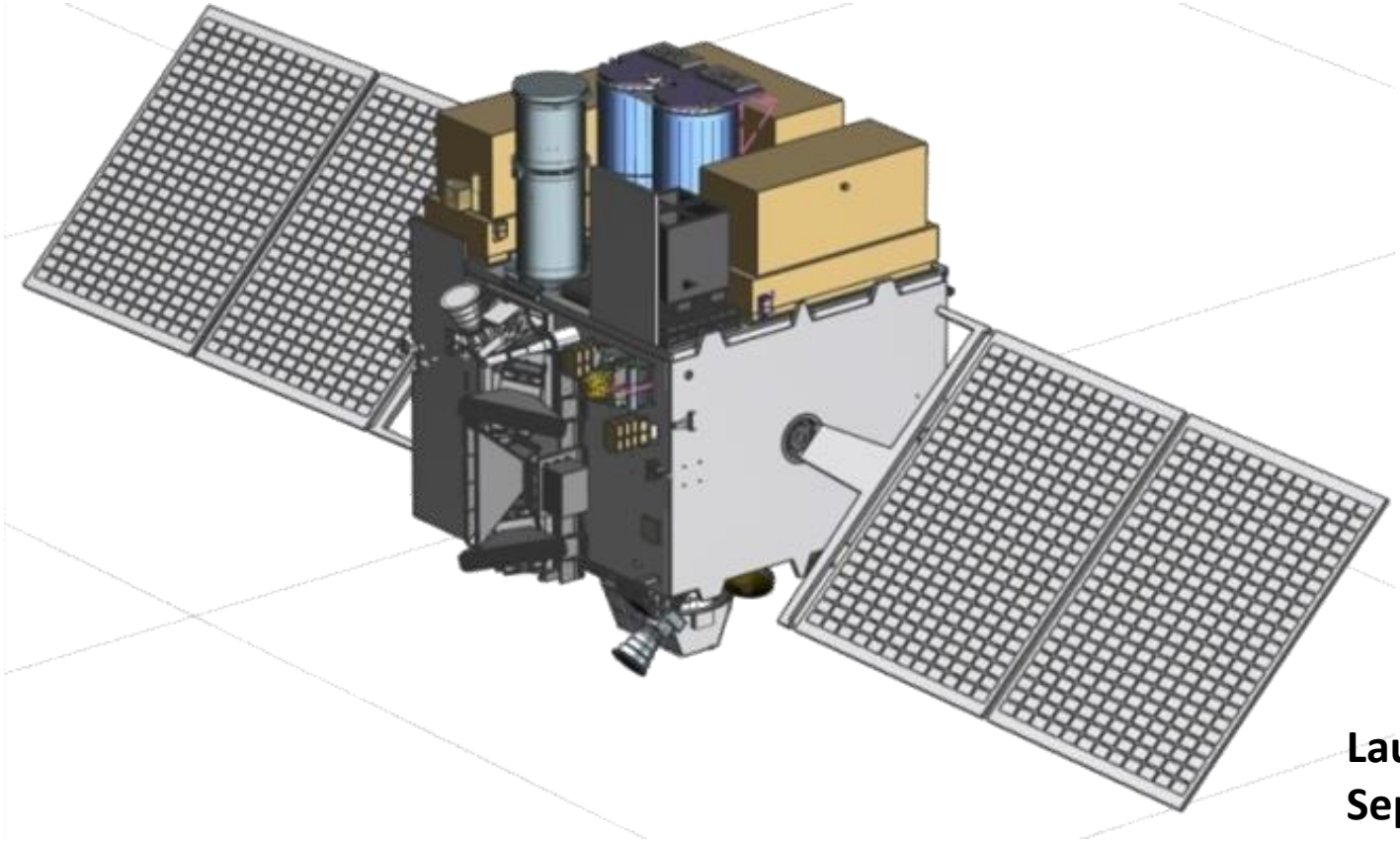
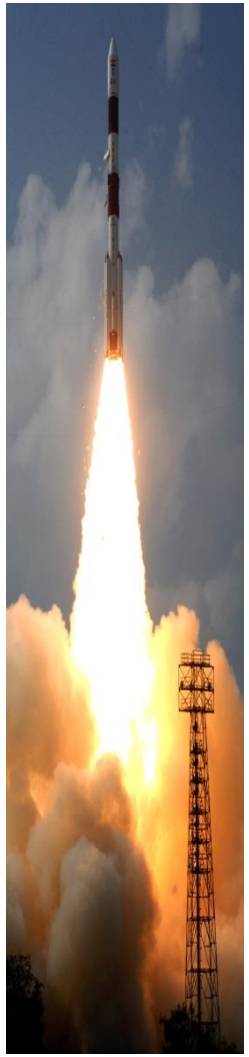
ASTROSAT

An Indian astronomy space mission





Launch:
September 28, 2015

Sudip Bhattacharyya

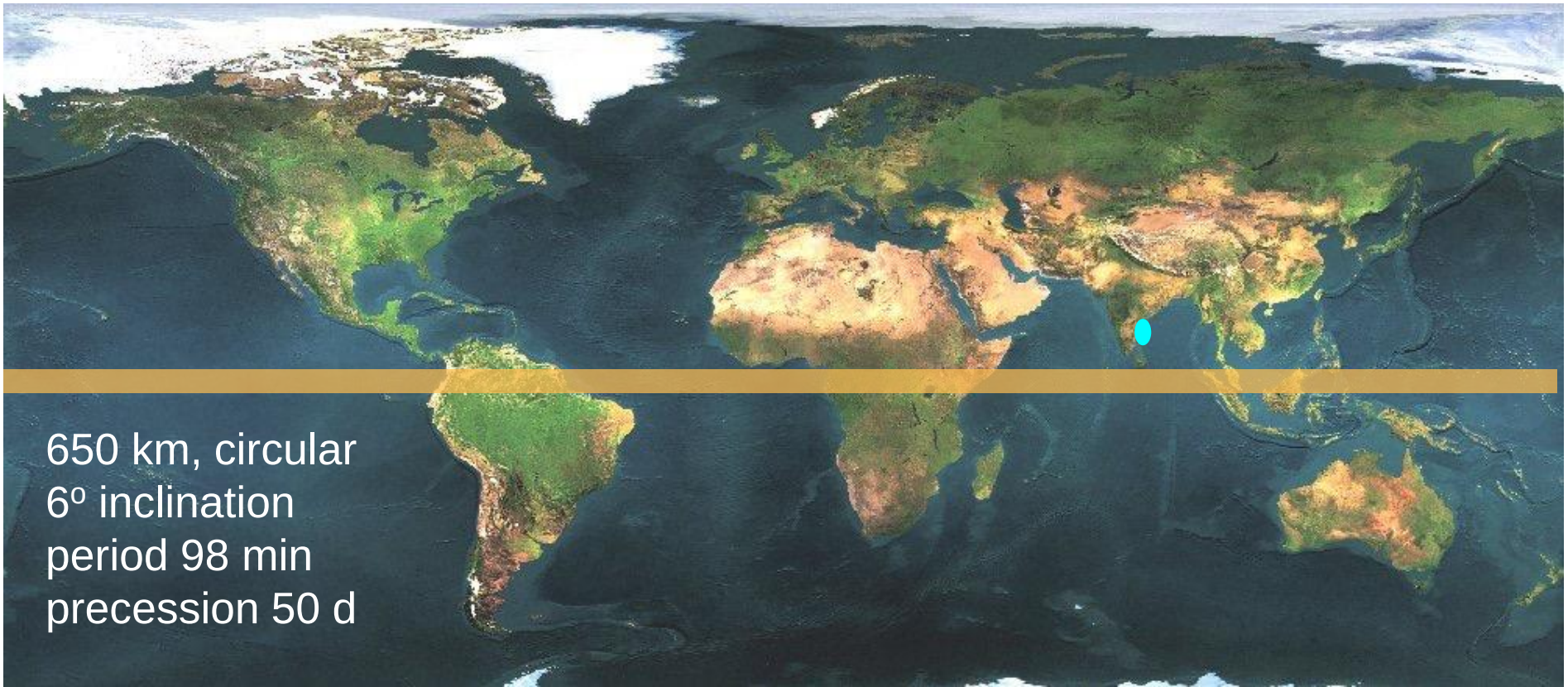
Tata Institute of Fundamental Research, Mumbai, India

Integrated AstroSat before launch
weight: 1.5 ton

PSLV XL Rocket
weight: 320 ton

Courtesy: D. Bhattacharya


28 September 2015 04:30 UT
SHAR, India
AstroSat


650 km, circular
6º inclination
period 98 min
precession 50 d

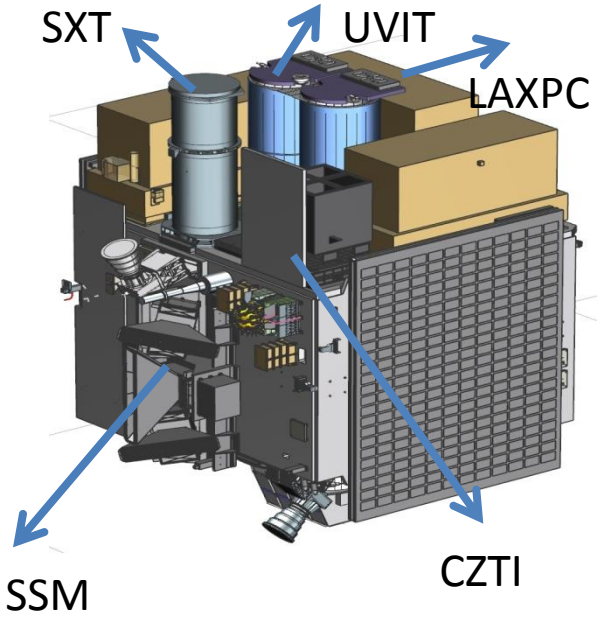
General information

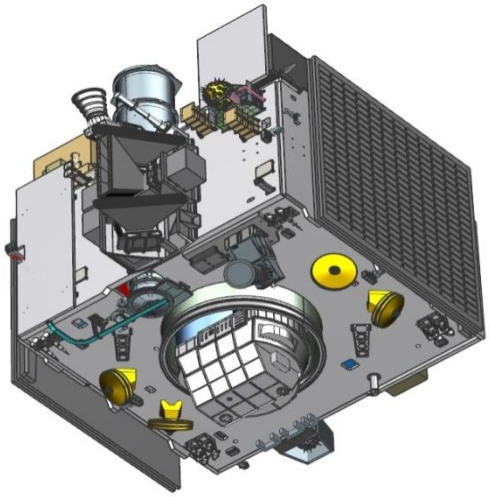
Launched into a nearly circular orbit with Altitude: 640 - 650 km; Inclination : 6 deg.

- **Orbital period : ~98 minutes;**
- **Eclipse period : 35 minutes; Sunlit period : 62 minutes**
- **Orientation by 4 reaction wheels and 3 magnetic torquers (capacity: 60 A m^2) + inputs from 3 dual gimbal gyros, 2 star sensors and 2 magnetometers.**
- **Pointing accuracy of ~1 arcsec with star sensors.**
- **Drift rate is expected to be 0.2 arcsec/s.**
- **Maximum slew rate will be 0.6^o/s.**
- **Solid-state recorder with 200 Gb storage (4 orbits).**
- **Operational life of > 5 years**

ASTROSAT – Payload Instruments

- **Large Area X-Ray Proportional Counter (LAXPC) [TIFR]**
- **Soft X-ray Telescope (SXT) [TIFR+UoL+ISRO]**
- **Cadmium Zinc Telluride Imager (CZTI) [TIFR+IUCAA +ISRO]**
- **Ultra Violet Imaging Telescope (UVIT) [IIA+ISRO+CSA+IUCAA+TIFR]**
- **Scanning Sky Monitor (SSM) [ISRO]**





Courtesy: K.S. Sarma

Key features of AstroSat

- **Built for Timing: individual photon recording in all bands, time resolution 10μs - 100ms**
- **Simultaneous broadband (~2 eV - 100 keV)**
- **Capability to handle high count rate in X-rays**
- **Hard X-ray polarisation**
- **Good imaging resolution at Ultraviolet bands**

