Large Area X-ray Proportional Counter (LAXPC)

Instrument, Calibration and Software

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

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

LAXPC Overview

- Non-imaging instrument designed and developed at TIFR to study X-ray binaries, Pulsars, Active Galactic Nuclei etc.
- Energy range: 3–80 keV
- Field of view determined by a collimator of about $1^{\circ} \times 1^{\circ}$.
- Energy resolution of 15–20% around 30 keV
- Total effective area of about 6000 cm^2 around 15 keV.
- Time resolution : 10 μs, each photon is recorded
- Total Mass : 414 kg, Total Power : 65 W

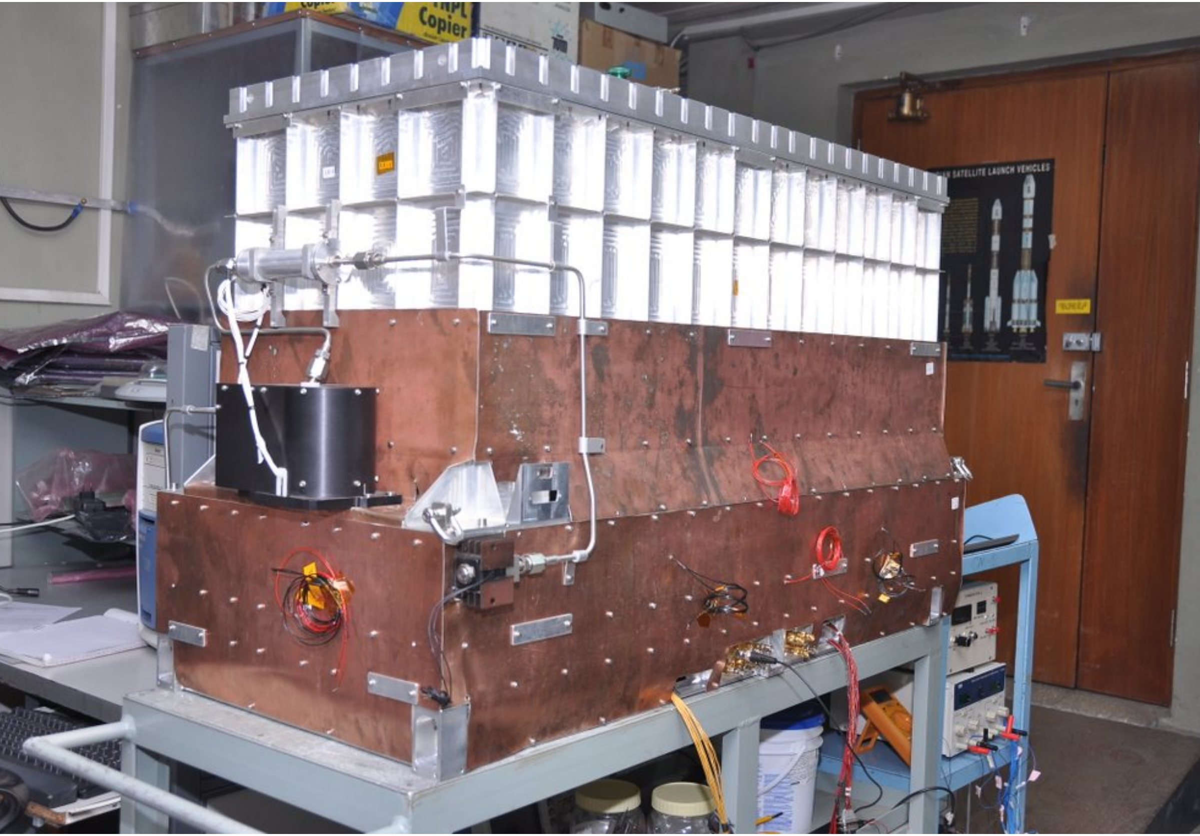
- LAXPC payload consists of 3 large area X-ray proportional counters

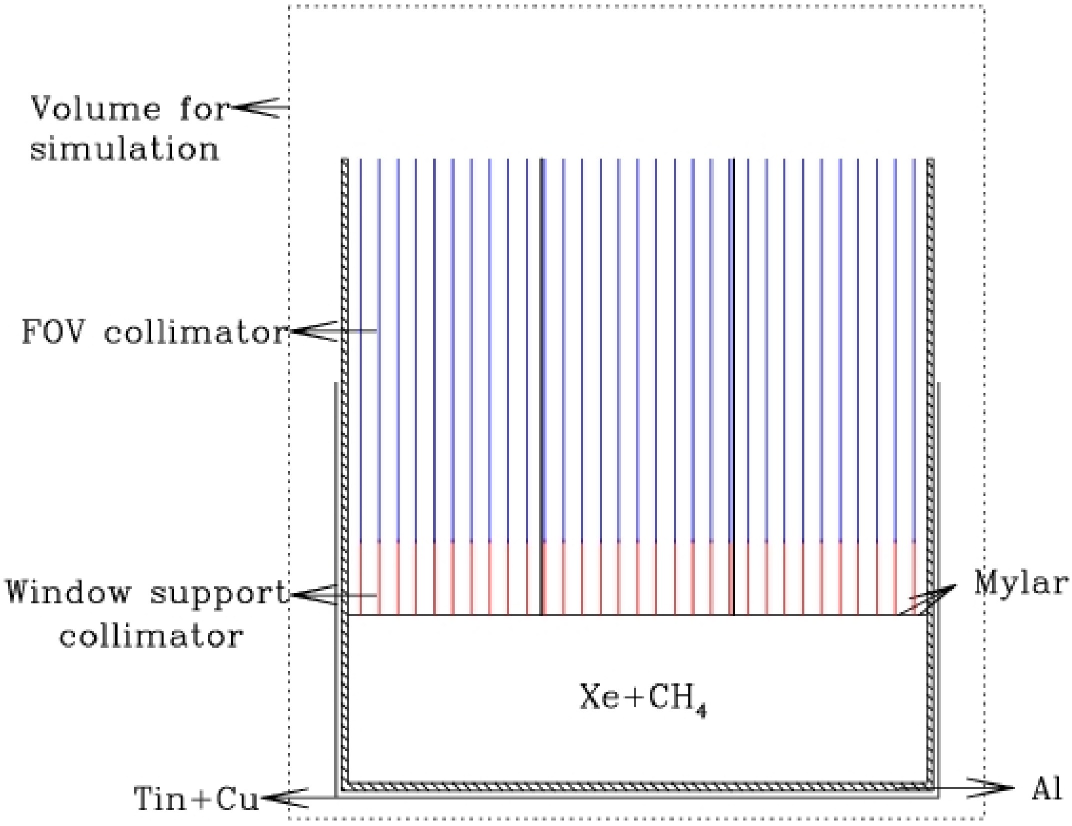
- Detector size: $100 \times 39 \times 16.5$ cm filled with a mixture of Xenon (90%) and Methane (10%) at a pressure of 2 atmospheres.

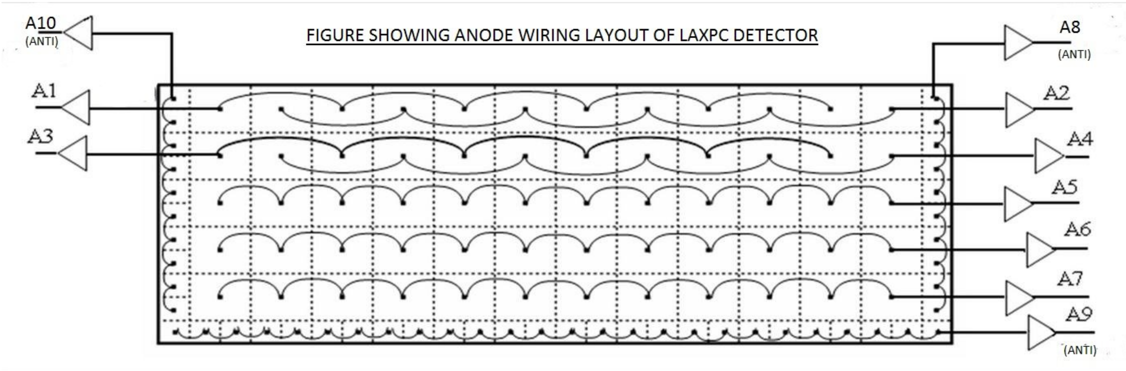
- Top of the detector is covered by a $50\ \mu$m thick Mylar window

- 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.

- Simulations use a volume of $120 \times 60 \times 80$ cm enclosing the entire detector.


Copier
SATELLITE LAUNCH VEHICLES


Volume for simulation
FOV collimator
Window support collimator
Mylar
Xe+CH4
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.

  Xe $K = 34.58$ keV, $K_\alpha = 29.8$ keV, $K_\beta = 33.64$ keV

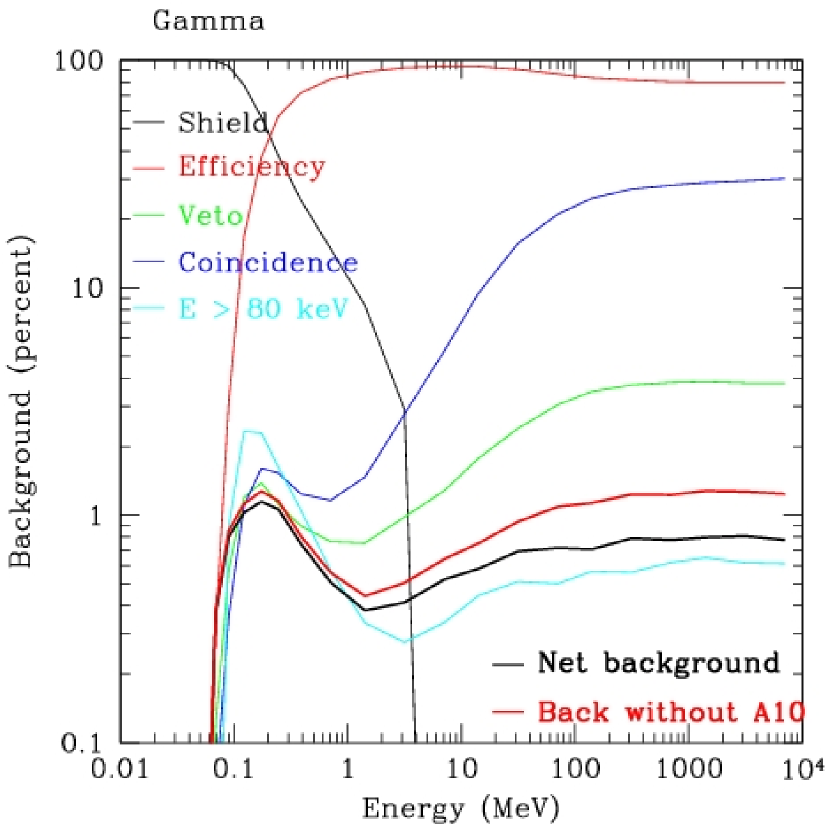
Simulation of background

- 10^6 particles uniformly distributed over entire surface area $120 \times 60 \times 80$ cm and in 2π solid angle

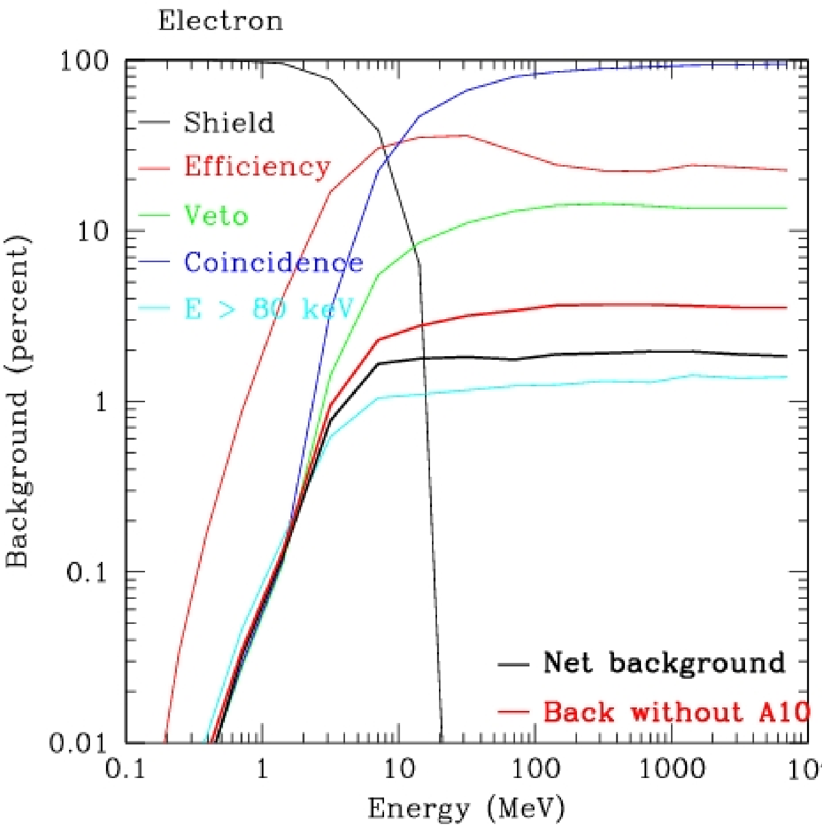
  about 233333 ± 1177 particle reach active detector volume $100 \times 39 \times 16.5$ cm

- Following factors contribute to background rejection
  1. The Shield
  2. The Detector efficiency
  3. Coincidence
  4. Veto layers
  5. Energy deposited > 80 keV

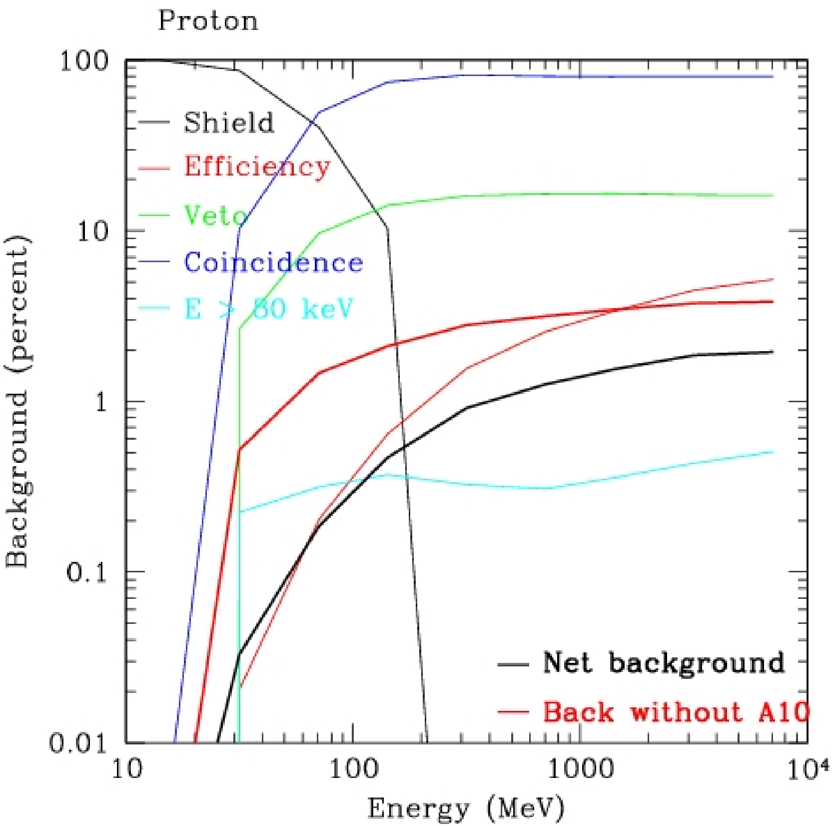
- Simulation were done with and without veto-anode A10 as in LX10 detector A10 has been disabled.



