ASTROSAT : India's first multiwavelength astronomy satellite

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Looking back …

- ISRO satellite program is nearly 40 yrs old
  – Space science experiments have been part of satellites starting from Aryabhata

  – Recent experiments
    - Solar X-ray Spectrometer (2003)
    - RT-2 experiment on Photon-Coronas satellite
    - Chandrayaan-1

Upcoming near-term programs

ASTROSAT

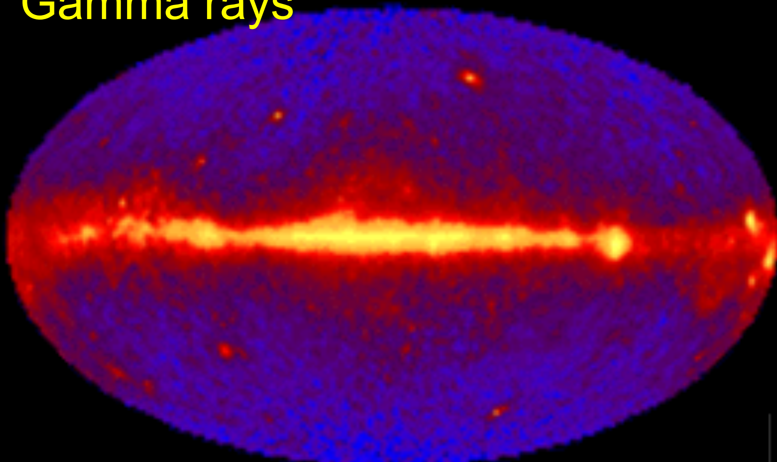
multiwavelength mission
(opt, UV, soft and hard X-ray)

Indo-UK collaboration on SXT
Indo-Canadian collaboration on UVIT

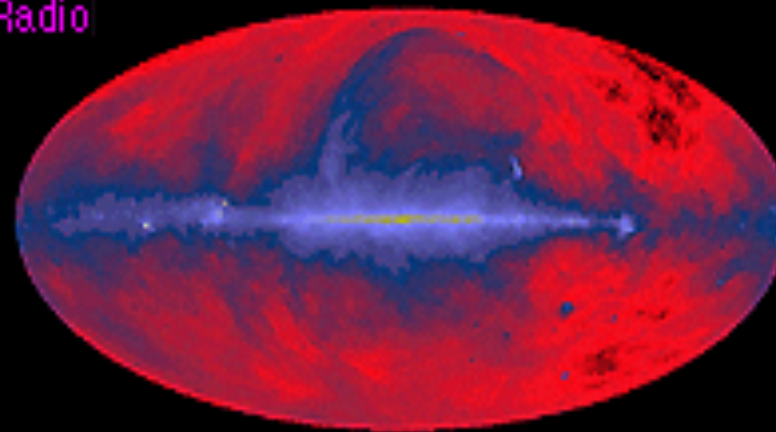
launch 2014

The next step “a multwavelength observatory”

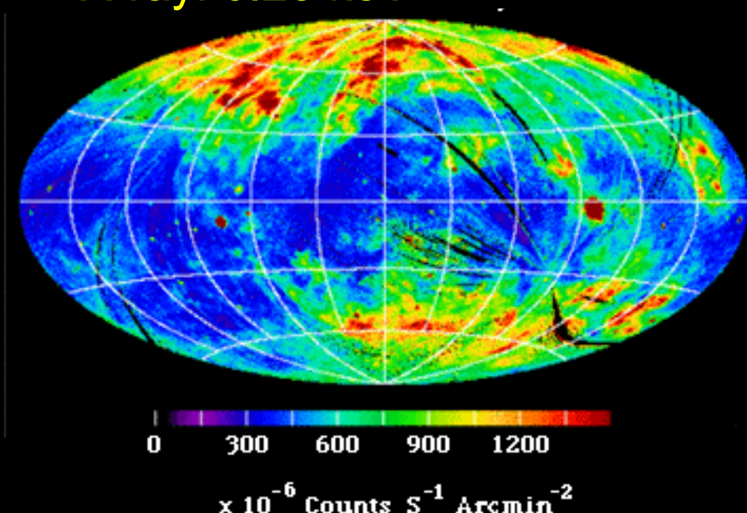
Gamma rays

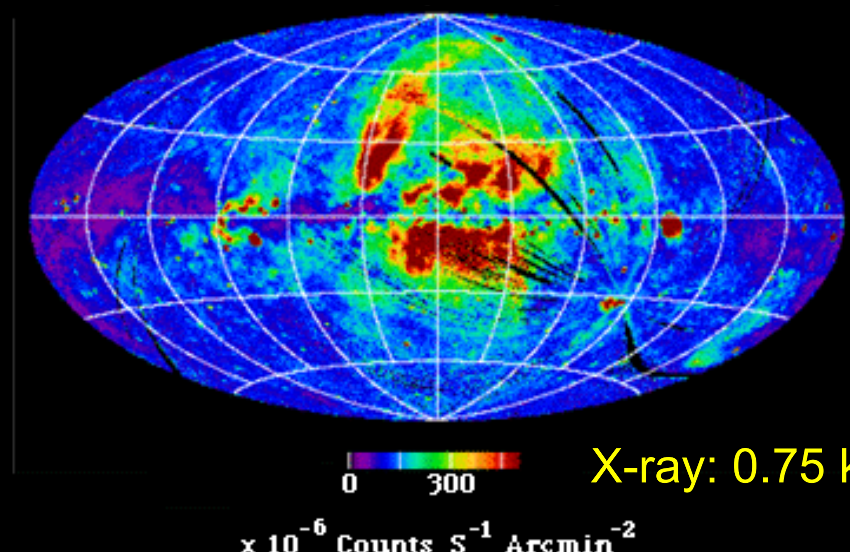


Radio



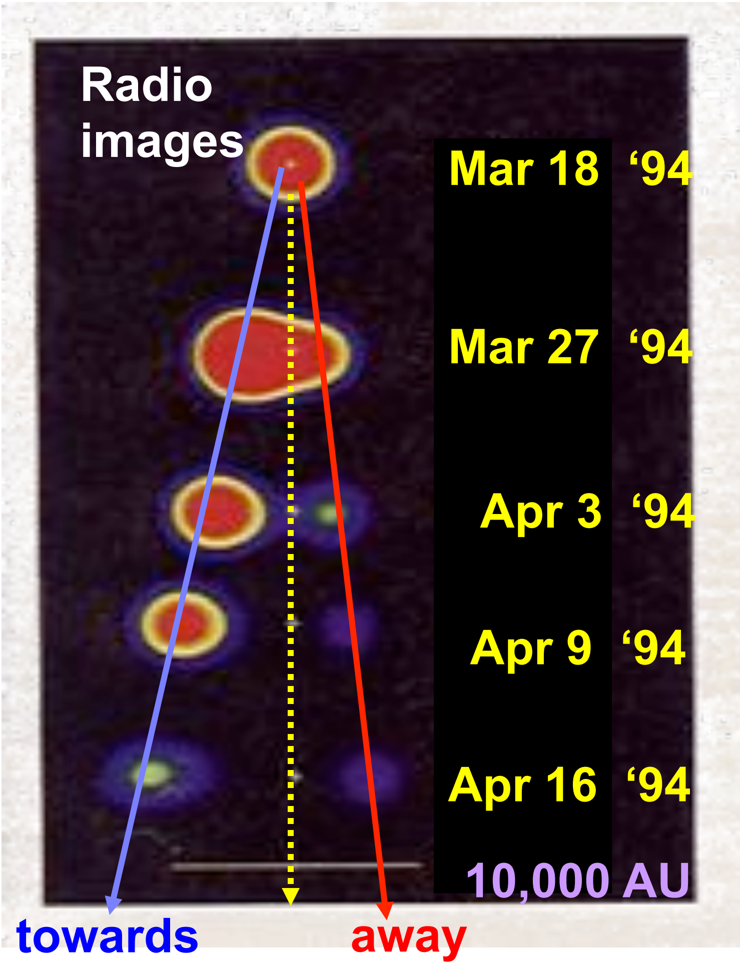
X-ray: 0.25 keV

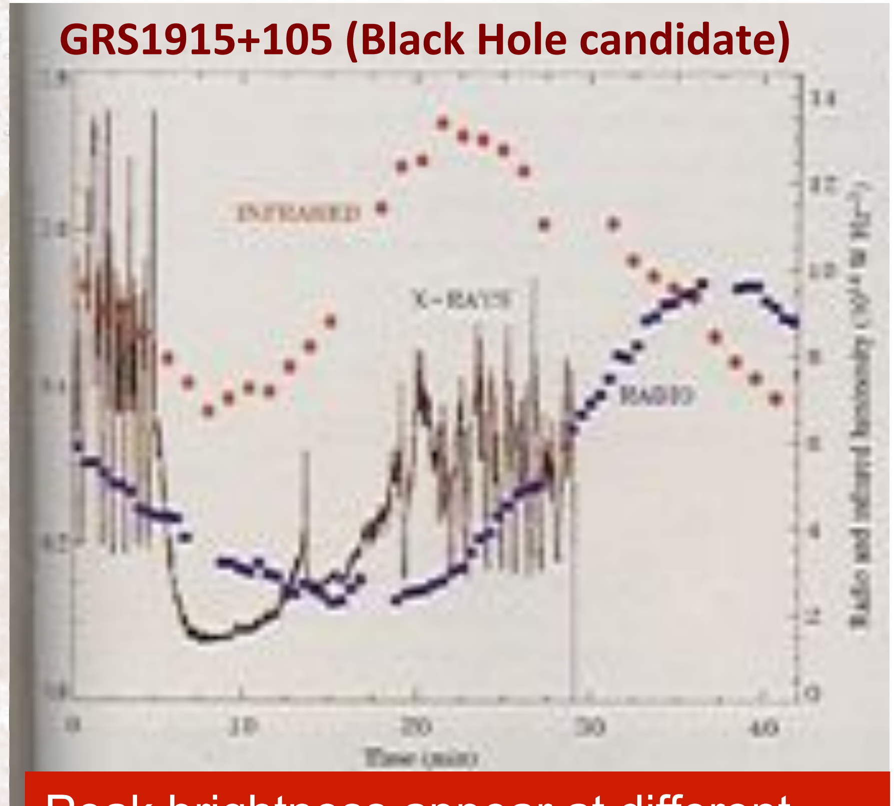




X-ray: 0.75 keV

Images courtesy HEASARC





Peak brightness appear at different times at different wavelengths

- Plasma blobs ejection (seen in VLA images; 1 week apart).
- X-ray dips when inner AD disappears; ejected plasma cloud emits in IR. 20 min later it expands; becomes transparent to radio emission.

ASTROSAT : India's first dedicated astronomy satellite

Planning started 1996 (after launch of IRS-P3)

Project report submitted 2000

Project Director identified 2002

Scheduled launch 2014

The international scene

- UV
  - **GALEX**
  - **FUSE** - terminated

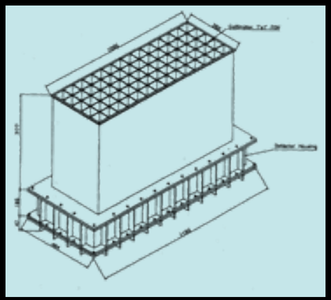
- X-ray
  - **CXO**
  - **XMM-NEWTON**
  - **SWIFT**
  - **SUZAKU**

Payloads on ASTROSAT

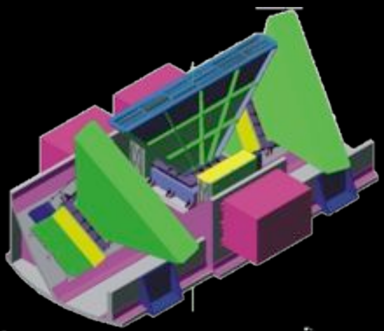
Parameters important for astronomy experiments

- **Detection efficiency**
- **Geometric area of detector**
- **Spectral resolution**
- **Angular resolution (2 arc sec to 1 deg)**
- **Sensitivity:** faintest source that can be detected
  - S/N $\propto$ geometric area
    1 / background
    sqrt (integration time)
    field of view

ASTROSAT INSTRUMENTS

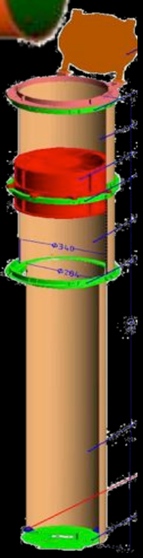


Large Area Xenon Proportional Counter

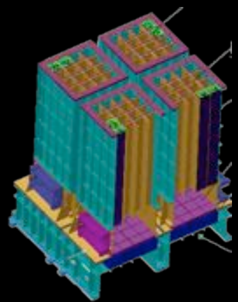


Scanning Sky Monitor (SSM)

UV Imaging Telescope



Soft X-ray telescope (SXT)



Cadmium Zinc Telluride Imager

Ultra-violet Imaging Telescope (UVIT)

(optical, NUV, FUV)

UVIT summary

- simultaneous large field (~ 30’) images in:
  - FUV (130-180 nm)
  - NUV (200- 300 nm)
  - VIS (350-550 nm)
- resolution < 1.8”
- sensitivity in FUV mag. 20 in 1000 s exp.

UVIT-
Mechanical
System

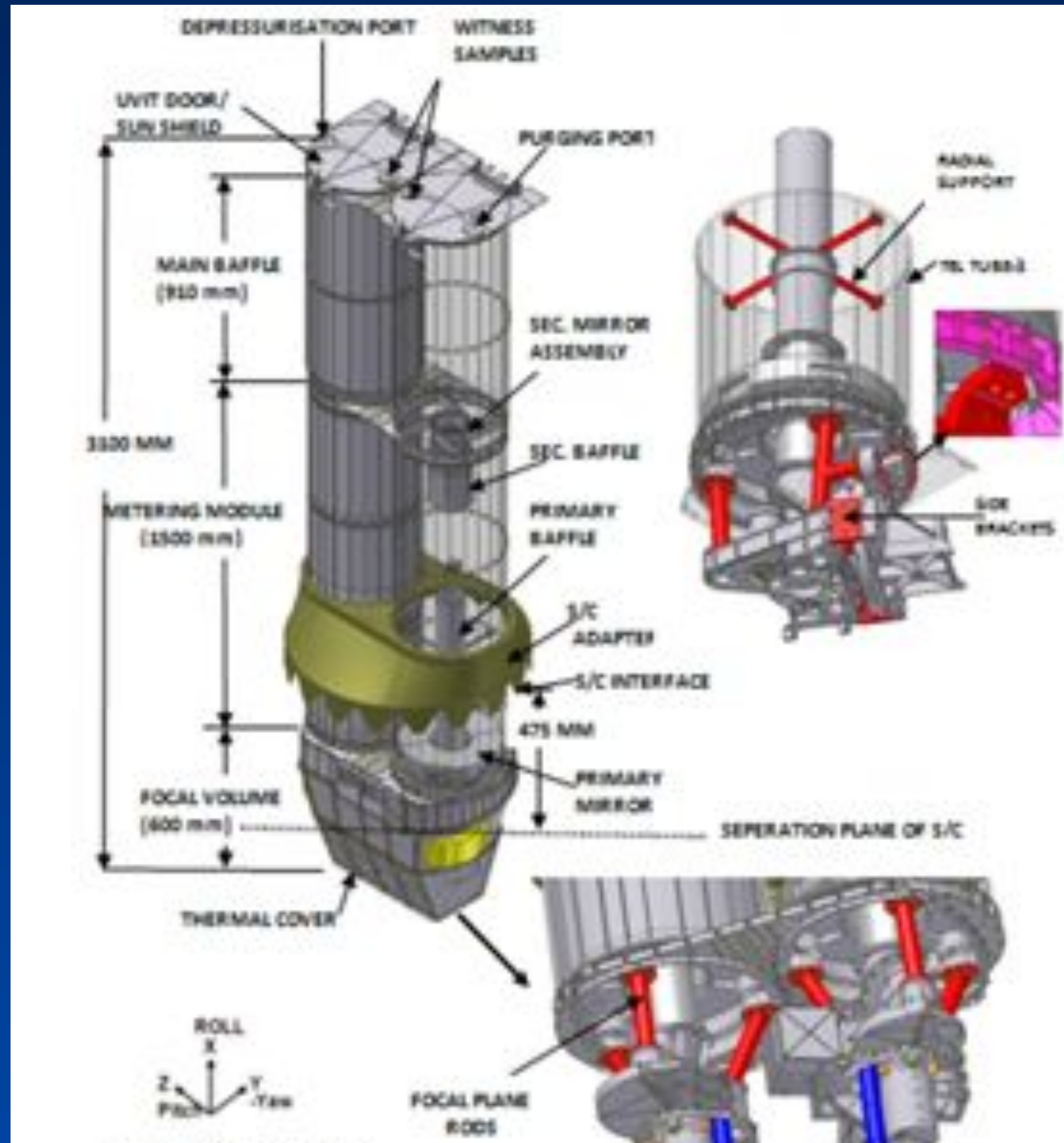
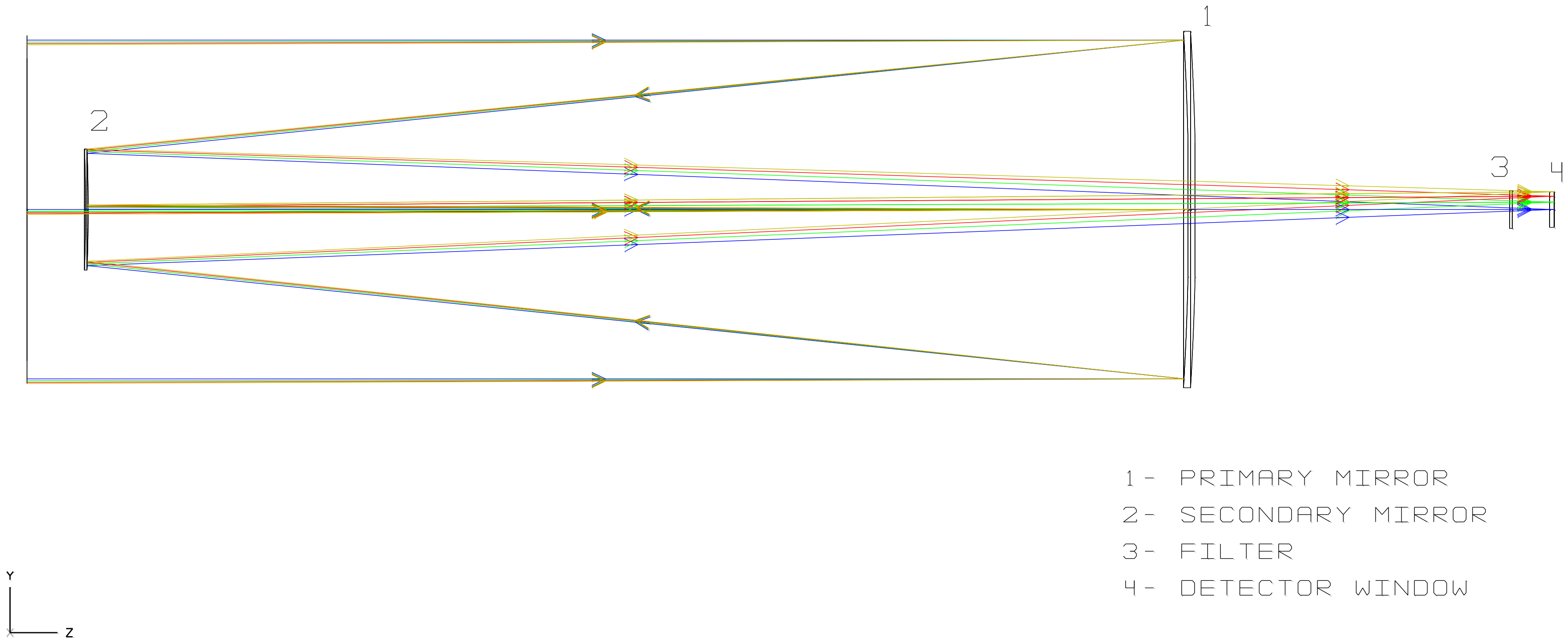


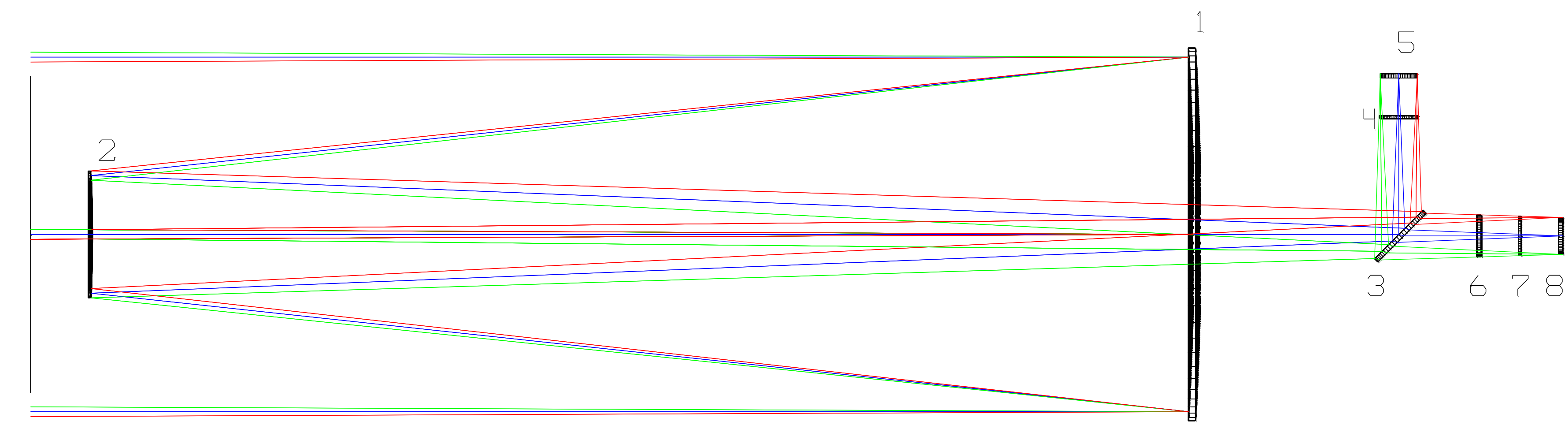
FIG 1: UVIT PAYLOAD
and Axis Definition

OPTICAL LAYOUT -- FUV CHANNEL



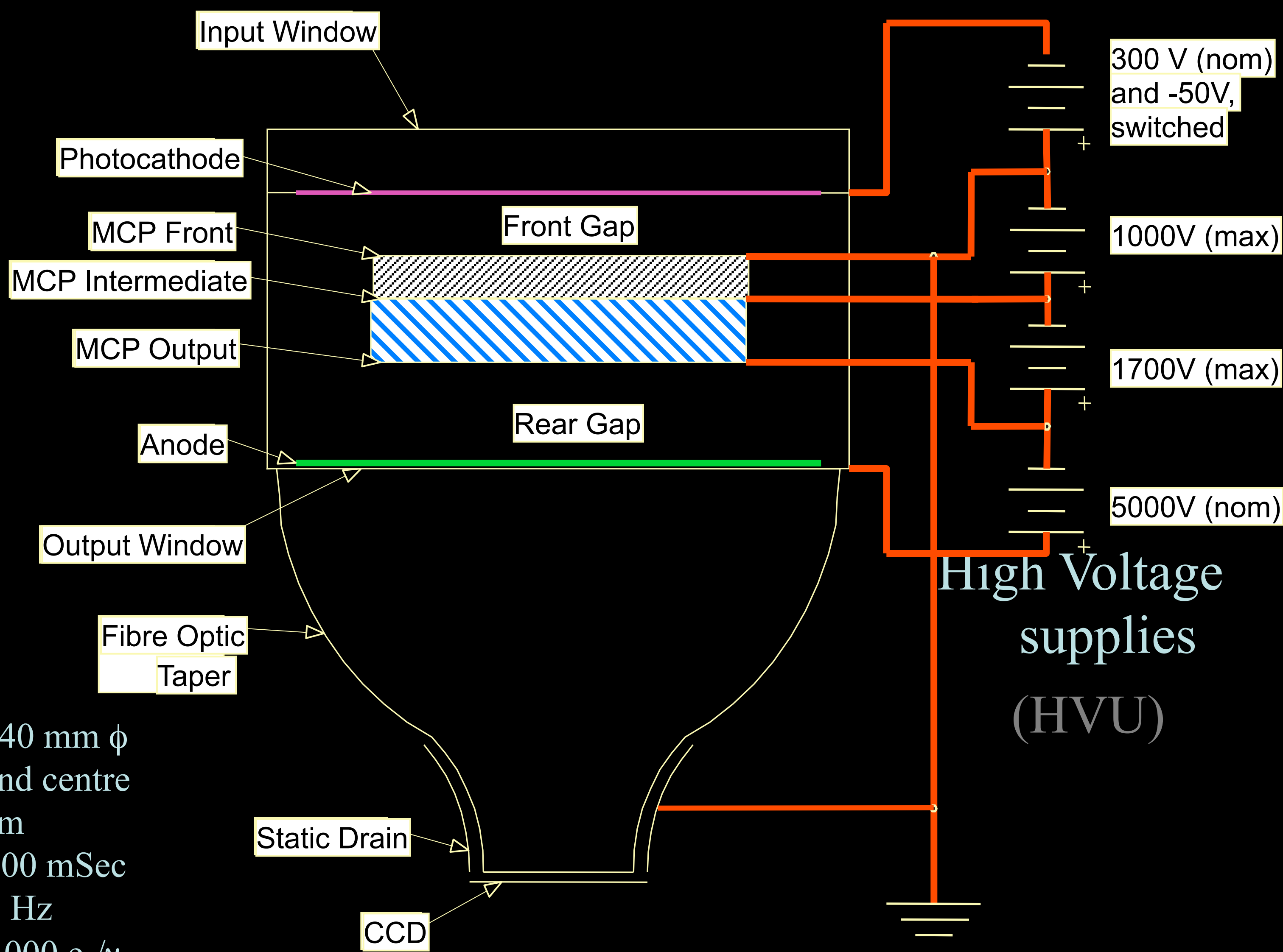
1- PRIMARY MIRROR
2- SECONDARY MIRROR
3- FILTER
4- DETECTOR WINDOW

