Black hole formation and early growth

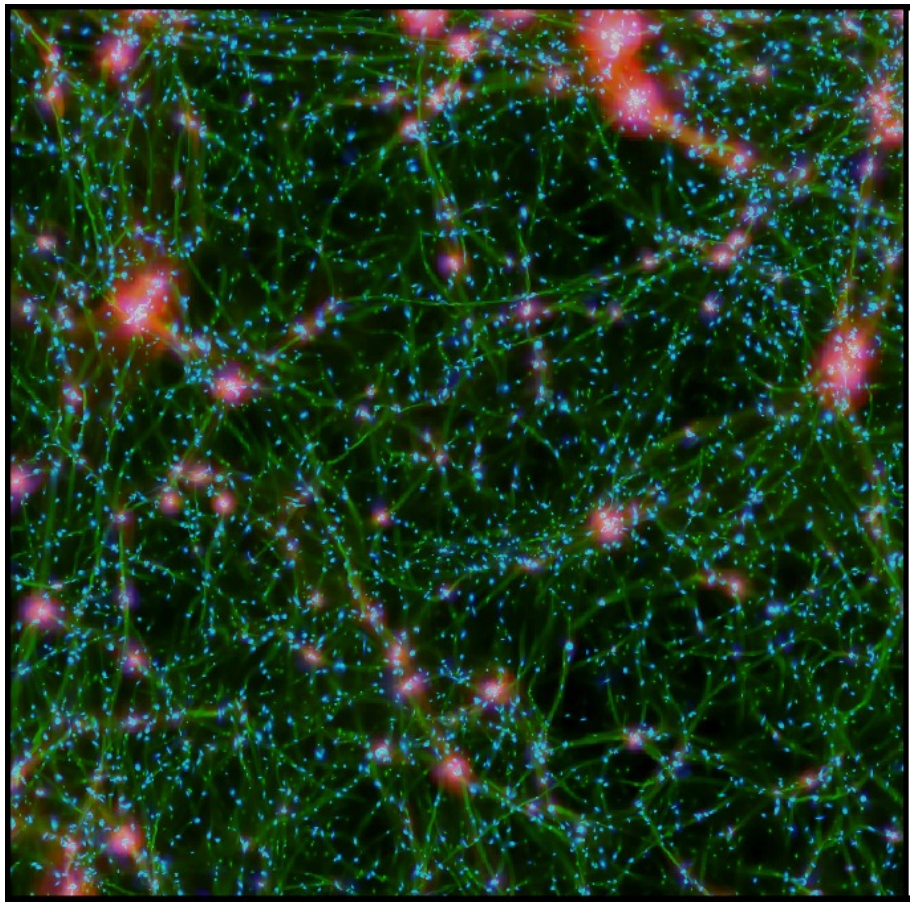
M. Habouzit

Marta Volonteri, Y. Dubois

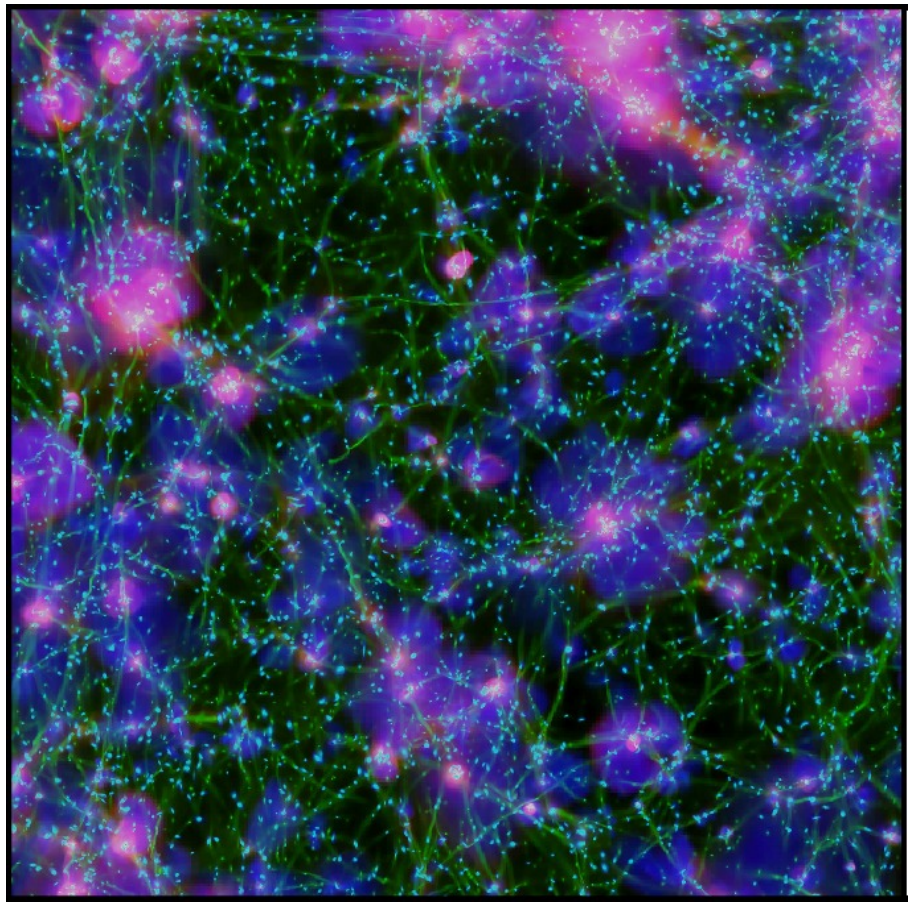
Christophe Pichon, Julien Devriendt

Quasars in large-volume simulations

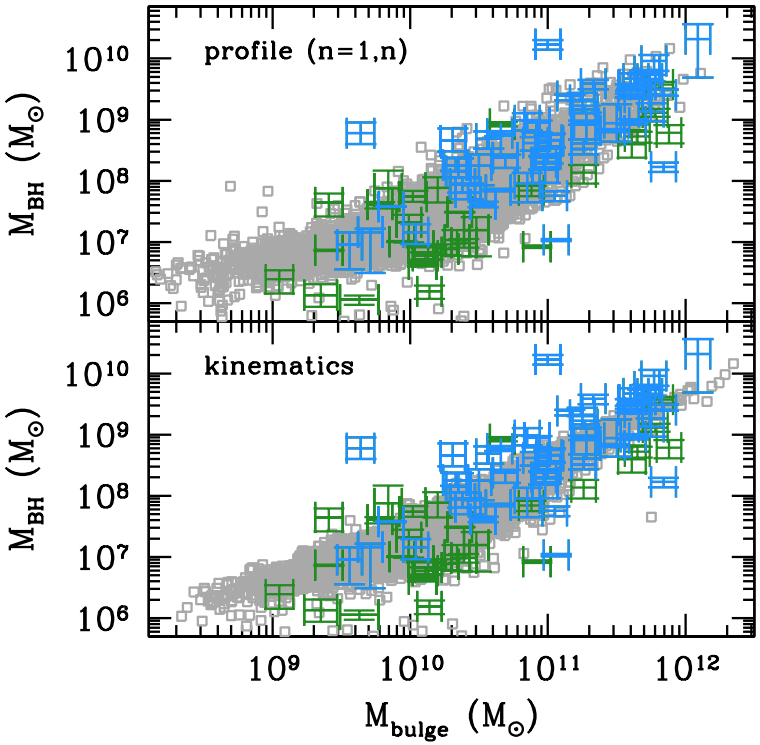
Horizon-noAGN

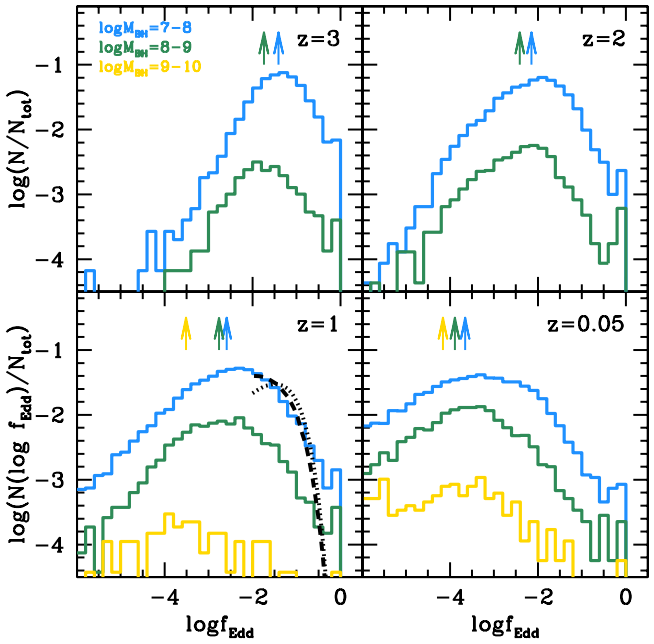


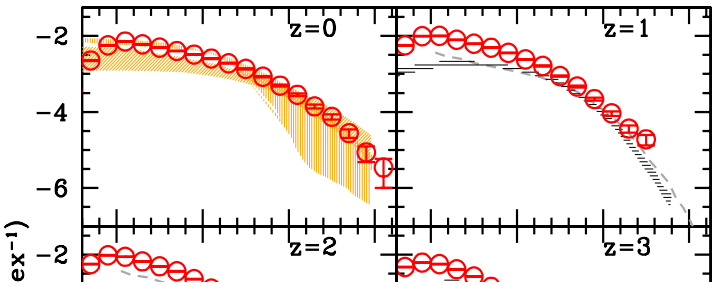
Horizon-AGN

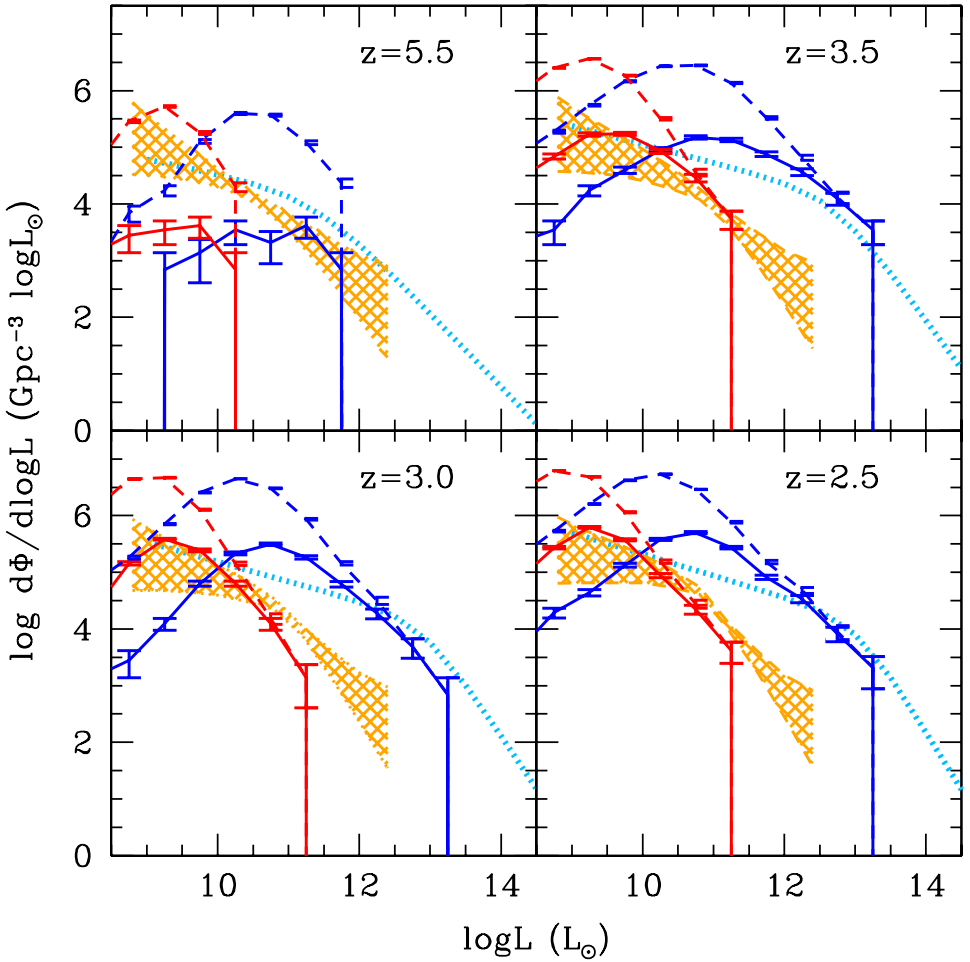


Horizon-AGN (Dubois+14): L_{box}=140 Mpc, 7x10^9 gas cells, dx~1 kpc, AMR (Ramses)
Green: gas density / Red: temperature / Blue: metallicity









MV, Dubois, Pichon, Devriendt 16

High-redshift AGN

Known powerful quasars at $z>6$, $L_{bol}>10^{46}$ erg/s

Searches for faint AGN, 10^{42}-10^{44} erg/s, in deep X-ray fields has led to inconclusive/conflicting results (Willott 2011; Fiore et al. 2012; Cowie et al. 2012; Treister et al. 2013, Giallongo et al. 2015; Weigel et al. 2015; Cappelluti et al. 2015; Vito et al. 2016)

A physical approach to seed cosmological simulations with MBHs

Ramses: - 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)

SuperChunky
Box size 10 cMpc
Dark matter resolution 1.65 x 10^6 $M_\odot$
Spatial resolution 76 pc
Redshift 100 2
3 SN feedback simulations

Habouzit, MV, Dubois 2016

Thermal SN feedback

releases only internal energy

Dubois & Teyssier (2008)

Kinetic SN feedback

reproduces a Sedov blast wave

Dubois & Teyssier (2008)

