АСТРОФИЗИКА

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ON THE EXTENDED BLAZAR SEQUENCE FOR γ-RAY EMITTING ACTIVE GALACTIC NUCLEI

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In this paper, we use the distributions of observed γ-ray properties, as well as orientation parameters of a sample of Fermi-LAT AGNs to investigate the hypothesis that γ-NLS1 objects are beamed sources with γ-ray emitting axes inclined at close angles to the line of sight. Based on these parameters we investigate the relationship between γ-NLS1s and other subclasses of γ-ray emitting jetted AGNs. Results show that γ-NLS1s are more highly beamed than both FSRQs and BL Lacs with mean value of core-dominance parameter $R_g \sim 9507$. γ-NLS1s and jetted Seyfert galaxies are continuous in distribution of the orientation parameter with average cone angles $\Phi_m \sim 8^{\circ}$ and 44° respectively. Furthermore, the spectral energy distribution of γ-NLS1 is comparable to those of FSRQs and BL Lacs suggestive that γ-NLS1s and blazars form a continuous spectral sequence. There is a significant anti-correlation ($r \sim -0.9$) between the γ-ray dominance D_g and γ-ray luminosity. There is a strong dependence of D_g on redshift ($r \sim -0.7$) suggestive that D_g is more sensitive to environmental factors than intrinsic γ-ray luminosity. The results suggest that γ-NLS1s are highly beamed γ-ray sources whose de-beamed counterparts can be found among Seyfert galaxy populations.

Keywords: *galaxies: active galaxies: Seyferts: jets*

1. *Introduction*. Seyfert galaxies are traditionally classified as radio-quiet class of active galactic nuclei (AGNs), with radio-loudness parameter defined in terms of the ratio of 5 GHz radio to optical blue-band flux densities, $f_{5GHz}/f_{b-band} < 10$ [1]. Based on the width of nuclear emission lines, two broad categories of Seyfert galaxies are distinguished, namely, Seyfert 1 and Seyfert 2. While Seyfert 1 galaxies have a set of broad emission lines, Seyfert 2 galaxies have narrow emission lines. However, a minority class of radio-loud Seyfert 1 galaxies with narrow emission lines, which have been detected in recent observations [2] pointed to a considerable overlap in spectral properties of the two classes of Seyfert galaxies [3]. In general, without ruling out the possibility of relativistic jets in radio-quiet sources [4], radio-loud Seyfert galaxies are believed to harbor powerful relativistic jets, with extended radio structures [5-8].

The discovery of powerful γ-ray emitting narrow-line Seyfert 1 (NLS1) galaxies [9,2,10] has provided substantial evidence that jets are not formed by massive black hole AGNs alone [11], as there are evidence of relativistic jets in low-mass and low jet-power AGNs [9,12]. The lack of small-mass jetted AGN in the traditional radio-loud/radio-quiet dichotomy has been attributed to bright-source selection bias [13]. Interestingly, [14] identified low-mass sources among Flat Spectrum Radio Quasar (FSRQ) population and argued that NLS1 galaxies are the most prominent AGNs in the low-mass class using $\mathrm{FWHM}(\mathrm{H}\beta) < 2000\ \mathrm{km\ s^{-1}}$, and the ratio between $[\mathrm{OIII}]/\mathrm{H}\beta < 3$, which along with high Eddington ratio, appears to fit the characteristics of NLS1s [15,16]. These results have been explained as consequences of the presence of a relatively low-mass black hole (10^6 - 10^8 M) and fast accretion, suggestive of young age of these objects [17].

There are several arguments in literatures about the true nature of/or the parent sources of NLS1s. Several characteristics have been adduced by authors to connect NLS1 with Compact Steep Spectrum (CSS) sources, such as signs of young age in terms of development of radio-lobes of not more than 10^5 years [17], small linear size and very fast flux variability [18]. Therefore, even though the true nature of these NLS1s is still an ongoing debate in literatures, several results suggest that they might represent young radio sources that are still growing and evolving [17,19], and might be extreme objects on the evolutionary path from radio-quiet Seyfert galaxies to radio-loud quasars [20] and as such, may be low-mass analogues of high-redshift quasars [3,15,21-23]. Furthermore, similarities between the nuclei of jetted Seyfert galaxies and radio-loud AGNs have often been pointed out [24-26] 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 [22,27-30]. In this regard, several authors [30,22] argued that in general, jetted Seyfert galaxies, BL Lac objects and radio galaxies could share similar characteristics in terms of jet luminosity-redshift ($P-z$) relation, suggestive of similar underlying environment.

