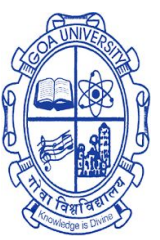


UV/X-ray broadband spectral analysis of NGC 4151 using *AstroSat* data



Advanced Astrosat Data Analysis Workshop
at Goa University

(09 - 15 January 2023)

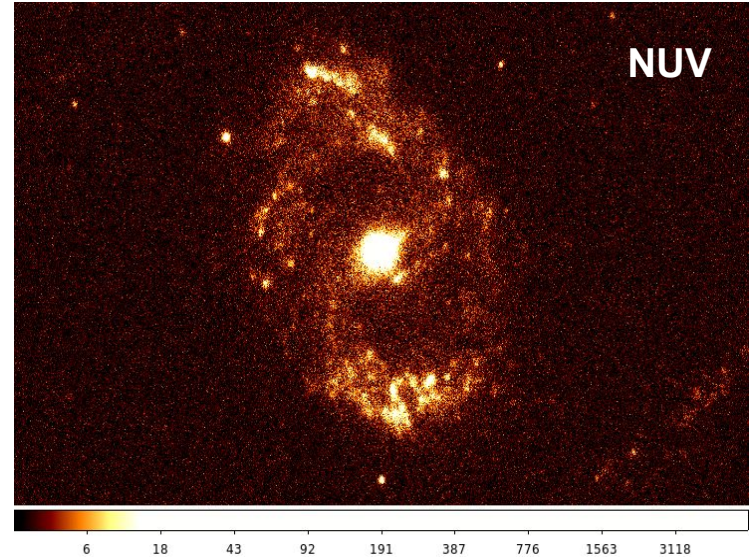
Group Members: **Prakash Tripathi, Shrabani Kumar, Kavita Kumari, Piyali Ganguly,
Anirban Dutta, Akhila K, Suvas Chaudhary**

OUTLINE

- ❖ The source NGC 4151
- ❖ *AstroSat* observations
- ❖ UVIT data analysis
- ❖ *X-ray* spectral analysis
- ❖ Joint FUV/X-ray SEDs
- ❖ *Future plans*

NGC 4151

- ❑ NGC 4151 is an intermediate Seyfert galaxy first mentioned by William Herschel on March 17, 1787 (RA= 12 10 32.57, Dec = +39 24 21.06).
- ❑ 1st X-ray observation Dec 1970 using Uhuru data.
- ❑ Redshift ~ **0.0033**
- ❑ $M_{\text{BH}} = (4-5) * 10^7 M_{\text{sun}}$ (Bentz et al. 2006)
- ❑ Variable flux in the entire EM spectrum.
- ❑ *AstroSat's* multi-wavelength (~7 eV to 150 keV) capability is helpful to investigate the UV/X-ray variability of NGC 4151.

