The influence of large-scale environment upon BH growth and feedback in early-type galaxies

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Single and Double Black Holes in Galaxies

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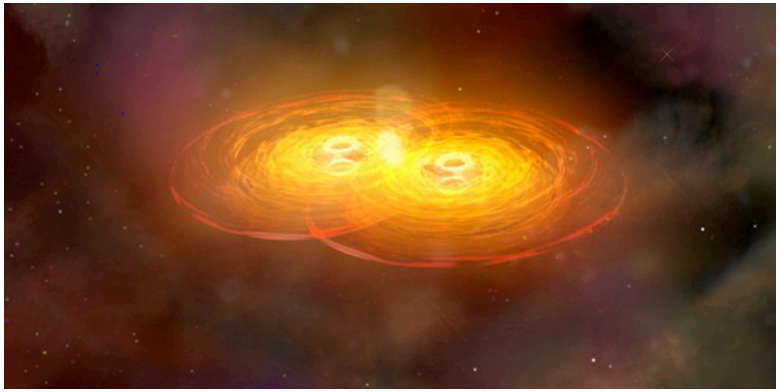
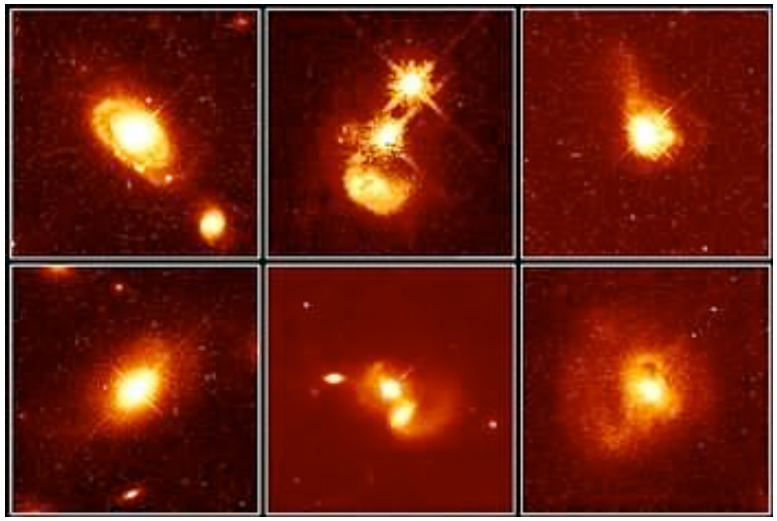
BH coalescence and mergers

- BH mergers aided by stellar, gas dynamics (Preto, Cuadra), gravitational wave emission (Schnittman)
- Major mergers can ignite quasars, including at first passage (da Silva) and at coalescence
- Quasar host galaxies often show direct evidence of recent mergers or interactions, which can drive gas to central SMBH

