Supermassive Black Hole Activity in Field and Cluster Early-Type Galaxies

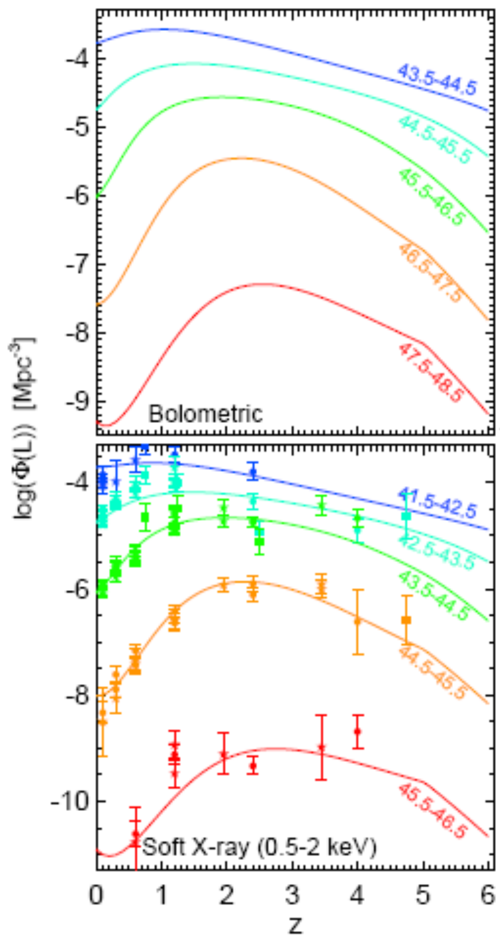
Brendan Miller

Structure in Clusters and Groups of Galaxies
in the Chandra Era

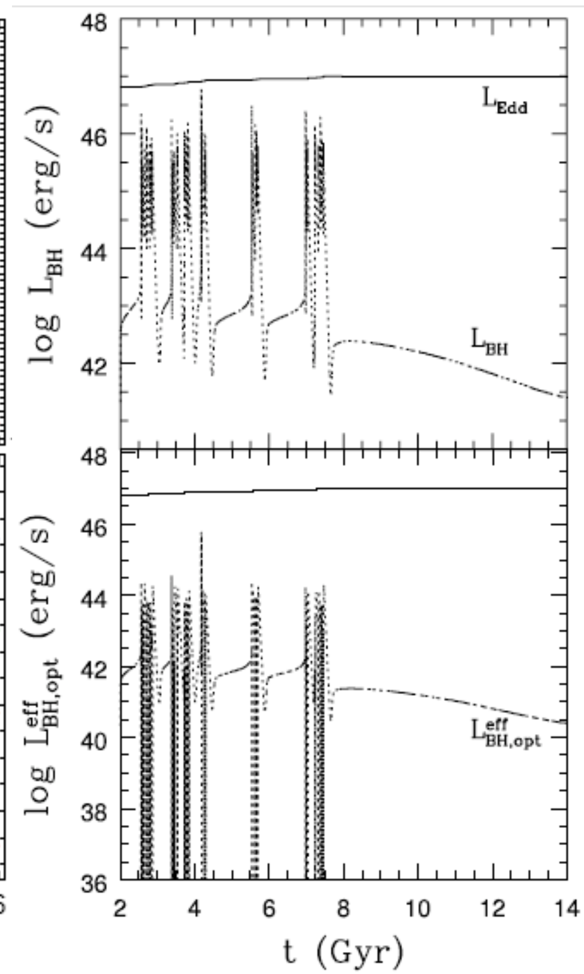
Elena Gallo, Tommaso Treu, Jong-Hak Woo,
Kayhan Gultekin

SMBH activity in quasars

- Supermassive black holes (SMBHs) power quasars, AGN
- Quasar density peaks near z~2; lower-luminosity quasars peak at lower redshifts (“downsizing”)
- Quasars accrete/radiate at 0.01-1 Eddington, but only for relatively short lifetimes (~10^8 yr)



