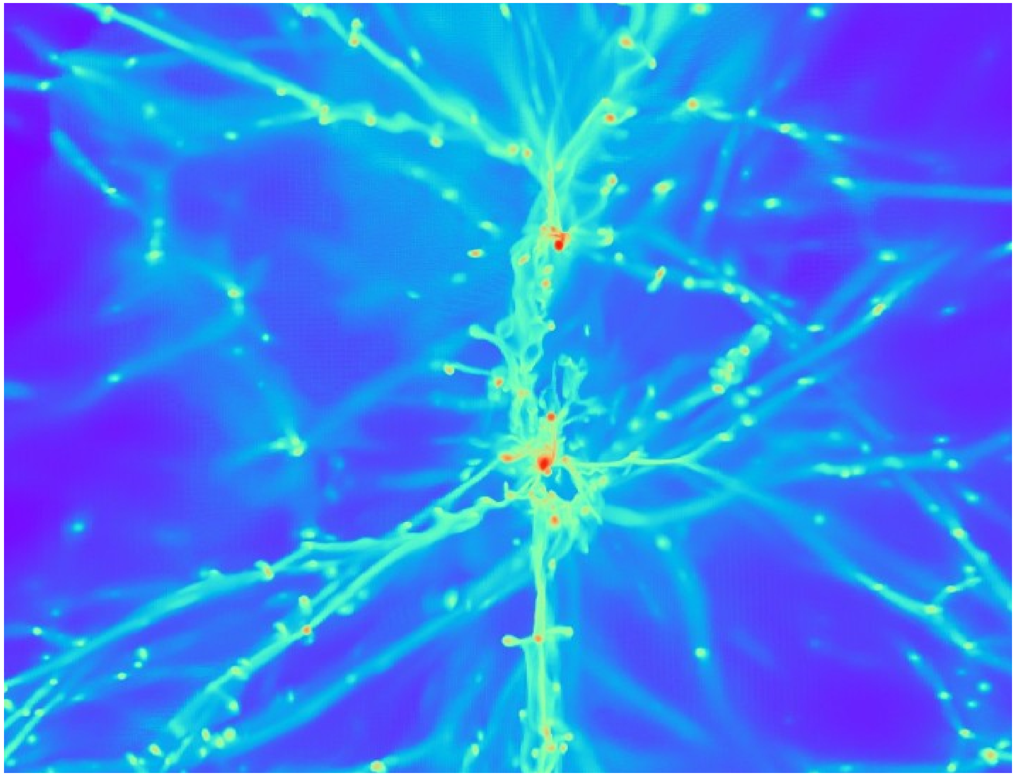
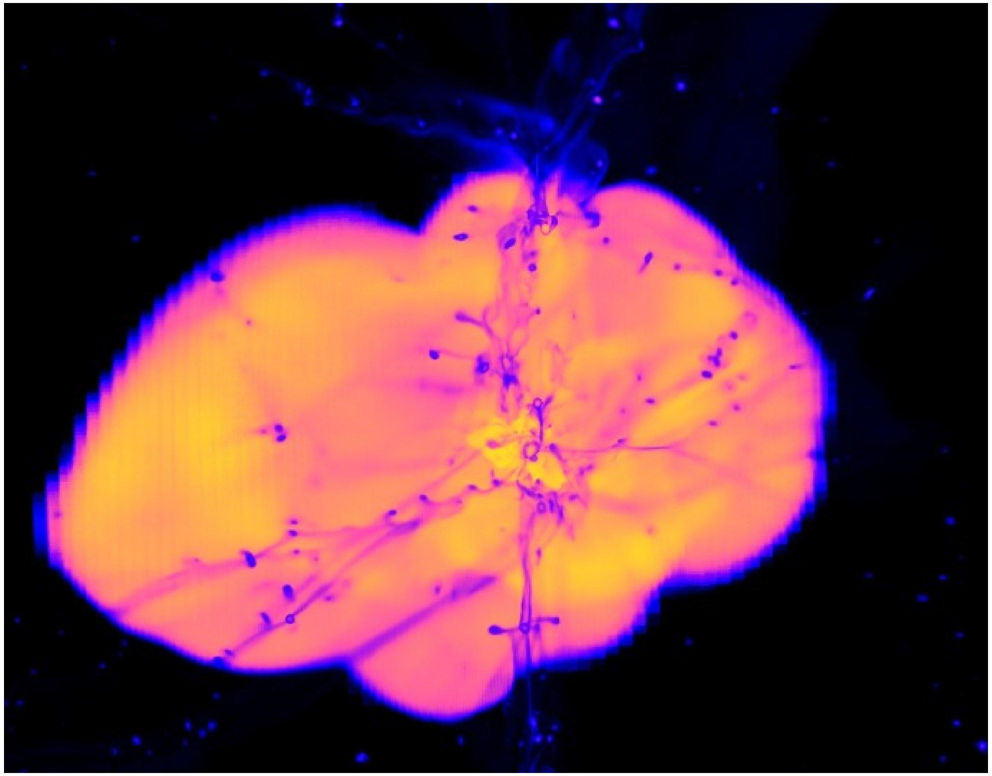
SMBH growth and feedback in the early Universe





Debora Sijacki

August 1 2018

Cosmological simulations of galaxy and structure formation

Provide ab initio physical understanding on all scales

Standard (and less standard) ingredients:

► “simple” ΛCDM assumption
(WDM, SIDM,…, evolving w,…, coupled DM+DE models,…)

► Newtonian gravity (dark matter and baryons)
(relativistic corrections, modified gravity models,...)

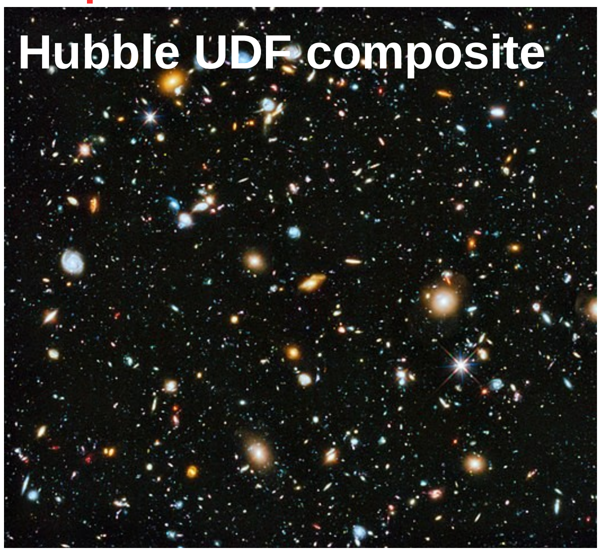
► Ideal gas hydrodynamics + collisionless dynamics of stars
(conduction, viscosity, MHD,…, stellar collisions, stellar hydro)

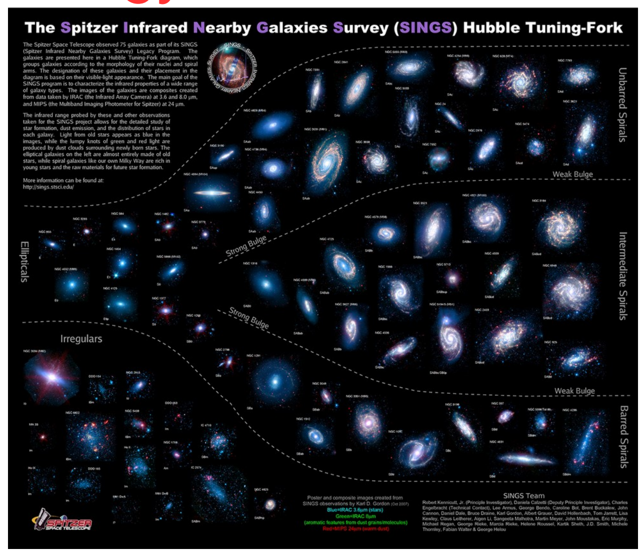
► Gas radiative cooling/heating, star & BH formation and feedback
(non equlibrium low T cooling, dust, turbulence, GMCs,…)

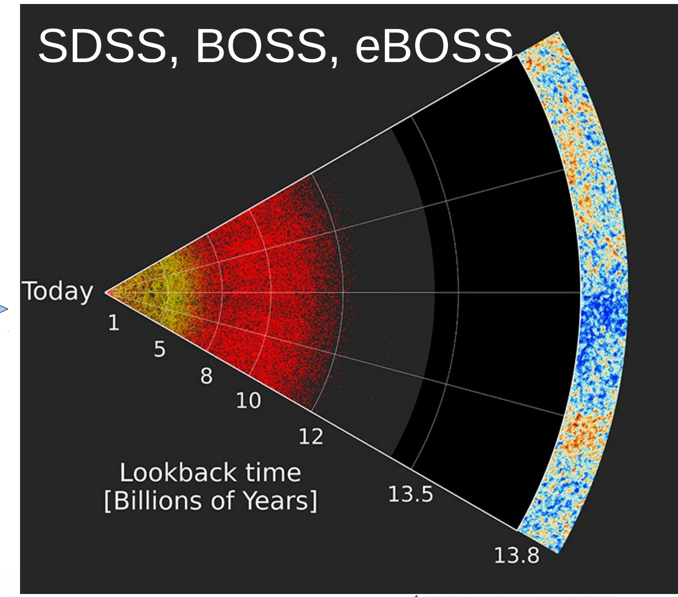
► Reionization in form of an uniform UV background
(simple accounting for the local sources,…, full RT on the fly)

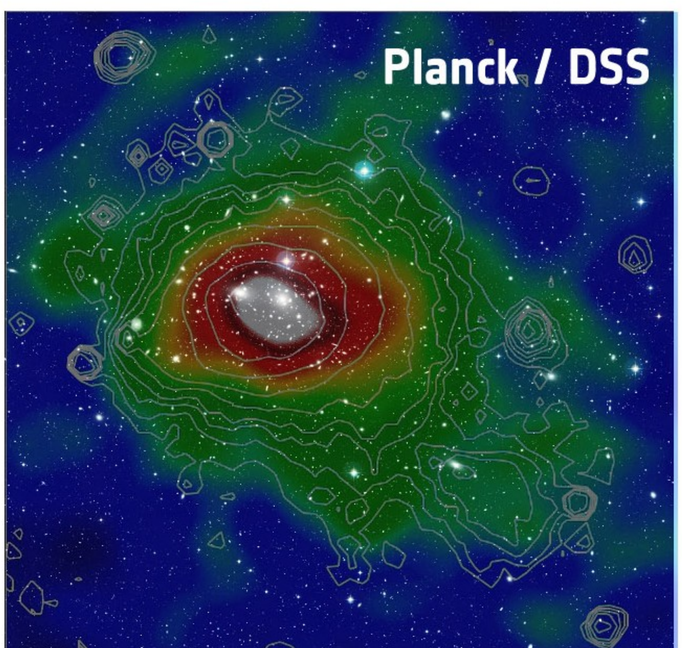
The importance of baryons

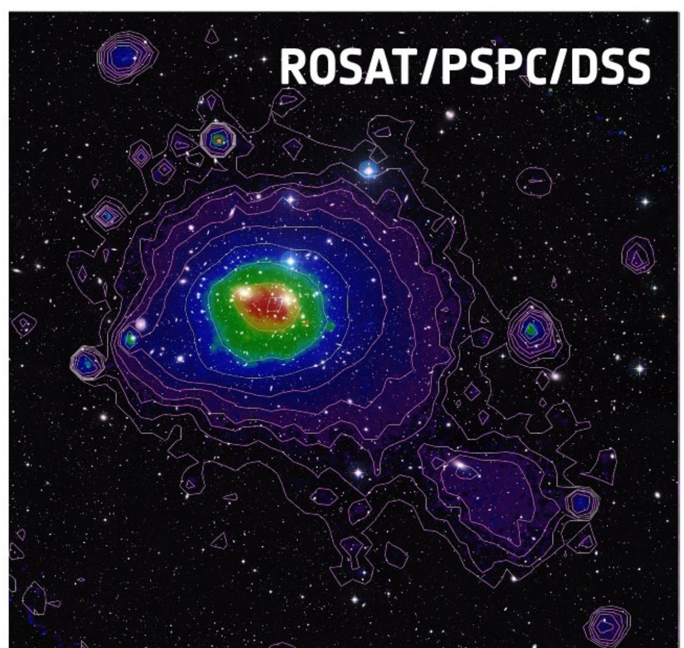
Baryons are directly observable and they affect the underlying dark matter distribution (contraction/expansion/shape/bias, WL,...) => profound implications for cosmology

