АСТРОФИЗИКА

ТОМ 66 МАЙ, 2023 ВЫПУСК 2

DOI: 10.54503/0571-7132-2023.66.2-169

ON THE UNIFIED SCHEME OF γ-RAY EMITTING JETTED ACTIVE GALACTIC NUCLEI

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Received 23 December 2022
Accepted 22 May 2023

The discovery of γ - ray emitting Seyfert galaxies has opened a new unified scheme of active galactic nuclei (AGN) in which jetted Seyfert galaxies are viewed as young counterparts of radio loud AGN. In this paper, we investigate the relationship between gamma-ray (γ - ray) properties of jetted Seyfert galaxies and those of traditionally radio galaxies, radio quasars and BL Lac objects. Results show that jetted Seyfert galaxies appear as low luminosity tail of the radio loud AGNs on the luminosity redshift ($L_{\gamma} - z$) plane, indicating an evolutionary link between them. Nevertheless, narrow-line Seyfert galaxies (NLS1s) do not share similar characteristics with Seyfert galaxies as they possess higher luminosities and redshift than Seyfert galaxies, suggestive that NLS1s are more evolved sources. Analyses of γ - ray and radio core-dominance show that for each subclass of jetted AGN, the beaming angle is wider for radio than for γ - ray emissions. While Seyferts and radio galaxies, on average, have similar low inclination to the line of sight, NLS1 objects have orientations similar to quasars and BL Lacs. There is a significant correlation ($r \sim 0.7$) between the γ - ray core dominance and γ - ray luminosity. The results are consistent with the revised unification scheme and suggests that NLS1s are highly beamed sources whose parent populations can be found among the regular Seyferts and/or radio galaxies

Keywords: *galaxies: active galaxies: Seyferts: jets: gamma-rays*

1. *Introduction*. Active galactic nuclei (AGNs) are classified according to their appearance, luminosity and spectra, yielding a zoo of different names. The differences among the various classes and subclasses of AGNs have been studied [1-4], and several unification frameworks have been put forward to explain the underlying similarities and/or differences [1,4]. In the context of the unification frameworks, appearance of an AGN strongly depends on the viewing angle of the complex arrangement of the torus-disk-jet system [5], and was pointed out that all the different classes of AGNs are the same objects whose different manifestations are caused by effects such as orientation, relativistic Doppler boosting, and view-dependent probability due to torus obscuration In the traditional AGN classification, radio-brightness categorizes AGNs into two broad classes, namely radio-loud AGNs (RL-AGNs) and radio-quiet AGNs (RQ-AGNs). However, a more fundamental physical difference between the traditional radio-loud and the radio-quiet AGNs has been proposed [6] which is dependent on presence or lack of strong relativistic jet in their structural morphologies. Consequently, the large

AGN family is generally divided into two broad classes, namely jetted AGN and non-jetted AGN. The jetted AGNs are characterized by strong relativistic jets, while their non-jetted counterparts display jet-like collimated outflows that are small, weak, and slow compared to those of jetted sources [7]. Jetted AGNs appear to be more clustered, undergoes mergers, reside in more massive galaxies, and spin faster than their non-jetted counterparts [6].

It is important to note that among traditional radio-quiet class of AGNs are Seyfert galaxies, with radio-loudness parameter $f(4400\text{Å})/f(6\,\text{см}) < 10$. Two broad categories of Seyfert galaxies have been identified based on the width of nuclear emission lines, namely, Seyfert 1 and Seyfert 2. Seyfert 1 galaxies have a set of broad emission lines, while Seyfert 2 galaxies have narrow emission lines. However, a minority class of Seyfert 1 with narrow emission lines (NLS1s) which have been detected in recent observations [9] pointed to a considerable overlap in spectral properties of the two classes of Seyfert galaxies [10]. In general, radio-loud Seyfert galaxies are believed to harbor powerful relativistic jets, with extended radio structures [11-14]. Thus, the new unified scheme of AGNs supposedly, embraces these jetted Seyfert galaxies as young counterparts of traditional radio-loud AGNs or instead a part of a larger AGN class observed under particular geometry and inclinations of the line of sight [15].

The discovery of powerful γ - ray emitting narrow-line Seyfert 1 (NLS1) galaxies [9,16,17] and γ - ray emitting compact steep spectrum sources (CSS) provides a substantial evidence that jetted-AGNs are not formed by massive black holes alone [18]; even low-mass AGNs with lower jet power can also launch relativistic jets [16,19]. It has been pointed out [20] that the lack of small-mass jetted AGN in the traditional radio-loud/radio-quiet AGN dichotomy was due to bright-source selection bias. The relations between Eddington ratio and Eddington-scaled jet power [21] divide jetted AGNs into two populations: one population comprises low-power radio galaxies, low-excitation FR IIs (LERGs) and young radio sources, in which their jet power dominates accretion power, while the other population is made up of flat-spectrum radio quasars (FSRQ), NLS1s and high excitation FR II radio galaxies (HERGs) in which accretion power dominates jet power. Padovani et al. [22] pointed out that BL Lacs and FSRQs are jetted AGN, both belonging to blazar class, and subsequently argued that the spectral energy distributions of blazars could serve as representative of all jetted AGN sources. On the basis of different accretion modes; weak accretion disc for BL Lacs, and strong disc for FSRQs [23,24], both hitherto associated with FR 1s and FR 2s radio galaxies respectively, are presently being accurately associated with FR (LERGs) and FR (HERGs) respectively [23-25].

