USING COSMOLOGICAL SIMULATIONS AS A LABORATORY FOR THE PHYSICS OF AGN

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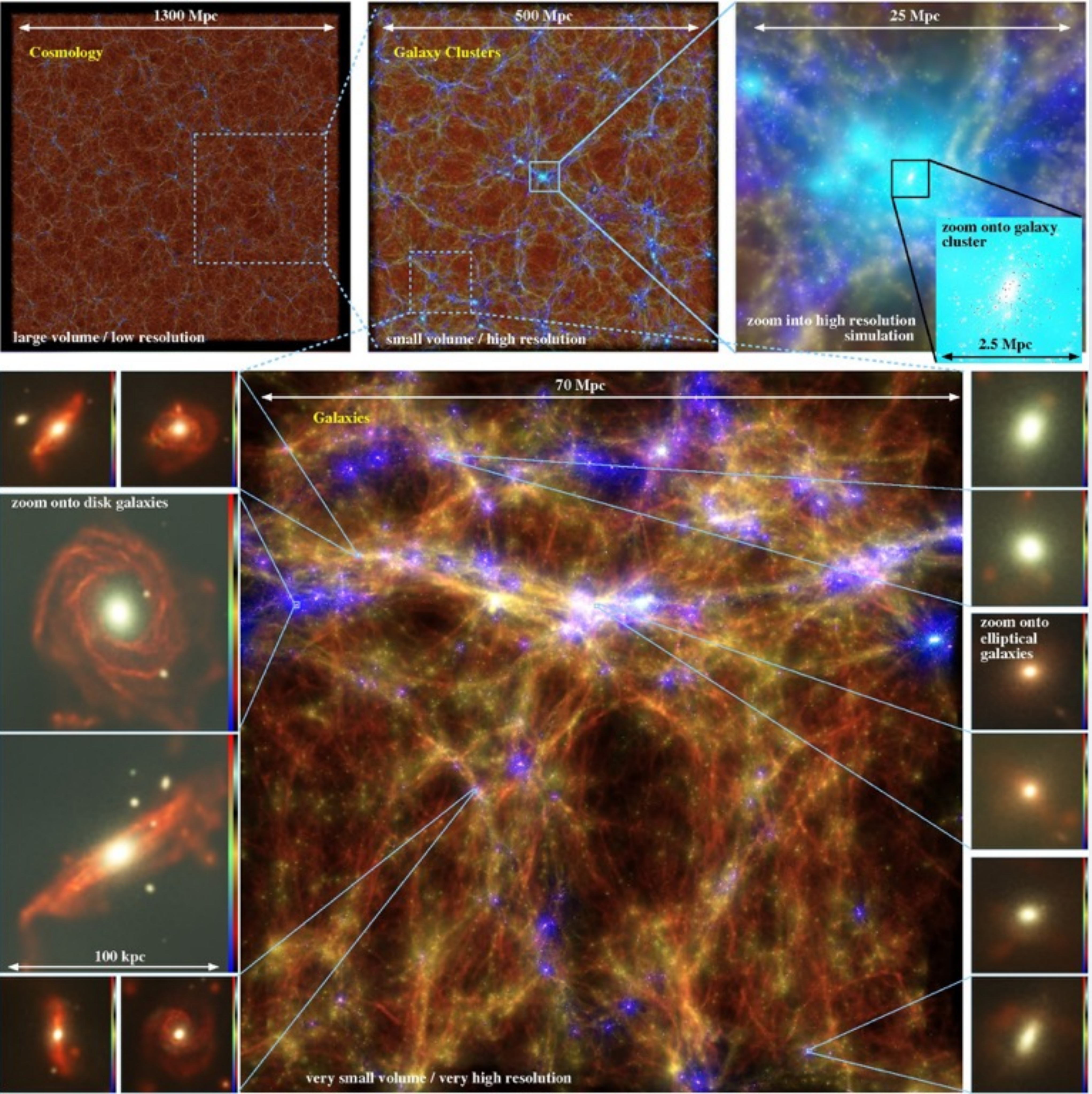
in collaboration with Klaus Dolag, Michaela Hirschmann, M. Almudena Prieto, Rhea-Silvia Remus, Julia M. Comerford, Adelheid F. Teklu, Mirko Krumpe



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

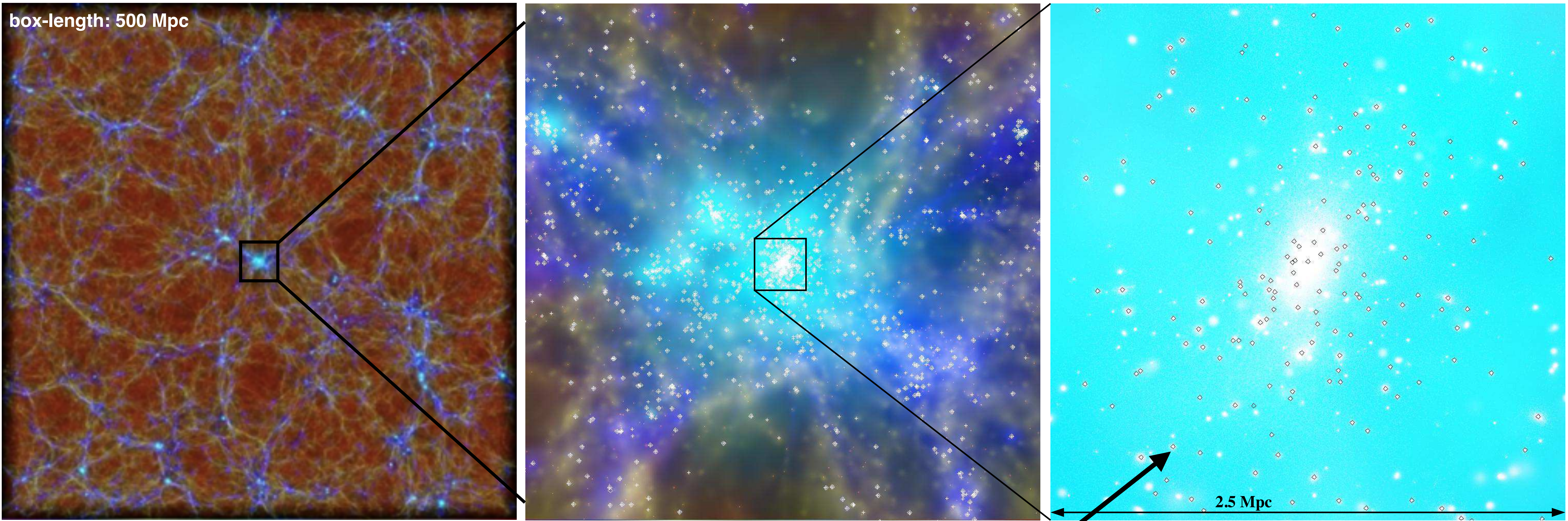
What makes the BHs in our simulations special?

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

www.magneticum.org

Hirschmann+14, Steinborn+15, Teklu+15, Bocquet+15, Dolag +15, Steinborn+16, Remus+16

BH model



$$M_{\rm dm} = 6.9 \cdot 10^8 M_\odot/h$$
$$M_{\rm gas} = 1.4 \cdot 10^8 M_\odot/h$$

