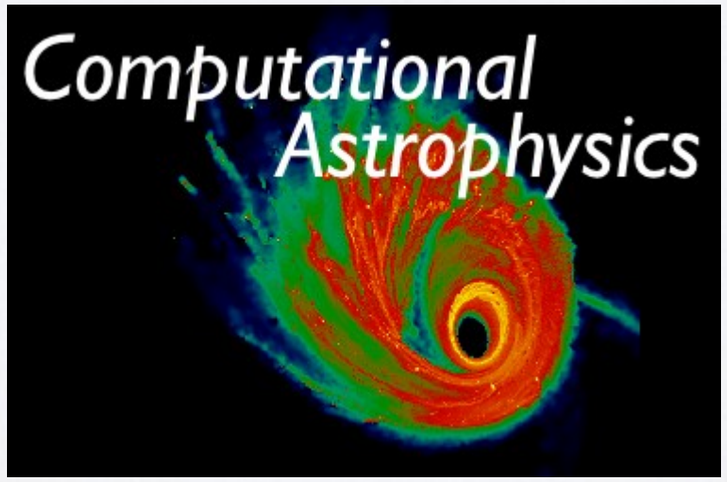
MODELING ACTIVE GALACTIC NUCLEI IN COSMOLOGICAL SIMULATIONS

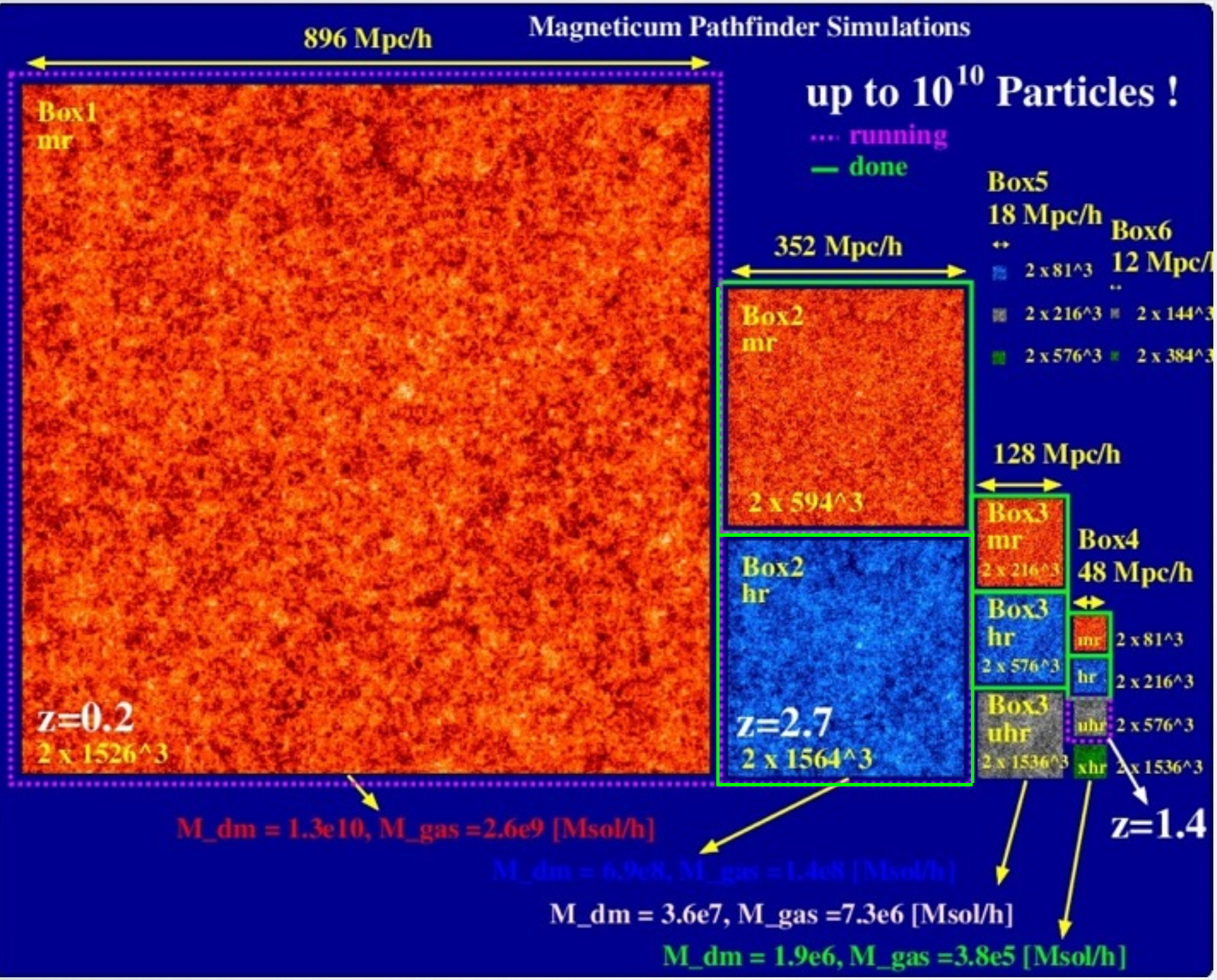
LISA KARIN BACHMANN

Universitäts-Sternwarte München

in collaboration with Klaus Dolag, Michaela Hirschmann, Almudena Prieto, Rhea-Silvia Remus, …



MAGNETICUM PATHFINDER SIMULATIONS



Our simulations include:

- thermal conduction (Dolag et al., 2004)
- star formation
- chemical enrichment
- supernova feedback (Tornatore et al. 2007)
- metals
- sixth-order Wendland kernel (Dehnen & Aly 2012)
- low viscosity SPH scheme
- magnetic fields (passive)
- BH growth and AGN feedback

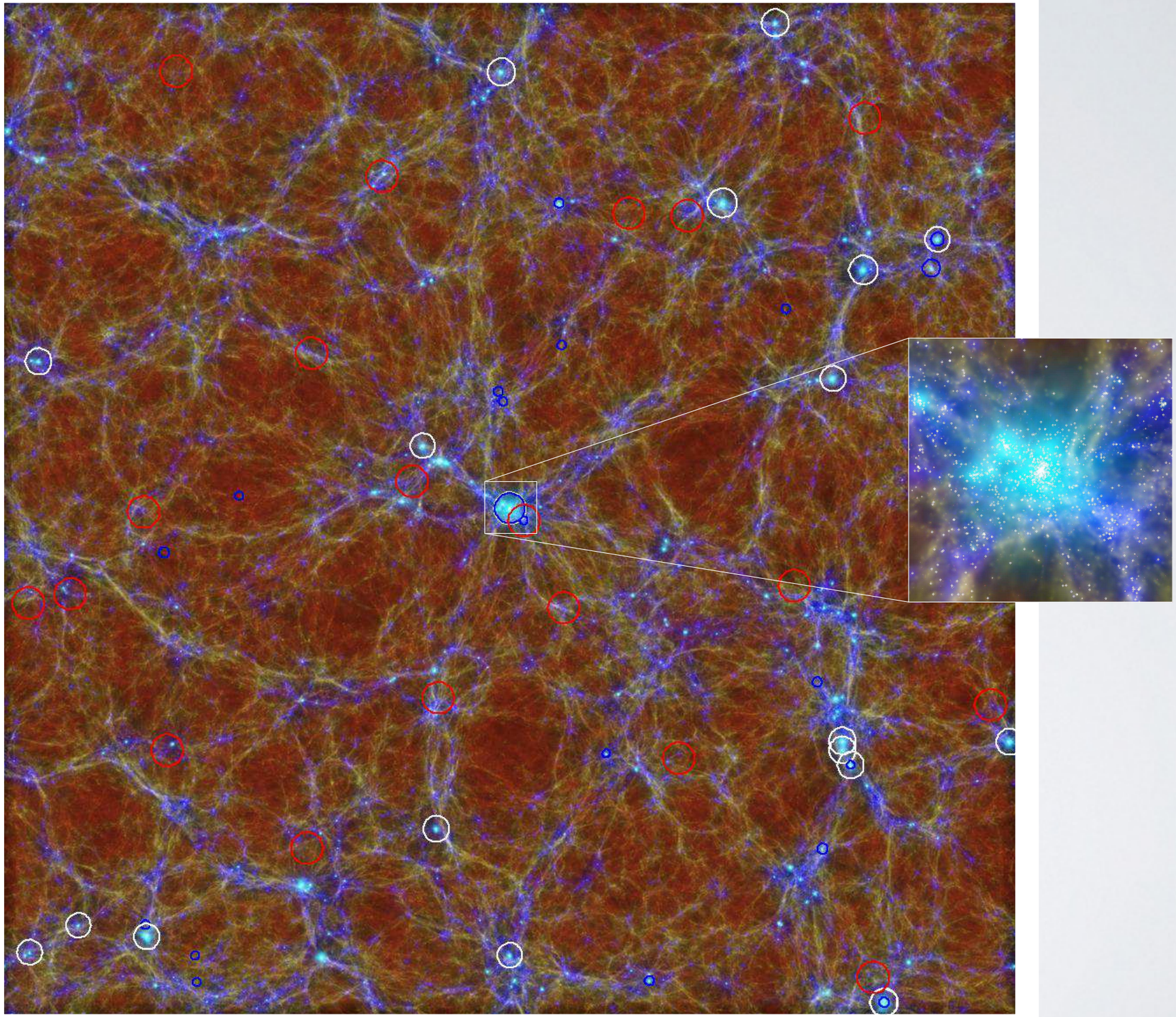
What makes the BHs in our simulations special?

- We do not force BHs to stay in the center of galaxies!

Dolag et al. in prep.