Similarities in the distributions of black hole mass and High Eddington ratio of source samples [31] appear to connect the misaligned Steep-spectrum NLS1s to their beamed flat-spectrum NLS1s counterparts. However, discrepancies in mass distribution reveal [15] that disk-hosted radio galaxies could form a link connecting low-mass, high-accretion NLSIs and high-mass, low-accretion BL Lac-like elliptical radio galaxies. In fact, it has been argued [15] that some of these "bridge objects" might simply be genuine type 1 or 2 Seyfert galaxies with their jets oriented at large inclination angles. These different manifestations of NLS1s have been attributed to orientation effects [32,15], suggestive that when the beamed jet is observed at different angles to the line of sight, it could appear as a regular Seyfert galaxy of type 1 or 2 depending on obscuration. In fact, several authors [32,15] posited that at different larger observing angles, Doppler broadening of the permitted lines can cause the NLS1 to be classified as broad- or narrow-line radio galaxies depending on the level of obscuration of the nuclear region. In these contexts, therefore, a young jetted AGNs with a strong accretion disk and photon rich environment that is observed along its relativistic jet might appears as NLS1, and when the nuclear region is obscured, the object might also appear as a type-2 AGN in optical band, and as a CSS in radio band [15,8]. The scheme appears to fit nicely with the usual unified model for older jetted-AGNs, in which high-excitation radio galaxies (HERGs) form the parent population of FSRQs [33].

NLS1s are a recently discovered class of γ -ray emitting AGN, that exhibit some blazar-like properties, namely: flat-spectrum radio spectra, superluminal motion and strong radiation with fast variability [34], which are explained with the presence of a relativistic jet viewed at small angles. Several authors strongly posited that the different blazar subclasses are just a different manifestation of the same physical process that differ only in bolometric luminosity [35,36], which led to the popular blazar sequence - a scheme that is recently argued to extend to all jetted AGNs [37]. The two known subclasses of blazars, namely BL Lacs and FSRQs, are believed to be the beamed counterparts of high- and low-luminosity radio galaxies, respectively with their jets inclined at close angles to the line of sight [34]. When blazars are observed at larger angles, they appear as radio-galaxies, and we expect to observe an analogue parent population for beamed γ -ray emitting NLS1s (γ -NLS1s). Thus, following our earlier work [38], in this paper we examine the observed gamma ray properties of a sample of blazars and γ -NLS1s in order to study the relationship between these subclasses of γ -ray emitting AGNs.

2. *Theoretical framework*. Orientation based unified scheme (OUS) for active galactic nuclei is often studied at any frequency band ν using an important orientation parameters, namely, the core-to-extended luminosity ratio R_ν expressed as a function of the viewing angle ϕ in the form [39,40]:

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

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 [41,42].

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 [43]:

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

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_γ is assumed to be isotropic [44]. Thus, following [56], 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 [45]:

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

In previous papers [41,42] these effects were studied for various samples in the radio band. In this paper, we extend the investigation to the γ-ray band, including NLS1s whose place in the revised unification scheme is gaining attention of authors.

However, with current extension of blazar sequence, to include other jetted AGNs [37], it has become increasingly important to study the position of γ-NLS1s in the extended scheme. Nevertheless, an important aspect of the blazar sequence that has gained attention [46,47], is the relationship between low-energy and high-energy components of the spectral energy distribution (SED). In fact, [35] introduced a broad-band parameter, namely, γ-ray dominance D_g, defined as the ratio of γ-ray luminosity L_g to the peak radio luminosity L_R ($D_g = L_g/L_R$), which the authors used to study blazar sequence for the energetic γ-ray experiment telescope (EGRET) blazars. Actually, D_g is expected to show a sequence of decrease from low-synchrotron luminosity end to high-synchrotron luminosity end of the sequence [48]. This sequence obviously suggests that the SED of FSRQs would be less dominated by γ-ray emission than the BL Lacs. However, this parameter seems to have been somewhat overlooked in earlier studies, partly due to insufficient γ-ray data for a large number of blazars known at that time.

