Revealing the driving mechanisms of AGN activity and star formation in cosmological simulations

Lisa K. Steinborn
Universitäts-Sternwarte München

in collaboration with: K. Dolag, M. Hirschmann, F. Shankar, S. Juneau, M. Krumpe, J. M. Comerford, R.-S. Remus, A. F. Teklu

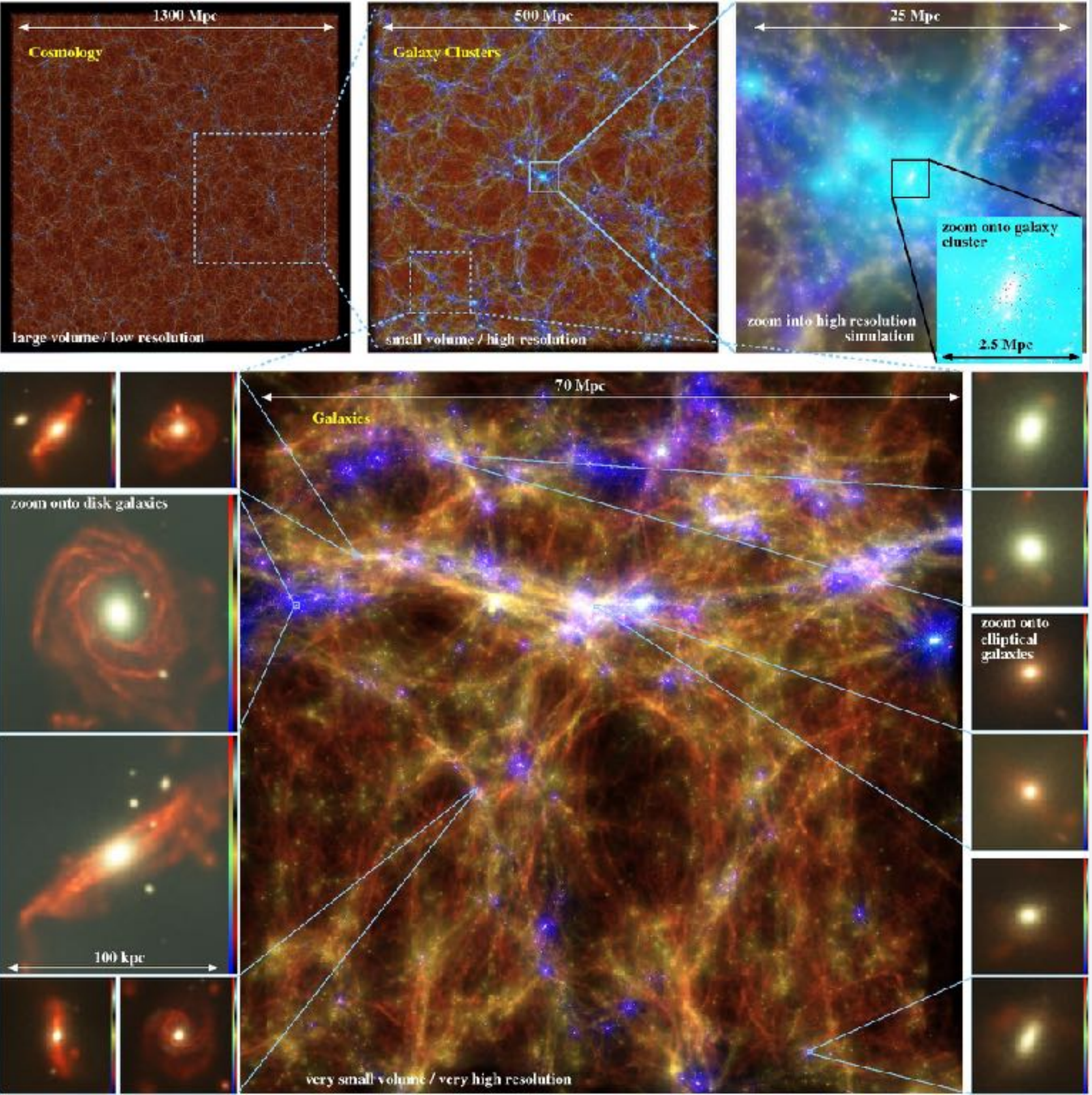
MAGNETICUM

LMU USM

CAST
Computational Astrophysics Group
Munich University Observatory

Bonn TR 33 München
The Dark Universe
Heidelberg

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

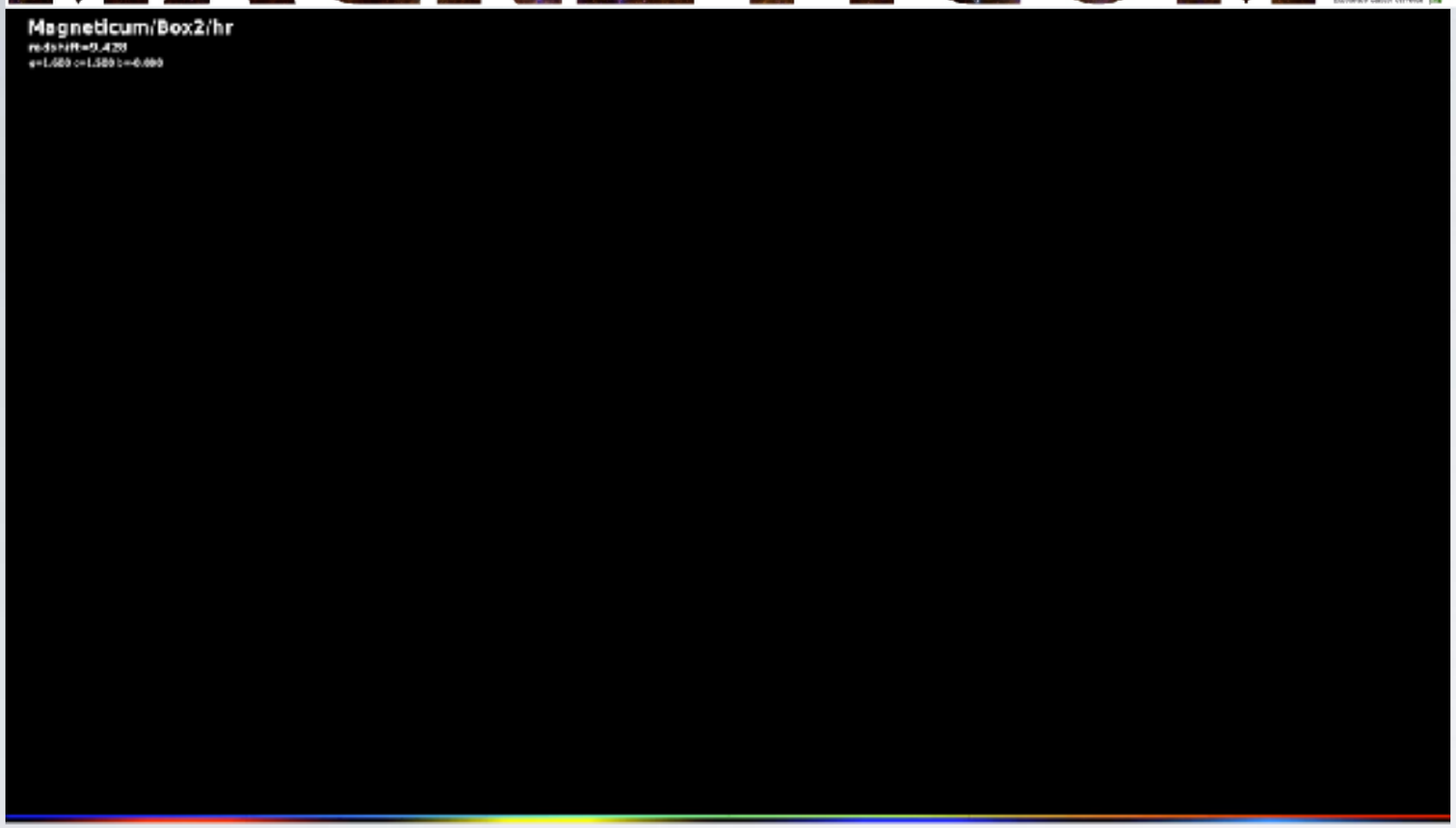
What makes the BHs in our simulations special?

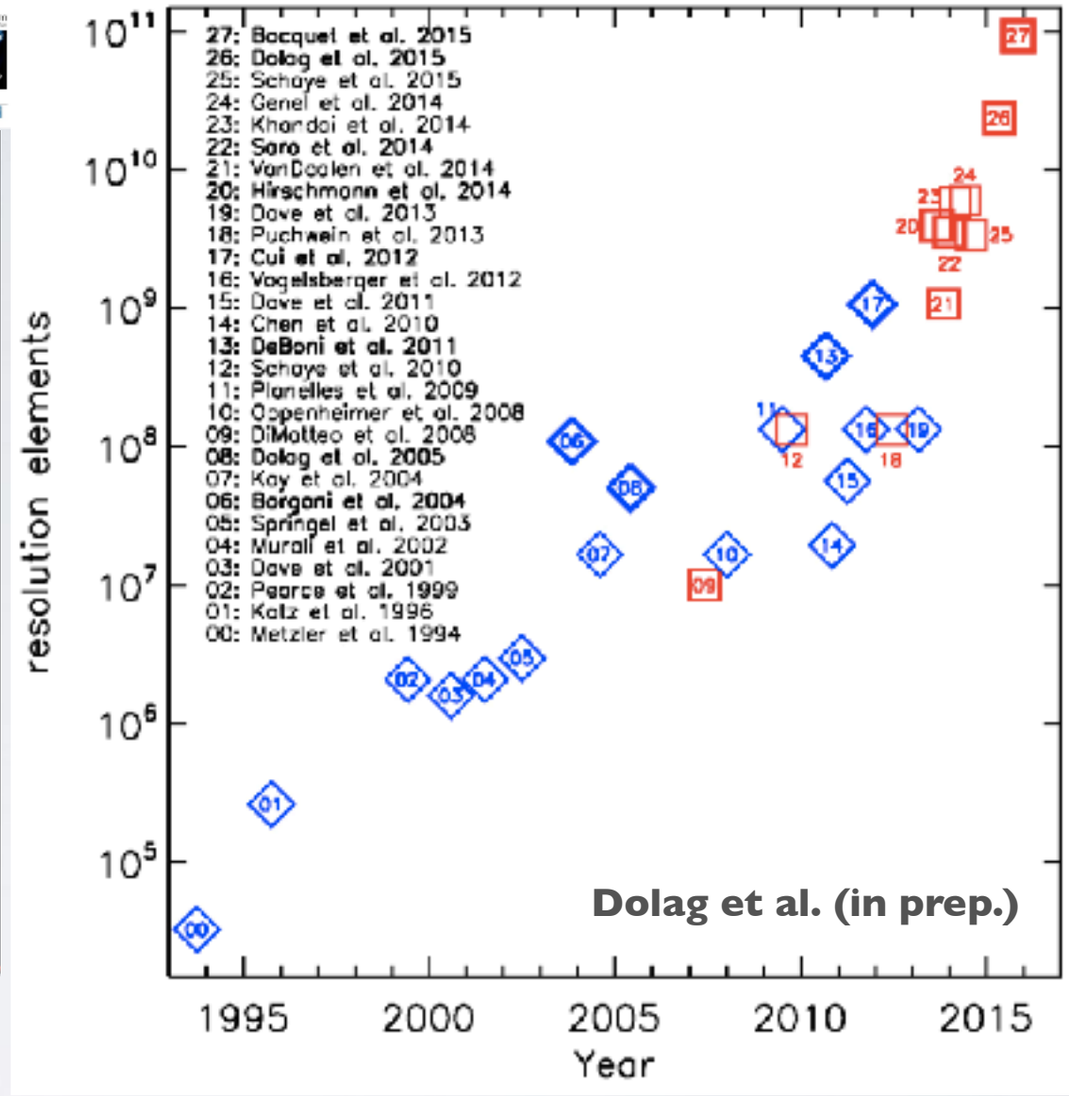
- We do not force BHs to stay in the centre of galaxies!

www.magneticum.org

Hirschmann+14, Steinborn+15/16/18, Teklu+15/17/18, Bocquet+15, Dolag+16/17, Remus+16/17, Biffi+18, Schulze+18

MAGNETICUM





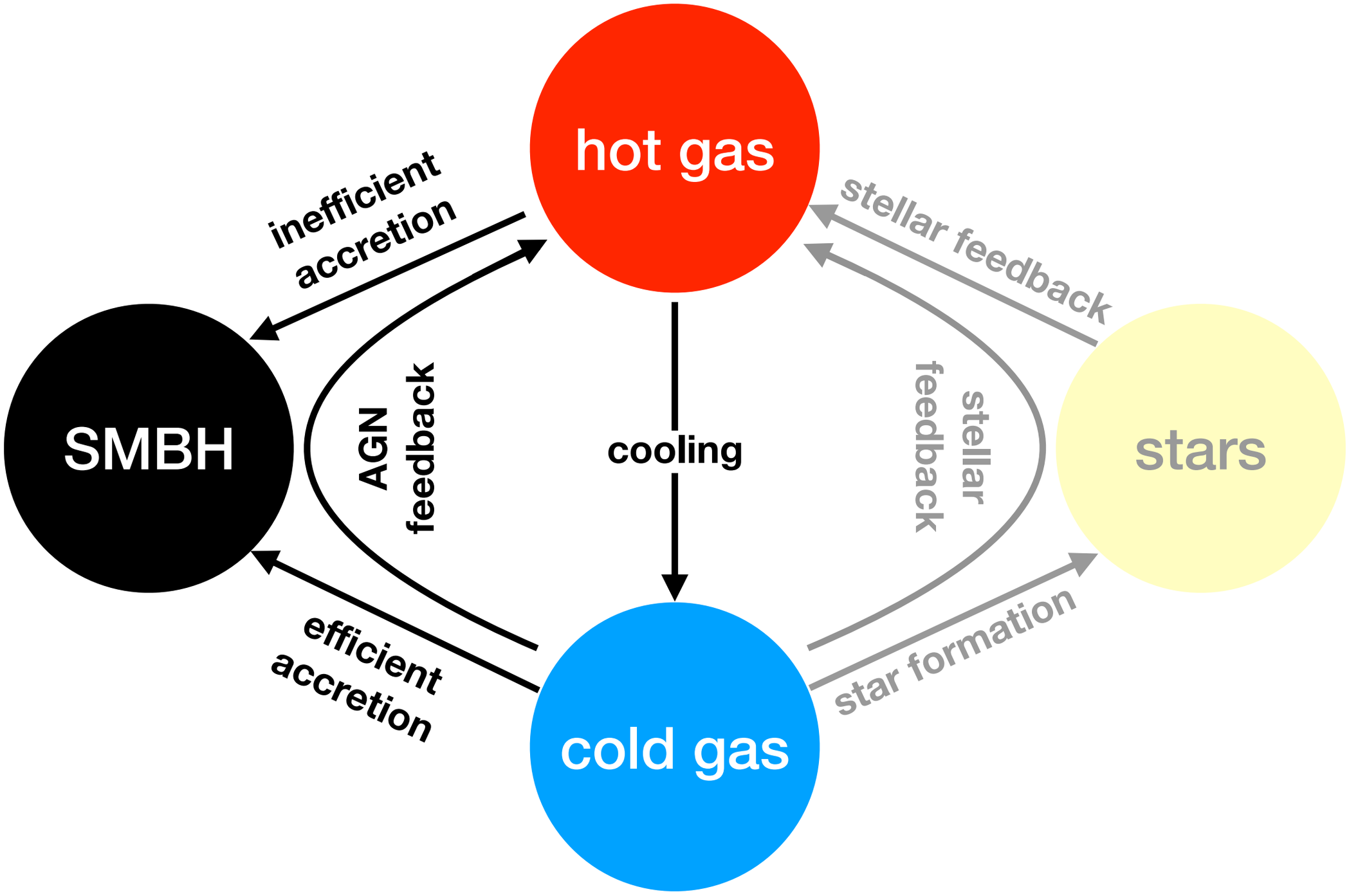
more information:
www.magneticum.org

	m_{dm}	m_{gas}	eps_{dm}	eps_{gas}	eps_{stars}
mr	1.3e10	2.6e9	10	10	5
hr	6.9e8	1.4e8	3.75	3.75	2
uhr	3.6e7	7.3e6	1.4	1.4	0.7
xhr	1.9e6	3.9e5	0.45	0.45	0.25

