AGN feedback and BH growth in high-redshift galaxies

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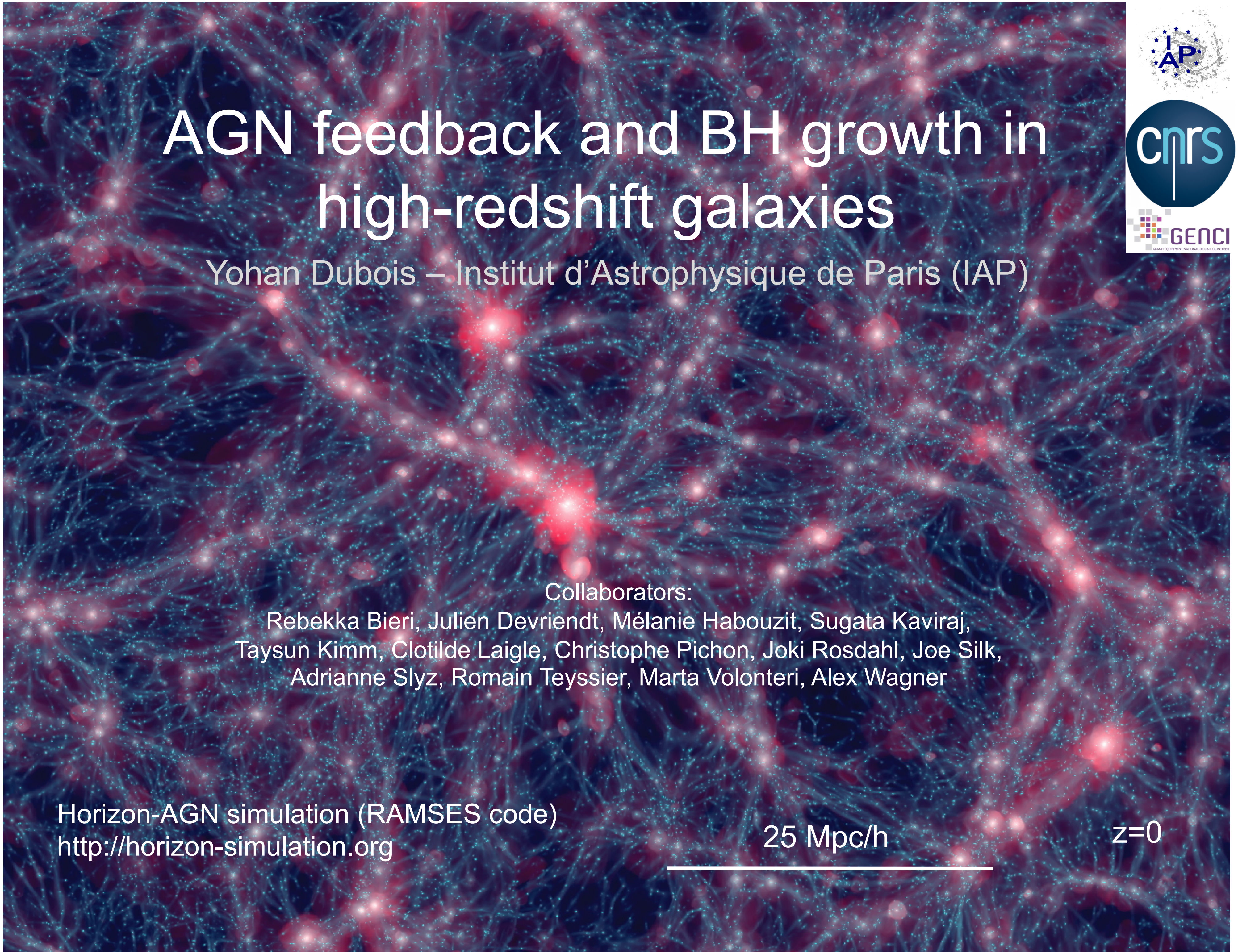
Adrianne Slyz, Romain Teyssier, Marta Volonteri, Alex Wagner



Horizon-AGN simulation (RAMSES code)
http://horizon-simulation.org

Take Home Message

- BH growth hindered by SN feedback in low-mass galaxies $M_{*}<10^{9}\ M_{sun}$

- Radiative AGN can drive massive outflows

Growing the first bright quasars

Observationnal facts:

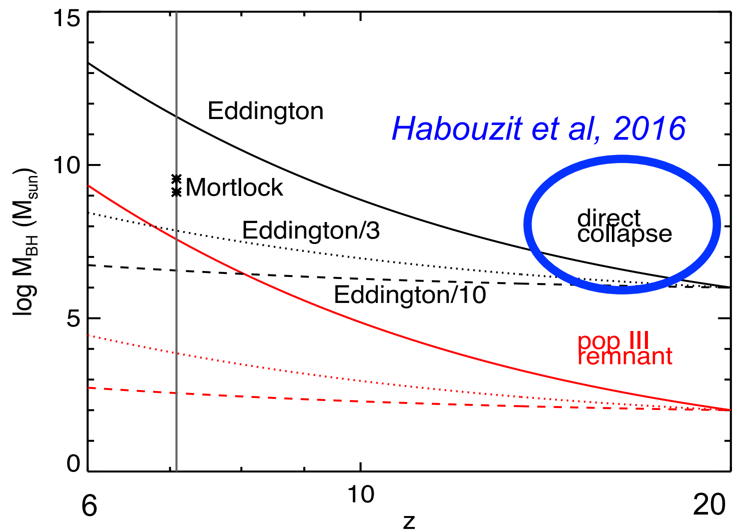
- Very bright quasars in the SDSS with z>6
(Willott et al., 2003; Fan et al., 2006; Jiang et al., 2009)
- Detection of a 2.10^9 M_{sun} BH at z=7
(Mortlock et al., 2011)

Requirement:

- Need to grow from 10^5-10^6 M_{sun} up to 10^9 M_{sun} in less than 700 Myrs! Eddington limit provides an e-folding time = 45 Myr

Question:

- How to bring gas sufficiently rapidly into the bulge of the galaxy?

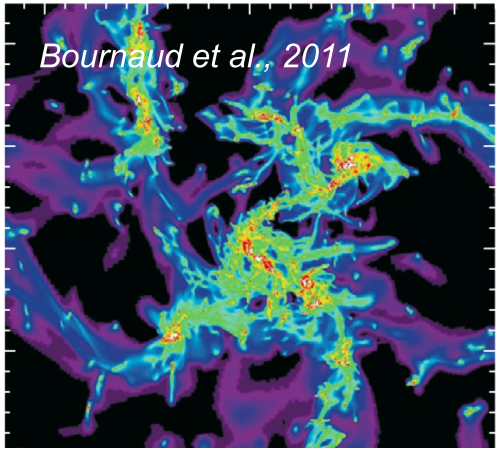


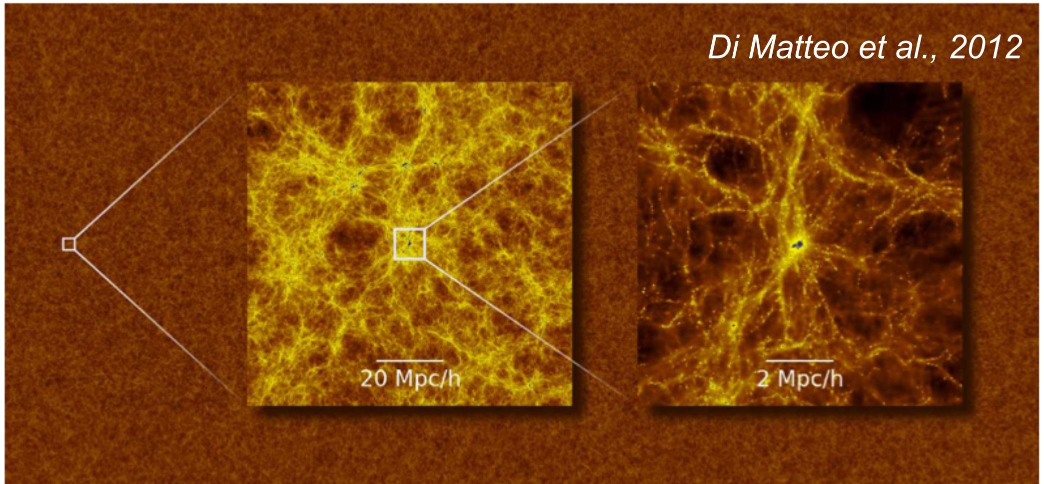
Growing the first bright quasars

- Direct accretion from the cosmic cold flows *(Di Matteo et al., 2012)*
Cosmological context with large statistics but low resolution (~1kpc)

Versus

- Violent disc instabilities
(Bournaud et al., 2011)
High resolution (1pc) but isolated disc





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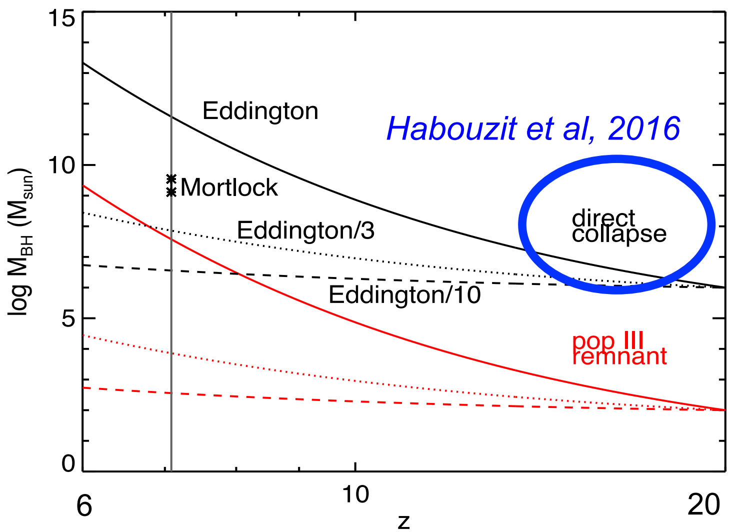

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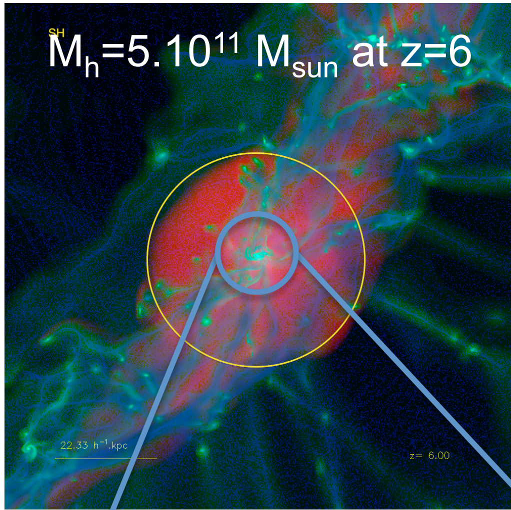
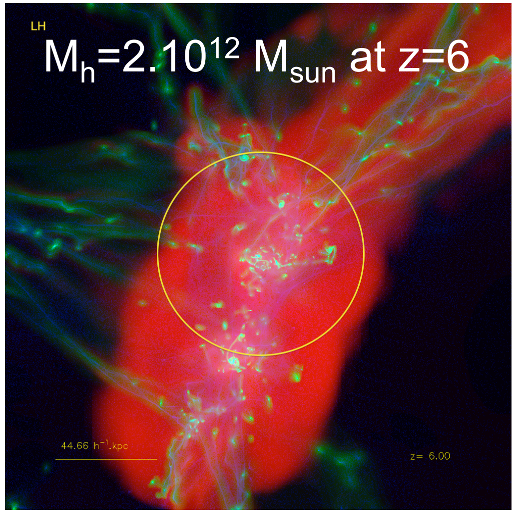
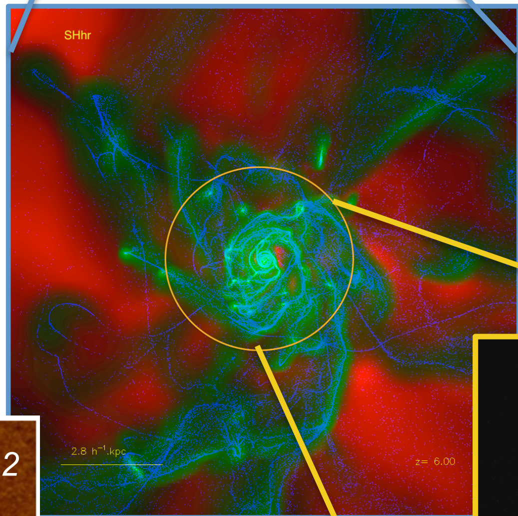
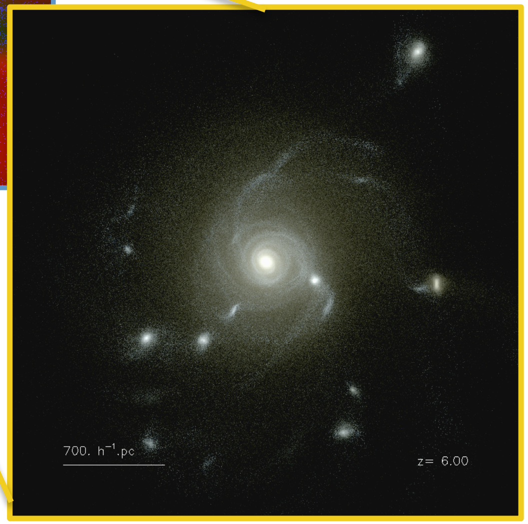


