On the two main classes of Active Galactic Nuclei

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Active Galactic Nuclei (AGN) are traditionally divided empirically into two main classes: "radio-loud" and "radio-quiet" sources. These labels, which are more than fifty years old, are obsolete, misleading, and wrong. I argue that AGN should be classified based on a fundamentally physical rather than just an observational difference, namely the presence (or lack) of strong relativistic jets, and that we should use the terms "jetted" and "non-jetted" AGN instead.

Everybody knows that AGN are powered by a supermassive black hole (SMBH). And (almost) everybody knows that there are two main classes of AGN: the "radio-loud" (RL) and the "radio-quiet" (RQ) ones. These classifications go all the way back to Sandage (1965), who realised, soon after the discovery of the first quasar, 3C 273, a very strong radio source, that there were many similar sources in the sky, which were however undetected by the radio telescopes of the time. It was later understood that these quasars were only "radio-faint", but the name stuck. Indeed, for the same optical power the radio powers of RQ quasars are a few orders of magnitude smaller than those of their RL counterparts. This is, in fact, how RQ quasars are characterised: relatively low radio-to-optical flux density ratios ($R \lesssim 10$) and radio powers ($P_{1.4\mathrm{GHz}} \lesssim 10^{24}$ W Hz^{-1} locally: e.g., Padovani, 2016).

We know now that RQ AGN are the norm, not the exception, as they make up the large majority ($> 90\%$) of the AGN class (e.g., Padovani, 2011). We also know that, despite what the odd labels might suggest, the differences between the two classes are not restricted to the radio band, far from it. And they are not simply taxonomic either, as the two classes represent *intrinsically* different objects, with most RL AGN emitting a large fraction of their energy non-thermally over the whole electromagnetic spectrum while the multi-wavelength emission of RQ AGN is dominated by thermal emission, directly or indirectly related to the accretion disk, which forms around the SMBH.

The most striking difference is in the hard X-ray to γ-ray band: while many (likely all: but see below) RL sources emit all the way up to GeV (2.4×10^{23} Hz), and sometimes TeV (2.4×10^{26} Hz), energies, nearby (RQ) bright Seyfert galaxies have a sharp cut-off at energies $\lesssim 1$ MeV (e.g., Malizia et al, 2014). This cut-off has to apply to the whole RQ AGN population in order not to violate the X-ray background above this energies (Comastri et al, 2005). Moreover, no RQ AGN has ever been detected in γ-rays (Ackermann et al, 2012a) with the exception of NGC 1068 and NGC 4945, two Seyfert 2 galaxies in which the γ-ray emission is thought to be related to their starburst component (Ackermann et al, 2012b). This means that, while RQ AGN are actually *not* radio-quiet, they are γ-ray-quiet.

What are the differences between the two classes due to? One simple thing: the presence (or absence) of a strong relativistic jet. The relative (and absolute) strength of the radio emission in the two classes is just a consequence of this fundamental *physical* difference. Hence the need for new and better names: jetted and non-jetted AGN (Padovani, 2016).

This is illustrated in Fig. 1, which compares the spectral energy distributions (SEDs) of typical non-jetted AGN with those of two jetted ones, a BL Lac and a flat-spectrum radio quasar (FSRQ). Both of these belong to the blazar class, which includes AGN with their jets oriented at a very small angle ($\lesssim 15-20^\circ$) with respect to the line of sight. Because of so-called unification models (e.g., Urry and Padovani, 1995), the SEDs of blazars are representative of *all* jetted sources as BL Lacs and FSRQs are intrinsically the same sources as low-and high-excitation radio galaxies (RGs) respectively, just seen at different angles (see also Heckman and Best, 2014). The SEDs of non-blazar, jetted AGN, are in fact just shifted to lower frequencies by δ^{-1} (where δ is the blazar Doppler factor; and to lower flux densities: Appendix B of Urry and Padovani 1995), and include also some extended, isotropic emission in the radio band and the host galaxy in the optical (typically swamped by the jet in blazars). As obvious from the Figure, the SED of non-jetted AGN has a cutoff at much lower energies than those of jetted AGN.

There are other reasons for dropping the old names. The classical distinction between RL and RQ sources (based either on R or radio power) is valid *only* for broad-lined, unobscured AGN, i.e. quasars and Seyfert 1s. Many RGs can have quite low R or radio power values, at levels typical of RQ AGN (Padovani et al 2011; Padovani 2016 and in particular Fig. 4 of Bonzini et al 2013). R is useful (and defined) for quasar samples, where it can be assumed that the optical flux is related to the accretion disk and therefore the radio-to-optical flux density ratio gives a measure of the jet/disk ratio. But it loses its meaning as an indicator of jet strength if the optical band is dominated by jet emission or by the host galaxy, as is the case in RGs. This has become quite obvious only recently with the study of the source populations in deep ($S_{\rm r} < 1$ mJy) radio fields, which have been detecting RL and RQ sources in similar numbers and at similar flux densities and radio powers (e.g., Padovani, 2016). Shall we start calling RGs with $R < 10$ "RQ AGN"? We should if we adhere to the old scheme but this would not make any sense.

