X-ray Emission from Seyfert Galaxies and the Unification Scheme

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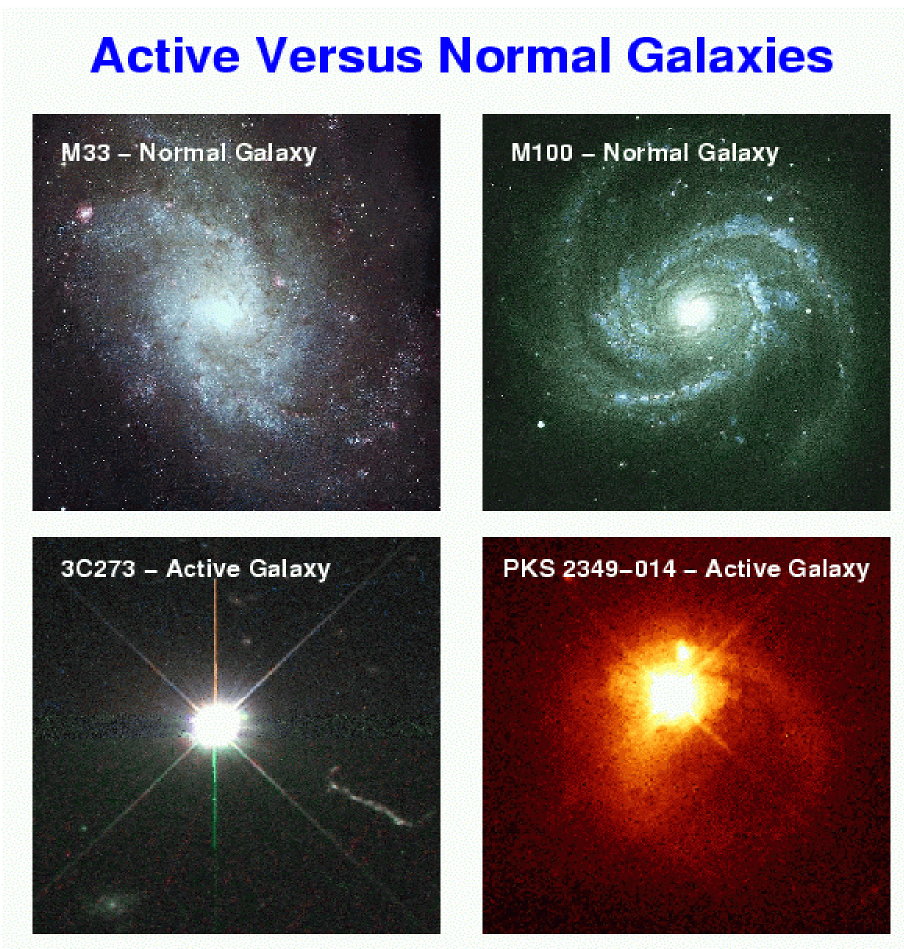
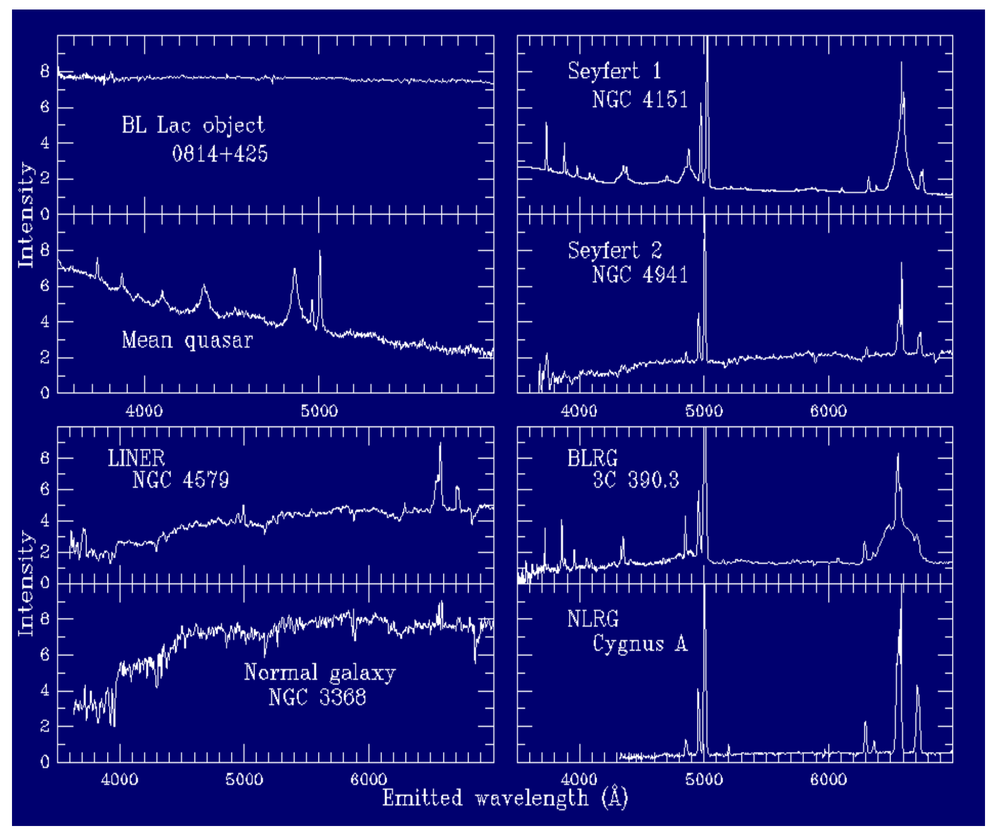
Talk Outline

- Introduction
- Motivation
- Objective
- Methodology
- Results
- Discussion & Conclusions

Active Galaxies

- Highly luminous compact nuclei.
- Emit radiation in entire electromagnetic spectrum.
- Variable outputs of different timescales in different wavebands.
- Consisting emission lines of wide range of ionization in their spectra.
- Compact nuclear emission often outshine the host galaxies and can not be explained by stellar processes.





Fundamental Ingredients of AGN

AGN are powered by accretion of surrounding matter on to the supermassive black hole located at the center of the galaxy.