WEAK SN FEEDBACK

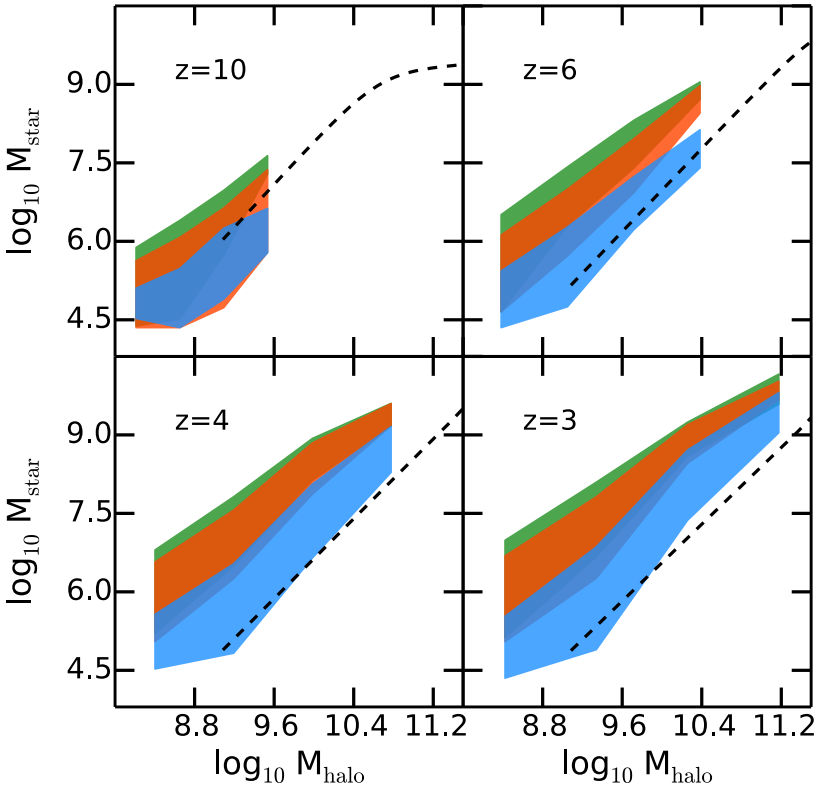
Delayed cooling SN feedback

Prevents cooling after a SN explosion

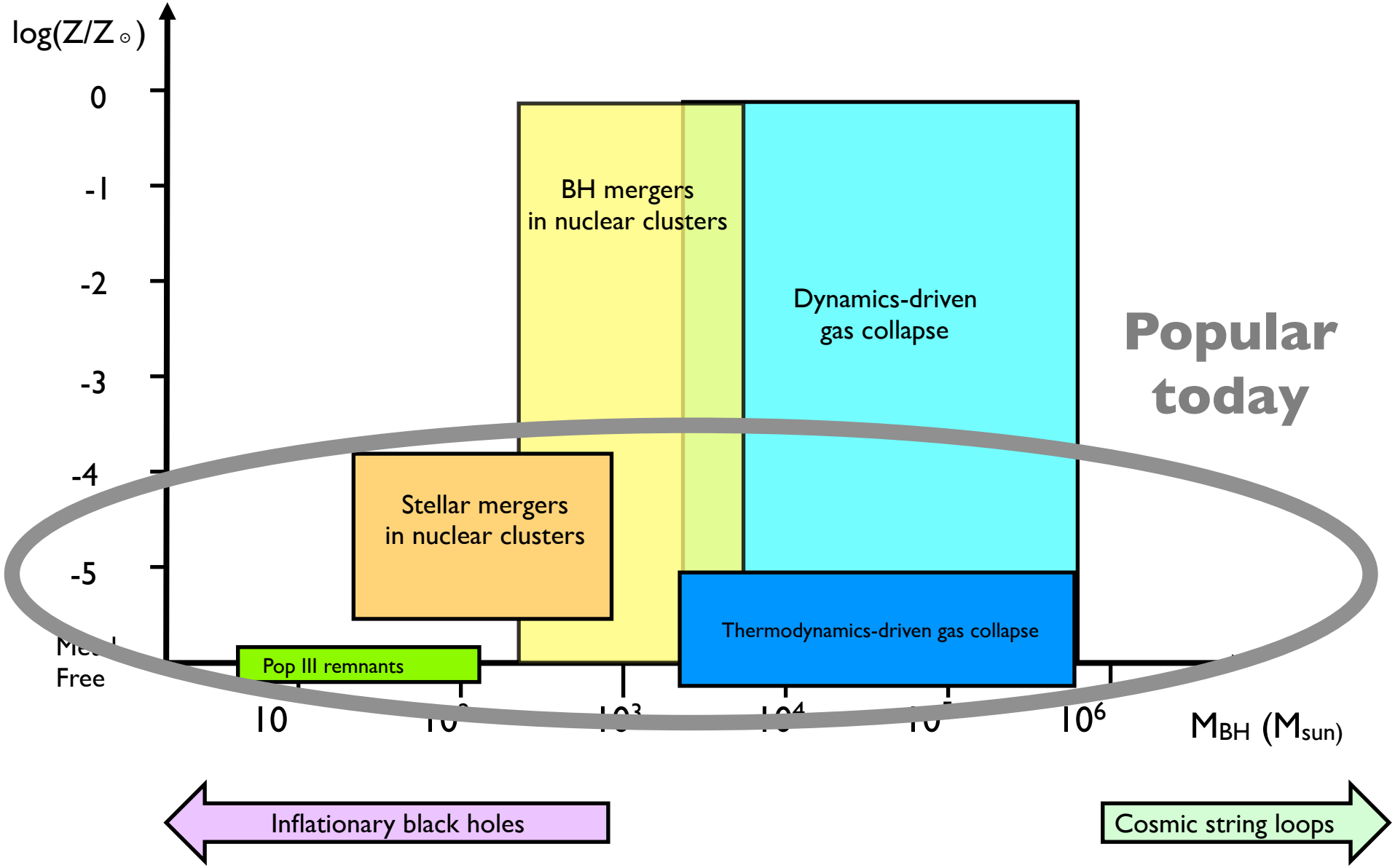
Teyssier et al. (2013)

Dubois et al. (2015)

