Science Highlight of AstroSat

Gulab Chand Dewangan
IUCAA, Pune (India)

Growing Black Holes: Accretion and mergers, 15-20 May 2022,Kathmandu, Nepal

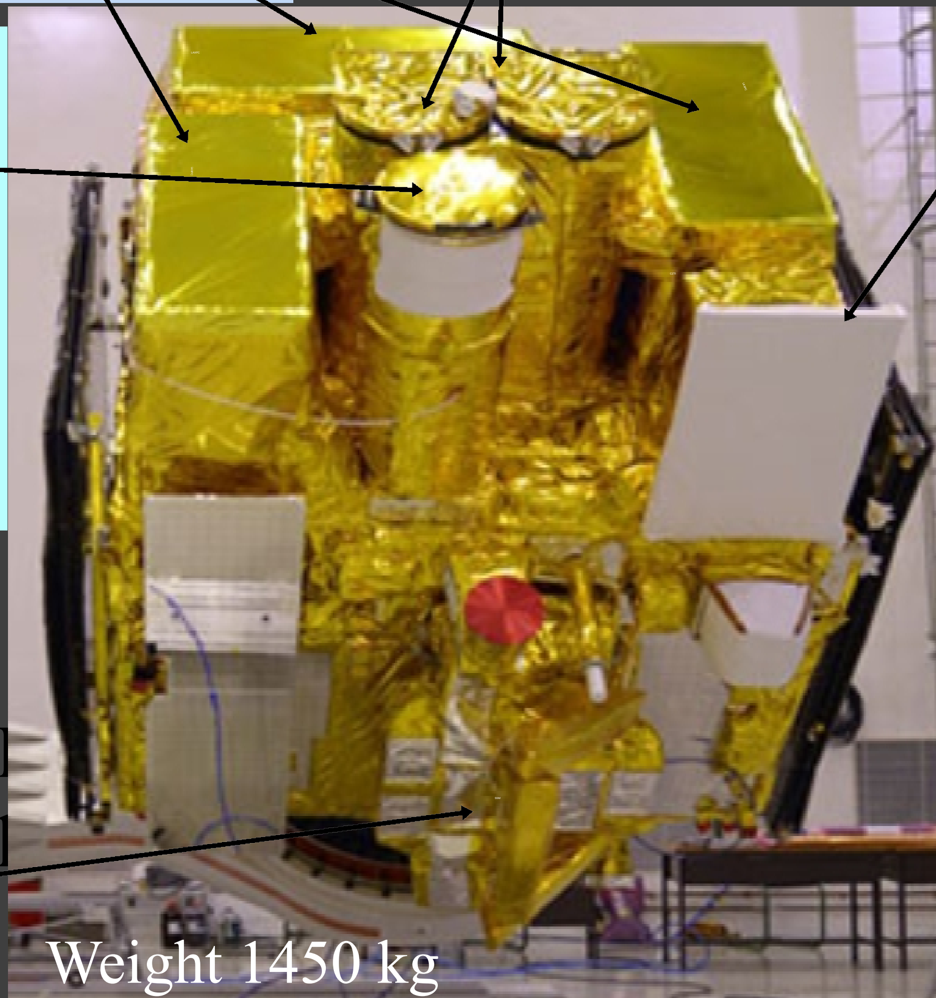
AstroSat - 1st Indian space observatory

LAXPC
3-80 keV X-ray Timing (10 micro-s), broadband spectroscopy

UVIT
1-1.5" UV imaging 1200-5500A & Slitless spectroscopy, photon counting

CZTI
Hard X-ray imaging, timing, spectroscopy, polarization, GRB monitor

SXT
0.2-8keV imaging spectroscopy, PSF~2arcmin, 0.278s(window) or 2.4s (full frame) time resolution



SSM
rotating 2-10 keV monitor

LAXPC: TIFR, RRI
SXT: TIFR, ISRO, UoL
CZTI: TIFR, ISRO, IUCAA, RRI, PRL
SSM: ISRO, IUCAA, RRI
UVIT: IIA, ISRO, IUCAA, CSA

Spacecraft & Operations: ISRO
Ground software: ISAC, SAC,TIFR, RRI, IIA, IUCAA, NCRA, PRL

AstroSat Science Support Cell: IUCAA

Launched 28 September 2015 by ISRO,
Circular orbit with 650 km altitude, and 6deg inclination

AstroSat Operations at a glance

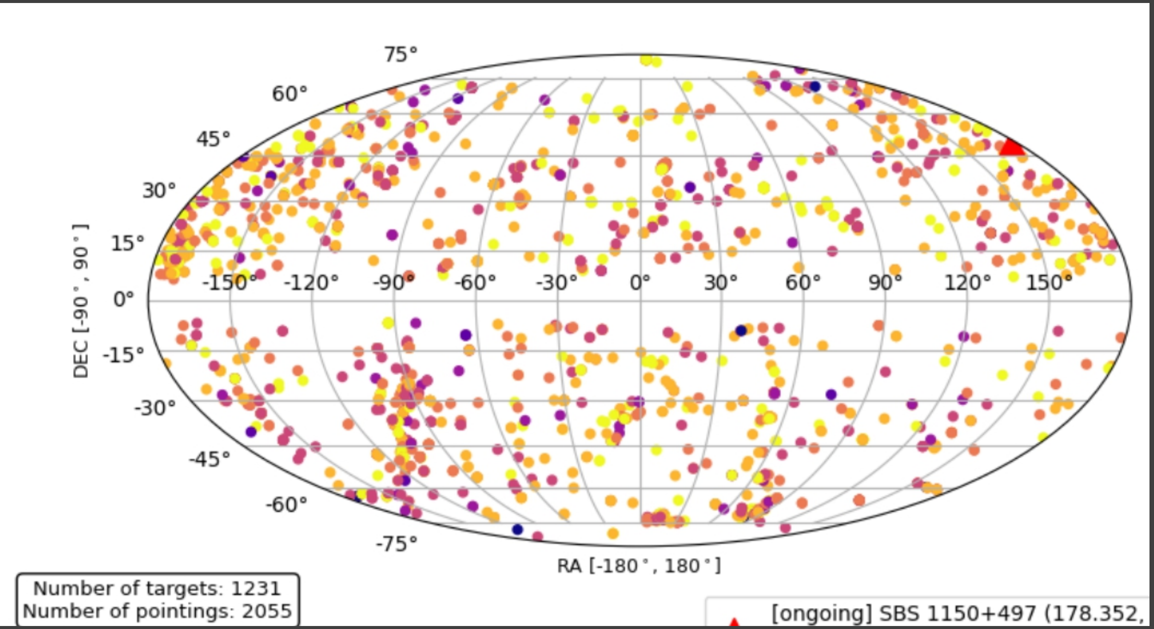
- MW coverage useful for a variety of cosmic sources
- Total pointings: 2055
- Targets observed: 1231 (XRBs with WD, NS, BHs, AGN and Blzars, stars, galaxies, deep surveys

Refereed papers

(Science): ~230 (2

Nature Astronomy)

Ph. D. thesis: ~20

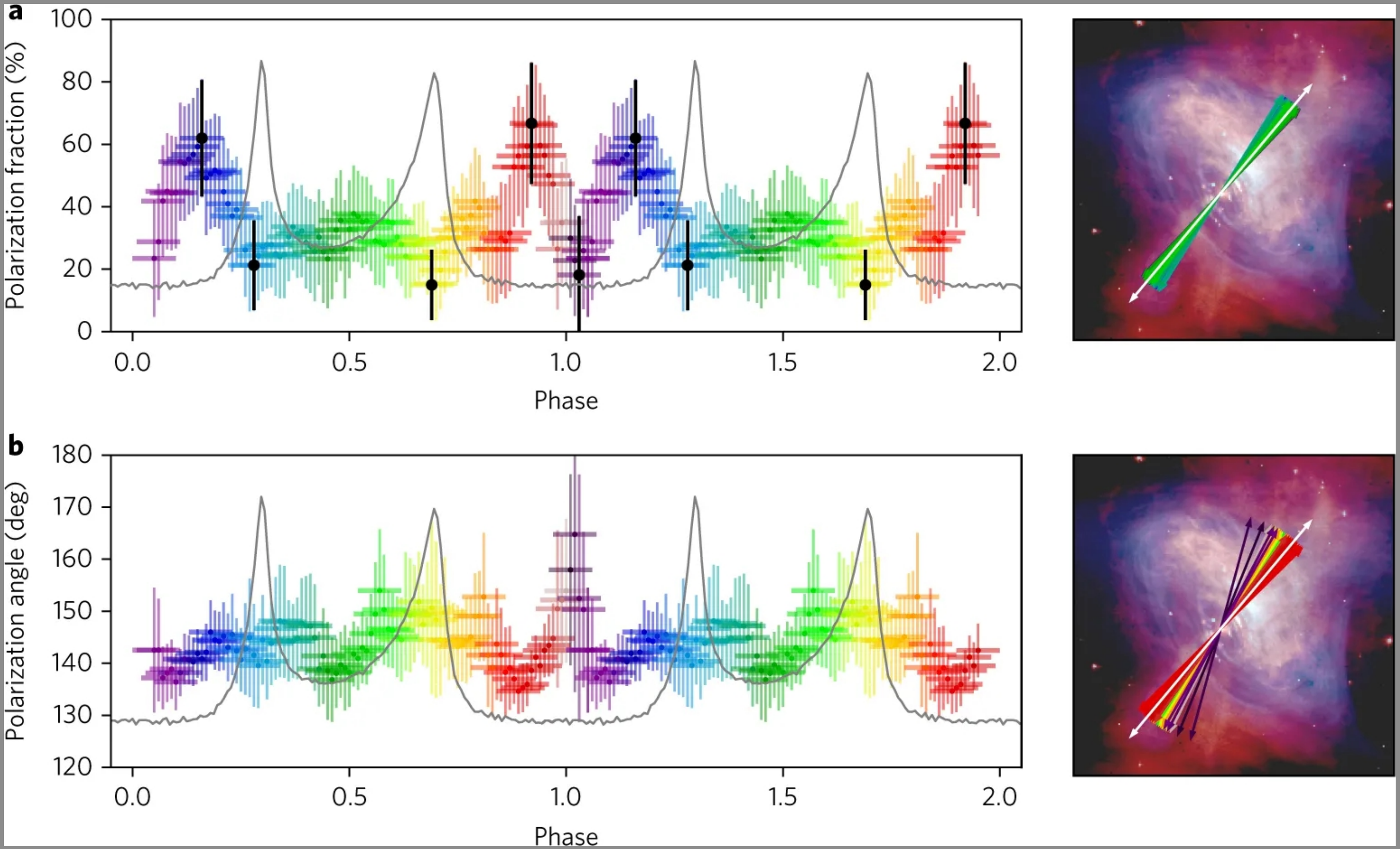


- CZTI as GRB monitor: 503 GRBs detected
- CZTI as Compton Polarimeter

Hard X-ray Polarisation with CZTI

Crab nebula and the pulsar

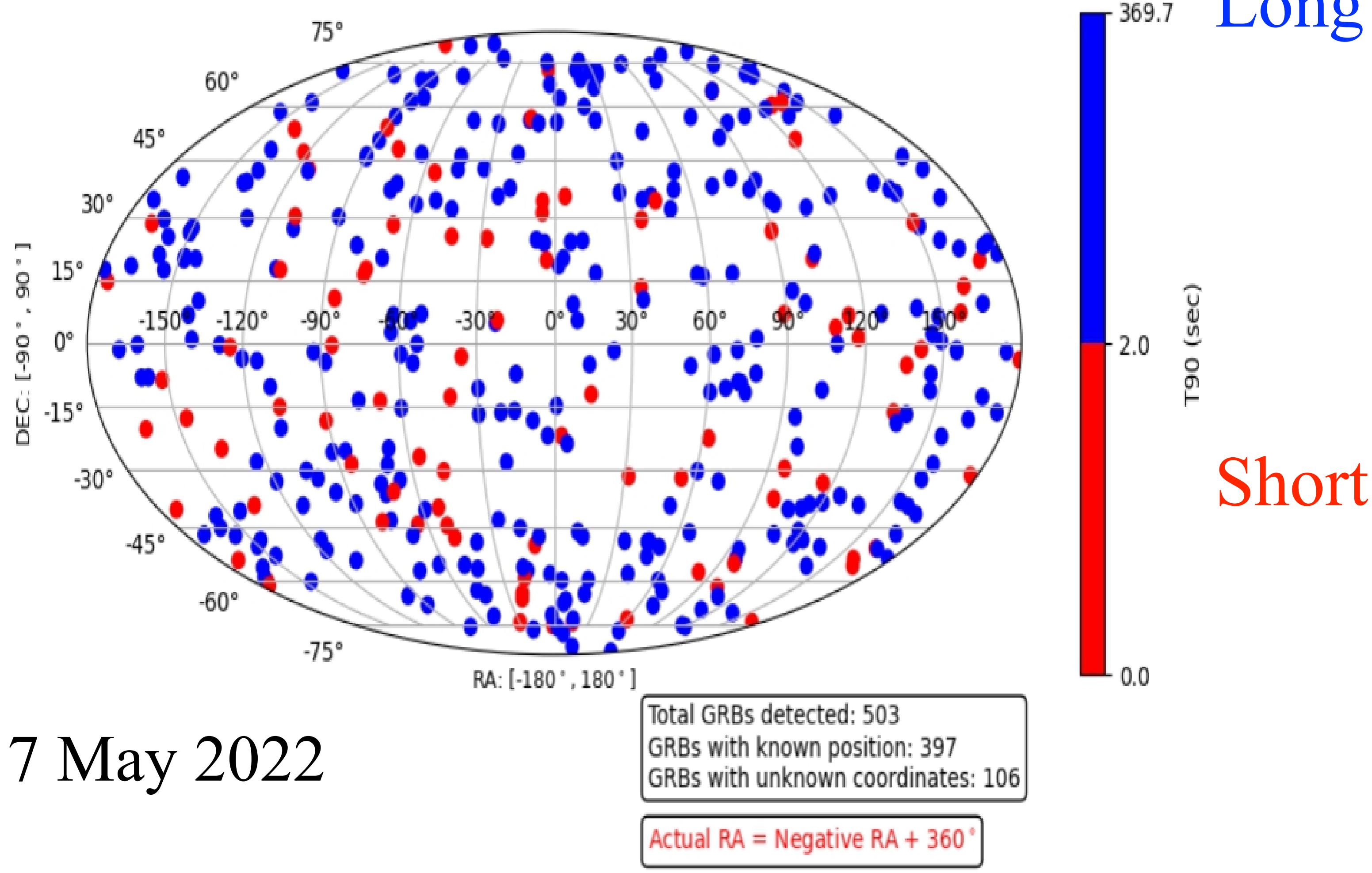
Vadawale et al. 2018, Nature Astronomy



- PA nearly parallel to spin axis at all phases
- Synchrotron emission from toroidal field in wind zone

