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The global properties of all variety of AGN

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Abstract. Active Galactic Nuclei (AGN) have been a challenging field of research for the past six decades. Nevertheless, many questions still remain unanswered today, regardless of the tremendous theoretical and technological advances. In this brief review I propose to take a step back from the usual discussion of AGN properties and draw attention to some topics that I believe are important to keep in mind as we strive forward in our pursuit of knowledge about these sources.

1. Foreword

The first class of Active Galactic Nuclei (AGN) was recognised over six decades ago when Carl Seyfert selected and studied a group of galaxies with unusual nuclear properties. Since then observational windows beyond the visual boundaries have been opened into the Universe and consequently a variety of phenomena have been discovered and catalogued. Complementary to the technological development, great steps forward have been made in both theory and interpretation providing the concept that unification of ultimately all AGN types is attainable. What I find interesting is that over the decades a circular pattern seems to have developed: a technological advancement, which is both possible and necessary by previous work, leads to the discovery of a new phenomenon requiring a massive investigation via surveying large numbers of sources, which in turn provokes a new wave of interpretation and theoretical modelling, thus prompting the building of new instruments. The circular pattern is renewed, and with each renewal we diversify the variety of phenomena, but at the same time our confidence in a unified picture increases.

What I propose to do in this review is to discuss some steps along the circular pattern in the search of understanding AGN that I am more familiar with, and which I believe are important to keep in mind as we strive forward. In particular, I will dedicate some time to the more general question of what is it that constitutes an AGN, their properties, and the ever present problem of selection effects. In the final Section I will mention the search for a parameter space that allows the unification of all types of AGN. I would like to point out, however, that I do not pretend to make a complete review of the subject (as this would be impossible given the time and scope of the present meeting), and apologise for leaving out many undoubtedly important, aspects of AGN studies.

2. What is an AGN?

What are the basic criteria that lead an object to be classified as an AGN? This is more than a simple academic question, and one that assumes particular relevance as we develop new and more sensitive instruments offering closer insights into the properties of the so-called ‘normal’ and ‘active galaxies’.

Clearly what is understood by an AGN is dependent on the ever evolving wealth of multi-wavelength data. Nevertheless, the underlying characteristic of these sources is their extra activity across the electromagnetic spectrum. For example, the galaxies studied by Carl Seyfert were peculiar in that they showed broader emission lines than the other, more usual, spiral galaxies. (In fact, finding broad emission lines in the spectrum of a given source is one of the most conclusive ways of determining the presence of an AGN.) A decade or so later after Seyfert published his work on the galaxies with unusual spectra, the advent of radio astronomy disclosed that some galaxies were strong emitters in this region of the electromagnetic spectrum. As we know, the discovery of the first quasar was a direct consequence of the optical identification of radio sources, and the subject of Active Galactic Nuclei was forever established.

Many years after, and many technological and theoretical steps forward, a paradigm for AGN has formed (see Figure 1). Its basic assertion is that AGN drive their power from the accretion of matter onto a supermassive ($M_{bh} \geq 10^5 M_\odot$) black hole. The signature of the disc is picked up across the spectrum in the optical, UV and X-rays. Broad emission lines are produced by gas moving rapidly in the potential of the black hole, while, further away from the black hole, slower moving gas is responsible for narrower line emission. Because some sources fail to show broad emission lines, except in polarized light, an obscuring torus or warped disc has been assumed although its morphology and properties is still subject of much work. In a subgroup (typically considered to be less than 20%) of the AGN population, strong radio emission is associated with relativistic jets and radio lobes that can extend over many kiloparsecs.

Even though Figure 1 summarises the acquired knowledge over decades of work, the fact is that much remains to be done and understood. Two comments should accompany the AGN diagram of Figure 1. Firstly, even if we have identified the different ingredients that are related to the AGN phenomena, we have yet to understand fully how the different combinations arise, or how they relate to each other. Why do some sources show the radio strong structures and others do not? Do the properties of the obscuring material vary with luminosity, type of source, redshift? These are just examples of questions that have persisted for years, in spite of being the topic of continued research. The second comment is concerned with the lack