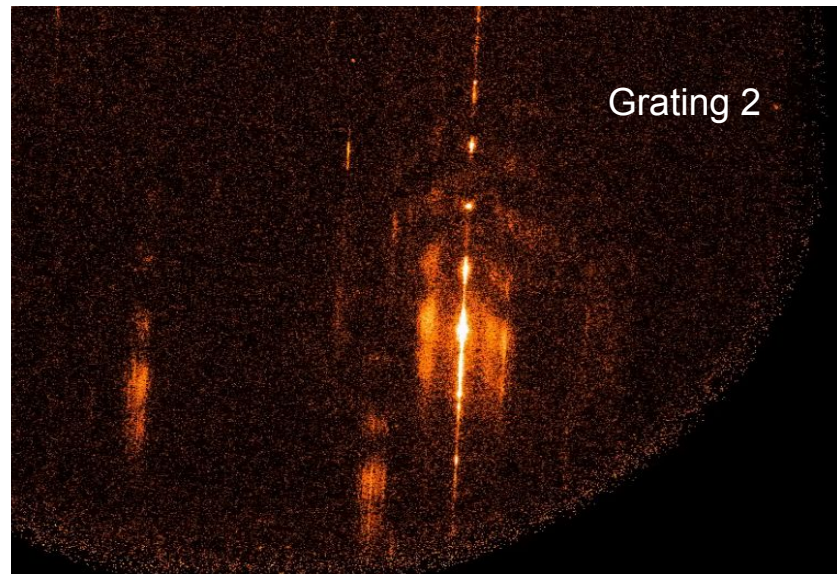
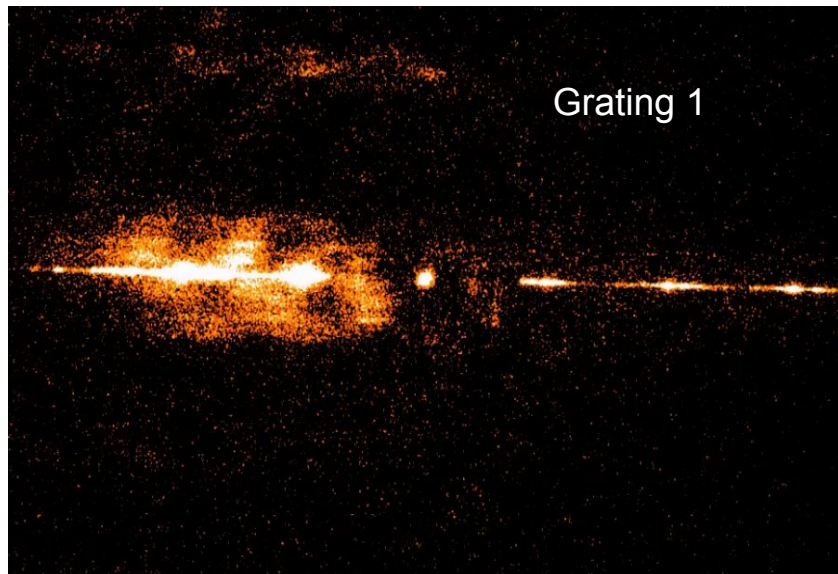


AstroSat Observations

Date of Obs. (YYYY/MM/DD)	Observation ID	UVIT		SXT		LAXPC 20 (Layer1)		CZTI	
		Net count rate (7.0 - 9.5 eV)	Exp. (ks)	Net count rate (0.5-7.0 keV)	Exp. (ks)	Net count rate (4-30 keV)	Exp. (ks)	Net count rate (22-150 keV)	Exp. (ks)
2017-02-07	G06_117T01_9000 001012	-	-	0.26 +/- 0.004	22.7	22.2 +/-0.006	30.7	1.14 +/- 0.15	23.3
2017-02-22	G06_117T01_9000 001046	-	-	0.22 +/- 0.003	31.9	21.1 +/- 0.005	50.1	0.90 +/- 0.1	54.7
2017-03-16	G06_117T01_9000 001086	-	-	0.19 +/- 0.003	31.6	14.7 +/- 0.005	47.2	0.58 +/- 0.1	53.1
2018-01-03	G08_064T01_9000 001814	G1: 8.53 +/- 0.05 G2: 11.85 +/- 0.06	3.9 3.4	0.25 +/- 0.003	28.6	19.6 +/- 0.005	59.3	1.00 +/- 0.08	75.0
2018-05-01	G08_064T01_9000 002070	G1: 7.27 +/- 0.04 G2: 9.63 +/- 0.05	3.9 3.7	0.25 +/- 0.003	30.3	20.2 +/- 0.009	6.5	0.59 +/- 0.11	44.4

FUV and X-ray count rates are variable

FUV Grating-1 & Grating-2 images



Spectral complexities in the optical/UV band

- ❑ **Intrinsic Extinction:** Extinction curve from Czerny et al. 2004 (1176-6666 Å).

