Host Galaxy Morphology and the AGN Unified Model

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Abstract. We use a sample of active galaxies from the Cosmic Evolution Survey to show that host galaxy morphology is tied to the accretion rate and X-ray obscuration of its active galactic nucleus (AGN). Unobscured and rapidly accreting broad-line AGNs are more likely to be in spheroid-dominated hosts than weak or obscured AGNs, and obscured AGNs are more likely to have disturbed host galaxies. Much of the disagreement in previous work on the AGN-merger connection is likely due to each study probing AGNs with different obscuration and accretion properties. Instead, only obscured AGNs seem to merger-driven, while weak AGNs are fed by stochastic processes in disks and rapidly-accreting broad-line AGNs require massive bulges. Our observed “unified model” for AGN hosts fits with theoretical models for merger-driven AGN evolution, but is also consistent with steady-state AGN activity.

1. Introduction

The most popular theoretical framework for coevolving active galactic nuclei (AGNs) and galaxies invokes major mergers to fuel both starbursts and quasars (Sanders et al. 1988; Hopkins et al. 2006). But there also exist secular processes which can grow AGNs in disks, through stochastic gas accretion and stellar mass loss (Hopkins & Hernquist 2006) or cold streams and disk instabilities (Bournaud et al. 2011). The relative dominance of these fueling modes may evolve: perhaps secular processes are efficient in the gas-rich $z > 0.5$ universe but mergers are required to funnel gas to galaxy nuclei at $z \sim 0$, in a way analogous to star-forming galaxies (e.g. Genzel et al. 2010).

Observations of AGN host galaxy morphologies have the potential to distinguish secular processes from merger fueling. Figure 1 shows examples of host morphology studies from X-ray AGNs at three different redshifts: $z \sim 0.03$ (Koss et al. 2010), $z \sim 0.75$ (Cisternas et al. 2011), and $z \sim 1.8$ (Kocevski et al. 2011). In each survey, AGNs and mass-matched inactive galaxies are blindly classified by visual inspection. Naively comparing the three results suggests evolution in the importance of merger fueling for AGNs, but each study is biased to selecting different kinds of AGNs.

Contrary to the classical unified model (Antonucci 1993), recent work has shown that rapidly accreting quasars have very different fueling and feedback modes from weak AGNs (Ho 2008; Trump et al. 2011; Antonucci 2011). In particular, Trump et al. (2011) shows that broad-line quasars have strong radiative winds and luminous accretion disks, while weakly accreting narrow-line AGNs have radiatively inefficient accretion flows and radio-mode feedback. Understanding AGN-galaxy coevolution then requires studying host galaxy type across the two axes of AGN accretion rate and obscuration. Yet previous AGN host studies (including those shown in Figure 1) have
Figure 1. The fraction of AGNs and inactive galaxies which are disturbed, measured from X-ray selected samples at three different redshifts: $z \sim 0.03$ (Koss et al. 2010), $z \sim 0.75$ (Cisternas et al. 2011), and $z \sim 1.8$ (Kocevski et al. 2011). At first glance, it appears that the AGN-merger connection evolves, with mergers driving AGNs locally but not in the past. However the apparent trend is probably caused by differences in the AGN samples rather than true evolution.

Generally not distinguished between weakly accreting LINERs, Compton-thick AGNs, and powerful quasars.

Here we study host galaxy morphologies for 70 X-ray selected AGNs from the Cosmic Evolution Survey (COSMOS, Scoville et al. 2007). These AGNs span three orders of magnitude in each of accretion rate and column density, and their observed data demonstrate that host galaxy type is connected to AGN properties.

2. Observational Data

We study AGN and host properties for the 70 COSMOS sources which have:

1. XMM point source detections from Brusa et al. (2010), with $L_X > 3 \times 10^{42}$ erg s$^{-1}$ and $> 40$ X-ray counts for accurate $N_H$ estimates.

2. High-confidence (> 90% likelihood as correct) redshifts and classification from optical spectroscopy (Trump et al. 2009a).

