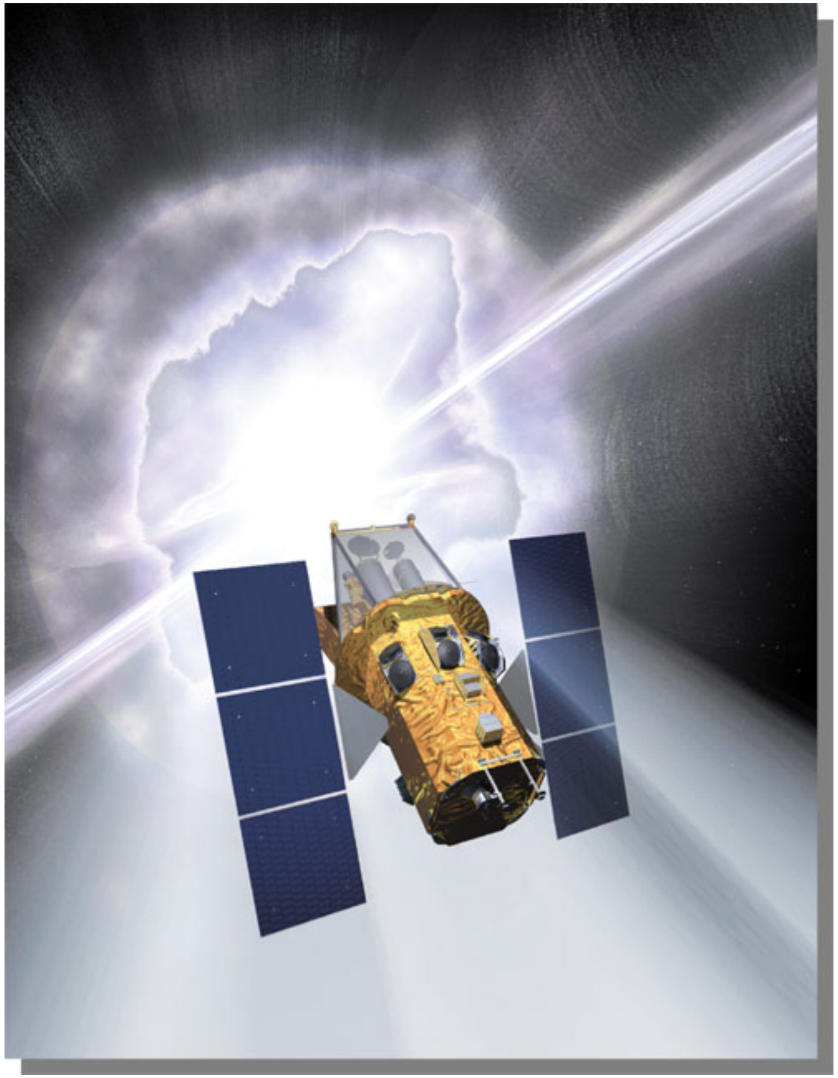
The Swift mission and AGN studies



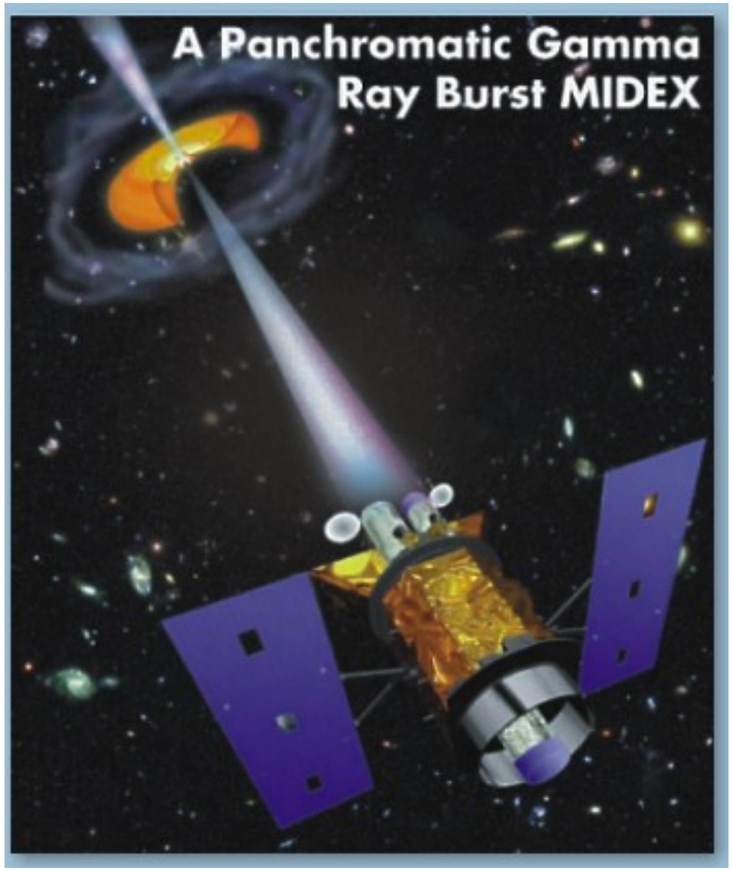
Valerio D'Elia

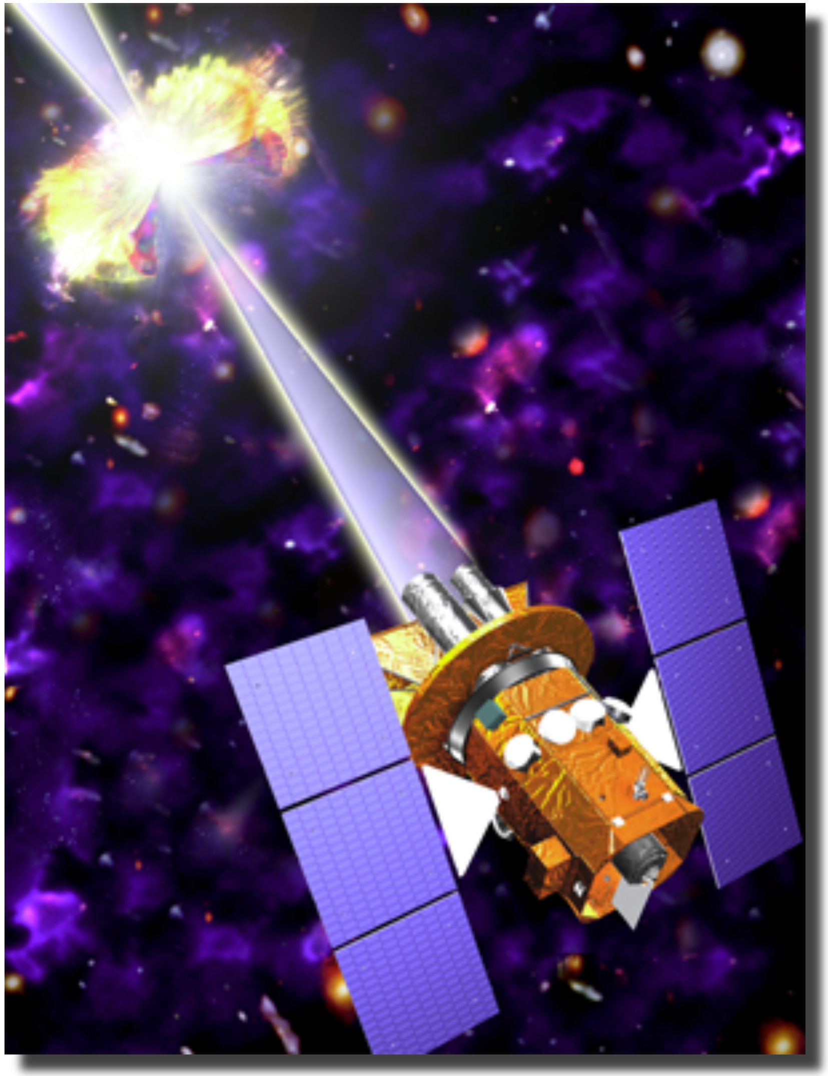
ASI Science Data Center

February 13, 2013

Swift Overview

- Objectives:
  - Study 100s of GRBs during mission
  - Determine origin of GRBs
  - Explore environment near GRBs
  - Use GRBs to probe the Universe
  - Perform all-sky hard X-ray survey
- Rapidly re-pointing spacecraft:
  - ~ 1 minute automated response
  - Quick response to Targets of Opportunity (TOO)
- Data distributed immediately to astronomical community:
  - Burst alerts in seconds
  - Follow-up observations in a day





- Selected by NASA on October 14, 1999.
- Launch: November 20, 2004
- International collaboration:
  - GSFC: lead institution
  - PSU: lead university partner
  - UK & Italy: key hardware collaborators
  - Spectrum Astro: spacecraft provider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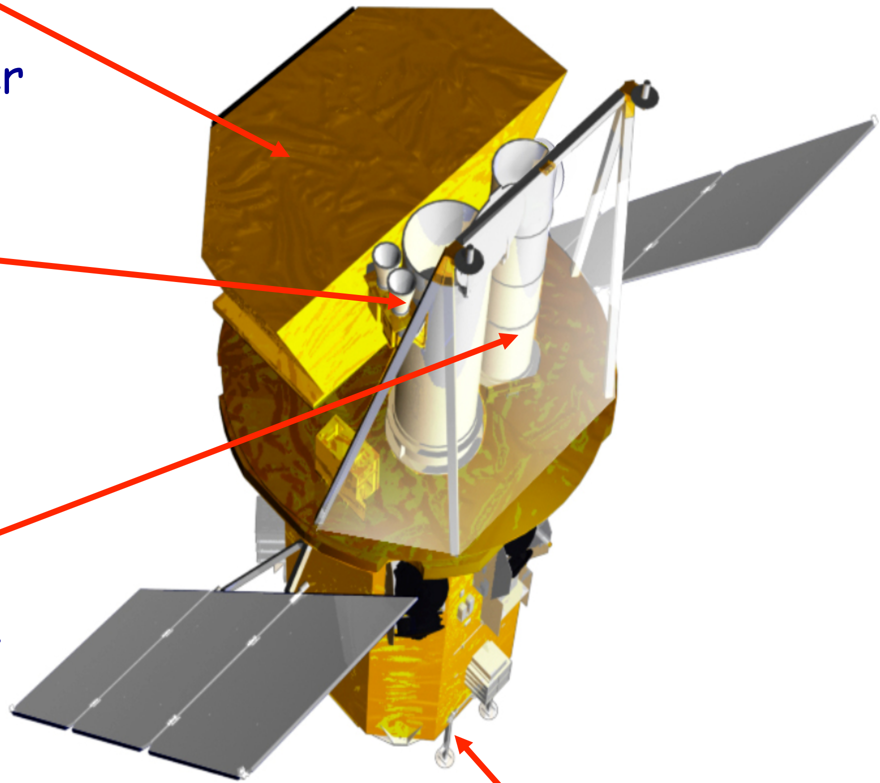
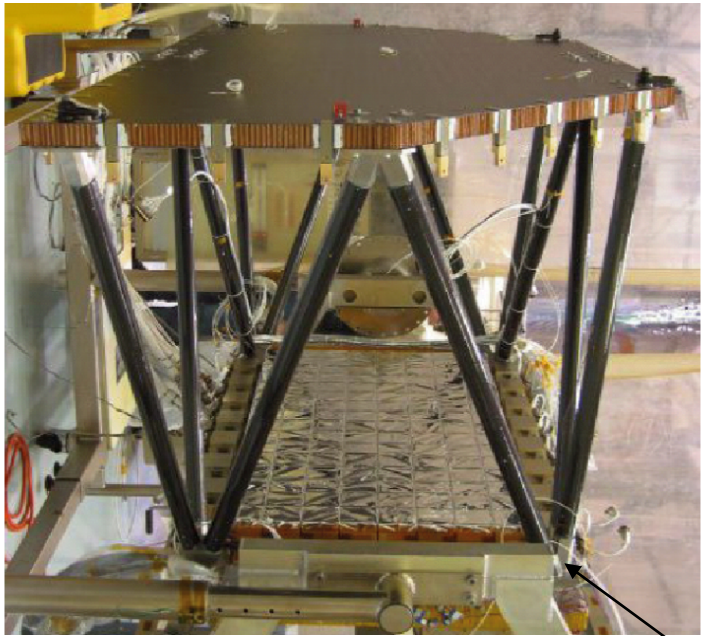
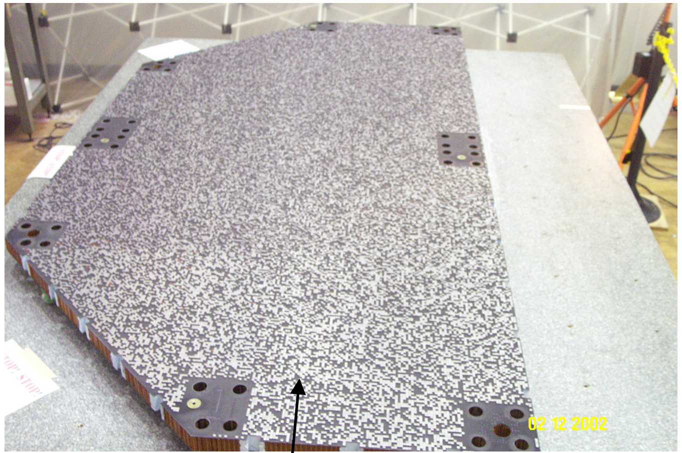
Swift Instruments