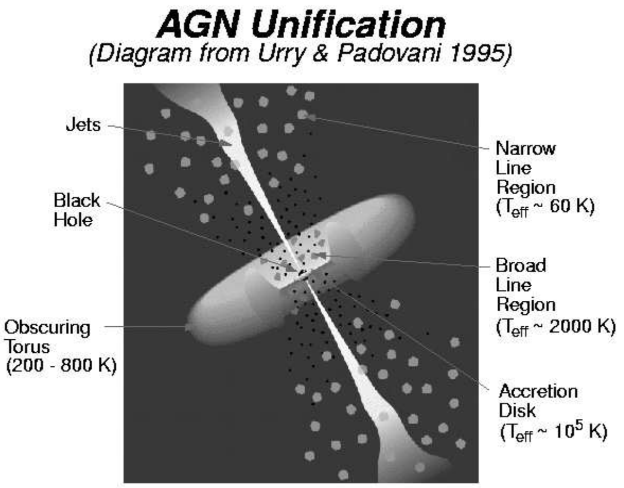

Fig. 1. The AGN diagram is taken from Urry & Padovani, (1995), and annotated by M. Voit. It shows the ingredients of all types of AGN: the central black hole and accretion disk, the broad line region and the obscuring torus that hides it from some directions of observation, the narrow line region further out from the black hole, and finally the radio jets and extended emission.

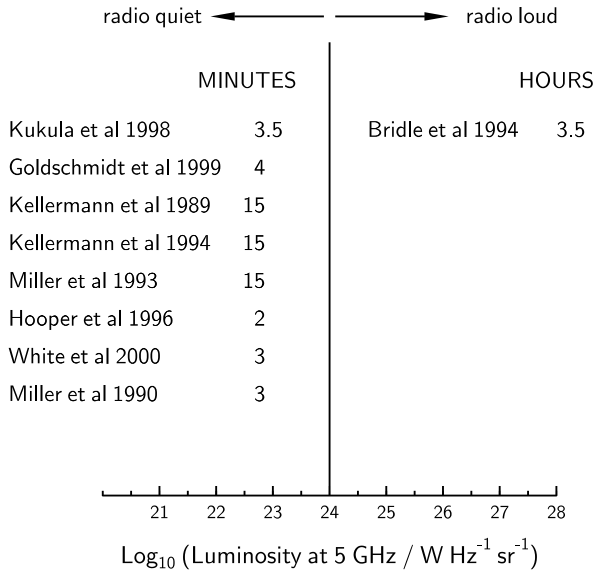

Fig. 2. The figure is taken from Blundell (2003 and it summarises the average integration time for observations of RQ and RL sources).

of spherical symmetry in AGN. Such lack of symmetry means that depending on the relative orientation between observer and source, the effects of projection, relativistic beaming, and obscuration, the same object can appear significantly different. Distinguishing between intrinsic differences and those induced by selection effects is not a simple task, but one which is always relevant when analysing AGN samples. This will be discussed in the next Section.

3. The properties of AGN

Surveys and catalogues are inevitable steps in any scientific area where quantitative results are pursued. The topic of AGN is no exception. We want to know how many there are, are they all the same, how are they distributed, how do the properties vary with cosmic time, or with luminosity, or any other property?

In order to answer these questions it is first necessary to create some order in the multitude of observed properties. Since optical and radio surveys of AGN were the first to be carried out, a great deal of the classification process is linked to the properties of sources in these two regions of the electromagnetic spectrum. For instance, the classification of Quasar was given to those sources that appeared point like on the optical charts but whose spectra showed broad emission lines, whereas the term Radio Galaxy was assigned to those sources with strong radio emission but which appeared fuzzy in optical catalogues. Many other classes and sub-classes of AGN are now in use depending on the combination of properties such as detectability, polarization, spectra and variability. However, in 1995 Urry & Padovani proposed a simplification of the AGN diversity by suggesting three classes of sources according to the optical and UV spectra:

Type 1 AGN: those with bright continua and broad emission lines in their spectra. These include Seyfert type 1, Quasars and Broad Line Radio Galaxies (BLRGs). According to the diagram of Figure 1, these sources correspond to those that the observer sees at angles that allow direct observation of the broad line region.

Type 2 AGN: those with weak continua and only narrow emission lines in their spectra. These broadly include Seyfert type 2, Narrow Line Radio Galaxies (NLRGs). In the framework of the AGN diagram of Figure 1, these sources correspond to those objects which the observer sees along the direction of the obscuring 'torus'.