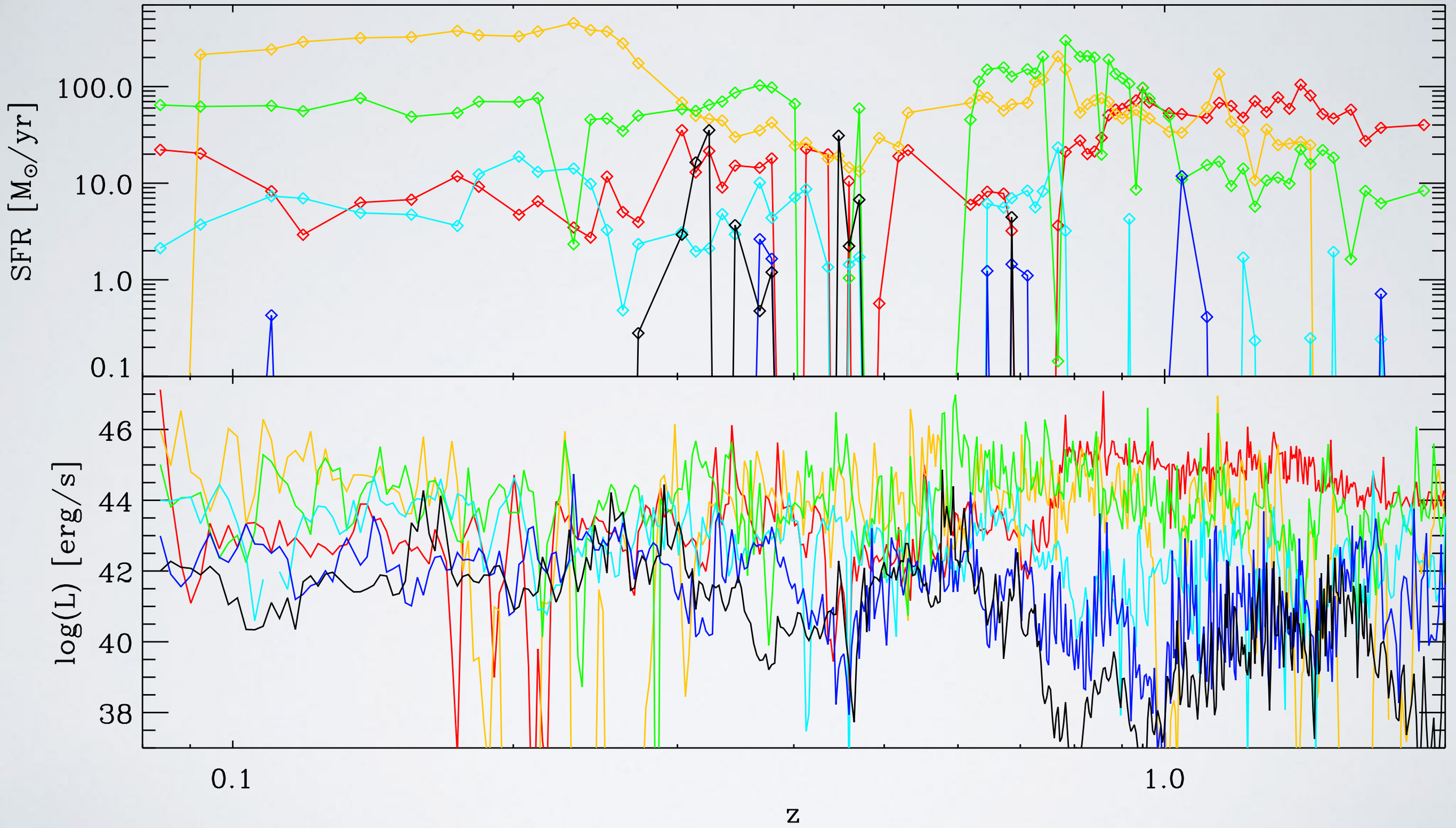
Table 2: Mass of dm and gas particles (in Msol/h) at the different resolution levels and the according softenings (in kpc/h) used.

	Box0	Box1	Box2b	Box2	Box3	Box4	Box5
[Mpc/h]	2688	896	640	352	128	48	18
mr	$2*4536^3$	$2*1526^3$		$2*594^3$	$2*216^3$	$2*81^3$	
hr			$2*2880^3$	$2*1584^3$	$2*576^3$	$2*216^3$	$2*81^3$
uhr					$2*1536^3$	$2*576^3$	$2*216^3$
xhr						$2*1536^3$	$2*576^3$

Table 1: Number of particles used in the *Magneticum Pathfinder* and *Magneticum* simulations for the different resolution levels *mr*, *hr*, *uhr* and *xhr*. The red entries mark simulations which are currently running or not ran to z=0, the gray entries mark future, planned simulations.

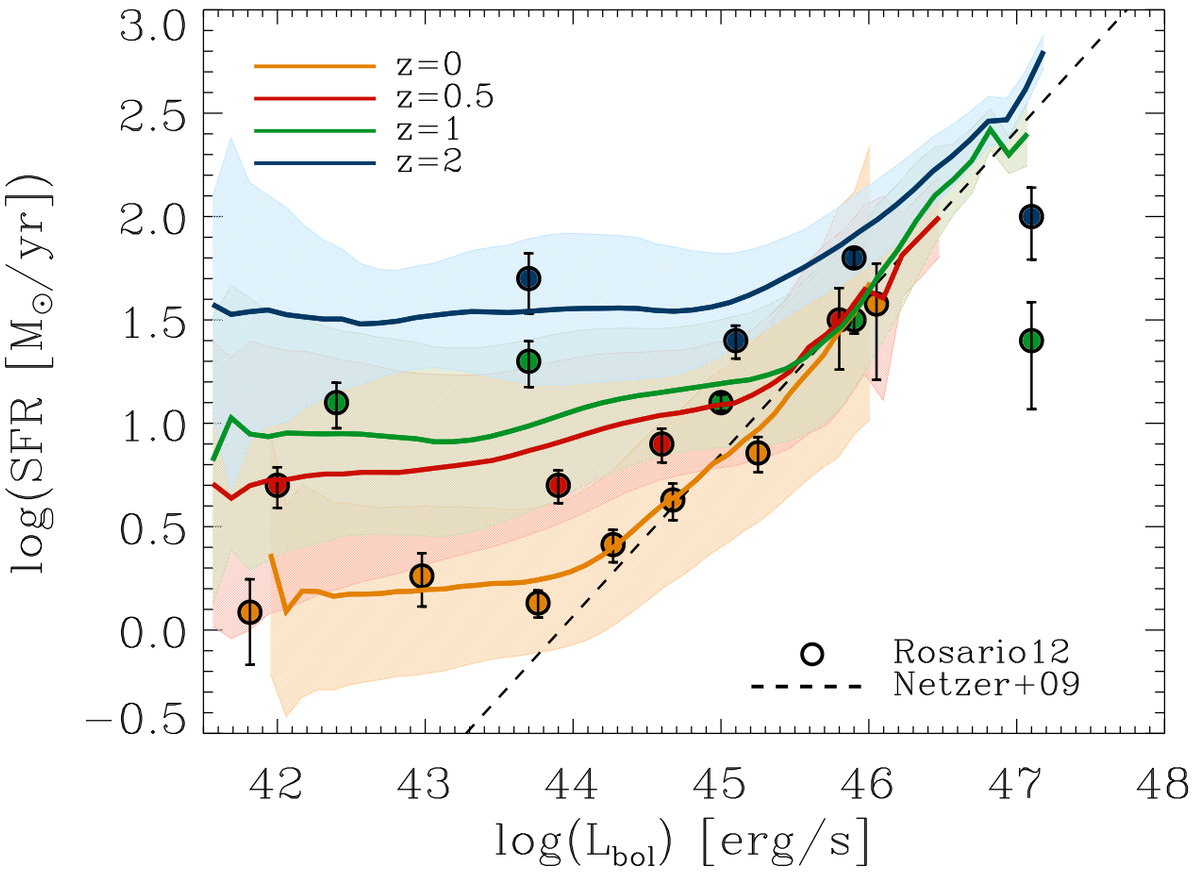

hot gas
inefficient accretion
stellar feedback
SMBH
AGN feedback
cooling
stellar feedback
stars
efficient accretion
star formation
cold gas

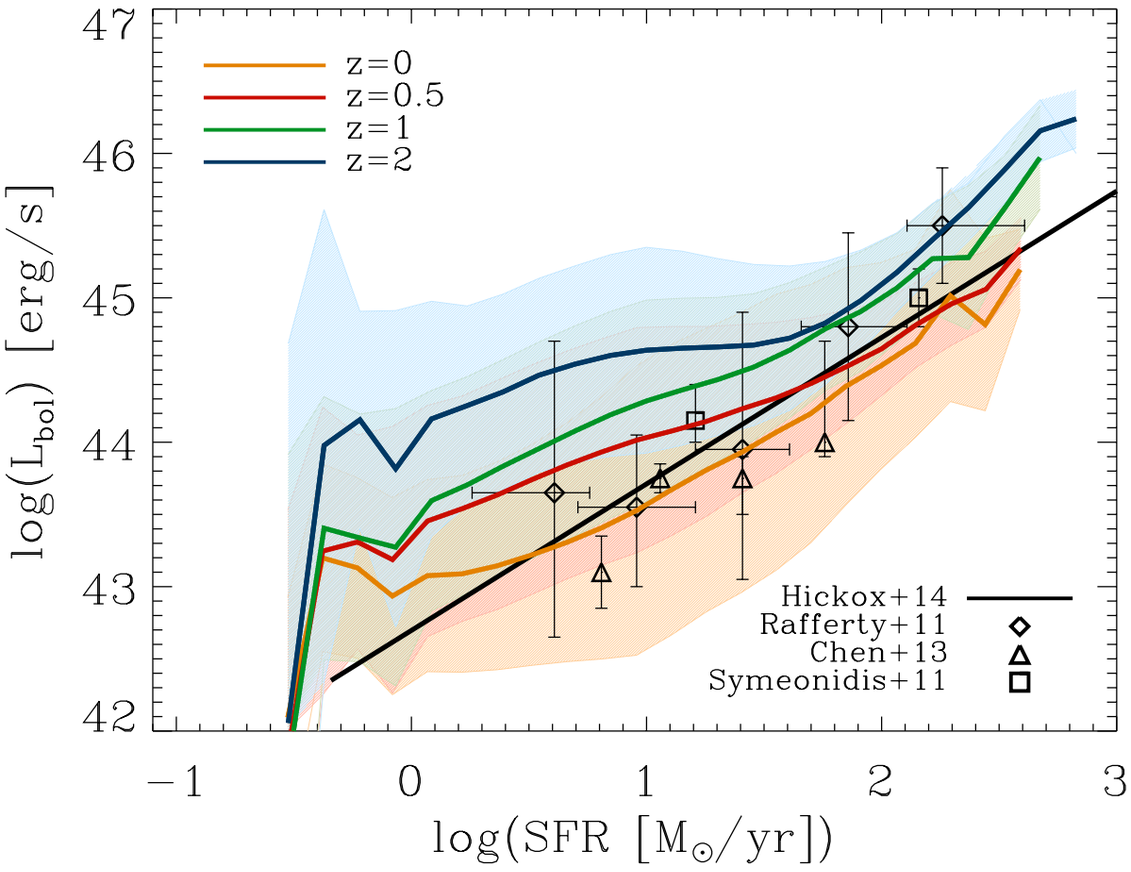
AGN AND STAR FORMATION



AGN act on much shorter time scales than SF!

AGN AND STAR FORMATION



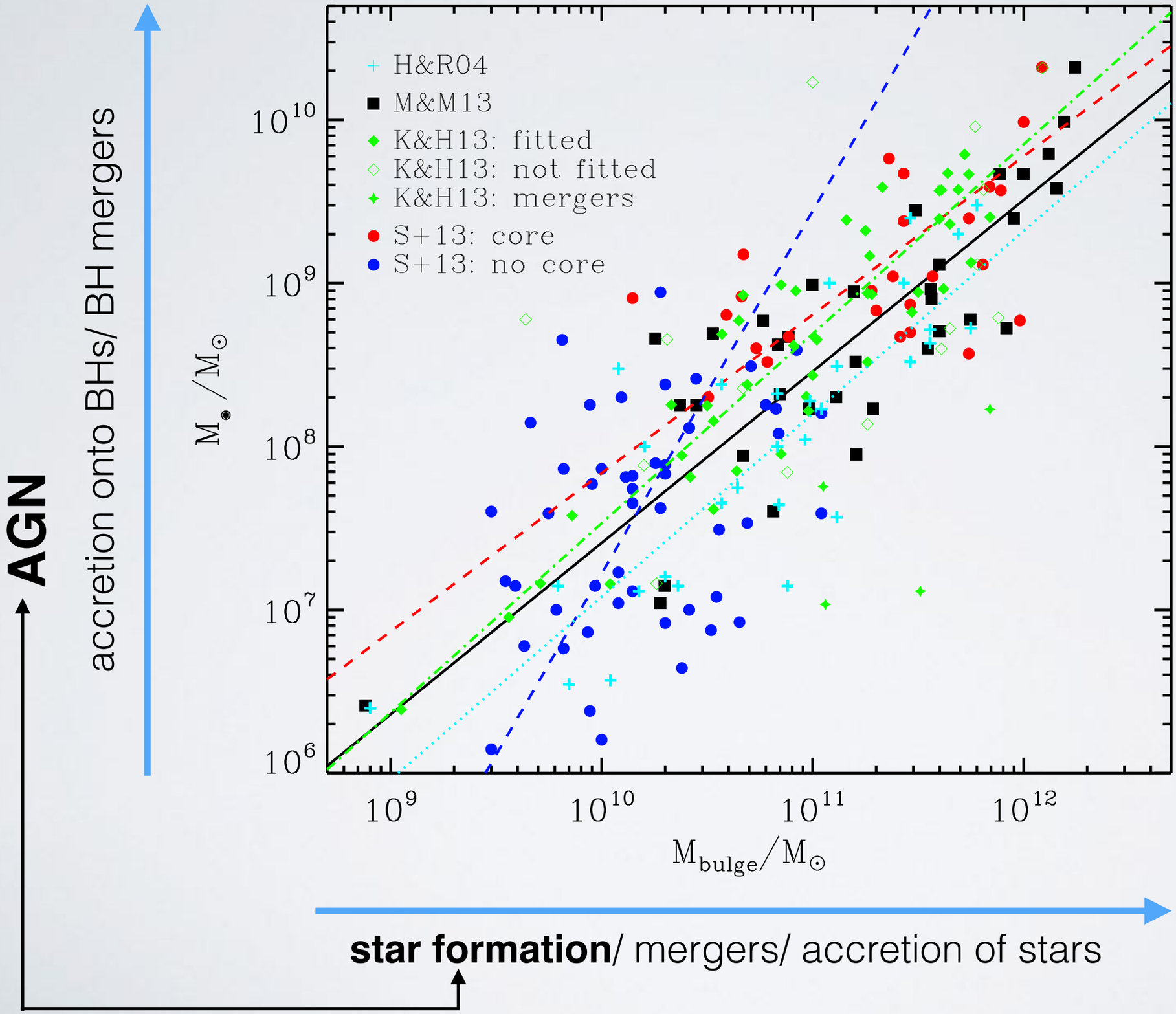


Hirschmann et al. (in prep.)

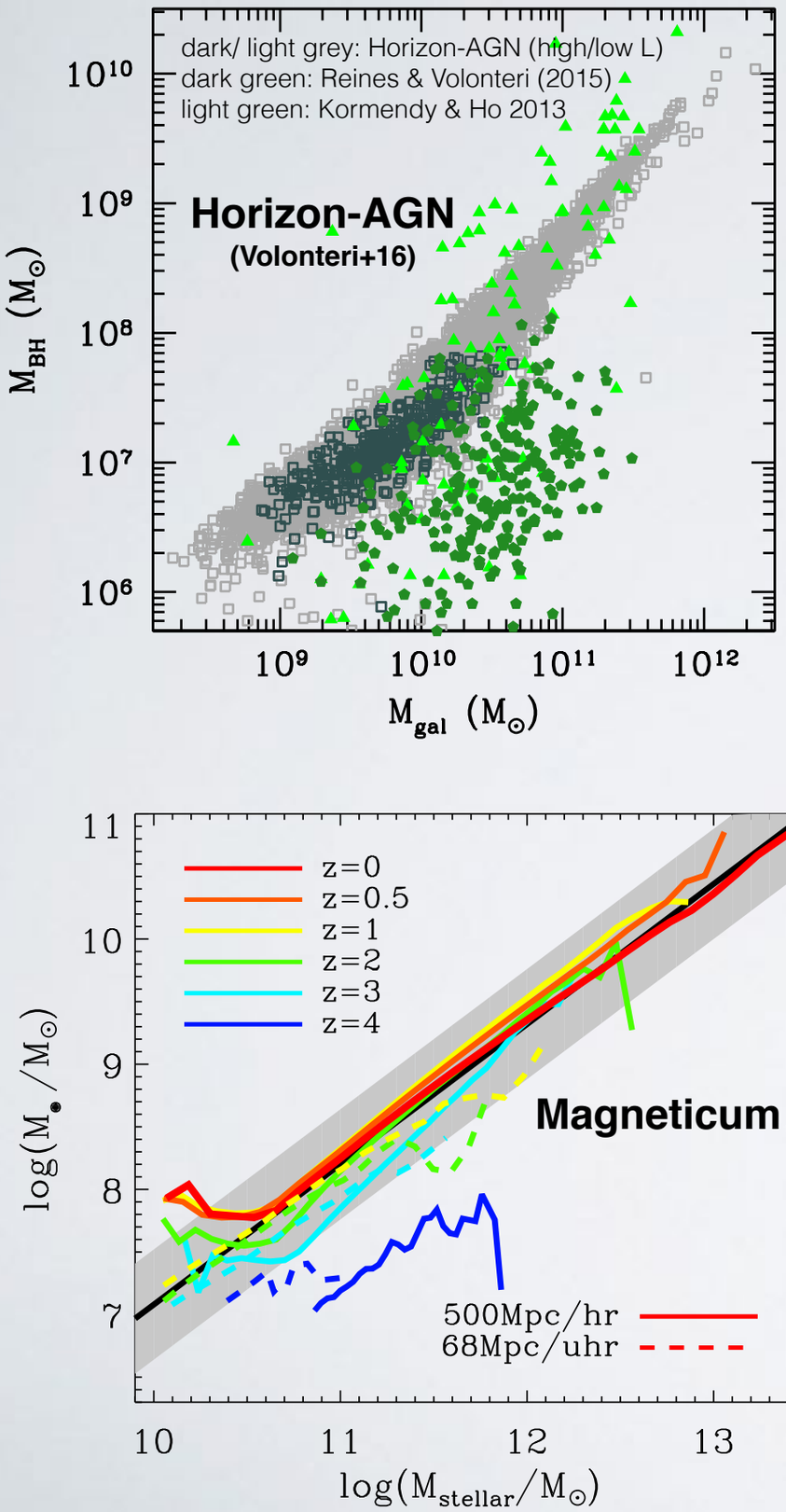
AGN act on much shorter time scales than SF!