3. Rest-frame optical host galaxy morphologies from Gabor et al. (2009), restricted to $z < 1$ AGNs with HST/ACS imaging (Koekemoer et al. 2007).

The 70 AGNs include 5 broad-line, 38 narrow-line, and 27 optically dull AGNs.

We parameterize AGN accretion rate using the Eddington ratio, $\lambda_{\text{Edd}} \equiv L_{\text{bol}}/L_{\text{Edd}} \sim L_{\text{bol}}/M_{\text{BH}}$. Trump et al. (2011) already estimated $\lambda_{\text{Edd}}$ for unobscured ($N_H < 10^{22}$ cm$^{-2}$) AGNs in our sample, with $L_{\text{bol}}$ from model fits to the multiwavelength SEDs and $M_{\text{BH}}$. 
from broad emission lines (when available) or the $M_{BH} - M_*$ relation. For obscured ($N_H > 10^{22} \text{ cm}^{-2}$) AGNs, we cannot estimate $L_{bol}$ in the same fashion because most of the SED is heavily extincted. Instead we estimate $L_{bol}$ using an infrared bolometric correction, $L_{bol} = 8L_{6\mu m}$ (Richards et al. 2006). Note that for unobscured AGNs, this bolometric correction is roughly consistent with $L_{bol}$ measured from the SED method. For all AGNs $N_H$ is estimated from the X-ray spectra, using either the XMM-COSMOS data or the deeper Chandra data (Elvis et al. 2009) when available.

Morphology measurements for the host galaxies of the 70 AGNs are presented by Gabor et al. (2009). Briefly, HST/ACS images were fit with GALFIT (Peng et al. 2002), using a point source component to describe the AGN and a single Sérsic (1968) function to describe the extended galaxy. For many of narrow-line and lineless AGNs, a better fit was obtained without the point source component: for these systems we use the Sérsic-only fit of Gabor et al. (2009). In addition to the Sérsic index $n$, Gabor et al. (2009) also measure the asymmetry parameter $A$. We use $n$ and $A$ to group AGN host galaxies into three categories: $A > 0.5$ galaxies are disturbed, $n > 2.5$ galaxies are spheroid-dominated, and $n < 2.5$ galaxies are disks.

3. The Host Galaxies of Active Galactic Nuclei

Figure 2 shows the host galaxy morphology with AGN accretion rate and obscuration. Each quadrant of the figure corresponds to a different preferred host type. All 5 of the broad-line AGNs, which have the highest accretion rates among unobscured ($N_H < 10^{22} \text{ cm}^{-2}$) AGNs, have spheroid-dominated hosts. Weaker and obscured AGNs are frequently in disk galaxies, and hosts of obscured ($N_H > 10^{22} \text{ cm}^{-2}$) AGNs are more likely to be disturbed.

The changes in host type with AGN accretion rate and obscuration are consistent with merger-driven evolutionary models. For example, while weak AGNs might be fed by stochastic processes in disk galaxies (Hopkins & Hernquist 2006), mergers drive obscured AGNs (Sanders et al. 1988). Further, Hopkins et al. (2006) suggest that quasar feedback eventually blows out the obscuring material, resulting in a post-merger spheroid with an unobscured quasar. However, we cannot rule out steady-state AGN fueling: it may simply be that disturbed systems have more obscuring material, and efficiently fueling an unobscured quasar requires a massive spheroid. In either case, our work is additional evidence for a strong connection between galaxy properties and the growth and obscuration of their supermassive black holes.

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Figure 2. Accretion rate and obscuration for the AGNs in our sample, with host galaxy type shown by the symbols and colors. Host type comes from Gabor et al. (2009), and is determined after subtracting the point-source AGN. Spheroid hosts (with $n > 2.5$) are shown by filled red circles, disk hosts ($n < 2.5$) by blue bars, and irregular hosts ($A > 0.5$) by green asterisks. Error bars show the 1σ errors in accretion rate and obscuration from the model fits. Unobscured and rapidly accreting broad line AGNs prefer spheroid hosts, while weakly accreting AGNs are more frequently in disk galaxies and obscured AGNs are often disturbed.

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