Large Area X-ray Proportional Counter (LAXPC)

Calibration and Data Reduction

H. M. Antia

Tata Institute of Fundamental Research

antia@tifr.res.in **www.tifr.res.in/~antia**

I thank all members of LAXPC and ISRO team for support and guidance.

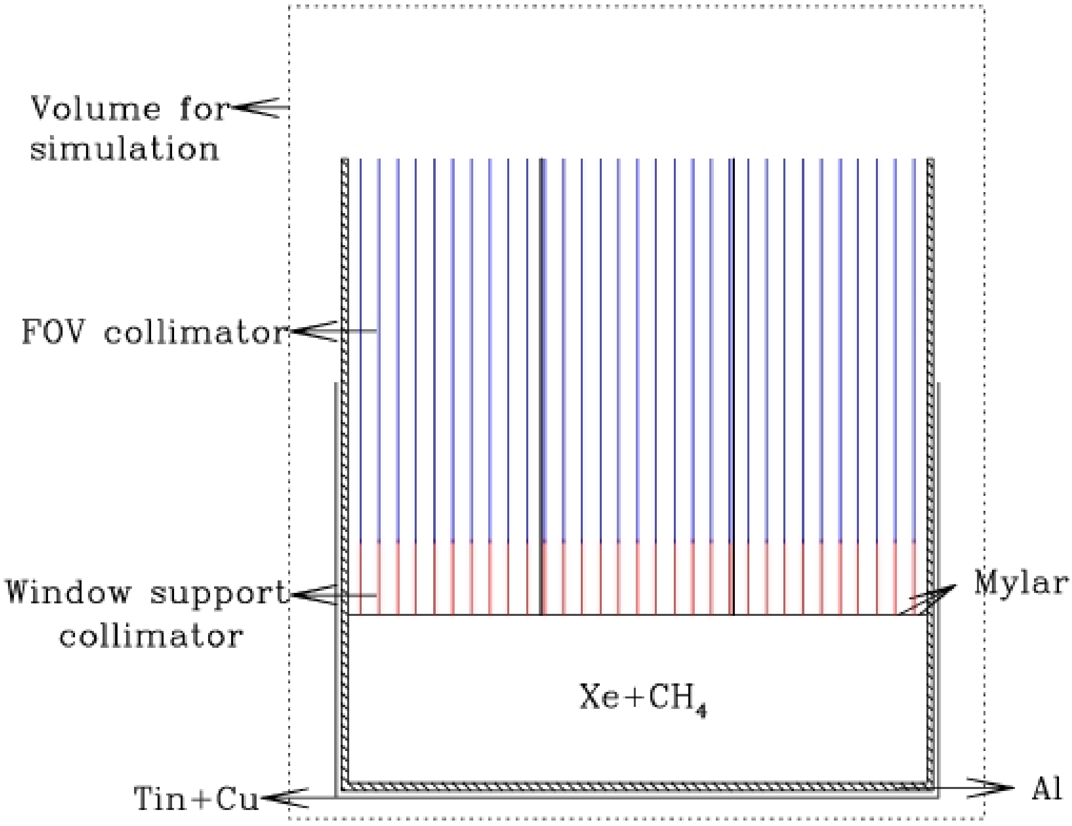
LAXPC website: http://www.tifr.res.in/~astrosat_laxpc

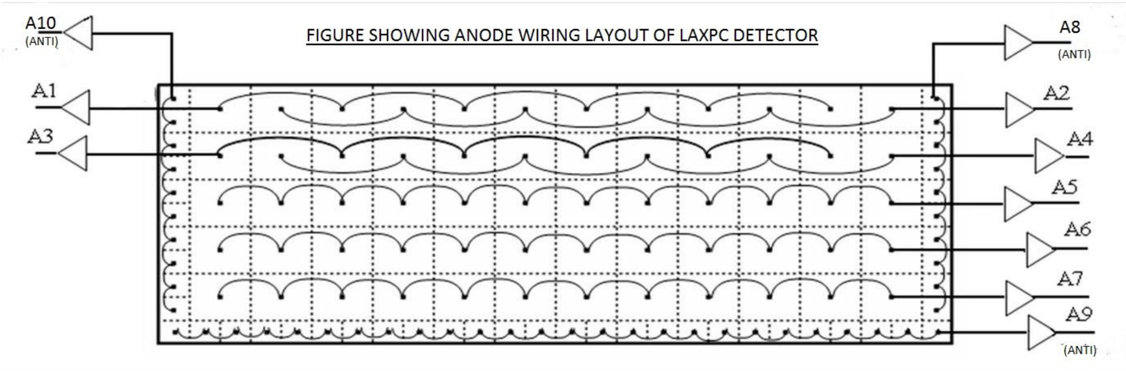
- LAXPC payload consists of 3 large area X-ray proportional counters

- Detector size: $100 \times 39 \times 16.5$ cm filled with a mixture of Xenon (90%) and Methane (10%) at a pressure of 2 atmospheres.

- Top of the detector is covered by a $50\ \mu$m thick Mylar window

- Above the Mylar window there is a window support collimator of height 7.5 cm and the field of view collimator of height 37 cm. These collimators have mesh with a pitch of 7 mm.


Volume for simulation
FOV collimator
Window support collimator
Mylar
$Xe+CH_4$
Tin+Cu
Al



Main Anodes : A1–A7 in 5 layers

Veto Anodes : A8, A9, A10 on 3 sides

No Veto Anodes on two small sides (39×16.5 cm)

Mylar and collimator on the top side

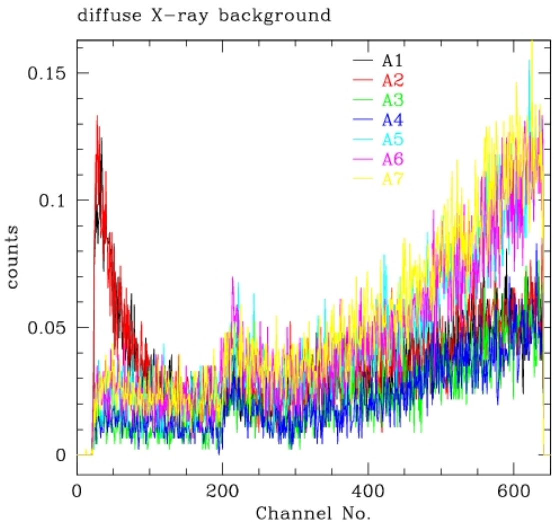
- GEANT4 simulation of 10^6 photons with fixed energy.
- Initial Photon trajectory is normal to detector top (except for FOV and background)
- Uniformly distributed over detector area.
- For background simulation the flux is assumed to be uniform and isotropic.

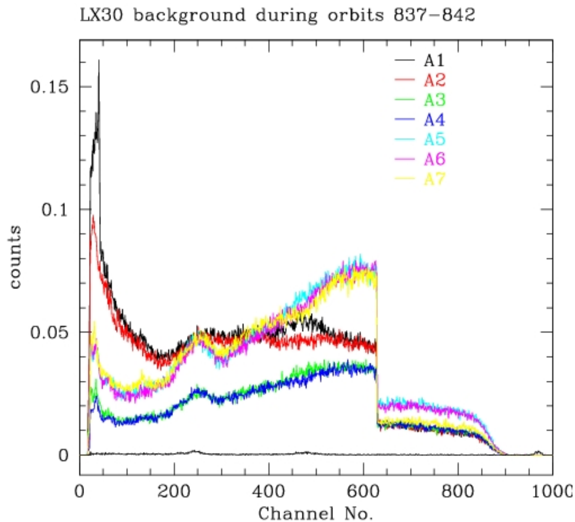
To reject background events the following logic is implemented which is consistent with the processing electronics:

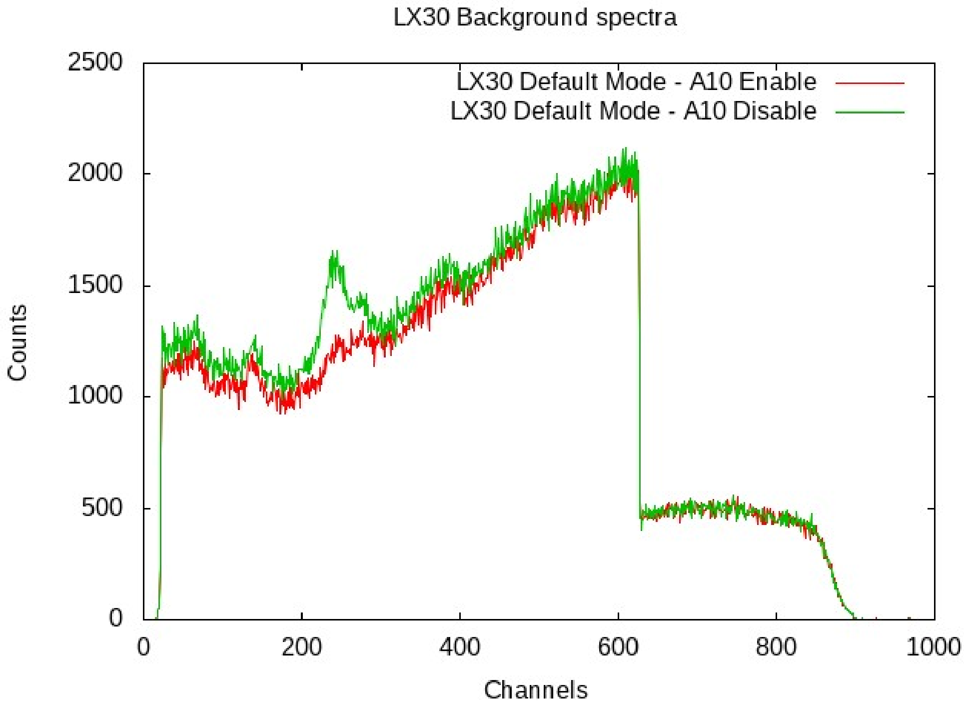
- Any event that is recorded in veto-anodes (A8–A10)
- Any event that deposits more than an upper limit (80 keV) in any anode
- Any event that is recorded in more than 2 main anodes (A1–A7)
- If an event is recorded in two main anodes, then it is accepted only if at least one of the energy is in K-threshold for Xe (30 ± 4.5 keV). If the event is accepted the energies in two anodes are added and it is recorded as a single event of combined energy.

- Background from cosmic diffuse X-ray background (Dean et al. 1991) gives background 165 s^{-1} in 1 detector

$$\frac{dN}{dE} = 87.4\, E^{-2.3}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{keV}^{-1}\mathrm{steradian}^{-1}$$







A10 enabled : 146 s^{-1}, A10 disabled : 156 s^{-1}

Detector Calibration using Radioactive Sources

- Three radioactive sources Fe^{55} (5.9 keV), Cd^{109} (22 keV), Am^{241} (59.6 keV with Xe K-escape peaks at 29.8 keV and 26 keV) were used for calibration.

- For each source, energy deposited in each cell (60 main anode cells and 3 veto anodes) during each event is recorded.

- To account for finite resolution, a random number with Normal distribution with 0 mean and $\sigma = E_p \sigma_i$ is added.

- Effective energy in all cells in an anode are added.

  For LX10: For C1, $0.95E_p$ is used for C12, $1.05E_p$ is used.

  For A4 C1, $0.74E_p$ was used. A10 is disabled.

  For LX20, LX30: For C1 and C12, $0.95E_p$ is used

- Rejection and K-escape logic as used in PE is applied and total energy in each anode is converted to channel No.

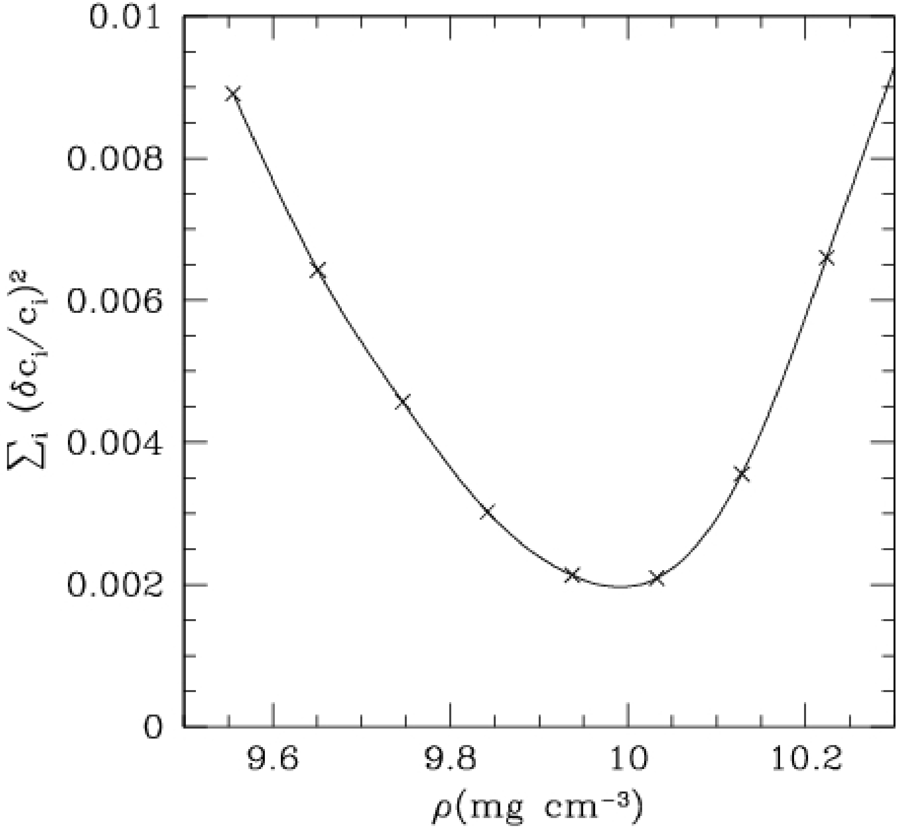
$$n_c = e_0 + e_1 E_p (1 + e_2 E_p)$$

- The simulated spectrum is compared with observed spectrum after subtracting the background. For normalisation the simulated spectrum is multiplied by a constant to match the total counts under one peak.

