SSM onboard ASTROSAT and study of X-ray transients with SSM

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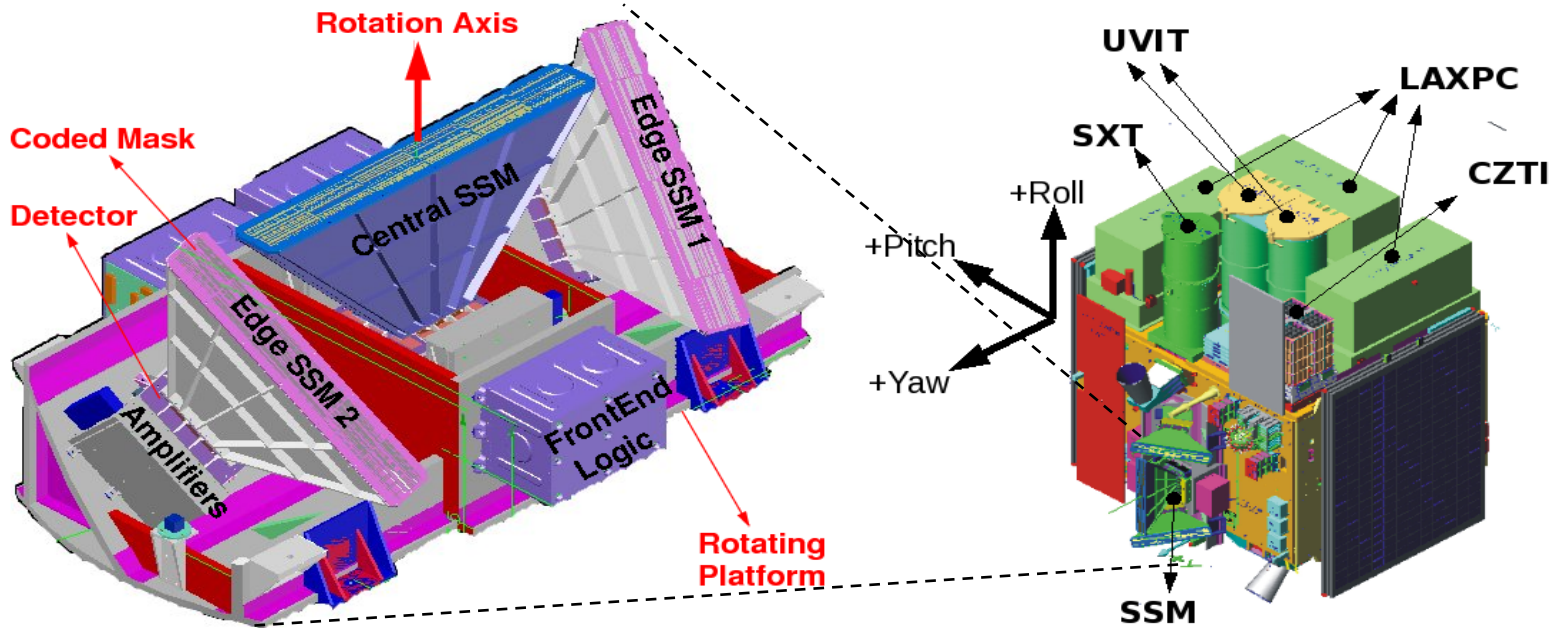
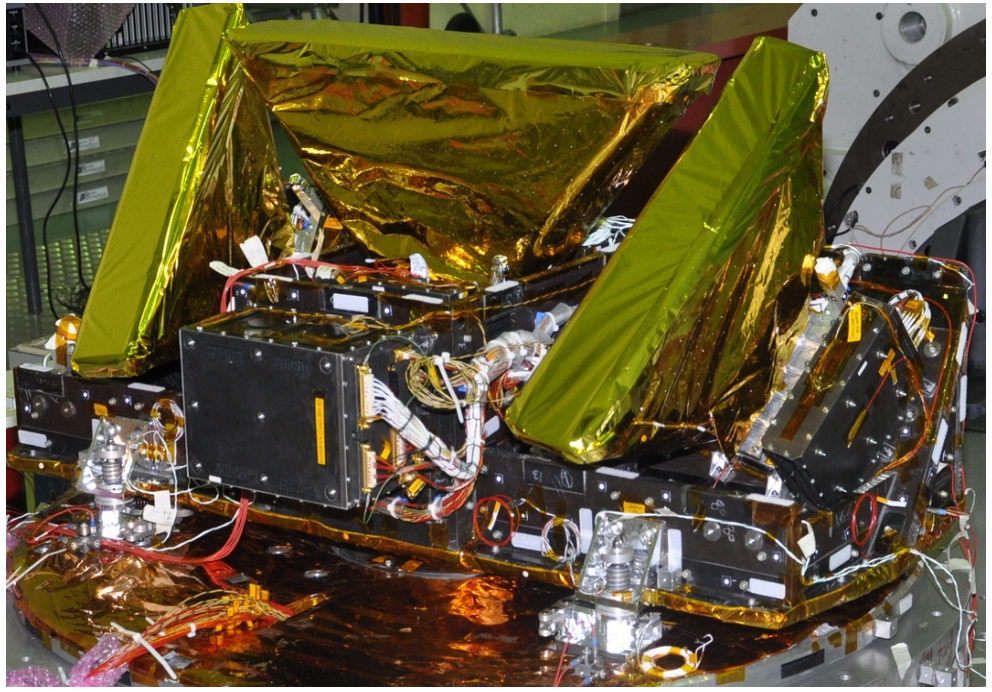
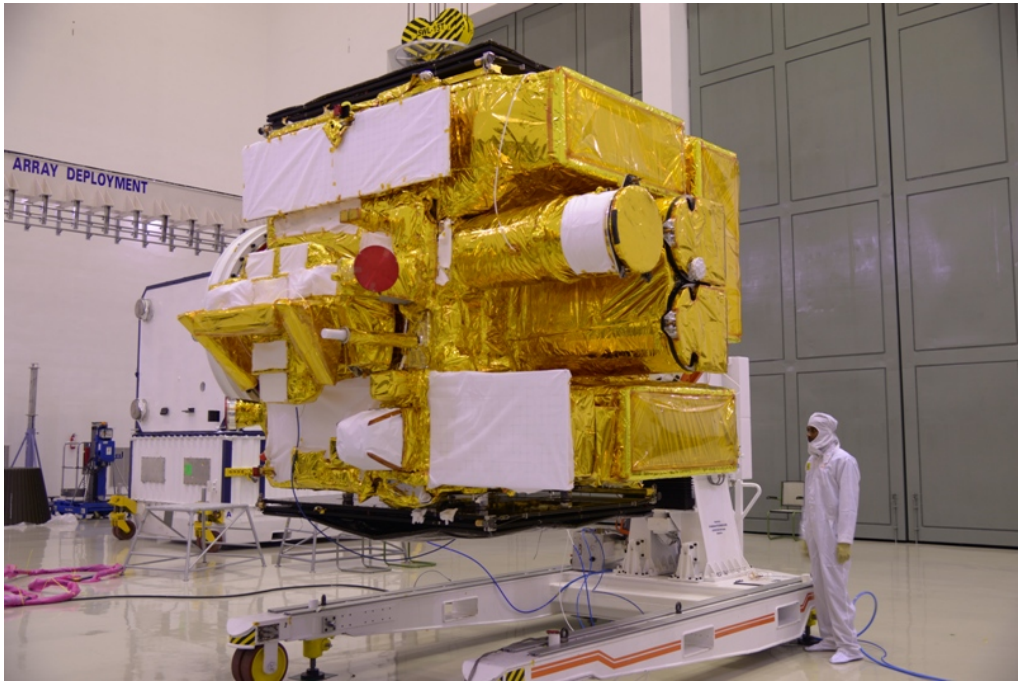
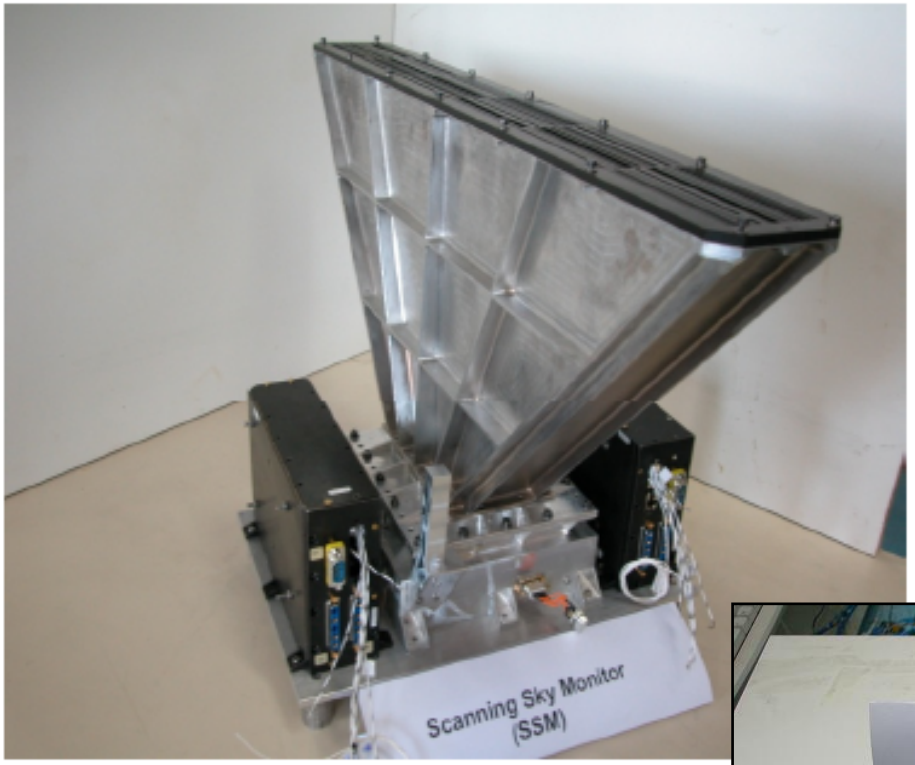
SSM onboard ASTROSAT







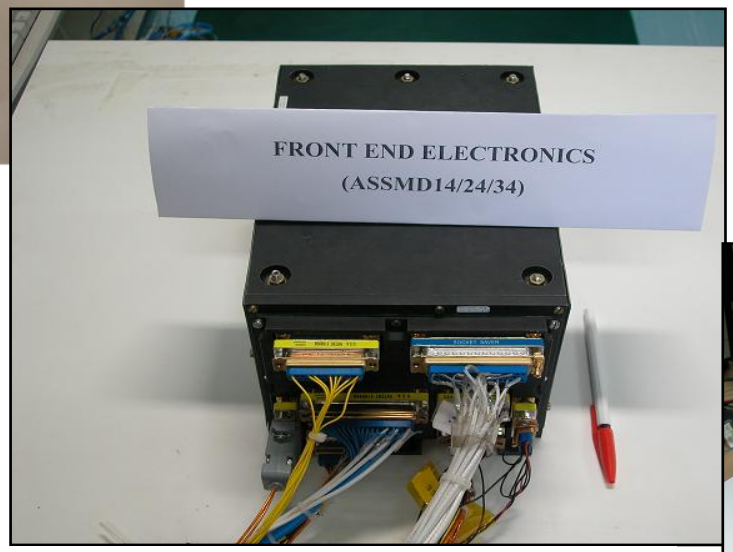
SSM (one unit) with electronics

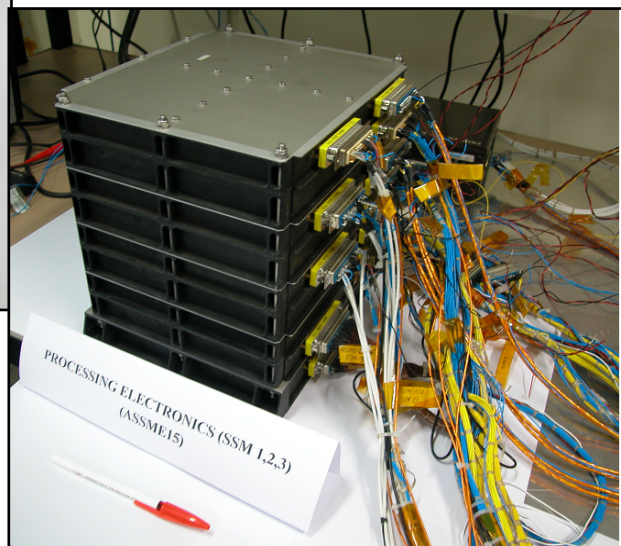


One SSM unit comprises

1. Detector
2. Electronics
3. Coded Mask for Imaging

There are 3 such units
mounted on a platform
with rotation mechanism



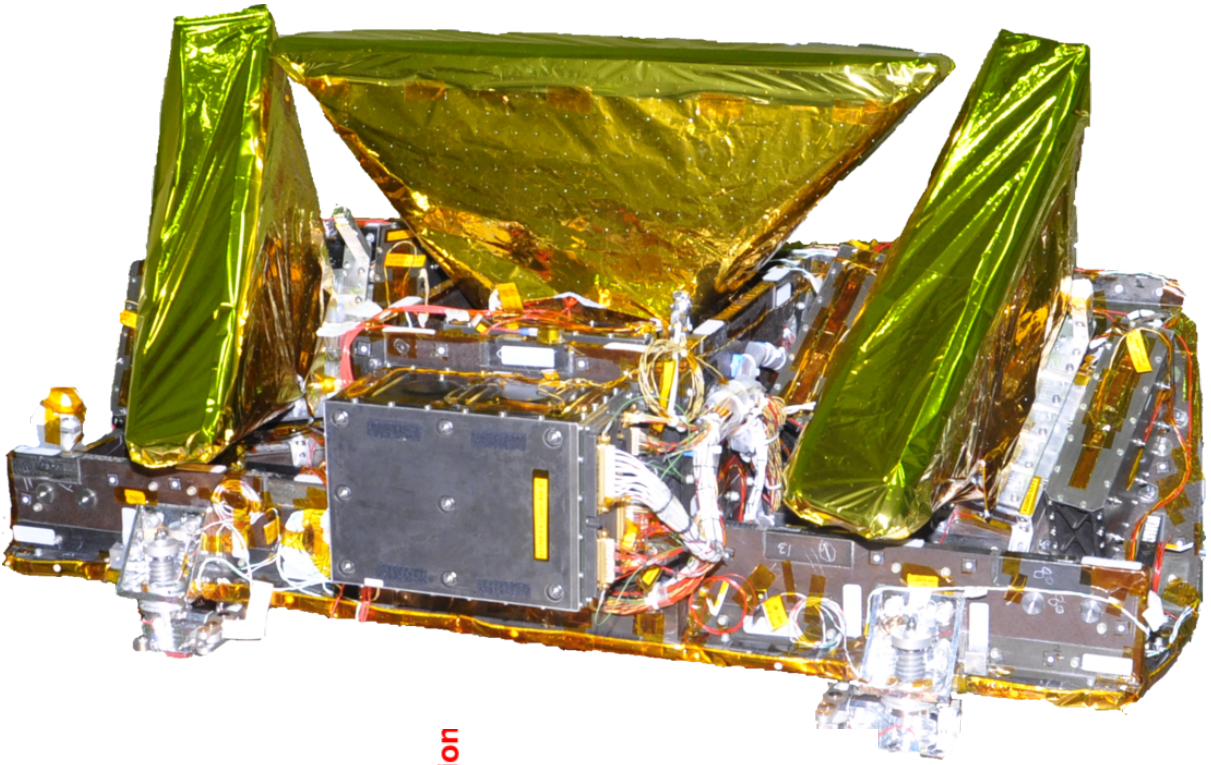


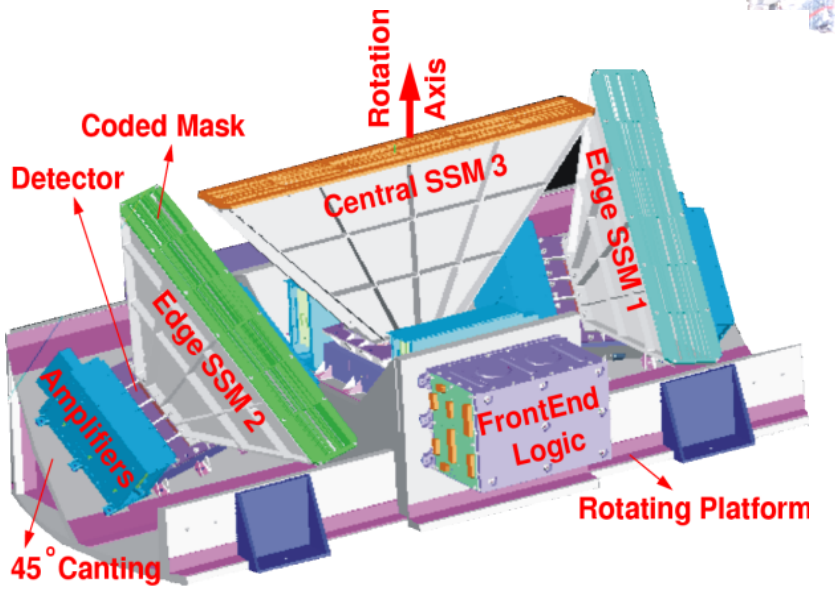
Detector: Position Sensitive Proportional Counter

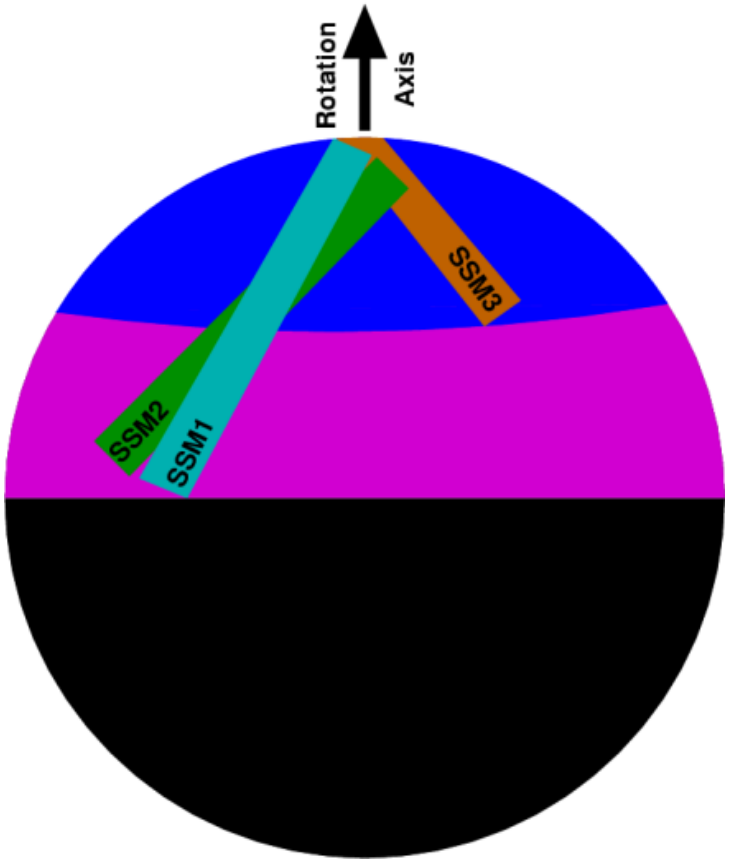
Electronics : CSPAs + FE + PE

Coded Mask: 1D

SSM and FOV in one full rotation

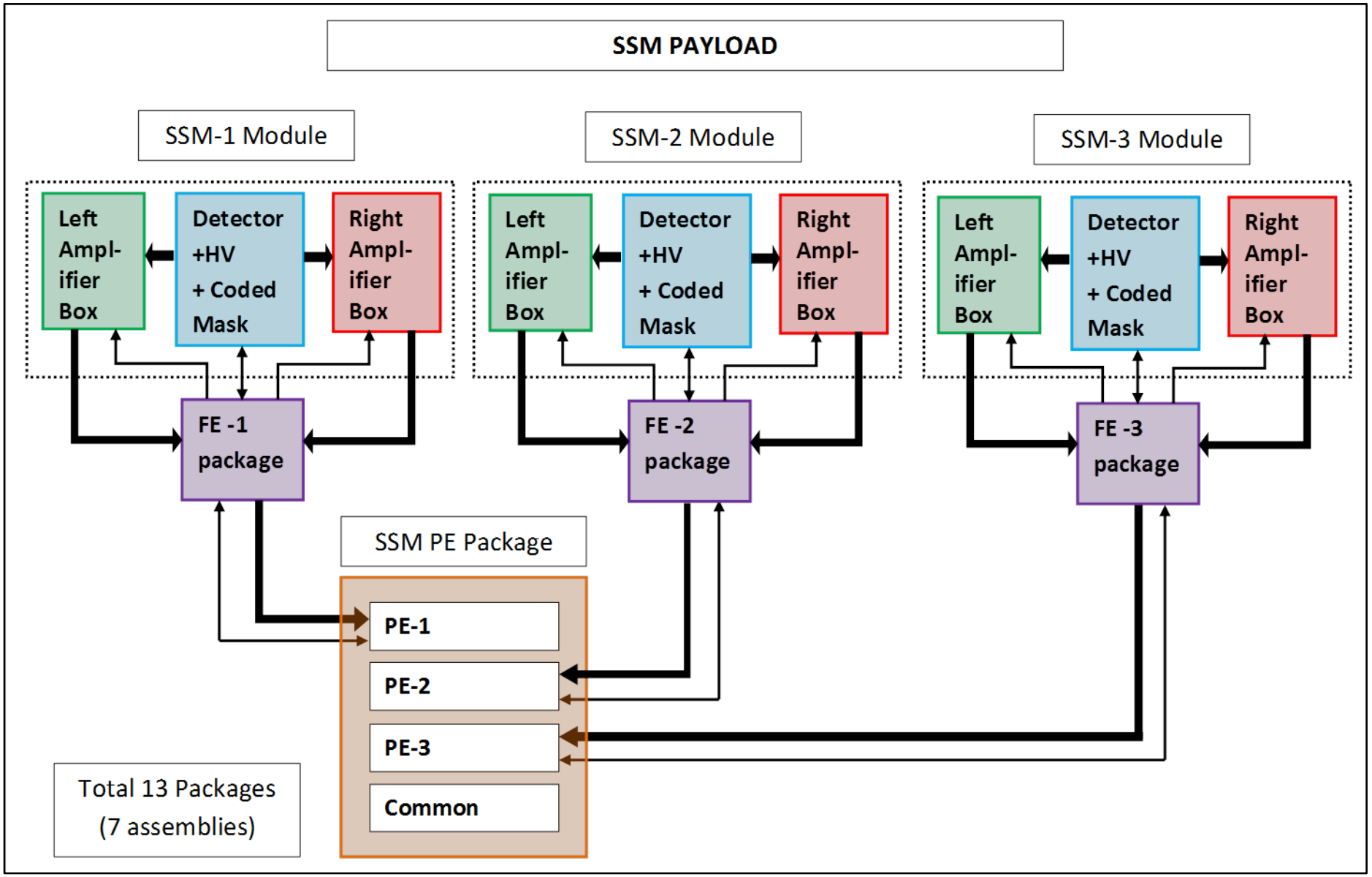






Scan region of the sky covered by one full rotation

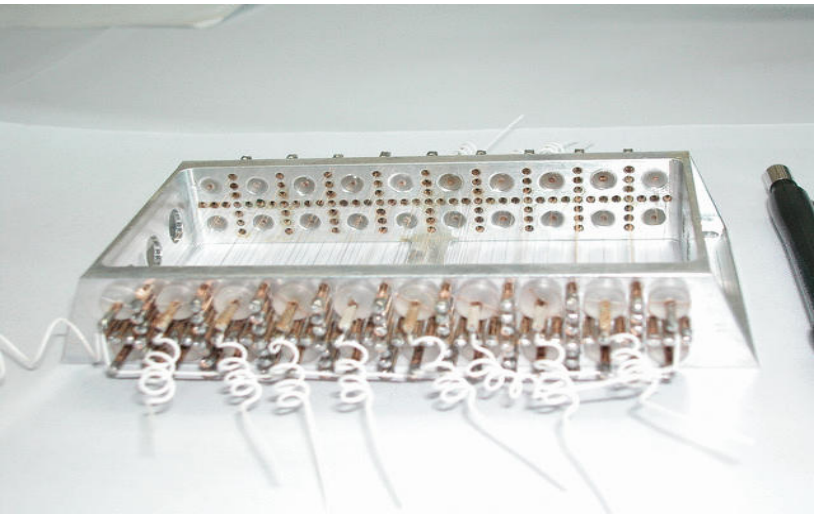
Block diagram of SSM

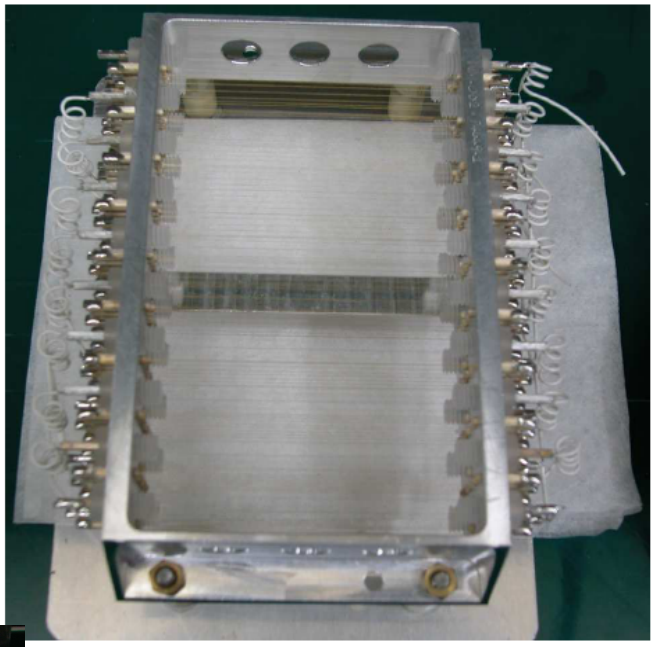


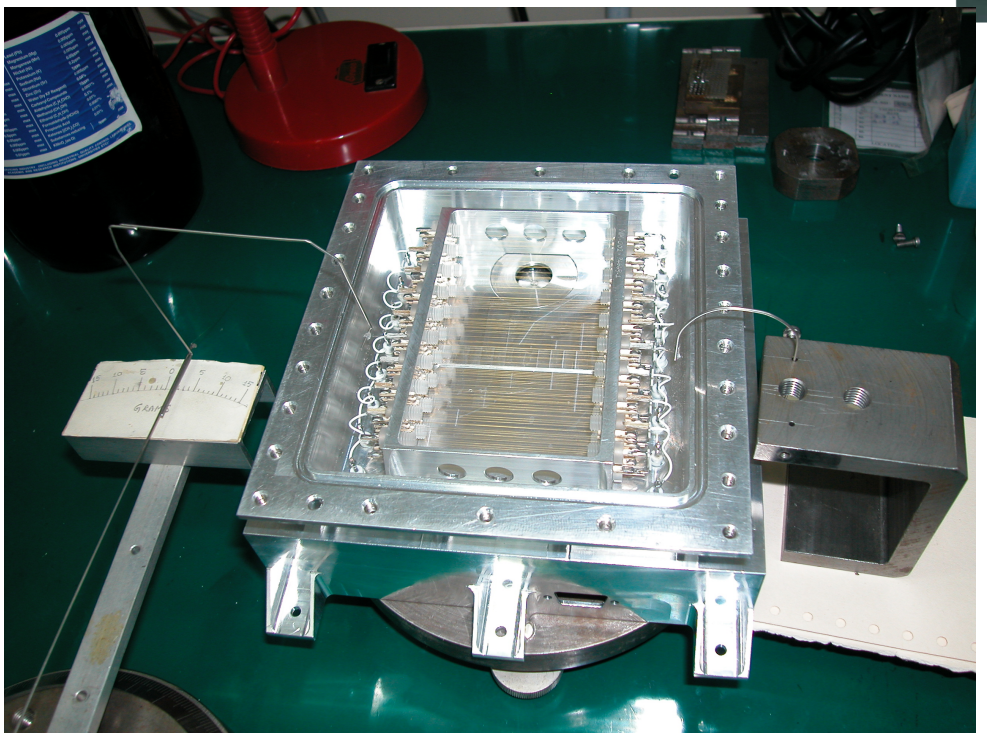
Instrument details

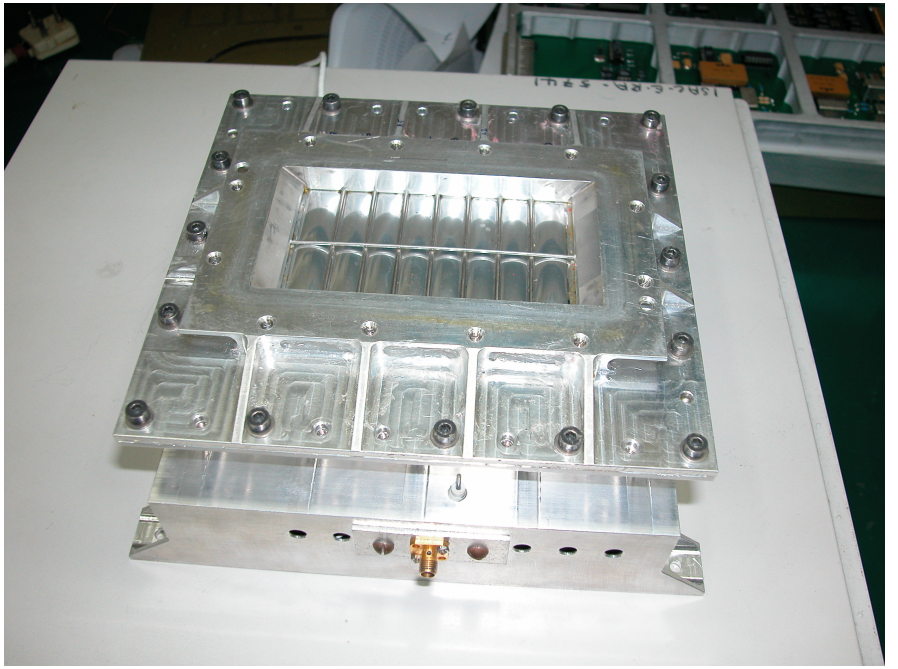
Detector	One dimensional position sensitive gas-filled proportional counter
Gas mixture	25% Xe + 75% P-10 (P-10 is 90% Argon + 10% Methane)
Gas pressure	800 torr
Diameter of anode	25 micron
Active length of anode	60 mm
Type of anode wires	Carbon-coated Quartz
Diameter of cathode wires	75 microns
Entrance Window	25 micron thick Aluminized Mylar
Detector operating voltage	~1500 volts
Unit Slit size of coded mask	0.95 mm
Memory required	200Mbyte per orbit
Payload weight & power	~52 kg; ~49 W
Geometric area	180 cm^2
Effective area	30 cm^2 @ 2keV ; 80 cm^2 @ 5 keV
FOV	Edge SSMs: $26.8^o \times 100^o$, Central SSM: $22.1^o \times 100^o$
Energy resolution	17% at 6 keV
Angular resolution	10 arcmin in the coding direction, 2.5^o across
Time resolution	1 ms
Sensitivity (Obs time)	~30millicrab (300s) (3 sigma)

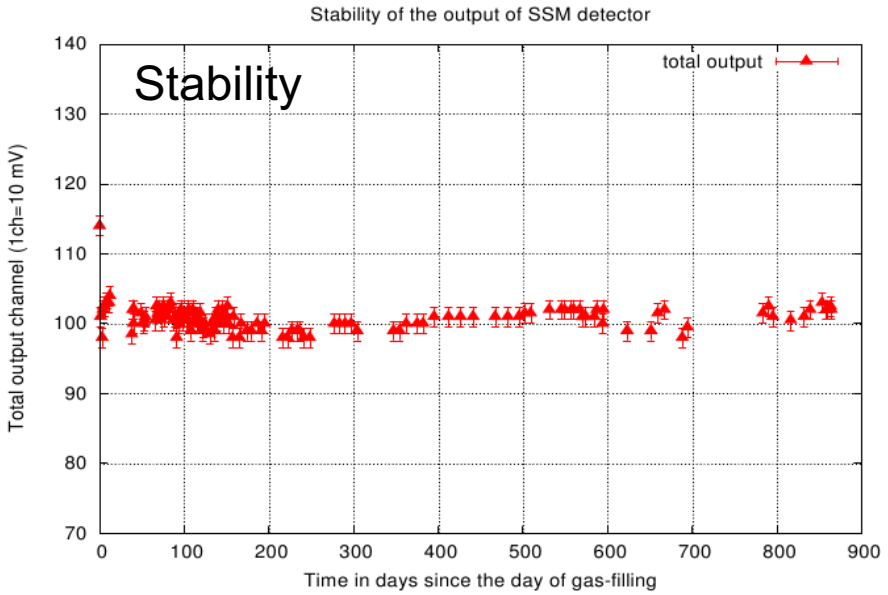
SSM Wire module

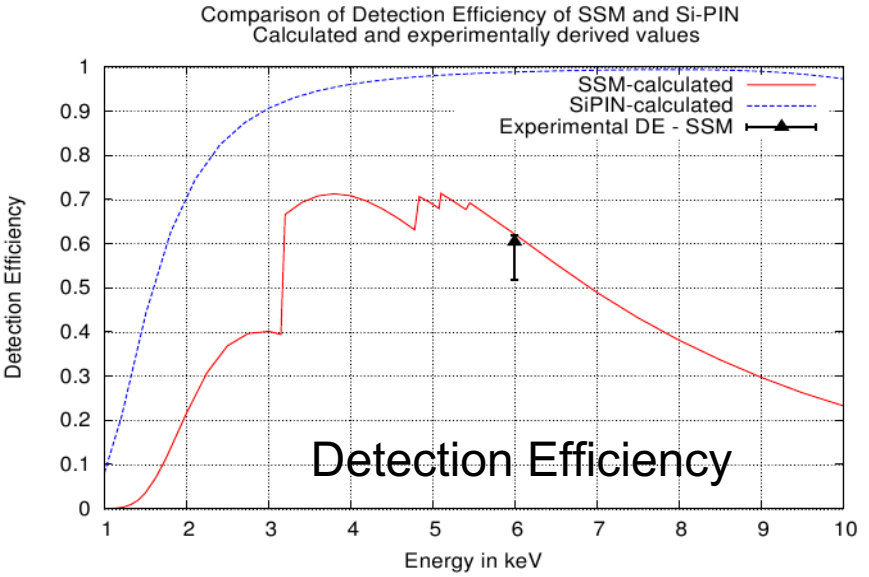


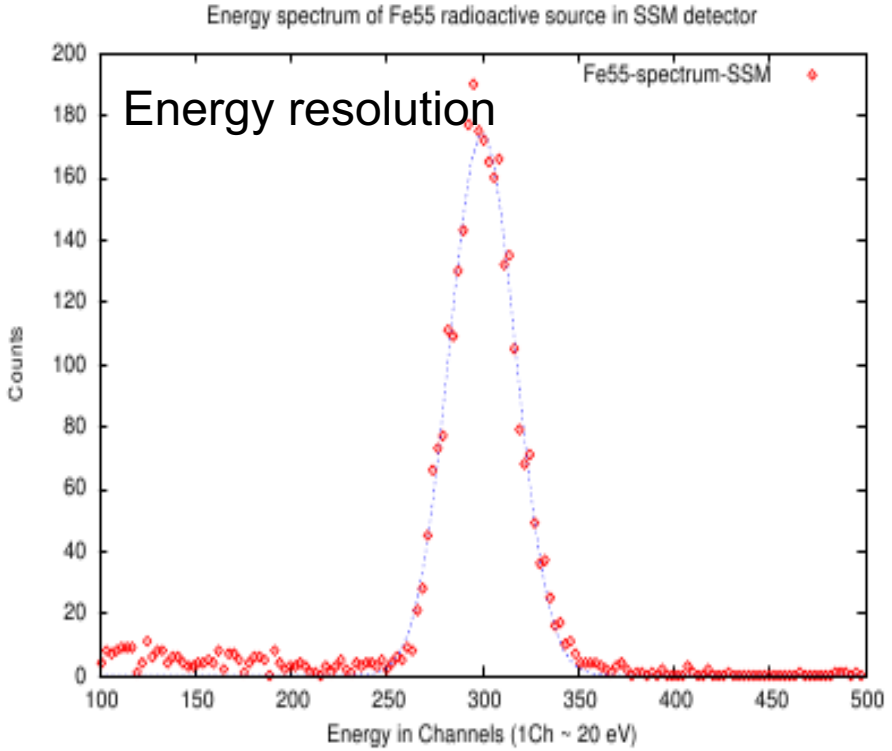


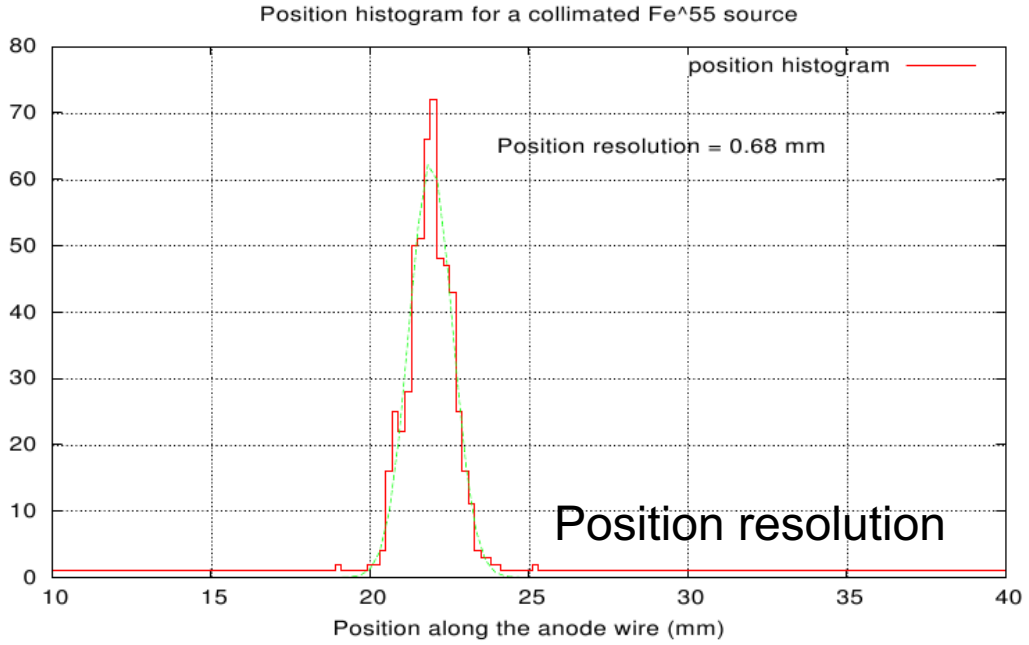


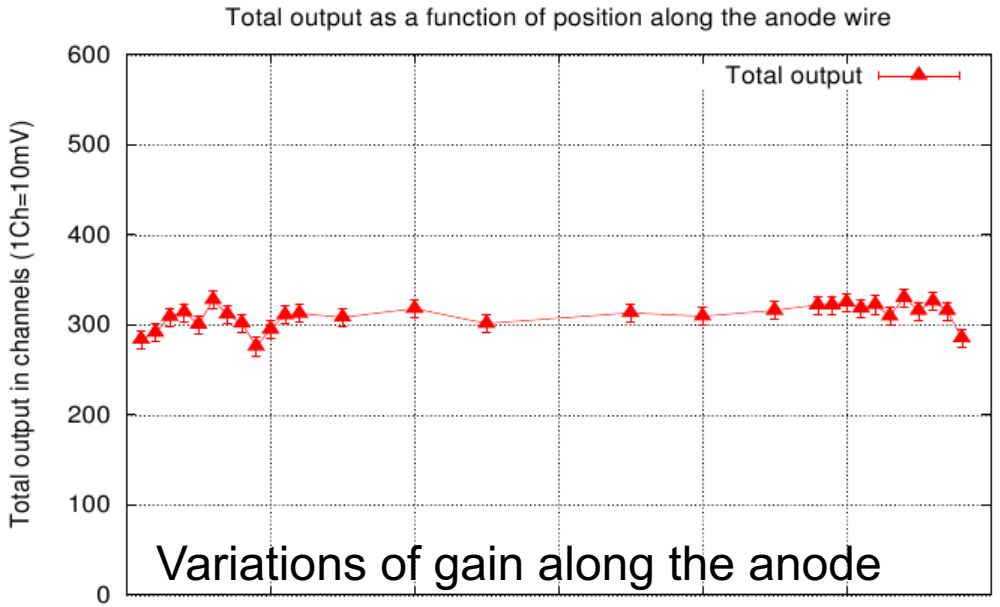


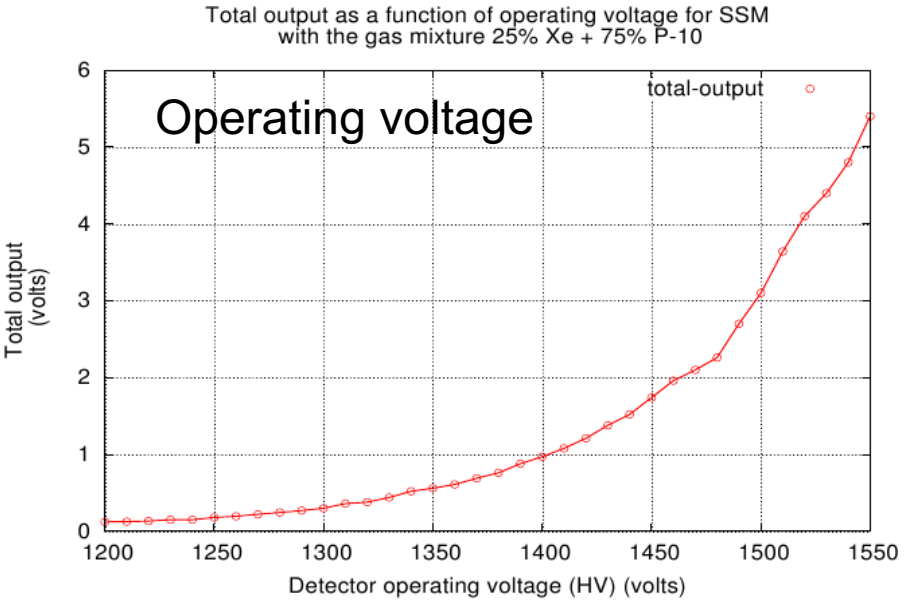

Stability of the output of SSM detector
Stability
total output
Total output channel (1ch=10 mV)
Time in days since the day of gas-filling