Gamma
Shield
Efficiency
Veto
Coincidence
E > 80 keV
Net background
Back without A10
Background (percent)
100
10
1
0.1
0.01
0.1
1
10
100
1000
10⁴
Energy (MeV)

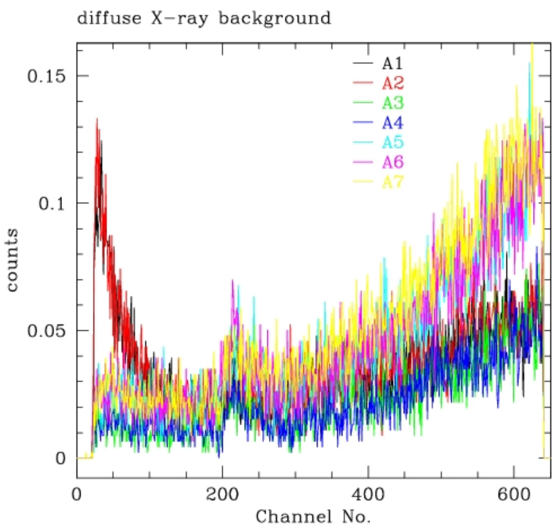


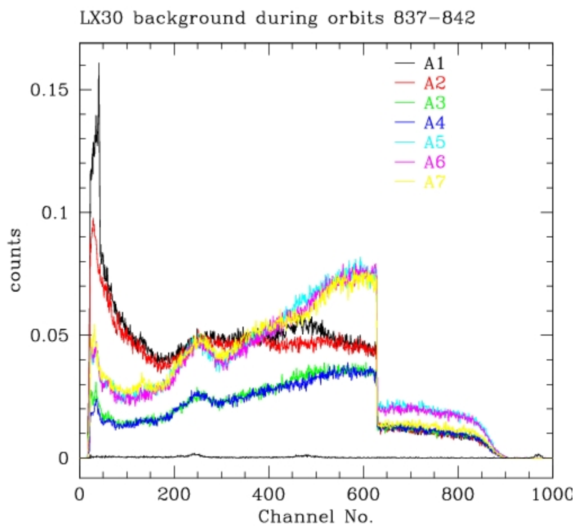
Electron
Shield
Efficiency
Veto
Coincidence
E > 80 keV
Net background
Back without A10
Background (percent)
Energy (MeV)
100
10
1
0.1
0.01
0.1
1
10
100
1000
10^4

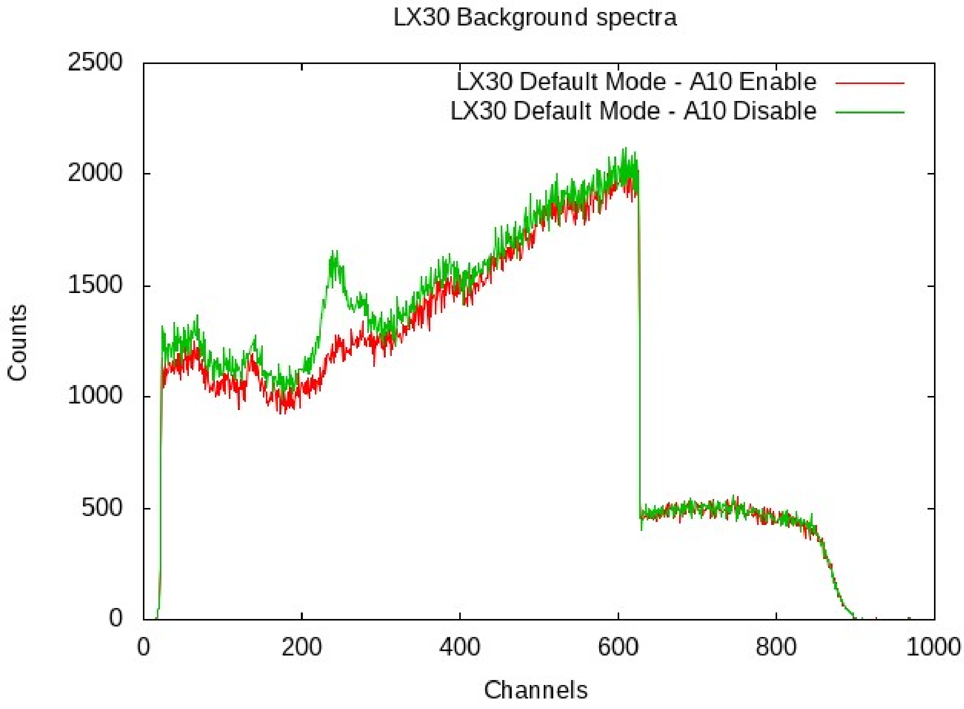

Proton
Shield
Efficiency
Veto
Coincidence
E > 80 keV
Net background
Back without A10
Background (percent)
100
10
1
0.1
0.01
10
100
1000
10^4
Energy (MeV)

- 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.

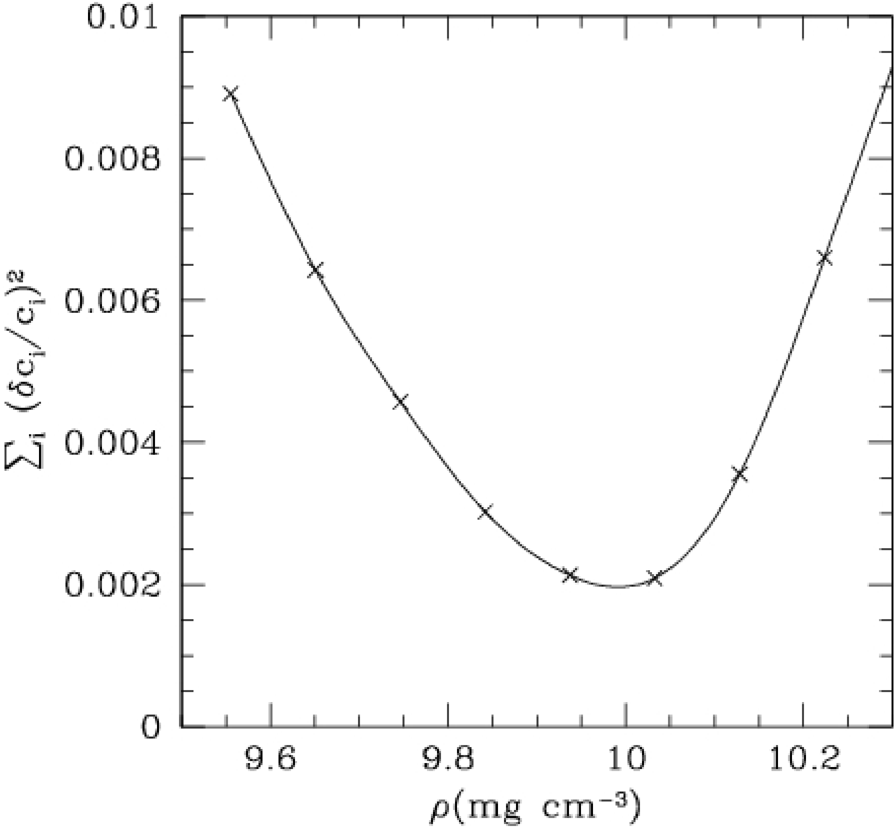
$$n_c = e_0 + e_1 E_p (1 + e_2 E_p)$$

- 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
$\sum_i (\delta c_i/c_i)^2$
ρ(mg cm^{-3})

- The channel to energy mapping is determined by fitting

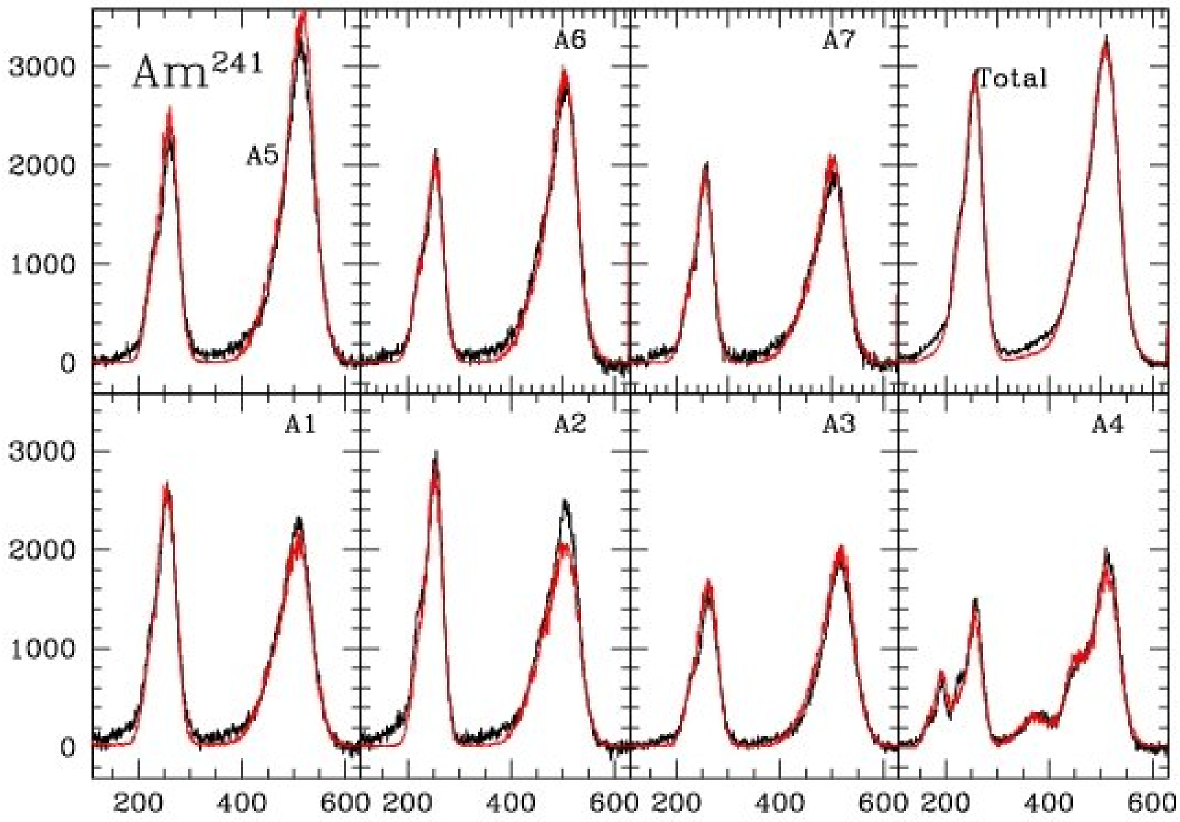
$$n_c = e_0 + e_1 E_p (1 + e_2 E_p)$$

  Here, e_0, e_1, e_2 and the resolution σ_i are fitted using calibration data from radioactive sources.

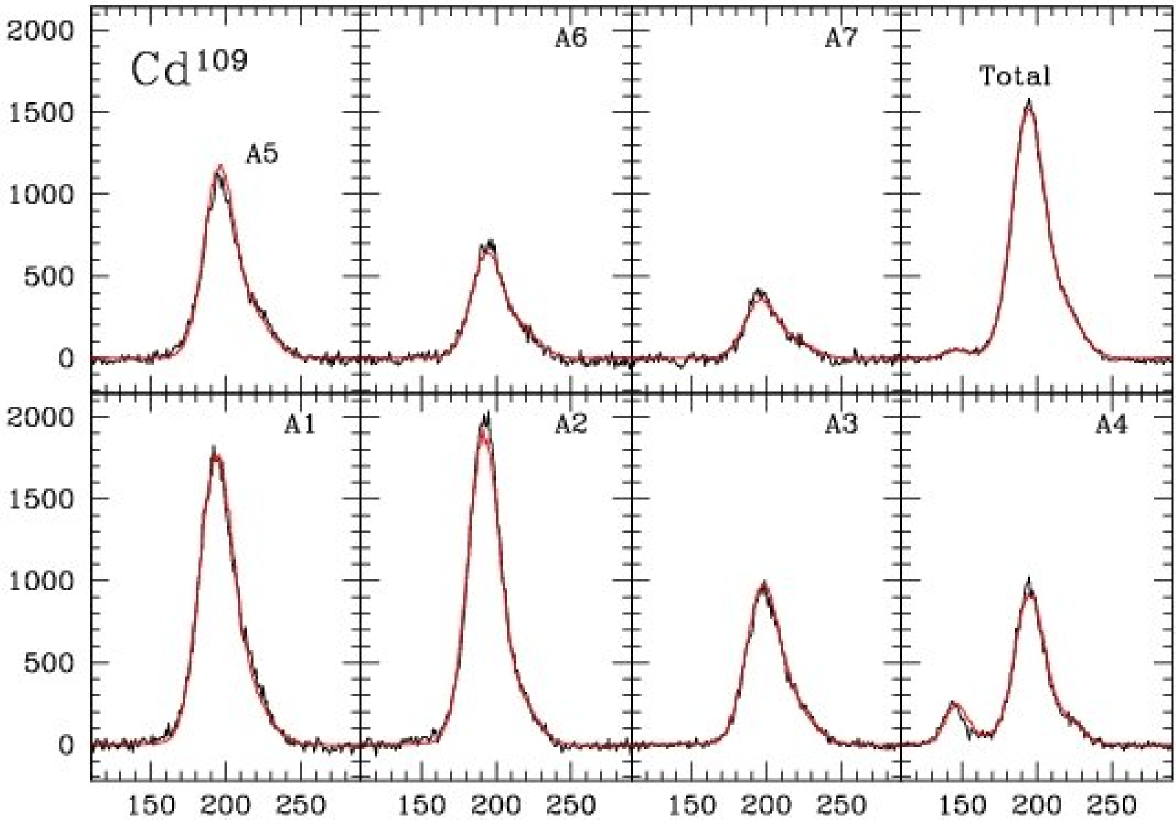
- The resolution as a function of energy is determined by fitting a linear spline with 3 knots to $\sigma^2(E^{-1})$

- 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.

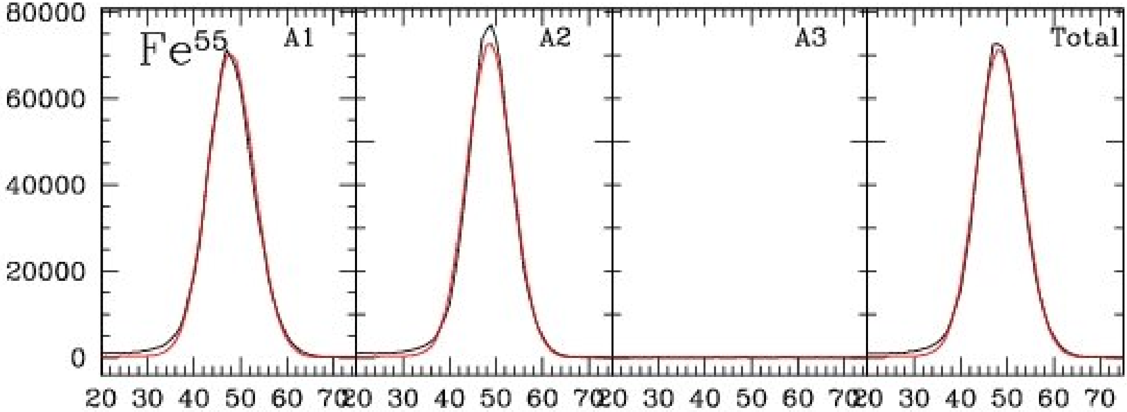
- To calculate detector response for other energies we need $\sigma(E,T), n_c(E,T)$



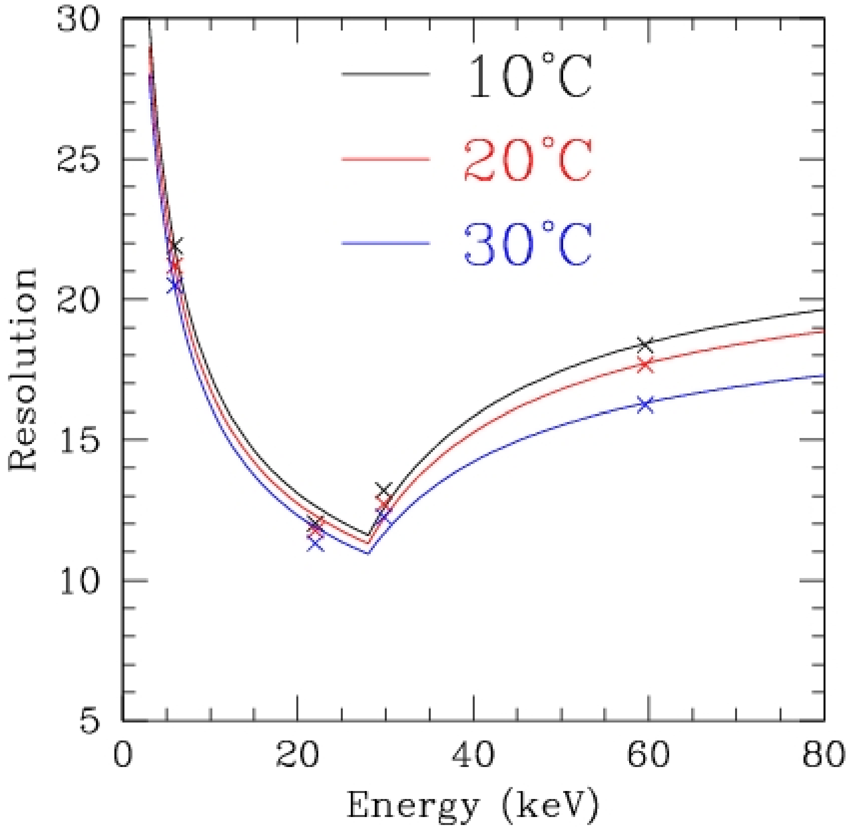
Am^{241}
A5
A6
A7
Total
A1
A2
A3
A4
3000
2000
1000
0
200
400
600



