Quenching and Quiescence

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Before we even got started, we were shown that the process of shocking…

… can lead to quenching …

… or (temporary?) quiescence …

… but that it can also trigger the formation of stars …

… and alien life forms ?

Mechanisms:

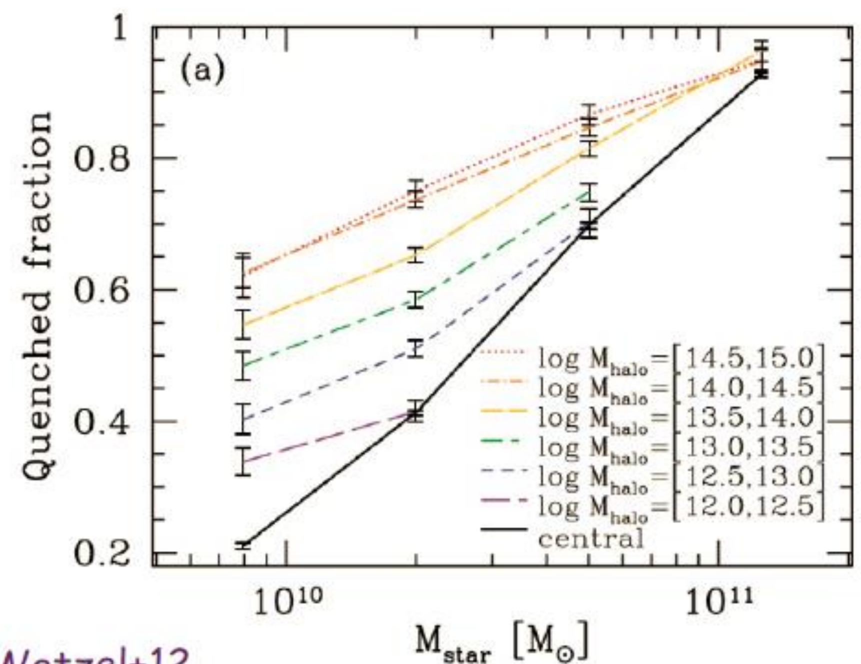
quenching	maintenance
Halo Quenching Preheating Quasar Mode Feedback Stellar Feedback Morphological Quenching	Gravitational Heating Thermal Conduction & Diffusion Radio Mode Feedback AGB Heating

Satellites
Strangulation
Ram-Pressure Stripping Tidal Stripping

Van den Bosch

Are satellite-specific quenching mechanisms required?

- *Wilson, vd Bosch:* Quenched fraction depends both on galaxy and environment, separable at z=0
- *Wilson:*
  - Stellar mass acts as dimmer
  - Environment acts as switch

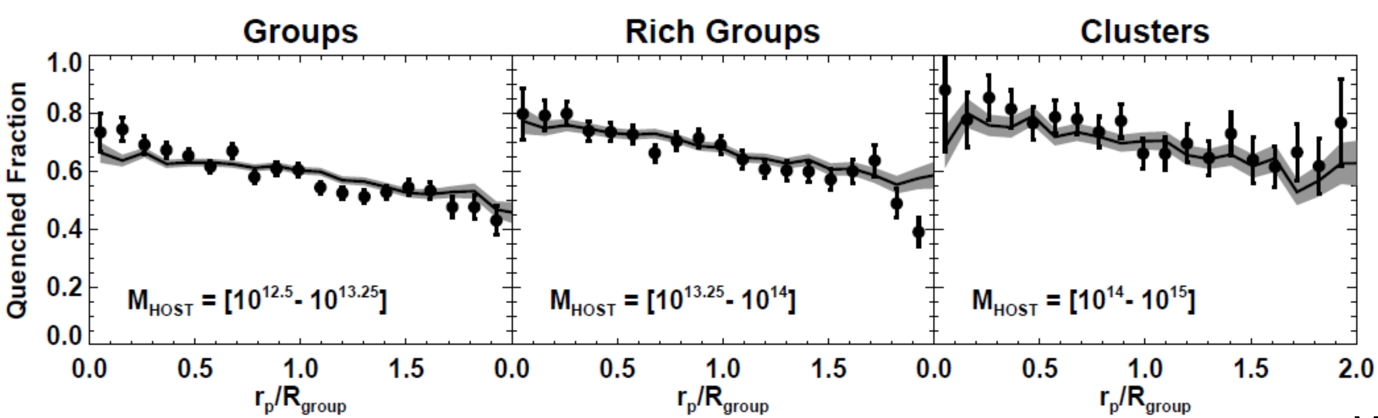


Wetzel+12

- *Moster, Behroozi, Rudnick:* Satellites are like

Are satellite-specific quenching mechanisms required?

