Feedback from Active Galactic Nuclei in Galaxy and Galaxy Cluster Evolution
-
The Simulation Perspective

Rainer Weinberger
ITC fellow
Center for Astrophysics | Harvard & Smithsonian

In collaboration with:
Kristian Ehlert, Christoph Pfrommer, Rüdiger Pakmor, Volker Springel
& on behalf of the IllustrisTNG team

06/21/2019 | Supermassive Black Holes - Environment & Evolution | Corfu, Greece

redshift: 4.43

Behroozi+ (2013), including ICL

stellar mass fraction [%]

0
5
10
15
20

10^{11}
10^{12}
10^{13}
10^{14}

$M_{200,\mathrm{c}}$ [$\mathrm{M}_\odot$]

RW et al (2017)

z=4
z=2
z=1
z=0
-7
-8
-9
-10
-11
-12
-13
-14
9.5
10.5
11.5
$\log_{10}$(specific star formation rate [yr^{-1}])
$\log_{10}$(stellar mass [$\mathrm{M}_\odot$])
RW et al (2018)

Behroozi+ (2013), including ICL

stellar mass fraction [%]

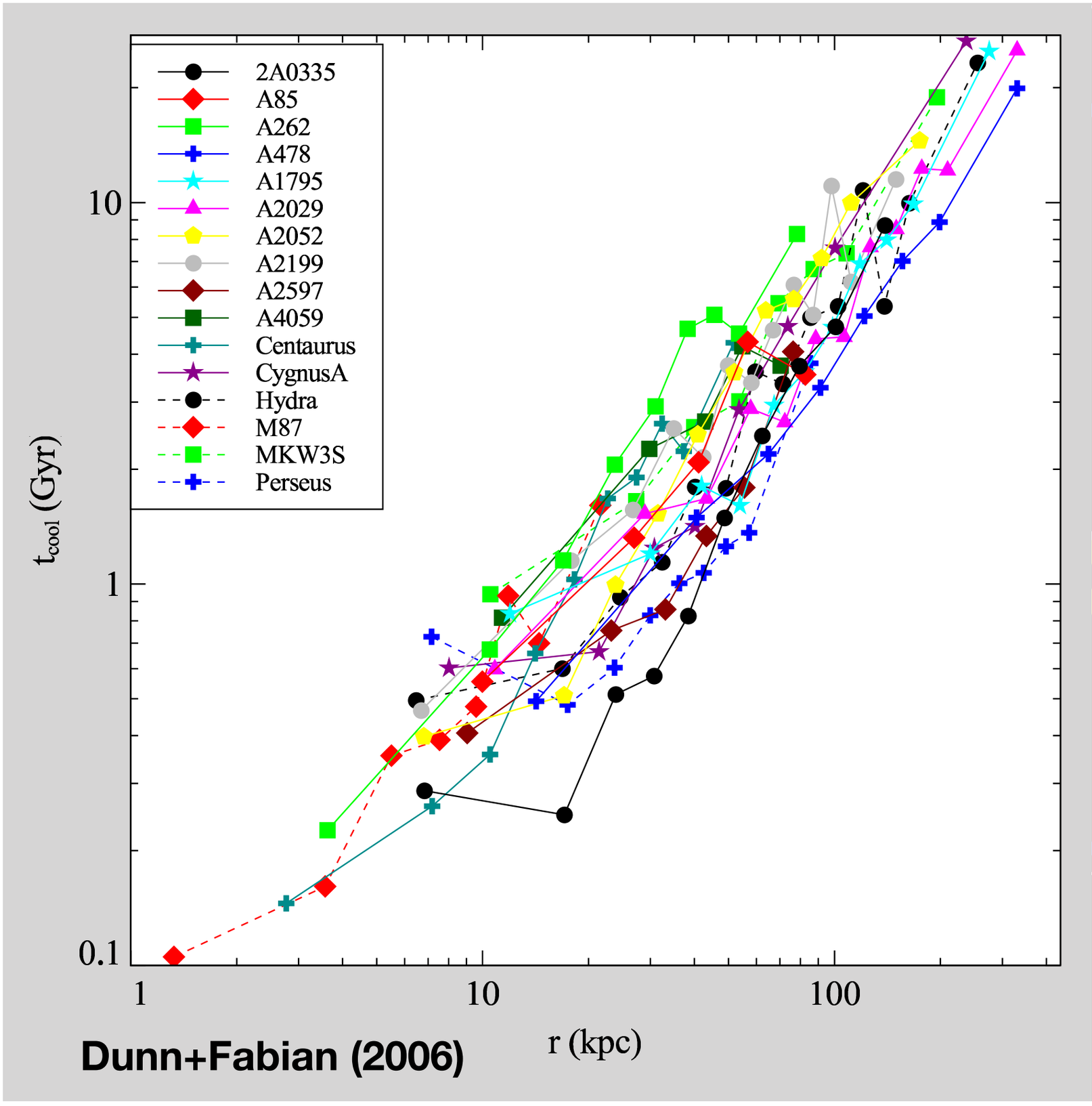
0
5
10
15
20

10^{11}
10^{12}
10^{13}
10^{14}

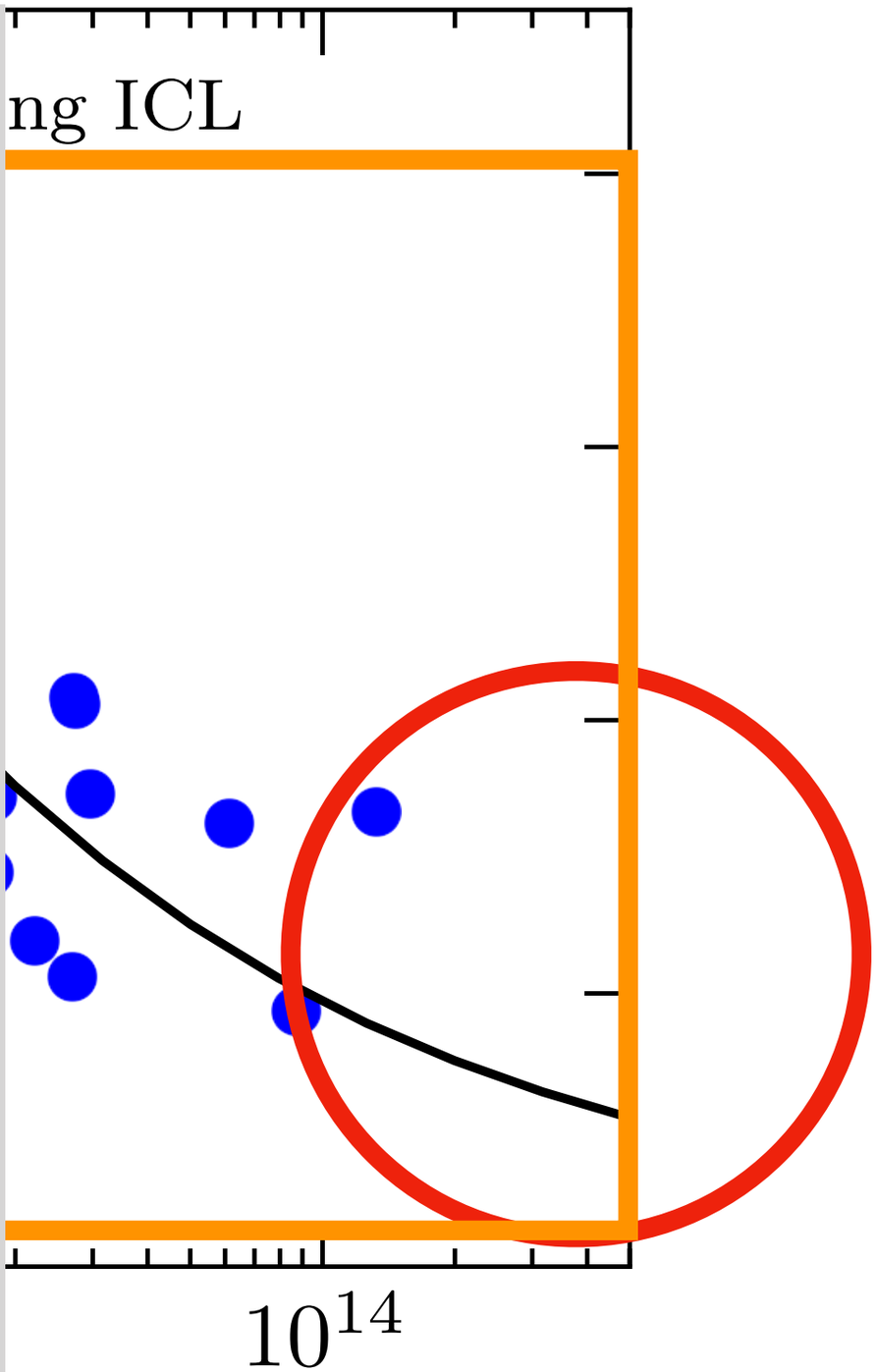
$M_{200,\mathrm{c}}$ [$\mathrm{M}_\odot$]

RW et al (2017)

