WHY ARE THEY NOT AGN?

Roberto Soria[1], **Alister W. Graham**[2], **Giuseppina Fabbiano**[1], **Alessandro Baldi**[1], **Martin Elvis**[1], **Helmut Jerjen**[2], **Silvia Pellegrini**[3], **and Aneta Siemiginowska**[1]

[1]Harvard-Smithsonian Center for Astrophysics, 60 Garden st, Cambridge, MA 02138, USA
[2]RSAA, Australian National University, Cotter Rd, ACT 2611, Australia
[3]Astronomy Department, Bologna University, Italy

ABSTRACT

We have studied the X-ray luminosity of the nuclear SMBH of a sample of quiescent early-type galaxies, and the inflow rate of the hot gas, feeding the SMBH. We have also studied the additional contribution of warm gas from stellar winds. Assuming an ADAF-like radiative efficiency, we find that only a fraction $\sim$ 1–10% of the gas is accreted onto the SMBH; the rest must be removed or used to form new stars. Self-regulated feedback from the SMBH can provide the power necessary to remove the gas. Slow outflows can remove most of the mass, while a fast jet can carry out most of the accretion power.

Key words: galaxies: nuclei — X-rays: galaxies.

1. NUCLEAR X-RAY EMISSION FROM QUIESCENT EARLY-TYPE GALAXIES

Most of the galaxies in the nearby universe have inactive nuclei (X-ray luminosities $\lesssim 10^{40}$ erg s^{-1}). This may be due to an interplay of different factors: low rate of gas injection/inflow inside the "sphere of influence" of the supermassive black hole (SMBH); low fraction of the available gas being accreted onto the SMBH; low radiative efficiency of accretion, with the rest of the accretion power being advected, or carried out as mechanical luminosity by a jet or an outflow. Our goal is to estimate these factors quantitatively, to discriminate between different radiatively-inefficient scenarios, and to outline the power and mass budget inside the sphere of influence. To do so, we have selected a sample of six quiescent early-type galaxies with known SMBH mass (Table 1). Using new *Chandra* data, we have determined: the X-ray luminosity of the nuclear sources; the radial profile, average temperature and central density of the surrounding hot interstellar medium (ISM); and the classical Bondi rate ($\dot{M}_{\rm B}$) of inflow of the hot ISM into the SMBH sphere of influence (Soria et al. 2006a, 2006b). Typical hot-gas densities are ~ 0.01–0.03 cm^{-3}. The other main results are summarized in Table 1. We found that the nuclear sources are much fainter than predicted by the standard-disk scenario (which is also ruled out by other theoretical considerations at such low accretion rates). However, they are brighter than predicted by radiatively-inefficient models, in particular by the advection-dominated accretion flow (ADAF) model. This suggests that, when we take into account only the X-ray emitting gas, we are underestimating the true accretion rate $\dot{M}$ (Soria et al. 2006a). We then considered another eighteen galaxies for which the SMBH X-ray luminosity and the Bondi inflow rate have been calculated or constrained from previous work (Pellegrini 2005, and references therein). For most of these galaxies, the SMBH X-ray luminosity is lower than predicted by the standard ADAF model, suggesting that the true accretion rate $\dot{M} \ll \dot{M}_{\rm B}$. Overall, there is little or no correlation between Bondi rate and X-ray luminosity of the SMBH (Fig. 14 in Soria et al. 2006a).

2. HOW MUCH OF THE GAS AVAILABLE IS ACCRETED?

To make sense of these contradictory findings, we need to keep in mind that the hot, X-ray emitting ISM may represent only a small fraction of the gas fuelling the SMBH. That can be the case in systems where gas can cool efficiently (cooling timescale < accretion timescale), or, vice versa, if gas is injected into the inner regions in a cool or warm phase and is accreted before it has time to virialize. We use optical brightness profiles to obtain a complementary estimate of the gas injection rate into the SMBH sphere of influence (Soria et al. 2006b). The stellar contribution can be estimated by deprojecting the optical brightness profiles to obtain the volumetric luminosity densities, and applying standard relations between optical luminosity, stellar densities and ages, and mass loss rates. We found typical stellar mass loss rates $\sim 10^{-4}$–$10^{-3} M_{\odot}$ yr^{-1}; on the other hand, the hot gas content varies greatly, leading to X-ray-estimated Bondi rates from $\lesssim 10^{-5}$ to $\sim 10^{-2} M_{\odot}$ yr^{-1} over the full sample of galaxies.

Table 1. Mass accretion rate and X-ray luminosity of the SMBH in our target galaxies.