$$\frac{A_\lambda}{E(B - V)} = k_\lambda = -1.36 + 13 \log \frac{1}{\lambda}$$

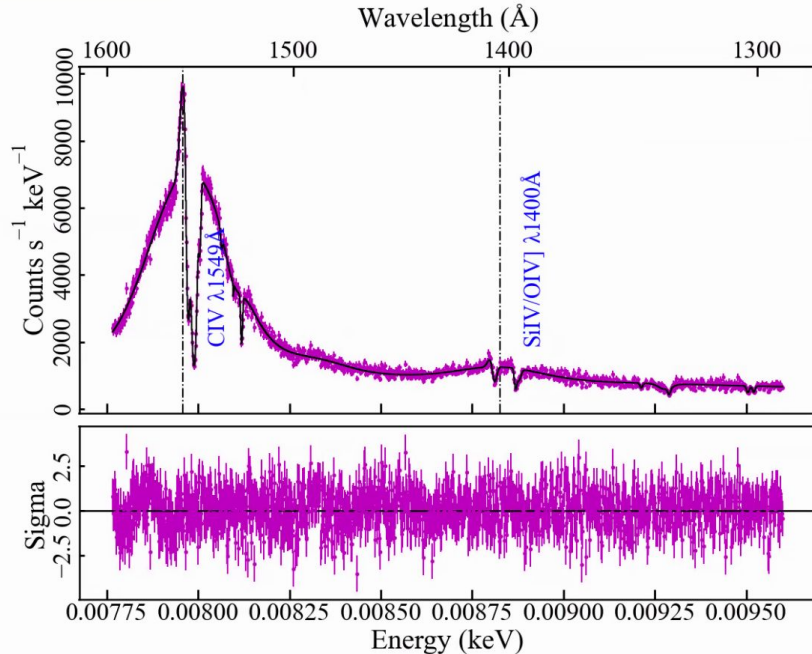
$$E(B - V) = \frac{2.5}{k(\lambda_{H_\alpha}) - k(\lambda_{H_\beta})} \log_{10} \left[\frac{(H_\alpha/H_\beta)_{obs}}{(H_\alpha/H_\beta)_{int}} \right]$$

Intrinsic Balmer decrement = 2.72 (Gaskell 2017).

⇒ Implemented in XSPEC using FORTRAN.

- ❑ **Emissions/absorptions from BLR/NLR:** One or more Gaussian components.
- ❑ **Fe II emission (1100-5000 Å):** Template model from Vestergaard et al. 2001.
- ❑ **Host galaxy contamination**
- ❑ **Galactic reddening:** XSPEC model *REDDEN* (Cardelli et al., 1989)

HST/FOS Spectral Analysis (1300 – 1600 Å)



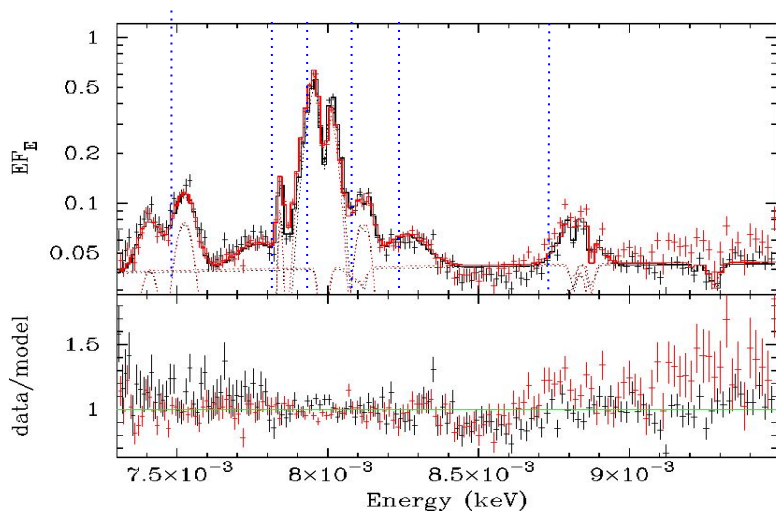
- ❑ Reduced chi-square : 1.13
- ❑ Photon index : 2.75+/-0.21
- ❑ Balmer decrement : 3.16+/-0.01
- ❑ Fe II emission is weak

IUE spectrum (1240 - 3000 Å) :