Interestingly, Foschini [26] identified low-mass sources among FSRQ population and argued that NLS1 galaxies are the most prominent AGNs in the low-mass class using $\text{FWHM}(\text{H}\beta) < 2000\ \text{km s}^{-1}$, and the ratio between $[\text{OIII}]/\text{H}\beta < 3$.

Berton et al., Foschini et al. [7,27] outlined some of the characteristic features of NLS1 galaxies relative to quasars to include small-mass central black hole, high accretion luminosity, prominent optical emission lines and relatively weak jet power, consistent with [19] who showed via jet-disk luminosities that NLS1 galaxies are small-mass highly accreting compact objects whose physical characteristics appear to be consistent with FSRQs.

The search for parent population of NLS1 sources revealed a connection with Compact Steep Spectrum (CSS) sources that are characterized by signs of young age [28] such as radio lobe structure of not more than 10^5 years, small linear size and very fast variability [30]. Therefore, NLS1 radio galaxies might be young radio sources that are still growing and evolving [28,29]. Although, there is still an ongoing debate in the literature about the true nature of these NLS1s, there is increasing evidence that NLS1s might be extreme objects on the evolutionary path from radio-quiet Seyfert galaxies to radio-loud quasars [31] and as such, may be low-mass analogues of high-redshift quasars [10,32-34]. In fact, Berton et al. [7] pointed out that the radio-luminosity function of flat-spectrum NLS1 galaxies suggest strongly that they might be the low-luminosity tail of FSRQs, suggesting that there might be some forms of evolutionary link between radio-loud quasars and NLS1s [31]. Furthermore, similarities between the nuclei of Seyfert galaxies and radio-loud AGNs have often been pointed out [35-37] and numerous efforts have been made to demonstrate a continuity in overall distributions of observed properties of the jetted Seyfert galaxies and traditional radio-loud AGNs [33,38-41]. In this regard, several authors [33,38] argued that in general, jetted Seyfert galaxies, BL Lac objects and radio galaxies could share similar characteristics in terms of jet luminosity-redshift ($L-z$) relation, suggestive of similar underlying environment. Thus, the shift in AGN evolutionary unification paradigm might be from a small-mass highly accreting and low-redshift jetted Seyfert galaxies (analogous of early quasars) through radio galaxies and moderate-mass highly accreting radio-loud quasars to large-mass, poorly accreting black hole BL Lac objects - a sequence of Young-Adult-Old scenario [42].

In lines with the predictions of the revised unified scheme for RL-AGN, Berton et al. [14] investigated the different manifestations of young jetted AGNs with a strong accretion disk and photon rich environments, and argued that when the young object is observed along its relativistic jet, it appears as NLS1, but as the inclination angle increases, the same object would appear as CSS or HERG. However, when the same object is viewed along the line that intercept with the molecular torus surrounding its nucleus, it then appears as a type-2 AGN in optical band, and as a CSS in radio band. The scheme fits in nicely with the usual unified model for older jetted-AGNs, in which HERGs form the parent population of FSRQs [25]. In fact, Pei et al. [43] alluded to a possible unification of quasars with jetted Seyfert galaxies via relativistic beaming and source orientation as the authors found that the radio core-dominance parameter is strongly correlated with luminosity in a sample of quasars and Seyfert galaxies. Hence, the exercise to search for links between jetted Seyfert galaxies and traditionally radio-loud AGNs is a worthy one and is partly the motivation for current investigation. In this paper, we investigate these effects using observed γ - ray properties of a well-defined sample of jetted AGNs.

2. *Theoretical modelling.* Orientation based unified scheme (OUS) for extragalactic radio sources is often studied at any frequency band ν using an important orientation parameters, namely, the core-to- extended luminosity ratio expressed as a function of the viewing angle ϕ in the form [44,45]:

$$R_\nu = \frac{L_C}{L_E} = \frac{R_T}{2}\left[(1-\beta\cos\phi)^{-n+\alpha} + (1+\beta\cos\phi)^{-n+\alpha}\right], \tag{1}$$

where L_C and L_E are the core and extended luminosities respectively, $R_T = R$ ($\phi = 90^\circ$), n is a jet model dependent parameter ($n = 2$ for continuous jet model and $n = 3$ for blob model) while α is the spectral index ($S_\nu \sim \nu^{\pm\alpha}$). The distributions of observed R_ν for various samples have been shown by several authors in the past to be quite consistent with the OUS for both high-luminosity and low luminosity sources [46,47].