BLACK HOLES IN BOX2 HR

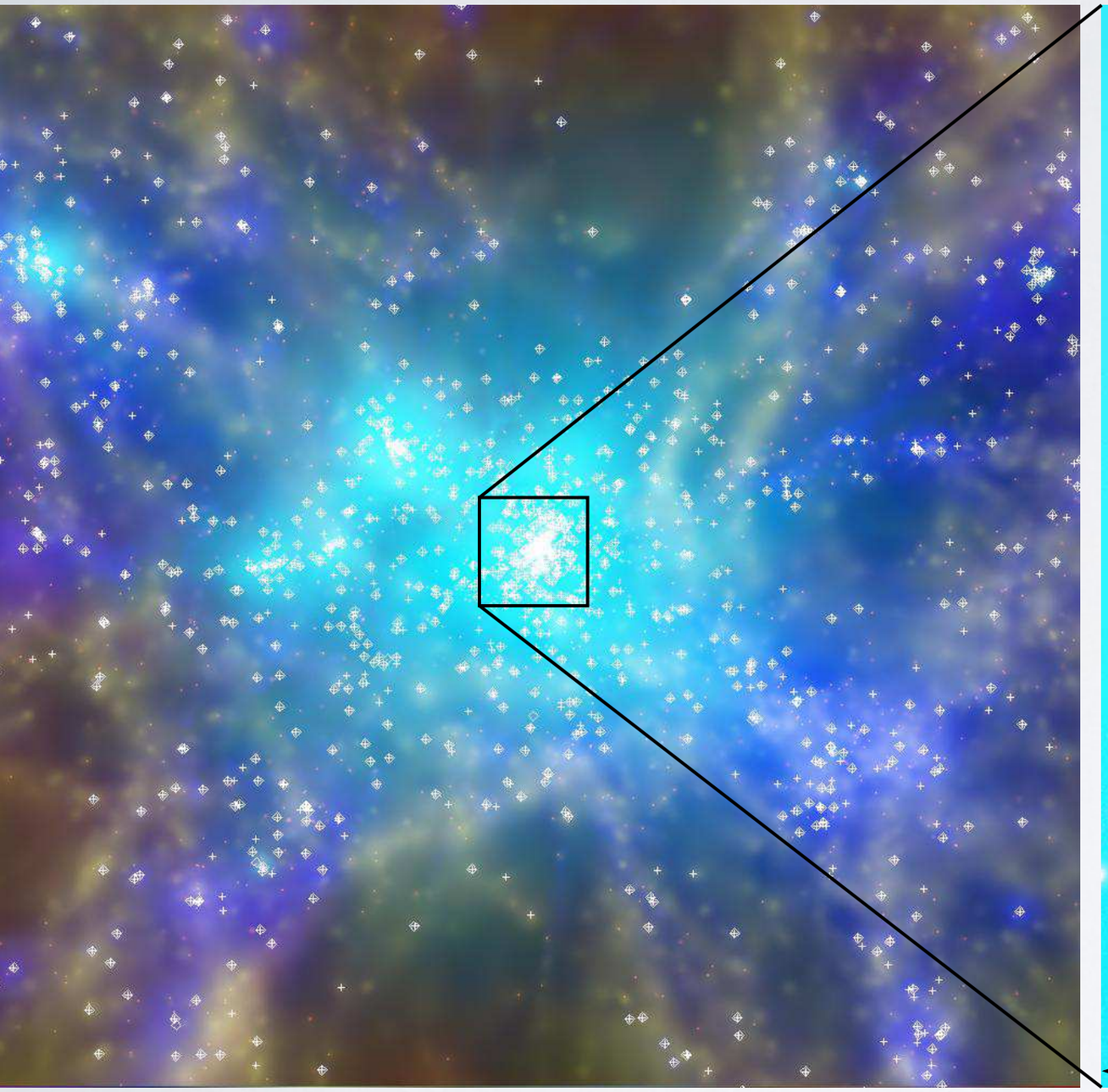
Box size: 500 Mpc

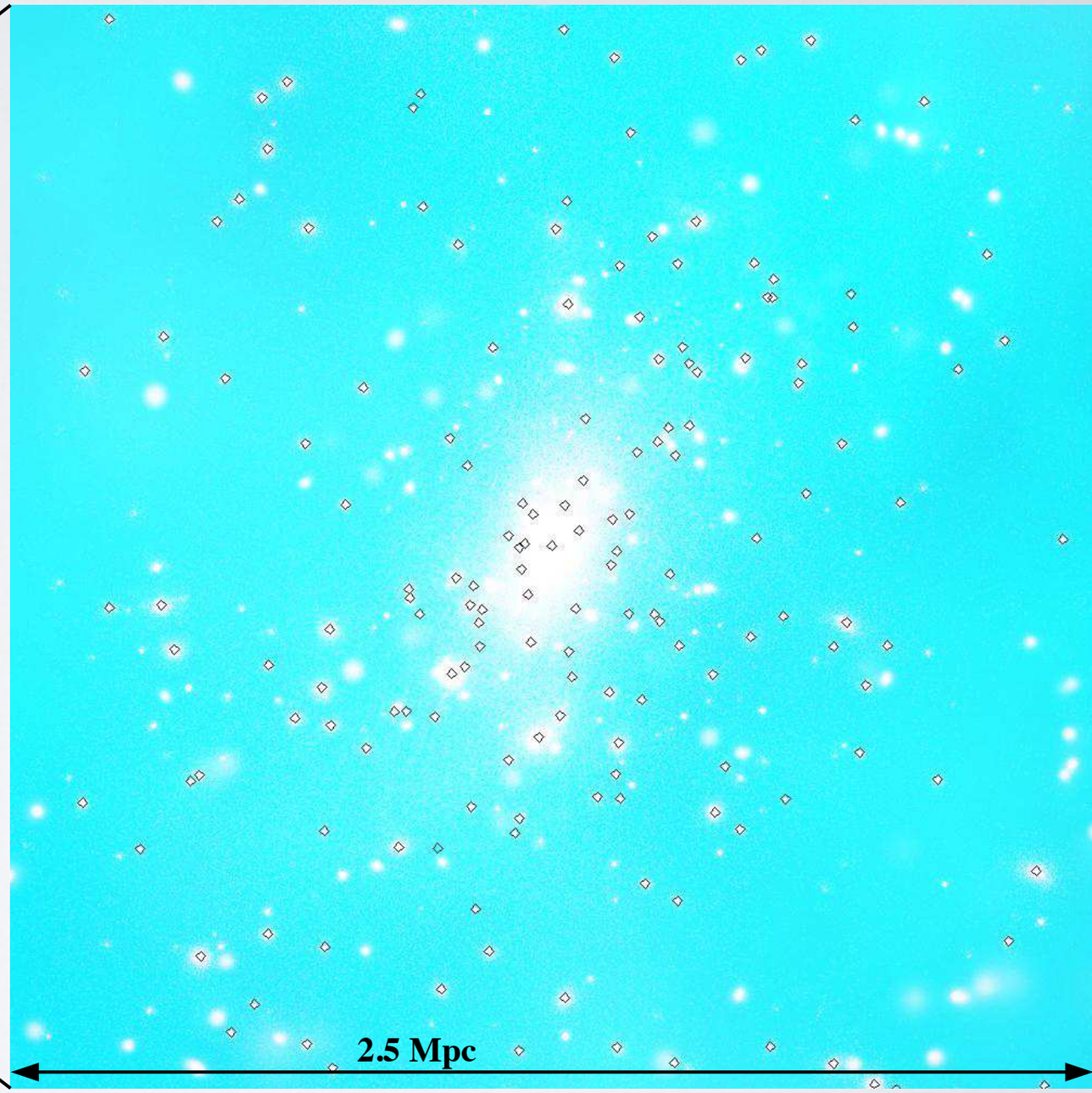


white: highest masses
blue: highest Eddington ratio
red: highest accretion rates

Hirschmann et al. (2013)

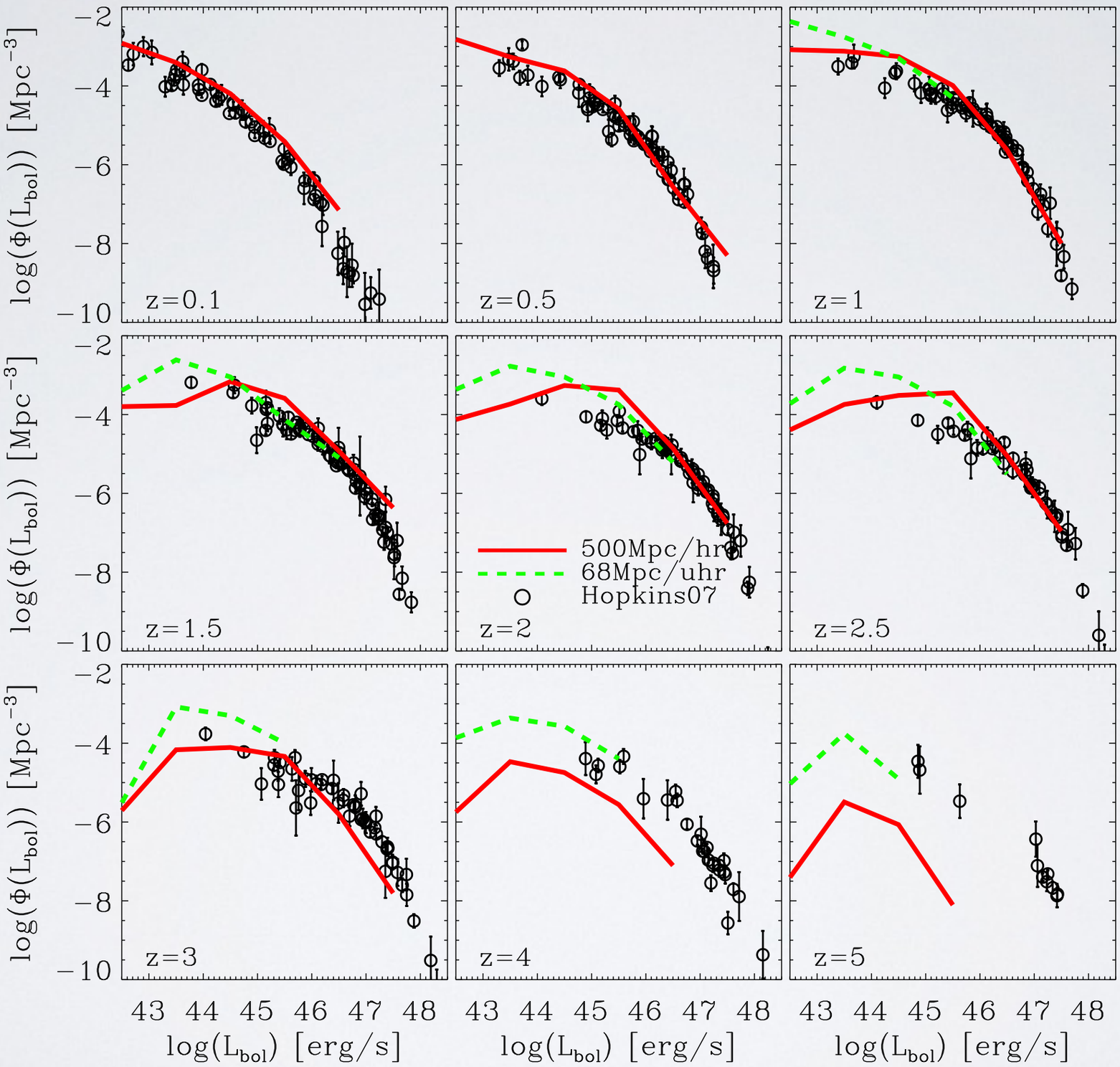
BLACK HOLES IN BOX2 HR





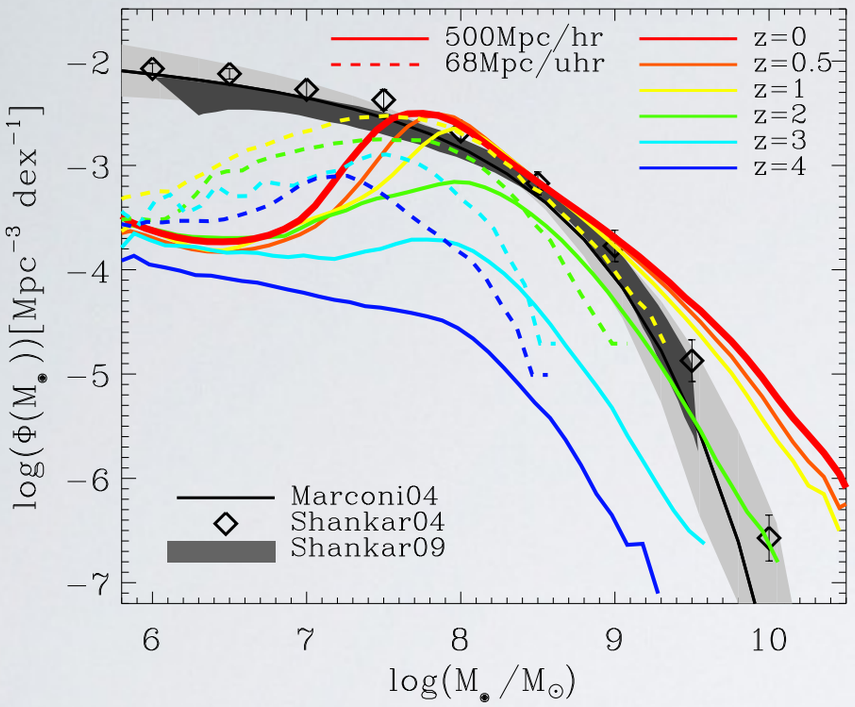
Hirschmann et al. (2013)

LUMINOSITY FUNCTIONS

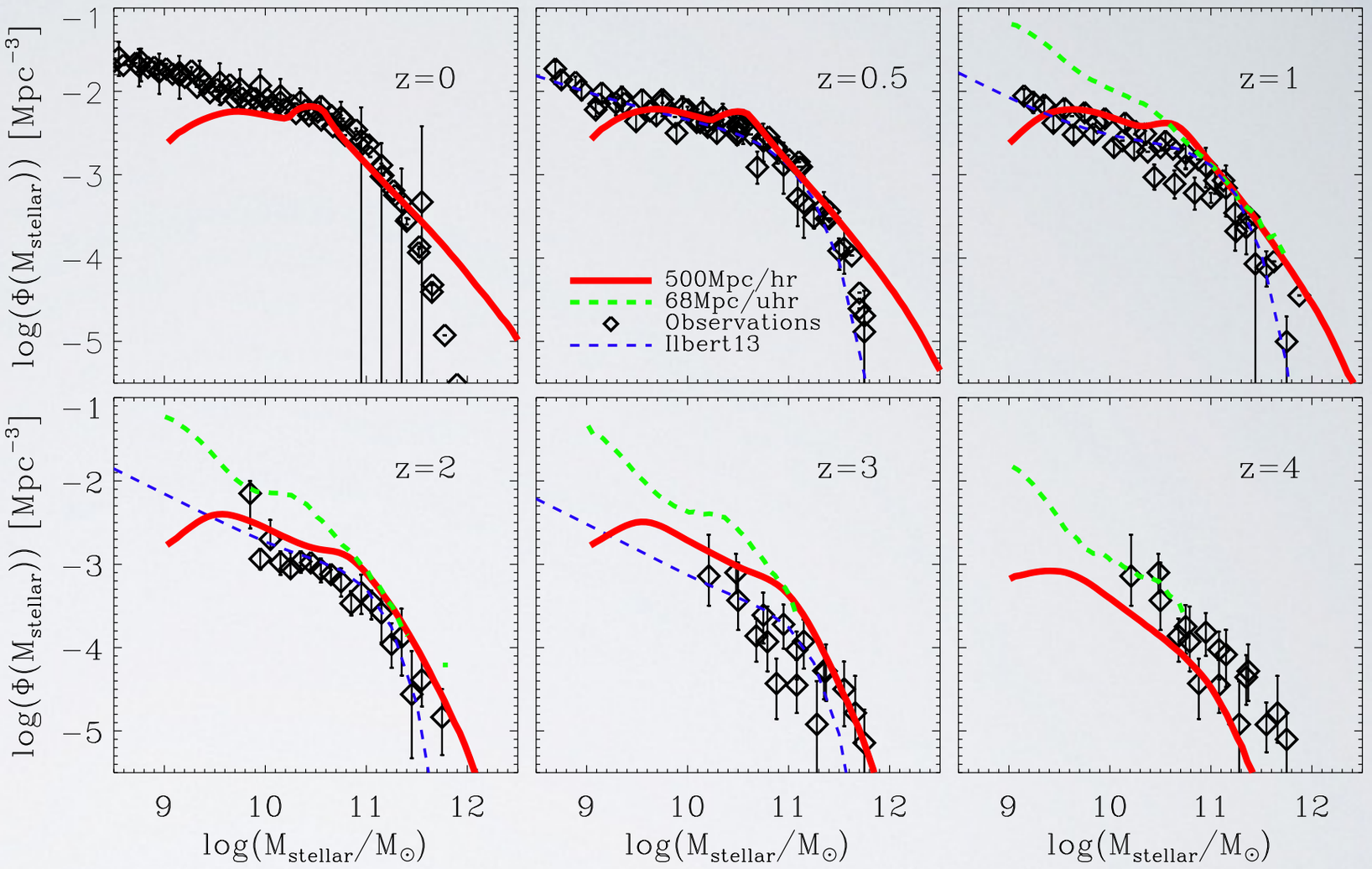


Hirschmann et al. (2013)

BH mass function



stellar mass function



This looks already good!
But: overestimation of the high mass end!