STRONG SN FEEDBACK

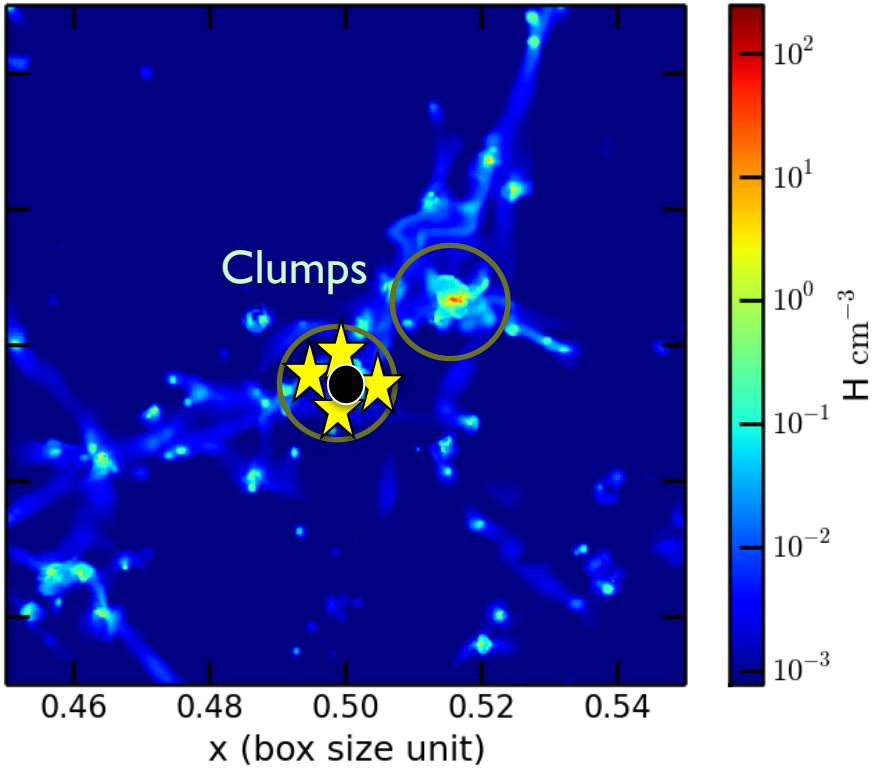


How do MBHs form?



MBH seeds (sink particles) formed in:

- overdense bound collapsing regions
- metal-poor ($Z<10^{-3.5}\,Z_{sun}$)
- initial mass of BH:
  - one by one
  - based on stellar IMF + stellar mergers



→ Clump identification
Bleuler & Teyssier 2014

→ Stellar mass

→ Formation of BH sink particle

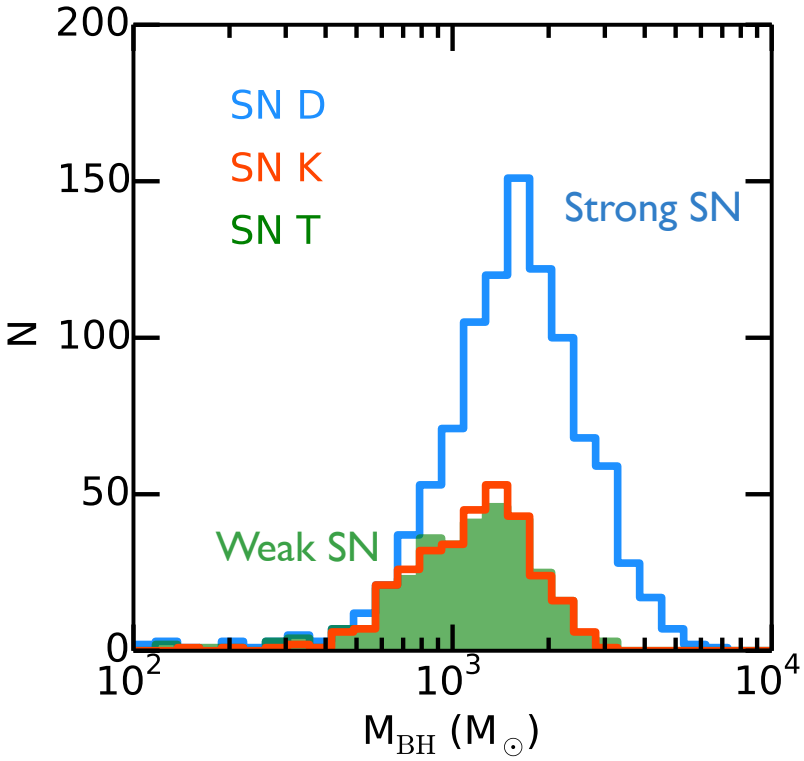
Habouzit, MV, Dubois 2016

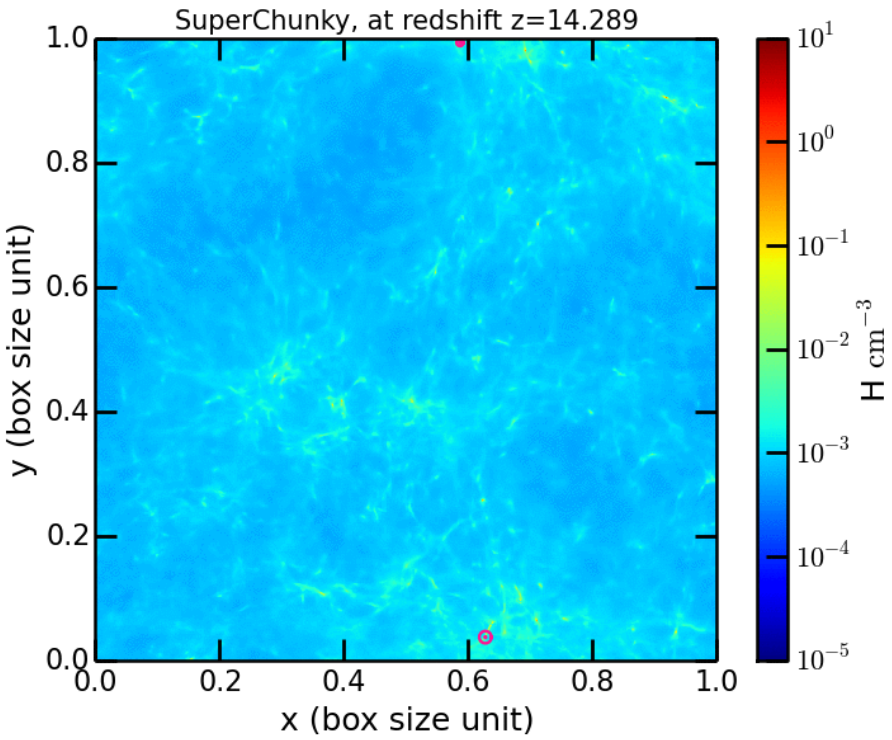
- BH initial mass:
  - Computed one by one on-the-fly
  - With a logarithmically flat IMF, stellar mass in [1, 500 $M_\odot$]

$$M_{BH} = f_{BH} \times \epsilon_{BH} \times M_\star$$

Mass fraction of >260 $M_\odot$ Pop III stars, by integration the IMF in mass in the range [260, 500 $M_\odot$]

