IR/X-ray Selected AGN and Their Host Galaxies

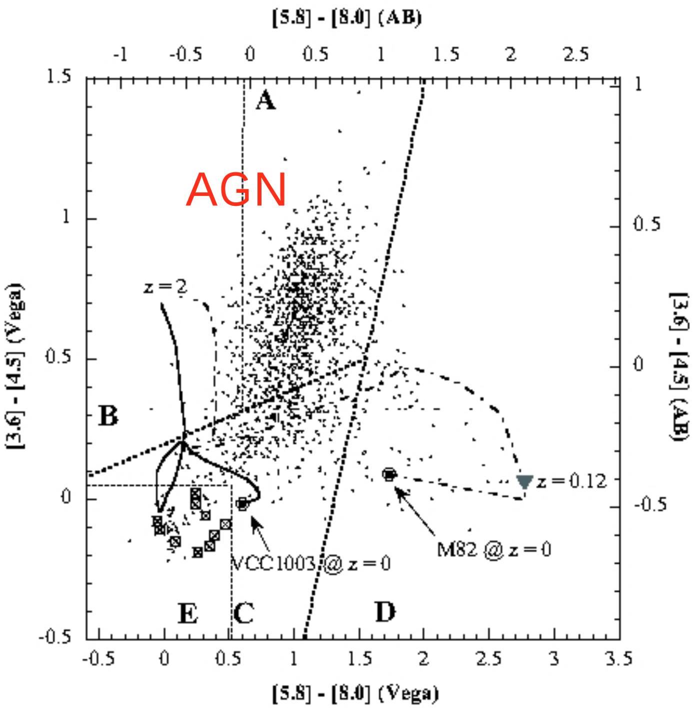
Forman, Hickox (thesis), Murray, Jones,
and the Bootes Team

Two Bootes topics:

- IR (color) selected AGN (z=0.7-3)
    - Show bimodal color distribution
    - Define IRAGN1 (839) and IRAGN2 (640)
    - IR-opt correlations ==> obscuration
    - X-ray HR's confirm 640 absorbed IRAGN2
- X-ray selected z < 0.8 AGN + radio sample
    - Mostly/many "galaxies" - XBONGS - HOST colors
    - Red sequence/blue cloud but green peak of X-ray AGN
    - Correlation functions show color dependence
        - Red (and radio) - denser environments (wrt galaxies)
        - Blue - less dense environments
        - Red - spectra harder- different accretion mode
        - Cold vs. hot gas accretion?

IR/X-ray Selected AGN
(Hickox+07 ApJ 671, 1365)

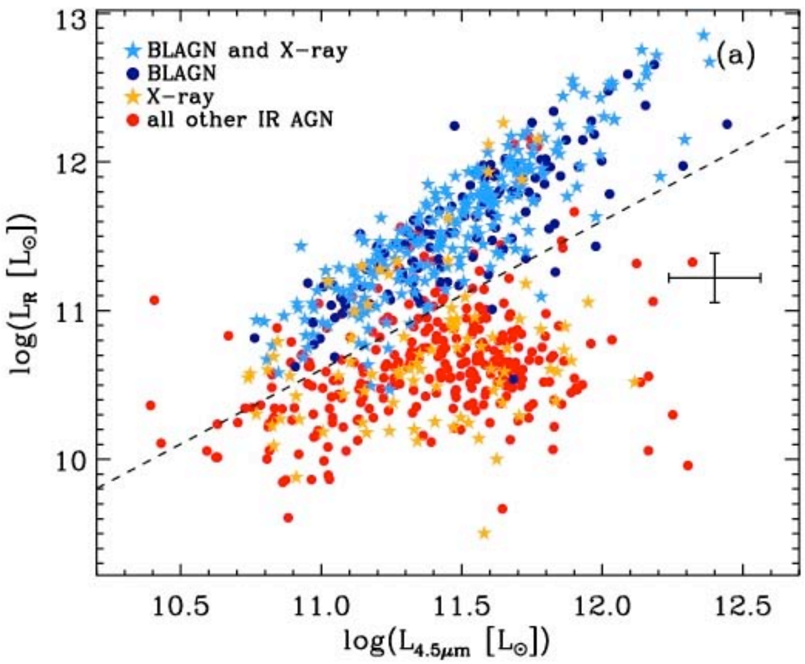
- "Wedge" selected
  - IRAC color-color selected AGN (a la Stern+05)
  - 1479 AGN
- IR-O-X study
  - X-ray Bootes data
  - NDWFS optical photometry (3 bands)
  - AGES spectra (50%) + photo z's (50%)



The IR Wedge: 1325 XBOOTES sources Gorjian+08

L_R (optical) vs. $L_{4.5\mu}$

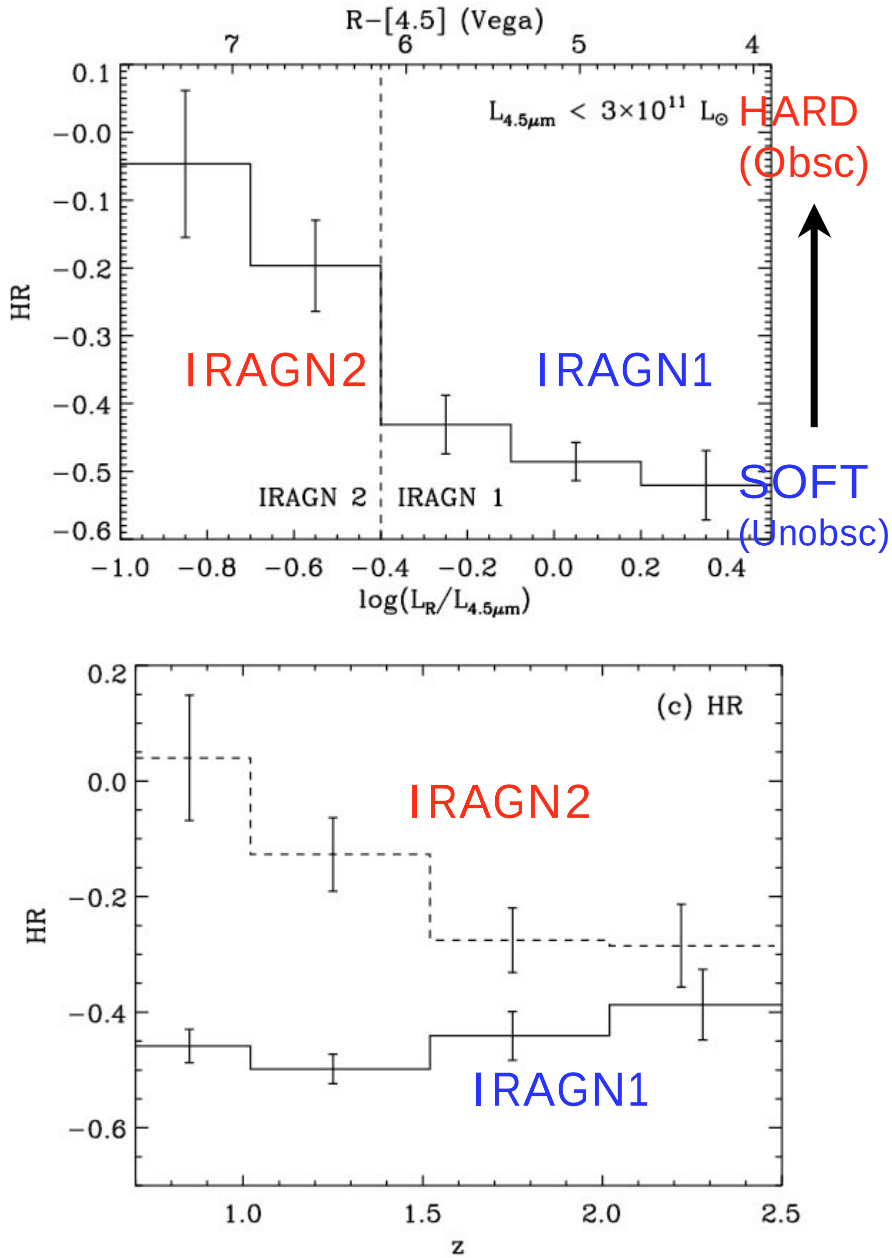
- $L_{4.5\mu}$ not heavily obscured
- Compare $L_{4.5\mu}$ with L_R=optical
- Bimodal distribution
  - BL AGN ≡ IRAGN1
  - NO broad line ≡ IRAGN2
  - X-ray detected (*)
- IRAGN1 = unobscured
  - Increase $L_{4.5\mu}$ ==> increase L_R
- IRAGN2 = obscured
  - Increase $L_{4.5\mu}$ but L_R ~constant
- X-ray test
  - measure absorption
  - verify optical obscuration



