

A proposed Italian contribution to the MIRAX Scientific Payload

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on behalf of groups at:

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Univ. of Ferrara: F. Frontera, ..

INAF HQs: A. Argan

Univ. of Pavia: P. Malcovati, ...

Outline

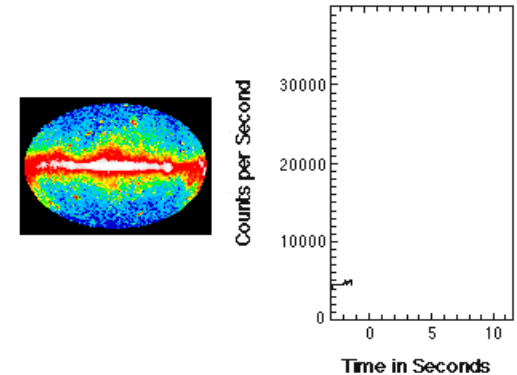
- Science Motivation
- International experimental scenario
- Instrumental background
- A proposal for MIRAX
- Expected MIRAX Performance

Scientific Motivation

- Wide band spectroscopy of the prompt emission of Gamma Ray Bursts
- All Sky Monitoring

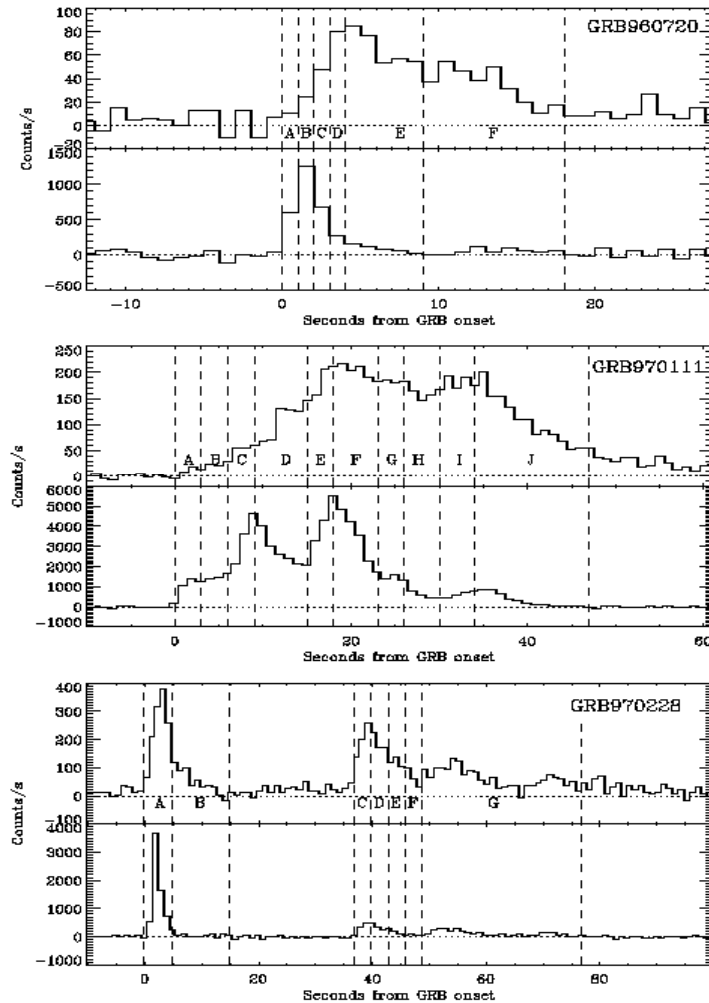
GRB prompt emission: status and prospects

- ❑ Despite the huge advances occurred in the last years, the GRB phenomenon is still far to be fully understood
- ❑ It is recognized that the GRB phenomenon can be understood only going back to the study of the Prompt Emission
- ❑ A very broad energy band down to soft X-rays is needed.
- ❑ Measurements down to a few keV were provided in the past by BeppoSAX, but a higher sensitivity and energy resolution is urgently needed.
- ❑ Present GRB experiments are limited to prompt emission $> \sim 10$ keV; future (SVOM, EXIST,) $> \sim 5 - 8$ keV

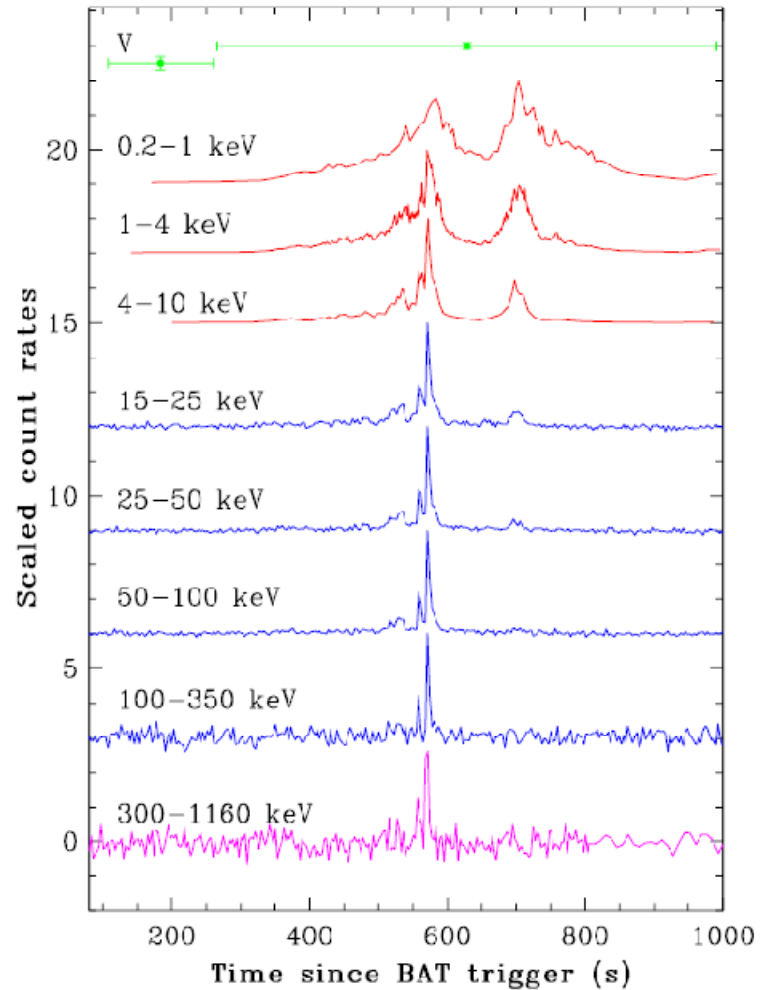


See F. Frontera's Talk

□ Relevance of GRB prompt low energy (<15 keV) X-ray emission

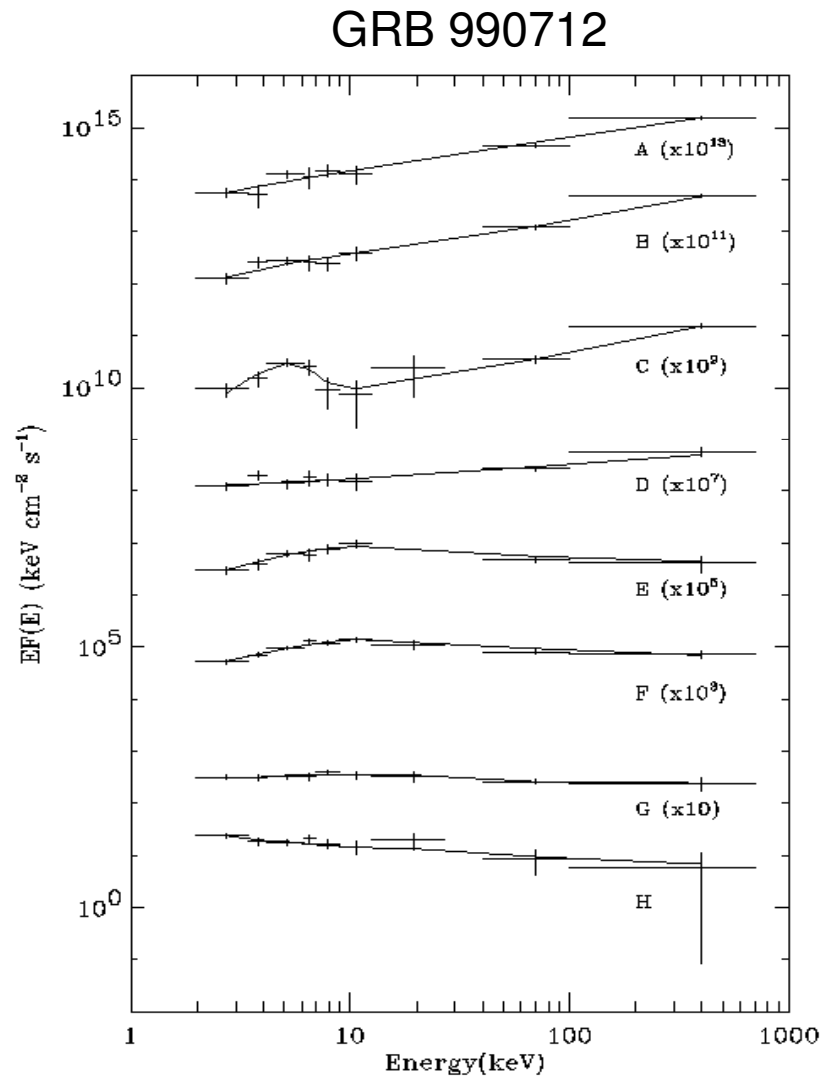


BeppoSAX (top: 2-28 keV,
bottom: 40-700 keV)



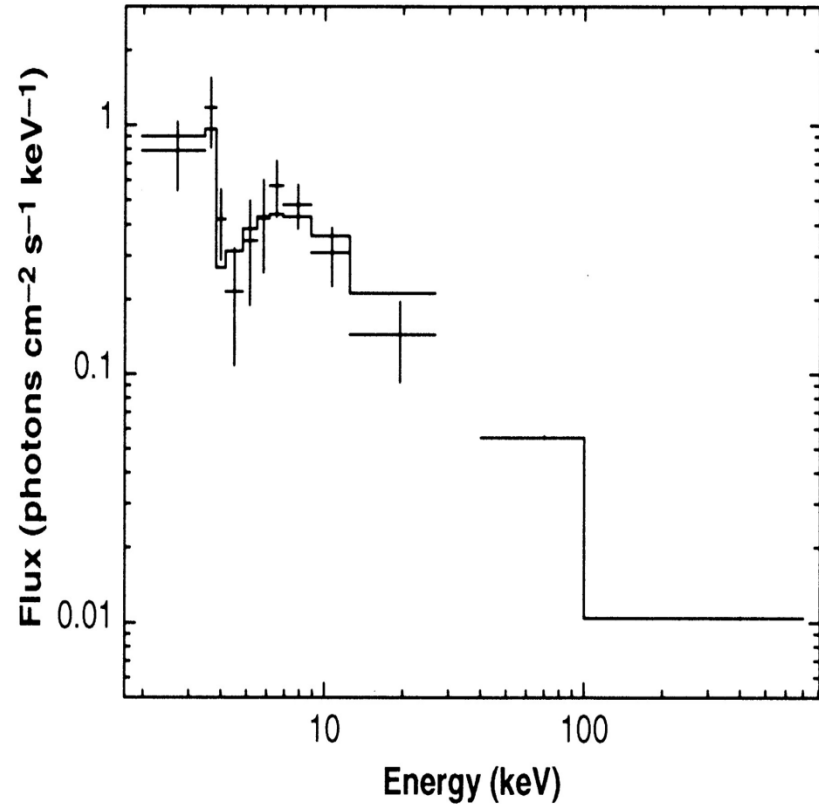
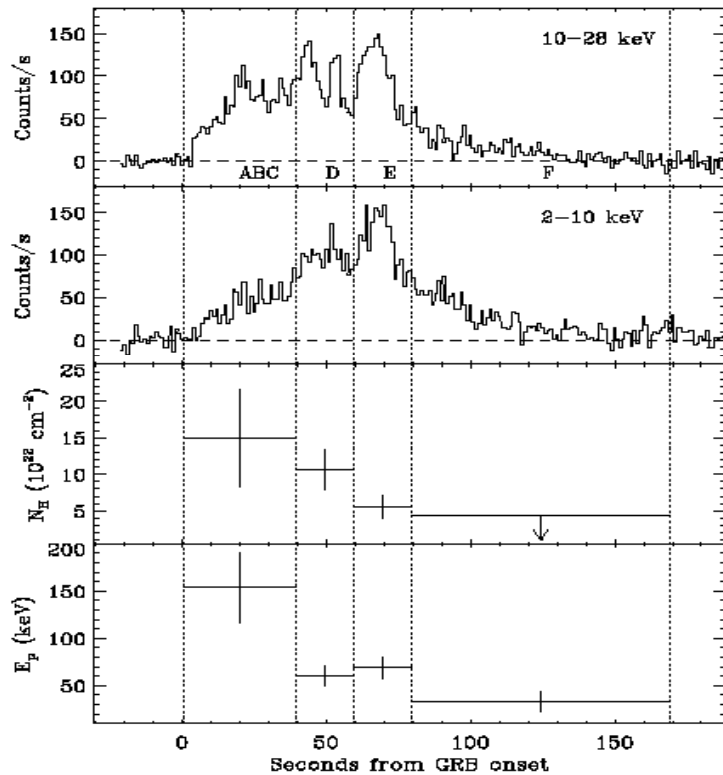
Swift XRT (rare / unique case)
+ Swift/BAT + konus/WIND

□ Tansient bump, consistent with a 2 keV blackbody, observed in the low energy band with BeppoSAX WFC



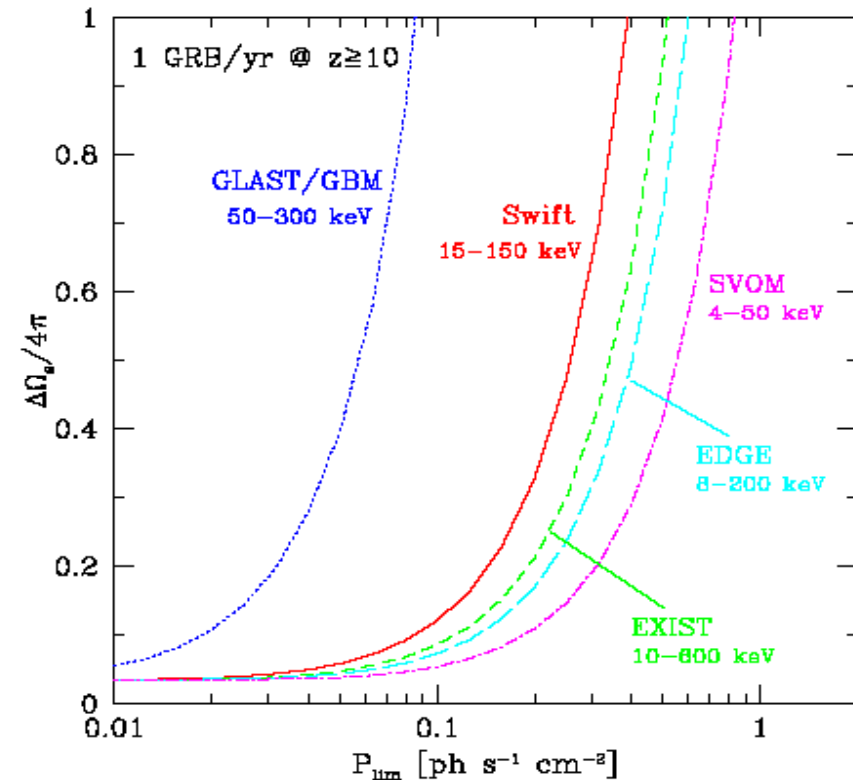
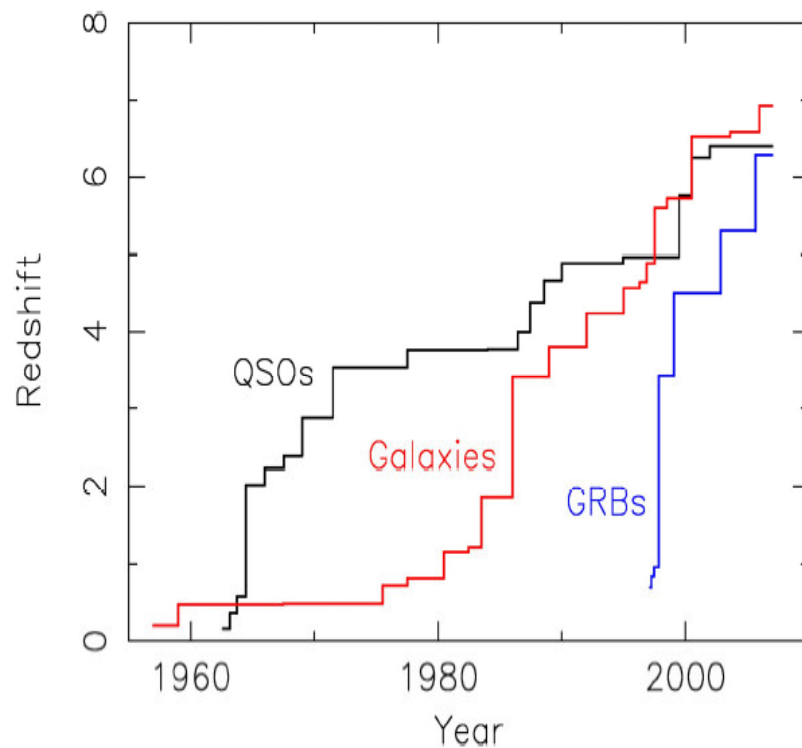
Frontera et al. 2001

□ X-ray features: properties (density profile, composition) of circum-burst environment (progenitors, X-ray redshift)



(Frontera et al., ApJ, 2004, Amati et al, Science, 2000)

□ Increasing the detection rate of high- z GRB with low energy threshold: SFR up to dark ages, pop III stars, ...



