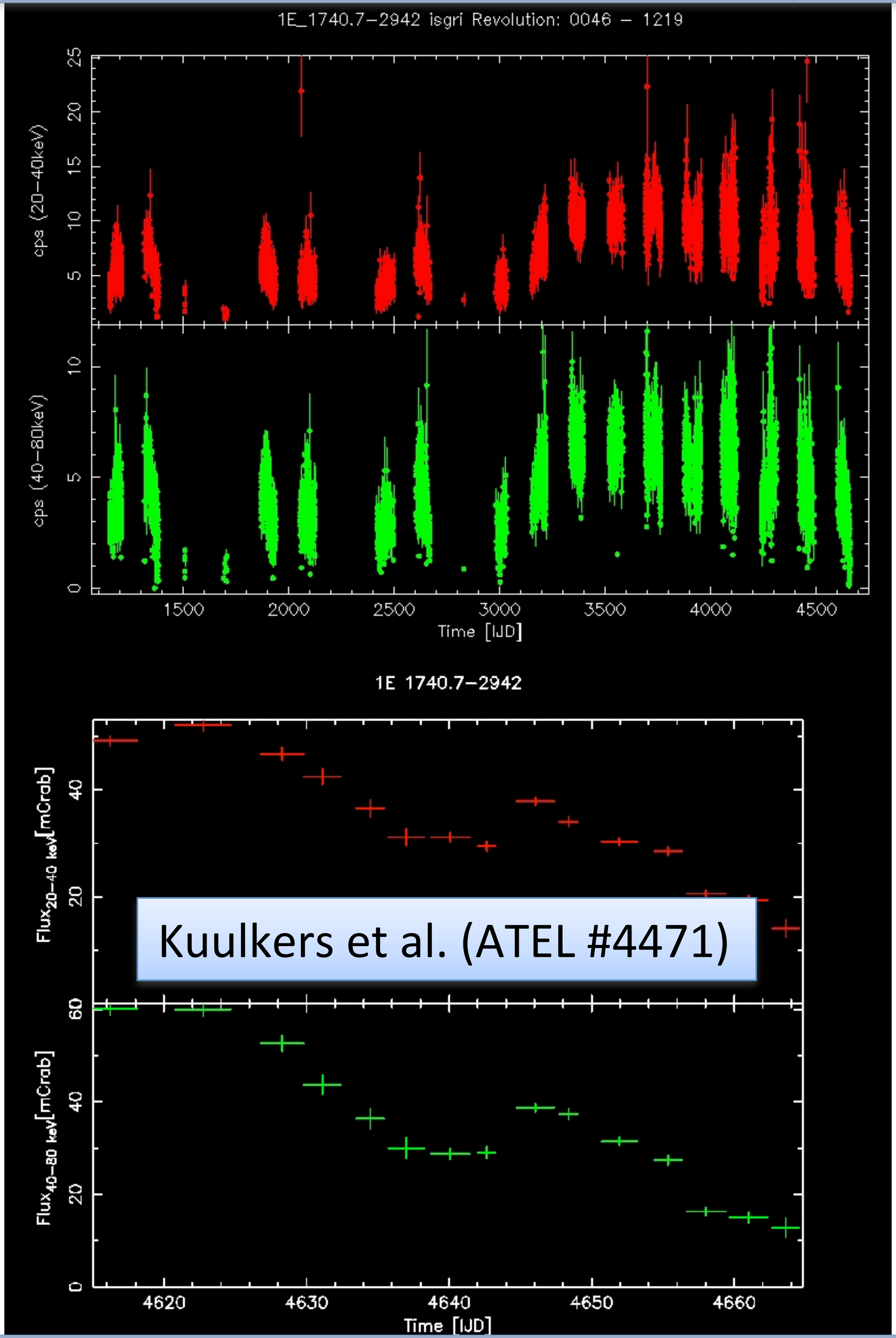
Gamma Ray Bursts

- Flashes of Gamma-rays (>20 keV) lasting from a fraction of a second to hundreds of seconds followed by afterglow emission at lower energy.
  - GRB are believed to be linked to the birth of a black-hole.
- INTEGRAL is equipped with ground based S/W to detect GRB on the fly: IBAS.
  - Triggers from the IBIS TM stream are sent worldwide for immediate follow-up (a few seconds after the event/ several per year).
  - SPI/ACS rate is processed, but events have no arrival direction (several per week).