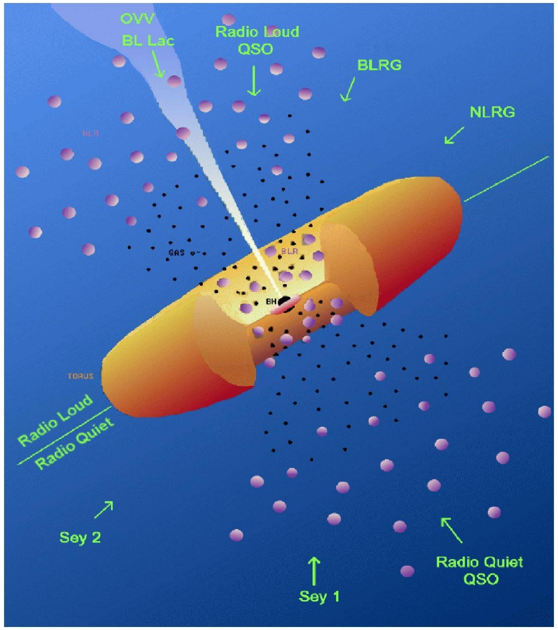
Super-massive Black Hole: ~ 10^{6}-10^{10} $M_{\odot}$

Accretion Disk and Corona: Heated by Magnetic and/or viscous processes so that it radiates at optical through soft X-ray energies.

Broad Line Region: High velocity, ionized clouds give rise to broad emission lines.

Narrow Line Region: Low velocity, ionized clouds give rise to narrow emission lines

Torus: Optically thick molecular gas and dust hiding central engine from some lines of sight.



Relativistic Jets: Form within ~100 Schwarzschild radii from the SMBH and extending outward for tens of Kpc, in some cases, up to Mpc

- Most of the galaxies, if not all, consist supermassive black hole $M_{SMBH} \sim 10^6 - 10^{10} M_\odot$ at their centre (Kormendy & Richstone 1995).

- Black hole mass is tightly correlated to the stellar velocity dispersion (σ) (Ferrarese & Merrit 2000).

- Active galaxies follow the same $M_{BH} - \sigma$ correlation as normal galaxies (Gebhardt et al. 2000b).

- This supports the notion that AGN are active versions of non-active normal galaxies and are powered by accretion of matter on to supermassive black hole.

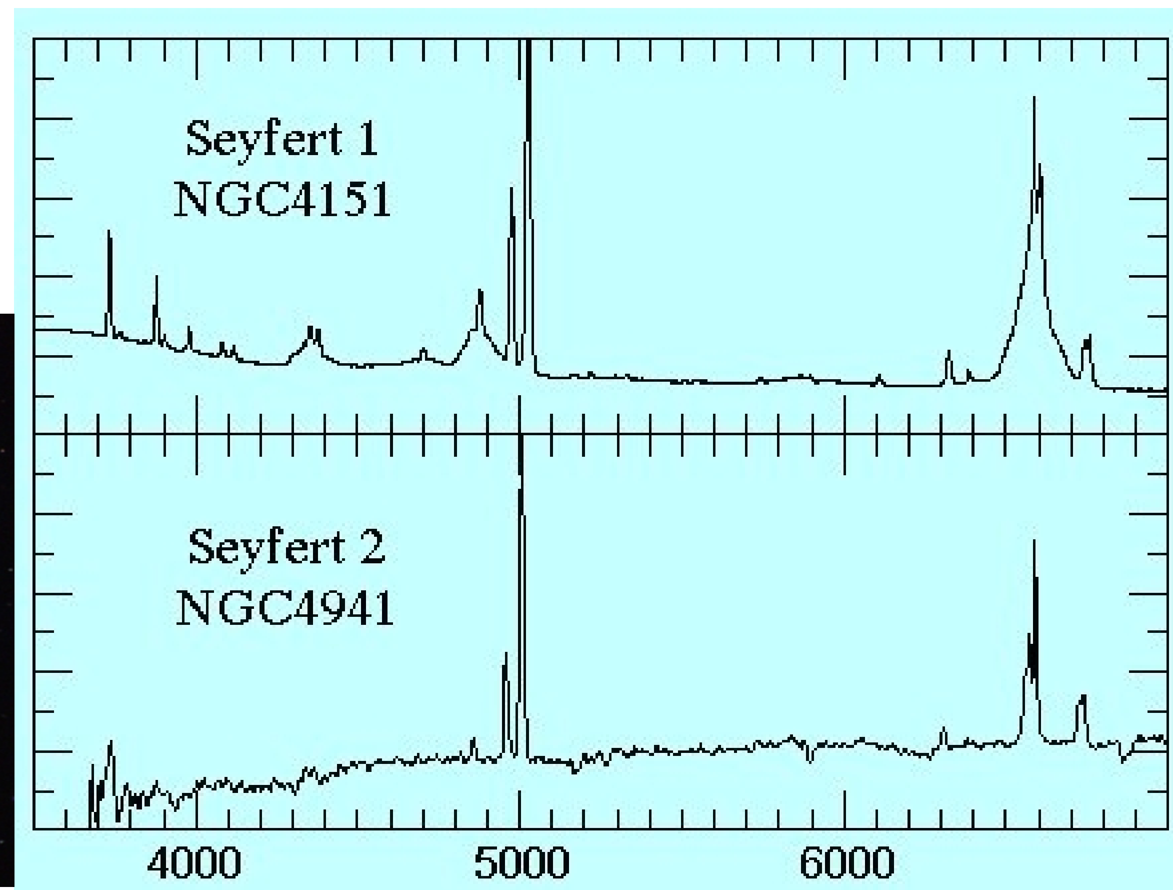
Seyfert Galaxies

- A subclass of AGN.
- Low luminosity, radio quiet (F_{5GHz} / $F_{B\ band}$ $\leq$ 10) AGN and host in spiral galaxies.
- Absolute B band Magnitude (M_B) > -23.

Classification

Type 1 : Broad permitted (FWHM $\geq$ 1000 km s^{-1})and narrow forbidden emission lines.
Type 2 : both permitted and forbidden are narrow.

$F_{[O\ III]}$ / $F_{H\beta}$ can also use to define the Seyfert class.