Type 0 AGN: those sources which lack strong emission or absorption features in the their spectra (BL Lacs), or those quasars which are highly polarized (HPQ for Highly Polarized Quasar), or extremely variable in the optical (the OVV for Optically Violently Variable). According to the schematic model for an AGN shown in Figure 1, these types of sources are thought to be those where the direction of the radio jet is well aligned with the line of sight.

Even though classification is an important stage in the pursuit of knowledge, the real scientific quest lies beyond that. In particular, the goal is is to try and look for relationships between classes and distinguish between those properties that are intrinsic, and those that are induced by the observing criteria and/or sensitivity of the instruments. In this Section I would like to draw attention to two outstanding issues that can be used to illustrate this point.

Case 1: The radio-loud/radio-quiet bimodality. The fact is that there seems to be a split in the the Spectral Energy Distribution (SED) of AGN at radio-frequencies, with the radio-quiet (RQ) AGN lacking the relativistic jet emission and lobe structures seen in their radio-loud (RL) counterparts. In order to discuss the subject more objectively, empirical criteria were independently set to separate the two sub-groups. Specifically, RQ AGN have been separated by requiring that either their radio luminosity at 5 GHz $L_5 < 10^{24}$ W Hz^{-1} sr^{-1} (Miller et al., 1990), or that the ratio of radio to optical flux ($r = S_{5GHz}/S_{4400\text{Å}} < 10$, Kellermann et al. 1994). Evidence for and against the bimodality using a variety of surveys has been found by a number of authors (White et al. 2000, Ivezic et al. 2002; Cirasuolo, et al 2003, just to mention a few more recent works). The issue is obviously of extreme importance for the understanding of the AGN phenomena. If there is truly a bimodality rather than a continuity in the radio properties of AGN, then we need to find out what is (are) the parameter(s) responsible for setting on/off the radio emission mechanism. At this point it may help to take a step back and ask the question of whether the bimodality claimed by some works could be the result of incompleteness or sensitivity related problems, rather than intrinsic differences in the population. This exercise is of particular relevance when recent claims that superluminal motion have been discovered in a couple of sources classified as RQ (Brunthaler et al. 2000, Blundell, et al., 2003a) according to the empirical criteria mentioned before. A closer look at these criteria reveals some potential problems with such sharp cutoffs. In the case of the ratio r, the danger is that the same cutoff value of 10, when applied to different samples, may introduce different biases. In general, the optical flux contains the contributions from both the host galaxy, and the AGN nucleus. However, the amounts of galaxy and nuclear light contributing to the flux measured through a fixed size aperture varies significantly with redshift. The consequence of this is that the optical flux measured for a sample of quasars will be mostly nuclear flux, while for a sample of close by objects the optical flux measured will include a significant contribution of the host galaxy light. Hence, the quantity r will actually measure different things in the two samples. This has been noted by Ho & Peng (2001) who have pointed out that a large fraction of Seyfert galaxies, usually considered to be RQ, would actually become RL objects according to the r criterion, if only their nuclear contribution was considered for the optical flux.

Looking now to the other parameter used to separate RL from RQ AGN, I draw attention to Figure 2 of Blundell (2003) which is reproduced here (Figure 2) where a simple listing of mean length of time-on-source for observations of RQ and RL sources is put side by side. It is striking to remark that the observations referring to the RQ sources range in the units of minutes, while those referring to the RL sources are in units of hours. Moreover, the author points out that in addition to the significantly shorter integration times for the RQ sources, these observations were usually made using the most extended VLA configurations which are less sensitive to low surface brightness, extended emission. As a conclusion, I would like to point out that it is remarkable that such a long standing issue in AGN such as the RQ/RL dichotomy/continuity is still plagued, not so much by the lack of good quality data, but rather by selection effects.

Case 2: The Radio Luminosity Function (RLF). One of the fundamental questions about AGN in general, but also about the different classes, is how many there are, how do they distribute themselves, and how did they come into being. Faced with the impossibility of following the life cycle of such a source, the best we can achieve is a statistical description of the data. A usual way of doing this is to determine the luminosity function (LF) that basically describes how the comoving number density of sources varies with luminosity. Traditionally, radio surveys have been preferred since radio waves are unaffected by dust obscuration, hence the determination of RLF for AGN. Two of the most recent determinations of the RLF at 1.4 GHz considering large number of sources (>500) are shown in Figure 3 (taken from Sadler et al. 2002). The triangles represent star forming galaxies (SF), and the squares the AGN. The full line represents the data from Sadler et al., and the dashed line that of Machalski & Godlowski (2000).

