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The toroidal obscuration in AGN

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Observations give strong support for the unification scheme of active galactic nuclei (AGN), based on toroidal dusty obscuration of the central engine. The inevitable spread in torus properties invalidates the widespread notion that type 1 and 2 AGNs are intrinsically the same objects. Instead, AGNs are drawn *preferentially* from the distribution of torus covering factors; type 1 are more likely drawn from the distribution lower end, type 2 from its higher end. Studies of unification statistics cannot be performed without taking into account the intrinsic distribution of torus covering factors. The only practical way to determine this distribution function is from modeling of the infrared emission of a complete sample of AGNs blindly selected from hard X-ray surveys, such as *INTEGRAL* observations.

The broad line region (BLR) and the dusty torus are, respectively, the inner and outer segments, across the dust sublimation radius, of a continuous cloud distribution. All clouds are embedded in a disk wind, whose mass outflow rate is diminishing as the accretion rate, i.e., AGN luminosity, is decreasing. Both the torus and BLR disappear at sufficiently low luminosities, leaving radio jets as the sole release channel for the accreted mass that does not reach the central black hole.

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[*] Speaker.

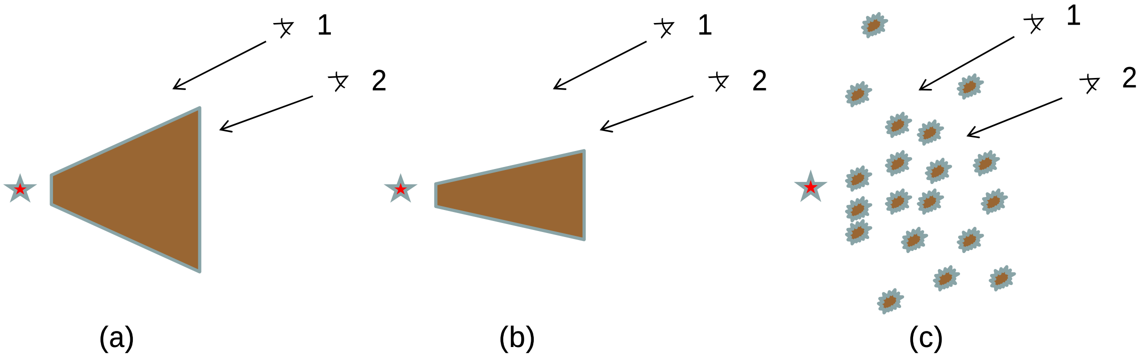

Figure 1: AGN classification in unified schemes. (*a*) In a smooth-density torus, everyone located inside the cone opening, such as observer 1, will see a type 1 source; outside—a type 2. (*b*) Decreasing the torus covering factor, the source becomes a type 1 AGN for more observers. (*c*) In a clumpy, soft-edge torus, the probability for direct viewing of the AGN decreases away from the axis, but is always finite.

1. AGN Unification

The basic premise of the unification scheme is that every AGN is intrinsically the same object: an accreting supermassive black hole. This central engine is surrounded by a dusty toroidal structure so that the observed diversity simply reflects different viewing angles of an axisymmetric geometry (figure 1). The classification of AGNs into types 1 and 2 is based on the extent to which the nuclear region is visible. Directions with clear sight of the central engine and the broad-line region (BLR) yield type 1 sources. Those blocked by the torus from direct view of the BLR result in type 2 objects, where the existence of the hidden BLR is revealed only in polarized light [1]. From basic considerations, Krolik & Begelman [15] concluded that the torus likely consists of a large number of individually very optically thick dusty clouds. Indeed, VLTI interferometic observations of the Circinus AGN provide strong evidence for a clumpy or filamentary dust structure [25].