Moreover, in the case of Seyfert galaxies R depends strongly on the spatial resolution of the optical and radio observations. Ho and Peng (2001) have shown that by considering their nuclear luminosities, most Seyfert 1 nuclei are RL, which further confuses the issue. Terashima and Wilson (2003) have introduced a new definition of the radio loudness parameter by using the ratio between radio and $2-10$ keV luminosity, $R_{\rm X}$. The idea was to avoid the extinction problems affecting the optical band in obscured AGN, which would lead to overestimated values of R. This might work if the $2-10$ keV luminosity were produced by the same emission mechanism in all RL AGN but we know this is not the case, as in some objects the X-ray luminosity can be dominated by the jet itself (e.g., Hardcastle et al, 2009).

How should the jetted and non-jetted AGN be defined? The RL/RQ division might not have been very meaningful when applied outside the quasar class but it had a simple (albeit of limited application) definition. I therefore provide here some guidance, on how to distinguish between the two classes.

1. Direct evidence of a strong jet. This is obviously easy for bright radio sources, where one can identify strong, large, and resolved relativistic jets, also by following them up over time to detect superluminal motion, a clear sign of jet speeds getting close to the speed of light (Appendix A of Urry and Padovani, 1995). However, in the deep radio fields discussed above most AGN have faint radio flux densities and are either unresolved or barely resolved.

2. γ-ray ($\gtrsim$ 1 MeV) emission (Fig. 1), as only jetted AGN manage to reach these energies. But even the Large Area Telescope on board *Fermi* has limited sensitivity: the surface density of jetted AGN in the γ-ray band is about four orders of magnitude lower than in the radio band (Padovani, 2016), which shows that present-day γ-ray observatories only probe AGN with much higher bolometric fluxes compared to the current generation of radio telescopes.

3. Radio-excess off the far-infrared (FIR) – radio correlation. The FIR and radio emission are strongly (and linearly) correlated in a variety of star-forming sources and non-jetted AGN (e.g., Padovani, 2016, and references therein). Recent star formation is believed to be the driver of this correlation, at least in star-forming galaxies. Jetted AGN, because of their strong jet-related radio emission, display instead a "radio excess", which puts them off the correlation. Non-jetted AGN can have a radio core with flux density larger than their extended, likely star-formation-related component (e.g., Maini et al, 2016, and references therein). Therefore, it somewhat matters where one draws the line (e.g., jetted AGN can be defined as being off the correlation by more than 2σ, where σ is the dispersion around the correlation). This radio-excess criterion, although indirect, is the simplest one to apply.

I want to stress that jetted AGN are characterised by *strong, relativistic* jets. Non-jetted AGN can also have radio structures similar to collimated outflows but these "jets" are small, weak, and slow compared to those of jetted sources (e.g., Middelberg et al, 2004).

Having understood the major difference between the two AGN classes, I think we should now concentrate on the physics and the really big and long-standing question: *Why are only a minority of AGN jetted*? We do have some hints, as jetted AGN *appear* to be more clustered, undergo mergers, reside in more massive, bulge-dominated galaxies (and perhaps spin faster) than non-jetted AGN. All we have to do is take advantage of the huge amount of radio data, which will be coming in the very near future (e.g. Padovani, 2016, and references therein) and answer it!

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References

Ackermann M, Ajello M, Allafort A, et al (2012a) Search for Gamma-ray Emission from X-Ray-selected Seyfert Galaxies with Fermi-LAT. Astrophys J 747:104, DOI 10.1088/0004-637X/747/2/104

Ackermann M, Ajello M, Allafort A, et al (2012b) GeV Observations of Star-forming Galaxies with the Fermi Large Area Telescope. Astrophys J 755:164, DOI 10.1088/0004-637X/755/2/164

Bonzini M, Padovani P, Mainieri V, et al (2013) The sub-mJy radio sky in the Extended Chandra Deep Field-South: source population. MNRAS 436:3759–3771, DOI 10.1093/mnras/stt1879

Comastri A, Gilli R, Hasinger G (2005) Rolling down from the 30 keV peak: Modelling the Hard X-Ray and γ-Ray Backgrounds. Experimental Astronomy 20:41–47, DOI 10.1007/s10686-006-9041-6

Hardcastle MJ, Evans DA, Croston JH (2009) The active nuclei of $z < 1.0$ 3CRR radio sources. MNRAS 396:1929–1952, DOI 10.1111/j.1365-2966.2009.14887.x

