Giants towards the Edge of the Universe: Mpc-scale radio galaxies at low and high redshift

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Back at the Edge of the Universe:
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ABSTRACT **Giant radio galaxies (GRGs), with a radio extent larger than 1 Mpc/h_{75}, are rare. Our research has recently increased their number to about 500.**

For 193 GRGs with SDSS spectra, we determined their activity types, measured their largest linear radio sizes, and classified their radio morphology into Fanaroff-Riley types. In order to better understand why the GRGs develop such large structures, we compare these characteristics between low-redshift (z<0.4) GRGs and high-redshift ones.

1. Finding Giant Radio Galaxies and Sample Selection

A visual search for extended, elongated radio sources in several large-scale radio surveys [2], as well as the use of automated algorithms search on digital images [12], have allowed our research group to duplicate the number of GRGs over that reported in the literature over the past few years. The volunteers of the Radio Galaxy Zoo project [11] drew attention to another ~100 new GRGs, and E. Flesch helped us to find a few dozen more GRGs in his MilliQuas catalog [7], such that our compilation currently has over 500 GRGs.

To find possible reasons for the extreme radio size of GRGs, we compare, for the first time, the spectral activity type of their host galaxies, based on spectra from SDSS [1], with parameters of their radio emission as function of redshift.

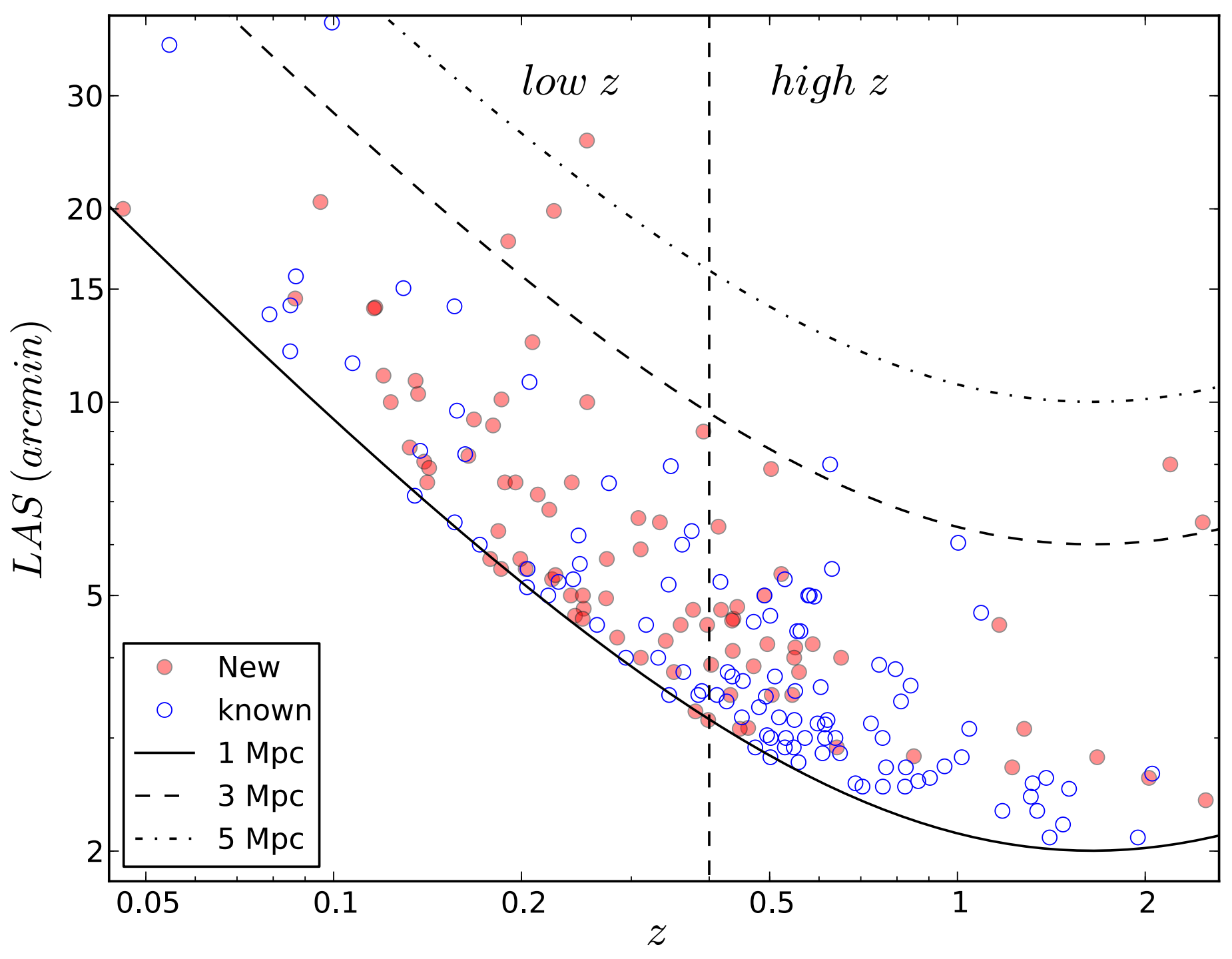

Fig. 1. Largest angular size (LAS) of 193 GRGs with optical spectra from SDSS DR12.

Pink symbols indicate GRGs found by us, open circles are those reportedby others.

The solid, dashed and dot-dashed lines indicate the angular size of 1-, 3- and 5-Mpc sized "standard rulers" in the cosmology used here (H_0=75 km/s/Mpc, Ω_m=0.3, Ω_Λ=0.7).

In Figure 1 we show the distribution of largest angular size (LAS) as function of redshift z of our sample of 193 GRG with SDSS spectra [1]. The three curves indicate the largest linear (projected) size (LLS; H_0 =75 km/s/Mpc, Ω_M=0.3, Ω_Λ=0.7). Due to the combination of good sensitivity to low radio surface brightness of the NVSS radio survey [5], the high angular resolution of the FIRST radio survey [3] and the superb depth of SDSS spectroscopy, the median redshift of these 193 GRGs is z~0.4, compared to z~0.25 for the GRGs found in the literature, and located over the entire sky.

2. Activity Types of GRG

Through visual inspection of the spectra, we determine six types of activity: QSO, Sy1, Sy2, LINER, dwAGN and NoEm. An example of each activity type is shown in Figure 2.

