How many Supermassive Black Holes are there?

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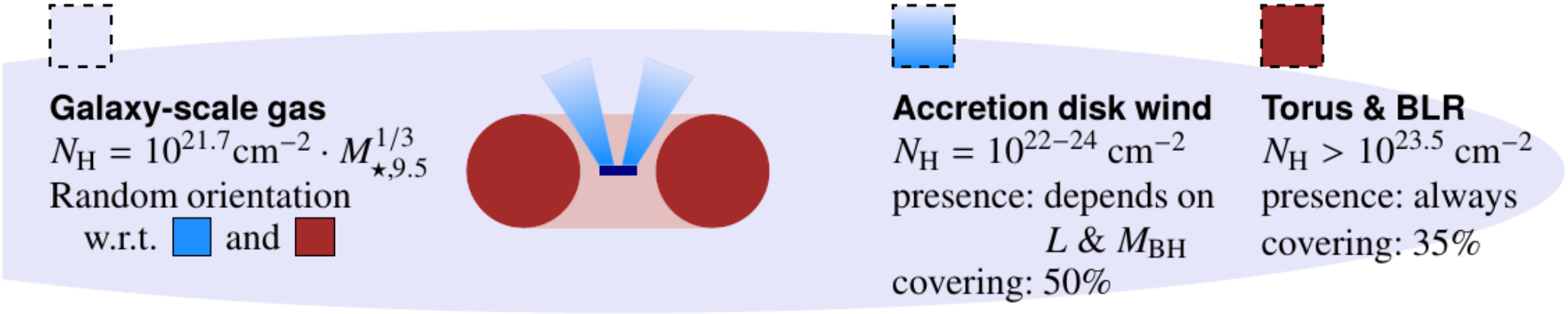
http://astrost.at/istics/

Collaborators (PUC & ETH): Ezequiel Treister, Franz Bauer, Lia Sartori, Kevin Schawinski, Roberto Gonzalez, Nelson Padilla

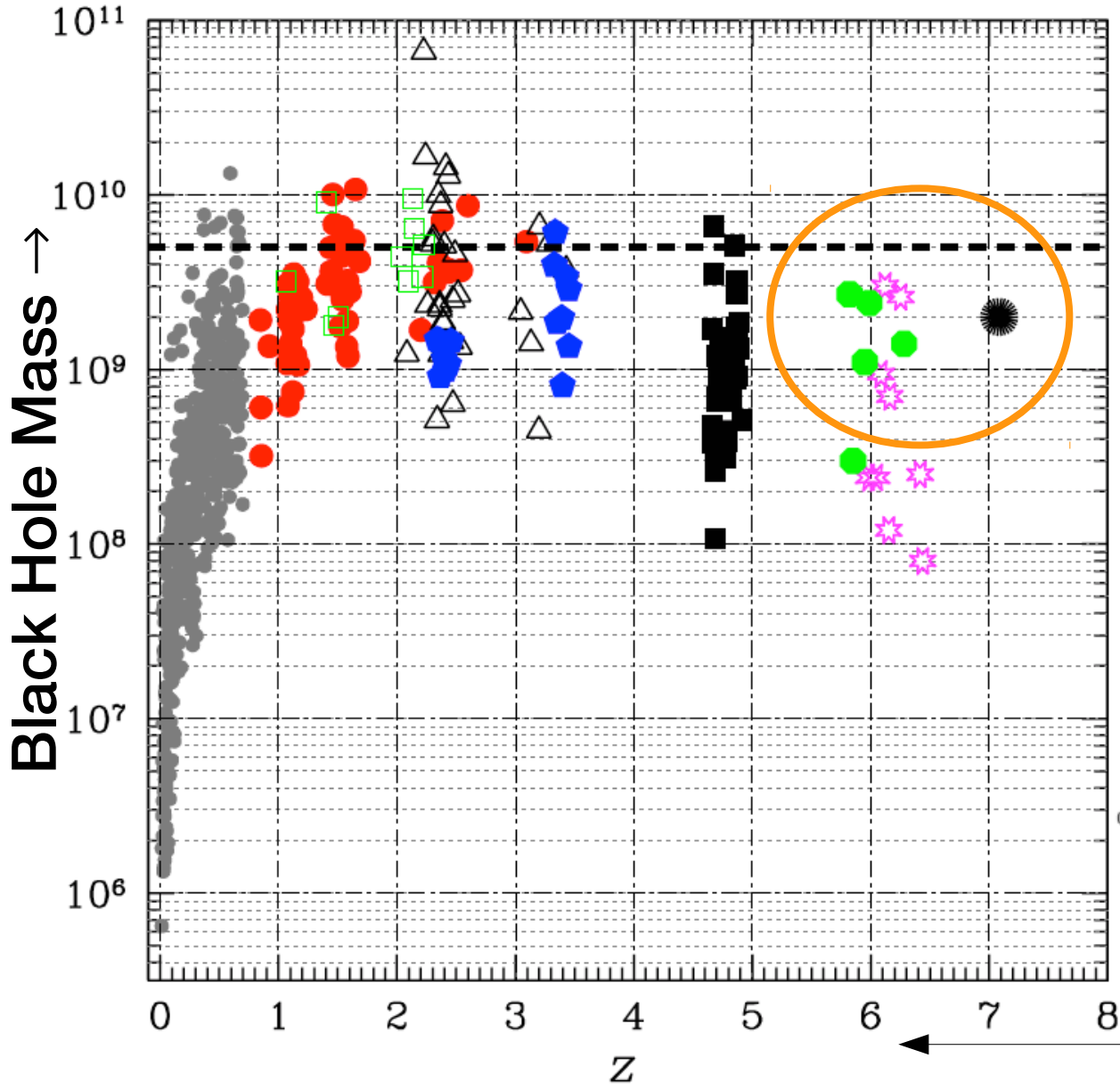
- Accretion history of the Universe — Buchner+15
- Compton-thick fraction — Buchner+15
- Geometry of the nuclear obscurer — Buchner+14,+19
- Galaxies as obscurers — Buchner+17a,b

poster 101

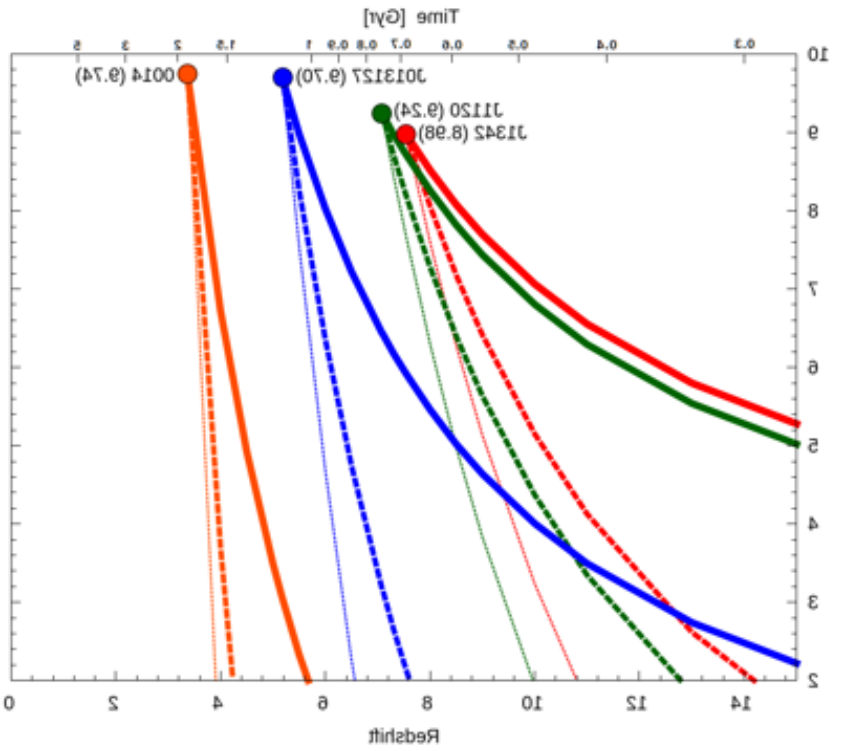


- Spectral fitting methodology (BXA) — Buchner+14
- Multi-catalog cross-matching (NWAY) — Salvato, Buchner+17

Timely growth



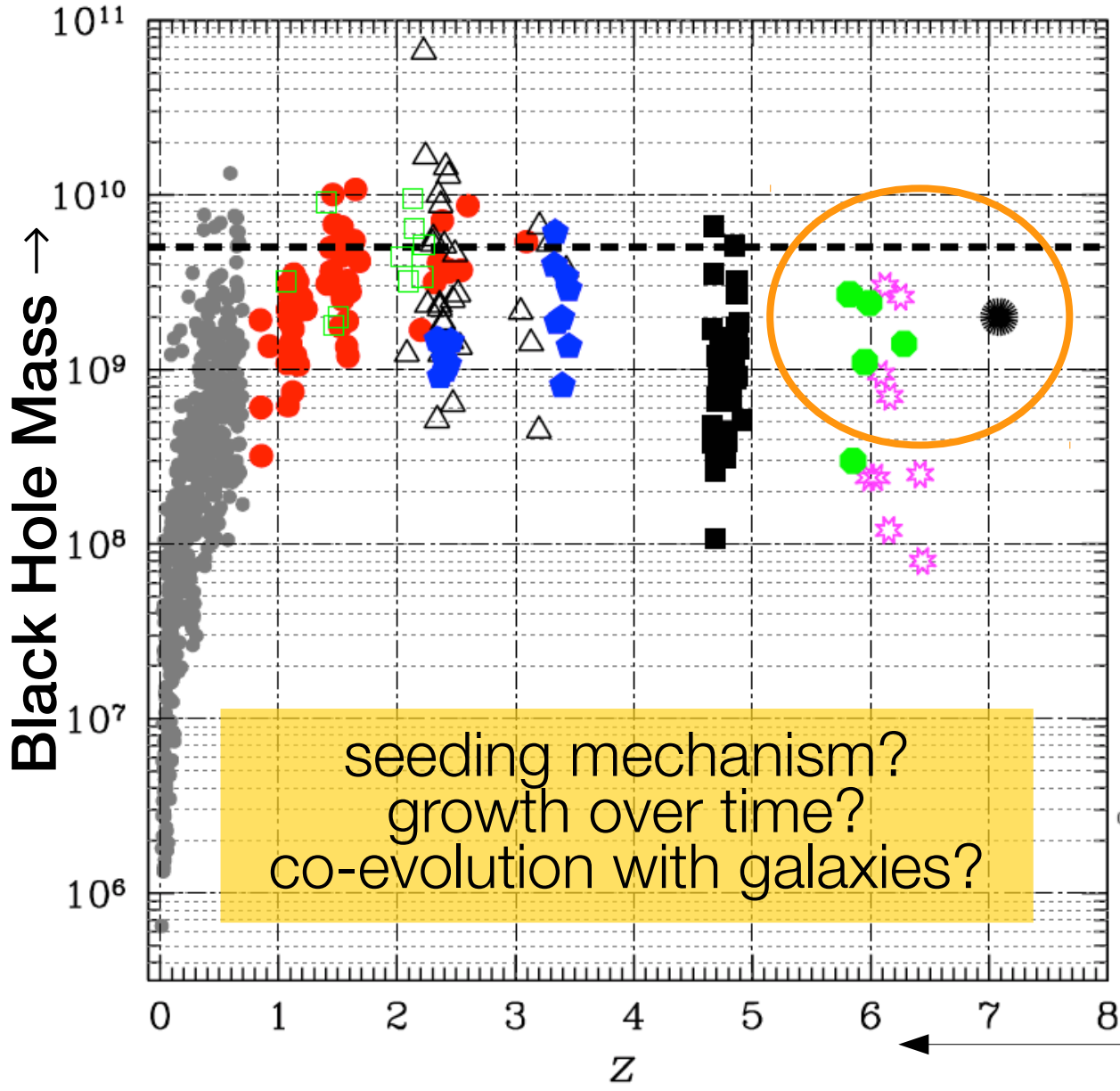
Eddington-rate limit relevant?
Gas supply available?