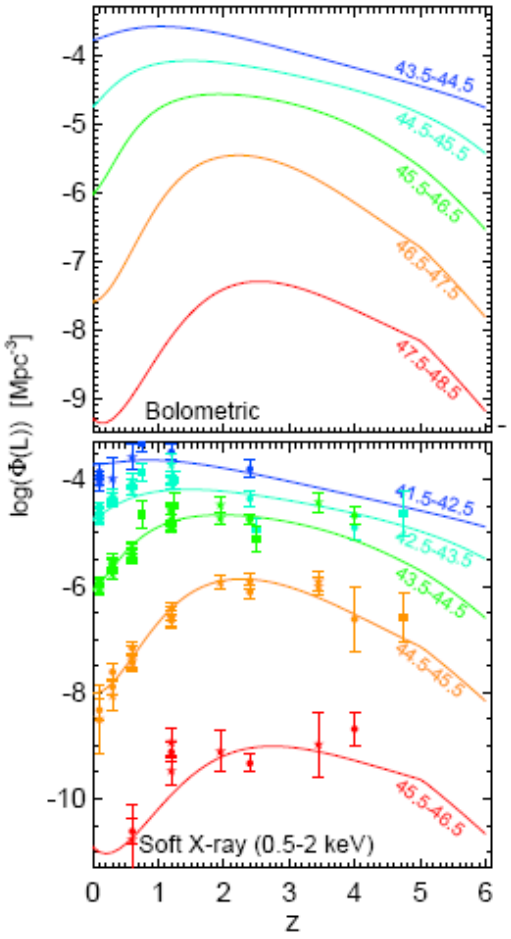




Top: credit CXC

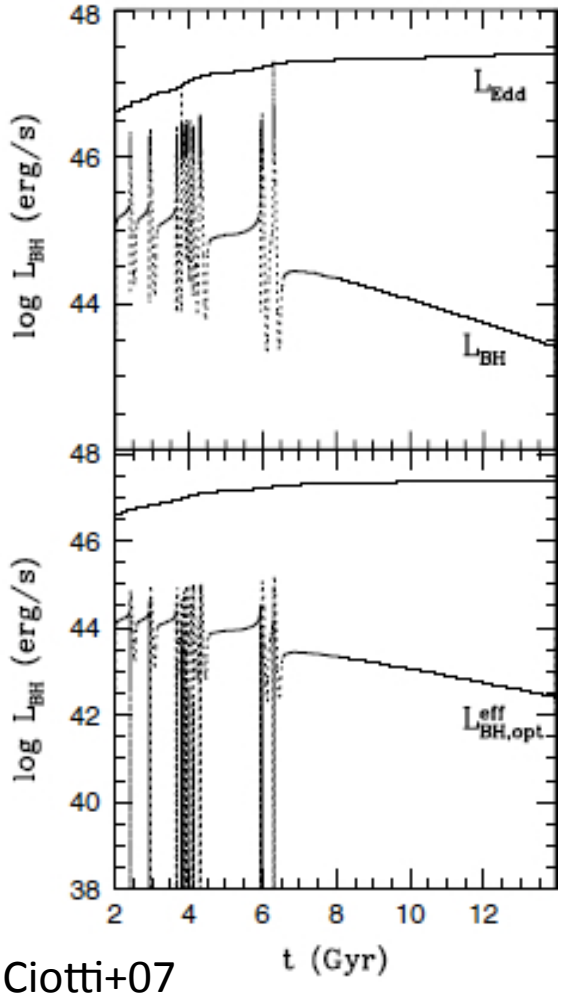
Bahcall+97

BH activity in quasars



Hopkins+07

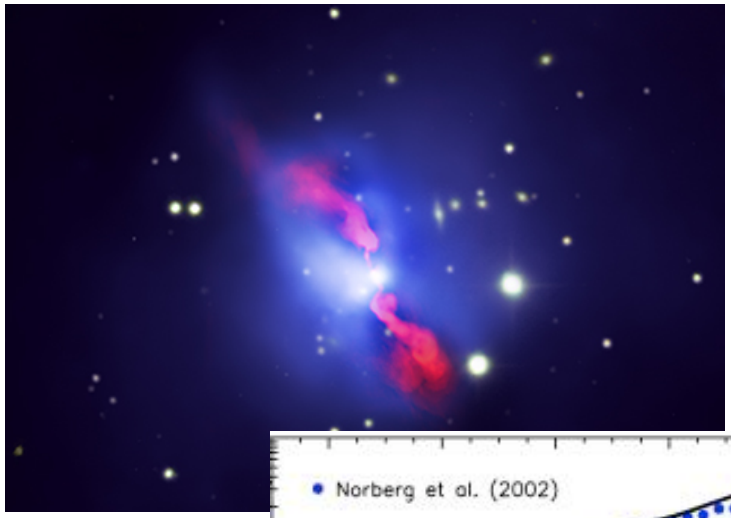
- Quasar density peaks near z~2; lower-luminosity quasars peak later ("downsizing")
- Quasars accrete and radiate at 0.01-1 Eddington, but only for relatively short lifetimes (~10^8 yr)



