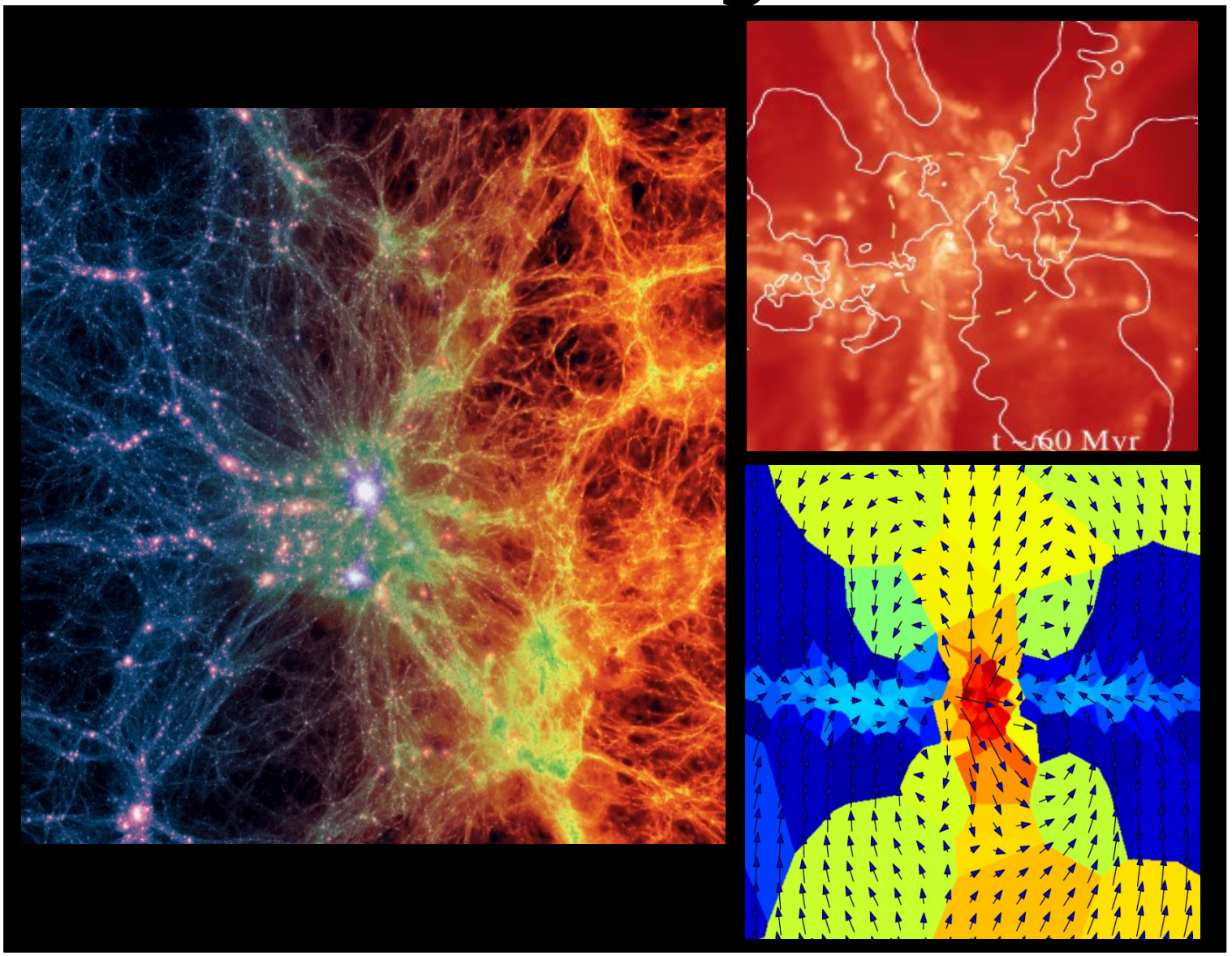
How to model AGN feedback in cosmological simulations?

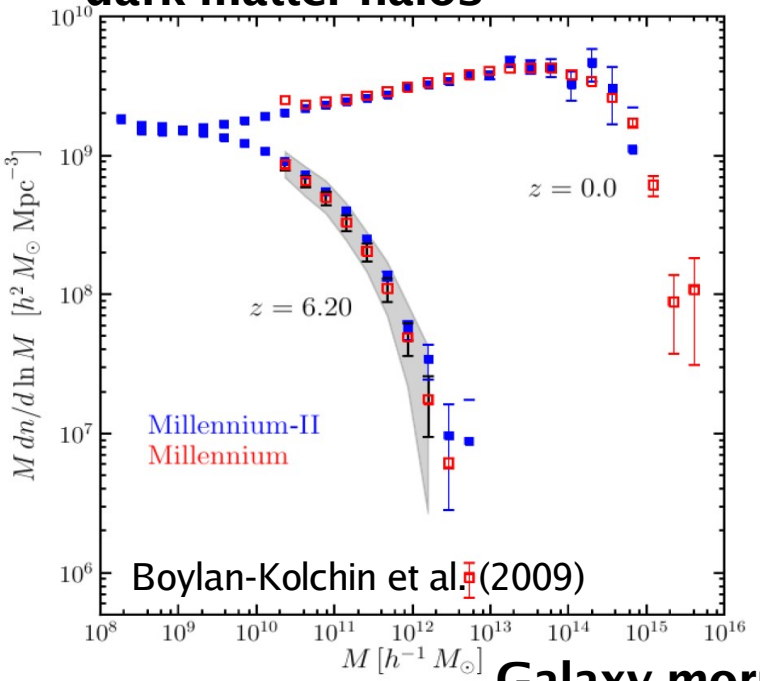


Debora Sijacki
IoA & KICC
Cambridge

IAU GA - Div J
August 7 2015

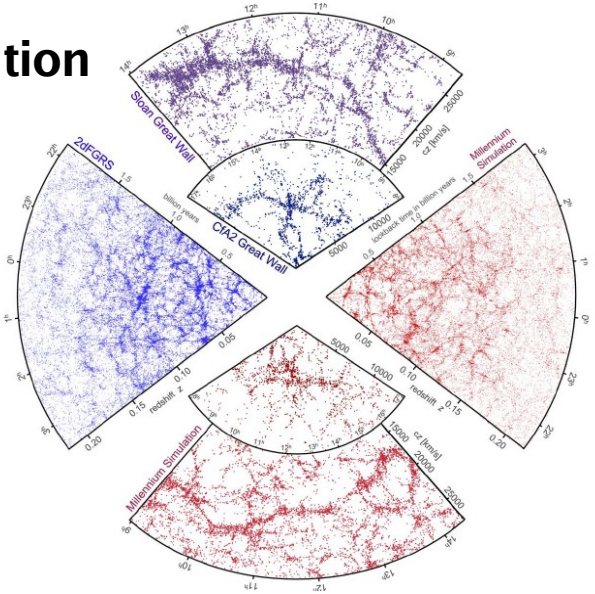
Cosmological simulations of galaxy and structure formation

Hierarchical growth of dark matter halos



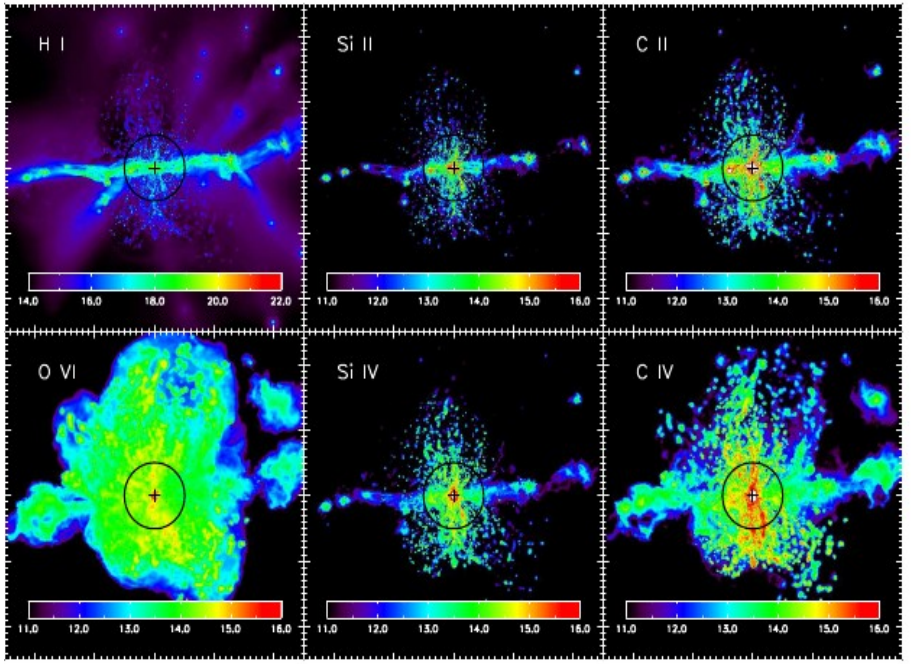
Boylan-Kolchin et al. (2009)