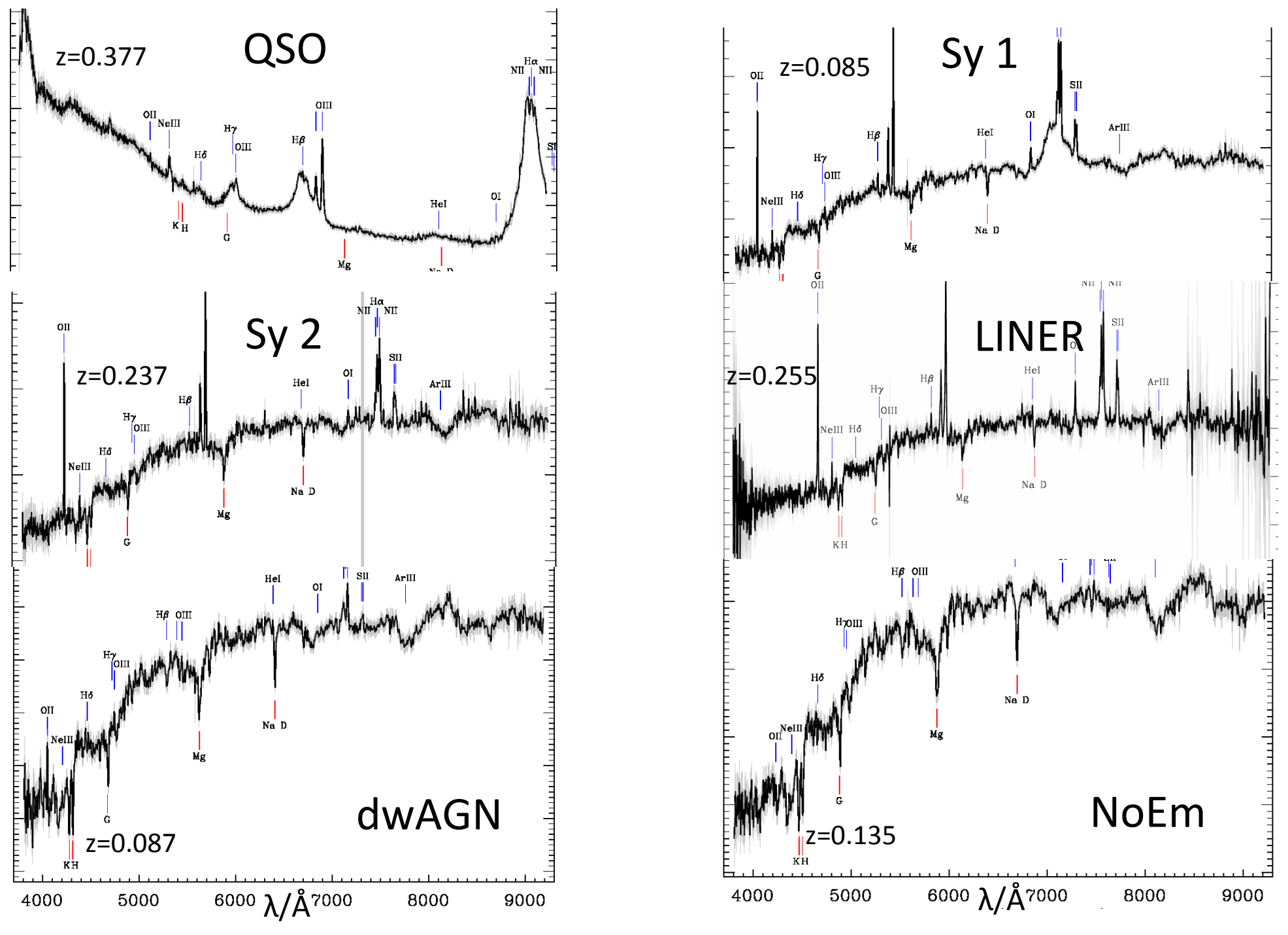

Fig. 2 SDSS sample spectra used to define the activity types of GRG hosts.

Table 1: Distribution of Activity Types of GRG Hosts

Act. type	% low z (<0.4)	% high z(>0.4)	% (low z) – %(high z)
QSO	5.8	21.9	−16.1
Sy1	23.3	26.0	−2.7
SY2	20.9	28.1	−7.2
LINER	2.3	4.2	−1.9
dwAGN	40.7	18.8	+21.9
NoEm	7.0	1.0	+6.0

Table 1 shows the percentage of activity types of GRG hosts at low and high redshift. Although the majority are AGNs (no star forming galaxies are observed), the GRGs show no specific activity type. The last column of Table 1 shows how the percentage of activity types changes from high (z>0.4) to low redshift (z<0.4): the number of QSOs significantly decreases, while the number of dwAGNs significantly increases. This suggests an evolution in cosmic time from high spectral activity (QSO/Sy1/Sy2/LINER) to a low one (dwAGN/NoEm).

In Figure 3 we verified that the change in activity type is not due to an observational bias, like e.g. a difference in radio surface brightness. The total 1.4-GHz fluxes for the GRGs were integrated on NVSS images. The mean radio surface brightness was then determined by dividing this flux by the integration area. Clearly, there is no indication that the radio surface brightness depends on the spectral activity of the GRG host, supporting the evidence of an evolution from high to low activity type with later cosmic epoch (i.e. from high to low z).