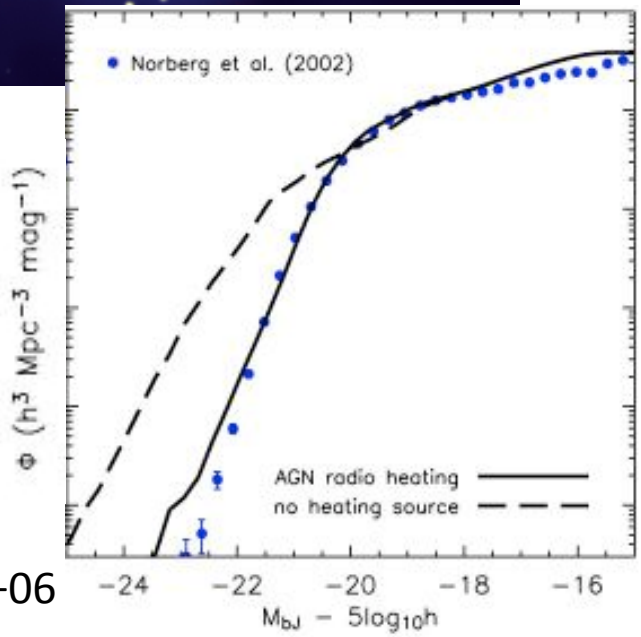
Ciotti+07

AGN feedback in BCGs

- Directly observe radio jets and inflated bubbles in hot ICM
- "Radio mode" feedback added to simulations inhibits SF; matches colors, LF
- Accretion in post-QSO phase is highly sub-Eddington and likely radiatively inefficient



Kirkpatrick+09



Croton+06

Large-scale environment

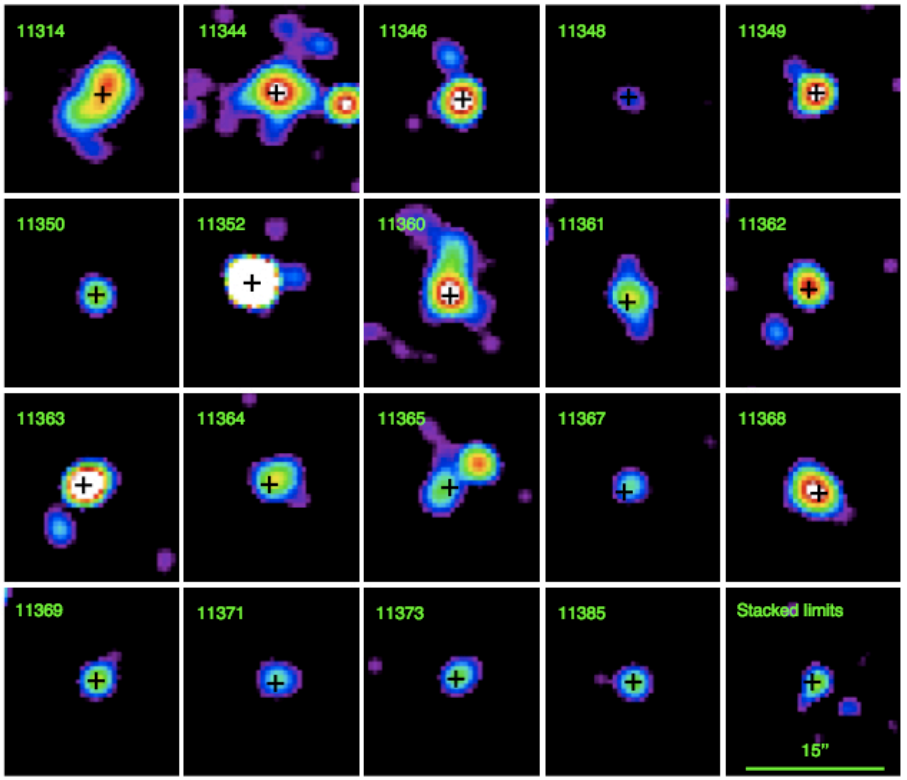
- Field galaxies tend to have more cold gas (Osterloo+10), younger stellar populations (Treu+05, Thomas+05)
- Cluster galaxies can lose gas from harassment, starvation (Treu+03)
- Outflows perhaps stifled in clusters (Brown+00)
- Older stellar populations in clusters could be due to direct environmental effects (Vittorini+05, Martig+09), or to more efficient quenching from nuclear feedback
- We investigate impact of large-scale environment on SMBH activity

The AMUSE surveys

- AGN MUlti-wavelength Survey in Early type galaxies
- Two Large *Chandra* Programs (~1 Ms) for Virgo and Field; bridge the gap between AGN and formally inactive galaxies
- Optical selection, volume-limited (Field <30 Mpc), sensitive to (0.3-10 keV) L_x = 2-3x10^{38} erg/s (i.e., about L_{Edd} for $2M_\odot$)
- Provide a census of nearby SMBH activity and investigate impact of large-scale environment (isolated, group, cluster)

