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Central black holes in giant radio quasars

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We analysed optical properties of giant radio quasars (with radio structures larger than 0.7 Mpc). To this day it is unclear why only a small fraction of radio sources attain such large sizes. There are a number of hypotheses attempting to explain this phenomenon, however the one treated in this paper has not yet been investigated in detail. This hypothesis assumes that the giant linear sizes of radio structures are due to internal properties of their central active galactic nuclei i. e. the specific properties of super-massive black holes and/or their accretion discs. We investigated whether a direct relation exists between the properties of the central "engine" and the origin of the Mpc scale radio structures. In our analysis, we did not find any relation between black hole mass and radio core power, however, we found a weak correlation between the accretion rate and radio core power. We also found a relation between a black hole's mass and linear size of the radio structure. The obtained results may suggest that giant radio quasars are similar to those of smaller size. There are also indications that giant radio quasars may be more evolved sources as compared with smaller radio quasars.

Key words: galaxies: active – quasars: emission lines – radio continuum: galaxies

INTRODUCTION

Giant radio sources (GRSs) are defined as powerful extragalactic radio sources (RSs) hosted by galaxies or quasars, with a projected linear size of radio structure larger than about 700 kpc (assuming $H_0 = 71\,\mathrm{km\,s^{-1}Mpc^{-1}}$, $\Omega_M = 0.27$, $\Omega_\Lambda = 0.73$). When looking through several recent "all-sky" radio surveys (e. g. 7C, WENSS, SUMSS, NVSS, FIRST) a large number of new giants were recognized. To this day, we know of about 230 GRSs, but only a small fraction of them (8%) are related to quasars. Almost all of these GRSs are enclosed in the new samples of giants presented in [4, 13, 15, 16, 23, 24] and in a list of giants known before the year 2000 published in [9].

GRSs are very useful for studying many astrophysical problems, e. g. evolution of radio sources, properties of the intergalactic medium (IGM) at different redshifts, and the nature of the central active galactic nucleus (AGN). However, it is still unclear why but a small fraction of RSs reaches such large sizes. It could be due to exceptional external conditions such as lower IGM density or internal properties of the "central engine". The most widely accepted explanations for the formation of the giants are: (1) GRS are very old sources which evolved to such large sizes; (2) GRS evolve in low density IGM; (3) GRS have more powerful engines than smaller radio sources; (4) GRS are sources with long lifetimes of radio activity or with recurrent jet activity. It is likely that none of the above mentioned explanations alone is sufficient.

It is believed that strong jet activity in an AGN is related to the pc/sub-pc scale condition of its host galaxy, more precisely to the properties of its central black hole (BH; [1, 2, 3]). Furthermore, if assuming that the power of the "central engine" is responsible for the linear-size evolution of a RS, it should be expected that the largest objects should be related to radio quasars (RQs), which host the most energetic AGNs. Recently, the dependence of radio activity and a BH mass is a subject of many scientific debates. A number of researchers investigated such relations for various types of objects, but their results greatly varied. For example, some authors [6, 14, 17, 18, 19] claim that there is a correlation between the radio loudness and the BH mass, while others (e. g. [8, 22, 26, 29, 30]) argue against any dependence between these two parameters.

The knowledge of the BH mass is essential for determining various physical parameters of an AGN and its evolution. A lot of different methods have been developed to estimate the BH mass (e. g. reverberation mapping, maser emission, velocity dispersion of the stars). The easiest one, not requiring monitoring of a particular object for a long time, is to use mass-scaling relations. They allow to determine a BH mass using the full width at half maximum (FWHM) of a broad emission line (e. g. C IV, Mg II, Hβ) and the monochromatic continuum luminosity (λL_λ) of a single-epoch optical spectrum. In our analysis we would like to address the question

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whether the large size of GRQs is related to their central BH mass. If the influence of the central AGN is significant, it will be necessary to take into account its contribution into evolution models of RS's, since giants are observed not only in the local Universe, but also at high redshifts [11]. In this paper we briefly describe our research method, which are presented in details in [12].

THE QUASARS SAMPLE AND DATA ANALYSIS

For the purpose of our analysis we used 21 known GRQs taken from literature, along with an additional 24 lobe-dominated giant RQs unrecognised before. As a comparison sample, we chose 31 smaller-size lobe-dominated RQs from a list of RSs compiled in [21] and 18 quasars selected by us from radio maps. More details about the sample selection and basic properties of studying objects are given in [12]. All of our sources possess a classic FRII radio morphology [7]. For nearly all of these objects, optical spectra from the SDSS as well as radio maps from the NVSS and FIRST surveys were available. All the radio and optical data were analysed through the standard procedures with the AIPS (radio data) and IRAF (optical data) packages. In order to determine BH mass of our objects based on the FWHM measurements for different emission lines, we applied the following equations:

$$M_{\rm BH}[{\rm H}_\beta(4861{\rm \AA})] = 8.13\cdot 10^6 \times \times \left(\frac{\lambda L_\lambda(5100{\rm \AA})}{10^{44}{\rm erg\,s^{-1}}}\right)^{0.50\pm0.06}\left(\frac{{\rm FWHM}({\rm H}_\beta)}{1000\,{\rm km\,s^{-1}}}\right)^2 M_\odot, \quad (1)$$