OPTICAL LAYOUT – NUV & VIS



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

Components in each Detector



Imaging area : ~ 40 mm ϕ
QE :> ~5% in band centre
Pos. res. < 100 µm
Exposure : 10-1000 mSec
Frame rate : > 20 Hz
Gain : 2000 – 20,000 e-/γ
Safety : electronic gating

	GALEX	UVIT
FoV (Circular dia)	1.24 degrees	27 arc-min
No. of bands	2 (NUV, FUV)	2 channels (NUV, FUV) + Vis
Filters in NUV	NIL	5 filters
Filters in FUV	NIL	5 filters
Spectroscopy	Grism	Grating
Resolution	R ~ 100-120	R ~ 100
No. of grism/grating	1 per band	2 per band
Angular resolution	4.5-6.0 arcsec	1.8 arc-sec (FWHM)
Saturation	< 10 mag	< 8.0 mag (neutral density filter)
		[can image fields with bright objects]
Time resolution	~ 10 milli-sec	~ 5.0 milli-sec (window mode)
		~ 30 milli-sec full field

Soft X-ray Telescope (UVIT)

(0.3 – 8 keV)

Soft X-ray telescope: Some challenges

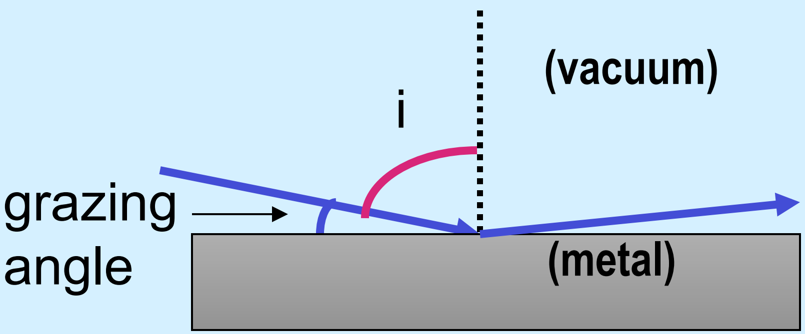
Refractive index n is:

$$n = 1 + N e^2/2^*\varepsilon_0 m (\omega_0^2-\omega^2) = 1 + \delta$$

Below UV energies ($\omega < \omega_0$) n >1
At X-ray energies ($\omega > \omega_0$) n <1

Total Internal Reflection

Critical angle = $\sqrt{2^*\delta}$



Typical grazing angle <0.5 deg)

$\delta = N e^2/2^*\varepsilon_0 m (\omega_0^2-\omega^2)$

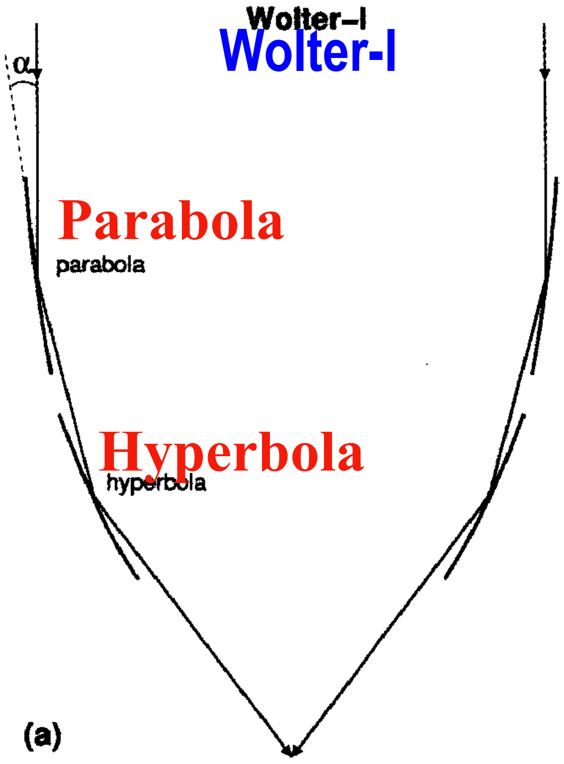
N =electron density in medium

ω_0 = freq of local oscillators (electrons)

ω = freq of incident radiation

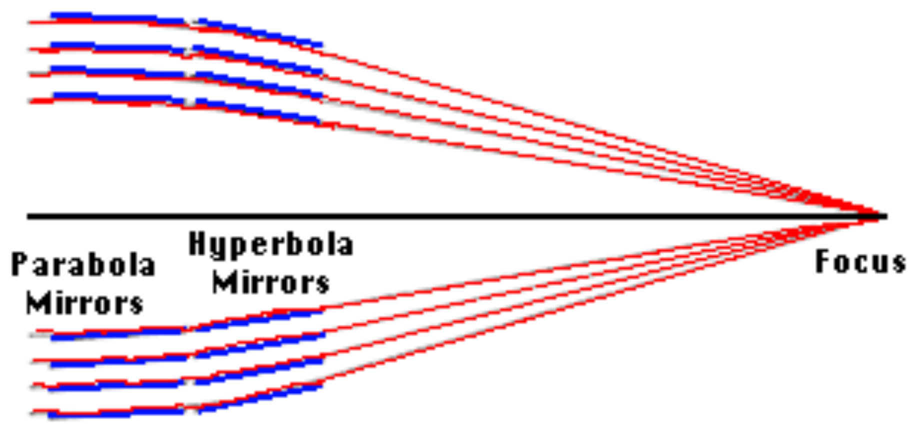
- Reflectivity = $\frac{(n - 1)^2}{(n + 1)^2}$ is very small
- However, with n <1 reflection of x-rays can happen via total internal reflection above the critical angle θ.
- At x-ray wavelengths critical angle ≈ 90 degree.

Principle of X-ray focussing



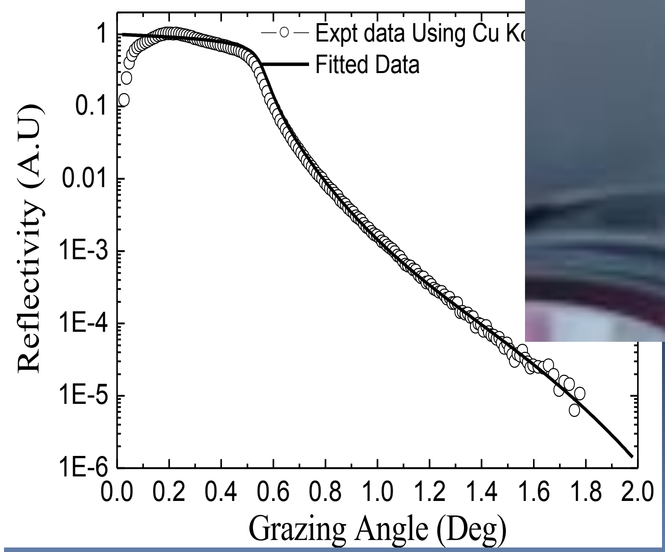
Double reflection needed to limit coma

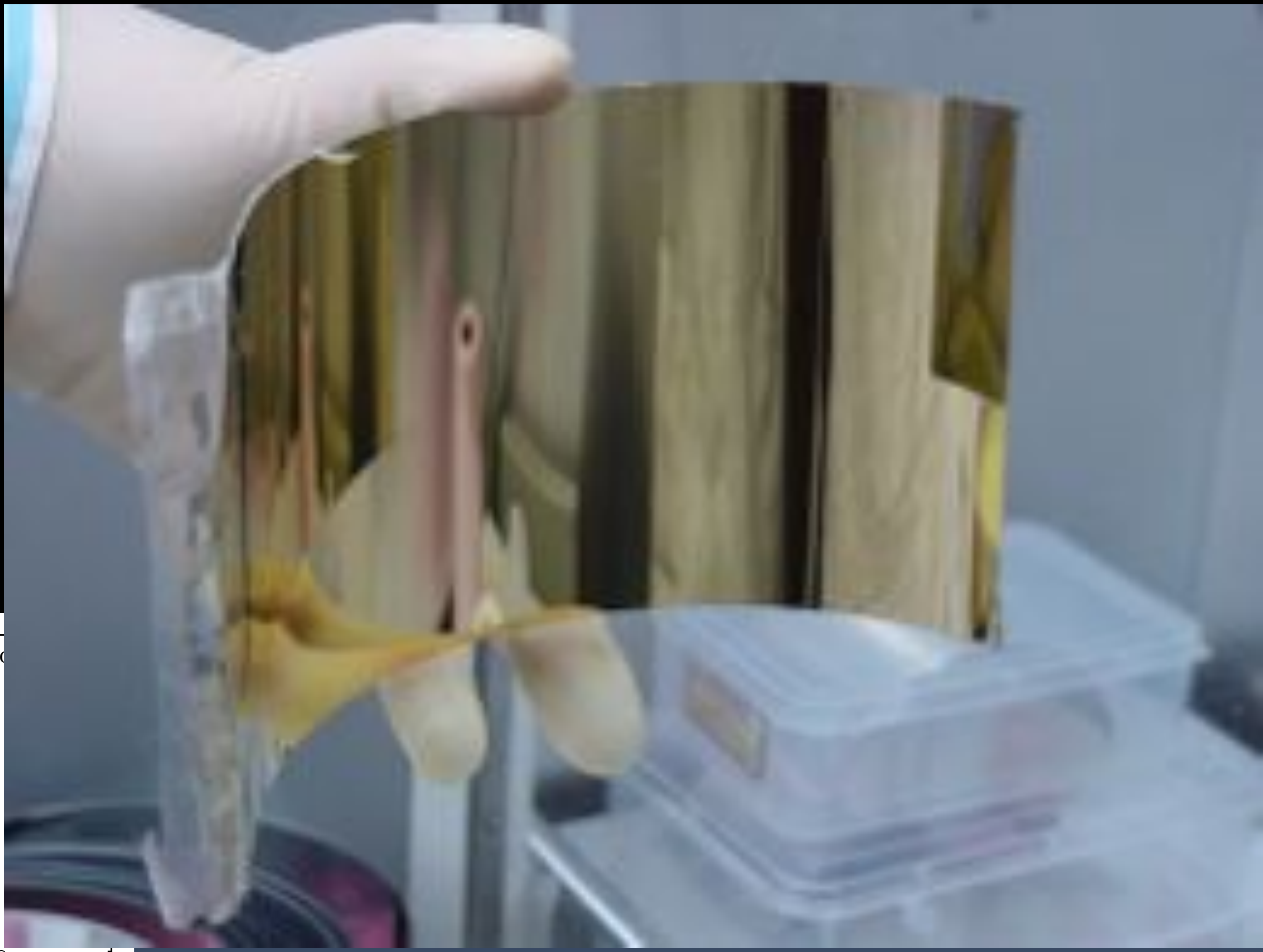
conical approx to Wolter-I geometry



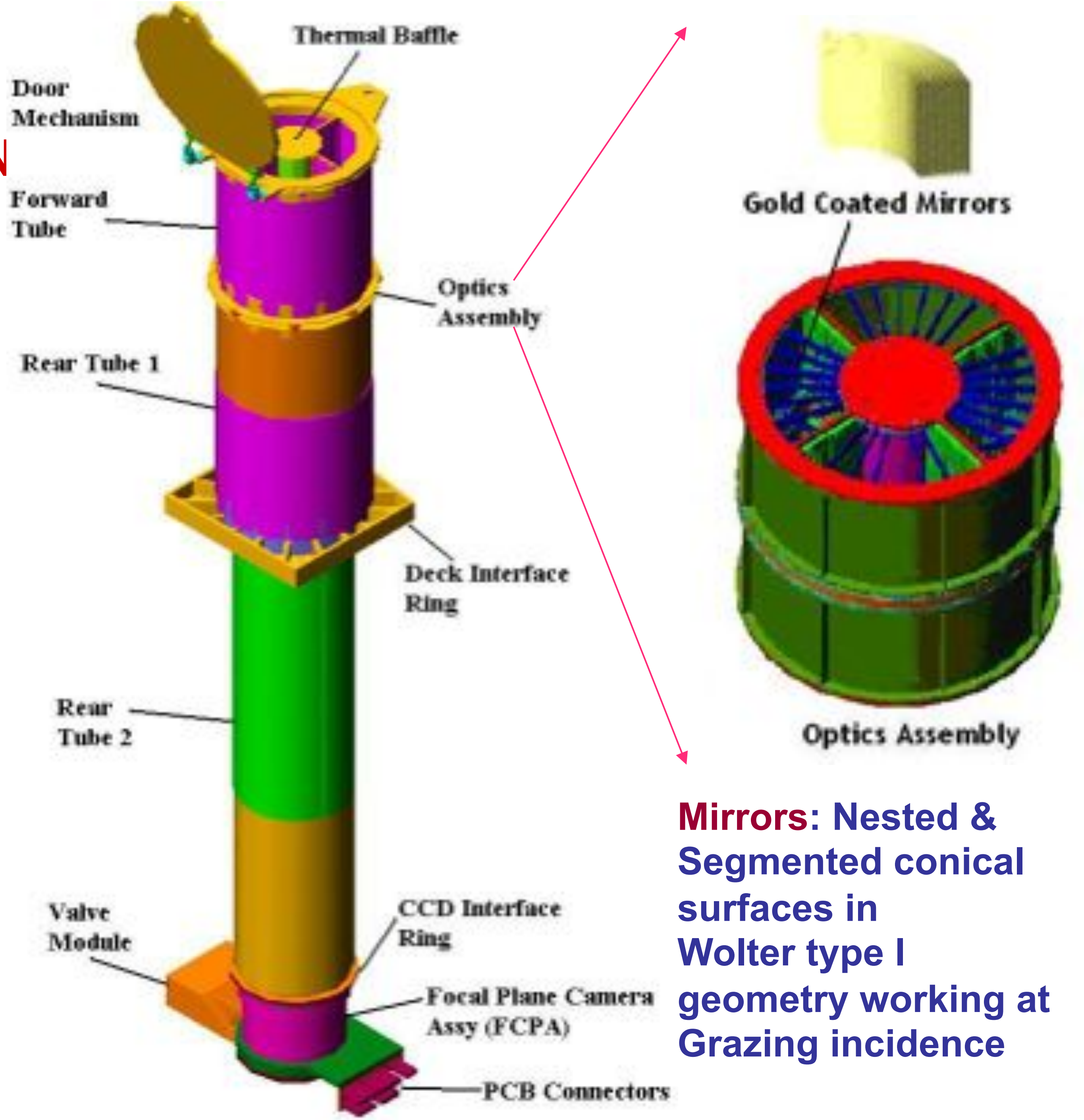
X-ray Reflectivity

Smoothness of
8 – 10 Angstroms





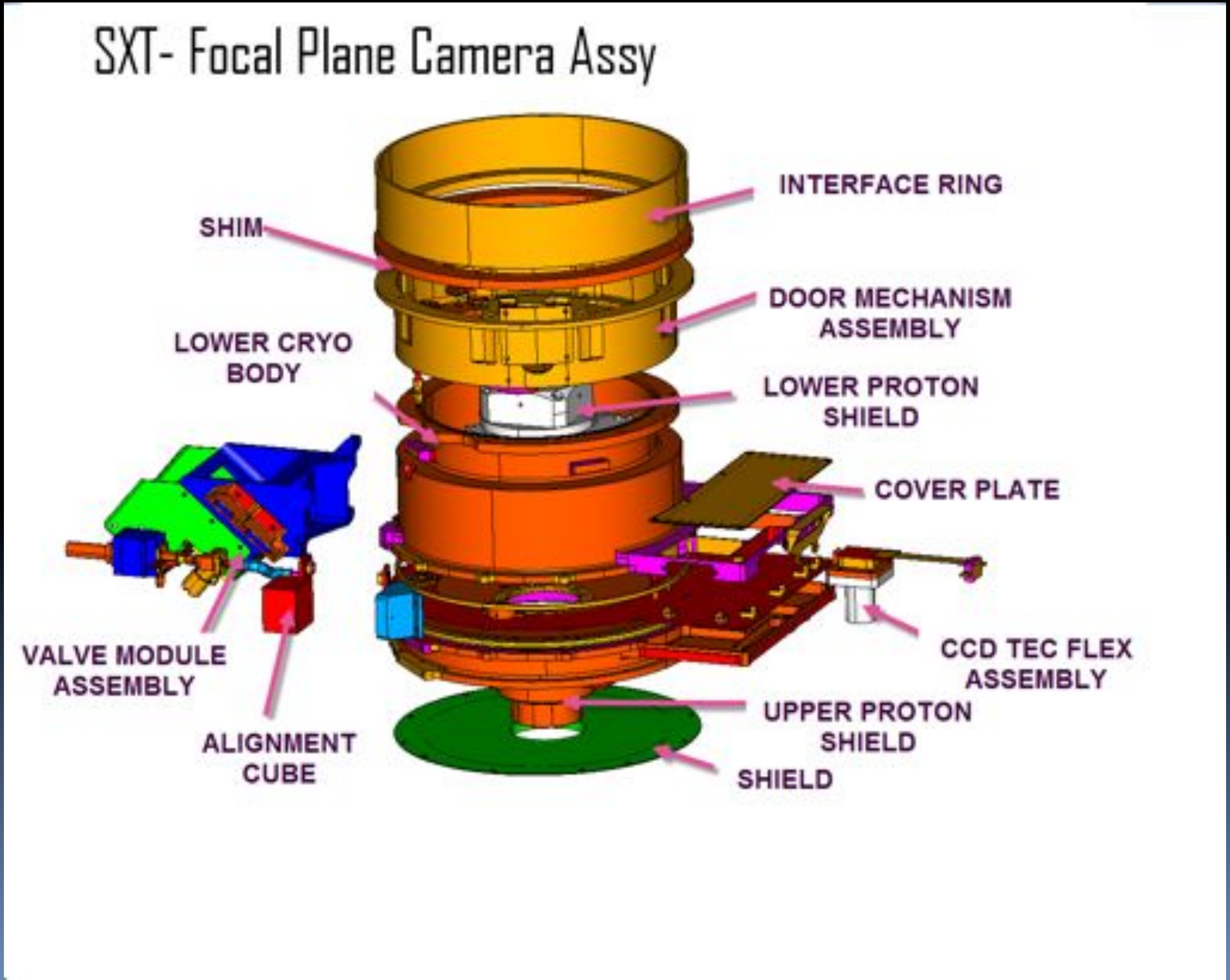
CONFIGURATION of SXT



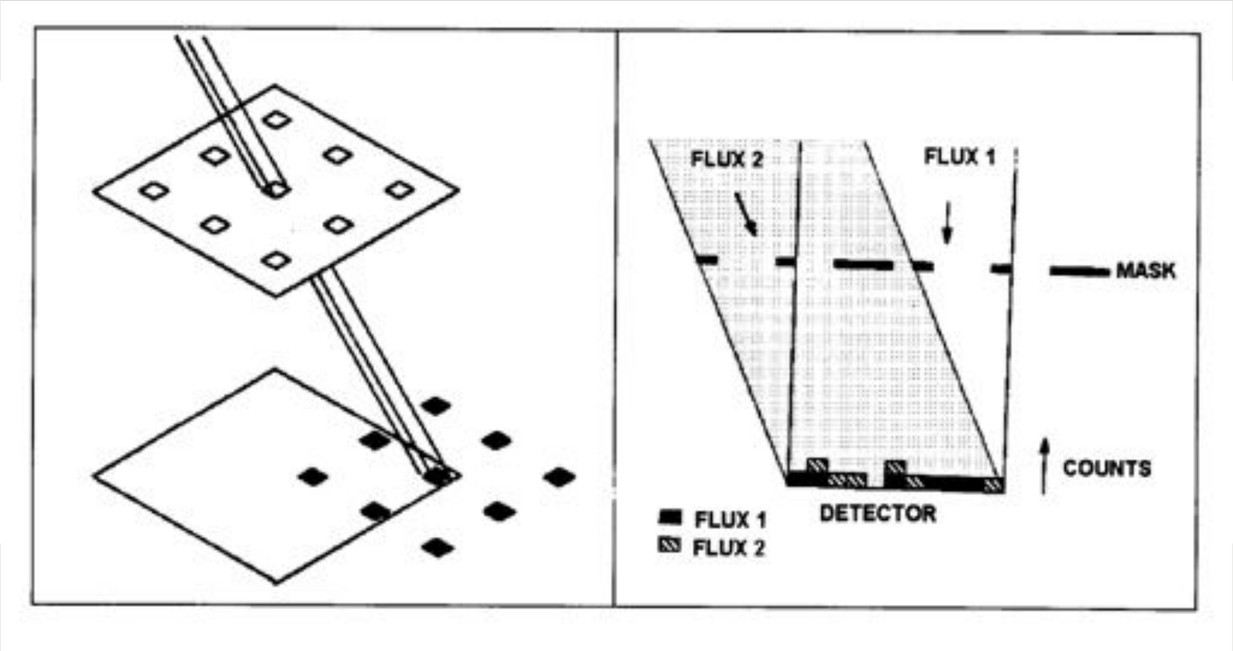
Mirrors: Nested & Segmented conical surfaces in Wolter type I geometry working at Grazing incidence

Foil mirrors in mirror assembly

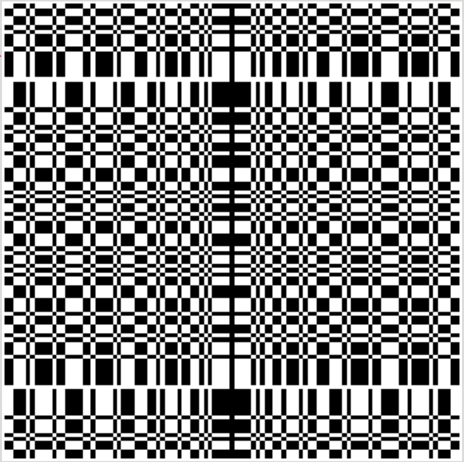
- Four Fe-55 calibration (corner) sources
- One Fe 55 calibration door source
- Optical Blocking Filter
- CCD Assy. including TEC



CODED MASK IMAGING



2-D mask

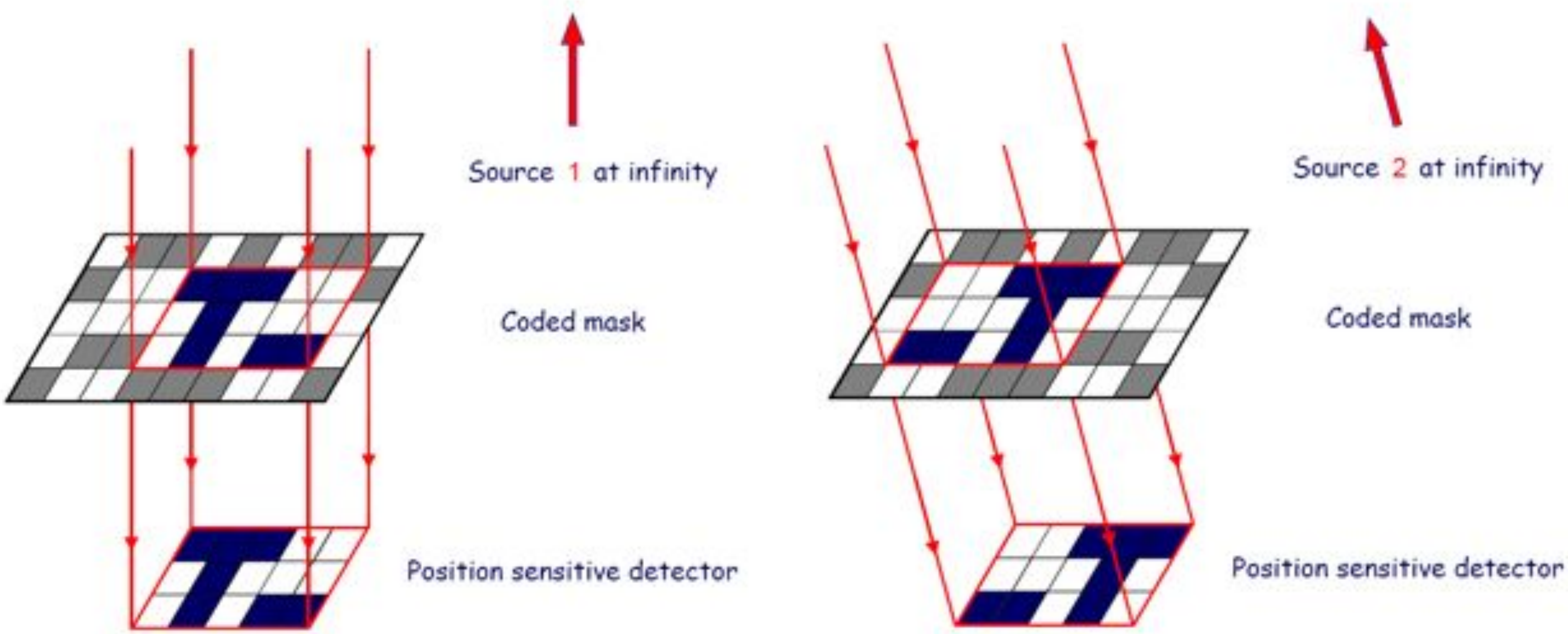


1-D mask

- Beyond 10 - 50 keV focussing of X-rays is difficult

- Casts a shadow pattern on the detector plane; combines good sensitivity and position resolution.