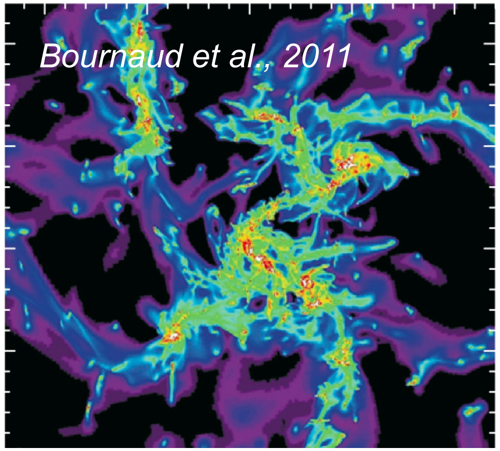


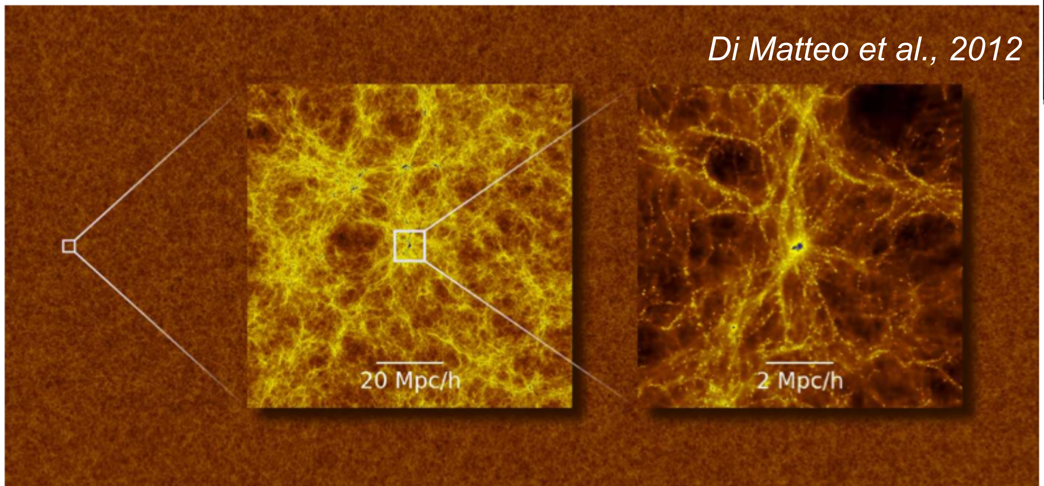


Cosmological zooms
10 pc resolution

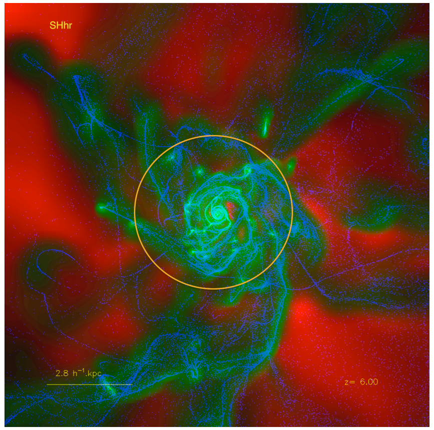
Dubois, Pichon, Haehnelt et al., 2012



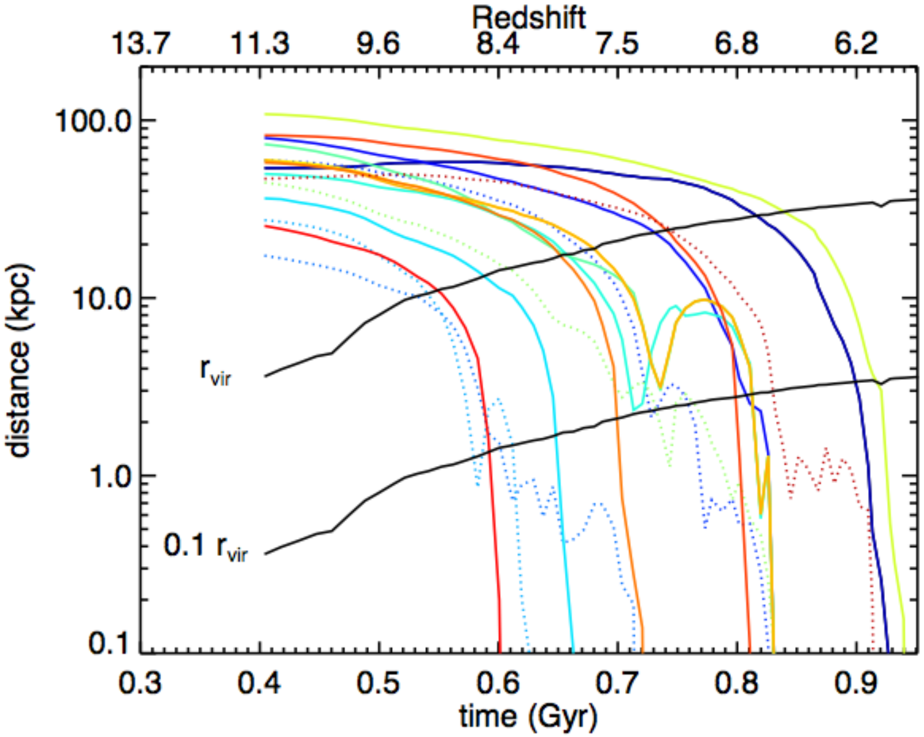


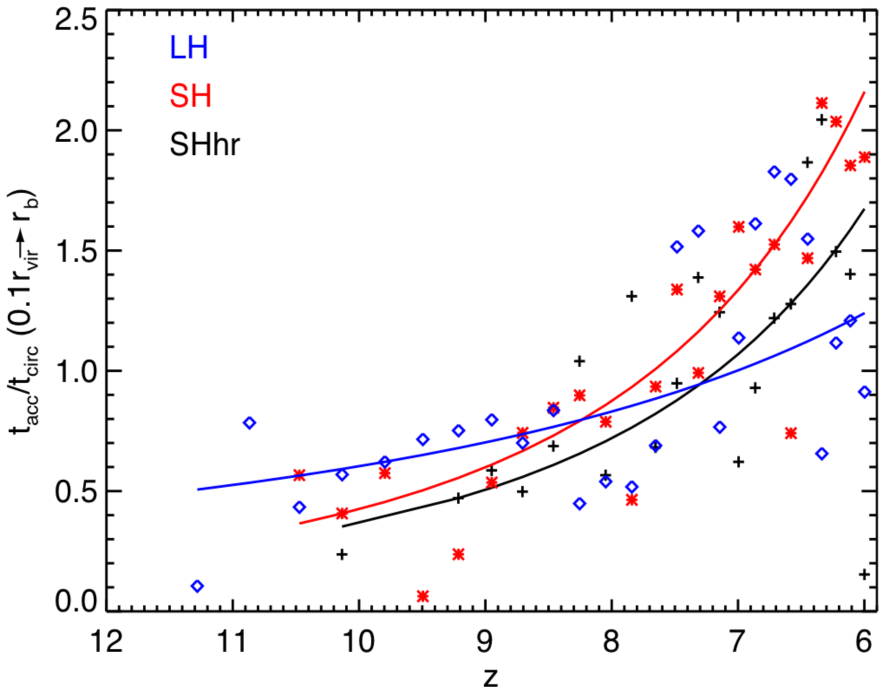


Follow the white rabbit



Take the gas tracer particles that belong to the galactic bulge

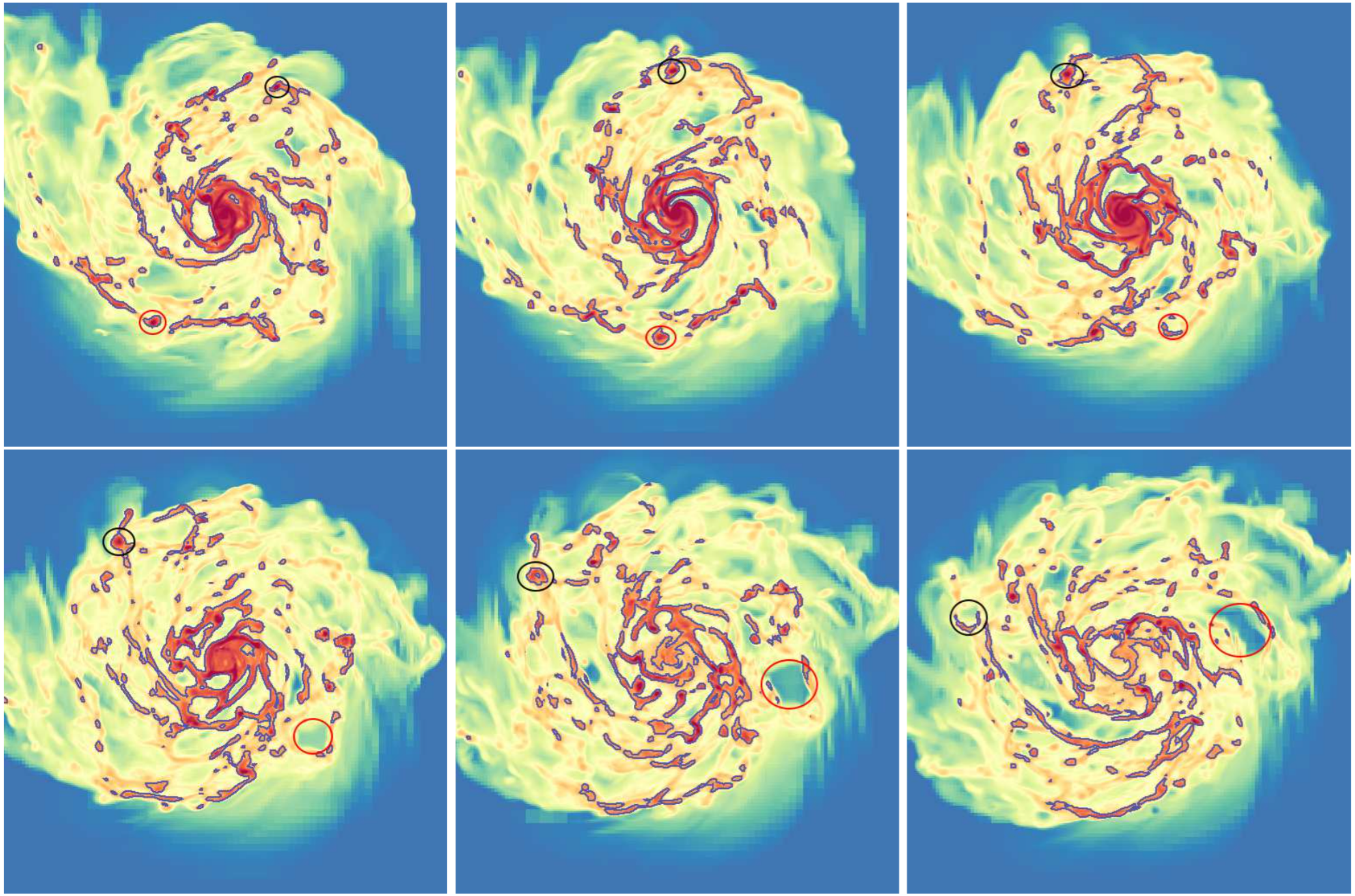




Dubois, Pichon, Haehnelt et al., 2012

Late time gas infall do more rotations before being accreted.
Compatible with late-time cosmic filamentary infall having more angular momentum (Pichon et al., 2011, Kimm et al., arXiv:1106.0538, Codis et al., 2012)

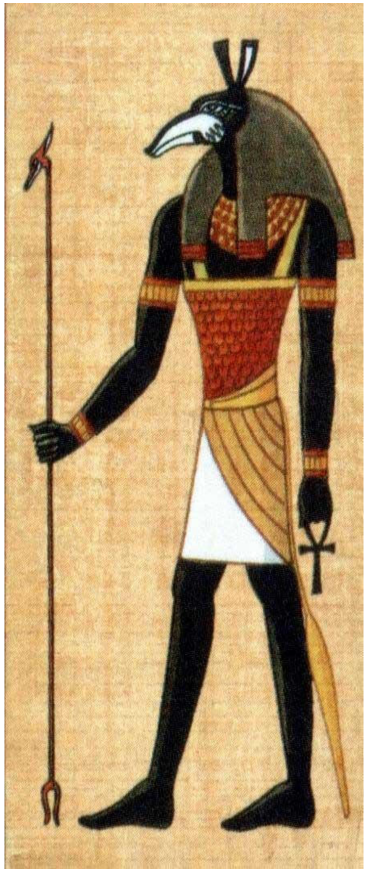
Does the SF clump destruction have any impact on BH growth?



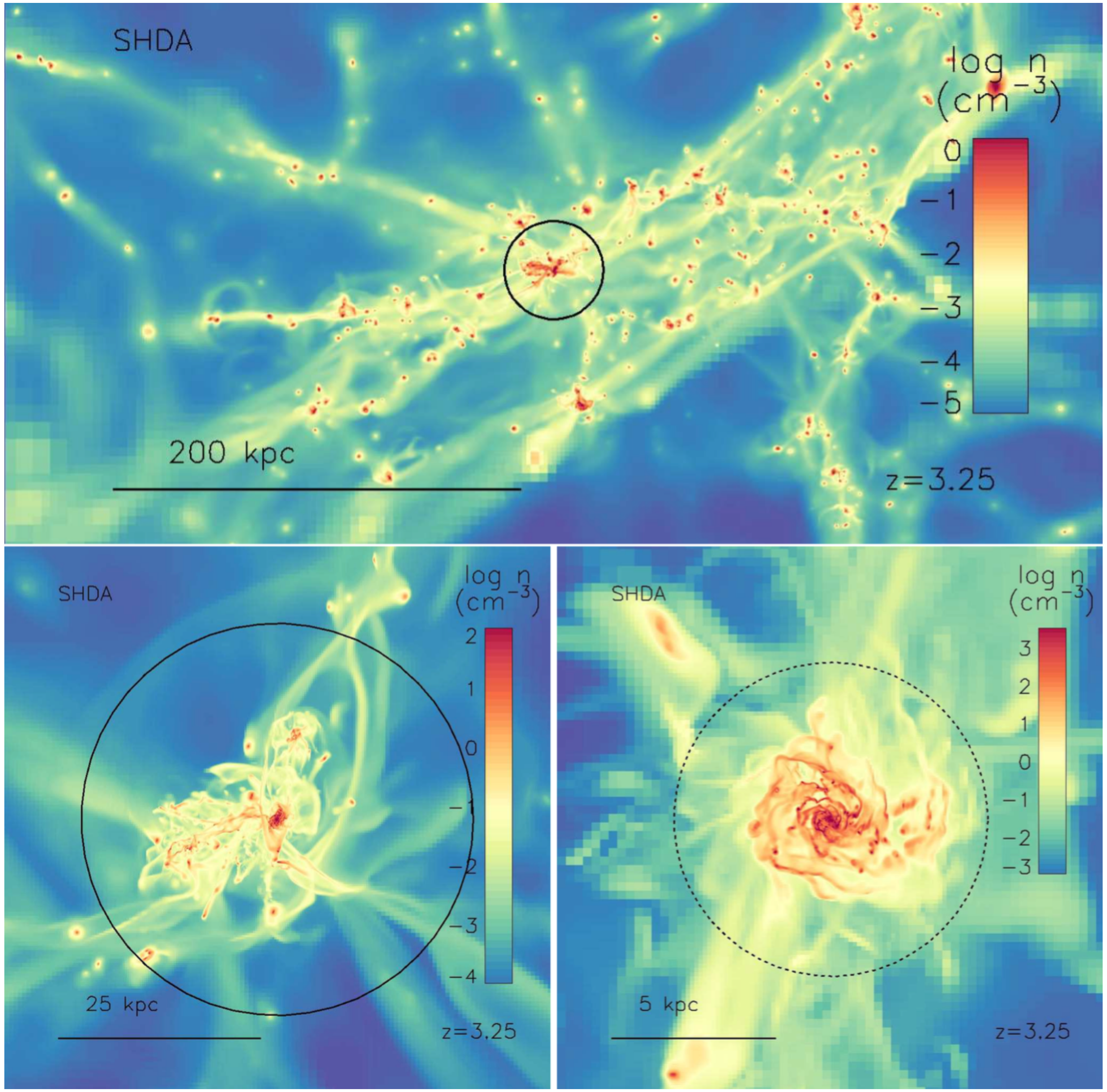
Dubois, Volonteri, Silk et al., 2014

Seth simulation

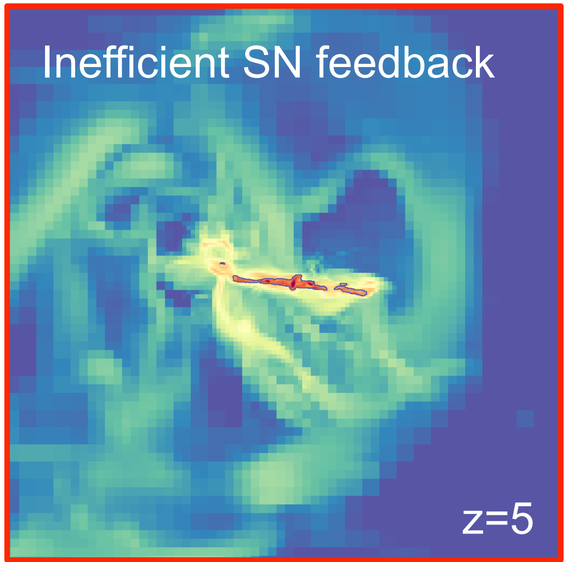
$M_h = 10^{12}\ M_{sun}$ @ $z=2$
$M_{DM,res} = 10^5\ M_{sun}$
$dx = 10$ pc

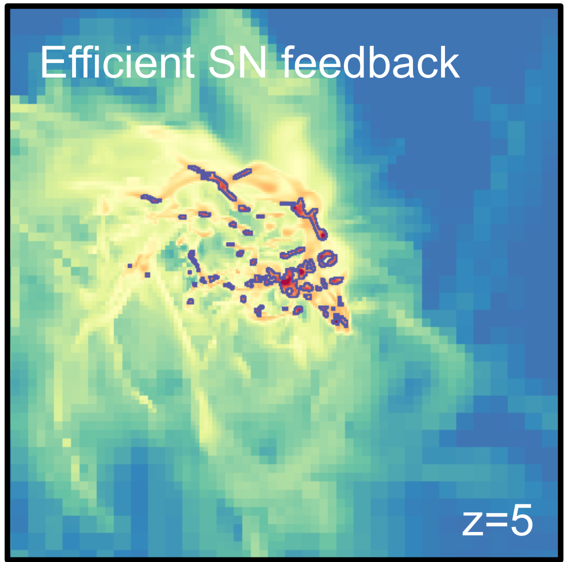


God of death, conflict, storms



BH growth delayed by efficient SN feedback





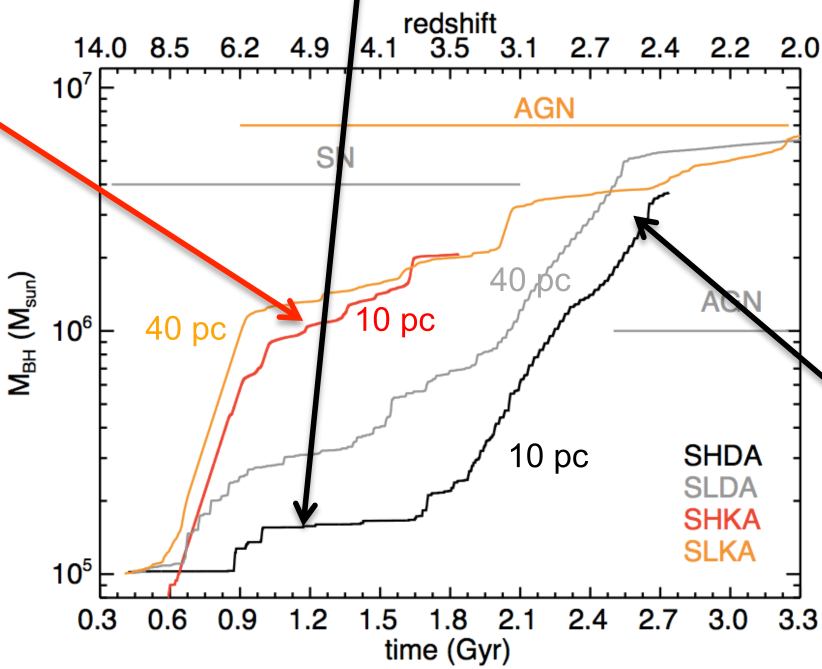
Bondi-capped-at-Eddington accretion rate
- AGN quasar heating $f_{Edd}>0.01$
- AGN radio jets $f_{Edd}<0.01$

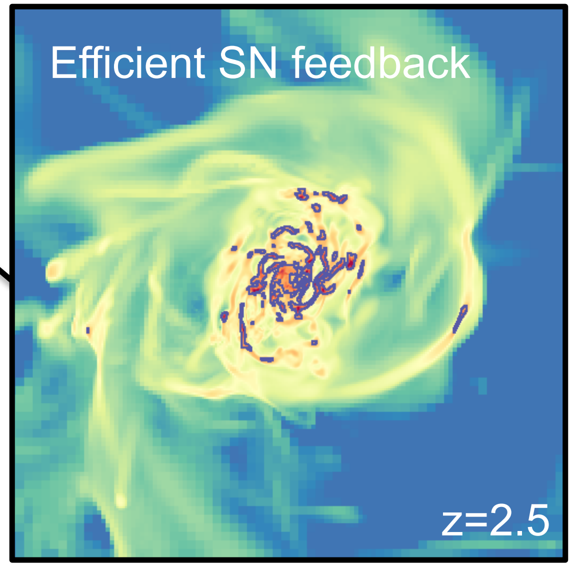
(Dubois et al, 2012)

& BH spin evolution with spin-dependent radiative efficiency (and Eddington accretion rate)
(Dubois et al, 2014)

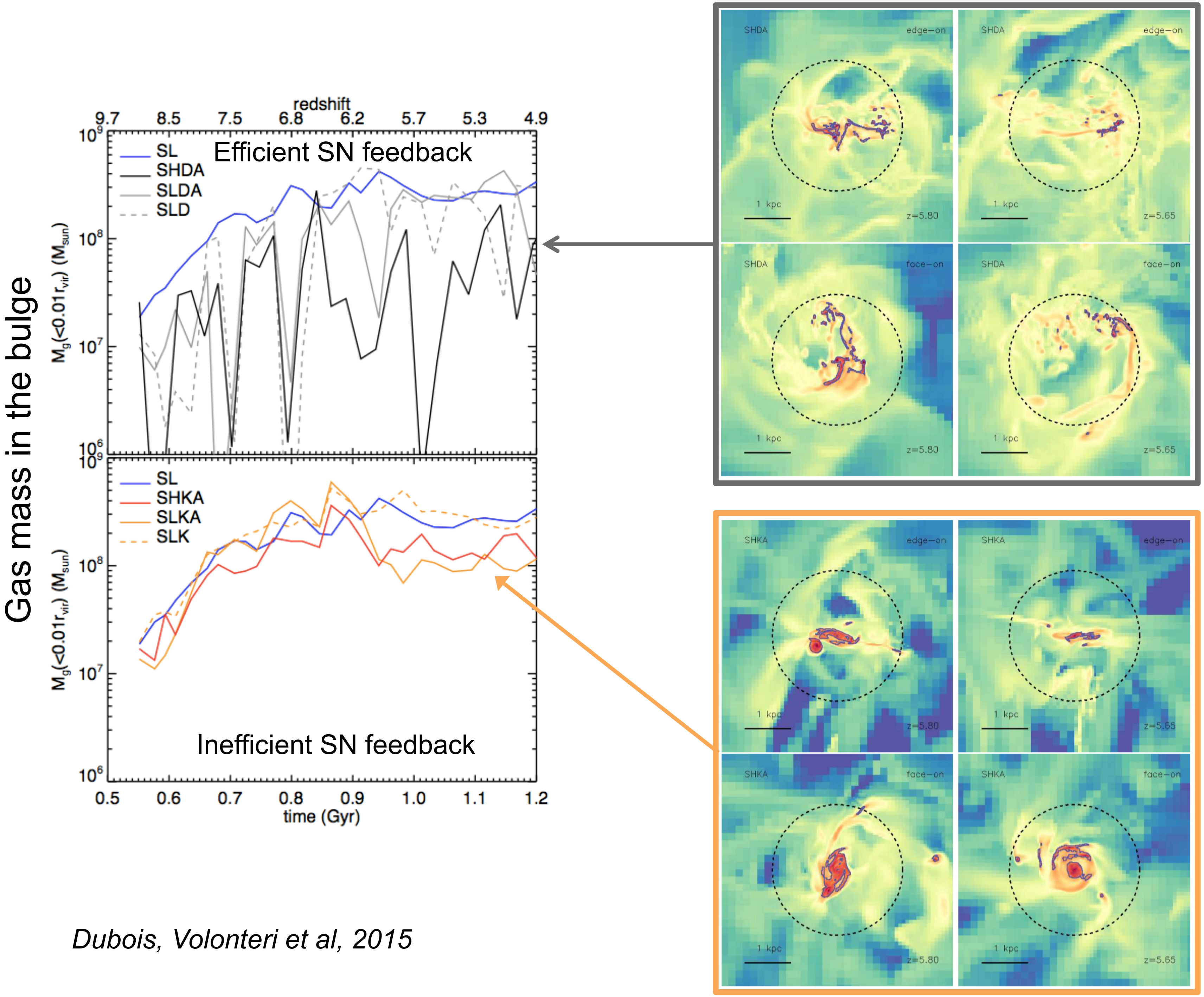
"Inefficient": kinetic blast wave model
(Dubois & Teyssier, 2008)