3. *Description of source sample*. The current analysis is based on a recent compilation of γ-ray emitting AGNs taken from the 4th Fermi-LAT AGN catalogue. From the 4th Fermi-LAT AGN catalogue, [49] has made a new sample of 1559 bona-fide γ-ray emitting jetted AGN, which include 12 γ-NLS1s. These objects were cross-correlated with the compilation by [50], where relevant derived radio data of a large number of objects in the catalogue are readily available. Furthermore, [51] also derived the γ-ray core dominance parameters R_g of a large number of blazars in the catalogue, which the authors used to argue for relativistic beaming of γ-ray emission in blazars. Three of the 12 γ-NLS1 do not overlap with these earlier compilations by [50,51] and hence, do not have complete data and were excluded in current investigation. Altogether, there are 697 γ-ray emitting jetted AGN with complete relevant data for our investigation, namely 238 BL Lacs, 18 FRI radio galaxies, 34 FRII radio galaxies, 270 FSRQs, 9 γ-NLS1s and 128 other Seyfert galaxies. This represents ~45% of the bona-fide γ-ray emitting jetted AGN and 76% of γ-NLS1s from the 4th Fermi-LAT catalogue. Although the FRIs, FRIIs, γ-NLS1s and other Seyfert galaxies in the sample are strong γ-ray emitters detected by the Fermi-LAT, their γ-ray core dominance parameters were yet to be comprehensively determined. Thus, we derive their γ-ray core dominance parameter based on empirical relations between R_g and radio core-dominance parameter R_R for γ-ray loud sources given by [51]. However, the regression constants derived by the authors are slightly different for BL Lacs and FSRQs in their data. Thus, for calculation of R_g in this paper, we use the average values of the constants for the two sub-classes and the relation yields:

$$\log R_g = 2.07 \log R_R + 1.32. \tag{6}$$

For investigation of extended blazar sequence in the sample, we calculated the γ-ray dominance D_g for all objects in our sample. Throughout the paper, we have adopted the cosmology with $H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ 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. *Analyses and results*. We show the distribution of FSRQs, BL Lacs and γ-NLS1s sub-sample in γ-ray dominance D_g in Fig.1. Obviously, the three subsamples are almost indistinguishable in the plot as they occupy the same range of D_g values. However, the distribution gives a mean value of 3.25 ± 0.43, on logarithmic scale, for the sub-samples taken together. This is consistent with γ-ray emission of blazars and γ-NLS1s being several orders of magnitude more prominent than radio emission [52,53,47], which shows that blazars and γ-NLS1s are strong γ-ray emitters. We interpret this result to mean that similar physical processes lead to variations in γ-ray dominance of blazars and γ-NLS1s.

However, the mean values for individual sub-samples on logarithmic scales are 3.1 ± 0.8, 2.7 ± 0.5 and 2.7 ± 0.2, respectively for BL Lacs, FSRQs and γ-NLS1s. Simple K-S test carried out on the data shows that at 5% significance, the underlying distributions of D_g for FSRQ and γ-NLS1 subclasses are same; the hypothesis that the distributions are same is not rejected, with $\rho \sim 0.1$. The cumulative distributions of D_g for the different subclasses are also shown in Fig.1b. Apparently, the SED parameter of γ-NLS1s is quite similar to that of FSRQs. Nevertheless, the cumulative distribution of BL Lac is different from those of FSRQ and γ-NLS1s: the SED of BL Lacs appears to be more γ-ray dominant than FSRQs and γ-NLS1s. Simple K-S test carried out on the data shows that at 5% significance, the underlying distributions of D_g for BL Lacs and other subclasses are significantly different; the hypothesis that the distributions are same is rejected, with $\rho < 10^{-5}$ in each case. The results suggest that although FSRQs are more luminous than BL Lacs and γ-NLS1s, the γ-ray luminosity may not be the leading driver of γ-ray dominance, suggestive that γ-ray dominance may be more sensitive to synchrotron activities in the jets [48]. Fig.1 shows an interesting feature that can be considered relevant for extended blazar sequence: there is similarity in distributions of γ-ray dominance of blazars and γ-NLS1s which supports the proposition that blazar sequence scheme can be extended to γ-NLS1s.