X-ray Absorption

- Stack X-ray photons
- Compute hardness ratios
  - HR= (H-S)/(H+S)
  - +1 = hard, -1 =soft
- IRAGN1 - soft
- IRAGN2 - hard
- Consistent with absorption and absence of broad lines for IRAGN2

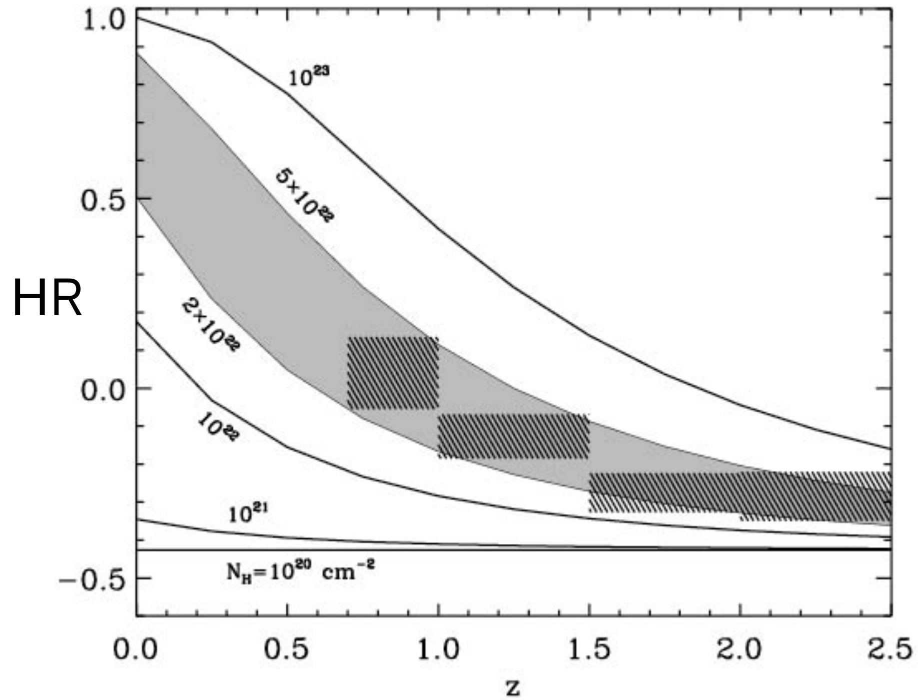
- Redshift dependence
  - Stack in redshift bins
  - absorption moves out of Chandra soft band for IRAGN2
  - IRAGN1 - no z dependence



Redshift Dependence of Absorption

- Fit spectral models to HR (z) for IRAGN2

- Mean/typical n_H ~2-5x10^{22} cm^{-2}
- Luminous sources Lbol ~ 10^{45}-10^{47} erg/s
- Large sample of moderately absorbed AGN - 640!
- Bimodal - separation between IRAGN1 to IRAGN2 is sharp, not gradual
- Disk geometry - abrupt onset of absorption, not slow increase as viewing angle varies



Topic 2: XBONGs in Bootes (Hickox+08)

X-ray AGN Selection: 0.25<z<0.8

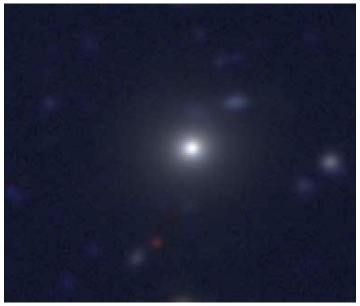
- Mostly "galaxies" - XBONGS
  - X-ray bright, optically "normal" galaxies
  - E.g., z = 0.238
  - No NLs or BLs; absorption spectrum
- 362 (157*) X-ray AGN

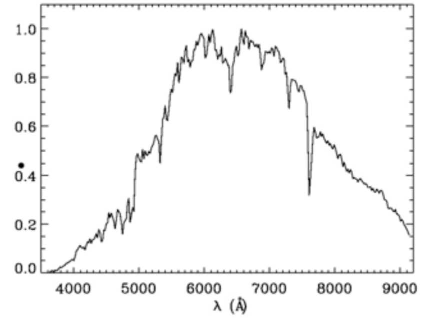
  Plus
- 122 (74*) Westerbork 1.4 GHz AGN
  (P>$5\mathrm{x}10^{23}$W/Hz)

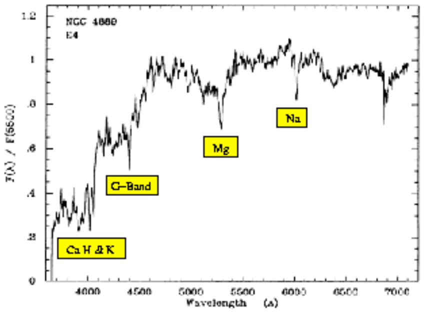
  Plus
- ~12000 (6000)AGES galaxies

Low z, nearby, study host galaxy with little contamination from AGN

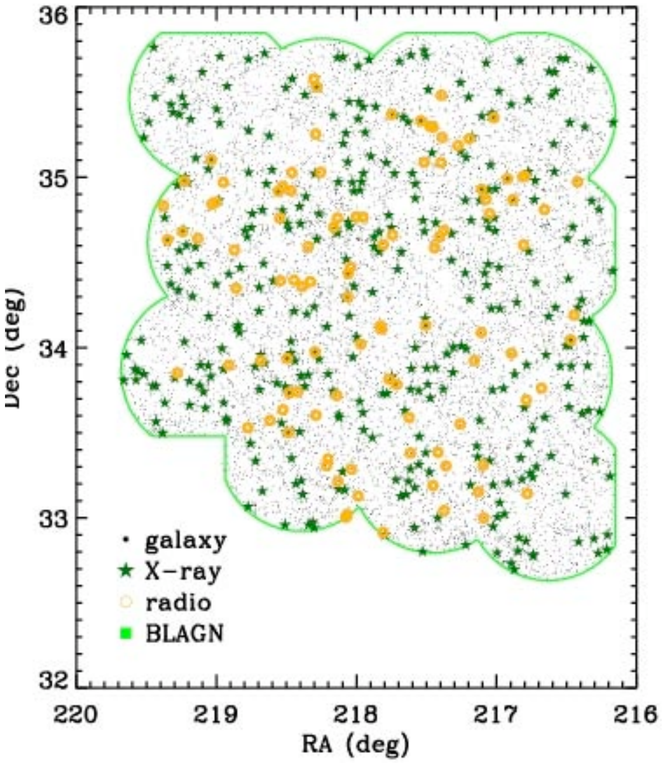
Note: * targeted AGES extended object used for correlation/spectral analysis; XBONGS, very few AGN

