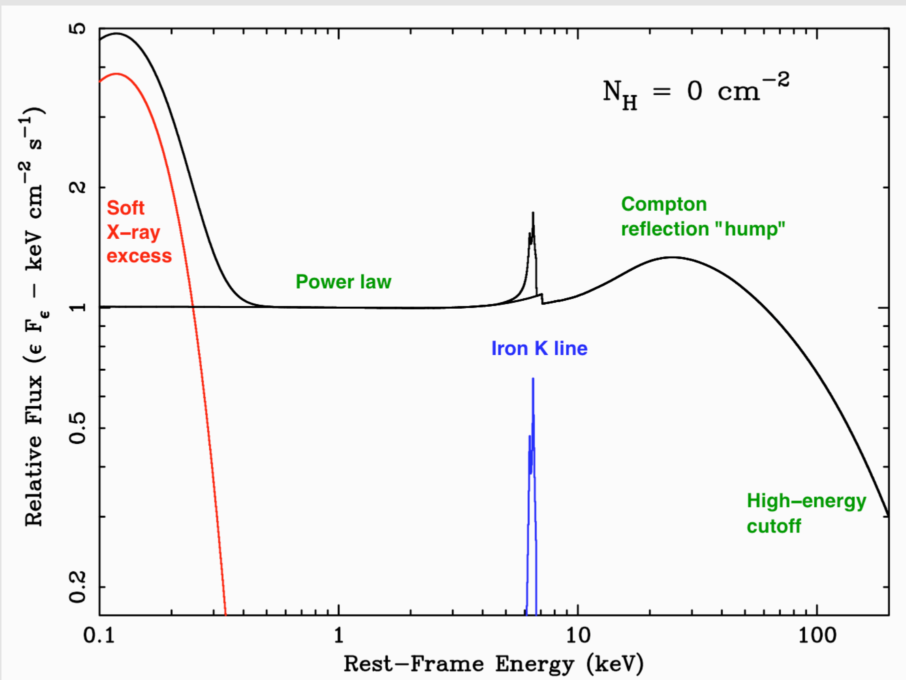
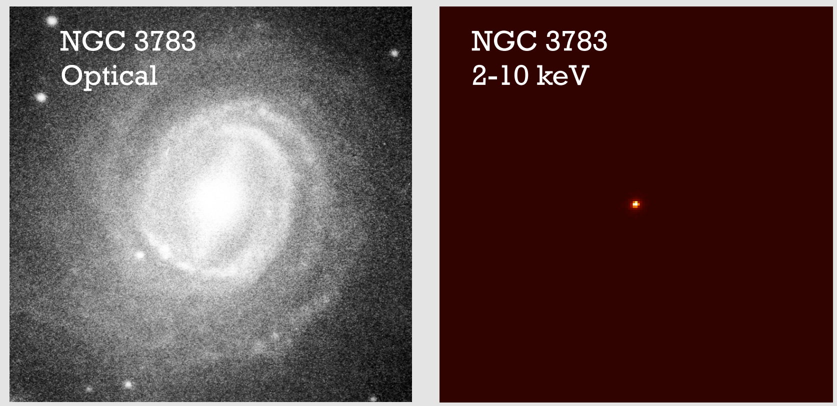
SMBH Ecology in the Distant Universe: Results from Cosmological X-ray Surveys

Reduced Absorption Bias for Majority Population



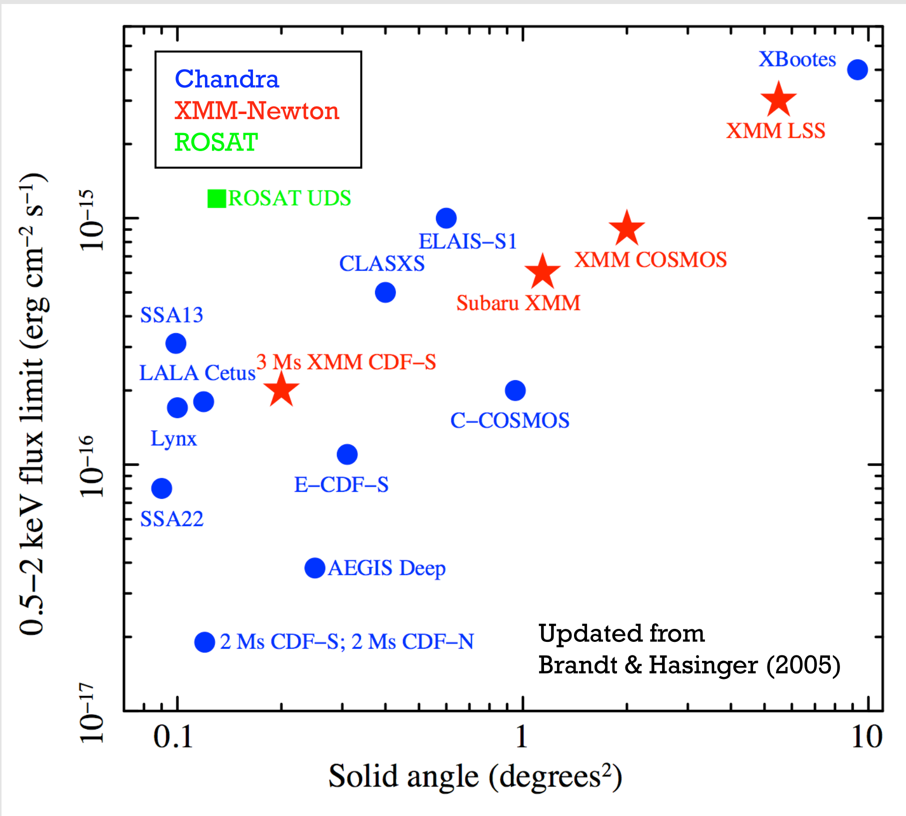
Minimal Dilution by Host Starlight

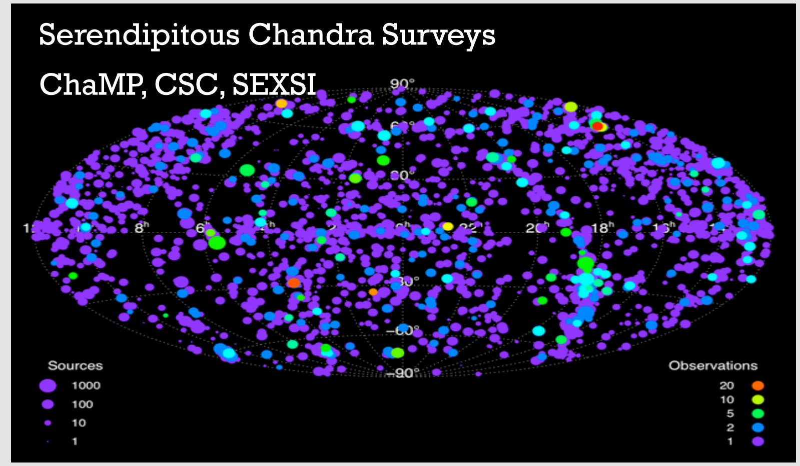


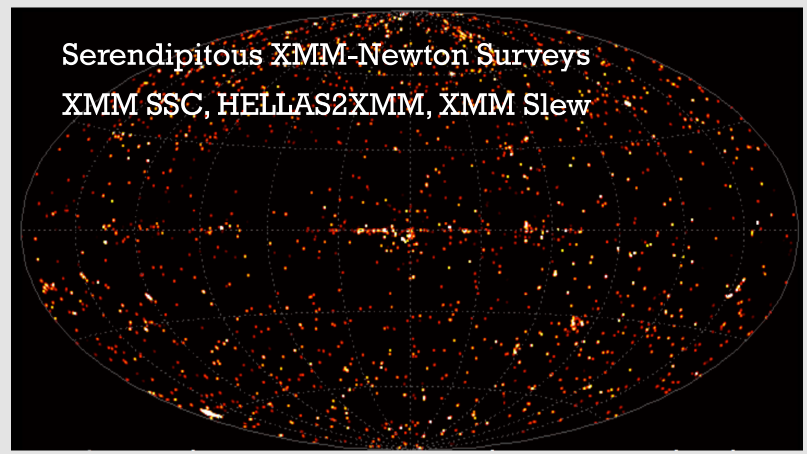
Large, clean, low-bias samples of moderate-luminosity AGNs from $z \sim 0.1$-5.

Multitude of X-ray AGN Surveys

Some Recent Contiguous X-ray Surveys





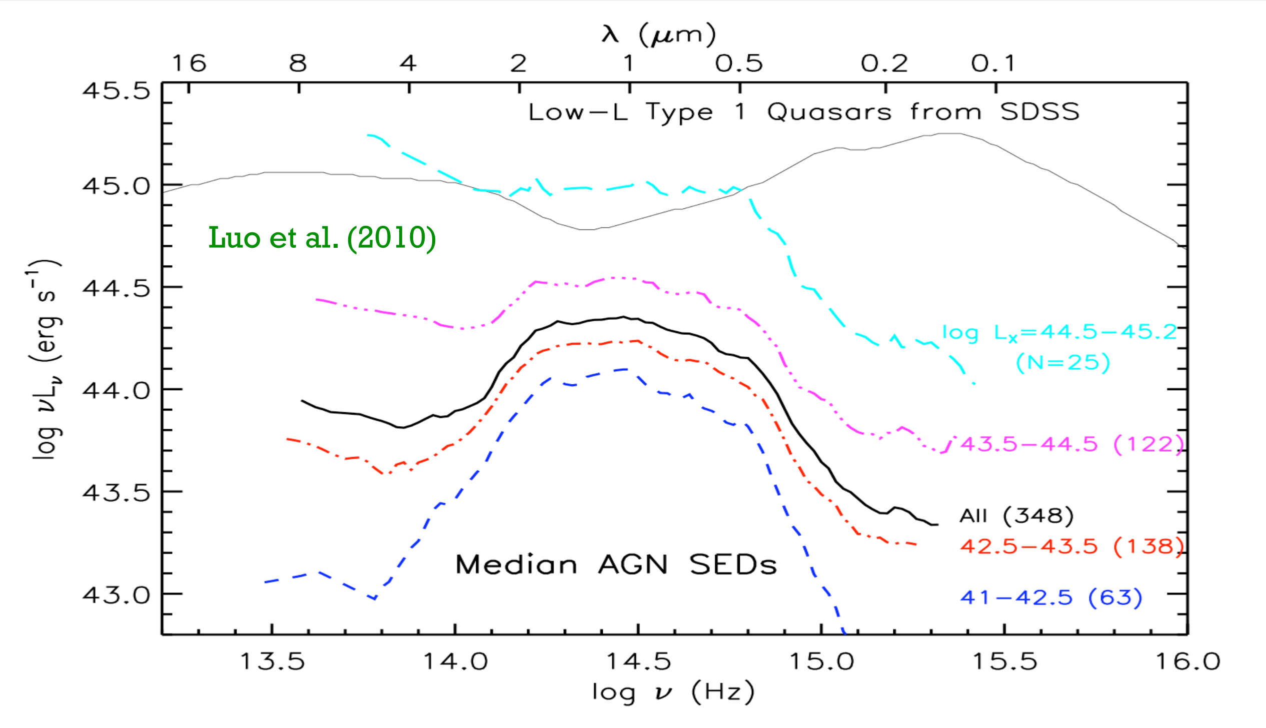


~ 25 ongoing Chandra and XMM-Newton surveys cover most of the practically accessible sensitivity vs. solid-angle "discovery space."

Together are providing a complete understanding of X-ray source populations.

Feasibility of Host-Galaxy Measurements

Mean AGN SEDs in Chandra Deep Field-South

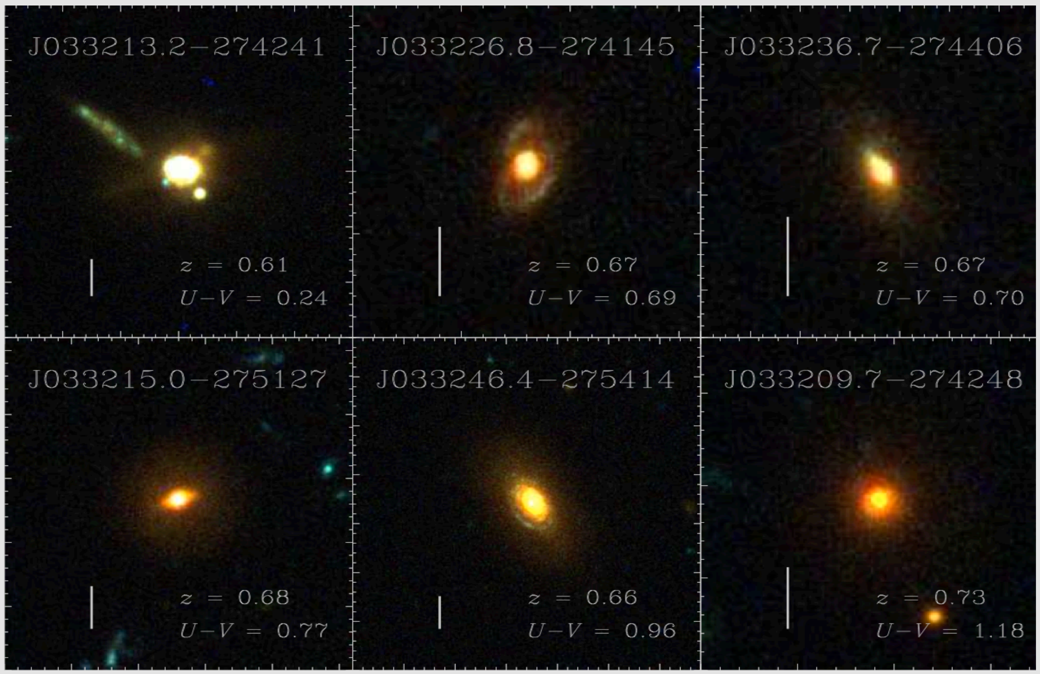


Many X-ray AGNs have optical-to-submm emission dominated by host light, so can measure host properties fairly well.