- To adjust the density of gas the square of relative difference in total counts for each anode layer for Cd^{109} is minimised

$$\sum_{i=1}^{5}\left(\frac{O_i - S_i}{O_i}\right)^2$$

This corrects for difference in temperature or pressure

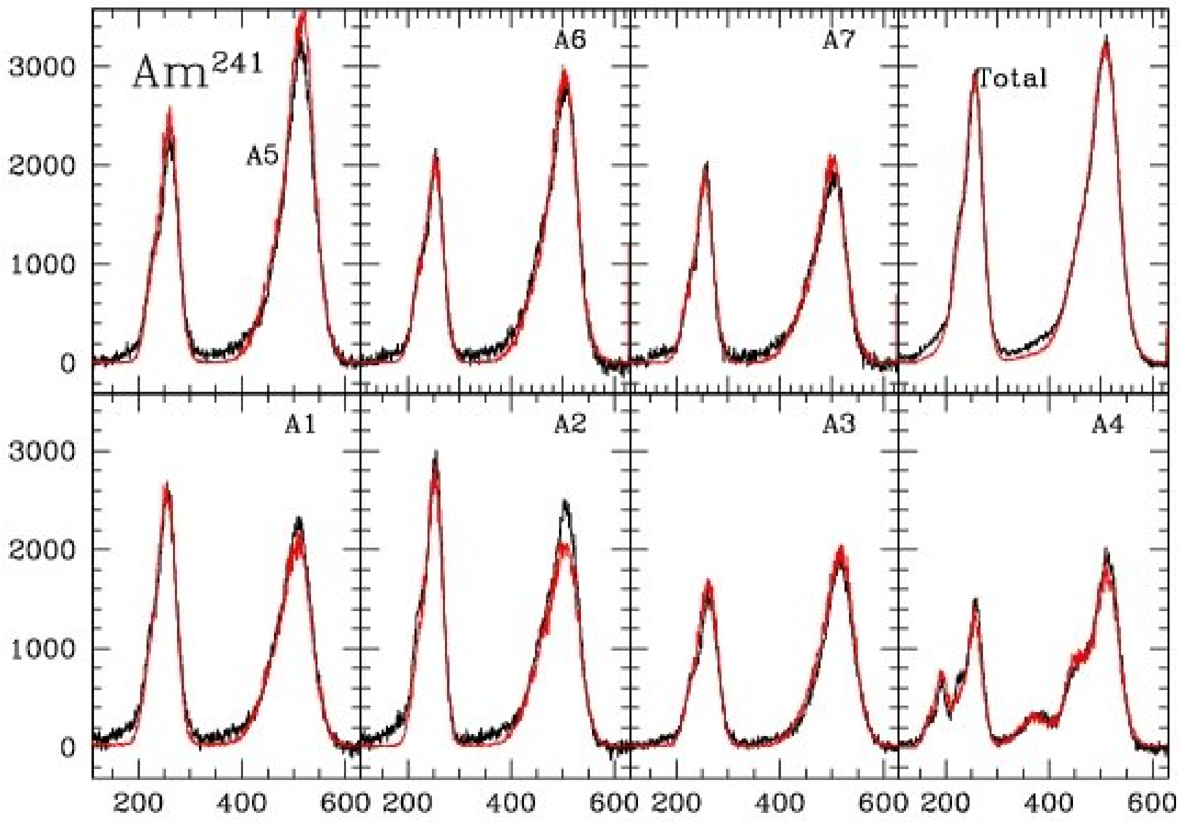


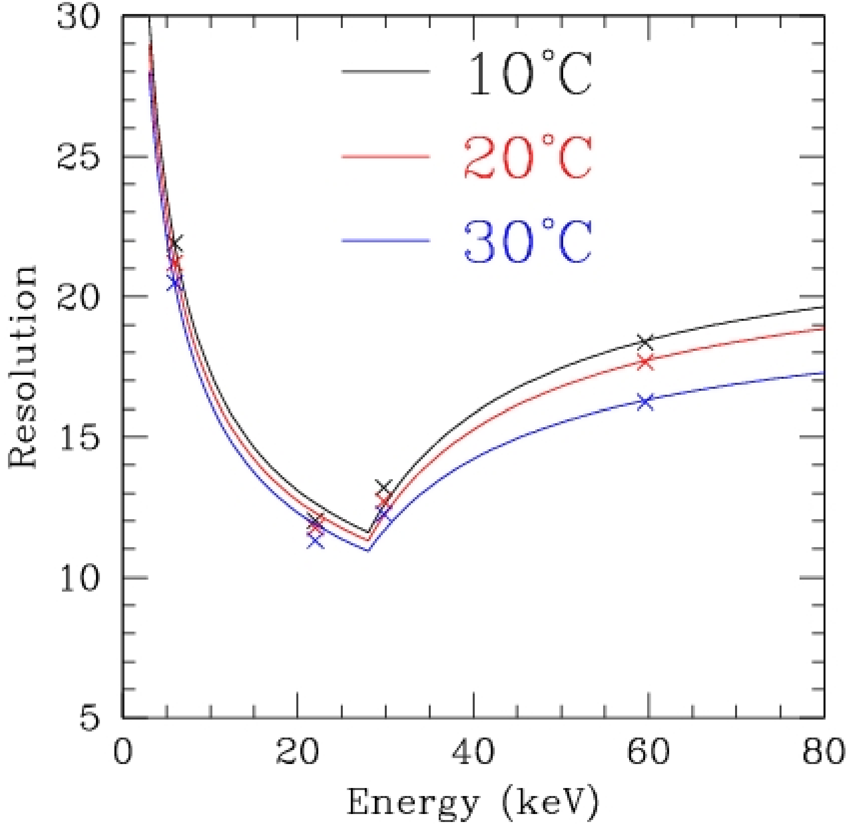
0.01
0.008
0.006
0.004
0.002
0
9.6
9.8
10
10.2
ρ(mg cm^{-3})
$\sum_i (\delta c_i/c_i)^2$

- The density at 20° C is found to be 10.0 mg cm^{-3} for LX10, 10.7 mg cm^{-3} for LX20 and 11.5 mg cm^{-3} for LX30.

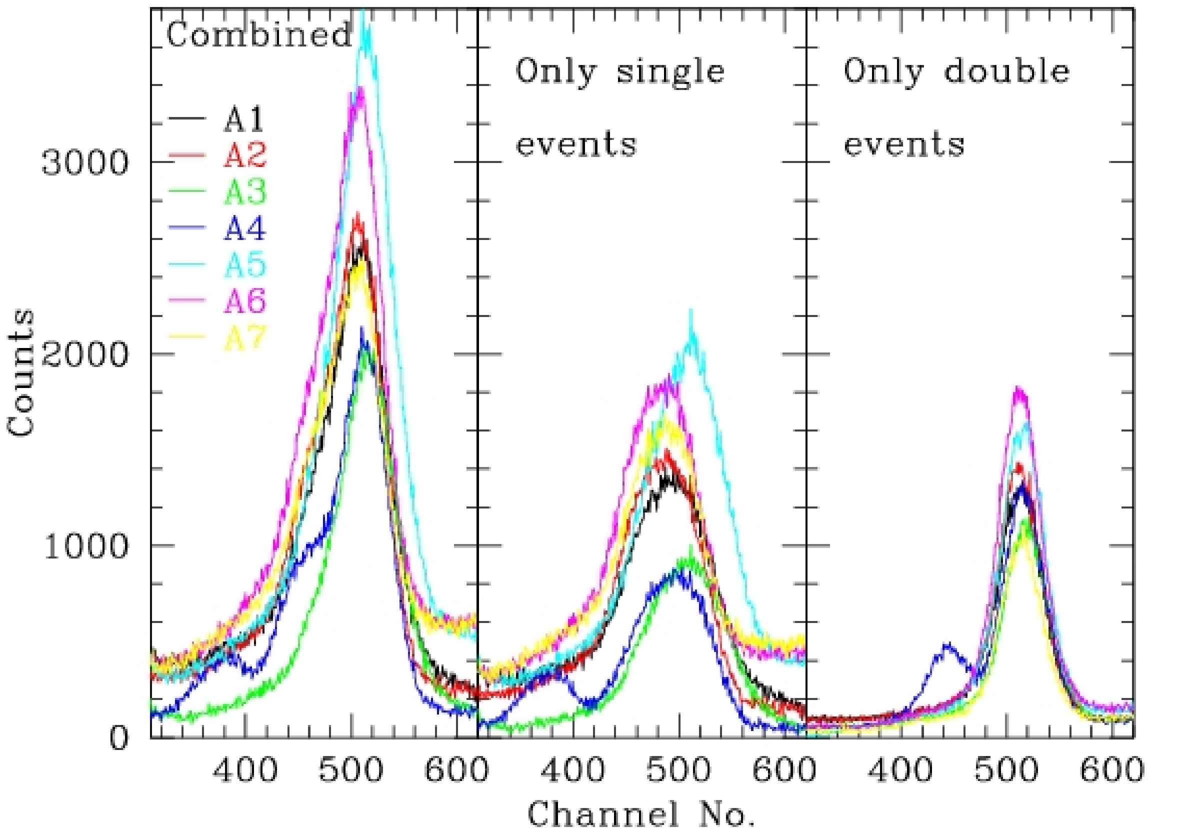
- The resolution as a function of energy is determined by fitting a linear spline with 3 knots to $\sigma^2(E^{-1})$

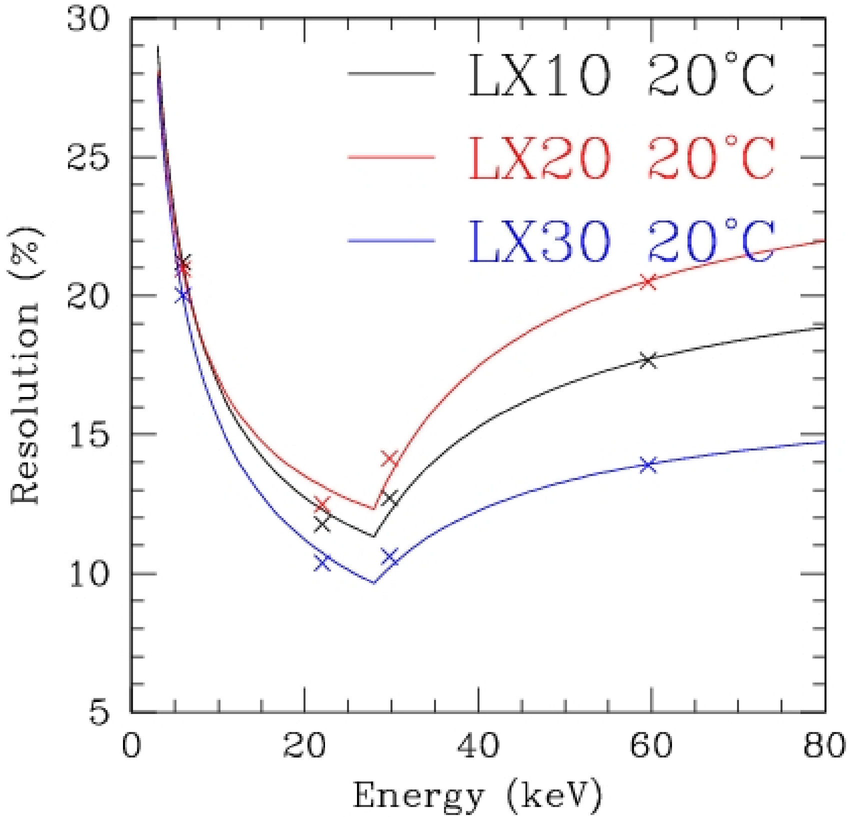
- To calculate detector response for other energies we need $\sigma(E,T), n_c(E,T)$


Am^241
A5
A6
A7
Total
A1
A2
A3
A4
0
1000
2000
3000
200
400
600

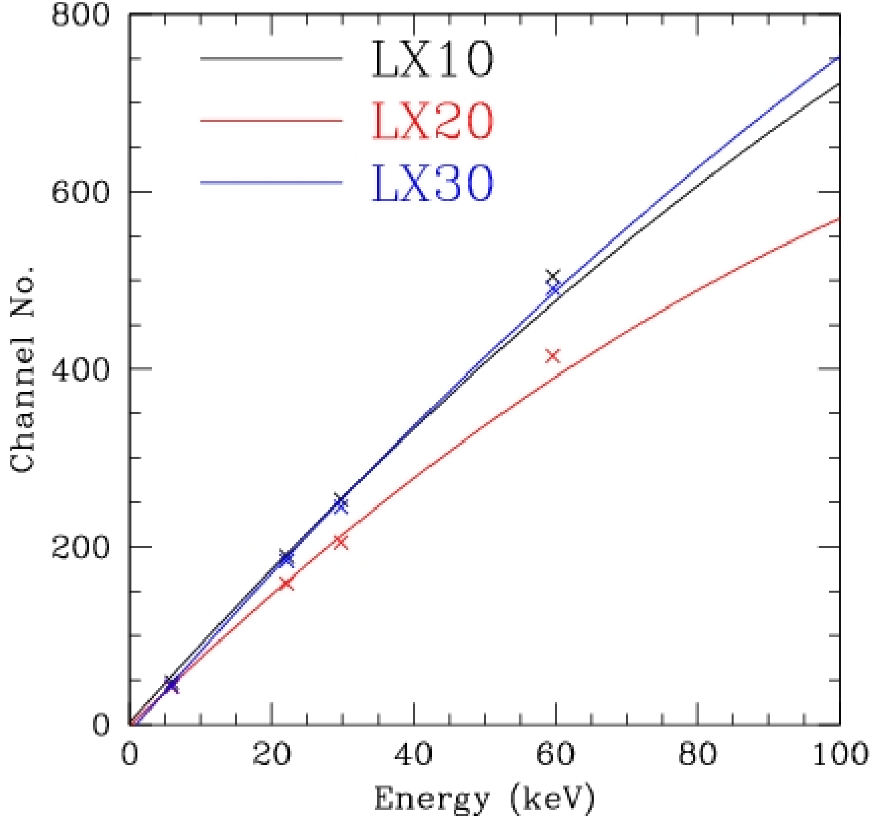


LAXPC10


Combined
Only single events
Only double events
A1
A2
A3
A4
A5
A6
A7
Counts
3000
2000
1000
0
400
500
600
Channel No.