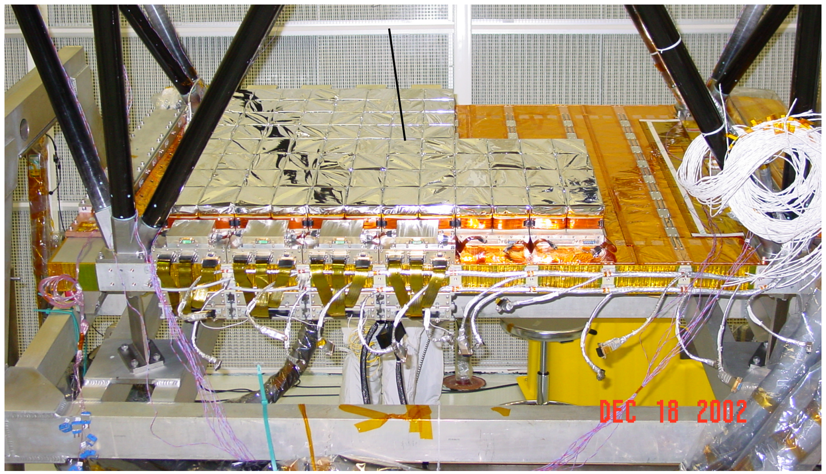
- Burst Alert Telescope (BAT)
  - CZT detectors & coded aperture
  - Most sensitive gamma-ray imager ever
- X-Ray Telescope (XRT)
  - Arcsecond GRB positions
  - CCD spectroscopy
  - Jet-X mirrors, XMM Detectors
- UV/Optical Telescope (UVOT)
  - Sub-arcsecond imaging; Finding chart
  - Grism spectroscopy
  - 24^{th} mag sensitivity (1000 sec)
  - Copy of XMM OM
- Autonomous re-pointing, 20 - 70 sec
- Onboard and ground triggers



The Burst Alert Telescope (BAT)





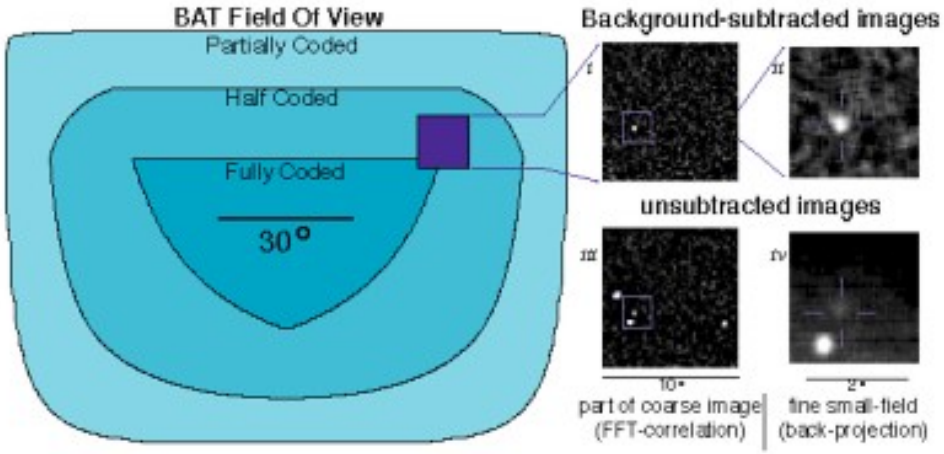


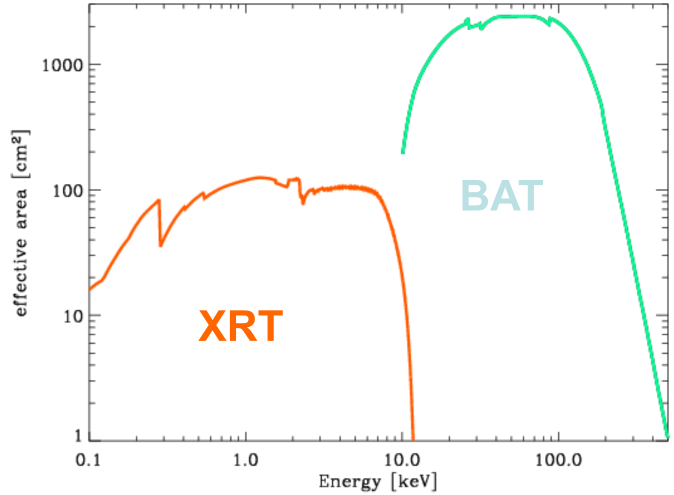
*The **BAT** is a wide field of view coded aperture instrument with a CdZnTe **detector plane**.*
*The detector plane is composed of 32,768 pieces of CdZnTe (4x4x2 mm) and the **coded aperture mask** is composed of 52,000 pieces of lead (5x5x1 mm) with a 1-m separation between mask and detector plane.*
P.I. of the instrument is S. Barthelmy (GSFC)

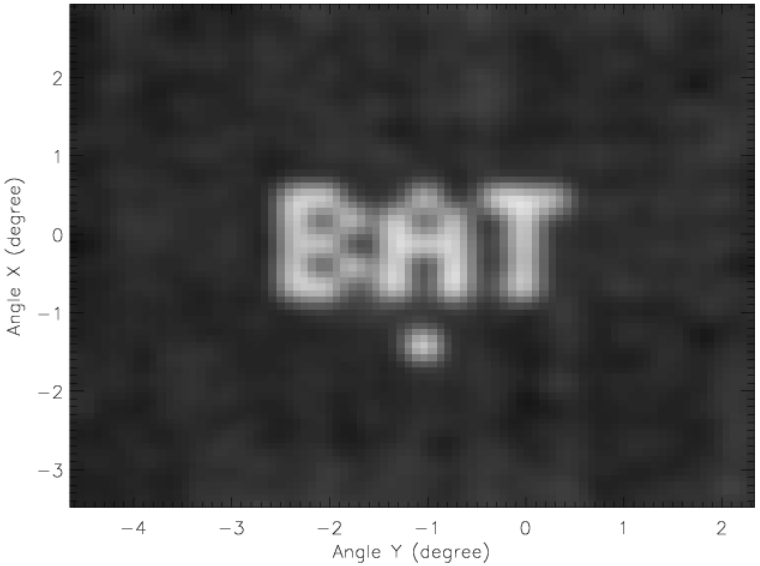
The Burst Alert Telescope (BAT)

Mask of the BAT instrument on-board Swift

The Burst Alert Telescope (BAT)

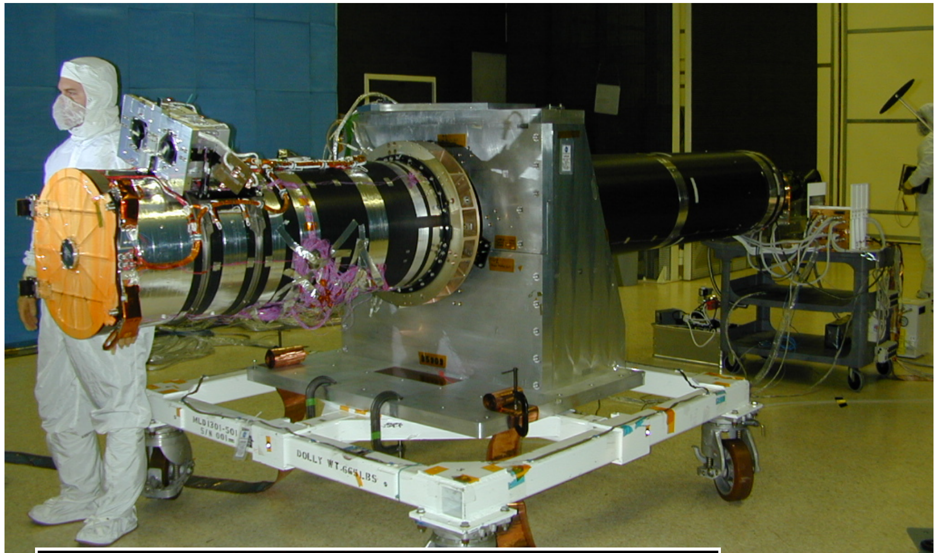


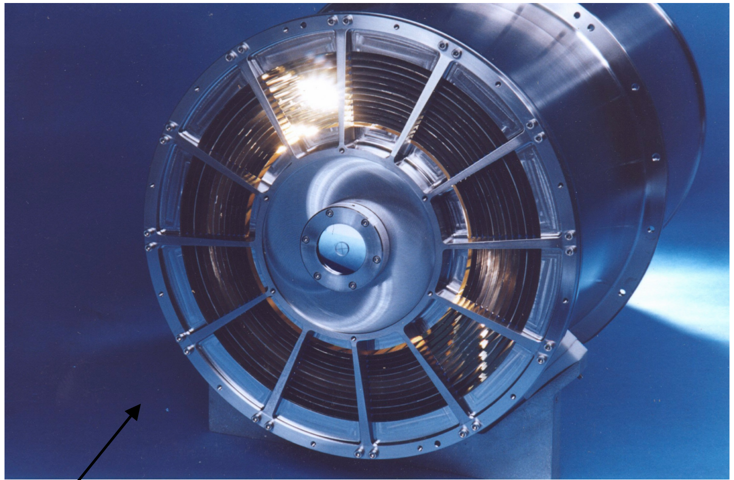


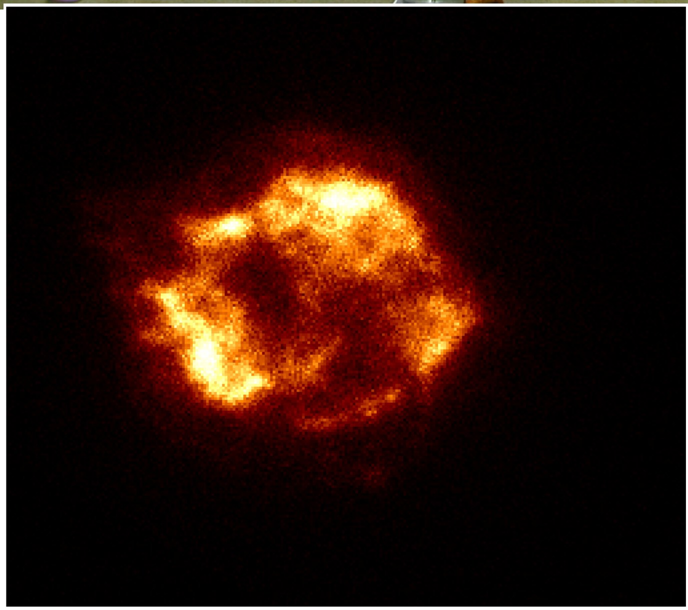


Telescope	Coded Aperture
Telescope PSF	17 arcmin FWHM
Position Accuracy	1-4 arcminutes
Detector	CZT
Detector Format	32768 pixels
Energy Resolution	7 keV FWHM (ave.)
Timing Resolution	100 microseconds
Field of View	2 Steradians, partially-coded
Energy Range	15 – 150 keV
Detector Area	5200 cm^2
Sensitivity	0.2 $photons/cm^2/s$
Max Flux	195,000 cps (entire array)
Operation	Autonomous

The X-ray Telescope (XRT)