We have to improve the BH model in our code!

Hirschmann et al. (2013)

Seeding

Accretion

MODELING BLACK HOLES IN COSMOLOGICAL SIMULATIONS

BH Merger

AGN Feedback

ACCRETION

Bondi model:

$$\dot{M}_{\rm B} = \frac{4\pi G^2 M^2 \rho_\infty}{(v^2 + c_{\rm s}^2)^{3/2}}$$

- Assumptions: Isothermal, isotropic sphere
- No difference between hot and cold gas

This does not work!

Boost factor

Commonly used in simulations:

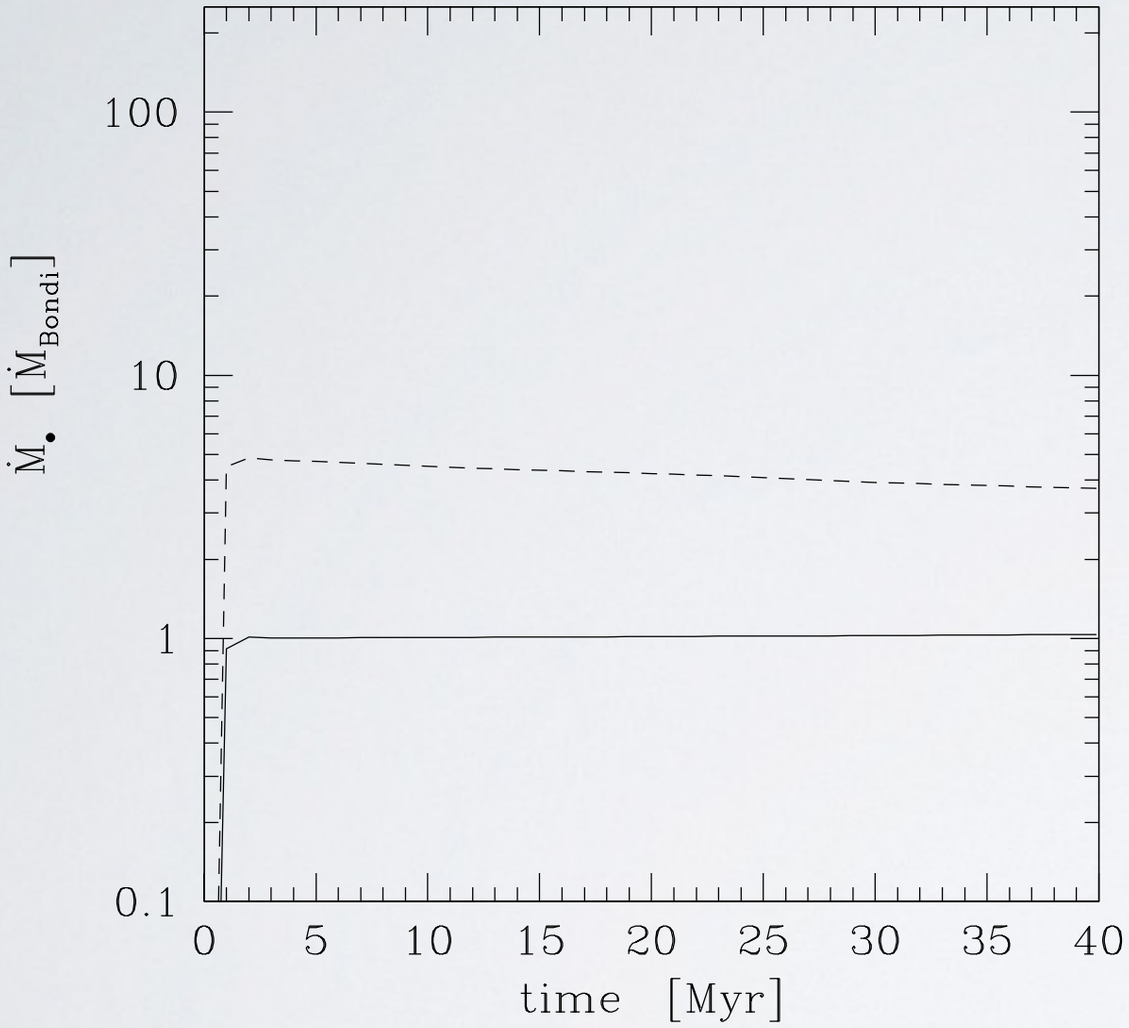
$$\dot{M}_{\rm B} = \frac{4\pi \alpha G^2 M_{\rm bh}^2 \langle \rho \rangle}{(\langle c_{\rm s} \rangle^2 + \langle v \rangle^2)^{3/2}}$$

Two reasons for the boost factor:

- Resolution
- Cold gas is not Bondi-like

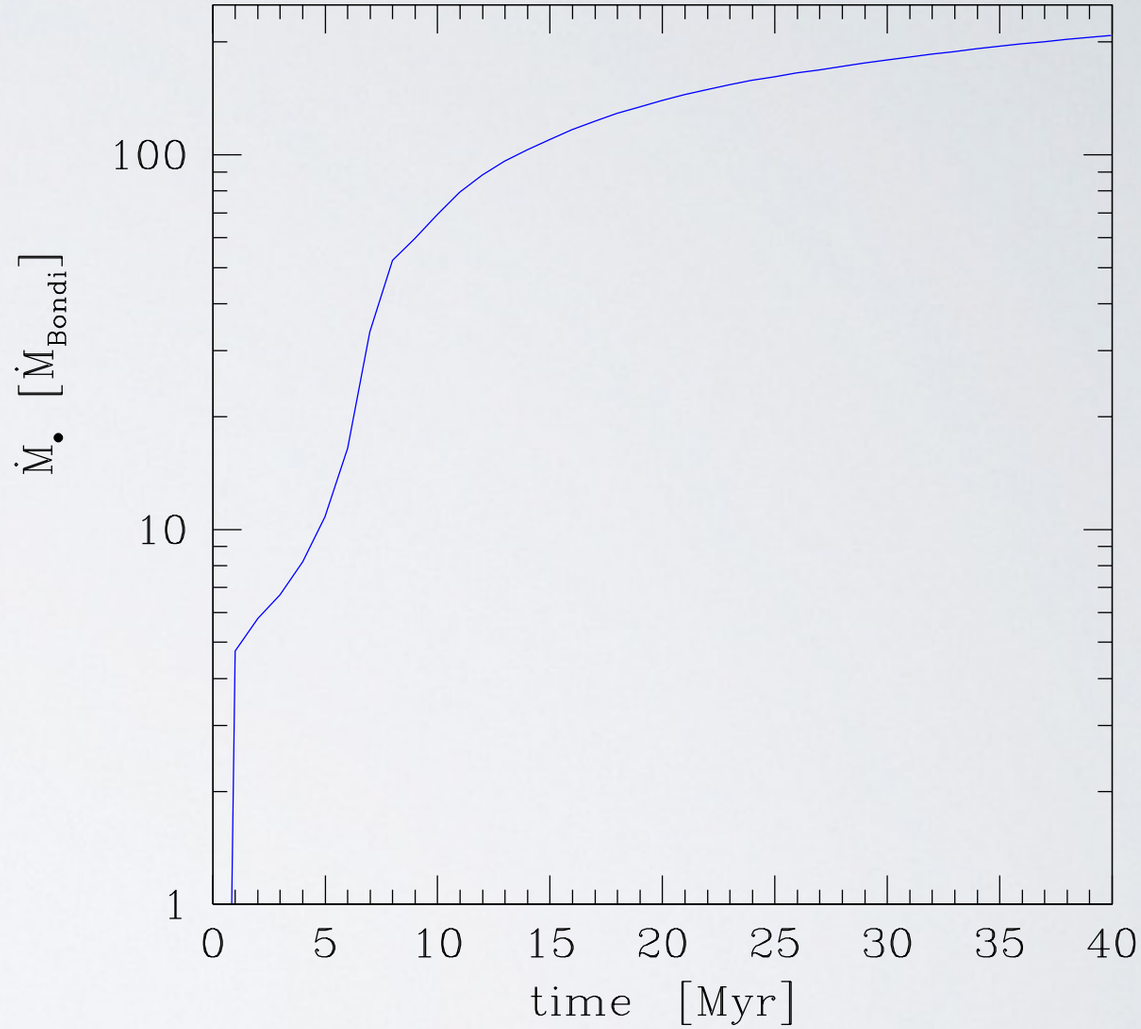
ACCRETION

Adiabatic (Bondi-like) accretion



Gaspari et al. (2013)

Accretion with cooling



$\alpha = 10$ $\alpha = 100$

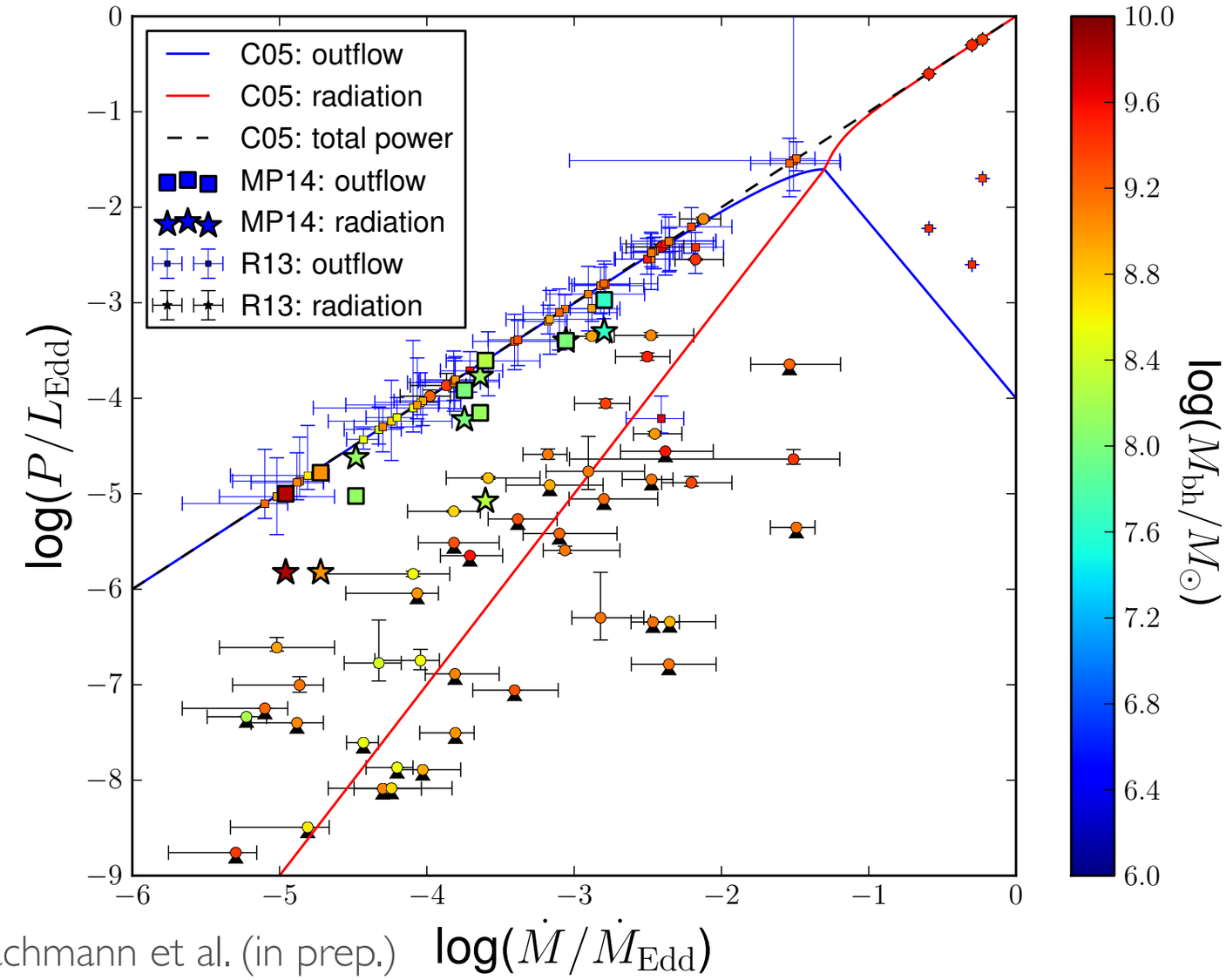
→ Our new accretion model:

$$\dot{M} = \min(\dot{M}_{\rm B,hot} + \dot{M}_{\rm B,cold}, \dot{M}_{\rm Edd})$$

AGN FEEDBACK

Commonly used in simulations: $\dot{E} = \epsilon_\mathrm{f} \epsilon_\mathrm{r} \dot{M} c^2$

But: Observers see something different!