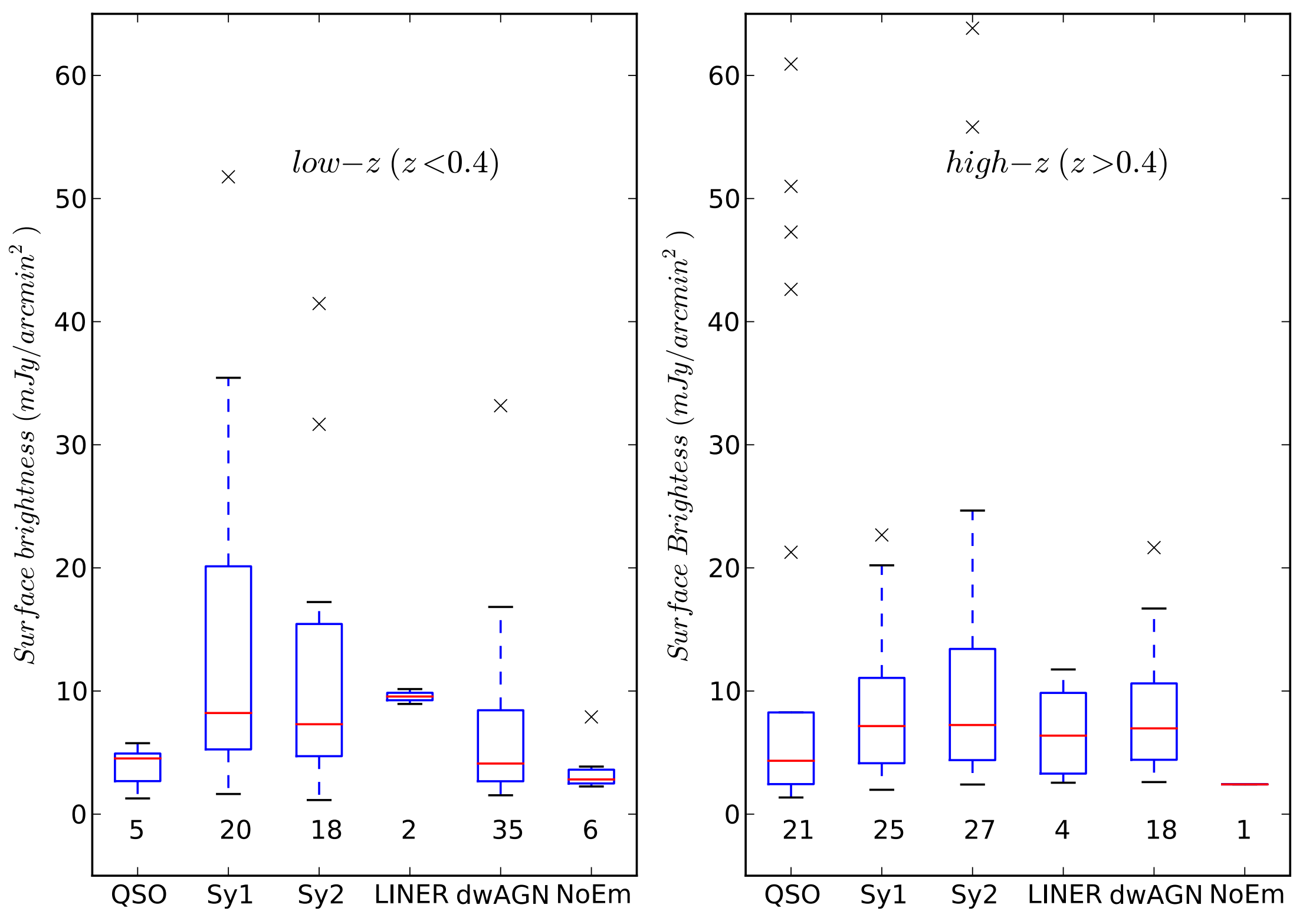

Fig. 3. Mean radio surface brightness of GRG hosts of different AcTypes for low and high z. The box extends from the 1st to the 3rd quartile, and the whiskers extend beyond these quartiles by 1.5 times the interquartile range. Outliers are plotted as crosses. The median is shown as a red horizontal bar.

3. LSS and radio morphology of GRGs

The variation of spectral activity type is consistent with a reduction of AGN luminosity with cosmic time. The question is whether this "evolution" is also observed in radio. To test this hypothesis, we calculated the largest linear (projected) radio size (LLS) of the GRG and determined their Fanaroff-Riley (FR) types. The LLS was determined from NVSS, correcting for its (large) beam size, except for GRGs terminating in well-defined hotspots for which we used FIRST images. We classified the radio morphology into FR classes I or II, following strictly the prescription by [6], i.e. assigning FR I to all sources with peak brightness within the inner half of the source extent (including core-dominant, double-double, and X-shaped sources). No class was assigned for 12 (6%) of the 193 sources. Another 10 in the low-z and 11 in the high-z sample had an intermediate type (I/II).