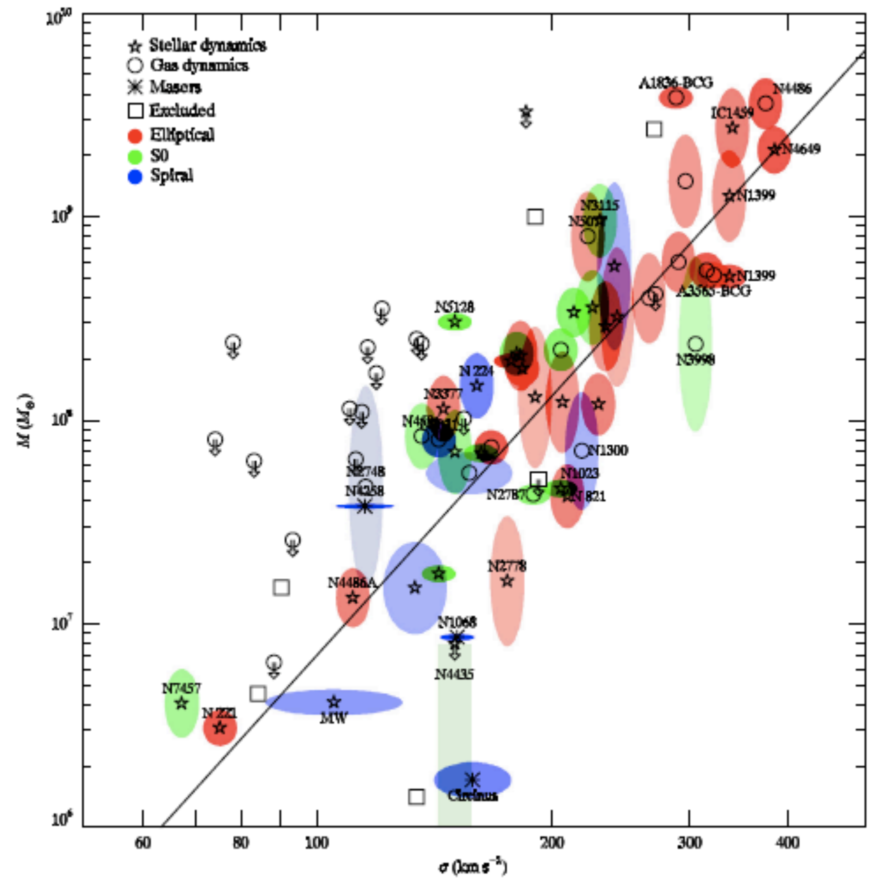
Hopkins+07



Ciotti+07

Black hole and bulge relations

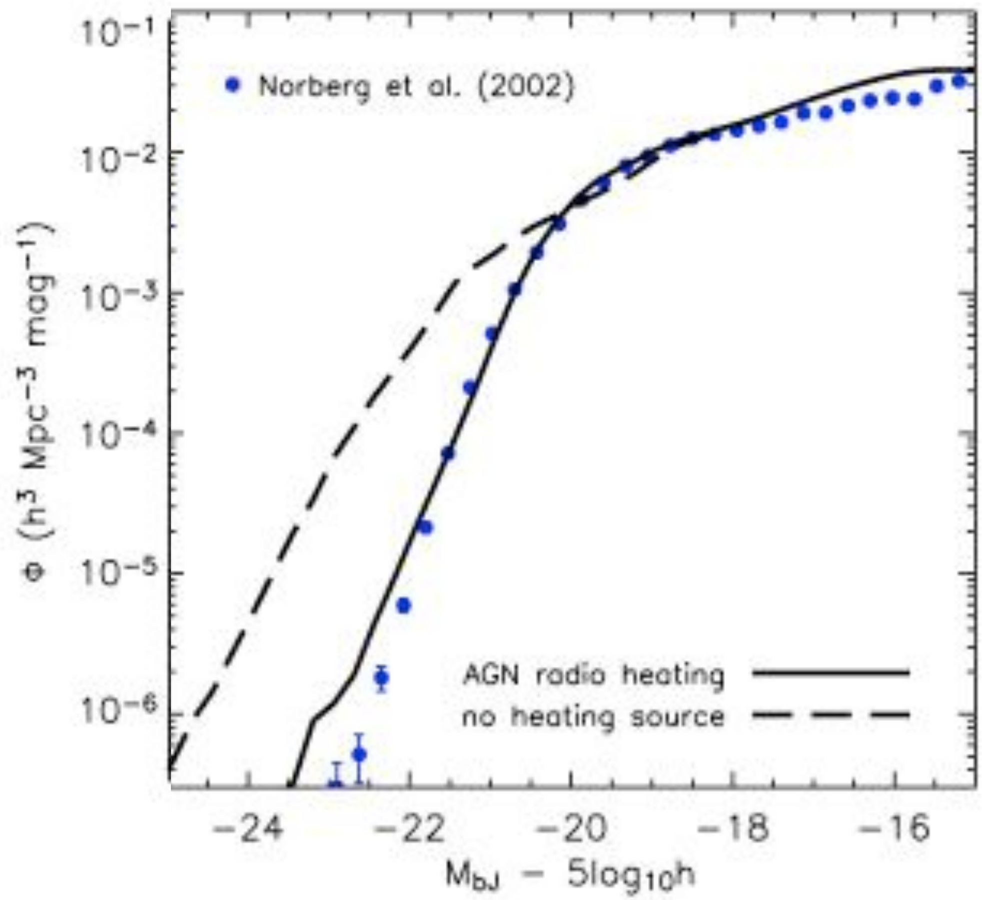
- Central black hole mass correlates with bulge properties: central stellar velocity dispersion, luminosity, Sersic index, etc
- Indicates evolutionary link between SMBH, galaxy
- Relations at low-mass end are poorly constrained, with increased scatter



Gultekin+09

Low-level black hole activity

- In post-quasar phase, accretion is highly sub-Eddington, radiatively inefficient
- Simulations indicate “radio mode” feedback at low z is required to inhibit star formation and match observed galaxy colors
- Nuclear X-ray emission provides probe of low-level SMBH activity



Croton+06

Environment

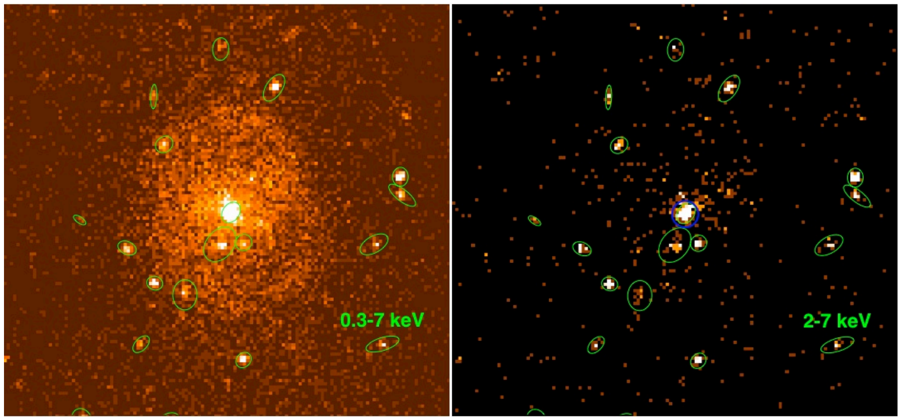
- Relative to their cluster counterparts, field early-type galaxies (ETGs) tend to
  - Encounter less harassment; high-speed interactions rarer
  - Avoid starvation including from ram pressure stripping or thermal evaporation (e.g., Treu+03); however, outflows may be less confined
  - Generally have more cold gas (e.g., higher HI content) and younger stellar populations (e.g., Treu+05, Thomas+05)
- Older stellar populations in cluster galaxies could be due to direct environmental effects (e.g., Vittorini+05, Martig +09), or alternatively to more efficient quenching from nuclear feedback
- We investigate impact of large-scale environment on SMBH activity