Quick-look of data

- A quick-look analysis is performed, data are scientifically validated by ISDC scientists, who also perform a search for relevant variability patterns of all objects in the field of view to reveal triggers for target of opportunity (TOO) observations
- The guest observer(s) are contacted for immediate publication of results in ATeLs and follow-up observations (time delay 1-2 days).
- *Support to guest observers is also provided on request*

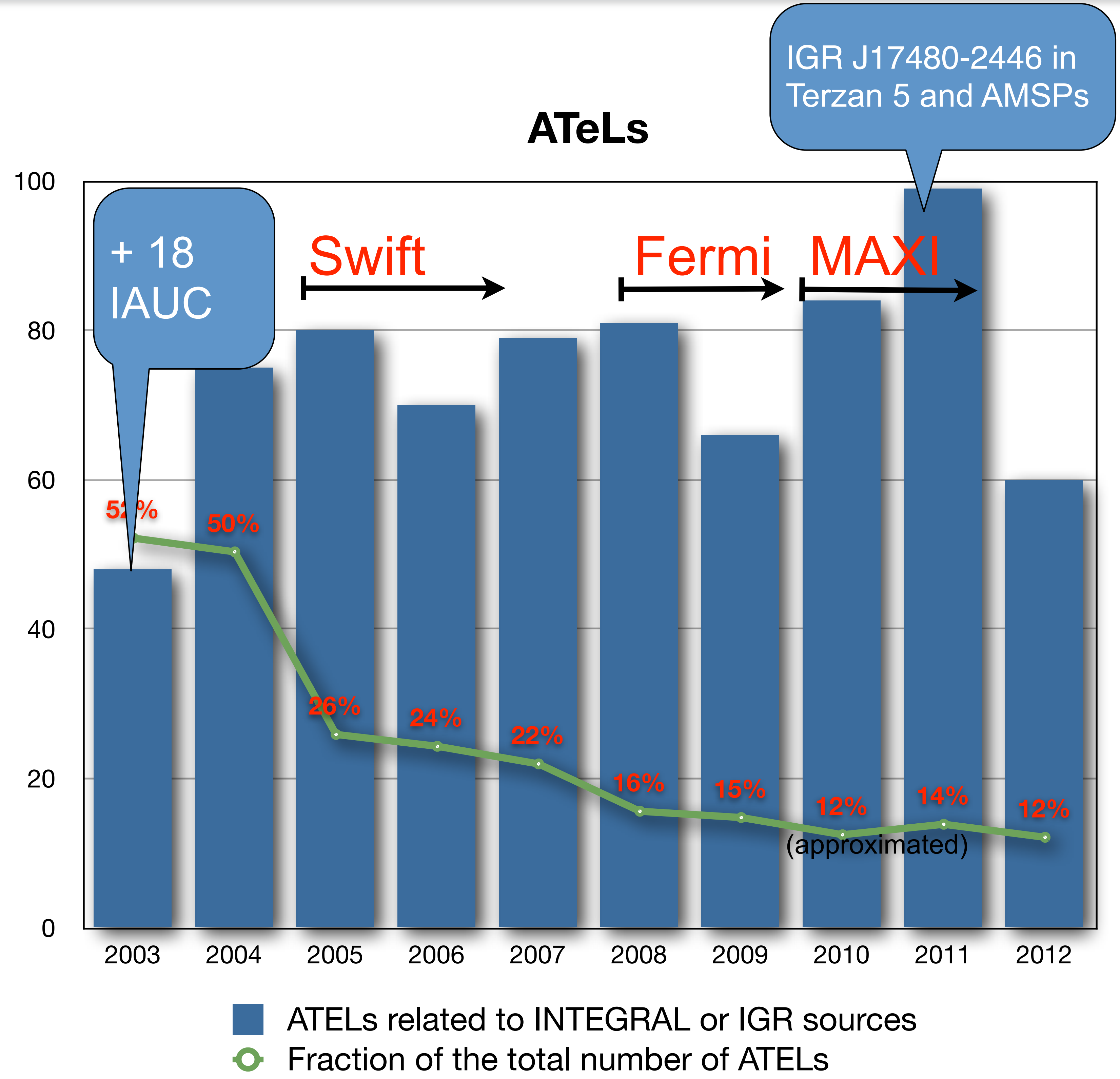


A rewarding effort

- Shift team: one scientist on duty (work-day), one operator (work-day and remote checks during WE), operation coordinator for transients and GRBs, S/W and H/W support (on call 24/7)