A coarse treatment of Eq. (1) suggests that once R_T is known, the mean value of the distribution of core-dominance parameter R_m can be used to estimate the mean viewing angle (ϕ_m) of a sample in the form [48]:

$$\phi_m \approx \cos^{-1}\left[1-\left(\frac{2R_m}{R_T}\right)^{-1/n+\alpha}\right]. \tag{2}$$

In a two-component beaming model, the total spectral luminosity L_ν may be expressed as a sum of the core- and extended components: $L_\nu = L_C + L_E$. While L_C is assumed to be relativistically beamed, L_ν is assumed to be isotropic [49]. Thus, following [45], the γ - ray core-dominance parameter R_γ defined as the ratio of the beamed to unbeamed luminosities can be expressed through equation (1) as

$$R_\gamma + 1 = \frac{L_\gamma}{L_E}. \tag{3}$$

Equation (3) above suggests that if L_E is isotropic, a correlation between R_γ and L_γ is envisaged in γ - ray emitting AGNs

However, the observed spectral luminosity L_ν of AGN is expected to depend on its redshift z, due to luminosity selection effect/evolution and is related to its spectral flux density S_ν according to the relation:

$$L_\nu = S_\nu \, d_L^2 (1+z)^{\alpha-1}, \tag{4}$$

where d_L is the luminosity distance which depends on the present Hubble constant H_0 and the present density parameter Ω_0 according to the relation [50]:

$$d_L = \frac{2c}{H_0 \Omega_0^2} \left\{ \Omega_0 z + (\Omega_0 - 2)\left[(\Omega_0 z + 1)^{1/2} - 1\right] \right\}. \tag{5}$$

In flux limited sample with flux density cut-off at $S_\nu = S_f$, equation (4) can be written in the form [51]:

$$L_\nu = 4\pi d_L^2 S_\nu H(S_\nu - S_f)(1+z)^{\alpha-1}, \tag{6}$$

where $H(S_\nu - S_f)$ is the Heaviside step function defined by:

$$H(S_\nu - S_f) = \left\{ \begin{array}{lll} 0 & \text{if} & S_\nu < S_f \\ 1 & \text{if} & S_\nu > S_f \end{array} \right\}.$$

Eq. (6) can be used to show a simple power law $L-z$ relation [52] as

$$\log L_\nu = \log L_c + \beta \log(1+z), \tag{7}$$

where $\log L_\nu = \log L_{\nu,z} + \beta \log(1+z)$ and β is the slope of the $L_{\nu,z} - z$ data.

However, for low density universe, it has been shown [51,53] that the slope of the $L-z$ relation β is not a constant over all values of z. In this scenario, β is expected to decrease monotonically from ∞ at $z = 0$ down to some critical value, β_c at $z = z_c$ and thereafter remains fairly constant. Thus, there should be a critical luminosity L_c above which the sources would be detected as a function of z. This should correspond to a given radio luminosity at $z = z_c$. Nevertheless, it has been demonstrated observationally [52] and theoretically [53] that $z_c = 0.3$ is consistent with quasar/galaxy unification for popular radio source samples. In previous papers [52,53], these effects were studied for various samples in the radio band. In this paper, we extend the investigation to the γ-ray band for jetted AGNs in the context of the revised unification scheme.

3. *Description of source sample*. The current analysis is primarily based on a catalogue of 661 extragalactic radio jets compiled by [11]. According to the authors, a jet is a narrow radio feature that is at least four times as long as its breath; separable from other extended structures by brightness contrast and aligned with the radio nucleus of its parent object. From this catalogue, [44] made a sample of 540 objects and calculated their 5 GHz radio core-dominance parameter R_R.

However, it is well-known that many Seyfert galaxy samples are often contaminated by spurious radio-loud objects [54,55]. As such, several objects identified as Seyfert galaxies in the [44] compilation are known radio galaxies (for example, 2121+248 and 0238-084 sources are known radio galaxies). Since studies of this nature would require clean, bona-fide jetted AGN, this original sample cannot provide a good platform for testing the unification scheme of jetted AGN. Nevertheless, this problem was palliated by [56], who by cross-correlating the [44] sample with third Fermi Large Area Telescope (Fermi-LAT) catalogue, compiled a sample of 80 gamma-ray emitting extragalactic radio jets from the [44] compilation. These 80 jets include 44 quasars, 22 BL Lac objects, 11 radio galaxies and 3 Seyfert galaxies. Arguably, most γ - ray emitting AGNs are jetted sources since the presence of powerful radio jets is of substantial importance for observing a significant γ - ray counterpart, even for misaligned sources [57]. Although flat-spectrum radio quasars and BL Lac objects are still the dominant populations in the Fermi LAT catalogues, there is a significant increase in the number of other objects. From the fourth Fermi LAT AGN catalogue, [58] has made a new sample of 1559 bona-fide γ - ray emitting jetted AGN, which include 4 Seyfert galaxies and 12 NLS1s. These objects were cross-correlated with a recent compilation by [43], where relevant derived data are readily available. 3 of the 12 NLS1s do not overlap with [43] and hence, do not have complete data and were excluded in current investigation. Altogether, there are 93 γ - ray emitting jetted AGN with complete relevant data for our investigation, namely 44 quasars, 22 BL Lacs, 11 radio galaxies, 7 Seyfert galaxies and 9 NLS1s.