The AMUSE surveys: science goals

- AGN MUlti-wavelength Survey in Early type galaxies (optical selection; X-ray, optical, MIR, and radio coverage)
- Two Large Chandra Programs (~1 Ms) designed to bridge the gap between AGN and formally inactive galaxies
- Provide a census of SMBH activity in the local universe, constrain local SMBH occupation fraction, and control for environmental effects on nuclear activity (cluster versus field galaxies)

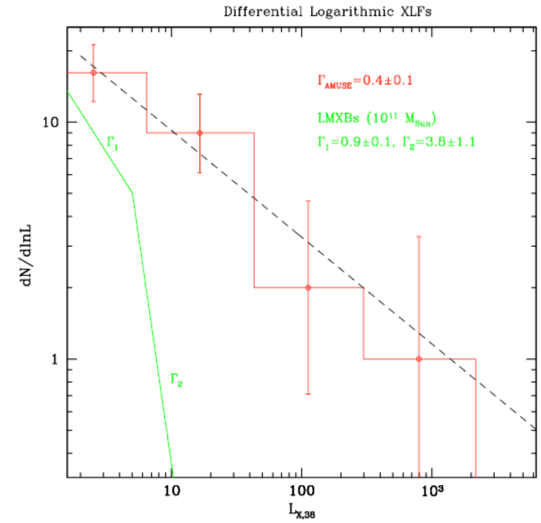
Methodology

- Virgo sample: 100 ETGs from HST/ACS VCS (Cote'+04)
- Field sample: 97/213 HLeda E/E-S0 galaxies with M_B<-13, within 30 Mpc, with |b|> 30^o, not in Virgo or Fornax
- Match astrometry to SDSS, filter lightcurves, identify sources with wavdetect, determine count rates using aperture photometry, calculate L_x (or else upper limit) for target for Γ=2 PL
- Use hard band for deeper archival exposures, avoid gas
- Determine M_{star} from M_B and colors (Bell+01,03), M_{BH} from σ or else M_B (Gultekin+09)

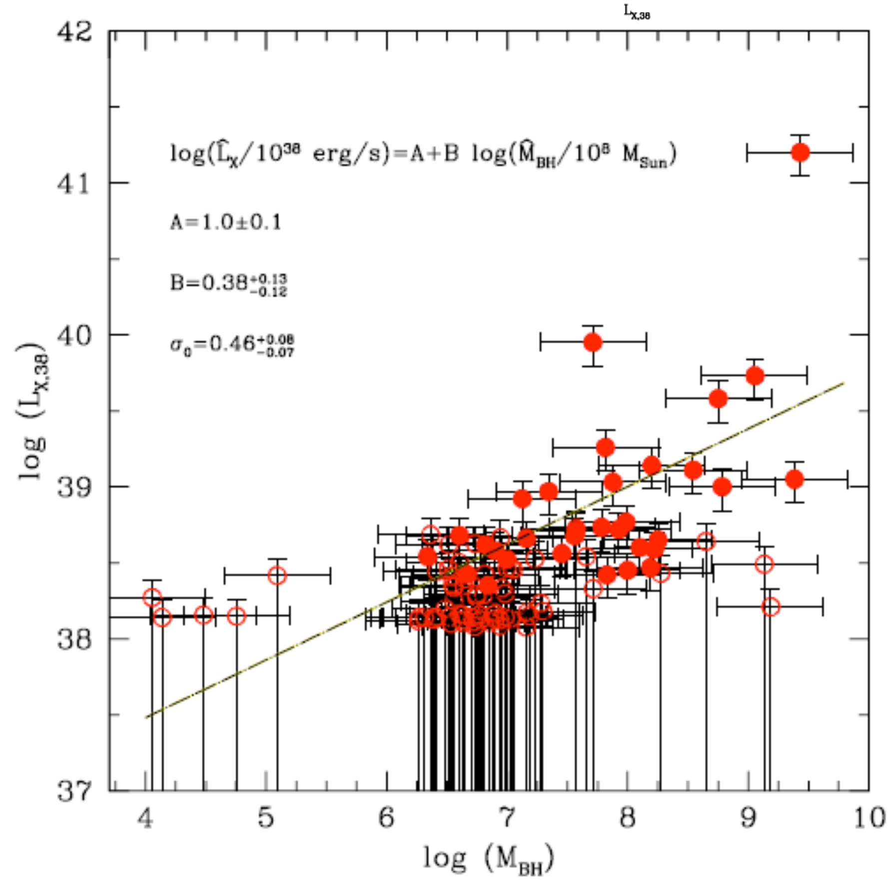


AMUSE-Virgo highlights

- 32 X-ray sources, 51 nuclear star clusters, 6 hybrids
- Clear detection of SMBHs within even lower-mass spheroids (X-ray luminosity function distinct from LMXBs)
- 24-34% of Virgo ETGs host an accreting SMBH; sets a lower limit on occupation fraction
- $L_x(M_{BH})$ correlation has slope +0.4, so $<L_x/L_{Edd}>$ scales as $M_{BH}^{-0.6}$ (downsizing trend)
- Also submitted or in prep: Spitzer results (Leipski+), off-nuclear sources (Katolik+)