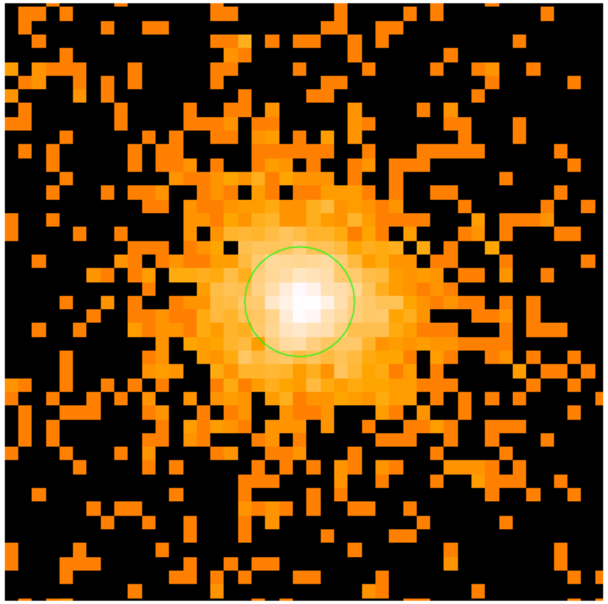


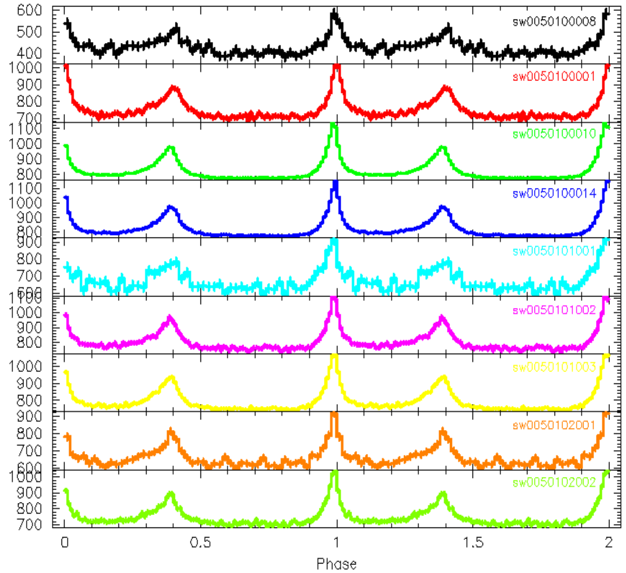


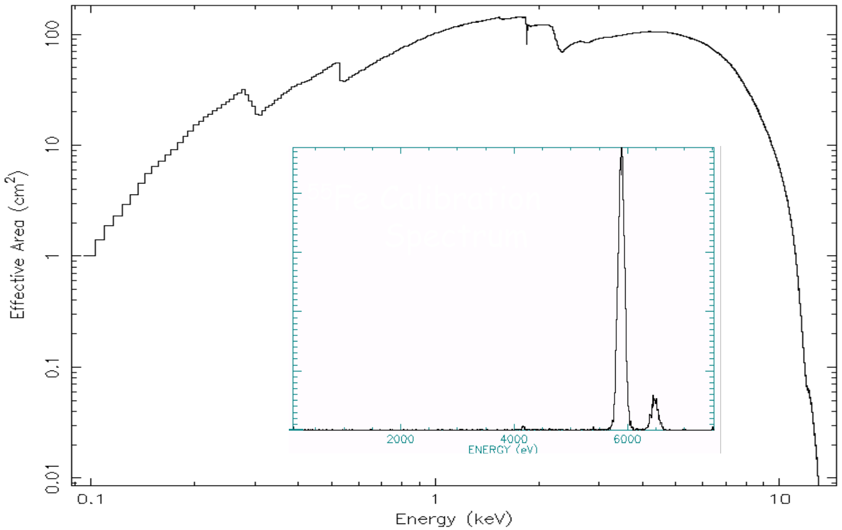
*The X-Ray Telescope was originally built for the Russian mission Spectrum X Gamma. The **optics** are developed and build by INAF-OAB, the camera is built at UL. It has 1 timing mode, (originally 2) for high rate sources and 1 event mode for low rate sources.*

The PI of the instrument is D. Burrows (PSU).

The X-ray Telescope (XRT)







Telescope	3.5 m Wolter I, 12 shells
Telescope PSF	15 arcsec HPD @ 1.5 keV
Position Accuracy	2.5 arcseconds (2 sigma)
Detector	E2V CCD-22
Detector Format	600 x 600 pixels
Energy Resolution	140 eV @ 5.9 keV
Timing Resolution	0.14 / 1.2 milliseconds
Field of View	23.6 x 23.6 arcminutes
Pixel Scale	2.36 arcsec / pixel
Energy Range	0.2 - 10 keV
Effective Area	110 cm^2@ 1.5 keV
Sensitivity	2×10^{-14} erg cm^{-2}s^{-1} in 2×10^{4} s
Max Flux	> 45 Crabs (45,000 cps)
Operation	Autonomous

Contribution of the ASI Science Data Center (ASDC, Frascati, Italy):

1. Responsible for the design, development and maintenance of the XRT Data Analysis Software (*XRTDAS*):

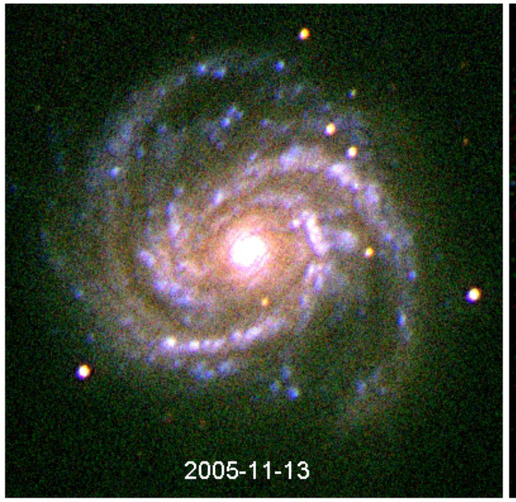
   - XRTDAS: set of FTOOLS specifically developed for the XRT instrument to generate high-level scientific data products from the FITS-formatted telemetry data. It is included in the pipeline processing at NASA/GSFC to generate the Swift-XRT archive.

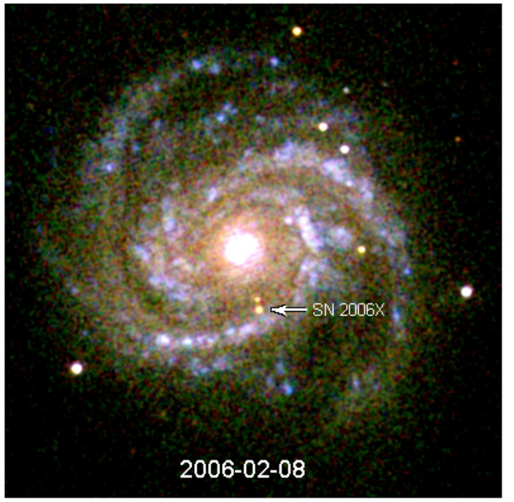
   - XRT data processing consists of three stages:
     - Stage 1: the data are *calibrated* using information from CALDB files, attitude and instrument housekeepings.
     - Stage 2: the calibrated data are *screened* by applying conditions on specified parameters (e.g. CCD Temperature).
     - Stage 3: standard high-level scientific products (spectra, light curves, images) are extracted from the Level 2 event files.

   - XRTDAS is distributed by NASA's HEASARC within the HEAsoft Package. Current version of HEAsoft (6.13) contains XRTDAS v.2.8.0(February 2012).

2. The ASI Science Data center hosts the Italian Site of the Swift Data Archive which is included in the ASDC Interactive Archive. At ASDC is available the XRT Interactive Quick Look Analysis tool.

UV/Optical Telescope (UVOT)

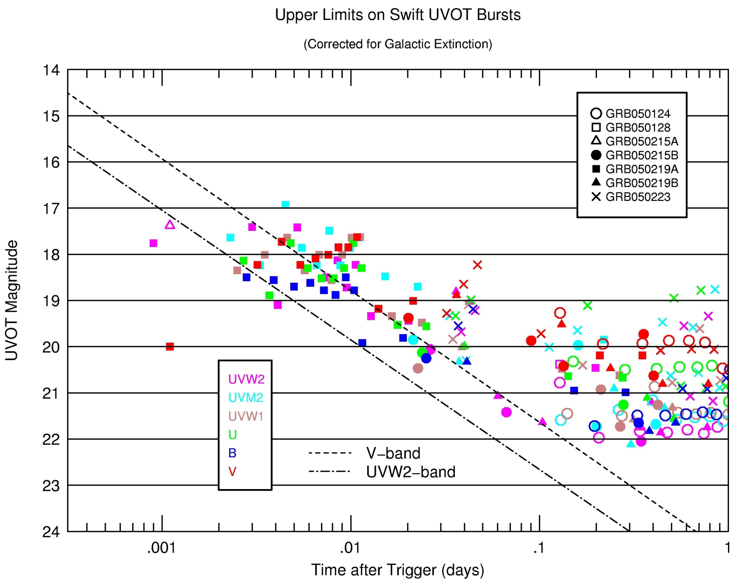


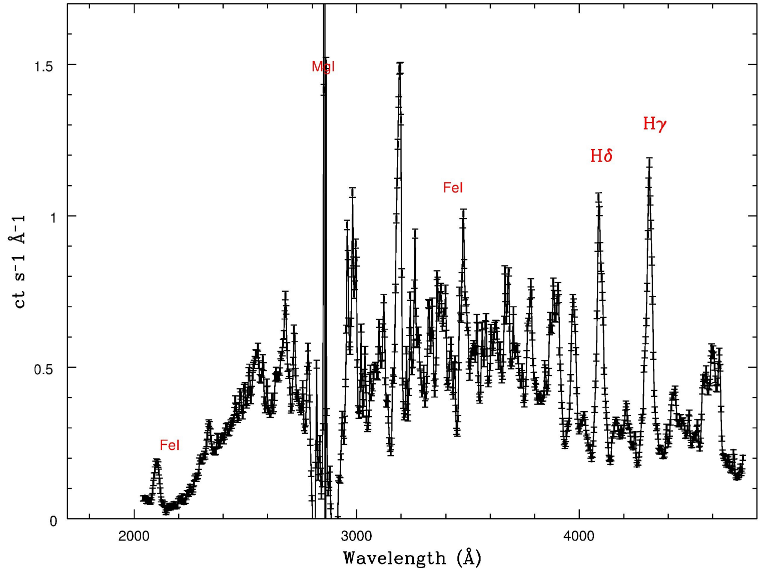


UVOT is the copy of the Optical Monitor of XMM. It is a 30 cm telescope operating in image and event mode. Developed at MSSL.

The PI of the instrument is P. Roming (PSU).

UV/Optical Telescope (UVOT)





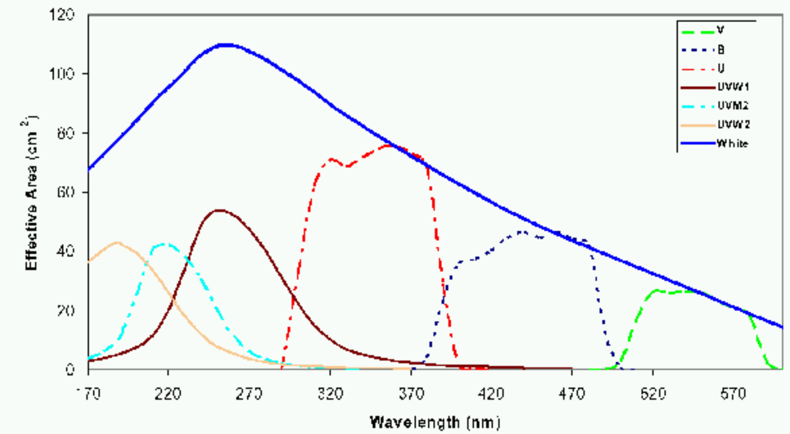
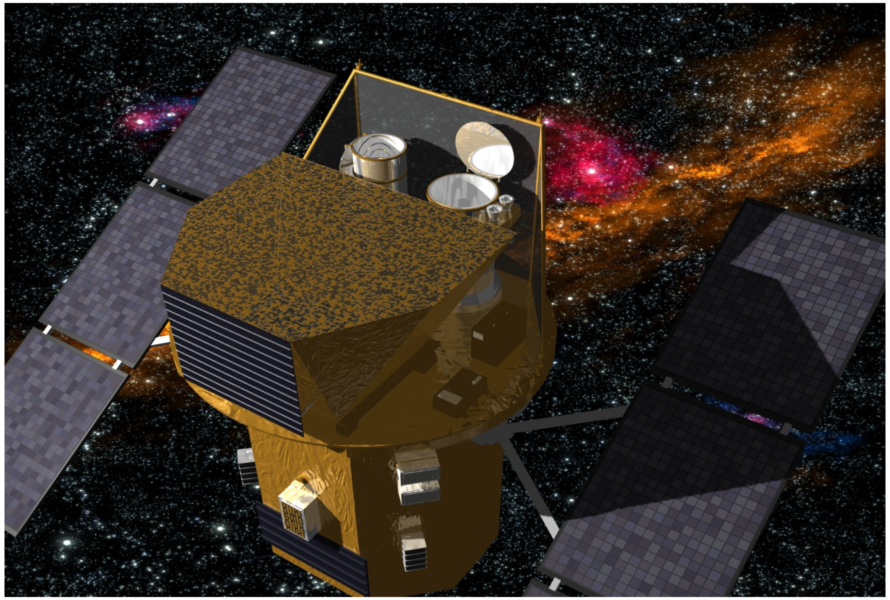