We show the scatter plot of γ-ray dominance D_g as a function of γ-ray luminosity L_g for blazars and γ-NLS1s in Fig.2. There is a clear trend in which D_g decreases with increasing luminosity. Regression analysis on the data yields $\log D_g = (0.42 \pm 0.02)\log L_g + (15.38 \pm 0.04)$, with a correlation coefficient $r = 0.98$ and chance probability $\rho \sim 10^{-9}$. The tight anti-correlation can be interpreted to mean that γ-ray dominance may be more sensitive to synchrotron activities in the jets than γ-ray emission, Apparently, a vast majority of FSRQs occupy high

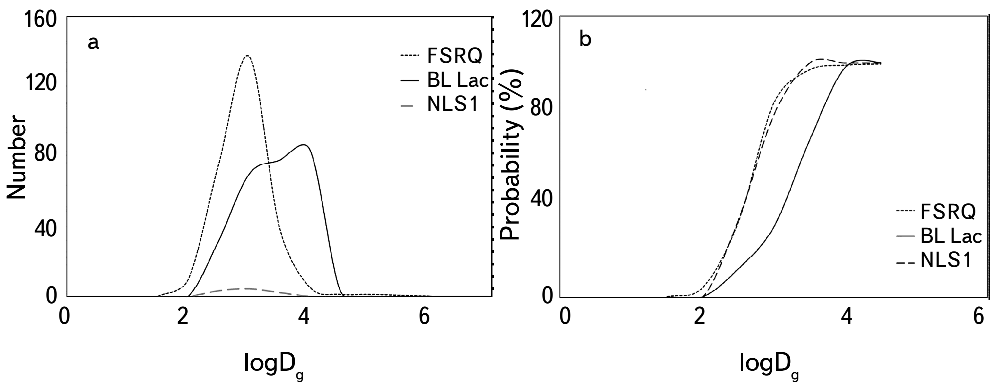


Fig.1. Distribution of blazars and NLS1s in γ-ray Dominance D_g.

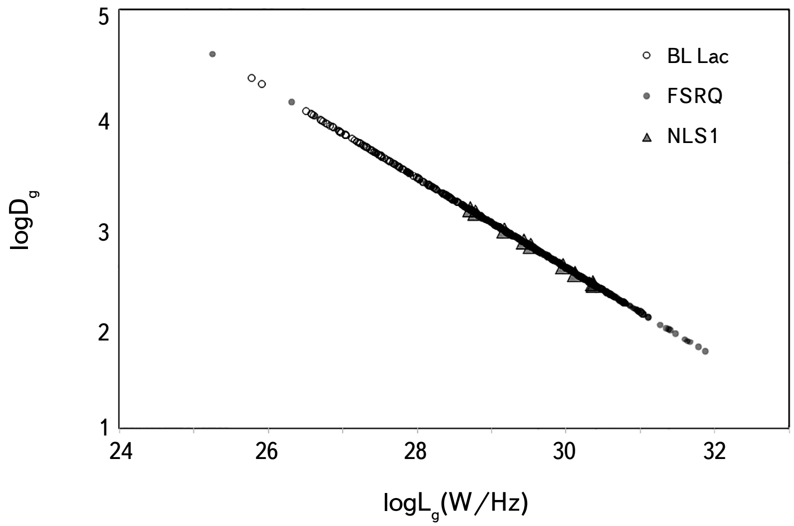
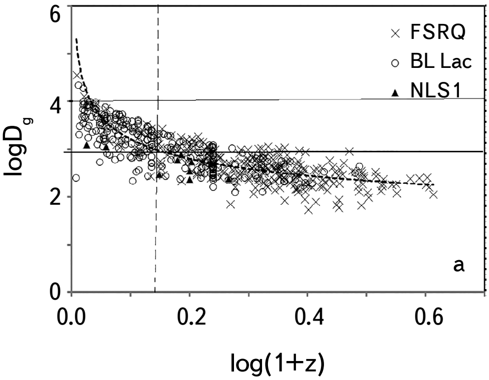


Fig.2. Scatter plot of D_g against γ -ray luminosity for blazars and NLS1s.

L_g - low D_g end of the distribution, with BL Lacs stretching over a wider range to high D_g - low L_g end, NLS1s appear to form a bridge-connector between BL Lacs and majority of the FSRQs. The distribution of the objects on D_g - L_g plane shows that there is a sequence of the SED from FSRQs to BL Lacs through NLS1s. Nevertheless, the presence of few extreme FSRQs with BL Lac-like SED appears to break the sequence.