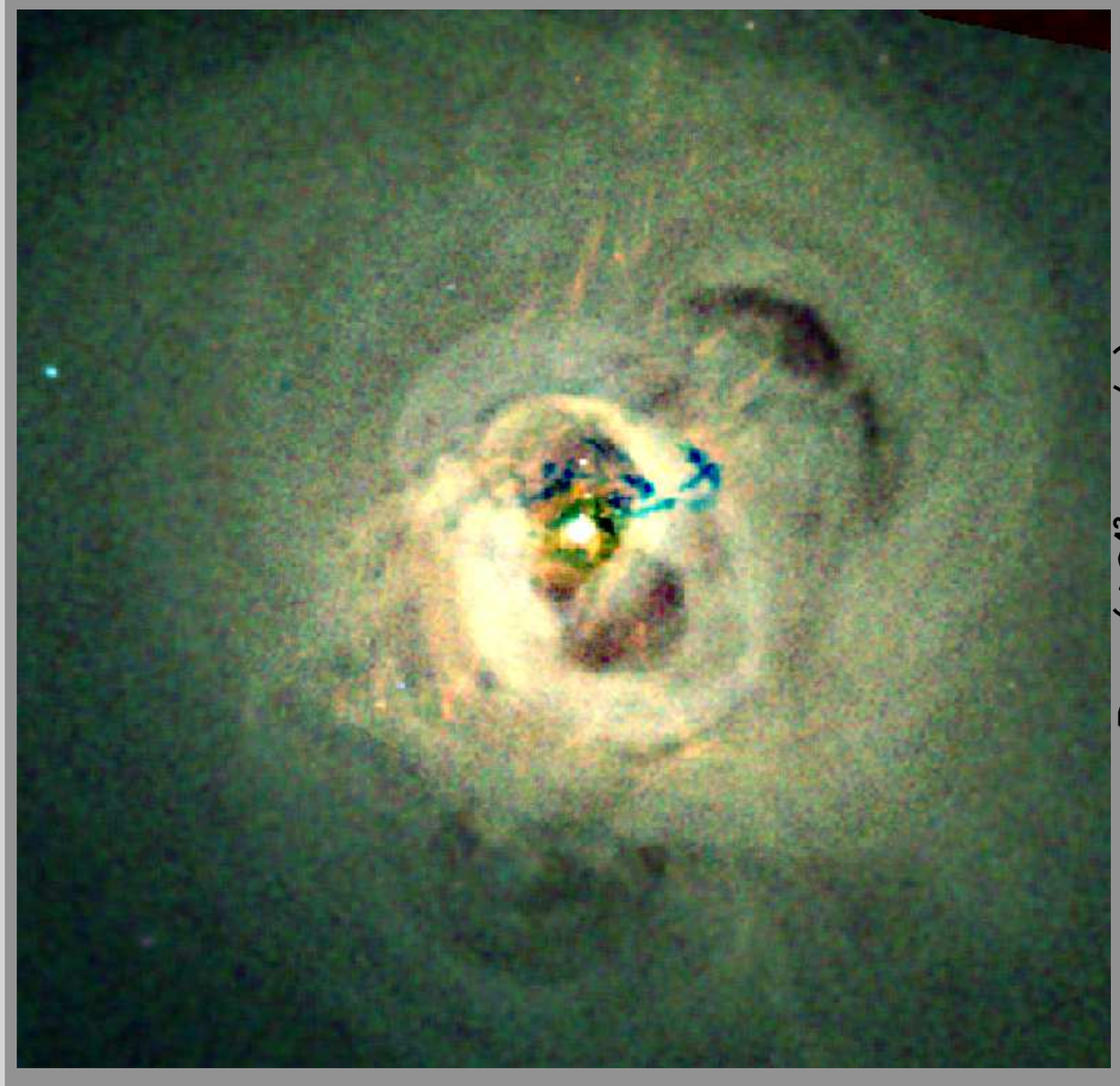
Clusters - The Cooling Flow Problem



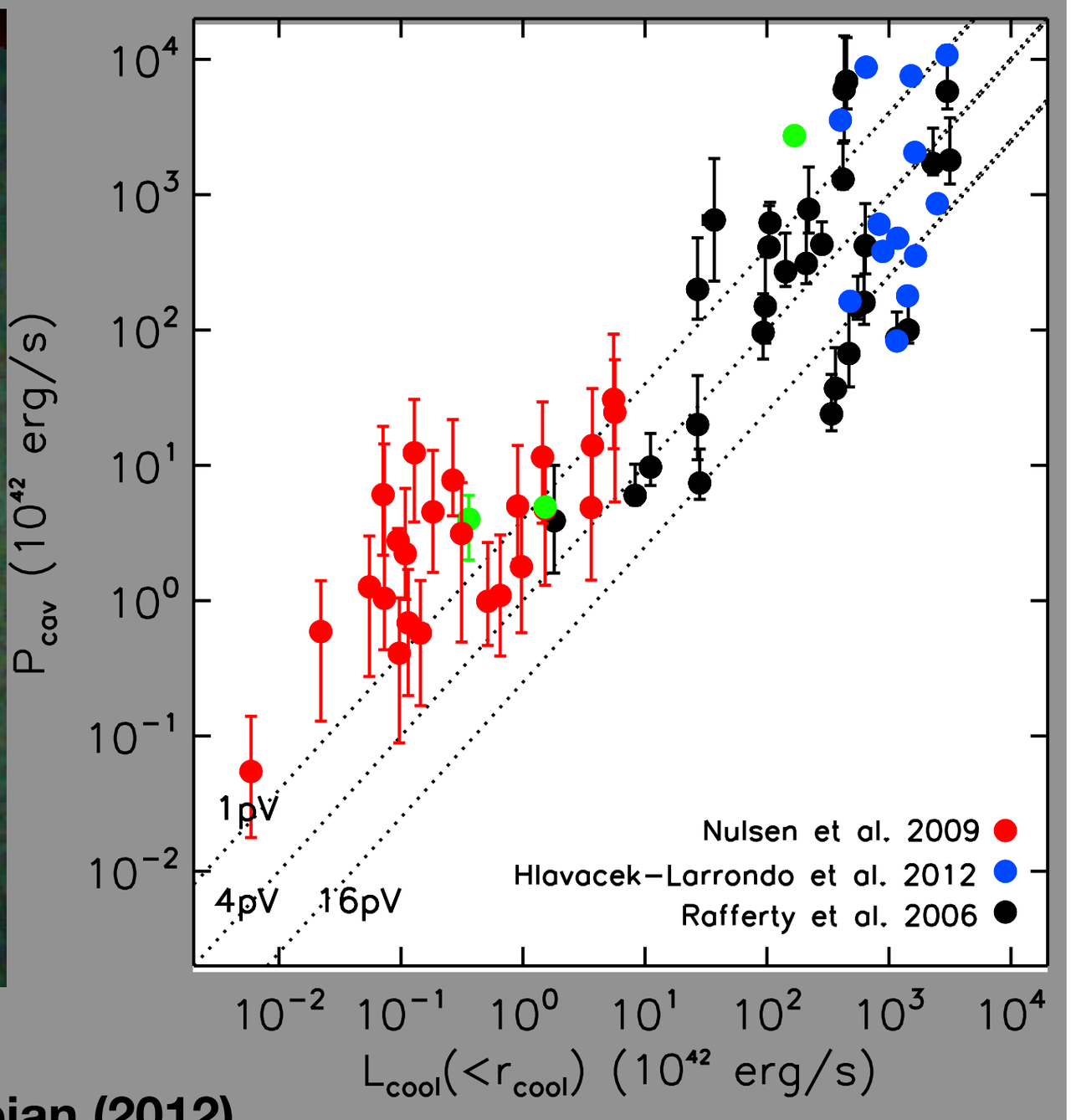
Dunn+Fabian (2006)



Clusters - The Cooling Flow Problem



Dunn+Fabian (2006)



Fabian (2012)

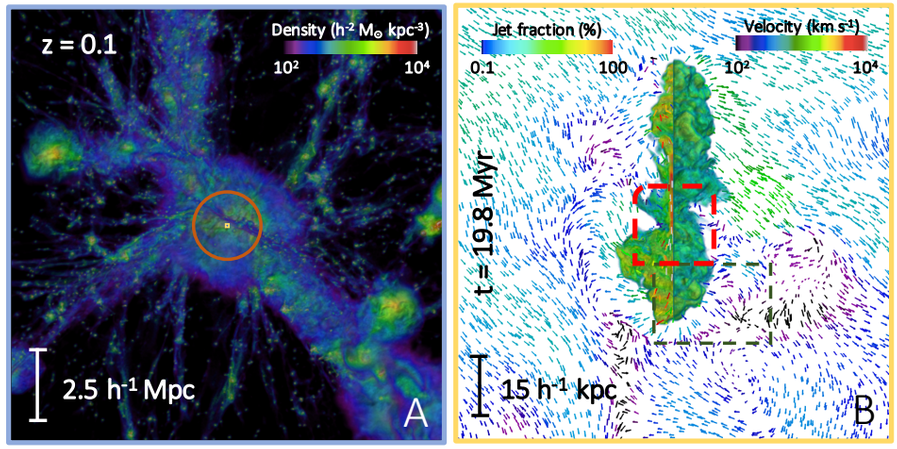
r (kpc)

Energy coupling efficiency

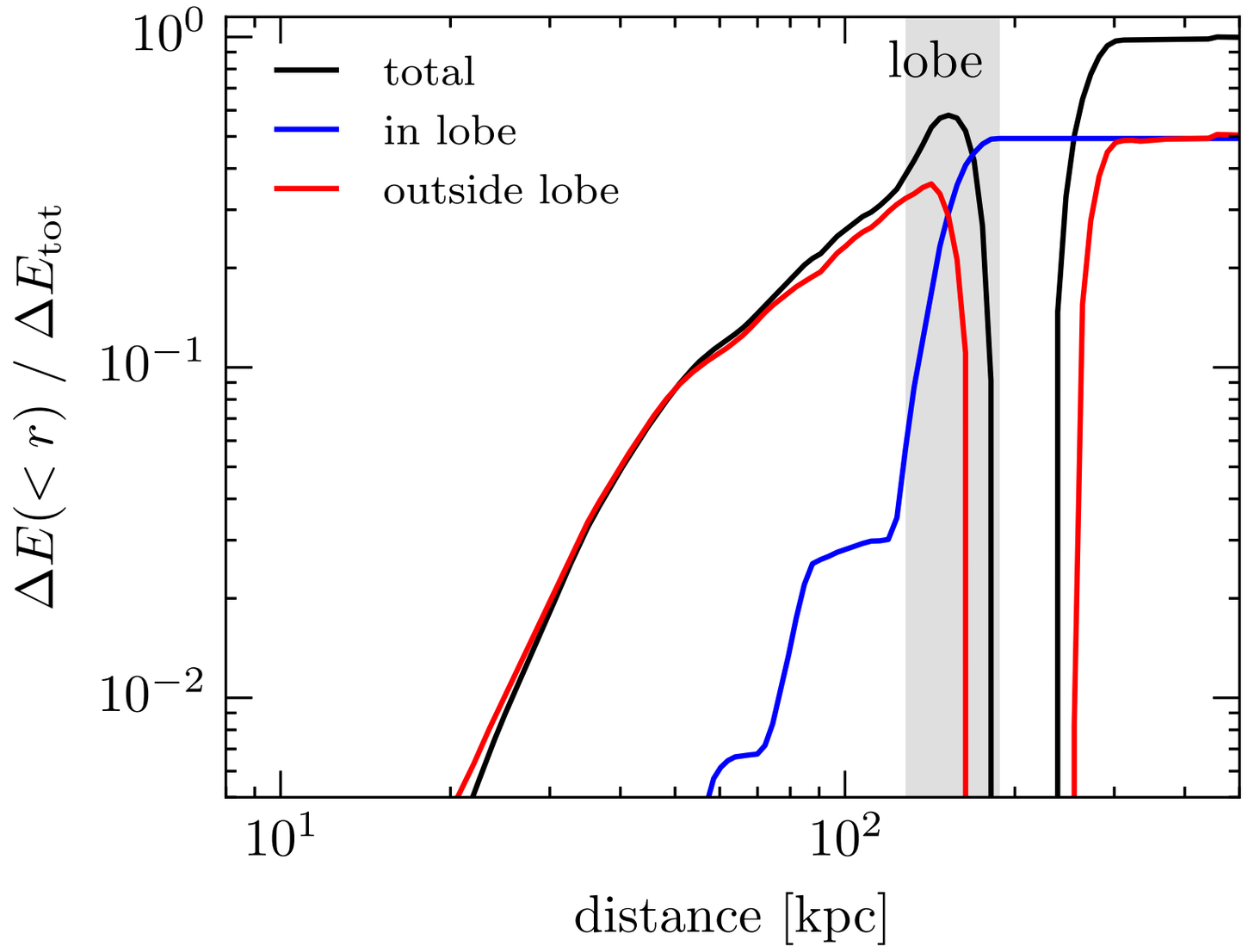
NASA/CXC/SAO//STScI/NSF/NRAO/AUI/VLA

RW et al. (2017b)