Large scale distribution of galaxies



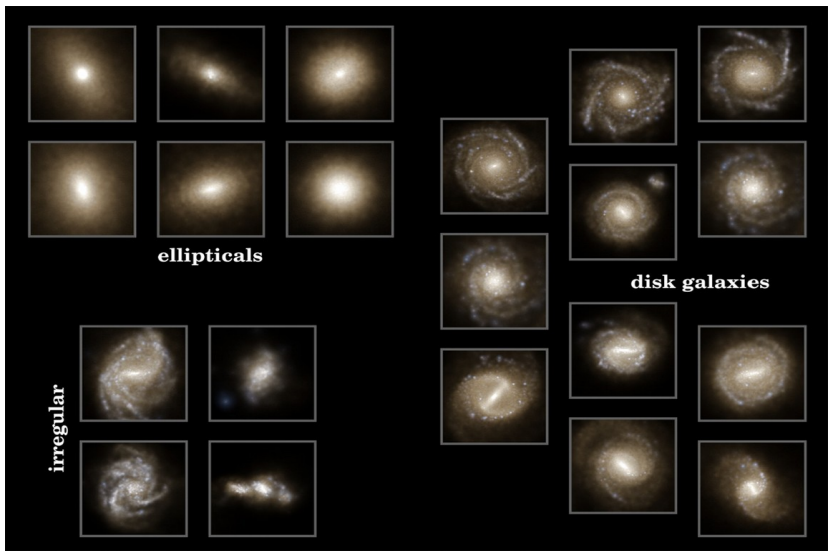
Springel et al. 2006

Large scale environments of galaxies: inflows and outflows

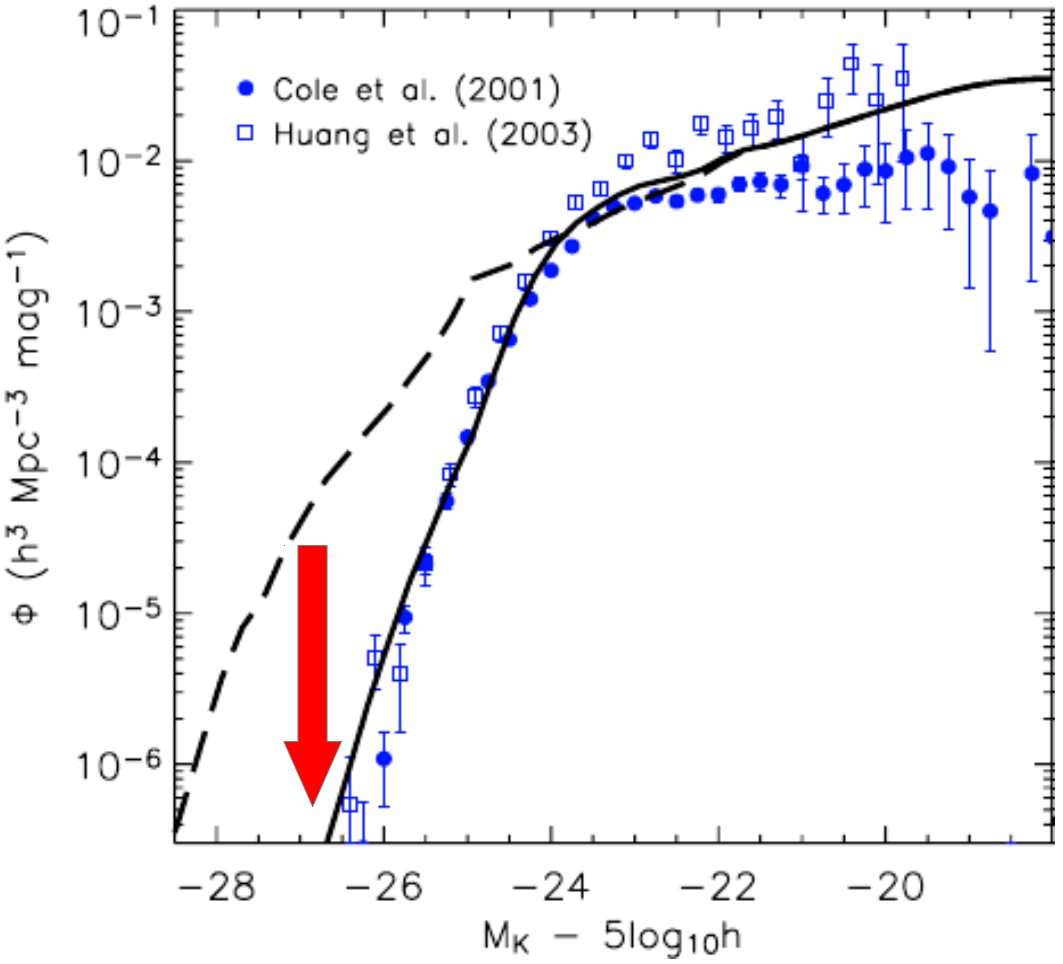


Shen et al. 2013

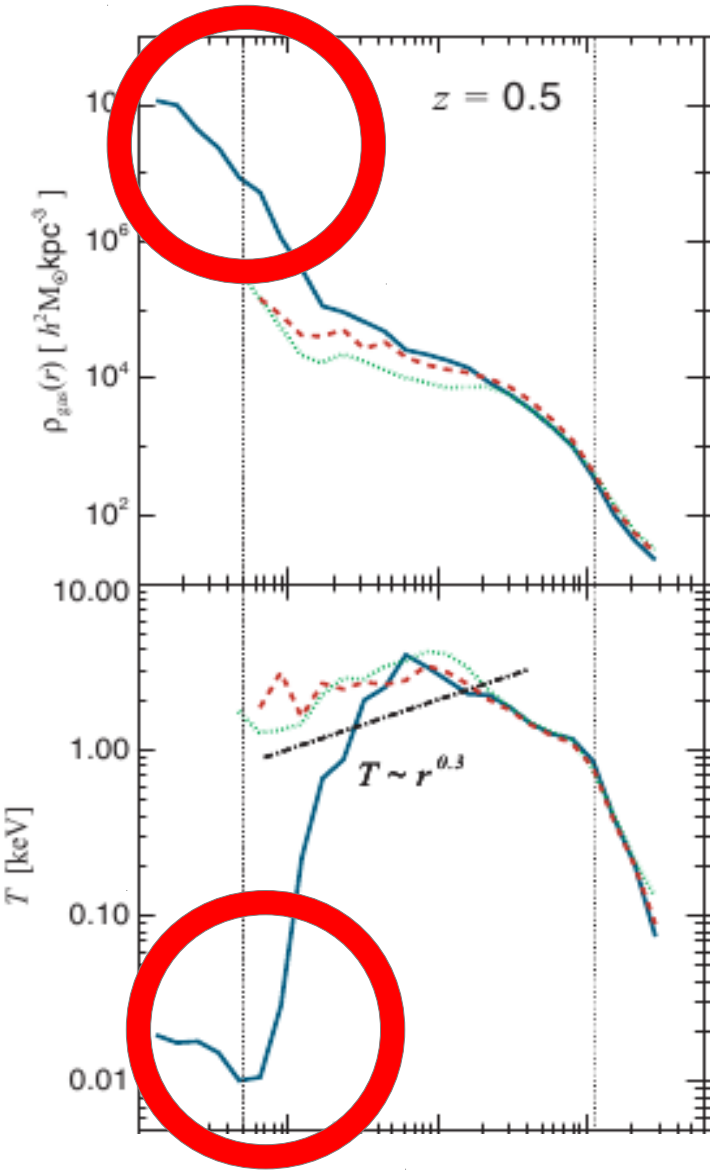
Galaxy morphologies Illustris project



One of the main issues:
Gas overcooling in massive galaxies



Croton et al. 2006



Sijacki et al. 2007

Observational evidence for the feedback from supermassive black holes: high z QSOs

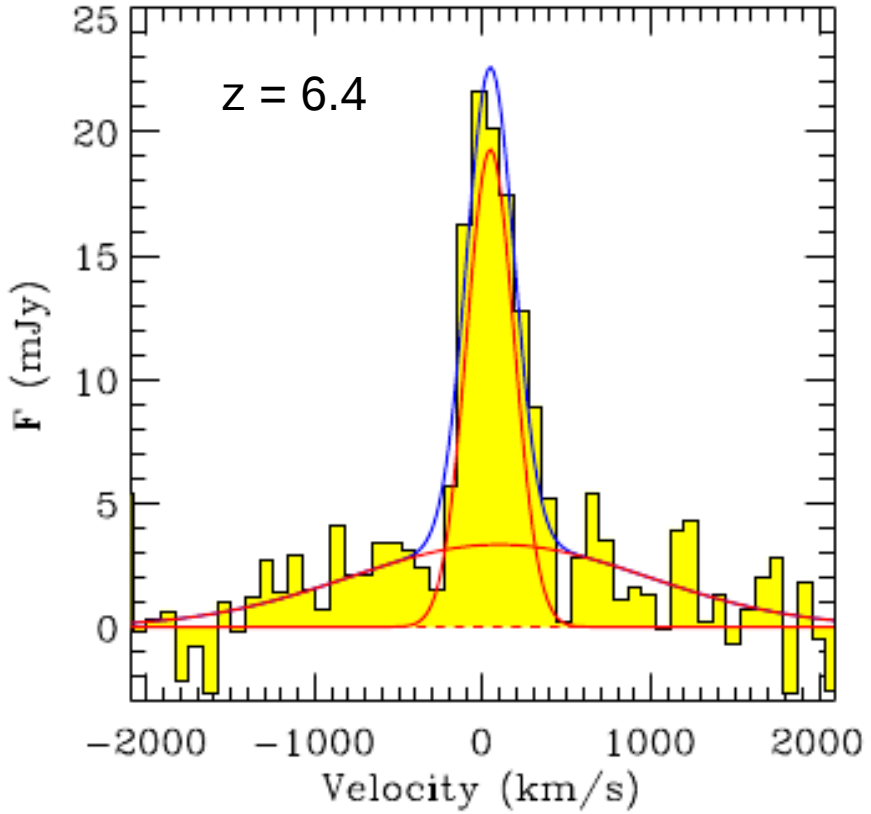
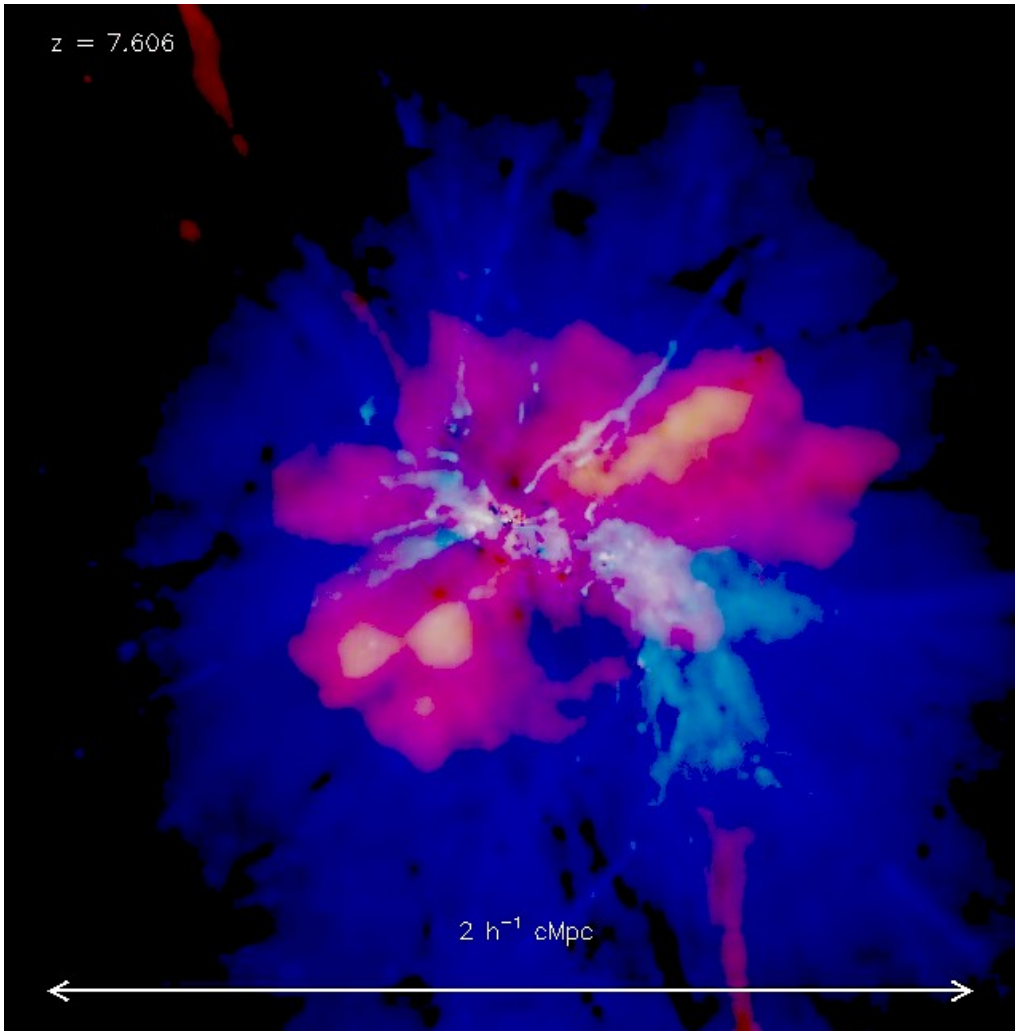


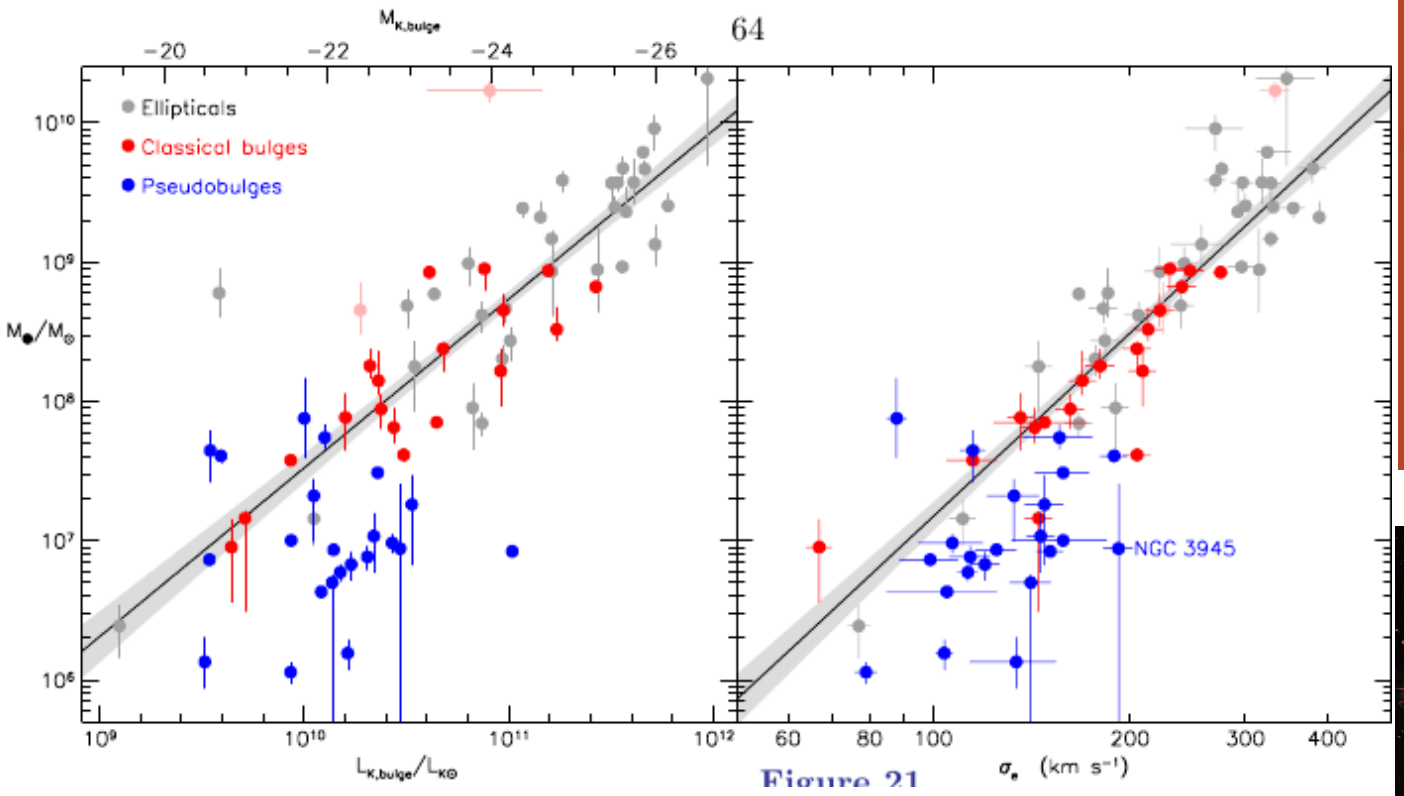
Figure 1. IRAM PdBI continuum-subtracted spectrum of the [CII]158μm line, redshifted to 256.172 GHz, in the host galaxy of the quasar J1148+5152 extracted from an aperture with a diameter of 4″, top, and 6″, bottom. The spectrum has been resampled to a bin size of 85 km s^{-1}. The red lines show a double Gaussian fit (FWHM=345 km s^{-1} and FWHM=2030 km s^{-1}) to the line profile, while the blue line shows the sum of the two Gaussian components.