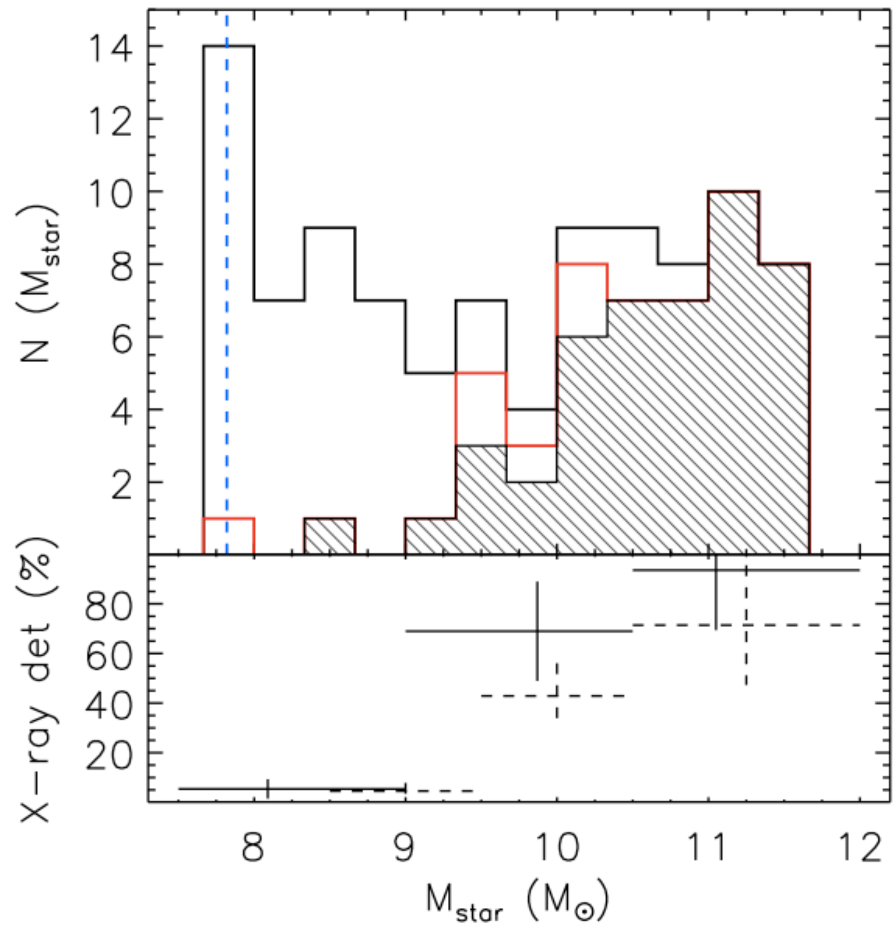


Gallo+08,10



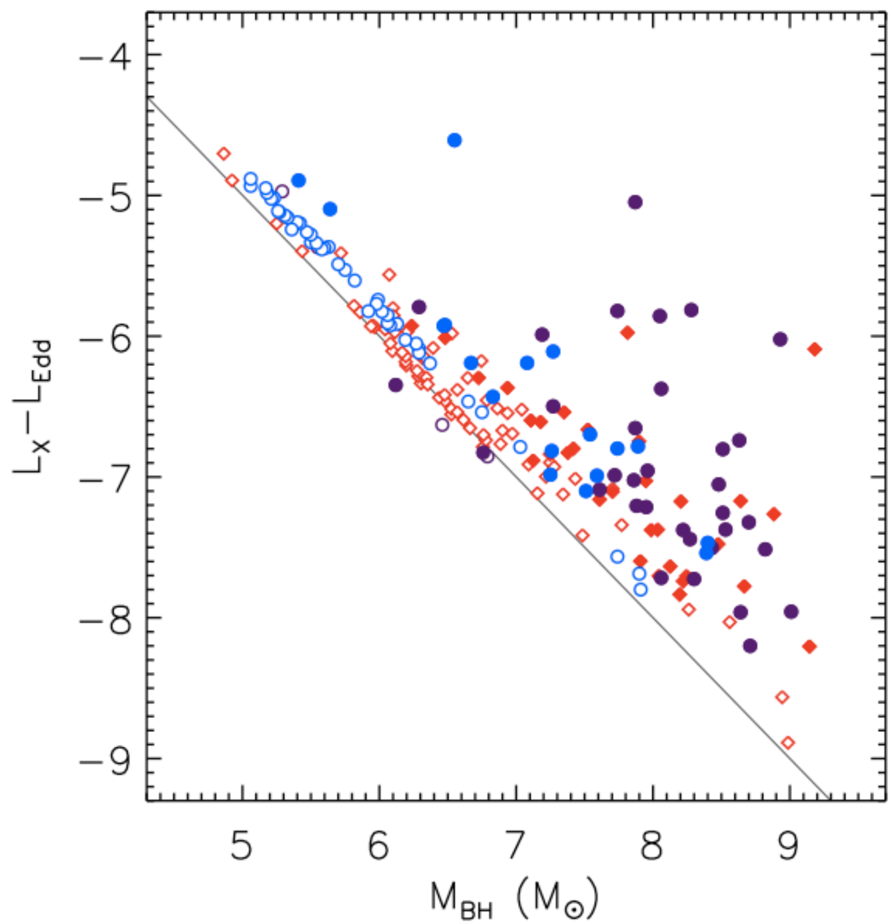
Field X-ray detection fraction

- Detect nuclear X-ray source in 51/97 ETGs (snapshots: 18/60, 30%)
- Estimate 6 cases may be LMXBs (all M_{star}<10.5)
- Active fraction is at least 46±8% (Virgo: 28±6%; Field exp-adjusted: 31%)
- Increase in detection fraction at higher M_{star} is mostly from "Eddington incompleteness"