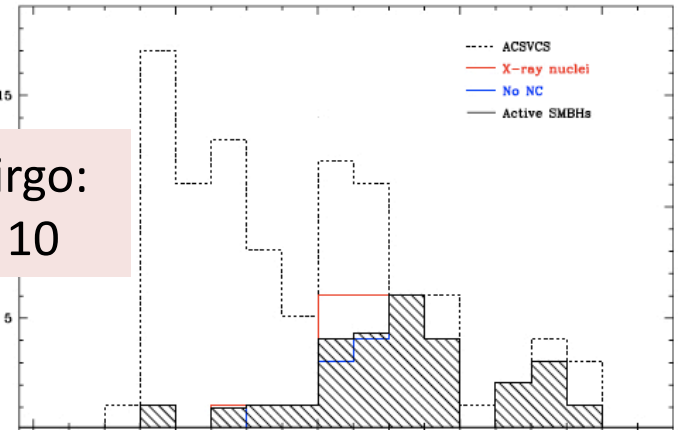
Survey parameters

- AMUSE-Virgo
  - 100 early-types from HST/ACS VCS (Cote'+04)
  - Spans wide mass range: $8.5 < \log M_{star} < 12$ and $4 < \log M_{BH} < 9.5$
- AMUSE-Field
  - 98 non-cluster early-types within 30 Mpc, satisfying M_B<-13
  - Has $7.5 < \log M_{star} < 11.5$ and $5 < \log M_{BH} < 9$

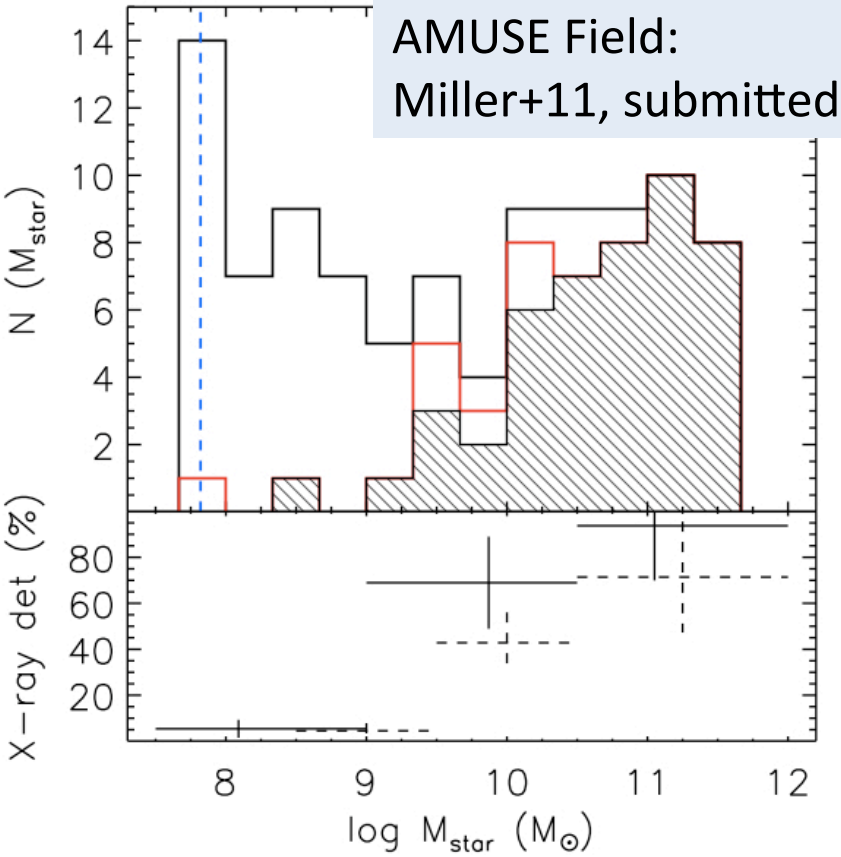


New X-ray detections from AMUSE-Field survey (smoothed 0.3-7 keV counts)