Harrison C (2014) Observational constraints on the influence of active galactic nuclei on the evolution of galaxies. PhD thesis, Durham University

Heckman TM, Best PN (2014) The Coevolution of Galaxies and Supermassive Black Holes: Insights from Surveys of the Contemporary Universe. Annu Rev of Astron and Astrophys 52:589–660, DOI 10.1146/annurev-astro-081913-035722

Ho LC, Peng CY (2001) Nuclear Luminosities and Radio Loudness of Seyfert Nuclei. Astrophys J 555:650–662, DOI 10.1086/321524

Maini A, Prandoni I, Norris RP, Giovannini G, Spitler LR (2016) Compact radio cores in radio-quiet active galactic nuclei. Astron Astrophys 589:L3, DOI 10.1051/0004-6361/201628305

Malizia A, Molina M, Bassani L, et al (2014) The INTEGRAL High-energy Cut-off Distribution of Type 1 Active Galactic Nuclei. Astrophys J Lett782:L25, DOI 10.1088/2041-8205/782/2/L25

Middelberg E, Roy AL, Nagar NM, et al (2004) Motion and properties of nuclear radio components in Seyfert galaxies seen with VLBI. Astron Astrophys 417:925–944, DOI 10.1051/0004-6361:20040019

Padovani P (2011) The microjansky and nanojansky radio sky: source population and multiwavelength properties. MNRAS 411:1547–1561, DOI 10.1111/j.1365-2966.2010.17789.x

Padovani P (2016) The faint radio sky: radio astronomy becomes mainstream. Astron Astrophys Rev 24:13, DOI 10.1007/s00159-016-0098-6

Padovani P, Miller N, Kellermann KI, et al (2011) The VLA Survey of Chandra Deep Field South. V. Evolution and Luminosity Functions of Sub-millijansky Radio Sources and the Issue of Radio Emission in Radio-quiet Active Galactic Nuclei. Astrophys J 740:20, DOI 10.1088/0004-637X/740/1/20

Padovani P, Alexander DM, Assef RJ, et al (2017) Active Galactic Nuclei: what's in a name? ArXiv e-prints (arXiv:1707.07134)

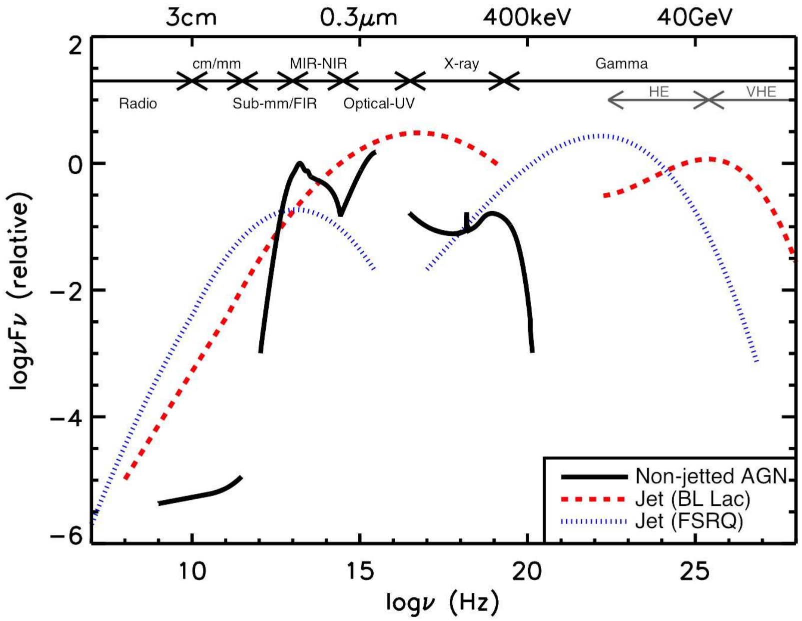

Figure 1: A schematic representation of AGN SEDs. The black solid curve represents the typical SED of non-jetted AGN, while the red and blue lines refer to two jetted AGN, namely a BL Lac (based on the SED of Mrk 421) and an FSRQ (based on the SED of 3C 454.3). Adapted from Harrison (2014) and Padovani et al (2017). Image credit: C. M. Harrison.

Sandage A (1965) The Existence of a Major New Constituent of the Universe: the Quasistellar Galaxies. Astrophys J 141:1560, DOI 10.1086/148245

Terashima Y, Wilson AS (2003) Chandra Snapshot Observations of Low-Luminosity Active Galactic Nuclei with a Compact Radio Source. Astrophys J 583:145–158, DOI 10.1086/345339

Urry CM, Padovani P (1995) Unified Schemes for Radio-Loud Active Galactic Nuclei. Publications Astron Soc Pacific 107:803, DOI 10.1086/133630

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