Coded-mask Imaging



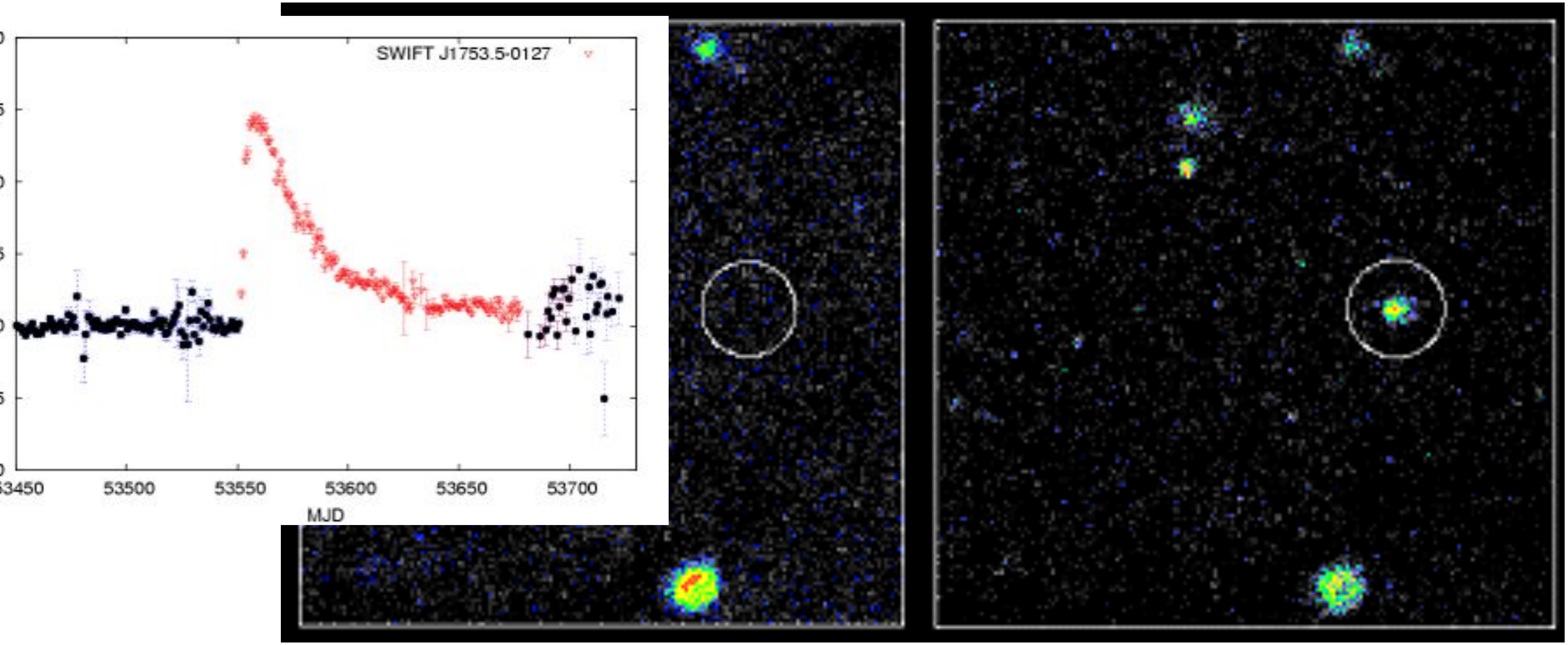
Scanning Sky Monitor(SSM)

(2 – 10 keV)

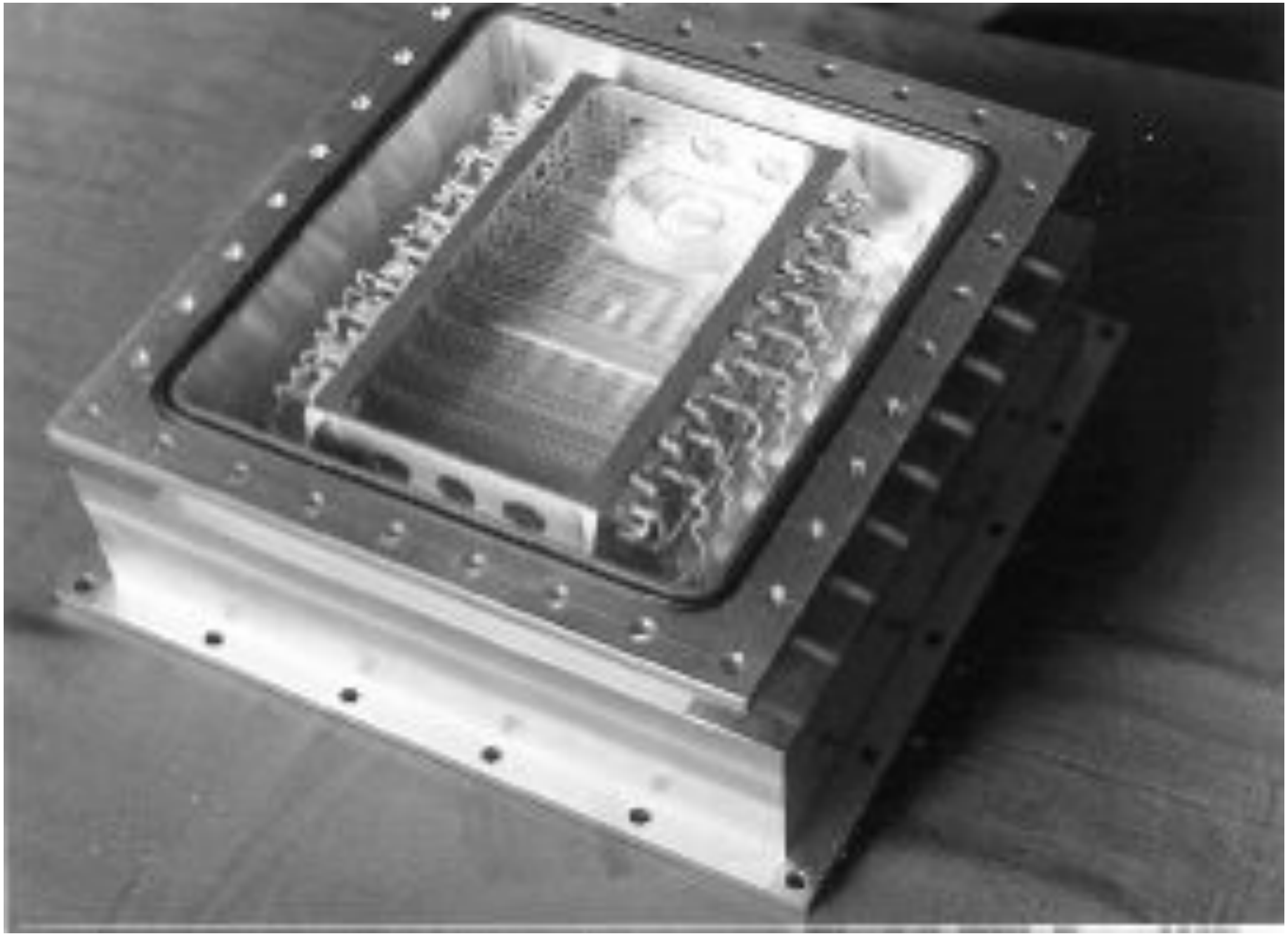
Scanning Sky Monitor (SSM)

Goals:

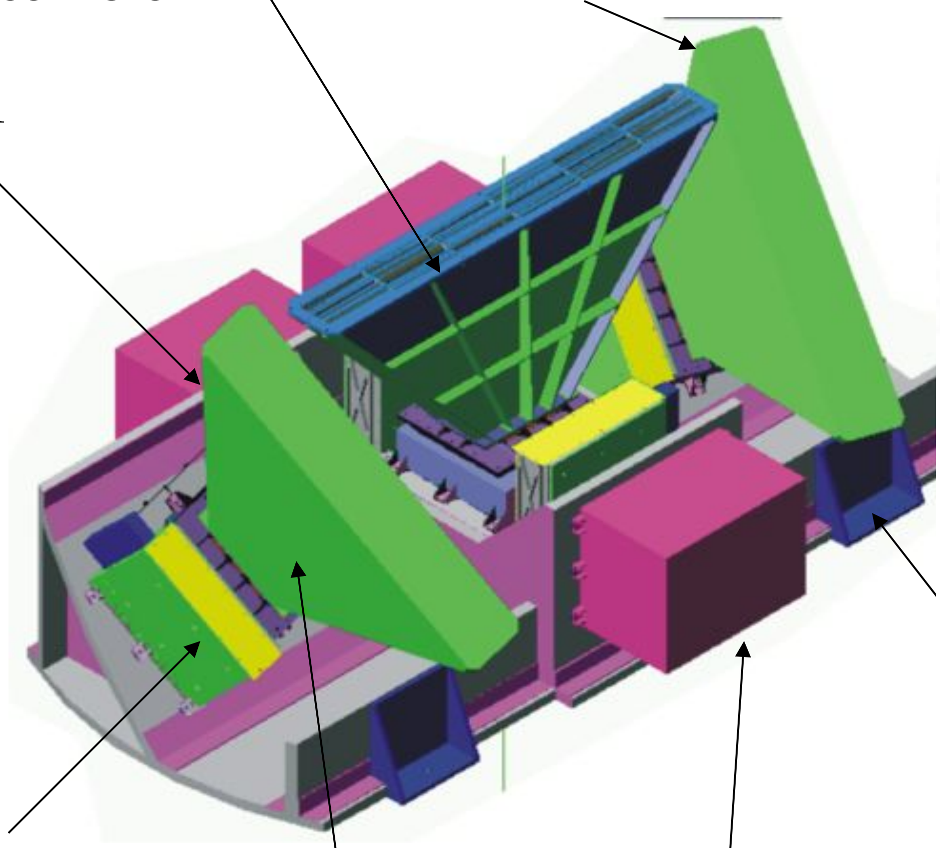
- to alert other experiments on ASTROSAT about x-ray transients
- to routinely monitor bright x-ray sources on the sky (many times a day)

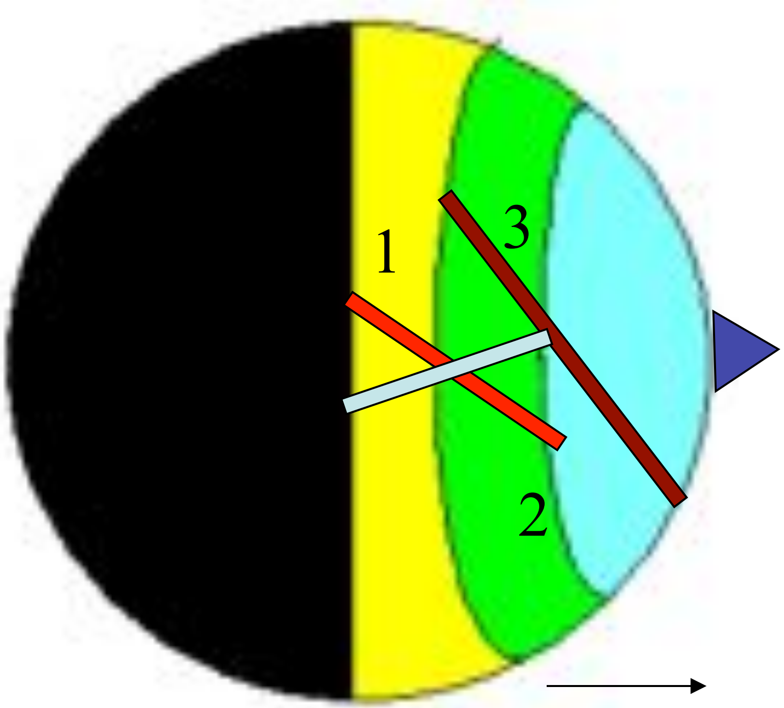


View of the SSM detector



Scanning Sky Monitor SSM)





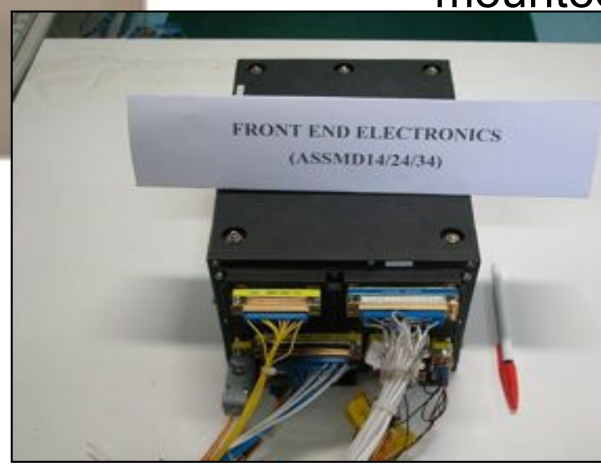
Rotating platform

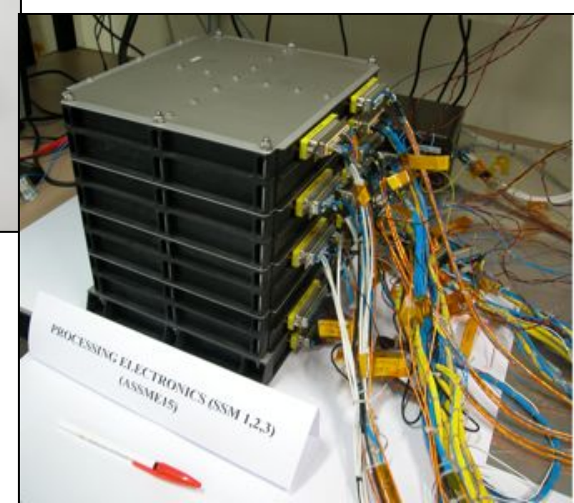
SSM (one unit) with front-end electronics (CSPA units)

One SSM unit consists of:

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

There are 3 such units mounted on a platform
tion
ism



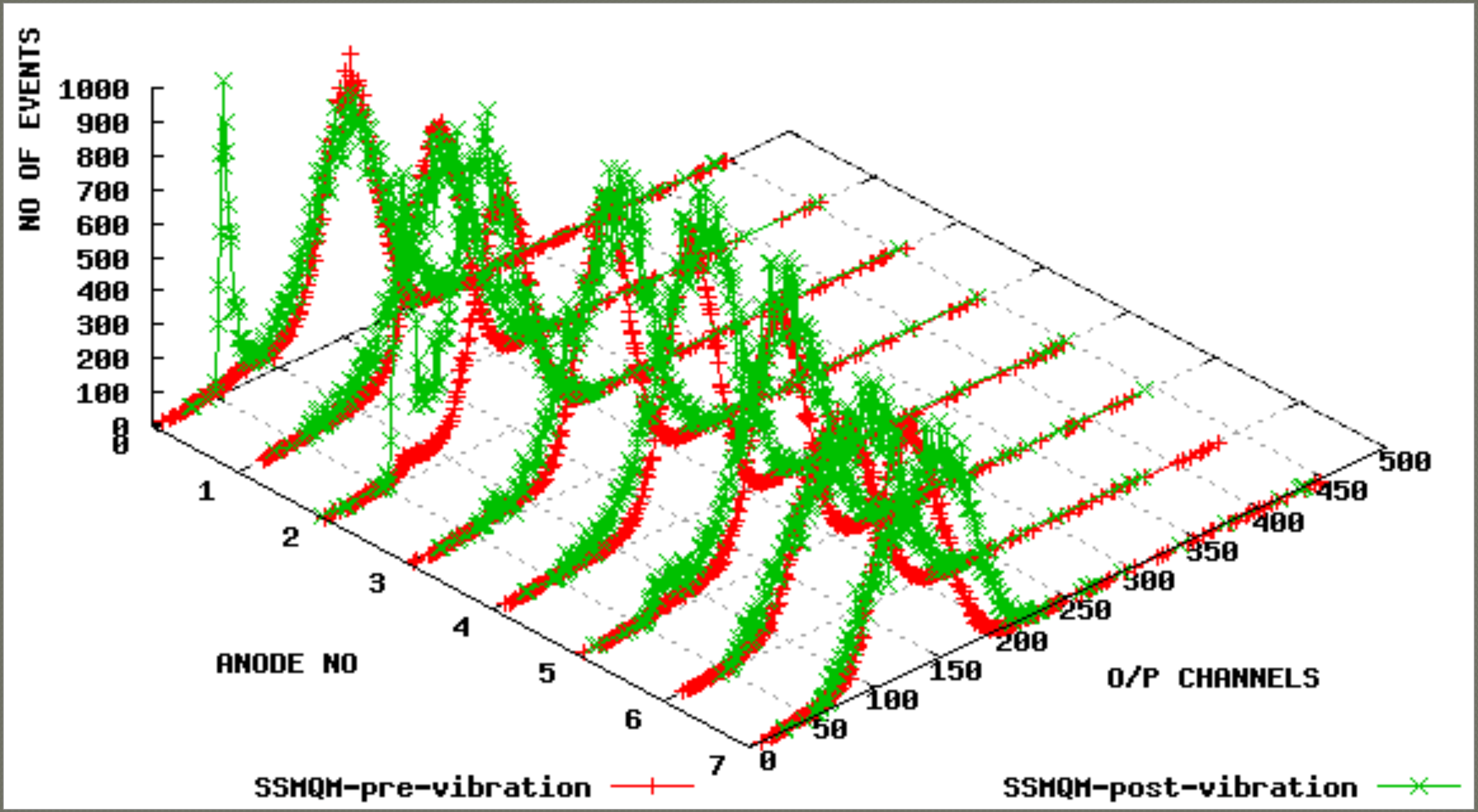


Detector: Position Sensitive Proportional Counter

Electronics : CSPAs + FE + PE

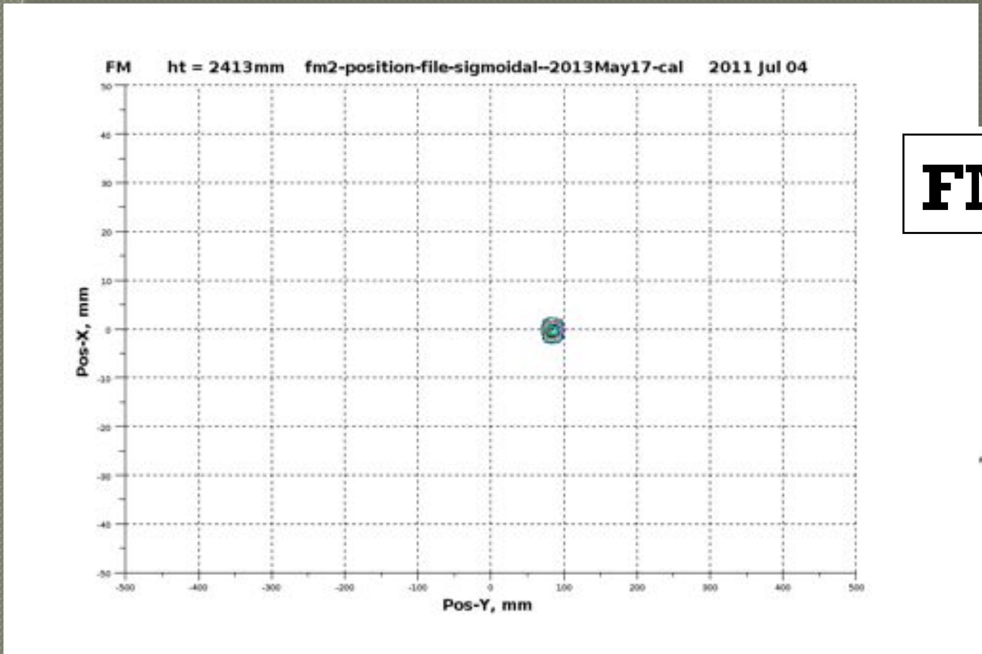
Coded Mask: 1D

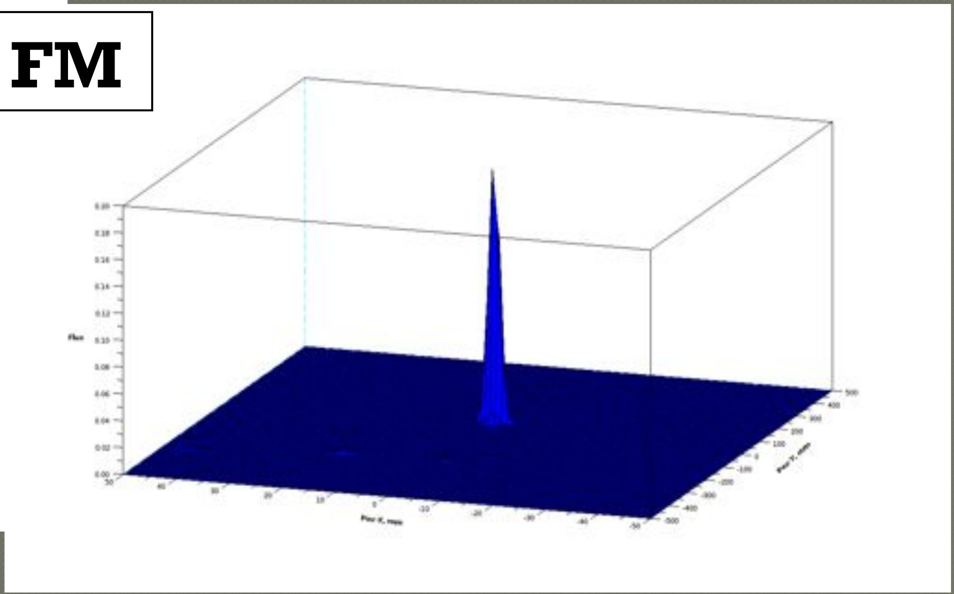
Pre-and-post vibration results (QM)



Total o/p of all the anodes pre (red points) and post vibration (green points)

Results of Imaging





The above are the contour and surface plots of the source plane image showing a single peak at the center of the FOV. This is from one of the FM detectors (now, FM spare)