(Salvaterra et al. 2007)

The ASM Science: Monitoring and Survey

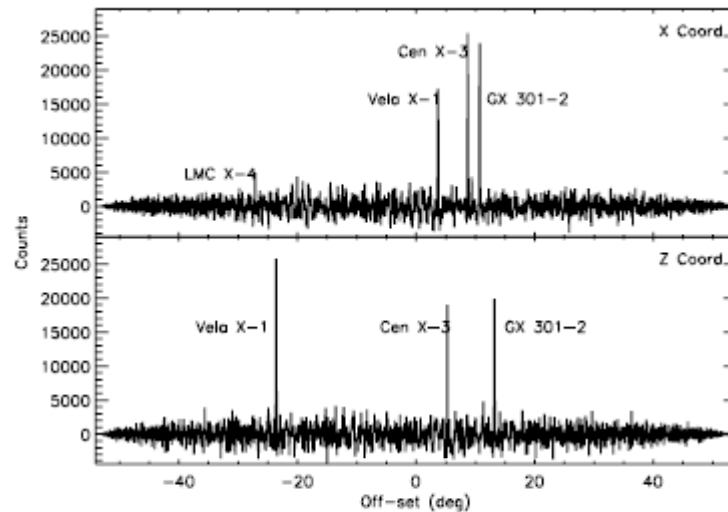
Science objectives opened by continuous All Sky Monitoring are extremely wide-spectrum, numerous and general. Long-term, continuous monitoring of Galactic sources allows the study of source/class properties not easily or unaccessible to specific, short observations, although more sensitive.

Examples are:

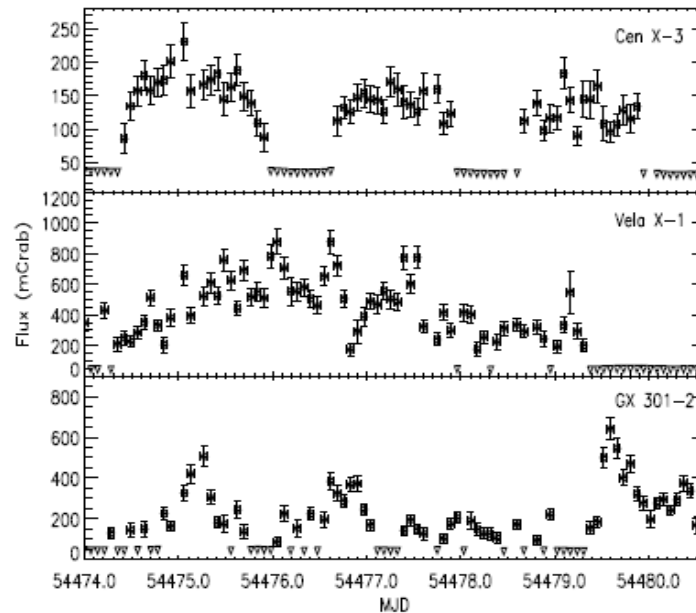
- discovery of new transient sources;
- discovery and long-term evolution of orbital, superorbital and spin periodicities, period derivatives and quasi-periodicities (QPOs);
- intensity and spectral state changes in BHC;
- multi-frequency correlation between timing, spectral and intensity parameters;
- discovery and monitoring of bursting behaviour (bursters, SGRs, AXPs, ...);
- a complete all sky survey.

Wide field of View – Simultaneous Monitoring a SuperAGILE snapshot of the the Vela region

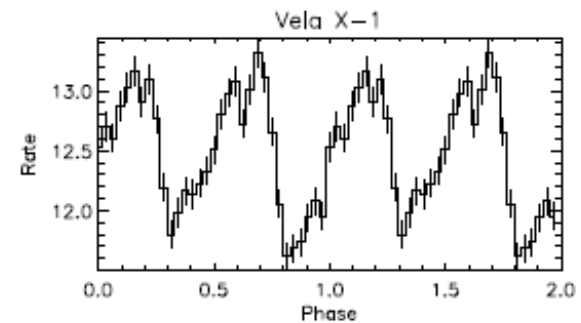
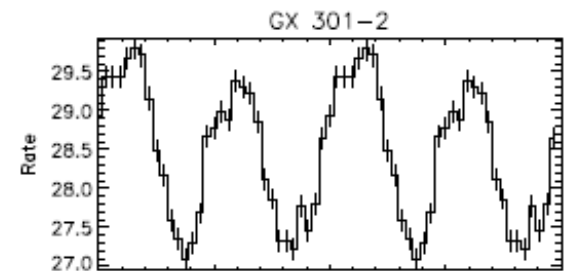
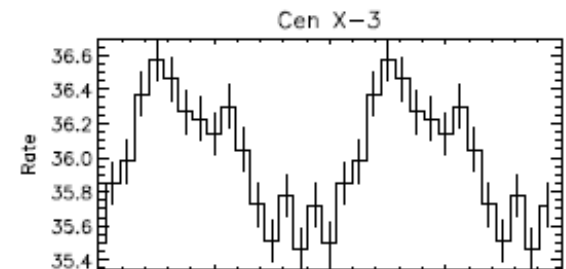
2 x 1D
images



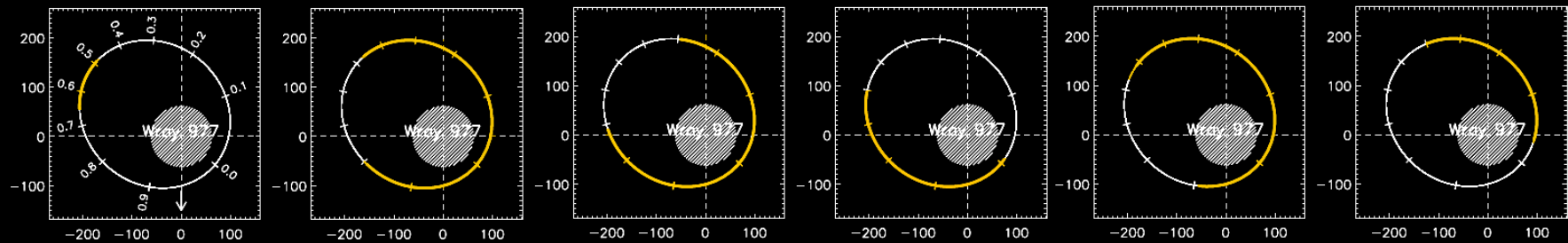
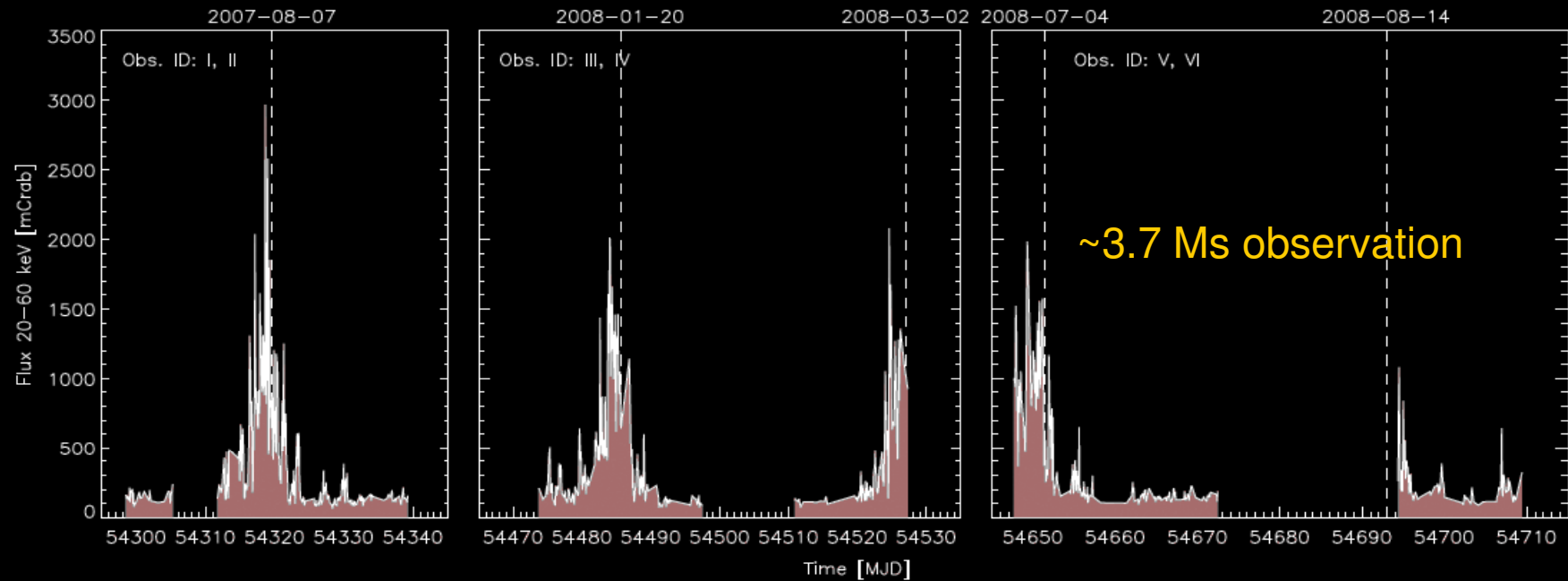
lightcurves



Folded Pulse Shapes



SuperAGILE observations of GX 301-2



Evangelista et al., ApJ 2010

The HMXB GX 301-2

Orbital parameters

$$P_{\text{orb}} \sim 41.482$$

$$P_{\text{spin}} = 670 - 690 \text{ s}$$

$$e = 0.44$$

$$a \sin i = 368.4$$

$$\omega = 310^\circ$$

System characteristics

Discovered in 1969 (balloon obs.)

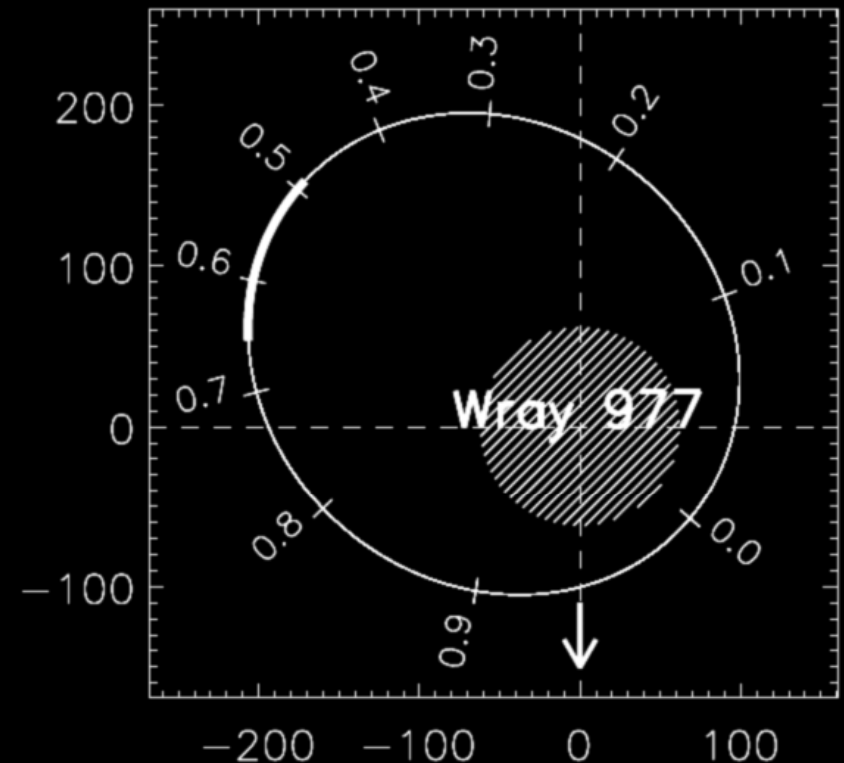
$$d = 3 \text{ kpc}$$

Hypergiant (B1 Ia+) companion Wray 977

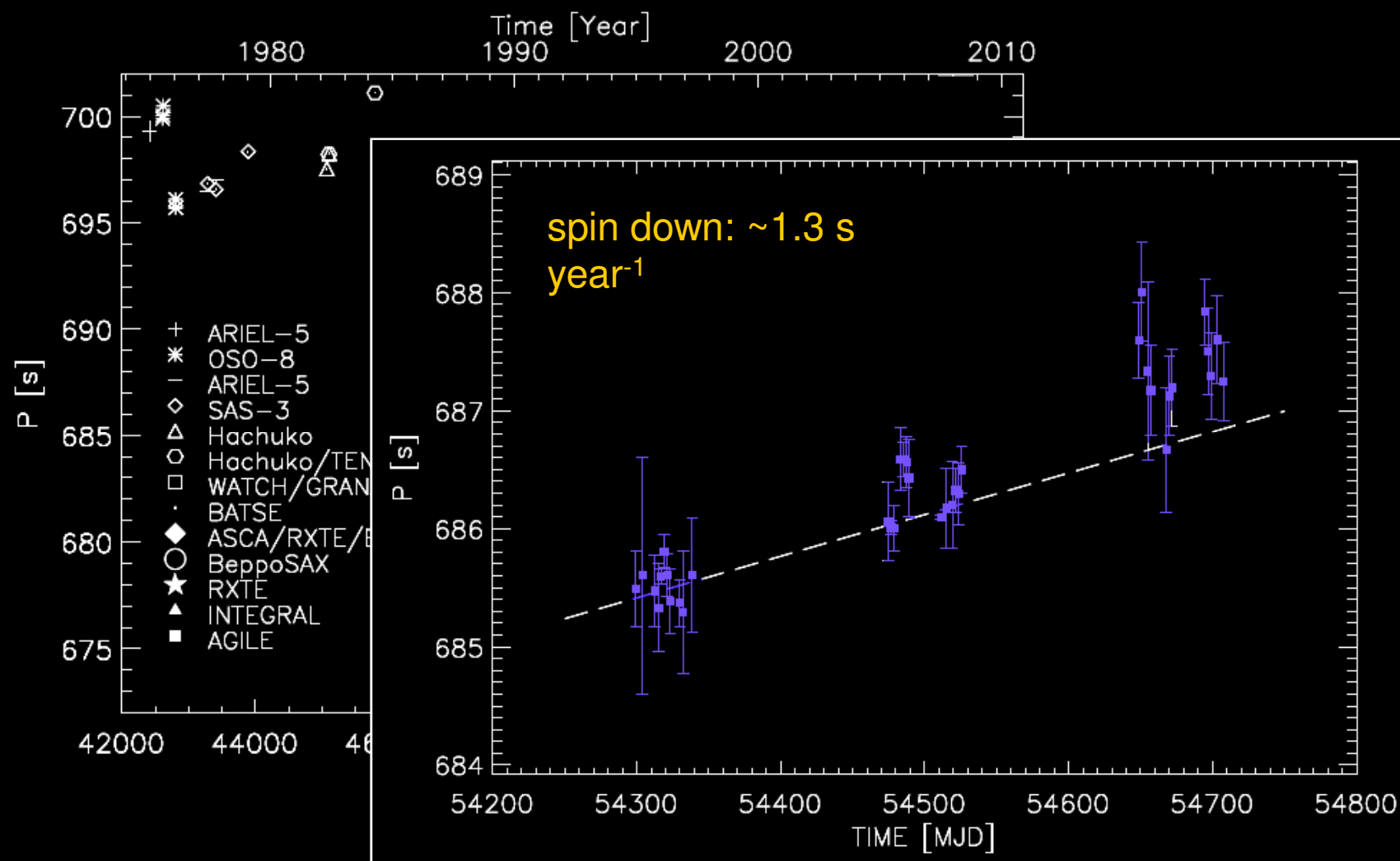
$$39 < M < 53 M_\odot$$

$$R = 62 R_\odot$$

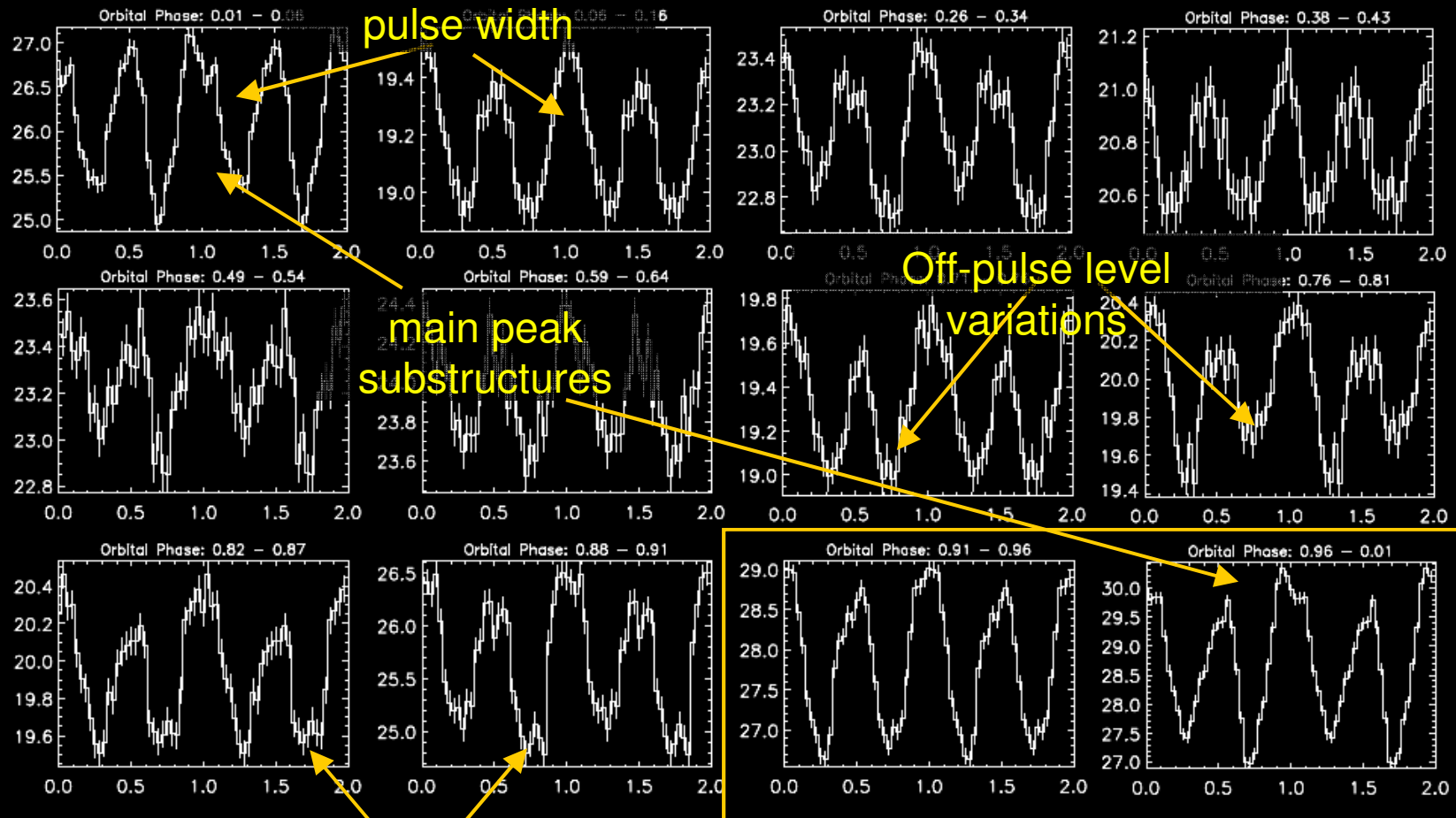
Flares regularly 1-2 days before periastron and, sometimes, at apastron