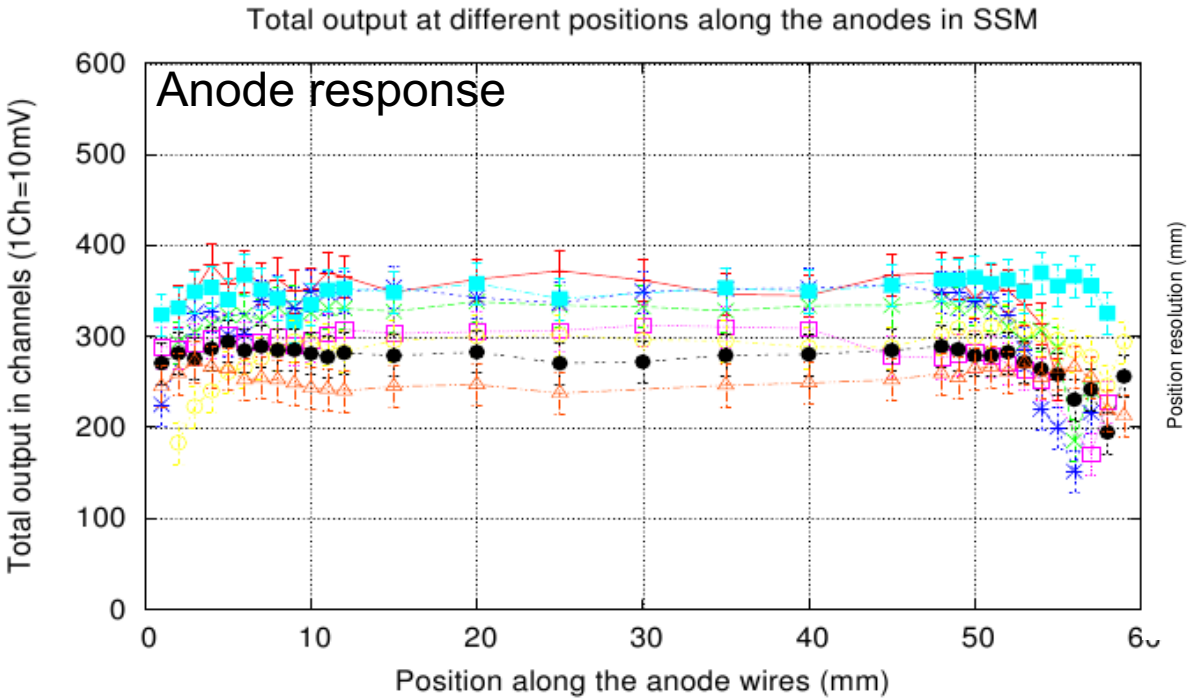

Comparison of Detection Efficiency of SSM and Si-PIN
Calculated and experimentally derived values
SSM-calculated
SiPIN-calculated
Experimental DE - SSM
Detection Efficiency
Detection Efficiency
Energy in keV

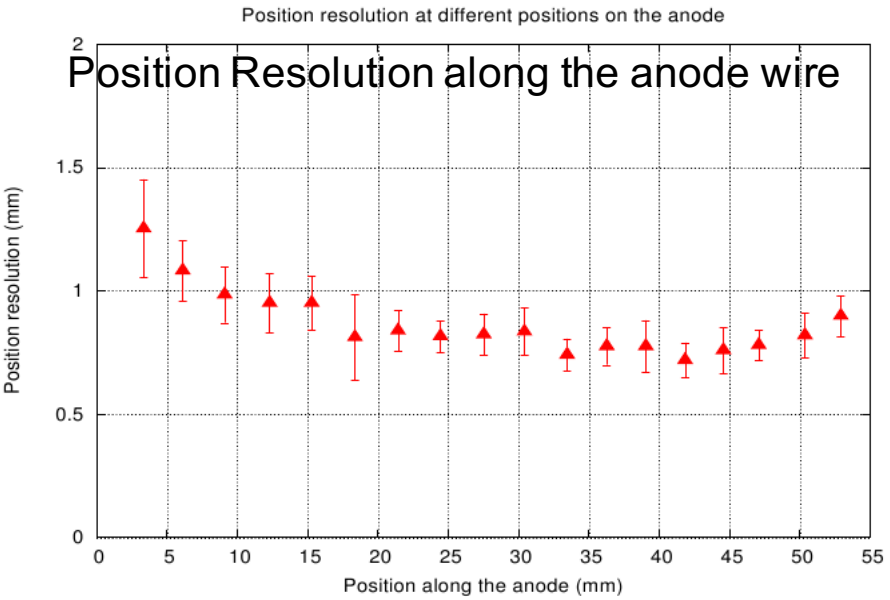

Energy spectrum of Fe55 radioactive source in SSM detector
Energy resolution
Fe55-spectrum-SSM
Counts
Energy in Channels (1Ch ~ 20 eV)


Position histogram for a collimated Fe^55 source
position histogram
Position resolution = 0.68 mm
Position resolution
Position along the anode wire (mm)

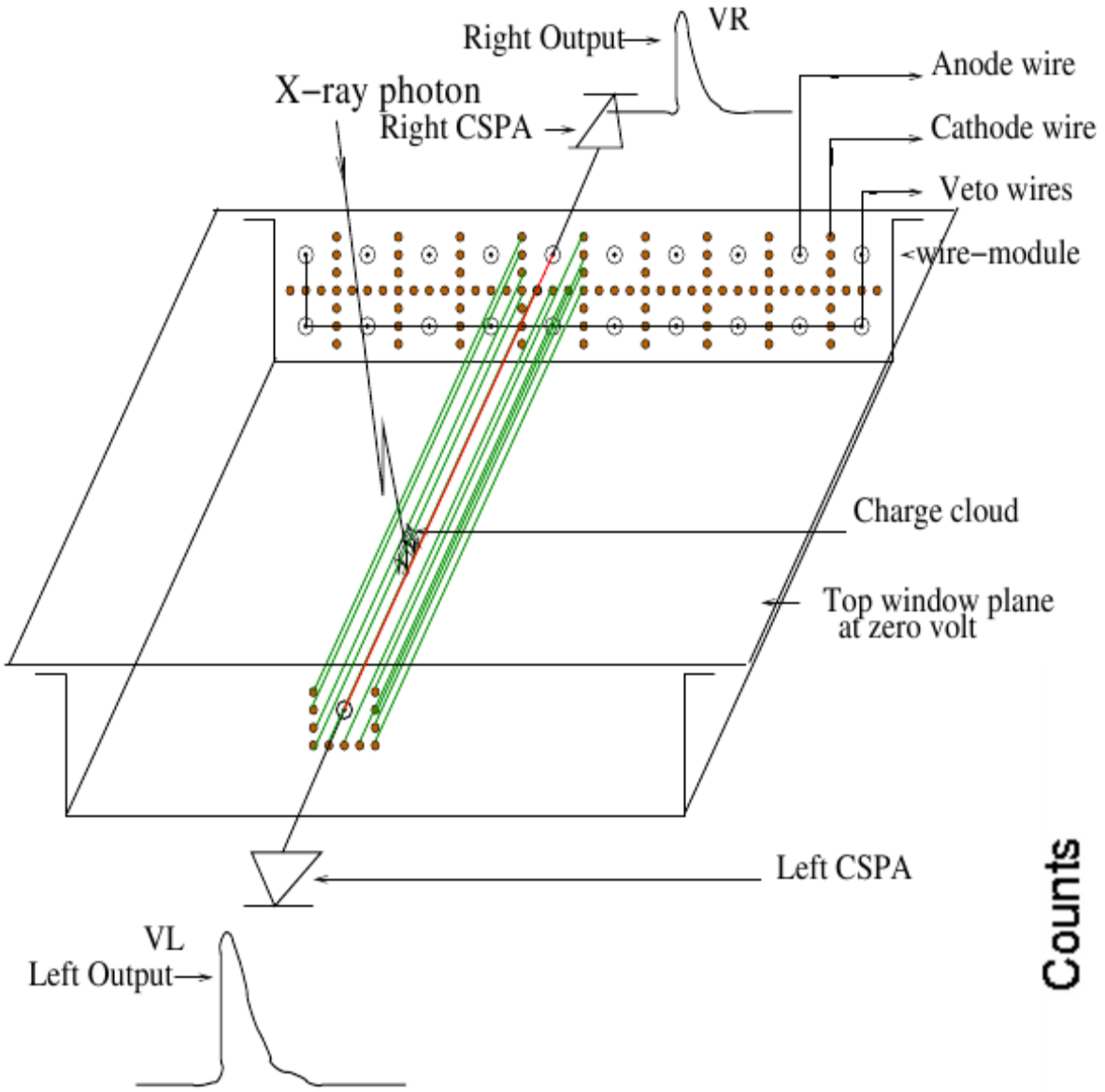

Total output as a function of position along the anode wire
Total output
Total output in channels (1Ch=10mV)
Variations of gain along the anode


Total output as a function of operating voltage for SSM
with the gas mixture 25% Xe + 75% P-10
total-output
Operating voltage
Total output (volts)
Detector operating voltage (HV) (volts)


Total output at different positions along the anodes in SSM
Anode response
Total output in channels (1Ch=10mV)
Position along the anode wires (mm)

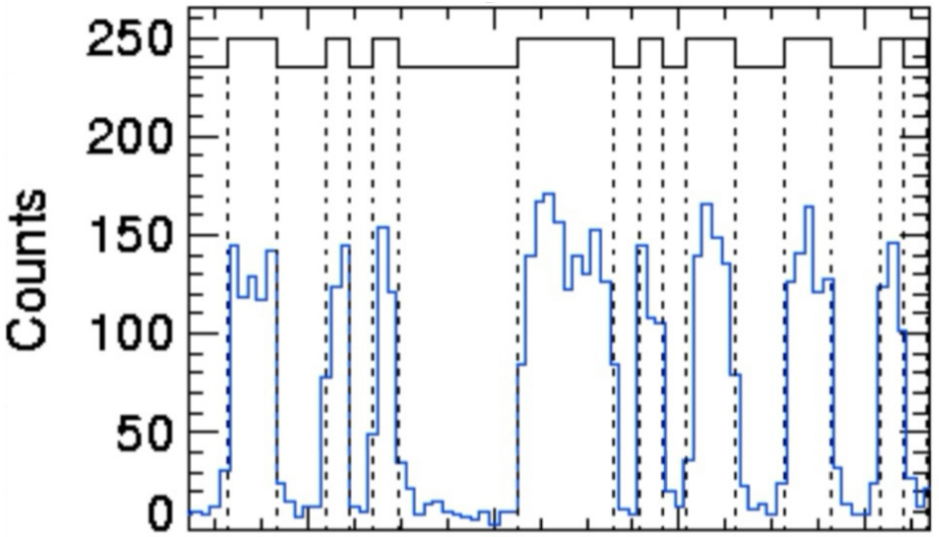

Position resolution at different positions on the anode
Position Resolution along the anode wire
Position resolution (mm)
Position along the anode (mm)

Principle of operation of SSM

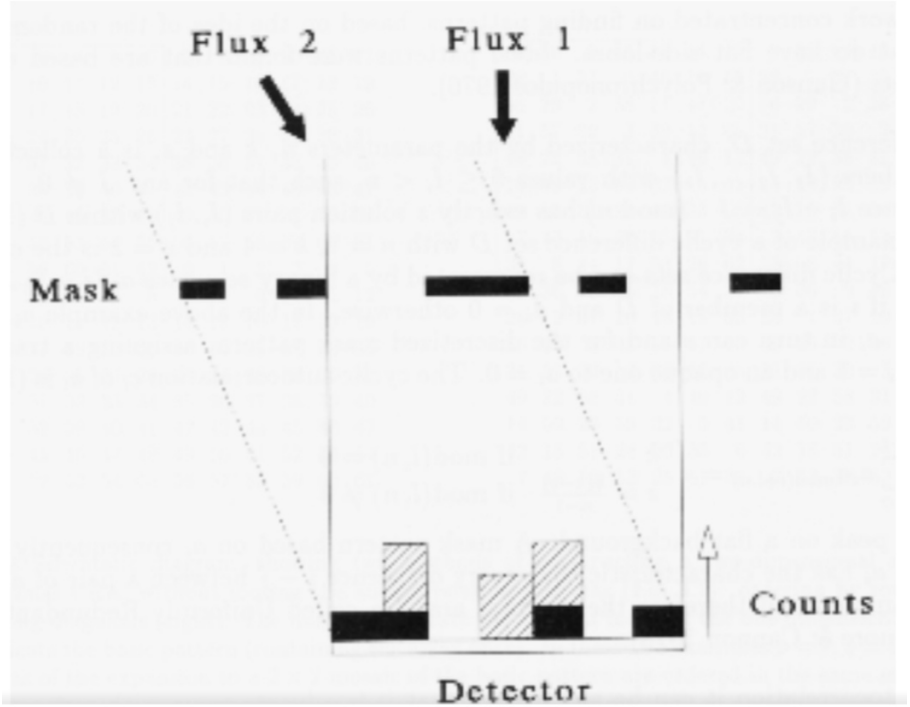


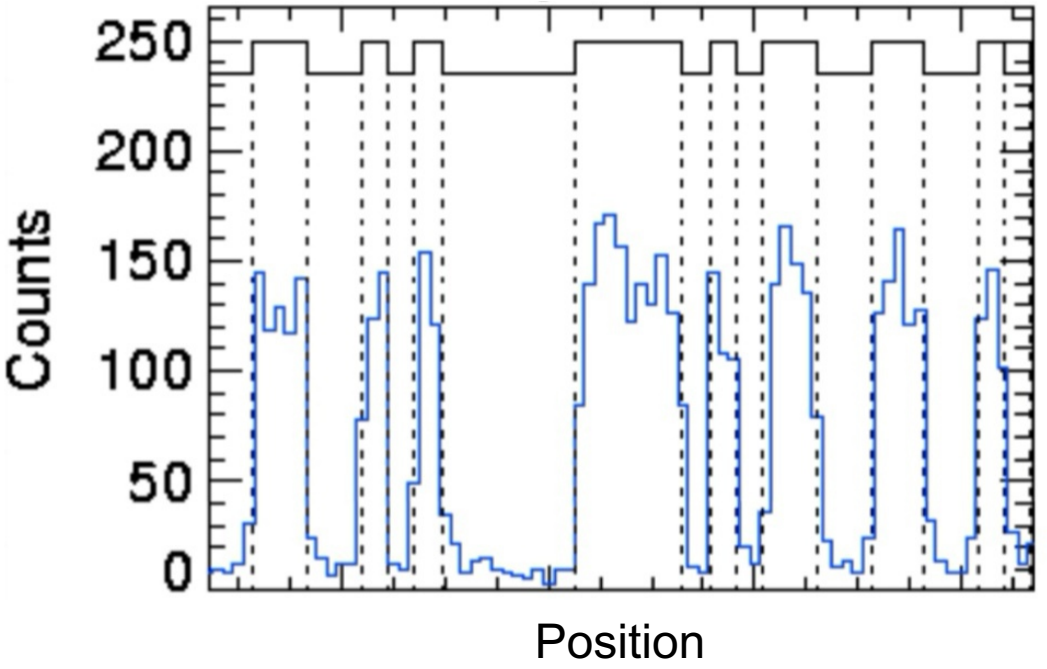
$$P = [(Q_L - Q_R)/(Q_L + Q_R)] * (L/2)$$

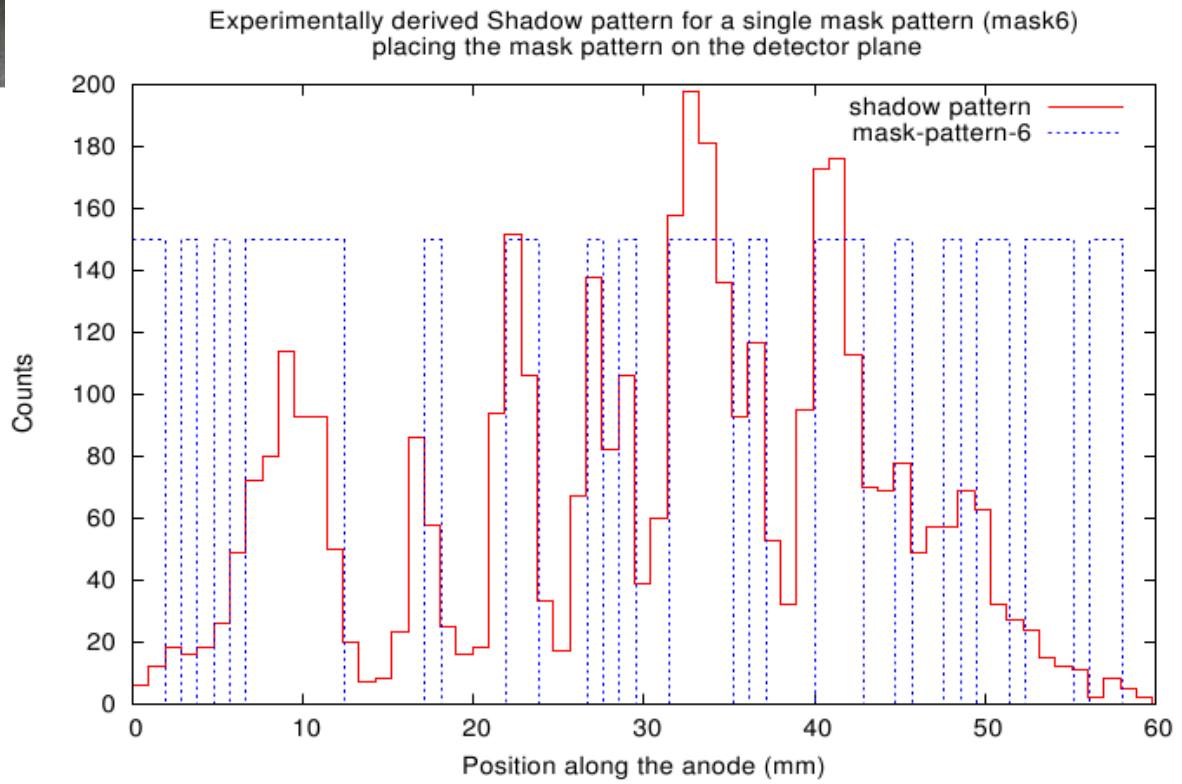
Charge ratio is converted to position using caldb and detector position histogram is generated.



Coded-mask for SSM






Experimentally derived Shadow pattern for a single mask pattern (mask6)
placing the mask pattern on the detector plane
shadow pattern
mask-pattern-6
Counts
Position along the anode (mm)
0
20
40
60
80
100
120
140
160
180
200
0
10
20
30
40
50
60

Calibration of SSM

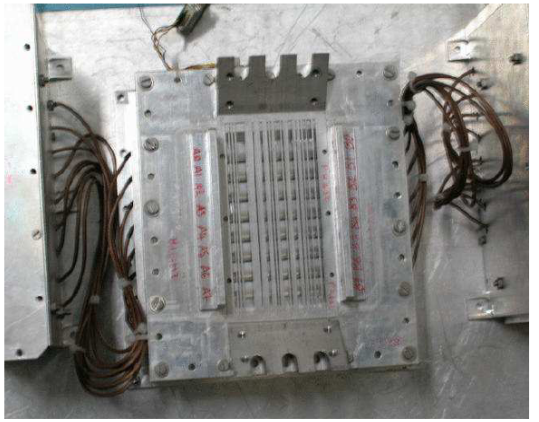
- **Imaging – Caldb**
  - Calibration constants for each anode wire
  - Position resolution along the anode wire
  - Anode response of each wire
  - E-Channel relation – binning the events into different energy bands
  - Detection Efficiency

  - Using the cal-constants derive the position of every event incident
  - DPH generated is input to imaging algorithm to generate the source plane image, estimating the location and flux of the source in the FOV

- **Spectral - Caldb**
  - E-ch relation
  - E-FWHM derived
  - Each monochromatic source spectrum is modelled with a function
  - Spectral response

- **Sensitivity**
  - Detection efficiency in the energy range 2-10 keV

Imaging



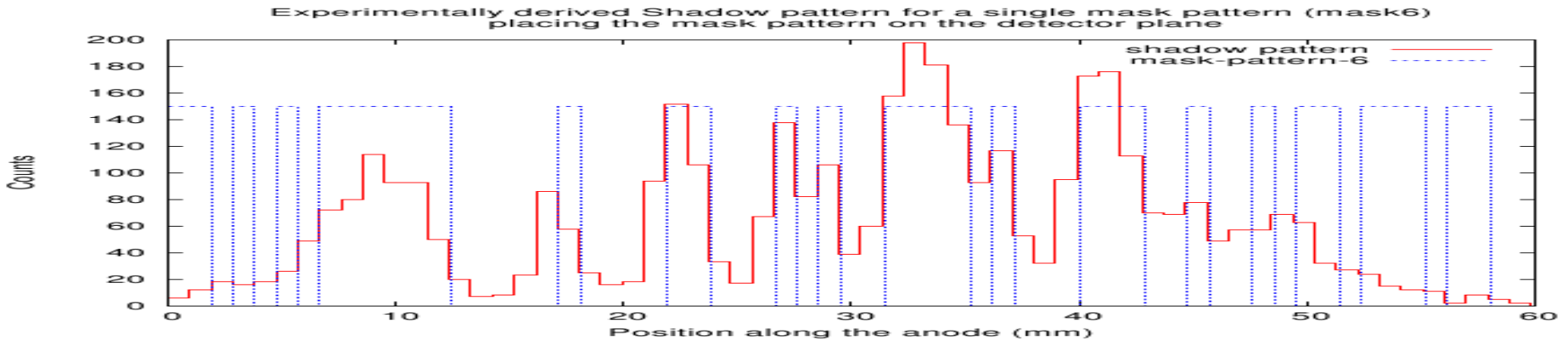
Deriving calibration constants

- Experimental Procedure
  - Mask plate placed on the detector
  - X-ray gun used for illuminating the detector+mask plate
  - Data acquired for a time period ‘t’

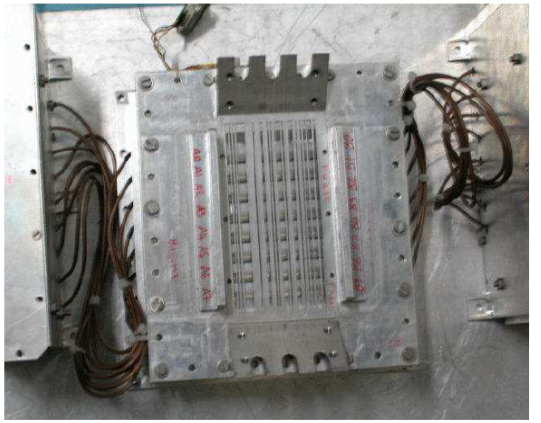
- Anode Ratio Histogram (ARH) is generated from binned charge ratios of all the events incident on the detector.
- Position of edges in the mask plate and the corresponding ratio edges in the ARH are noted and the data is used to derive the calibration constants
- Curve fitting done to the above mentioned data with a function g(x); function used here is

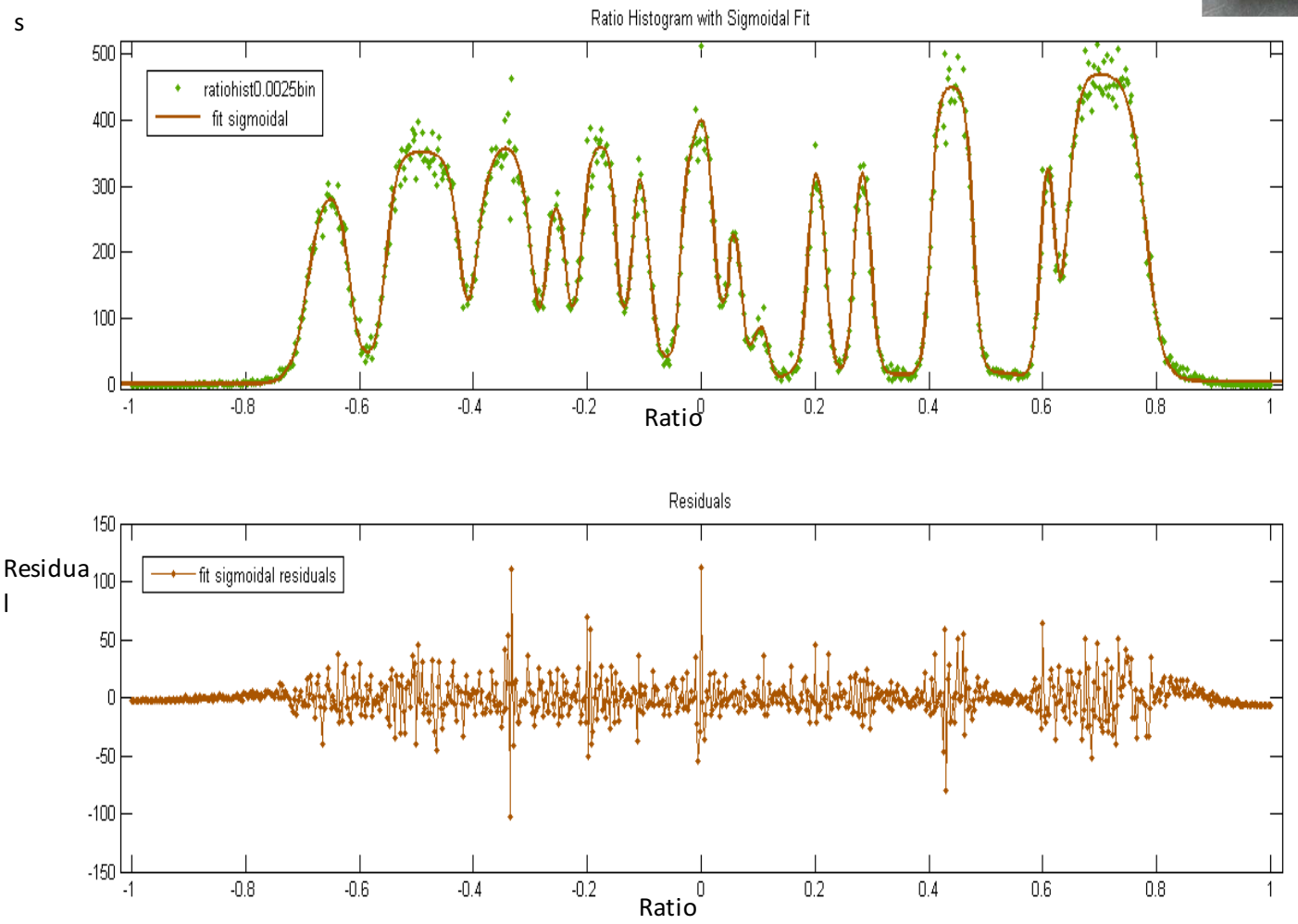
  g(x)=(p*x+q)/(x+r)

  Where p, q, and r are the calibration constants for the respective anode



ARH of one anode

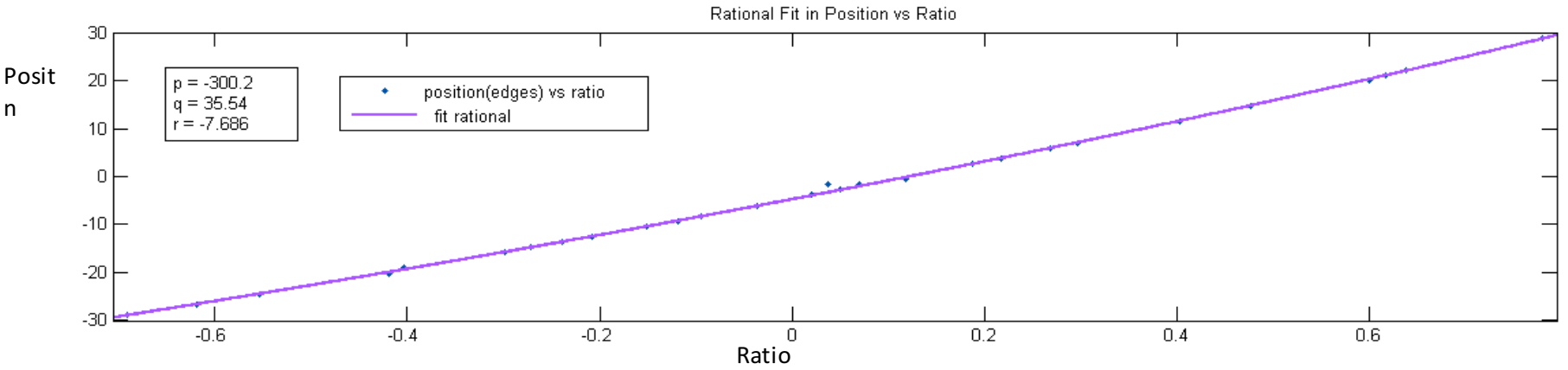


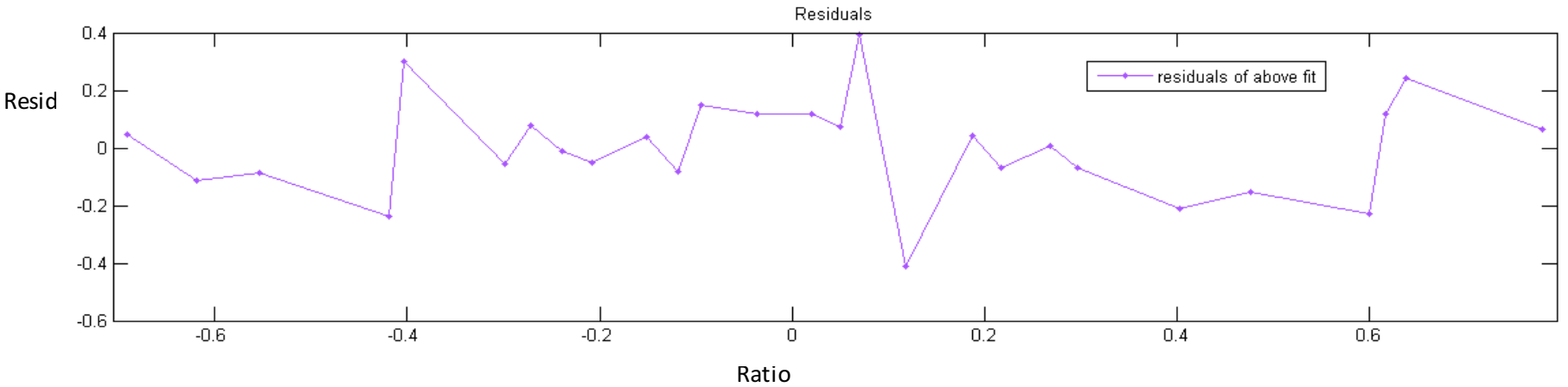


- Position of edges in the mask plate and the corresponding ratio edges in the ARH are noted and the data is used to derive the calibration constants
- Curve fitting done to the above mentioned data with a function g(x); function used here is a rational function