Courtesy: D. Bhattacharya

LAXPC

Three LAXPC units before launch

Courtesy: K.S. Sarma

LAXPC properties

1. No. of LAXPC Detectors: Three (3) “Identical” units

2. Detector size: 120 cm x 50 cm x 70 cm

3. X-ray detection volume: 100 cm x 36 cm x 15 cm

4. No. of anode layers: 5 anode layers : each has 12 anode cells

5. Collimator field of view: 1^o X 1^o for all the LAXPCs

6. Counting Gas: Xenon + Methane (Two atmosphere)

7. Energy range: 3-80 keV

8. Total Effective Area of 3 LAXPCs: About 8000 cm^2 in 5-20 keV

9. Energy resolution: 12% at 22 keV

10. Time resolution: 10 µs

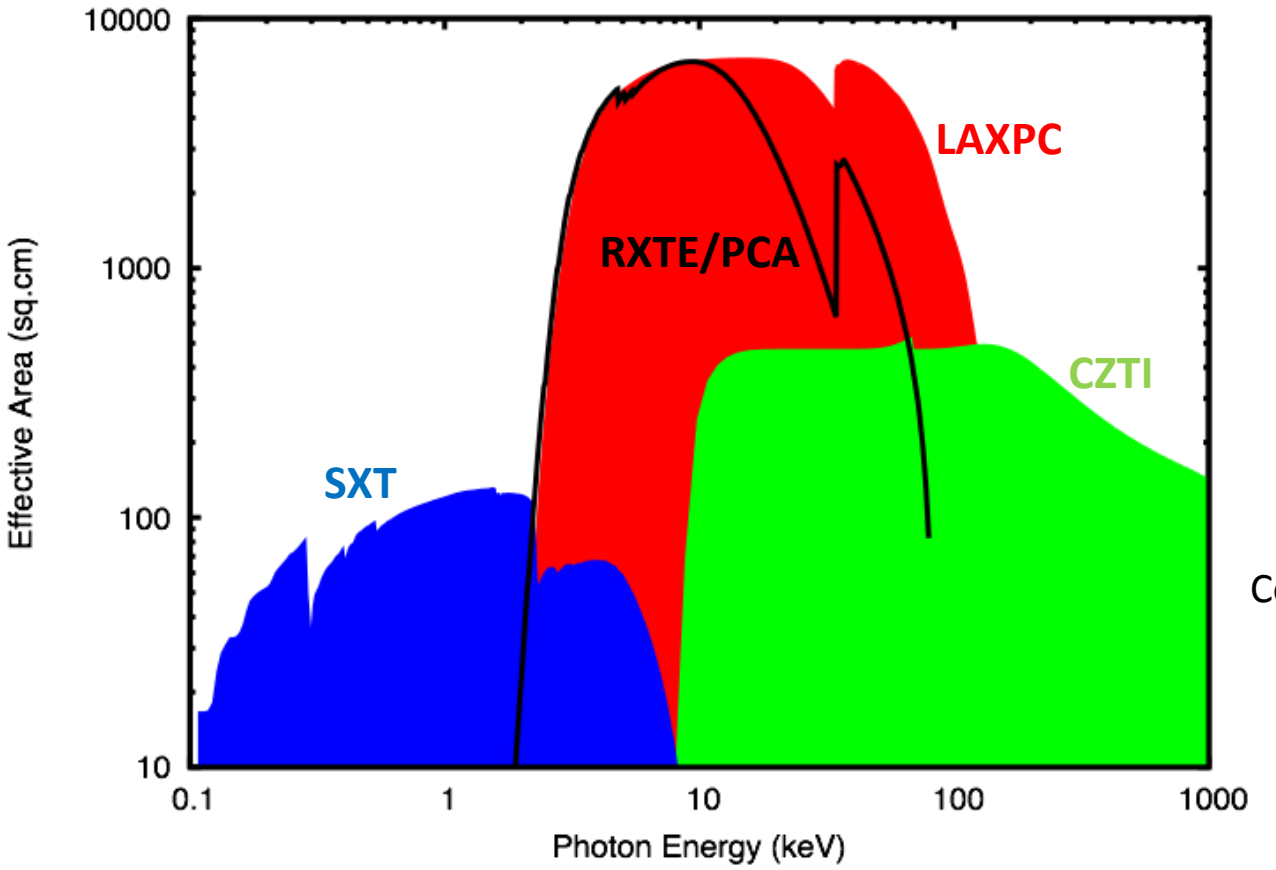
LAXPC modes

1. Normal (or Default) Modes of Operation :
In Normal operation there are two modes running simultaneously and data are acquired from each LAXPC.
(a) **Broad Band Counting Data:** Records the rate of occurrence of events in various energy bands with selectable time Bin (16 msec to 2048 msec). Default value is 128 msec.

(b**) Event Mode Data:** In this mode arrival time of each event is time tagged to an accuracy of 10 microseconds. Simultaneously the energy and identity of each event is also recorded. This mode generates 5 bytes data for each accepted and analyzed event. In this mode the dead time of the detector is around 42 microseconds.

2. Fast Counter Mode:
In this mode the event rate is measured only from the top layer of each LAXPC detector in 4 energy channels covering 3-20 keV band with a fixed time bin of 160 microsecond. In this mode dead time is about 10 microsecond. Each of 4 counters are 8 bit deep and cover 3-6, 6-8 , 8-12 and 12-20 keV energy bands. This mode is to be used for studying rapid variability during the short duration flares or outbursts of sources.

AstroSat and RXTE/PCA

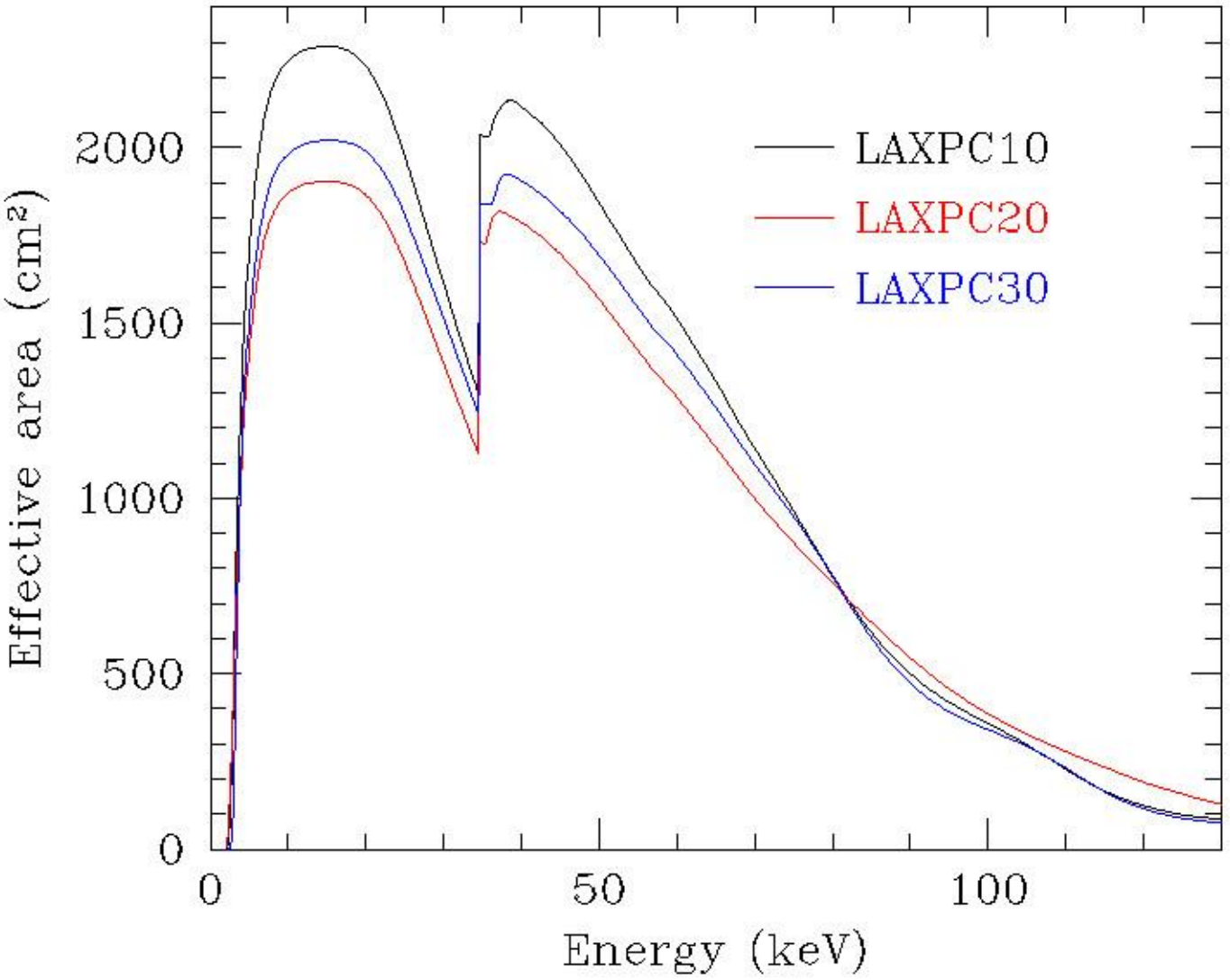


Courtesy: D. Bhattacharya

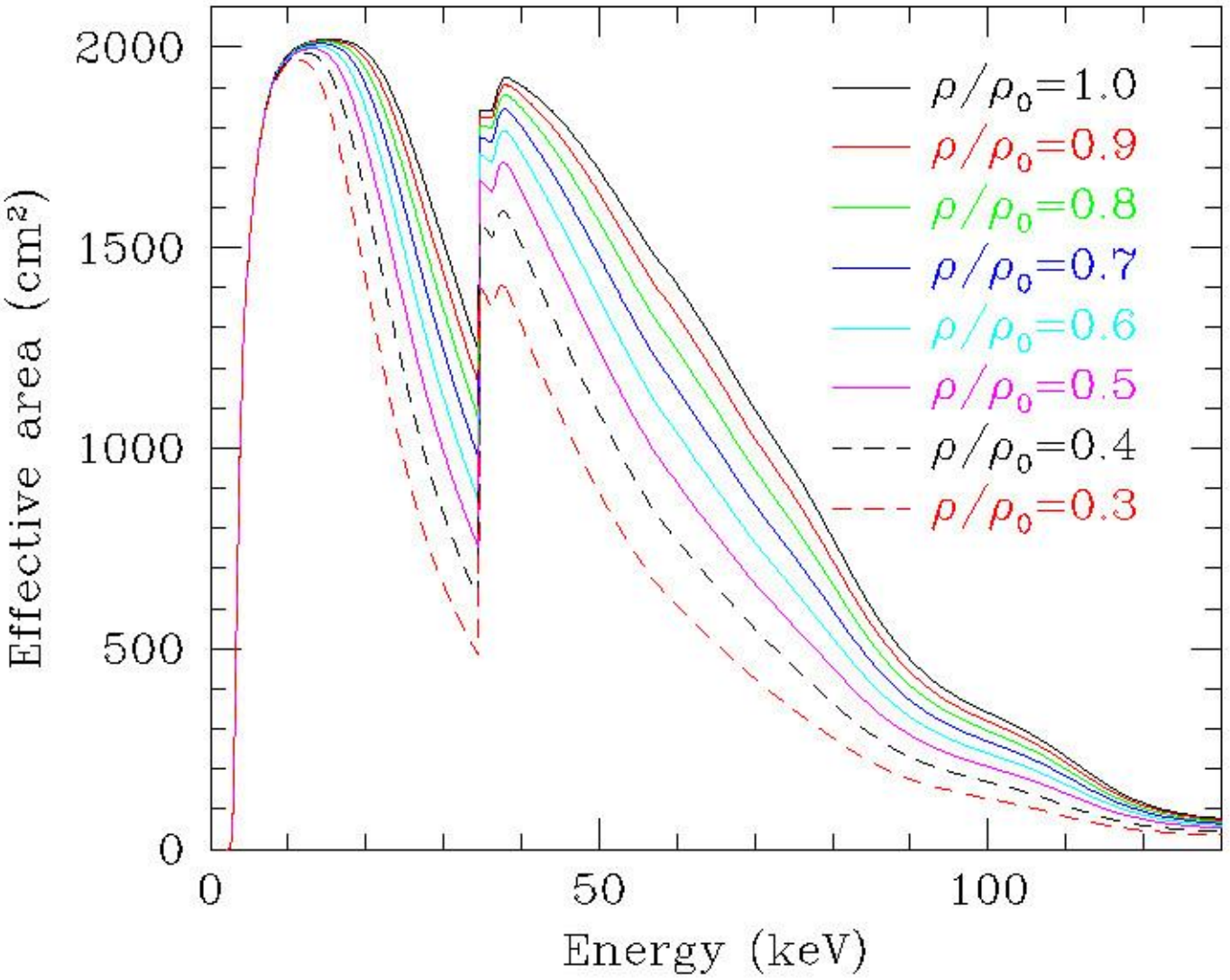
LAXPC: lots of photons in hard X-rays!