Maiolino et al. 2012

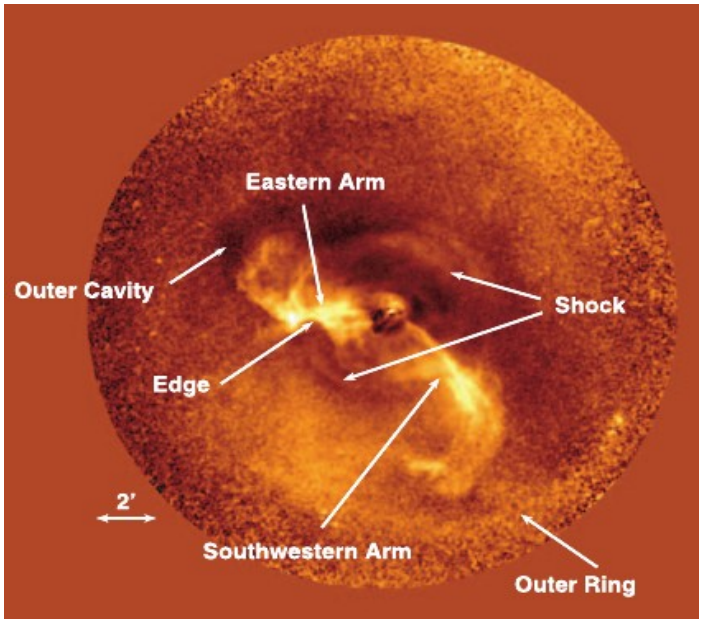


Costa, Sijacki, Trenti, Haehnelt 2012

Observational evidence for the feedback from supermassive black holes: low z Universe



Kormendy & Ho 2013



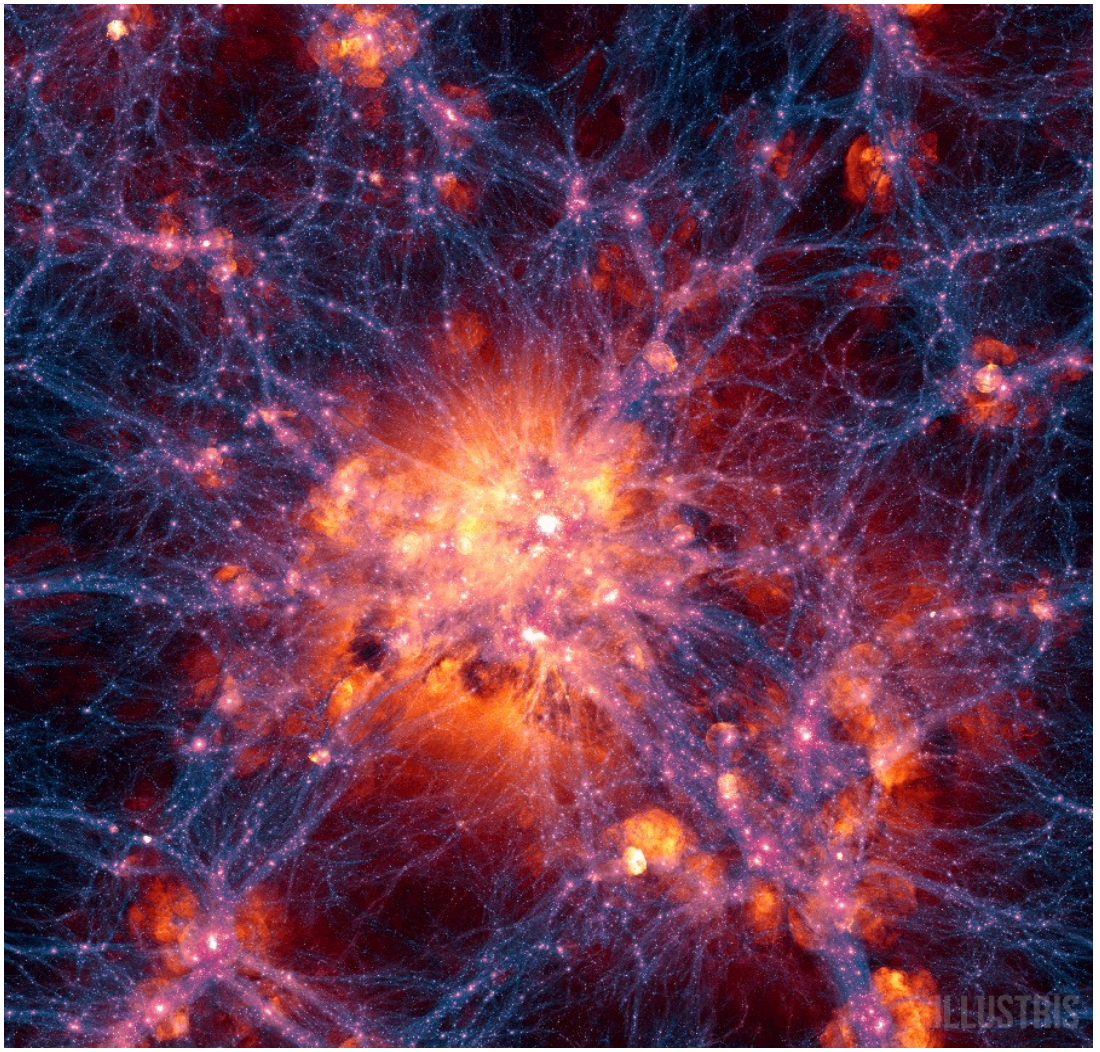
M87, Forman et al.

Perseus cluster, Fabian et al.

see also McConnell & Ma, 2013

The Illustris project

DM DENSITY with overlaid GAS VELOCITY



Box size = 106.5Mpc
Min cell size = 48pc
3 x 1820^3
dark matter particles
gas cells
passive tracers -> 18 billion
8192 cores, 19 MCPUh

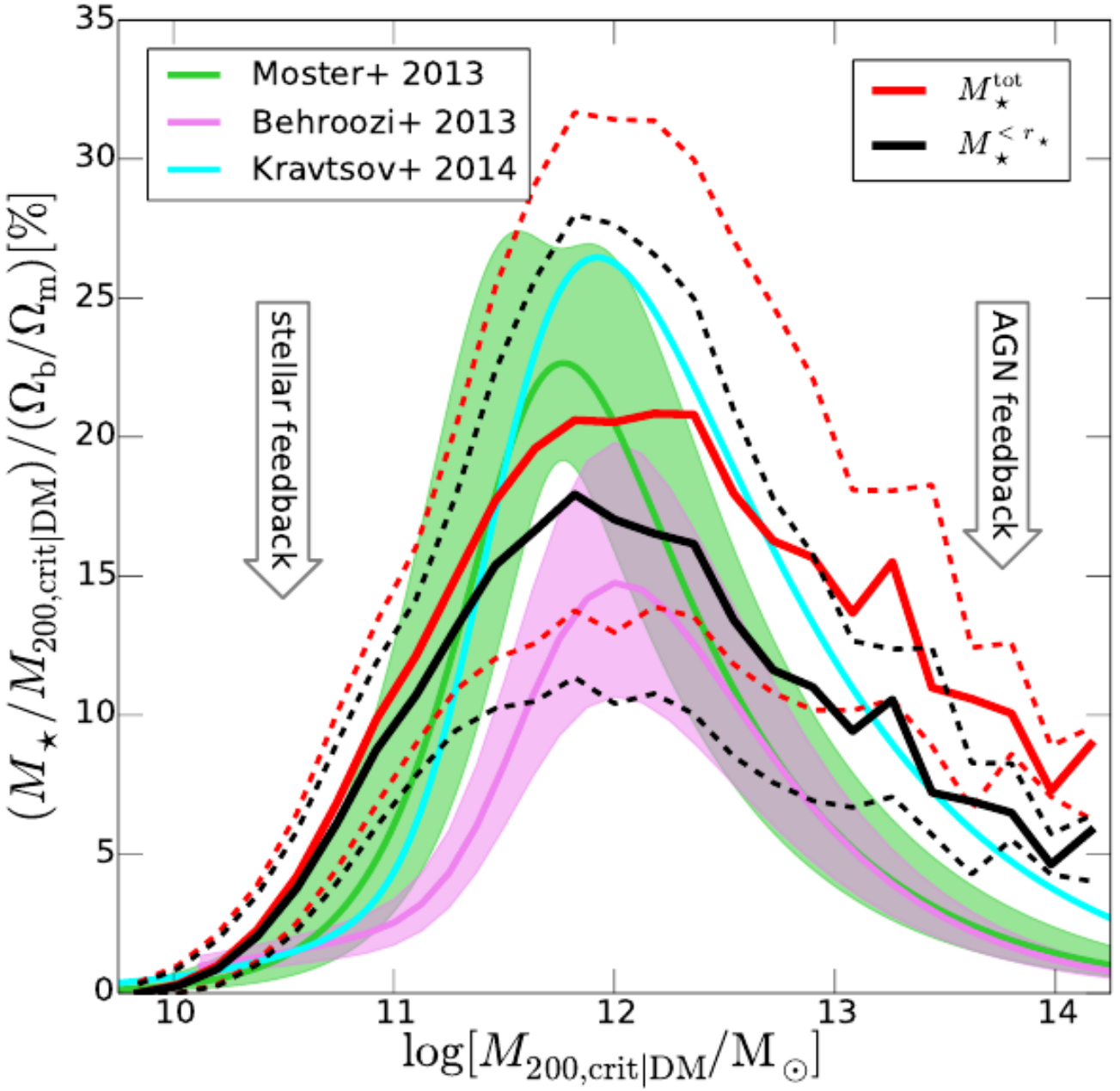
Physics:

primordial & metal line cooling
+ self-shielding
stellar evolution
stellar feedback
gas recycling
chemical enrichment
black hole growth
black hole feedback:
quasar, radiative and radio bubbles
(see Springel et al. 2005
Sijacki et al. 2007,
Vogelsberger et al. 2013)