- Need for:
  - significant redundancy of experienced staff for a continuous service
  - training and motivation for new scientists arriving to the institute

- Discovery of new sources by INTEGRAL, named as IGRJxxx
- 559 IGR sources, both from survey and quick-look analysis
- Some of the ATeLs reporting the discovery of interesting objects have many citations: Eckert et al., 2004 (35), Baldovin et al., 2009 (20) Bordas et al., 2010 (28).
- Follow-up work leads to referred papers

INTEGRAL and ATeLs



- ATELs related to INTEGRAL or IGR sources are steadily published over the mission lifetime.
- INTEGRAL results occupied half of ATELs during the first two years and possibly boosted the attention to transient X-ray sources
- Other missions and ground based experiments increased the total number of ATELs

IGR J18245-2452

IGR J18245-2452: a new hard X-ray transient discovered by INTEGRAL

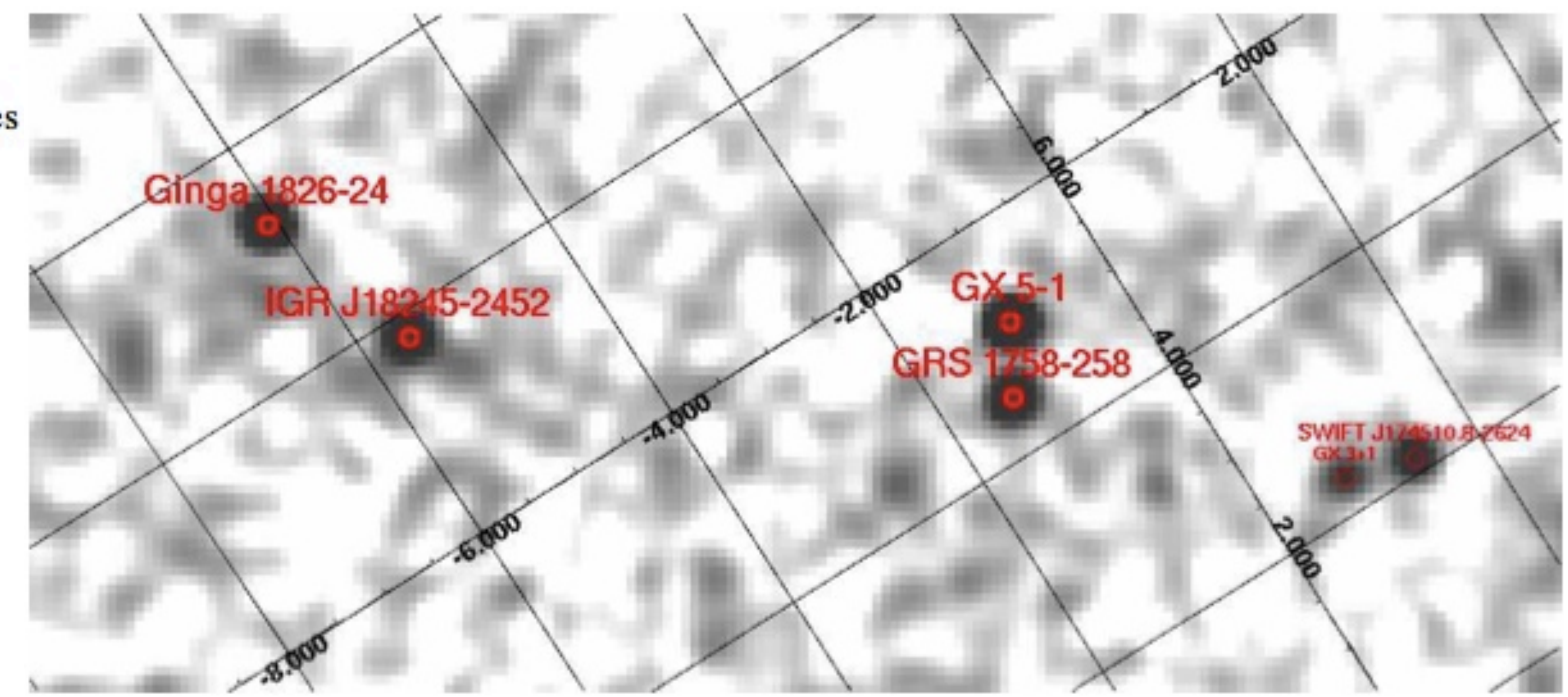
ATel #4925; D. Eckert (ISDC, Switzerland), M. Del Santo, A. Bazzano (INAF/IAPS Rome, Italy), K. Watanabe (FGCU, USA), A. Paizis (INAF-Milano, Italy), E. Bozzo, C. Ferrigno (ISDC, Switzerland), I. Caballero (CEA, France), L Sidoli (INAF-IASF Milano, Italy), L. Kuiper (SRON, Netherlands)
on 29 Mar 2013; 11:18 UT
Distributed as an Instant Email Notice Transients
Credential Certification: E. Bozzo (enrico.bozzo@unige.ch)