GRBs with AstroSat/CZTI

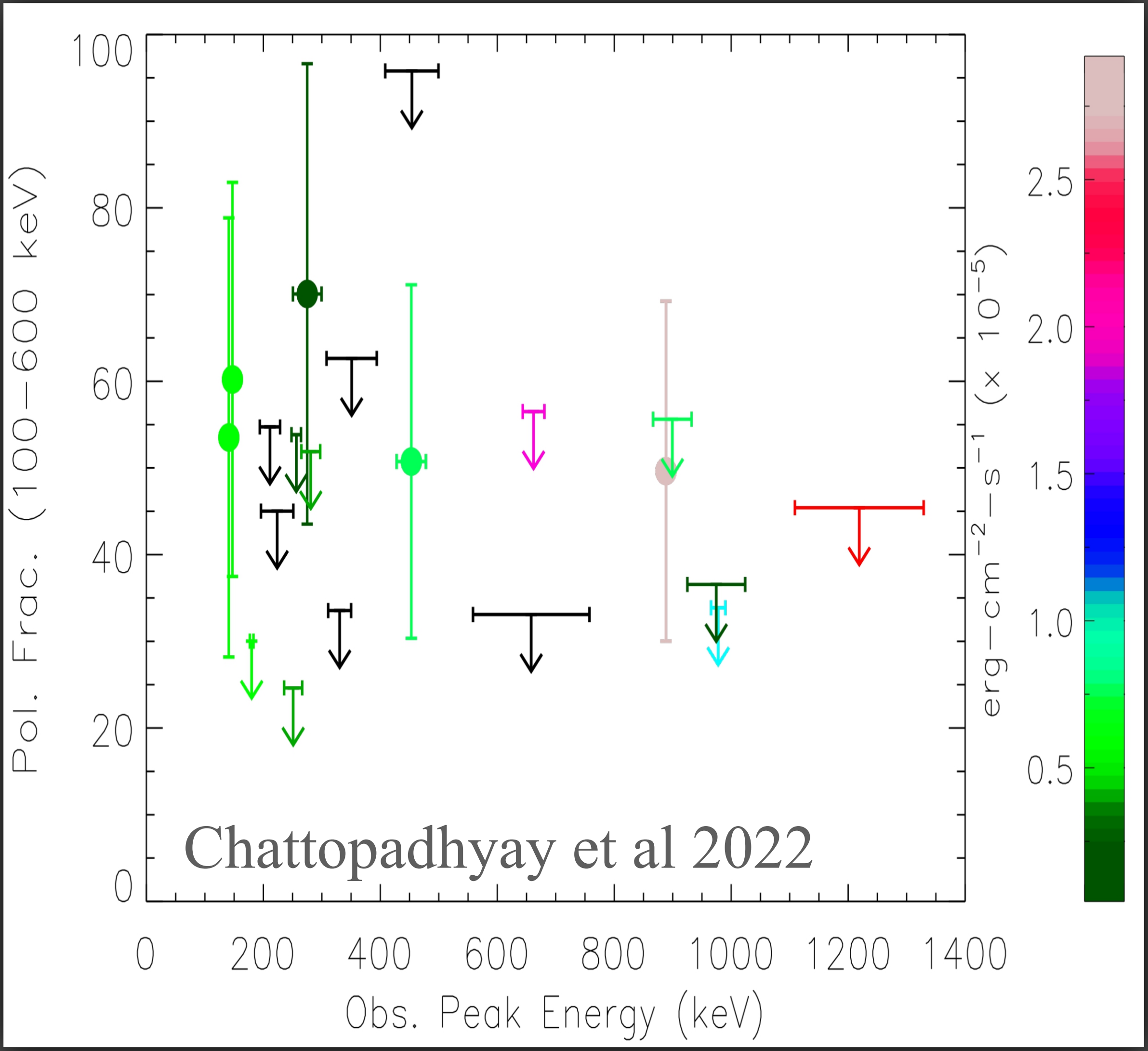
CZTI acts as an all sky detector above 100keV



17 May 2022

GRB Polarisation

20 measurements / confirmed upper limits in 5 years



NS X-ray Binaries

- Measurement of spin periods and their evolution, Cyclotron lines and magnetic fields using LAXPC observations of several accretion powered pulsars. (see Amin & Chakroborty 2020; Sarma et al. 2020, Varun et al. 2019, Mukerjee et al. 2020, Bala et al. 2020,Amin et al. 2020, Mukerjii et al. 2020)

- **ULX Pulsars**

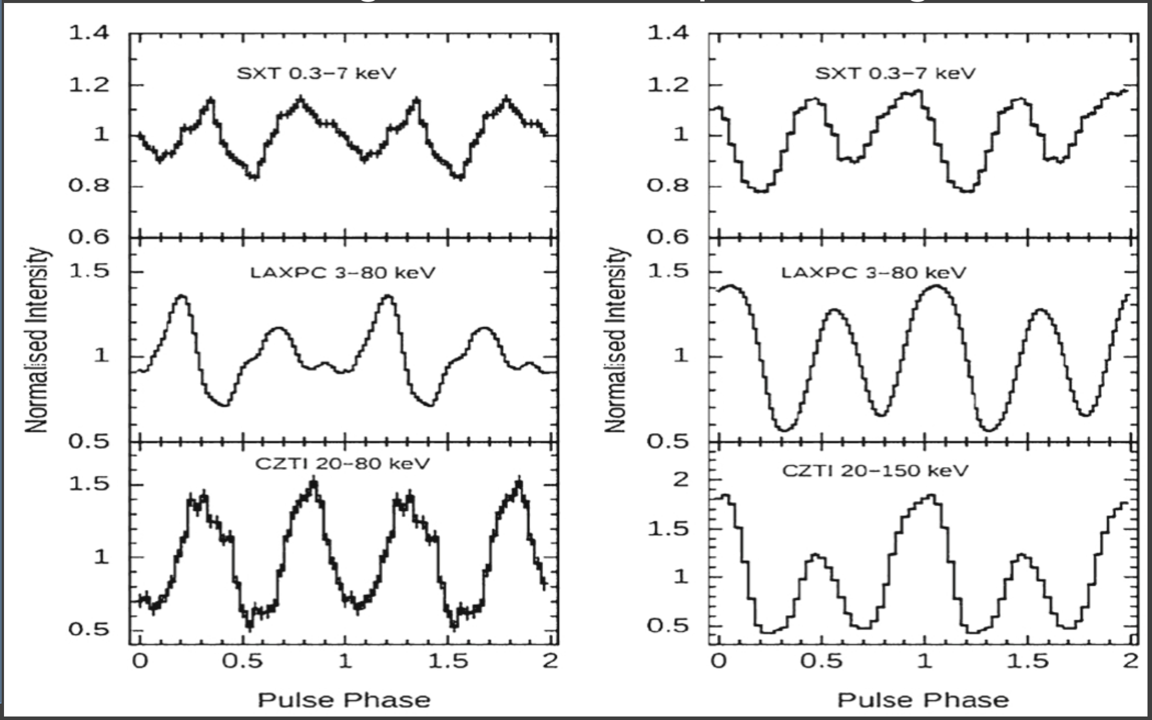
RX J0209.6-7427 in the Magellan Bridge (Chandra et al. 2020)

- Outburst after 26 years in 2019
- Lx ~ 1.6e39 ergs/s
- Pulsations with period 9.29s.

- Swift J0243.6+6124 - Galactic ULX Pulsar (Beri at al. 2020)
- Lx ~ 7e37 to 6e38 ergs/s
- P ~ 9.85s (upto 150keV)

Swift J0243.6+6124

Sub-Eddington Super-Eddington

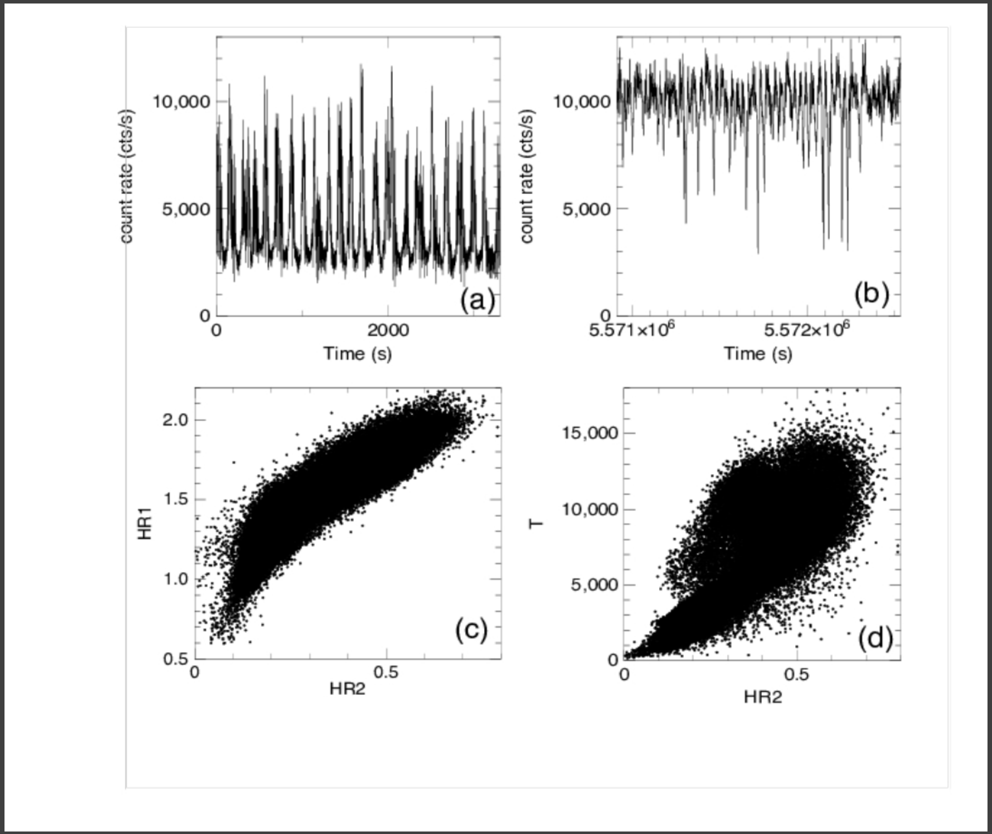


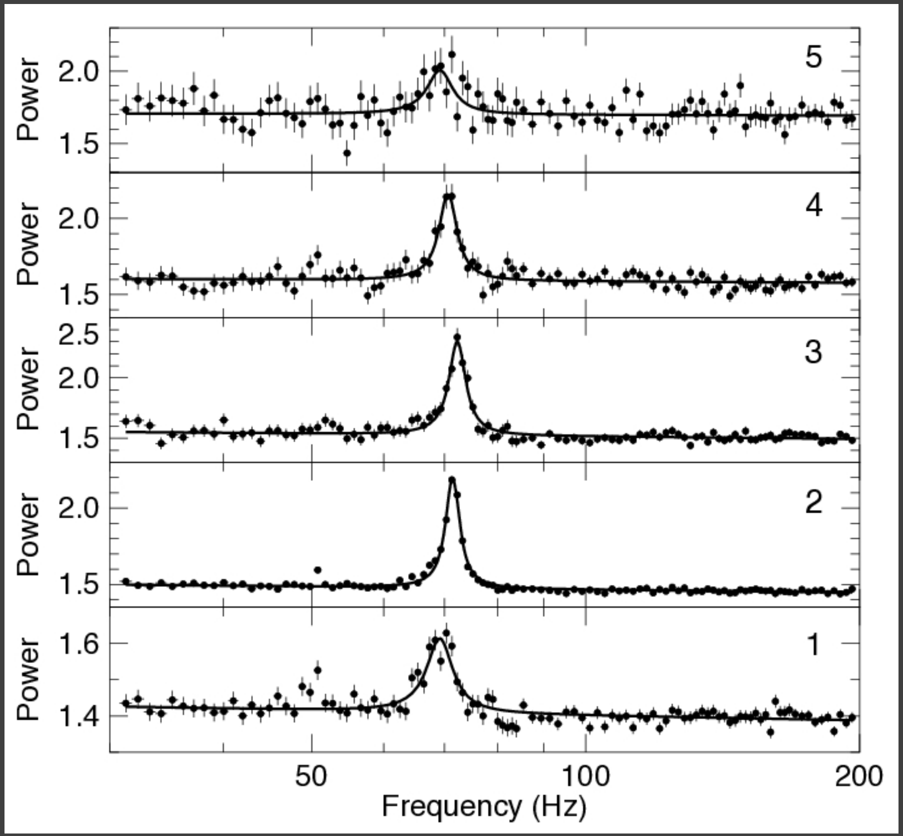
Black Hole XRBs

- Talks by Ranjeev Misra, Sneha Prakash Mudambi, Akash Garg, Poster by Nazma Husain highlight some results on BHBs.

- Variable (67.4-73.2 Hz) High Frequncy QPO from GRS1915+105

Belloni et al. 2019

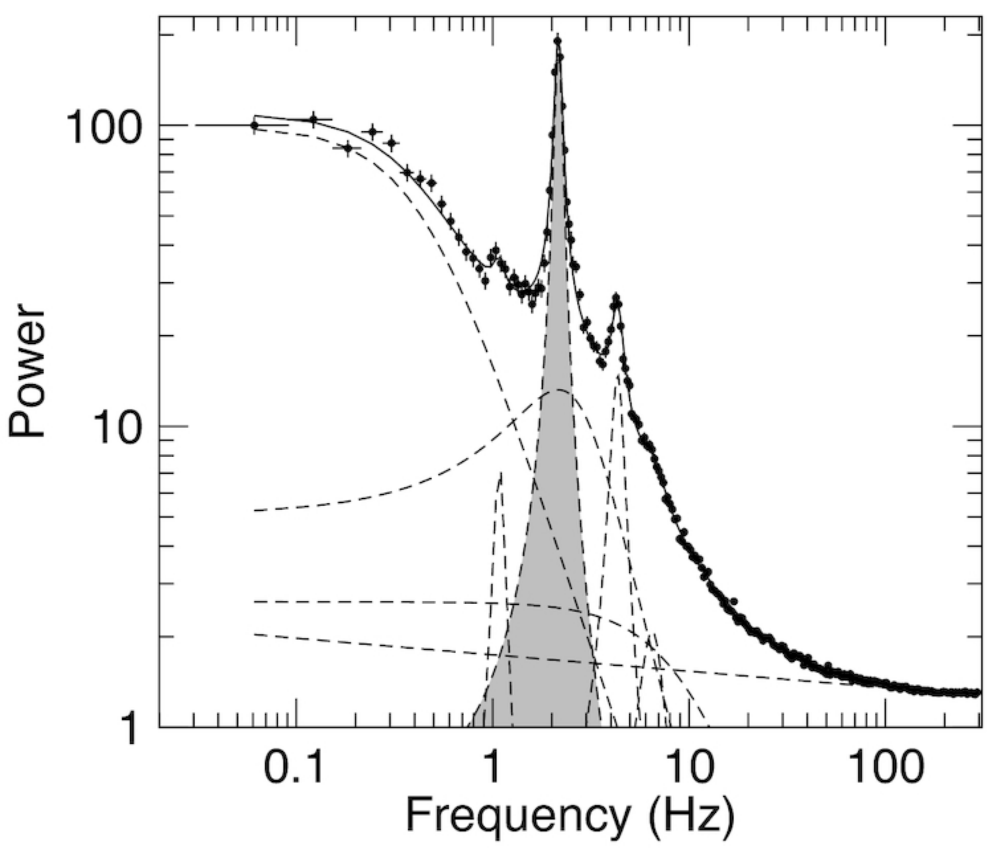




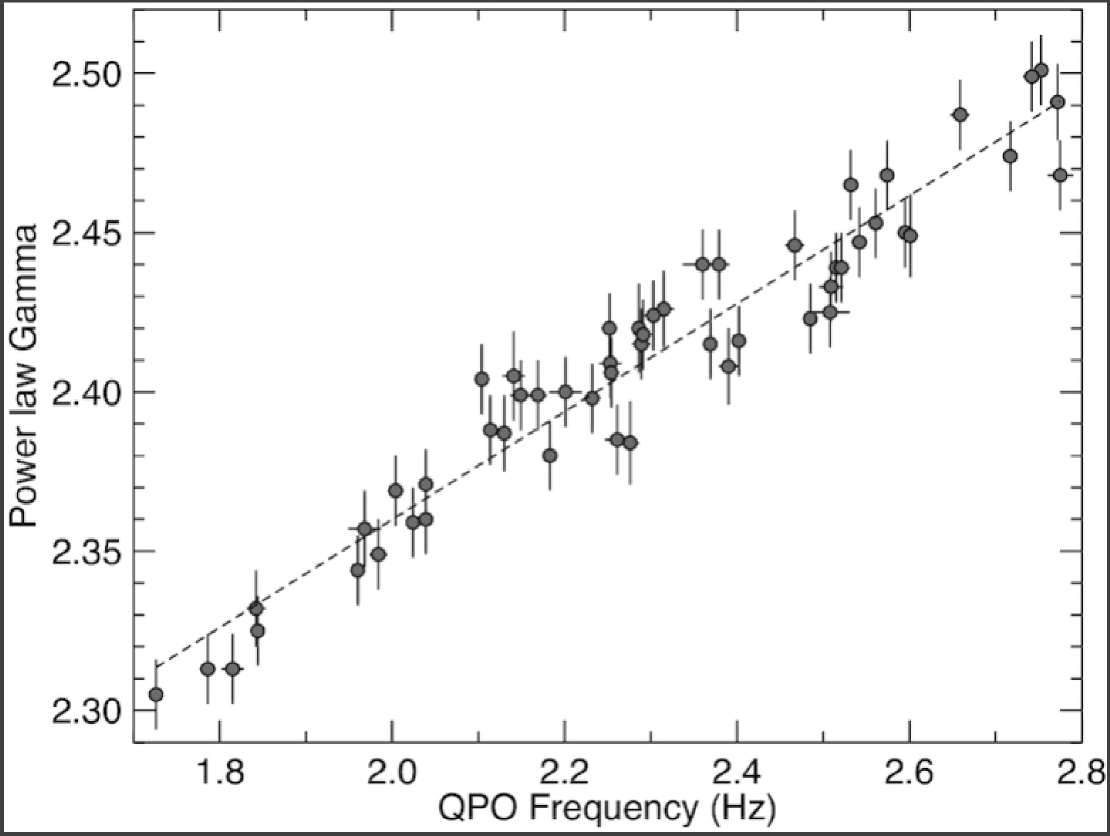
See also, Yadav et al. 2016;Majumder et al. 2022