Still must be wary of biases due to the AGN – subtract when possible.

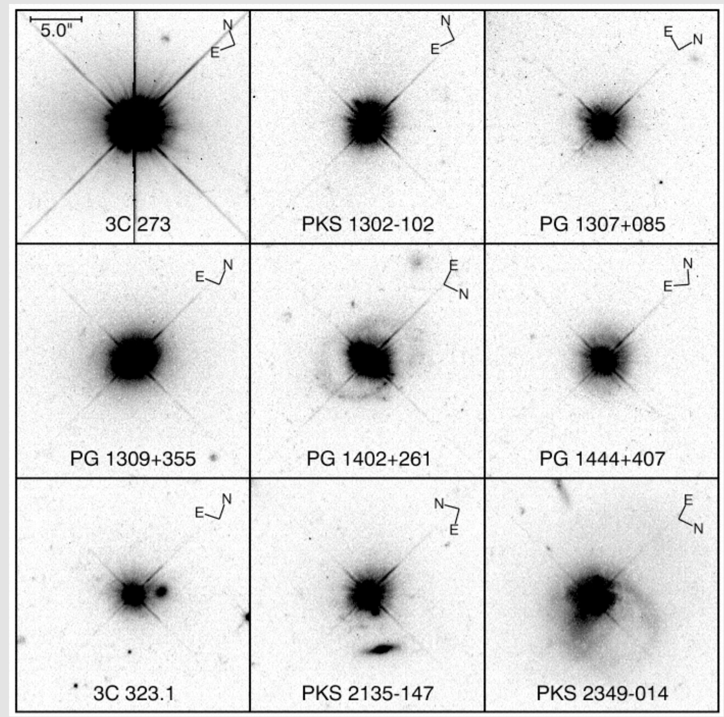
Feasibility of Host-Galaxy Measurements

HST Imaging of CDF-S X-ray AGNs



Silverman et al. (2008)

HST Imaging of Low-Redshift Quasars



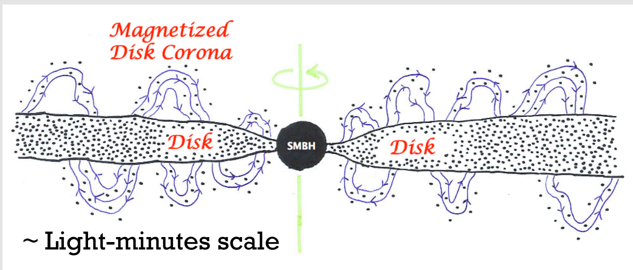
Bahcall et al. (1997)

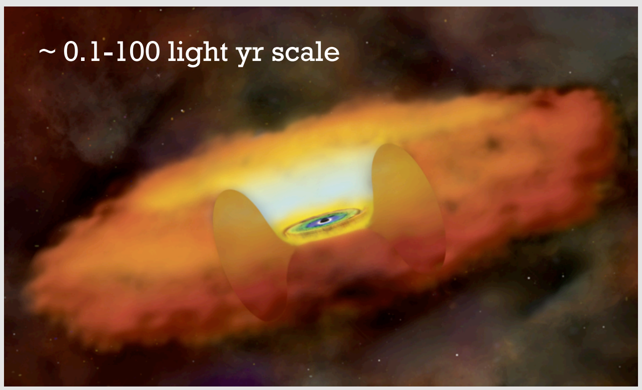
Many X-ray AGNs have optical-to-submm emission dominated by host light, so can measure host properties fairly well.

Still must be wary of biases due to the AGN – subtract when possible.

Distant SMBH Ecology - Measurements

Black-Hole and Torus Regions



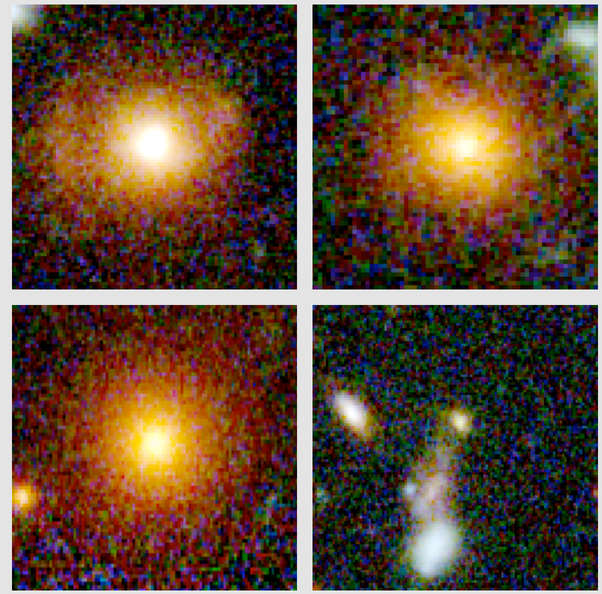


AGN Luminosity
SMBH Mass
SMBH Accretion Rate
Obscuration Properties

Fueling and Obscuration

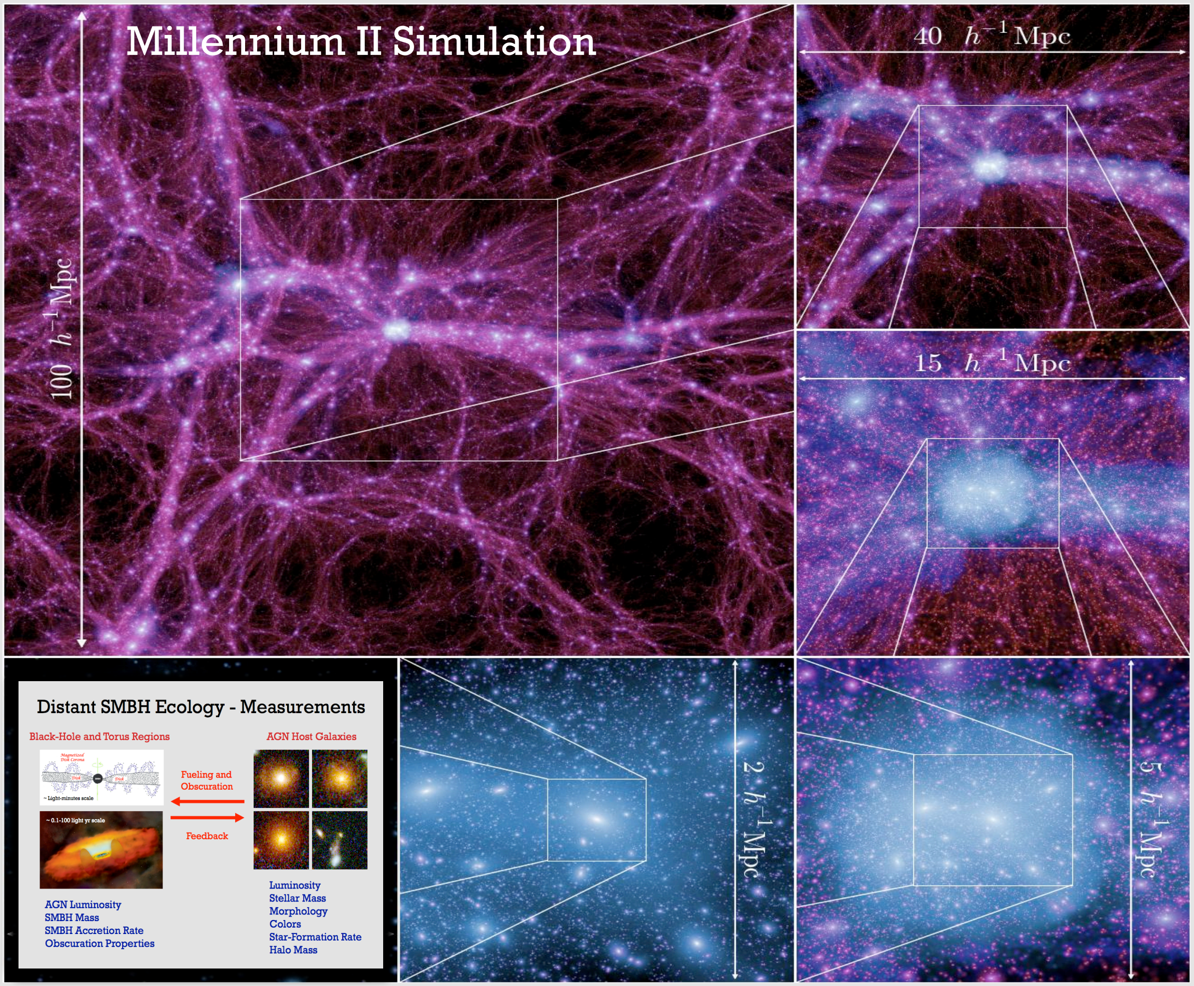
Feedback

AGN Host Galaxies



Luminosity
Stellar Mass
Morphology
Colors
Star-Formation Rate
Halo Mass

Large-Scale Cosmic Environment



Galaxy mergers

Feedback into IGM

IGM metal enrichment

Will mostly leave these larger scale effects to other speakers.

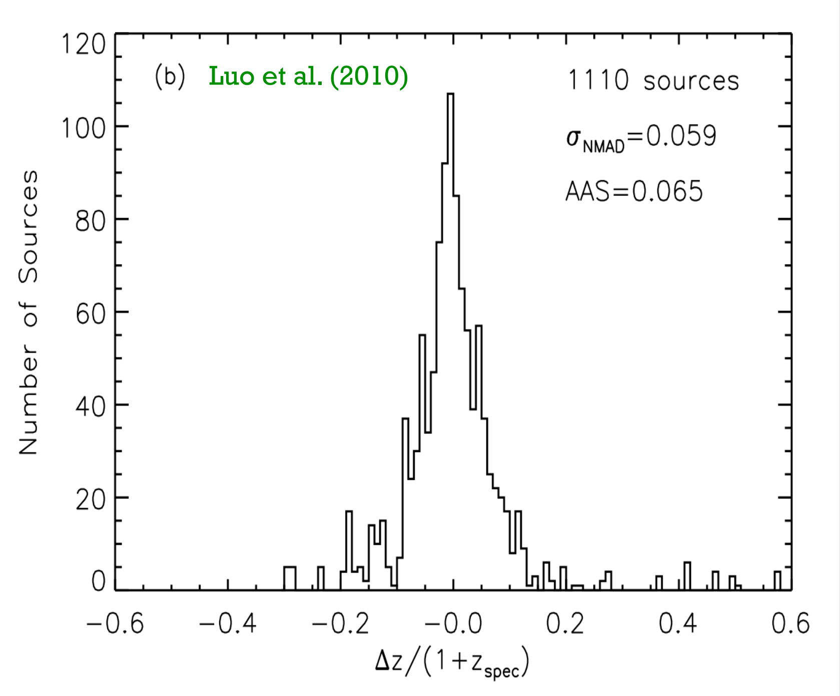
Why It's Hard Work

Sources are Often Faint

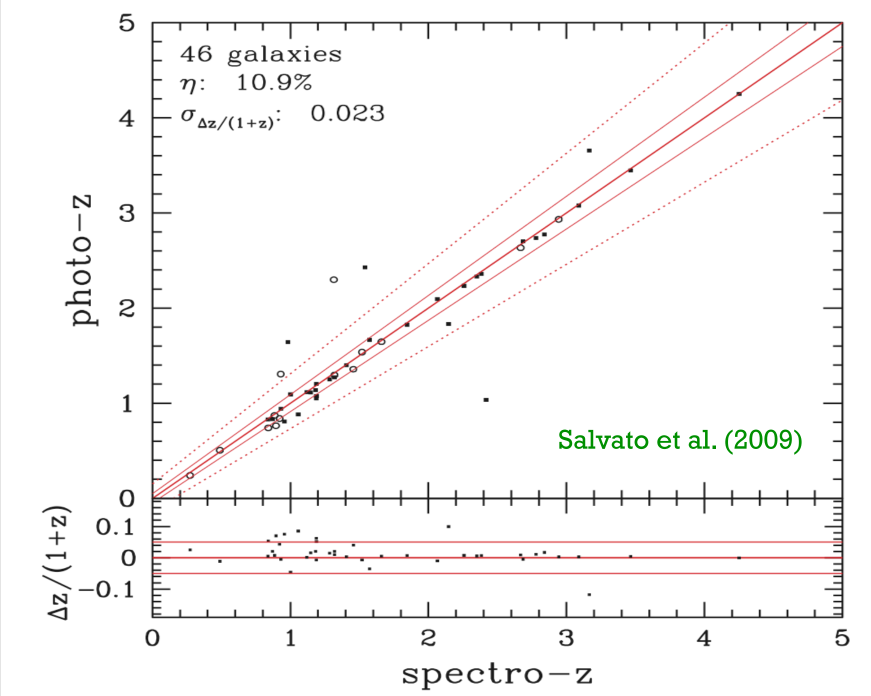
Measurements, even of basic redshifts, are challenging at $R \sim$ 23-27.