"Efficient": non-thermal component (CR, turbulence, magnetic fields) that delays gas cooling
(Teyssier, Pontzen, YD, Read, 2013)



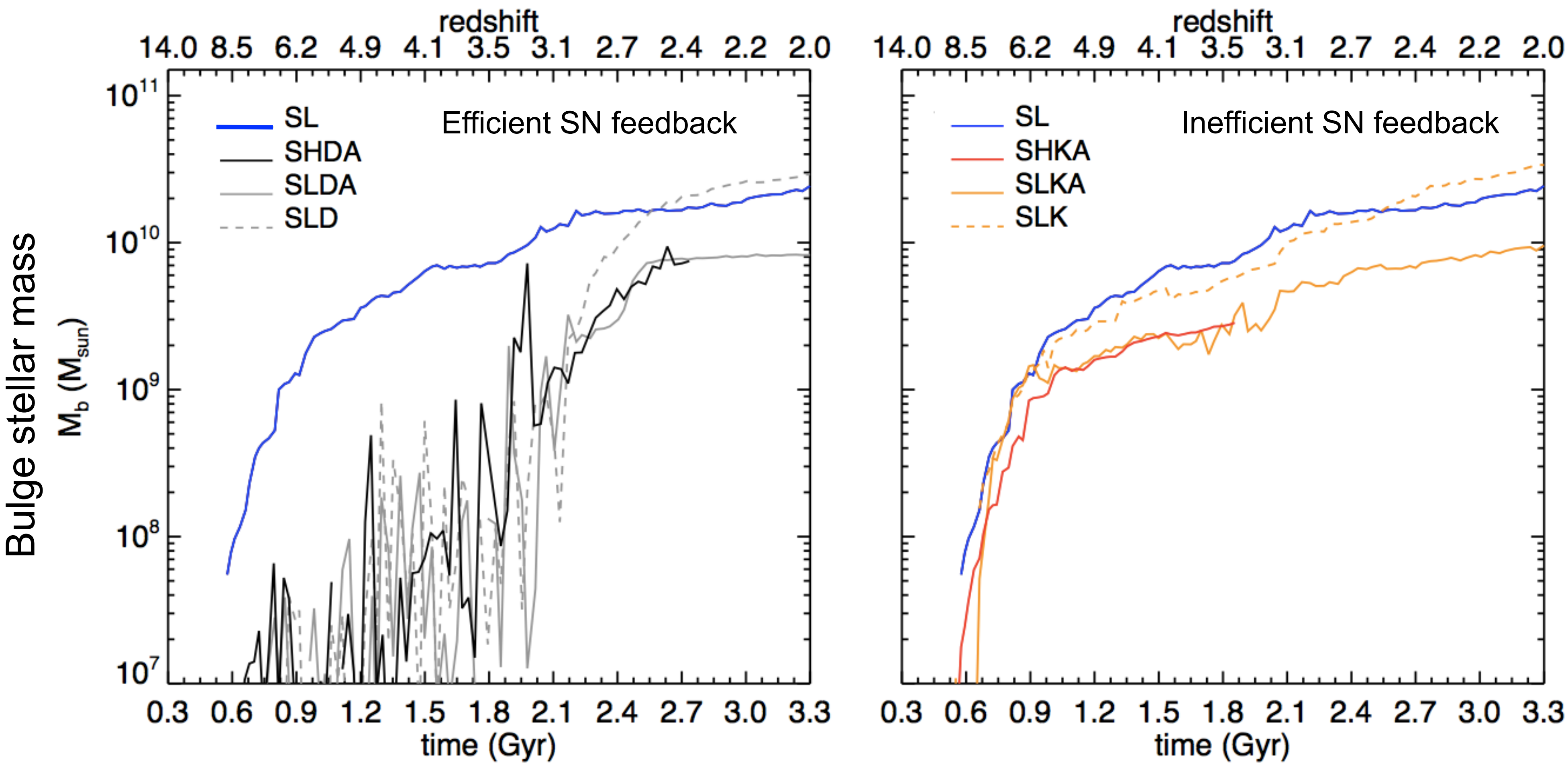


Dubois, Volonteri et al, 2015



Dubois, Volonteri et al, 2015

Efficient SN feedback delays bulge formation



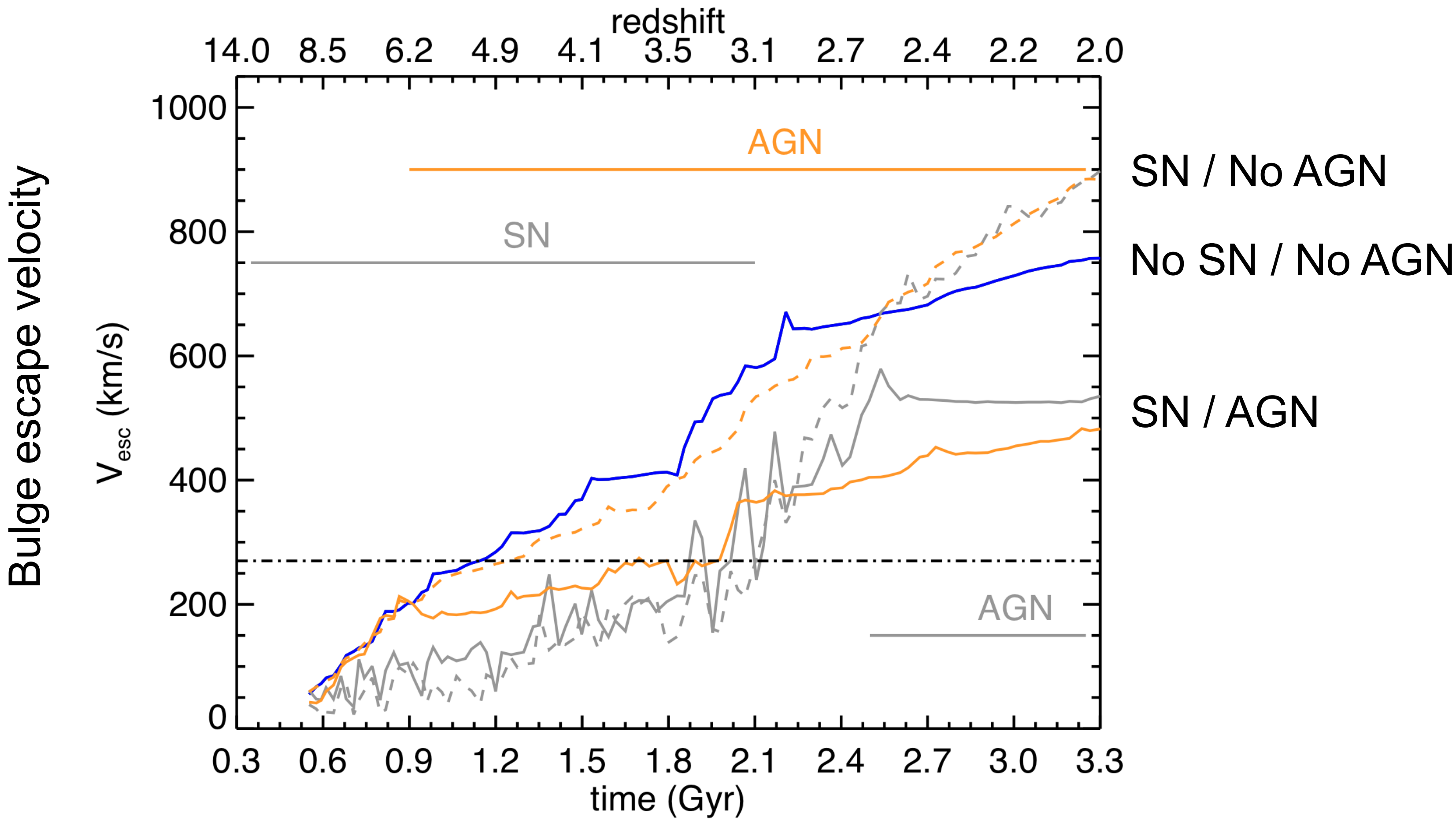
Dubois, Volonteri et al, 2015

$$u_{SN} = 1.2\sqrt{\frac{m_{new,s}\eta_{SN}e_{SN}}{m_g}}$$

$$\simeq 270\sqrt{\frac{\eta_{SN}}{0.1}}\sqrt{\frac{(m_{new,s}/m_g)}{0.1}}\,\mathrm{km\,s^{-1}}$$

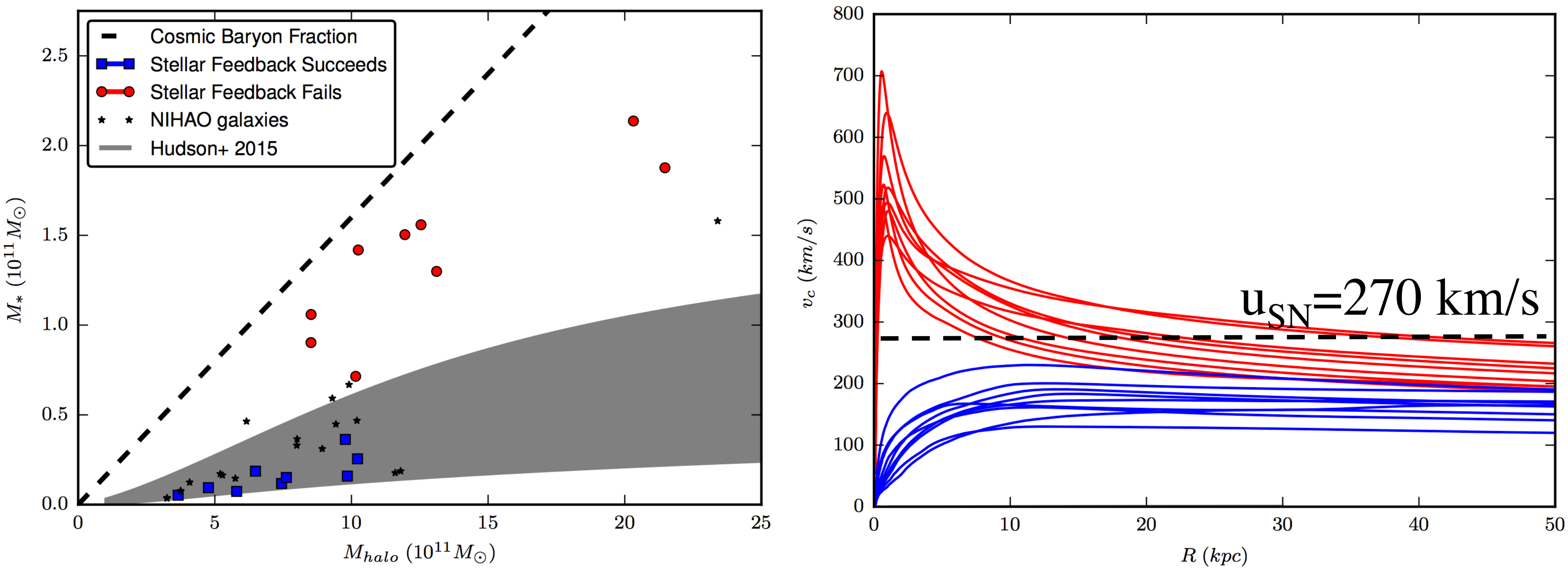
$$u_{esc} = \sqrt{\frac{2Gm_{cl}}{r_{cl}}}$$ ~ 300 km s^{-1}

For $m_{cl}=10^9$ M_{sun} and r_{cl}=100 pc



Dubois, Volonteri et al, 2015

Runaway bulge growth w/o AGN

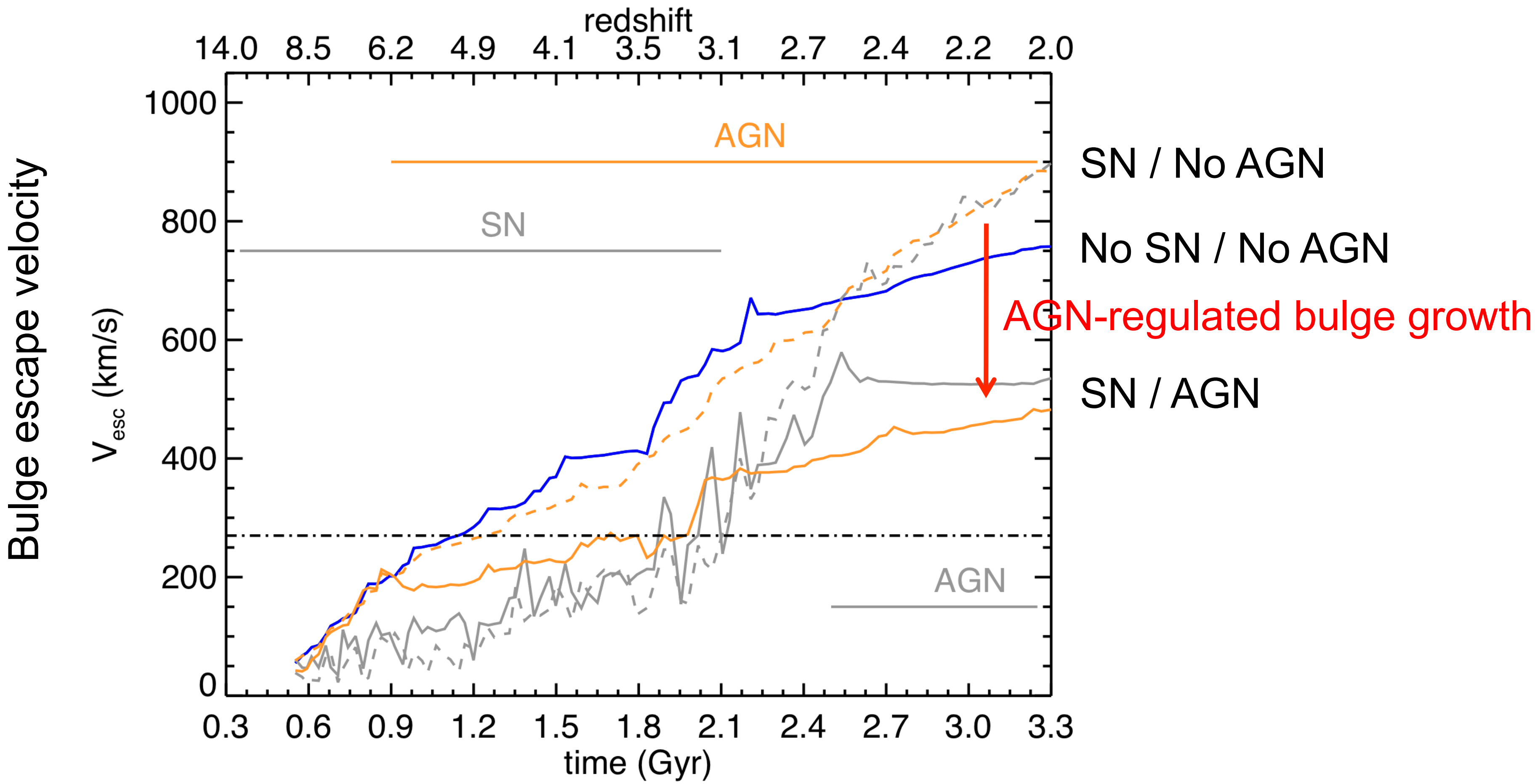


Keller, Wadsley, Couchman, 2016

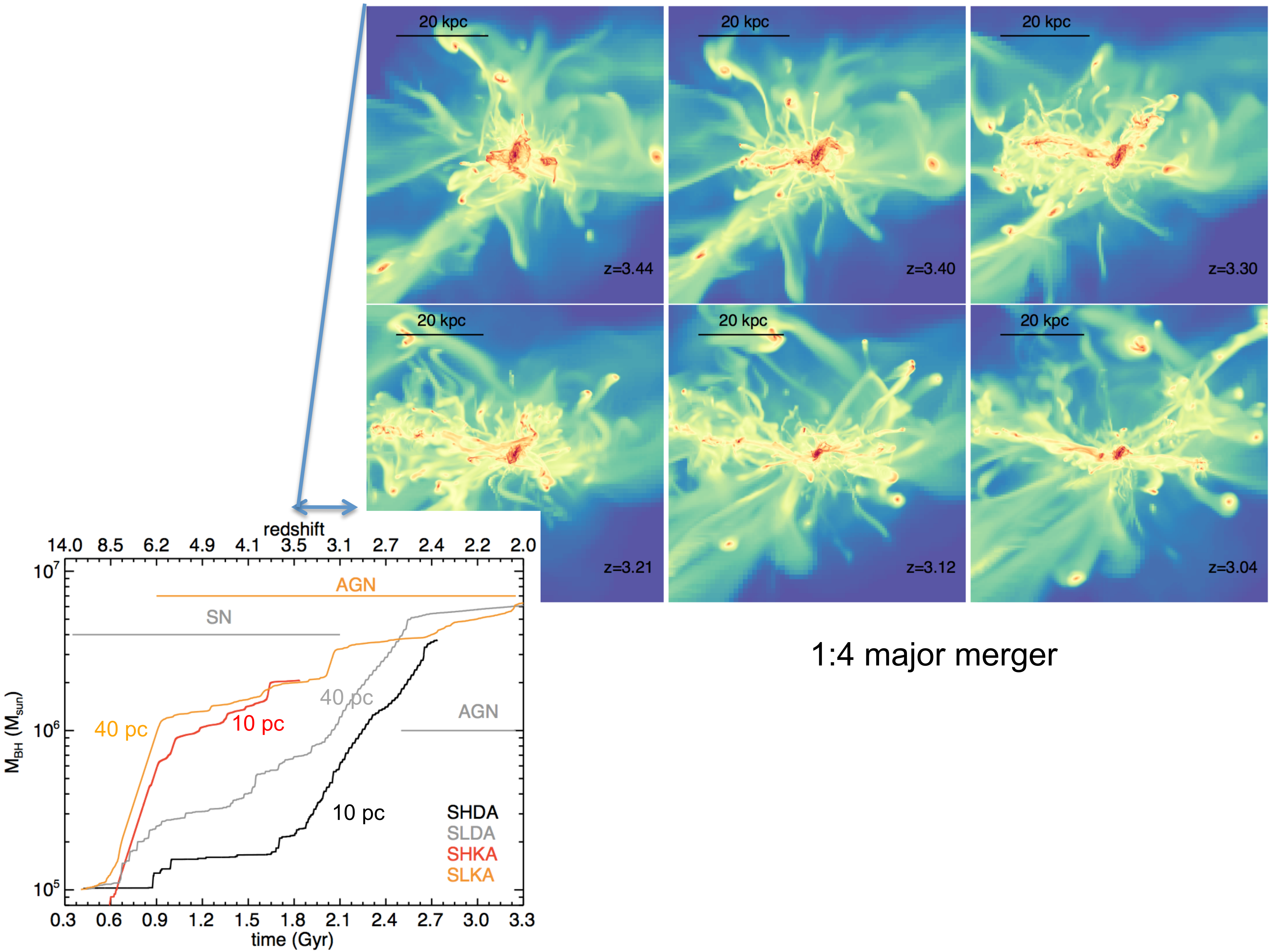
$$u_{\rm SN} = 1.2\sqrt{\frac{m_{\rm new,s}\eta_{\rm SN}e_{\rm SN}}{m_{\rm g}}}$$
$$\simeq 270\sqrt{\frac{\eta_{\rm SN}}{0.1}}\sqrt{\frac{(m_{\rm new,s}/m_{\rm g})}{0.1}}\,{\rm km\,s^{-1}}$$

$$u_{\rm esc} = \sqrt{\frac{2Gm_{\rm cl}}{r_{\rm cl}}} \sim 300\ {\rm km\ s^{-1}}$$

