Comparison of SEDs of very massive radio-loud and radio-quiet AGN

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ABSTRACT

The main objective of this work is to establish and interpret the dominant spectral components and their differences in radio-loud (RL) and radio-quiet (RQ) AGN with very massive black holes, and accreting at moderate rates. Such a sample is selected from the Swift/BAT catalogue of AGN having determined optical spectra types and hosting black holes with masses > 10^8.5 M⊙. We confirm our previous results, that radio loudness distribution of Swift/BAT AGN is bimodal and that radio galaxies are about two times X-ray louder than their radio-quiet counterparts. We show that the average X-ray loudness of Type 1 and Type 2 AGN is very similar. This similarity holds for both RL and RQ subsamples and indicates negligible dependence of the observed X-ray luminosities on the inclination angle in both populations. No statistically significant difference between RL and RQ AGN was found regarding: X-ray colours; UV-to-MIR luminosity ratios; and OIII-to-MIR luminosity ratios. In both the radiative output is dominated by mid-IR and hard X-ray components, and relatively weak UV luminosities indicate large amounts of dust in polar regions.

Key words: galaxies: active — galaxies: jets — accretion, accretion discs — radiation mechanisms: thermal — radiation mechanisms: non-thermal

1 INTRODUCTION

One of the biggest puzzles of the AGN phenomenon is its large diversity regarding the jet production efficiency. This is particularly apparent in AGN with higher accretion rates, where power of a jet traced by radio luminosity can be compared with accretion power traced by optical luminosity of accretion discs or IR luminosity resulting from reprocessing of optical-UV radiation by dusty obscurers. At each Eddington ratio the radio loudness spans by 3-4 orders of magnitude (e.g. Sikora et al. (2007)). In the case of Blandford-Znajek mechanism of a jet production such a diversity is expected to be related to the range of values of BH spins and magnetic fluxes threading them (Blandford & Znajek 1977). Studies of differences in spectra of RL and RQ objects may help to establish whether central accumulation of large net magnetic fluxes in RL AGN proceeds during the AGN radiatively efficient phase or prior to it (Sikora et al. (2013); Sikora & Begelman (2013) ).

Comparisons of multi-band spectra of RL and RQ AGN were performed in the past for the quasars (e.g. Elvis et al. (1994); Richards et al. (2006); Shang et al. (2011)) and for the samples composed from broad-line radio galaxies and Seyferts (e.g. Woźniak et al. (1998); Kataoka et al. (2011)). The main radiative differences noticed by these studies concern the X-ray properties. In particular, the RL objects were found to have on average larger X-ray luminosities and harder X-ray spectra than the RQ ones. However, noting that included in the compared samples RQ and RL objects were selected separately and that radio galaxies have on average larger BH masses and lower Eddington ratios than RQ Seyferts, the claimed differences might be at least partially affected by the selection methods. Trying to avoid biases resulting from separate selection of RL and RQ samples and from having RL and RQ samples with different average BH masses and Eddington ratios, we decided to carry such comparisons selecting AGN from the BAT AGN Spectroscopic Survey catalogue (BASS: Koss et al. (2017)) with similar ranges of BH masses and Eddington ratios. First results of these studies were presented by Gupta et al. (2018). We have confirmed there that RL AGN are X-ray louder than RQ AGN, but did not find statistically significant difference between their X-ray spectral slopes.

In this paper we extended our comparison studies of RL and RQ AGN by covering also other than hard X-ray spectral bands and taking advantage from having in our samples both Type 1 and Type 2 AGN. The latter allowed us to verify an isotropy of these radiative features, which are

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not expected to be affected by dusty molecular tori. This in particular concerns hard X-rays of Compton-thin AGN and narrow emission lines. Furthermore, having the RL and RQ samples divided into Type 1 and Type 2 subsamples allowed us to make sure that observed in Type 1 AGN UV radiation is dominated by AGN. In order to have reasonable sizes of statistically compared RL and RQ Type 1 and Type 2 subsamples we had to modify our previous selection criteria. The main change is that presently we included in our sample also those AGN, which before did not have known estimations of BH masses. We calculated their masses using relation between BH masses and NIR luminosities of their host galaxies (Marconi & Hunt 2003). And in order to avoid a large scatter of BH masses estimated using different methods, the known masses of other AGN were recalculated using also this method.

The work presented here is organized as follows: in Section 2 we describe procedure of selecting our sample; in Section 3 we present the results of X-ray analysis; the Section 4 deals with multi-band studies; in Section 5 we discuss our results in the broader context of AGN phenomenon; and the main results are summarized in Section 6.