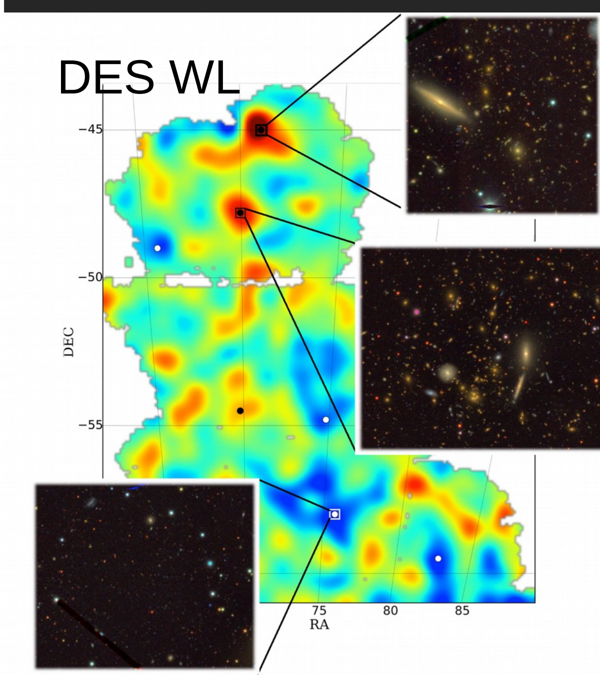






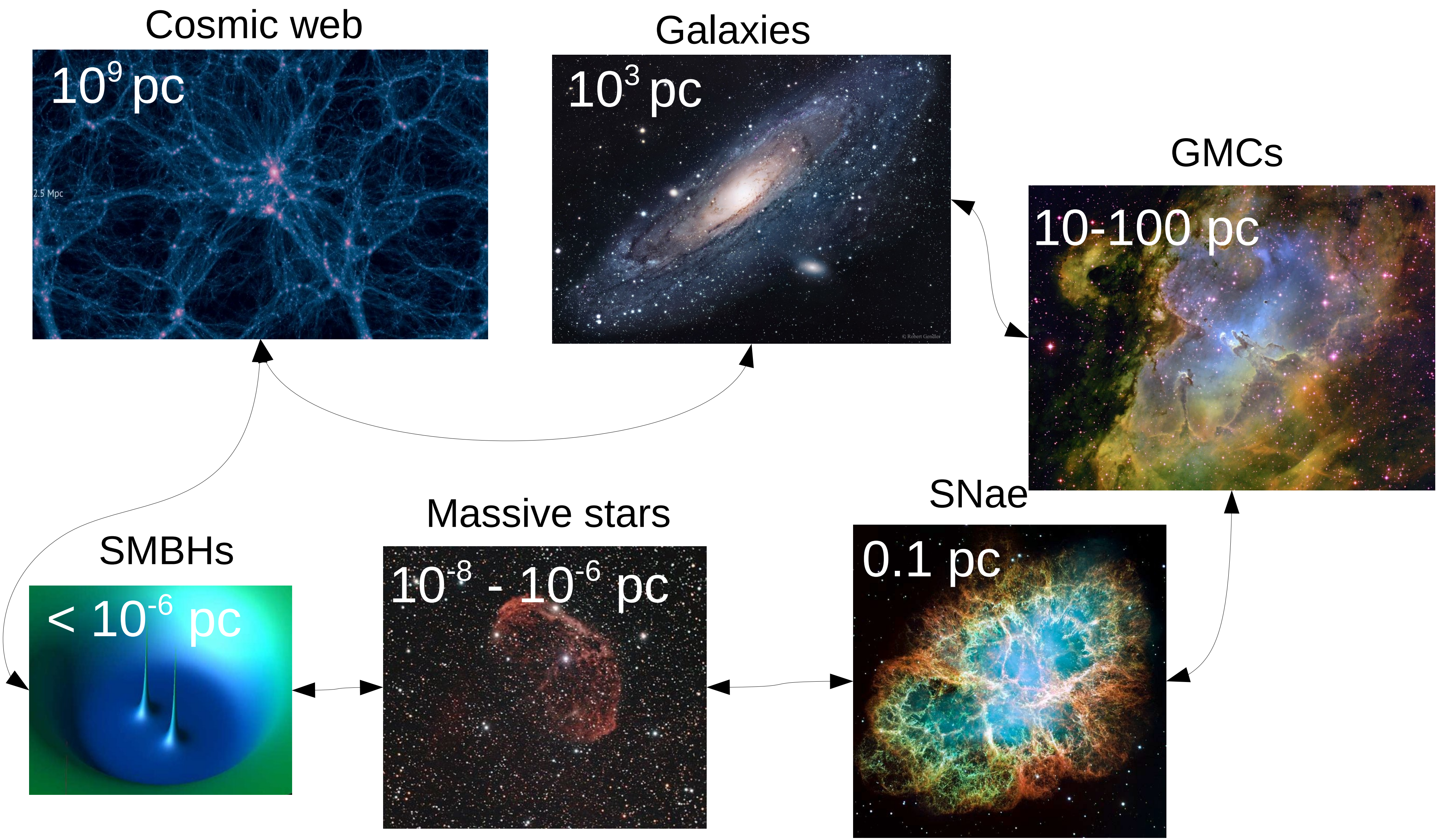






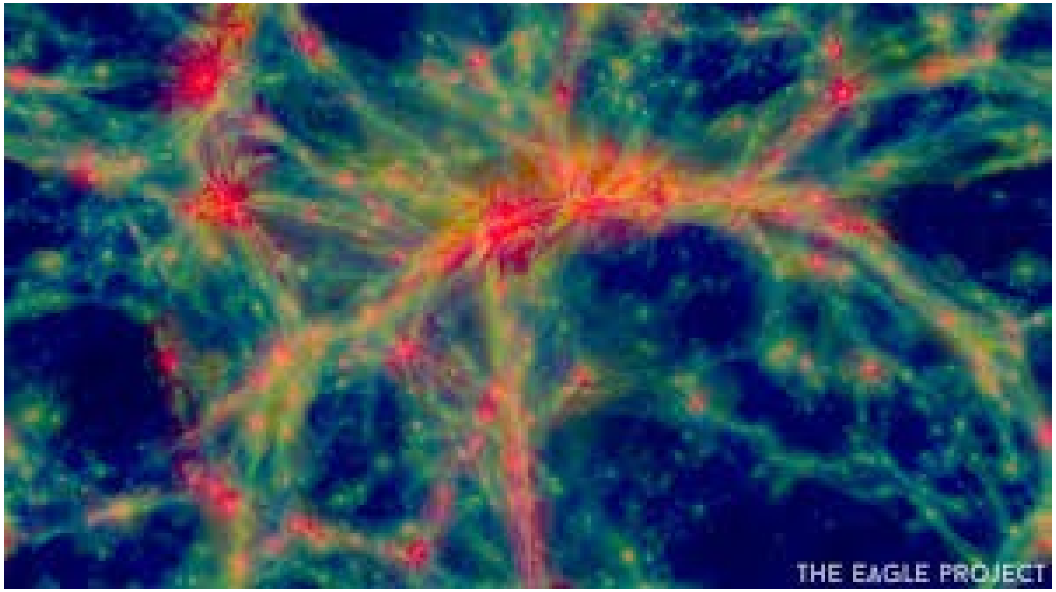
The importance of baryons

Vast range of spatial scales involved and very complex, non-linear physics → SUB-GRID models (“free parameters” constrained by obs)

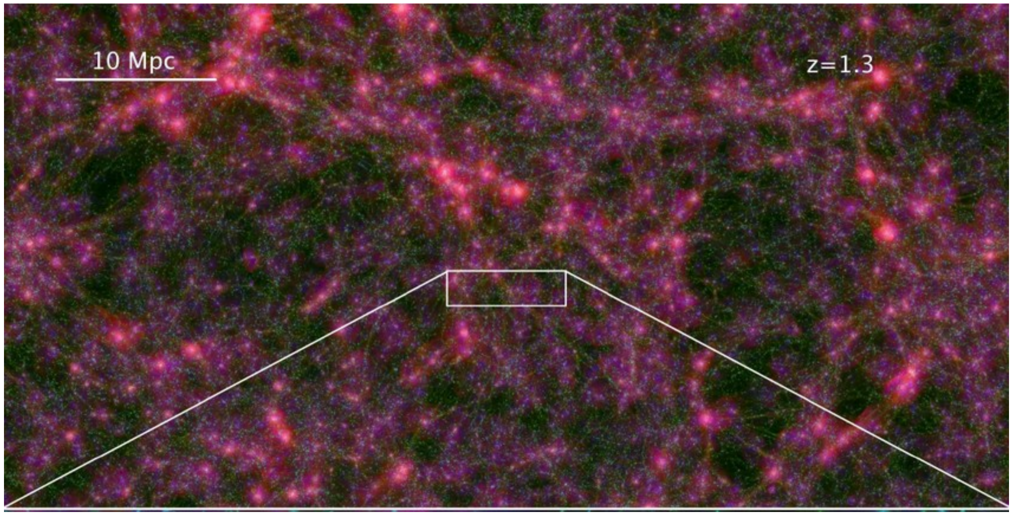


Current state-of-the-art in cosmological hydro simulations

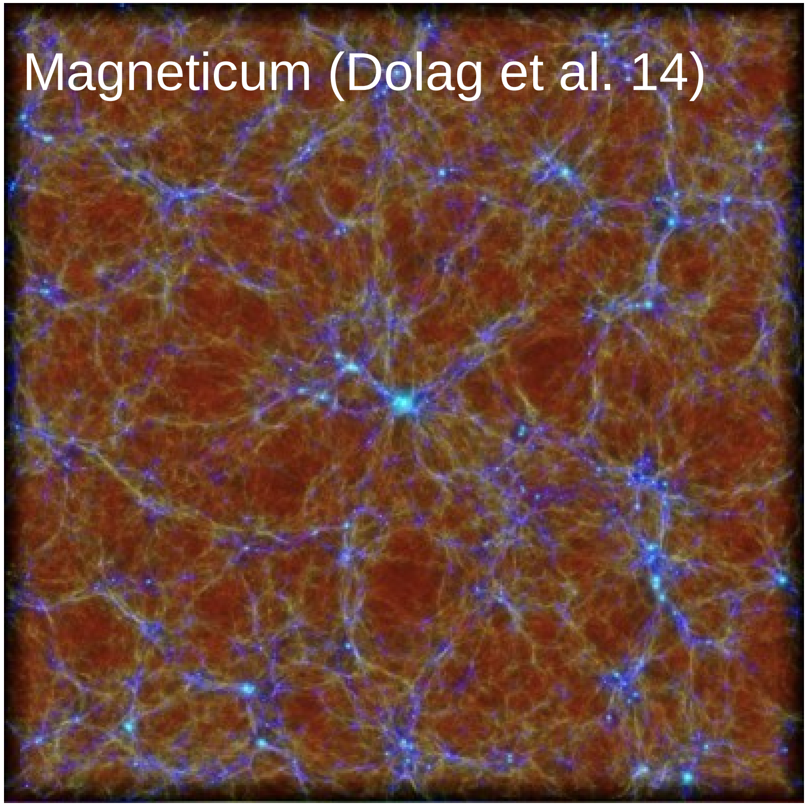
The Eagle Project (Schaye et al. 15)



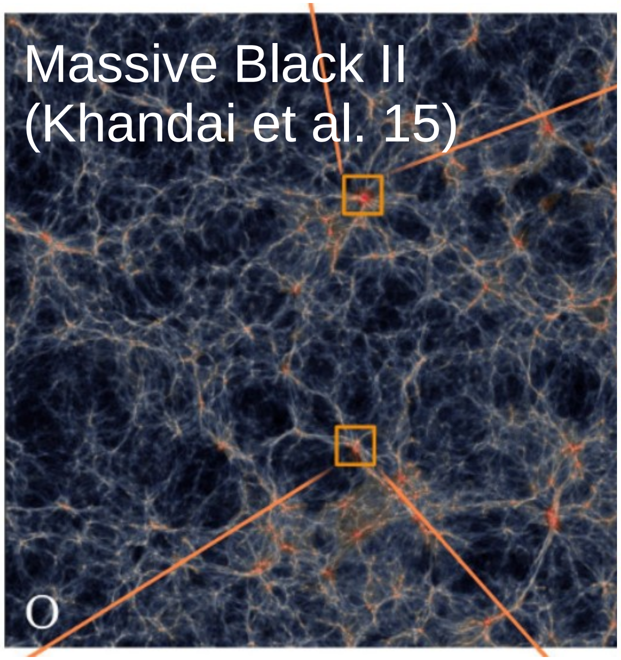
The Horizon AGN project (Dubois et al. 14)



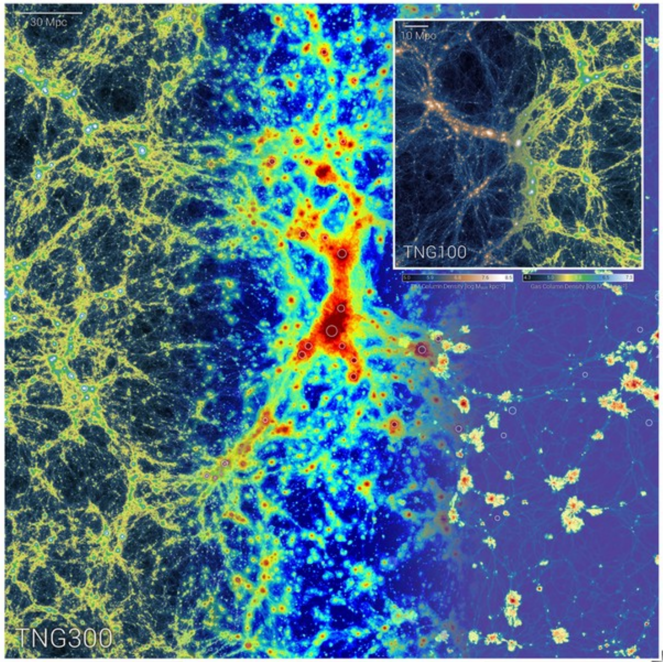
Magneticum (Dolag et al. 14)



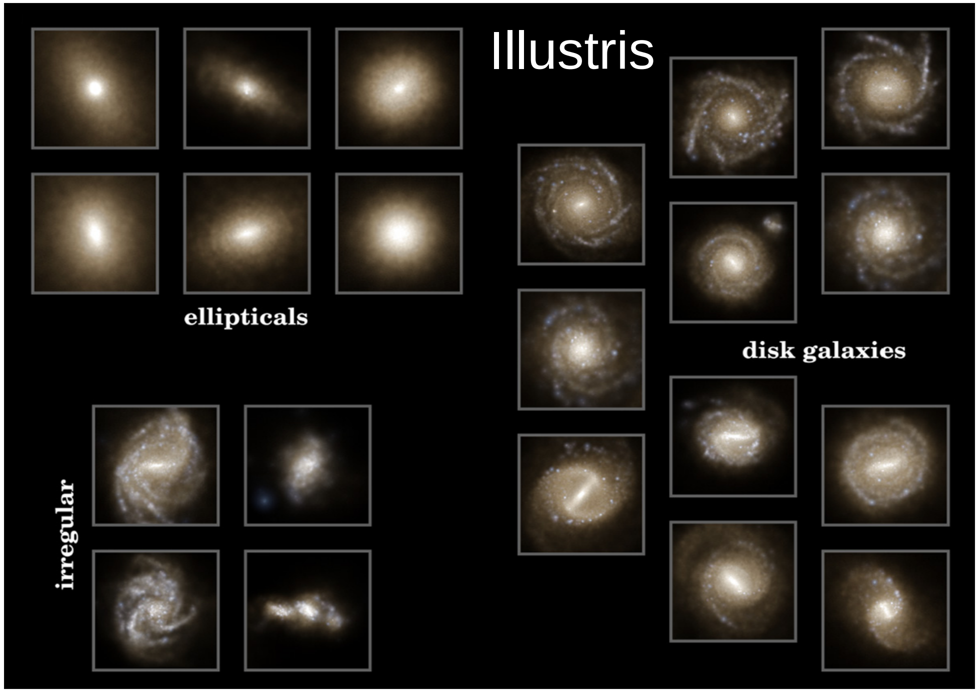
Massive Black II (Khandai et al. 15)

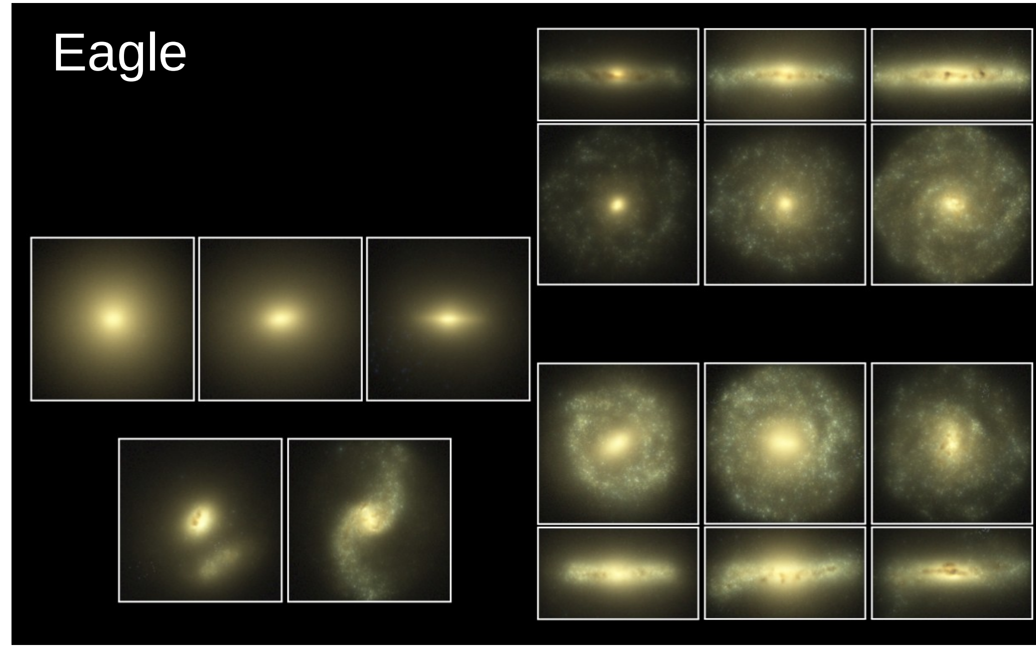


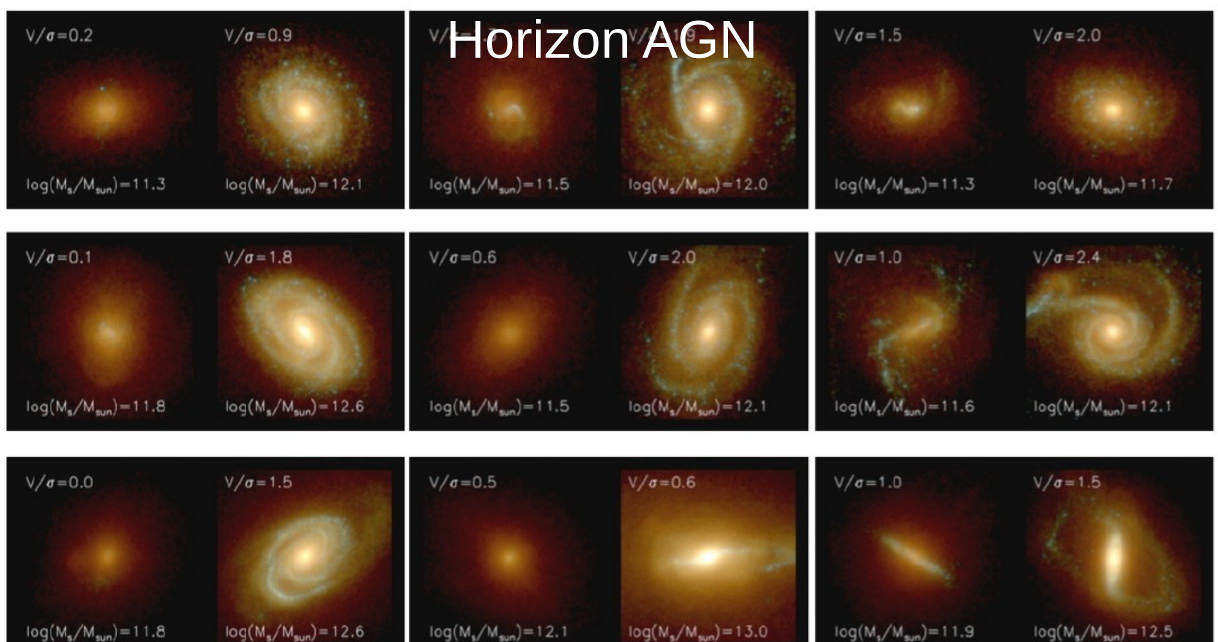
Illustris TNG (Springel et al. 17)