Energy coupling efficiency

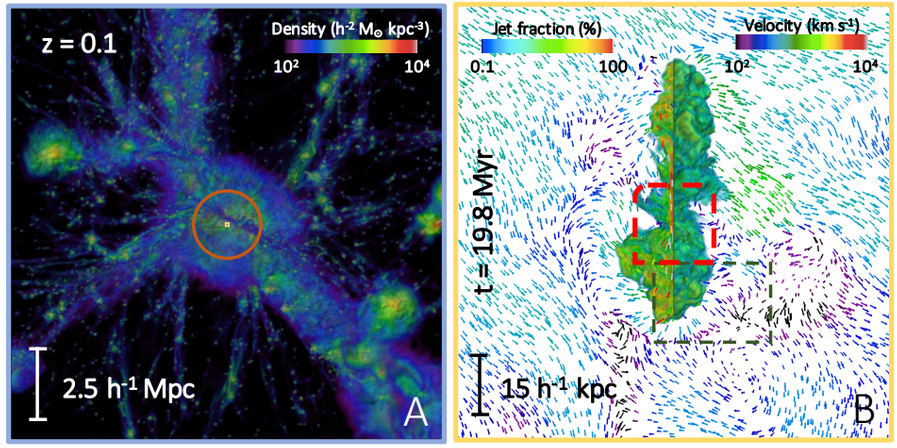


Bourne et al. (2019)

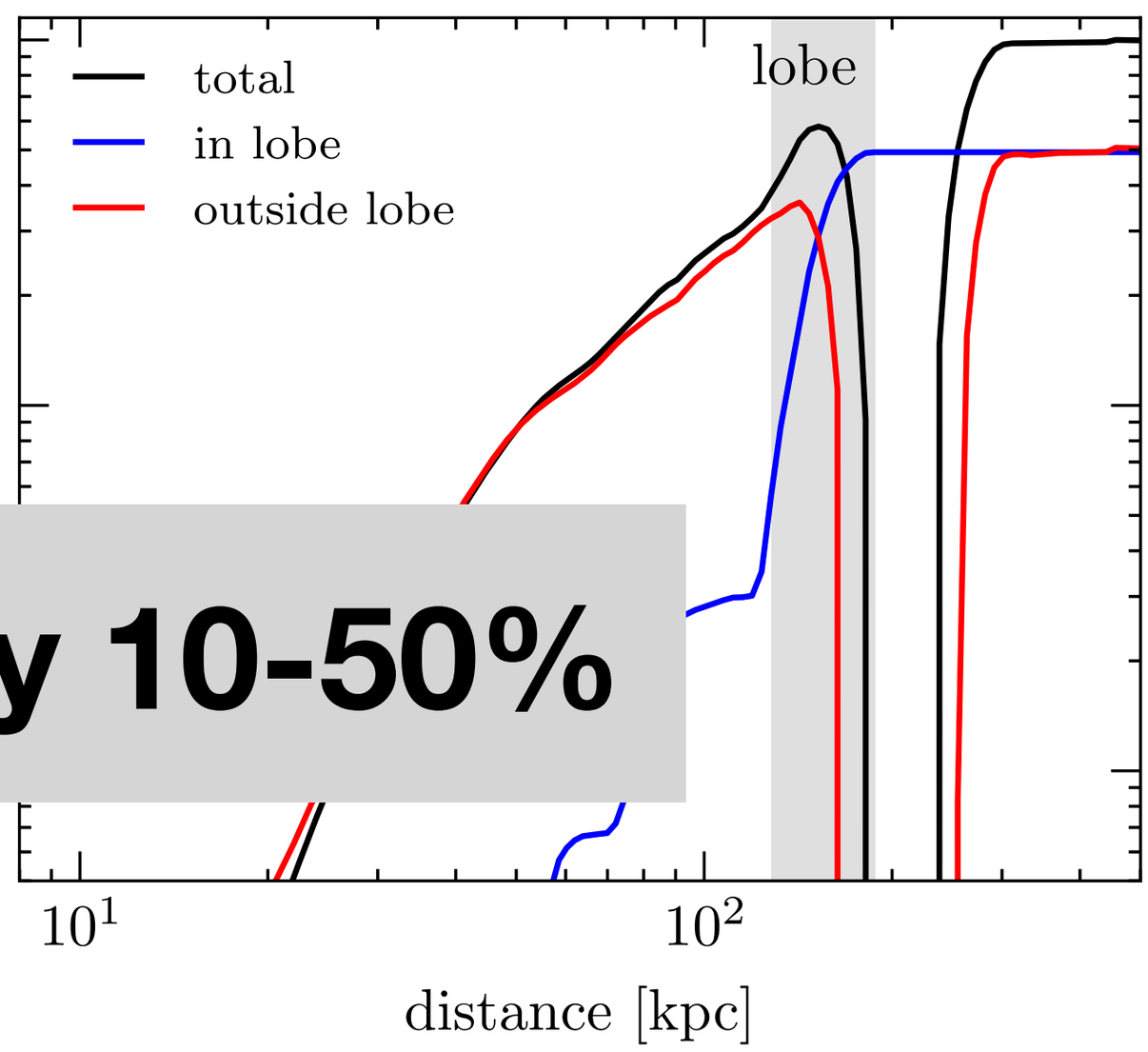


RW et al. (2017b)

Energy coupling efficiency



Bourne et al. (2019)



RW et al. (2017b)

Efficiency 10-50%

Lower mass systems

$$f_{\rm gas}\frac{G\,M^2}{R}\sim 6\times10^{63}{\rm erg}\frac{M^2}{R}\frac{2\,{\rm Mpc}}{(10^{15}\,{\rm M}_\odot)^2}\quad\propto M^{5/3}$$

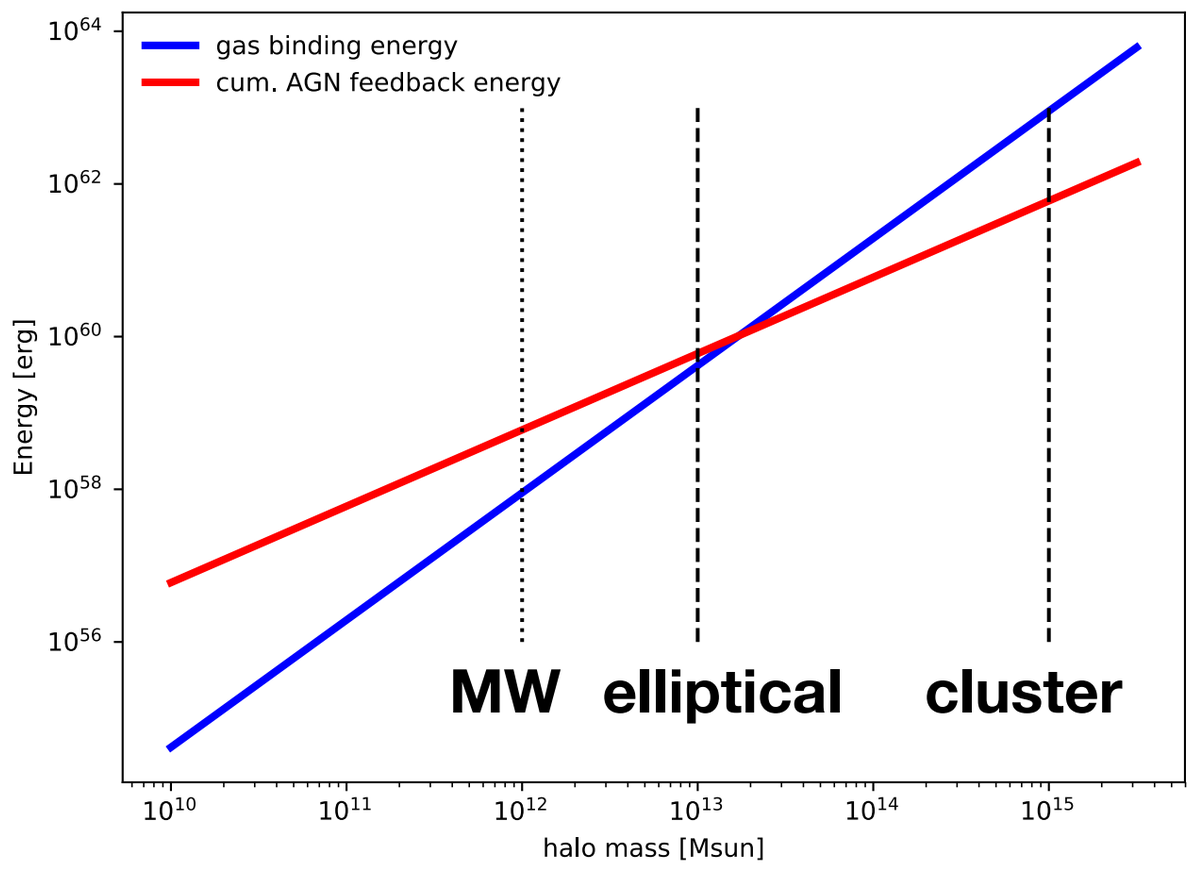
$$\eta E=0.1\,mc^2\sim m\frac{2\times10^{62}{\rm erg}}{10^9{\rm M}_\odot}$$

Lower mass systems

$$f_{\rm gas}\frac{G\,M^2}{R} \sim 6\times10^{63}{\rm erg}\,\frac{M^2}{R}\frac{2\,{\rm Mpc}}{(10^{15}\,{\rm M}_\odot)^2} \quad \propto M^{5/3}$$

$$\eta E = 0.1\,mc^2 \sim m\,\frac{2\times10^{62}{\rm erg}}{10^9{\rm M}_\odot}$$

assume $M \propto m, \quad f_{\rm gas} = 0.15 = {\rm const}, \quad \eta = 0.1 = {\rm const}$