To investigate the effect of evolution and environment on the parameters, we show the scatter plots of D_g and L_g against redshift z in Fig.3. Analysis of the data in Fig.3a shows that $D_g - z$ scatter best fits into a power-law function given by: $D_g \approx 2.0(1+z)^{-0.2}$, with a correlation coefficient $r\sim$ -0.8. The strong dependence of D_g on z suggests that environmental effect is playing a significant role in the variation of D_g in the sample. Nevertheless, it could be observed in Fig.3a that D_g decreases steeply with redshift at low redshift ($z \le 0.1$) corresponding to $D_g = 4.0$ and remains fairly constant at high redshift ($z \ge 0.3$), shown with a broken vertical line, corresponding to $D_g = 3.0$. Apparently, the figure reveals a transition region in the range: $0.1 \le z \le 0.3$. On the other hand, the $L_g - z$ scatter in Fig.3b yields a strong positive correlation with $r\sim$ 0.7, which can naturally be attributed to luminosity selection effect in the sample. Fig.3b is more or less a mirror image of Fig.3a and strongly suggests that intrinsic γ -ray luminosity is not the major determinant of D_g. It is obvious from Fig.3 that NLS1s form part of the continuous distribution from FSRQs to BL Lacs in both parameters, suggesting that NLS1s can be accommodated in the blazar sequence.

Since the community consensus appears to favour FR I/BL Lac and FR II/



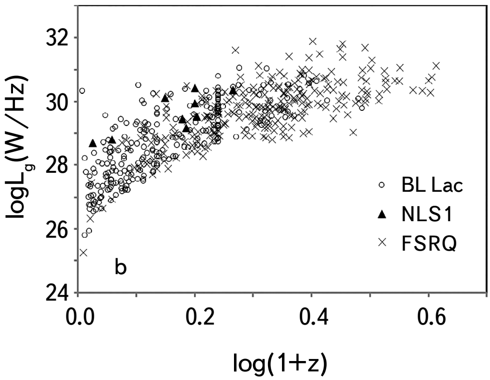


Fig.3. Variation of (a) γ -ray dominance (b) γ -ray luminosity with redshift.

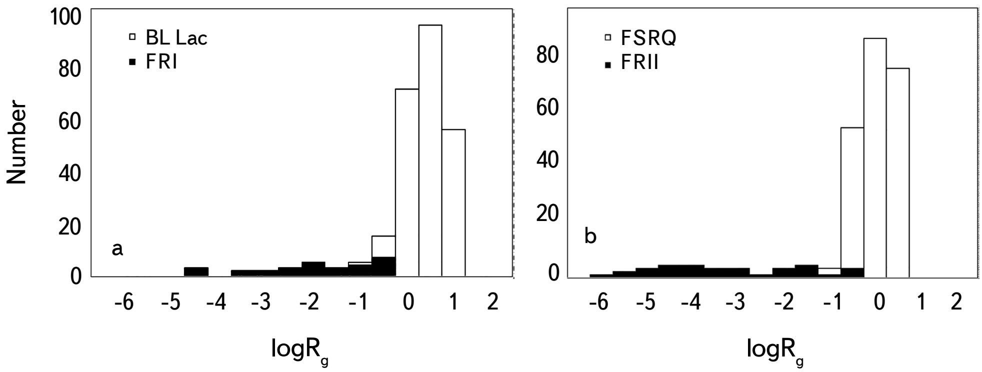
FSRQ unification, we compare the γ -ray core-dominance parameter R_g of NLS1s and Seyfert galaxies to find a possible connection between then via orientation. We show the distributions of R_g of different sub-groups in Fig.4, using Seyferts galaxies as the parent objects of NLS1s. Apparently, while the distributions are consistent with a scheme in which FSRQs and BL Lacs are more core-dominated than FR IIs and FR Is respectively, the scenario is somewhat different for NLS1s and Seyfert galaxies. In fact, NLS1s and Seyfert galaxies occupy the same range of R_g. Nevertheless, the distributions yield mean values R_m of 2.5 ± 0.9 and 0.7 ± 0.2, for BL Lacs and FR Is, respectively, $R_m \sim 3.5 \pm 1.0$ and 0.4 ± 0.3, for FSRQs and FR IIs, respectively, while $R_m \sim 9507.4 \pm 13.2$ for NLS1s and 1.4 ± 0.2, for Seyfert galaxies. For each group of sources, there is a clear continuity in distribution of the parameter. In general NLS1s are more core-dominated than FSRQs and BL Lacs. Two samples K-S test carried out on each distribution shows that at 5% significance, the null hypothesis that the fundamental distributions of each two categories of objects are same is not rejected, with $\rho > 0.05$ in each case.