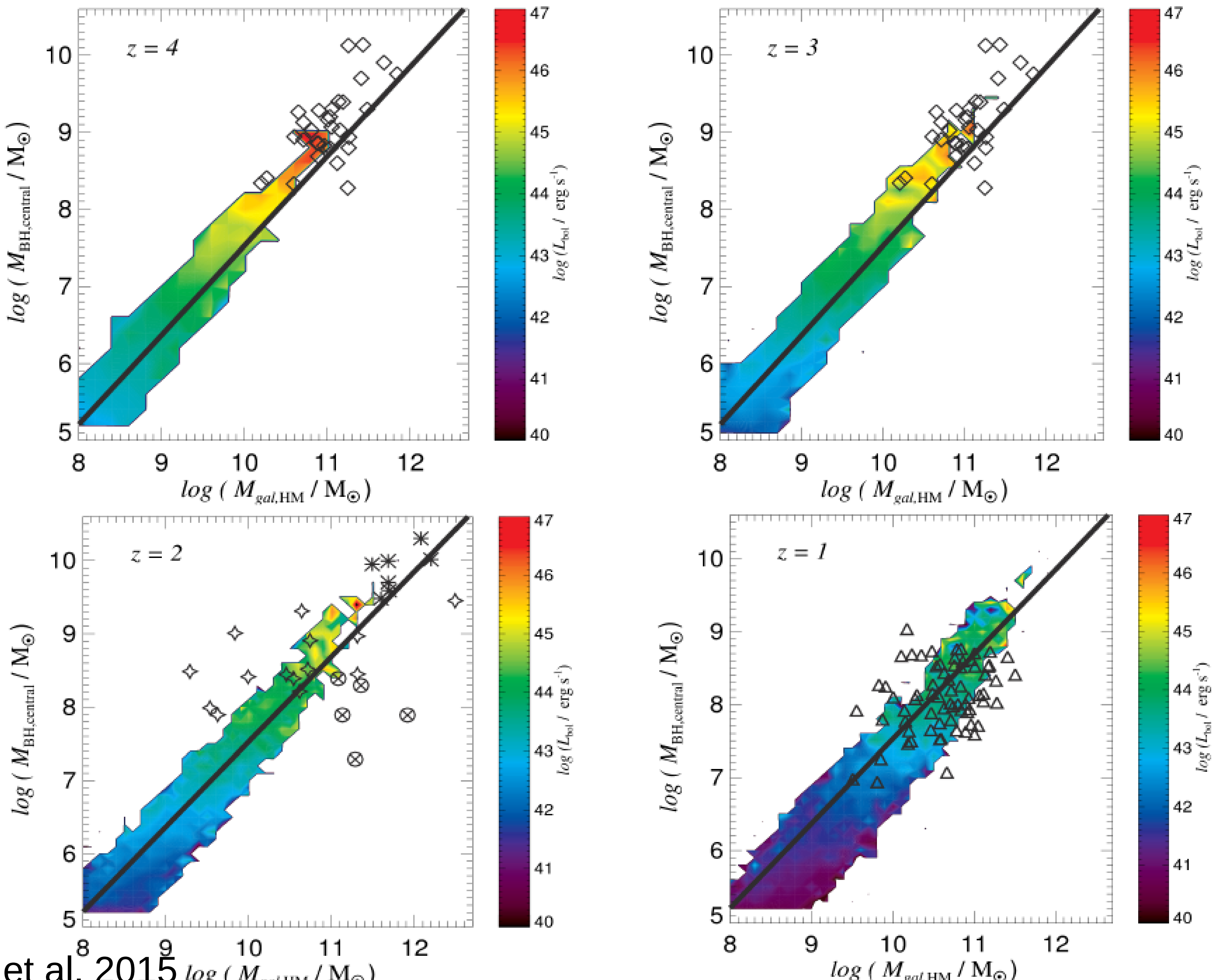
AGN feedback is the key for galaxy morphologies







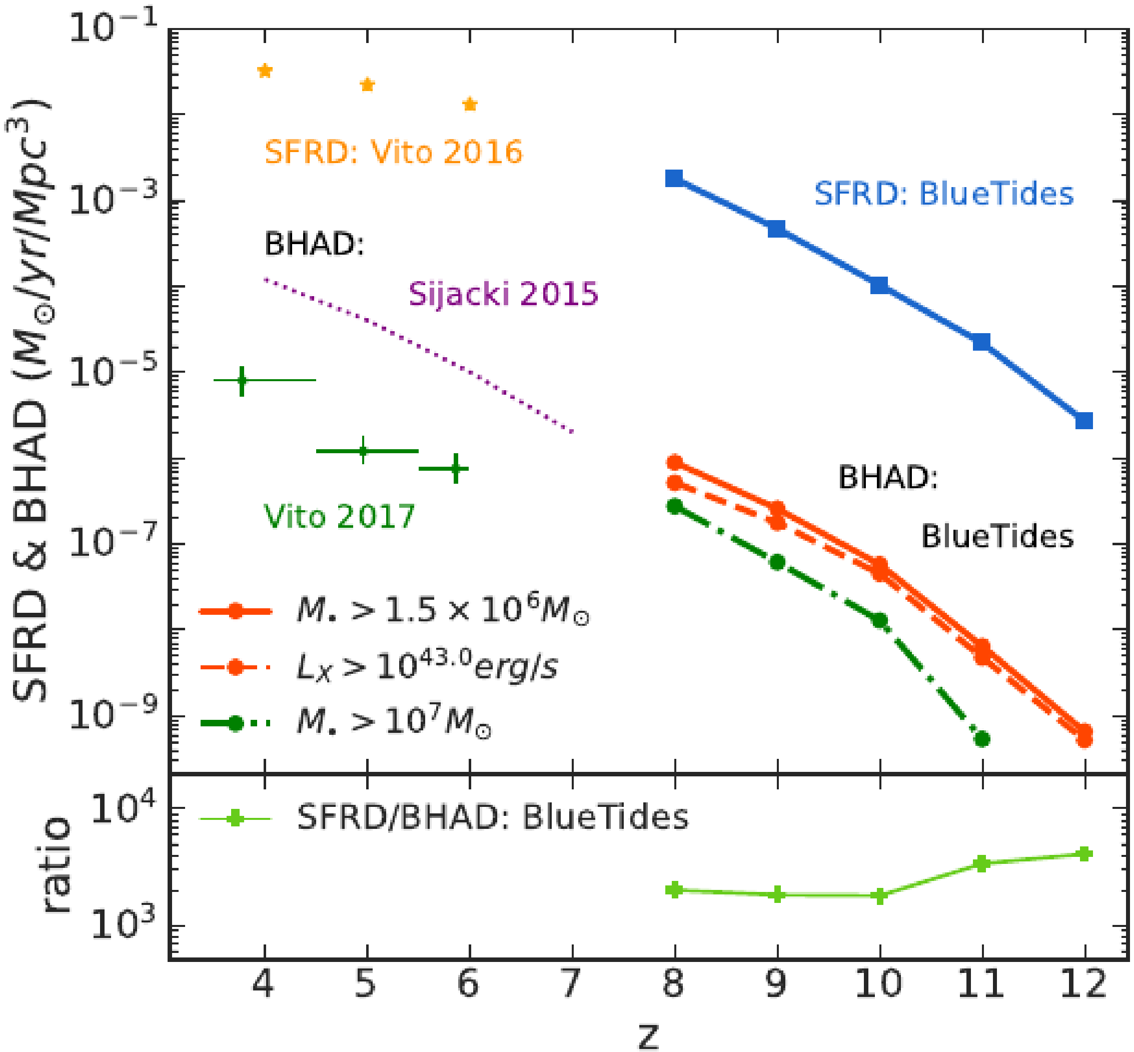
Feedback at higher z: BHs scaling relation evolution

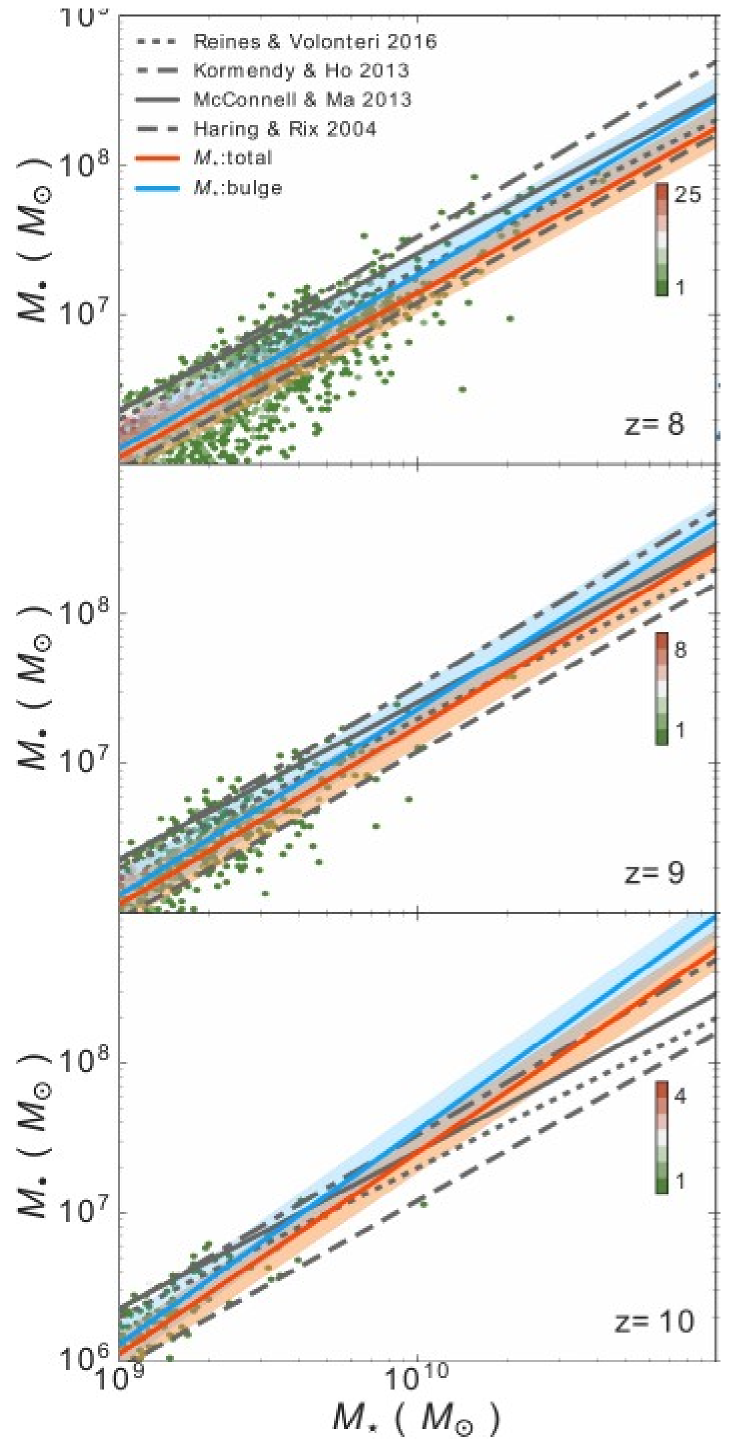


Kormendy & Ho, 2013
AGN/QSOs z = 0.1-4
RGs and SMGs z = 2

Sijacki et al. 2015

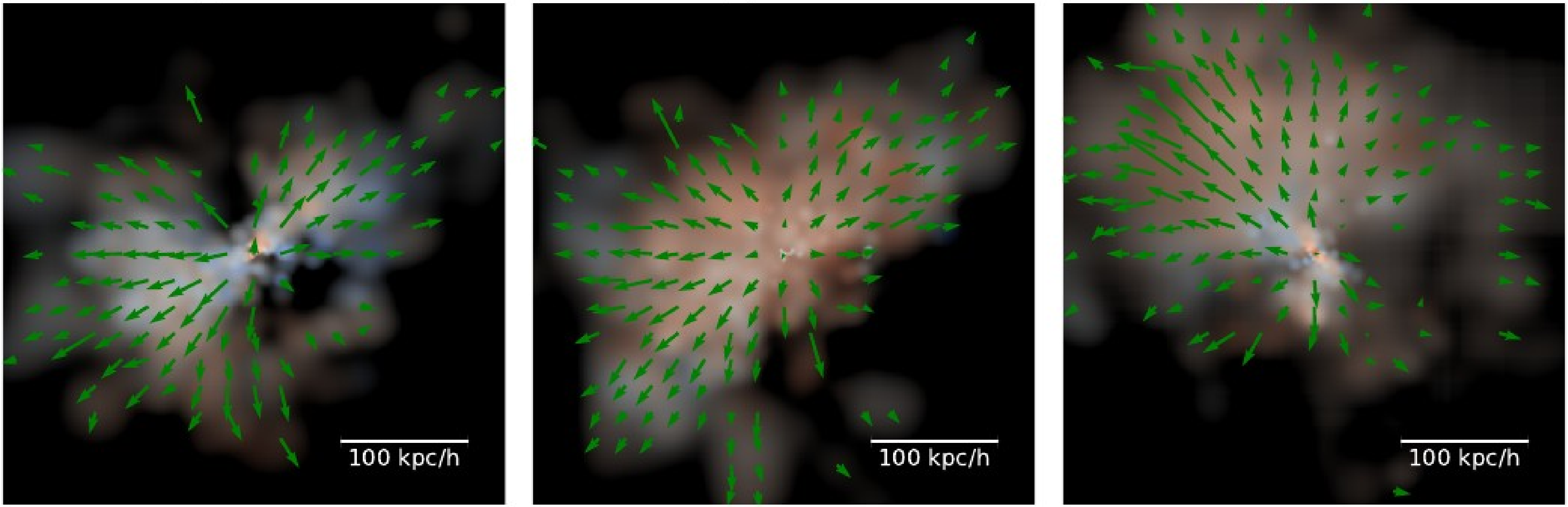
Feedback at higher z: BHs scaling relation evolution