Ultradeep spectroscopy and good photometric redshifts required.

Blind-Test of CDF-S Photometric Redshifts from 15-35 Bands to $R \sim 26$



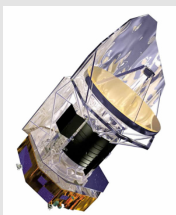
Blind-Test of COSMOS Photometric Redshifts for $i \sim$ 22.5-24.5

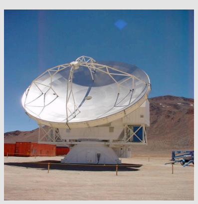


Need Broad Bandpass Coverage

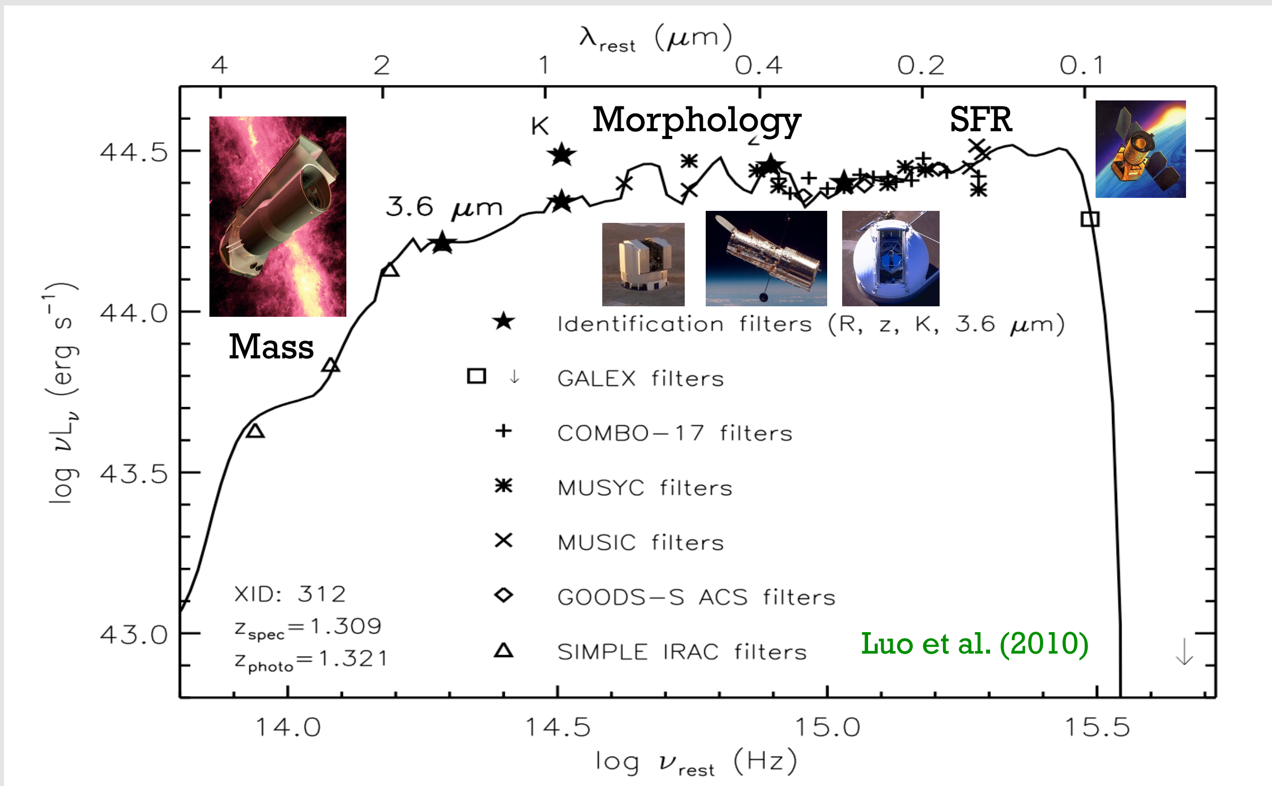
Critical to get host-galaxy properties.

SFR





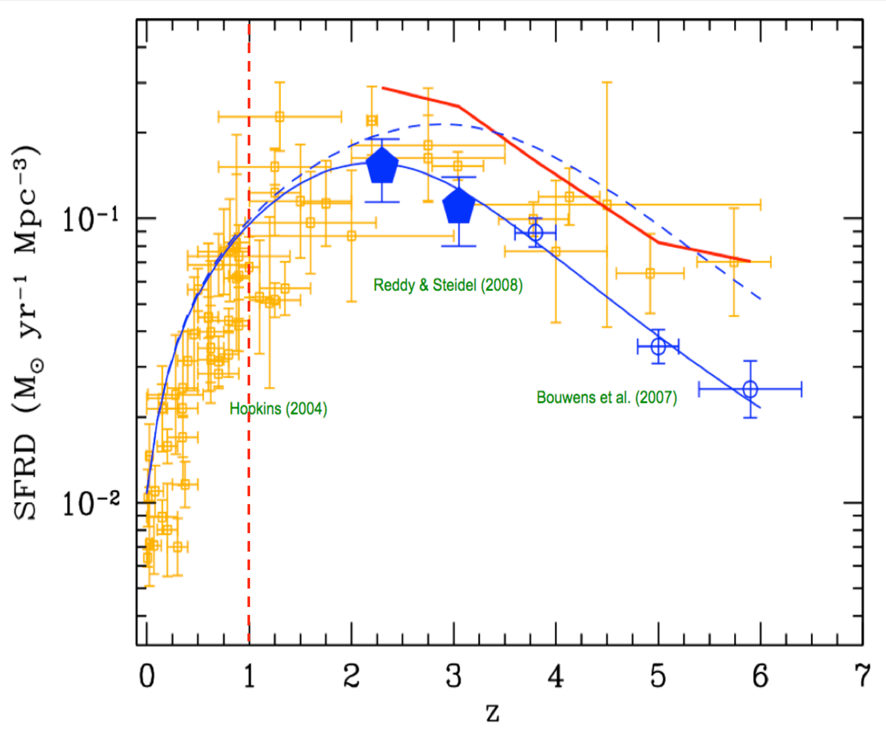
Example IR-to-UV SED with Fitted Template



Many Analyses Limited to $z < 1.0\text{-}1.5$

Probe the cosmic “fizzle” but not so well the cosmic “party”.

Cosmic Star-Formation History



Penn State: Number 1 Party School in USA for 2009-2010

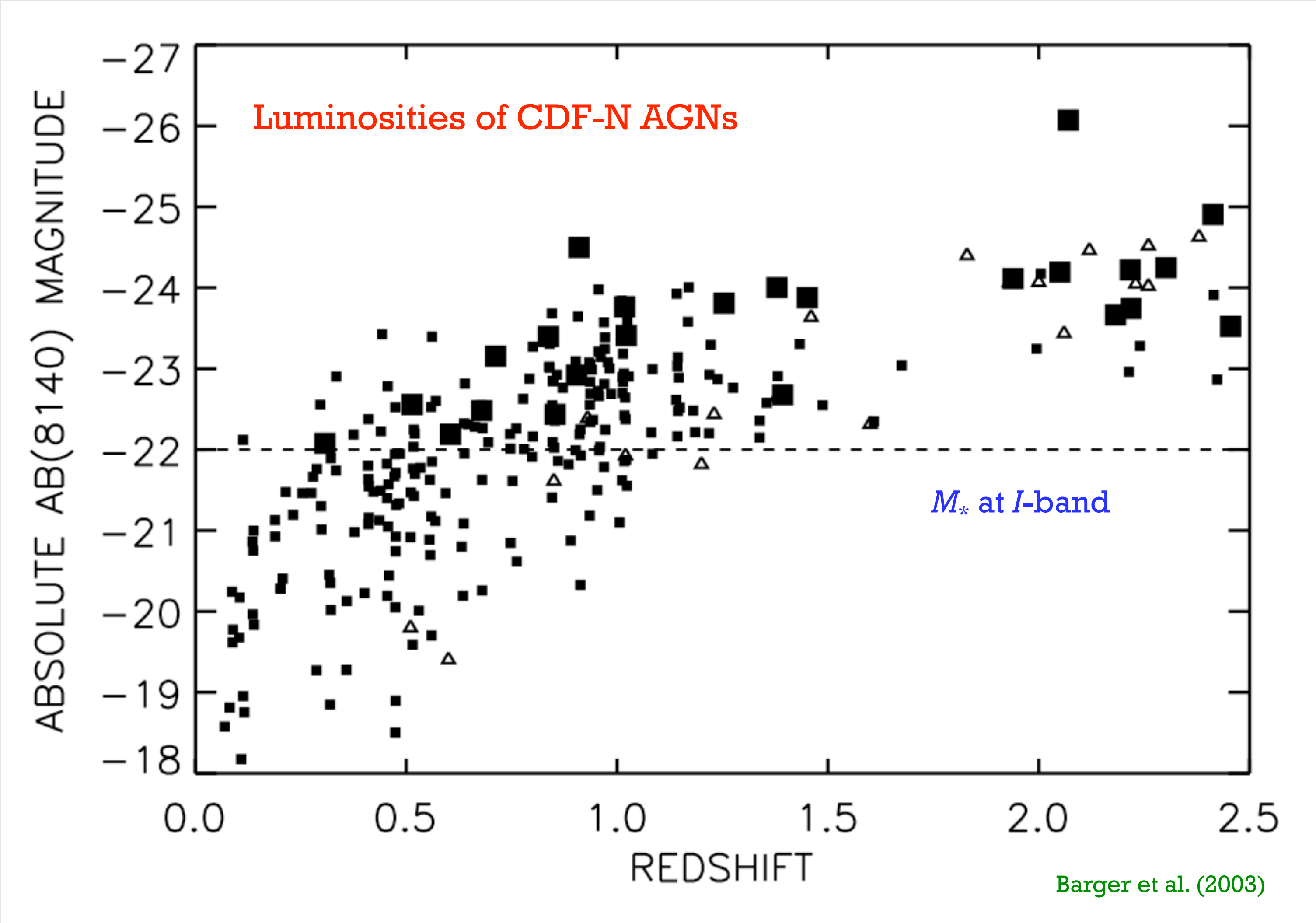

Penn State fans cheer during their team's 46-17 victory over the University of Michigan Wolverines at Beaver Stadium in University Park, Pa., Oct. 18. Penn State tops The Princeton Review's list of party schools this year.

