



**UNIVERSITÉ  
DE GENÈVE**

**FACULTÉ DES SCIENCES**  
Département d'astronomie

# Feedback from active galactic nuclei in galaxy groups

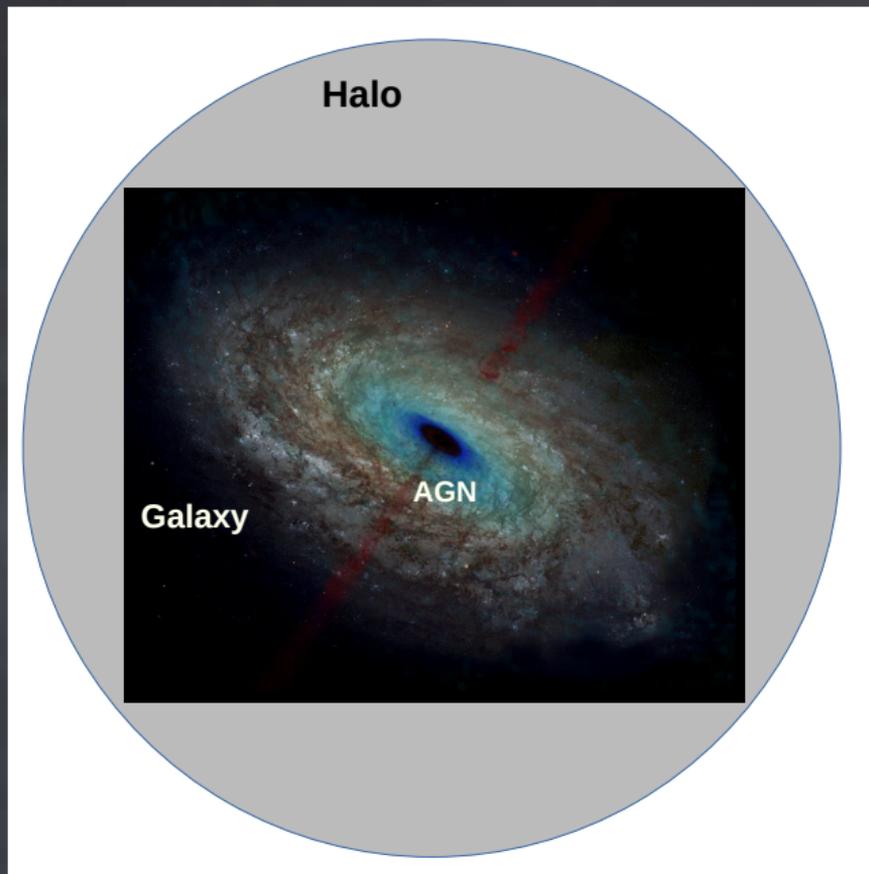
Dominique Eckert

Massimo Gaspari, Fabio Gastaldello, Amandine Le Brun, Ewan O'Sullivan  
Universe 7, 142: <https://www.mdpi.com/2218-1997/7/5/142>

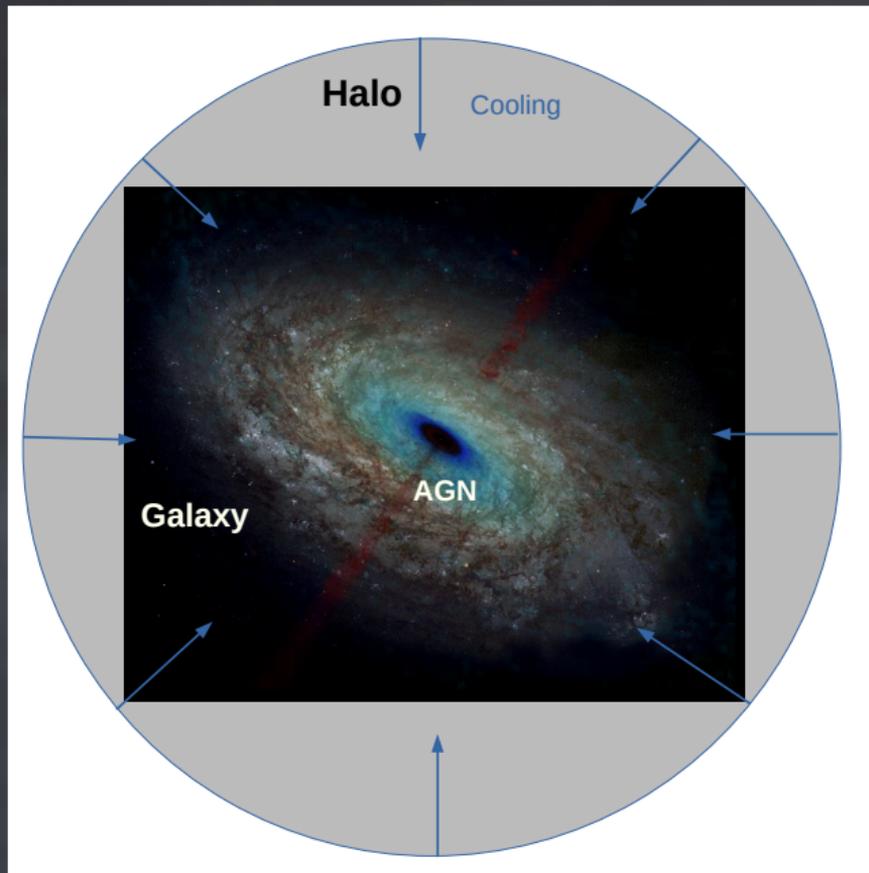
Department of Astronomy, University of Geneva

