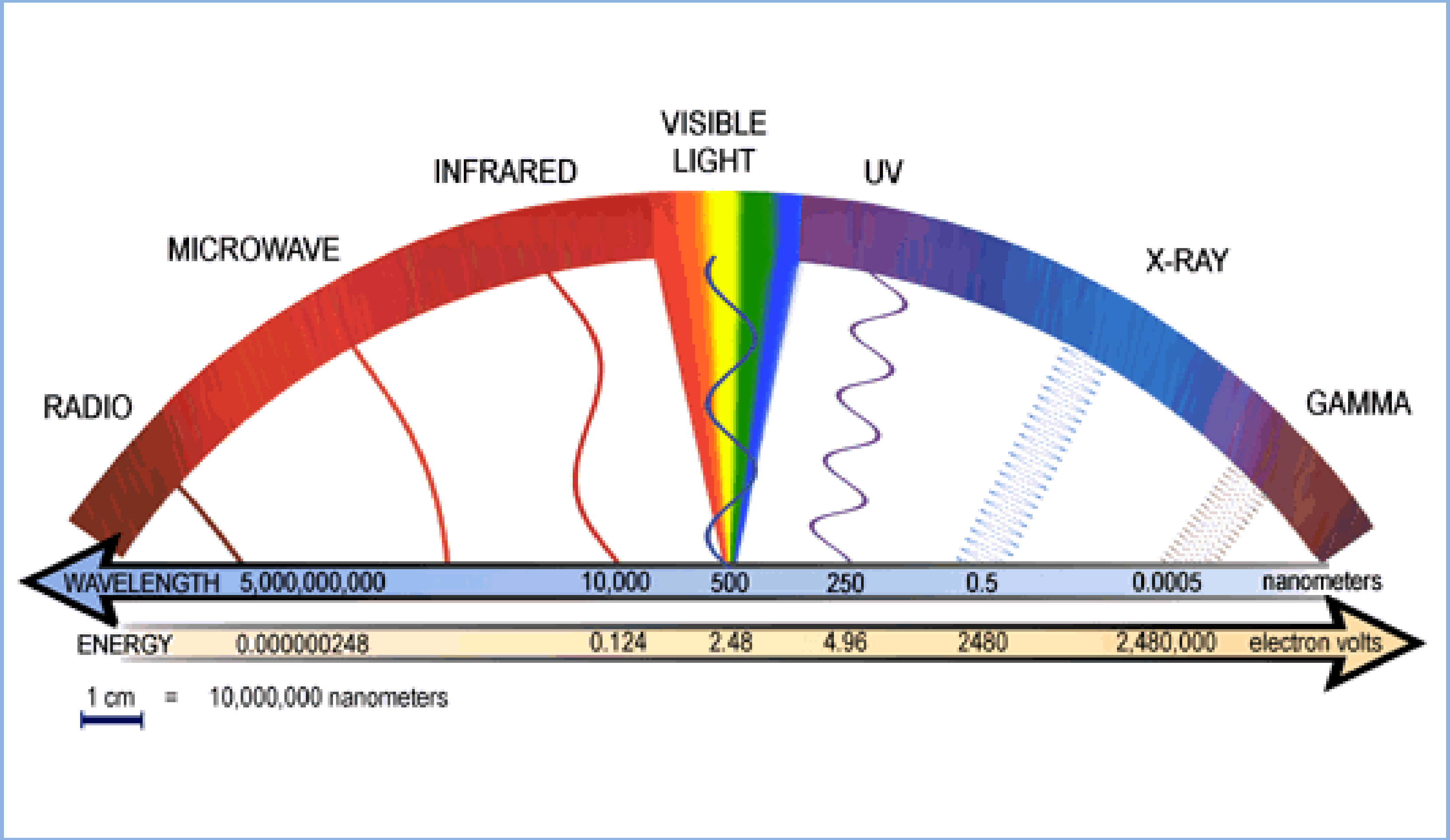
AstroSat/ LAXPC instrument and its performance

J. S. Yadav

Multi-wave Bands: Visible + NUV, FUV and X-rays

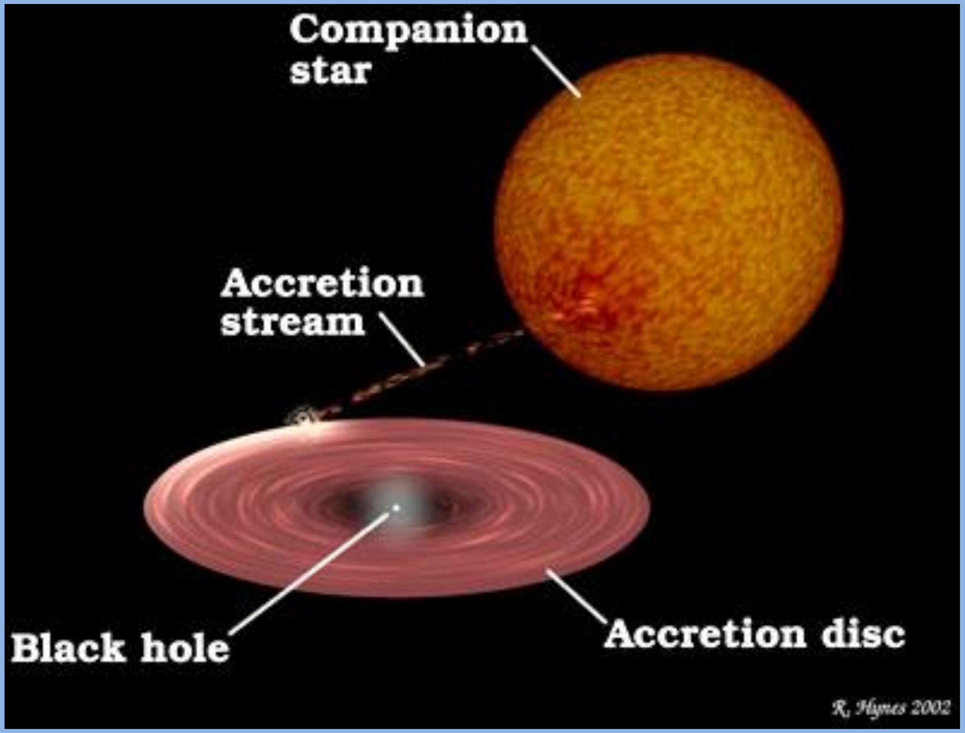


X-ray Band: 0.1 – 100 keV (120 to 0.12 Angstroms)

Soft X-ray .1 – 10 keV Hard X-ray above 10keV

Accretor has mass M and radius R, gravitational energy release/mass is

$$\Delta E_{acc} = \frac{GM}{R}$$



For accretion on to a neutron star

$$(M = M_{sun}, R = 10km)$$

$$\Delta E_{acc} = 10^{20} erg / gm$$

compare with nuclear fusion yield (mainly H→ He)

$$\Delta E_{nuc} = 0.007c^2 = 6\times10^{18}\, erg / gm$$

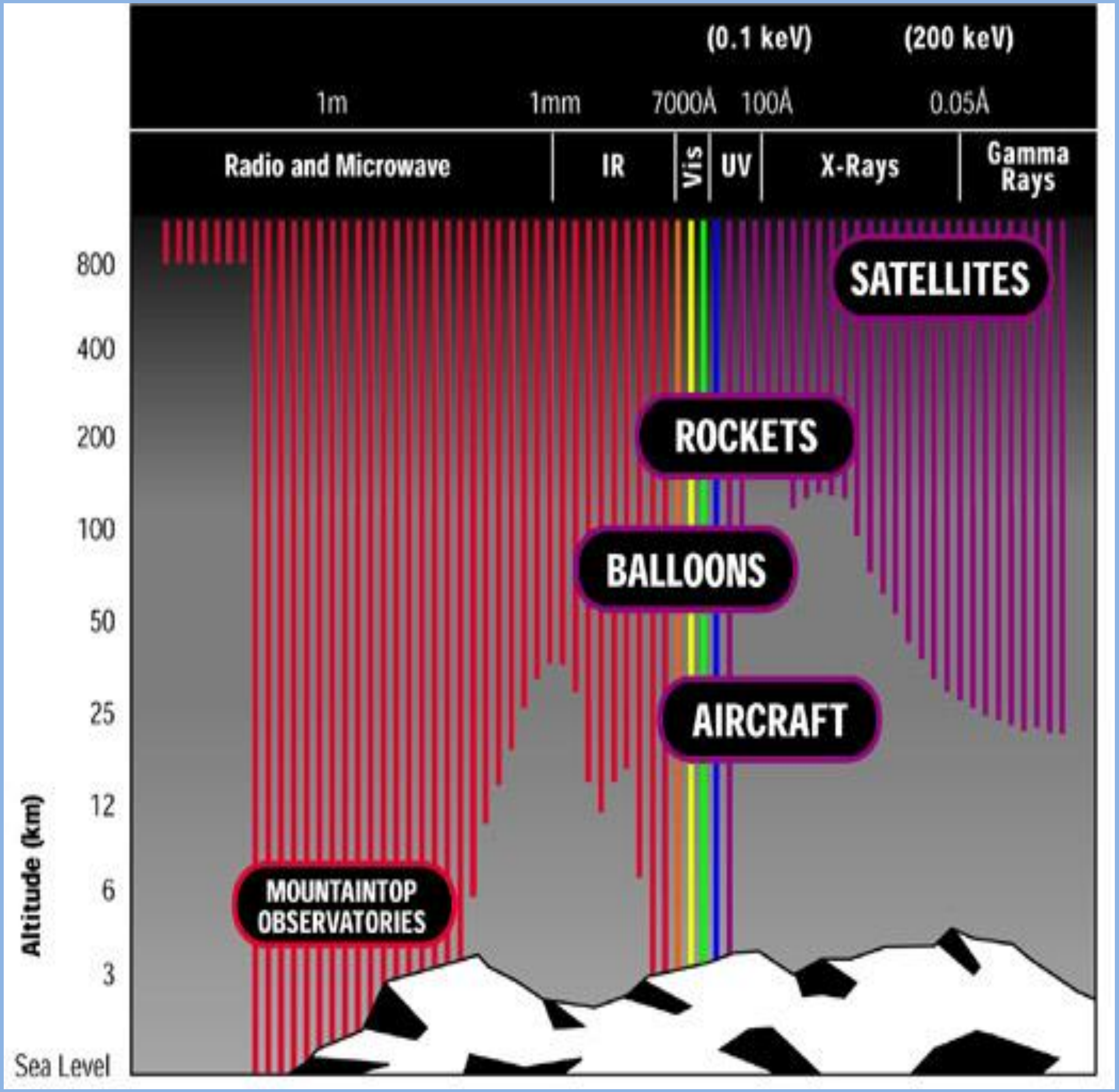
Accretion on to a black hole releases significant fraction of rest—mass energy:

$$R \approx 2GM / c^2 \Rightarrow \Delta E_{acc} \approx c^2 / 2$$

(in reality use GR to compute binding energy/mass: typical accretion yield is roughly 10% of rest mass)

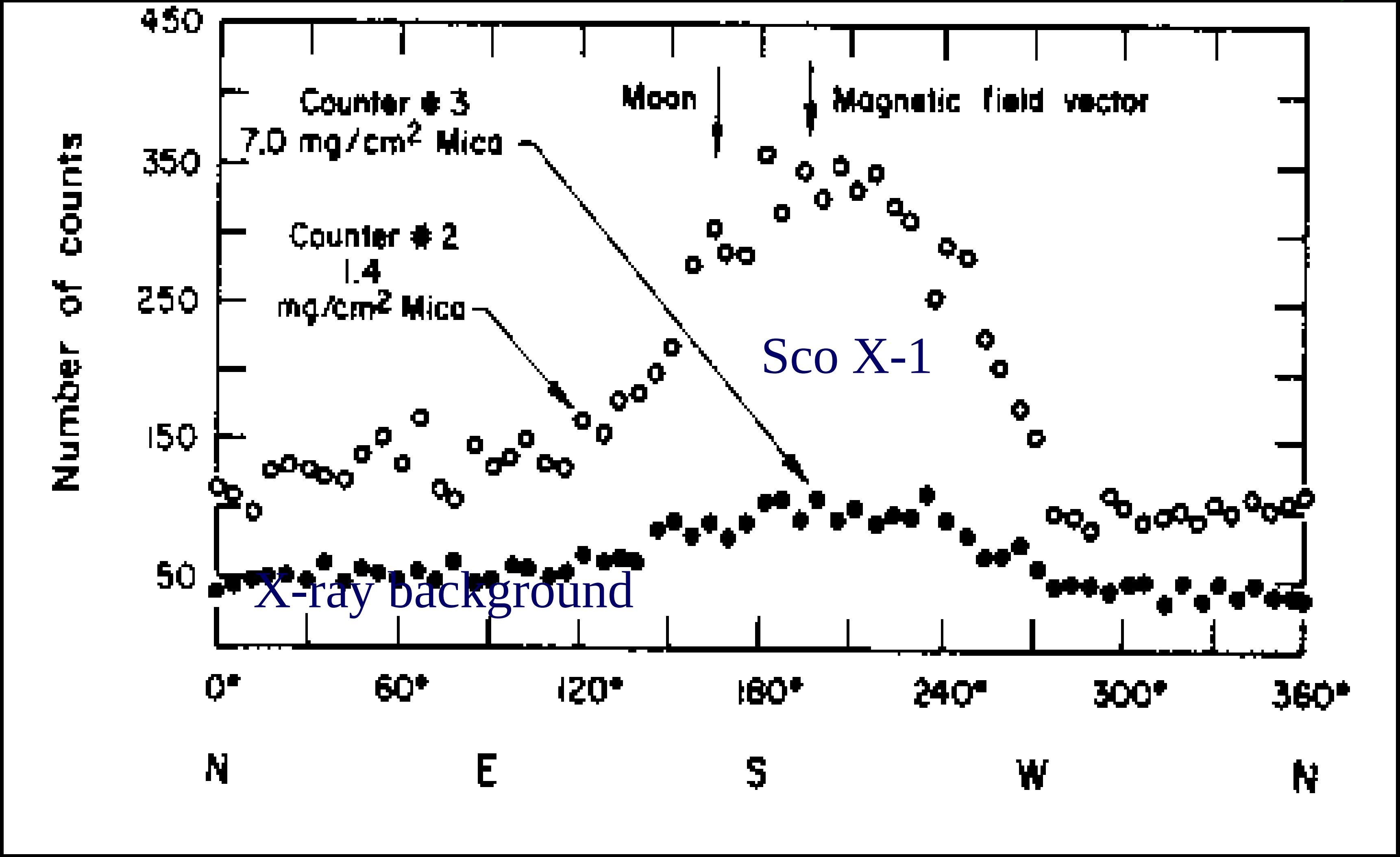
This is the most efficient known way of using mass to get energy:

UV and X-rays require space borne instruments



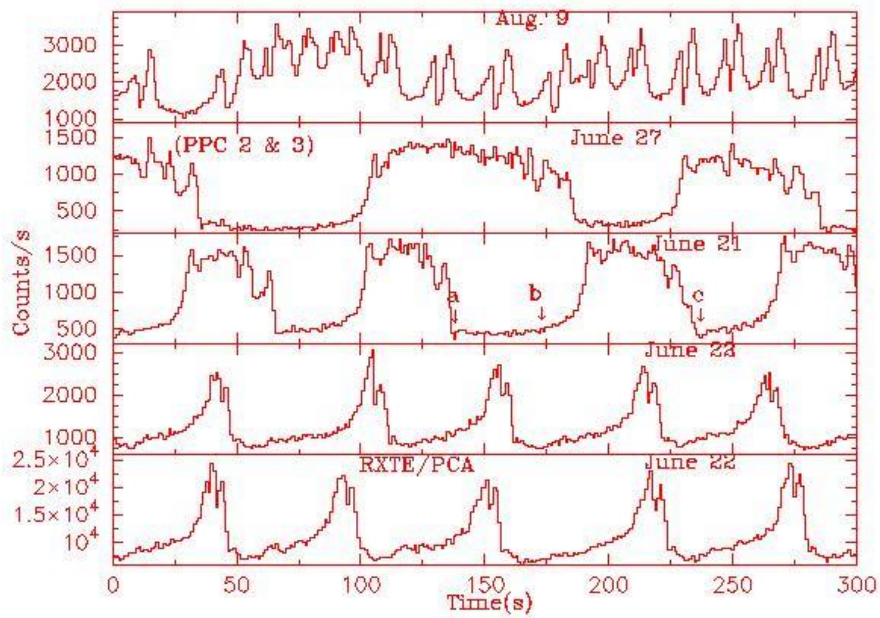
The First Extra-Solar X-ray Detection

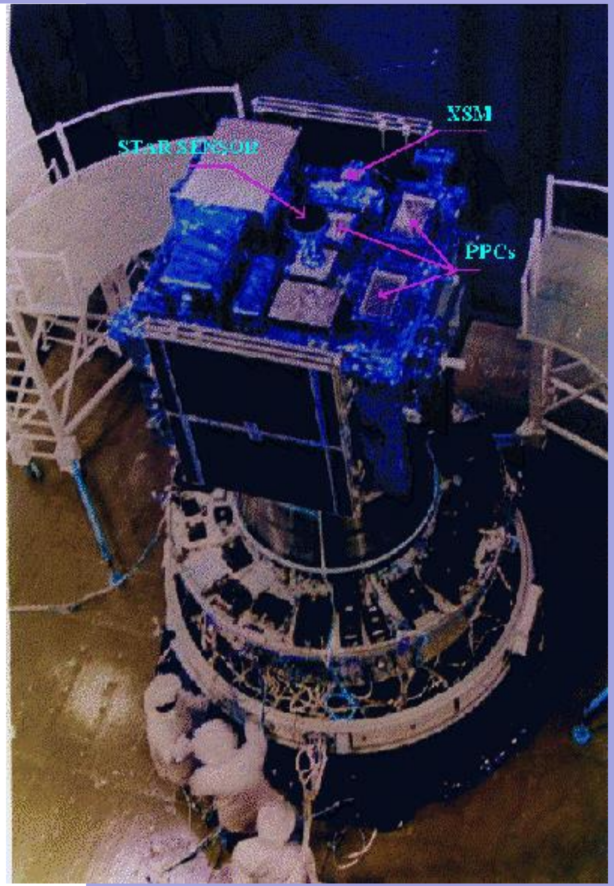
Giacconi et al., 1962



IXAE June-Aug. 1996-2001

Data of GRS 1915+105 observed in June 1997





J. S. Yadav et al ApJ (1999) v. 517,p 935

ASTROSAT –

India’s First Astronomy Satellite

simultaneous observations in multi-wave bands (UV to hard X-ray)

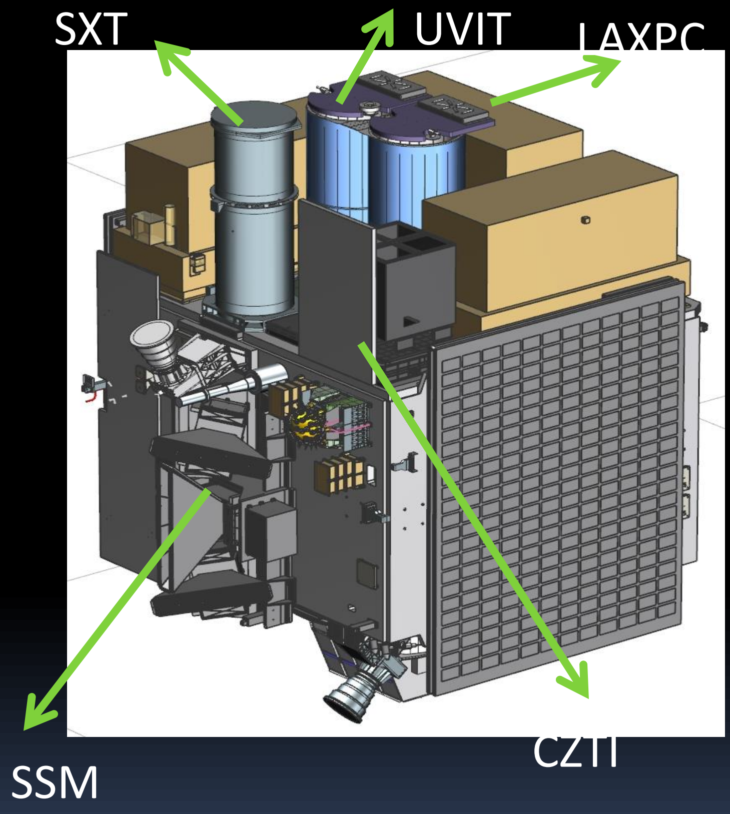
- Orbit Altitude : 650 km,
  Inclination : 6 deg (near equatorial)
- Mass :1550 kg (750 kg science payloads)
- Power: 2100 watts
- Payload pointing : 0.05 deg
- Slew rate : 0.6 deg/sec
- Launch: 28th Sept. 2015,
- Operational life : 5 years

Payloads Instruments:

ASTROSAT: Co-aligned multi-wave instruments

- **Large Area X-Ray Proportional Counter (LAXPC) -TIFR**
- **Soft x-ray Telescope (SXT) - TIFR**
- **Cadmium Zinc Telluride Imager (CZTI) –TIFR**

- **Ultra Violet Imaging Telescope (UVIT) – IIA**
- **Scanning Sky Monitor (SSM) – ISAC**



ASTROSAT Payload Characteristics

	UVIT	SXT	LAXPC	CZTI	SSM
Detector	Intensified CMOS	X-ray CCD	Proportional Counter	CdZnTe Detector Array	Position Sensitive Proportional Counter
Type	Imaging	Imaging	Non-Imaging	Imaging	Imaging
Bandwidth	1300 - 5500 Ang.	0.3 - 8 keV	3 - 80 keV	10 - 100 keV	2 - 10 keV
Effective Area (Cm^2)	8 - 50 (Depends on Filter)	128 @ 1.5 keV, 11 @ 6 keV	8000 @5 - 20 keV	1000 @ E > 10 keV	~60 @ 5 keV
Field of View (FWHM)	28' Dia	~40' Dia	47' x 47'	4.6° x 4.6°	22° x 100°
Energy Resolution	< 1000 A	~ 5 - 6 % @ 1.5 keV	12% @ 60 keV	8% @ 100 keV	20% @ 6 keV
Time Resolution	1.7 ms	278 ms	10 µs	1 ms	1 ms
Total Mass (Kg)	230	65	414	50	48
Prime Responsibility	IIA	TIFR	TIFR	TIFR	ISAC

Why Proportional Counter as detector of choice ?