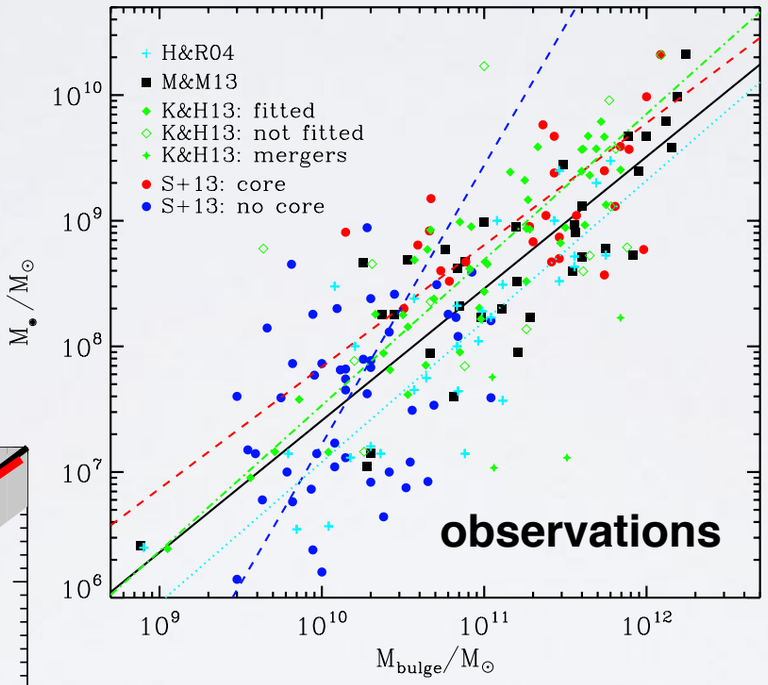
The driving mechanisms of AGN and SF must be connected!

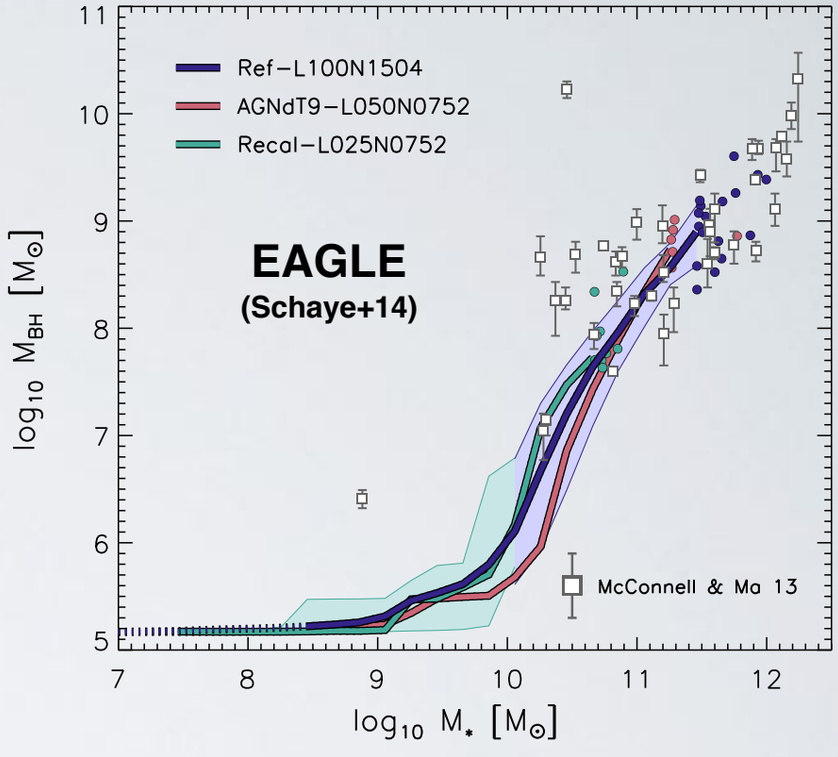
SCALING RELATIONS

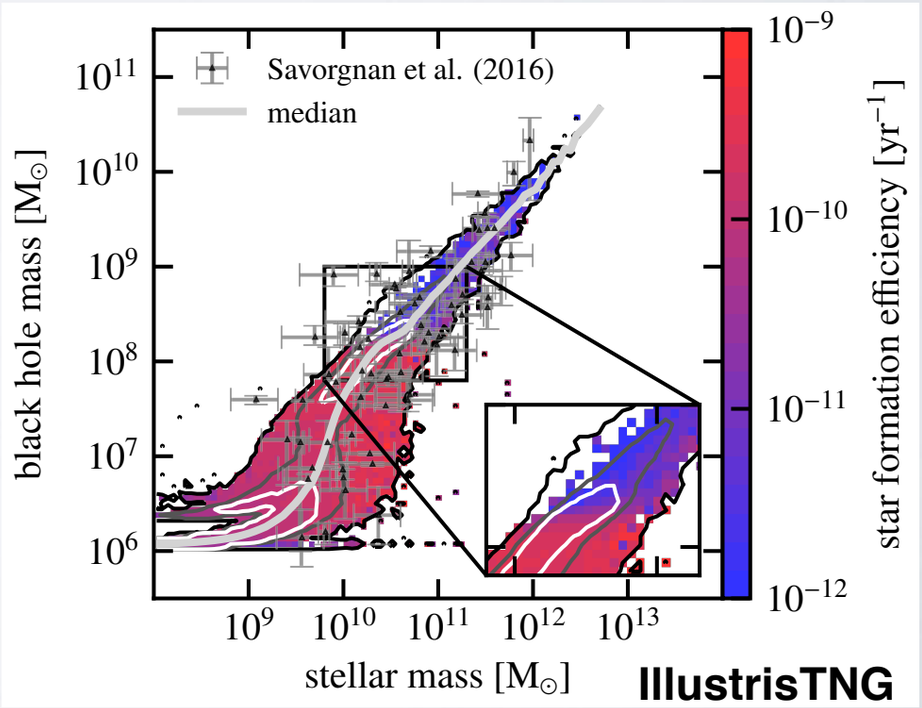


SCALING RELATIONS

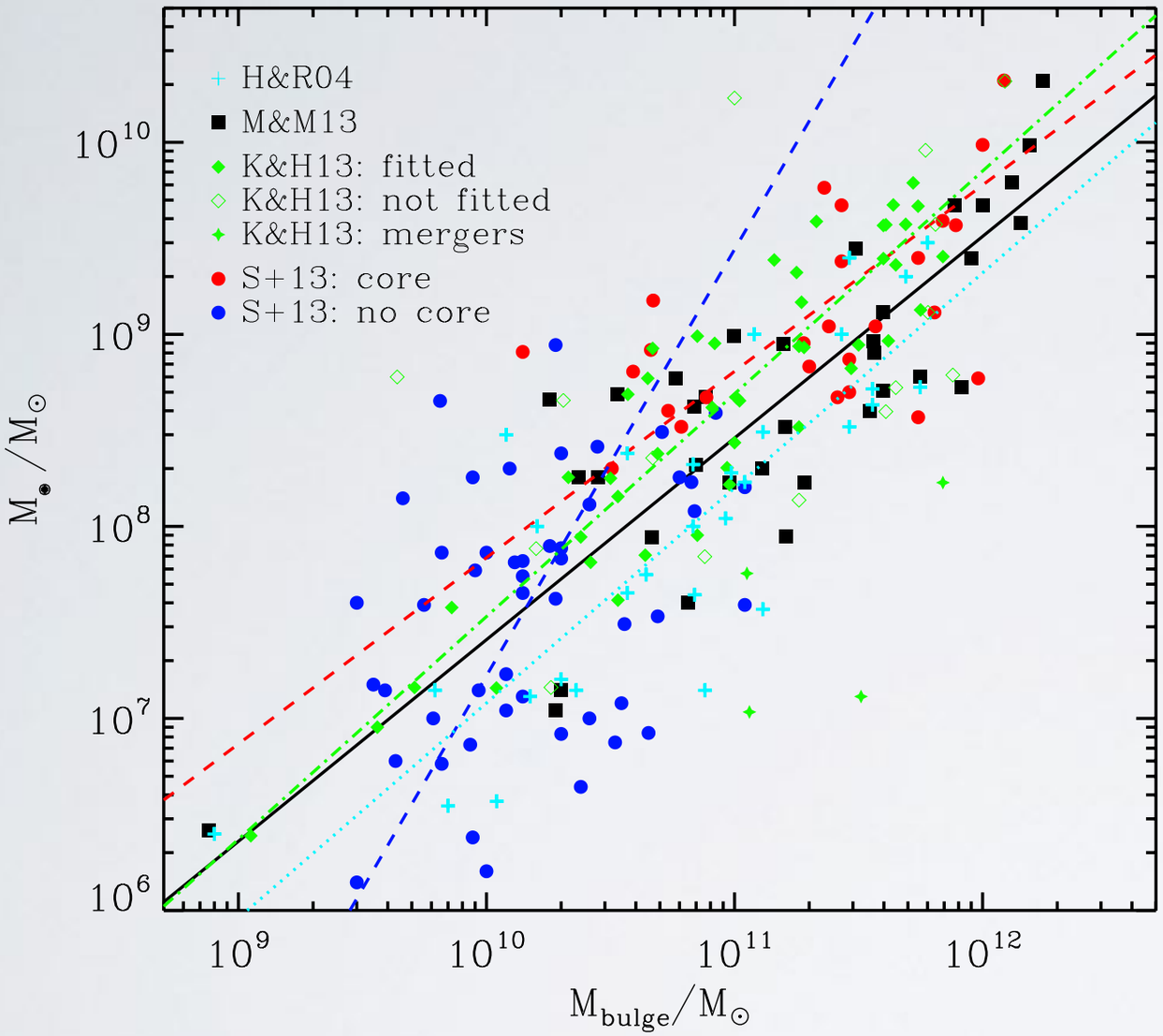


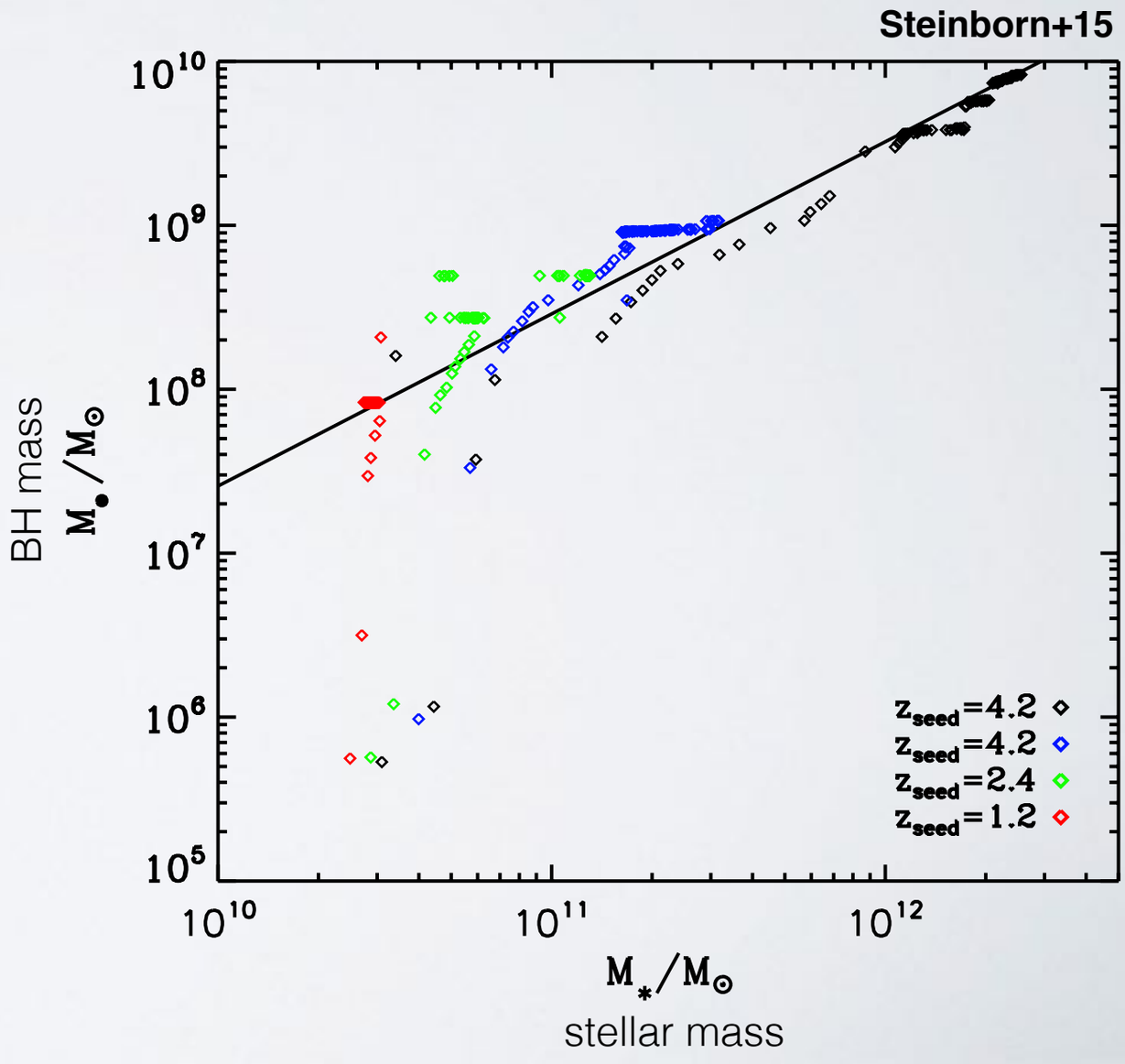






SCALING RELATIONS





SCALING RELATIONS

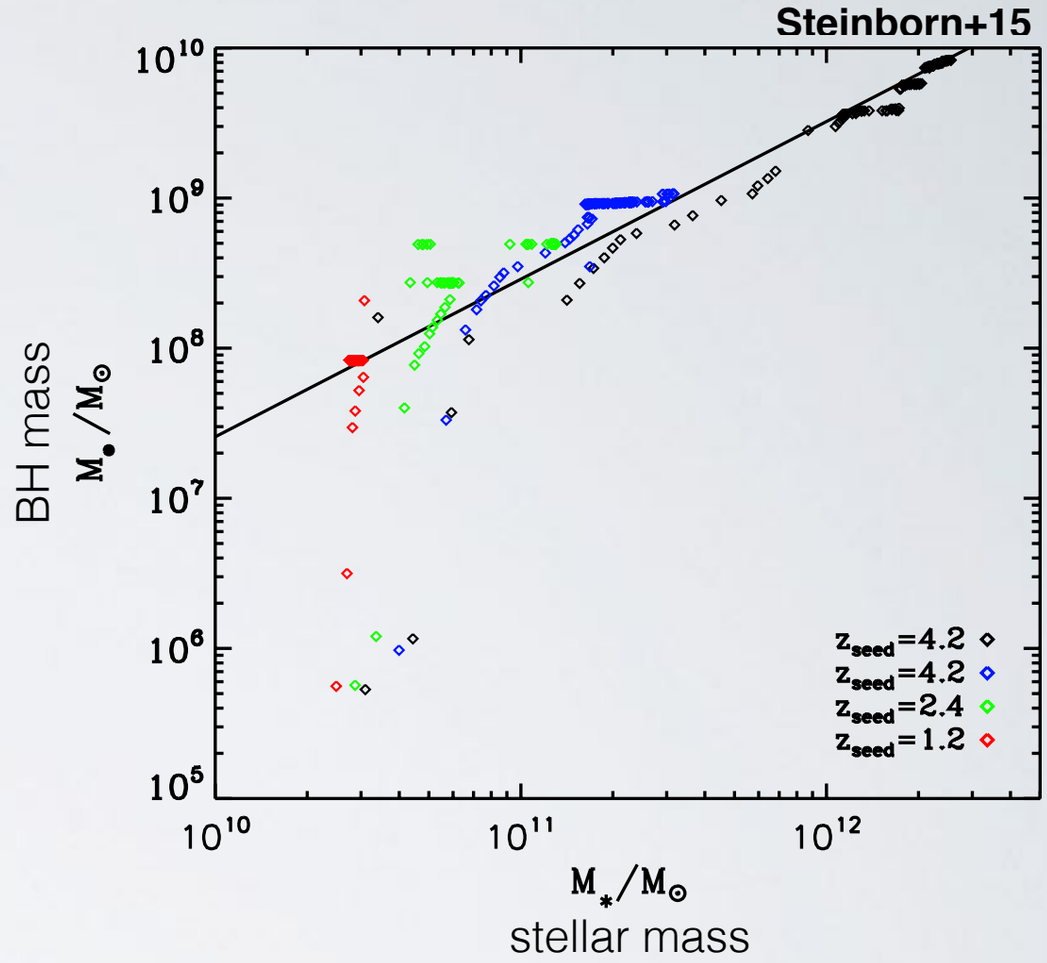
What keeps the BHs/ galaxies on this relation?

