The unifying model of Jetted AGNs: the contributions of relativistic and orientation Effects

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Introduction

Galaxy is a massive, gravitationally bound system that consists of stars and stellar remnants, an interstellar medium, and dark matter

(def. International Astronomical Union - IAU)

NGC 4414, Credit: NASA/HST

NGC 3923, Credit: NASA/HST

Name → Greek root 'galaxias' = 'milky' (refers to the Milky Way)

Galaxy components: in terms of their content
(in terms of their structure will come later)

- Tens to hundreds of billions of stars (including stellar clusters).
- Stellar remnants (white dwarfs, neutron stars, black holes).
- Interstellar medium (gas and dust).
- Dark matter (still an open question).

Andromeda galaxy (M31)
2.5 million ly away (2.4 x 10^{19} km)

Image credits: David Dayag

Active galactic nuclei (AGNs)

Supermassive black holes (SMBHs) in Galaxies

- SMBHs at centre of almost all known galaxies
- a few percent of these BHs are "active"
- "active" $\rightarrow$ luminous centres — may out-shine entire galaxy

Jets from AGN — Collimated outflows

- a few percent of AGN eject radio-emitting jets
- jets with relativistic charged particles

Powering source

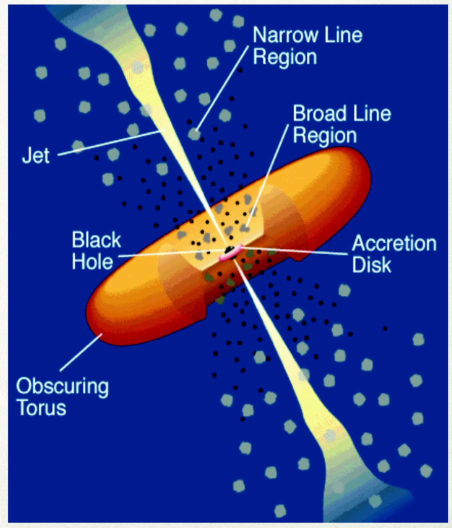
- BH & accretion $\rightarrow$ rotation & accretion-disk $\rightarrow$ radiation

Roles of AGNs in Astrophysical Sciences

- Formation of supermassive black hole
- Discovery of distant objects
- Study of intervening intergalactic medium
- Measurements of cosmological parameters
- Investigation of star formation and accretion history
- Principal probes of the Universe on large scales

Elements of AGNs

- SMBH in the centre $\sim 10^6 - 10^9 M_\odot$
- Accretion disk, large temperature range
- Obscuring torus (dust) may block view on disk
- Broad-line Region (BLR), linewidths $\sim 10^3 - 10^4$ km/s
- Narrow-line Region (NLR), linewidths ~ 500 km/s
- Jets (magnetsied plasma)



Classification of AGNs

Radio Loudness factor:

$$R_L = log\left[\frac{S_{5GHz}}{S_B}\right] \tag{1}$$

Minority of AGNs (10 - 15%) are radio-loud ($R_L \geq 10$),

Majorities (85 %) are radio-quiet ($R_L < 10$)

Intensity of the Powerful relativistic jets:

- Radio-Loud AGNs → Jetted AGN
- Radio-Quiet AGNs → Non-jetted AGN

Jetted active galactic nuclei

Observational Properties

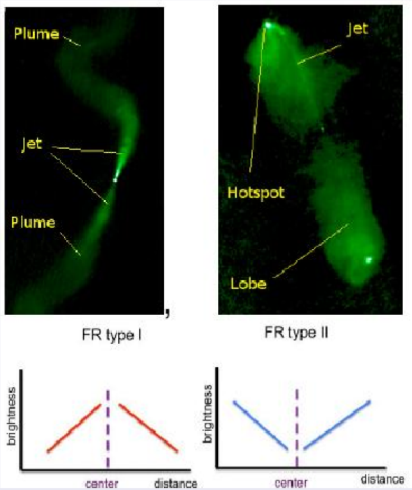
Blazars

- powered by relativistic jets
- rapid and large variation
- high and variable polarization
- superluminal motions
- high energetic GeV/ TeV emissions