- **PC chosen as its technology well proven. one can design and make large area detectors with multiple units to provide redundancy. TIFR group successfully developed Xenon-filled PCS of ~ 2500 cm^2 area and used successfully in several balloon experiments.**
- **Difficult to achieve Energy threshold of < 15 keV with large array CdTe/ CZT detectors as seen in INTEGRAL and SWIFT. Energy threshold of ~ 2 keV essential as most photons from cosmic sources in 2-15 keV.**
- **Silicon Drift detectors still in small size and not certain whether large arrays can be made with E < 2 keV.**

LAXPC: Large Area X-ray Proportional Counters (~419 Kg) (became fully operational on 19th Oct. 2015)

A broad energy band (3 - 80 keV) with high detection efficiency of X-ray above 20 keV and high timing resolution 10 µsec. .

•Three co-aligned identical LAXPC detectors

•Each with a multi-wire-multi-layer configuration filled with 90%Xe +10% Methane gas at 1520 torr. Energy resolution (12%@22 keV)

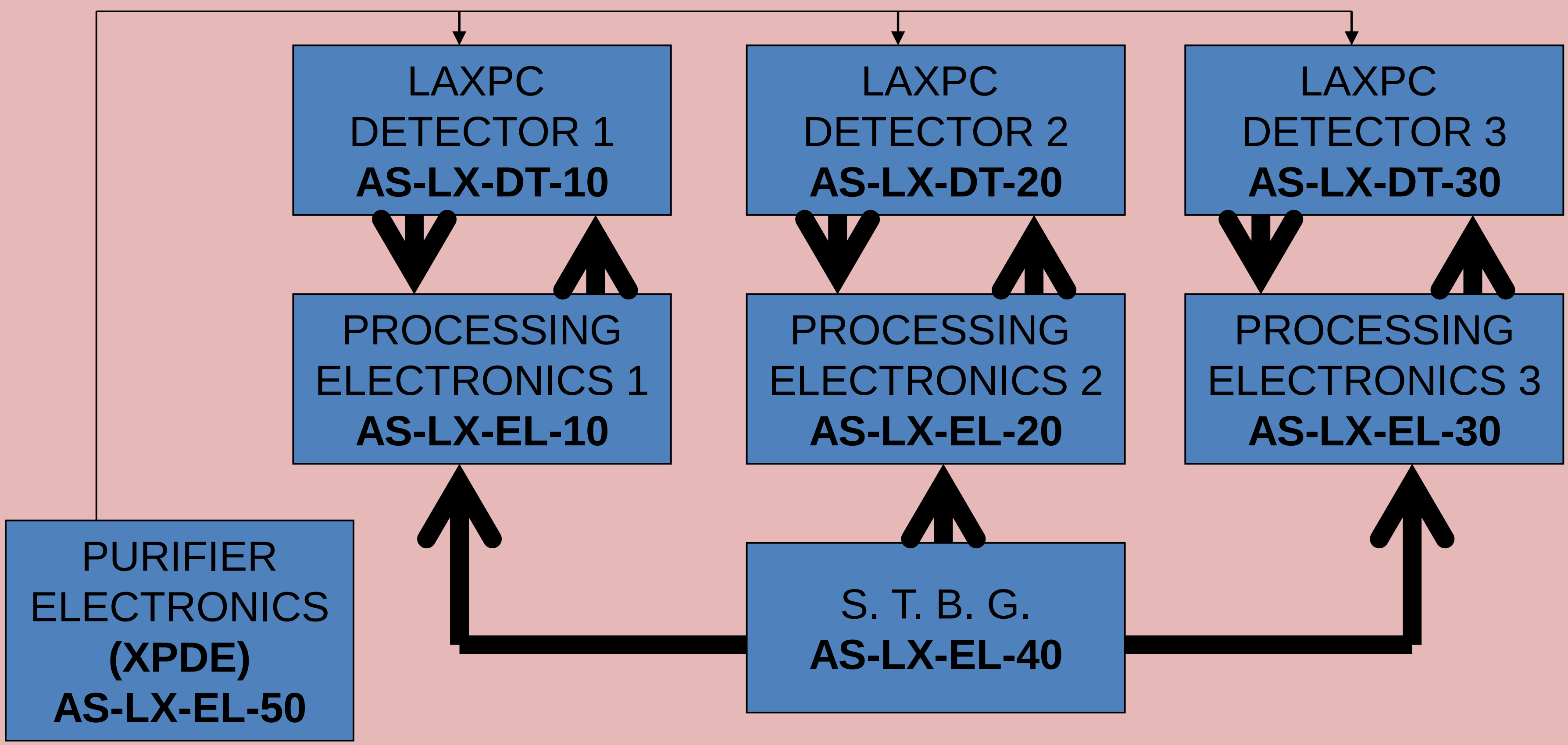
•A 50 micron thick aluminized Mylar window for X-ray entrance

Mylar film support -- by a honeycomb window support collimator

•A narrow field of view of .8x.8 degs provided by *mechanical collimators made of a sandwich of* 50µ Sn + 25µ Cu + 100µ Al co-aligned with the window support collimator and sitting above it.

•Blocking shield on sides and bottom : 1mm Sn + 0.2 mm Cu

LAXPC Flight Packages



- LAXPC payload has 8 flight packages.
- Three Detectors,
- Corresponding Processing Electronics,
- Common STBG package, & XPDE package

Time line

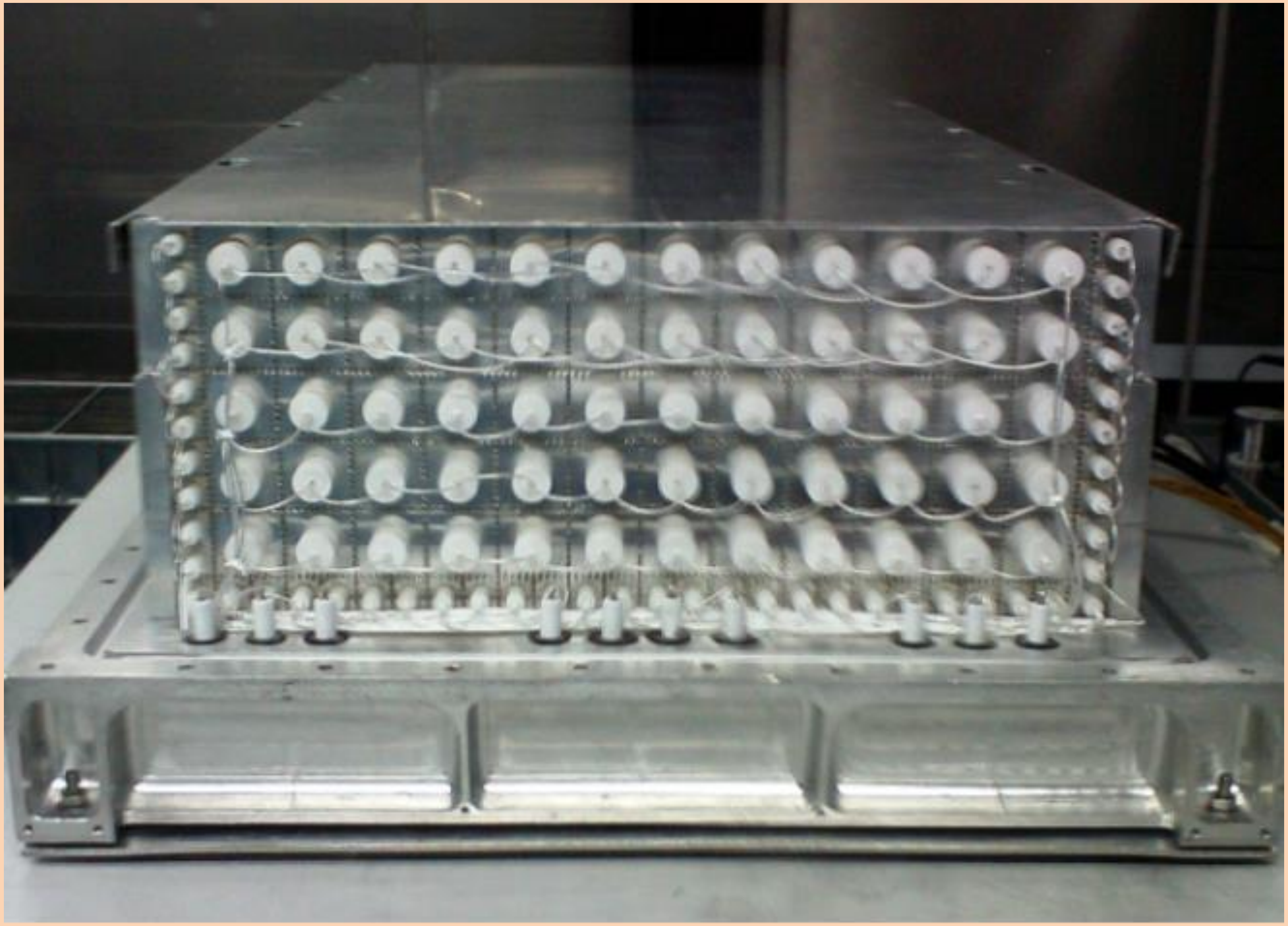
The CDR review of all other ASTROSAT instruments (except LAXPC) were completed in November 2012. LAXPC did not have proto type.

Critical design Review

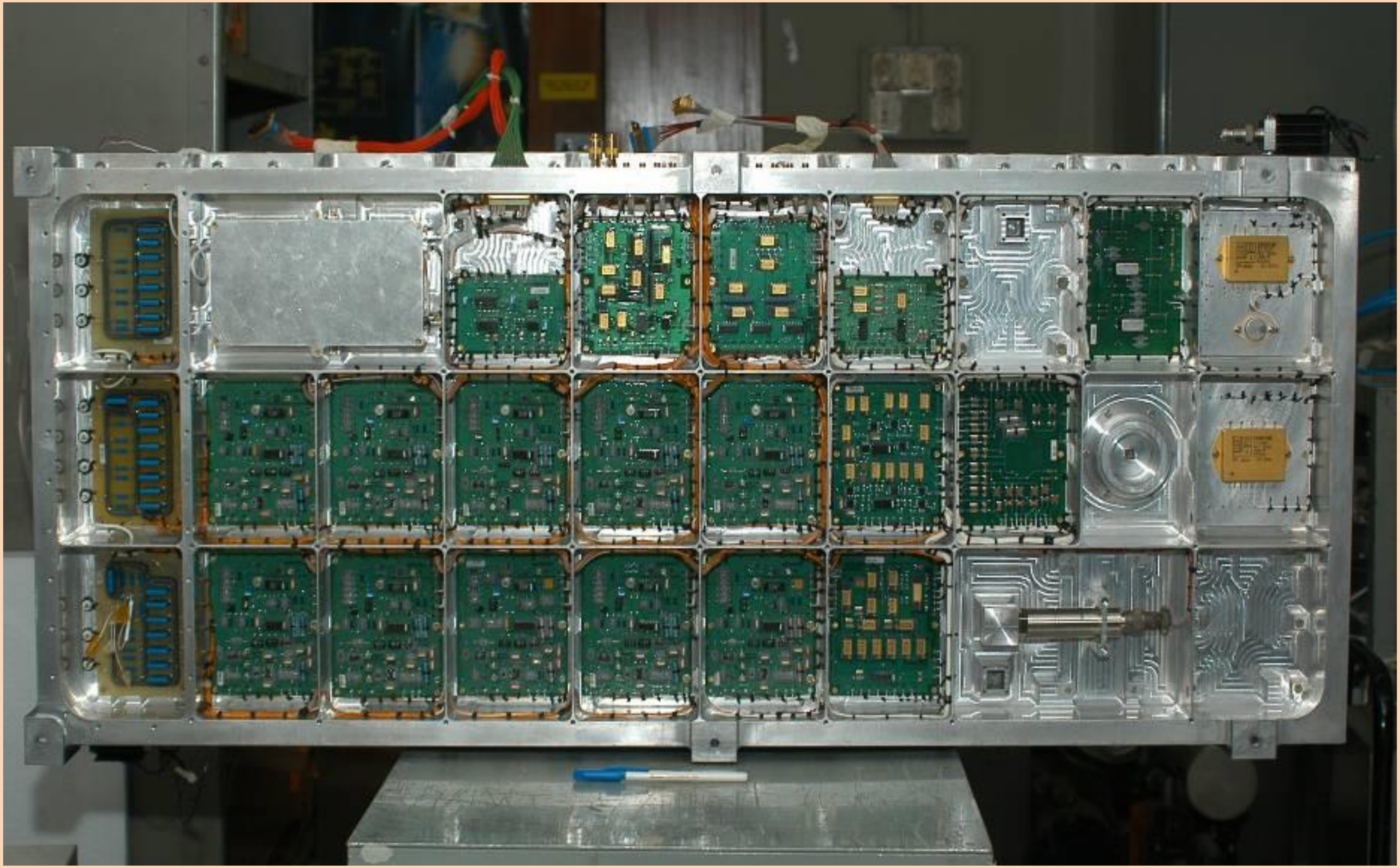
UVIT payload	*June 2011*
CZTI payload	*November 2012*
SXT payload	*November 2012*
SSM payload	*November 2012*
LAXPC payload	*January 2014*

