MULTIWAVELENGTH VIEW ON AGNS

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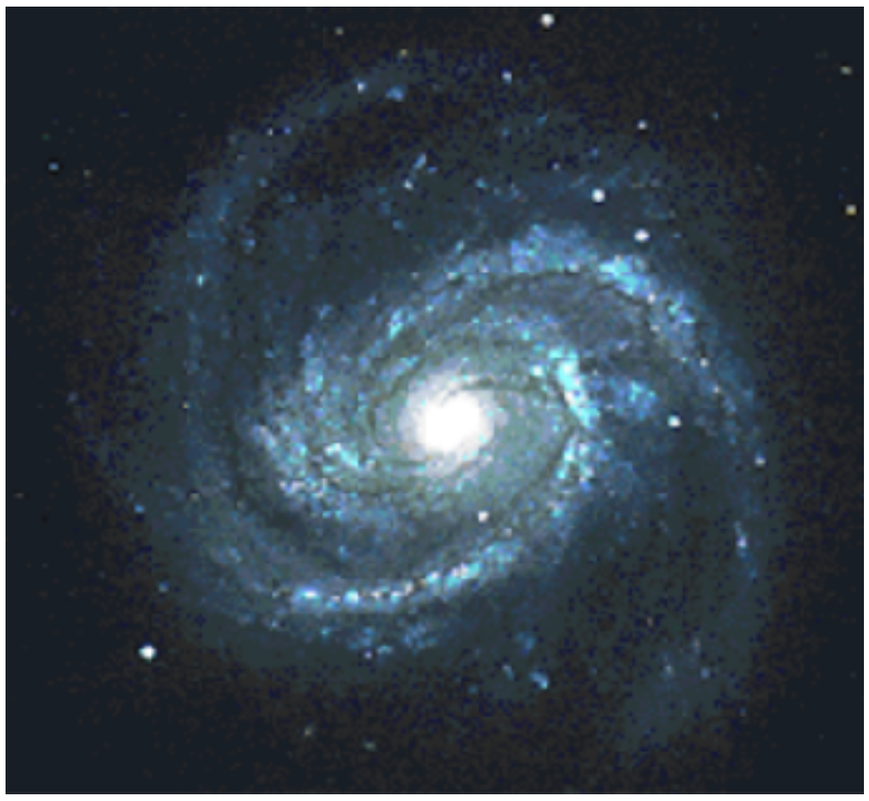
2018 Feb 16

Franco-Indian School: **From Re-ionization to Large Scale Structure- A Multiwavlength Approach**
11 - 17 February 2018, IUCAA, Pune- INDIA

PLAN

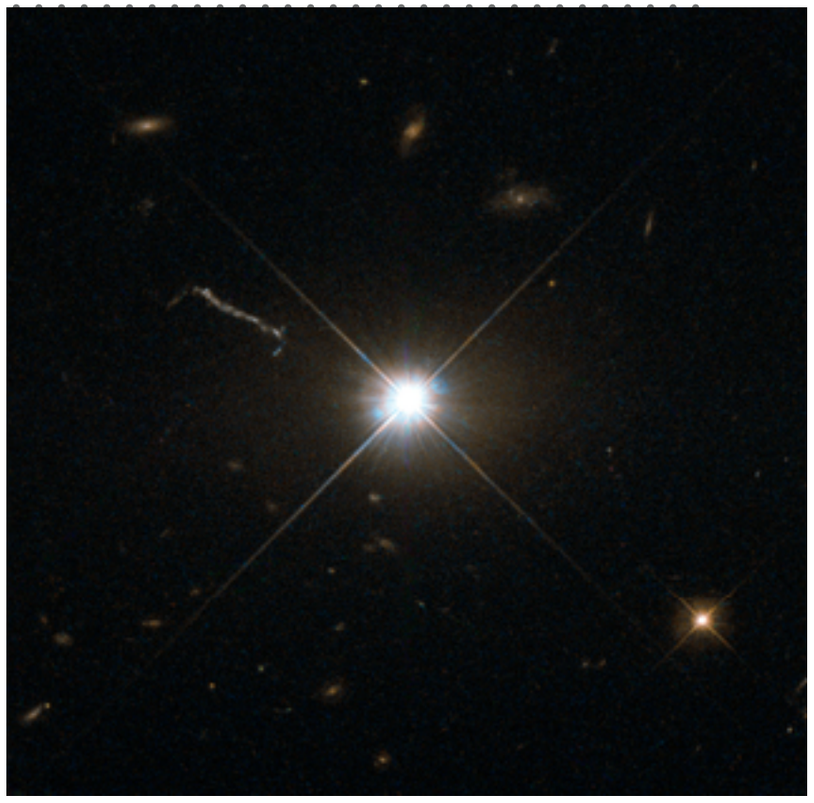
- Active Galactic Nuclei
  - different types
  - Seyfert galaxies
  - multiwavelength emission
- AstroSat
  - Instruments
  - Special features
- AstroSat results
  - NGC 4151, NGC 4051…
  - RE J1034+396

ACTIVE GALACTIC NUCLEI



M 100 (17 Mpc)

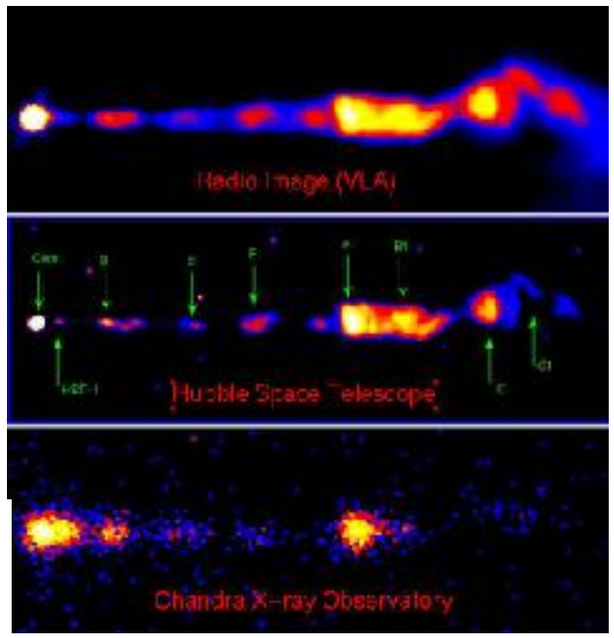
NGC 6814 (23 Mpc)



Hubble pictures

3C 273 (749 Mpc)

- . **Carl Seyfert (1943): strange emission line galaxies (non-stellar radiation)**
- **Very luminous core : rapid variability. —> small size**
- **Radio: Jets / lobes**
- **X-rays: Stellar mass black holes; Variability in AGN**



M87 (16 Mpc)

Table 1 The AGN zoo: list of AGN classes

Class/Acronym	Meaning
Quasar	Quasi-stellar radio source (originally)
Sey1	Seyfert 1
Sey2	Seyfert 2
QSO	Quasi-stellar object
QSO2	Quasi-stellar object 2
RQ AGN	Radio-quiet AGN
RL AGN	Radio-loud AGN
Jetted AGN	
Non-jetted AGN	
Type 1	
Type 2	
FR I	Fanaroff-Riley class I radio source
FR II	Fanaroff-Riley class II radio source
BL Lac	BL Lacertae object
Blazar	BL Lac and quasar
BAL	Broad absorption line (quasar)
BLO	Broad-line object
BLAGN	Broad-line AGN
BLRG	Broad-line radio galaxy
CDQ	Core-dominated quasar
CSS	Compact steep spectrum radio source
CT	Compton-thick
FR 0	Fanaroff-Riley class 0 radio source
FSRQ	Flat-spectrum radio quasar
GPS	Gigahertz-peaked radio source
HBL/HSP	High-energy cutoff BL Lac/blazar
HEG	High-excitation galaxy
HPQ	High polarization quasar
Jet-mode	
IBL/ISP	Intermediate-energy cutoff BL Lac/blazar
LINER	Low-ionization nuclear emission-line regions
LLAGN	Low-luminosity AGN
LBL/LSP	Low-energy cutoff BL Lac/blazar
LDQ	Lobe-dominated quasar
LEG	Low-excitation galaxy
LPQ	Low polarization quasar
NLAGN	Narrow-line AGN
NLRG	Narrow-line radio galaxy
NLS1	Narrow-line Seyfert 1
OVV	Optically violently variable (quasar)
Population A	
Population B	
Radiative-mode	
RBL	Radio-selected BL Lac
Sey1.5	Seyfert 1.5
Sey1.8	Seyfert 1.8
Sey1.9	Seyfert 1.9
SSRQ	Steep-spectrum radio quasar
USS	Ultra-steep spectrum source
XBL	X-ray-selected BL Lac
XBONG	X-ray bright optically normal galaxy

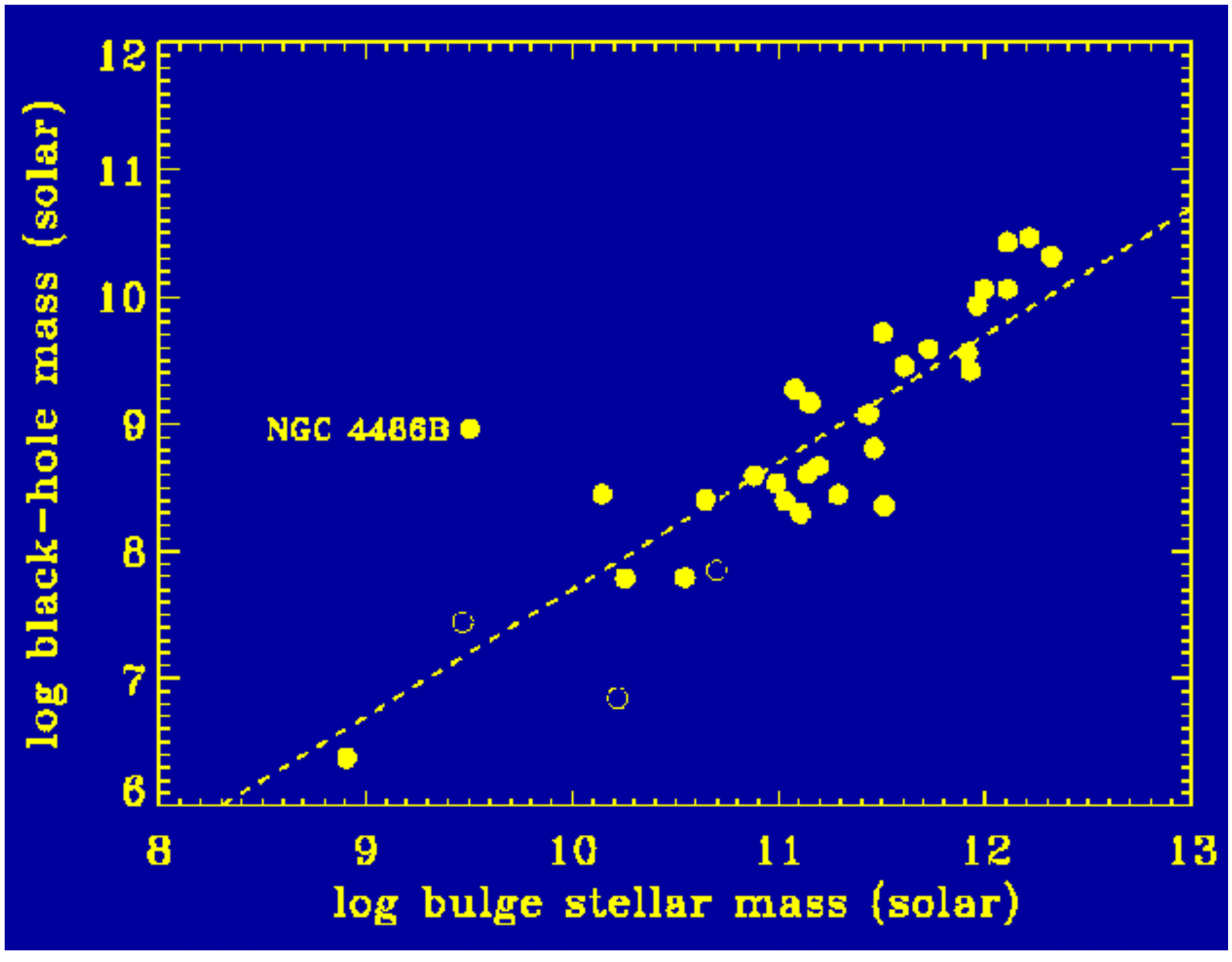
Padovani+ 2017

AGN TYPES

- Seyferts. (type 1 and 2)
- Quasars/ QSOs
- RQ/ RL AGN
- FR I, II
- BL Lac/ Blazar

AGN MASSES

- Reverberation technique
- Gas dynamics



Eddington Luminosity

Gravity $dP/dr = -\rho g = -GM\rho/r^2$

Luminosity $dP/dr = -(\sigma_T \rho/m_p c)\ (L/4\pi r^2)$

σ_T = Thomson Cross section

$L_{Edd} = 4\pi GMm_p c/\sigma_T$

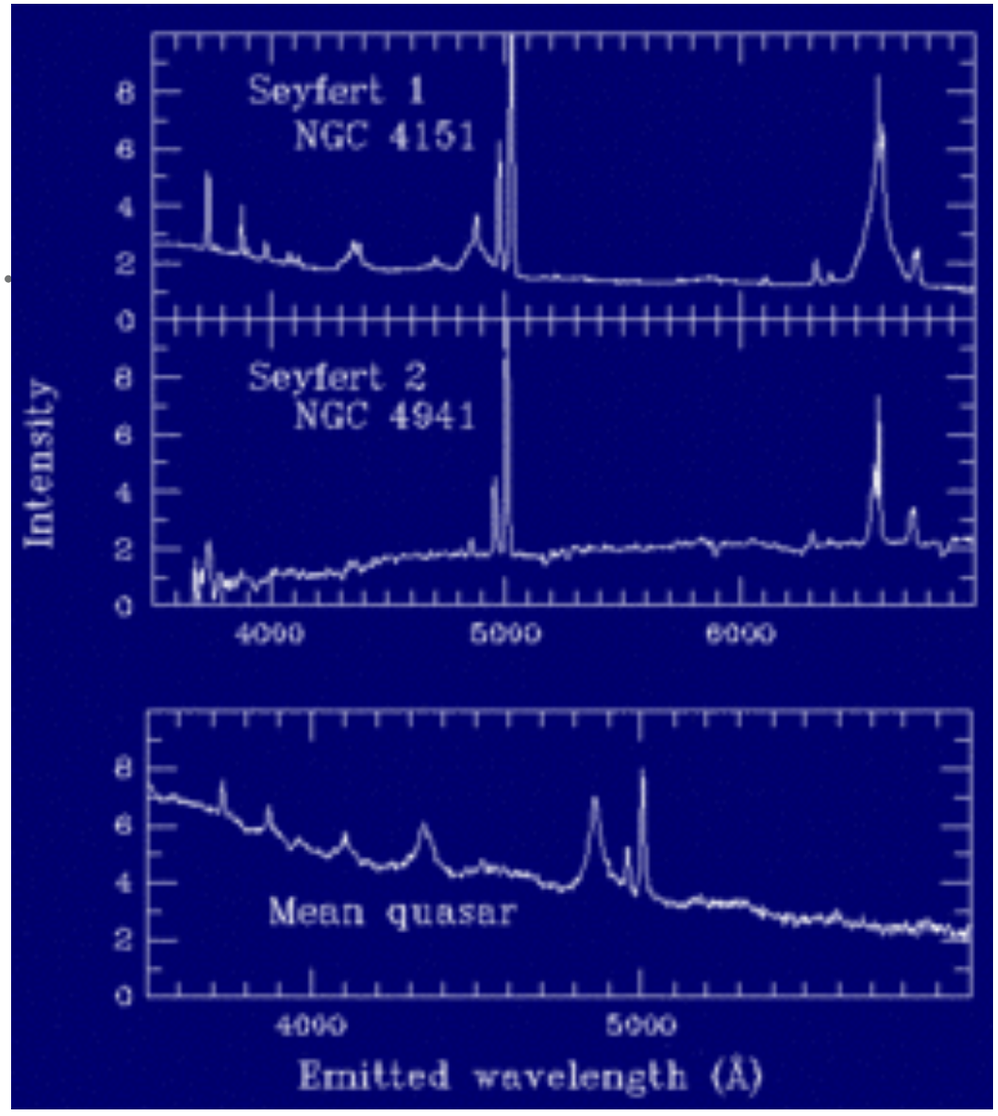
$= 3.3 \times 10^4\ L_\odot (M/M_\odot)$

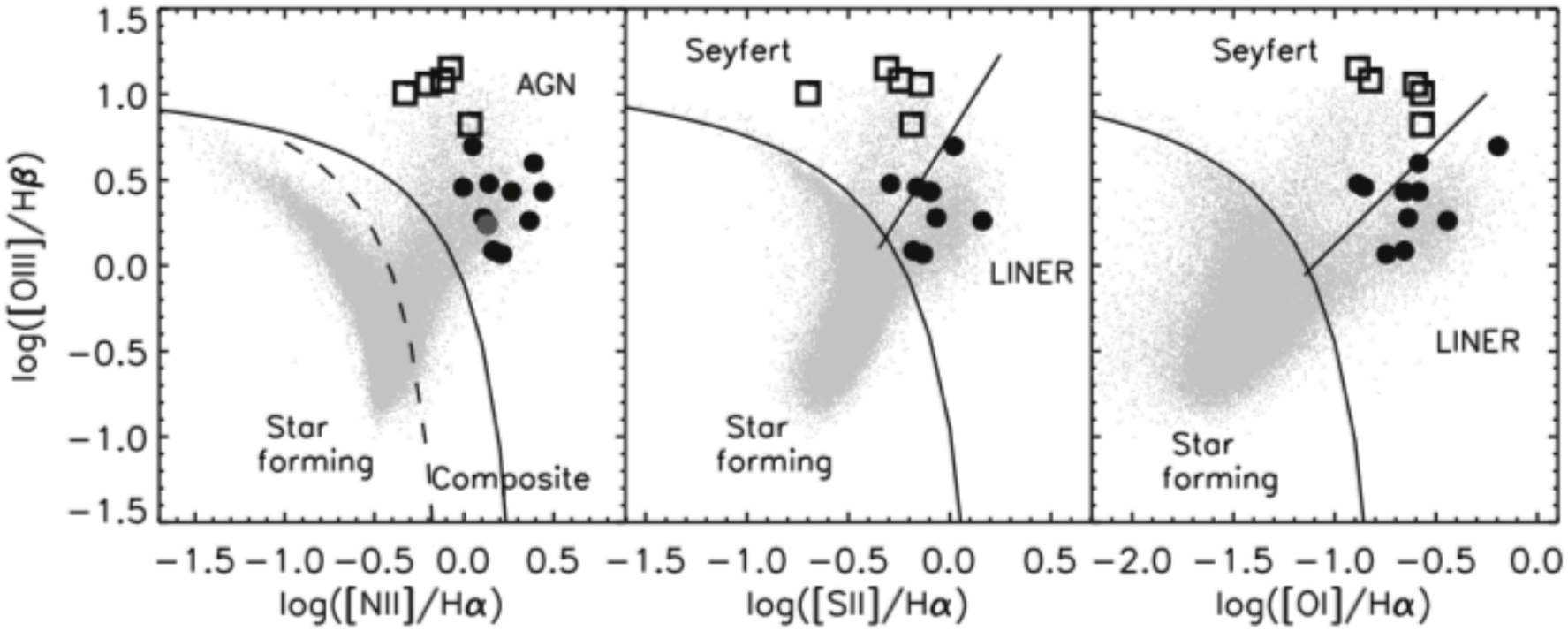
Standard Disk:

$T \sim M^{-1/4}$ 1 keV for 1 $M_\odot$ and a few eV $10^8\ M_\odot$

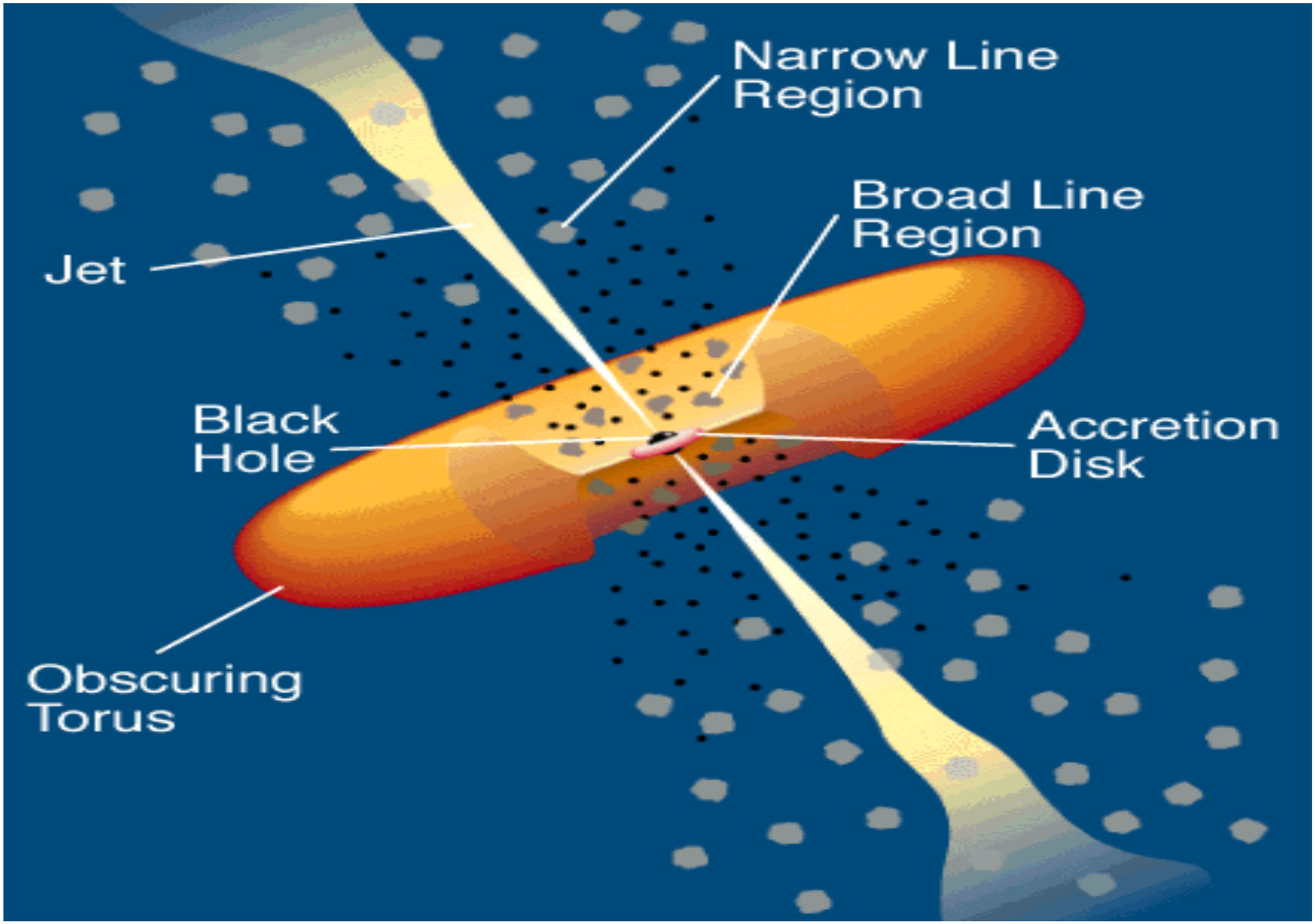
- Massive AGN brighter than the galaxy
- Stellar mass BH: high energy electrons; AGN: atomic physics
- 15% AGN jetted - superluminal motion
- Seen along the jet - the brightest objects

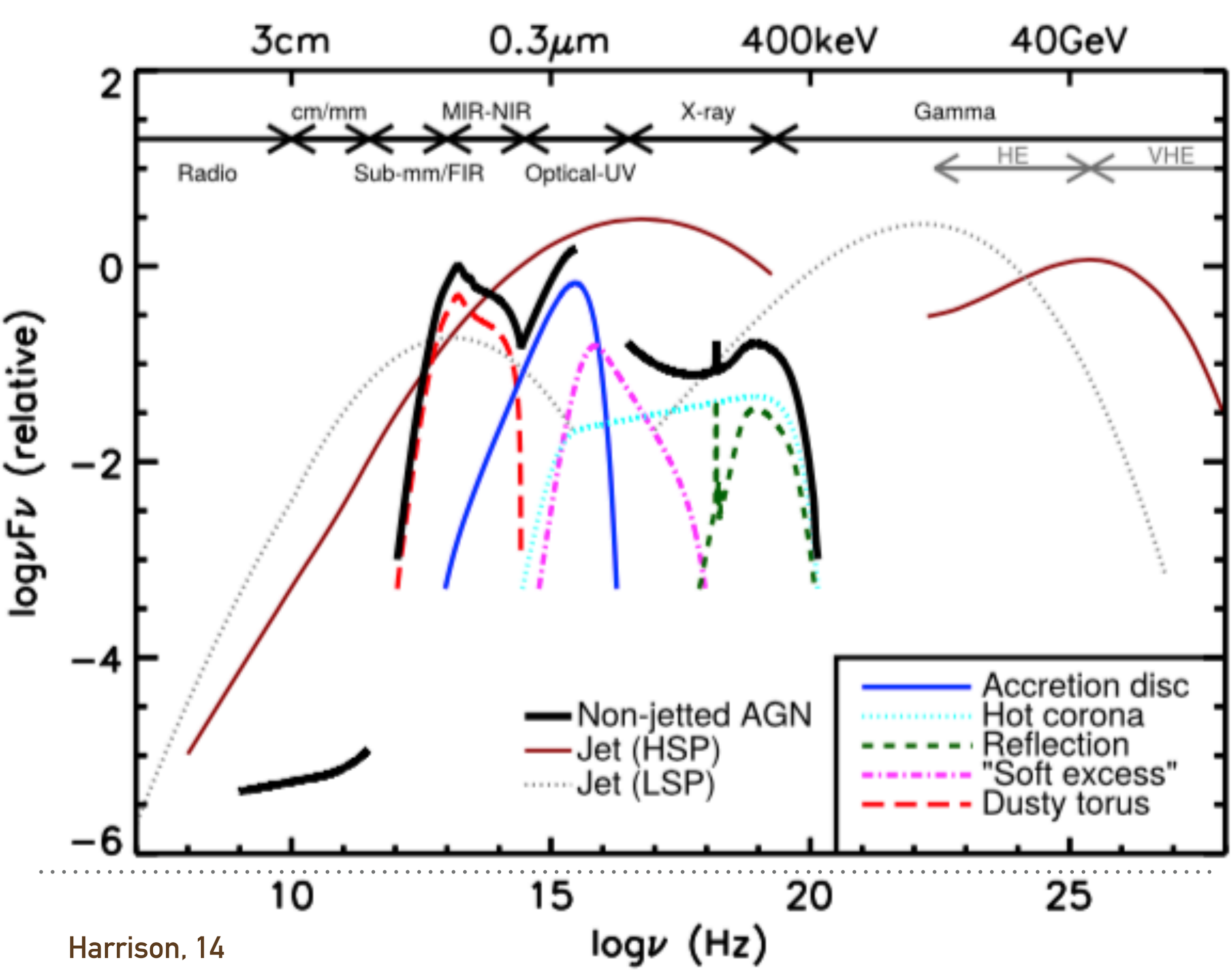
EMISSION LINES





AGN: The Working Paradigm




3cm
0.3μm
400keV
40GeV
cm/mm
MIR-NIR
X-ray
Gamma
Radio
Sub-mm/FIR
Optical-UV
HE
VHE
2
0
−2
−4
−6
logνFν (relative)
10
15
20
25
logν (Hz)
Non-jetted AGN
Jet (HSP)
Jet (LSP)
Accretion disc
Hot corona
Reflection
"Soft excess"
Dusty torus

Harrison, 14

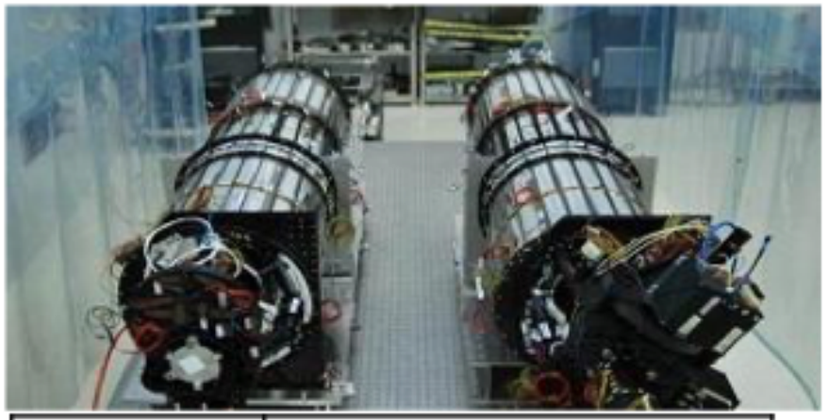
AGN STUDIES

- Inner-most accretion disk: structure
- Jet launching mechanism
- Role of spin
- Disk-jet connection
- Jet dynamics