AMUSE Virgo:
Gallo+08, 10



AMUSE Field:
Miller+11, submitted

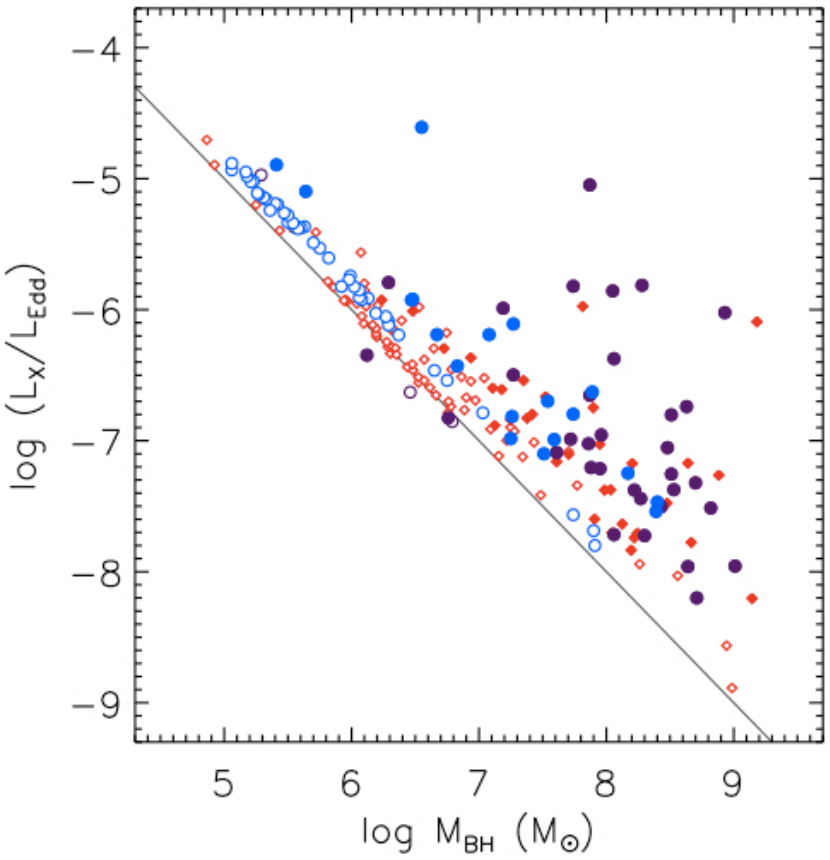


X-ray census

- Virgo: 32/100 detected, calculate 24-34% nuclear active fraction
- Field: 52/98 detected, 40-54% active (has more deep exposures)
- Lower limit to SMBH occupation fraction
- Detection rate increases with M_{star} : “Eddington incompleteness”