Detector hardware

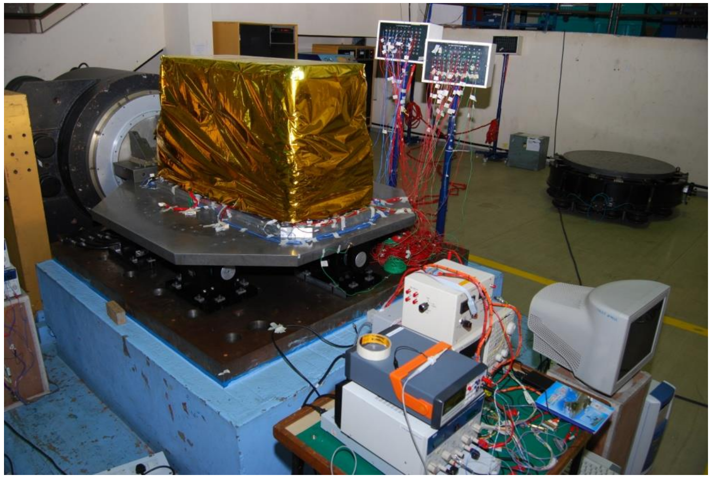
Harness wiring of detector

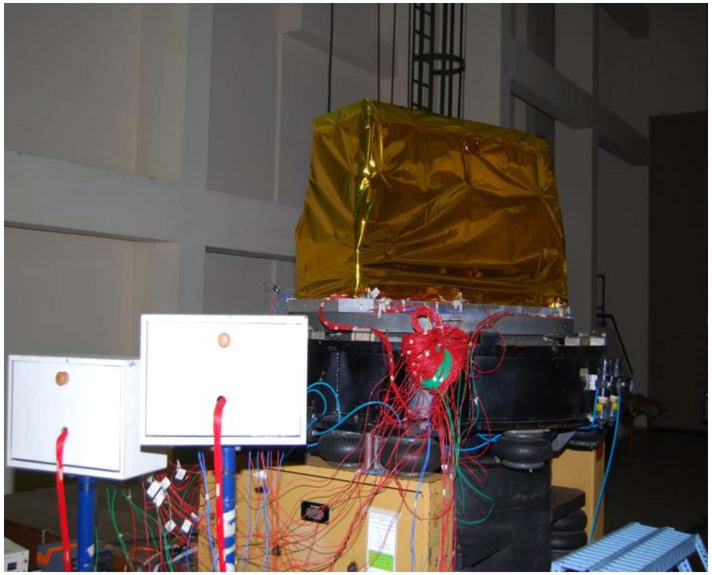


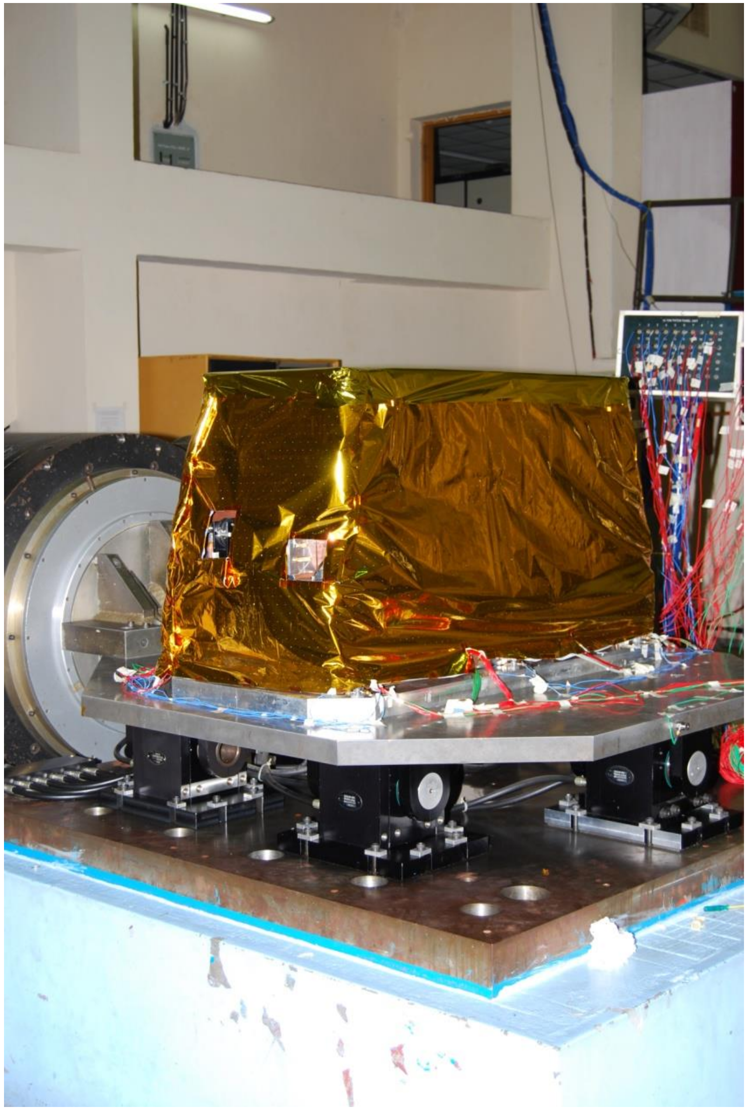
Detector Front-End Electronics



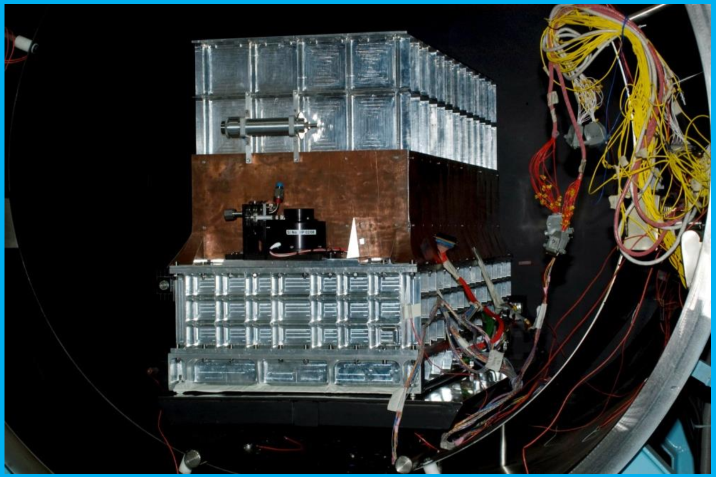
LAXPC Detector on vibration table

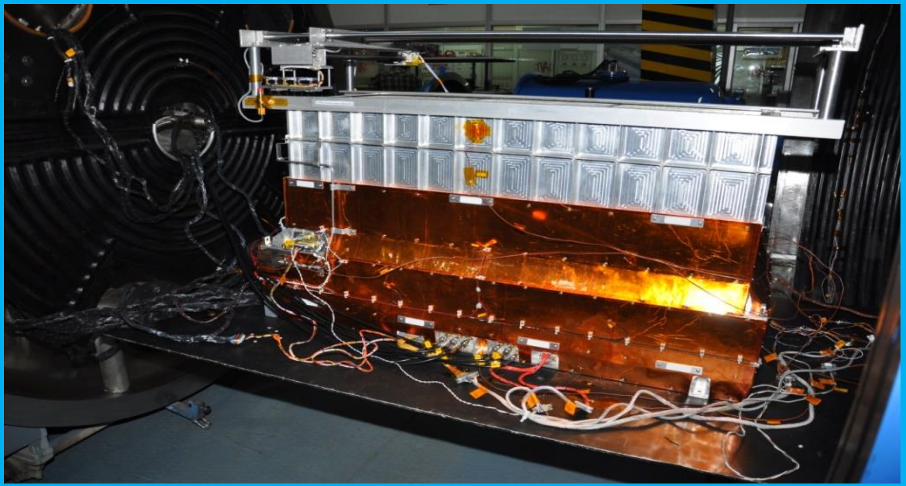






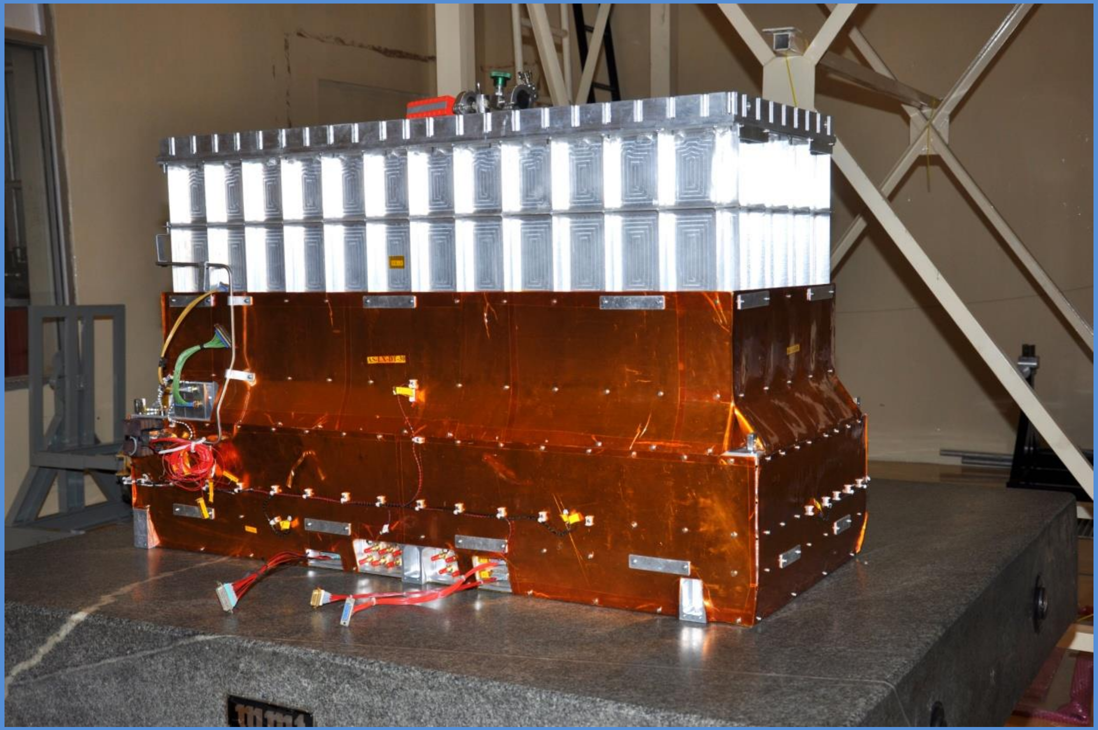
Thermovac test of LAXPC





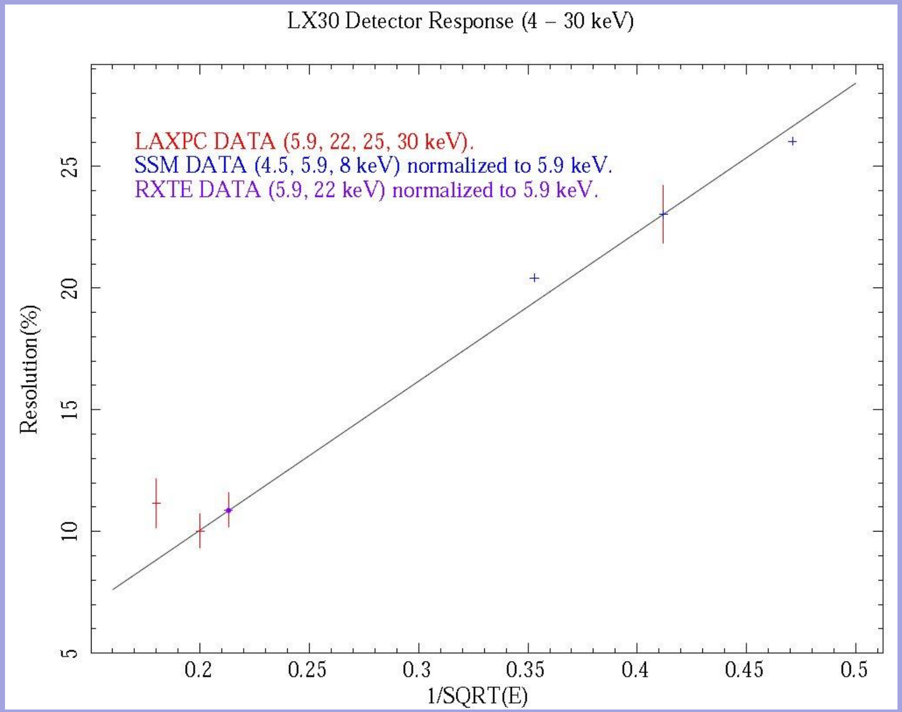
All the parameters and functionality
found OK
and tests successfully completed

Alignment of LAXPC units; two units of LAXPC instrument are being tested on satellite bus



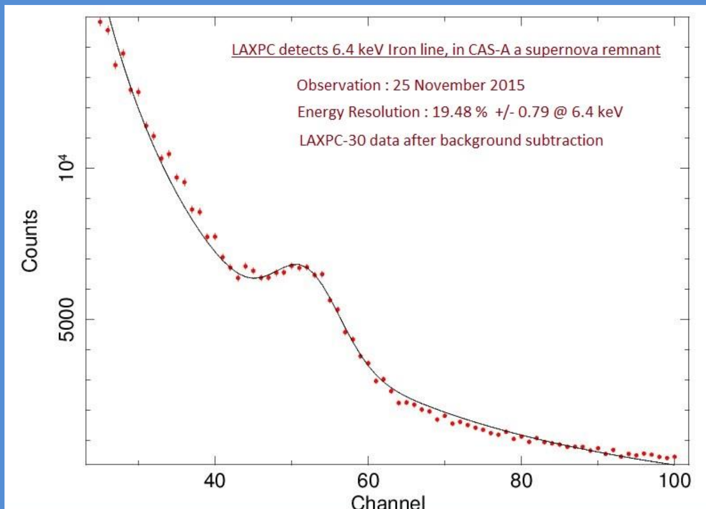
Energy resolution

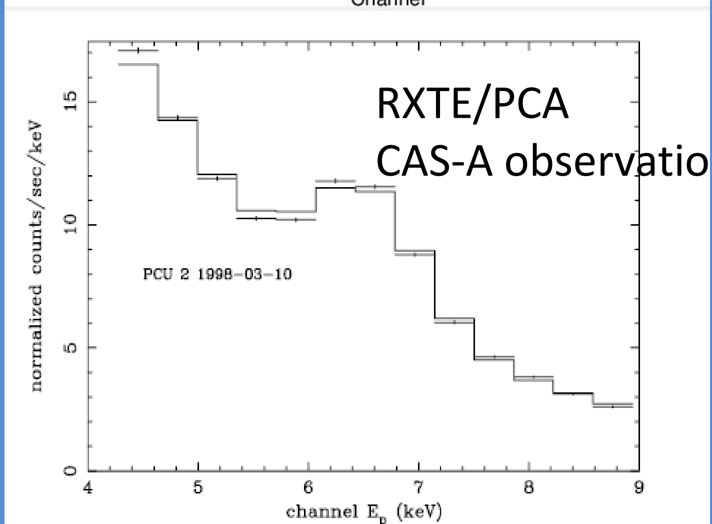
The energy resolution for LAXPC30 is plotted as function of 1/SQRT(E) In the low energy range (4-30 keV). The 30 keV is due to double events Of 60 keV line.



LAXPC energy resolution is similar to CZTI around 40 keV. While Below 40 keV, LAXPC energy resolution is better but worse at higher energies (at 22 keV ~12% For LAXPC and ~31% for CZTI while at 60 keV ~14% for LAXPC and 8% For CZTI.

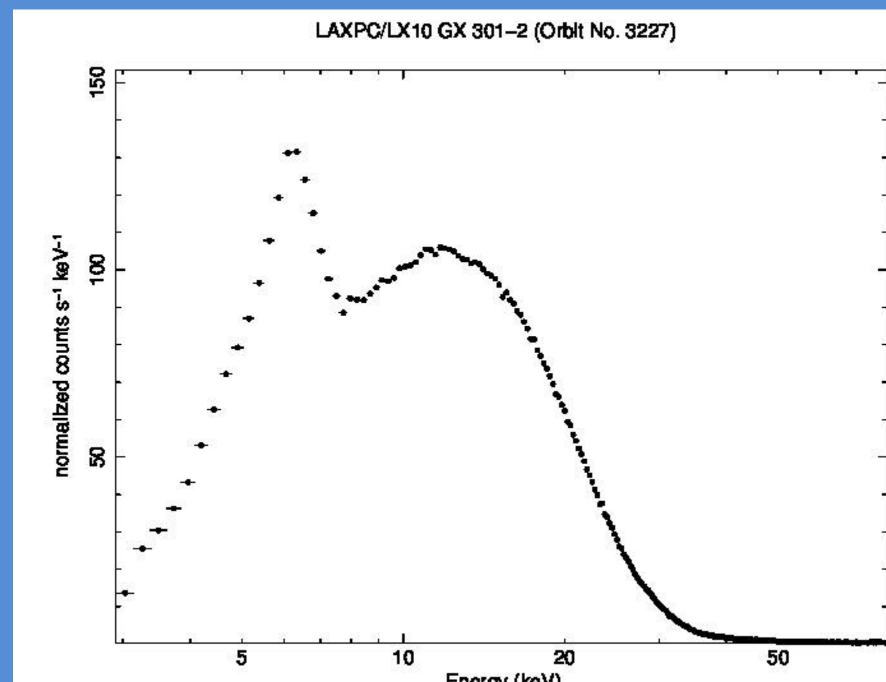
Energy resolution at 6.4 keV in orbit: We achieved around 20% Energy resolution as proposed.



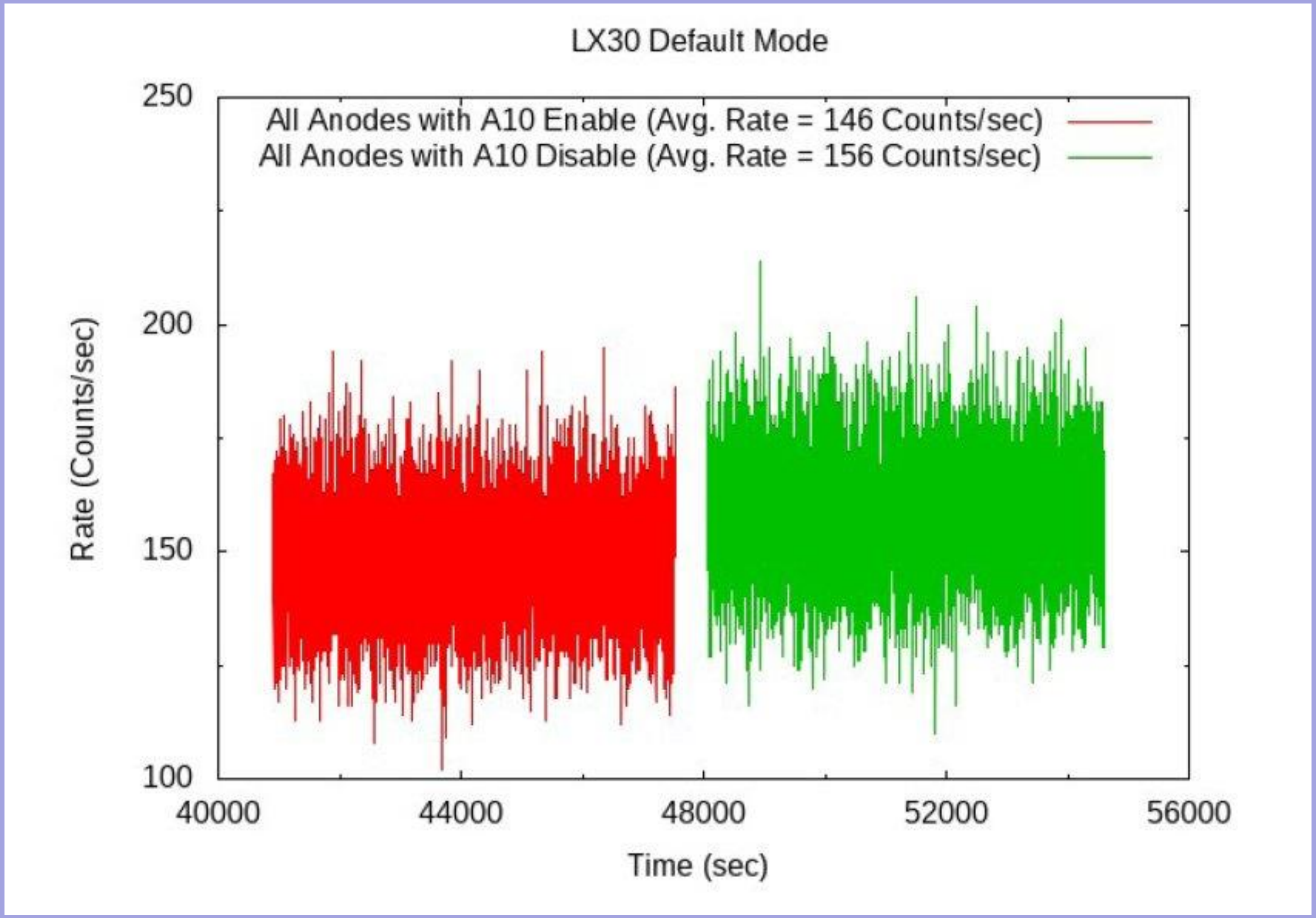


CAS –A (supernova remnant) observation LAXPC30 (left top) and RXTE/PCA (left bottom).

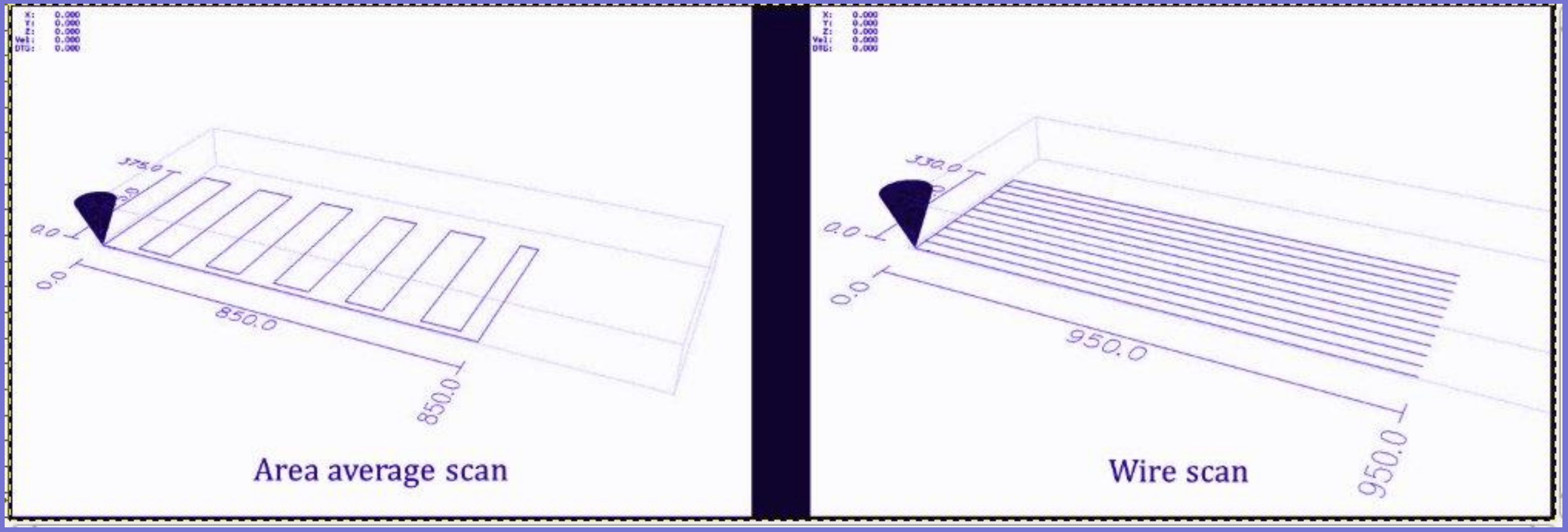
GX 301-2 observation in early May 2016 show similar Resolution (Iron line is clearly visible ar 6.4 keV)



Anti Anode A10 of AS-LX-DT-10 package made in-operational due to HV loading in Anode 10 during Post vibration thermovac.