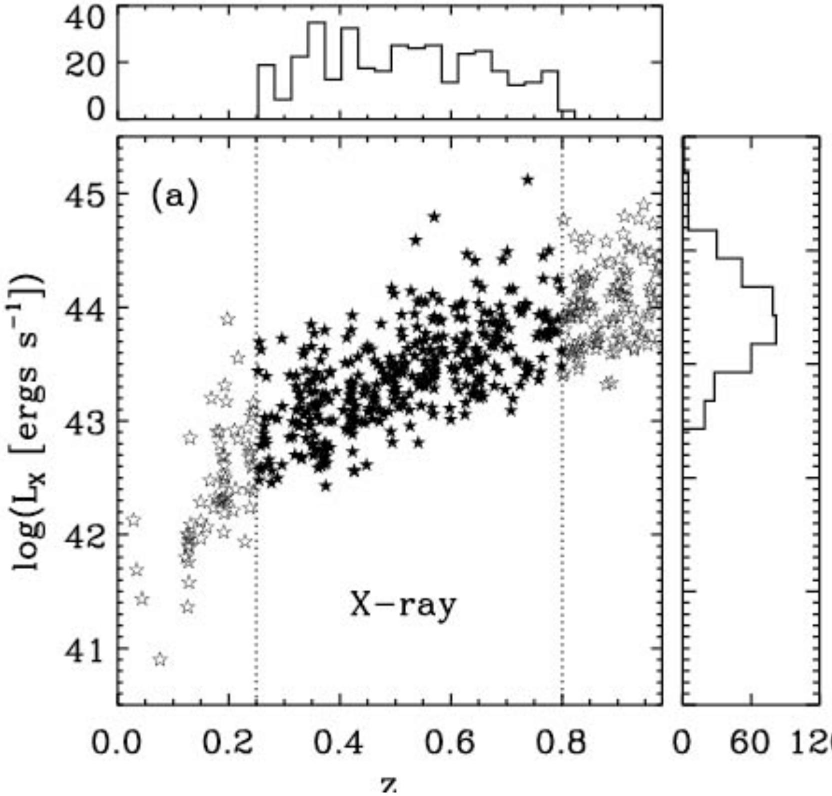






The Sample





Moderate L_x

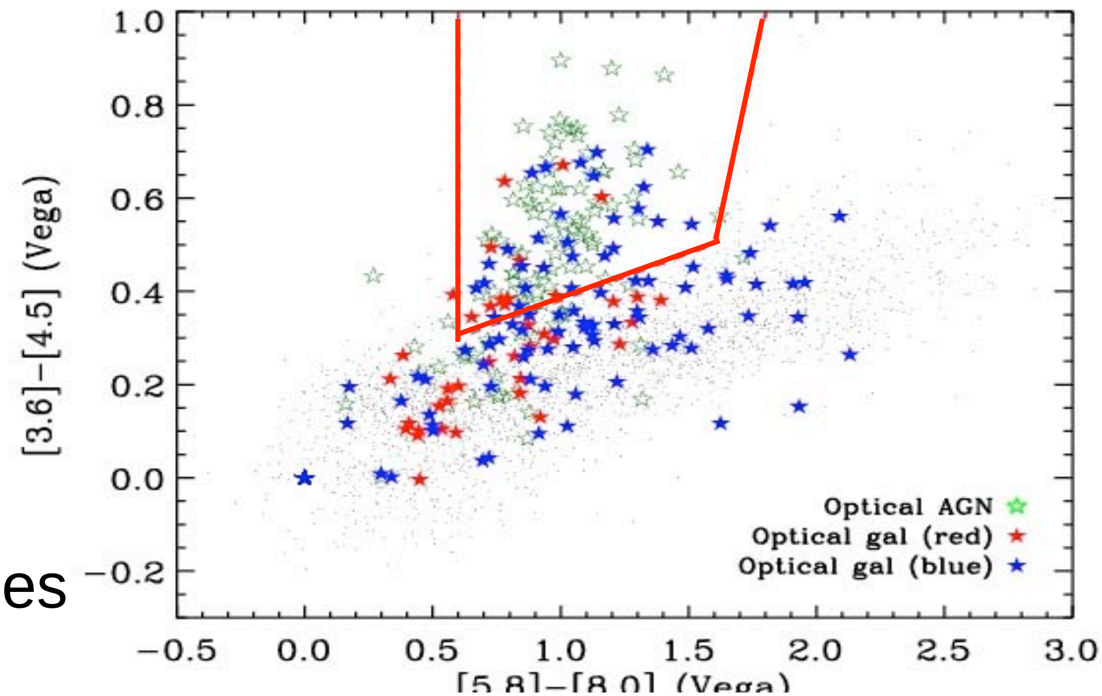
"Complete" optical selection

for R<19.2, 20% of 19<R<20, ...

Comparison to IR AGN Wedge

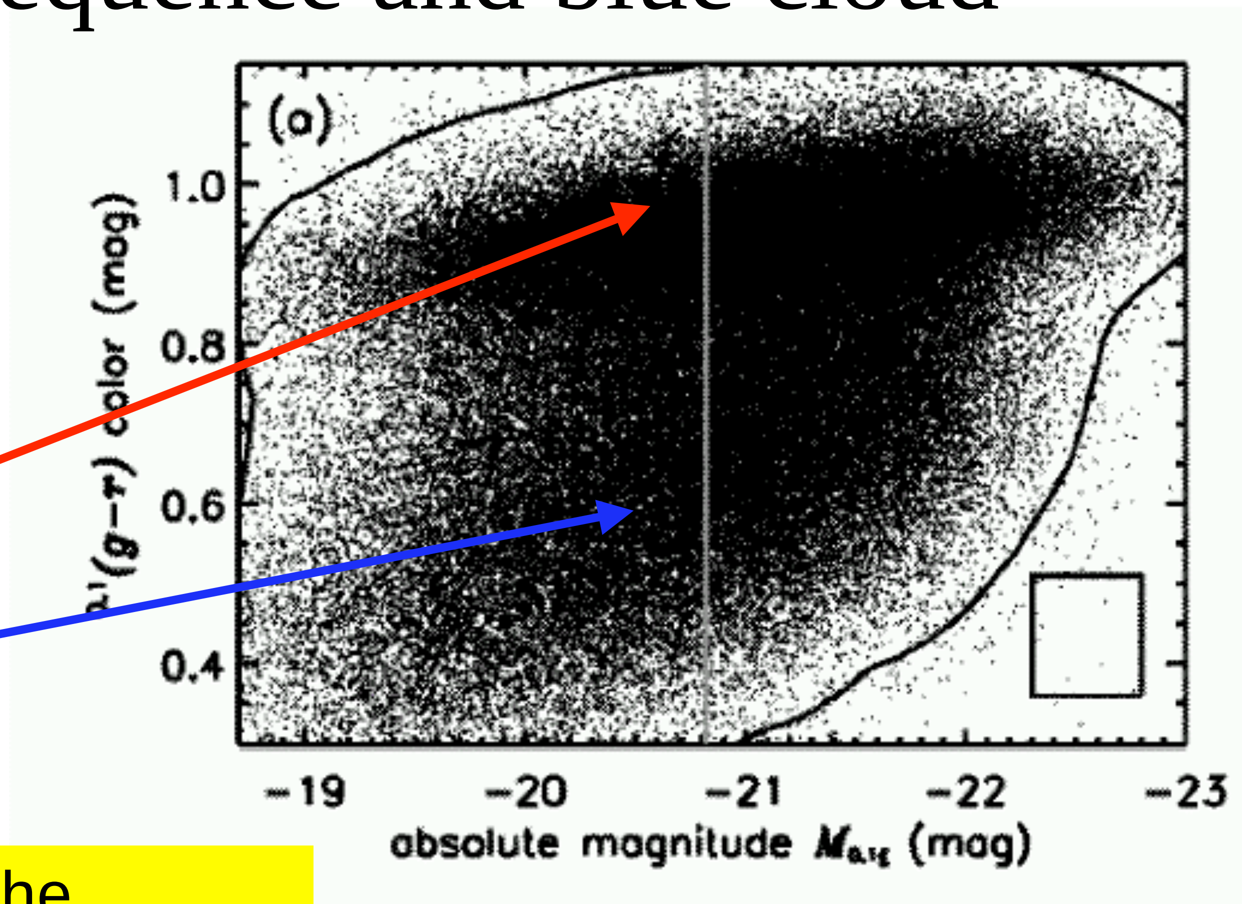
Spectroscopic classes

- AGN
  - 99 BL AGN
  - 27 NL AGN
- Galaxies 236
  - "Red" 52
  - "Blue" 105
  - Mean z increases upward
  - Many low L_X AGN outside the IR wedge
    - Dilution of BLs/NLs