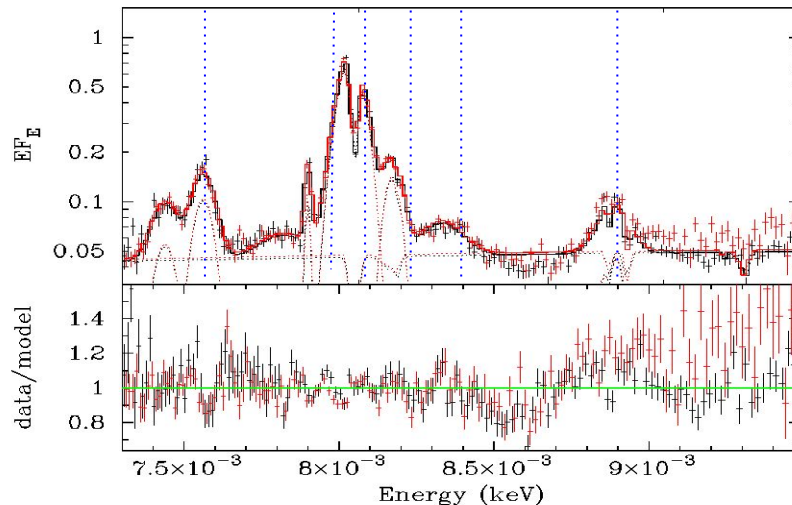
- ★ Fitted with reddened power-law in line free windows to verify intrinsic extinction with FOS spectrum.
- ★ The emission line identification in 1600 - 1700 Å

UVIT Grating best-fit (obs 1814 & 2070)

- Model : $reden * czerny * (diskbb + c1(gauss1 + ...) + gauss6 + ...) * c2$
c1= emission lines scale factor, c2= multiplicative const between the gratings.
- Emission lines: He II (1640), C IV (1549), NIV] (1486), Si IV/O IV] (1400). Two additional - 1525 and 1591
- Line width ~ 2300 - 6460 km s⁻¹



Reduced chi-sq: 479/277 ~ 1.69
kT_in > 12.5 eV

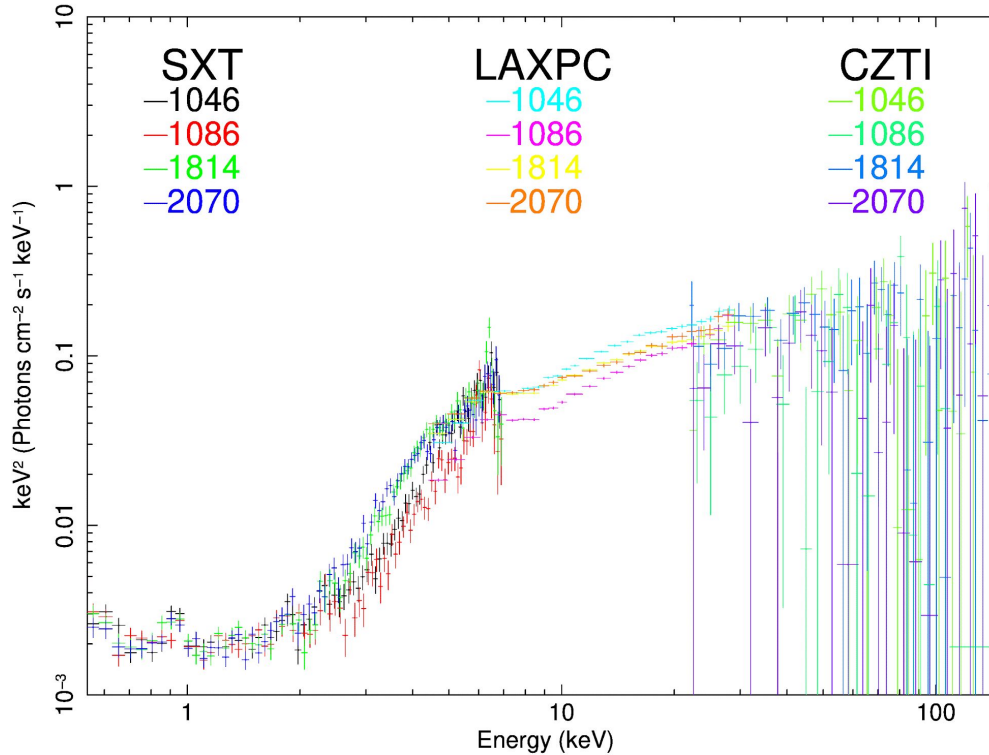


C1 = 0.62 (for obsID 1814) and
0.74 (for obsID 2070)