Finally, we derive the γ - ray core dominance parameter of all objects in the sample using the empirical relations between it and radio core-dominance parameter given [45] by: $\log R_g = 2.1 \log R_R + 1$. Throughout the paper, we have adopted the cosmology with $H_0 = 70$ km s^{-1} Mpc^{-1} and $\Omega_0 = \Omega_m + \Omega_\Lambda = 1$ ($\Omega_m = 0.3$; $\Omega_\Lambda = 0.7$). For analyses in this paper, the degree of relationship between source parameters is deduced by Pearson Product Moment correlation coefficient r using PYTHON.

4. *Data analysis and results*. We show the distributions of the sample in redshift z in Fig.1a. There is considerable overlap in z for different subsamples of the extragalactic radio jets. The distributions yield mean z-values $z_{jm} \sim 1.06$ for quasars, 0.31 for BL Lacs, 0.47 for NLSIs, 0.18 for radio galaxies and 0.18 for Seyferts. Obviously, radio galaxies and Seyferts are almost indistinguishable in distribution of z. On average, the distribution of z is consistent with a sequence in which quasars $>$ NLS1 $>$ BL Lacs $>$ Radio galaxies/Seyfert galaxies. NLS1s appear somewhat between radio quasars and Seyfert galaxies, suggestive that NLS1s could be an evolutionary phase between the Seyfert galaxies and quasars [32]. Simple Kolmogorov-Smirnoff (K - S) test shows that at 5% significance, the hypothesis that the underlying distributions of the subsamples in z are same is not rejected with probability ($p > 0.08$)) in each case, which suggests that the distributions of the objects in the parameter is continuous for the different subclasses of objects. The cumulative z-distribution curves are shown in Fig.1b.

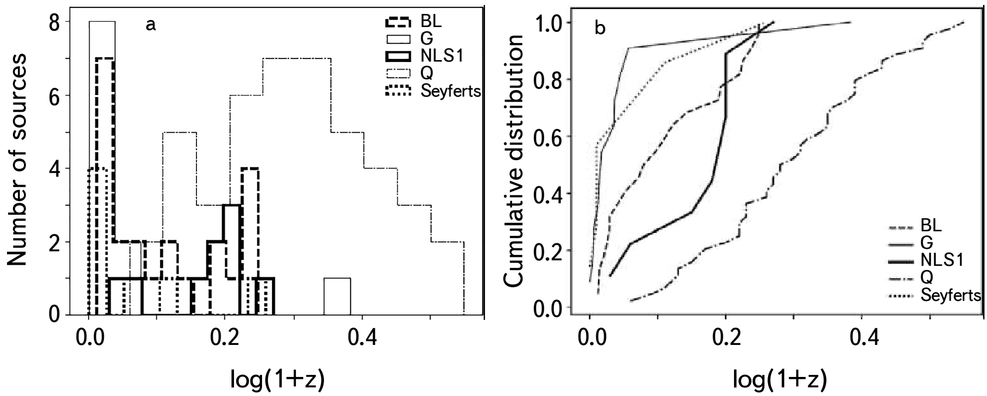

Fig.1. Distributions of the 93 gamma ray objects in redshift.

Similarly, the distribution of logarithmic values of the γ-ray luminosity L_γ of the different subsamples of the jetted AGNs is shown in Fig.2a. Apparently, while Seyferts and radio galaxies are almost indistinguishable, occupying the low L_γ regime, BL Lacs, NLS1 and quasars are displaced to higher L_γ. Nevertheless, the Seyfert galaxies are observed to extend to the lowest L_γ regime below the bounds of radio galaxies in a continuous distribution. The distributions yield mean $\log L_m$ values of 43.82 erg/s for Seyfert galaxies, 43.81 erg/s for radio galaxies, 46.98 erg/s for quasars, 45.69 erg/s for NLS1s, and 45.48 erg/s for BL Lacs. Thus, on average, the L_γ distribution appears to be consistent with a sequence in which quasars > BL Lacs > NLS1 > radio galaxies/Seyfert galaxies. Apparently, the distribution is continuous from Seyfert/radio galaxies at lowest L_γ through NLS1 and BL Lacs to quasars at highest L_γ regime. Similarly, we carried out K-S test on the L_γ data of NLS1 and Seyfert galaxies and at 5% significance, the hypothesis that