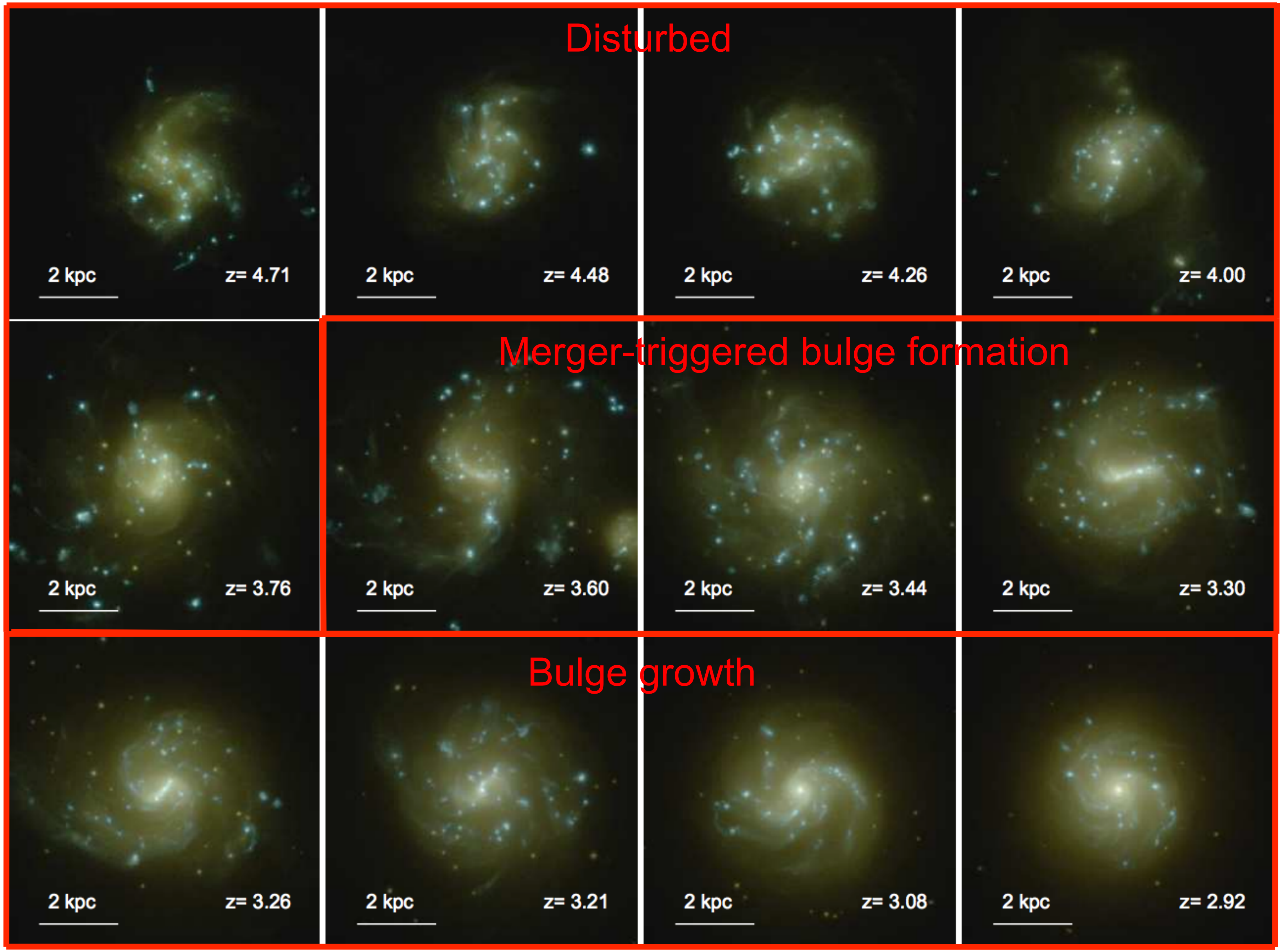
For $m_{cl}=10^9\ M_{sun}$ and $r_{cl}=100$ pc



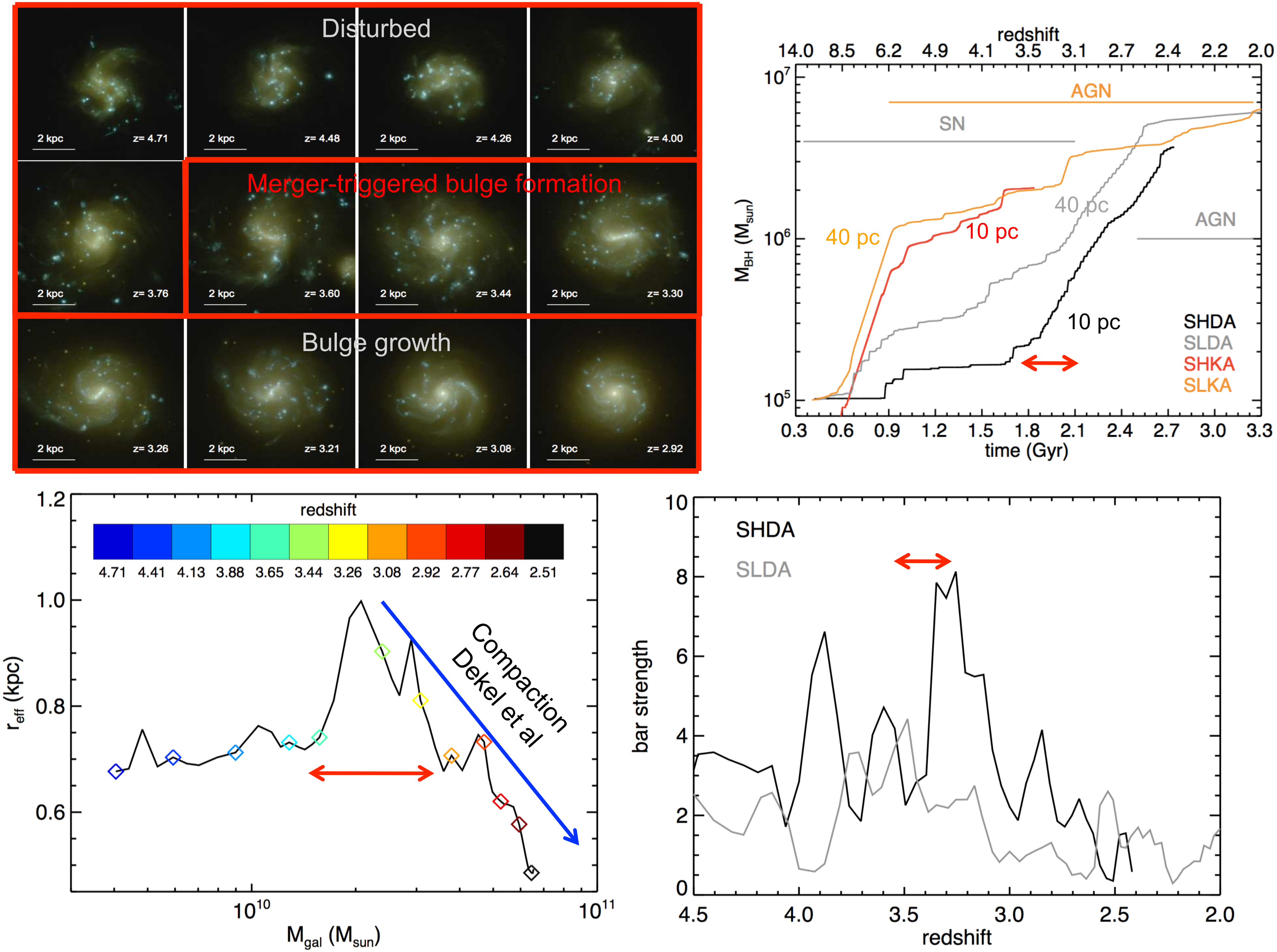
Dubois, Volonteri et al, 2015



1:4 major merger



Disturbed
2 kpc
z= 4.71
2 kpc
z= 4.48
2 kpc
z= 4.26
2 kpc
z= 4.00
Merger-triggered bulge formation
2 kpc
z= 3.76
2 kpc
z= 3.60
2 kpc
z= 3.44
2 kpc
z= 3.30
Bulge growth
2 kpc
z= 3.26
2 kpc
z= 3.21
2 kpc
z= 3.08
2 kpc
z= 2.92



Disturbed
2 kpc
z= 4.71
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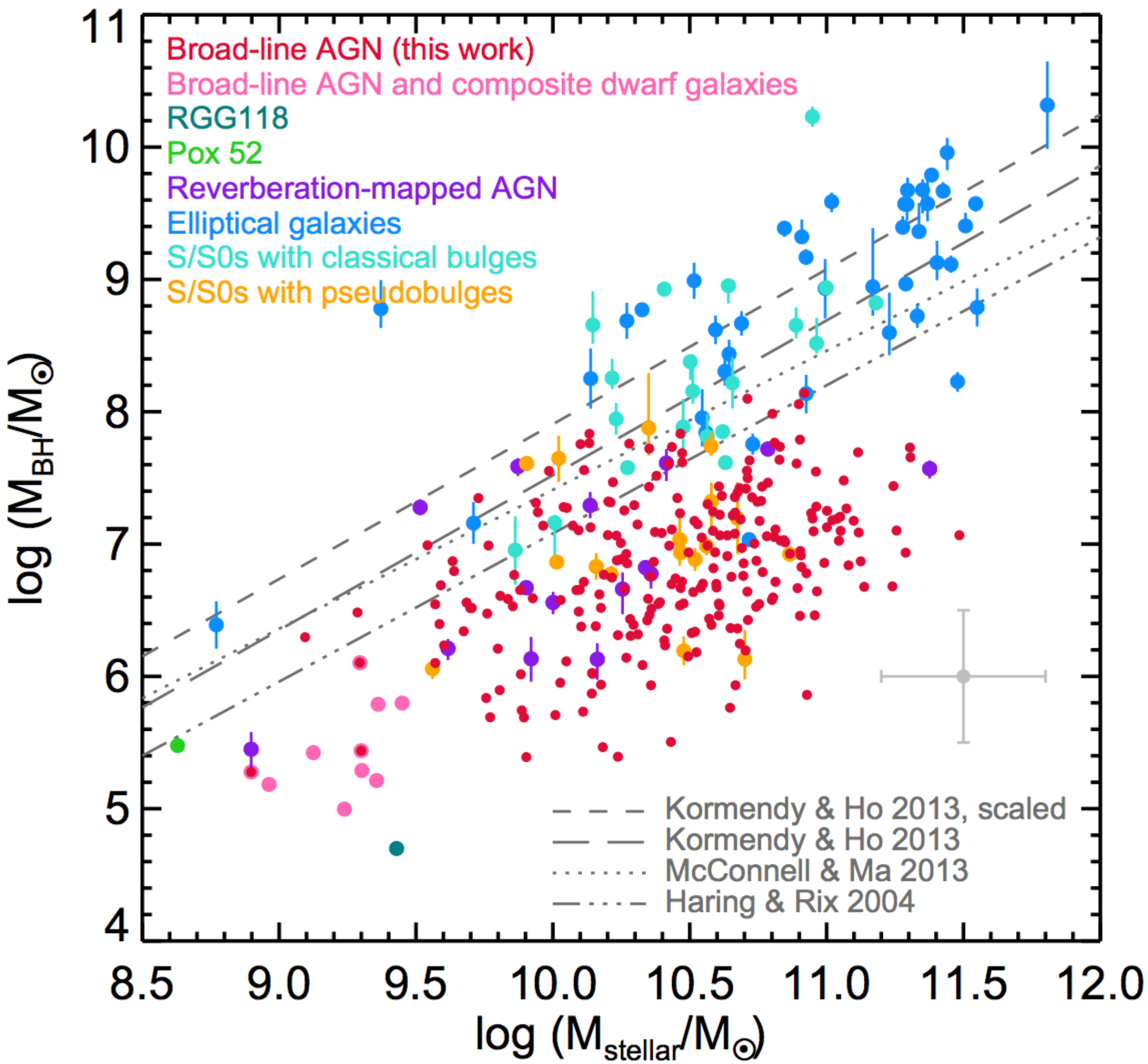
Merger-triggered bulge formation
z= 3.76
z= 3.60
z= 3.44
z= 3.30
Bulge growth
z= 3.26
z= 3.21
z= 3.08
z= 2.92
redshift
14.0 8.5 6.2 4.9 4.1 3.5 3.1 2.7 2.4 2.2 2.0
AGN
SN
40 pc
10 pc
40 pc
AGN
10 pc
SHDA
SLDA
SHKA
SLKA
M_{BH} (M_{sun})
10^7
10^6
10^5
0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 3.3
time (Gyr)
redshift
4.71 4.41 4.13 3.88 3.65 3.44 3.26 3.08 2.92 2.77 2.64 2.51
Compaction
Dekel et al
r_{eff} (kpc)
1.2
1.0
0.8
0.6
10^{10}
10^{11}
M_{gal} (M_{sun})
SHDA
SLDA
bar strength
10
8
6
4
2
0
4.5 4.0 3.5 3.0 2.5 2.0
redshift

Observations

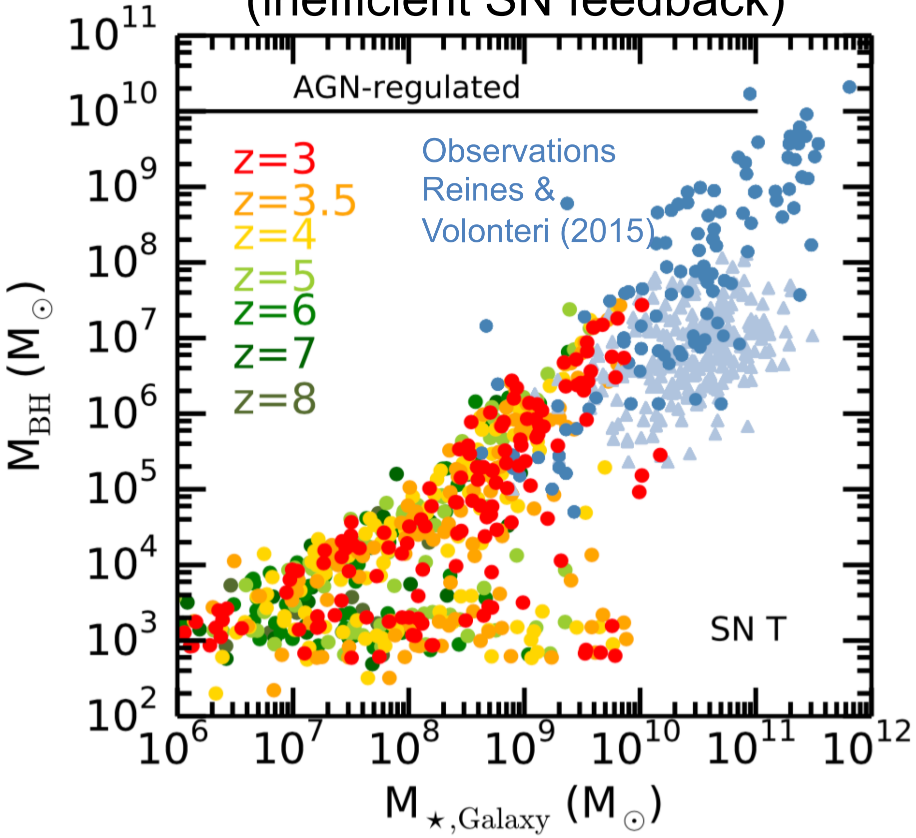


Reines & Volonteri, 2015

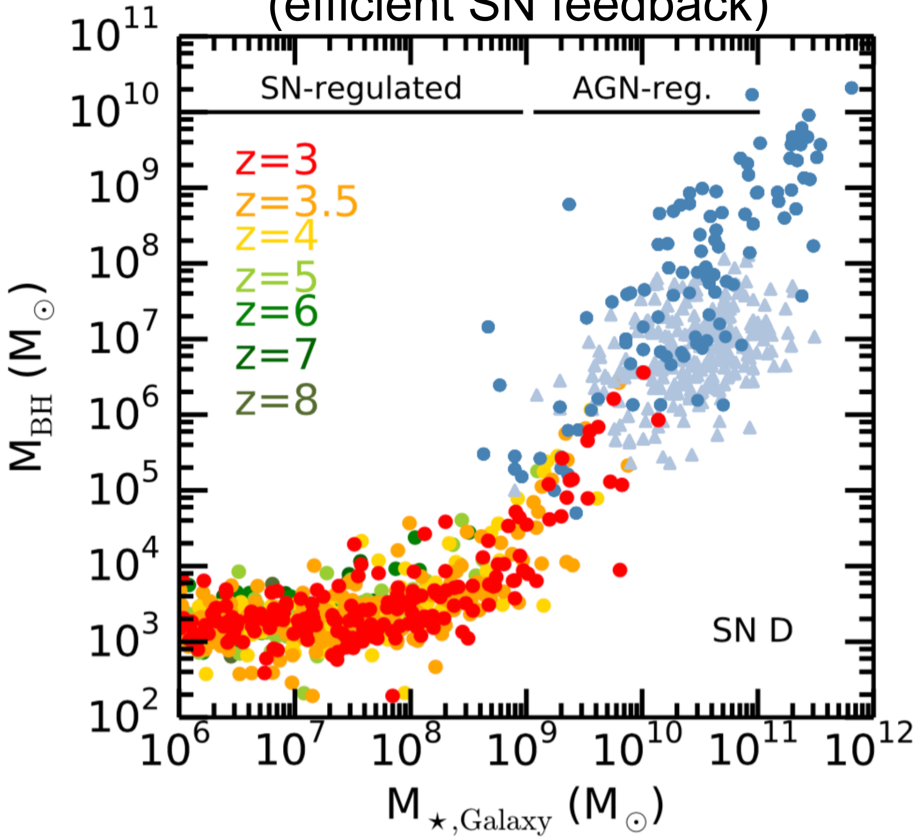
Confirmed in a statistical sense

10 Mpc volume with 80 pc spatial resolution
Using pop III BH seeding

Non-delayed cooling
(inefficient SN feedback)