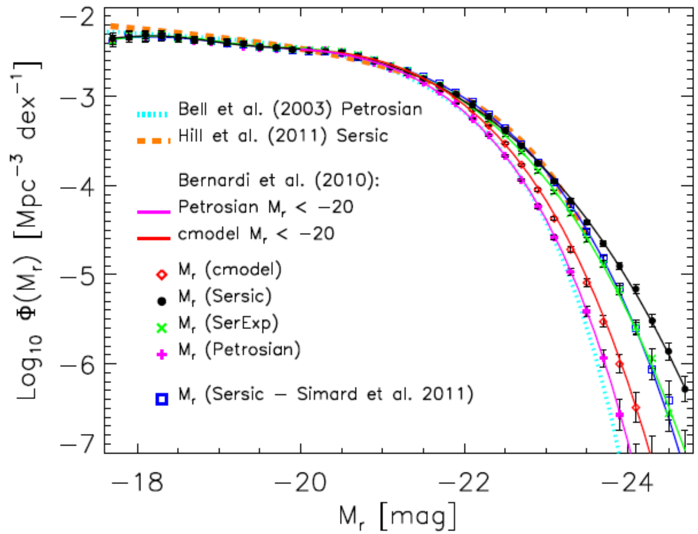
- *Somerville:* SAMs use them, but quench satellites too effectively
- *Van den Bosch:* Hearin/Watson showed that abundance + age matching reproduces observations.
  - Subhalo formation time is all that matters
  - No need for satellite specific processes

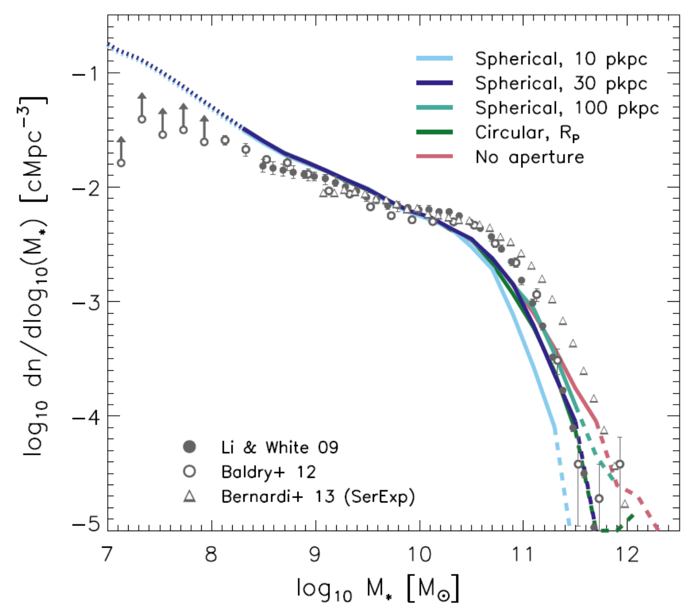


Watson+ '14

Do massive galaxies grow more than we thought?

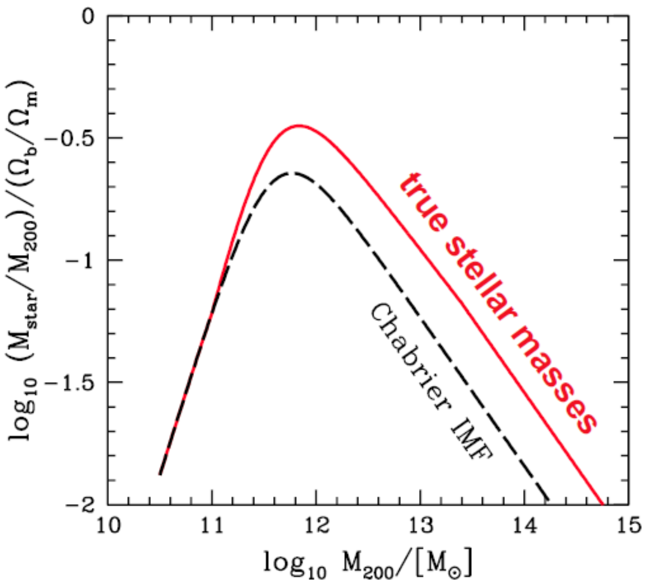
- *Bernardi:* Sky subtraction, aperture size, choice of Sersic fit, M/L at fixed IMF all important. Decline of mass function less steep than before.
- *Crain:* Models may not need changing, need to do comparison properly.
- Less quenching? Outer parts probably accreted → formed in lower mass galaxies!