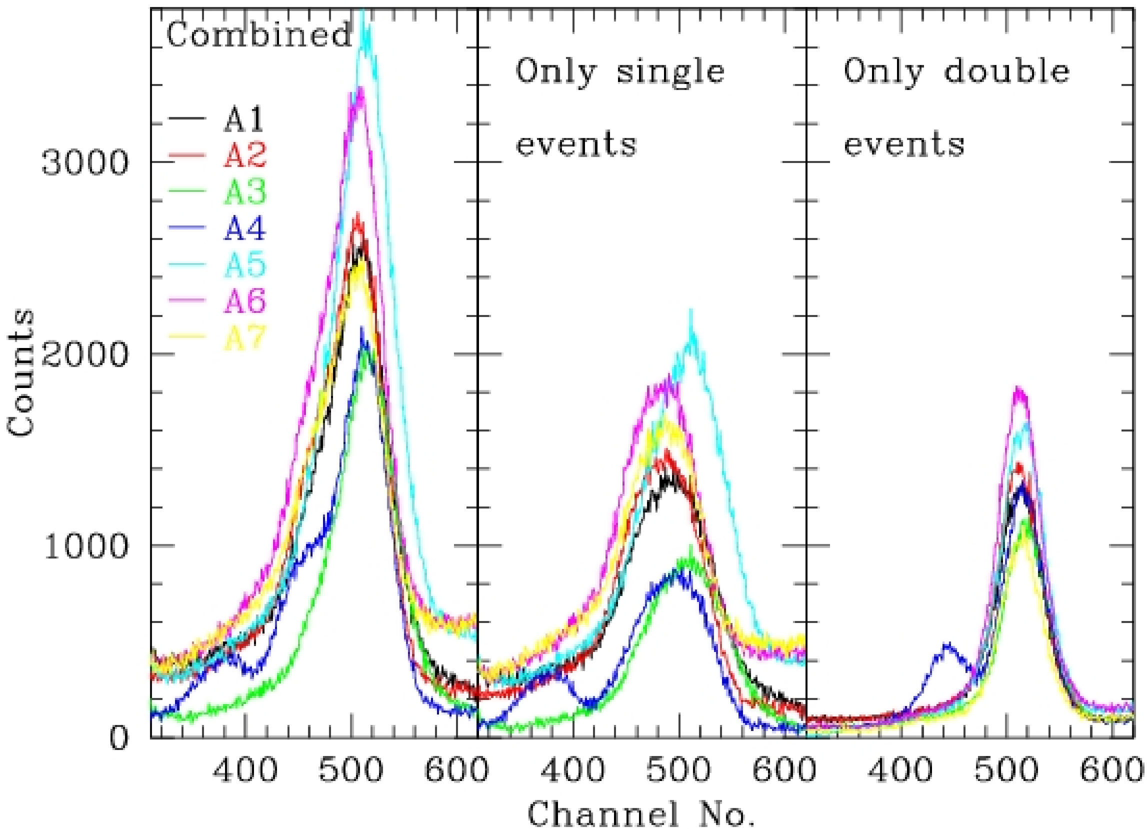
Cd^{109}
A5
A6
A7
Total
A1
A2
A3
A4
2000
1500
1000
500
0
150
200
250

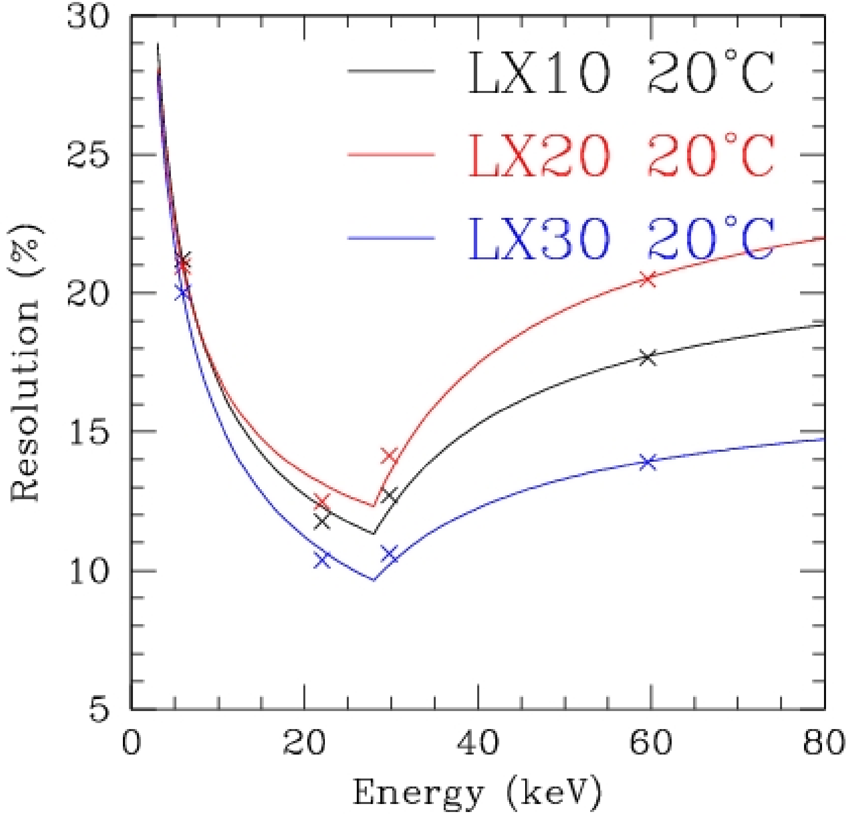


80000
60000
40000
20000
0
Fe^{55}
A1
A2
A3
Total
20 30 40 50 60 70

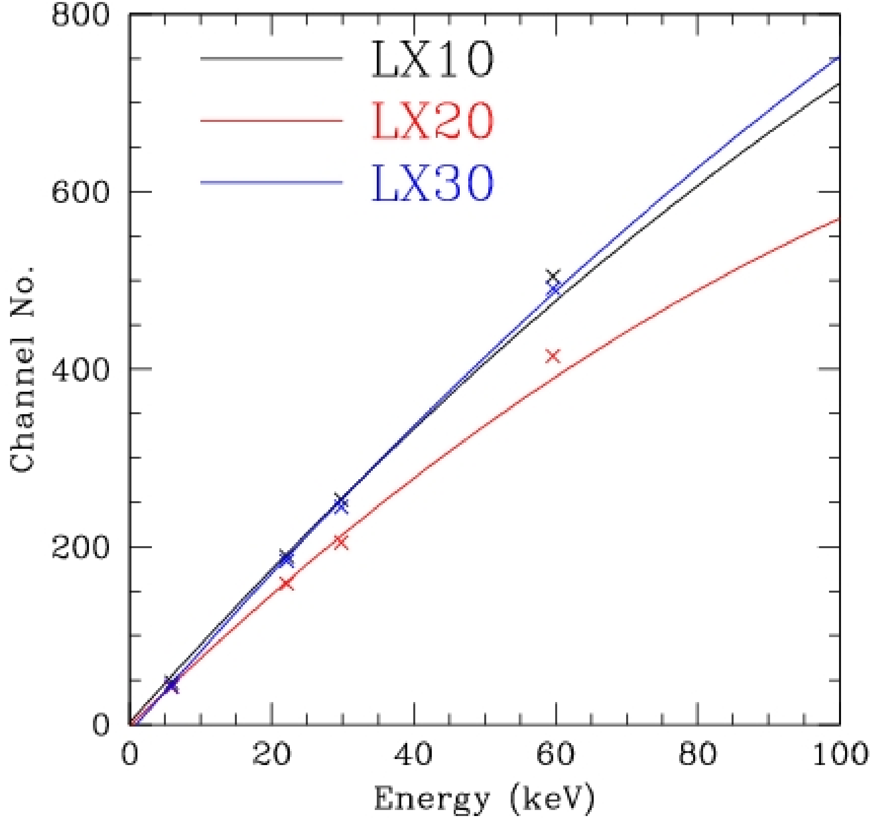


LAXPC10


Combined
Only single events
Only double events
A1
A2
A3
A4
A5
A6
A7
Counts
0
1000
2000
3000
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

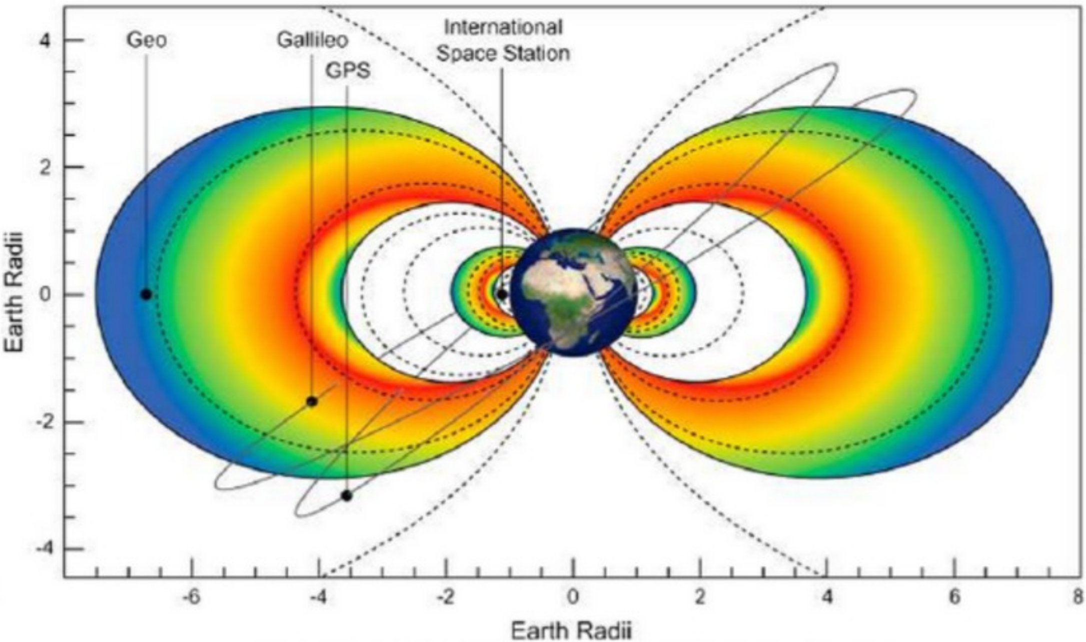


LX10
LX20
LX30
Channel No.
Energy (keV)
0
200
400
600
800
0
20
40
60
80
100

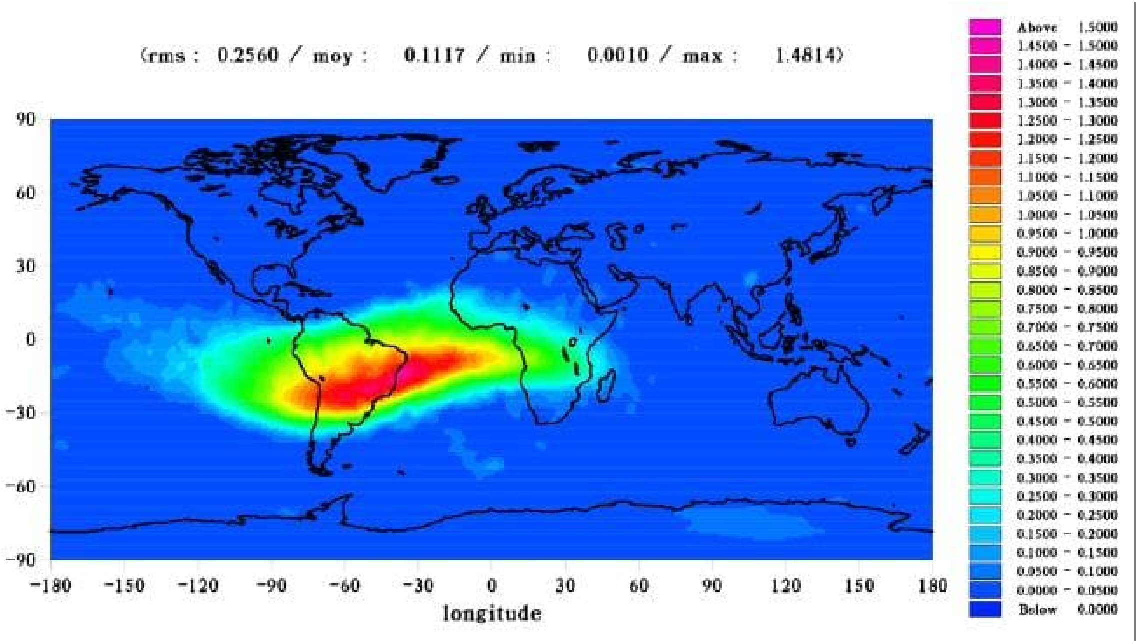
LAXPC/AstroSat time-line

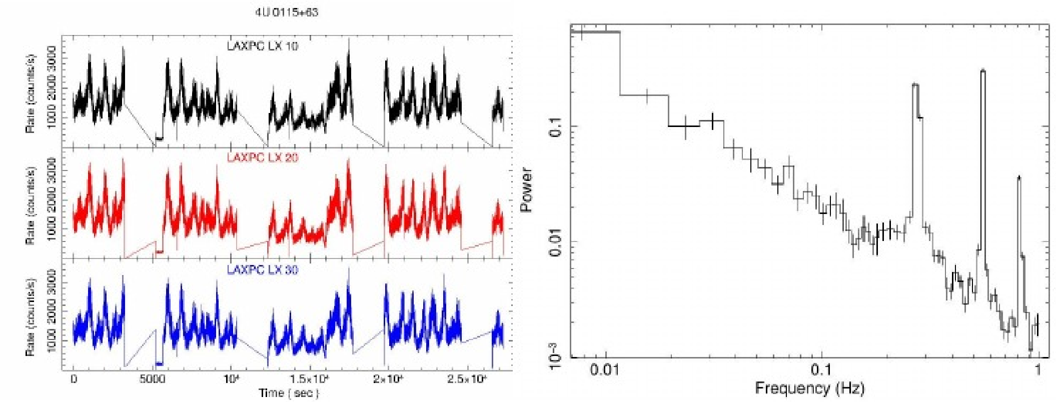
- All flight models delivered to ISRO by October 2014
- AstroSat launched on 28 Sep 2015 at 10:00 hrs from Shriharikota on PSLV C30 in a 650 km orbit with inclination of 6°.
- The System Time Base Generator (STBG) powered on 29 Sep 2015
- Processing electronics switched on 30 Sep 2015
- High-Voltage turned on 19 Oct 2015 (First light)
- Nominal life-time of AstroSat is 5 years

The Earth's Electron Radiation Belts



The South Atlantic Anomaly (SAA)





The light curve of 4U 0115-63 in outburst mode on 24 October 2015 and its power density spectrum.

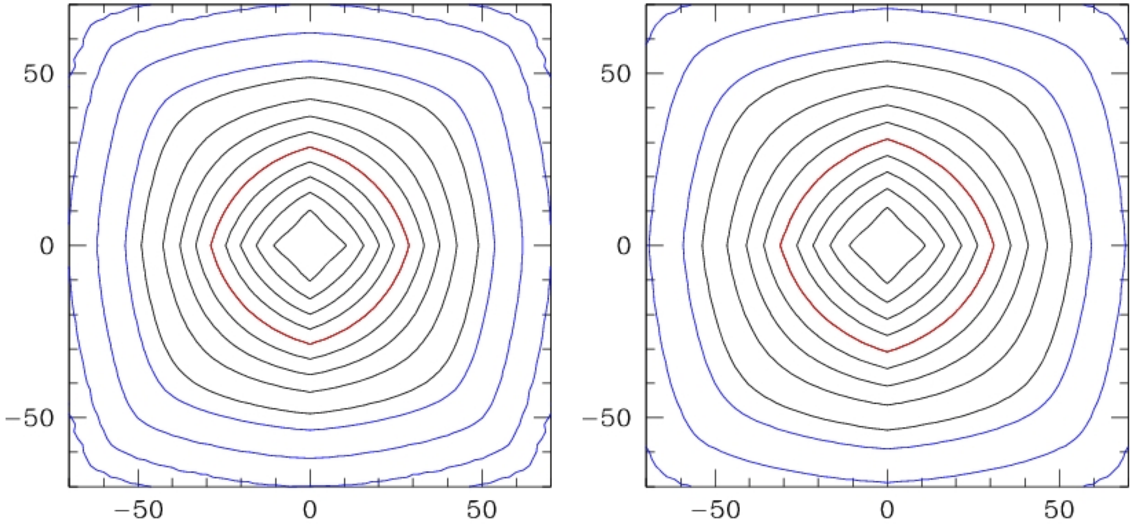
- AstroSat orbit is about 97 min

- 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.