Subjects: X-ray, Gamma Ray, Request for Observations, Black Hole, Neutron Star, Transient

Referred to by ATel #: 4927, 4929, 4934, 4959, 4960, 4961, 4964, 4981, 5003

During the observations of the Galactic Center performed on 2013 March 28 from 2:56 to 17:38 (UTC), the hard X-ray imager IBIS on-board INTEGRAL detected a new transient source, dubbed IGR J18245-2452, at:
RA=276.1383
DEC=-24.8793
with an associated uncertainty of 1.4 arcmin (all uncertainties

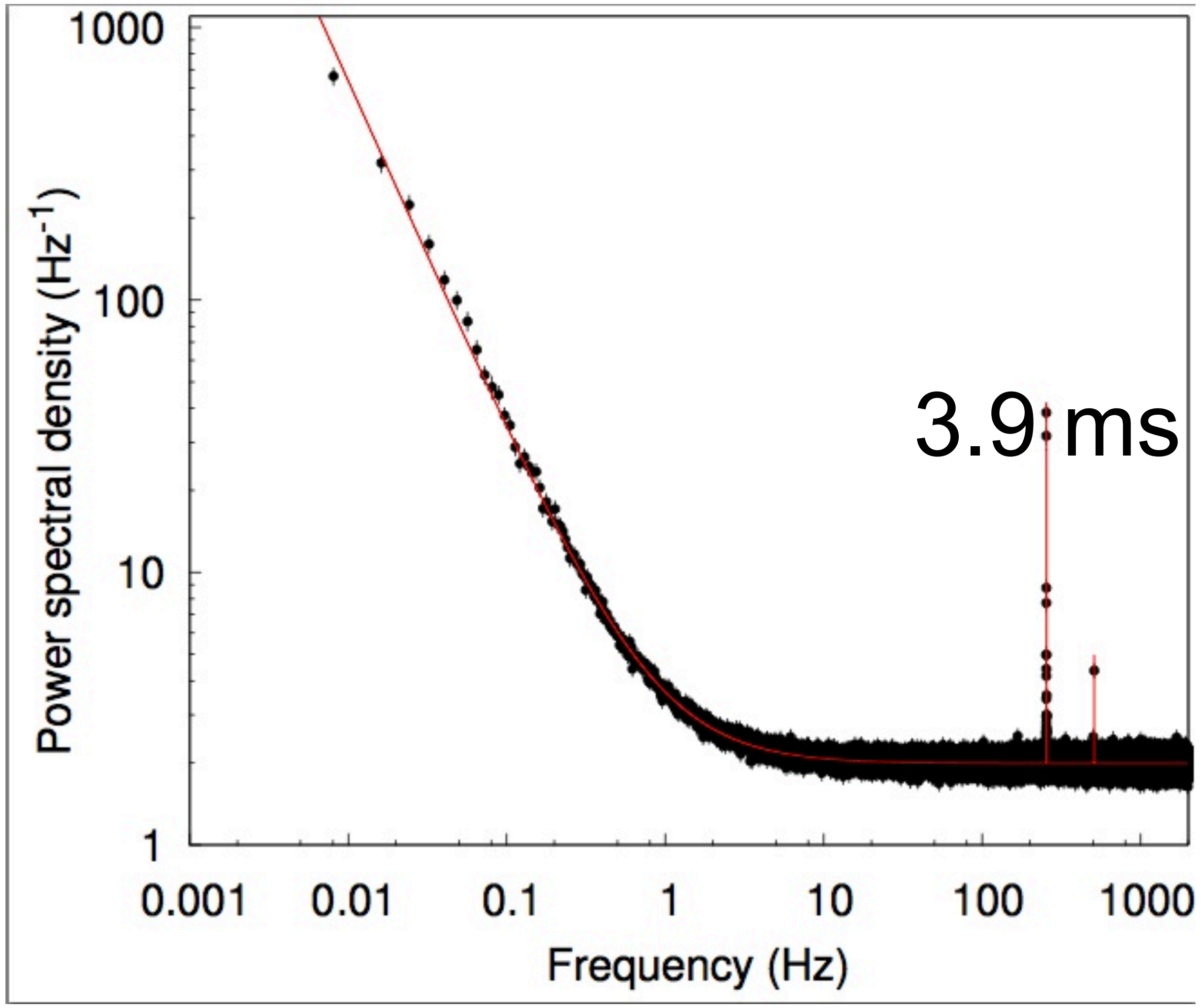
- We triggered Swift, XMM-Newton, Chandra,INTEGRAL, ATCA follow-up observations
- Others have looked into the HST archive