Do massive galaxies grow more than we thought?

- *Dutton:* Dense galaxies have bottom-heavy IMF → more massive than we thought
- Note:
  - IMF would then vary with radius → most of the extra mass may have more ordinary IMF
  - Models and observations care mostly about massive stars. Low-mass stars only affect gas consumption and gravity → no big changes needed to accommodate bottom-heavy IMF

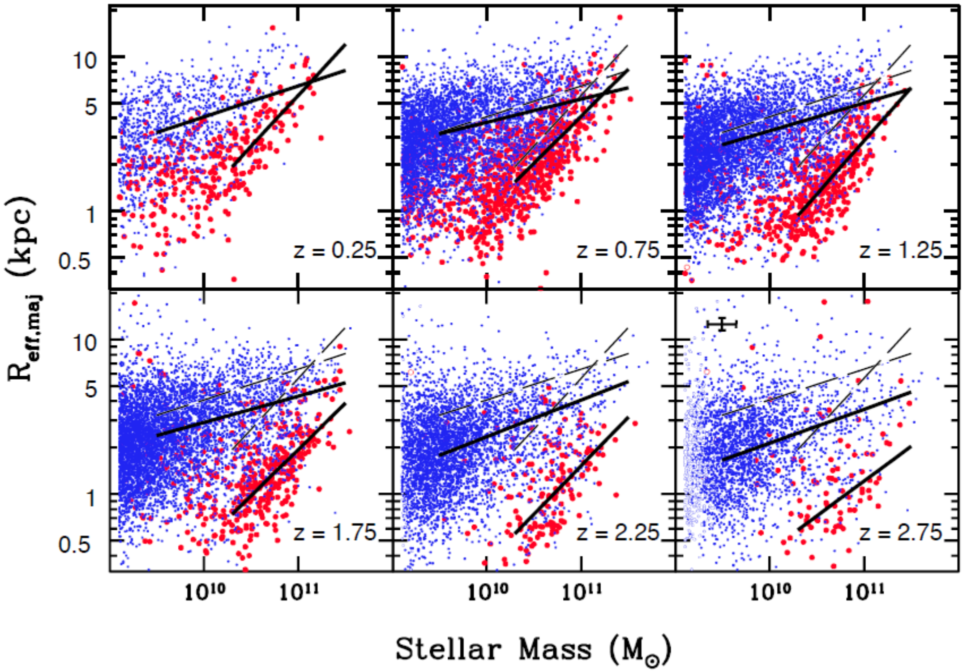


Do massive galaxies grow more than we thought?

- *Kaviraj:* UV observations indicate that SF in ETGs adds 30% of stellar mass after z~1.
- *Davis:*
  - > 22% of Es have molecular gas, which is forming stars at relatively low efficiency (*Martig:* Morphological quenching)
  - Kinematics suggest gas has external origin (accreted or cooled as opposed to stellar mass loss)
  - No cold gas in slow rotators (i.e. most massive Es)