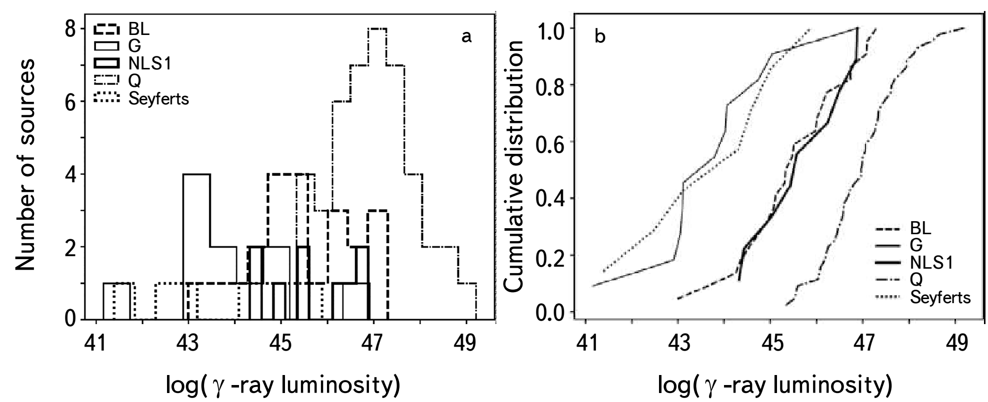

Fig.2. Distributions of the 93 objects in gamma ray luminosity.

the distribution of L_γ is same is rejected with $\rho < 10^{-5}$. On the other hand K-S test on the L_γ data of NLS1 and quasars shows that at 5% significance, the hypothesis that the distribution of L_γ is same is not rejected with $\rho \sim 0.1$. The probability of the K-S test between radio quasars and BL Lacs, as well as between BL Lacs and NLS1 is $\rho \sim 0$ at 5%. The cumulative distribution curves of L_γ are also shown in Fig.2b.

Furthermore, we show the distributions of our sample in γ - ray core dominance parameter (on logarithm values) in Fig.3. The distributions yield mean values R_m of 69.6 for quasars, 31.7 for BL Lacs, 780.4 for NLS1s, 0.1 for radio galaxies and 1.5 for Seyfert galaxies. This nicely compares with mean values obtained for radio core-dominance ~9.8, 4.1, 16.6, 0.5 and 0.98, for quasars, BL Lacs, NLS1, radio galaxies and Seyfert galaxies, respectively, with some scaling factors. A summary of the results of all distributions is shown in Table 1.

To estimate the mean cone angle for observing γ - ray emission of the different subclasses of the jetted AGNs, the choice of R_T plays a key role [46,47]. Although the community consensus appears to favour a unification of BL Lacs and FR I radio galaxies, the discovery of some FSRQs with very low energies [59,60] and BL Lacs with high energies in γ - ray band by the Fermi-LAT [9] appear to break the simple dichotomy between traditional low and high luminosity sources and suggests that BL Lacs and FSRQs are a continuum in distributions of observational properties. R_T should thus be a constant for all classes of the AGN. In fact, several authors [61] have argued that $R_T < 0.1$ is satisfied by most objects. Hence, using $R_T = 0.024$, which appears to be consistent with the general unification of radio loud AGNs across different frequency bands [45,49,61], we estimate the mean cone angles for γ - ray and radio emissions of each subsample using equation (2). A summary of the results is also shown in Table 1.

In line with equation (1), the distribution of the cone angles of different subsamples as shown in Table 1 seems to suggest that the difference between the different subclasses of jetted AGN arises due to varying orientation of their emission axes to the line of sight. Perhaps, orientation effect can be playing a

Table 1

DISTRIBUTION OF CONE ANGLES OF JETTED AGNs

Objects	Number	z	$\log L_\gamma$ erg/s	R_g	R_r	ϕ_g^o	ϕ_r^o
Quasars	44	1.06±0.01	46.98±0.02	69.6± 4.2	9.8±0.6	18.27	27.13
BL Lacs	22	0.31±0.01	45.48±0.05	31.7± 4.2	4.1±0.3	21.87	30.68
NLS1	9	0.47±0.03	45.69±0.09	780.4±13.2	16.6±2.1	12.84	24.50
Galaxies	11	0.18±0.04	43.81±0.13	0.1±0.5	0.5±0.1	59.54	44.77
Seyferts	7	0.18±0.04	43.82±0.08	1.5±3.2	1.0±0.2	36.87	39.65

