The first black holes and AGN

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High-redshift quasars and local MBHs

As massive as the largest MBHs today, but when the Universe was ~ Gyr old

POX 52, NGC 4395: stellar mass $4 \times 10^8 \, M_\odot$, $M_{\text{BH}} \sim 3 \times 10^5 \, M_\odot$

Galaxies without MBHs too

RGG18: $M_{\text{BH}} \sim 5 \times 10^4 \, M_\odot$
High-redshift quasars

Very bright quasars in SDSS, CFHQ, UKIDDS with $z>6$ (Willott et al., 2003; Fan et al., 2006; Jiang et al., 2009)

Detection of a $2 \times 10^9 M_{\text{sun}}$ BH at $z=7$ and a $10^{10} M_{\text{sun}}$ BH at $z=6.3$ (Mortlock et al., 2011, Wu et al. 2015)

Requirement:
- Need to grow at the Eddington limit for the whole time ($M_0 \sim 300 M_{\text{sun}}$) or 60% of the time ($M_0 \sim 10^5 M_{\text{sun}}$)
Eddington limit?

Gas infalls from the galaxy: how does the galaxy know that it has to feed the MBH exactly at the Eddington limit?

Super-Eddington accretion does not imply highly super-Eddington luminosity

Trapping of radiation: photons are advected inward with the gas, rather than diffuse out

Luminosity highly suppressed \[ L \propto \ln(M) \]

Only short periods needed to ease constraints (e.g. MV & Rees 2005; MV, Silk & Dubus 2015; Pacucci, MV et al. 2015a,b; Lupi et al. 2016)
High-redshift AGN

No detection in X-ray stacking of LBGs at $z>6$: $L_X < 10^{42}$ erg/s (Willott 2011; Fiore et al. 2012; Cowie et al. 2012; Treister et al. 2013)

Searches for point sources in deep X-ray fields has also led to inconclusive/conflicting results (Giallongo et al. 2015; Weigel et al. 2015; Cappelluti et al. 2015)
High-redshift MBHs

The billion solar masses MBHs powering the observed $z>6$ quasars are the tip of the iceberg.

Very biased, dense halos

What do we expect for *normal* MBHs in *normal* galaxies?
How do MBHs form?

- Metal Free
- Pop III remnants
- Stellar mergers in nuclear clusters
- BH mergers in nuclear clusters
- Dynamics-driven gas collapse
- Thermodynamics-driven gas collapse
- Inflationary black holes
- Cosmic string loops

$\log\left(\frac{Z}{Z_{\odot}}\right)$

$M_{\text{BH}}\left(M_{\odot}\right)$
A physical approach to seed cosmological simulations with MBHs

**Ramses:** Grid-based hydro solver with mesh refinement (Teyssier 2002)
- Cooling/Star formation (Rasera & Teyssier 2006)
- Supernova feedback (Dubois & Teyssier 2008, Teyssier et al. 2013, Dubois et al. 2015)
- BH accretion + AGN feedback (Dubois et al. 2012)

**MBH seeds (sink particles)** formed in:
- overdense bound collapsing regions
- metal-poor ($Z<10^{-3.5} Z_{\odot}$)
- initial mass of BH:
  - one by one
  - based on stellar IMF + stellar mergers
Density map
BHs form only in high gas-density regions

Metallicity map
BHs form in low-metallicity regions

(10 Mpc)$^3$ cosmo hydro simulation:
Spatial resolution 80 pc
DM resolution $2 \times 10^6$ $M_{\text{sun}}$

Habouzit, MV, Dubois 2016
How do galaxies feed *normal* MBHs?

Low-mass BHs in low-mass galaxies: fragile environment

Interplay between SN feedback and MBH accretion: SN feedback is sufficient to energize the gas and suppress accretion (Dubois+14)
SETH, Ramses Cosmological Zoom, ~5pc resolution, Dubois, MV+14
How do galaxies feed normal MBHs?

$z=0$ BHs and AGN (Reines & Volonteri 2015)

10 Mpc cosmological volume, ~80pc resolution

Habouzit, MV, Dubois 2016
How do galaxies feed normal MBHs?
Growing black holes in growing galaxies
Searches for AGN in galaxies with stellar masses $\sim 10^9 \, M_{\text{sun}}$ at $z > 6$ have found very few, if any, black holes.

(Willott 2011; Fiore et al. 2012; Cowie et al. 2012; Treister 2013; Giallongo et al. 2015; Weigel et al. 2015; Cappelluti et al. 2016)

Expect $M_{\text{BH}} \sim 10^6 \, M_{\text{sun}}$.
$M_{BH}$ vs galaxy at high redshift

BH mass vs. total galaxy stellar mass

(341 nearby galaxies)

Reines & MV 2015
$M_{BH}$ vs galaxy at high redshift

$M_{BH} \sim 10^{-3} M_{gal}$

$M_{BH} \sim 10^{-4} M_{gal}$

Reines & MV 2015
$M_{BH}$ vs galaxy at high redshift

stellar mass $\sim 10^9$ $M_{\text{sun}}$

- $M_{BH} \sim 10^{-3}$ $M_{\text{gal}}$
- $M_{BH} \sim 10^6$ $M_{\text{sun}}$

- $M_{BH} \sim 10^{-4}$ $M_{\text{gal}}$
- $M_{BH} \sim 10^5$ $M_{\text{sun}}$

AGN expected to be less luminous

Expect 0-3 AGN with $L_X > 10^{42}$ erg/s in the 4Ms CDFS

Consistent with current limits/candidates

MV & Reines 2016
High-redshift MBHs

Current limits/candidates high-z AGN compatible with a population of MBHs similar to low-z counterpart in galaxies of similar mass

How about the high-z quasars?
Current large-shallow surveys select only the most luminous quasars, $L_{\text{bol}} > 10^{46}$ erg/s $\Rightarrow$ the most massive holes at a given stellar mass.

$L_{\text{bol}} > 46$

$L_{\text{bol}}$ is the bolometric luminosity, which includes all wavelengths of electromagnetic radiation.
Growing black holes in growing galaxies
Growing black holes in growing galaxies: contribution to reionization

Galaxies form stars and emit ionizing photons

MBHs accrete and emit ionizing photons

Relative Role of Stars and Quasars in Cosmic Reionization

MBHs predicted to contribute 20-50% of ionizing photons (MV & Gnedin 2009)
Growing black holes in growing galaxies: contribution to reionization

MV & Gnedin 2009
High-redshift MBHs

“Ab-normal” MBHs in “normal” galaxies are those that grow fast and can be detected as luminous quasars.

“Normal” MBHs in “normal” galaxies may grow slowly.

Current limits/candidates high-z AGN compatible with a population of MBHs similar to low-z counterpart in galaxies of similar mass.

Relative role of stars and MBHs in cosmic reionization.