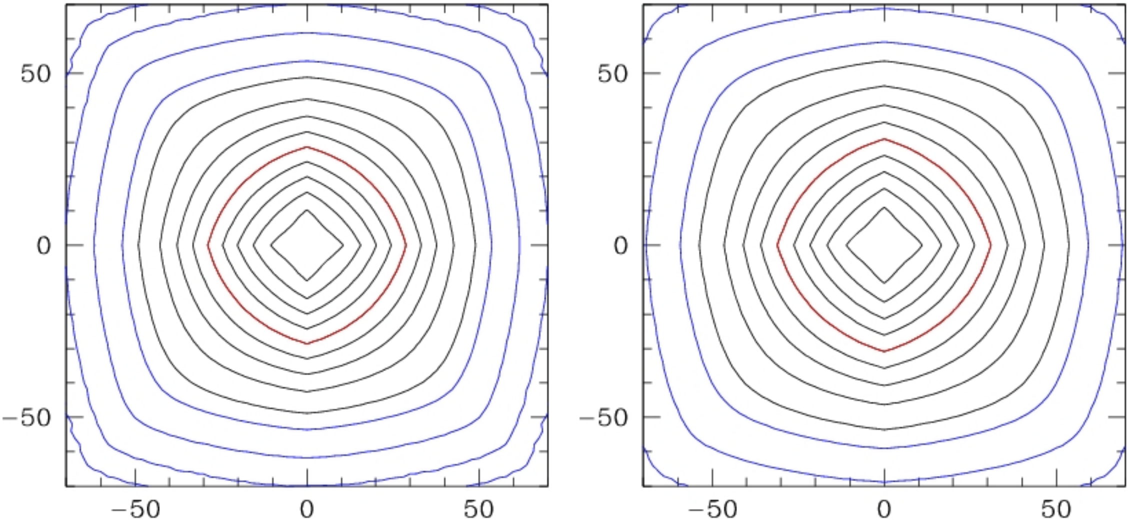
LX10 20°C
LX20 20°C
LX30 20°C
Resolution (%)
Energy (keV)
30
25
20
15
10
5
0
20
40
60
80



800
600
400
200
0
0
20
40
60
80
100
Channel No.
Energy (keV)
LX10
LX20
LX30

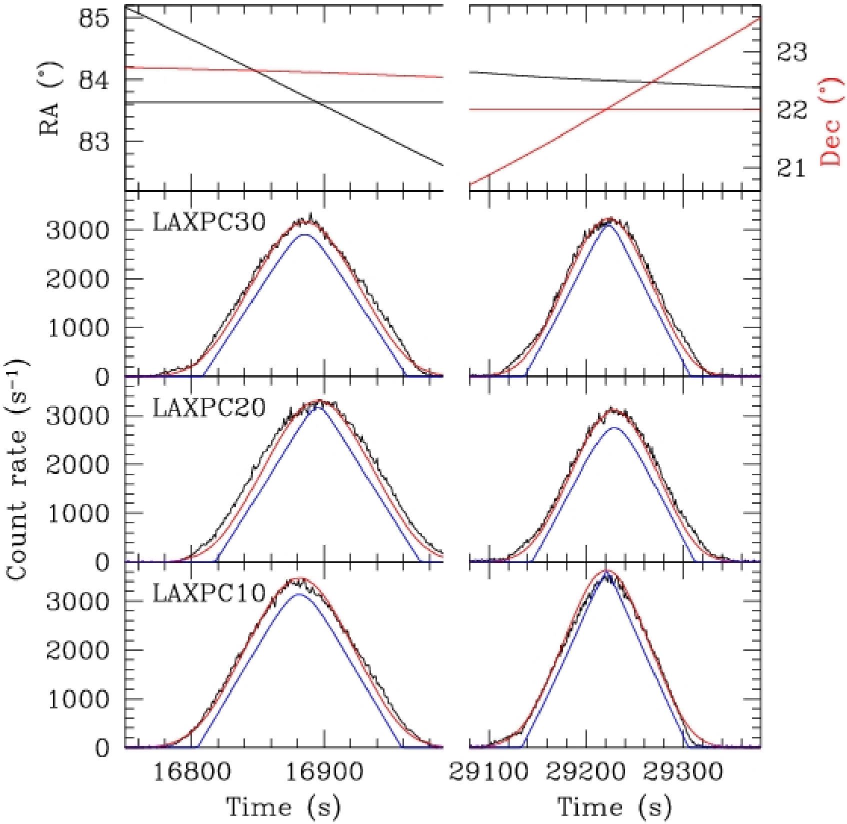
- AstroSat orbital period is about 98 min
- Data are dumped when AstroSat is over the ground station near Bengaluru. This does not happen during every orbit, but data for multiple orbit is stored on board and is dumped when link is available.
- HV of all LAXPC detectors is turned off during SAA passage of about 30 minutes. At all other times the detectors are always on and recording data.
- In addition depending on the source position the source may be behind the Earth for some time, which gives a typical observations efficiency of 45%.

Calibration of the Field of View

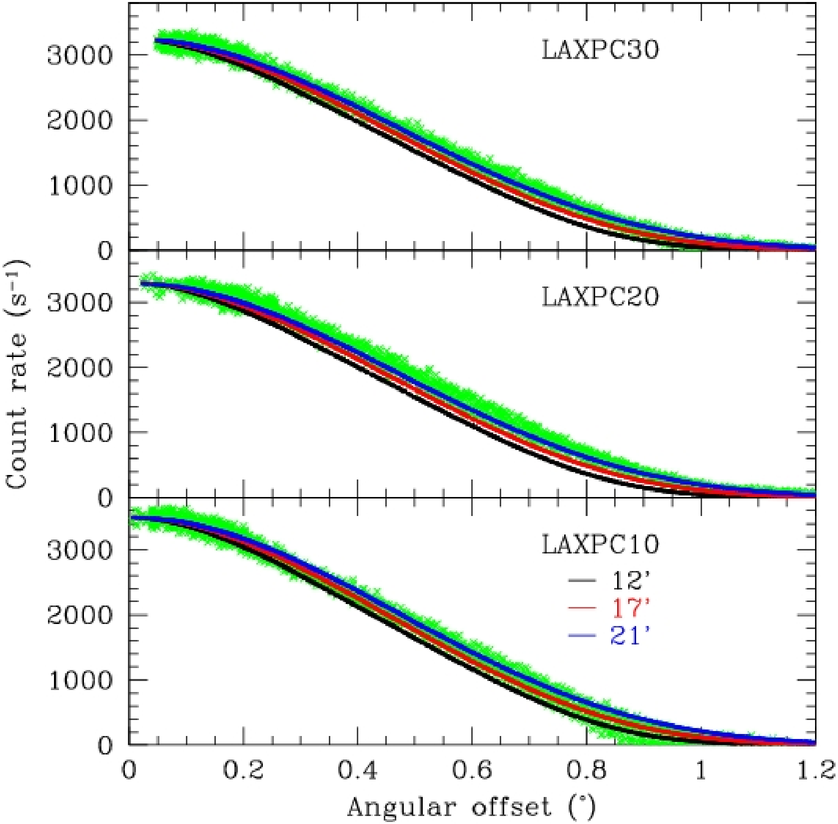


15 keV: FWHM $= 55' = 0.92°$ 50 keV: FWHM $= 63' = 1.05°$

FOV is determined by scan across the Crab source.



RA (°)
Dec (°)
85
84
83
23
22
21
LAXPC30
LAXPC20
LAXPC10
Count rate (s^{-1})
0
1000
2000
3000
16800
16900
29100
29200
29300
Time (s)
Time (s)

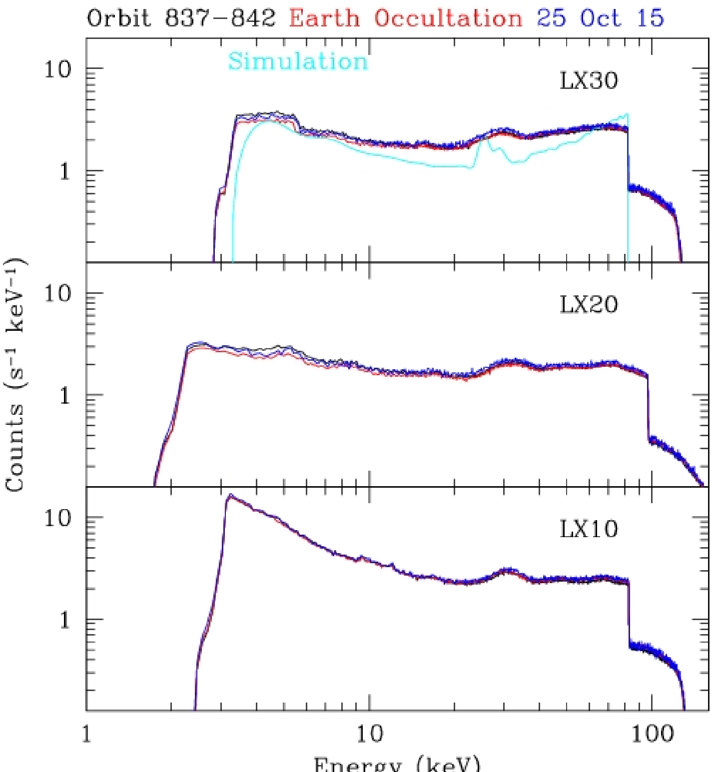

LAXPC30
LAXPC20
LAXPC10
12'
17'
21'
Count rate (s^{-1})
Angular offset (°)
0
1000
2000
3000
0.2
0.4
0.6
0.8
1
1.2

- LAXPC offset from scan on 3 February 2016

	RA (°)	DEC (°)	Offset (°)
LX10	83.78	22.01	0.15
LX20	83.63	22.08	0.07
LX30	83.74	22.03	0.11
Mean	83.72	22.04	0.09
Crab	83.63	22.01	

- Satellite pointing depends on the primary payload for observations. Hence, the relative normalisation of 3 detectors should be kept free.