Vogelsberger et al., MNRAS, 2014
Genel et al., MNRAS, 2014

The Illustris project

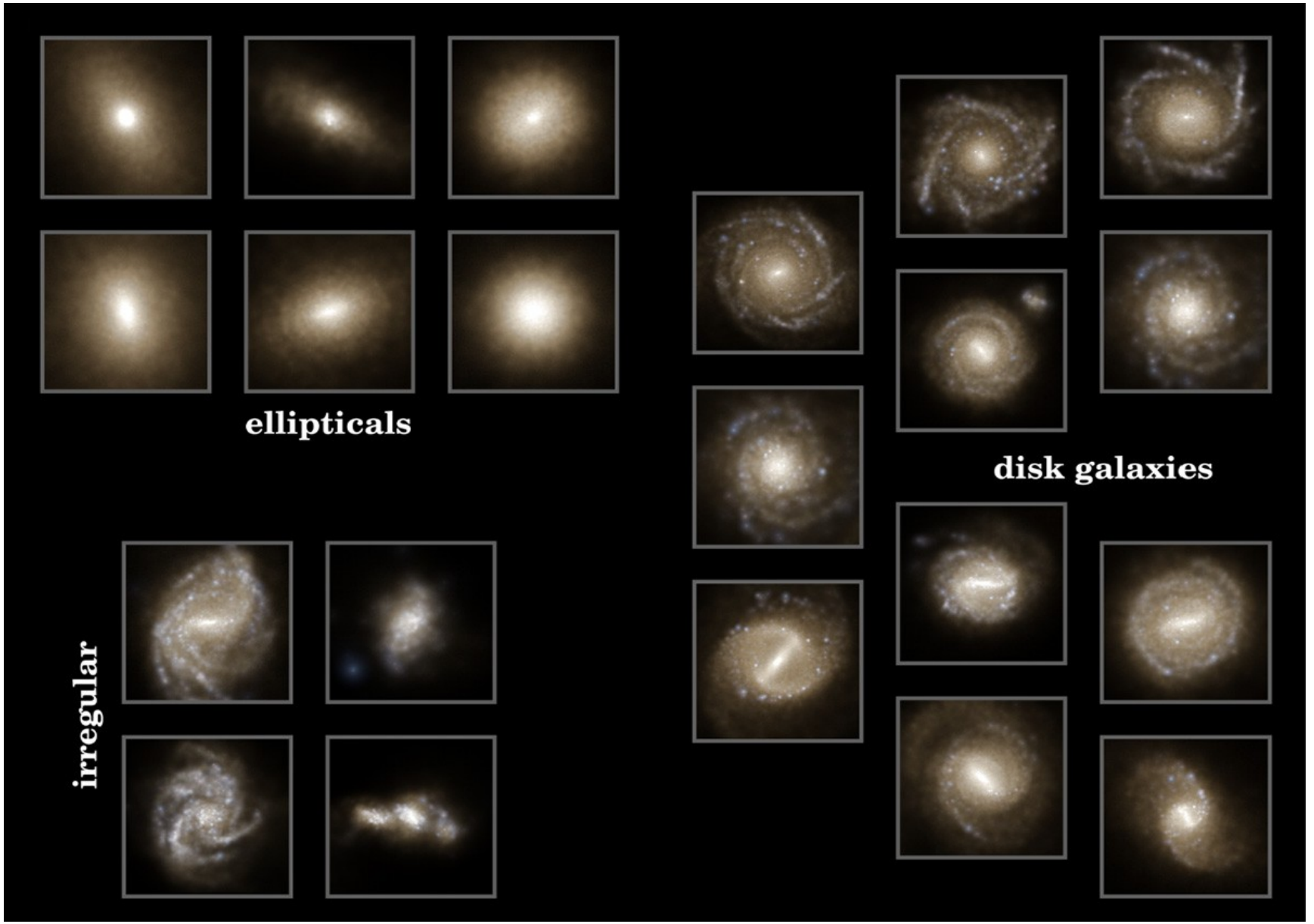
STELLAR VS. HALO MASS



Vogelsberger, Genel, Springel, Torrey, Sijacki, et al., MNRAS, 2014

The Illustris project

GALAXY MORPHOLOGIES

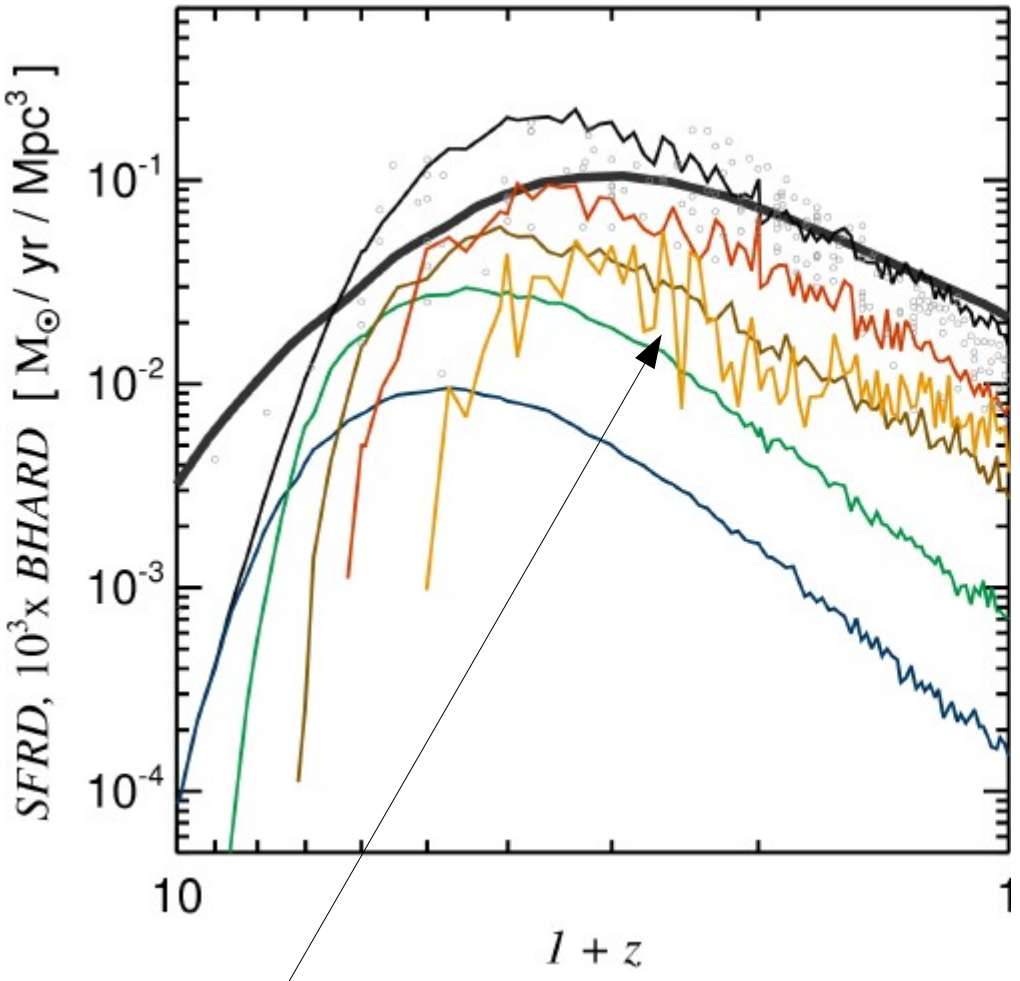


Vogelsberger et al., MNRAS, 2014
Genel et al., MNRAS, 2014

see also e.g. EAGLE, HORIZON AGN, MASSIVE BLACK and MAGNETICUM projects

BHs in Illustris

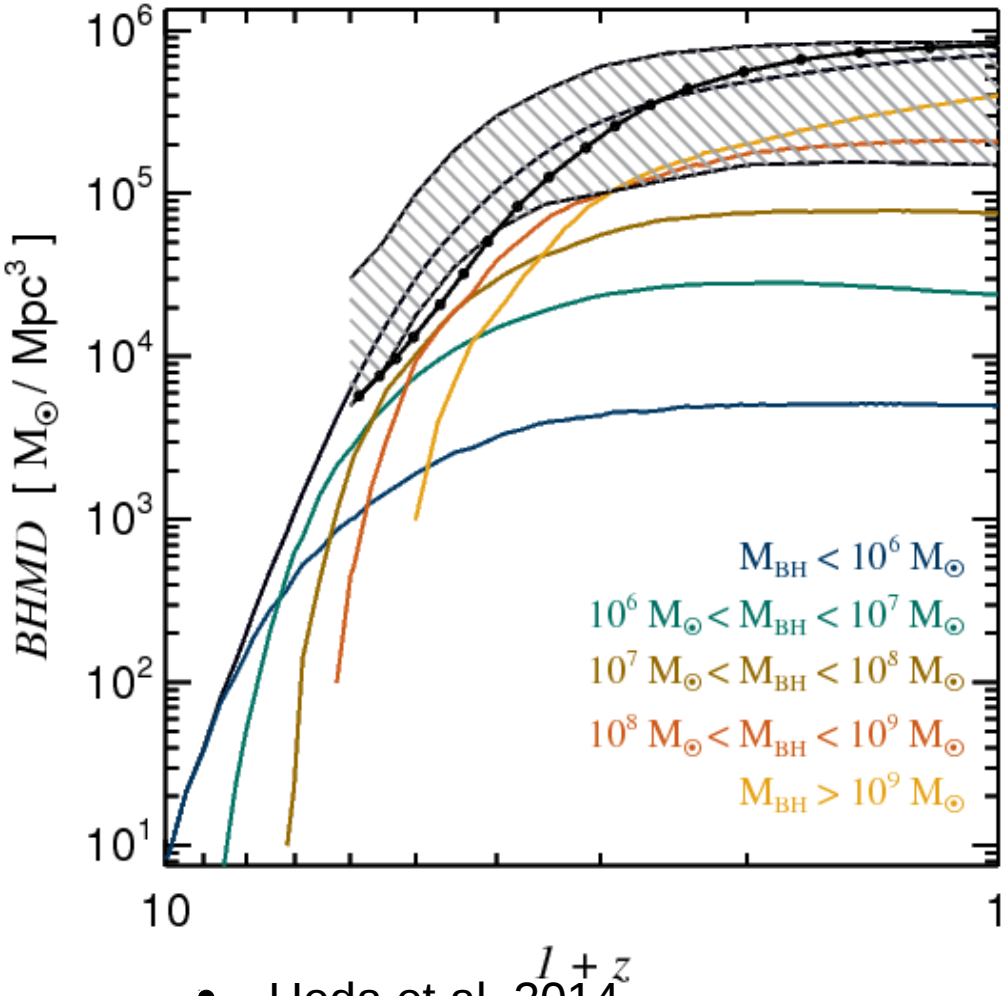
SFR DENSITY &
BH ACCRETION RATE DENSITY



DUTY CYCLE DUE TO THE RADIO MODE

Sijacki et al., 2015

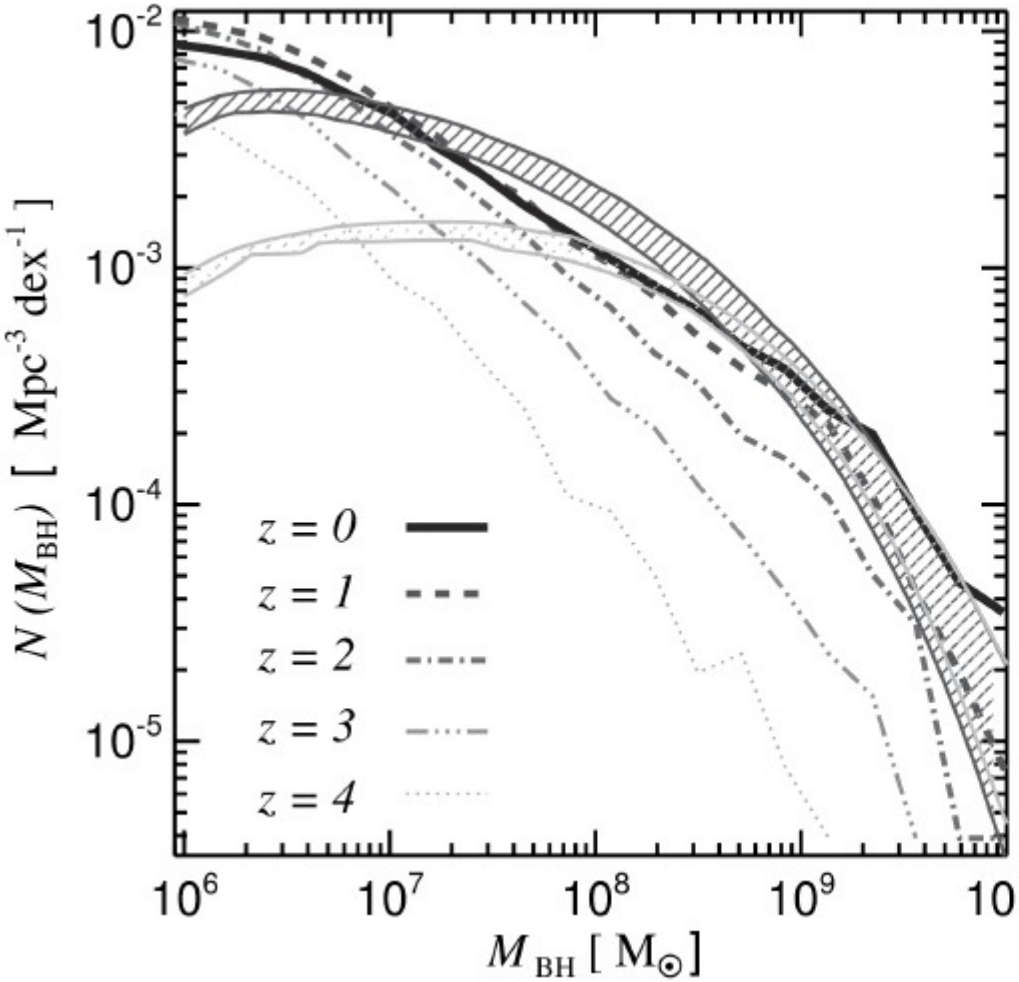
BH MASS DENSITY



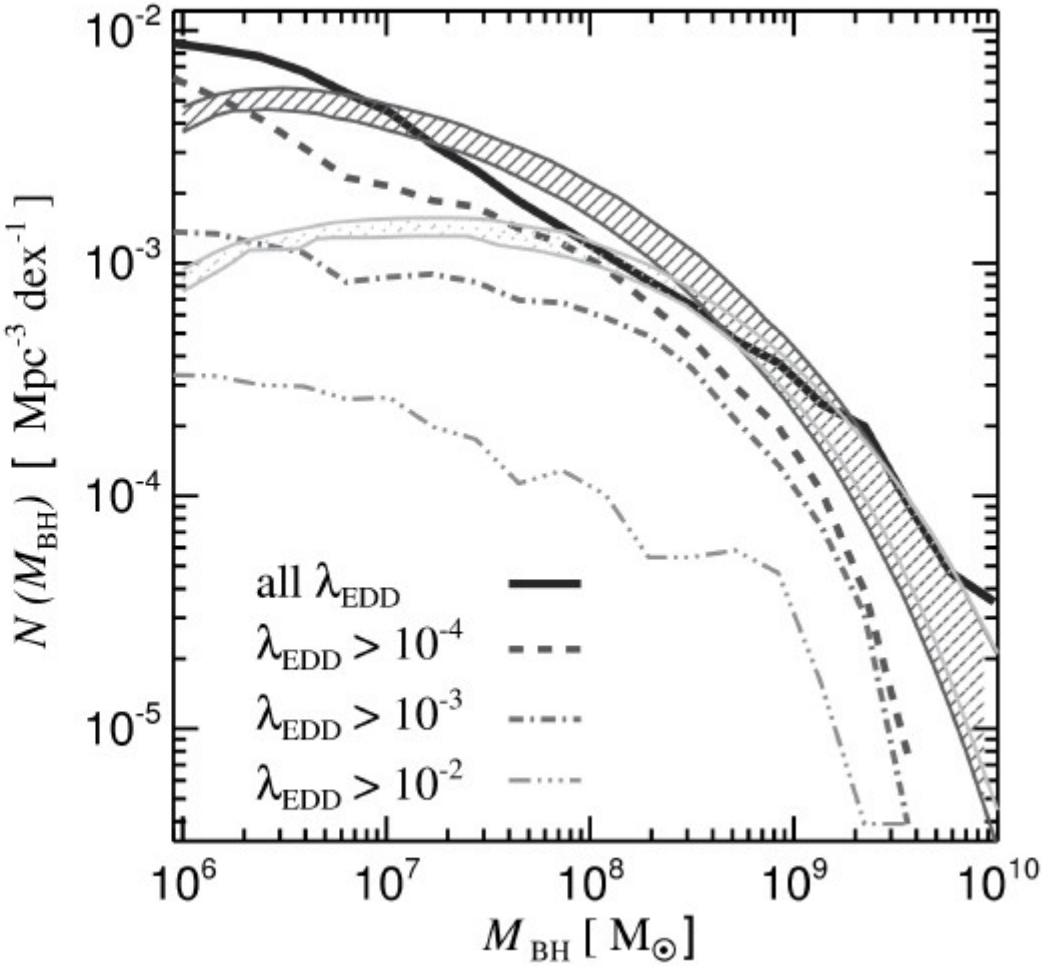
- Ueda et al. 2014
- Volonteri et al. 2013

BHs in Illustris

BH MASS FUNCTION
split by redshift



BH MASS FUNCTION
split by Eddington ratio at z = 0

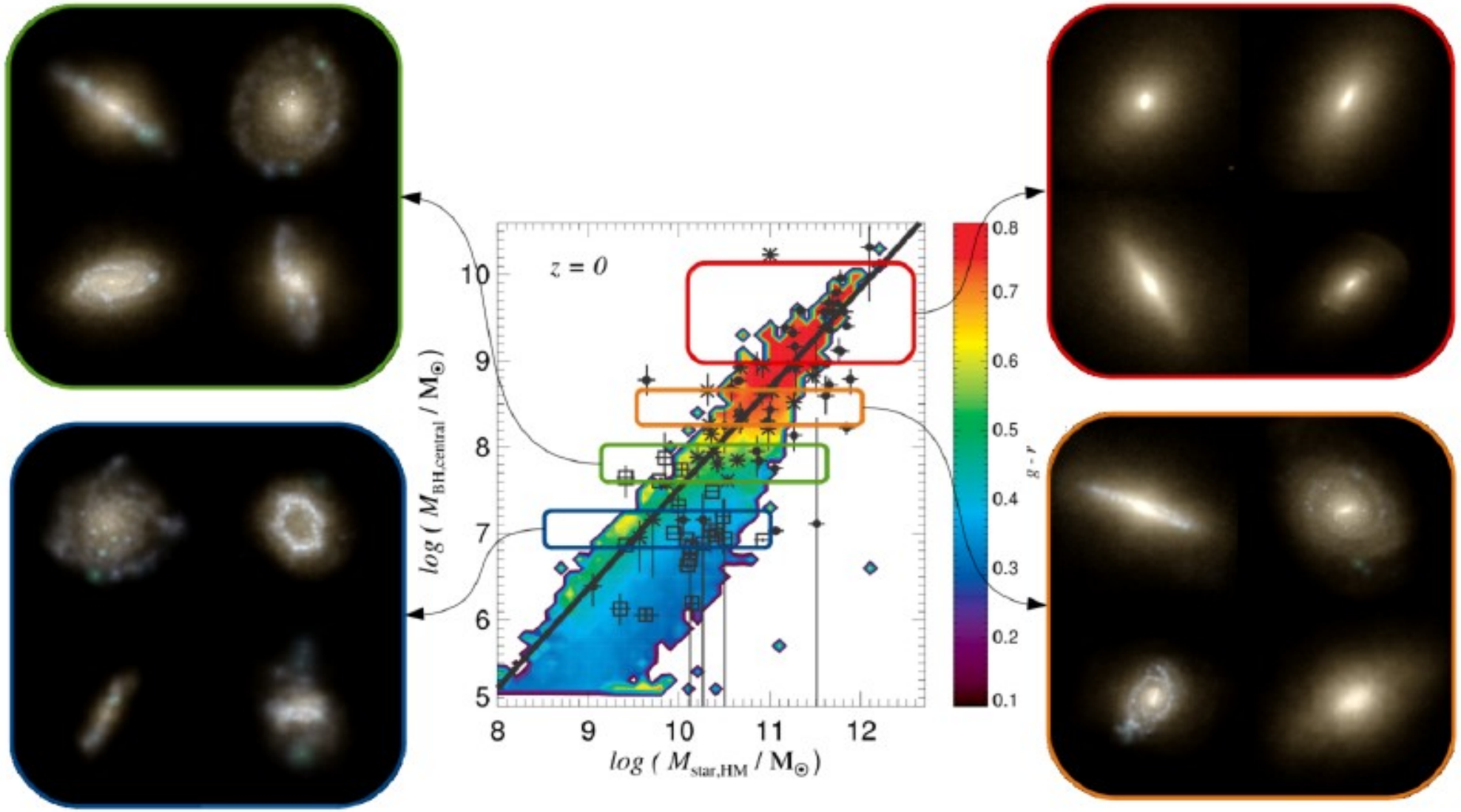


Shankar et al. 2013 (Mbh-sigma from McConnell & Ma, 2013)