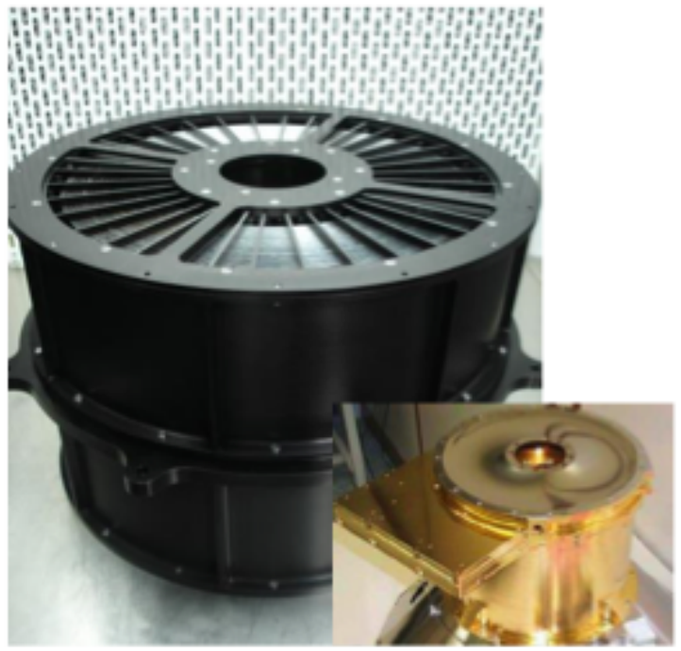
AstroSat

- Large Area X-ray Proportional Counter (LAXPC)
- Soft X-ray Telescope (SXT)
- Cadmium Zinc Telluride Imager (CZTI)
- Ultra-Violet Imaging Telescope (UVIT)
- Sky Survey Monitor (SSM)
- Charge Particle Monitor (CPM)

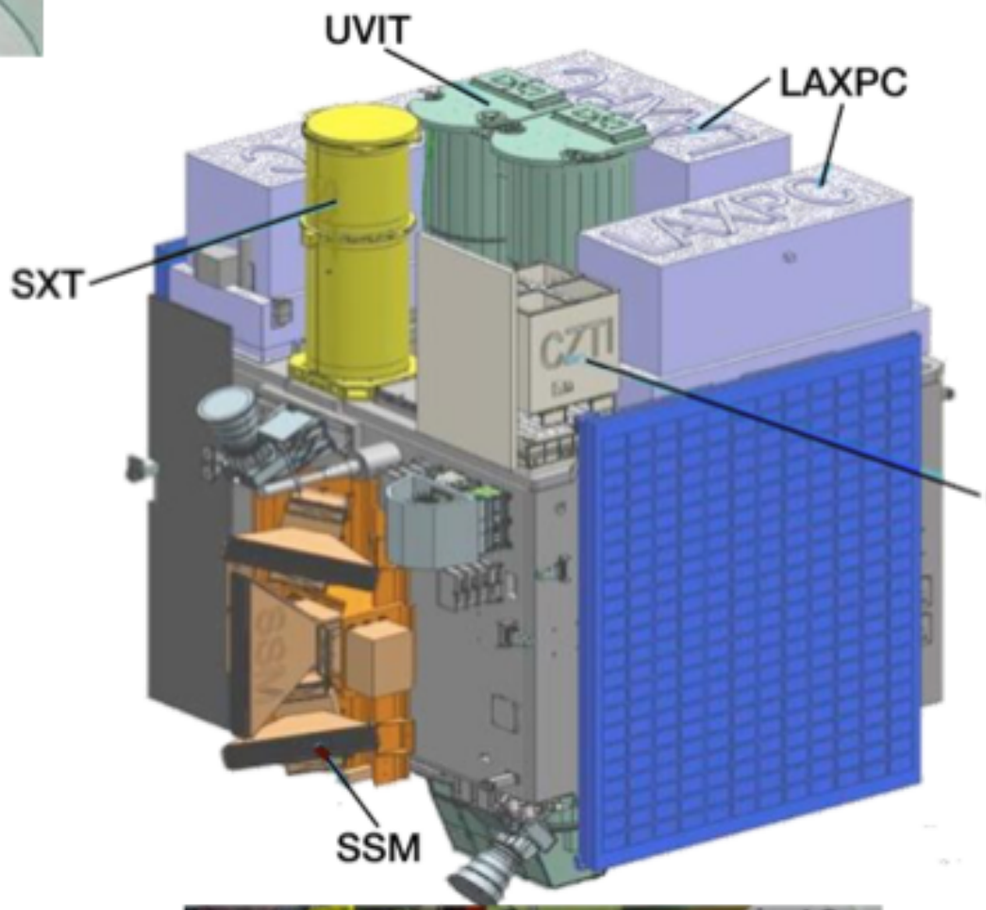
AstroSat

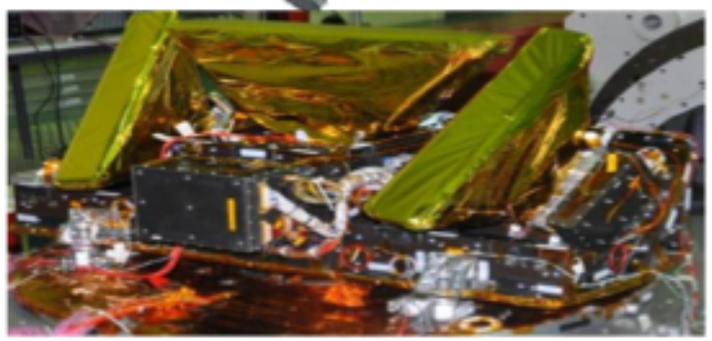


Detector	Photon-counting (Intensified) CMOS imagers
Optics	Twin Ritchie Chretian 2 mirror system
Bandwidth	130-180 nm 200-300 nm 320-550 nm
Angular Resolution	1.8 arc sec

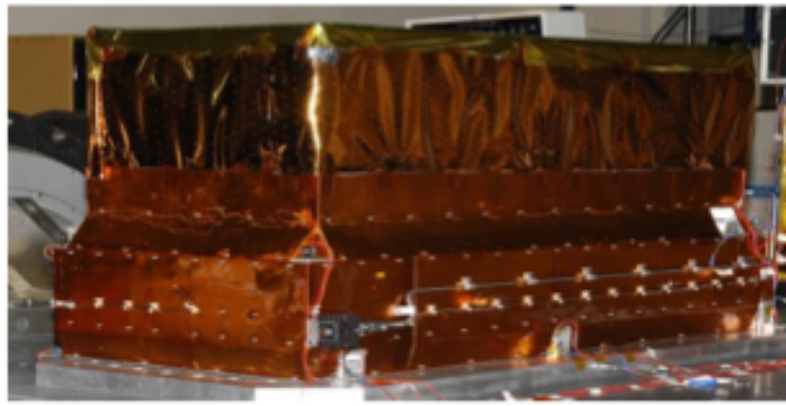


Detector	X-Ray CCD at the focal plane
Optics	Conical foil (Wolter-I) Mirrors
Bandwidth	0.3 - 8 keV
Energy Resolution	2.34% @ 5.9 keV
Angular Resolution	2 arc min (HPD)

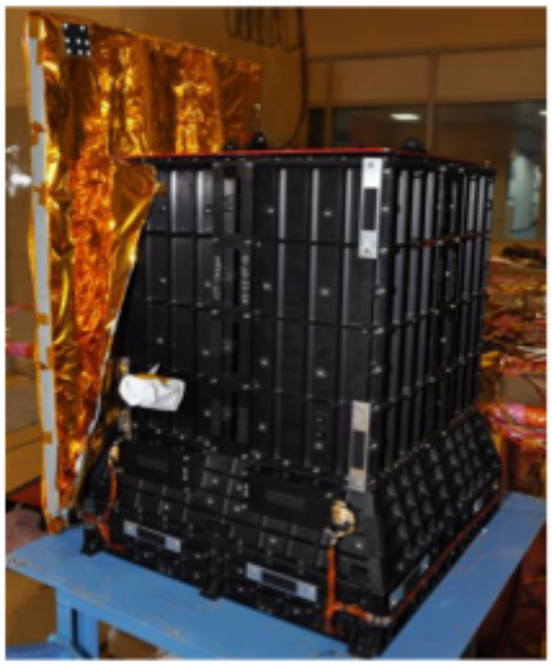




Detector	Position sensitive Proportional Counter(3)
Optics	1-D coded Mask
Bandwidth	2.5 - 10 keV
Energy Resolution	25% @ 6 keV



Detector	Proportional counter
Optics	Collimator
Bandwidth	3 - 80 keV
Energy Resolution	12% @ 22 keV
Time resolution	10 microsec
Effective area	8000 cm2



Detector	CdZnTe Detector
Optics	2-D coded Mask
Bandwidth	15 - 100 keV
Energy Resolution	6% @100 keV
Time resolution	20 microsec

Participating Institutes…

- ISRO Centers

  Satellite, rocket, T&E, Launch, Orbit, SSM,

  Level 1&2 software + overall management

- Research Institutes

  Tata Institute of Fundamental Research

  LAXPC, CZTI, SXT

  Indian Institute of Astrophysics UVIT

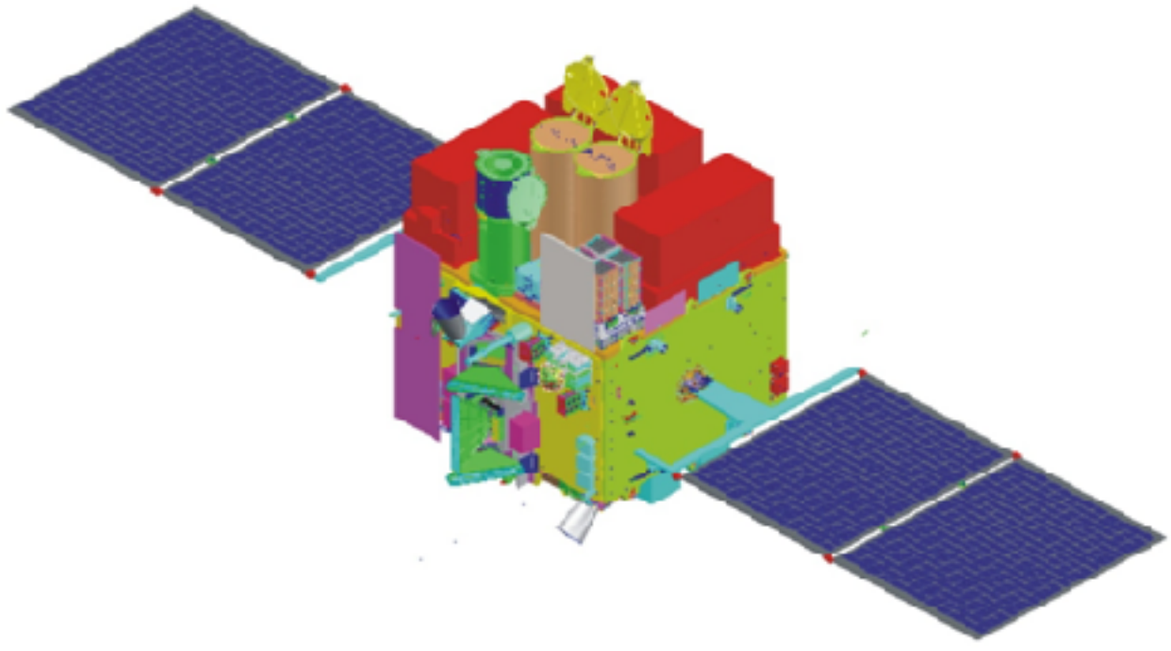
  IUCAA SSM, CZTI

  RRI LAXPC

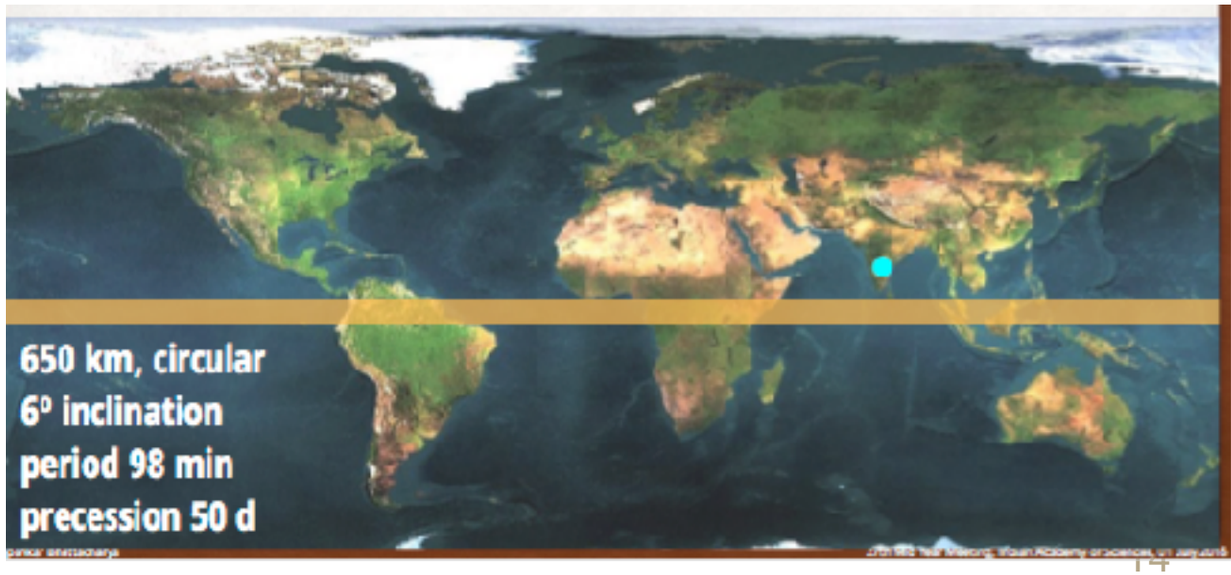
  PRL, Universities,

- Leicester Uty (SXT), Canadian Space Agency (UVIT)

AstroSat



- **IRS (Indian Remote Sensing) Clas**
- **Launch PSLV C30** from SHAR
- Altitude : 650 km.
- **Inclination : 6 deg.**
- Mass 1550 kg. (780 kg. Payloads)
- Power : 2200 watts
- **200 Gb (210 Mb/sec)**
- Satellite Positioning System for orbit and time data
- **Payload pointing (3σ): 0.05 degree**
- **Slew rate : 0.6 deg/sec**
- Launch: 2015 September 28
- Operational life > 5 years



LAXPC:
Large area Xenon-filled Proportional Counters

Energy range : 3 – 80 keV

Time Resolution: 10 μsec

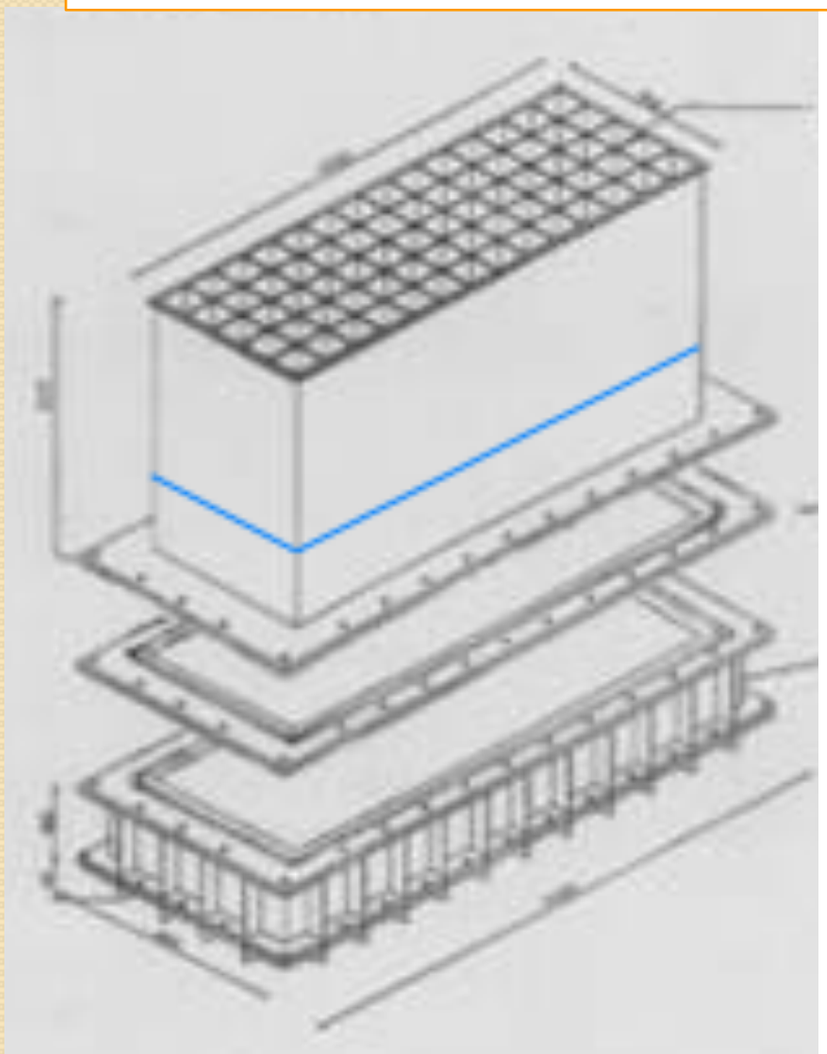
Area : 6000 cm^2 (7980)

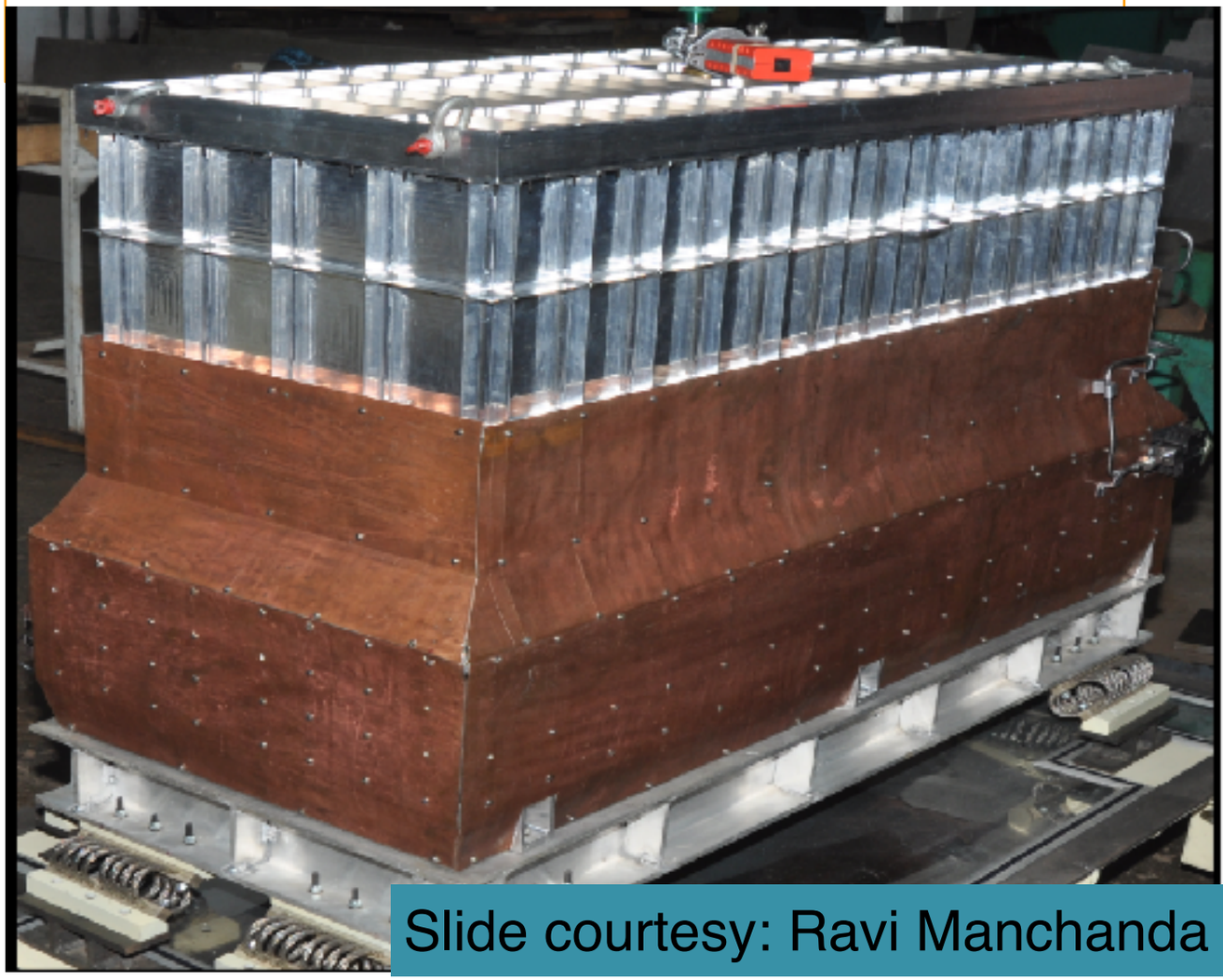
E /ΔE ~ 3 - 7

Three identical xenon filled proportional counters. Multi layer and multi cell geometry with 60 anode cells and 28 anti cells

Xenon + methane mixture at a pressure 1500 mm of Hg.

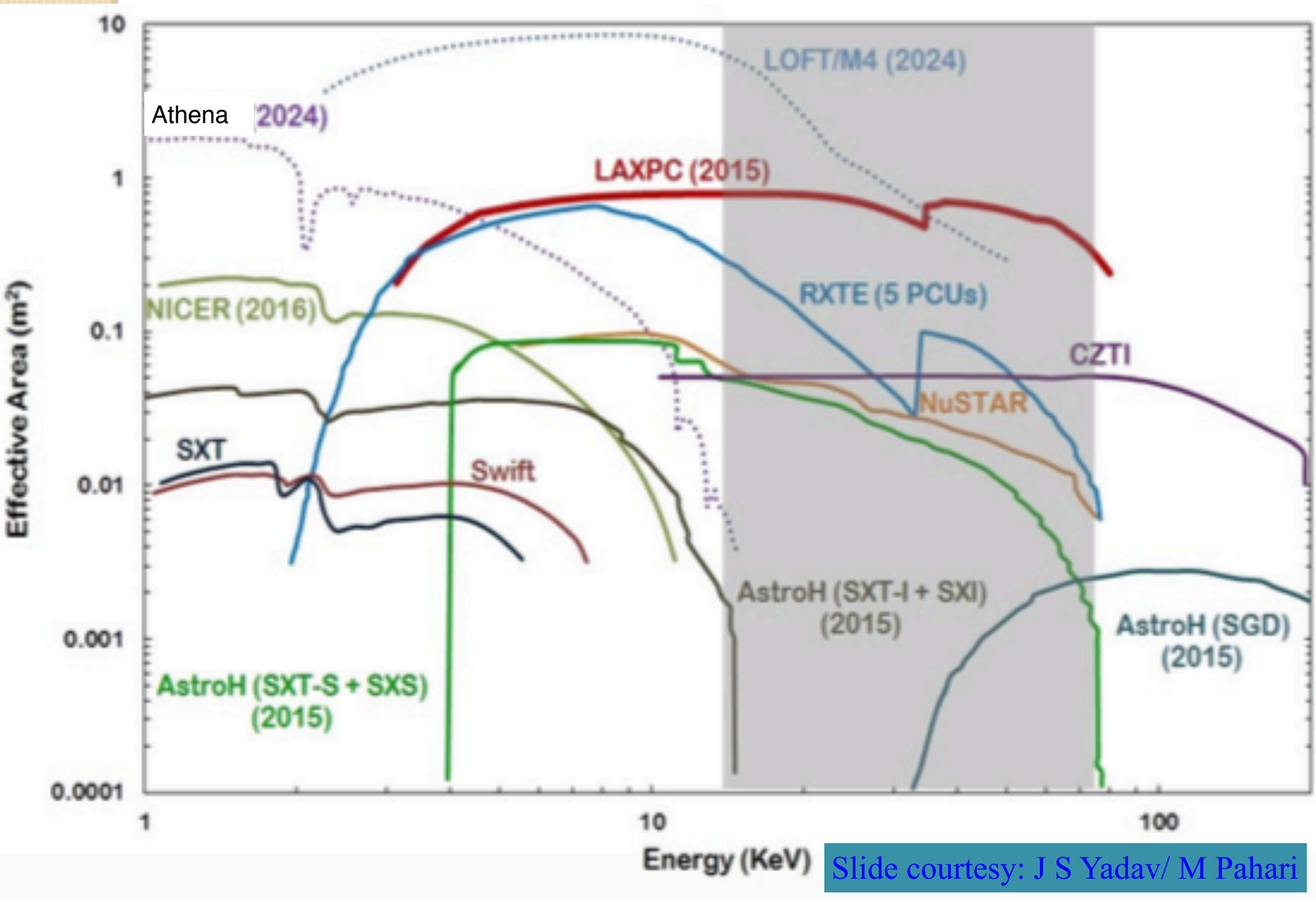
50 micron thick aluminized Mylar window with a FOV of 1^ox1^o





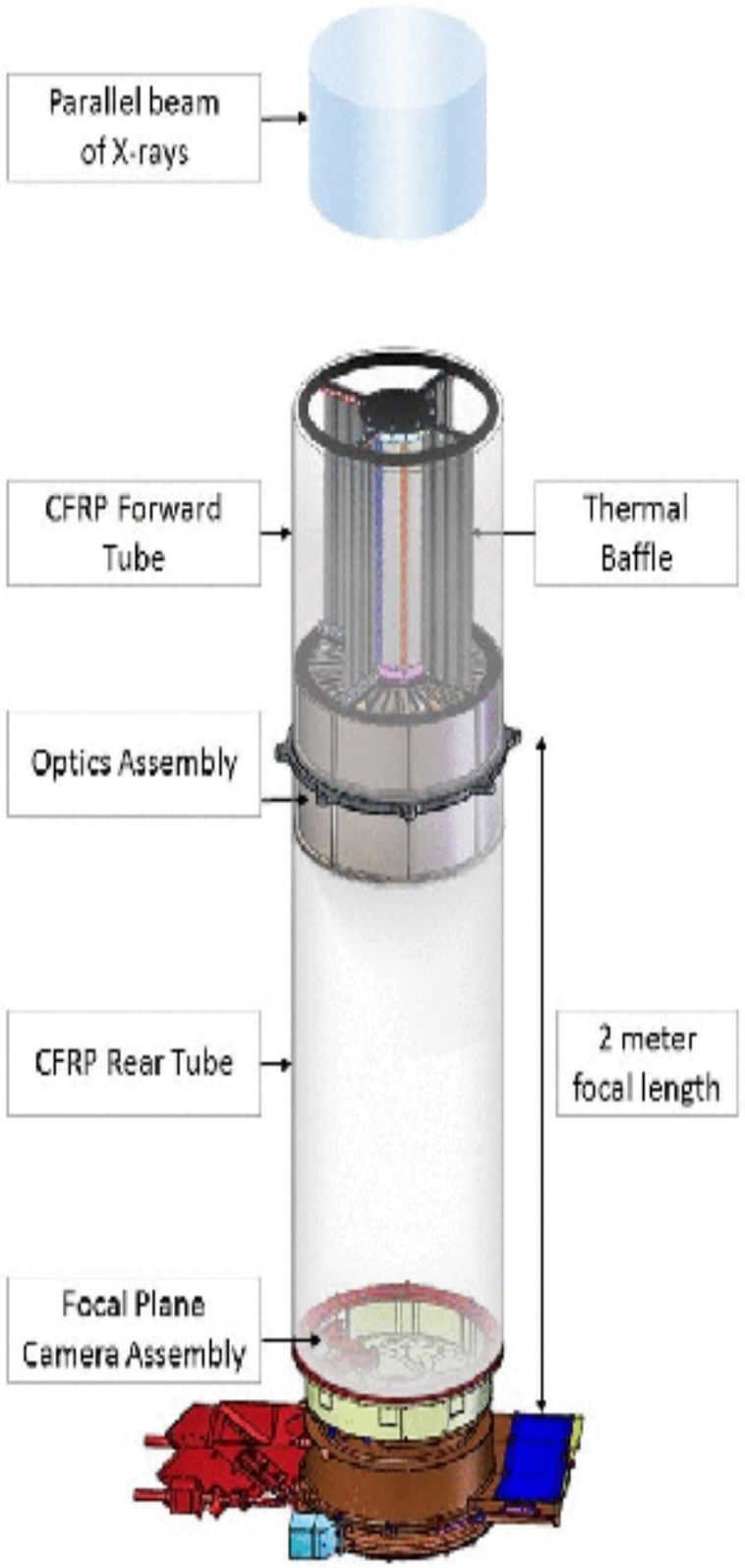
Slide courtesy: Ravi Manchanda

LAXPC Effective Area



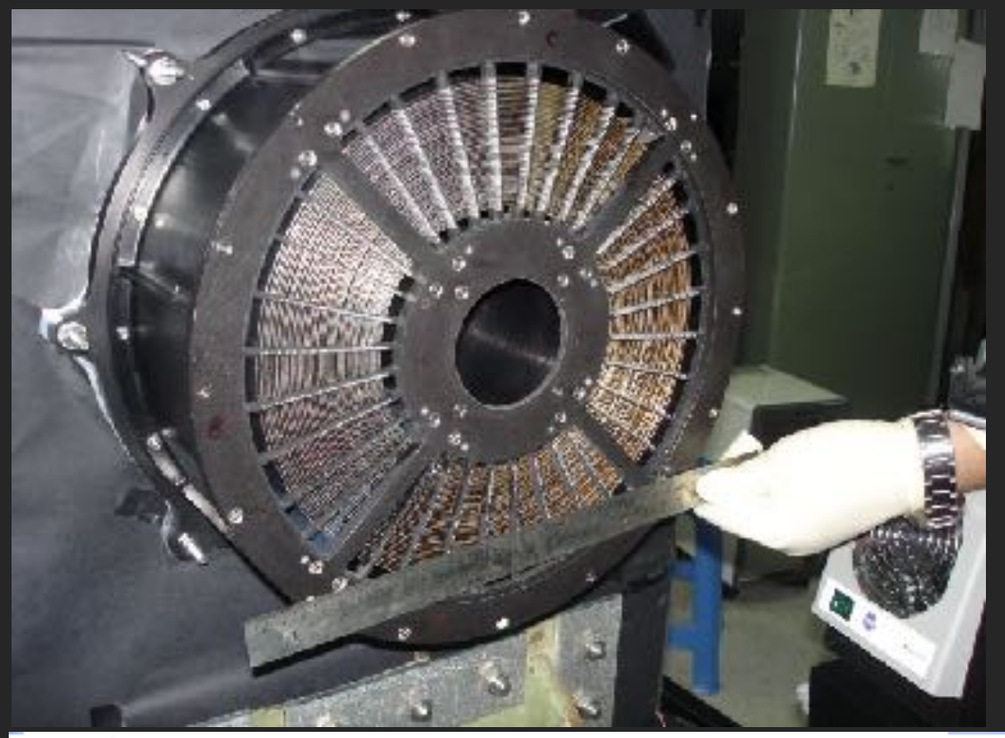
Slide courtesy: J S Yadav/ M Pahari

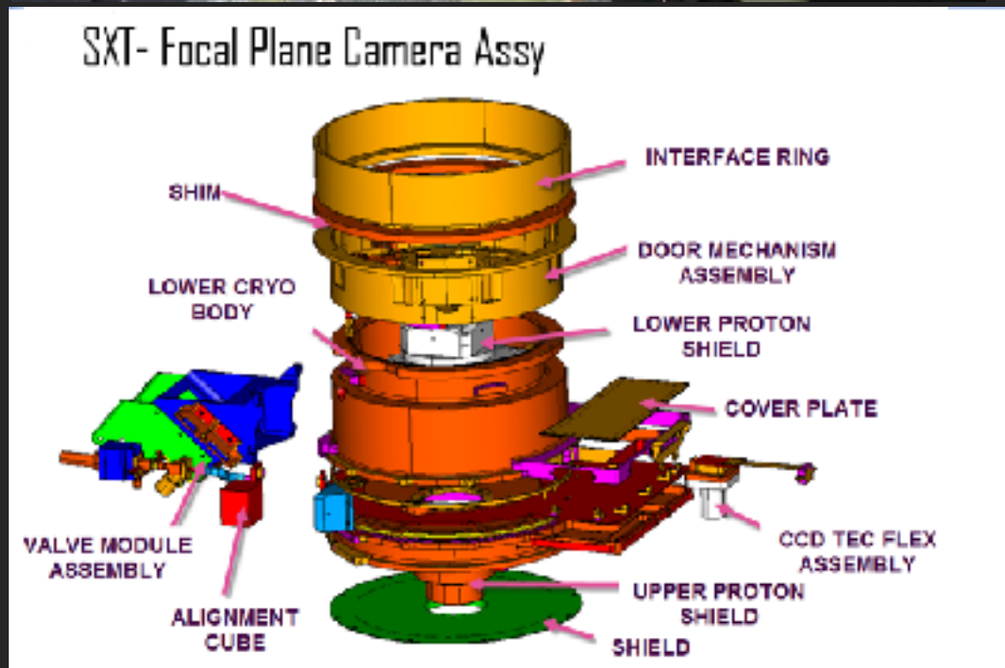
Soft X-ray Telescope



40 shells (130 – 260 mm dia)