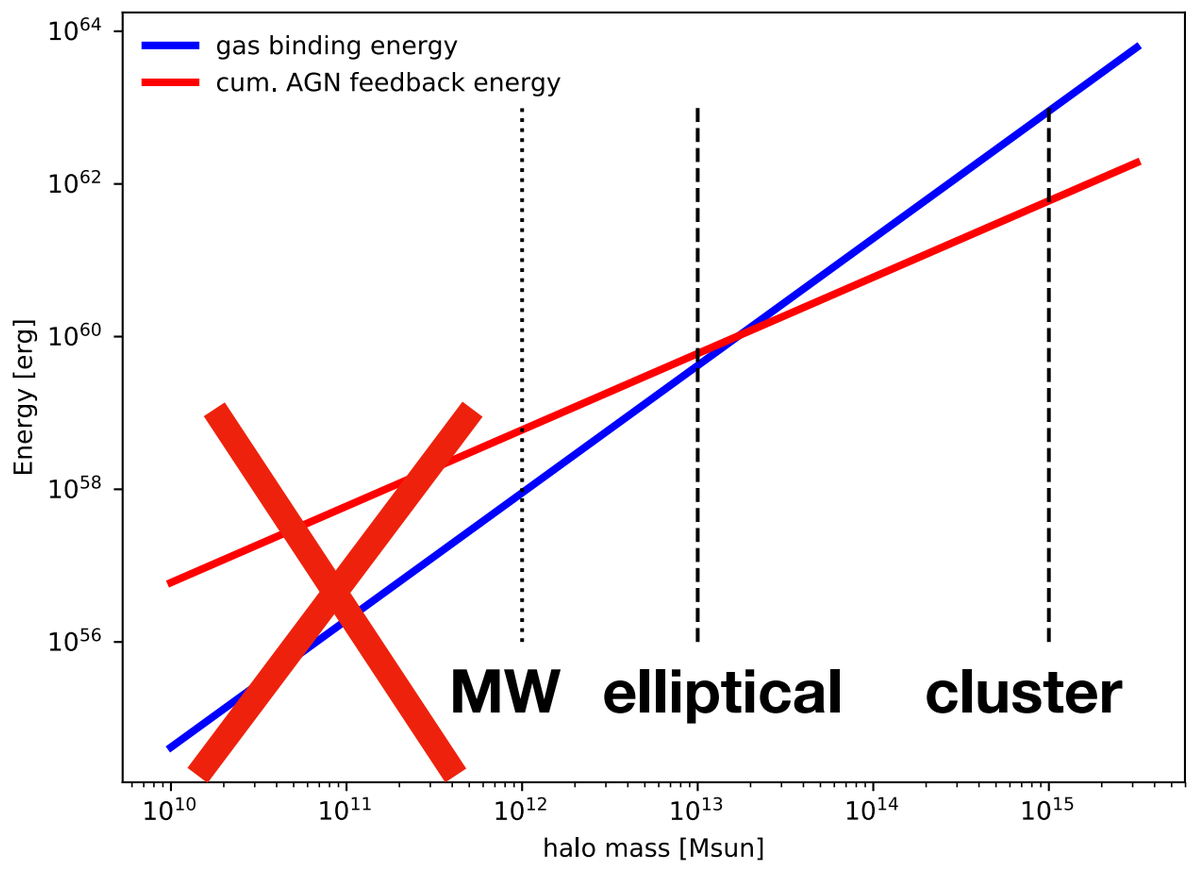


Lower mass systems

$$f_{\rm gas}\frac{G\,M^2}{R} \sim 6\times10^{63}{\rm erg}\,\frac{M^2}{R}\frac{2\,{\rm Mpc}}{(10^{15}\,{\rm M}_\odot)^2} \quad \propto M^{5/3}$$

$$\eta E = 0.1\,mc^2 \sim m\,\frac{2\times10^{62}{\rm erg}}{10^9{\rm M}_\odot}$$

assume $M \propto m, \quad f_{\rm gas} = 0.15 = {\rm const}, \quad \eta = 0.1 = {\rm const}$

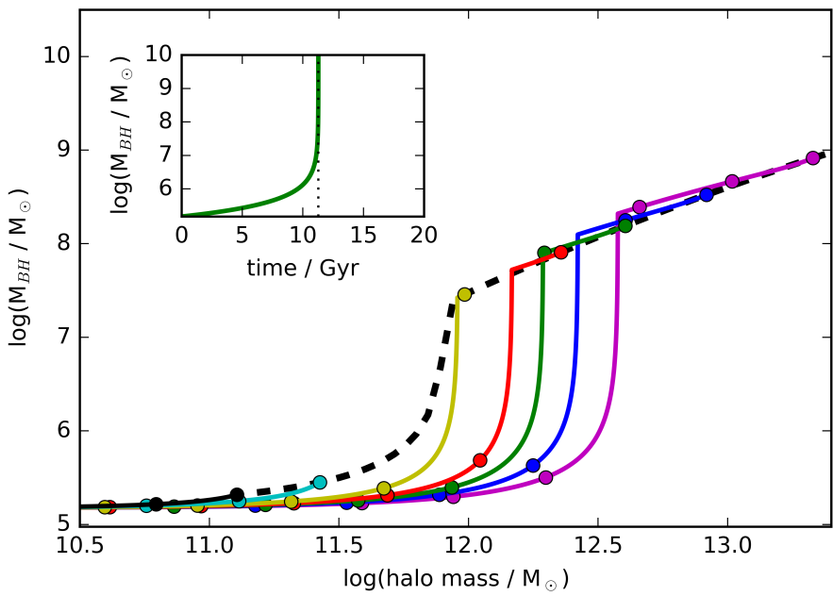


Lower mass systems

$$f_{\rm gas}\frac{G\,M^2}{R} \sim 6\times10^{63}{\rm erg}\,\frac{M^2}{R}\,\frac{2\,{\rm Mpc}}{(10^{15}\,{\rm M}_\odot)^2} \quad \propto M^{5/3}$$

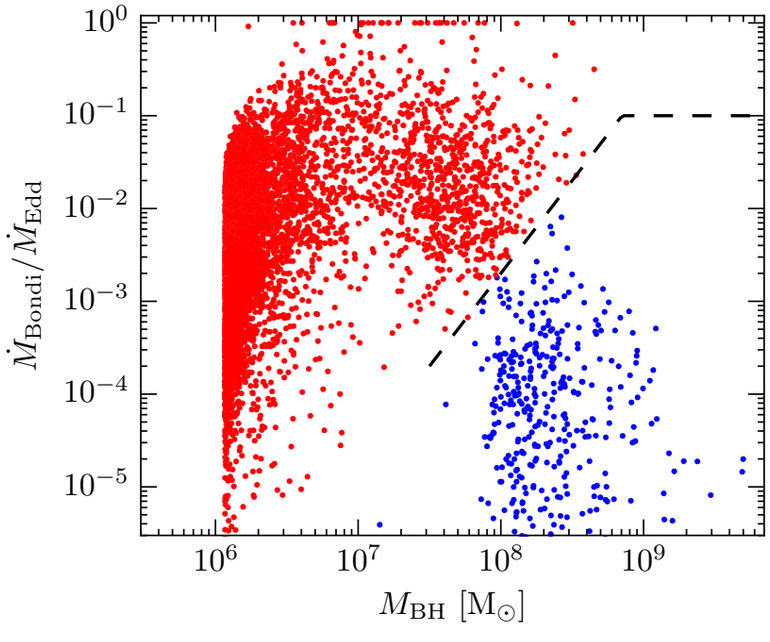
$$\eta E = 0.1\,mc^2 \sim m\,\frac{2\times10^{62}{\rm erg}}{10^9{\rm M}_\odot}$$

assume $M \propto m,$ $f_{\rm gas} = 0.15 = {\rm const},$ $\eta = 0.1 = {\rm const}$



Bower et al. 2017 - EAGLE

see also: talk by D. Angles-Alcazar yesterday



Weinberger et al. 2017 - TNG

The IllustrisTNG project

http://www.tng-project.org

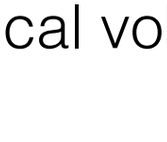
- Cosmological volume simulation
- Include the physics effects that we believe to be important for galaxy formation
- Star formation + feedback
- SMBH growth
- AGN feedback

	TNG50	TNG100	TNG300
L	52 Mpc	106 Mpc	303 Mpc
N	2160^3	1820^3	2500^3
dm-softening	0.3 kpc	0.7 kpc	1.5 kpc
target mass	8×10^4	1.3×10^6	10^7 Msun

Volker Springel
Heidelberg Institute for Theoretical Studies ➜ MPA
PI: Overall TNG Project

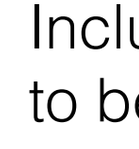
Lars Hernquist
Harvard University

Annalisa Pillepich
Max Planck Institute for Astronomy, Heidelberg
Co-PI: TNG50 Project



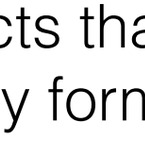
Rüdiger Pakmor
Heidelberg Institute for Theoretical Studies ➜ MPA

Dylan Nelson
Max Planck Institute for Astrophysics, Garching
Co-PI: TNG50 Project



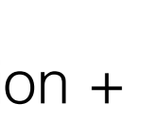
Rainer Weinberger
Heidelberg Institute for Theoretical Studies ➜ CFA

Federico Marinacci
Massachusetts Institute of Technology ➜ Bologna



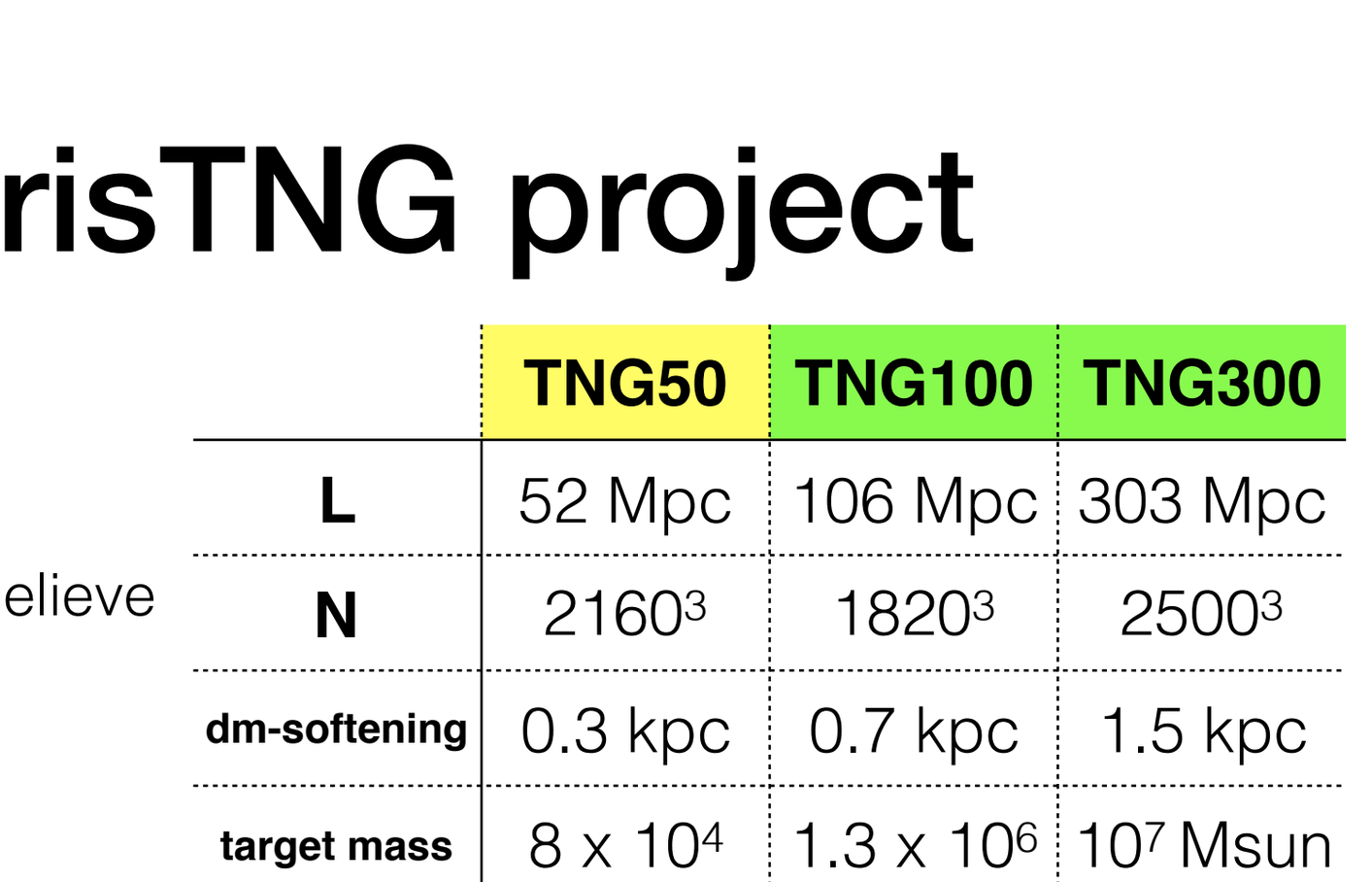
Jill Naiman
Harvard University ➜ NCSA/UIUC