Table 2: Distribution of FR types and median LLS of GRGs

	Low z (N = 82)			High z (N = 99)		
Act. type	% FR I	% FR II	LLS (Mpc)	% FR I	% FR II	LLS (Mpc)
QSO	0	6	1.15	1	16	1.29
Sy1	4	16	1.23	1	21	1.29
SY2	4	17	1.48	3	26	1.33
LINER	1	1	1.64	0	4	1.56
dwAGN	6	31	1.28	1	15	1.26
NoEm	2	4	1.07	1	0	1.30

In table 2 we see that the percentages of FR II in the QSO/Sy1/Sy2 decrease significantly from high to low redshift, while it increases for the dwAGNs. This is consistent with what we observed for the change of activity type, supporting the evidence of an evolution from high to low activity type with later cosmic epoch.

Since the number of GRGs larger than a given size (LLS) decreases as a very steep power law with exponent −3, in table 2 we compared the median LLS for each activity type in the low- and high-z sample. The boxplots in figure 4 confirm that there is no significant difference in LLS, neither for the different activity types, nor as function of redshift. The latter is a further argument against the view that a low-density environment is the only origin for GRGs, in accordance with [8], who studied the environment of low-redshift GRGs.

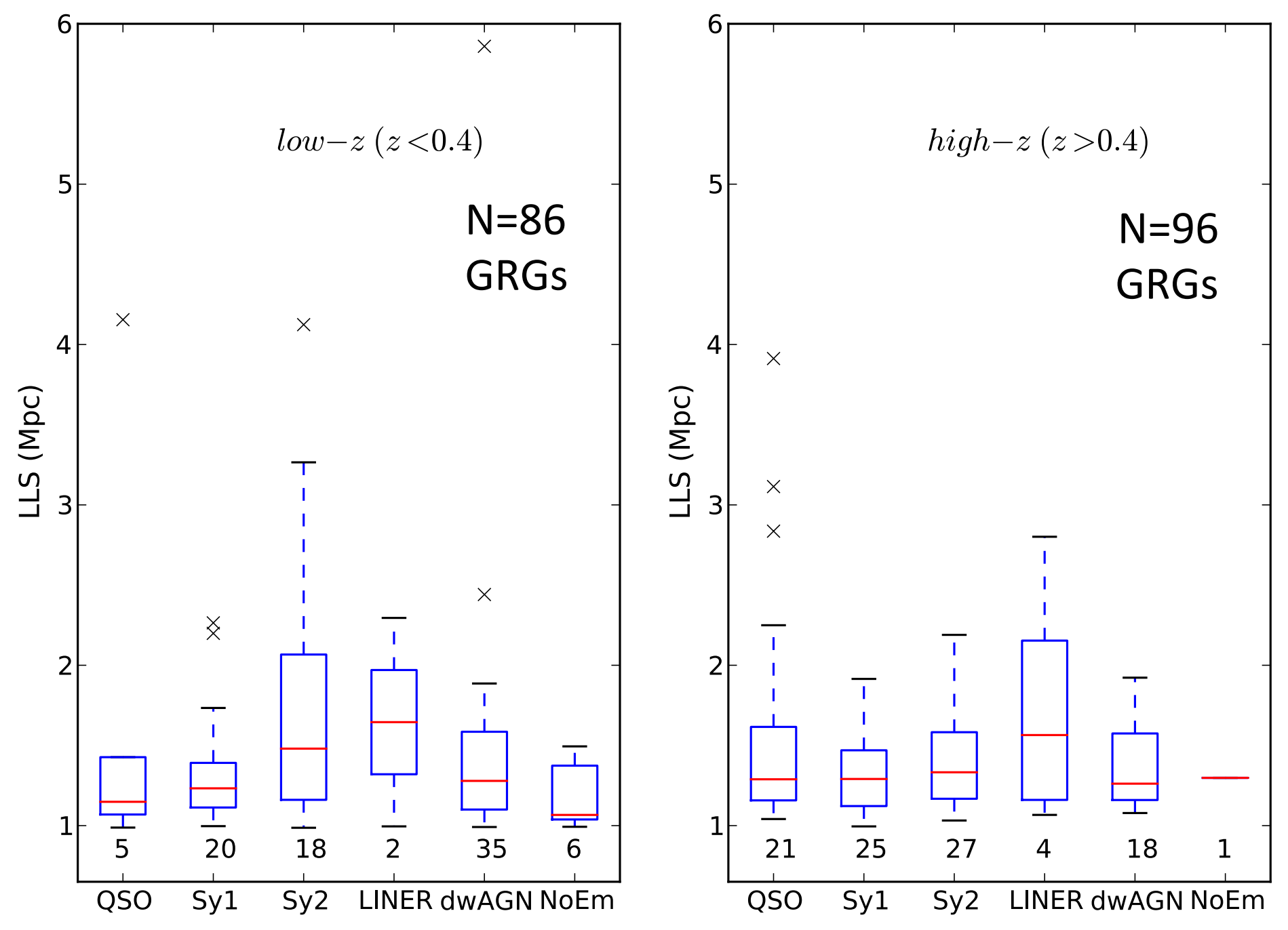

Fig. 4 The distribution of largest linear size (LLS) for the different activity types at low (left) and high (right) redshift. The boxes' layout is the same as in Fig. 3.

In Figure 5 we plot the radio luminosity versus the optical luminosity for our low-z (left) and high-z samples of GRGs. The shape of the symbol denotes the FR type of the radio morphology, while their color indicates the activity type. The dashed lines are formal regressions, but neither sample shows a significant correlation; the dot-dashed lines are the FR I/II boundaries as taken from [4,9].