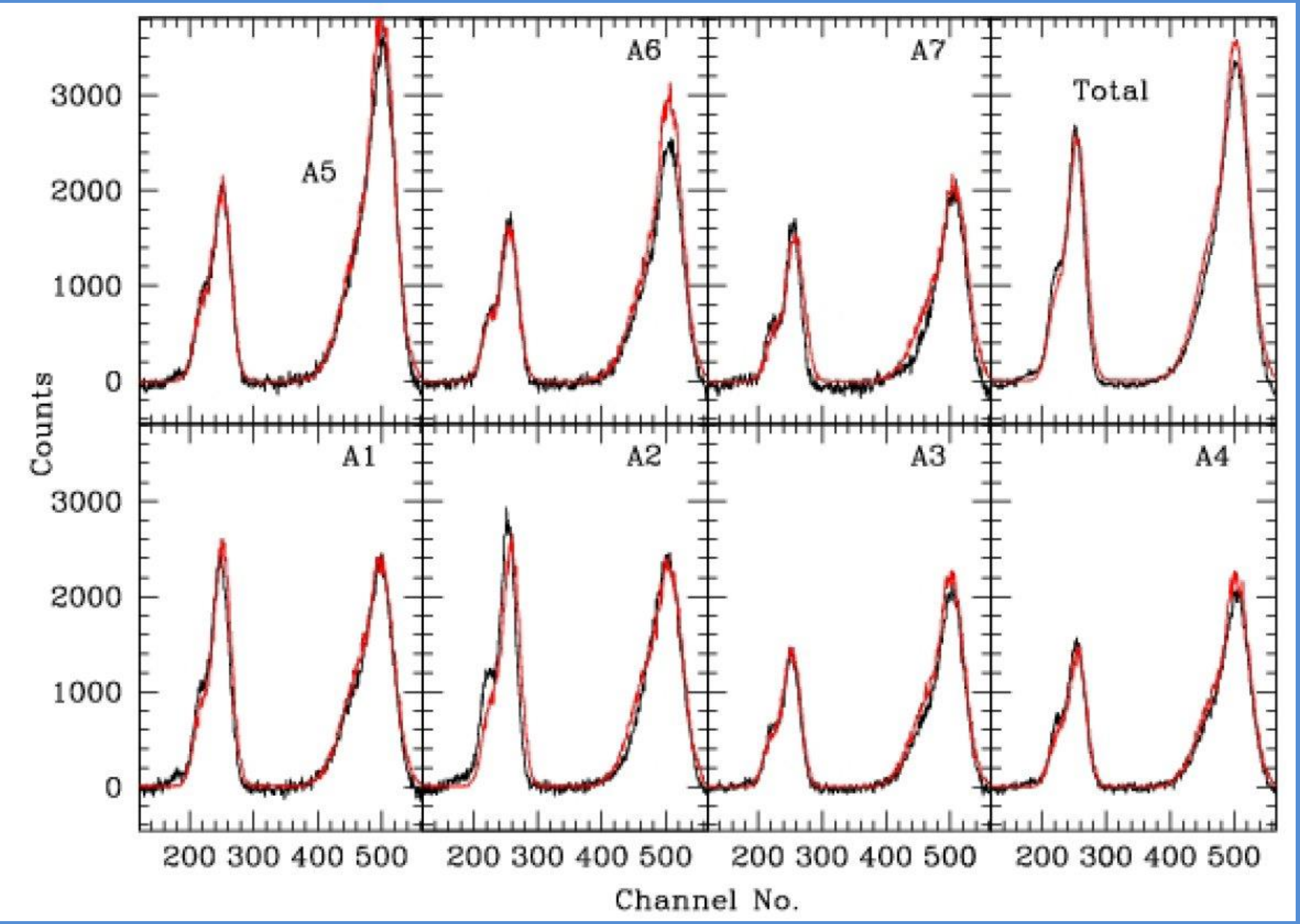


Calibration scan profile



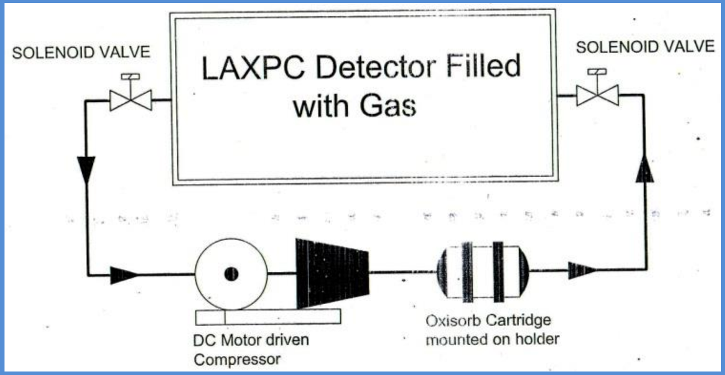
Lab calibration: GEANT4 simulation for LAXPC30 unit & results for Am source (all 5 layers)

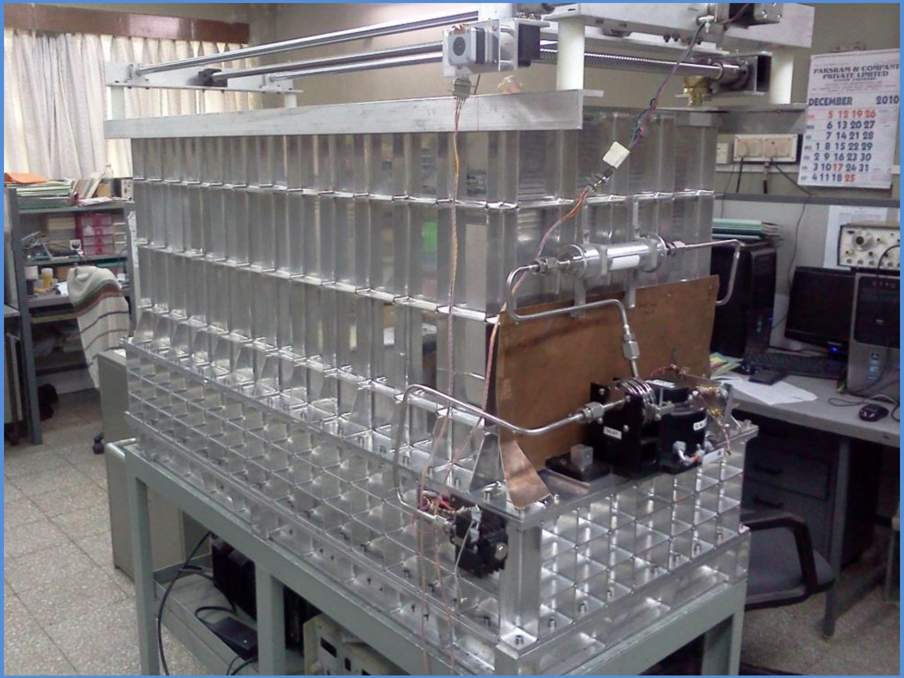
Antia et al. 2017



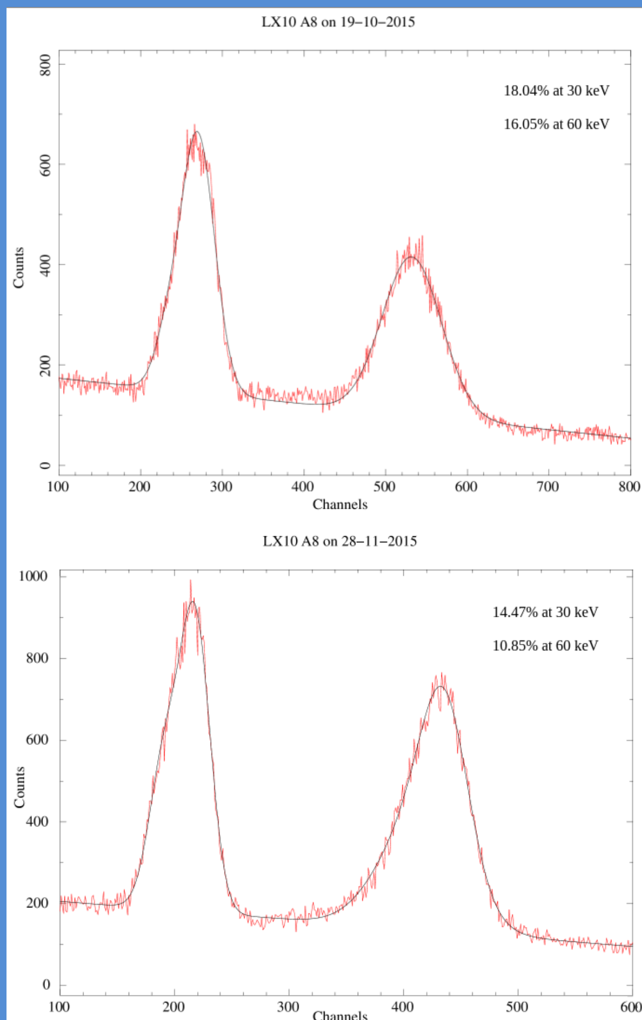
Detector performance:
On-board Purification & Detector energy resolution

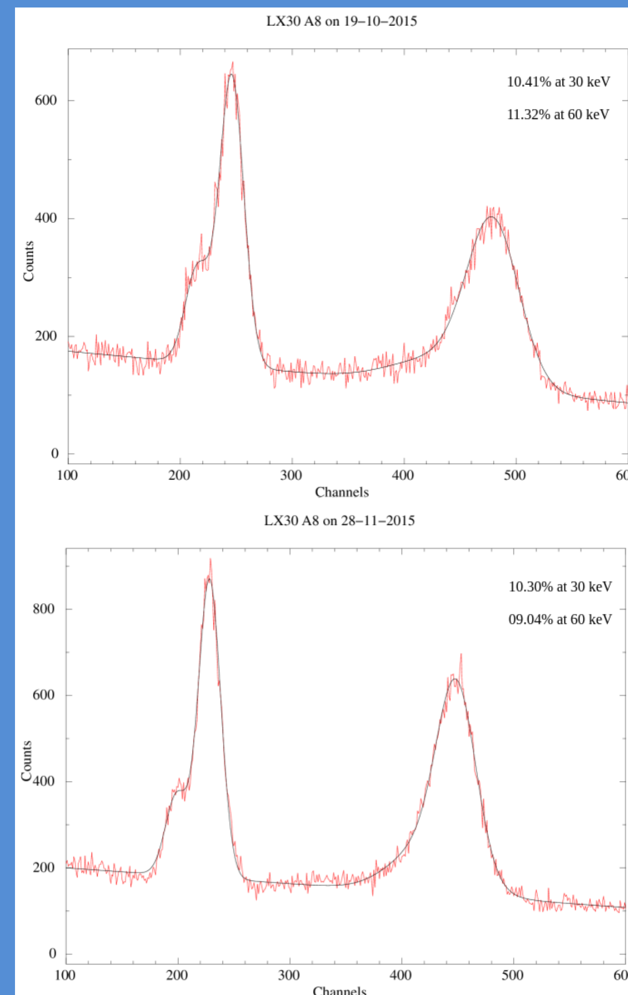
- On-Board Purification for Flight Detectors





Each of the LAXPC detectors has an onboard gas purification system. This system will be operated as and when required to purify the gas filled in the detector by command. It is expected that energy resolution of LAXPC detector will degrade as impurity increases.



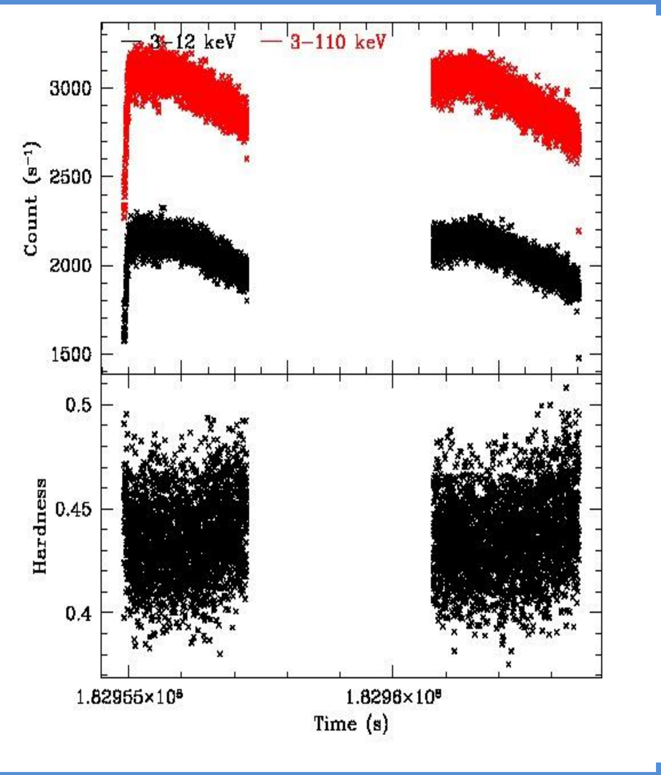


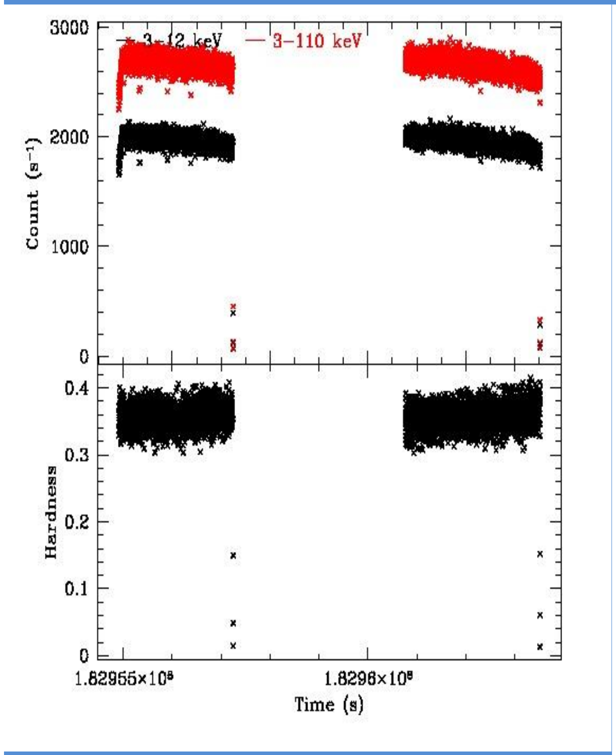
Sorting out purification cartridge issue in LAXPC30 at ISAC on 20th August, 2014

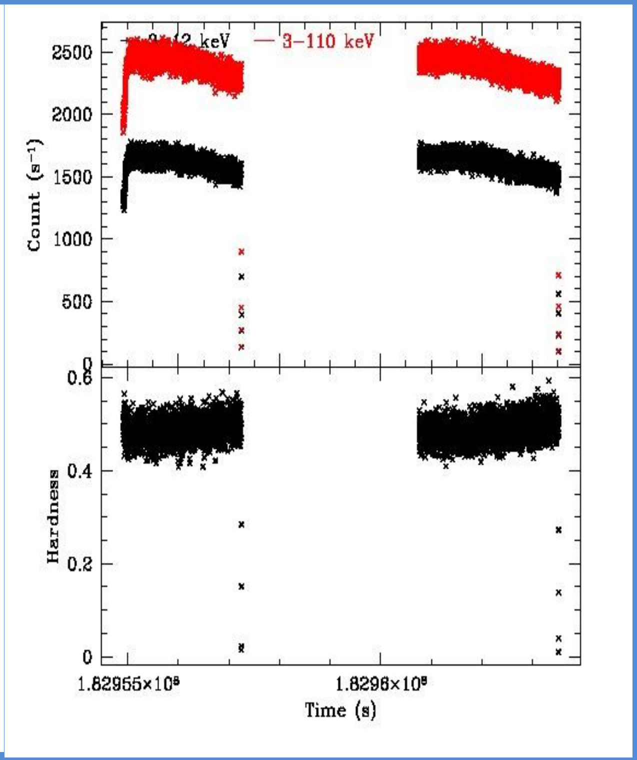
After completing all electronic & detector tests and final calibration, all three flight units of LAXPC instrument were handed over to ISRO for integration with satellite on 20th October, 2014.

Sriharikota 25 August, 2015, last lab tests

LAXPC data quality on 1st day of switching on (on 19th October, 2015 before adjusting detector gains) for all three detectors during Crab observation

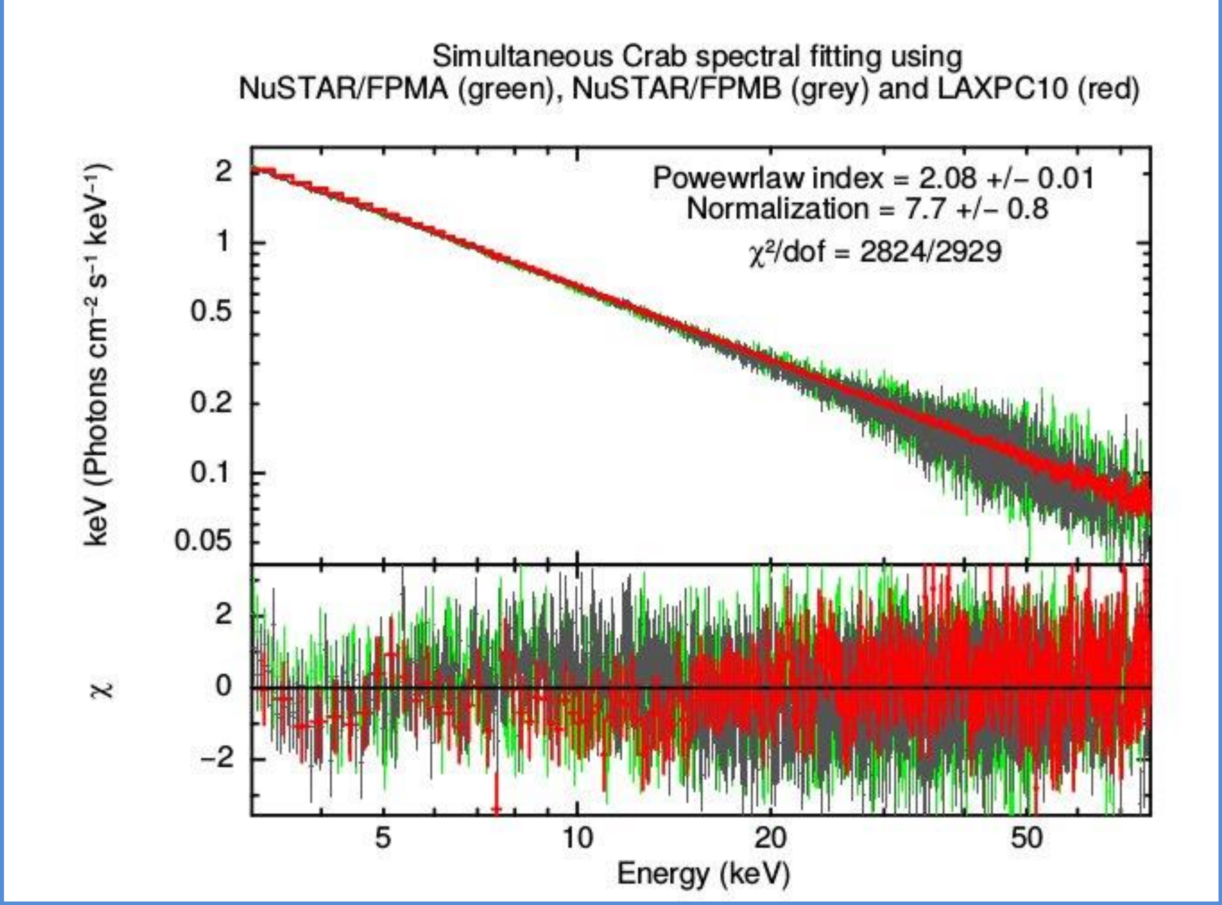






LAXPC instrument capabilities: Crab

At present, NASA,s Nustar and LAXPC instrument are only two X-ray space instruments which cover 3-80 keV energy range. Here we show fit to simultaneous LAXPC and Nustar data of Crab (a X-ray pulsar) taken on 1st April, 2016 . It is a good fit with reduced chi square ~ 1 . Nustar data shows large spread at high energy which suggests that its detection efficiency decreases fast at > 30 keV.



Comparison of LAXPC with RXTE/PCA

The Astrophysical Journal Supplement Series, 231:10 (29pp), 2017 July https://doi.org/10.3847/1538-4365/aa7a0e

Calibration of the Large Area X-Ray Proportional Counter (LAXPC) Instrument on board *AstroSat*

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Abstract

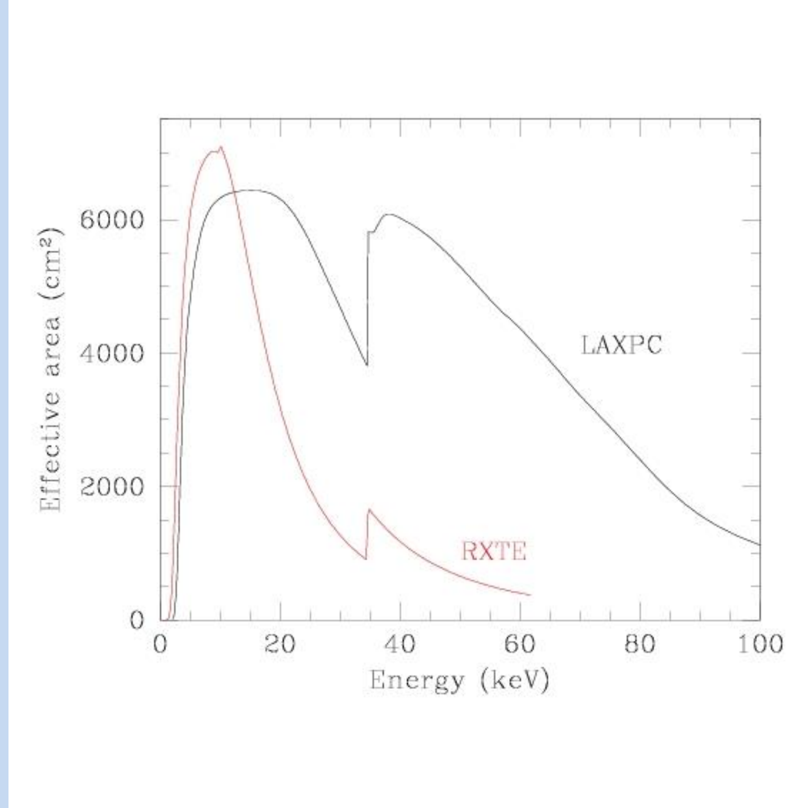
We present the calibration and background model for the Large Area X-ray Proportional Counter (LAXPC) detectors on board *AstroSat*. The LAXPC instrument has three nominally identical detectors to achieve a large collecting area. These detectors are independent of each other, and in the event analysis mode they record the arrival time and energy of each photon that is detected. The detectors have a time resolution of 10 μs and a dead-time of about 42 μs. This makes LAXPC ideal for timing studies. The energy resolution and peak channel-to-energy mapping were obtained from calibration on the ground using radioactive sources coupled with GEANT4 simulations of the detectors. The response matrix was further refined from observations of the Crab after launch. At around 20 keV the energy resolution of the detectors is 10%–15%, while the combined effective area of the three detectors is about 6000 cm^2.