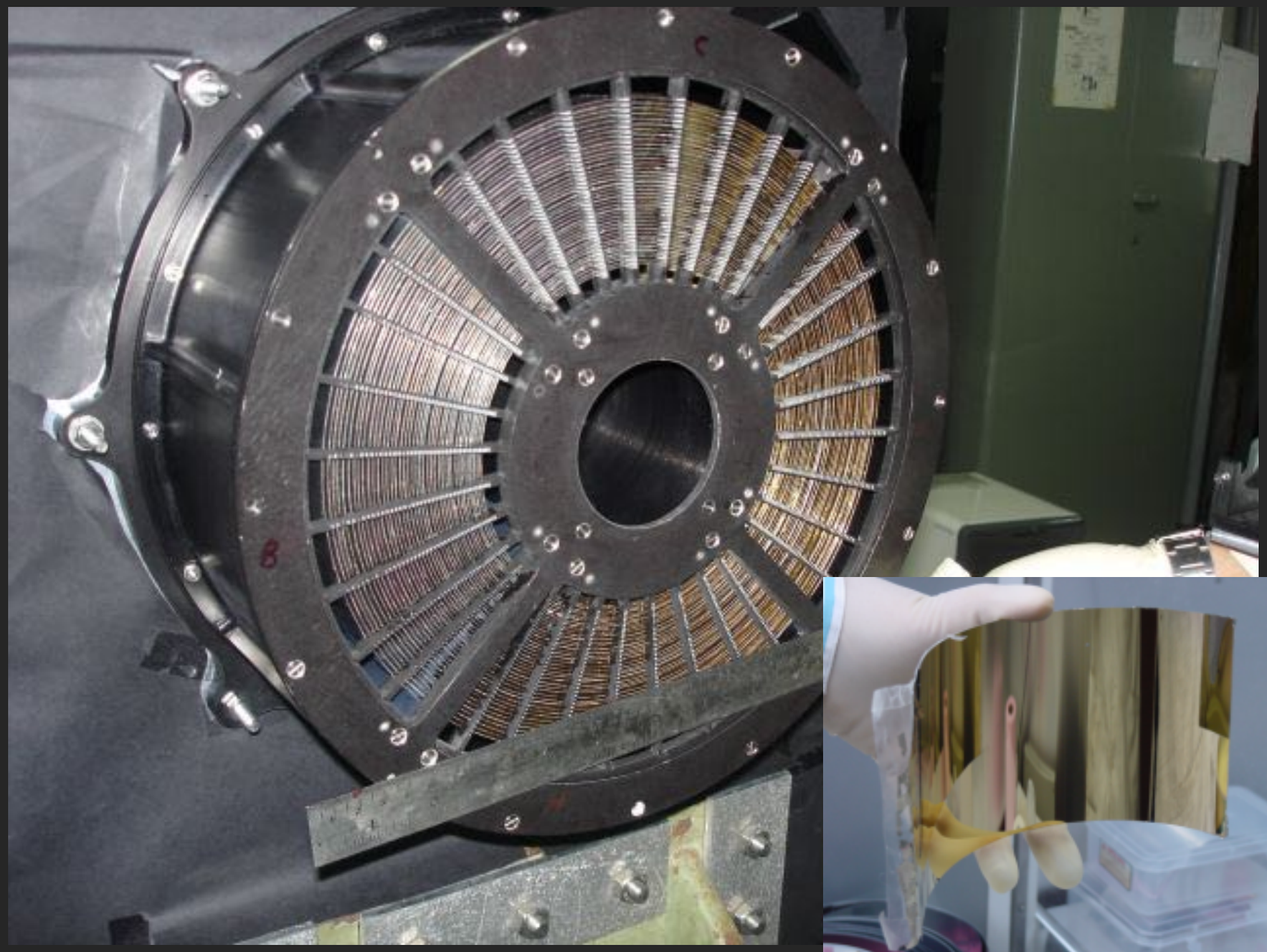
- Thin Optical Blocking Filter
- CCD Assy. including TEC
- PCB with front-end electronics
- Four Fe-55 corner sources for calibration





Modified from Swift; Using spare MOS CCD22 from XMM: 600 x 600 pix, 40 microns

SXT: Optics — *Replicated Thin foil mirrors made in TIFR (following Suzaku)*



2 m focal length; ~2 arcmin FWHM; 40 shells (130 – 260 mm dia); Only 12 Kg !

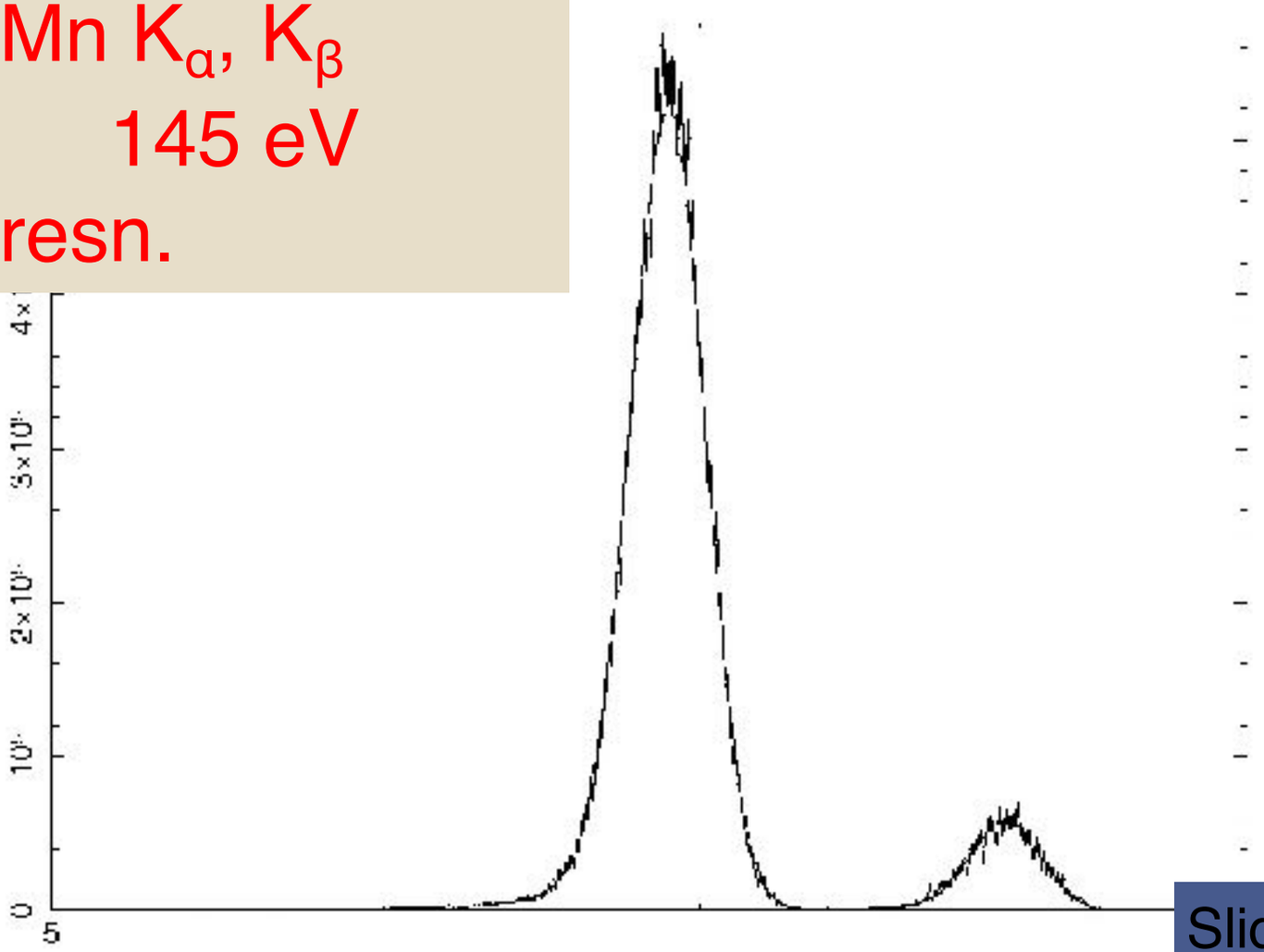
Mirror roughness 7 – 10 Angstroms : Exp. Ast. (2011)28,11

CCD: X-ray illumination

CCD: Optical illumination

Mn K_α, K_β

145 eV resn.



Slide courtesy: K P Singh

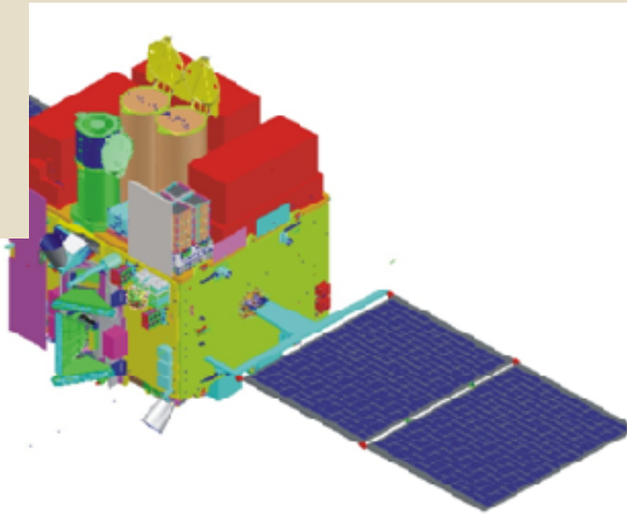
CZT-Imager

Weight - 50 kg

Size: 60 cm

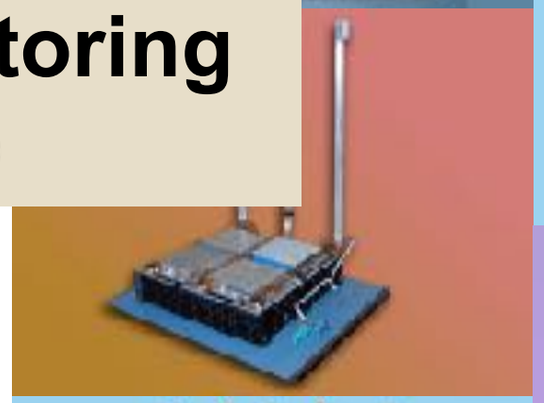
Integral
(2000 kg; 500 cm; 25.6°)
Swift (1500 kg; 560 cm; 20°)

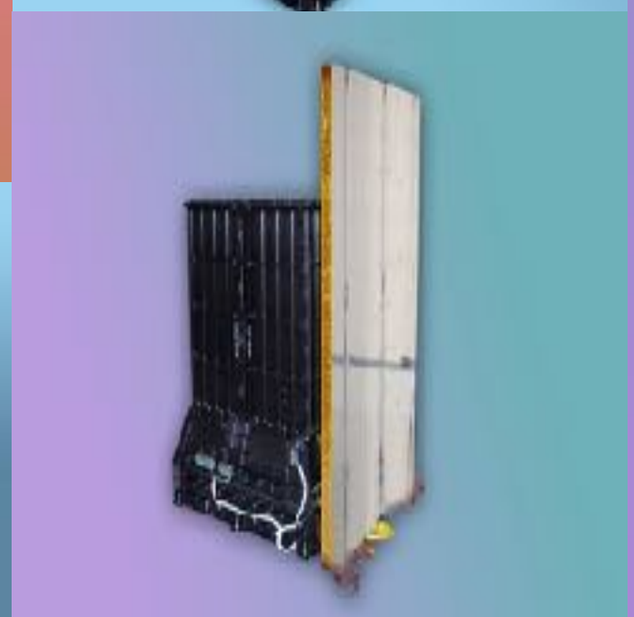
Low Inclination 6°

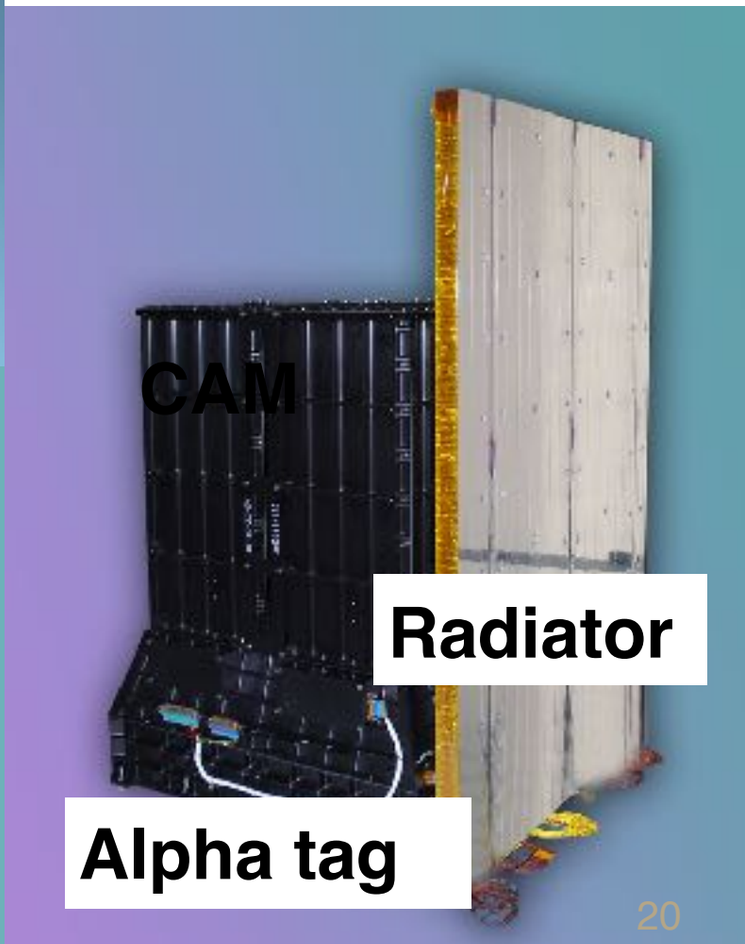


Continuous time-tagged individual photon data (20 micro-sec)

Hard X-ray monitoring (above ~ 80 keV)



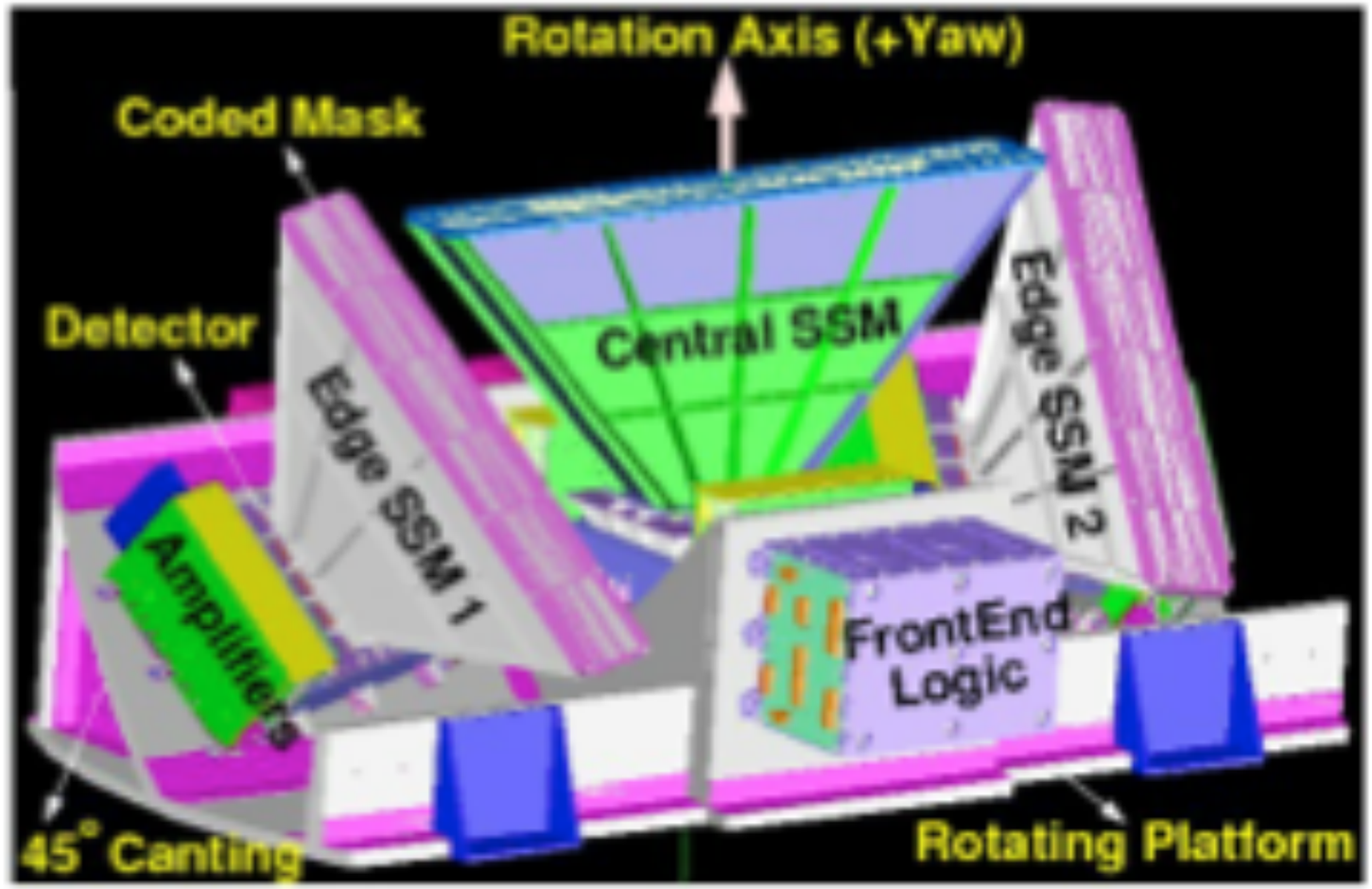


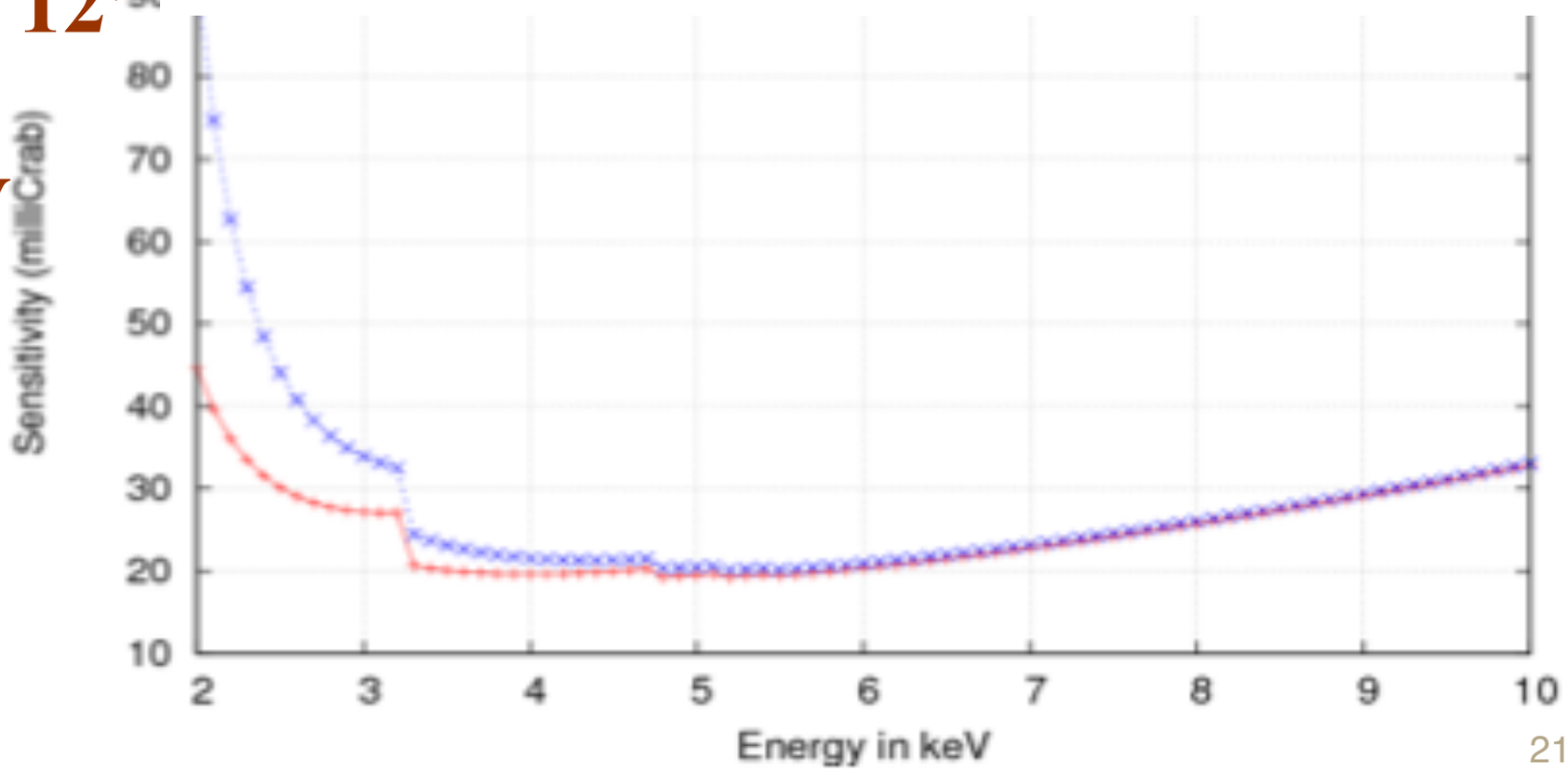


Bhalerao et al. 2016 (JAA, 38, 31)

Scanning Sky Monitor (SSM)

- 3 PSPC
- Area 60 cm² (5 keV)
- Ang res. : 2.5° & 12’
- Res 20%@ 6 keV





Ultraviolet Imaging Telescope (UVIT)

Doors

Main-baffles

Secondary Mirror

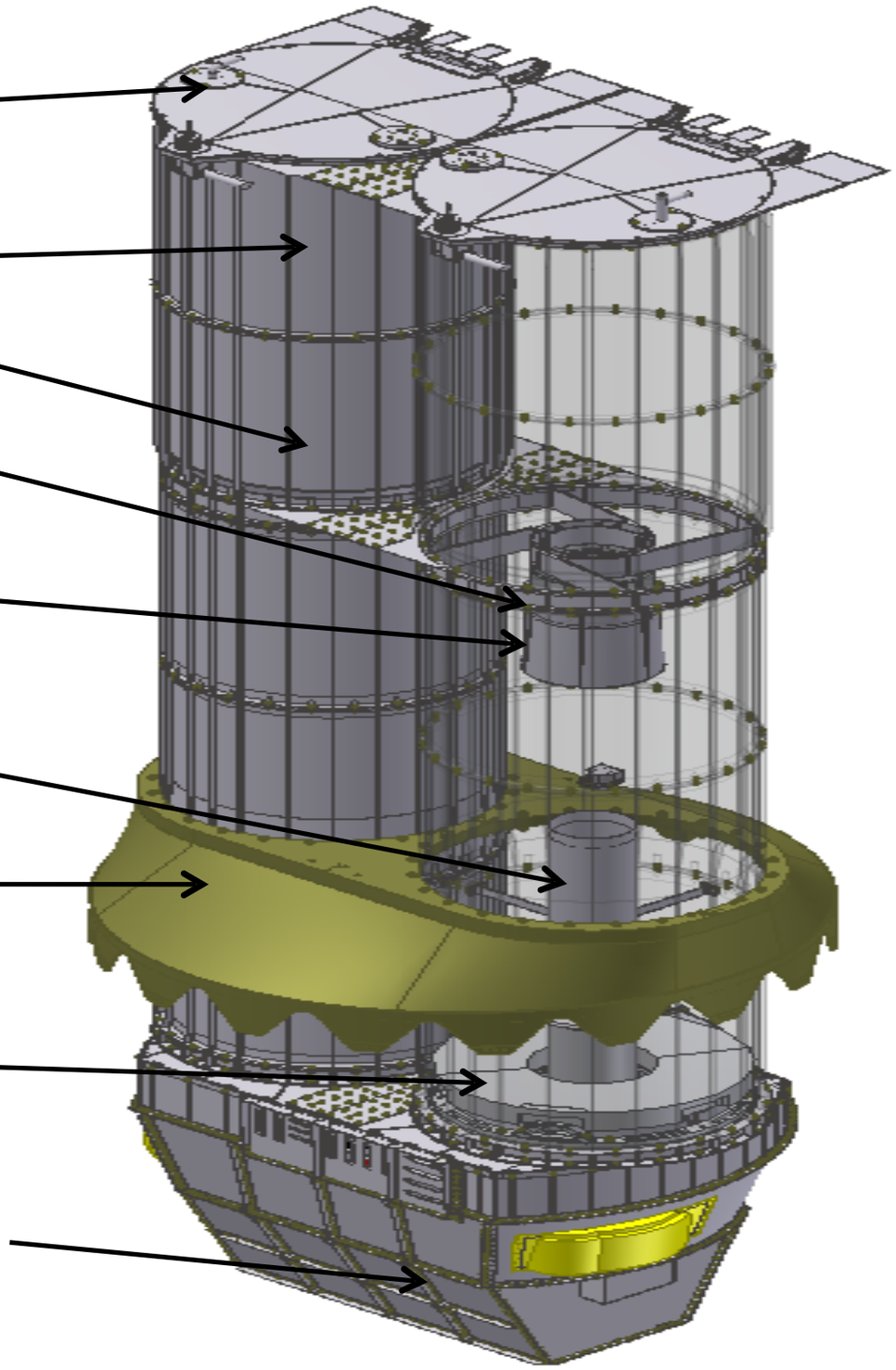
Sec. Baffle

Primary Baffle

TiCone (interface
With S/C)

Primary mirror (375 mm)

Thermal cover (this encloses
Detectors and filter-wheels)



~3100 mm

Slide courtesy: Swarna Ghosh

Comparison of UVIT with GALEX (#1 of 2)

parameter	GALEX	UVIT
No. of telescopes	1	2
Telescope optics	RC, f/6	RC, f/12; RC, f/12
Primary Mirror size (dia)	50 cm	38 cm, 38 cm
FoV (Circular dia)	75 arc-min	28 arc-min
No. of bands	2 (Far-UV =FUV Near-UV=NUV)	3 channels FUV (125-180 nm) NUV (180-300 nm) Visible=VIS (320-550 nm)
Filters in FUV	1 fixed band	4 filters
Filters in NUV	1 fixed band	5 filters
Filters in VIS	----------	5 filters