By John H. Beale, for USA TODAY

Princeton Review rankings: Penn State is life of the party

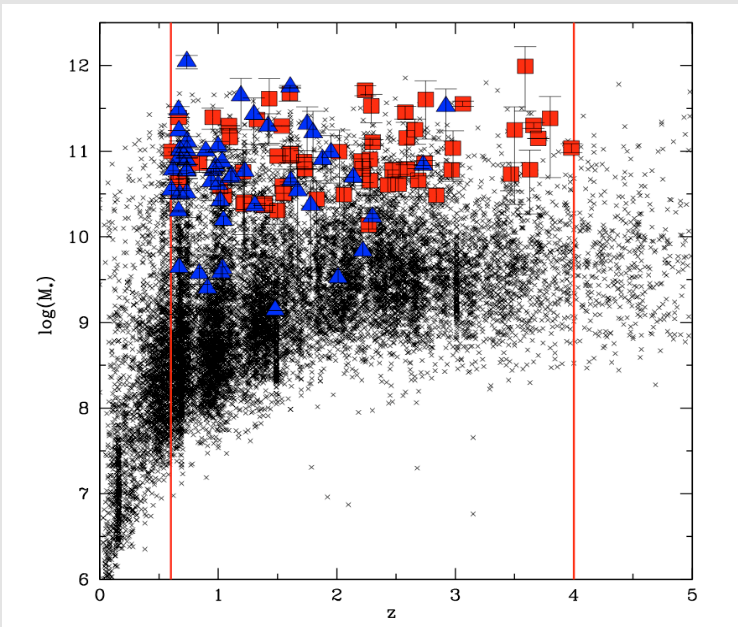
Luminosities and Masses

Hosts are Luminous and Massive



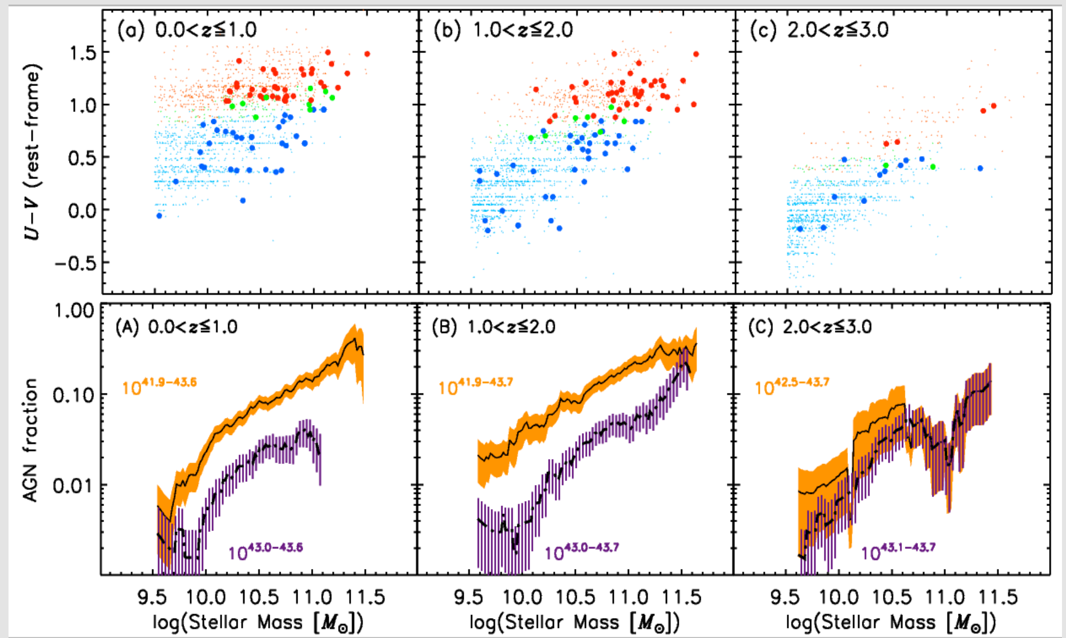
Hosts are Luminous and Massive

Stellar Mass vs. Redshift for CDF-S AGNs



e.g., Brusa et al. (2009)

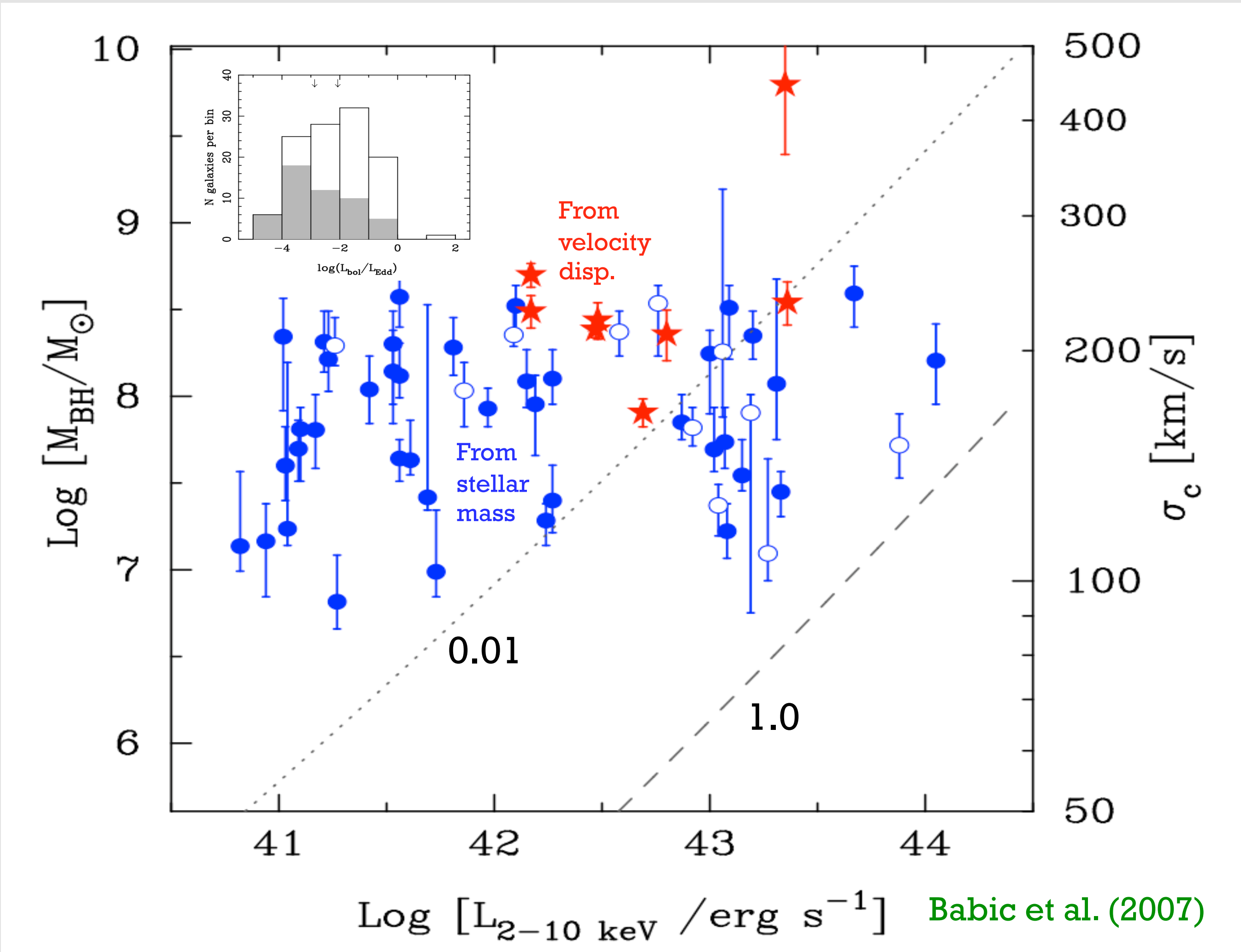
AGN Fraction Increases Toward High Stellar Mass – AGNs Are Large Dots



e.g., Xue et al. (2010)

Often Low L / L_{Edd} at $z < 1$

Chandra Deep Field-South AGNs at $z < 1$



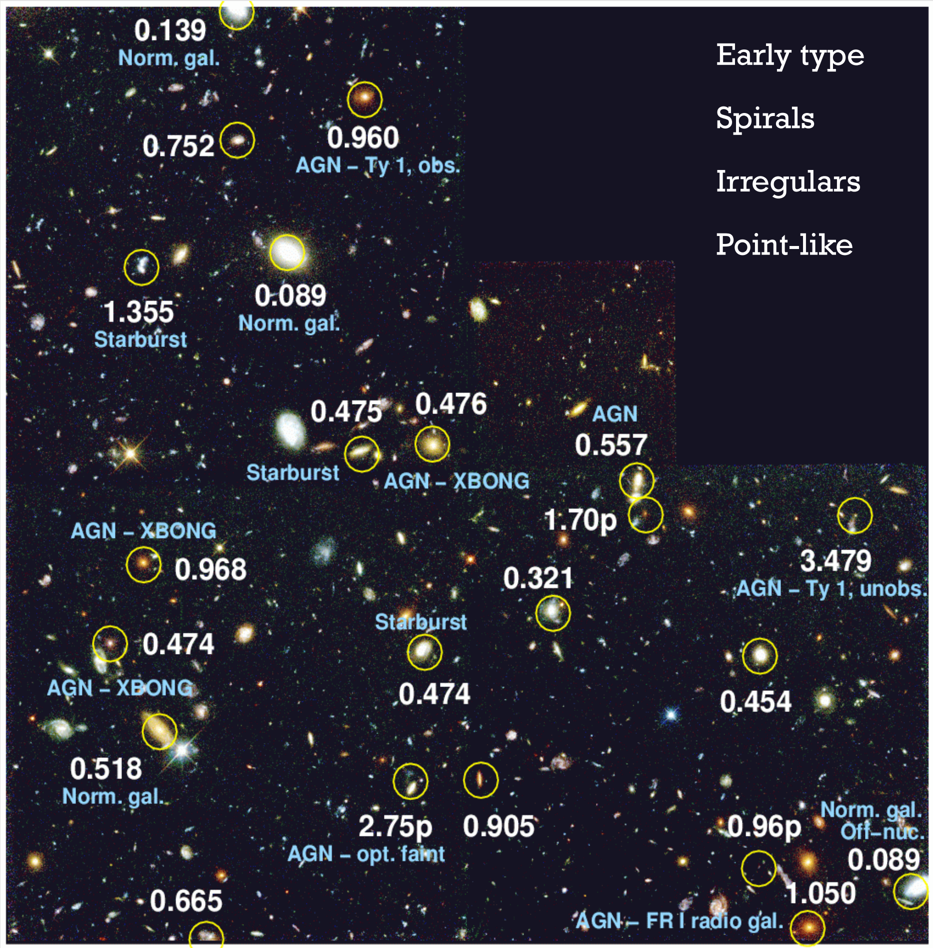
Babic et al. (2007)

X-ray surveys often select low L / L_{Edd} sources at $z < 1$

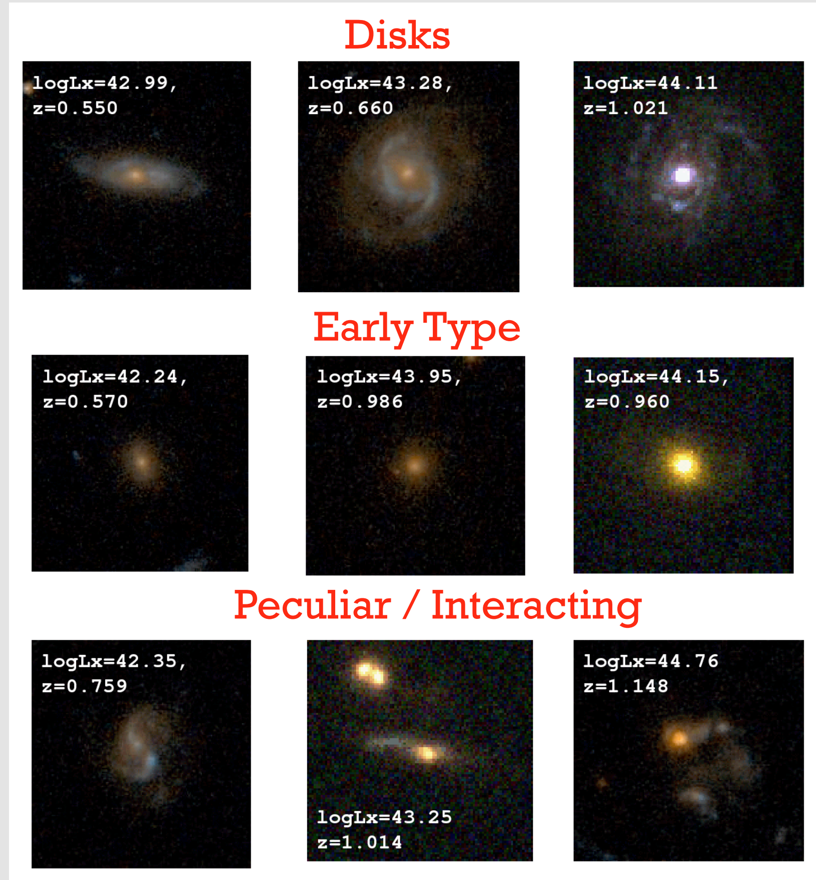
Most of the mass growth for these SMBHs apparently occurred at $z > 1$

Morphologies

Wide Diversity of Morphological Types



e.g., Brandt et al. (2001); Koekemoer et al. (2002)

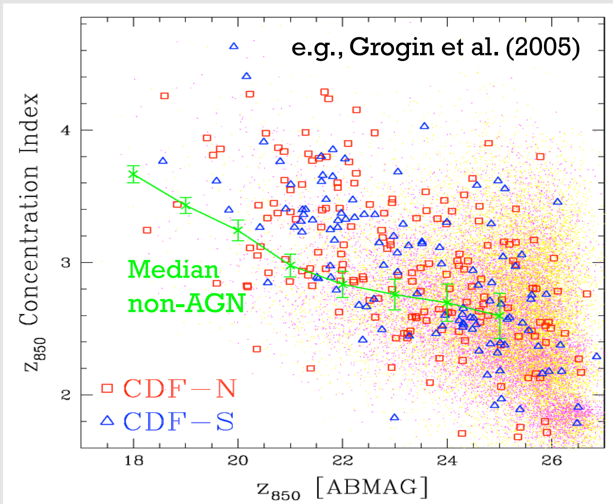


Georgakakis et al. (2009)

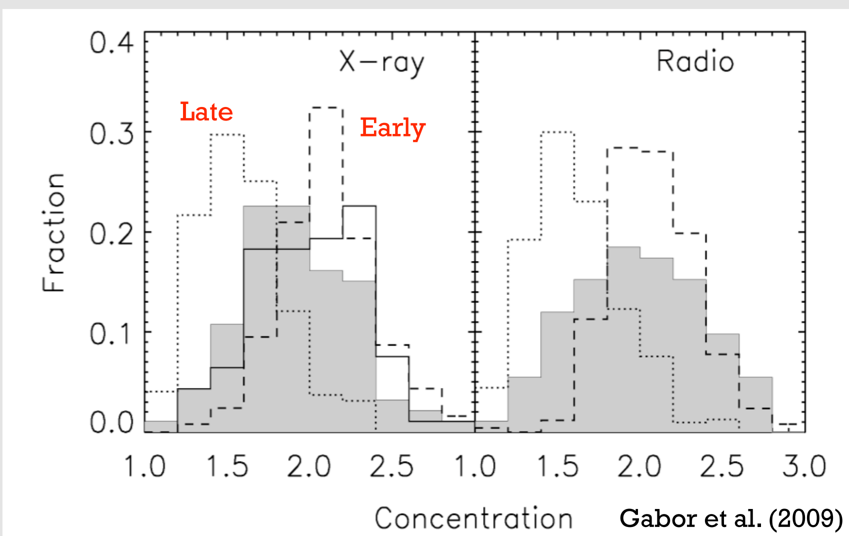
Broadly speaking, about 40-50% early types, 20-30% late types, rest irregular or point-like.