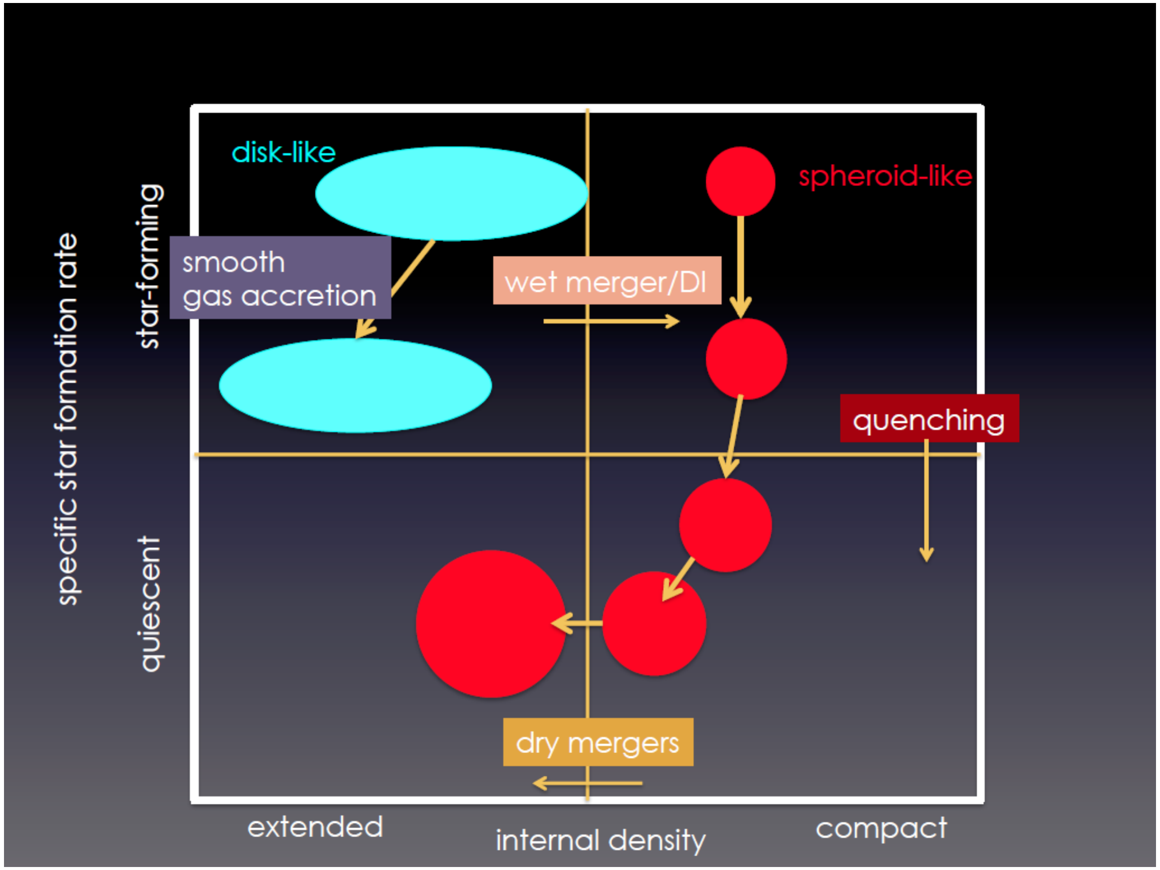
What do quenched galaxies look like?

- *Bell, van der Wel, Somerville, Bernardi:*
  - $n_s > 2.5$
  - Large B/D (Jahnke: bulge not an active player)
  - $M_* > 3e9\ M_\odot$ if central
  - Oblate/triaxial axis ratio
  - High surface density
  - High velocity dispersion
  - Compact



How/when are galaxies quenched?

- *Somerville/Schawinski:* Observations indicate quenching + morphological transformation go together.



Halo quenching

- *Birnboim/van de Voort*: Change of accretion mode at ~$10^{12}\ M_\odot$
- *Van de Voort:* Transition to hot halo does not quench by itself, need AGN
- Why then do quenched galaxies live in haloes with $M > 10^{12}\ M_\odot$?
  - SAMs (Fanidakis/Somerville): Affects accretion mode, BH fed by hot halo → radio mode. Works well for galaxy and BH properties. Not for ICM?
  - Questions: Why would BH mode care about accretion onto galaxy? Could it be that the same feedback operates differently in a hot halo?

Anything Goes Now feedback?

- Enormous amount of energy to play with: $0.1\, M_{BH} c^2 \gg M_{*,bulge} \sigma^2$
- Black hole radius of influence completely unresolved

→ anything goes!

Anything Goes Now feedback?