Churazov+05:

cooling rate of the gas = heating rate of the AGN

M_{BH}-σ relation

M_{BH}-$M_{stellar}$ relation



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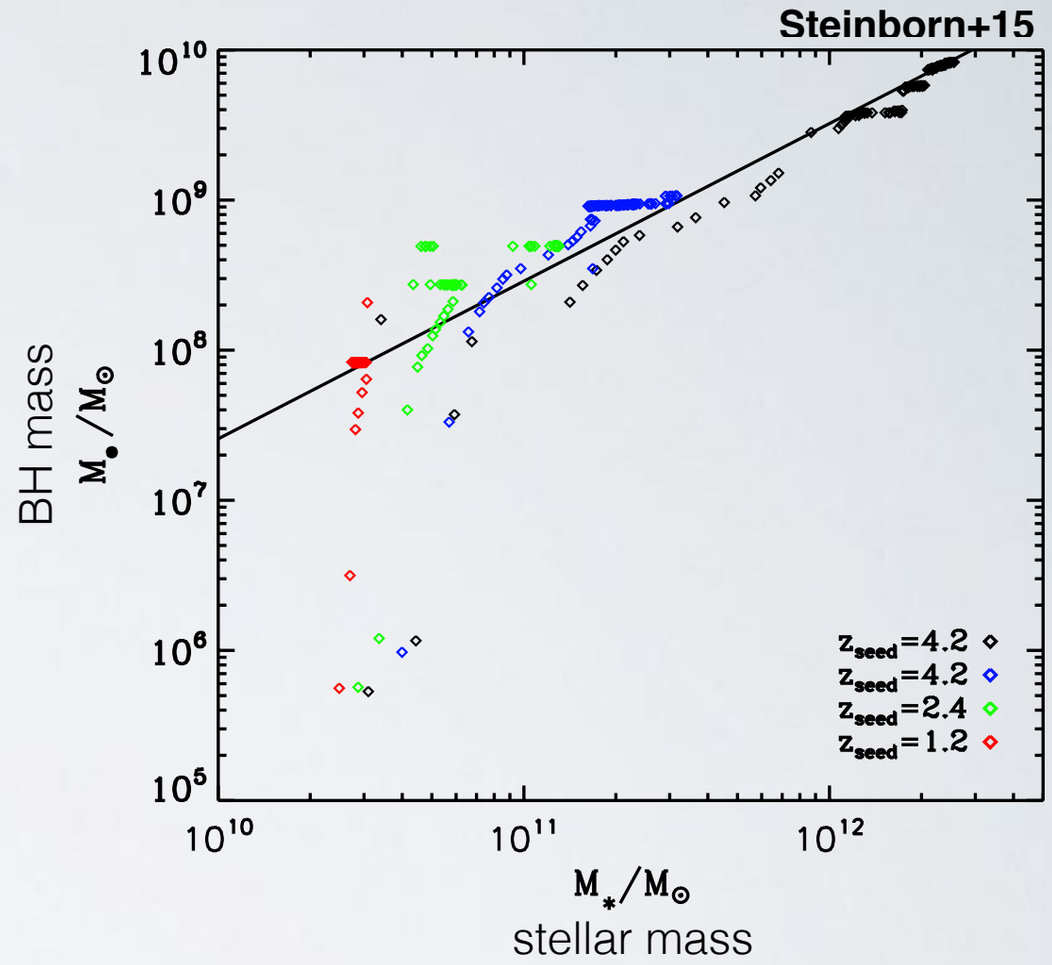


M_{BH}-σ relation

↓

M_{BH}-$M_{stellar}$ relation

The scaling relations reflect an equilibrium between cooling and heating!

SCALING RELATIONS

What keeps the BHs/ galaxies on this relation?

Churazov+05:

cooling rate of the gas = heating rate of the AGN

$$\dot{E} = (\epsilon_o + \epsilon_f \epsilon_r) \dot{M}_\bullet c^2$$

mechanical outflows

radiation

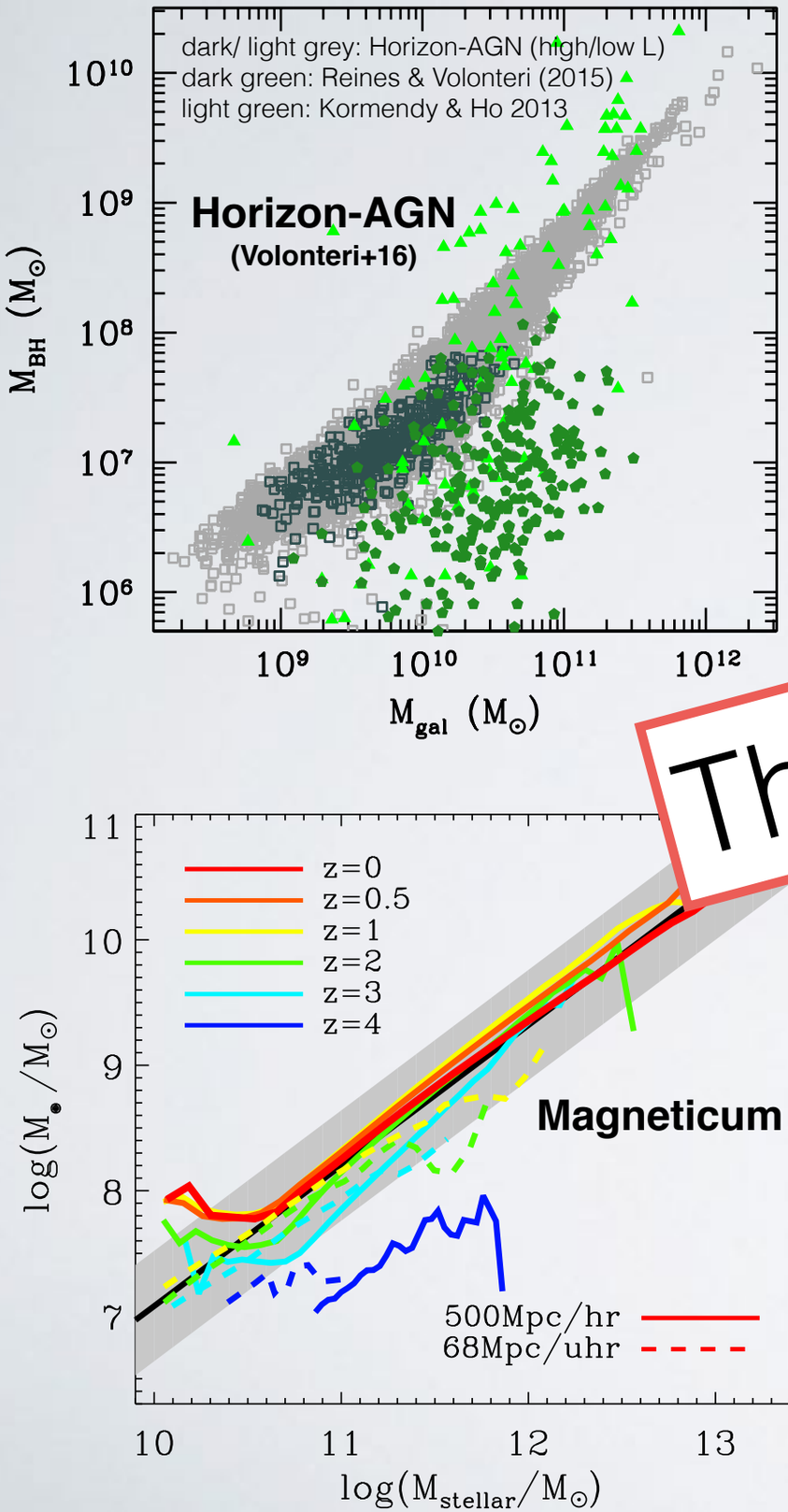
The scaling relations are tuned using the efficiency of the AGN feedback.

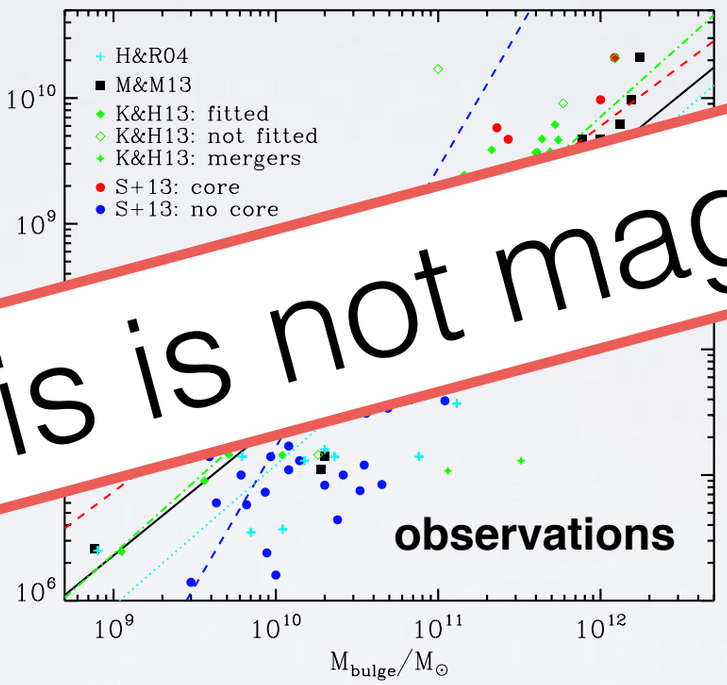
M_{BH}-σ relation

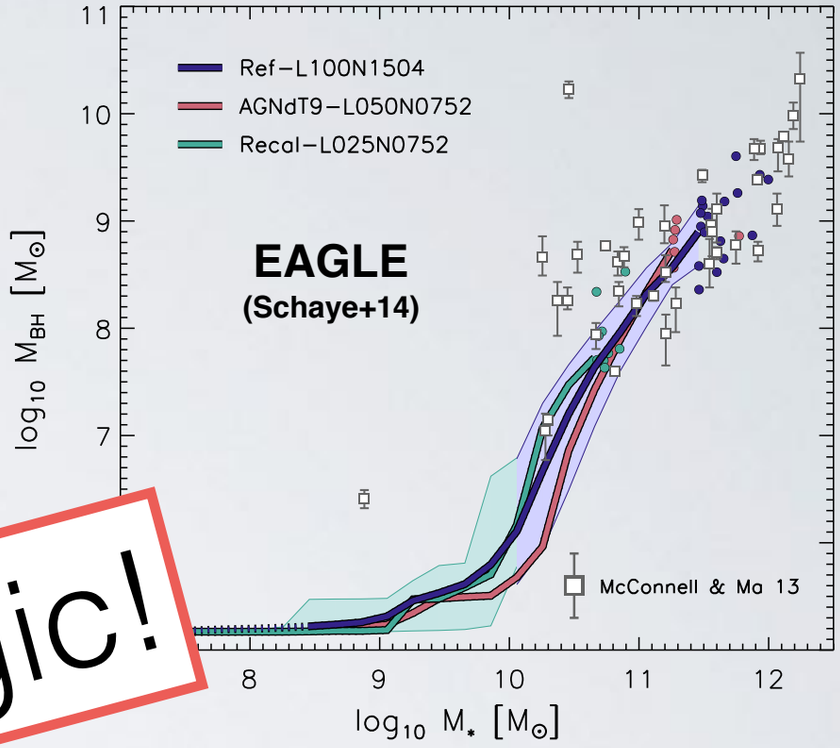
M_{BH}-$M_{stellar}$ relation

The scaling relations reflect an equilibrium between cooling and heating!

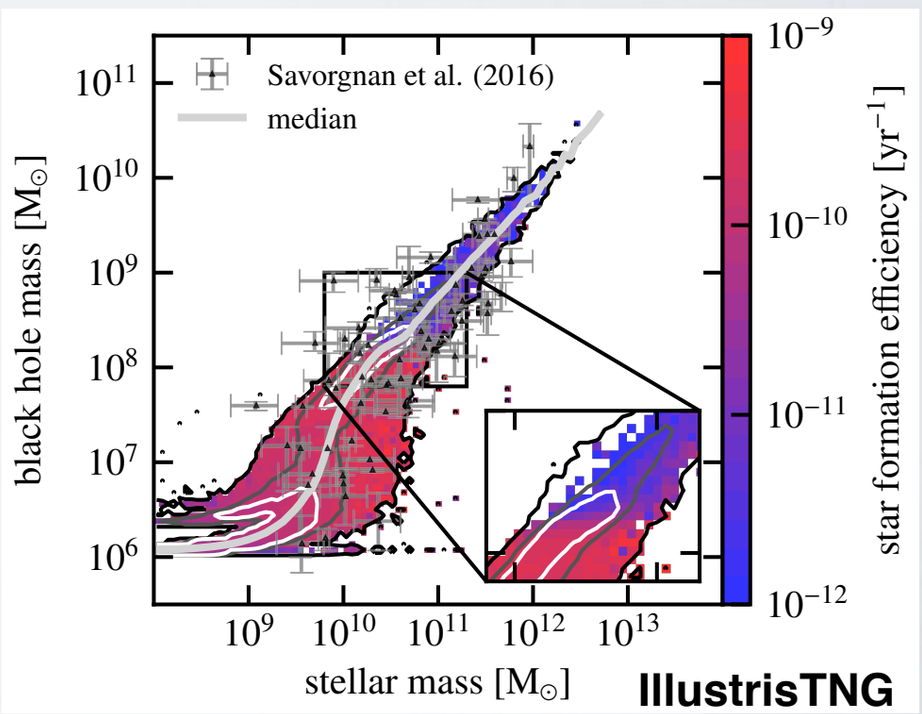
SCALING RELATIONS



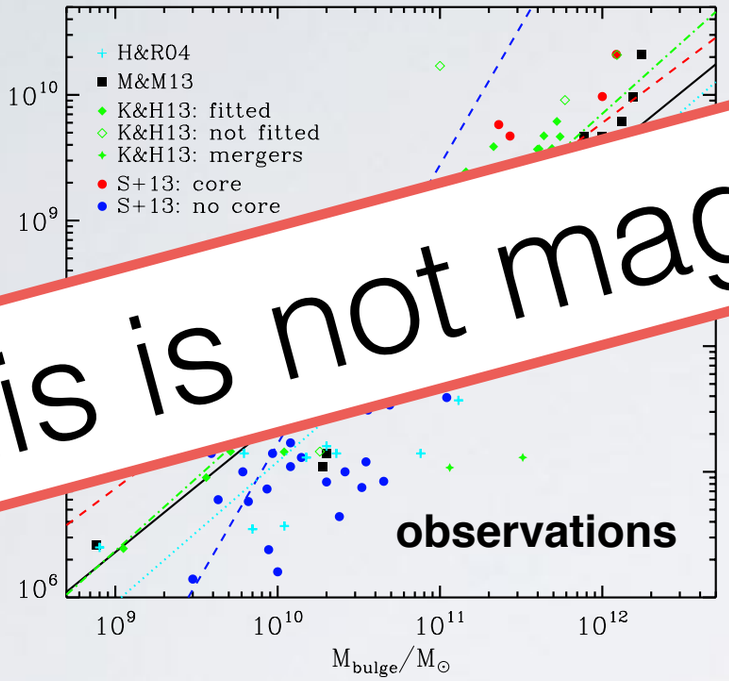




This is not magic!