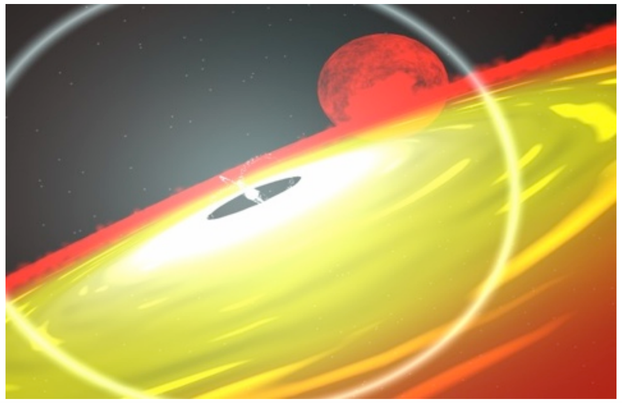


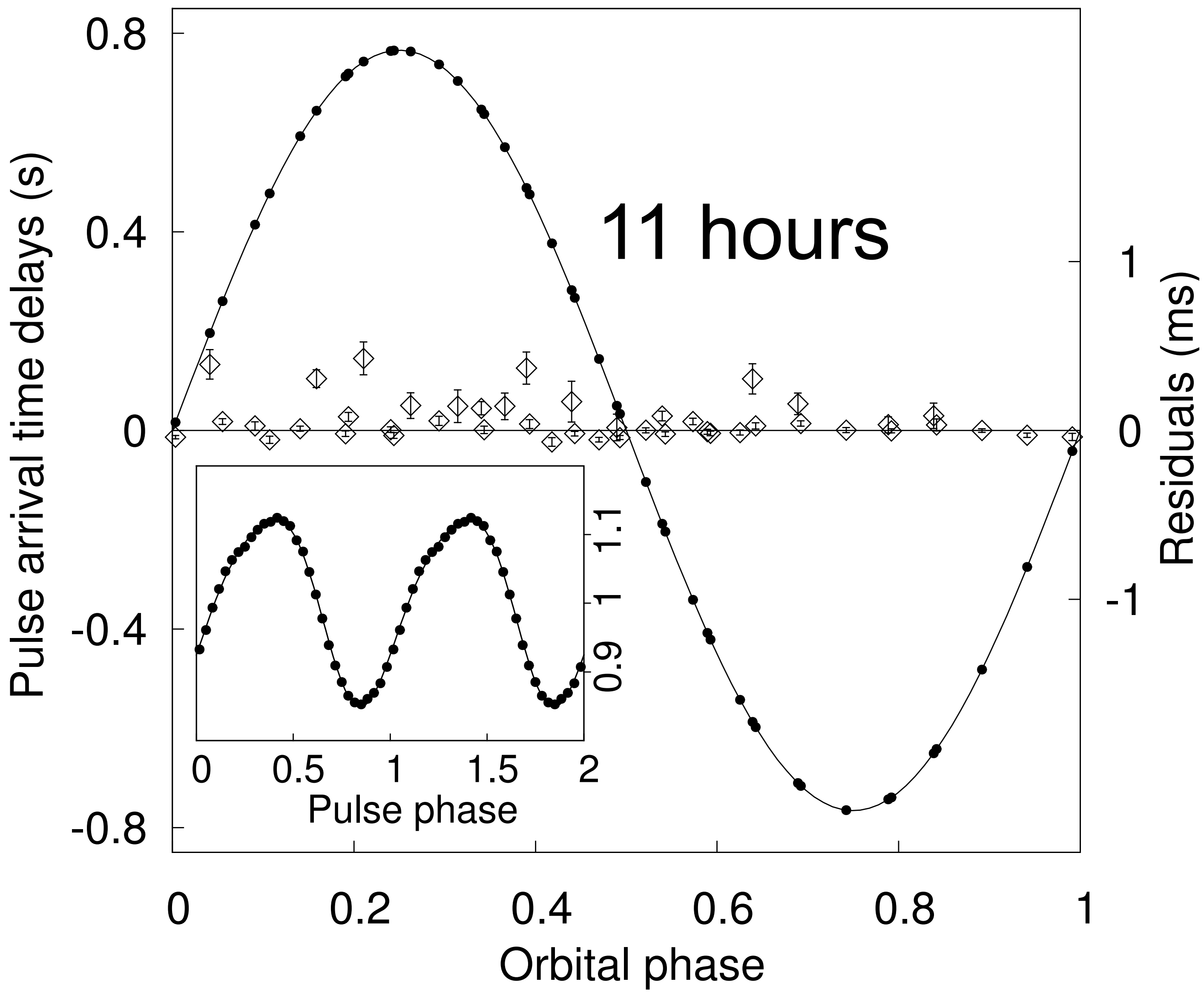
- Discovered during our quick-look of INTEGRAL data
- Located in the globular cluster M 28

Need for high S/N !

Sensitive X-ray telescope: 30 ks + 70 ks XMM-Newton TOOs
It is the 15th accreting millisecond pulsar ... but a special one







Papitto, Ferrigno + (2013)

