RADIO-LOUDNESS OF AGN: OBSERVATIONAL FACTS AND THEORETICAL IMPLICATIONS

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ABSTRACT

We study relations between the radio-loudness and the accretion rate parameters in several different kinds of AGNs, including Seyfert Galaxies and LINERS, FR I Radio Galaxies, Broad-Line Radio Galaxies and Quasars, as well as Optically-Selected Quasars. We find that these objects form two distinct and well-separated patterns on the radio-loudness — accretion rate plane. The 'upper' pattern is composed from radio-loud quasars and Radio Galaxies, while the 'lower' one consists of Seyfert Galaxies, LINERS and radio-quiet quasars. Both patterns indicate an increase of the radio-loudness with a decrease of the Eddington ratio (with possible saturation at low accretion rates). We propose that this finding can be explained assuming that production of relativistic jets is mediated by spinning black holes, and that black holes rotate much more slowly (on average) in spiral galaxies than in giant ellipticals. We discuss possible evolutionary scenarios which may lead to such a spin-distribution dichotomy. We also comment on possible mechanisms leading to suppression and intermittency of radio (jet) activity at high accretion rates within the framework of the proposed interpretation.

1. THE SAMPLE

Our studies include: radio-loud broad-line AGNs (BLRGs plus radio-loud quasars); Seyfert galaxies with the addition of a few LINERS; FR I radio galaxies; and optically selected quasars. The subsamples were selected to share the following criteria:

- they do not include blazars;
- the optical flux of the central, unresolved source is known;
- the total radio flux is known (including extended emission if present);
- black hole masses or necessary parameters to estimate them are available in the literature.

Other criteria, applied individually for different subsamples, are specified in Sikora, Stawarz & Lasota (2006). Our sample does not include blazars, because their observed emission is significantly

Doppler boosted, and narrow line radio galaxies (NRLGs), because their optical nuclei are hidden by dusty tori, which makes estimation of the accretion rates very uncertain.

2. OBSERVATIONAL FACTS

Radio-loudness, $\mathcal{R} \equiv L_{\nu_5}/L_{\nu_B}$ vs. Eddington ratio, $\lambda \equiv L_{bol}/L_{Edd}$, is plotted in Figure 1, where $\nu_5 = 5$GHz, $\nu_B = c/\lambda_B$, $\lambda_B = 4400\mathring{A}$, L_{bol} is the bolometric luminosity of the accretion disk, and L_{Edd} is the Eddington luminosity. Our subsamples form two sequences, with the upper one almost exclusively populated by objects with black hole masses $\mathcal{M}_{BH} > 10^8\mathcal{M}_\odot$, and the lower one dominated by objects with less massive black holes. Both sequences follow the same trend: the increase of the radio-loudness with the decrease of the Eddington ratio. Such a trend was originally found by Ho (2002), but without recognition of a double-structure. It should be noted, however, that the gap between sequences in our plots is presumably an artifact of selection effects and they should be considered as upper radio bounds of objects with $\mathcal{M}_{BH} > 10^8\mathcal{M}_\odot$ hosted by giant elliptical galaxies and of objects with $\mathcal{M}_{BH} < 10^8\mathcal{M}_\odot$ hosted predominantly by spiral galaxies.

In Figure 2, we plot radio luminosities vs. optical luminosities, both in Eddington units. The results can be compared with an analogous figure presented by Gallo et al. (2003) for BH X-ray binaries. The similarities between the shape of the AGN sequences and the shape of the BH XRB sequence suggests that the evolutionary tracks of individual AGNs are the same as those of XRB. They are schematically marked in Figure 3 by arrows.

3. THEORETICAL IMPLICATIONS

In order to explain a very large difference between radio-loudness of objects belonging to two sequences, an extra parameter is required in addition to the accretion power. We postulate that it is the spin of the black hole, $a \equiv J/J_{max}$, where $J_{max} = G\mathcal{M}_{BH}^2/c$, i.e. that the efficiency of jet production and radio emission depend on the black hole rotation rate. To make the spin paradigm to work, the following conditions must be satisfied:

- the spin distribution of BHs hosted by giant ellipticals must extend to much larger values than in the case of spiral galaxies;
- production of a jet at high accretion rates should be intermittent, despite approximate constancy of the spin during the quasar life-time.

