Formation Mechanisms and Seed Black Holes

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Galaxies and Black Holes

Are interconnected.

Gultekin+09

Bulge velocity dispersion (km/s)

Black Hole Mass

Stellar dynamics
Gas dynamics
Masses
Excluded
Elliptical
S0
Spiral

Gultekin+09
But what about...

- Dwarf galaxies
- Bulgeless galaxies

Henize 2-10

$M_{BH} \sim 10^6 M_\odot$

Reines+ 11, Barth+ 04
But what about...

- Dwarf galaxies
- Bulgeless galaxies

NGC 4395
$M_{\text{BH}} \sim 10^5 M_\odot$

Filippenko & Ho 2003
But what about...

- Dwarf galaxies
- Bulgeless galaxies

M33
$M_{BH} < 1500 M_\odot$

Gebhardt+ 01
Which galaxies host BHs?

- Massive galaxies
  \[ M > 10^{10} \, M_\odot \]  
  Ferrarese+ 06, Wehner+06

- At least some low mass galaxies
  \[ M \sim 10^{10} \, M_\odot \]

Why?
How do galaxies get central BHs?

- How do they form?
- What are their histories?
- What is the occupation fraction of BHs in galaxies?
How do seed BHs form?

- Population III star remnants
  - Seed mass = 100 - 1000 $M_\odot$
  - Formation redshift $z \sim 30$
  - e.g. Madau & Rees 2001

- Direct collapse of gas
  - Seed mass = $10^4 - 10^6$ $M_\odot$
  - Formation redshift $z \sim 15$
  - e.g. Begelman+ 06, Lodato+ 06

- Runaway collapse of nuclear clusters
  - Seed mass = $10^3 - 10^5$ $M_\odot$
  - Formation redshift $z \sim 10$
  - e.g. Devecchi+ 09, Davies Miller & Bellovary 11
GASOLINE

• SPH N-body code (Wadsley et al. 2004)
  - Star formation, supernova feedback, metal diffusion, metal line cooling

• New additions:
  - Seed BH formation
  - BH mergers
  - BH accretion
  - BH feedback
Seed BH Prescription

- Forming Seed BHs
  - Form seed black holes out of cold, dense, zero-metallicity gas
  - Probability of forming star or black hole
  - Seed mass same as gas particle
    \[(10^4 - 10^6 \, M_\odot)\]

Purely local prescription
Testing BH seed formation

hz1

at $z = 5$:

$M = 6 \times 10^{11} \, M_\odot$

at $z = 0$:

Massive elliptical
hz1 to z = 5
Testing BH seed formation

\textbf{h258}

\textbf{at } z = 5:
\[ M = 3 \times 10^{10} \, M_\odot \]

\textbf{at } z = 0:
\textbf{Milky Way mass}
h258 to z = 5
Testing BH seed formation

\[ h603 \]
\[ \text{At } z = 5: \]
\[ M = 8 \times 10^9 \, M_\odot \]
\[ \text{at } z = 0: \]
Low-mass disk galaxy
h603 to z = 5
Testing BH seed formation

• Three galaxies to $z=5$

• Four values of BH formation efficiency $(0.05, 0.1, 0.3, 0.5)$
BH Seeds Form in Massive Halos

$z = 5$

$h_{258}^{\text{eff}} = 0.1$
BH seeds form early

- $h_{258}$
- eff = 0.1
- $z = 5$

Bellovary+ 11
BH seeds form early

hz1
h258
h603

Eff = 0.1
Halo Mass at time of BH formation

Eff = 0.1

Bellovary+ 11
BH Halo Occupation Fraction

$z = 5$

Bellovary + 11
$h_{258}^{\text{eff}} = 0.3$
Low-Mass $M-\sigma$ Relation

Massive seeds
Pop III seeds

Van Wassenhove+ 10,
Volonteri+ 08,
Gultekin+ 09
Summary

- Seed BHs form in halos with mass between $10^7 - 10^9 \, M_\odot$.
- Galaxies with mass $> 10^{10} \, M_\odot$ always host a BH at $z = 5$.
- Galaxies with mass $\sim 10^9 \, M_\odot$ may be ideal testbeds for the true BH seed formation efficiency.
- Bulgeless and dwarf galaxies may host supermassive black holes.
Unsolved Questions

• How do the seeds of SMBHs form?
• Which galaxies host SMBHs and why?
• Are there observational clues that can help determine how SMBH seeds form?