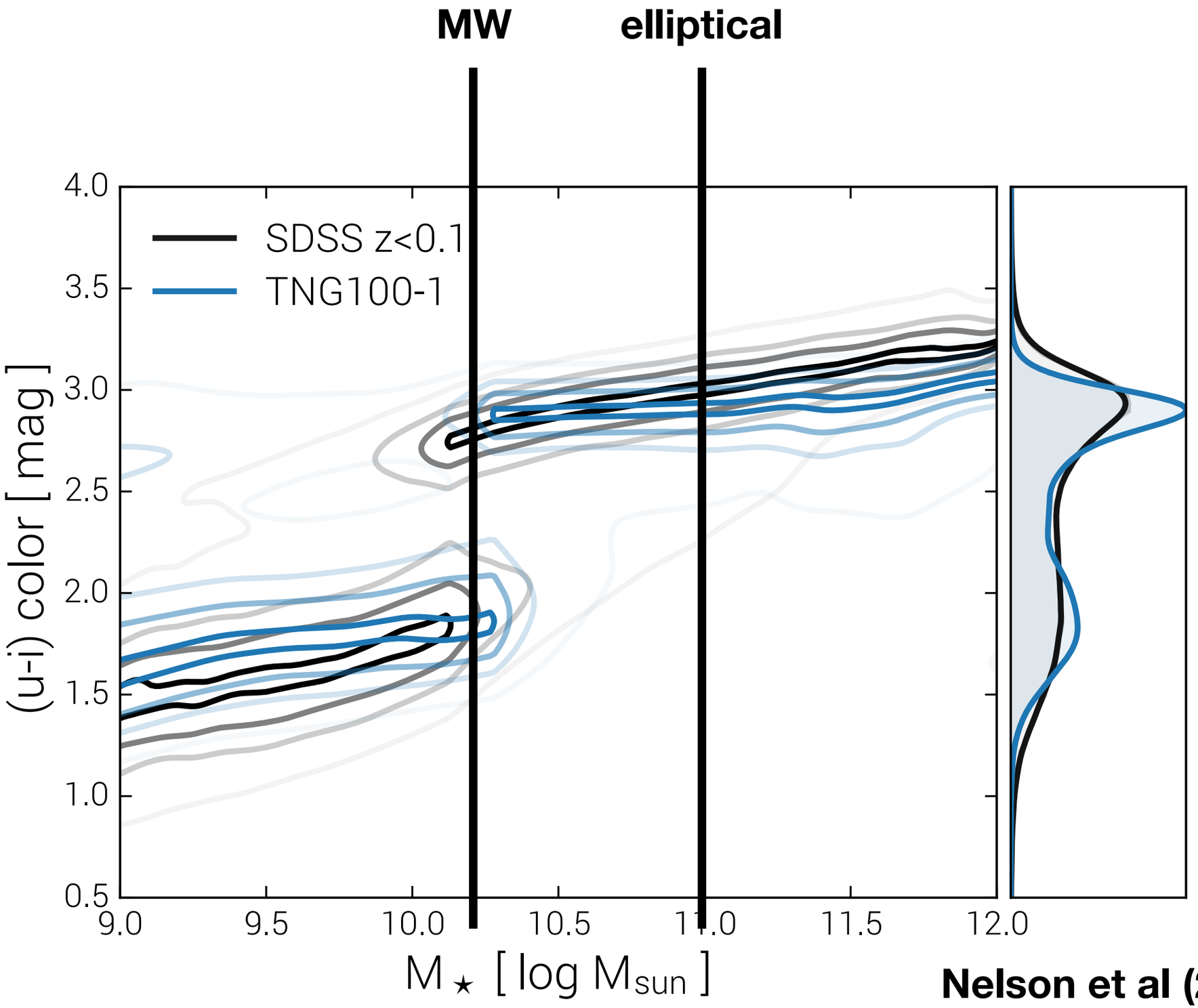
Mark Vogelsberger
Massachusetts Institute of Technology



Shy Genel
Center for Computational Astrophysics, Flatiron Institute

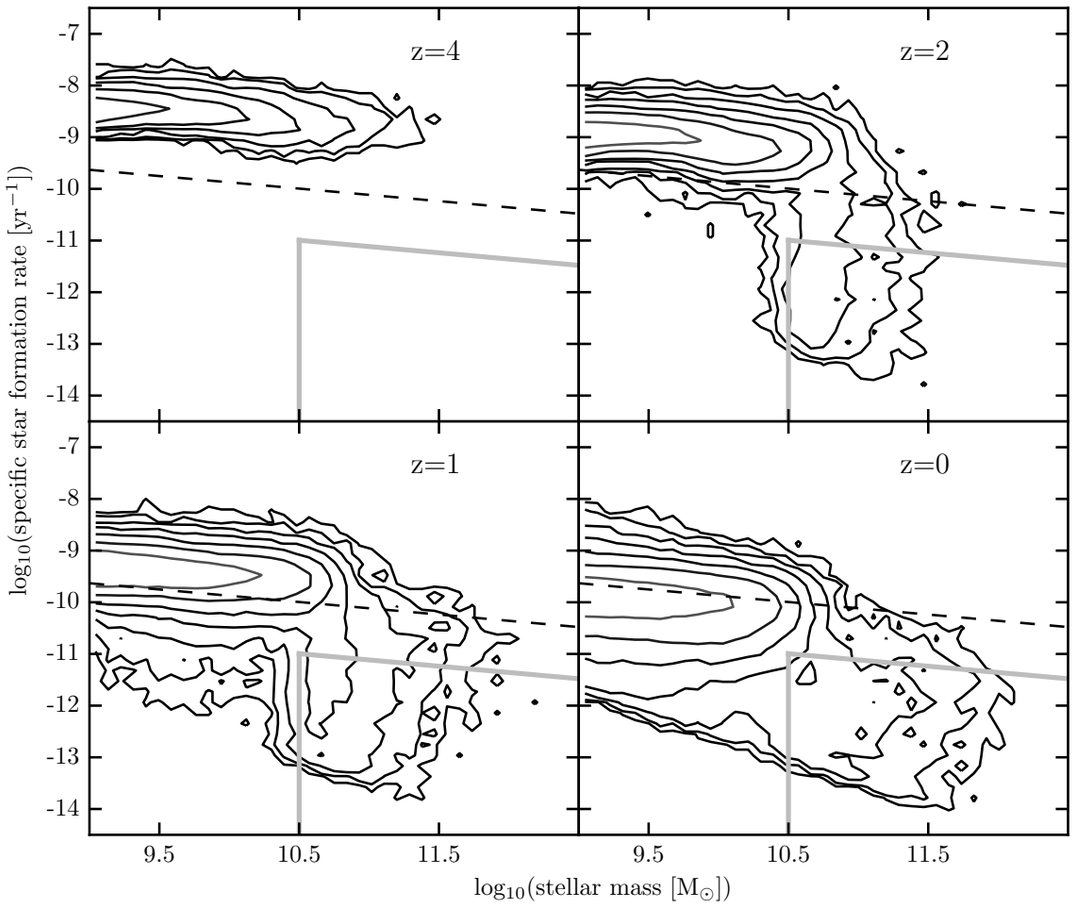
Paul Torrey
Massachusetts Institute of Technology ➜ Florida

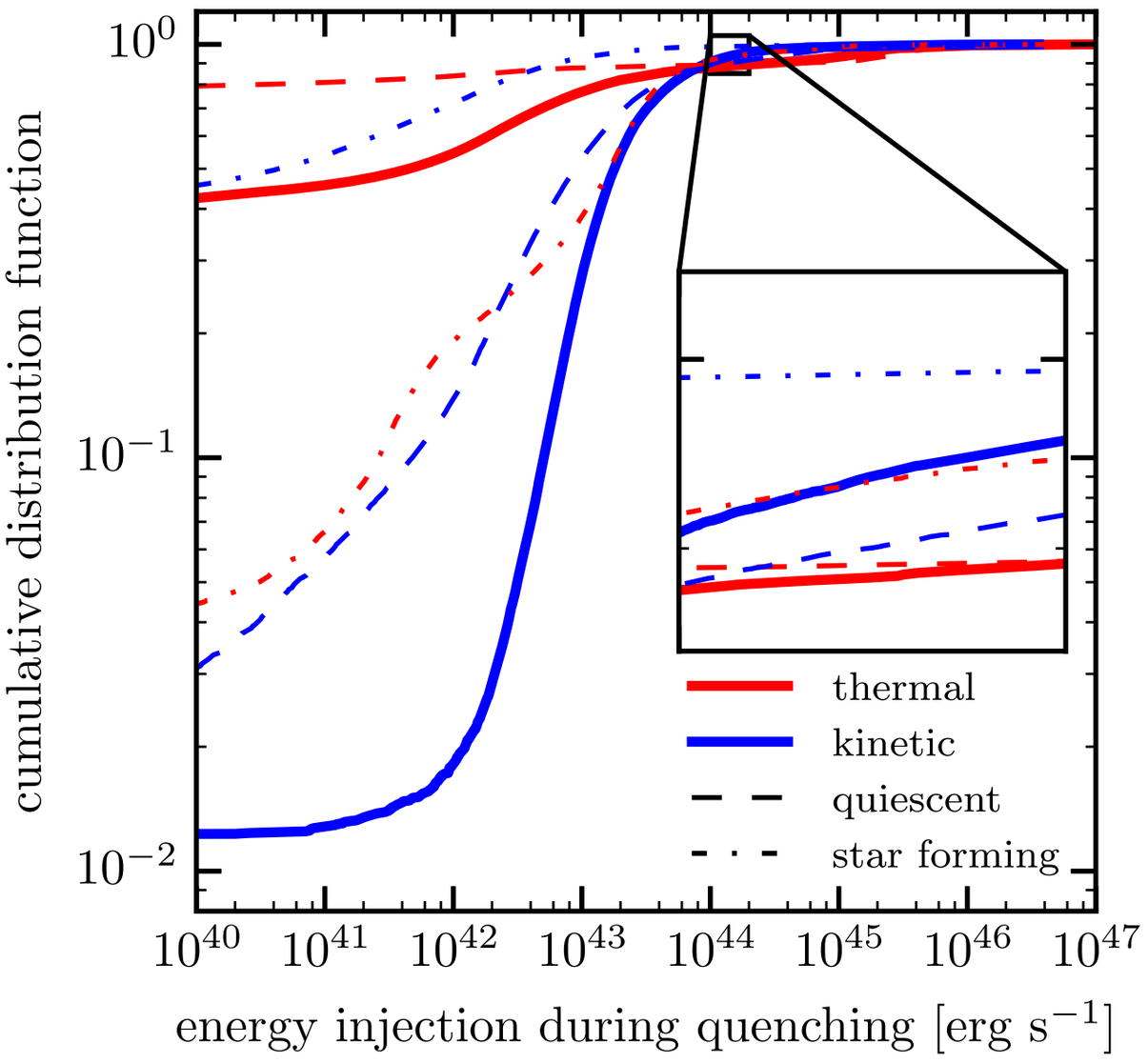




Nelson et al (2018)