Key words: instrumentation: detectors – space vehicles: instruments

1. Introduction

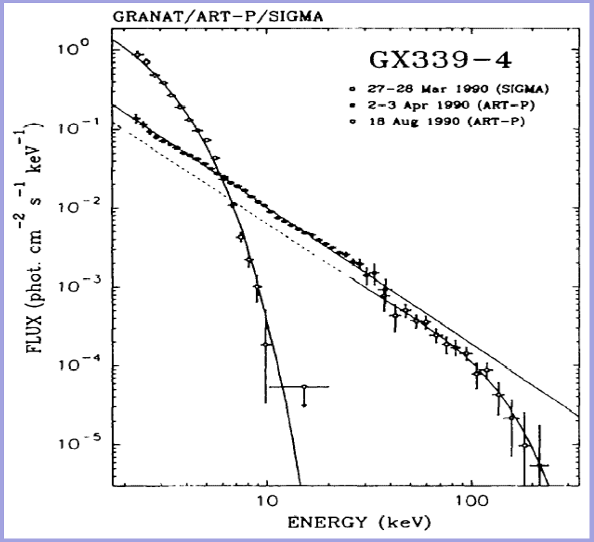
The Large Area X-ray Proportional Counter (LAXPC) instrument on board the Indian Astronomy mission *AstroSat* consists of three co-aligned large-area proportional counter units for X-ray timing and spectral studies over the energy range 3–80 keV (Agrawal 2006; Yadav et al. 2016a). *AstroSat* was launched on 2015 September 28 with five major astronomy payloads (Agrawal 2006; Singh et al. 2014). Apart from LAXPC, these are the Ultra Violet Imaging Telescope, Soft

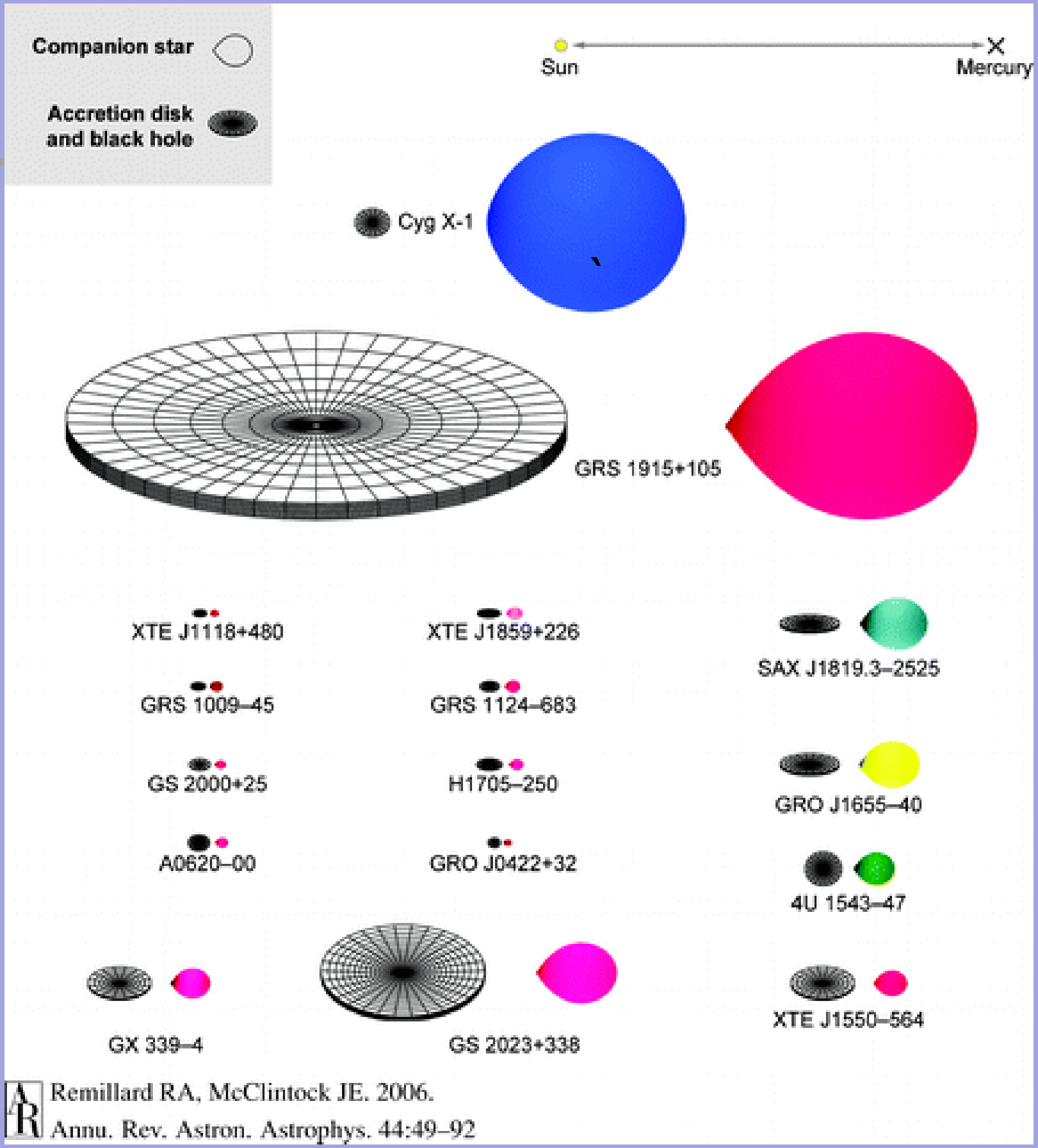
The rest of the paper is organized as follows. Section 2 gives an overview of the instrument. Section 3 describes the ground calibration for energy resolution and energy scale. Section 4 describes the GEANT4 simulations and resulting response matrix. Section 5 describes in-orbit calibration using the Crab and Cas A sources. Section 6 describes attempts to characterize the background. Section 7 describes the long-term performance of the LAXPC detectors in orbit. Section 8 gives a summary of the calibration.



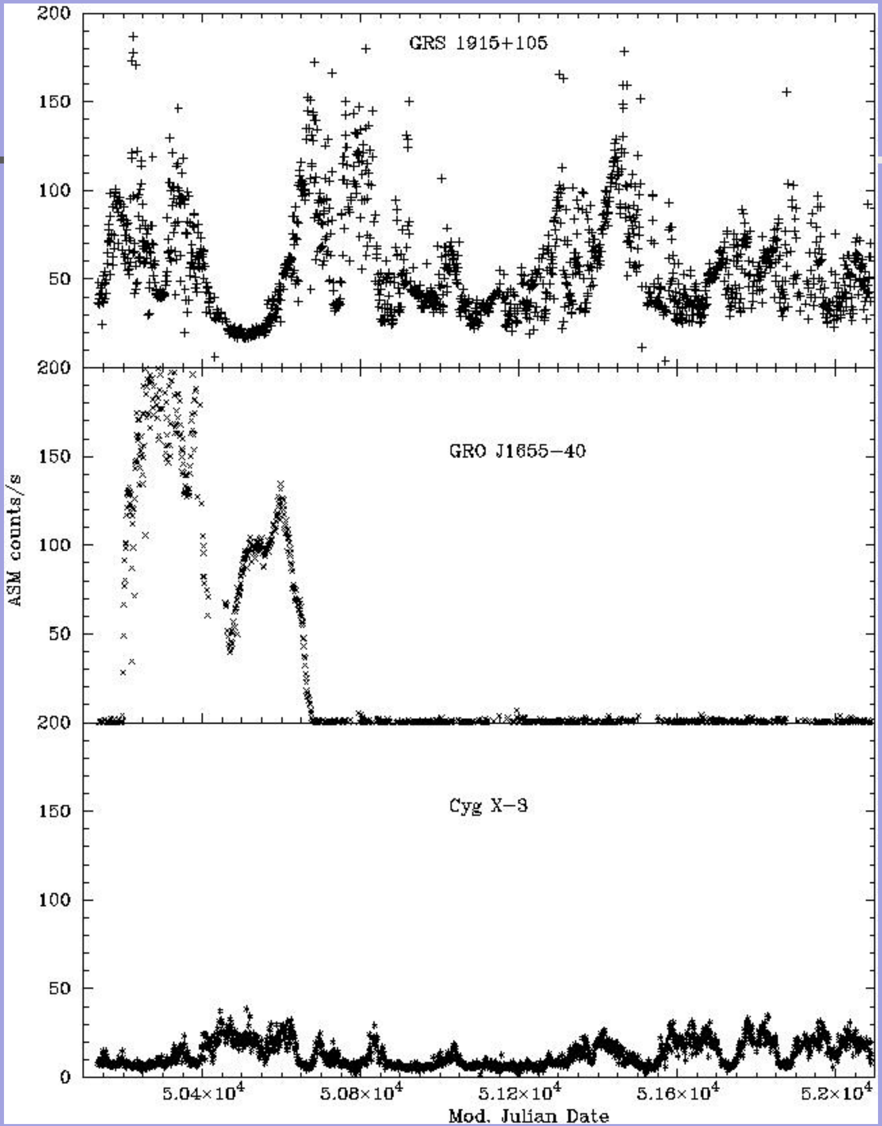
LAXPC instrument will have four times or more effective area above 30 keV as compared to RXTE/PCA. It can detect 0.1 mcrab sources in few thousand second.

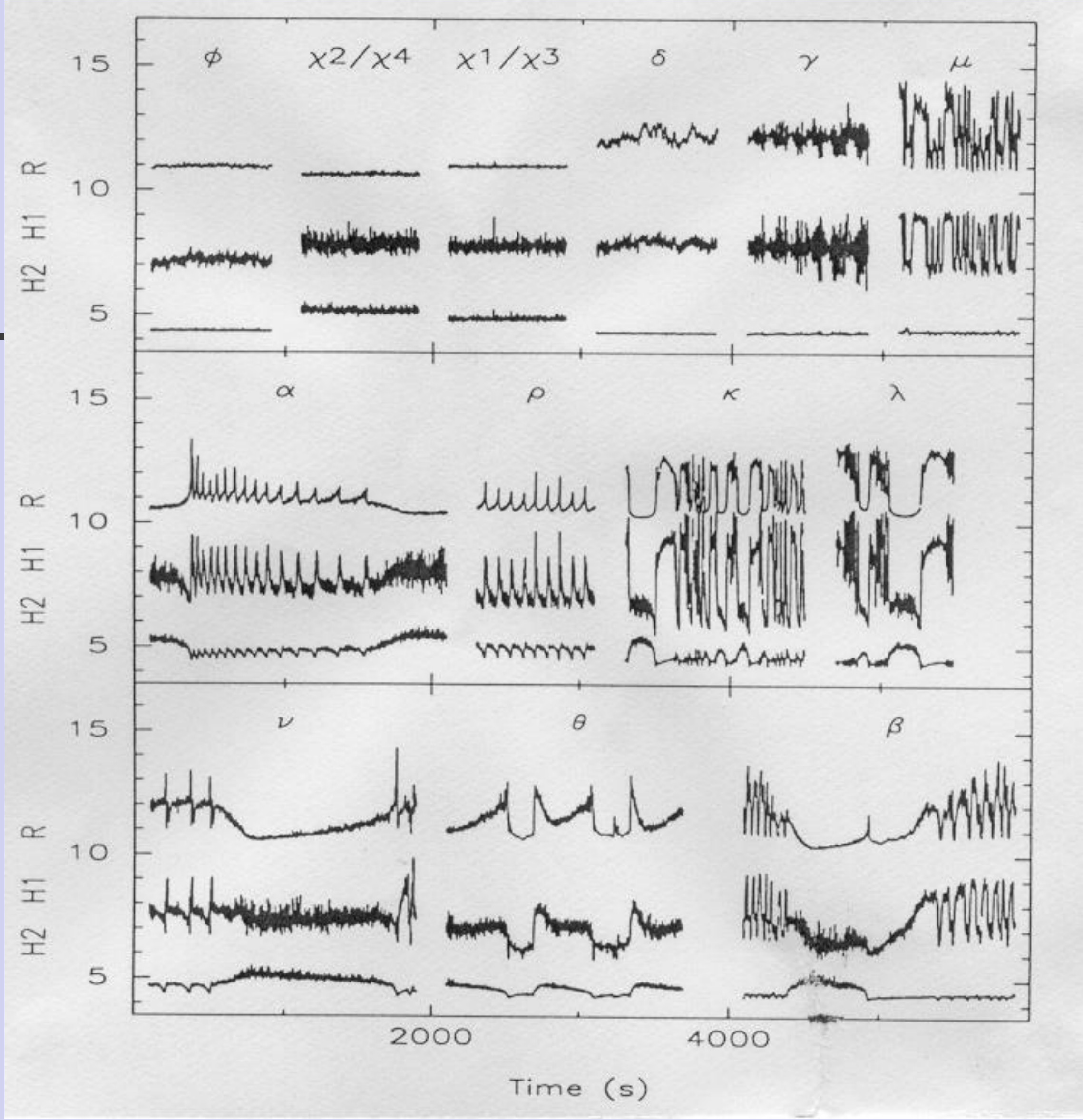
Before RXTE launch in 1995, only low hard state, And High soft states are known.





Frequent outbursts

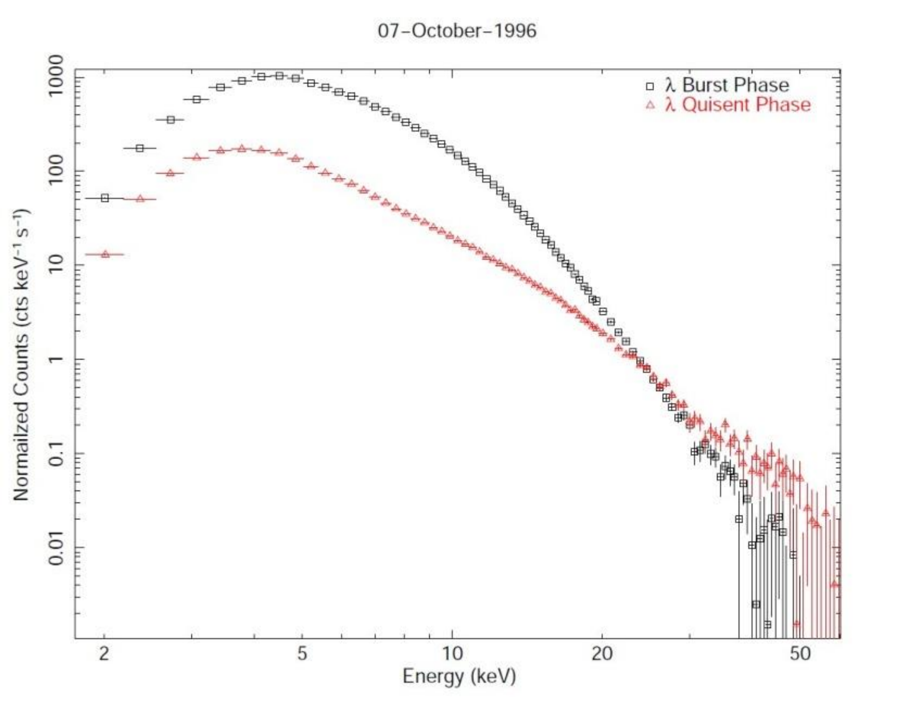




Radio quiet X-ray class: Rho, Kappa, Lambda, Omega

Radio loud X-ray class: Theta, Beta

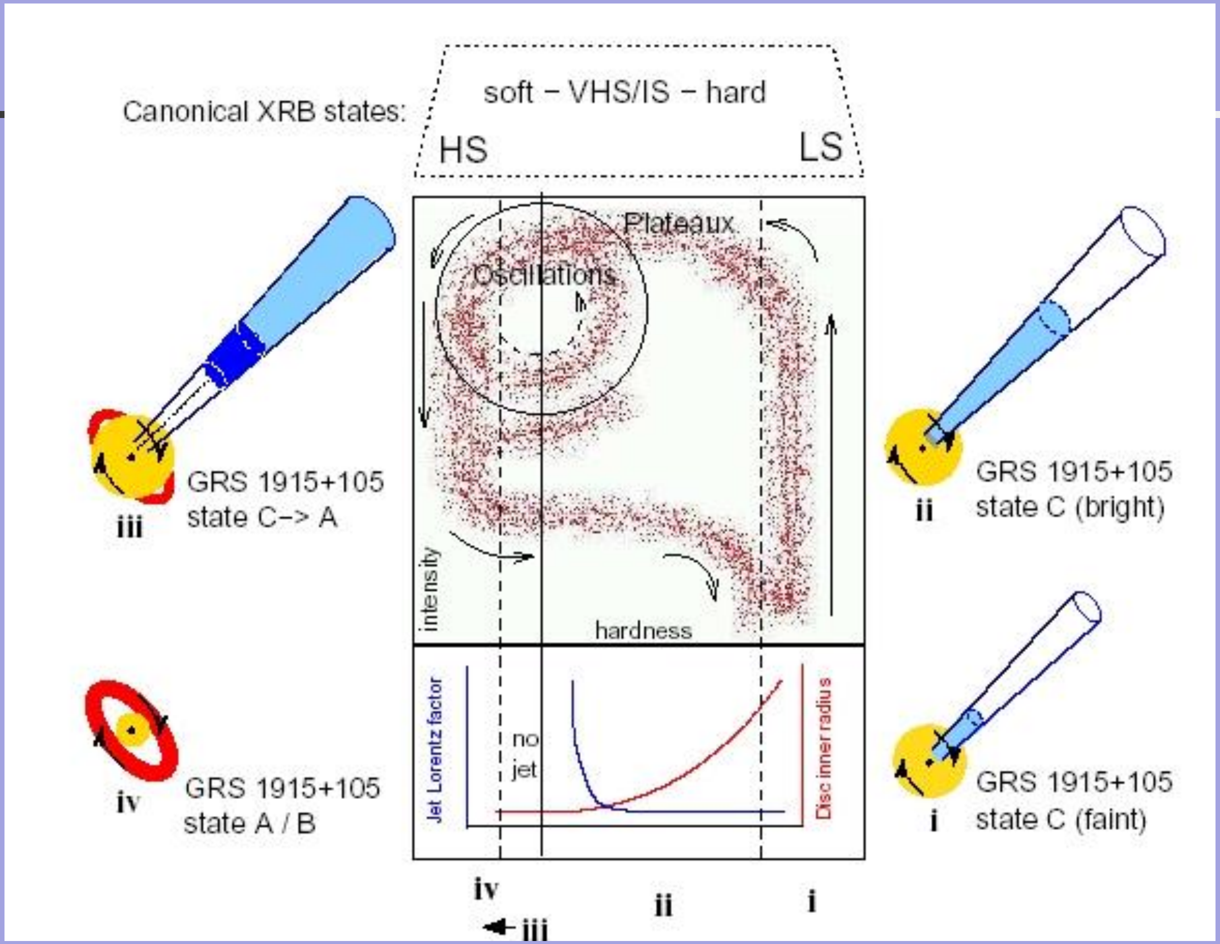
Belloni et. al A&A (2000) 355



Bursts are explained as removal
And replenishment of matter forming
Inner disk due to a thermal-viscous
instability
Belloni et al 1997, Paul et al 1998, Yadav et al 1999

But it does not explain the source of hard
X-rays

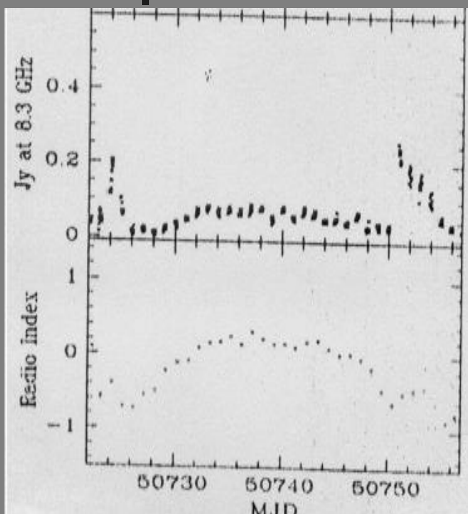
Outburst: X-ray and radio jet connection



Fender and Belloni 2004; jet line , Unified jet model

Radio emission

1. Persistent emission

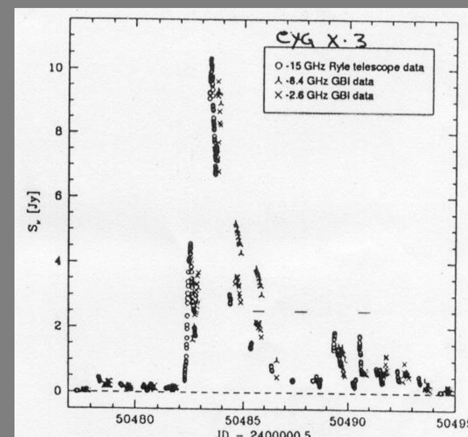


10-100 mJy , Flat radio Emission close to the Compact object (< 50 AU)

GRS1915+105, Cyg-X-1, Cyg X-3, XTE J1118+480 others.