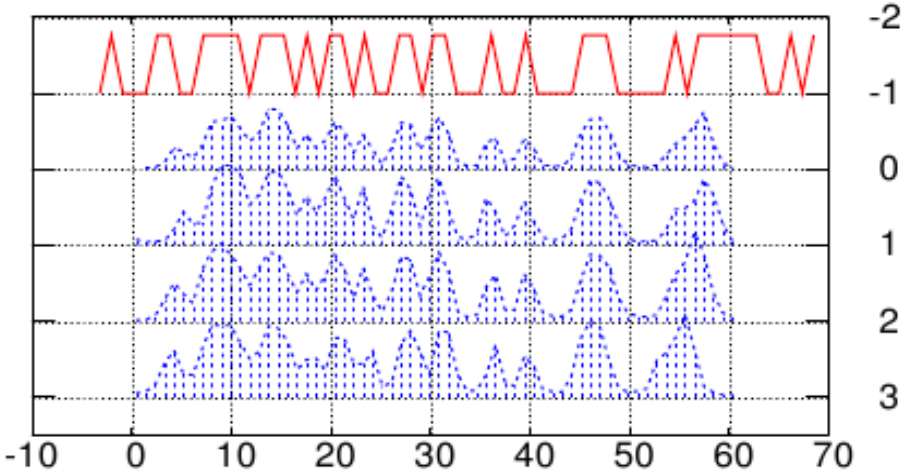
$$g(x)=(p*x+q)/(x+r)$$

Where p, q, and r are the calibration constants for the respective anode

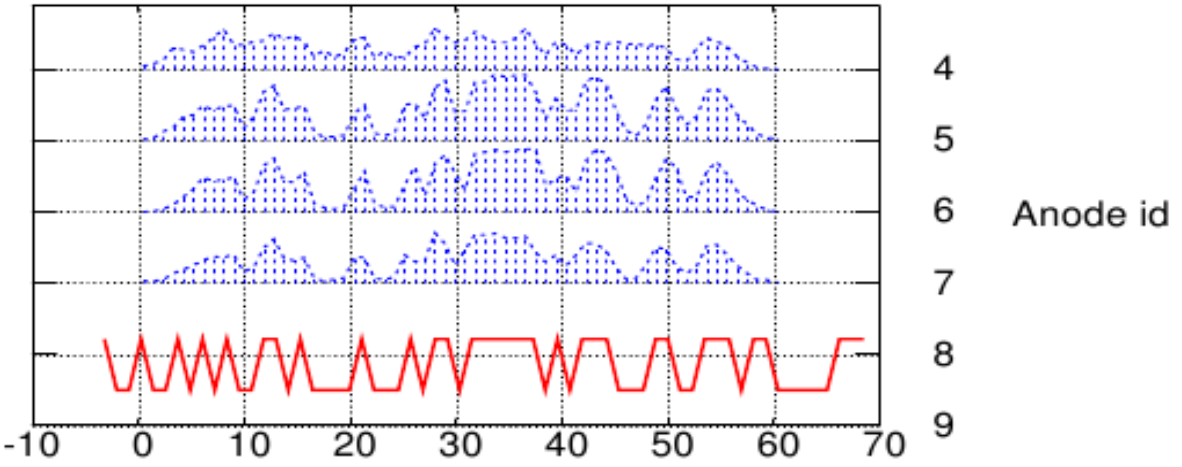




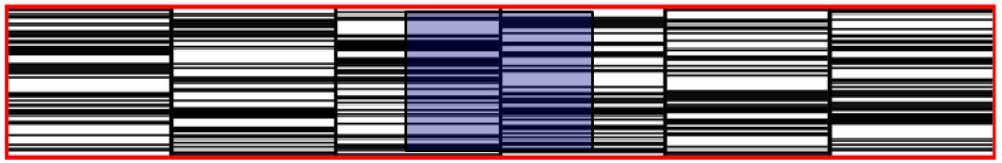
Experiments to derive the position of the source in FOV of SSM



observed shadow of mask-C
mask-C with divergence factor

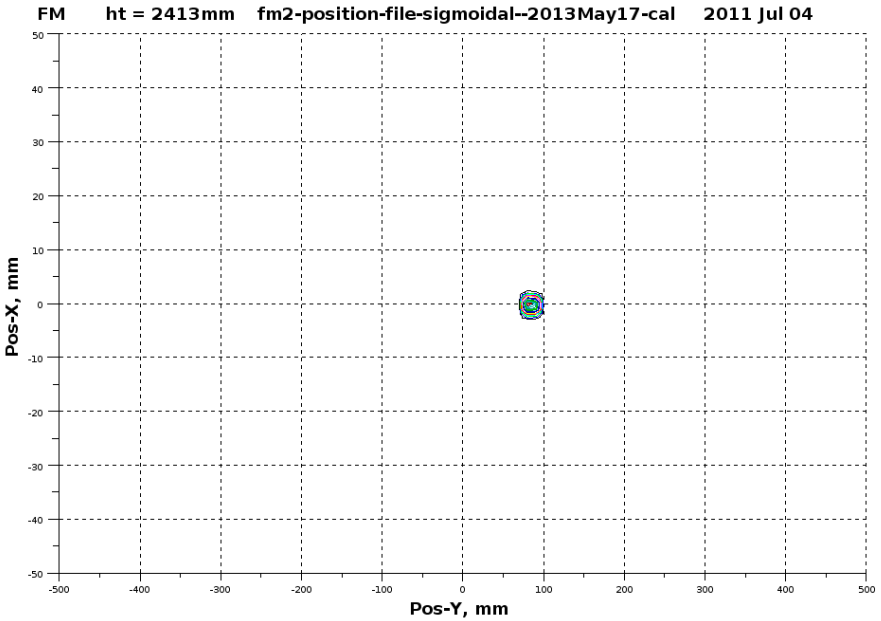


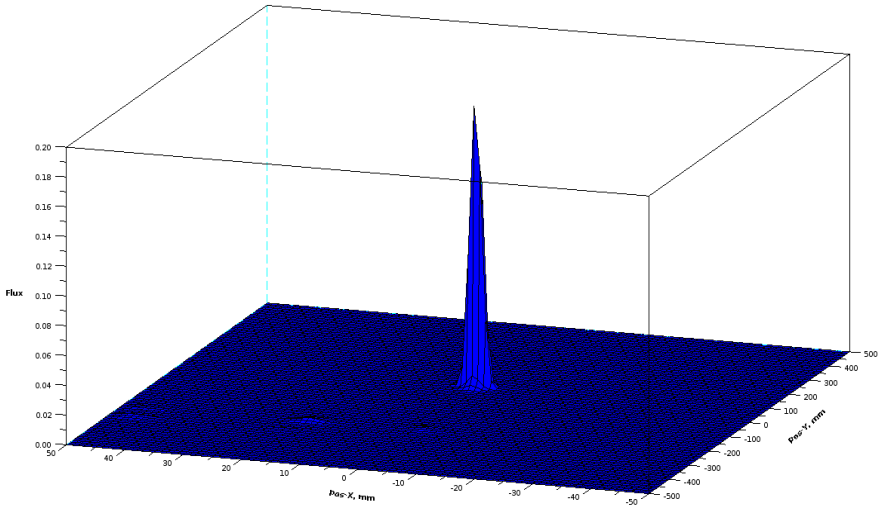
Position along the anode wire



shadow pattern of mask D
mask pattern D with divergence factor

Results of Imaging



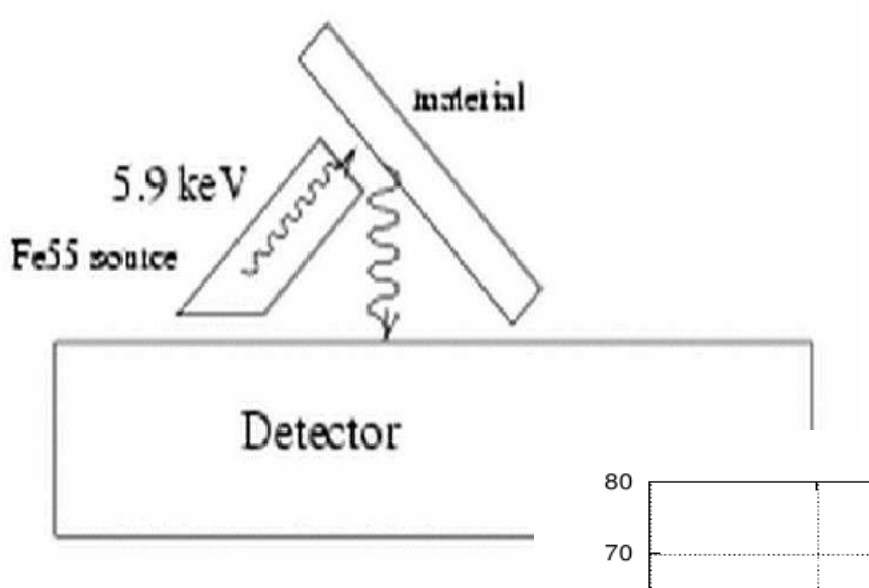


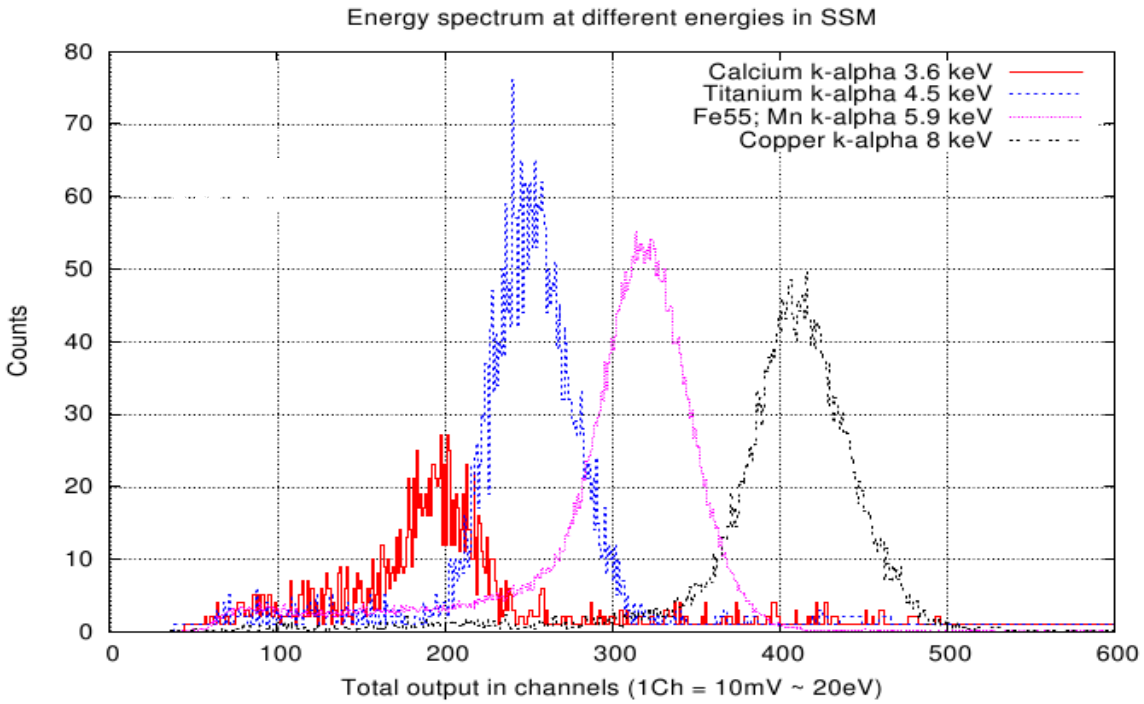
The above are the contour and surface plots of the source plane image showing a single peak at the expected position in the FOV. This is from one of the FM detectors.

Spectral

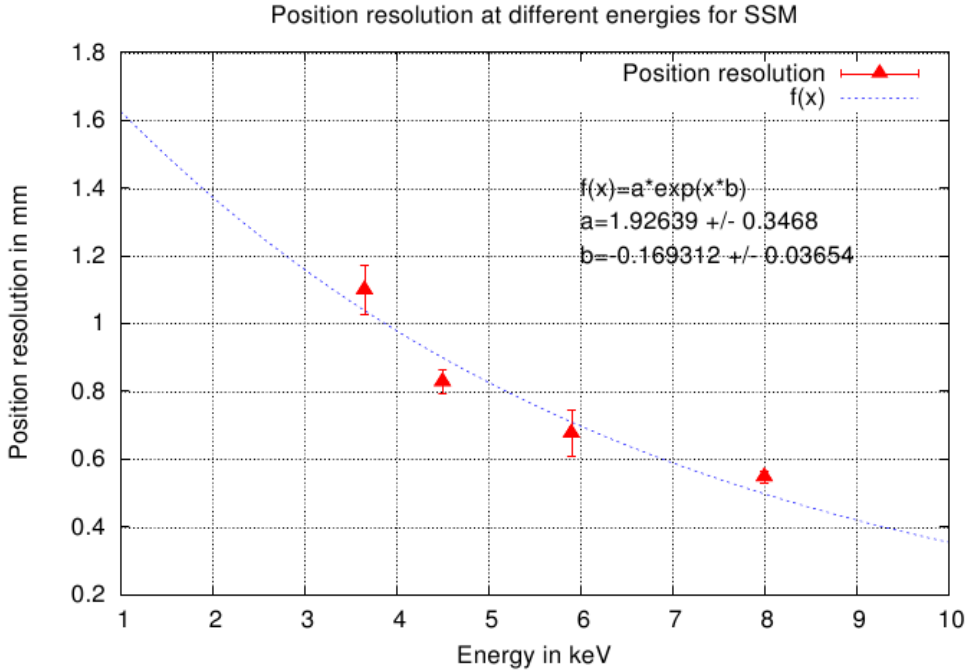
- Calibration of SSM at different energies
- Deriving E-chan relation
- Estimating the energy and position resolution at different energies
- Estimating the effective area of SSM
- Deriving the spectral response for SSM

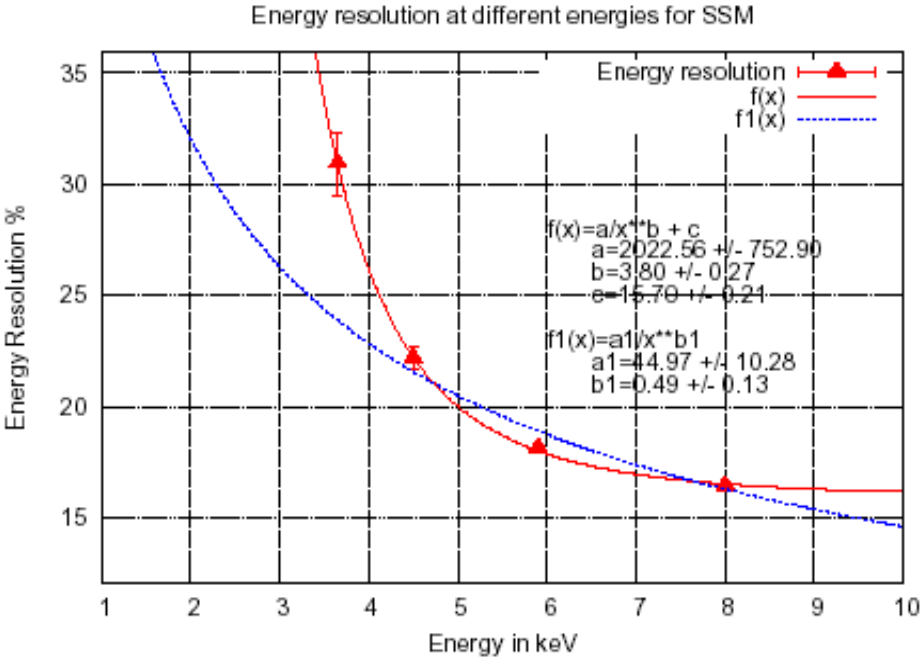
Spectral calibration of SSM at different energies

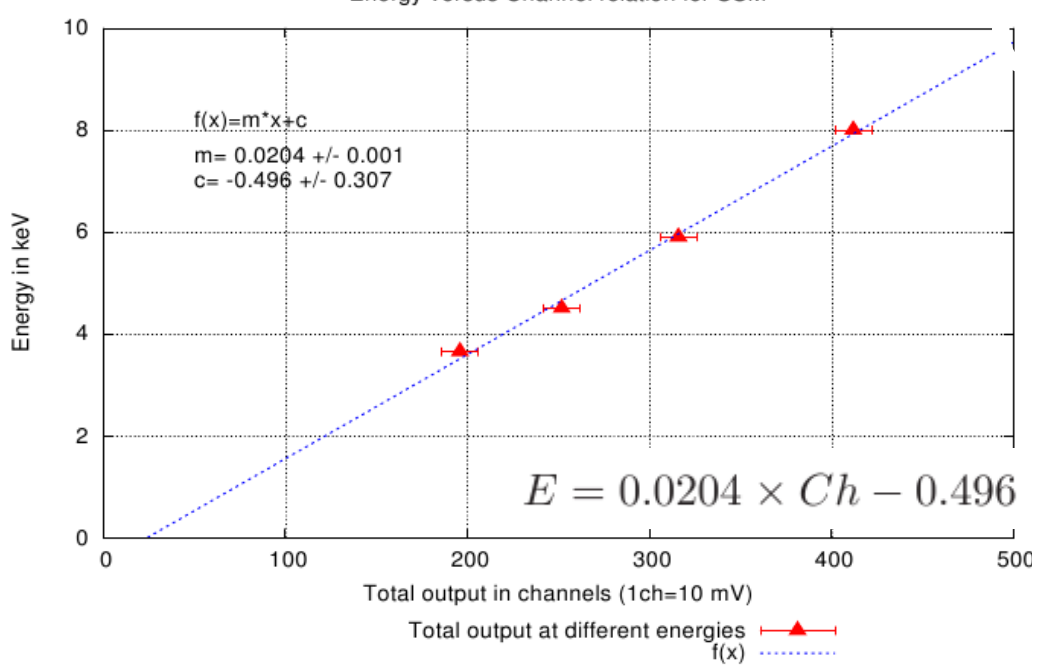


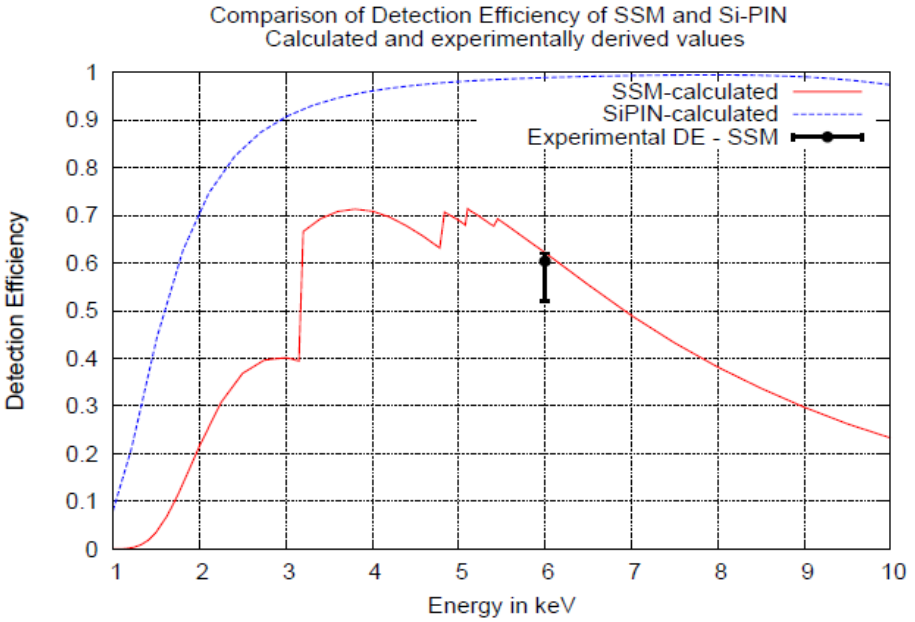


Energy-channel relation, Energy Resolution, Position Resolution and Detection Efficiency









Spectral response for SSM

SRF for SSM is modelled with three gaussians:
photopeak and two escape peaks

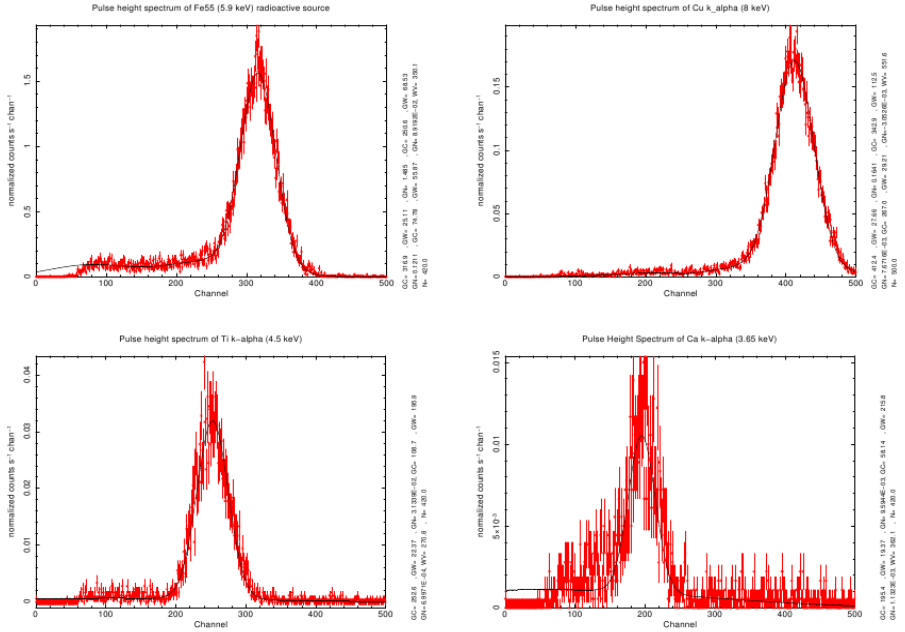
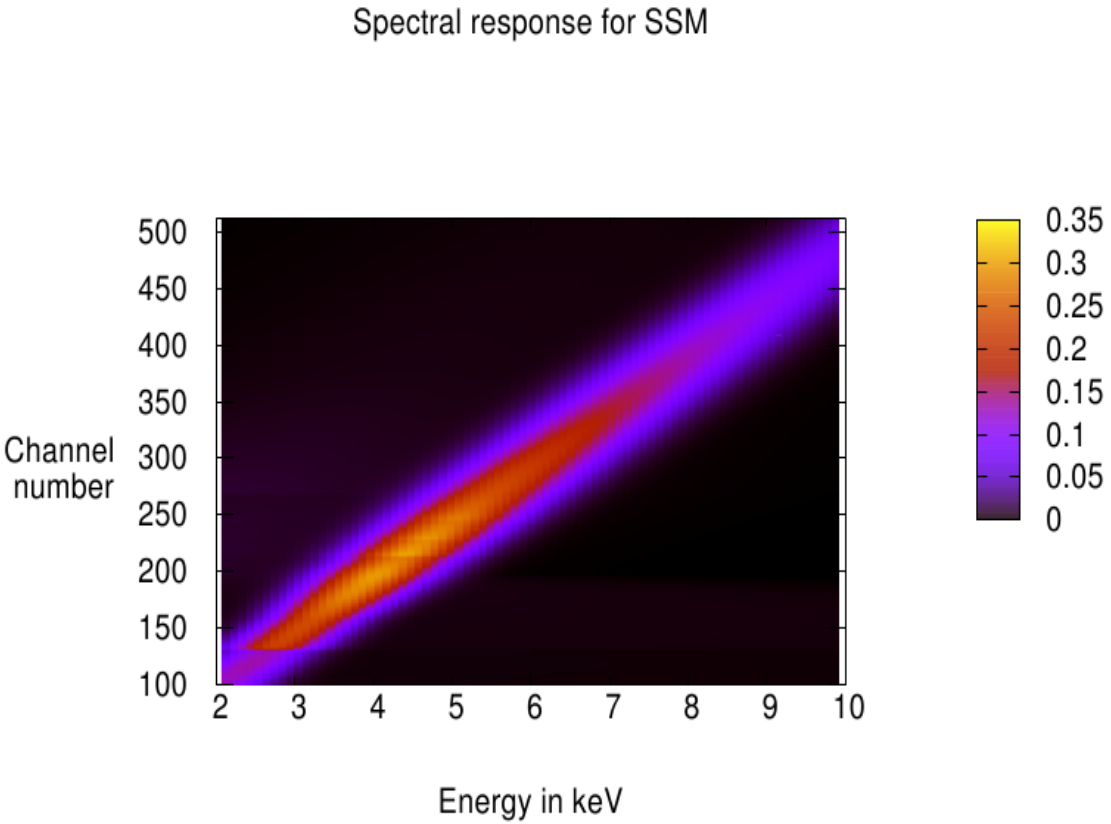


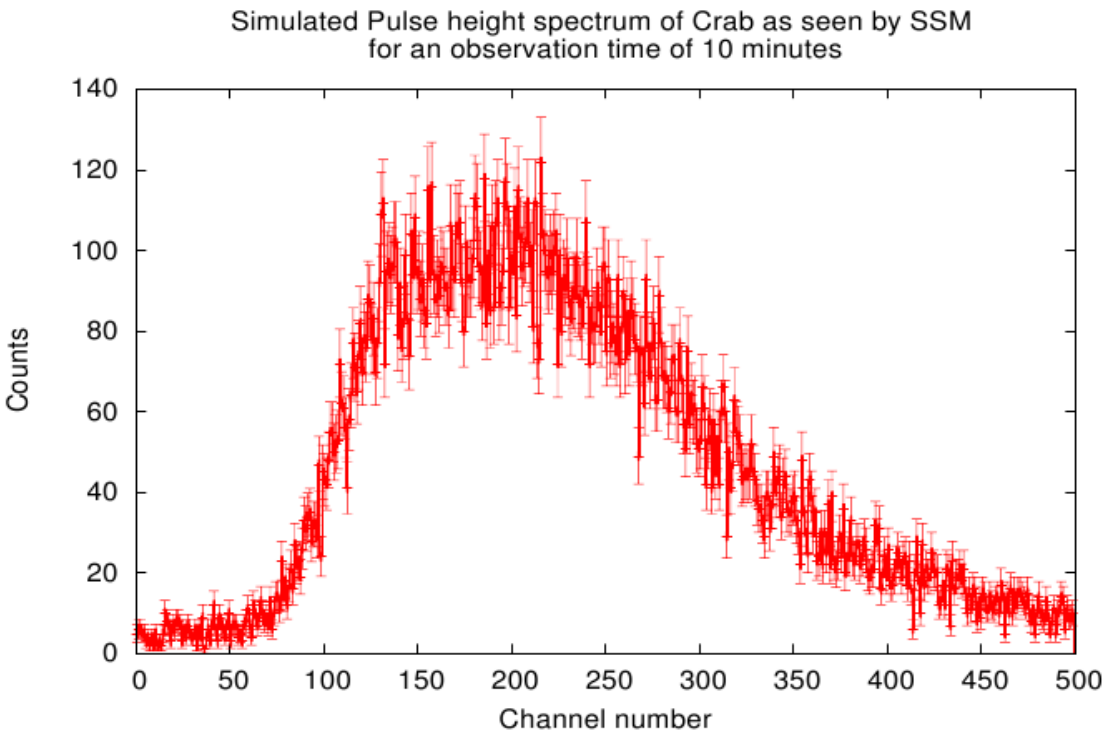
FIGURE 4.8: Pulse height spectrum of Fe^{55} radioactive source, Cu K_α source, Ti K_α source and Ca K_α source modelled with three gaussians each



X-ray Source	X-ray-Energy	Centroid Energy
Ca K_α	3.65	3.48 ± 0.02
Ti K_α	4.51	4.69 ± 0.01
Fe^{55} (Mn K_α)	5.89	6.00 ± 0.03
Cu K_α	8.04	7.96 ± 0.01

On-board gain calibration for SSM

- **There is no calibration source placed inside SSM for its on-board calibration.**
- **The standard celestial X-ray calibration source 'Crab' is used for SSM calibration on-board.**
- **Simulated pulse height spectrum of Crab as observed by SSM is shown here**



Using the spectral response the spectrum of Crab nebula is simulated.

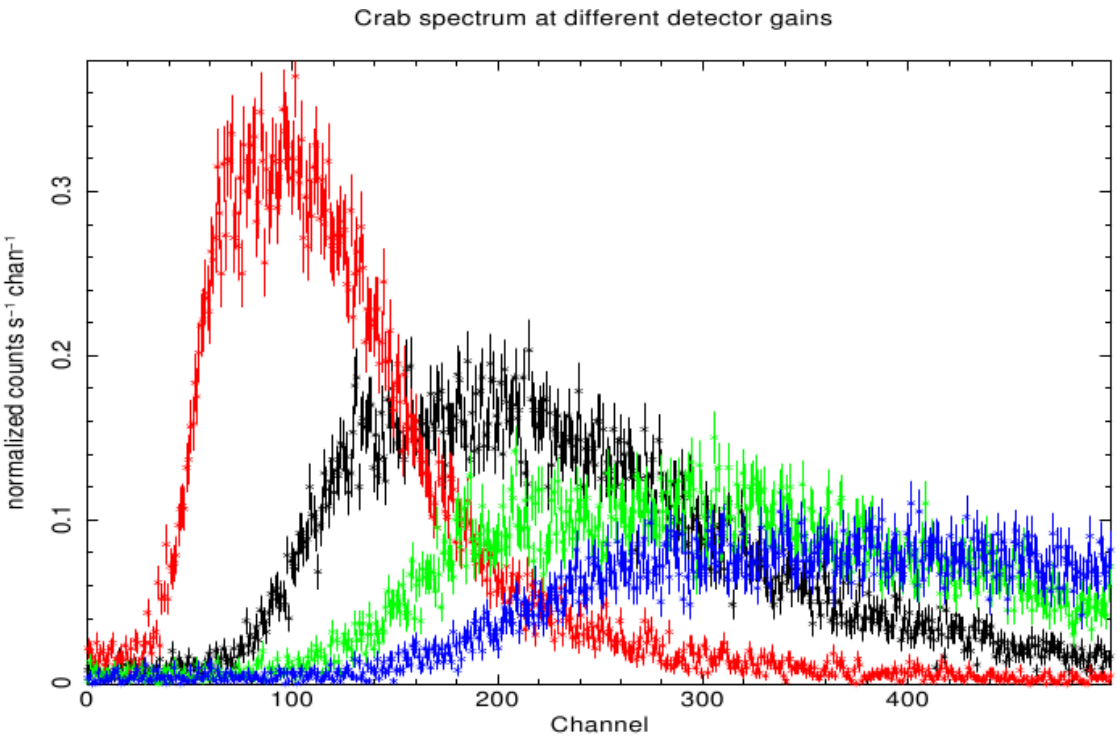
The spectrum of the Crab nebula is given by

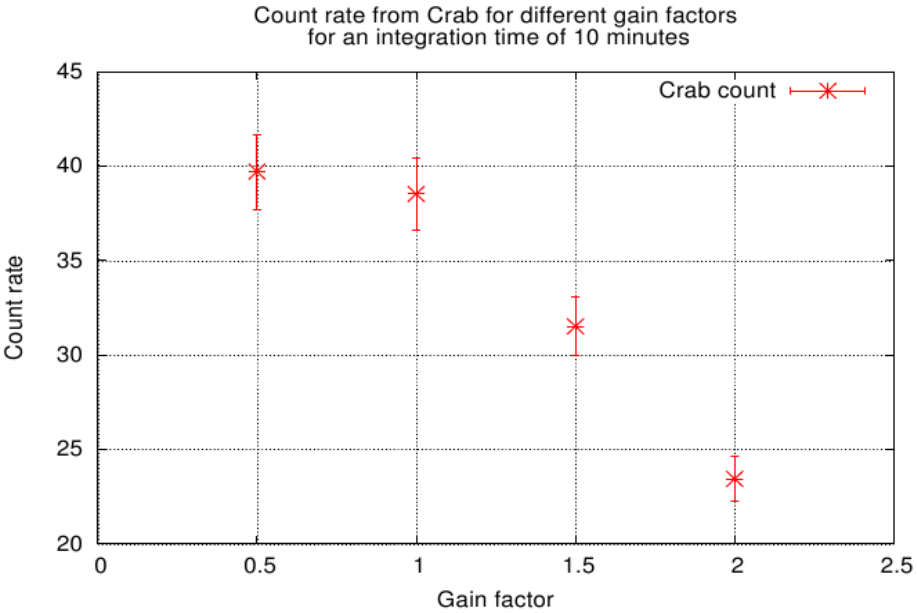
$$N = A\,E^{-\Gamma}$$

Where A is the norm = 9.7 ± 1.0,
Γ is the photon index = 2.108 ± 0.006

Integrated counts in the pulse height spectrum is ~28 counts/sec, which is the Crab count for SSM

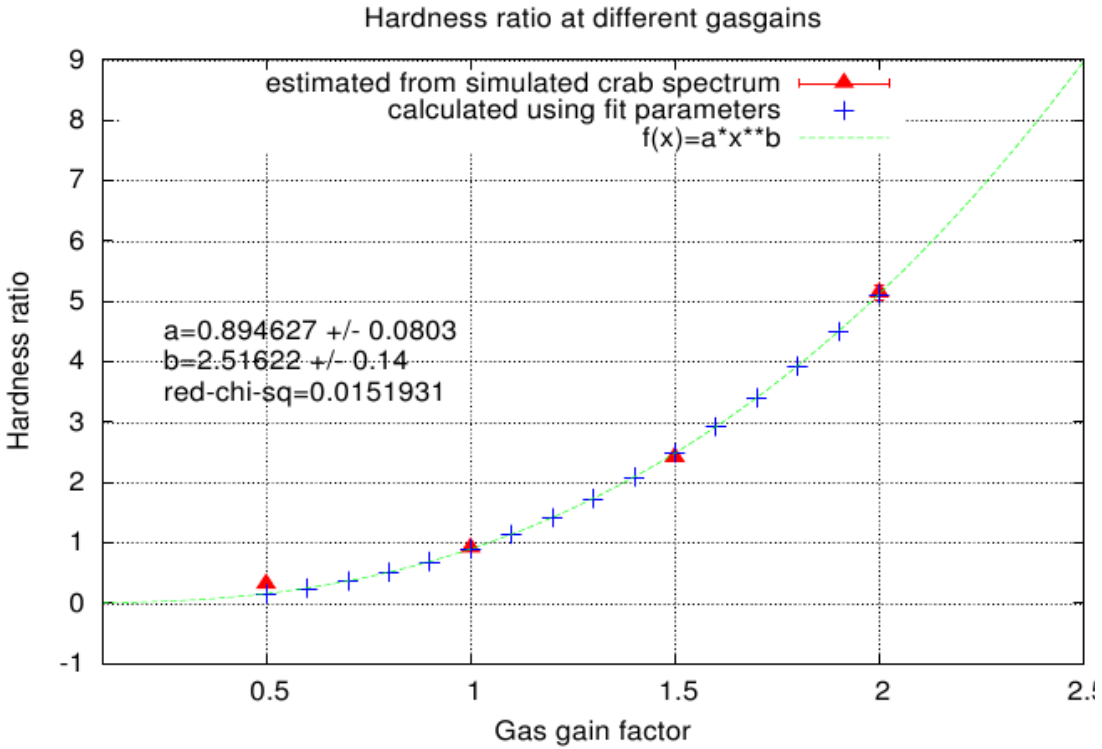
Estimated SSM Crab counts : 28 counts/sec

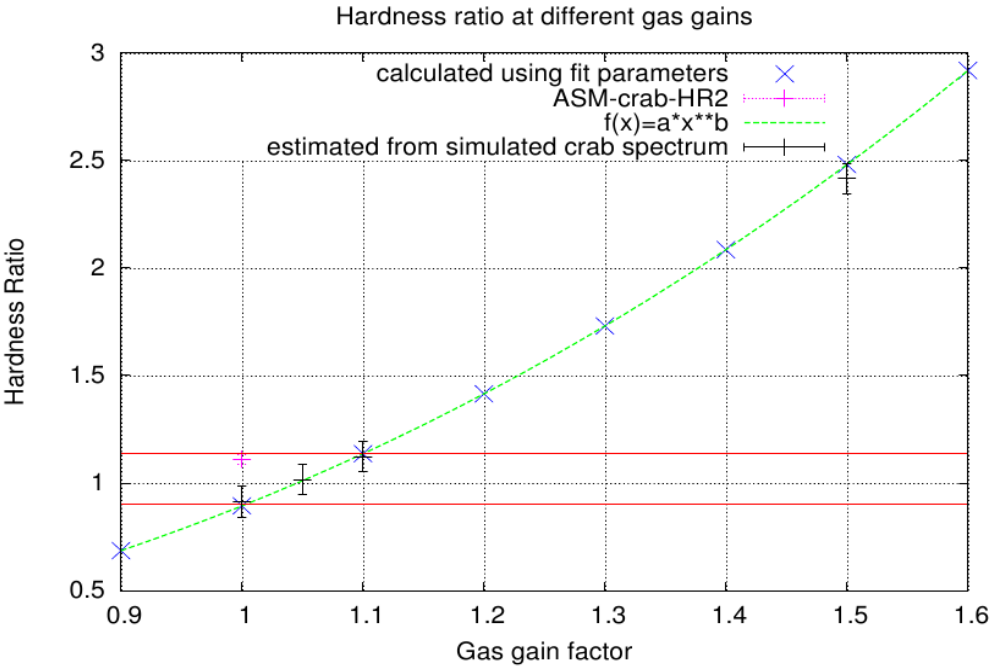




Hardness Ratio:

Ratio of flux in 3-5 keV to 5-10 keV





10% variation in gas gain can be tuned using HV steps on-board

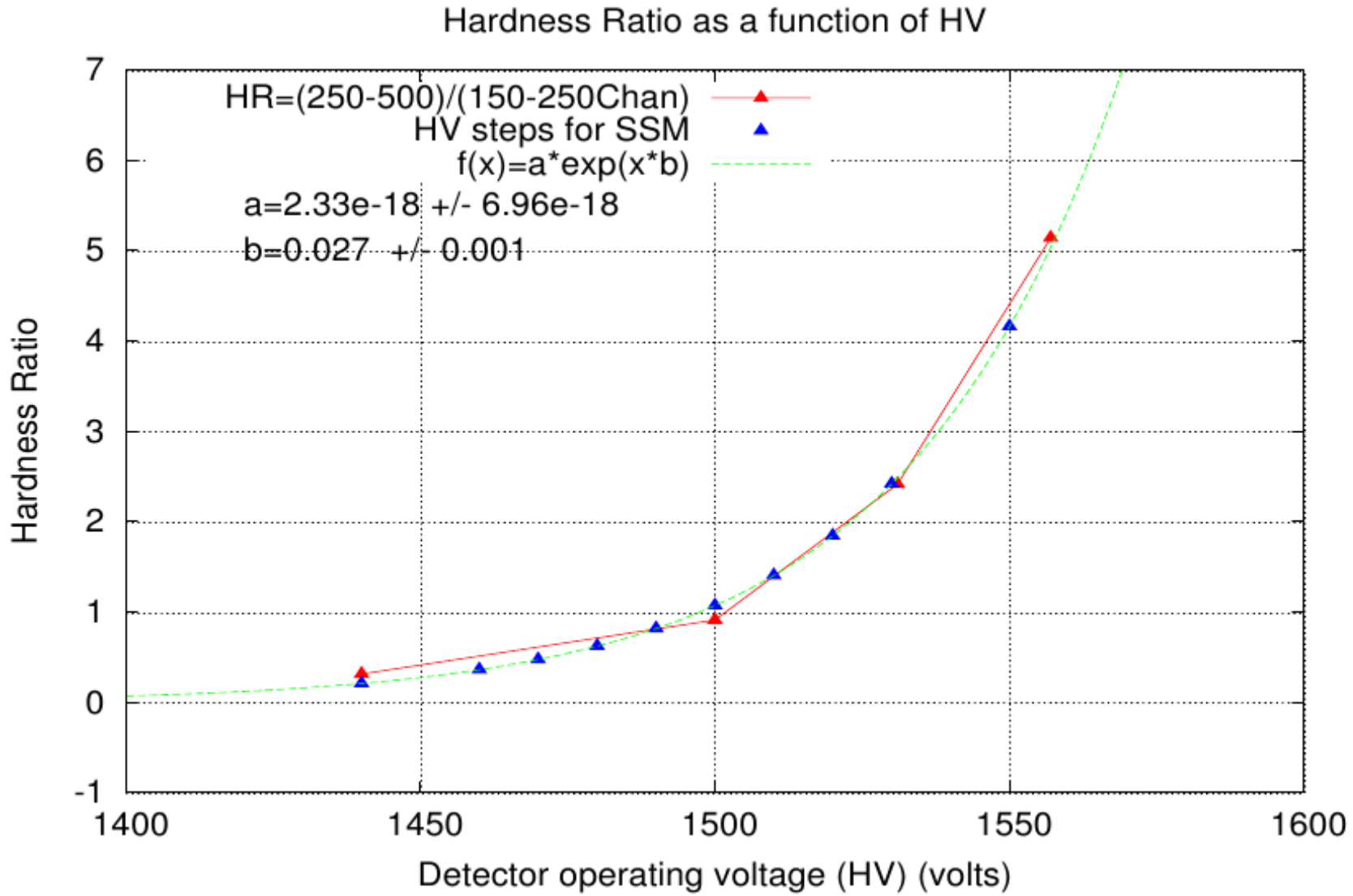
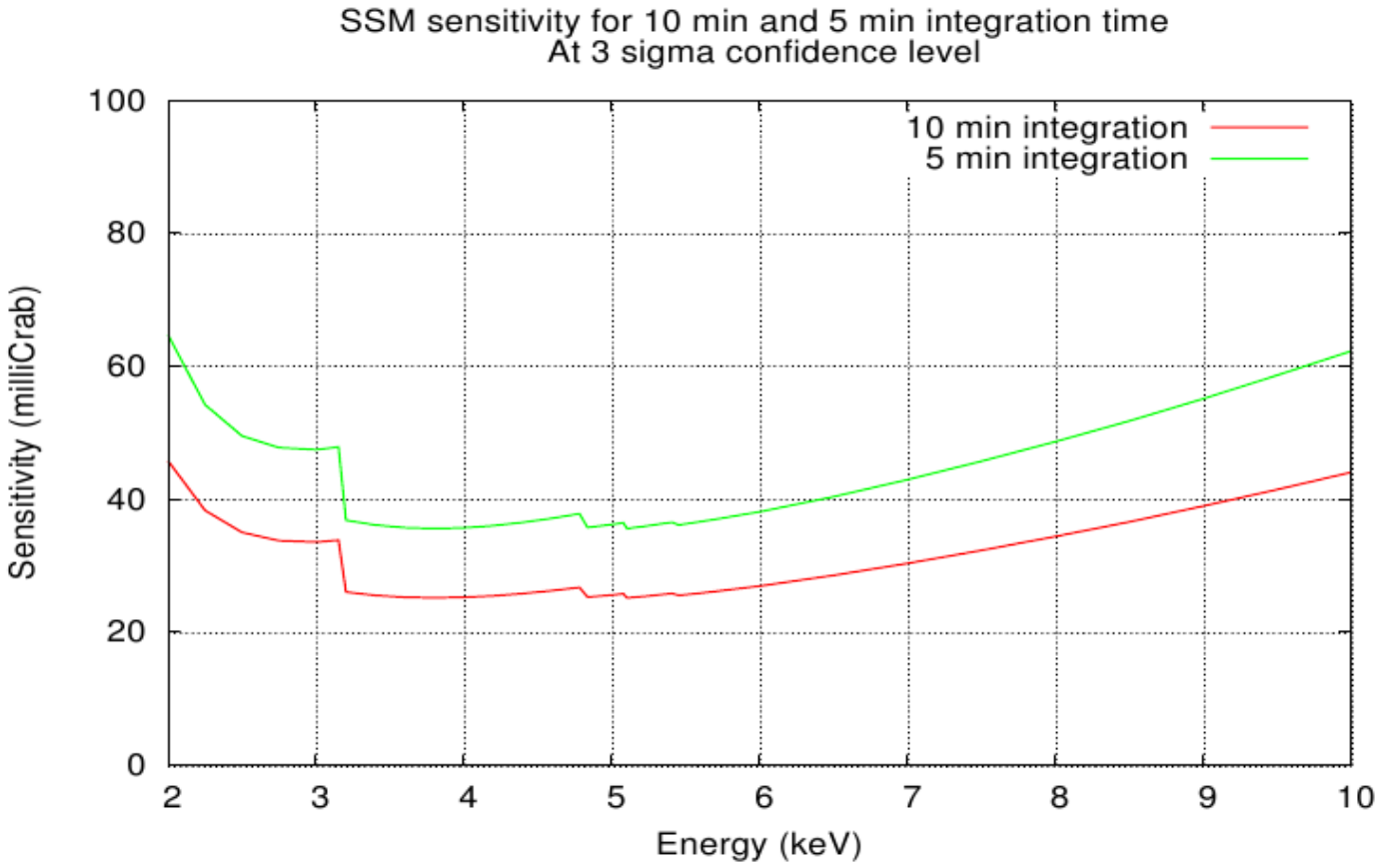


Figure above shows that a 10% variation in gas gain as seen in HR can be very well tuned by using HV steps on-board

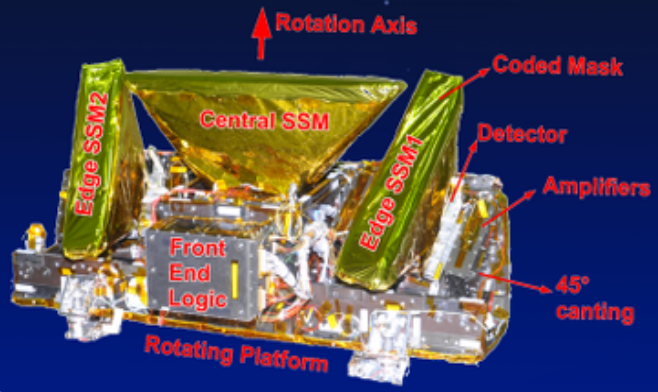


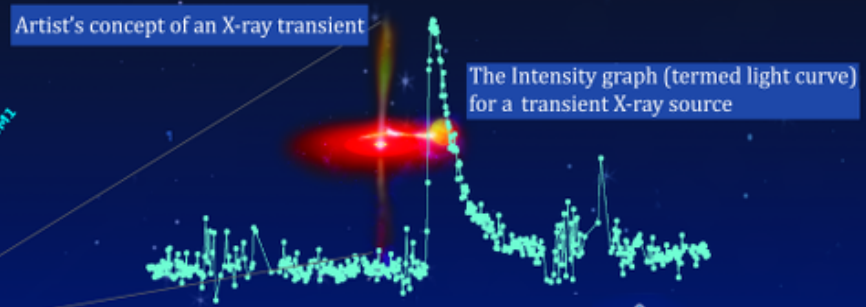
$$S[E] = 3\sqrt{\frac{(\frac{B_1}{A} + B_2[E]\Omega)}{(gfA)(ht)\epsilon[E]}}$$

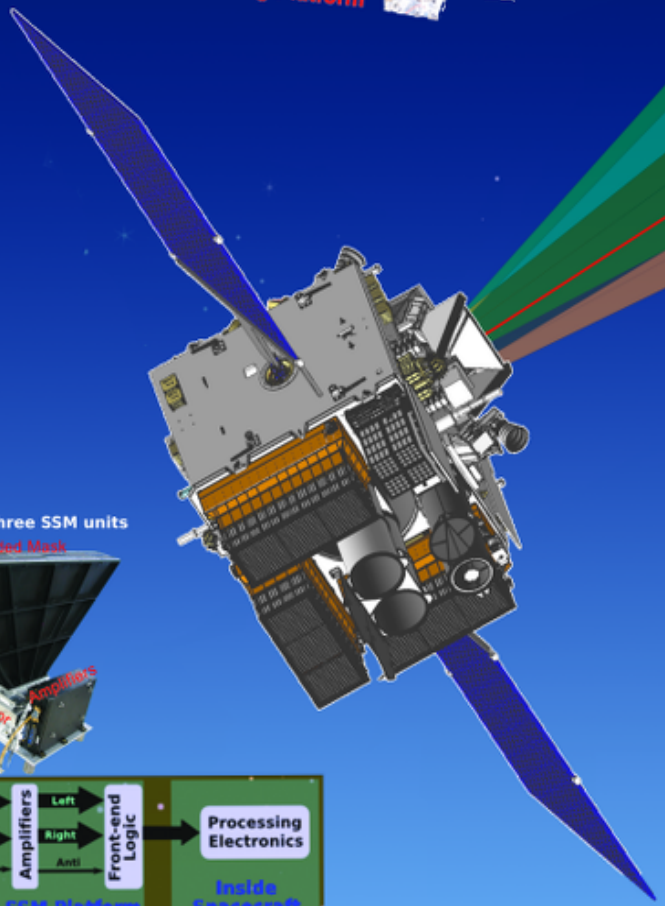
Sensitivity of SSM at 6 keV is ~30 milliCrab

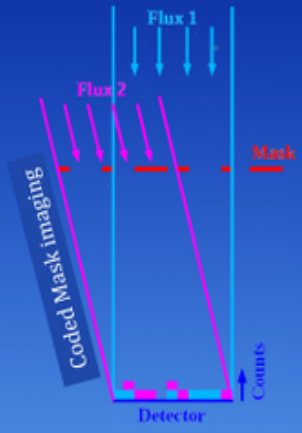
SCANNING SKY MONITOR (SSM) ABOARD ASTROSAT

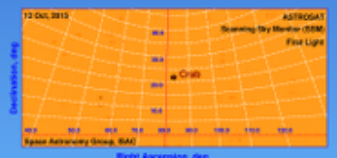
To detect and locate X-ray transients











SSM Firstlight image of Grab Nebula

- *scan almost 50% of the sky in one full rotation of the platform in 6 hours*
- *Step and Stare mode*
- *10 min stare at every 10 deg*
- *5 to 355 deg rotation*

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

ISRO/IUCAA

ssm@isac.gov.in

Science Objectives

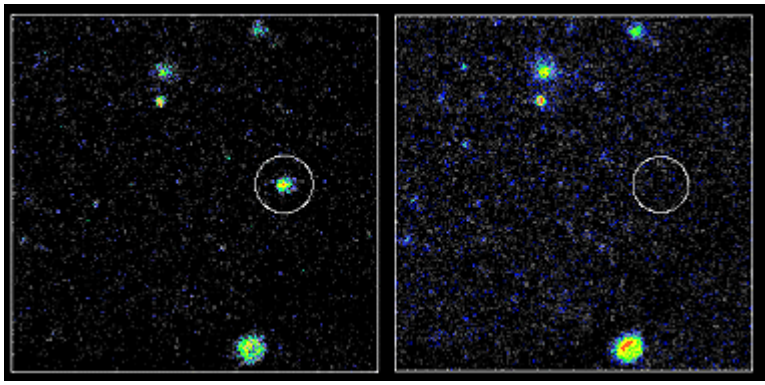
- *Detect and locate transient sources*
- *Long-term time variability*
- *Transient Alert generation*
- *Catalog updation*

scan almost 50% of the sky in one full rotation of the platform once in every 6 hours

Step and Stare mode (10 min at every 10 deg)

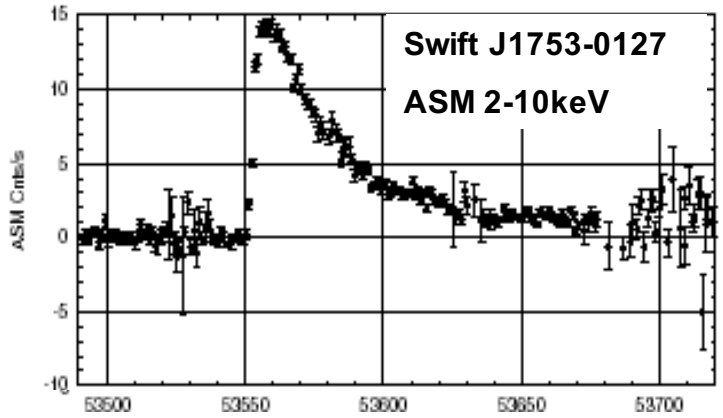
Sensitivity of 30 mCrab in 10 min

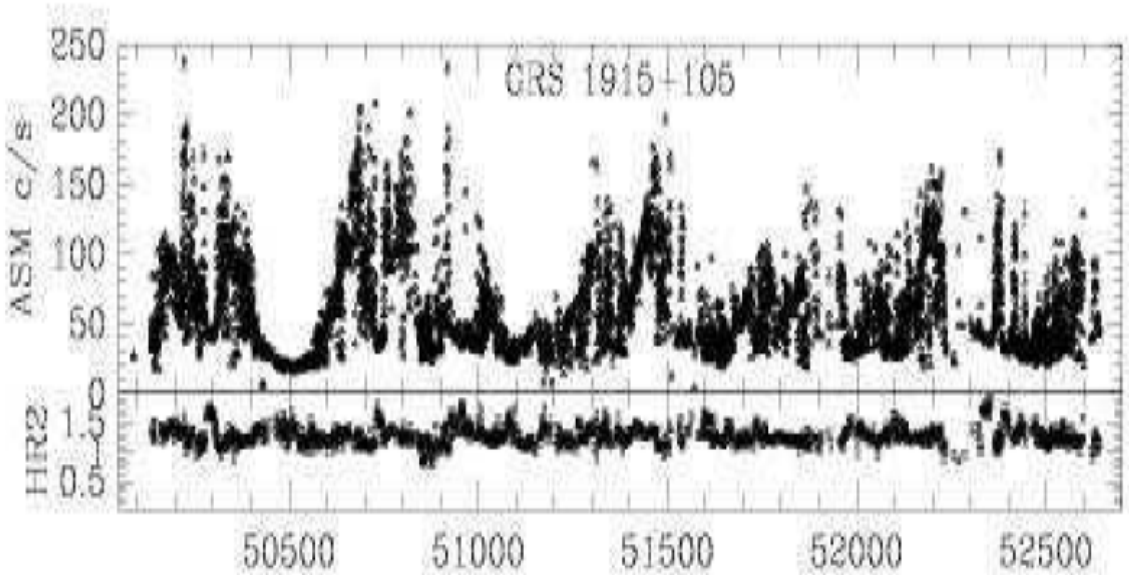
Xray Transients



(ROSAT sky) RX J0045.4+4154

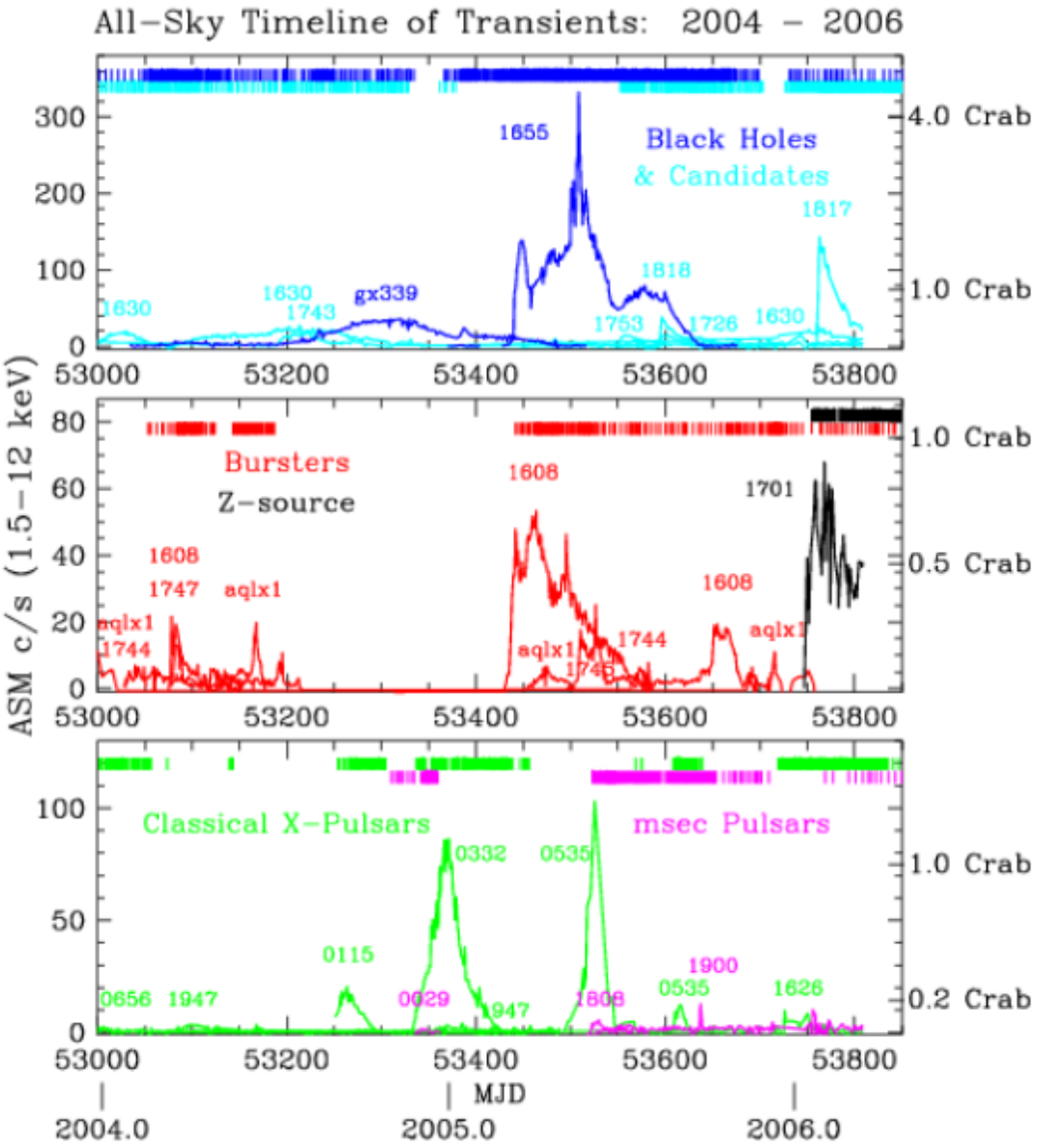
- *Enhanced X-ray emission*
  - *Transients - various timescales*
  - *Persitent sources*
- *NS & BH systems (HMXBs & LMXBs)*
  - *Typical transient outbursts*
  - *Thermonuclear bursts, superbursts etc.*





Light curves of X-ray transients

- ✔ *Light curves of variety of sources*
  - ✔ *Black Hole systems and*
  - ✔ *Neutron Star systems*
    - *Z-sources*
    - *Bursters*
    - *Pulsars*
    - *Etc.*
- ✔ *Large number of sources with varied emission*
  - ✔ *Large dynamic range of intensities*
  - ✔ *Different levels of variabilities - Different phenomenon*



Remillard, 2010

HIGHLY VARIABLE X-RAY SKY

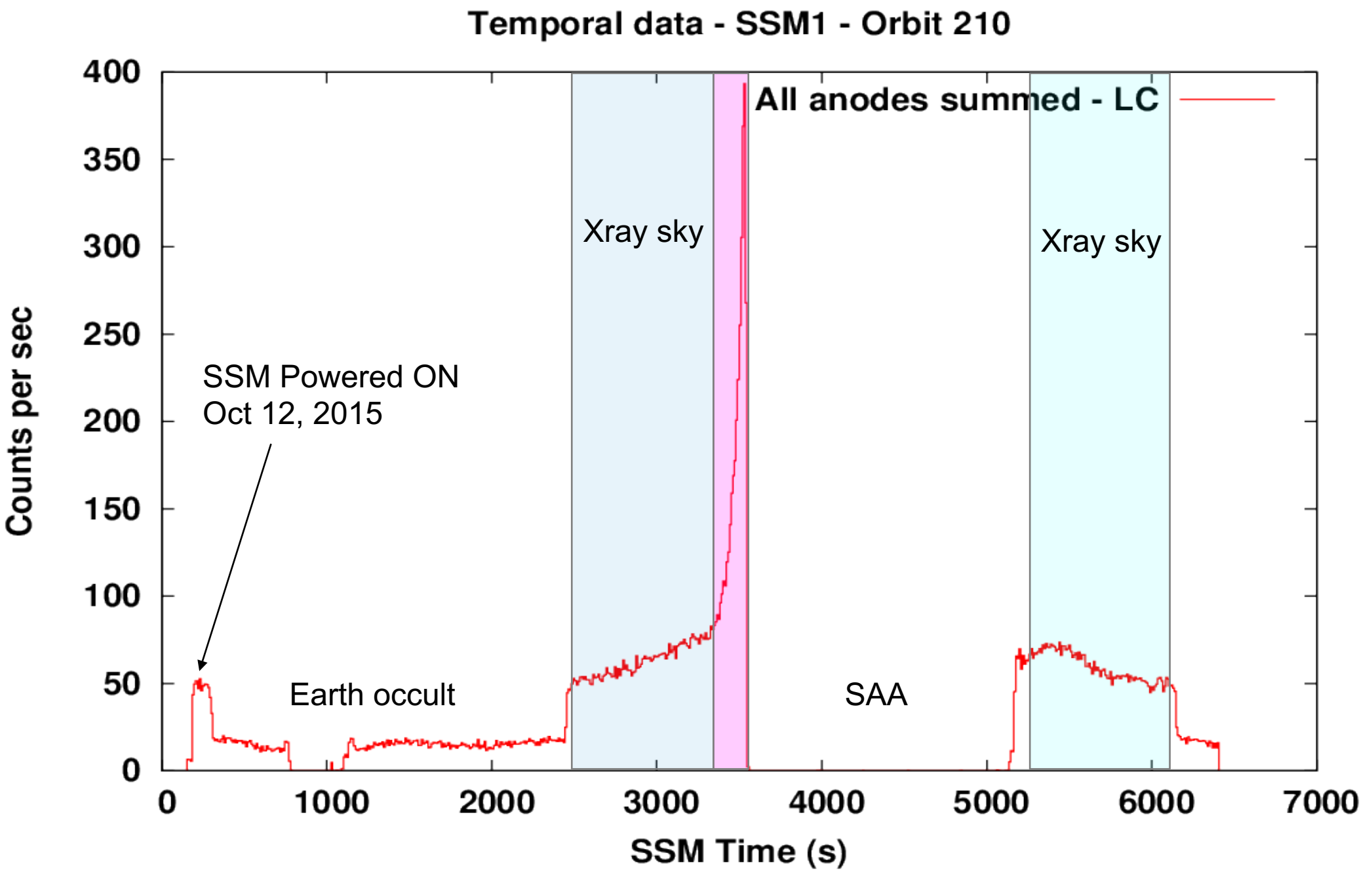
Xray Sky Monitors

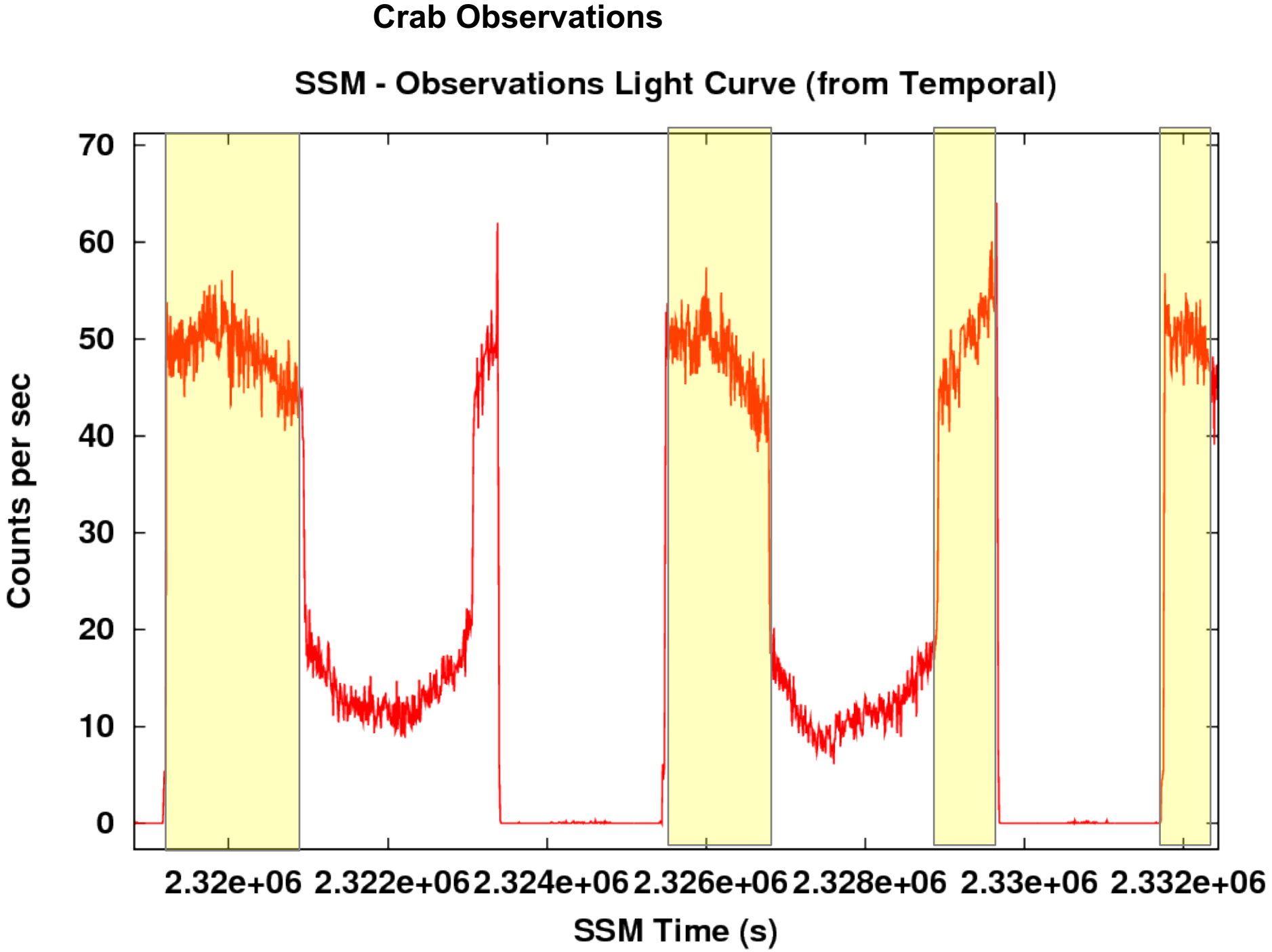
- ➔ *Scan large portion of the sky in short periods – sky survey*
- ➔ *Discovery of new sources and new types of sources*
- ➔ *Long term monitoring of different class of objects – Variabilities - recurrence timescales - Lightcurves of varied sources – transients and persistent sources*
- ➔ *Hardness-Intensity diagrams - continuous monitoring - indicating state transitions - for detailed study – like spectra, Fe line emission/profile, Pds for any features etc.*
- ➔ *Monitoring large dynamic range of accretion rates and luminosities*
- ➔ *Possible only with a large FOV instruments – sky monitors*

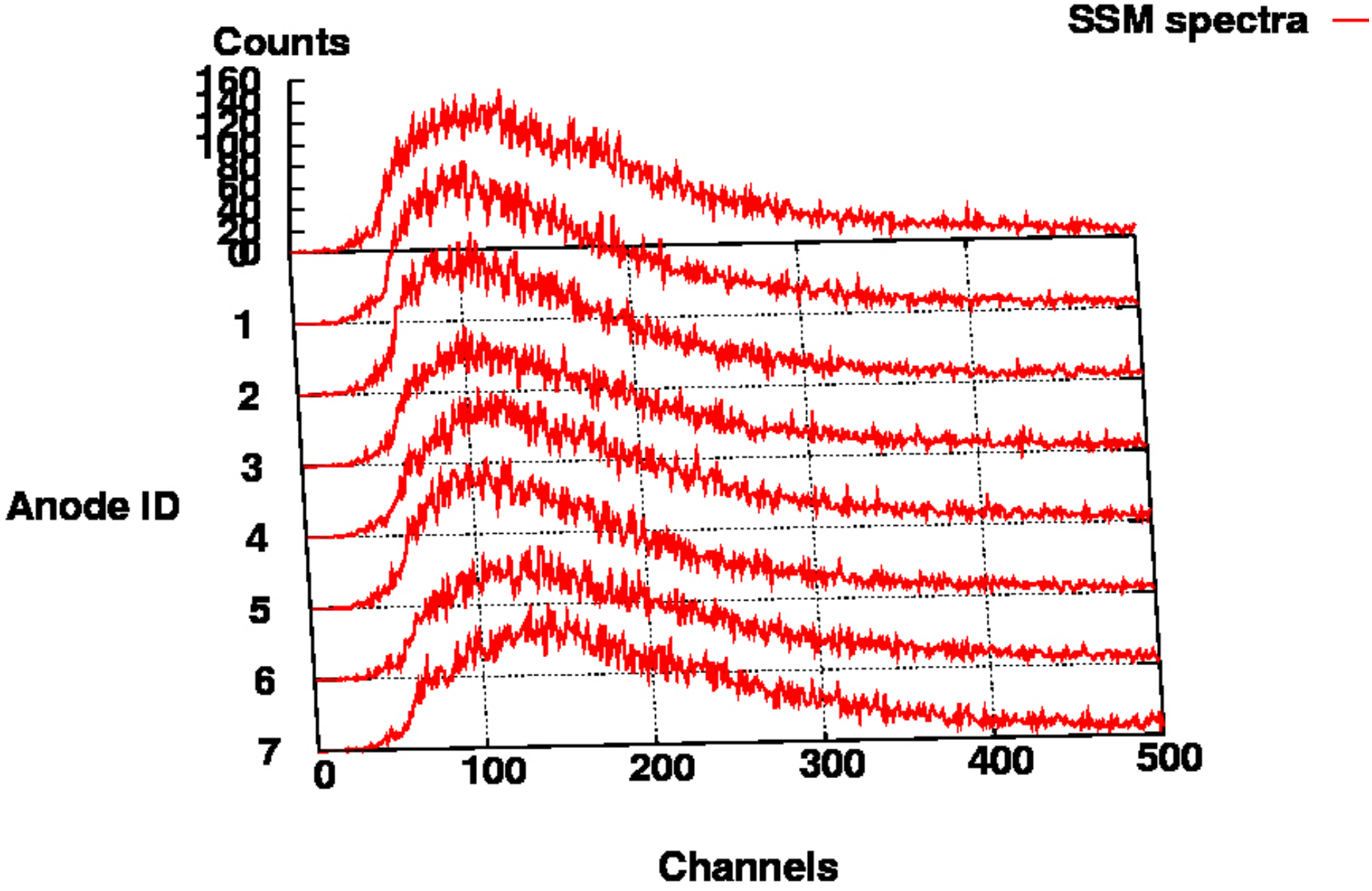
DEDICATED SKY MONITORING REQUIRED

SSM onboard - observations, calibration & results

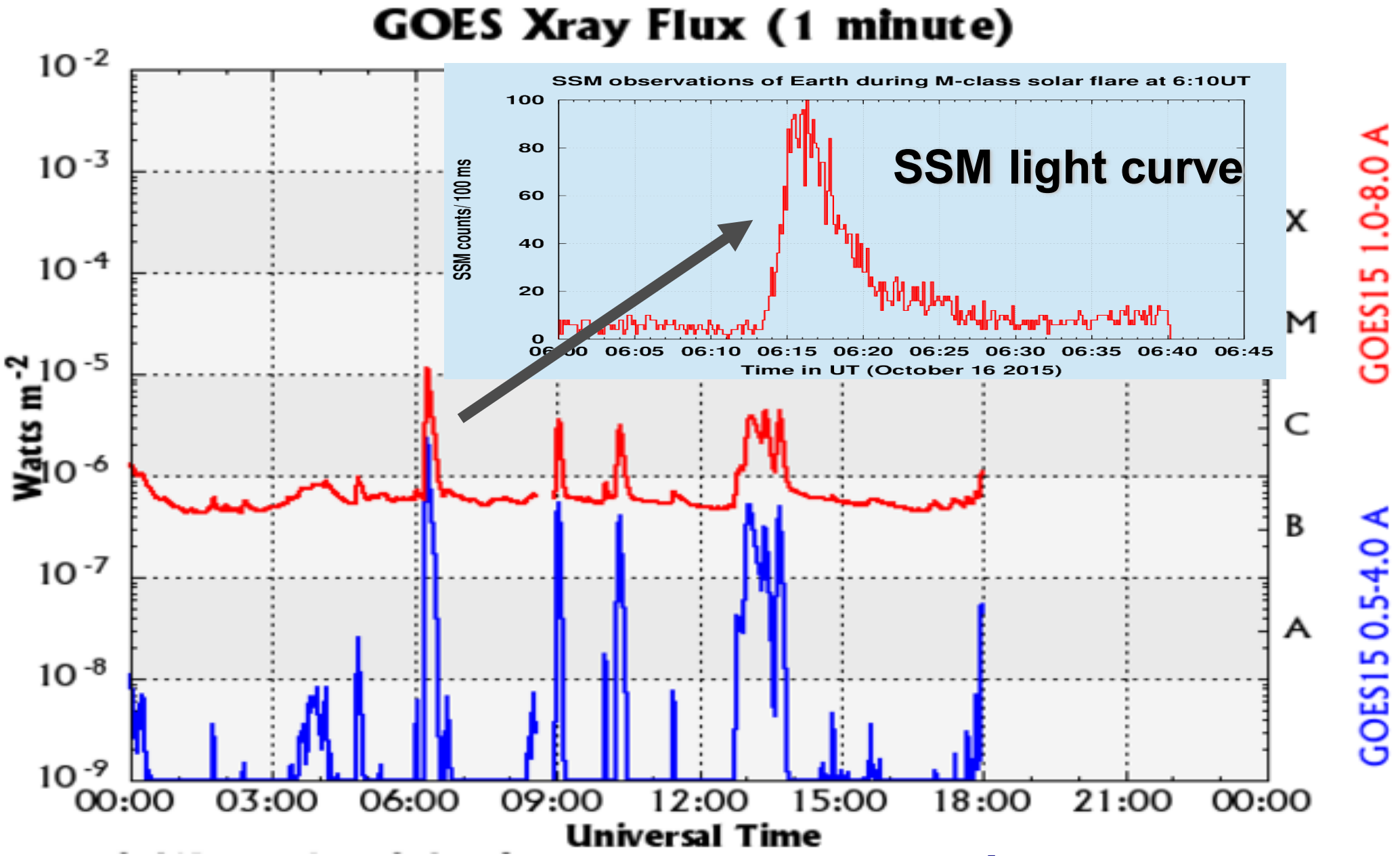
SSM onboard – first power ON




Crab Observations
SSM - Observations Light Curve (from Temporal)
Counts per sec
70
60
50
40
30
20
10
0
2.32e+06
2.322e+06
2.324e+06
2.326e+06
2.328e+06
2.33e+06
2.332e+06
SSM Time (s)

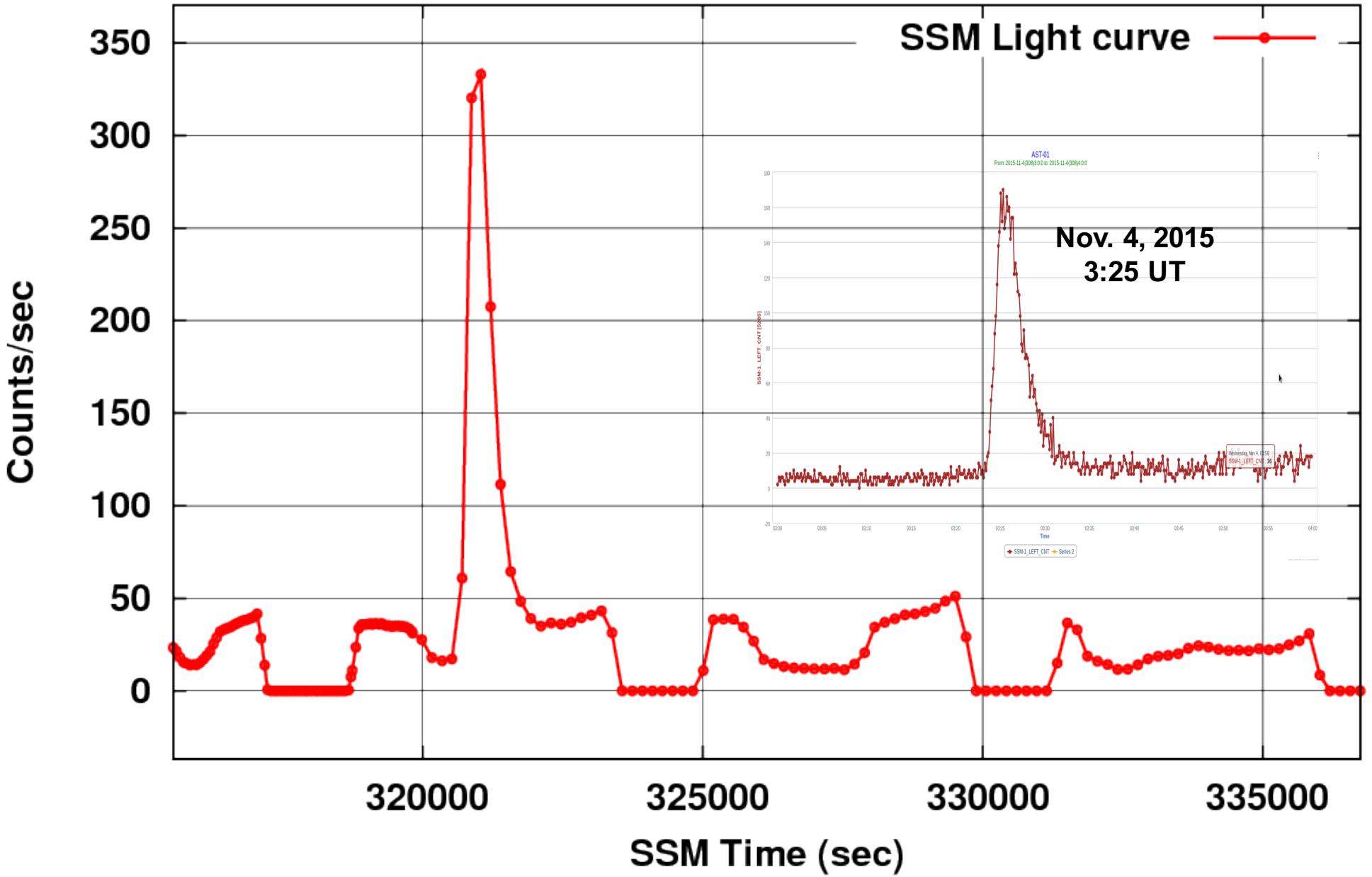

Orbit 210 - SSM Crab Observations
SSM spectra
Counts
Anode ID
1
2
3
4
5
6
7
0
100
200
300
400
500
Channels