Red sequence and blue cloud

SDSS color-magnitude diagram Hogg+03



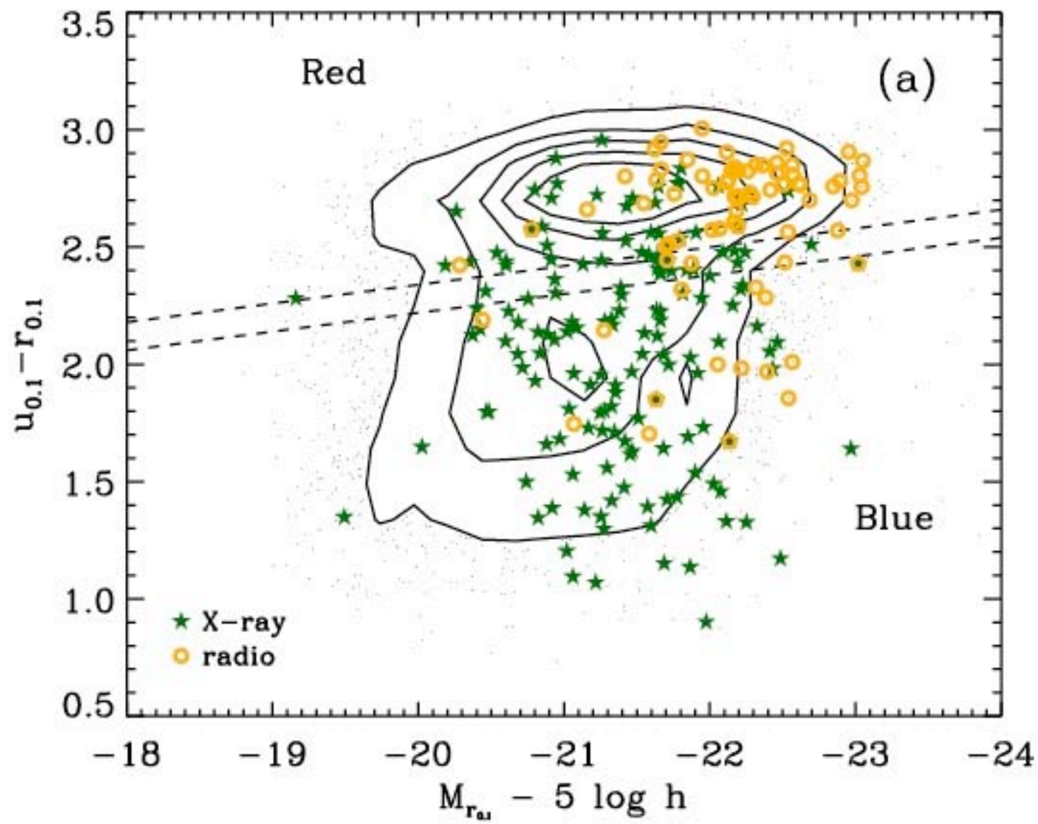
Red (early-type) galaxy sequence

Blue Cloud

Where are the Bootes X-ray AGN?

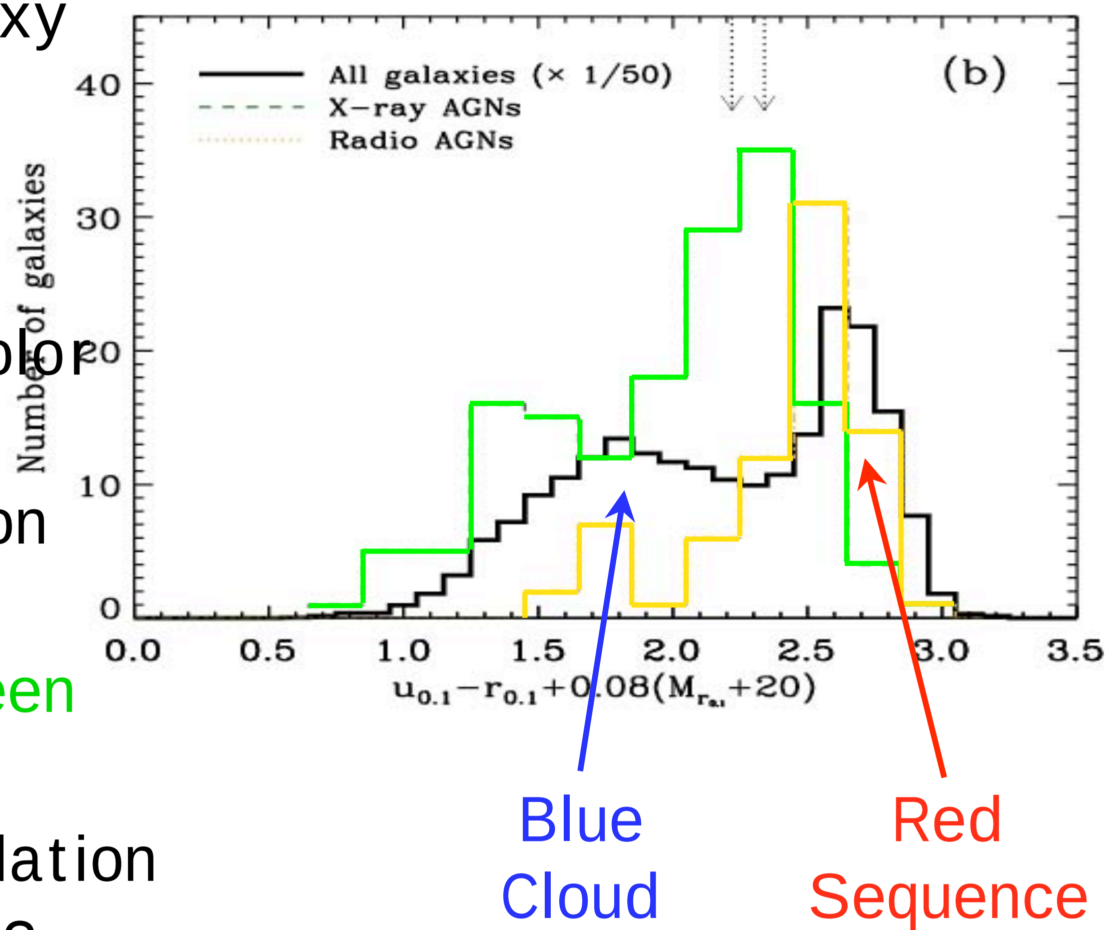
Bootes AGN Hosts

- 0.25 z< 0.8 AGES galaxies (~6000)
  - •Red sequence/blue cloud in AGES
- •Radio AGN Hosts
  - •Red (and)
  - •Luminous
  - •BCG-like
- •X-ray AGN
  - •Not concentrated in red cloud



AGN Color Distribution

- Bimodal AGES galaxy color distribution
  - Red sequence
  - Blue cloud
- Radio AGN - red color
- X-ray AGN
  - Broad distibution but
  - Peak in the "green valley"
  - Transition population from blue to red?