Galaxy (1)	Distance (Mpc) (2)	$M_{\rm BH}$ ($M_\odot$) (3)	$\log(\dot{M}_{\rm B}/\dot{M}_{\rm Edd})$ (4)	$\log L_{\rm X}$ (erg s^{-1}) (5)	$\log(L_{\rm X}/L_{\rm Edd})$ (6)	$\dot{M}_*/\dot{M}_{\rm B}$ (7)	$\log L^{\rm A}_{\rm X}$ (erg s^{-1}) (8)	$\dot{M}/\dot{M}_{\rm t}$ (9)
N821	24.1	$0.85^{+0.35}_{-0.35}$	-4.7	< 38.7	< -7.3	19	41.3	$< 7\%$
N3377	11.2	$1.0^{+0.9}_{-0.1}$	-4.9	38.5	-7.6	93	42.5	2%
N4486B	16.9	$0.5^{+0.5}_{-0.2}$	< -5.0	38.4	-7.4	> 2	39.0	50%
N4564	15.0	$0.56^{+0.03}_{-0.08}$	-5.4	38.9	-7.0	74	41.0	12%
N4697	11.7	$1.7^{+0.2}_{-0.1}$	-4.4	38.6	-7.7	6	41.2	7%
N5845	25.9	$2.4^{+0.4}_{-1.4}$	-4.7	39.4	-7.0	31	42.1	7%

Notes: Col. 4: $\dot{M}_{\rm B}$ is the classical Bondi inflow rate estimated from BH mass, density and temperature of the X-ray emitting gas; Col. 5: 0.3–10 keV luminosity of the nuclear source; Col. 7: $\dot{M}_*$ is the estimated warm gas inflow rate from stellar winds, inside the SMBH sphere of influence; Col. 8: predicted X-ray luminosity if all the inflowing hot and warm gas were accreted at ADAF efficiency; Col. 9: fraction of the inflowing gas that has to be accreted, assuming ADAF efficiency, to reproduce the observed SMBH X-ray luminosity. See details in Soria et al. (2006a, 2006b).

We have added these two components ($\dot{M}_{\rm B}$ and $\dot{M}_*$) to estimate the total mass injection rate $\dot{M}_{\rm t}$. Only an *a priori* unknown fraction of this gas reaches the SMBH (the rest being re-ejected, stored, or turned into new stars), which adds another parameter to the model. And only an *a priori* unknown fraction of the accretion power is released as X-ray flux (the rest being advected or carried out as mechanical luminosity, in a radio jet or a wind). Various accretion flow solutions (standard disk, ADAF, etc.) have different predictions for the fraction of gas accreted by the BH, and for its radiative efficiency. Assuming the ADAF radiative efficiency $\eta \approx 10\dot{M}/\dot{M}_{\rm Edd}$, the observed X-ray luminosities imply that, for most galaxies, only $\sim$ 1–10% of the inflowing gas is accreting onto their SMBHs (Table 1, Col. 9). We suggest that the intrinsic scatter in $\dot{M}_*$ and in the accretion fraction is the main reason for the lack of correlation between the Bondi rate and the X-ray luminosity of the SMBH.

3. MASS AND ENERGY BUDGET OF THE NUCLEAR SMBH

What are the conditions for mass equilibrium inside the SMBH sphere of influence, and the fate of the gas that does not sink into the SMBH? It is possible that in some cases (most notably in NGC 5845), part of the excess gas may cool down, settle into a dusty/stellar disk, and eventually form new stars, even inside the Bondi accretion radius. In our current work (Soria et al. 2006b), we have used the simplifying assumption that star formation is negligible, and most of the gas is removed from the nuclear region by slow, massive outflows. Soria et al. (2006b) discuss possible sources of energy that can remove that amount of gas. To reach a steady state, avoiding an implausible degree of fine-tuning between injection, accretion, and outflow rates, both the accretion rate and the outflow rate must be self-regulating. This happens, for example, if the accretion rate is proportional to the gas density or total mass inside the sphere of influence of the SMBH, and the power carried by the outflow is proportional to the accretion power. In this case, the system can reach an asymptotic equilibrium; this mechanism relies on the idea of SMBH feedback.

We have estimated what fraction of the accretion power has to be used to drive away the excess gas. Pure ADAF solutions require a highly efficient feedback coupling, essentially because most of the accretion power is lost into the BH. Other radiatively inefficient solutions (e.g., the ADIOS model) only require that $\lesssim 1\%$ of the available accretion power be used for the feedback. Hence, a fast jet may still carry outwards $\gtrsim 99\%$ of the accretion power. If the jet is fully relativistic, it can carry outwards $\sim 0.1\%$ of the inflowing mass, with the rest being either accreted or removed by feedback-driven, slow outflows. If the jet is only midly relativistic ($v_{\rm w} \lesssim 0.5c$), it can carry away an amount of mass comparable to what sinks into the SMB, $\sim 10\%$ of the inflowing gas, with the difference being removed by a slower outflow component.

REFERENCES

Pellegrini, S. 2005, ApJ, 624, 155

Soria, R., Fabbiano, G., Graham, A. W., et al. 2006a, ApJ, in press

Soria, R., Graham, A. W., Fabbiano, G., et al. 2006b, ApJ, in press