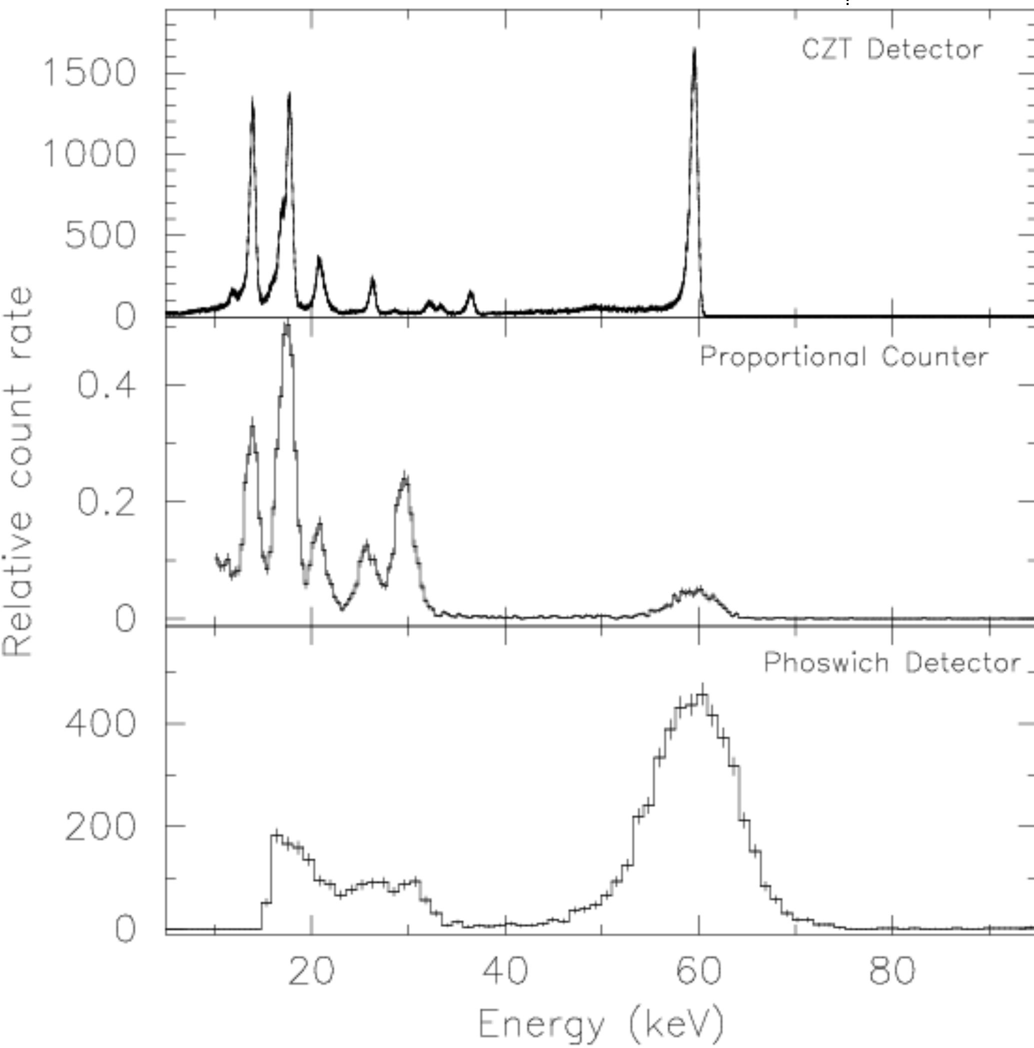
Major scientific investigations planned

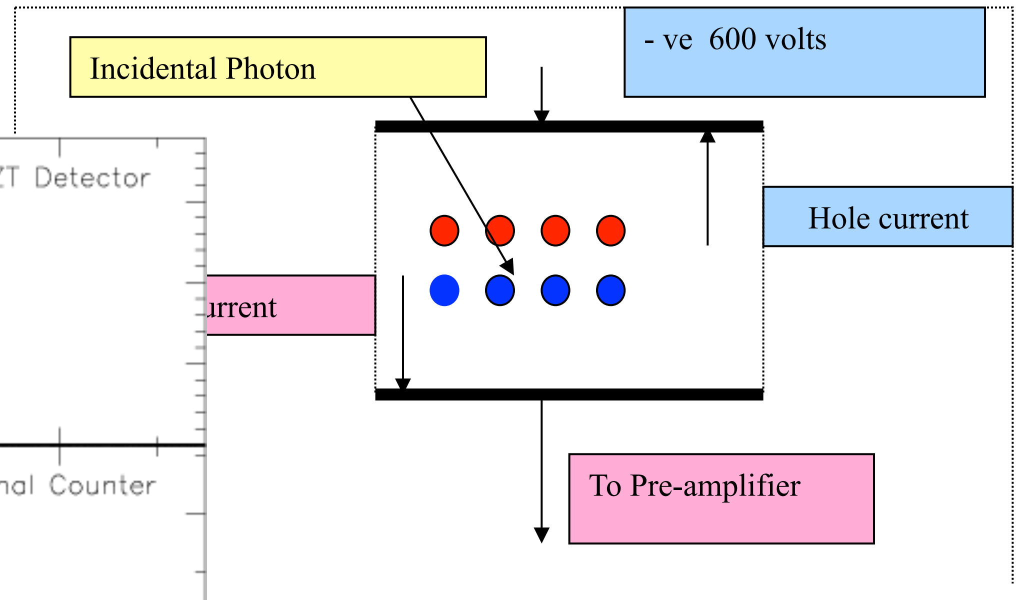
- Correlated intensity variation studies across visible, UV, soft and hard X-ray bands to address the origin of radiation
- Study magnetic fields of neutron stars (NS)
- Search for black hole (BH) sources
- Probe immediate environments of BH (including supermassive ones) & NS
- Discover new X-ray sources
- Probe the farthest regions of the UV Universe

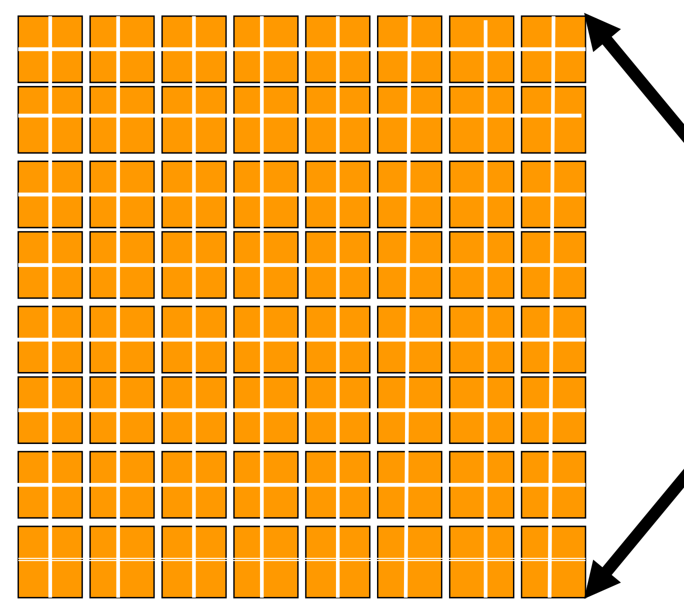
Cadmium Zinc Telluride Imager (CZTI)

(10 – 100 keV)

CZT Imager on ASTROSAT





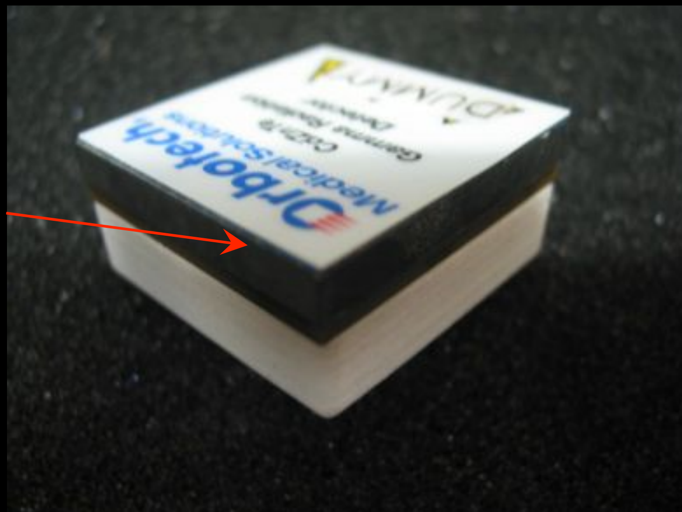


16 X 16 CZT PIXEL ARRAY

CZT Detector

4 cm X 4 cm

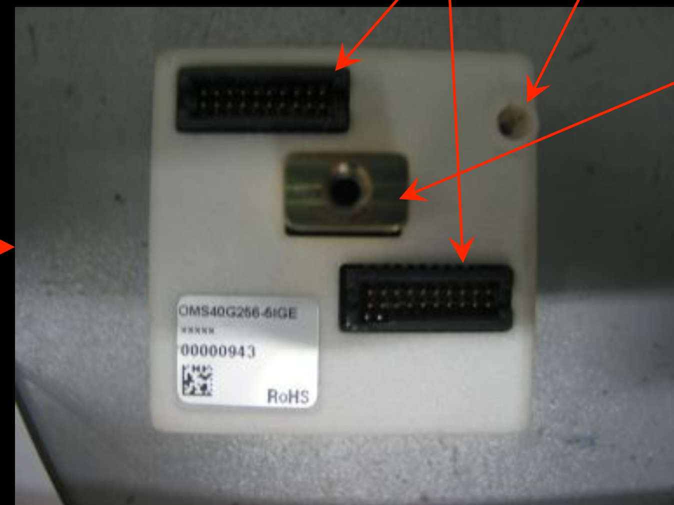
CZT crystal

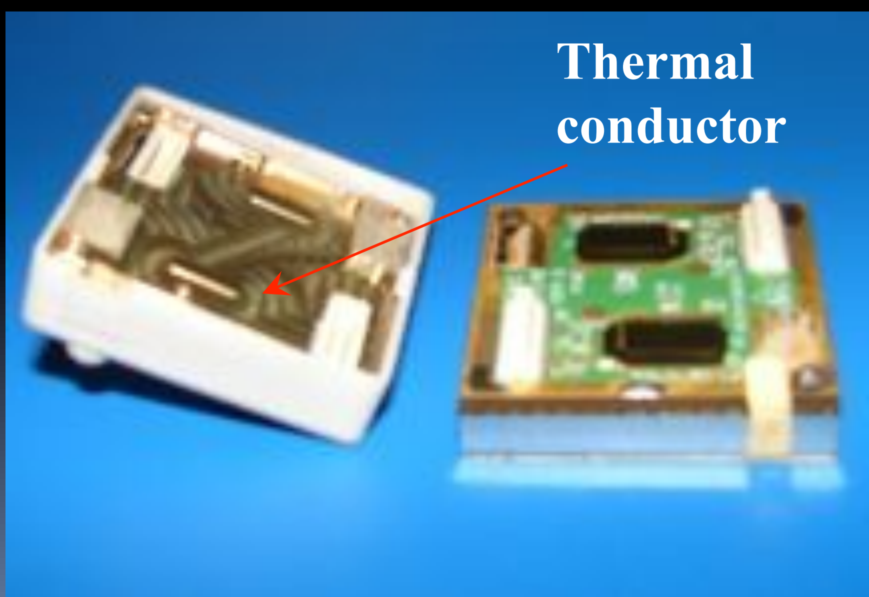


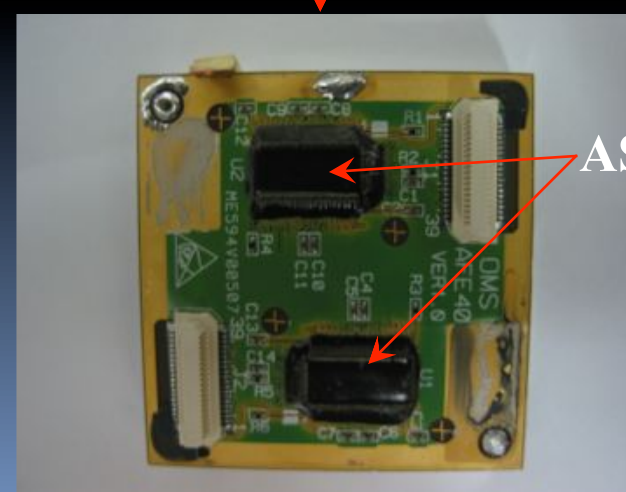
Connectors

HV Connector

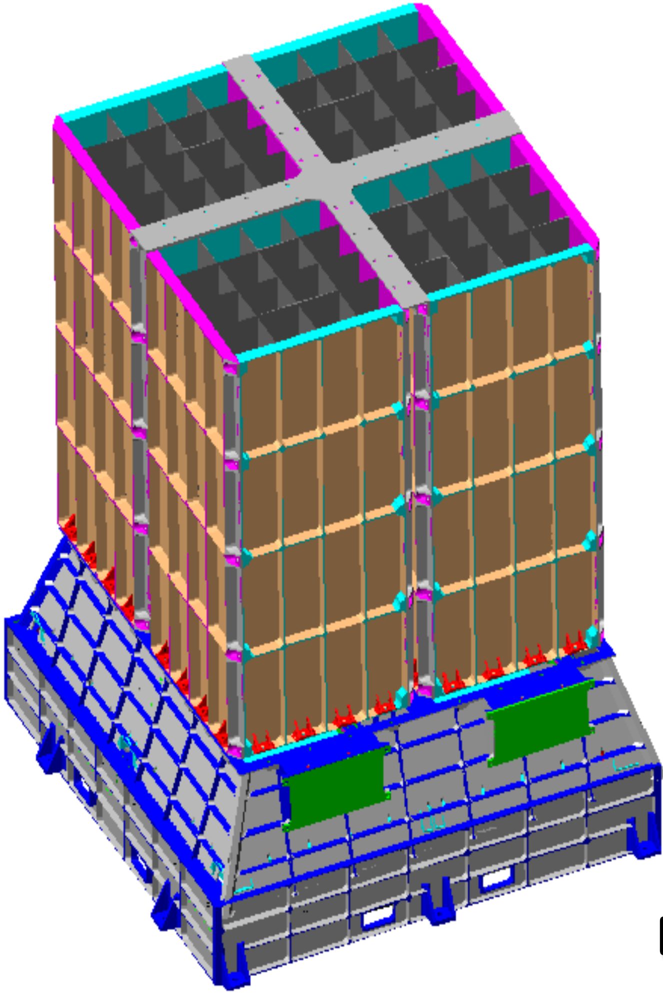
Thermal conductor



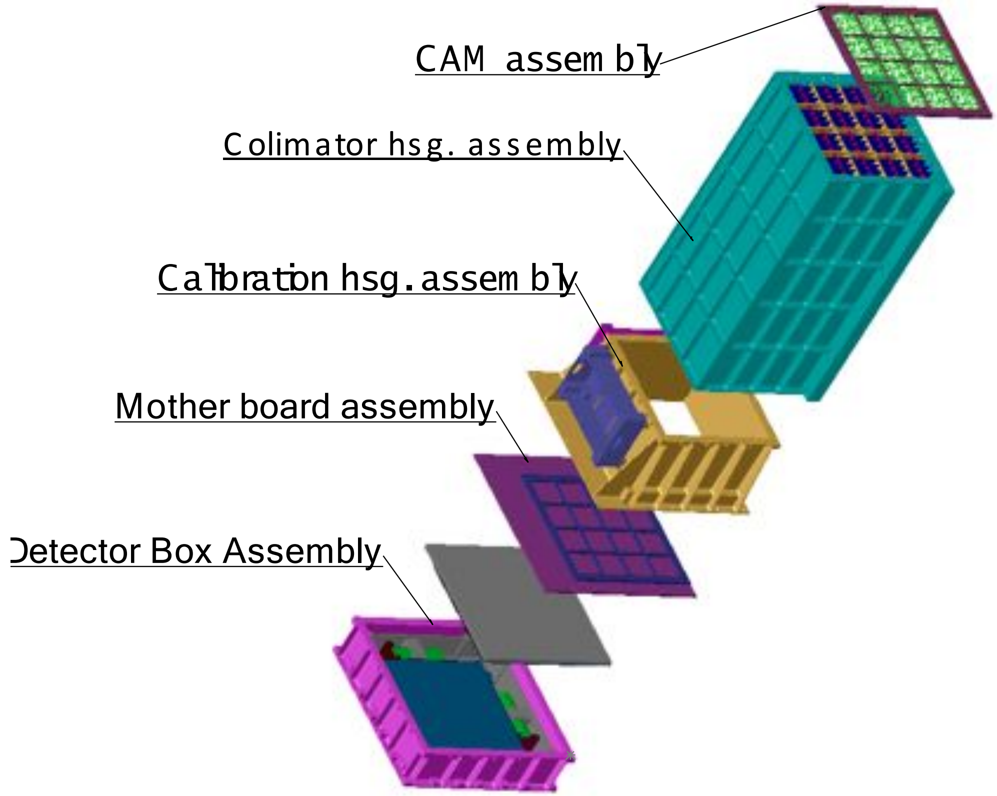




ASIC



Details of a Quadrant



Four Independent Quadrants of Detector

Size - 484 x 484 x 600 mm

Power- 50 Watts

Weight - 50 K gm

Collimators - 6 x 6 Degree, 17 x 17 Degree

Graded Shield Material – Tantalum + Aluminum (For Passive shielding)

Assembled CZT-Imager (Qualification Model)

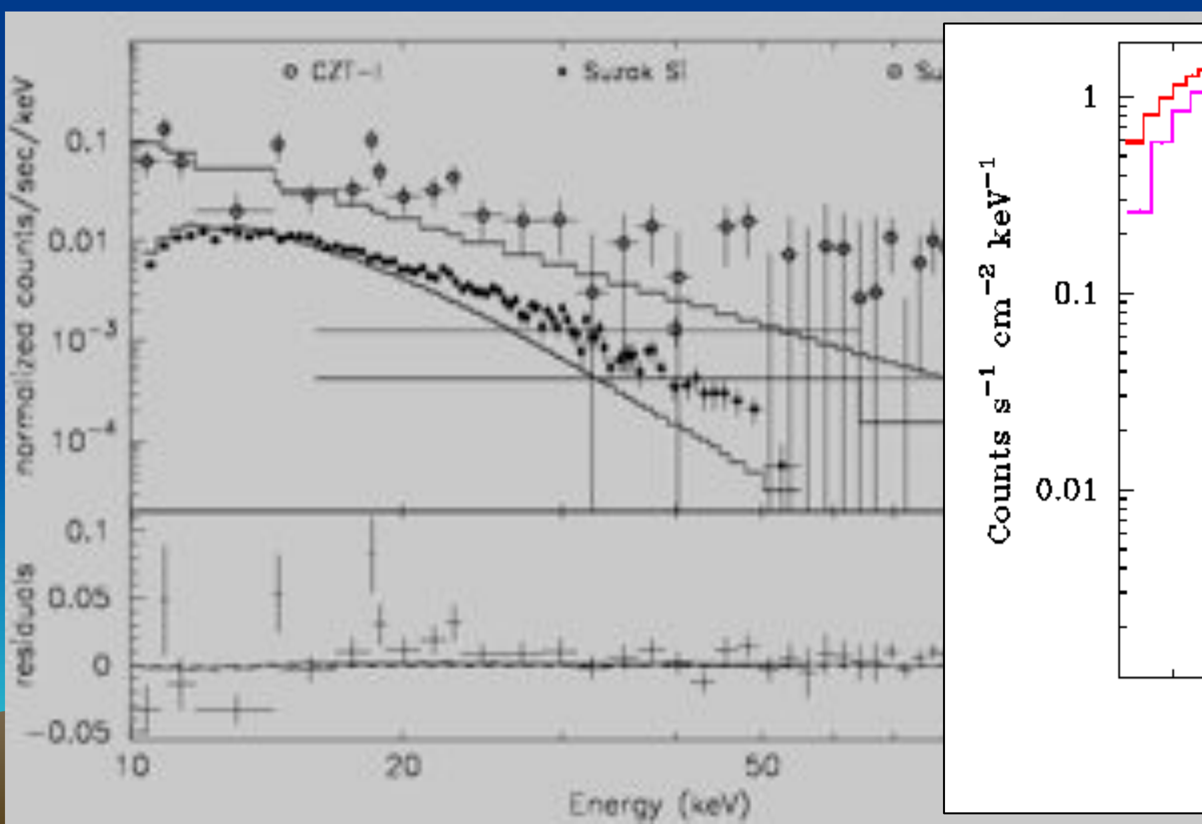
Energy Resolution:

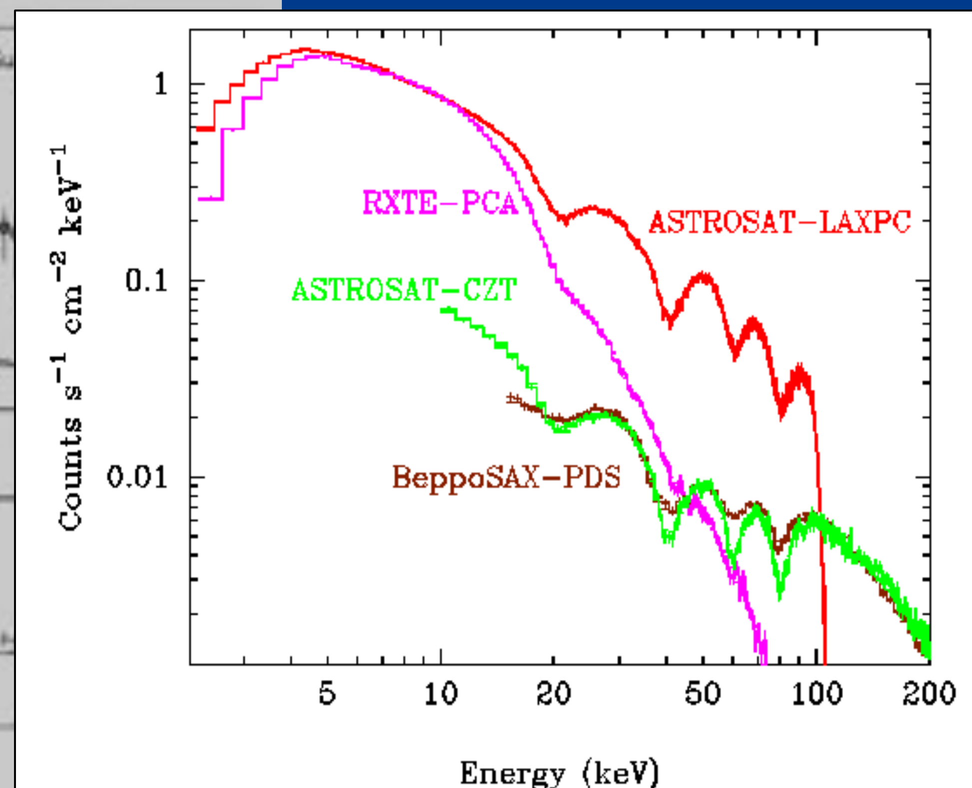
- Proposal: 5%@ 60 keV (attempt for 3%)
- PDR: 5%@60 keV (tests ~7%)
- RT-2/Exe. Sum.: 5%@100 keV (~9%@60 keV)
- QM: 10 – 11%@60 keV;   6-7% @122 keV
  (room temperature)
- 9.0+/-0.5 %@ 60 keV; 5+/-0.5% @122 keV
  (operating temp : 0 – 15 C)

Implications

AGN: Faint Source
No Impact
(~90% of obs)

Pulsars
Critical observations
(Some Impact)



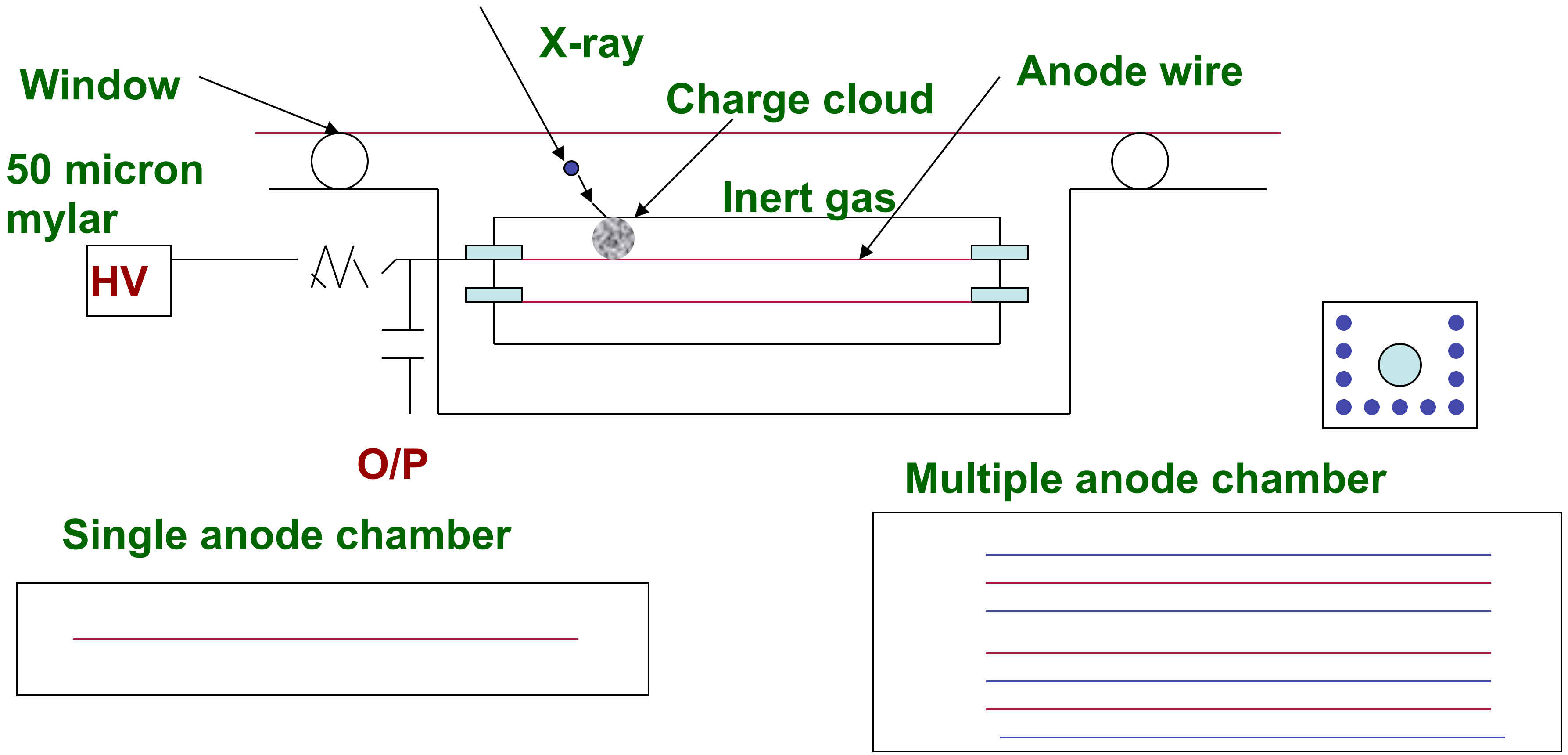


Large Area X-ray Proportional Counter (LAXPC)