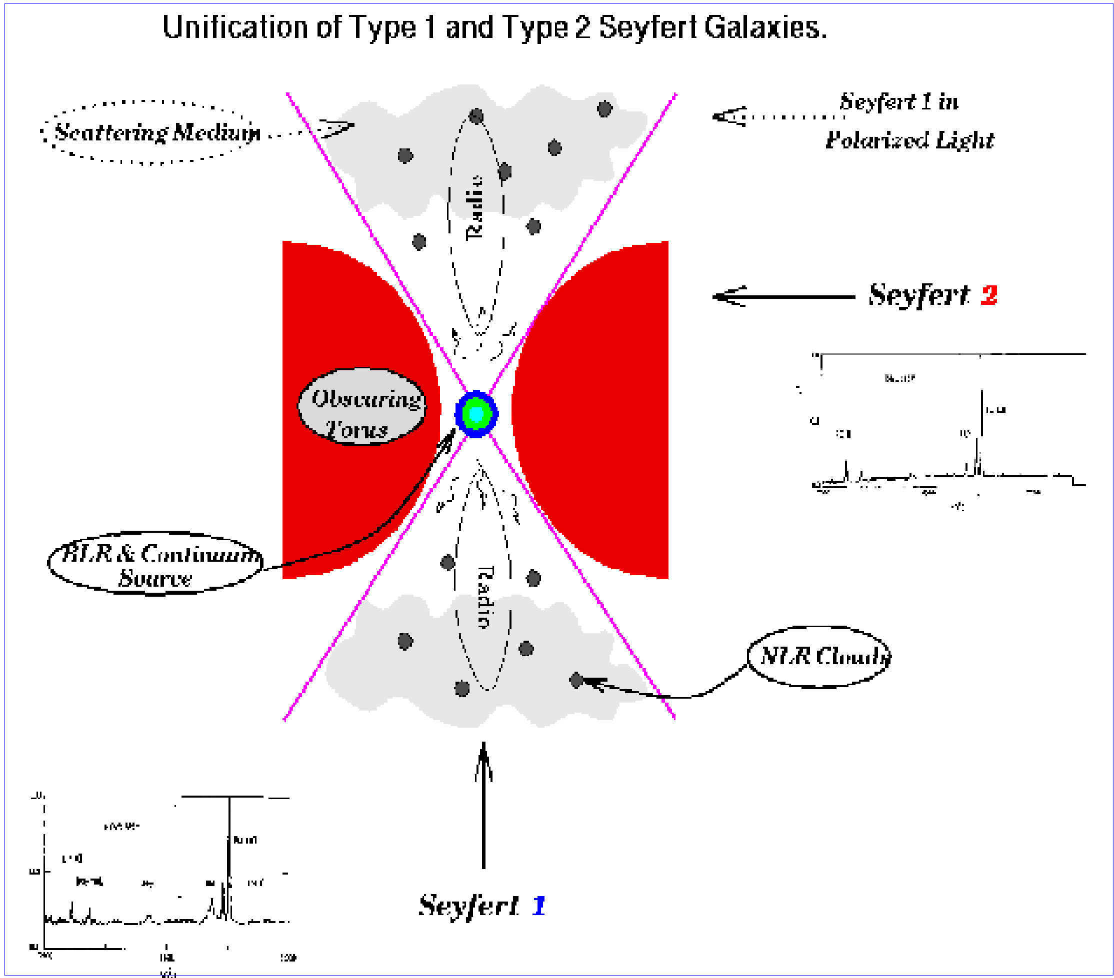


Unification of Seyfert Galaxies

Antonucci and Miller (1985), detected polarized broad emission lines in spectropolarimetry observations of NGC 1068 (Seyfert type 2) and later on in few more type 2 Seyferts. Which is spectral characteristics of Seyfert 1s according to classification definition.

To explain above observations,
It was suggested that broad line region in Seyfert type 2 is completely hidden by optically thick torus, as a result, only a fraction of BLR emission which is scattered by the electron well above the central engine, resulting a polarized broad emission component.

Unification Scheme hypothesizes that Seyfert 1s and 2s constitute the same parent population and appear different solely due to their differing orientations. In Seyfert type 2, molecular dusty torus intercepts the observer's line of sight and blocks the direct view of nuclear region, however, in type 1, observer line of sight is away from torus and central region is visible.