Reduced chi-sq: 514/277 ~ 1.86
kT_in > 24 eV

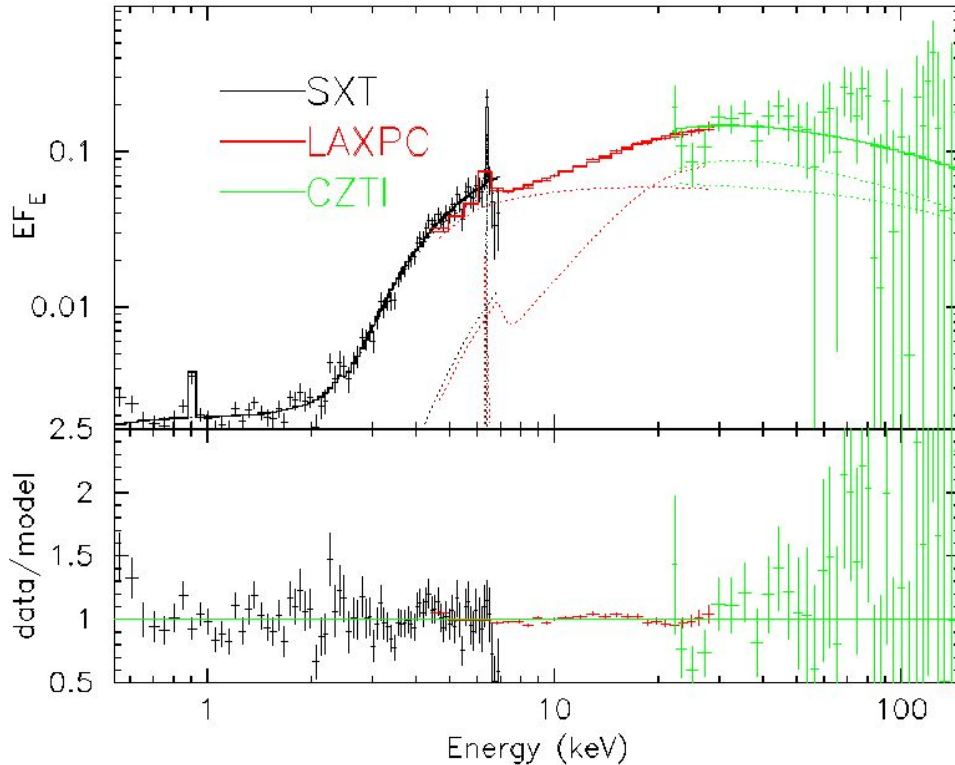
X-ray spectra of NGC 4151

X-ray data for multiple observations



X-ray Spectrum : ObsID 1814

ObsID 1814 (X-ray Fitting)



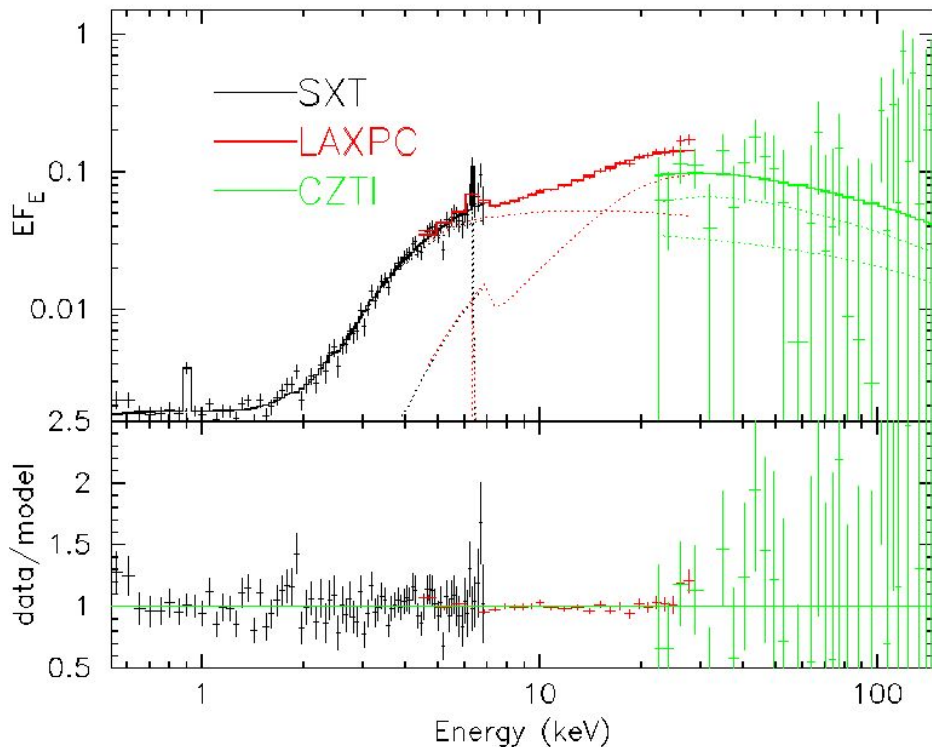
Model : *constant * TBabs * zxipcf * (nthComp + pexrav + zgauss + zgauss)*