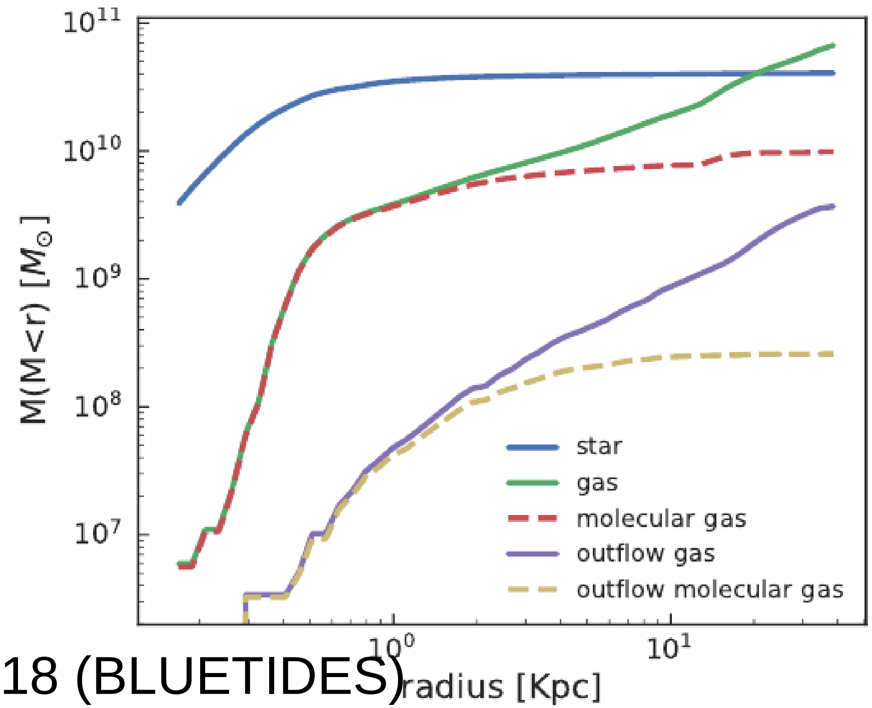


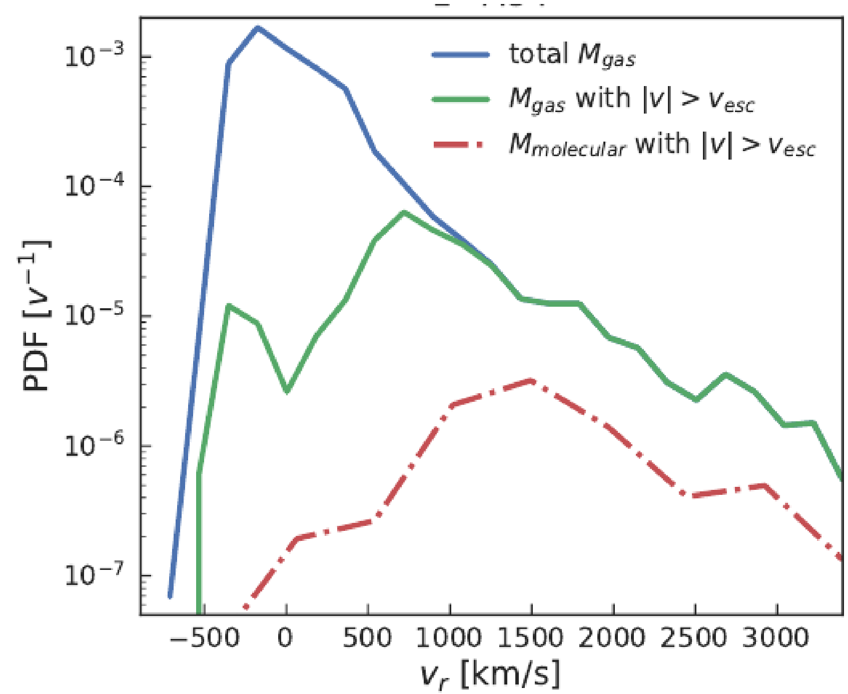
Huang et al. 2018 (BLUETIDES: 400Mpc/h box)

SMBH feedback at high z



(d) outflow gas, z=7.95 (e) outflow gas, z=7.85 (f) outflow gas, z=7.54



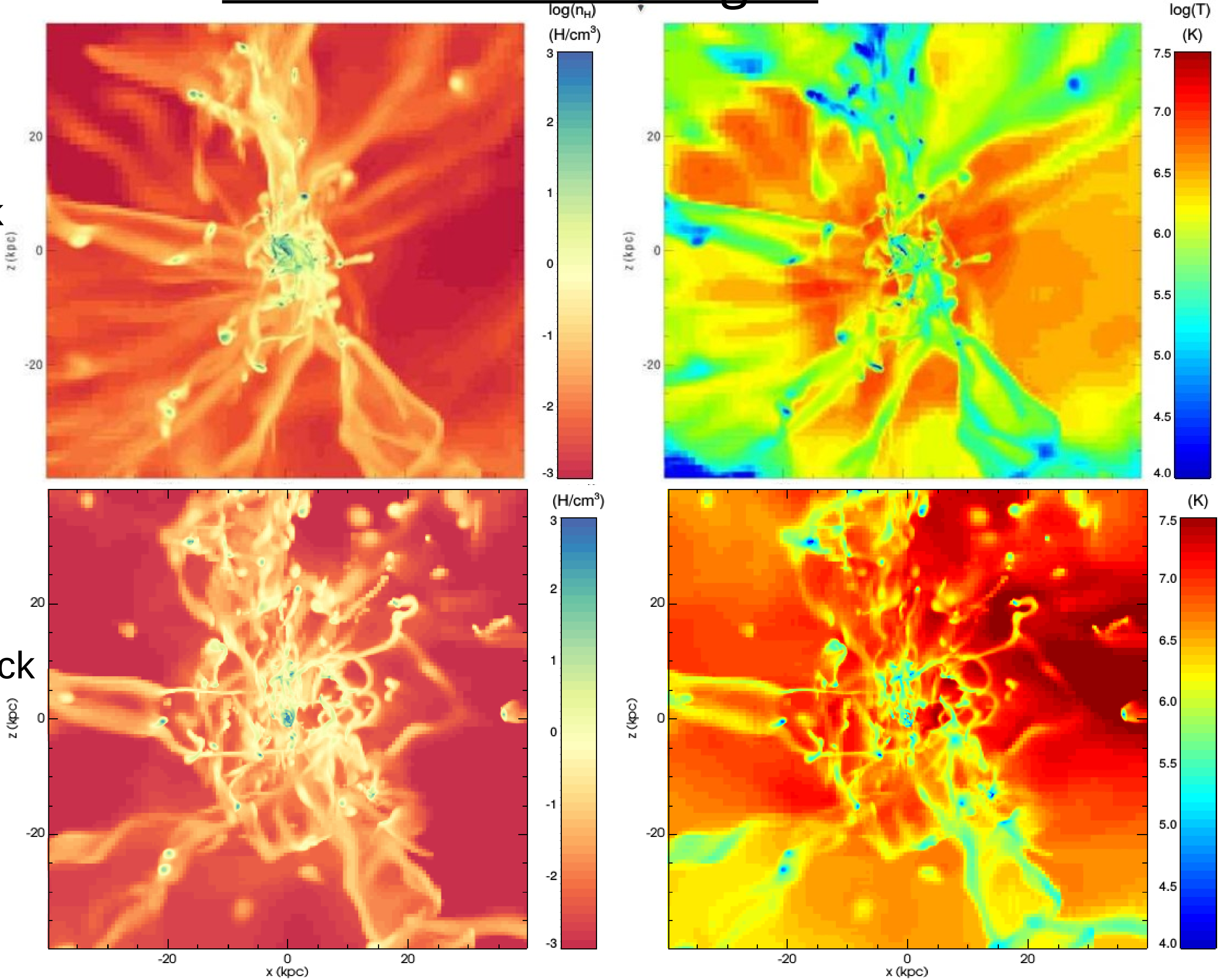


Ni et al. 2018 (BLUETIDES)

SMBH feedback at high z

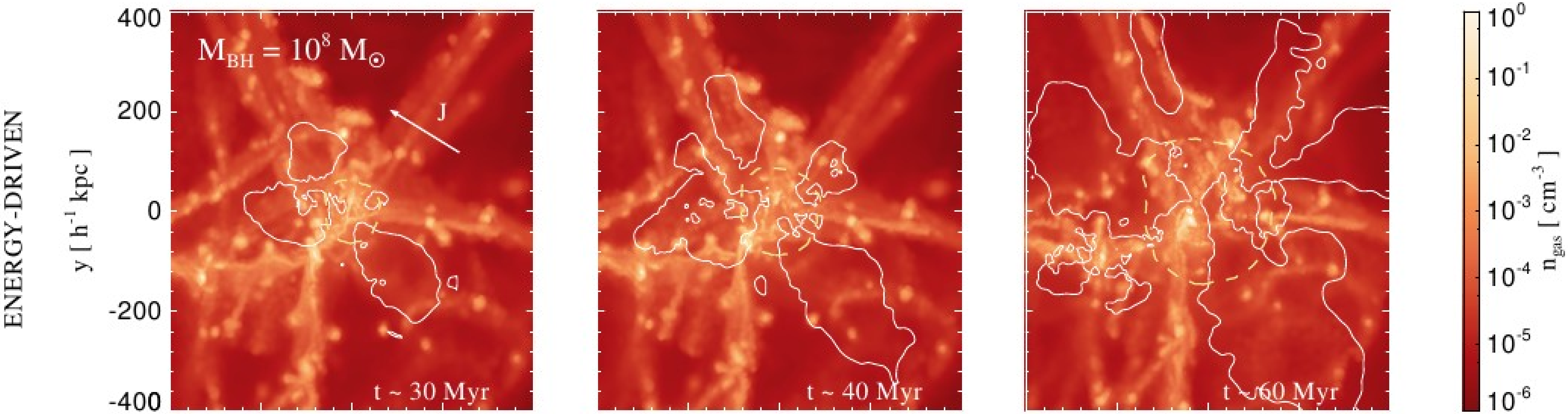
SN feedback

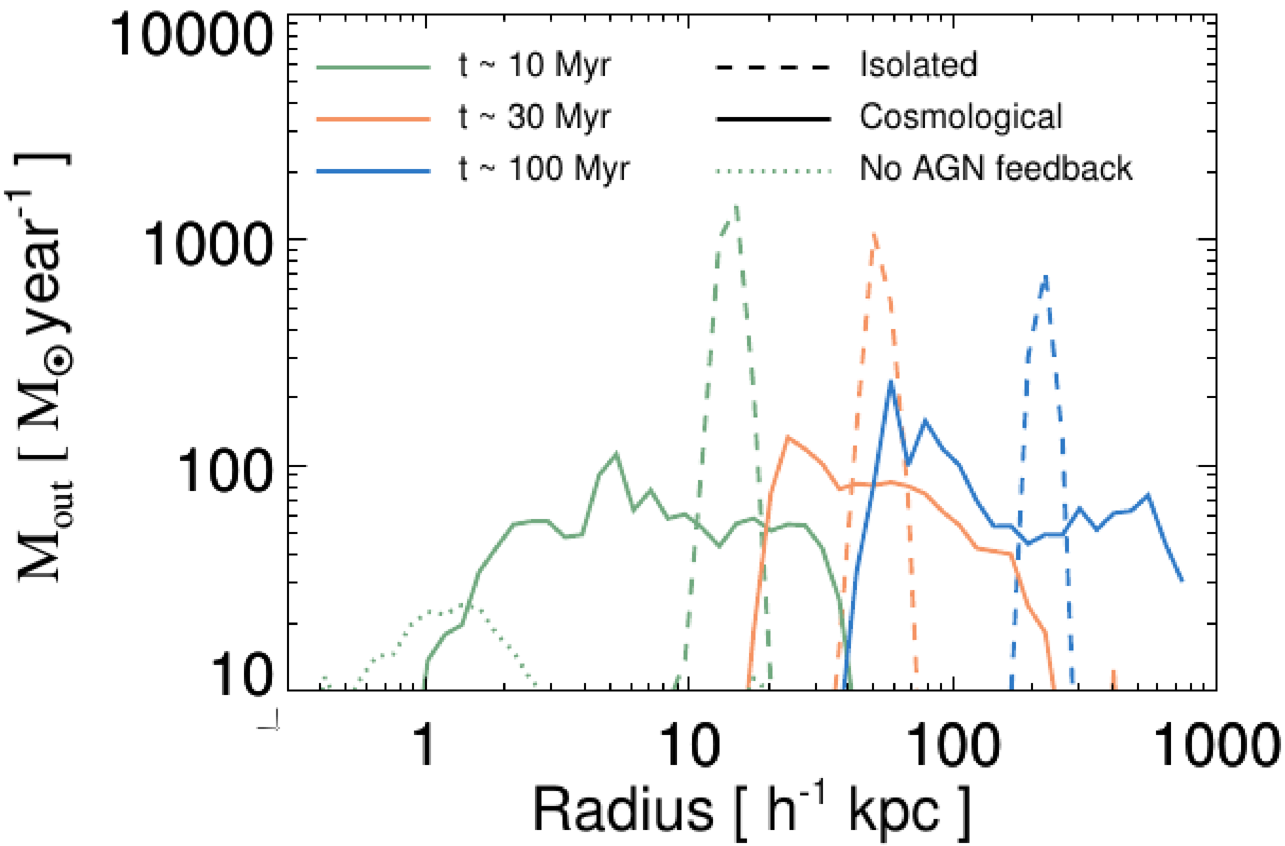
AGN feedback



Dubois et al. 2013 (see also Barai et al. 2018, Biernacki et al. 2018, Zubovas et al. 2014)

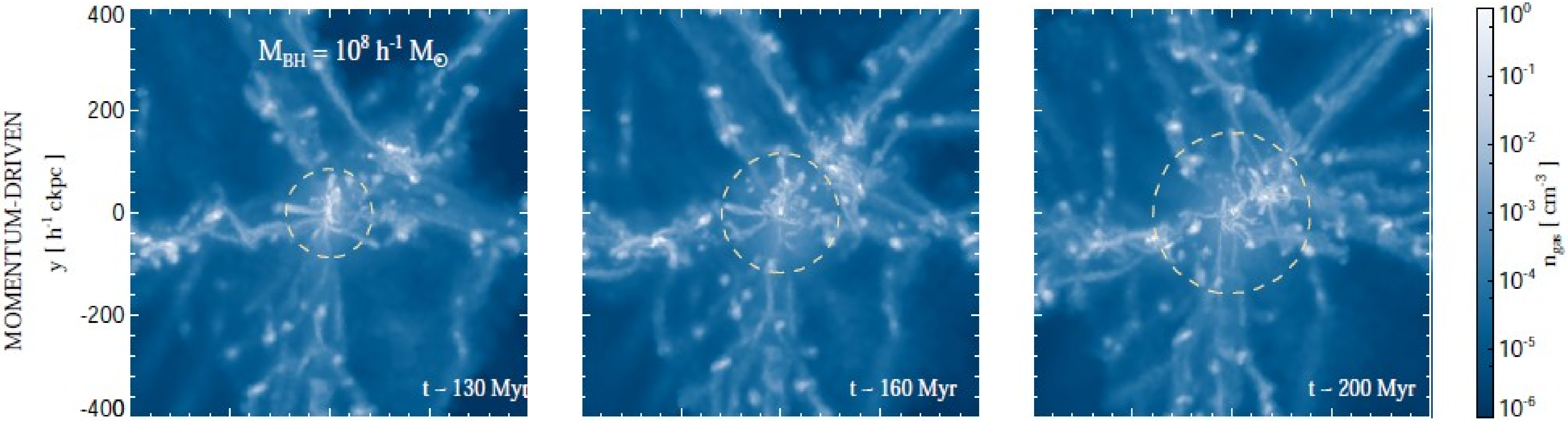
Calibrating AGN feedback: Energy-driven outflow