Time

Campitiello+18, Marziani & Sulentic (2012)

Timely growth



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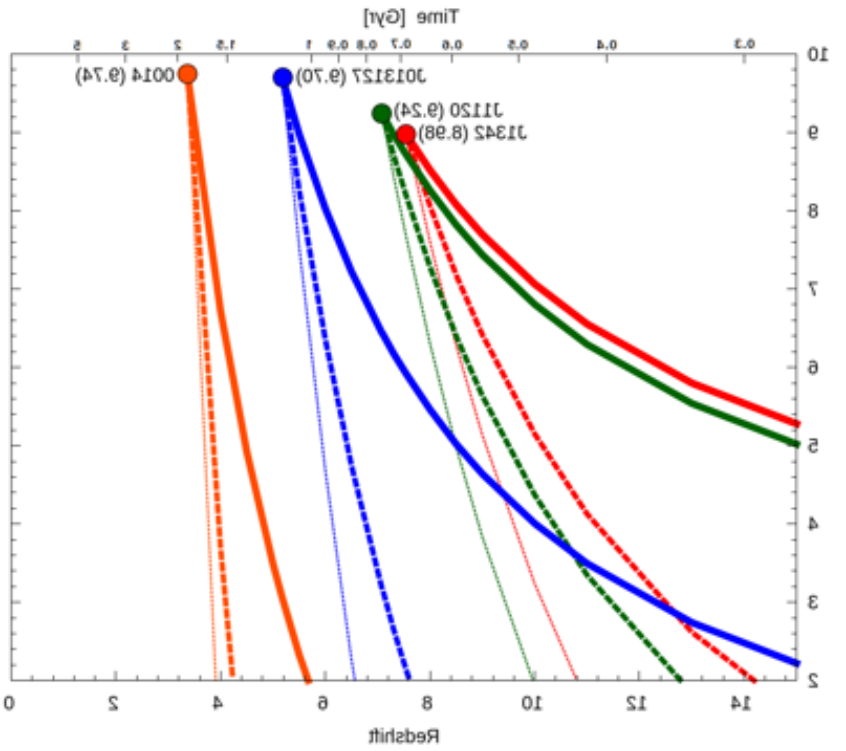

Time

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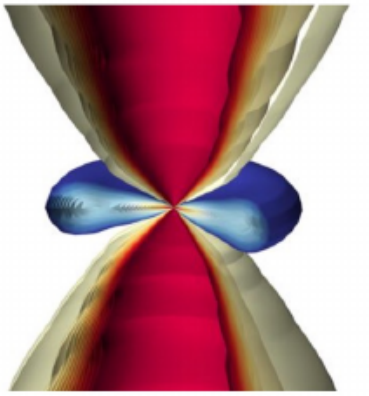
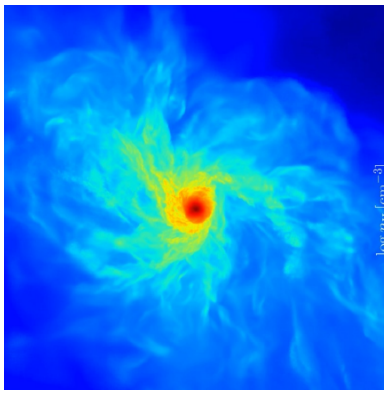
The origin of super-massive black holes

Light



Heavy

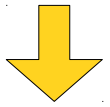


- **PopIII stars** plus
  - sustained super-Edd accretion
  - metallicity, chemistry & feedback-dep.
  - special halos?
- **Direct collapse**:
  - high-resolution,
  - chemistry, feedback-dep. growth
  - special halos?

→ Many assumptions, complex physics

→ EM predictions not unique

difficult to make progress



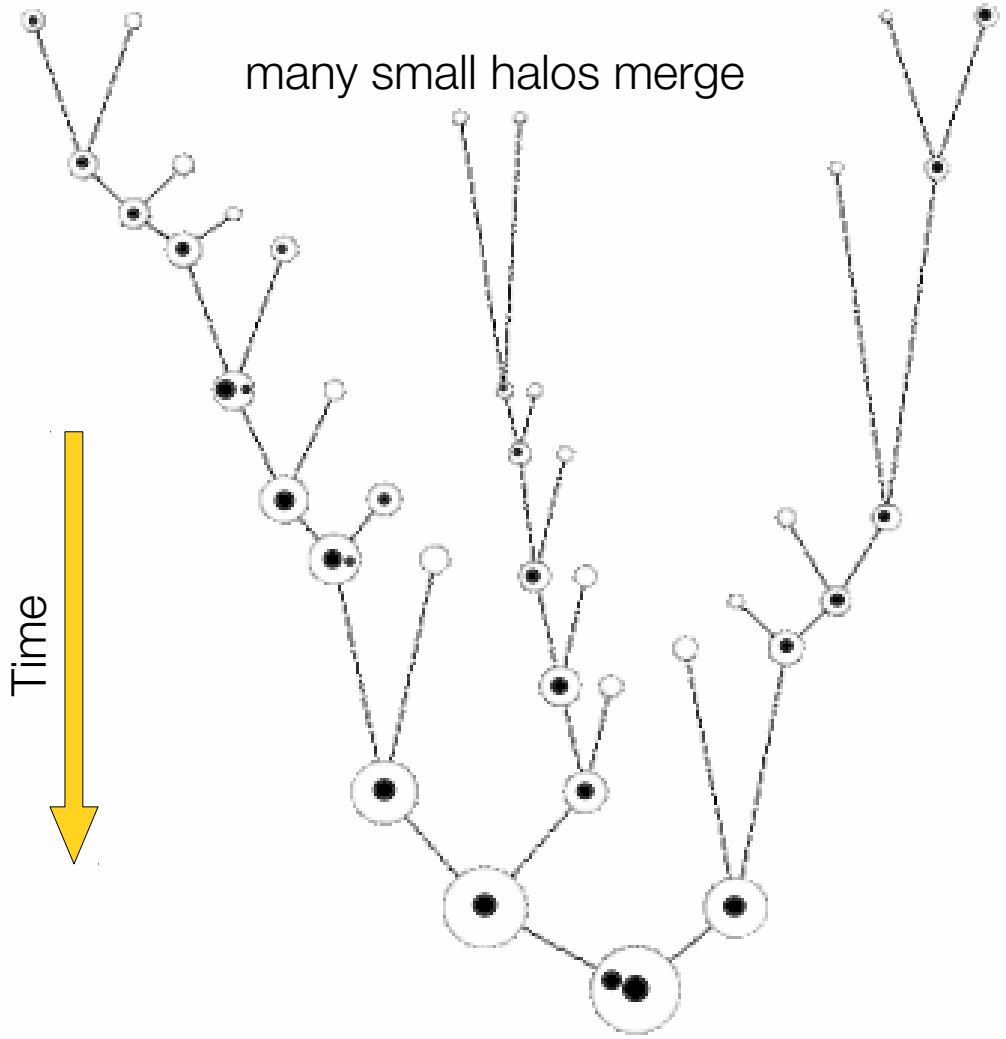
Cosmological sims: BH seeded in ~$10^{10} M_o$ halos

Becerra+15, Kuiper&Hosokawa+19

Volonteri 2012, Rees 1978

How often does the process need to succeed?

Ansatz



local galaxies host SMBHs

credit: M. Volonteri
see also Menou+01

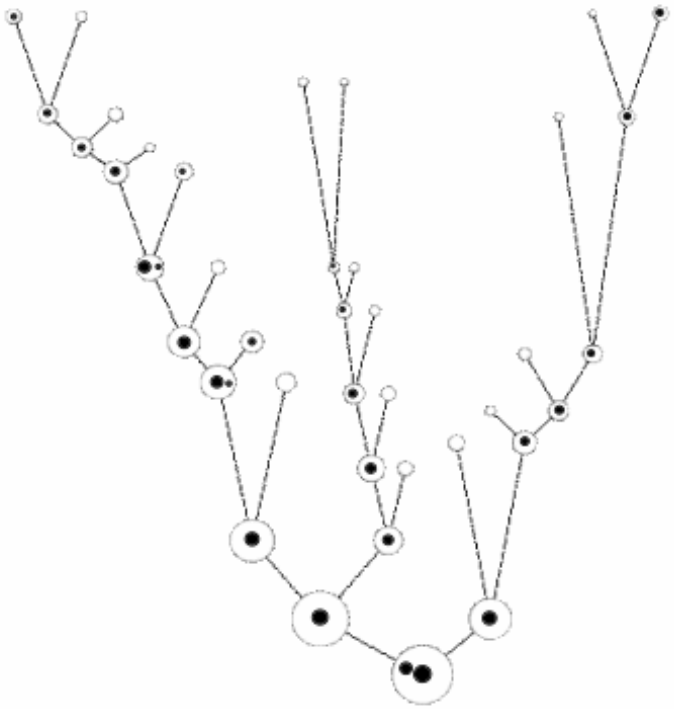
- Halos are born and grow
- At some threshold mass $\mathbf{M_c}$: chance **p** for seeding success

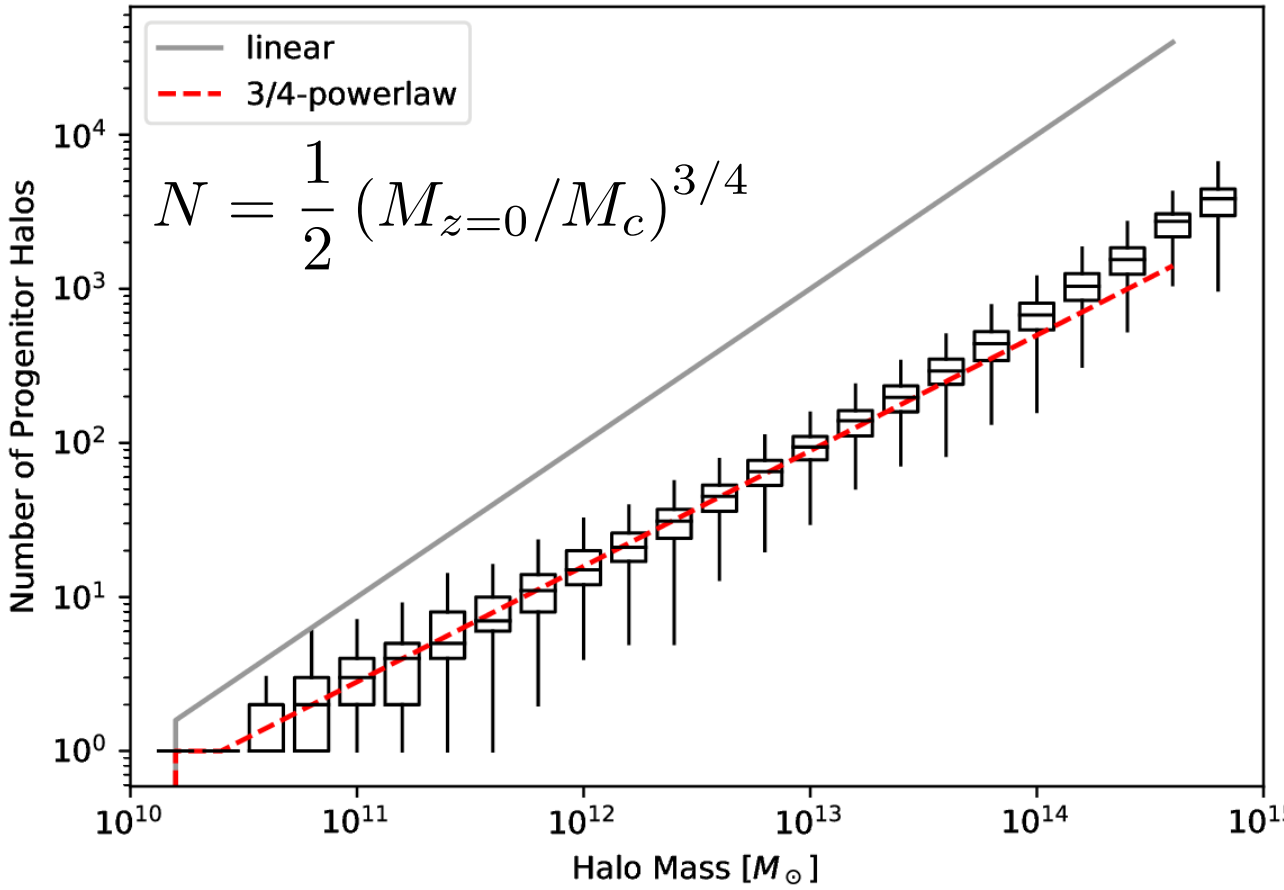
- Can approximate physical seeding mechanisms