Sijacki et al, 2015

BHs in Illustris

BH MASS – BULGE MASS RELATION

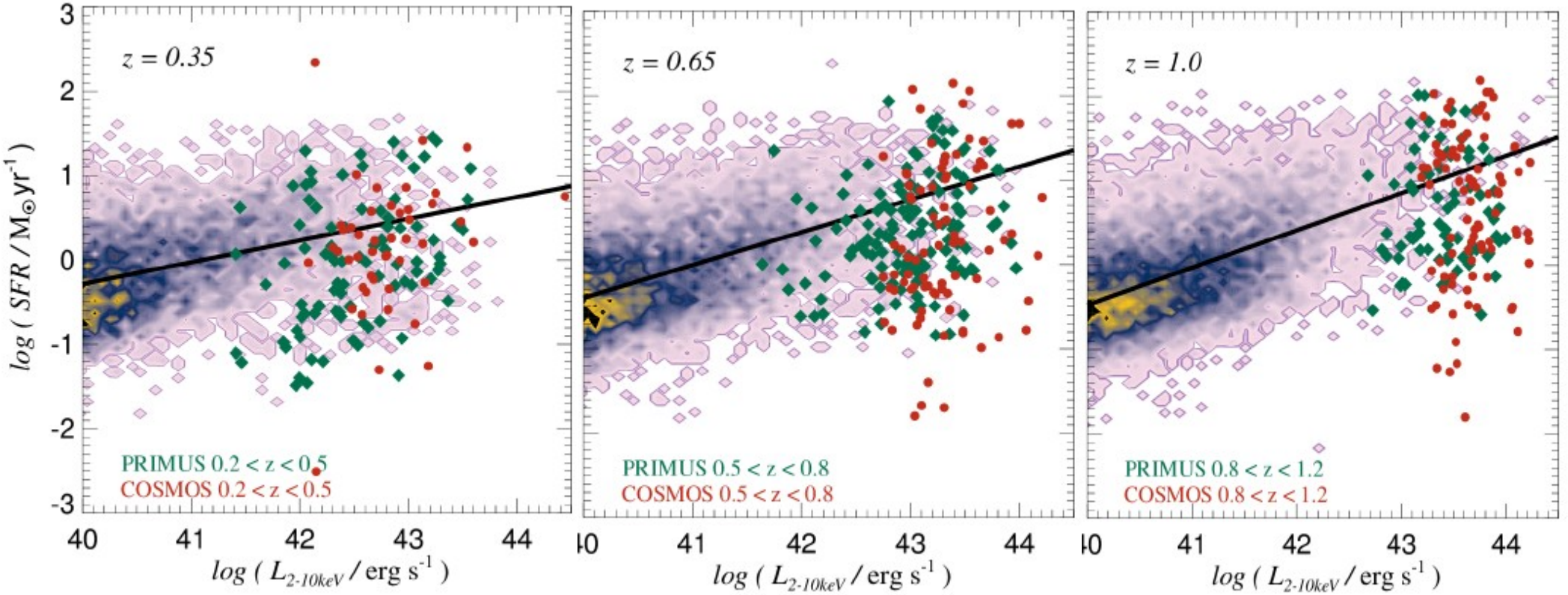


Kormendy & Ho, 2013: best fit
circles: ellipticals; stars: spirals with bulges; squares: pseudo bulges

Sijacki et al, 2015

BHs in Illustris

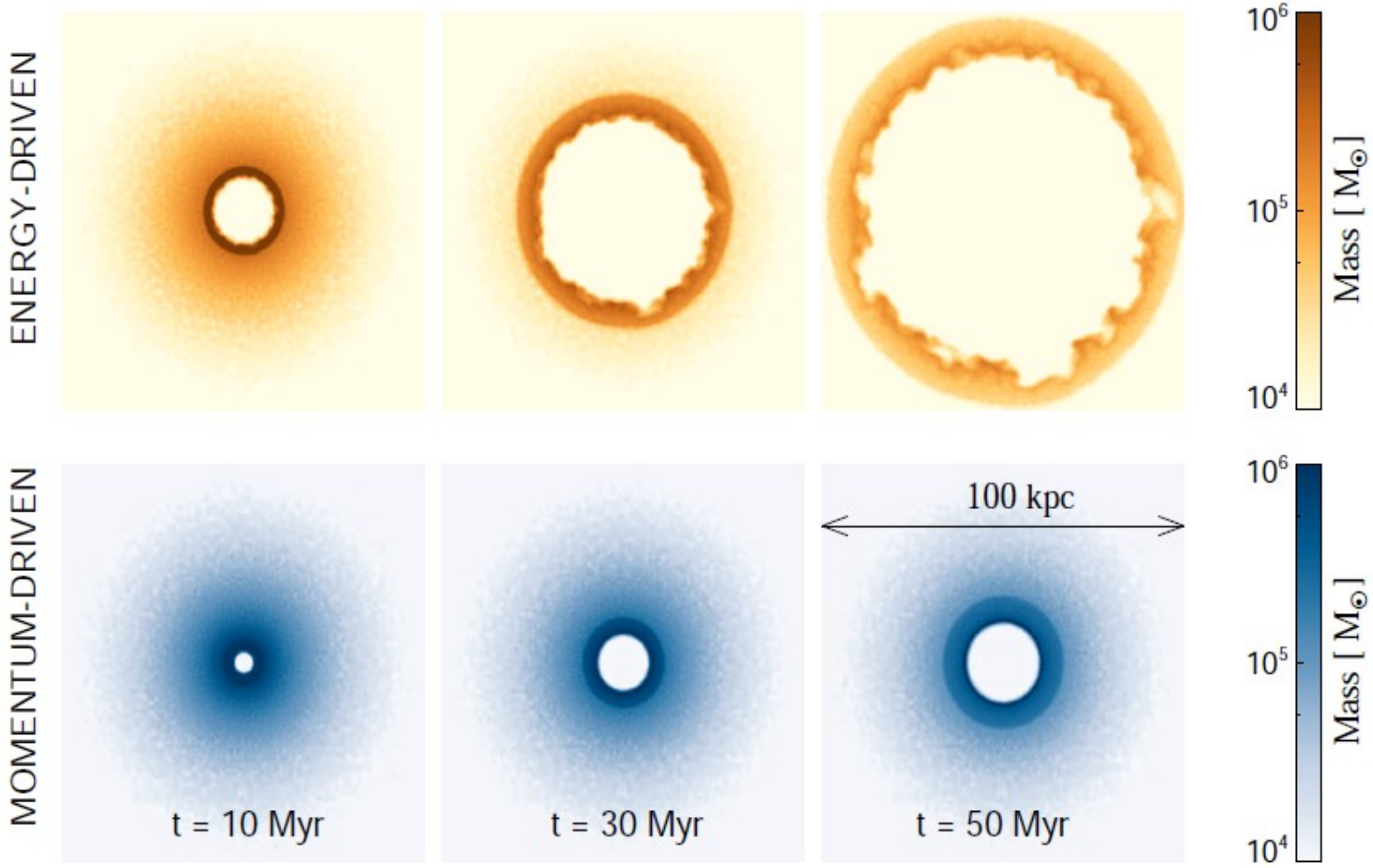
SF VS. AGN TRIGGERING
SFR and Lx



Sijacki et al, 2015

Calibrating AGN feedback

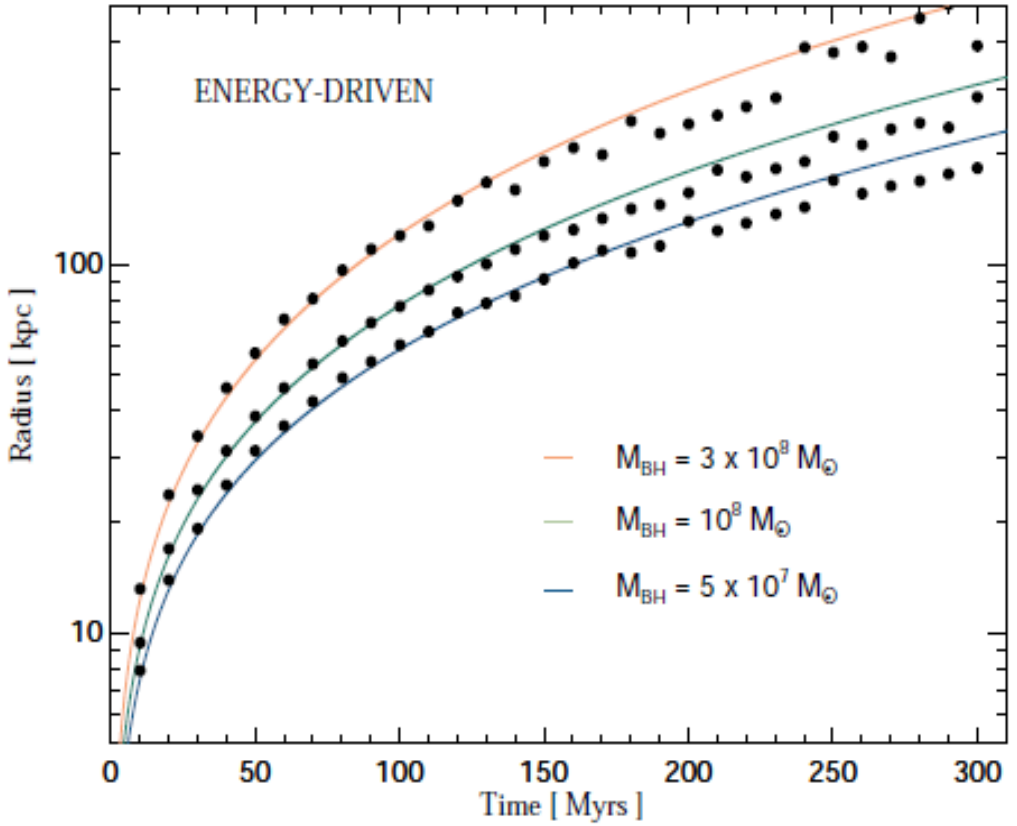
MOMENTUM VS. ENERGY-DRIVING IN ISOLATED HALOS

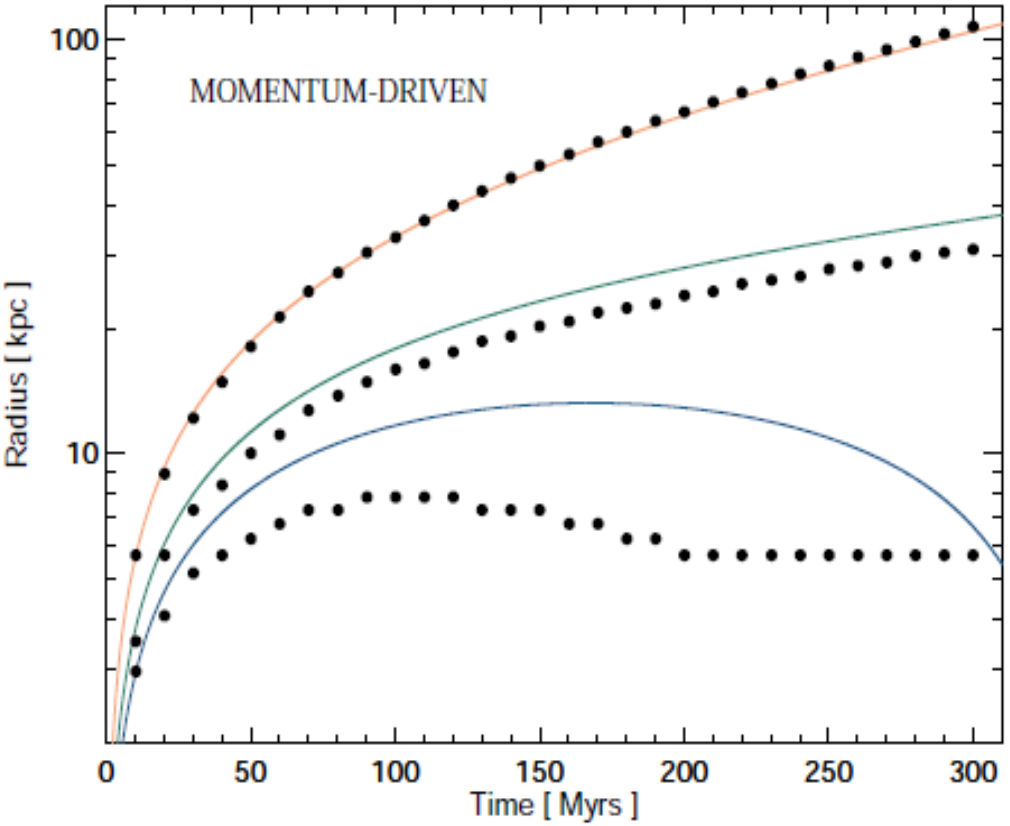


Costa, Sijacki & Haehnelt, MNRAS, 2014

Calibrating AGN feedback

BLAST WAVE PROPAGATION: comparison of simulations to analytic solutions (King et al.)