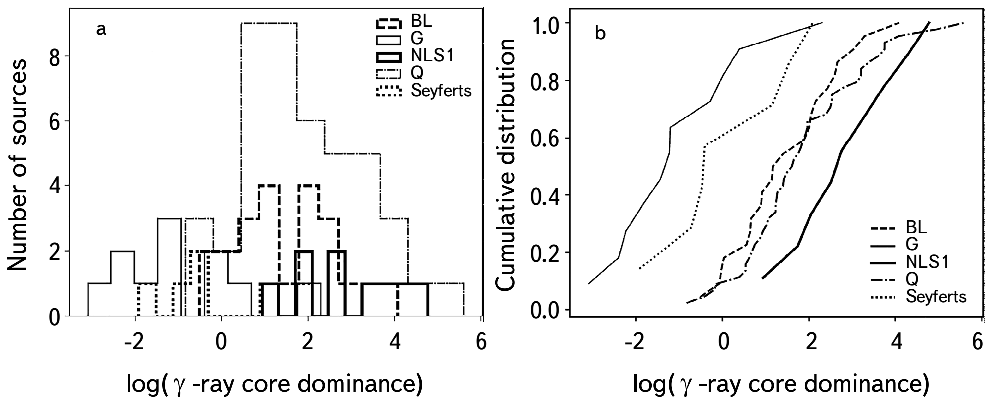

Fig.3. Distribution of gamma ray core-dominance parameter.

significant role in explaining the underlying connection between the subclasses of jetted AGN.

To investigate the evolution of γ - ray luminosity of the different subsamples of the jetted AGNs the scatter plot of $L_\gamma - z$ data is shown in Fig.4. There is a tight correlation ($r > 0.7$) for the entire sample taken together. Radio quasars apparently occupy the highest $L_\gamma - z$ range. Although the NLS1s possess higher luminosities and redshift than the Seyfert galaxies, their position in the plot is such that they form the lower luminosity counterpart of the radio quasars. When the different subclasses are considered separately, the following results were obtained: $\log L_\gamma = 5.01\log(1+z) + 45.47$, with correlation coefficient $r \sim 0.7$, for quasars;

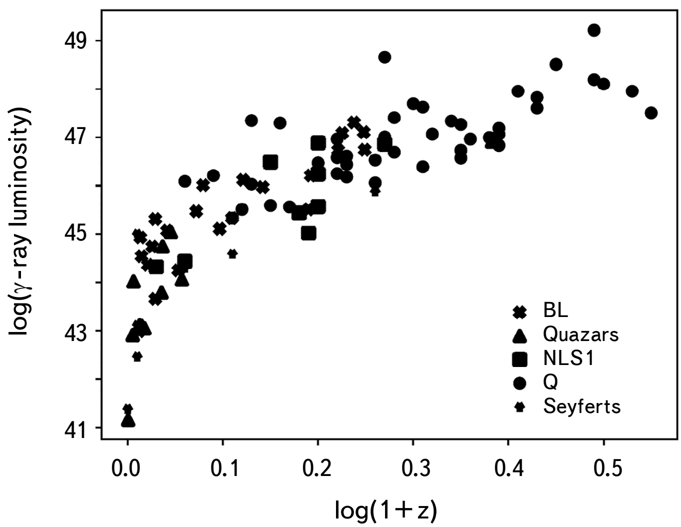

Fig.4. Scatter plot of γ - ray luminosity L_γ against redshift z for the 93 objects.

$\log L_\gamma = 1.18\log(1+z) + 44.87$, with $r \sim 0.9$ for BL Lacs; $\log L_\gamma = 10.37\log(1+z) +$ $+43.23$, with $r \sim 0.8$ for radio galaxies; $\log L_\gamma = 12\log(1+z) + 43.04$, with $r \sim 0.7$ for Seyfert galaxies, and $\log L_\gamma = 10.28\log(1+z) + 44.02$, with $r \sim 0.8$ for NLS1s. These correlations suggest that the samples follow similar evolutionary track from jetted Seyfert galaxies at lowest $L_\gamma - z$ regime, to quasars at highest $L_\gamma - z$ range.

To investigate the effects of relativistic beaming in the sample, the scatter plot of γ - ray core-dominance parameter R against γ - ray luminosity of the different subsamples is shown in Fig.5a. There is a somewhat positive trend in the $L_\gamma - R_g$ relation of the entire sample. Regression analysis of the data yields $\log L_\gamma = -0.42\log R_g + 9.73$ with correlation coefficient $r \sim +0.5$. However, when considered separately, the results are as follows: $\log L_\gamma = -0.23\log R_g + 12.73$ with $r \sim +0.1$ for quasars; $\log L_\gamma = -0.23\log R_g + 12.73$ with $r \sim 0.1$ for BL Lacs; $\log L_\gamma = 0.68\log R_g - 30.92$ with $r \sim +0.1$ for radio galaxies; $\log L_\gamma = 0.36\log R_g - 15.71$ with $r \sim 0.2$ for Seyfert galaxies and $\log L_\gamma = 0.82\log R_g - 34.48$ with $r \sim 0.5$ for NLS1s. It is thus arguable from current analyses that NLS1s are more highly beamed than quasars and BL Lacs.