+

Event mode data with full spectral resolution + No data gap + Stable background



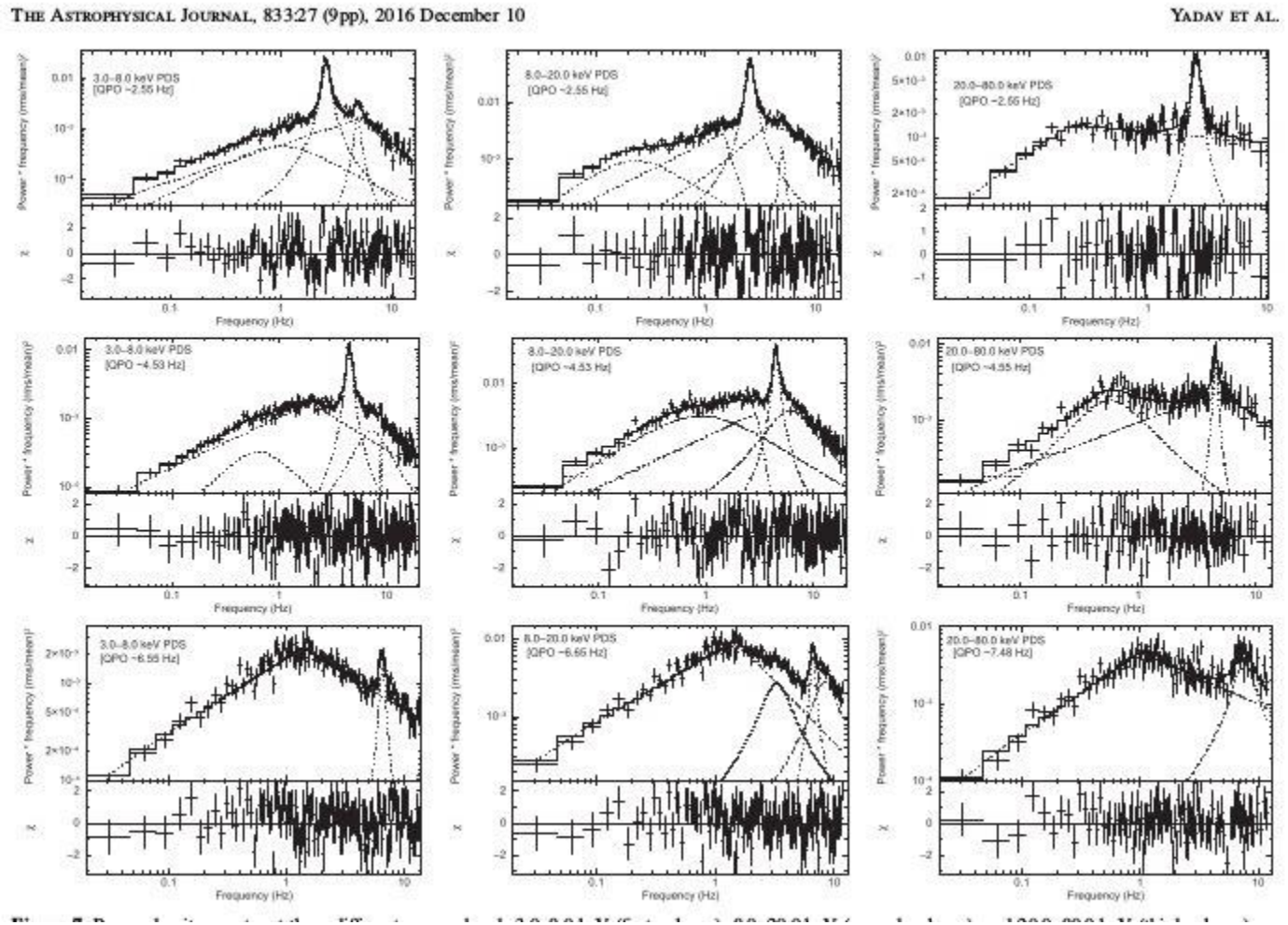
Courtesy: LAXPC team



P_o = 2 atm → original gas pressure

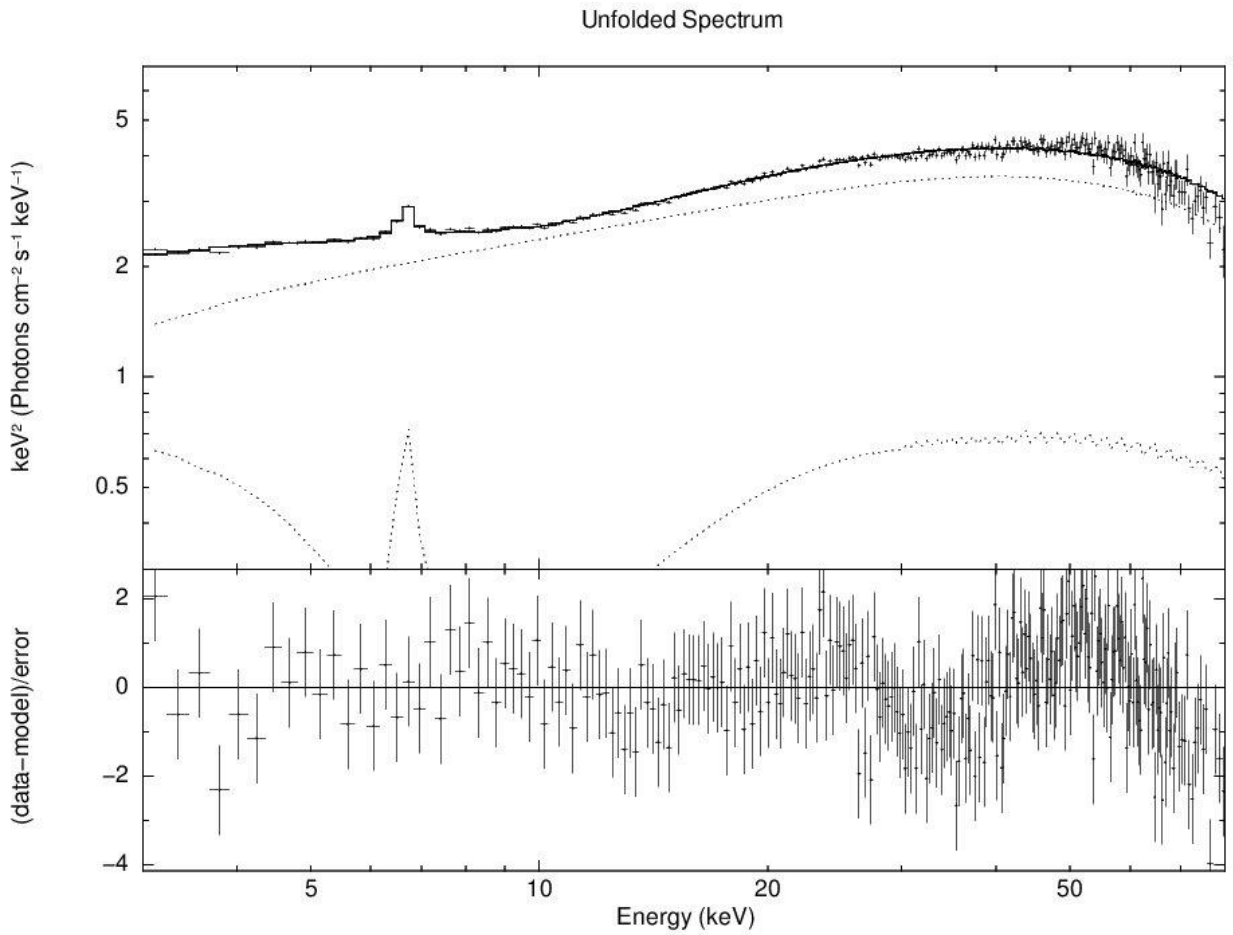
Courtesy: LAXPC team

AstroSat/LAXPC study of GRS 1915+105 (a transient black hole binary) in very high state (SPL state)



Yadav et al., 2016, Astrophysical Journal, 833, 27

AstroSat/LAXPC study of Cyg X-1 (a persistent black hole binary) in low hard (LH) state

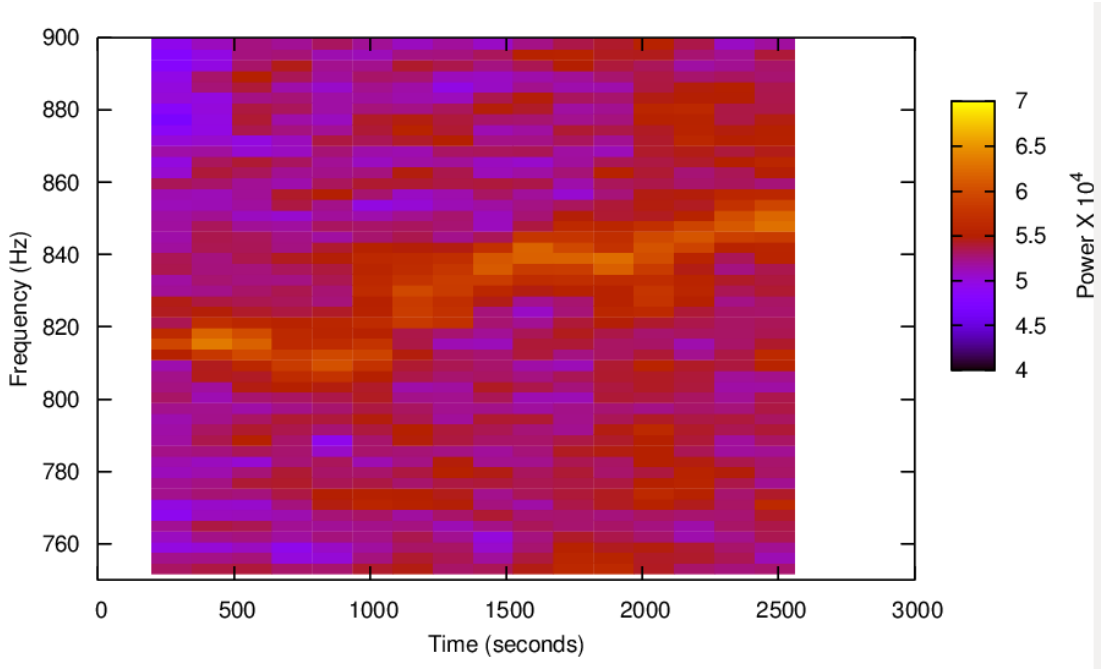


Misra et al., 2016 Astrophysical Journal in press (arXiv:1612.08793)

AstroSat/LAXPC study of the NS LMXB 4U 1728-34

KHz Quasi-periodic Oscillations (KHz QPOs) :

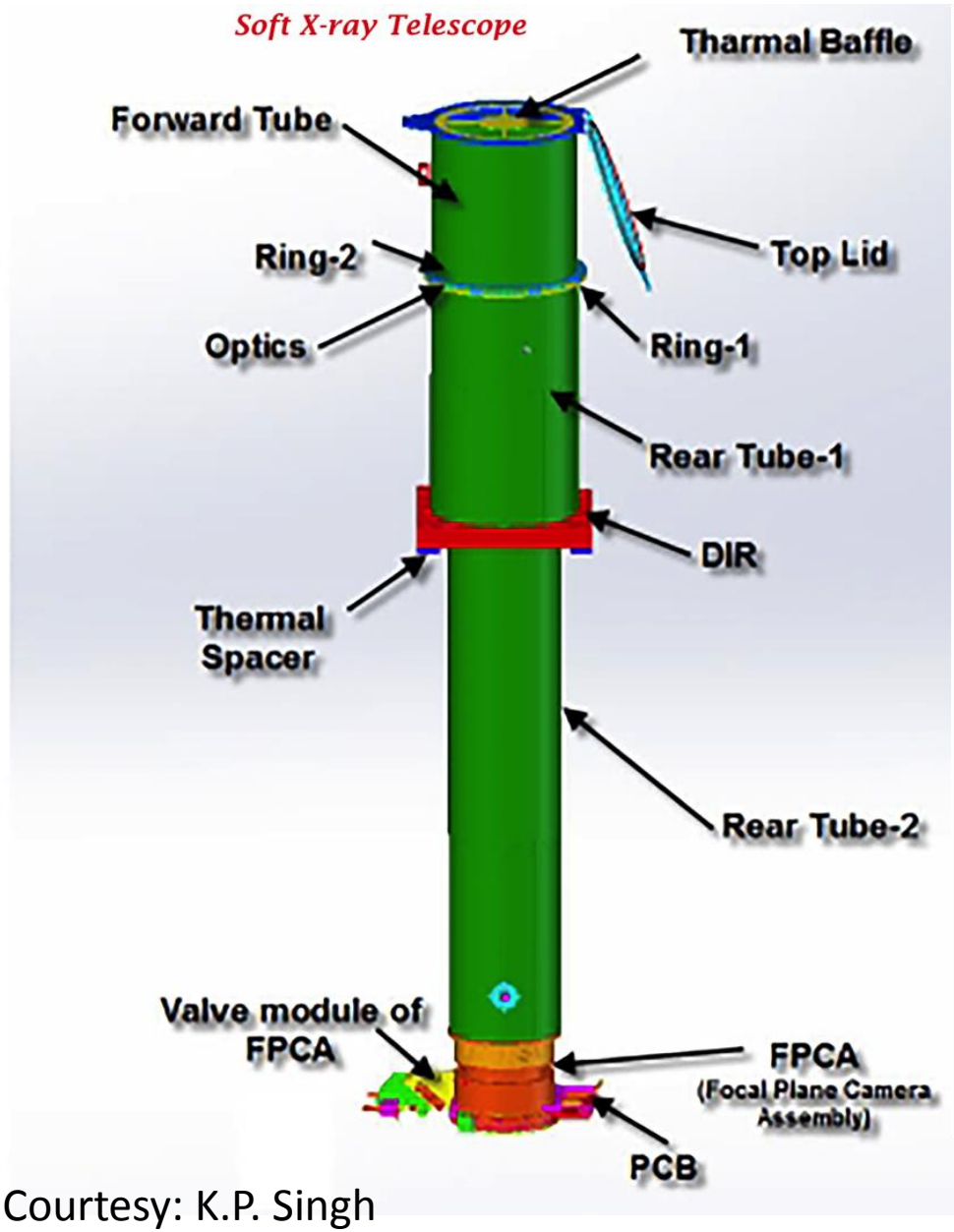
Figure below shows dynamic power density Spectrum from LAXPC observation of 4U 1728-34. About 815 Hz QPOs were observed, which drifted to around 850 Hz by the end of the observation.