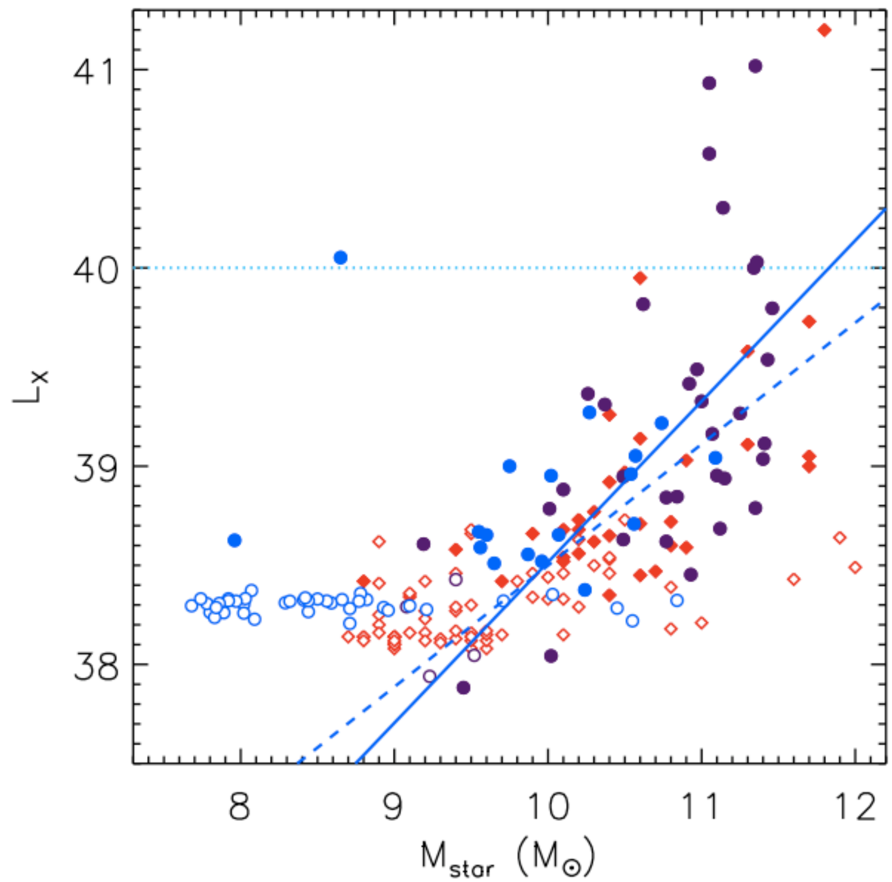
Eddington fraction

- Field sample = circles (blue/purple are snapshot/archival), Virgo sample = red diamonds; upper limits are open
- Solid line shows Virgo sensitivity limit
- As for Virgo (Gallo+10), Field has $-9 < L_x - L_{Edd} < -4$ (similar range found in other studies of ETGs, such as Pellegrini 05, 10)



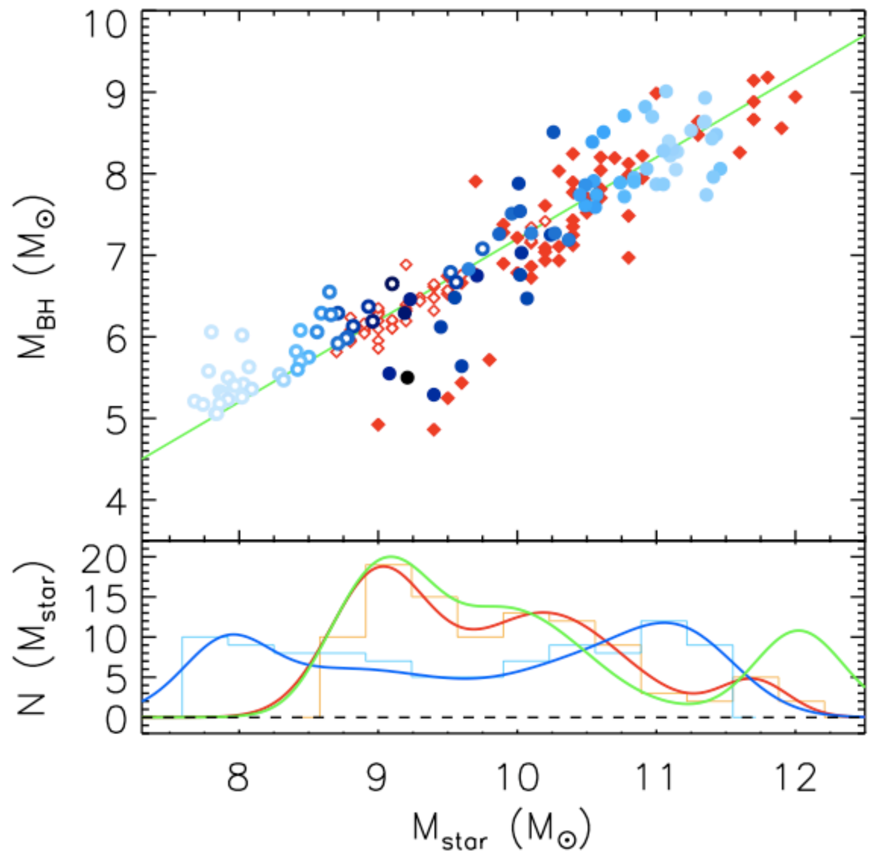
X-ray luminosity and stellar mass

- Nuclear X-ray luminosity increases with increasing stellar mass
- Solid line is fit to Field sample (Kelly07 code; handles limits, errors)
- Dashed line excludes objects with $L_x > 40$
- Majority of Virgo detections lie below Field trend (fit: similar slope, lower intercept)



