Multi-wavelength studies of AGN

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in collaboration with

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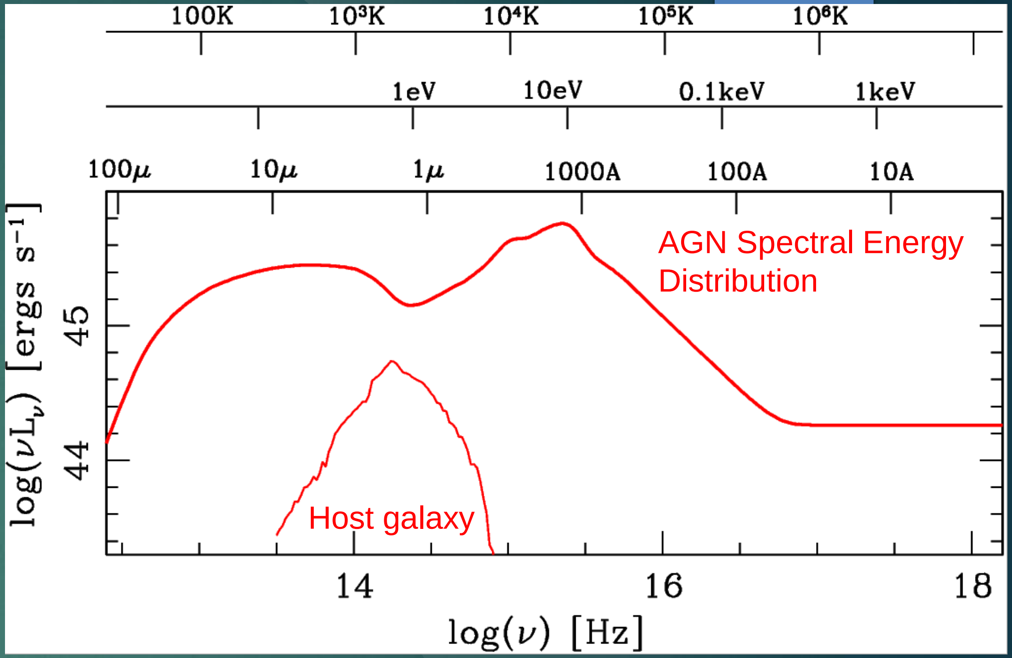
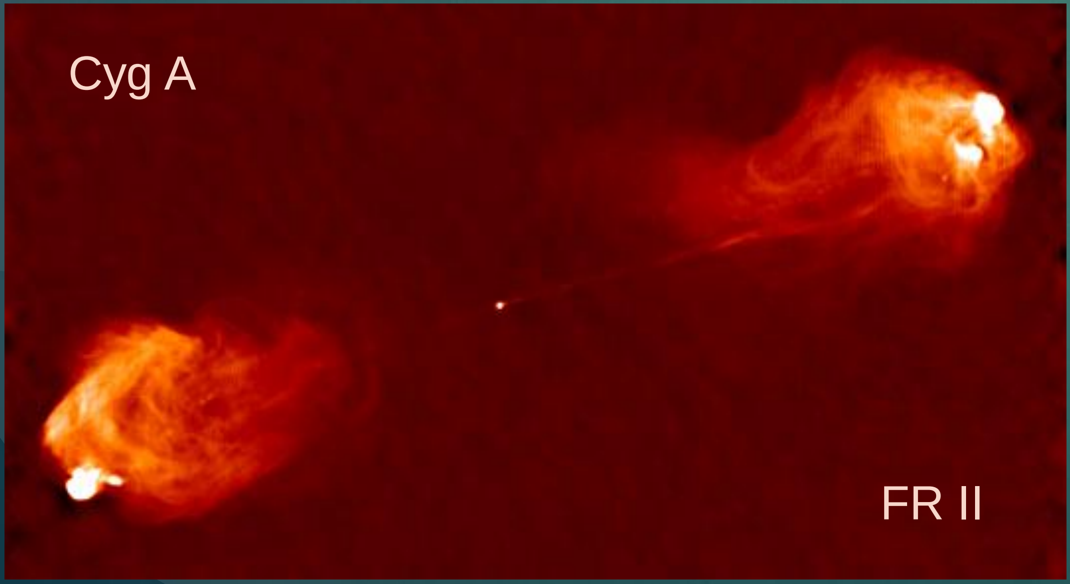
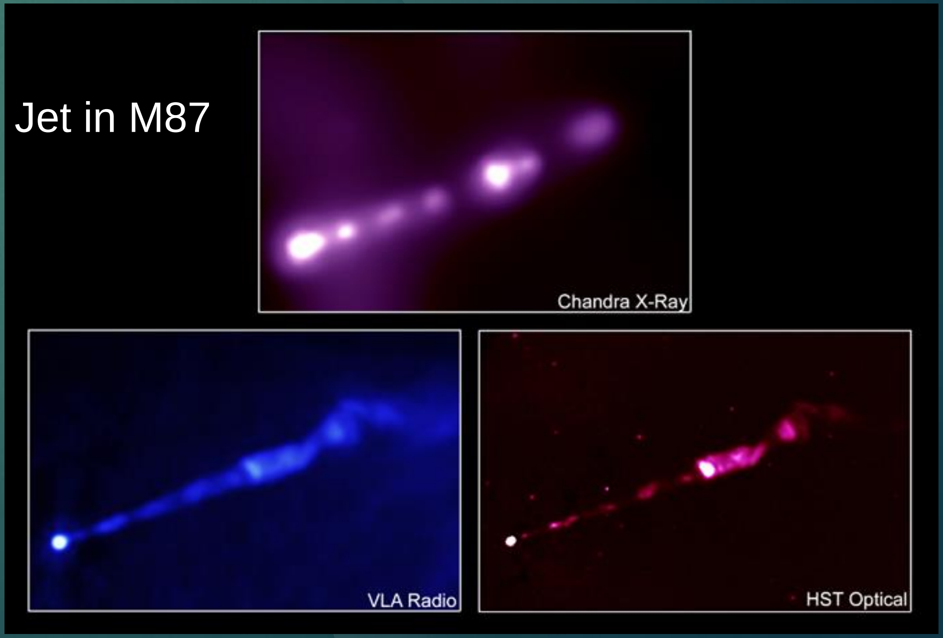
Active Galactic Nuclei (AGN)