Good correlation between X-ray and radio

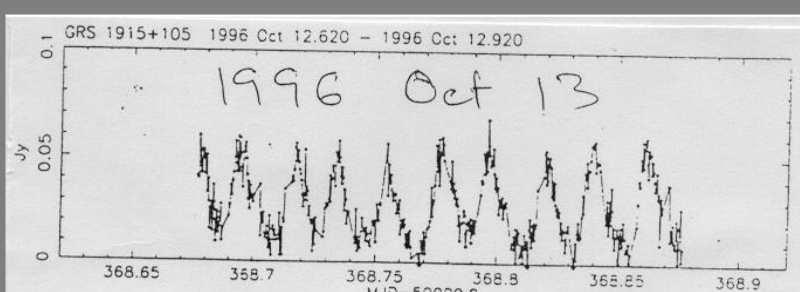
2. Superluminal radio jets



~1Jy steep radio emission, 400-5000AU from the Compact object, decay Time few days.

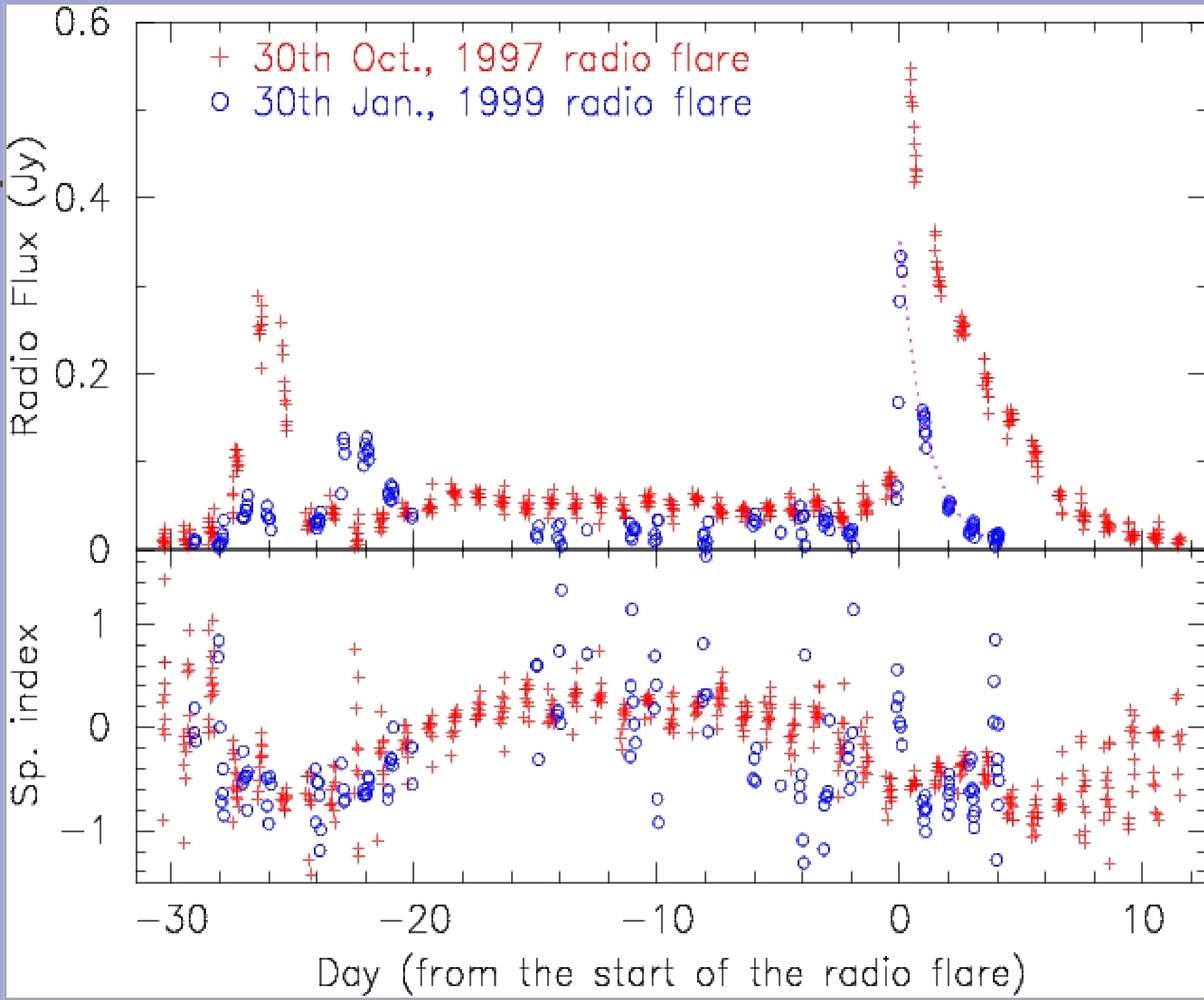
GRS 1915+105, Cyg X-3, GRO J1655-40

3. Transient IR and radio jets (baby jets)



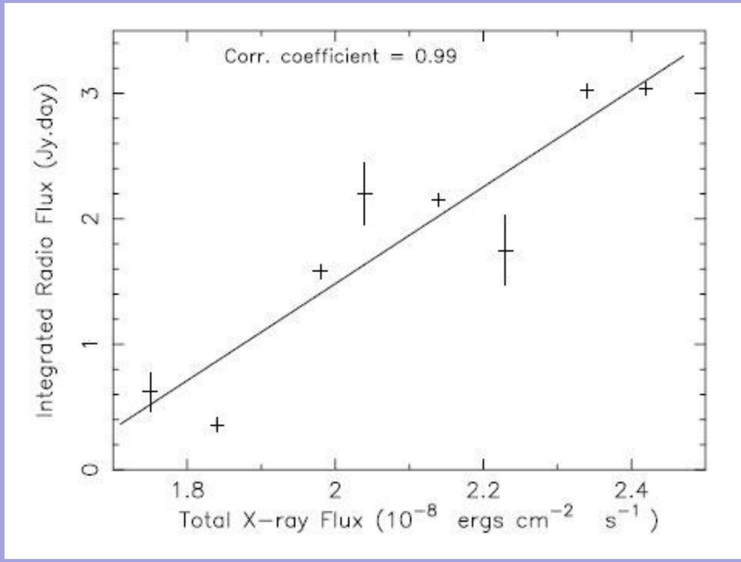
20-200 mJy flat radio spectrum close to the Compact object (<300 AU), decay time in hours.

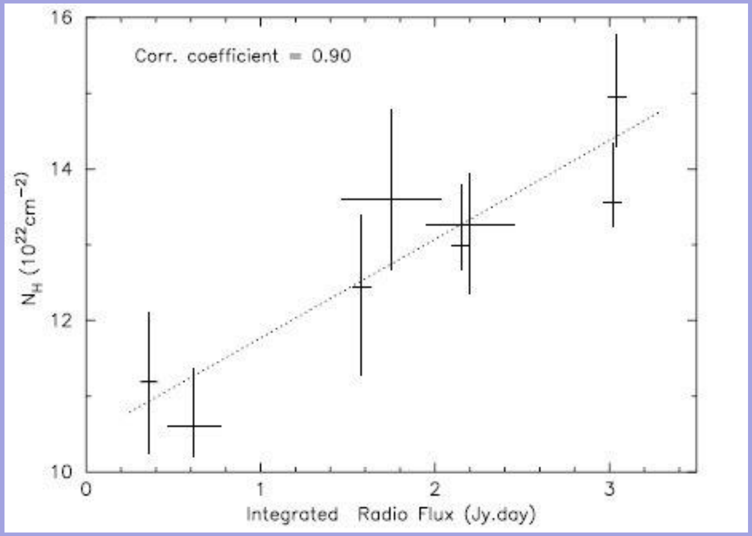
GRS 1915+105



0.6
0.4
0.2
0
Radio Flux (Jy)
+ 30th Oct., 1997 radio flare
o 30th Jan., 1999 radio flare
1
0
−1
Sp. index
−30
−20
−10
0
10
Day (from the start of the radio flare)

Connection between accretion disk and large superluminal radio jets



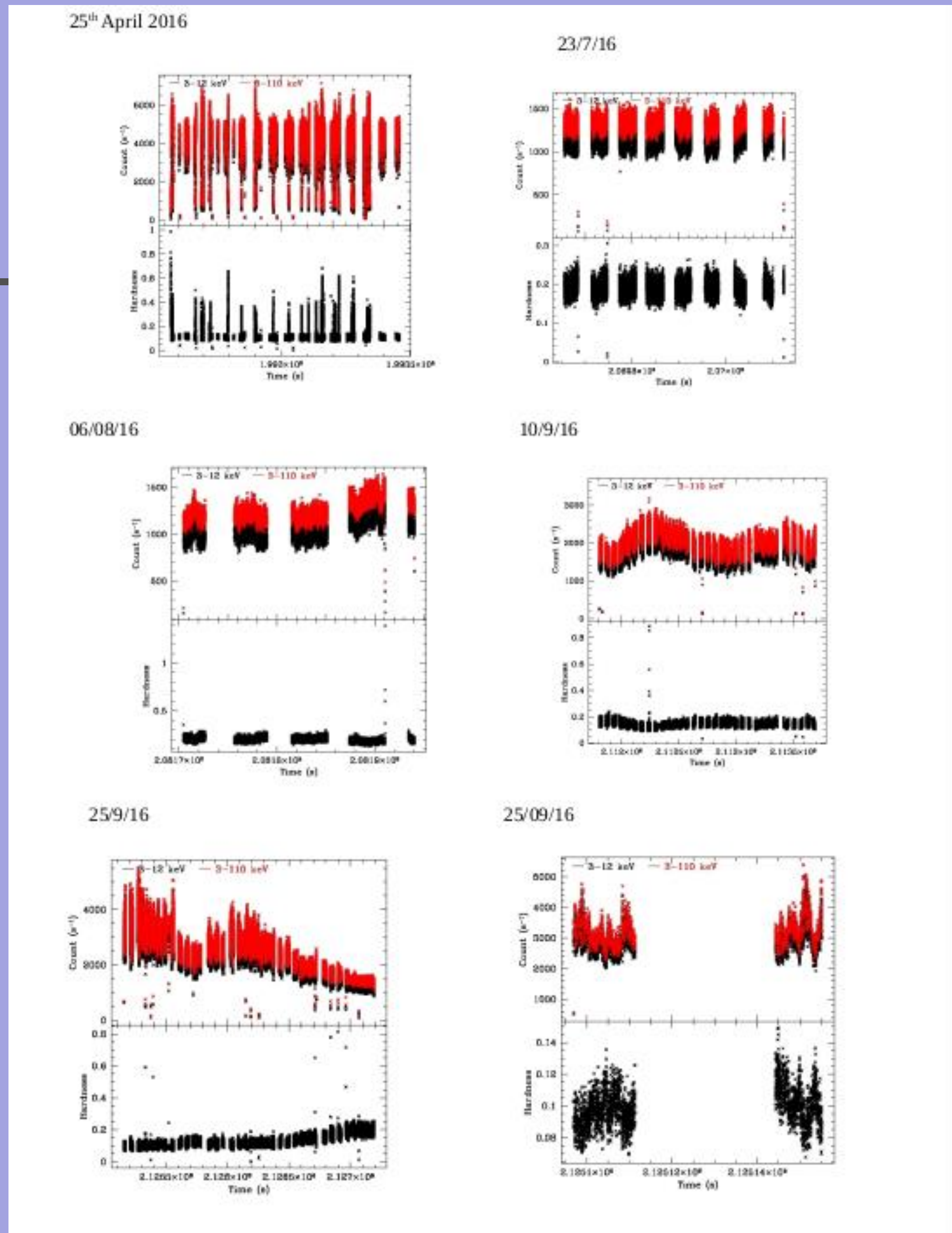


Yadav J S ApJ (2006) 646, p385

LAXPC
Observation log of Cyg X-3

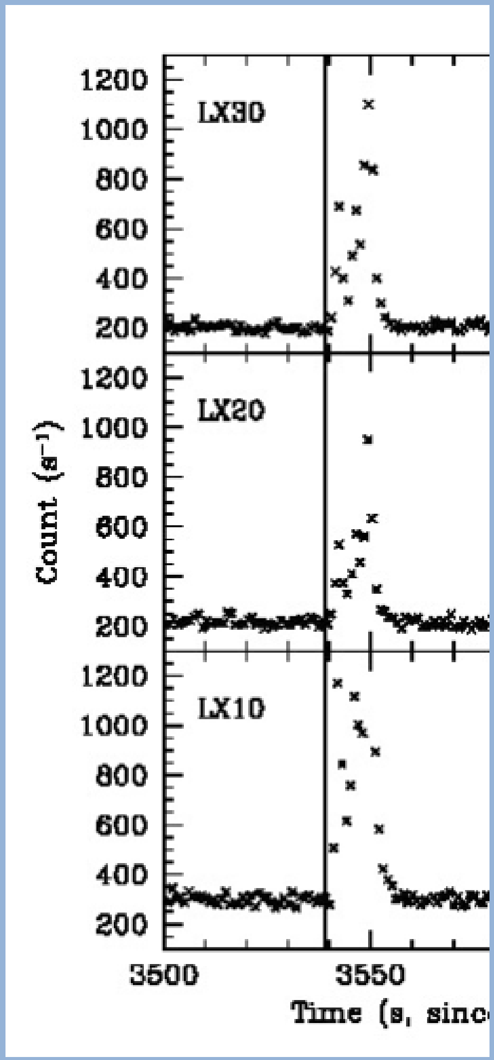
20160812_G05_192T01_9000000594	Cyg X-3	dedhia	lxp1	45.5	0.000	27200
20160812_G05_192T01_9000000594	Cyg X-3	dedhia	lxp2	45.5	0.000	27200
20160812_G05_192T01_9000000594	Cyg X-3	dedhia	lxp3	45.5	0.010	27200
20161120_G06_103T01_9000000812	Cyg X-3	jsyadav	lxp1	42.7	7.520	42200
20161120_G06_103T01_9000000812	Cyg X-3	jsyadav	lxp2	42.7	7.590	42100
20161120_G06_103T01_9000000812	Cyg X-3	jsyadav	lxp3	43.0	6.650	42400
20170401_G07_043T01_9000001126	Cyg X-3	jsyadav	lxp1	43.7	0.690	40800
20170401_G07_043T01_9000001126	Cyg X-3	jsyadav	lxp2	43.8	0.530	40900
20170401_G07_043T01_9000001126	Cyg X-3	jsyadav	lxp3	43.8	0.660	40900
20170827_G07_048T01_9000001494	Cyg X-3	jsyadav	lxp1	42.8	4.350	32800
20170827_G07_048T01_9000001494	Cyg X-3	jsyadav	lxp2	43.2	4.500	33100
20170827_G07_048T01_9000001494	Cyg X-3	jsyadav	lxp3	42.6	5.300	32600
20171110_G08_032T01_9000001680	Cyg X-3	jsyadav	lxp1	34.0	0.000	14900
20171110_G08_032T01_9000001680	Cyg X-3	jsyadav	lxp2	33.9	0.000	14900
20171110_G08_032T01_9000001680	Cyg X-3	jsyadav	lxp3	33.9	0.010	14900
20180331_G08_032T01_9000001998	Cyg X-3	jsyadav	lxp1	48.8	1.950	12756
20180331_G08_032T01_9000001998	Cyg X-3	jsyadav	lxp2	57.8	1.860	15126
20180331_G08_032T01_9000001998	Cyg X-3	jsyadav	lxp3	0.0	0.000	0

Some observation og GRS 1915+105



LAXPC observed GRB in April, 2016: light curves and energy spectrum: This was not in LAXPC objectives, but we can study them. It will need some efforts to modify detector response.