Does not need assumptions of
- seed black hole mass
- accretion
- feedback
- galaxies

Building blocks

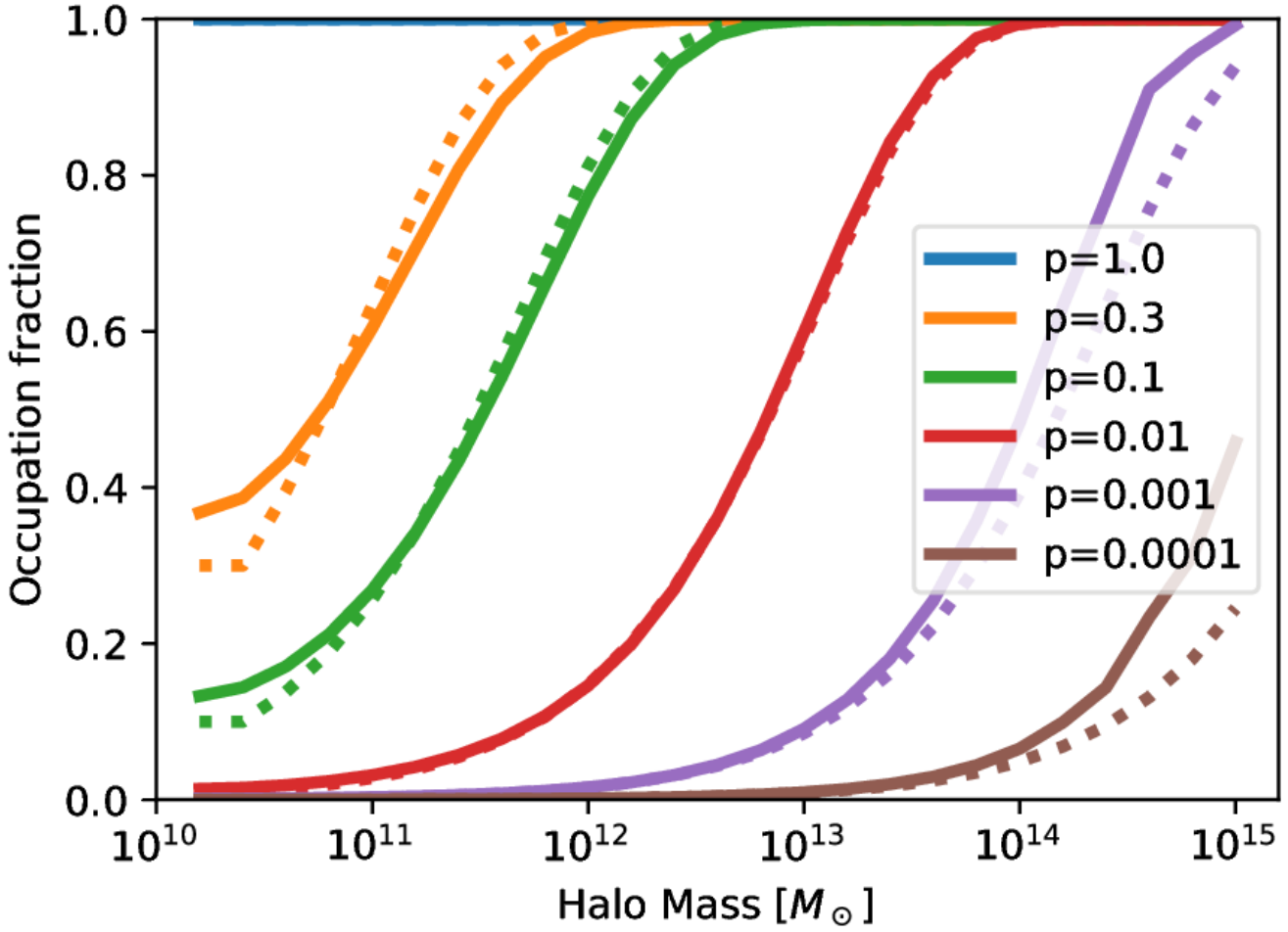
- Count leaves of merger tree
- z=0 halo building blocks of size $M_c = 10^{10} M_\odot$





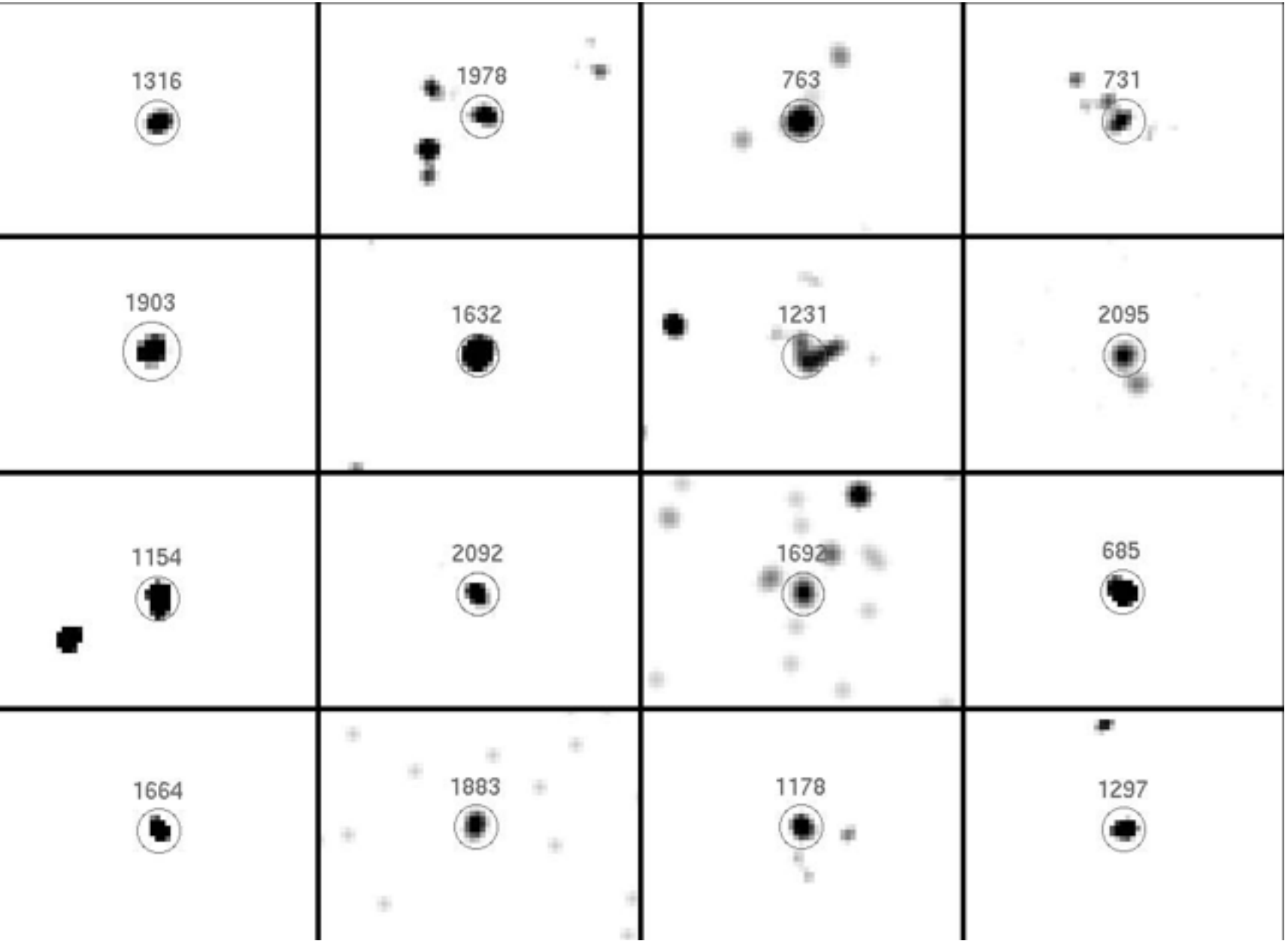
SMDPL dark-matter simulation
Rockstar subhalos
Planck cosmology