Parameter	Best fit value
Nh (10^{22})	8.11 (7.85, 8.80)
Gamma	2.04 (1.91, 2.16)
kT_e (keV)	> 133.31

Reduced Statistics :
136.52 with 132 d.o.f.

X-ray Spectrum: ObsID 2070

ObsID 2070 (X-ray Fitting)



**Model : constant * TBabs * zxipcf *
(nthComp + pexrav + zgauss + zgauss)**

Parameter	Best fit value
Nh (10^{22})	7.87 (7.64, 8.11)
Gamma	2.13 (2.01, 2.26)
kT_e (keV)	> 203.34

**Reduced Statistics :
120.58 with 127 d.o.f.**

Similarly SXT, LAXPC, and CZTI spectral data from other 3 observations were modeled.

Photon Index : Obs1086 : 1.91 (1.81, 2.01) Obs1046: 1.89 (1.80, 2.00)

FUV/X-ray SED : ObsID 2070

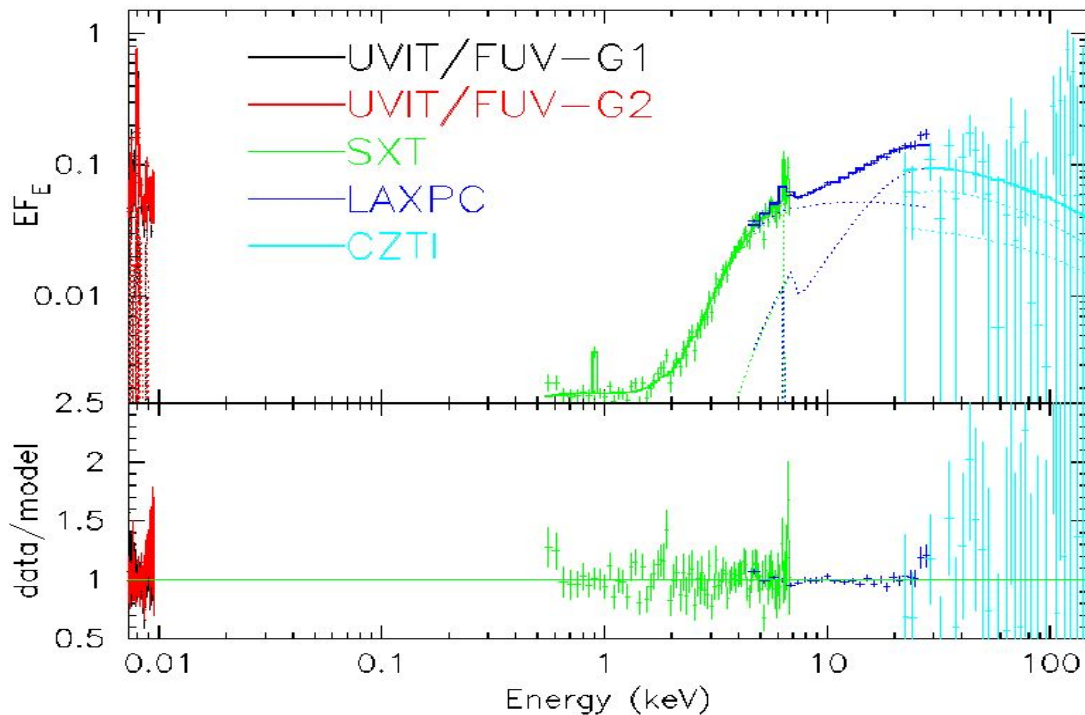
Best fit Model: $\text{constant} * \text{zxipcf} * \text{TBabs} * \text{gabs}(15) * \text{czerny} * \text{redden} * (\text{gaussian}(4) + \text{constant} * (\text{gaussian}(5) + \text{nthComp} + \text{pexrav} + \text{zgauss} + \text{zgauss} + \text{diskbb}))$