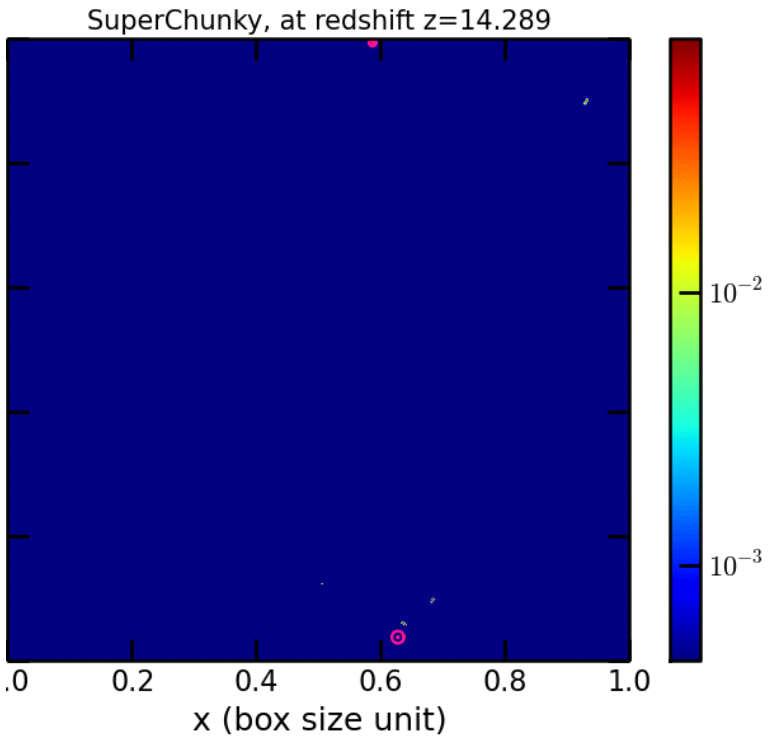
Fraction of stellar mass retained by the BH





Density map

BHs form only in high gas-density regions



Metallicity map

BHs form in low-metallicity regions

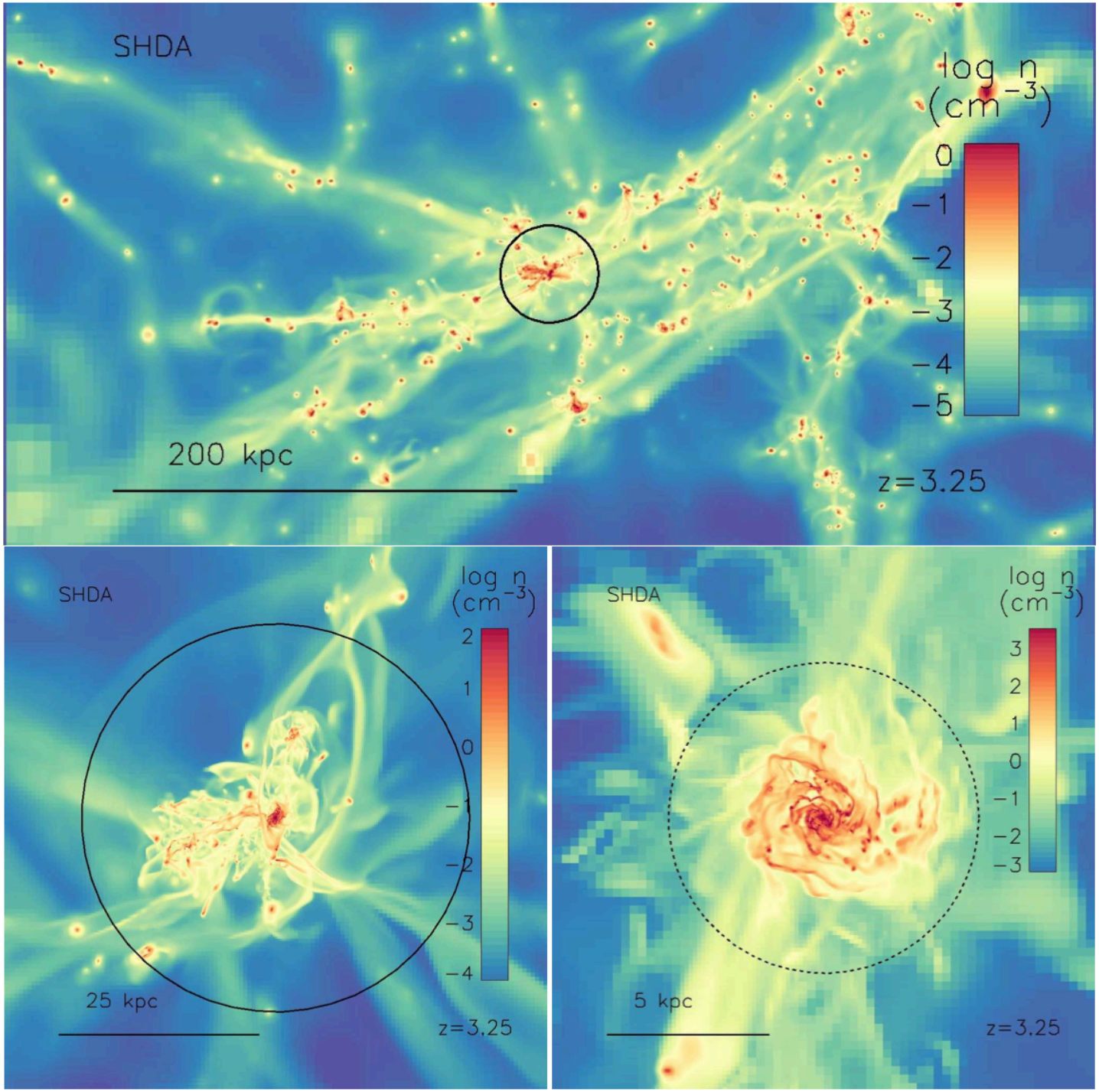
Habouzit, MV, Dubois 2016

How do galaxies feed *normal* MBHs?