Occupation at z=0



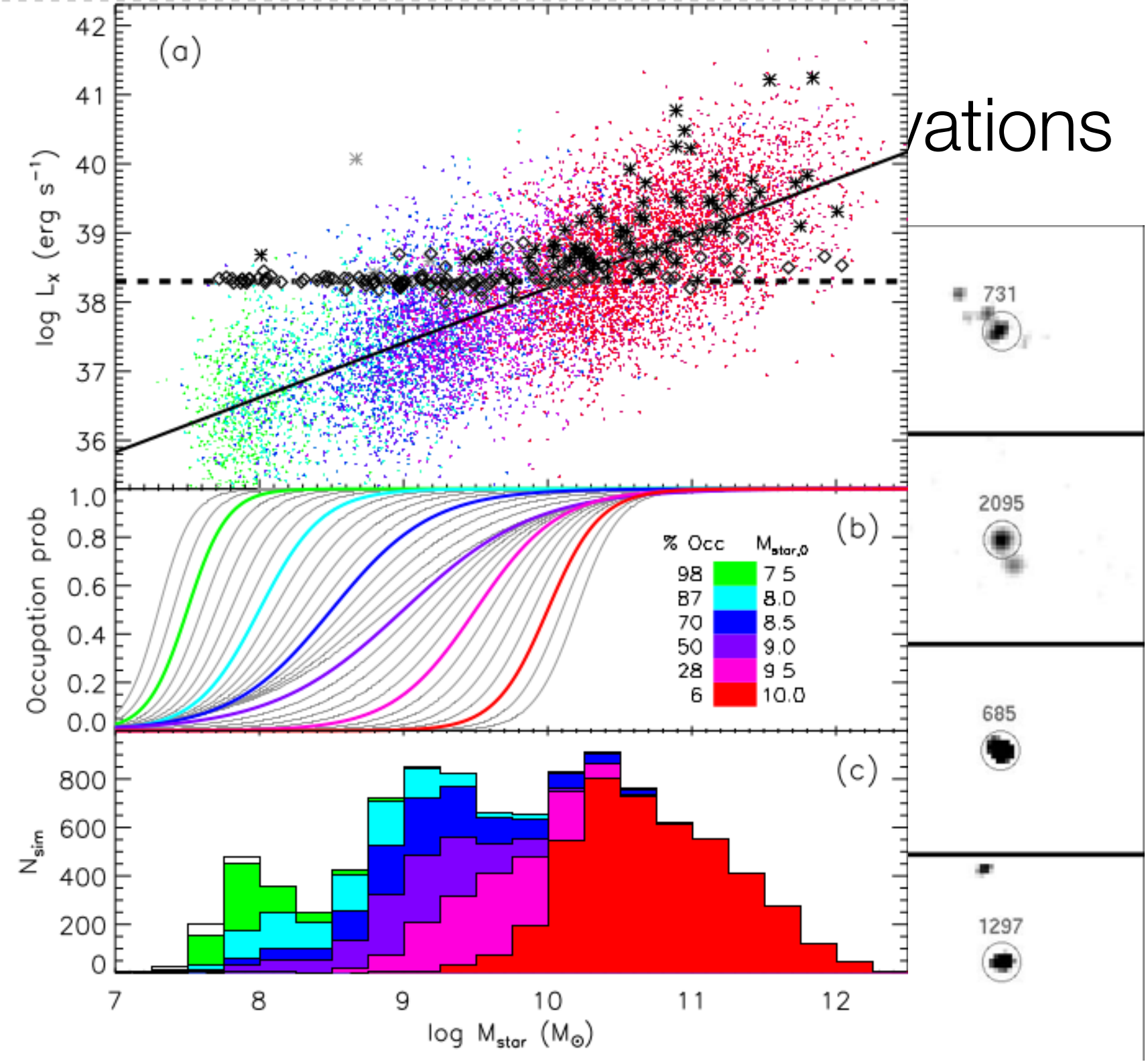
$M_c = 10^{10} M_\odot$

Occupation Observations



Gallo+10,
Miller+15
AMUSE-Virgo

vations



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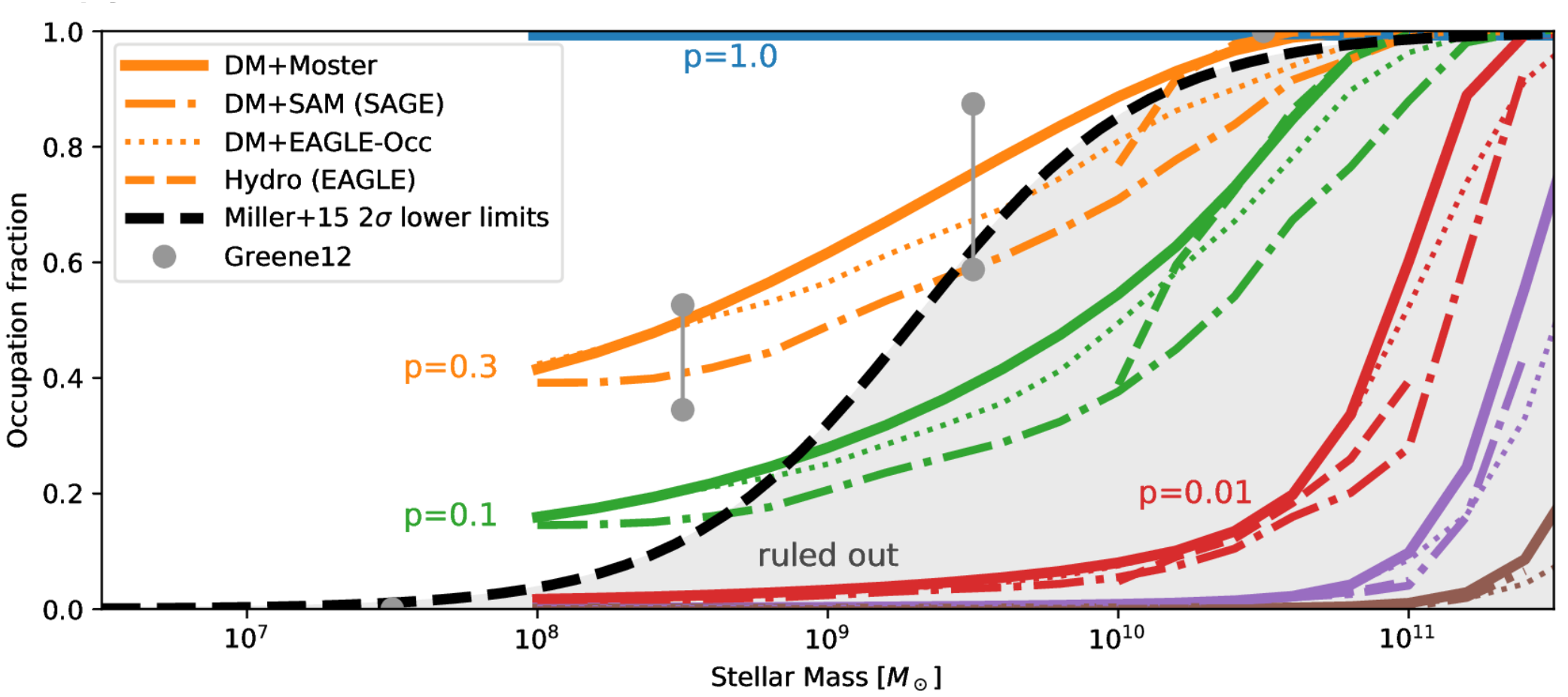
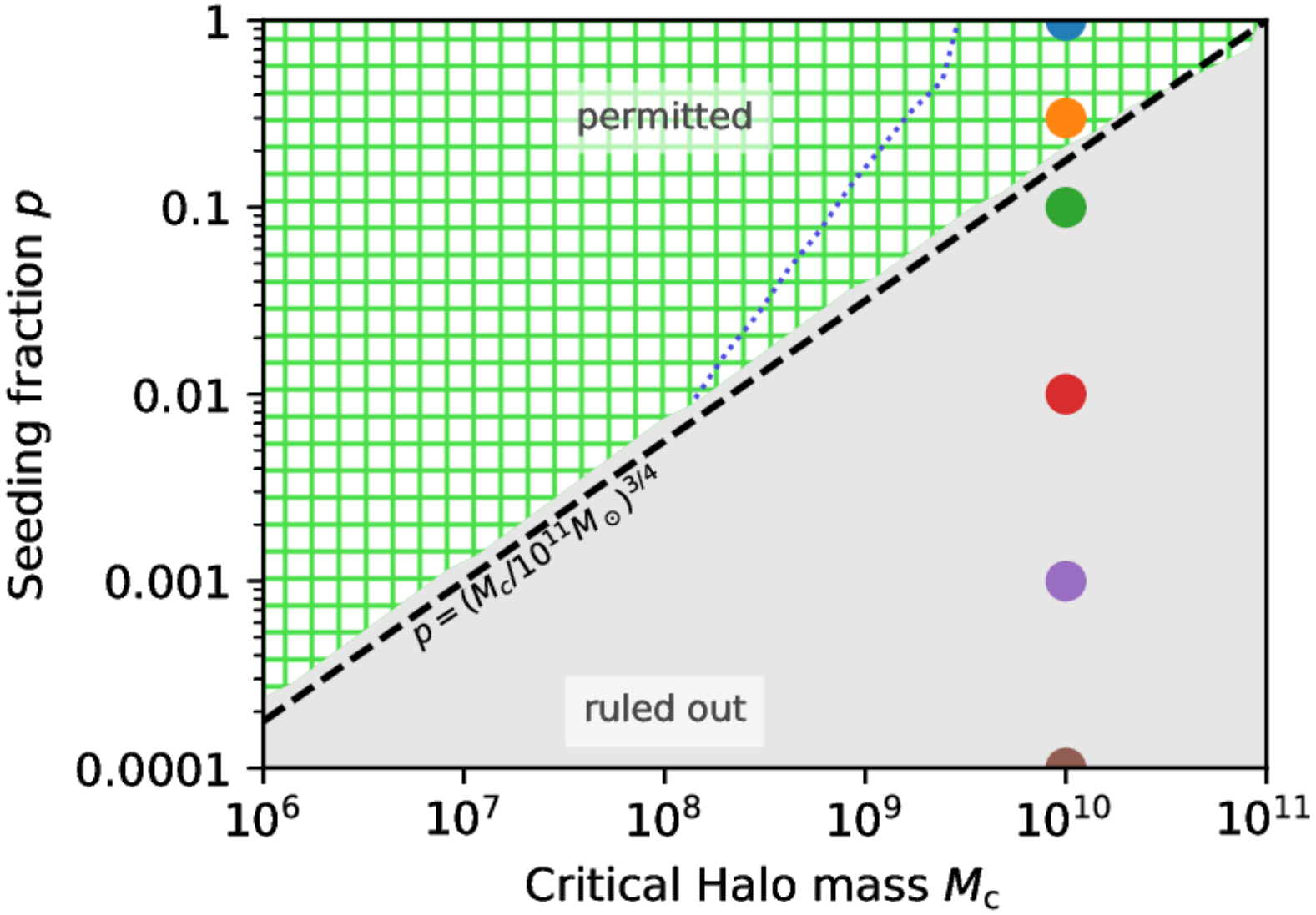


Buchner et al. (in prep)