To derive the mean cone angle for observing γ -ray emission in different

Table 1

DISTRIBUTIONS OF DERIVED γ -RAY PARAMETERS OF CURRENT SAMPLE OF γ -RAY AGN

Objects	Number	Z	D_g	L_g (W/Hz)	R_g	$\phi_g{}^{o}$
BL Lacs	238	0.46±0.18	3.1±0.8	28.69±1.77	2.5±0.9	33.7±1.6
FRI	18	0.44±0.14	3.7±0.4	27.25±1.82	0.7±0.2	63.6±2.1
FRII	34	0.82±0.17	3.4±0.9	27.88±2.27	0.4±0.3	72.9±4.1
FSRQS	270	1.13±0.42	2.7±0.5	29.71±2.11	3.2±0.8	22.3±1.4
Seyferts	128	0.15±0.08	4.1±0.7	26.43±1.95	1.4±0.2	44.2±23
γ -NLS1s	9	0.47±0.21	2.7±0.2	28.69±2.23	9507.4±13.2	8.1±0.6



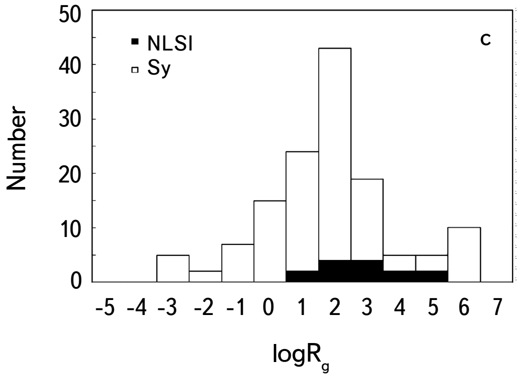


Fig.4. Distributions of the subsamples in R_g: (a) BL Lacs and FR I, (b) FSRQs and FR II (c) NLS1s and Seyferts.

subclasses of the AGNs, the choice of R_T plays a key role [41,42]. In fact, several authors [54] have argued that $R_T < 0.1$ is satisfied by most AGN samples. Hence, using $R_T = 0.024$, which appears to be consistent with the general unification of radio loud AGNs across different frequency bands [44,54,40], we estimated 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.

5. *Discussion*. Narrow line Seyfert 1 objects (NLS1s) are a new class of γ-ray emitting AGN, with blazar-like properties, which are explained with the presence of a relativistic jet viewed at small angles to the line of sight [20]. The two classes of blazars, namely, FSRQs and BL Lac objects have been remarkably unified with their de-beamed parent populations of FR II and FR I radio galaxies [41,42]. It therefore becomes important to search for de-beamed parent population of the γ-NLS1s, whose position in the revised unification scheme has gained the attention of authors [49].

Our results have shown that there is a close connection between γ-ray spectral energy distribution (SED) of FSRQs, γ-NLS1s and BL Lac objects, which can be understood in the framework of blazar sequence. The blazar sequence posits that subclasses of blazars are different manifestations of the same physical process that differ only by bolometric luminosity [35,36]. The simple implication of this is that there should be continuity in spectral energy distribution of different subclasses of blazars. Distribution of the objects in γ -ray dominance is apparently in agreement with the scheme and suggests that similar physical mechanisms give rise to the observed SEDs of γ -NLS1s, BL Lacs and FSRQs. The result is quite consistent with recent results obtained from different source catalogues of γ -ray emitting AGNs [55] in which γ -NLS1s share similar physical properties with blazars once normalized for black hole mass.

However, the distribution of the objects in γ -ray dominance does not evidently show that FSRQs are more γ -ray dominant than BL Lacs and γ -NLS1s. It is an indication that more efficient γ -ray emitters are not the more γ -ray dominant sources [48]. However, in Fig.1b, there appears to be a general trend in variation of γ -ray dominance from FSRQs to BL Lacs, through γ -NLS1s.