To investigate the parent population of the highly beamed NLS1s, which appears to be more relevant in recent investigations [43], we re-plotted the $L_\gamma - R_g$ data, excluding quasars and BL Lacs in Fig.5b. The scatter is substantially reduced

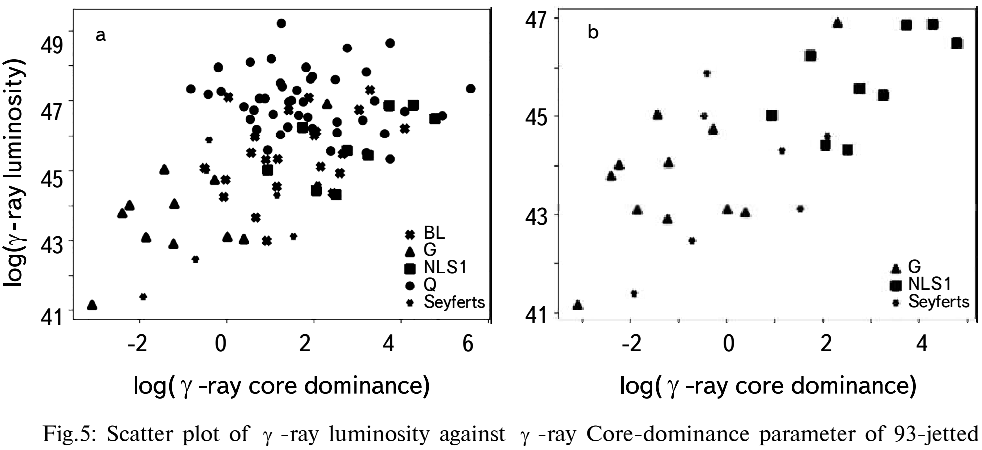

Fig.5: Scatter plot of γ -ray luminosity against γ -ray Core-dominance parameter of 93-jetted AGN.

and there is a clear correlation with correlation coefficient $r \approx +0.7$. Thus, the $L_\gamma - R$ data of current sample suggests that relativistic beaming and orientation effects may be necessary in explaining the underlying connection between NLS1s and jetted Seyferts and/or radio galaxies. We interpret this result to mean that the misaligned parent population of NLS1s could be found among Seyfert galaxies and/or radio galaxies.

5. *Discussion*. Seyfert galaxies present rich and multifaceted astrophysical phenomena where emission and absorption lines provide diagnostics for composition of the surrounding torus. Only a small fraction of Seyfert galaxies are radio-loud and exhibit core-jet radio structures. The detection of GeV gamma-ray emitting radio-loud Seyfert galaxies, with a beamed relativistic jet in Fermi LAT observations in 2008, was remarkable for AGN phenomena [9]. Thus, they could be considered a distinct subclass of AGNs emitting GeV gamma-rays under evolutionary and/or orientation interpretations.

We have shown in our results that the γ-ray luminosity L_γ distribution of the sample is continuous with jetted Seyfert galaxies somewhat occupying the lowest L_γ regime while quasars occupy the highest L_γ regime of the distribution. Since γ-ray emission is strongly believed to originate from the jets, the lower jet power of Seyfert galaxies is suggestive of a very weak accretion mode [26,7], typical of young jetted sources [14]. It is interesting to observe that NLSIs possess much higher luminosity (being up to 2 orders of magnitude more luminous in the γ-ray band) than the other jetted Seyfert galaxies. The result supports the supposition that NLS1s are a distinct subclass of AGN and are the most prominent AGNs in the low-mass class [26]. Perhaps, the high luminosity of NLS1 can be interpreted in terms of strong relativistic beaming effect at small orientation angles to the line of sight [12].

Another important aspect of our results is the high γ-ray core-dominance parameter exhibited by NLS1s in the sample. In fact, it has been argued that the detection of extended radio emissions in γ-ray-emitting NLS1s is of primary importance for understanding the jet activities of the NLS1 class in the framework of the unified scheme of jetted AGN since NLS1s with kpc-scale radio structures exhibit a core with significantly higher luminosity than that of extended emissions [12]. Nevertheless, three of the nine NLS1s, namely: PMN J0948+0022, FBQS J1644+2619 and 1H 0323+342 are known to exhibit two-sided radio structures at kpc scales with high radio-core dominance parameter [12] comparable to those of radio quasars. The popular physical explanation to the origin of the high core dominance is relativistic Doppler boosting of the cores [49] and this suggests that relativistic beaming is playing a significant role in NLS1s. It can thus be argued that the low jet luminosity of Seyfert and radio galaxies could have arisen due to their larger cone angles to the line of sight, leading to de-beamed jet luminosity Perhaps, the γ-ray emitting NLS1s are analogous to early (low z) quasars whose parent populations could be found among regular Seyfert or radio galaxy populations.