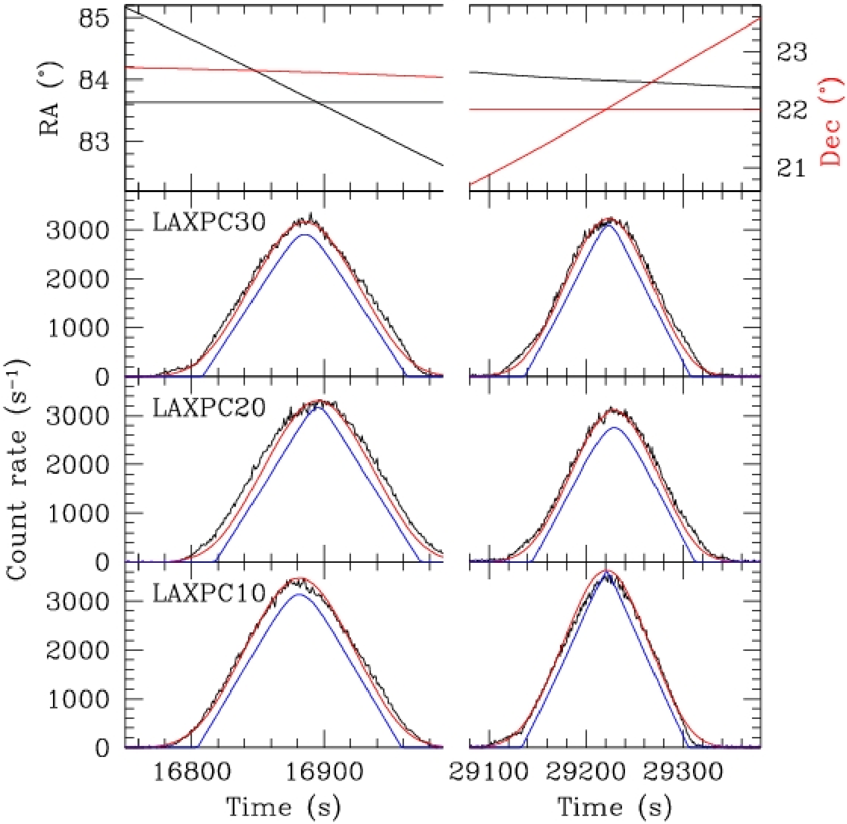
- In addition depending on the source position the source may be behind the Earth for some time, which gives a typical observations efficiency of 45%.

Calibration of the Field of View

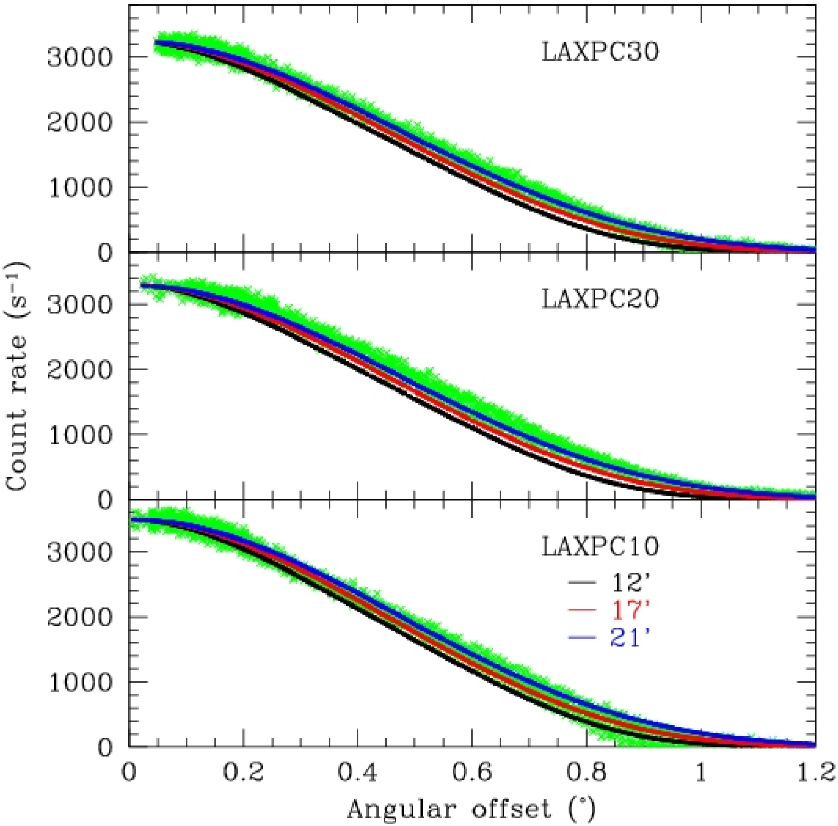


15 keV: FWHM $= 55' = 0.92°$ 50 keV: FWHM $= 63' = 1.05°$

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)

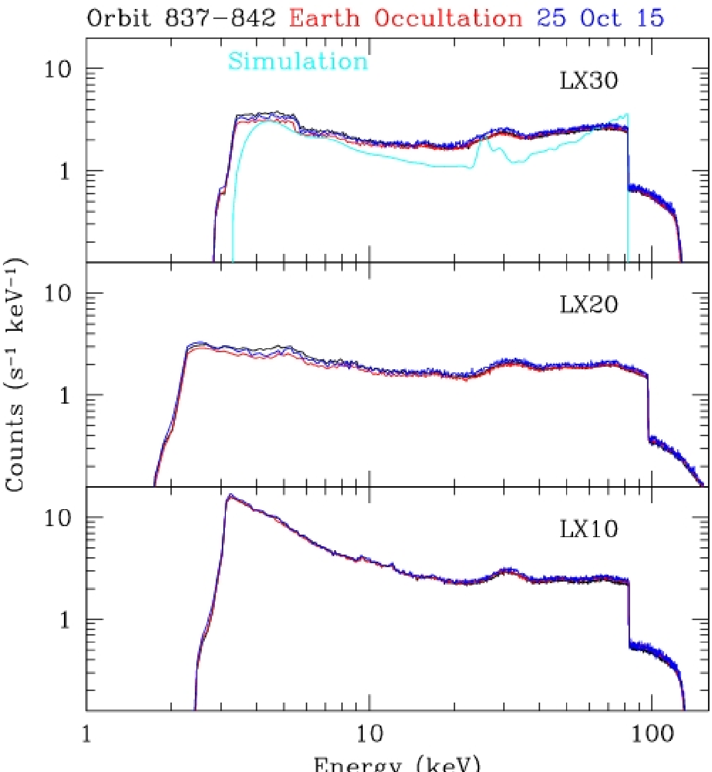

LAXPC30
LAXPC20
LAXPC10
12'
17'
21'
Count rate (s^{-1})
Angular offset (°)
0
1000
2000
3000
0
0.2
0.4
0.6
0.8
1
1.2

- 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

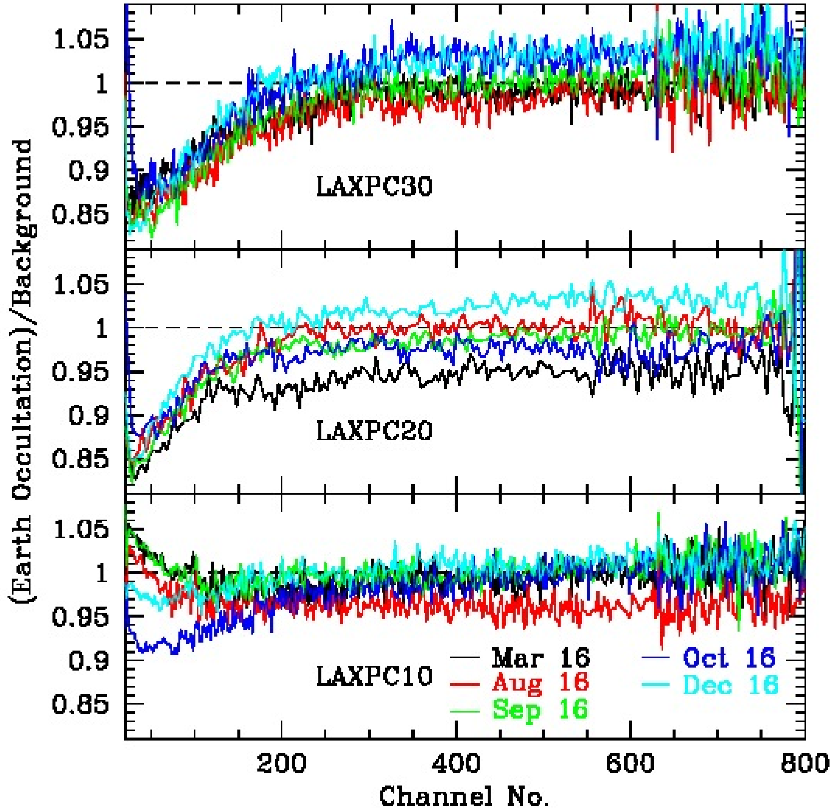


Count rates:

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

Earth Occultation

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

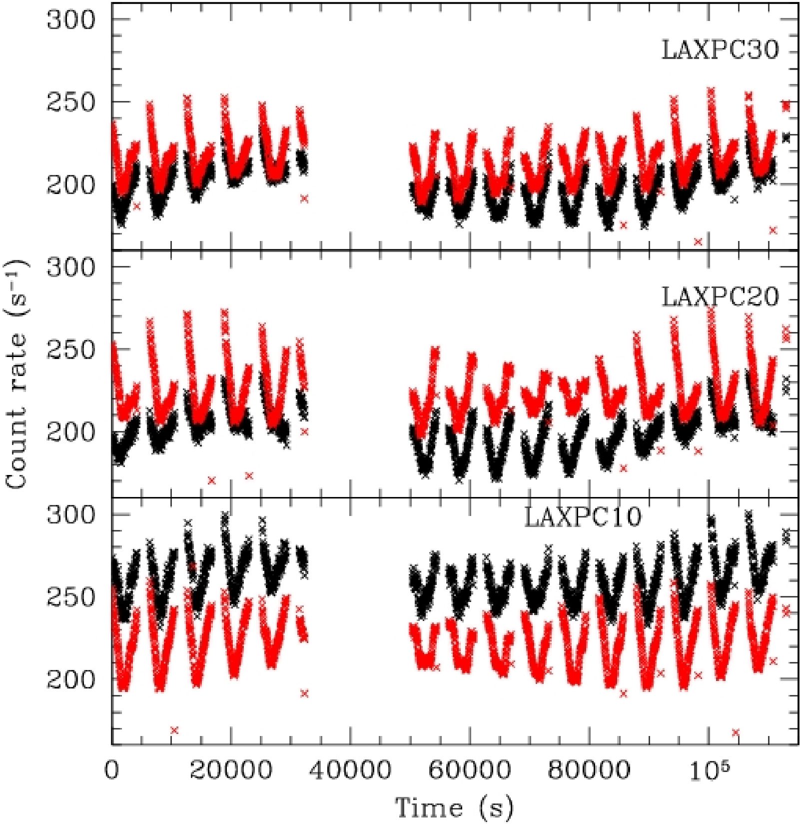


LAXPC30
LAXPC20
LAXPC10
Mar 16
Aug 16
Sep 16
Oct 16
Dec 16
(Earth Occultation)/Background
Channel No.
1.05
1
0.95
0.9
0.85
200
400
600
800

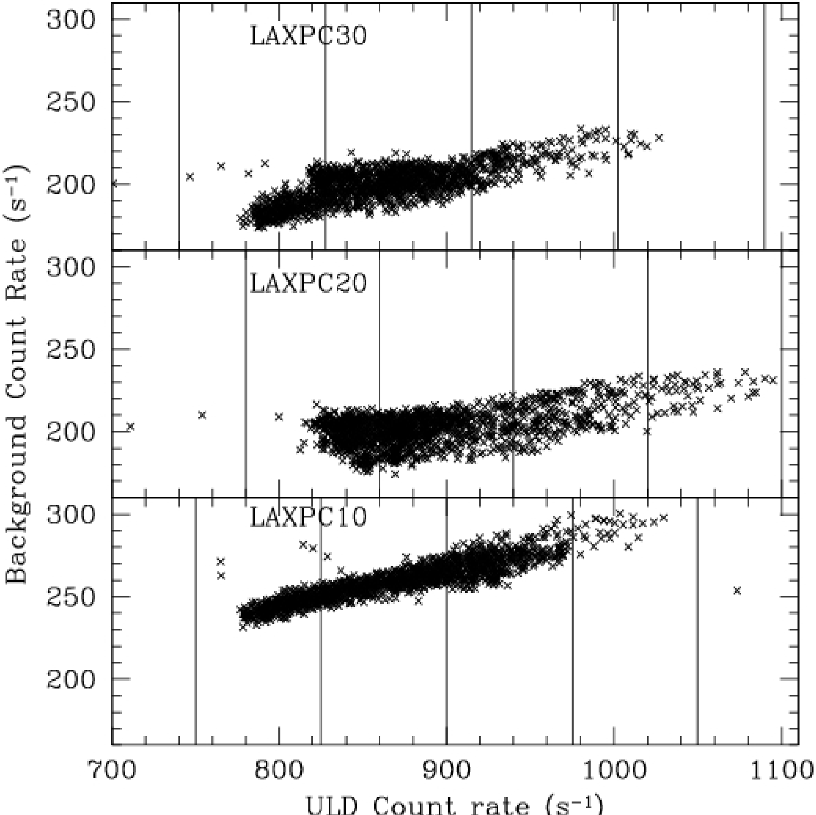
Background Model

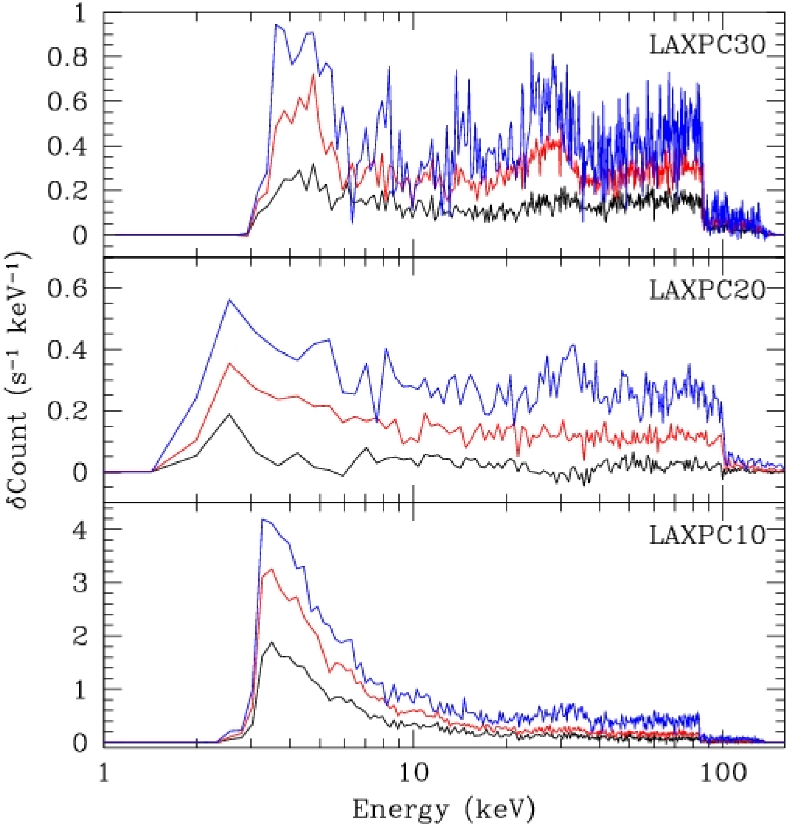
- Different models have been tried

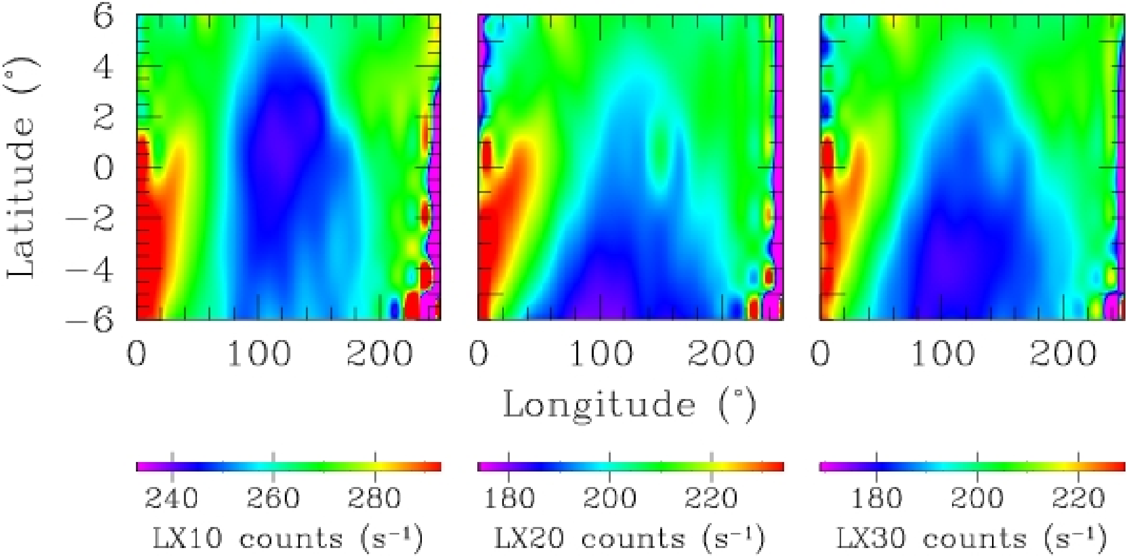
1. Using ULD (Upper Level Discrimination) counts (sensitive to gain shift)
2. Fitting background count rate as a function of latitude and longitude (sensitive to temporal variation)
3. For faint sources, instead of ULD we can use counts at high energy to scale the background (R. Misra)
4. Observation during Earth Occultation (affected by Earth albedo/shadow)