Required Seeding Efficiency



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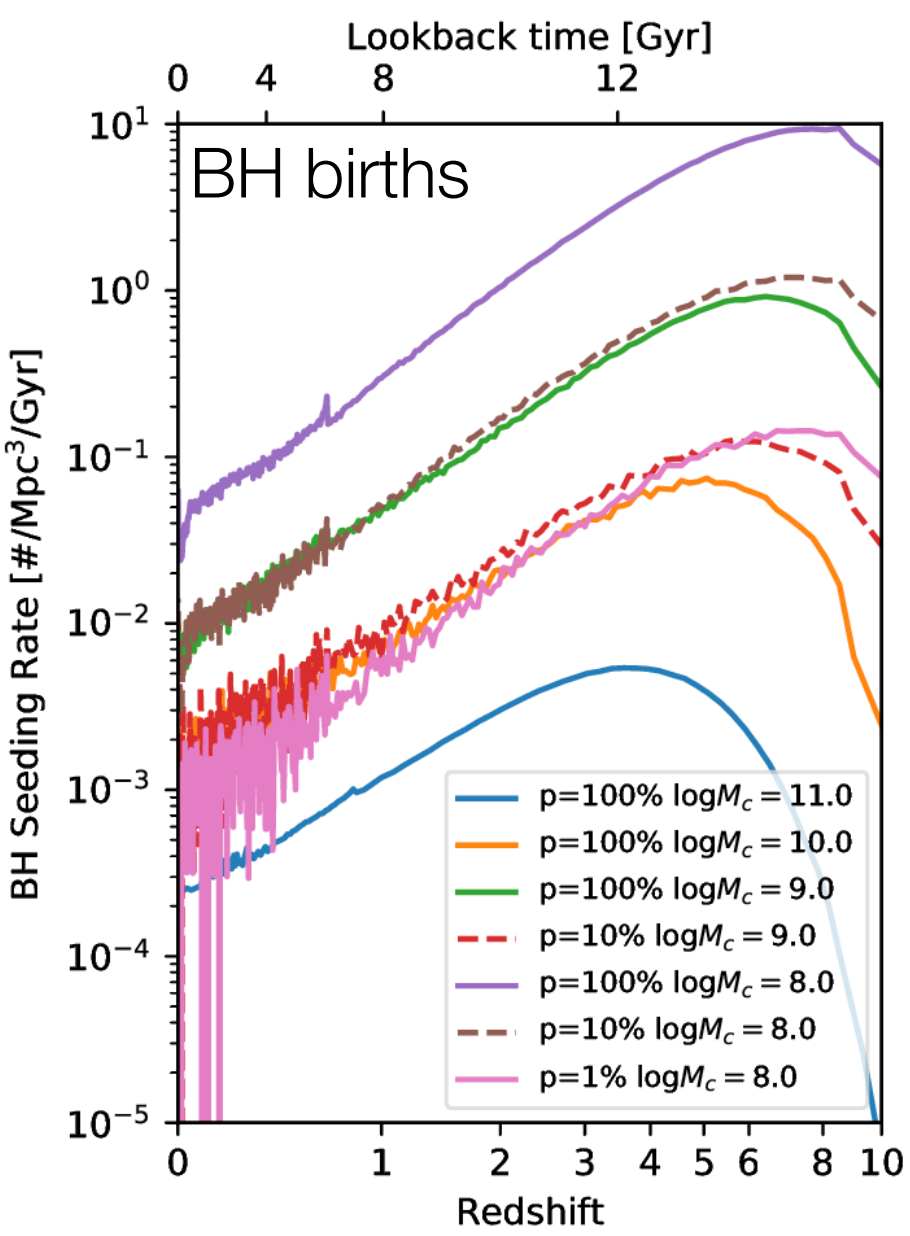
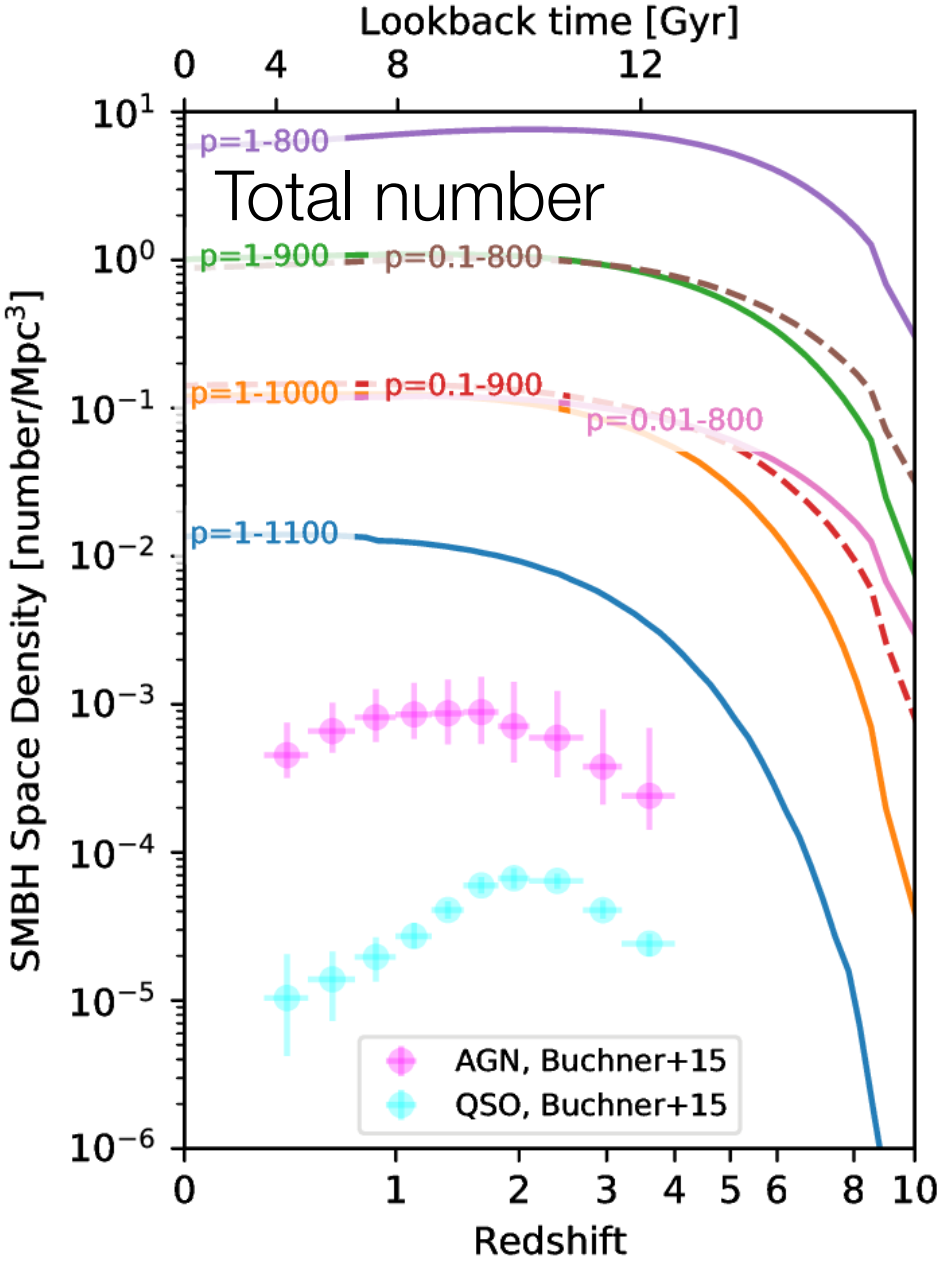
Population Evolution





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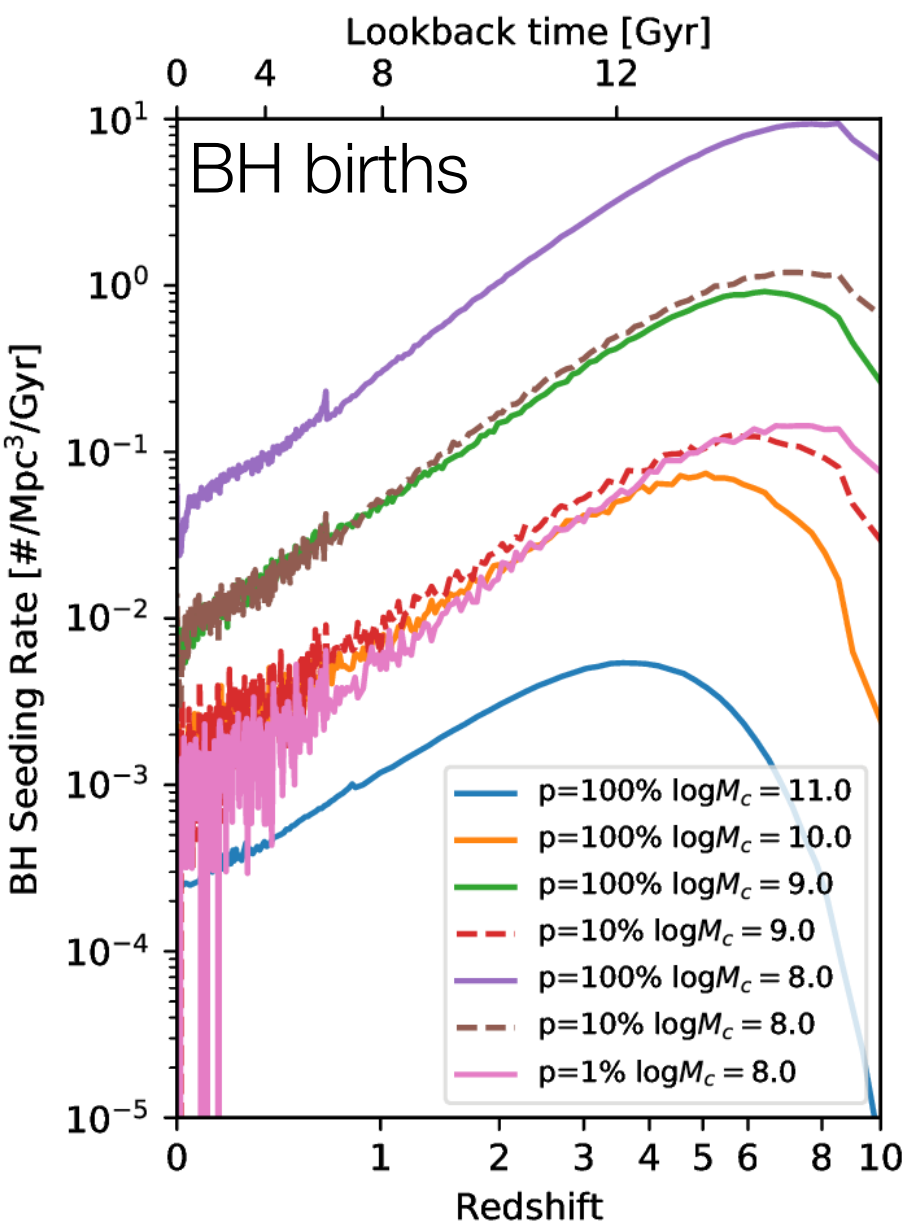
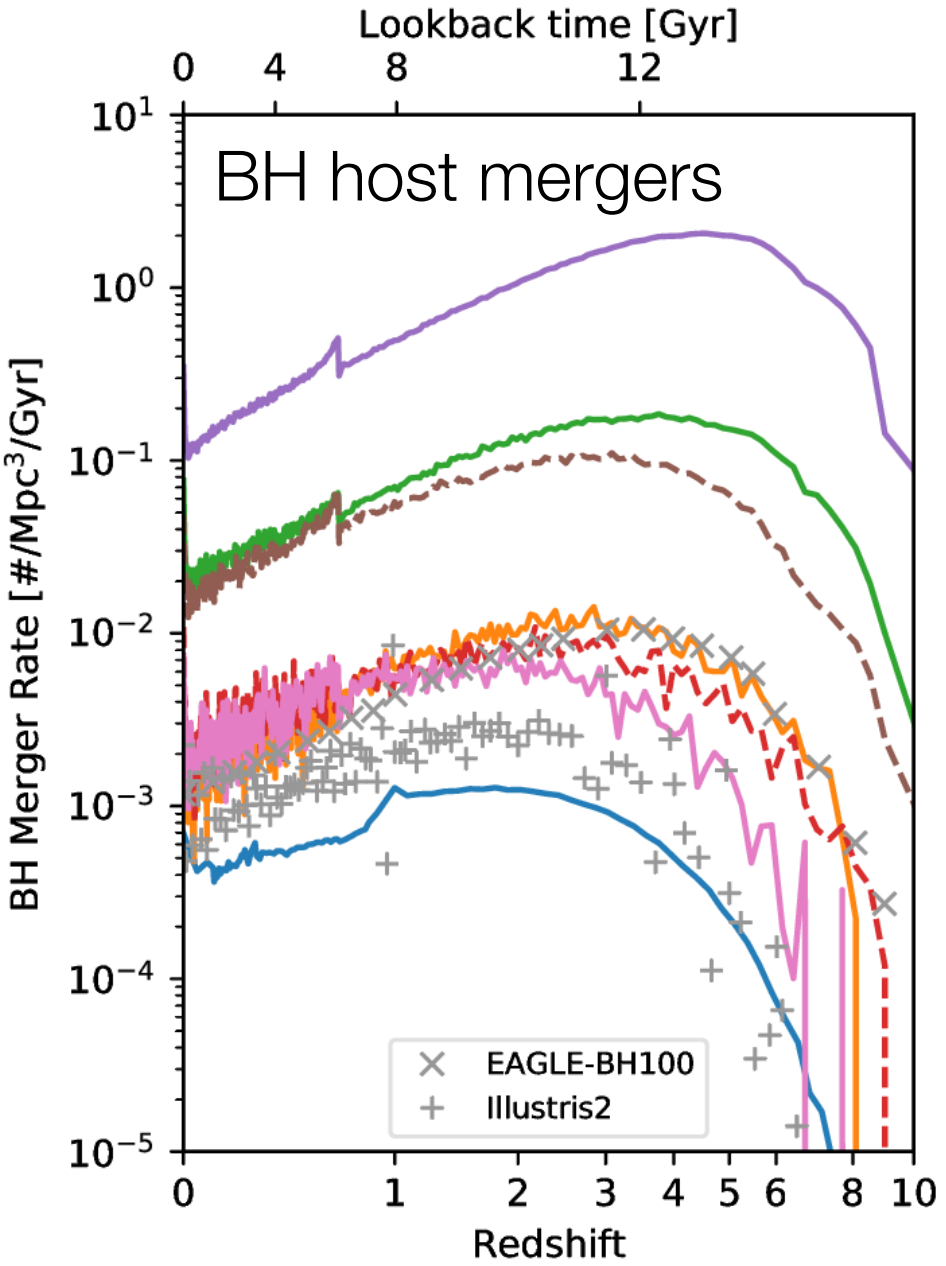
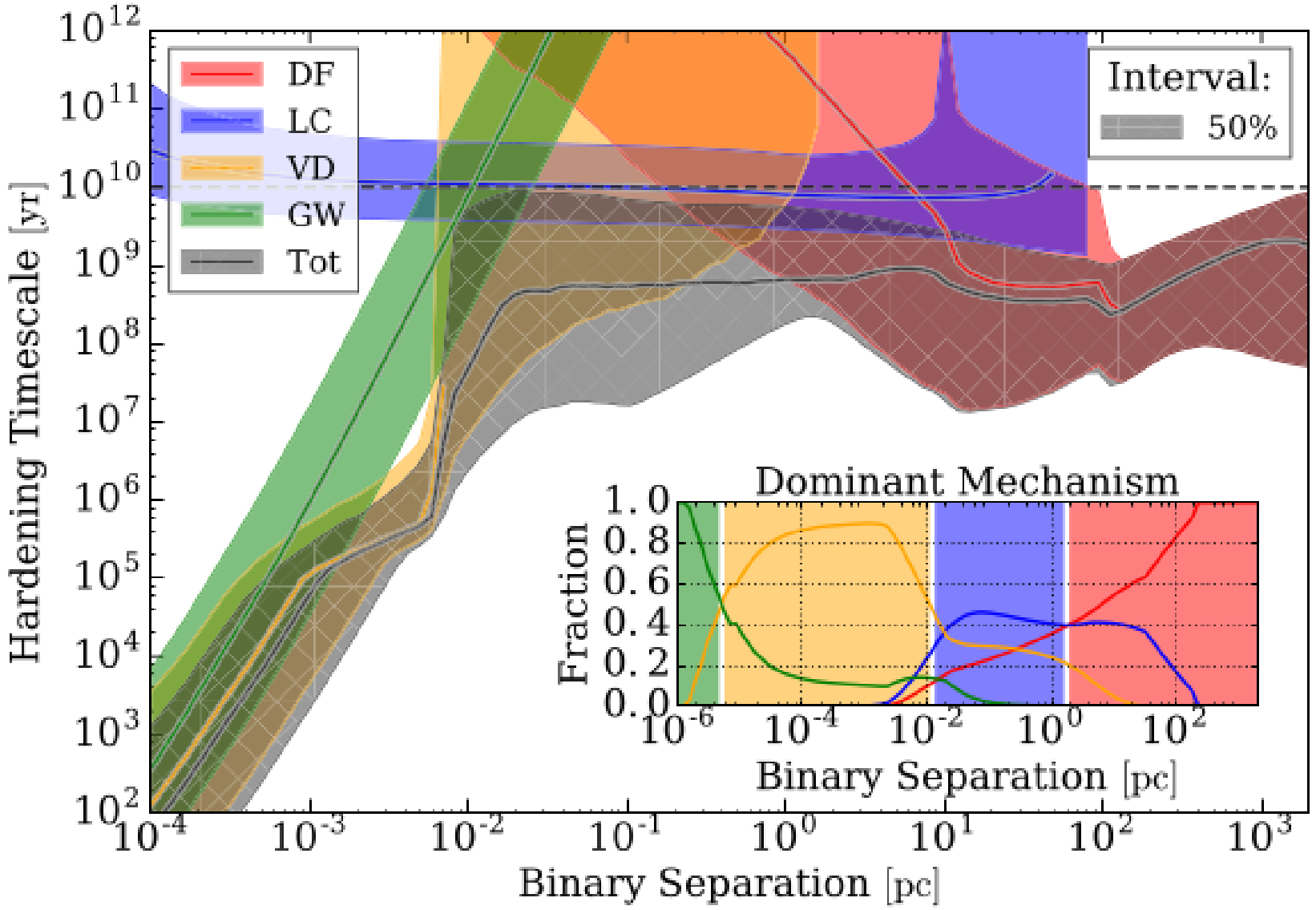