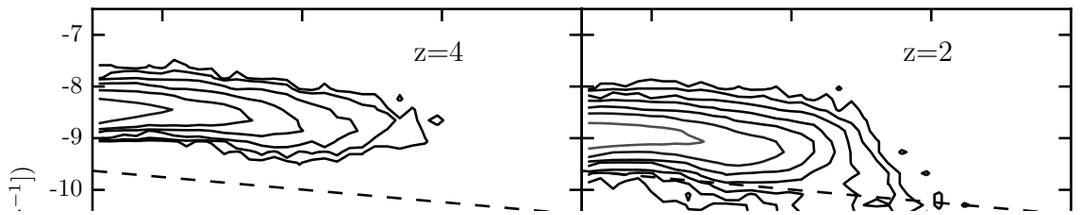
What quenches galaxies in the simulation?

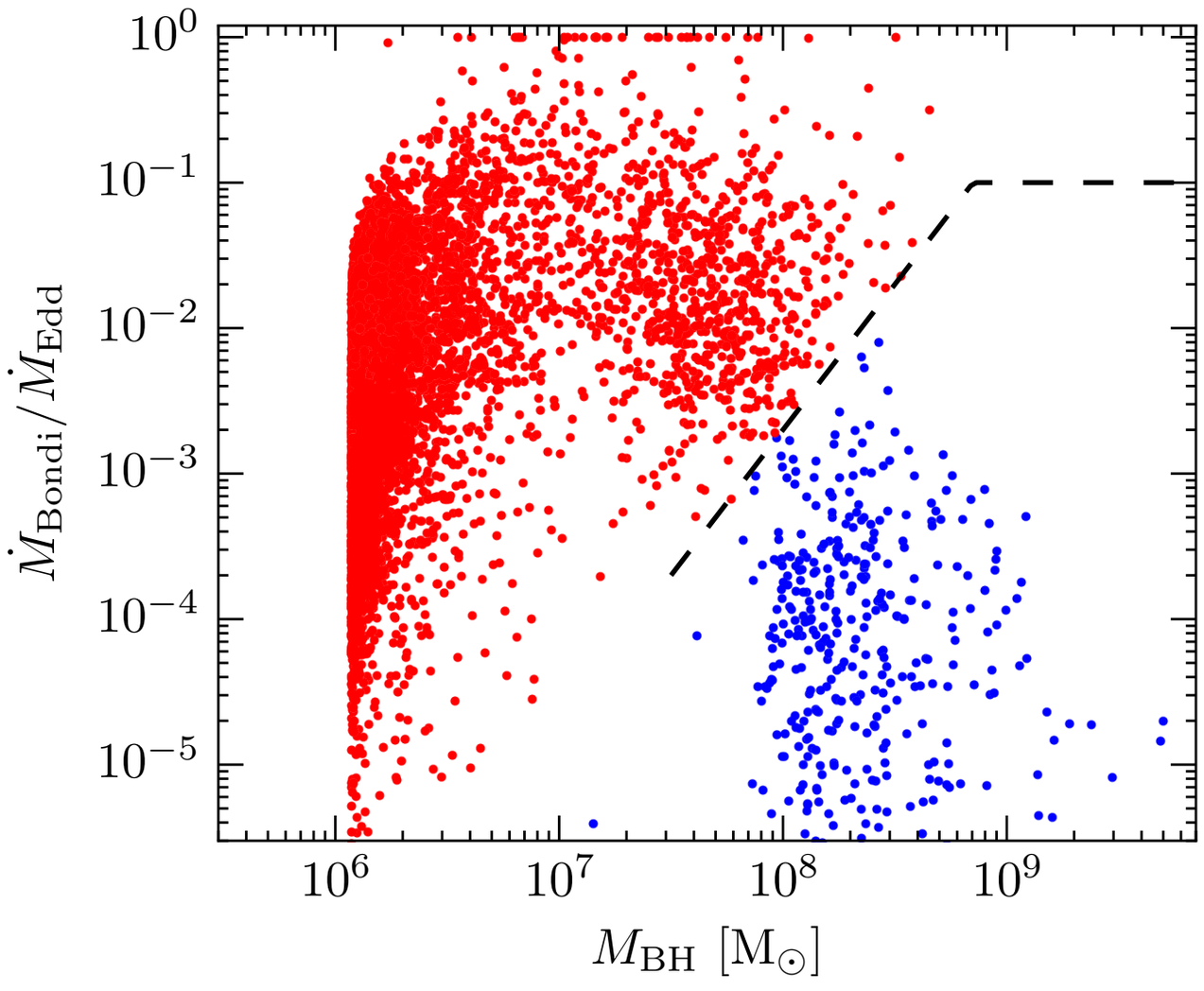


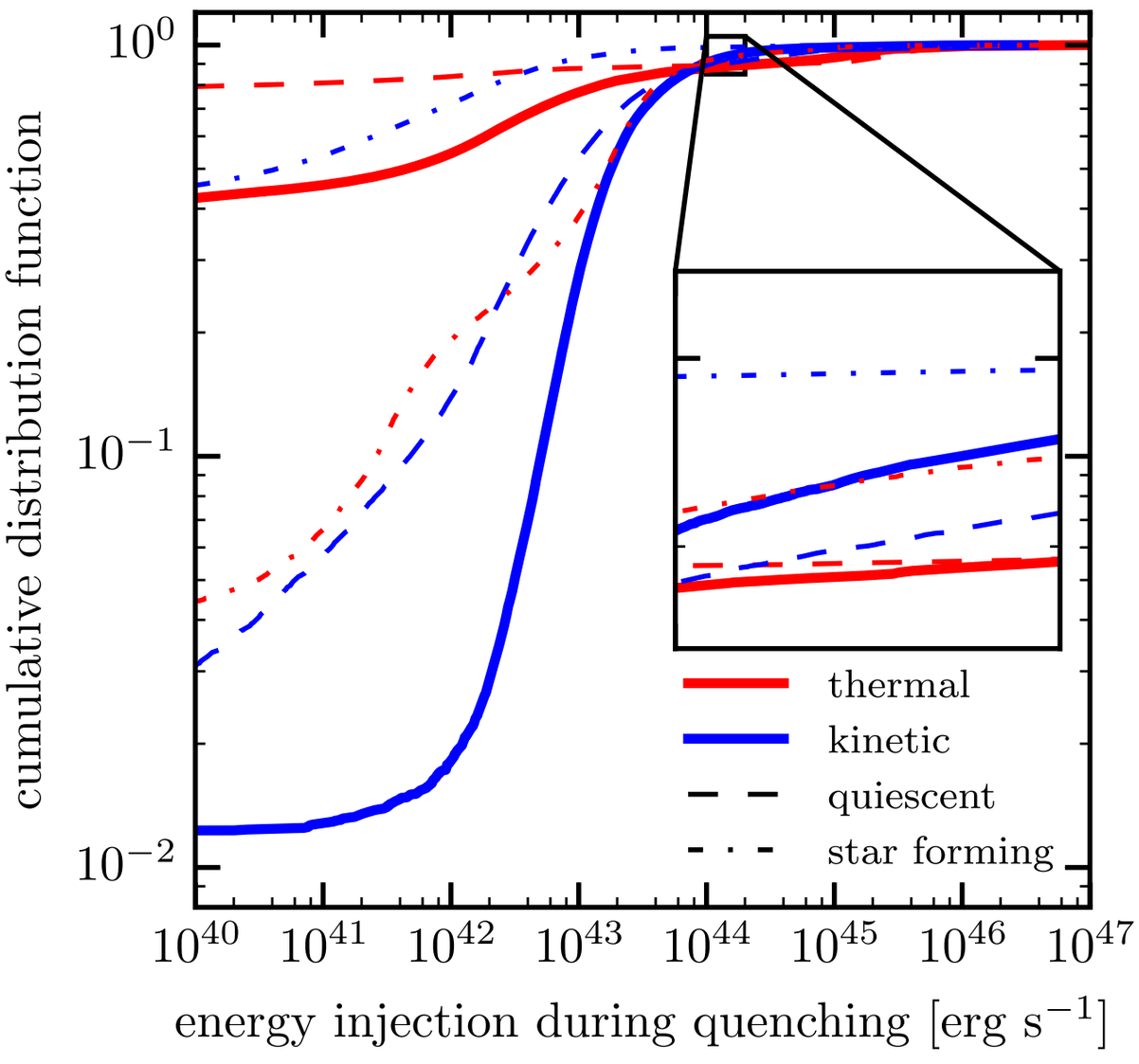


RW et al. (2018)

What quenches galaxies in the simulation?