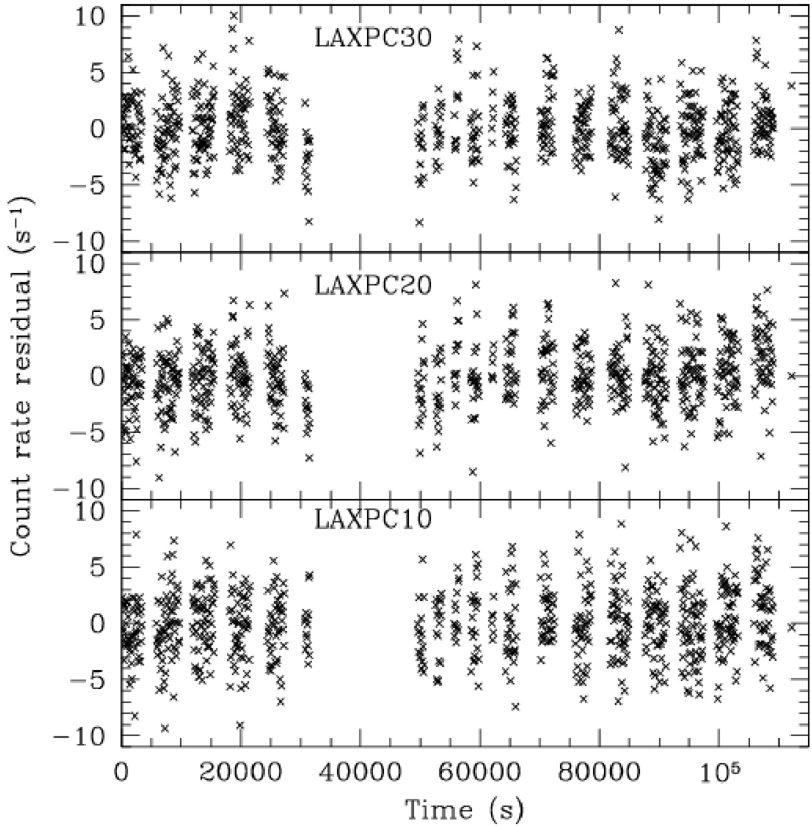
LAXPC30
LAXPC20
LAXPC10
Count rate (s⁻¹)
Time (s)
300
250
200
0
20000
40000
60000
80000
10⁵


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

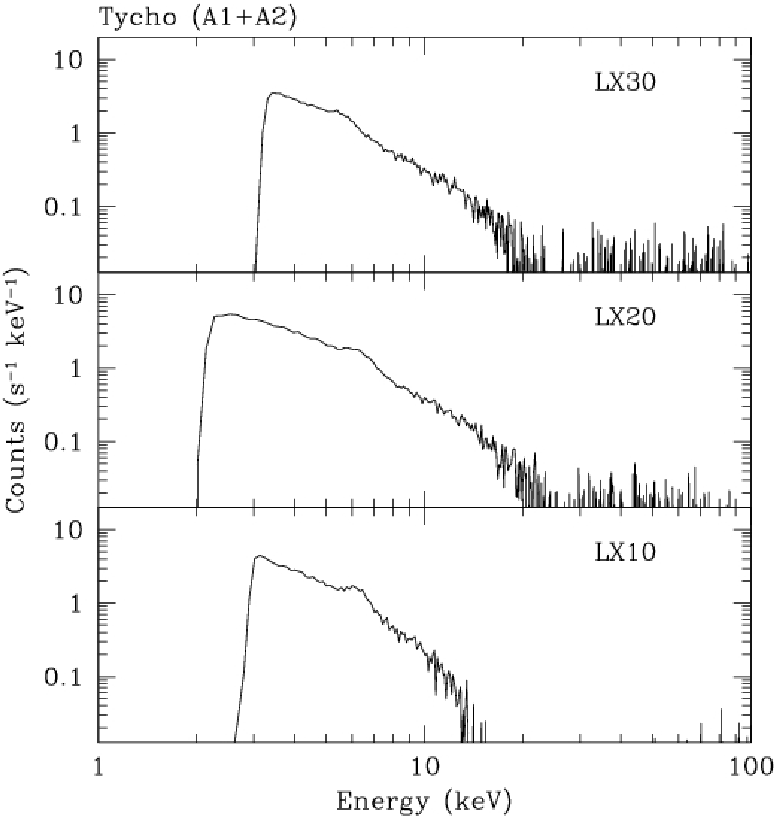

LAXPC30
LAXPC20
LAXPC10
δCount (s⁻¹ keV⁻¹)
Energy (keV)
1
10
100
0
0.2
0.4
0.6
0.8
1
0
0.2
0.4
0.6
0
1
2
3
4



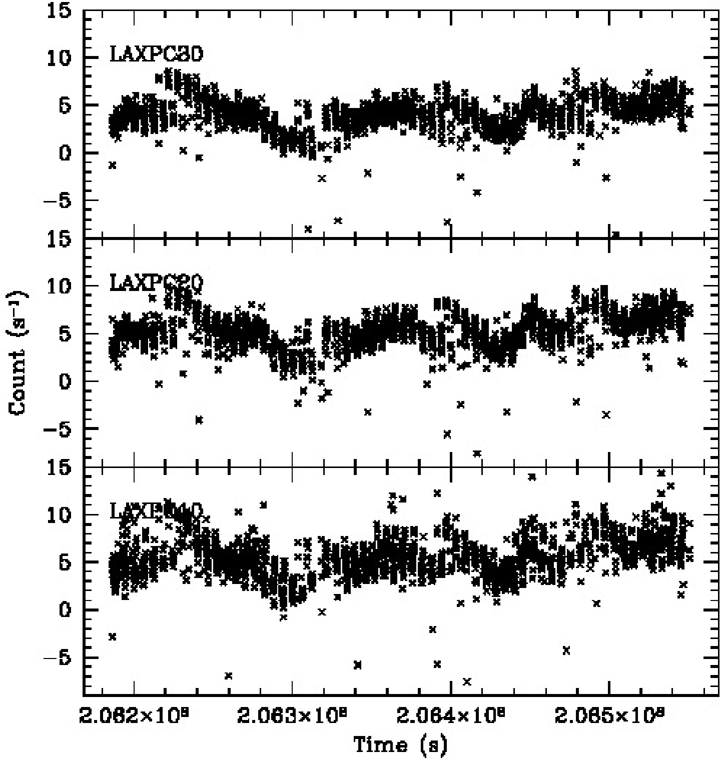
Latitude (°)
6
4
2
0
−2
−4
−6
0
100
200
Longitude (°)
240
260
280
LX10 counts (s⁻¹)
180
200
220
LX20 counts (s⁻¹)
180
200
220
LX30 counts (s⁻¹)



LAXPC30
LAXPC20
LAXPC10
Count rate residual (s^{-1})
10
5
0
−5
−10
0
20000
40000
60000
80000
10^5
Time (s)

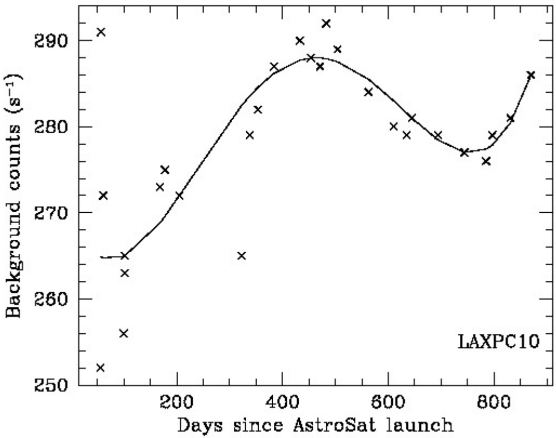


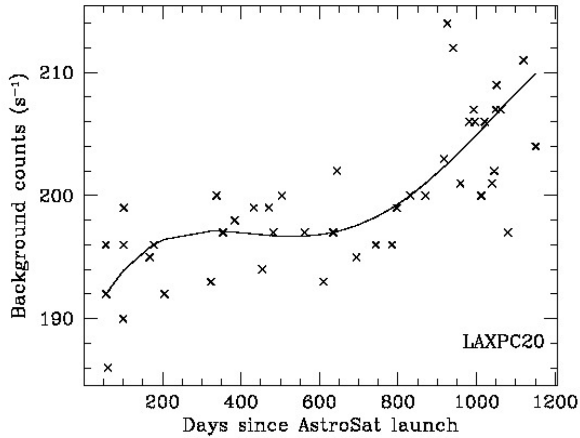
Tycho (A1+A2)
LX30
LX20
LX10
10
1
0.1
Counts (s⁻¹ keV⁻¹)
1
10
100
Energy (keV)


LAXPC30
LAXPC20
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.

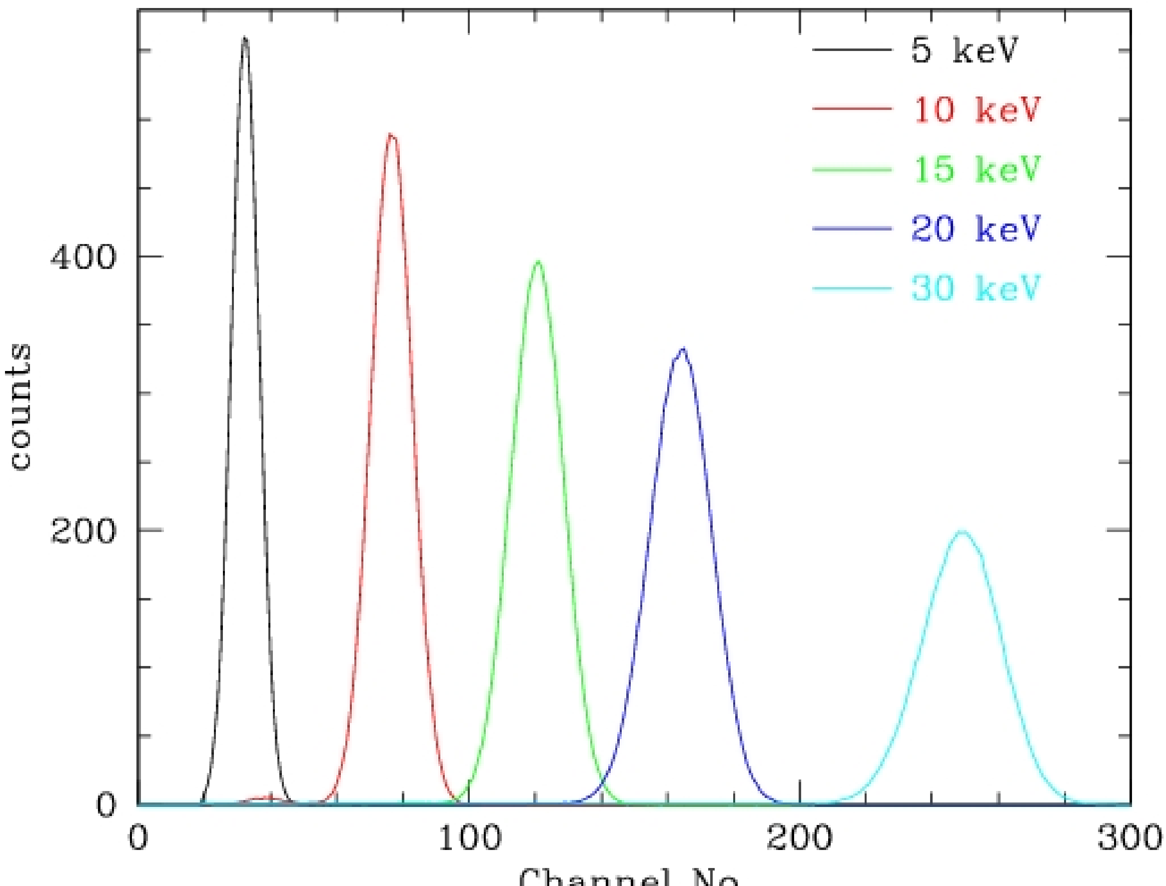
- To take care of even-odd fluctuation in counts with channel the no. of channels is reduced to 512 for LX10, LX30, and to 256 for LX20.

- The effect of dead-time is incorporated in the spectrum.

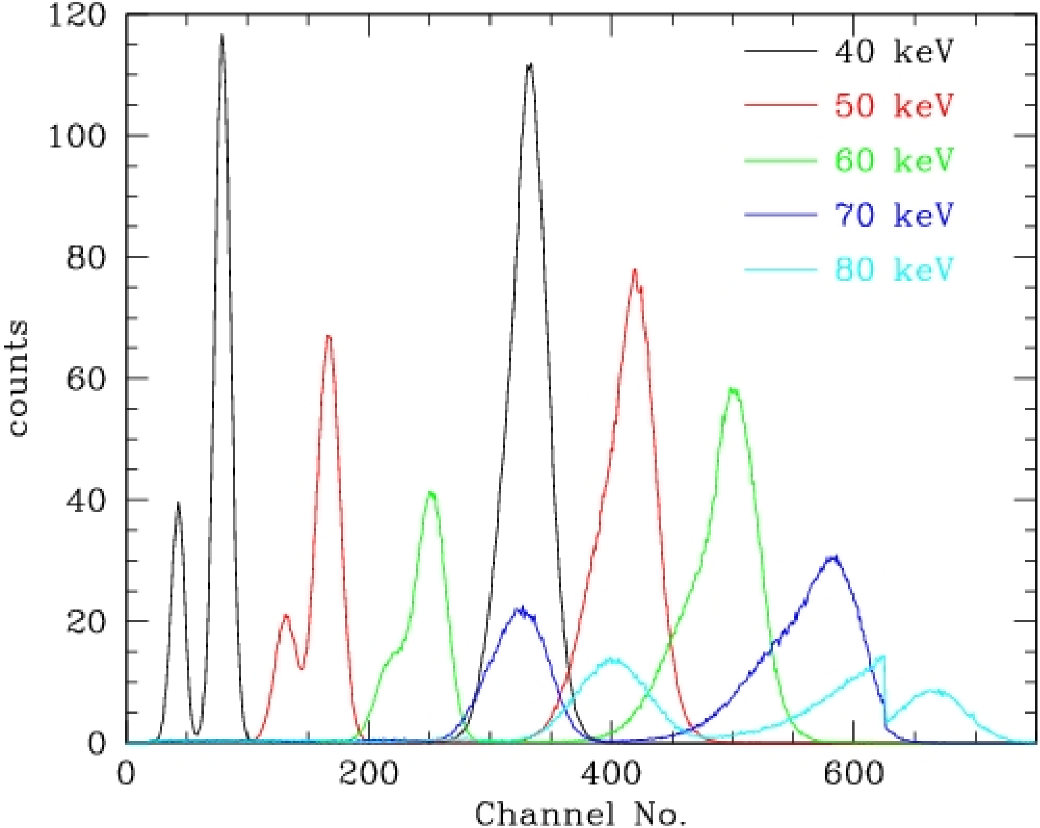
- Inclusion of flux leakage from side of the detector which gives a hump around 30 keV from Xenon K X-rays.