Radio galaxies

- powered by relativistic jets
- strong variable polarization
- superluminal motion in their radio jets
- emit radio waves by synchrotron process

Radio Galaxy Classification



- morphology of double structure
- jets, lobes and hotspots
- by Fanaroff & Riley (FR) in 1974
- division on *radio* structures
- FR I: edge-darkened
- FR I e.g. Centaurus A
- FR II: edge-brightened
- RGs seen in VHE seem to be FR I
- Cen A, M 87, NGC 1275, PKS 0625-354, IC 310, Per A

Blazar classification based on synchrotron peak frequency

Blazars are divided into two:

- BL Lacertae Objects (BL Lacs)
- Flat Spectrum Radio Quasars(FSRQs)

BL Lacs:

- Low synchrotron peaked (LSPs)
  $\log \nu_{peak}^{syn} < 14(H_z)$
- Intermediate synchrotron peaked (ISPs)
  $14 < \log \nu_{peak}^{syn} < 15(H_z)$
- High synchrotron peaked (HSPs)
  $\log \nu_{peak}^{syn} > 15(H_z)$

FSRQs

- $\log \nu_{peak}^{syn} < 12(H_z)$

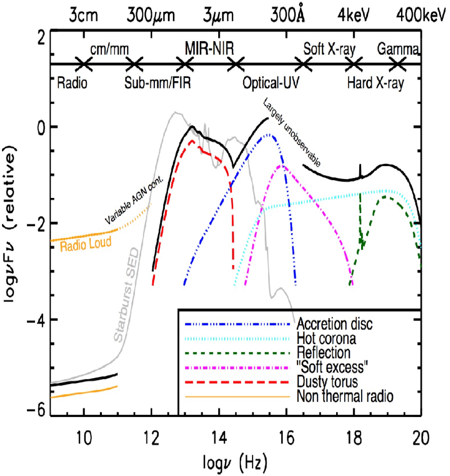
AGNs Emissions

Broad Spectral Energy Distribution

AGNs emissions are

- Thermal/Disk dominated ($\simeq$ 90 %)
- Non-thermal/Jet dominated (less $>$ 10 %)

Non-thermal emissions occur at all wavelengths



Unification of AGNs

Unification Models include:

- Unification of AGNs based on Intrinsic Properties and Evolution
- Unification of AGNs on the basis of Relativistic Beaming and Orientation effect
- Unification via Blazar Sequence

Evidence in favour or against any of the unification model does not invalidate other models; each model is independent of the other

Relativistic Beaming Concept and Basic Assumption

In relativistic beaming model, the emission from radio sources are produced by two components:

- Boosted core (beamed) emission
- Isotropic lobe (unbeamed) emission

Radio Core-dominance

$$R_r = \frac{L_{r,b}}{L_{r,unb}} = \frac{R_T}{2}\left[(1-\beta cos\theta)^{-2}(1+\beta cos\theta)^{-2}\right] \quad (2)$$

Relativistic Beaming Concept and Basic Assumption

The radio beaming factor

$$g_r(\beta, \theta) = \frac{1}{2}\left[(1 - \beta cos\theta)^{-2}(1 + \beta cos\theta)^{-2}\right] \tag{3}$$

$\gamma - ray$ Core-dominance:- ratio of the core to lobe $\gamma - ray$ luminosity components

- beamed γ-ray emission
- unbeamed γ-ray emission

Relativistic Beaming Concept and Basic Assumption

$\gamma - ray$ core-dominance parameter

$$R_\gamma = \frac{L_{\gamma,b}}{L_{\gamma,unb}} = \frac{R_T}{2}\left[(1-\beta cos\theta)^{-2} + (1-\beta cos\theta)^{-2}\right] \tag{4}$$

If the $\gamma - ray$ beaming factor is

$$g_\gamma(\beta,\theta) = \frac{1}{2}\left[(1-\beta cos\theta)^{-2} + (1-\beta cos\theta)^{-2}\right] \tag{5}$$