Throughout the paper we assume a ΛCDM cosmology with $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m = 0.3$, and $\Omega_{\Lambda} = 0.70$.

## 2 THE SAMPLES

The primary sample of AGN selected in this work is the same as in Gupta et al. (2018). It is taken from the BAT AGN Spectroscopic Survey (BASS) (Ricci et al. 2017) and then reduced by excluding blazars and Compton-thick (log $N_H > 24$) AGN. Such a sample, counting 664 objects, was further reduced by excluding those AGN which miss in Koss et al. (2017) the optical spectroscopic classification. Following this we selected 394 Type 1 AGN and 232 Type 2 AGN, where the Type 1 sample includes all AGN having at least one broad emission line. All AGN in these samples have data on hard X-ray fluxes from Swift/Burst Alert Telescope (Baumgartner et al. 2013) and on mid-IR fluxes from Wide-field Infrared Survey Explorer mission (WISE) (Wright et al. 2010; Gupta et al. 2018). Distributions of their X-ray luminosities in the band 14–195 keV and of mid-IR luminosities at $\nu W_3 = 2.5 \times 10^{15}$ Hz, i.e. $L_{W3} \equiv \nu W_3 L_{\nu W_3}$, are presented in Fig. 1. They are calculated from fluxes using a standard cosmological formula, but ignoring the K-corrections which for studied by us AGN are negligible because their small redshifts. As we can see in this figure, there is a significant overlap between the distributions of Type 1 and Type 2 AGN. It is confirmed by very low Kolmogorov-Smirnov (KS) test statistic p-values of $2.6 \times 10^{-5}$ for the X-ray luminosities and $2 \times 10^{-7}$ for the mid-IR luminosity. This reasserts the unified scheme for AGN (Urry & Padovani 1995) and affirms that hard X-rays and MIR are both produced quasi-isotropically. As a result we can treat these properties in the Type 1 and Type 2 AGN samples uniformly.

The above Type 1 and Type 2 BAT-AGN subsamples have then been cross-matched with radio catalogues using the same procedure and the same radio catalogues as in Gupta et al. (2018). Following this we divided our samples for radio-loud (RL), radio-intermediate (RI) and radio-quiet (RQ) AGN, where the RI AGN are defined to have the radio loudness parameter $R \equiv L_{1.4}/L_{\nu W_3} > 10$ and RQ AGN are defined to have $R < 1$.

Noting that RL AGN are very poorly represented by those with smaller BH masses (McLure & Jarvis (2004); Koziel-Wierzbowska et al. (2017); Gupta et al. (2018), we leave in our samples only AGN with BH masses larger than $10^8 M_\odot$. Such BHs typically reside in giant ellipticals and

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1. Note that the radio loudness defined by us is about 10 times lower than the one introduced by Kellermann et al. (1989)( see section 2.4 in Gupta et al. (2018)).
their masses can be estimated by using galactic luminosities of old stellar populations provided they dominate contribution to near-IR radiation (Marconi & Hunt (2003); Graham (2007)). The latter condition is satisfied not only in Type 2 AGN, but also in Type 1 AGN if accreting at not very high rates. As we demonstrate in Appendix A, near-IR luminosities of Type 1 AGN are only by a factor 1.47 larger than near-IR luminosities of Type 2 AGN. Hence, after applying respective corrections, the $M_{\text{BH}} - L_{\text{NIR}}$ relation can be applied also for Type 1 AGN in our sample.

In order to keep reasonable number of objects in our subsamples to carry statistical comparisons we did not impose in the present work constraints on maximum BH mass nor on Eddington ratio range. This loosens the $M_{\text{BH}}$ and Eddington ratio counterpartness between RL and RQ AGN. However, as we can see in Fig. 2, most of Swift/BAT objects occupy pretty compact region in the plane $L_{\text{gal}}$ vs. $L_{W3}/L_{\text{gal}}$, where $L_{\text{gal}}$ is traced by $L_K = \nu \int L_{\nu}$ (see Appendix A) and after conversion of $L_K$ to BH masses and applying bolometric corrections for MIR luminosities one can find that almost all objects of our final sample are enclosed within the Eddington ratio range $0.002 - 0.03$ (see Appendix B), and only a few of them have BH masses larger than $10^{9.5} M_\odot$. The radio loudness histogram of our final sample (i.e. after removing AGN with $M_{\text{BH}} < 10^{8.5} M_\odot$) is shown in Fig. 3. The sample consists of 290 AGN (315 AGN while including RI). Its RL subset has 44 objects (27 Type 1 and 17 Type 2) and the RQ subset has 246 objects (153 Type 1 and 93 Type 2).²

² The complete catalogue is available as supplementary material online.