GX 301-2: spin history



Phase-resolved Pulse shape variability

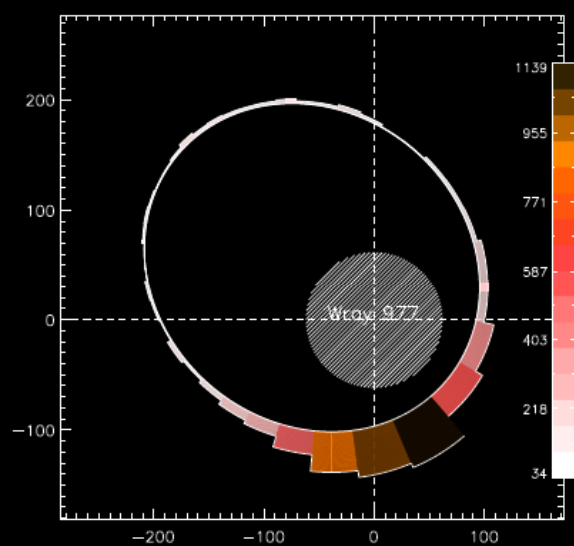


pre-periastron
passage

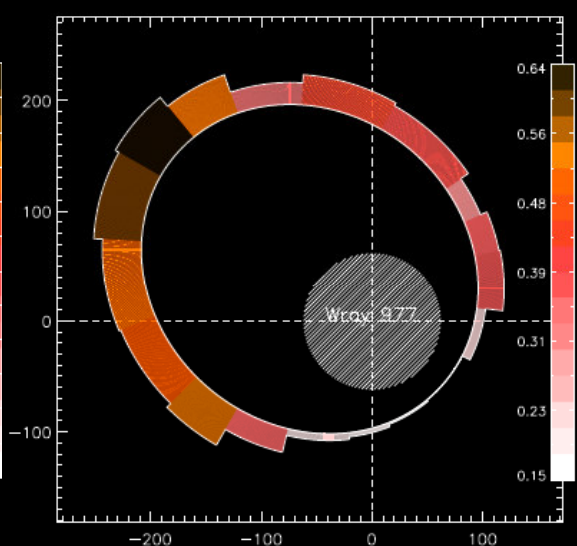
smoothest light curve

Summary of source behavior along the orbit

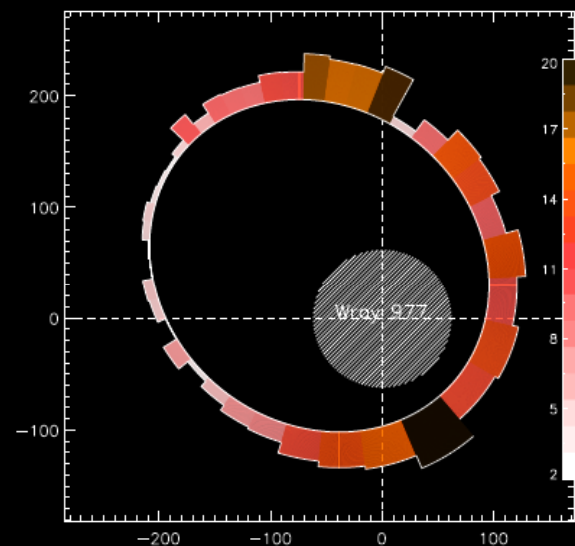
flux 18-60 keV



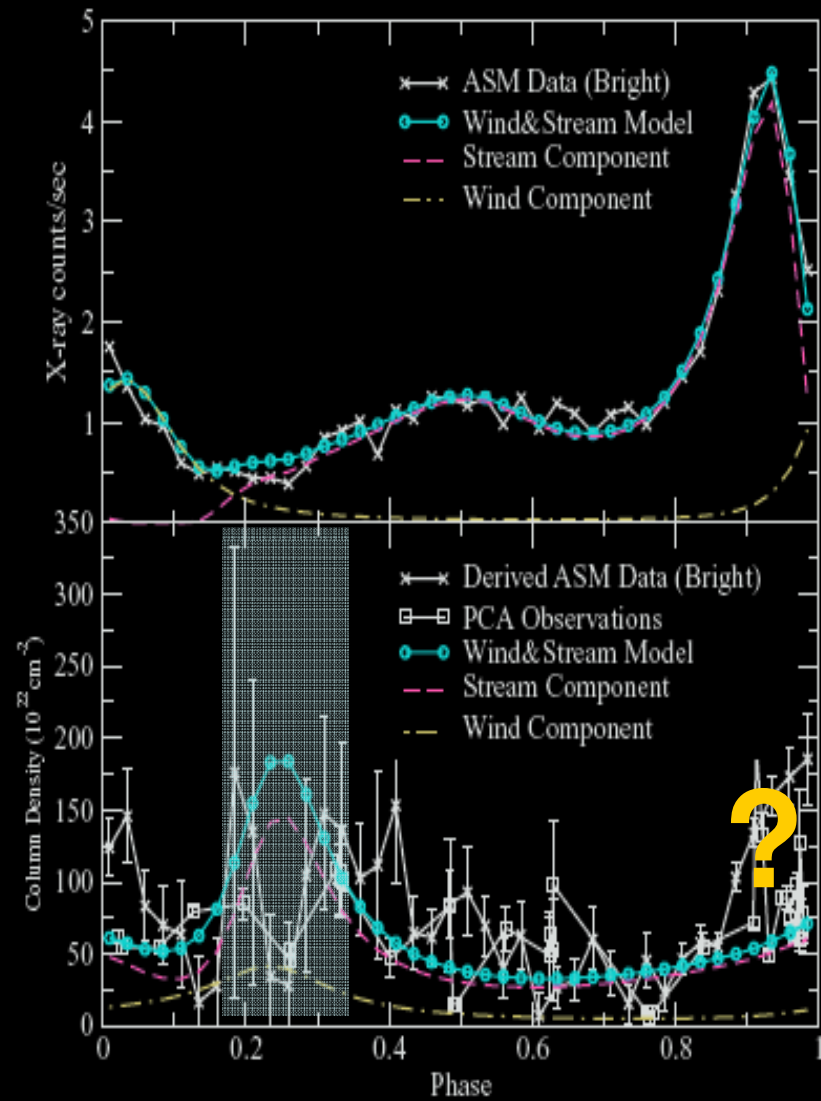
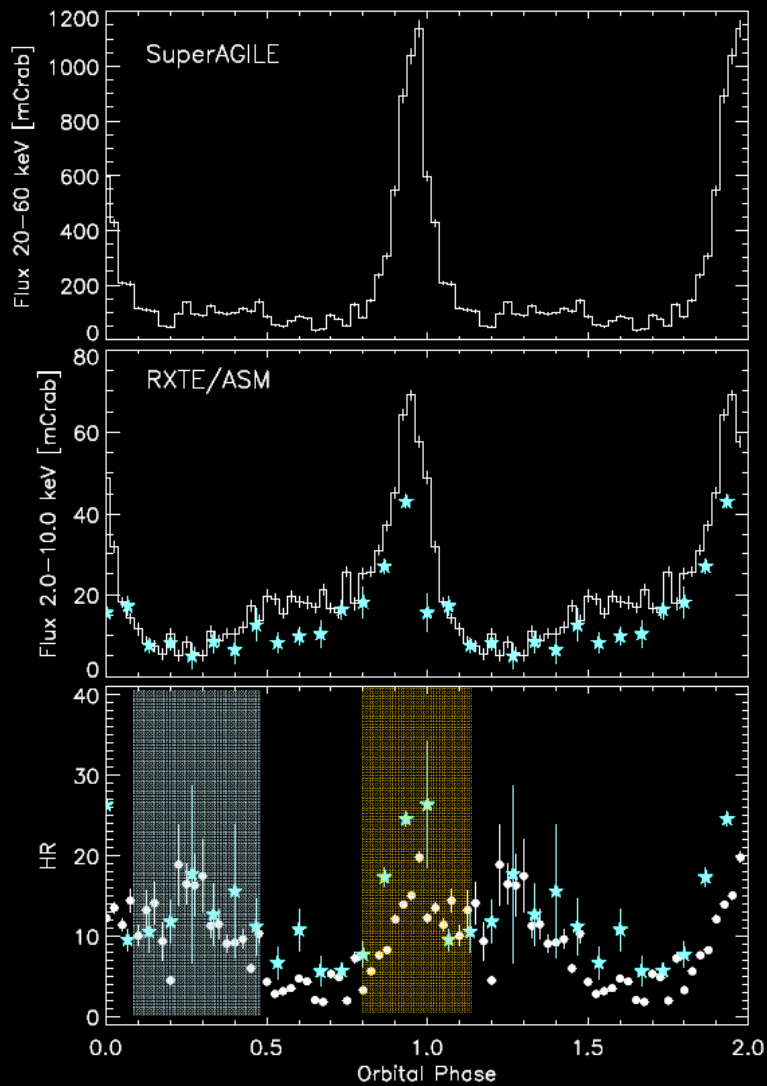
pulsed fraction



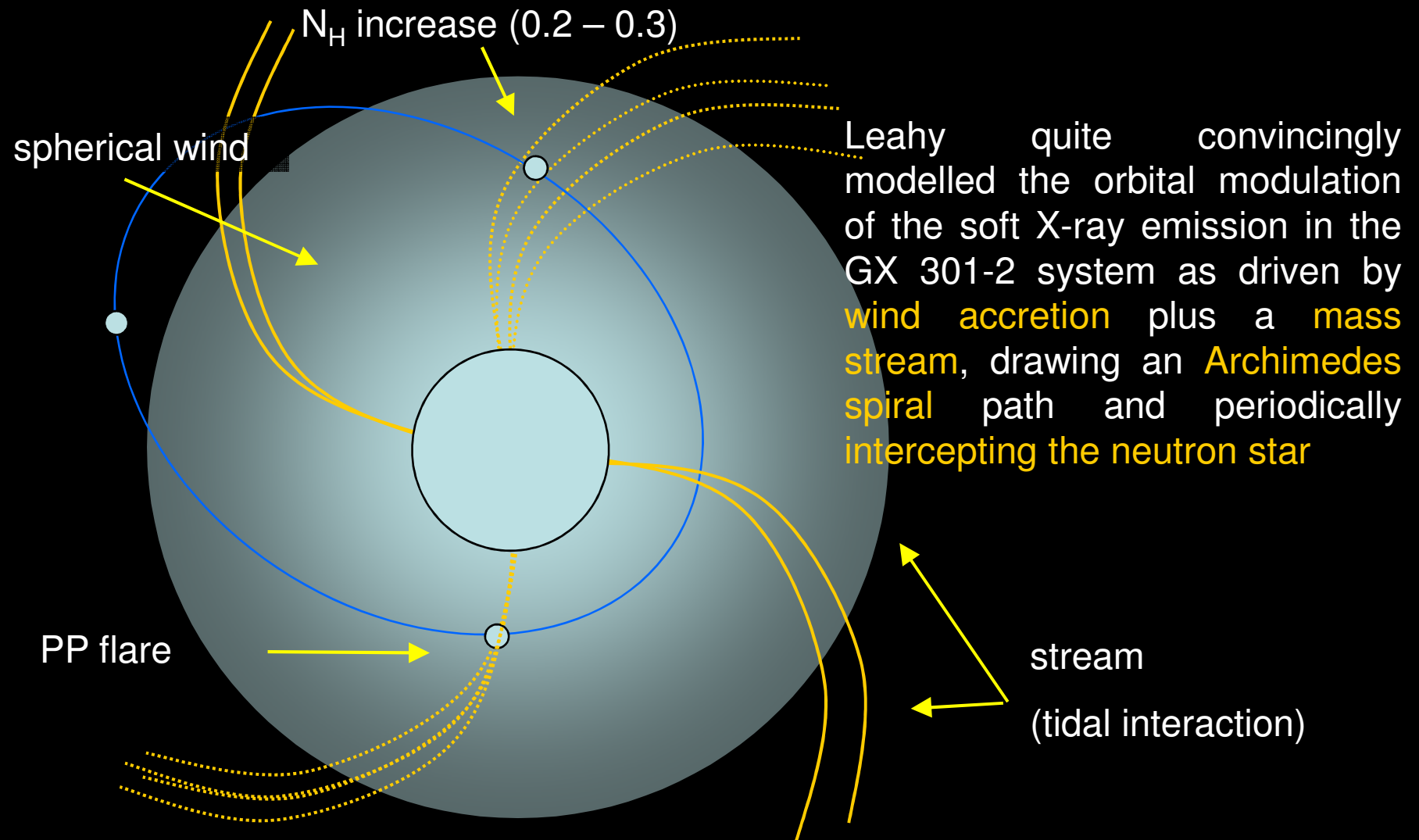
hardness



Spectral variability (HR) – (wind + stream model)?

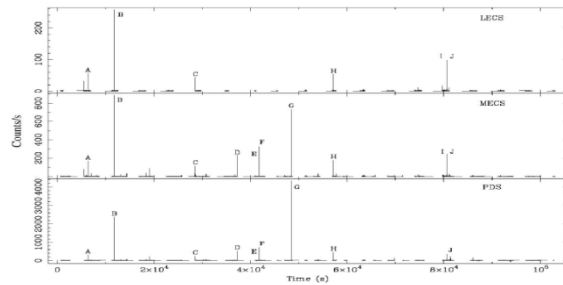


Wind + stream model (Leahy 2008)



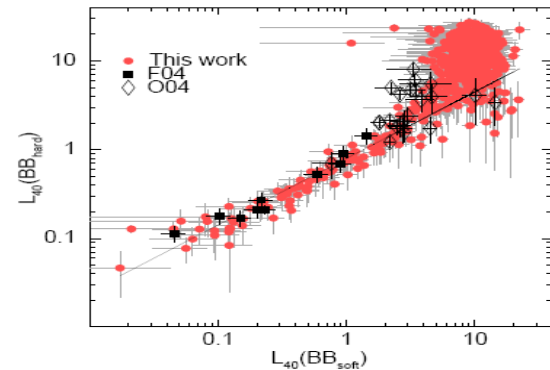
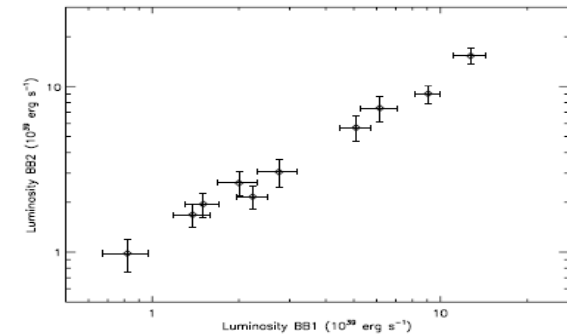
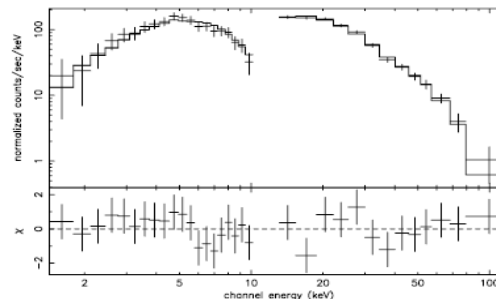
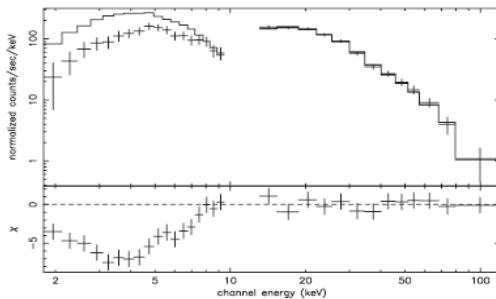
The low energy side of Magnetars

Historically, energy spectra of short bursts from SGRs have been phenomenologically well described ($E > 15$ keV) with an OTTB law, although the emitting process was always thought to be “optically thick”. Thanks to the low energy extension, the BeppoSAX measurements of the wide-band energy spectrum of short bursts from SGR 1900+14 demonstrated that a 2BB model is more suitable and easier to understand, in the framework of the magnetar model. Further measurements with Swift/BAT from the same source confirmed the BeppoSAX findings.