Hirschmann+14

BHs

accretion

feedback

$L_{\rm SXR} > 10^{43} {\rm erg/s}$

AGN

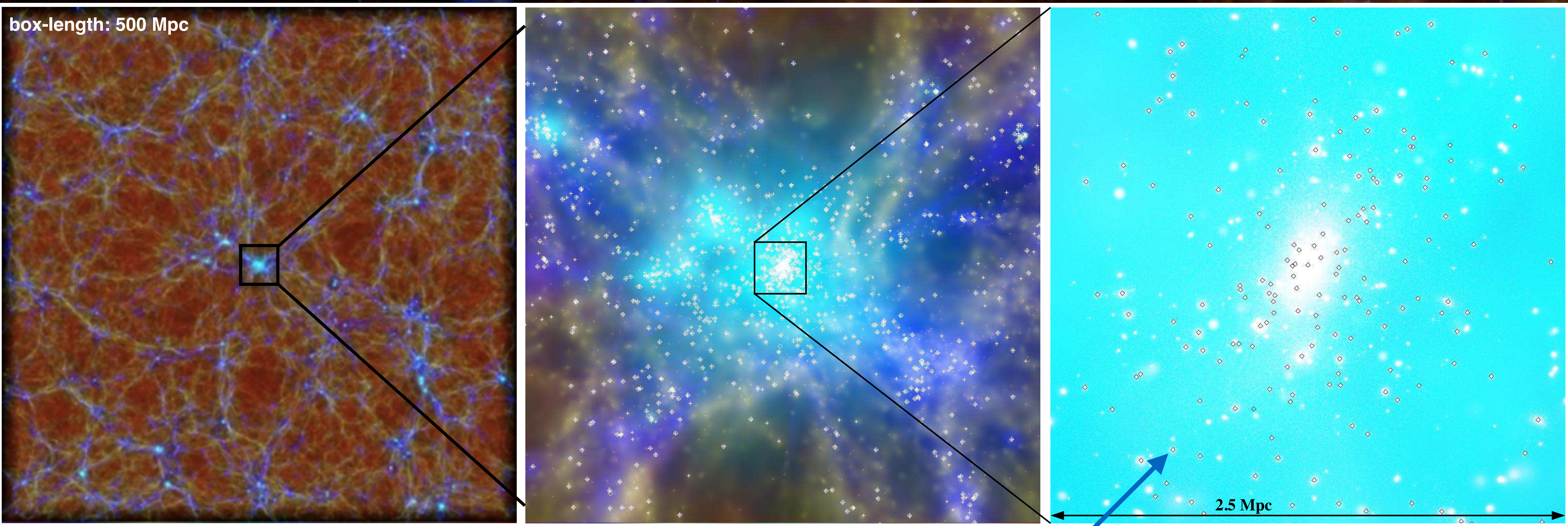
$$\dot{M}_{\rm B} = \frac{4\pi\alpha G^2 M_\bullet^2 \langle\rho\rangle}{(\langle c_{\rm s}\rangle^2 + \langle v\rangle^2)^{3/2}}$$

$$\dot{M}_\bullet = \min(\dot{M}_{\rm B}, \dot{M}_{\rm Edd})$$

$$L = \epsilon_{\rm r} \dot{M}_\bullet c^2$$

$$\dot{E} = \epsilon_{\rm f} \epsilon_{\rm r} \dot{M}_\bullet c^2$$

(thermal feedback)



Hirschmann+14

BHs

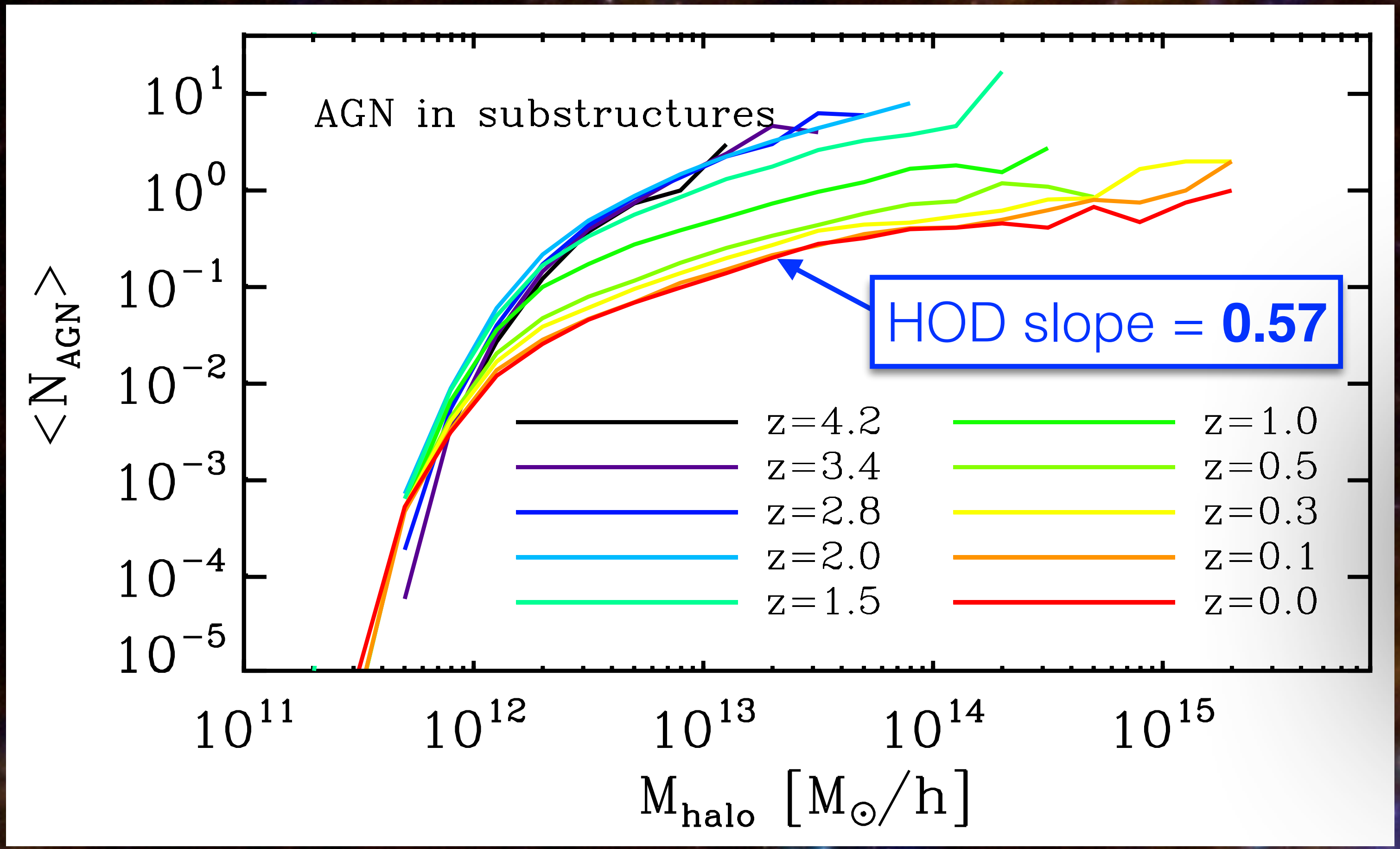
No pinning to the potential minimum!

BHs do <u>not</u> merge as long as:

- the relative velocity of the BHs to each other is > 0.5*sound speed,
- the distance is > 5*softening length and the BHs are not gravitationally bound to each other.

dual/offset AGN

AGN clustering



The HOD slope is smaller than for galaxies (1.15)!

AGN are not just random events!

There must be certain conditions which increase the probability for AGN activity!

mergers?

secular evolution?

environment?

gas reservoir?

Dual and offset AGN

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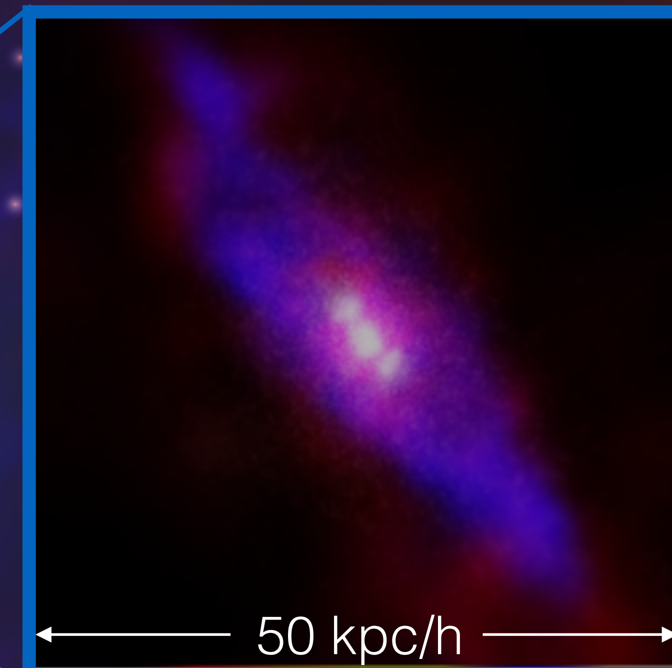
dual AGN — r<10kpc — AGN log(L)>43 / AGN log(L)>43

offset AGN — r<10kpc — AGN log(L)>43 / inactive BH log(L)<43

dual BHs without AGN — r<10kpc — inactive BH log(L)<43 / inactive BH log(L)<43

What do we need to produce dual/offset AGN?