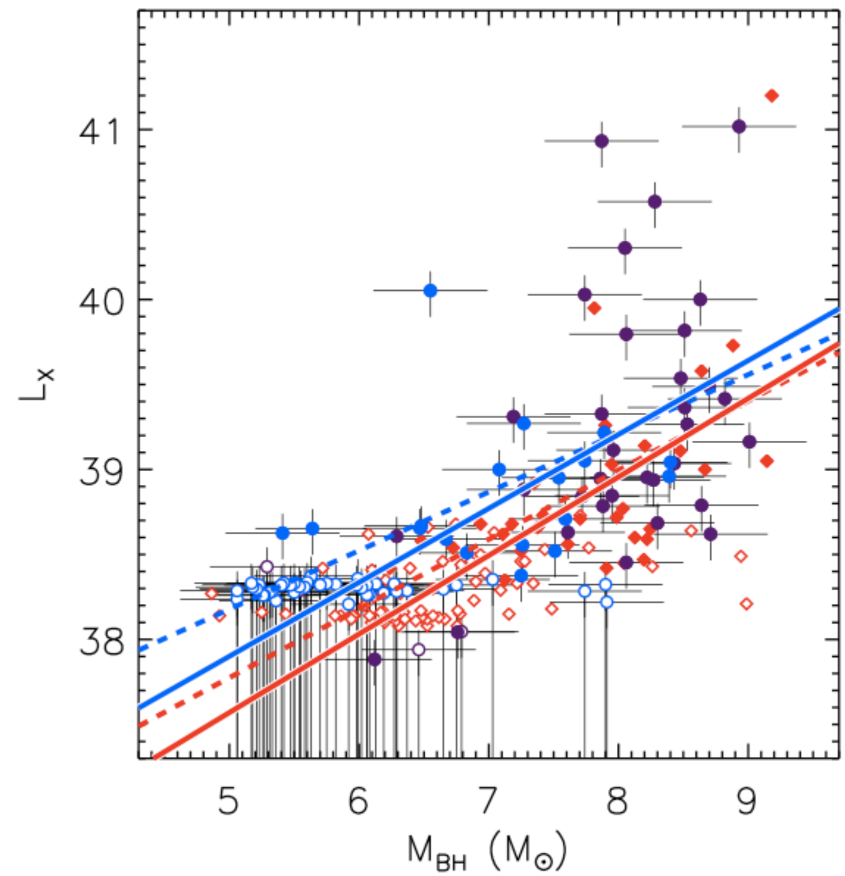
Matched samples

- Plot shows M_{star} vs M_{BH} (filled points from σ), with median M_{star} - M_{BH} of 2.8
- Field and Virgo M_{star} distributions formally inconsistent (KS $p<0.001$)
- Draw subsamples from Field weighted to match Virgo (bottom panel); color of Field points (top panel) indicates inclusion rate
- Virgo, Field ETGs with σ do have consistent M_{star} dist



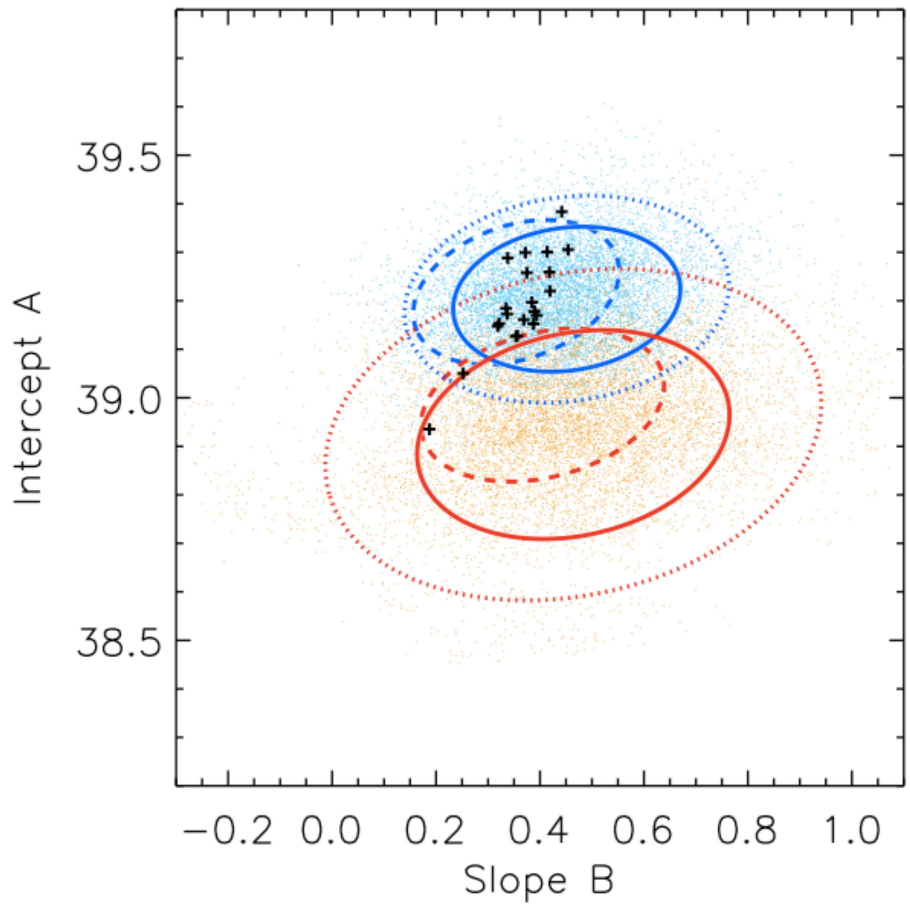
Correlation with black hole mass

- Bayesian fitting (Gallo+10) handles limits, errors; prior of rotational invariance on slope, log uniformity on M_{BH} dist
- Dashed lines are for full samples, solid lines σ-only
- Similar results hold for detections only; other methods also find marginally greater intercept for Field sample



Parameter confidence regions

- Solid/dotted lines are 68/90% confidence ellipses for σ-only fits (cyan/orange points show posterior dist)
- Dashed lines are 68% conf for full samples
- Black crosses are medians for 21 weighted subsamples of 46 Field objects each