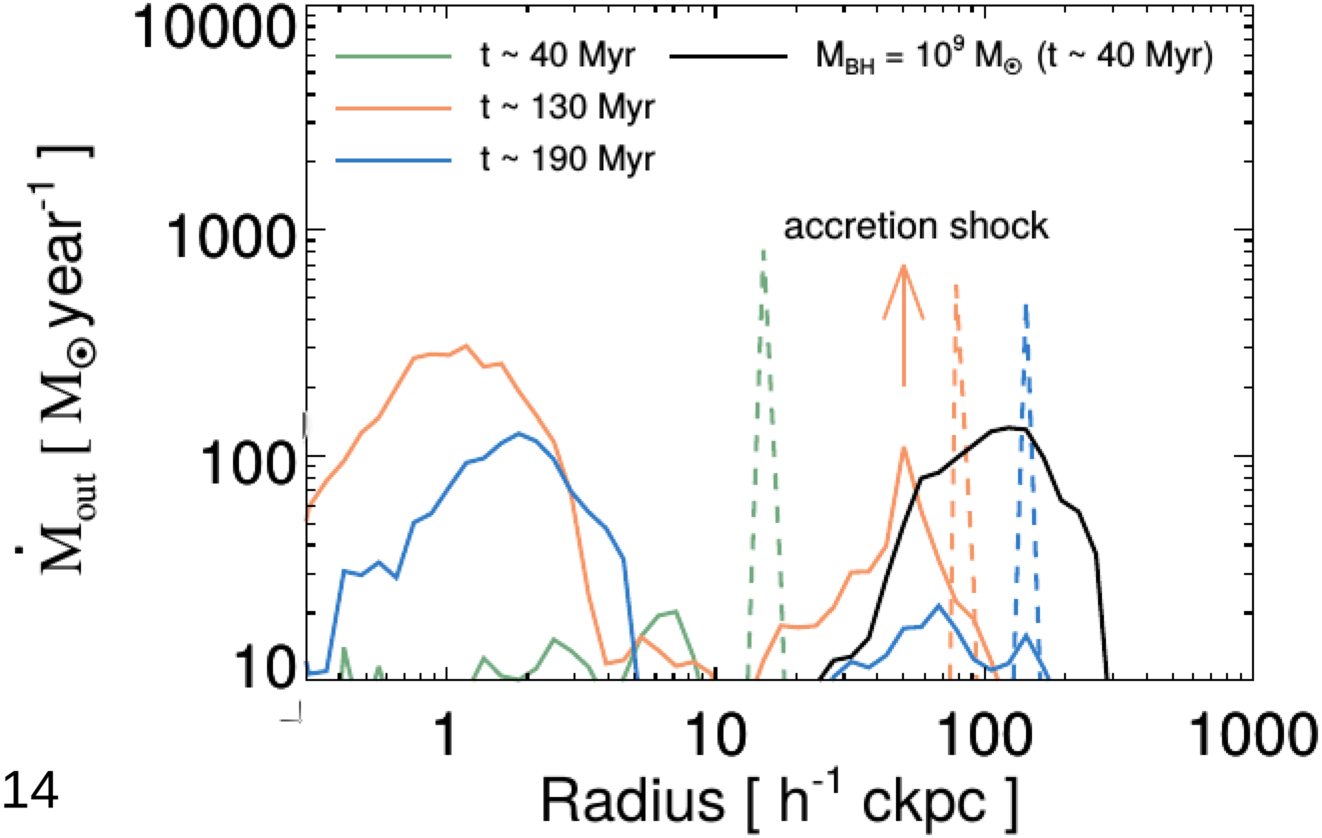




Costa, Sijacki & Haehnelt, 2014

Calibrating AGN feedback: Momentum-driven outflow

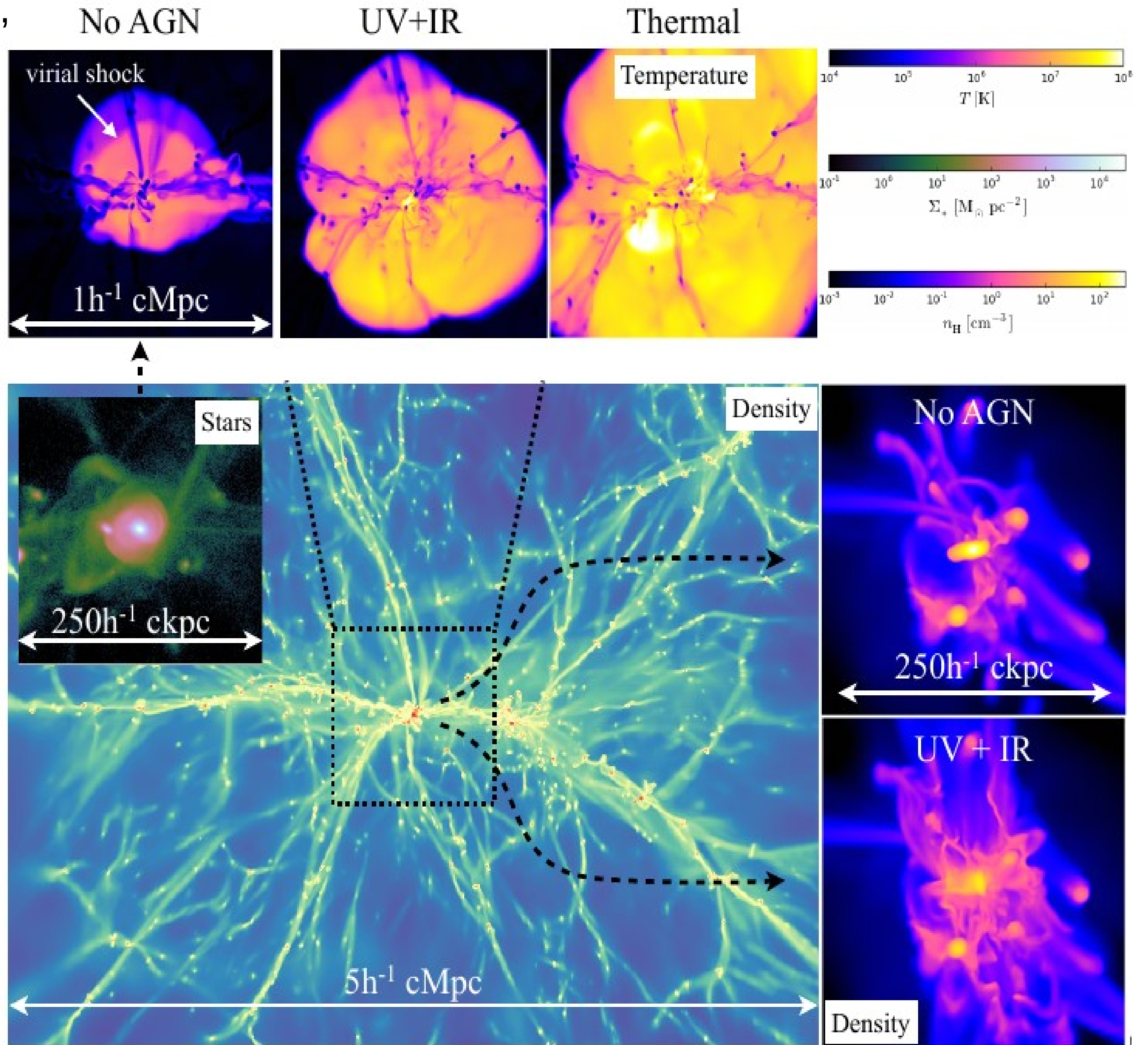




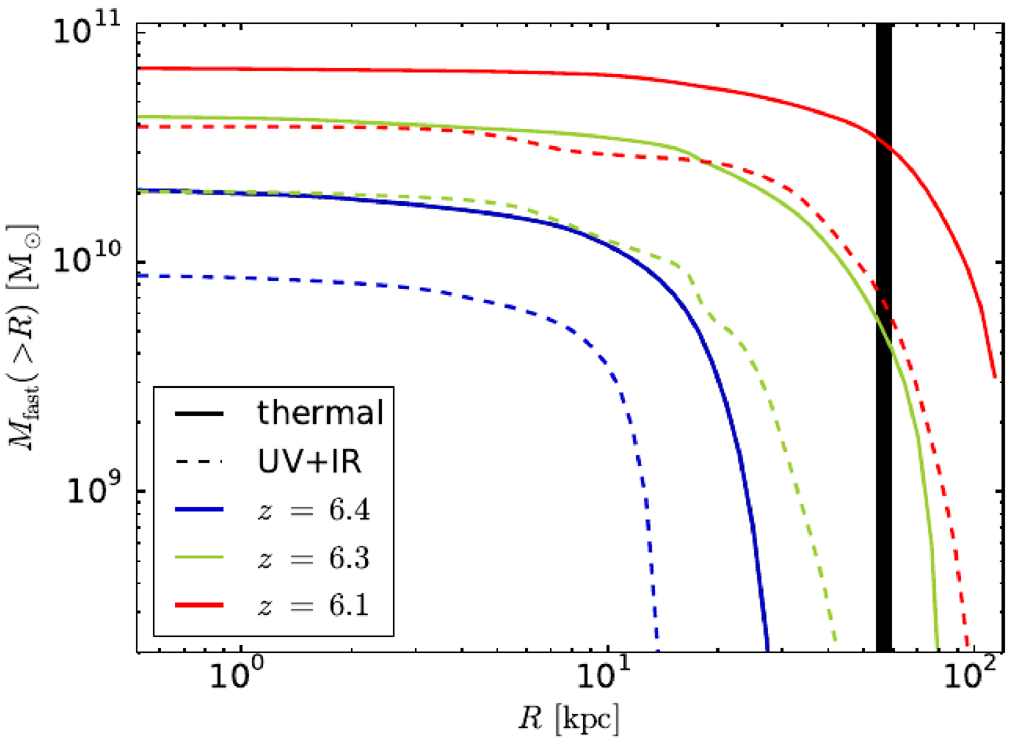
Costa, Sijacki & Haehnelt, 2014

Calibrating AGN feedback: RP-driven outflow

Costa, Rosdahl, Sijacki, Haehnelt, 2018

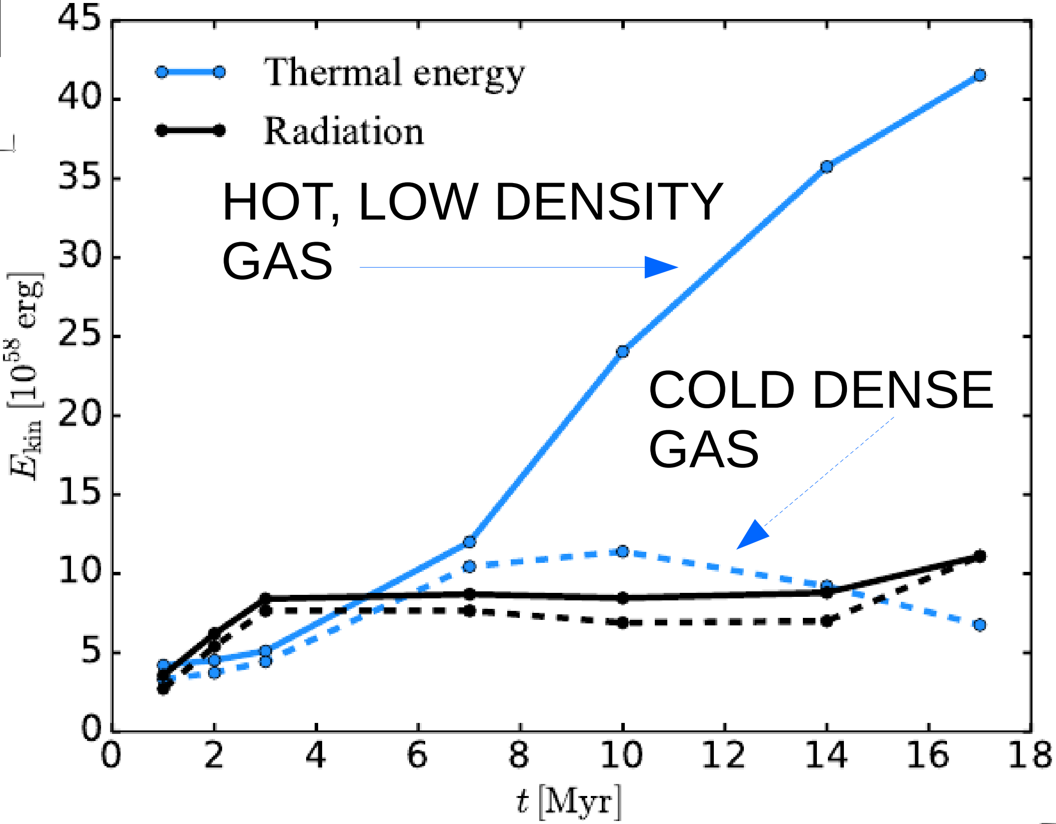


Calibrating AGN feedback: RP-driven outflow



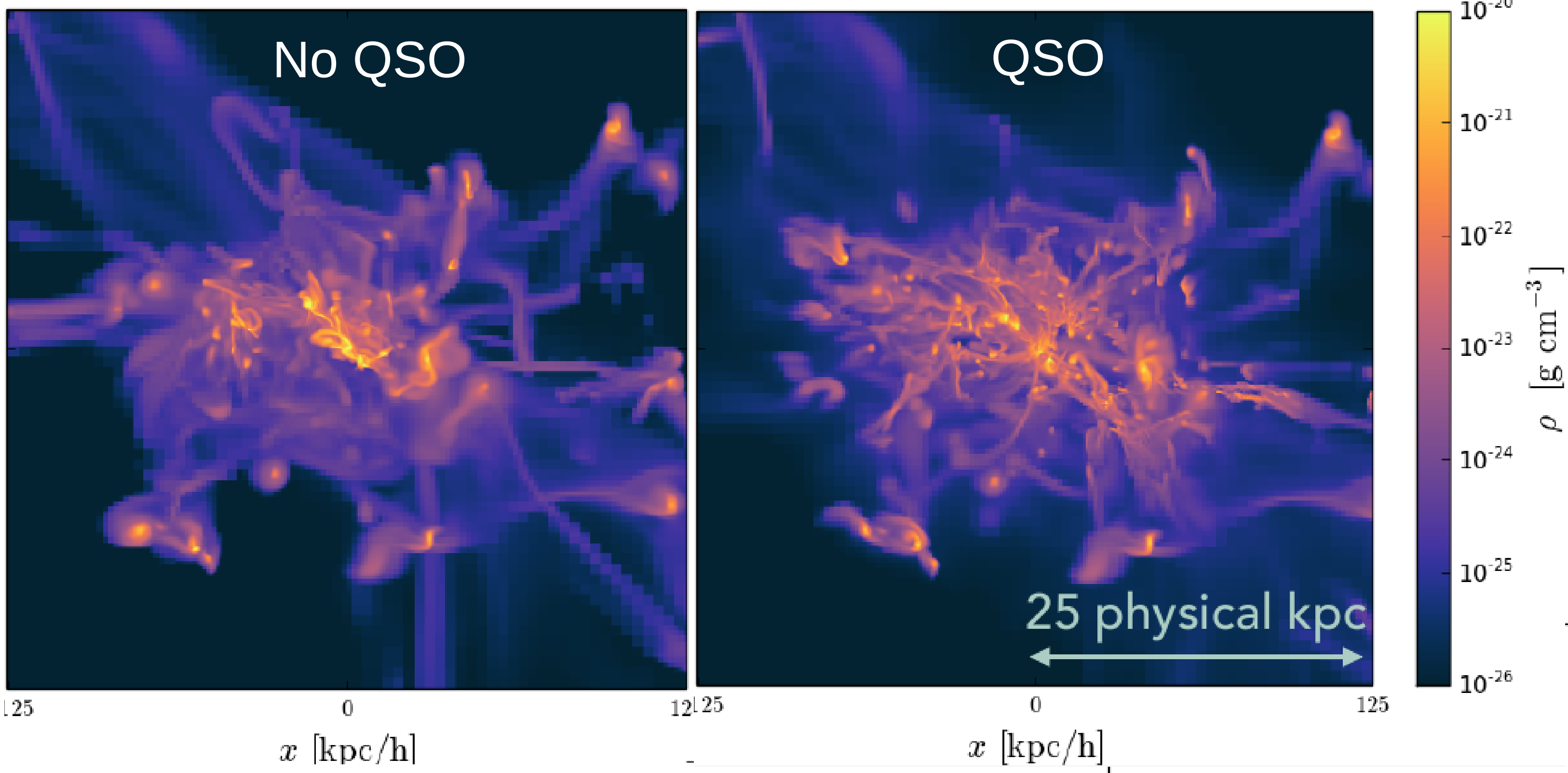
Gas mass distribution with v_R > 500 km/s