- Exceptionally bright & compact .
- It shows emission line spectra
- Extremely high flux variability in the entire EM bands.
- Non-thermal continuum spectra.
- Some AGNs have highly collimated relativistic jets (mostly radiate in radio, optical and X-rays bands)

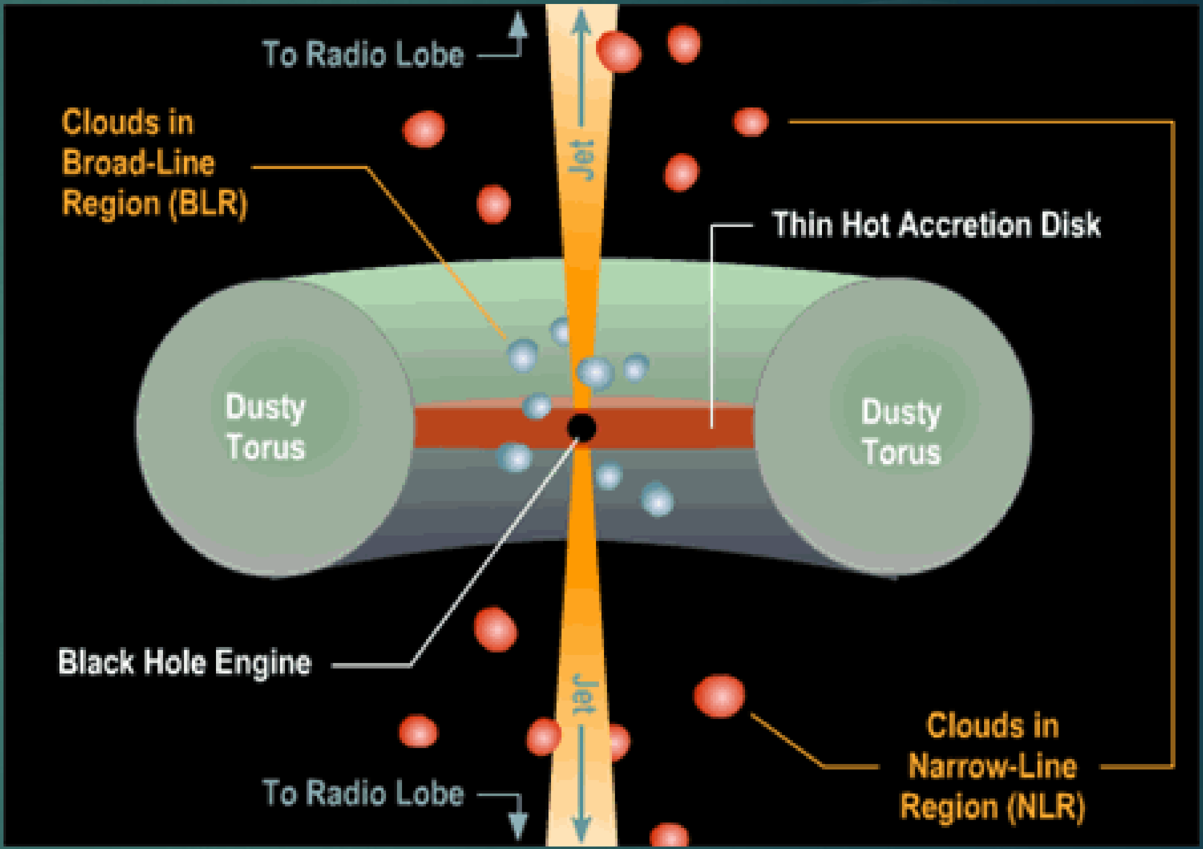






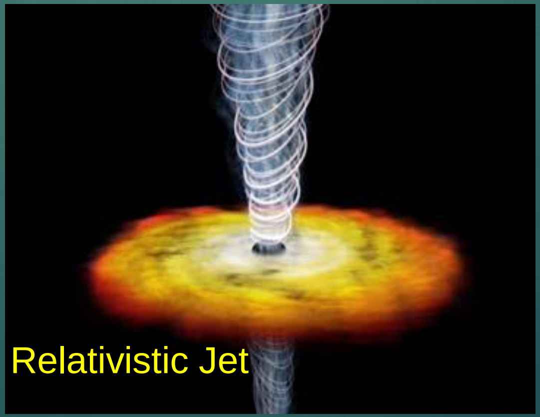
Current AGN model

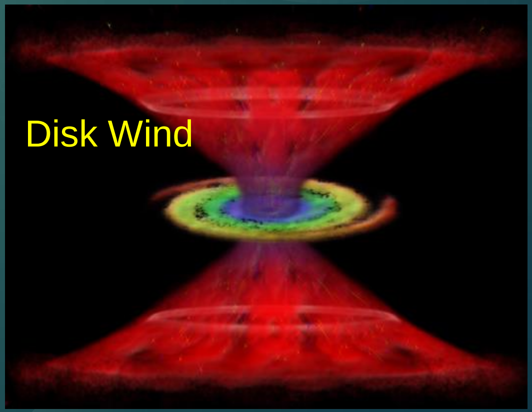
- Supermassive black hole (SMBH)
- Accretion disc
- Broad Line Region (BLR)
- Dusty Torus
- Narrow line region (NLR)
- Jets
- Corona



