AGN in the Distant Galaxy Population

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Poorer quality spectra and statistics than local studies
Majority of the growth of black holes: $z \sim 0.5-3$

Build up of the black-hole mass density

See also, for example, Barger et al. (2001, 2005); Ueda et al. (2003); Hasinger et al. (2005); Silverman et al. (2005, 2008); Aird et al. (2008, 2010)
Rapid growth epoch of massive black holes

Heckman et al. (2004)

See Goulding et al. (2010) amongst others for lower black-hole mass constraints.
Connection to the growth of massive spheroids

Driver: Star formation (gas accretion/mergers)

\[ \frac{M_{bh}}{M_{sph}} \sim 10^{-3} \]

See also, for example, Magorrian et al. (1998); Ferrarese & Merritt (2000); Gebhardt et al. (2000); Marconi & Hunt (2003); Haring & Rix (2004); Gultekin et al. (2009)

Tremaine et al. (2002)
Key Questions

When and where did today’s massive black holes grow?

How was the black-hole growth initiated?

What is the connection between AGN activity and star formation?

Have we found all of the sites of black-hole growth?
Finding the AGN: a multi-scale, multi-component, multi-wavelength challenge

- Black Hole
- Accretion Disk
- Central engine
- Gaseous and Dusty torus
- Star formation and host galaxy extinction/dilution

Problem: accretion disk is spatially unresolved

Problem: obscuration changes the observed AGN signatures

Problem: host galaxy can dilute/extinguish AGN signatures

Huge difference in size scale (from galaxy to black hole)
• Similar average SEDs - infrared due to dust emission; optical-X-ray differences due to absorption by dust and gas

• Host galaxy also produces strong infrared emission (star formation; Elbaz talk) but weak X-rays

**Method of AGN selection is important**

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**Primary source** (X-ray-optical) ≈ Reprocessed emission (infrared/submm)

- Central engine
- Gaseous and Dusty torus

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Infrared

X-rays

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- Dust particle: ~0.001 mm
X-ray Surveys: Penetrating Probe of AGN activity

Murray et al. (2005)
5 ks Bootes

2-4 Ms CDF-N & CDF-S
Alexander et al. (2003);
Luo et al. (2008); Xue et al. (2011)

Penetrate large gas columns
Observational constraints on the growth of distant black holes
Accretion density of black holes

- Moderate to high luminosity AGNs ($L_X \sim 10^{43}-10^{45}$ erg/s) dominate (~80%) black-hole growth
- Most luminous AGNs peaked at high-z, contrary to lower-luminosity AGNs

See also, for example, Barger et al. (2001, 2005); Ueda et al. (2003); Hasinger et al. (2005); Silverman et al. (2005, 2008); Hopkins et al. (2007); Aird et al. (2008)
Host galaxies are typically luminous (~L*) and massive (>3x10^{10} solar masses). AGNs in low-mass black holes can be particularly challenging to identify: low X-ray luminosities, difficult to distinguish from starbursts (e.g., Shi et al. 2008).

What about the host galaxies?

Optical-near-IR emission typically dominated by the host galaxy - AGN becomes more prominent at higher X-ray luminosities (e.g., Brusa et al. 2009).

Host galaxies are typically luminous (~L*) and massive (>3x10^{10} solar masses).

AGNs in low-mass black holes can be particularly challenging to identify: low X-ray luminosities, difficult to distinguish from starbursts (e.g., Shi et al. 2008).
When consider non-AGN galaxies of the same mass there are no significant differences in the location of AGNs and non-AGNs in the colour-magnitude diagram.

Original suggestion that AGNs lie in special region in the “green valley” have shown to be due to a mismatched selection of non-AGN galaxies.
Host-galaxy morphologies?

Broad range of morphologies but big differences between massive galaxies with or without AGN activity

See also, e.g., Grogin et al. (2005), Pierce et al. (2007, 2010), Georgakakis et al. (2009), Cisternas et al. (2010), Schawinski et al. (2011)
AGN triggering mechanism?

Only ~15% are clearly mergers but difficult to determine clear merger signatures from morphologies, could be as much as ~50%: no clear difference between AGNs and non AGNs

See also, e.g., Grogin et al. (2005), Pierce et al. (2007, 2010), Georgakakis et al. (2009), Cisternas et al. (2010), Schawinski et al. (2011)
Specific star-formation rates (stellar mass/star formation rate) track those seen in non AGNs. Driven by same processes.