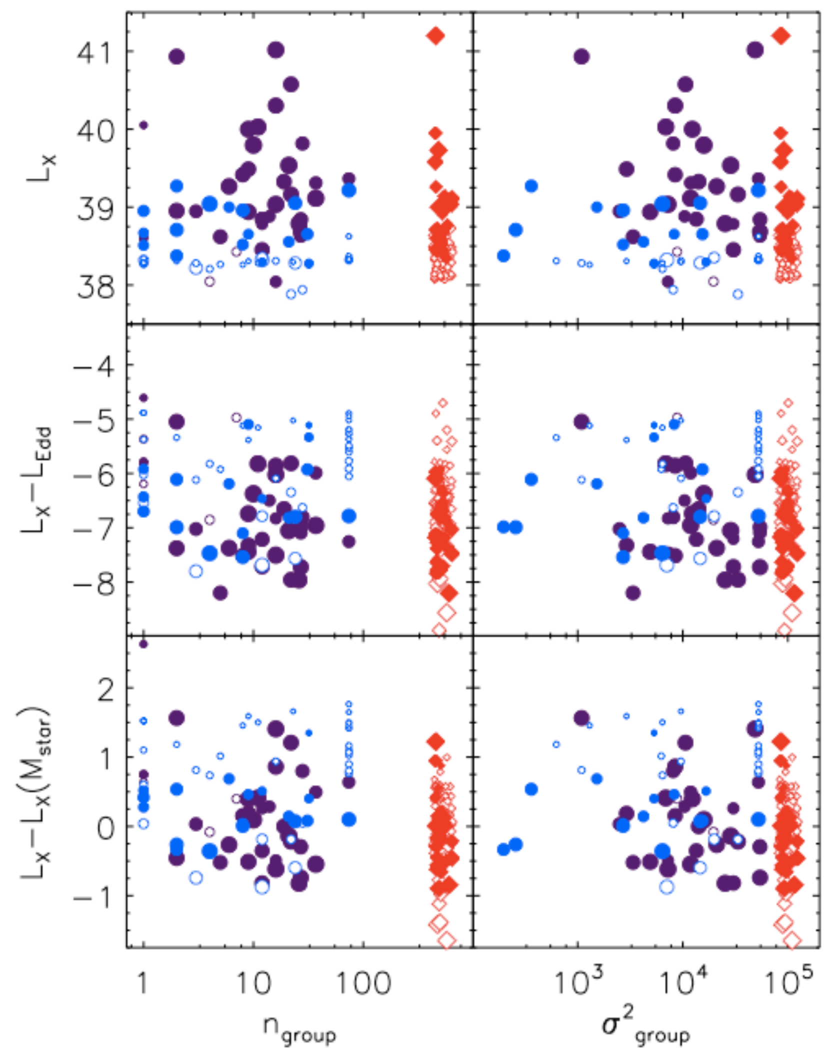


SMBH activity in field vs cluster

- Marginal evidence of modestly enhanced nuclear X-ray luminosities in Field vs Virgo ETGs, as a function of either M_{star} or M_{BH}
- For presumed similar accretion structures, observed difference is consistent with a more abundant gas supply in Field ETGs
- Virgo ETGs do not show greater activity than Field; disfavors nuclear feedback as primary explanation for cluster older stellar populations

Groups

- Field galaxies assigned to groups based on catalog of Makarov+11
- 89/97 included, 68/89 in group (n>3), 41/89 in group with σ>100 km/s
- Plot L_x, L_x-L_{Edd}, and L_x-$L_x(M_{star})$ versus n, σ^2, also for Virgo (artificial scatter); size shows M_{star}
- ETGs in groups seem to have intermediate relative X-ray luminosities

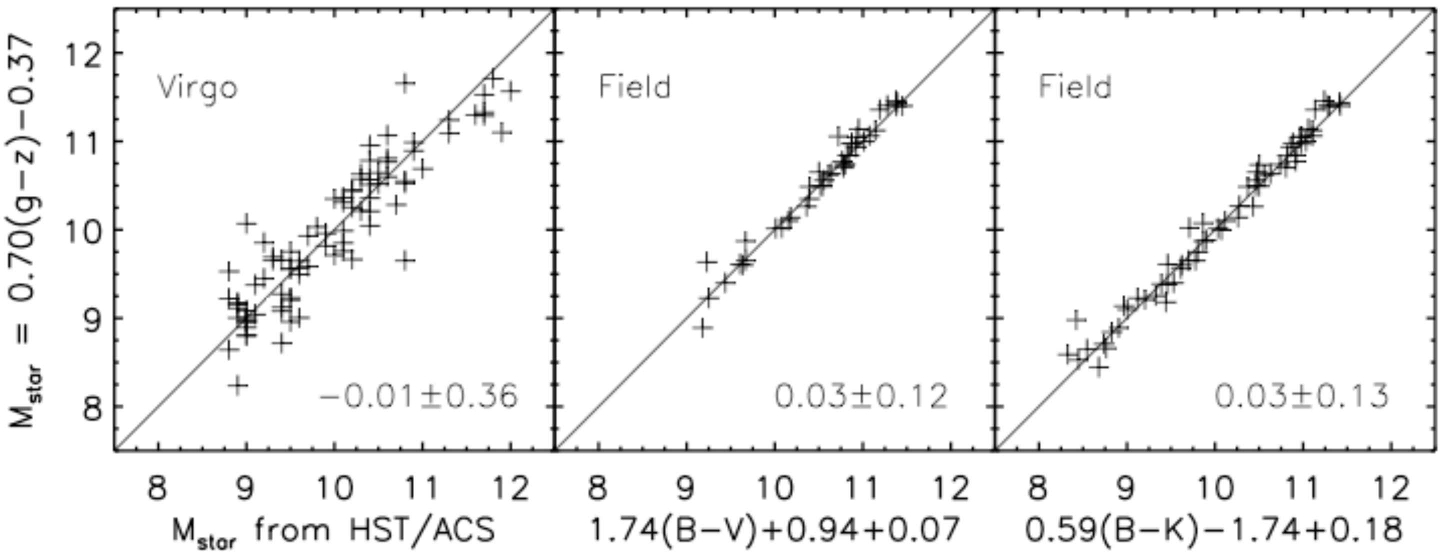


Summary

- AMUSE surveys study SMBH activity in ~200 ETGs in Virgo (Gallo+08,10), Field
- Set lower limit on active fraction of 46%, 28% within Field, Virgo samples
- Targets ($-9 < L_x - L_{Edd} < -4$) bridge the gap between AGN and inactive galaxies
- Confirm downsizing trend: Virgo and Field galaxies with lower M_{BH} tend to shine closer to Eddington