Bachmann et al. (in prep.)

Observations from:
- Russell et al. (2013)
- Mezcua & Prieto (2014)

Theory:
- Churazov et al. (2005)

Outflow: $P_\mathrm{o} = \epsilon_\mathrm{o} \dot{M} c^2$

Radiation: $L = \epsilon_\mathrm{r} \dot{M} c^2$

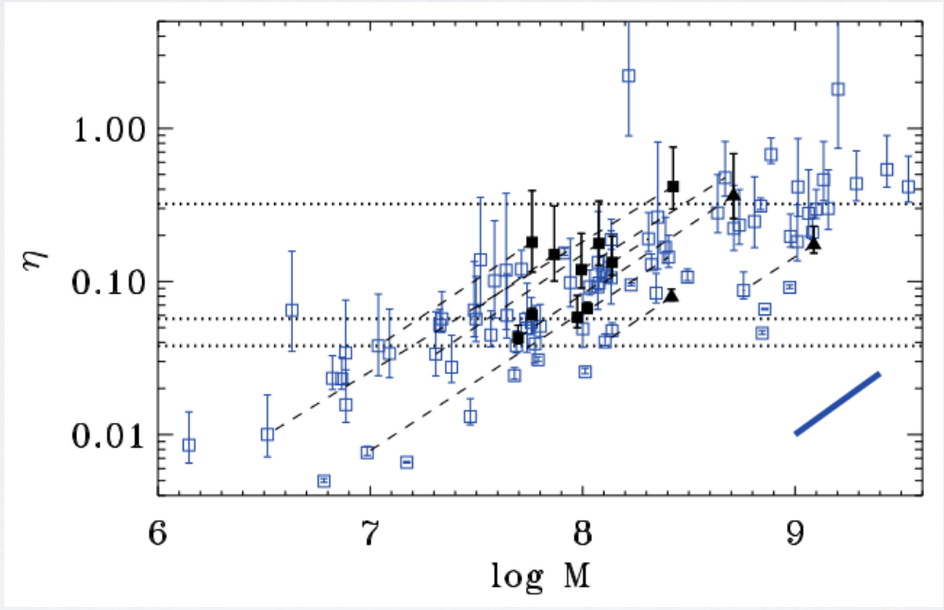
- We use two efficiencies!
- Both are implemented as thermal feedback!

$$\dot{E} = (\epsilon_\mathrm{o} + \epsilon_\mathrm{f} \epsilon_\mathrm{r}) \dot{M} c^2$$

AGN FEEDBACK

In simulations we need efficiencies!

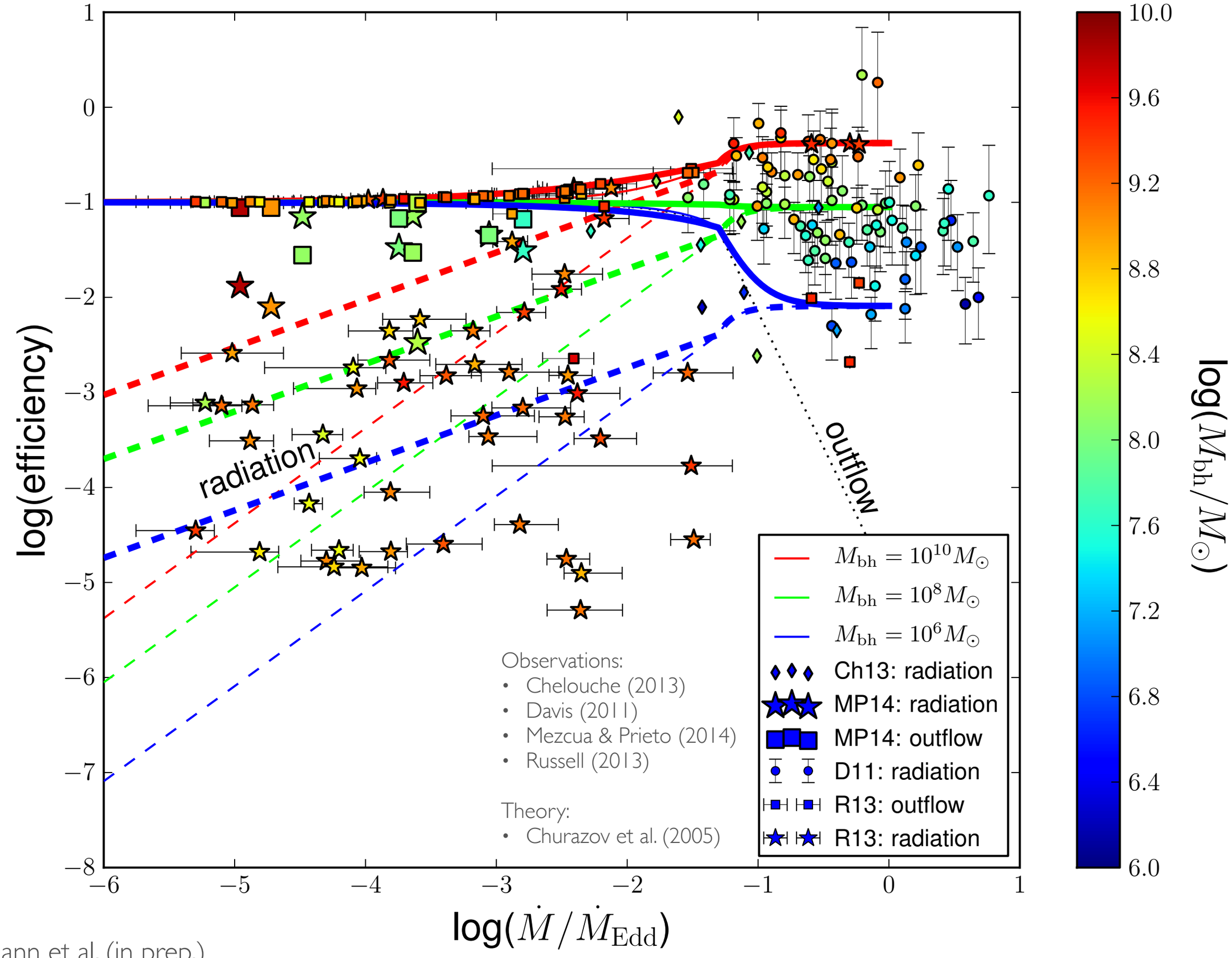
But: The radiative efficiency depends on the mass!



Davis and Laor (2010)

⟶ We combine this with the prediction by Churazov et al. (2005)

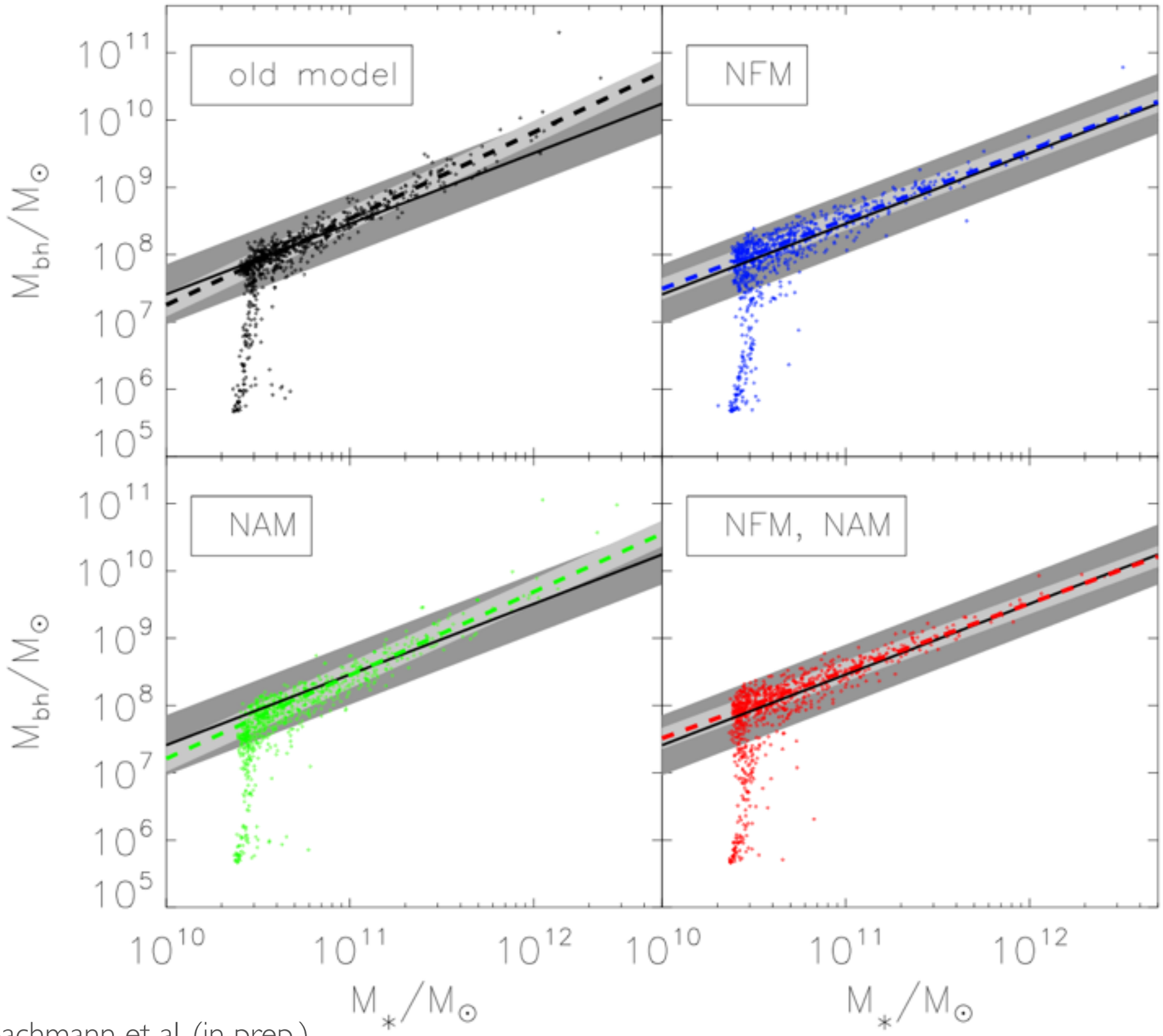
For simulations we need efficiencies!



Bachmann et al. (in prep.)