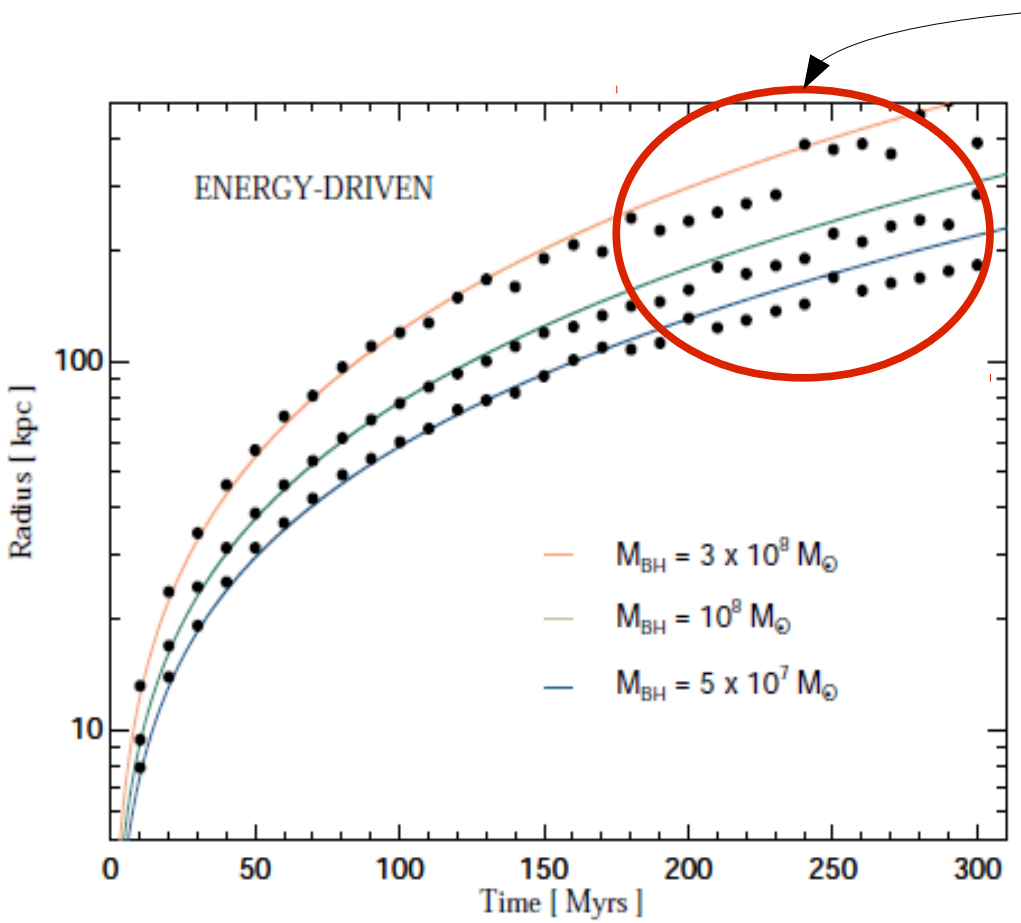


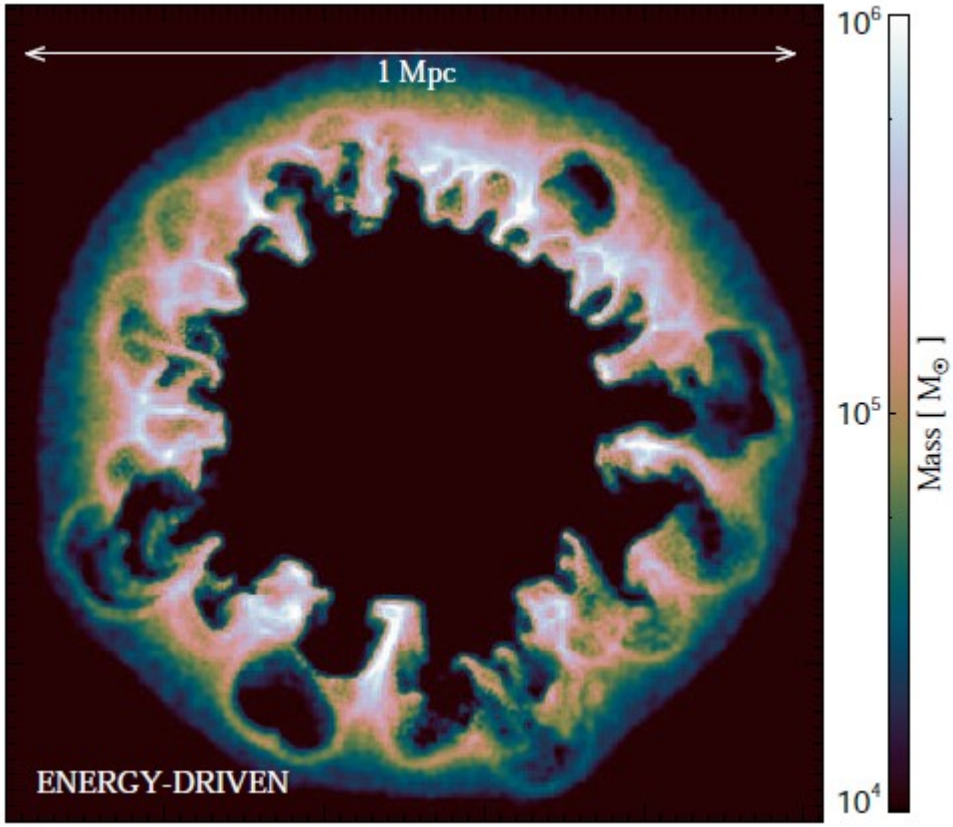


Costa, Sijacki & Haehnelt, 2014

Calibrating AGN feedback

RT INSTABILITIES

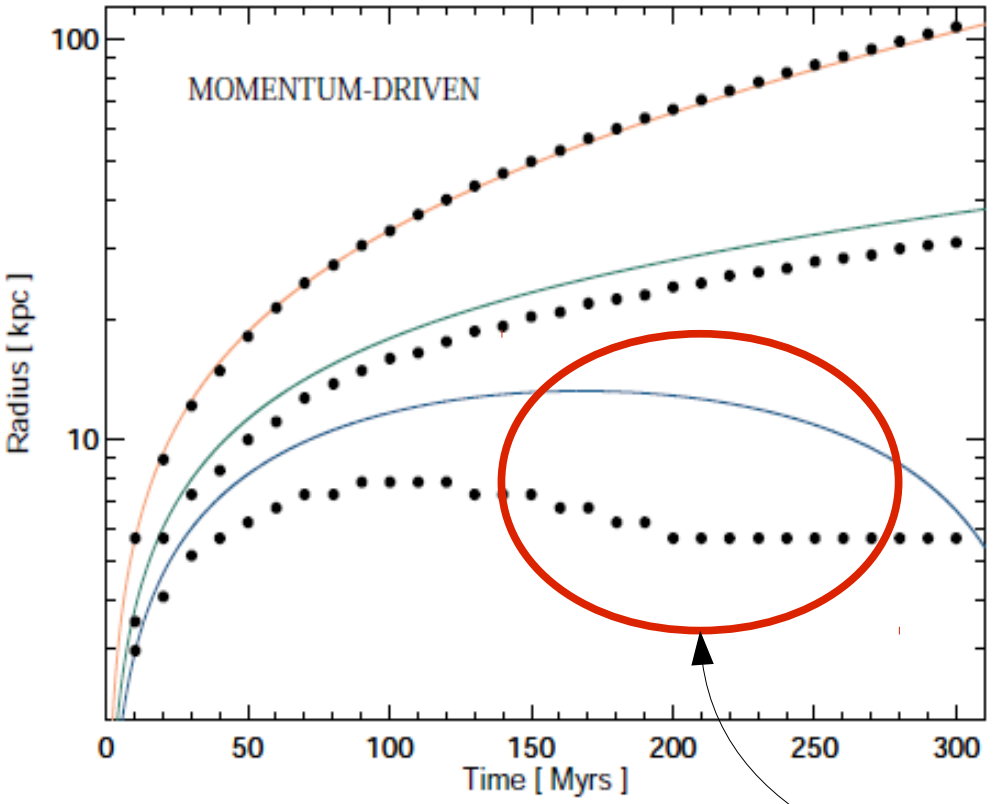


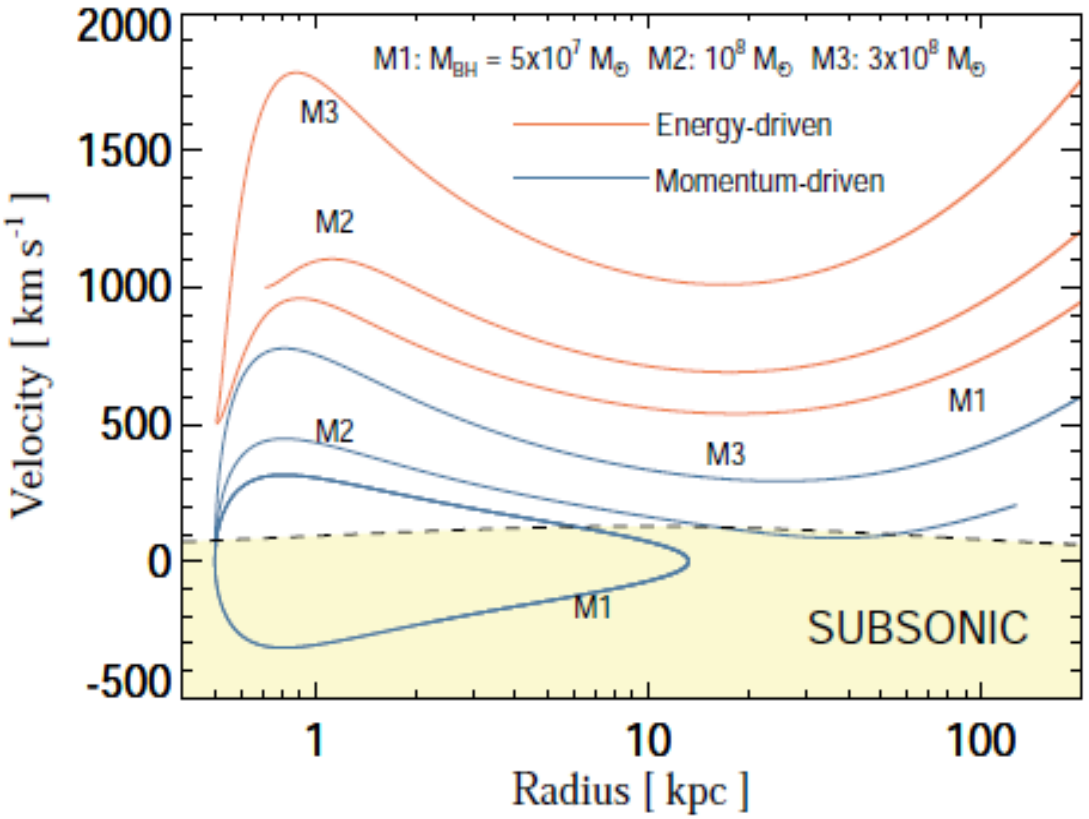


Costa, Sijacki & Haehnelt, 2014

Calibrating AGN feedback

SUBSONIC REGIME

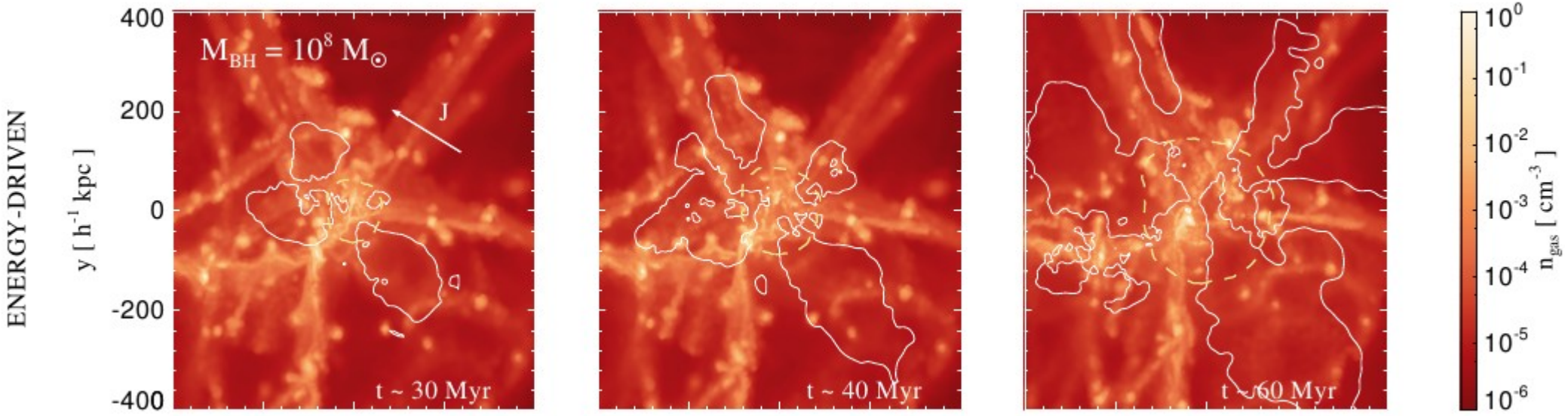




Costa, Sijacki & Haehnelt, 2014

Calibrating AGN feedback

ISOLATED VS COSMOLOGICAL HALOS: ENERGY-DRIVEN
- same DM potential
- same and constant BH mass & Eddington accretion