Slide courtesy: Swarna Ghosh

Comparison of UVIT with GALEX (#2 of 2)

parameter	GALEX	UVIT
Slitless Spectroscopy with	Grism	Grating
Spectral Resolution	R ~ 100-200	R ~ 100-200
No. of grism/grating	1 per band	2 per band (orthogonal pair)
Angular resolution(FWHM)	4.5-6.0 arc-sec	< 1.8 arc-sec
Peak Effective area	FUV : 37 cm²	FUV : ~15 cm²
	NUV : 62 cm²	NUV : ~50 cm²
	---	VIS : 50 cm²
Saturation (m_{AB})	< 10 mag	< 8.0 mag (with ND filter)
Time resolution	~ 10 milli-sec	< 5 milli-sec

Slide courtesy: Swarna Ghosh

LAXPC		RXTE PCA
3 – 80 keV	Energy range	2 – 60 keV
12% (22 keV)	Energy resolution	< 18% (6 keV)
8000 cm^2	Effective area	6500 cm^2 *
1 deg^2	FOV & Resolution	1 deg^2
10 microsec	Time resolution	1 microsec
0.1 mCrab (3σ, 1ks)	Sensitivity	0.1 mCrab

SSM		RXTE ASM
2.5 – 10 keV	Energy range	2 – 10 keV
25% (6 keV)	Energy resolution	3 bands
53 cm^2 (5 keV)	Effective area	90 cm^2 (geometric)
10° × 90° (3' × 12")	FOV & Resolution	6° × 90° (3' × 15")
80% sky / 90 min	Time coverage	80% sky / 90 min
28 mCrab	Sensitivity	30 mCrab

SXT		Swift XRT
0.3 – 8 keV	Energy range	0.2 – 10 keV
5 – 6% (1.5 keV)	Energy resolution	~ 8% (1/5 keV)
128 cm2 (1.5 keV)	Effective area	110 cm2 (1.5 keV)
40’ (2’)	FOV & Resolution	23.6’ (18”)
2.4s, 0.3s	Time resolution	2.5, 2.2 ms (WT)
10^{-13} (5σ, 20ks)	Sensitivity	2×10^{-14} (10ks)

UVIT		Swift UVOT
130 – 550 nm	Energy range	170 – 650 nm
13 (220 – 430 nm)	Filters	6 (212 – 543 nm)
FUV, NUV	Grisms	UV (>170nm), V
8 – 50 cm^2	Effective area	15 – 50 cm^2
28’ (1.8” UV, 2.2” V)	FOV & Resolution	17’ (2.5” at 350 nm)
20 mag (130-180 nm)	Sensitivity (5σ, 200s)	19.4 mag (UVW2)

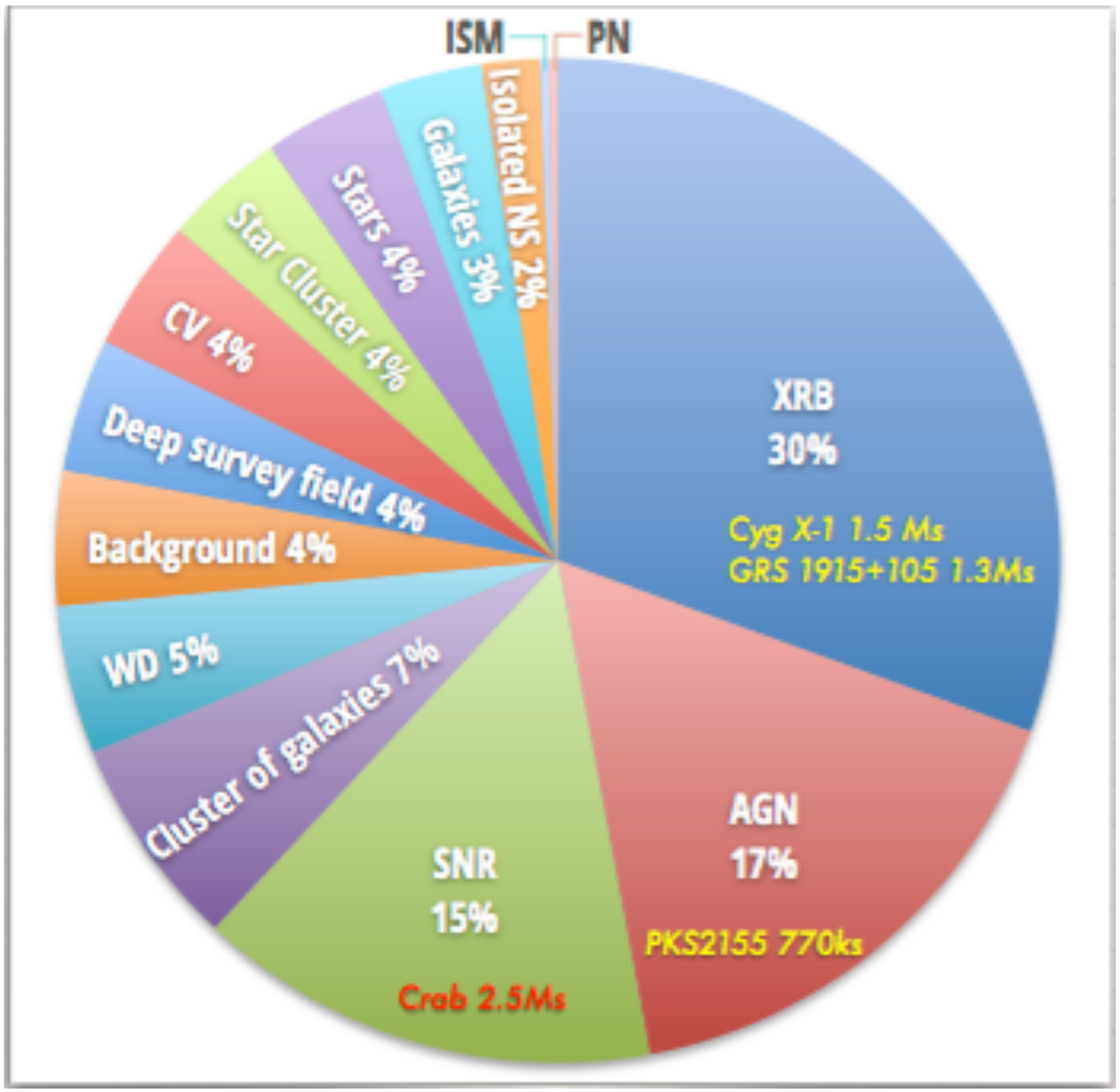
CZTI		Swift BAT
20 – 200 keV	Energy range	15 – 150 keV
Photon counting	Operation	Survey mode (coadd) / Burst mode (photon counting)
1000 cm^2	Effective area	5200 cm^2
36 sq deg (8')	FOV & Resolution	4600 sq deg (17')
1 msec	Time resolution	5 sec / 0.1 msec
0.5 mCrab	Sensitivity (3σ, 1ks)	~40 mCrab

Astrosat Advantages:

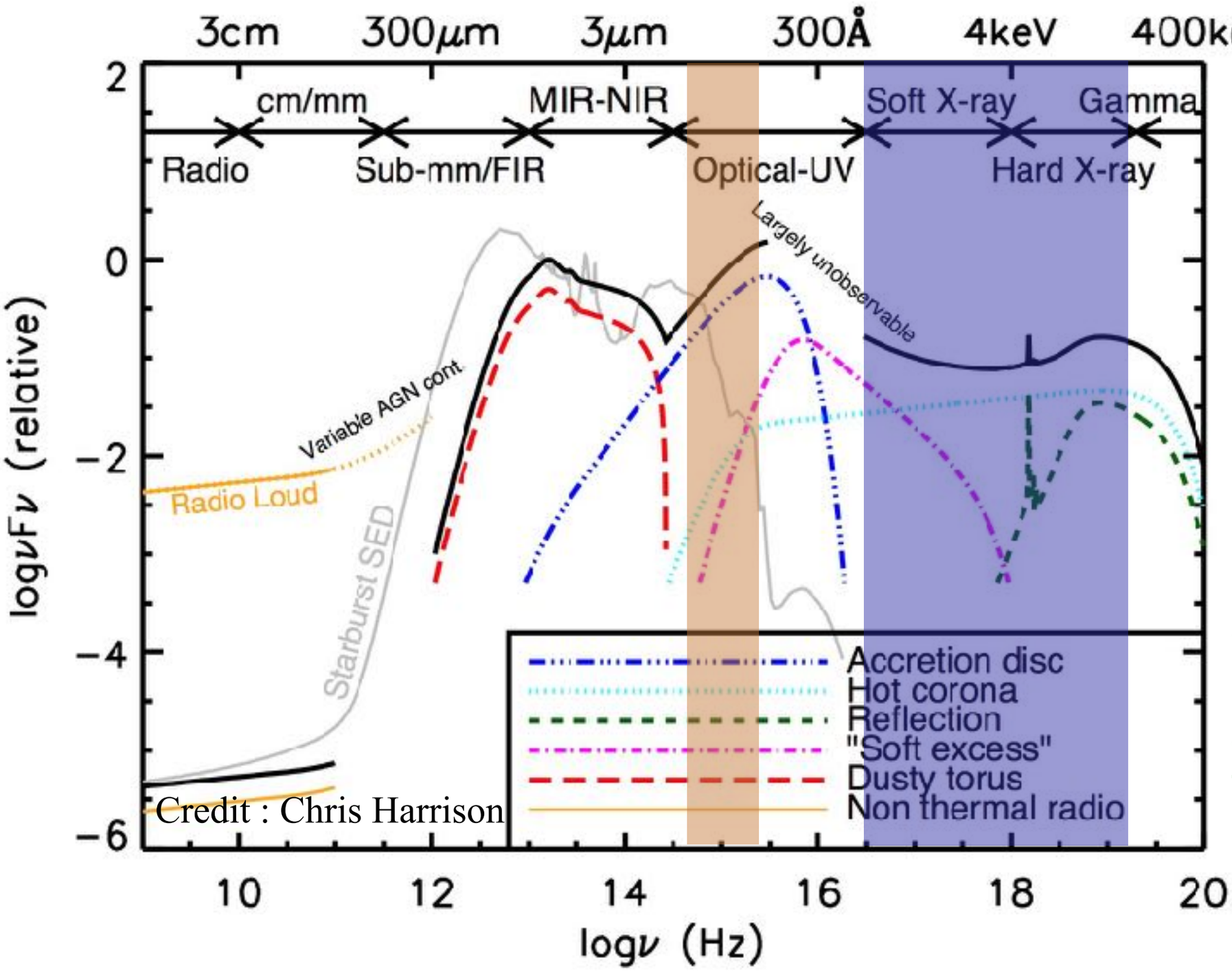
- *Low Inclination*
- *Continuous time-tagged data (LAXPC, CZTI & SSM) - micro-seconds*
- *Bright source observing capability of SXT*
- *Facility to adjust SSM observation time*
- *Hard X-ray (above ~ 80 keV) monitoring*

The first year of *AstroSat*

- Six months PV phase
- Six months GT
- 30 Ms
  Efficiency :
  ~10% (UVIT) to
  ~ 55% (CZTI)
- 140 sources, 337 targets



AGN SED & Astrosat coverage



UVIT : FUV/NUV/VIS
15 optical/UV filters
(1300 - 5500A)

SXT (0.2-8 keV)

LAXPC (3-80 keV)

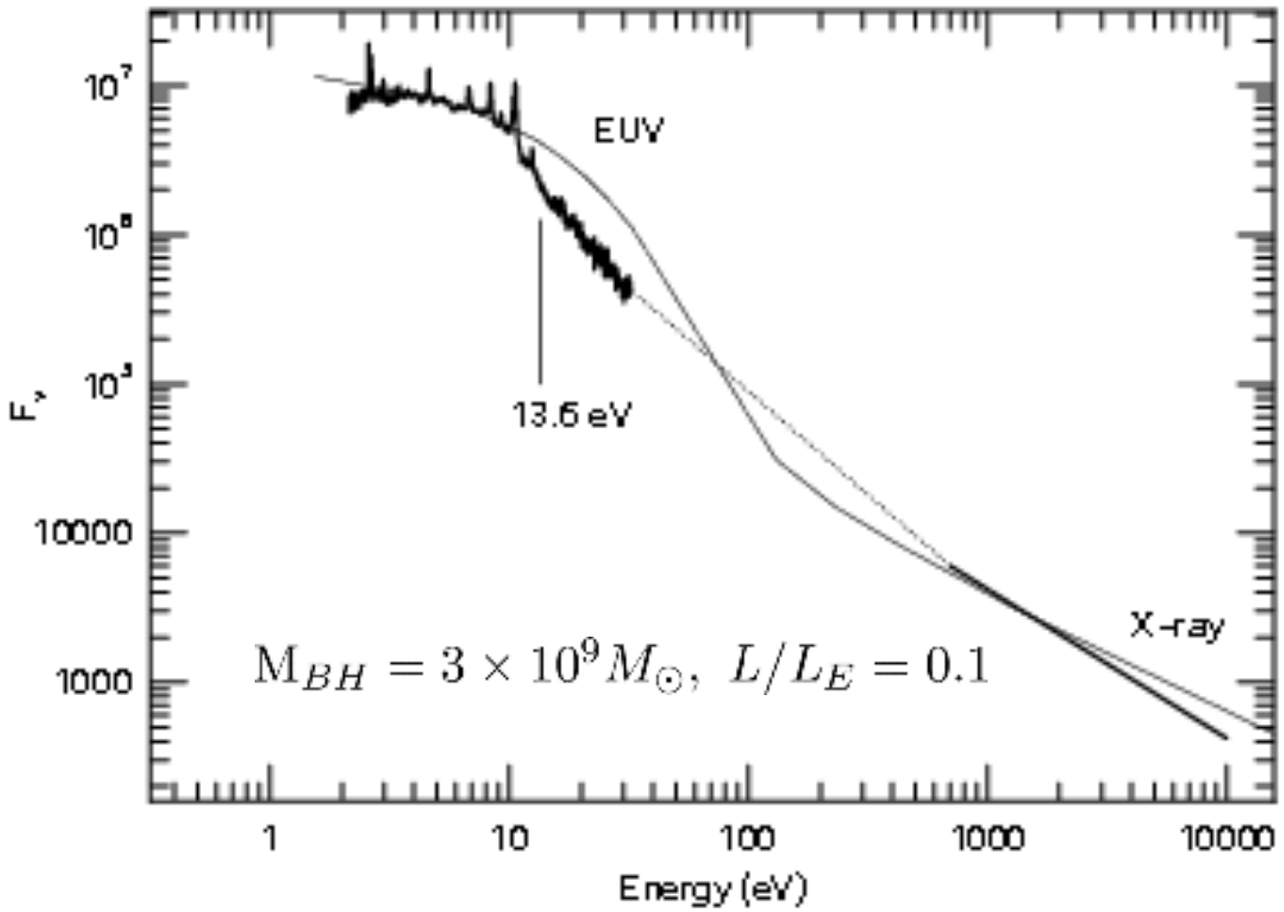
CZTI (10-100 keV)

AGN truly MW objects

Astrosat well suited for Central Engines nearby AGN

UV/X-ray emission from RQ AGN

Netzer (2005) in Physics of AGN at all Scales



- Based on mostly Non-simultaneous data

- Optical/UV emission not well described by the standard disk model.
- Many AGN accrete at high accretion rates.
- Is the assumption of standard SS accretion disk correct?

MW emission from type 1 AGN

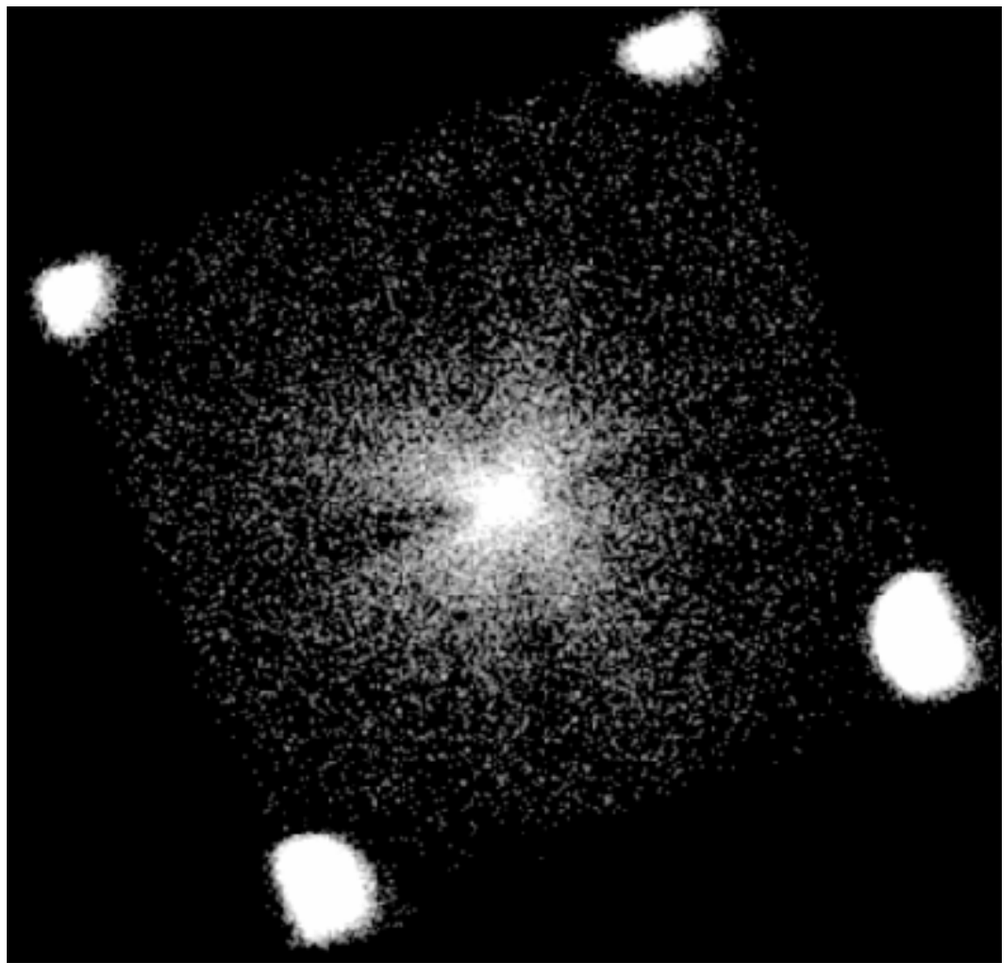
AstroSat observations

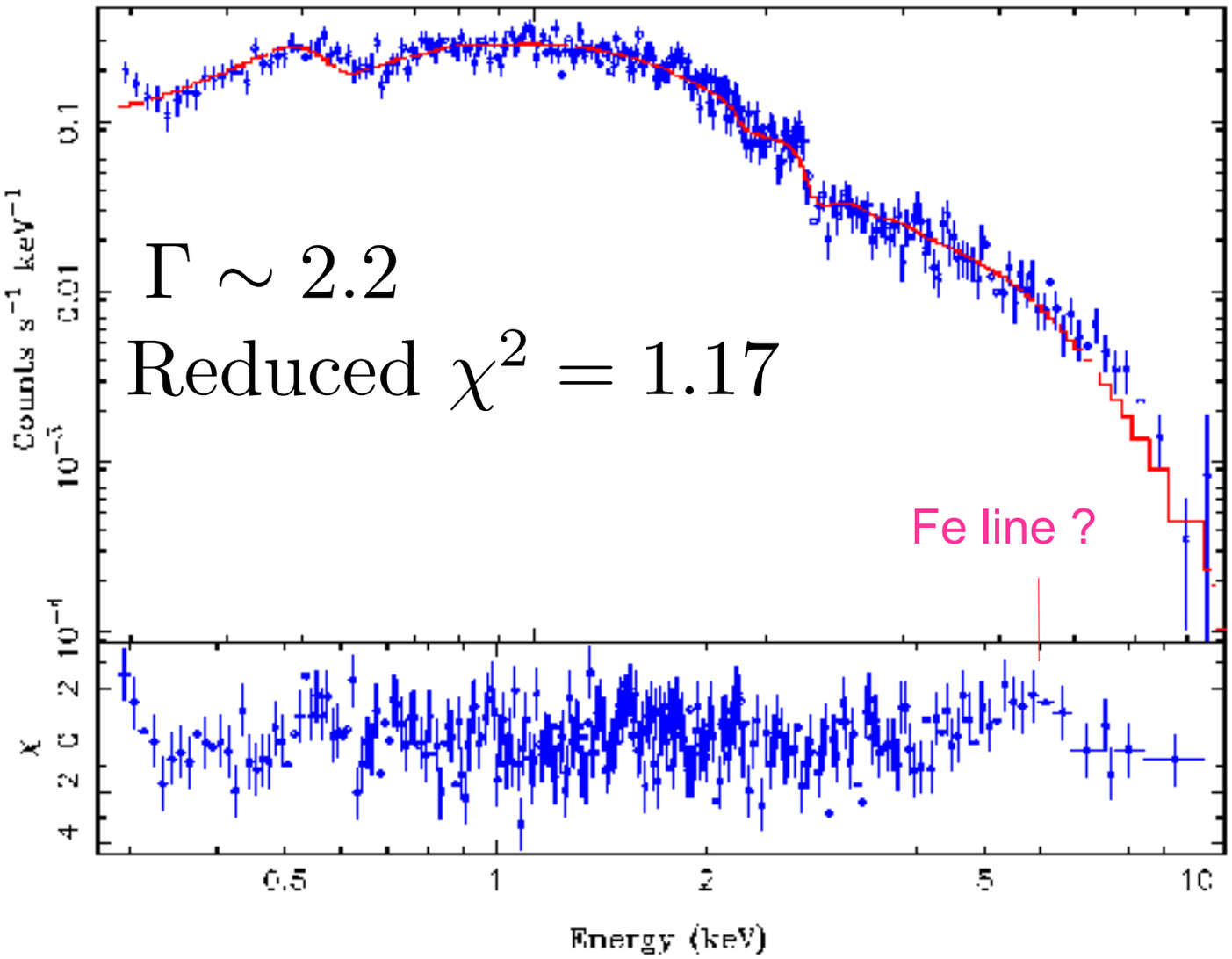
- Fairall 9 : Bright Seyfert 1
  (2-10 keV flux ~2e-11 cgs, V=13.8)
  - No intrinsic X-ray absorbption

- AstroSat MW observations (G06_157)
  - 30ks (SXT as primary inst)

Fairall 9 : SXT Data

- Net exposure : 25.8ks, source : 0.46 counts/s

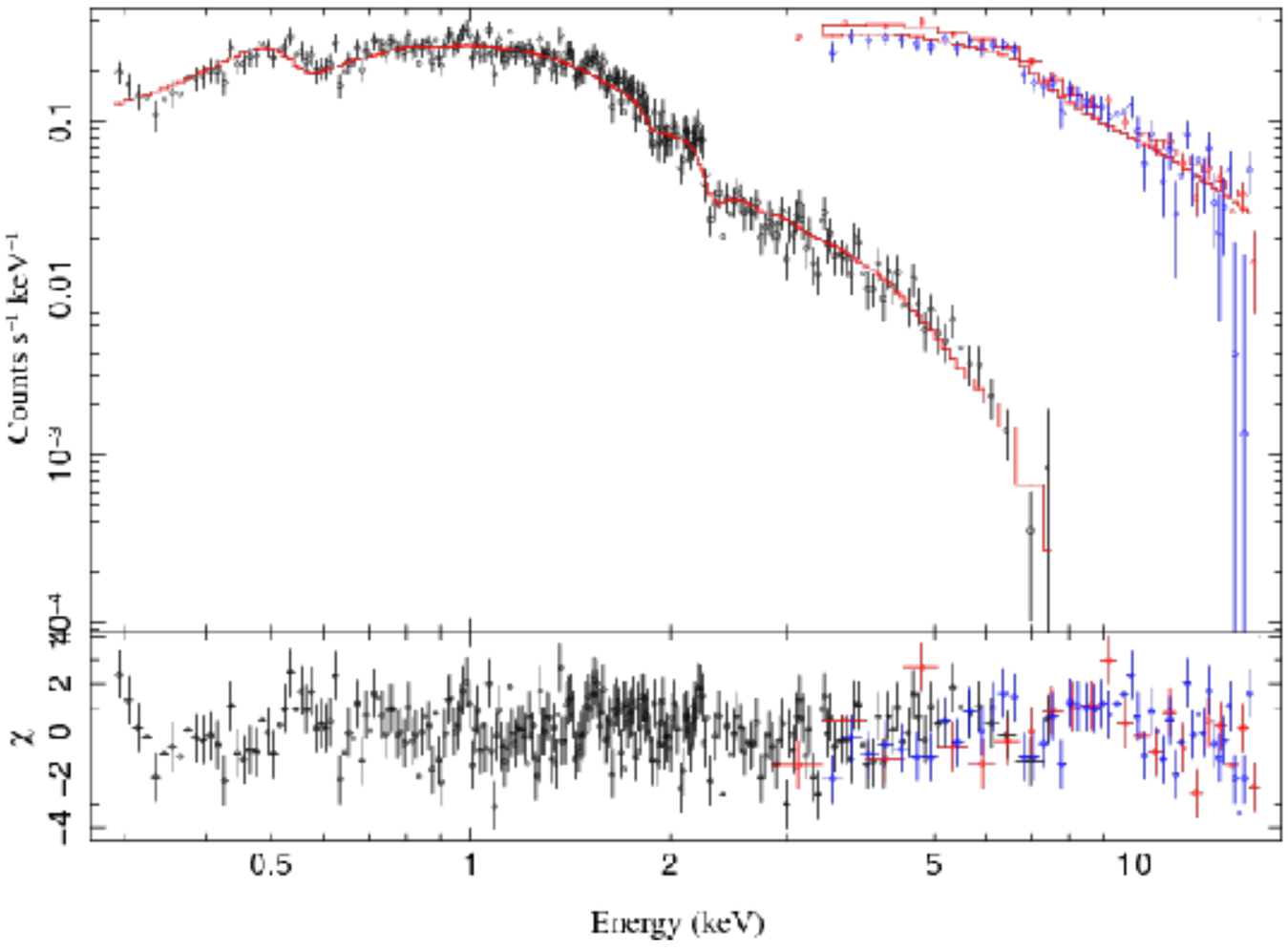


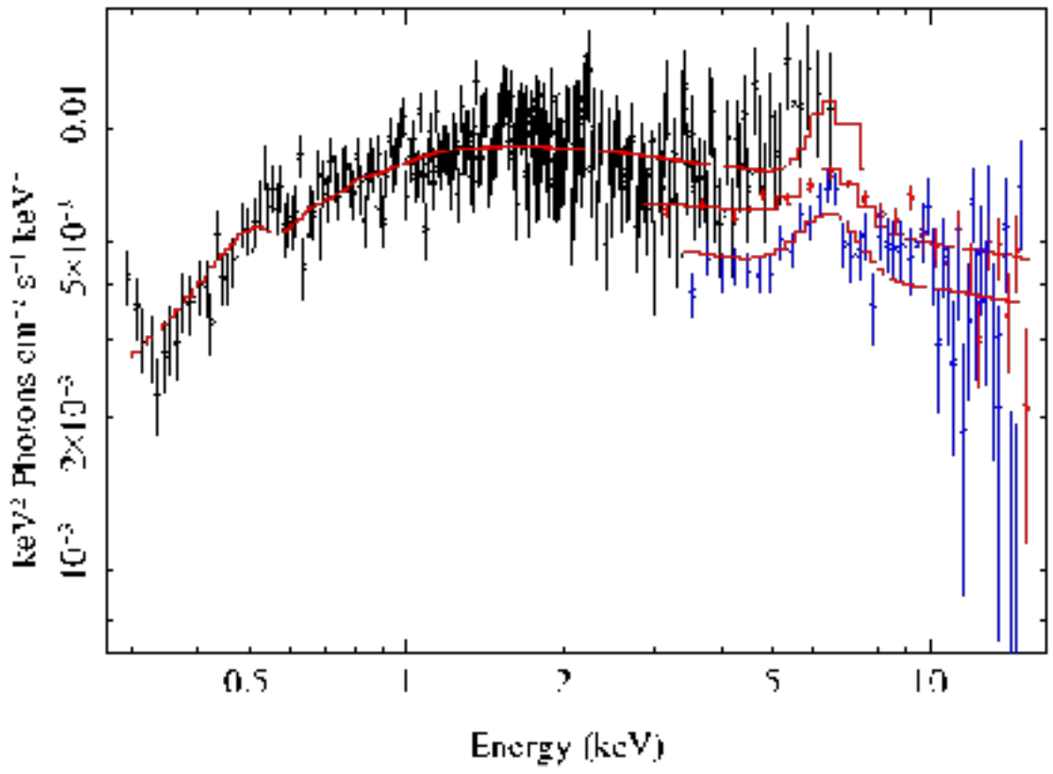


Simple absorbed powerlaw model

Fairall 9: SXT+LAXPC data

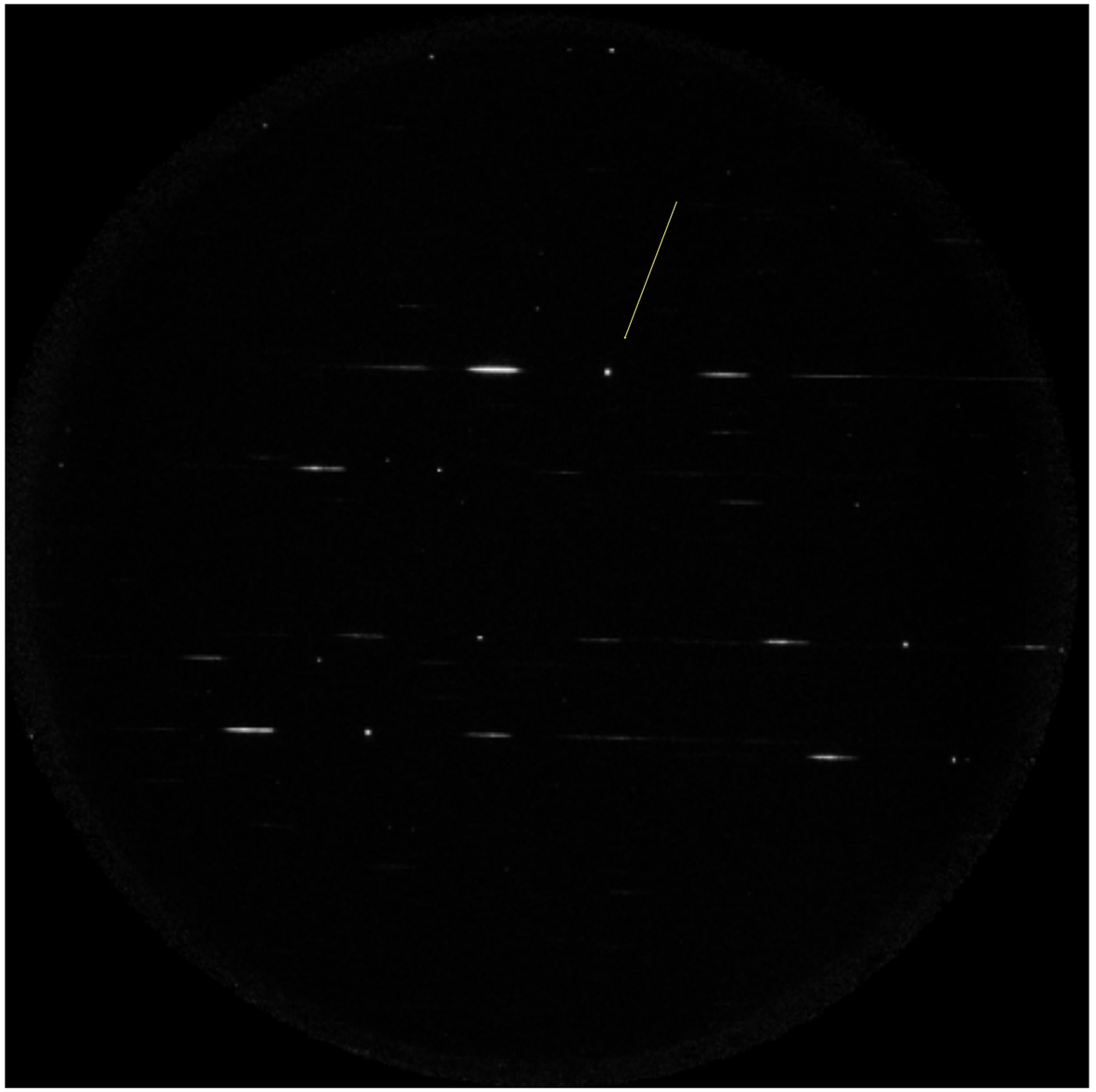
- Net LAXPC10 exposure : 52.7ks, source : 2 counts/s (3-15 keV, LAXPC1)