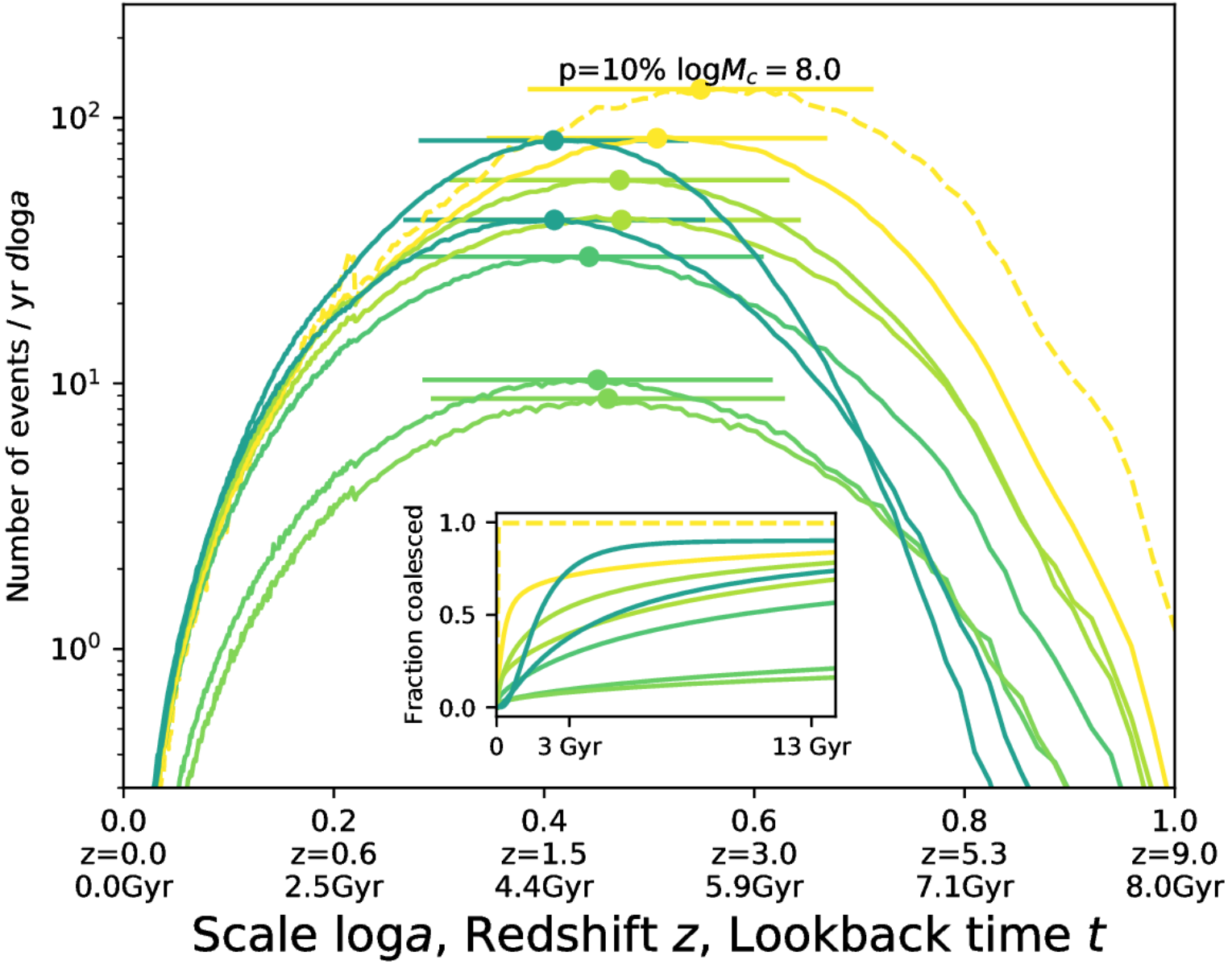
SMBH merger delays



Kelley+17

Dynamical friction, Light cone scattering, Viscous drag, Gravitational waves

SMBH merger delays



Kelley+17

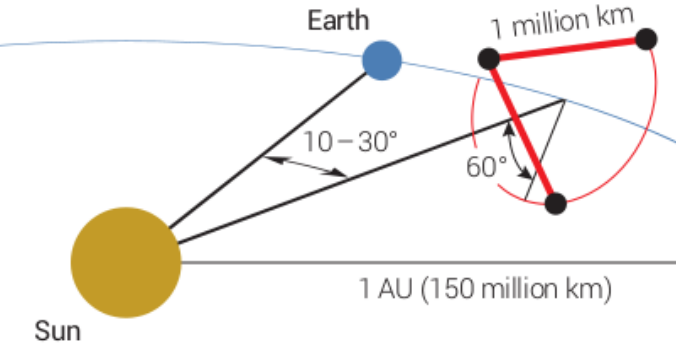
LISA GW Diagnostic Diagram

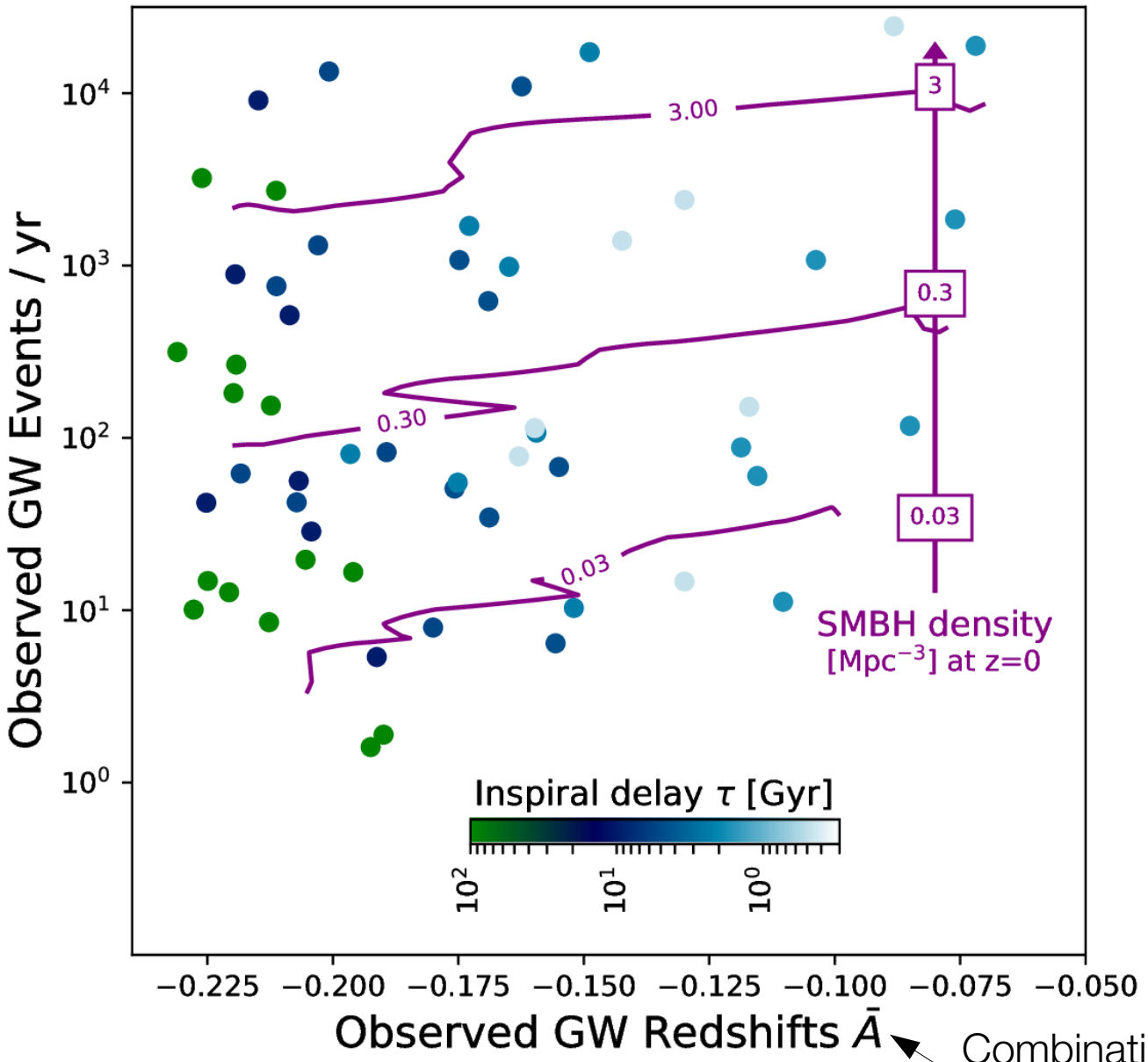
Buchner+19

$10^{4\text{-}8}$ M_o
z=0-13

Virtually all SMBH mergers will be detected by LISA (Salcido+16, EAGLE sim + waveshape modelling)