Observed background in Orbit

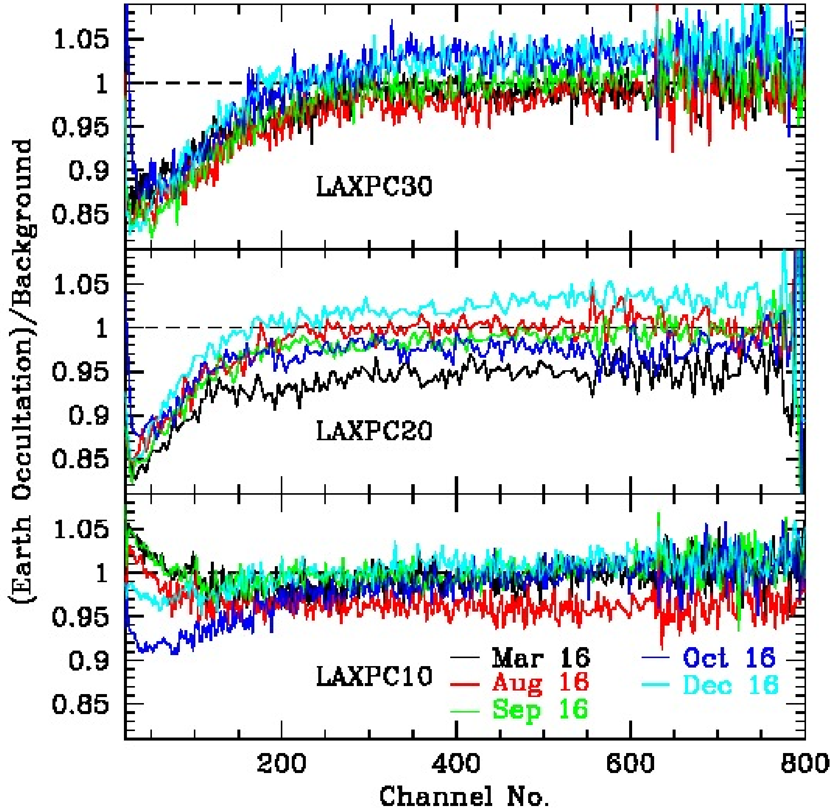


Count rates:

- LX10: 244 s^{-1}
- LX20: 192 s^{-1}
- LX30: 202 s^{-1}

Earth Occultation

- LX10: 257 s^{-1}
- LX20: 201 s^{-1}
- LX30: 214 s^{-1}



LAXPC30
LAXPC20
LAXPC10
Mar 16
Aug 16
Sep 16
Oct 16
Dec 16
1.05
1
0.95
0.9
0.85
200
400
600
800
Channel No.
(Earth Occultation)/Background

Background Model

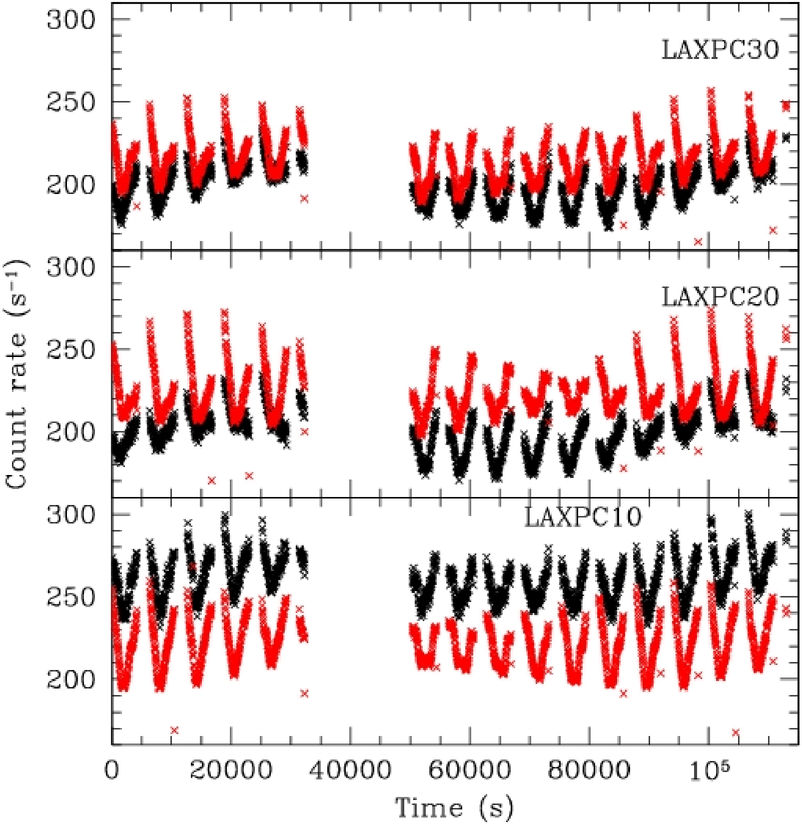
- Different models have been tried

1. Using ULD (Upper Level Discrimination) counts (sensitive to gain shift)

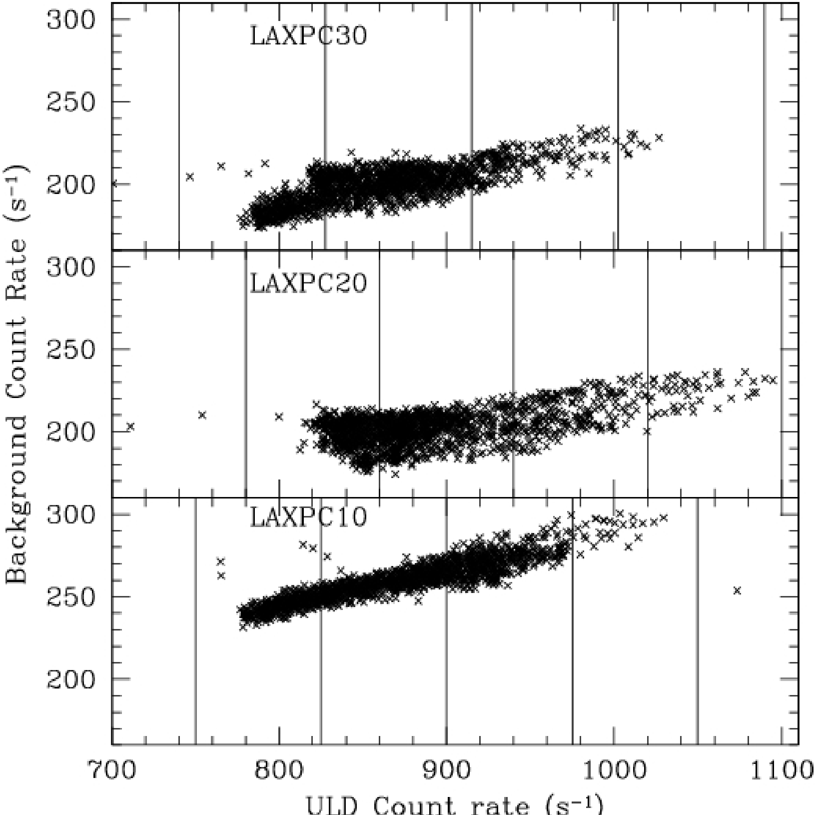
2. Fitting background count rate as a function of latitude and longitude (sensitive to temporal variation)

3. For faint sources, instead of ULD we can use counts at high energy to scale the background (R. Misra)

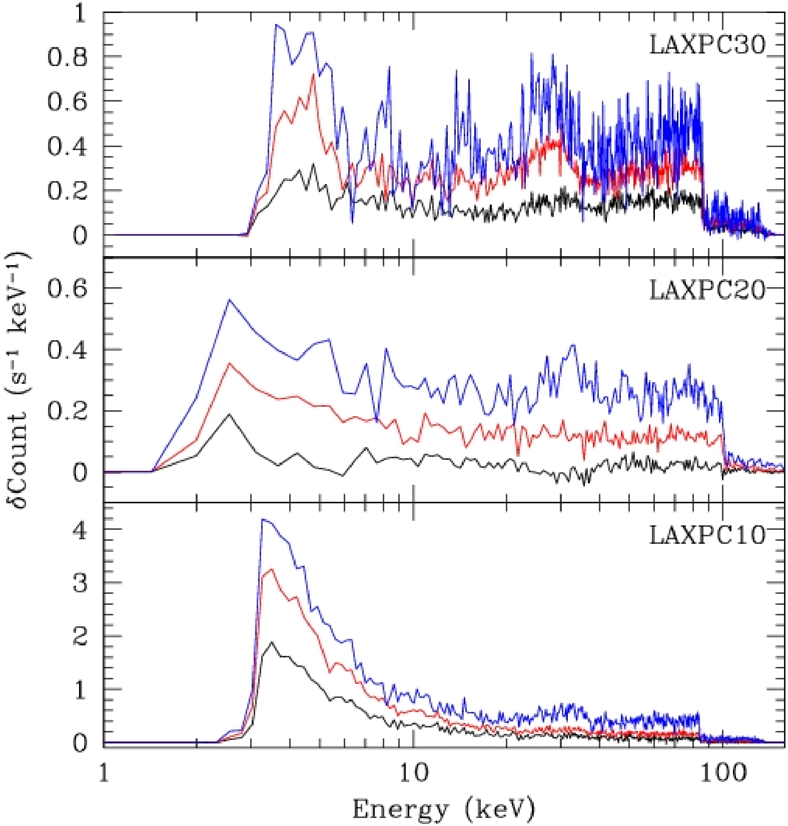
4. Observation during Earth Occultation (affected by Earth albedo/shadow)

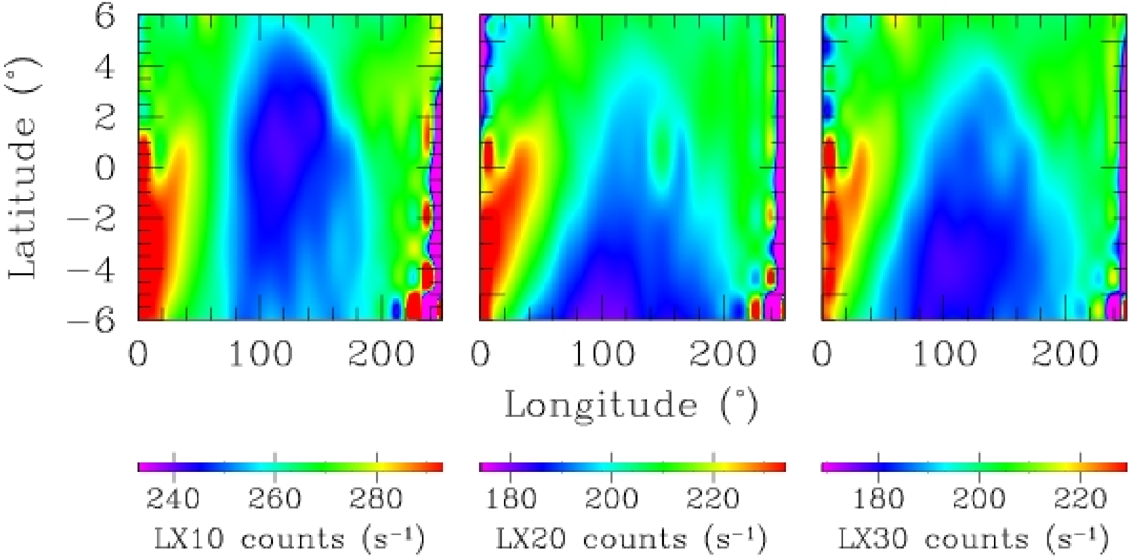


LAXPC30
LAXPC20
LAXPC10
Count rate (s⁻¹)
Time (s)
300
250
200
0
20000
40000
60000
80000
10⁵

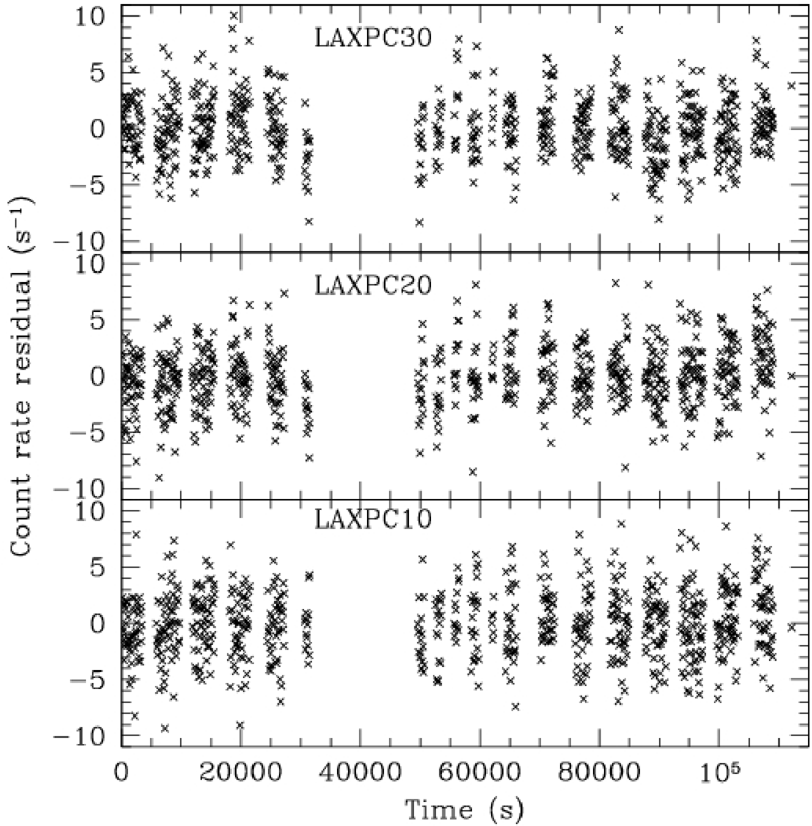


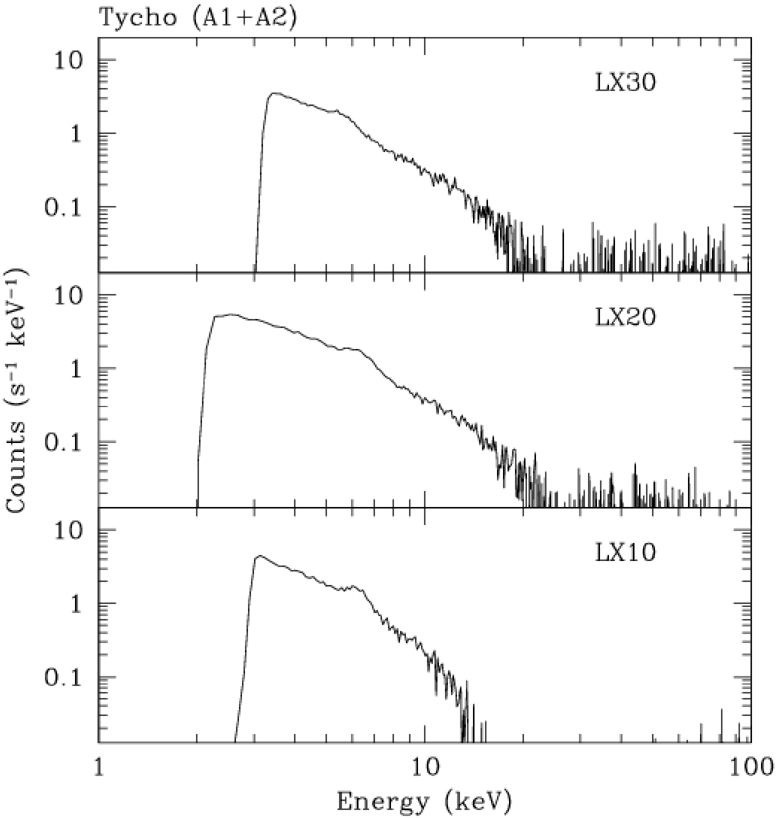
LAXPC30
LAXPC20
LAXPC10
Background Count Rate (s⁻¹)
ULD Count rate (s⁻¹)
300
250
200
700
800
900
1000
1100