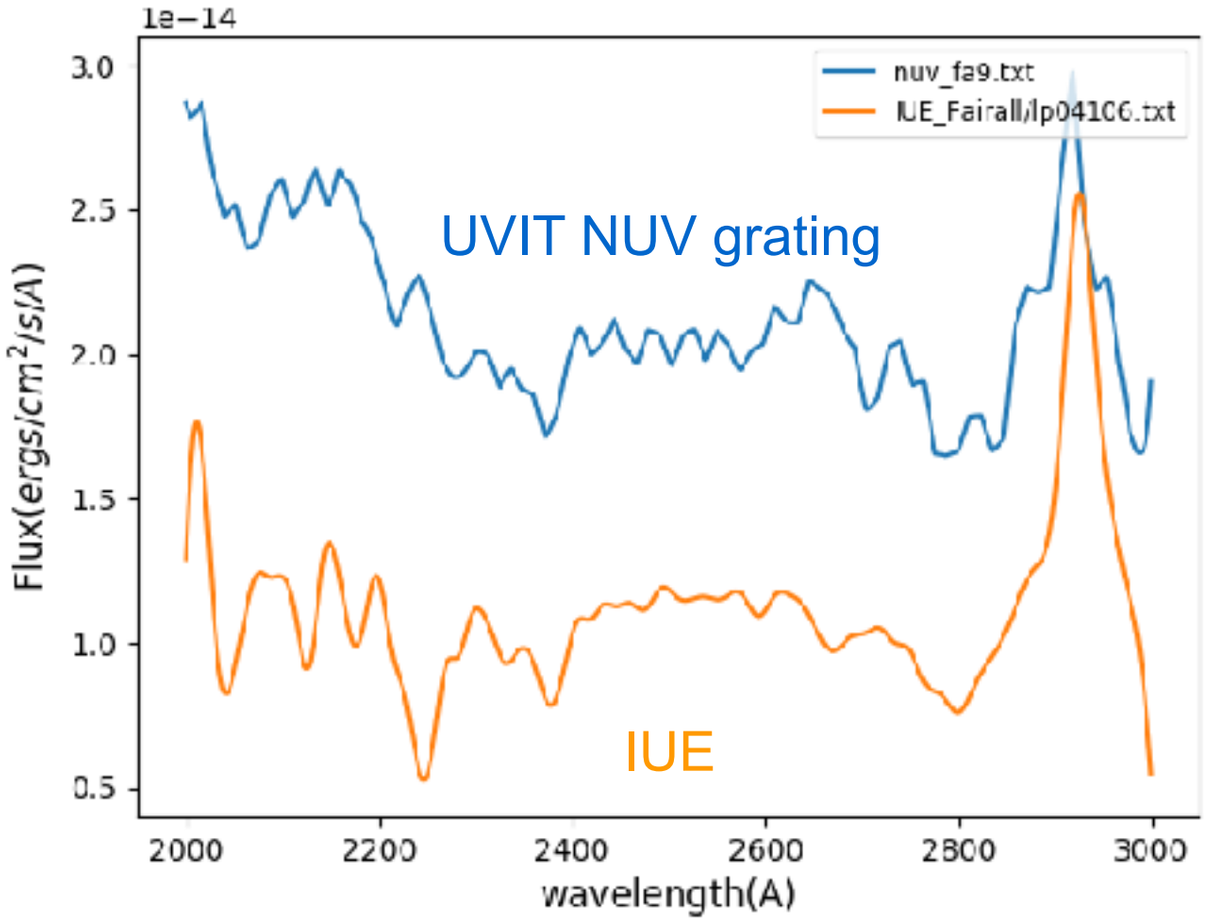




Fairall 9: UVIT observations

- NUV Grating exposure : 6000s

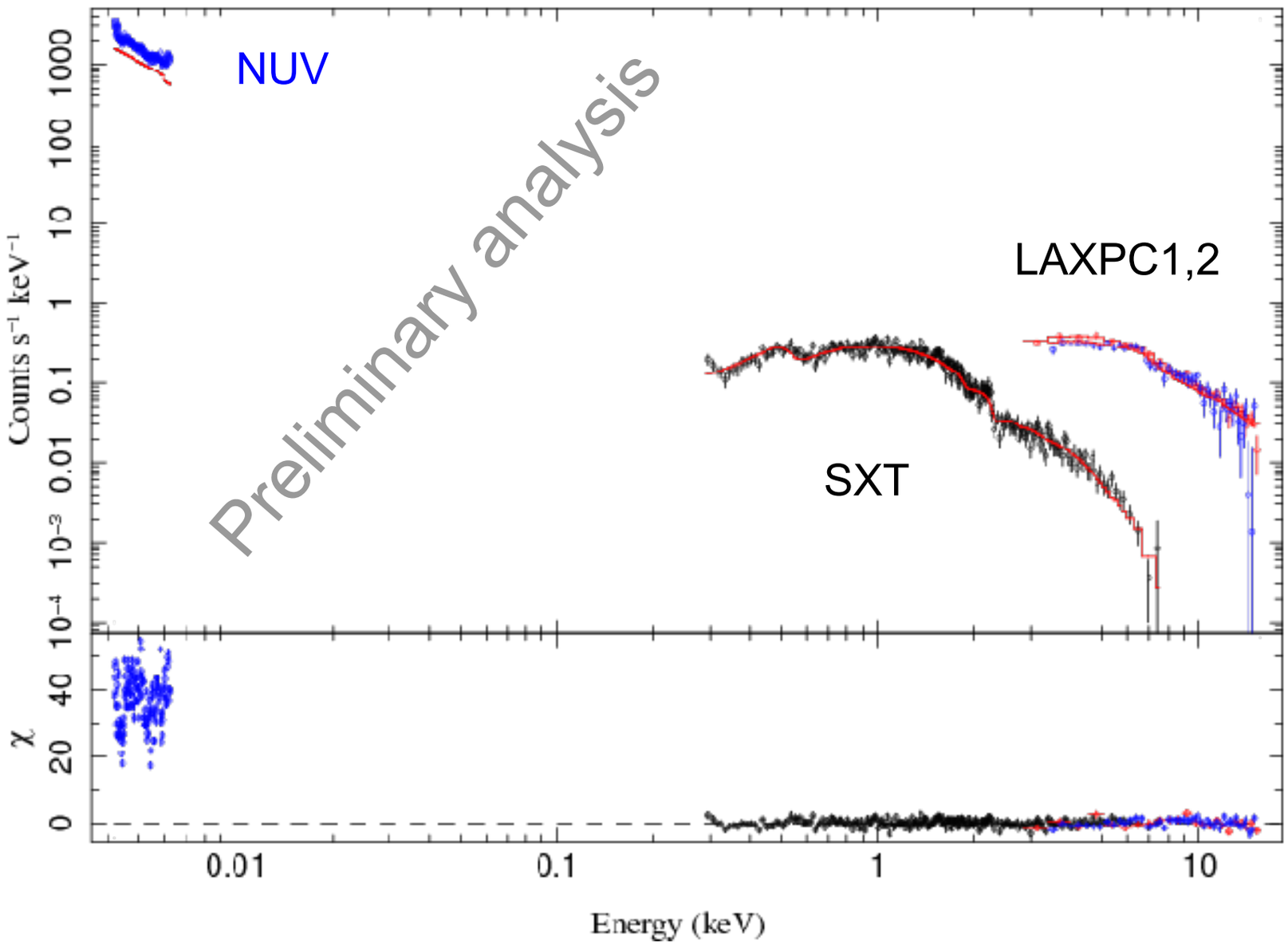




Sriram, UVIT POC

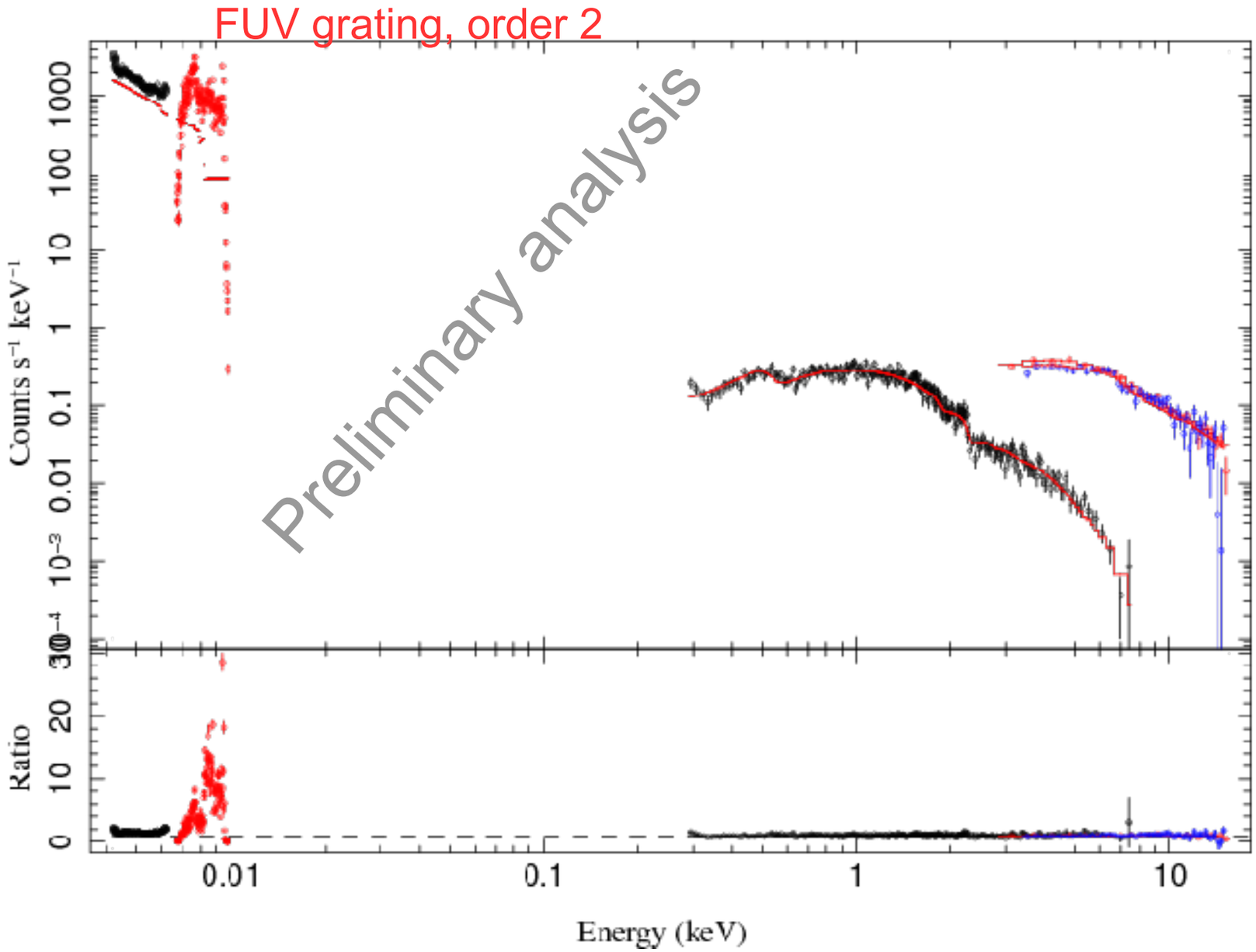
Fairall 9: SXT+LAXPC+NUV grating data

- Excess NUV emission

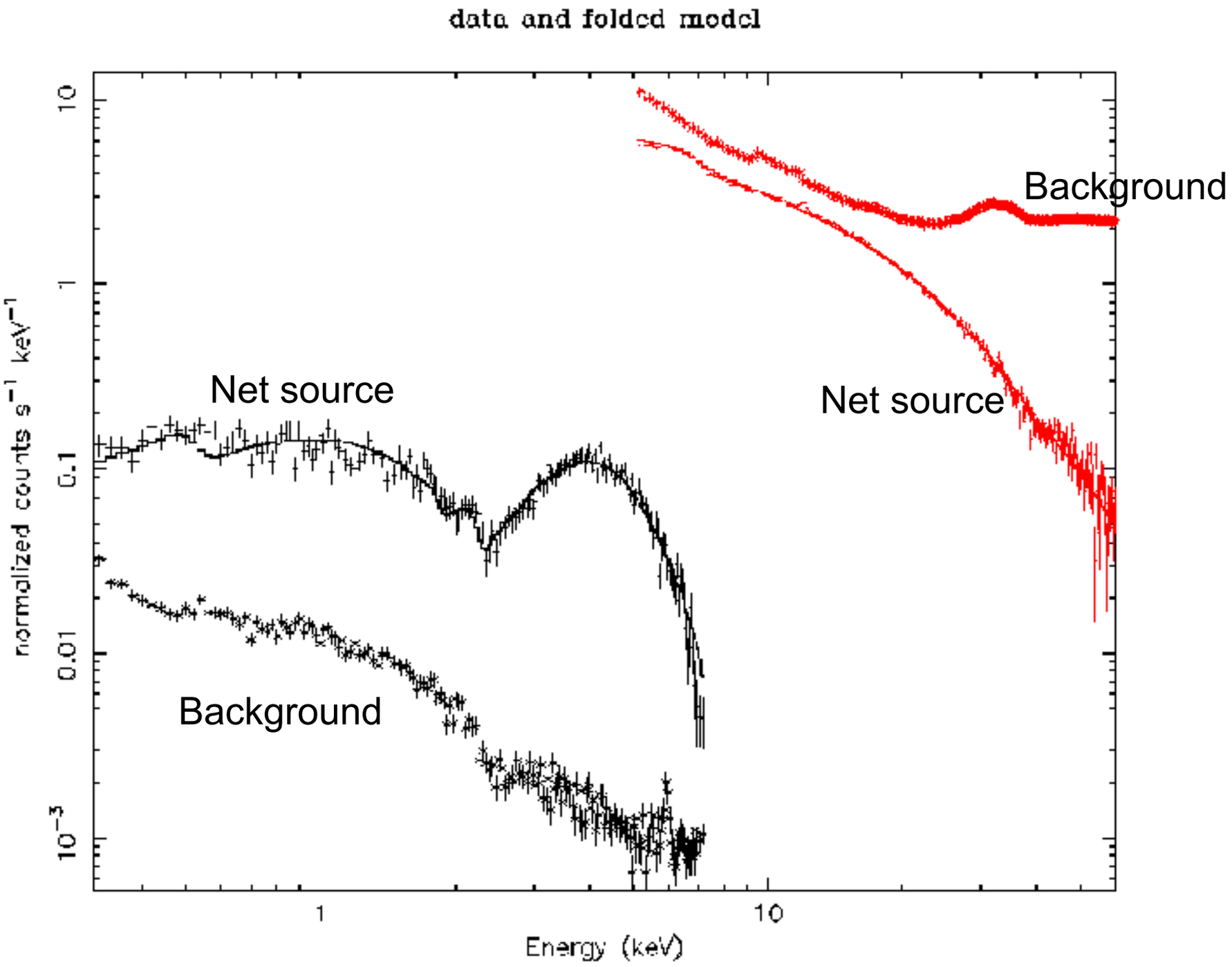


Fairall 9: SXT+LAXPC+NUV+FUV grating data

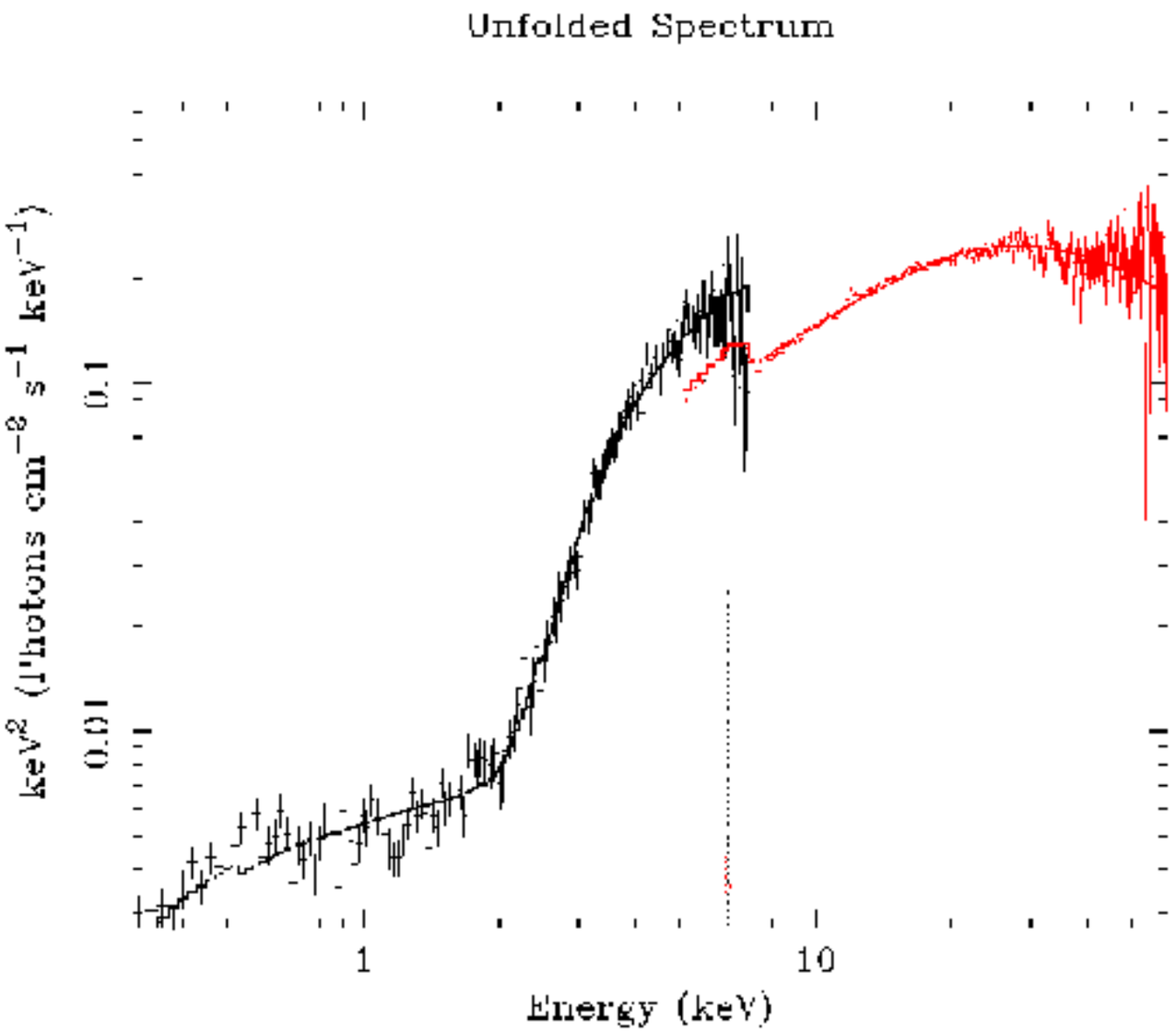
- Excess NUV emission



NGC4151 : AstroSat SXT/LAXPC
broadband continuum



NGC4151 : spectral model



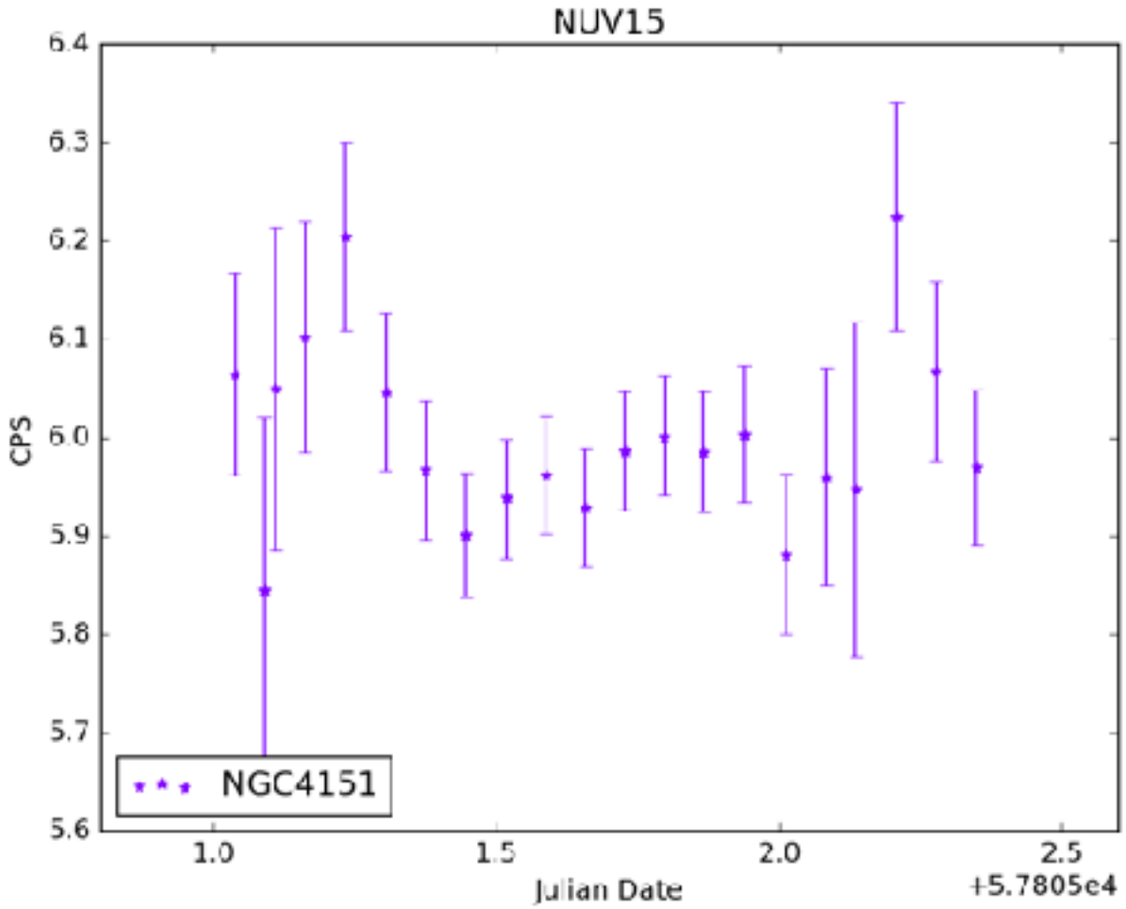
Model : wabs*pcfabs(pexrav+gauss)

