From WFC3/IR: The Quenching Effect of AGN Feedback on Host Galaxies

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Abstract

AGN feedback may contribute to quenching of star formation by the expulsion or heating of cold gas, causing the host galaxy to evolve onto the red sequence (e.g., Di Matteo et al. 2005, Hopkins et al. 2006, Menci et al. 2008, etc). We probe for the effects of feedback on the stellar populations of 100 X-ray-selected AGN hosts at z ~ 1 in the Chandra Deep Field South (CDFS). Combining high spatial resolution optical imaging from HST ACS and near-IR imaging from WFC3/IR, NICMOS, and ISAAC, we test for the presence of young stars on kiloparsec scales, independent of dust extinction. In our sample, color contamination from AGN emission is reduced to ~0.02 magnitudes in NUV-R by (1) cutting objects from the sample that are morphologically dominated by a point source and (2) using wide, annular photometric apertures. **Due to large systematic errors caused by color contamination from AGN emission, integrated photometry is not reliable for evaluating host galaxy color in unobscured sources at z ~ 1.**

Correlations between near-UV / optical colors (tracing star formation on ~kpc scales) and AGN obscuration / X-ray hardness ratio (tracing the conditions of gas on ~pc scales) are expected if supermassive black holes play a role in the quenching of massive galaxies. Indeed, several QSO-mode feedback models (e.g., Hopkins et al. 2006, Menci et al. 2008) predict quenched, red stellar populations in unobscured AGN hosts. **However, we find little (< 0.3 mags) difference between the mean NUV - R color of the obscured (hard in X-ray) hosts and the unobscured (soft in X-ray) hosts beyond ~6 kpc, suggesting that the unobscured sources are not increasingly quenched of star formation.** We measure NUV – R color gradients with high-spatial resolution WFC3/IR imaging in the Early Release Science Region (ERS). **The mean NUV – R color gradients of unobscured and obscured sources differ by less than ~ 0.5 magnitudes at all radii greater than the resolution limit of ~1 kpc.** Both observations are inconsistent with an AGN feedback scenario involving *rapid, extended* quenching beyond ~ 1 kpc.

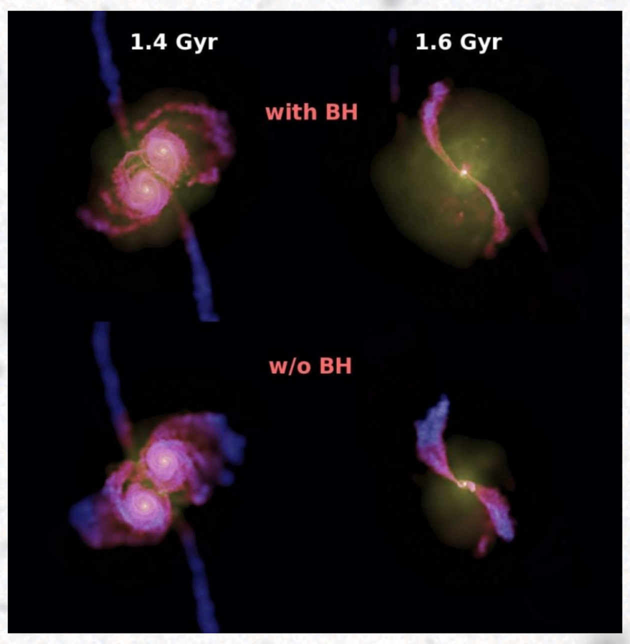
Observable Consequences of AGN-Driven Quenching

A consequence of the most energetic "AGN feedback" processes may be the expulsion of a majority of the galactic gas (Sanders et al. 1988; Di Matteo et al. 2005; Hopkins et al. 2006). This quenching of star formation may be a mechanism by which AGN activity controls the evolution of galaxies from the quiescent blue cloud to the red sequence.

