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Silent Super-Massive Black Holes

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Abstract This paper reviews some recent work on high-resolution *Chandra* observations of inactive Super-Massive Black Holes (SMBHs) in nearby galaxies. The aim of this work is to explore observationally nuclear feedback in galaxy formation by understanding the interaction between accretion and black hole activity in these extreme quiescent nuclei.

Key words: nuclei – X-rays: galaxies

1 INTRODUCTION

The work presented in this paper is the result of collaboration with many colleagues, including S. Pellegrini, R. Soria, A. Siemiginovska, A. Baldi, L. Greenhill and M. Elvis.

The question that we want to investigate is the lack of AGN activity in most galaxies. That AGNs are only a small percentage of all galaxies has been a well known fact since their discovery. But now, it is also well established that all massive bulges host a super-massive black hole (SMBH; see Tremaine et al. 2002 and refs. therein), and one would expect that even moderate accretion on these SMBHs would cause AGN activity. Observationally, we seek to investigate the properties of these quiescent galactic nuclei, principally in the X-ray band, but also in the entire wavelength spectrum when possible. We also seek to constrain observationally the amount of fuel available to these SMBHs, and search for observational evidence of past nuclear activity. The sub-arcsecond angular resolution of *Chandra* provides the necessary sensitivity and imaging capability for these investigations.

Why are most SMBHs quiescent? What is their X-ray luminosity? A possibility is that they are heavily obscured AGNs, but it is also possible that there is only limited gas available for accretion. With *Chandra*, we can detect luminosities corresponding to 10^{-8}–10^{-7} of the Eddington luminosity of the SMBH, constrain the amount and properties of the hot component of the ISM that may fuel the SMHBs (e.g. Fabbiano et al. 2003; Soria et al. 2006a, b; Pellegrini et al. 2007a, b), and image the relics of past nuclear activity in this hot ISM (e.g. Jones et al. 2002; Fabbiano et al. 2004).

2 ARE SILENT SMBHS COMPTON-THICK OBSCURED AGNS?

An AGN may emit little in the soft X-rays, if the nucleus is surrounded by dense enough clouds; these obscured AGNs tend to have prominent fluorescent Fe K 6.4 keV emission lines in their X-ray spectra (e.g. Ueno et al. 1994). In at least one case, IC1459 (Fabbiano et al. 2003), we can exclude an obscured AGN. IC1459, has a nuclear source with a luminosity $L_{\rm X} \sim 10^{-6} L_{\rm E}$, where $L_{\rm E}$ is the Eddington luminosity, for its $10^8 M_\odot$ SMBH, and the constraint on the Equivalent Width of an Fe K 6.4 keV line is stringent enough to exclude a Compton-thick spectrum. The radio-to-X-rays SED can be fitted with a jet model. However, in other cases (see NGC 821 below) this option cannot be excluded.

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3 WHAT REGULATES NUCLEAR ACCRETION?

If obscuration is not the culprit, then accretion (or lack thereof), may be. Pellegrini (2005) studied a sample of silent SMBHs in early-type galaxies using archival *Chandra* observations, from which the luminosity of the nucleus and the Bondi accretion rate of the surrounding hot ISM could be derived. In all cases, the X-ray luminosity $L_{\rm X}$ is well below the Eddington luminosity for the standard efficient accretion model. Moreover, Pellegrini finds that $L_{\rm X}$ is: (1) not correlated with the mass of the SMBH; (2) also not correlated with the Bondi accretion rate. These results may be suggestive of nuclear feedback during past active phases disrupting the accretion flow (Binney & Tabor 1995; Ciotti & Ostriker 2001). Moreover, the majority of these faint nuclei have $L_{\rm X}$ even lower than predicted by inefficient ADAF models (e.g. Narayan 2005), with Bondi accretion rate, giving rise the following possibilities: (a) either accretion may be impeded (e.g. by angular momentum in the flow); or (b) the accretion power may be carried out via mechanical energy (jet/outflow); or (c) accretion may be lost to star formation; or finally (d) there might be something wrong with our interpretation of the diffuse X-ray emission as gaseous and/or with our assumption of gas parameters.

In Soria et al. (2006a, b) we revisited these issues with the observations of a sample of extremely quiet SMBHs, galaxies with well-measured dynamical black hole masses and no evidence whatsoever of nuclear activity at any observed frequency. Compared with the nuclei compiled by Pellegrini, these observations show that the detected luminosities exceed those predicted for ADAF models with accretion at the Bondi rate, derived from the diffuse X-ray emission. This suggests that there must be an additional source of fuel: colder ISM, not visible in X-rays, resulting from stellar outgassing in the nuclear vicinities (the latter had also been considered in the case of NGC 821, one of these galaxies, by Fabbiano et al. 2004). Modeling of optical observations of the circum-nuclear regions shows indeed that there is plenty of this fuel available, even too much! The accretion fraction needed to explain the observations is only 1%–50% of the available fuel. Where does this gas go? A possibility is jets, since these nuclei are indeed marginally consistent with the Merloni et al. (2003) 'fundamental plane' of accreting black holes. Other possibilities include dark nuclear outflows or star formation in the vicinities of the nuclei; we are exploring the latter with *Spitzer* observations.