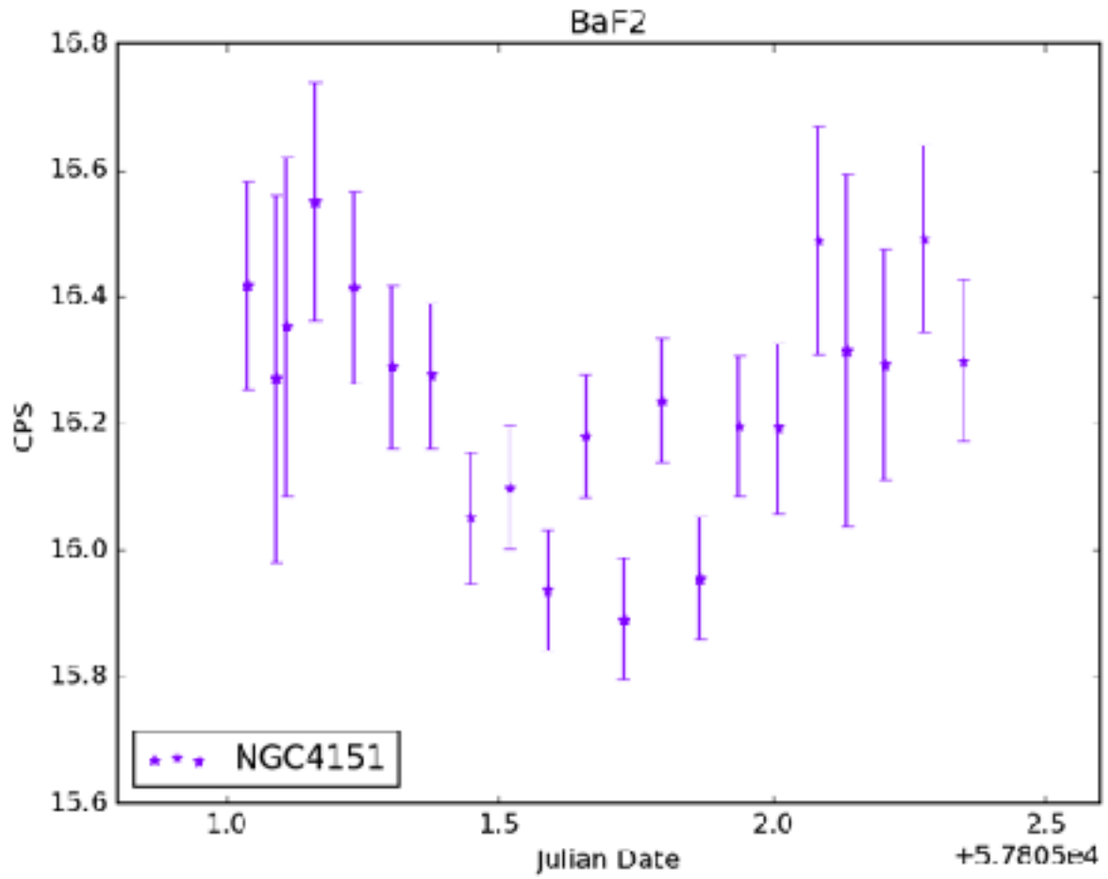
$$\Gamma \sim 1.7$$

$$R \sim 1$$

$$E_{cut} = 62 - 72keV$$

UVIT observations of NGC4151





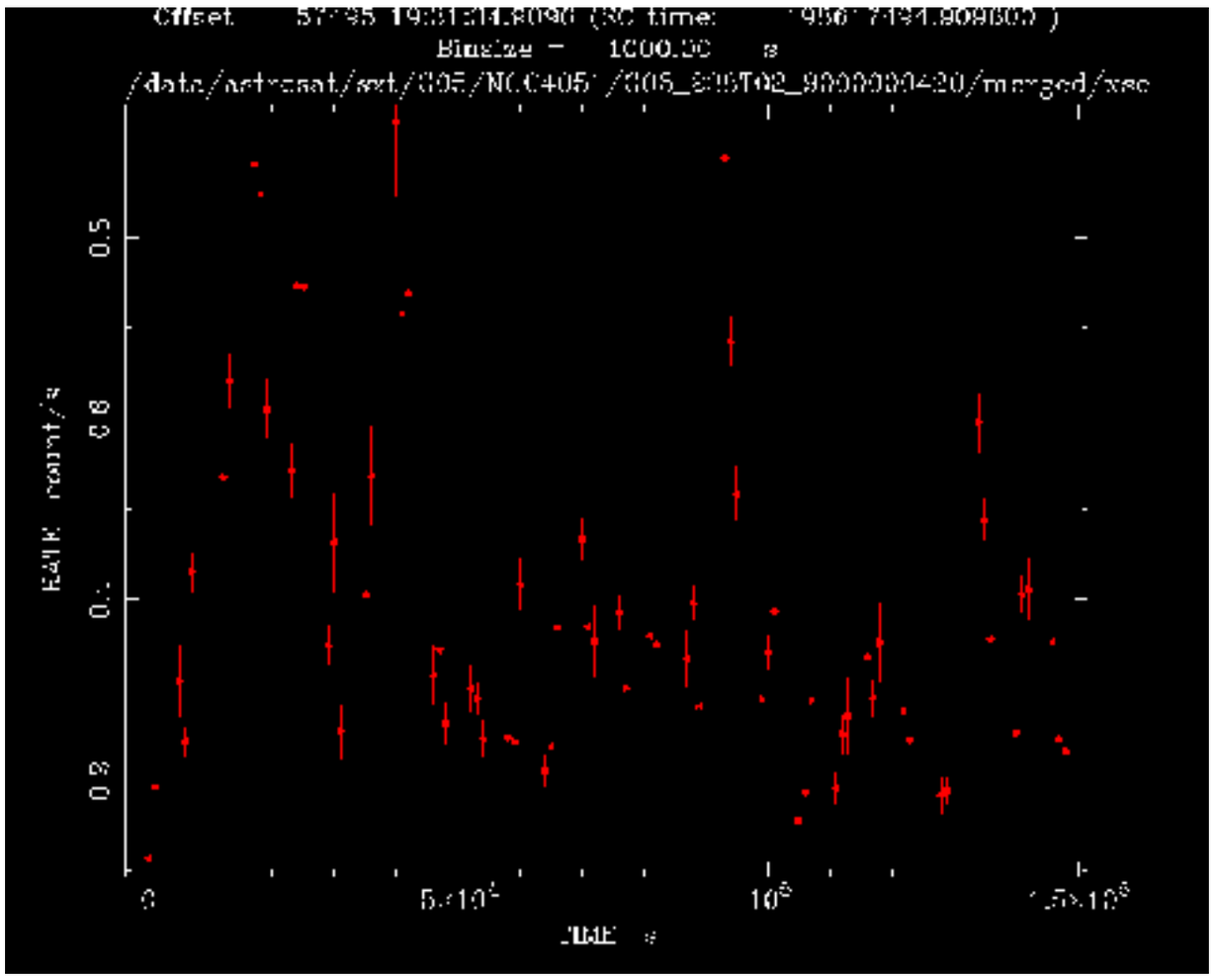
PI : K. P. Singh

Lightcurves provided by Stalin/Prajwal

UV/X-ray varibility

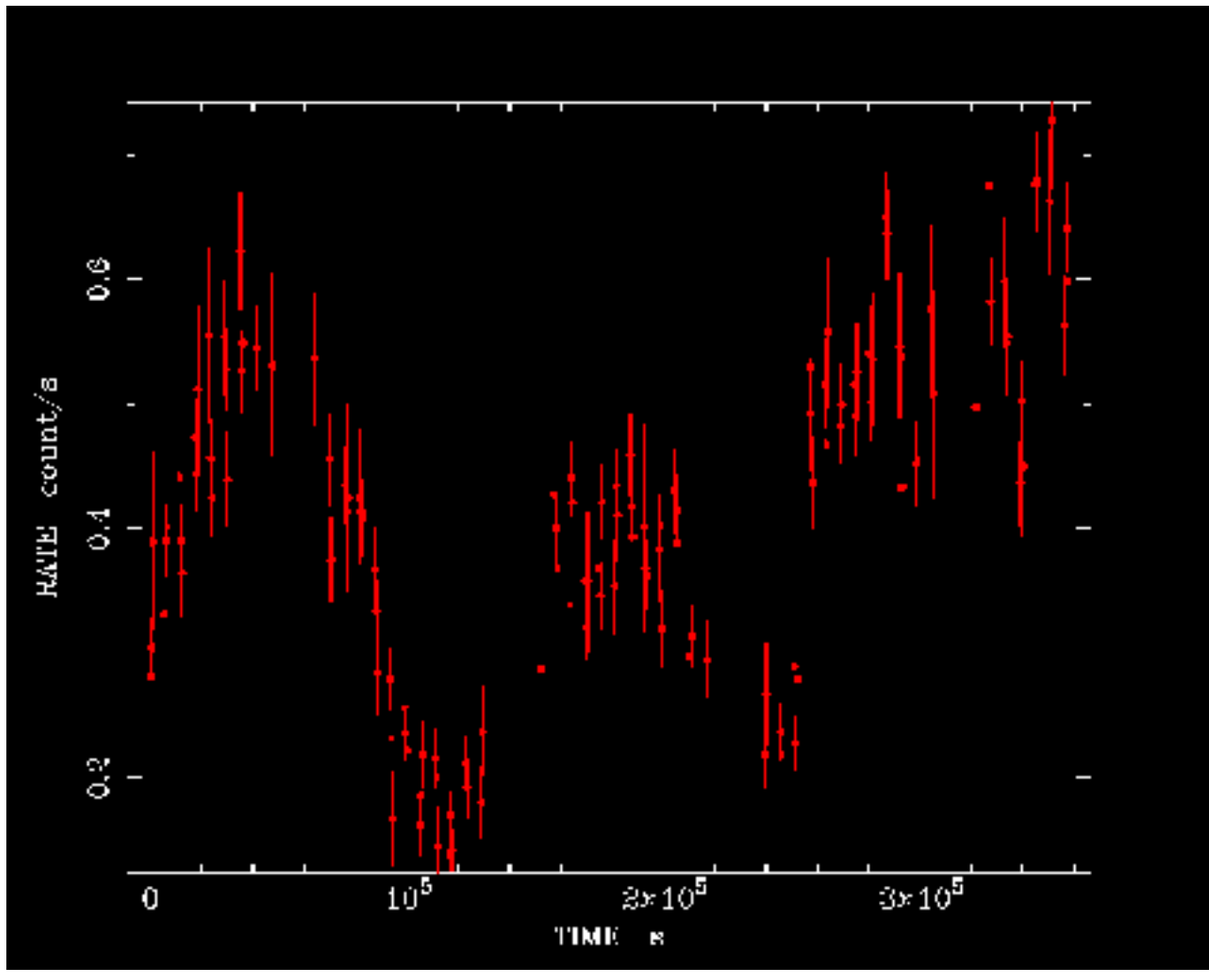
SXT observations of low BH mass AGN

NGC4051



PI : K. P. Singh (SXT GT)

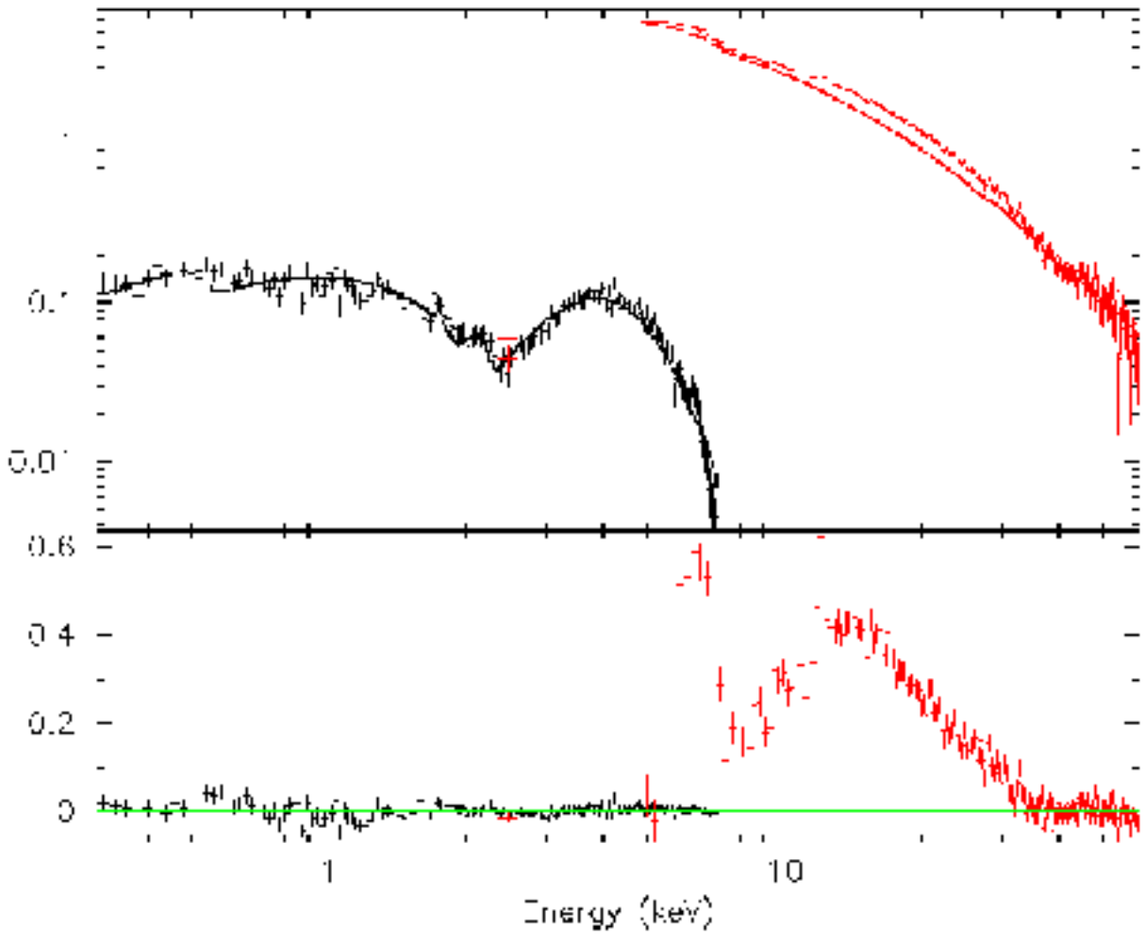
NGC4593



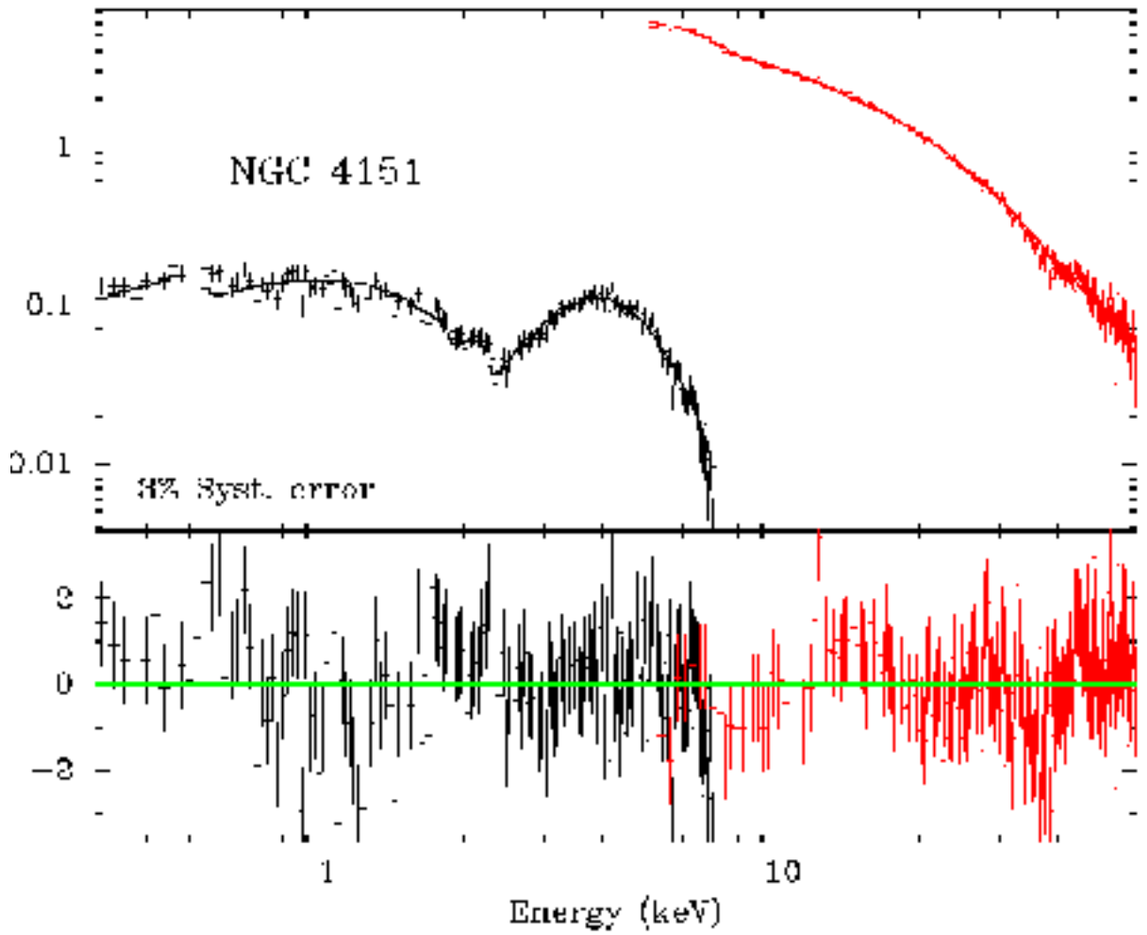
PI : D. Bhattacharya (CZTI PV)

NGC4151: SXT+LAXPC spectrum

Absorbed PL (0.3-5keV, 7-10, 40-60keV)

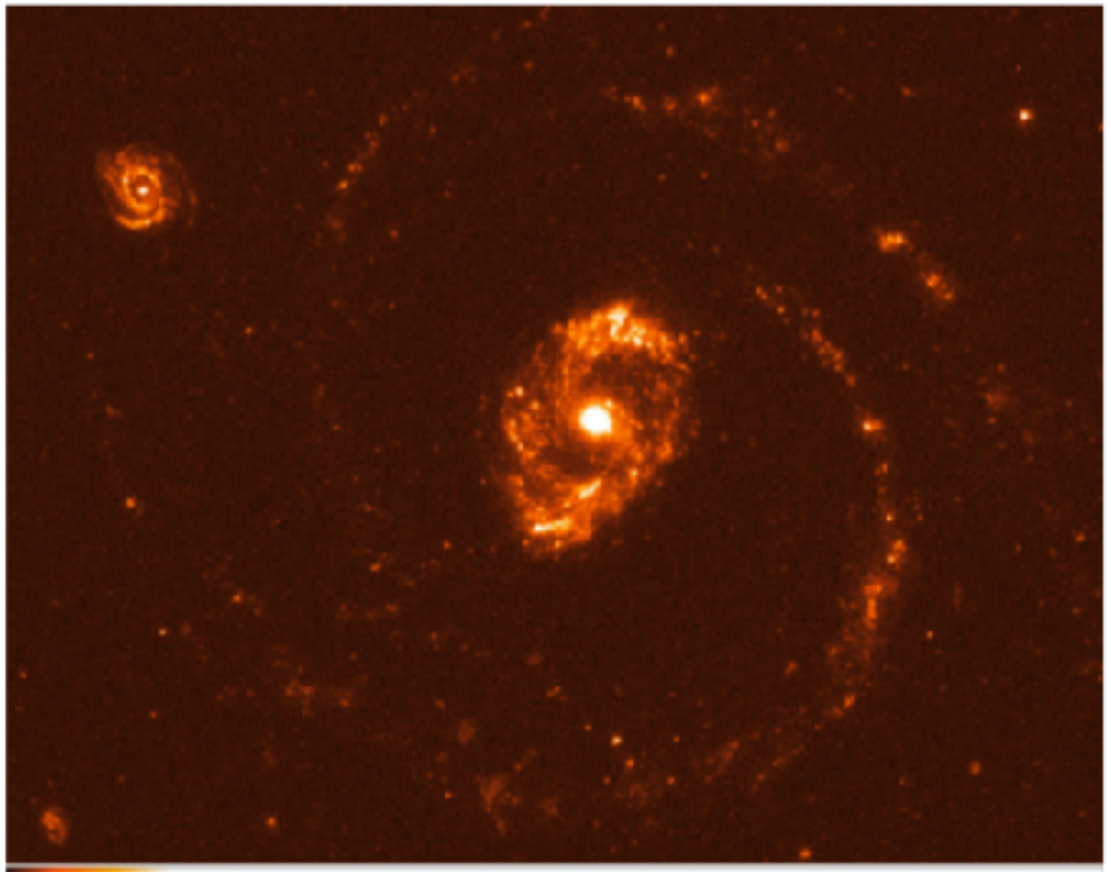


pcfabs*(pexrav + gauss)

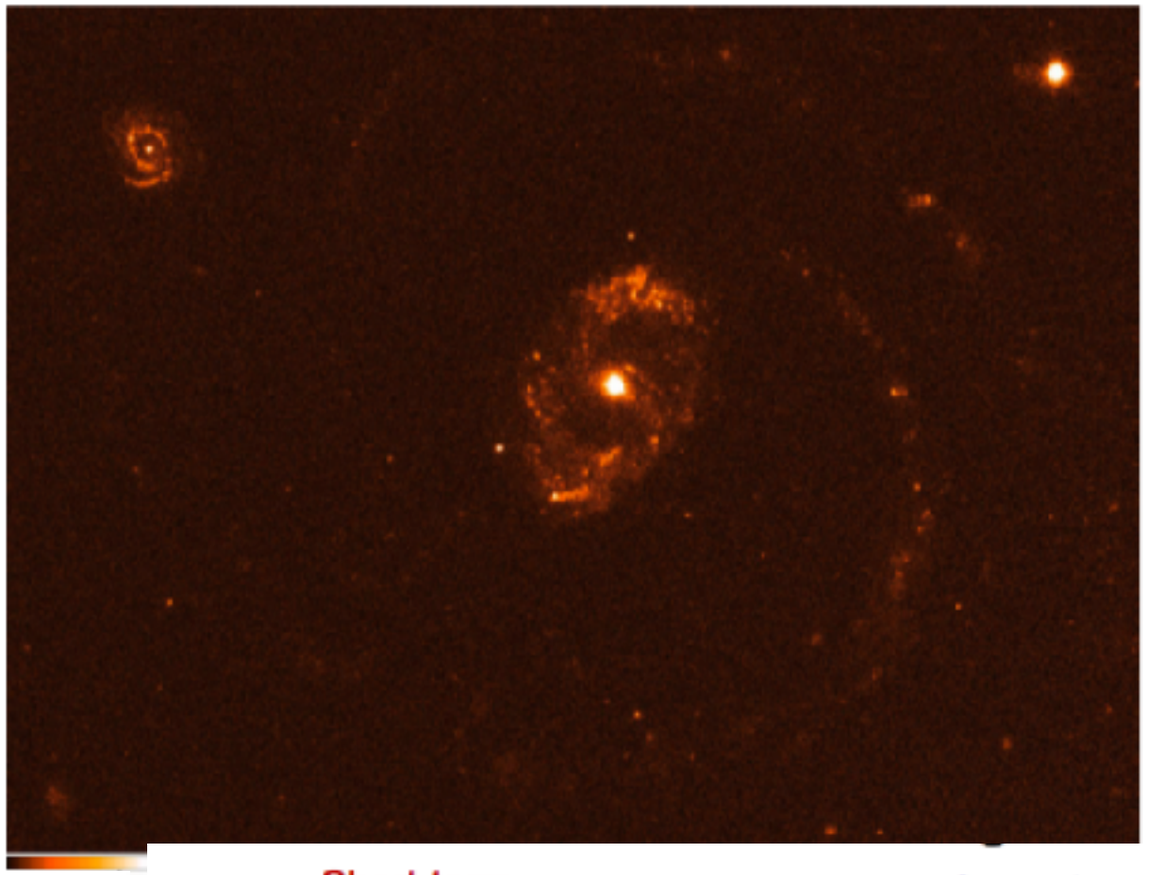


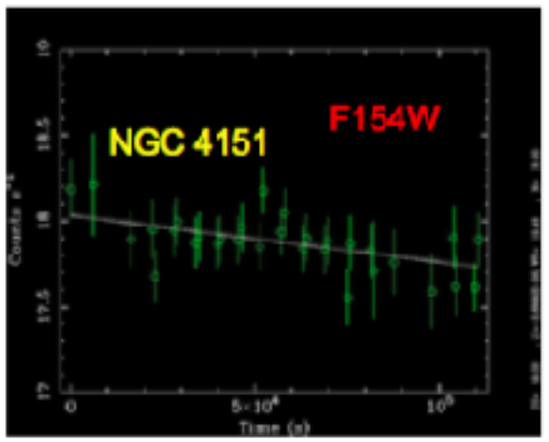
Reduced chi^2 = 1.3

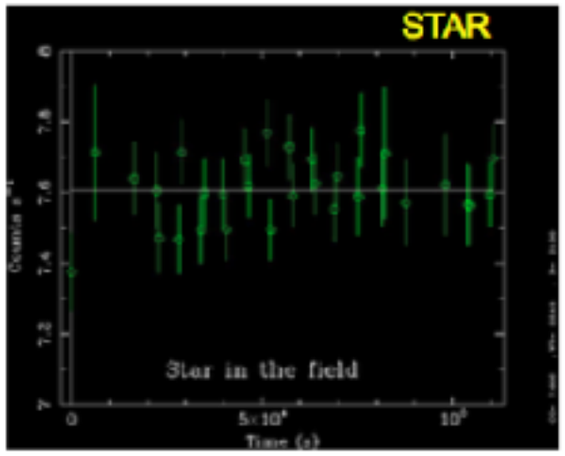
NGC4151 FUV BaF2/F154W (G06-III)

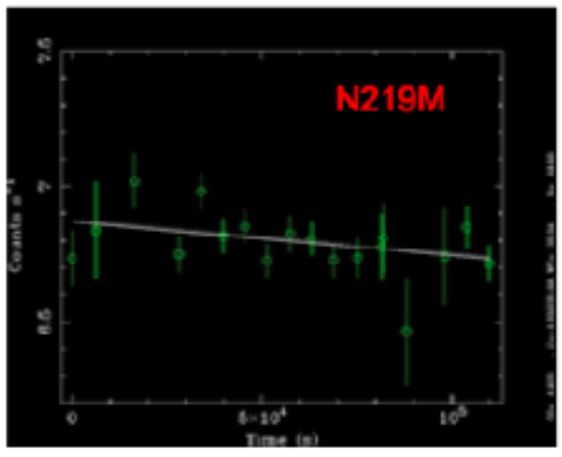


NGC4151 G06-III NUV B15/N219M



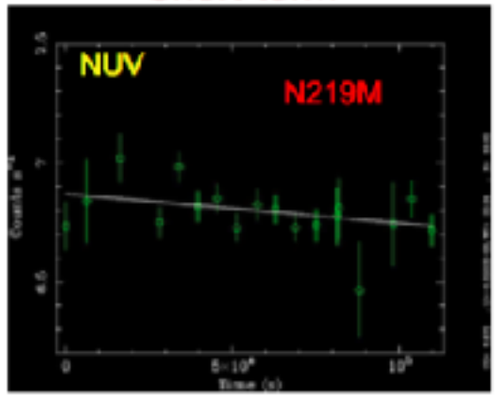


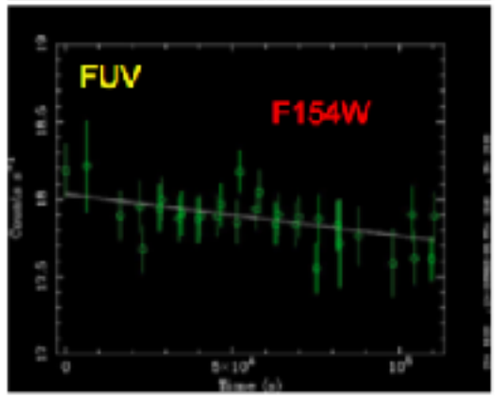




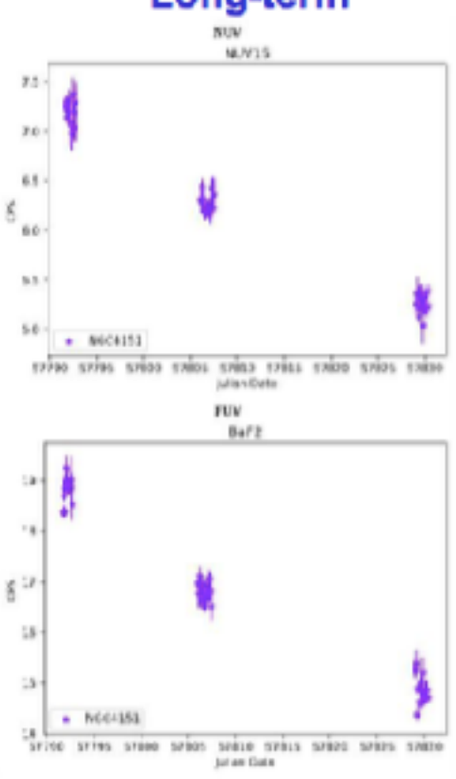
Marginal evidence for declining FUV and NUV flux