In unification's simplest form, dubbed the straw person model (SPM) by Antonucci [1], the AGN viewing angle is the sole factor determining its classification; that is, the torus is assumed identical for all AGNs of the same luminosity.[1] However, all AGNs cannot be expected to have the exact same torus; there must be a spread in torus properties, even among AGNs with the same luminosity. This has immediate, fundamental consequences. In panel (a) of figure 1, observer 1 will see the AGN as type 1, observer 2 as type 2. In panel (b) the AGN orientation is the same as in panel (a), only its torus has a smaller covering factor. Now both observers see a type 1 object even though their viewing angles have not changed. Evidently, the torus covering factor C_T is as central to AGN classification as is the viewing angle because an AGN whose torus has a larger covering factor has a higher probability to be viewed as type 2 by a random observer. This is obvious also for the more realistic clumpy torus, shown in panel (c) of figure 1. Therefore, in a sample of AGNs with a distribution of covering factors, those with a larger C_T will have a higher probability to be viewed as type-2 by a random observer, implying that

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[1] For the variation of torus covering factor with AGN luminosity see [16] and references therein.

> *AGNs are drawn* **preferentially** *from the distribution of covering factors; type-1 are more likely drawn from the distribution lower end, type-2 from its higher end.*

This is a more realistic formulation of the unification scheme than SPM, with profound implications for AGN studies. Contrary to the widespread notion that type 1 and type 2 AGNs are intrinsically the same objects, fundamental differences between their average properties do exist. Covering factors deduced from analysis of type 2 sources do not necessarily apply to type 1, and vice versa. This explains why the fraction of Compton thick AGNs (X-ray obscuring column $N_{\rm H} \gtrsim 10^{24}\,\rm cm^{-2}$) was determined to be as high as 50% in a pre-selected sample of Seyfert 2 [21, 11] but only $\sim$ 20% in complete X-ray samples without spectroscopic pre-selection [17, 2]. It also explains the seemingly puzzling results of the recent study [20] by Ricci et al of all $z < 0.2$ Seyfert galaxies detected with *INTEGRAL* (see also talk by R. Walter in these proceedings). They analyzed in detail stacked hard X-ray spectra (50–200 keV). In agreement with the basic tenets of unification, both Seyfert 1 and Seyfert 2 were found to have the same average nuclear emission continuum, with a photon index of $\Gamma = 1.8$. But in apparent contradiction with unification, the reflection component was significantly stronger for the average spectrum of Compton thin Seyfert 2 than for Seyfert 1. Ricci et al find this discrepancy to arise from a further sub-division among the Seyfert 2 AGNs. The “lightly obscured" ones ($N_{\rm H} < 10^{23}$ cm^{-2}) have the same reflection component as Seyfert 1, $R \lesssim 0.4$, but those that are “mildly obscured" ($10^{23}\,\rm cm^{-2} \le N_{\rm H} < 10^{24}\,\rm cm^{-2}$) display a much stronger reflection with $R = 2.2^{+4.5}_{-1.1}$. While this finding contradicts the simplistic forms of unification, it is precisely the behavior expected from its realistic formulation: Seyfert 1 and lightly obscured Seyfert 2 correspond to different viewing angles of intrinsically similar AGNs, drawn from the low end of the covering factor distribution, thus they conform, on average, to simplistic unification. But in mildly obscured Seyfert 2 the absorber/reflector covers a larger fraction of the X-ray source, producing stronger reflection that is not seen in the average Seyfert 1 spectrum, where large covering factors are rare. The large difference between the average reflection spectra of Seyfert 1 and 2 arises from a significant difference in their average intrinsic properties.

Implicitly or explicitly, all studies of AGN statistics assume that type 1 and type 2 are intrinsically the same objects. This conflicts not only with the realistic formulation of unification but also with observations [20], and may contribute to discrepancies among studies of AGN statistics. Schmitt et al [22] find that the type 2 fraction among Seyfert galaxies is $\sim$70%, while Hao et al [12] find it to be only $\sim$50%. However, Schmitt et al used IR emission for sample selection; thanks to the larger covering factor of their torus, Seyfert 2 convert a larger fraction of their luminosity to IR, therefore IR-selection is biased in their favor. The opposite afflicts the line selection criterion of Hao et al, which introduces preference for smaller covering factors and type 1 AGNs. All previous findings involving unification statistics, including the synthesis of the cosmic X-ray background (e.g., [9, 24]), therefore need a critical reexamination and revision. One cannot draw statistical inferences from AGN populations without folding in the intrinsic distribution of torus covering factors, which is unknown. A reliable determination of this distribution requires an unbiased, complete sample of AGNs, which can only be selected through hard X-ray surveys.[2] From the catalogue of *INTEGRAL* observations in the 20–40 keV band, Malizia et al [17] extracted a

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[2] Note, however, that hard X-ray selection is still biased against sources absorbed with column density above 10^{25} cm^{-2}; i.e., these surveys miss the heavily obscured Compton thick AGN [2, 4].

complete sample of 88 AGNs, including type classification. Using 0.3–195 keV data from *Swift*–BAT observations and the *XMM-Newton* archive, Burlon et al [2] have recently compiled another complete sample that contains 199 type classified AGNs. Identifying *Spitzer* counterparts to AGNs in these samples and fitting their IR observations with clumpy torus models is the only feasible approach to determining the distribution function of torus covering factors.