BH XRBs - Spectro-Timing behavior

LAXPC data on MAXI J1535-57



- Strong correlation between QPO frequency and power-law photon index



QPOs arise in the Comptonising medium

(Bhargava et al. 2019)

AstroSat observation of MAXI J1820+070

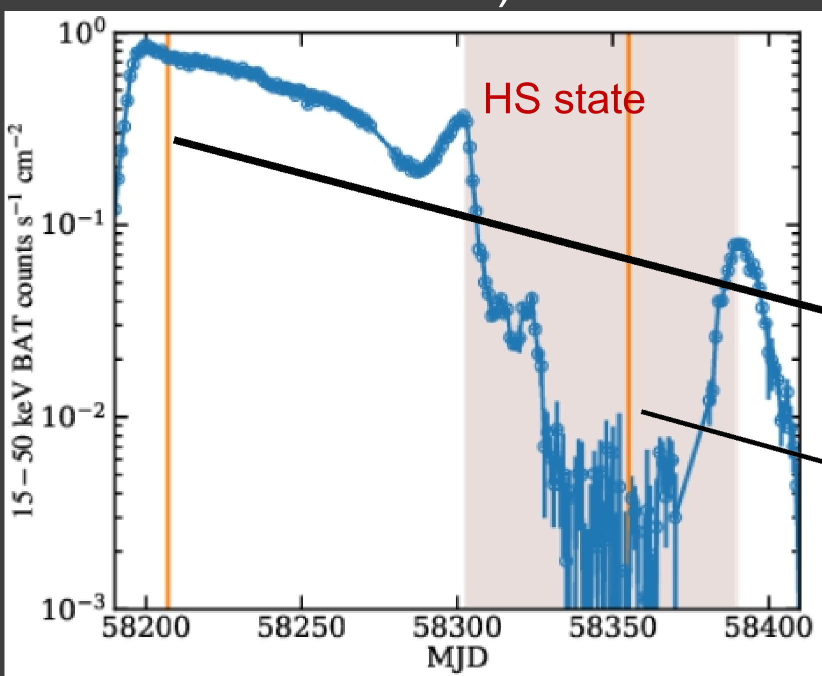
GCD, Benerjee, C. Knigge, G. Maria, P. Gandhi

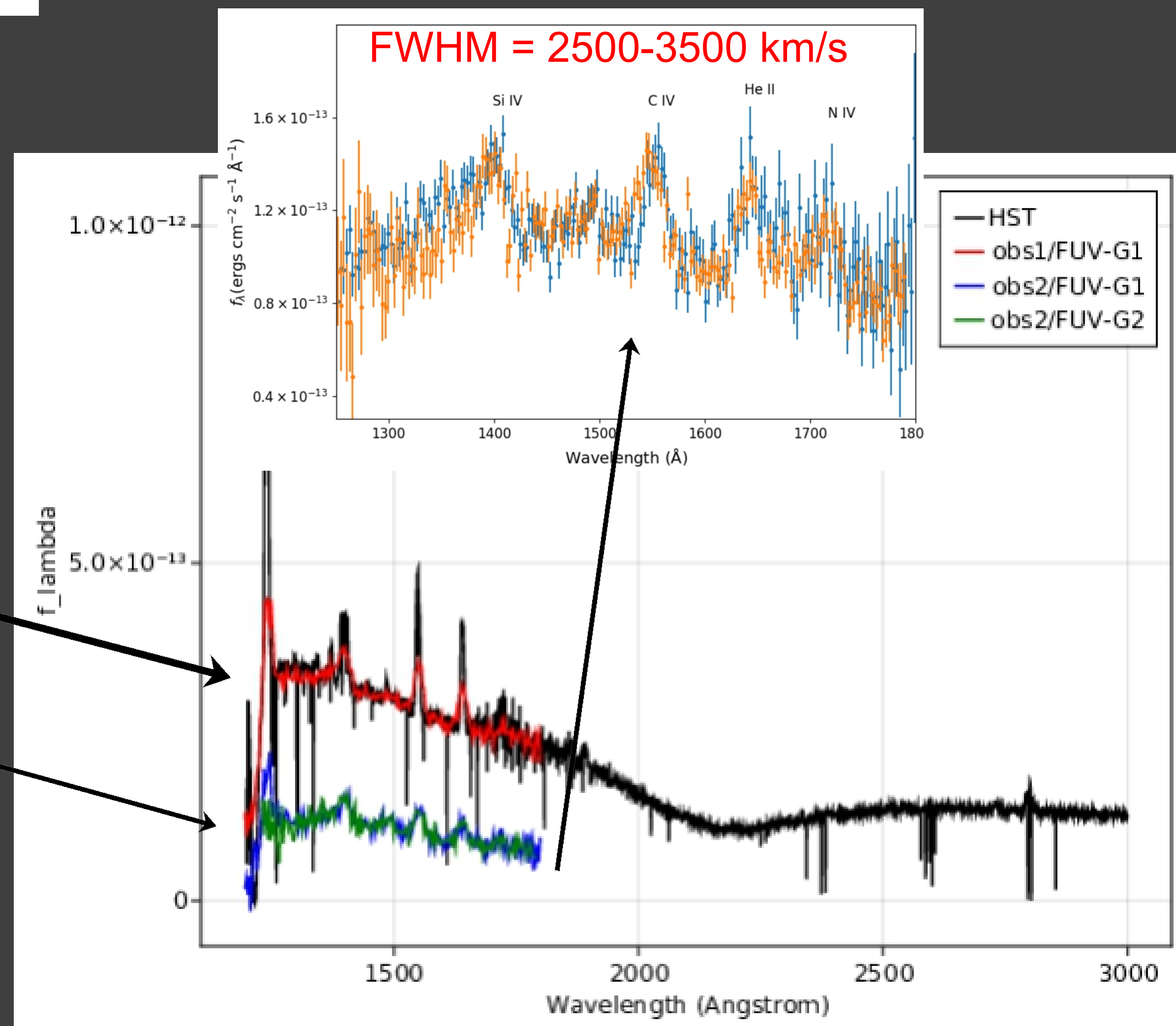
A Galactic BHB that went into powerful outburst starting on 6 Mar 2018.

$M_{BH} = 7\text{–}8 M_\odot$ (Torres et al. 2019)
$d = 3.5\text{kpc}$ (Gandhi et al. 2019)

Both AstroSat observations with UVIT gratings and X-ray instruments.

1st AstroSat observation in the hard state (Chakraborty et al., Mudambi et al. 2020)

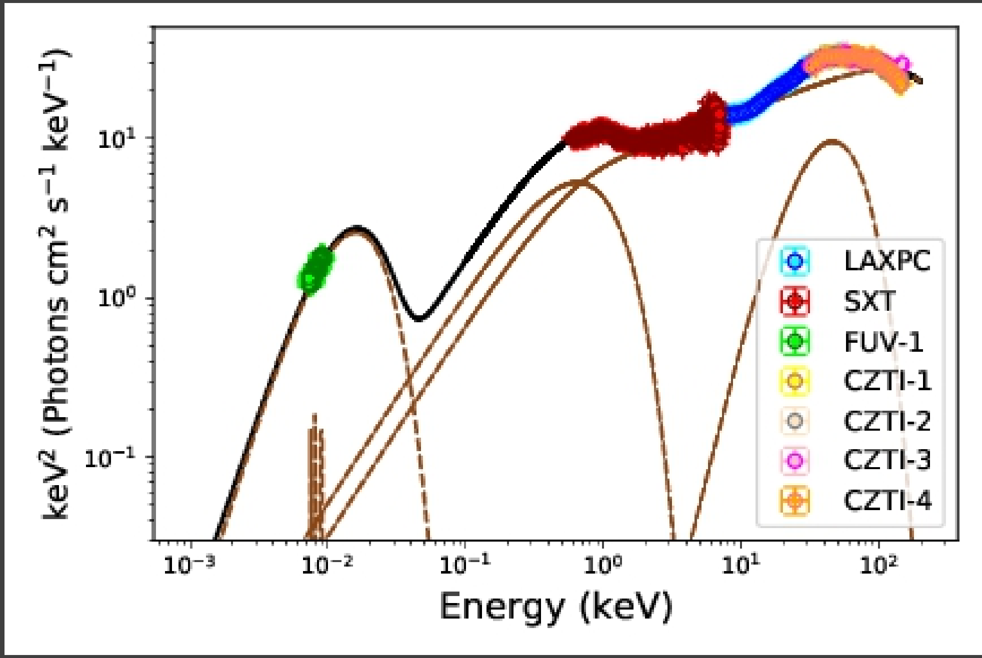




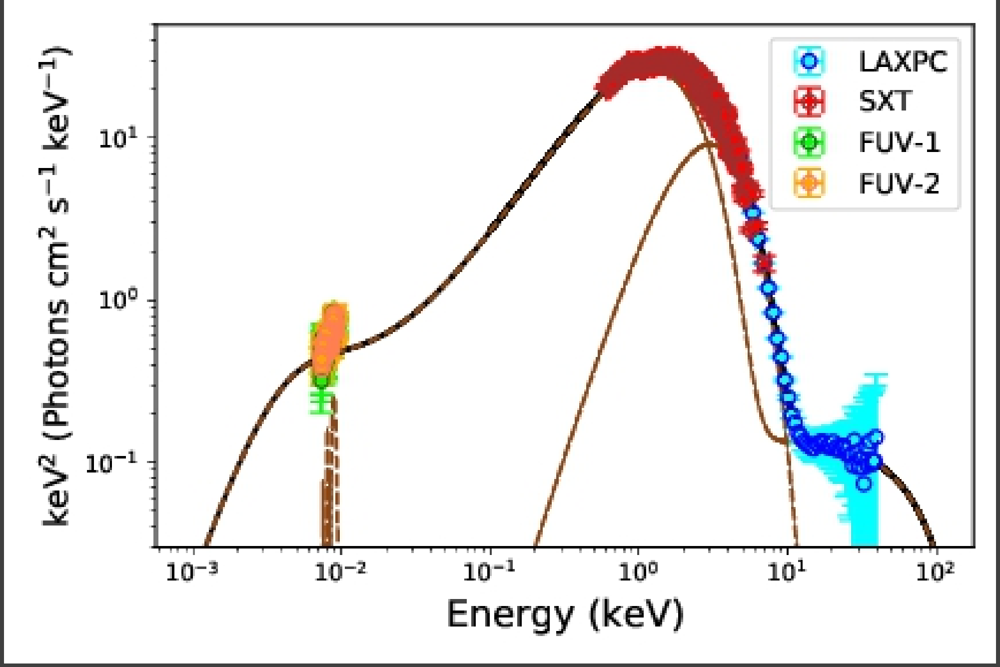
MAXI1820-070- UV/X-ray Spectral Transition

AstroSat UVIT/SXT/LAXPC/CZTI

Hard State



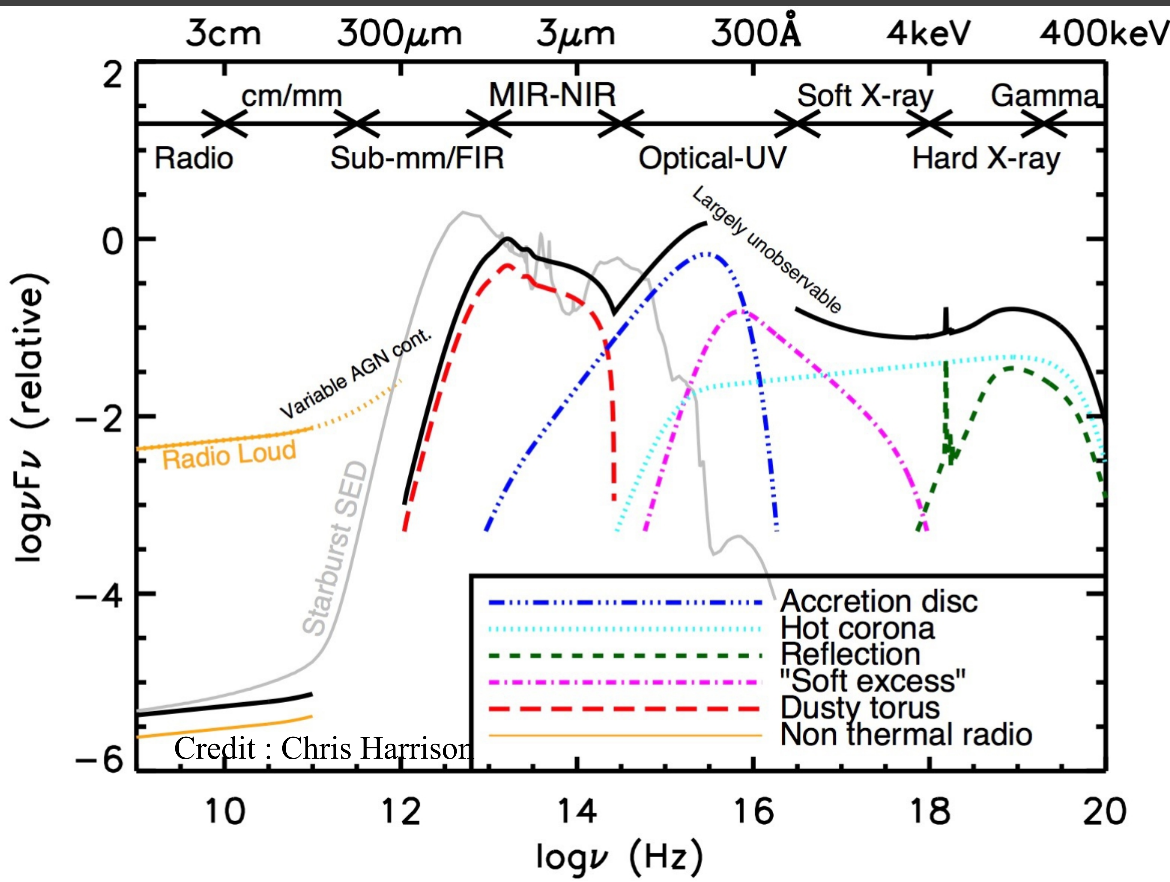
Soft State



- Both States show UV excess
- Stronger UV excess in the hard state

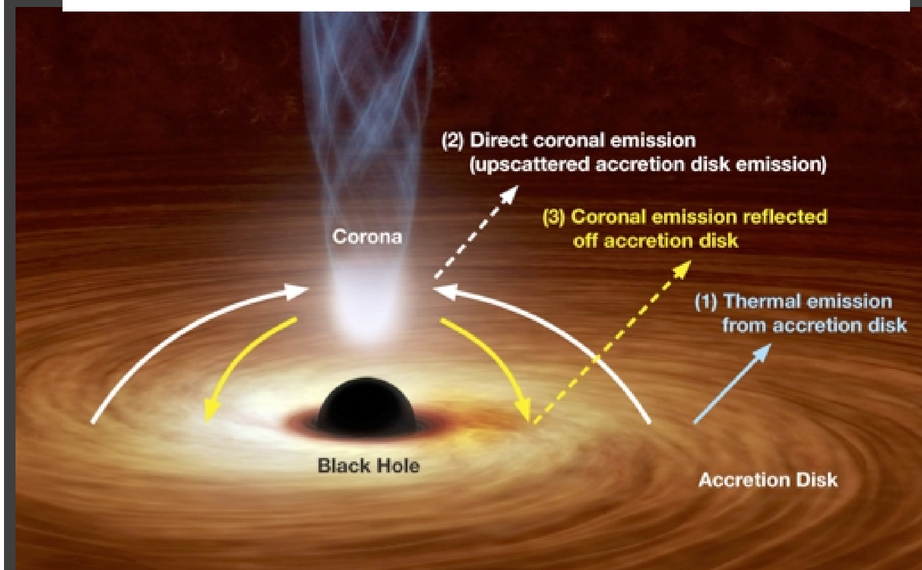
GCD, Benerjee, C. Knigge, G. Maria, P. Gandhi, 2022, in progress

AGN SED & AstroSat advantage



AGN Central engine

Cold accretion disk + Hot corona



AstroSat coverage:

UVIT : FUV/NUV/VIS

- FUV : 5 filters, 2 gratings
- NUV: 5 filters, 1 grating

SXT (0.2-8 keV),

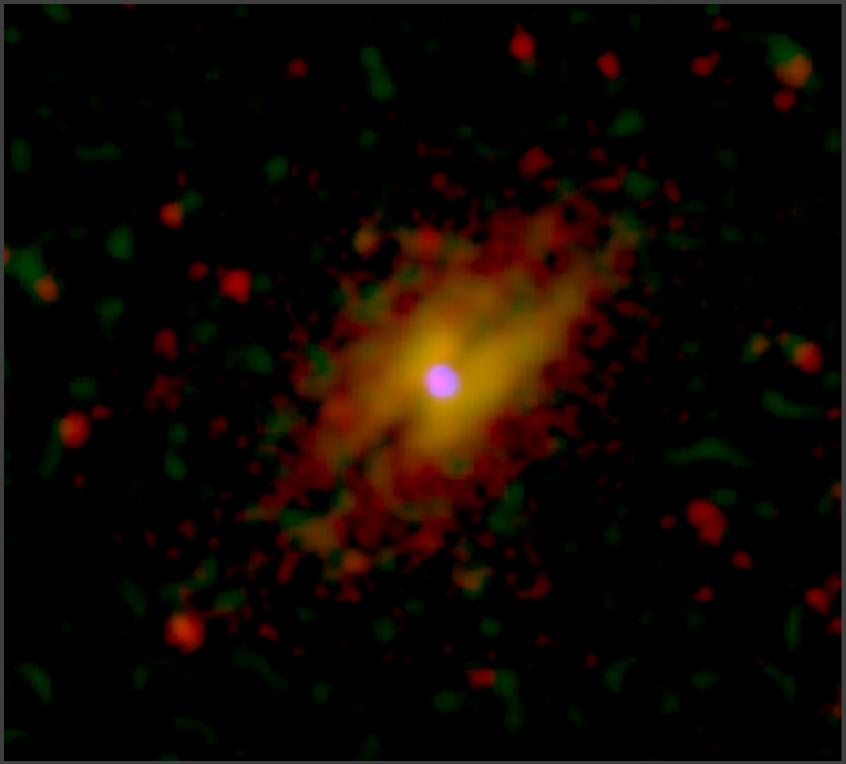
LAXPC (3-80 keV), CZTI (10-100 keV)

Probe Accretion disk, Soft X-ray excess and the Hot corona and the interplay between them

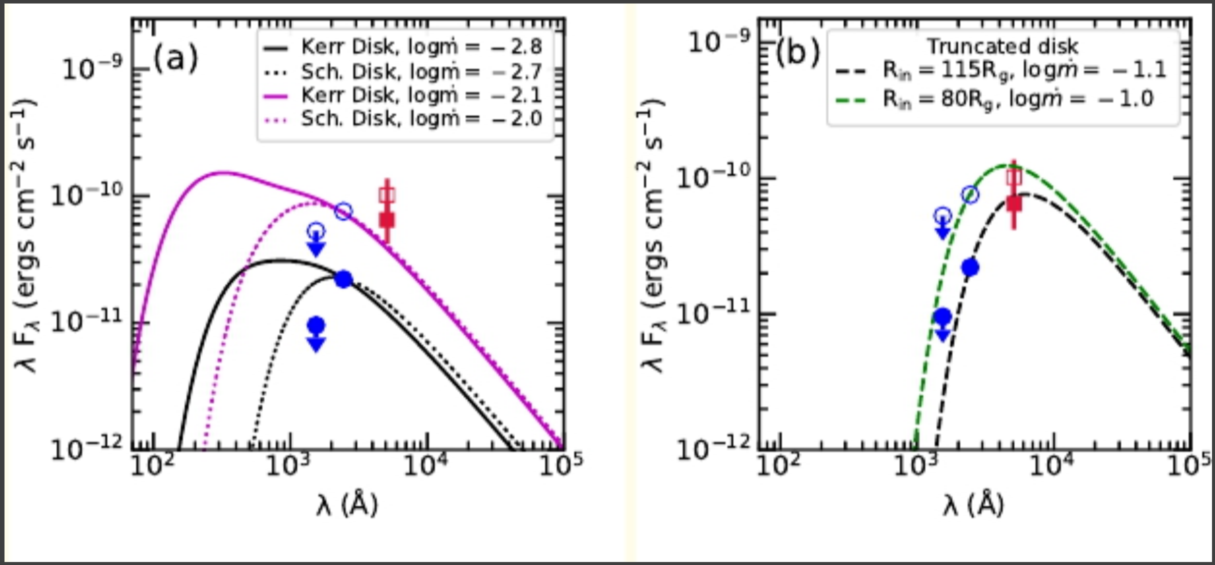
Truncated accretion disk in IC4329A

- Superior spatial resolution of AstroSat/UVIT separates AGN emission

AstroSat/UVIT FUV+NUV+Chandra



- Intrinsic continuum UV flux (AstroSat) and optical (HST) compated with standard accretion disk models.



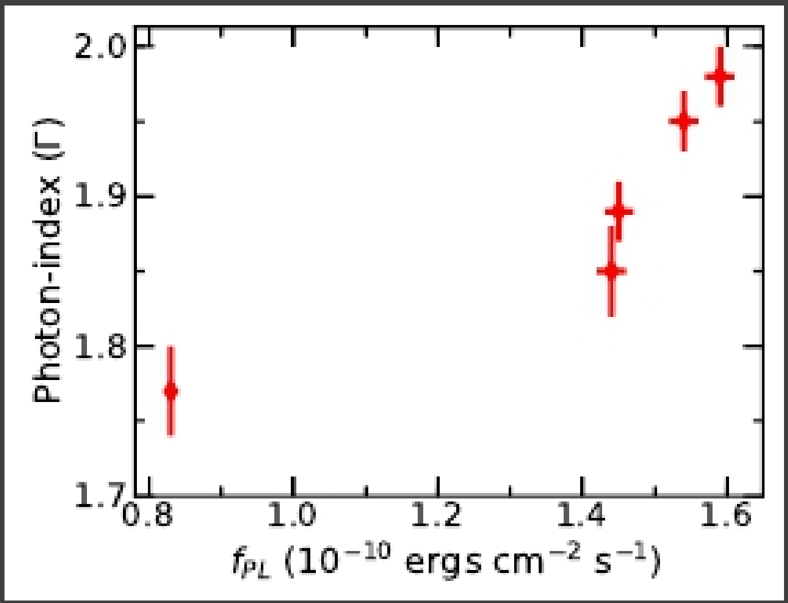
Full and truncated disk models

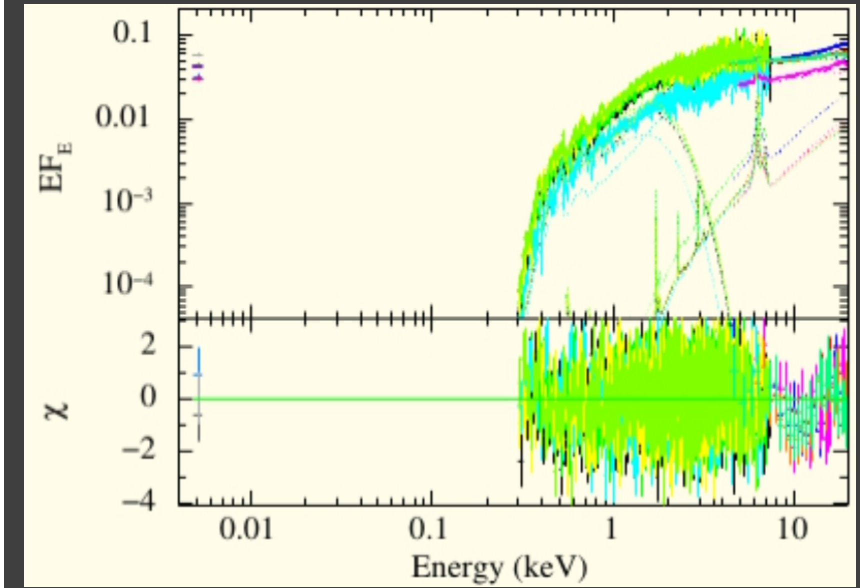
Czerny et al. extinction law, E(B-V)=1.0, 0.8

Truncated accretion disk R_{in}~80-150R_g

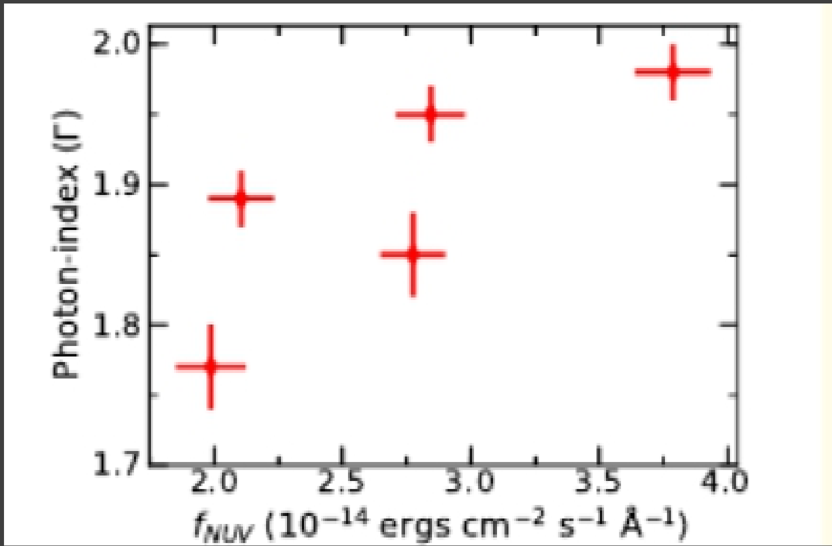
GCD, Prakash Tripathi+ 2021, MNRAS

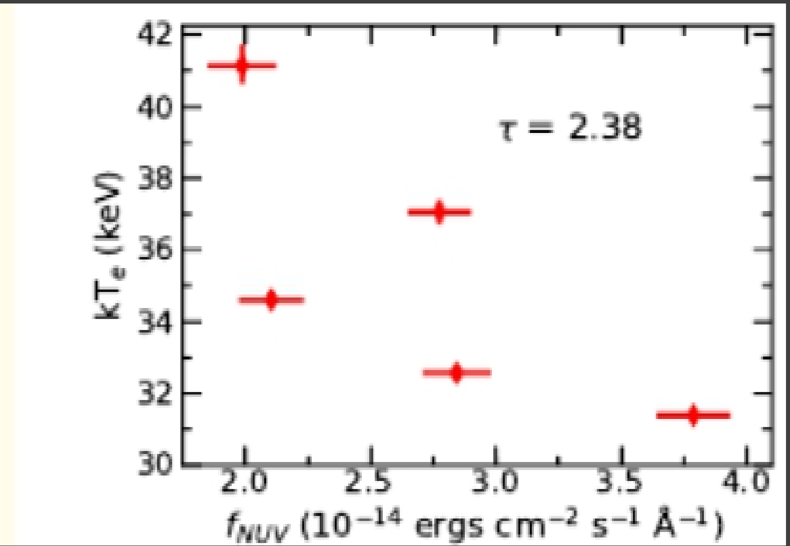
Seed photons for Thermal Comptonisation in IC4329A





Accretion disk + ThComp + reflection model



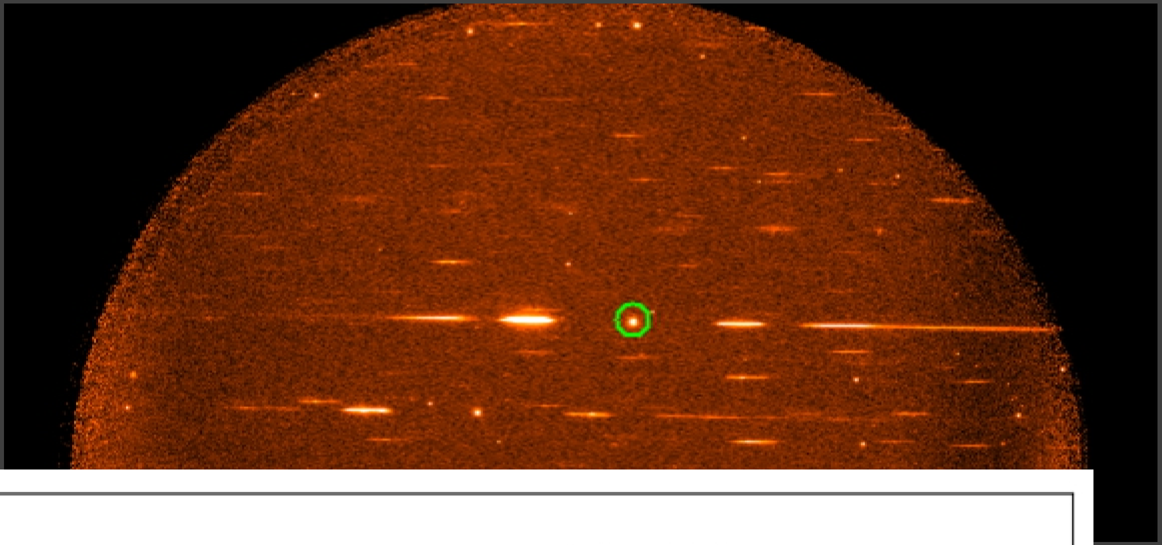


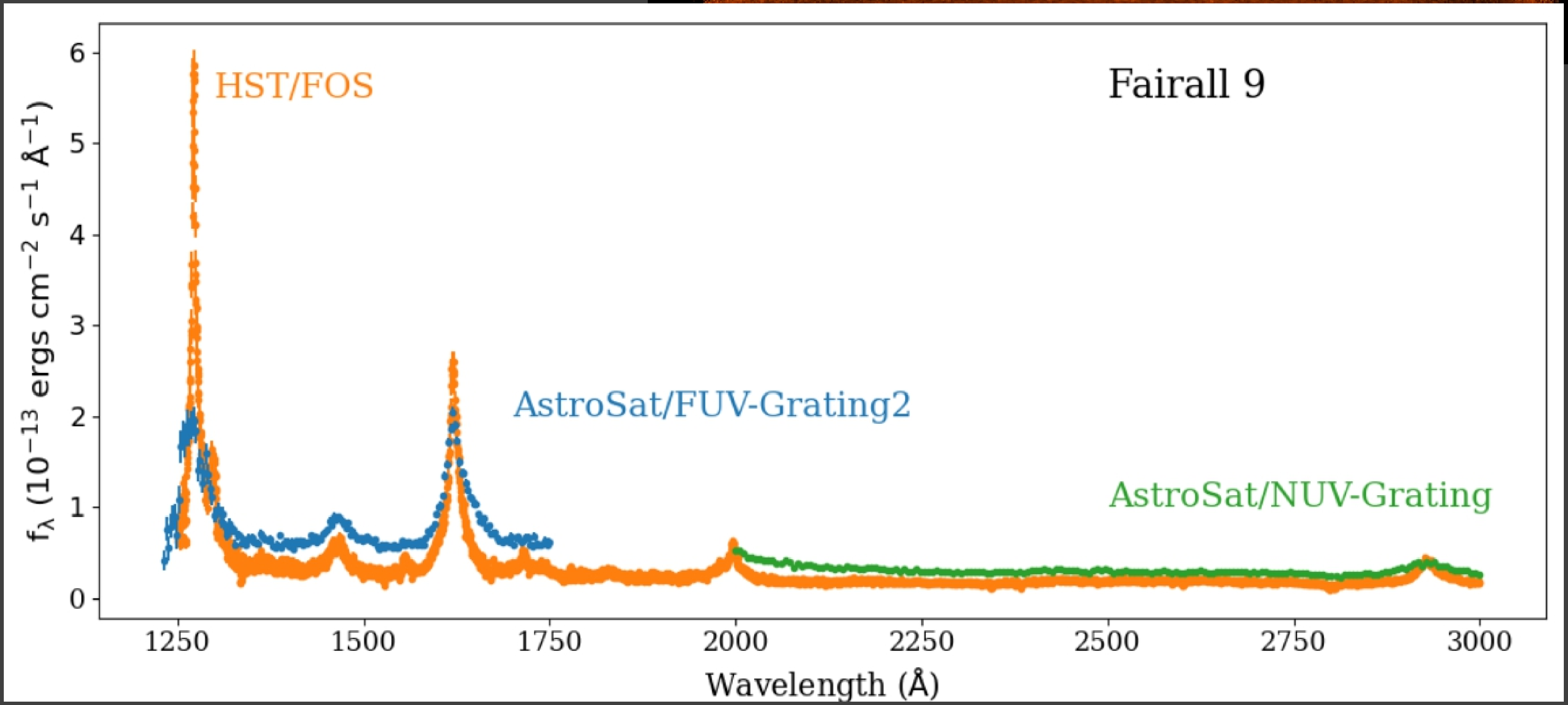
Prakash Tripathi, GCD+ 2021, ApJ

Increasing UV emission from the disk cooling the hot corona!