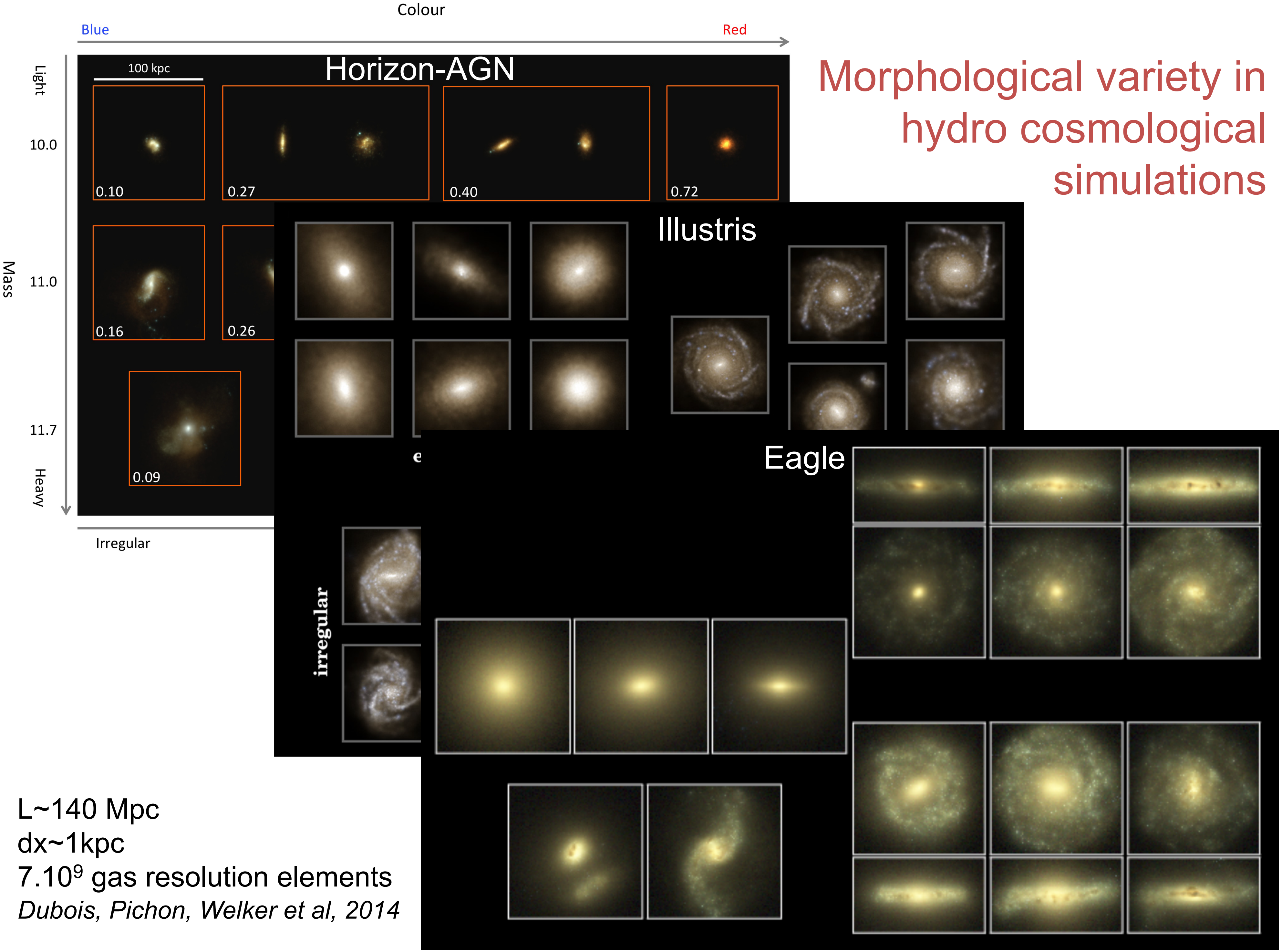


Delayed cooling
(efficient SN feedback)

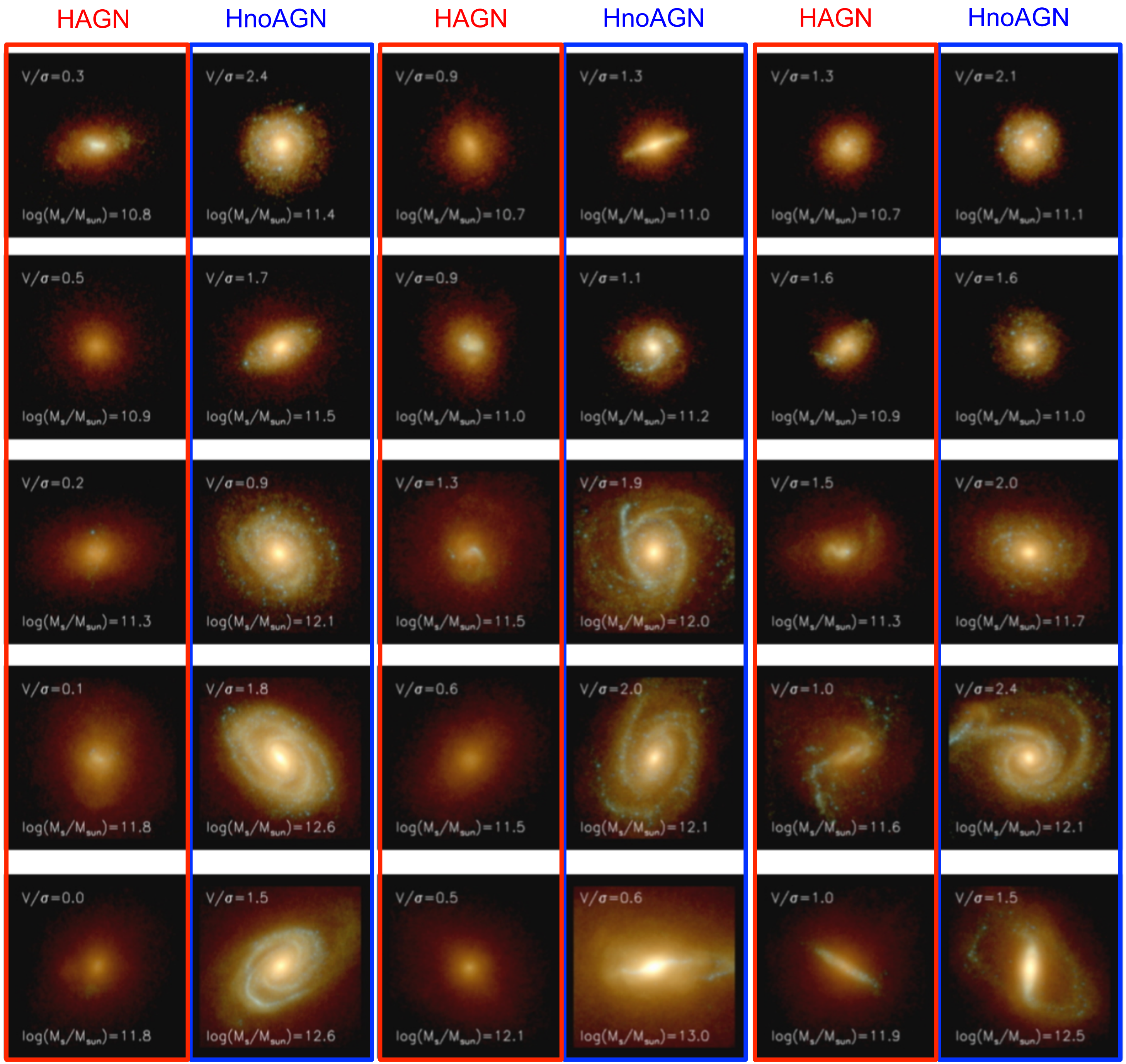


Habouzit, Volonteri, YD, sub.

Morphological variety in hydro cosmological simulations

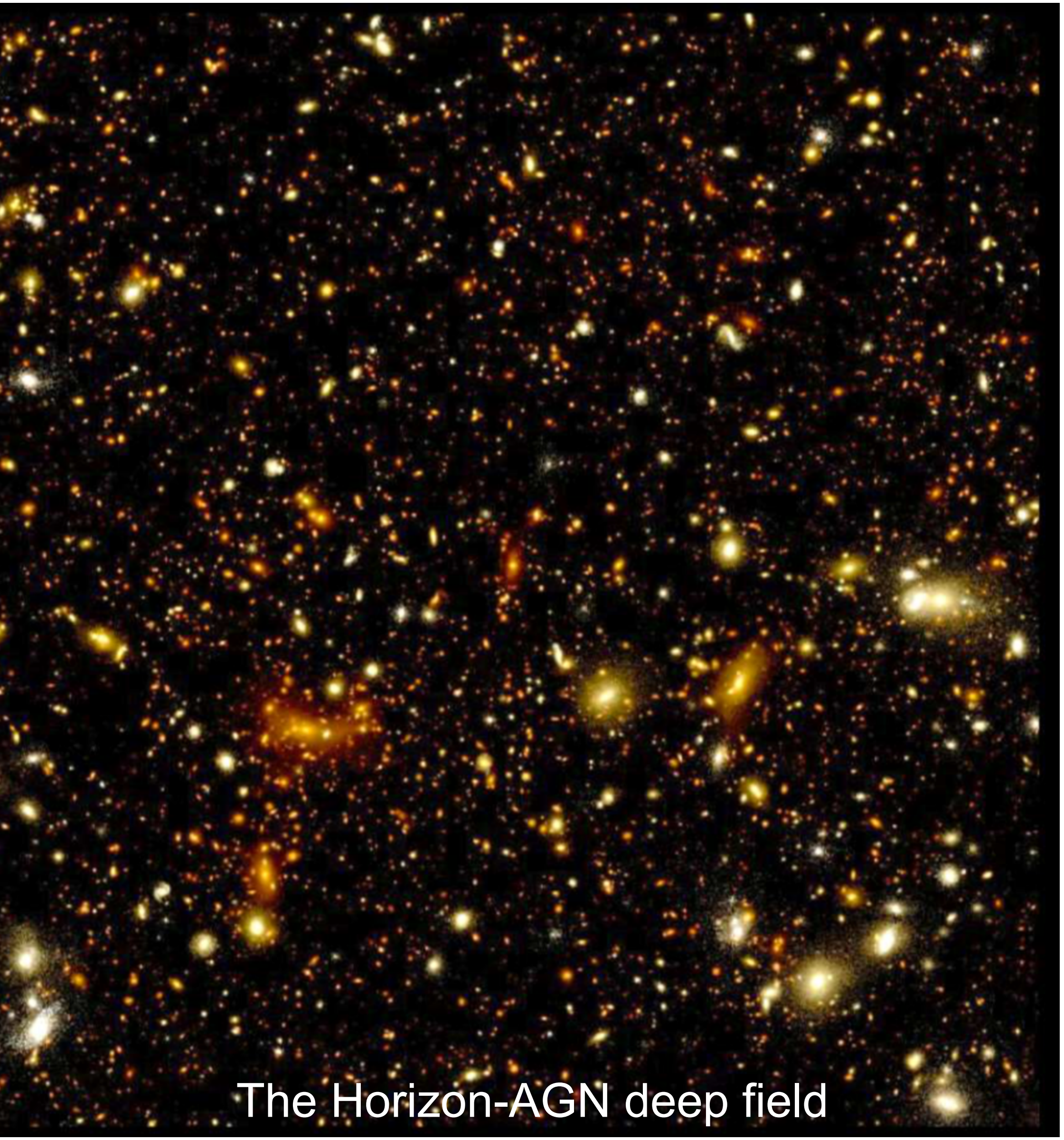


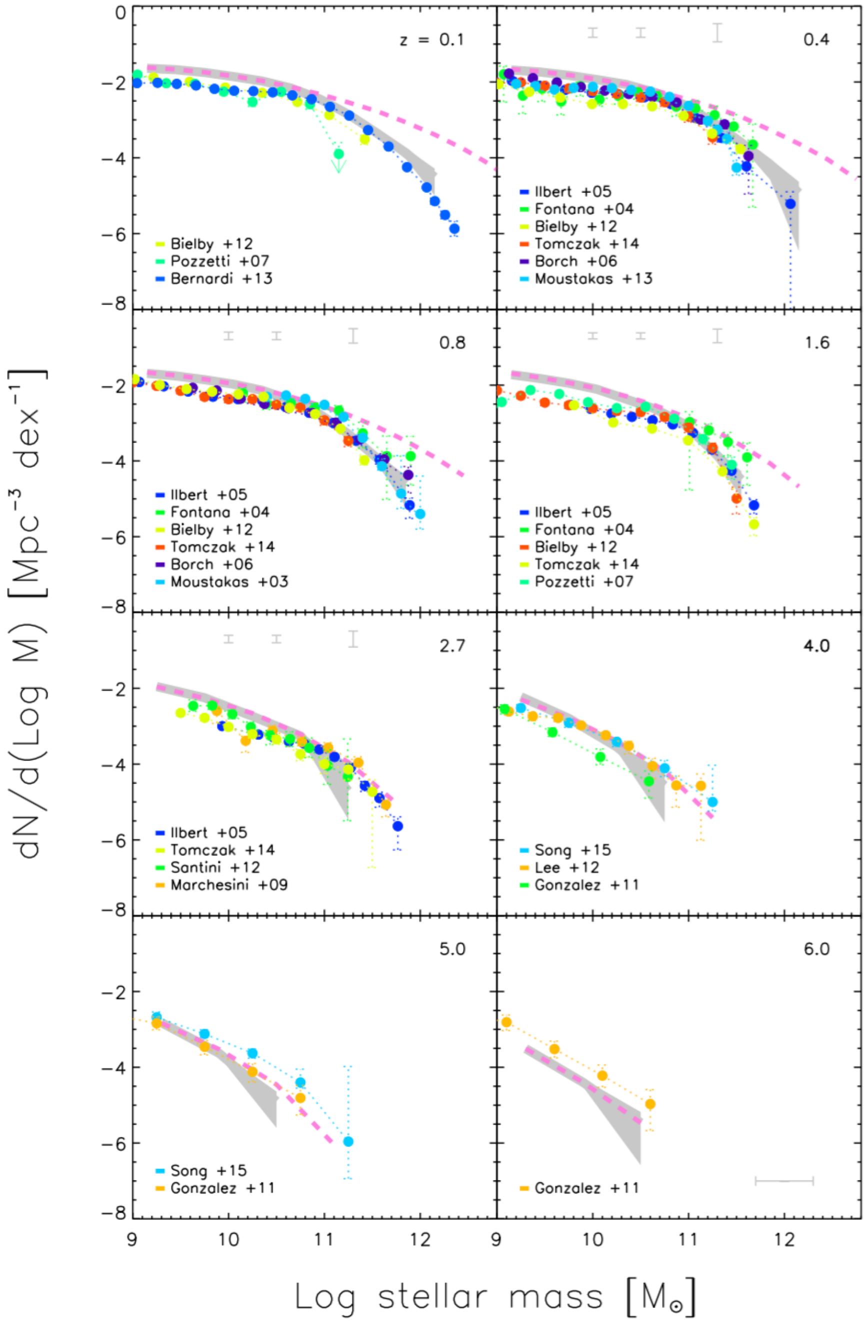
L~140 Mpc
dx~1kpc
7.10^9 gas resolution elements
Dubois, Pichon, Welker et al, 2014



Dubois, Peirani, et al, sub.