(3 – 80 keV)

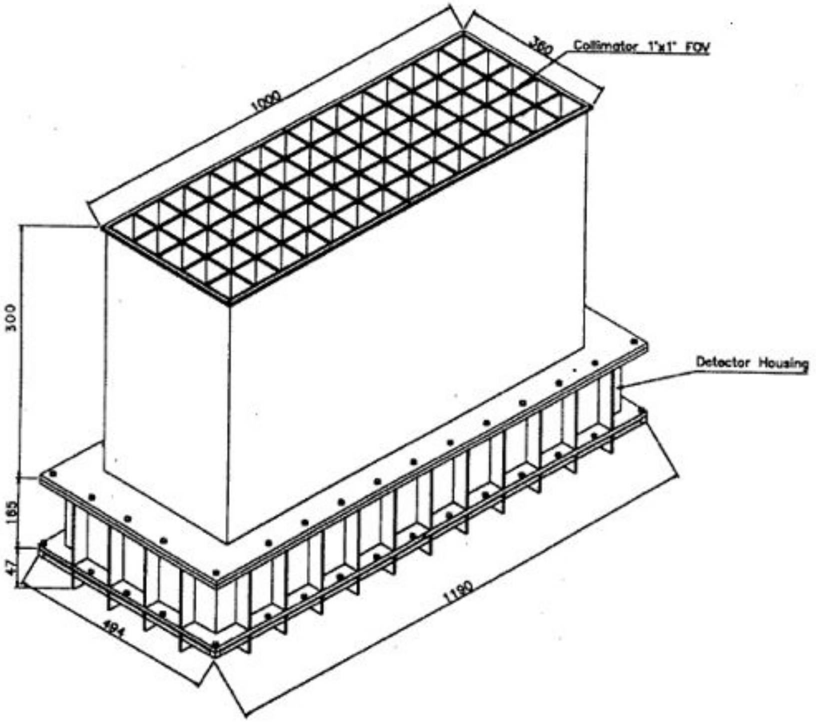
LAXPC on ASTROSAT

- Large Area gas filled proportional counters
- Multiwire, multi layer counter



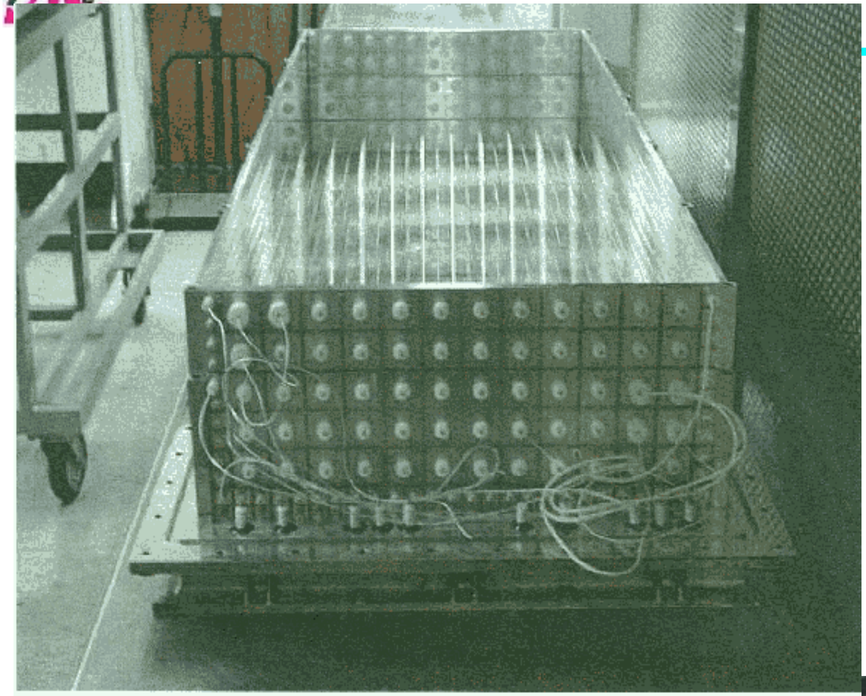
LAXPC : brief description

The X-ray detection volume consists of 60 anode cells of 3.0 cm x 3.0 cm cross-section arranged in 5 layers and surrounded on 3 sides with veto layers

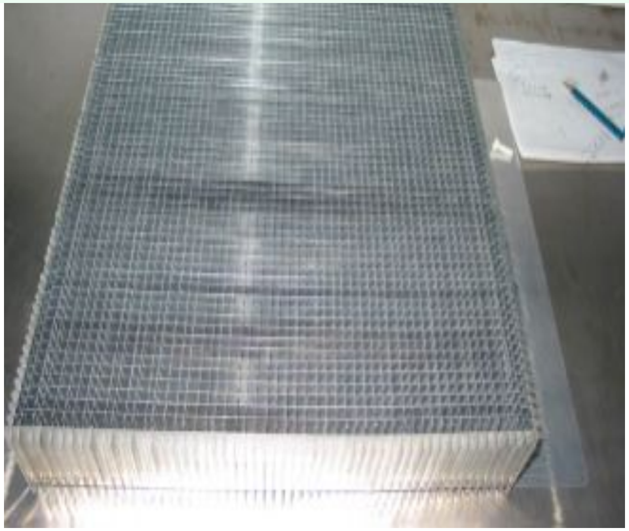


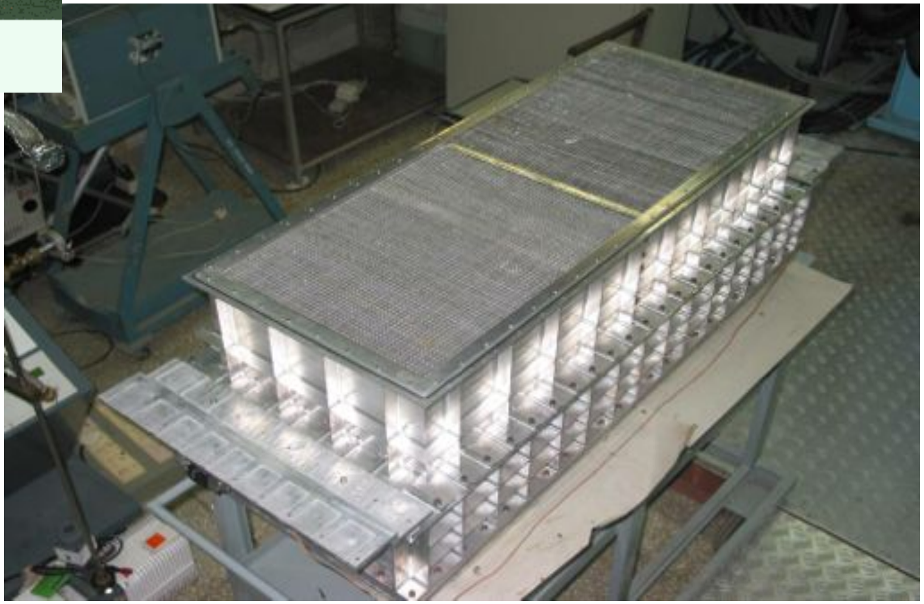
Weight 395 kg

LAXPC on ASTROSAT



A view of the LAXPC wired Anode Assembly

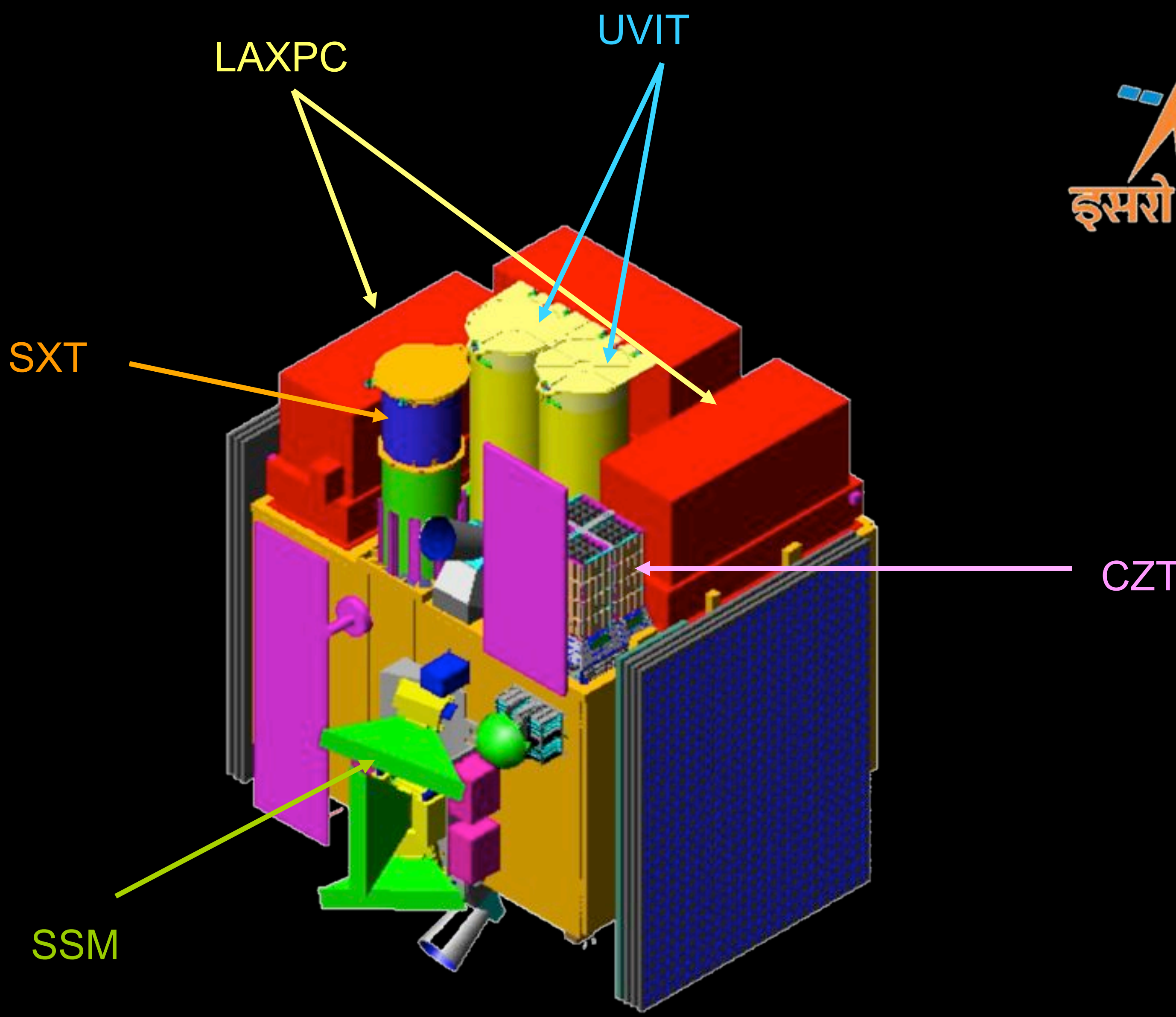




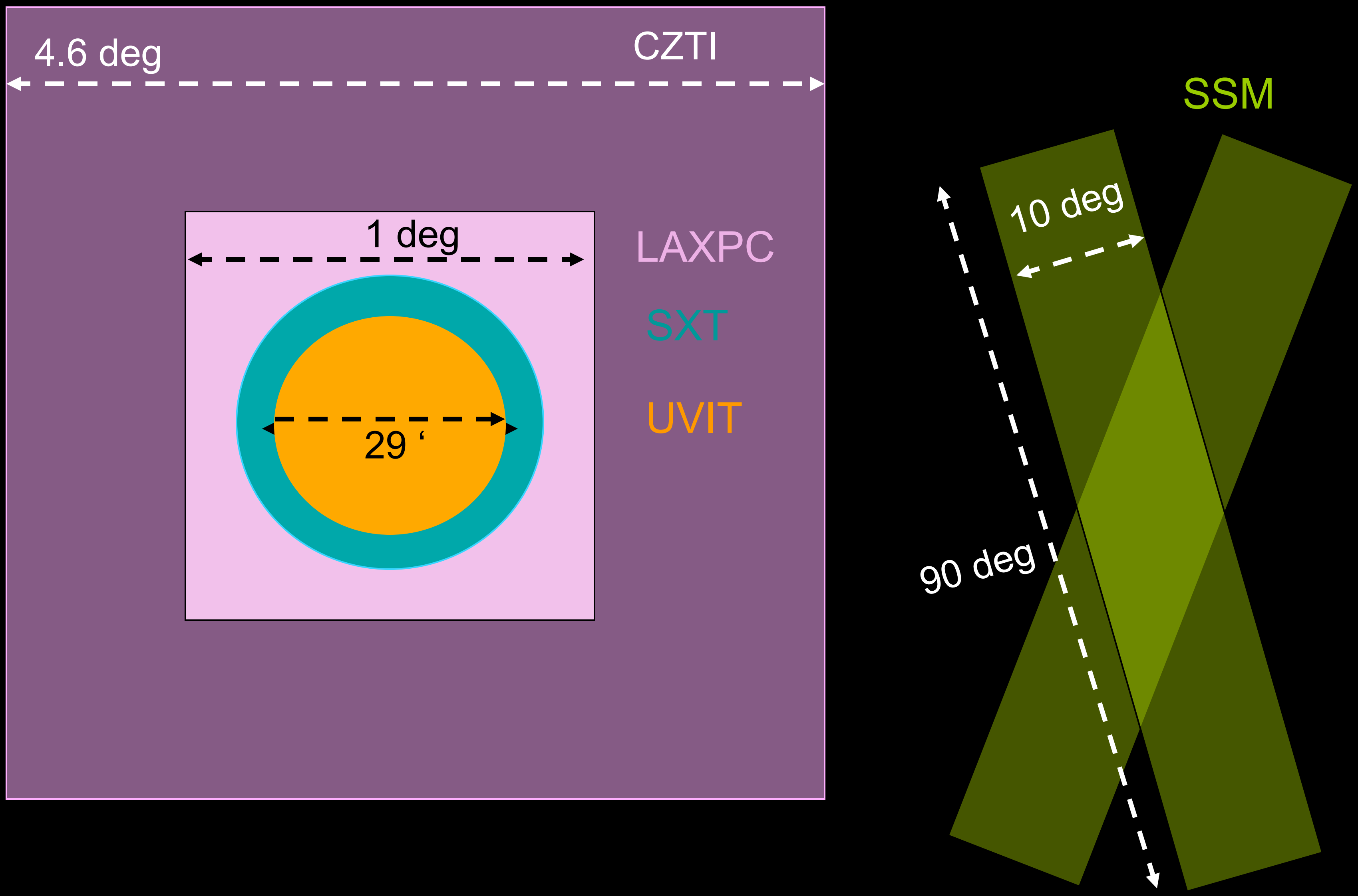
	Energy range	Description	Angular resolution	sensitivity
SXT	0.3 – 8 keV	Focussing X-ray mirror + CCD (39 shells) FOV=42’	3 – 4 arcmin	~0.01milliCrab (10,000 sec)
LAXPC	3 – 80 keV	Large proportional counters (3)	~5arcmin (scan mode)	0.1 milliCrab (1000 sec)
CZT-imager	10 – 100 keV	CZT array (hard X-ray imager)	8 arcmin	0.5 milliCrab (1000 sec)
SSM	2 – 10 keV	All sky monitor (3) on a boom	5 – 10 arcmin	30 milliCrab (300 sec)
UVIT	1300 – 3000 Ang	Twin RC telescopes – 40 cm each (NUV, FUV)	1 arc sec	20 magnitude (1000 sec)

ASTROSAT: specific capabilities

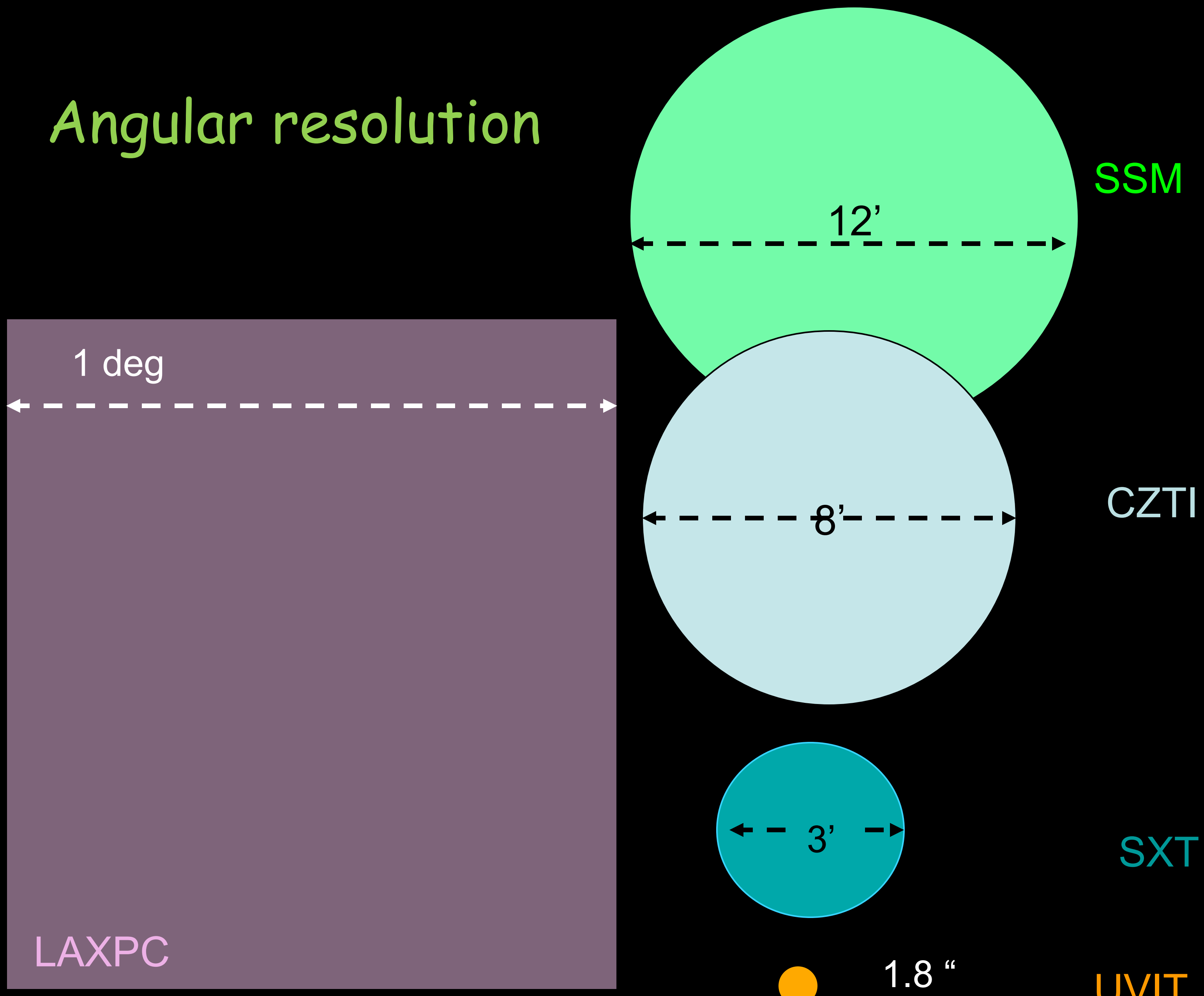
- Simultaneous multi-wavelength observations using single satellite covering optical, UV, low and high energy x-rays
- Highest angular resolution UV imager to date.