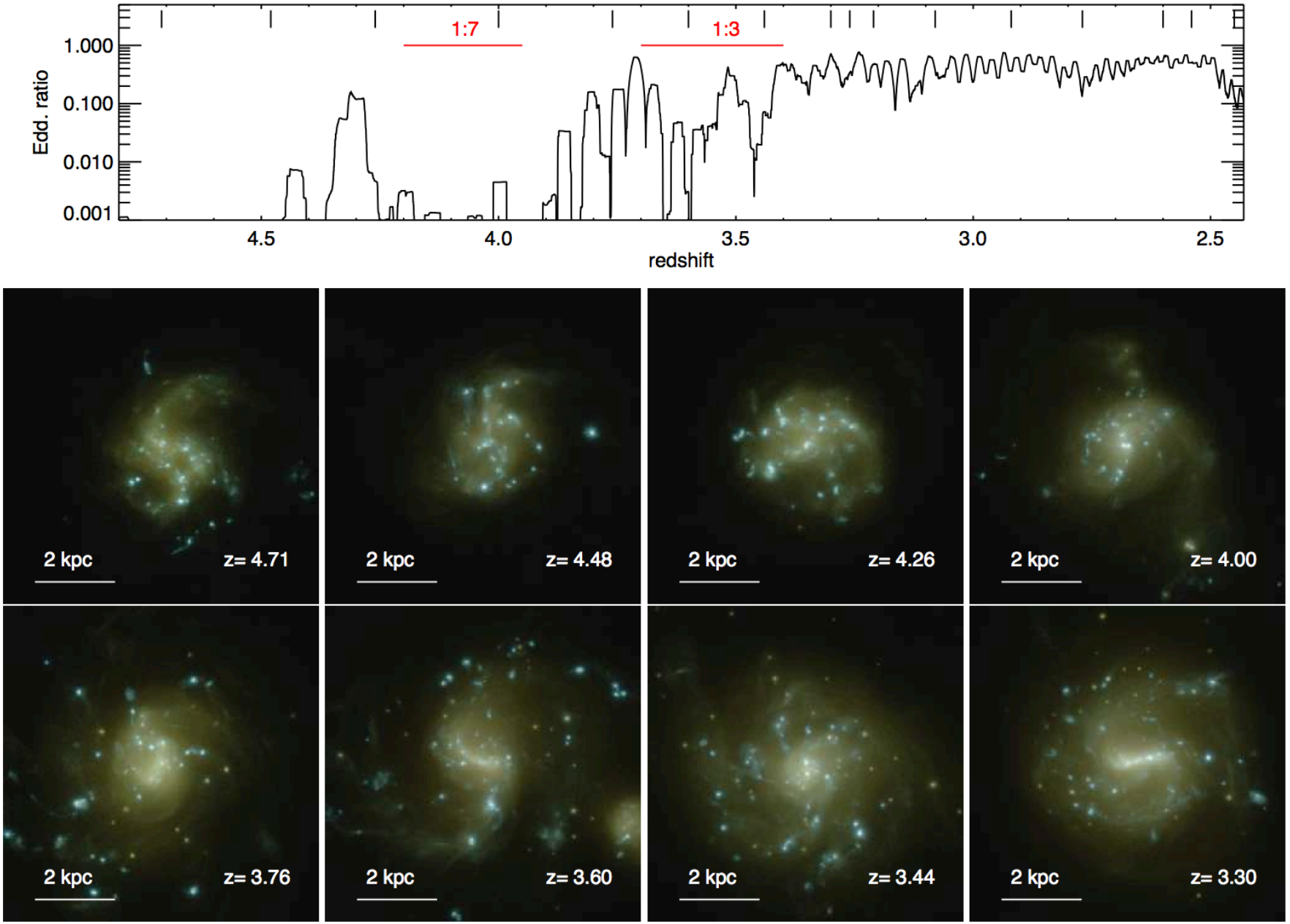
Low-mass BHs in low-mass galaxies: fragile environment

Interplay between SN feedback and MBH accretion: SN feedback is sufficient to energize the gas and suppress accretion (Dubois+14)

How do galaxies feed *normal* MBHs?



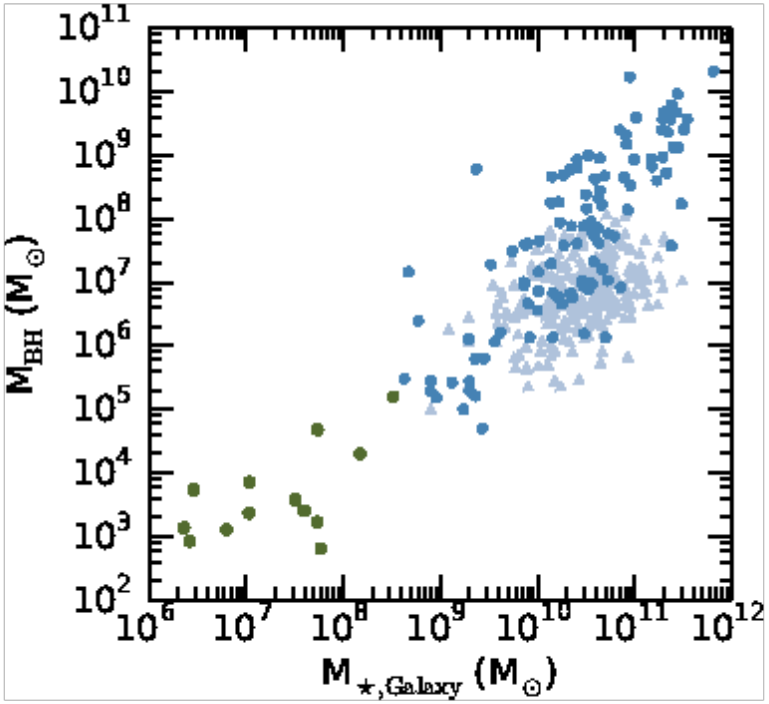
SETH
Ramses
Cosmological Zoom
~5pc resolution
Dubois+14



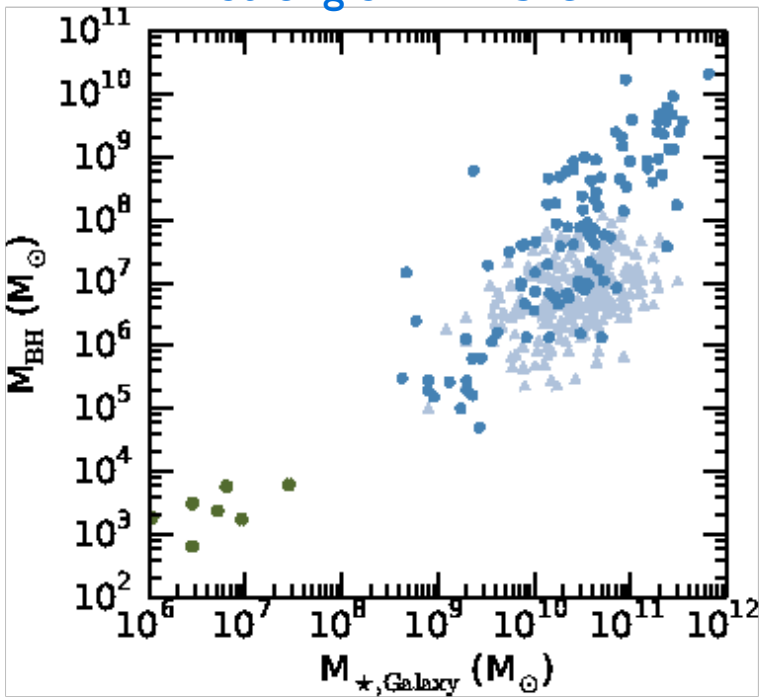
SETH, Ramses Cosmological Zoom, ~5pc resolution, Dubois, MV+15

How do galaxies feed MBHs?