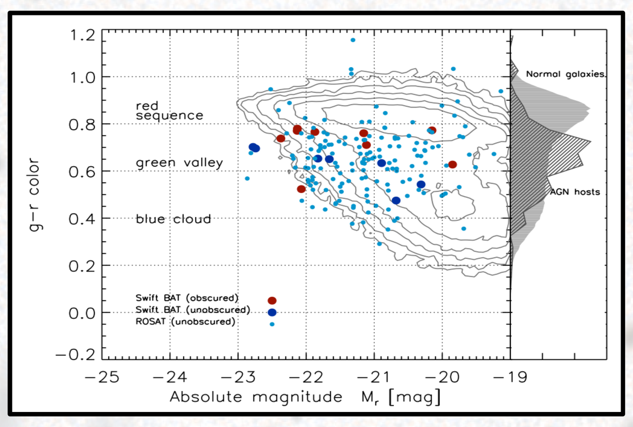
One feature of a model that includes rapid, AGN-induced quenching is an evolution between obscured and unobscured AGN states (Di Matteo et al. 2005; Hopkins et al. 2006; Menci et al. 2008). The ejection of gas/dust in the central core of the galaxy is quickly followed by gas removal on kpc scales. This process naturally produces a positive correlation between AGN obscuration and the mass fraction of young stars (a consequence of sufficient gas supply) in the host galaxies, ***such that unobscured AGN hosts should be redder than obscured AGN hosts*** (Menci et al. 2008).

Some observations are consistent with this expectation: Local obscured Seyferts are more associated with starforming activity than unobscured hosts (Cid Fernandes & Terlevich 1995; Gonzalez Delgado et al. 2001; Lacy et al. 2007; Ballantyne, D. 2008).

We study the NUV - R colors of AGN hosts at z ~ 1 and ***compare obscured and unobscured populations beyond a radius of ~ 6 kpc*** to probe for the effects of AGN feedback.



From Figure 2 of Di Matteo et al. (2005). Illustration of the effect of merger-driven AGN feedback on the colors of the merger remnant. The unobscured phase may be associated with quenched star formation and redder colors.



From Figure 2 of Schawinski et al. (2009). Host colors of local X-ray selected AGN appear to be independent of AGN obscuration.

X-ray-Selected Sample in CDFS

The Chandra Deep Field South (CDFS) has ACS imaging over 160 sq. arcminutes, matching deep ISAAC JHK imaging, and WFC3/IR F110W and F160 W over 50 sq. arcminutes.

Selection Criteria

1. 10^{42} ergs/s < L_X < 10^{45} ergs/s
2. Redshift cuts: 0.5 < z < 1.5
3. Spec. redshift available (R < 24)

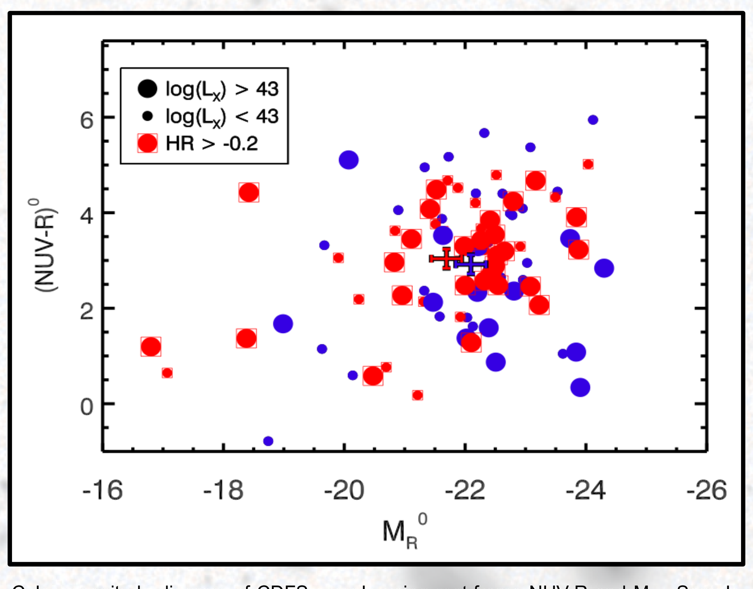
- We measure AGN host colors with *elliptical, annular apertures of large radius (projected radii 0.75" < r < 1.5")*
- We compare the mean rest-frame SED for obscured AGN hosts to unobscured AGN hosts
- Sample cuts are determined by an artificial galaxy test and the constraint to match redshifts of subsamples