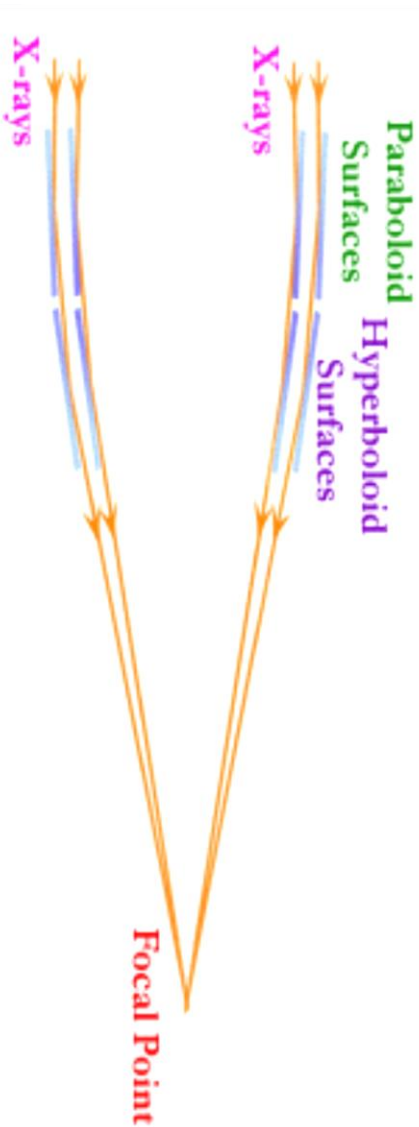


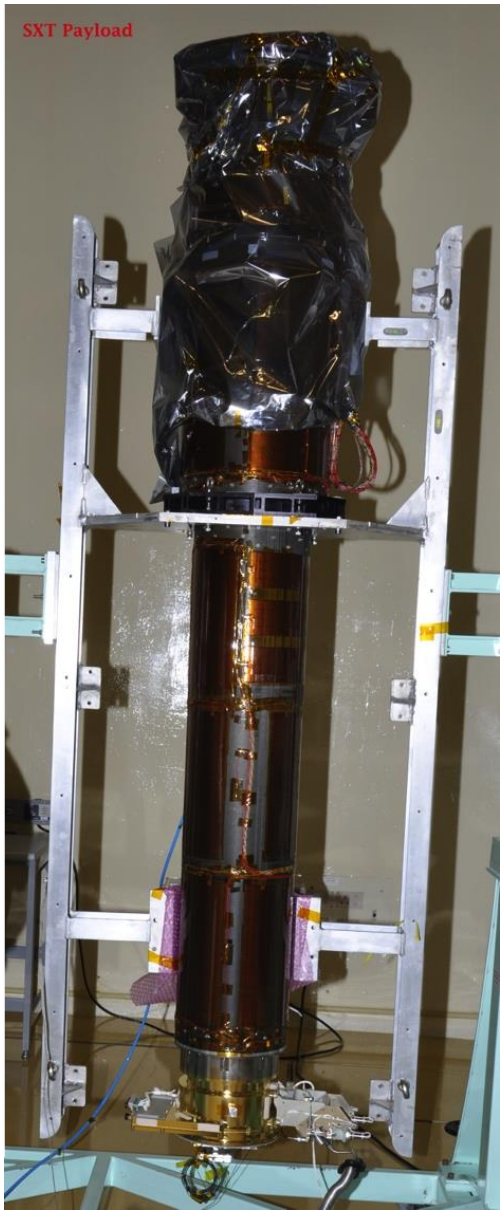
Jai Verdhan et al 2017

Courtesy: J S Yadav

SXT: Optics + CCD based FPCA(~65 Kg)







Courtesy: K.P. Singh

ASTROSAT

Performance Parameters of the scientific Instruments

	UVIT	SXT	LAXPC	CZTI	SSM
Detector	Intensified CMOS, used in photon counting mode or integration mode	X-ray (MOS) CCD at the focal plane. (XMM & Swift heritage)	Proportional counter	CdZnTe detector array	Position-sensitive proportional counter
Imaging / non-imaging	Imaging	Imaging	Non-imaging	Imaging	Imaging
Optics	Twin Ritchey-Chretian 2 mirror system.	Conical foils (~Wolter-I) mirrors. 2-m focal length	Collimator	2- D coded mask	1- D coded mask
Bandwidth	1300-5500 Angstroms	0.3 - 8 keV	3 - 80 keV	10 - 100 keV	2.5 - 10 keV
Geometric Area (cm2)	~1100	~250	10800	1024	~180
Effective Area (cm2)	8 - 50 (depends on filter)	~128@1.5 keV ~22@6 keV	8000@5-20 keV	1000 (E>10 keV)	~11 @ 2 keV ~53 @ 5 keV
Field of View (FWHM)	28' dia	~ 40' dia	1^0 x 1^0	6^0 x 6^0	10^0 x 90^0
Energy Resolution	<1000 A (depends on filter)	~5-6%@1.5 keV ~2.5%@6keV	12%@22 keV	5% at 100 keV	25% @ 6 keV
Angular Resolution	1.8 arcsec (FUV,NUV) 2.2 arcsec (Vis)	~2 arcmin (HPD)	~(1-5) arcmin (in scan mode only)	8 arcmin	~12 arcmin
Time resolution	1.7 ms	2.4 s, 278 ms	10 μs	1 ms	1 ms
Typical observation time per target	30 min	0.5 - 1 day	1 - 2 days	2 days	10 min
Sensitivity (Obs. Time)	Mag. 20 (5σ) 200 s (130-180 nm)	~10^{-13} ergs cm^{-2} s^{-1} (5 σ) (20000 s)	0.1 milliCrab (3σ) (1000 s)	0.5 milliCrab (3σ) (1000s)	~28 milliCrab (3σ) (600s)

Courtesy: K.P. Singh

Readout Modes of the CCD

(1) Photon Counting Mode (PC), [The Default Mode - includes the calibration sources]

(2) Photon Counting Window Mode (PCW) – 5 pre-defined windows recommended

(3) Fast Window Mode (FW),

(4) Bias Map Mode (BM), and

(5) Calibration Mode (CM).

•X-ray spectral information available in all the modes.

•Time resolution in the PC, PCW, CM modes is 2.4 s, and 0.278 s in the FW mode.

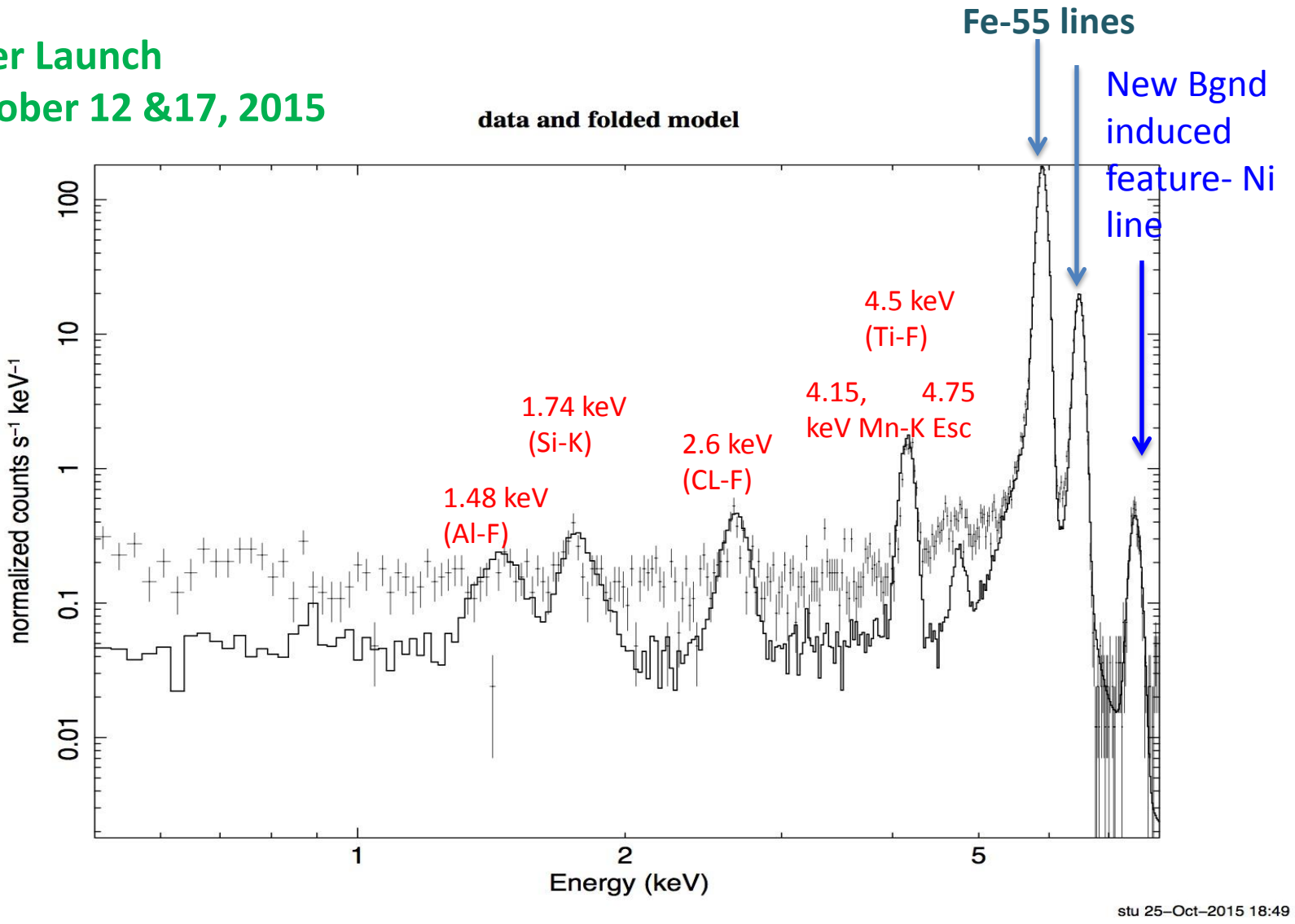
•FW reads only the central 150 x 150 pixels of the CCD.

•For observing very strong cosmic sources, FW mode is recommended.

Courtesy: K.P. Singh

SXT FM: Electronics: NIM:A (2009), 604,747; Energy Calibration spectrum measured using internal sources*: Single Pix events;* CCD @ -82+/-2 C