LAXPC30
LAXPC20
LAXPC10
δCount (s⁻¹ keV⁻¹)
Energy (keV)
1
10
100
0
0.2
0.4
0.6
0.8
1
0
0.2
0.4
0.6
0
1
2
3
4

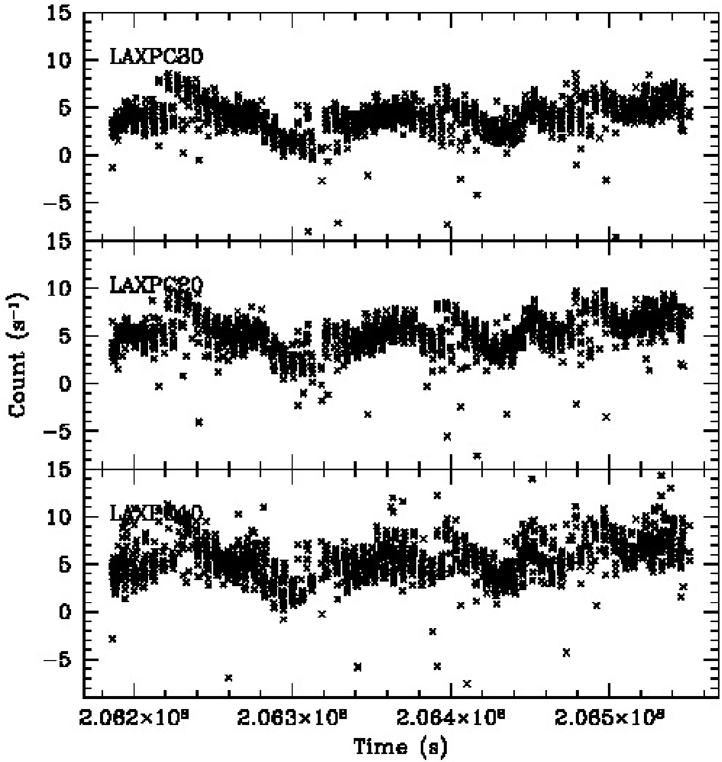


Latitude (°)
6
4
2
0
−2
−4
−6
0
100
200
Longitude (°)
240
260
280
LX10 counts (s⁻¹)
180
200
220
LX20 counts (s⁻¹)
180
200
220
LX30 counts (s⁻¹)


LAXPC30
LAXPC20
LAXPC10
Count rate residual (s−1)
Time (s)
10
5
0
−5
−10
0
20000
40000
60000
80000
10⁵

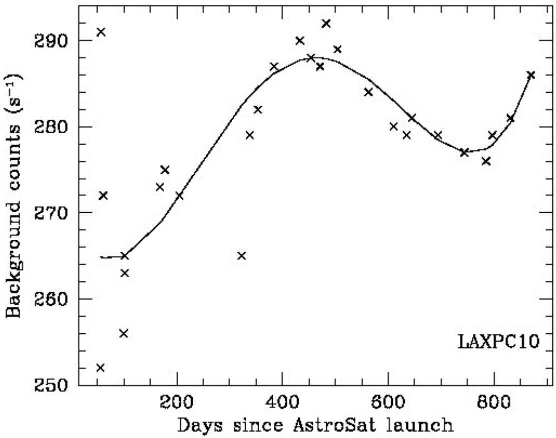


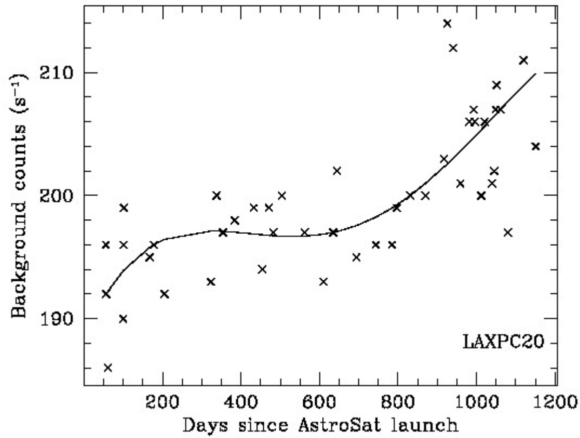
Tycho (A1+A2)
LX30
LX20
LX10
Counts (s⁻¹ keV⁻¹)
Energy (keV)
10
1
0.1
1
10
100


LAXPC30
LAXPC20
LAXPC10
Count (s⁻¹)
Time (s)
2.062×10⁸
2.063×10⁸
2.064×10⁸
2.065×10⁸
15
10
5
0
−5

NGC 4593

Long term variation in background counts

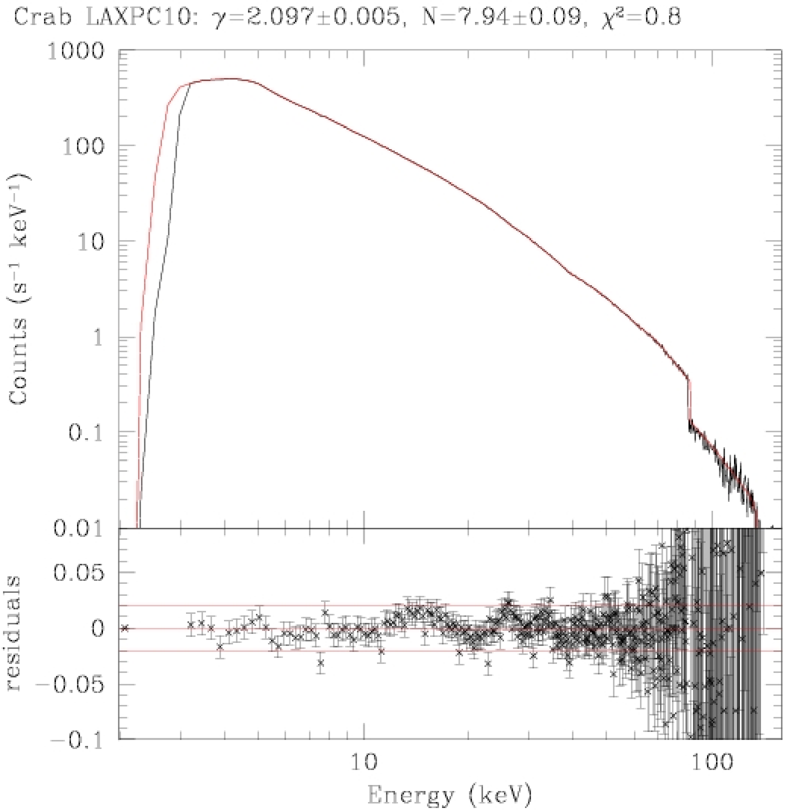


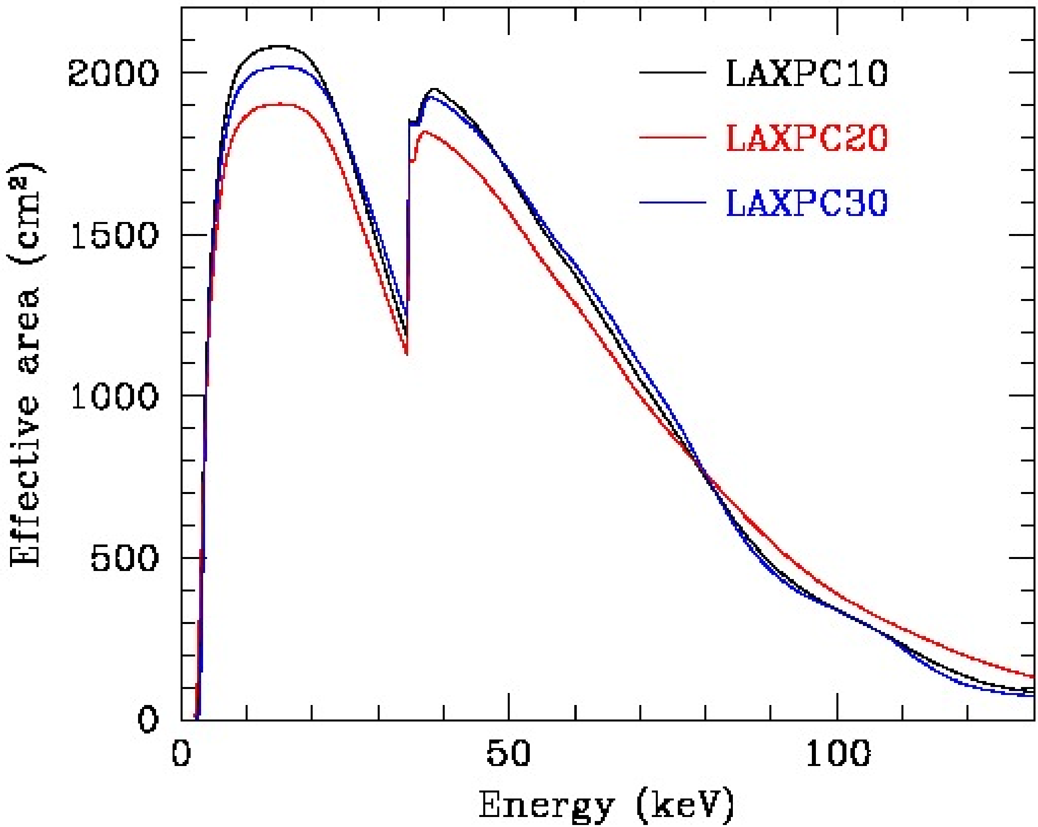


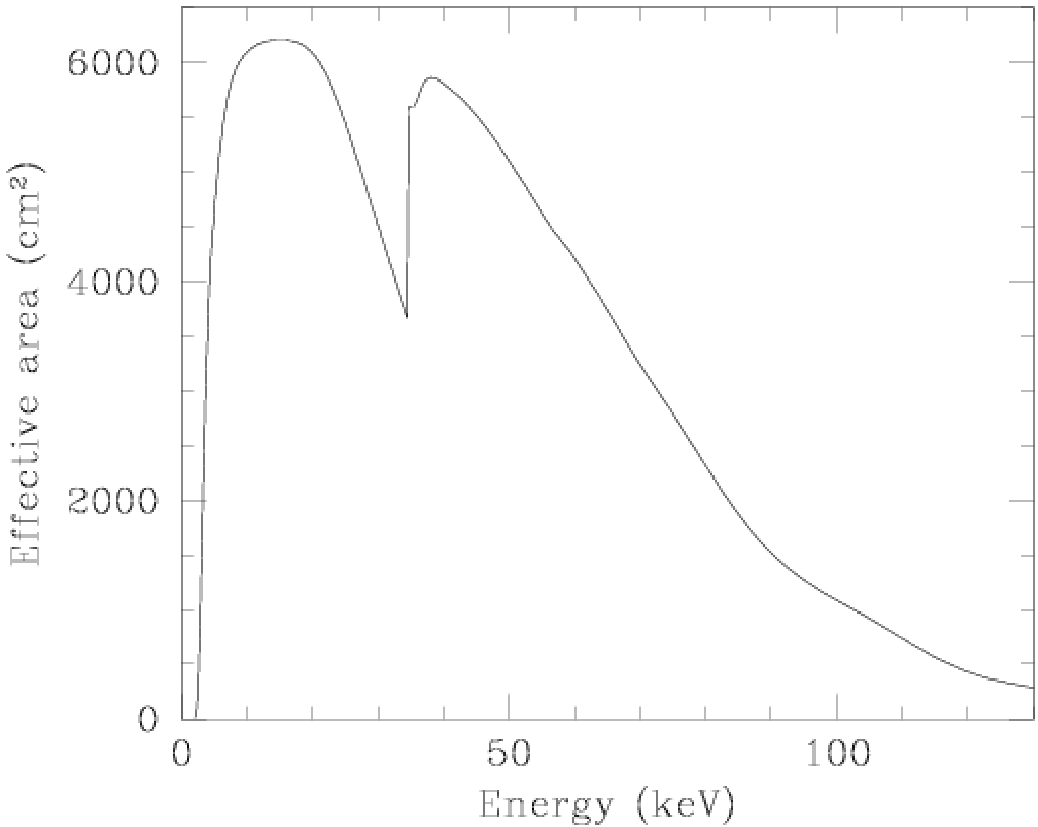
Detector Response Matrix

- The channel to energy mapping was adjusted to match the Crab spectrum observed after launch.
- Since the detector gain drifts with time, response matrix is generated for differing gain in the 30 keV calibration peak.
- A log of gain shift is maintained using the calibration source (Am^{241}) in veto anode A8. Normally, events recorded in anode A8 are rejected, but the detector electronics is designed to accept a small fraction of events in A8 which would include the counts due to calibration source.
- The calibration source has two peaks around 30 and 60 keV and using them it is not possible to determine the 3 coefficients in channel to energy mapping. Only the shift in 30 keV peak is used to estimate the gain shift.