3 COMPARISON OF X-RAY PROPERTIES

3.1 X-ray loudness

We define the X-ray loudness as the ratio of the hard X-ray luminosities in the band 14-195 keV to the mid-IR luminosities at $\nu = \nu_{W3}$. Distributions of X-ray loudness of RL and RQ AGN are shown in Fig. 4. As we can see these distributions have similar shapes, but are shifted against each other, with the median of X-ray loudness of RL AGN being about two times larger. This is in agreement with the result found in our previous work, despite having somewhat differently selected final sample.
3.2 Isotropy of hard X-rays

As we argued in our previous paper (Gupta et al. 2018), similar slopes of high energy spectra and of their high energy breaks in the radio-loud and radio-quiet Swift/BAT AGN suggest same location and mechanism of their production in both subsamples. Therefore the larger X-ray loudness of RL AGN may not result from contribution of jets to the hard X-ray spectra, but rather from larger efficiency of hard X-ray production in accretion flows in RL than in RQ AGN. Since the MIR radiation is expected to be isotropic (see eg. Lusso et al. (2013)), this premise can be verified by checking, whether X-ray loudness depends on the angle of view, and if yes, whether it depends similarly in case of RL and RQ AGN. This can be done by noting that the Type 1 AGN are on average observed at much smaller inclination angles than the Type 2 AGN. Results of such a test are presented in the Fig. 5a and 5a. As we can see, the averaged X-ray loudness of Type 1 and Type 2 subsamples of AGN. These results strongly support our earlier premise that the X-ray emission in both RL and RQ AGN is dominated by the accretion flow and is quasi-isotropic.

3.3 X-ray colours

We define the X-ray colour as the ratio of X-ray luminosity in the 2-10 keV band to the luminosity in the 14-195 keV band - \( \frac{L_{2-10}}{L_{14-195}} \). Figures 6a and 6b show the normalized distribution of the X-ray colour for the Type 1 (panel a) and Type 2 (panel b) samples. In each panel we have shown the distributions of the RL (hatched red) and RQ (filled blue) subsamples of AGN. The median values are presented as dashed lines for each sample.

Figure 5. The normalized distribution of the hard X-rays \( \frac{L_{14-195}}{L_{1-10}} \) for the RL (panel a) and RQ (panel b) samples. The hard X-ray luminosity has been normalized w.r.t. to the W3 luminosity. We present here the distributions of the Type 1 (hatched red) and Type 2 (filled blue) subsamples of AGN. The median values are presented as dashed lines for each sample.

Figure 6. The normalized distribution of the X-ray colour \( \frac{L_{2-10}}{L_{14-195}} \) for the Type 1 (panel a) and Type 2 (panel b) samples. We present here the distributions of the RL (hatched red) and RQ (filled blue) subsamples of AGN. The median values are presented as dashed lines for each sample.
4 SPECTRAL ENERGY DISTRIBUTION

We compare the SEDs of RL and RQ AGN using photometric data covering MIR, NIR, optical-UV (O-UV), and hard X-rays spectral bands. They are collected from WISE, 2MASS, UVOT, GALEX, and Swift/BAT catalogues. The ways they are recovered using WISE and Swift/BAT catalogues were discussed in Section 2; the usage of 2MASS data is presented in the Appendix A; and below we refer to the UV data.

4.1 UV Data

4.1.1 GALEX

The Galaxy Evolution Explorer (GALEX) is an orbiting space telescope observing galaxies in ultraviolet light. It imaged the sky in two ultraviolet (UV) bands, far-UV (FUV, $\lambda_{\text{eff}} \sim 1528\,\text{Å}$), and near-UV (NUV, $\lambda_{\text{eff}} \sim 3310\,\text{Å}$), delivering the first comprehensive sky surveys at these wavelengths. Associations of GALEX sources with our objects have been performed using 2 arcsec matching radius. The UV fluxes were taken from the GALEX catalogue "\texttt{GUVcatMiSGr6+7}" (Bianchi et al. 2017) and corrected for extinction in the Milky Way, using the standard relation

$$F_{\lambda} = 10^{(0.4A_{\lambda})} \times F_{\lambda,0},$$

where $A_{\lambda}$ is given by

$$A_{\lambda} = \begin{cases} A_{\lambda}(E_{B-V}) \times E_{(B-V)}; & \text{for } \lambda = \lambda_{\text{FUV}} \text{ or } \lambda_{\text{NUV}} \text{ and } \text{Galactic reddening } E_{(B-V)} \text{ in directions to associated with our AGN UV sources are provided in the GALEX catalogue.} \\
\end{cases}$$