June 14, 2021

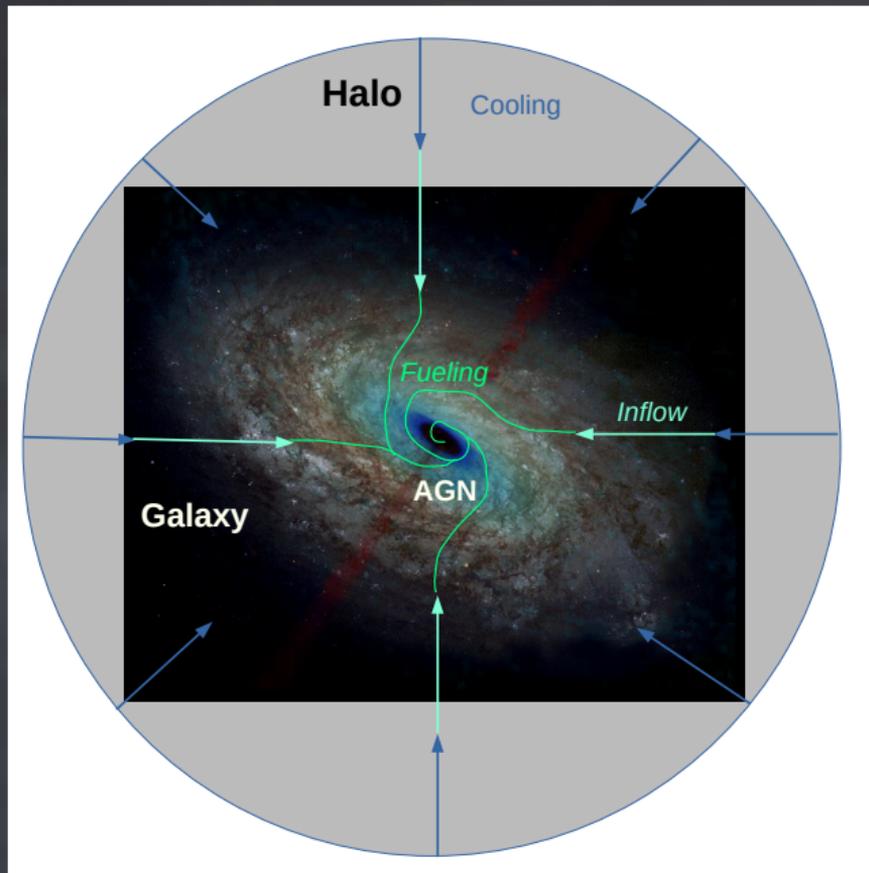
# AGN feedback in a nutshell



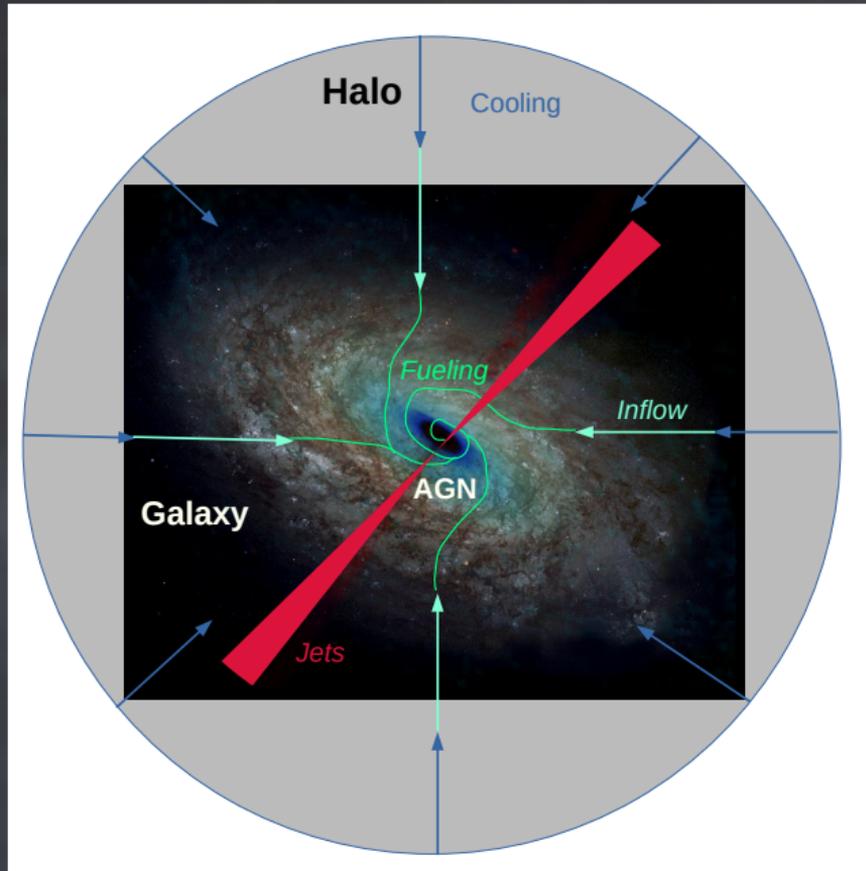
# AGN feedback in a nutshell



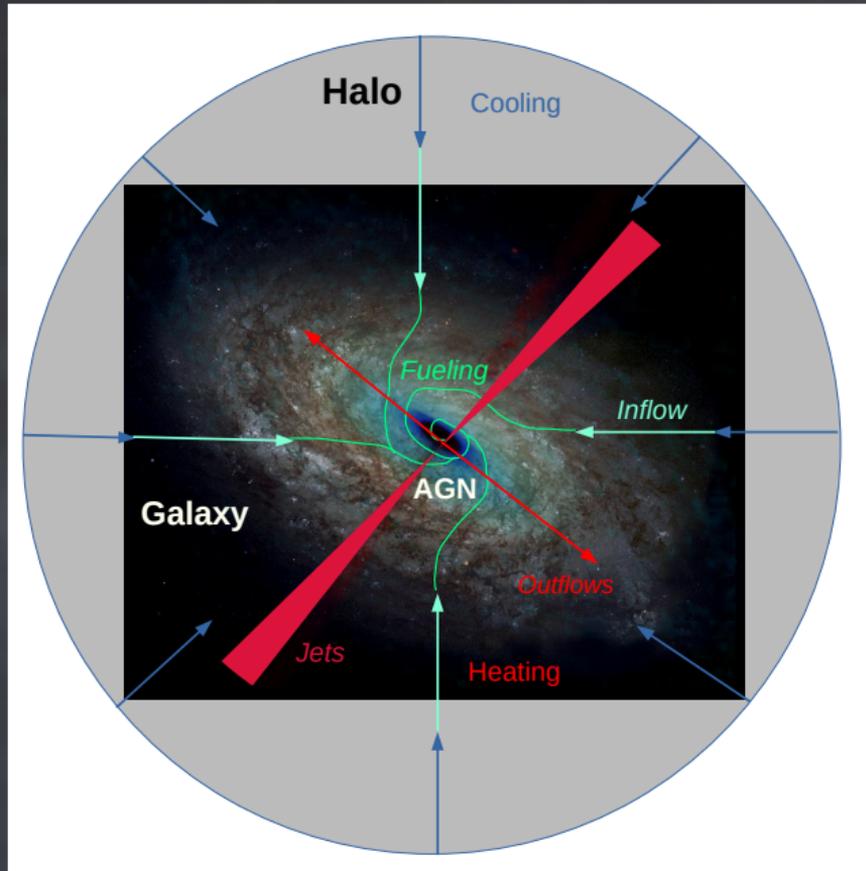
# AGN feedback in a nutshell



# AGN feedback in a nutshell

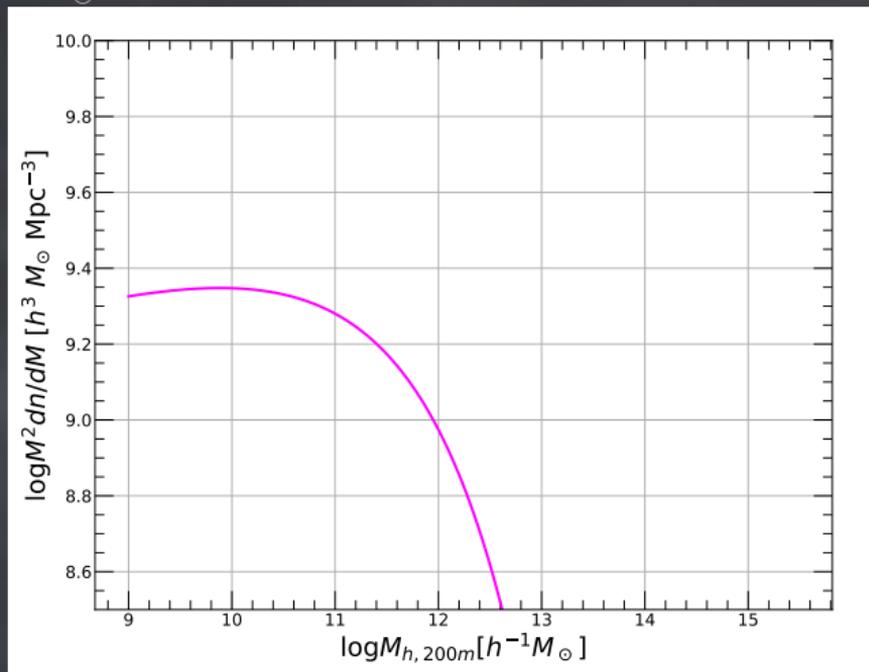


# AGN feedback in a nutshell



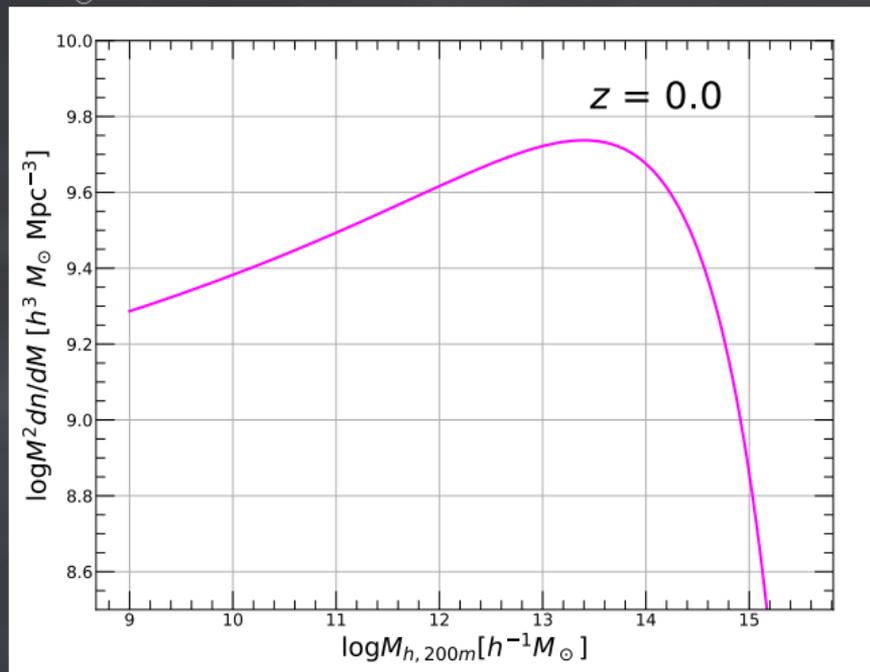
# Why galaxy groups? /1

We define “galaxy groups” as concentrations of galaxies with halo masses in the range  $M_{200} = 10^{13} - 10^{14} M_{\odot}$



# Why galaxy groups? /1

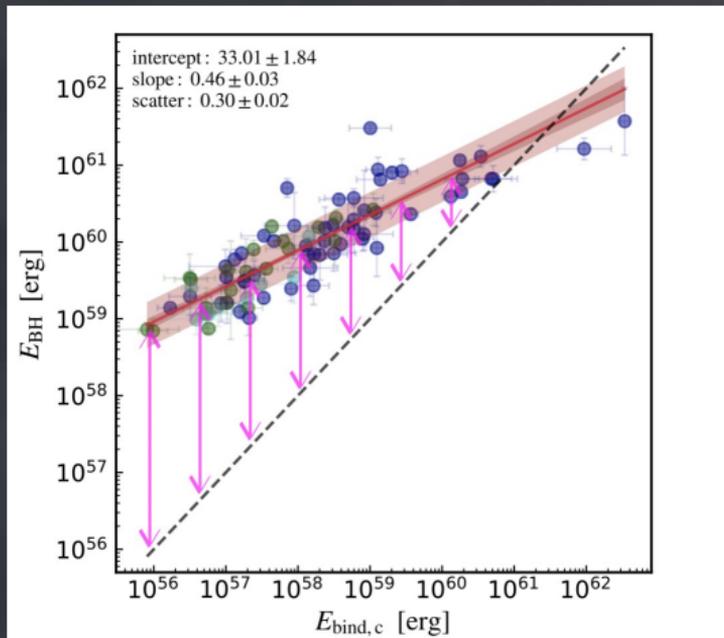
We define “galaxy groups” as concentrations of galaxies with halo masses in the range  $M_{200} = 10^{13} - 10^{14} M_{\odot}$



In the local Universe *the peak of the halo mass density is at the galaxy group scale*

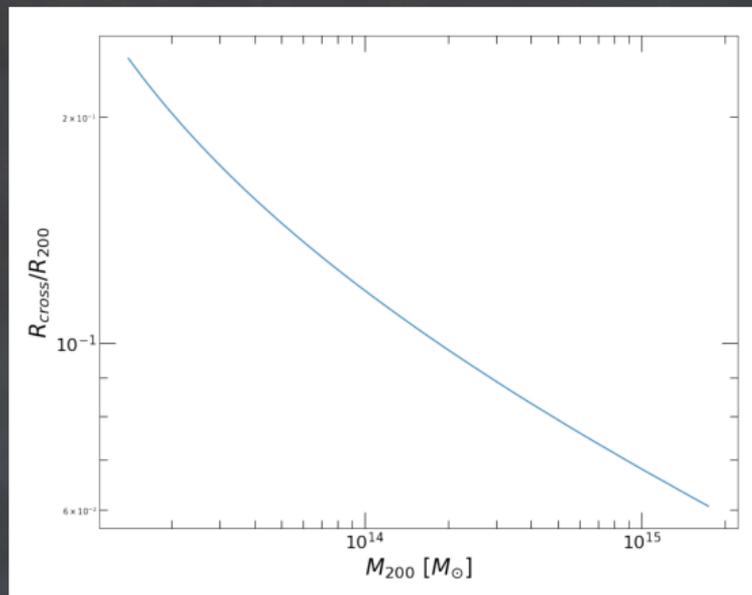
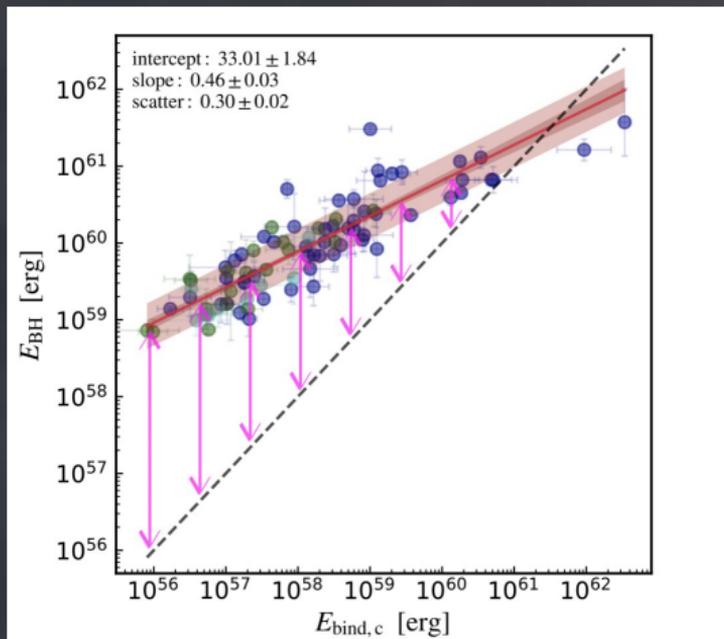
# Why galaxy groups? /2

The feedback energy is comparable to the gravitational binding energy of galaxy groups



# Why galaxy groups? /2

The feedback energy is comparable to the gravitational binding energy of galaxy groups