- Nuclear X-ray luminosity not strongly dependent on large-scale environment
- Field galaxies perhaps marginally X-ray brighter (plausibly due to more ready access to fuel)
- Groups show intermediate L_x-L_{Edd}, L_x-$L_x(M_{star})$ values?
- Ongoing work for Field: nuclear star clusters, more σ measurements, off-nuclear source properties

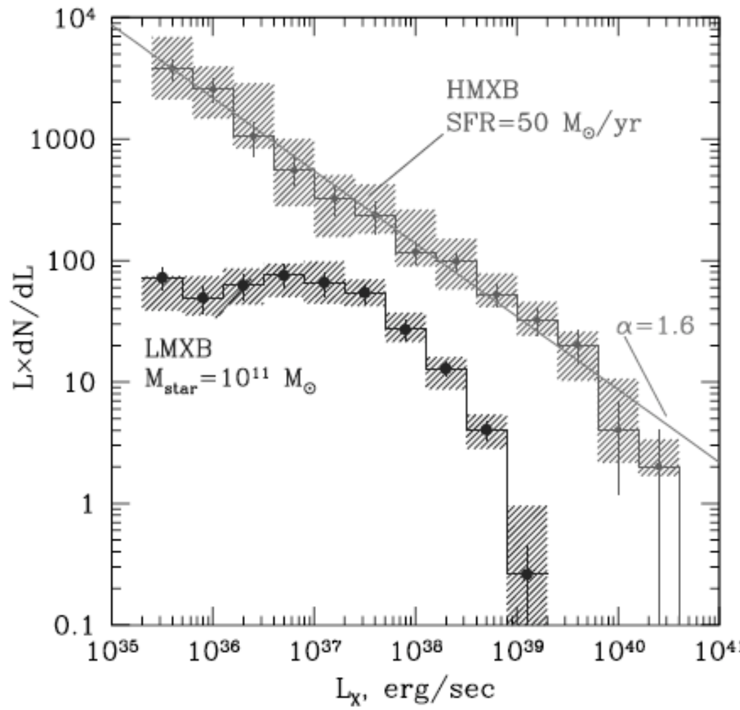
Stellar mass for Field galaxies



- Stellar mass M_{star} (use log, solar units) calculated from B-band luminosity and g-z, B-V, or B-K color (Bell+01,03)
- HST/ACS and SDSS colors agree (Virgo); applied median offsets (Field) to align B-V, B-K with g-z relations

LMXB contamination

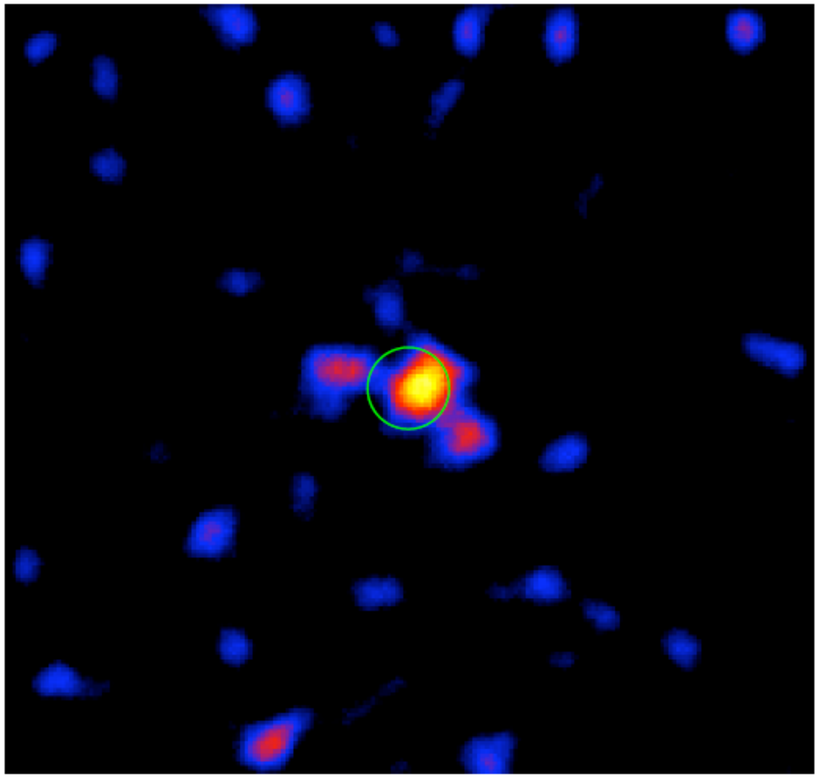
- Sampling ETGs avoids HMXBs; however, sensitivity to low L_x ~ 38.3 enters LMXB regime
- Chandra angular resolution eliminates most problems
- Virgo: estimate probability of LMXB using luminosity function of Gilfanov +04, unless HST/ACS imaging IDs nuclear star cluster, in which case use Sivakoff+07 (globular clusters)
- Field: mostly lack HST/ACS imaging (but Gallo proposal accepted); estimate overall LMXB contamination based on Virgo



Gilfanov+04

Stacking snapshot non-detections

- Stacked 0.3-7 keV images of snapshot observations lacking nuclear X-ray detection (after removing off-nuclear X-ray sources); 291 ks of net exposure
- In 5" aperture, 75 total, 44 bg, 31 net counts
- For average distance, the L_x ~ 37.7 is consistent with an LMXB origin



X-ray brightness vs stellar mass