GRB 160422A



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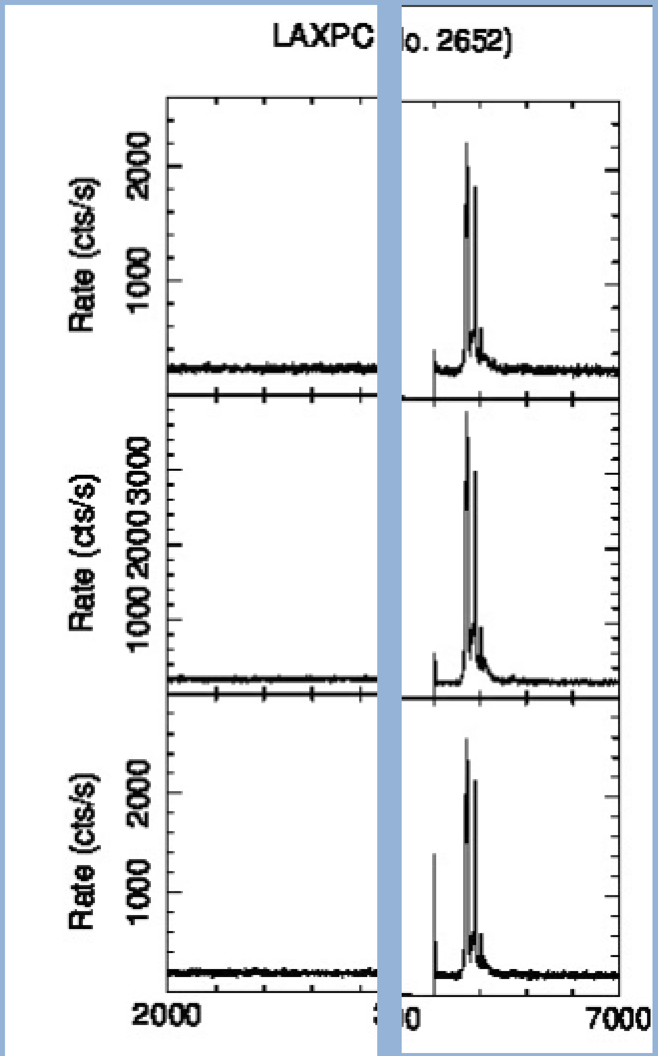
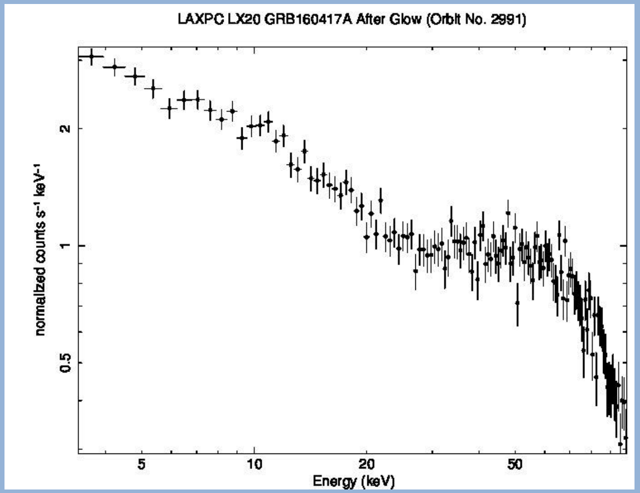
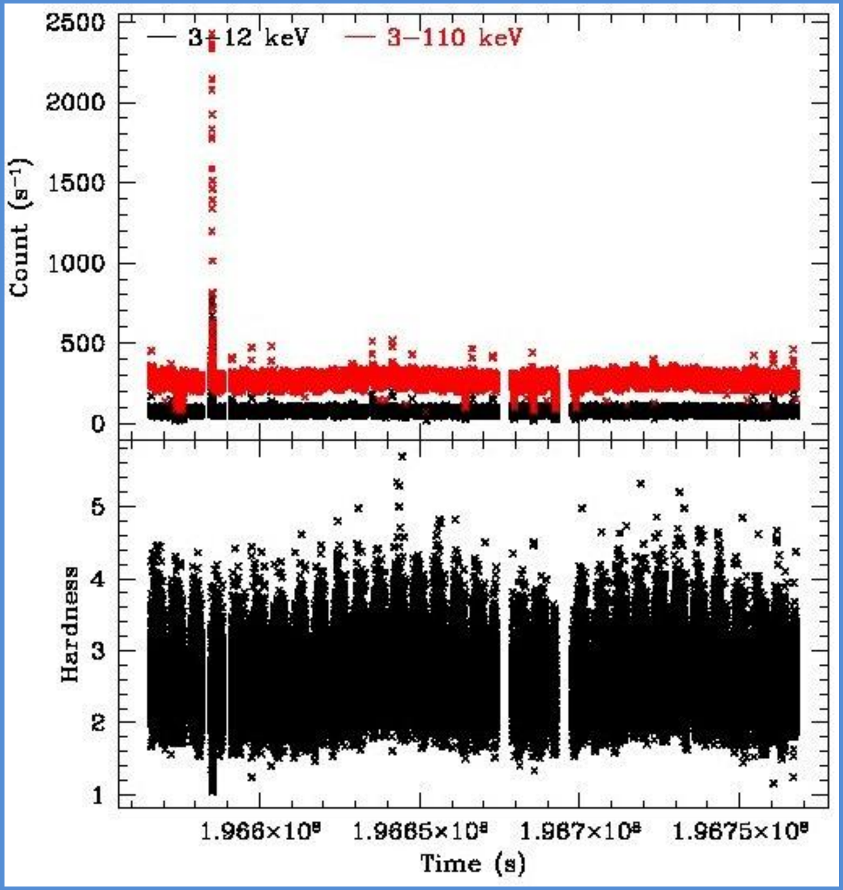
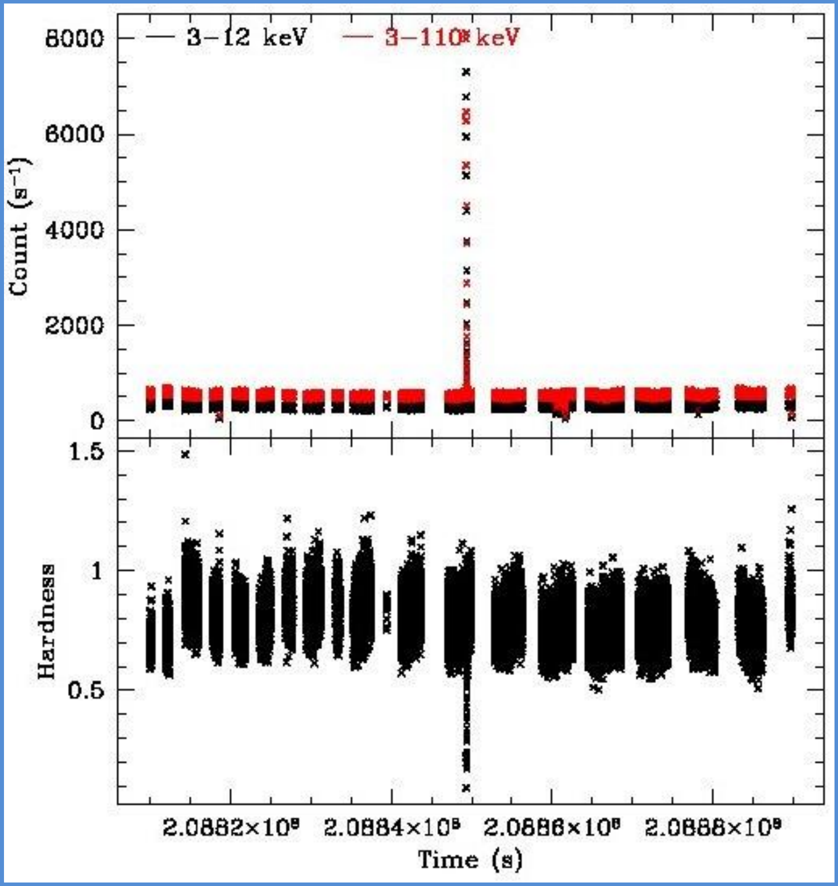




Quick look results: light curve and hardness ratio:

Observation of GRBs and X-ray thermonuclear burst/ flares

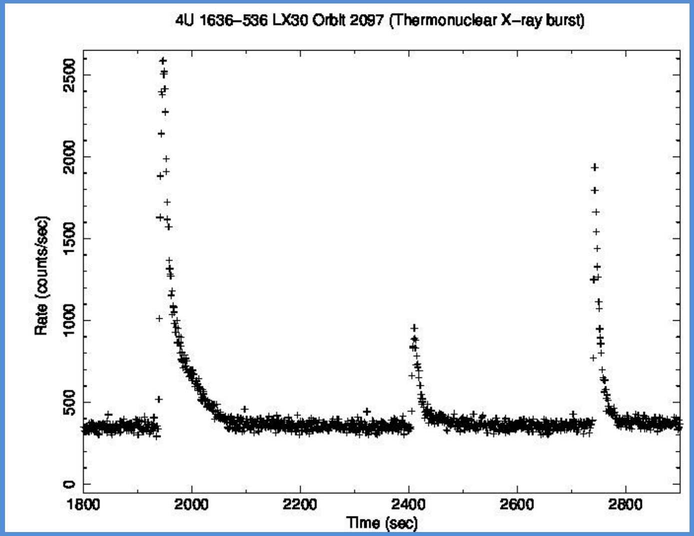


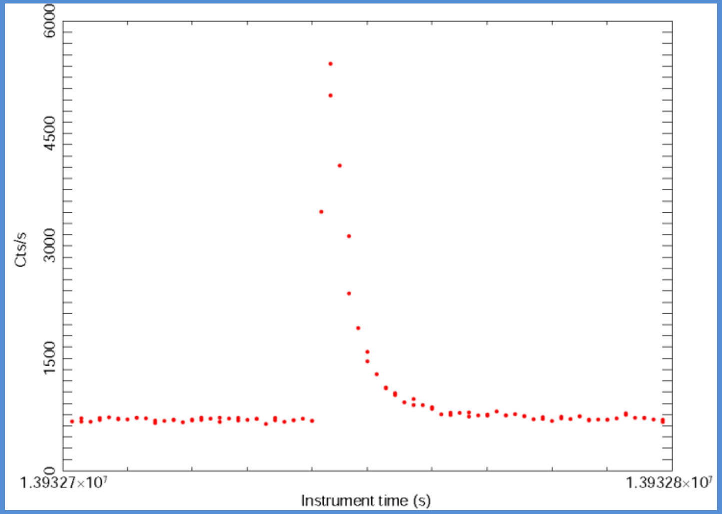


LAXPC observation of Thermonuclear bursts and high frequency Quasi Periodic Oscillation (HF QPOs):

LAXPC observed thermonuclear bursts in two neutron star X-ray binaries; 4U 1636-536 and 4U 1728-34 during instrument verification phase. These are thermonuclear (atom bomb) explosions on accreting neutron star. Rise time is ~ 1 sec (X-ray flux rises by a factor of ~10) and decay time 10-100 sec.

4U 1728-34



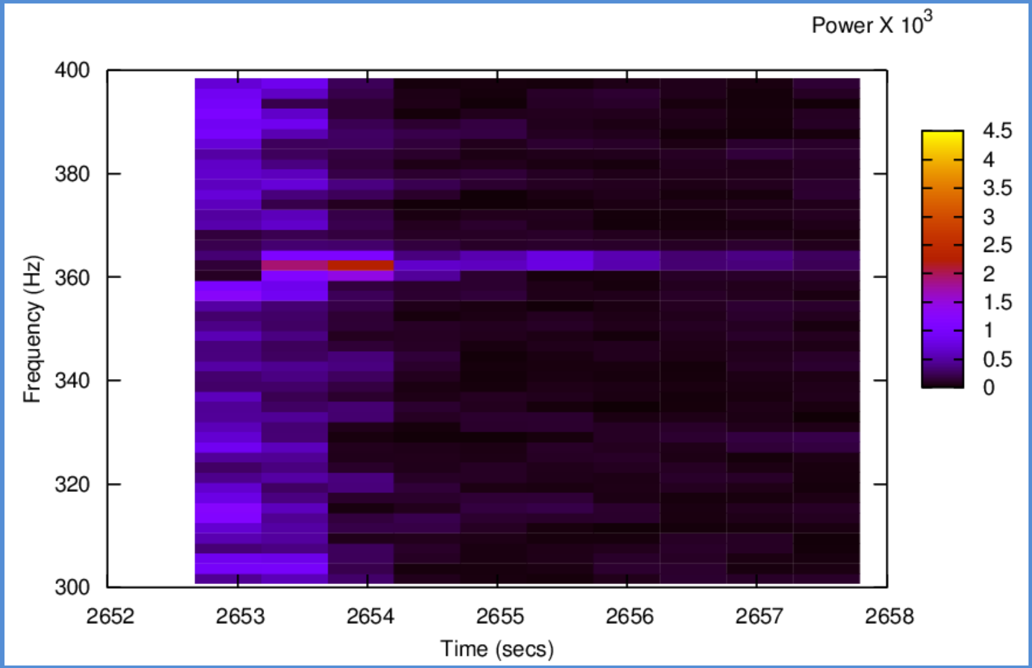


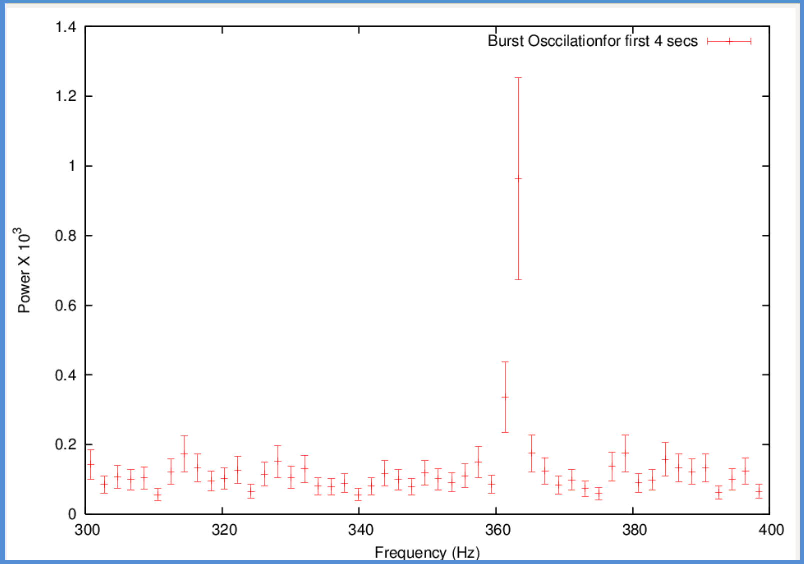
Beri Aru et al, 2019

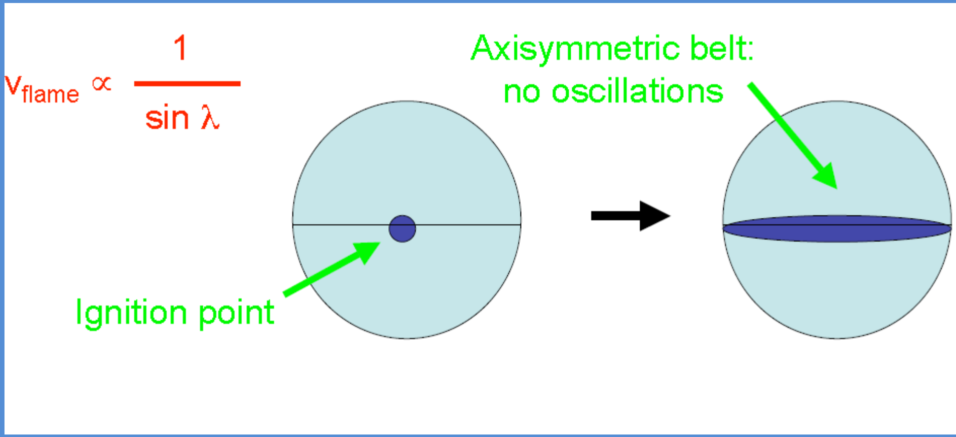
Sudip et al 2018

Top panel shows dynamic power density Spectrum from LAXPC observation of 4U 1728-34.

We observed burst oscillation for first Four sec at 362.7 Hz (top panel). It suggests that this thermonuclear bursts happens at Equator and spreads in four sec and Become axisymmetric belt and QPO Disappears (bottom panel)







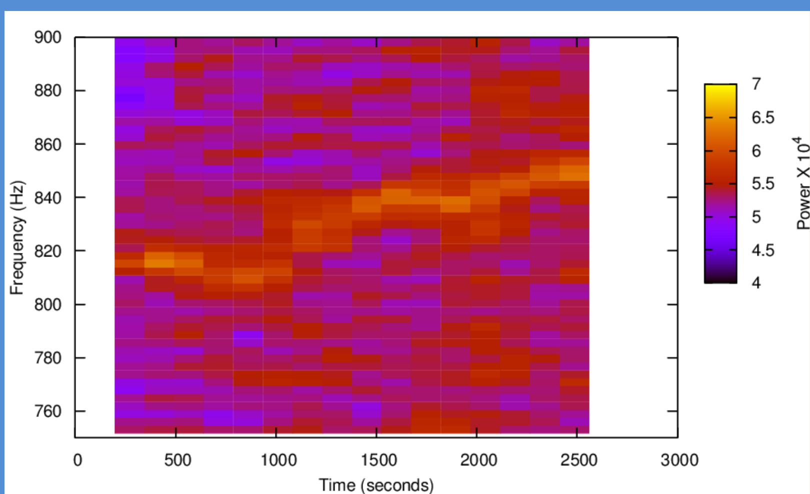
High Frequency Quasi-periodic Oscillations (HF QPOs) :

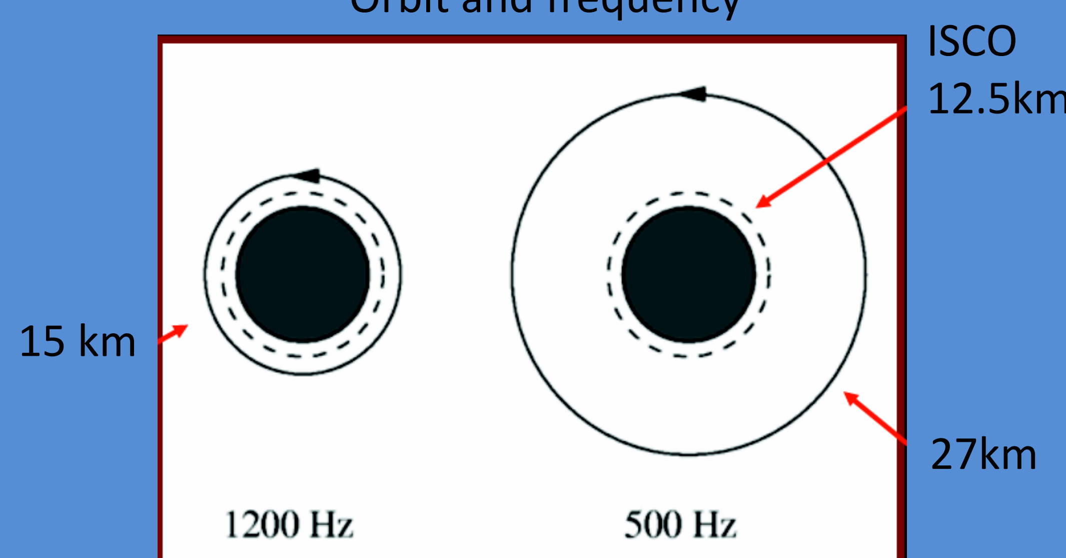
HF QPOs probe regions close to the compact objects (Neutron star and black hole Systems) which are characterized by very high gravity and magnetic field.

Observed frequency is always < 1.2 KHz (for ~2 M_{sun}). The innermost stable circular orbit (ISCO) Is around 12. 5 km which corresponds to 1.2 KHz (right panel). Left panel shows dynamic Power density spectrum from LAXPC observations. As mass falls, qpo evolves (rises) and explores extreme conditions near neutron star. QPO frequency evolves from ~820 Hz to 850 Hz

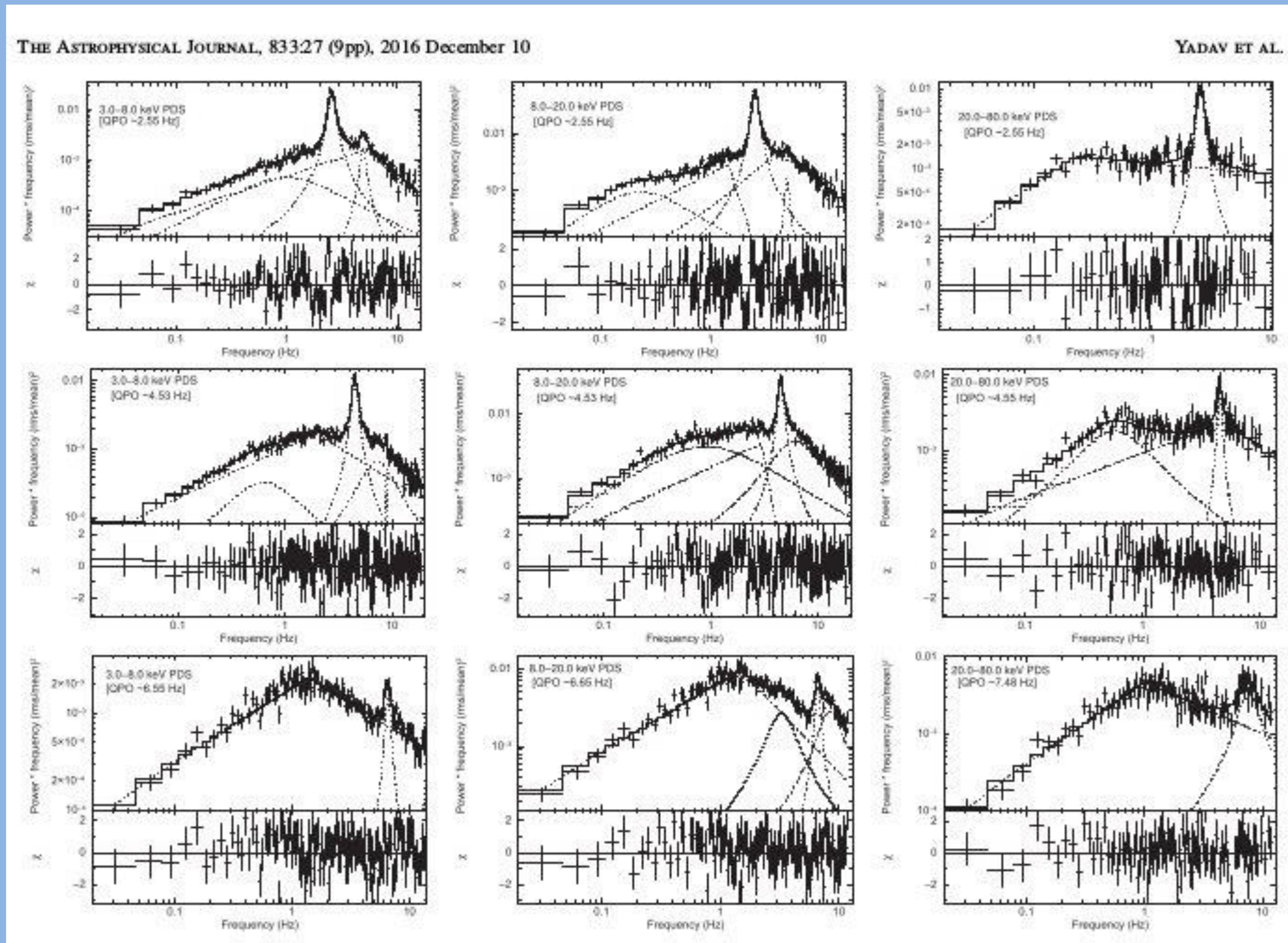
Left panel shows dynamic power density Spectrum from LAXPC observation of 4U 1728-34. We observed 820 Hz HF QPOs showing drift to higher frequency.