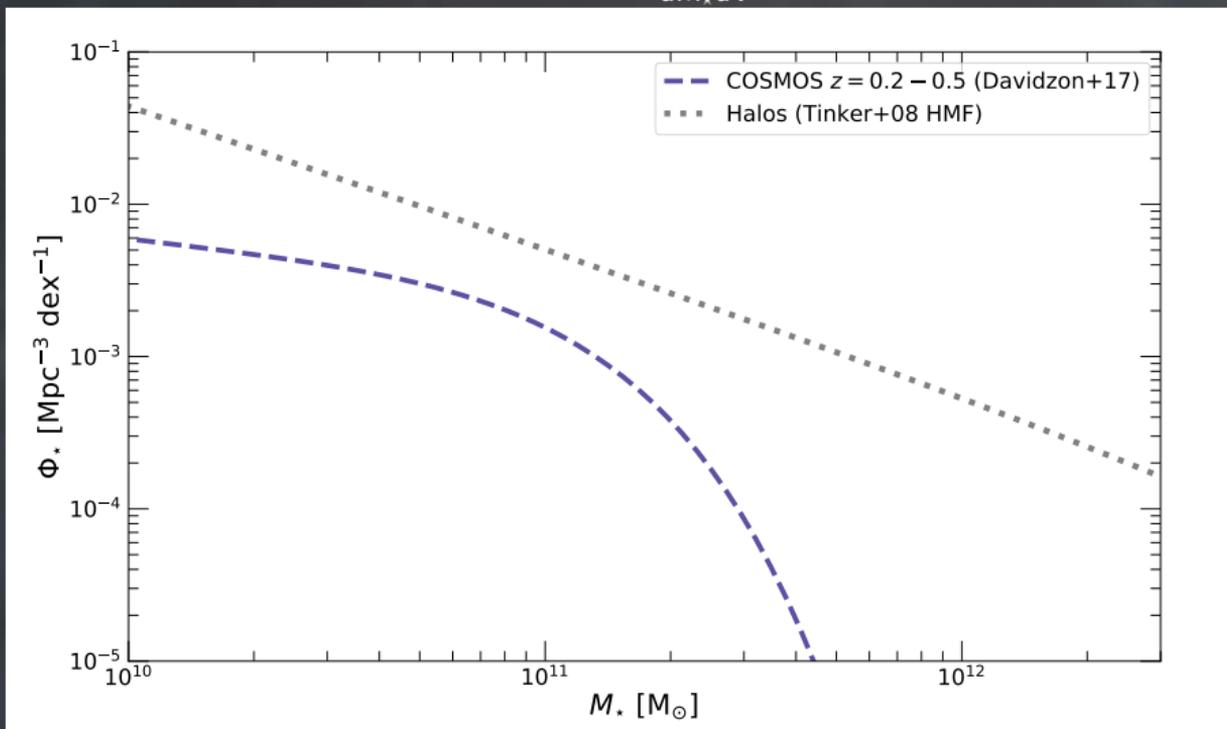


The influence of AGN extends farther out than in more massive systems

- AGN feedback in galaxy evolution
- Observational evidence: entropy, cavities, shocks...
- Theoretical framework
- Impact of feedback on the large-scale distribution of baryons: gas fraction, matter power spectrum
- Future prospects

# The galaxy stellar mass function

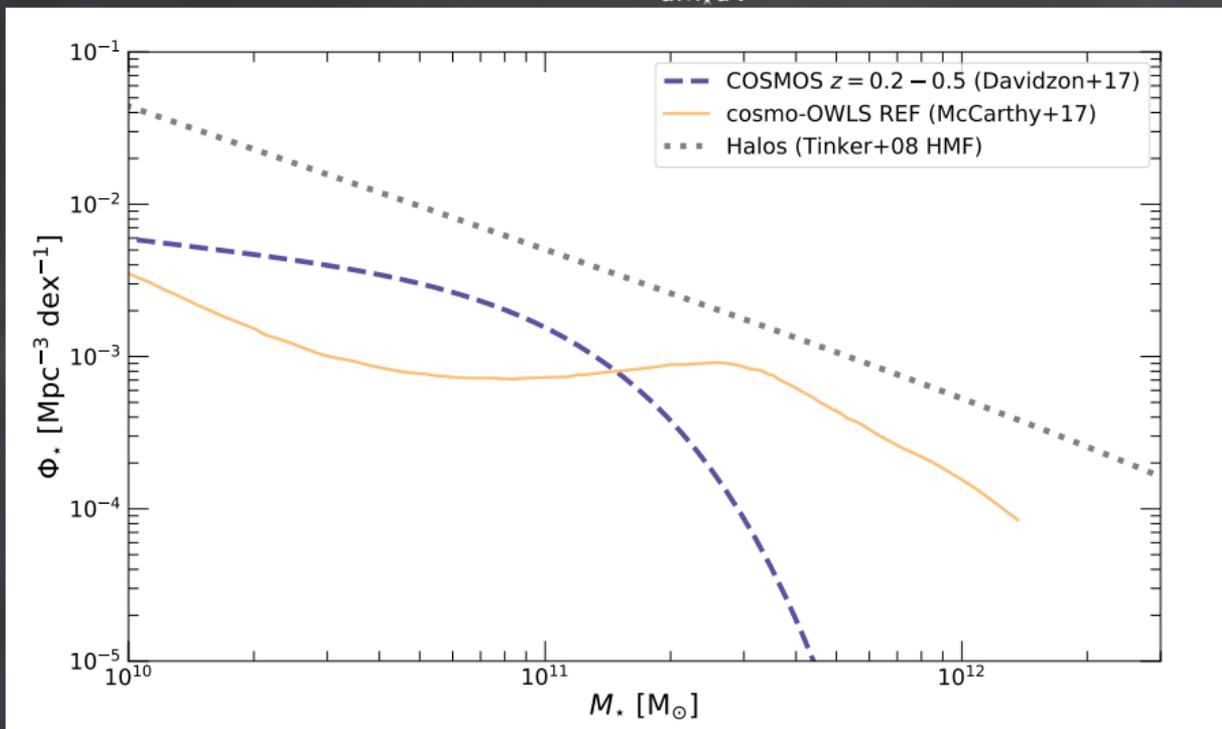
$$\Phi_*(M_*) = \frac{dN_{gal}}{dM_*dV}$$



The shape of the stellar mass function does not match what we would expect in a “naive” self-similar galaxy formation model

# The galaxy stellar mass function

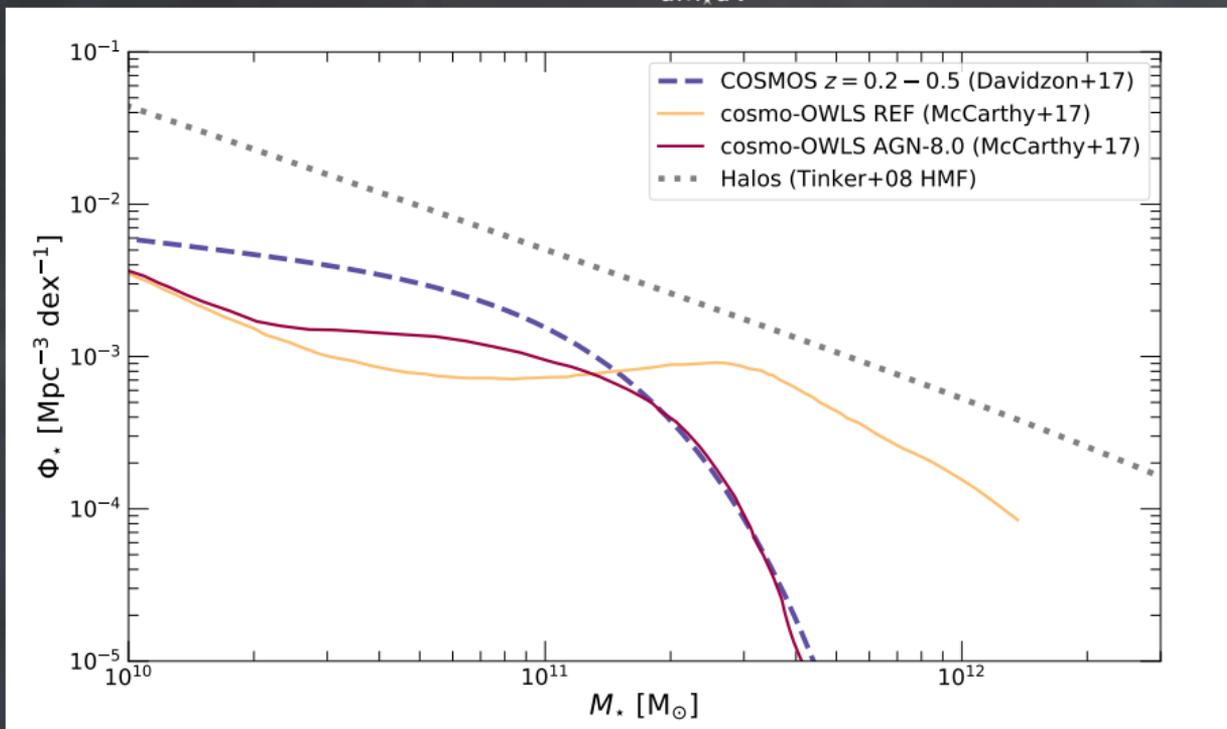
$$\Phi_*(M_*) = \frac{dN_{gal}}{dM_*dV}$$



The shape of the stellar mass function does not match what we would expect in a “naive” self-similar galaxy formation model

# The galaxy stellar mass function

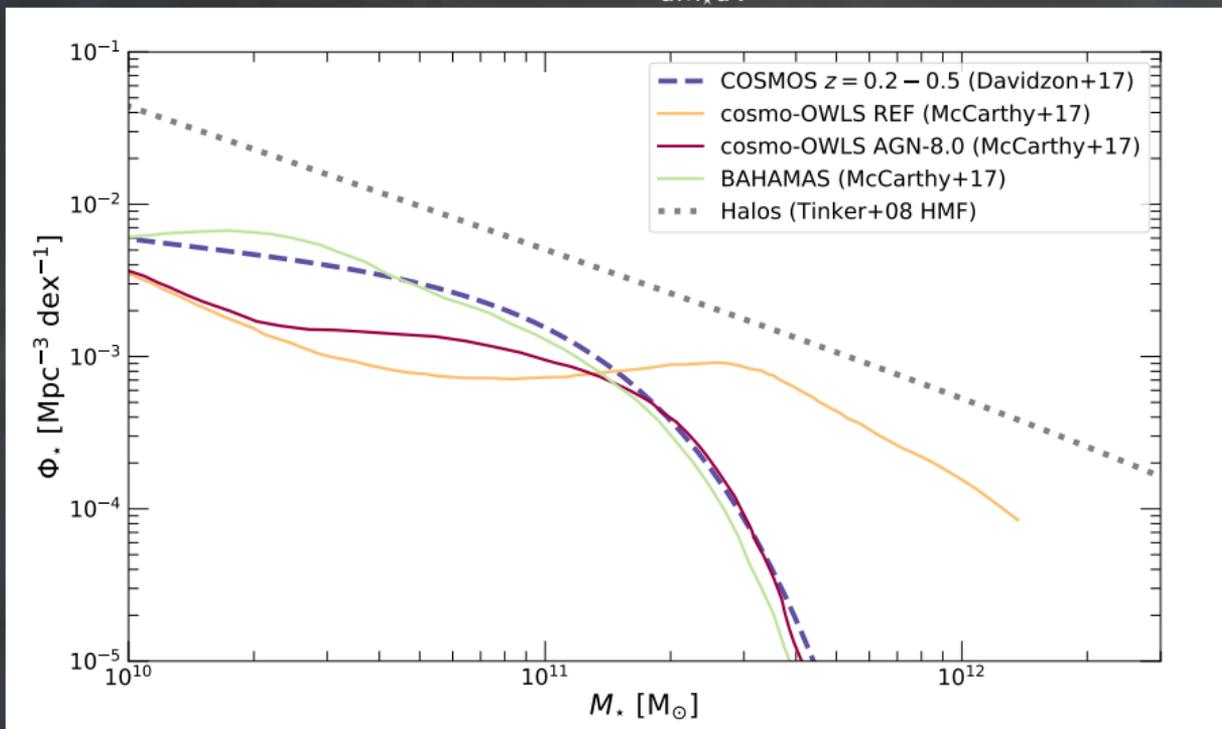
$$\Phi_*(M_*) = \frac{dN_{gal}}{dM_* dV}$$