After Launch
October 12 &17, 2015

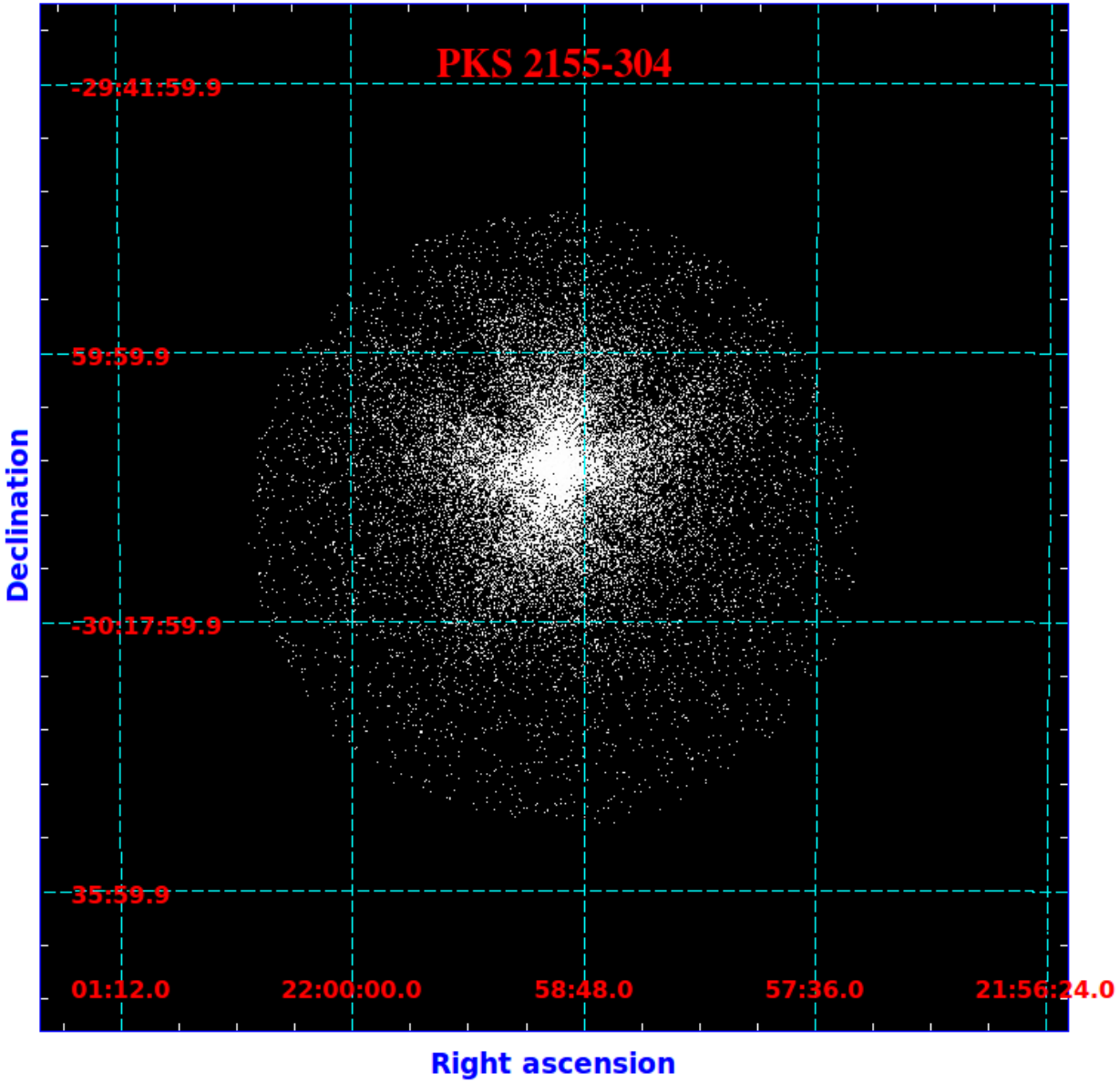


Courtesy: K.P. Singh

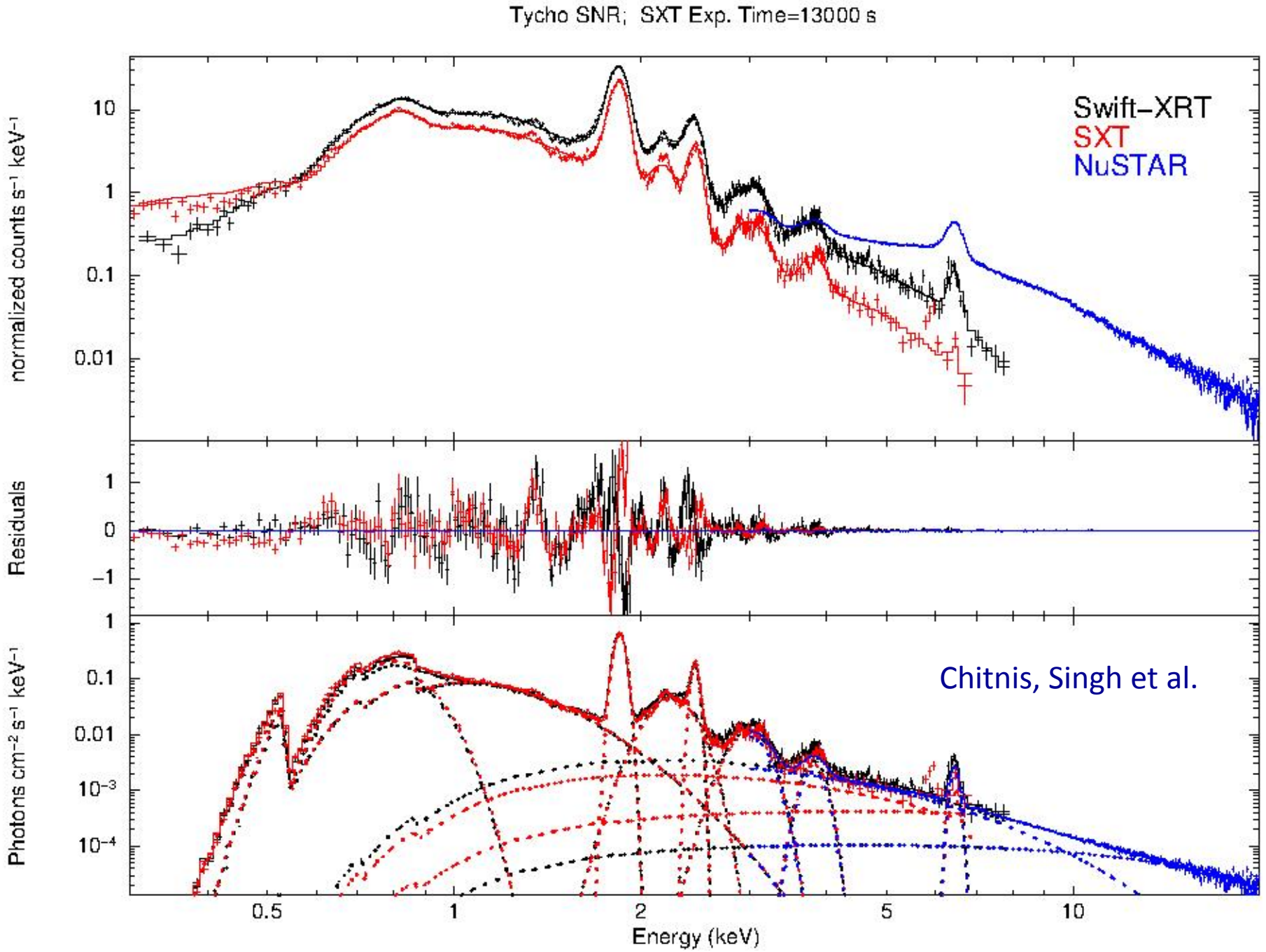
SXT FIRST LIGHT

- Telescope (Optics) Door opening - Oct 15th
- Camera Door Opening - Oct 26th @ 06:30 UT
- First Light – Oct 26th

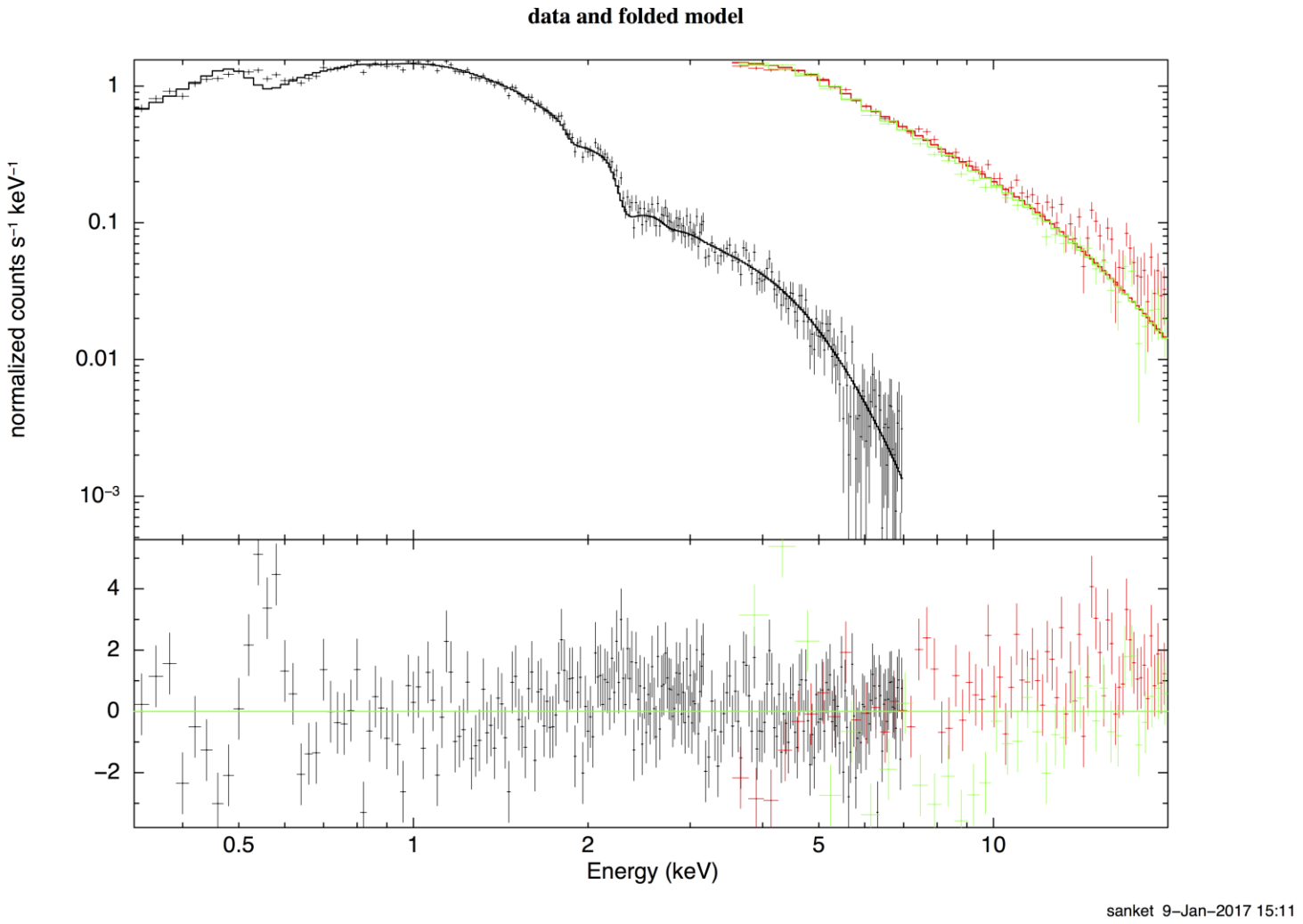
Pointed at and observed- PKS2155-304 (Quasar) at redshift of 0.116



Courtesy: K.P. Singh


Tycho SNR; SXT Exp. Time=13000 s
Swift–XRT
SXT
NuSTAR
normalized counts s⁻¹ keV⁻¹
Residuals
Photons cm⁻² s⁻¹ keV⁻¹
Energy (keV)
Chitnis, Singh et al.

SXT + LAXPC spectrum: Mrk 501



Cadmium Zinc Telluride Imager (CZTI)

Area: 976 cm^2

Pixels: 16384 (64 modules of 256 pixels each)
Pixel size 2.46 mm X 2.46 mm (5 mm thick)

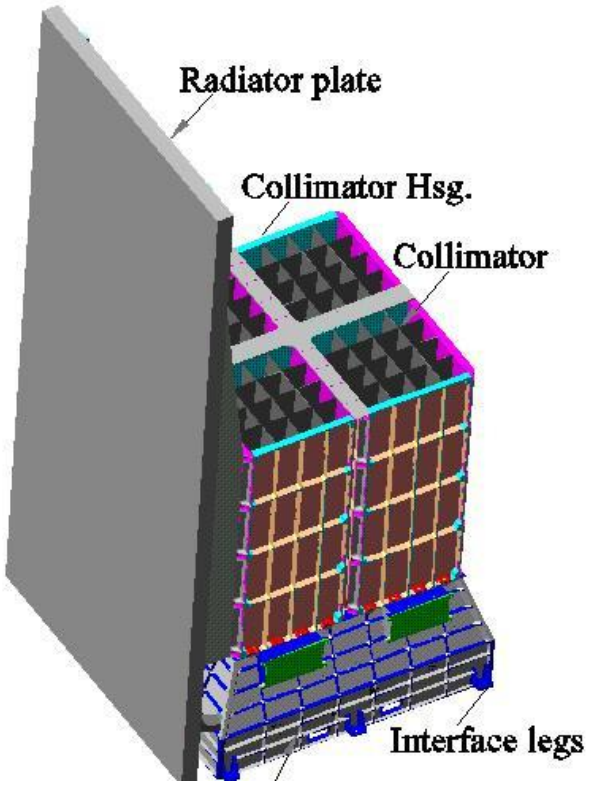
Imaging method Coded Aperture Mask (CAM)

Field of View (10-100 keV):
4.6° X 4.6° FWHM (primary FOV)
11.8° X 11.8° FWZM (incl. illumination leakage)

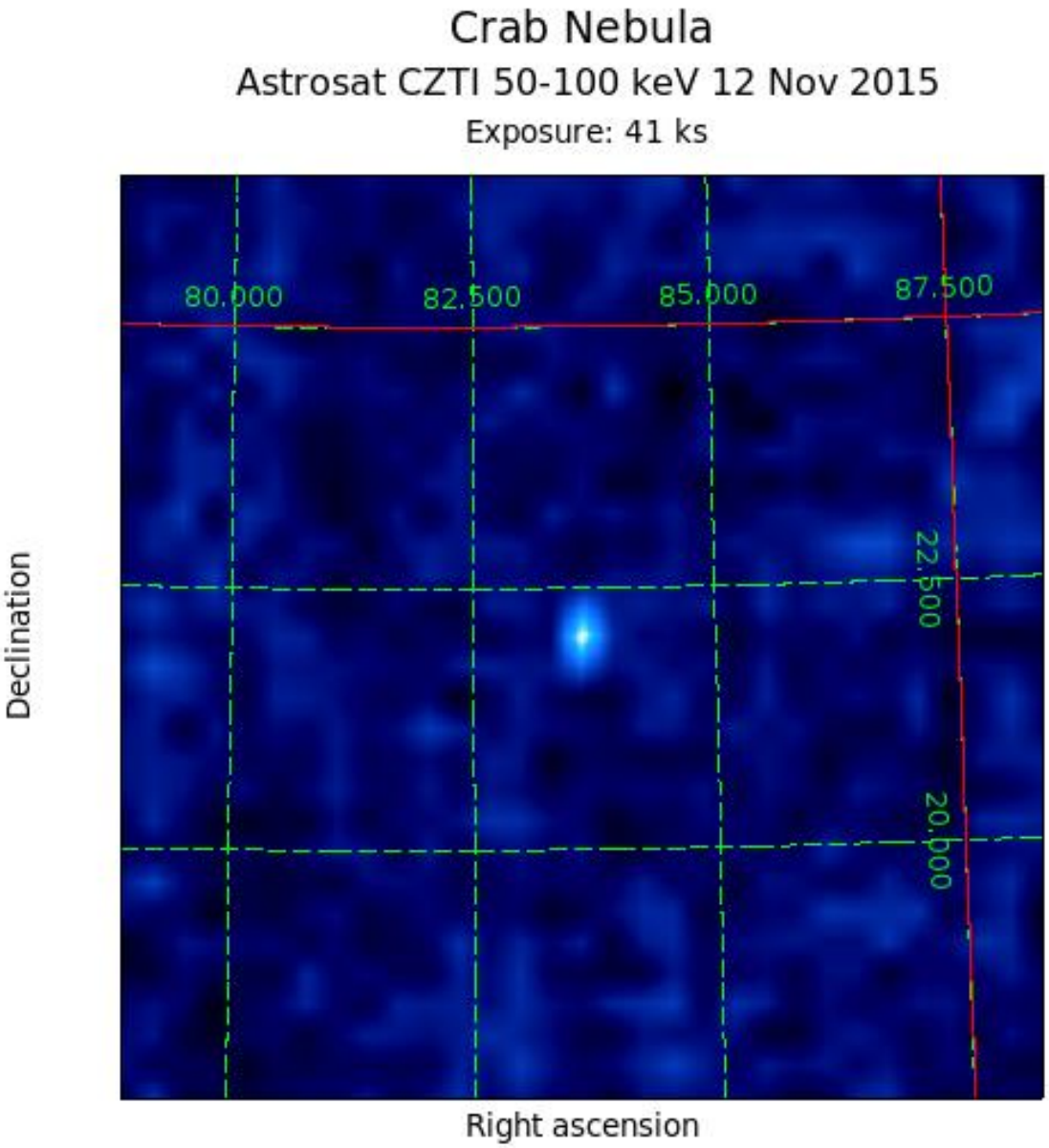
Angular resolution ~ 8 arcmin
Energy resolution ~ 8% @ 100 keV
Energy range: 10 – 100 keV