Overall Importance of AGN studies

- Extremely luminous, hence visible out to high redshifts (**z = 7.54 *Banados et al. 2018, Nature***). The existence of this SMBH when the universe was only 690 Myr old, i.e., just 5% of its current age.
- Study of IGM by looking at absorption lines in the spectra of distant quasars, as can gravitational lensing effects.
- AGNs are an essential part of typical galaxies, if only for small duty cycles, and they exert strong feedback on their environments.
- Emit ~ 5-10% of the total power in the Universe, since the formation of galaxies.
- Extreme physical environments in the Universe (Inner disk & corona, jets, winds). Extreme gravitational fields allow to study GTR (e.g. broad, skewed Fe-line profiles in their X-ray spectra)





AGN Taxonomy or Unification !!

Radio loud AGN ~ 10% – 15%,

Radio quite AGN ~ 85% – 90%,

$$\frac{L_{5GHz}}{L_B} \geqslant 10$$

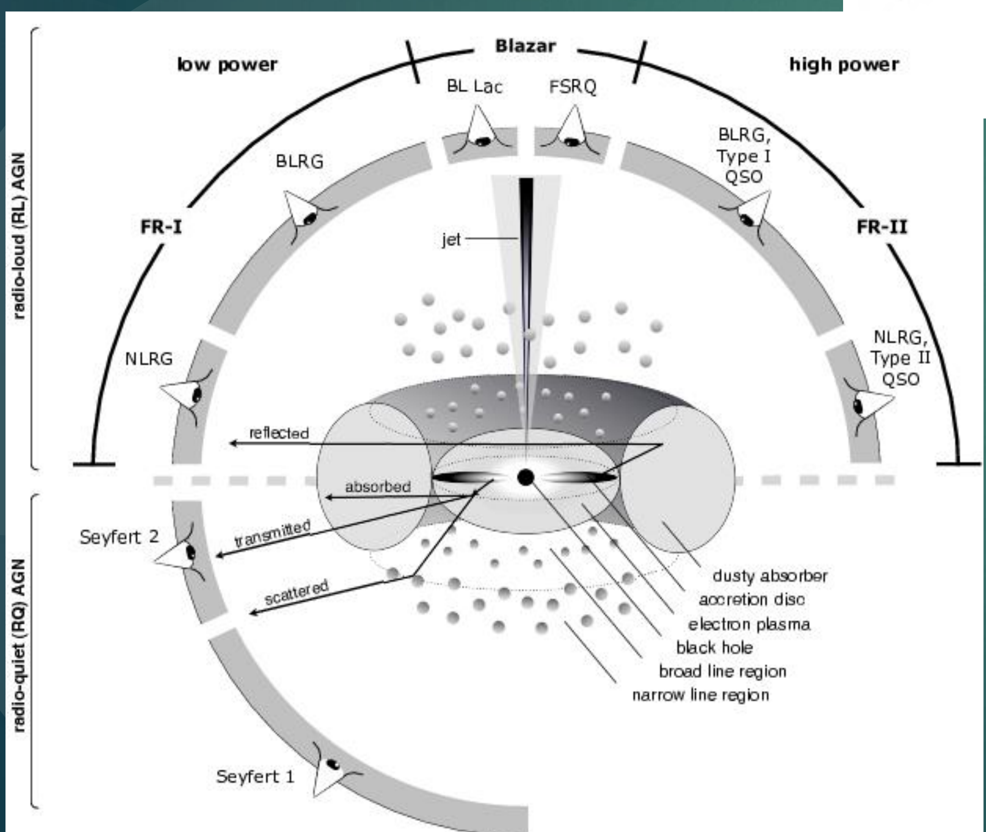
$$\frac{L_{5GHz}}{L_B} < 10$$

TABLE 1
AGN Taxonomy
Optical Emission Line Properties

Radio Loudness	Type 2 (Narrow Line)	Type 1 (Broad Line)	Type 0 (Unusual)
Radio-quiet:	Sy 2 NELG IR Quasar?	Sy 1 QSO	 BAL QSO?
Radio-loud:	NLRG {FR I, FR II}	BLRG SSRQ FSRQ	Blazars {BL Lac Objects, (FSRQ)}

Black Hole Spin? (↓)

Decreasing angle to line of sight (→)



Based on Optical emission line properties

(Urry & Padovani 1995)