Relativistic Beaming Concept

$\gamma - ray$ Core-dominance

$$R_\gamma = \frac{L_{\gamma,b}}{L_{\gamma,unb}} = g_\gamma(\beta,\theta) \tag{6}$$

The viewing angle (θ_m) can be estimated assuming $\beta = 1$

$$\theta_m = cos^{-1}\left[\frac{2R_m + R_T - [R_T(8R_m + R_T)]^{1/2}}{2R_m}\right]^{1/2} \tag{7}$$

Aim, Sample Description and Calculation

Aim:

- Dervive the γ -ray coredominance to investogate the relativistic beaming and orientation effects

Blazar Sample: *Fermi* Large Area Telescope (4FGL)

- 397 blazar selected from the *Fermi*-Large Area Telescope (*Fermi* LAT, 4FGL)

153 Non *Fermi*-detected Radio galaxies (46 FR Is and 107 FR IIs) from the VLA survey

- The beamed and unbeamed γ-ray emissions computed using

$$L_{\gamma} = 4\pi_{L}^{2} F(1+z)^{\alpha_{\gamma}-1} \quad (8)$$

Analysis and Results

Distribution of γ-ray Core-dominance

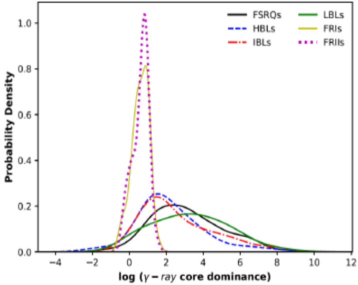


Fig. 3: *Density distribution of beamed gamma-ray emission*

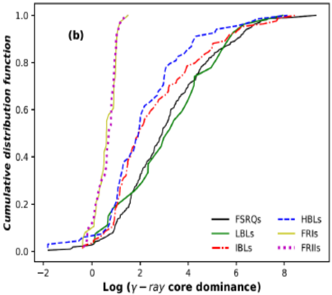


Fig: 4: Cumulative distribution of beamed gamma-ray emission

Parameter	*Subsamples*	*n*	*d*	*p*
γ-ray Core-dominance	RGs – HSPs	64 – 138	0.19	0.000008
γ-ray Core-dominance	RGs – LSPs	64 – 133	0.21	0.0006074
γ-ray Core-dominance	RGs – ISPs	64 – 130	0.17	0.0002334
γ-ray Core-dominance	RGs – FSRQs	64 – 279	0.20	0.0007663

Results cont'd

Distribution of X-ray Core-dominance

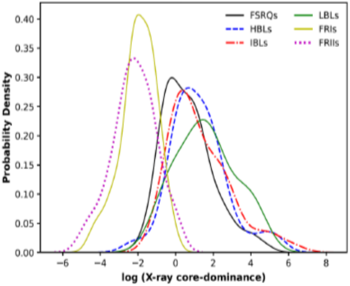


Fig. 3: *Density distribution of beamed gamma-ray emission*

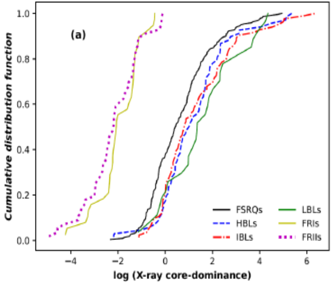


Fig: 4: *Cumulative distribution of beamed gamma-ray emission*

Parameter	*Subsamples*	*n*	*d*	*p*
X-ray Core-dominance	RGs – HSPs	64 – 138	0.23	0.0005
X-ray Core-dominance	RGs – LSPs	64 – 133	0.16	0.00060
X-ray Core-dominance	RGs – ISPs	64 – 130	0.21	0.00086
X-ray Core-dominance	RGs – FSRQs	64 – 279	0.19	0.00098