A couple of noteworthy points should be made about these results. The first is that the SF galaxies and AGN contribute significantly to the local RLF for radio powers below 10^{24} W Hz^{-1}. The second point is that the agreement between the two works represented in Figure 3 over much of the range of luminosities covered, breaks down when the samples are split into SF and AGN. In the estimate of Machalski & Godlowski 2000 (dashed line) the contribution of SF galaxies decreases below radio powers of roughly 10^{24} W/Hz, whereas in the estimate by Sadler et al. (full line) this contribution continues to rise all the way radio powers of $\sim 10^{22}$ W/Hz. Can this discrepancy be the consequence of selection effects? Sadler et al. (2002) actually discusses briefly the possible reasons for this divergence in the contribution of SF galaxies at low radio powers. Their conclusion is that both selection differences and misclassification of low power AGN as SF galaxies can be responsible for incompleteness in the Machalski & Godlowski data. Such conclusion brings to the fore, once again, the importance of identification and classification of sources.

Basic difficulties such as being able to separate and recognise AGN activity will be particularly relevant in forthcoming surveys at the μ-Jy level where extrapolations of the local RLF suggest that a mixture of AGN and SF galaxies will be found at all redshifts (see Sadler et al. 2002 for references).

4. Searching for the parameter space where unification is possible

The idea that the diversity of AGN can be understood via a reduced number of parameters has been around for some time now. The first suggestions of a unifying scheme had obscuration and orientation as fundamental parameters (Rowan-Robison 1976, Lawrence & Elvis, 1982). The discovery of superluminal motion in flat radio spectrum sources, and its consequent interpretation in terms of bulk relativistic motion, implied that the appearance of a radio-loud object could change dramatically depending on the orientation. Hence, obscuration, orientation, and Doppler boosting had to be taken into account in order to unify all types of AGN.

In general, unification is discussed in two parallel schemes: one for the radio-quiet, where Seyfert 1 and Seyfert 2 galaxies are interpreted as intrinsically the same but where the latter are seen along a direction that hides the broad line region behind a 'torus' (Antonucci & Miller, 1985). On the other hand,

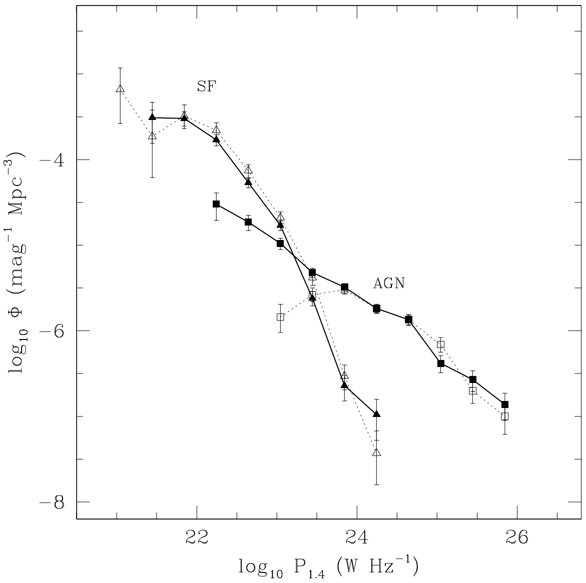

Fig. 3. The RLF from Sadler et al. (2002). The triangles refer to star forming galaxies and squares to AGN; the dashed lines refer to the estimate of Machalski & Godlowski (2000).).

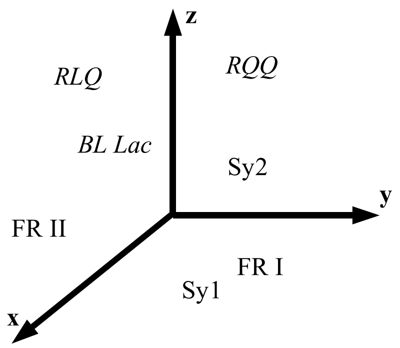

Fig. 4. Schematic representation of the parameter space to unify the AGN diversity. The challenge is to establish x, y, z as the parameters that control the life cycle of and AGN.).

the scheme for radio-loud sources, needs to complement orientation and obscuration with the effects of Doppler boosting in order to unify the lobe-dominated and core-dominated sources (Orr & Browne, 1982; Barthel, 1989; Urry & Padovani, 1995).