Orbit and frequency



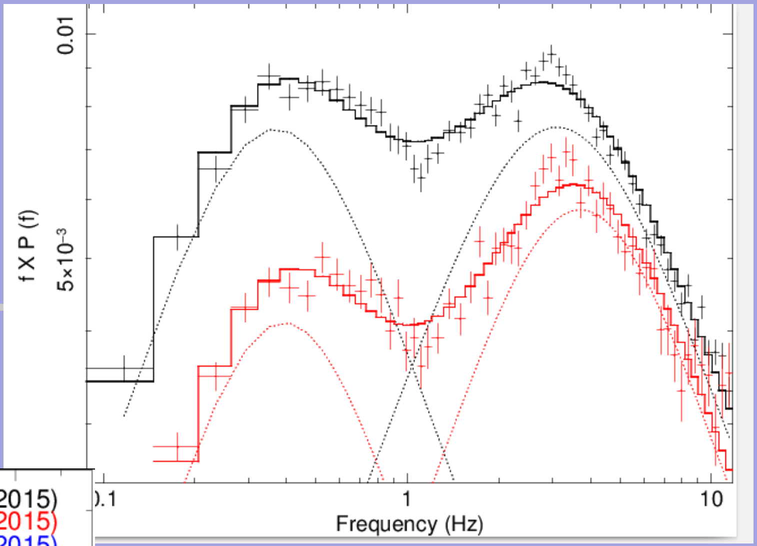


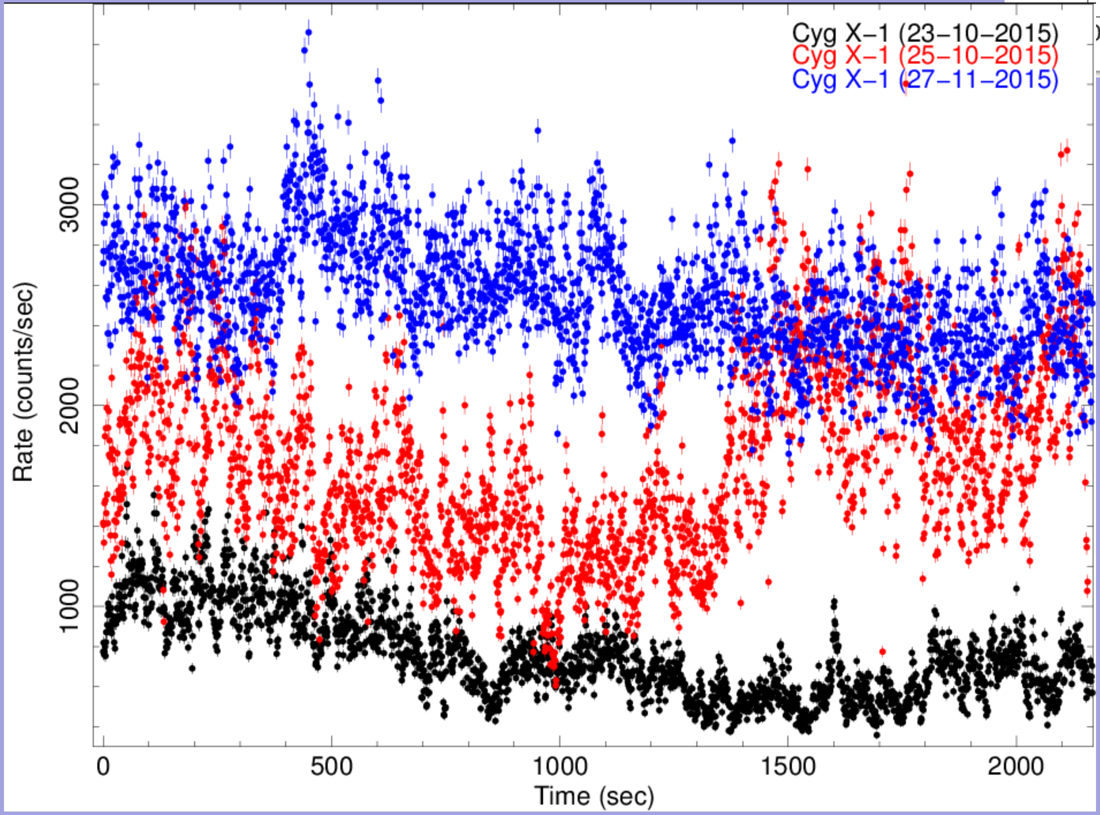
Jai Verdhan et al 2017



Yadav et al. ApJ 2016

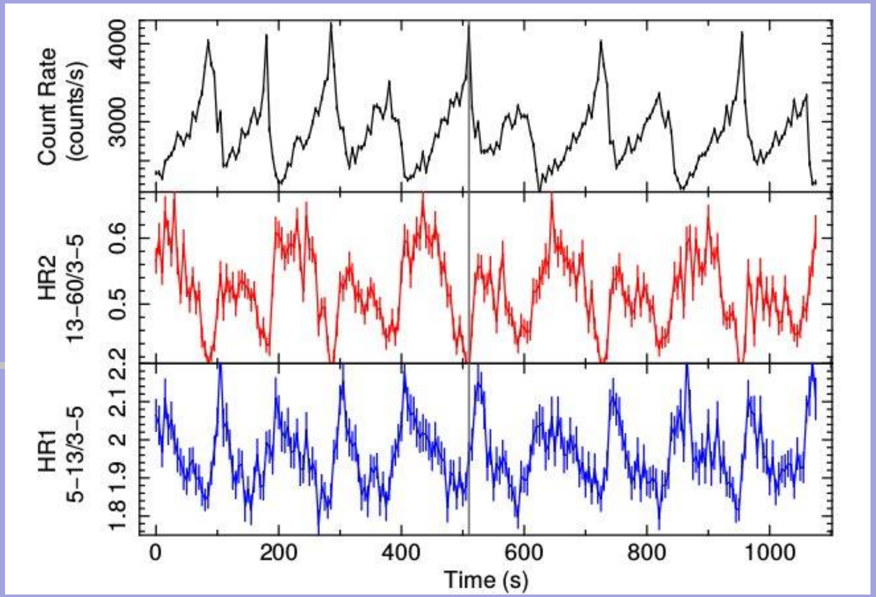
Ranjeev Misra et al 2017 ApJ

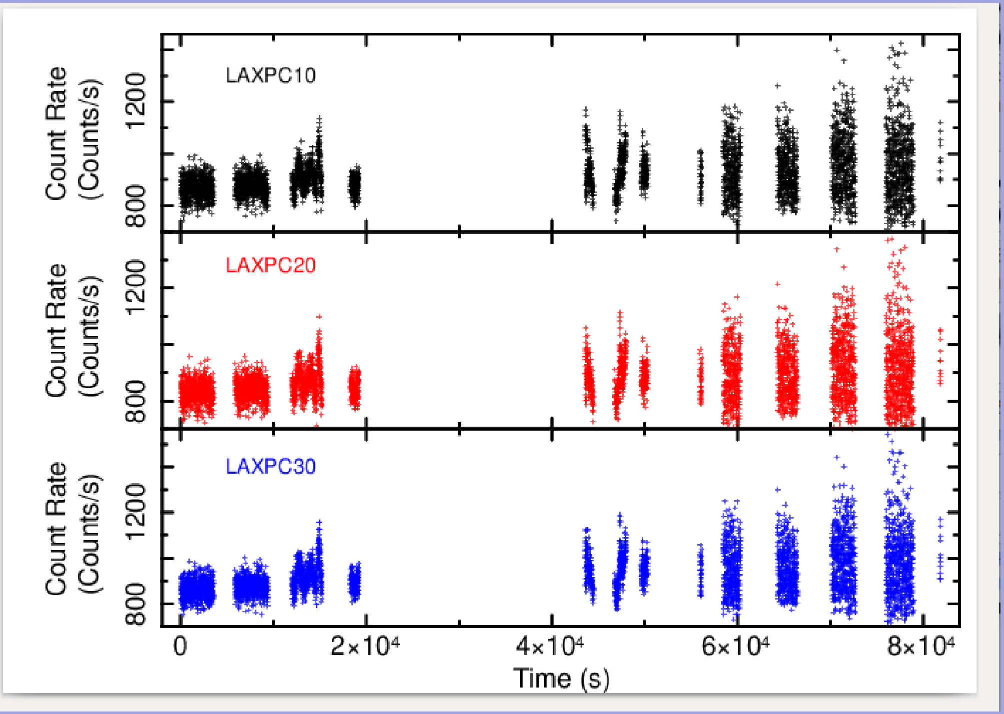


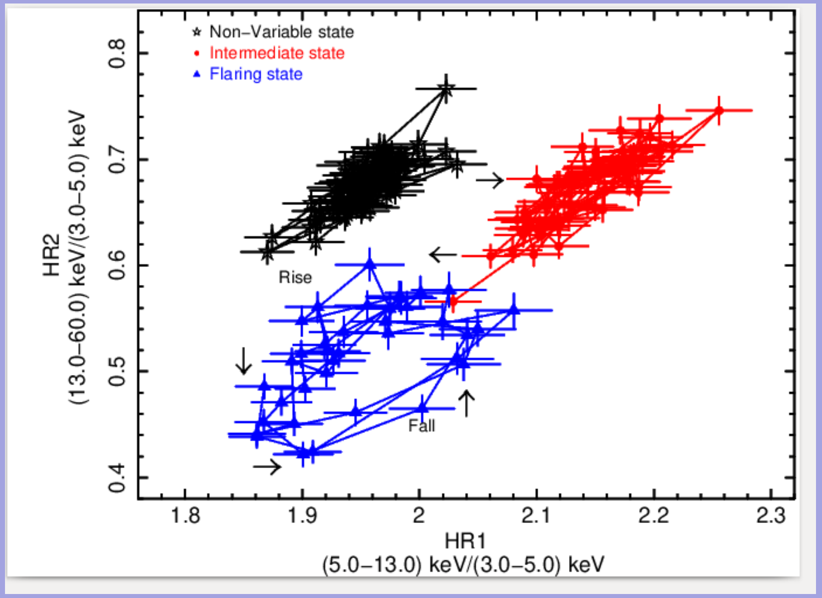


LAXPC/AstroSat; new type of X-rays flares in GRS 1915

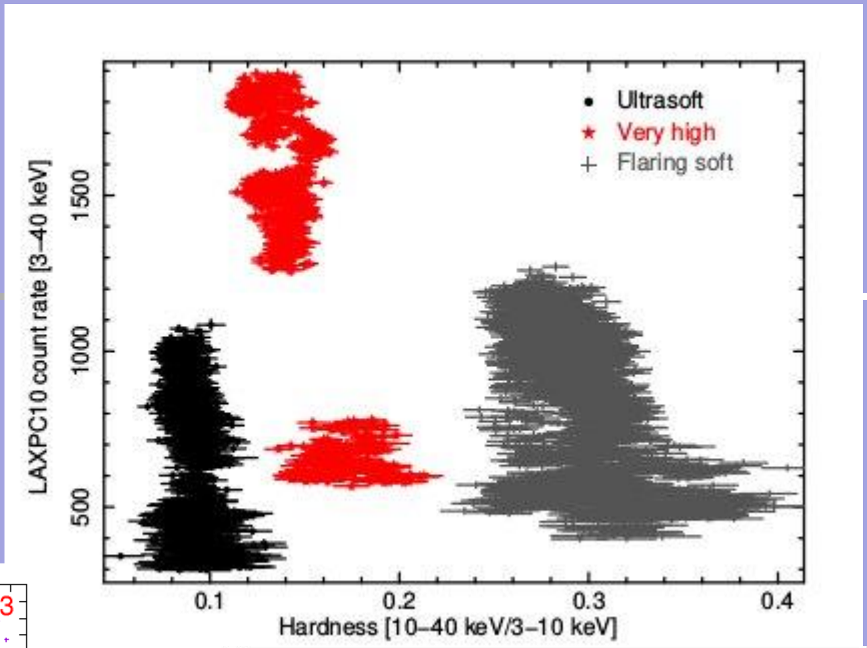
X ray flares during hard Intermediate state (hard state), Divya Rawat et al ApJ, 2018

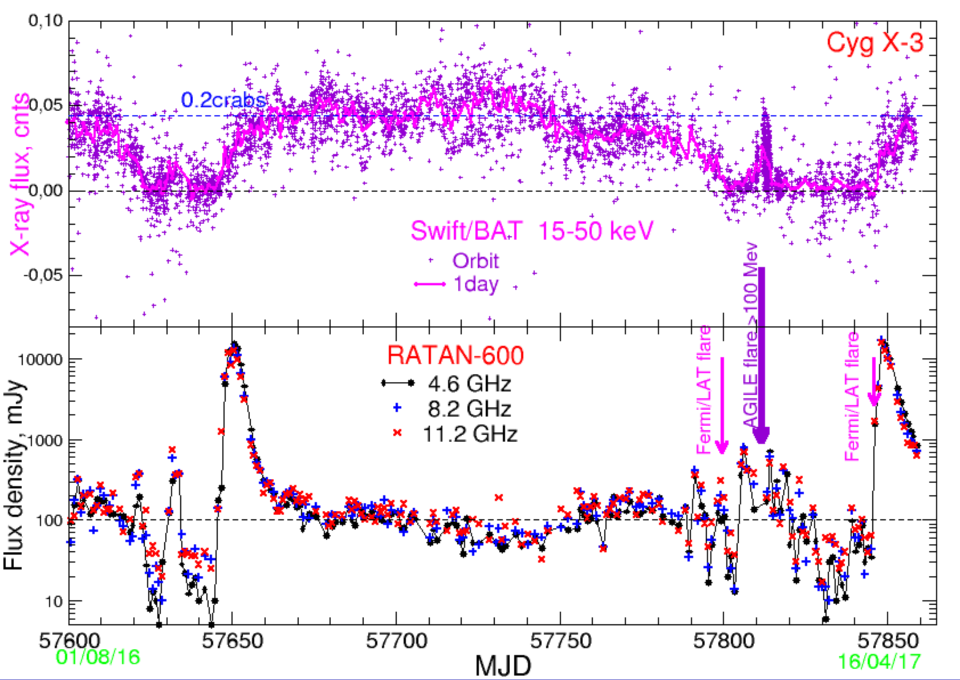


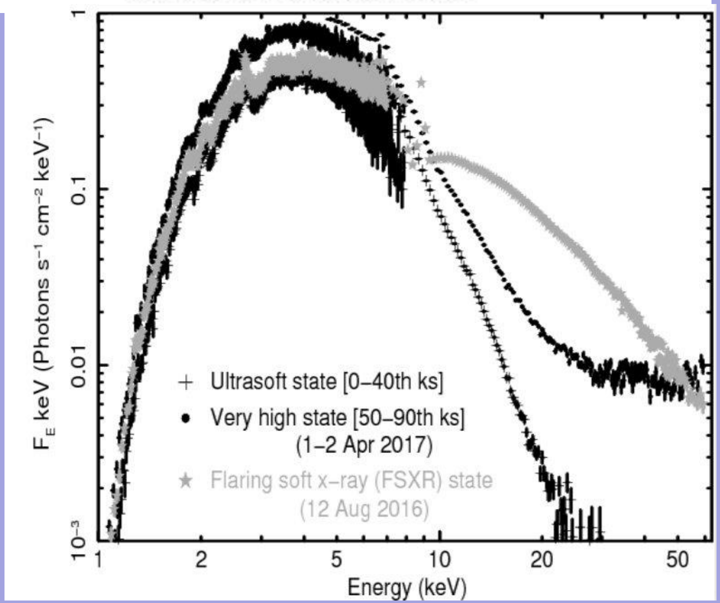




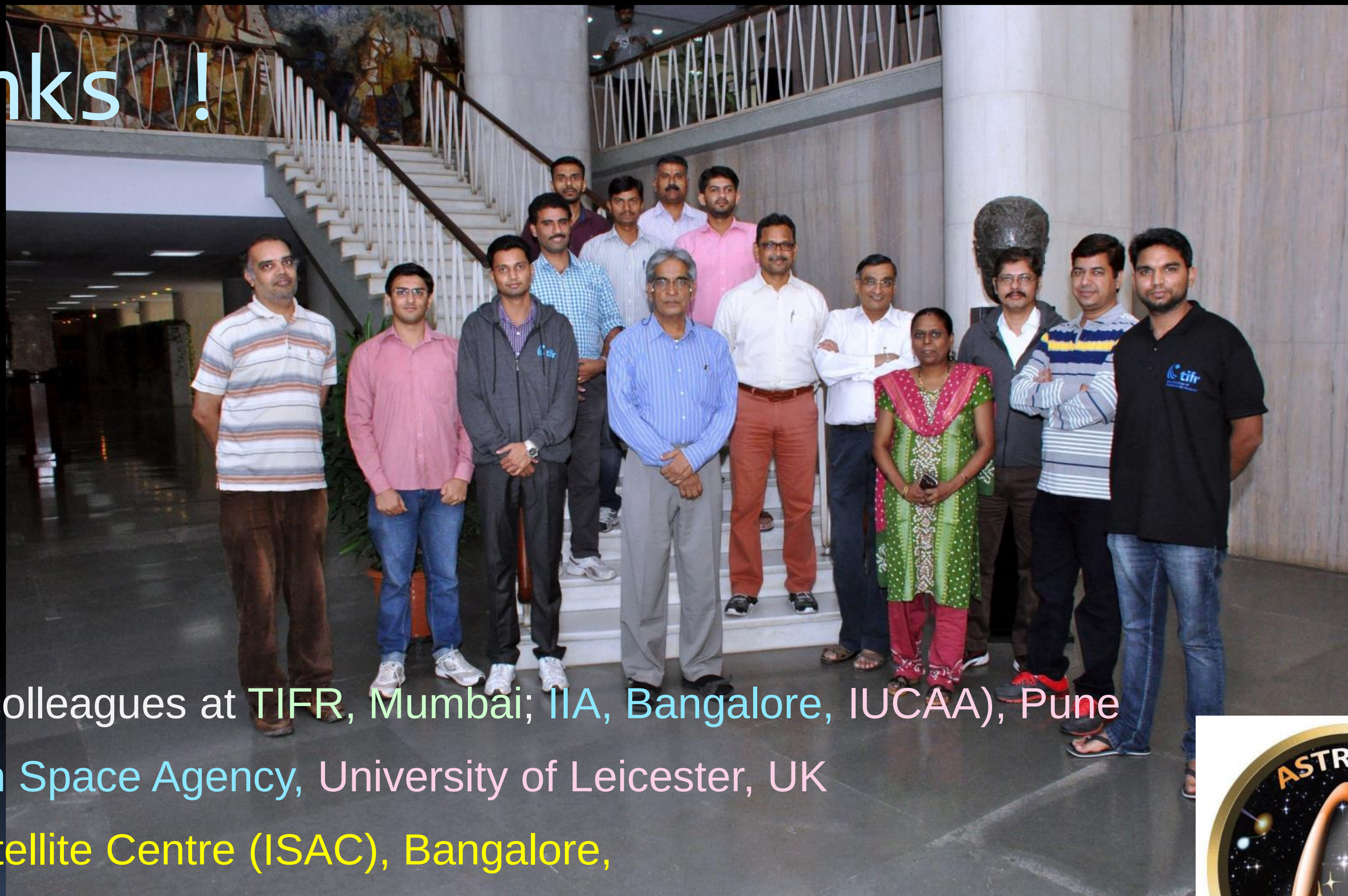
AstroSat observation of Cyg X-3 during ~ 20 Jy radio jet : Mayukh et. al Astrophysical Journal letter, January 2018







LAXPC Instrument team



Thanks !

Several colleagues at TIFR, Mumbai; IIA, Bangalore, IUCAA), Pune

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ISRO Satellite Centre (ISAC), Bangalore,

Raman Research Institute, Bangalore

Vikram Sarabhai Space Centre, Trivandrum,

Space Applications Centre, Ahmedabad & Physical Research Laboratory, Ahmedabad