Finally a simpler classification

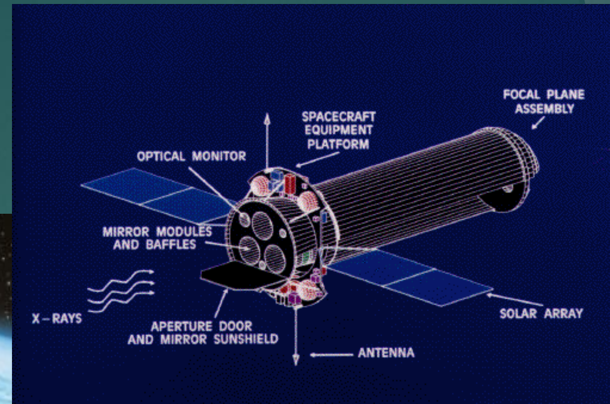
Jetted and non-jetted

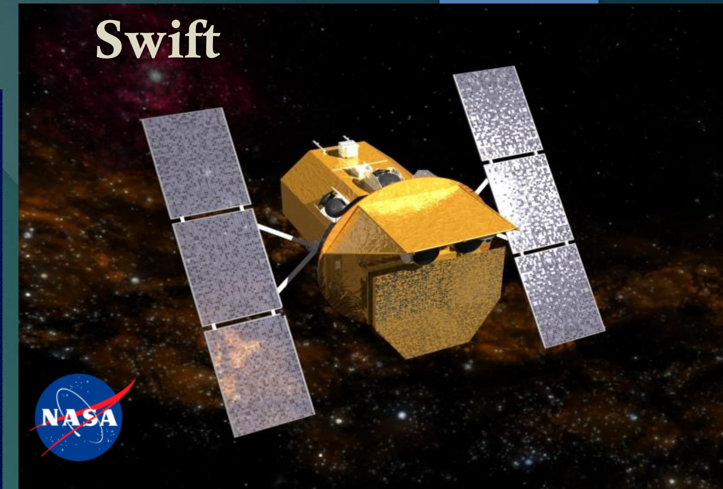
(*Padovani 2017*)

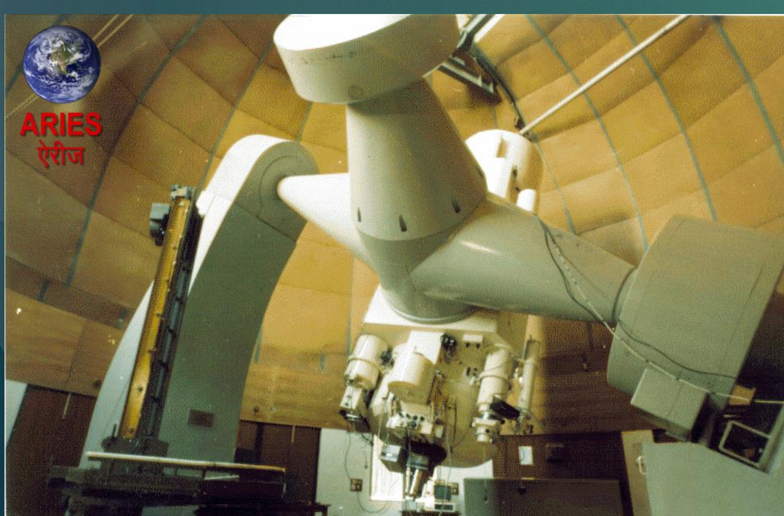
Key research interests

- Different variability properties observed in AGNs.
- Emission and absorption lines in X-ray spectra of AGN in order to understand BH physics.
- Study of soft excess in FSRQs & its connection with X-ray hard continuum
- X-ray and optical Reverberation Mapping.
- Investigating the connection between accretion disc, jet and corona.
- Multi-wavelength SED modeling to understand jet structure and dynamics.

Observing Facilities







Data Processing

- Data → NASA's **HEASARC** data archive
- Data processing → **Heasoft** (NASA) and **SAS** (ESA) software
- X-ray spectral fitting package ***XSPEC*** → For spectral analysis.
- Energy range 0.3 – 10 keV for X-ray.
- For optical data → IRAF & DAOPHOT (learning)

Blazars: Extreme class of AGN

- ~ 1% radio – loud AGNs are blazars
- Rapid flux Variability : Blazars are multi-wavelength, and multi-time scale phenomena

Intraday (IDV) –minutes to less than a day
Short term (STV) – few days to few months
Long term (LTV) – few months to several years

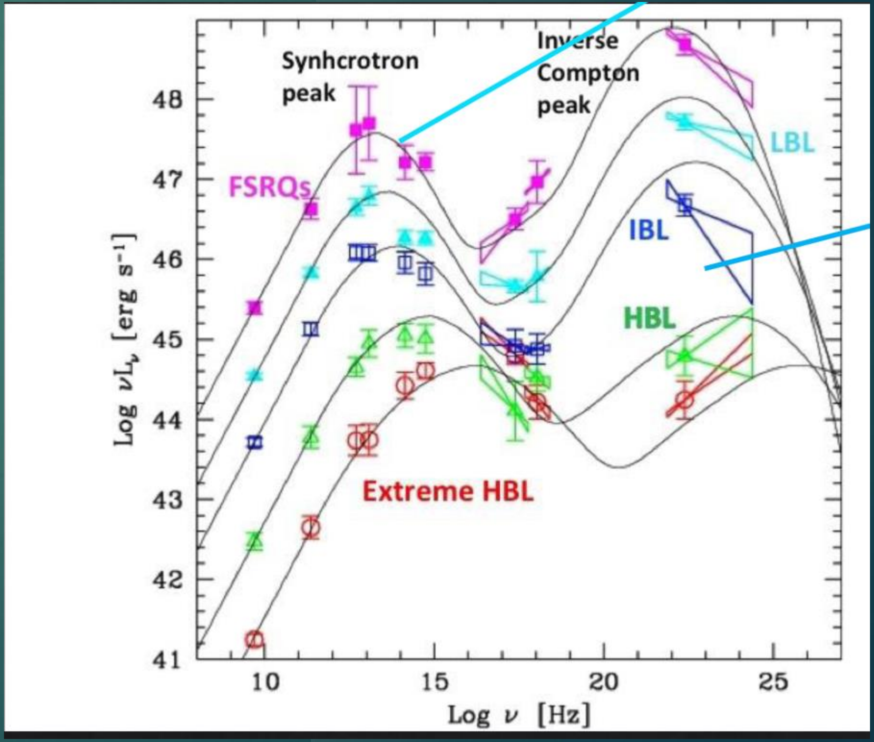
- Variable Polarization from radio to optical bands
- Jet axis angle < 10º
- BL Lacs (Featureless optical spectra) + FSRQs (prominent emission lines in optical Spectra)