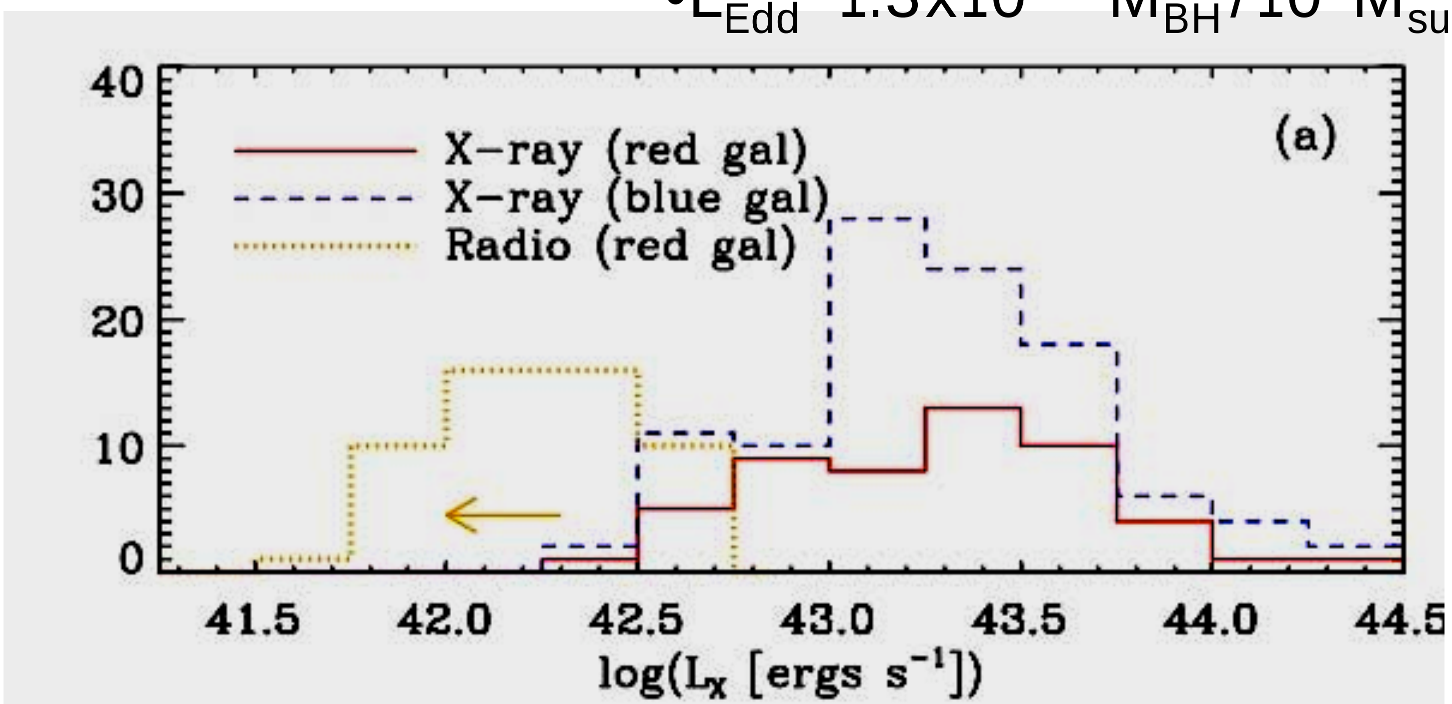
Accretion Modes - L_{bol}/L_{Edd}

L_x--> L_{bol}

- Bolometric correction - BC(L)
- x 10-20 (Hopkins+07)

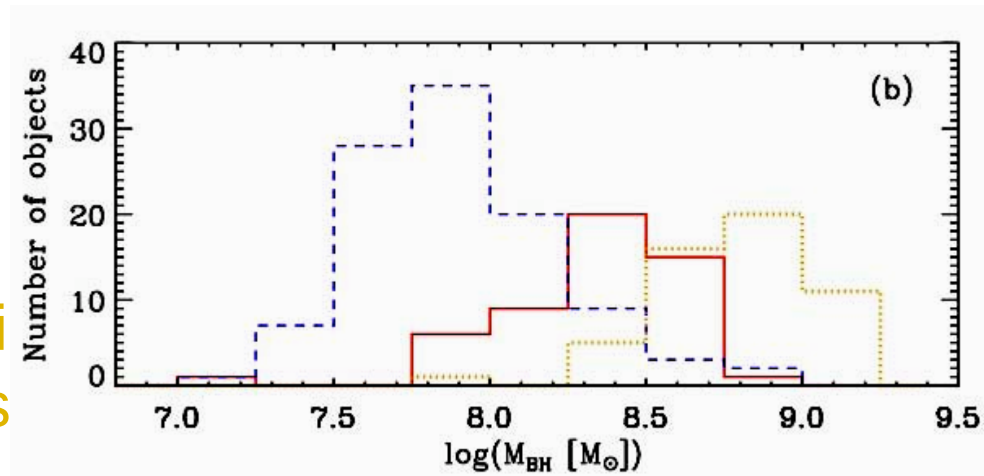
L_{gal}-->L_{bulge}--> M_{BH}--> L_{Edd}

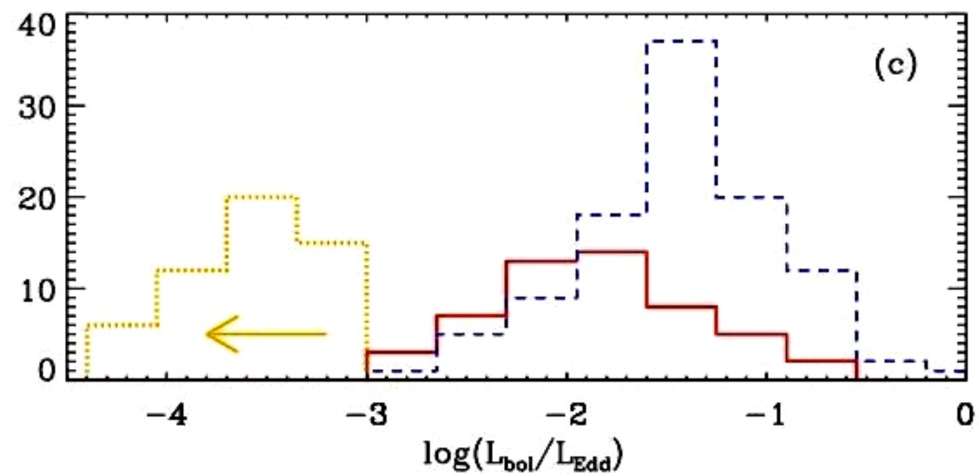
- Bulge decomposition (Millenium Gal Cat. Allen+06)
- Bulge-black hole correlation Marconi & Hunt 03
- L_{Edd}~1.3×10^{44} $M_{BH}/10^6 M_{sun}$ erg/s