SSM – Indication of a M - class Solar Flare

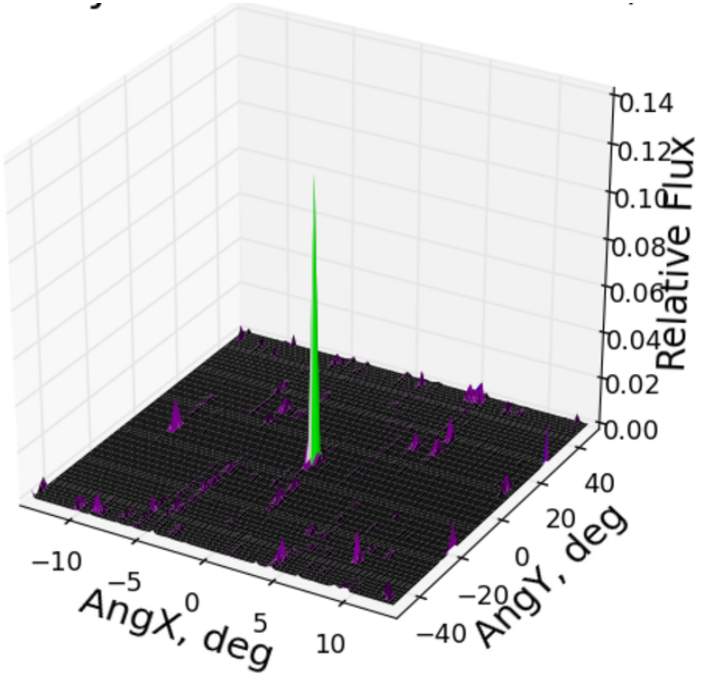


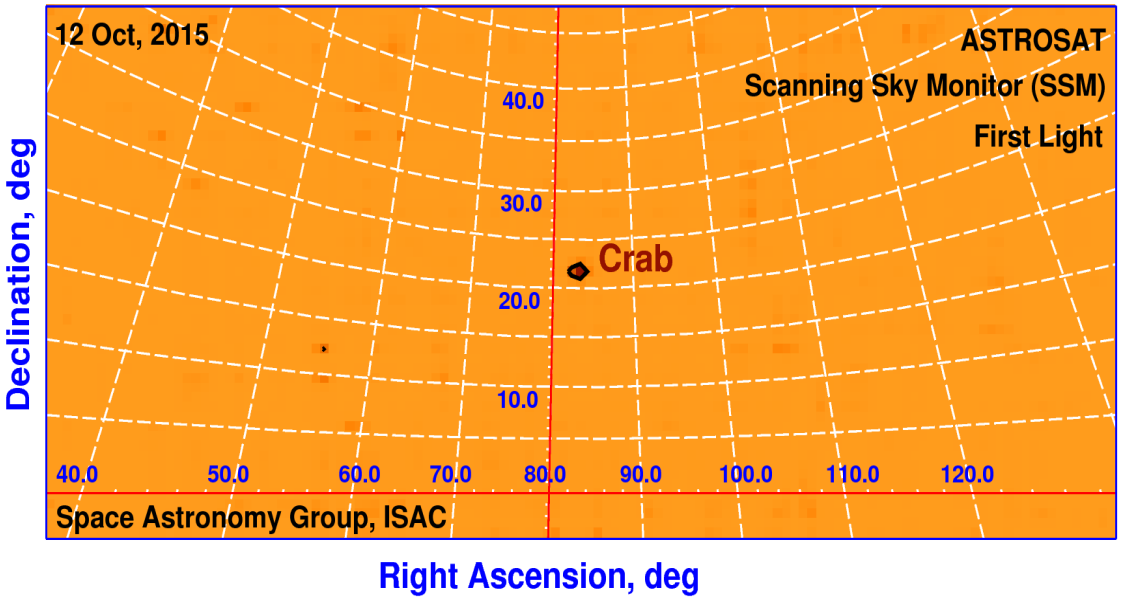
on 16th October 2015

SSM Light Curve
Indicating a solar flare event while observing Earth during Earth Occult



SSM FOV First light of Crab

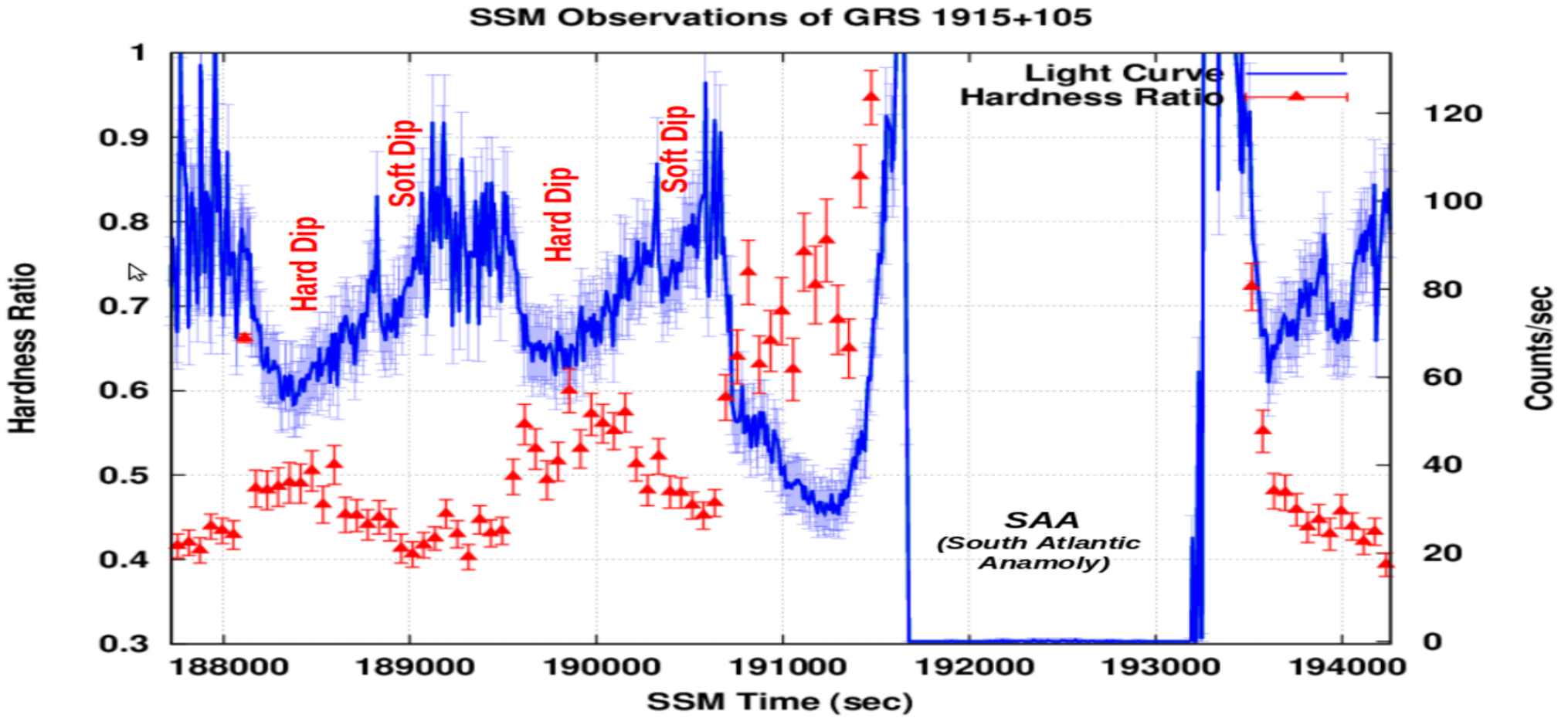




Angular resolution – expected 12 arcmin;

- Observed - Confined within a pixel (12 arcmin X 2.5 deg)

SSM Observations
Black Hole source GRS 1915+105



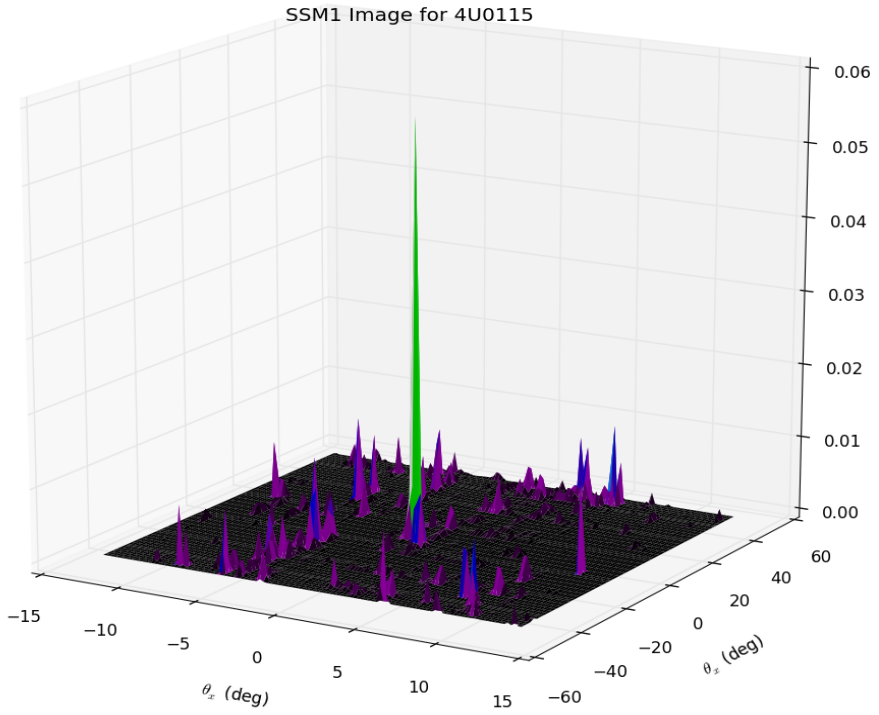
Hardness ratio *with the "Hard Dip" and "Soft Dip" in the light curve is as expected during this variability state of the source.*

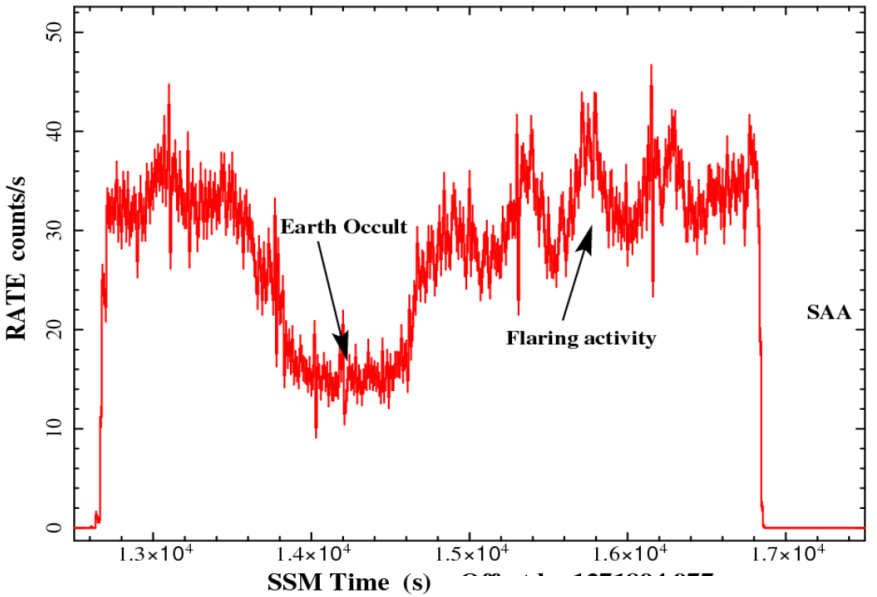
Astronomer's Telegram on the detection of "Beta Class variability" in GRS 1915+105;

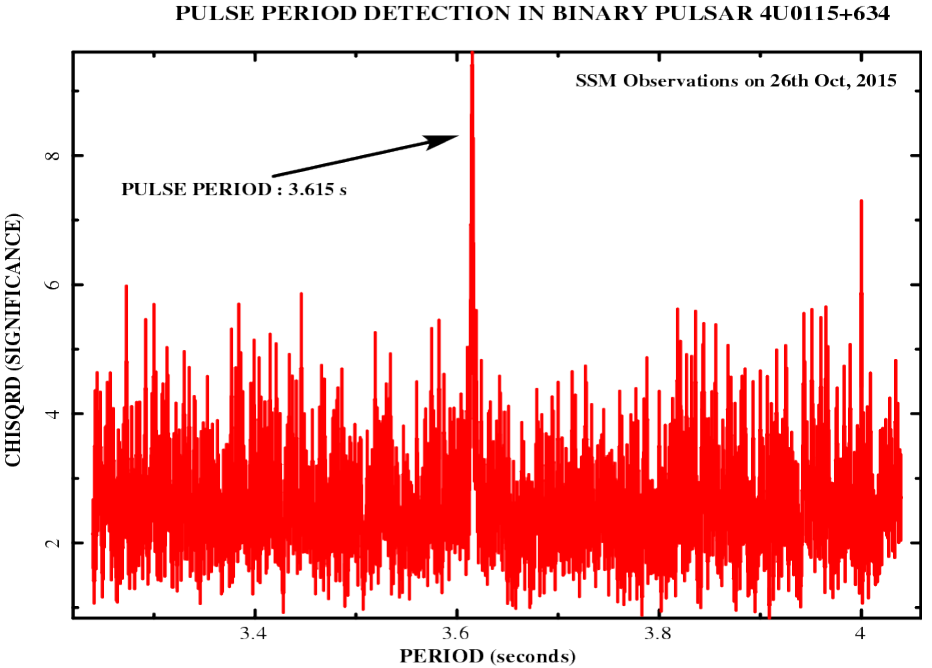
ATel#8185 on 18th Oct 2015

During its first observations in Oct 2015

SSM Observations of a Be X-ray binary pulsar 4U0115+63

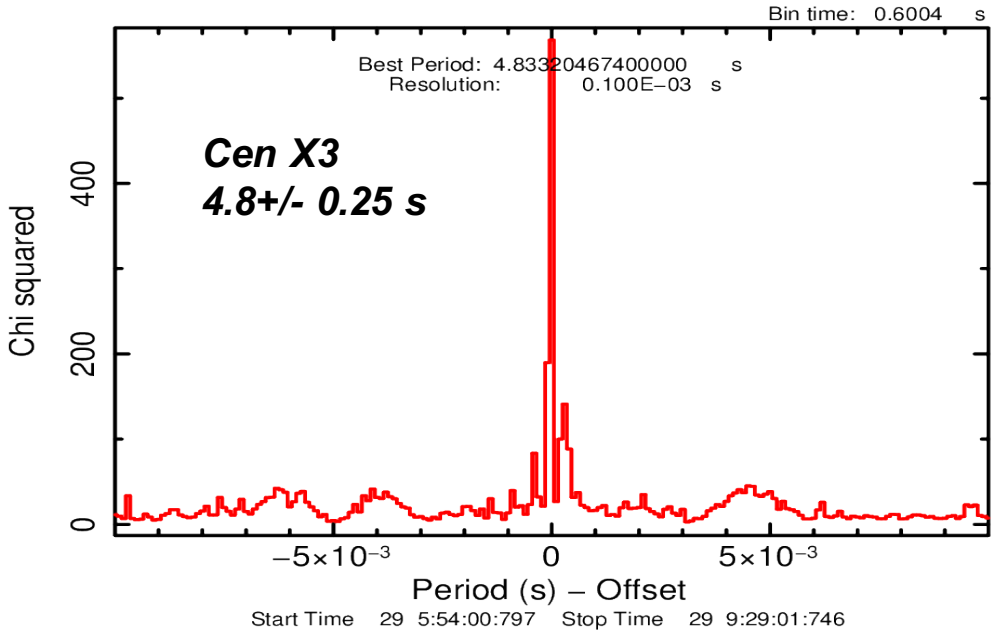




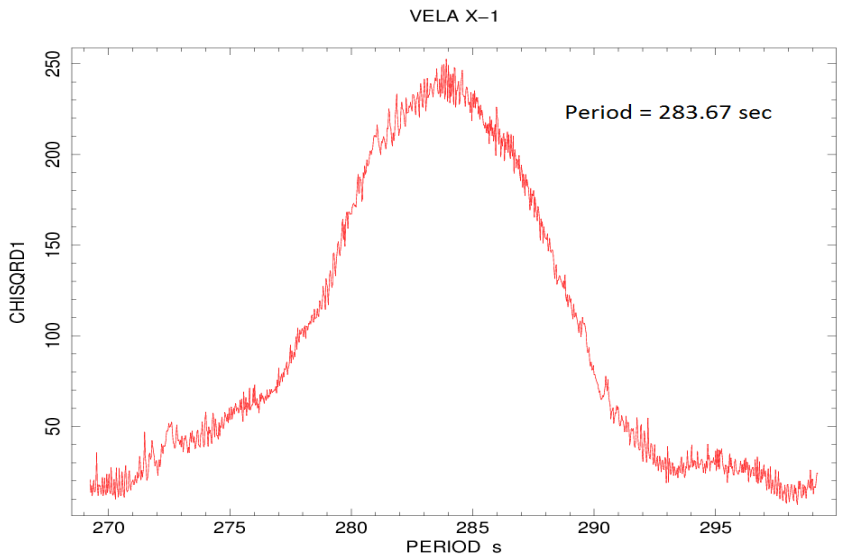


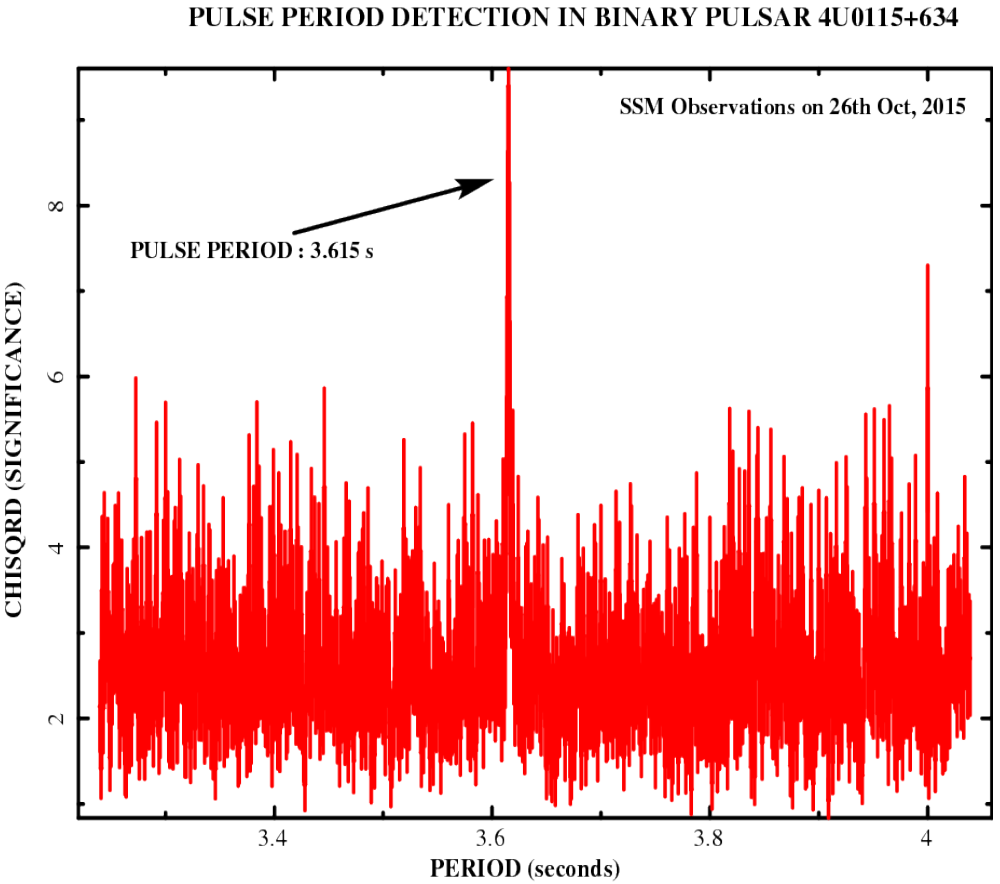
Observed on October 26, 2015

Pulsations from binary X-ay pulsars

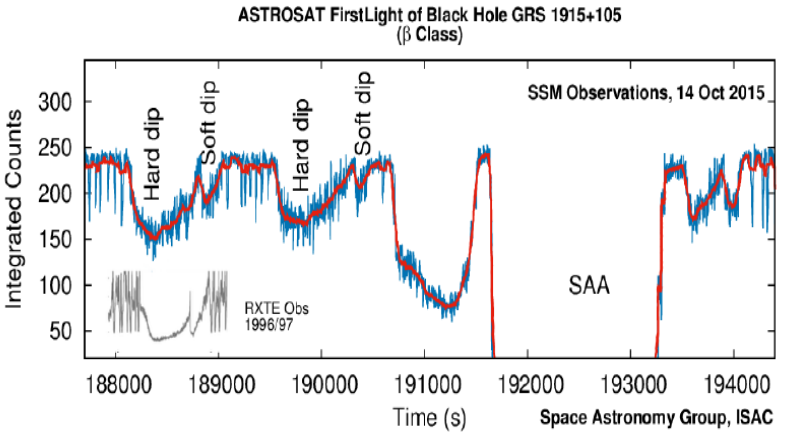


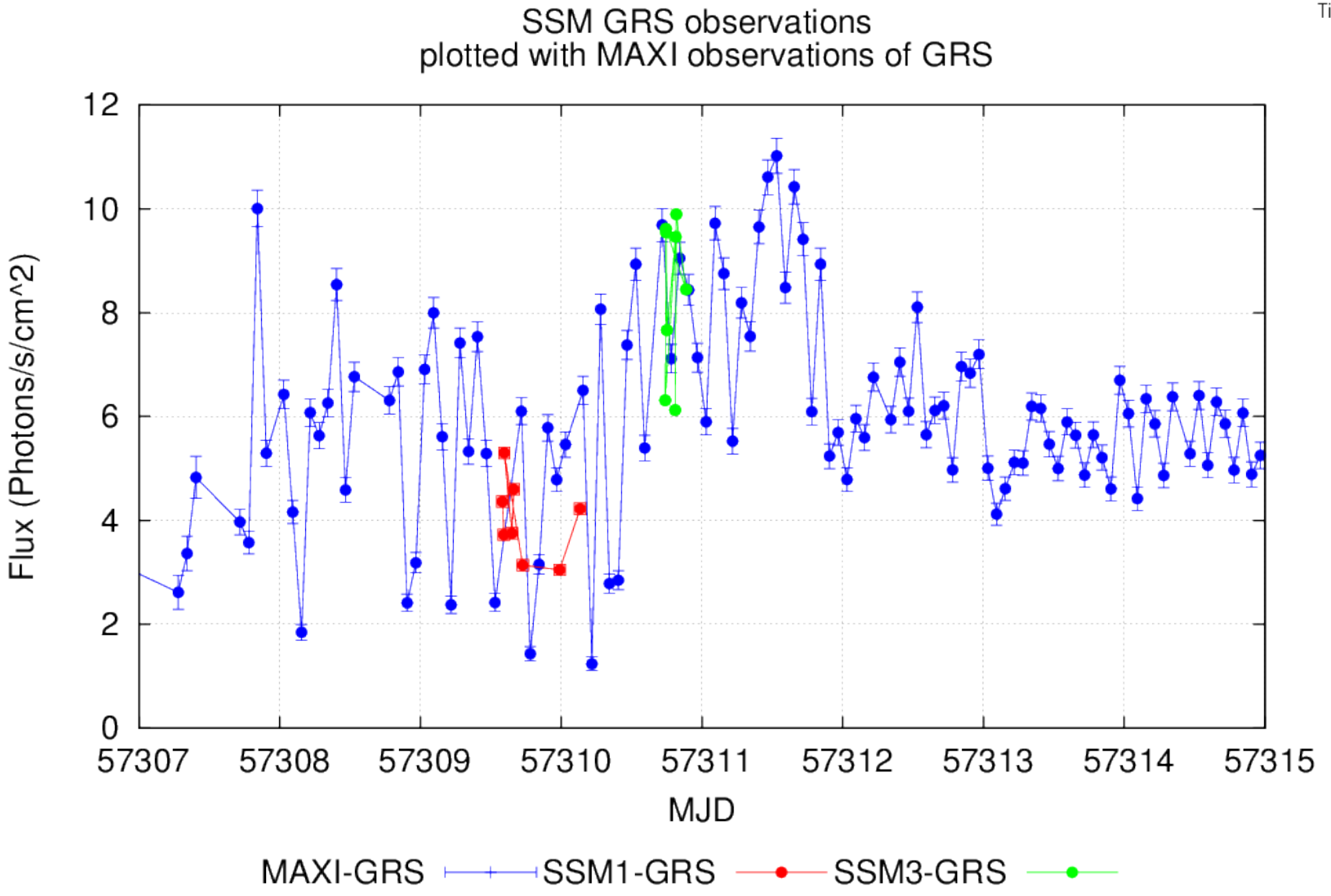
Vela X1 283+/-0.8 s



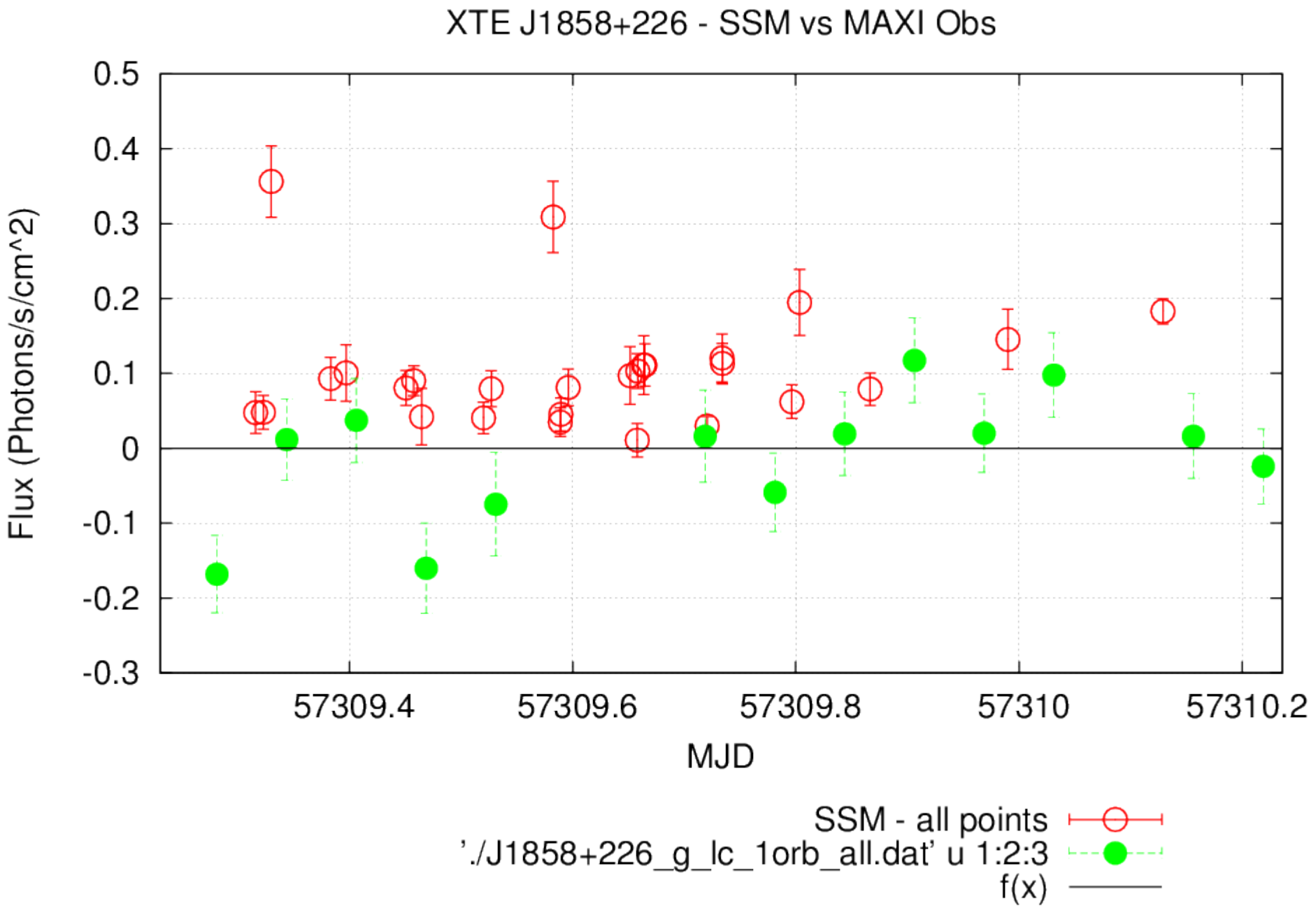


GRS 1915+105 – Oct 2015 Observations

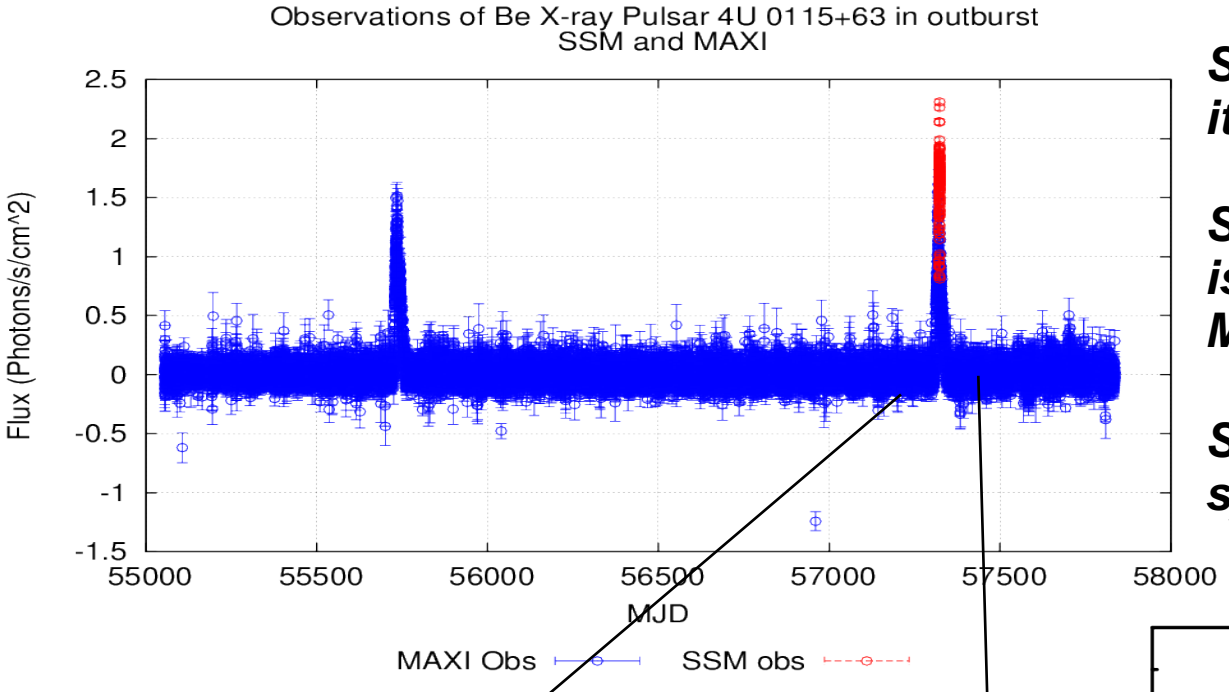


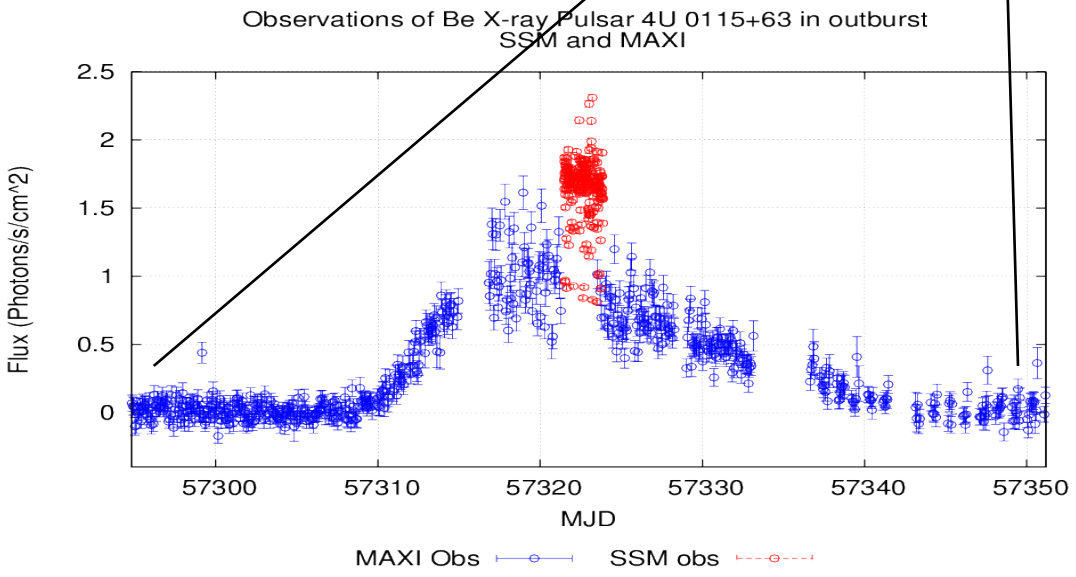


Flux for this faint source has been reported faithfully even without any background removal by SSM (this could be a rather faint field without any bright sources in the FOV)



SSM Observations of a Be X-ray pulsar 4U0115+63 in its outburst Oct. 2015

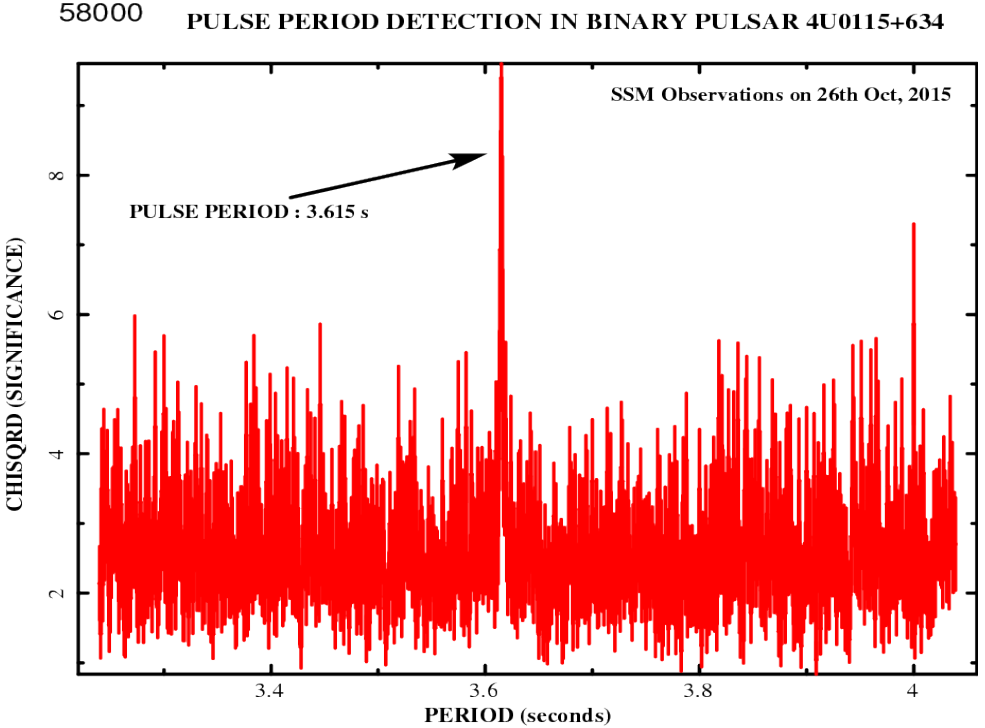




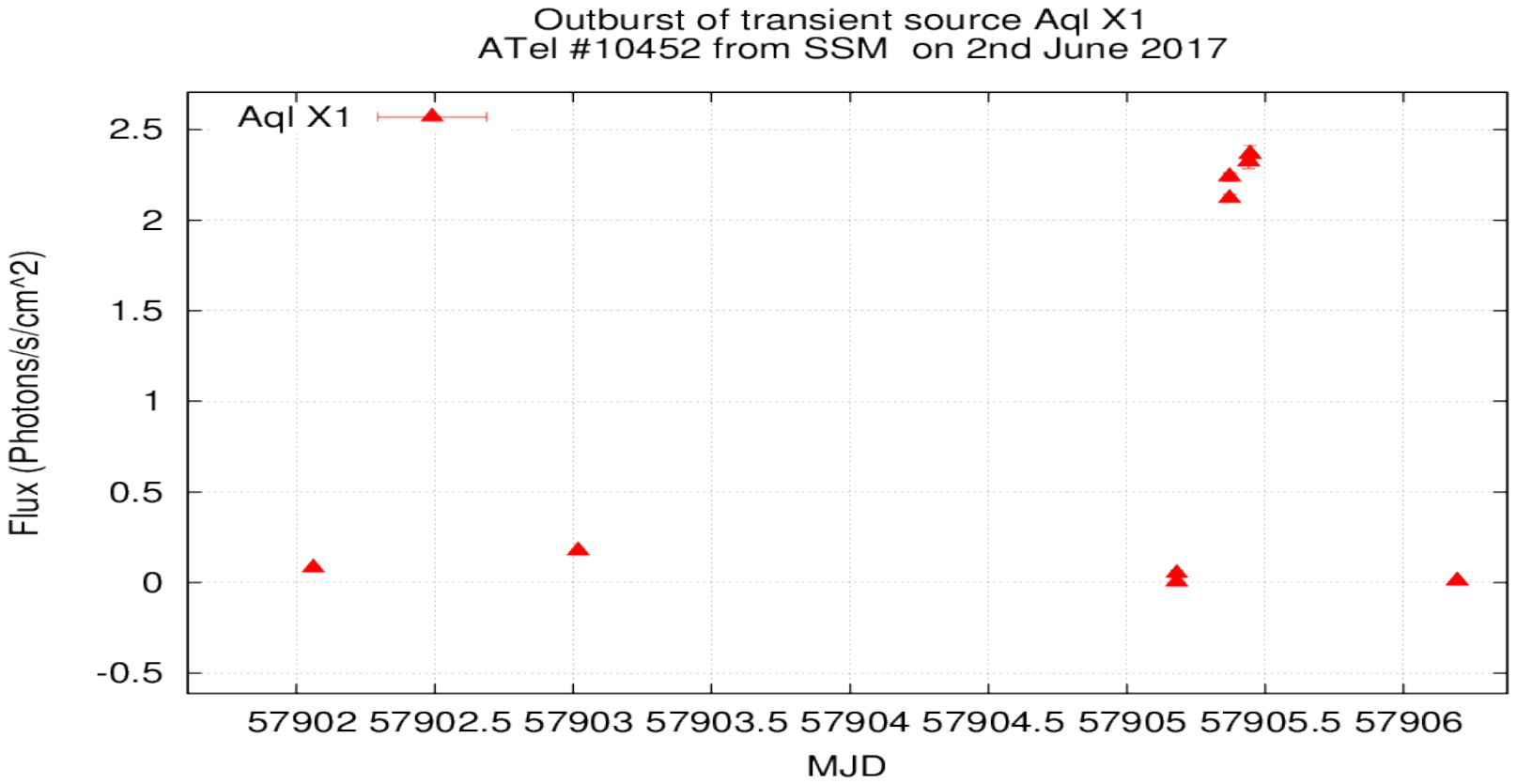
SSM observed the Be Xray pulsar in its outburst in Oct 2015.