- high resolution -> uhr (down to 2 kpc)
- large volume (only 1% of all AGN!)
- no pinning!



-> Box3/uhr of the Magneticum Simulations (ran down to z=2)

128Mpc/h

ultra-high resolution

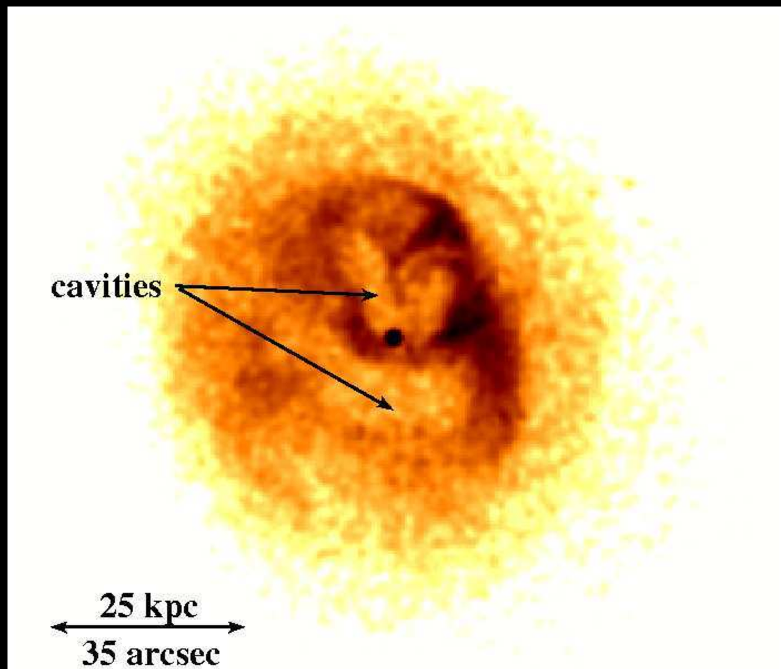
14903 BHs
1864 AGN

9 dual AGN
14 offset AGN
11 dual BHs without AGN

10 Mpc/h

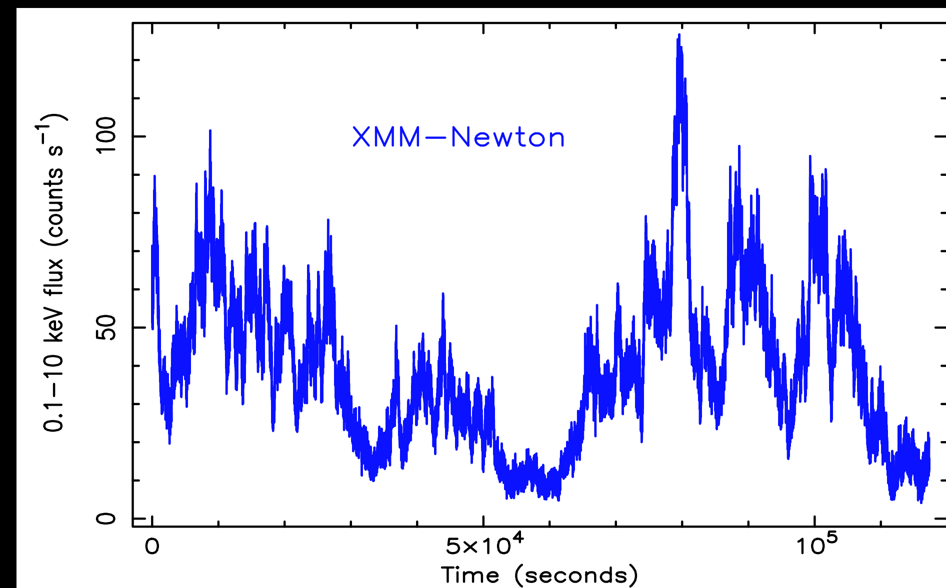
What is an AGN?

X-ray cavities in Abell 2052

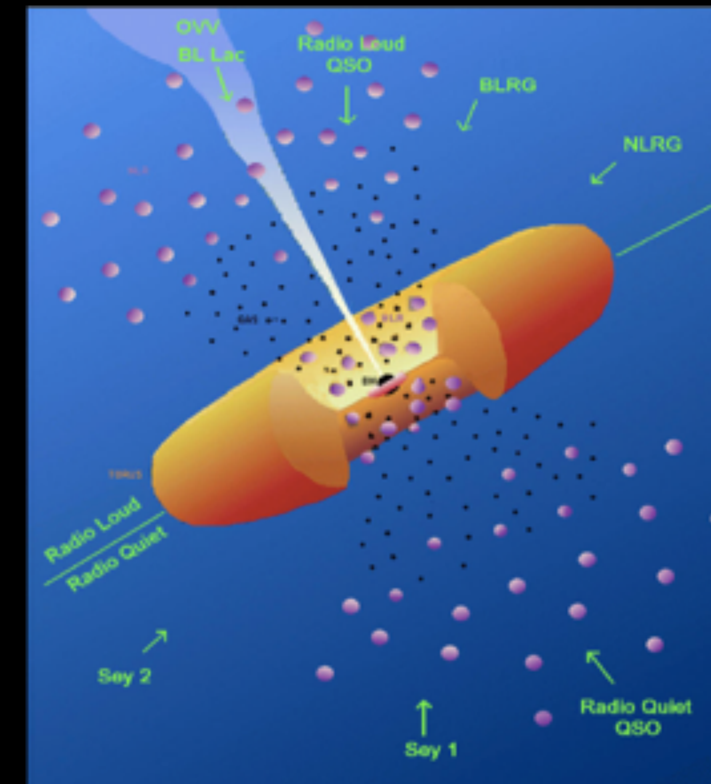


Russell et al. (2013)

NGC 4051

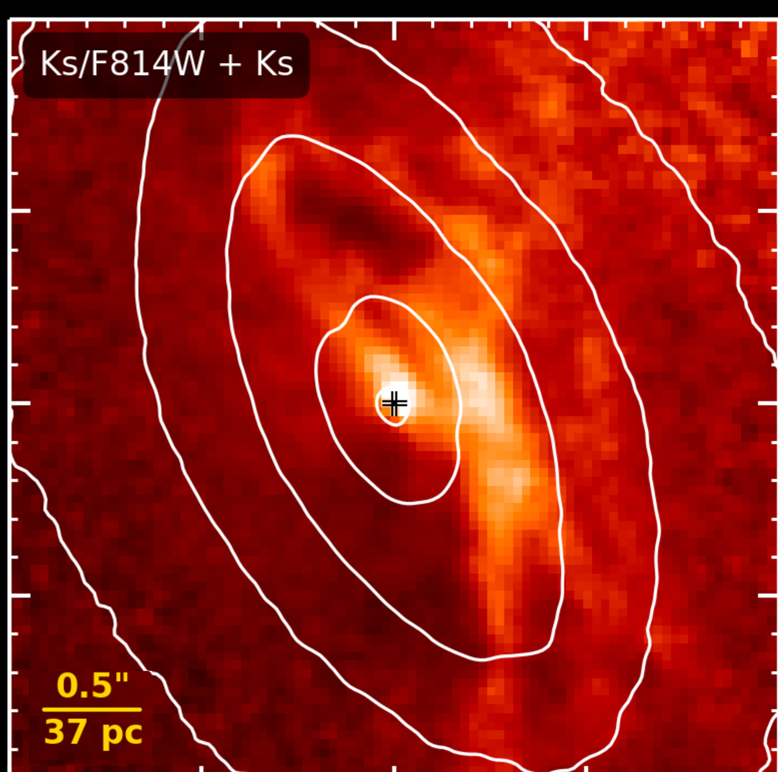


McHardy et al. (2004)