2013: discovery of the missing link

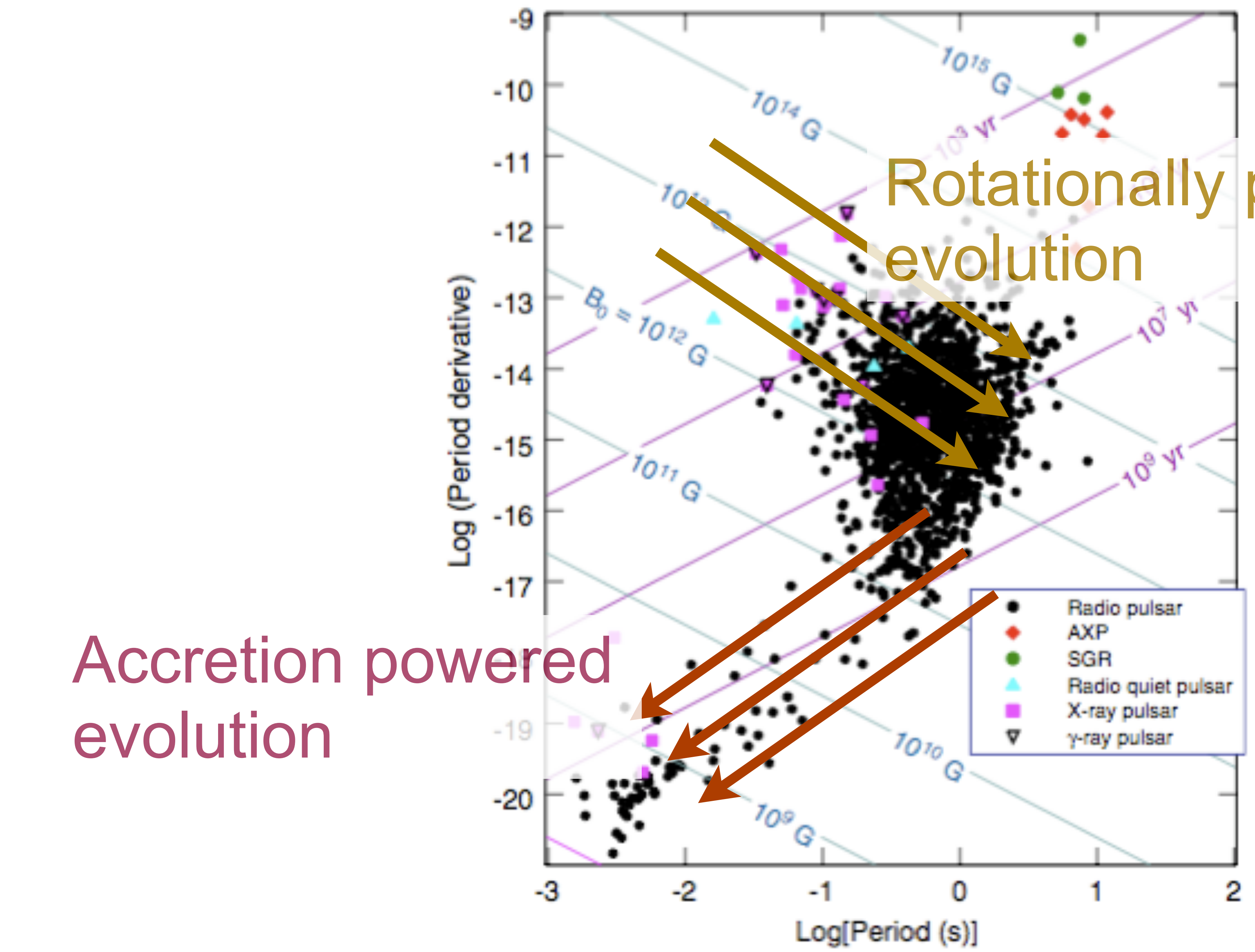
Table 1: Spin and orbital parameters of IGR J18245–2452 and PSR J1824–2452I.

Parameter	IGR J18245–2452	PSR J1824–2452I
Right Ascension (J2000)	$18^h\ 24^m\ 32.53(4)^s$	
Declination (J2000)	$-24^\circ\ 52'\ 08.6(6)''$	
Reference epoch (MJD)	56386.0	
Spin period (ms)	3.931852641(2)	3.93185(1)
Spin period derivative	$< 2 \times 10^{-17}$	
RMS of pulse time delays (ms)	0.1	
Orbital period (hr)	11.025781(2)	11.0258(2)
Projected semi-major axis (lt-s)	0.76591(1)	0.7658(1)
Epoch of zero mean anomaly (MJD)	56395.216889(5)	
Eccentricity	$\leq 1 \times 10^{-4}$	
Pulsar mass function ($M_\odot$)	$2.2831(1) \times 10^{-3}$	$2.282(1) \times 10^{-3}$
Minimum companion mass ($M_\odot$)	0.174(3)	0.17(1)
Median companion mass ($M_\odot$)	0.204(3)	0.20(1)
	X-ray	Radio

Radio signal is weak and characterized by irregular "eclispes", due to intra-binary plasma.