SSM light curve (red) of the source is plotted with the light curve from MAXI (blue) onboard ISS

SSM also detected pulsations (3.62 s) in the source.



Neutron star X-ray transient, Aql X-1 in its outburst



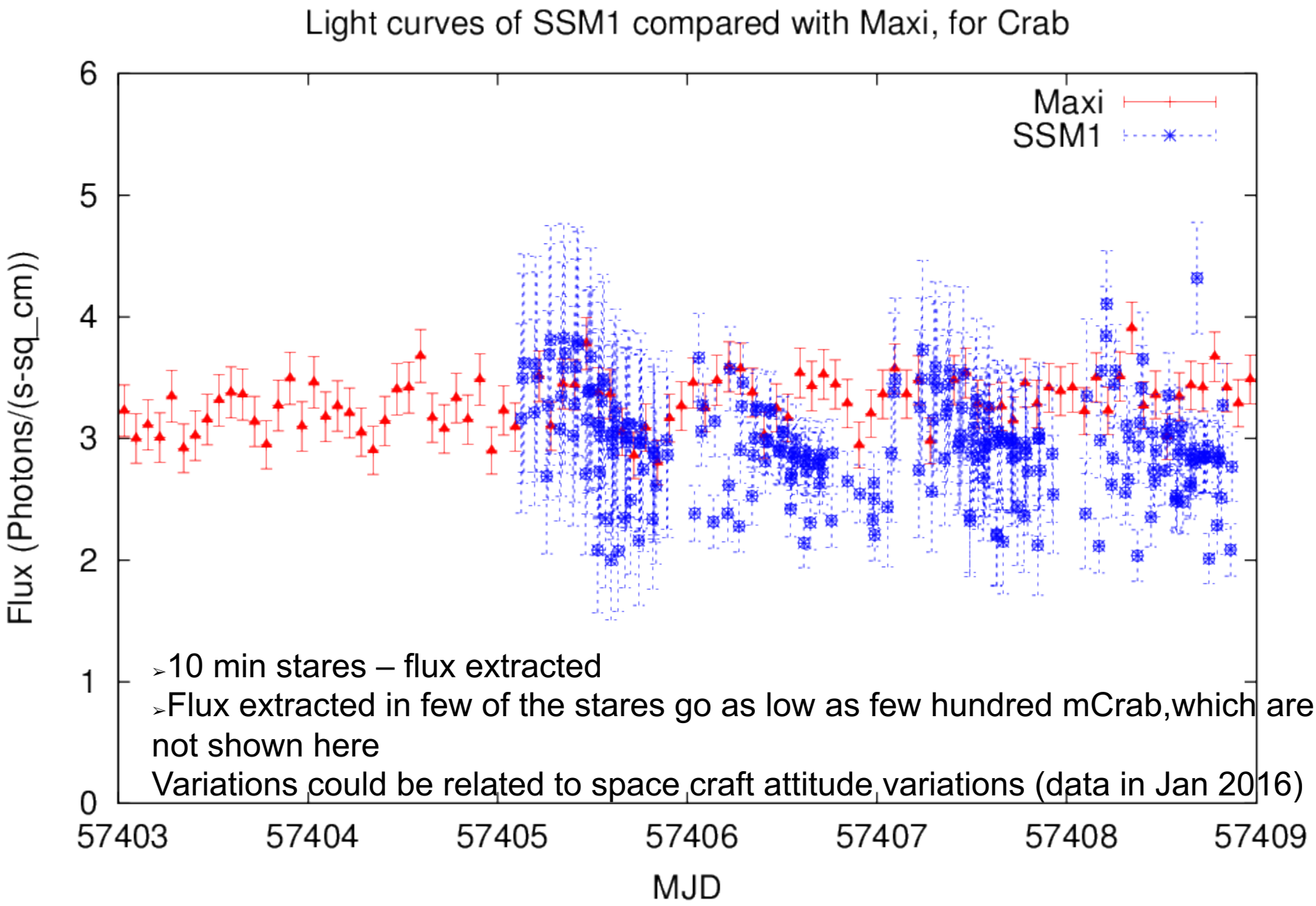
ATel#10452 on June 2nd, 2017

SSM reported on the X-ray outburst of the neutron star X-ray source Aql X-1.

Flux reported by SSM on its first observation of the source during this outburst on 01 June 2017 at 08:55 UT is about 820 milliCrab.

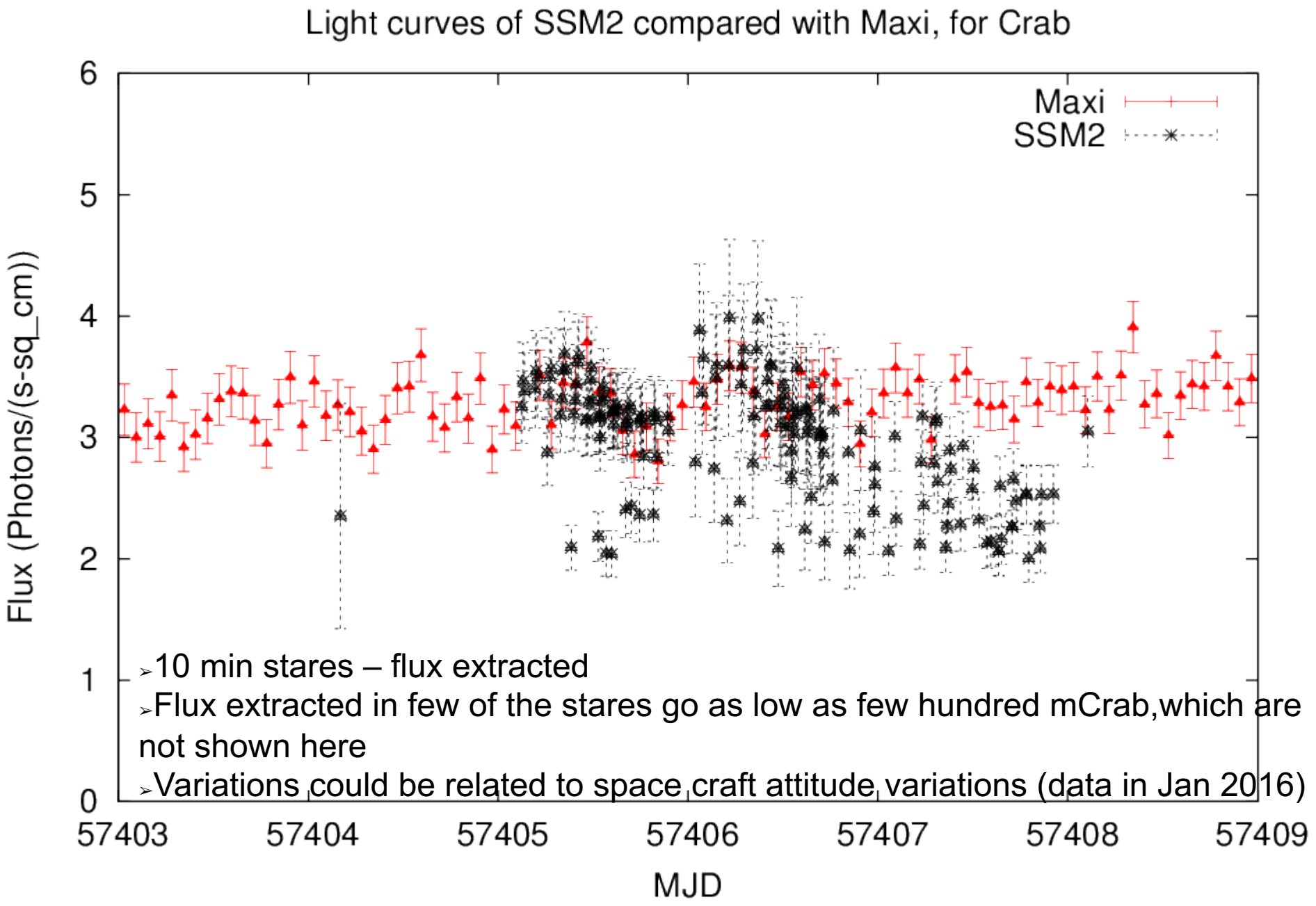
In addition, Swift/BAT had reported an increase in hard X-rays on the same day.

SSM Crab light curve



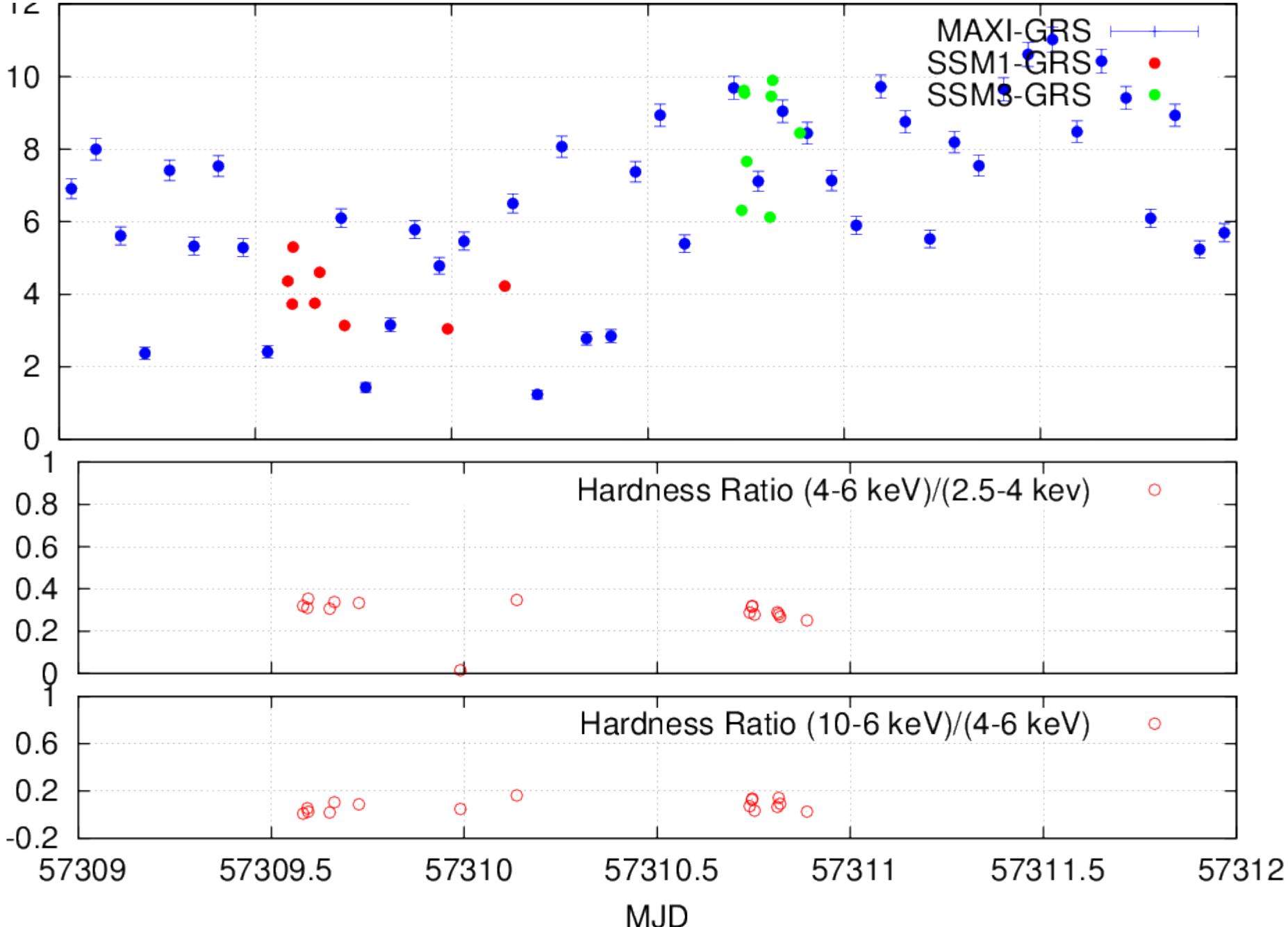
- 10 min stares – flux extracted
- Flux extracted in few of the stares go as low as few hundred mCrab,which are not shown here

Variations could be related to space craft attitude variations (data in Jan 2016)

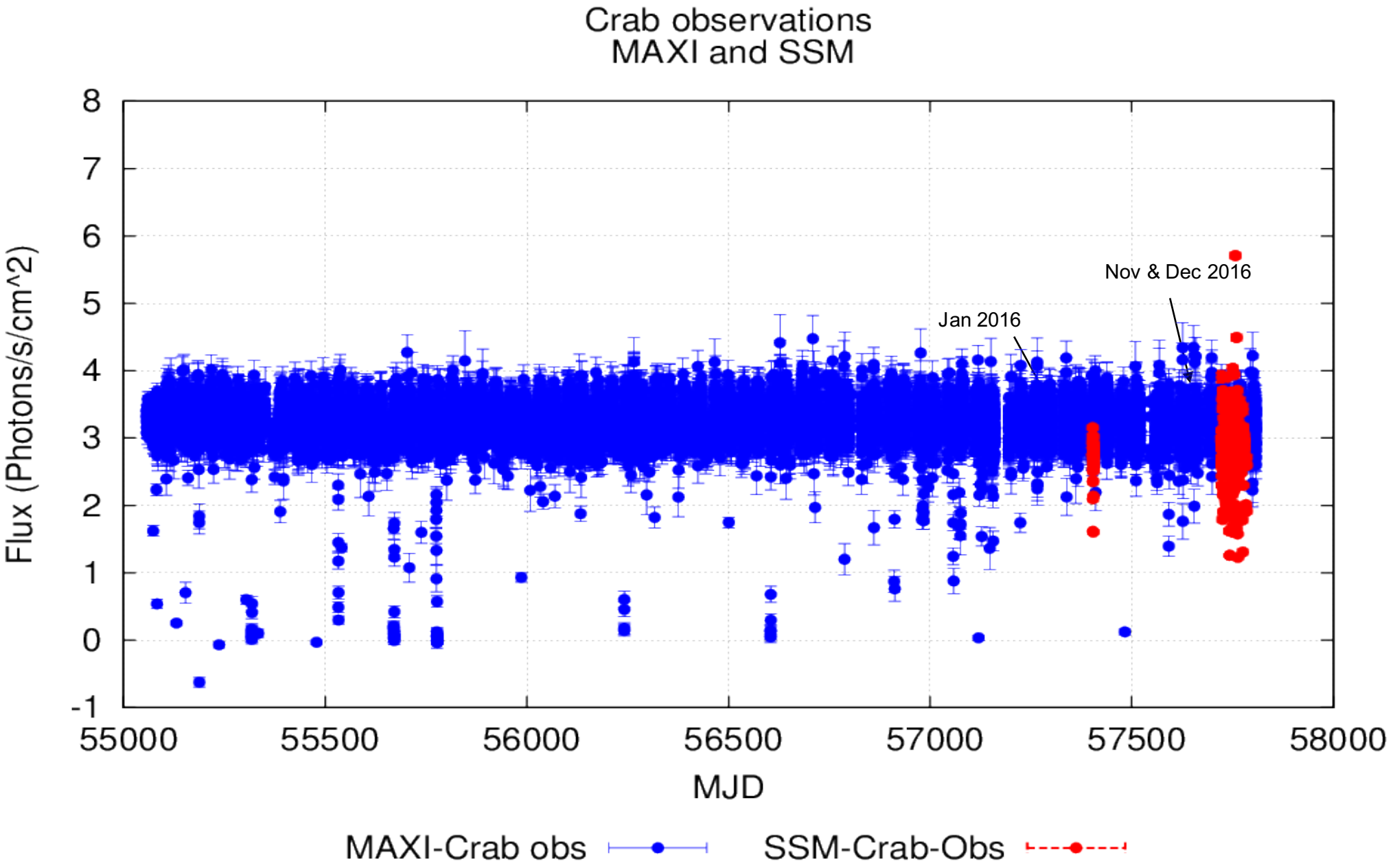


- 10 min stares – flux extracted
- Flux extracted in few of the stares go as low as few hundred mCrab,which are not shown here
- Variations could be related to space craft attitude variations (data in Jan 2016)

GRS 1915+105


MAXI-GRS
SSM1-GRS
SSM3-GRS
Hardness Ratio (4-6 keV)/(2.5-4 kev)
Hardness Ratio (10-6 keV)/(4-6 keV)
MJD

SSM (Red) and MAXI (Blue) light curve of Crab
Crab flux Cross checks

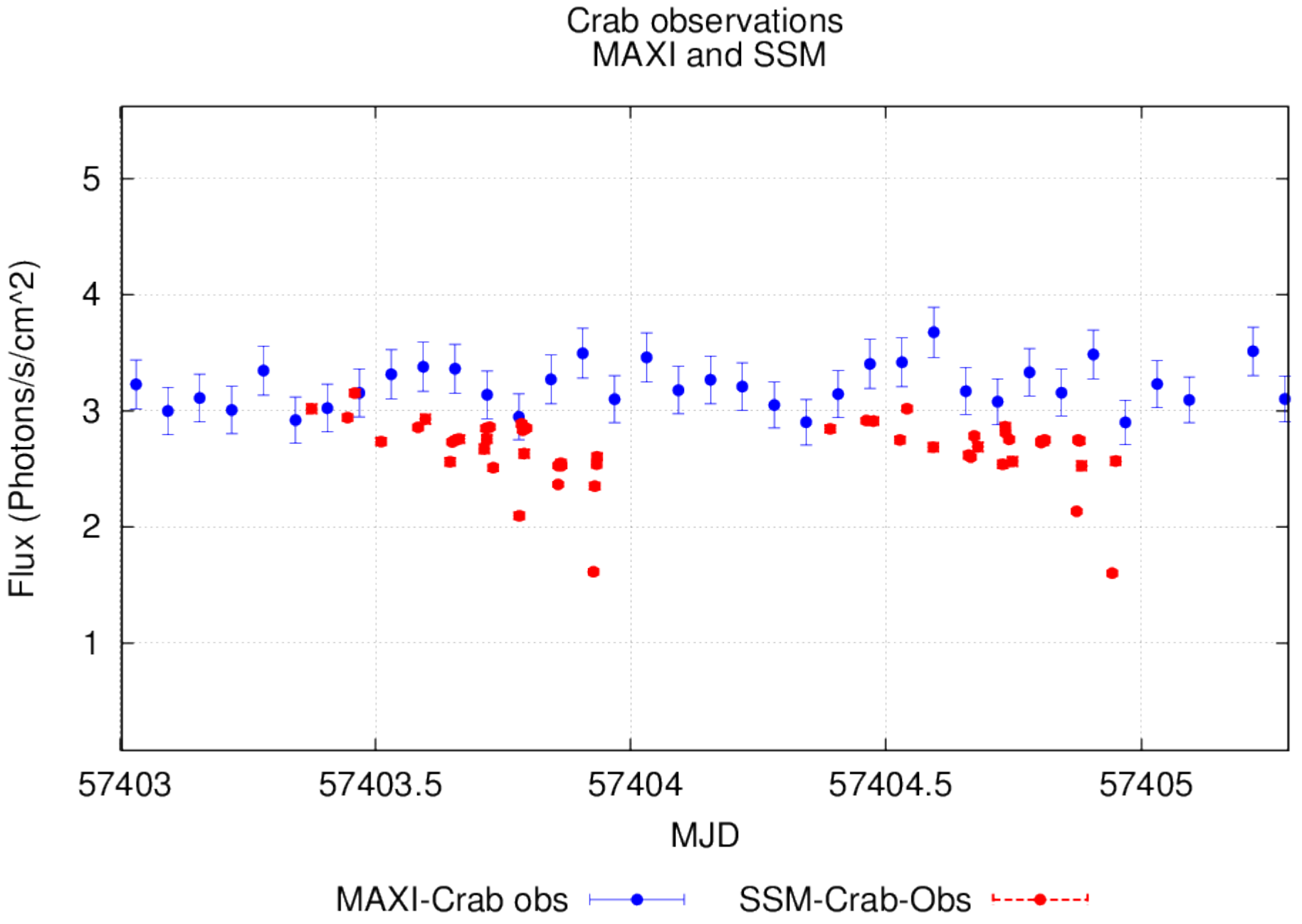


The observations of Crab source with SSM onboard AstroSat (red) and MAXI on ISS (blue) is shown here and are found to be consistent with each other.

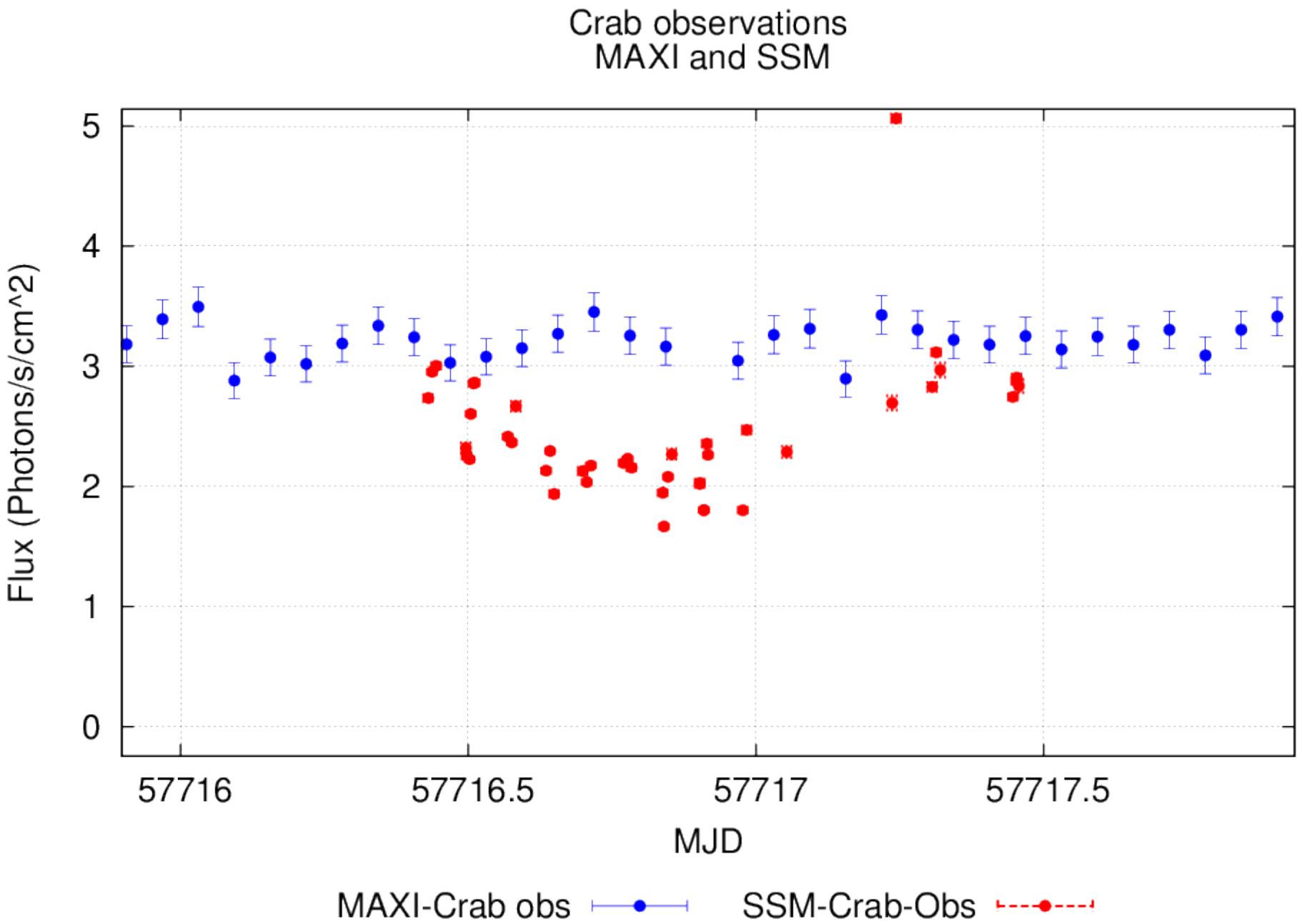
Crab at one particular location in SSM FOV – **Jan 2016 Observations**

Systematic changes seen in the flux attributed to orbital variations – one day periodic;

- yet to be modelled and corrected -



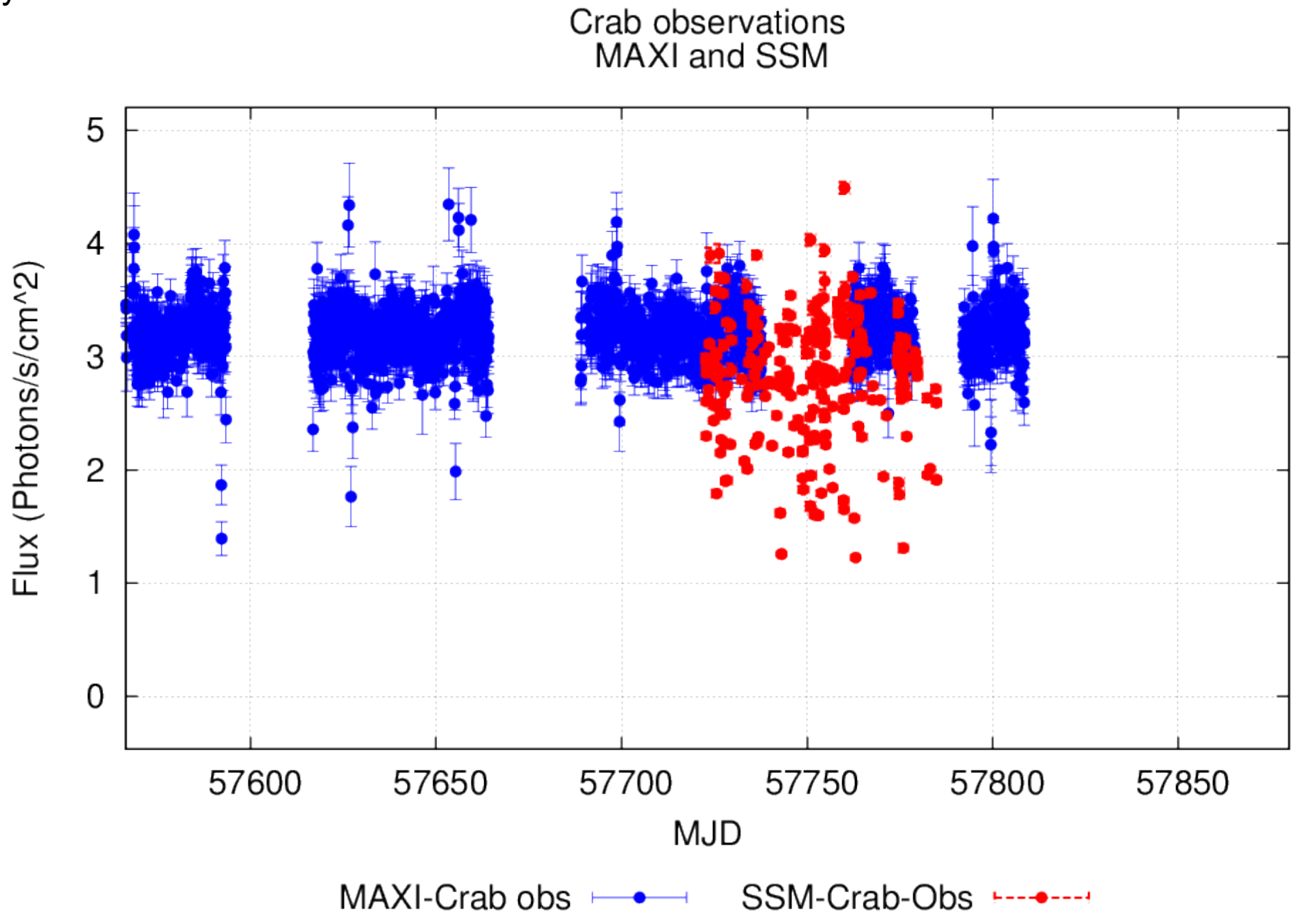
Crab at one particular location in SSM FOV – **Nov 2016 Observations**
Systematic changes seen in the flux attributed to orbital variations – one day periodic;
- yet to be modelled and corrected -



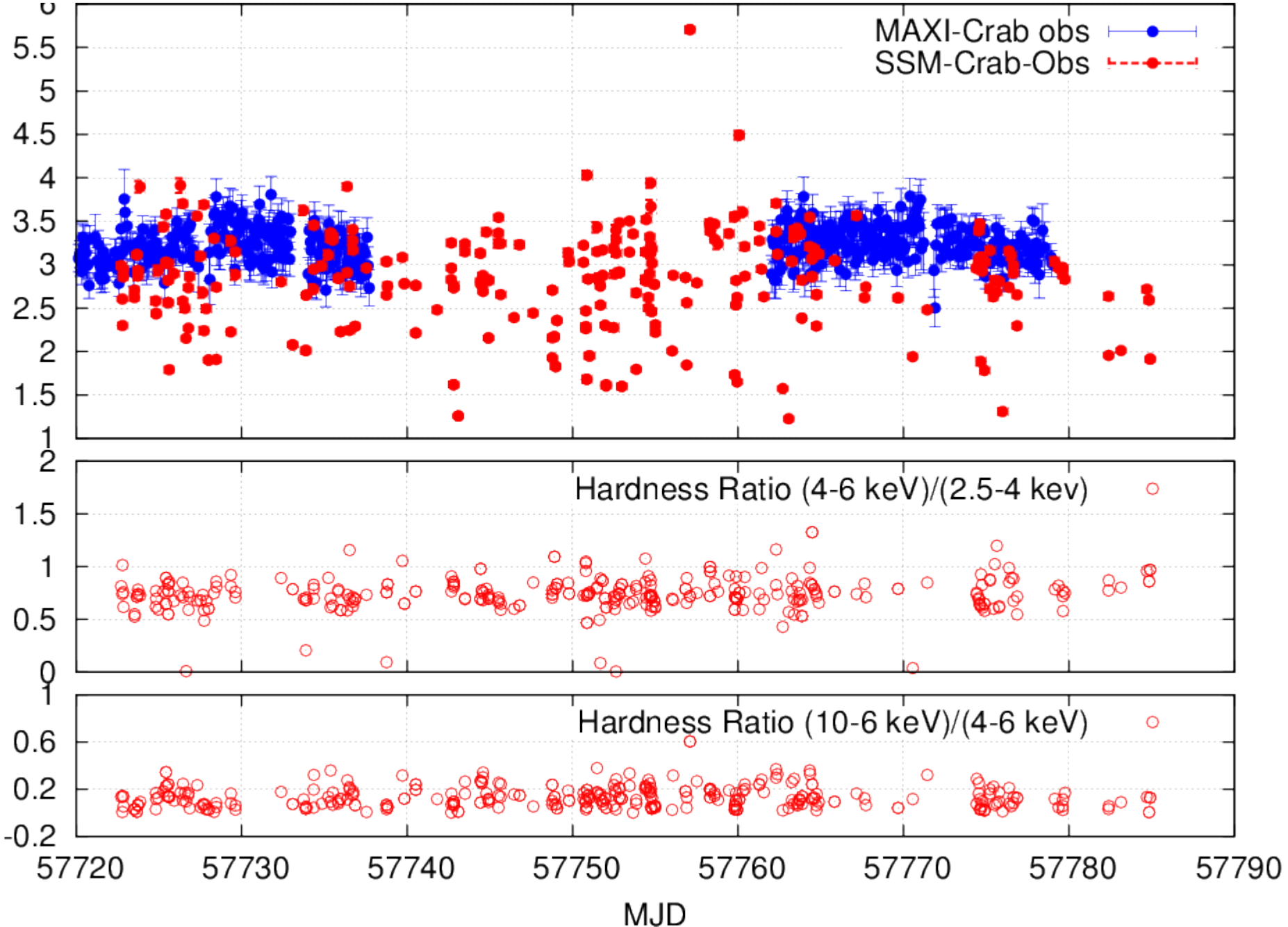
Crab at various locations in SSM FOV – **Dec 2016 Observations**

Changes seen in the flux include orbital effects, statistics of the data for observations away from the central regions of FOV, background modelling etc.