The first condition can be satisfied, if spin-up of BHs in spiral galaxies is limited by multi-accretion events with random angular momentum orientations and small accretion-mass increments

$$m/\mathcal{M}_{BH} \ll a\sqrt{R_g/R_w} \tag{1}$$

where R_g is the gravitational radius and R_w ($\sim 10 - 10^3 R_g$) is the distance of the warp produced by the Bardeen-Petterson process in the accretion disk, which at large distances is inclined to the equatorial plane of the rotating black hole (Bardeen & Petterson 1975). With these conditions, a co- or counter-rotating disk is formed in the vicinity of the black hole depending on the orientation of the disk on a large scale (King et al. 2005). A sequence of randomly oriented accretion events will keep the BH spin at low values (see Moderski & Sikora 1996; Moderski et al. 1998). Contrary to spiral galaxies, ellipticals underwent at least one major merger in the past (see, e.g., Hopkins et al. 2006). Such mergers are probably followed by accretion events which are too massive to satisfy the condition given by Eq. (1). Then, regardless of whether the disk was initially counter- or co-rotating, due to the alignment process (Natarajan & Pringle 1998) all disks will co-rotate (counter-rotating disks undergo flips). Provided that $m/\mathcal{M} \sim 1$, they spin-up the black hole to $a \sim 1$.

The second condition can be satisfied assuming that: (i) at high accretion rates the accretion disk switches between the state where it is driven by MHD winds and the state where it is driven by viscous torques; and (ii) the intermittent production of narrow jets is related to the intermittent collimation provided by the disk wind (see, e.g., Bogovalov & Tsinganos 2005; Beskin & Nokhrina 2005). It is tempting to speculate that the disk state switches are stimulated by thermal/viscous instabilities and that the duty cycle of such switches determines whether a strongly modulated jet will accumulate enough power to build up extended radio structures.

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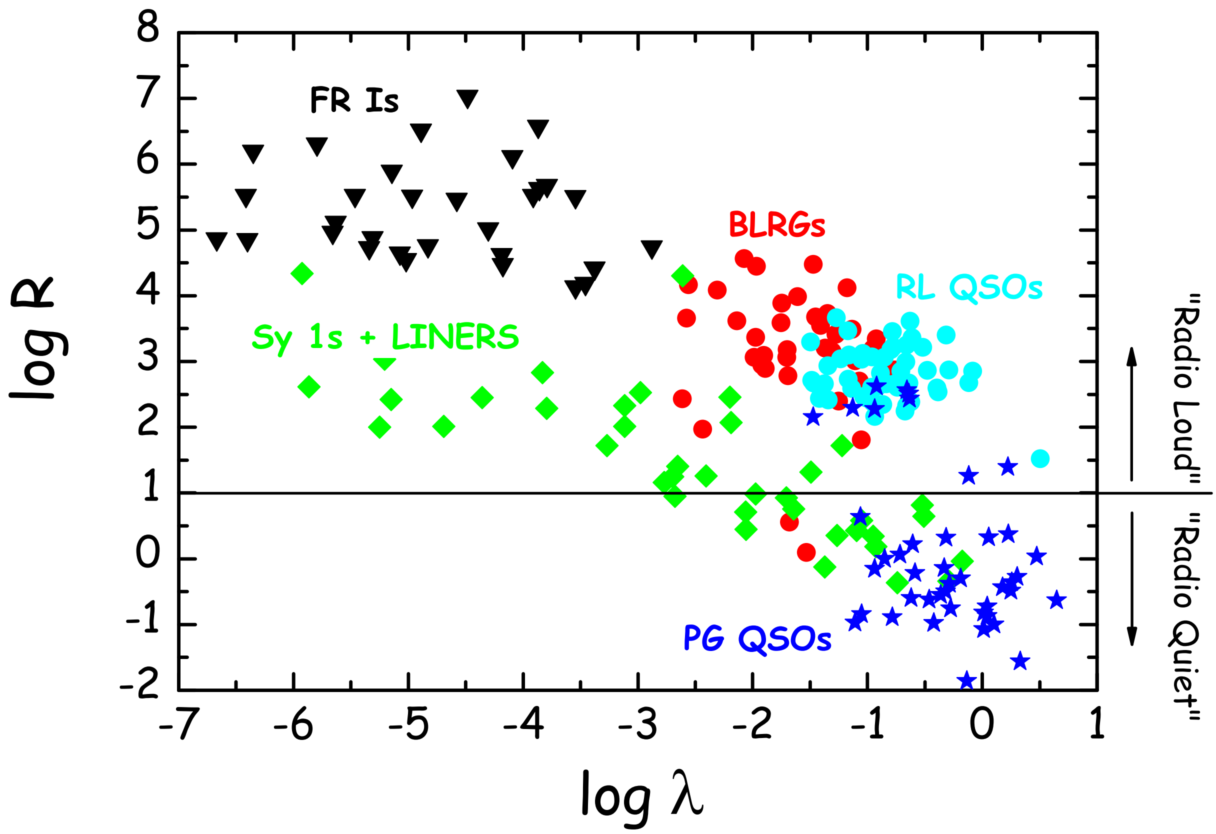