Figure 4

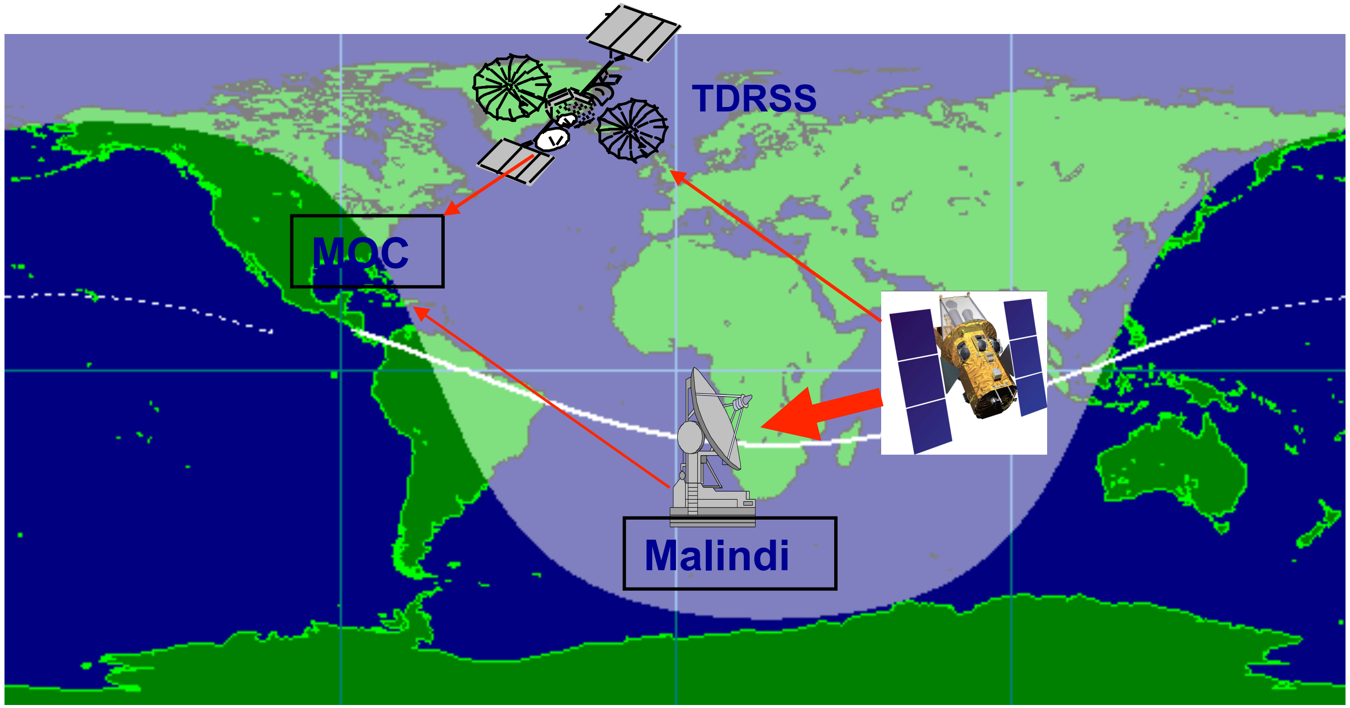
Telescope	30 cm Ritchie-Cretien
Telescope PSF	0.9 arcsec FWHM @ 350 nm
Position Accuracy	0.3 arcseconds (2 sigma)
Detector	Microchannel-intensified CCD
Detector Format	2048 x 2048 pixels
Spectral Resolutn	>300 @ 300 nm for M_v < 17
Timing Resolution	11 milliseconds
Field of View	17 x 17 arcminutes
Pixel Scale	0.5 arcsec / pixel
Spectral Range	170 – 600 nm
Sensitivity	24th magnitude in 1000 s
Max source	8th magnitude
Operation	Autonomous

Observatory Capabilities

- TOO response in ~1 hour to any transient
- Transient searches over much of sky every orbit by BAT
- Multi-wavelength campaigns available on single spacecraft
- ~4 targets per 90 min. orbit - huge number of observations
- All Swift data are public!

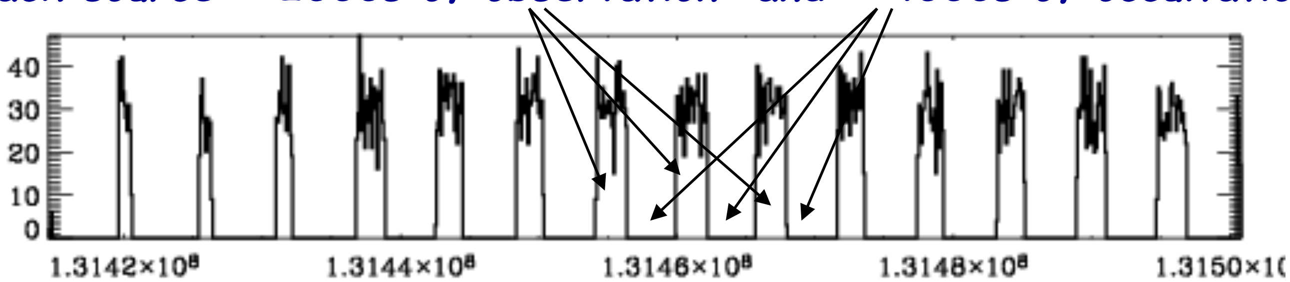


A day in the life of Swift



- 1 orbit ~ 5800 s.
- ~ 4 targets per orbit
- 1500 s for each target for each orbit

For each source: ~2000s of observation and ~ 4000s of occultation



Swift unique Time Domain Astronomy sampling and wavelength coverage

- Conceived as a mission for rapid follow-up of GRBs, Swift has also proven to be highly flexible and responsive to allow observations of nearly every type of astronomical object

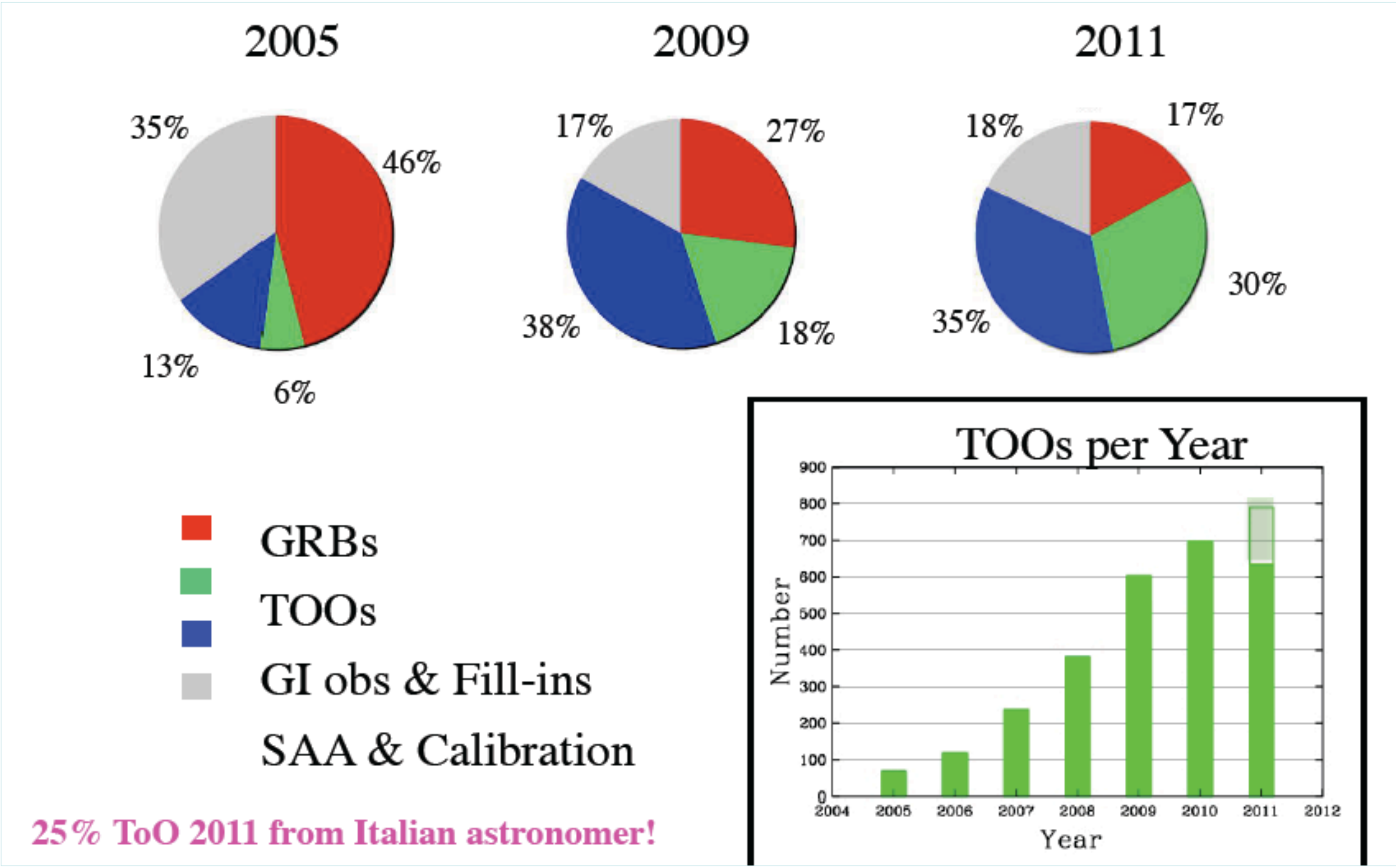
- Up to 75 targets per day, >1000 observing programs per year

- Autonomous response => observations in seconds to minutes of GRBs, SGRs, flare stars, supergiant fast X-ray transients and other hard X-ray transients

- ToOs response in as little as ten minutes, or samplings over periods of time ranging from minutes to hours, days or months