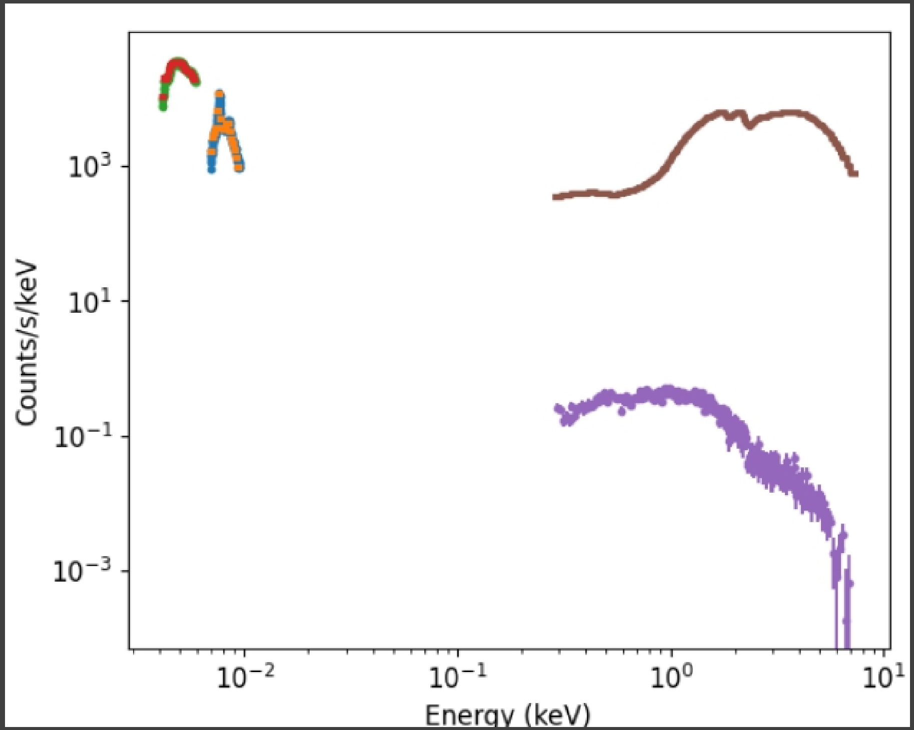
Fairall 9: FUV/NUV Gratings + SXT spectra

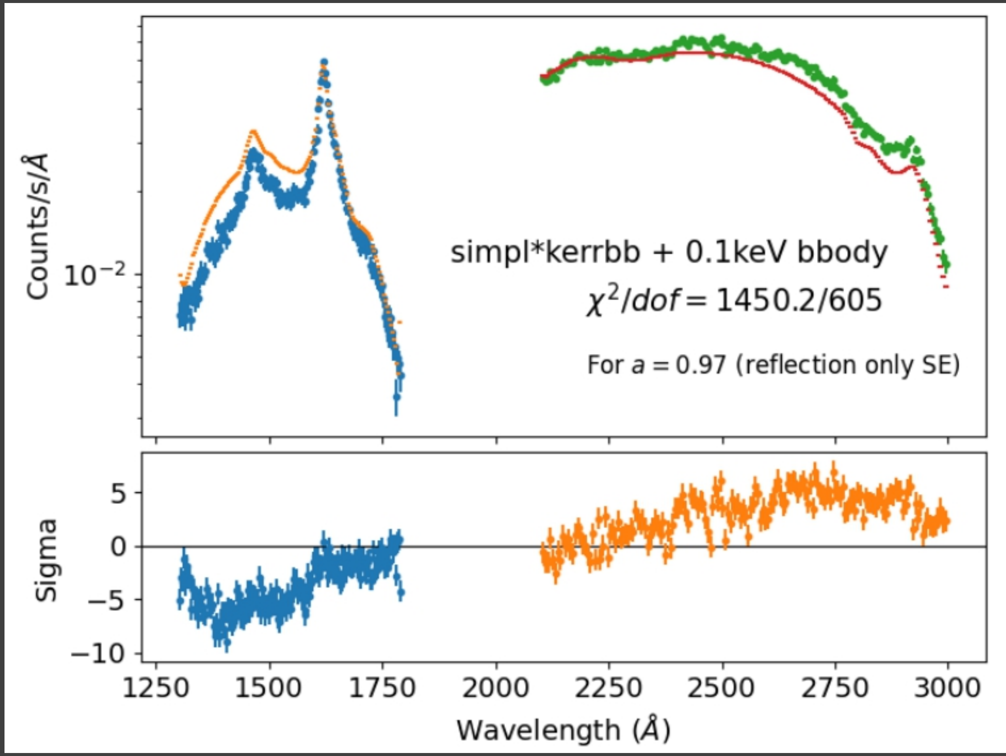
- A point-like UV source, no host galaxy contamination
- Bare Sy1, negligible internal extinction





Fairall 9: AstroSat FUV/NUV Gratings + SXT





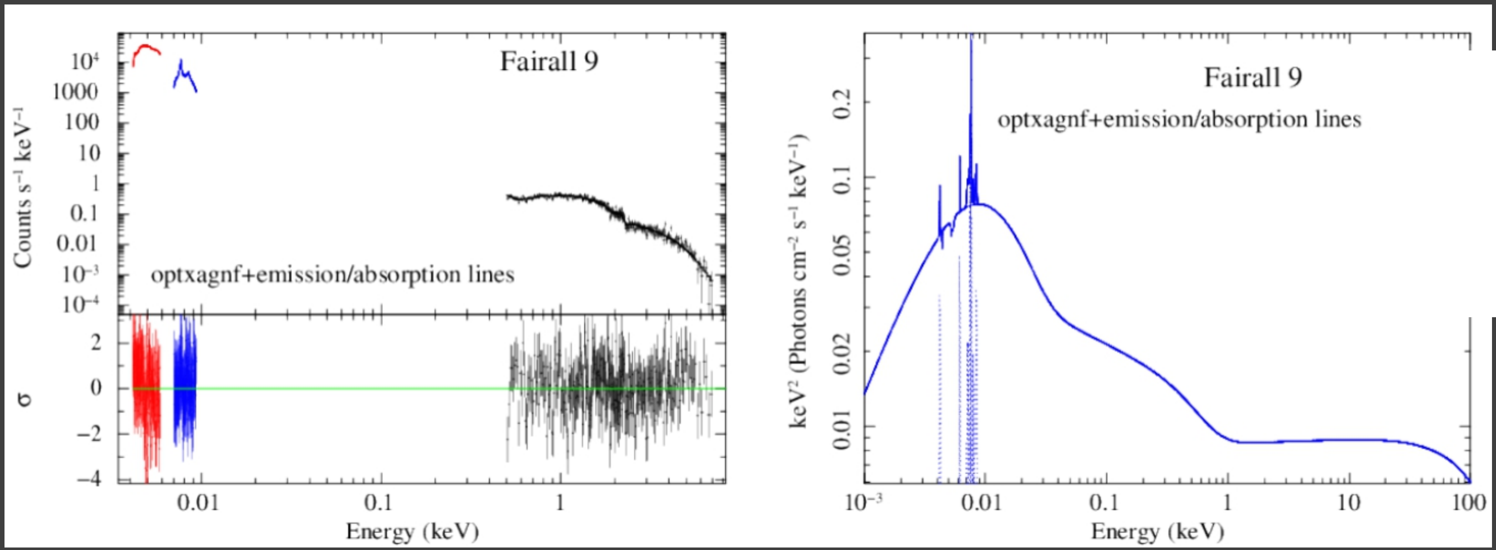
- Simple powerlaw, Gaussian emission lines reddened by Gal. extinction fit FUV+NUV grating data
- Extrapolating the best-fit UV model to the SXT band shows huge deficit

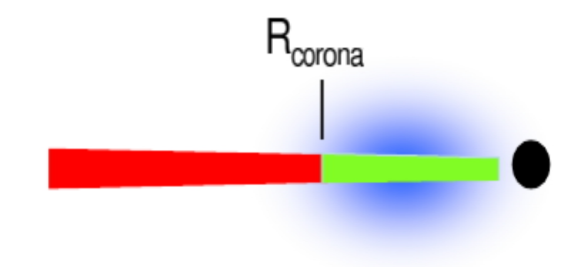
=> Big Blue Bump in the UV band

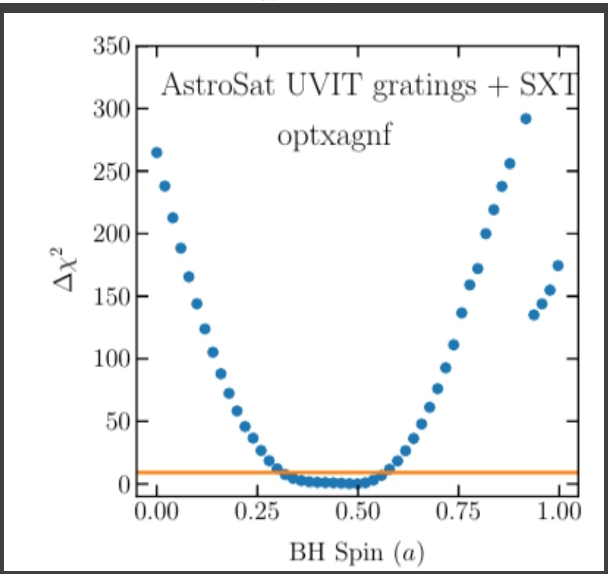
BH spin=0.97 from soft excess as blurred reflection (Lohfink et al. 2016)

Accretion disk around Kerr BH with a=0.97 does not describe the UV continuum.

Constraints on BH spin of Fairall 9







A truncated std disk (r_{in}~$20r_g$) + inner warm disk (kT_e~0.12keV, tau=23) + hot corona (Γ~2, f_{pl}=0.57)
L/L_{Edd} ~ 0.1, BH spin $a=0.49^{+0.04}_{-0.15}$

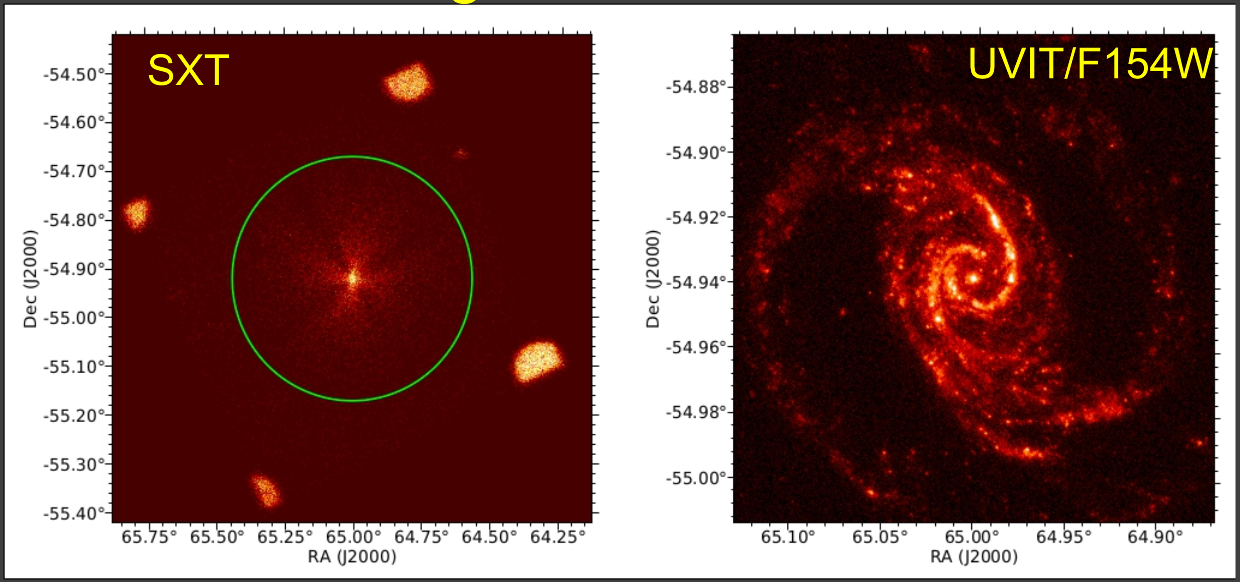
Need to account for reprocessed UV emission in the models.

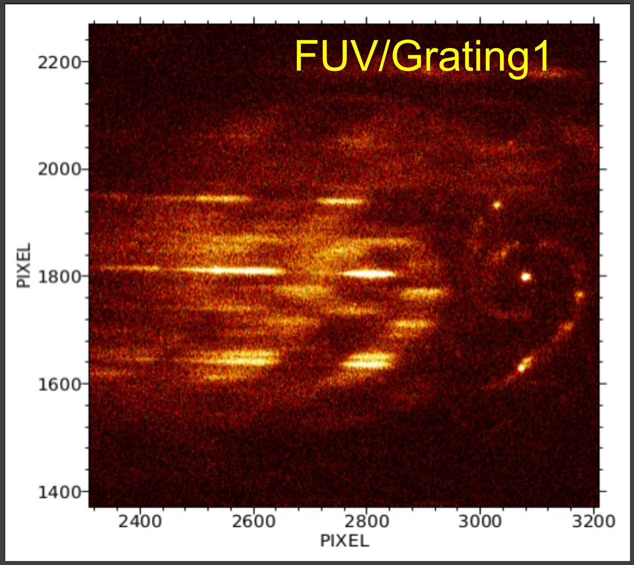
GCD+2022, in prep

Catching spectral Transition in NGC1566 with AstroSat

- NGC1566 : A changing-look AGN
- 2018 Outburst with peak in June 2018 (Swift/XMM-Newton)
- AstroSat ToO observations in August & October 2018