However, we do have some understanding (*King, Costa*):

- Outflow first momentum-driven, but becomes energy-driven at ~ 10^2 pc
- Expect ~ 5% of radiated energy to be coupled

→ Thermal bomb on a scale ~ resolution of simulations

Anything Goes Now feedback?

If BH growth is self-regulating, as in most models, then freedom is severely limited (*Croft, Teyssier*):

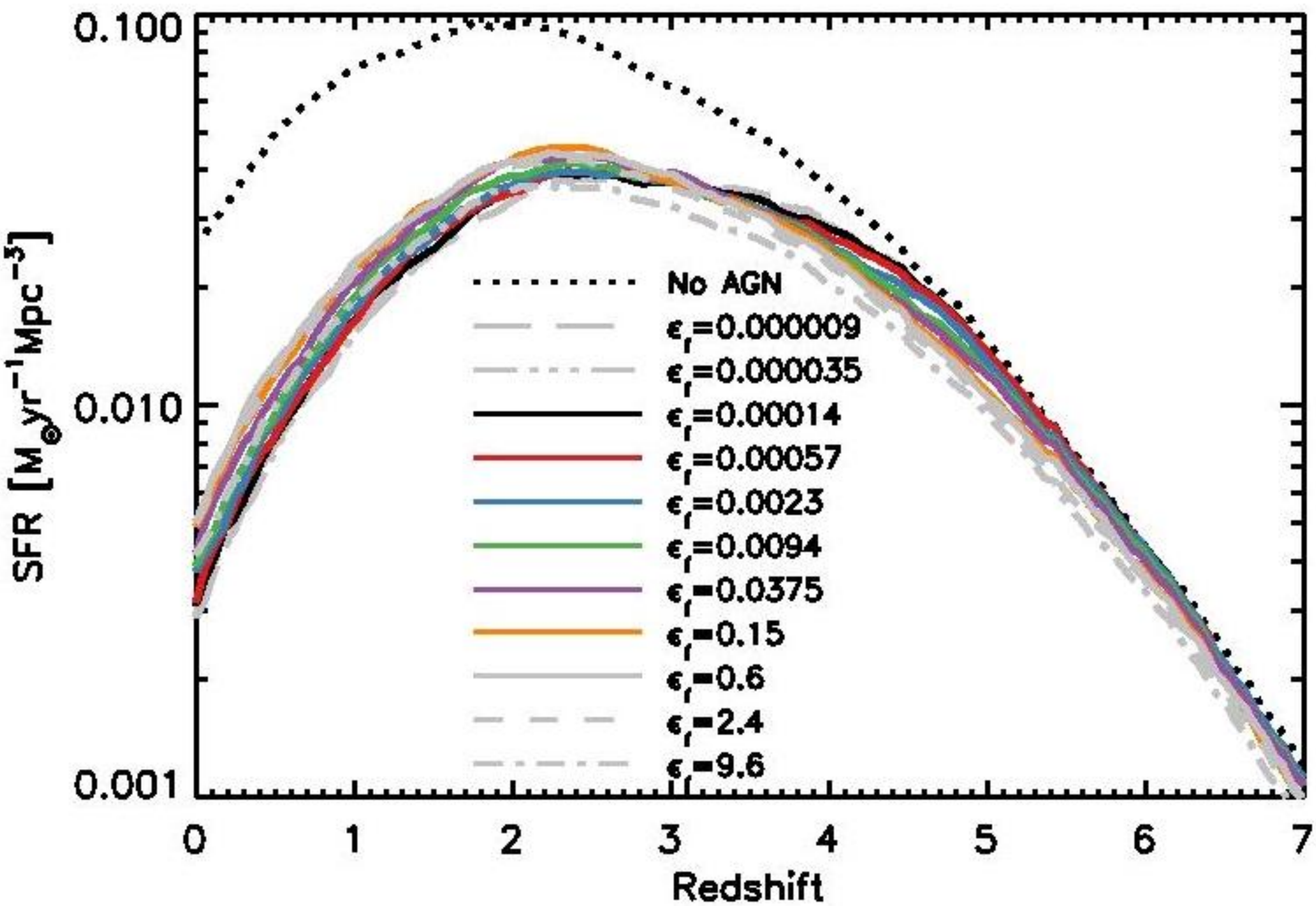
- BH mass is the only thing that depends on fraction of accretion energy that is in the bombs
- Result insensitive to details like accretion and seeding, provided the BH grows in absence of feedback