Actually, it can be argued from the distributions of the average cone angles derived from current analysis that when the young object is observed along its relativistic jet, it appears as NLS1, but as the inclination angle increases, the same object would appear as a Seyfert galaxy or a radio galaxy. The distributions of average cone angles for the different subclasses of AGNs apparently show that in the context of the revised unification scheme, NLS1s are observed at significantly higher inclinations than Seyferts and radio galaxies. Perhaps, the very narrow beam angle for observation of γ - ray emission from NLS1s could account for the yet small number of γ - ray emitting NLS1s so far detected by the Fermi-LAT [58]. On the other hand, the distributions of average viewing angles do not apparently show that Seyfert galaxies are observed at significantly different inclinations from radio galaxies. Thus, current results suggest that orientation effect may not be the major difference between Seyferts and radio galaxies and that relativistic beaming is less important in these objects.

It is obvious from the distribution of the objects in z that there is no tendency for jetted Seyfert galaxies to be located at high redshifts, which is consistent with the supposition that jetted Seyfert galaxies are nearby low-luminosity versions of the same phenomenon observed in quasars. The low L_{γ} - low z result for Seyfert galaxies can be interpreted to mean that jetted Seyferts are young growing sources [62]. If this is actually the case, then the evolutionary connection between jetted Seyferts and quasars is suggested in which the γ - ray source starts out at lowest redshifts as Seyfert galaxy and evolves into a quasar as the source ages [15,42].

6. *Conclusion*. We have investigated the relationship between jetted Seyfert galaxies and other subclasses of radio loud AGNs using observed γ - ray properties of a sample of jetted AGN. We showed from the distributions of γ - ray luminosity that jetted Seyfert galaxies form the low luminosity tail of traditionally radio loud AGN which is consistent with the scenario that jetted Seyfert galaxies are young growing objects. Furthermore, distributions of the objects on luminosity-redshift (L- z) plane shows that different subclasses of jetted AGN possess similar evolutionary histories. In particular Seyfert galaxies and radio galaxies are located in similar environments. NLS1 sources are, however, more evolved sources compared to Seyfert galaxies. There is a significant $L_{\gamma} - R$ correlation ($r \sim 0.7$) in NLS1 objects, which has been interpreted in terms of a connection via relativistic beaming and orientation. In all subclasses of jetted AGN, the beam angle for radio on average, is wider than that of γ - ray emission, All these results suggest that in addition to evolutionary link between jetted Seyfert galaxies and other radio loud AGNs, relativistic beaming and orientation effects can also be playing a significant role.

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ОБ УНИФИЦИРОВАННОЙ СХЕМЕ γ-ИЗЛУЧАЮЩИХ АКТИВНЫХ ЯДЕР ГАЛАКТИК СО СТРУЯМИ

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Открытие сейфертовских галактик с гамма-излучением позволило представить новую унифицированную схему активных ядер галактик (АЯГ), в которой сейфертовские галактики со струями (джеты) рассматриваются как молодые аналоги радиогромких АЯГ. В этой статье исследована взаимосвязь между свойствами гамма-излучения сейфертовских галактик со струями и свойствами радиогалактик, радиоквазаров и лацертидов. Результаты показывают, что на диаграмме светимость - красное смещение ($L_\gamma - z$), сейфертовские галактики со струями выглядят как хвост низкой светимости радиогромких активных ядер, что указывает на эволюционную связь между ними. Однако сейфертовские галактики с узкими линиями (NLS1) не имеют схожих характеристик с сейфертовскими галактиками, поскольку они обладают большей светимостью и красным смещением, чем сейфертовские галактики, что позволяет предположить, что NLS1 являются более развитыми источниками. Анализ параметров доминирования ядер (γ-излучения и радиоизлучения) показывает, что для каждого подкласса AGN со струями угол излучения шире для радиоизлучения, чем для γ-излучения. В то время как сейфертовские галактики и радиогалактики в среднем имеют одинаковое малое наклонение к лучу зрения, объекты NLS1 имеют ориентацию, аналогичную квазарам и BL Lacs. Существует значимая корреляция ($r \sim 0.7$) между параметром доминирования ядра γ-излучения и светимостью γ-излучения. Результаты согласуются с пересмотренной унифицированной схемой и предполагают, что NLS1 представляют собой сильные лучевые источники, чьи родительские популяции можно найти среди обычных сейфертовских галактик и/или радиогалактик.

Ключевые слова: *галактики: активные галактики: сейферты: джеты: гамма излучение*

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