RESULTS

Box size: 68 Mpc

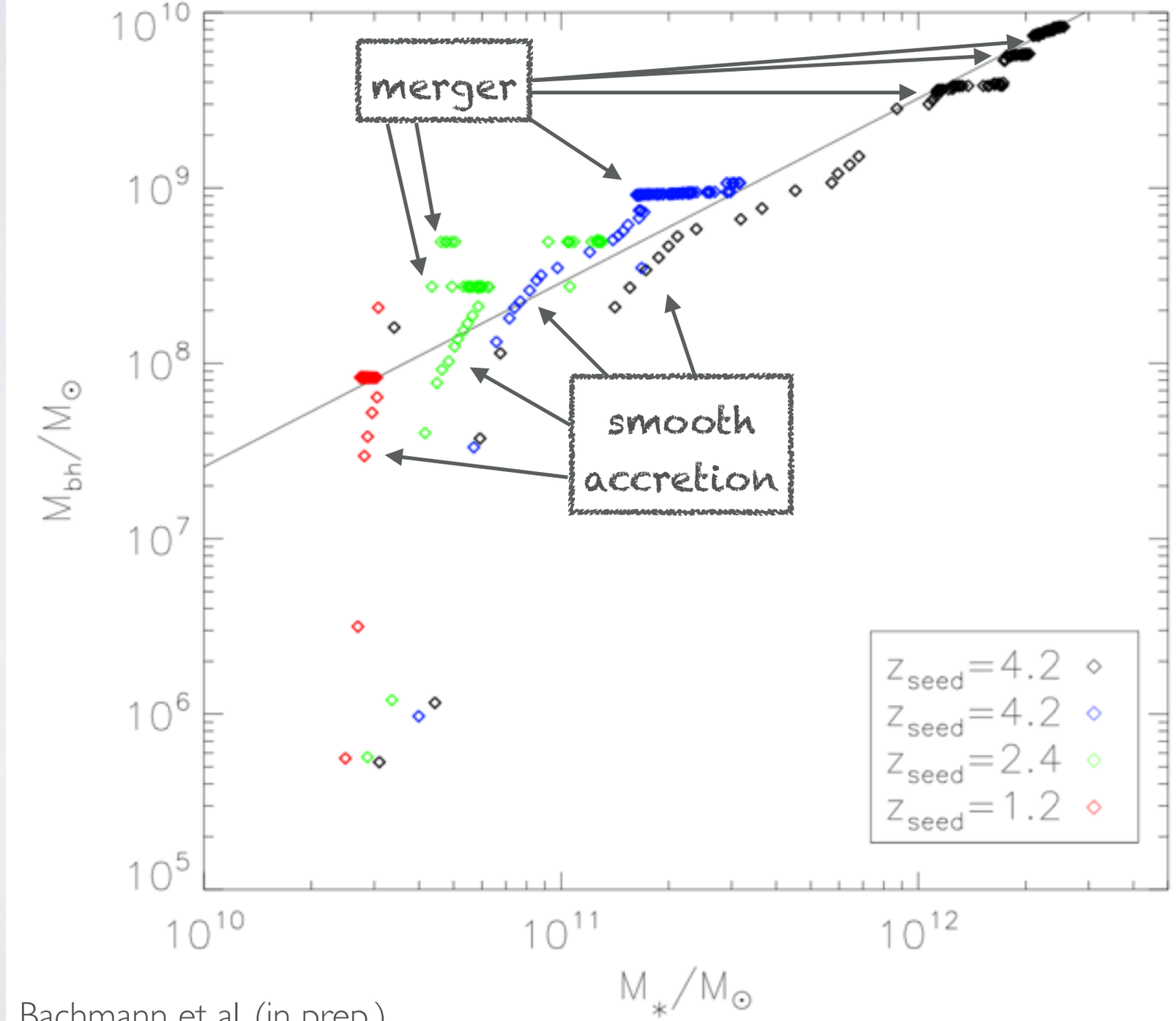


Bachmann et al. (in prep.)

RESULTS

Evolution of BHs and their host galaxies

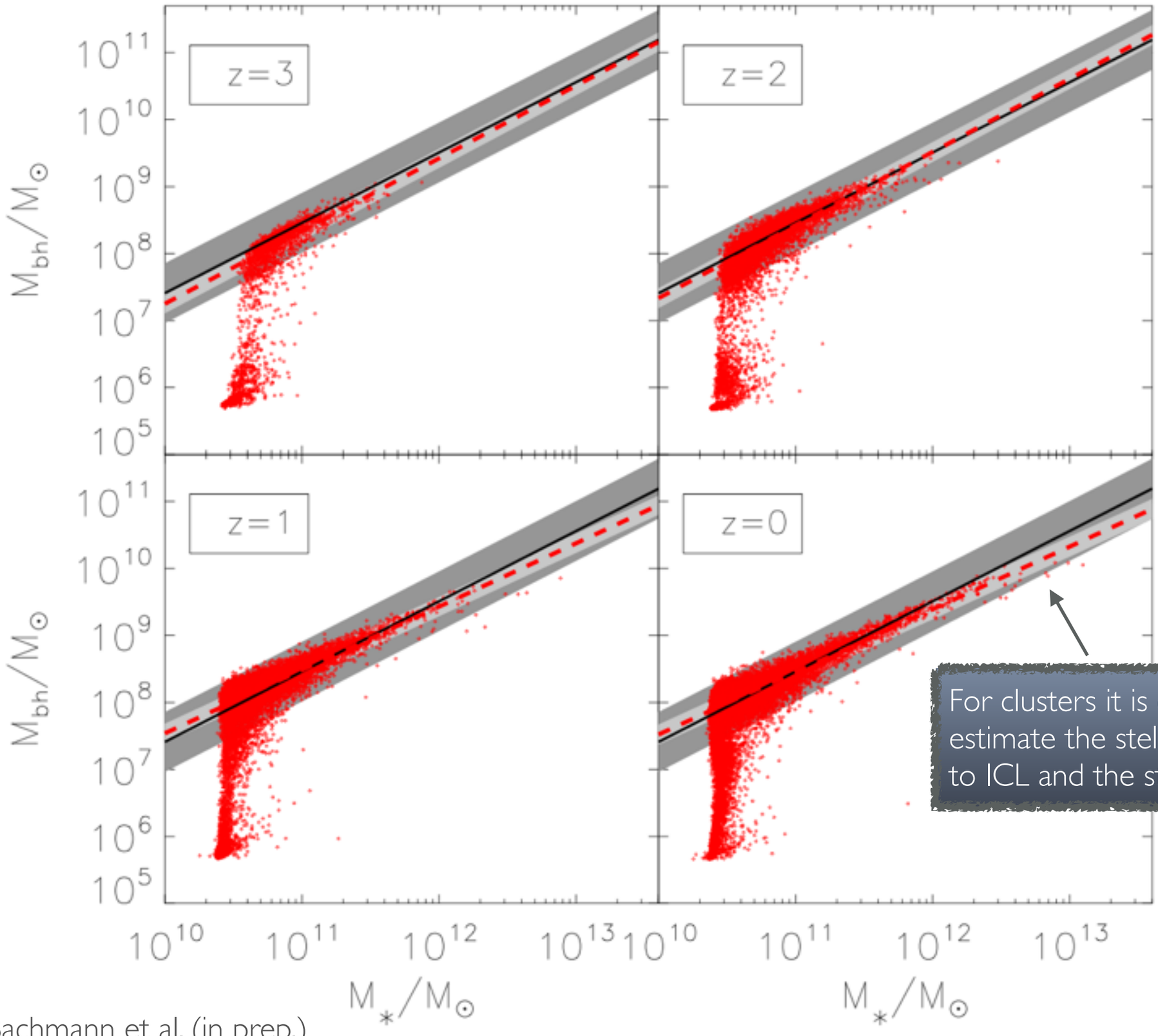
Box size: 68 Mpc



Bachmann et al. (in prep.)

RESULTS

Box size: 182 Mpc



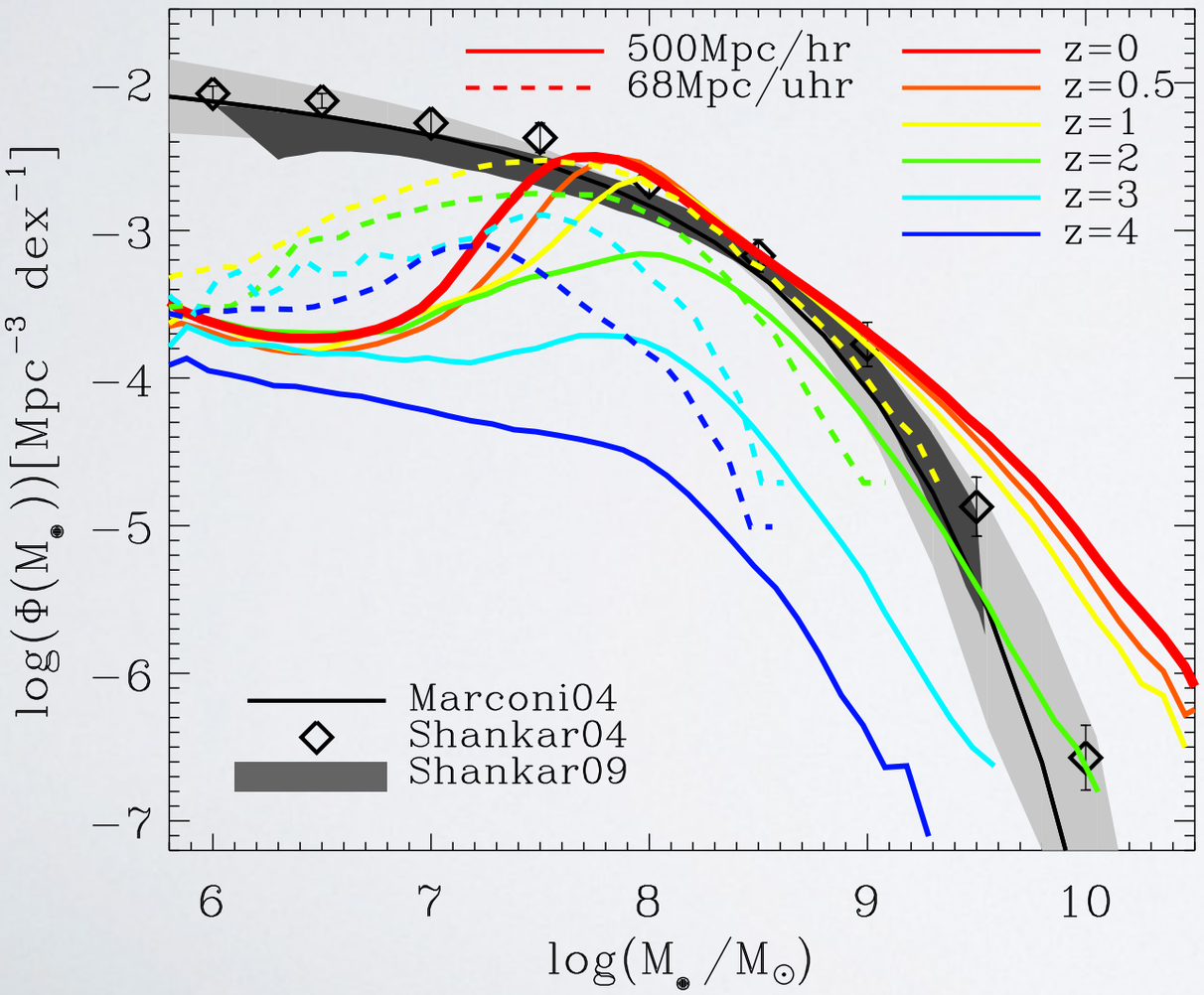
For clusters it is difficult to estimate the stellar mass due to ICL and the stellar halo!

Bachmann et al. (in prep.)

RESULTS

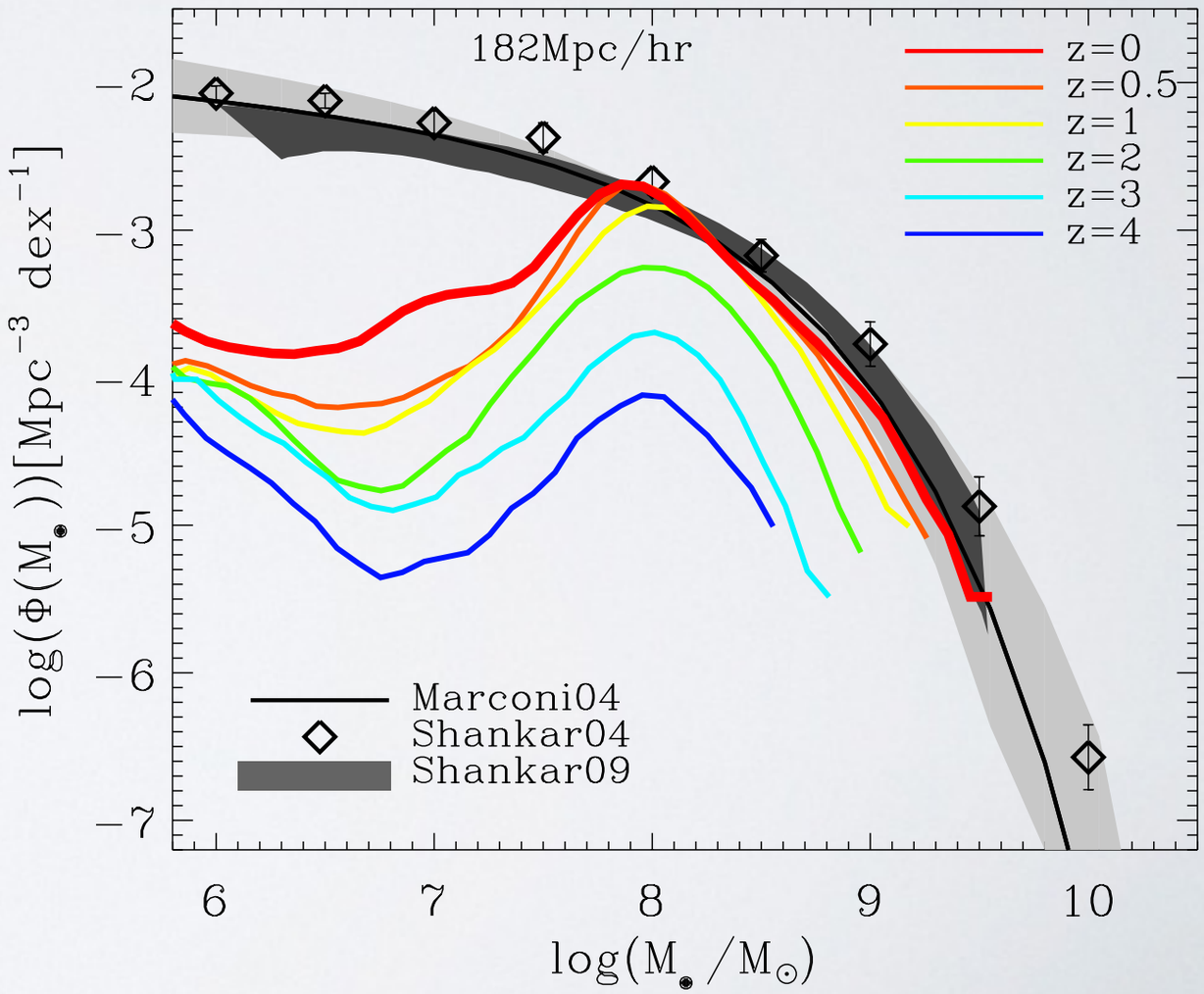
BH mass function

old run



Hirschmann et al. (2013)