Jahnke: BH scaling relations result of merging, not self-regulation

However:

- *Sensible for quenched galaxies, but Soltan argument implies gas accretion drives growth for active galaxies?*
- *Very important to extend BH scaling relation to star-forming galaxies*

Varying the efficiency of AGN feedback



Booth & JS (2009, 2010)
Also *Teyssier* talk

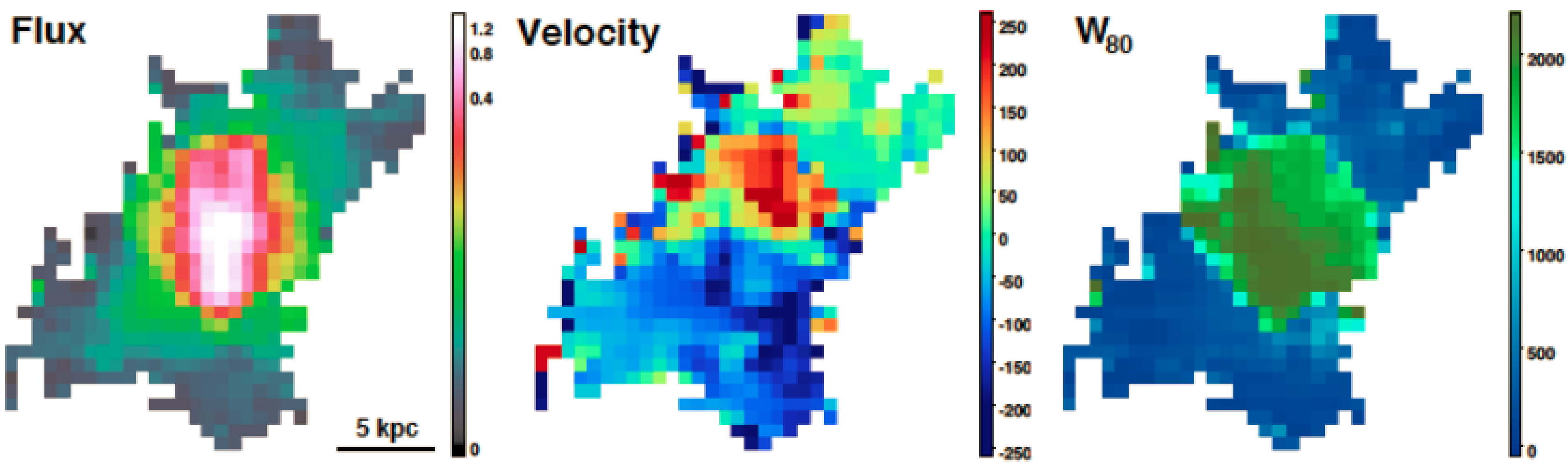
Anything Goes Now feedback?

- Stellar mass dependent on assumed efficiency of feedback from star formation
- Efficiency (thermal losses) cannot be predicted until structure of ISM is resolved

→ Stellar feedback is no less (more?) "anything goes" than AGN feedback

Evidence for quasar-mode feedback:

- *Zakamska:* High-L radio-quiet QSOs surrounded by spectecular OIII nebulae.
  - Spectra suggest outflow of ~800 km/s over ~10 kpc.
  - Energy in outflow accounts for ~ 2% of L_{AGN}