WFC3 Early Release Science (ERS) Sample

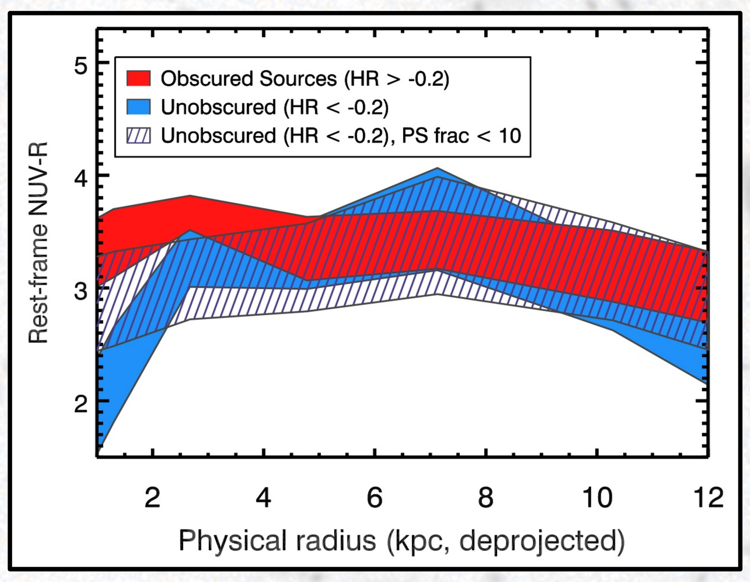
- WFC3/IR has observed 47 X-ray sources with 0.5 < z < 2 in GOODS ERS
- ***Color gradients of obscured and unobscured sources are similar*** following removal of objects contaminated by central point sources

Bin Name	Redshift Range	Mean z	# of sources
Strong Type I	$0.5 < z < 1.2$	0.848	18
Strong Type II	$0.5 < z < 1.3$	0.852	34
Weak Type I	$0.55 < z < 1.5$	0.834	22
Weak Type II	$0.5 < z < 1.5$	0.823	15

Number of GOODS sources in each bin after matching mean redshifts. **Type I:** unobscured or HR < -0.2; **Type II**: obscured or HR > -0.2; **Strong:** $L_X > 10^{43}$ erg/s; **Weak:** $L_X < 10^{43}$ erg/s



Color-magnitude diagram of CDFS sample using rest-frame NUV-R and M_R. Sample means are shown for the unobscured (blue circles) and obscured (red circles) as small central points with error bars.