new run

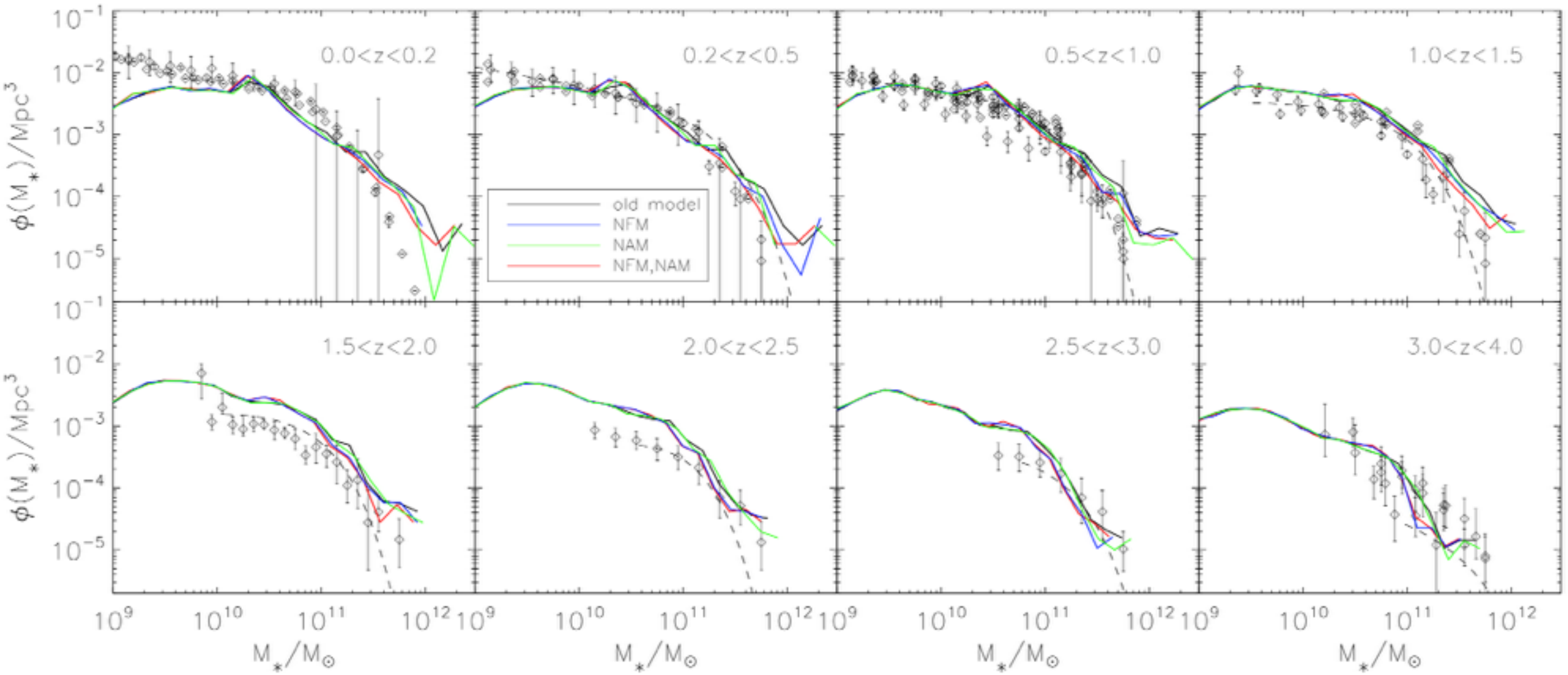


Bachmann et al. (in prep.)

RESULTS

Stellar mass function

Box size: 68 Mpc



Observations:

dashed line:

- Muzzin et al. (2013)

diamonds:

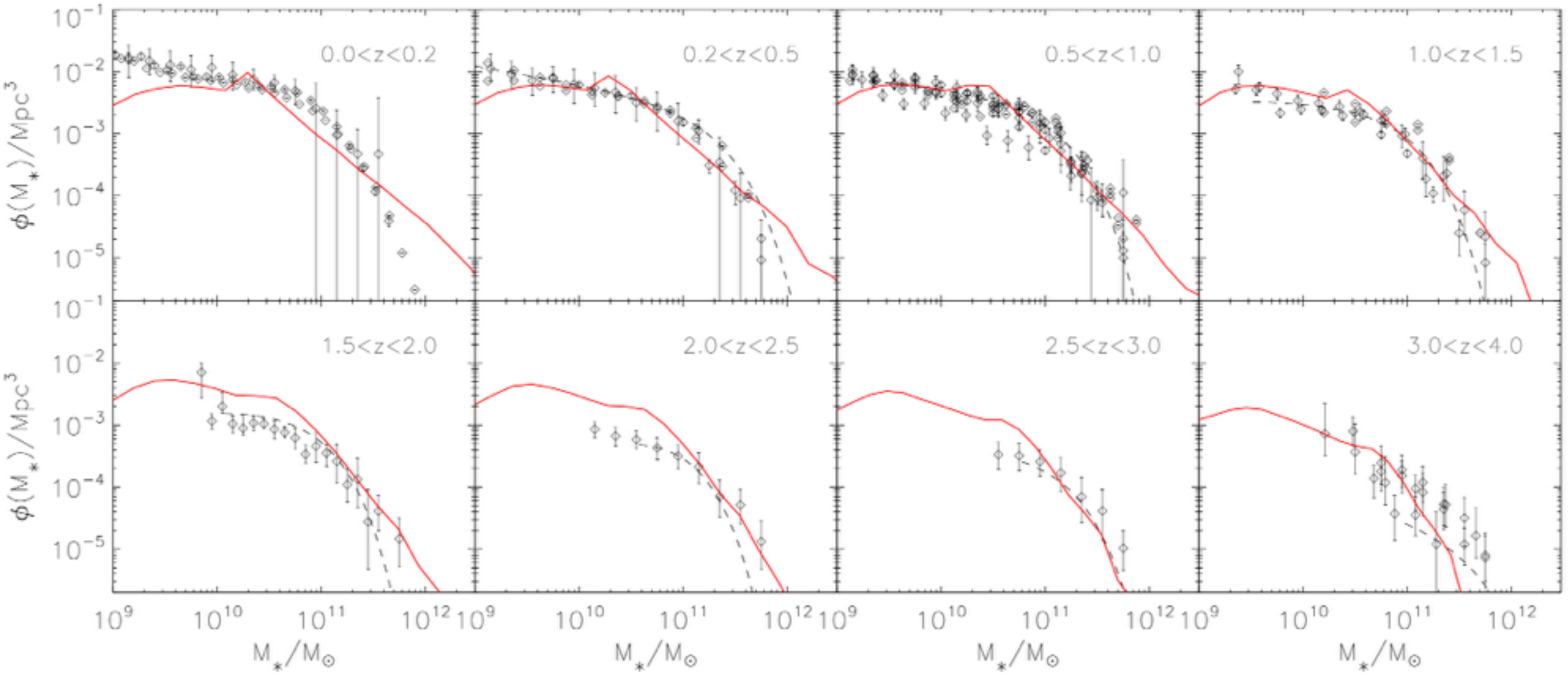
- Panter et al. (2014)
- Cole et al. (2001)
- Bell et al. (2003)
- Pérez-Gonzáles et al. (2007)
- Borsch et al.(2006)
- Bundy et al. (2005)
- Drory et al. (2004)
- Fontana et al. (2006)
- Marchesini et al. (2008)

Bachmann et al. (in prep.)

RESULTS

Stellar mass function

Box size: 182 Mpc



Bachmann et al. (in prep.)

Observations:

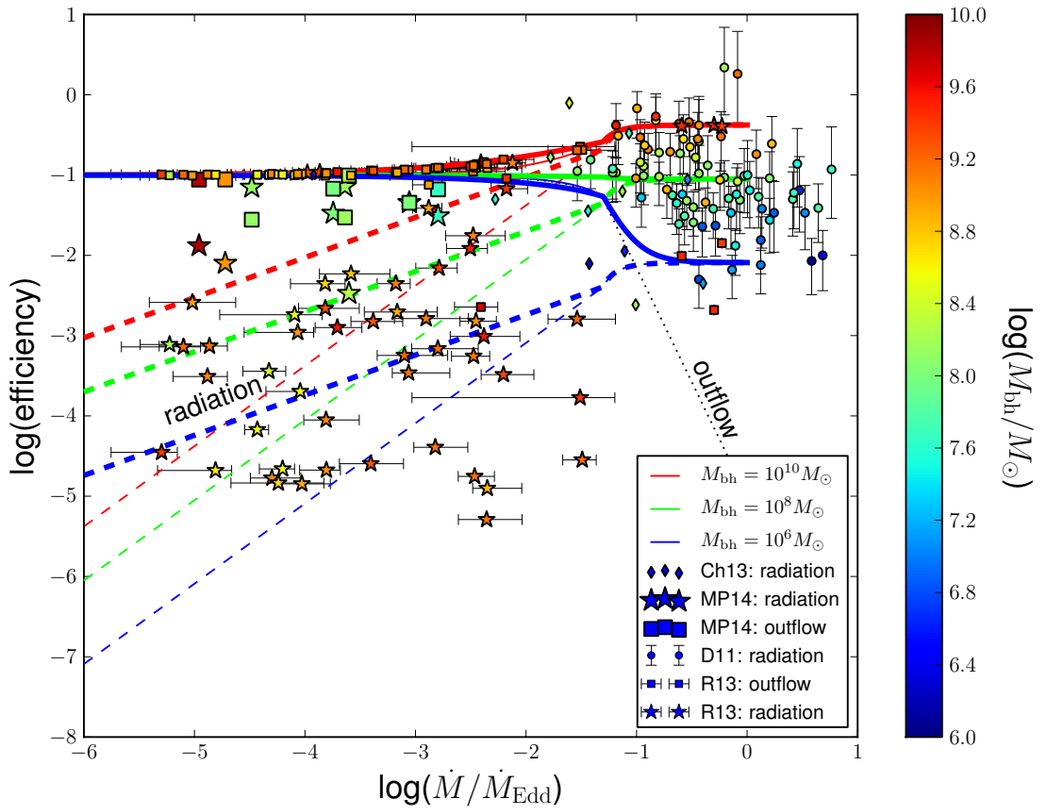
dashed line:
- Muzzin et al. (2013)

diamonds:
- Panter et al. (2014)
- Cole et al. (2001)
- Bell et al. (2003)
- Pérez-Gonzáles et al. (2007)
- Borsch et al.(2006)
- Bundy et al. (2005)
- Drory et al. (2004)
- Fontana et al. (2006)
- Marchesini et al. (2008)