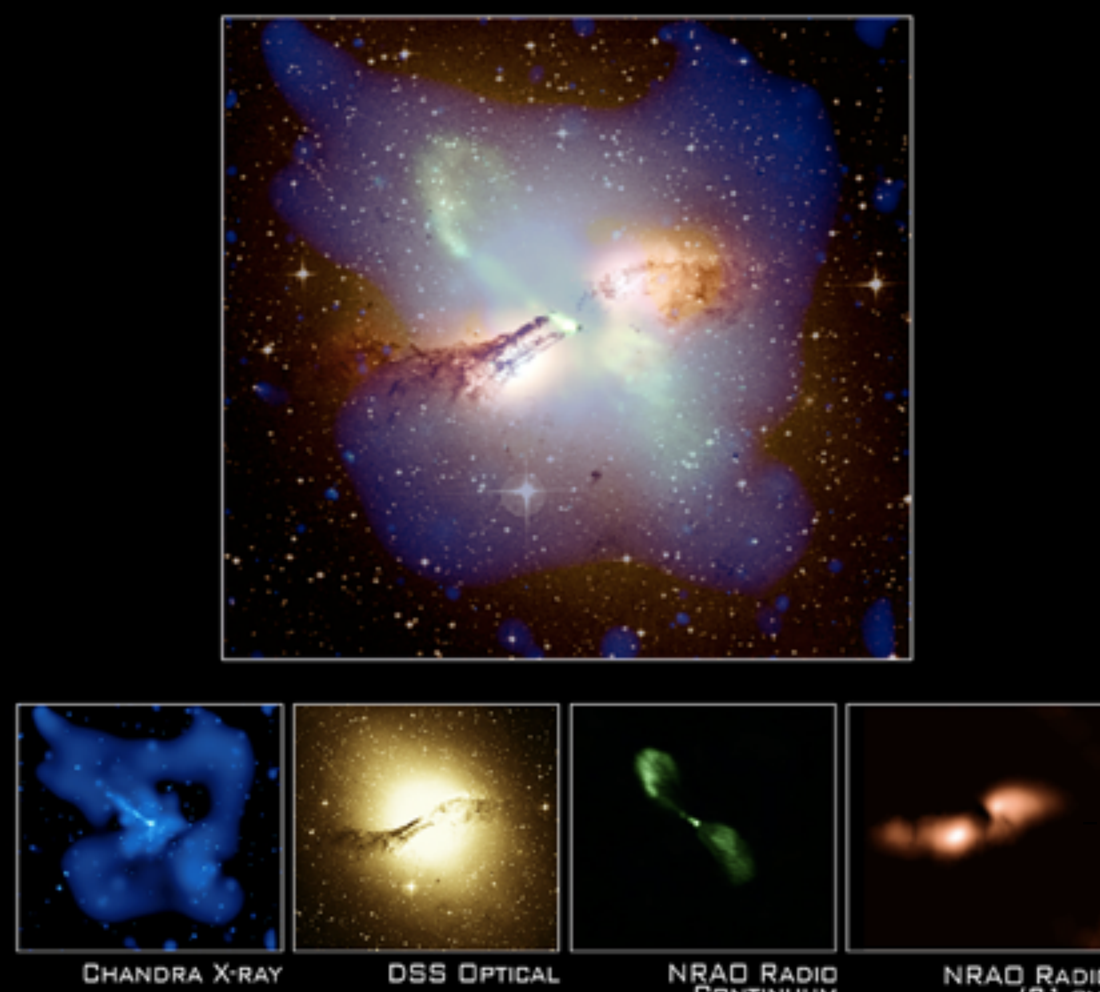
Urry & Padovani (1995)

Dust extinction map of the centre of NGC 1386



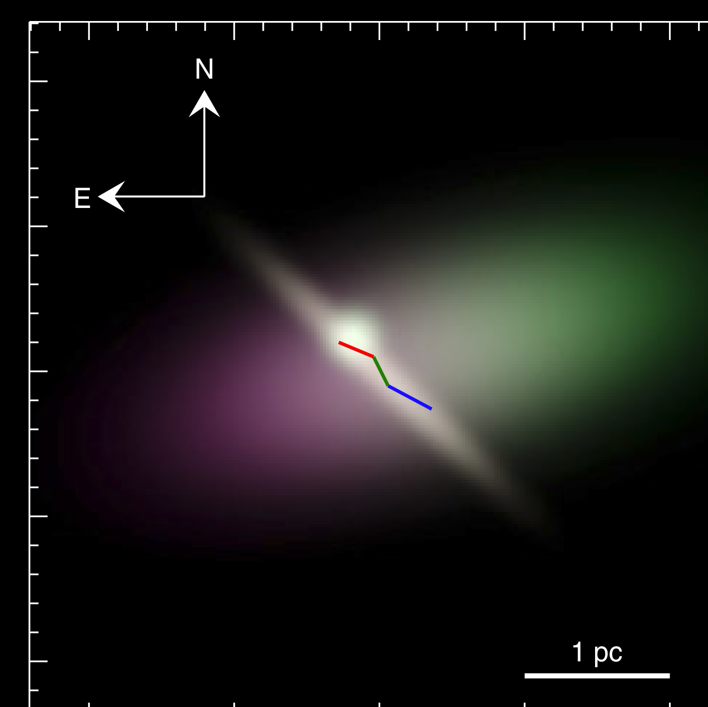
Prieto et al. (2014)

Centaurus A



http://chandra.harvard.edu

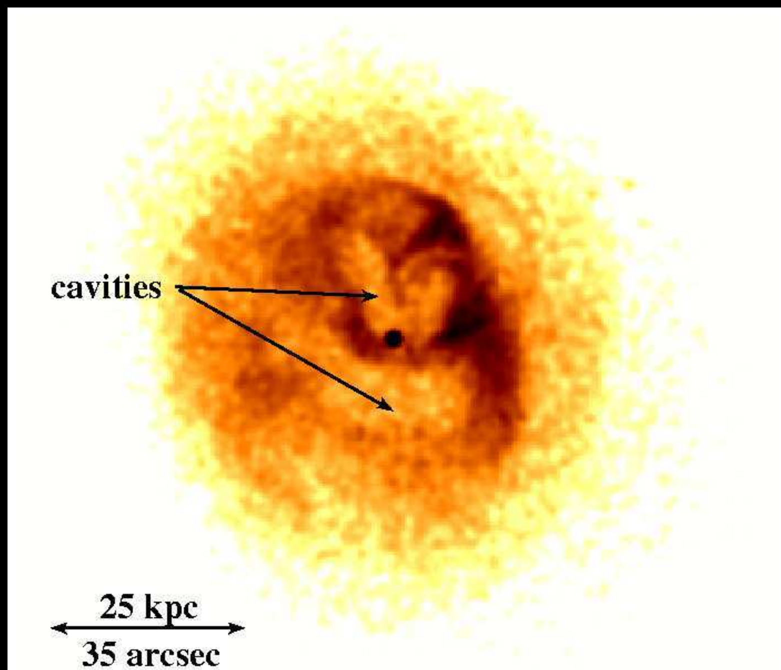
MIR emission of the nucleus of Circinus



Tristram et al. (2014)

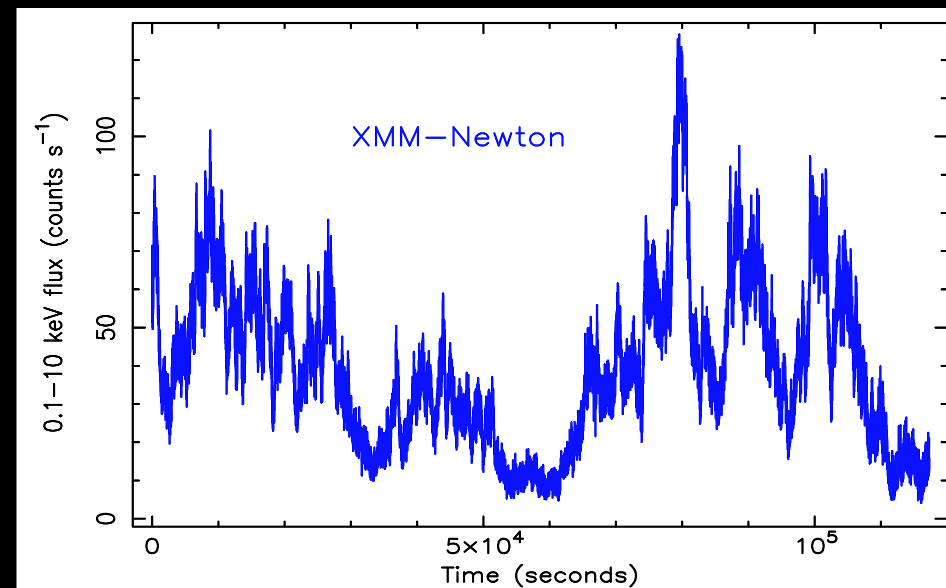
What is an AGN?