SCALING RELATIONS

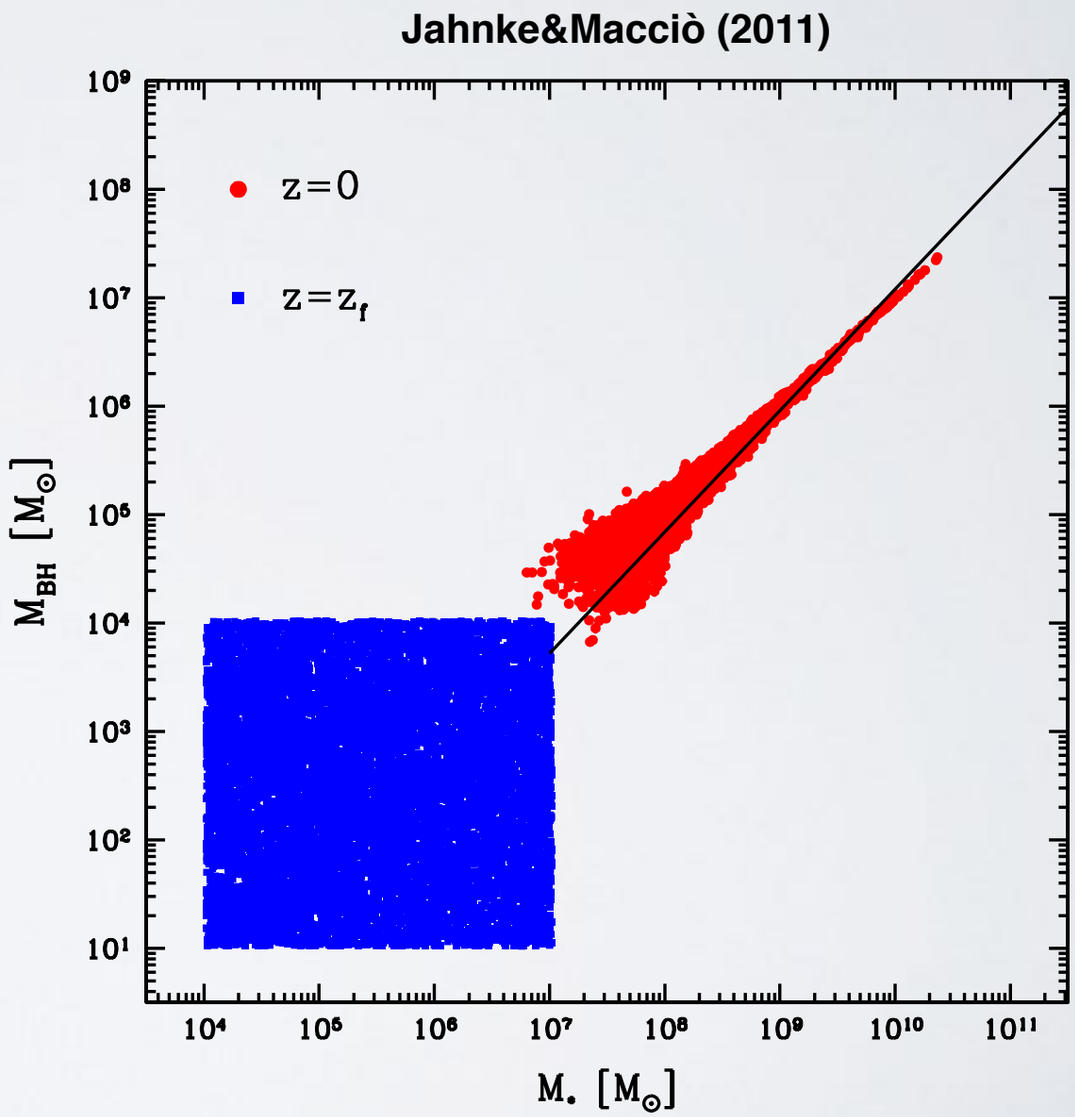


This is not magic!

The coevolution between SMBHs and their host galaxies is self-regulated.

↓

It does not depend on the accretion model, as long as you accrete enough.



A theorists perspective ...

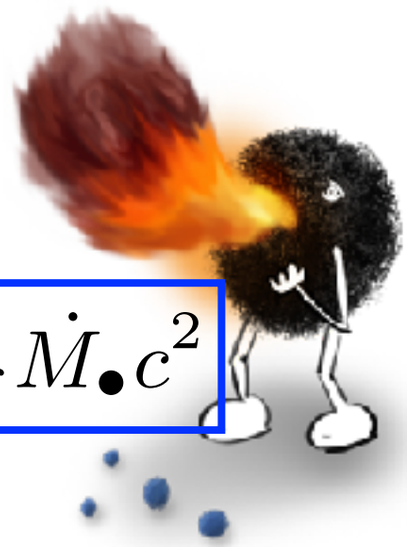
BHs

accretion

mech. feedback

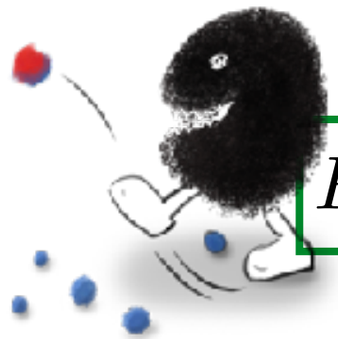
radiative feedback

AGN



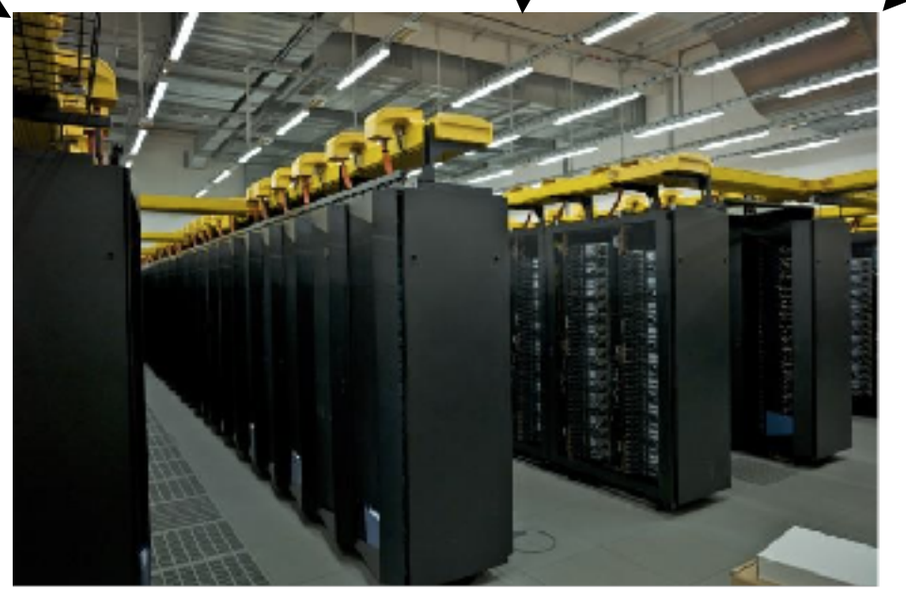
$$\dot{M}_{\rm B} = \frac{4\pi\alpha G^2 M_\bullet^2 \langle\rho\rangle}{(\langle c_{\rm s}\rangle^2 + \langle v\rangle^2)^{3/2}}$$

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



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

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



AGN are not just random events!

BH GROWTH IN SIMULATIONS

The coevolution between SMBHs and their host galaxies is self-regulated.

↓

It does not depend on the accretion model, as long as you accrete enough.

What Simulations match:

- BH-galaxy scaling relations
- AGN luminosity function
- BH mass function
- stellar mass function

What simulations cannot do properly yet:

- detailed accretion state
- AGN types

Simulations match BH growth, but not (exactly) how BHs grow!

We can link AGN activity to the surrounding gas properties.

↓

What are the driving mechanisms of AGN?

AGN are not just random events!

There must be certain conditions which increase the probability for AGN activity (AGN trigger mechanisms)!

secular evolution

gas reservoir

mergers

bar/disk instabilities
(Shlosman+89)

environment

violently instable disks
(Dekel+09, Bournaud+11)

gas cooling from the hot halo
(Croton+06)

Do mergers drive AGN activity?

Steinborn+18

z=2.0 z=2.3 z=2.8

200kpc/h

20kpc/h

43.4
46.3

44.7
45.2

43.8
42.7

2:3

200kpc/h

20kpc/h

43.4
44.9

44.5
45.2

43.9
43.9

1:1

100kpc/h

20kpc/h

44.4
46.0

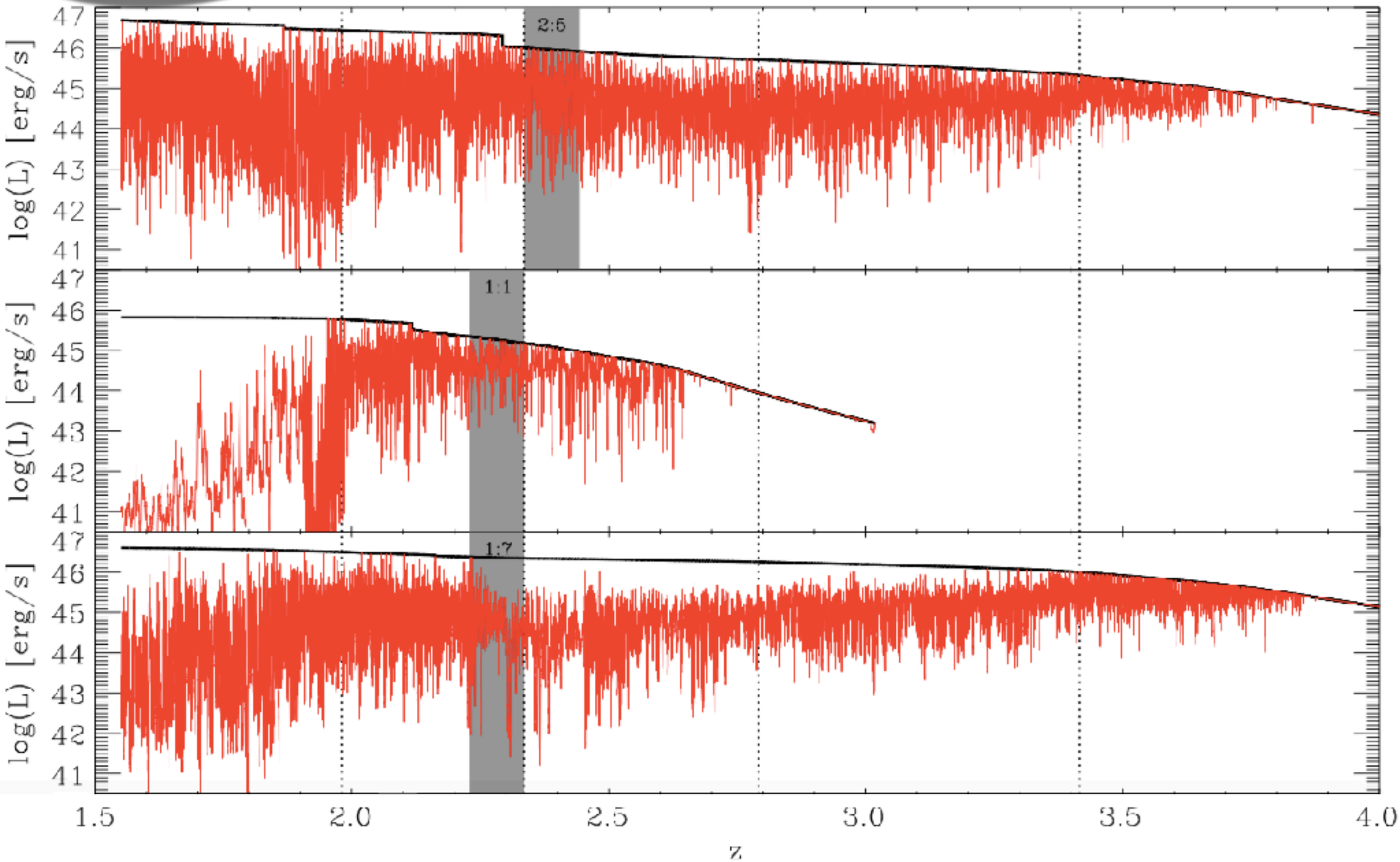
44.5
44.4

44.9
44.4

1:7

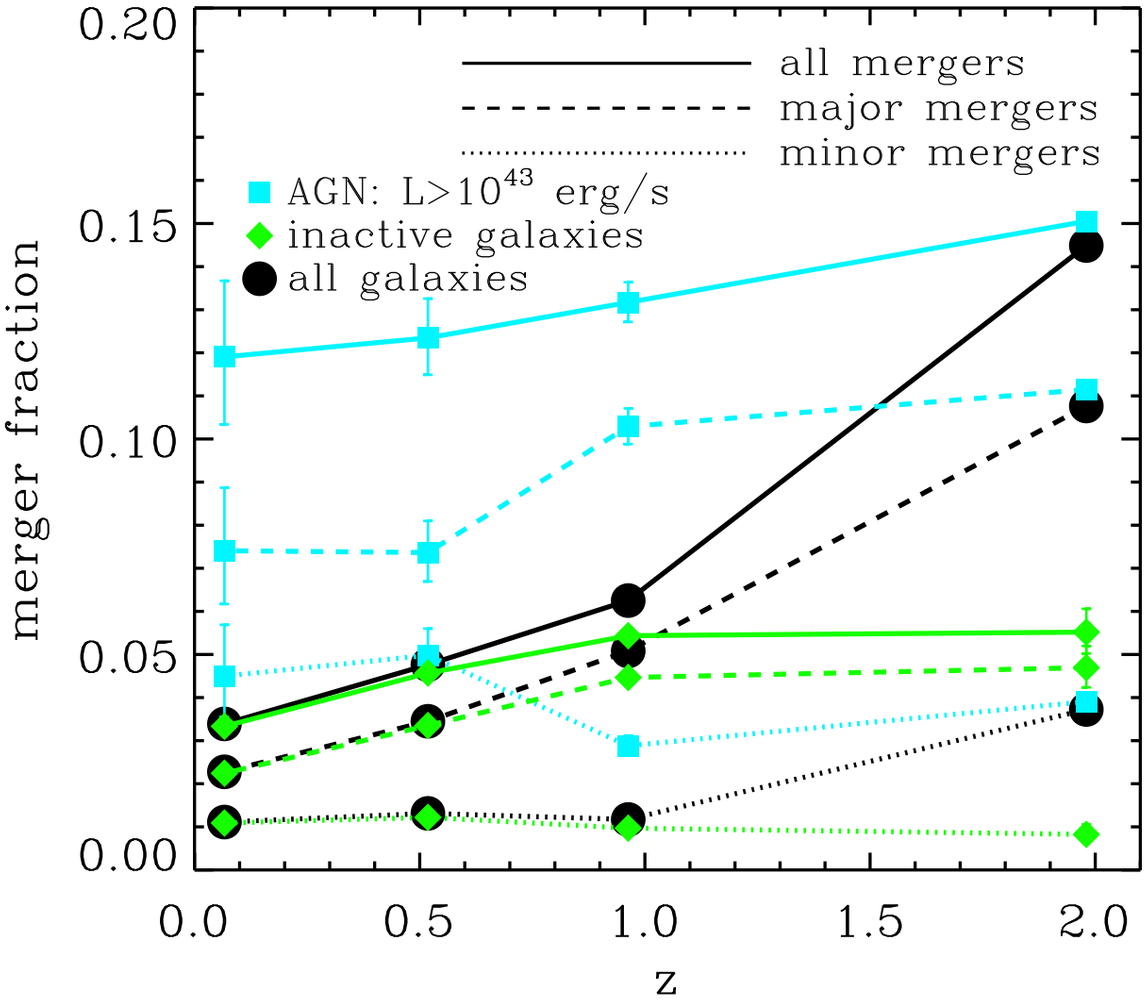
Do mergers drive AGN activity?

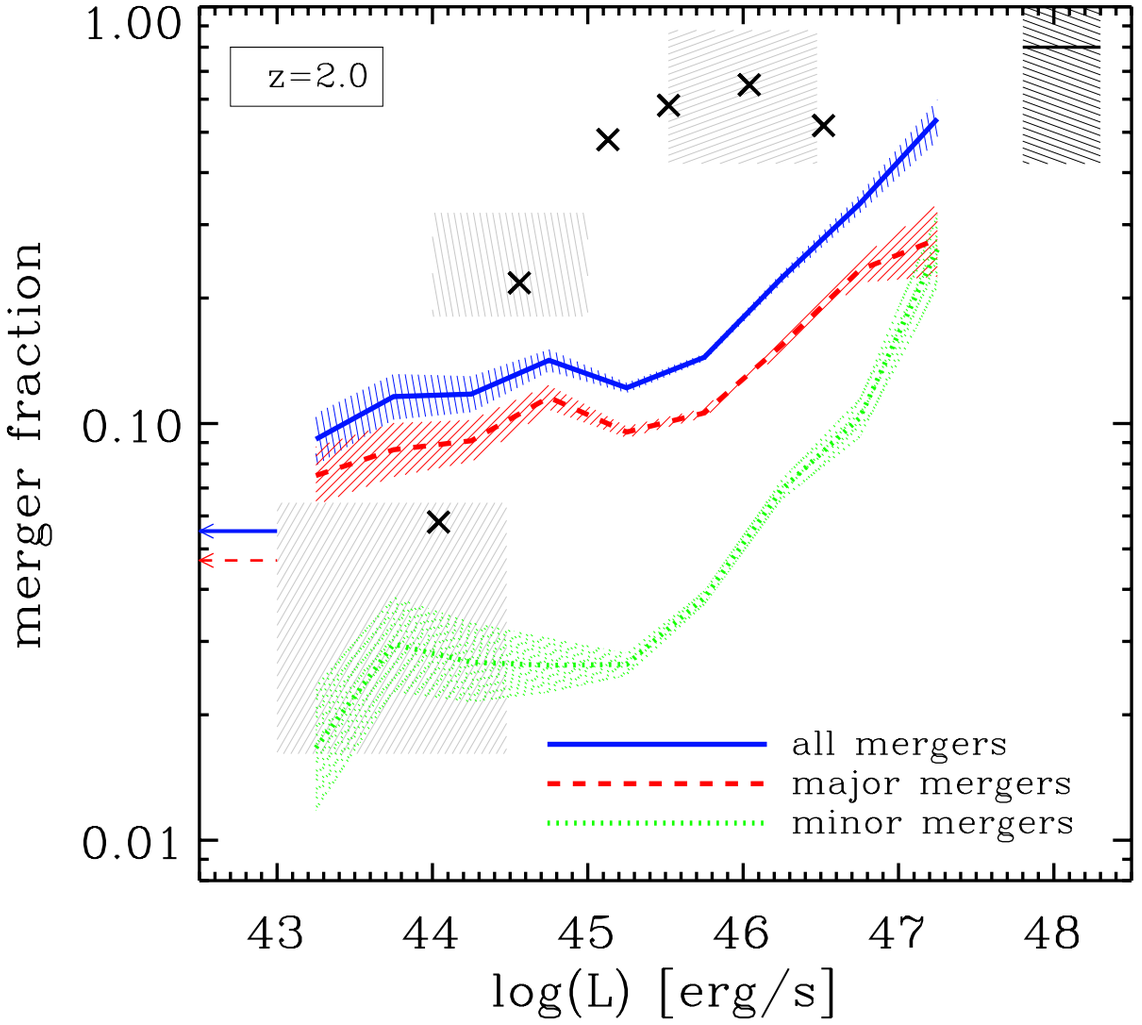
Steinborn+18



Do mergers drive AGN activity?