- To account for leak in LX30 the responses are generated with different density.

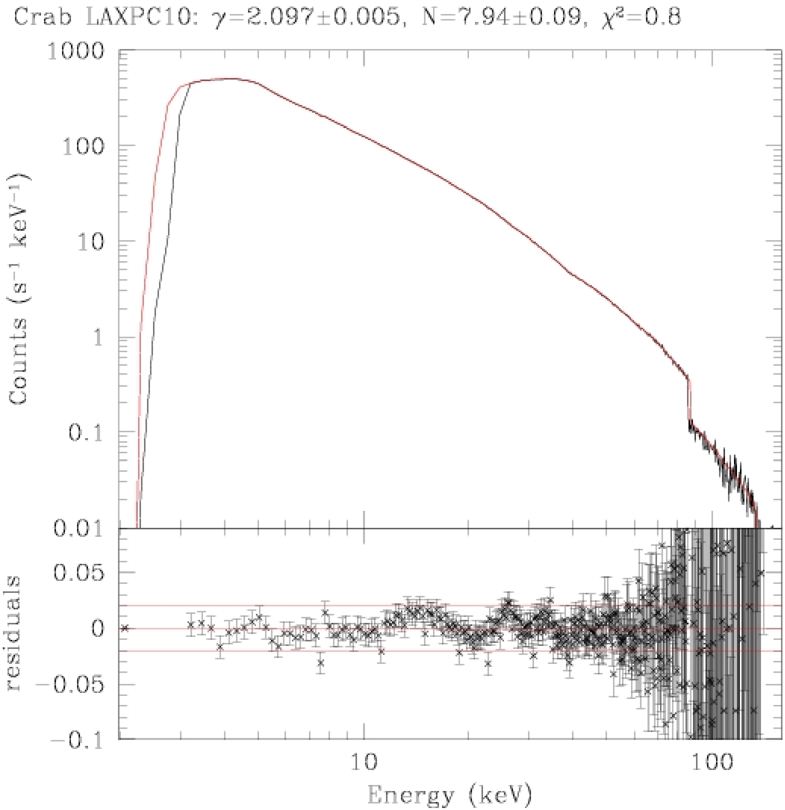
- The normalisation for effective area is estimated by cross-calibration with NuSTAR observation.



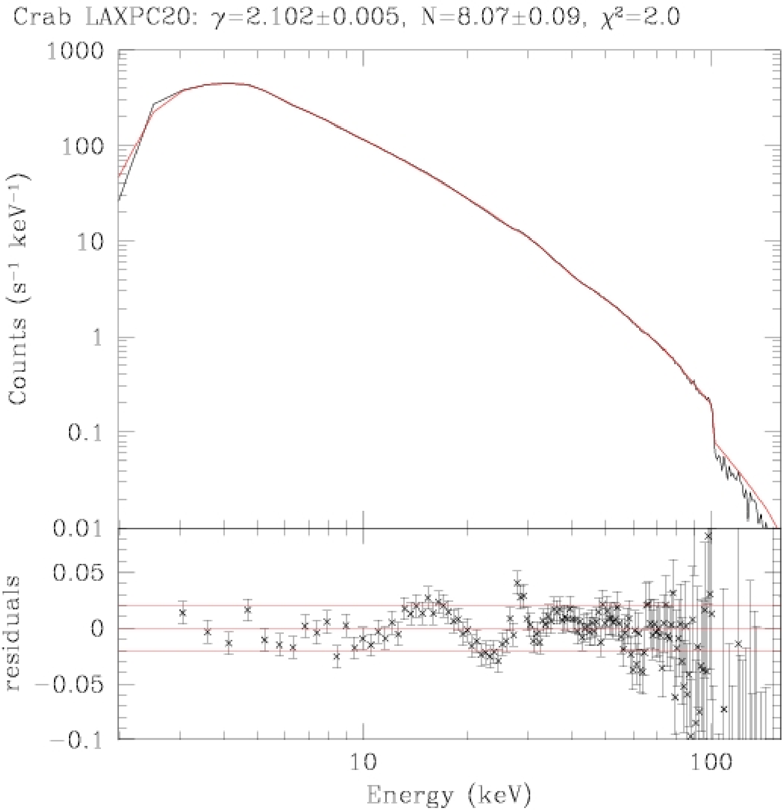
5 keV
10 keV
15 keV
20 keV
30 keV
counts
400
200
0
0
100
200
300



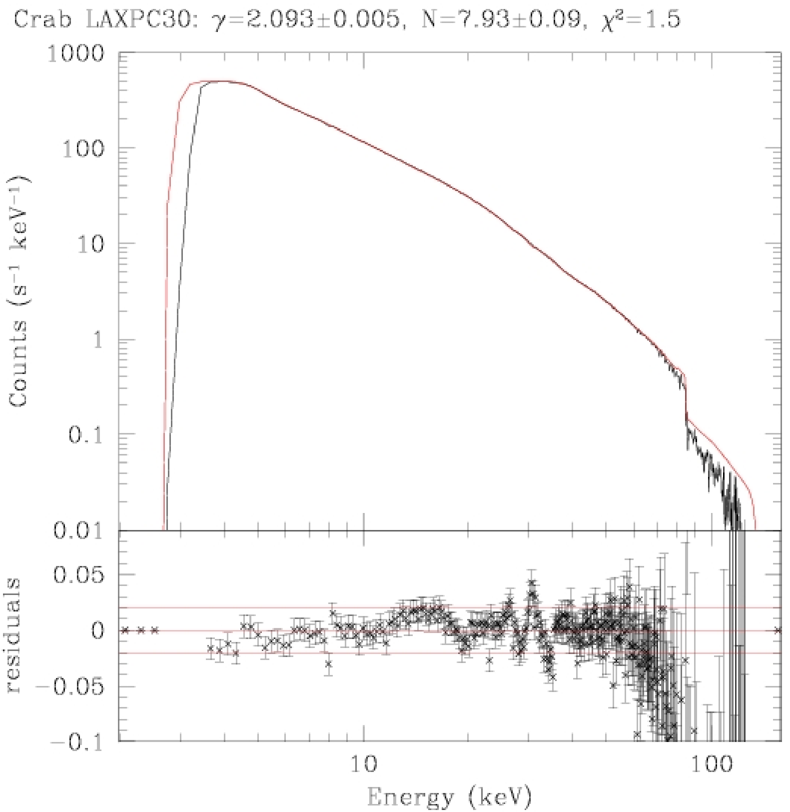
120
100
80
60
40
20
0
counts
0
200
400
600
Channel No.
40 keV
50 keV
60 keV
70 keV
80 keV



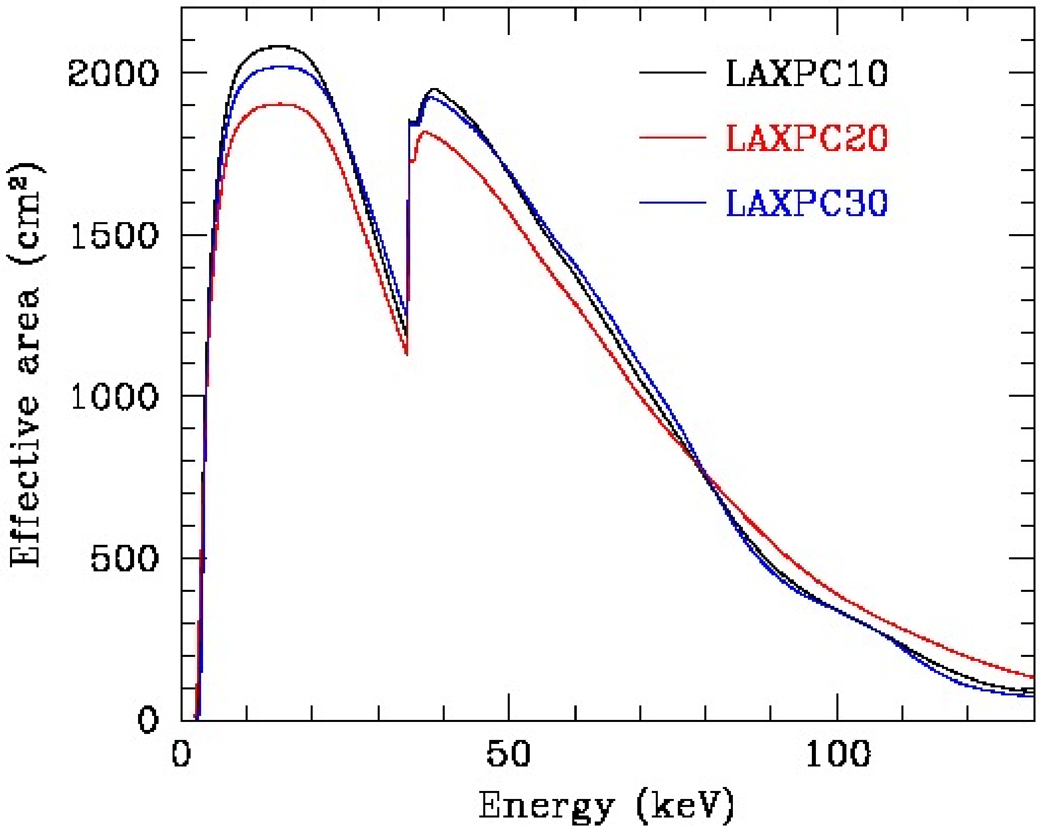
Crab LAXPC10: γ=2.097±0.005, N=7.94±0.09, χ²=0.8
1000
100
10
1
0.1
0.01
Counts (s⁻¹ keV⁻¹)
0.05
0
−0.05
−0.1
residuals
10
100
Energy (keV)



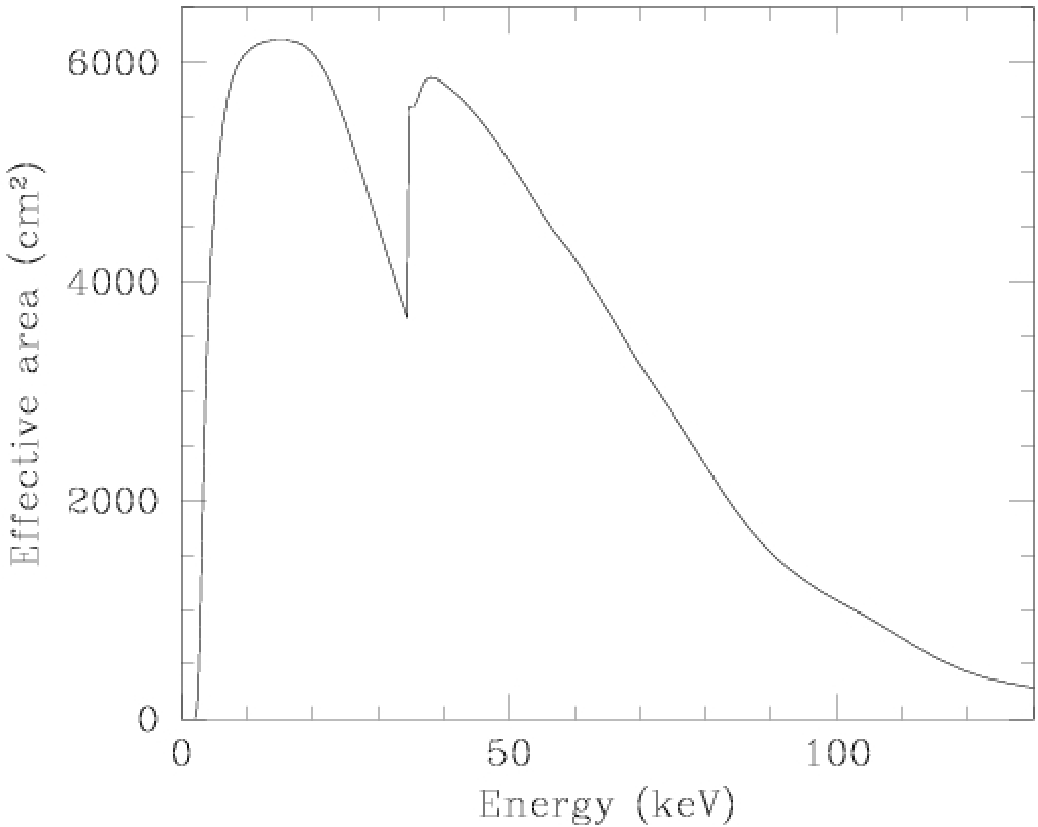
Crab LAXPC20: γ=2.102±0.005, N=8.07±0.09, χ²=2.0
1000
100
10
1
0.1
0.01
Counts (s⁻¹ keV⁻¹)
0.05
0
−0.05
−0.1
residuals
10
100
Energy (keV)

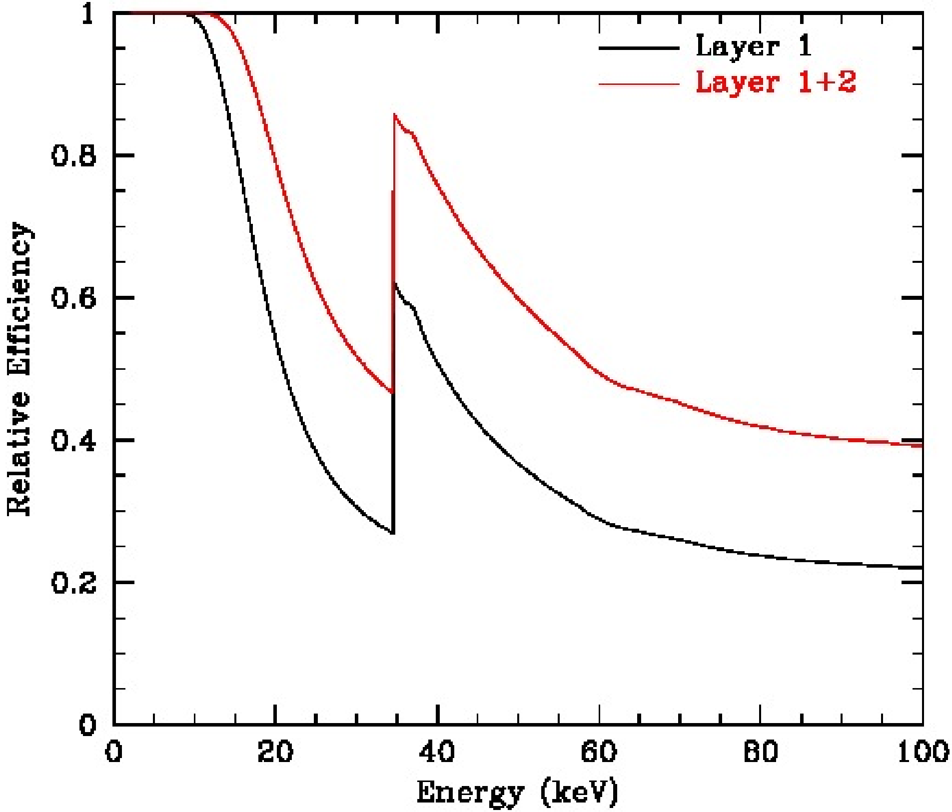


Crab LAXPC30: γ=2.093±0.005, N=7.93±0.09, χ^2=1.5
1000
100
10
1
0.1
0.01
Counts (s^{-1} keV^{-1})
0.05
0
−0.05
−0.1
residuals
10
100
Energy (keV)



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


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


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

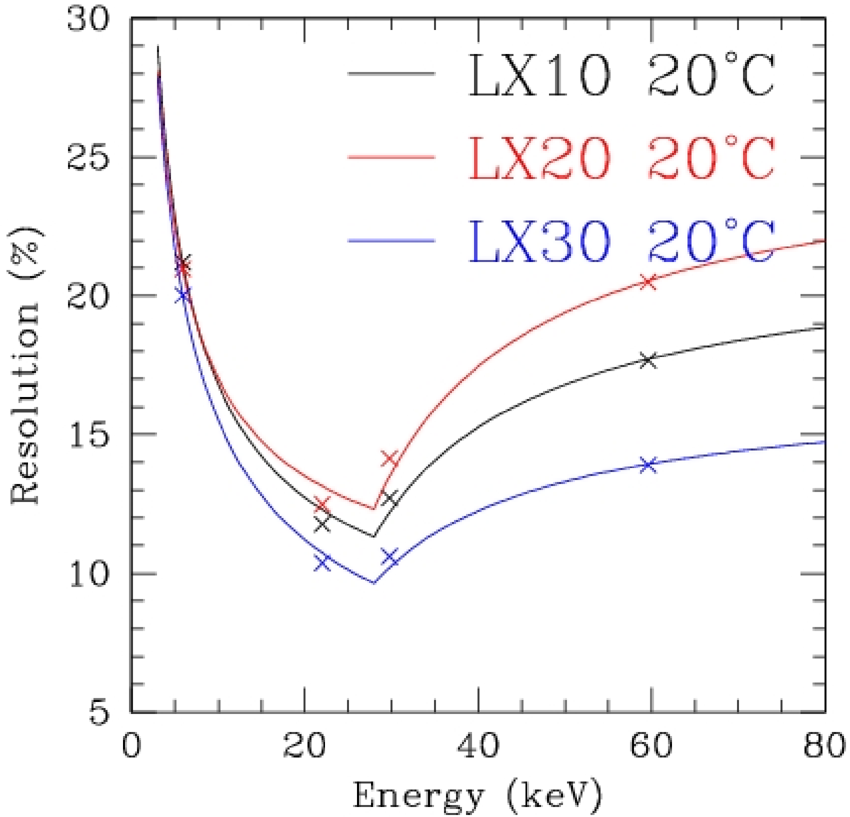
Long Term Performance in Orbit

- AstroSat has been in orbit for over 1220 days and has completed over 18000 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.