We have also shown in the results that there is a tight correlation ($r > 0.9$) between D_g and L_g for blazars and γ -NLS1s. Typical SED of blazars from which the blazar sequence scheme was proposed shows that the luminosity at synchrotron peak (usually in the radio band) is systematically displaced from low frequency at high luminosity end to high frequency at low luminosity end [35,36,56], which suggests an anti-correlation between spectral luminosity and frequency peak. The tight anti-correlation between D_g and L_g in this paper not only suggests that current data is consistent with a blazar sequence, but that γ -NLS1s can also be accommodated in the sequence. Nevertheless, [57,58] argued that although the distributions of spectral properties of γ -NLS1s and blazars support the supposition of an extended blazar sequence, the physical mechanism responsible for spectral curvatures of γ -NLS1s is quite different from those of other subclasses of blazars. Actually, [50] argued that in the radio band, spectral indices are fundamentally different for different subclasses of blazars.

Another important result of present analysis is the tight dependence of γ -ray dominance on redshift. We have shown that there is a significant anti-correlation between D_g and redshift z ($r > 0.7$). Hence, it can be argued that at constant beam power, low redshift sources would have higher γ -ray dominance as γ -ray emission from such sources may suffer less scattering in the intergalactic medium. Actually, [59] obtained a similar result using composite spectral indices as SED parameter, which the authors used to argue for an evolutionary link between Seyfert galaxies and blazars. Perhaps the low D_g observed among FSRQs could have arisen from their location at high redshift, suggestive that the variation in D_g among different subclasses of AGN may be environmental rather than intrinsic effect. This supports an earlier finding that the jets in FSRQs are embedded in complex external physical environment, which may lead to their complex physical properties [60]. For BL Lacs, the high D_g is as expected since they are mostly located at low redshift. We have shown in Table 1 that distribution of the sample in redshift yields mean values of 1.13 ± 0.42, 0.46 ± 0.18 and 0.47 ± 0.21 respectively for FSRQs, BL Lacs and NLSIs. Thus, while NLS1s and BL Lacs are similar in redshift distribution, FSRQ seem to be more distant. This has a heavy consequence on the completeness of the samples. Nevertheless, it can be observed from Fig.3 that only 2 NLSIs are located at low ($z < 0.3$) redshift, representing ~16% of the NLSI population in the 4th Fermi-LAT catalogue. Thus, a vast majority of NLSIs (~84%) reside in similar environment with FSRQs.

It is evident from the distributions of the objects in Fig.3b that some FSRQs are located at extremely low redshift. Actually, these anomalous FSRQs were observed to possess high D_g. Perhaps the low D_g of γ-NLS1s compared to FSRQs arises from the supposition that γ-NLS1s possess intrinsically lower γ-ray luminosities than FSRQs. If this is actually the case, then the result is in good agreement with an earlier supposition that γ-NLS1s are low luminosity/low redshift analogues of FSRQs [20].

It is arguable that the tight D_g - L_g anti-correlation may have arisen from the strong redshift effects on the parameters. Thus we subtracted out the common dependence of D_g and L_g on redshift from the D_g - L_g anti-correlation using Spearman's partial correlation statistic given [48] by:

$$r_{DL,z} = \frac{r_{DL} - r_{Dz} r_{Lz}}{\left[\left(1 - r_{Dz}^2\right)\left(1 - r_{Lz}^2\right)\right]^{1/2}}. \tag{7}$$

The result yields $r_{DL,z} \approx 0.96$ as the D_g - L_g correlation coefficient independent of redshift. Hence, there is an intrinsic D_g - L_g anti-correlation, which is quite consistent with a prediction of the blazar sequence.

Distribution of γ-ray core dominance parameter reveals high γ-ray core-dominance exhibited by γ-NLS1s in the sample. In fact, it has been argued that the detection of extended radio emissions in γ-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 [6]. Nevertheless, three of the nine γ-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 [6] 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 [44] and this suggests that relativistic beaming is playing a significant role in γ-NLS1s. In a similar way, we tested for the effect of redshift on R_g. The results as shown in Table 2 show that the dependence of R_g on redshift is not significant with $r \le 0.2$ in each case.