Host Concentrations for X-ray AGNs

Concentrations of GOODS AGNs



Concentrations of COSMOS AGNs



Broad range of concentrations seen.

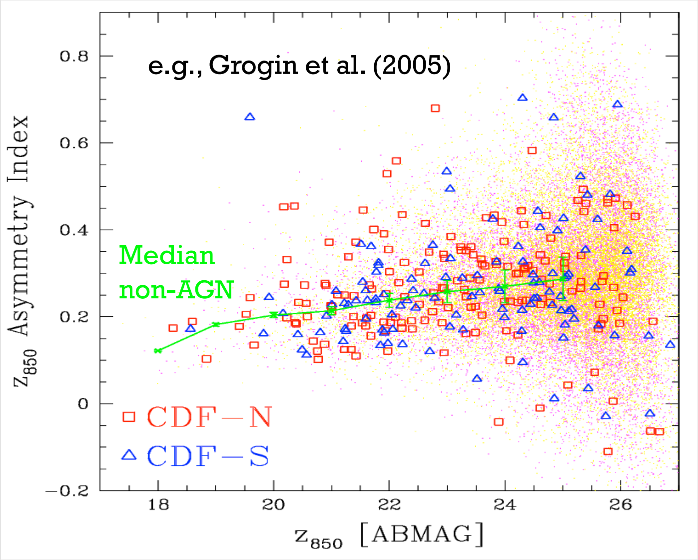
X-ray AGNs prefer galaxies with higher concentrations to $z \sim 1.5$.

Tend to be more bulge dominated than the galaxy population overall, consistent with local results.

Generally intermediate between late-type and early-type inactive galaxies.

Host Asymmetries for X-ray AGNs

Asymmetries of GOODS AGNs



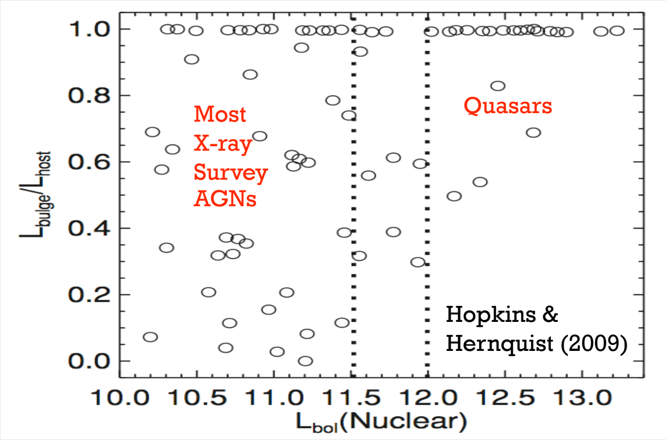
X-ray AGNs show no strong asymmetry vs. non-AGNs; most in relatively undisturbed systems.

No obvious connection between recent strong galaxy mergers and moderate-luminosity AGNs.

Merger signatures may fade before onset of AGN.

Secular host-galaxy processes also probably lead to SMBH fueling in these systems.

Bulge Fraction vs. AGN Luminosity



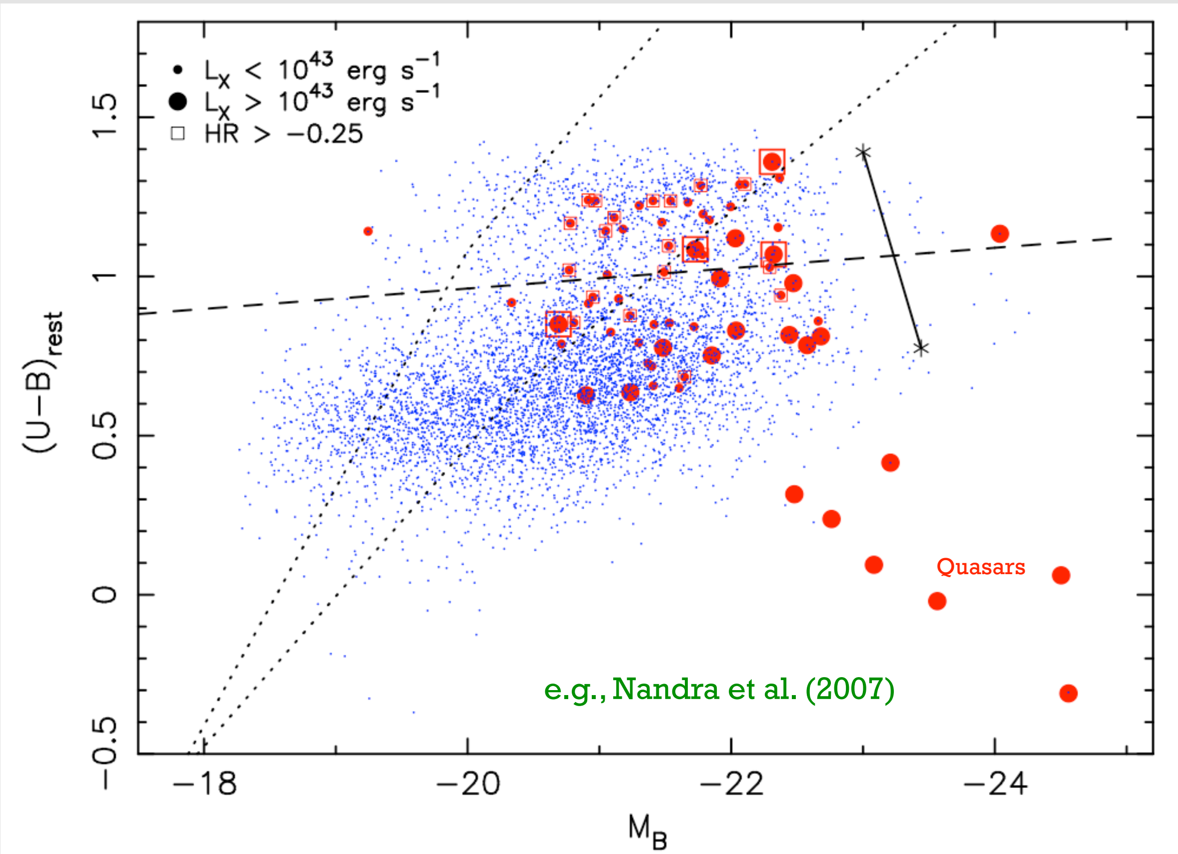
Likely contrasts with high-luminosity quasars.

These often show merger activity and are hosted largely in "merger remnant" ellipticals.

Colors

Apparent "Clustering" of AGNs in the Color-Magnitude Diagram

CMD with AGNs Marked as Large Dots (z = 0.6-1.4)



AGN hosts have broad color range, peaking in "green valley" or "red sequence".

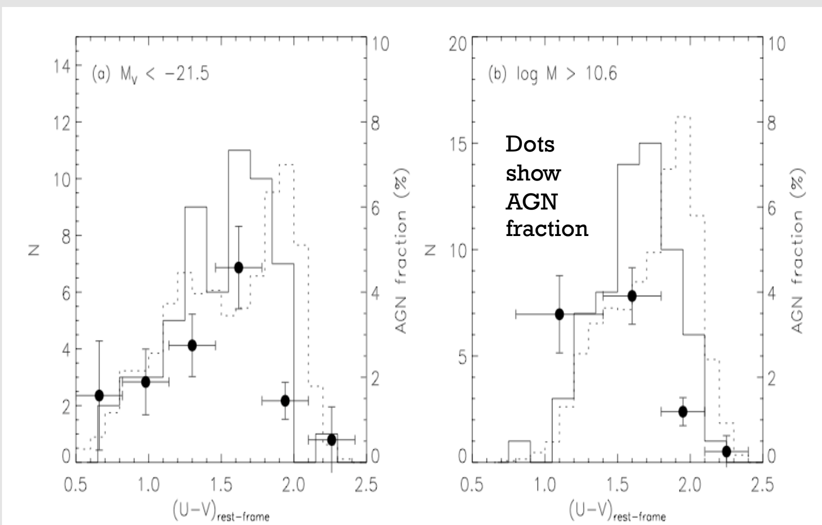
AGN playing a role in transitioning galaxies from blue cloud to red sequence via "quenching" of star formation?

Rejuvenation of bulge-dominated systems by addition of a gas-rich disk over cosmic time (e.g., Hasinger 2008)?

Sample Construction Problems?

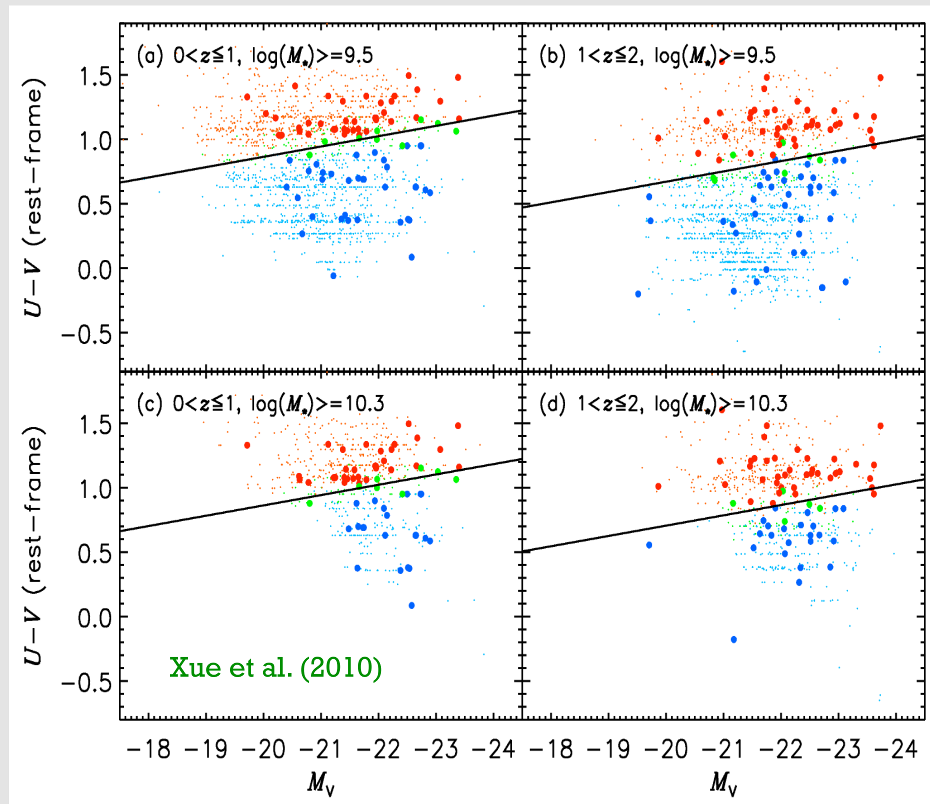
After accounting for galaxy mass, evidence for special clustering of AGNs in CMDs is reduced.