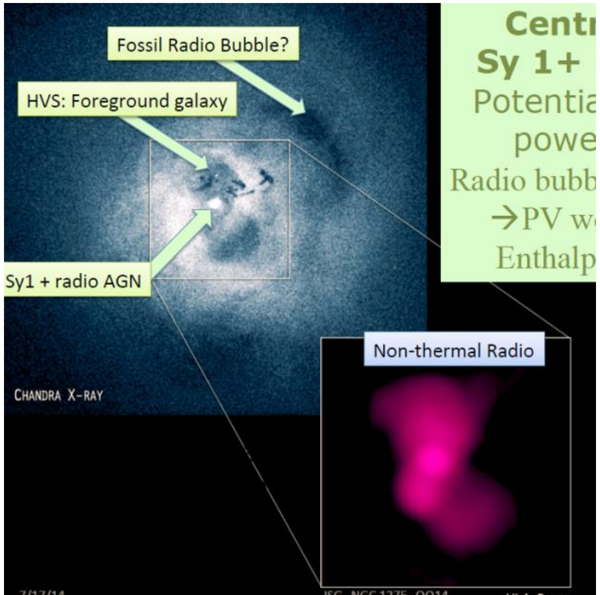


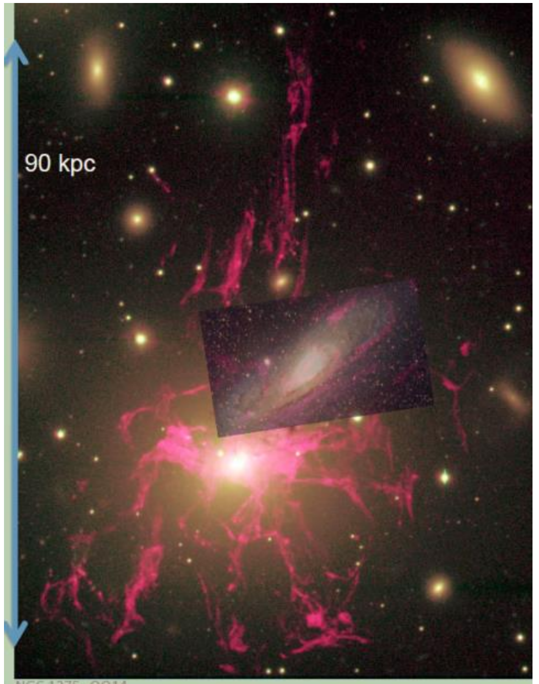
Can AGN quench disks?

- Difficult because outflow takes path of least resistance *(Cielo, Costa)*
- Hot bubble may induce rather than halt SF *(King)*
- Fortunately, we heard that observations indicate that they do not have to:
  - Only Es need to be quenched fast *(Schawinsky, Somerville)*
  - Disk SSFRs independent of M_* → tilt of MS due to change in B/T (Abramson+ '14)

Radio mode (= maintenance mode?)

- *La Franca:* No radio loud/radio quiet bimodality
- Strong evidence that ICM knows about radio mode (*Pfrommer, Canning, Gallaghar)*
  - Is the cool gas uplifted or does it condense out? Probably the latter (Canning, Gallaghar)
  - Does cool gas trigger the AGN or does the jet trigger cooling? Second option would not give self-regulation…
- Cosmic ray heating (*Pfrommer)*





Can radio mode be the quenching mechanism?

- Quenching must happen in low-mass groups, not clusters
- Can low f_{gas} within R_{500} be caused by buoyant bubbles?
- Radio mode operates when BH growth is slow → Difficult to explain BH scaling relations

Maintenance:
Balancing cooling w/o AGN:

- Conduction: no (*O'Shea, Hopkins*)
- Stellar mass loss: no, may even make it harder (*Hopkins, Bregman)*
- Gravitational heating: no *(Hopkins)*
- SNIa (bulge/low-mass Es): yes *(Bogdan, Groves)*

CGM

- Cool/warm gas (absorption):
  - Not much difference between red and blue galaxies, except for OVI *(Werk)*
  - Lots of gas and metals around galaxies *(Werk, Hennawi)*
  - Complexity not captured by simulations *(Hennawi)*
- Hot gas in emission *(Anderson):*
  - No break in X-ray scaling relations from clusters to galaxies
  - Hot gas around isolated Es does not account for missing baryons