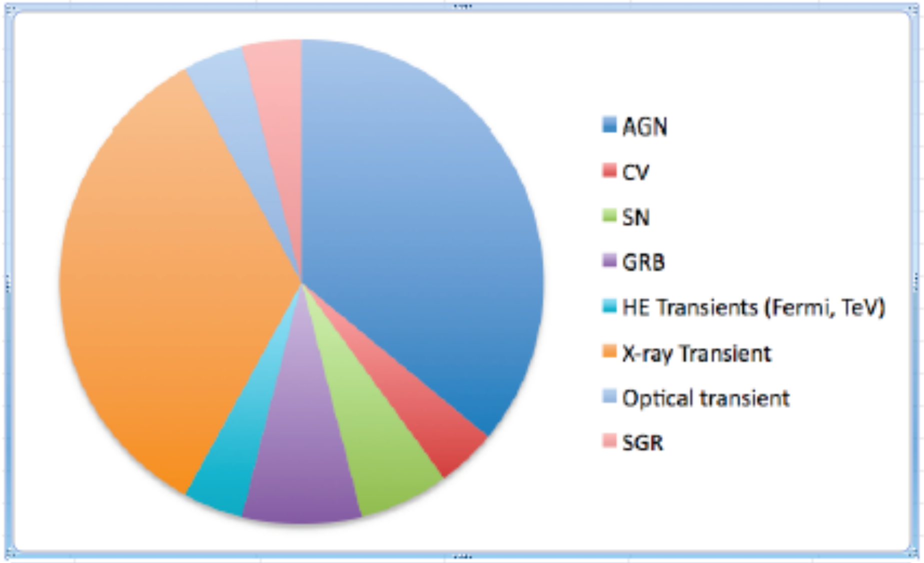
Courtesy of G. Tagliaferri

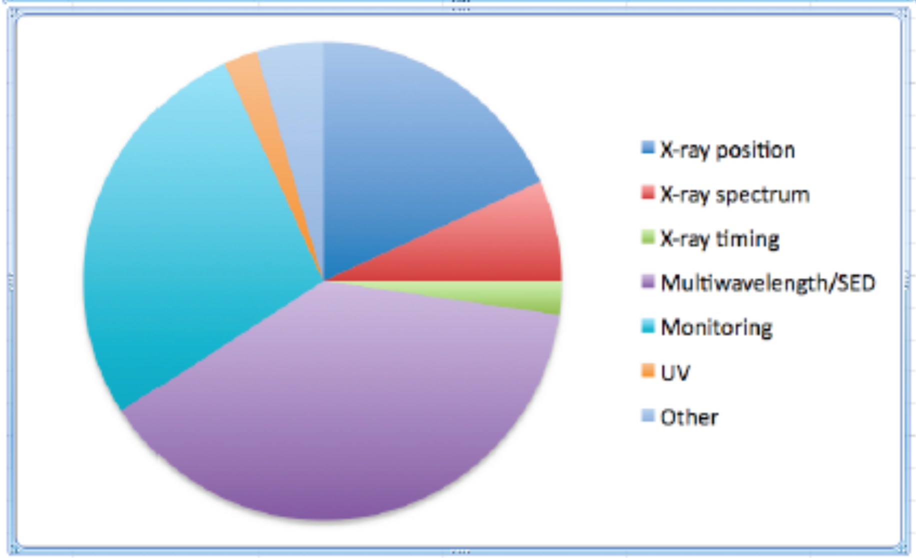
Swift evolving observing time



Courtesy of G. Tagliaferri

Swift breakdown of ToO requests (2009)s





Courtesy of G. Tagliaferri

Swift Institutions

NASA

GSFC

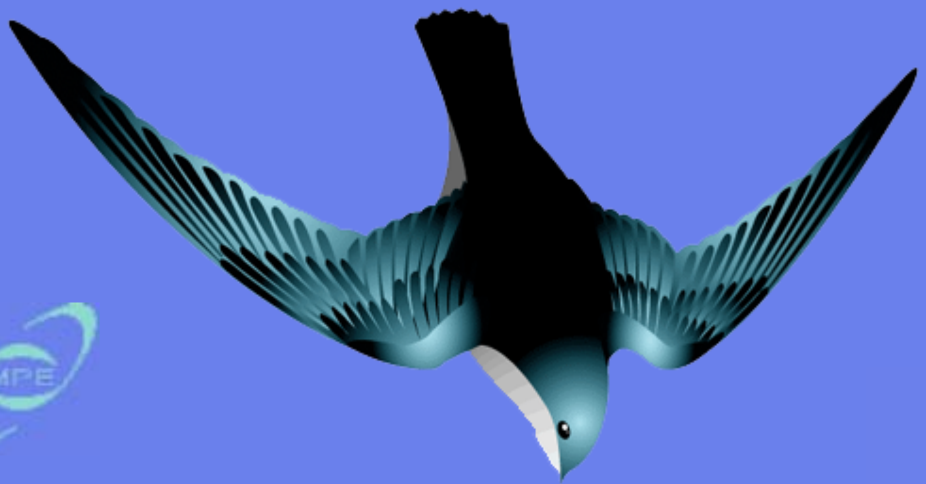
PENNSTATE 1855

University of Leicester

agenzia spaziale italiana

SONOMA STATE UNIVERSITY · LUX MENTIS · LUX ORBIS · 1960

OSSERVATORIO ASTRONOMICO DI BRERA



MPE

eV PRODUCTS

UCL MSSL

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THE UNIVERSITY OF CALIFORNIA · LET THERE BE LIGHT · 1868

SwRI

ISAS

SWALES AEROSPACE

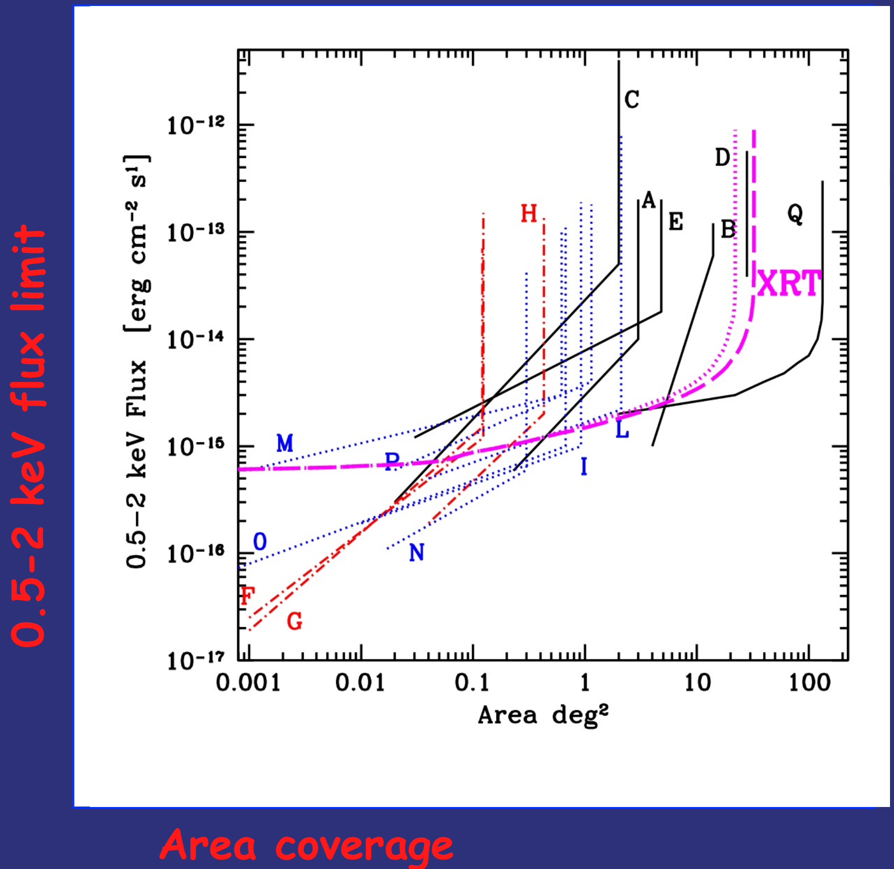
OMITRON inc.

Los Alamos NATIONAL LABORATORY

Swift and AGNs

- Multiwavelegth studies of AGNs (see Paolo's Talk)
- BAT 60 AGN catalog
- XRT Deep survey (SwiftFT)
- 1SWXRT (XRT point source catalog)
- The tidal disruption event **Swift J1644493+573451**

X-ray Surveys



RED: Very deep pencil beam survey:

F: CDFN, G: CDFS, H: LockmanHole

✓ detection the population of faintest X-ray sources, especially the new population of `normal" galaxies (Brandt & Hasinger 2005).

X sample very small sky regions=> strongly affected by cosmic variance.

Blue: Wide Shallow contiguous survey:

I: C-COSMOS, L: XMM-COSMOS, M: ELAIS-S1, N: ECDFS, O: AEGISX, P:SXDS

✓ less affected by cosmic variance than the deep pencil by covering a much larger area of the sky.

X reach relatively high fluxes, losing a large fraction of faint AGN.

BLACK: Very large non contiguous surveys: **A: H2XMM, B: ChaMP, C: SEXSI, D: XMM-BBS, E: AXIS , Q: twoXMM (|b|>20)**

✓ very large sky area => rare objects, like the highest luminosity, obscured AGN, QSO2 (see e.g. HELLAS2XMM, Fiore et al. 2003).

✓ investigation of field to field variations of the X-ray source density, which may trace filaments and voids in the underlying large-scale structure.

X medium depth!

WHY Swift-XRT? Many advantages!

1. Long exposure time: afterglow follow-up up to 1.17 Msec, GRB060729.
2. Very low XRT background ($\sim$1-2X10^{-4}ct/arcmin2/s in the 0.3-3 keV band).

=> **long exposure times + low background = DEEP Survey!**

Flux limit (0.5-2 kev)~ 7X10^{-16}erg cm^{-2}s^{-1})

3. The XRT Point Spread Function and vignetting factor, approximately constant across the field of view.

=> **a rather uniform sky sensitivity.**

4. Large AREA => ~32.55 deg2, and ~22.15 deg2 at high Galactic latitude, i.e. |b|>=20°

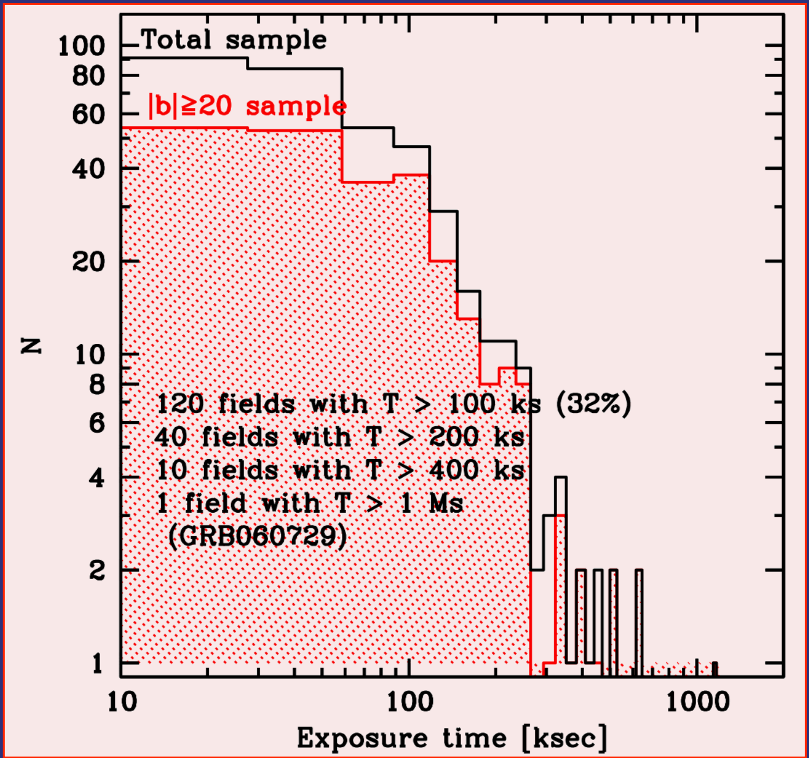
=> **rare objects!**

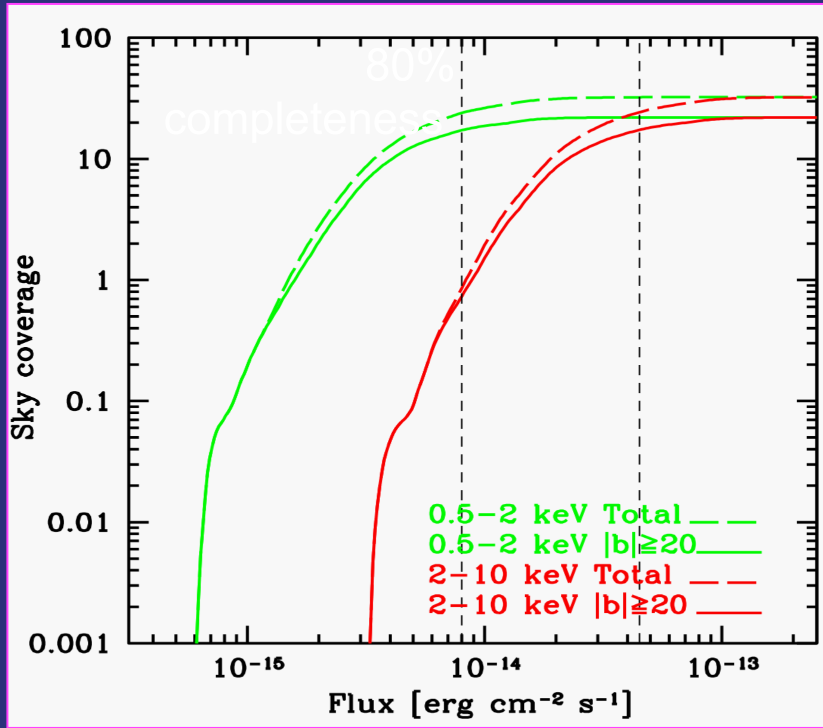
5. The GRBs explode randomly in the sky, with isotropic distribution (Briggs 1996) and SwiftFT does not suffer of possible biases towards already known bright X-ray sources, as the large serendipitous surveys based on X-ray archival data, like Einstein, ROSAT, Chandra and XMM-Newton data.

=> **unbiased investigation of the clustering properties of the X-ray sources!**

The SwiftFT Survey

- X-ray serendipitous point-like sources detected in the fields of Gamma Ray Burst **followed by XRT from January 2005 to December 2008 with exposure time >= 10 ks: 374 fields (~32.55 deg^2), 254 fields (~22.15 deg^2) at high Galactic latitude, i.e. |b|>=20°**
- The detection algorithm was applied on a total event file, obtained, for each GRB by the sum of the individual sequences.