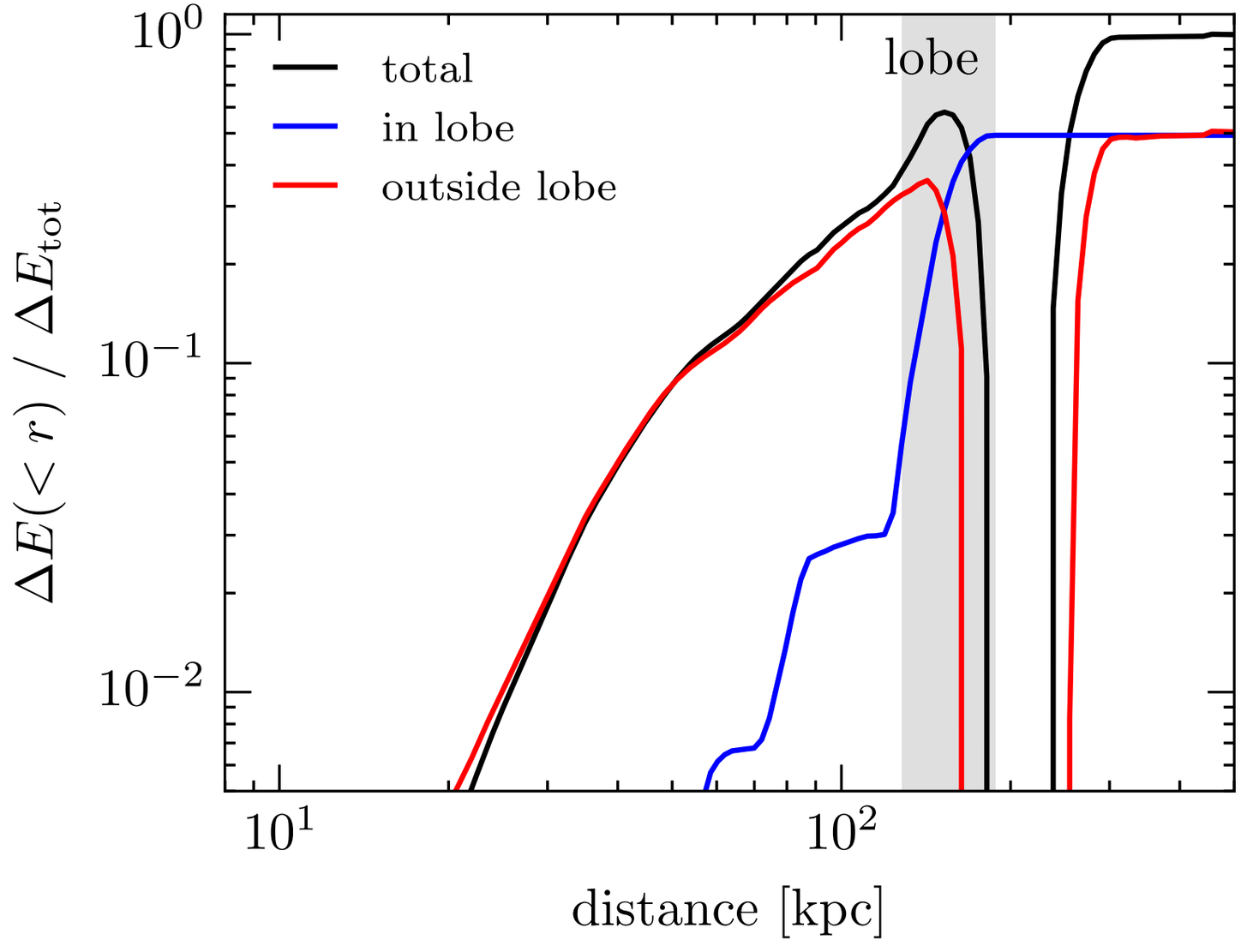


RW et al. (2018)

What can we learn from this?

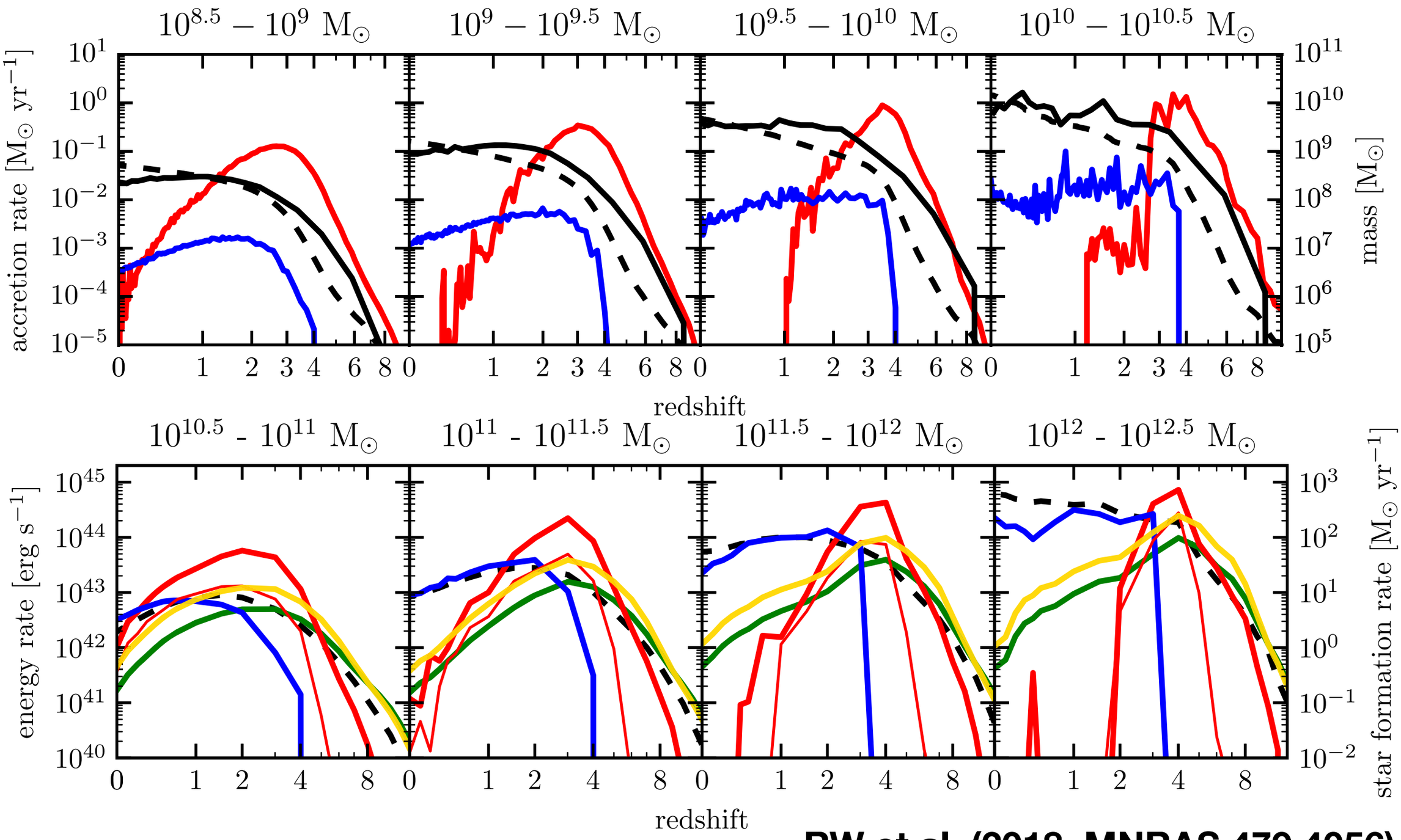
Lesson 1: Jet mode feedback in galaxy clusters is efficient

- Hydrodynamics and gravity enough
- Possible changes due to plasma-physics effects
  - Viscosity
  - Thermal conduction
  - Cosmic rays



RW et al. (2017, MNRAS.470.4530)

Lesson 2: Feedback might not be proportional to luminosity

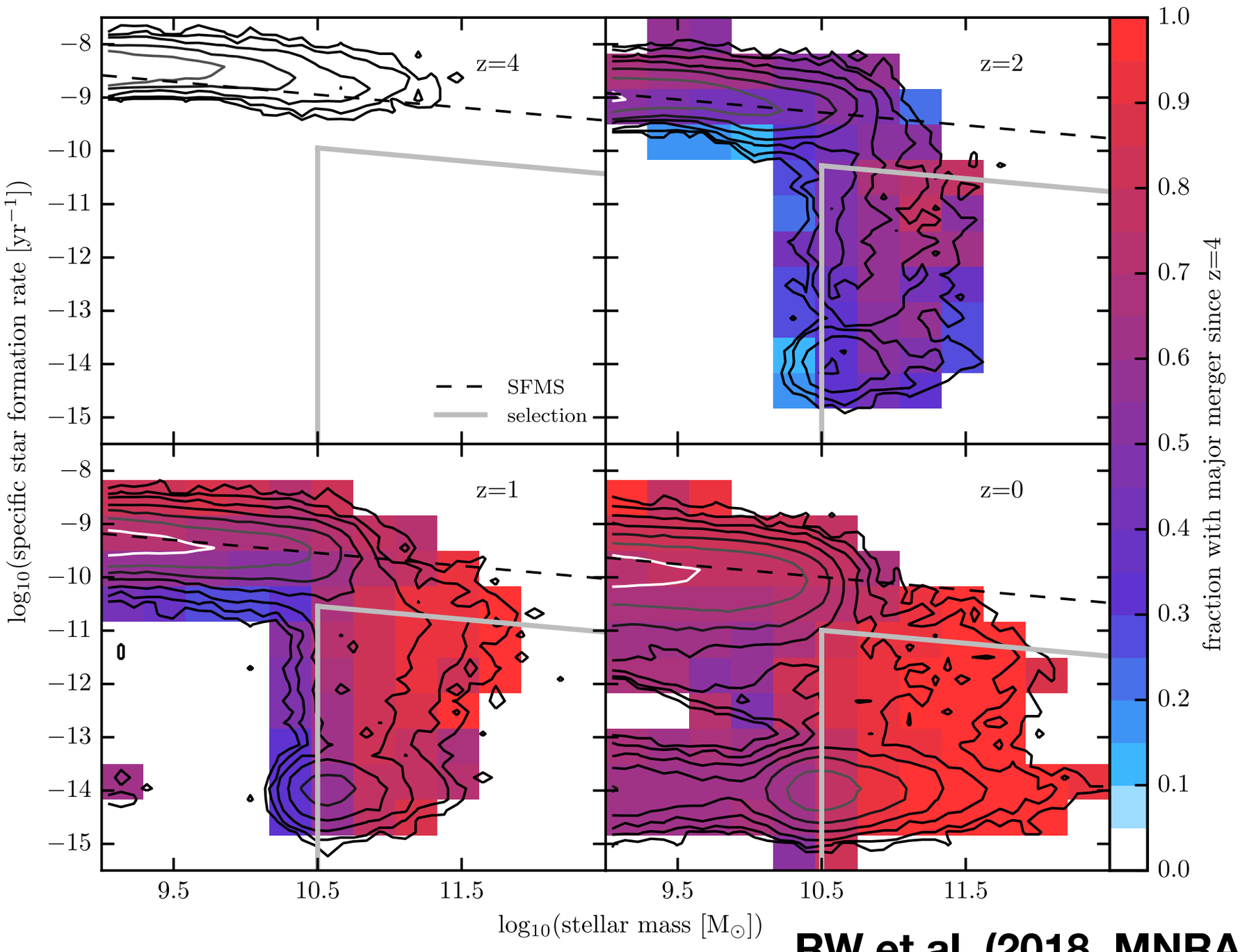


RW et al. (2018, MNRAS.479.4056)

Lesson 3: Quasar-mode feedback not necessarily required from a galaxy formation point of view