(talk by Sesana)





Combination of z mean and std

Summary: Model-independent seeding

- Seeding efficiency $p > \left(M_c/10^{11} M_\odot\right)^{3/4}$

- LISA will directly
  - Detect >1 merger/year
  - Measure the SMBH space density
  - Measure the merger delay time

For X-rays:
→ James Aird's talk

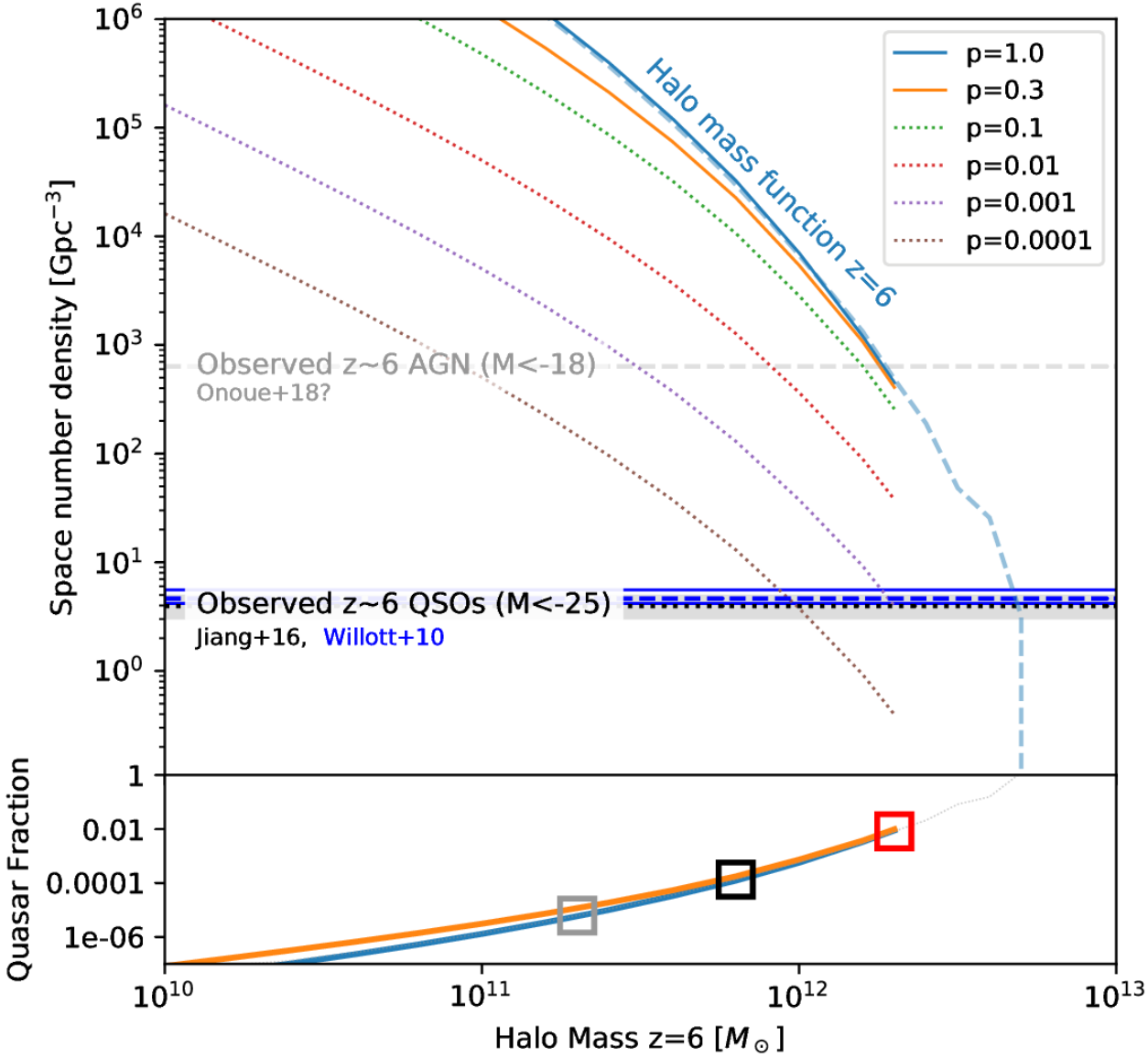
- High-z Quasar host environments are diverse

see Buchner+19, ApJ (1901.04500)

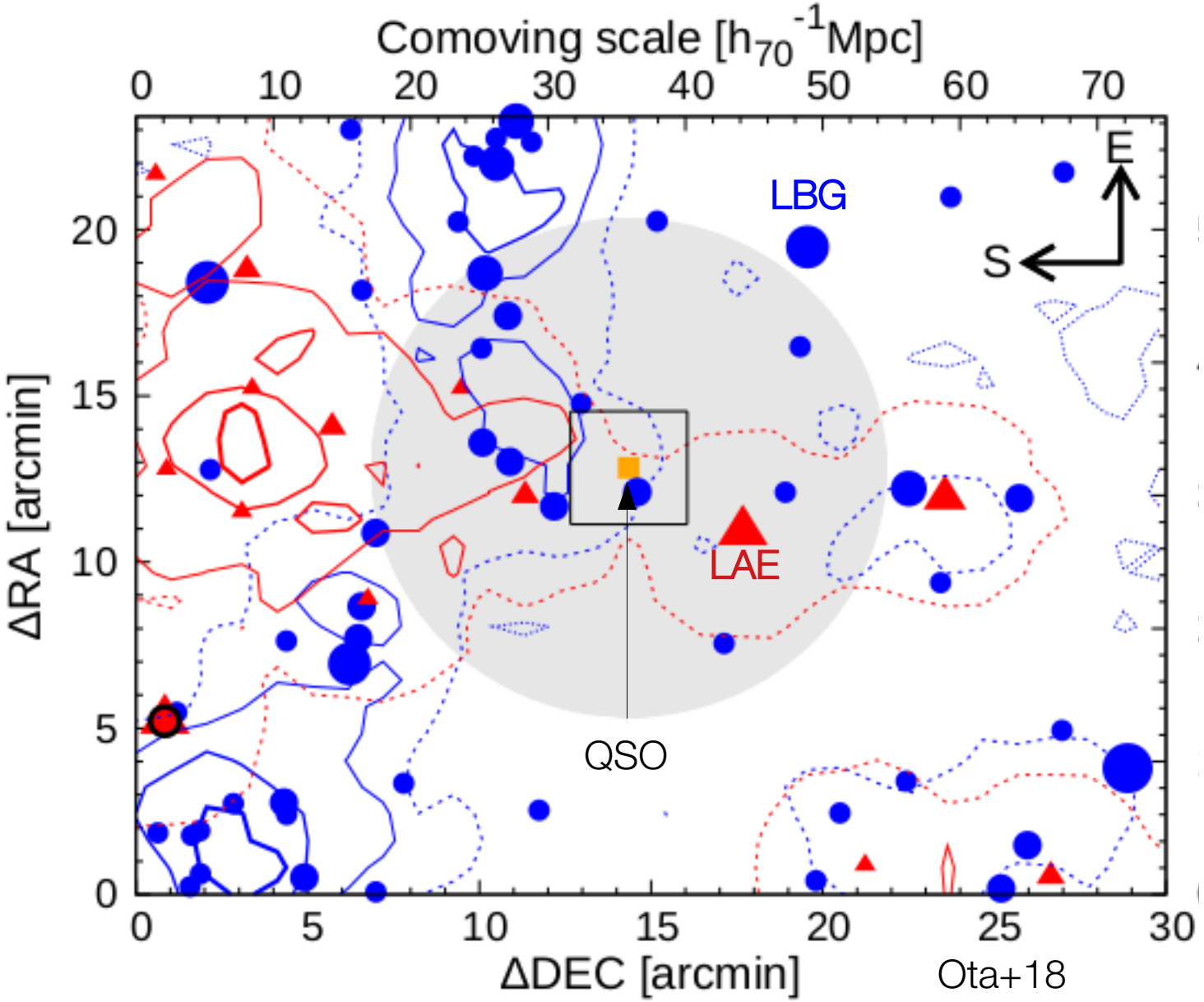
High-redshift quasars

- z=6 QSO surveys (SDSS)
- Earliest census of active SMBH population
- There are more SMBHs
- Live in massive halos?

- Massive halos or duty cycle?



Overdensities near Quasars



Ota+18

Literature has conflicting results:

- Overdensities
- Equal
- Underdensities

compared to control fields

What is happening?

Overdensity predictions

- QSO Hosts definition:
  - Halo mass cut, e.g.:

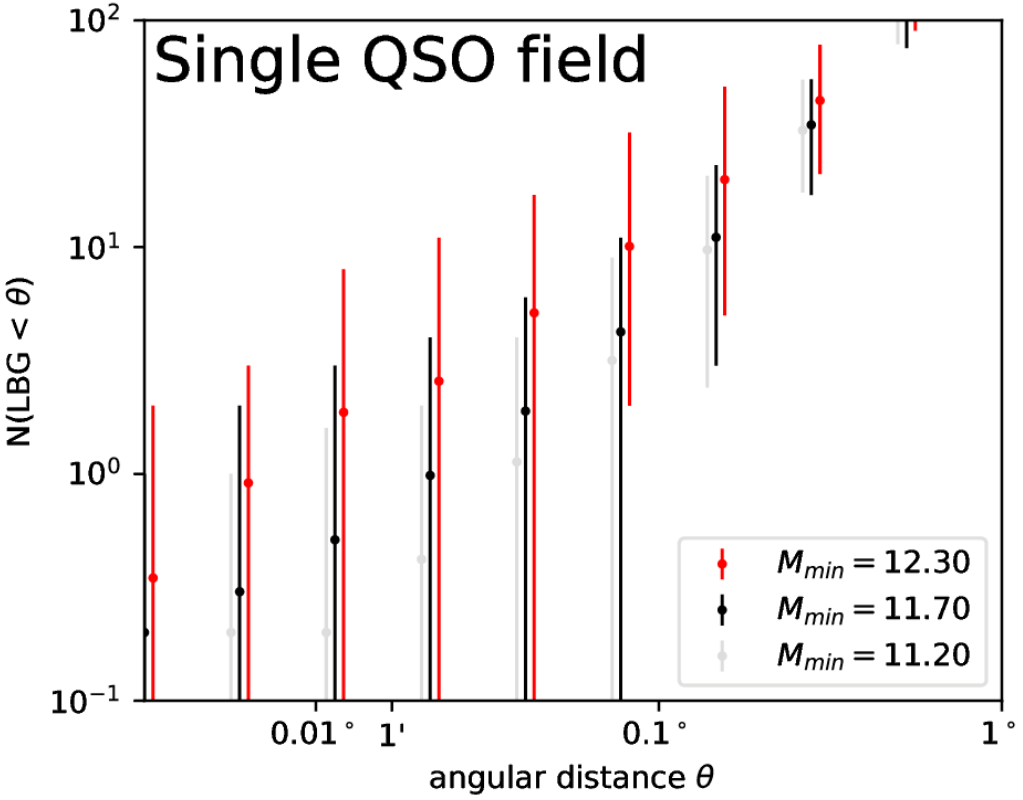
    only $>10^{12.3} M_O$
- Look at neighbourhood