Despite the relative success of the unification schemes for the AGN diversity, there is a growing feeling that a broader unification is necessary if we are to understand the phenomena in its entirety. The realisation that all galactic nuclei contain a black hole whose mass is closely related to macroscopic quantities such as the luminosity and the stellar velocity dispersion (Magorrian, et al. 1998; Gebhardt, et al. 2000; merritt & Ferrarese, 2001) gave a new impetus to the concept of unification schemes. In fact, schemes are no longer just sought for understanding AGN diversity 'per se'. The goal is now to obtain a 'grand unifying scheme' that can offer a 'global' connection between AGN and galaxy formation and evolution, since AGN activity seems inevitably related to a phase (or phases), in the life cycle of a galaxy. What we seek now is to identify the axis x, y, z of a parameter space (see Figure 4) where the AGN diversity is understood in terms of an evolutionary process that involves the characteristics of the black hole at the centre, and its immediate and more ample environment.

The present knowledge about AGN and black hole physics gives hints as to what parameters will play a role: mass accretion rate seems to be extremely important for the emission properties of the central source (Meier, 2002), and it may be responsible for triggering on/off the AGN activity or even a sequence in the activity (Urry, 2003; Cavaliere & d'Elia, 2002; Cao, 2003). On the other hand, black hole spin has long been deemed relevant for the jet production (Blandford & Znajek, 1977; Meier 2002 for references), and though much work seems to be required especially in what concerns the magnetic field, it is likely that this characteristic will have a role to play in the grand unification scheme of AGN. Finally, environment and interaction between galaxies is bound to influence significantly the observed properties of AGN, as they may dictate when and how this 'active' phase is triggered. As a concluding remark, I would argue that finding the axis of the parameter space that trace the AGN/galaxy evolution, and diversity, is one of the biggest and challenging endeavours in the study of Active Galactic nuclei.

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References

Antonucci, R.R.J., & Miller, J.S., 1985, ApJ, 297, 621.
Barthel, P.D., 1989, ApJ, 336, 606.
Blandford, R.D., & Znajek, R., 1977, MNRAS, 179, 433.
Blundell, K.M., Beasley, A.J., Bicknell, G.V., 2003a, ApJ. 591, L103.
Blundell, K.M., 2003, NewAR, 47, 593.
Brunthaler, A., Falcke, H., Bower,G.C., Aller, M.F., Aller, H.D., Tersranta, H., Lobanov, A.P., Krichbaum, T.P., Patnaik, A.R., 2000, A&A, 357, L45.
Cavaliere, A. & D'Elia, V., 2002, ApJ, 571, 226.
Cao, X., 2003, ApJ, 599, 147.
Cirasuolo, M., Celotti, A., Magliocchetti, M., Danese, L., 2003, MNRAS, 346, 447.
Fanaroff, B. L. & Riley, J. M., 1974, MNRAS, 167, 31.

Gebhardt, K. et al., 2000, ApJ, 539, L13.
Ho, L.C. & Peng, C.Y., 2001, ApJ, 555, 650.
Ivezic, Z. et al. 2002, AJ, 124, 2364.
Kellermann, K.I., Sramek, R.A., Schmidt, M., Green, R.F., Shaffer, D.B., 1994, AJ, 108, 1163.
Lawrence, A. & Elvis, M., 1985, ApJ, 256, 410.
Machalski, J. & Godlowski, W., 2000, A&A, 360, 463.
Magorrian, J., et al., 1998, AJ, 115, 2285.
Meier, D.L., 2002, NewAR, 46, 247.
merritt, D. & Ferrarese, L., 2001, MNRAS, 320, L30.
Miller, L., Peacock, J.A., Mead, A.R.G., 1990, MNRAS, 244, 207.
Orr, M.J.L., Browne, I.W.A., 1982, MNRAS, 200, 1067.
Rowan-Robinson, M., 1976, ApJ, 213, 635.
Sadler, E.M. et al., 2002, MNRAS, 329, 227.
Urry C.M. & Padovani, P., 1995, PASP, 107, 803.
Urry, C.M., 2003, In: Active Galactic Nuclei: from Central Engine to Host Galaxy, Eds.: S. Collin, F. Combes and I. Shlosman. ASP Conference Series, 290, p. 3.
White, R.L., et al., 2000, ApJS, 126, 133.