We found 105 NUV and 101 FUV associations for Type 1 objects and 49 NUV and 41 FUV associations for Type 2 AGN. Due to limited angular resolution of GALEX, the UV radiation in Type 1 objects must be considered to be contributed not only by AGN but also by hot stars, in Type 2 objects – only by hot stars. Comparing UV-to-MIR luminosity ratios for Type 1 and Type 2 (see Figs. 7a, 7b, 8a and 8b) we can see that UV luminosities in Type 1 are much larger than those of Type 2 for both RL and RQ AGN. This implies that the UV luminosities measured in Type 1 AGN sample (both RL and RQ) are strongly dominated by AGN accretion disks.

4.1.2 UVOT

The Ultraviolet/Optical Telescope (UVOT) is part of the multi-wavelength Swift observatory (Roming et al. 2005). The range of optical and UV filters can accommodate wavelength bands between 1700Å and 6500Å providing data in 6 bands namely U ($\lambda_{\text{eff}} \sim 3465\,\text{Å}$), B ($\lambda_{\text{eff}} \sim 4392\,\text{Å}$), V ($\lambda_{\text{eff}} \sim 5468\,\text{Å}$), UVW1 ($\lambda_{\text{eff}} \sim 2600\,\text{Å}$), UV2 ($\lambda_{\text{eff}} \sim 2246\,\text{Å}$) and UVW2 ($\lambda_{\text{eff}} \sim 1928\,\text{Å}$) and an angular resolution of 2.3 arcseconds. Using a similar procedure as described above for GALEX, we use a matching radius of 5 arcsec to determine the closest match and associate it with each of the sources.

4.2 SED / Multi-band spectra

Having constructed our Type 1 and Type 2 RL and RQ subsets and determined the luminosity in different bands, we proceed to construct the composite SED for each of these samples. For each object in the sample, every available luminosity is normalized with respect to the W3 luminosity. We determine the median of the luminosities in each band for the RL and RQ subsets. The median values are calculated irrespective of the number of objects having valid data in that band. We prefer using the median in the SED instead of the mean since it is very effective in rejecting the outliers and preventing any extreme objects from dominating the final SEDs. In order to plot the hard X-ray portion of the SED we use the 14-195 keV luminosity along with the photon index for that band provided by Ricci et al. (2017). The average hard X-ray spectra for RL and RQ AGN are constructed combining median integrated X-ray luminosities with the median spectral slope. We plot also in these figures templates of the giant ellipticals. They are scaled to be equal in the K band to the median luminosities of the RL and RQ samples.

The composite SEDs of Type 1 and Type 2 AGN are presented in Fig. 9 and Fig. 10, respectively. All luminosities are calculated ignoring K-corrections and, hence, presented as a function of the observed frequency. As we can see the SEDs of our objects are contributed not only by AGN, but also by stars of hosting them galaxies. The latter dominate radiation in the NIR and optical bands. The non-AGN contributions can arise also in other SED portions, in particular in the MIR and UV band as provided there by star formation regions (SFRs). However their significance in studied by us samples is rather minor: in the MIR band – because SFRs are predicted to produce much redder MIR spectra than observed in selected by us objects (e.g. Ichikawa et al. (2017); Lyu & Rieke (2018)), and in the UV band – because in case of domination of UV radiation by SFR the UV luminosities should be similar in Type 1 and Type 2 AGN, whereas our Type 1 objects are more UV luminous than Type 2 objects (see subsection 4.1.1 and Figs. 9 and 10). Hence the SEDs of Type 1 AGN in our samples are dominated by three components, the MIR, UV and hard X-ray ones. Their relative contributions to the total observed luminosities are of the same order. This concerns both RL and RQ AGN, and statistically significant differences appear only in the X-ray band, where the RL AGN are 2.25 times more luminous than the RQ ones. We use them in Appendix B to estimate bolometric luminosities and Eddington ratios.

