Formation Mechanisms and Seed Black Holes

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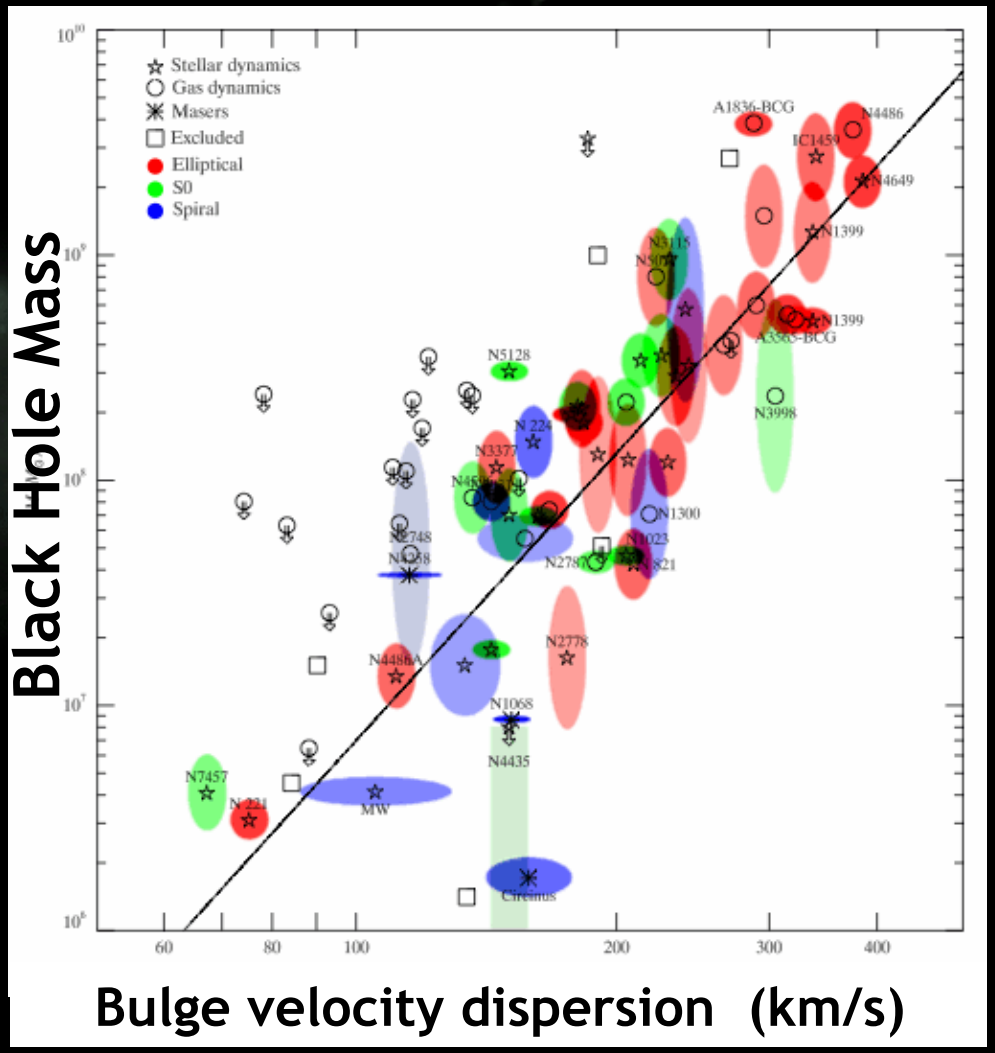
Galaxies and Black Holes

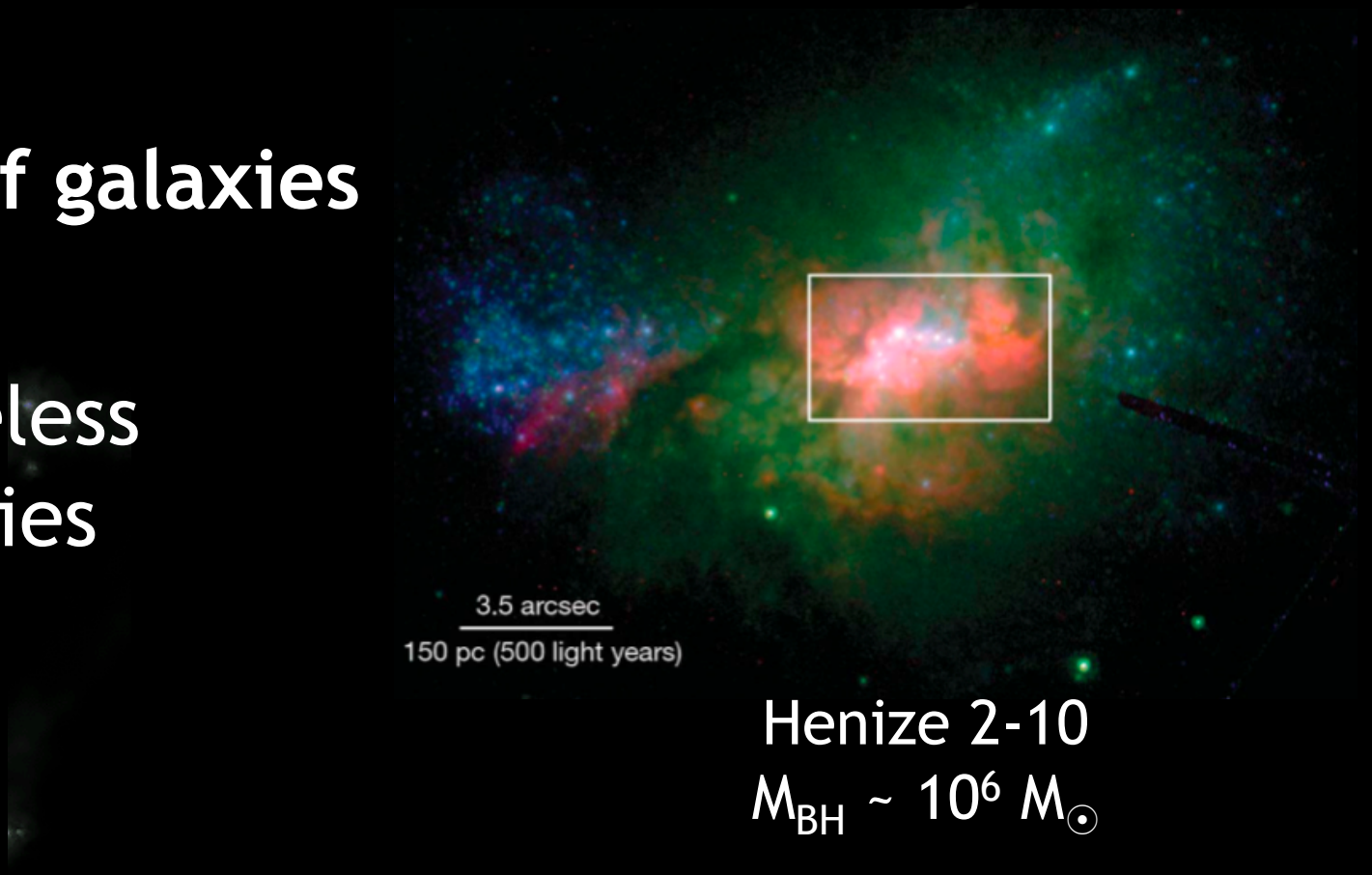
Are interconnected.