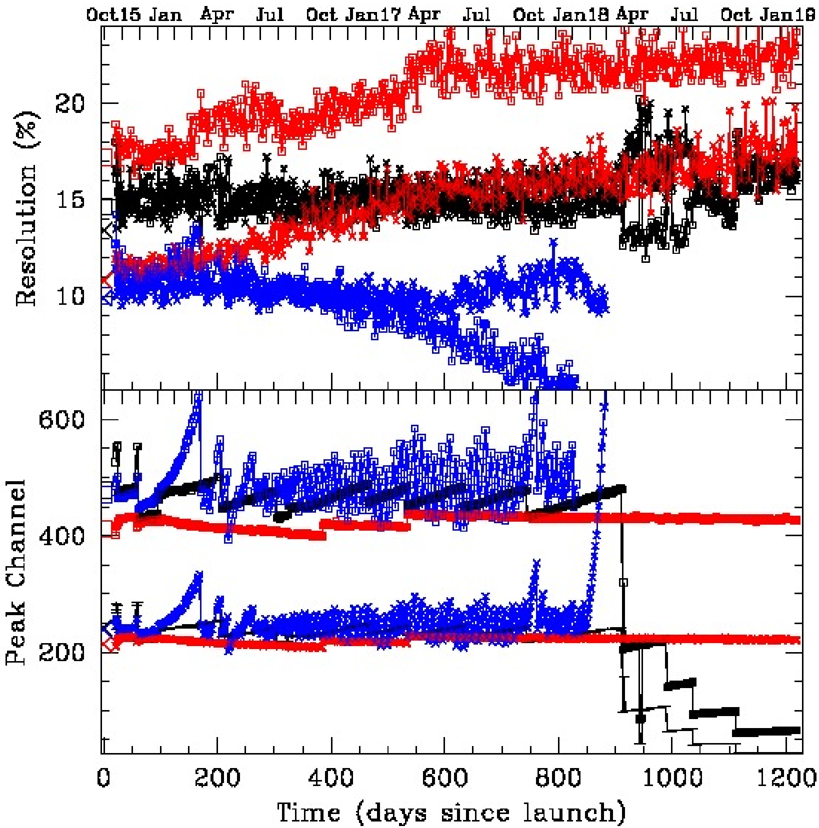
- LX30 developed a fine leak soon after launch leading to peak channel shifting upwards. The HV was adjusted from time-to-time to bring the gain in reasonable range.
- On 22 January 2018 the HV of LX30 was reduced to minimum permissible value. After that the gain kept shifting upwards.
- On 8 March 2018 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 3.5 years.

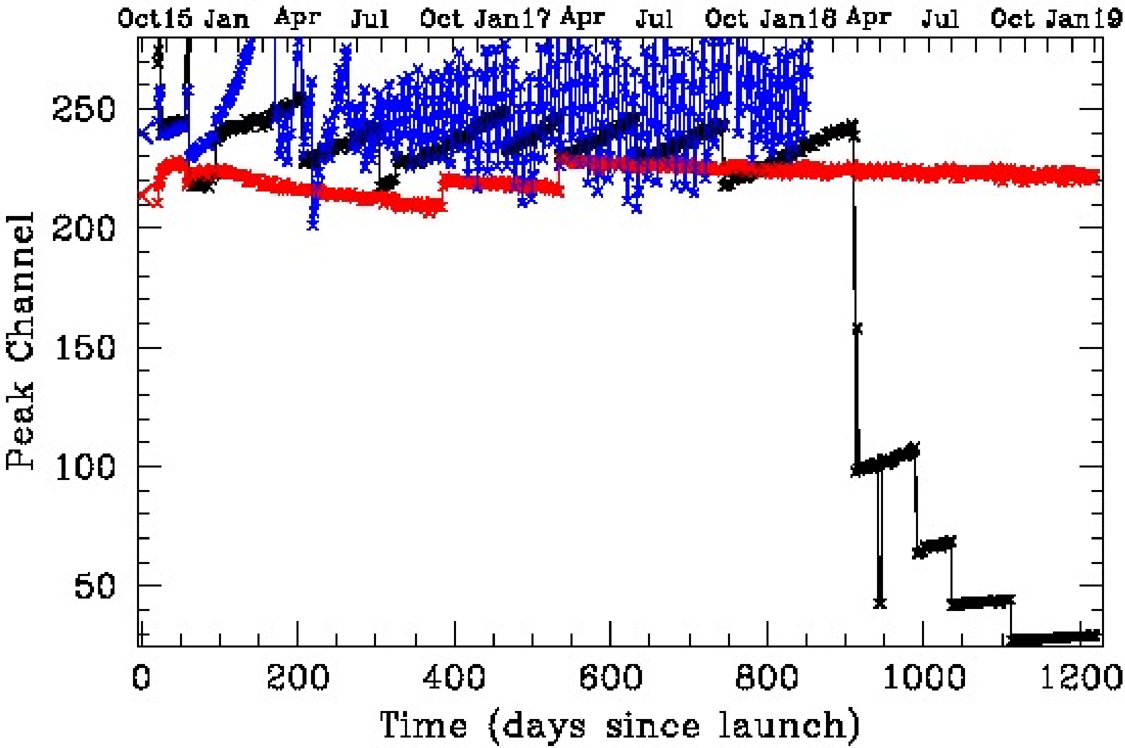
- On 26 March 2018, LX10 showed erratic counts with frequent bursts and its HV was reduced to stabilise the counts. Since then the HV has been reduced a few times. As a result, it is operating at very low gain and currently its low energy cutoff is around 15–20 keV.

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

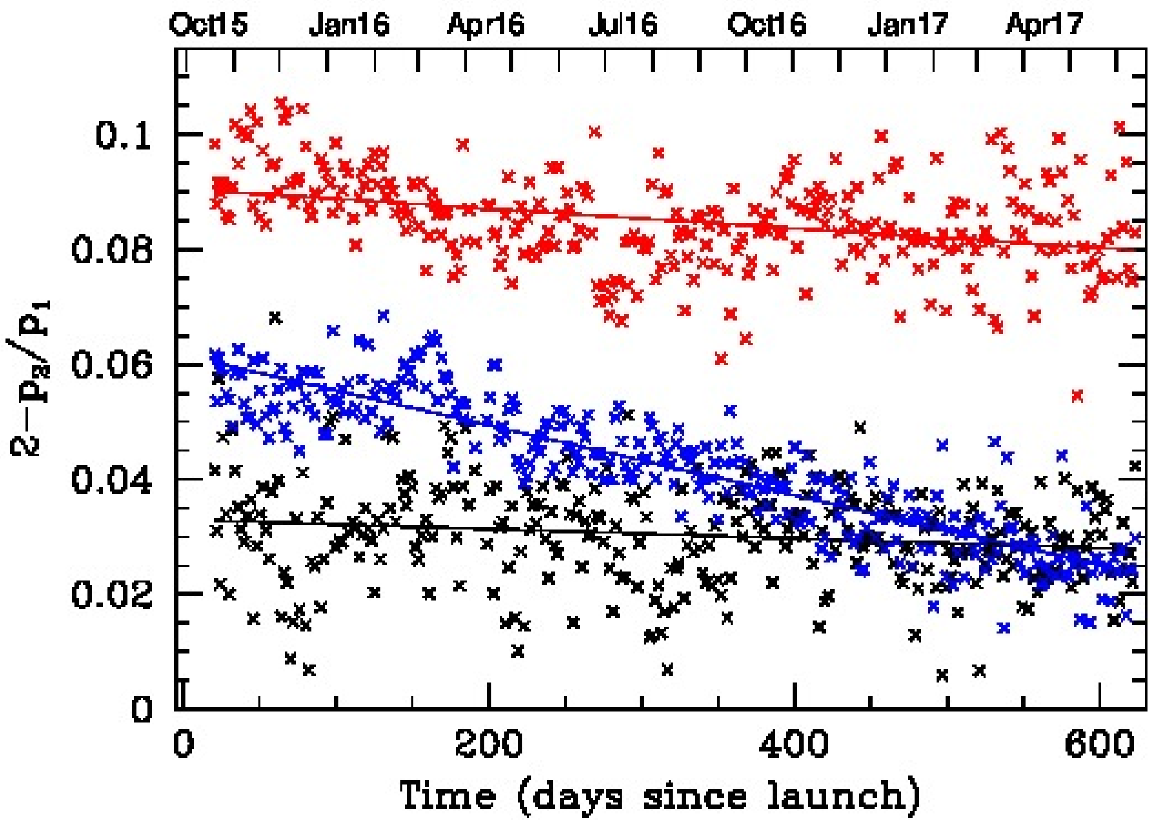


LX10 20°C
LX20 20°C
LX30 20°C
Resolution (%)
Energy (keV)
30
25
20
15
10
5
0
20
40
60
80

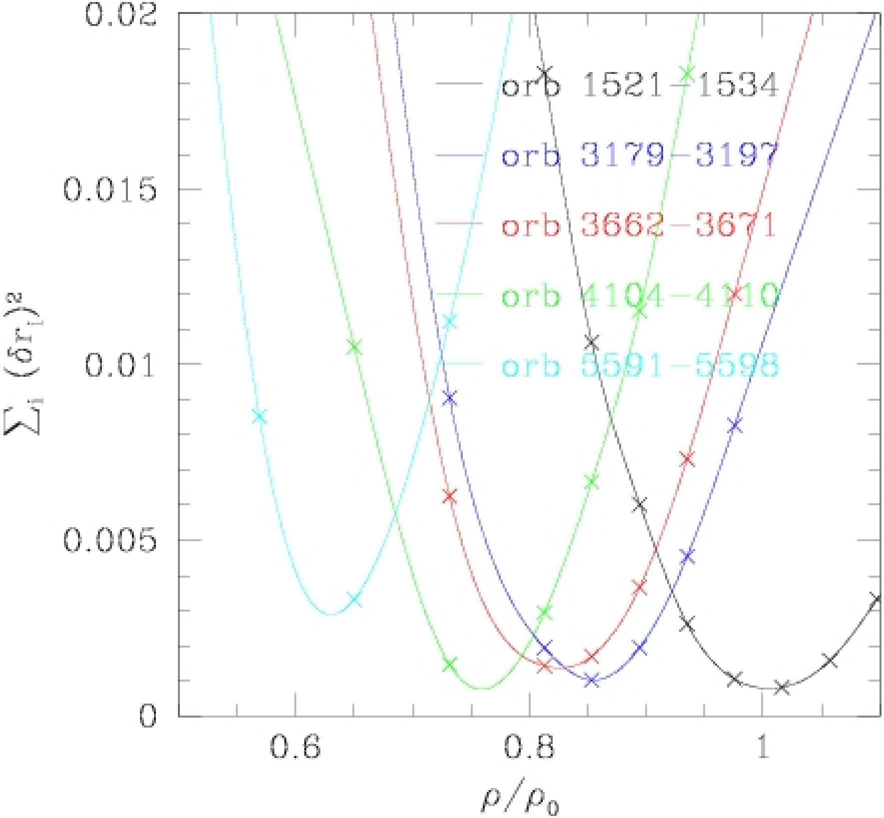

Oct15 Jan Apr Jul Oct Jan17 Apr Jul Oct Jan18 Apr Jul Oct Jan19
Resolution (%)
20
15
10
Peak Channel
600
400
200
0
200
400
600
800
1000
1200
Time (days since launch)



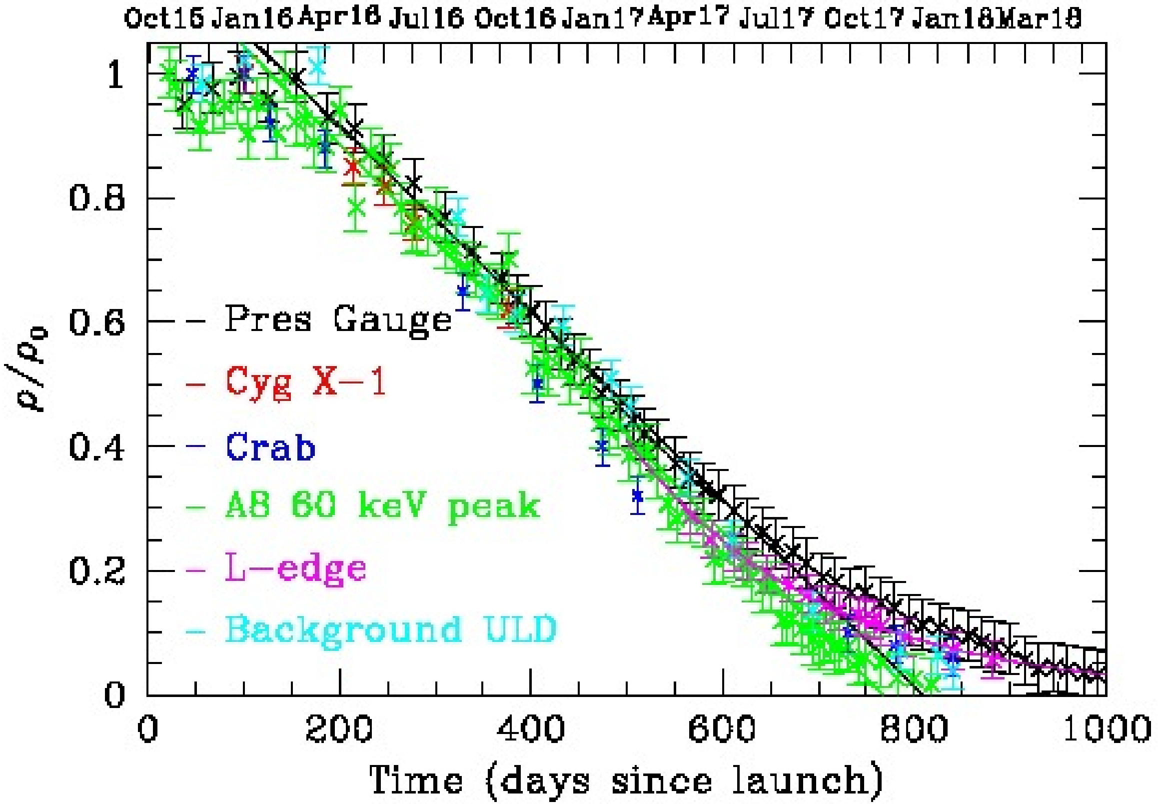
Oct15 Jan Apr Jul Oct Jan17 Apr Jul Oct Jan18 Apr Jul Oct Jan19
Peak Channel
250
200
150
100
50
0
200
400
600
800
1000
1200
Time (days since launch)