SED based Classification

1. Low Synchrotron peaked (**LSP**) : IR

2. Intermediate Synchrotron Peaked (**ISP**): Optical -near UV

3. High Synchrotron Peaked (**HSP**): X- rays



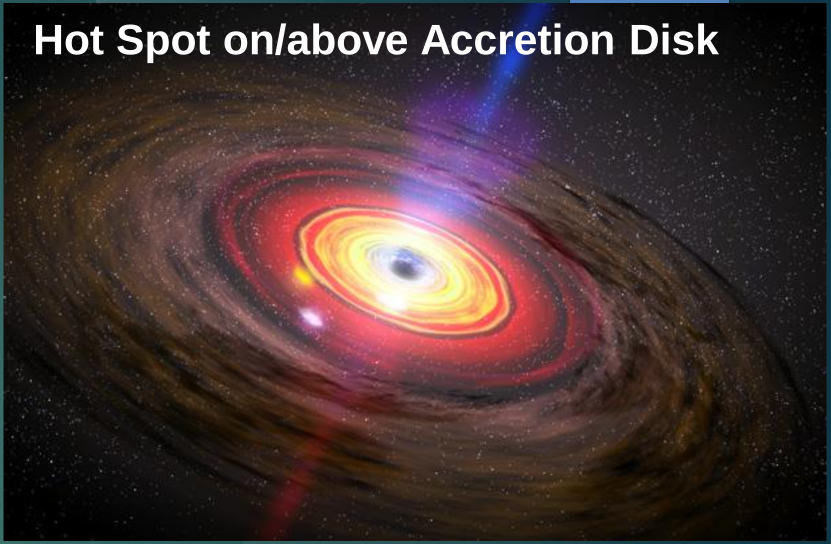
Source of Variability

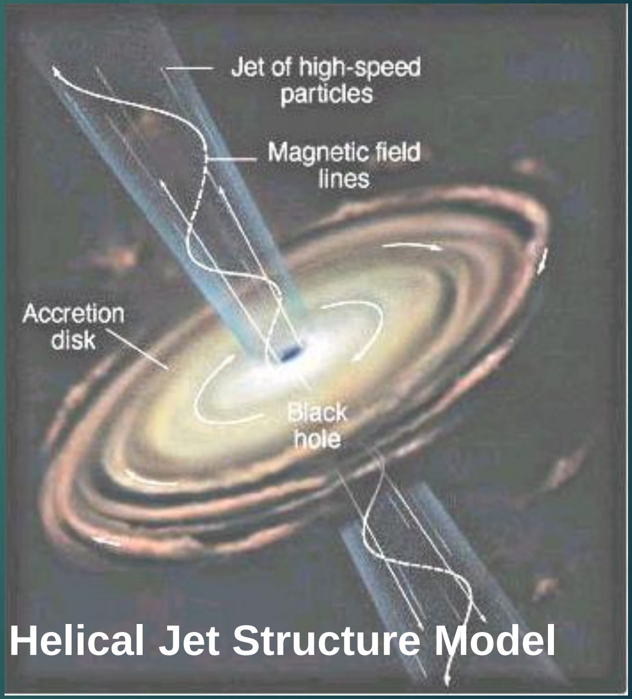
Accretion disc

- Instabilities or hot spots on the accretion disk (variability in the Low-state) (IDV and STV)
- Binary Black Hole Model (LTV)

Relativistic jets

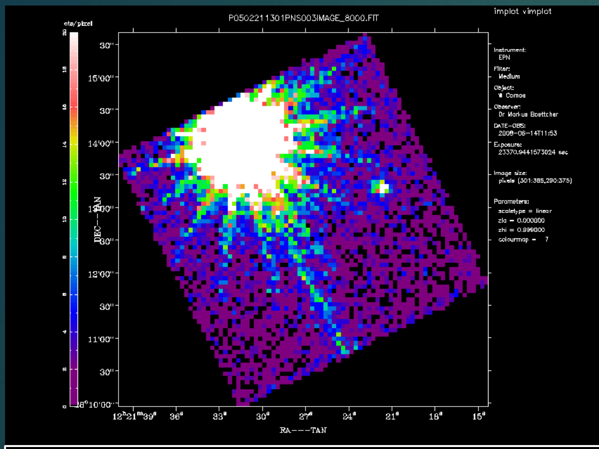
- Shock fronts in the jets (IDV & STV)
- From helical motion
- Instabilities



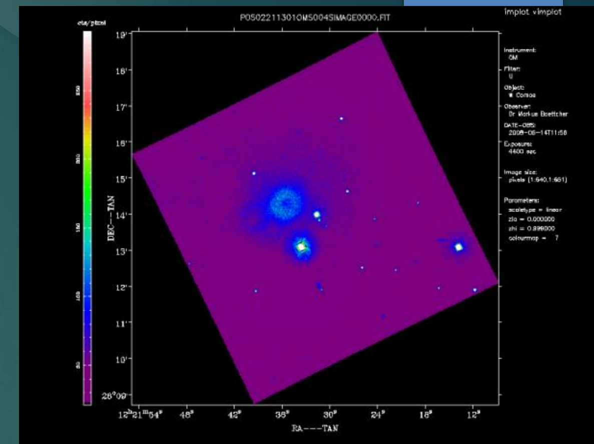


Blandford & Marscher,

Current Work: X-ray study of the blazar *ON 231* in outburst state



X-ray image of the source



Optical image of the source

X-ray Intraday variability (IDV) Analysis:

- ON 231 is the first TeV emitting ISP which went to an outburst state in June, 2008.
- Excess variance & Fractional rms variability (F_{var}) are calculated (listed in the table below)
- Source was dominantly emitting below 4 keV i.e., soft X-ray emitter.