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
$M_{BH} \sim 10^5 M_\odot$

Filippenko & Ho 2003

But what about...

- Dwarf galaxies
- **Bulgeless galaxies**

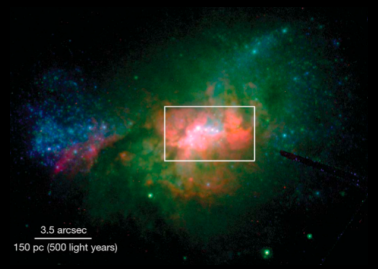
M33
$M_{BH} < 1500\ M_{\odot}$

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

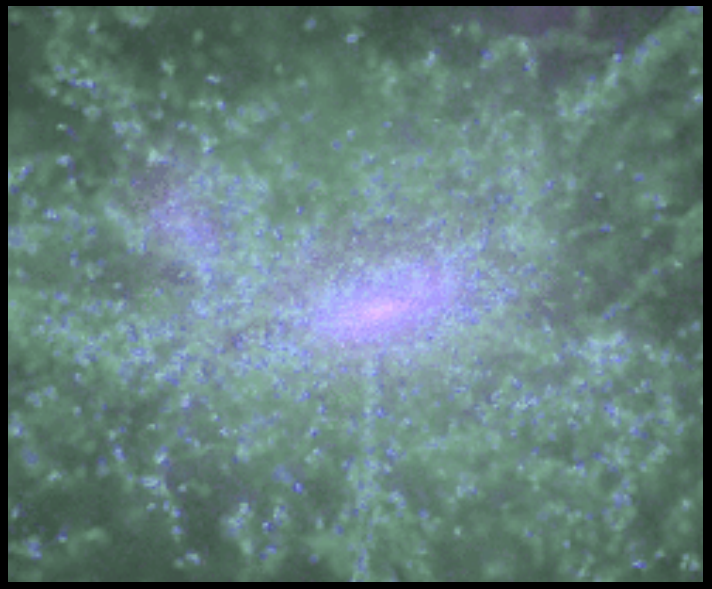
hz1

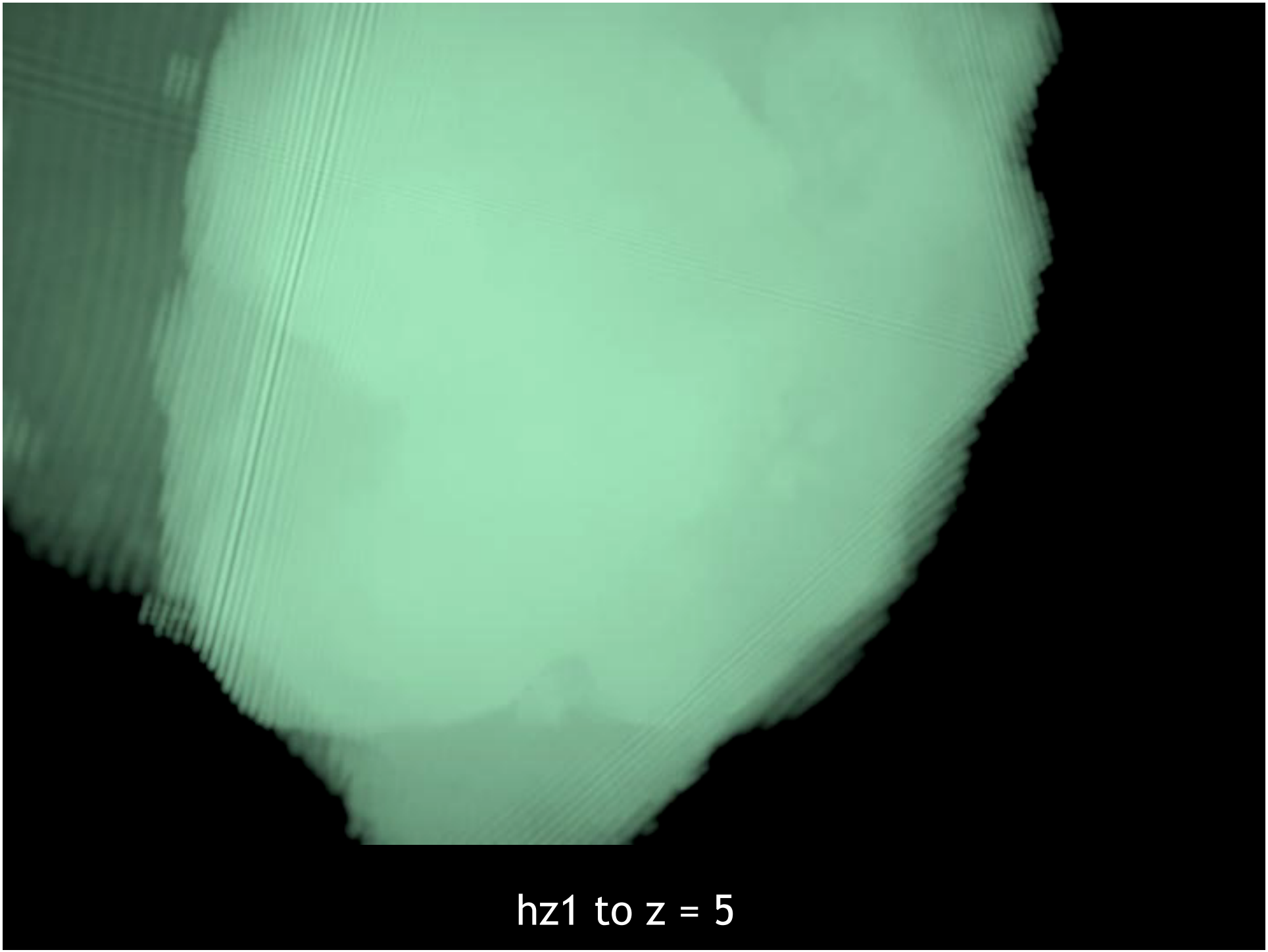
at z = 5:

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

at z = 0:

Massive elliptical




hz1 to z = 5

Testing BH seed formation

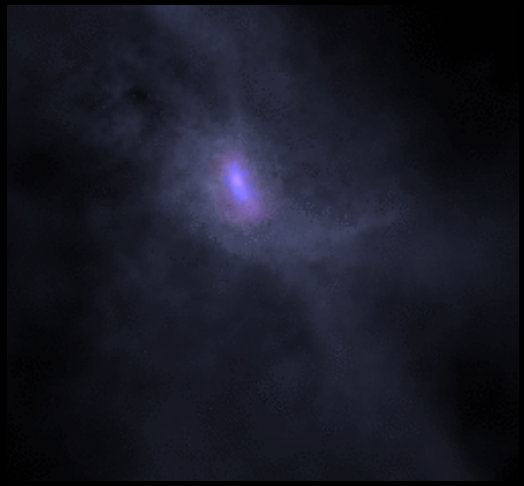
h258

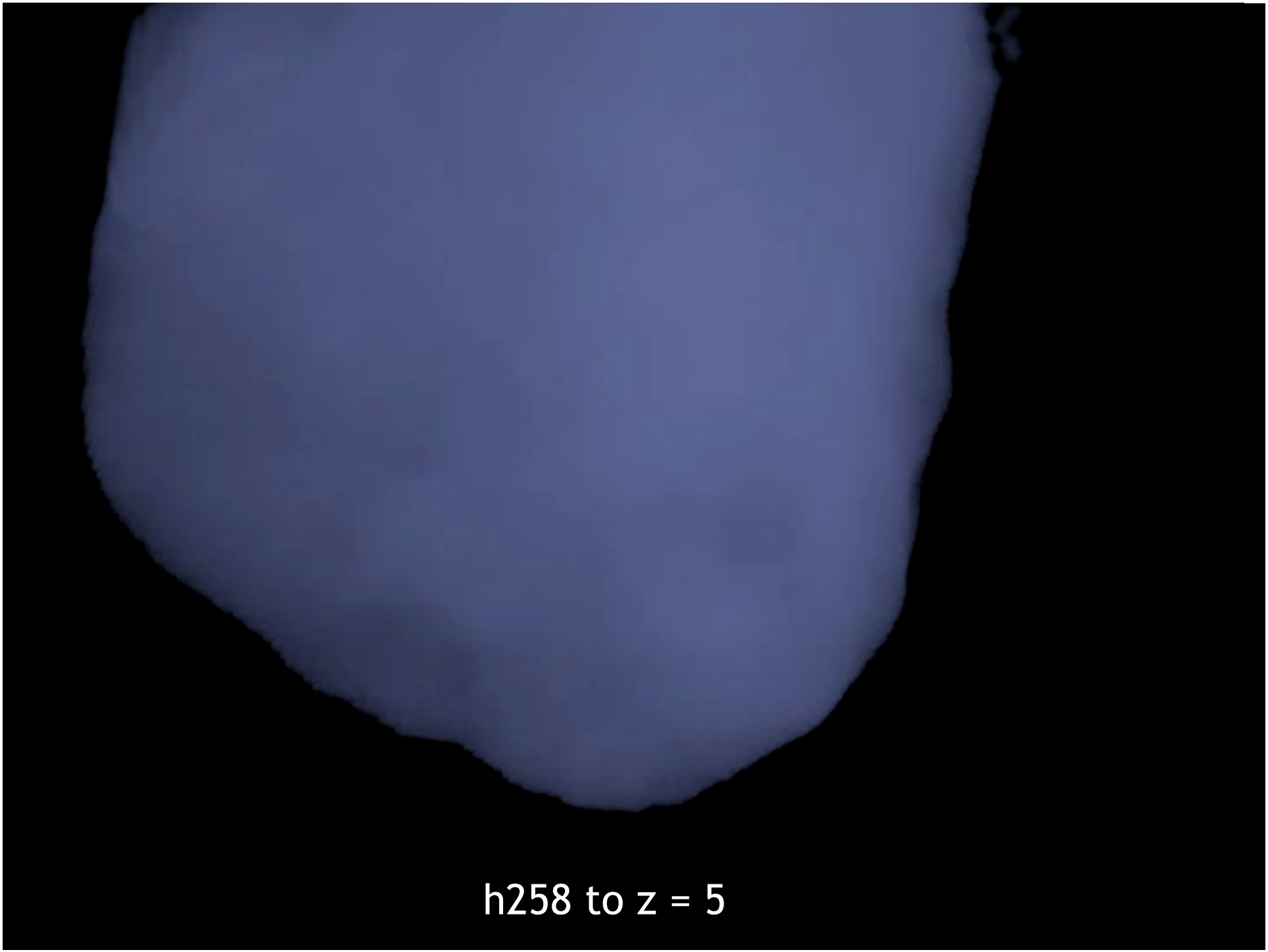
at z = 5:

$M = 3 \times 10^{10} M_{\odot}$

at z = 0:

Milky Way mass




h258 to z = 5

Testing BH seed formation

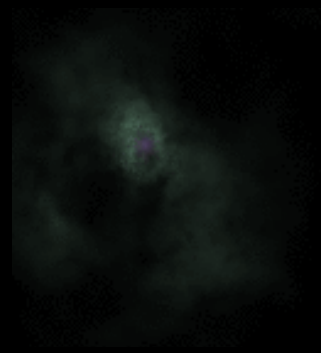
h603

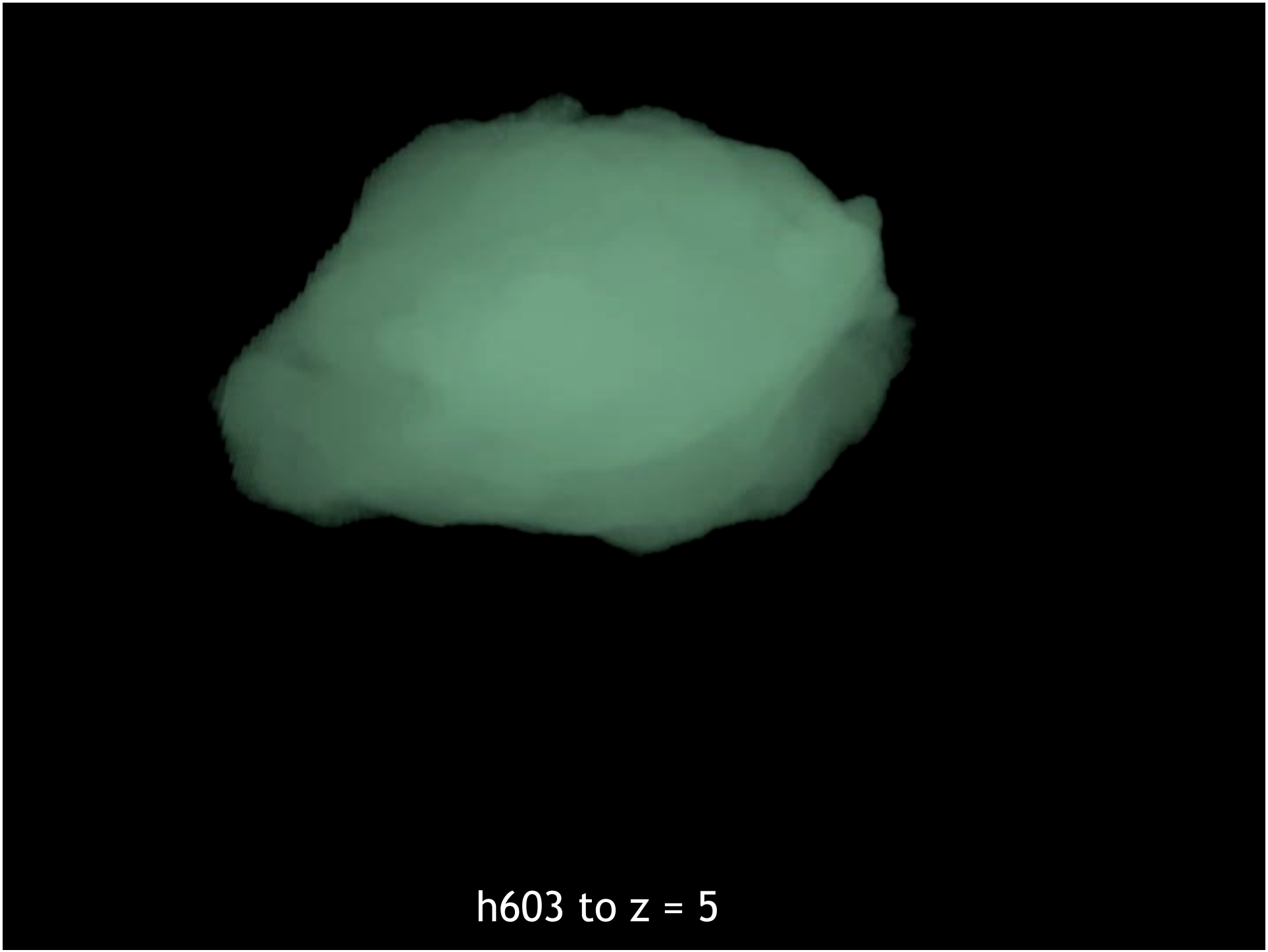
At z = 5:

$M = 8 \times 10^9 M_\odot$

at z = 0:

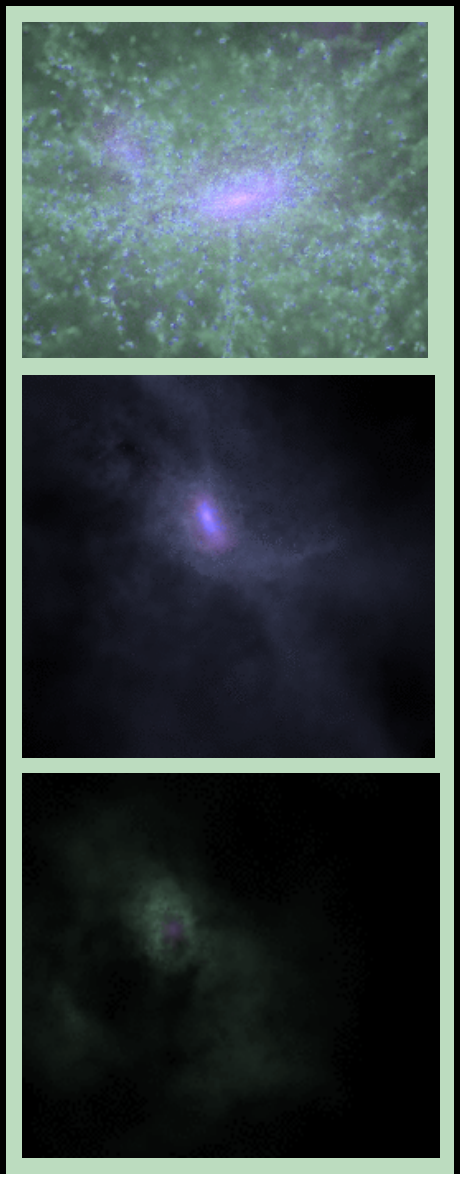
Low-mass disk galaxy



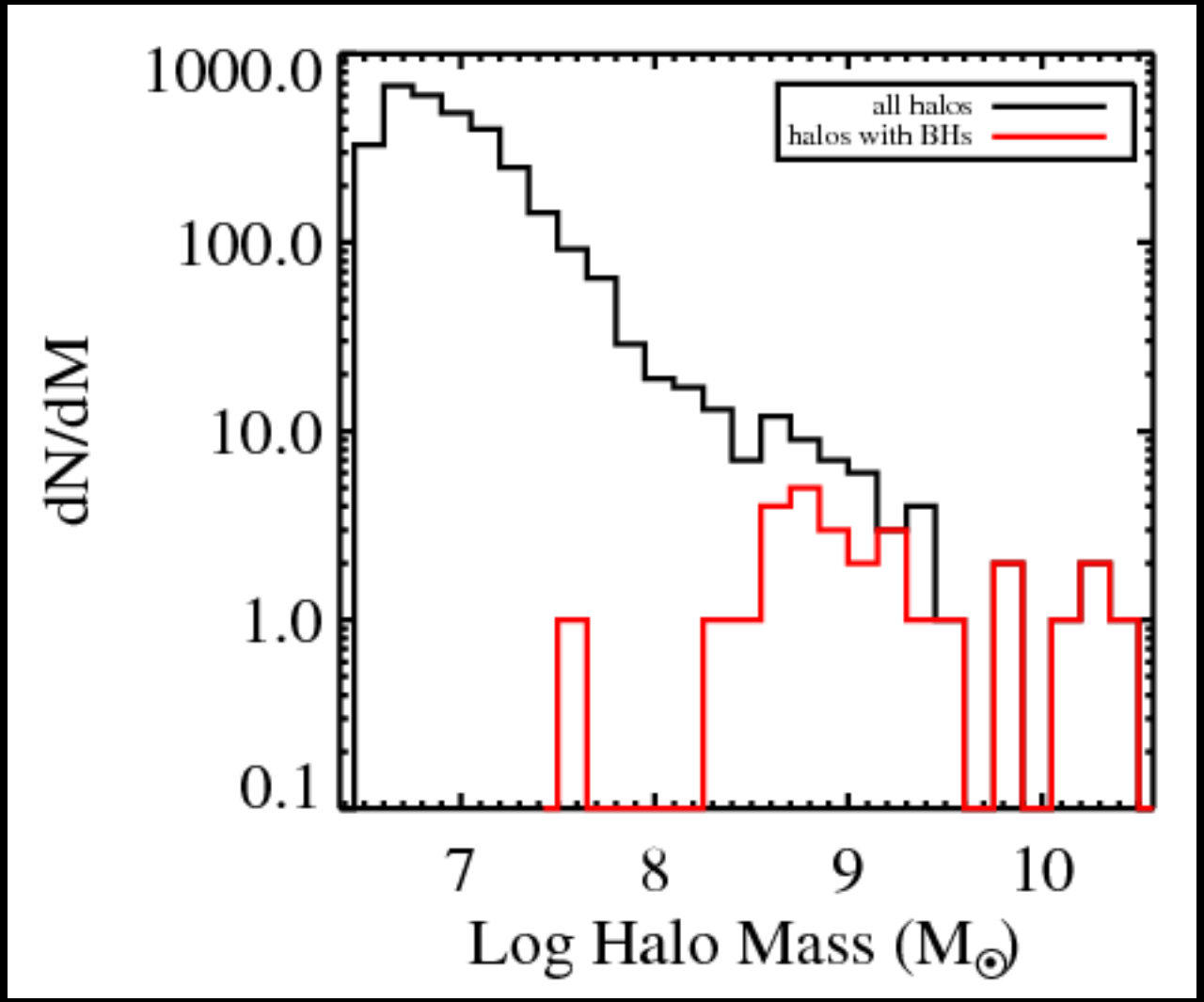

h603 to z = 5

Testing BH seed formation

- Three galaxies to z=5
- Four values of BH formation efficiency (0.05, 0.1, 0.3, 0.5)