Steinborn+18





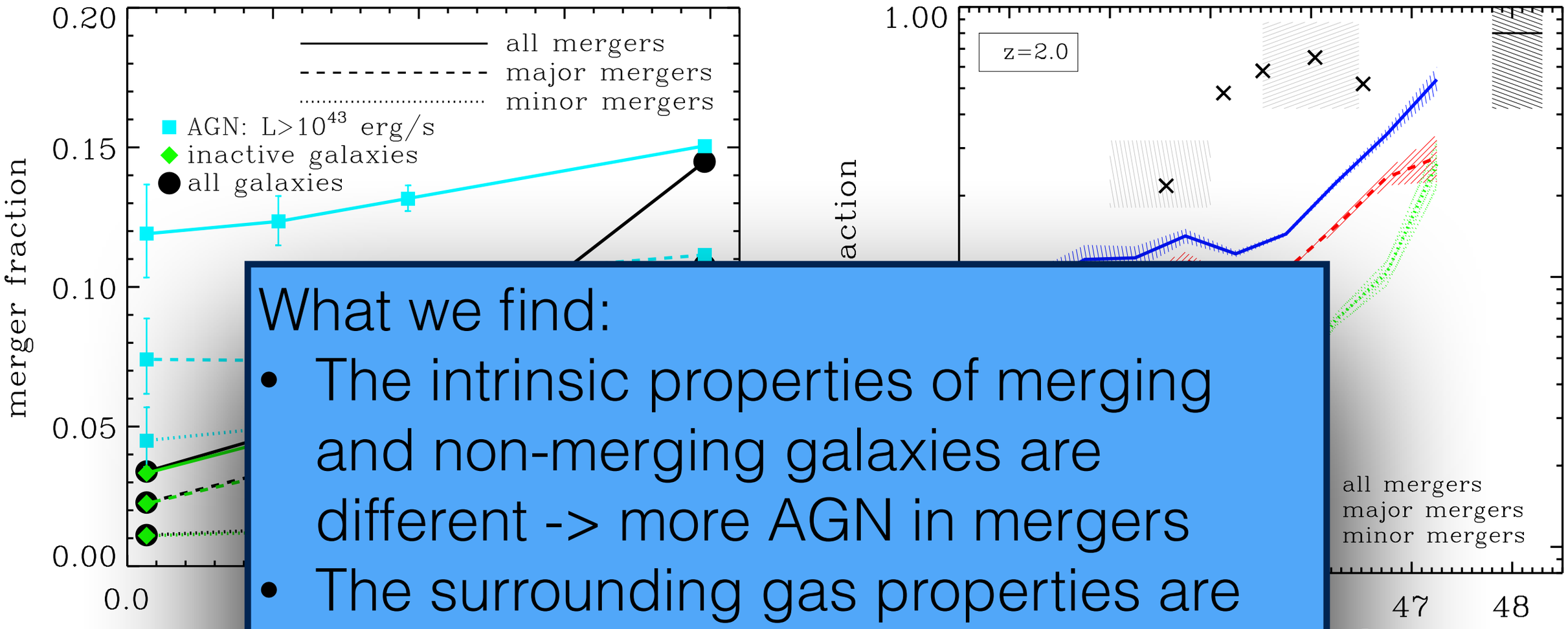
There is a relation between mergers and AGN!

BUT

This does not mean that mergers trigger AGN!

Do mergers drive AGN activity?

Steinborn+18



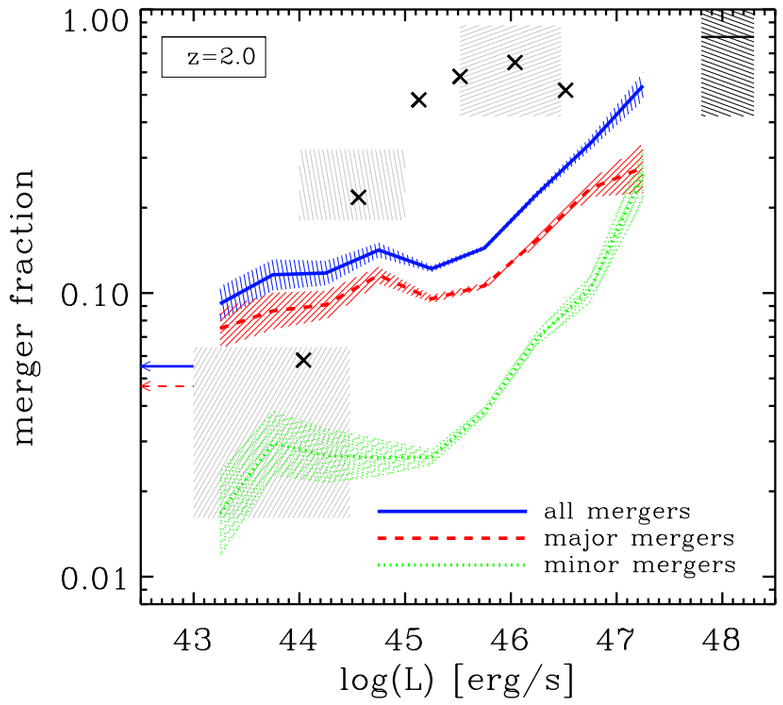
What we find:

- The intrinsic properties of merging and non-merging galaxies are different -> more AGN in mergers
- The surrounding gas properties are most important for triggering AGN (independently of the merger history!)

Th N!

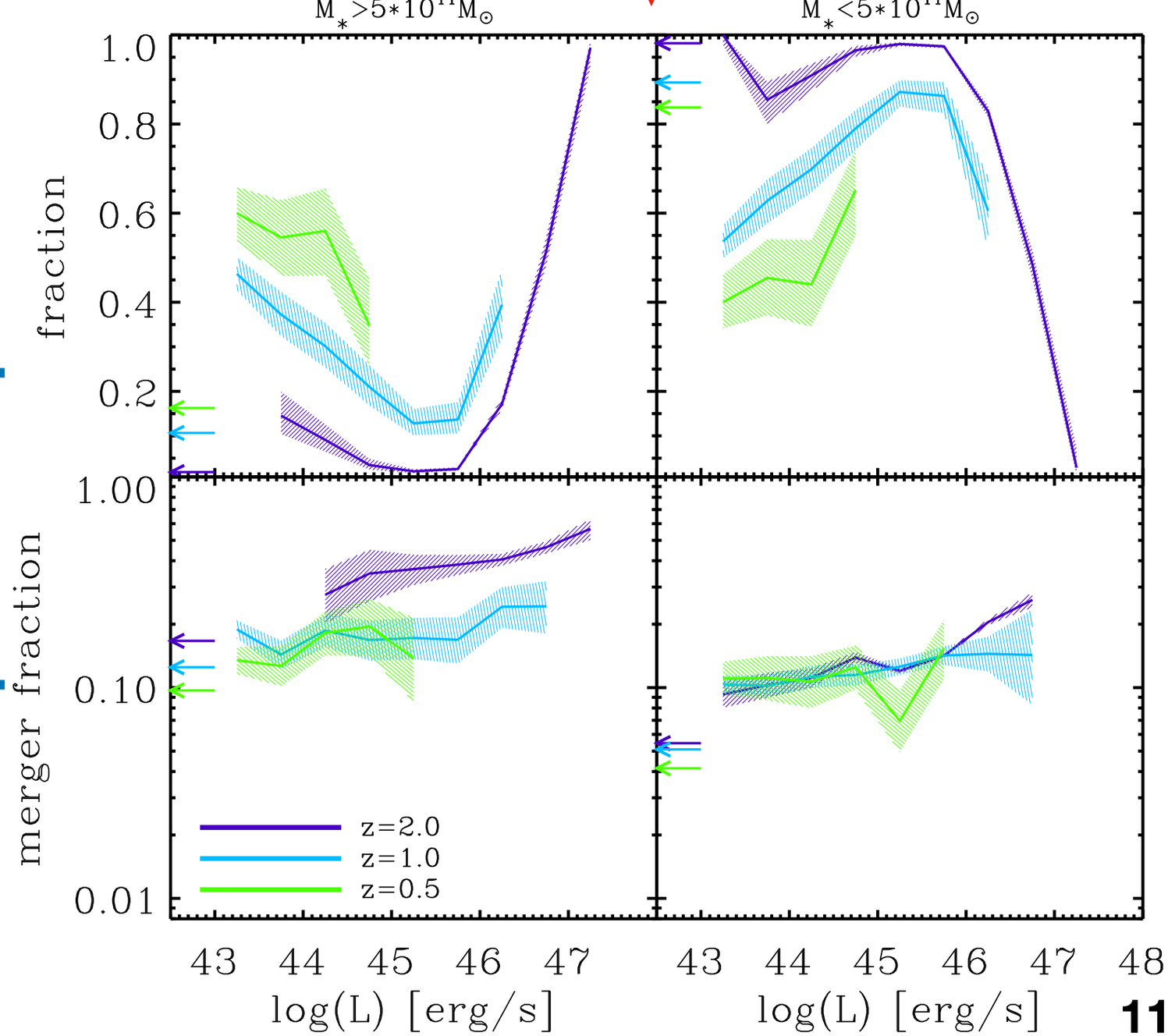
BUT

This does not mean that mergers trigger AGN!



What is the origin of this relation?

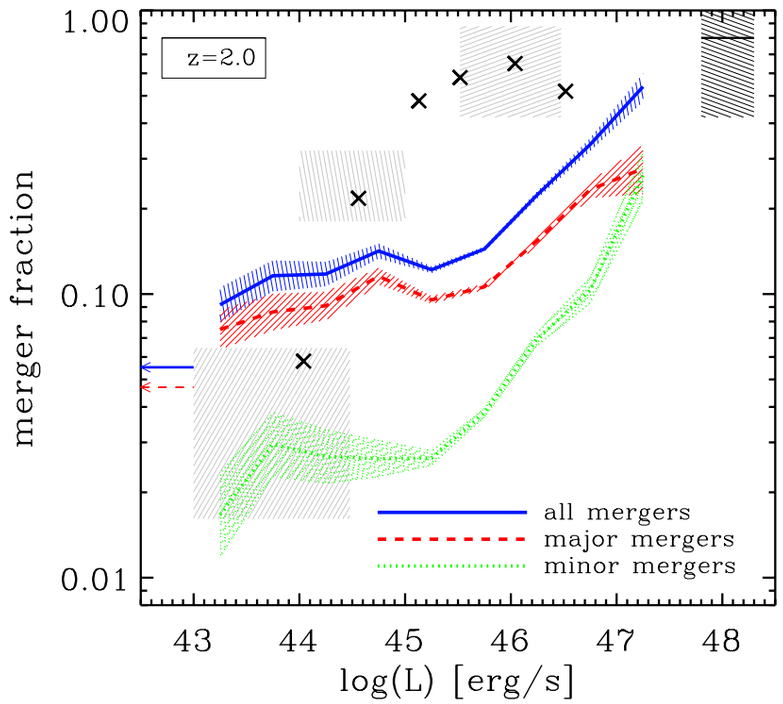
This does not mean that luminous AGN are triggered by mergers!



More massive galaxies do on average host more luminous AGN!

+

More massive galaxies did more likely have a recent merger event!

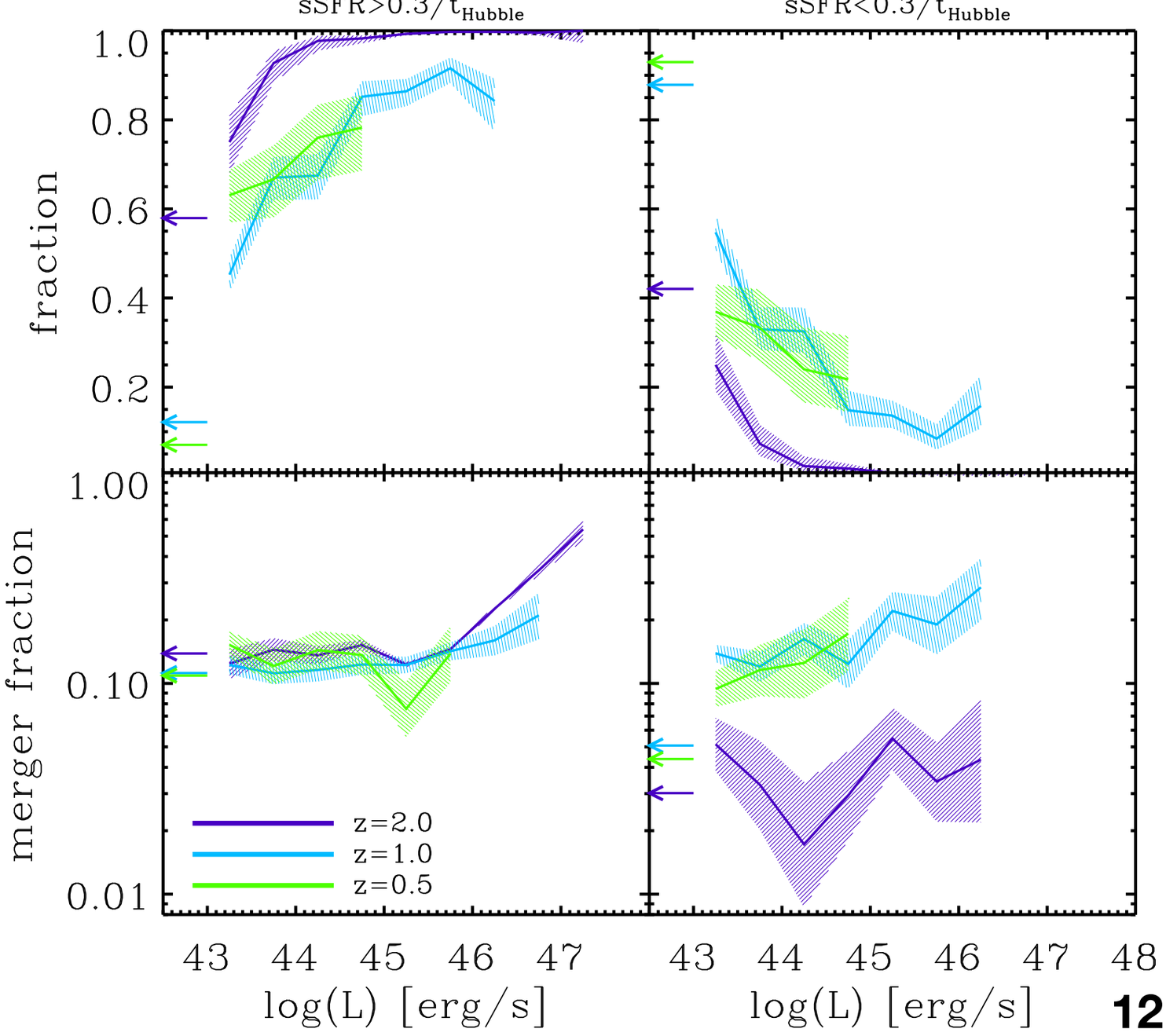


What is the origin of this relation?