Accretion Properties

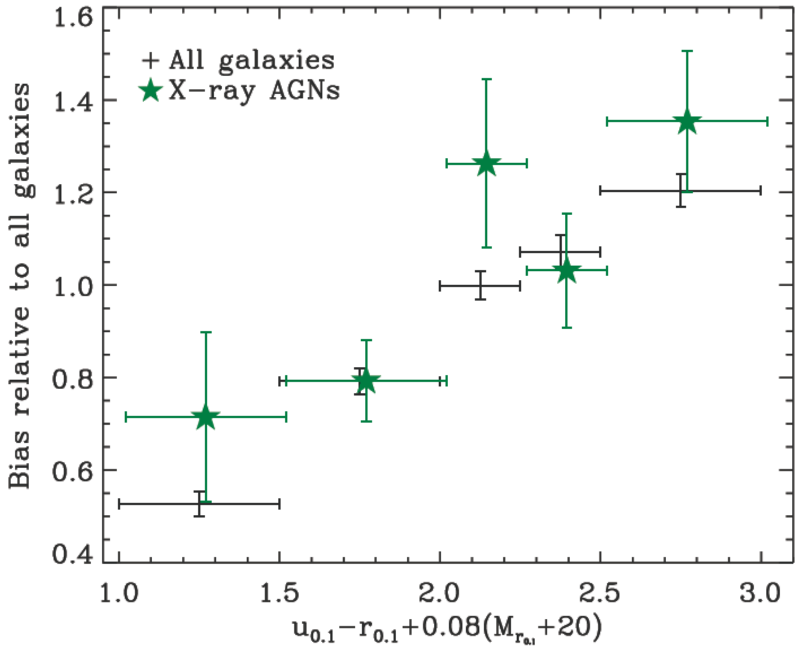
- Radio
  - Most massive
  - In largest,red gals
  - Very low L_{bol}/L_{Edd}
  - BCG's + Bondi accreti
  - Hot gas L_x~10^{41} erg/s
- Red AGN
  - Moderate mass
  - Intermediate L_{bol}/L_{edd}
- Blue AGN
  - Lowest mass
  - Highest L_{bol}/L_{edd}
  - Active star formation
  - Active cold accretion





Correlation Analysis - Red vs. Blue

Characterizes dark matter halos
and environment
w_p = correlation (integrated
along 25 Mpc)
Bias = AGN-galaxy/galaxy-galaxy
(averaged over 0.3-10 h^{-1} Mpc)
measure of excess galaxy density
compared to galaxy sample

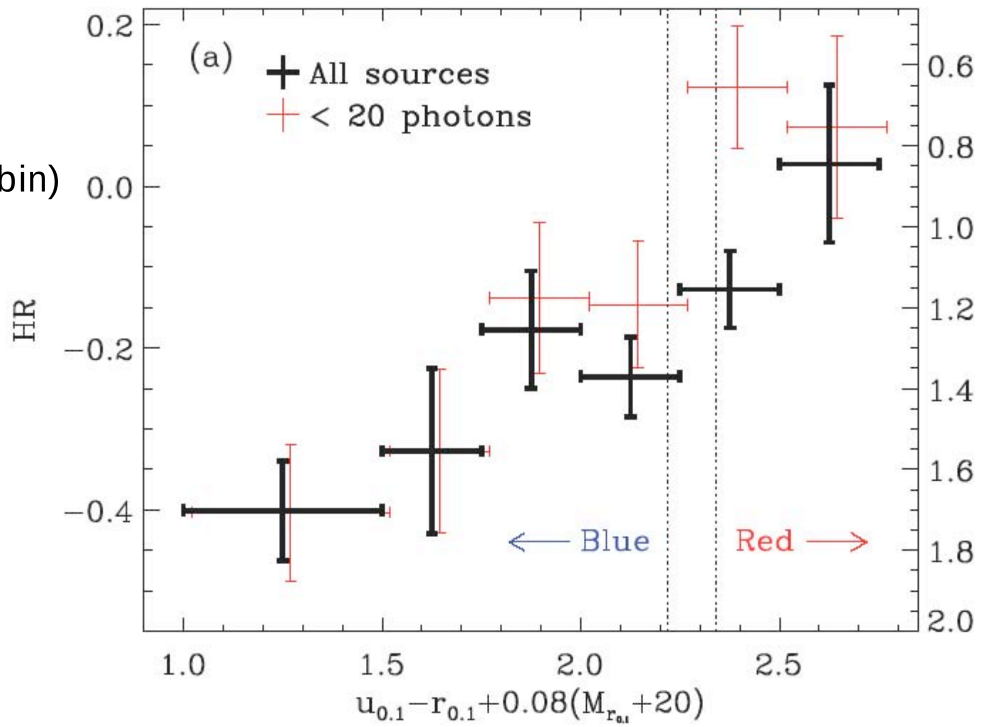


For AGES galaxies and hosts of X-ray selected AGN
Red - more strongly clustered/denser environment
Blue - less strongly clustered/less dense environment
Radio (reddest; most massive hosts) - densest galaxy environments

AGN host environments same as non-AGN galaxies
follow host color (relative to entire AGES sample)

X-ray "spectra"

- Red galaxies
  - very hard: $\alpha \sim 1$
  - Spectral fits (broader color bin)
    - α=1.1-1.3
    - for $\alpha \equiv 1.9$, n_H=0.7-1.1x10^{22} cm^{-2}
- Blue galaxies
  - Typical AGN spectrum
  - $\alpha \sim$ 1.6-1.8
  - Spectral fits
    - α = 1.55-1.75
- AGN (BL/NL objects)
  - spectral fits
    - α = 1.8-2.3



Conclusions

Select IR AGN from "wedge" (Hickox+07, ApJ 671, 1365)

- Minimize absorption effect in IR
- $0.7 < z < 3$
- Bimodal distribution of type I and type II with/without broad lines
- IR/optical ==> unabsorbed and absorbed
- X-ray "spectra" confirm absorption properties
    - IRAGN1 - optical lines, no absorption
    - IRAGN2 - no detected lines, $n_H \sim 2\text{-}5 \times 10^{22}$ cm^{-2}
- Onset of absorption is abrupt; disk geometry

- Study AGN hosts at $0.25 < z < 0.8$ (Hickox+08 in prep.)
- AGN (XBONG) host colors peak in the "green valley"
- AGN hosts - bias is color dependent; same as non-AGN gals
    - Red - denser environments; blue - less dense environments
    - Radio AGN - reddest & densest environments; BCG's?
- Red AGN - very hard spectra; ADAF/ADIOS accretion?
    - Transition population between active star formation, and quiescent systems (early type galaxies)