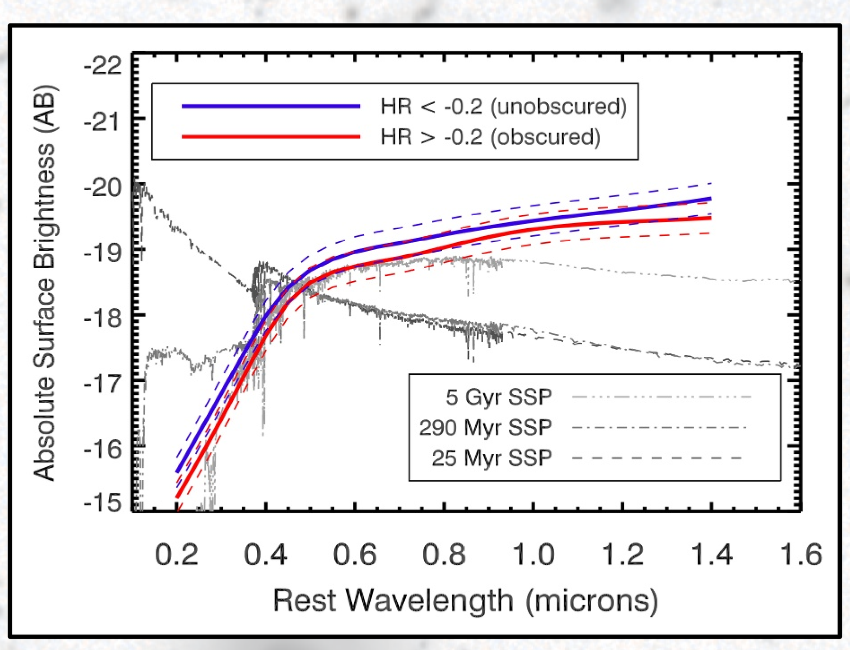


Mean color gradients for three populations in the WFC3 ERS sample: Obscured sources (HR > -0.2), all unobscured sources (HR < -0.2), and only unobscured sources with little point source contamination (Point Source Fraction < 10). Filled regions are 1σ confidence intervals. With the removal of sources strongly contaminated by central point sources, ***the mean color gradients of the obscured and unobscured sources are similar to ~0.5 magnitudes at all radii greater than 1 kpc.***

Unobscured and Obscured AGN Host SEDs are Similar

The mean SEDs of AGN hosts beyond r ~ 6 kpc are largely similar across X-ray obscuration. The unobscured AGN are 0.2 ± 0.22 magnitudes bluer in NUV – R than the obscured AGN, which is consistent with no difference.

We have checked this result with a stacking exercise, in which aperture photometry is performed on a stack of the processed images of a particular population. Stacking suggests that the unobscured AGN are 0.47 ± 0.25 magnitudes bluer in NUV - R than the obscured population. This value is changed by 0.02 magnitudes when aperture corrections are not computed, *suggesting that contamination of host color by AGN emission is insignificant.*



Logarithmic mean of surface brightnesses for unobscured sample and obscured sample. The dashed lines represent the one sigma uncertainties on the mean SEDs. Red lines denote measurements for unobscured AGN and blue lines denote measurements for obscured AGN. Single Stellar Population models (Bruzual & Charlot 2003) with solar metallicity and varying ages (5 Gyr, 290 Myr, 25 Myr) are shown for comparison.

Our sample includes only 2 objects with QSO-like luminosities (log L_X > 44) yet with low point source contamination (measured with concentration: $C_{0.2/1.0}$). However, quenched merger remnants are expected to fall into intermediate-luminosity range shortly after the QSO episode, so surveys of intermediate-luminosity AGN have some leverage over QSO-mode scenarios. These observations do not provide support for or against a major merger-driven fueling scenario, as energetic AGN feedback has been proposed without major mergers as a triggering mechanism (Ciotti & Ostriker 2007).

The observations are consistent with:
1. Quenching of star formation not associated with SMBH activity or
2. AGN-driven quenching *delayed or uncorrelated* with conditions of stellar populations beyond r ~ 6 kpc

The observations are inconsistent with:
1. AGN-driven quenching being *rapid and extended* (beyond r ~ 6 kpc) during AGN phase

Are Obscured AGN Hosts More Dusty than Unobscured AGN Hosts?

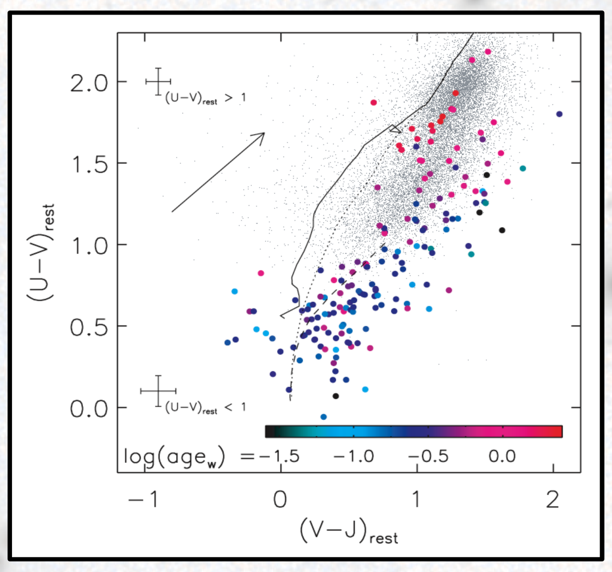


Figure 4 of Wuyts et al. 2007. Rest-frame U - V vs. V - J color-color diagram of all galaxies in a mid-IR selected sample with $L_V > 5 \times 10^9$ $L_\odot$. SDSS+2MASS galaxies (small gray dots) are plotted as a local reference. Stellar age affects rest-frame U – V color more than V - J.