OTTB

2BB



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The ASM Science: “Service”

The most sensitive observatories of any generation carry state-of-the-art detectors and experiments, allowing to perform unprecedented studies of individual sources, over a narrow field of view ($\sim 1^\circ$ or less).

A monitoring experiment is then needed to trigger ToOs, to catch the most interesting states of the sources, often unpredictable. Also, specific observations can be put in the context of the history or evolution of the source (or class of sources) if monitoring is continuously available.

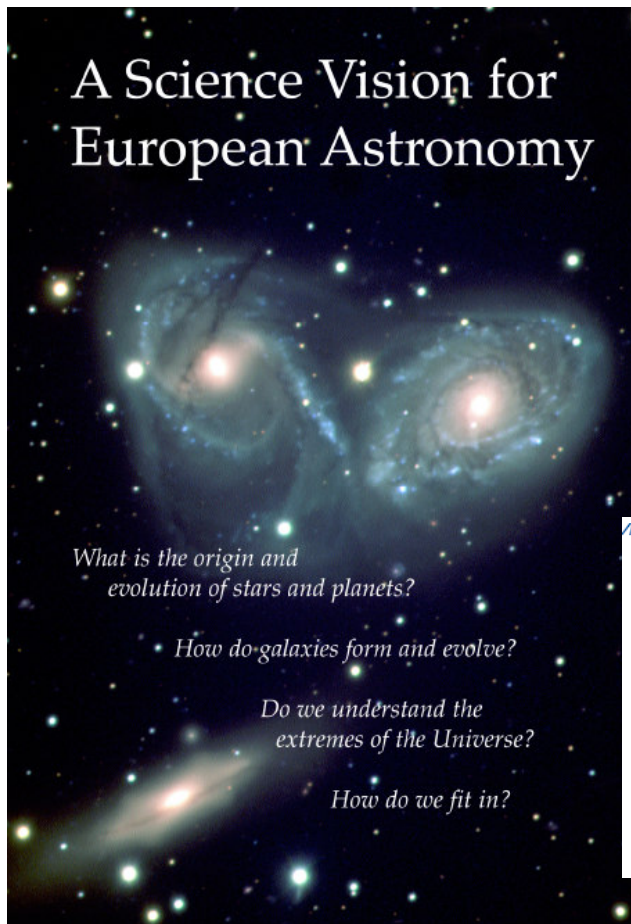
Several X-ray missions have put wide field experiments in their baseline requirements (e.g., RXTE, BSAX, INTEGRAL, Suzaku, ...). Over the last decade, the RXTE/ASM - and now Swift/BAT, ISS/MAXI and INTEGRAL/IBIS - have made All Sky Monitoring a task “taken for granted” by our Community. But these experiments will not be up there forever ...

International Scenario for All-Sky/Wide-Field Monitoring

Mission	Experiment	Energy Range (keV)	Angular Resolution (arcmin)	50 ks Sensitivity (mCrab)	Field of View FWZR (deg)	Area (cm²)	Nominal Operation/ Launch
INTEGRAL (ESA)	ISGRI	20-200	12	~3-5	29 x 29	2600	2002-2012
SWIFT (USA)	BAT	15-150	17	~5	100 x 60	5240	2005-2008+
RossixTE (USA)	ASM	2-12	12	~5	12 x 110 (scan)	90	1996-2010
AGILE (Italy)	SuperAGILE	18-60	6	10	107 x 68	1400	Jul 2007-?
ISS (Japan)	MAXI	2-30/0.5-10	90/90	2/4	1.5 x 160 (scan)	5350/200	2009-2011+
ASTROSAT (India)	SSM CZTI	2-10 10-100	10 8	10 0.2	6 x 90 (scan) 17 x 17	180 1000	2011 (?)
SVOM/ECLAIRs (France, China)	CXG/SXC	4-300/1-12	40/2	3/N/A	105 x 105	1000/100	2012
EXIST (USA)	LET/HET	5-30/10-600	0.9/5	N/A	131 x 65	56000	>2015(?)

Strategic Importance of All Sky Monitoring: Recommendations by ASTRONET (2008) *Infrastructure Roadmap: A Strategic Plan for European Astronomy*

HIGH ENERGY ASTROPHYSICS, ASTROPARTICLE ASTROPHYSICS AND GRAVITATIONAL WAVES (PANEL A)



3.2.5.2 Specific Gaps Identified from the Science Vision

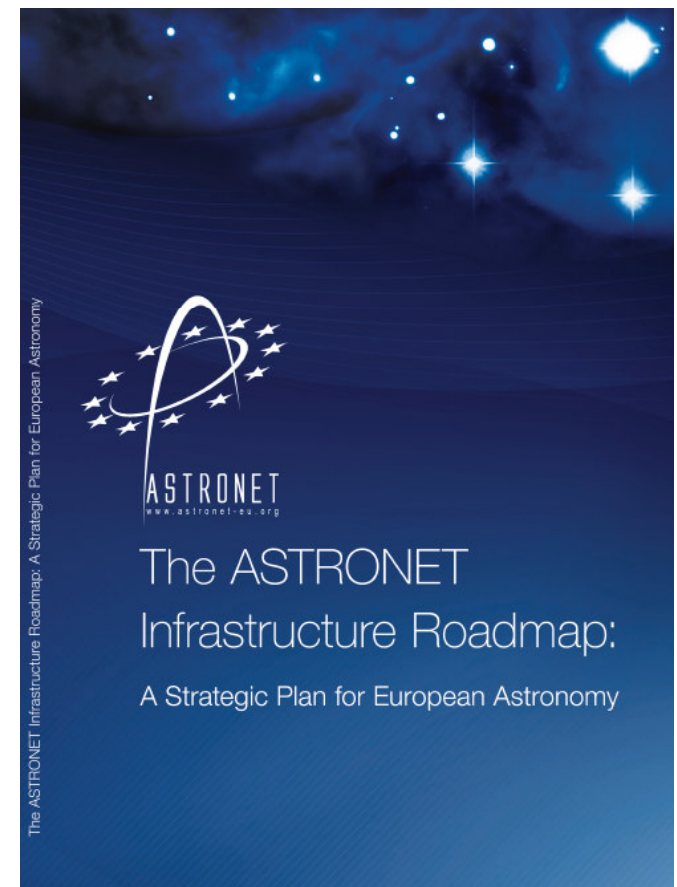
Our Panel has identified some capabilities that are strongly called for in the Science Vision, but are not yet programmatically ready and/or do not yet provide large improvements over existing experiments at affordable cost. Further development of existing and new technologies should be encouraged in these areas in order to fully address the challenges set out in the Science Vision.

One such area is imaging and spectroscopy in the very difficult 0.1–10 MeV photon energy range. The spectroscopy of nuclear and annihilation lines and the correct identification of the sources of these lines requires considerable progress in sensitivity and resolution in this energy range, in order to make progress in the understanding of the outputs of black hole sources and of the chemical evolution of the Universe through enrichment from various stellar processes.

vision

Another area is all-sky monitoring (ASM) of instantaneously large solid angles for transient and variable sources, in all X- and gamma-ray energies. Some missions are still ongoing or planned for the next decade, but there is a clear threat of lack of continuity in this area in the long term and a need for new concepts to enable the next generation of ASMs. Since many of the high energy sources we need to study are transient or highly variable, the Science Vision calls for continued capability in sensitive all-sky monitoring (e.g., for GRBs, outbursts of black hole sources, XRBs, etc).

The follow-up of large numbers of GRBs to find and study in detail the highest redshift events as cosmological probes is also an important goal in the Science Vision, for which future projects need to be further developed.



The Instrumental Background for Silicon-based Wide Field Cameras

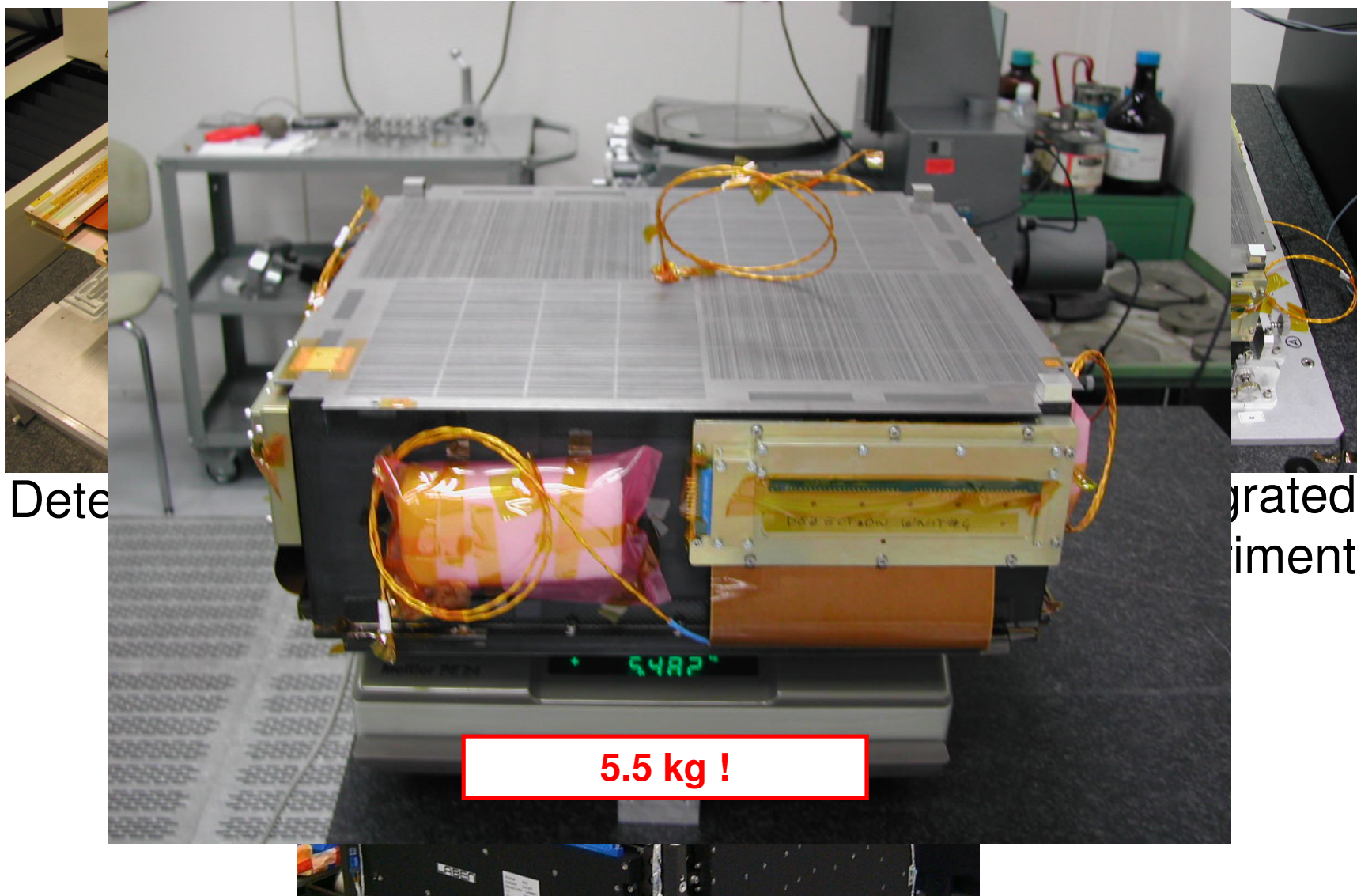
Key Instrumental Points

- High Spatial Resolution ($\sim 100\mu\text{m}$) solid state detectors allows good angular resolution with short mask-detector distance
=> short shielding (low weight)
- Low-energy bandpass (below 40-50 keV) requires only thin shielding and mask => low weight
- Strip (1D) read-out => high ratio geometric area vs power
- (and steep spectra of cosmic sources help
=> higher fluxes at lower energies)



Silicon: Established and Improving Technology
High Commercial availability
Fine Pitch
Low Energy

Background: SuperAGILE



Where is the difference ?

	Energy Range (keV)	Angular Resolution (arcmin)	1-day Sensitivity (mCrab)	Field of View (deg ²)	Area (cm ²)	Detector Position Res. (mm)	Mask-Detector Dist. (mm)	Weight (kg)
INTEGRAL/IBIS	20-2000	12	~3-5	29 x 29	2600	4.6	3200	700
Swift/BAT	15-150	17	~5 ^(*)	100 x 60	5240	4	1000	>200 ^(*)
ISS/MAXI	2-30	6	2	1.5 x 160	5350	1	770	490
BeppoSAX/WFC	2-28	5	~5	40 x 40	140	0.5	700	43
RossiXTE/ASM	2-12	12	10	12 x 110	90	0.5	300	>30 ^(*)
HETE-2/WXM	2-25	36	N/A	90 x 80	175	1	187	>20 ^(*)
AGILE/SuperAGILE	18-60	6	~15	106 x 68	1444	0.121	140	5.5

(*) Not available from literature: “reasonable guess” based on the instrument/mask properties



A Step Forward: the ALICE Silicon Drift Detector

- ALICE-D4 detectors, designed by INFN-Trieste (A. Vacchi et al.) and manufactured by Canberra, Inc.
- Designed for particle tracking in the ALICE experiment at LHC



- 256 anodes for each half of the detector tile
- 35 mm max drift length
- 294 μm pitch (distance between anodes)
- 300 μm thickness

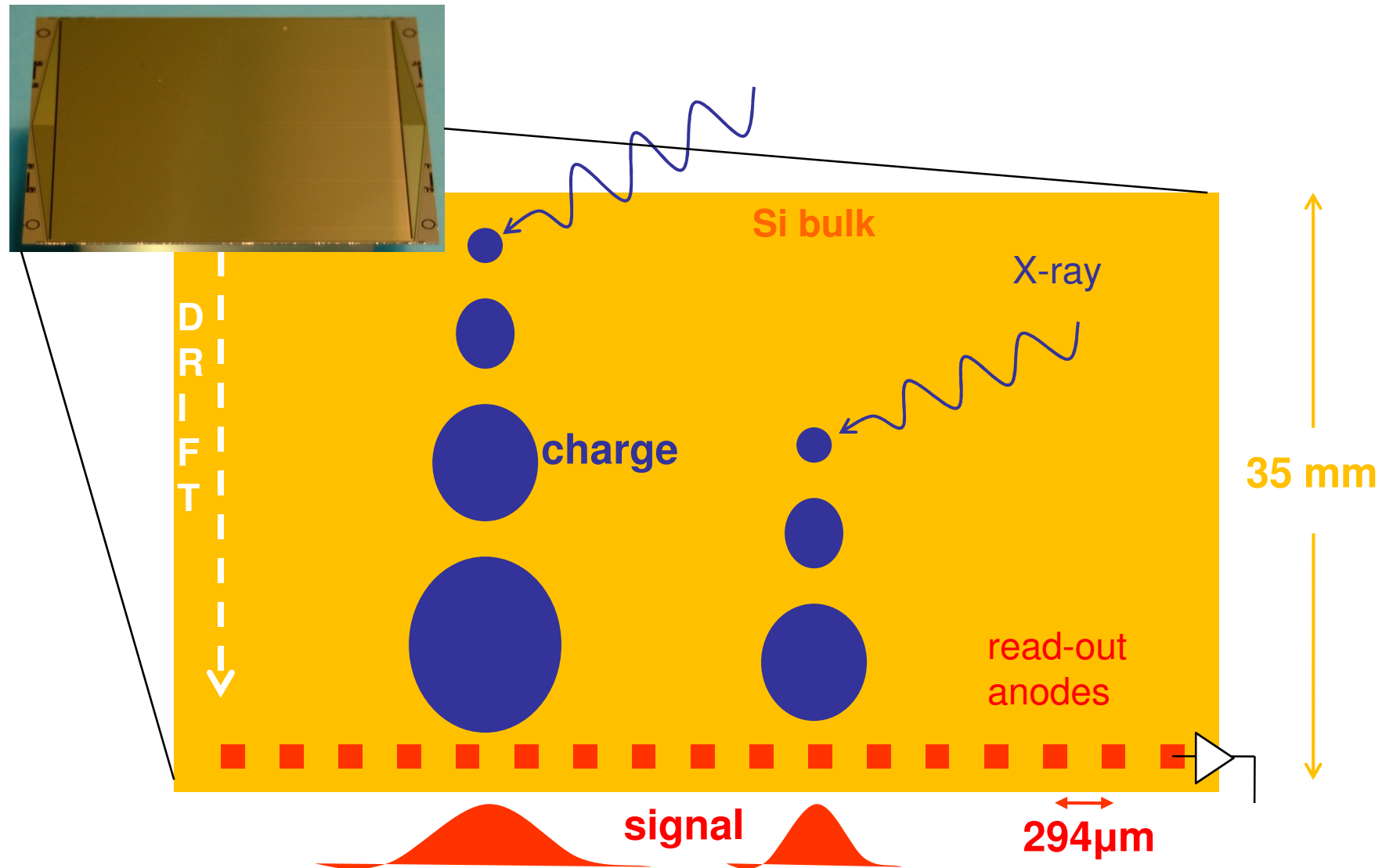
The ALICE-D4 Silicon Drift Detector

- 600 detectors have been produced; 260 installed at the ALICE experiment at CERN (1.5 m² total area, 80% production efficiency)
- Spatial resolution of 30 μm for particle tracking
- Very low leakage current
- Continuously operating since 2 years