Quenching of star formation by AGN feedback is necessary to regulate the growth of the most massive galaxies

# The galaxy stellar mass function

$$\Phi_*(M_*) = \frac{dN_{gal}}{dM_* dV}$$



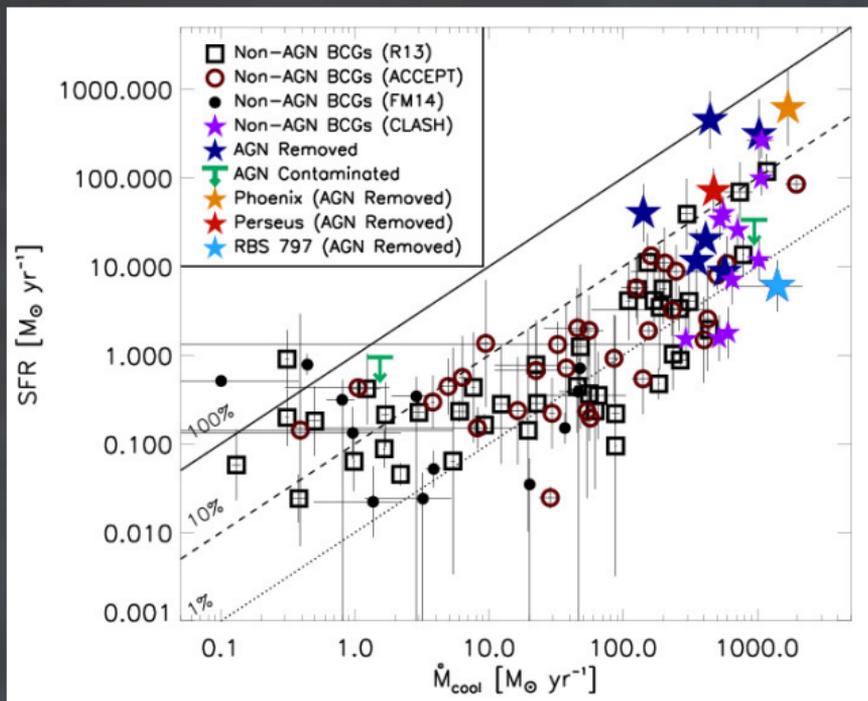
Quenching of star formation by AGN feedback is necessary to regulate the growth of the most massive galaxies





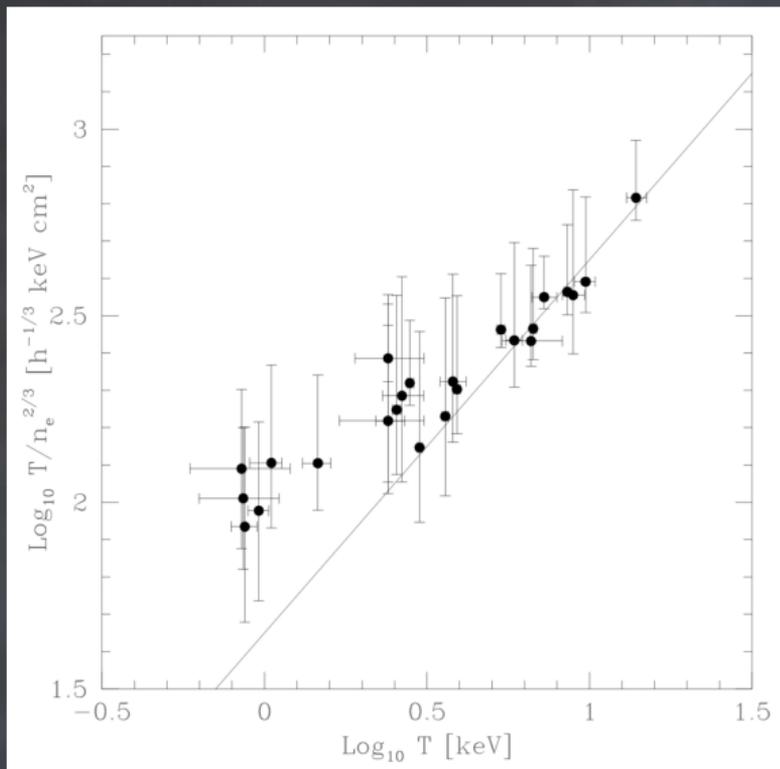
# “Cooling flows”

- Hot halos contain vast reservoirs of gas; regulate star formation activity
- In the central regions of clusters and groups radiative cooling is efficient  
⇒ Strong X-ray emission, low  $T$ ,  $t_{cool} \ll \frac{1}{H_0}$
- The cooling of the gas in nearby clusters is largely suppressed (by factors 10-100)



McDonald et al. 2018

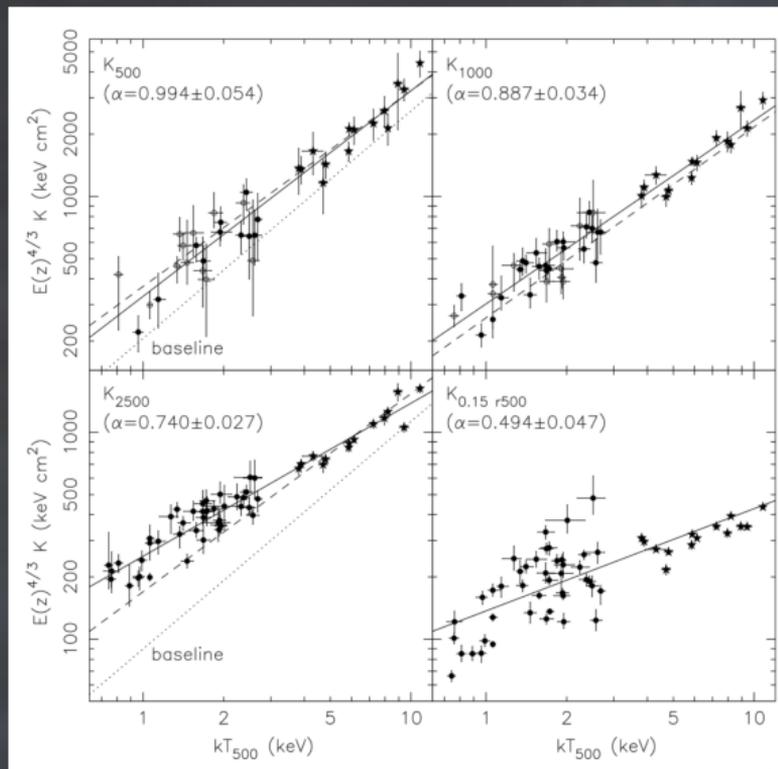
- Early observations (late 1990s) showed that the entropy of galaxy groups exceeds the predictions of gravitational collapse models



*Ponman et al. 1998*

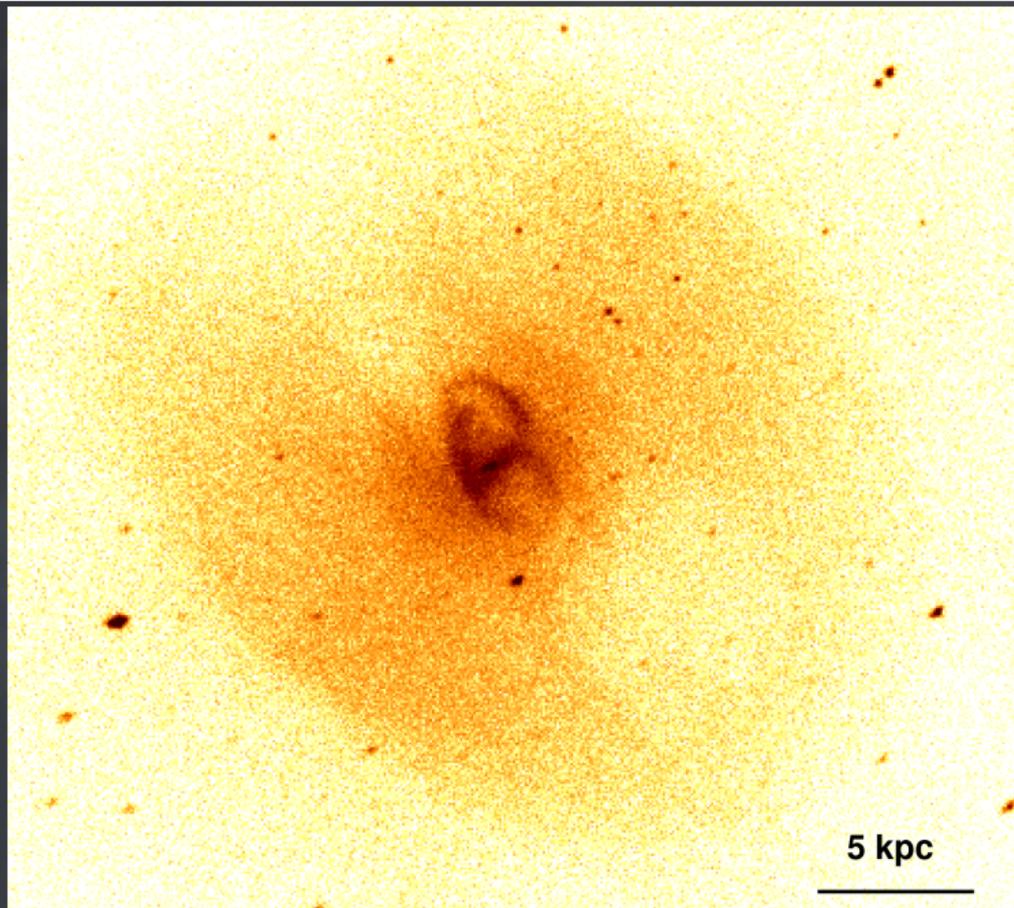
# Entropy excess

- Early observations (late 1990s) showed that the entropy of galaxy groups exceeds the predictions of gravitational collapse models
- The cores of galaxy groups are **over-heated**; expected in the AGN feedback scenario