FR Is
BLRGs
RL QSOs
Sy 1s + LINERS
PG QSOs
"Radio Loud"
"Radio Quiet"
log R
log λ
8
7
6
5
4
3
2
1
0
-1
-2
-7
-6
-5
-4
-3
-2
-1
0
1

Fig. 1.—

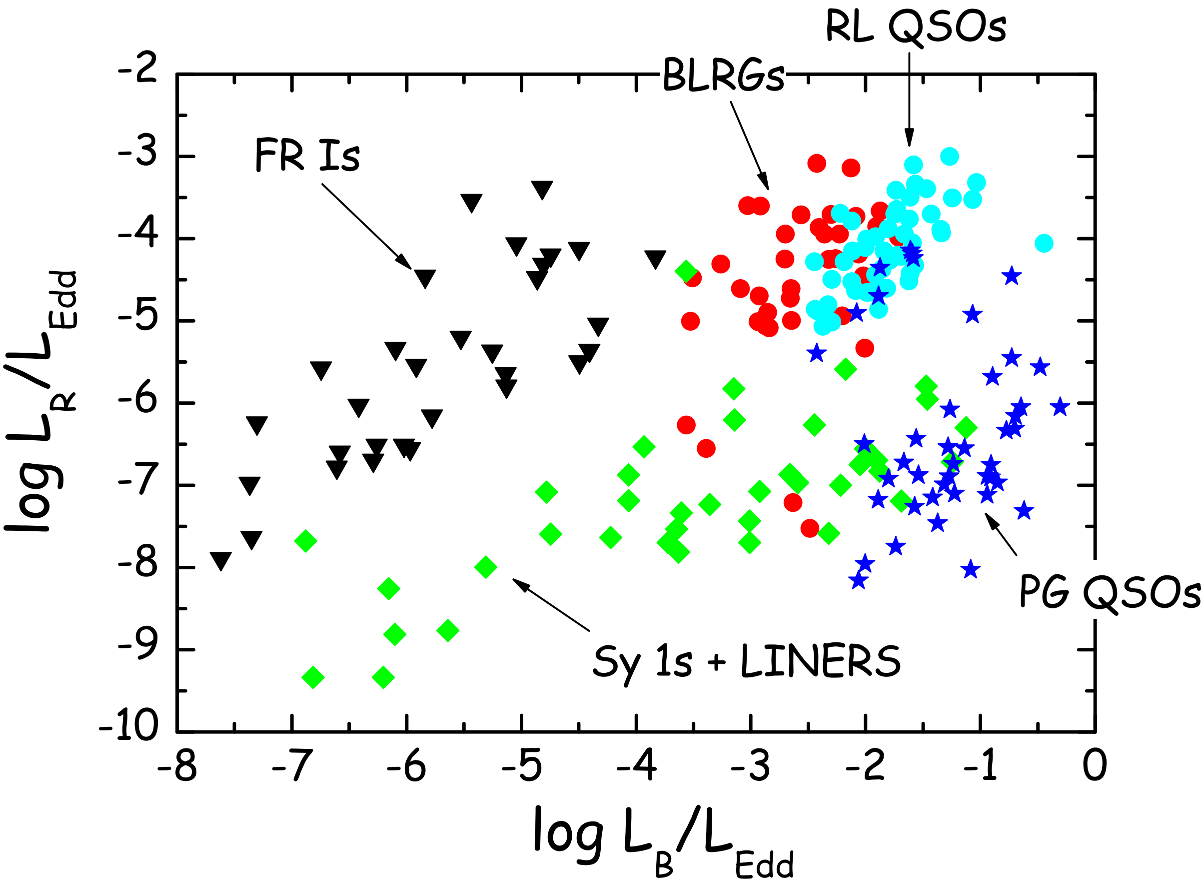
RL QSOs
BLRGs
FR Is
PG QSOs
Sy 1s + LINERS
log L_R/L_Edd
log L_B/L_Edd
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Fig. 2.—