Costa, Sijacki & Haehnelt, 2014

Calibrating AGN feedback

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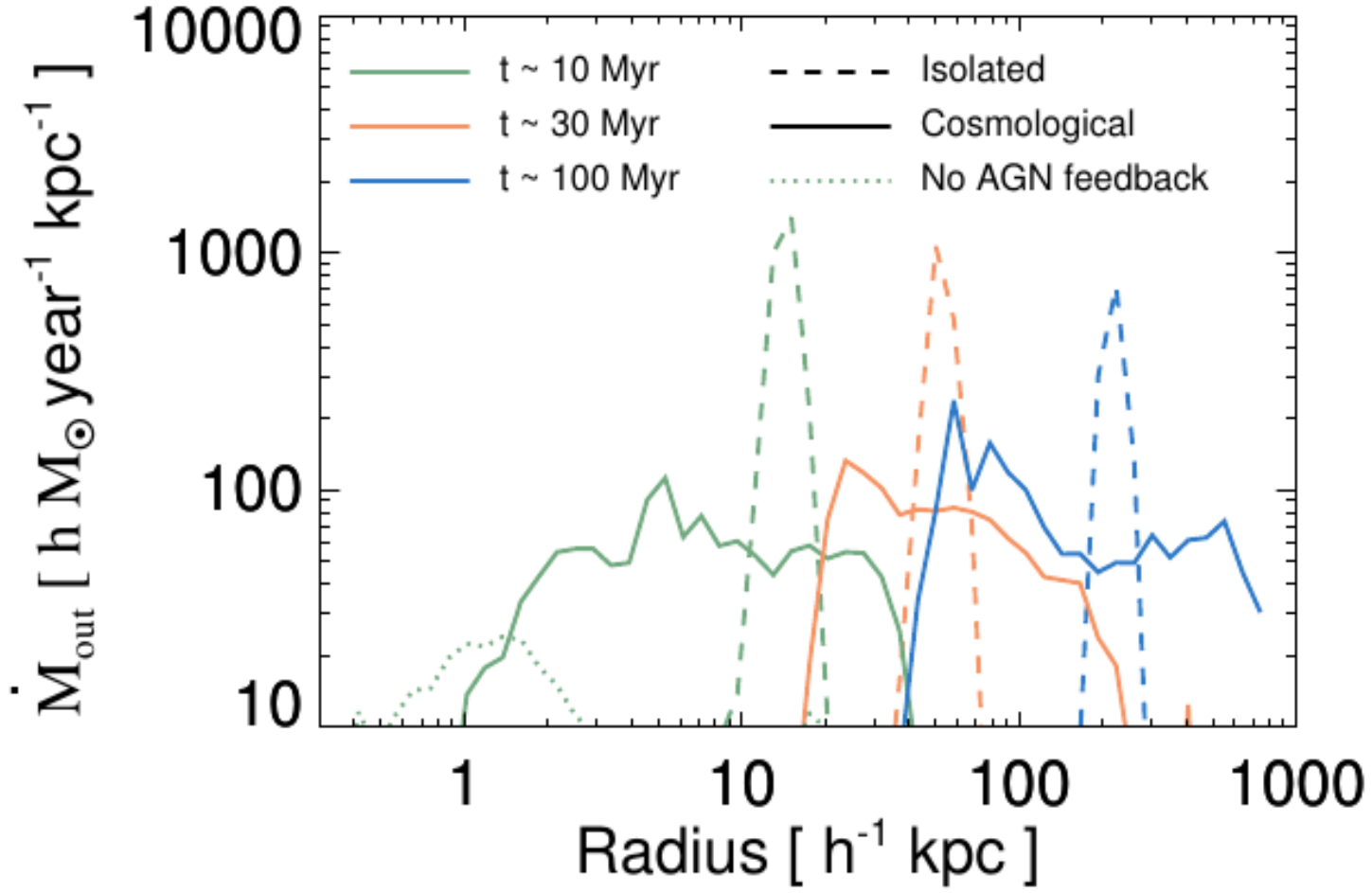

Costa, Sijacki & Haehnelt, 2014

Calibrating AGN feedback

ISOLATED VS COSMOLOGICAL HALOS: MOMENTUM-DRIVEN
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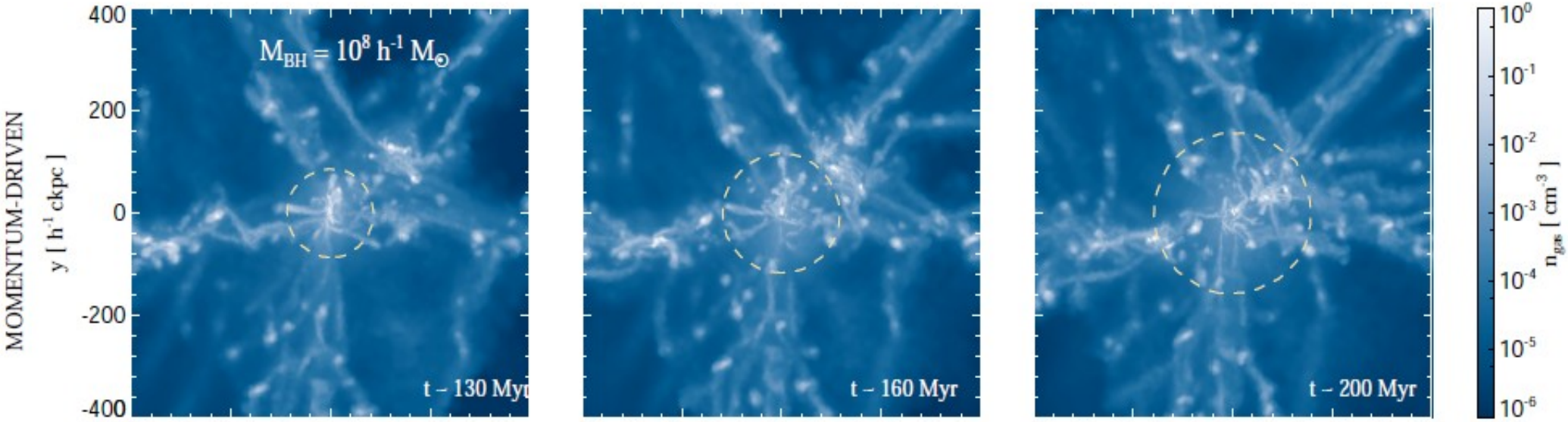
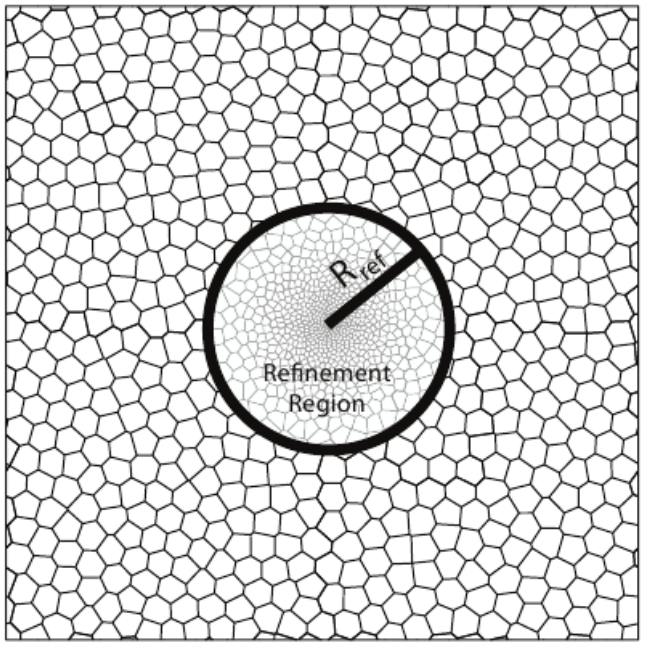
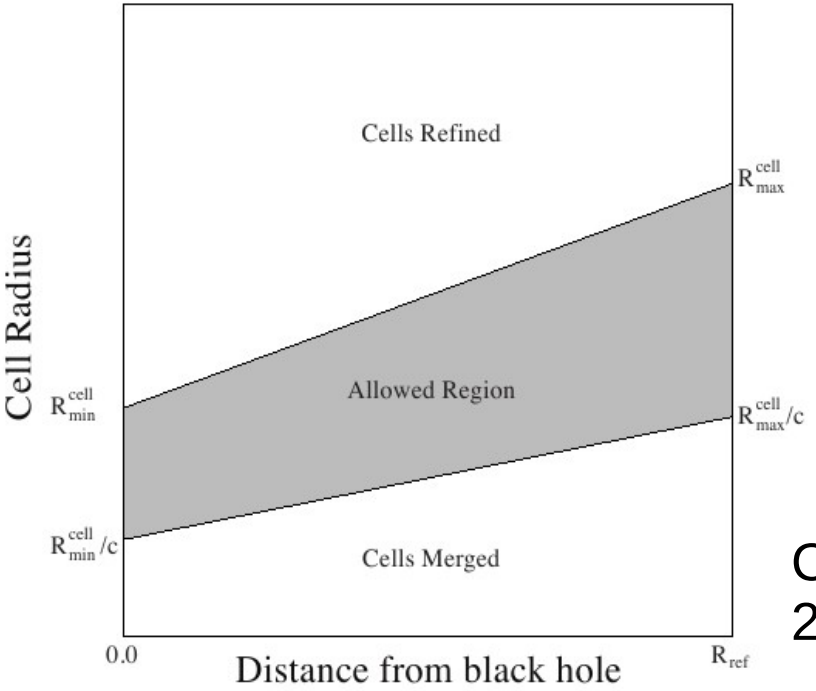