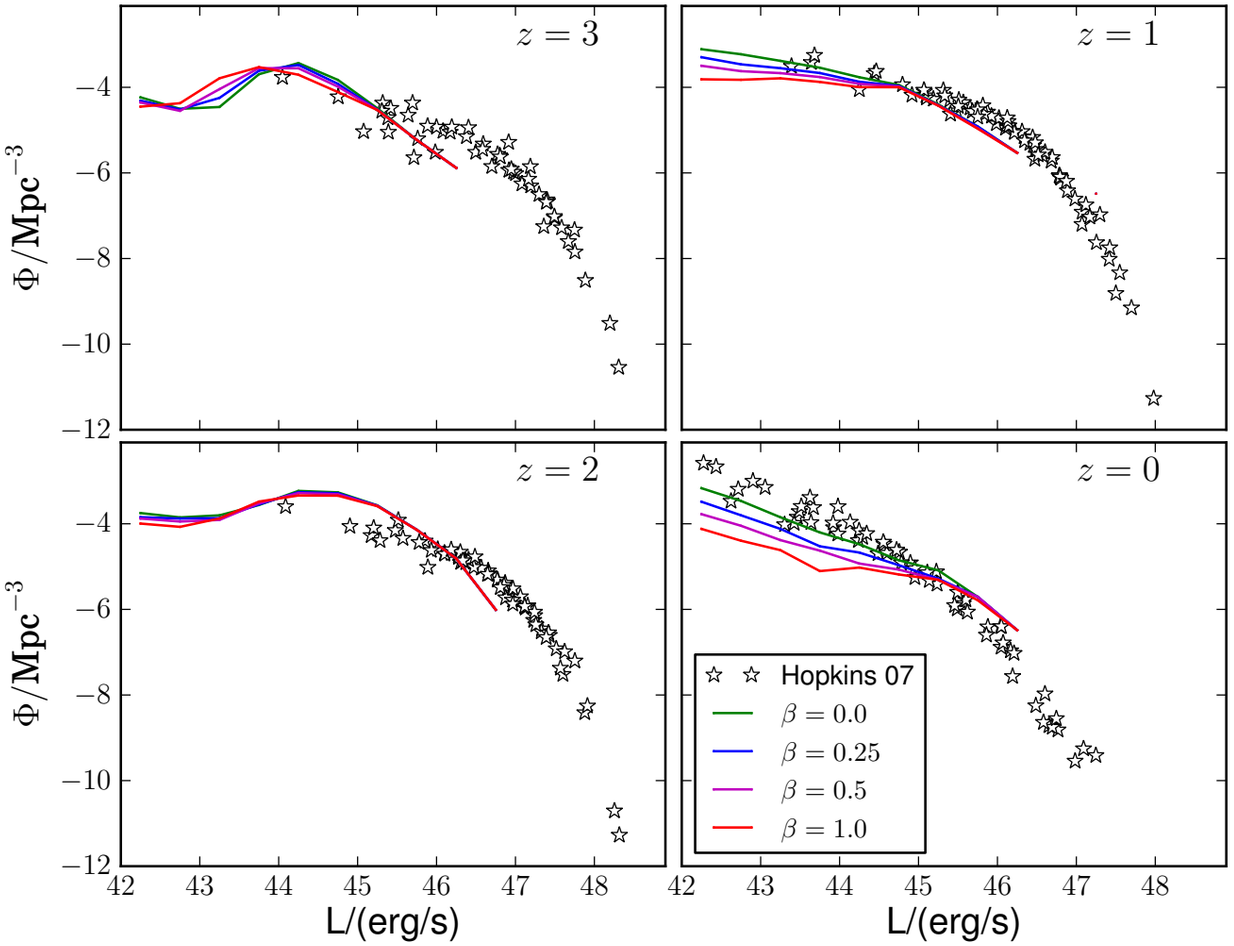
DISCUSSION

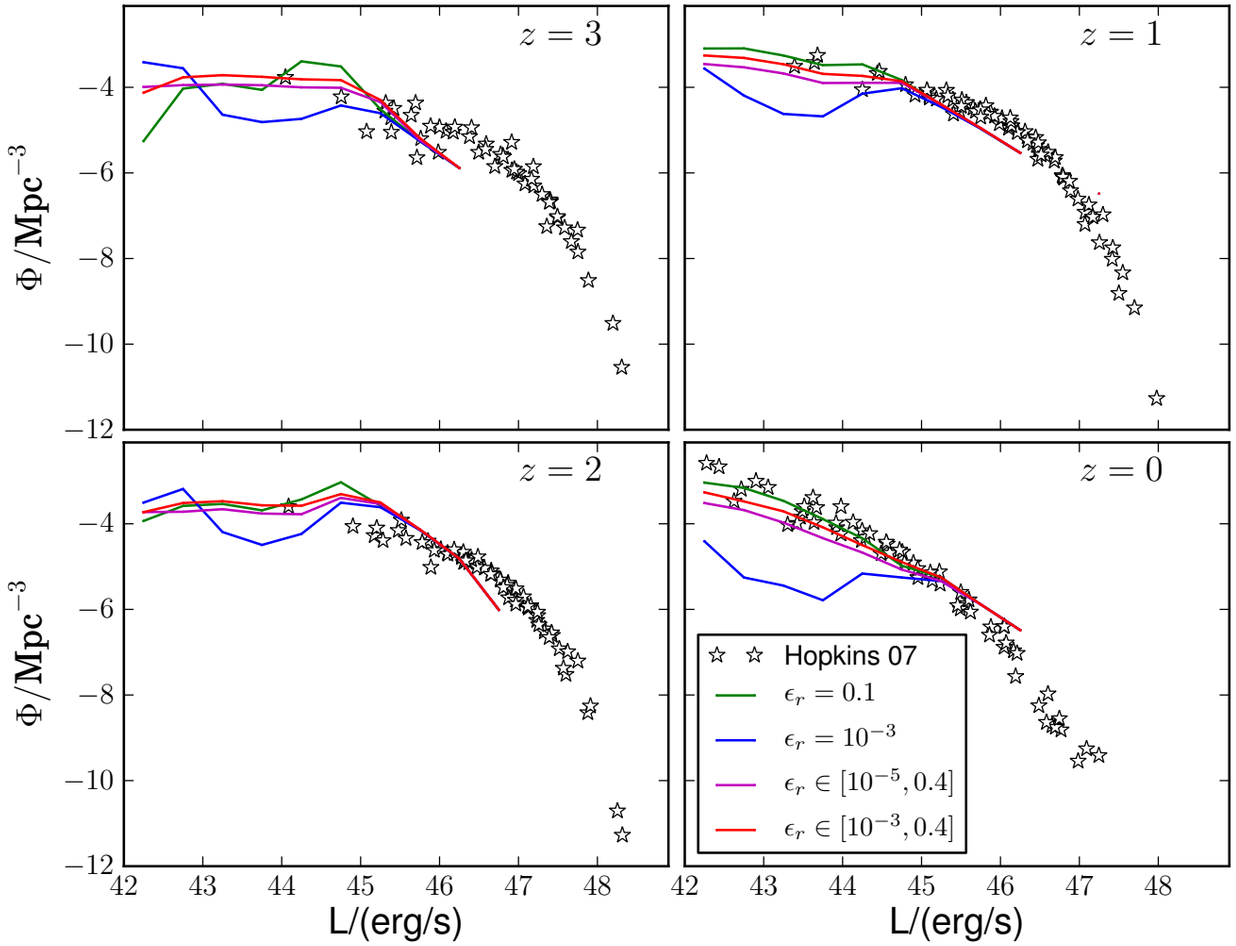
Luminosity functions

The luminosities depend
on the feedback model!



Bachmann et al. (in prep.)





DISCUSSION

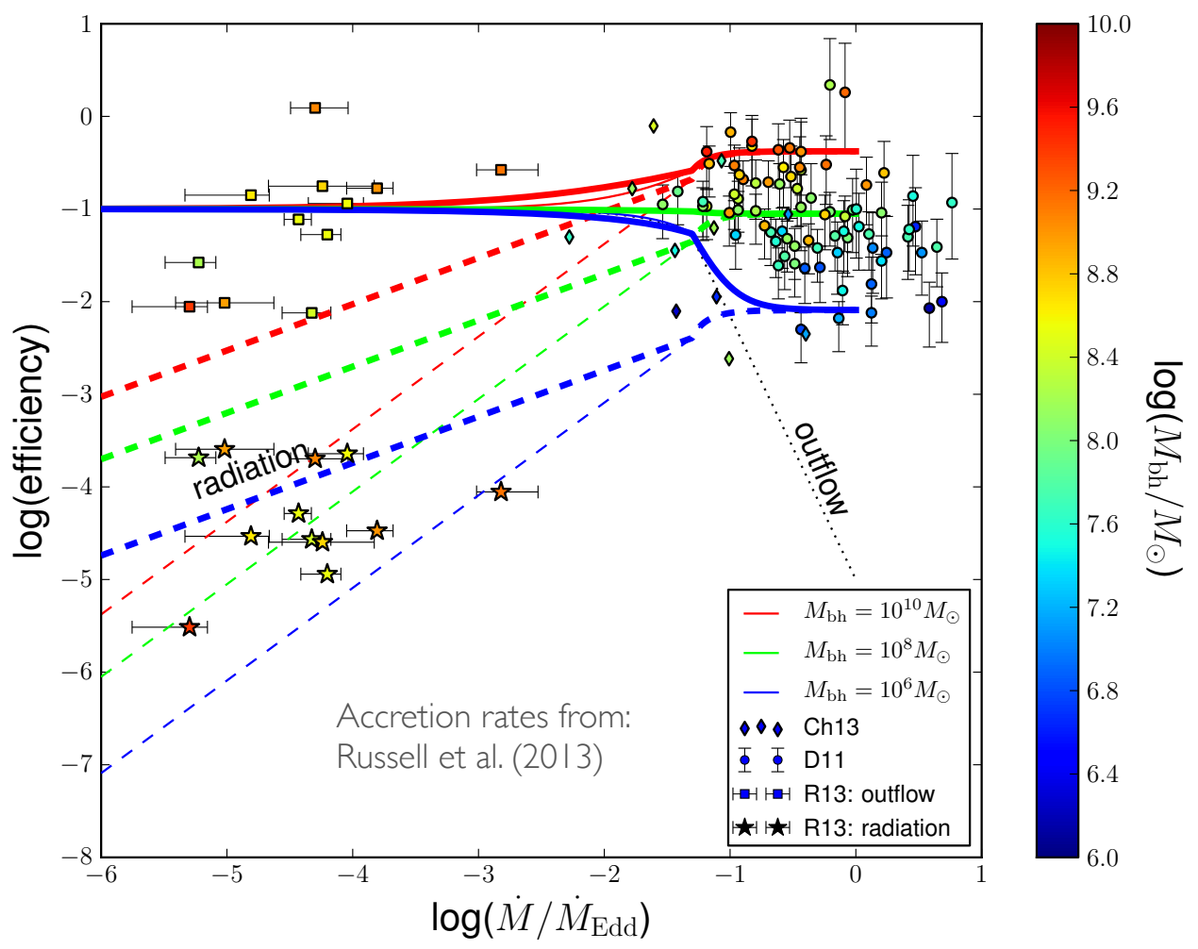
$$\eta := \epsilon_{\mathrm{o}} + \epsilon_{\mathrm{r}}$$

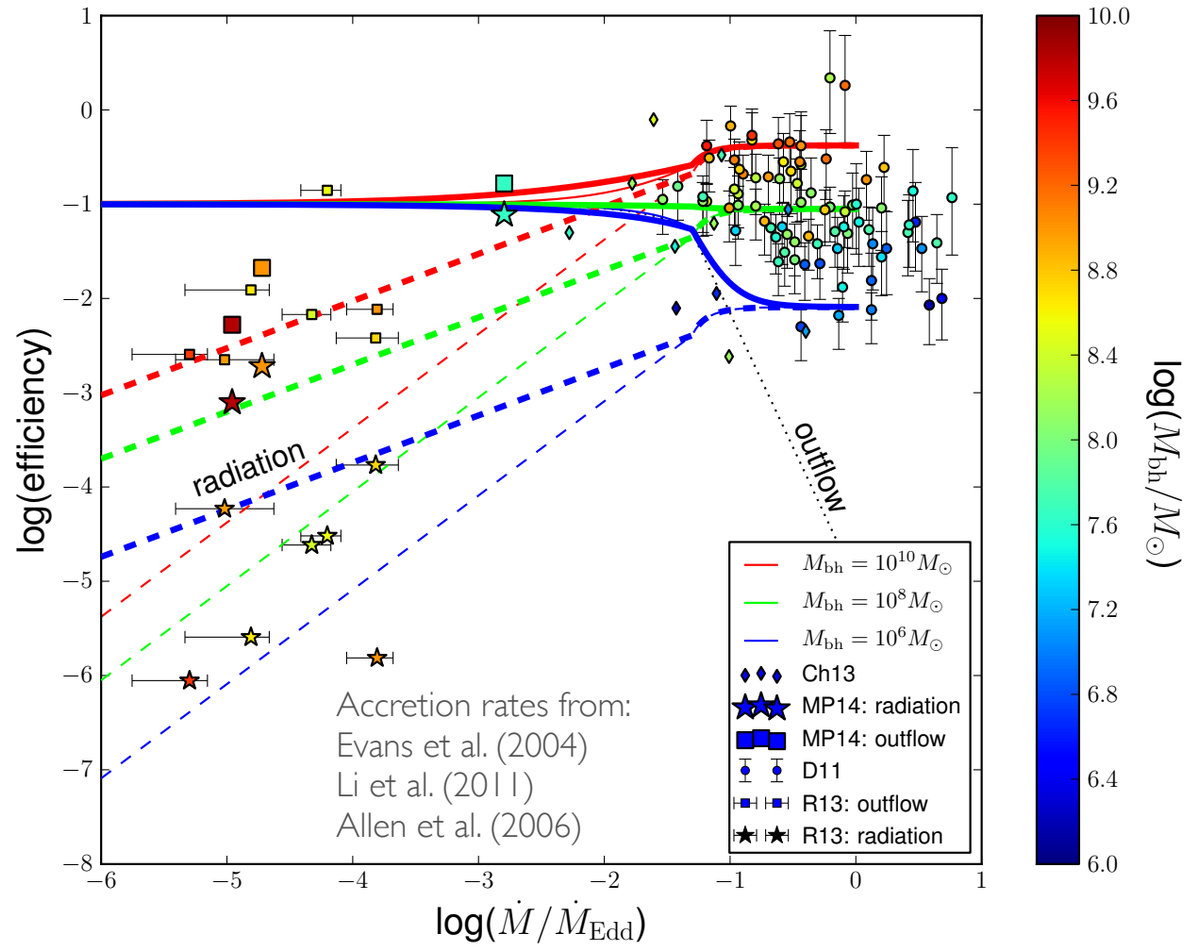
$$\eta = \frac{L_{\mathrm{Edd}}}{\dot{M}_{\mathrm{Edd}} c^2} = \frac{L_{\mathrm{bol}} \frac{\dot{M}}{\dot{M}_{\mathrm{Edd}}}}{\frac{L_{\mathrm{bol}}}{L_{\mathrm{Edd}}} \dot{M} c^2}$$