August 2018 AstroSat observations

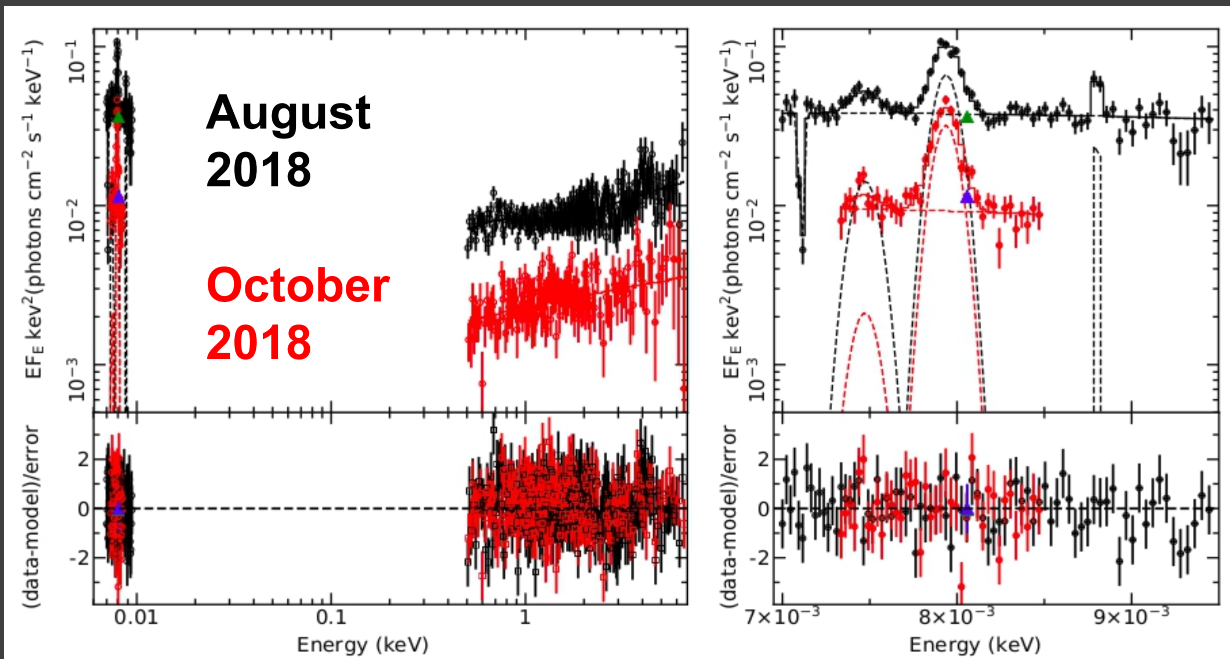




Prakash Tripathi, GCD, ApJ, 2022

FUV/X-ray SEDs with SXT and UVIT data

AstroSat: Far UV Grating/X-ray observations



UV: Accr disk + emission lines

Soft Excess: Warm Comptonisation

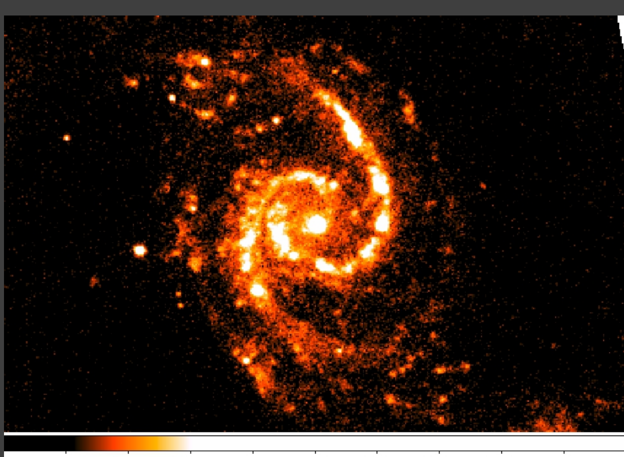
X-ray PL: Hot Comptonisation

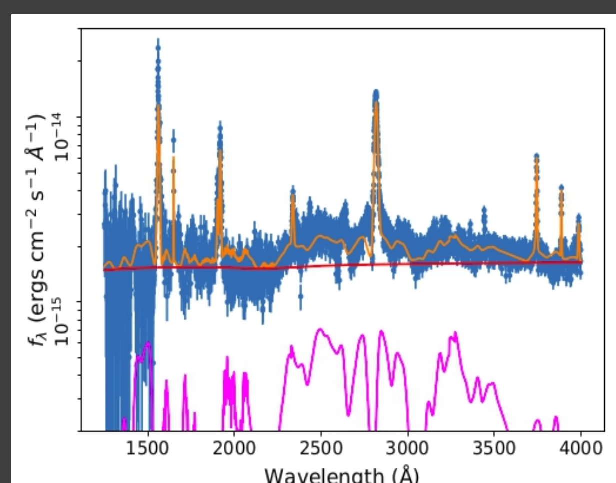
L/L_{Edd} ~ 1.5 % to 0.4 %,

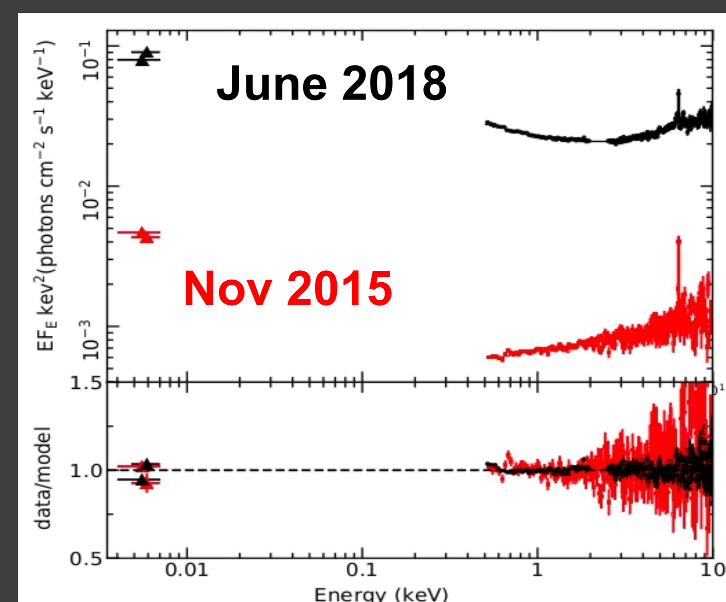
Std disk R_{in} ~50 R_g to 40 R_g

Tripathi, GCD, ApJ, 2022

XMM: near UV broadband filter/X-ray observations

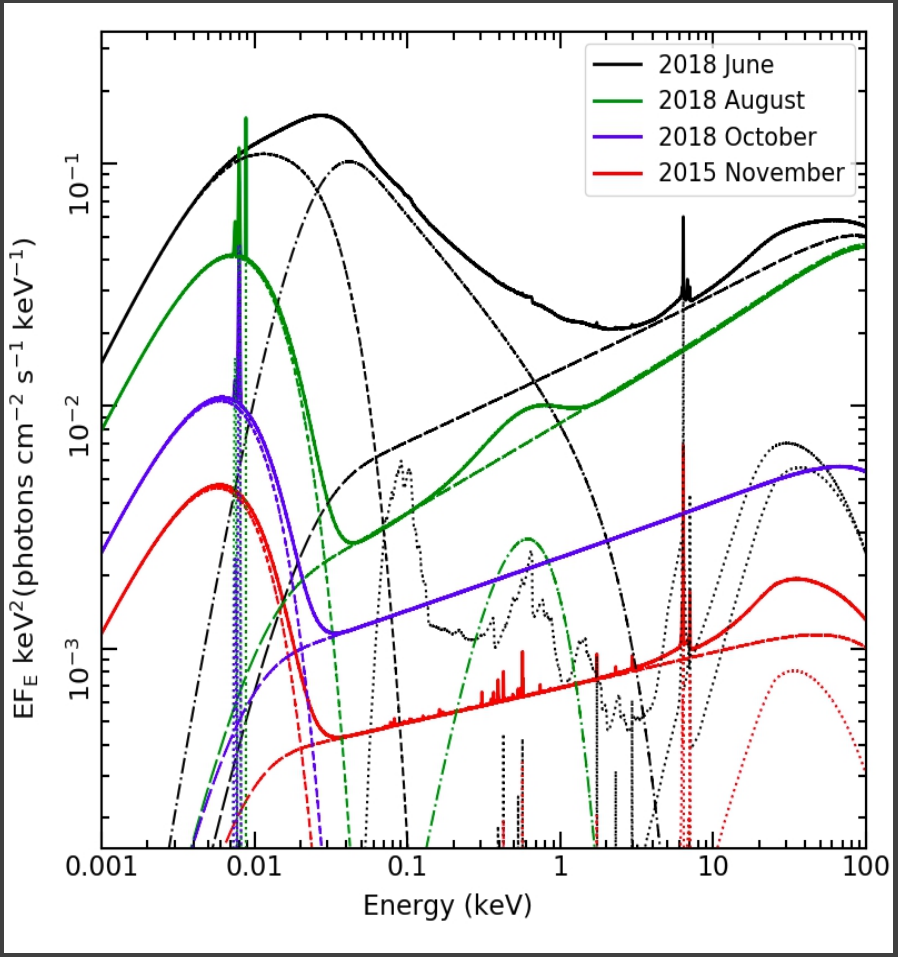






NGC1566: UV/X-ray spectral evolution during the 2018 Outburst

	Pre(2015)-to-peak (June 2018) outburst	Peak (June 2018) to low state (Oct 2018)
Accretion disk	30 ⇧	13 ⇩
X-ray PL	25 ⇧	7 ⇩
Soft X-ray excess	**Undetectable (2015), >240** ⇧	**Decreased by factor of 7 in Aug 2018, undetectable in Oct 2018, >40** ⇩
L/L_{bol}	0.1%(2015) 5% (June 2018) A factor 50 ⇧	1.5% (Aug 2018) 0.3% (Oct 2018) A factor 17 ⇩



Formation and disruption of the soft excess emitting region

P. Tripathi, GCD, ApJ, 2022

Spectral Transition in NGC1566

High Luminosity, Standard disk + Warm Comptonising region + Hot corona

Low Luminosity, only standard disk + Hot corona

Accretion disk Time scales (at $50R_g$, inner extent of the std disk)

$$\text{Dynamical}: \quad t_{dyn} = \left(\frac{r^3}{GM_{BH}}\right)^{1/2} \sim 0.17 \text{ days}$$

$$\text{Thermal}: \quad t_{th} = \frac{1}{\alpha} t_{dyn} \sim 1.7 \text{ days}$$

$$\text{Viscous}: \quad t_{vis} \approx \frac{1}{\alpha}\left(\frac{r}{h}\right)^2 t_{dyn} \sim 2.4\times10^4 \text{ years}$$

Outburst decline time ~ 6 months

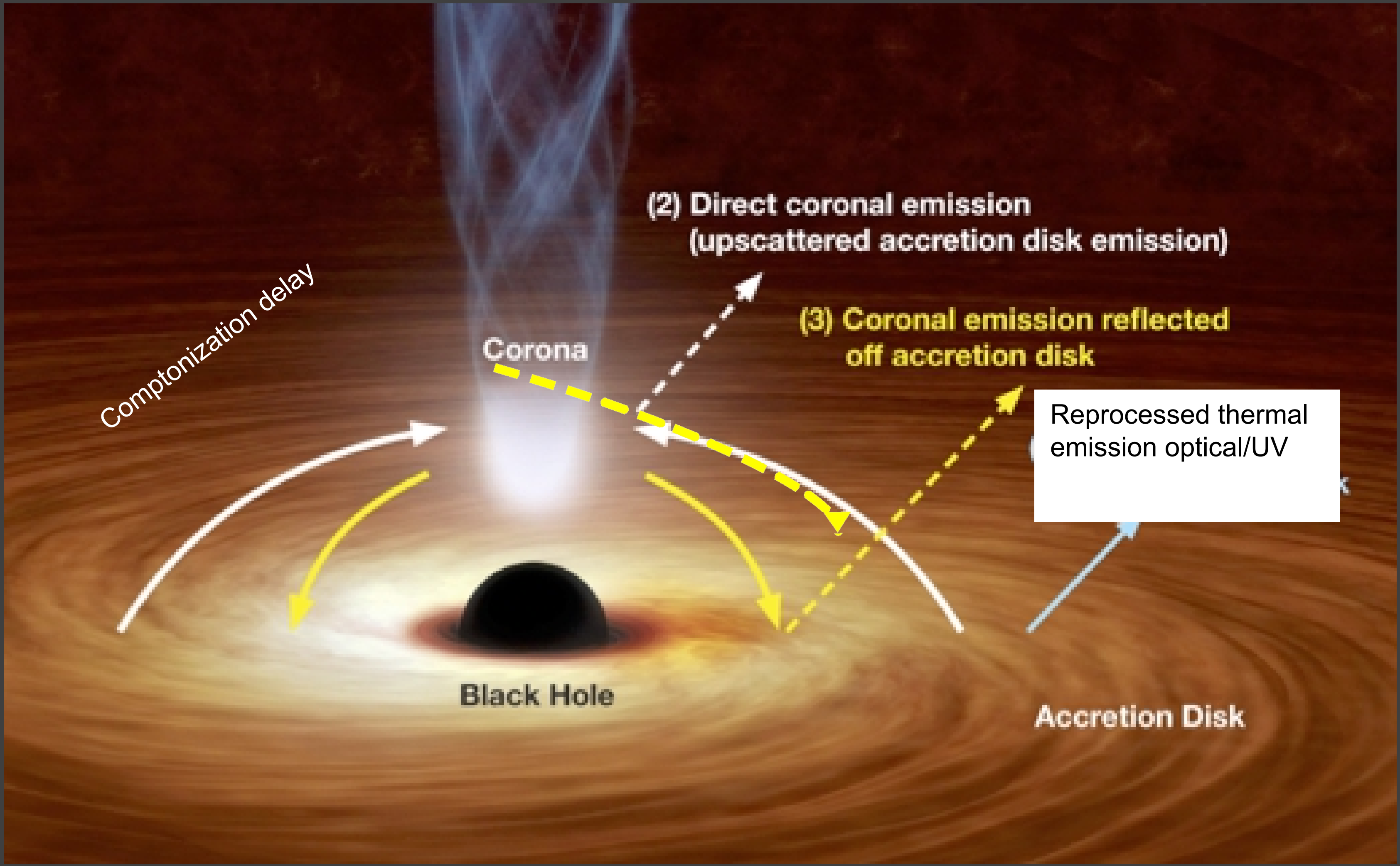
$$\text{Sound crossing time}: \quad t_s \sim 50R_g/c_s \sim 1 \text{ year}$$

Outburst possibly due to Radiation pressure instability.

How does the accretion disk change on time scales much shorter than viscous time scale? A puzzle!