This does not mean that luminous AGN are triggered by mergers!

star forming galaxies

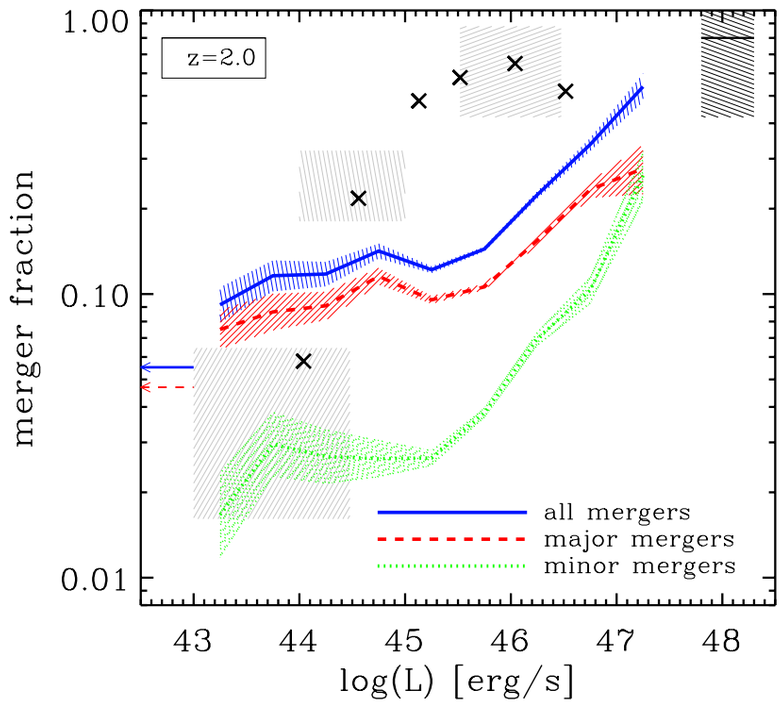
quiescent galaxies



Star forming galaxies do on average host more luminous AGN!

+

Star forming galaxies did more likely have a recent merger event!
(also for inactive galaxies!)

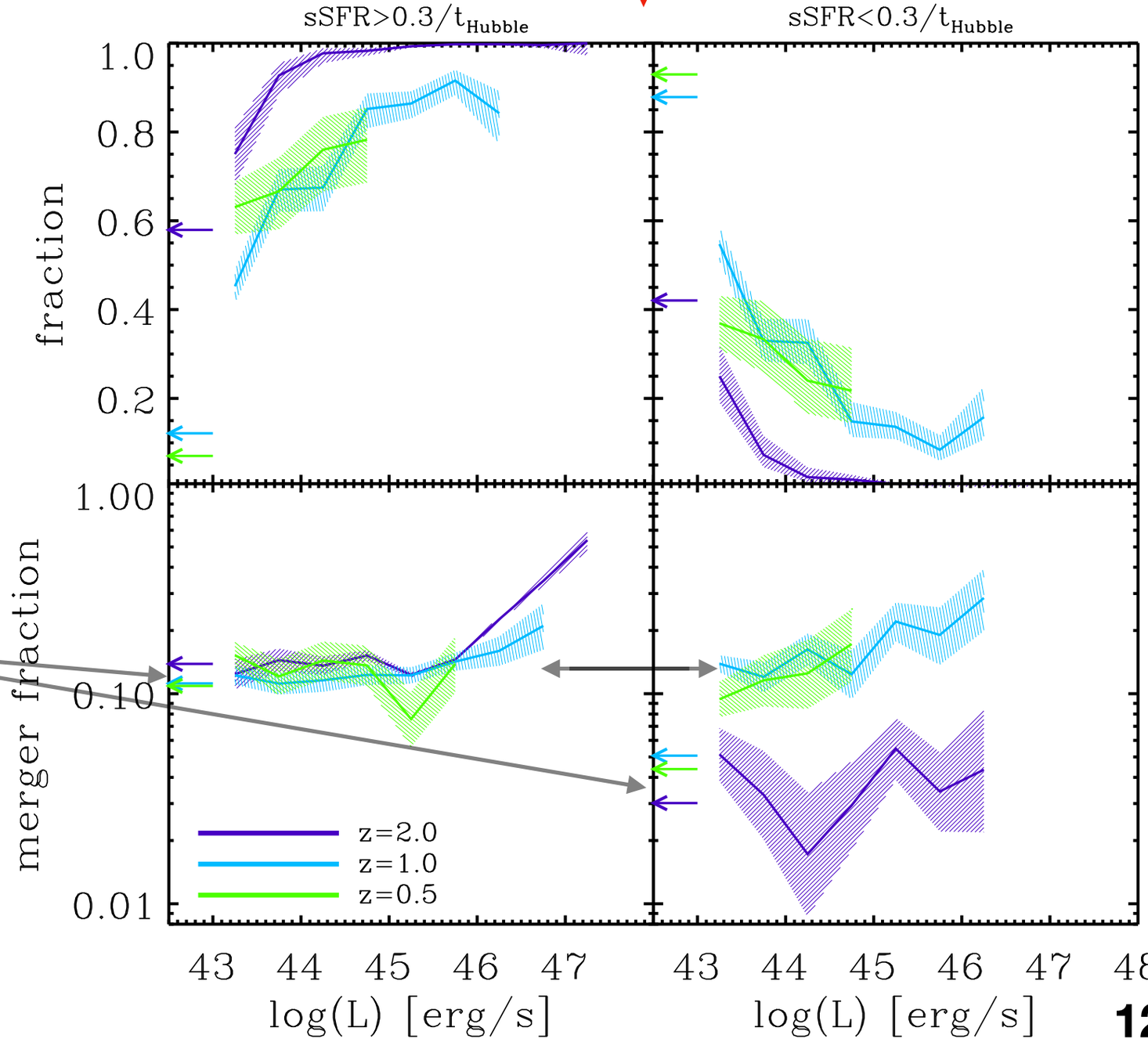


What is the origin of this relation?

This does not mean that luminous AGN are triggered by mergers!

There is a connection between AGN activity and star formation activity!

But this is not induced by mergers!



Take homes

- **There is a correlation between SF and AGN activity.**
- **AGN act on much shorter time scales than SF.**
- **Scaling relations link SF and AGN activity.**
- **Simulations are tuned to match these relations.**
- **With Magneticum we can learn which mechanisms drive AGN.**
- **Mergers play only a minor role for driving AGN.**
- **At z=2 there is a relation between AGN luminosity and the merger fraction, which is correlated to the SFR.**
- **The relation between AGN and SF is independent of the merger history.**

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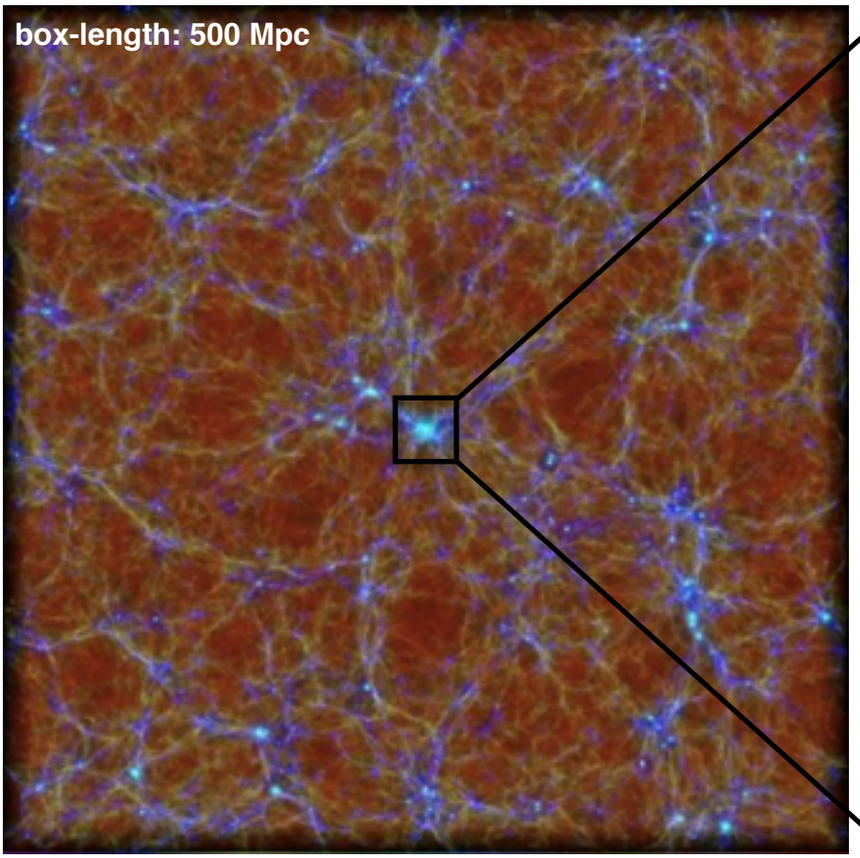
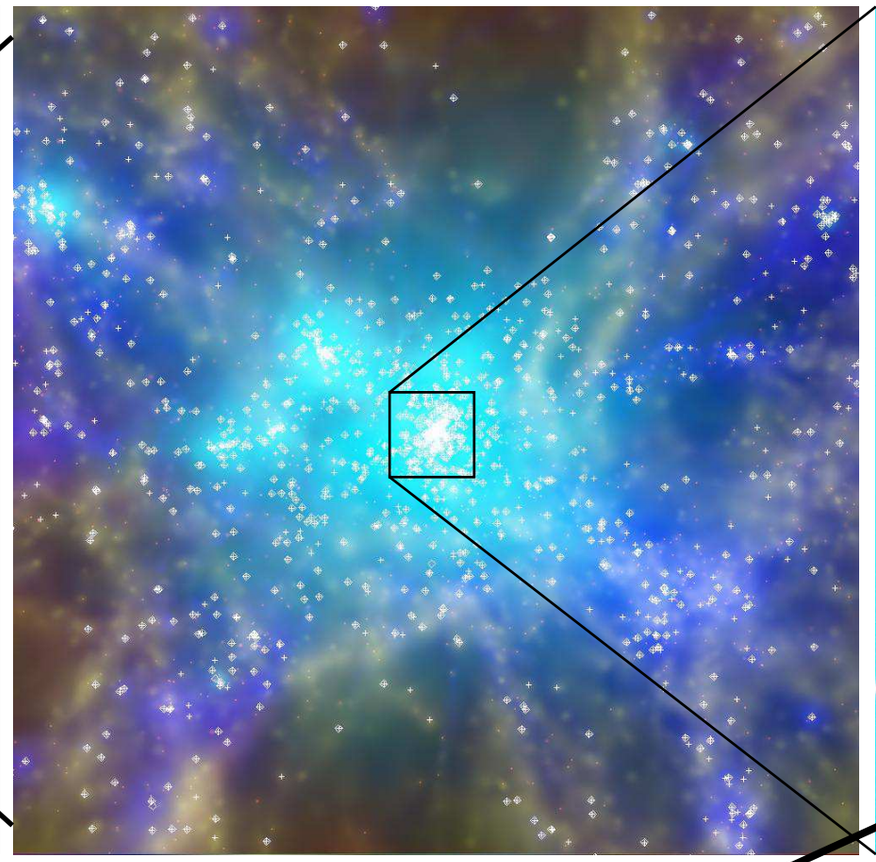
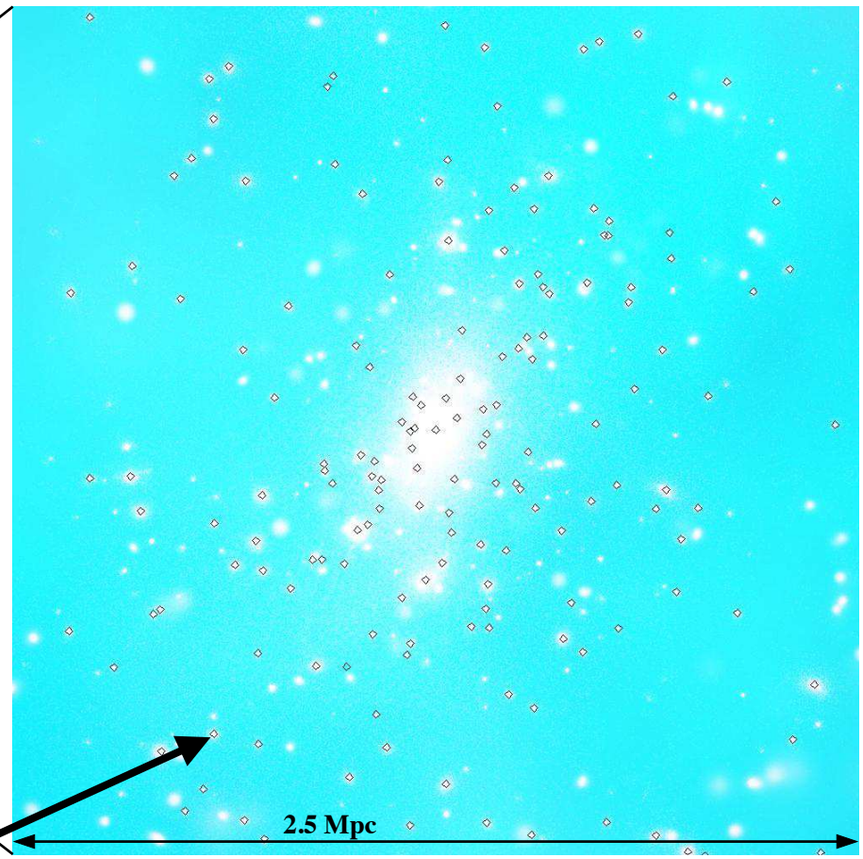
Appendix: BH model







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

Hirschmann+14

variable

BH

radiation

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

accretion

mech. outflow

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

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

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

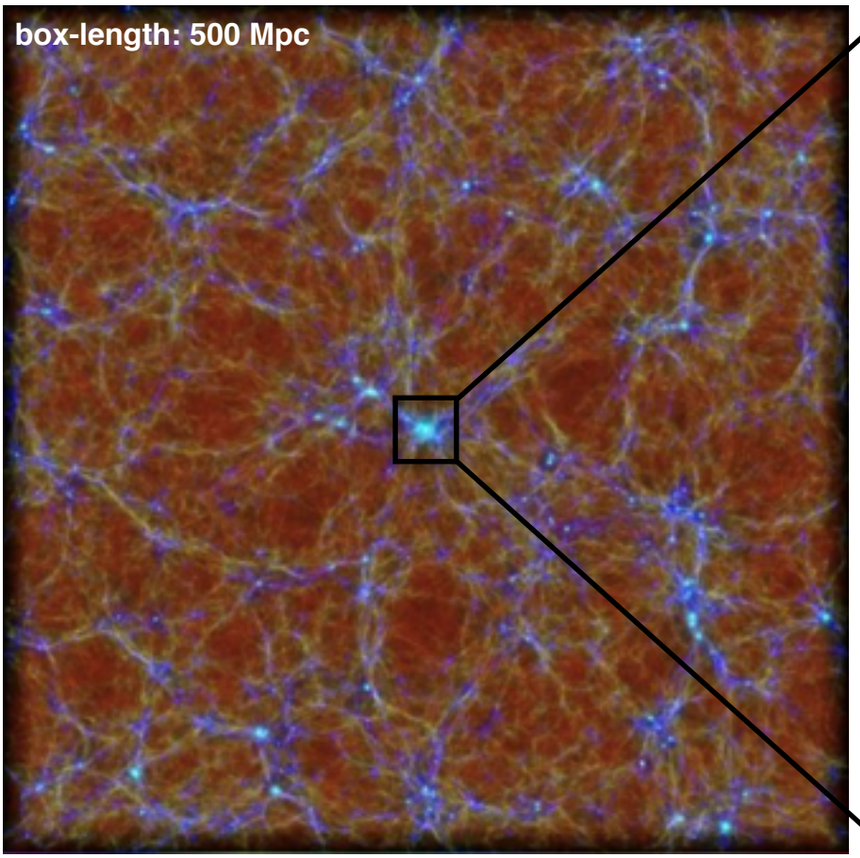
(thermal feedback)

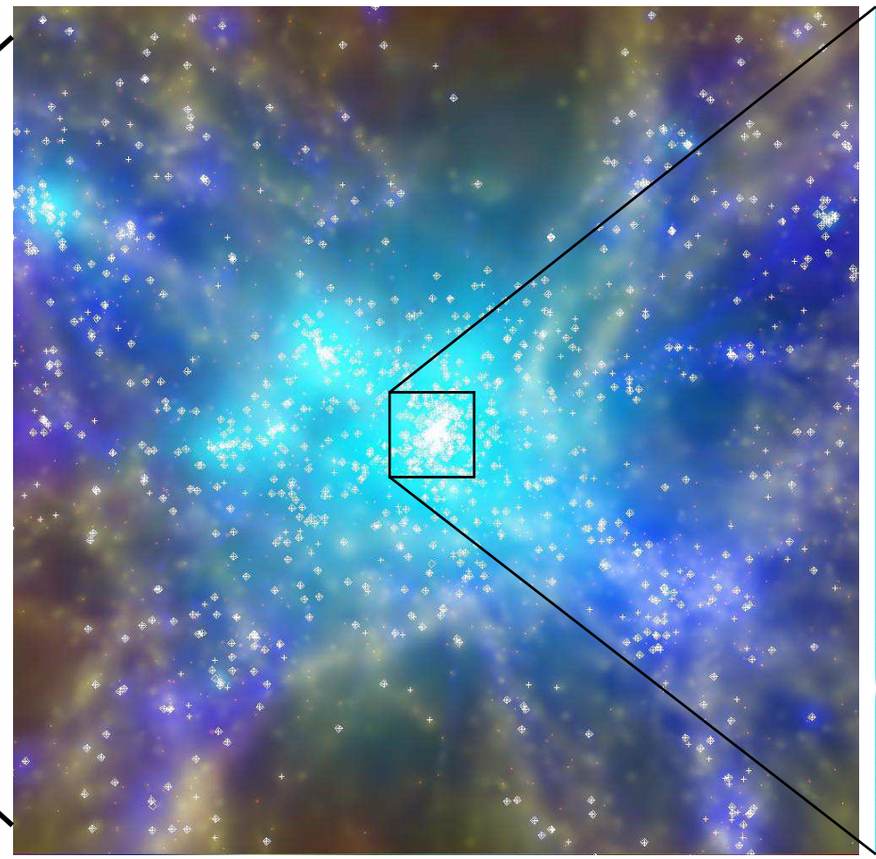
$$P_{\rm o} = \epsilon_{\rm o} \dot{M}_\bullet c^2$$