Gas kinetic energy with v_R > 300 km/s

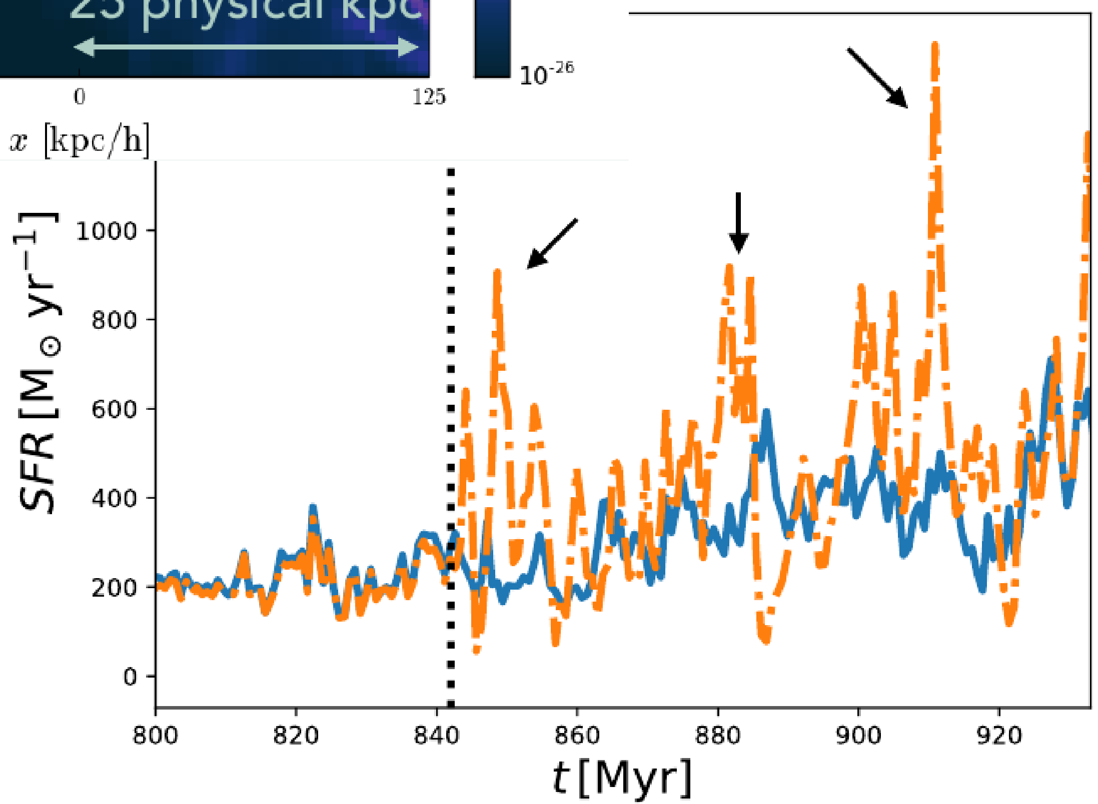


Costa, Rosdahl, Sijacki, Haehnelt, 2018

Calibrating AGN feedback: RP-driven positive feedback?



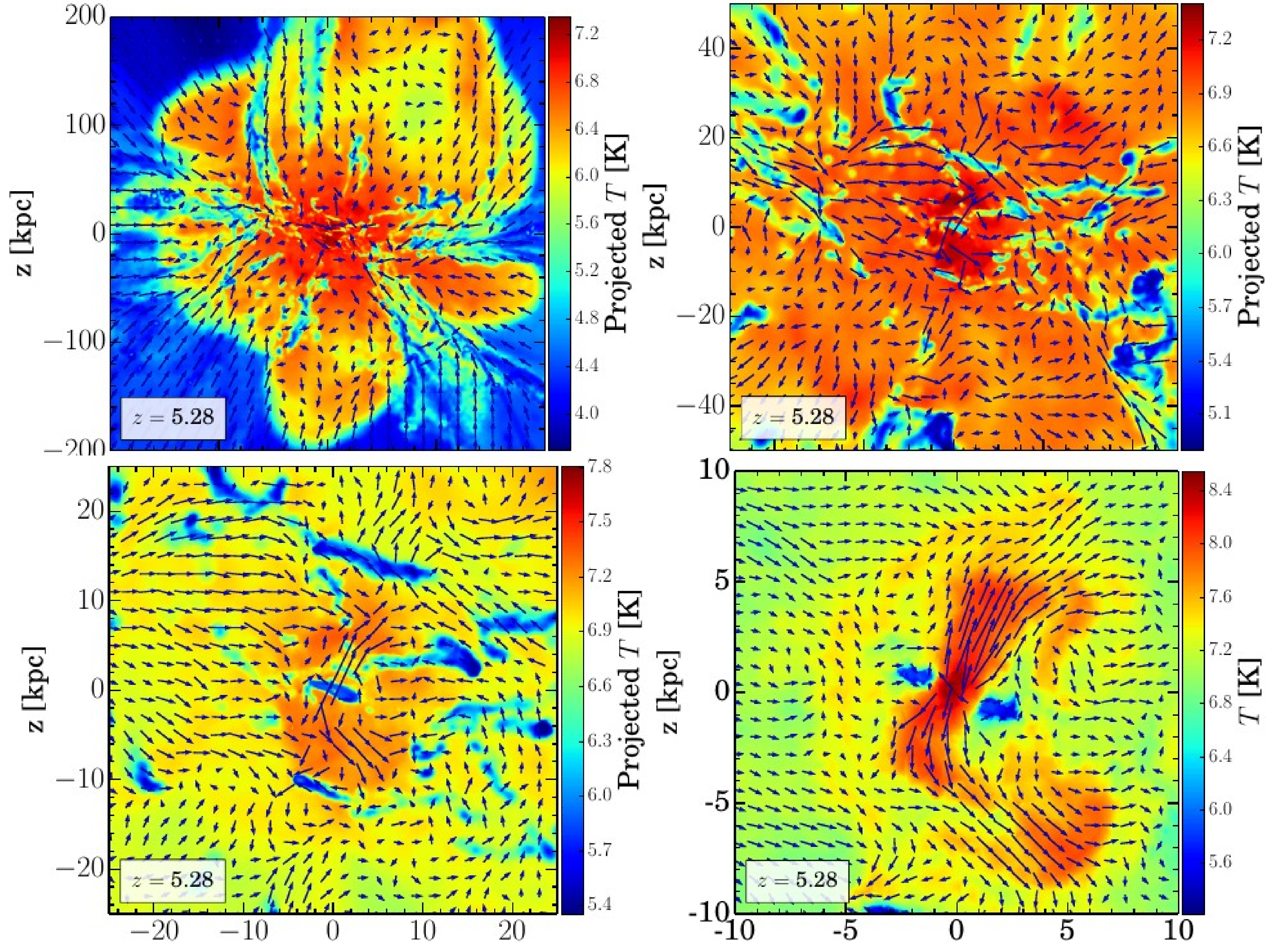
Different SF prescription changes the nature of AGN feedback



Costa, Rosdahl & Kimm, in prep.

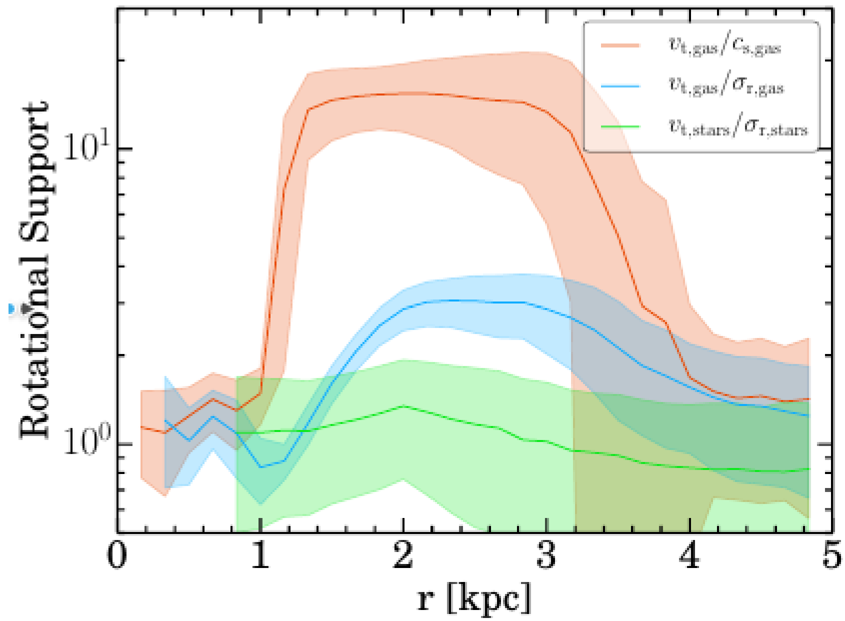
Calibrating AGN feedback: resolution effects

Curtis & Sijacki 2016

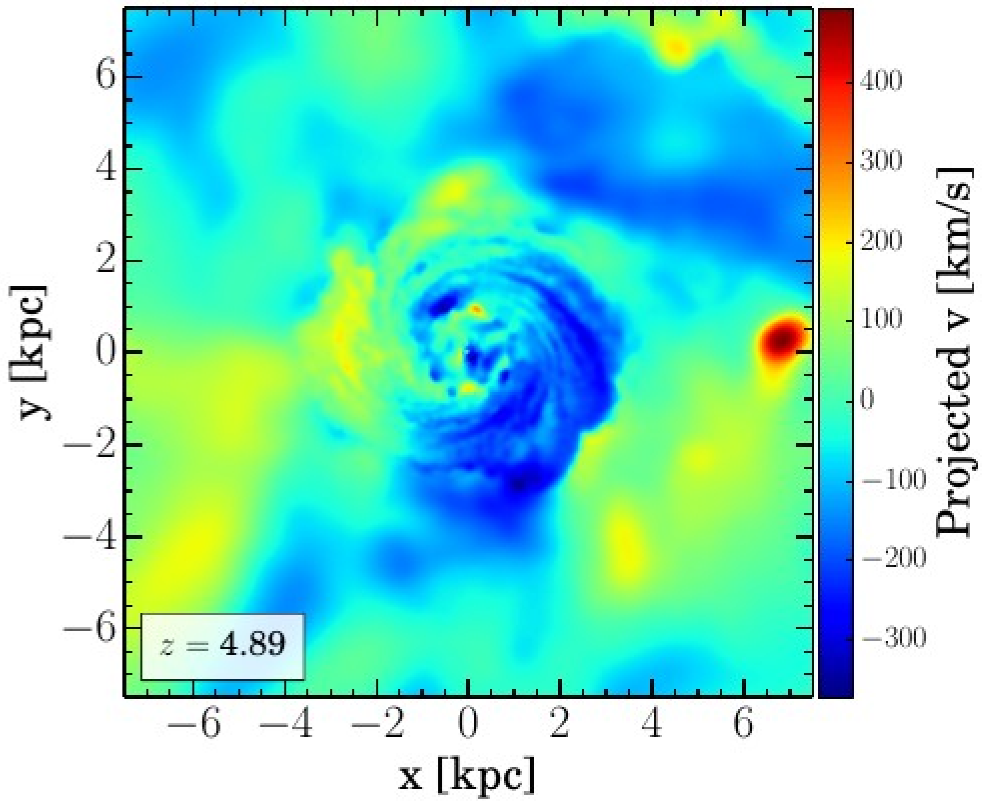


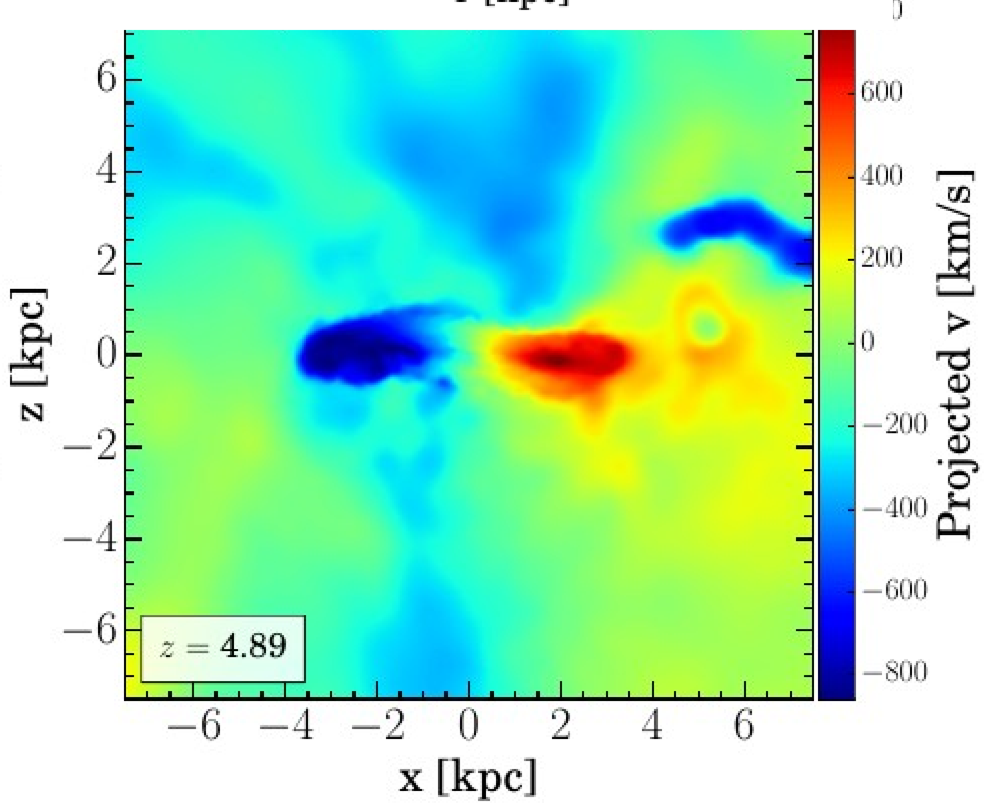
Calibrating AGN feedback: resolution effects

Have we understood morphological evolution of galaxies and quenching?