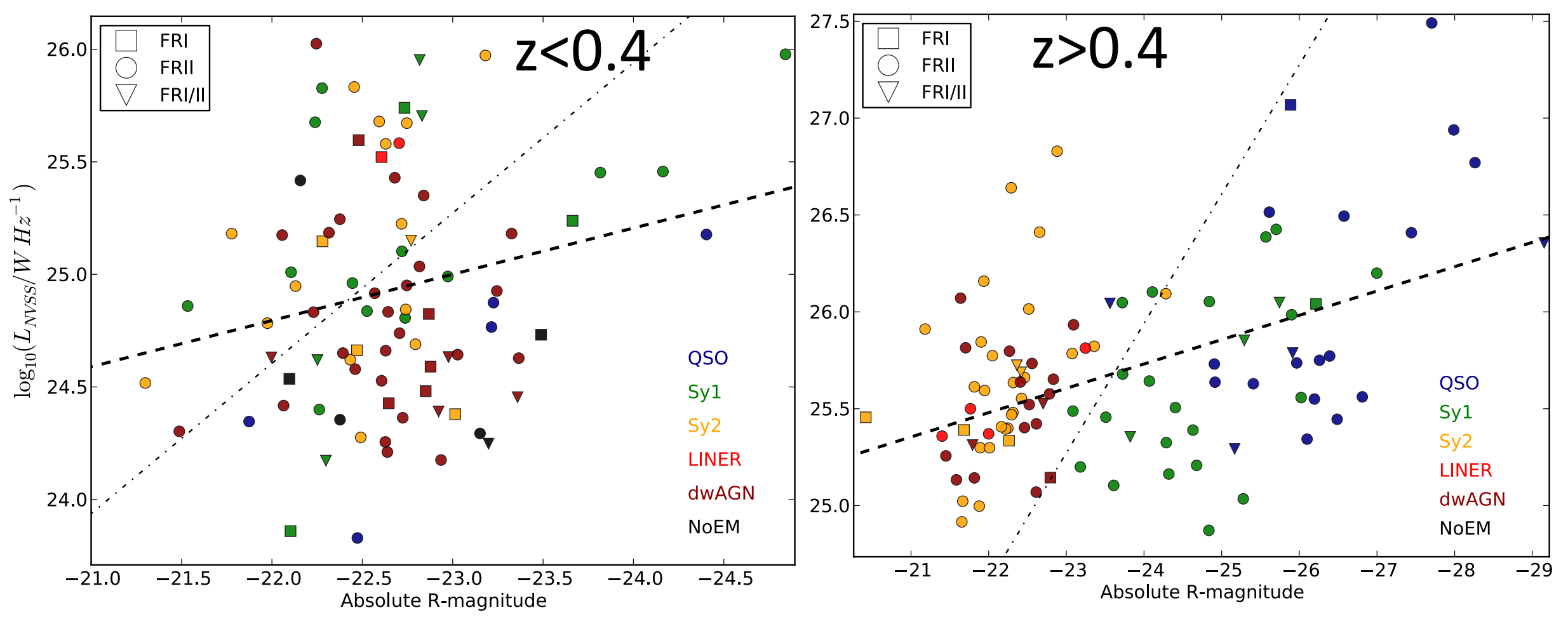

Fig. 5. Radio luminosity versus optical luminosity of GRGs with different activity type at low (left) and high redshift (right).

In 1993 Owen [10] proposed that the radio luminosity L_R separating the FR I (low L_R) and FRII (high L_R) radio galaxies, increases with optical luminosity. Although we see a trend consistent with this prediction at low redshift, our data do not support a clear segregation, since we find GRGs of FR II in great number also in the low-L_R part of the diagram. Even more so, we do not see any clear segregation at high z. In both redshift ranges, no distinction in L_R between FRI and FR II, nor of GRGs with different activity types. At high z, the segregation in M_{abs} of the various activity types is due to the definition of low– and high–luminosity AGNs.

7. Conclusions

- GRGs are mostly AGNs, but show no specific activity type.
- High luminosity AGNs (QSO/Sy1/Sy2), are more common at redshifts z > 0.4, while low luminosity AGNs (dwAGN) dominates at low redshift.
- There is no trend of largest linear projected radio size with neither activity type nor redshift in general.
- We find no clear separation in radio luminosity between the FR I and FR II neither at low nor at high redshift.
- However, the percentage of FR II decreases at low redshift in the QSO/Sy1/Sy2 and increases proportionally at low redshift in the dwAGN.

We observe a variation in redshift of the percentage of activity types and FR types, which is consistent with an evolution in cosmic time from high AGN activity (QSO/Sy1/Sy2) to a lower one (dwAGN/NoEm). And, since we see no significant trend for the linear sizes or radio luminosity of the sources to change with neither redshift nor activity type, it would seem that the evolution of the radio activity occurs on a different time scale than that of the spectral activity.