MORE

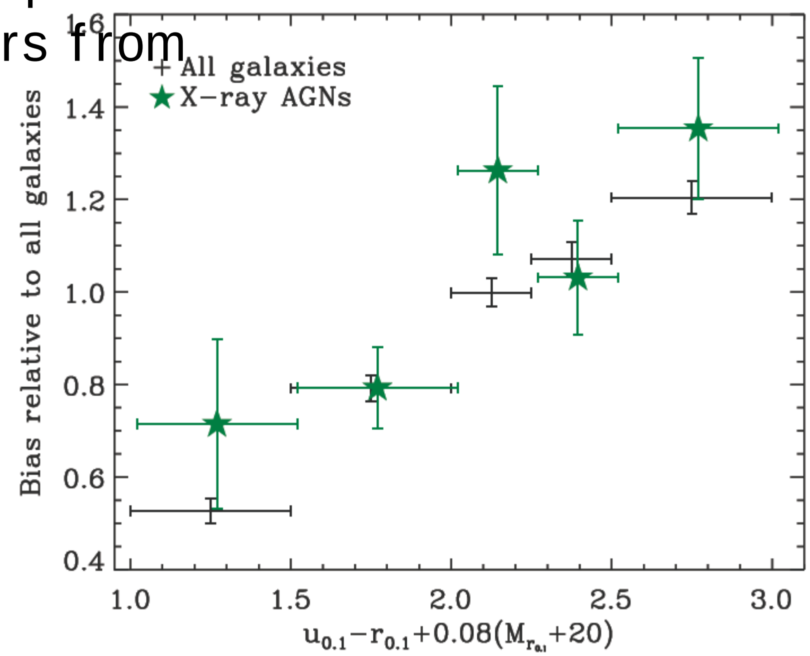
Correlation Analysis - Red vs. Blue

•Characterizes dark matter halos and environment

w_p = correlation integrated over 25 Mpc

ξ + 1 = # of pairs observed / # of pairs from random

$$w_p(r_p) = 2\int_0^{\pi_{max}} \xi(r_p, \pi) d\pi$$

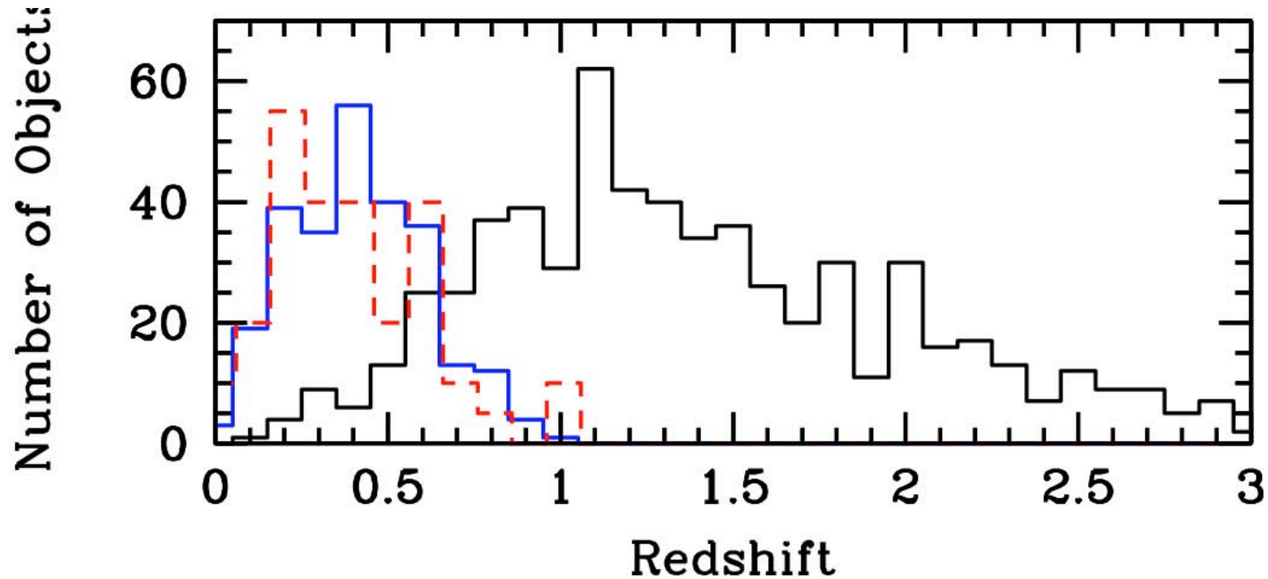


Red - stronger correlation
Blue - weaker correlation
Radio - strongest

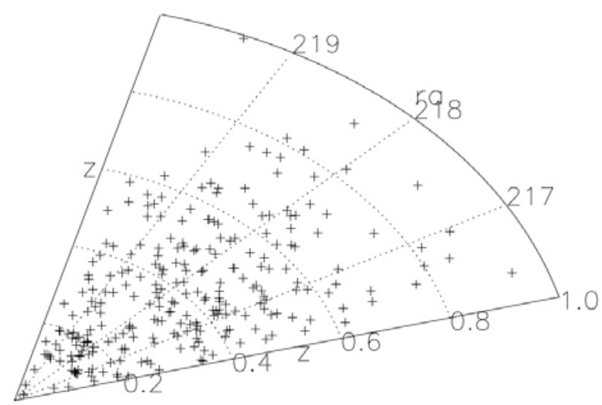
Holds in AGN environment
i.e., measure of galaxy mass (and of SMBH)