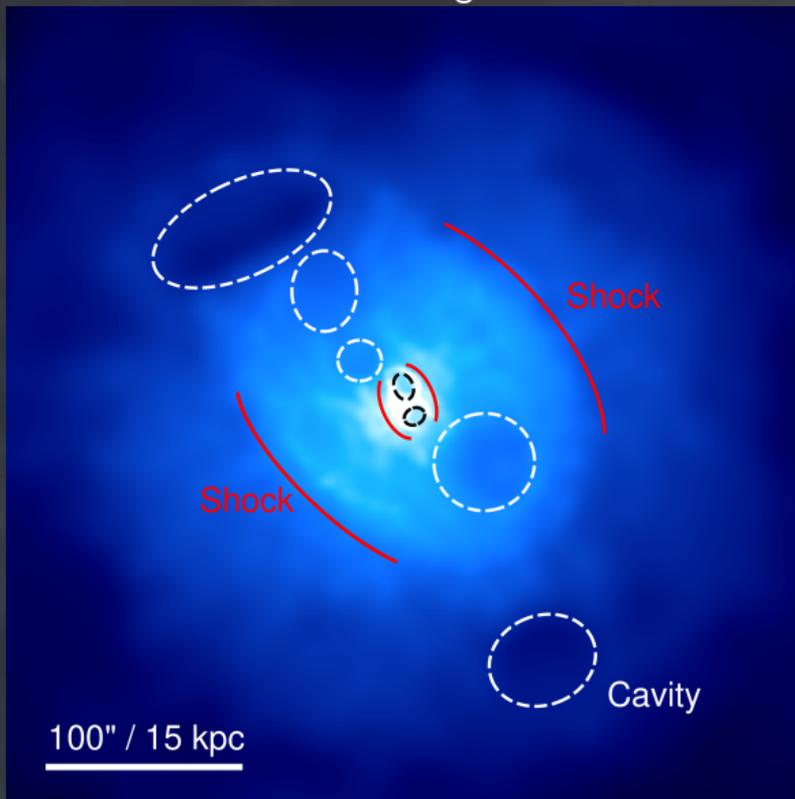
*Sun et al. 2009*

# High-resolution X-ray observations of NGC 5813

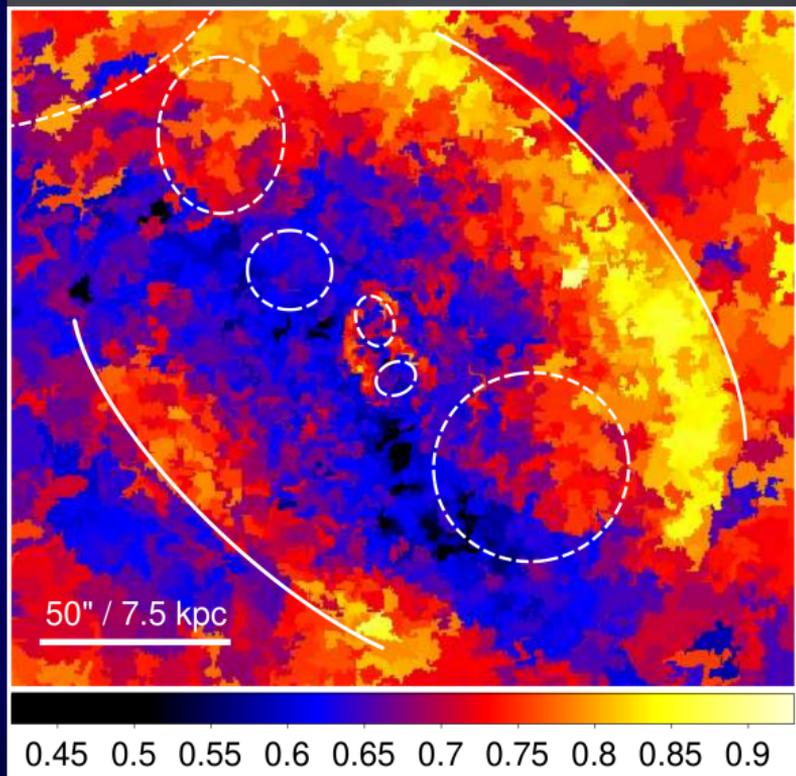


# High-resolution X-ray observations of NGC 5813

Surface brightness



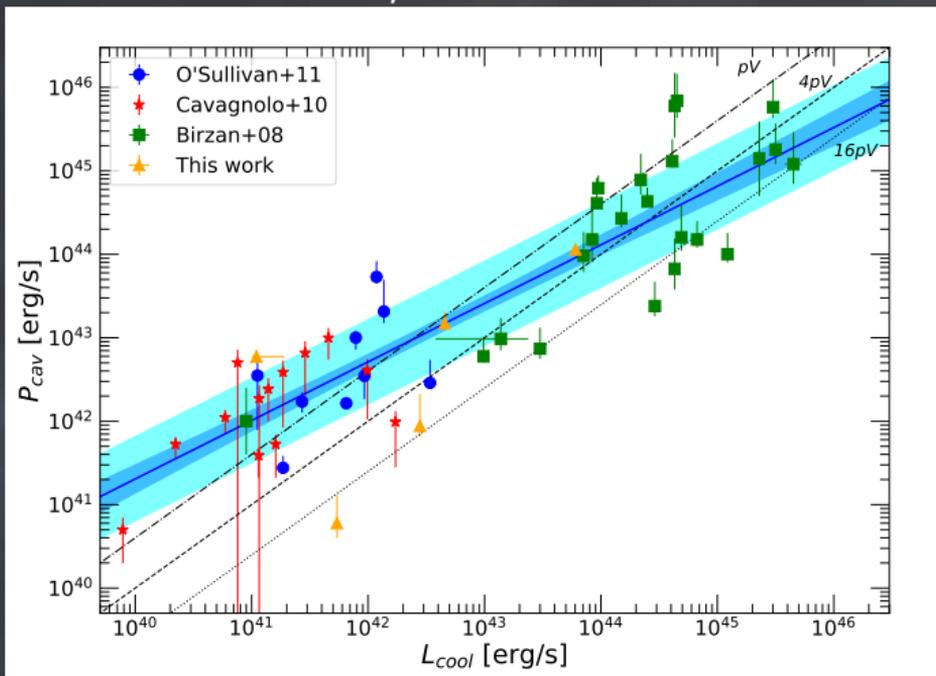
Temperature



# Cooling luminosity to cavity power relation

We define  $L_{cool} = L_X(< R_{cool})$  with  $t_{cool}(R_{cool}) = \frac{t_H}{2}$

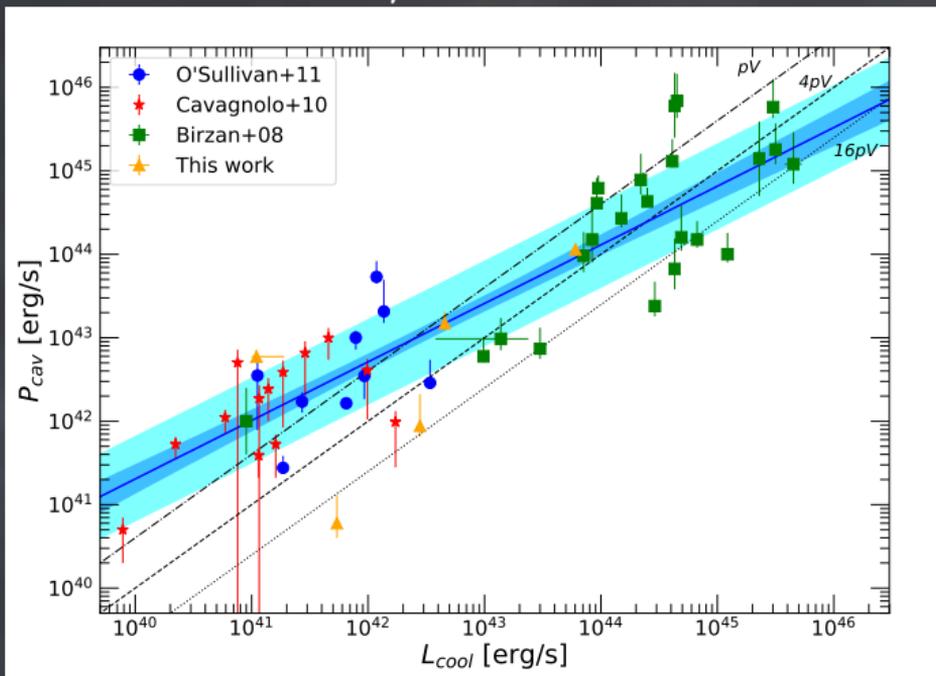
The cavity enthalpy is  $H = U + pV = \frac{\gamma}{\gamma-1} pV$



# Cooling luminosity to cavity power relation

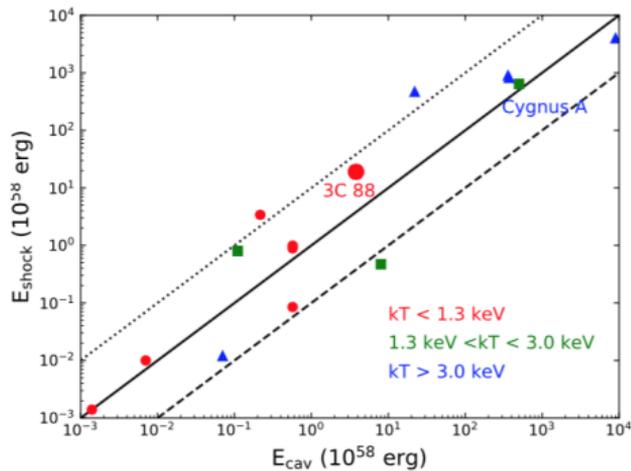
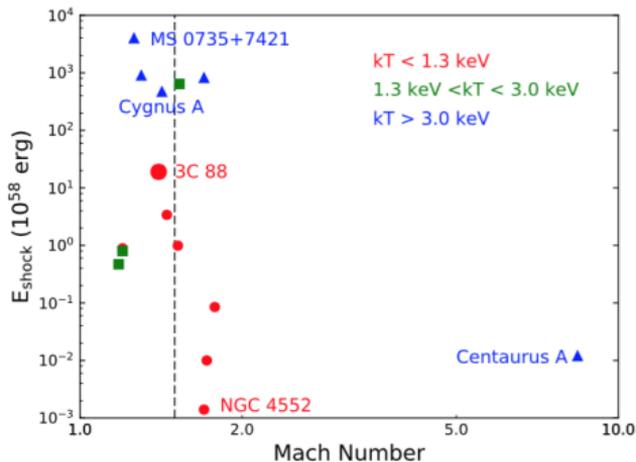
We define  $L_{cool} = L_X(< R_{cool})$  with  $t_{cool}(R_{cool}) = \frac{t_H}{2}$

The cavity enthalpy is  $H = U + pV = \frac{\gamma}{\gamma-1} pV$



$L_{cool}$  correlates with the power injected by cavities; cavities inject *more power* in groups than in clusters