In 2009, [8] have proposed that it is the longer time scale of radio activity of a small fraction of radio galaxies that makes GRGs grow to their extreme sizes. However, we believe our results are more consistent with a difference in accretion efficiency [13]. GRGs achieve very large radio sizes because their accretion onto the central black hole occurs at higher efficiency compared normal radio sources. Since a higher fraction of the energy released in the BH accretion, goes into the radio activity, then this shortens the timescale of their optical activity, explaining our findings.

8. References

1. Alam S., Albareti F.D., Allende Prieto C., et al., 2015, arXiv:1501.00963 (SDSS DR12)
2. Andernach H, et al. 2012, cf. adsabs.harvard.edu/abs/2012sngi.confP...1A
3. Becker R.H., et al., 1995, ApJ, 450, 559; sundog.stsci.edu, third.ucllnl.org/cgi-bin/firstcutout
4. Best P.N., 2009, AN, 330, 184
5. Condon J.J., et al., 1998, AJ, 115, 1693; http://www.cv.nrao.edu/nvss/
6. Fanaroff B., Riley J., 1974, MNRAS, 167, P31
7. Flesch E.: The Million Quasars (MILLIQUAS) catalogue, quasars.org/milliquas.htm
8. Komberg B.V., Pashchenko I.N., 2009, Astronomy Reports, 53, 1086
9. Ledlow M.J., Owen F.N., Eilek J.A., 2002, NewAR 46, 343
10. Owen F.N., 1993, Lecture Notes in Physics, 421, p. 273
11. Radio Galaxy Zoo, Citizen Science, launched Dec.2013, radio.galaxyzoo.org
12. Santiago-Bautista I., et al., 2015, Proc. "The Universe of Digital Sky Surveys", Ap&SS, in press
13. Sikora M., Begelman, M., 2013, ApJ, 764, L24

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