COSMOS AGN Colors for Luminosity and Mass Selected Samples

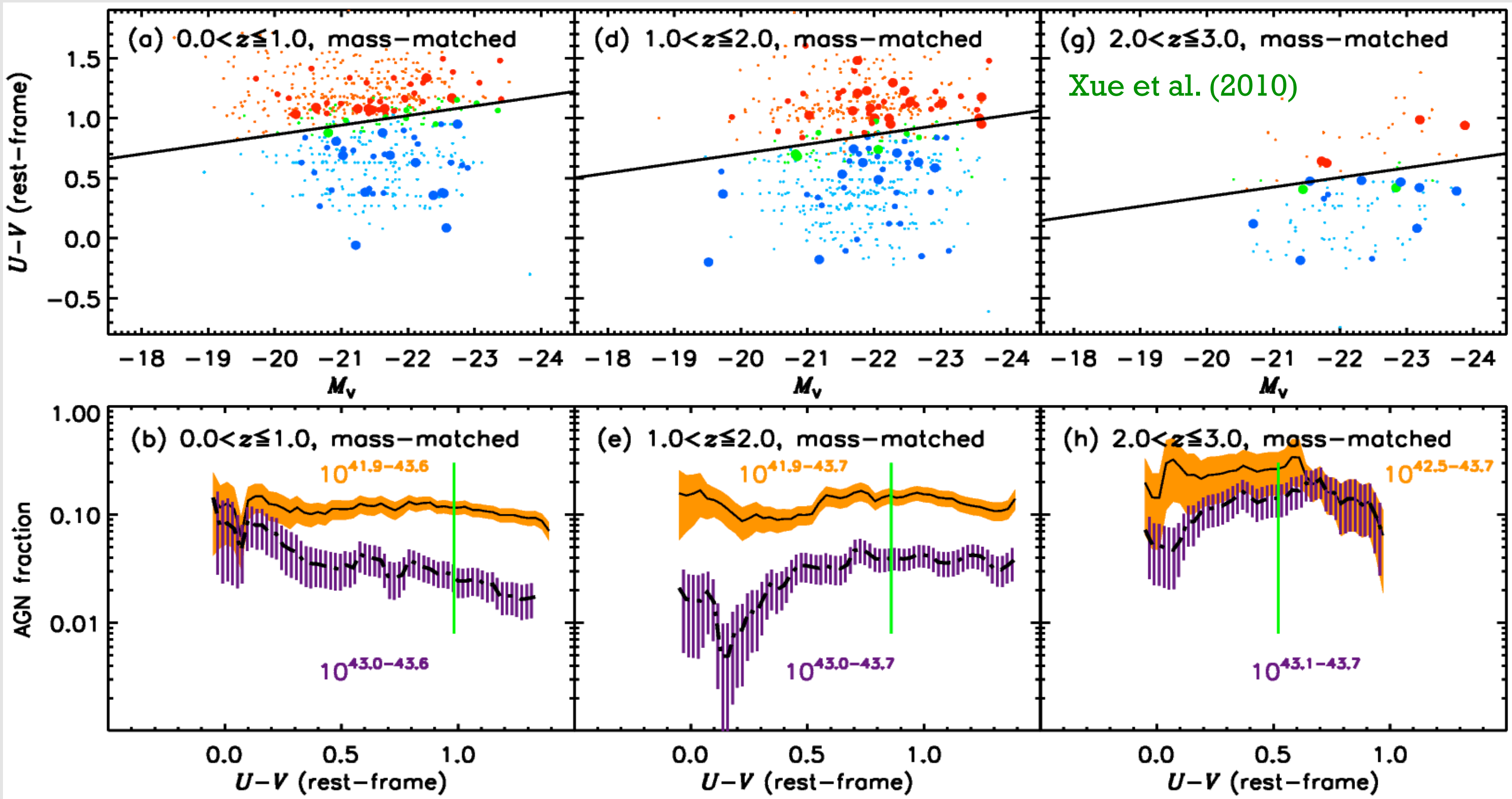


Silverman et al. (2009)

Chandra Deep Fields CMDs with Mass Cuts



Mass-Matched Sample Results



Constructed a mass-matched sample via random draws from galaxy population.

AGN fractions flat or perhaps declining toward red colors.

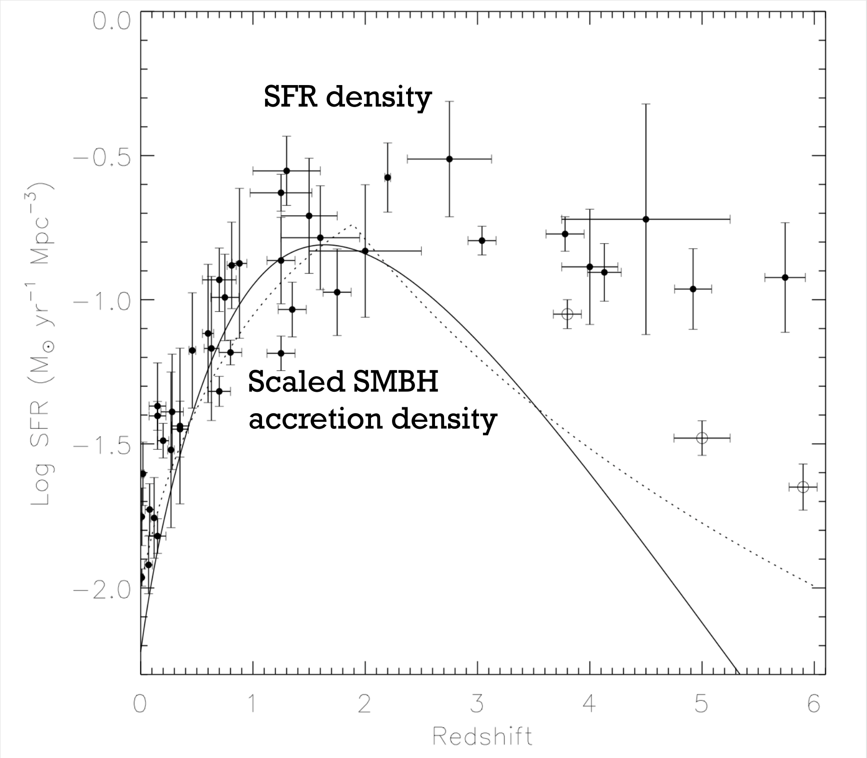
AGN hosts have the expected colors for galaxies of their mass.

Now splitting up by host morphology using ACS General Catalog (Griffith et al.).

Star Formation Rates

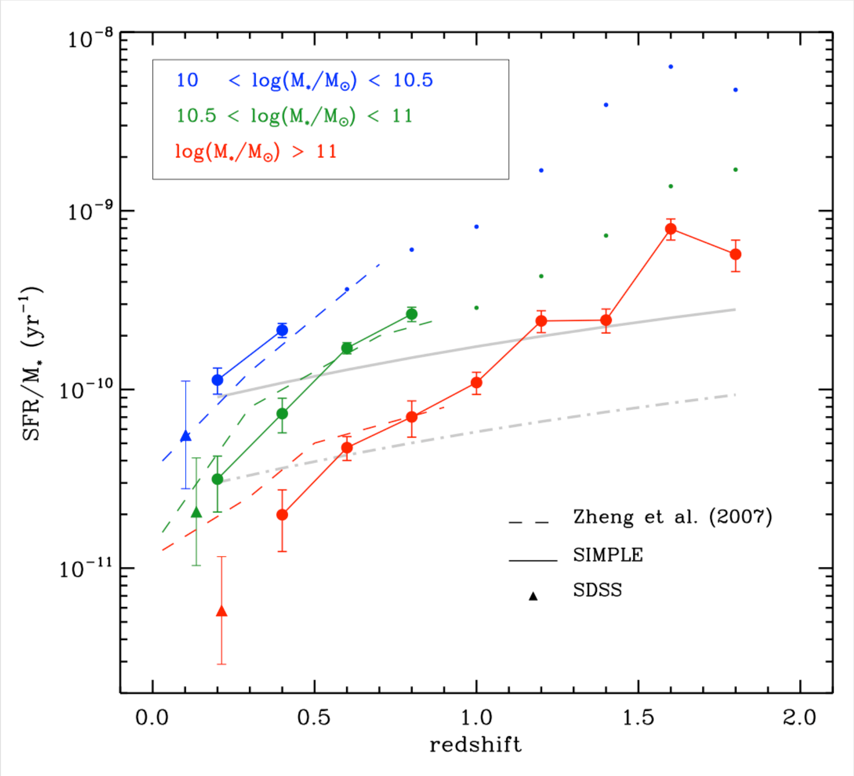
SFR and SMBH Accretion Histories

Broadly Similar AGN-SFR Evolution for Most of Cosmic Time ($z < 2$)



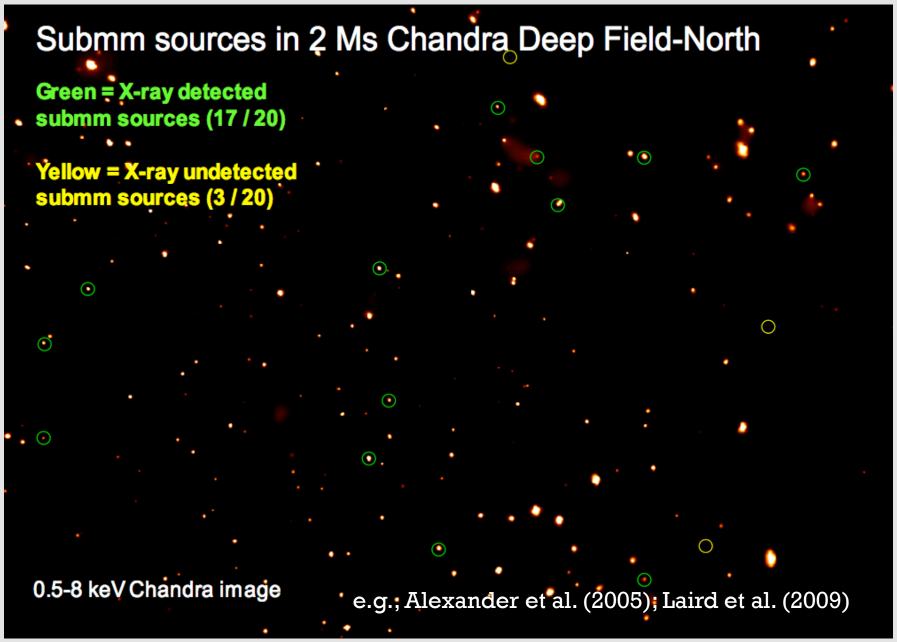
e.g., Silverman et al. (2008)

Downsizing of Star Formation in Galaxies

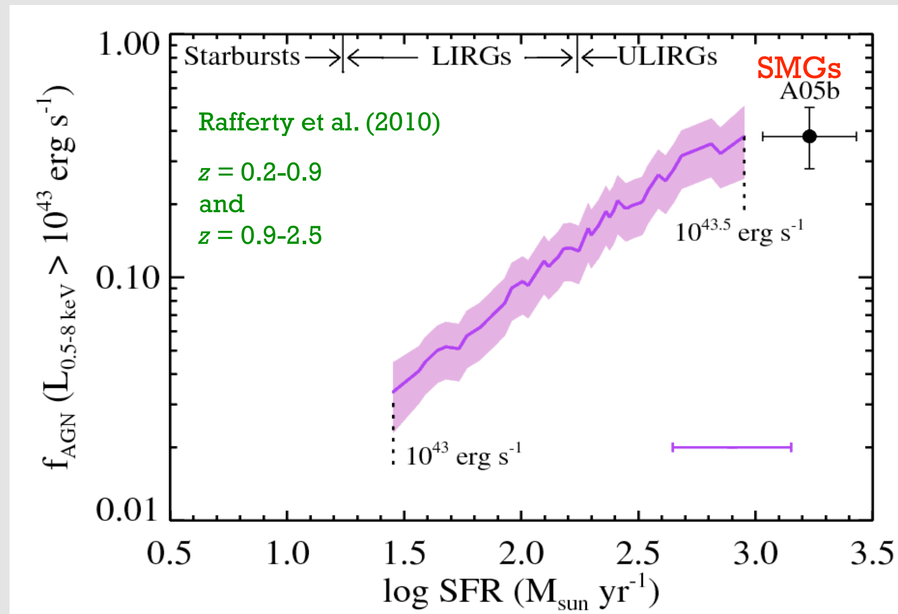


e.g., Damen et al. (2009)

X-ray AGNs in Distant Star-Forming Galaxies



AGN Fraction for $L_X > 10^{43}$ erg s^{-1}



A remarkably high fraction of submm galaxies at $z \sim 1$-4 are detected as X-ray sources in the deepest X-ray surveys.