LAXPC
UVIT
SXT
CZT
SSM

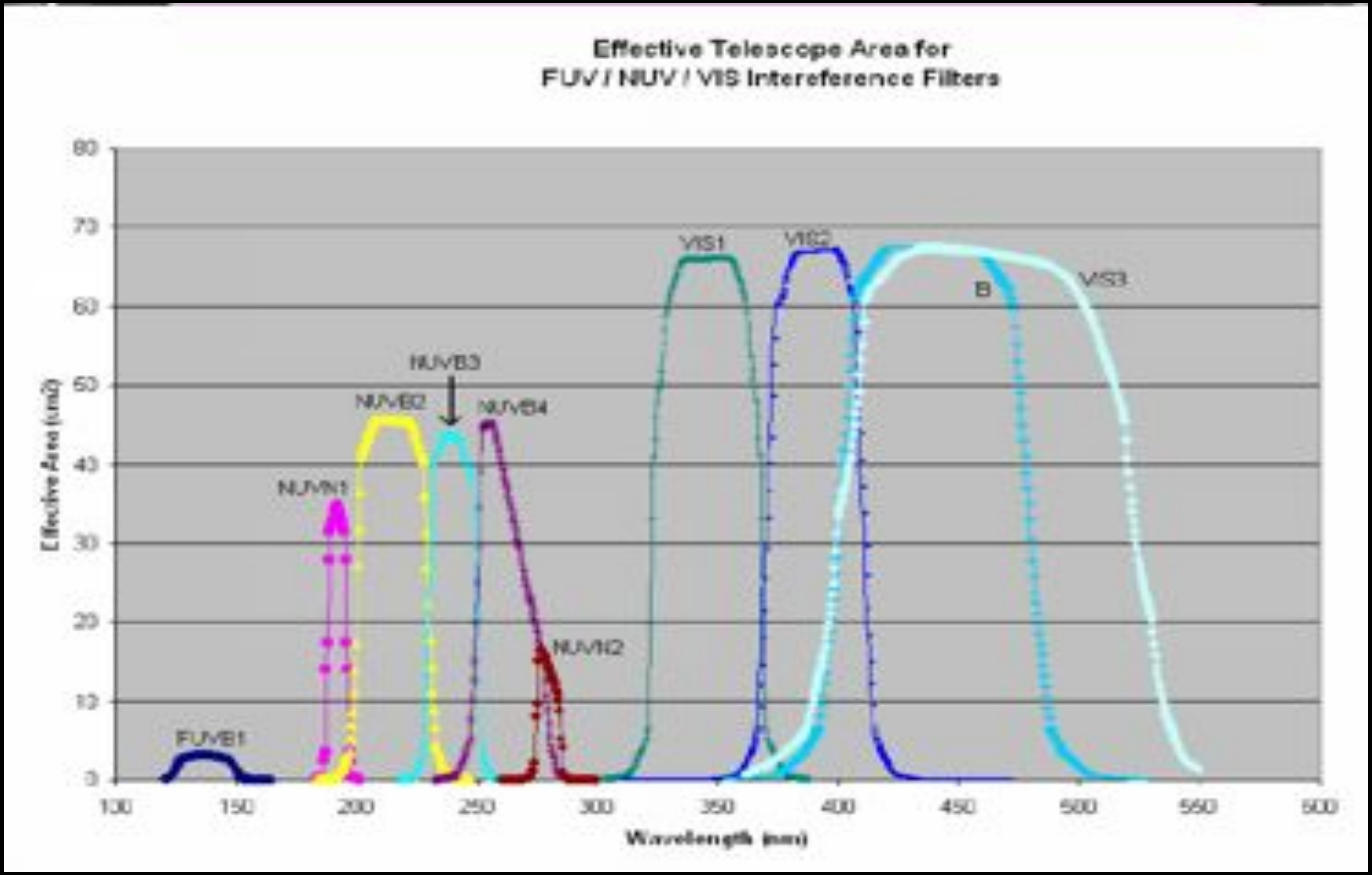
Instrument FOVs



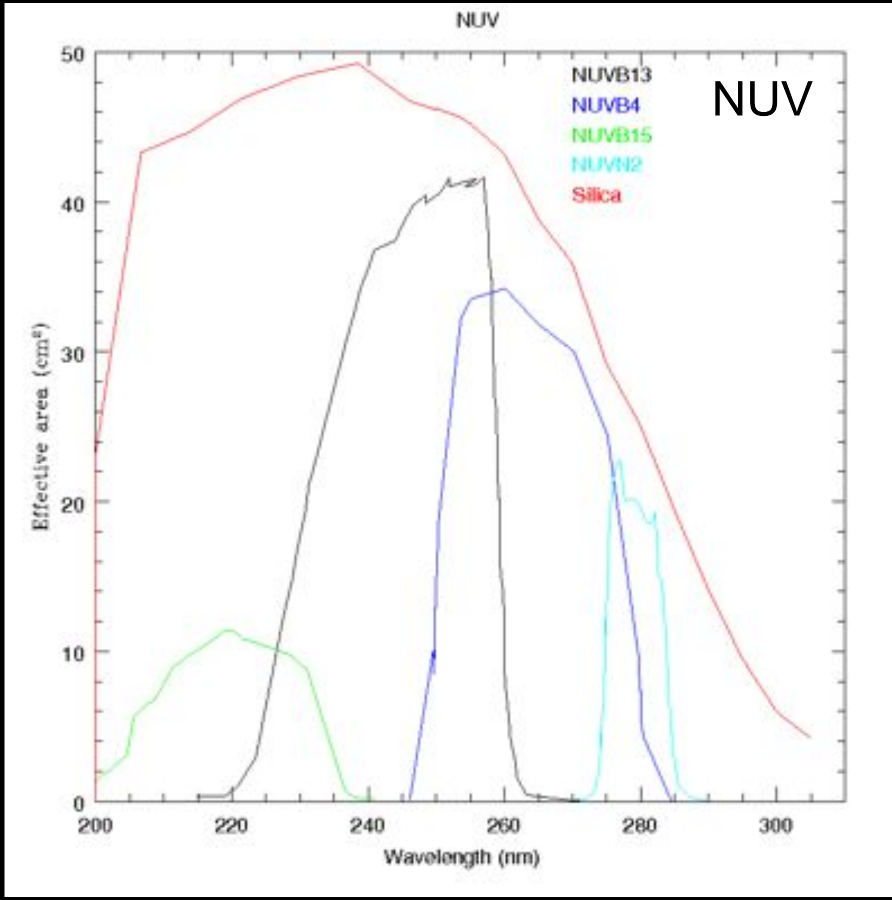
Angular resolution

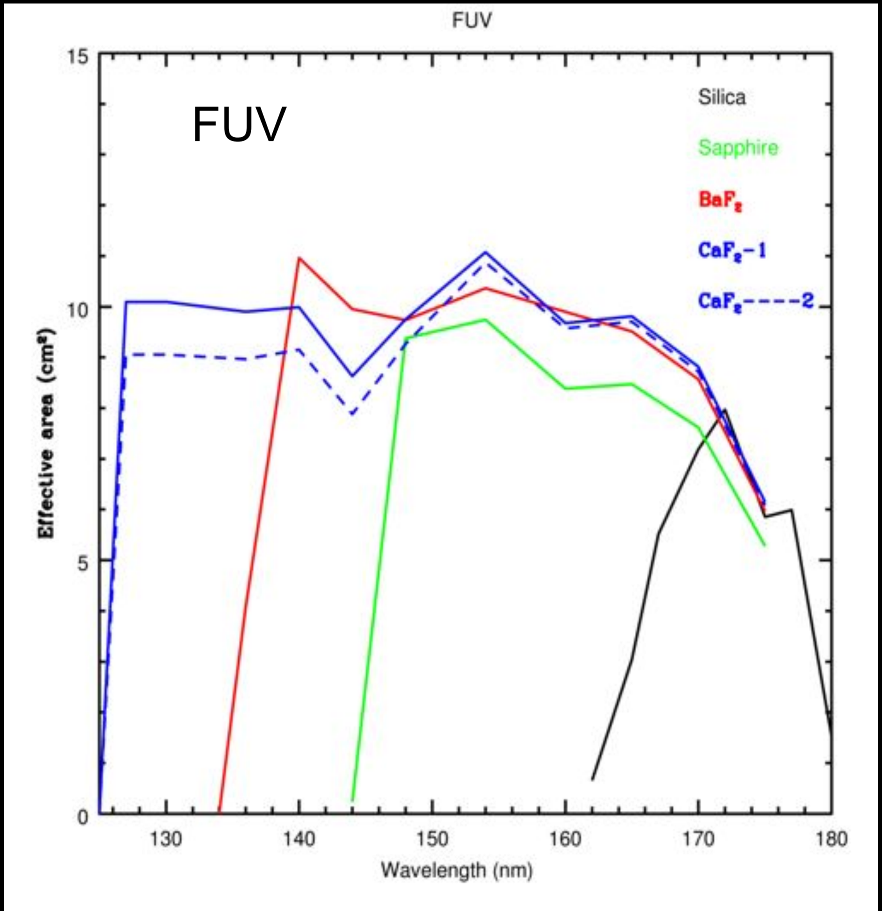


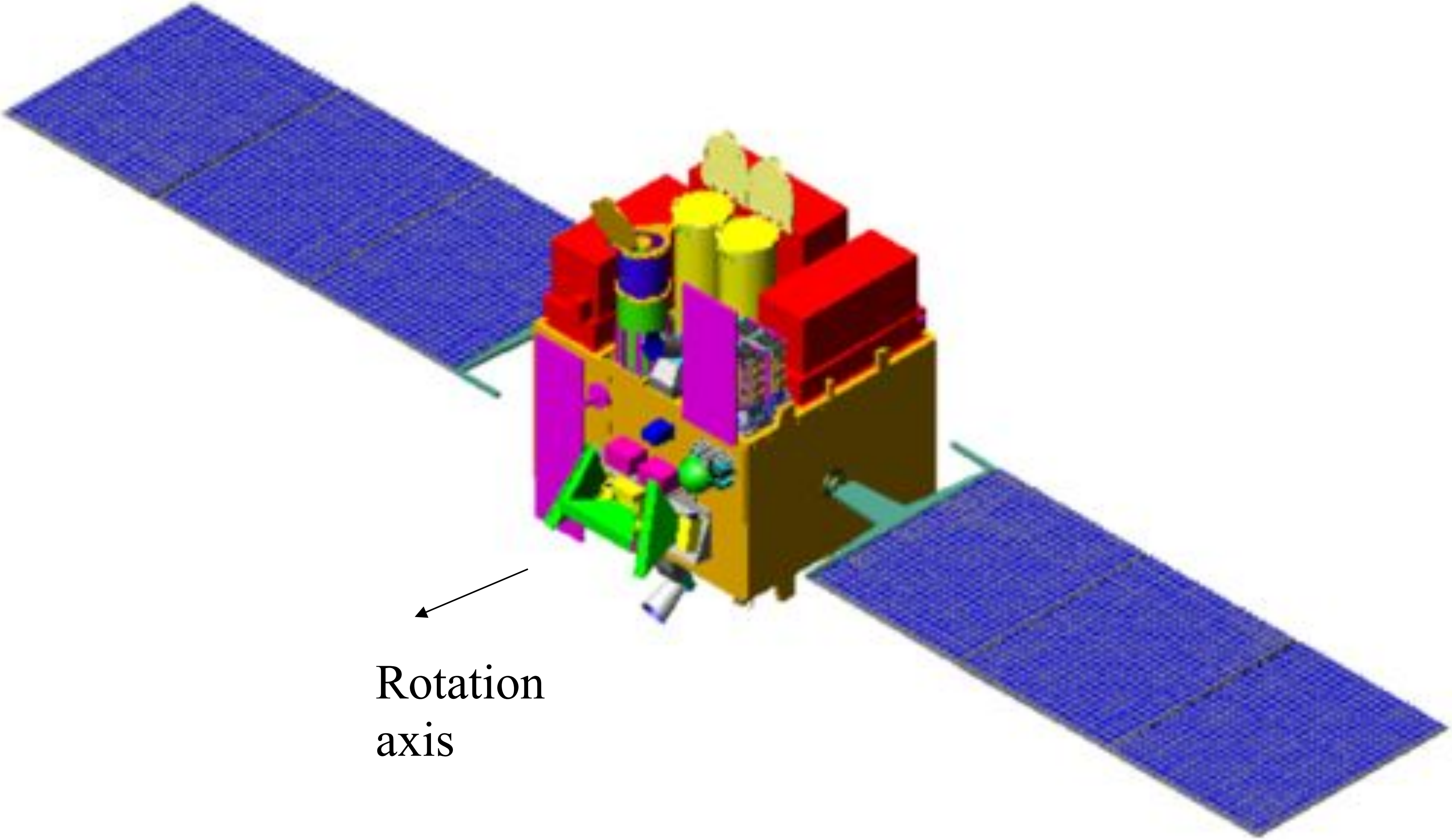
UVIT filters



Effective area of UVIT channels

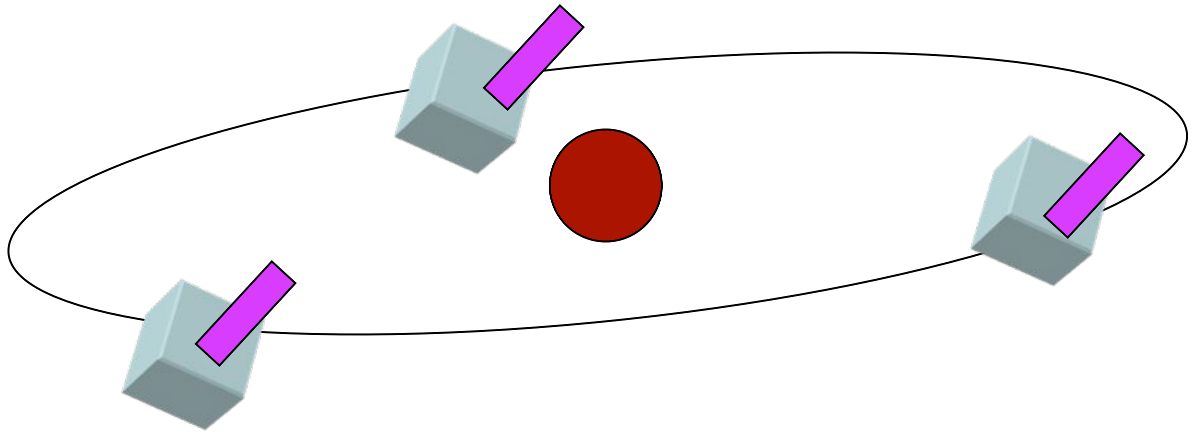





Rotation
axis

ASTROSAT Mission

- Altitude : 650 km
- Inclination : 8 deg.
- Mass : 1500 kg. (780 kg. Payloads)
- Power : 940 watts
- PSLV launch
- Operational life of minimum 5 years



Inertial pointing with nearly equatorial orbit

Earth occultation , SAA passage

ASTROSAT : challenges

- Platform pointing accuracy
- Contamination control
- Re-orient to any part of the sky
- Soft-x-ray telescope mirror fabrication
- Boom-mounted rotation of SSM
- UVIT optics, structure, calibration
- Total ASTROSAT science data management

Science from ASTROSAT

Processes producing optical, UV and X-ray photons

- Black body radiation
- Atomic transitions- Lines (Absorption/Emission)
- Fluorescence
- Bremsstrahlung
- Synchrotron
- Cyclotron features
- Inverse Compton

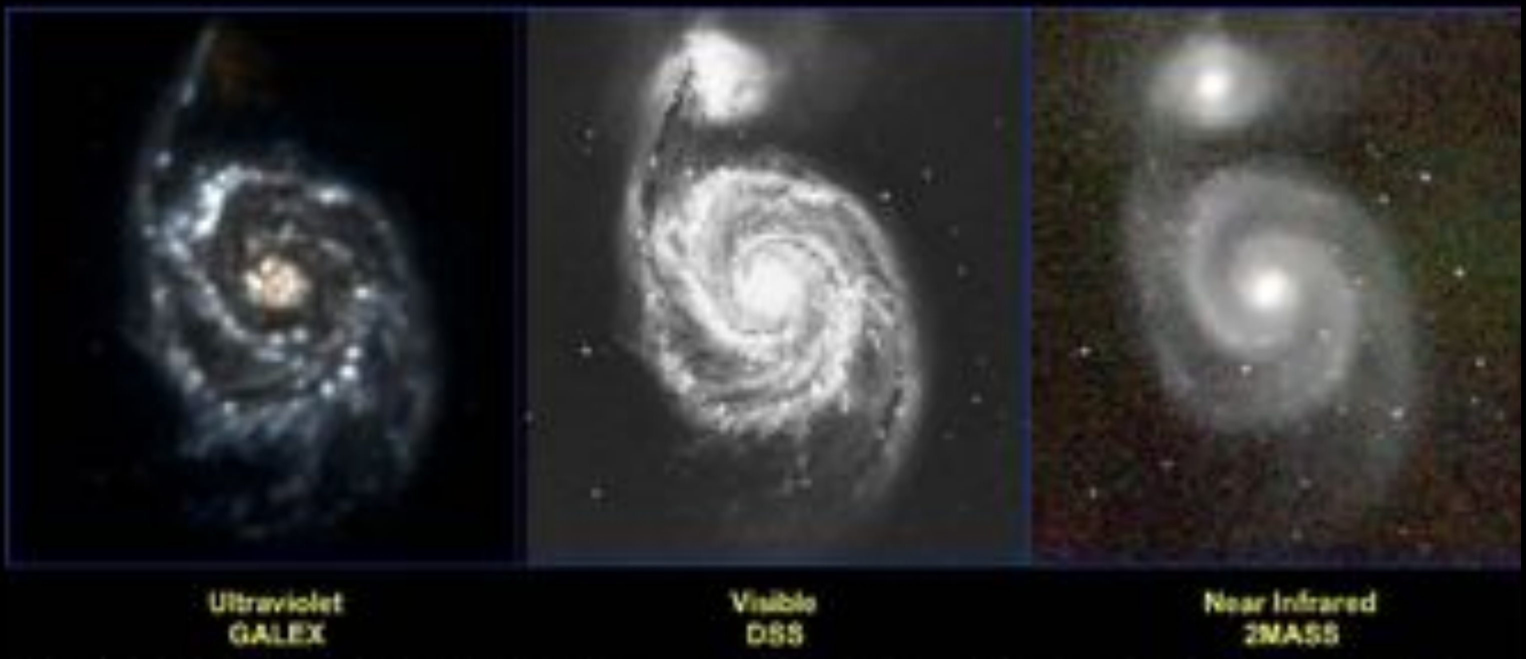
ASTROSAT observational capabilities

- **Timing**
  - **High resolution (ms to microsec) timing studies- long observations**
    - Temporal variability across bands – correlation / anti-correlation
    - Detection of new Accreting ms Binaries.
    - Quasi periodic oscillations
    - X-ray transient detection

- **Imaging**
  - **High resolution imaging (~2 arc sec) in UV and moderate (few arcmin) imaging in soft X-rays**
    - emission nebulae and supernova remnants
    - Hot stars in nearby galaxies; UV Morphology of galaxies;
    - Deep surveys of specific regions down to 20th mag in UV (sp. bands)

- **Spectral**
  - **Broadband spectral and timing studies**
    - Continuum emission from all classes of UV and X-ray sources.
    - Thermal and non-thermal emission;
    - Detection and profiles of Cyclotron Features

M51 seen in three bands



UVIT on ASTROSAT will produce the highest angular resolution images in UV. It has an angular resolution 3-4 times better than GALEX

Study of Star-formation rates & Galaxy Luminosity function

$\text{SFR } (M_{\bullet}\ yr^{-1}) = 1.4 \times 10^{-28}\ L_{FUV}(\text{ergs } s^{-1}\ Hz^{-1})$ (Kennicutt 1998)

- SFR declines rapidly from about z~1 by nearly a factor of 5 (Madau et al 1996, Schiminovich et al 2005) – maybe linked with the strong decline in UV-luminous galaxies with time.
- SFR shifts from high stellar mass systems at high z to low stellar mass systems at low z (downsizing)
- Combined studies on clustering properties of UV-luminous galaxies using ASTROSAT & SDSS/2dFGRS data – can address spatial distribution of star formation in the Universe from high z to low z.(Heinis et al astroph 7Jun 2007)
- Study dependence of UV luminosity on other galaxy characteristics
  - Color
  - surface brightness
  - Environment
  - Metallicity
  - stellar mass

Galaxy luminosity function

observational determination of the galaxy UV luminosity function

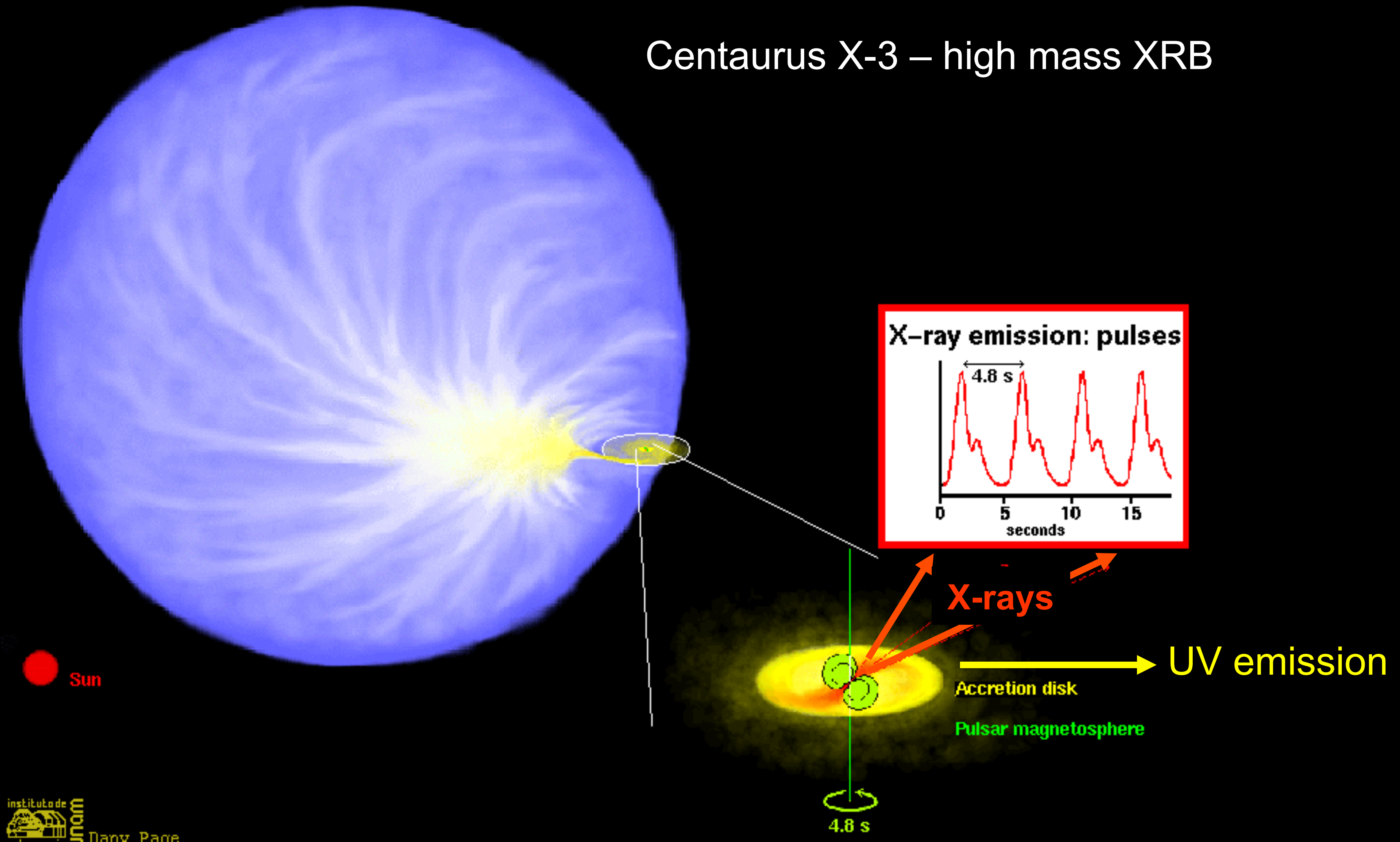
- Number counts of galaxies in two bands (FUV and NUV) provides unique, homogeneously calibrated values covering a very wide range in UV magnitude.
- GALEX data shows both the FUV and NUV counts are consistent with an evolution model (essentially luminosity evolution).
- Derive contribution to UV background (GALEX reports - 0.68 ± 0.10 nW m-2 sr-1 at 1530 Å and 0.99 ± 0.15 nW m-2 sr-1 at 2310 Å.)