Weak SN feedback



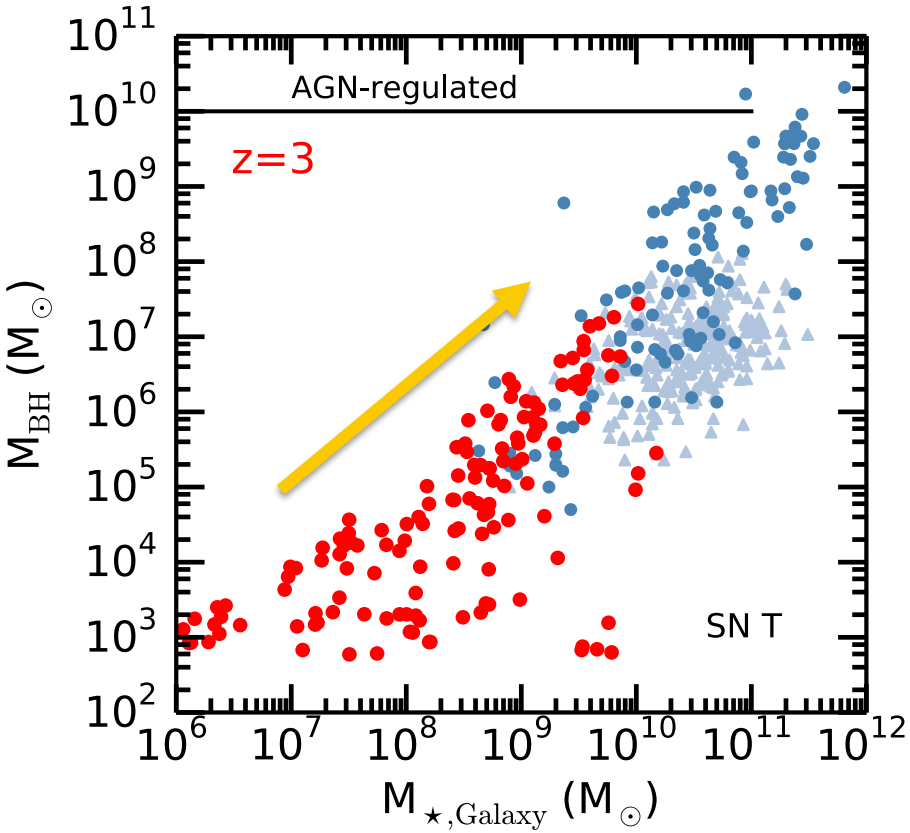
Strong SN feedback



Observational sample of
local galaxies with z<0.055

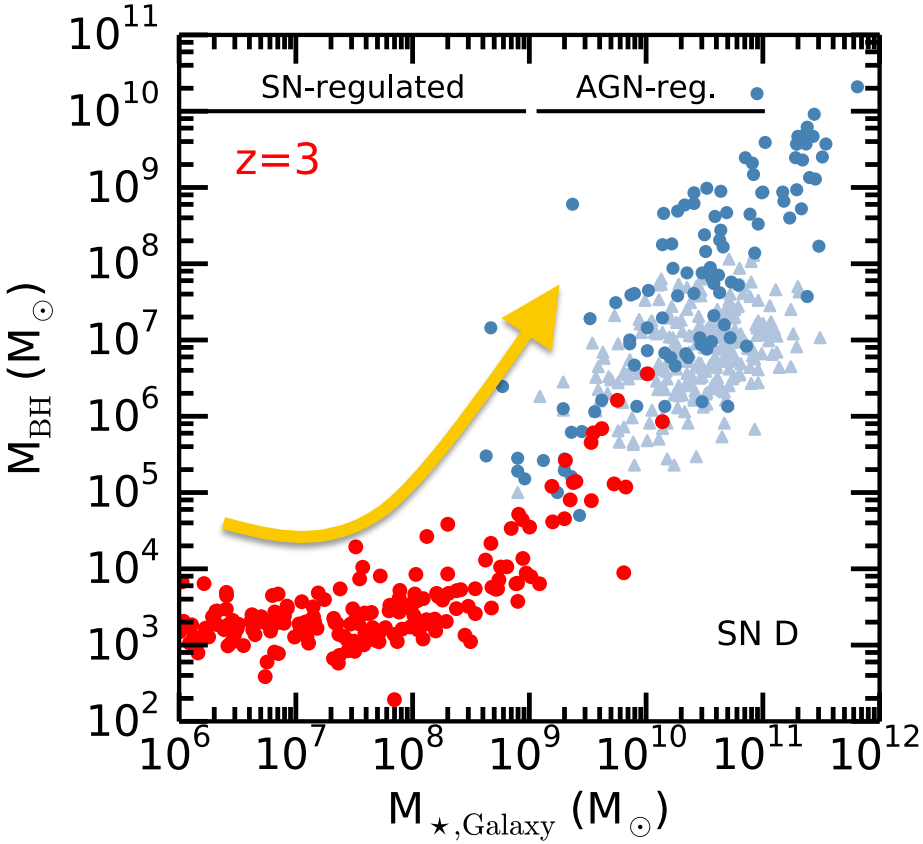
Reines & Volonteri 2015

Weak SN feedback

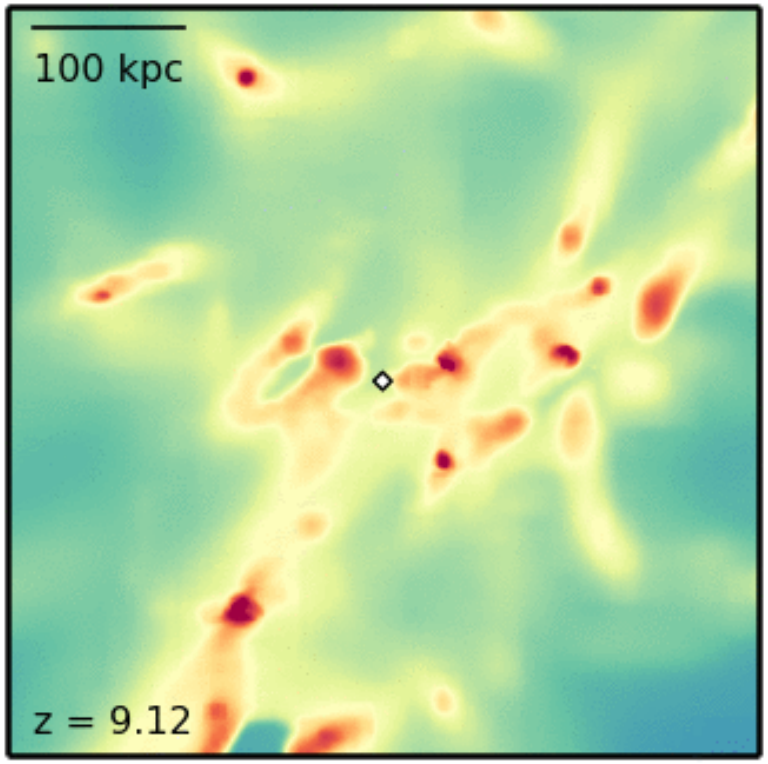


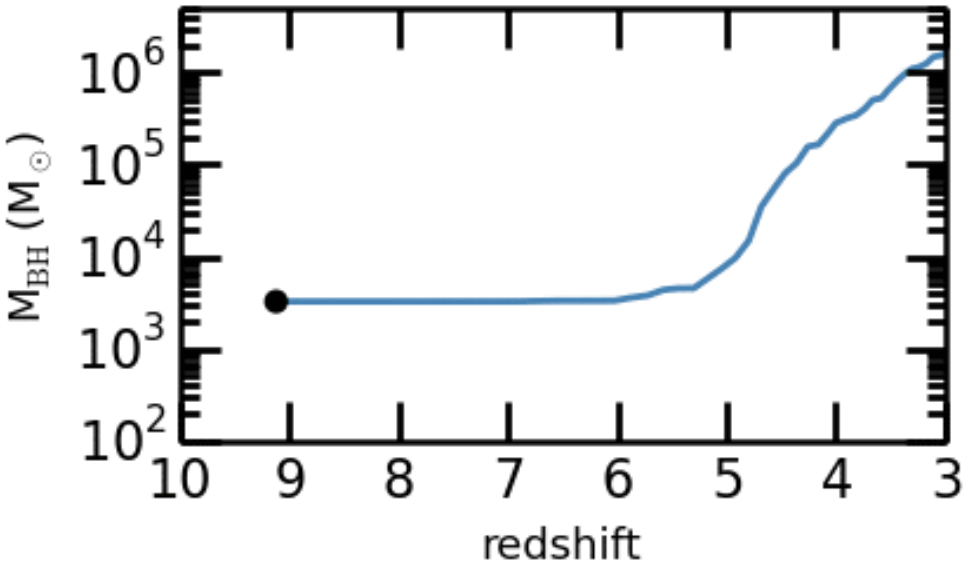
- Linear co-evolution between BHs and their host galaxies
- BH growth is regulated by AGN feedback

Strong SN feedback

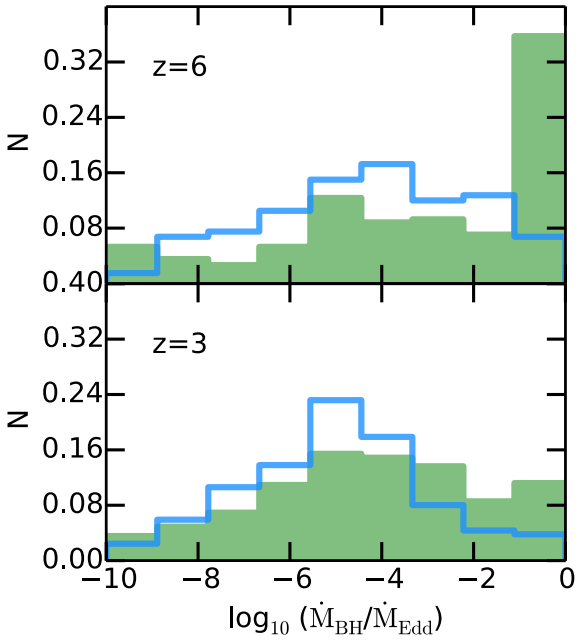


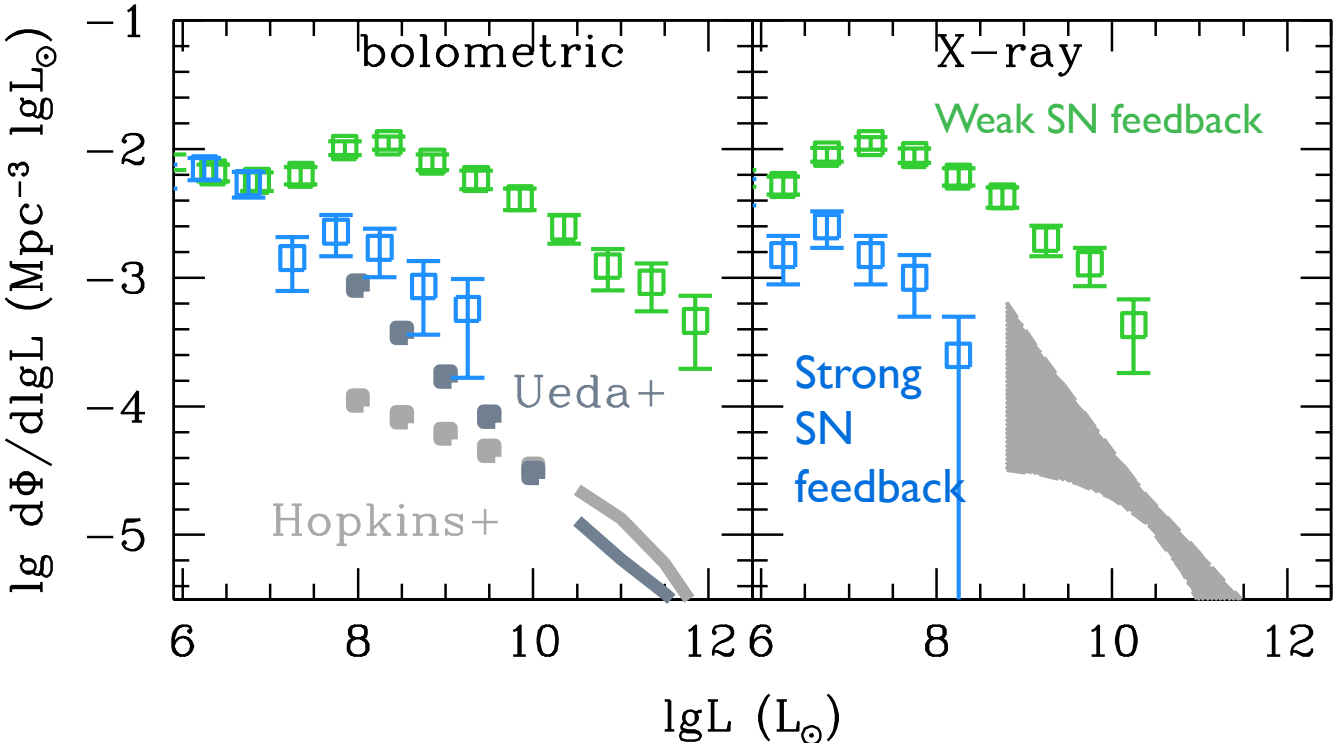
- Non linear co-evolution between BHs and their host galaxies
- BH growth is first regulated by SN feedback, and then by AGN feedback





BH accretion rate





→ 0-3 AGN candidates in CDF-S at z>6 *Giallongo et al. 2015, Weigel et al. 2015, Vito et al. 2016*

Estimate the number of AGN in the equivalent volume of the CSF-S in SuperChunky

- Weak SN feedback: several tens or hundreds
- Strong SN feedback: 3-5 AGN, in better agreement with the observations

Black hole formation and early growth

- Implementation of BH formation in Ramses
- Stronger SN feedback produces galaxies with stellar masses closer to those predicted by the relation with halo mass.
- SN feedback stunts BH accretion in galaxies with $M_* < 10^9\ M_{\odot,}$ as well as star formation.
- Good agreement with the BH luminosity function, and with the lack of AGN detections in high-z galaxies.