AGN-galaxy co-evolution

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Shiny black holes out there....

Hubble Deep Field
all galaxies

Chandra Deep Field
active galaxies
black holes
M_{BH} - host relations: co-evolution of MBHs and galaxies

SMBHs

stellar bulges host

DM halos (???)

Correlation Between Black Hole Mass and Bulge Mass

Increasing

Mass of central bulge

Black hole mass

One billion solar masses

One million solar masses

No black hole
$M_{BH}$- host relations: co-evolution of MBHs and galaxies

Colpi et al 2007
**M_{BH}- hosts at high-z**

SCUBA galaxies: MBH lags the stellar growth - adjustment

QSOs: galaxy lags the MBH growth - dominance

Alexander et al. 2007
What we want to know

‣ How and when MBHs form
‣ How and when MBHs accrete mass
‣ What’s the interplay between mergers and accretion?
WHEN do you make the first massive black holes?

The highest redshift quasar currently known
SDSS 1148+3251 at $z=6.4$
has estimates of the SMBH mass
$M_{BH} = 2-6 \times 10^9 M_{\text{sun}}$ (Willott et al 2003, Barth et al 2003)

As massive as the largest SMBHs today, but when the Universe was 1 Gyr old!
Hierarchical Galaxy Formation

**BARYONS:** need to **COOL** MOST MASSIVE HALOS HIGHEST DENSITY FLUCTUATIONS $z \sim 20-30$
**How can you make the first massive black holes?**

- **PopIII stars remnants**
  - Simulations suggest that the first stars are massive $M \sim 100-600 \, M_{\odot}$ (e.g., Abel et al., Bromm et al.)
  - Metal free dying stars with $M > 260M_{\odot}$ leave remnant BHs with $M_{\text{seed}} \geq 100M_{\odot}$ (Fryer, Woosley & Heger)

- **Gas-dynamical processes**

- **Stellar dynamical processes**
  - (Devecchi & MV 2009, Omukai et al. 2009)
Gas/stellar dynamical processes

NEED DEEP POTENTIAL WELL FOR EFFICIENT GAS COLLECTION

✔ the most massive galaxies at very high redshift

ANGULAR MOMENTUM TRANSPORT
Collapsing gas clouds become rotationally supported at $10^{6-8}$ Schwarzschild radii.

MORE EFFICIENT THAN STAR FORMATION
✔ competition in gas consumption

✔ SNe can blow away the gas reservoir

NO H2/ZERO METALLICITY/TURBULENCE HELP AVOID FRAGMENTATION
The central regions can fulfill the conditions for MBH formation: quasistars?  
Begelman, MV & Rees 2006
Seeds are allowed to form if:
- zero metallicity
- $n_{\text{gas}} > 1 \text{ cm}^{-3}$

Truncation of seed BH formation at a redshift $\sim 3.5$ due to metal enrichment

Bellovary et al. 2010
Stellar-dynamical processes

Devecchi & MV 2009

DM

Mildly unstable

very low Z

Collisions

Runaway growth

Fragmentation
if \( n > n_{\text{crit}} \): inner region only

BH

dense star cluster formation
Mass function of seed MBHs

(MV, Lodato & Natarajan 2008; Devecchi & MV 2009)
SMBHs are grown from seed pregalactic BHs. These seeds are incorporated in larger and larger halos, accreting gas and dynamically interacting after mergers.
The seeds at $z>20$ are small, $\sim 100-10^4$ $M_{\text{sun}}$.

How do MBH seeds grow with their hosts?
The seeds at $z > 20$ are small, $\sim 100-10^4 \, M_{\odot}$

How do MBH seeds grow to become supermassive?

- BH-BH mergers
- gas accretion

Total mass density in MBHs is almost constant in time: just reshuffle the mass function

Total mass density in MBHs grows with time
Hierarchical evolution of MBHs

Mass evolution:
- mergers: dynamical evolution
- accretion: active galactic nuclei, quasar phase

Assumptions:
- triggered by mergers
- self-regulated with host (feedback)
- on or below Eddington limit
How do MBH seeds grow to become supermassive?

**Gas accretion vs BH-BH mergers**

\[
\rho^B_{\text{qso}(0)} = 2 \times 10^5 [0.1 (1 - \epsilon) / \epsilon] \text{M}_\odot \text{ Mpc}^{-3}
\]

\[
\rho^X_{\text{qso}(0)} = 2 \div 4 \times 10^5 [0.1 (1 - \epsilon) / \epsilon] \text{M}_\odot \text{ Mpc}^{-3}
\]

\[
\rho_{\text{SMBH}} = 2.5 \div 4.5 \times 10^5 \text{M}_\odot \text{ Mpc}^{-3}
\]

Yu & Tremaine 2002, Elvis et al 2002, Merloni et al 2004, Marconi et al. 2004 etc...

**Soltan’s argument**

**MBH mass evolution**

**dominated by accretion at z\approx 3-5**
Mass growth of MBHs

Soltan’s argument

Direct collapse

BH-BH mergers vs gas accretion

Total mass density in MBHs constant in time

vs

Total mass density in MBHs grows with time
Journey to the M-sigma relation

(MV & Natarajan 2009)

The smallest galaxies retain memory of the initial conditions: quiet life... no major mergers, no accretion

seeds (direct collapse)
Journey to the M-sigma relation

MBHs move onto the M-sigma from below

seeds (PopIII remnants)
PopIII remnants lags the actual BH mass - adjustment

MBH lags the host growth - dominance

galaxy lags the MBH growth - dominance

Direct collapse
Summary

- **MBH formation**: the initial conditions – determine dominance vs adjustment, at least at early times

- find clues on initial conditions at low MBH masses

- MBH growth dominated by *accretion*

- *accretion*: need to study jointly with *dynamics* and *thermodynamics*
Outlook

- **MBH formation:** direct simulations of MBH formation + model the high-z (mini)quasar/MBH population (ALMA, JWST, LISA, IXO)

- **accretion:** impact of gas consumption due to star formation and SNe feedback on MBH fueling

- test ‘merger-driven’ quasar activity and MBH occupation via occurrence of **double AGNs**