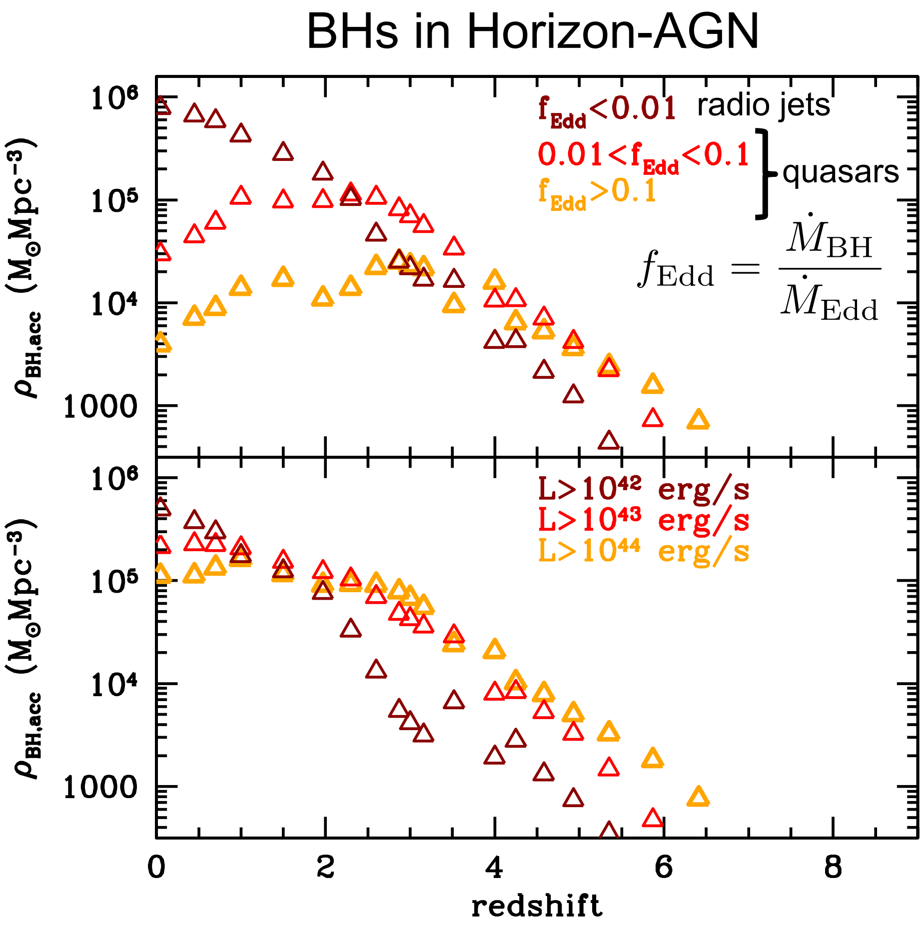
Mass function in Horizon-AGN



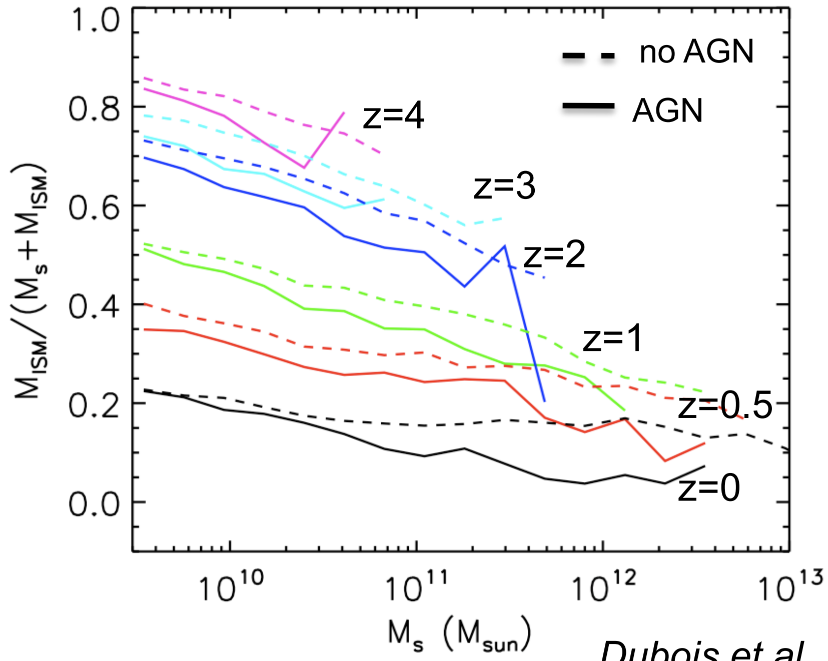


Kaviraj, Laigle et al, sub.

Radio mode or quasar mode ?



Volonteri, YD, Pichon, Devriendt, 2016

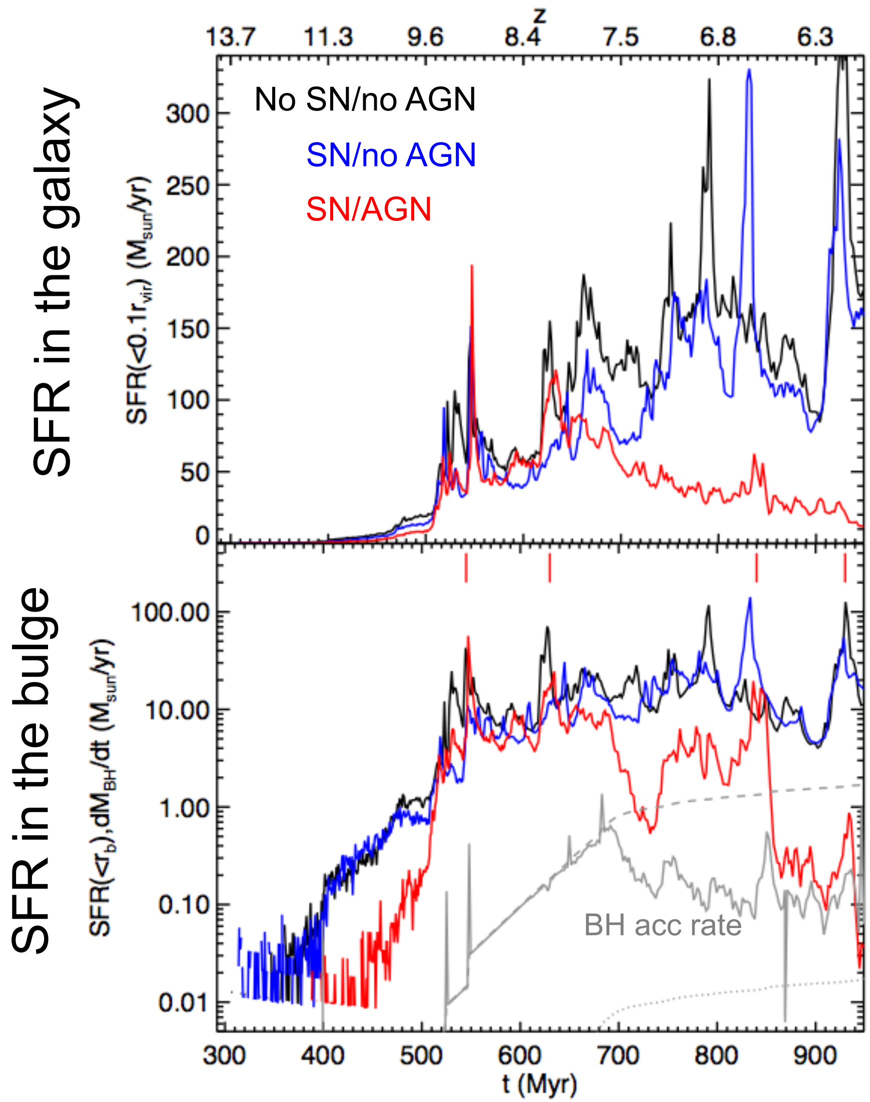


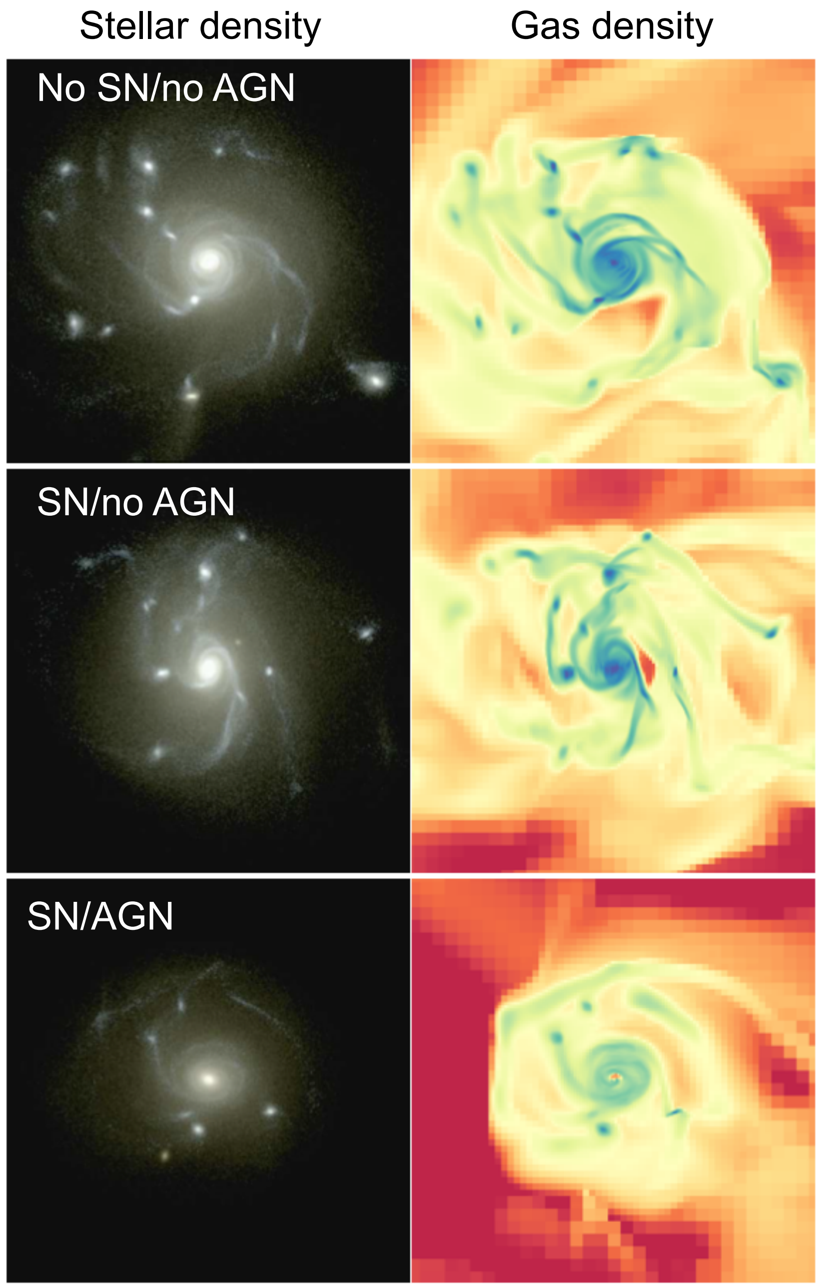
Dubois et al, 2012

Galaxies are gas-rich at high-redshift

Star formation and feedback consumes/ removes/ prevents from collapsing the gas

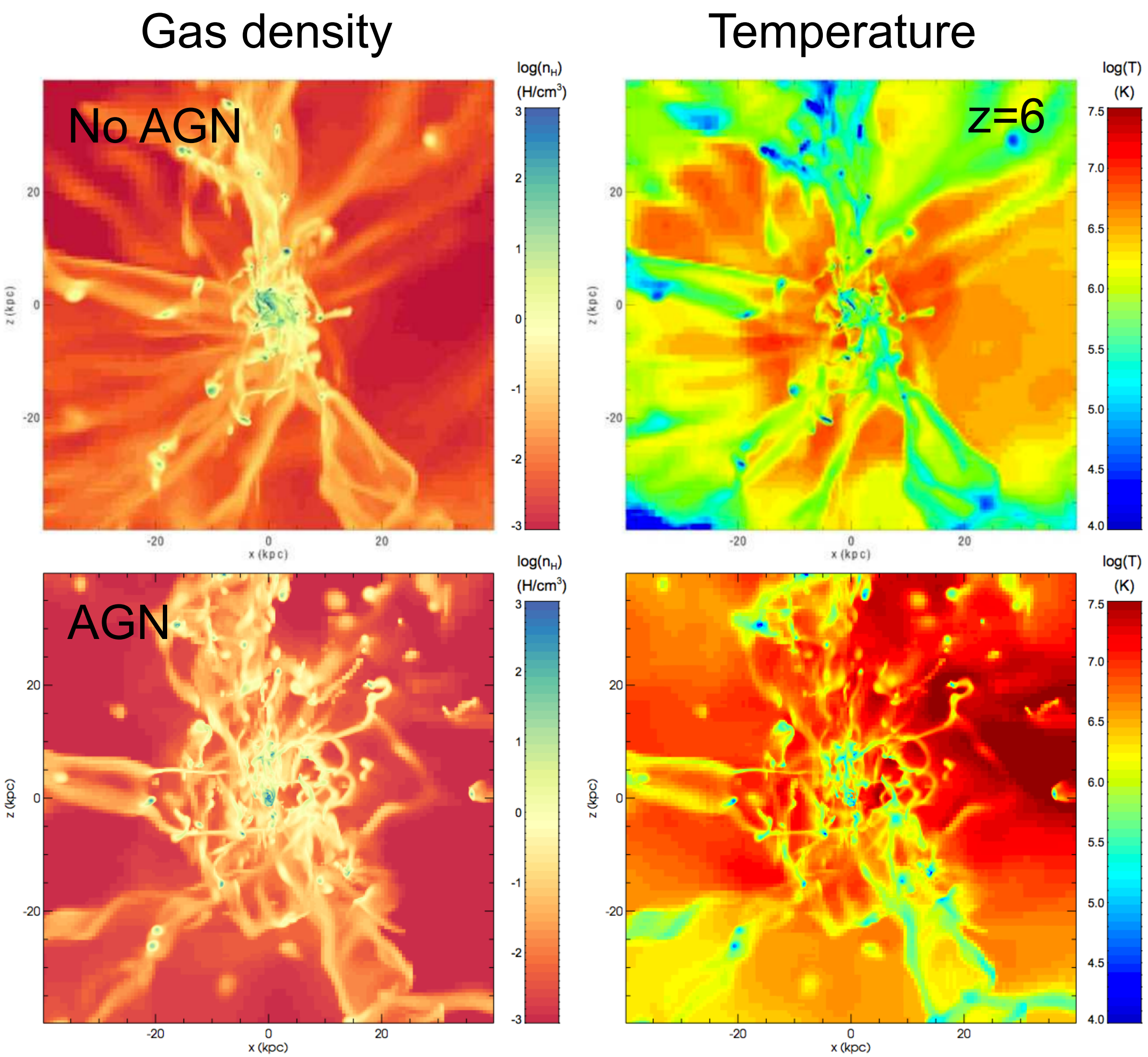
Quasar mode AGN do not destroy discs





Dubois, Pichon et al, 2013

Quasar mode AGN strangulate galaxies (and can blow cold flows away)



Gas is driven out hot from the central galaxy due to AGN.

Cold filaments are repelled from the halo.
Their structure is strongly perturbed.

Dubois, Pichon et al., 2013

Radiation hydrodynamics

•Uses moment method with M1 closure to solve radiative transfer in RAMSES (Rosdahl et al, 2013, Rosdahl & Teyssier 2015)
•Solving non-equilibrium evolution of ionisation fractions of H, HeI, HeI

•Radiation Pressure + diffusion of multi-scattering IR radiation included

$$\kappa_{\mathrm{D,UV}} = 1000\,\mathrm{g\,cm^{-2}}$$

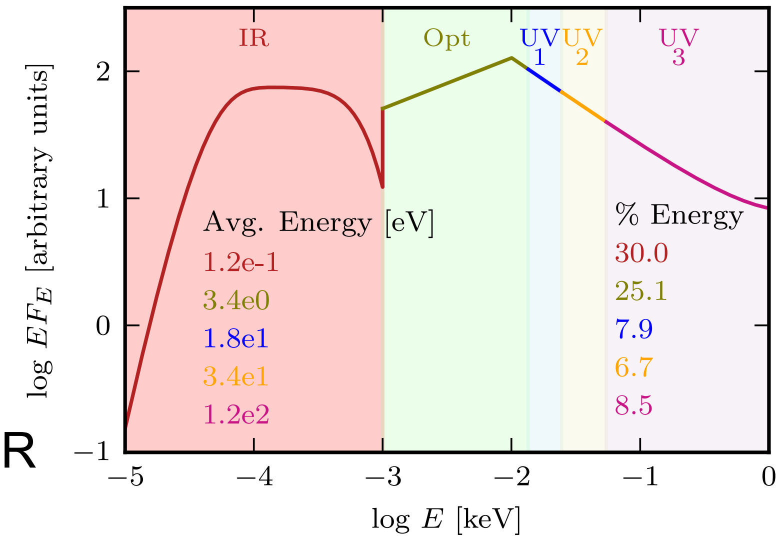
•Dust opacities $\kappa_{\mathrm{D,IR}} = 10\,\mathrm{g\,cm^{-2}}$

$$\kappa_{\mathrm{D}} = 0 \text{ if } \mathrm{T} > 10^5\,\mathrm{K}$$

•Solar metallicity with all metals in dust content
•Two AGN luminosities 10^{46} erg/s & 10^{43} erg/s

•Reduced speed of light approximation c_{red}=0.2 c (Gnedin & Abel 2001)

5 photon groups



Sazonov+ 2004

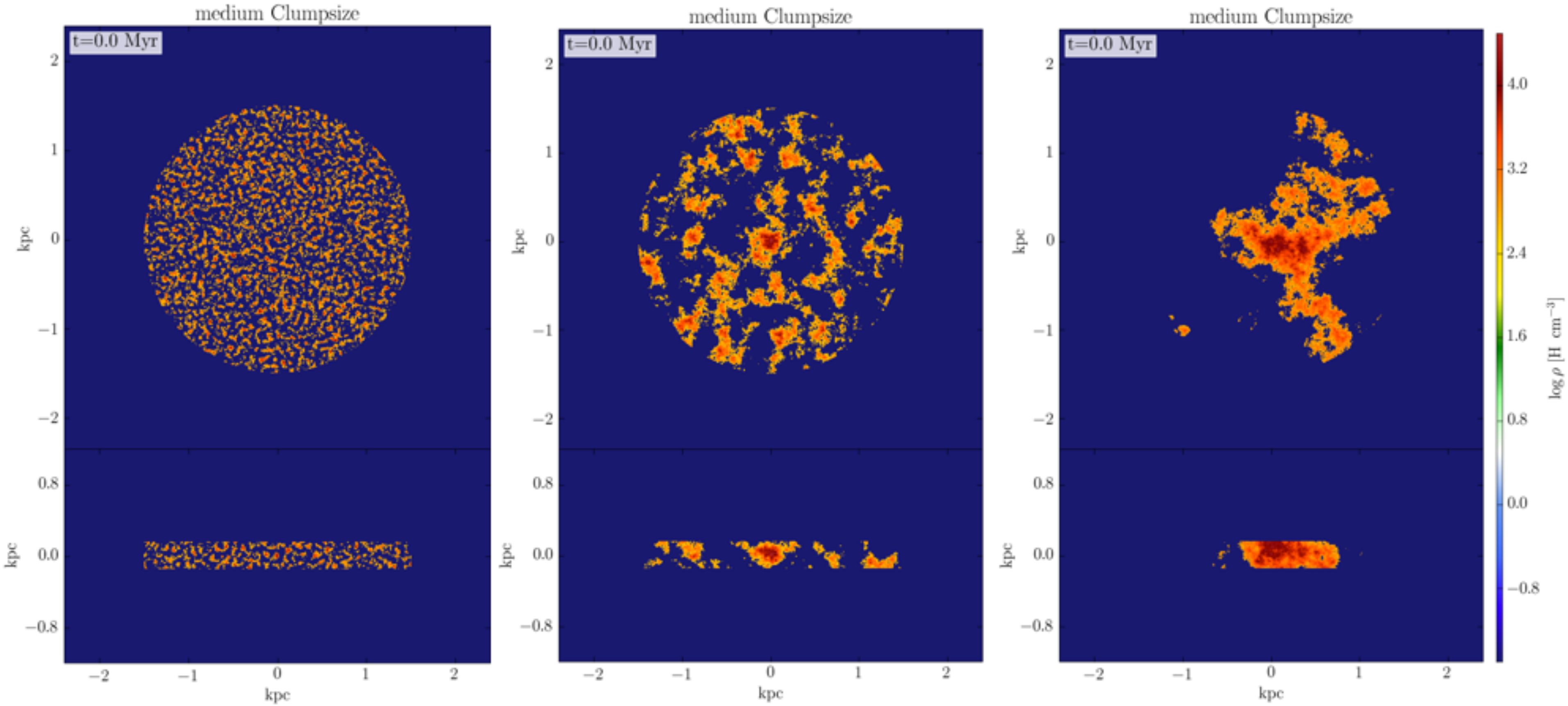
<u>Big Caveat:</u>
No gravity
No cooling
No SF

Bieri, YD, Rosdahl+, sub.