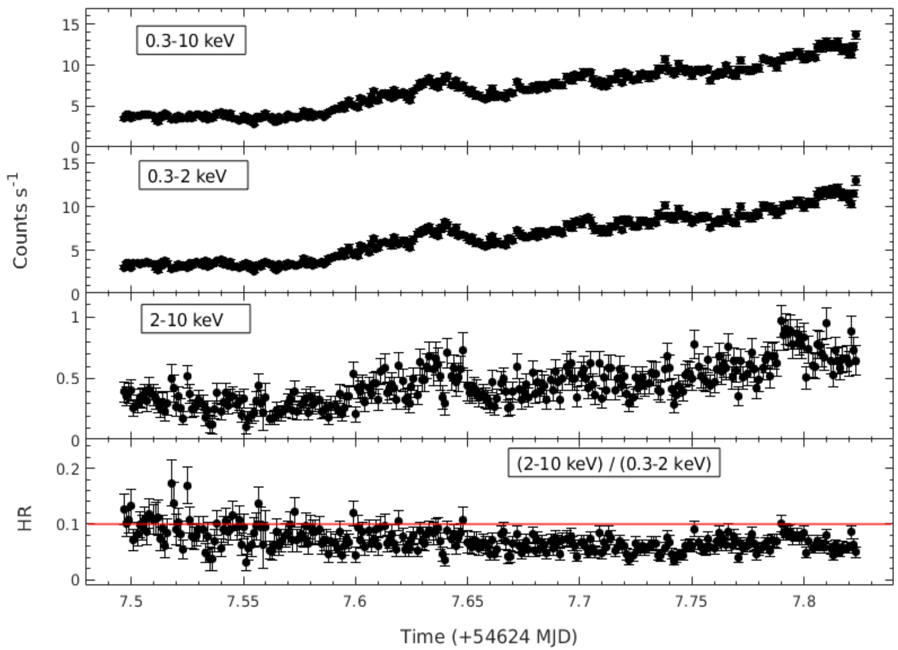
Table 1. Details of *XMM-Newton* observations and variability charecteristic of ON 231

Observatory	Date of Obs.	Obs.ID	Revolution	Window Mode	GTI[a] (ks)	Pile up	Filter	Mean counts s^{-1}	σ^2_{XS}	F_{var} (%)
XMM-Newton	2008 June 14	0502211301	1559	Small	28.2	No	MEDIUM	7.02±0.33	7.11	38.02±0.28
	2008 June 16	0502211401	1560	Small	16.1	No	MEDIUM	4.67±0.28	1.64	27.48±0.47
	2008 June 18	0502211201	1561	Small	11.4	No	MEDIUM	4.82±0.28	1.78	27.63±0.55

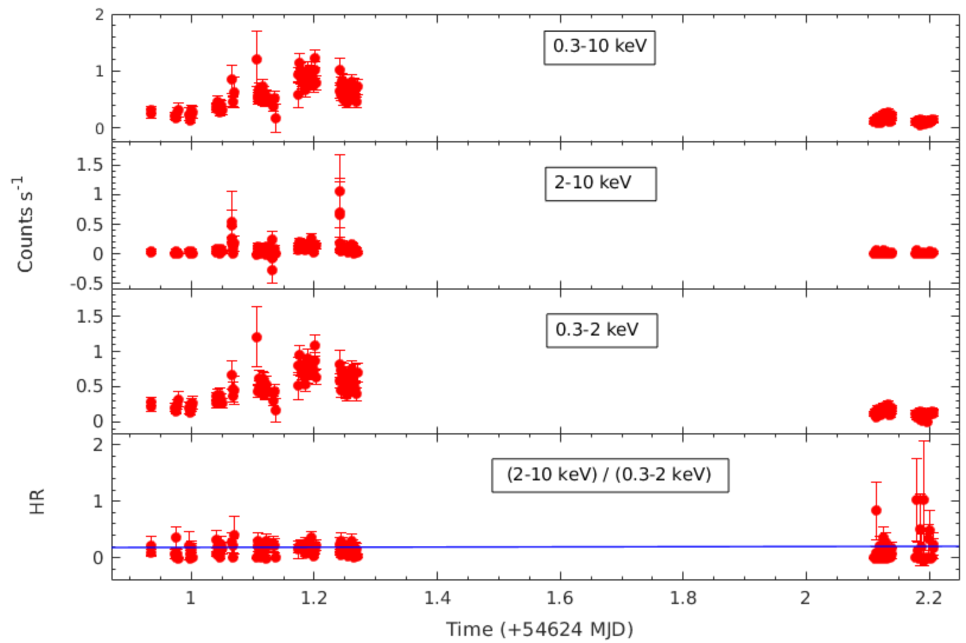
[a] Good Time Interval.