Curtis & Sijacki 2016





Caveats

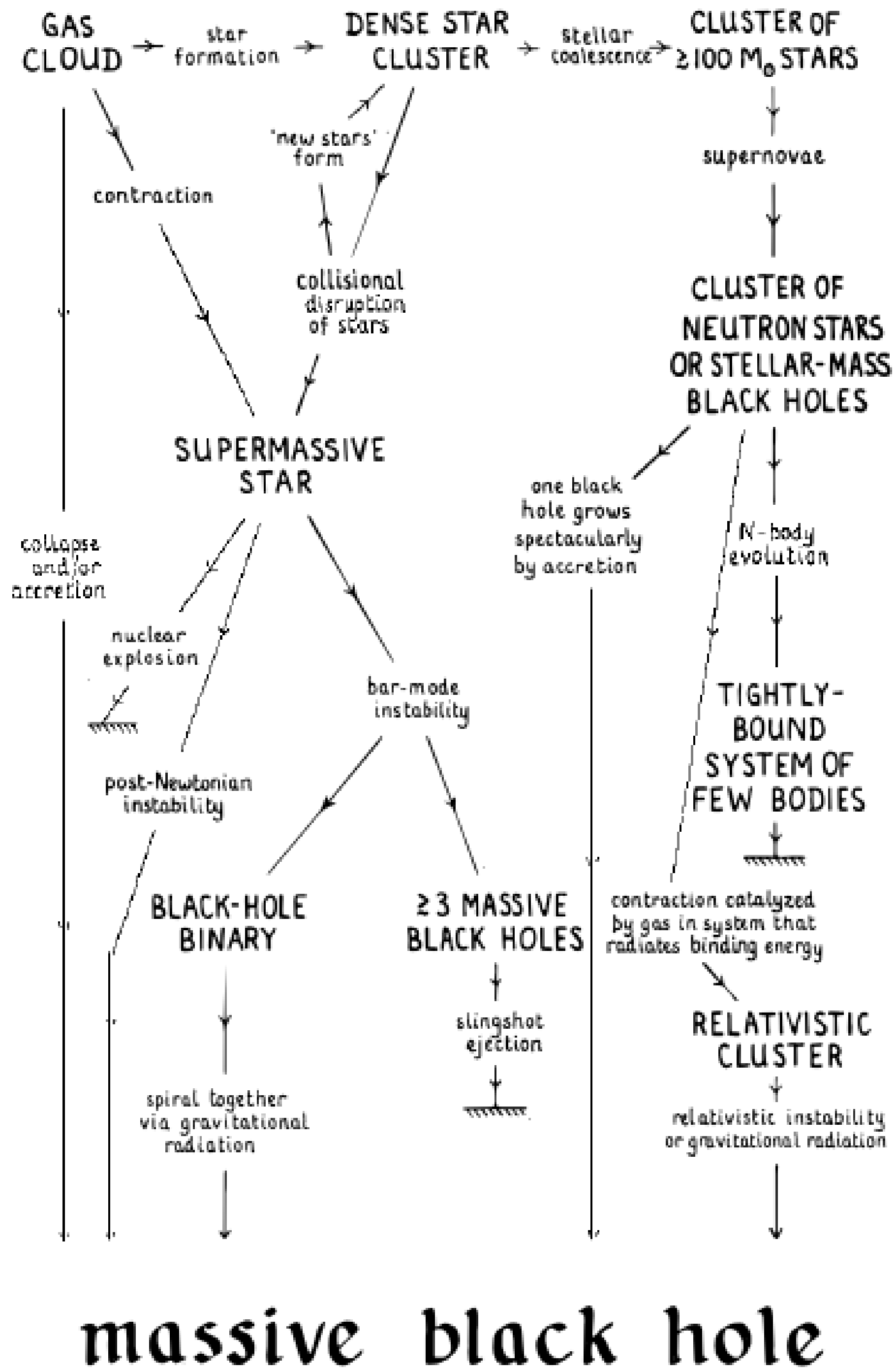
- Majority of these models assume very massive seeds → helps kick start BH growth for z ~6 QSOs

- Majority of these models assumes all massive haloes have SMBHs seeds

- Majority of these models assumes “Bondi-Hoyle”-like accretion → helps kick start BH growth and reach Eddington limit

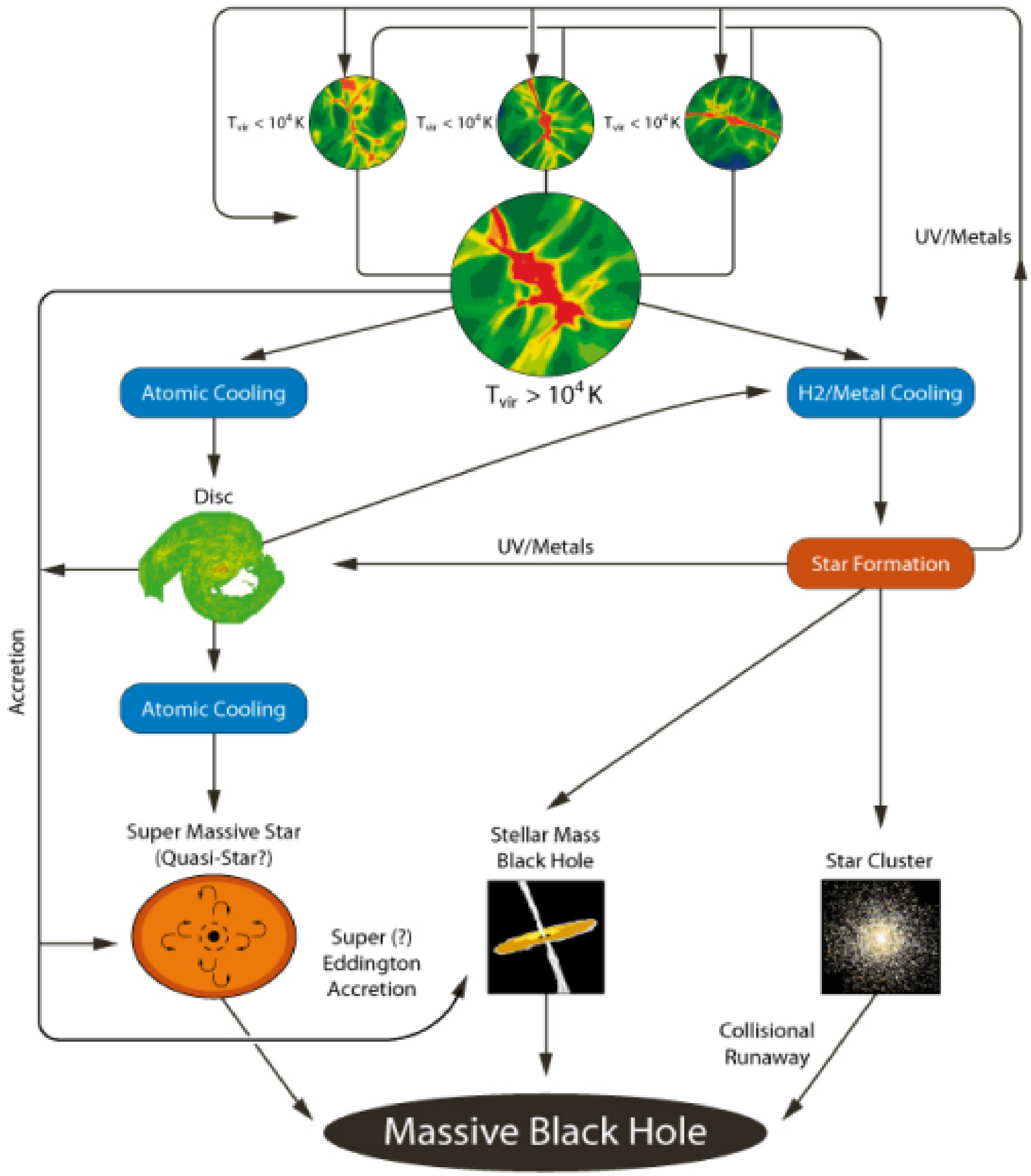
- Majority of these models neglects various early feedback processes, e.g. radiation from stars, stellar winds, etc. which could stall BH growth

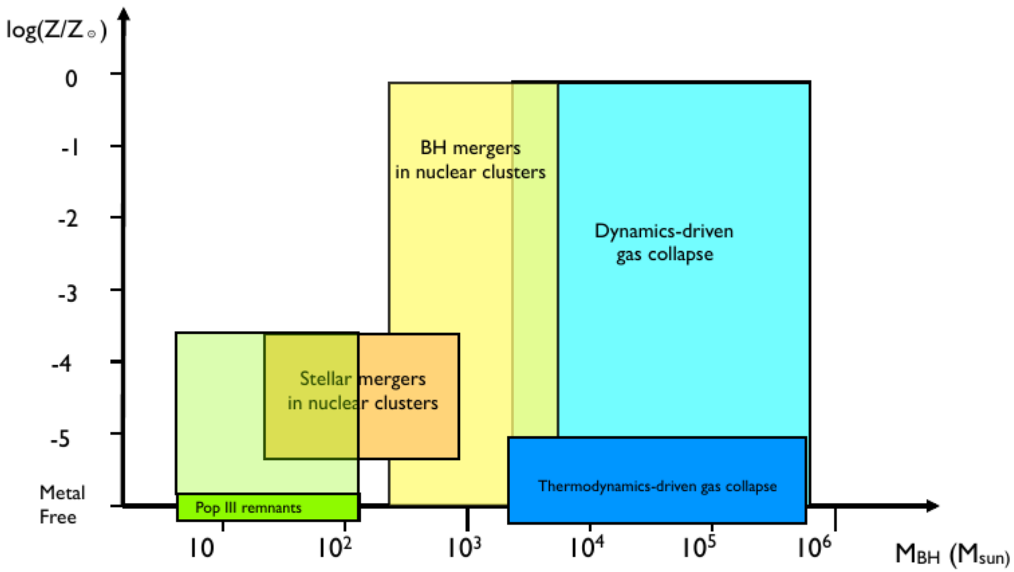
BH seed formation pathways



Martin Rees, ARA&A 1984

BH seed formation pathways

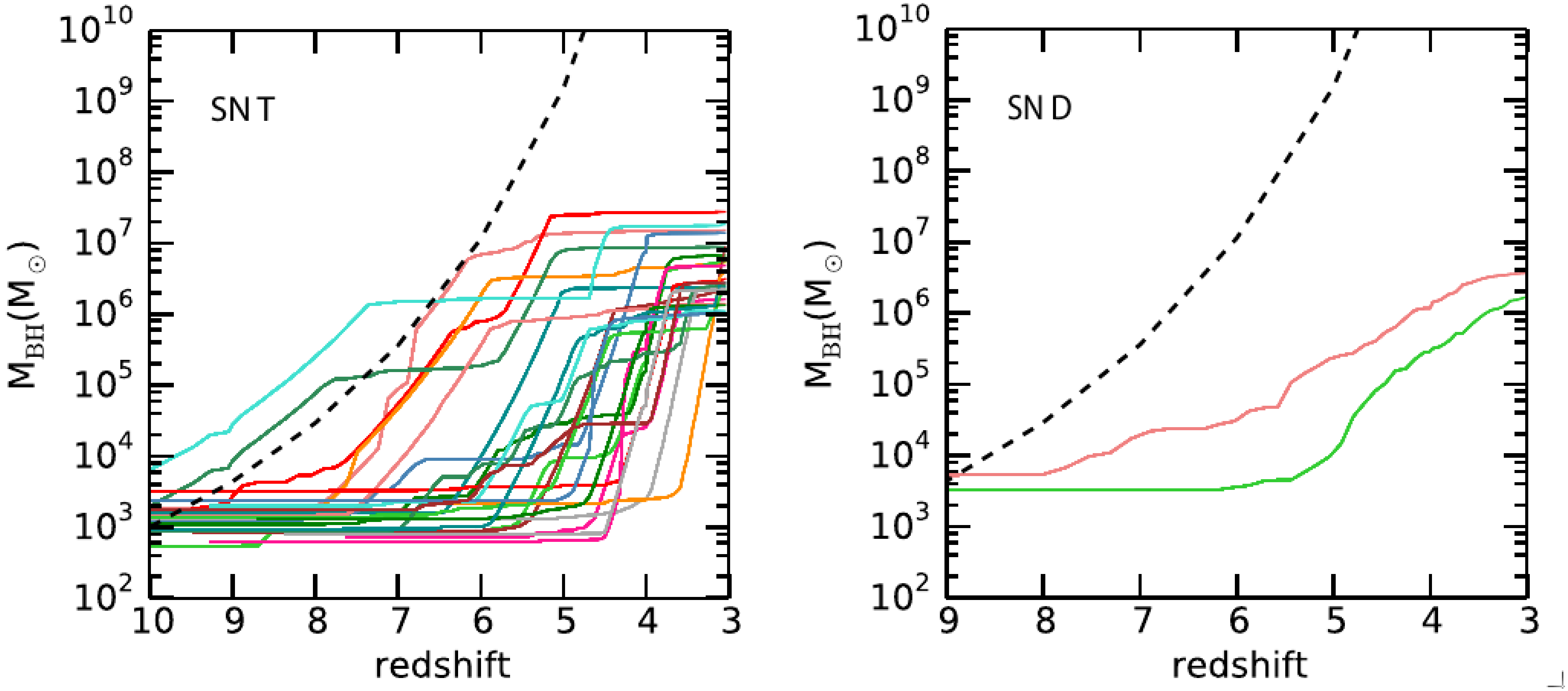




Volonteri et al., 2015

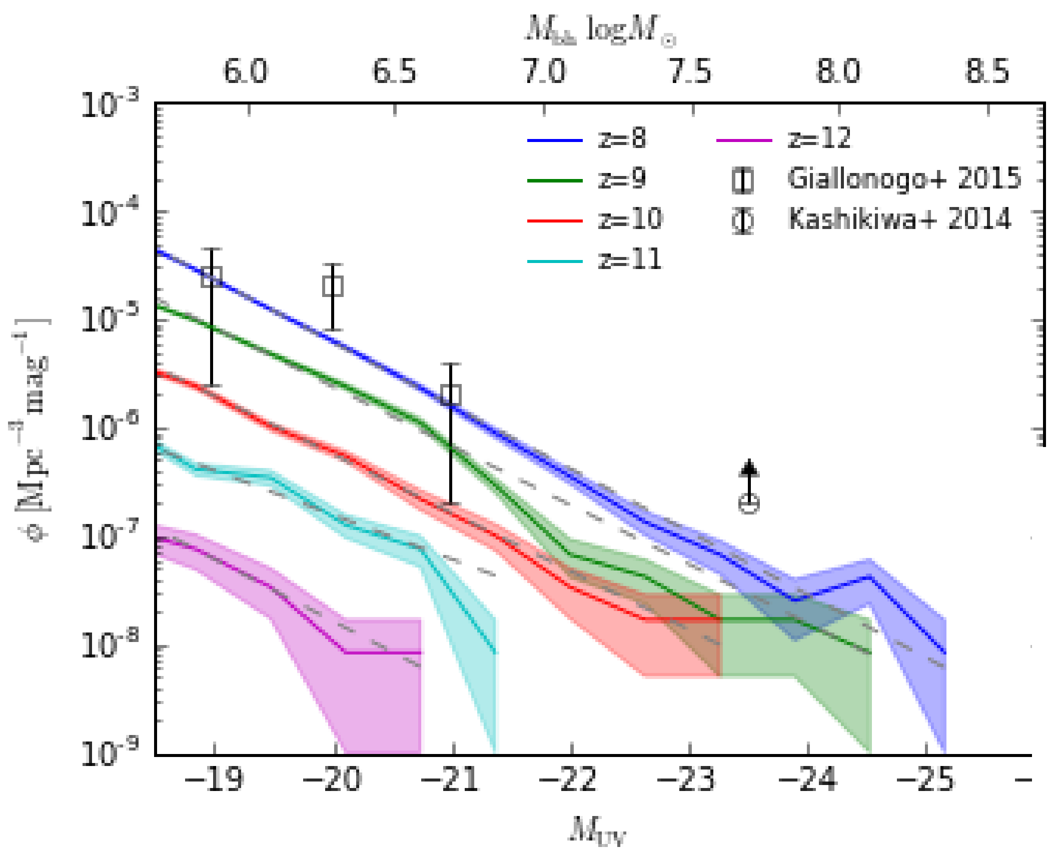
Regan & Haehnelt, 2009

SN feedback: implications for SMBH growth & mergers



Habouzit et al., 2017
(see also Sijacki et al. 2007, Dubois et al. 2015, McAlpine et al. 2018)

Constraining BH growth in the early Universe?