Shining a quasar in a multiphase medium

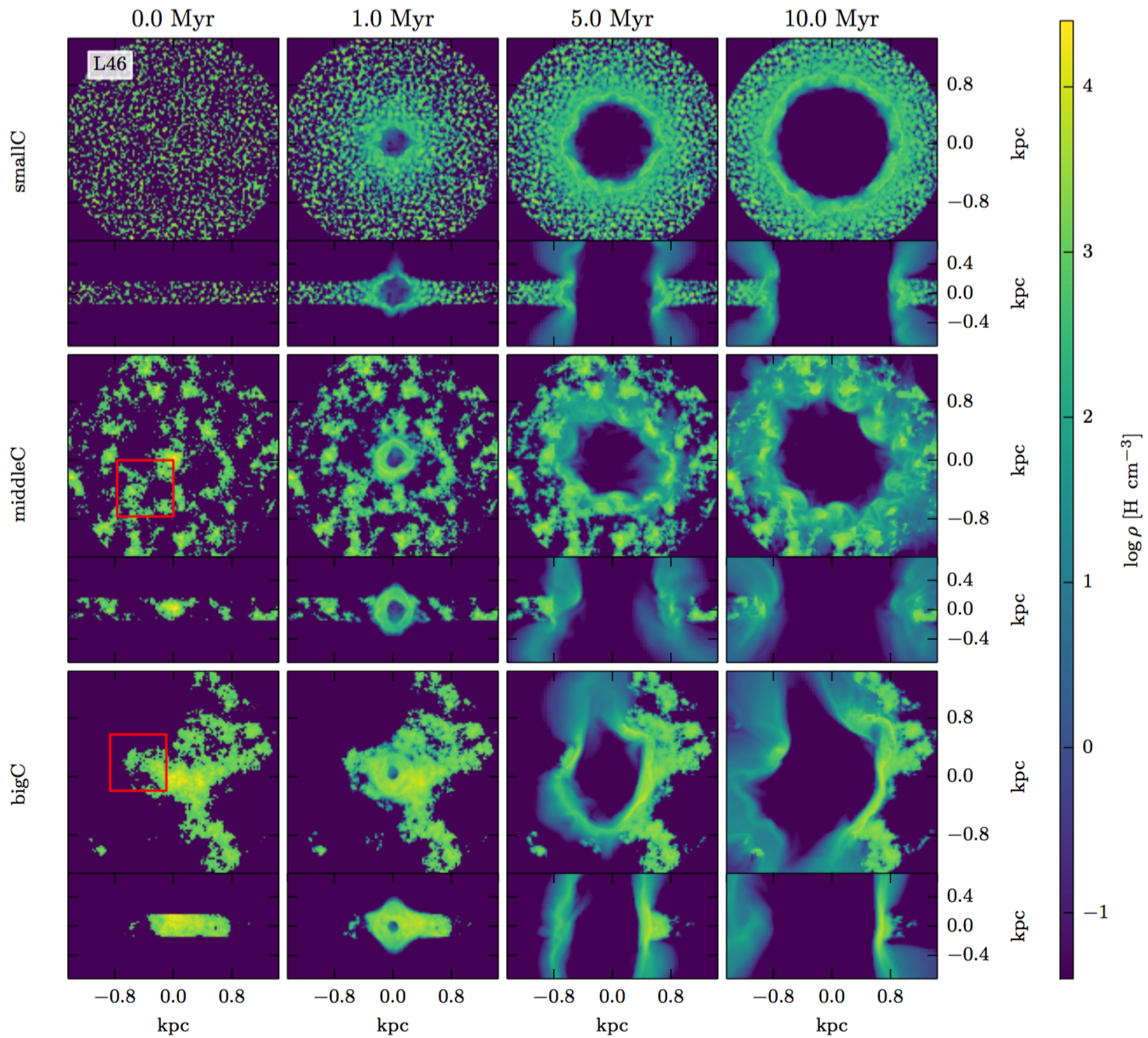
Log Normal pdf for gas density
Power spectrum $k^{-5/3}$ (and different cloud size)
ICs from Wagner & Bicknell (2011)

Galaxy mass is 2.10^{10} M_{sun}
With 100% gas (no DM, no stars)
Resolution is 5 pc in clouds

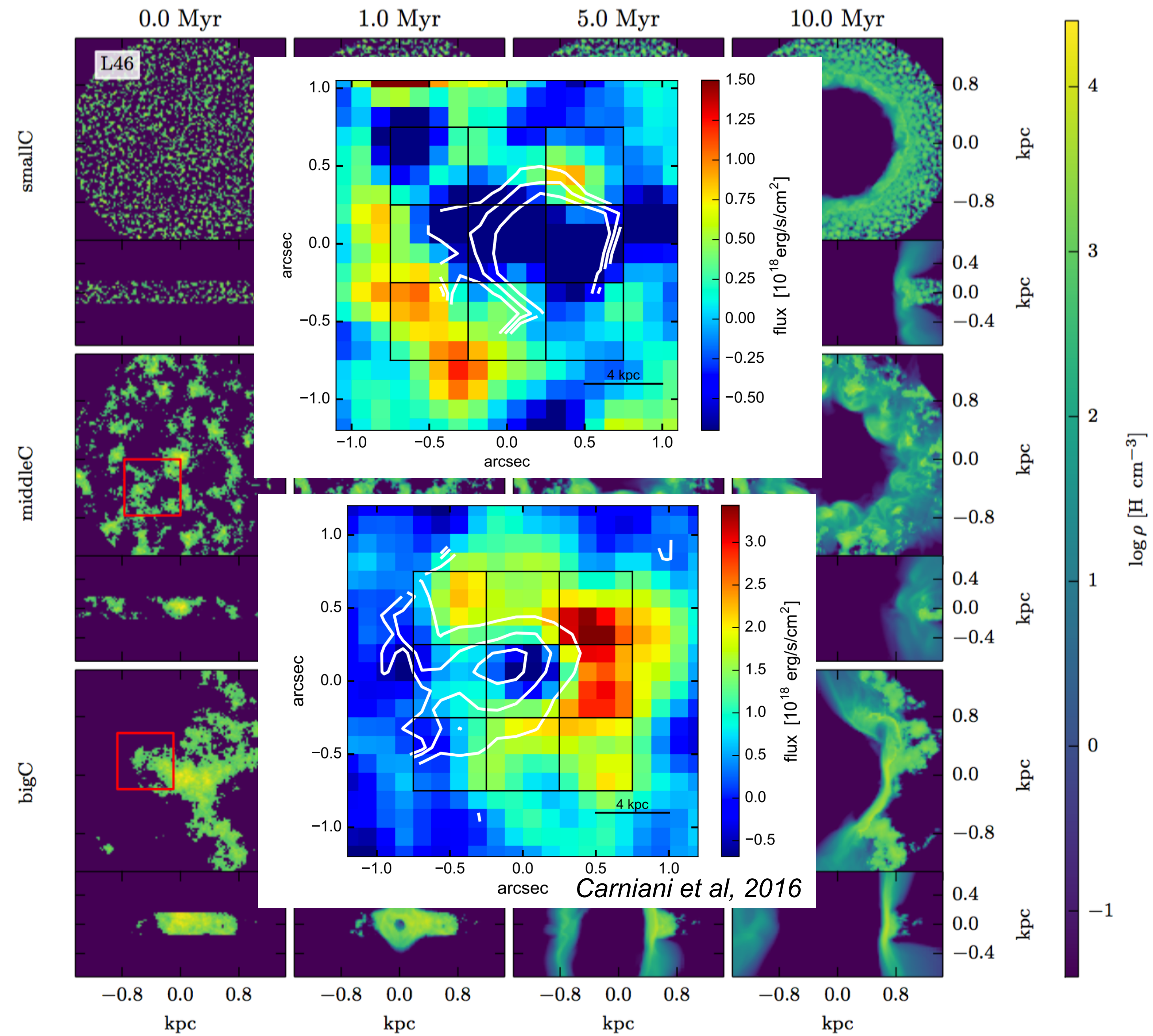


L_{cloud}=50 pc L_{cloud}=300 pc L_{cloud}=1 kpc

Bieri, YD, Rosdahl+, sub.

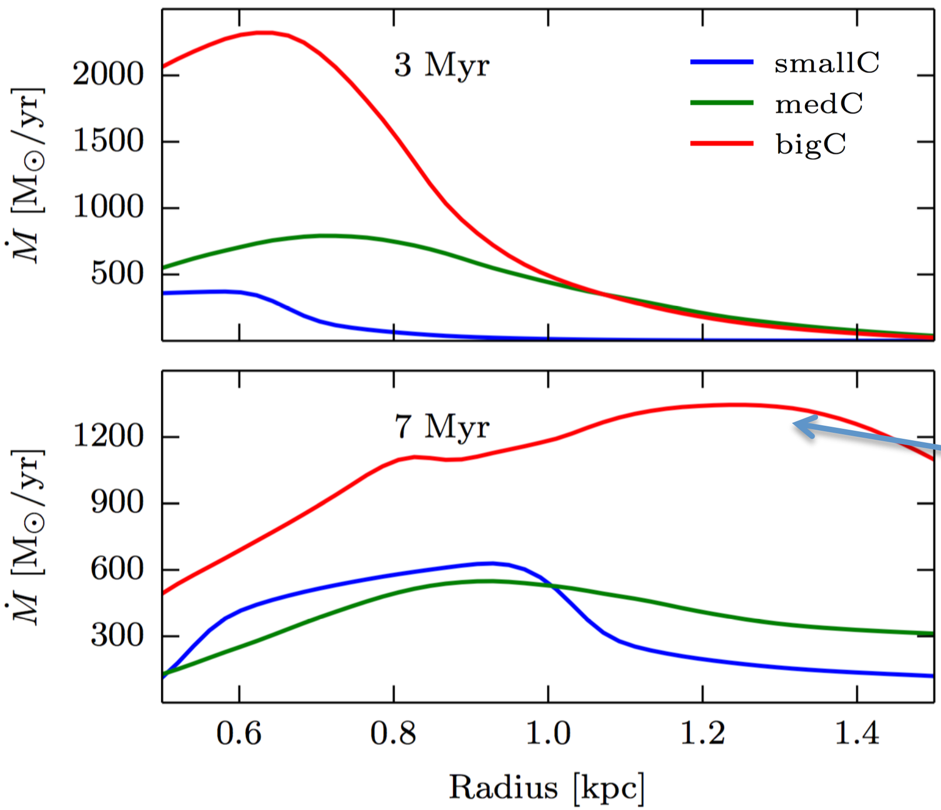


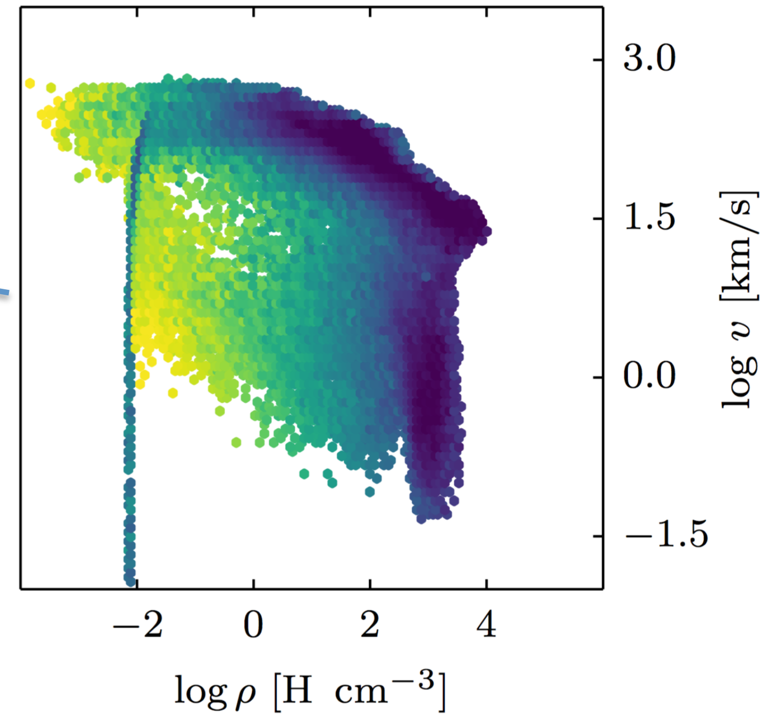
Bieri, YD, Rosdahl+, sub.



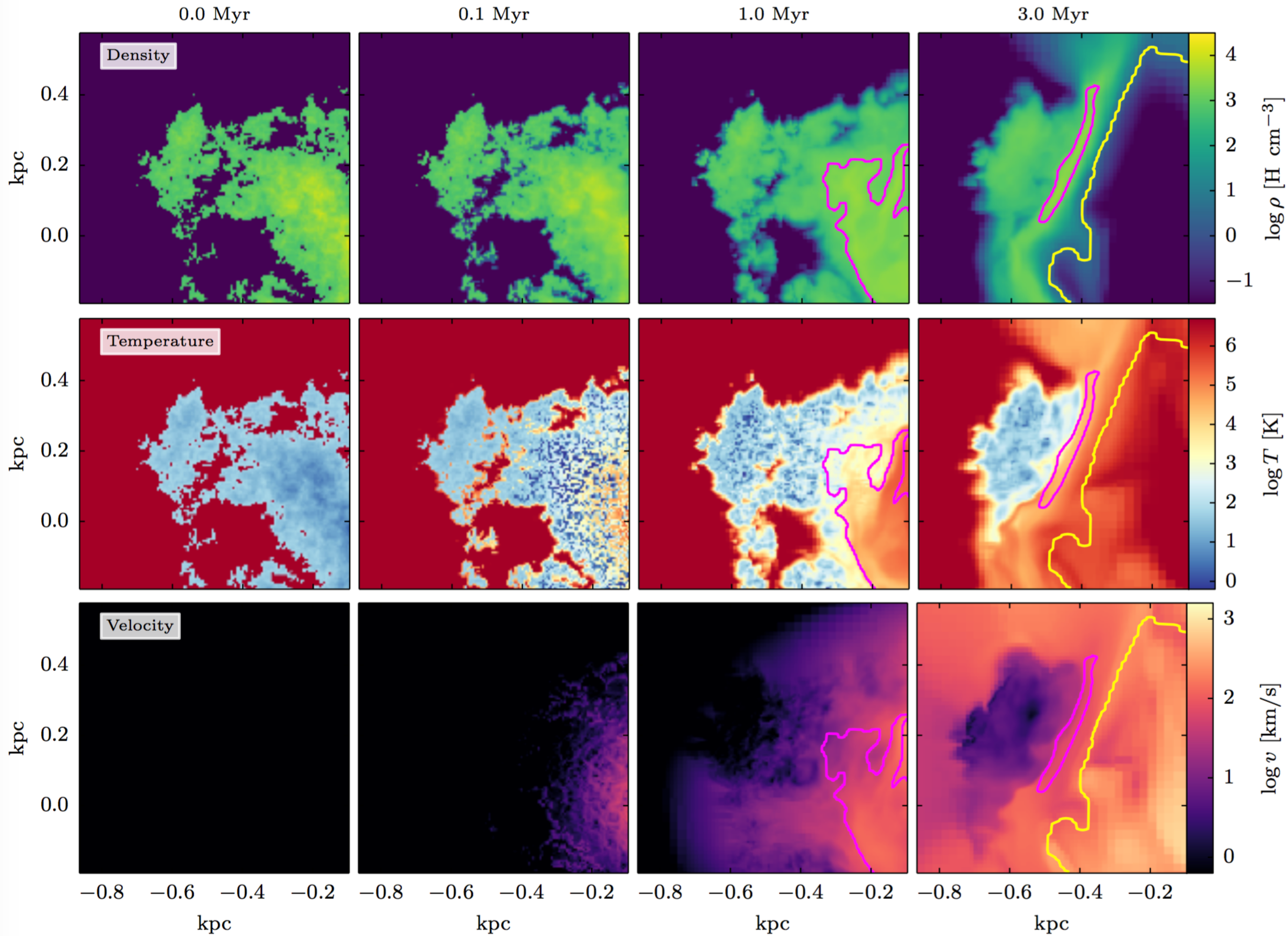
Bieri, YD, Rosdahl+, sub.

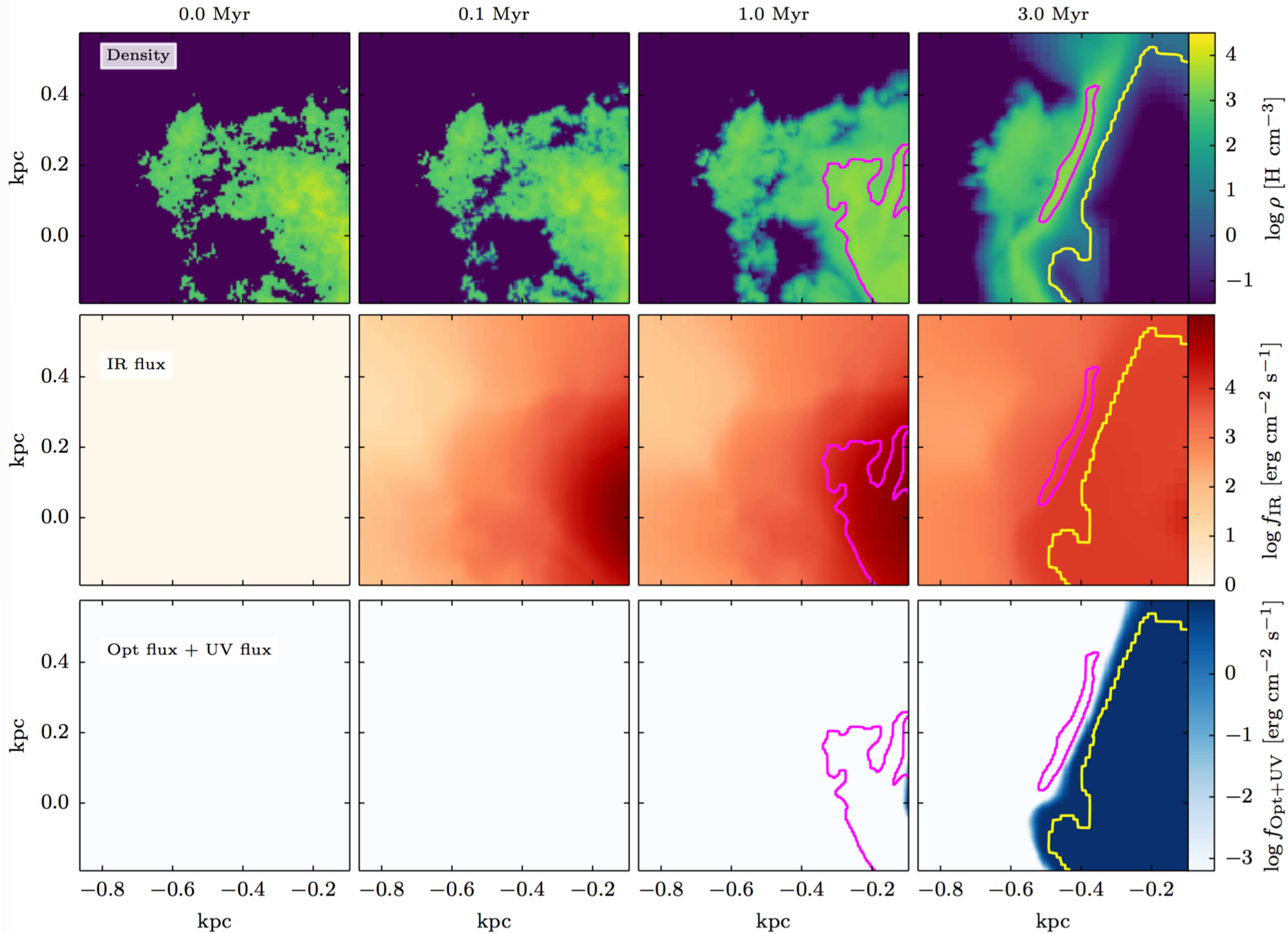
Large Mass Outflow Rates





Bieri, YD, Rosdahl+, sub.