$$M_{\rm BH}[{\rm Mg\,II}(2798{\rm \AA})] = 7.24\cdot 10^6 \times \times \left(\frac{\lambda L_\lambda(3000A)}{10^{44}{\rm erg\,s^{-1}}}\right)^{0.5}\left(\frac{{\rm FWHM}({\rm Mg\,II})}{1000\,{\rm km\,s^{-1}}}\right)^2 M_\odot, \quad (2)$$

where equation (1) was taken from [27] and equation (2) from [28]. Using the obtained BH masses and the λL_λ we also calculated the accretion rate, defined as: $\dot{m}(3000{\rm \AA}) = L_{\rm bol}/L_{\rm Edd}$, where $L_{\rm bol}$ is the bolometric luminosity, assumed as: $L_{bol} = 5.9\lambda L_\lambda(3000{\rm \AA})$ [20] and $L_{\rm Edd}$ is the Eddington luminosity given by: $L_{\rm Edd} = 1.45\cdot 10^{38} M_{\rm BH}[{\rm Mg\,II}]/M_\odot {\rm erg\,s^{-1}}$ [5].

RESULTS

The comparison between the basic radio properties and the central BH mass of lobe-dominated RQs are provided in Figures 1–4. It can be clearly seen (Figure 1) that there is no correlation between the power of the radio core and the BH mass. The distributions of BH masses for both samples (GRQs – filled circles; comparison sample – open circles) are similar. The values of BH masses estimated using the MgII emission line are in the range of $1.6\cdot 10^8 M_\odot < M_{\rm BH} < 12.2\cdot 10^8 M_\odot$ and $1.0\cdot 10^8 M_\odot < M_{\rm BH} < 20.3\cdot 10^8 M_\odot$ for GRQs and smaller radio sources, respectively. We compared our BH mass estimations with results from [25], where BH masses and another physical parameters were calculated for a large SDSS DR7 quasar sample. Our calculations are systematically lower than those taken from [25], by approximately 0.2 in dex, however this small difference does not qualitatively change the final results.

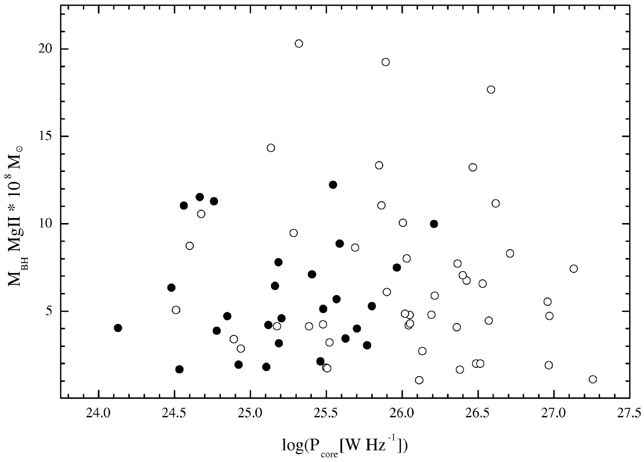

Fig. 1: Relation between BH mass and radio core luminosity at 1.4 GHz.

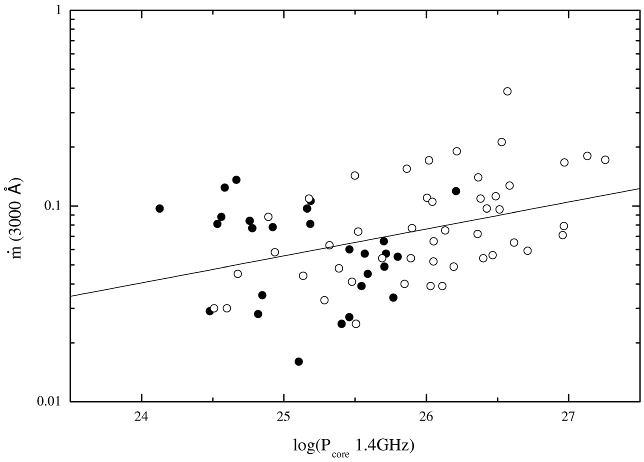

Fig. 2: Accretion rate as a function of radio core luminosity.

For GRQs we obtained a mean value of accretion rate equal to 0.07 which is slightly lower than that of smaller radio quasars. In Figure 2 we present the dependence of accretion rate $\dot{m}(3000{\rm \AA})$ on the core radio luminosity. There is a distinct trend for larger accretion rates to be observed in quasars with larger radio luminosity. The linear fit is given by the line: $\dot{m}(3000) = 0.138(\pm0.038)\log(P_{\rm core}) - 4.696(\pm0.984)$ with a correlation coefficient of 0.39.