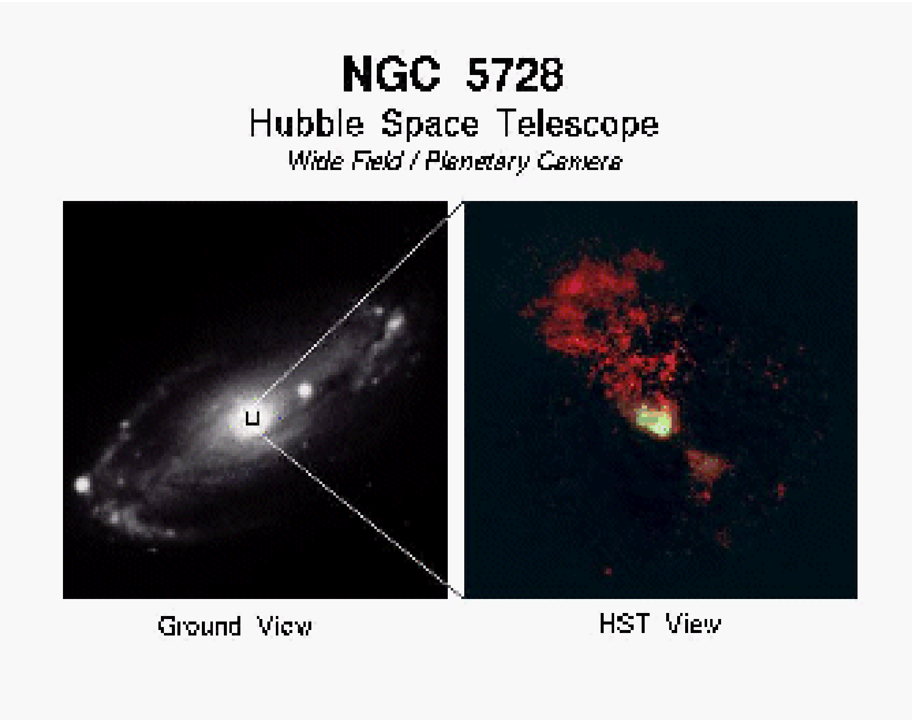


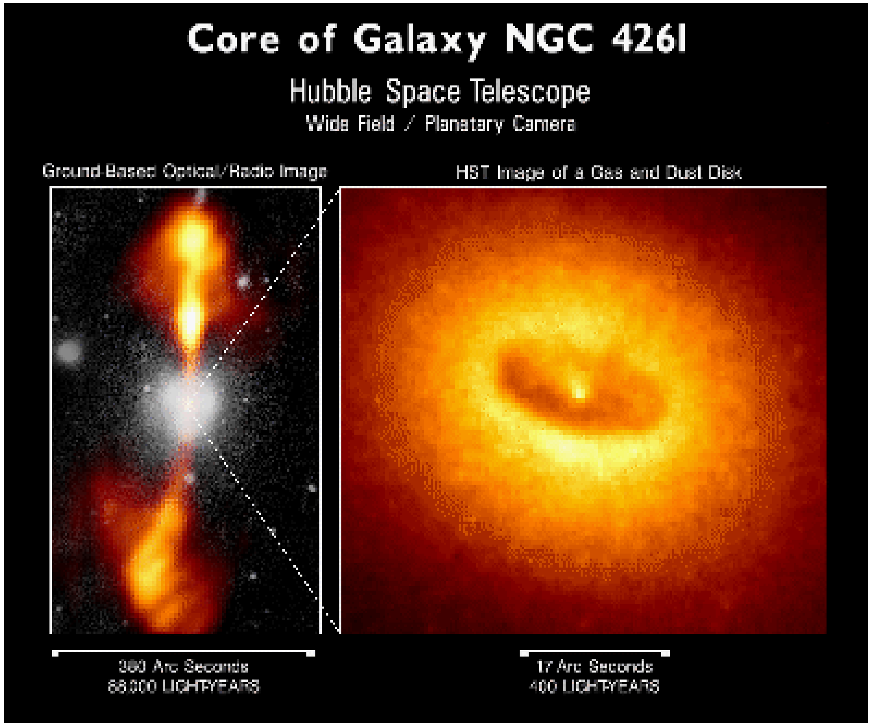
Observational Evidence

Soft X-ray continuum is relatively weaker in type 2 than type 1 (Lawrence and Elvis 1982, Fabbiano et al. 1986) Column density of type 2 AGNs deduced from X-ray measurements suggest the obscured nucleus (Mulchaey et al. 1992).

Anisotropic Illumination of Narrow Emission Lines Gas: Ionizing light cones has been seen in direct imaging of many nearby type 2 AGNs. HST imaging of NGC 1068 in light of O[III] (Evans et al. 1991) confirm an ionizing cone with apex at an obscured nucleus (Pogge 1988).

Biconical Structure suggest that an obscured nuclear source is photoionizing gas in the extended narrow line region (Robinson et al. 1987; Baum and Heckman 1989; Wilson et al. 1993)





Motivation

Issues About Seyfert Unification

◆ Spectropolarimetric Surveys of complete sample of Seyfert 2s suggest that ≥50% Seyfert 2s do not show polarised broad emission lines (Tran et al. 2001, 2003).

◆ 10-30% Seyfert 2s are found unabsorbed in X-rays (Panessa & Bassani 2002), even 50% among ROSAT selected Seyfert galaxies (Gallo et. al. 2006).

◆ It is suggested that many Seyfert 2s lack BLR and are intrinsically weak and therefore constitute a new subclass non-HBLR Seyfert 2s (Gu & Huang 2002; Laor 2003).

It seems that orientation based Unification Scheme of Seyfert Galaxies alone is not sufficient to explain all the observed properties in all Seyferts and role of fundamental parameters e.g. Black hole mass, accretion rate, radiative efficiency of accrtion disc etc. should be taken into account.

Motivation

Disk-Jet Connection

- Recent Observations have shown that all the AGN are radio sources at some level. There is high detection rate of radio cores in radio-quiet AGN and radio emission probably results from some sort of outflow of radio plasma from the nucleus, in the form of jets, bubbles or plasmoids (Wilson & Ulvestad 1987).

- The issue that all AGN could host a jet and be synchrotron emitter, is in apparent contrast with sharp division observed between radio-loud and radio-quiet AGN.

- The theoretical assumption is that both accretion and jet are fundamental manifestation of nuclear activity and are somehow physically connected (Begelman et al 1984; Falcke and Biermann 1995; Heinz and Sunyaev 2003).

Objectives

- ◆ To test the predictions of unification hypothesis of Seyfert galaxies for a rigorously selected sample using radio and X-ray Observations.

- ◆ We make an attempt to examine accretion disk- jet coupling in Seyfert galaxies by studying the nuclear emission in hard X-ray and radio bands, and the correlations among various parameters e.g. L_X , L_{Radio} , $L_{[O\ III]}$, M_{SMBH} .

- ◆ The basic goal is to understand the role of fundamental parameters which triggers the different levels of nuclear activity, and governs the behaviour of AGN and in particular, among low luminosity AGN (Seyfert), apart from orientational effects.

Methodology

Our methodology include the study of correlation and comparison between nuclear X- ray, and core radio emission and their spectral properties for a rigorously selected sample of Seyfert galaxies in the frame work of unification scheme.

Why Only Radio and X-ray ?

Nuclear radiation at radio and (hard) X-ray frequencies is the most direct prob of nuclear activity as extinction is unimportant in radio band and in X-ray the absorption effect can be taken in to account from spectral analysis.

The Sample

We have rigorously selected sample of 20 Seyfert galaxies out of which 10 are type 1 and 10 are type 2.

Sample Selection Criteria

In order to rigorously test the predictions of unification scheme, the sample of two Seyfert subclasses being compared should be intrinsically similar within the framework of unification scheme. Therefore, sample of two subclasses should be matched in the properties, which are independent of the orientation of the AGN (Lal et al. 2002).

In Our sample two subclasses of Seyferts are matched in orientation independent parameters e.g. cosmological redshift, [O III] line emission which originate from NLR and is proxy for AGN power, bulge magnitude, host galaxy luminosity and Hubble type of the host galaxy.