X-ray cavities in Abell 2052



Russell et al. (2013)

NGC 4051



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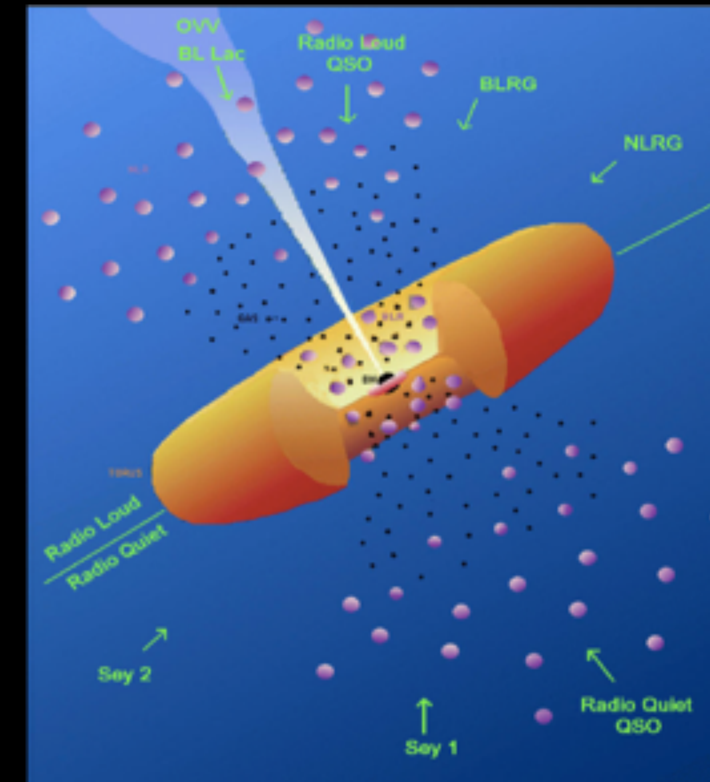
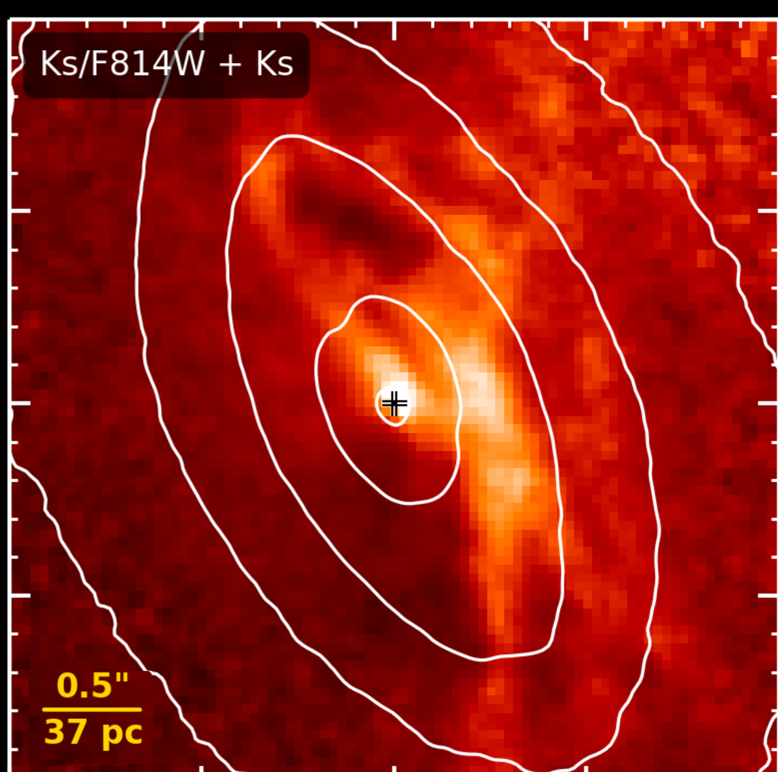


Urry & Padovani (1995)

How can we make our AGN somewhat more realistic?

D… centre of NGC 1386



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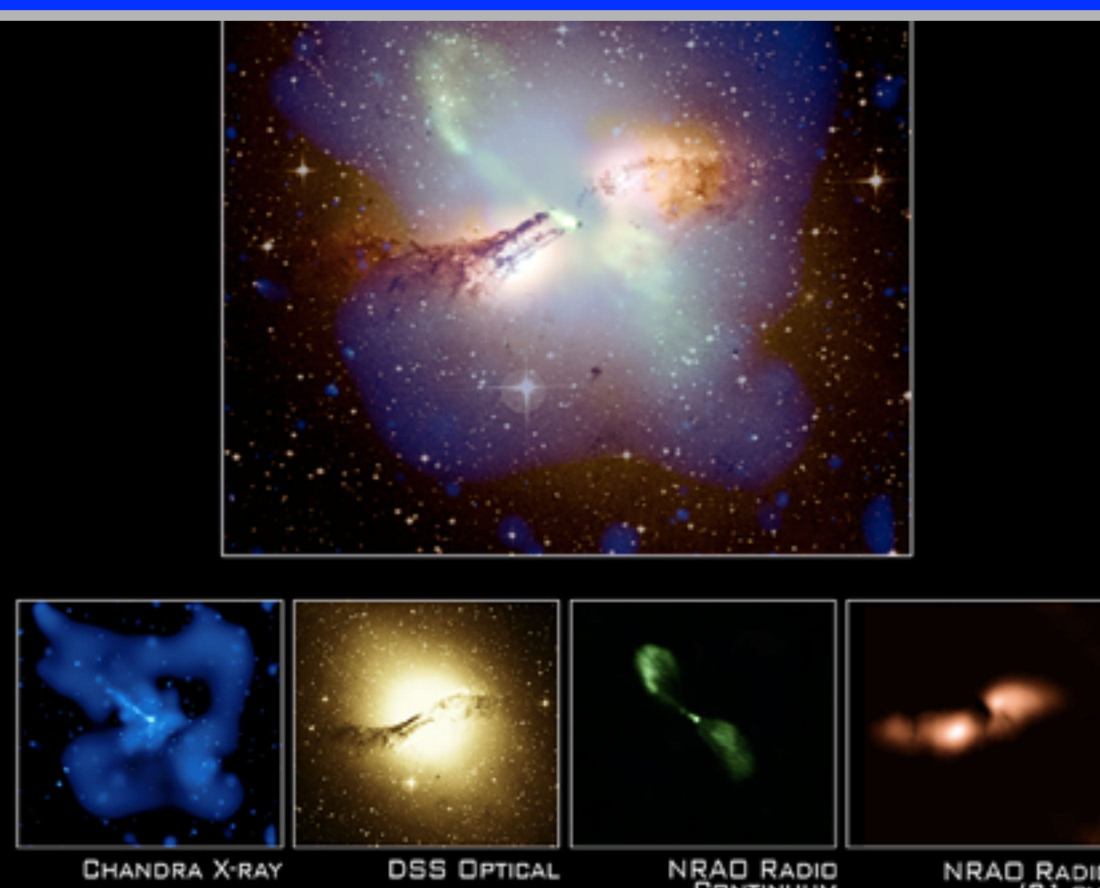