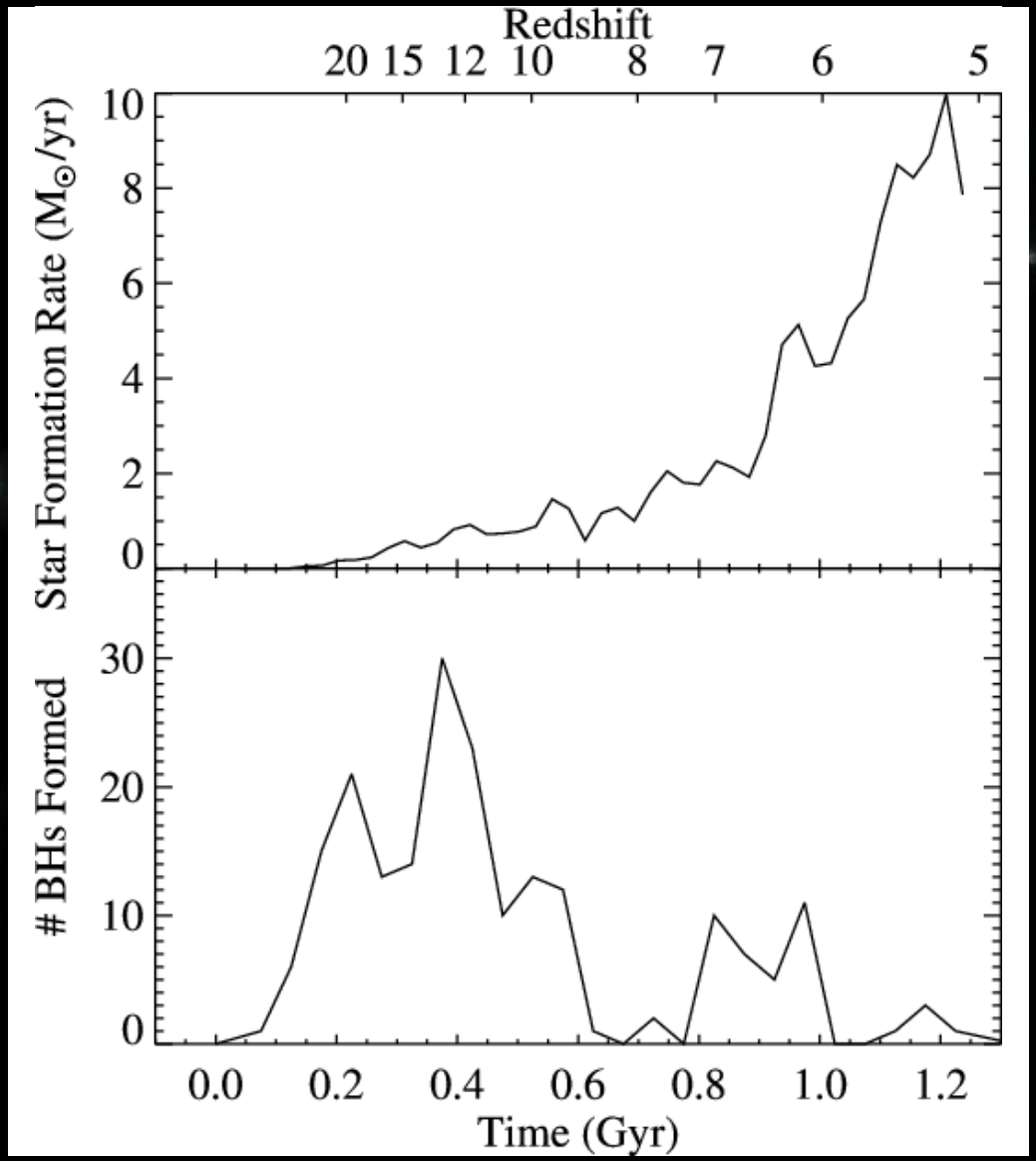
BH Seeds Form in Massive Halos



h258
eff = 0.1

z = 5

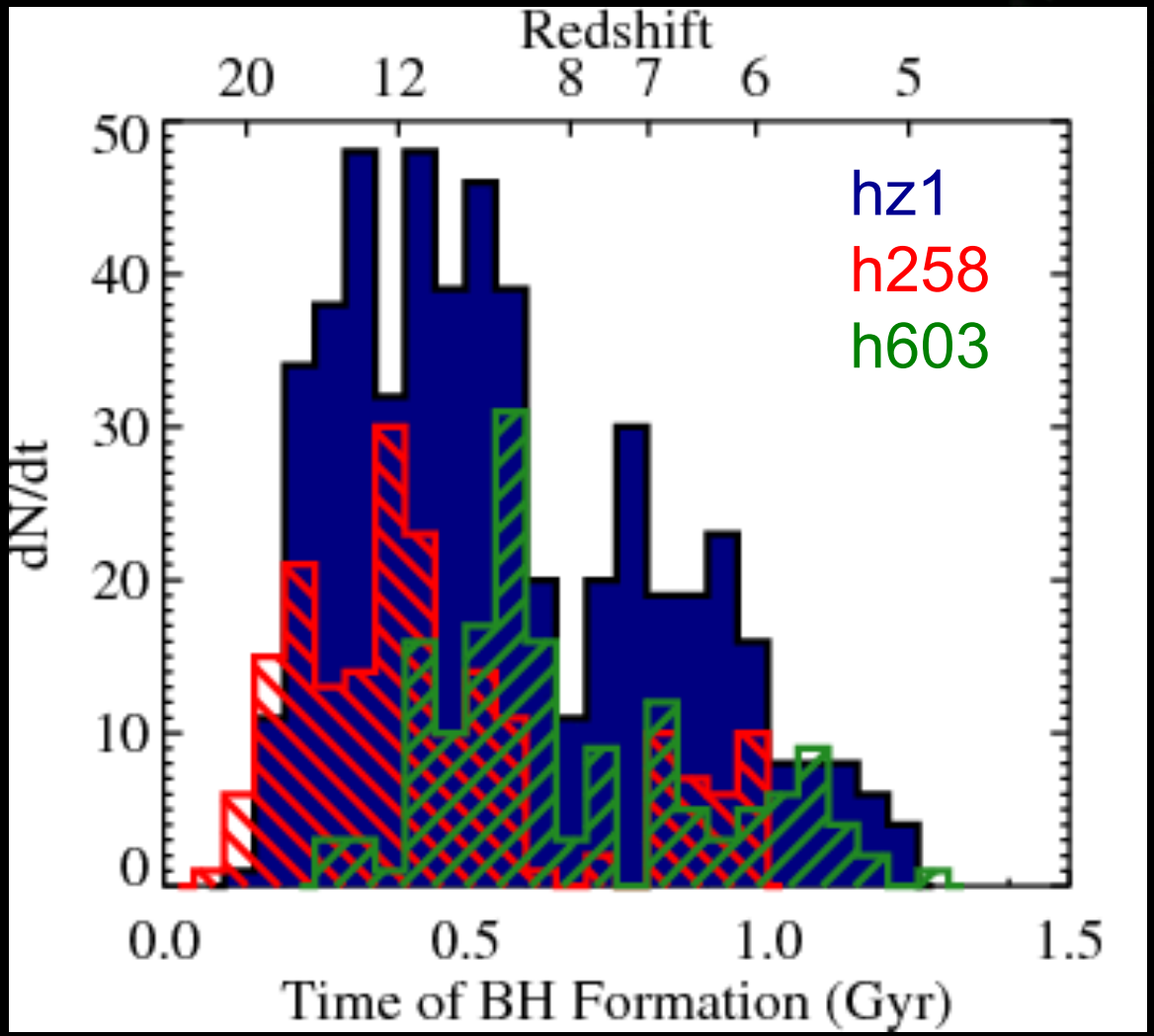
BH seeds form early



h258
eff = 0.1
z = 5

Bellovary+ 11

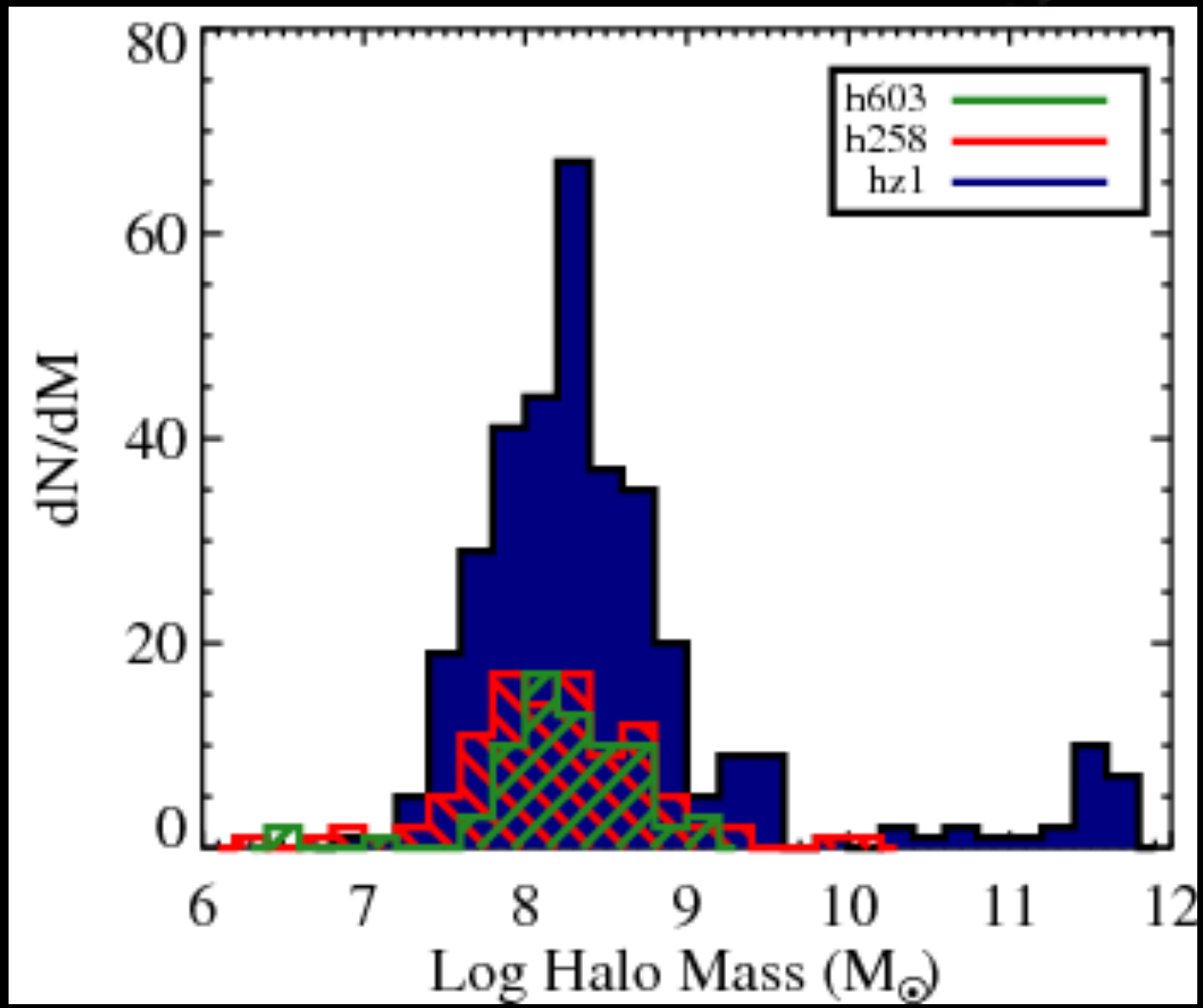