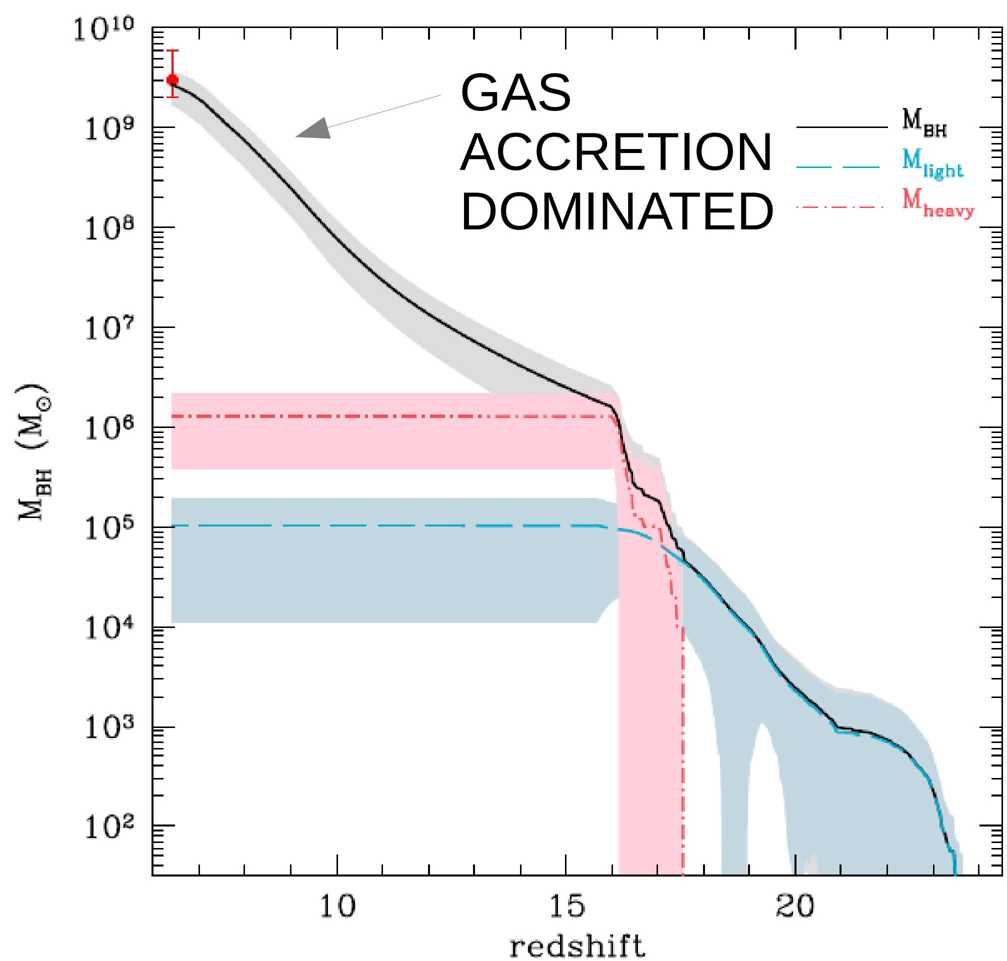


AGN luminosity functions at very high z

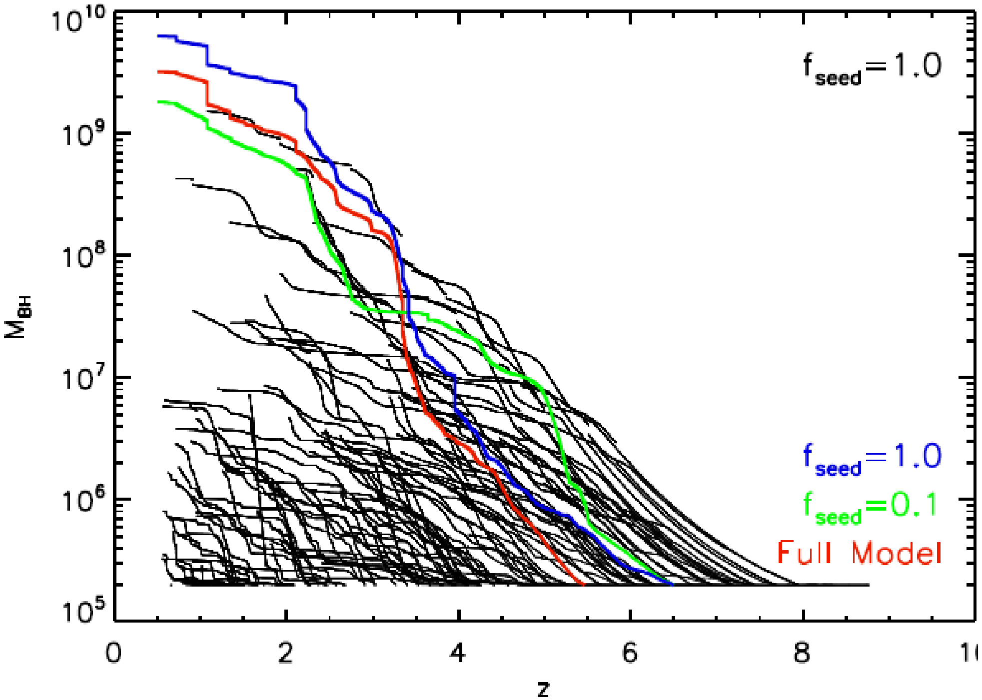
Feng et al., 2016

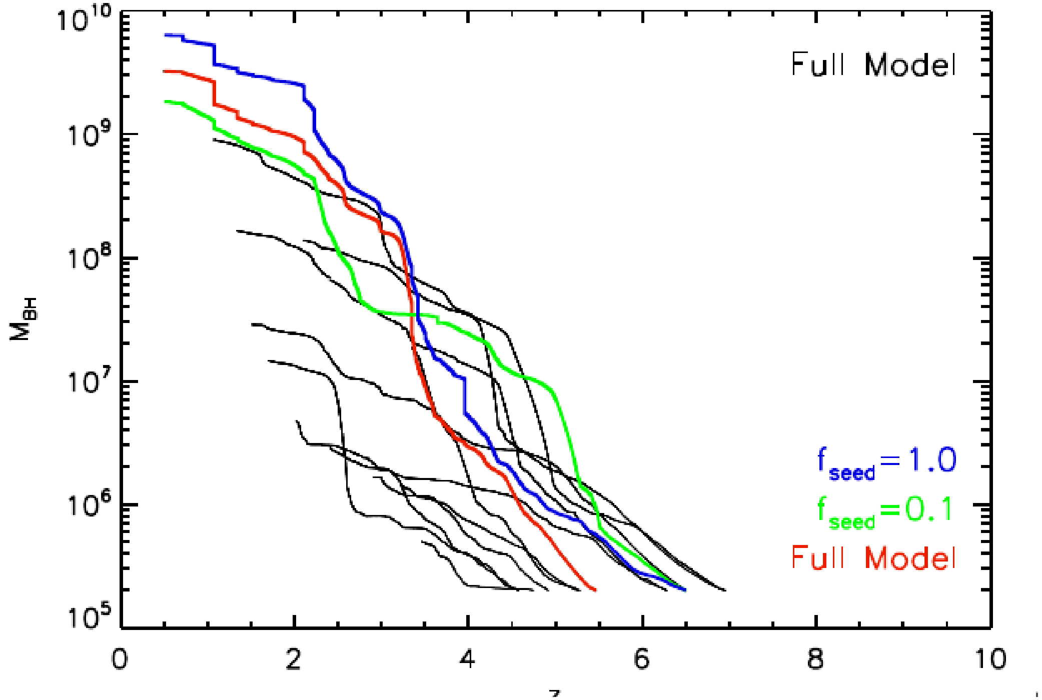
Early growth very sensitive on the assumed seeding

Valiante et al., 2016

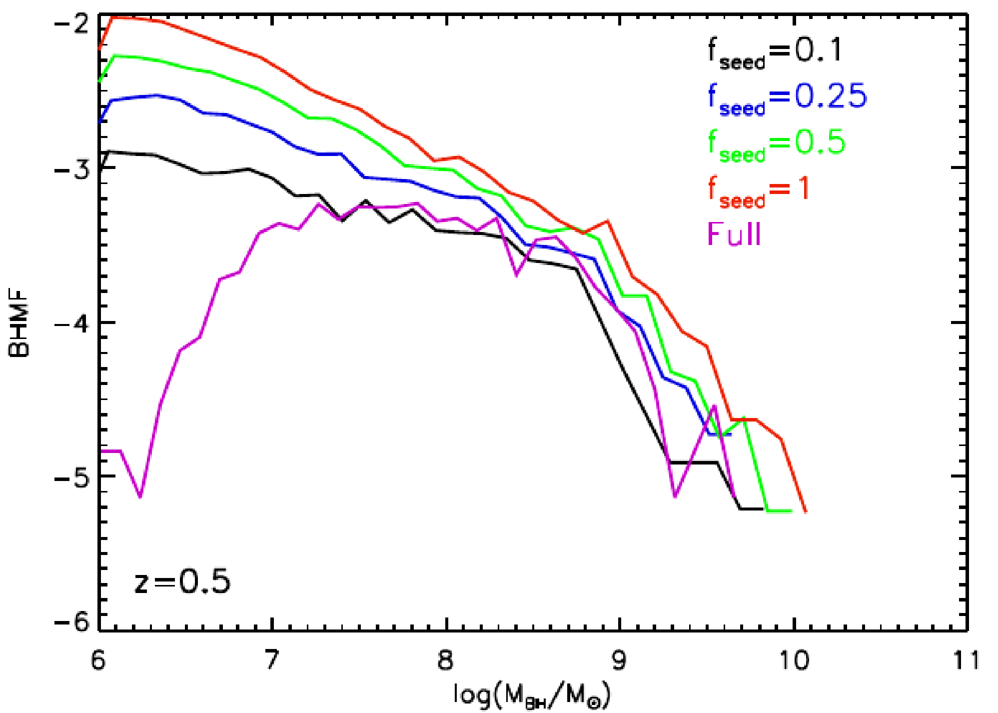


BH seeding: implications for merger rates



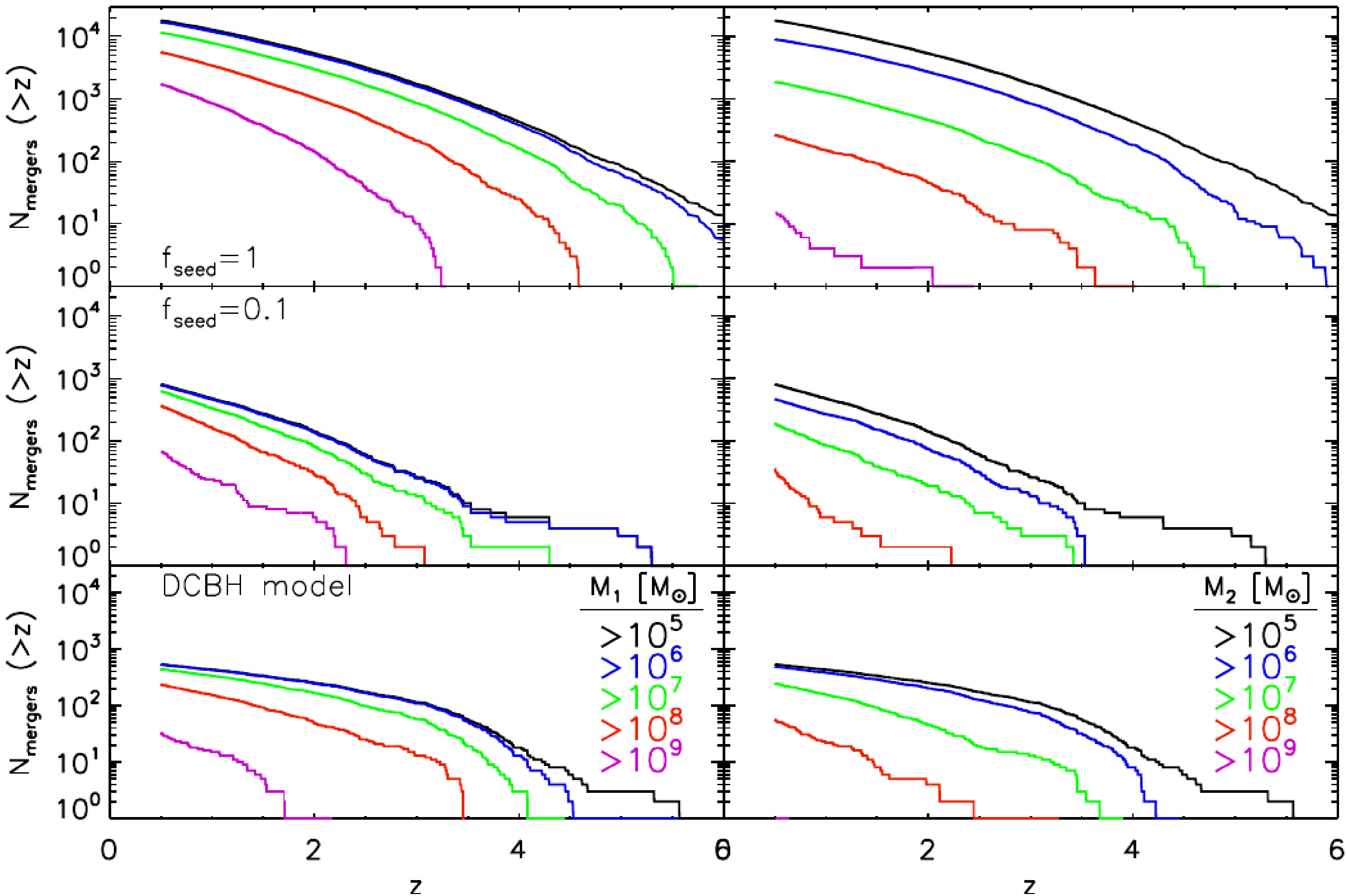


Different seeding models affect BHMF especially at the low mass end



DeGraf & Sijacki, 2018, in prep.

BH seeding: implications for merger rates



DeGraf & Sijacki, 2018, in prep.

Constraints from LISA & IPTA

Conclusions

- AGN feedback is the key ingredient in galaxy formation theory

- The details, however, of its *modus operandi* are not clear and there are several competing models (which may act in conjunction)

- This is further complicated by the very complex interaction with stellar and SN feedback processes

- Future high redshift Universe observations (JWST, SKA, Athena, LISA) will be crucial in constraining the SMBH seed, growth and feedback processes where the physics of SMBH is more sensitive to the “initial conditions”