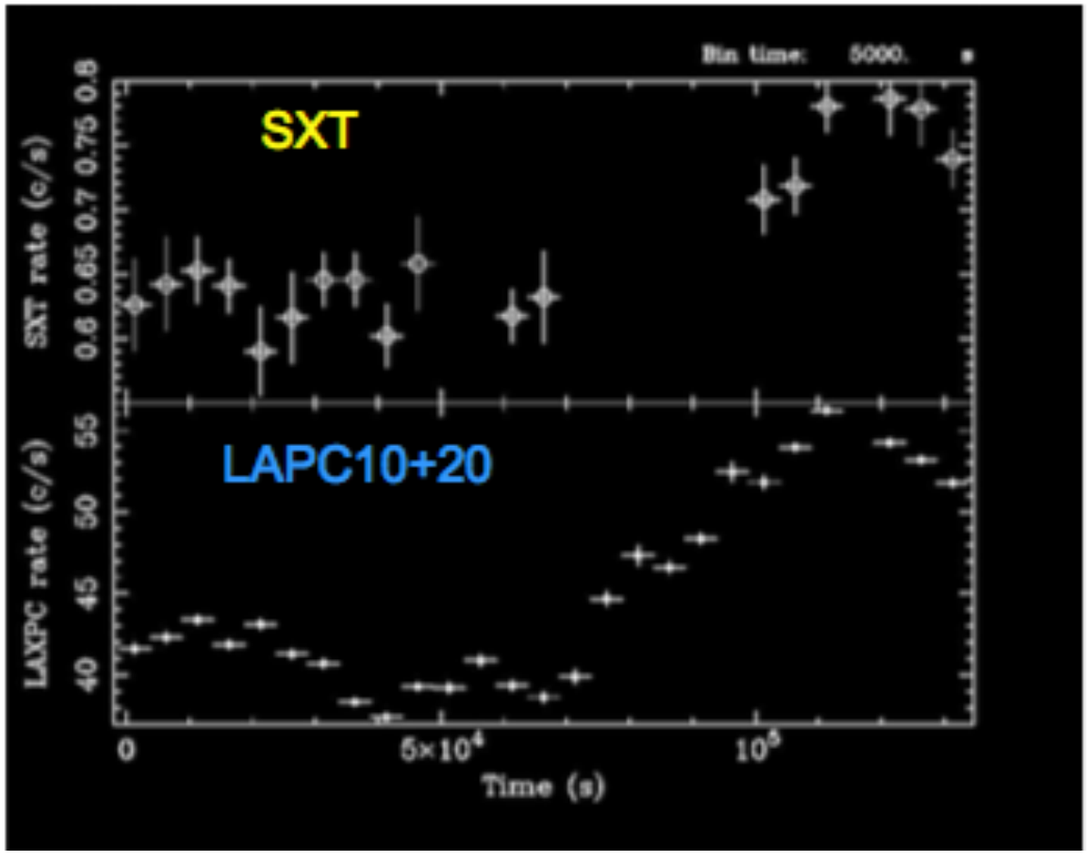
Short-term

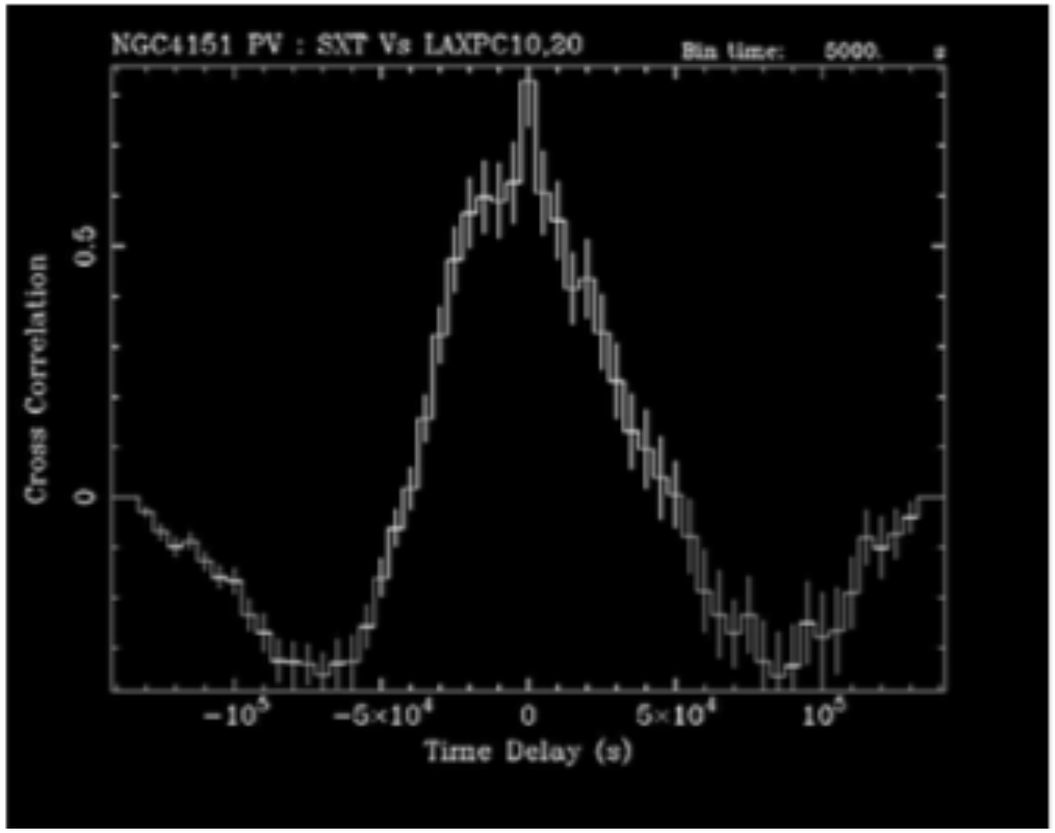




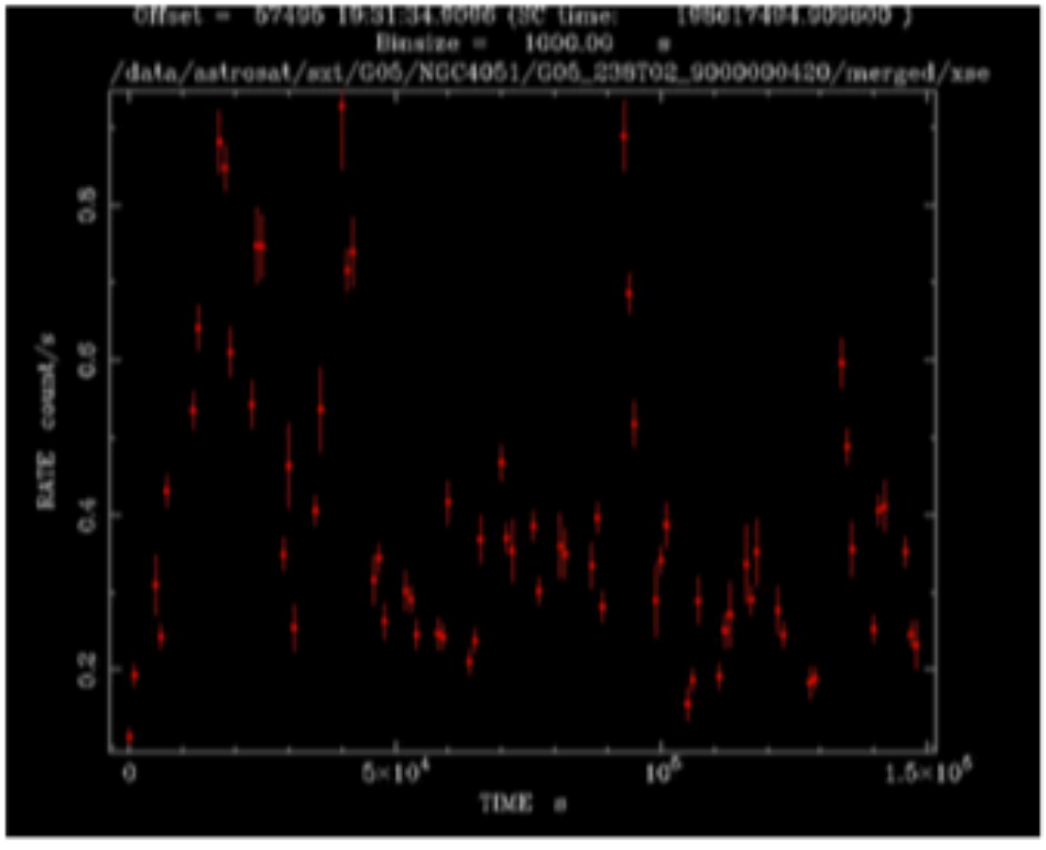
Long-term



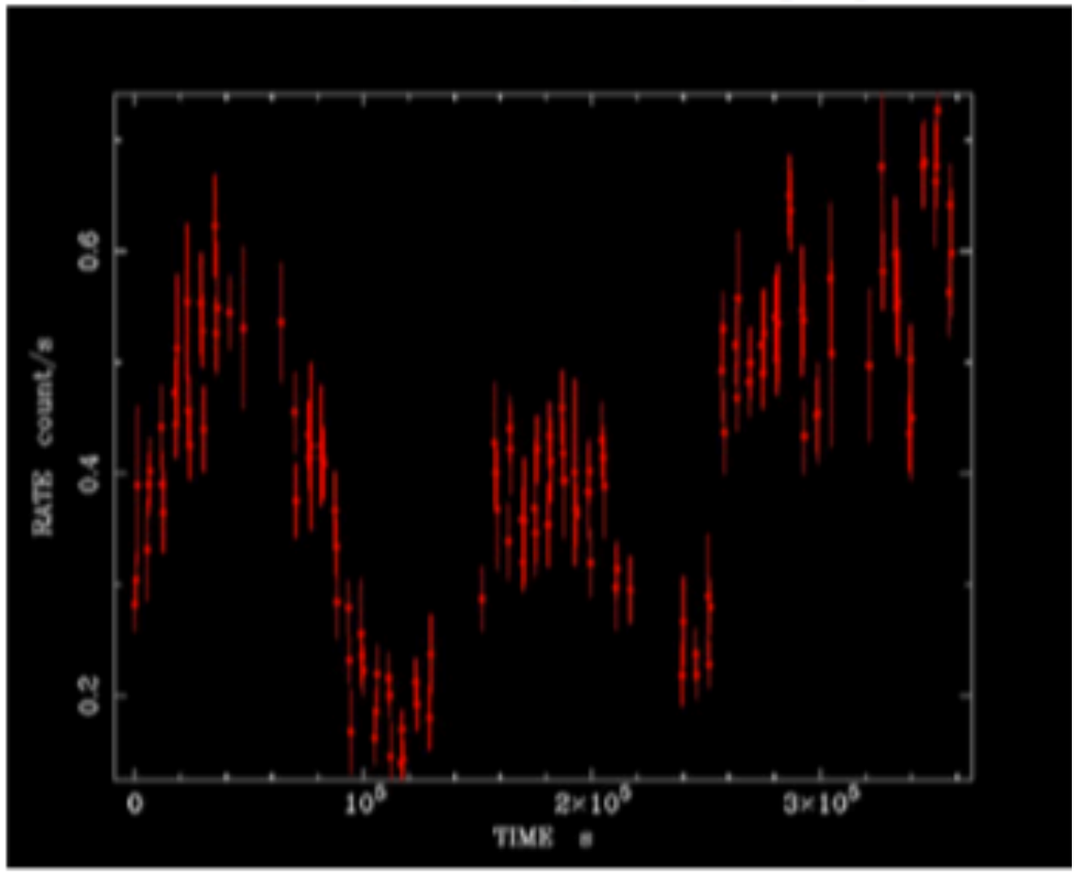


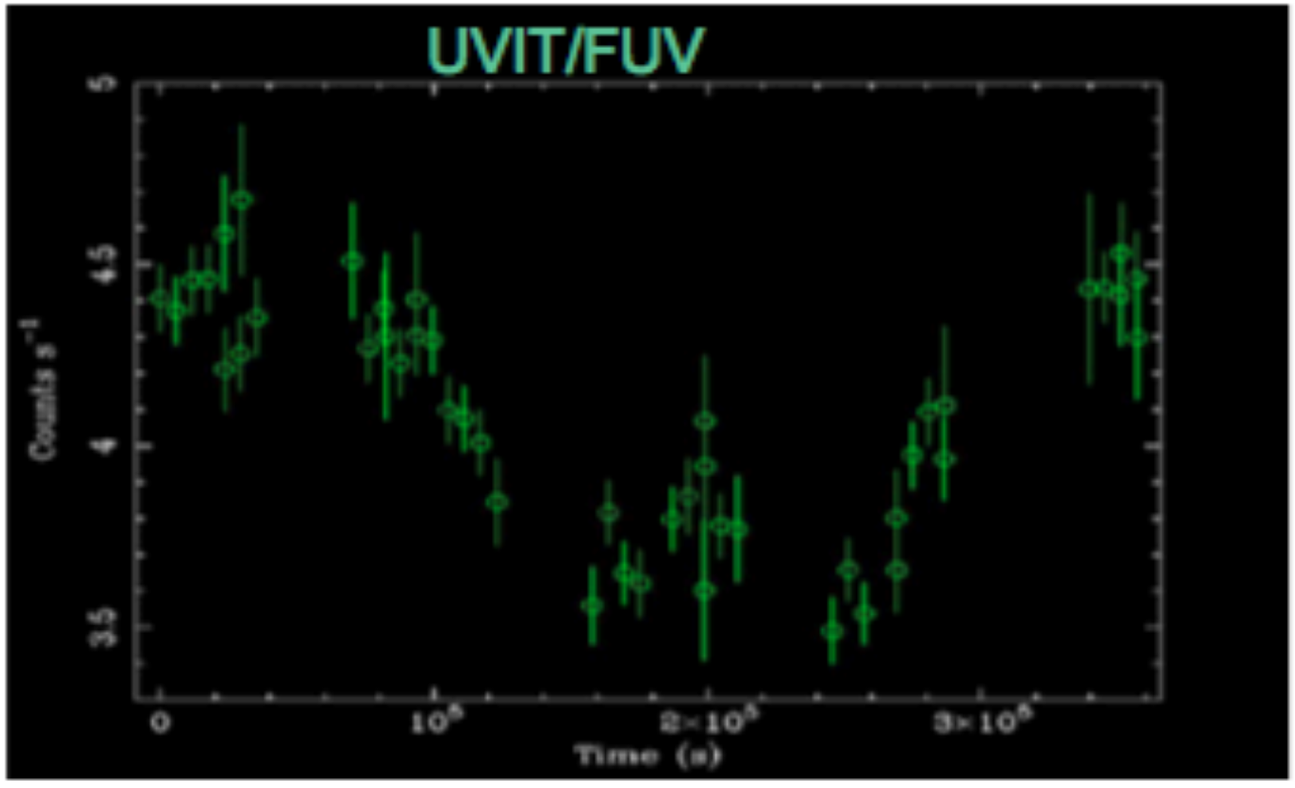


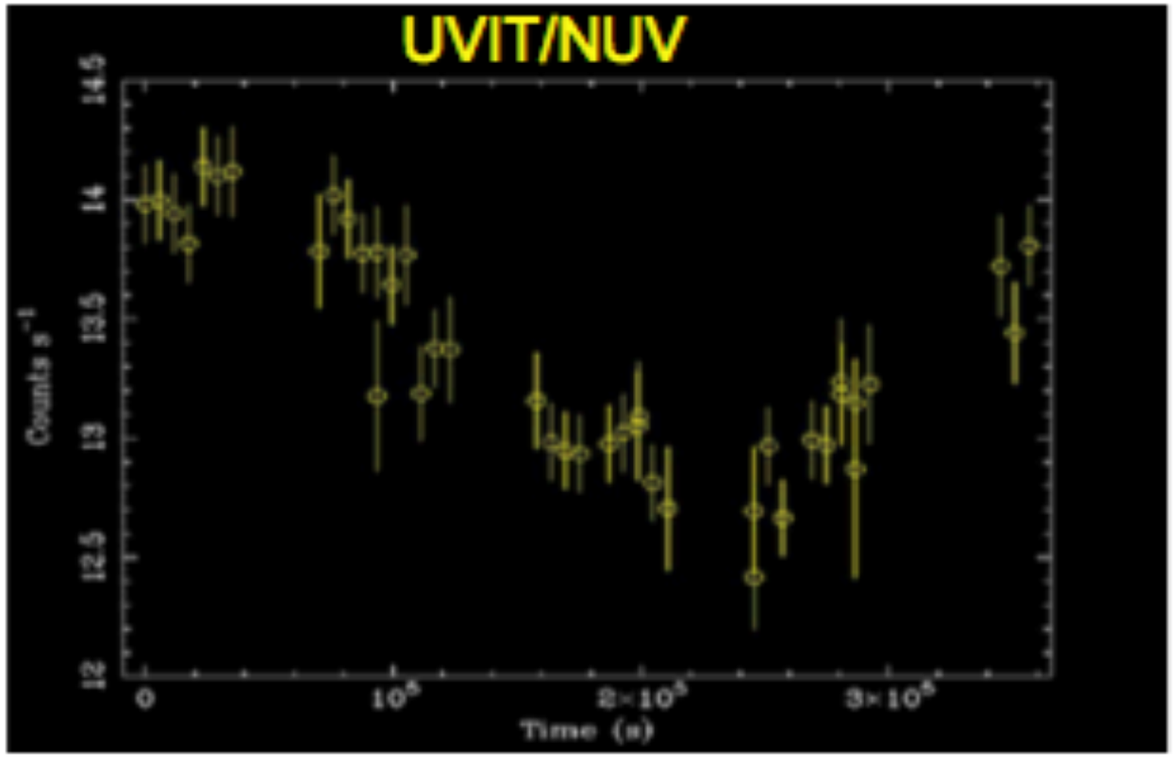
NGC4051 (1.7 days)

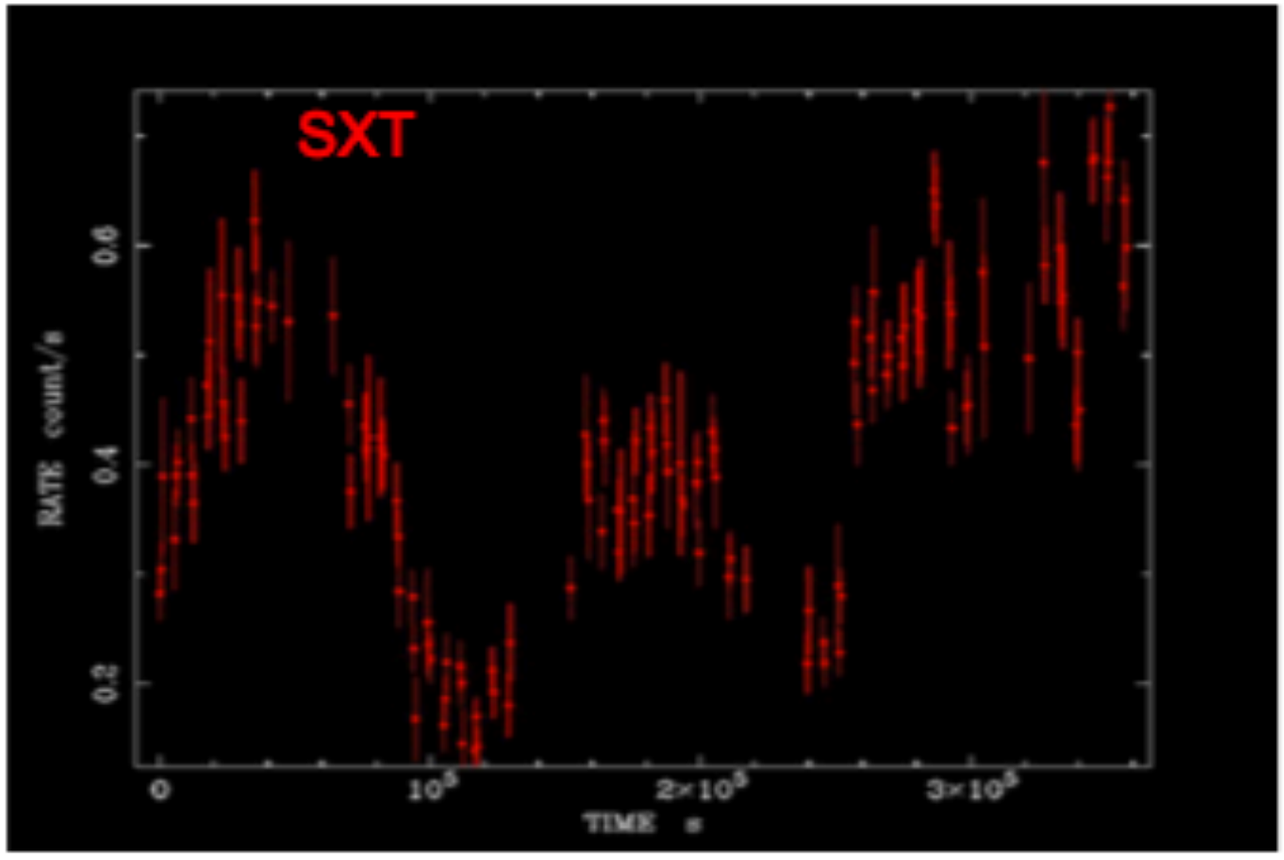


NGC4593 (~4 days)

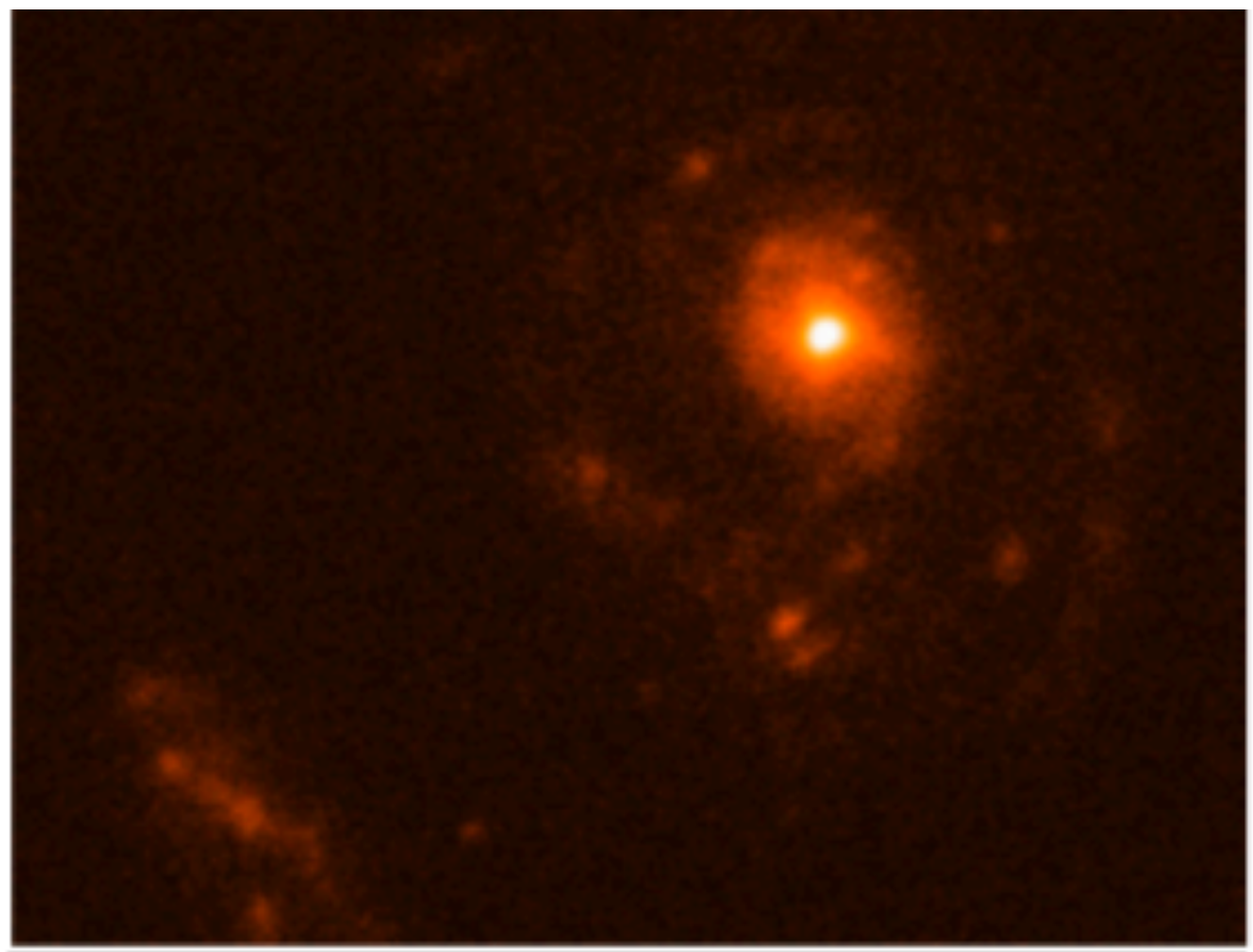


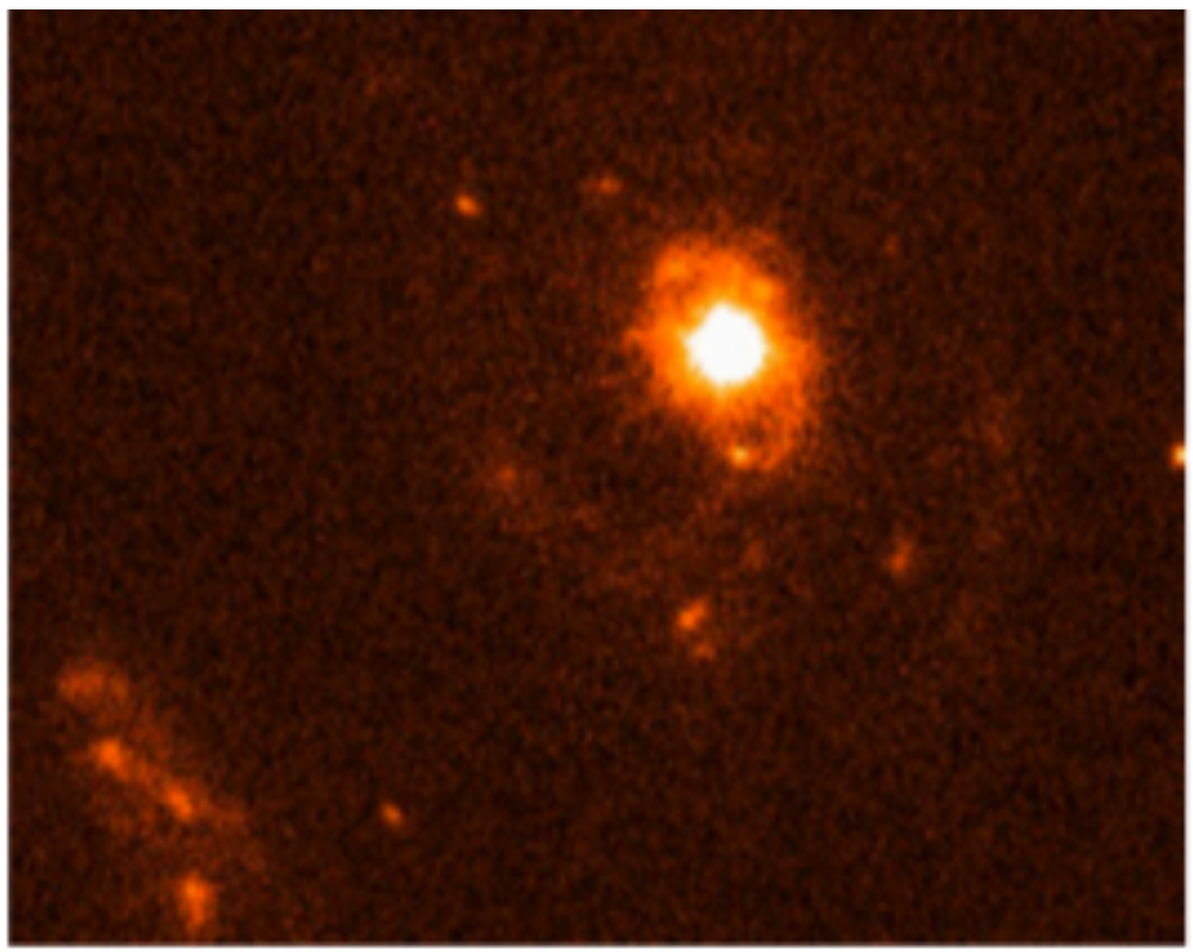


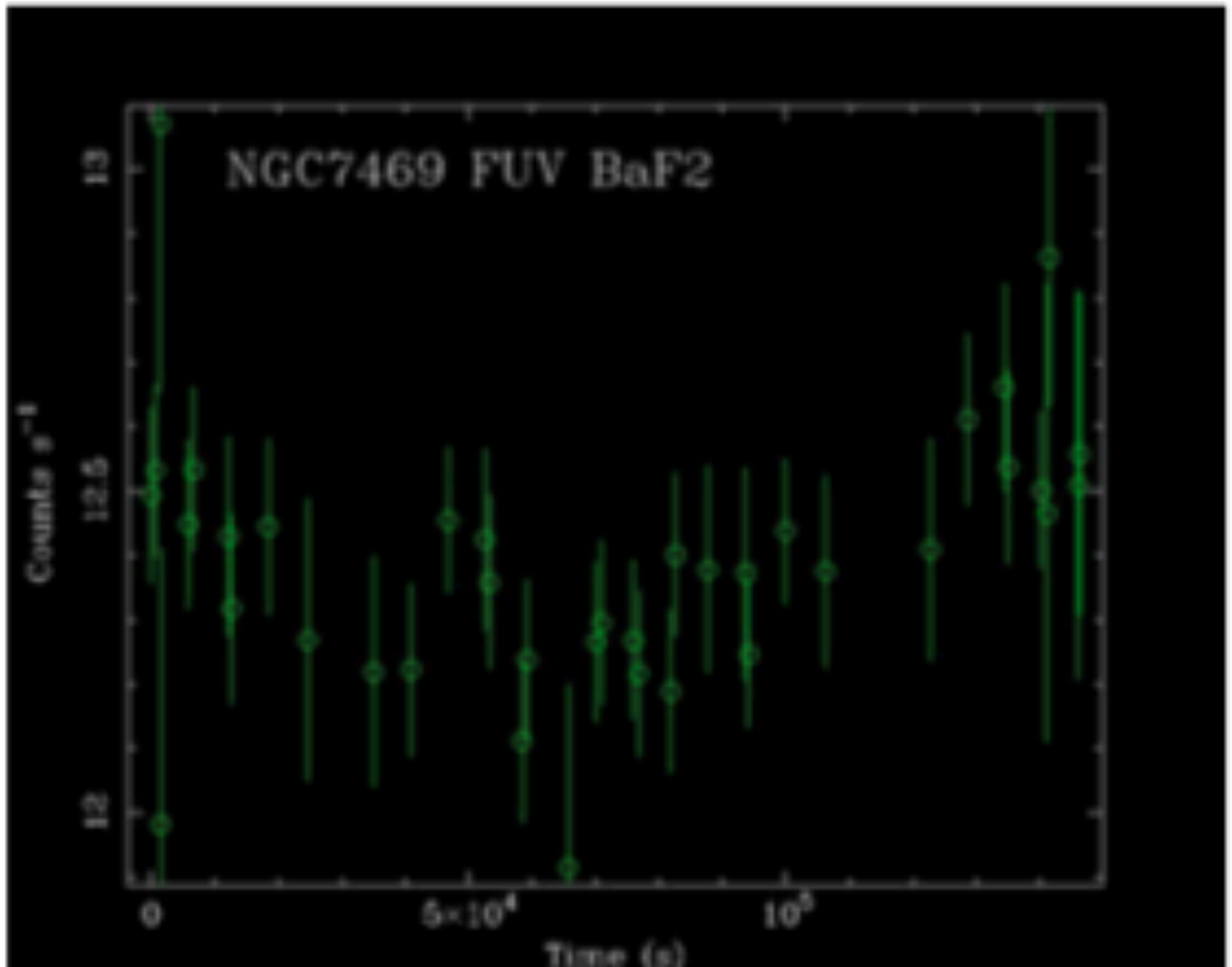


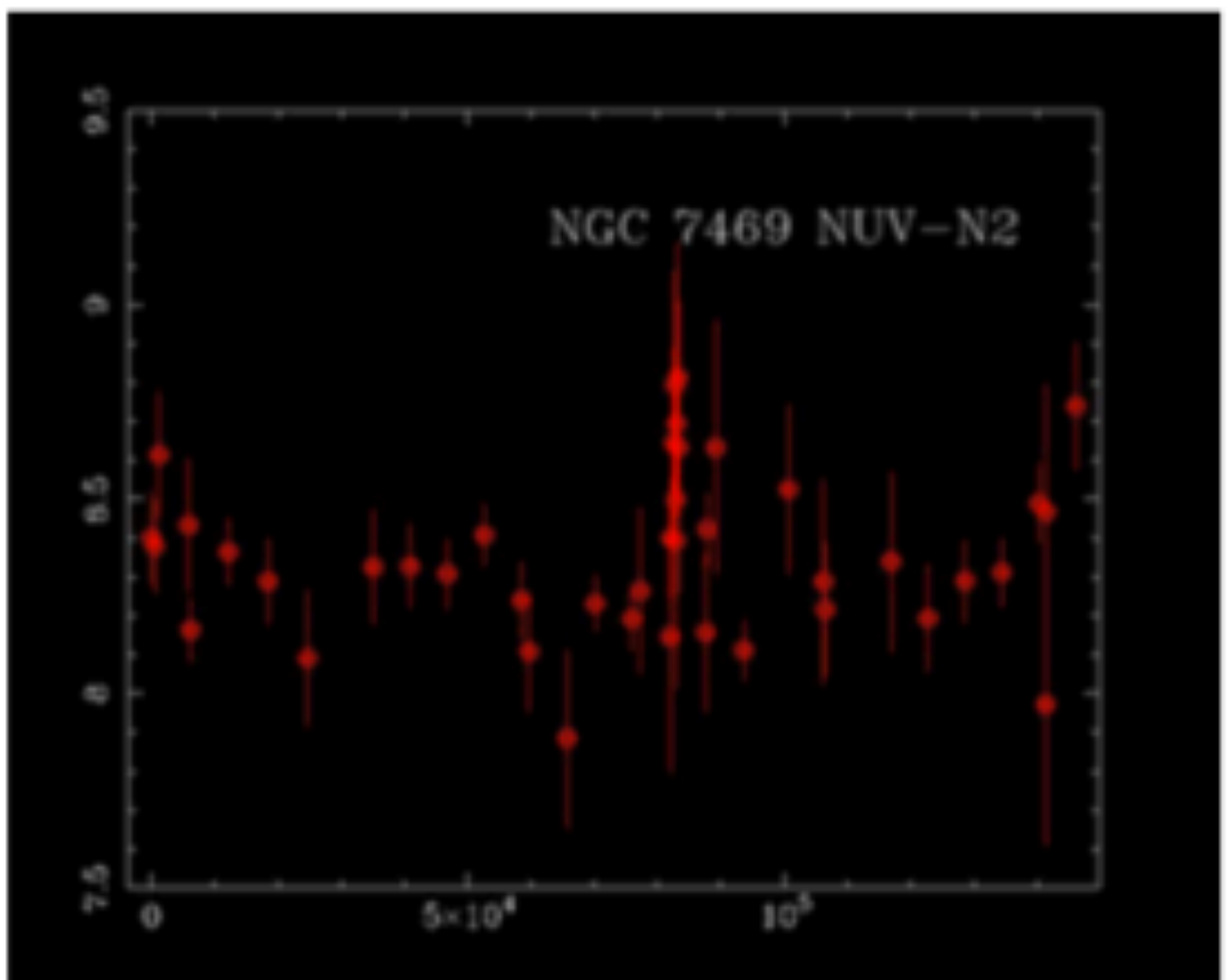


UV Variability in NGC4593 dominated by X-ray reprocessing

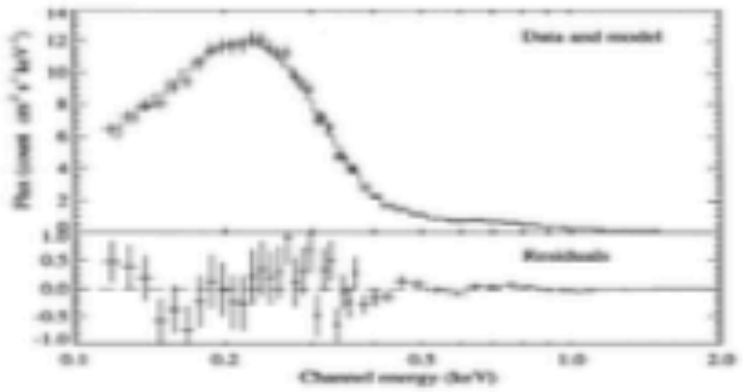




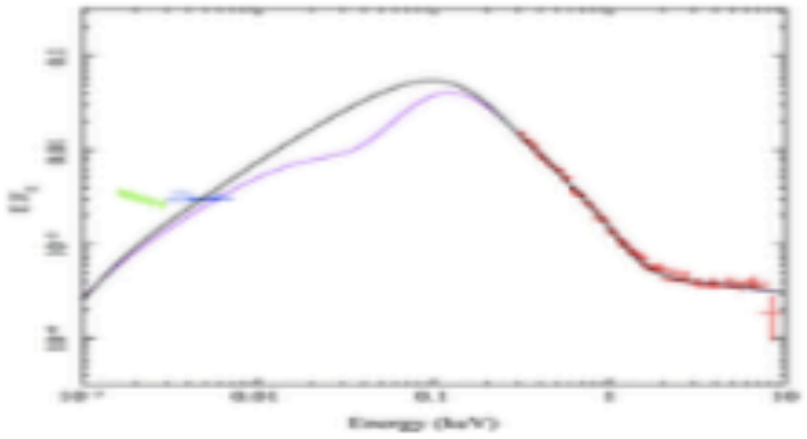

NGC7469 FUV BaF2
13
12.5
12
Counts s^{-1}
0
5×10^4
10^5
Time (s)


