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

**Galaxy-scale gas**

\[ N_H = 10^{21.7} \text{ cm}^{-2} \cdot M_9^{1/3} \]
Random orientation w.r.t. \( \text{blue} \) and \( \text{red} \)

**Accretion disk wind**

\[ N_H = 10^{22-24} \text{ cm}^{-2} \]
Presence: depends on \( L, M_{\text{BH}} \)
Covering: 50%

**Torus & BLR**

\[ N_H > 10^{23.5} \text{ cm}^{-2} \]
Presence: always
Covering: 35%

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

Eddington-rate limit relevant?
Gas supply available?

Campitiello+18, Marziani & Sulentic (2012)
Timely growth

Eddington-rate limit relevant? Gas supply available?

seeding mechanism? growth over time? co-evolution with galaxies?

Campitiello+18, Marziani & Sulentic (2012)
The origin of super-massive black holes

- **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 $\sim 10^{10}M_\odot$ halos

How often does the process need to succeed?

Becerra+15, Kuiper&Hosokawa+19  
Volonteri 2012, Rees 1978
Ansatz

- Halos are born and grow
- At some threshold mass $M_c$: chance $p$ for seeding success
- Can approximate physical seeding mechanisms

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

credit: M. Volonteri
see also Menou+01
Building blocks

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

$$N = \frac{1}{2} \left( \frac{M_{z=0}}{M_c} \right)^{3/4}$$

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
Occupation Observations

Gallo+10, Miller+15
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Occupation at $z=0$

Buchner et al. (in prep)
Required Seeding Efficiency

Buchner et al. (in prep)
Population Evolution

BH births

Lookback time [Gyr]

BH Seeding Rate [#/Mpc³/Gyr]

Redshift

0 1 2 3 4 5 6 7 8 9 10

10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1}

Total number

Lookback time [Gyr]

SMBH Space Density [number/Mpc³]

Redshift

0 1 2 3 4 5 6 7 8 9 10

10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1}

AGN, Buchner+15

QSO, Buchner+15
Population Evolution

BH births vs. BH host mergers

BH Seeding Rate [#/Mpc³/Gyr] vs. Redshift

BH Merger Rate [#/Mpc³/Gyr] vs. Redshift
SMBH merger delays

Dynamical friction, Light cone scattering, Viscous drag, Gravitational waves
$10^{4-8} M_\odot$

$z=0-13$

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

(talk by Sesana)
Summary: Model-independent seeding

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

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

- 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

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 $>10^{12.3}M_\odot$

- 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

Large diversity!
Large volume in z!

Poisson noise!
Understanding high-z quasars

LBG

LAE

Buchner et al. (in prep)
Understanding high-z quasars

**LBG**

20 QSO fields

**LAE**

10 QSO fields

\[ N(LBG < \theta) \]

\[ N(LAE < \theta) \]

- \( M_{min} = 12.30 \)
- \( M_{min} = 11.70 \)
- \( M_{min} = 11.30 \)