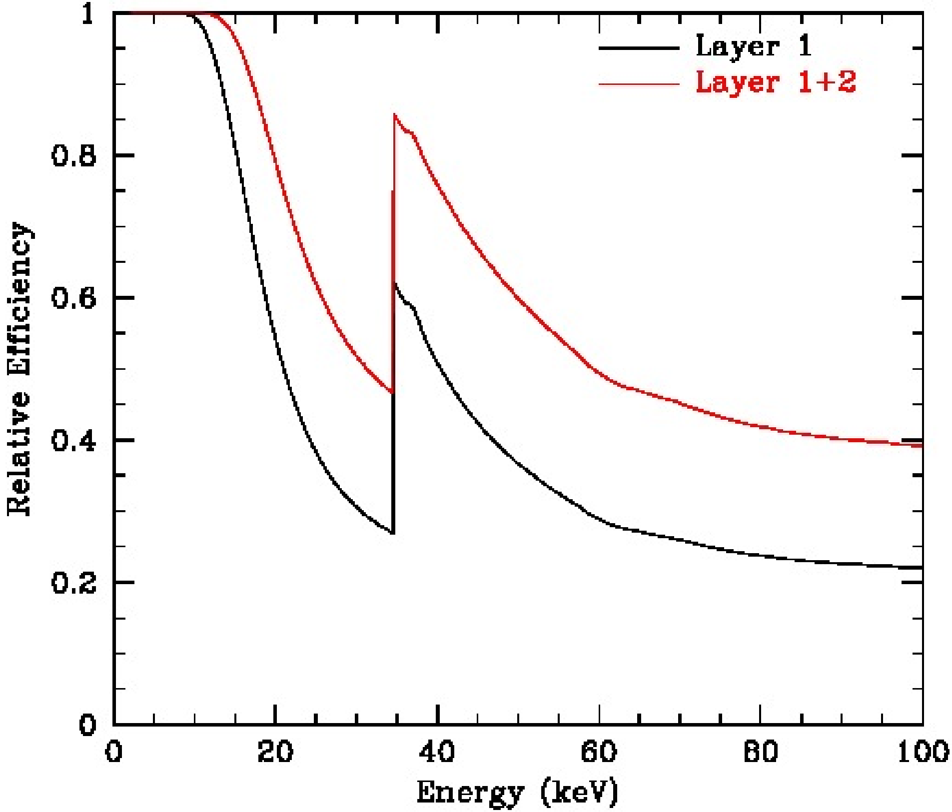
- To take care of even-odd fluctuation in counts with channel the no. of channels is reduced to 512 for LX10, LX30, and to 256 for LX20.
- The effect of dead-time is incorporated in the spectrum and light curve.
- Inclusion of flux leakage from side of the detector which gives a hump around 30 keV from Xenon K X-rays.
- To account for leak in LX30 the responses are generated with different density.
- The normalisation for effective area is estimated by cross-calibration with NuSTAR observation.


Crab LAXPC10: γ=2.097±0.005, N=7.94±0.09, χ²=0.8
Counts (s⁻¹ keV⁻¹)
1000
100
10
1
0.1
0.01
residuals
0.05
0
−0.05
−0.1
10
100
Energy (keV)


LAXPC10
LAXPC20
LAXPC30
2000
1500
1000
500
0
0
50
100
Effective area (cm²)
Energy (keV)

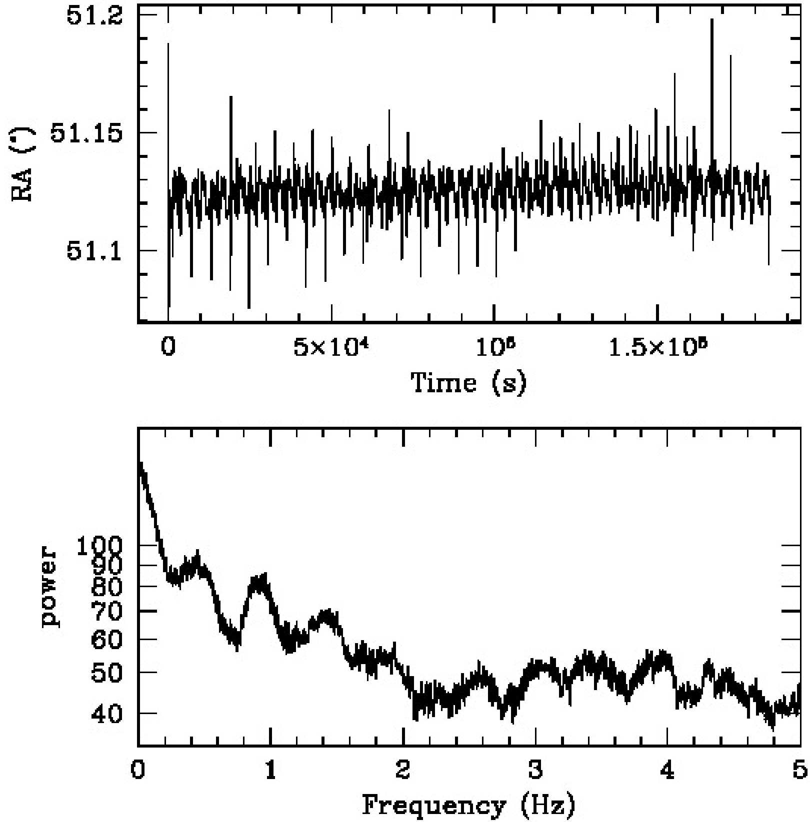


6000
4000
2000
0
0
50
100
Effective area (cm²)
Energy (keV)



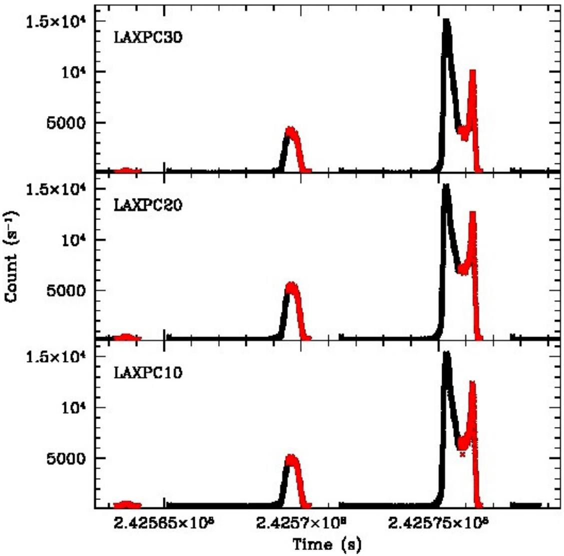
Layer 1
Layer 1+2
Relative Efficiency
Energy (keV)
0
0.2
0.4
0.6
0.8
1
0
20
40
60
80
100

Effect of Pointing Fluctuations

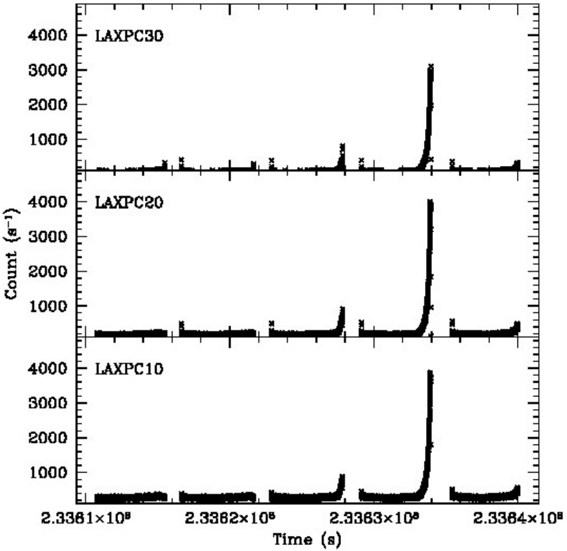


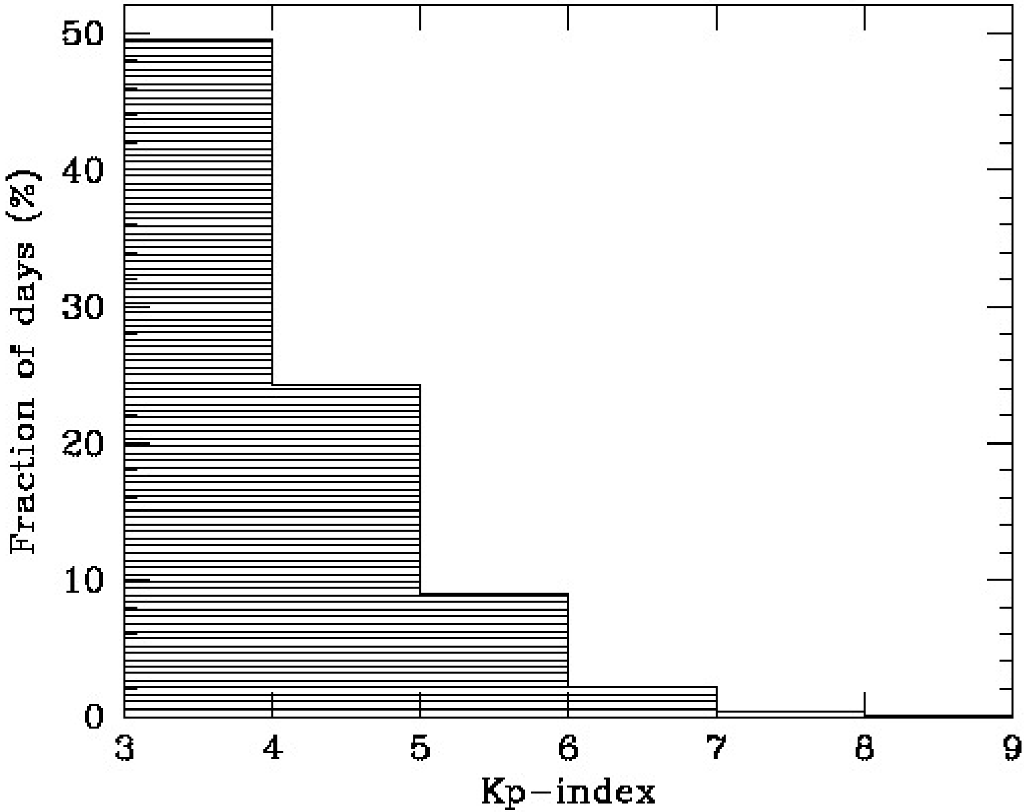
Effect of Geomagnetic Storms

8 September 2017 ($Kp = 8^+$)



28 May 2017 ($Kp = 7$)





Fraction of days (%)
0
10
20
30
40
50
3
4
5
6
7
8
9
Kp−index

Long Term Performance in Orbit

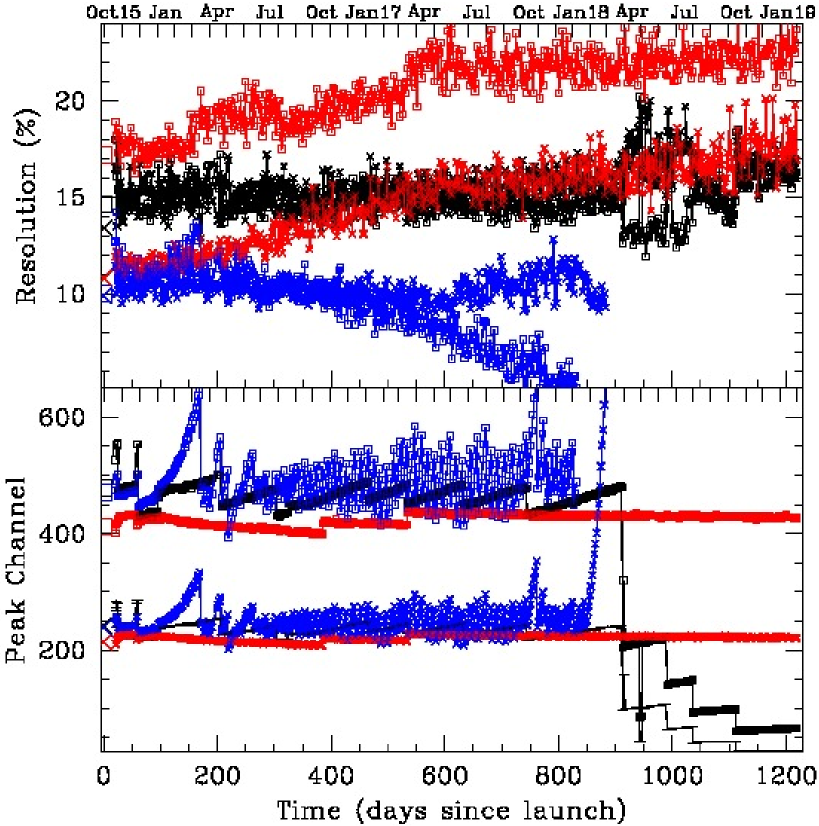
- AstroSat has been in orbit for over 1250 days and has completed over 18500 orbits
- LAXPC has made over 1300 observations with different pointings.
- Long term performance is being monitored using the calibration source in veto anode A8 to check the gain and resolution of the detectors.
- The calibration source has two peaks around 30 and 60 keV which are fitted to get the peak position and energy resolution.