The Sample

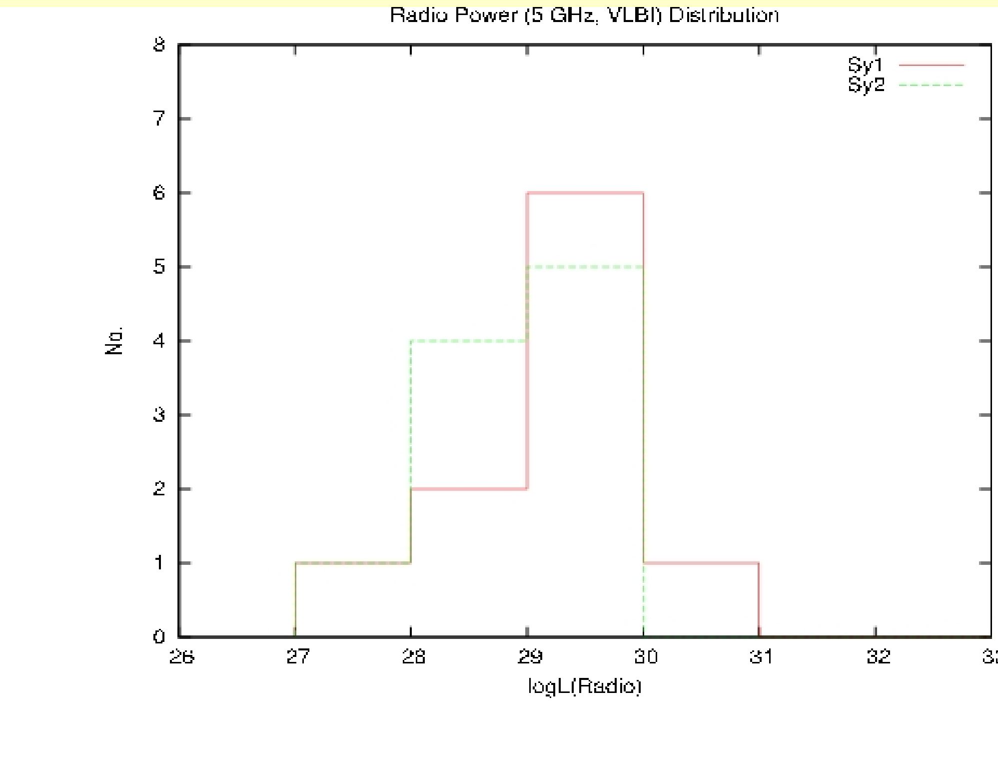
Name	Redshift (z)	$\log L_{[O\,III]}$ (erg s^{-1})	Ref.	$\log L_{(R,5\,Ghz)}$ (erg s^{-1})	$\log L_{(0.2\text{-}2.4keV)}$ (erg s^{-1})	Ref.	$\Gamma_{(0.2\text{-}2.4\,keV)}$	Ref.	$\log L_{(2\text{-}10keV)}$ (erg s^{-1})	Ref.	$\Gamma_{(2.0\text{-}10keV)}$	Ref.	$\log M_{BH}$	Ref.
Seyfert 1s														
NGC 2639	0.011	39.88	5	29.02	40.81^R	6	2.16	9	41.66^A	18	2.4	22	8.07	25
NGC 4151	0.003	41.35	1	27.29	41.34^R	6	2.46	9	43.08^A	11	1.58	11	7.13	24
NGC 7469	0.016	41.51	1	28.62	43.38^R	6	2.37	9	43.56^A	21	2.02	21	6.84	24
Mrk 231	0.042	41.97	4	30.84	41.86^R	6			42.90^A	11				
Mrk 530	0.03	40.98	1	29.29	43.18^R	6	2.09	9					8.08	25
Mrk 766	0.013	41.16	2	28.37	43.19^R	6	2.63	9	43.08^A	11	2.16	11	6.64	26
Mrk 926	0.047	42.18	4	29.4	43.80^R	6			44.43^A	11	1.73	11		
Mrk 1218	0.029	41.50	4	29.44	43.12^R	6	1.5	9						
Ark 564	0.024	41.31	3	29.06	43.74^R	6			43.80^A	12	2.7	12	6.5	26
MCG 8-11-11	0.025	41.95	2	29.03	$<44.55^E$				43.54^A	11	1.55	11		
Seyfert 2s														
NGC 2273	0.006	40.41	1	27.78	39.95^R	9	2.3	9	41.93^A	18			7.3	24
NGC 5135	0.014	40.97	1	28.33	41.37^R	6	2.3	8	41.23^A	13	2.91	13		
NGC 5929	0.009	40.21	1	28.1	40.37^R	6	2.65	9	42.47^G	16			7.25	24
NGC 7212	0.027	42.15	2	29.11	$>41.16^X$	10			42.15^A	14	1.87	14	7.47	25
NGC 7682	0.017	41.16	1	28.95	42.50^R	8	2.64	8	43.22^H	19			7.28	24
Mrk 1	0.016	41.28	3	28.59	$<41.37^E$	7			40.45^A	20			7.16	24
Mrk 78	0.037	42.31	1	29.44	41.45^R	6	4.32	9	43.51^G	17	1.45	23	7.87	24
Mrk 348	0.015	41.31	2	29.75	40.81^R	6	2.43	9	42.63^A	14	1.6	14	7.21	24
Mrk 477	0.038	42.70	3	29.53	$<42.31^E$	7			42.81^A	14	1.57	14		
Mrk 533	0.029	41.99	2	29.59	41.84^R	6	4.41	9	43.22^A	15	1.42	15	7.56	24

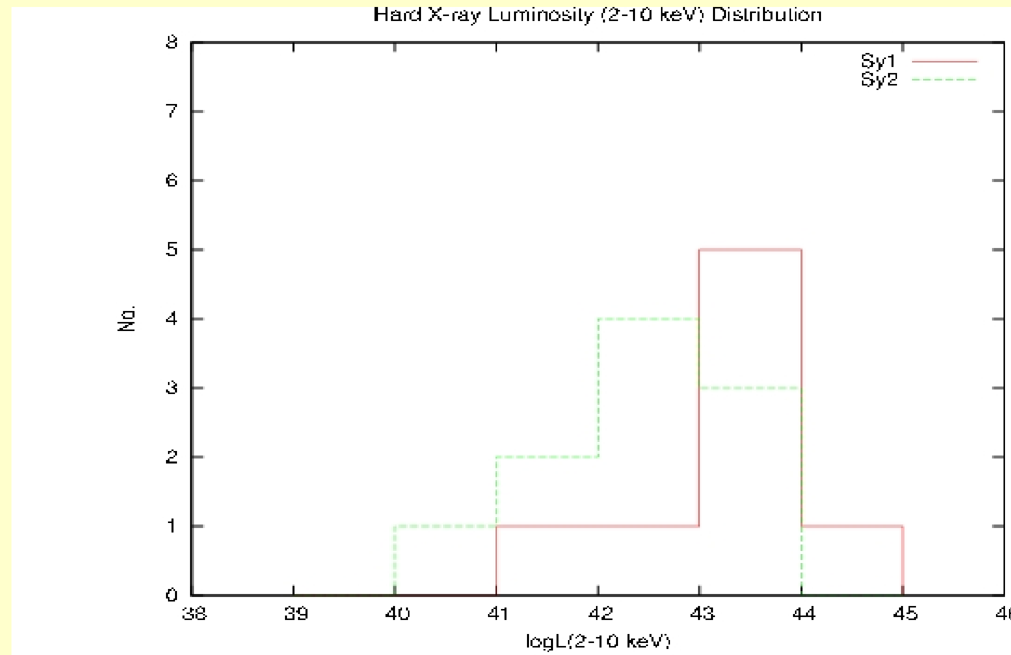
Column 1: Source Name; Column 2: Heliocentric Redshift; Column 3: logarithmic of [O III] luminosity; Column 4: References for [O III] luminosity; Column 5: Logarithmic of radio luminosity extracted from Lal et al. 2004 and references therein, measured by Very Long Baseline Interferometric (VLBI) observations at 5 GHz; Column 6: Logarithmic of (0.2-2.4) soft X-ray luminosity; Column7: References for $L_{(0.2\text{-}2.4\,keV)}$; Column 8: Soft X-ray photon index; Coumn 9: References for $\Gamma_{(0.2\text{-}2.4\,keV)}$; Column 10: logarithmic of X-ray luminosity in hard (2.0-10) keV band; Column 11: References for $L_{(2\text{-}10\,keV)}$; Column 12: Hard (2.0 – 10 keV) X-ray photon index; Column 13: References for $\Gamma(_{2.0\text{-}10\,keV})$; Column 14: Logarithmic of mass of the supermassive black hole; Column 15: References for M_{BH}.

