THE CO-EVOLUTION OF GALAXIES & BLACK HOLES

Clues in the Local Universe
The Co-Evolution Across Cosmic Time

Marconi et al.
The “Fossil Record”

Marconi & Hunt

Gultekin et al.
Two-way communication

- How are supermassive black holes fed?
- How is their growth regulated? “local feedback”
- How do supermassive black holes affect their surroundings on galactic scales? “global feedback”
- How is this related to the host galaxy?
Global Feedback

- Cures “over-cooling” problem at high masses? (e.g. Croton et al.)
Global Feedback

The bimodal galaxy population
How do galaxies move from “blue” to “red”?
What keeps massive/dense galaxies “dead”?
Global Feedback & the IGM

- Heating/raising the entropy of the IGM (I. McCarthy)
- Photoionizing the IGM (Lyman Alpha forest)
An AGN Primer

- Two primary independent modes in the local universe
- **Seyfert galaxies:** High accretion rate (>1% Edd)
  Radiated power >> jet power
- **Radio galaxies:** Low accretion rates & jet-dominated
  (Jet power > radiated power, which is <<1% Eddington)
Co-Evolution: Seyfert Galaxies
Obscured vs. “Naked” AGN

- Orientation: AGN obscured by dusty torus
- Can study the host galaxy without interference
- Use narrow high-ionization emission-lines and MIR from the torus to characterize the AGN
Global properties of hosts $z \sim 0$

- The fraction of galaxies with an AGN peaks in the “Green Valley” (transition from blue to red sequence)
- The brightest star-forming galaxies have the highest mean AGN luminosity (Martin et al.)
• The strongest link is between the amount of star formation in the bulge & the growth rate of the black hole.
• A young disk is necessary…but not sufficient for the growth of the bulge and black hole
• Disk gas: the long-term reservoir for bulge & black hole

Kauffmann et al.
Where are BHs growing now?

> It's the lower mass black holes in the lower mass bulges

> In galaxies with bulges (BH) and an unusually young stellar population (copious fuel supply)
Coordinated down-sizing

- The mass-doubling timescales of the populations of black holes and bulges both increase in parallel with increasing mass.
What is the fueling mechanism?

Reichard et al. (2009)
• Measure “lopsidedness” of galaxy
• Signpost of interactions & minor mergers
Lopsidedness vs. BH growth

> See strong primary correlations between:

1) lopsidedness and star-formation in the bulge
2) star formation in the bulge and black hole growth

> No independent correlation between lopsidedness & black hole growth
Fueling & Feedback: the role of stars

- Star formation accompanies black hole growth
- Dying stars inject mass and energy into the bulge
- Fast ejecta (supernovae and O/WR winds) provide feedback
- Slow ejecta (AGB and red giants) could provide fuel
Test: Response to a Starburst

- Black hole growth is suppressed until the supernova rate drops
- Accretion rate then tracks mass loss from intermediate mass stars
- Roughly 0.5% accreted by black hole
- 1000:1 ratio of new stars to black hole mass growth over the event

Wild et al (see also Davies et al; L. Trouille)
Similar results at later stages

- The age-dependence of the black hole growth rate for older systems is also consistent with the capture of about 0.5% of the mass lost by evolved stars in the bulge (GK & TH)
Universal log-normal shape for “living” bulges. SNe feedback causes growth rate to saturate?

Age-dependent power-law for “dead” ones. Higher stellar mass loss rate leads to higher accretion rate.
What about global feedback?

- Galaxy-scale winds are generic in starbursts (C. Martin & C. Steidel)
- The AGN/SF connection means this feedback is present even without the AGN’s contribution
Global AGN Feedback

• High-velocity molecular outflows seen in ULIRGs with AGN (Sturm et al. 2011)
• Galaxy-scale disturbed ionized gas in Type 2 QSOs (Greene et al. 2011)
Co-Evolution: Radio Galaxies

Radio Galaxy 3C272.1 = M84 = NGC4374
Radio/optical superposition

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Masses

- Radio galaxies are the most massive galaxies
- Radio luminosity function strongly mass-dependent
- Best et al.
Structures and ages

- Structural properties: giant elliptical galaxies
- Old stellar populations (normal)
- Very different from the Seyfert galaxies
Fueling by Cooling of Hot Gas

- Best et al.
- McNamara & Nulsen ARAA
Feedback from radio sources

• Weak radio sources excavate cavities in the hot ISM of typical giant ellipticals
• Scaled-down versions of objects discussed by B. McNamara
Radio Feedback: Global Values

- Heating by radio sources sufficient to balance cooling in typical massive elliptical galaxies? (Best et al.)
- Detailed physics of coupling still unclear
Summary: The Living...

> AGN require a black hole (bulge) and cold gas in the bulge
> This combination now exists only in less massive bulges (“downsizing”)
> Fueling: Intermediate mass stars
> Feedback from massive stars
> Global AGN feedback may be important at the highest luminosities
...and the Dead

- The most massive black holes (and their host galaxies) formed at redshifts ~ 2 to 3
- “Dead quasars” simmer as radio galaxies & low luminosity AGN
- Fueled by slow cooling of hot gas (evolved stars plus accretion flows)
- Radio source heating suppresses star formation
- Keeps galaxies red & dead, but not “transformative”
Points to provoke discussion

In the present-day universe:

• Mergers are not the direct driver of black hole growth
• Stellar mass loss in bulges is a major fuel source
• “Local” feedback from supernovae is important for regulation of black hole growth
• There is good evidence for “global” feedback that is generic in starbursts and radio-loud AGN but not yet for typical radio-quiet AGN
Are most LINERs AGN?

- Contamination by post-AGB stars possible below $L/L_{\text{Edd}} \sim 0.001$