Study of Galactic binary systems

inner-edge of disk ~ 10 MK or larger ➔ intense emission at X-rays
outer-edge is cooler (10,000K) ➔ emission peaks at UV energies

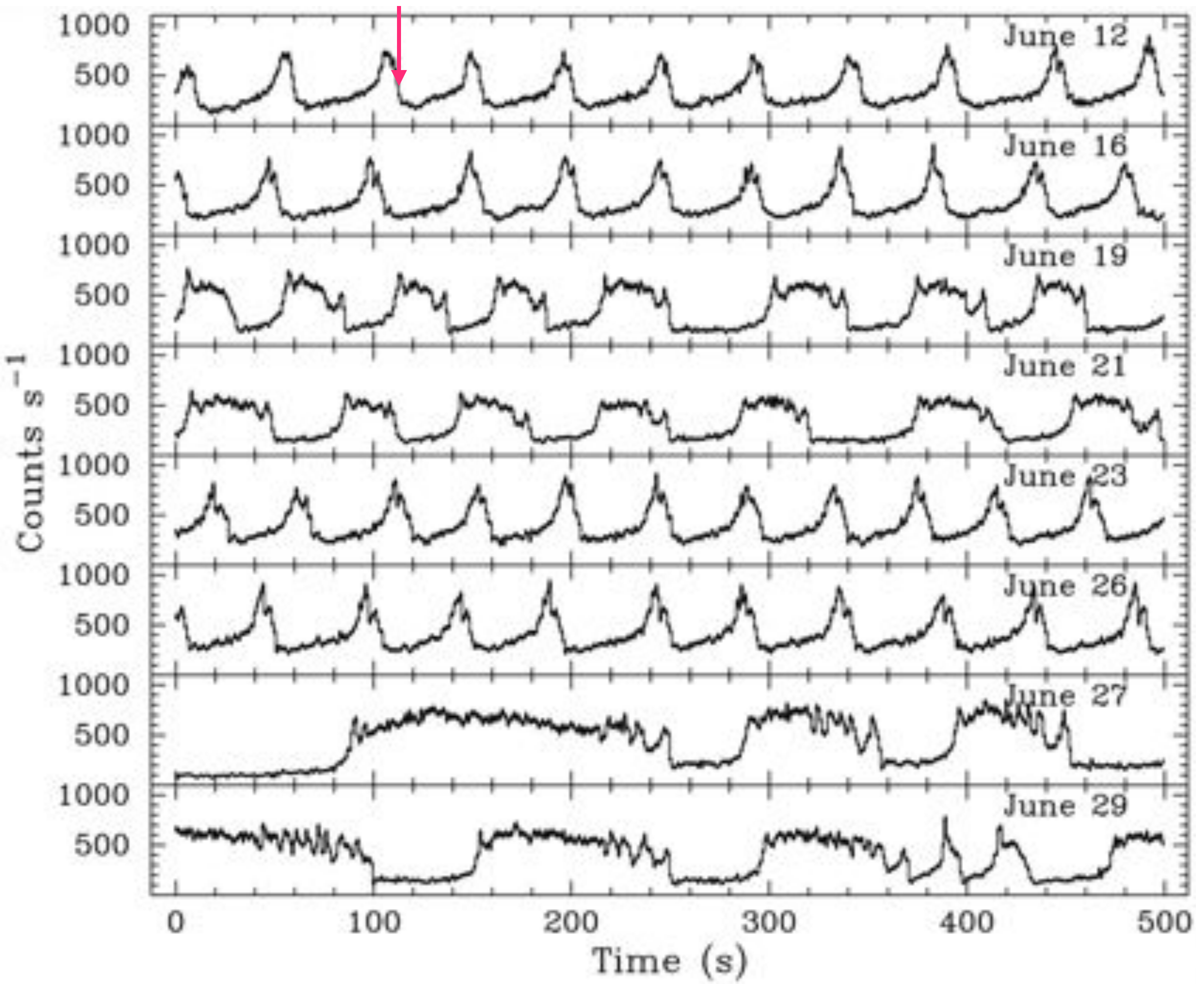
ASTROSAT has unique ability to simultaneously study these two emission

Centaurus X-3 – high mass XRB



Time profiles of emission from GRS1915+105 – IXAE data

Paul et al



Study of Galactic binary systems :

inner-edge of disk ~ 10 MK or larger ➔ intense emission at X-rays
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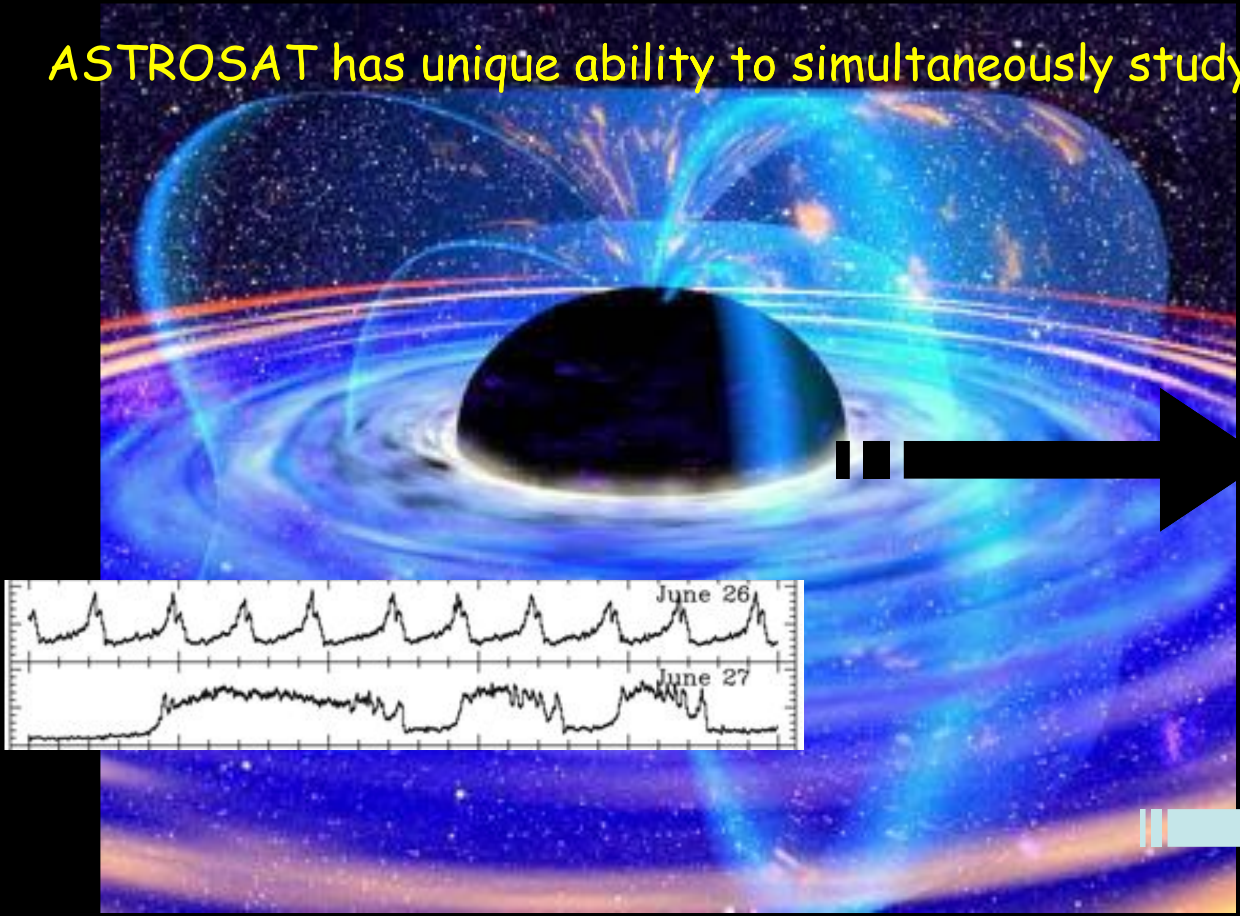
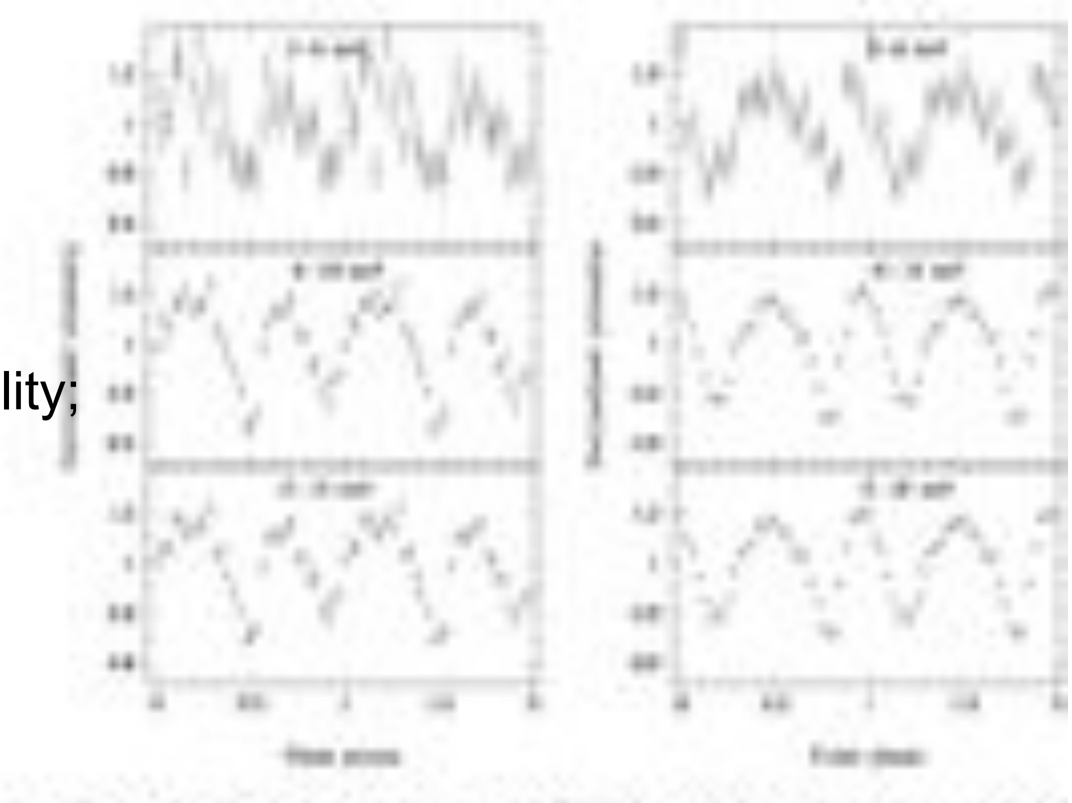


Temporal data

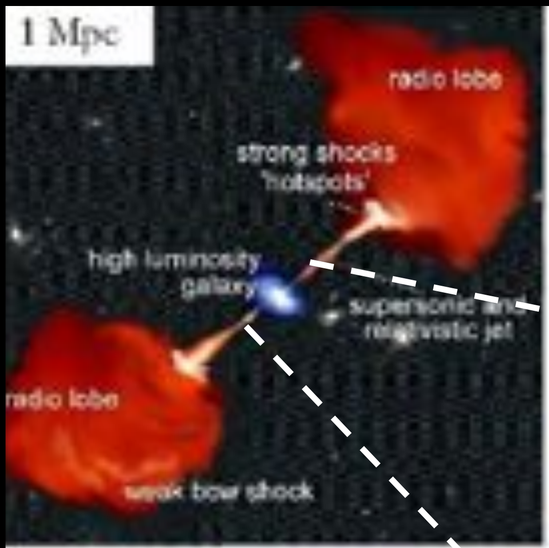
- Intensity vs. time

- Used to measure variability;
  - Rotation period;
  - Pulse arrival times;
  - Binary periods;
  - Flares Outbursts

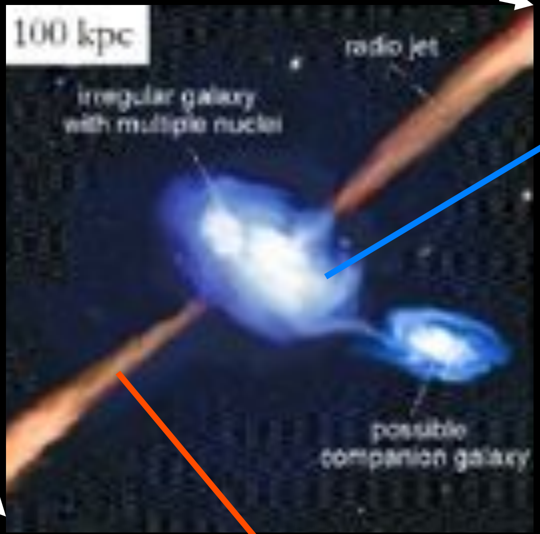


XTE J1946+271

Study of extragalactic systems: Active galactic nulei



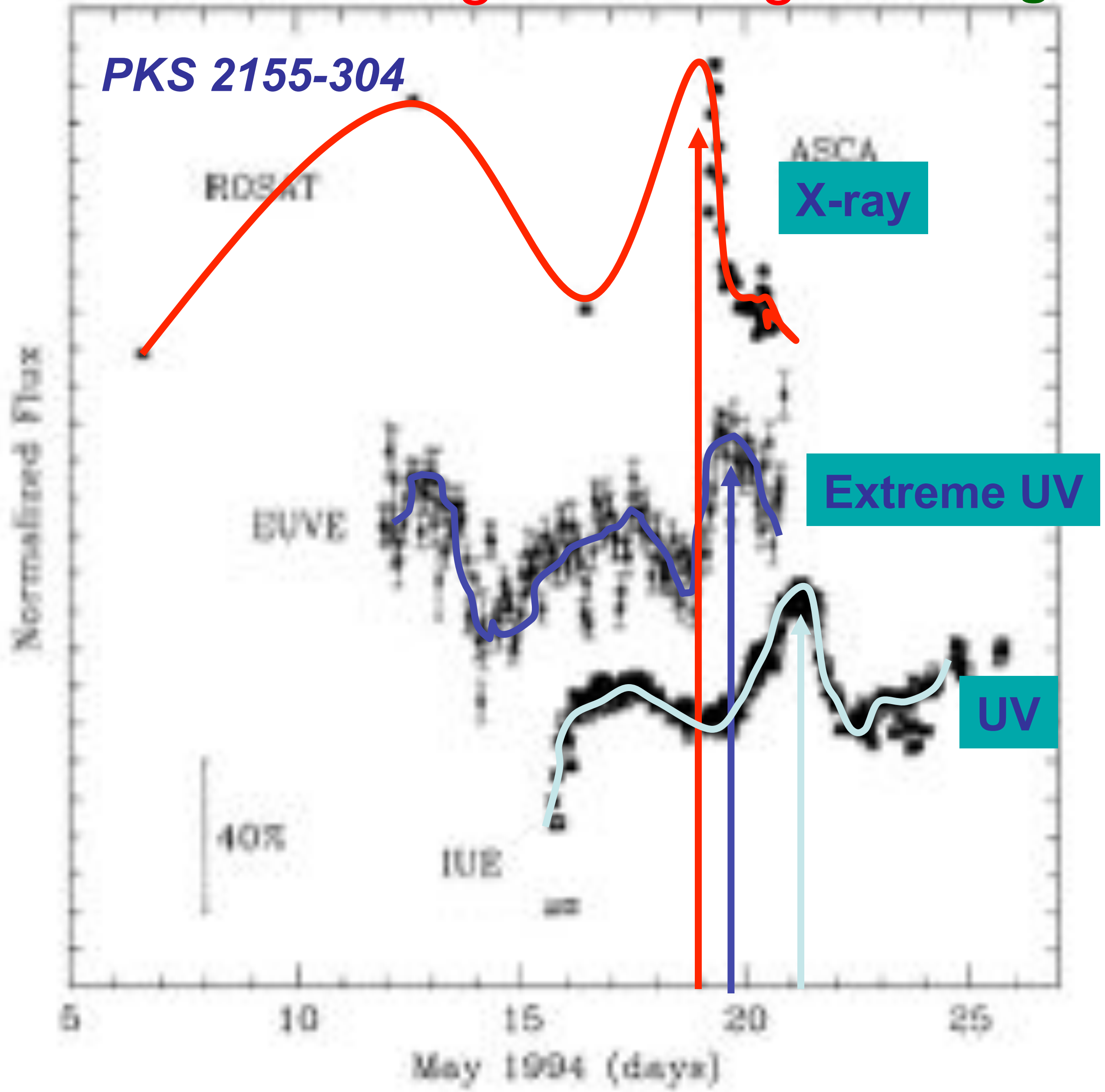
ASTROSAT has unique ability to simultaneously study these two emission



UV produced in disk

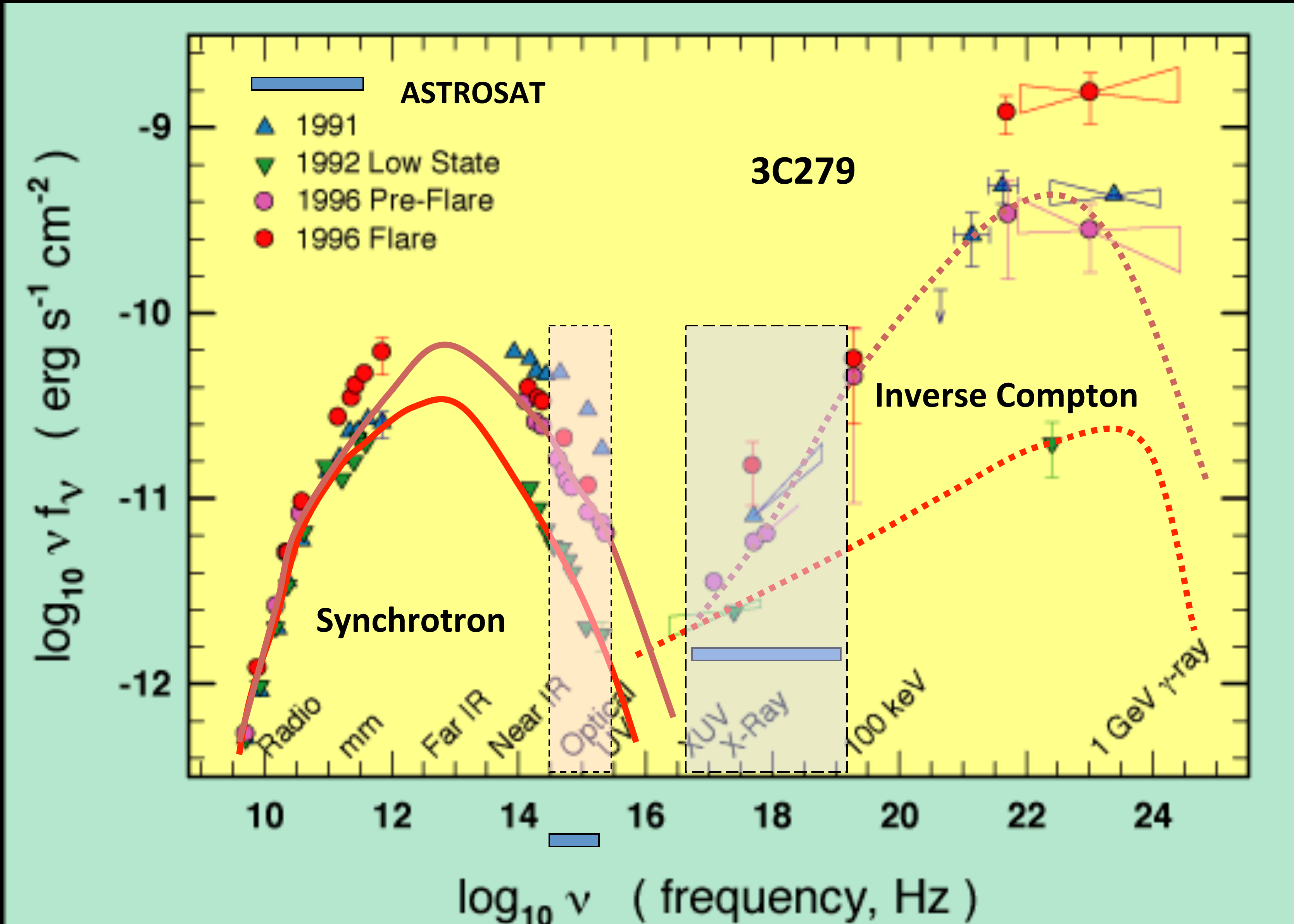
X-rays produced in jet

Simultaneous multiwavelength coverage: Timing



The x-ray outburst is delayed by hours (EUV) to days (UV) at lower frequencies

Simultaneous multiwavelength coverage: Broad-band Spectral studies

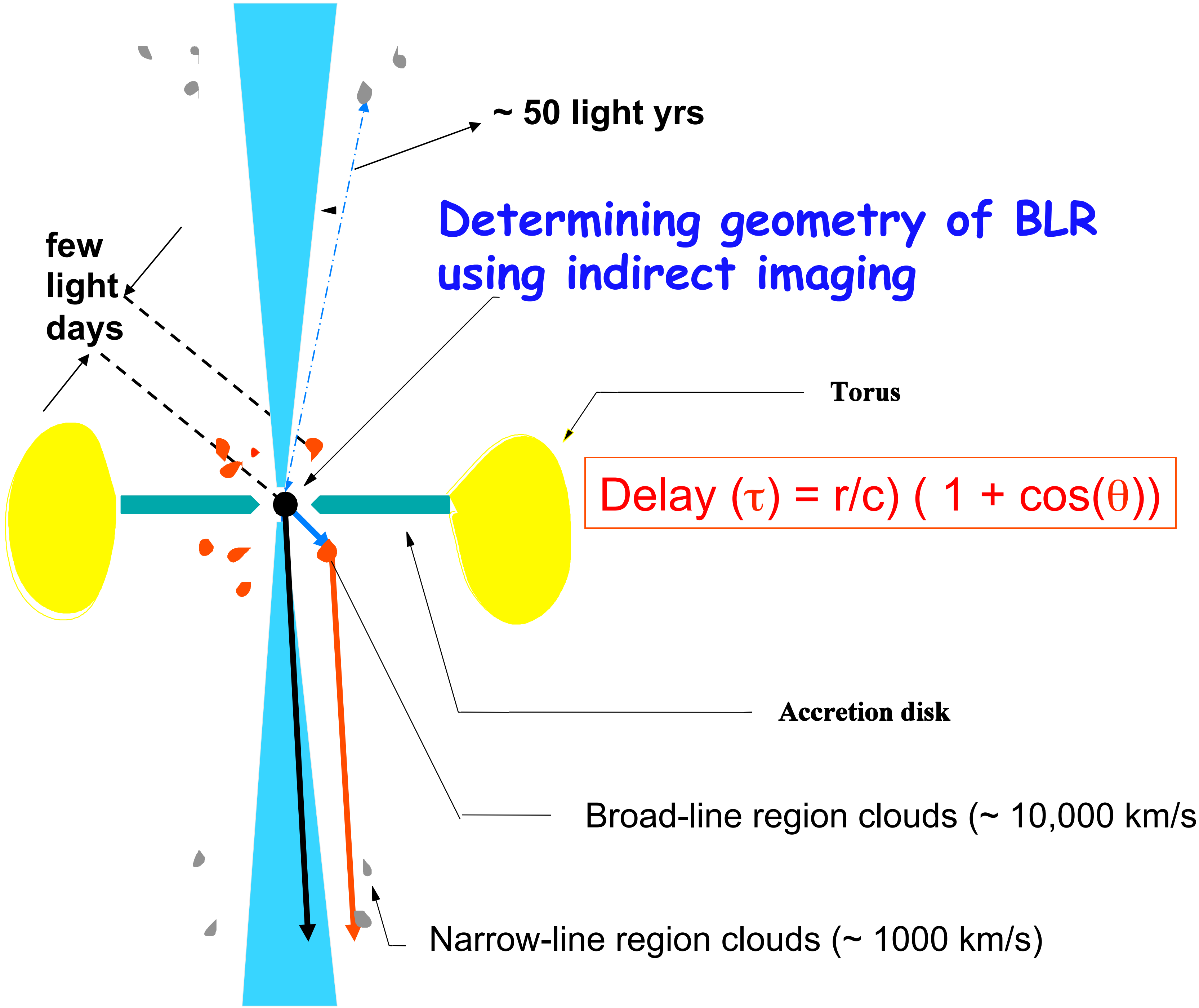


Special observations

Very Long - duration observations - weeks on a target

Determining geometry of BLR using indirect imaging

$$\text{Delay } (\tau) = r/c)\ (\ 1 + \cos(\theta))$$



Complementary data coming from current missions

- SWIFT – GRBs in FOV of ASTROSAT , simultaneous observations of hard X-ray sources
- AGILE / FERMI- SED of AGNs, Unidentified γ-sources
- GALEX – high-res survey of crowded fields

- How to maximise quality of data
  - Coordination of observations

ASTROSAT Collaboration

1. Tata Institute of Fundamental Research, Mumbai
2. Indian Institute of Astrophysics, Bangalore
3. Inter-University Centre for Astronomy & Astrophysics, Pune.
4. Raman Research Institute, Bangalore
5. Various ISRO Centers
6. Physical Research Laboratory, Ahmedabad
7. Bhabha Atomic Research Centre, Mumbai
8. Canadian Space Agency, Canada
9. University of Leicester, U.K.

Data pipeline

UVIT Data Analysis Pipeline

Compiled by -
Swarna K Ghosh

Inputs from : UVIT team, SAC-ISRO team, ISAC-ISRO team, ...

End-to-end overview :

UVIT --> Science stream data -->
S/C Data Handling Unit -->
Solid State Recorder --> ....
Transmission to ground
(+ House Keeping; LBT; Aux ...)

Ground reception -->
Data Ingest Front End Processor -->
Raw data -->
Level-1 data --> Data Analysis Pipeline
Level-2 data -->
(end-user / astronomer friendly)
.....

Key requirements of Level-1 to Level-2 data processing pipeline :

Sky images in FUV / NUV / VIS,
corrected for various instrument effects,
spacecraft drifts, jitters, thermal effects, ...

Recovering angular resolution,
& Absolute aspect

Quick Look Display (near real time)

For Photon Counting (PC : FUV, NUV) & Integration (IM : VIS) Modes -

reject affected data : drop-outs, parity error, cosmic rays, ...