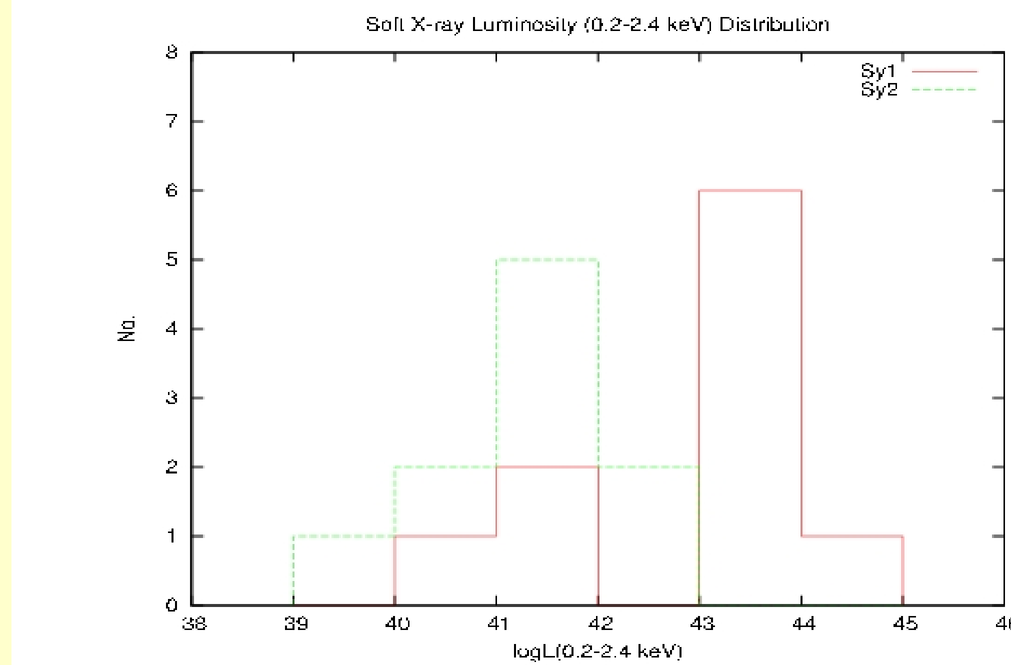
References: 1. Whittle 1992; 2. Schmitt et al. 03; 3. de Grijp et al. 1992; 4. Dahari et al. 1988; 5. Keel 1983; 6. WGA ROSAT Catalog; 7. Whittle 1994; 8. Rush1996; 9. Pfefferkorn et al. 2001; 10. Guainazzi et al. 2005; 11. Turner et al. 1999A; 12. Turner et al. 1999B; 13. Turner et al. 1997; 14.Awaki et al. 2000A; 15. Awaki et al. 2000B; 16. Awaki 1991; 17.Awaki & Koyama 1993; 18. Terashima et al. 2000; 19. Della Ceca et al. 1990; 20. Ueda et al. 2001; 21. Reynolds 1997; 22. Wilson et al. 1998; 23. Malguti et al. 1994; 24. Woo & Urry 2002; 25 M-σ (Tremain et al. 2002); 26.Wang & Lu 2001

^{R}ROSAT , ^{E} Einstein, ^{X} XMM Newton, ^{A} ASCA, ^{G} Ginga, ^{H} HEAO 1 A-2