- LX30 developed a fine leak soon after launch leading to peak channel shifting upwards. The HV was adjusted from time-to-time to bring the gain in reasonable range.
- On 22 January 2018 the HV of LX30 was reduced to minimum permissible value. After that the gain kept shifting upwards.
- On 8 March 2018 the HV of LX30 was turned off when the pressure had reduced to about 5% of its original value and ULD had reduced to 15–20 keV.
- The gain of LX10 also has been drifting upwards gradually and it also likely has a leak and the pressure has reduced by a few percent over 3 years.

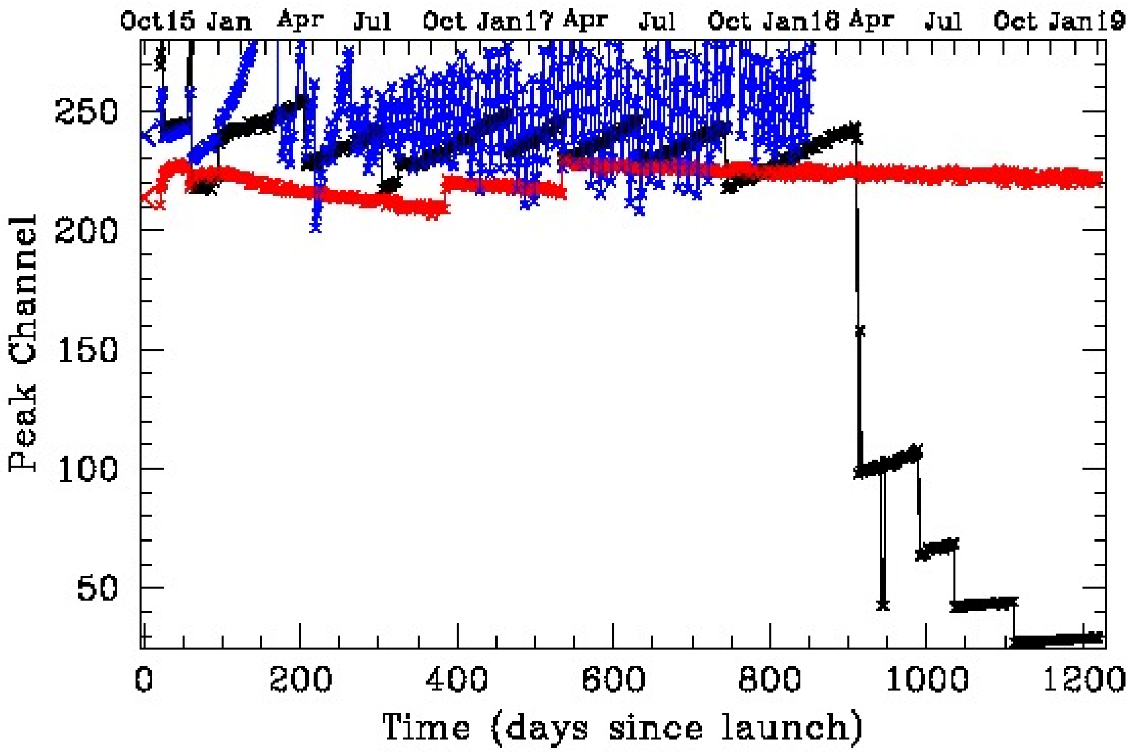
- On 26 March 2018, LX10 showed erratic counts with frequent bursts and its HV was reduced to stabilise the counts. Since then the HV has been reduced a few times. As a result, it is operating at very low gain and currently its low energy cutoff is around 15–20 keV.

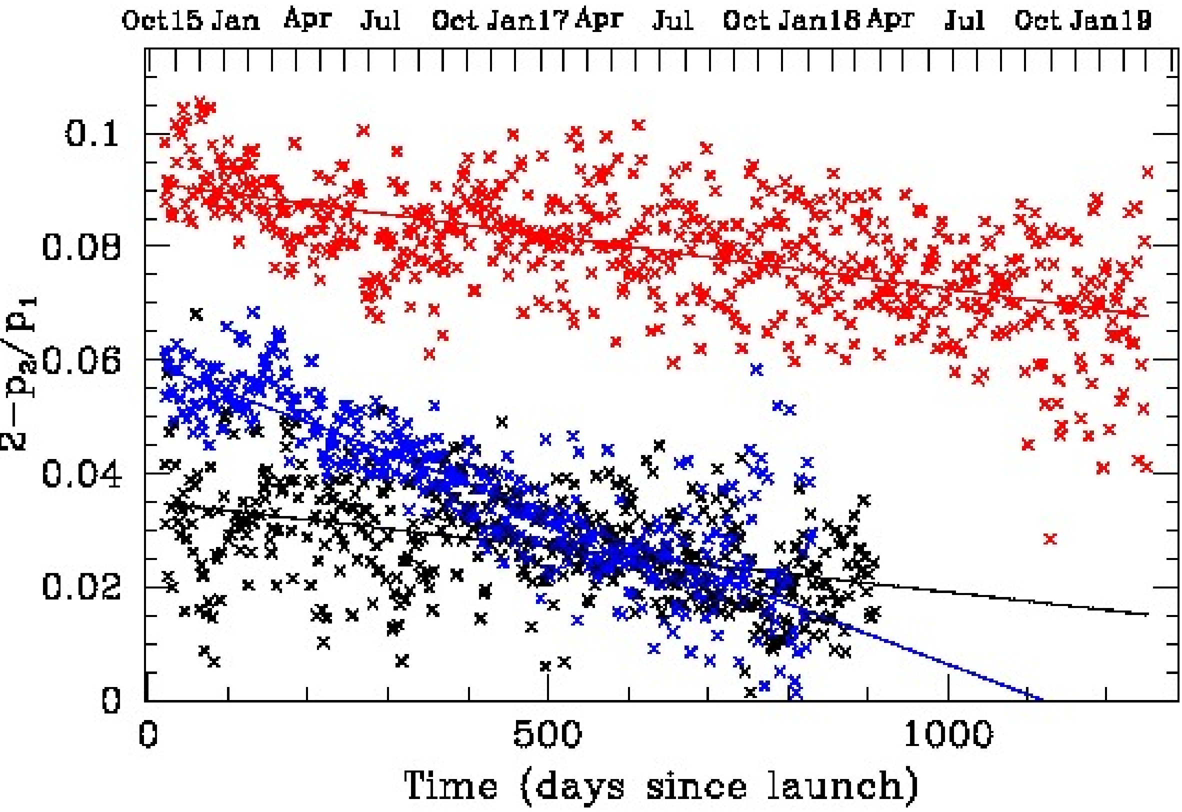
- The gain of LX20 has been steady and only a few HV adjustments have been made, with the last one in March 2017.

- The energy resolution of LX20 has been deteriorating with time, but has stabilised during the last one year.

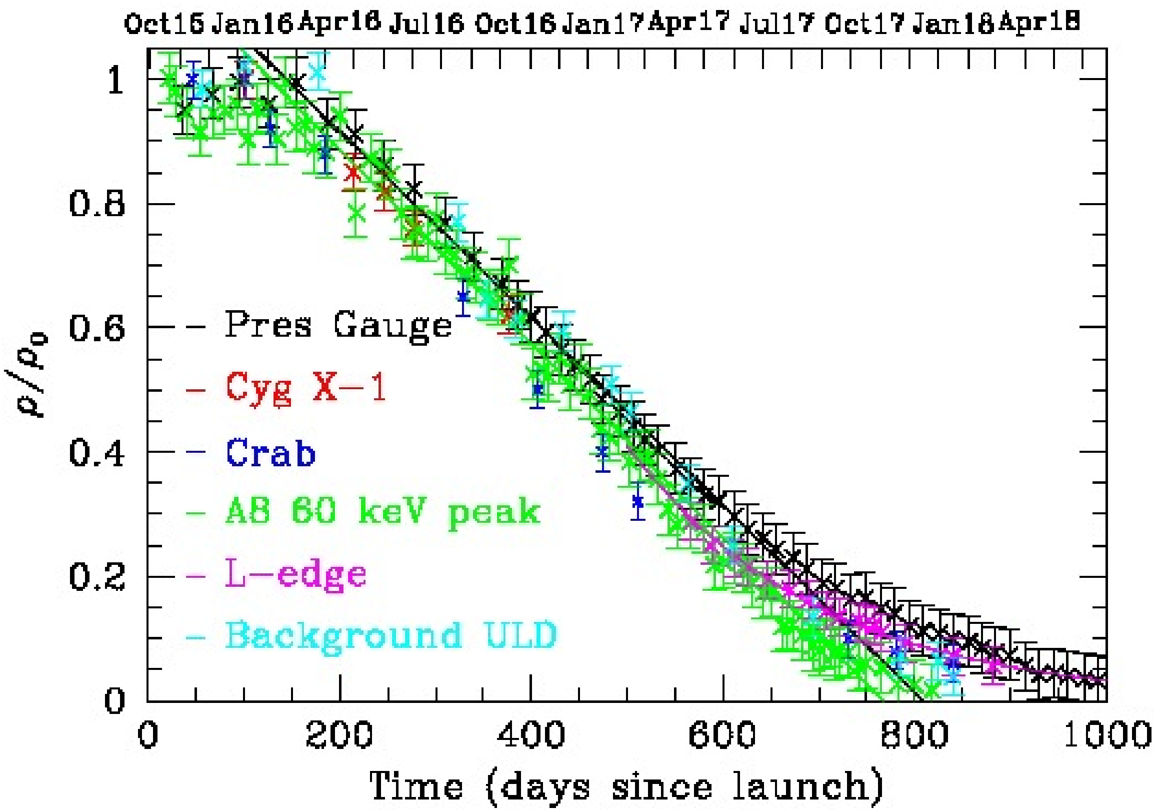


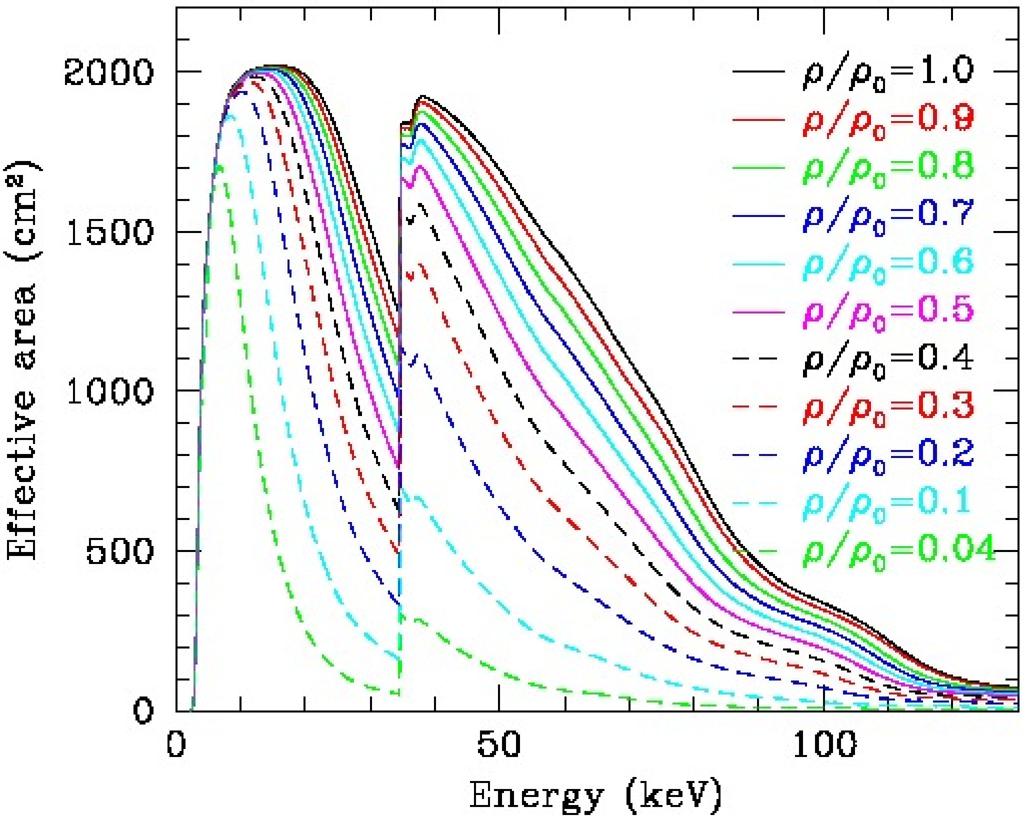
Oct15 Jan Apr Jul Oct Jan17 Apr Jul Oct Jan18 Apr Jul Oct Jan19
Resolution (%)
10
15
20
Peak Channel
200
400
600
0
200
400
600
800
1000
1200
Time (days since launch)


Oct15 Jan Apr Jul Oct Jan17 Apr Jul Oct Jan18 Apr Jul Oct Jan19
Peak Channel
250
200
150
100
50
0
200
400
600
800
1000
1200
Time (days since launch)