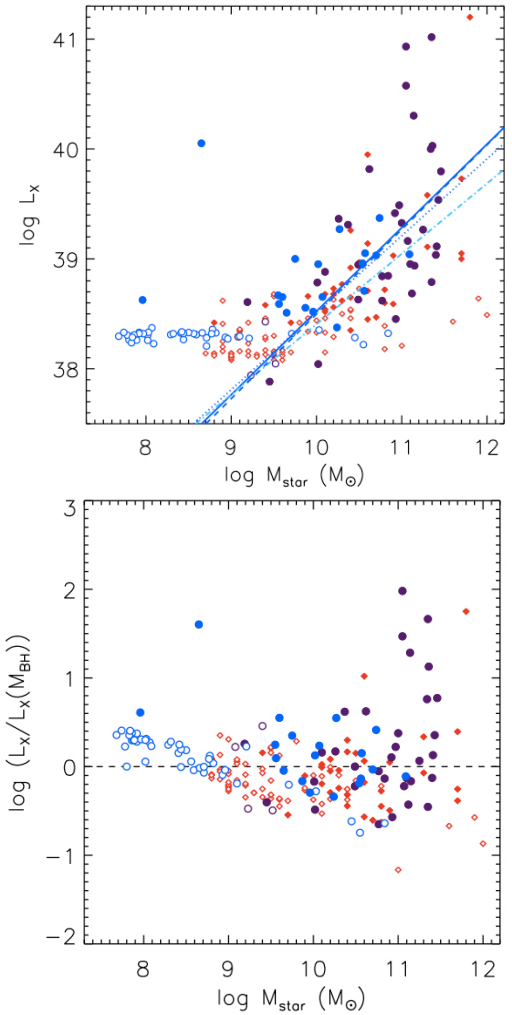
X-ray-to-Eddington ratios

- Both Virgo (red) and Field (blue, purple) have low $-9 < \log(L_x/L_{Edd}) < -4$
- Scarcity of high-mass BHs with "high" L_x/L_{edd} ?
- Higher fraction of "X-ray bright" objects in Field
- Field sample has more low-mass (M_{BH} or M_{star}) galaxies than Virgo

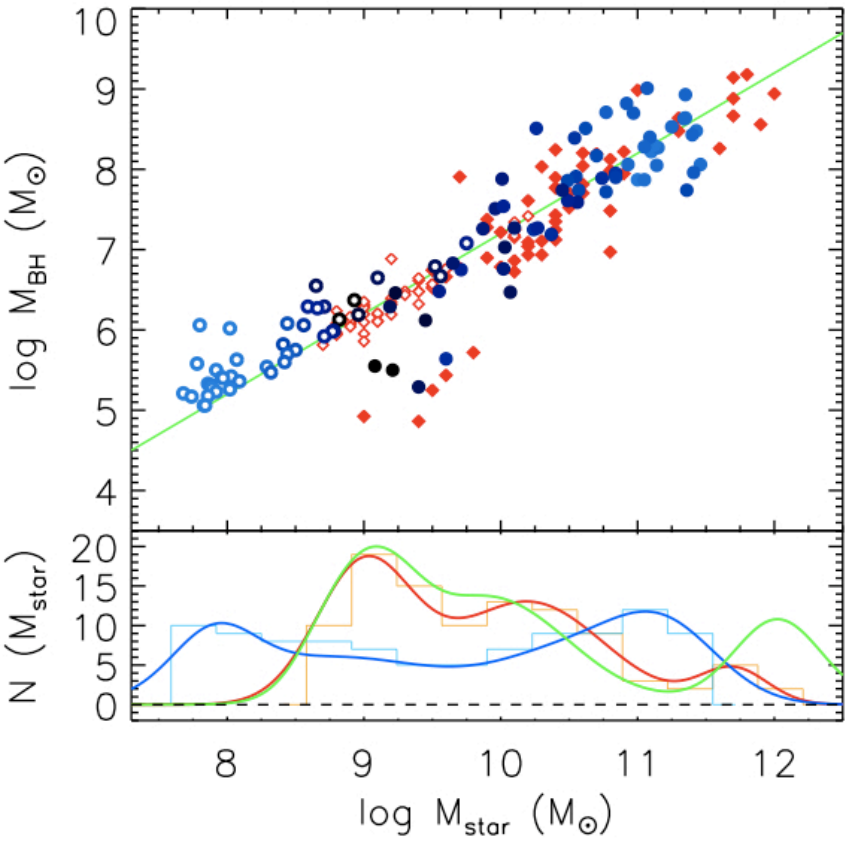


Correlations with L_x

- Nuclear X-ray luminosity increases with M_{star} or with M_{BH}, which are themselves correlated
- Kendall's partial tau test, with X-ray censoring, indicates all correlations are significant
- Want to assess whether cluster galaxies are more active than in field, through comparing Virgo to matched Field subsamples