Radio and X-ray Luminosity Distributions



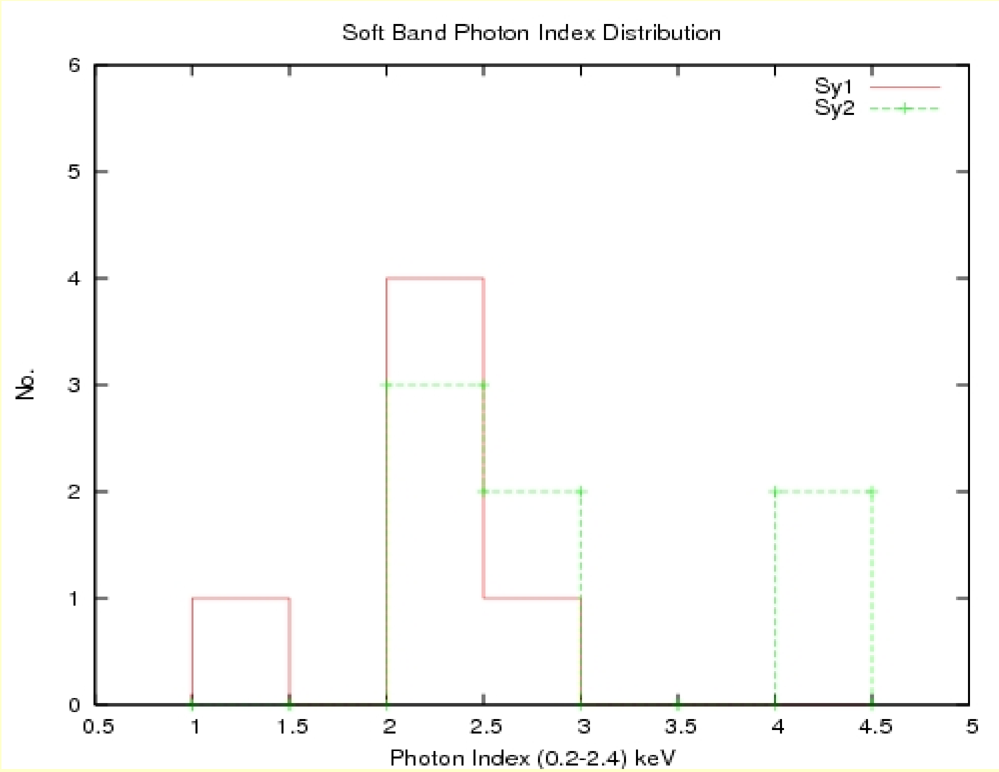


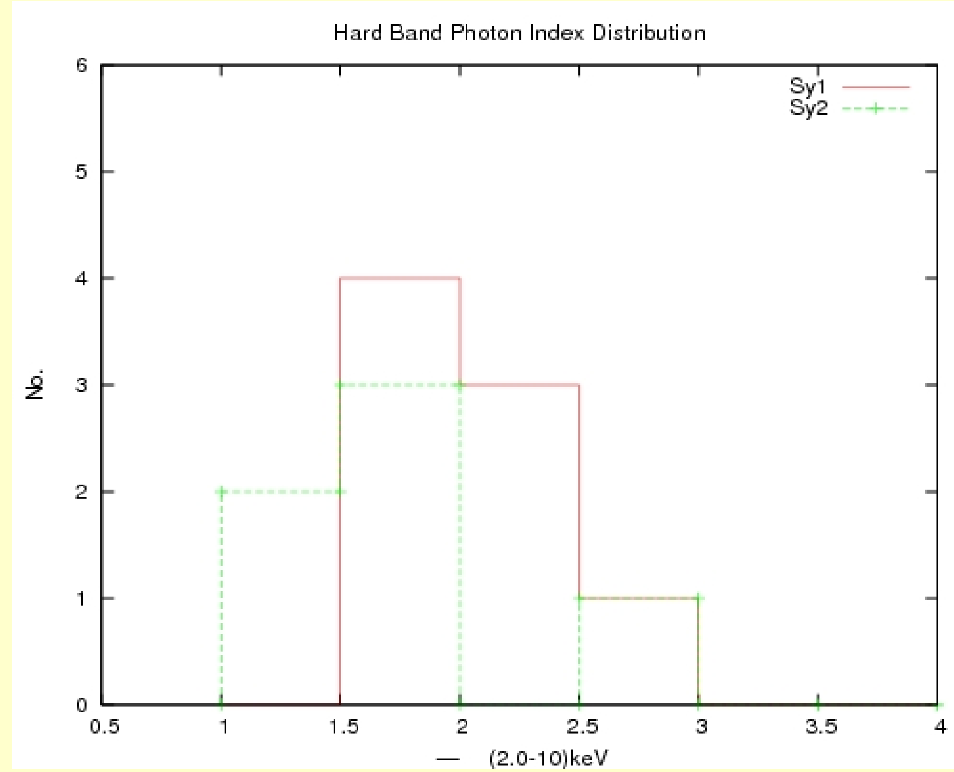


Distribution	**Kolmogorov Smirnov two sample test**	
	D Value	*p-value*
log L $_{\mathbf{(R,\ 5GHz)}}$	0.2	0.9883
log L $_{\mathbf{soft\ X\text{-}ray}}$	0.7	0.0148
log L $_{\mathbf{hard\ X\text{-}ray}}$	0.4	0.4005

D=sup x | S1(x) ?S2(x)|

where S1 and S2 are the empirical distribution functions for the two samples.





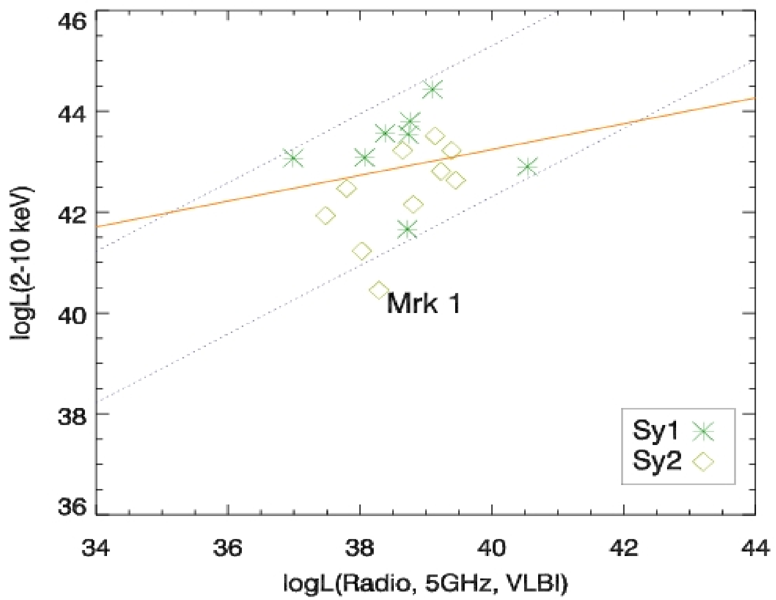
Distribution	*Mean*		*Difference*	*Median*		*Difference*
	Sy 1	Sy 2		Sy 1	Sy 2	
log L $_{\mathbf{(R,\ 5GHz)}}$	29.042	28.917	0.125	29.045	29.03	0.015
log L $_{\mathbf{soft\ X\text{-}ray}}$	42.90	41.31	1.59	43.19	41.37	1.82
log L $_{\mathbf{hard\ X\text{-}ray}}$	43.26	42.36	0.9	43.31	42.55	0.76
Γ $_{\mathbf{(0.2\ -\ 2.4\ keV)}}$	2.20	3.0	0.8	2.27	2.64	0.37
Γ $_{\mathbf{(2\ -\ 10\ keV)}}$	1.98	1.80	0.18	1.88	1.59	0.29

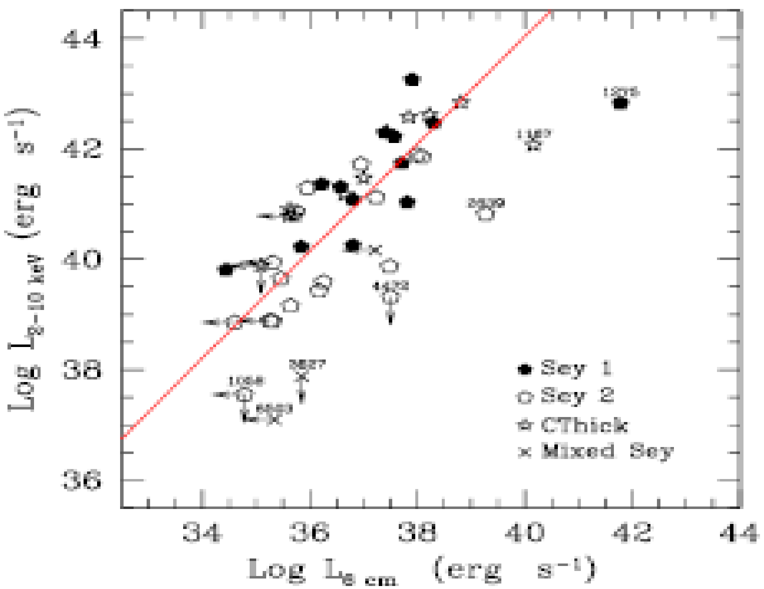
- The statistical tests show that core radio power distributions of two Seyfert subclasses are similar and in X-ray regime difference decreases as one move from soft to hard band.