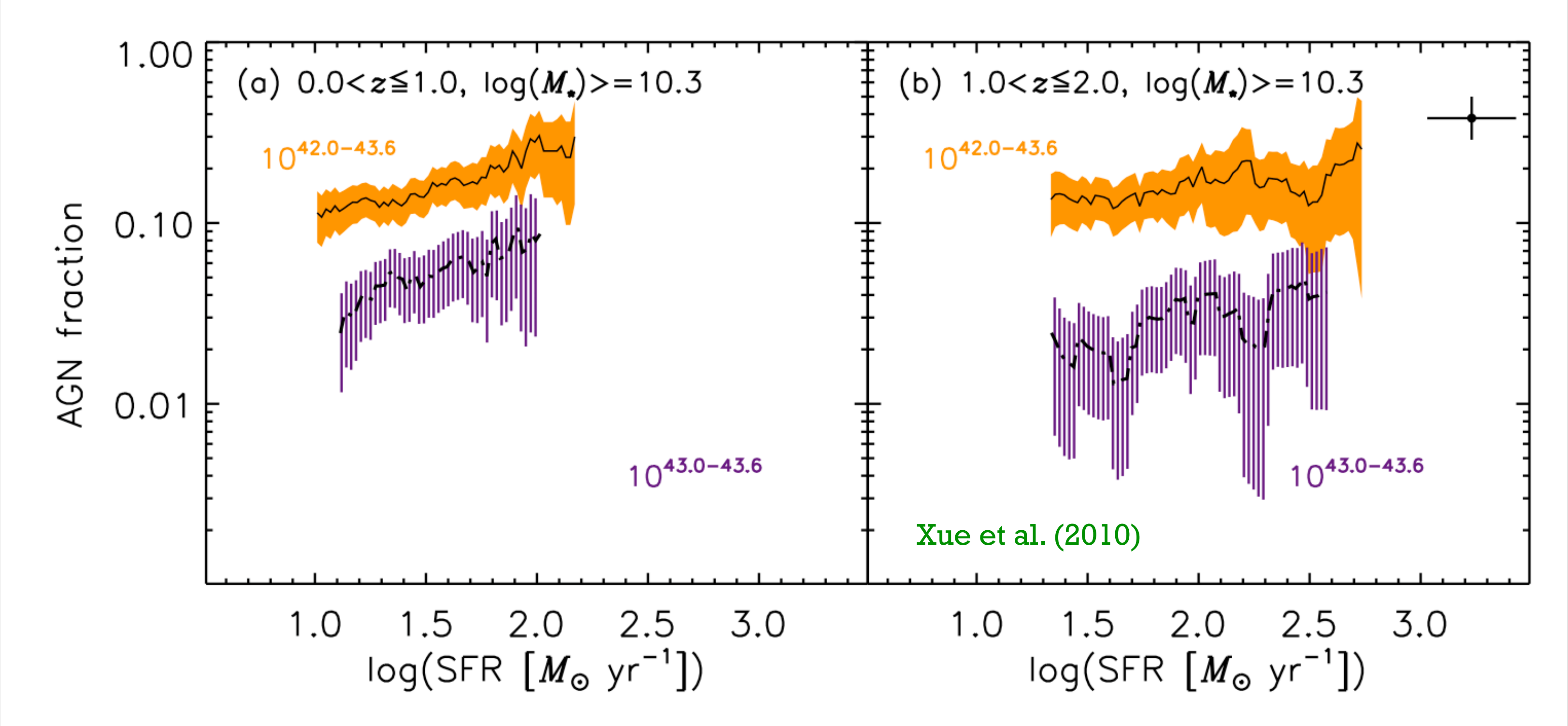
Often evidence for AGN activity. AGN fraction ~ 20-35%.

Suggests high duty cycle of SMBH growth in forming spheroids.

But submm samples small, difficult to use reliably, and only probe highest SFRs.

Spitzer FIDEL + Chandra samples indicate distant AGN fraction rises with SFR.

AGN Fraction vs. SFR with Mass-Matched Samples

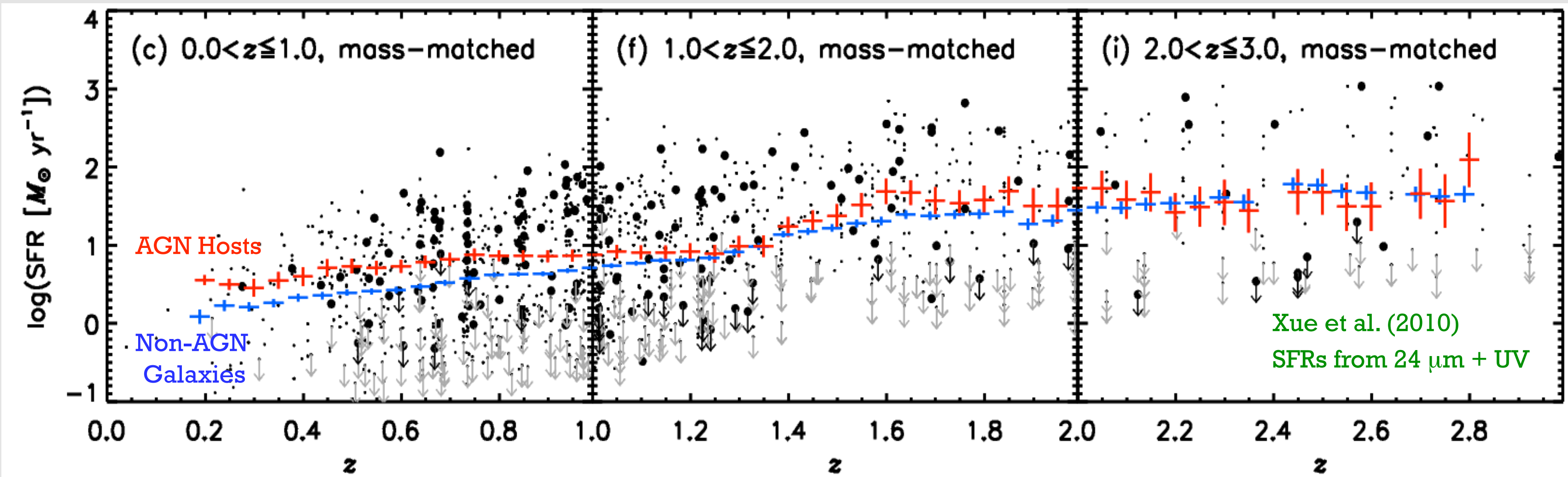


Dependence of AGN fraction upon SSFR becomes more modest (z ~ 0-1) or largely vanishes (z ~ 1-2).

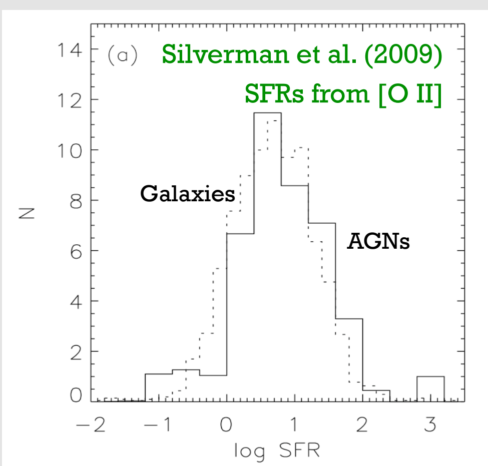
High AGN fraction of submm galaxies may be largely due to high masses instead of high SFRs.

SFRs in AGN Host Galaxies

Comparisons of SFRs for AGN Hosts and Non-AGN Galaxies from $z \sim$ 0-3



AGN Hosts at $z \sim$ 0.5-1



In mass-matched samples, AGN hosts show elevated SSFRs from $z \sim$ 0.3-1 by an average factor of ~ 2-3.

But this enhancement fades at higher redshifts, as the whole galaxy population moves to higher SSFRs.

Summary and Some Future Prospects

Main Results on X-ray AGN Hosts

Lots of progress but remains hard work, especially at $z > 1$.

Generally luminous and massive.

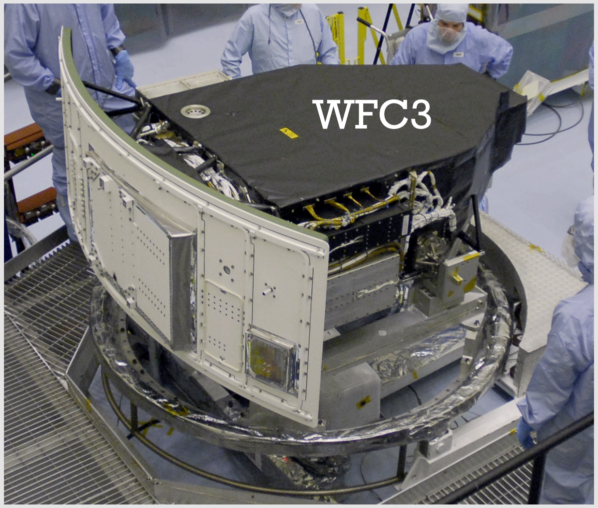
$L / L_{\mathrm{Edd}} \sim 10^{-4}$ to 1 – at least at $z < 1$.

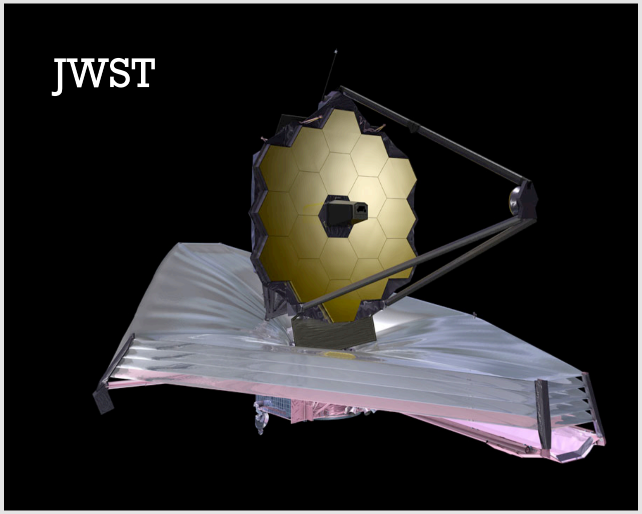
Morphologies diverse, but generally show prominent bulges and no enhanced asymmetry.

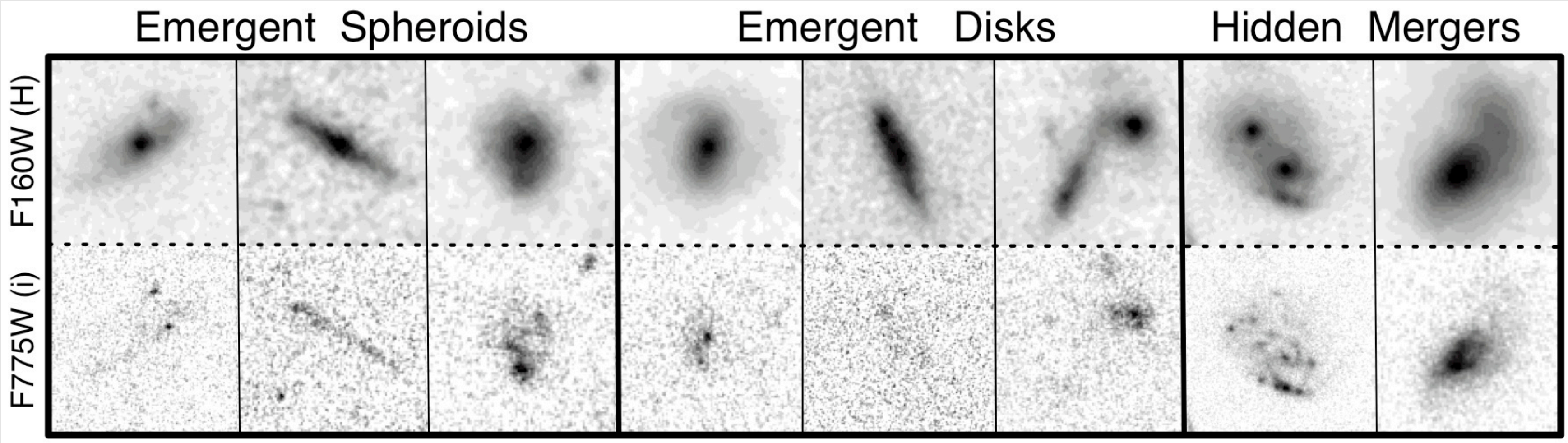
CMD behavior like that of comparably massive non-AGN galaxies – no special CMD clustering?

SSFRs of AGN hosts mildly elevated to $z \sim 1$, but apparently not at higher redshifts.