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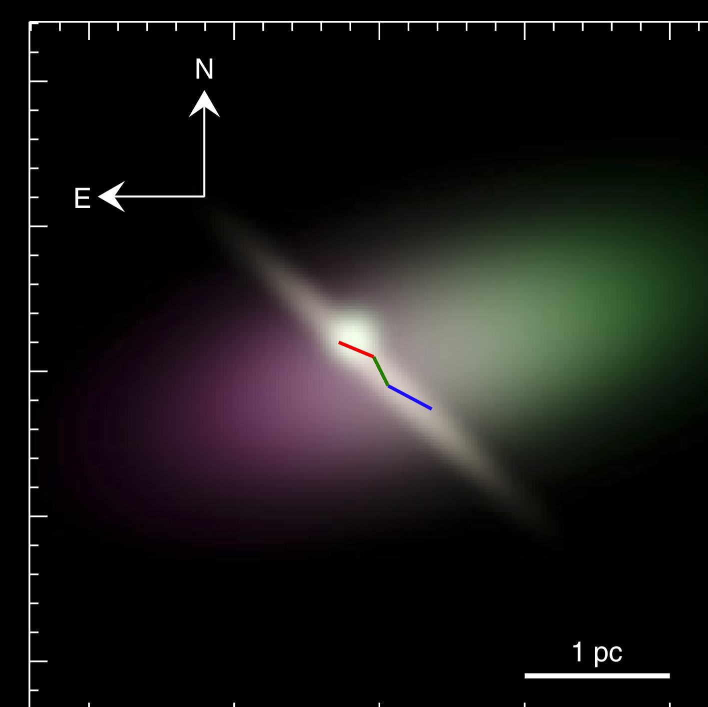
…e nucleus of Circinus

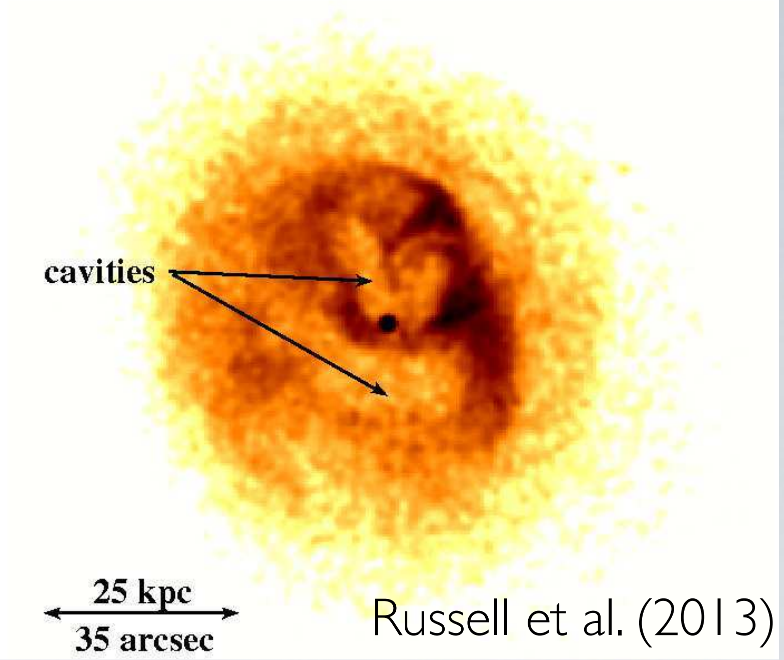


Tristram et al. (2014)

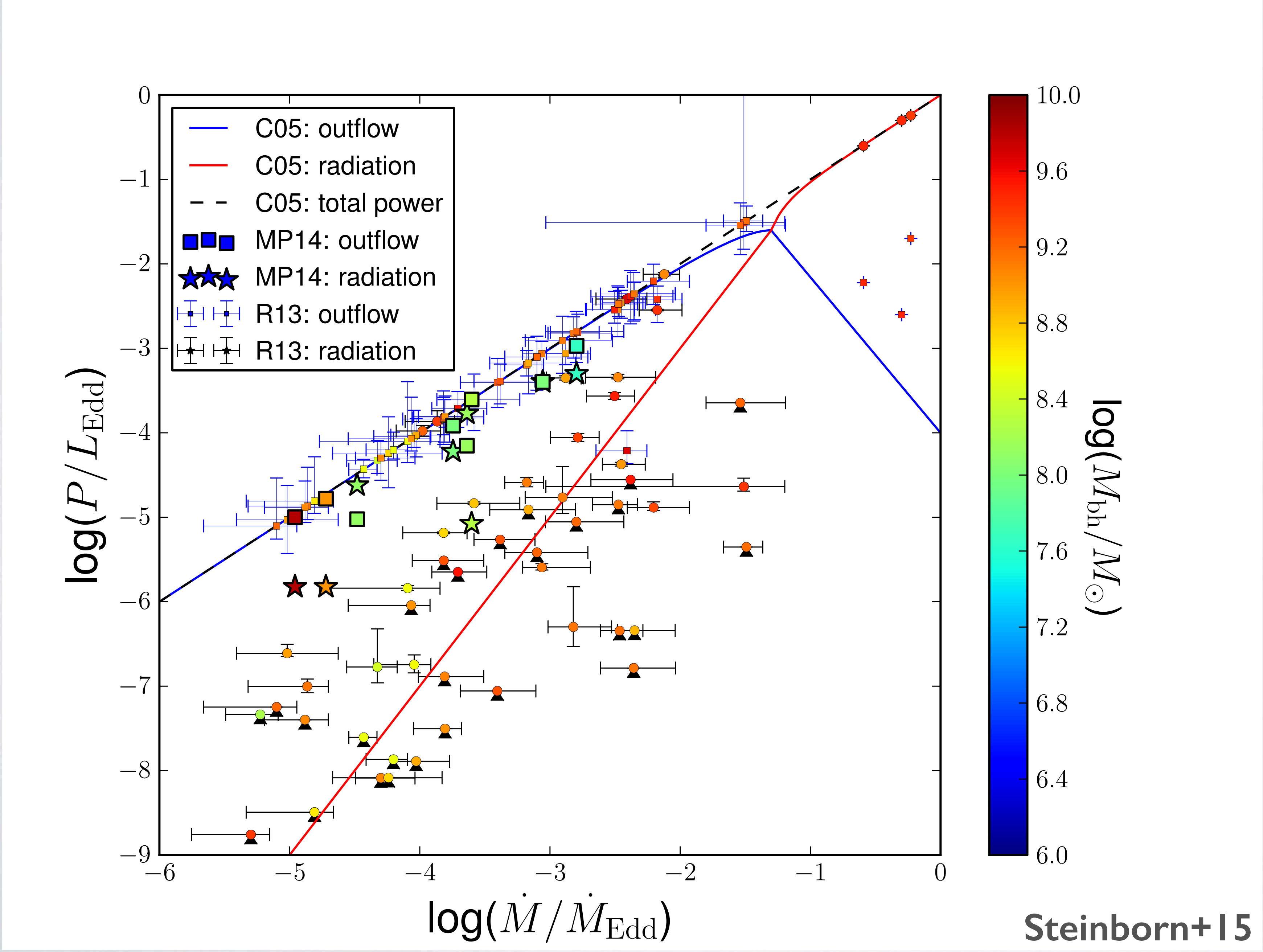
AGN FEEDBACK

Commonly used in simulations:

$$\dot{E} = \epsilon_{\rm f}\,\epsilon_{\rm r}\,\dot{M}_{\bullet} c^2$$



Russell et al. (2013)



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Observations from:

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

Theory:

- Churazov et al. (2005)

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

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

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

$$\dot{E} = (\epsilon_{\rm o} + \epsilon_{\rm f}\,\epsilon_{\rm r})\,\dot{M}_{\bullet} c^2$$

ACCRETION

Bondi model:

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

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

This does not work!

Commonly used in simulations:

Boost factor

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

Two reasons for the boost factor:

- Resolution
- Cold gas is not Bondi-like

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

New approach: hot vs. cold gas accretion

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

Old model:

constant

BH —accretion→ / —feedback→

$$L = \epsilon_{\rm r} \dot{M}_\bullet c^2$$

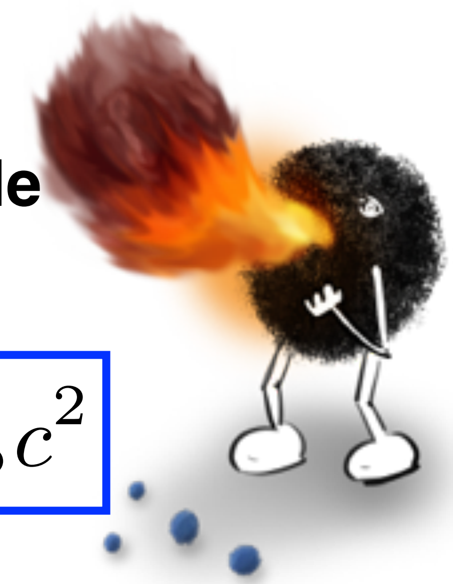
$$\dot{M}_{\rm B} = \frac{4\pi\alpha G^2 M_\bullet^2 \langle\rho\rangle}{(\langle c_{\rm s}\rangle^2 + \langle v\rangle^2)^{3/2}}$$

$$\dot{M}_\bullet = \min(\dot{M}_{\rm B}, \dot{M}_{\rm Edd})$$

$$\dot{E} = \epsilon_{\rm f}\epsilon_{\rm r} \dot{M}_\bullet c^2$$

(thermal feedback)