M_{star} matched subsamples

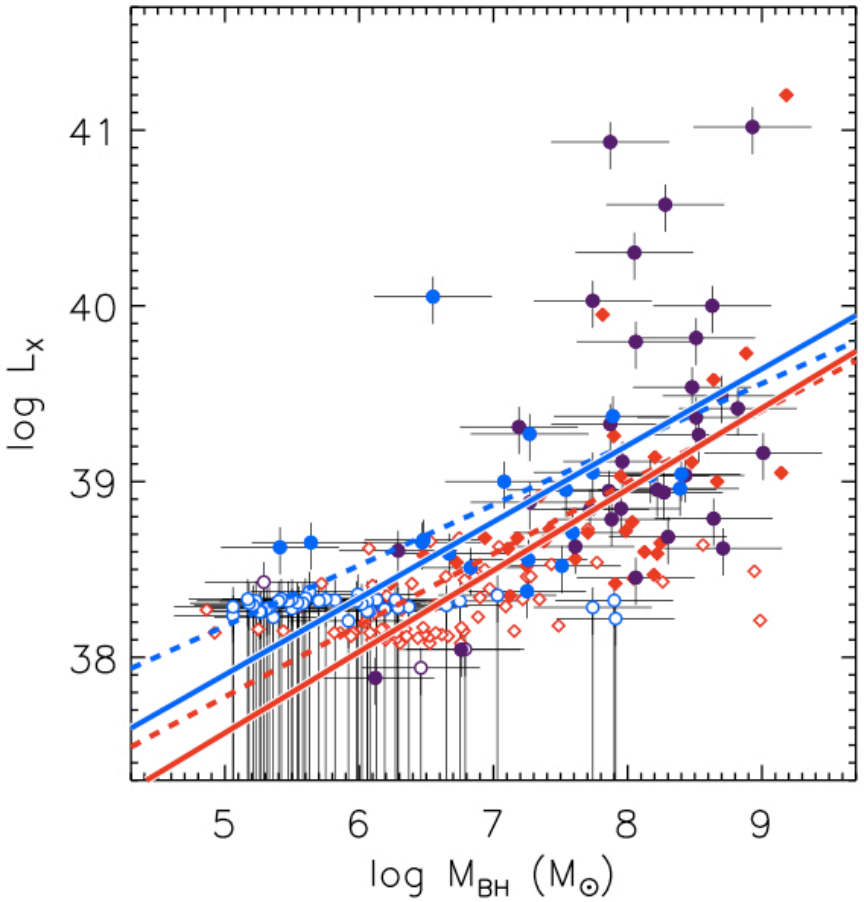


Miller+11, in prep

- Plot shows M_{star} vs M_{BH} (filled points from σ)
- Field and Virgo M_{star} distributions formally inconsistent (KS p<0.001)
- Draw subsamples from Field weighted to match Virgo, to conduct controlled comparison of $L_x(M_{BH})$
- Virgo, Field galaxies with σ do have consistent M_{star} dist

$L_x(M_{BH})$ for Field and Virgo

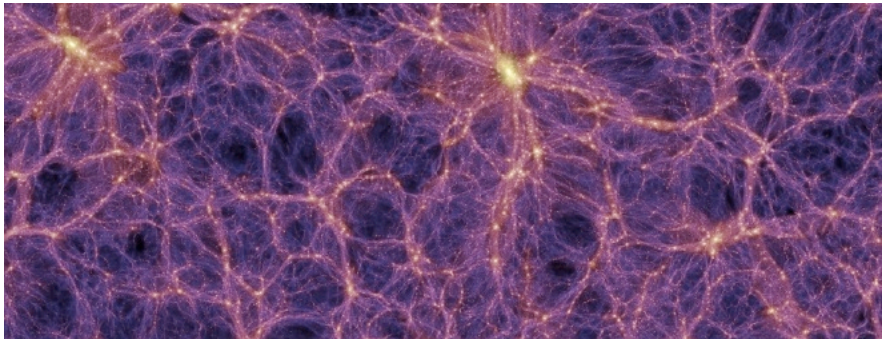
- Bayesian fitting method following Gallo+10
- Consistent slopes of ~0.4 imply $\langle L_x/L_{Edd} \rangle \sim M_{BH}^{-0.6}$ (BH activity downsizing)
- Field intercept marginally higher; modestly X-ray brighter for a given M_{BH}
- Results hold for M_{star} matched subsamples