BH seeds form early



Eff = 0.1

Bellovary+ 11

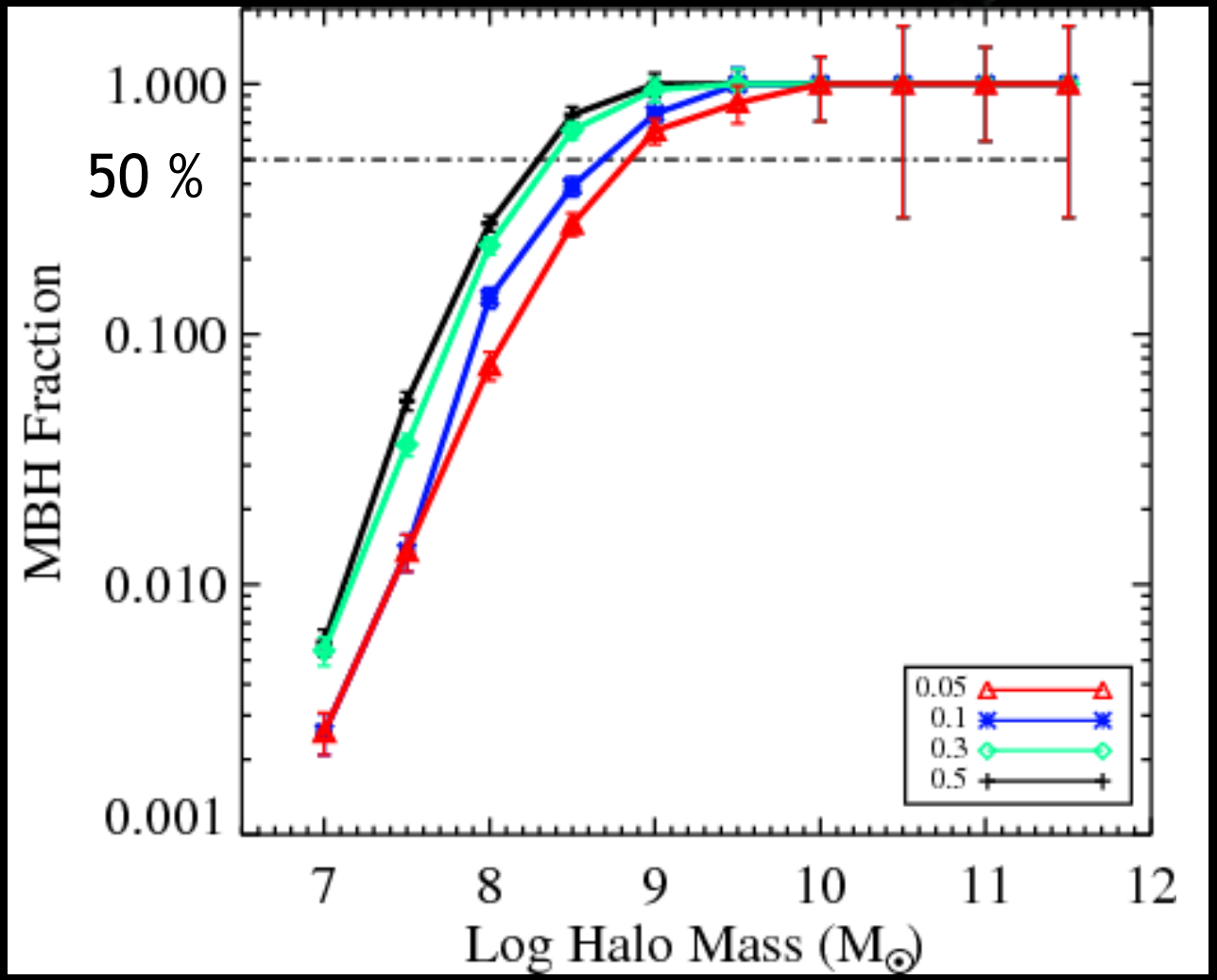
Halo Mass at time of BH formation



Eff = 0.1

Bellovary+ 11

BH Halo Occupation Fraction

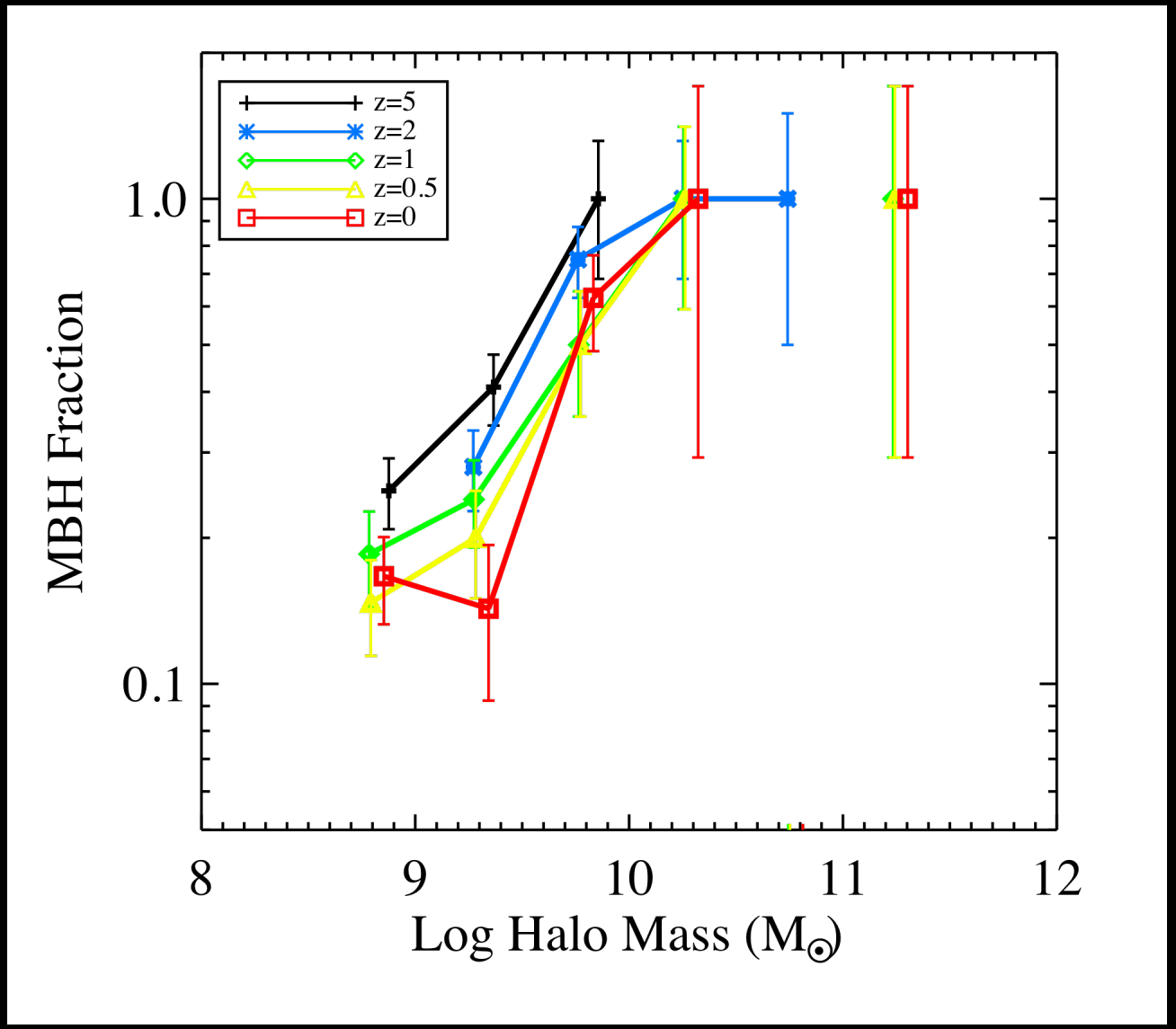