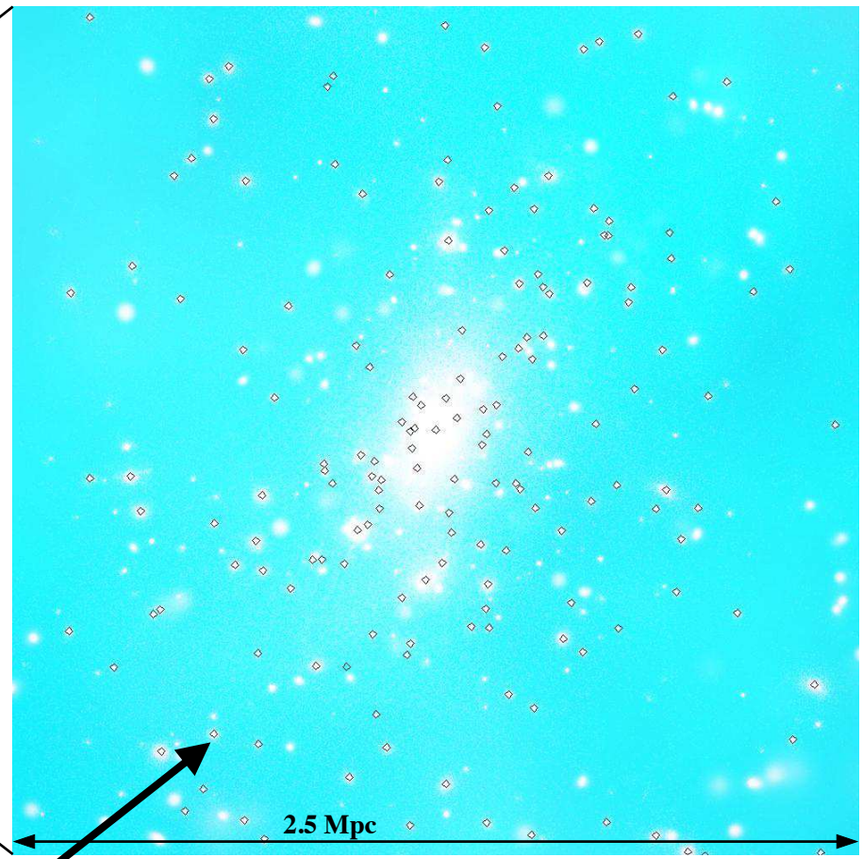
variable

Steinborn+15

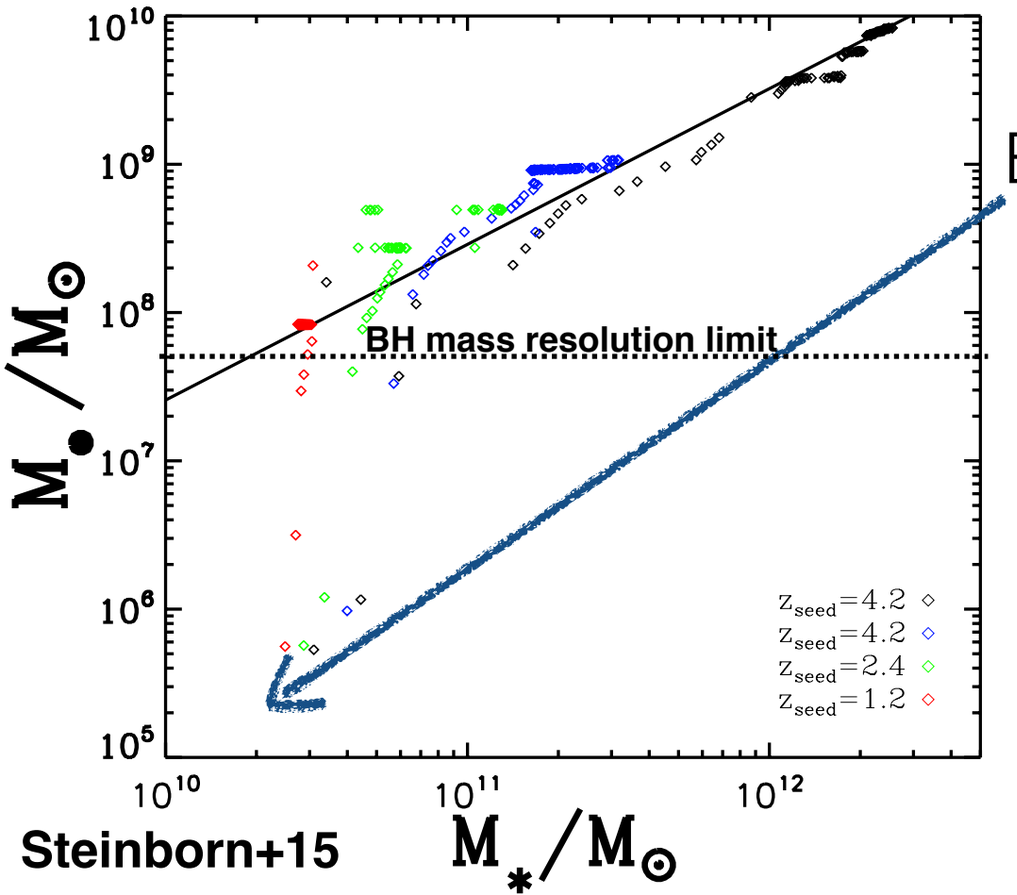
Appendix: BH model







Hirschmann+14



Steinborn+15

BH seeding → BHs

No pinning to the potential minimum!

BHs do not 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.

→ BH mergers

A theorists perspective ...

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

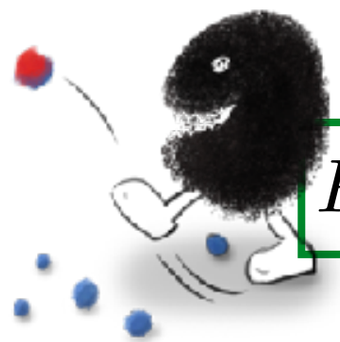
$$\dot{M}_\bullet = \min(\dot{M}_{\rm B}, \dot{M}_{\rm Edd})$$

BHs

accretion

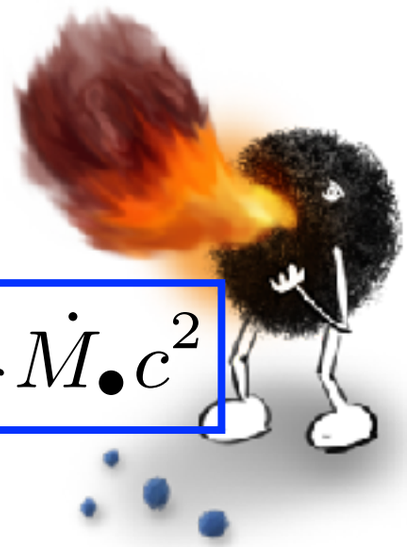
mech. feedback

radiative feedback



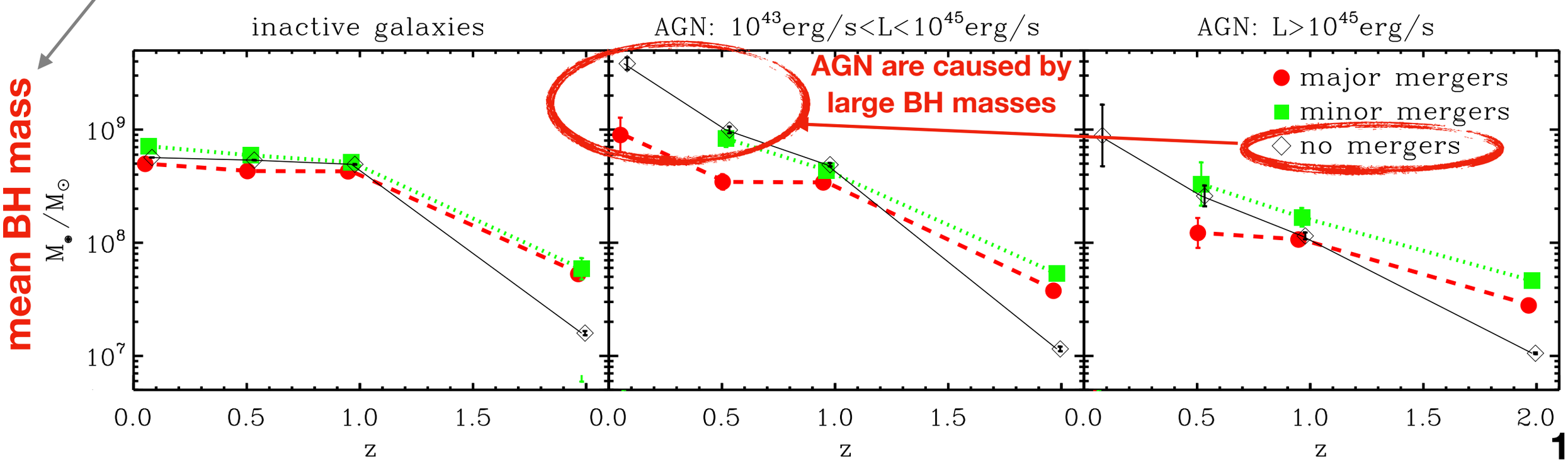
$$P_{\rm o} = \epsilon_{\rm o}\dot{M}_\bullet c^2$$

AGN



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

What else triggers AGN?



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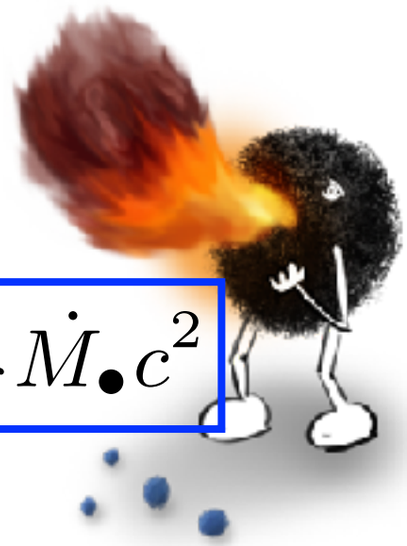

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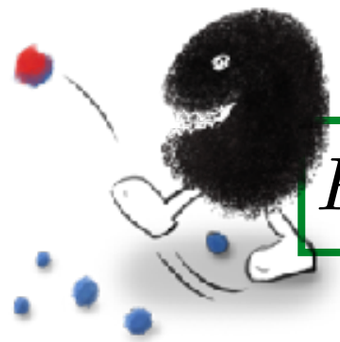

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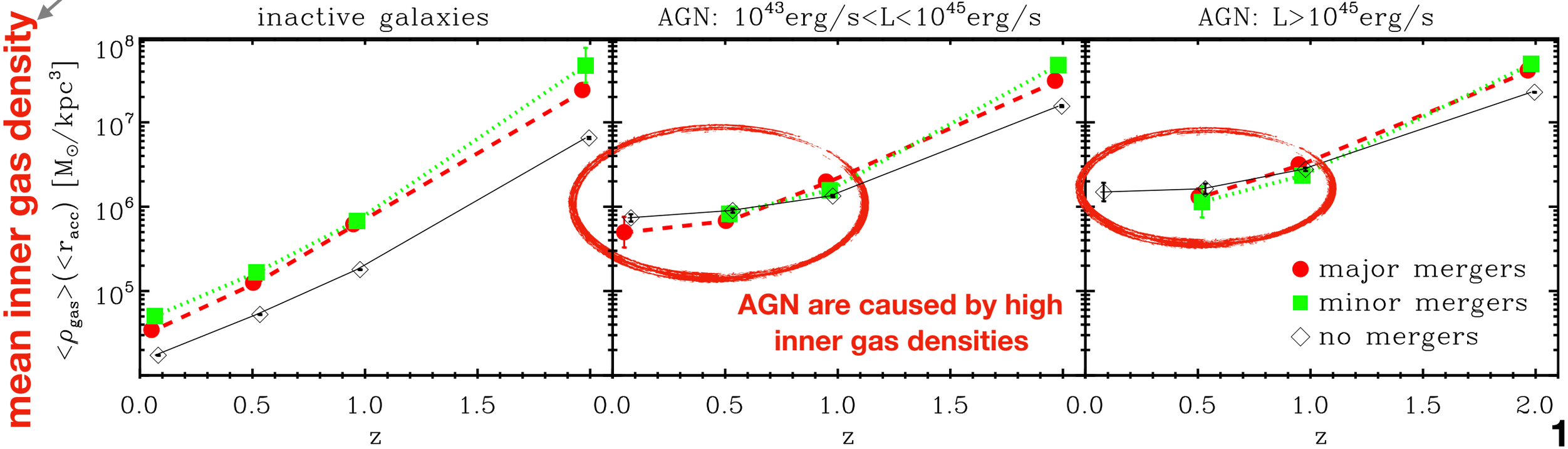

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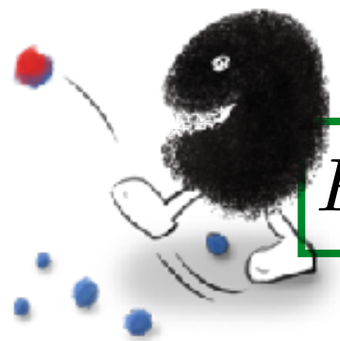

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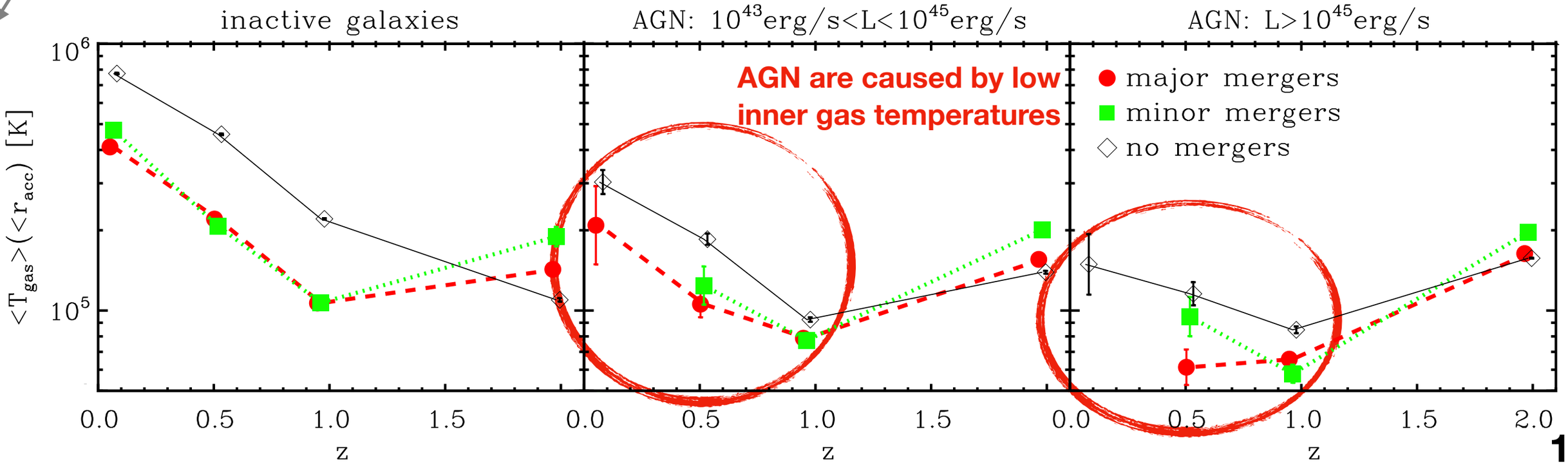
What else triggers AGN?

mean inner gas temperature



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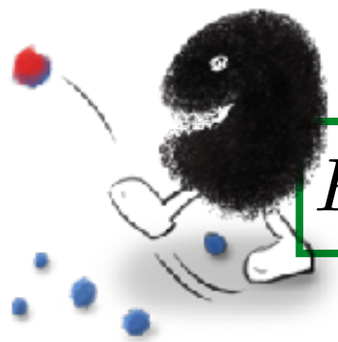

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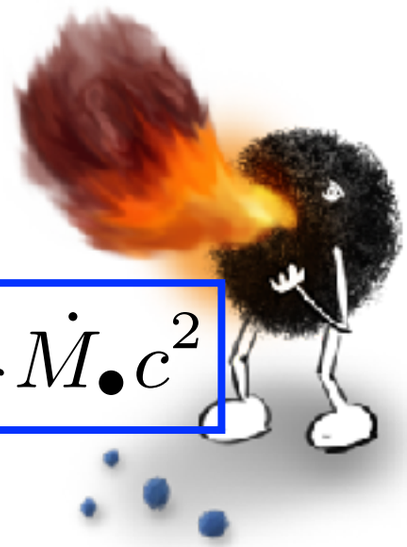

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