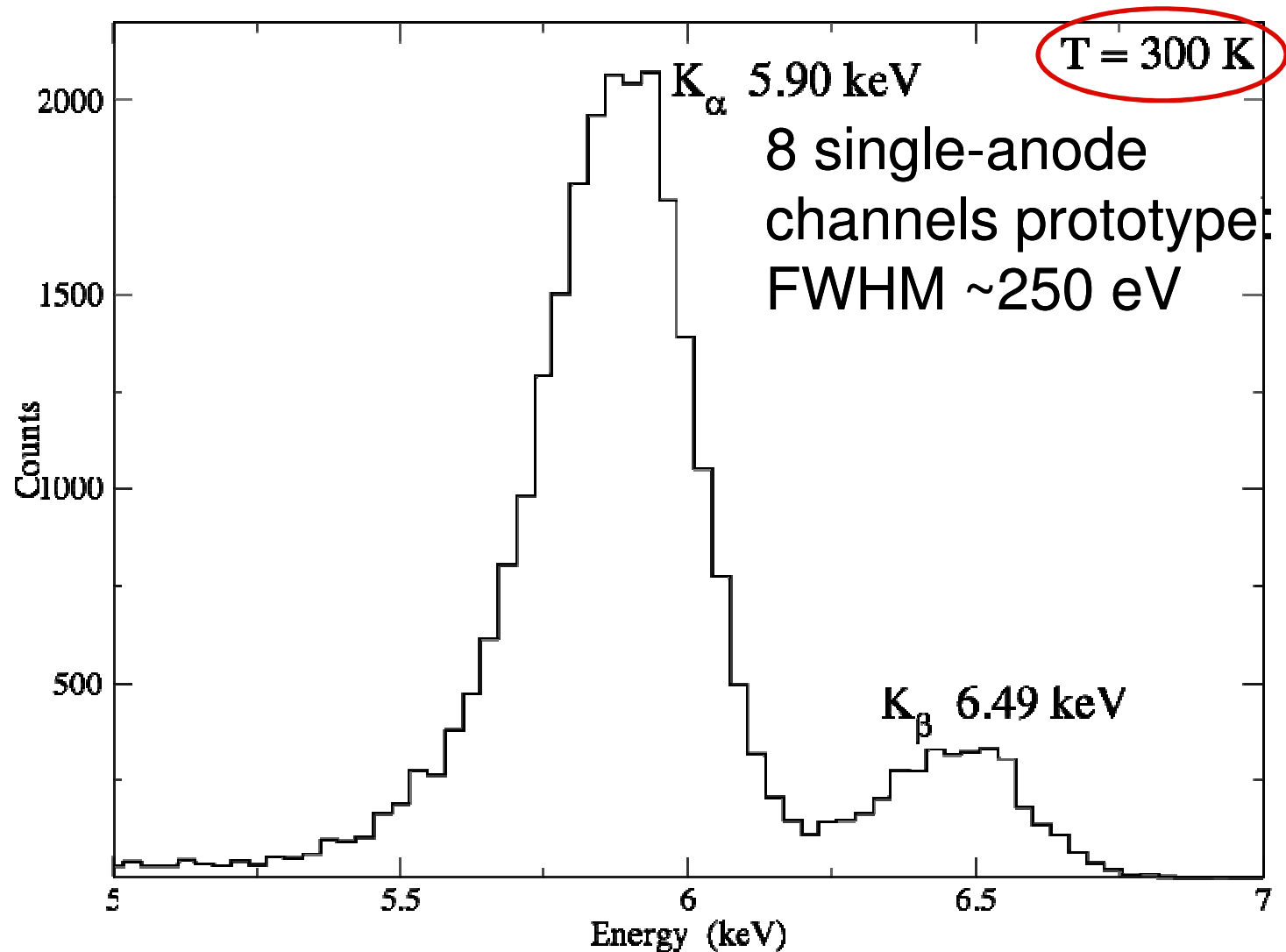
The ALICE experiment

The ALICE-SDC Working Principle

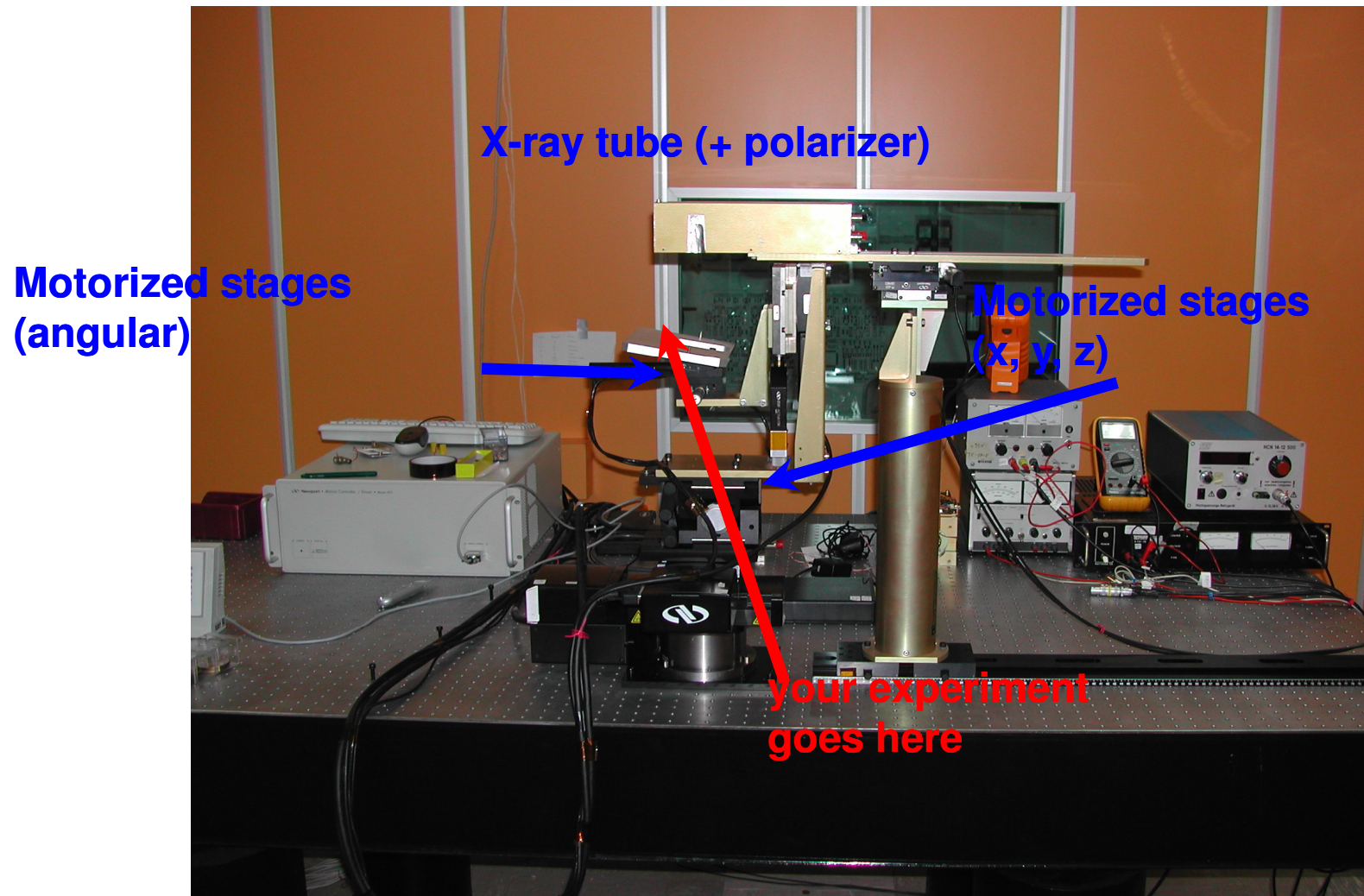


Test Results with a Lab Prototype

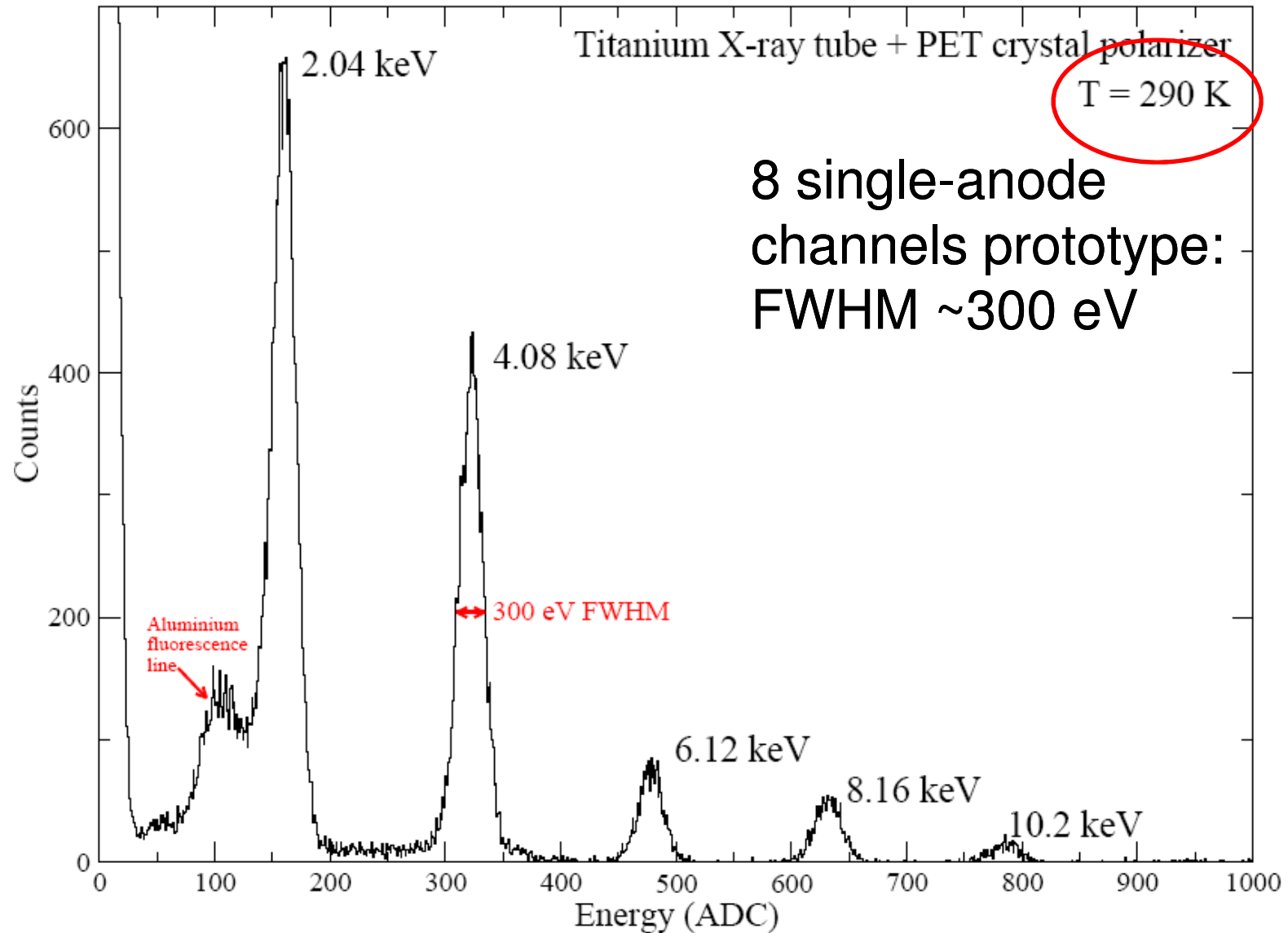
Fe-55 radioactive source



X-ray facility at IASF-Rome

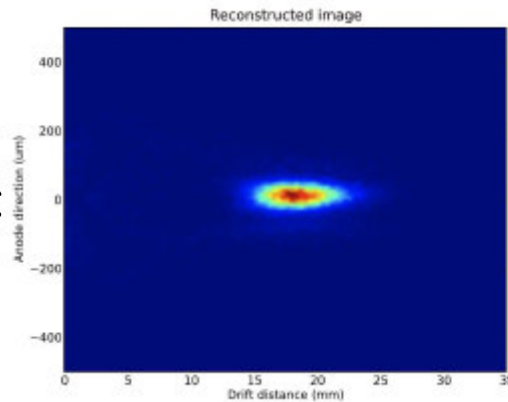


Test Results with a Lab Prototype



Position Resolution

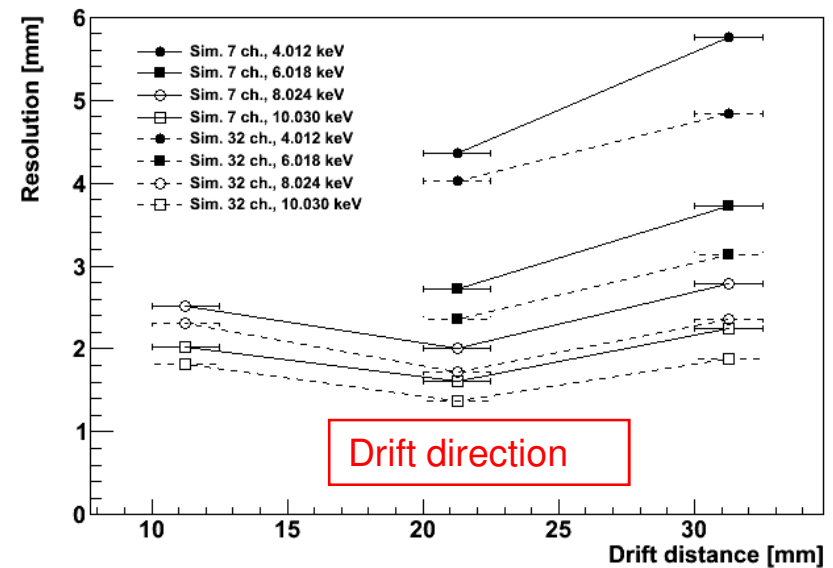
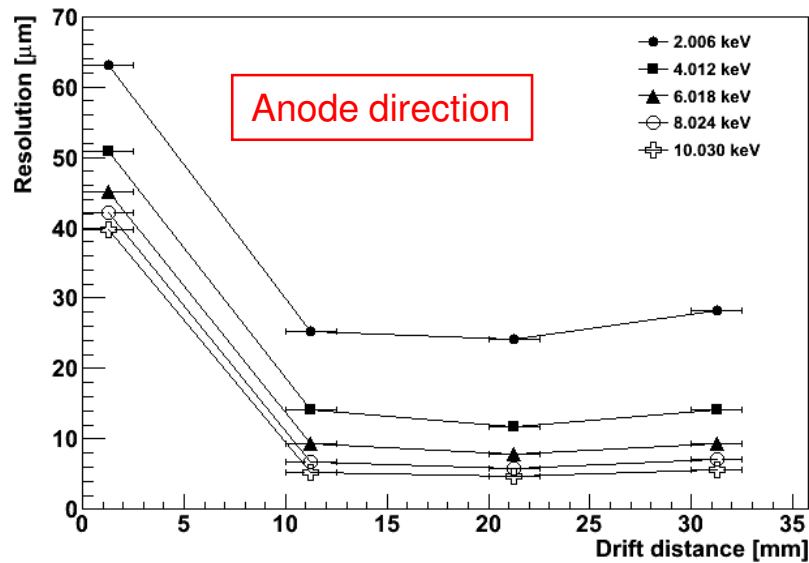
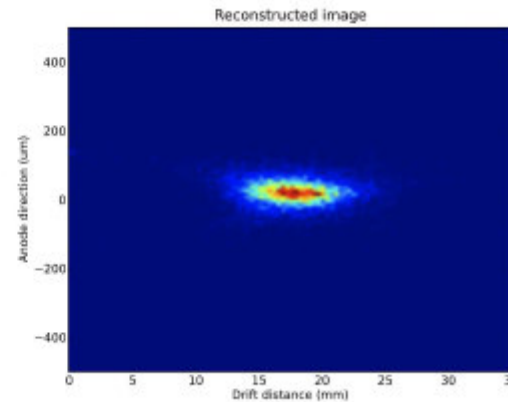
4.5 keV Measured



100 μm

5 mm

4.5 keV Simulated



The proposed MIRAX Science Payload

Mission Profile

The *Lattes* mission will bring a $\sim 1\text{ m} \times 1\text{ m} \times 1\text{ m}$ Payload Bay.

The *Lattes* Payload Bay will host two scientific missions:

- the MIRAX high energy astrophysics mission
- the EQUARS atmospheric science mission

The *Lattes* satellite will “fly” over the Earth, always exposing the same orientation to the Nadir and Zenith directions. This strategy will allow the two missions to operate simultaneously (EQUARS will always look at the atmosphere, MIRAX will always look at the open sky).