4 A VERY DEEP MULTI-WAVELENGTH LOOK AT THE SILENT SMBH OF NGC 821

NGC 821 is an elliptical galaxy ($D = 24$ Mpc) with an old stellar population and a SMBH mass of $8.7{\times}10^7 M_\odot$ (corresponding to $L_{\rm E} \sim 1 \times 10^{46}$ erg s^{-1}); NGC 821 has a remarkably inactive nucleus (see refs. in Fabbiano et al. 2004; Pellegrini et al. 2007a). Our study of this galaxy demonstrates the need of deep high-resolution observations to explore inactive or weekly active SMBHs. NGC 821 was observed with *Chandra* first in 2002 for 39 ks (Fabbiano et al. 2004); this observation revealed a fuzzy, kpc-size S-shaped central emission, suggestive of a jet or hot filament, a handful of point-like sources (most likely luminous low-mass X-ray binaries - LMXBs, with $L_{\rm X} > 1.2 \times 10^{38}$ erg s^{-1}), and some circumnuclear diffuse emission, which could be due to hot gas, and therefore be a source of fuel for the SMBH.

These results were tantalizing enough to grant a deeper look. We now have a total of 230 ks with *Chandra* (Pellegrini et al. 2007a, b), which have led to the detection of 41 sources ($L_{\rm X} > 3 \times 10^{37}$ erg s^{-1}), with typical LMXB colors and luminosity function. Using globular clusters detected in both the *Chandra* and *Hubble* images of NGC 821 for accurate astrometry, we have identified the nuclear source, which is a slightly extended, hard ($\Gamma = 1.5$) emission region with $L_{\rm X} \sim 6 \times 10^{38}$ erg s^{-1}, near which there is some elongated (possibly jet-like) emission.

These deep observations also set a stringent upper limit of $< 1/10$ of the diffuse emission to the possible amount of circumnuclear hot ISM; most if not all of the diffuse emission can be explained with unresolved LMXBs. The spectrum of the diffuse emission, after all the detected LMXBs are subtracted, is hard and compatible with that of the LMXBs; moreover, the spatial distribution of this emission follows that of the stellar light and of the number density of detected LMXBs; finally, a comparison of hot and soft bands shows that a soft excess is only marginally possible in the central 10" (and within the uncertainties it may not be present). The extrapolation of the X-ray luminosity function of detected LMXBs to lower luminosity, and the inclusion of the expected stellar X-ray emission also accounts entirely for any residual diffuse emission.

If there is no hot ISM, there could still be some cold/warm ISM from stellar outgassing in the central region of NGC 821. Pellegrini ran a numerical simulation of the evolution of the ISM (cold and hot) and concluded that a small accumulation resulting in an accretion rate of a few $10^{-5} M_{\odot}\mathrm{yr}^{-1}$ could be expected. If this material ends up in a standard Shakura-Suniaev accretion disk, the accretion luminosity would be $\sim (1-4) \times 10^{41}$ erg s^{-1}, exceeding the bolometric luminosity of a few 10^{39} erg s^{-1} that we derive from the radio-to-X-rays SED of this nucleus.

Why is this nucleus so faint?

We considered various options: (a) The accretion flow may be disrupted, either because of angular momentum or because of circumnuclear star formation. Or, (b) the disk may be radiatively inefficient and coupled with outflows (e.g. Narayan 2005); this possibility may be supported by the jet-like emission we detect with *Chandra* and by the agreement of the NGC 821 nucleus with the Merloni (2003) diagram (although we only have an X-ray upper limit on a point source at the nucleus). Or, (c) the disk may be unstable (Janiuk et al. 2004). Finally (d), we may have an obscured AGN; given the faintness of the source we cannot set stringent limits on the Fe K 6.4 keV emission line, and otherwise this option would be consistent with the observed SED of the nucleus.The deciding factor would be an high-imaging-resolution IR observation to test for nuclear extinction.

5 SUMMARY

In conclusion, *Chandra* detections and sensitive limits show that quiescent SMBHs are extremely sub-Eddington. In some cases, very little hot ISM may be available for fueling the SMBH and stellar outgassing may dominate the fuel supply. However, typically only a small fraction of fuel is accreted; do we have winds? Dark jets? Nuclear feedback? Star formation? Not a single accretion and emission mechanism is emerging: the SED of IC1459 may be explained with a jet model; in the case of NGC 821 - an extreme quiet galactic nucleus - various possibilities exist, including disruption of the accretion flow, inefficient disk with outflow, disk instability, and an obscured AGN.

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