The Central Engines of Low-Luminosity AGNs

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Abstract. I summarize the main characteristics of AGNs in nearby galaxies and present a physical picture of their central engines.

1. The “Top 10” Properties of Low-luminosity AGNs

Although the physical nature of some low-luminosity AGNs (LLAGNs) is still not fully understood, the weight of the recent cumulative evidence suggests that a significant fraction of them are genuinely accretion-powered sources. Here I identify the most important observational characteristics of these objects, which point to some novel insights on the structure of their central engines.

(1) **Demography.** LLAGNs are very common. According to the Palomar survey (Ho, Filippenko, & Sargent 1997), over 40% of nearby galaxies, and an even greater fraction of bulge-dominated systems, contain LLAGNs.

(2) **Low ionization.** The dominant population (2/3) of LLAGNs have low-ionization state spectra. They are classified as either LINERs or transition objects.

(3) **Low accretion power.** LLAGNs are intrinsically faint. Figure 1a, from Ho (2003), shows the distributions of bolometric luminosities for \( \sim 250 \) objects from the Palomar survey. Note that nearly all the objects have \( L_{\text{bol}} < 10^{44} \text{ erg s}^{-1} \), and most significantly less. Seyferts are on average 10 times more luminous than LINERs or transition objects.

(4) **Sub-Eddington.** LLAGNs are highly sub-Eddington systems, as shown in Figure 1b. Most have \( \lambda = L_{\text{bol}} / L_{\text{Edd}} < 10^{-2} \). Seyferts have systematically lower \( \lambda \) than LINERs or transition objects.

(5) **Radiatively inefficient.** Direct measurements of accretion rates are not available, but rough estimates can be made of the likely minimum rates supplied *in situ* through stellar mass loss and Bondi capture of hot gas. Ho (2003) finds \( \dot{M} \gtrsim 10^{-5} - 10^{-3} M_\odot \text{ yr}^{-1} \). If this gas were to be all accreted and radiates with a standard efficiency of \( \eta = 10\% \), the nuclei should be \( 1 - 4 \) orders of magnitude more luminous than observed. This suggests that either only a tiny fraction of the available gas gets accreted (the rest, e.g., being driven out by winds) or that \( \eta \) is much less than 10%. The latter possibility is consistent with models for radiatively inefficient accretion flows (e.g., Quataert 2001). (Incidentally, the above estimates indicate that, insofar as the majority of nearby AGNs are concerned, there is no motivation to seek additional sources of fuel supply, such as through bar dissipation. Far from needing to find ways to feed the nucleus from gas on large scales, the problem is in fact the opposite, namely how to get rid of or hide the material that is already there.)
(6) No “big blue bump.” With few exceptions, the spectral energy distributions (SEDs) of LLAGNs lack the optical–UV “big blue bump,” a feature usually attributed to thermal emission from an optically thick, geometrically thin accretion disk (Ho 1999; Ho et al. 2000). Instead, there appears to be an IR excess.

(7) “Big red bump.” Most of the SEDs contain a maximum in the IR, whose peak is currently poorly defined because of the current lack of sufficient high-resolution IR data.

(8) Radio loud. The SEDs of LLAGNs are also generically radio loud. This is true of most LINERs (Ho 1999, 2002; Ho et al. 2000; Terashima & Wilson 2003), and, contrary to persistent popular misconception, is true even for most Seyfert nuclei (Ho & Peng 2001).

(9) No broad Fe Kα line. The 6.4 keV Fe Kα line is detected in some LLAGNs, but it is almost always narrow (Terashima et al. 2002).

(10) “Batman” line profiles. Emission lines with broad, double-peaked profiles, taken to be the kinematic signature of a relativistically broadened disk, are found quite often in LLAGNs (Ho et al. 2000, and references therein; Barth et al. 2001; Eracleous & Halpern 2001).

2. A Physical Picture of the Central Engine

I propose that the above set of characteristics, common to most LLAGNs studied in detail thus far, suggest that nearby galaxy bulges contain central engines as schematically depicted in Figure 2. Most galaxies with bulges contain active nuclei because most, if not all, bulges contain massive black holes. This is the picture that is emerging from recent kinematical studies of nearby galaxies (e.g., Gebhardt et al. 2003). In the present-day universe, and especially in the centers
of big bulges, the amount of gas available for accretion is quite small, plausibly well below the Eddington rate for the associated black hole mass (Ho 2003). In such a regime, the low-density, tenuous material is optically thin and cannot cool efficiently. Rather than settling into a classical optically thick, geometrically thin disk, the hot accretion flow assumes a quasi-spherical configuration, whose dynamics may be dominated by advection, convection, or outflows (see Quataert 2001 for a review). For simplicity, I follow Quataert (2001) and simply call these low-radiative efficiency accretion flows (LRAFs). The existence of LRAFs in these systems, or conversely the absence of classical thin disks extending all the way to small radii (few $R_S$), is suggested by their (1) low luminosities, (2) low Eddington ratios, (3) low inferred radiative efficiencies, (4) lack of a big blue bump, and (5) lack of relativistically broadened Fe Kα lines.

Apart from a central LRAF, two additional components generally seem to be required. First, detailed considerations of the broadband SED show that the baseline LRAF spectrum underpredicts the observed radio power (e.g., Quataert et al. 1999; Ulvestad & Ho 2001). Most of the radio luminosity, which is substantial because these objects tend to be “radio-loud,” must come from another component, and the most likely candidate is a compact jet. Does the puffed-up structure of an LRAF, or its propensity for outflows, somehow facilitate the generation of relativistic jets? Second, an outer thin disk, truncated at perhaps $\sim 100 - 1000 R_S$, seems necessary to explain (1) the existence of the “big red bump” in the SED (e.g., Quataert et al. 1999) and (2) the prevalence of double-peaked broad emission lines (Chen, Halpern, & Filippenko 1989; Ho et al. 2000).
Lastly, we note that low-ionization spectra may emerge quite naturally in the scenario suggested above. In the context of AGN photoionization models, it is well known that LINER-like spectra can be produced largely by lowering the “ionization parameter” $\dot{U}$, typically by a factor of $\sim 10$ below that in Seyferts (e.g., Halpern & Steiner 1983; Ferland & Netzer 1983). The characteristically low luminosities of LINERs (Fig. 1a), coupled with their low densities (Ho, Filippenko, & Sargent 2003), naturally lead to low values of $\dot{U}$. Two other effects, however, are also important in boosting the low-ionization lines. All else being equal, hardening the ionizing spectrum (by removing the big blue bump) in photoionization calculations creates a deeper partially ionized zone from which low-ionization transitions, especially $[\text{O I}] \lambda\lambda 6300, 6363$, are created. Because of the prominence of the radio spectrum, cosmic-ray heating of the line-emitting gas by the radio-emitting plasma may be nonnegligible; one consequence of this process is again to enhance the low-ionization lines (Ferland & Mushotzky 1984).

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