P. Tripathi, GCD, ApJ, 2022

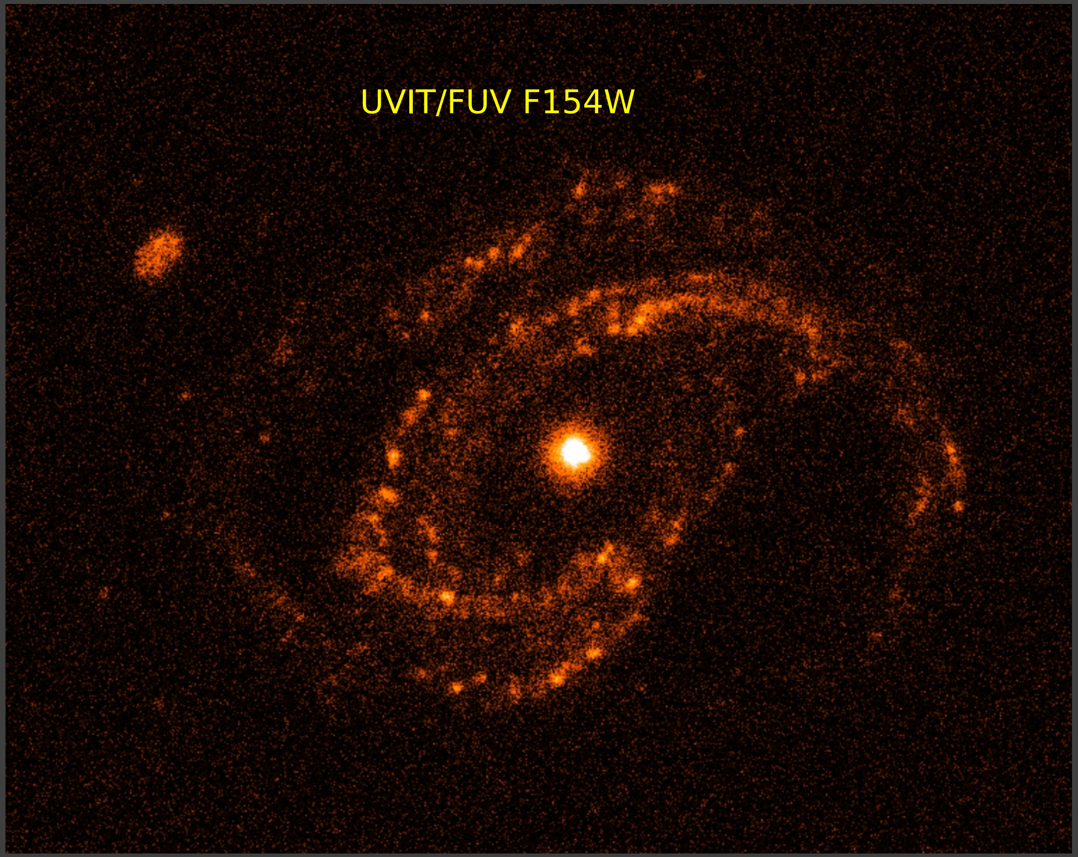
UV/X-ray temporal connection in RQ AGN

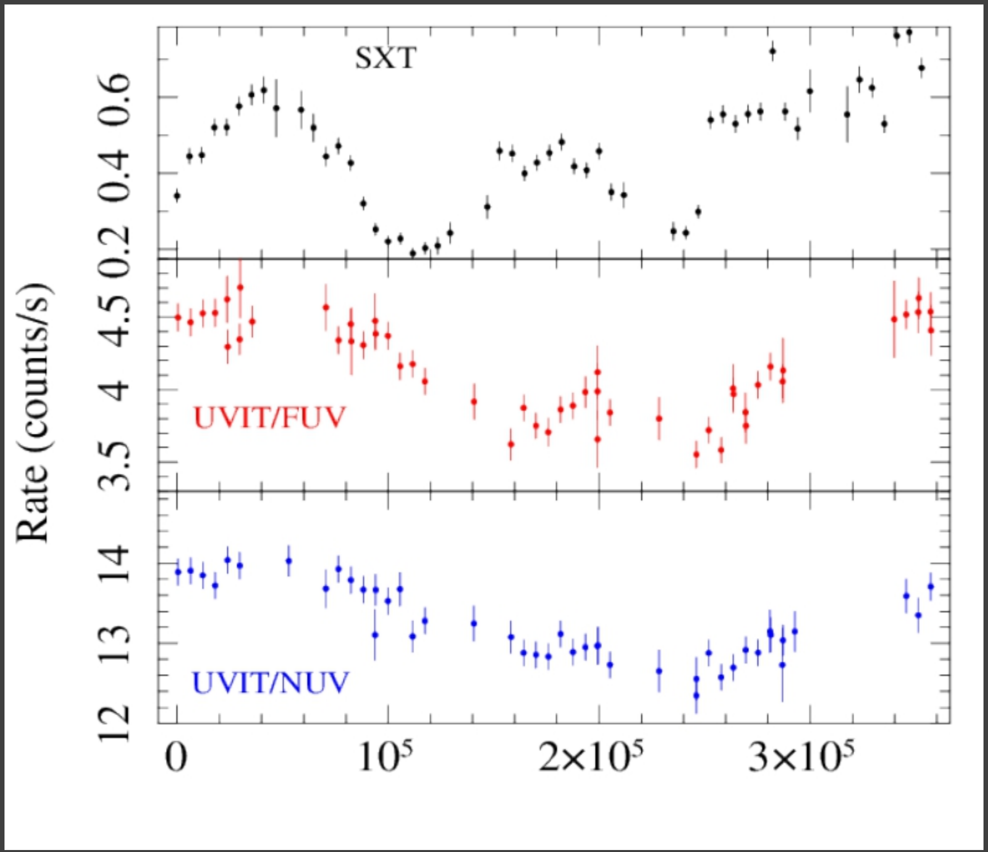


Measuring UV/X-ray time lag with AstroSat

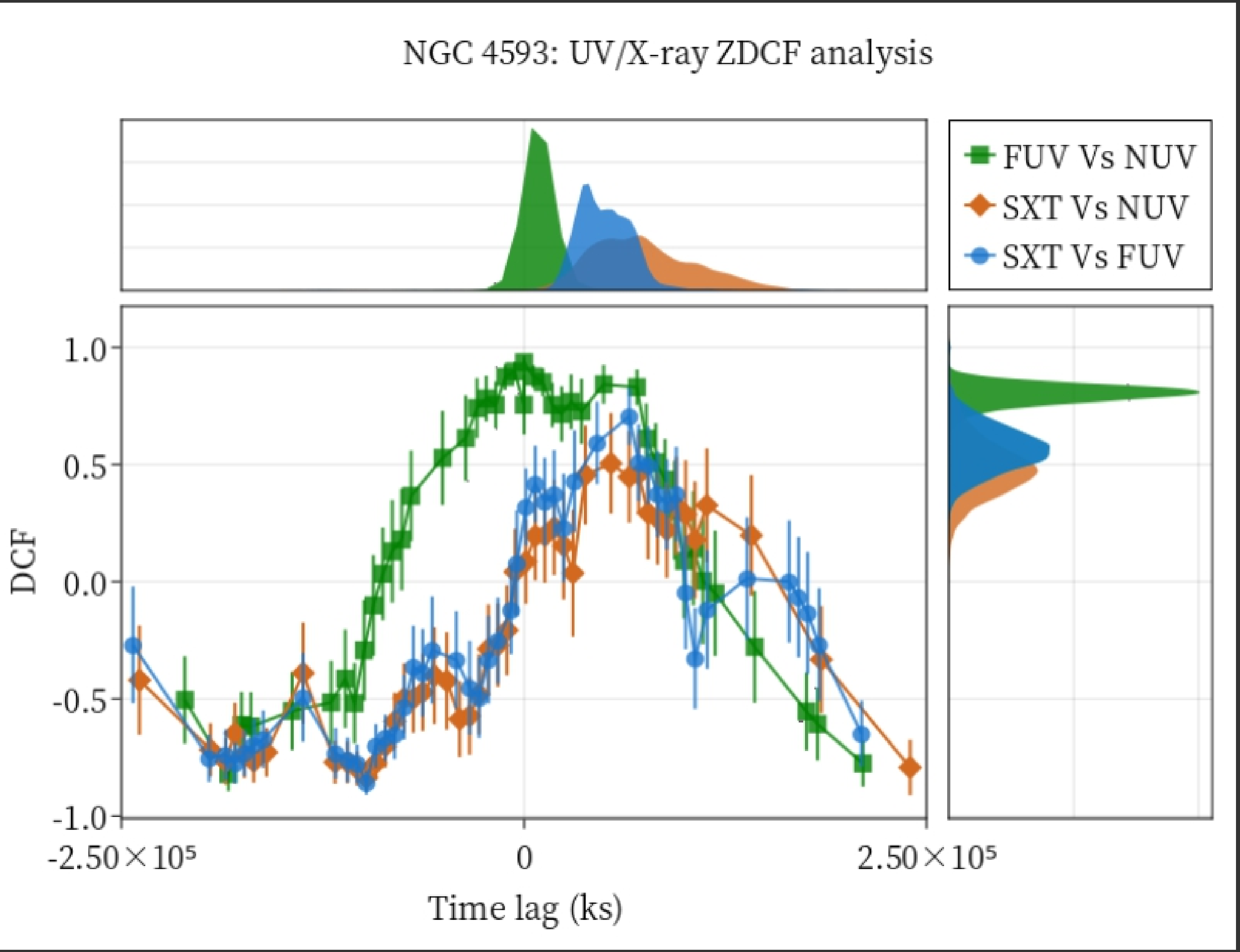
NGC4593 : A Seyfert 1 galaxy

4 day long AstroSat observation





UV/X-ray time lags in NGC4593



Time lags in ks
(relative to X-rays)

Method	SXT/FUV	SXT/NUV
DCF	61^{+20}_{-12}	87^{+40}_{-11}
ZDCF	65^{+3}_{-31}	57^{+53}_{-14}

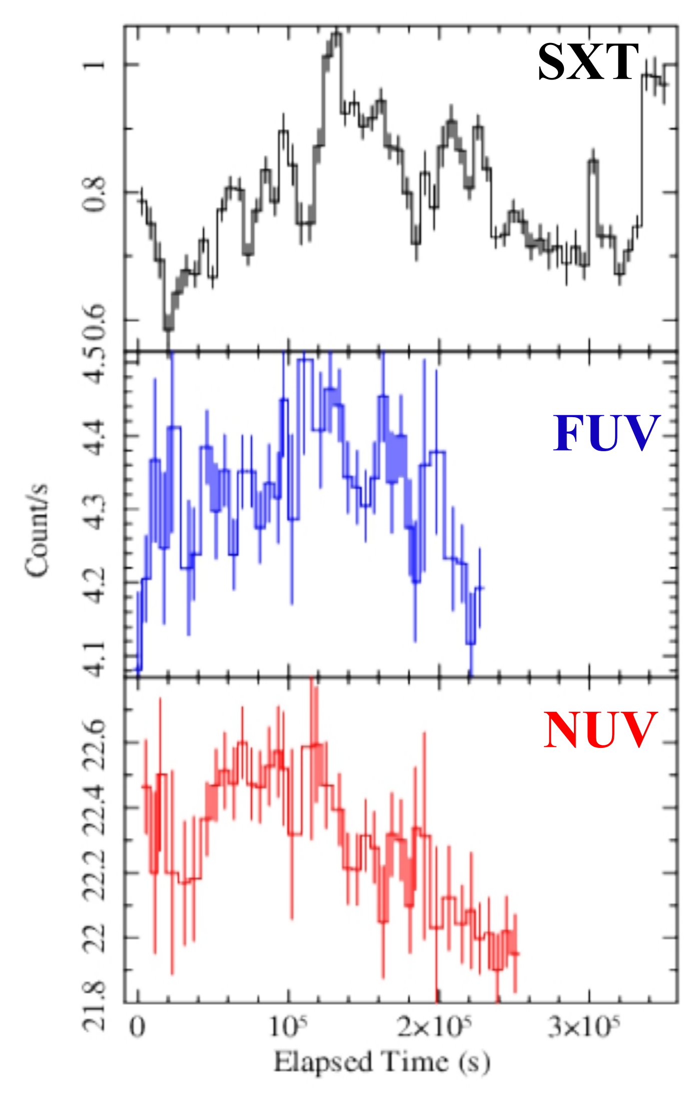
Swift observations during July 13-18, 2016. UVW2 lagging the X-rays by 0.66± 0.15 days or ~57 ks

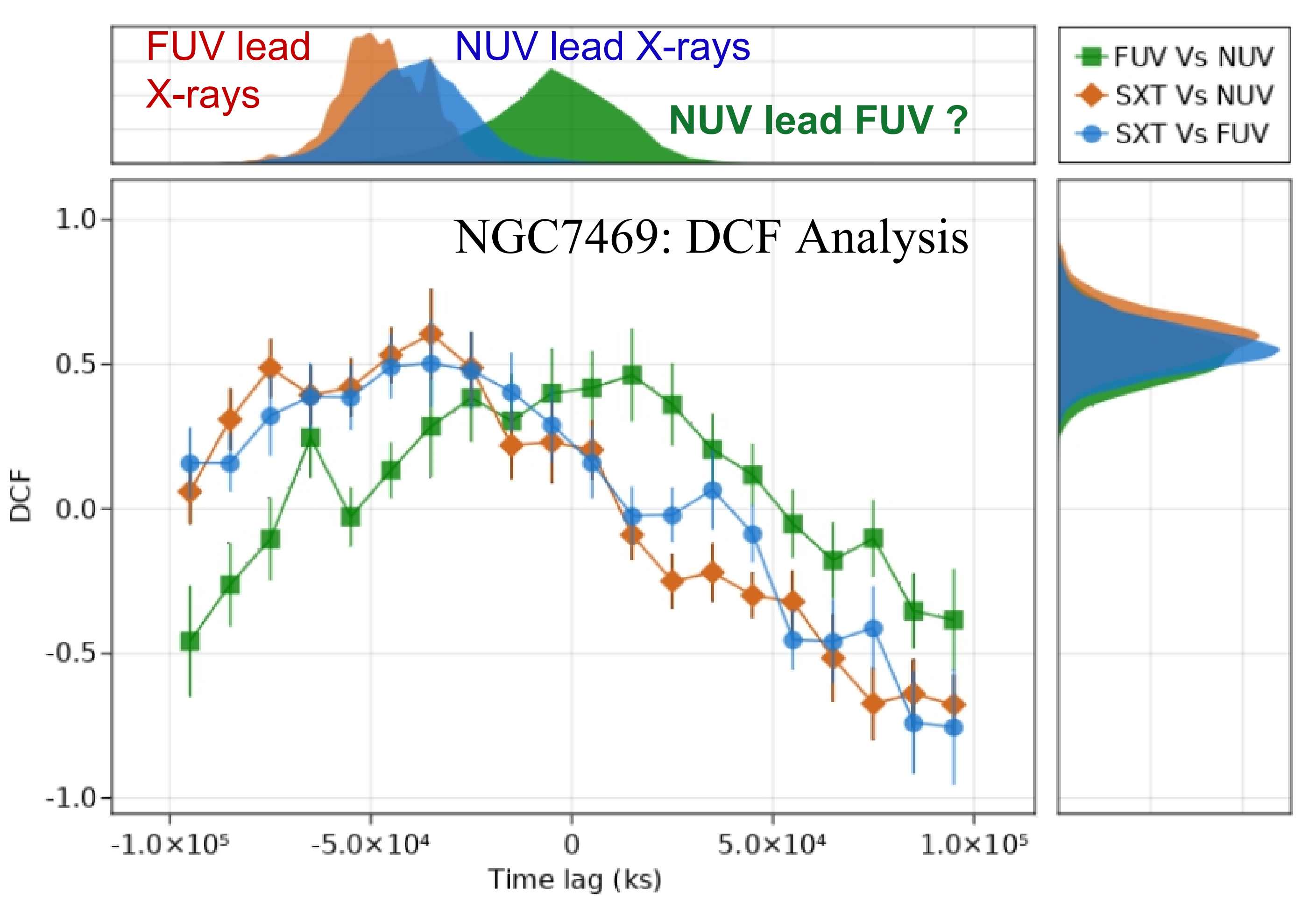
X-ray reprocessing in accretion disk (McHardy et al. 2018)

AstroSat UVIT/SXT observations can measure time lags in AGN

NGC7469: UV leading X-rays

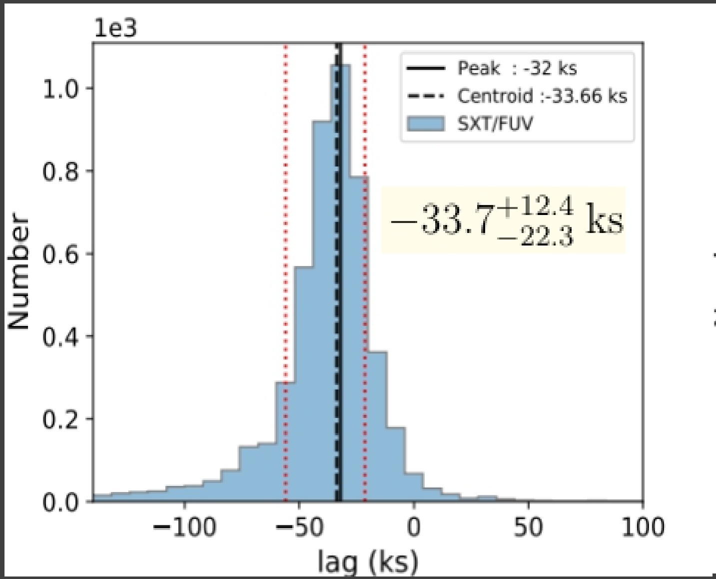
AstroSat UV/X-ray observations

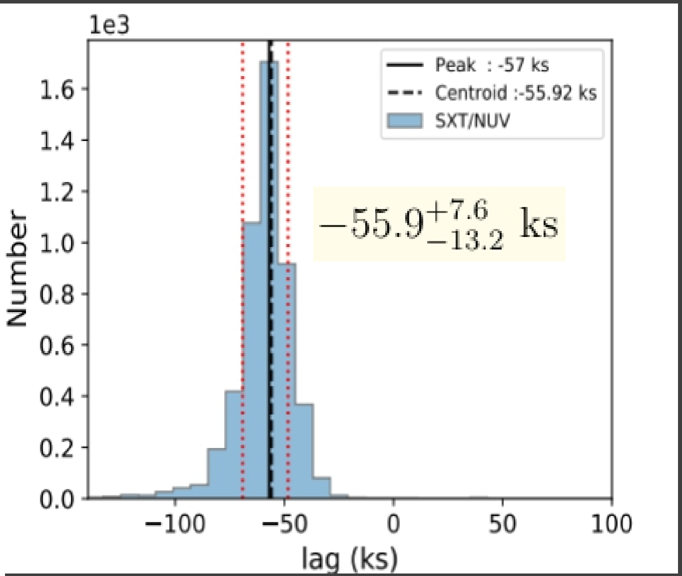


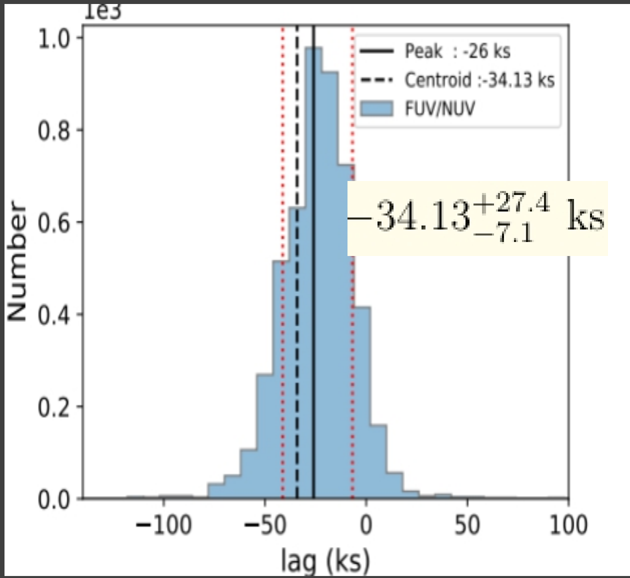


FR/RSS Technique

ZDCF Results with 68 % confidence interval



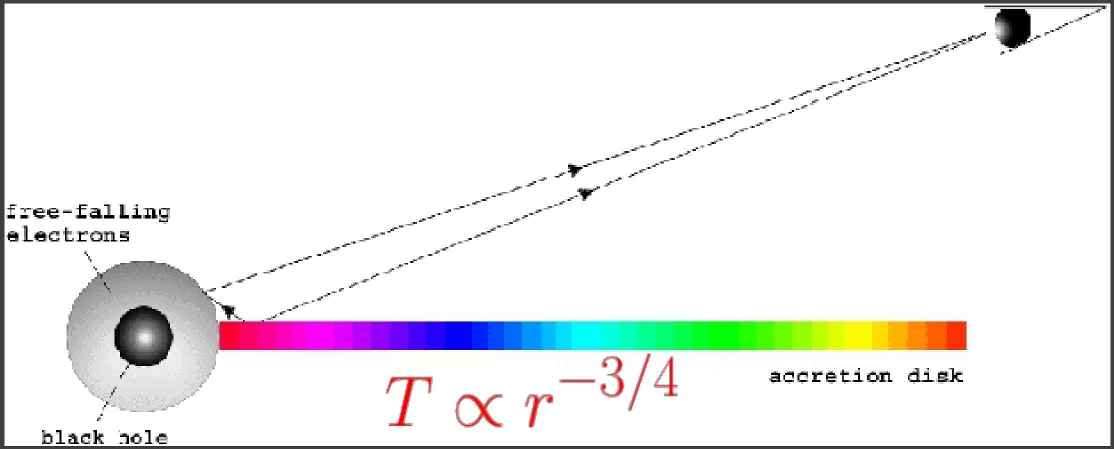




UV lead in NGC7469

UV emission not dominated by X-ray reprocessing in NGC7469!