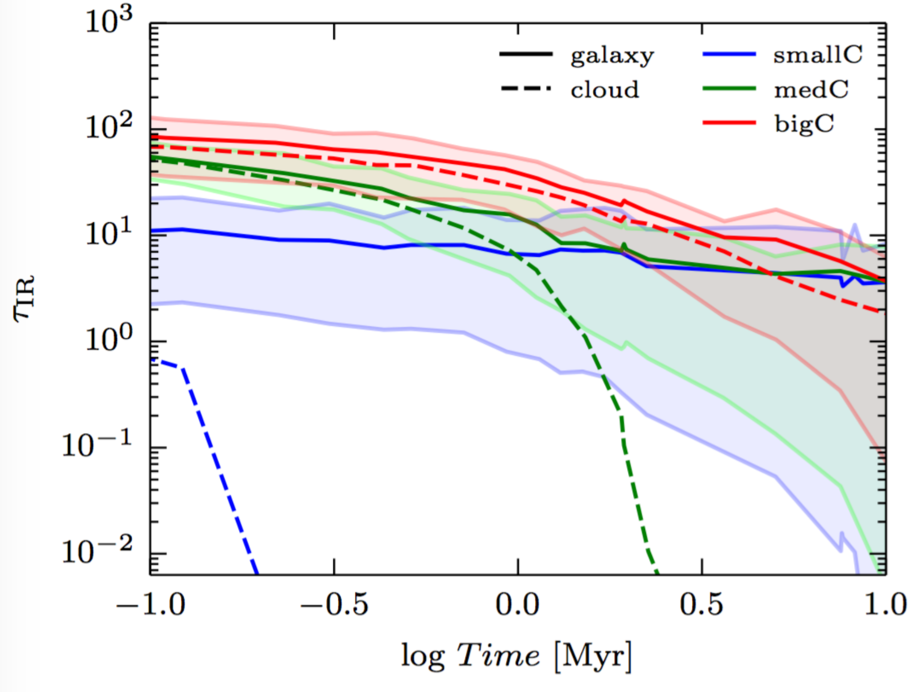

0.0 Myr
0.1 Myr
1.0 Myr
3.0 Myr
Density
Temperature
Velocity
kpc
0.4
0.2
0.0
−0.8
−0.6
−0.4
−0.2
log ρ [H cm−3]
4
3
2
1
0
−1
log T [K]
6
5
4
3
2
1
0
log v [km/s]
3
2
1
0



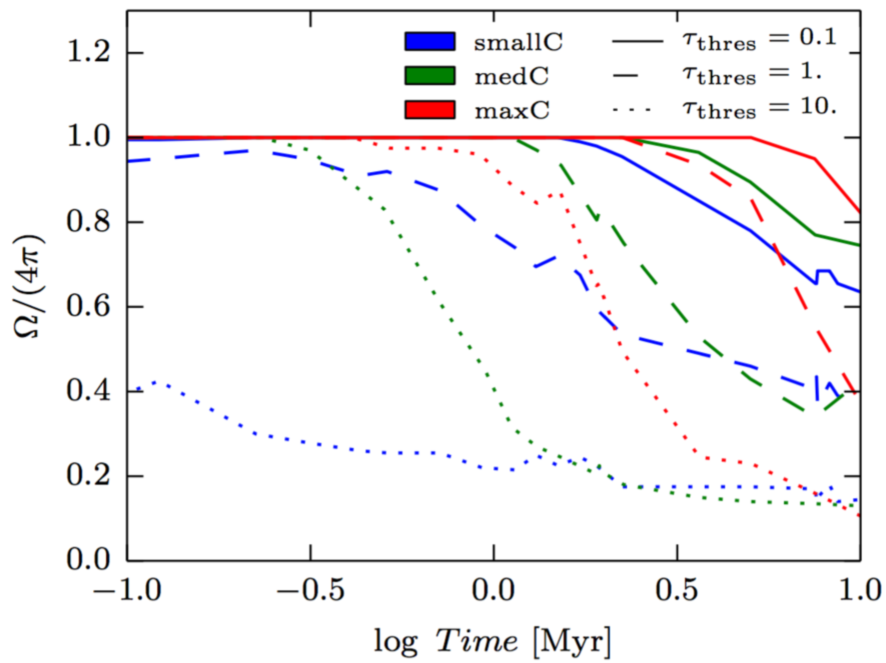
0.0 Myr
0.1 Myr
1.0 Myr
3.0 Myr
Density
IR flux
Opt flux + UV flux
kpc
0.4
0.2
0.0
−0.8
−0.6
−0.4
−0.2
log ρ [H cm−3]
log fIR [erg cm−2 s−1]
log fOpt+UV [erg cm−2 s−1]

Optical depth and cloud break-up

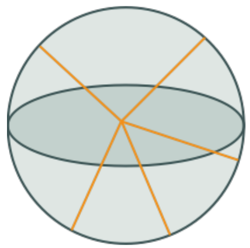
Optical depth



Fraction of solid angle with $\tau > \tau_{\rm thres}$

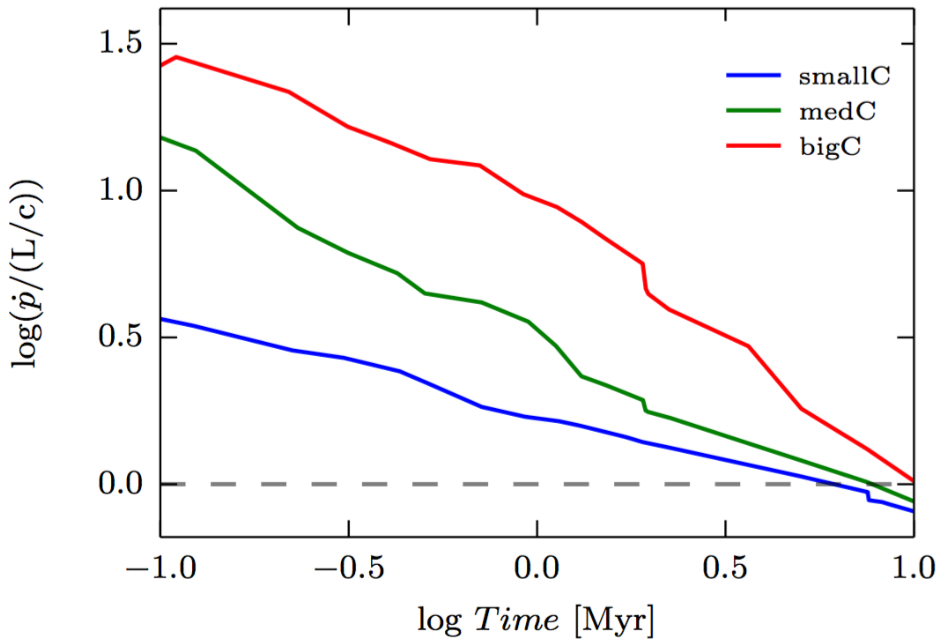


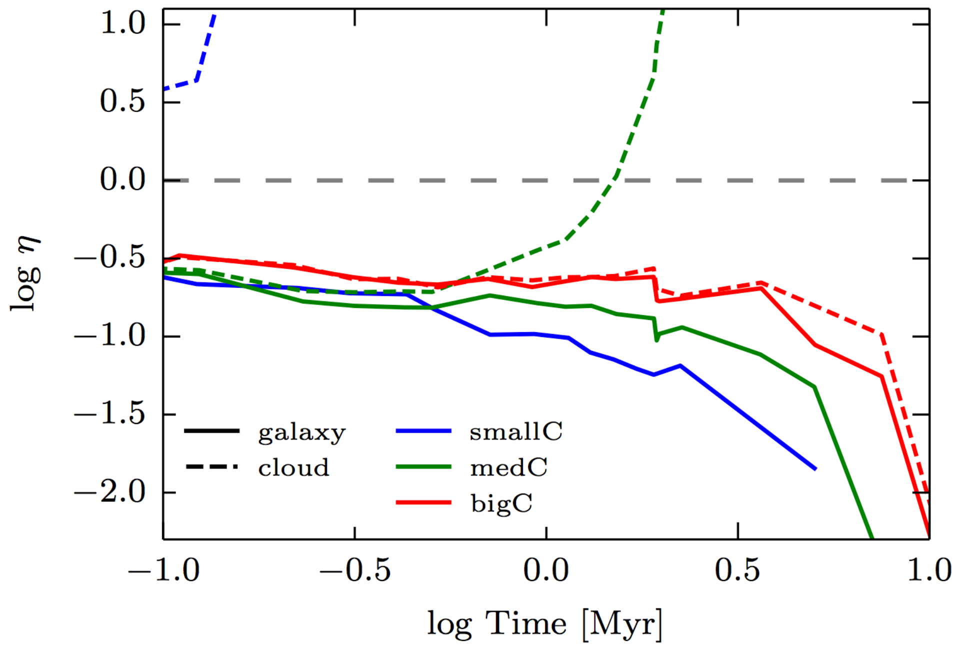
500 rays are cast to measure $\tau_{\rm IR}$



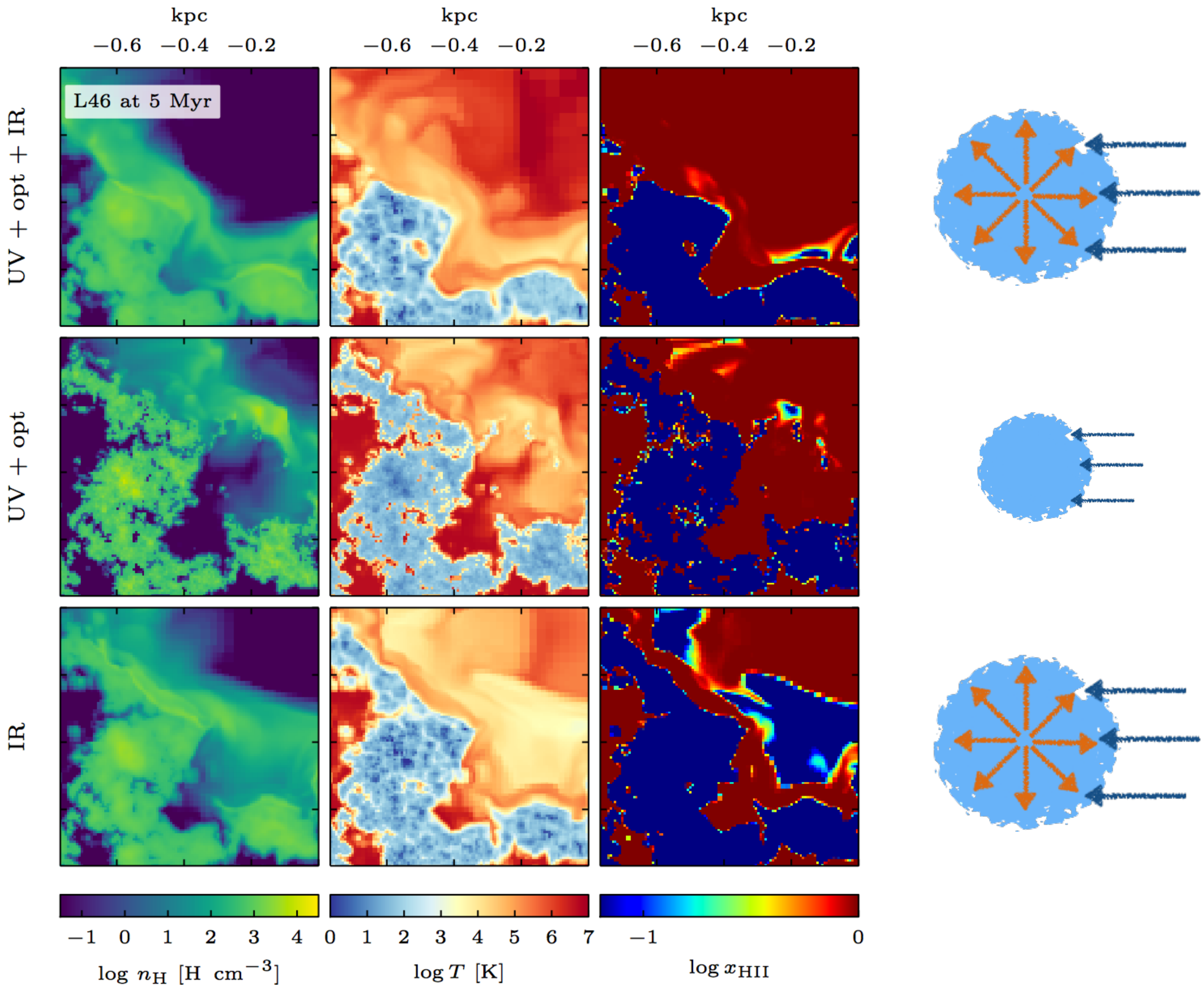
Mechanical advantage

$$\dot{p} = (1 + \eta \tau_{\rm IR}) \frac{L}{c}$$



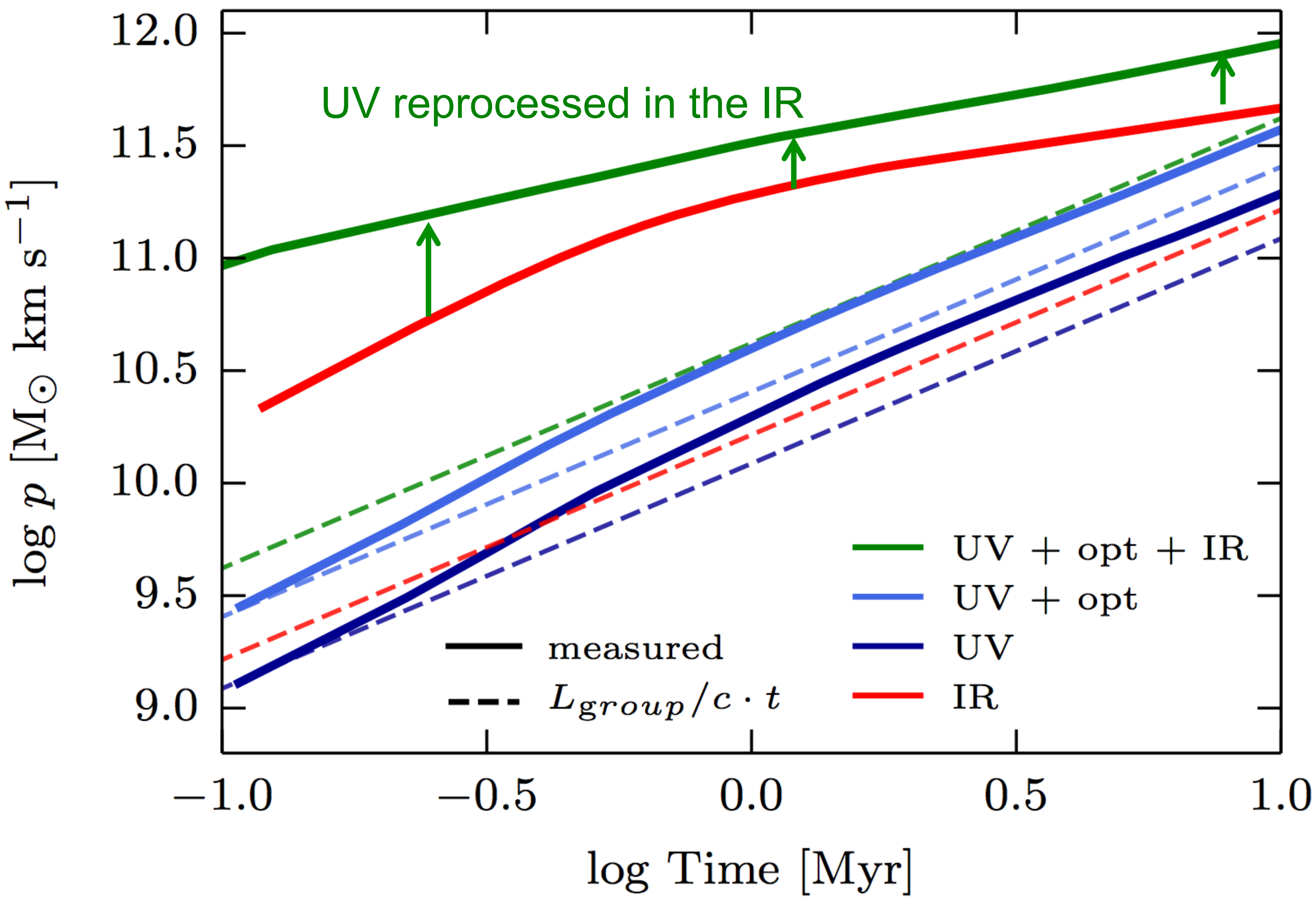


Bieri, YD, Rosdahl+, sub.



kpc
−0.6 −0.4 −0.2
L46 at 5 Myr
UV + opt + IR
UV + opt
IR
−1 0 1 2 3 4
log n_H [H cm^{-3}]
0 1 2 3 4 5 6 7
log T [K]
−1 0
log x_{HII}

Mechanical advantage considering different groups



Summary

- BH growth at high redshift:
  - Fed by cosmic cold flows early on and by disc instabilities later on
  - SN feedback can suppress BH growth in high-redshift low-mass galaxies $M_{bulge}<10^9$ M_{sun} (or $V_{esc}<270$ km/s)
  - Burst of AGN activity triggered by wet mergers associated with compaction

- Quasar mode with photons only:
  - Can drive winds because of IR multi-scattering
    - Though fewer scatters than theoretically inferred
  - Destroys the disc
    - Need to be confirmed in more realistic set-up