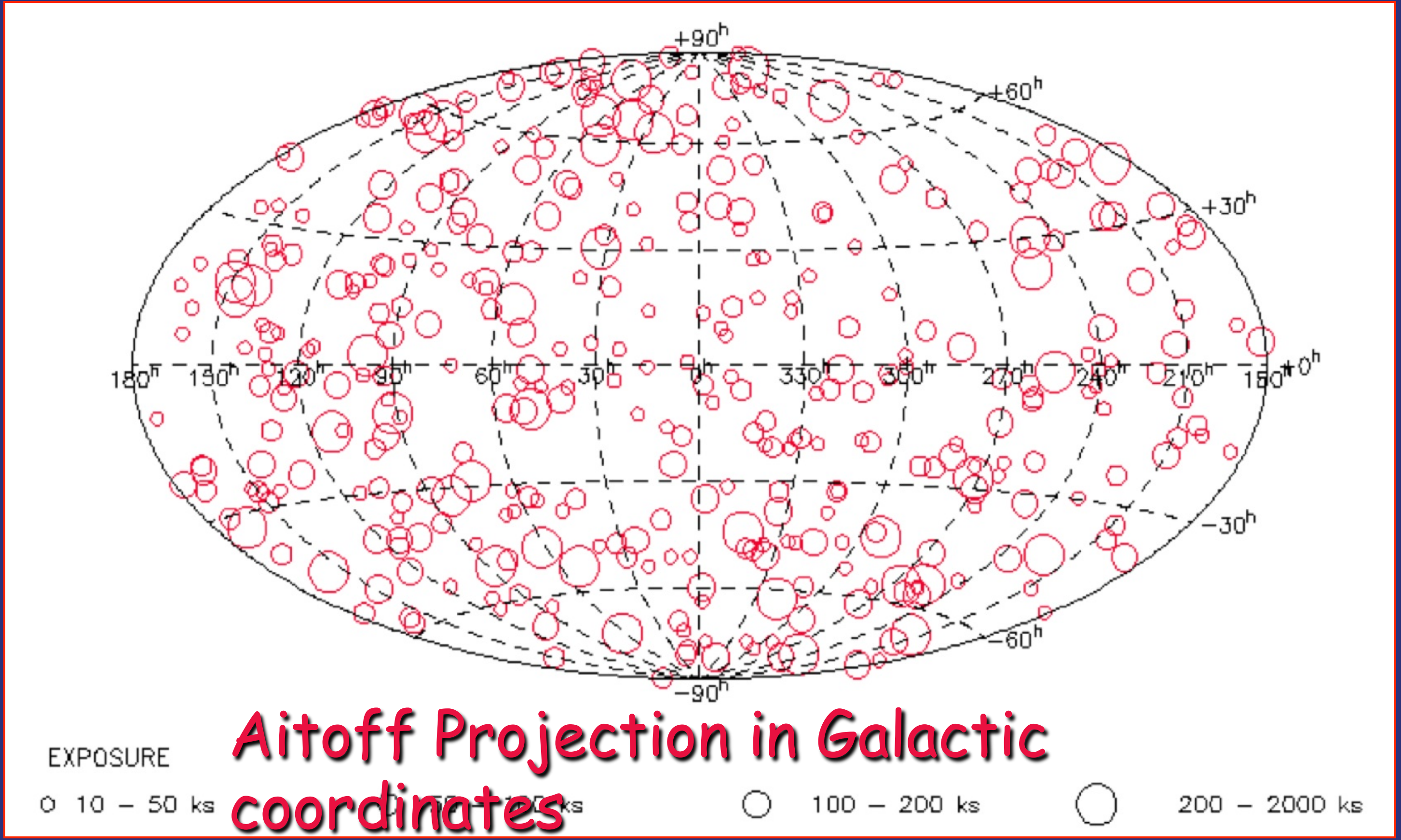
Puccetti et al. 2010

The SwiftFT Survey:point-like catalog

- **10304 point-like sources detected with a significance level <= 4×10^{-4}** in at least one of the 3 energy band: 0.3-3, 2-10, 0.3-10 keV.

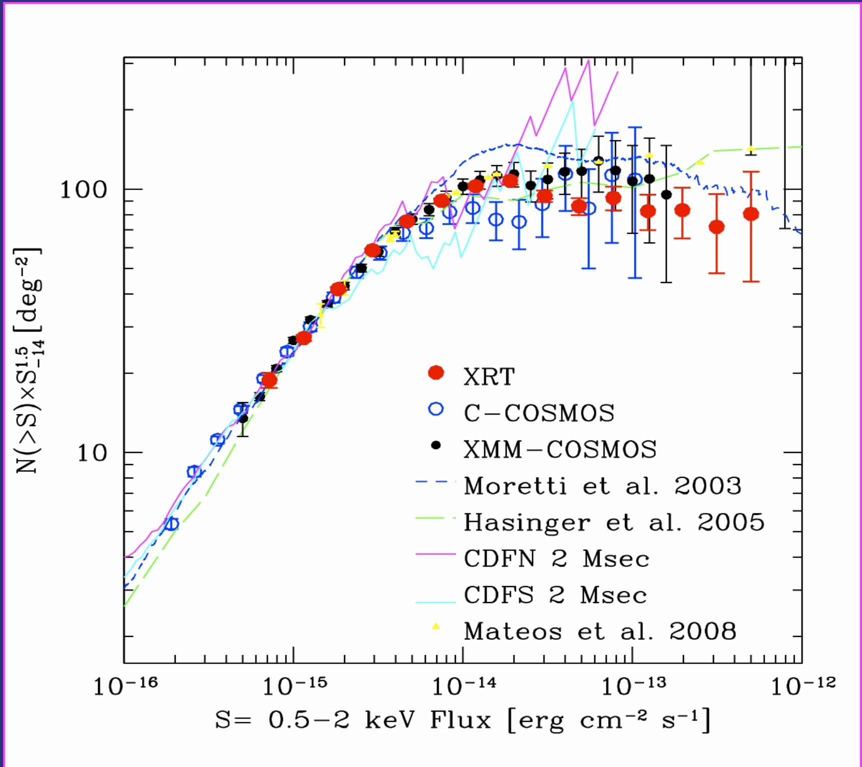
- **First catalog release:** conservatively cut at a significance level <= 2×10^{-5} ,which corresponds at less than 0.24 spurious sources for each field:

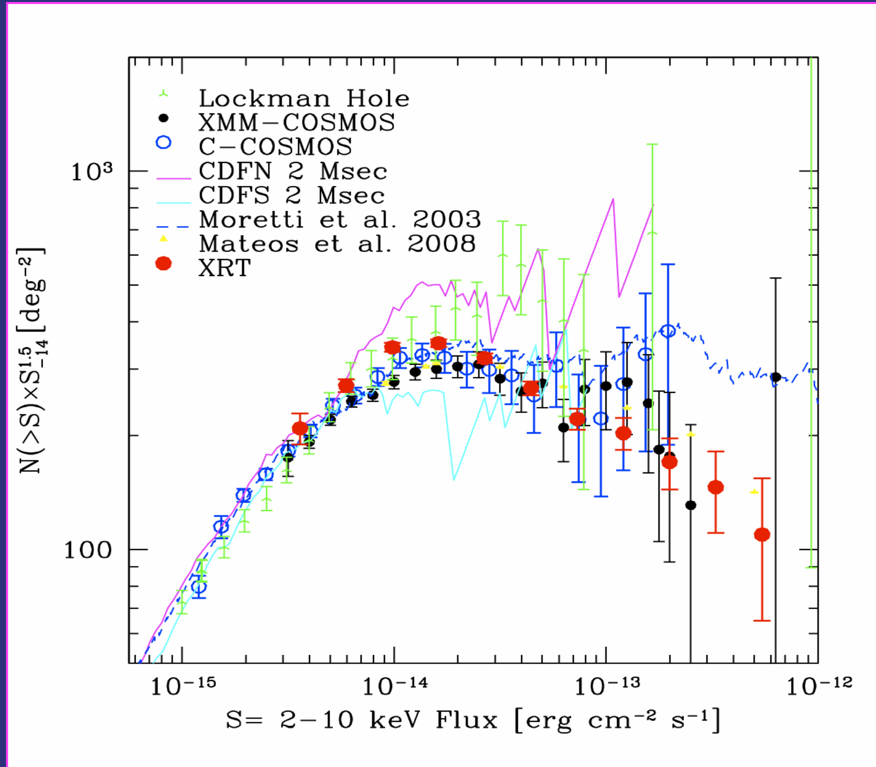
9387 sources (7071 at |b|>20) ,0.5-2 keV flux limit ~ $7X10^{-16}$erg $cm^{-2}s^{-1}$, 2-10 keV flux limit ~ $4X10^{-15}$erg $cm^{-2}s^{-1}$



Aitoff Projection in Galactic coordinates

The High Galactic latitude sample: X-RAY Number Counts





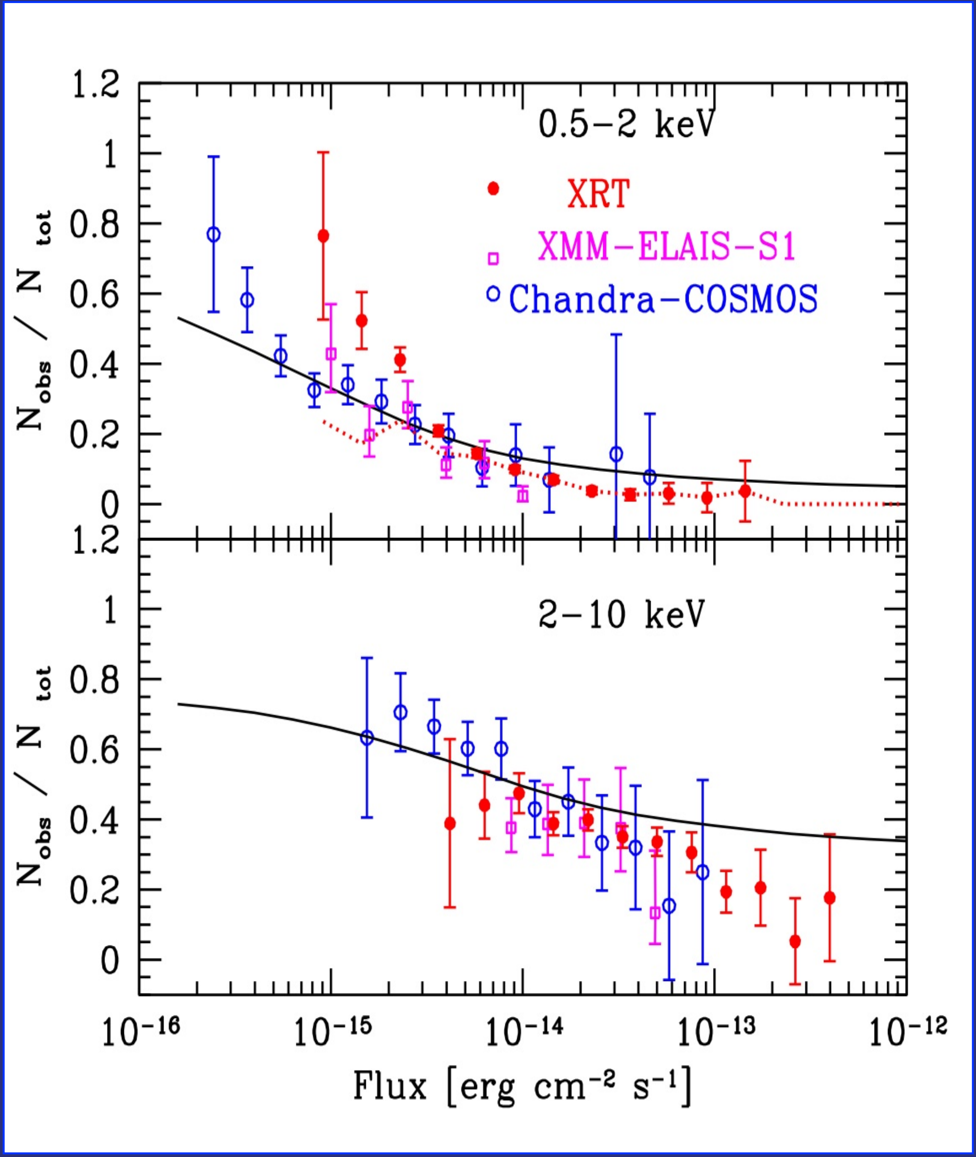
- The X-ray number counts are normalized to the Euclidean slope (multiplied by $S^{1.5}$). The deviation from the Euclidean slope are clearly evident, as is the flattening of counts towards faint fluxes.
- The XRT number counts nicely matches with previous measurements.
- At bright fluxes, XRT provides a more robust evaluation of the source counts, thanks to better statistics of the data.