As one can see in Figs. 9 and 10, there are some disagreements between UVOT and GALEX near-UV luminosities of RL AGN. In the case of the Type 1 AGN (Fig. 9) this is likely to be the consequence of having only a few RL AGN detected in the UV band by UVOT. In the case of the Type 2 AGN (Fig. 10), where UV is totally dominated by hot stars the difference between UVOT and GALEX near-
UV luminosities can additionally result from the different angular resolutions of UVOT and GALEX. Another feature which deserves comment is that optical luminosities of Type 2 AGN are lower than optical luminosities of the giant elliptical template. This can be explained by the fact that with UVOT angular resolution only limited portion of the host galaxy light is detected. Finally, questioned can be the difference between median near-IR luminosities of Type 1 and Type 2 AGN. Since these luminosities are dominated by stars of host galaxies, one might expect them independent on AGN type. The reason why they differ is that luminosities in Figs. 9 and 10 are normalized by MIR luminosities which are a little larger for Type 1 AGN than for Type 2 (see Fig. 1). The latter difference results from the selection criteria used by Koss to specify the optical spectral types of Swift/BAT AGN (Koss et al. 2017).

5 DISCUSSION

The hard X-ray AGN with black hole masses > $10^{8.5}M_\odot$ selected by us are found to accrete at the rates corresponding to Eddington-ratio – if not counting a few outliers – enclosed between 0.001 and 0.03 (see Fig. B1). They have bimodal distribution of radio loudness and a fraction of radio-loud objects is about 0.15. The observed radiative output of RL and RQ AGN is dominated by MIR and X-ray components and the only significant difference between them is that the RL AGN are on average ~ twice times X-ray louder than their RQ counterparts. Possible interpretations of these results are discussed below.

5.1 The origin of hard X-rays in RQ and RL AGN

Production of hard X-rays is commonly interpreted as a result of comptonization of optical-UV radiation of cold accretion disk by hot electrons ($kT_e \sim 100$ keV) in optically thin coronas (Kubota & Done (2018) and refs. therein). Such coronas are likely heated by magnetic reconnection (Galeev et al. (1979); Beloborodov (2017)). Another possibility is that hot coronas represent central portions of accretion flows which are predicted by some models to result from conversion of the cold, optically thick and geometrically thin disks into hot, optically thin and geometrically thick inflows (Meyer & Meyer-Hofmeister (2002); Hogg & Reynolds (2018)). Such models are often applied for AGN in which X-ray reflection features are weak and the radiative output is not dominated by UV bump (e.g. Prieto et al. 2018).
Figure 9. Medians of the dominant SED components of the RL (red) and RQ (blue) Type 1 objects of the sample. All luminosities have been normalized w.r.t. to the W3 luminosity. We also present here SED template of the giant elliptical which has been scaled to K-band luminosity. Centre frequencies of each band are labelled apart from the UVOT bands. The UVOT bands’ wavelengths are U ($\lambda_{\text{eff}} \sim 3465\AA$), B ($\lambda_{\text{eff}} \sim 4392\AA$), V ($\lambda_{\text{eff}} \sim 5468\AA$), UVW1 ($\lambda_{\text{eff}} \sim 2600\AA$), UVM2 ($\lambda_{\text{eff}} \sim 2246\AA$) and UVW2 ($\lambda_{\text{eff}} \sim 1928\AA$).

Figure 10. Medians of the dominant SED components of the RL (red) and RQ (blue) Type 2 objects of the sample. All luminosities have been normalized w.r.t. to the W3 luminosity. We also present here SED template of the giant elliptical which has been scaled to K-band luminosity. Centre frequencies of each band are labelled apart from the UVOT bands. The UVOT bands’ wavelengths are U ($\lambda_{\text{eff}} \sim 3465\AA$), B ($\lambda_{\text{eff}} \sim 4392\AA$), V ($\lambda_{\text{eff}} \sim 5468\AA$), UVW1 ($\lambda_{\text{eff}} \sim 2600\AA$), UVM2 ($\lambda_{\text{eff}} \sim 2246\AA$) and UVW2 ($\lambda_{\text{eff}} \sim 1928\AA$).
Figure 11. The normalized distribution of the L$_{\text{OIII}}$ for the RL (panel a) and RQ (panel b) samples. The luminosity has been normalized w.r.t. to the W3 luminosity. We present here the distributions of the Type 1 (hatched red) and Type 2 (filled blue) subsamples of AGN. The median values are presented as dashed lines for each sample.