Up to 1 MeV (Photometric); no imaging above 100 keV

Sensitivity: 0.5 mCrab (5 sigma; 10^4 s)



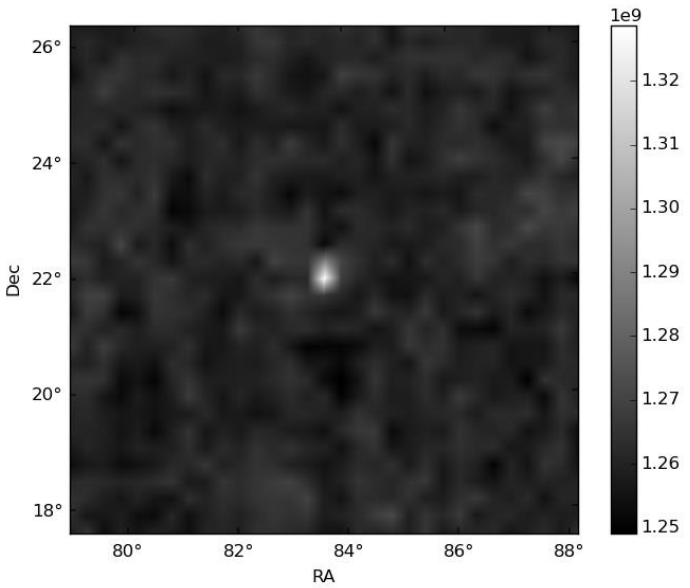
CZTI image of Crab



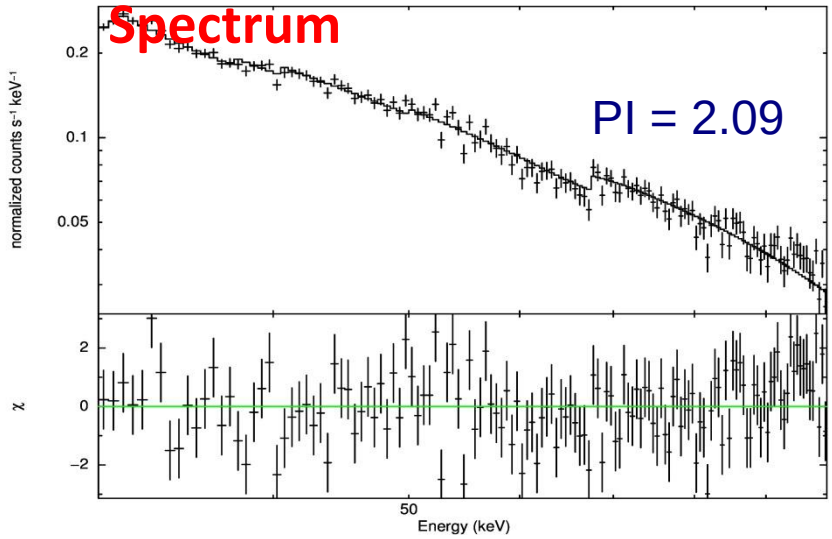
Courtesy: A.R. Rao, D.Bhattacharyya, S. Vadawale

Instrument Performance: CZTI

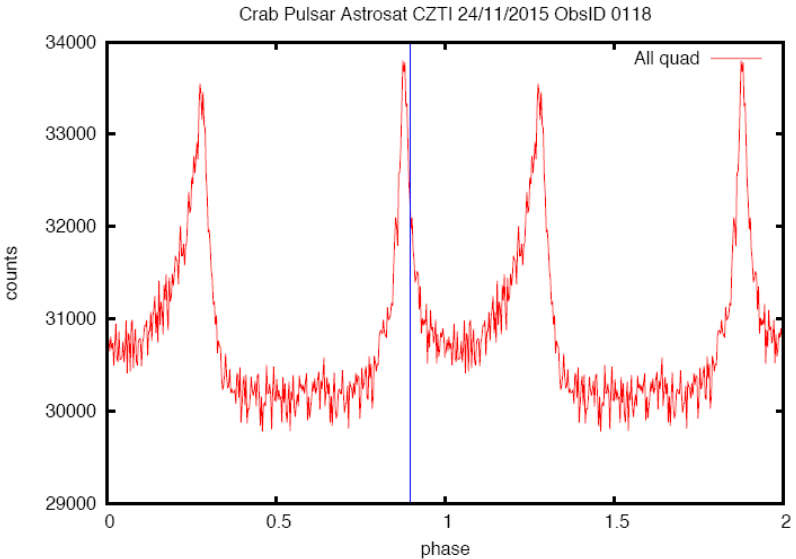
- Crab spin down (36 ns/day) detected clearly in one day observation
- X-ray pulse known to lead radio pulse by ~300 μs (Integral)
- CZTI pulse leads radio by ~490±150 μs
- Absolute time accuracy: ~200 μs



Spectrum



Pulse profile



Vadawale et al. 2016a; Rao 2016

Polarisation fraction and angle of Crab nebula and pulsar measured by CZT Imager.

(a) The polarisation fraction and

(b) polarisation angle.

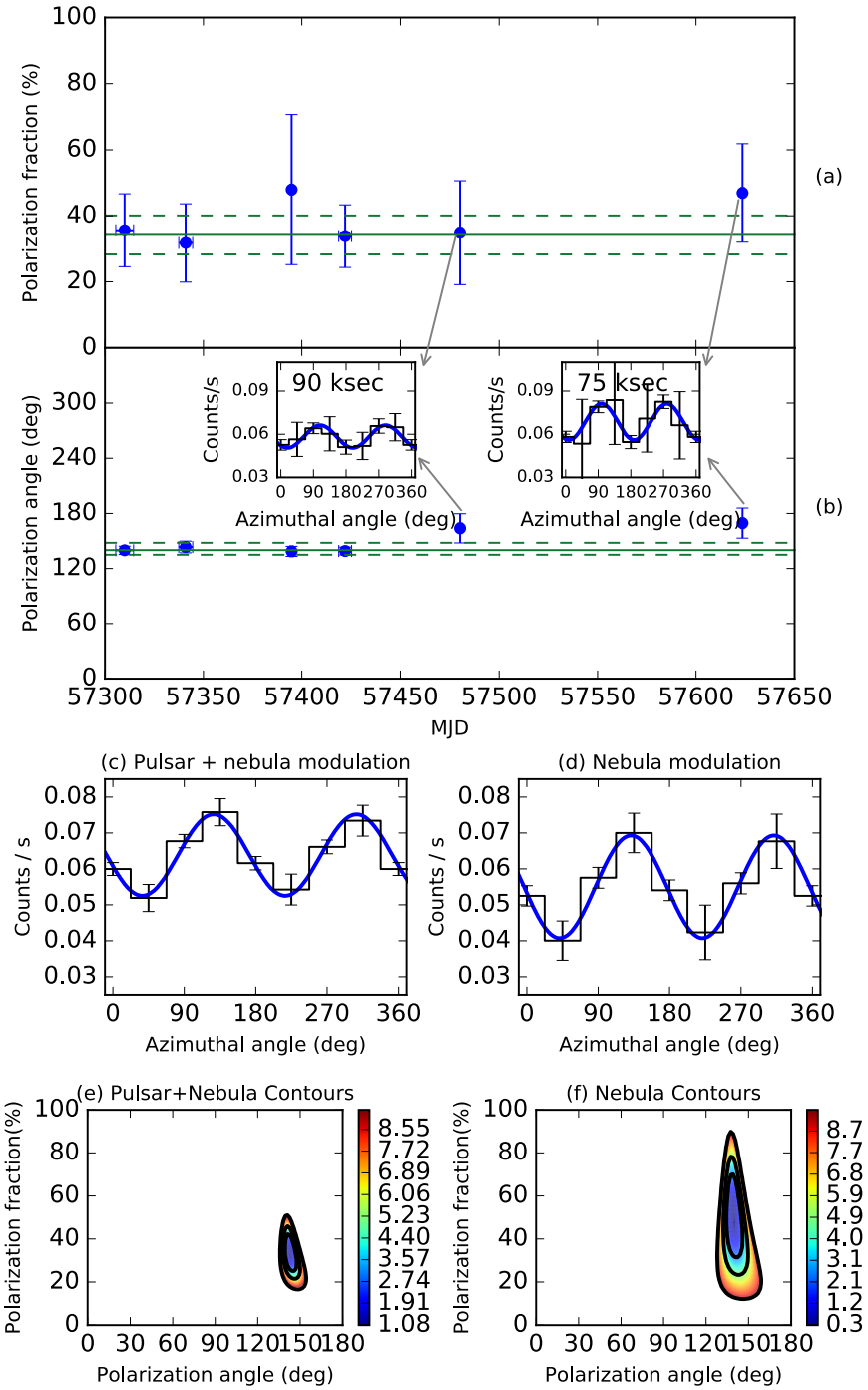
Representative modulation curves are shown in the insets.

(c) The modulation curve obtained by co-adding all observations (550 ks.)

fraction is 33.4% ± 5.8%

and polarisation angle is 143.0° **±** 2.8° NE

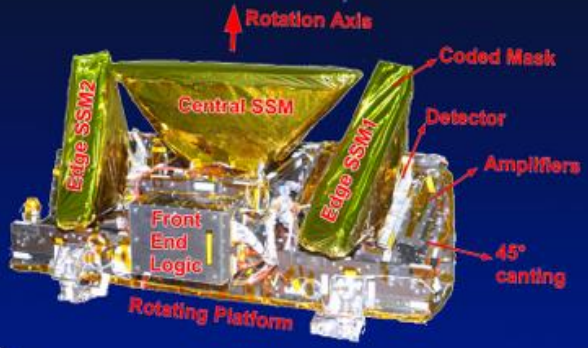
(e) & (f) Confidence contours

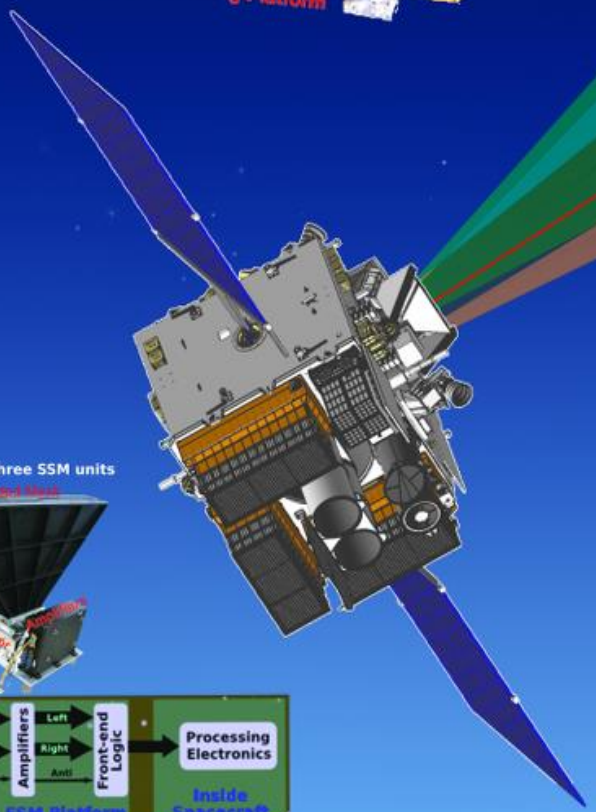


Vadawale et al. 2017

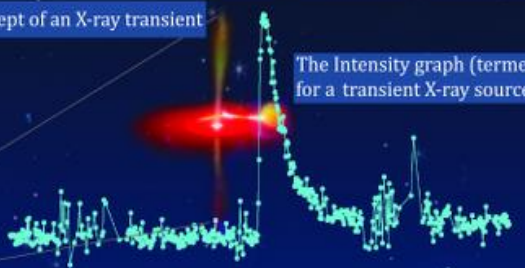
SCANNING SKY MONITOR (SSM) ABOARD ASTROSAT

To detect and locate X-ray transients





Artist's concept of an X-ray transient

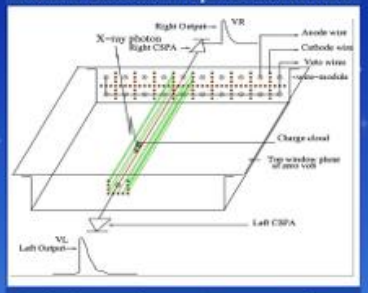


The Intensity graph (termed light curve) for a transient X-ray source

The shadow of the mask is processed to generate the X-ray sky image

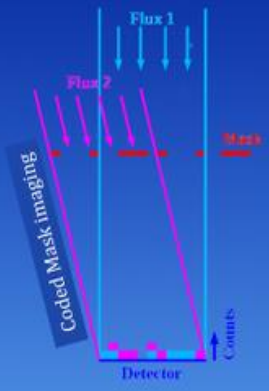
A simulated Sky Plane image

Position Sensitive Proportional Counter

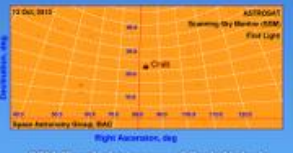


Each X-ray photon is converted into charge by the detector which is further processed by the electronics