2. Low-Luminosity AGNs

In spite of the considerable success of the unification scheme there is now clear evidence [14] that the BLR is actually missing, and not just hidden, in many low-luminosity AGNs (LLAGNs); these sources have been named “pure” or “true” type 2 AGNs. The BLR disappearance finds a natural explanation in the disk-wind scenario, first proposed by Emmering et al [8]. The AGN accretion disk appears to be fed by a midplane influx of cold, clumpy material from the main body of the galaxy. Approaching the center, conditions for developing hydromagnetically- or radiatively-driven clumpy winds above this equatorial inflow become more favorable. The composition along each streamline reflects the origin of the outflow material at the disk surface. The disk outer regions are dusty and molecular, as observed in water masers in some edge-on cases [10]. Moving inward, at some smaller radius the dust is destroyed and the disk composition switches to atomic and ionized. The outflow from the inner atomic/ionized region feeds the BLR while the dusty clouds in the wind outer regions obscure the inner zones. As clouds rise away from the disk they expand and lose their column density, limiting the vertical scope of both broad-line emission and dust obscuration and emission. The result is a toroidal geometry for both the BLR and the obscuring region, i.e., the torus, which may be more appropriately named in this scenario the Toroidal Obscuration Region (TOR). Thus the toroidal obscuration arises in this picture from a dynamic rather than hydrostatic structure. An immediate consequence of this scenario is the prediction that the TOR and BLR disappear at low bolometric luminosities (i.e., low accretion rates; [7, 5]). The reason is that, as the mass accretion rate decreases, the mass outflow rate of a disk wind with fixed radial column decreases more slowly and thus cannot be sustained below a certain accretion limit. This unavoidable conclusion follows from simple considerations of mass conservation. In accordance with this model predictions, data from a nearly complete sample of nearby AGNs show that the BLR disappears at luminosities lower than $5\times10^{39}\,(M_\bullet/10^7M_\odot)^{2/3}$ erg s^{-1} [6]; every source below this limit is a “true” type 2 AGN. The TOR disappearance has been verified, too, in a number of independent studies which show the lack of obscuration [3, 18] and of thermal dust emission [27, 19, 26] in LLAGNs.

Since the accreted mass cannot be channeled in full into the central black hole, with the disk-wind turning off the system must find another release for the excess mass, and the only remaining channel is the radio jets. Indeed, Ho [13] finds that the AGN radio loudness $\mathscr{R} = L_{\rm radio}/L_{\rm opt}$ is *inversely* correlated with the mass accretion rate $L/L_{\rm Edd}$. This finding is supported by Sikora et al [23][3], who have greatly expanded this correlation and found an intriguing result: $\mathscr{R}$ indeed increases inversely with $L/L_{\rm Edd}$, but only so long as $L/L_{\rm Edd}$ remains $\gtrsim 10^{-3}$. At smaller accretion

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[3] As pointed out by the authors, the Sikora et al sample is incomplete and might underestimate the luminosity of the FR I radio galaxies, for which there are no direct signatures of accretion flow, by a factor > 10. This could have an impact on their correlation.

rates, which include all FR I radio galaxies, the radio loudness saturates and remains constant at $\mathscr{R} \sim 10^4$. This is precisely the expected behavior if as the outflow diminishes, the jets are fed an increasingly larger fraction of the accreted mass and finally, once the outflow is extinguished, all the inflowing material not funneled into the black hole is channeled into the jets, whose feeding thus saturates at a high conversion efficiency of accreted mass. It is important to note that radio loudness reflects the relative contribution of radio to the overall radiative emission; a source can be radio loud even at a low level of radio emission if its overall luminosity is small, and vice versa.

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