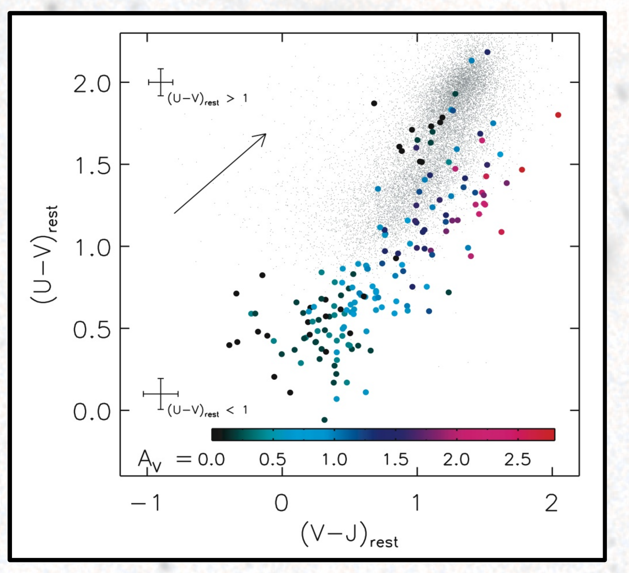
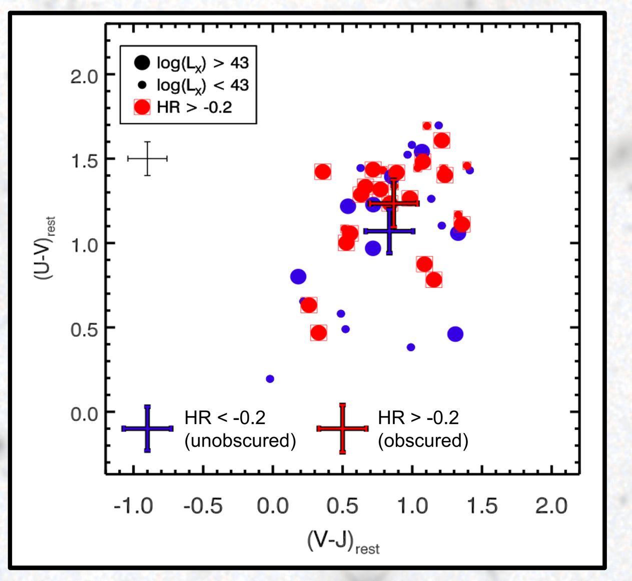


Figure 5 of Wuyts et al. 2007. Rest-frame U - V vs. V - J color-color diagram of all galaxies in a mid-IR selected sample with $L_V > 5 \times 10^9$ $L_\odot$. Dust extinction affects rest-frame V - J color more than U - V.

NUV – R is a sensitive probe of low levels of star formation (Salim et al. 2007), but it can be affected by dust extinction. Here we search for systematic differences in galactic dust extinction between the obscured and unobscured AGN host populations.

In a rest-frame U-V, V-J color-color diagram, the effects of dust extinction can be partially separated from the effects of stellar age (see Figure 4 and 5 of Wuyts et al. 2007). V-J color is more sensitive to dust extinction than stellar age. The mean loci of the obscured and unobscured populations in this color-color diagram are similar in V-J, *suggesting that the two populations are not distinct in galactic dust extinction.*



Rest-frame U - V vs. V - J color-color diagram for sample AGN beyond r ~ 6 kpc. The mean colors are shown in the center of the diagram; the obscured locus is very close to the unobscured locus in V – J, suggesting that the populations have similar mean extinctions.

References

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