X-ray photons from a celestial source cast the shadow of the coded mask on the detector plane



One of the three SSM units



SSM Firstlight image of Crab Nebula

SSM Specification Table

Parameters	Specification
Energy Range	2.5 keV - 10 keV
Detector	One-dimensional position-sensitive gas-filled proportional counter
Gas mixture	25% Xe + 75% P-10 (P-10 is 90% Argon + 10% Methane)
Gas pressure	800 torr
Diameter of anode	25 micron
Active length of anode	80 mm
Type of anode wire	Carbon-coated Quartz
Cell Size	12 mm square
Entrance Window	30 micron thick Aluminized Mylar (Al thickness is 1000 Å)
Detector operating voltage	~1500 Volt
Unit Bit size of coded mask	8.55 mm
Energy resolution	~25% at 6 keV
Position Resolution	~1.5 mm (FWHM)
Angular resolution	10' – 12' in the scanning direction, 2.5° across
Time resolution	0.1 ms
Sensitivity (4σ/1s, 3 sigma, 2.5-10 keV)	~23 mCrab for SSM1 & 2 ~28 mCrab for SSM3
Field of view (FOV) FWZR	Central SSM: 10.3° x 100° Edge SSMs: 26.8° x 100°
Payload Weight	65.9 kg
Payload Power	~40 W
Effective area (for all three SSM cameras)	~21 cm² @ 2.5 keV ~92 cm² @ 6 keV
Memory Required (for all three SSM cameras)	300 Mbyte per orbit
Event Rate	Nominal 400 c s⁻¹, max 5,800 c s⁻¹; electronics designed for 30,000 c s⁻¹

Credits: Artist's impression of GRS1915+105, CfA; ASM lightcurve of SWIFT J1753.5-0127

ISRO/IUCAA

ssm@isac.gov.in

Courtesy: Ramadevi

ASTROSAT

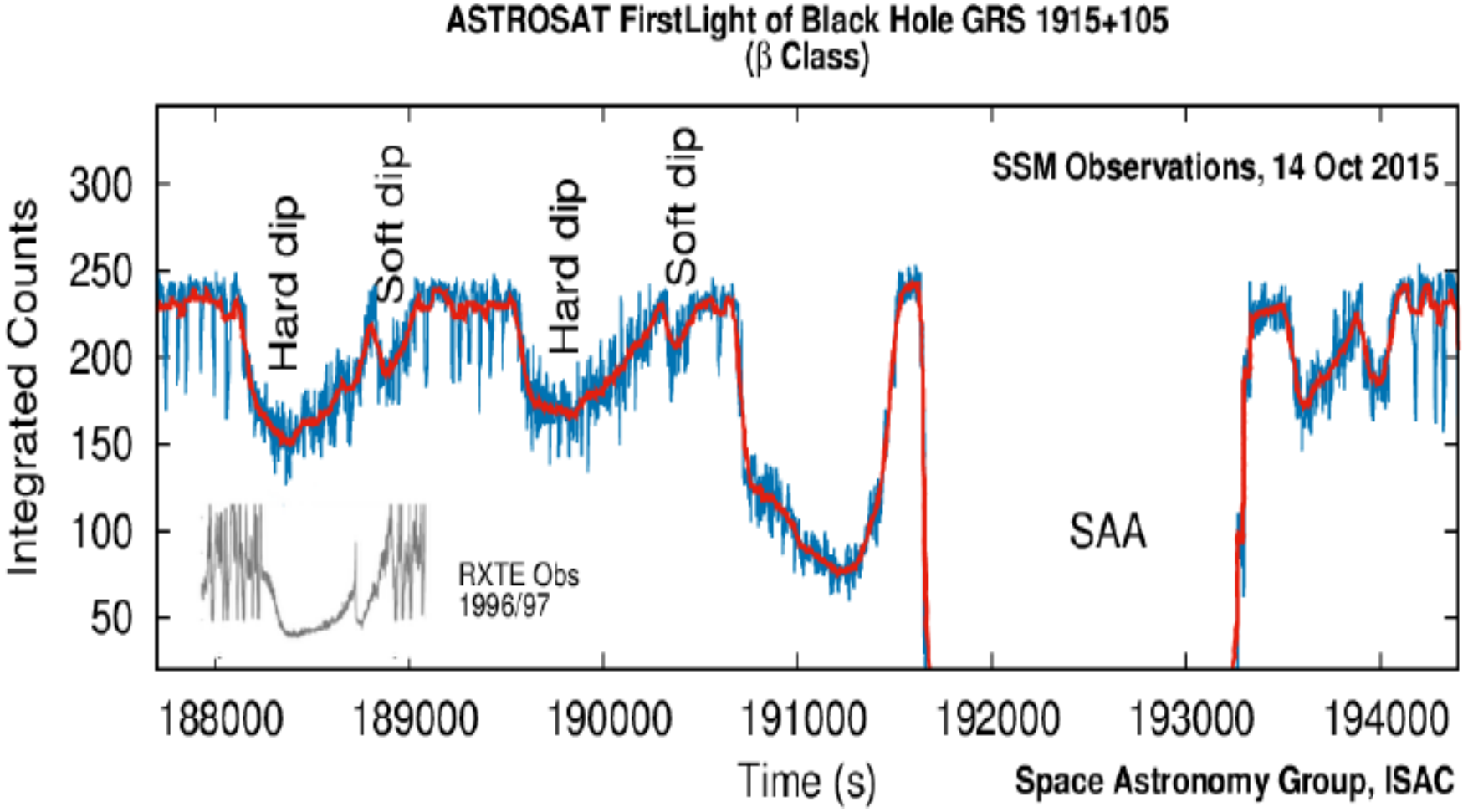
Performance Parameters of the scientific Instruments

	UVIT	SXT	LAXPC	CZTI	SSM
Detector	Intensified CMOS, used in photon counting mode or integration mode	X-ray (MOS) CCD at the focal plane. (XMM & Swift heritage)	Proportional counter	CdZnTe detector array	Position-sensitive proportional counter
Imaging / non-imaging	Imaging	Imaging	Non-imaging	Imaging	Imaging
Optics	Twin Ritchey-Chretian 2 mirror system.	Conical foils (~Wolter-I) mirrors. 2-m focal length	Collimator	2- D coded mask	1- D coded mask
Bandwidth	1300-5500 Angstroms	0.3 - 8 keV	3 - 80 keV	10 - 100 keV	2.5 - 10 keV
Geometric Area (cm2)	~1100	~250	10800	1024	~180
Effective Area (cm2)	8 - 50 (depends on filter)	~128@1.5 keV ~22@6 keV	8000@5-20 keV	1000 (E>10 keV)	~11 @ 2 keV ~53 @ 5 keV
Field of View (FWHM)	28' dia	~ 40' dia	1^0 x 1^0	6^0 x 6^0	10^0 x 90^0
Energy Resolution	<1000 A (depends on filter)	~5-6%@1.5 keV ~2.5%@6keV	12%@22 keV	5% at 100 keV	25% @ 6 keV
Angular Resolution	1.8 arcsec (FUV,NUV) 2.2 arcsec (Vis)	~2 arcmin (HPD)	~(1-5) arcmin (in scan mode only)	8 arcmin	~12 arcmin
Time resolution	1.7 ms	2.4 s, 278 ms	10 μs	1 ms	1 ms
Typical observation time per target	30 min	0.5 - 1 day	1 - 2 days	2 days	10 min
Sensitivity (Obs. Time)	Mag. 20 (5σ) 200 s (130-180 nm)	~10^{-13} ergs cm^{-2} s^{-1} (5 σ) (20000 s)	0.1 milliCrab (3σ) (1000 s)	0.5 milliCrab (3σ) (1000s)	~28 milliCrab (3σ) (600s)

Courtesy: K.P. Singh

SSM – GRS 1915+105

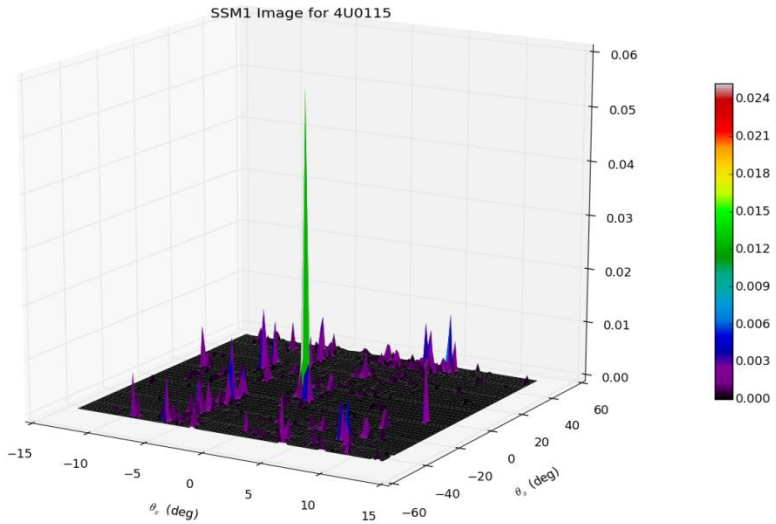
Black Hole source Observations; Oct 15, 2015

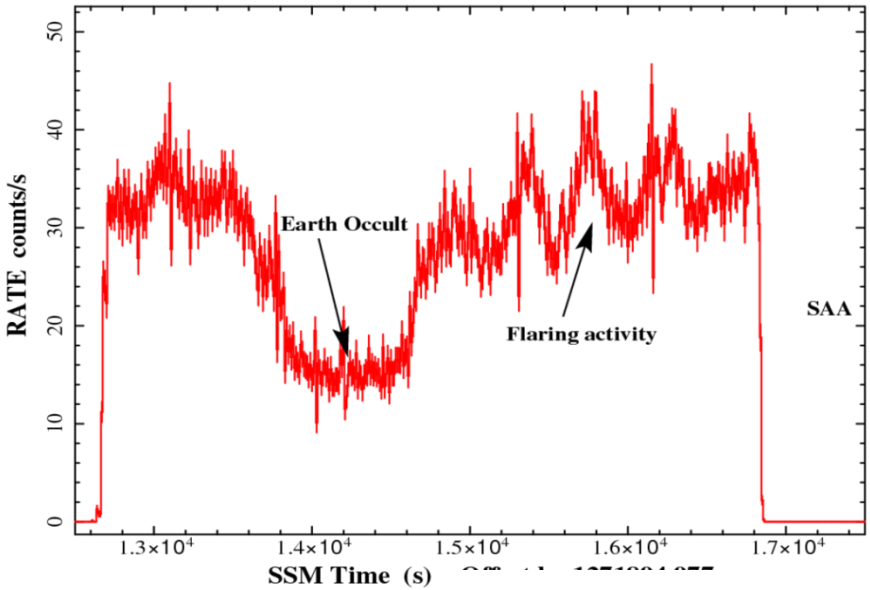


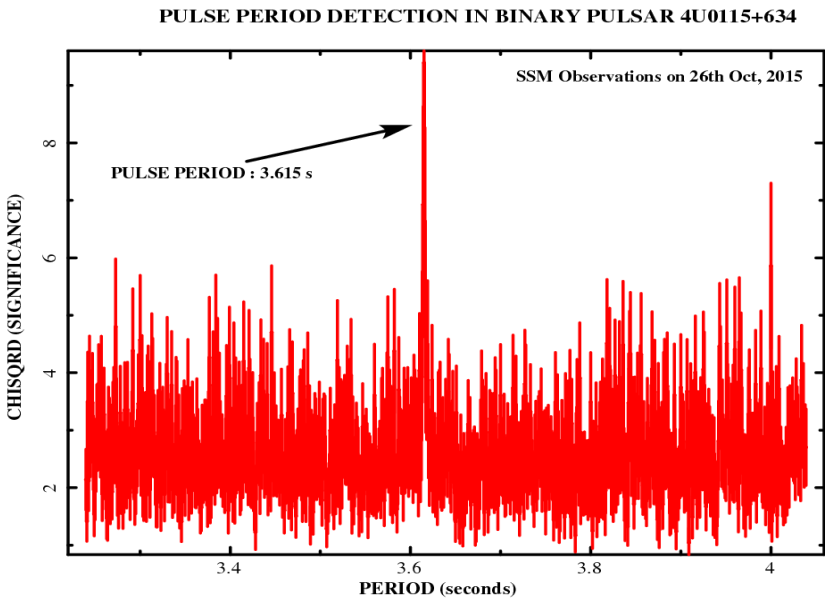
Astronomer's Telegram ATel#8185 generated on the above detection of variability in GRS 1915+105