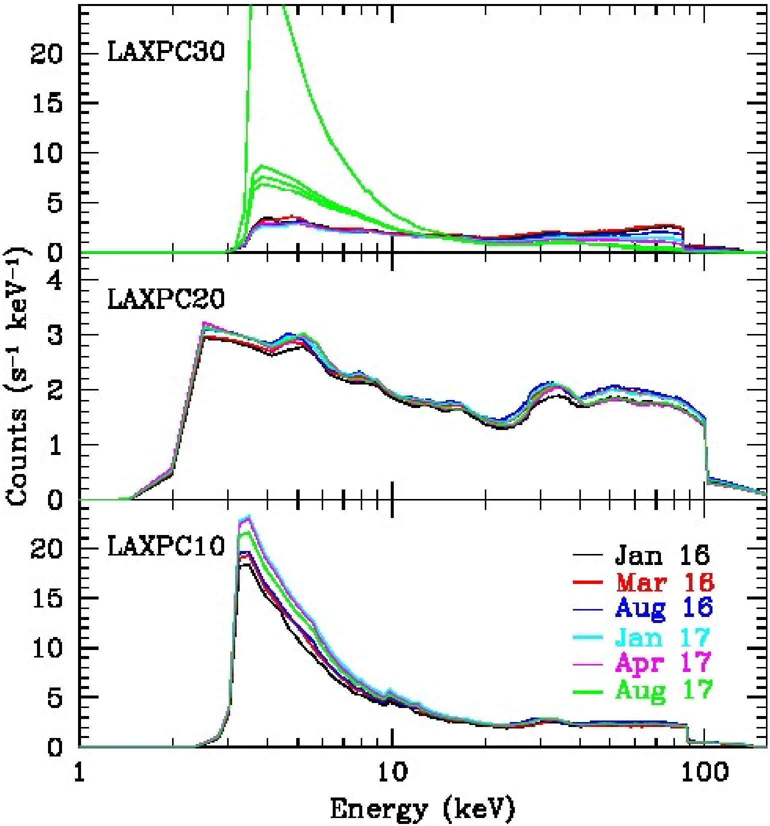


Oct15 Jan Apr Jul Oct Jan17 Apr Jul Oct Jan18 Apr Jul Oct Jan19
0.1
0.08
0.06
0.04
0.02
0
2−p2/p1
0
500
1000
Time (days since launch)

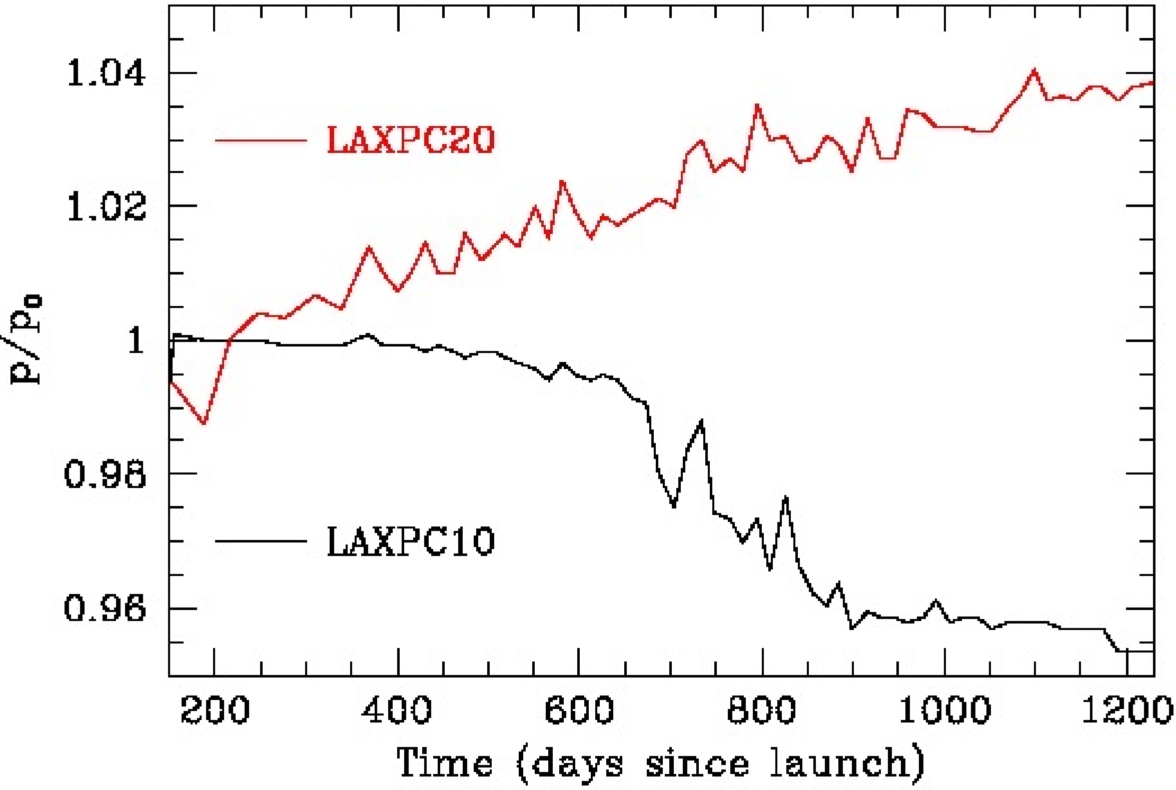

Oct15 Jan16 Apr16 Jul16 Oct16 Jan17 Apr17 Jul17 Oct17 Jan18 Apr18
1
0.8
0.6
0.4
0.2
0
ρ/ρ0
Pres Gauge
Cyg X-1
Crab
A8 60 keV peak
L-edge
Background ULD
0
200
400
600
800
1000
Time (days since launch)



ρ/ρ0=1.0
ρ/ρ0=0.9
ρ/ρ0=0.8
ρ/ρ0=0.7
ρ/ρ0=0.6
ρ/ρ0=0.5
ρ/ρ0=0.4
ρ/ρ0=0.3
ρ/ρ0=0.2
ρ/ρ0=0.1
ρ/ρ0=0.04
Effective area (cm²)
Energy (keV)
0
500
1000
1500
2000
0
50
100



LAXPC30
LAXPC20
LAXPC10
Jan 16
Mar 16
Aug 16
Jan 17
Apr 17
Aug 17
Counts (s⁻¹ keV⁻¹)
Energy (keV)


1.04
1.02
1
0.98
0.96
P/P₀
LAXPC20
LAXPC10
200
400
600
800
1000
1200
Time (days since launch)

Summary

- Spectral analysis of LAXPC data needs to account for the gain shift and density variations.

- To account for the shift in gain the background spectrum needs to be shifted to align with source before subtraction. Using only 2 calibration peaks it is not possible to get the energy to channel mapping.

- All shifts are being applied by assuming that only linear term needs to be changed to fit the 30 keV peak.

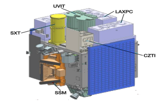
- To account for the shift in gain between the source and the response use the appropriate response with gain shift to analyse the spectrum.

- Considering the fluctuation in background count rate it is not possible to study sources fainter than a few mCrab. Even for bright sources the same will apply at high energies.
- LAXPC appears to be well suited for timing studies, although detailed timing analysis by comparison with Crab radio data needs to be performed.
- Software and response files for analysing LAXPC data are available at
  http://www.tifr.res.in/~antia/laxpc.html
  http://www.tifr.res.in/~astrosat_laxpc
  http://astrosat-ssc.iucaa.in
- Data can be downloaded from ISSDC server
  https://apps.issdc.gov.in:8181/apps/auth/login.jsp
  All TOO data and some other data sets are public.

Large Area X-ray Proportional Counter (LAXPC) AstroSat

Department of Astronomy & Astrophysics, TIFR

Launched on September 28, 2015



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India's first dedicated multi-wavelength astronomy satellite, AstroSat got launched at 10:00 AM on 28th September by PSLV C-30 from Satish Dhawan Space Centre (SDSC), SHAR. It has five science payloads which will cover from X-ray to UV wavelength. The Large Area X-ray Proportional Counter (LAXPC) is one of the major payloads on AstroSat, which covers 3-80 keV energy range. The three LAXPC units on Astrosat has large effective area and sensitivity. The LAXPC instrument will bring a wealth of data on a variety of astrophysical objects in the 3-80 keV X-ray band, with fine time resolution of 10 microseconds.

The LAXPC Detectors in clean room during integration on AstroSat.

The LAXPC instrument is designed & developed at TIFR. The principal scientific objectives of LAXPC instrument are as follows:

- Detailed studies of stellar-mass black holes with masses ~ 3-10 $M_{\odot}$ in our Galaxy

Latest News

DT-10 Status.

High Voltage of DT-30 Switched Off 08:13UT @ 08th March, 2018

Milestones

First Light of LAXPC on 19th Oct, 2015

Detector Front End Electronics Switched ON 1st Oct, 2015

Electronics Switched ON 30th Sept. 2015

STBG Switched ON 29th Sept. 2015

- Data are divided orbit wise, which is identified by the orbit during which the data are downloaded from the spacecraft and can contain data from multiple orbits before that.
- The merged data for a given observation are also available separately in one file typically during the last orbit.
- There is some time overlap between consecutive or neighbouring orbits and the software takes care of this overlap.
- In some cases there are time gaps between two successive orbits which are filled in subsequent orbit and it may be necessary to delete data for some orbits.

- Three different software are available for processing level-1 data.

  LAXPClevel2DataPipeline: Developed by Biswajit Paul (RRI) with support from SAC, Ahmedabad (contact person: B. Paul)

  LaxpcSoft: developed at TIFR and IUCAA has two packages with some overlap

  `laxpcl1.f` and `backshiftv3.f` developed by H. M. Antia to generate, event file, light curve, spectrum, background, GTI, etc.

  A suit of packages for calculating light curve, spectrum, event file, power density spectrum, time lag, background model for faint sources etc., based on `laxpcl1.f` developed by R. Misra (IUCAA)

LAXPC data

- The level-1 data is available from the ISSDC site and can be used directly by any of the software for analysing LAXPC data.
- The data are grouped into observation ID which defines a fixed pointing of the satellite. Each observation can have multiple orbits and data for each orbit are available in a separate tar file. In addition there are merged orbits which combine the data from all orbits into a single file.
- A typical file name for level-1 data is
  `LEVL1AS1LXP20190126A05_159T01_9000002678_18024.tar_V1.0`
  This starts with the satellite, instrument, date (the UTC date on which the observation started), obsID and orbit no.
  V1.0 is for individual orbit and V2.1 for merged orbit.

- When the files are extracted from tar file it will create a directory

  `20190126_A05_159T01_9000002678_level1/laxpc`

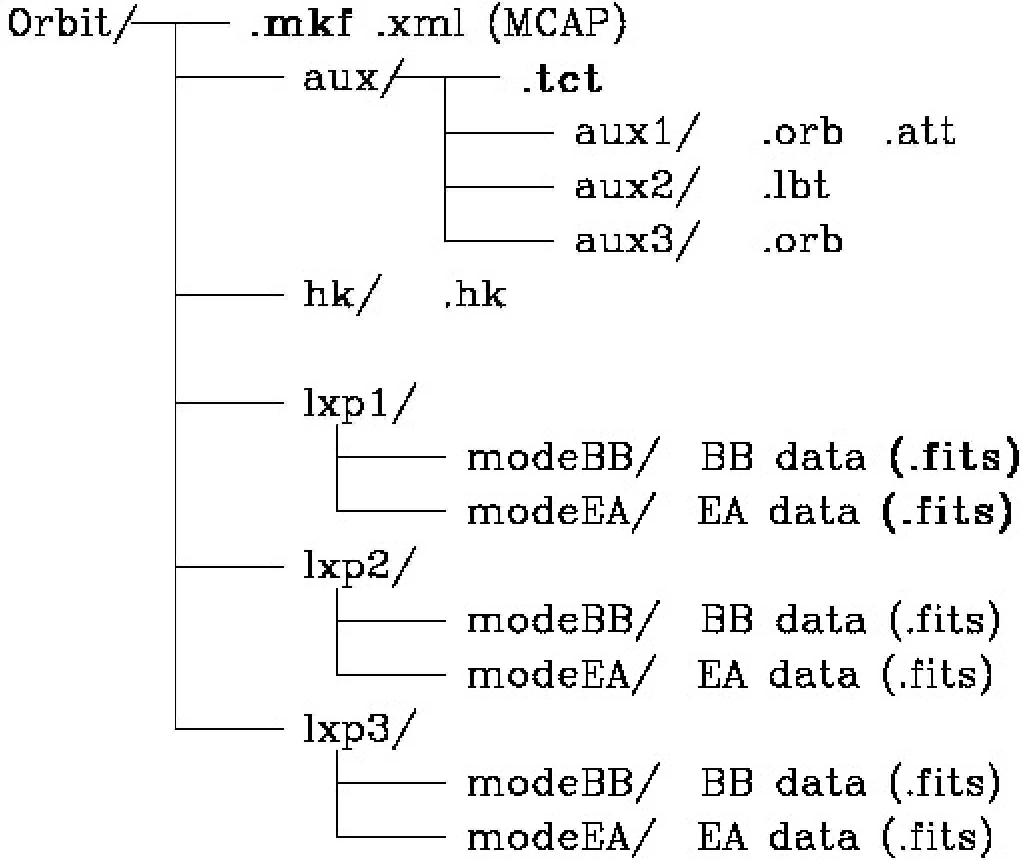
  At next level there is a subdirectory for each orbit, 5-digit name, e.g., 18024 etc.

  Within each orbit the

  `AS1A05_159T01_9000002678lxp_level1.mkf`

  file which contains information about satellite and basic parameters, like HV for the detectors as a function of UTC time.

- Apart from `.mkf` file there are 5 other subdirectories


Orbit/
.mkf .xml (MCAP)
aux/
.tct
aux1/ .orb .att
aux2/ .lbt
aux3/ .orb
hk/ .hk
lxp1/
modeBB/ BB data (.fits)
modeEA/ EA data (.fits)
lxp2/
modeBB/ BB data (.fits)
modeEA/ EA data (.fits)
lxp3/
modeBB/ BB data (.fits)
modeEA/ EA data (.fits)