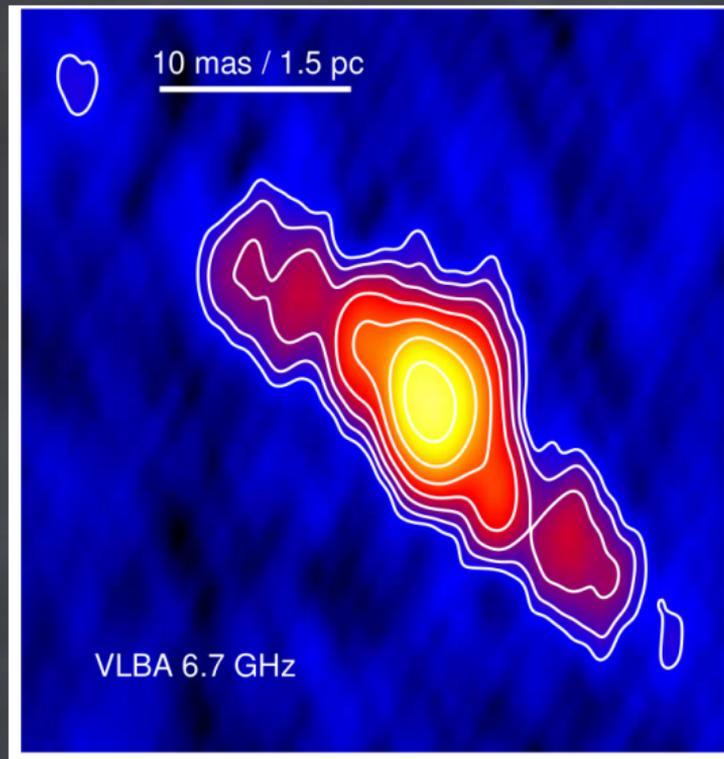
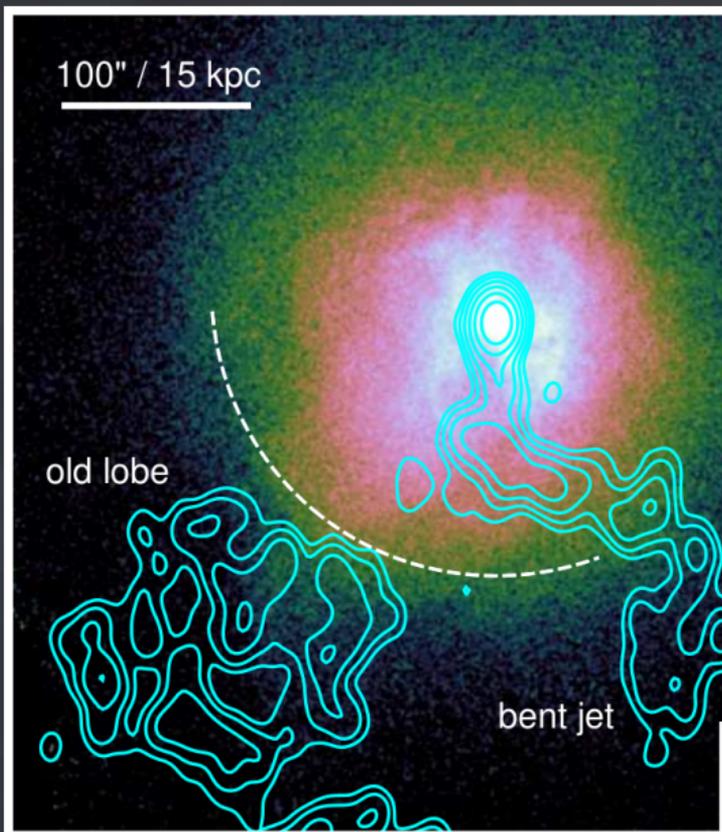
# Integrated shock energy



*Liu et al. 2019*

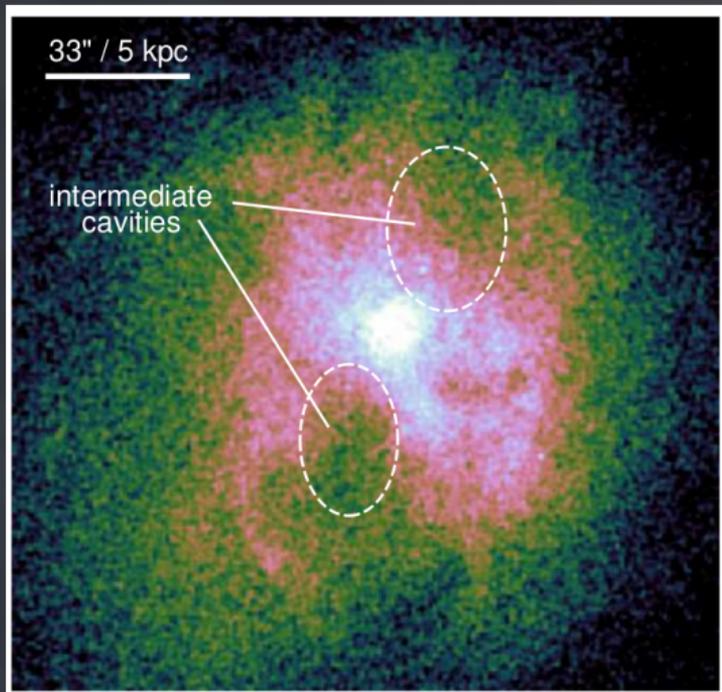
Successive shocks inject a comparable amount of energy as cavities in the surrounding medium