z = 5

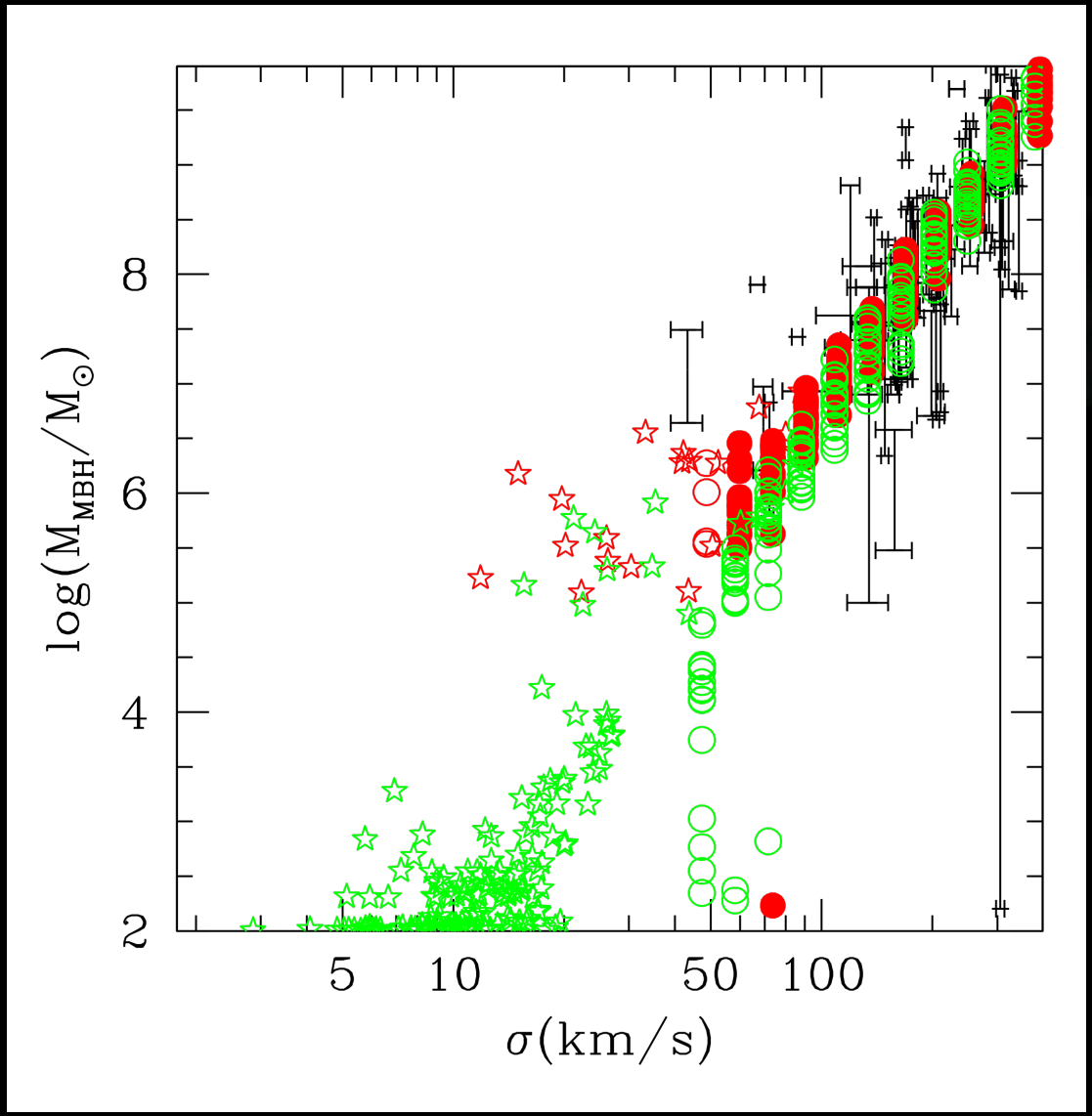
Bellovary+ 11

BH Halo Occupation Fraction

h258
eff = 0.3



Low-Mass M-σ 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 ~ 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?