Redshift Distribution

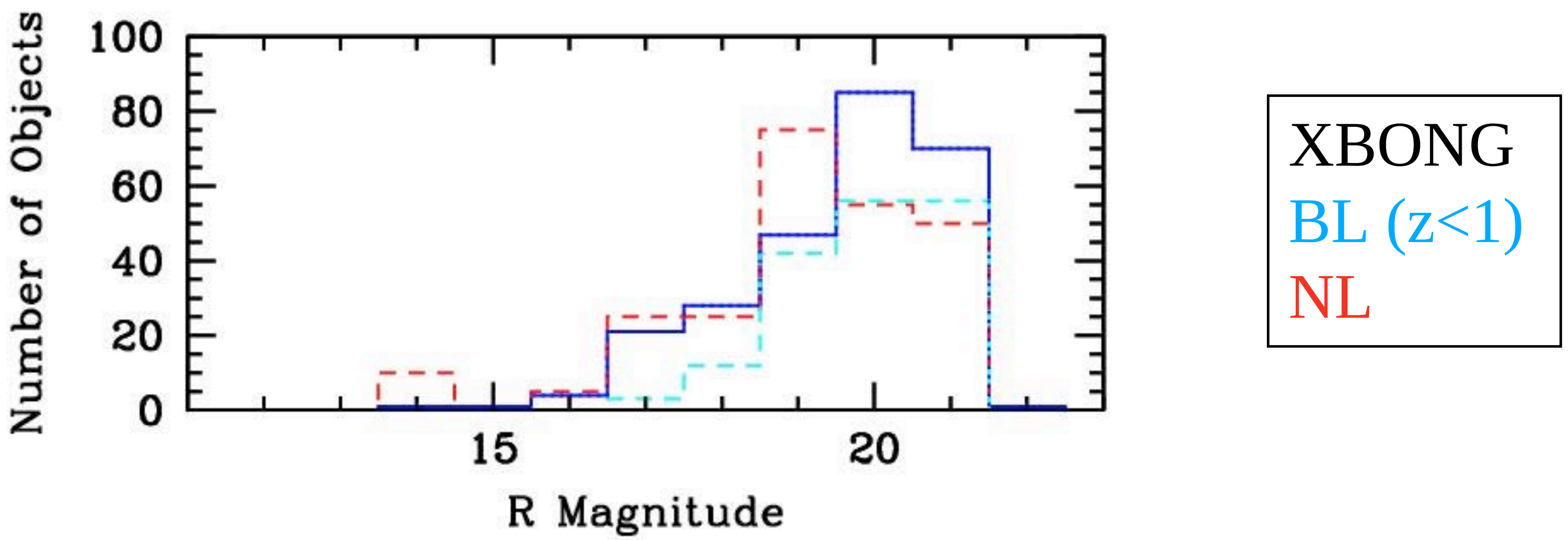
XBONGS
Broad line AGN
Narrow line AGN



XBONGS and NL AGN
same distribution



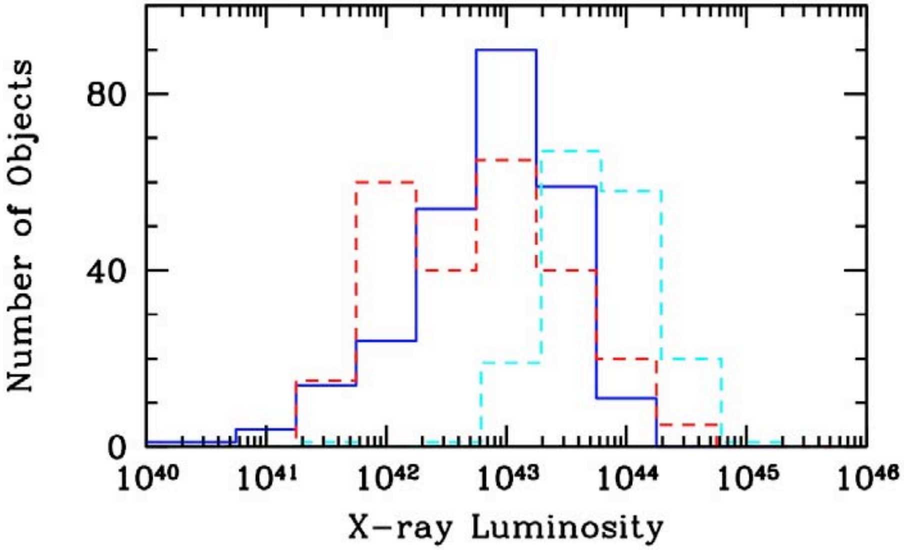
XBONG Magnitude Distribution

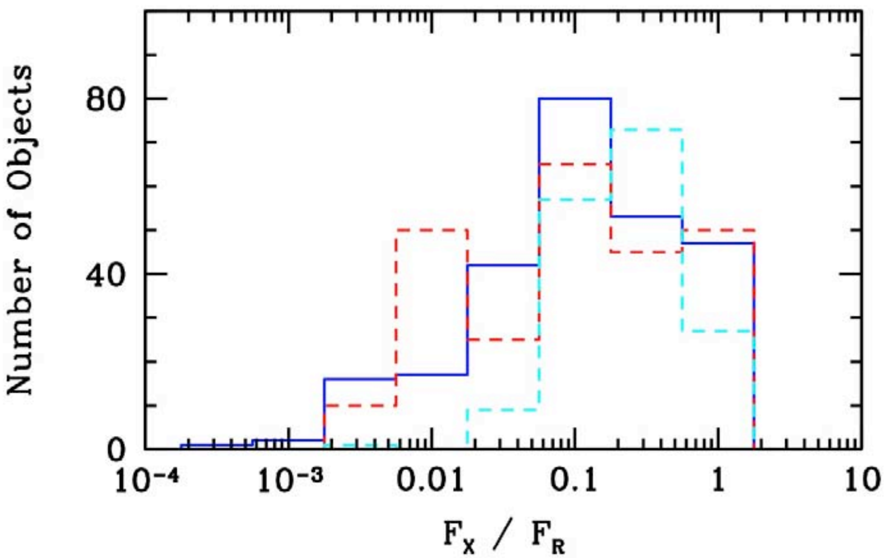


XBONG counterparts similar to NL/BL AGN
possibly somewhat fainter than NL AGN

Argues against significant dilution of lines by
underlying host galaxy for all of sample

Luminosity Distributions





- 200 XBONGs with $L_x > 10^{42}$ erg/s
- 50% with $L_x > 10^{43}$ erg/s
- XBONG's and NL AGN
  - Similar L_x
  - Similar F_x/F_R
- Argues against dilution for all of sample

XBONG
BL (z<1)
NL

Merged X-ray Spectra

Type	α (90% error) and no absorption
Red Ellipticals	**1.12-1.32**
Blue Ellipticals	1.55-1.73
"AGN"	1.83-2.25
Interacting	1.28-1.56

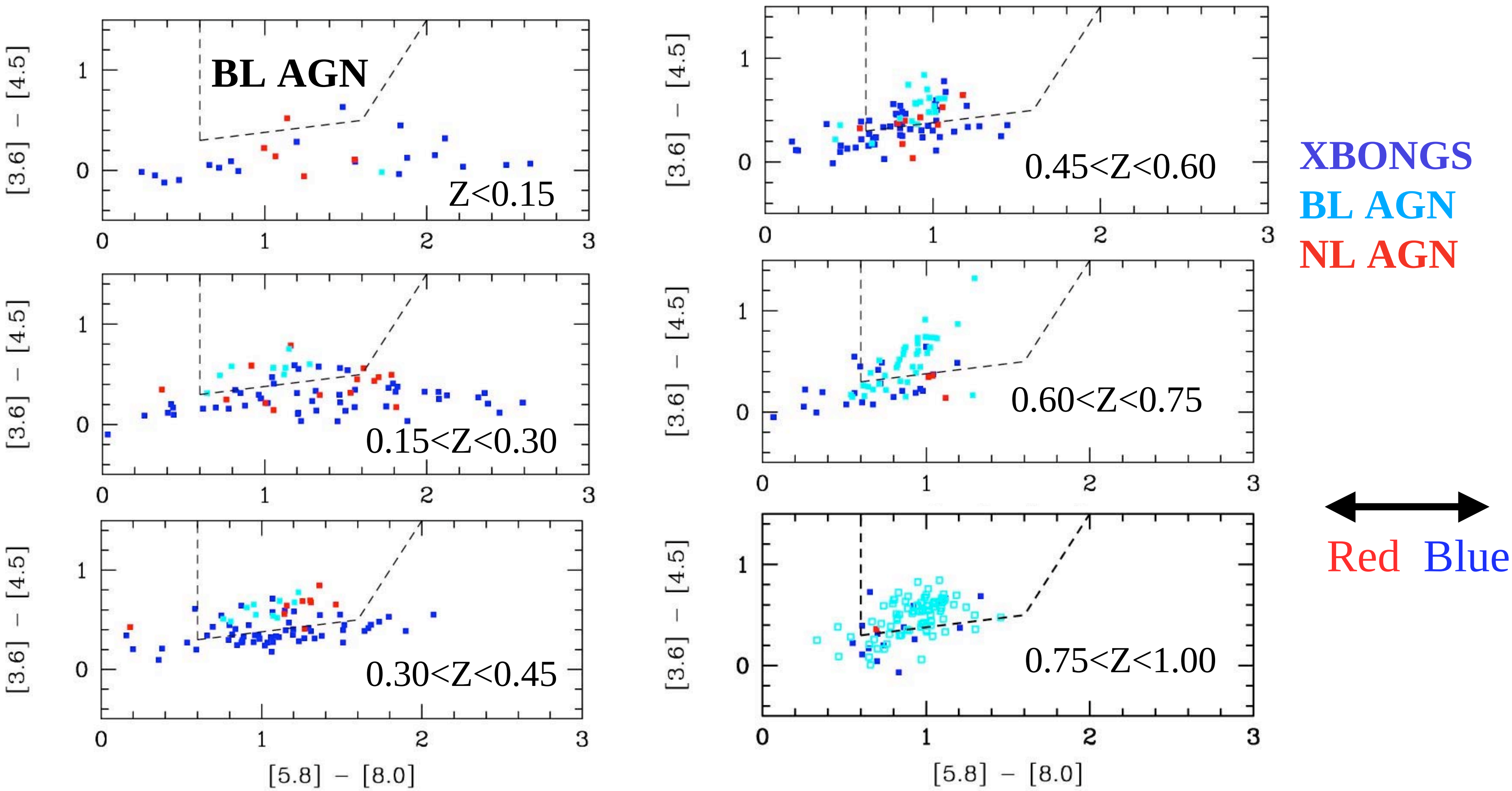
(confirmed by hardness ratios)

Red ellipticals - for an assumed α=1.9 power law

$n_H \sim 0.7\text{-}1.1 \times 10^{22}\ cm^{-2}$ (90% confidence)

- Some "types" absorbed, some not absorbed

IRAC Color-Color Diagrams (following Stern et al.)



z<0.3 Dilution - about 30%; consistent with Georgantopoulos et al. dilution criterion

z>0.3 XBONGS concentrated under AGN wedge

Radiatively Inefficient Accretion Flows (RIAF)

- At low accretion rates (Yuan & Narayan)
  - Optically thick disk is truncated at R_{trans}
  - Interior to R_{trans} flow is RIAF (radiatively inefficient; optically thin)
  - Observed in high state galactic black holes
  - X-rays from inverse Compton in RIAF
  - Little optical or UV since no disk at small radii
  - **model requires $L/L_{edd} < 0.03$**
- Test RIAF model with spheroidal sample of XBONGS
  - Use optical luminosity as proxy for M_{BH} (10^8-10^9 M_{sun})
  - M_{BH} yields L_{edd}
  - Derive AGN L_{BOL} from SED (Elvis et al.)
  - For 46 XBONGS, $L_{BOL} / L_{edd} < 0.01$

VIABLE MODEL - needs detailed SED's