The MIRAX attitude will scan the sky at the speed of $4^\circ/\text{minute}$. This will enable the MIRAX ASM and GRBM experiments to scan almost the full sky, avoiding the Earth blockage .

MIRAX Astrophysical Observatory

Science Drivers:

1. Wide-band spectroscopy of the prompt emission of GRBs
2. All-sky monitoring of Galactic and Extragalactic X-ray sources

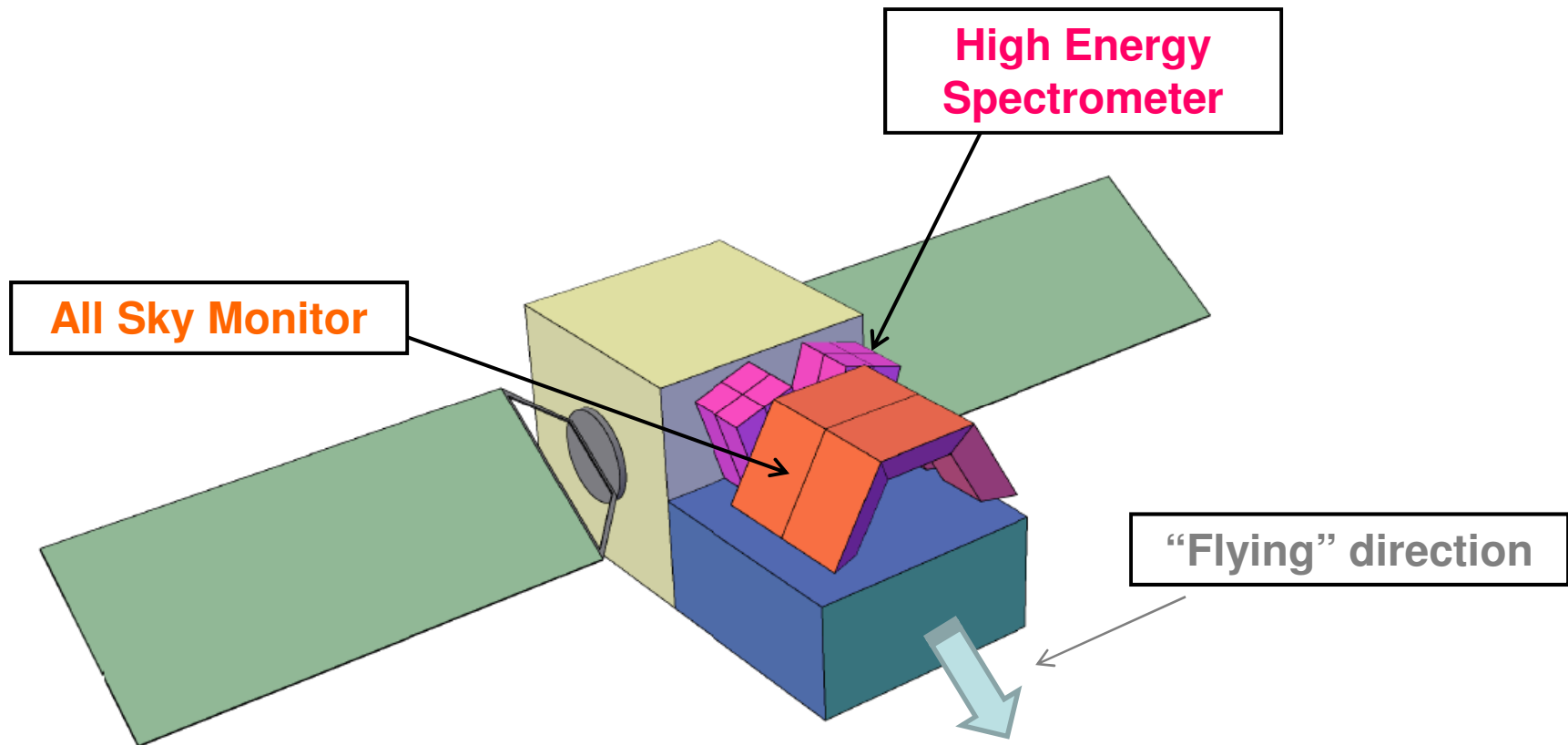
Instrument Requirements:

1. High sensitivity ($\sim$ few mCrab) over a broad energy band (few keV to few MeV)
2. Arcmin X-ray imaging over full sky

Proposed Implementation:

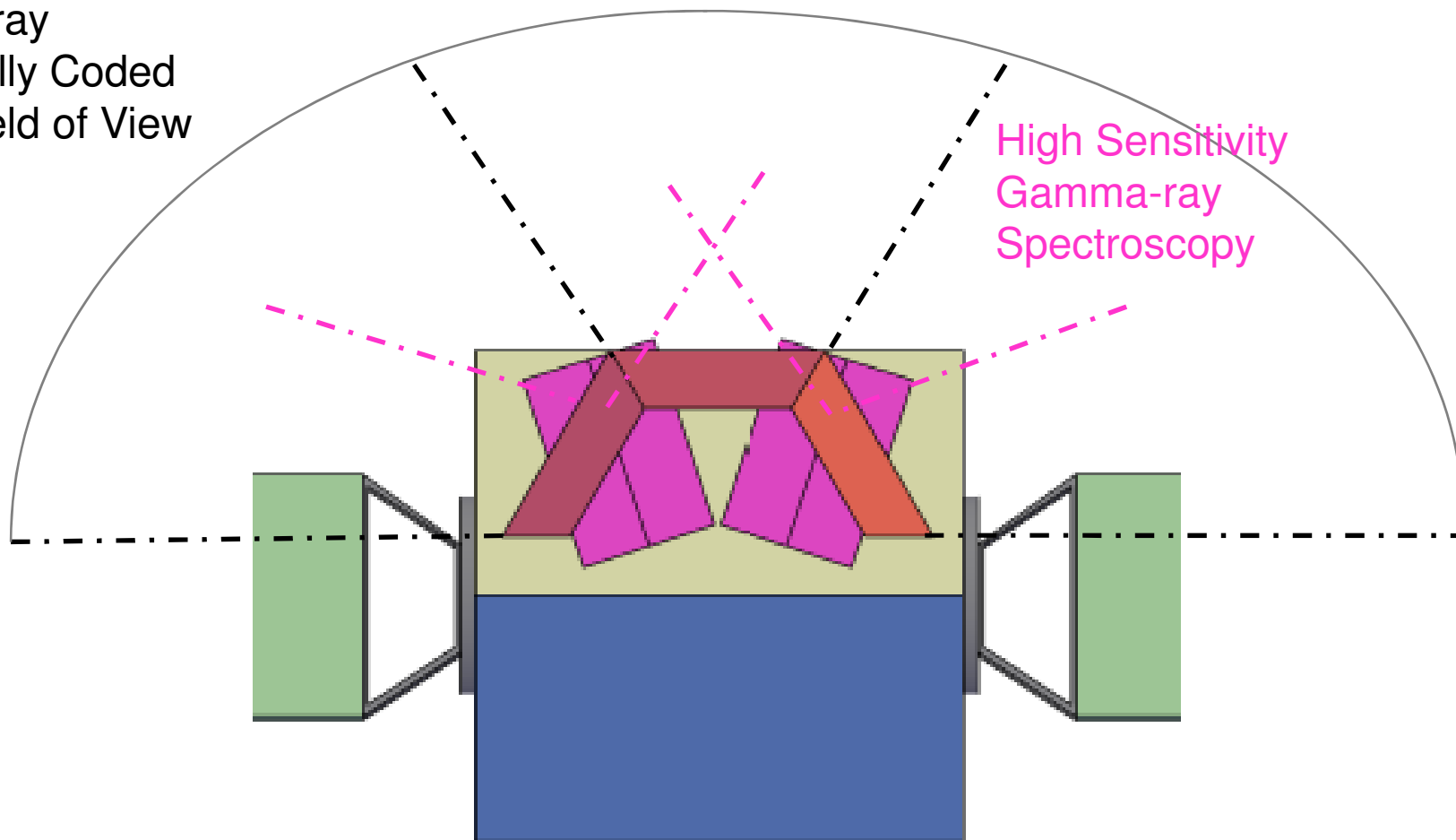
- All-Sky X-ray Monitor:
2-50 keV, 6 units, Imaging, Silicon Drift Detectors with Coded Mask
- High Energy Spectrometer:
20 keV – 5 MeV, non-imaging, NaI(Tl)/CsI(Na) crystals in phoswich configuration

Possible Payload Configuration



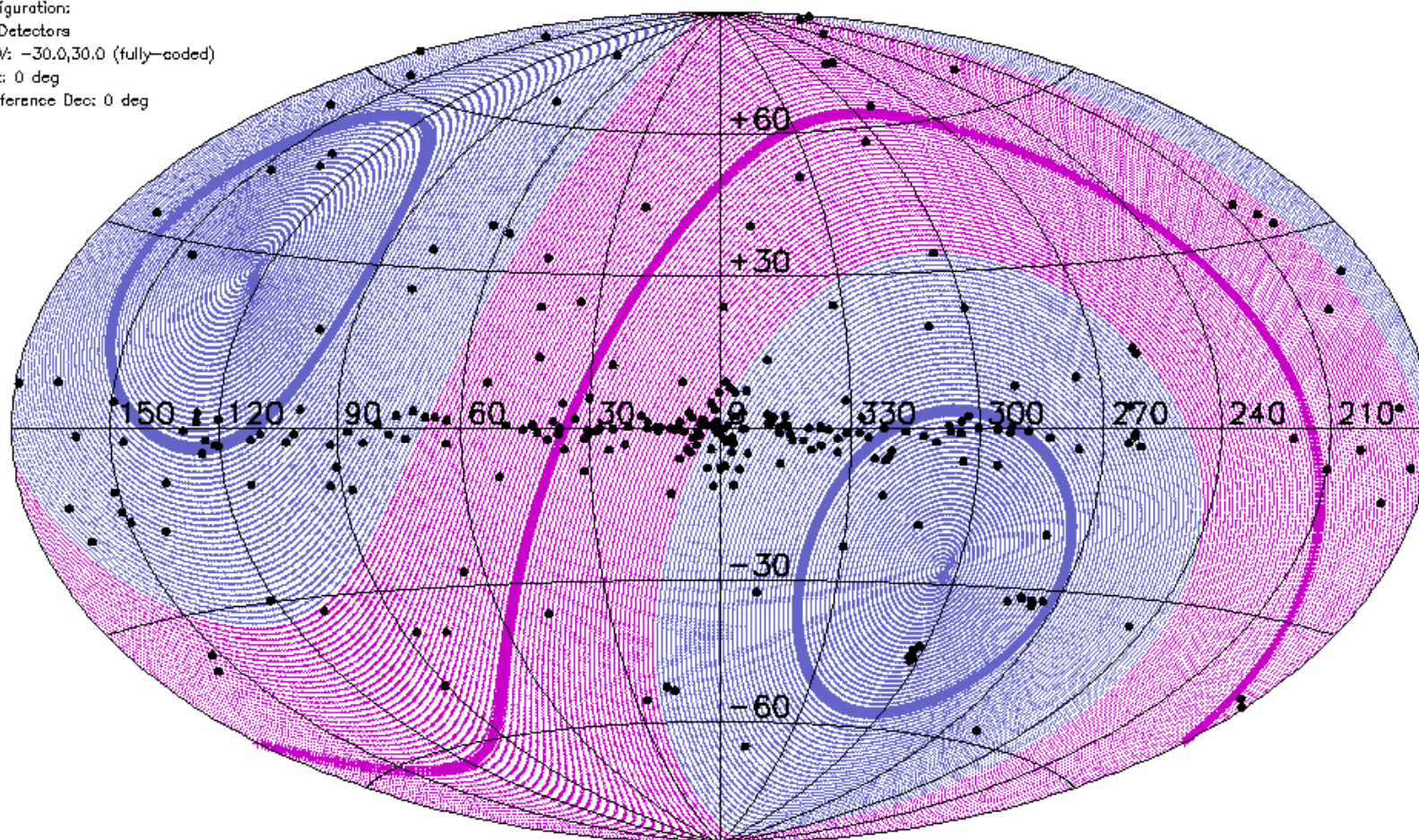
X-ray
Fully Coded
Field of View

High Sensitivity
Gamma-ray
Spectroscopy



X-ray Sky Coverage every orbit (90 minutes)

Configuration:
3 Detectors
FoV: $-30.0, 30.0$ (fully-coded)
Tilt: 0 deg
Reference Dec: 0 deg



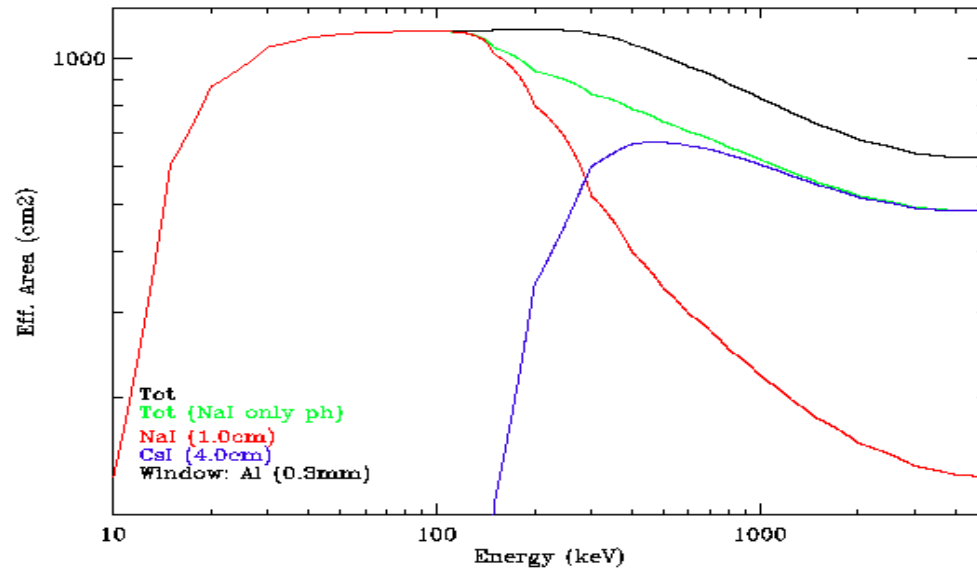
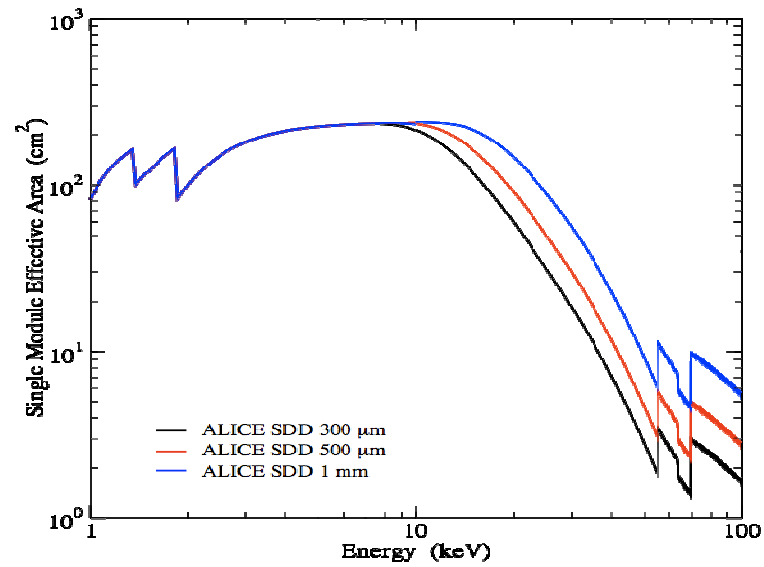
X-ray Monitor

Parameter	Expected Value
Energy Range	2-50 keV
Energy Resolution	From 250 to 500 eV FWHM
Time Resolution	~10 μ s
Effective Area	~550 cm ² in FCFoV (spectroscopy)
Angular Resolution	5 arcminutes
Point Source Location Accuracy	<1 arcminute
Field of View	~2.5 steradians FCFoV ~3.5 steradians PCFoV
Sensitivity (5- σ , 1 detector, imaging, for spectroscopy 1.4 better)	700 mCrab or ~2 ph/cm ² /s in 1s, FCFOV 90 mCrab or ~0.3 ph/cm ² /s in 60s, FCFOV <26 mCrab/orbit in >Half Sky <10 mCrab/elapsed day over All Sky ~ 3 mCrab/50 ks
Source Transit Time in FoV	700 s /orbit
Telemetry (orbit average)	3800 kbits/s

Soft Gamma-ray Spectrometer

Energy band	20 – 5000 keV
Effective Area	~ 1000 cm² up to 200 keV
	~500 cm² up to 1 MeV
Field of View	~ 2 sr
Bkg reduction up to	300 keV
Energy Resolution	15% @60 keV
Time resolution	< 10 μs
Gain control system	Yes
In-flight calibration system	Yes

Broad Band Spectral Coverage



The ASM Experiment Concept

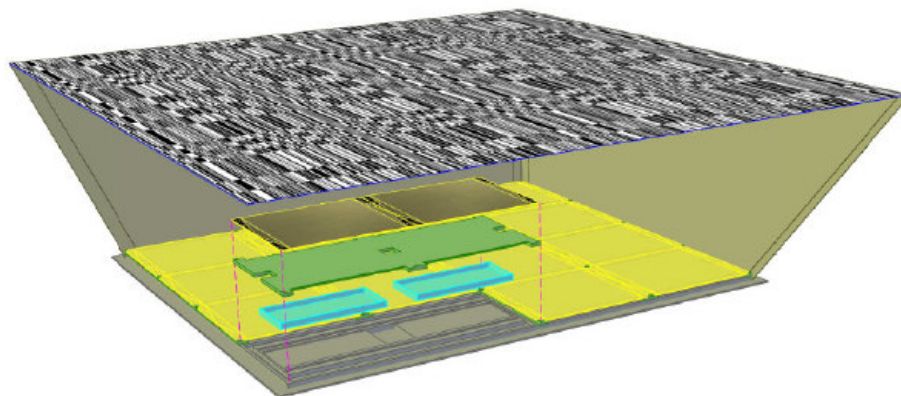
The SDC detector has asymmetric position resolution: $\leq 100\mu\text{m}$ in one direction and $\sim 2\text{-}3\text{ mm}$ in the orthogonal direction.