# NGC 5044: precessing radio jets

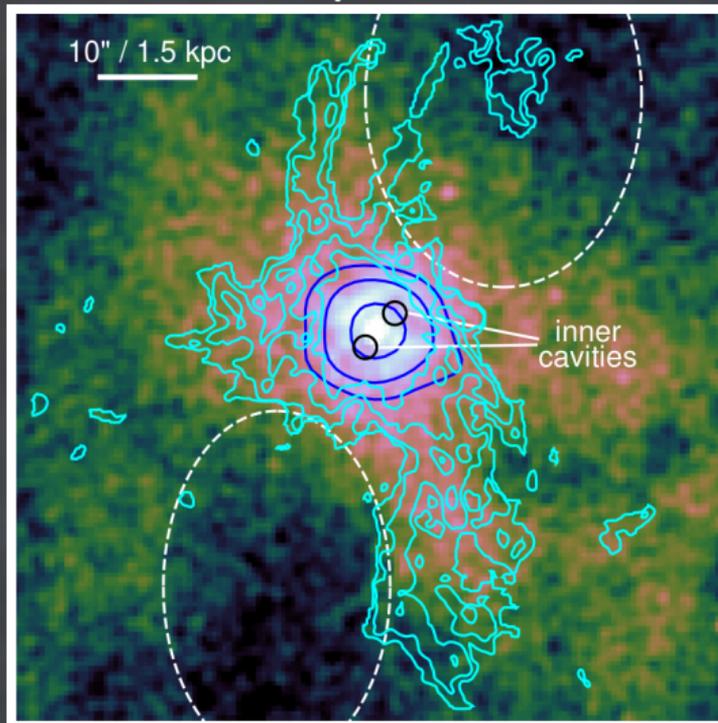


# NGC 5044: cooling, $H\alpha$ nebula, molecular gas

X-ray

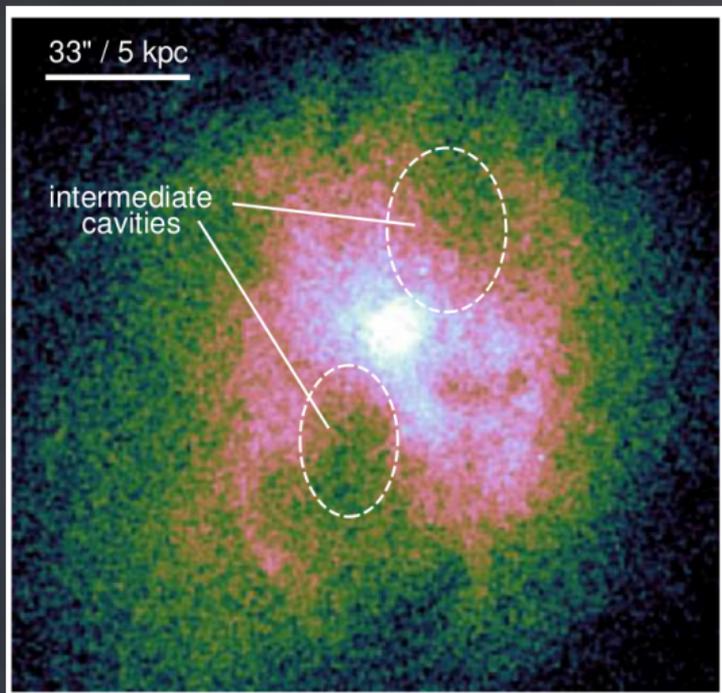


X-ray+ $H\alpha$

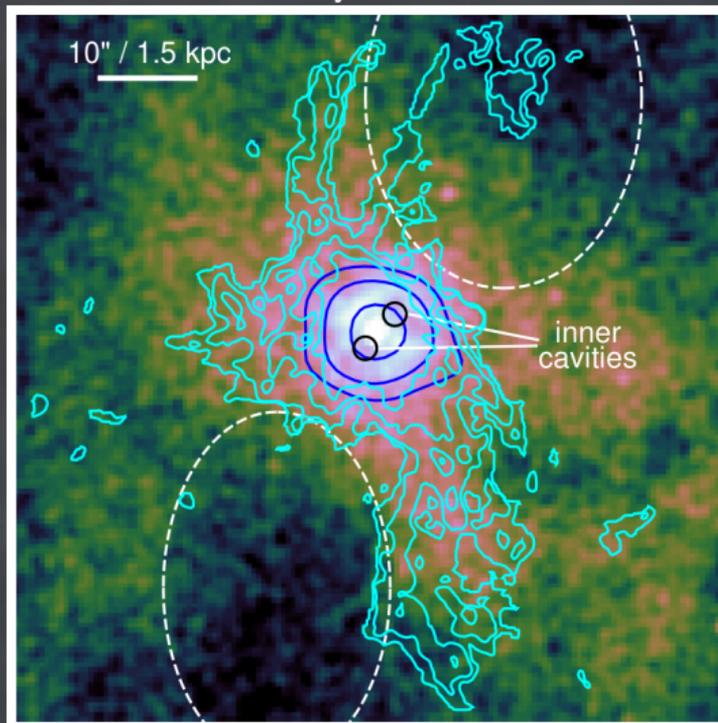


# NGC 5044: cooling, H $\alpha$ nebula, molecular gas

X-ray

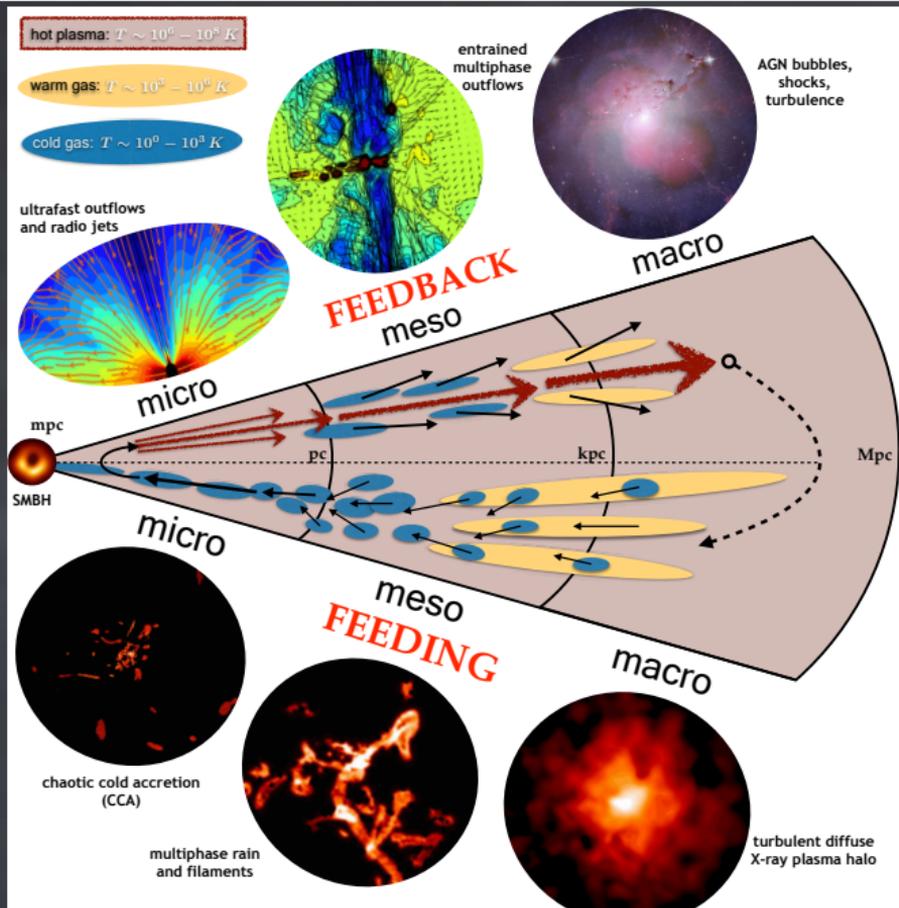


X-ray+H $\alpha$



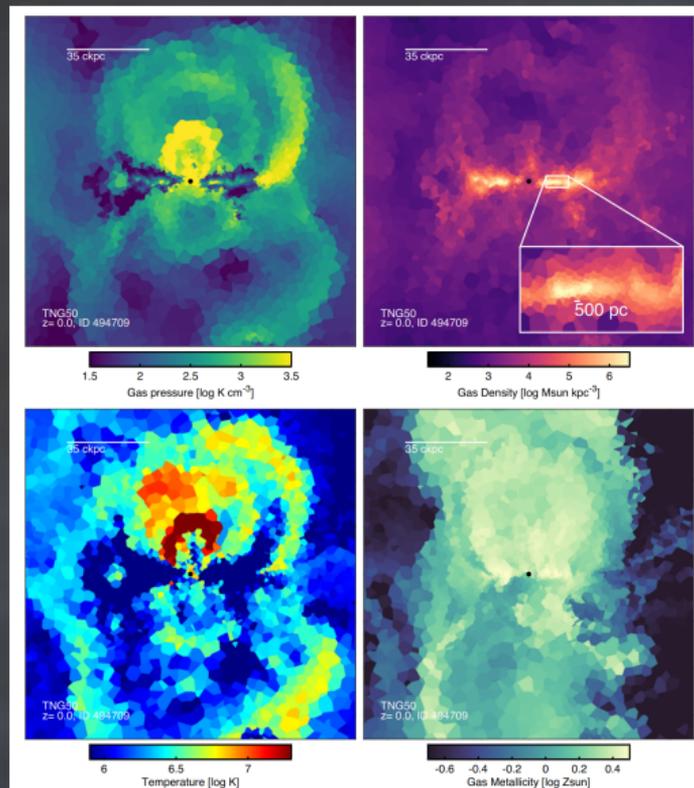
Catastrophic gas cooling occurs perpendicular to the direction of jets/cavities

# The AGN feedback cycle



# AGN feedback in cosmological simulations

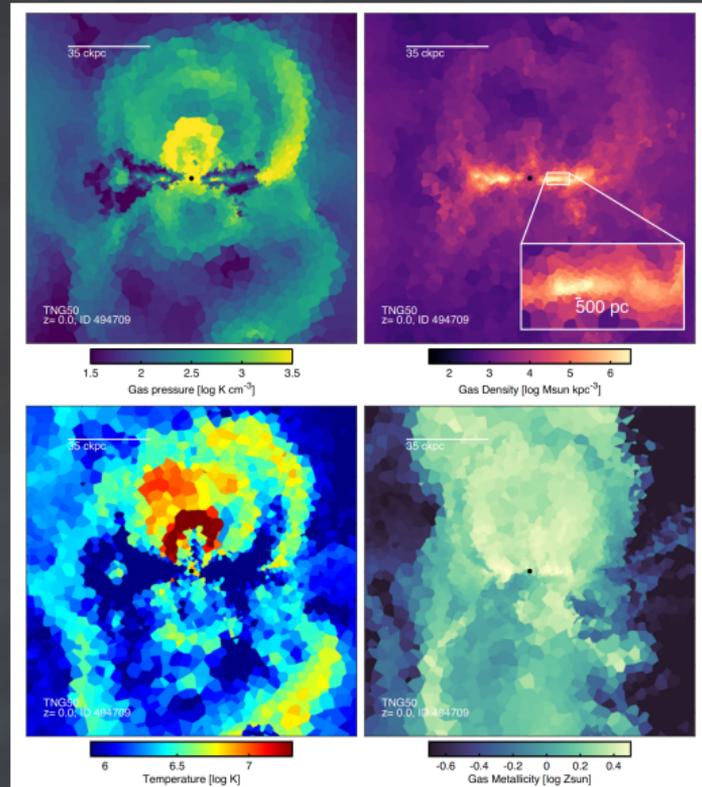
- *ALL* modern galaxy evolution models include a prescription for AGN feedback



TNG50, Pillepich et al. 2021

# AGN feedback in cosmological simulations

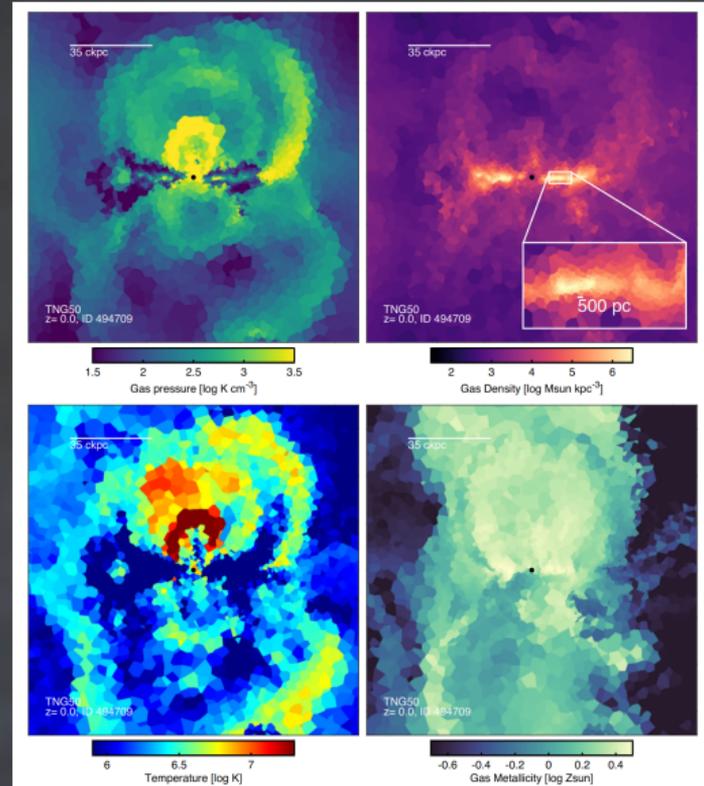
- *ALL* modern galaxy evolution models include a prescription for AGN feedback
- Thermal feedback: BHs “store” a given amount of energy and release it thermally by heating the surrounding gas particles



TNG50, Pillepich et al. 2021

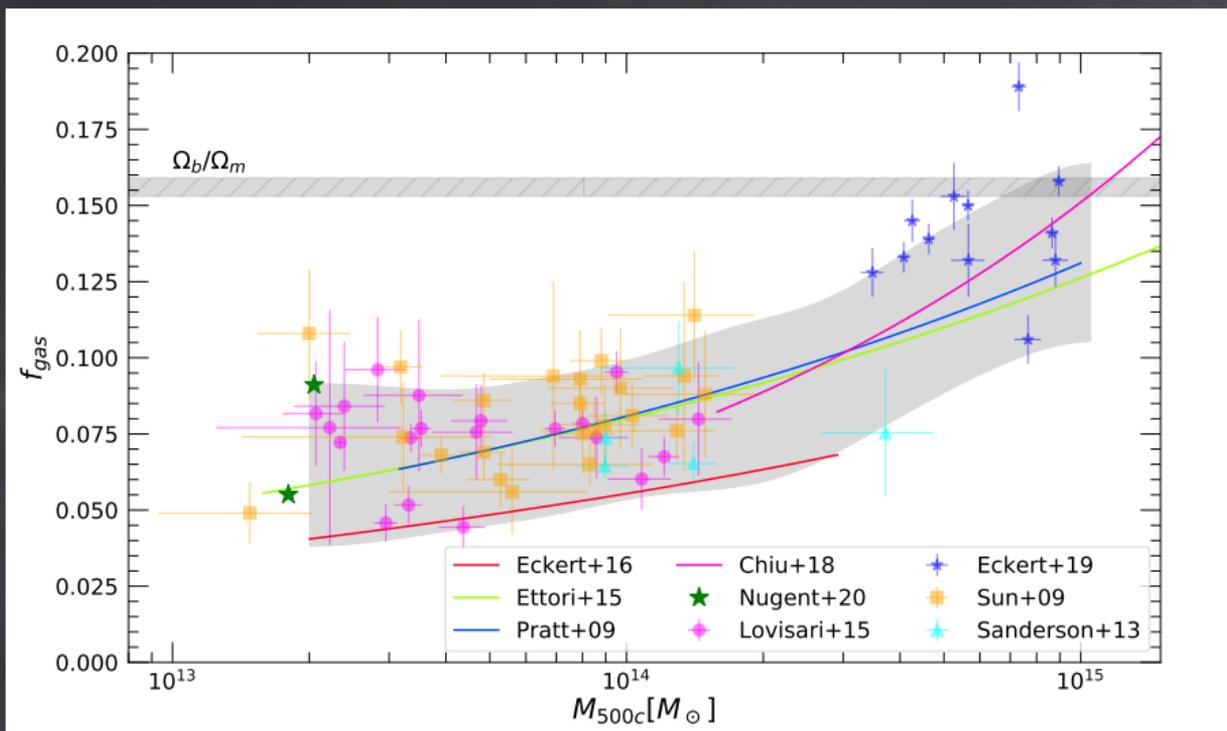
# AGN feedback in cosmological simulations

- ALL modern galaxy evolution models include a prescription for AGN feedback
- Thermal feedback: BHs “store” a given amount of energy and release it thermally by heating the surrounding gas particles
- Kinetic feedback: BHs launch outflows which release energy collisionally