UV lead consistent with Comptonization delay.



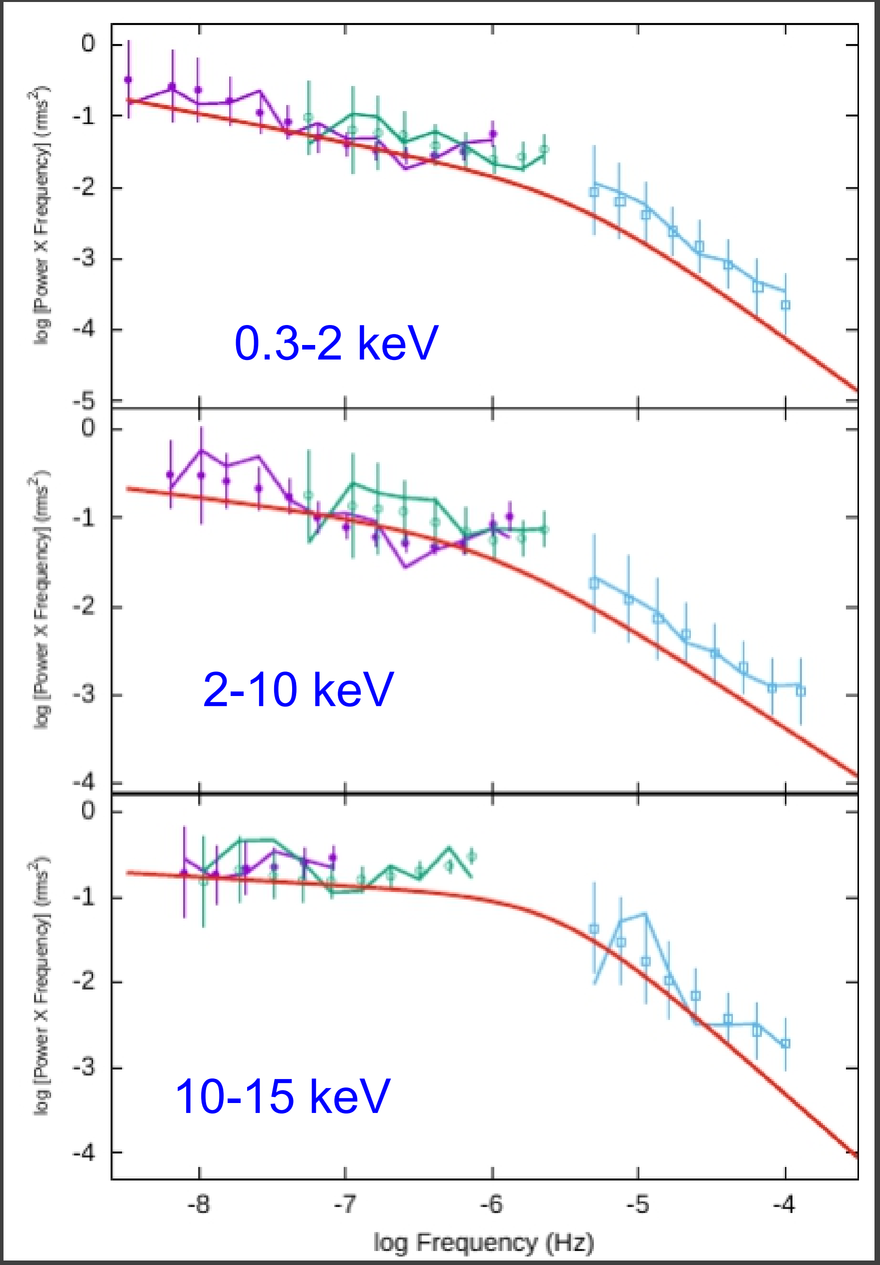
Kavita Kumari, GCD+, 2022, prep.

Disk-Jet connection in the Blazar Mkn421
using AstroSat SXT/LAXPC

(Chatterjee et al. 2018)

- PSD break in Mkn 421, a BL Lac type Blazar
- Characteristic timescale in X-ray variability

- Break time scale similar to that observed from BH XRB and Seyfert 1s.
- Translation of disk-corona variability to jet emission variability.



Summary

- AstroSat's LAXPC is revealing high resolution timing characteristics of XRBs.
- The SXT+LAXPC observations of BH XRBs are providing broadband spectro-timing studies and helping to gain insights on the origin of QPOs and emission mechanisms.
- CZTI has detected more than 500 GRBs and measured hard X-ray polarisation of 20 GRBs.
- UV+X-ray observations of AGN with AstroSat are providing important information on the accretion disk and its connection with hot corona.
- Many more interesting results yet to come from unanalyzed UV/X-ray data.
- ASSC (AstroSat Science Support Cell) website provides information on proposal writing, archival data, processing and analysis software, calibration, etc. **See http://astrosat-ssc.iucaa.in/**

ASSC - http://astrosat-ssc.iucaa.in

ASTROSAT
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Home

Welcome to the **Astrosat Science Support Cell (ASSC),** operated jointly by the **Indian Space Research Organisation (ISRO)** and the **Inter-University Centre for Astronomy and Astrophysics (IUCAA).** The ASSC assists Guest Observers in making observing proposals and analyzing the science data acquired by the **AstroSat** mission. This site provides tools and documentation required for proposal writing and data analysis, along with necessary updates. The ASSC also organizes workshops/meetings and operates a helpdesk. The ASSC works in close collaboration with the **Indian Space Science Data Centre (ISSDC)** and the Payload Operation Centres of **UVIT, LAXPC, SXT,** and **CZTI** instruments.

IMPORTANT NOTE:

New!!

26.03.22: Upcoming workshop: Three-day workshop on High Energy Astrophysics from 9th-11th May 2022. Last date of application is 31st March 2022

07.09.21: Problem of gaps in X-centroid in the L1 data of UVIT

01.09.21: The JAA has published a special issue titled "AstroSat: 5 years in orbit"

Thanks:

ISRO, Payload Managers & Payload Teams, Operation Team, ASSC support

Collaborators (AstroSat Work):

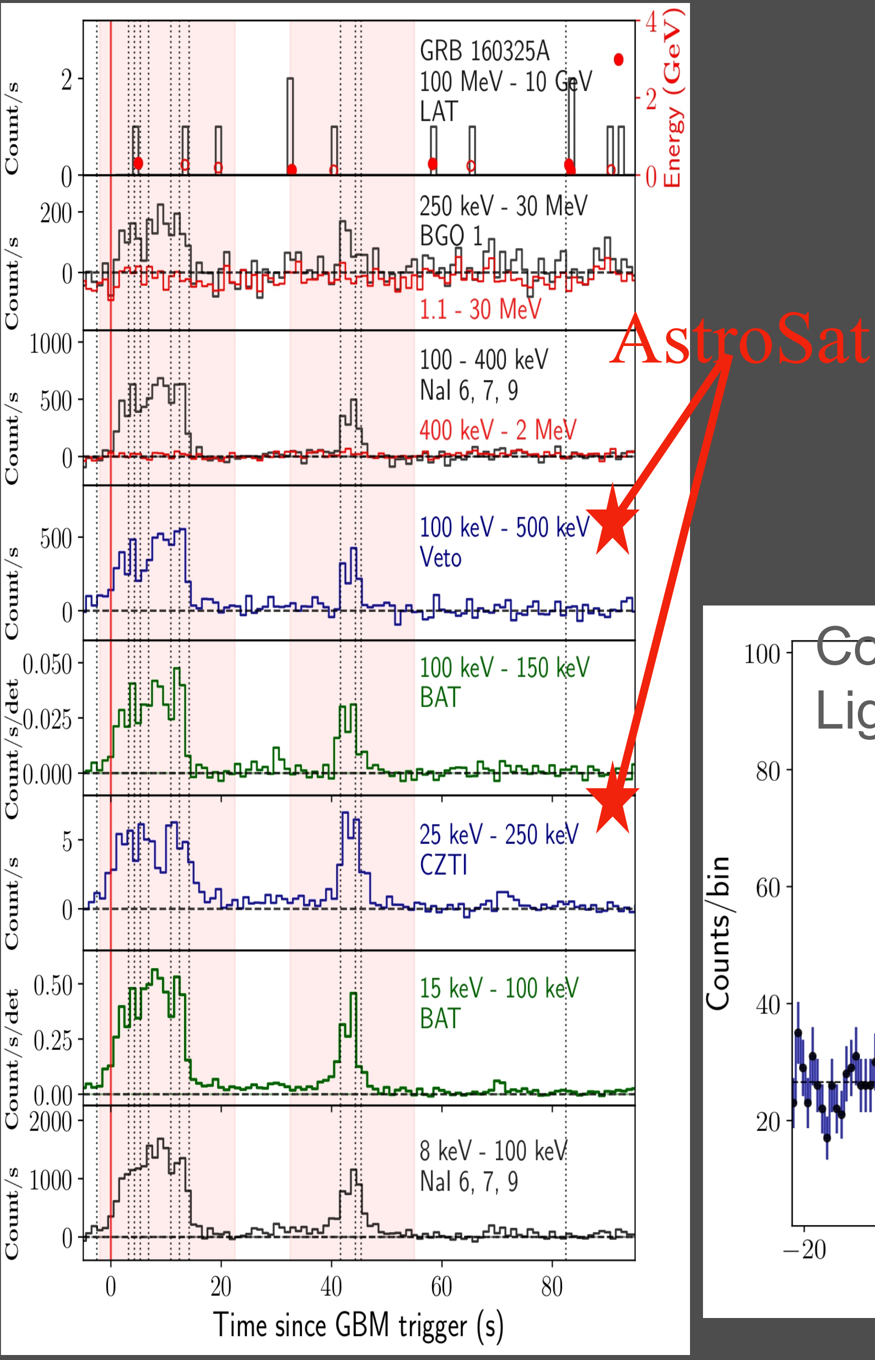
K. P. Singh (IISER, Mohali), Iossif Papadakis (Univ of Crete, Greece)

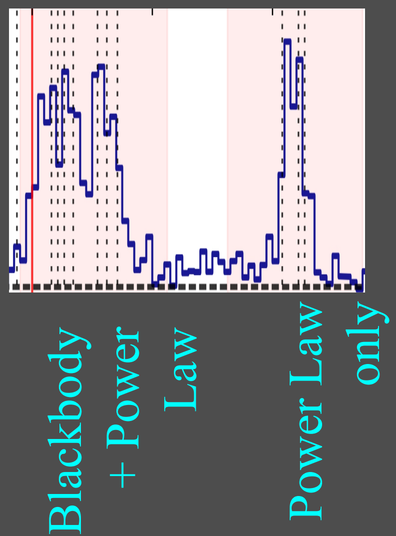
Prakash Tripathi, Shrabani Kumar, Kavita Kumari, Piyali Ganguli (IUCAA), Subhashree Swain (Univ of Pondicherry), Swadesh Chand & Parijat Thakur (Central Univ, Bilaspur)

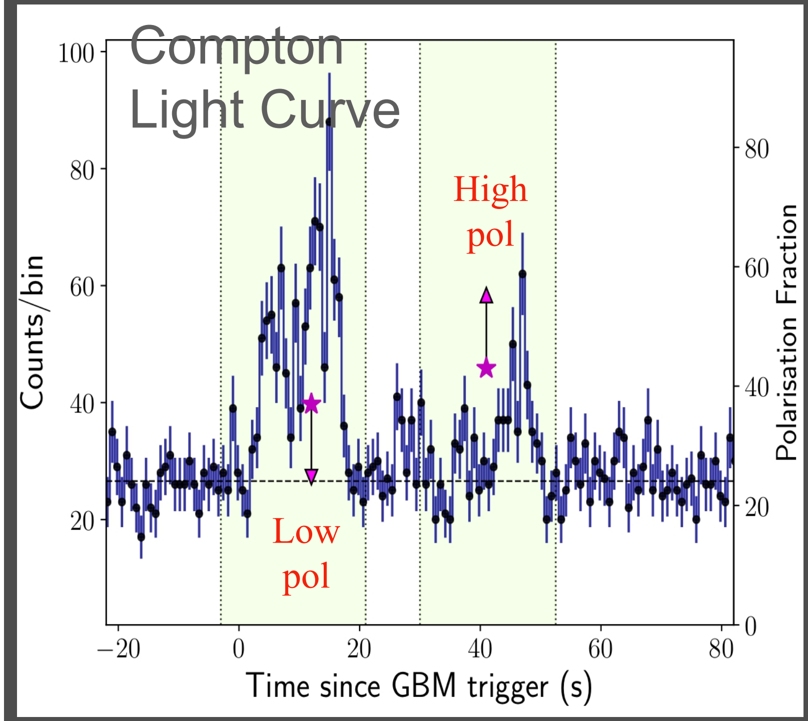
Priyanka Rani, Srimanta Benerjee, Savithri Ezhikode, Pramod Pawar (IUCAA)

Phil Charles, Ian McHardy, Poshak Gandhi, Christian Knigge (Univ of Southampton)

Time resolved GRB Spectro-polarimetry







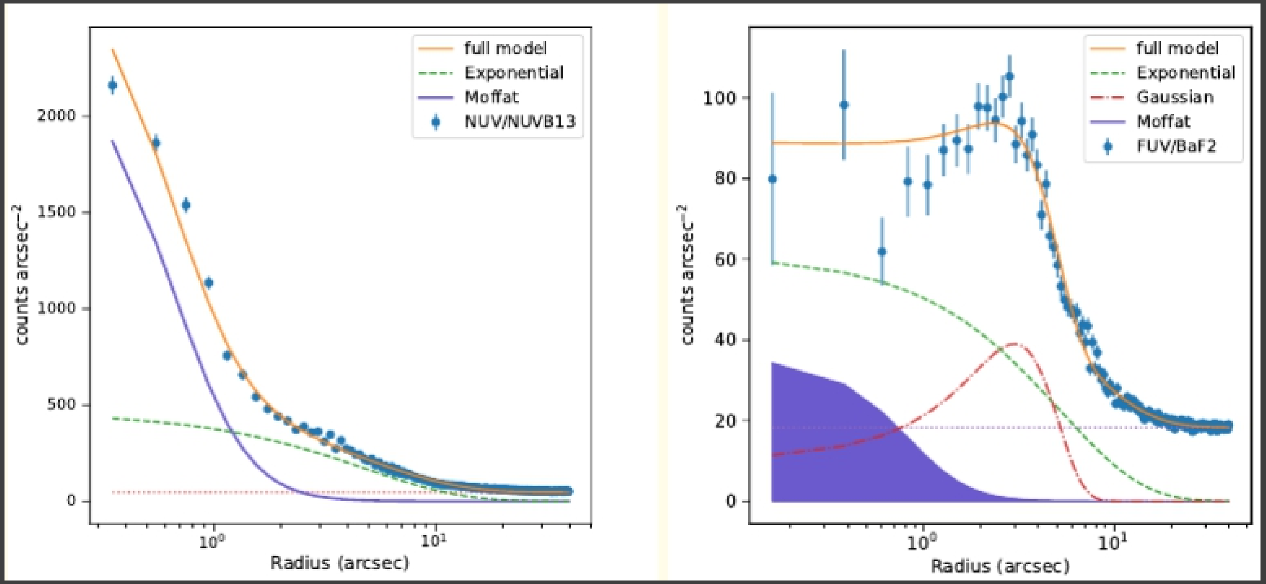
- First episode has BB component and low pol, indicateing photospheric emission
- Second episode has pure power-law spectrum and high pol: non-thermal synchrotron in ordered magnetic field

Sharma et al 2020

IC4329A: AstroSat UVIT

Finding intrinsic AGN continnum emission

GCD, Praksh Tripathi+2021, MNRAS



Separating AGN & host galaxy emission

Galactic Extinction

Cardelli et al. extinction law with E(B-V)=0.052, R_V=3.1

Internal Extinction

Czerny et al. (2004) extin. law

E(B-V)=0.8 (Balmer decrement)

E(B-V)=1.0 (Continnum fitting by Mehdipour & Constantini 2018)

Gaskell & Banker (2007) extin. law

E(B-V)=0.97, R_V=3.1

SB extinction law (Calzetti etal 2000)

E(B-V)=1.07, R_V=4.05

Correction for BLR/NLR contrinution