It is obvious from Table 1 that on average, γ-NLS1s are viewed at closer

Table 2

CORRELATIONS AMONG PARAMETERS OF γ-RAY EMITTING AGNs

Objects	Parameters				
	D_g - L_g	L_g - z	R_g - z	D_g - R_g	D_g - z
All objects	0.9	0.6	-0.1	-0.2	-0.7
BL Lacs	07	0.8	-0.2	0.1	-0.8
FSRQs	0.7	0.7	0.1	-0.1	-0.7
γ-NLS1s	0.8	0.8	0.2	-0.6	-0.8

inclination than jetted Seyfert galaxies, which is somewhat consistent with an orientation scenario between the two subclasses of jetted AGN [38]. This observation appears to suggest that the parent population of beamed γ-NLS1s can be found among Seyfert galaxies [31]. The scenario fits nicely with FSRQ/FR II and BL Lac/FR I orientation-based unified schemes. Although orientation scenario provides a natural explanation for the more extreme R_g properties of γ-NLS1s than Seyfert galaxies, the fact that at sharper inclination, γ-NLS1s possess lower black hole mass than Seyfert galaxies, as reported by several authors [57,58,61] does not support the proposition that Seyfert galaxies form the de-beamed parent population of γ-NLS1s. Actually, our result (c.f. Fig.4) shows that γ-NLS1s occupy similar range of R_g as Seyfert galaxies suggestive that the fundamental difference between the two subclasses of objects may not be orientation. Perhaps, the inconsistency observed with the distributions of R_g for the two groups of objects may have arisen from small number statistics of the γ-NLS1s.

6. *Conclusion*. We have investigated the relationship between γ-NLS1s and other subclasses of γ-ray emitting AGNs using observed γ-ray properties of a sample. We showed from the distributions of γ-ray dominance that the spectral energy distribution of γ-NLS1s is comparable to those of BL Lacs and FSRQs in a manner that is consistent with blazar sequence. Distribution of γ-ray dominance indicates that the parameter is redshift dependent, which we have interpreted to mean that variations in γ-ray dominance is more sensitive to environmental effects rather than intrinsic γ-ray luminosity. In the γ-ray band, γ-NLS1s are strongly beamed with average cone angle of 8° compared to Seyfert galaxies that have average cone angle of 44°. All these results suggest that γ-NLS1s form a peculiar class of highly beamed γ-ray sources with some form of orientation connection with Seyfert galaxies. Nevertheless, the sample size is small and larger samples of γ-NLSIs would be required to confirm the results.

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О РАСШИРЕННОЙ ПОСЛЕДОВАТЕЛЬНОСТИ БЛАЗАРОВ ДЛЯ АКТИВНЫХ ГАЛАКТИК С ГАММА-ИЗЛУЧЕНИЕМ

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В данной работе используется распределение наблюдаемых свойств γ-излучения, а также параметры ориентации для выборки AGN, зарегистрированных с помощью Fermi-LAT, чтобы исследовать гипотезу о том, что объекты γ-NLS1 являются источниками излучения, направленными с осями γ-излучения, наклоненными под малым углом к лучу зрения. Основываясь на этих параметрах, исследована взаимосвязь между γ-NLS1 и другими подтипами активных галактик с релятивистскими джетами, испускающих γ-излучение. Результаты показывают, что γ-NLS1 более сфокусированы, чем FSRQ и BL Lac с средним значением параметра доминирования ядра $R_g \sim$ 9507. γ-NLS1 и сейфертовские галактики с джетами образуют непрерывное распределение по параметру ориентации, со средними углами конусов $\Phi_m \sim$ 8° и 44°, соответственно. Кроме того, спектральное распределение энергии γ-NLS1 сопоставимо с распределением для FSRQ и BL Lac, что указывает на то, что γ-NLS1 и блазары образуют непрерывную спектральную последовательность. Наблюдается значительная антикорреляция ($r \sim -0.9$) между доминированием γ-излучения D_g и гамма-лучевой светимостью. Также обнаружена сильная зависимость D_g от красного смещения ($r \sim -0.7$), что указывает на большую чувствительность D_g к факторам окружающей среды, чем к собственной светимости γ-излучения. Результаты предполагают, что γ-NLS1 являются сильно сфокусированными источниками γ-излучения, де-фокусированные аналоги которых можно найти среди популяций сейфертовских галактик.

Ключевые слова: *галактики: активные галактики: сейфертовские галактики: джеты*

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