Costa, Sijacki & Haehnelt, 2014

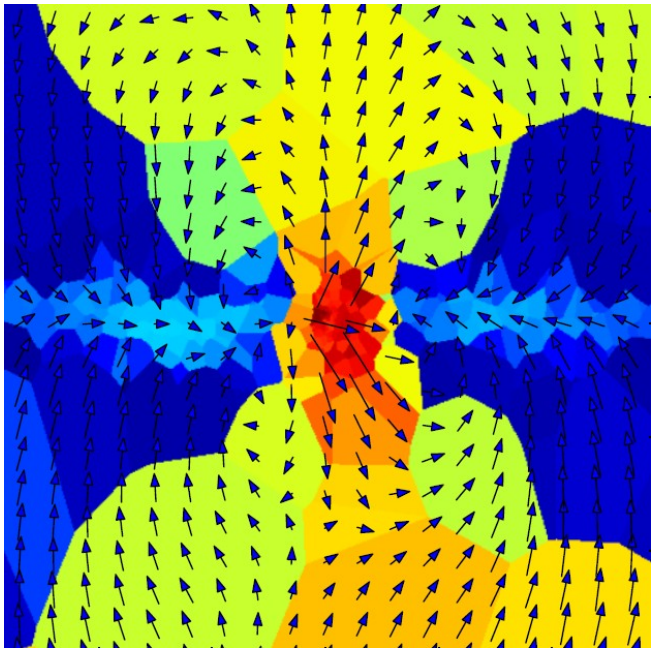
Resolving flows onto BHs

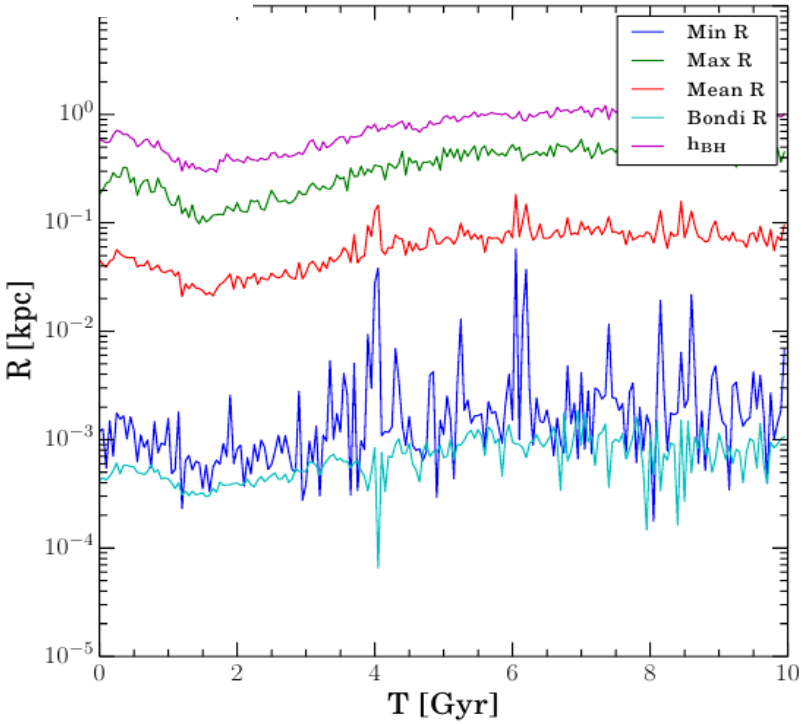




Curtis & Sijacki, MNRAS, 2015

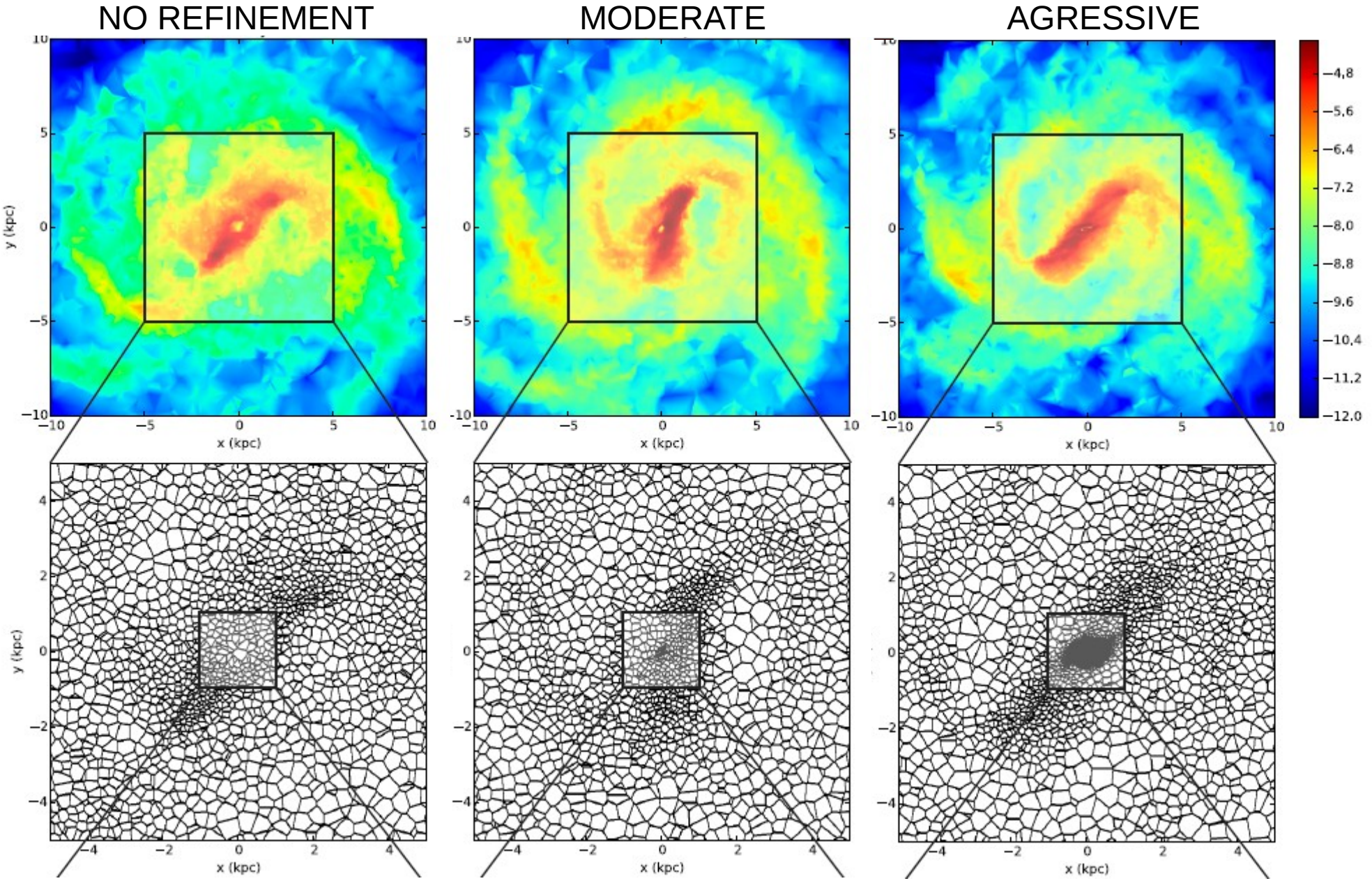
super-Lagrangian refinement





Resolving flows onto BHs

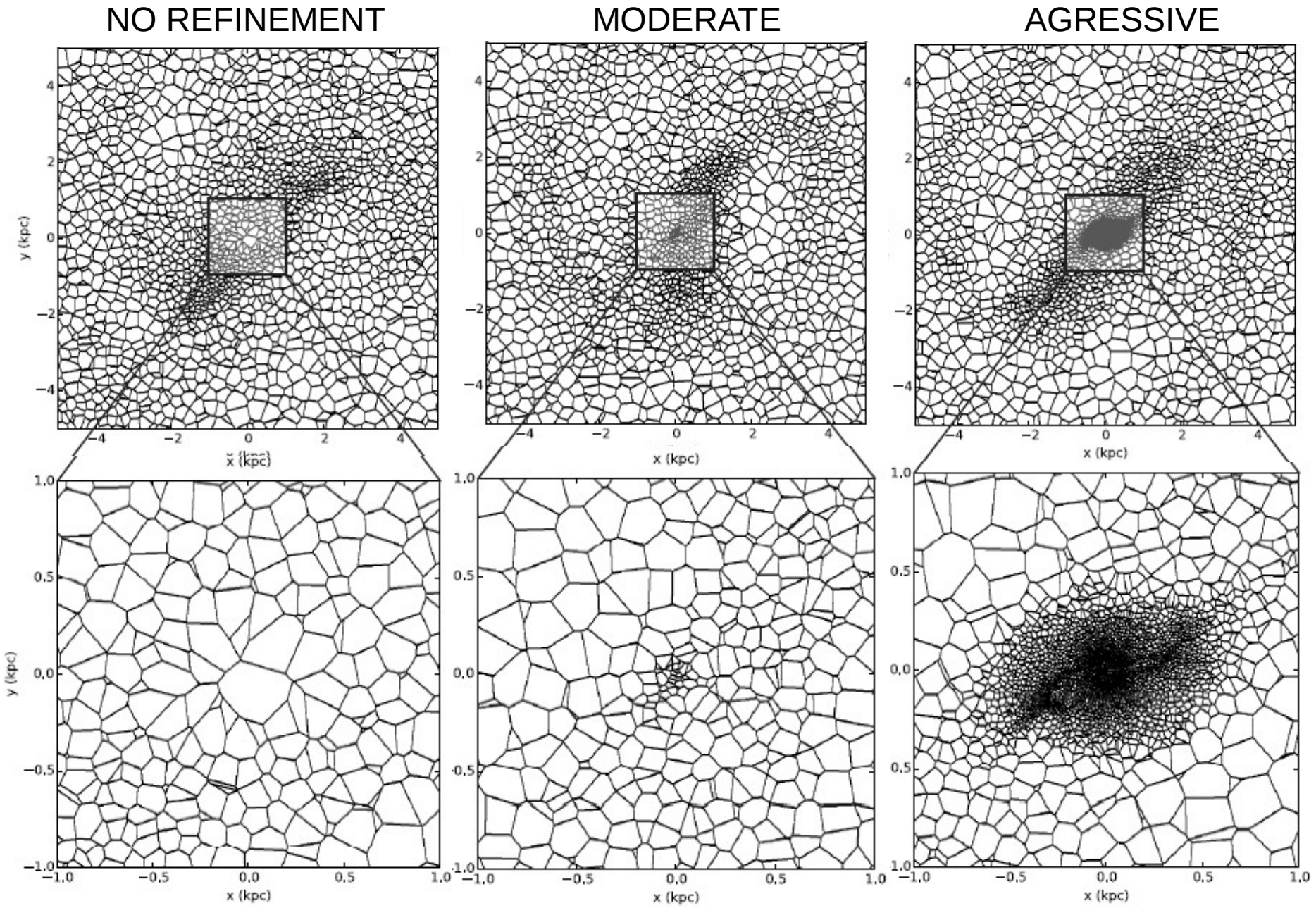
GAS DENSITY MAPS + VORONOI MESH



Curtis & Sijacki, 2015

Resolving flows onto BHs

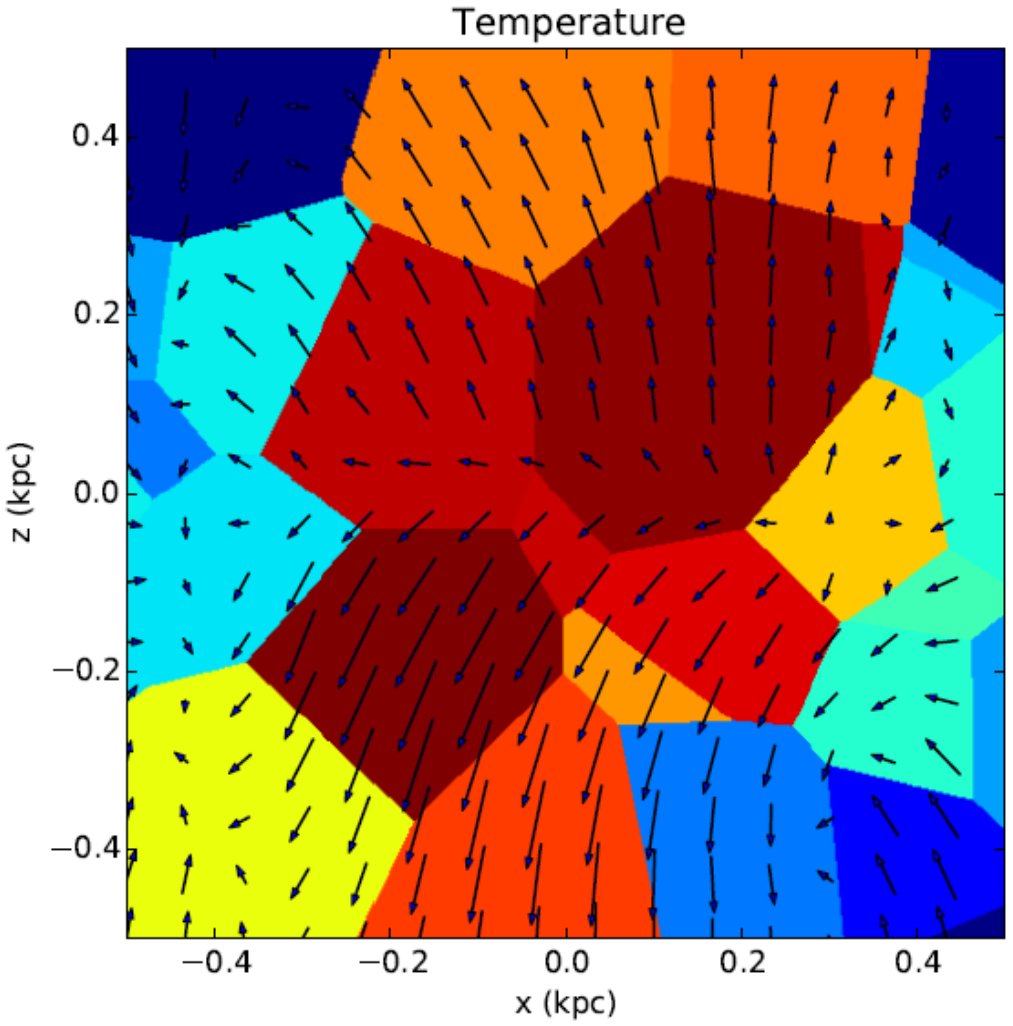
VORONOI MESH



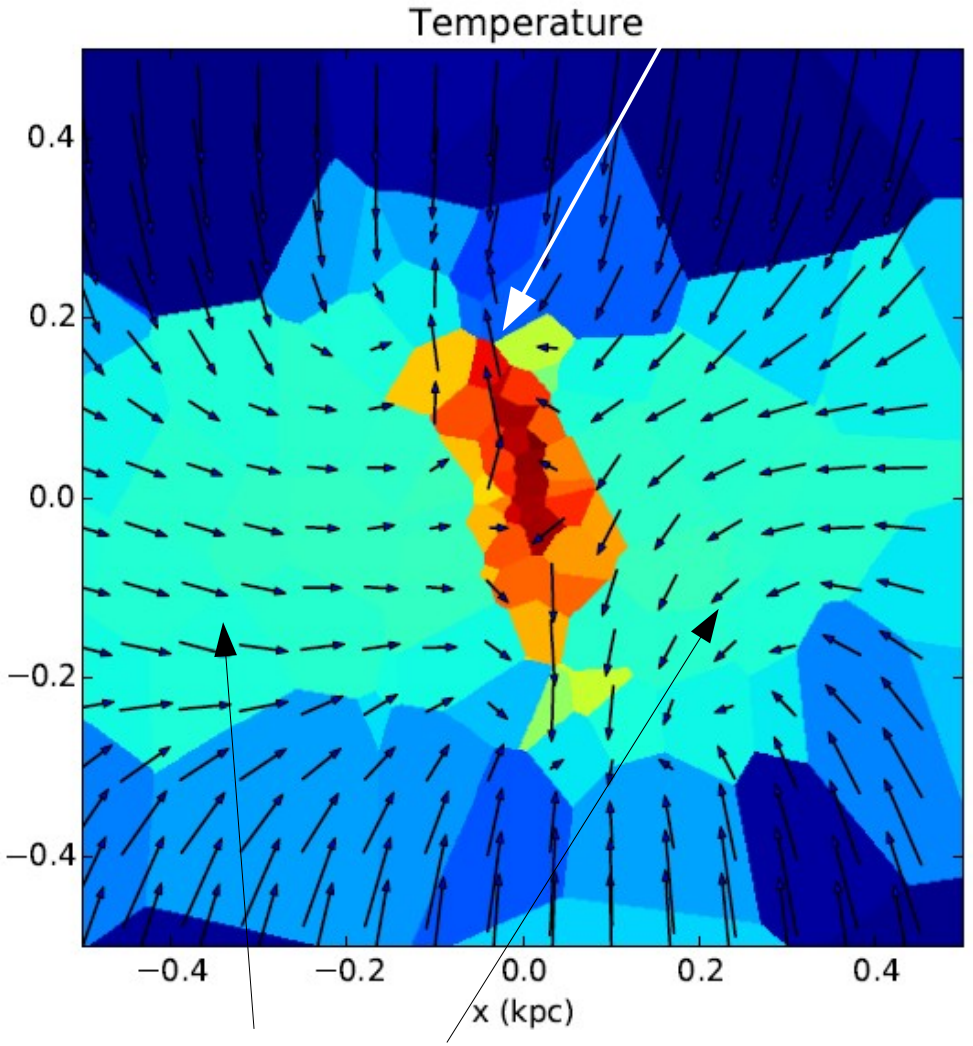
Curtis & Sijacki, 2015

Resolving flows onto BHs

GAS TEMPERATURE MAPS (edge on)



hot outflow



cold disk inflow

Curtis & Sijacki, 2015

Conclusions

→ Calibrating galaxy formation physics in simulations requires careful study of numerics and unbiased comparison with large observational datasets

→ Black hole – host galaxy scaling relation in very good agreement with observations:

1. steepeing at the massive end
2. no strong correlation for low mass, blue star-forming galaxies

→ Physical link between SF and AGN triggering possibly more complex than previously envisaged

→ AGN-driven outflows likely energy-driven

→ Gas angular momentum and AGN feedback play a crucial role in the growth of SMBHs