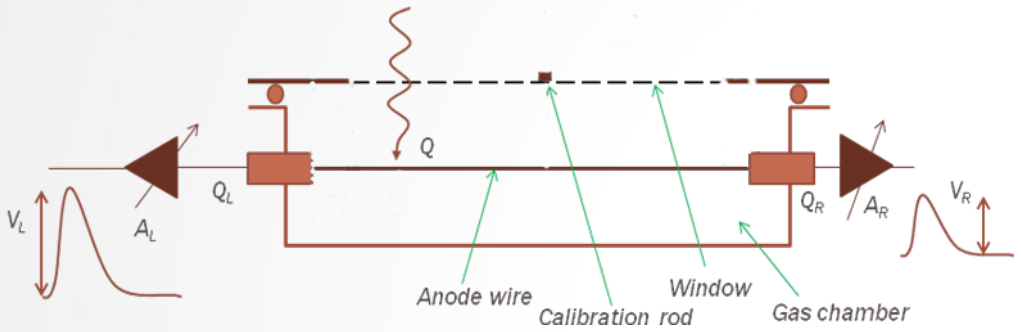
- yet to be modelled and corrected -

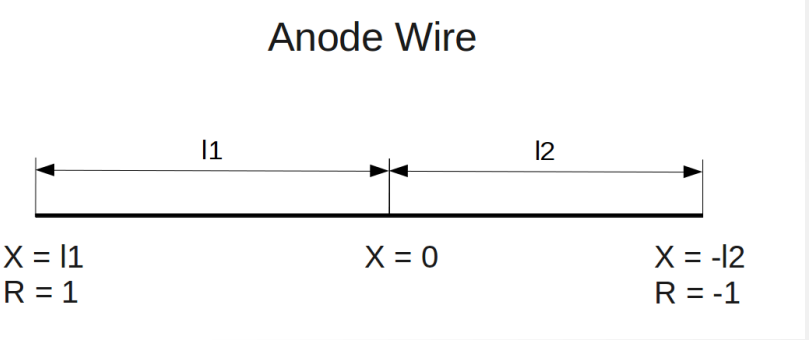


Crab


MAXI-Crab obs
SSM-Crab-Obs
Hardness Ratio (4-6 keV)/(2.5-4 kev)
Hardness Ratio (10-6 keV)/(4-6 keV)
MJD

Calibration Function

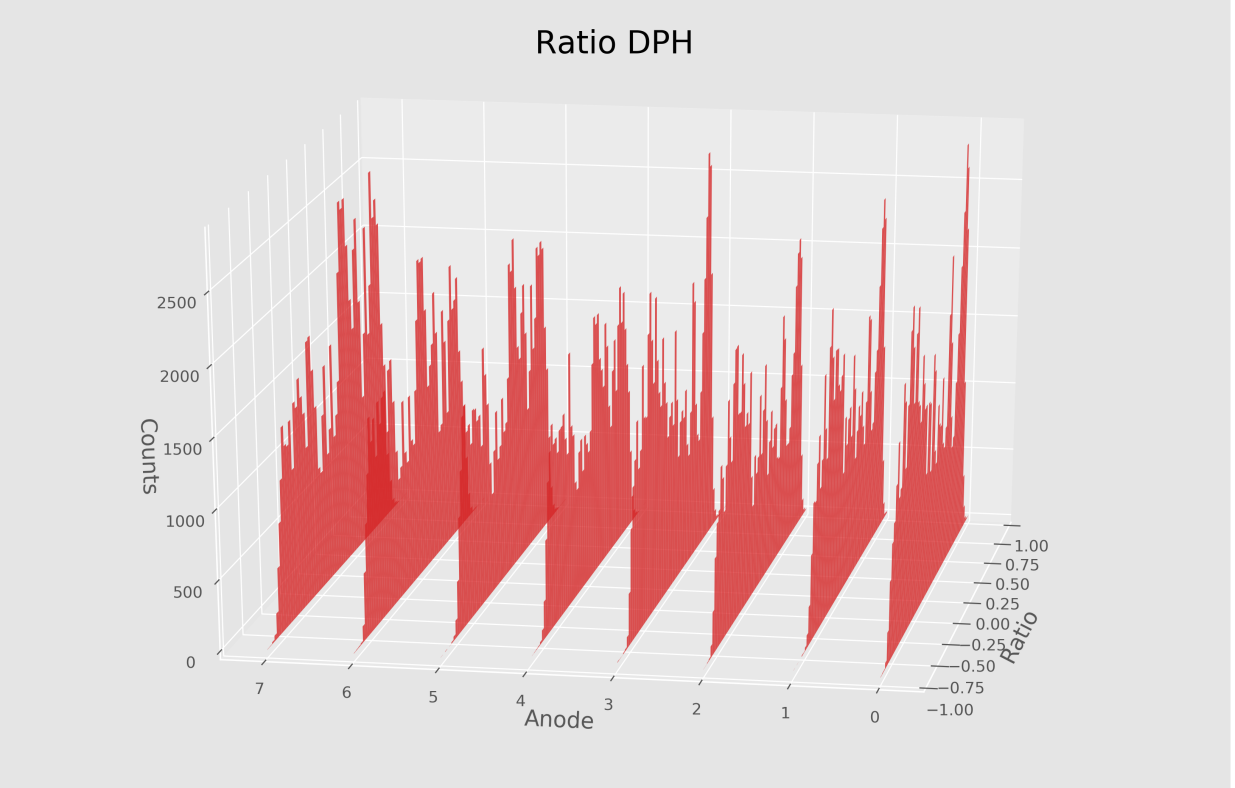




- Based on charge division in the anode wire, position can be determined by ratio
- Ratio $R=(V_L-V_R)/(V_L+V_R)$
- Calibration Function $=[R(A_R l_1+A_L l_2)+(A_R l_1-A_L l_2)]/[R(A_R-A_L)+(A_R+A_L$
- Four Calibration parameters – A_L, A_R, l_1, l_2

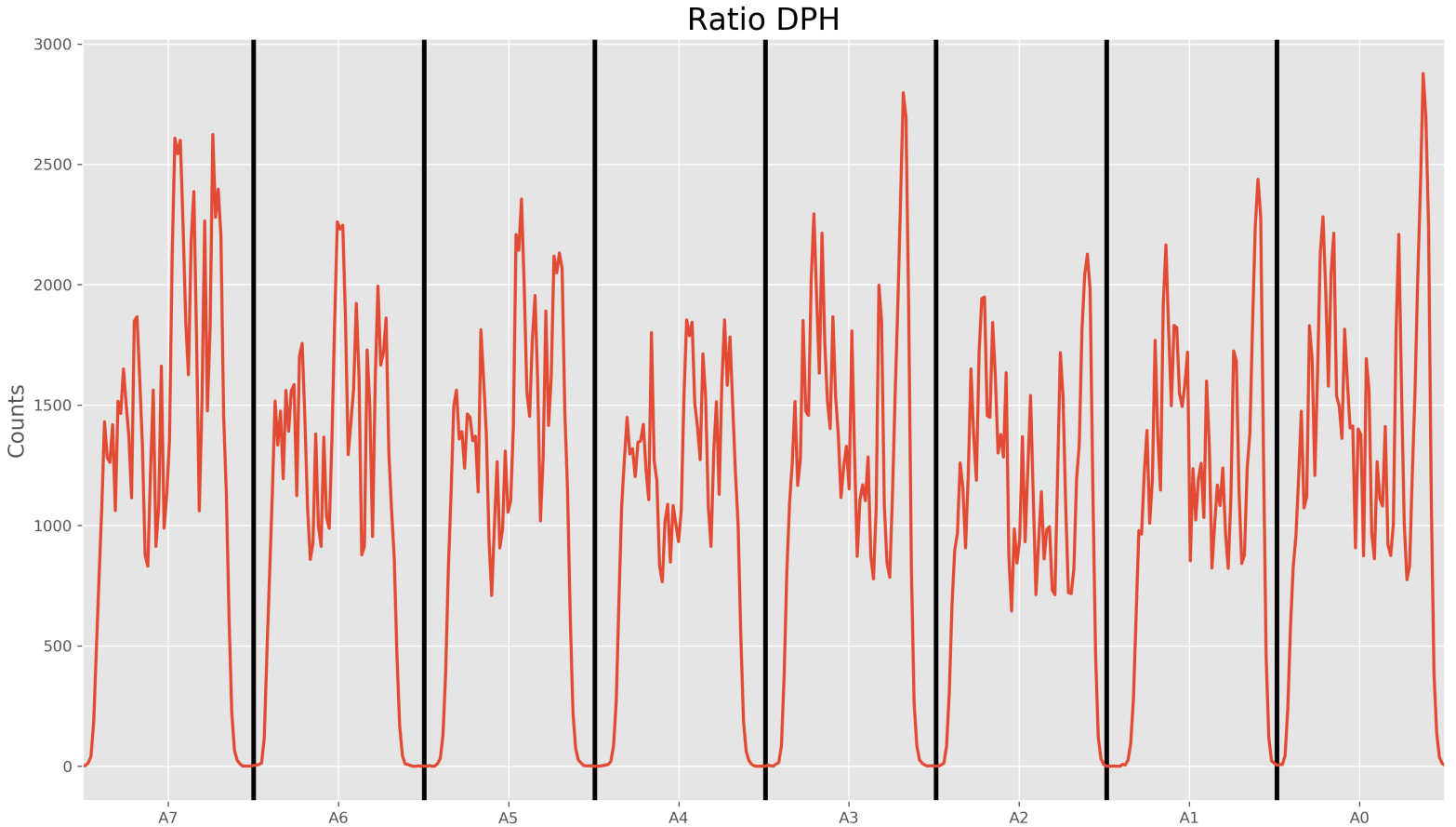
Calibration Data

- Pointed mode observation of Crab for ~15ks exposure time
- Angular position of Crab in detector plane – (0.6deg, 0.5deg)
- Detector Plane Histogram (DPH) of ratios of all the events



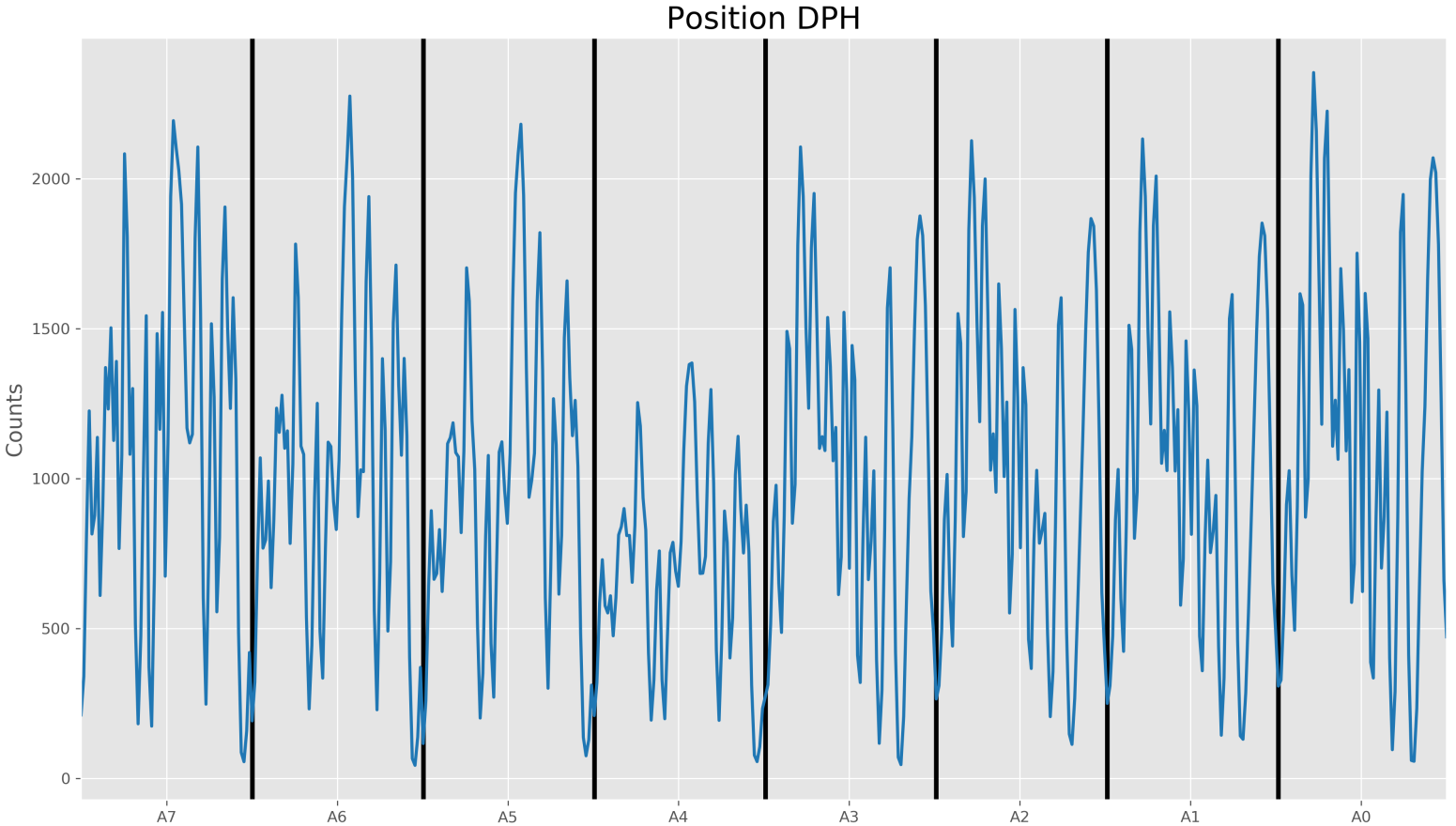
Calibration Data

- Pointed mode observation of Crab for ~15ks exposure time
- Angular position of Crab in detector plane – (0.6deg, 0.5deg)
- Detector Plane Histogram (DPH) of ratios of all the events

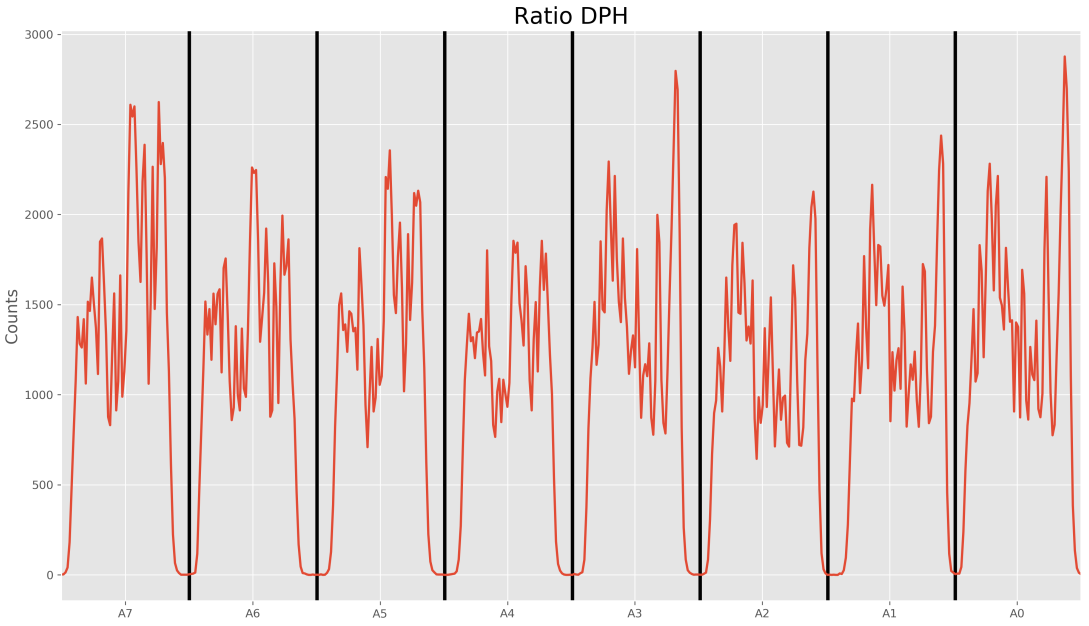


Monte-Carlo Simulation Shadow Response

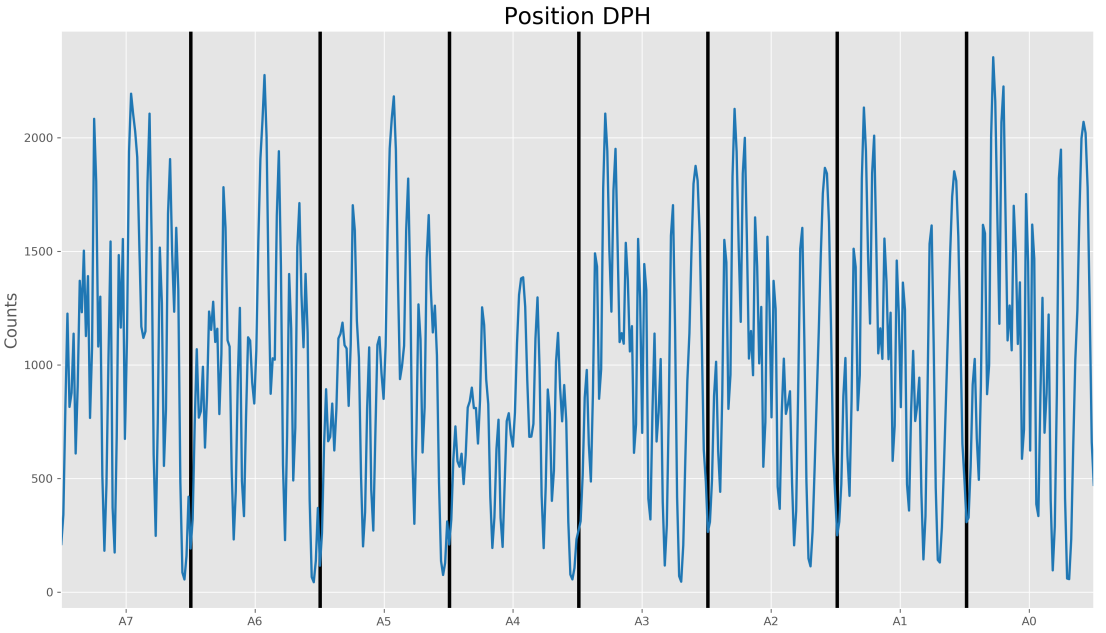
- Mask pattern, Geometry of detector, Flux and position of X-ray sources within FOV, Collimator Response
- Mean Free Path, Quantum Effieciency
- Simulated Detector Plane Histogram (DPH) of positions



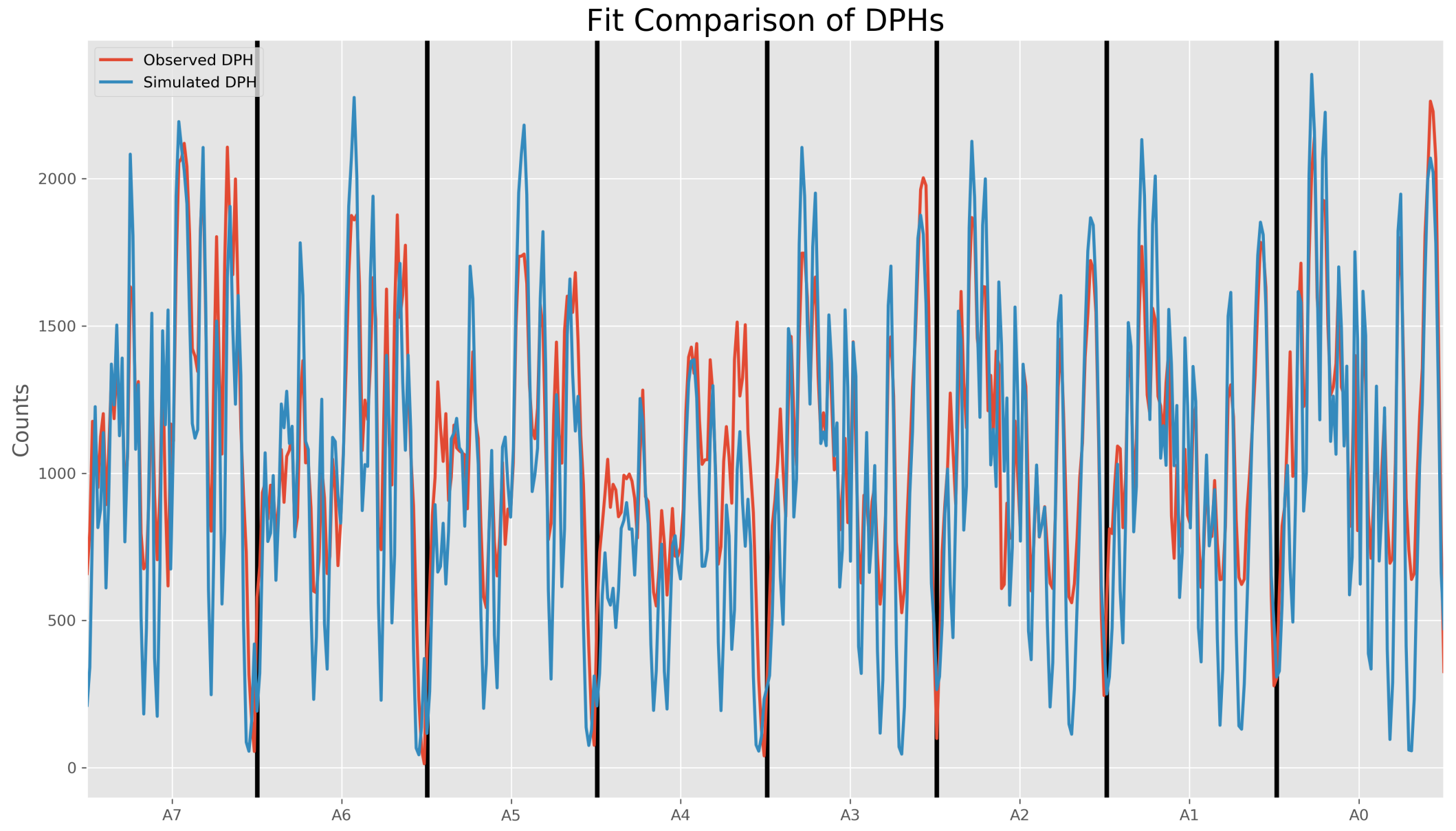
Calibration Parameters Determination



Initial cal parameters



Calibration Fit Results



Calibration Parameters Determination

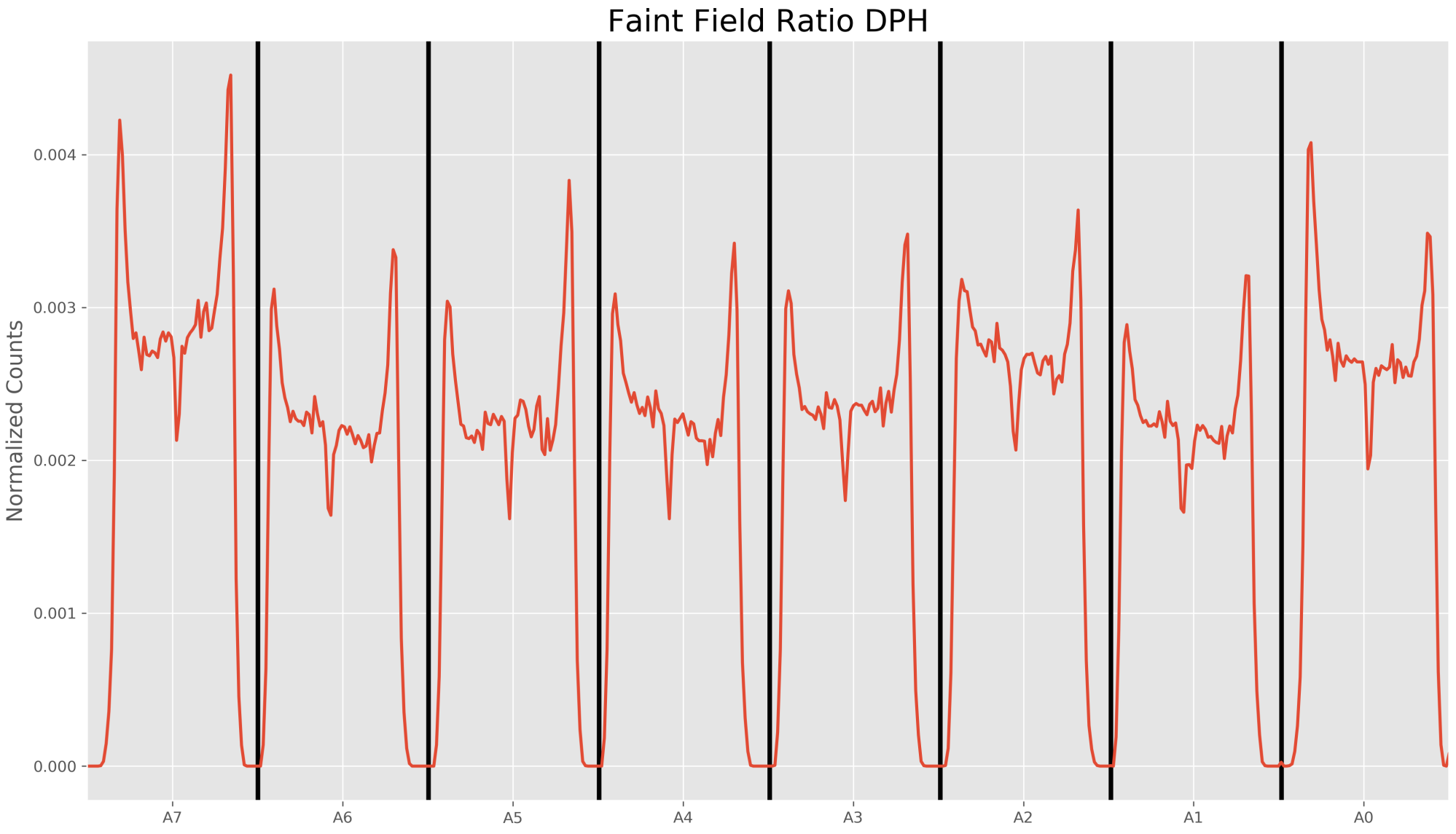
- Calibration Parameters A_L, A_R, l_1, l_2
- Calibration Function $= [R(A_R l_1 + A_L l_2) + (A_R l_1 - A_L l_2)] / [R(A_R - A_L) + (A_R + A_L$

$u = histogram(calfunc(R, A_L, A_R, l_1, l_2))$ $v = Simulated\ Position\ Histogram$

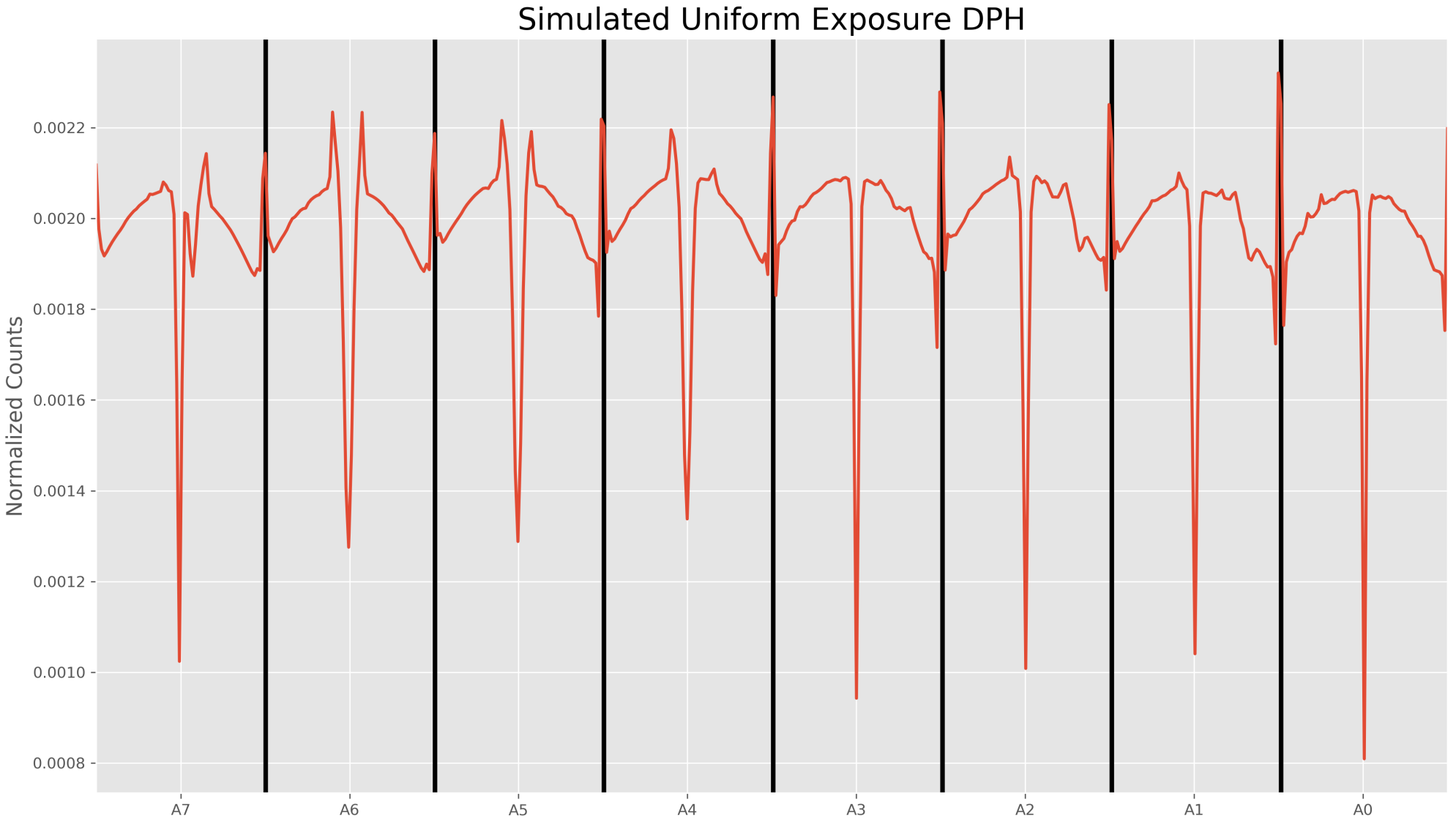
- Minimize $\Sigma[(u_i - v_i)^2 / u_i]$ wrt A_L, A_R, l_1, l_2

Faint Field Data

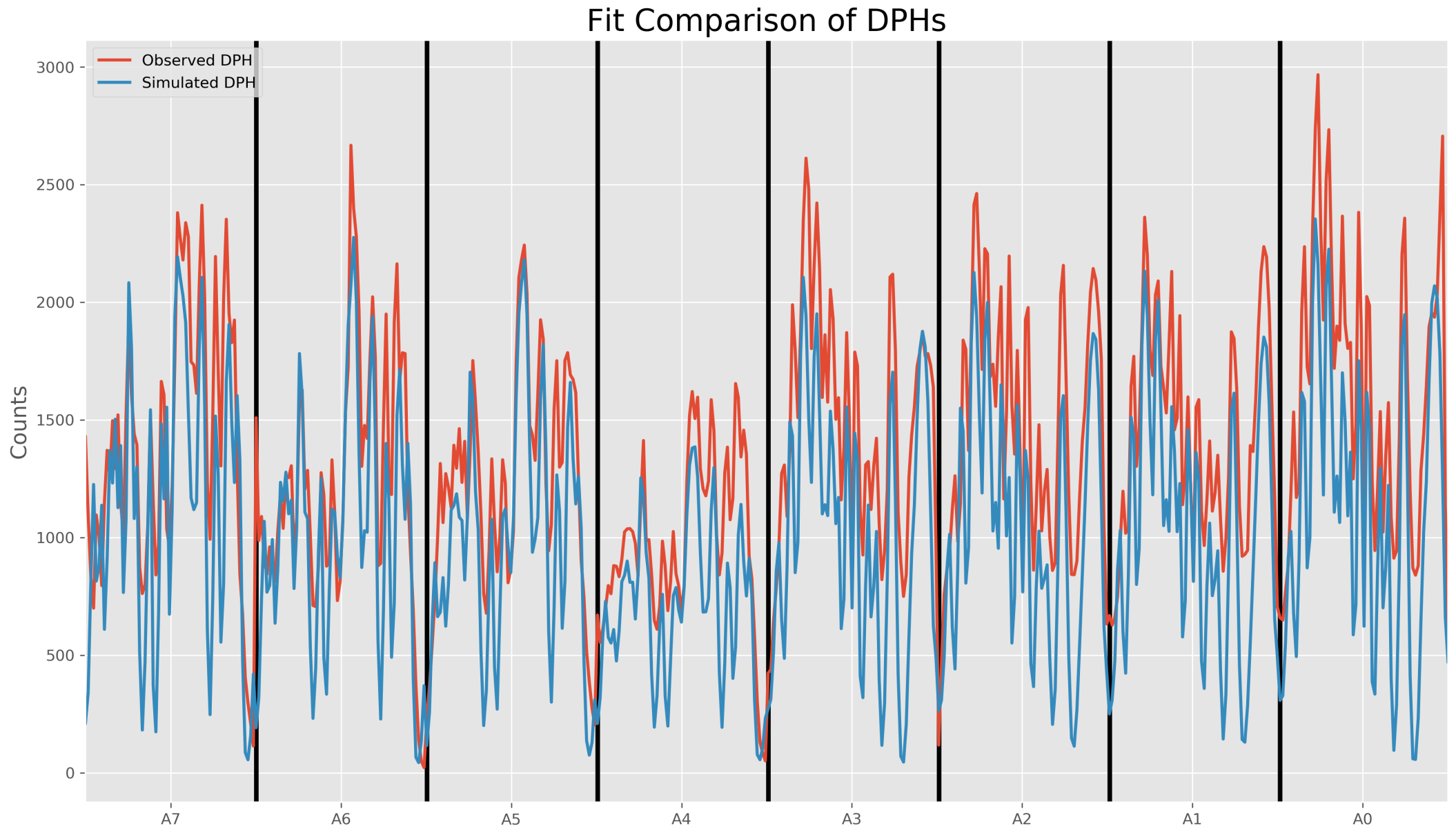
- Calibration Wire Dip, Background, Anode Response

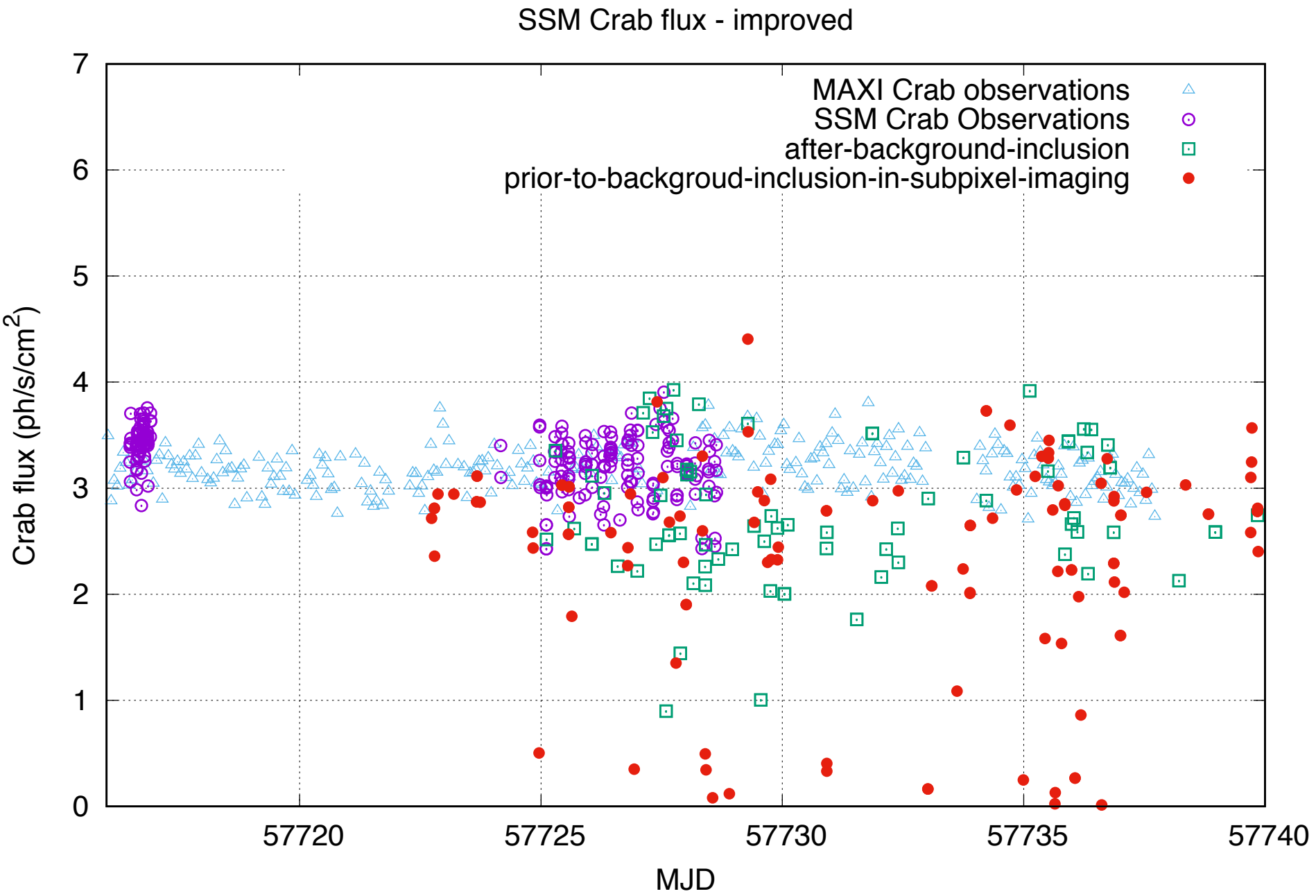


Simulated Uniform Exposure DPH

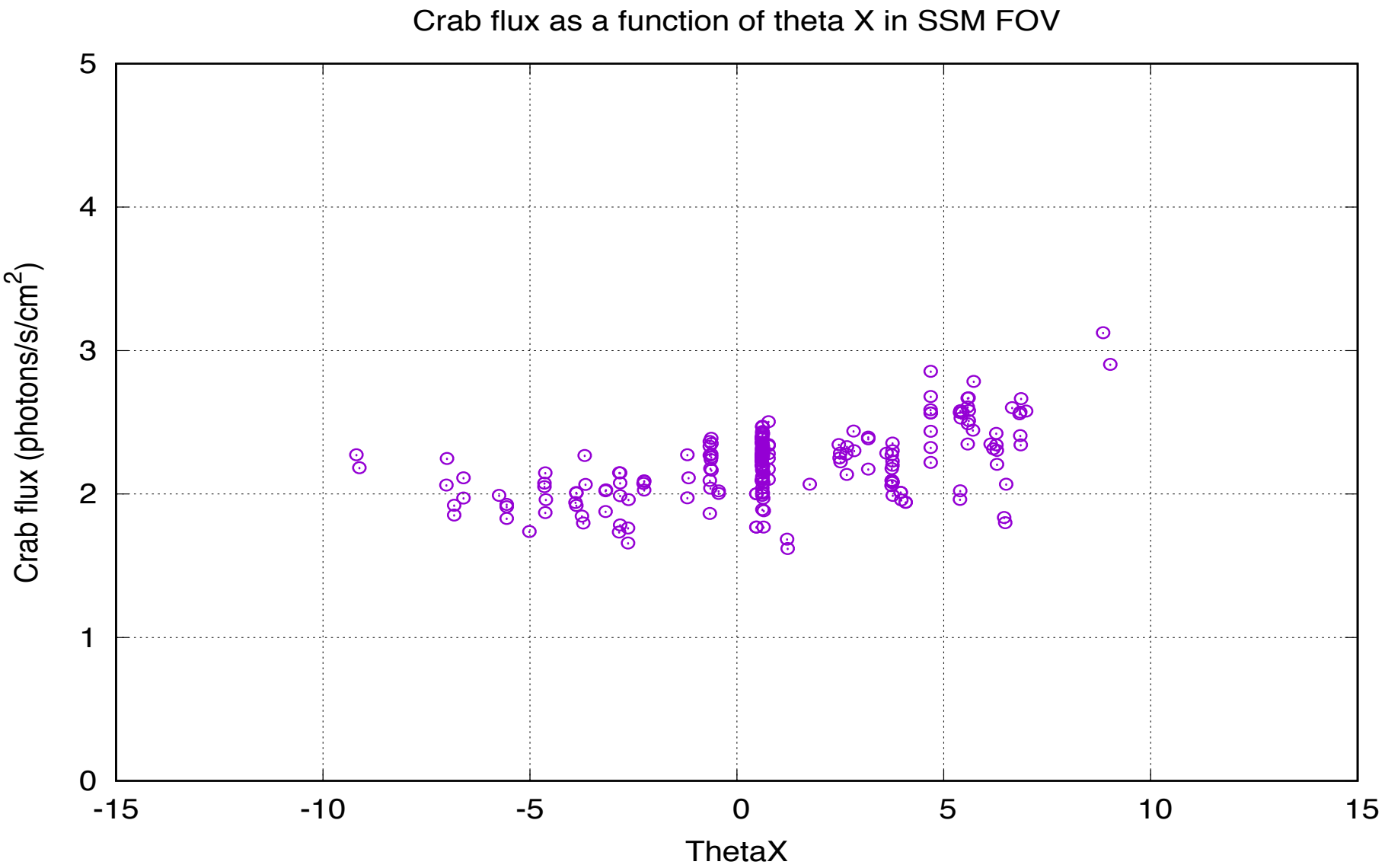


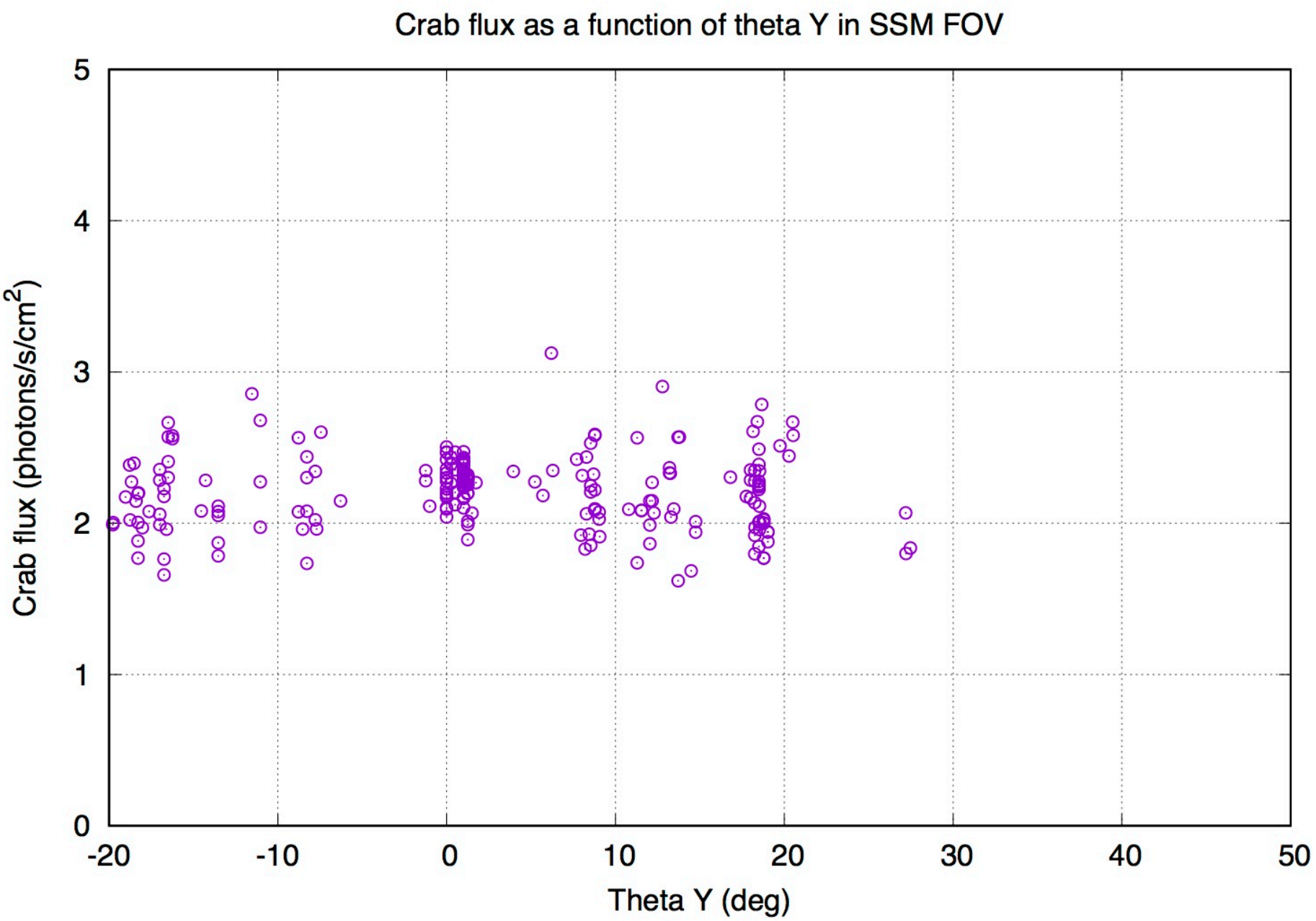
Calibration Fit Results – with background