- Galaxies definition:
  - LBG: Hatfield+17
  - LAE: Kovač+07, Sobacchi&Mesinger+15
  - selection as in observations (redshift window, magnitude)

Simply count galaxies within radial shells around quasar

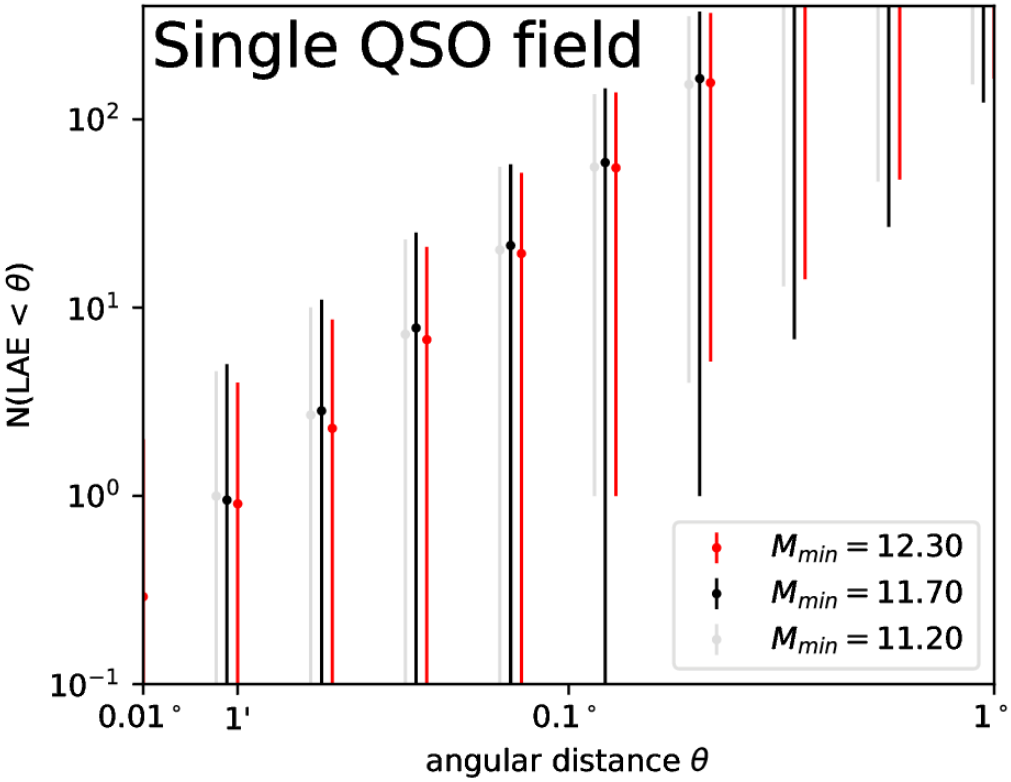
Understanding high-z quasars

LBG



Large diversity!
Large volume in z!

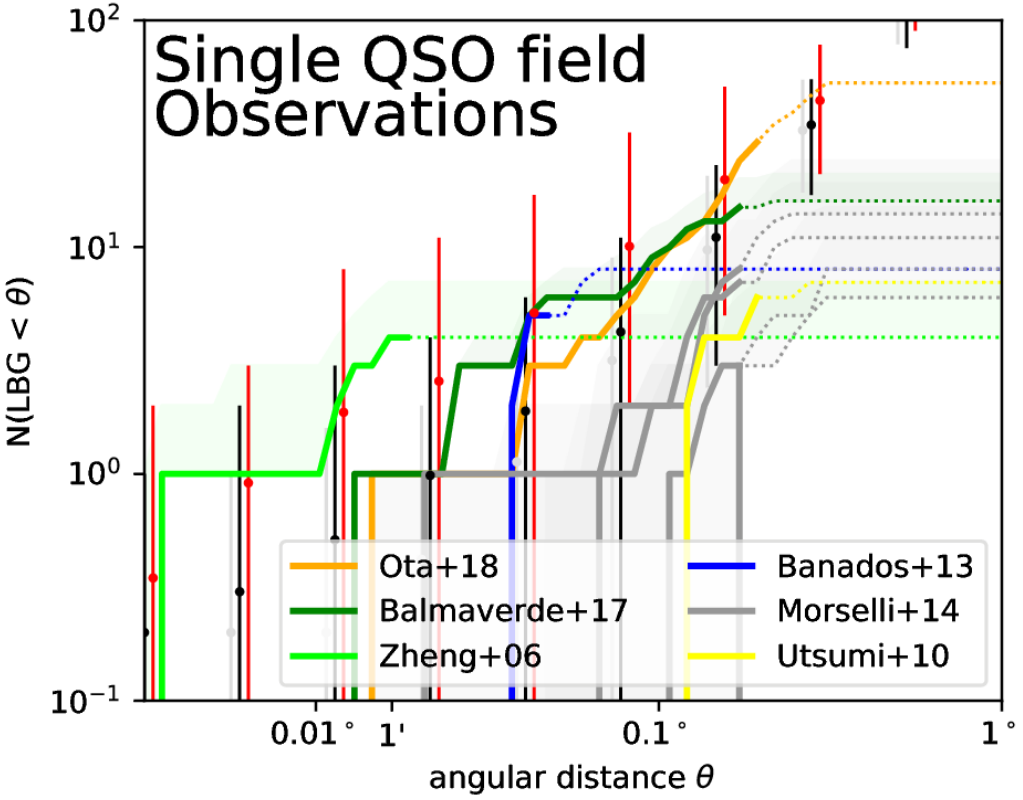
LAE



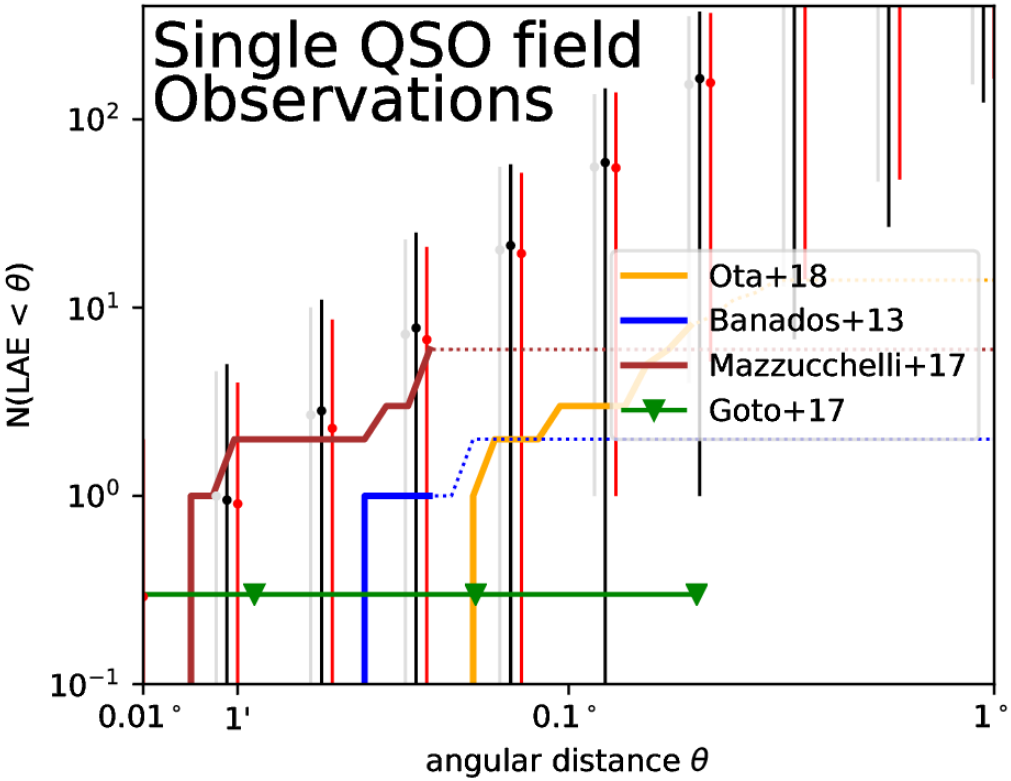
Large diversity!
Poisson noise!

Understanding high-z quasars

LBG



LAE



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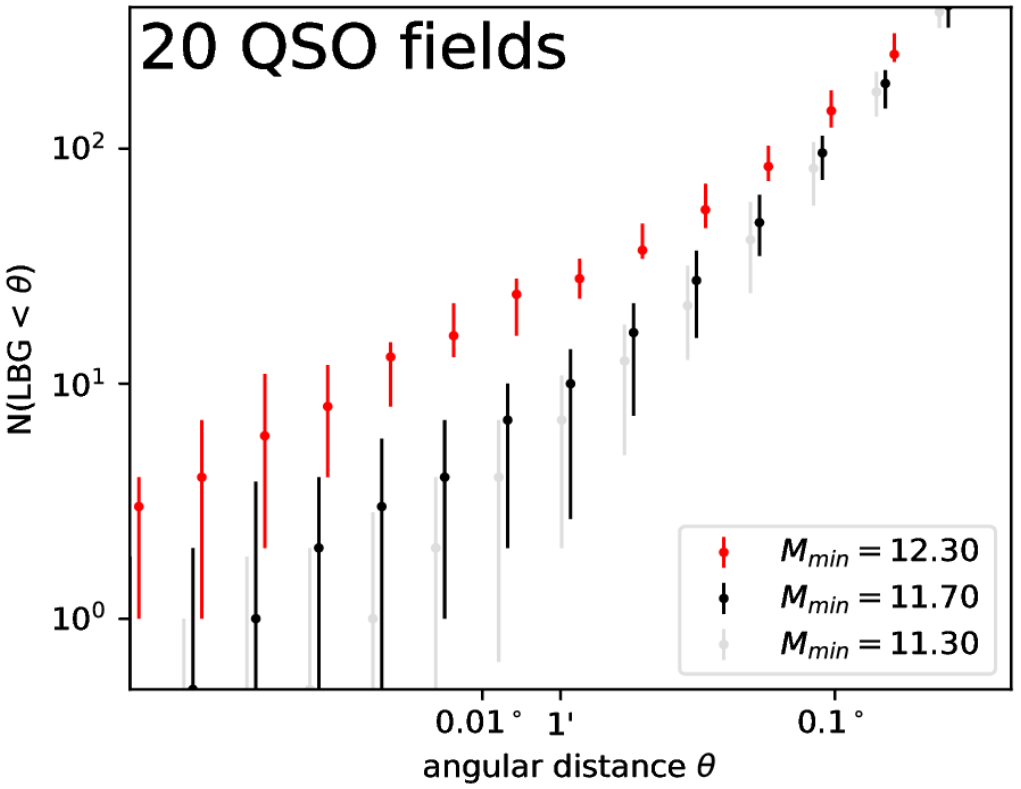
Understanding high-z quasars

LBG



LAE