often unknown!

- The efficiencies in the radio regime are still unknown
- We assumed $\eta = 0.1$
- We need more observations of accretion rates!

Bachmann et al. (in prep.)

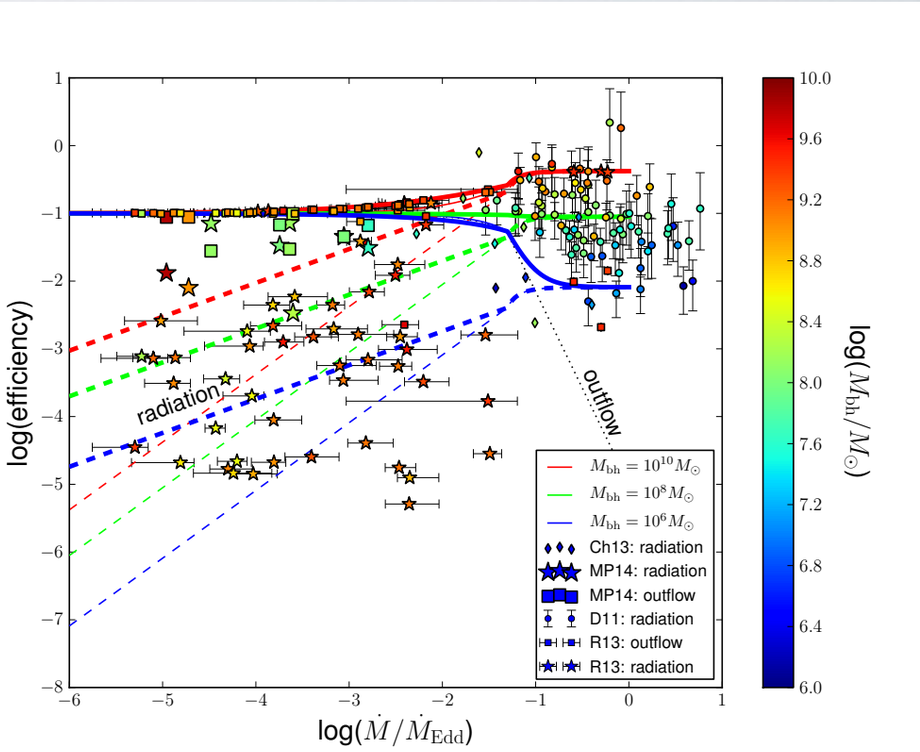




SUMMARY

We improved the BH model for cosmological simulations by implementing …

- two gas phases,
- two different ways of AGN feedback: radiation and outflow,
- a smooth transition between radio and quasar mode and
- a radiative efficiency, which depends on the BH mass.



We could improve …

- the relation between BH mass and stellar mass
- the black hole mass function
- the stellar mass functions

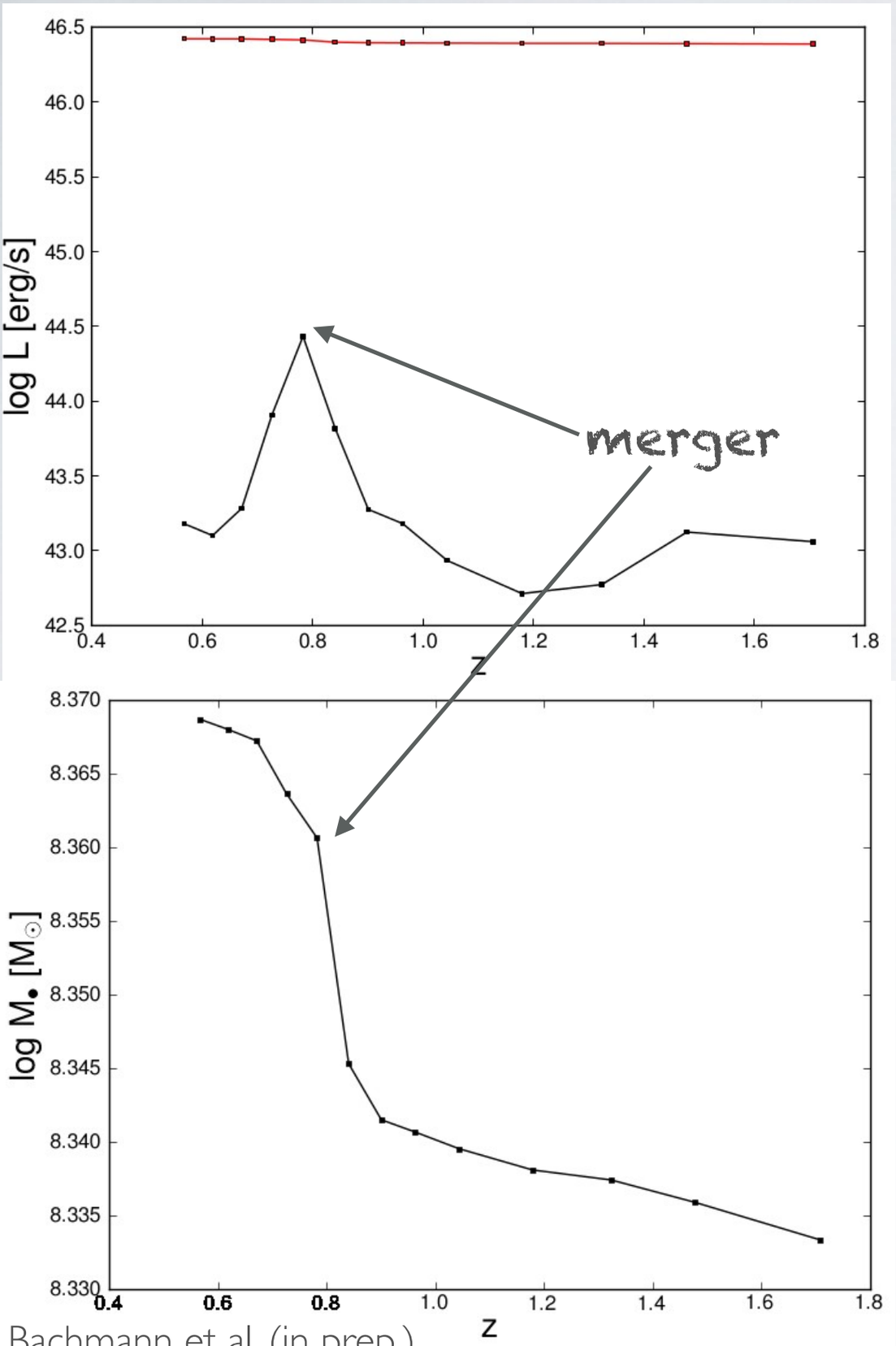
We found that …

- BHs first grow mainly due to smooth accretion and later mainly due to mergers.
- in clusters the total stellar mass of a galaxy is not equal to the stellar mass of the bulge.
- the luminosities strongly depend on the feedback model.

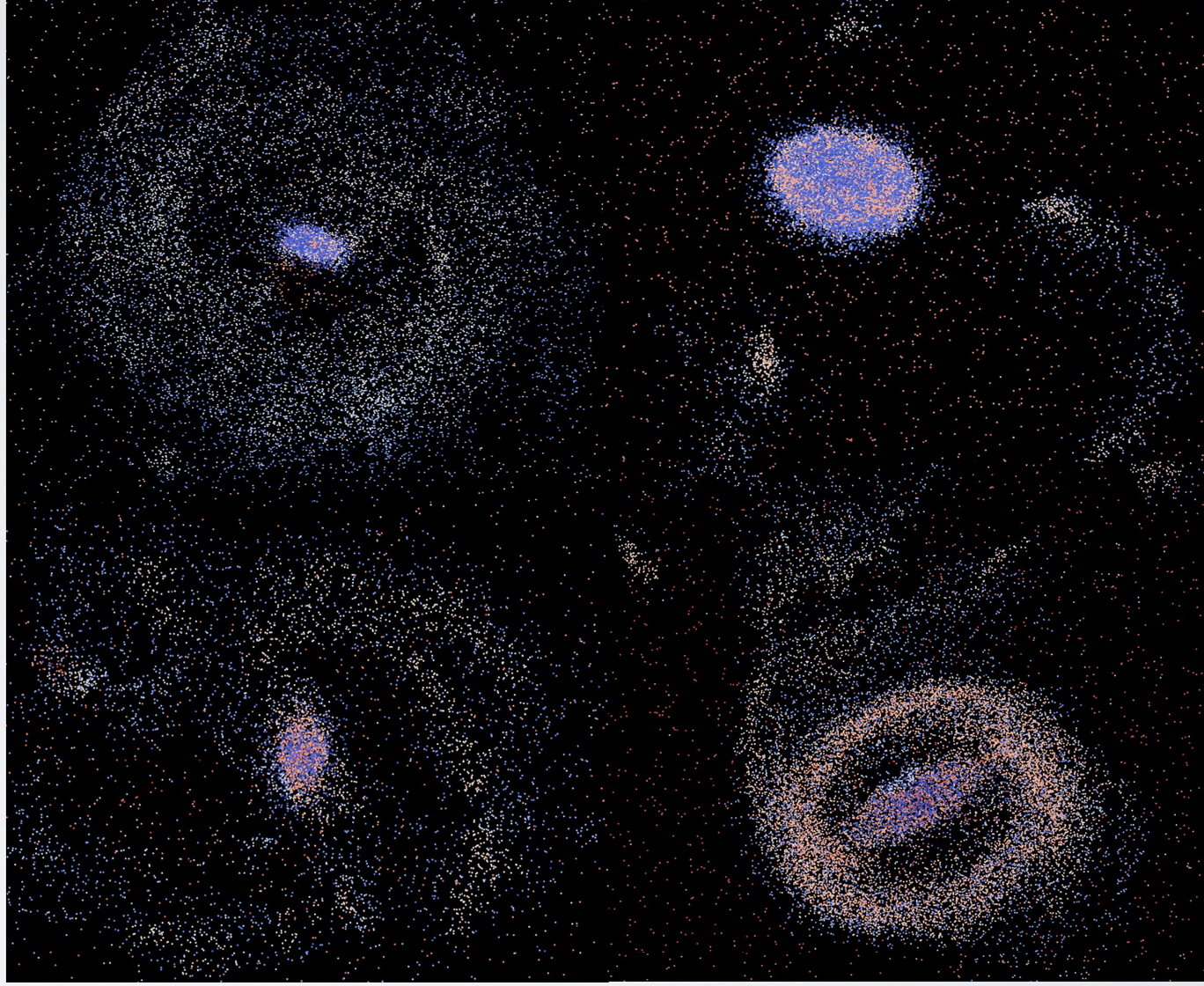
We would like to know more about …

- outflow efficiencies,
- radiative efficiencies and/or
- accretion rates.

Prospects for the future



Bachmann et al. (in prep.)



With higher resolution we can study …

- the co-evolution between AGN and their host galaxies
- galaxy classification
- AGN trigger mechanisms
- alternative accretion models
- …

Thank you
for your attention!