Temporal Analysis: *Fractional variability Amplitude*

XMM-Newton Light curve & Hardness ratio

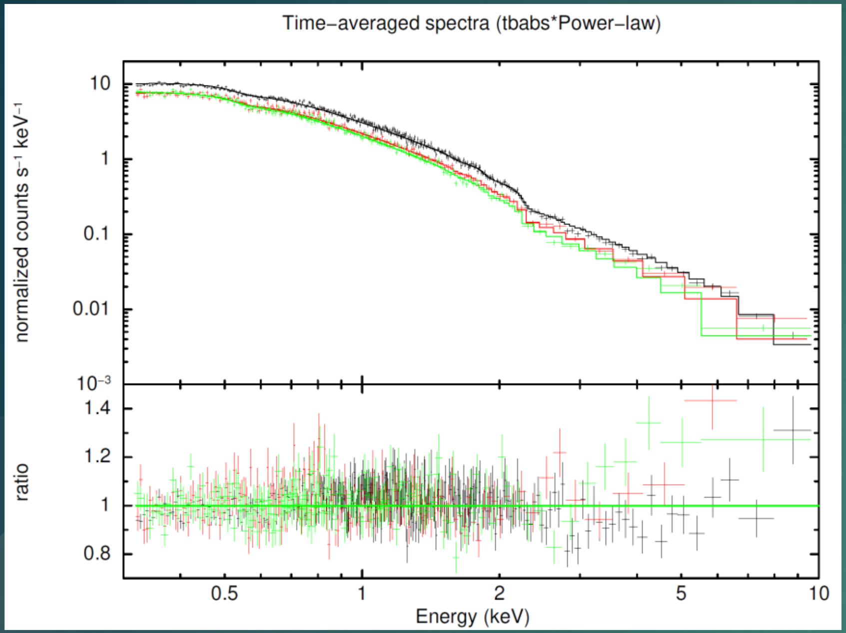


Swift-XRT Light curve & Hardness ratio



- Swift-XRT and XMM-Newton EPIC-pn observations are used to study the event
- Highly variable on IDV timescale, F_{var} = 27- 39%
- The 0.3 – 10 keV light curves (LCs) are splitted into 2 energy bands, soft (0.3-2 keV) and hard (2-10 keV) for hardness ratio analysis (bottom panel of the figures)
- A "softer when brighter" behavior is evident after 7.65 (+54624 MJD) (first figure, bottom panel)

Spectral Analysis: *Time-averaged spectra*



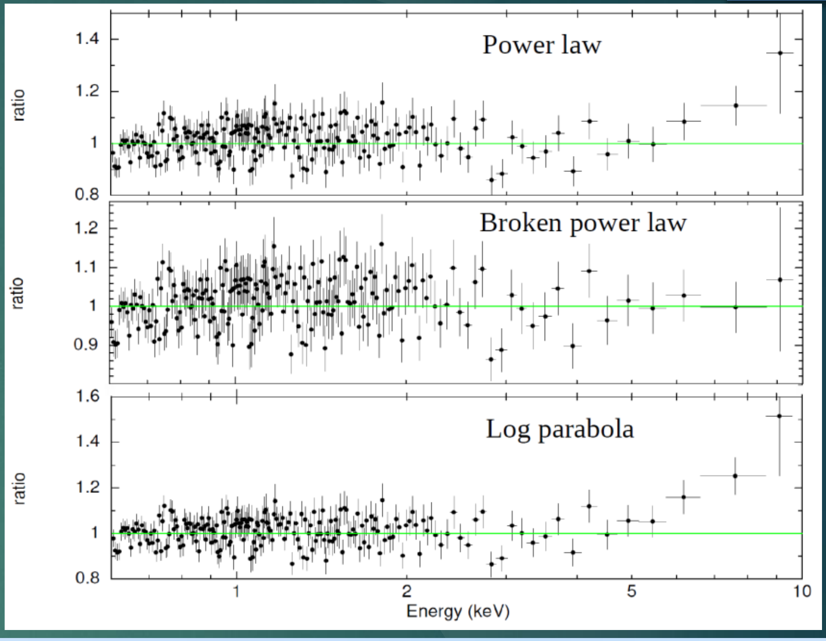


Fig. 1 Data to model ratios for different spectral models. The broken power-law with galactic absorption gives the best fit to the spectra. A hard tail is observed above ~4 keV in all the observations.

- The total spectra in the energy range 0.6 - 10 keV for all the 3 XMM-Newton obs.s
- Spectra fitting with Power law model and galactic absorption is shown.
- Above 4 keV the fit is not good (see the data to model ratio plot, bottom panel in the figure).
- Double power-law and Broken power-law give similar fits.
- Spectral analysis is being done in order to find the best fit model.

Temporal Analysis: *Energy Dependent Variability*

- To check the energy dependence of the variability amplitude, we calculate F_{var} in five (0.3–0.5, 0.5 – 0.75, 0.75 – 1, 1– 4, and 4–10 keV) energy bands.
- Searching for variability Correlations between unevenly sampled discrete time series data
- Estimate time lag between different emission bands
- The DCF function is presented as below

$$UDCF_{ij}(\tau) = \frac{(x_i - \bar{x})(y_j - \bar{y})}{\sqrt{({\sigma_x}^2 - {e_x}^2)({\sigma_y}^2 - {e_y}^2)}}$$

$$DCF(\tau) = \frac{\sum_{k=1}^{m} UDCF_k}{m}$$

Where, $\bar{x}$ & $\bar{y}$ are mean values of x_i & y_i, with standard deviation of σ_x and σ_y, respectively and e_x & e_y are their corresponding measurement errors. Each value of $UDCF_{ij}(\tau)$ is associated with the time delay, $\Delta t_{ij} = (t_j - t_i)$.