The High Galactic sample: hardness ratio

To roughly separate obscured sources from unobscured, following Hasinger et al. (2003), **we used a threshold of the hardness ratio (H-S)/(H+S)** corresponding to NH >21.5, 22.2, 22.7 at redshift =0,1,2 respectively (assuming a photon index=1.8)

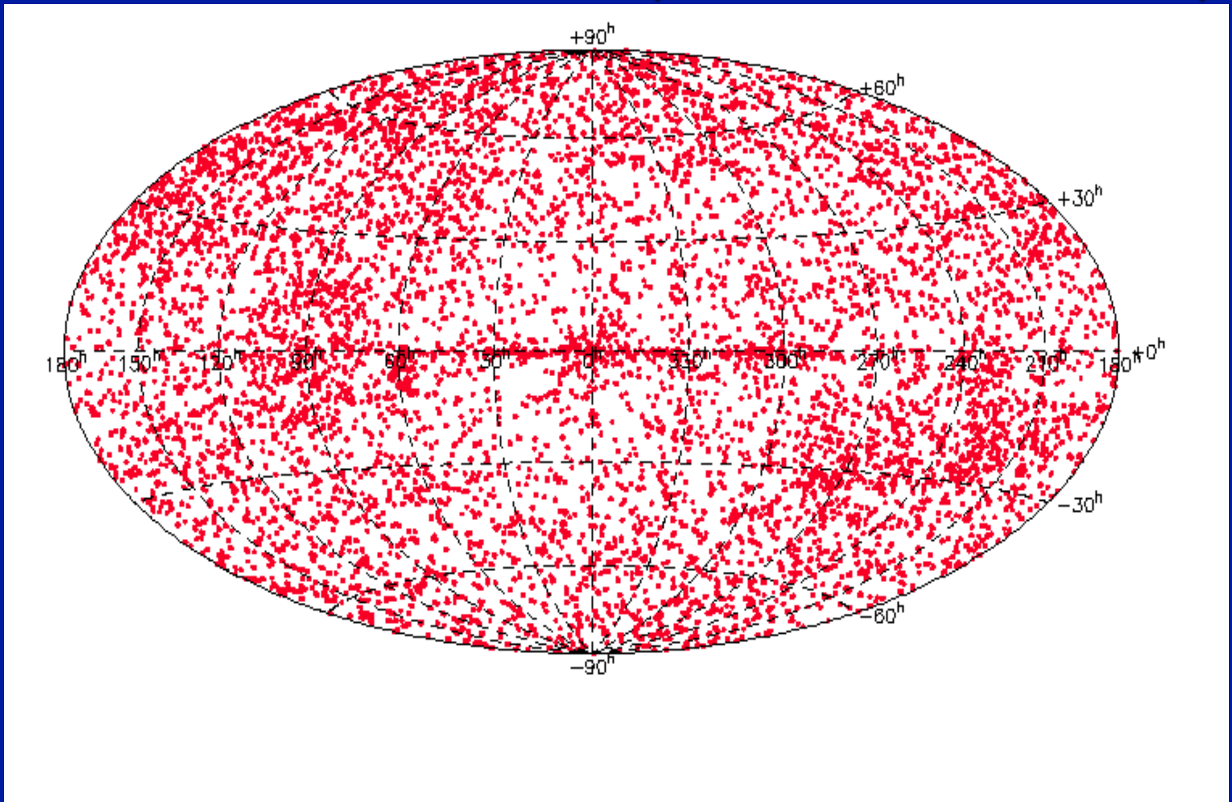
- ~37.0%±0.5% (15%) of the 2-10keV (0.3-3 keV) sources turn out to be obscured, consistently with the ~36%±4% in ELAIS-S1 which has similar flux limit!

- The fraction of obscured sources increases with the energy of the X-ray band, consistently with the XRB models (see e.g. Gilli et al. 2007, black solid line in figure).



THE 1SWXRT CATAOLG

- point-like X-ray sources detected in PC from Jan 2005 to Dec 2011
- detection in all individual XRT observations (no merging)
- including all fields with expotime > 500s
- number of fields analyzed: 35,011. Total exposure time: 140 Ms



Aitoff Projection in Galactic coordinates

D'Elia et al. 2013

Results

- 89,347 detections of point-like sources (Full and/or Soft and/or Hard):
- Of these, 2,166 refer to GRBs and 1,947 are affected by pile-up
- A good sample is thus constituted by 85,286 detections. Of these:

  - 80,318 detections in the *full* band (11,620 full only)
  - 70,129 detections in the *soft* band (4,241 soft only)
  - 25,579 detections in the *hard* band (718 hard only)

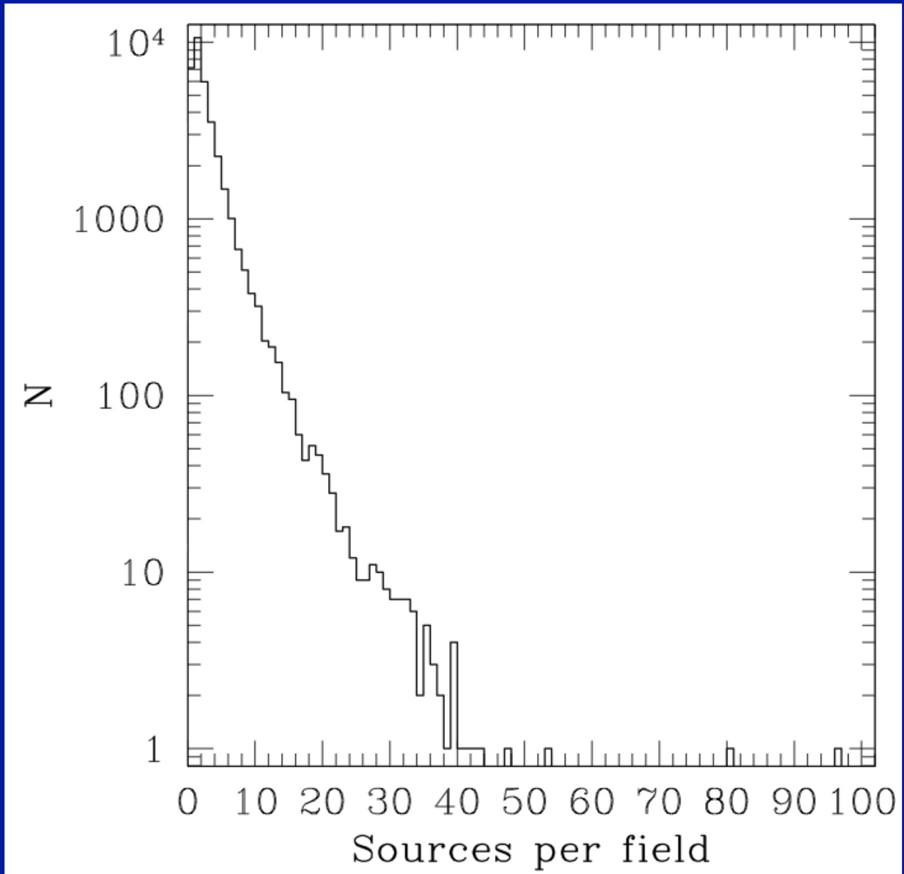
If a source is observed several times, different entries are stored in the database ⇒ light-curves, variability etc.

To estimate the number of distinct celestial sources, we compress the catalog over a radius of 12 arcsec (typical uncertainty of the weakest XRT sources) ⇒

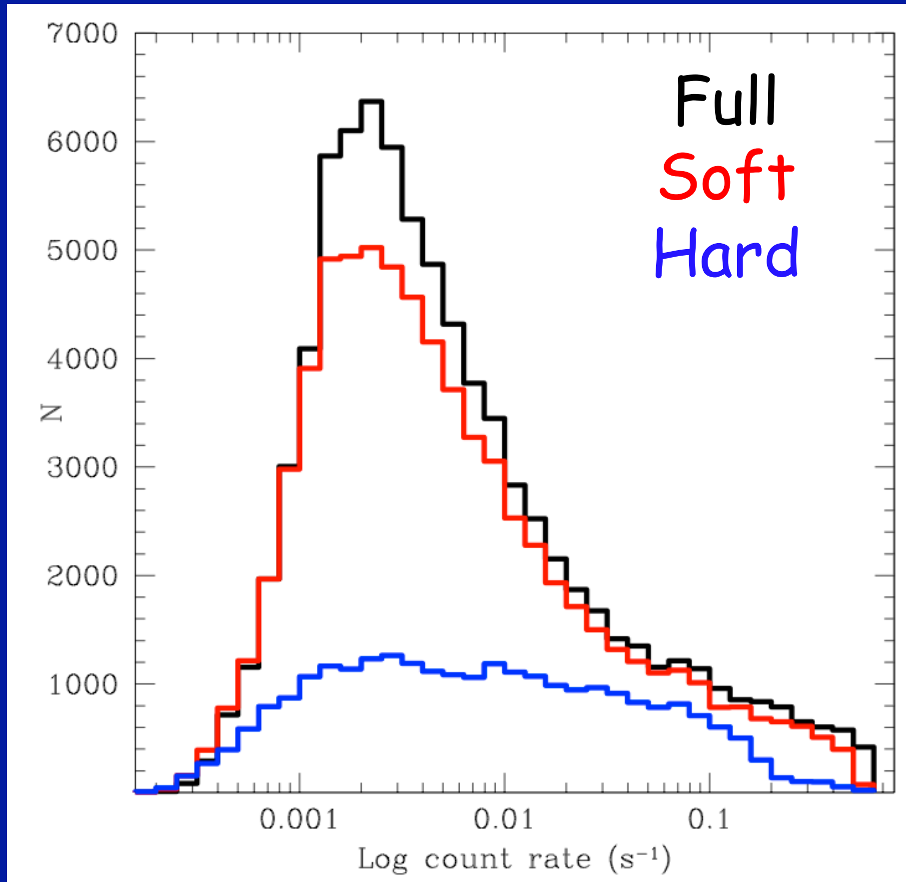
~36,000 distinct sources

Results

Sources per field



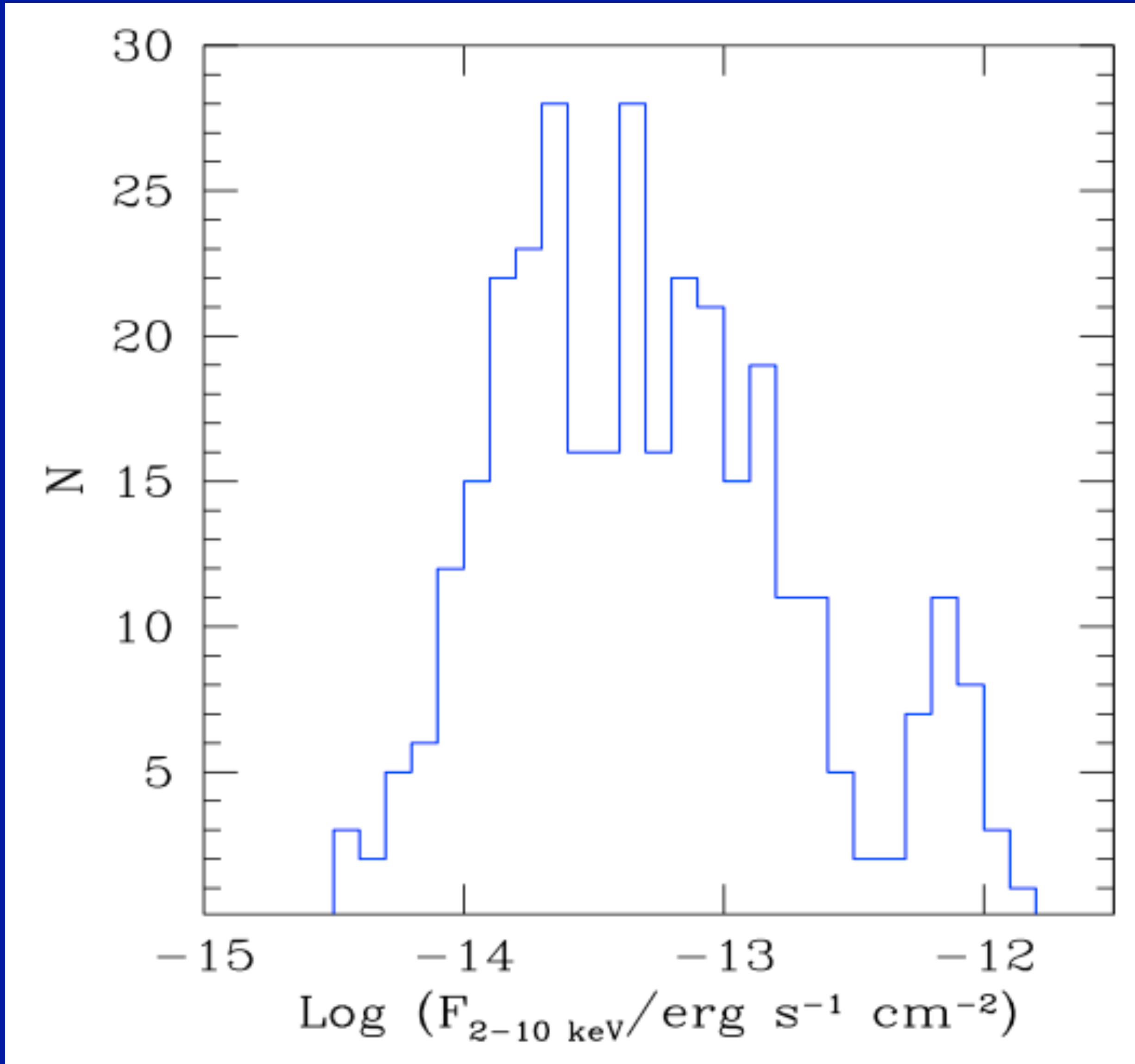
Count rate distribution



Science

Hard sources 330 objects detected in H only

- Hard band less sensitive than S: these sources are good obscured AGN candidates