New model:



variable

BH —accretion→ / —radiation→ / —mech. outflow→

$$L = \epsilon_{\rm r} \dot{M}_\bullet c^2$$

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

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

(thermal feedback)

$$P_{\rm o} = \epsilon_{\rm o} \dot{M}_\bullet c^2$$

variable

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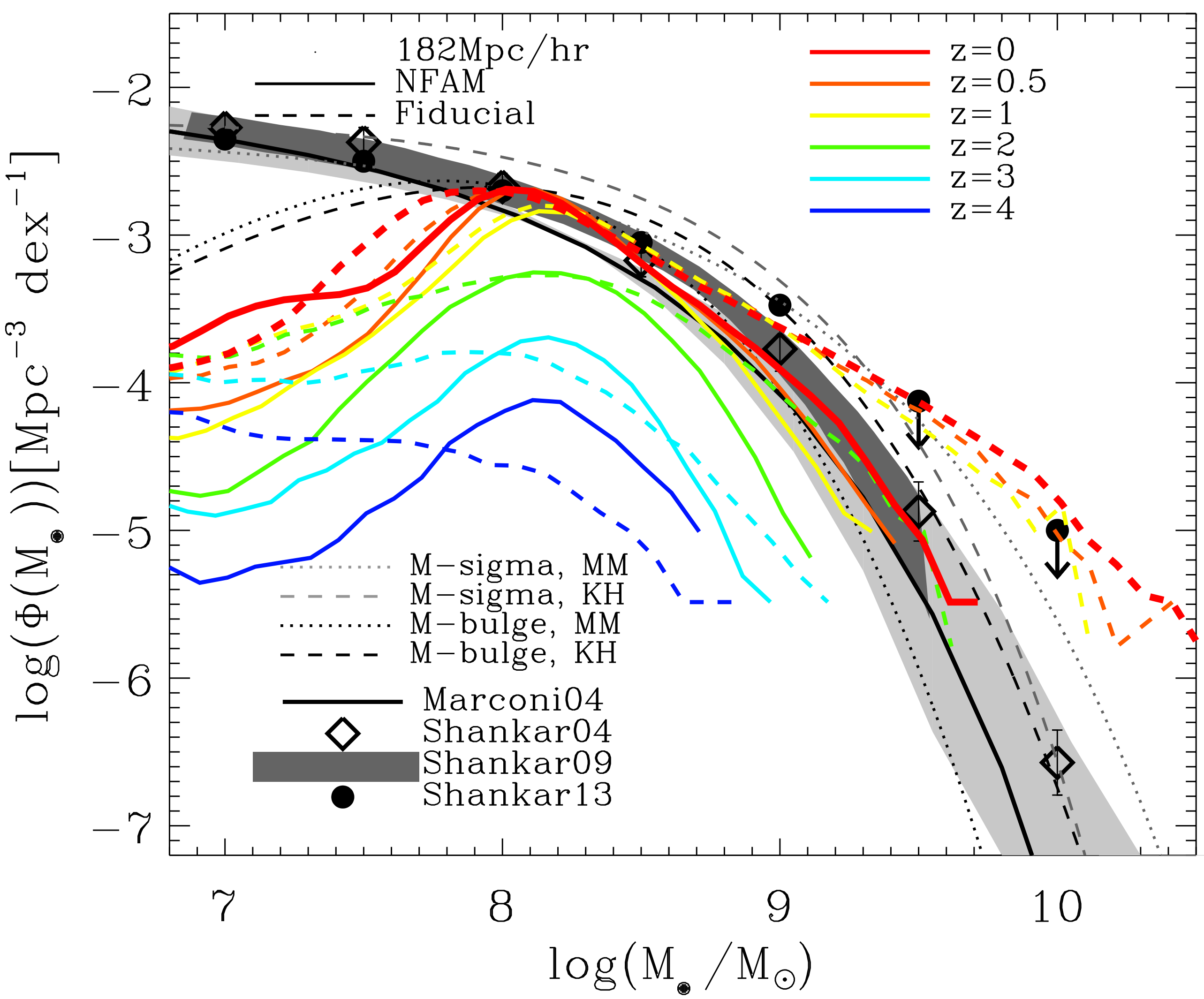
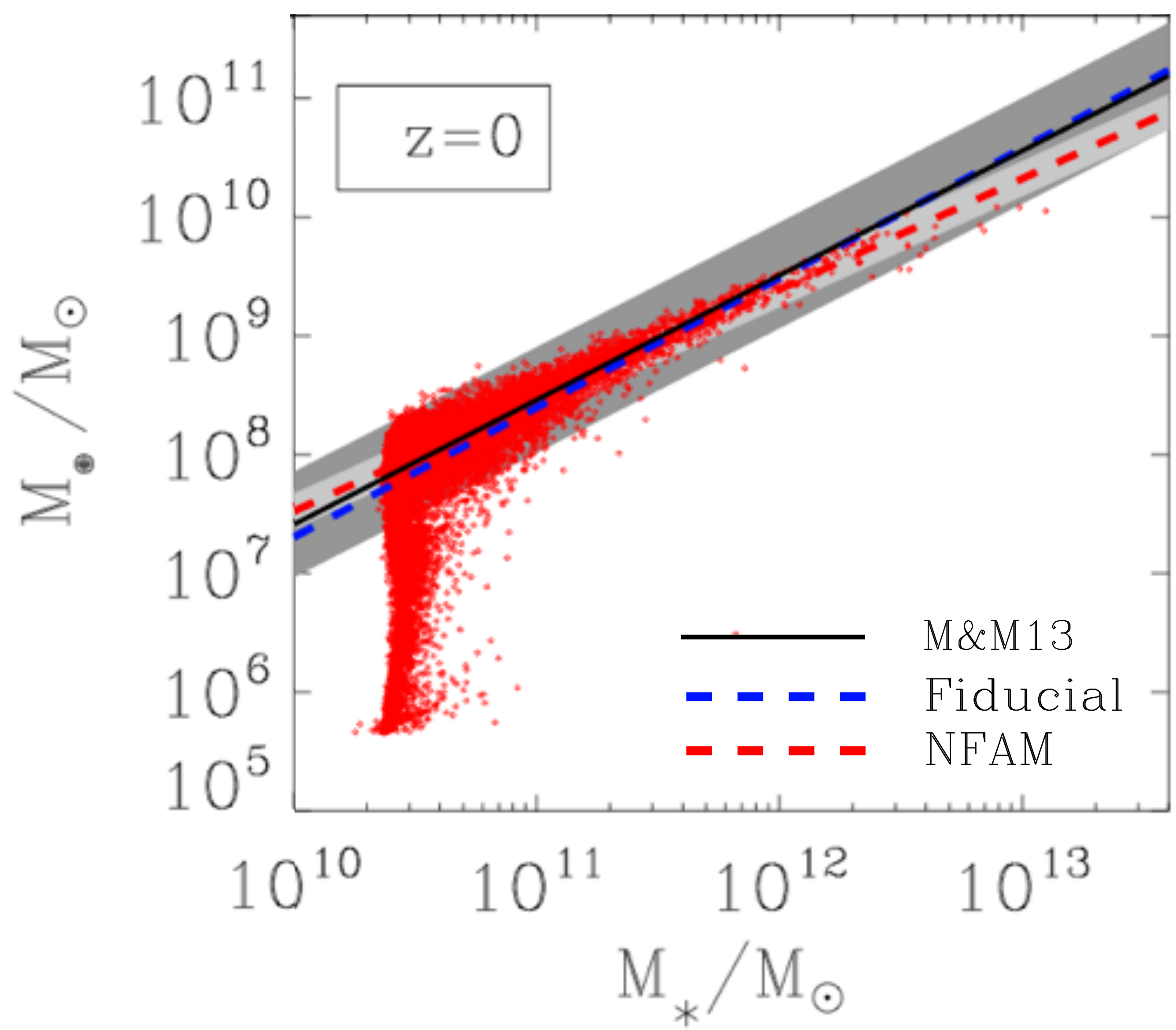
COMPARISON WITH OBSERVATIONS