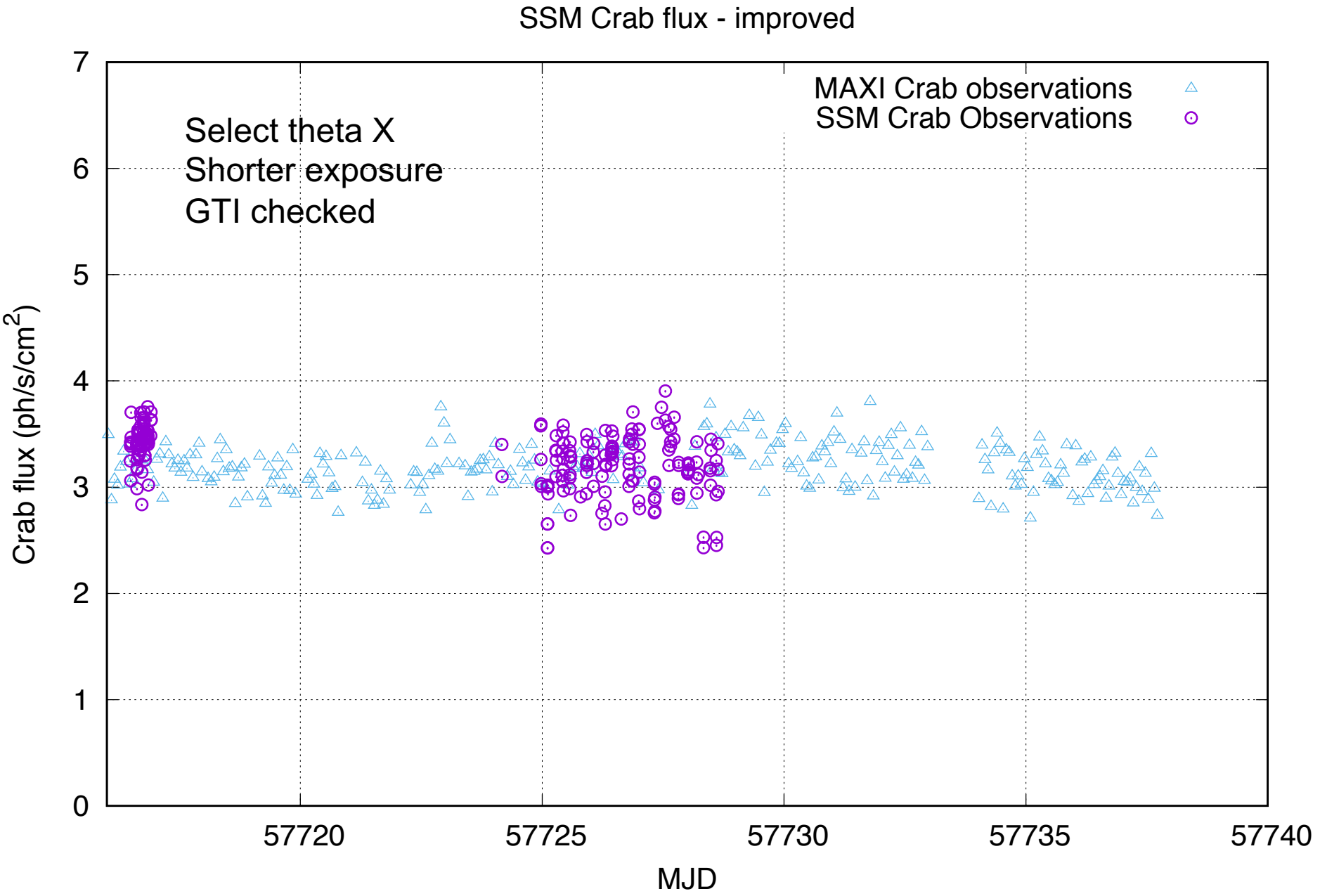



SSM Crab flux - improved
MAXI Crab observations
SSM Crab Observations
after-background-inclusion
prior-to-backgroud-inclusion-in-subpixel-imaging
Crab flux (ph/s/cm2)
MJD
0
1
2
3
4
5
6
7
57720
57725
57730
57735
57740

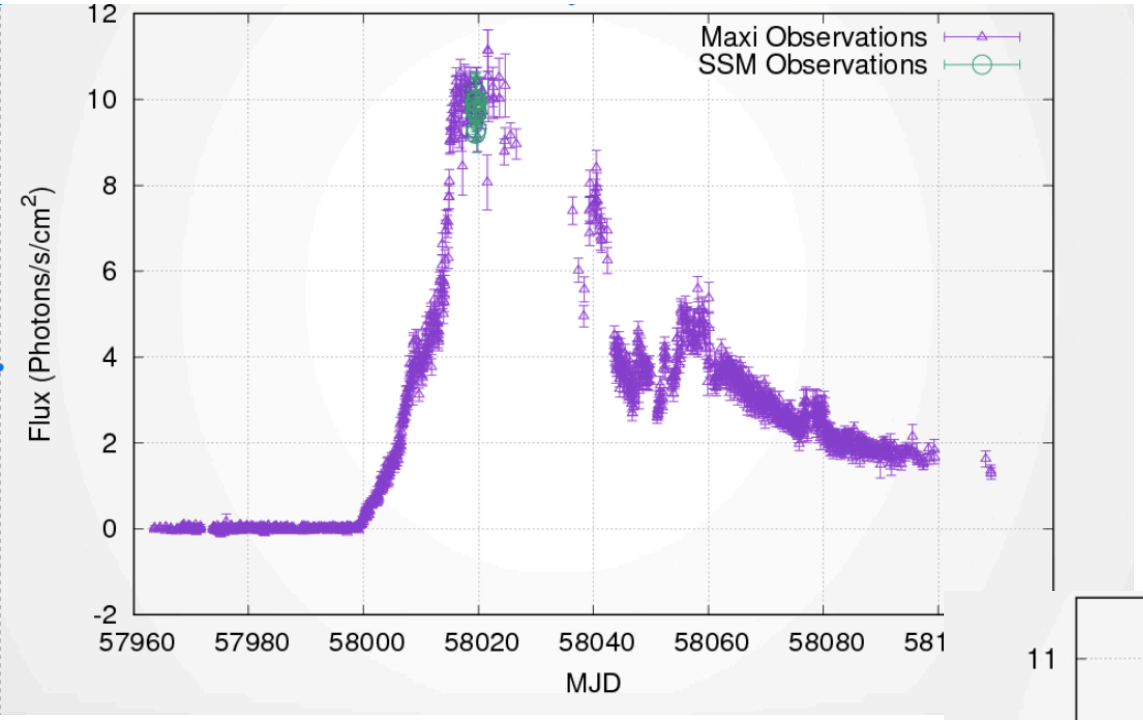
Collimator response to be tuned

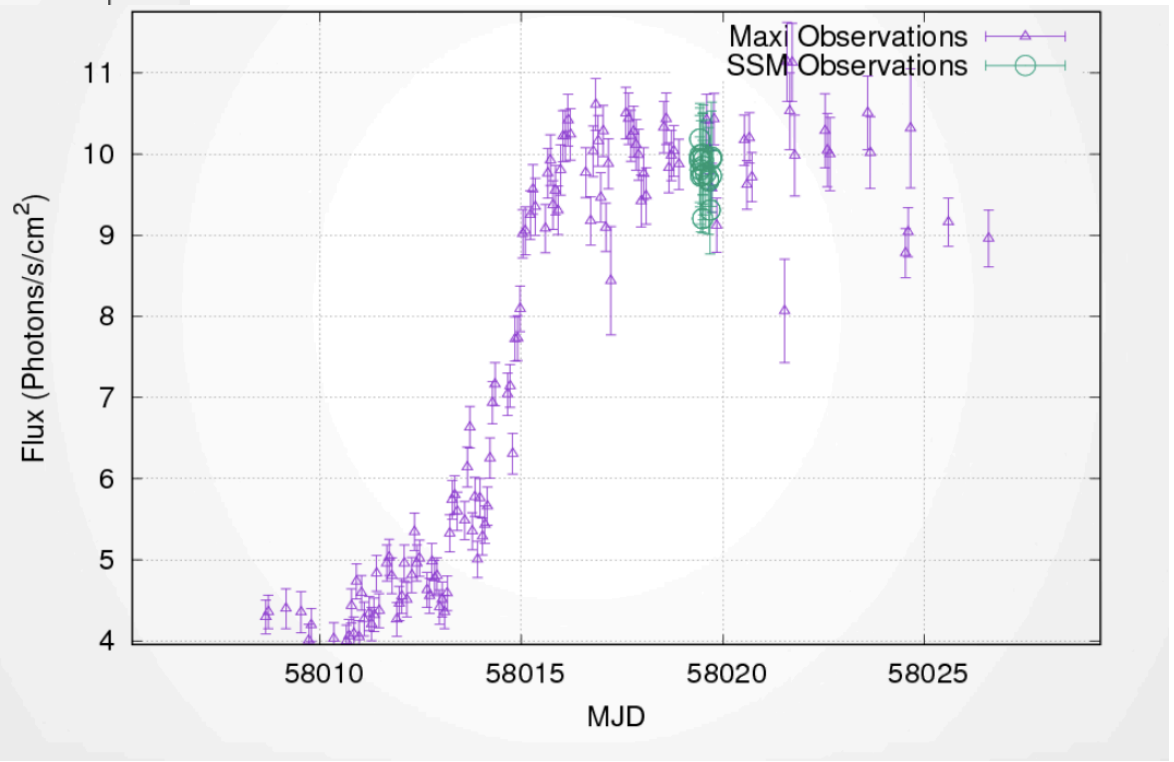



Crab flux as a function of theta Y in SSM FOV
Crab flux (photons/s/cm^2)
Theta Y (deg)
5
4
3
2
1
0
-20
-10
0
10
20
30
40
50


SSM Crab flux - improved
MAXI Crab observations
SSM Crab Observations
Select theta X
Shorter exposure
GTI checked
Crab flux (ph/s/cm^2)
MJD
0
1
2
3
4
5
6
7
57720
57725
57730
57735
57740

A new X-ray transient Maxi J1535-572 (Dec 2018 Obs)





➢ Data processing – data pipeline software – end to end runs took a while

➢ New requirements were introduced in the pipeline after launch – like Earth angle computation to estimate source occult duration, time correlation aspects etc.

➢ Parallel codes were written for data analysis till the data-pipeline was made available.

➢ Implementation of caldb database in the imaging code

➢ Fine tuning of calibration parameters

➢ Background modelling using faint field observations

➢ Imaging algorithm – different approaches – SUB-PIXEL Imaging introduced

➢ Including background model in the stage of sub-pixel imaging where the flux is estimated and reported

➢**Results improved a lot**

- GTI checks and exposure time estimations – to be checked carefully

- Further changes in the imaging algorithm like

    - sorting and picking the flux of brightest source in the FOV first and then for fainter ones
    - handling input source catalog for brighter sources first and then for fainter ones etc. needs to be incorporated.

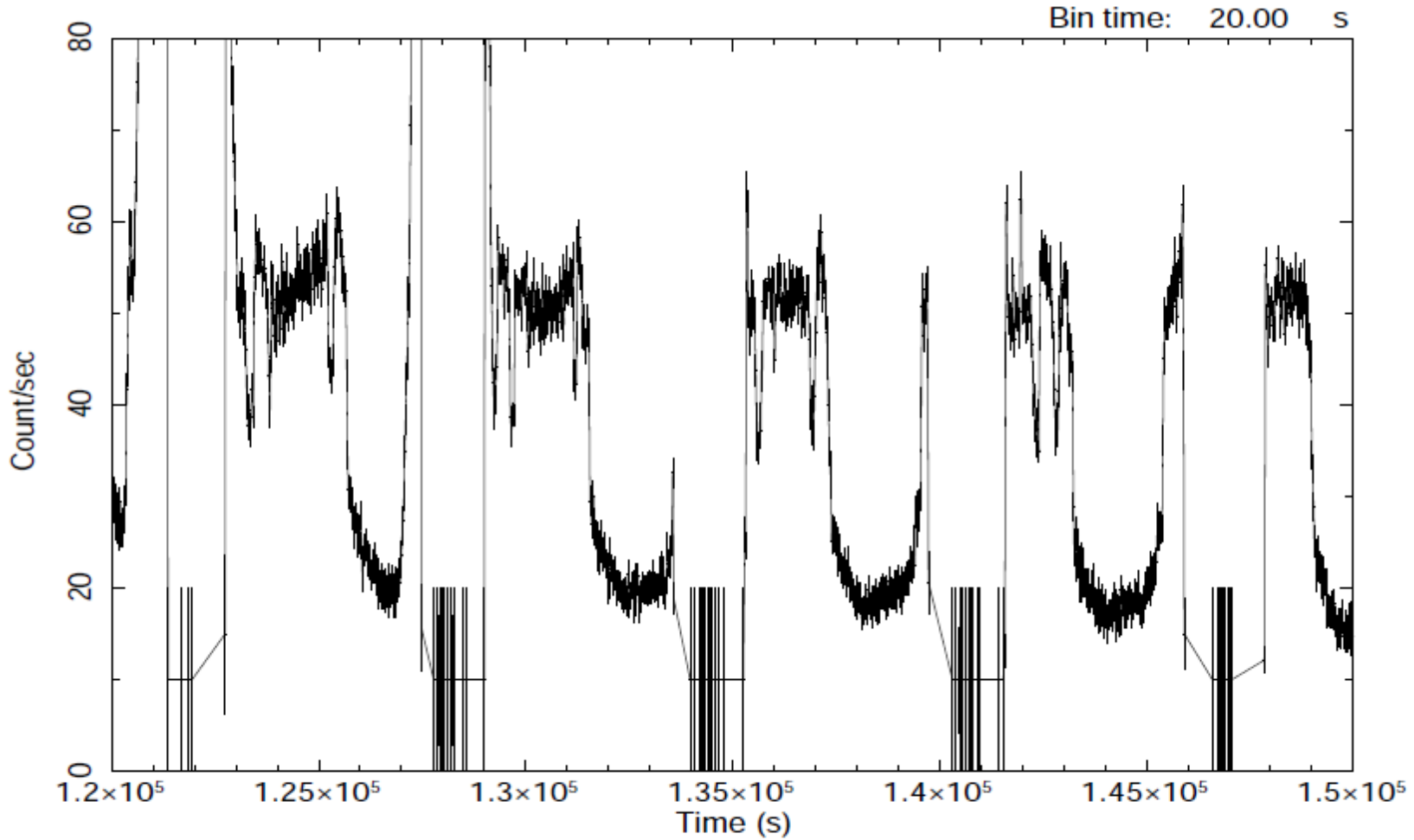
- Collimator response to be fine tuned

- Possible spacecraft attitude variations needs to be handled in the shadow response library

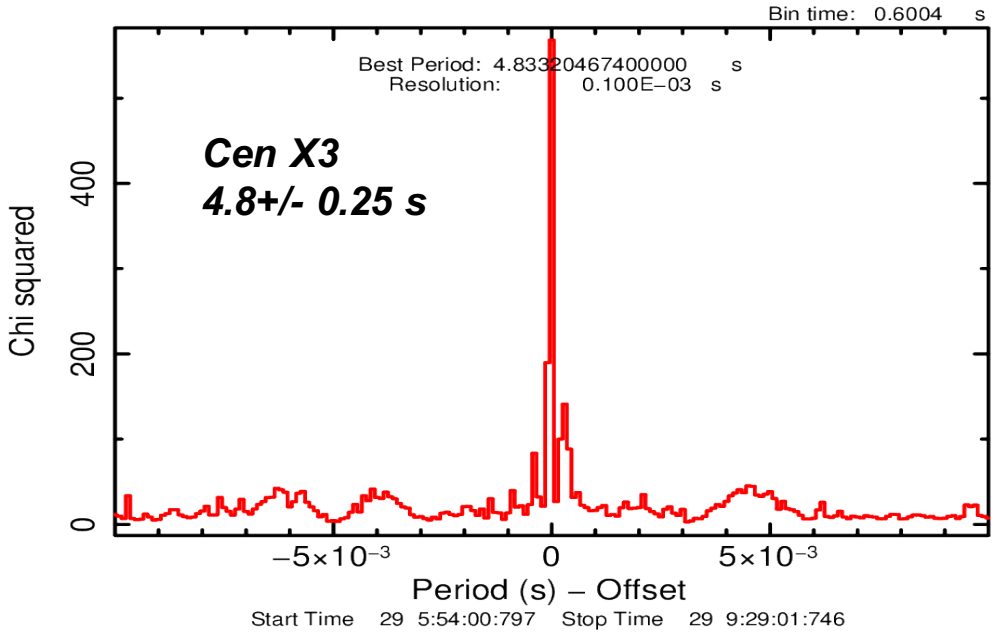
- All data needs to be reprocessed with above changes

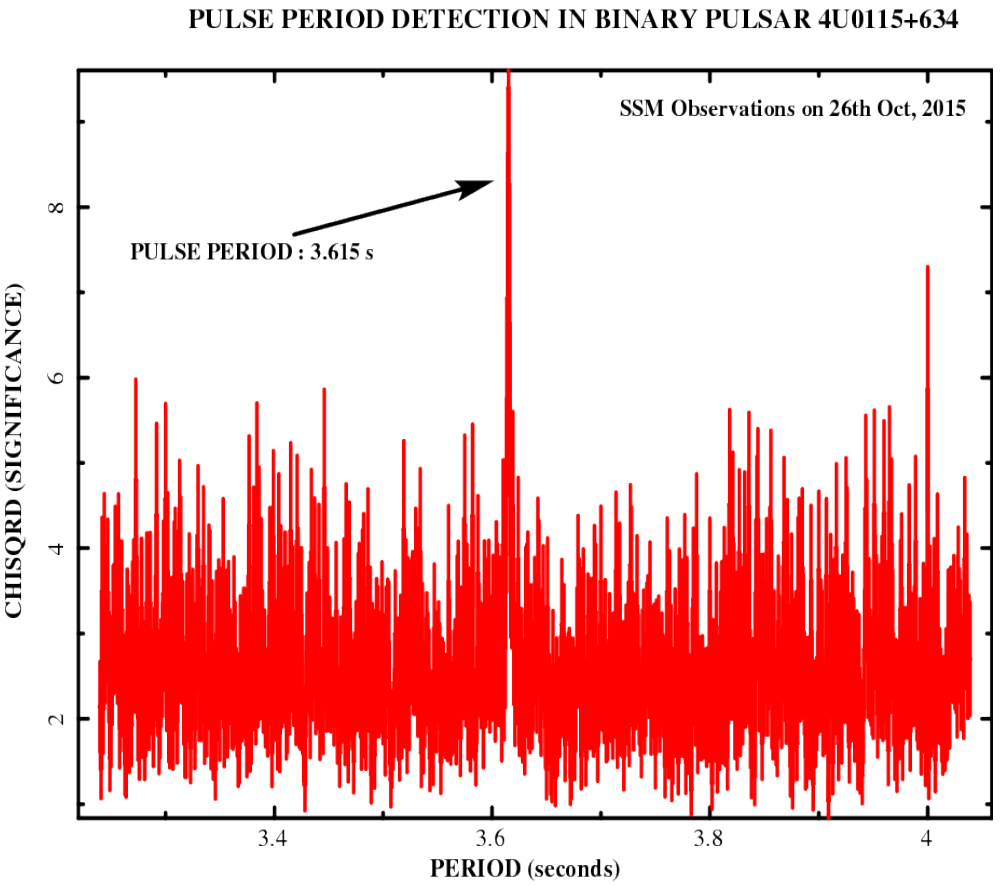
Few more science aspects with event mode data from SSM

GRS variability – Lambda class - September 2017 observations

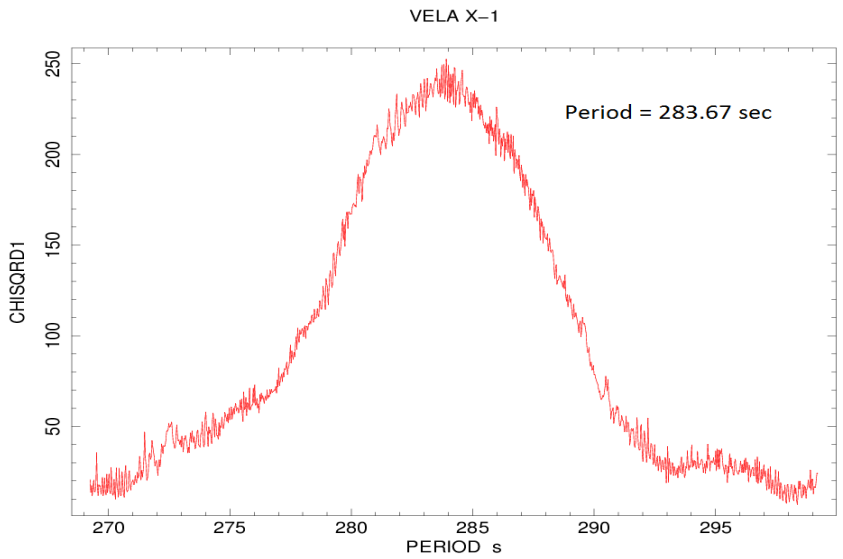


Pulsations from binary X-ay pulsars and search for pulsars with SSM data



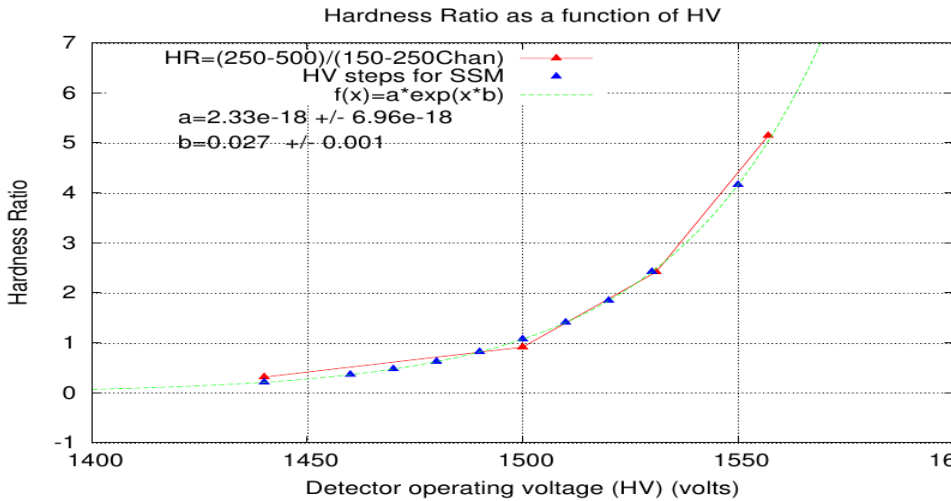


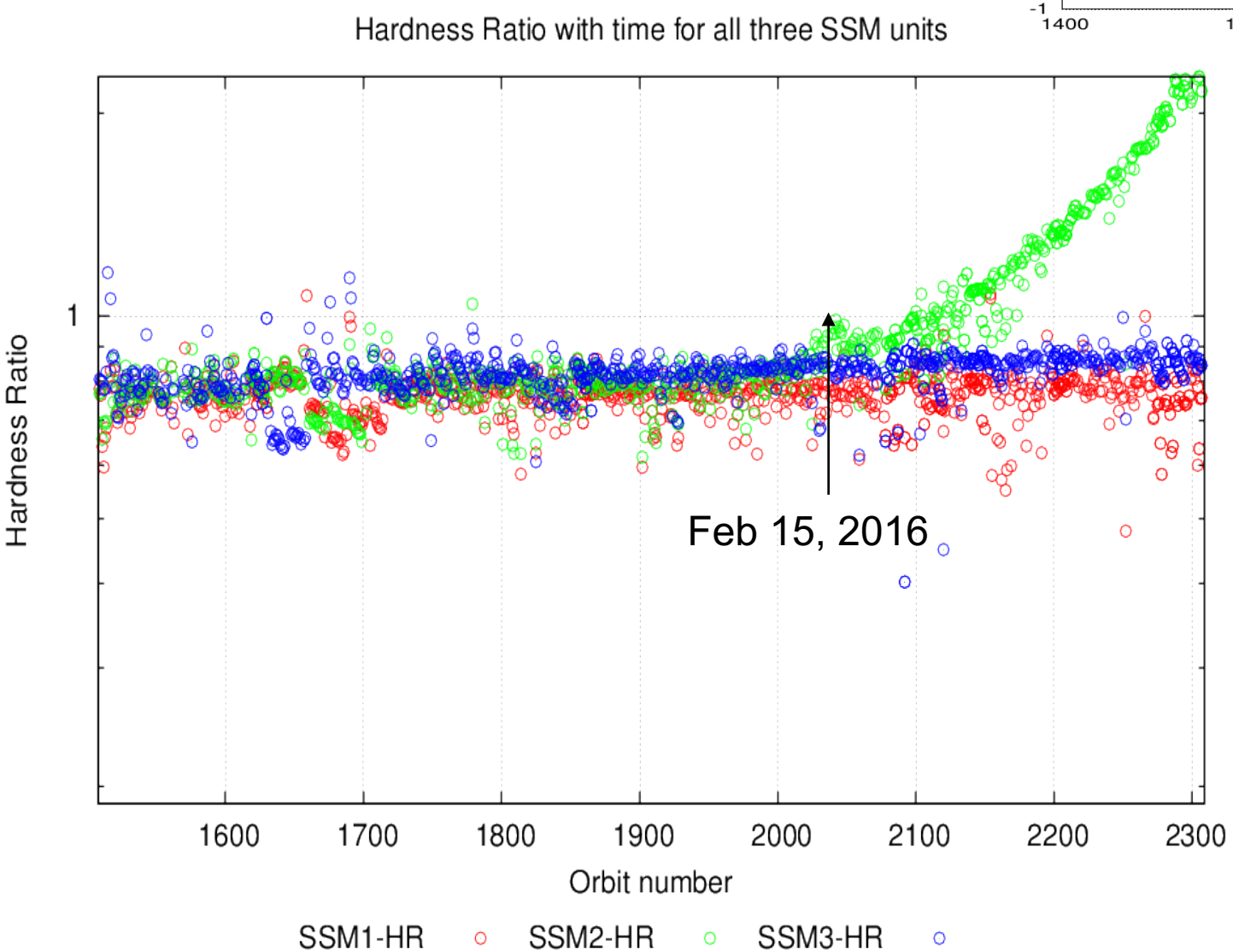
Vela X1 283+/-0.8 s



Mask weighted approach to be tried for bright source studies

SSM 1 & 2 gain change onboard





Out of three units, SSM2 is OFF, as it developed a leak since Feb 15, 2016 and operated till Aug 17th, 2016 with a reduced HV.

SSM1 is operated with a reduced HV step.

SSM3 is continuing to operate with the same gain since launch.

SSM web page

Scanning Sky Monitor

An X-ray sky monitor on board ASTROSAT

Welcome, Guest Login / Register

Home | Source Catalog | Light Curves | Downloads | Alerts | Contact

Scanning Sky Monitor

The Scanning Sky Monitor (SSM) is a scientific instrument on board AstroSat, India's first multiwavelength mission. The main objective of SSM is to locate transient sources in the sky as well as monitor the intensity variation in known bright X-ray sources. SSM is designed to work in the X-ray energy band of 2.5 keV - 10 keV.

SSM has 3 cameras which will monitor and look for the cosmic sources emitting X-rays in the designated energy band. SSM will generate alerts, if there are any flux excursions in known sources or if it is a new source. Information about these alerts will be made available in this website and can be made use of by other ground and space based observatories to take up follow-up observations of the source of interest.

A catalog of the sources detected by SSM can be obtained from this website. In addition, the light curve data file for every source detected by SSM can also be obtained after proper authentication.

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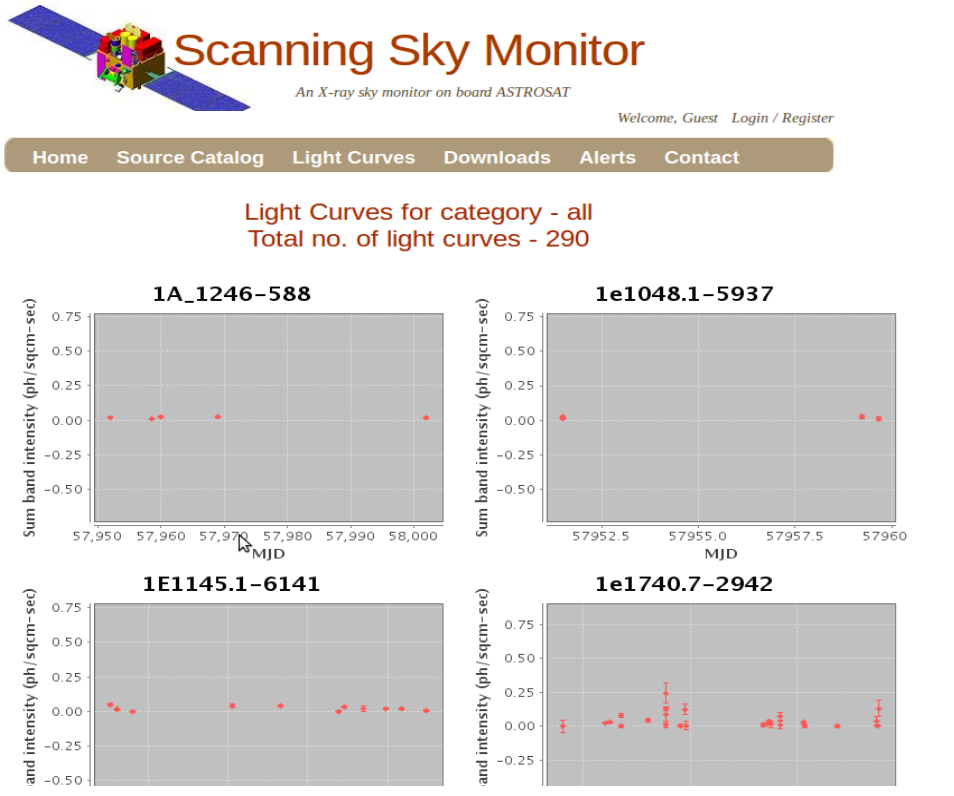
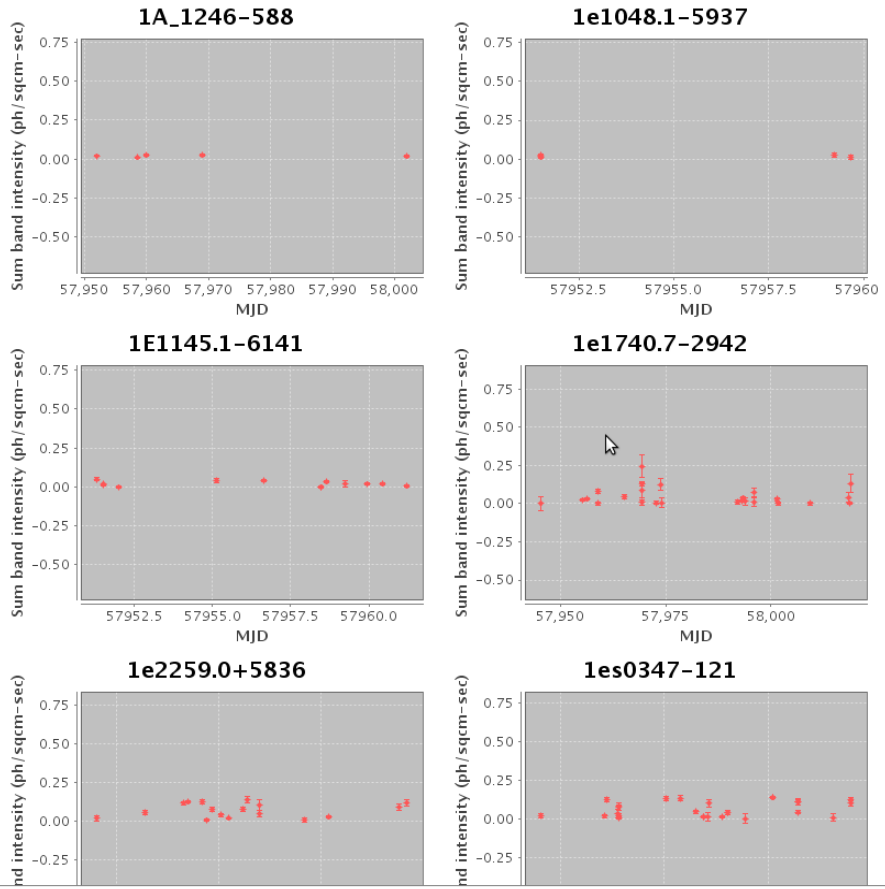
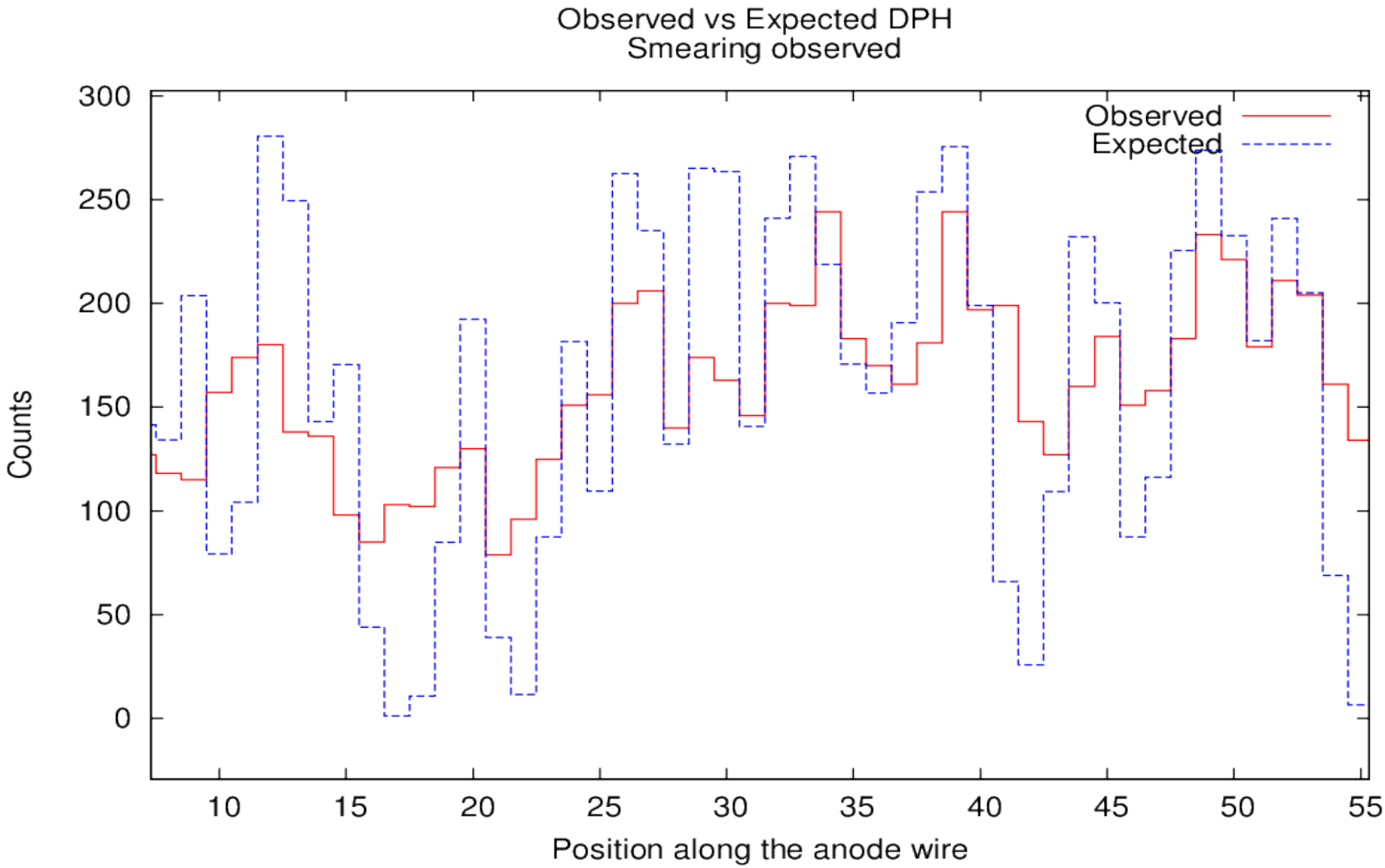
BEST VIEWED IN MOZILLA FIREFOX 1280 X 960

Light curves on SSM web page





Smearing of DPH probably due to attitude variations



Simulated DPHs for attitude variations