Group membership

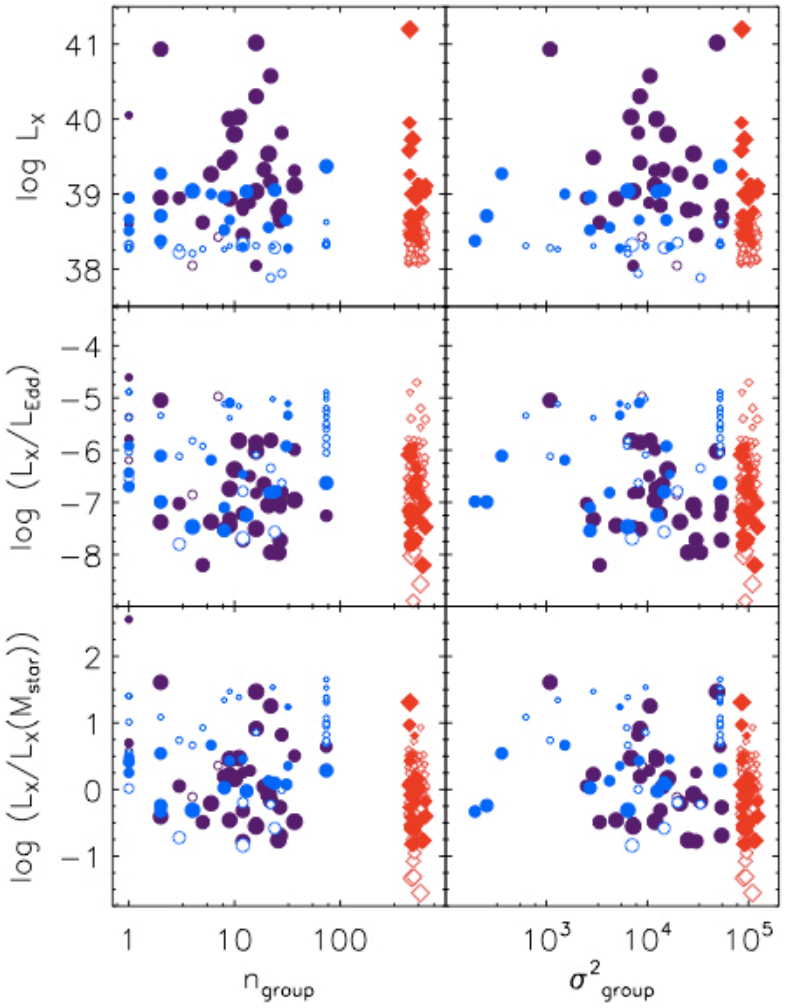
- Can also examine influence of galaxy density within Field
- Lower galaxy velocity dispersions within groups conducive to strong interactions
- Interactions with medium weaker in groups than clusters

- Field galaxies assigned to groups based on catalog of Makarov+11
- Analyze 90 galaxies which have $1 < n_{group} < 74$
- 69 are in groups, 21 in triples/pairs/isolated



Millenium simulation dark matter

X-ray brightness and richness



- Median Eddington-scaled or residual X-ray luminosities ~0.3 dex higher in isolated galaxies versus groups
- Due to large scatter, distributions consistent
- Apparent smooth progression from isolated to group to cluster properties

Influence of environment

- Marginal evidence of modestly enhanced nuclear X-ray luminosities in Field versus Virgo early-type galaxies, as a function of either M_{star} or M_{BH}
- Disagrees with *ROSAT* L_x/L_B trend, but that necessarily also included X-ray emission from LMXBs and hot gas
- Virgo spheroids do not show greater activity than Field; disfavors persistent low-level nuclear feedback as primary cause of cluster older stellar populations (in non-BCGs)
- Decreasing scaled X-ray luminosity from isolated to group to cluster galaxies is consistent with increasing gas starvation in progressively richer environments

Summary

- AMUSE surveys study SMBH activity in ~200 early-type galaxies in Virgo, Field
- Lower limit on occupation fraction of 28%, 47% within Virgo, Field samples
- These galaxies bridge the gap between AGN and formally inactive galaxies
- Observe downsizing trend: galaxies with lower M_{BH} tend to shine closer to their Eddington luminosities
- Nuclear X-ray luminosity is not strongly dependent on large-scale environment
- Field galaxies perhaps marginally X-ray brighter (plausibly due to more ready access to fuel)
- Apparent progression in scaled X-ray luminosities: isolated, group, cluster
- Ongoing work: new σ values, new HST coverage, off-nuclear sources

Open questions

- Is the SMBH occupation fraction within local spheroids ~100%? (Bellovary, Moran)
- Is merger history necessarily relevant to current low-level SMBH activity? (Mathur, Schawinski)
- Does relative accretion rate slightly decrease with increasing galaxy density?
- Is the incidence of nuclear star clusters related to large-scale environment? (Seth)