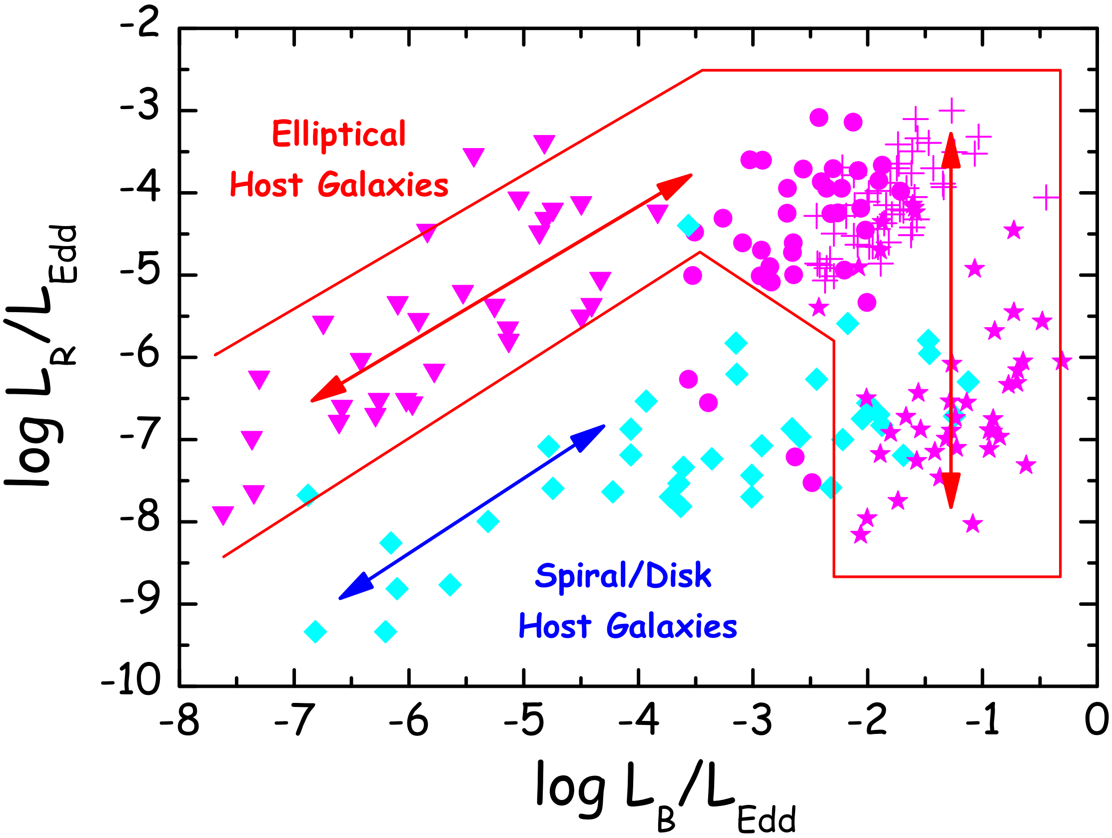
Elliptical
Host Galaxies
Spiral/Disk
Host Galaxies
log L_R/L_Edd
log L_B/L_Edd
-2
-3
-4
-5
-6
-7
-8
-9
-10
-8
-7
-6
-5
-4
-3
-2
-1
0

Fig. 3.—