Science

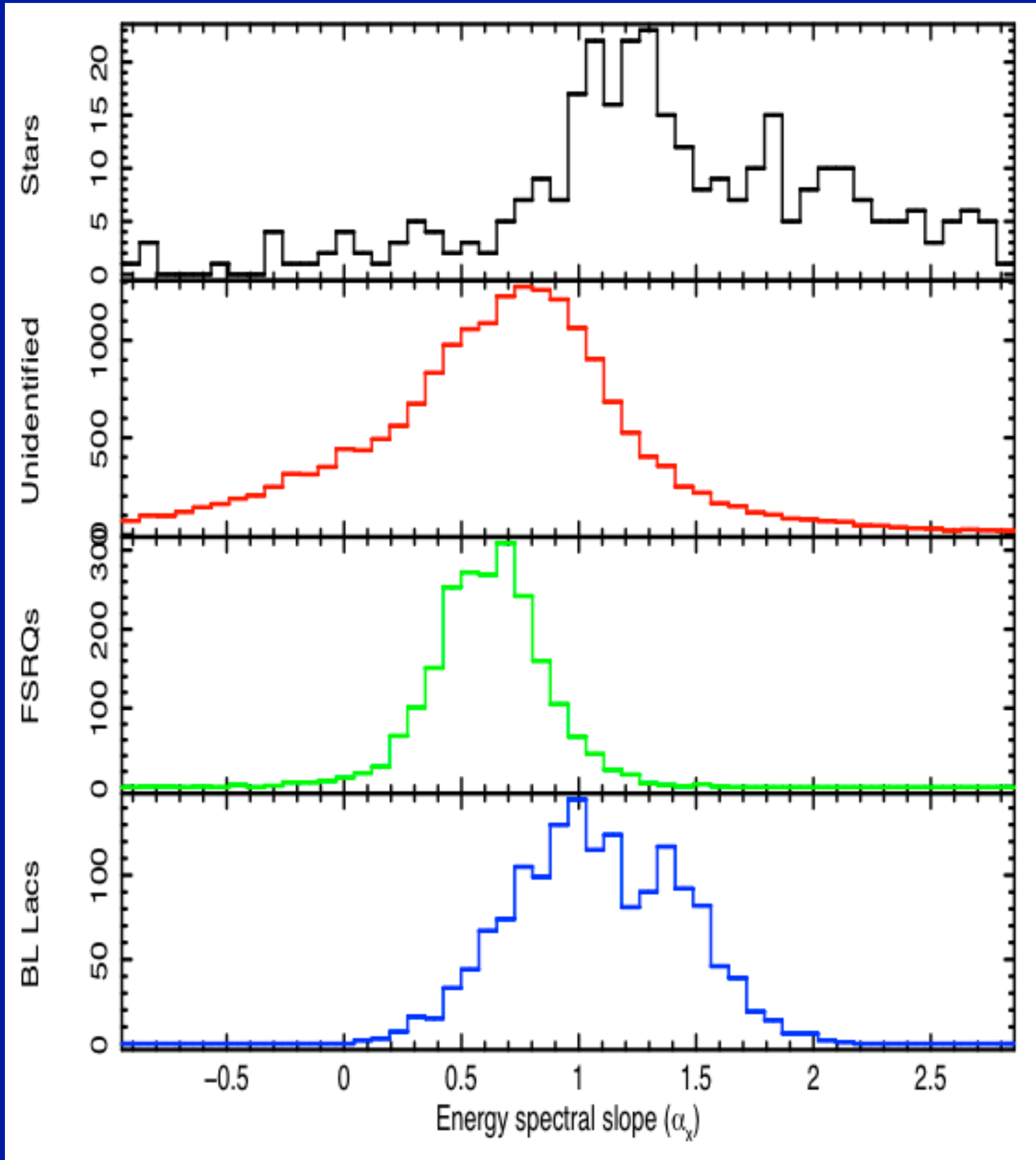
Cross-correlation with multi-wavelength catalogs

- Example: correlation with BZCAT

- XRT FSRQs are harder than BL Lacs.

FSRQs: sampling the low energy tail of the IC component.

BL Lacs: sampling the high energy tail of the Syn. component

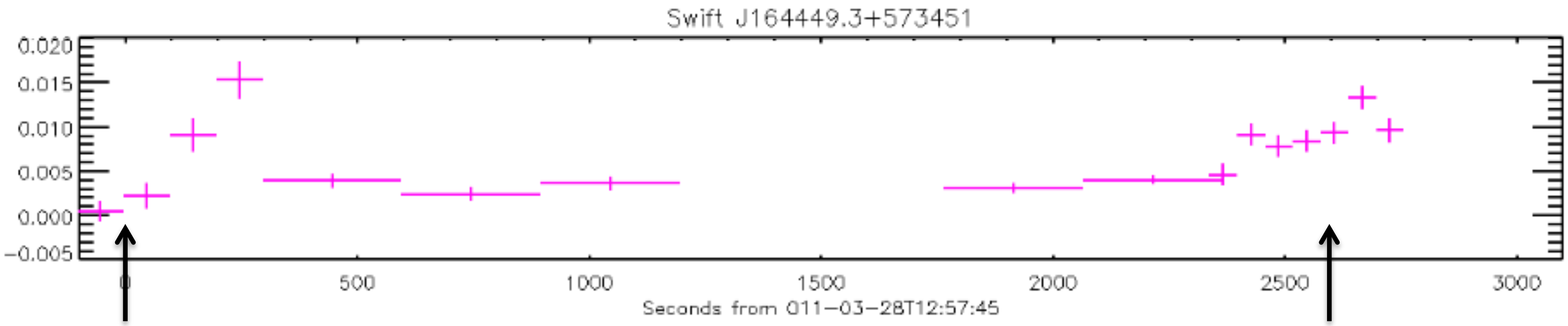


THE GRB110328A DISCOVERY BY SWIFT

Burrows et al. 2011

- **BAT triggered at 13:18:15 UT on 28 March 2011**
  - **1208 s Image Trigger that began at 12:57:45 UT**
  - **Swift slewed immediately**
  - **XRT began observing at 13:22:19.8 UT**
    - **Found bright X-ray source**

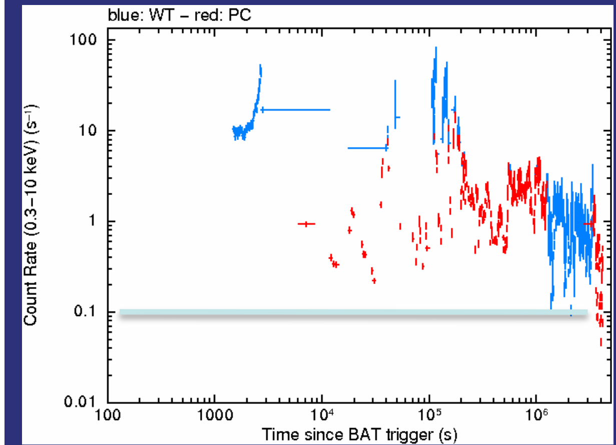
- **BAT triggered again ~22 minutes later on same source**
  - **64 s Image Trigger that began at 13:40:41 UT**
  - **Clearly not a GRB! Renamed Swift J164449.3+573451, based on initial XRT position**

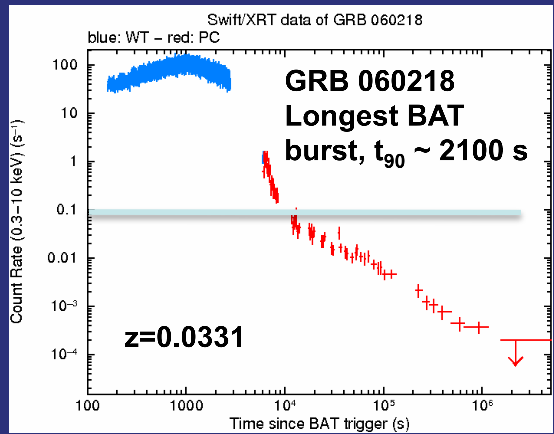


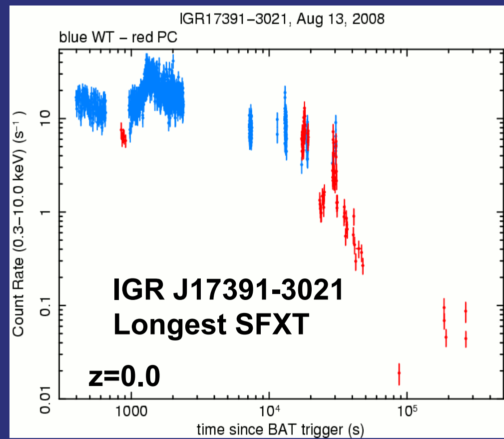
FACTS

• X-ray lightcurve shape:

The source is different from every transient observed to now





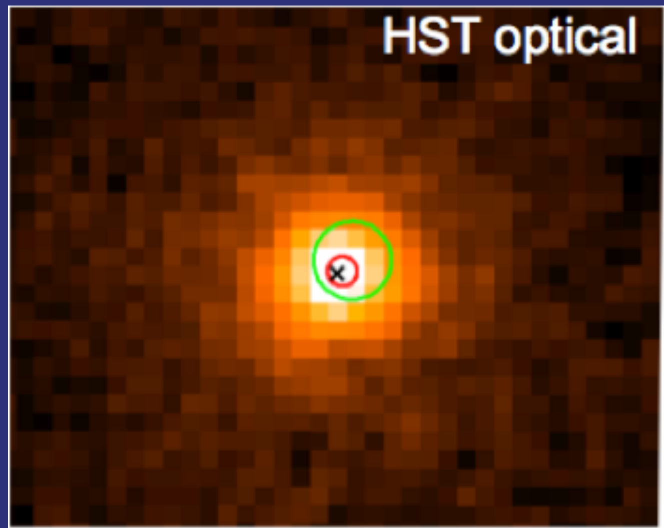


• Position:

source superimposed to a z=0.35 galaxy. Chance coincidence extremely low

In addition, HST and radio observations place the source within 150 pc from the galactic nucleus (at z=0.35)

⇒ The source is extragalactic at D_L=1815 Mpc



FACTS

• Energetics:

• Isotropic X-ray luminosity: $L_X = 10^{45}$ - 4 10^{48} erg/s
• Released energy in the first 23 days: E_X= 3 10^{53} erg
• Galactic transients cannot account for such energies
• GRB energetics compatible, but this is persistent (~ 3 months!) and located in the host center

⇒ AGN-like activity

• Size:

• Variability timescale ~ 100s ⇒ $M_{BH}<8\ 10^6\ M_\odot$
• Assuming that all galactic mass (few $10^9 M_\odot$) and light (few $10^9 L_\odot$) arise from the bulge, using correlations between galactic mass/ luminosity and BH masses, $M_{BH}<10^7\ M_\odot$

⇒ $M_{BH}\sim 10^6 - 10^7\ M_\odot$

FACTS

"Classic" AGN activation?

- Sphere of influence radius of SMBH $r_{SOI} \sim$ 1pc, bulge velocity dispersion $\sigma \sim$ 100 km/s: need 10^4 yr to alter the accretion rate near the BH
- The rise in luminosity is too abrupt and near the Eddington limit
- There is no sign of a companion galaxy

⇒ Tidal disruption event

A star is disrupted by tidal forces at a distance rd > rs.
Half of the matter escapes on unbound orbits, the other half is trapped and forms an accretion disk.