⇒ Asymmetric 2D coded mask

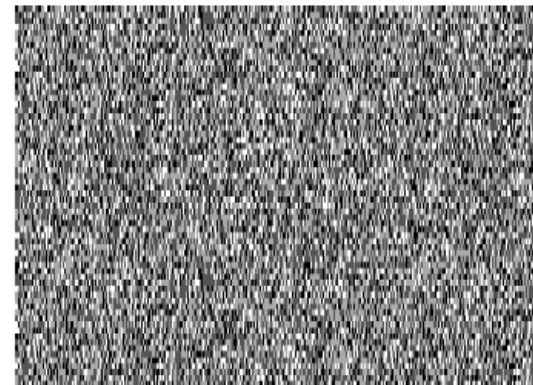
⇒ 2 orthogonal units always looking at the same FoV to guarantee arcmin prompt localization of Gamma Ray Bursts (double area for persistent sources)

Modular approach: the detector size can be adjusted to match the scientific requirements and fit the mass/volume/power/telemetry/budget constraints.

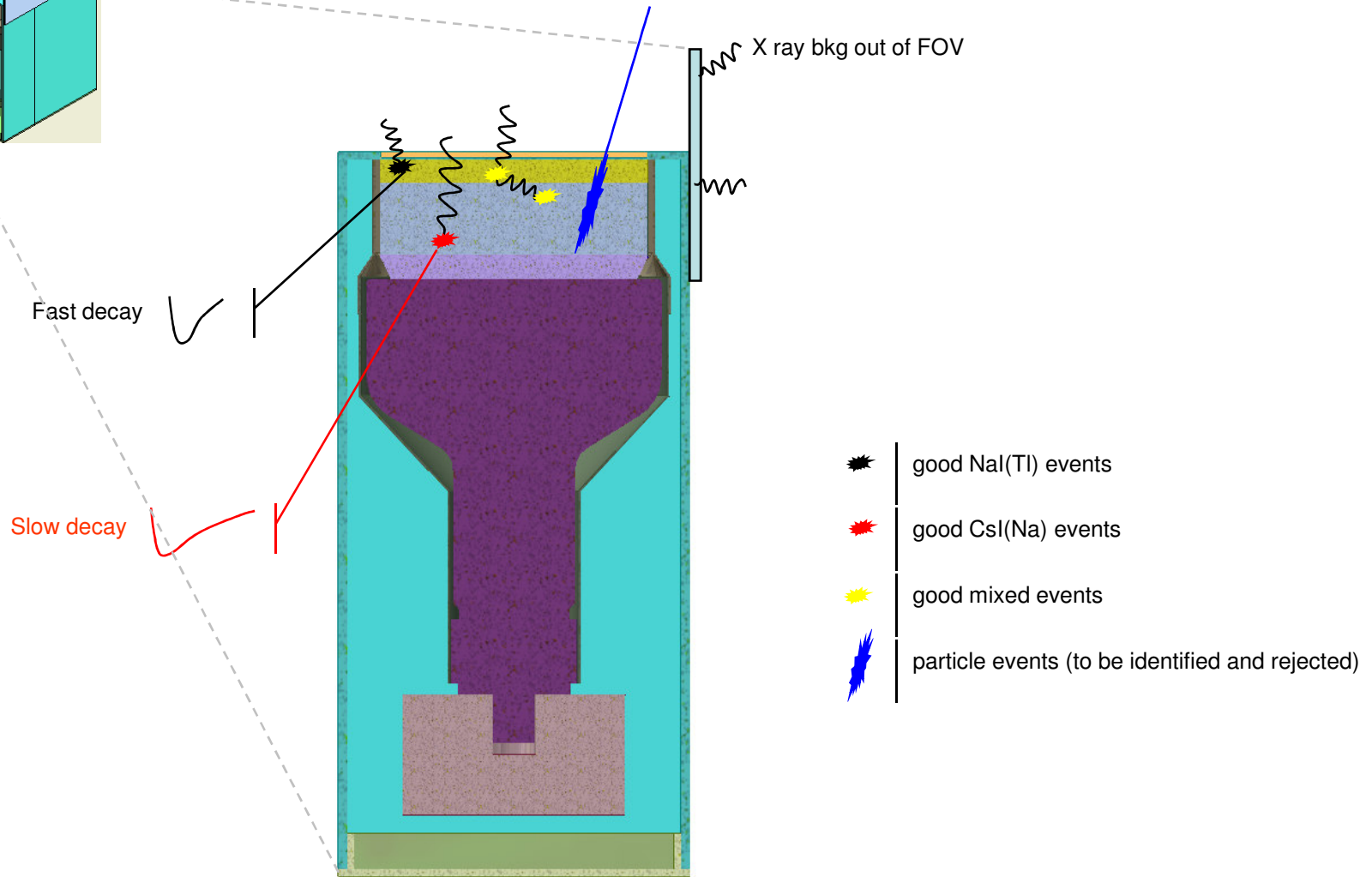
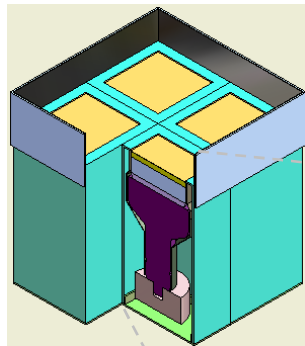
Single Camera Module



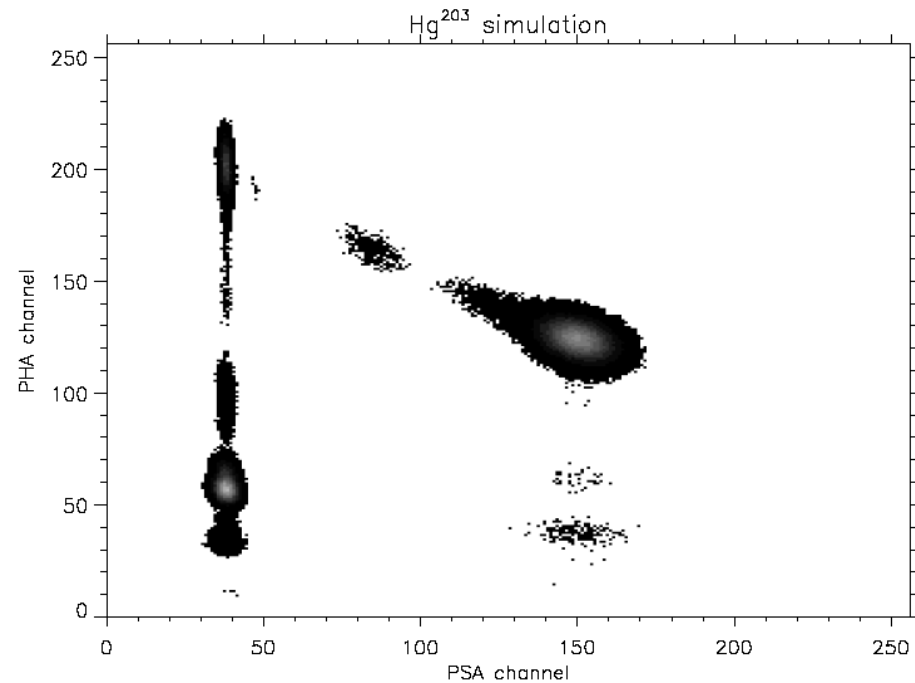
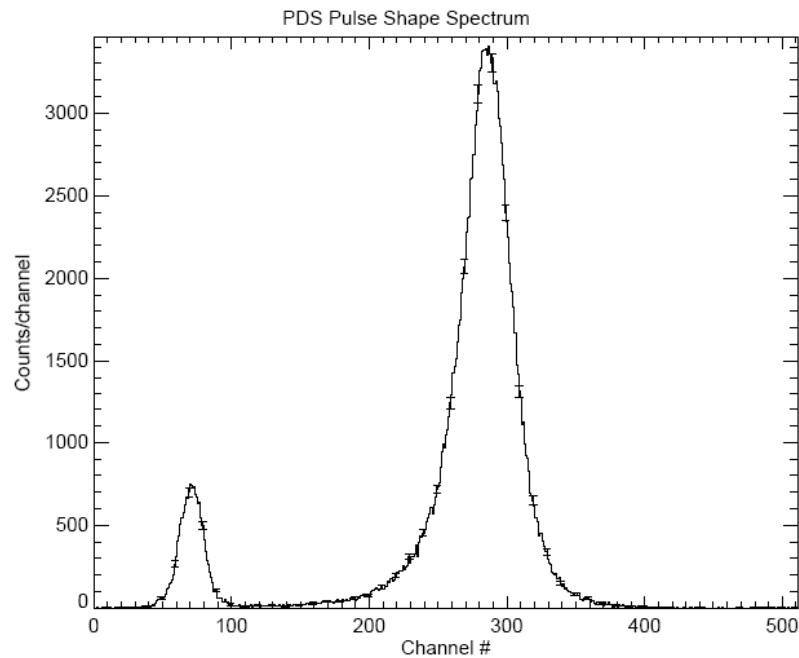
2D Asymmetric Coded Mask



Phoswich configuration



Phoswich configuration



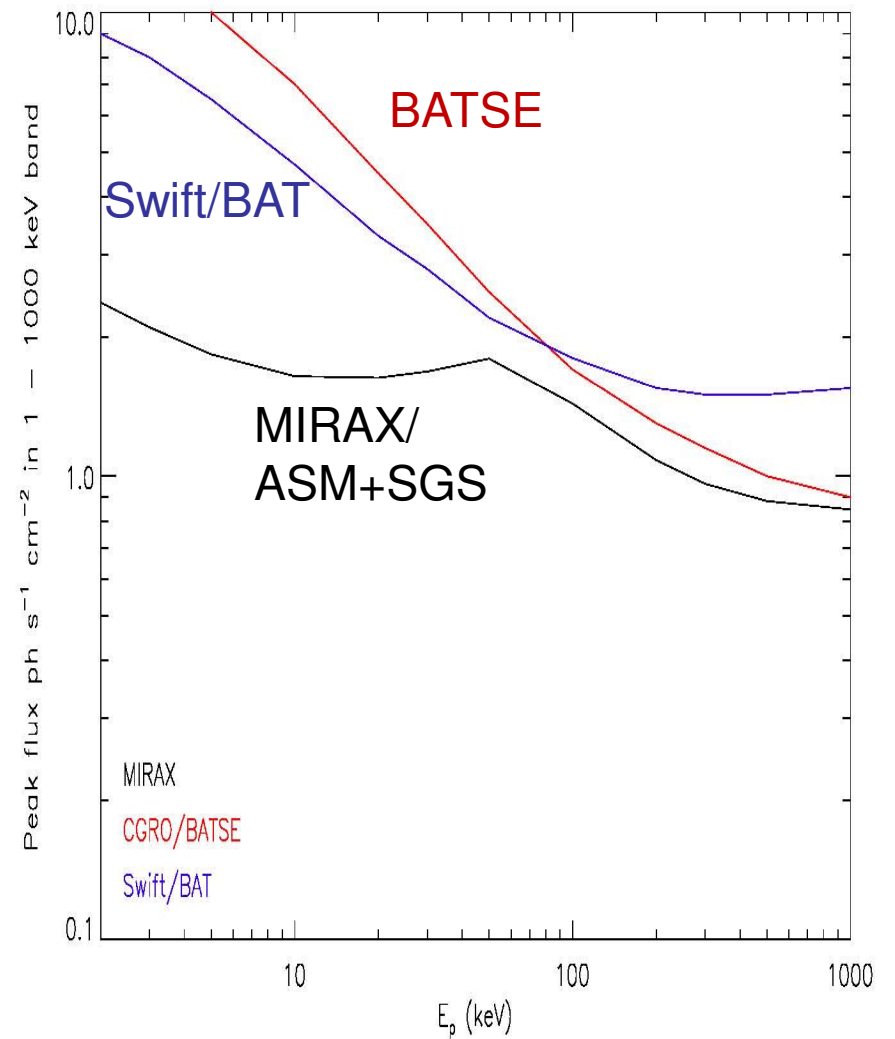
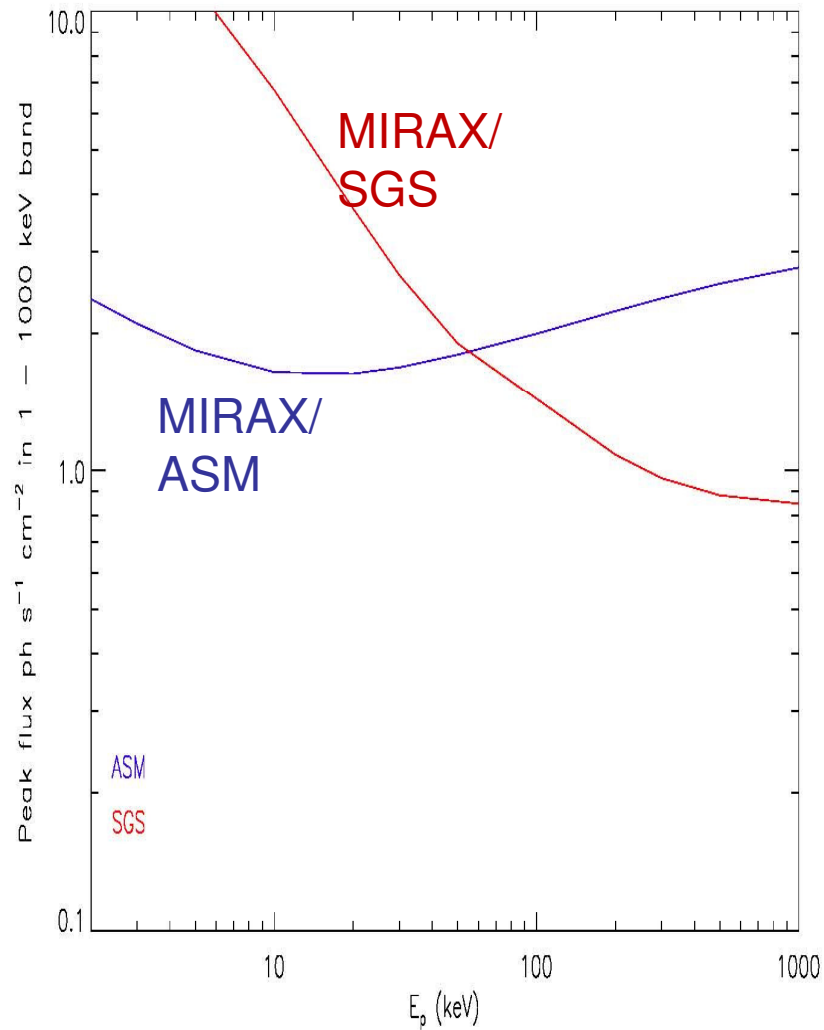
Effectiveness of the Pulse Shape Analysis (PSA) for the phoswich detectors of the BeppoSAX/PDS instrument

PSA parameter is a measure of the duration in time of a fraction of the signal (typically from 20% to 90% of the maximum)