Papitto, Ferrigno + (2013)

Accretion evolution theory (1982)



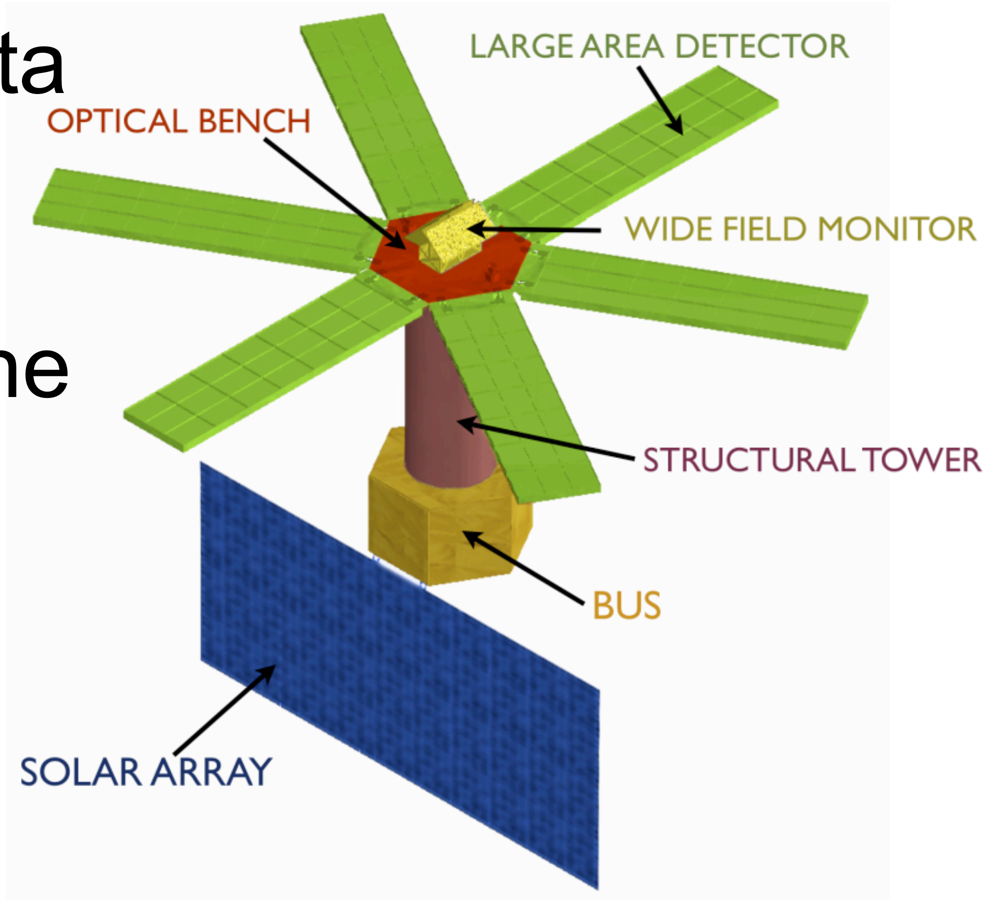
$$B \simeq 6.4\ 10^{19}\sqrt{P\dot{P}}\ [\mathrm{G}]$$

$$\tau = \frac{P}{2\dot{P}}$$

- Accretion of material spins-up an old pulsar giving it new life.
- Search for a link since 1982, first accreting ms pulsar in 1998.

Conclusions

- The quick-look analysis of INTEGRAL data performed at ISDC not only provides scientific validation of data,TOO triggers, and GBRs, but also valuable results for the X-ray transients.
- The visibility of the mission has remained very high also owing to this activity and interesting sources underwent intense follow-up campaigns.
- A monitoring facility and telescopes with high throughput are a winning combination to study X-ray sources.
- New project like LOFT, combining wide field monitor and large detectors will hopefully boost our knowledge.



- LOFT is one of the four M3 mission candidates selected by ESA in 2011 to compete for a launch opportunity in ~2020.
- Payload:
  - Large Area Detector (LAD) Area ~12 m^2 - 200 eV spectral resolution in 2-80 keV band
  - Wide Field Monitor (WFM) 2 sr FOV - arcmim localization - 2-80 keV band -80 cm^2 area