NGC 7469 NUV−N2
9.5
9
8.5
8
7.5
0
5×10^4
10^5

RE J1034+396

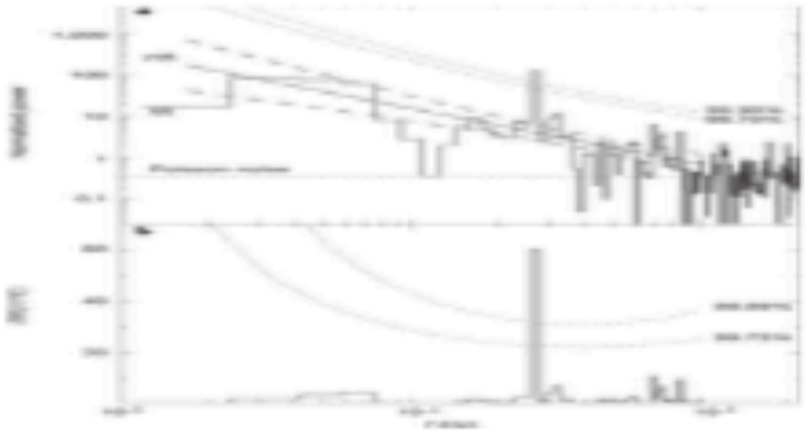


Big Blue Bump (BBB)(Puchnarewicz et al., 1995, 1998): 0.1-2.4 keV spectrum with ROSAT (PSPC) at high temperature ($kT \sim 100$ eV) whose high energy turnover is observed in soft X-rays at 0.4 keV

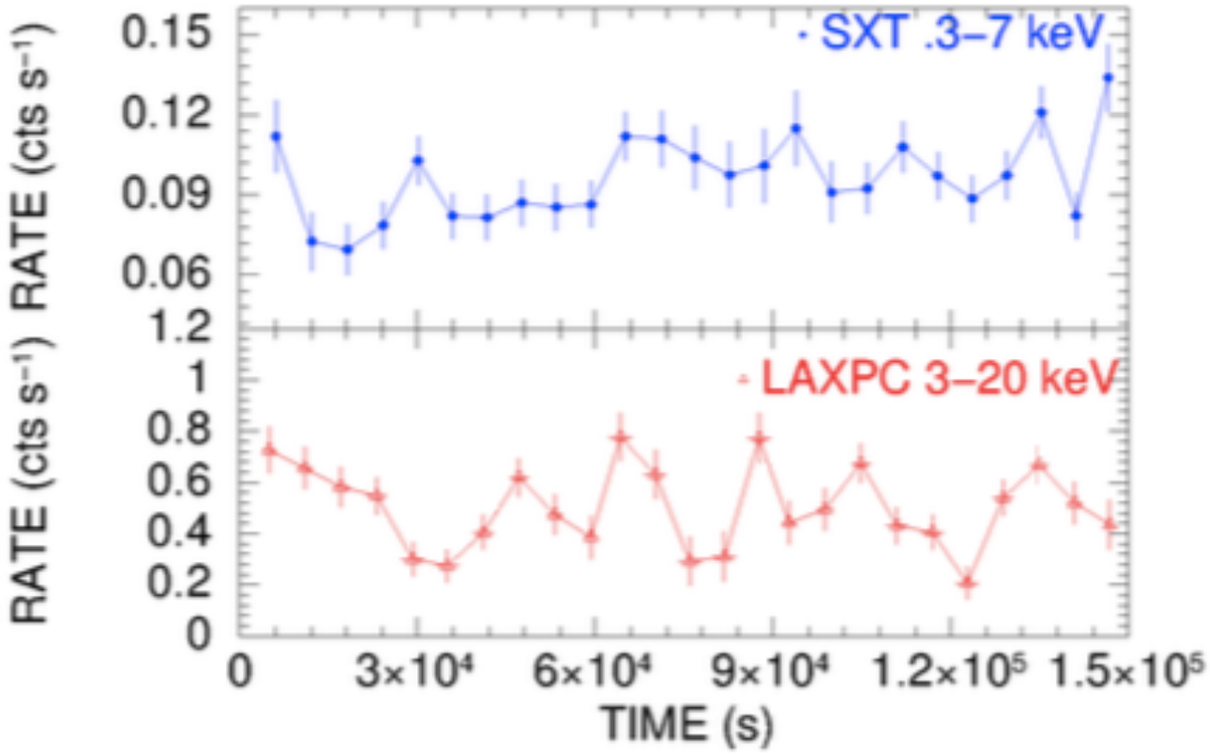


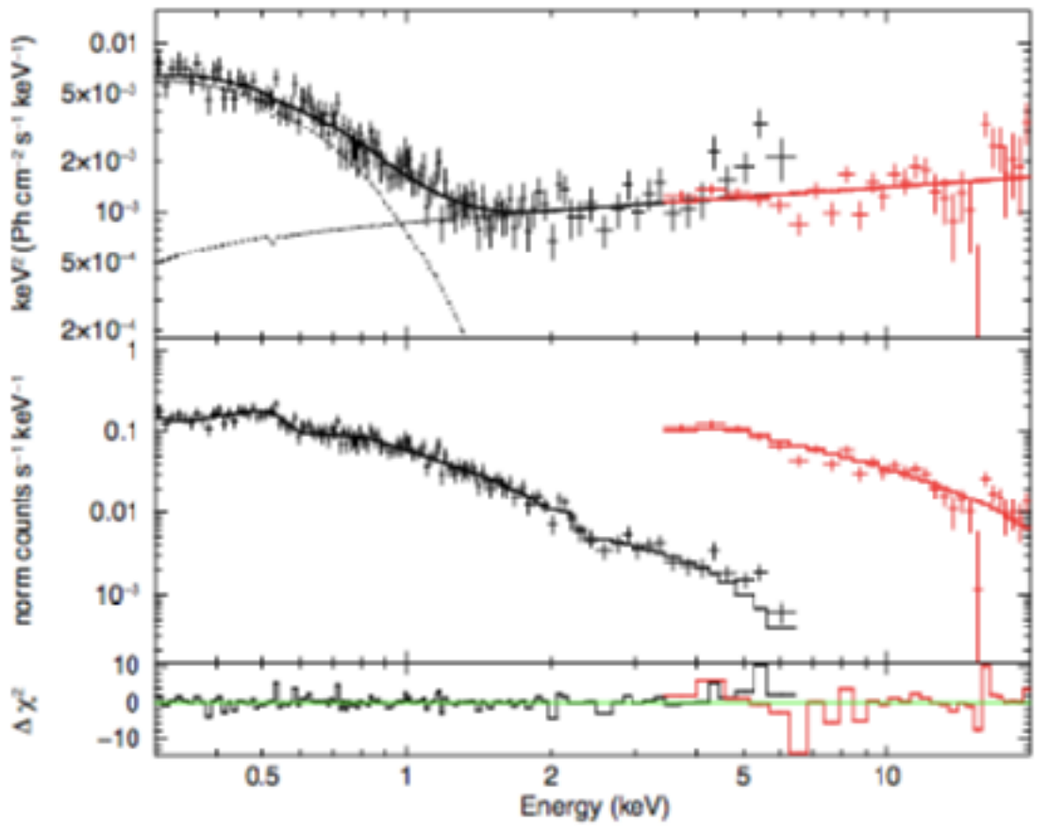
Spectral Energy Distribution (SED)(Done et al., 2012):

1. A black body from the disk (representing the BBB)
2. A hard coronal component (power law at high energies)
3. A low temperature high optical depth Comptonization of the disc emission in the soft X-ray region.



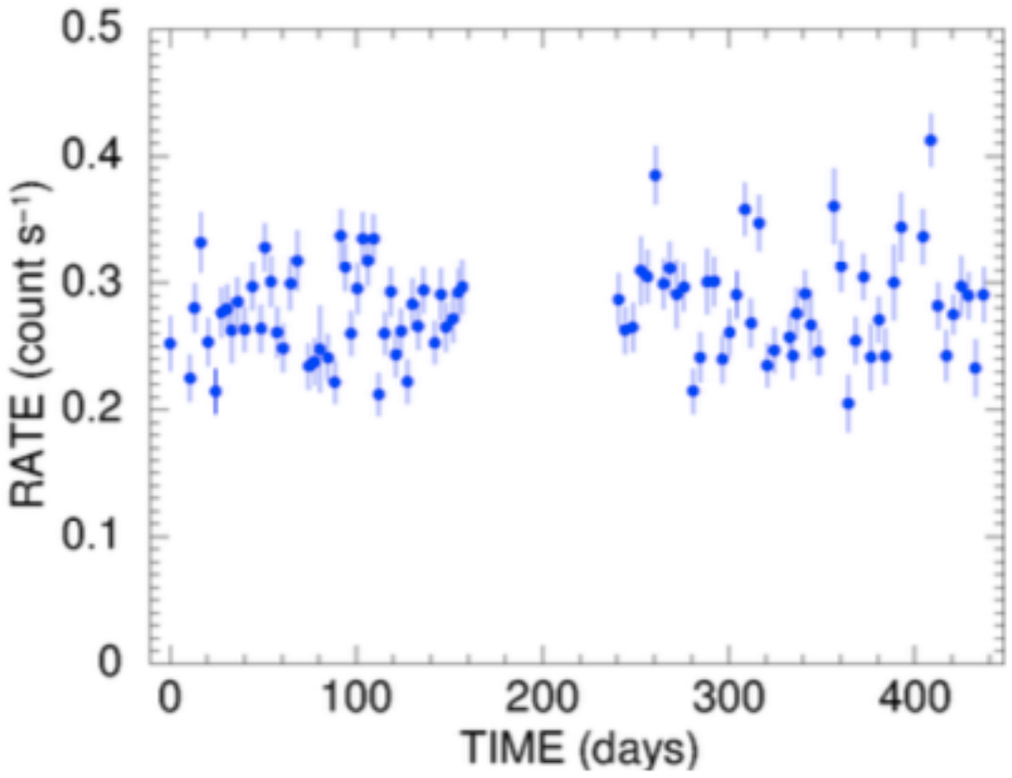
Quasi-Periodic Oscillations (QPO)(Gierliński et al., 2008; Middleton et al., 2009, 2011): 91 ks
XMM-Newton data showed a significant QPO at $\nu = 2.7 \times 10^{-4}$ Hz, period $\sim$ 1h



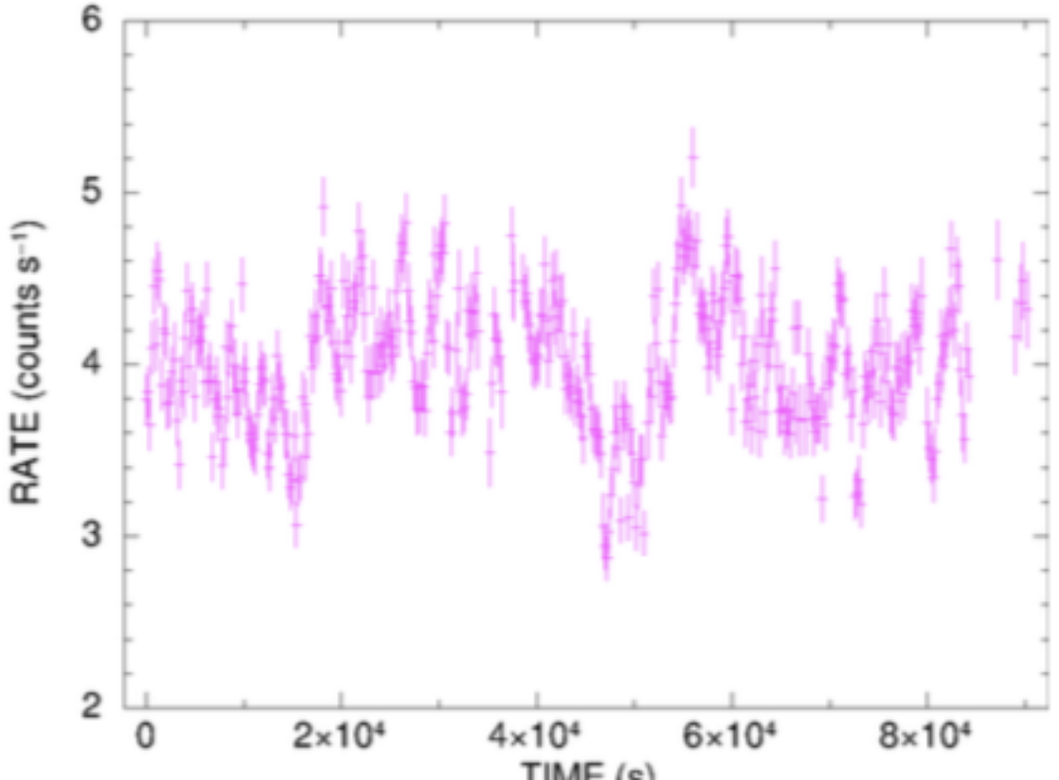


...

Swift XRT

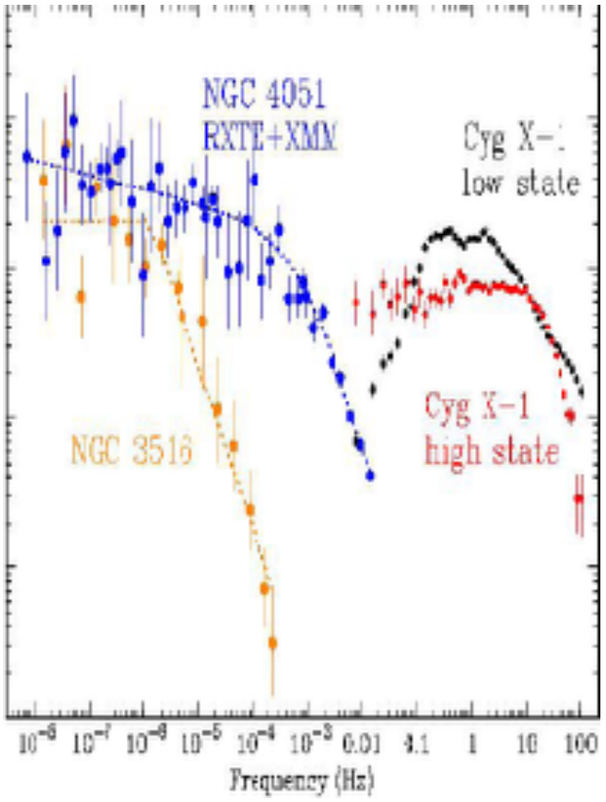


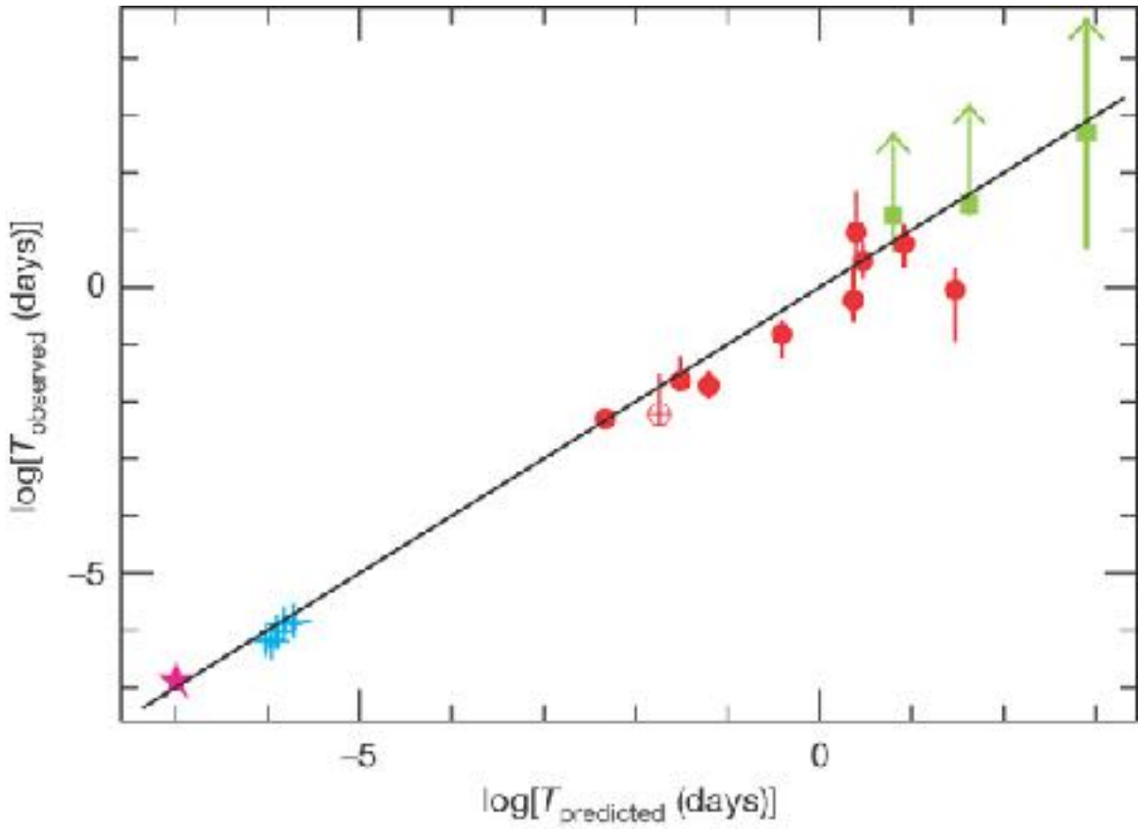
XMM Newton



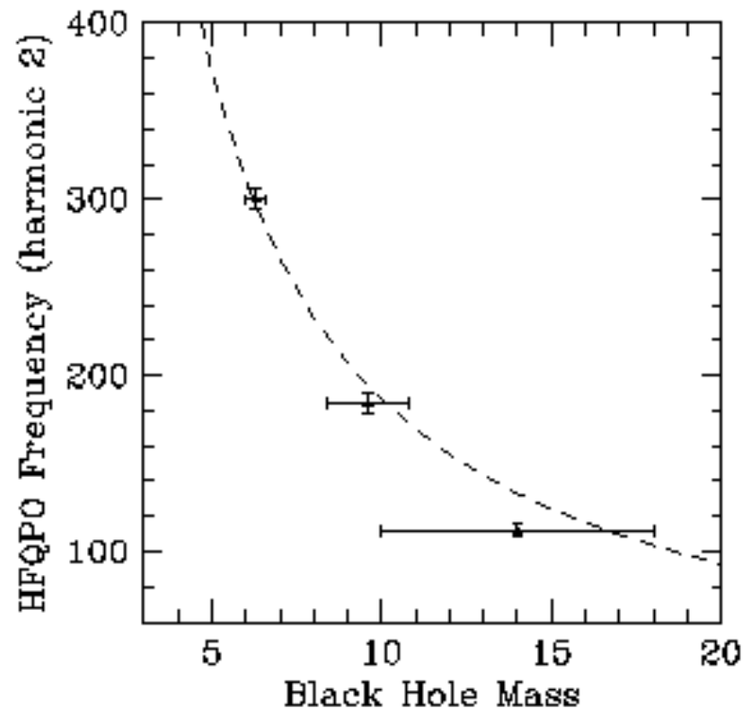
POWER SPECTRAL DENSITY: AGN AND XRB

McHardy et al. 2006





High Frequency QPOs



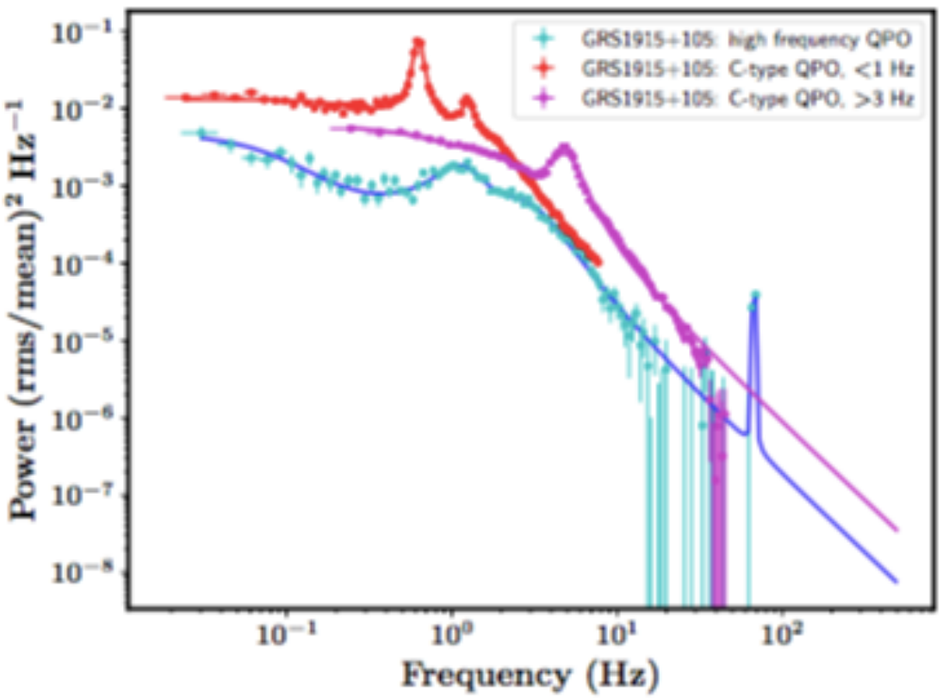
RE J1034+396: wide band PSD

Similar to HFQPO

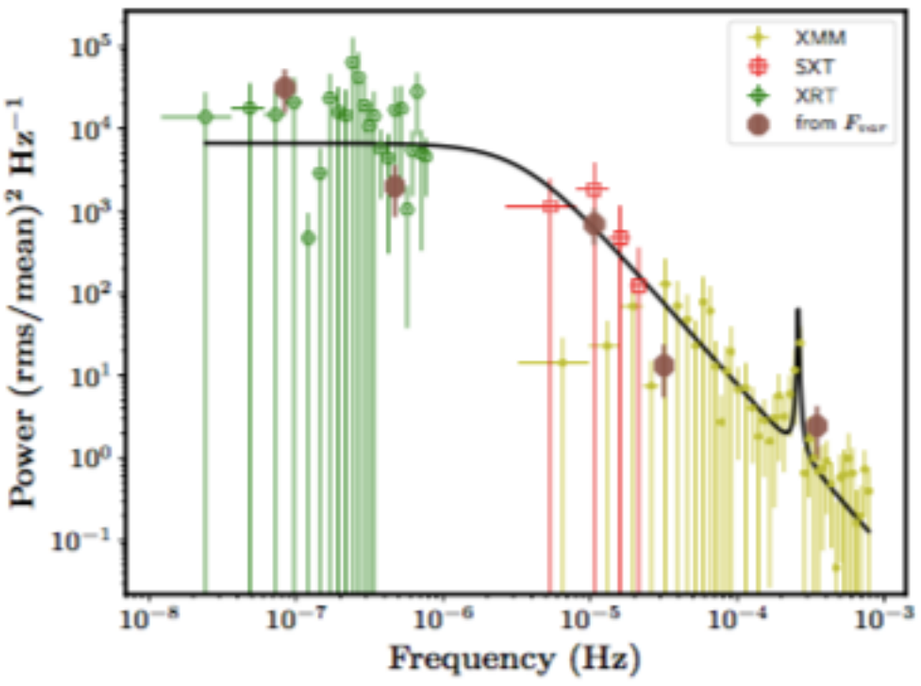
Mass of the BH can be measured

- **3 10^6 $M_\odot$**

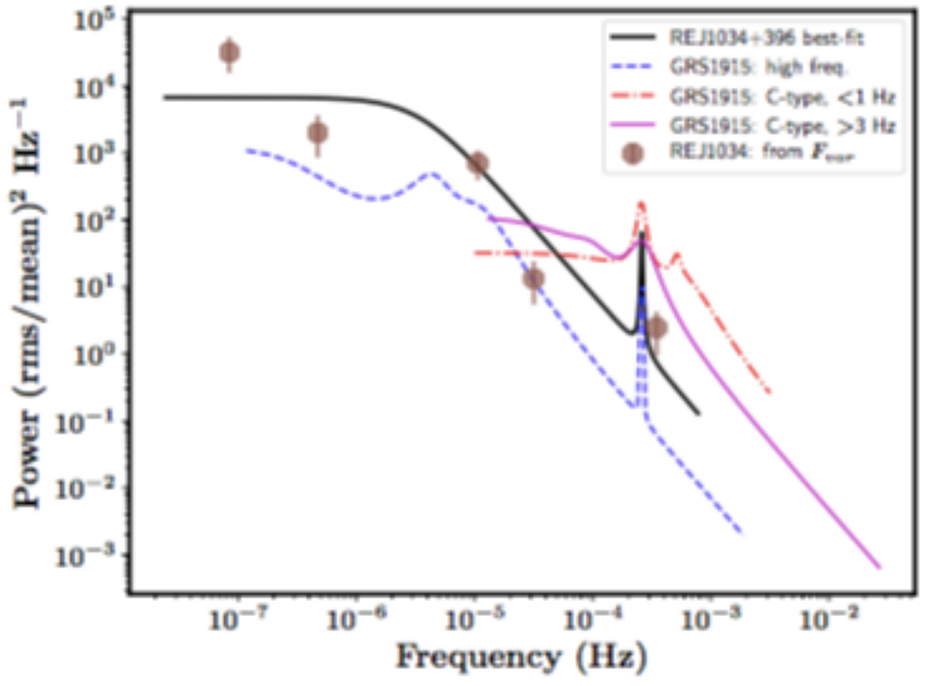
GRS 1915+105



RE J1034+396



RE J1034+396 & GRS 1915+105



Conclusions

AstroSat instruments are working very well.

Wide band multiwavelength (UV to hard X-rays) observations in a single platform for nearby bright AGN.

- **Structure of inner accretion disk.**
- **Spin measurements.**
- **Disk jet coupling**