PHA is Pulse Height Amplitude of the signal

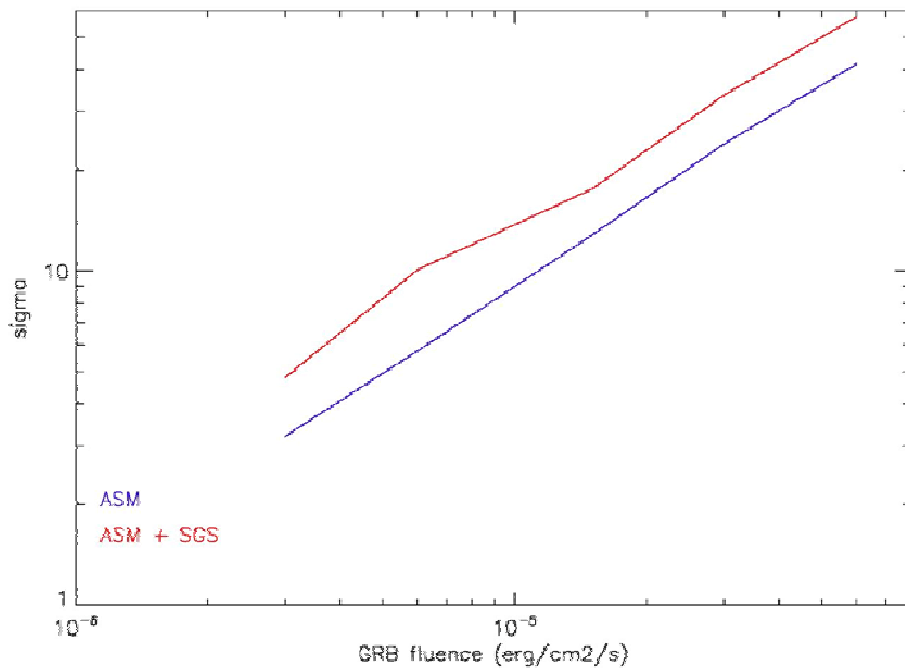
The expected MIRAX Science Performance

GRB trigger sensitivity

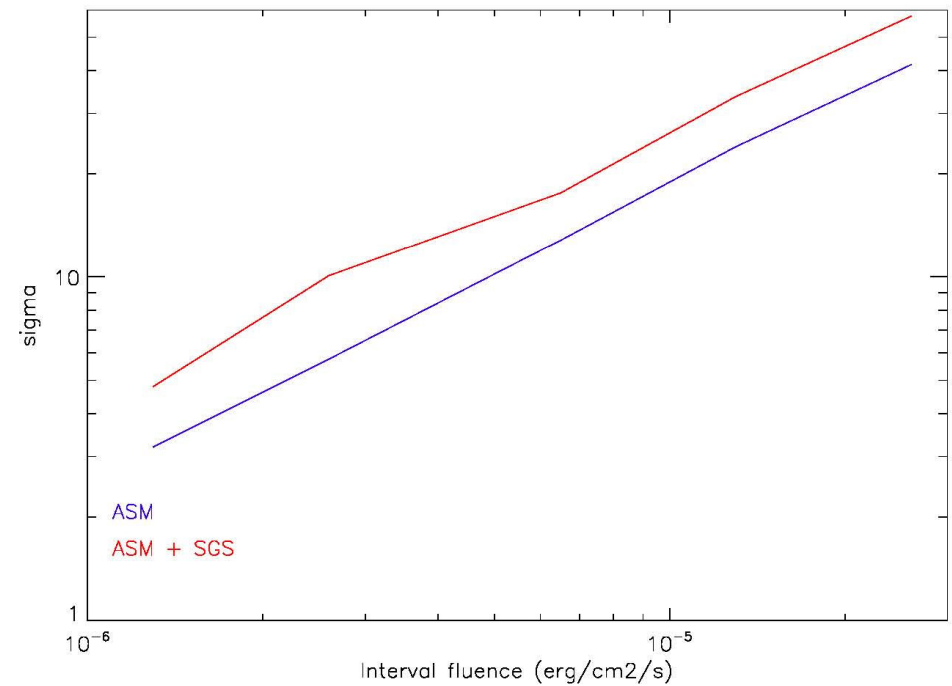


Sensitivity to absorption line/K-edge

Sensitivity vs. GRB total fluence

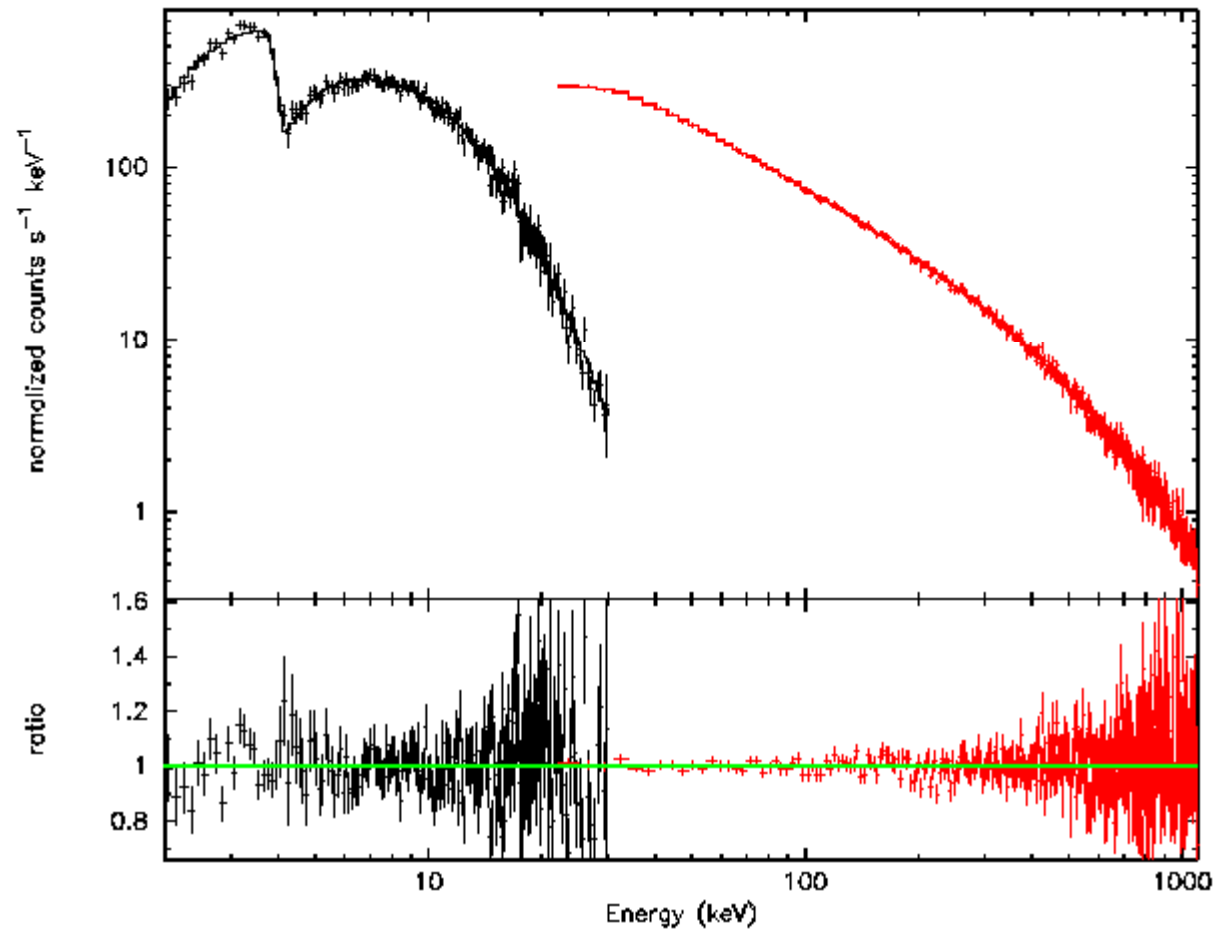


Sensitivity vs. fluence during GRB rise



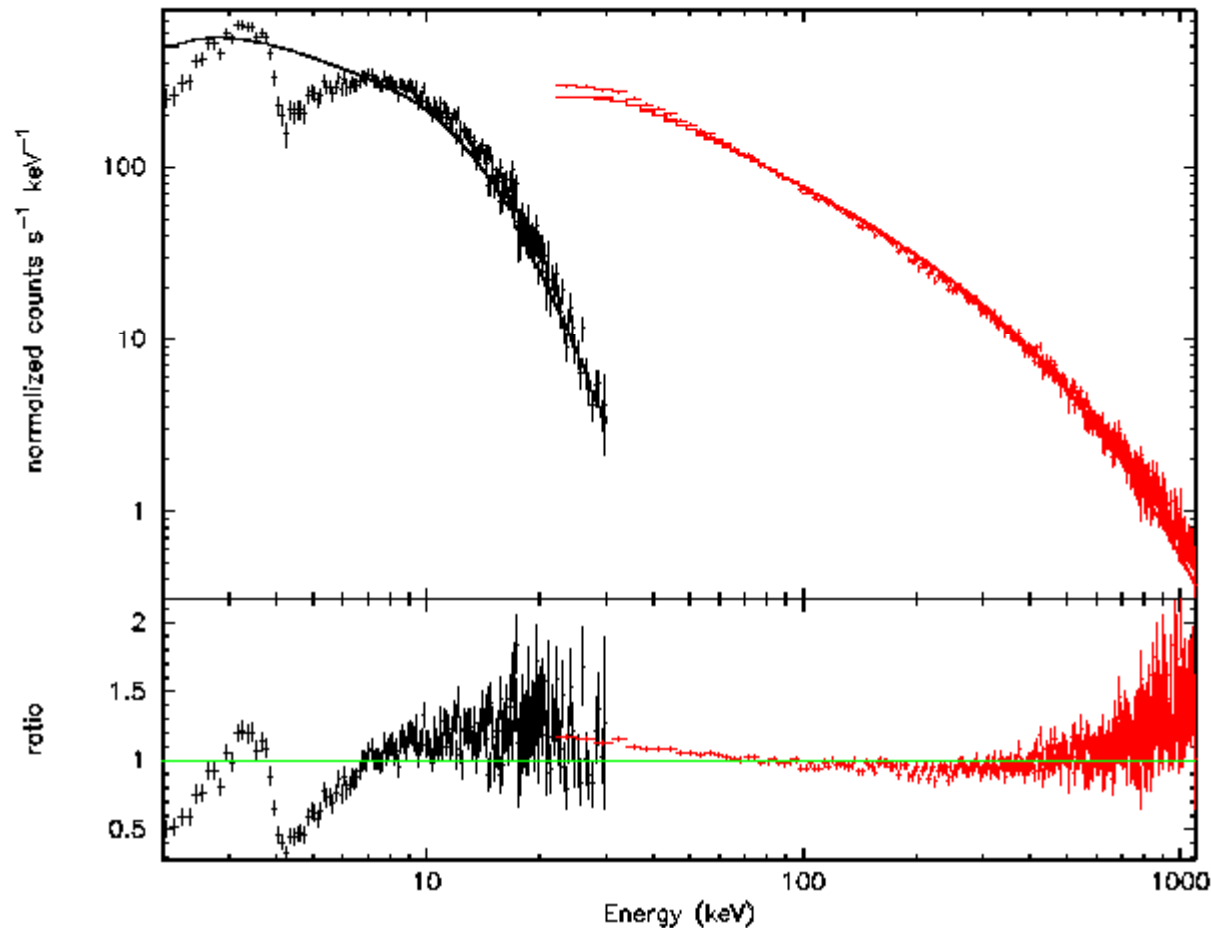
Assumption: the same spectral shape and K-edge optical depth (1.5) of GRB 990705

The energy spectrum of GRB990705 (k-edge)



**Spectrum
MIRAX
ASM+SGS,
fit with an
absorbed
Band law
plus a K-
edge.**

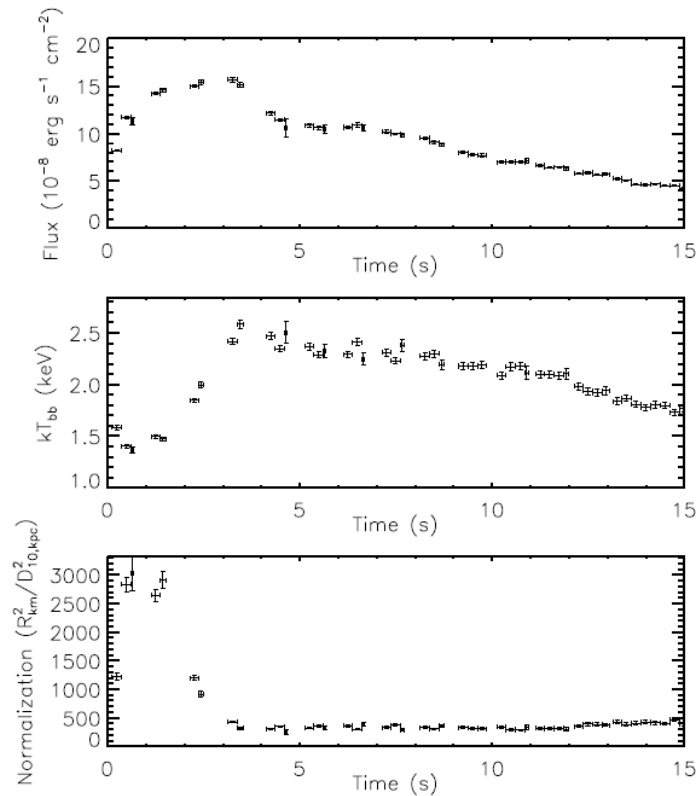
MIRAX Simulation of the energy spectrum observed from GRB990705 with BSAX/WFC



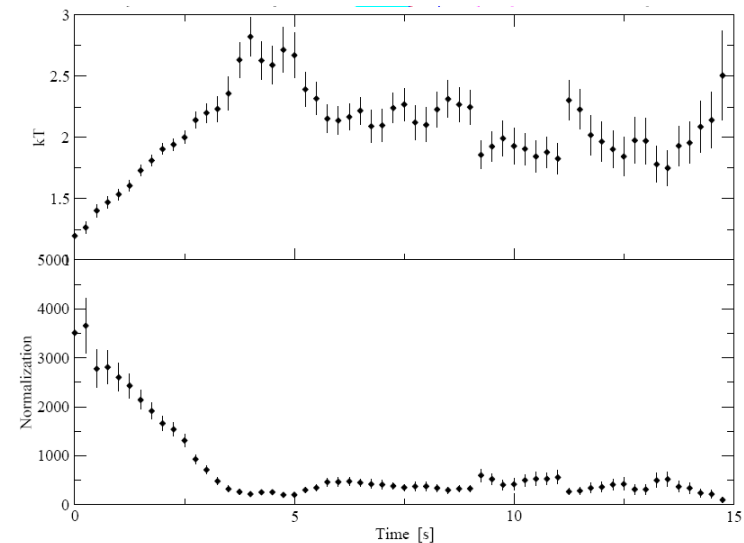
**Spectrum
ASM+SGS,
fit with an
absorbed
Band law**

Constraints to NS Equations of State from thermonuclear PRE X-ray bursts in 4U 1608-52

In Low Mass X-ray Binaries with known distance, a time-resolved spectral modelling of PRE (Photospheric Radius Expansion) type I X-ray bursts can provide information about the Mass and the Radius of the Neutron Star (by measuring the “touchdown flux” and the BB normalization). Below the case of 4U 1608-52 as studied by Gruver et al. (ApJ 2010) with RXTE/PCA.



MIRAX Simulated Observation



The Microquasar GRS 1915+105

Galactic microquasar GRS 1915+105 displays an unpredictable and largely not yet understood variability. Here the case of a simultaneous radio-X flare, observed with BeppoSAX/NFI and Ryle Telescope. Spectral evolution is well described by the temporary emptying of the inner accretion disk during the X-ray dip following the flare, and coincident with the radio flare.

BeppoSAX/NFI

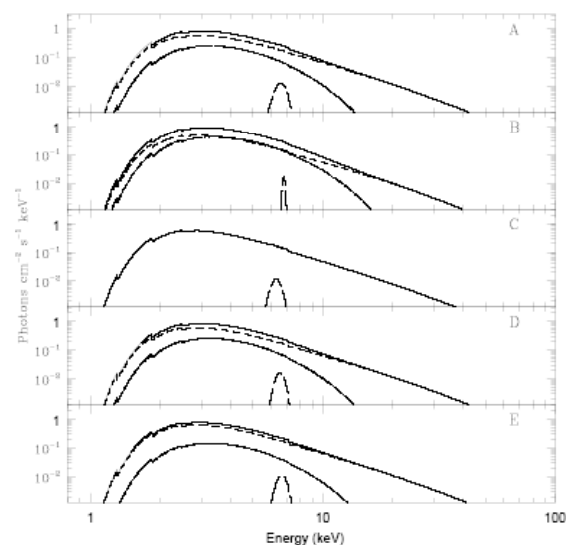


Fig. 4. Best fit models for the broad band BeppoSAX spectra in the five sections shown in Fig. 1. The model include an absorbed ($N_H \sim 5.6 \times 10^{22}$) power law with a high energy cut-off and a Compton reflection component from a disk (dashed curve), a multi-temperature disk blackbody (dot-dash), and an Iron line (long dash). The continuous line shows the sum of the various components.

Marco Feroci
INAF/IASF Rome

MIRAX

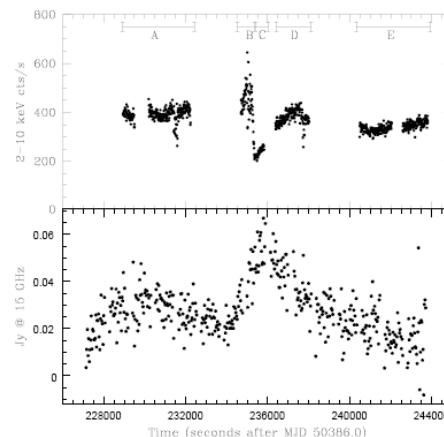
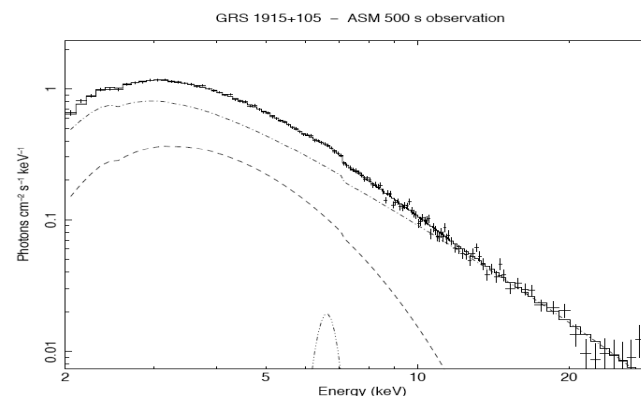


Fig. 2. BeppoSAX MECS (2–10 keV, bin size 10 s) and Ryle Telescope (15 GHz, 32 s bin size) light curve of the flare from GRS 1915+105.



Parameter	BSAX	MIRAX
kT	1.53±0.05	1.53±0.06
Γ	2.36±0.04	2.38±0.06
E_{line}	6.57±0.14	6.60±0.10
Integration Time	3500 s	500 s

Thank you

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