Correlation study with DCF

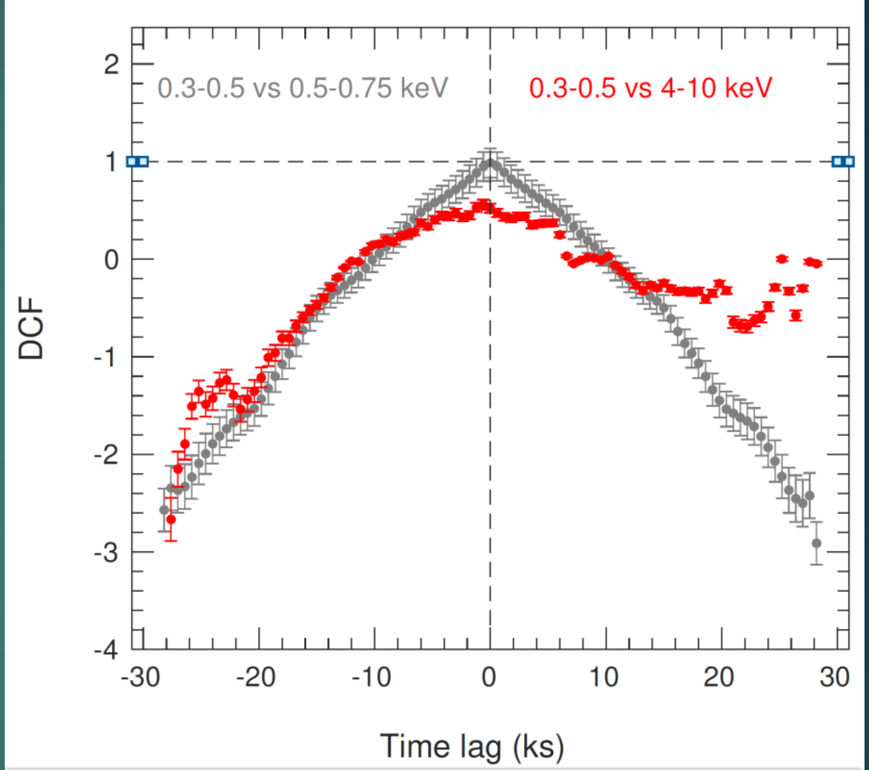
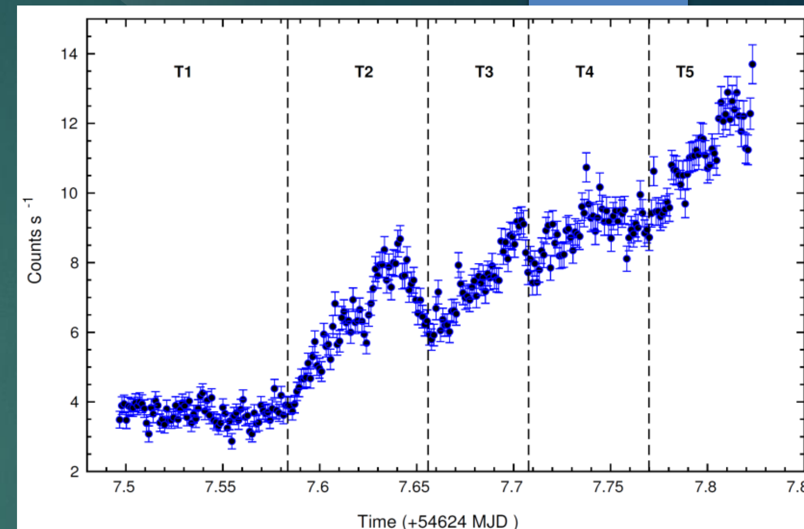
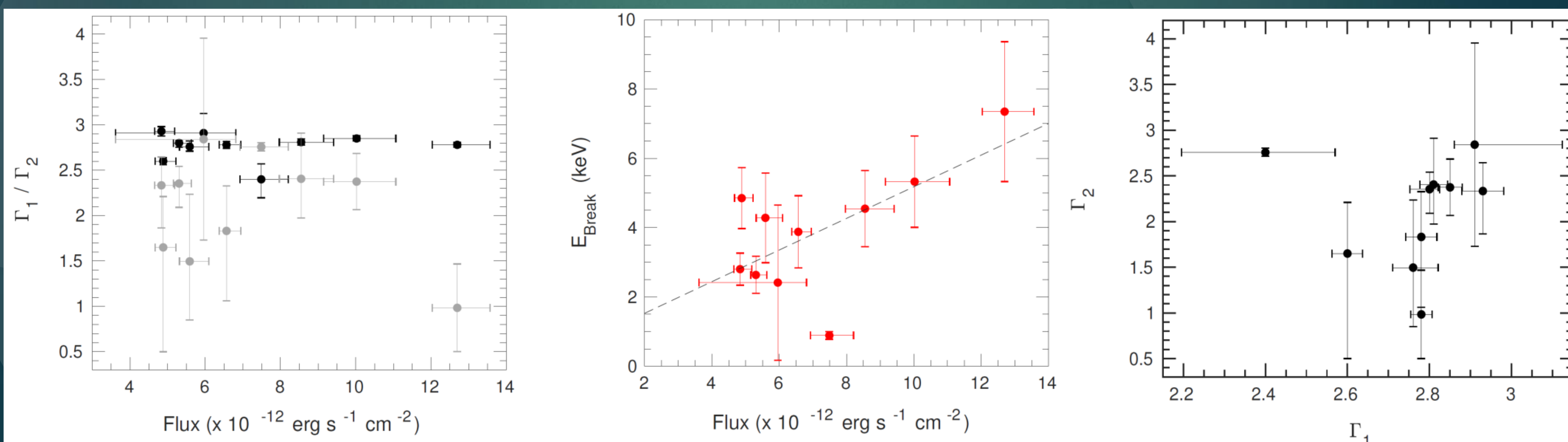


Figure. shows DCF plot between difernt energy bands. **A soft lag of -600s** is detected between the 0.3-0.5 vs 4-10 keV bands (red curve).

Spectral Analysis: *Time-resolved spectra*

- XMM-Newton LCs show multiple flaring events. One of the LC is shown in the figure.
- In order to investigate the spectral variability of the synchrotron and IC emissions and their sum, we divide the entire observation into several intervals
- The vertically dashed lines shows 5 isolated episodes (T1, T2, T3, T4 & T5) used for the time-resolved spectral analysis





Thank You

For Your Attention…!