(2010); Toba et al. (2019); Younes et al. (2019)). However noting that weaker reflection features may result also from higher ionization of accretion disks in such AGN, while their relatively lower UV luminosities can come from extinction associated with the polar dust (see section 5.2), truncation of cold accretion disks may not be required.

Interpretation of the hard X-ray origin is even more uncertain in case of RL AGN. Their larger X-ray loudness than of RQ ones may suggest that X-rays in these objects are partially contributed by the jet base (e.g. Wozniak et al. (1998)). However, as we noticed in our previous paper (Gupta et al. 2018), despite the difference in the X-ray loudness, the spectral slopes and high energy breaks are very similar in RL and RQ AGN selected to have similar BH masses and Eddington ratios. We used this as an argument in favor of the same location and same emission mechanism of hard X-ray sources in RL and RQ AGN, the location being the hot corona in the innermost portions of accretion flow and the mechanism – Compton up-scattering of lower energy disk photons. In this paper we explore such interpretation by taking advantage of having in our samples Type 1 and Type 2 AGN which allows to verify dependence of the X-ray radiation luminosity on the inclination angle. We carried out such verification by comparing distributions of X-ray to MIR luminosity. They are found very similar for Type 1 and type 2 AGN for both RL and RQ AGN, which suggests that the departure of hard X-rays from the isotropy is statistically insignificant. The isotropy indicates also that X-ray sources in both RQ and RL AGN cannot be too compact, otherwise their isotropy would be strongly affected by gravitational lensing. If trying to interpret the larger X-ray loudness of RL AGN by the jet contribution, this would require tight tuning of parameters describing the geometry and kinematics of a jet. Furthermore, production of X-rays by a slow jet with similar luminosity as by accretion flow would imply that most of the jet energy required to efficiently power the radio lobes is dissipated and radiatively lost already at the base. Hence, we are tempted to speculate that in both RQ and RL AGN production of X-rays is dominated by hot coronas associated with central portions of accretion flows and that more efficient X-ray production in RL AGN result from larger magnetization of innermost portions of accretion flows and from larger BH spins which are required to afford efficient jet production in the MAD scenario involving the Blandford-Znajek mechanism.

5.2 UV luminosities and the ‘polar’ dust

Having reprocessed UV radiation of accretion disk to MIR radiation in dusty molecular tori and assuming absence of dust in ionization cones (the zone not protected against the UV radiation by the torus) one might expect to get the ratio of MIR to O-UV luminosity of the order CF $\propto N_{\text{Type2}}/(N_{\text{Type1}} + N_{\text{Type2}})$, where $N_{\text{Type1}}$ and $N_{\text{Type2}}$ are the numbers of Type 1 AGN and Type 2 AGN, respectively (Gupta et al. 2016) and refs therein). Hence, noting that in our sample the latter ratio is 0.38, while integrated mid-IR luminosity reaches or even exceeds UV luminosities of Type 1 AGN strongly implies that a significant fraction of UV radiation is extincted and reprocessed into IR radiation by the dust located within the ionization cone. Presence of such, often called, polar dust is theoretically predicted to be common in the AGN accreting at moderate rates, and this is because at such rates the pressure of UV radiation is too small to protect the ionization zone against the dusty stuff (Hönig et al. (2013); Hönig & Kishimoto (2017); Ricci et al. (2017); Lyu & Rieke (2018)). Existence of the polar dust is observationally confirmed by mid-IR interferometric observations (Horst et al. (2009); Gandhi et al. (2009); Kishimoto et al. (2011); Tristram & Schartmann (2011); López-Gonzaga et al. (2016)). They show the extension of mid-IR images along the ionization cones.

Comparing the UV fluxes of our RL and RQ Type 1 AGN (Figs 7a, 8a and 9) we can see that UV is less extincted in RL objects. This may result from smaller amount of dust in the vicinity of powerful jets. However this result is statistically weak and need confirmation by future studies using larger samples.

We compared also luminosities of [OIII] lines. For both RL and RQ AGN they are found on average stronger in Type 2 objects than in Type 1 AGN (Fig. 11a and 11b). This difference can be explained by the polar gradient of the dust distribution within the ionization zone.
6 SUMMARY

We summarize our results as follows:

- AGN selected from the Swift/BAT catalogue with black hole masses $>10^{8.5}\text{M}_\odot$ have bimodal distribution of radio loudness. Medians of radio loudness distribution of RL and RQ AGN differ by a factor 429, and the radio-loud fraction is $\sim 0.15$.