Courtesy: Ramadevi

SSM Observations of a Be X-ray pulsar 4U0115+63 in its outburst

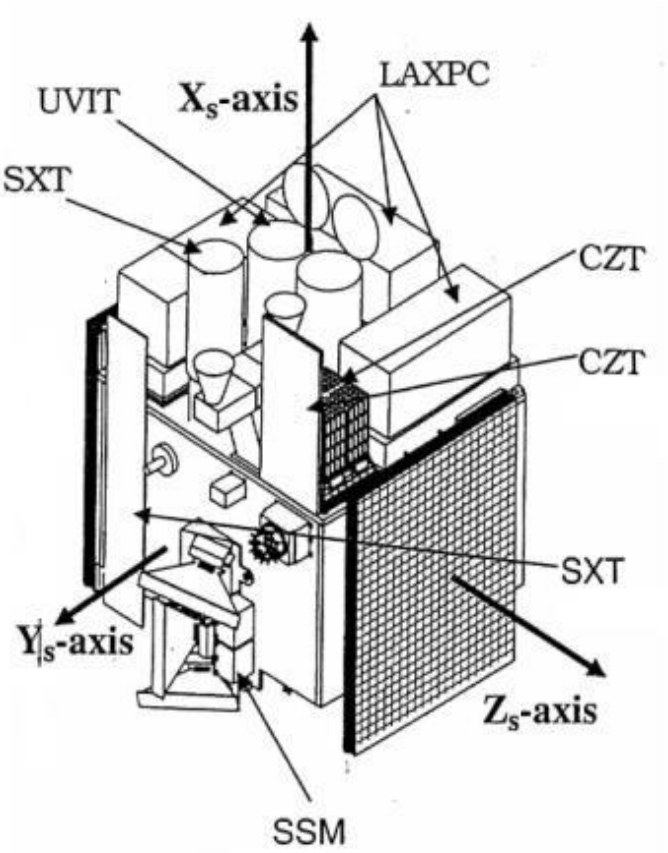




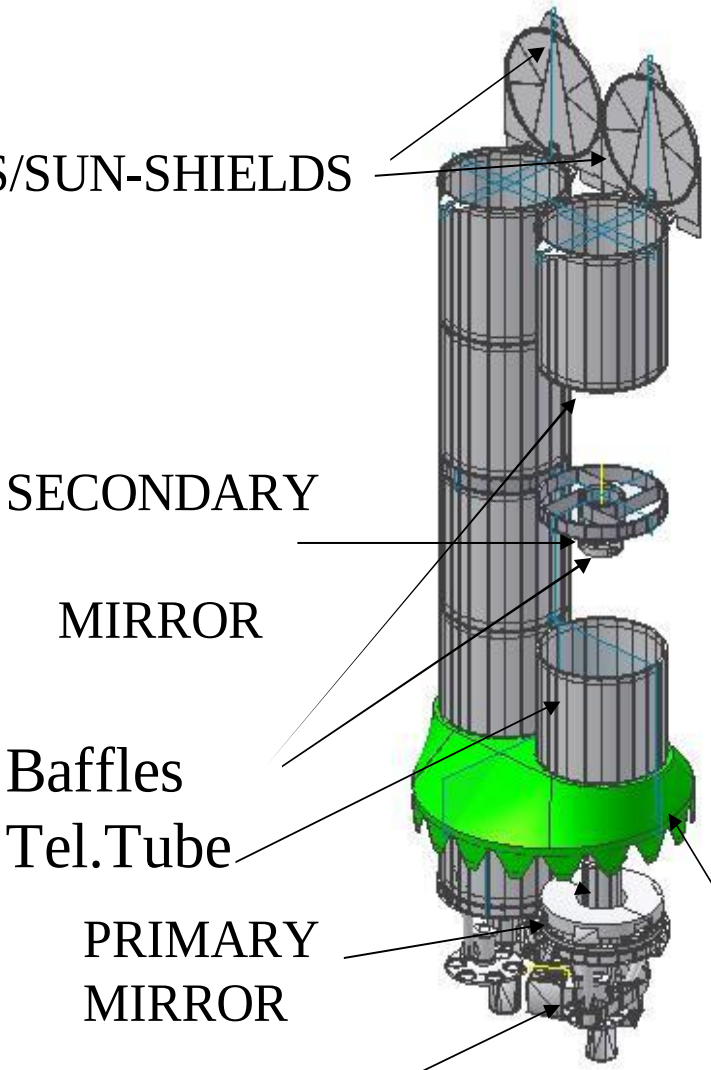


Courtesy: Ramadevi

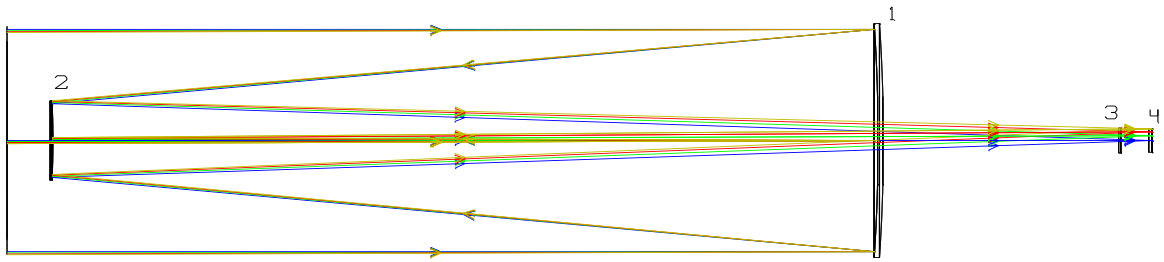
CONFIGURATION OF UVIT IN ASTROSAT



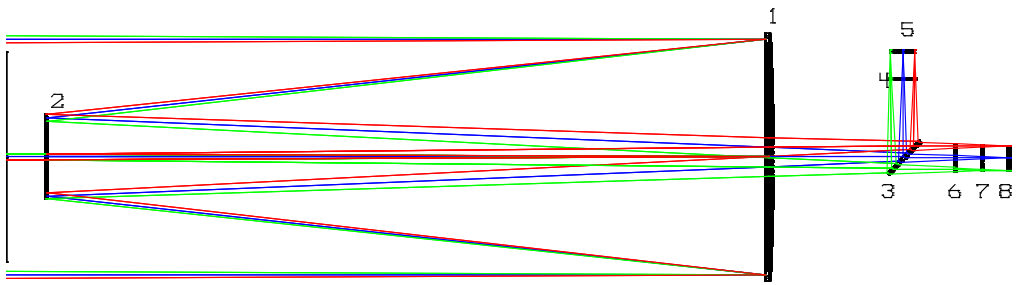
Courtesy: S.N. Tandon



OPTICAL LAYOUT -- FUV CHANNEL
f/12 Cassegrain, ~ 380 mm aperture



OPTICAL LAYOUT – NUV & VIS
f/12 Cassegrain, ~ 380 mm aperture



1- PRIMARY MIRROR
2- SECONDARY MIRROR
3- BEAM SPLITTER
4- NUV FILTER/grating
5- NUV DETECTOR WINDOW
6- VIS CORRECTOR
7- VIS FILTER
8- VIS DETECTOR WINDOW

WIREFRAME

UVIT S.SRIRAM

UVIT is primarily an imaging instrument. Images are made simultaneously in three channels: FUV (130-180 nm), NUV (200-300 nm), and VIS (320-550 nm), in a field ~ 28' circle. The spatial resolution (FWHM) is < 1.8" for the FUV and NUV channels, and it is ~ 2.2" for the VIS channel. In each channel, a set of filters are available, in the filter-wheels, for selecting a band. In the two ultraviolet channels, gratings are provided for low resolution (~ 100) spectroscopy.

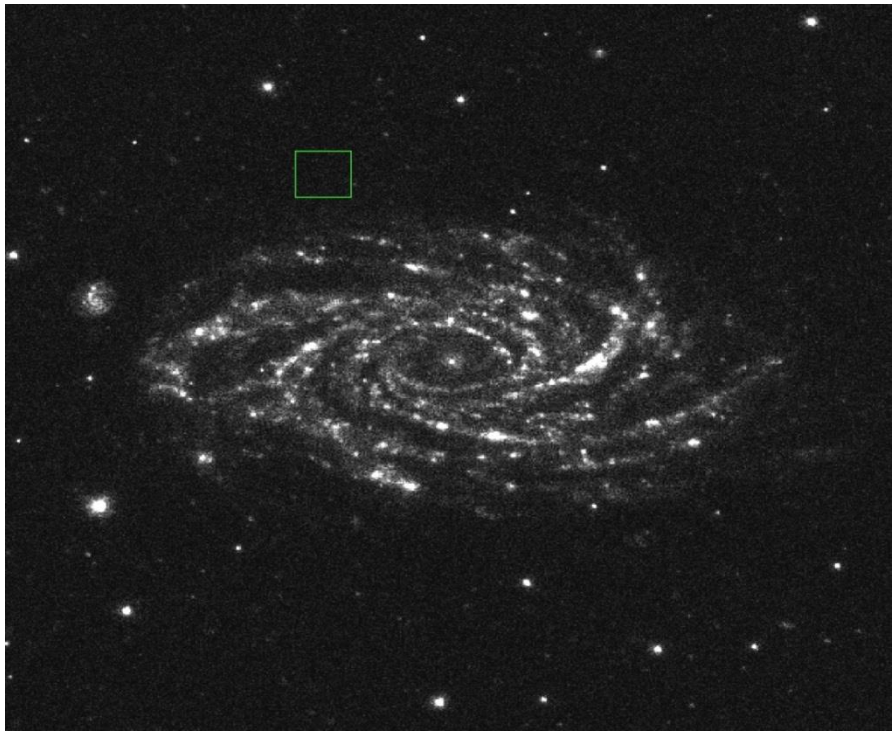
ASTROSAT

Performance Parameters of the scientific Instruments

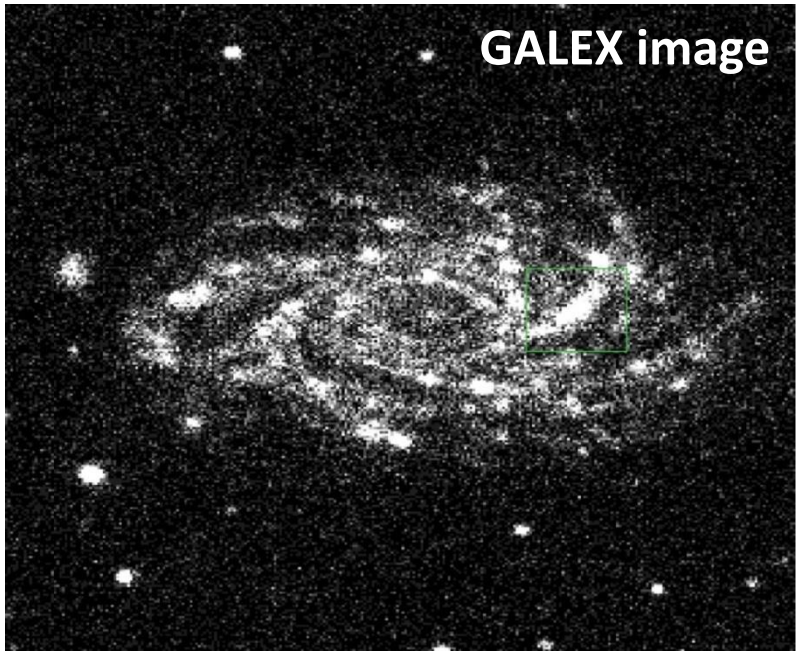
	UVIT	SXT	LAXPC	CZTI	SSM
Detector	Intensified CMOS, used in photon counting mode or integration mode	X-ray (MOS) CCD at the focal plane. (XMM & Swift heritage)	Proportional counter	CdZnTe detector array	Position-sensitive proportional counter
Imaging / non-imaging	Imaging	Imaging	Non-imaging	Imaging	Imaging
Optics	Twin Ritchey-Chretian 2 mirror system.	Conical foils (~Wolter-I) mirrors. 2-m focal length	Collimator	2- D coded mask	1- D coded mask
Bandwidth	1300-5500 Angstroms	0.3 - 8 keV	3 - 80 keV	10 - 100 keV	2.5 - 10 keV
Geometric Area (cm2)	~1100	~250	10800	1024	~180
Effective Area (cm2)	8 - 50 (depends on filter)	~128@1.5 keV ~22@6 keV	8000@5-20 keV	1000 (E>10 keV)	~11 @ 2 keV ~53 @ 5 keV
Field of View (FWHM)	28' dia	~ 40' dia	1^0 x 1^0	6^0 x 6^0	10^0 x 90^0
Energy Resolution	<1000 A (depends on filter)	~5-6%@1.5 keV ~2.5%@6keV	12%@22 keV	5% at 100 keV	25% @ 6 keV
Angular Resolution	1.8 arcsec (FUV,NUV) 2.2 arcsec (Vis)	~2 arcmin (HPD)	~(1-5) arcmin (in scan mode only)	8 arcmin	~12 arcmin
Time resolution	1.7 ms	2.4 s, 278 ms	10 μs	1 ms	1 ms
Typical observation time per target	30 min	0.5 - 1 day	1 - 2 days	2 days	10 min
Sensitivity (Obs. Time)	Mag. 20 (5σ) 200 s (130-180 nm)	~10^{-13} ergs cm^{-2} s^{-1} (5 σ) (20000 s)	0.1 milliCrab (3σ) (1000 s)	0.5 milliCrab (3σ) (1000s)	~28 milliCrab (3σ) (600s)

Courtesy: K.P. Singh

Image of NGC 2336: a comparison



UVIT NUV image



Right: colour ground-based image

Courtesy: S.N. Tandon

ASTROSAT observation plan

0-6 months (~ Oct. 2015 – Mar. 2016): Performance Verification

6-12 months (~ Apr. 2016 – Sep. 2016): Guaranteed Time Observations (GTO)

Year 2 (~ Oct. 2016 – Sep. 2017): AO: Indian PIs: 35% and GTO: 50%

Year 3 (~ Oct. 2017 – Sep. 2018): AO: Indian PIs: 45%, Other PIs: 10% and GTO: 30%

Year 4 (~ Oct. 2018 – Sep. 2019): AO: Indian PIs: 65% and Other PIs: 20%

From Year 2: CSA: 5%, Leicester: 3%, ToO: 5%

Throughout the mission: Calibration: 2%

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