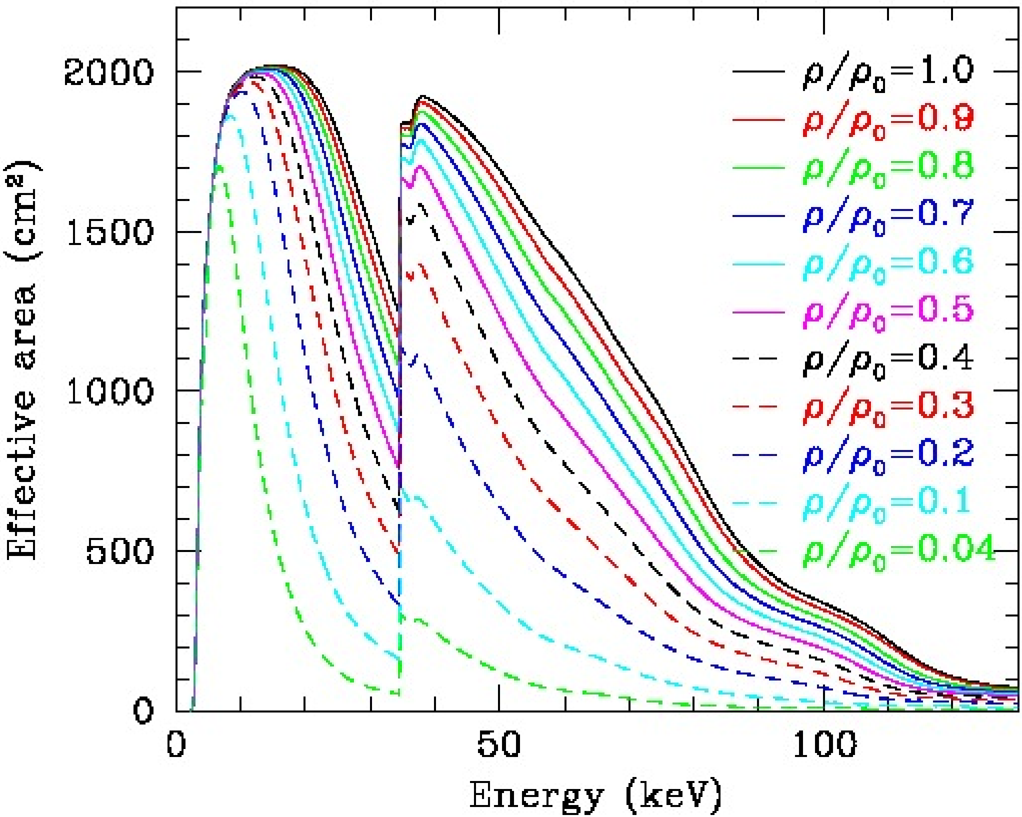
Oct15
Jan16
Apr16
Jul16
Oct16
Jan17
Apr17
0.1
0.08
0.06
0.04
0.02
0
$2-P_2/P_1$
0
200
400
600
Time (days since launch)



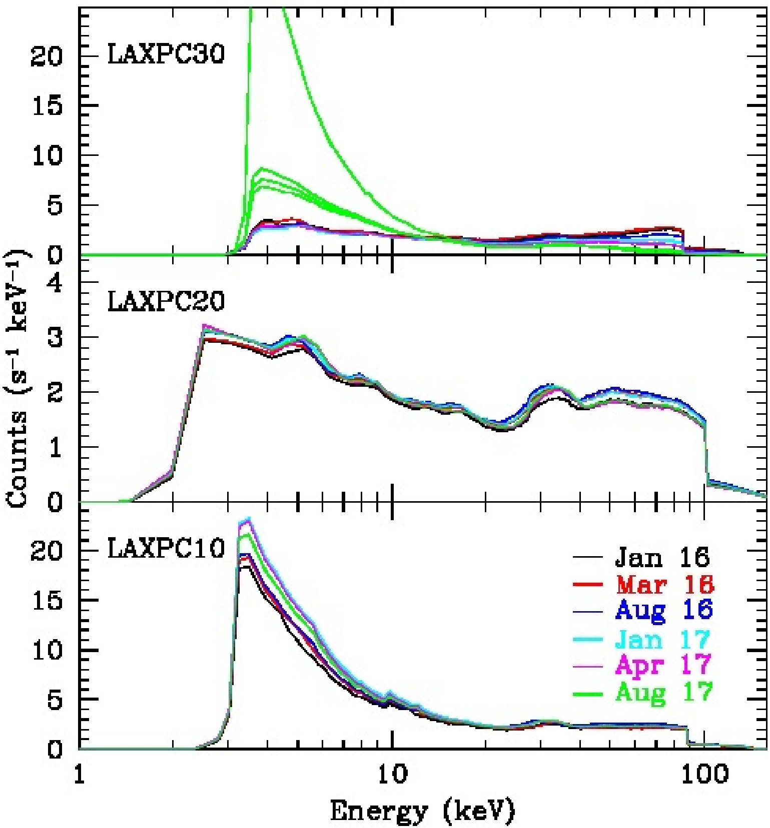
orb 1521−1534
orb 3179−3197
orb 3662−3671
orb 4104−4110
orb 5591−5598
0.02
0.015
0.01
0.005
0
0.6
0.8
1
$\sum_i (\delta r_i)^2$
ρ/ρ_0

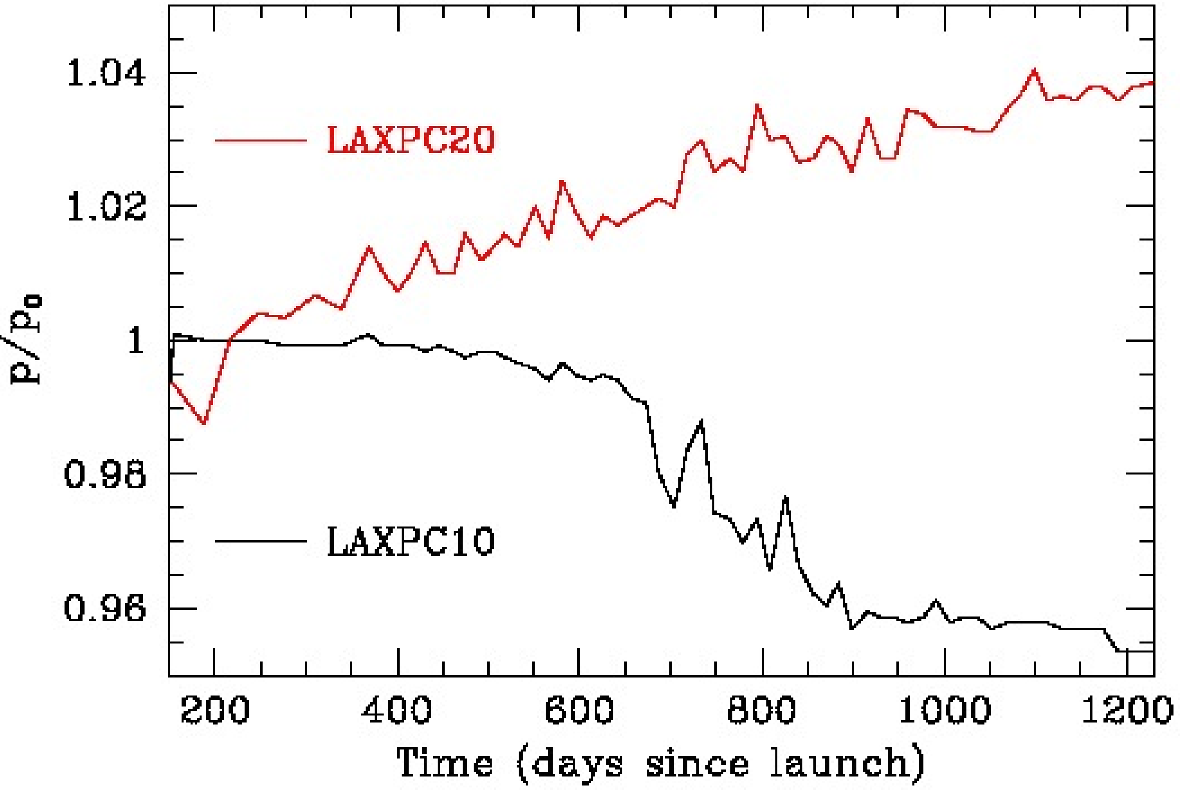


Oct15 Jan16 Apr16 Jul16 Oct16 Jan17 Apr17 Jul17 Oct17 Jan18 Mar18
1
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
ρ/ρ_0
Time (days since launch)
Pres Gauge
Cyg X-1
Crab
A8 60 keV peak
L-edge
Background ULD



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


LAXPC30
LAXPC20
LAXPC10
Jan 16
Mar 16
Aug 16
Jan 17
Apr 17
Aug 17
Counts (s⁻¹ keV⁻¹)
Energy (keV)
1
10
100
0
5
10
15
20
0
1
2
3
4



LAXPC20
LAXPC10
1.04
1.02
1
0.98
0.96
p/p₀
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

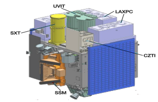
  http://www.tifr.res.in/~astrosat_laxpc

  http://astrosat-ssc.iucaa.in

Large Area X-ray Proportional Counter (LAXPC) AstroSat

Department of Astronomy & Astrophysics, TIFR

Launched on September 28, 2015



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.

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

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

LAXPC Payload Operation Centre (POC)

- The POC is operated at TIFR where all data are downloaded and checked.
- Automated level-1 data download from ISSDC server every hour. About 1.3 GB of data is downloaded every day.
- Level-1 data is processed to generate level-2 products and data quality reports for each observation. These are uploaded back to ISSDC for dissemination to PI or public.
- All operational control commands for proper functioning of LAXPC detectors are provided by POC.
- LAXPC website is maintained to provide latest release of LAXPC software and also provides quick-look light curves for all observations.

- These 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.

- These 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.

- 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 softwares 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)
```

LAXPC software

- `laxpcl1.f` : To process multiple orbits of level-1 data and produce light curve, event file (time, energy and anode for each photon), spectrum, background, gti (good time intervals). Output is in ASCII and FITS files. The FITS files confirm to requirement of xspec etc.
- `backshiftv3.f` : To apply gain shift to background spectrum to align with source spectrum and apply correction to light curve and to identify the response files to be used.
- Check the readme files for more details
- Both are independent programs which do not need any external library. There could be some differences in RECL parameter in different compilers.

laxpcl1.f

- This needs 4 files from each orbit
  `*.mkf` file for information about spacecraft position, pointing etc.
  `aux/*.tct` file for translating the instrument time to UTC time. Instrument time starts from the time when STBG was switched on (29 Sep 2015) while UTC starts from 1 Jan 2010.
  `lxp1/modeBB/*.fits` BB (broadband counting) mode data for getting ULD and some other count rates.
  `lxp1/modeEA/*.fits` EA (Event Analysis) mode data giving time, energy, anode ID for each recorded event.
- These file names should be provided in the `laxpcl1.inp` file in the above order for each orbit one after another. The orbits should be in increasing order of time.

- The first two files are common for all LAXPC detectors. The last two would be different, but the input file should only specify the lxp1 files. The program will automatically change the name to process data for other detector.

- A script `findfile` is provided to find these files. The base directory name needs to be edited. In some cases it may find additional files, which can be deleted. The list is returned in a file `ls1`.

- The program stops reading more files when it encounters a file that is missing or the list is over. To make sure that all intended files are read, check the `.mkf` file in output which would have the list of files read, one per orbit.

- Another input file is `back4.inp`, which specifies the background observation and model to be used. This should generally be the one that is closest in time, but if the HV has been adjusted in between or if there is a large gain shift for other reasons another background may be preferred. The program `backshiftv3.f` may give some recommendation on this.

- The 1st line specifies the fit to background to be used.

- The next 4 lines are for the ULD model which is not preferred and files are available only for `mar16` observations, so these should be left as such, unless more files are available.

- The 6th line specifies the background spectrum to be used. This should normally be consistent with entry in 1st line.

- The 7th line applies to 3d background model which is available only for mar16 data, as it is not preferred.

```
backfit.lxp10nov18
backlxp10mar16ul1.pha
backlxp10mar16ul2.pha
backlxp10mar16ul3.pha
backlxp10mar16ul4.pha
backlxp10nov18.pha
backfit3.lxp10aug16
```

- Another input file is `gti.inp` which gives the good time intervals to be used to calculate the spectrum and the source light curve. To start with this can be a file with '0' in the first line.

- The 1st line specifies the no. of gtis. It can be 0, in which case no spectrum will be produced.

- The subsequent lines give the specified gtis. The first two entries give the interval in instrument time, which is actually used. The next two entries specify the same in UTC, but the program ignores these. The UTC times are only for user reference.

- `laxpcl1.f` itself generates the gti file, which is output as `.gti`. Ideally, the first pass to `laxpcl1.f` can be made with 0 gti entries and the `.gti` file produced can be copied to `gti.inp` and the second pass can be made to get the required results. If necessary the `gti.inp` file can be edited to eliminate unwanted time intervals. While generating the gti file the time-bin should be of the order of 1 sec.

  1

  105369059.0 105455459.0

- Apart from these `laxpcl1.f` also reads some input from the terminal. Type '/' to use default values.

- lxp, tbin, ian (detector, time-bin, anode)

- icl,icu (range of channel to be used [0 1023])

- nca (No. of channels, 512 for lxp1, lxp3 and 256 for lxp2)

- nul, je, iev (ULD bin[-1,-2], $\mathrm{je} = \pm 1$ for source/Earth occult, event selection). $\mathrm{iev} < 0$ will write the event file. $\mathrm{iev} = \pm 1$ for single event only. Use $\mathrm{nul} = -2$ to fit only top layer background in low energies.

- For weak sources try $\mathrm{ian} = 1$, $\mathrm{nul} = -2$, $\mathrm{iev} = 1$ and icu suitably reduced to select only low energies up to 20–30 keV.

- The following output FITS files are produced:
- `lxpilevel2.evn` (if $\text{iev} < 0$) all recorded events, no selection with gti
- `lxpilevel2.lcurv` : The light curve covering only gti. count rate is from specified anode and channels corrected for dead-time.
- `lxpilevel2.lcbk` : The light curve of fitted background. Similar to `.lcurv`
- `lxpilevel2.spec` : The source spectrum for selected anode in nca channels corrected for dead-time averaged over time intervals in gti file.
- `lxpilevel2back.spec` : The background spectrum for selected anode in nca channels corrected for dead-time.
- `AstroSat.orb` : Orbit file to be used for barycentric correction

backshiftv3.f

- This reads output from `laxpcl1.f` and corrects the light curve and background spectrum for gain shift. This program reads the ASCII version of output from `laxpcl1.f` though the correction is applied to both ASCII and FITS versions.

- Input file `backshiftv3.inp` gives the list of input and background files that are available and should not be edited if the files are available in the current directory.

- Input files `gaina8.dat` and `lxhv.dat` contain the log of gain shift and HV adjustments and may need to be updated from LAXPC web-site. Additional background files with `backshiftv3.inp` may also need to be updated.

- The following inputs are taken from the terminal
- lxp, ian, idi (detector, anode, flag for diurnal oscillations $0/1$)
- tbin, lcl, lcu, nul (time-bin, channel range, $\mathrm{nul} = -2$ for fitting low energy background using only top layer.
- filename of the background spectrum file (ASCII). Type '$/$' to use default. If this file is not available the program will try to ask more questions to identify the background, but that is not desirable.

- The following output files are generated.
- `*_shifted.pha` : ASCII background spectrum after shifting
- `*_shifted.spec` : FITS background spectrum after shifting. The shifted spectrum should be subtracted from source spectrum while fitting the spectrum.
- `*_shifted.lc` : ASCII light curve file corrected for background shift.
- `*_shifted.lcbk` : FITS background light curve file corrected for shift. This should be subtracted from `.lcurv` to get source counts.
- `*_corr.lcsr` : FITS source light curve file after correcting for shift and subtracting the background. If $\mathrm{idi} = 0$, diurnal oscillation is also removed. This can sometime remove real variation in the source.

- This program also suggests which response file should be used. There are 4 response files for each gain. One for all anodes and events, with no qualifier in the name. Second for all anodes but for single events only, with SE in the name. Two more are for top layer only for all events or single events with L1 or L1SE in the name.

- The correct variant should be chosen, the program may not suggest that in all cases.

- The first set of response files have names of form

  `lx20v1.0.rmf` OR `lx20cshm??v1.0.rmf` OR

  `lx20cshp??v1.0.rmf`

  For LX10 there could be v1.1 (to be used instead of v1.0) and after March 2018, v2.0, v2.1, v2.2

Files with `cshm??` are for negative gain shift and `cshp??` for positive gain shift.

- For LX30 there is additional qualifier `rho??` in the name for responses with reduced density as identified by the program. rho30 is for density of 30%. E.g.,

  `lx30cshp16rho30v1.0.rmf` or

  `lx30cshp16rho30L1v1.0.rmf`

  Currently, there are no SE response files for reduced density.

- The recommended response should be close to optimum, but one can try neighbouring responses in gain or rho.

Summary

- `laxpcl1.f` has to be run twice, first time with tbin around 1 sec to generate `.gti` file. After copying `.gti` to `gti.inp` run the program again with required tbin and other parameters.

- Choose the correct background in `back4.inp` (1st and 6th line)

- Use `backshiftv3.f` to correct for gain shift and use the shifted background spectrum and light curve in further analysis.

- The spectrum and light curve are dead-time corrected.

- The barycentric correction can be applied to light curve or event file using `as1bary` (available from AstroSat support cell) with orbit file provided by `AstroSat.orb`

- While fitting the spectrum please note that all channels cannot be considered as independent. To get correct statistics bin the channels considering a nominal resolution of 16–20%.