- The only statistically significant difference between SEDs of RL and RQ AGN are larger X-ray luminosities in the formers. Deduced by us isotropy of X-ray luminosities in both RL and RQ AGN from finding that hard X-ray-to-MIR luminosity ratios in Type 1 and Type 2 AGN do not differ seems to disfavor explanation of this difference by postulating the jet contribution to hard X-rays in RL AGN. Together with previous findings that slopes and high energy breaks of their hard X-ray spectra are on average very similar in both RL and RQ AGN seems to support our premise that in both samples the hard X-ray are produced in hot central portions of accretion flows and that luminosity difference can be associated with having faster rotating BHs and larger magnetic fluxes in AGN producing jets;

- The radiative output of both RL and RQ AGN is dominated by radiation in the MIR and hard X-ray bands. Their observed UV luminosities are likely to be suppressed due to extinction. Lower UV luminosities as compared with those predicted by standard accretion disk models can also result from the accretion disk truncation. However this alone cannot explain MIR luminosities larger than $C_{\text{FL}} \text{UV,em}$.

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APPENDIX A: $M_{BH}$ ESTIMATIONS

As it is stated in Section 1, BH masses of all AGN in our sample are calculated using method which is based on the relation between luminosities of host galaxies and black hole masses (Marconi & Hunt (2003); Graham (2007)). We adopted the formula from Graham (2007)

$$\log(M_{BH}/M_\odot) = -0.37\pm0.04(M_K + 24) + 8.29\pm0.08,$$

where $M_K$ is the absolute K-band magnitude of the galaxy. This method can be directly applied for Type 2 AGN, where AGN contribution to near-IR is negligible if any. Using this formula for Type 1 AGN needs to be assured that contribution of AGN radiation to near-IR is much smaller than of the host galaxy. While it is not the case in high accretion rate objects like quasars, for AGN accreting at rates corresponding with Eddington ratio smaller than 0.03 the domination of the near-IR luminosities by the host galaxies is well documented (Prieto et al. (2010); Stern & Laor (2012)). Nevertheless since some contribution from AGN is unavoidable, in order to minimize overestimation of BH masses in Type 1 AGN by ignoring it, the K-luminosity used in Graham’s formula is not taken
directly from observations but derived from J-luminosity using the template of giant elliptical (Silva et al. 1998).

This leads to lowering the BH mass overestimation because AGN contribution to near-IR is larger in K-band than in J-band. Following this procedure the difference between median values of K-luminosity distributions in Type 1 and Type 2 AGN dissappears (see Fig. A1 and A2). This is what one might expect to get adopting the Unified Scheme (Urry & Padovani 1995) and having strongly dominated near-IR luminosity by host galaxies.

The K and J data for our objects have been obtained from the 2MASS (Two-Micron-All-Sky-Survey) extended (XSC) and point source (PSC) catalogues (Skrutskie et al. 2006); NASA/IPAC Infrared Science Archive), the latter for objects not having matches in XSC catalogue.

APPENDIX B: BOLOMETRIC LUMINOSITIES AND EDDINGTON RATIO

The SEDs of Type 1 AGN are usually dominated by optical-UV, hard X-ray, and MIR components, where the latter can be contributed by dust in the molecular torus as well, as by the polar dust. When amount of the latter is too small to extinct significantly optical-UV radiation, then the bolometric luminosity, defined to be equal to amount of energy produced by the accretion flow per unit of time, is a sum of only two first components. Situation complicates if extinction by the polar dust is not negligible and leads to conversion of some portion of optical-UV radiation to the IR-band. In such a case the bolometric luminosity is given by formula $L_{\text{bol}} = L_{\text{UV}} + L_{\text{IR}}$, where $L_{\text{UV}}, L_{\text{IR}}$ are the infrared luminosity produced in the polar zone. Since the observed MIR luminosity is the sum of MIR emitted in the polar region and in the torus, in order to calculate $L_{\text{bol}}$ we need to know what fraction of the total IR luminosity is produced in the polar zone. This could be evaluated from extinction measurements using decrements of narrow emission lines. However the fraction of objects in our sample for which such data are available is very small. Fortunately, we can avoid this problem if noting that the fraction of optical-UV radiation converted to MIR in the circumnuclear molecular torus can be approximated by formula

$$L_{\text{bol}} = L_X + \frac{(L_{\text{UV}} + L_{\text{IR}})}{(1 + CF)}.$$ 

Having spectra of our Type 1 AGN dominated by $L_{\text{14-195}}, L_{\text{MIR}}$ and $L_{\text{UV}}$, and calculating medians of these luminosities normalized by $L_{\text{W3}}$, we estimate the average ‘W3-bolometric corrections’

$$K_{\text{W3}} = \left( \frac{L_{\text{bol}}}{L_{\text{W3}}} \right) = \left( \frac{L_{\text{14-195}}}{L_{\text{W3}}} \right) + \left( \frac{L_{\text{UV}} + L_{\text{MIR}}}{L_{\text{W3}}} \right) \times \frac{1}{1 + CF}.$$ 