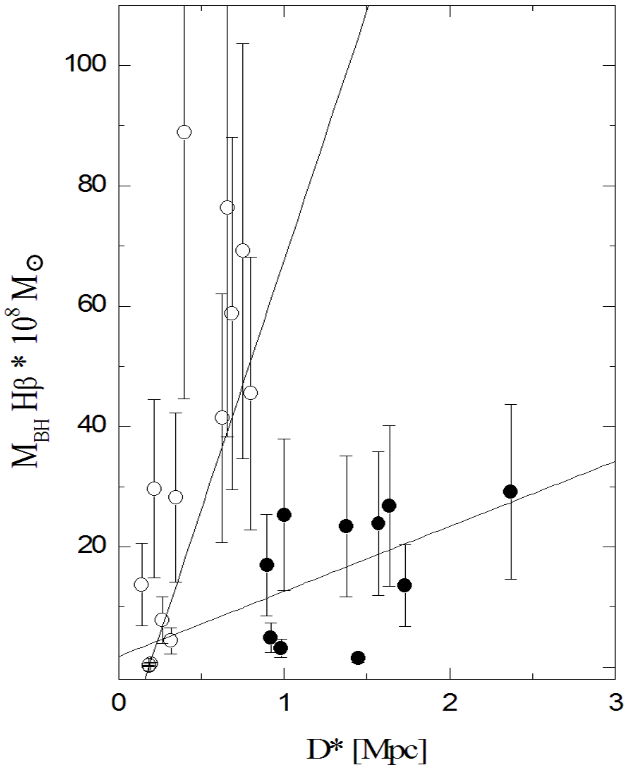

Fig. 3: Dependence between the BH mass derived from the Hβ emission line, and the unprojected linear size of the radio structure.

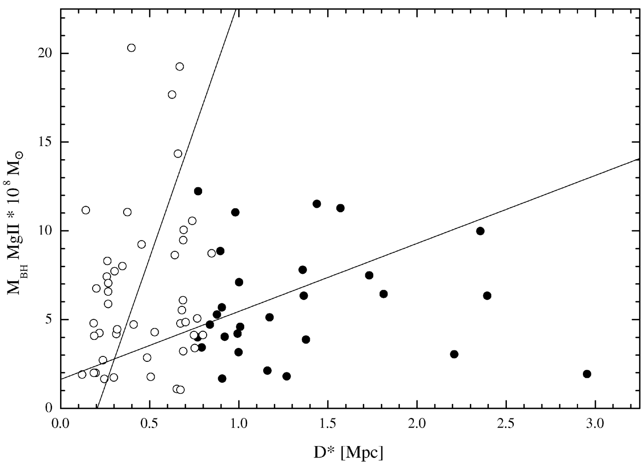

Fig. 4: Dependence between the BH masses derived from the MgII emission line, and the unprojected linear sizes of the radio structures (for details see the text).

For the lobe-dominated RQs, we also checked whether there is any correlation between their BH mass and the unprojected linear size ($D*$) of their radio structure. $D*$ was derived taking into account the inclination angle i [12] as $D^* = D/\sin(i)$, where D is the projected linear size. An element of interest can be discerned in Figure 3. For the Hβ BH mass estimations one can clearly see that there is a correlation between linear size and a BH mass, but surprisingly, for H_β mass estimations, the correlations for GRQs and quasars from the comparison sample, are different. The slope of the linear fit for small-sized quasars is steeper than that for GRQs. The best fits are:

$$M_{\rm BH}[{\rm H}_\beta] = 10.81(\pm6.95)\cdot D^* + 1.78(\pm10.16)$$

for GRQs, and

$$M_{\rm BH}[{\rm H}_\beta] = 83.50(\pm25.36)\cdot D^* + 0.12(\pm11.94)$$

for the comparison sample, with correlation coefficients 0.48 and 0.74, respectively. The plotted uncertainties in Figure 3 are on the level of 0.3 dex [10]. We also plotted these two lines in Figure 4 taking into account the obtained scaling factor $M_{\rm BH}[{\rm H}_\beta] \sim 2.87\cdot M_{\rm BH}[{\rm MgII}]$. We can see that giants and small-sized RQs more or less follow these relations.

CONCLUSIONS

Our estimates of BH mass for both samples of radio quasars are typical of powerful AGNs. We did not find any relation between BH mass and radio power.

Using H_β BH masses, we obtained a correlation between linear size of radio structure and BH mass. This can indicate that the sizes of RQs are related to the properties of their central engines. Surprisingly, for the H_β mass there are two different relations, separately for GRQs and for smaller RQs, which may suggest that the GRQs and the small-sized RQs represent two different groups of objects. To confirm our result, however, we need to have optical spectra in a wider range of wavelength. The influence of the central BH on the size of RQs is still unclear. It is essential to have spectroscopic data for a larger number of lobe-dominated RQs. We plan to perform a similar analysis for the giant radio galaxies and then compare the results with those obtained for GRQs.

The difference of $\dot{m}$(3000Å) and BH mass between the small-size and large-size radio quasars is, however, not as significant. On average, the accretion rate for GRQs is a slightly lower than for a smaller-size RQ. This could indicate similarities in their evolution, however GRQs could be more evolved (older) sources, the accretion process of which have either slowed down or nearly stopped. We found a weak correlation between the accretion rates and the radio core luminosity, which confirms a connection between the accretion processes and the radio emission.

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