BH mass function



BH mass vs. stellar mass



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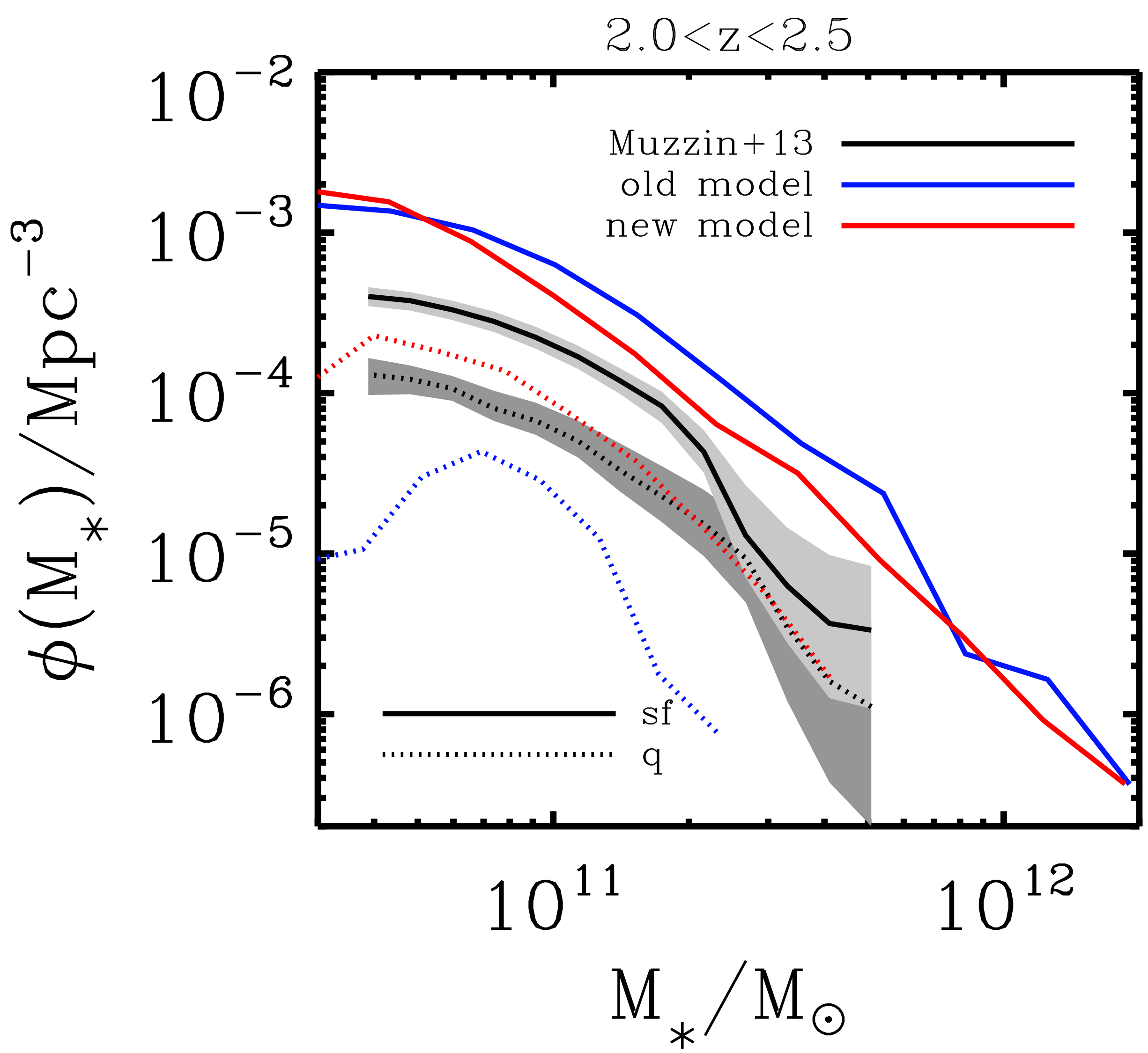
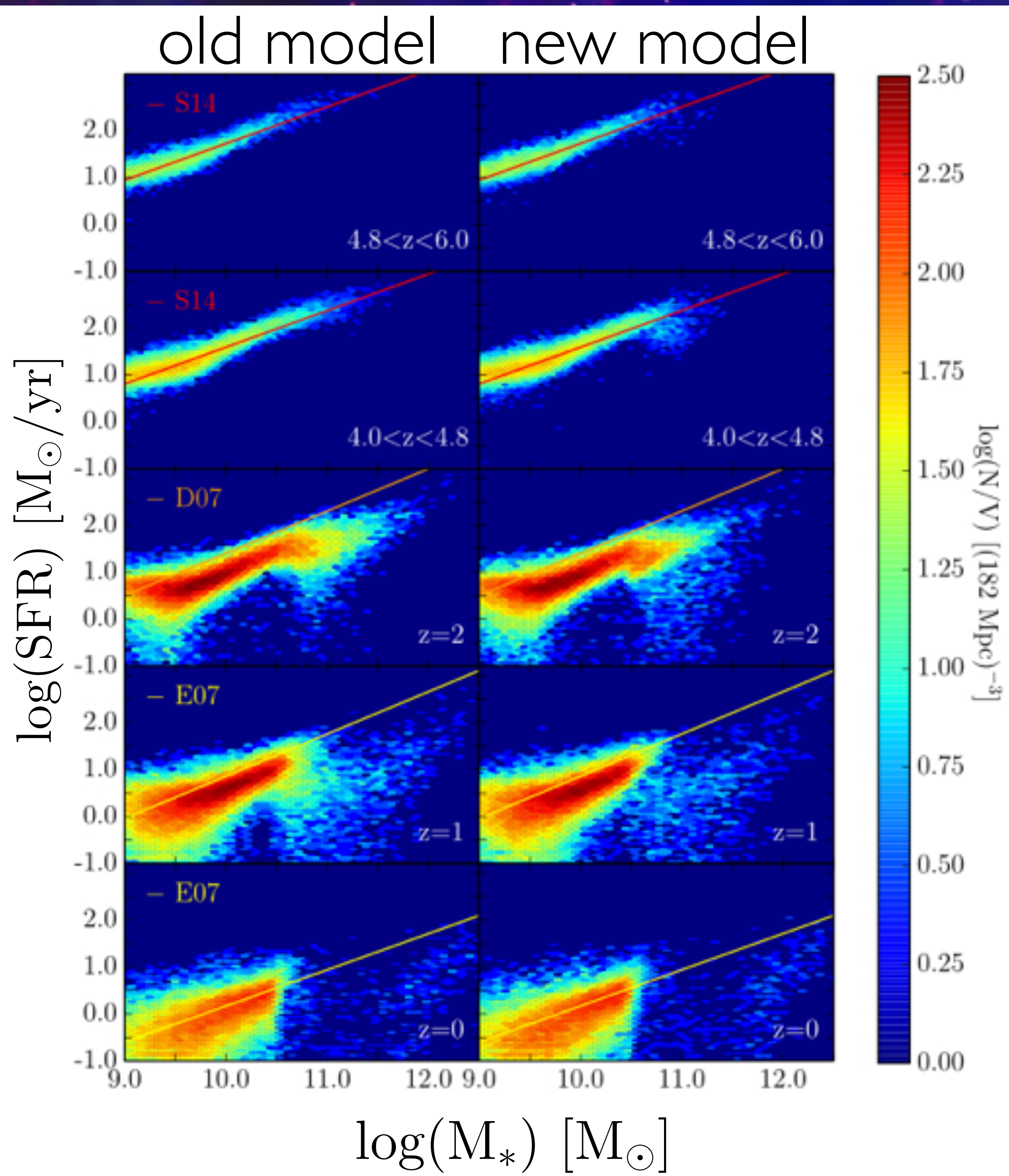
HOW DOES THE NEW MODEL INFLUENCE STAR FORMATION?





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SUMMARY

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Larger volumes and higher resolutions require a more detailed BH model!

Steinborn+15

- 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 amount of quiescent galaxies

Poster 18:
effect on SZ-properties of galaxy clusters

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