ObsID 2070 (Joint Fitting)

Total fit statistic: 727.59 with 406 d.o.f.

$$\chi^2_{\nu} = 1.79$$

Parameter	Best fit value
Nh (10^{22})	7.87 (7.64, 8.12)
Gamma	2.13 (2.00, 2.26)
kT_e (keV)	> 207.97



FUV/X-ray SED : ObsID 1814

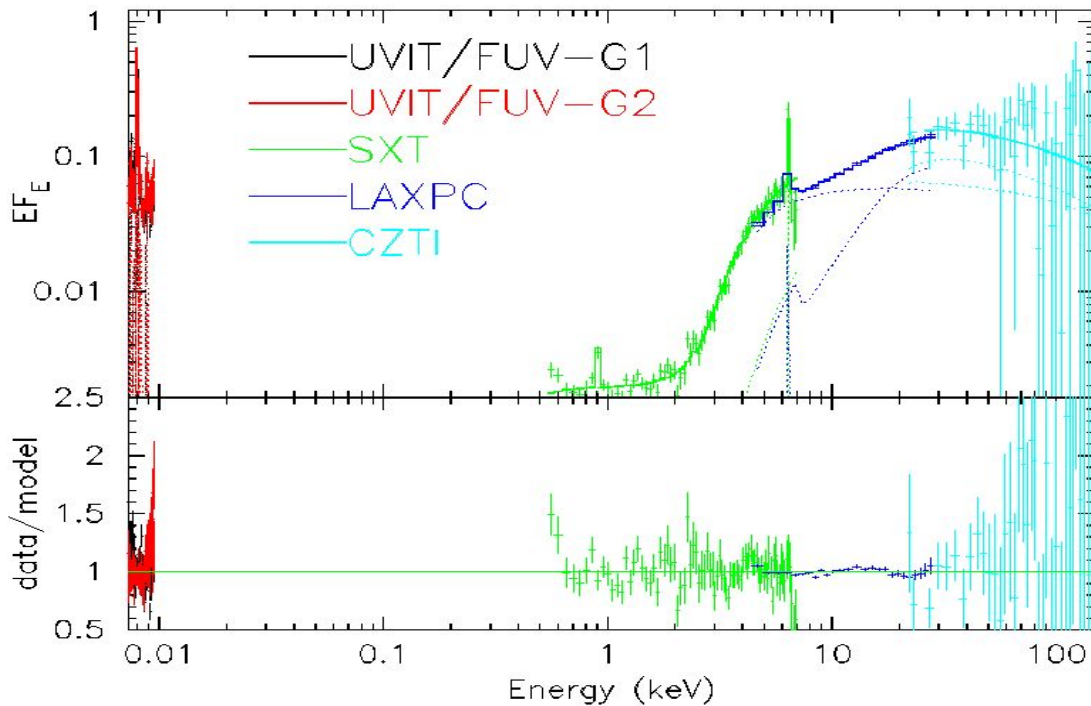
Best fit Model: **constant*zxipcf*TBabs*gabs(15)*czerny*redden*(gaussian(4) + constant*(gaussian(5) + nthComp + pexrav + zgauss + zgauss + diskbb)**

ObsID 1814 (Joint Fitting)

Total fit statistic: 609.56 with 411 d.o.f.

$$\chi^2_{\nu} = 1.48$$

Parameter	Best fit value
Nh (10^{22})	8.07 (7.78, 8.33)
Gamma	2.07 (1.95, 2.19)
kT_e (keV)	> 118.72



Future Plan:

1. Deriving FUV count rates of AGN for other three observations using FUV broadband filters data \Rightarrow Aperture photometry on clean images
2. Separate AGN and host galaxy emission, Galactic and internal reddening correction, and subtract BLR/NLR contributions.
3. Joint analysis of UVIT, SXT, LAXPC, and CZTI spectra data using thermal Comptonization model ***ThComp*** and reflection model ***Xillver / XillverCp***.
4. Investigate for the UV/X-ray spectral variability.

Thank You