- The distribution of X-ray photon index for two Seyfert subclasses are not systematically different in hard band, however in soft X-ray band Seyfert 2s photon index is systematically steeper than 1s.

Radio, X-ray Luminosity Correlation in the context of Disk-Jet Connection

- ◆ Hard X-ray emission originate from accretion disk-corona system.
- ◆ Core radio emission originate from the base of small scale jet like outflow.





$\log L_{X(2-10\ keV)} = 0.26 \log L_{R\ (5\ GHz)} + 33$

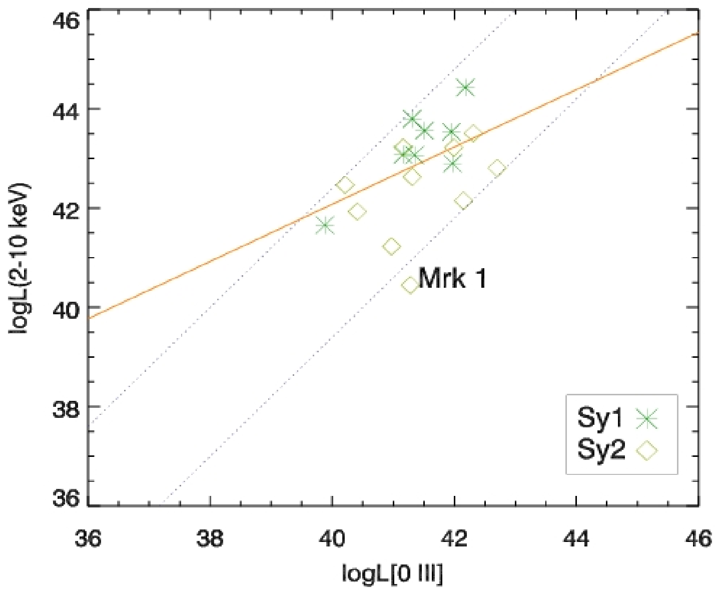
$\log L_{X(2-10\ keV)} = 0.97 \log L_{R\ (5\ GHz)} + (5.23+\_0.0.28)$

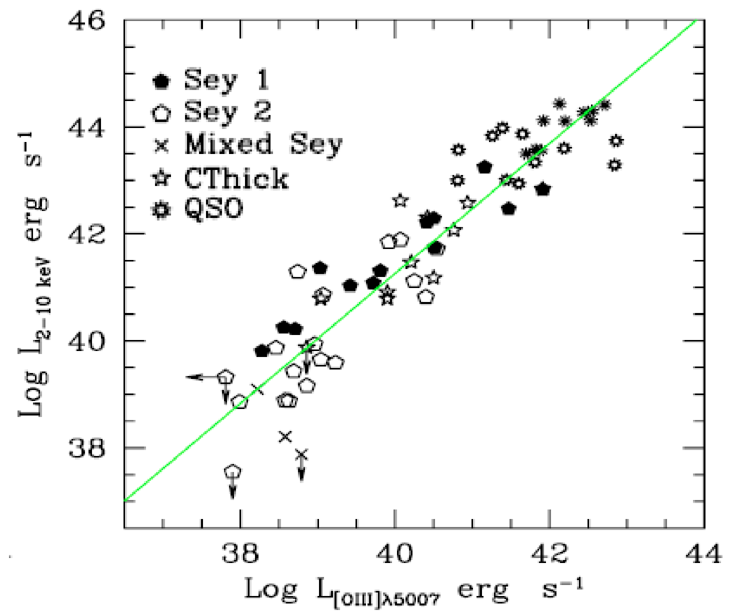
(Panessa et al. 2007)

Brinkmann et al. (2000) reported correlation between ROSAT 2 keV monochromatic luminosity and 5GHz (VLA) radio luminosity for radio quiet sources with slope 1.012 +_0.083.

Selection effects are probably introduced in Panessa et. al. (2007) Seyfert sample as it has been derived from optical flux limited Palomar Survey causes bias towards high luminosity sources.

[O III] and X-ray luminosity Correlation





$\log L_{X(2\text{-}10\ keV)} = 0.58 \log L_{[O\ III]} + 19$

$\log L_{X(2\text{-}10\ keV)} = (1.22+\_0.66) \log L_{[OIII]} + (-7.33+\_2.53)$

(Panessa et al.2006)

	Spearman's rank correlation		Kendall's rank correlation	
Parameters	ρ- value	p-value	τ-value	p-value
log L $_{(R,\ 5GHz)}$ **Vs log L** $_{(2\text{-}10\ keV)}$	0.24	0.35	0.17	0.34
log L $_{[O\ III]}$ **Vs log L** $_{(2\text{-}10\ keV)}$	0.49	0.045	0.32	0.076

[O III] luminosity is considered as proxy of intrinsic power of AGN central engine.

Panessa et al. (2006) confirms strong correlation between (2-10 keV) X-ray luminosity and [O III] luminosity which shows the same slope as for highly luminous AGN and thus correlation is independent of level of nuclear activity.

Heckmann et al. (2005) found significant correlation between L_X and $L_{[O\ III]}$ in sample hard X-ray selected AGN.

Discussion and Conclusions

- For our matched sample of Seyferts, core radio luminosity distributions are statistically similar for both Seyfert subclasses. The core radio power of both types of Seyfert is expected to be similar, as it is unaffected by obscuration and orientation.

- The X-ray luminosity of Seyfert 1s is systematically higher than that of Seyfert 2s in both soft (0.2-2.4 keV) and hard (2.0-10 keV) energy bands, however, the difference decreases in hard band. In X-ray regime, soft X-ray photons are absorbed by the torus in Seyfert 2s, leading to an apparent reduction in X-ray luminosity, while, hard X-ray photons are less affected by absorption and differences between luminosities of two subclasses decreases.

- The hard X-ray photon indices are similar for both types of Seyferts, however, soft X-ray photon index for Seyfert 2s is systematically steeper than 1s, which is against the prediction of unification scheme as absorption by the torus in this band makes spectrum flatter. This may be due to significant contamination of extended off nuclear emission in this band.

- All the above results except soft X-ray photon index distribution, are broadly consistent with the orientation based unification scheme of Seyfert galaxies.

Discussion and Conclusions

- We see a week trend of increasing X-ray luminosity with [O III] luminosity, which is likely, if [O III] luminosity is true proxy for AGN power and most of the X-ray emission comes from central engine.

- We find a moderate correlation between hard (2 – 10 keV) nuclear X-ray and core radio luminosity for our Seyfert sample, which suggest that there is some level of connection between accretion and radio jet/outflow . Since hard X-ray originate from disk-corona system, while core radio emission originate from the base of the small scale jet.

Thanks