See also, for example, Lutz et al. (2010), Mullaney et al. (2010); Shao et al. (2010)
Typical “active halo mass” \((3-10) \times 10^{12}\) solar masses (e.g., Croton et al. 2006). Radio galaxies have more massive halos - quenched fuel?

AGN evolution was earlier and more rapid in overdense regions (e.g., Lehmer et al. 2009a,b): environment plays a key role
Typically modest black-hole growth rates

- Typical black-hole mass: $\sim 10^8$ solar masses
- Median Eddington ratio of $\sim 0.01$ (for $L_X > 10^{42}$ erg/s): divide between optically thin and thick accretion discs (bolometric corrections?)
- $z\sim 1$ black holes growing more rapidly than $\sim 10^8$ solar-mass black holes locally but growth times still typically the age of the Universe
- Poorer constraints for typical AGNs at higher redshift

See also, for example, Ballo et al. (2007), Alonso-Herrero et al. (2008), Hickox et al. (2009); Simmons et al. (2011)
An example of a more rapidly growing $z \sim 2$ black hole

Alexander et al. (2008, 2010)

Harrison et al. (in prep); see poster 6.26 for more objects

TALKS: Martin; Steidel
POSTER: Collet

See also, for example, Nesvadba et al. (2006, 2007, 2008, 2011)
What drives the growth of distant black holes?

No discernible unique signatures of AGN activity on average - whatever drives the growth of massive galaxies drives the growth of black holes

~10% of massive galaxies host a moderate-luminosity AGN (e.g., Bundy et al. 2008; Xue et al. 2010) so ~10% of the time the gas reaches the black hole

The triggers of gas onto the black hole are spatially unresolved and/or occurred a long time ago (initial signature will be lost)

Dark-matter halo seems important
Conundrum: increasing $L_{\text{IR}}/L_X$ with redshift

Significant caveats:
- Changing bulge vs disc star formation?
- Changing AGN fraction?
- Missing AGNs?
- Changing IMF?

Mullaney et al. (2011)

Increase in $L_{\text{IR}}/L_X$ with redshift implies more star formation without more black-hole growth
Missing AGNs?
Have we missed any distant luminous AGNs?

Yes: typical rest-frame energies for current X-ray observatories at $z \sim 1$.

$N_H \sim 10^{24} \text{ cm}^{-2}$

See, for example, Daddi et al. (2007), Fiore et al. (2008, 2009), Alexander et al. (2008, 2011), Treister et al. (2010), Luo et al. (2011)
New opportunities: revealing the AGN-heated dust

Herschel key project in GOODS fields: 100+160um (250+350+500um)

PI: D Elbaz

Herschel+Spitzer: infrared SEDs (3-500um) to identify AGN and star formation
Efficient and effective method of identifying heavily obscured AGNs

Comparison of AGN identification techniques (X-ray AGN=green; IR AGN=square)

- Better than simple colour selection - finds X-ray undetected AGNs (~40% of IR AGN are X-ray undetected in deepest X-ray surveys)
- Suggests a large number of likely luminous Compton-thick quasars at z~2 not revealed in X-ray surveys

Del Moro et al. (in prep)
Majority of the distant black-hole growth appears to have occurred in massive galaxies - the host galaxies of AGNs and non AGNs appear very similar. No clear unique AGN trigger signatures (size resolution, time resolution?). Issues with identifying AGNs in lower-mass galaxies?

The X-ray surveys generally identify massive (>10^8 solar mass) black holes, which are growing with a ~10% duty cycle. Growth rates are modest but more rapid than similar mass black holes locally: evidence for black-hole downsizing? Possible energetic outflows in some sources.

More star formation per unit AGN activity at higher redshift than seen today: a conundrum? Significant caveats: amount of spheroid star formation, changing AGN fraction, hidden AGNs

Hidden AGN missed by X-ray surveys can be found from detailed infrared SED modelling: ~40% of the luminous X-ray AGNs are undetected in X-rays. A population of heavily obscured (possibly Compton thick) AGNs?