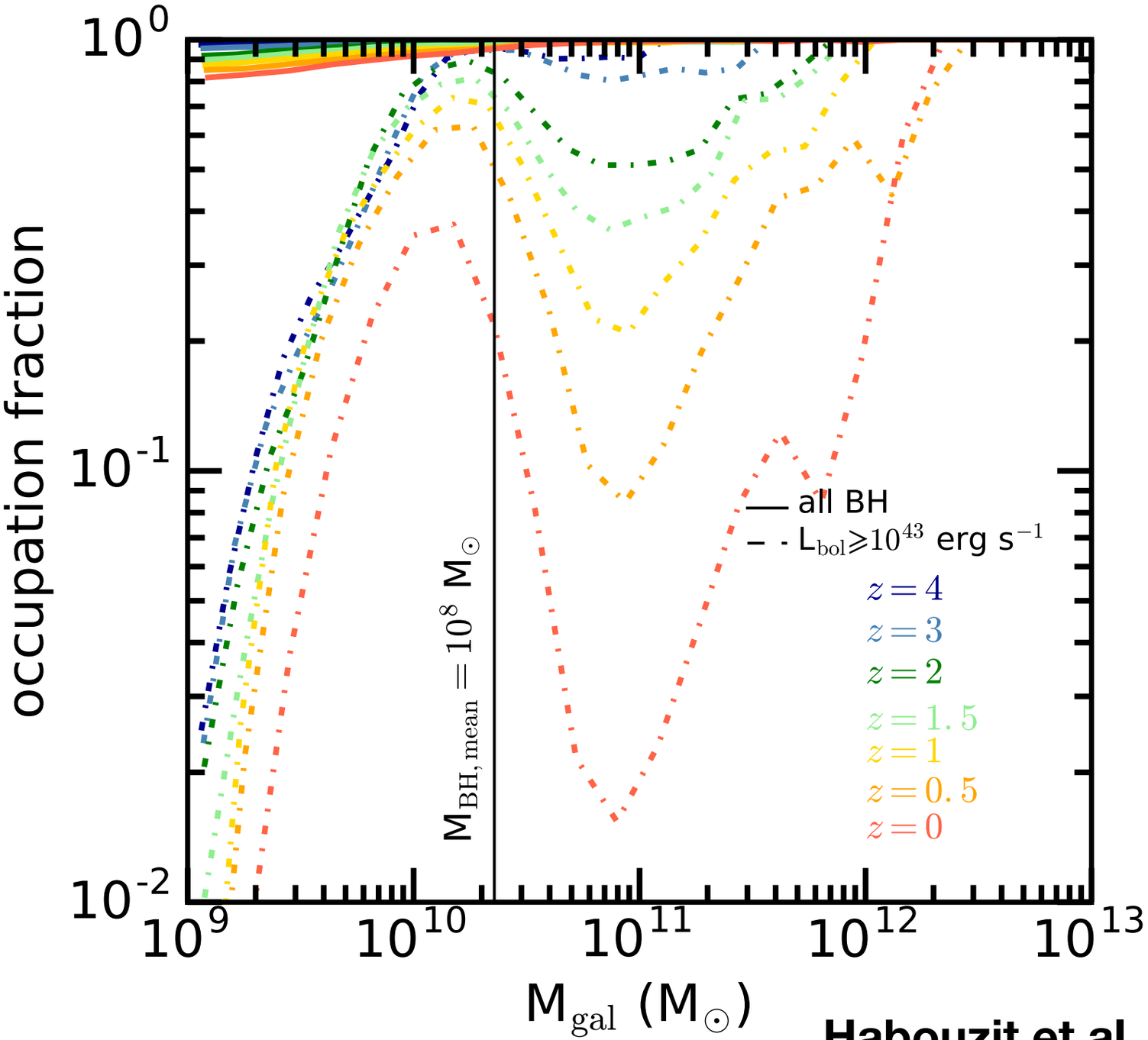
- Kinetic feedback enough for quenching star formation
- Quasars might be important, but not necessarily needed

Lesson 4: Quenching not triggered by galaxy merges



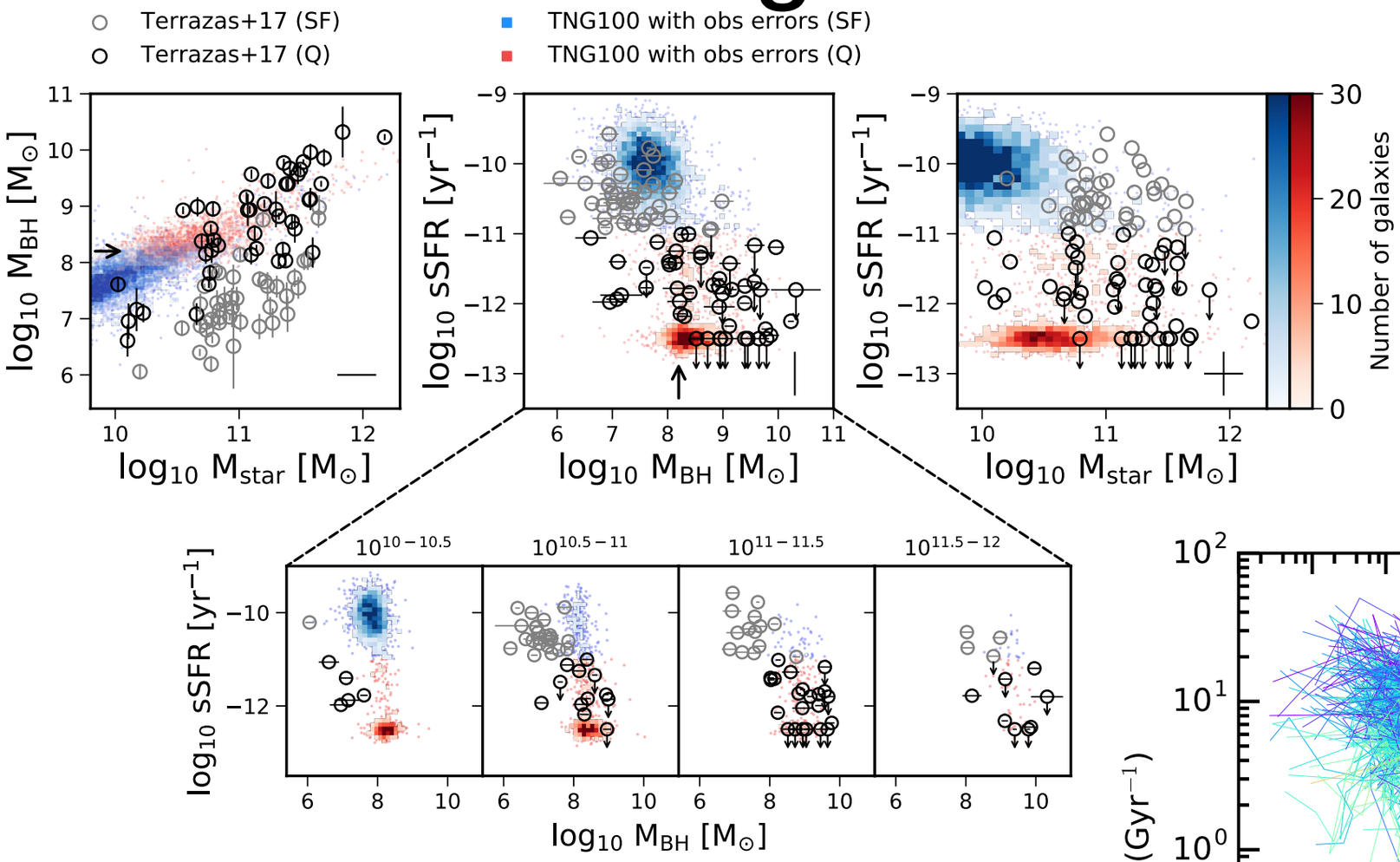
RW et al. (2018, MNRAS.479.4056)

Lesson 5: AGN occupation fraction as prediction of model

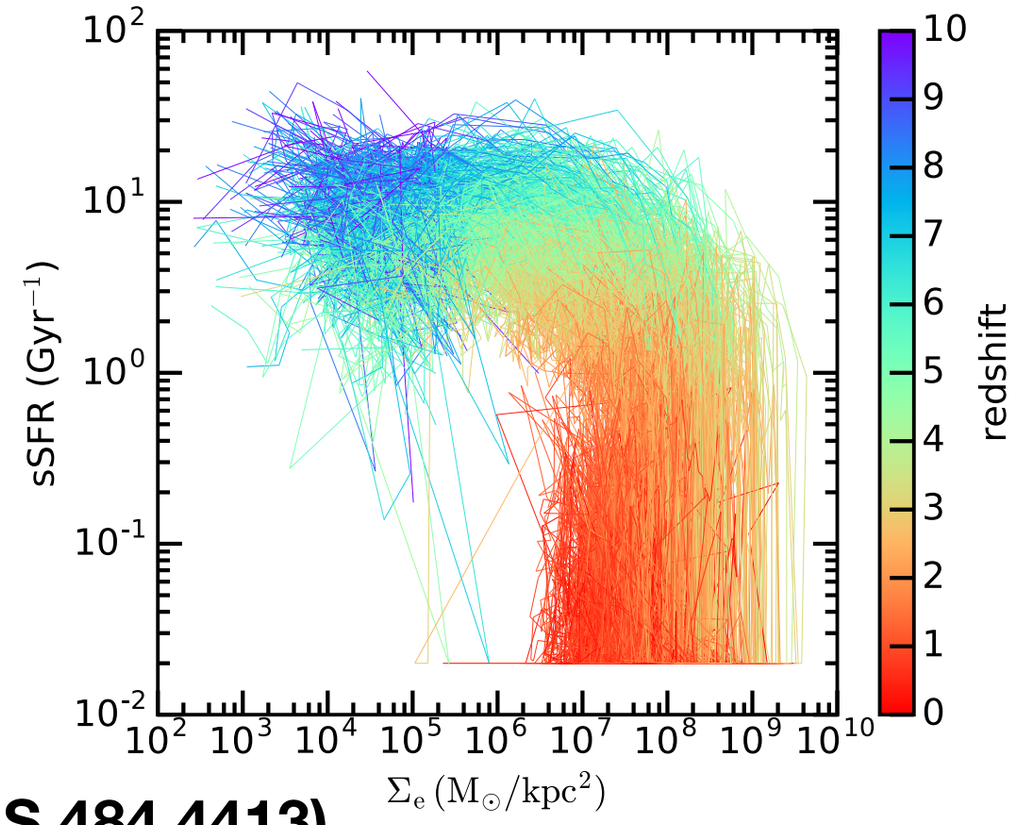


Habouzit et al. (2019, MNRAS.484.4413)

Lesson 6: Moderate mass SMBH demographics and connection to host galaxies



Terrazas et al. (submitted, arXiv: 190602747)



Habouzit et al. (2019, MNRAS.484.4413)

Future directions

- Connection with observed AGN types
- Is kinetic feedback in elliptical galaxies the same as in galaxy clusters?
- Degeneracy between quasar mode feedback and stellar feedback -> quasar luminosity function