Results cont'd

Approximate Viewing Angles

Subsamples	average of log R_x	average of log R_γ	θ_m from (R_x)	θ_m from (R_γ)
RGs	0.93 ± 0.30	0.89 ± 0.32	39.6°	38.2°
FSRQs	0.93 ± 0.21	0.97 ± 0.24	22.4°	21.6°
HBLs	1.32 ± 0.05	1.21 ± 0.07	18.8°	19.1°
LBLs	1.21 ± 0.08	1.22 ± 0.05	14.4°	15.2°
IBLs	0.58 ± 0.29	0.79 ± 0.31	13.9°	13.5°

Results cont'd

Distribution of beamed gamma-ray emission

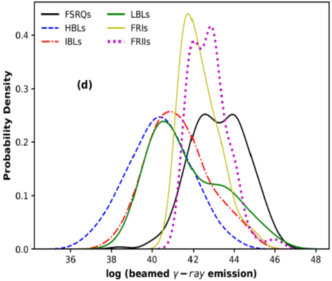


Fig. 3: ***Density distribution of beamed gamma-ray emission***

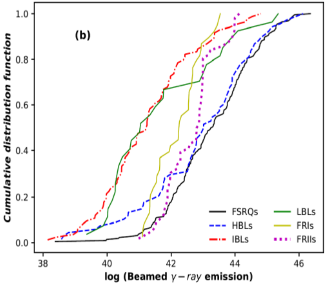


Fig: 4: Cumulative distribution of beamed gamma-ray emission

Parameter	*Subsamples*	*n*	*d*	*p*
Beamed gamma-ray emission	RGs – HSPs	64 – 138	0.39	0.000864
Beamed gamma-ray emission	RGs – LSPs	64 – 133	0.66	0.0003569
Beamed gamma-ray emission	RGs – ISPs	64 – 130	0.71	0.00087534
Beamed gamma-ray emission	RGs – FSRQs	64 – 279	0.87	0.0002344

Results cont'd

Distribution of Unbeamed gamma-ray emission

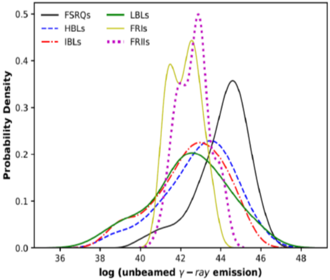


Fig. 1 *Density distribution of unbeamed gamma-ray emission*

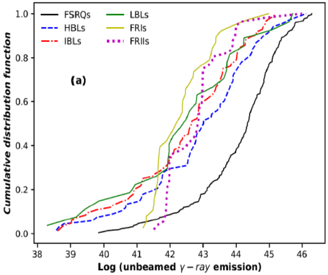
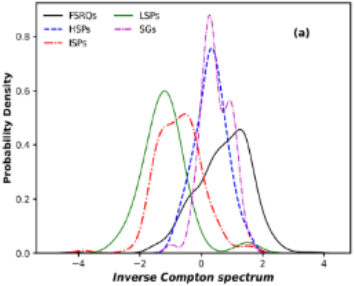


Fig. 2 *Cumulative distribution of unbeamed gamma-ray emission*

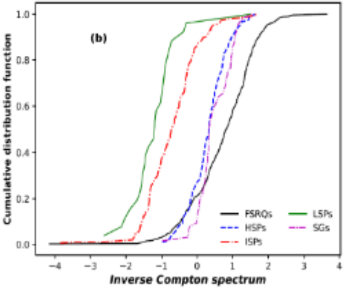
Parameter	*Subsamples*	*n*	*d*	*p*
unbeamed gamma-ray emission	RGs – HSPs	64 – 138	0.39	0.000864
unbeamed gamma-ray emission	RGs – LSPs	64 – 133	0.66	0.0003569
unbeamed gamma-ray emission	RGs – ISPs	64 – 130	0.71	0.00087534
unbeamed gamma-ray emission	RGs – FSRQs	64 – 279	0.87	0.0002344