Instrumental effects corrected for :

- response variation over FoV; bad pixels
- temperature dependence of QE
- temperature dependence of MCP gain (IM only)
- distortion introduced by Detector assembly
- distortion introduced by Optic assembly
- systematic effects in extraction of photon location from event centroid (PC only) – dark, bias,

- thermal effects on inter-channel mis-alignment;

Areas needing attention

Areas where new collaborators can get involved

- **Instrument calibration**
  - UVIT (excellent experience for students and researchers who plan to analyse the data from UVIT)
- **Calibration data → Instrument response**
  - **X-ray cal data**
    - Generation of response matrix, data analysis pipeline development
  - **UVIT cal data**
    - Flat fields (with wavelength/filter)
    - QE and resolution with position/wavelength
    - Geometrical distortion
    - Noisy and dead areas
    - Dynamic range and non-linearity
    - All above with temperature range
    - Small window fast read; integrate mode

Areas where new collaborators can get involved (contd)

- **Data interpretation**
  - Some examples:
    - SED of AGNs (eg: blazars)
    - Modeling transfer function to derive source geometry
- **Complementary observations**
  - ground (optical / IR / radio / TeV)
  - space (correlated observations – IR/ X-ray/ γ-ray)

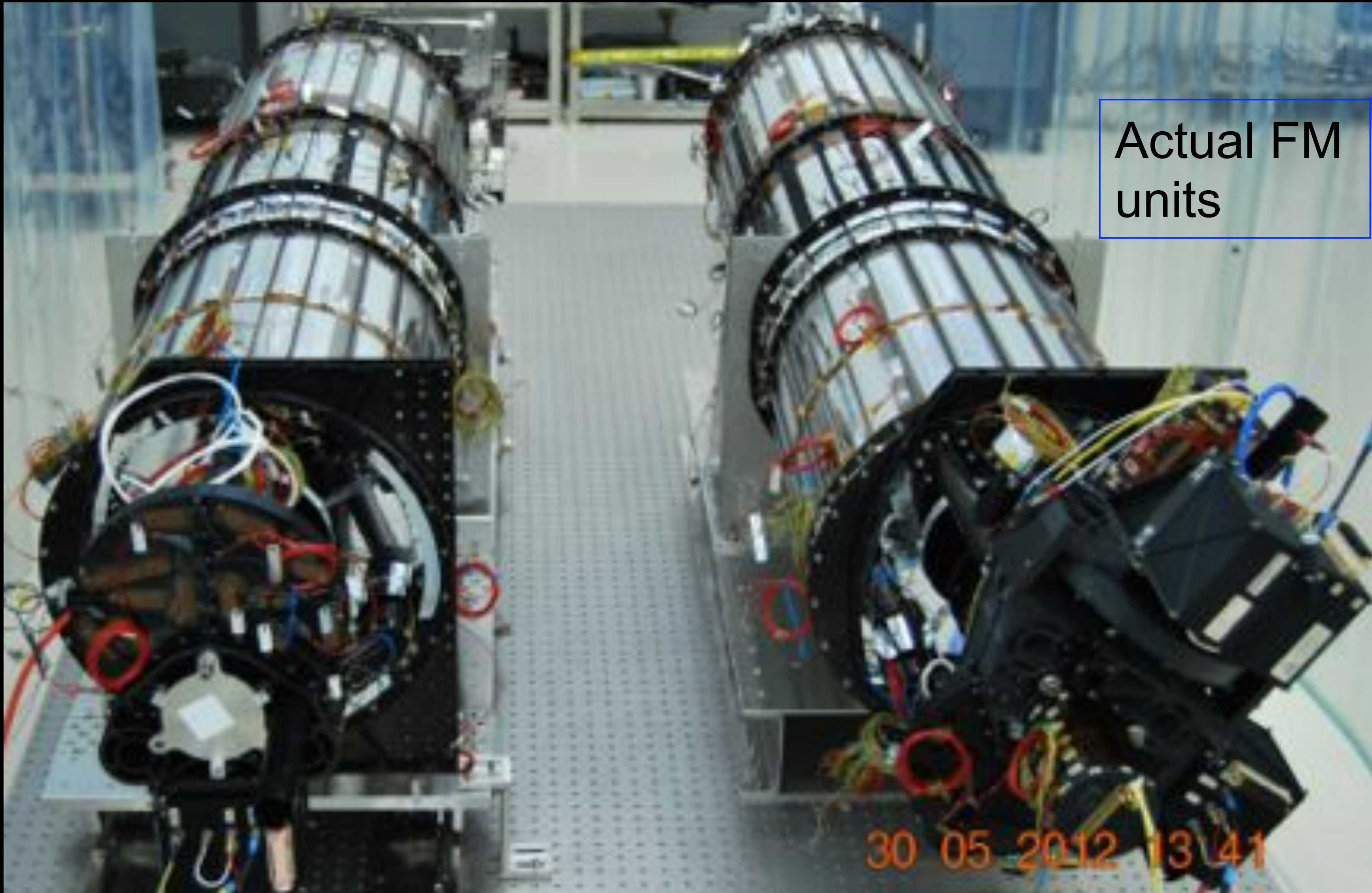
Some of the end products expected

- Determination of black hole masses ; linkages between microquasars and quasars (if any)
- Details on nature of transient behaviour, QPO and its evolution, period evolution
- Continued contribution to the existing data on correlation between spectral states and source intensity in many sources
- A better understanding of AGN geometry and activity ; additional clues on the central source
- Improved UV morphology, star formation and its evolution, galaxy luminosity function and many more…..

UVIT –EM – single telescope

FUV telescope

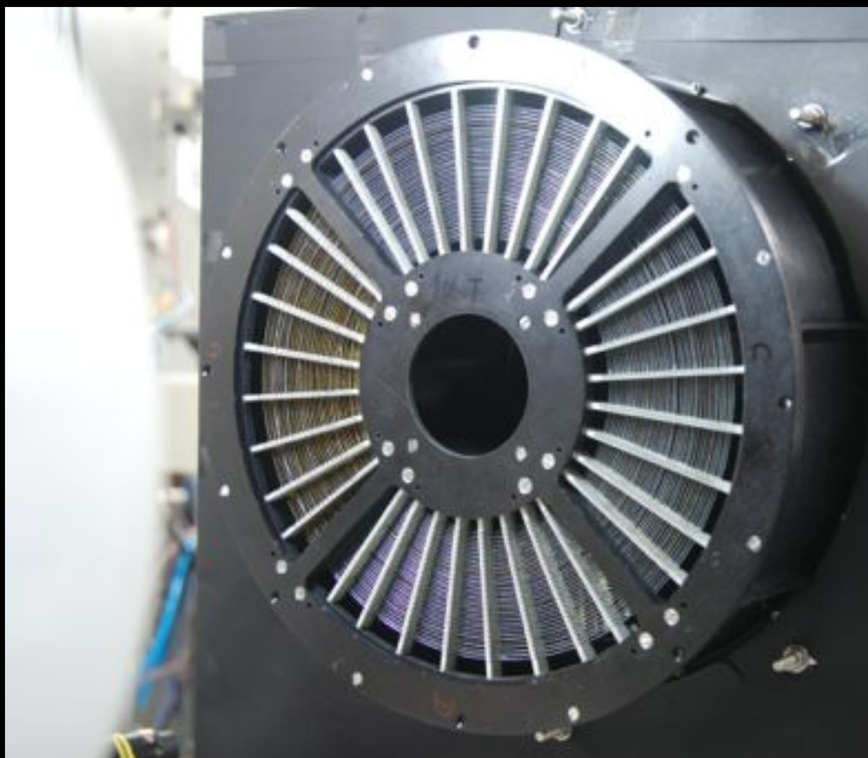
NUV/vis telescope



Scanning Sky Monitor

Soft X-ray Telescope

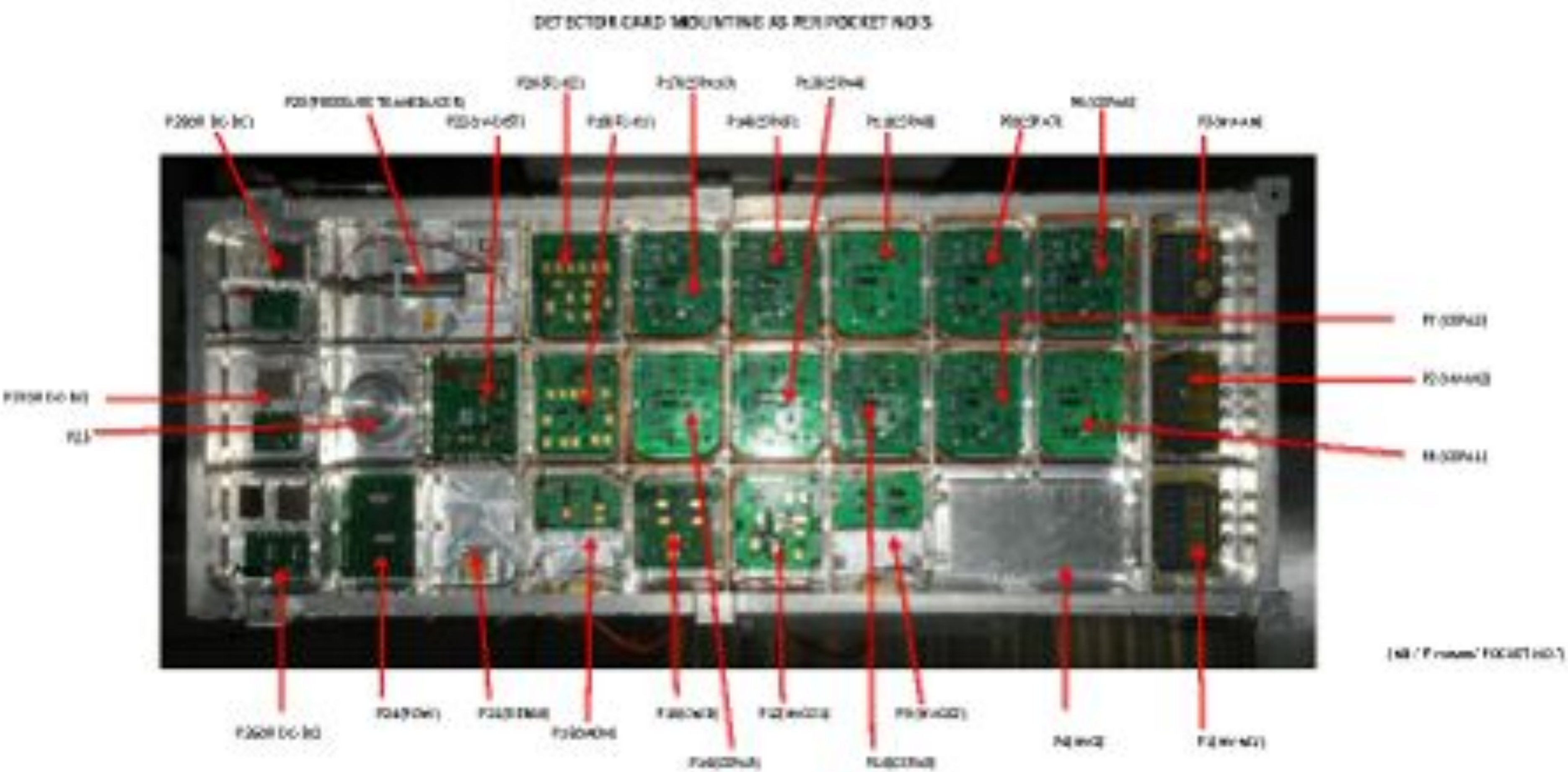
SXT Engineering and Flight Models – X-ray mirror



Large Area X-ray-Prop Counter

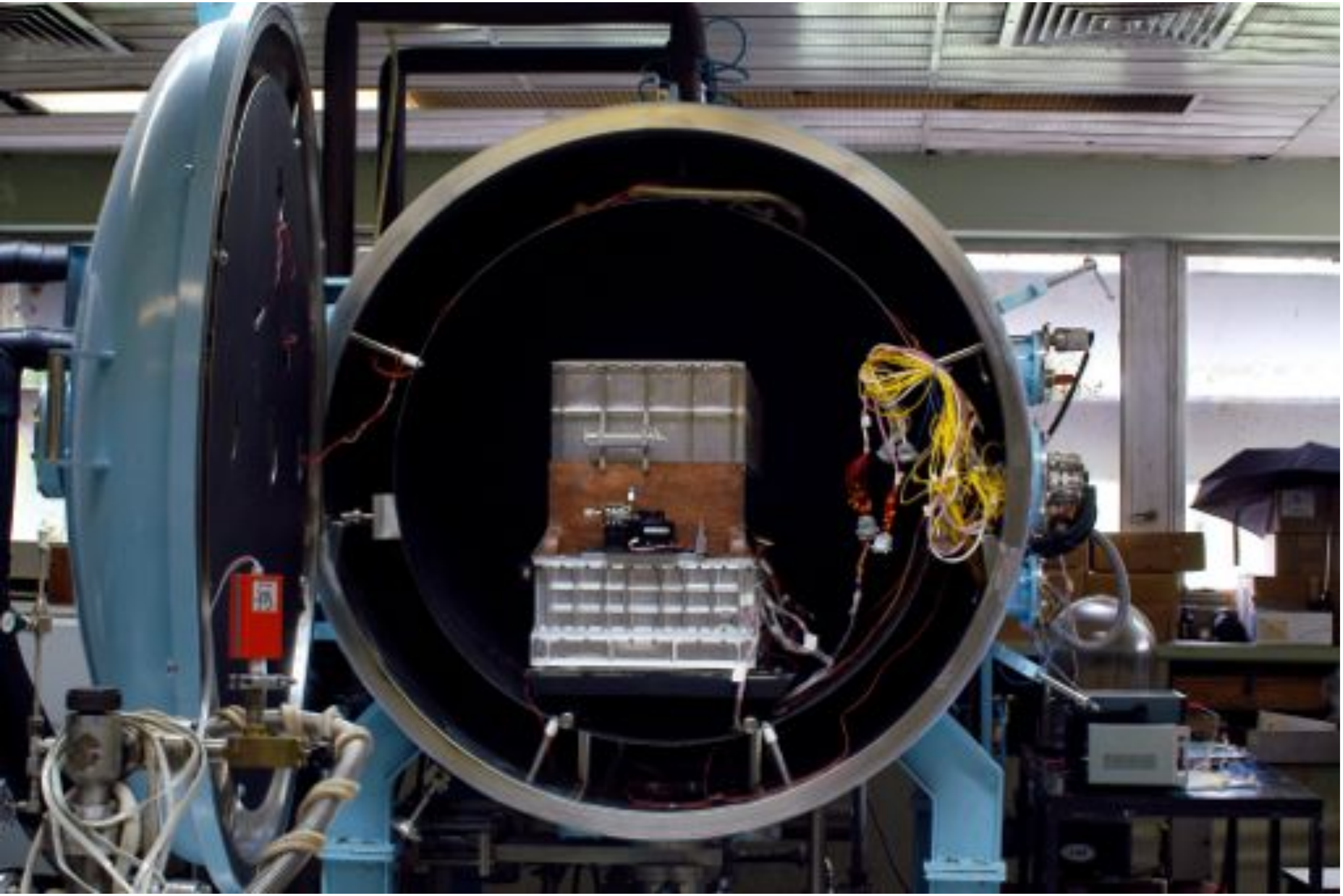
Assembly of FOV collimator

Detector Front-End Electronics

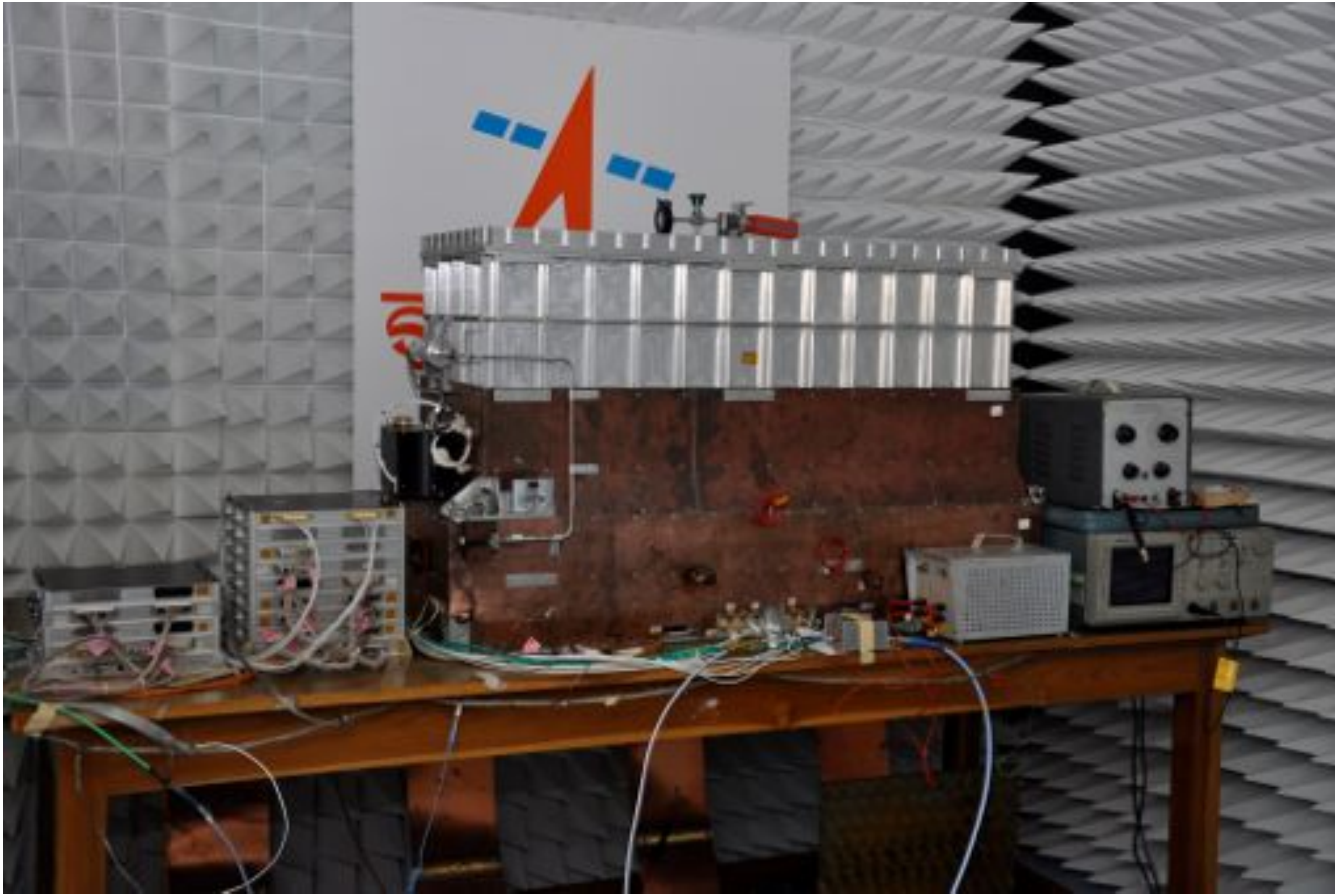


Second LAXPC Flight Detector being shipped to ISAC. Jan 2013

Progress and status after 1st Nov. 2012



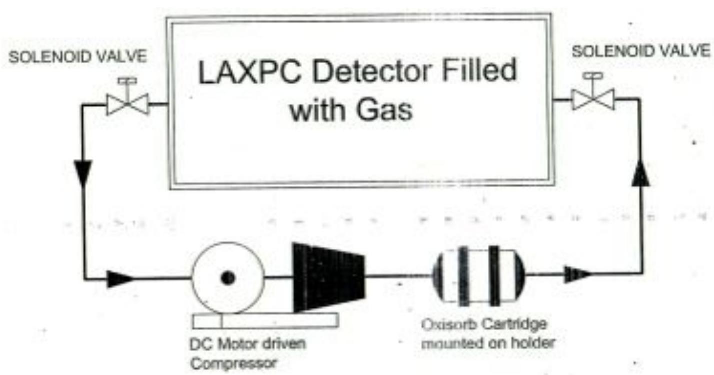
Full Chain EMI-EMC

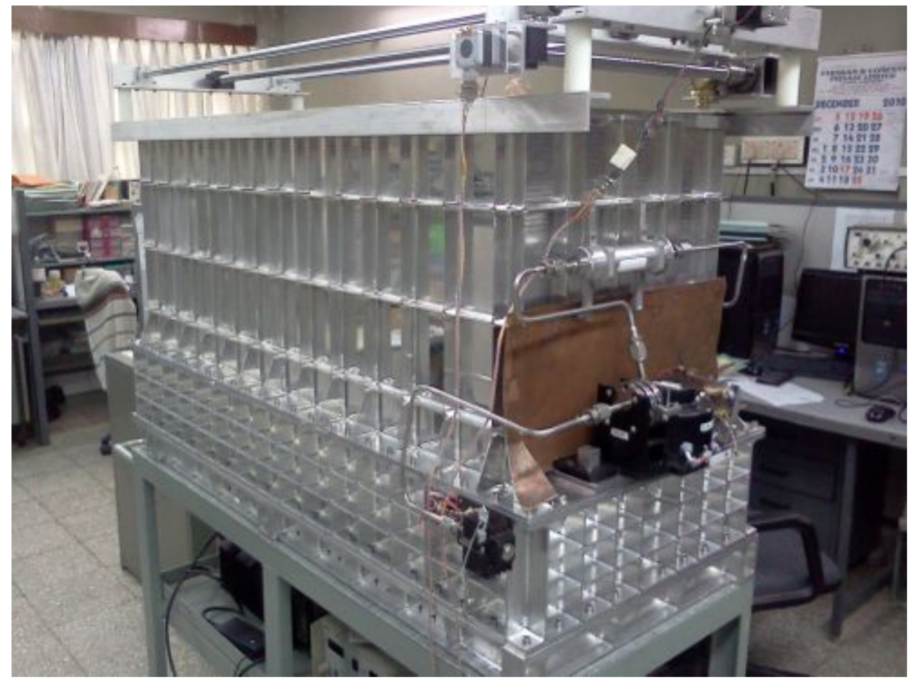


First LAXPC Flight Detector being shipped to ISAC. March 2012

LAXPC Detector On-board Purification

- On-Board Purification for Flight Detectors





➢MATERIALS USED.

INVAR: Metering structure:
(E: 148Gpa, Yield: 240 Mpa, CTE: ~3 ppm, Density: 8050 kg/m^3)

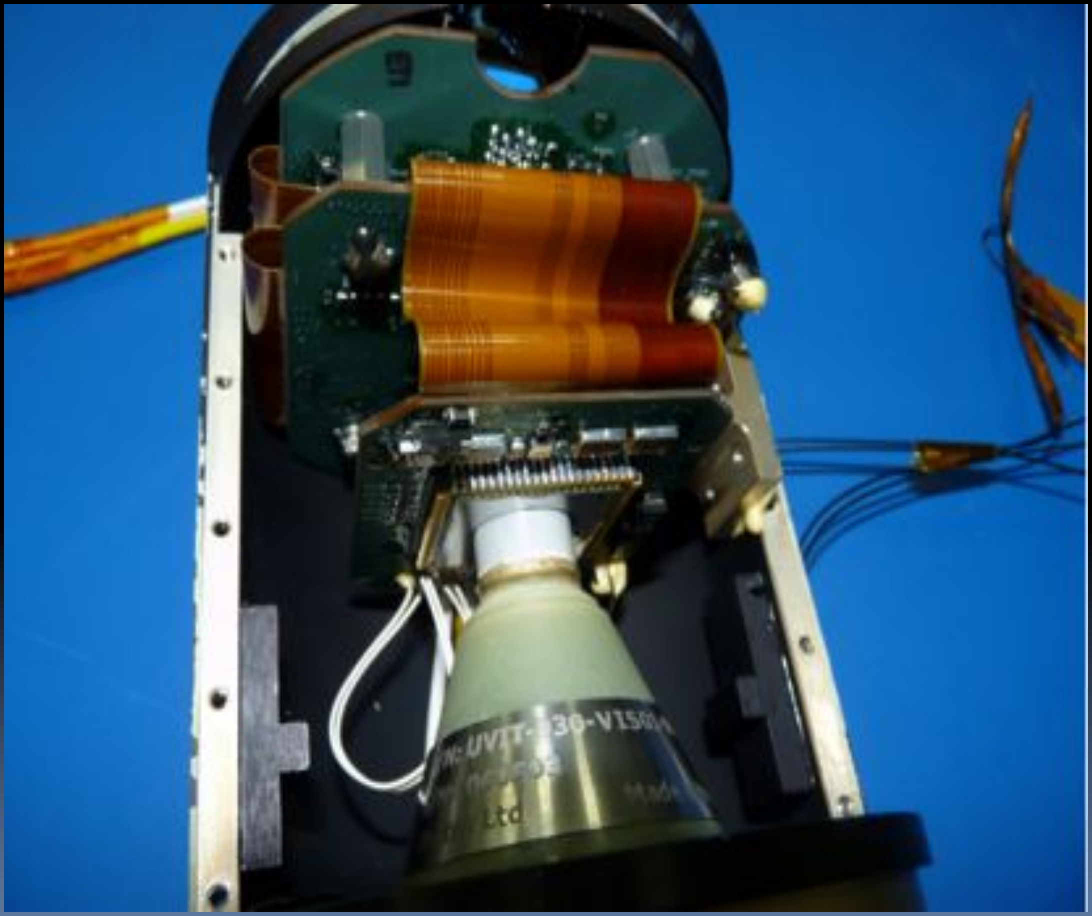
AL6061T6: Baffles, brackets, thermal cover.
(E: 69 Gpa, Yield: 320 Mpa, CTE: ~23 ppm. Density: 2700kg/m^3)

Ti6AL4V: Spacecraft adapter.
(E: 115 Gpa, Yield: 880 Mpa, CTE: ~8.6 ppm, density:4300 kg/m^3)

ASTROSAT : UVIT under tests

Investigation on VIS-CPU contd...

- CSA representative came to IIA and opened it.
- Visibly, there was no damage observed.
- The unit is being sent to CSA for the rectification of problem.



Some lessons learned ...

- Too small a team to build such a large observatory
- Too few graduate students involved in the project
- Inadequate amount of internal discussions / meetings – could not evolve a peer-driven schedule and system performance
- Lost some enthusiasm due to long delay in the program

Awaiting a launch next year …..

Thankyou

Reverberation mapping

$$L(v,t) = \int_{-\infty}^{+\infty} \psi(v,\tau)\, C(t-\tau)\, d\tau$$

plot of $\psi(v,\tau)$ from Debbijoy Bhattacharya

$L(v,t)$ = line intensity

$C(t)$ = continuum intensity

$\psi(v,\tau)$ = transfer function,

which depends on BLR geometry, kinematics and reprocessing physics