This gives $K_{\text{W3,RL}} \approx 7.2$ and $K_{\text{W3,RQ}} \approx 5.3$. Then calculating bolometric luminosities of all objects from $K_{\text{W3}}L_{\text{W3}}$ and dividing them by Eddington luminosities we obtain distributions of Eddington-ratio presented in Fig. B1. As we can see most objects in our samples have Eddington ratios enclosed within the range 0.002 – 0.03 and their medians are $-1.83$ and $-2.18$ for RL and RQ samples, respectively.
APPENDIX C: CATALOGUE

The complete catalogue is available as supplementary material online. Table C1: gives a brief description of the columns in the catalogue.

This paper has been typeset from a TeX/LaTeX file prepared by the author.
Table C1. Description of the RL & RQ catalogue. The catalogue is available as supplementary material online.

| Column Name       | Unit | Description                                                                 |
|-------------------|------|-----------------------------------------------------------------------------|
| Name              |      | Counterpart name from Swift/BAT catalogue of AGN                           |
| RA                | deg  | Counterpart RA coordinates from Swift/BAT catalogue of AGN                 |
| DEC               | deg  | Counterpart DEC coordinates from Swift/BAT catalogue of AGN                |
| $z$               |      | Redshift                                                                    |
| log$_{R}$         |      | Log of the radio loudness                                                  |
| Radio_class       |      | Radio classification of object (RL/RQ)                                     |
| Optical_type      |      | Optical classification                                                     |
| log$_{MBH}$       | $M_\odot$ | BH mass determined from K-band luminosity                                 |
| log$_{Eddington\_ratio}$ |      | Eddington ratio                                                            |
| log$_{J\_W1}$     | erg s$^{-1}$ | WISE Luminosity at $\nu_{W1}$                                             |
| log$_{J\_W2}$     | erg s$^{-1}$ | WISE Luminosity at $\nu_{W2}$                                             |
| log$_{J\_W3}$     | erg s$^{-1}$ | WISE Luminosity at $\nu_{W3}$                                             |
| log$_{J\_W4}$     | erg s$^{-1}$ | WISE Luminosity at $\nu_{W4}$                                             |
| log$_{J\_J}$      | erg s$^{-1}$ | 2MASS Luminosity at $\nu_{J}$                                             |
| log$_{J\_H}$      | erg s$^{-1}$ | 2MASS Luminosity at $\nu_{H}$                                             |
| log$_{J\_K}$      | erg s$^{-1}$ | 2MASS Luminosity at $\nu_{K}$                                             |
| log$_{J\_V}$      | erg s$^{-1}$ | UVOT Luminosity at $\nu_{V}$                                              |
| log$_{J\_B}$      | erg s$^{-1}$ | UVOT Luminosity at $\nu_{B}$                                              |
| log$_{J\_U}$      | erg s$^{-1}$ | UVOT Luminosity at $\nu_{U}$                                              |
| log$_{J\_UVW1}$   | erg s$^{-1}$ | UVOT Luminosity at $\nu_{UVW1}$                                           |
| log$_{J\_UVM2}$   | erg s$^{-1}$ | UVOT Luminosity at $\nu_{UVM2}$                                           |
| log$_{J\_UVW2}$   | erg s$^{-1}$ | UVOT Luminosity at $\nu_{UVW2}$                                           |
| log$_{J\_FUV}$    | erg s$^{-1}$ | GALEX Luminosity at $\nu_{FUV}$                                           |
| log$_{J\_NUV}$    | erg s$^{-1}$ | GALEX Luminosity at $\nu_{NUV}$                                           |
| log$_{J\_2\_10}$  | erg s$^{-1}$ | X-ray Luminosity in the 2-10 keV band                                       |
| log$_{J\_14\_195}$| erg s$^{-1}$ | X-ray Luminosity in the 14-195 keV band                                    |
| Gamma$_{14\_195}$ |      | Photon index in the X-ray band 14-195 keV                                  |