Results cont'd

Distribution of Inverse Compton Spectrum



(a) *Density distribution of Compton spectrum*



(b) *Cumulative distribution function Compton spectrum*

Parameter	*Subsamples*	*n*	*d*	*p*
Inverse Compton spectrum	RGs – HSPs	64 – 138	0.63	4.21×10^{-06}
Inverse Compton spectrum	RGs – LSPs	64 – 133	0.56	3.07×10^{-04}
Inverse Compton spectrum	RGs – ISPs	64 – 130	0.48	1.08×10^{-05}
Inverse Compton spectrum	RGs – FSRQs	64 – 279	0.53	2.98×10^{-07}

Results cont'd

Correlations among the Beaming Parameters

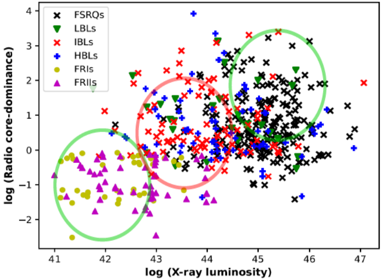


Fig. 5: Rr – Lr plot for FSRQs, radio galaxies and BL Lacs

- radio galaxies – BLs – FSRQs are aligned
- FSRQs are most luminous and beamed

Table 1: Results of linear regression fitting

plots	Sample	k	Δk	k_0	$Δk_0$	r	p
Rr – Lx	Whole sample	0.96	0.24	-6.22	0.40	0.62	1.91×10^{-6}
Rr – Lx	radio galaxies	0.82	0.20	-5.03	0.20	0.71	2.03×10^{-6}
Rr – Lx	Blazars	0.74	0.18	-5.20	0.30	0.57	3.26×10^{-6}

Correlations among the relativistic beaming parameters

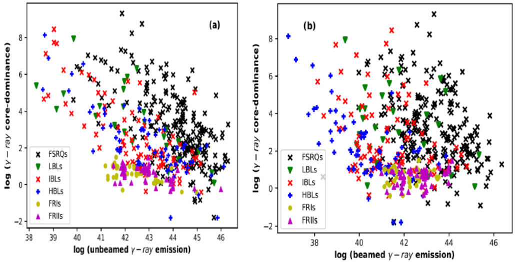


Fig. 6: (a) Ry – L,b and (b) Ry – L,b plot for FSRQs, radio galaxies and BL Lacs

- radio galaxies – lowest in *Ry*
- FSRQs – highest in beamed/unbeamed

Common factor that change linearly is responsible for the variation

plots	Sample	k	Δk	k_0	Δk_0	r	p
$R_\gamma - L_{\gamma,b}$	Whole sample	-0.93	0.31	2.17	0.08	-0.65	10^{-6}
$R_\gamma - L_{\gamma,b}$	Radio galaxies	-0.75	0.26	1.08	0.06	-0.52	10^{-6}
$R_\gamma - L_{\gamma,b}$	BL Lacs	-0.56	0.23	2.90	0.10	-0.62	10^{-6}
$R_\gamma - L_{\gamma,b}$	FSRQs	-0.56	0.32	2.90	0.10	-0.68	10^{-6}

plots	Sample	k	Δk	k_0	Δk_0	r	p
$R_\gamma - L_{\gamma,unb}$	Whole sample	1.14	0.34	0.72	0.38	-0.57	10^{-7}
$R_\gamma - L_{\gamma,unb}$	Radio galaxies	2.03	0.20	0.22	0.26	-0.56	10^{-8}
$R_\gamma - L_{\gamma,unb}$	BL Lacs	1.25	0.23	-4.32	0.30	-0.58	10^{-7}
$R_\gamma - L_{\gamma,unb}$	FSRQs	1.30	0.16	-5.01	0.20	-0.61	10^{-7}

Conclusion

- Relativistic beaming parameters of blazars and radio galaxies were used to quantitatively test for the consistency of Unified scheme of jetted jetted AGNs
- From the comparison of the distributions of $L_{\gamma,b}$ and $L_{\gamma,unb}$, it is observed that FSRQs could be the extreme version of radio galaxy populations
- This indicates that jetted AGN may start off as a radio galaxy and grow through BL Lacs to FSRQs
- Signifying that radio galaxies are the youngest subclasses of the jetted AGNs with least beaming effect.

Questions/Comments/Suggestions

Me

You

Thanks for Listening