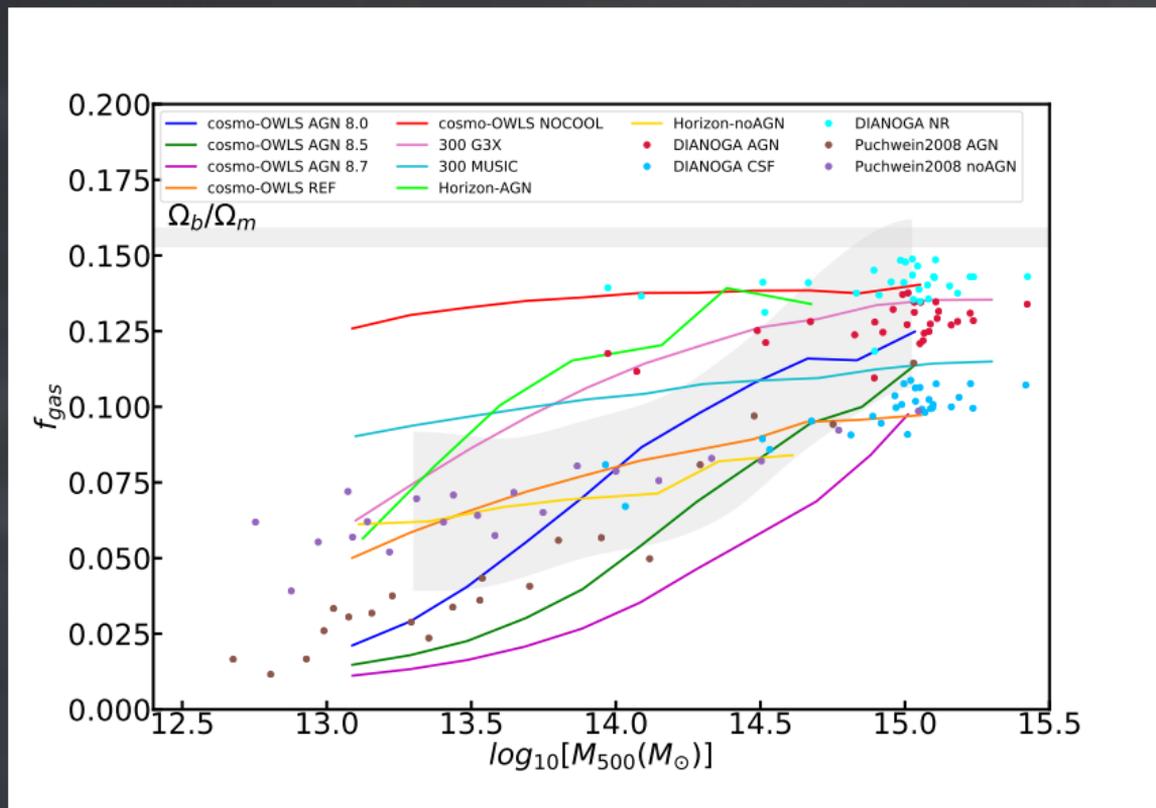
TNG50, Pillepich et al. 2021

# The gas fraction of groups as a probe of AGN feedback



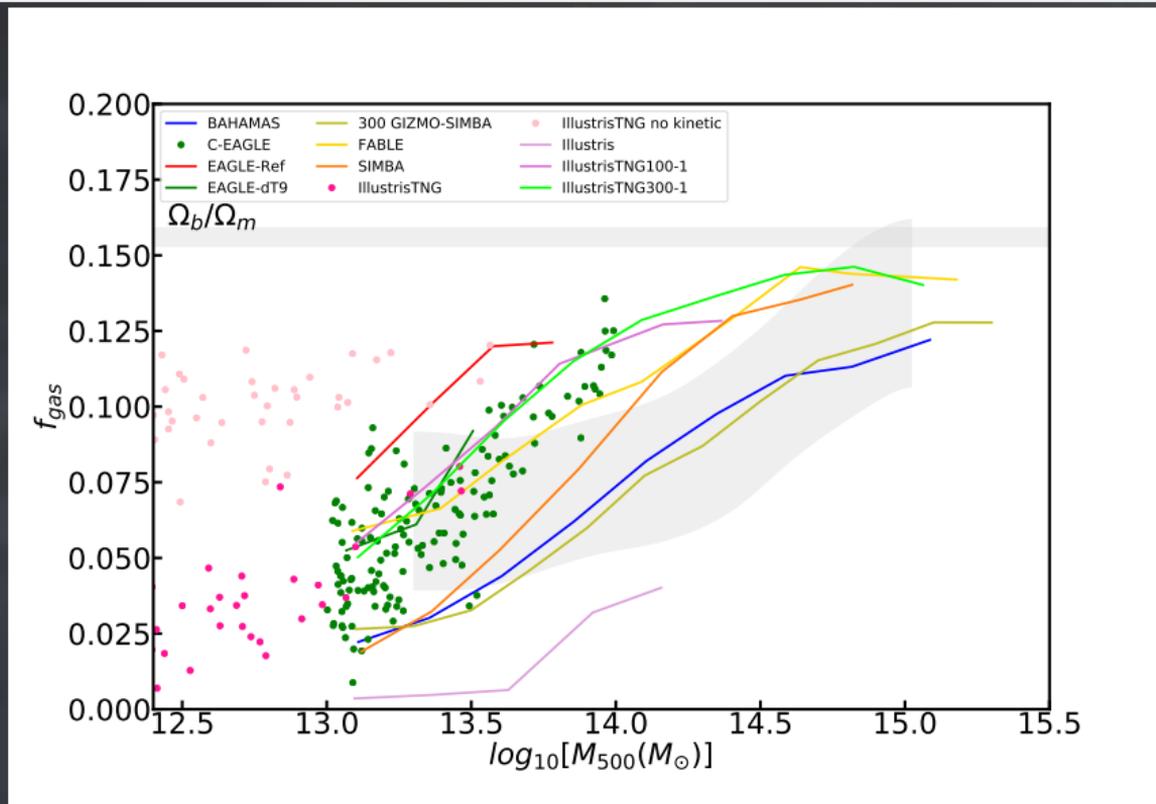
The integrated gas fraction  $f_{\text{gas}} = M_{\text{gas}}/M_{\text{tot}}$  is a strong function of halo mass; so is the total baryon fraction (gas+stars)

# The gas fraction of groups as a probe of AGN feedback /2



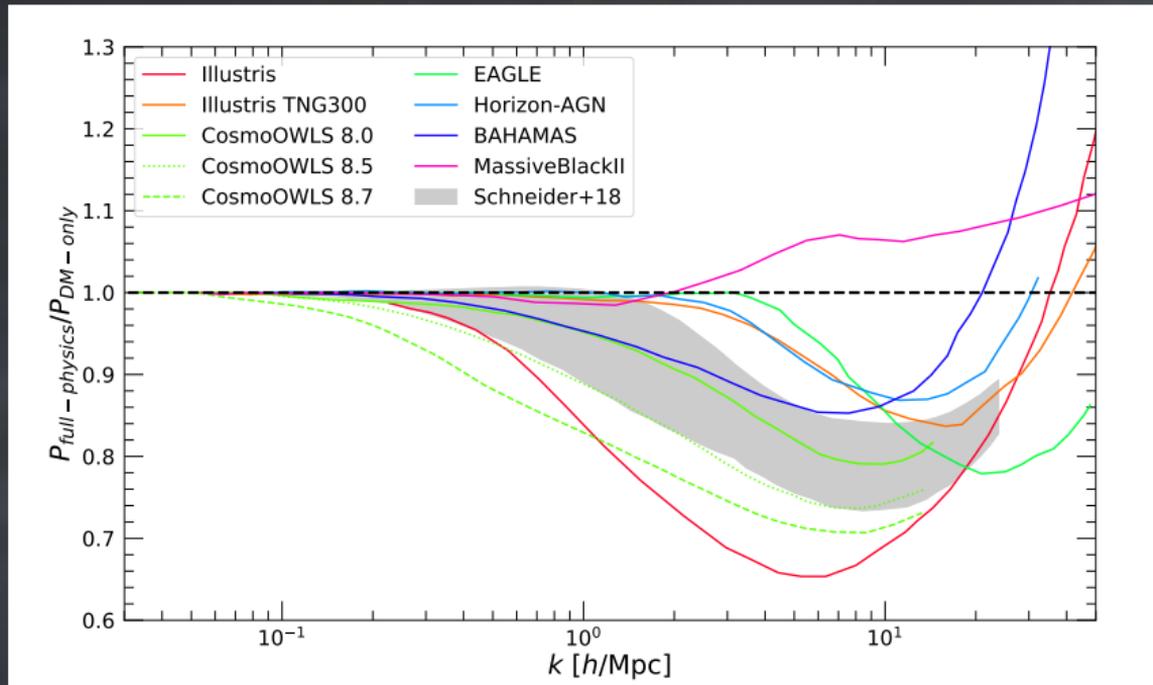
Changing the AGN feedback scheme has a wide impact on  $f_{\text{gas}}$  at galaxy group scales

# The gas fraction of groups as a probe of AGN feedback /3



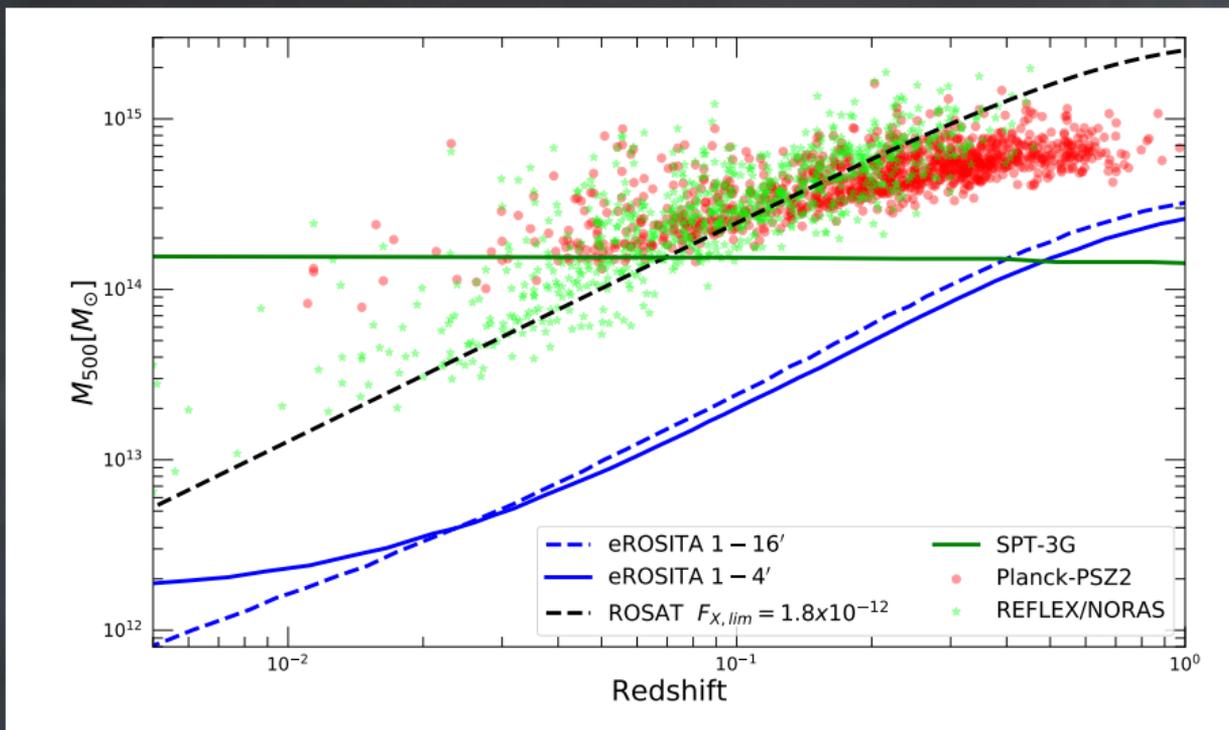
Even the most recent galaxy evolution models vastly differ in their prediction for the gas fraction of groups

# Impact on the matter power spectrum



AGN feedback alters the overall distribution of matter and thus the shape of the local matter power spectrum; leading source of systematic for upcoming cosmological experiments (Euclid, LSST)

# Galaxy groups with eROSITA



eROSITA will deliver large and well selected samples of galaxy groups to answer these outstanding questions