Host Morphologies at $z > 1.5$

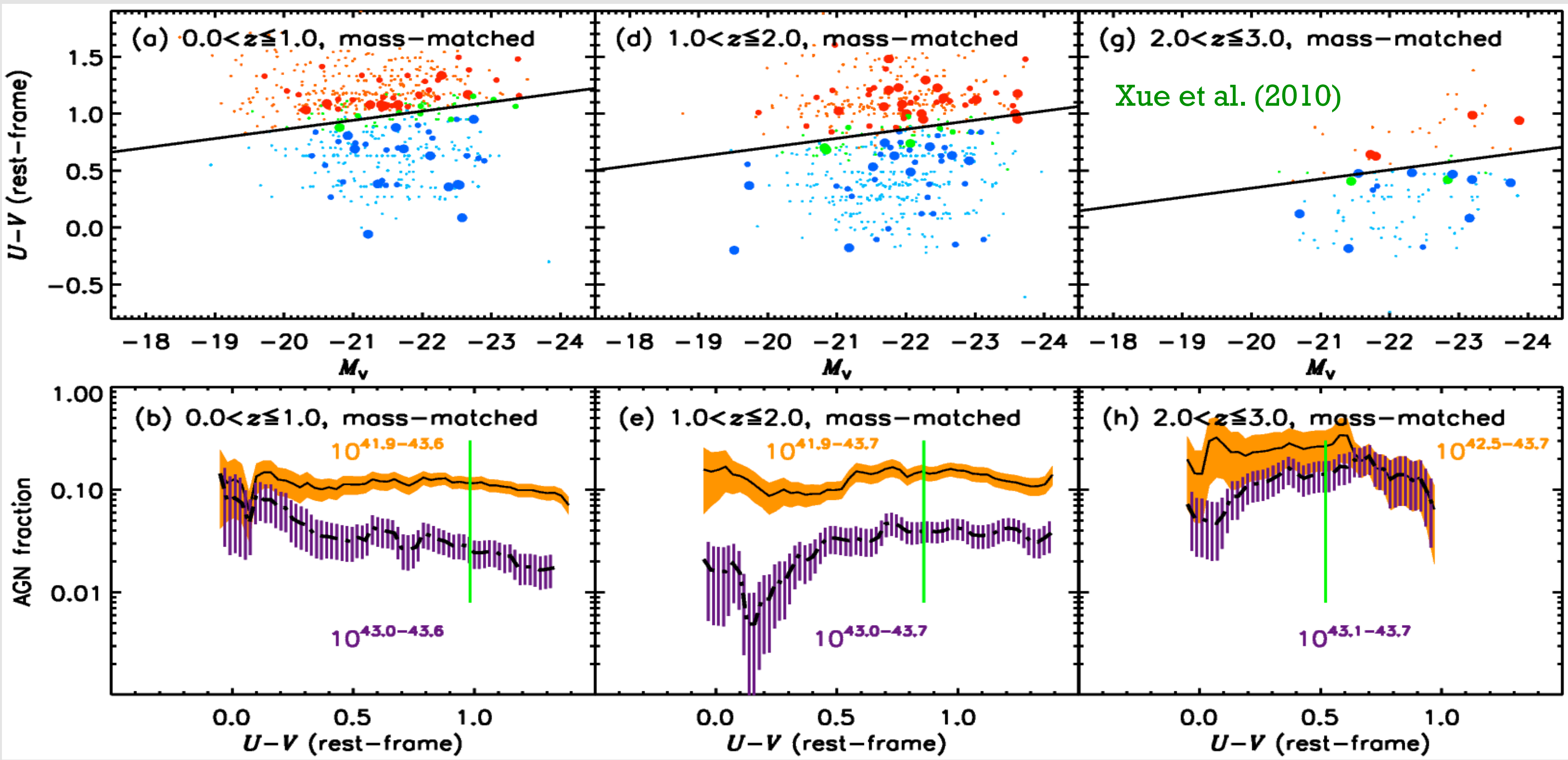






Faber, Ferguson et al.

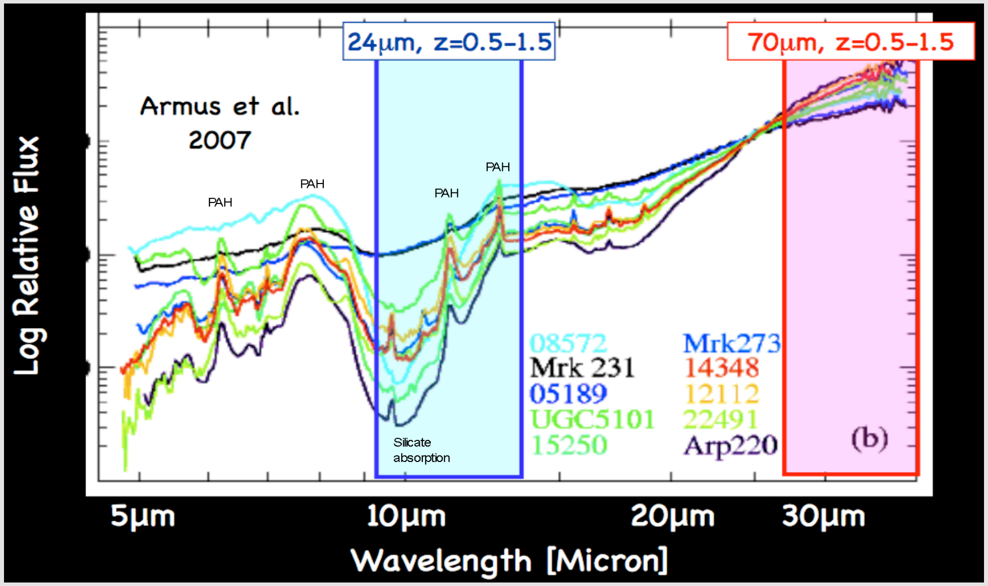
What's Up with High-Redshift CMDs?

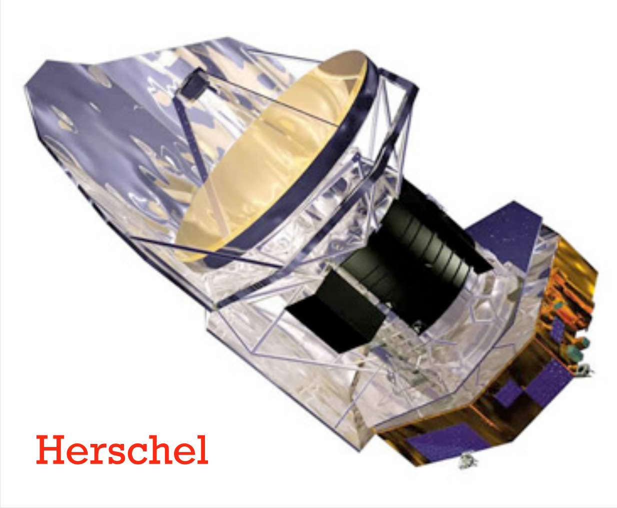


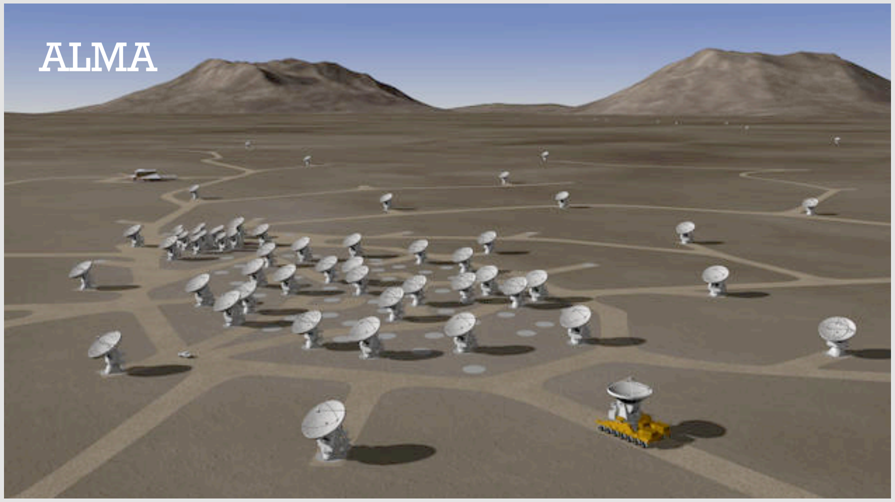
Over ~ 80% of cosmic time during which most of galaxy formation occurred, AGN hosts look like normal massive galaxies.

Would be nice to see some clear feedback signature.

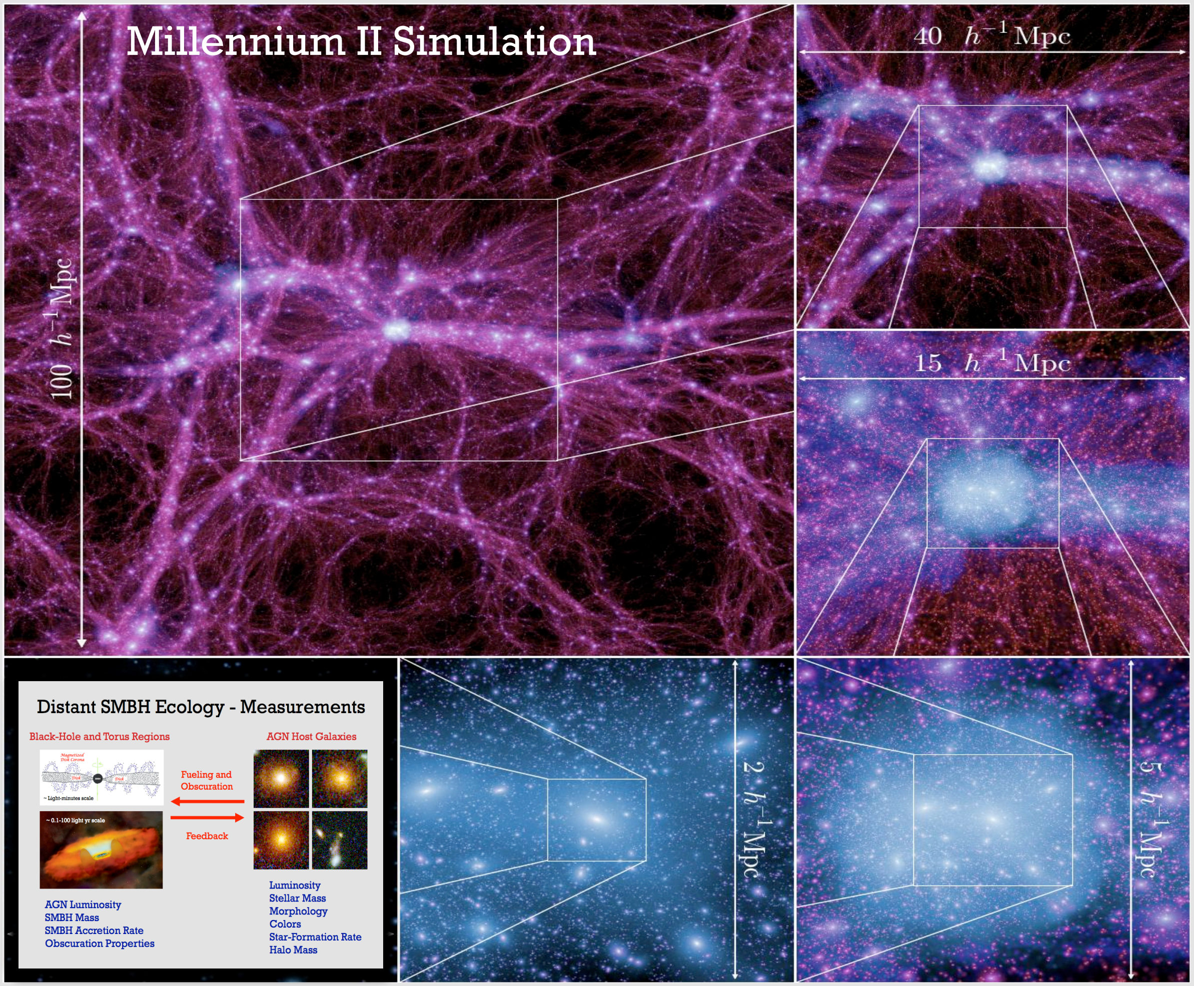
Better Star-Formation Measurements

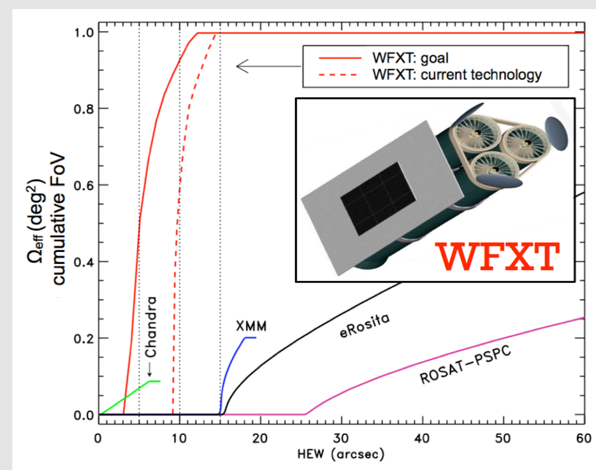






What are Effects of Cosmic Environment?





Need more X-ray surveys with sufficient areal coverage + sensitivity and wide-field X-ray missions.

The End