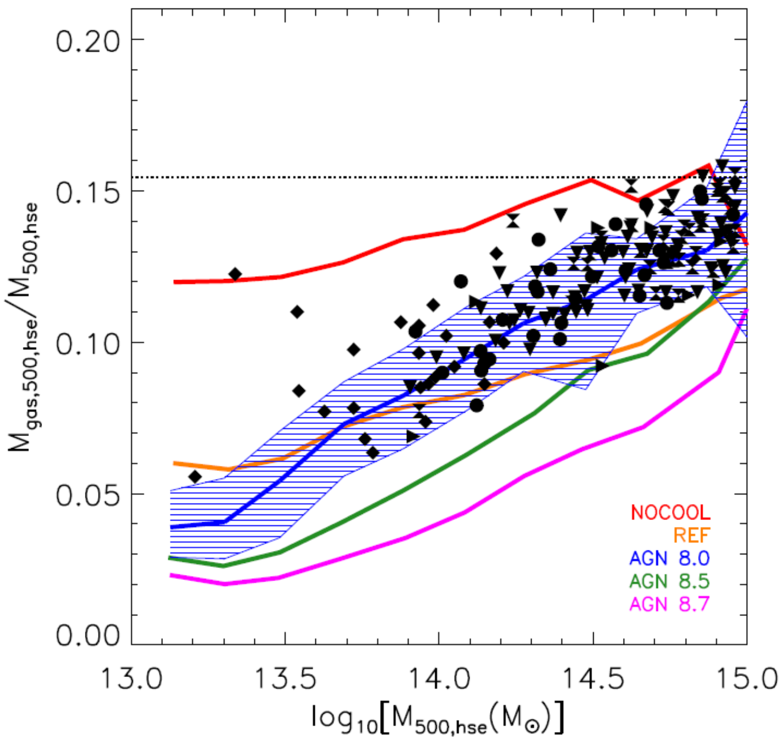
Radiation

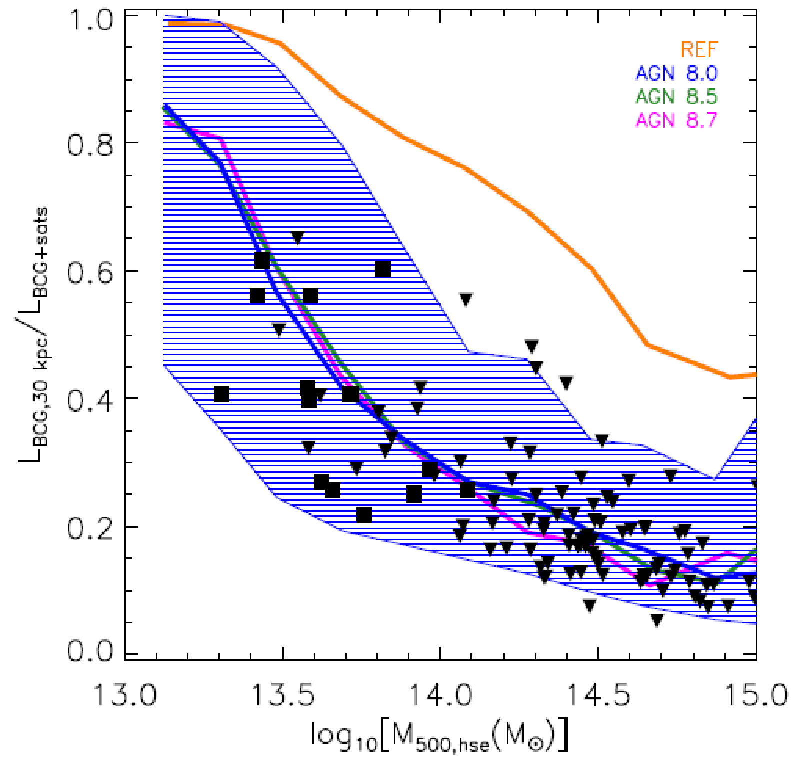
- Sources: AGN *(Lusso)*, X-ray binaries, WDs *(Gilfanov)*, (Post-)AGB *(Marigo)*
- HeII4686 rules out accreting WDs as progenitors of SNIa *(Woods)*
- LINERS are mostly not AGN → don't just throw them out of your sample *(Singh)*
- *Gnedin:* Usually unimportant and don't need radiative transfer where it matters

Damping/self-regulation

- Photo-ionisation by XRBs suppresses CGM cooling rate, changes transition from cold to hot accretion *(Cantalupo, Kannan)*
  - Note: scales as SFR → regulation rather than quenching
- Non-equilibrium can slow down (or speed up) cooling. Cannot just assume ionisation/chemical equilibrium *(Richings)*
- *Martig:* Morphological transformation accompanied by Morphological Quenching (Damping?). Bulge stabelizes disk due to lower disk mass and larger shear/Coriolis.
- *Meidt:* Streaming motions reduce SF efficiency

Look at stars and CGM simultaneously

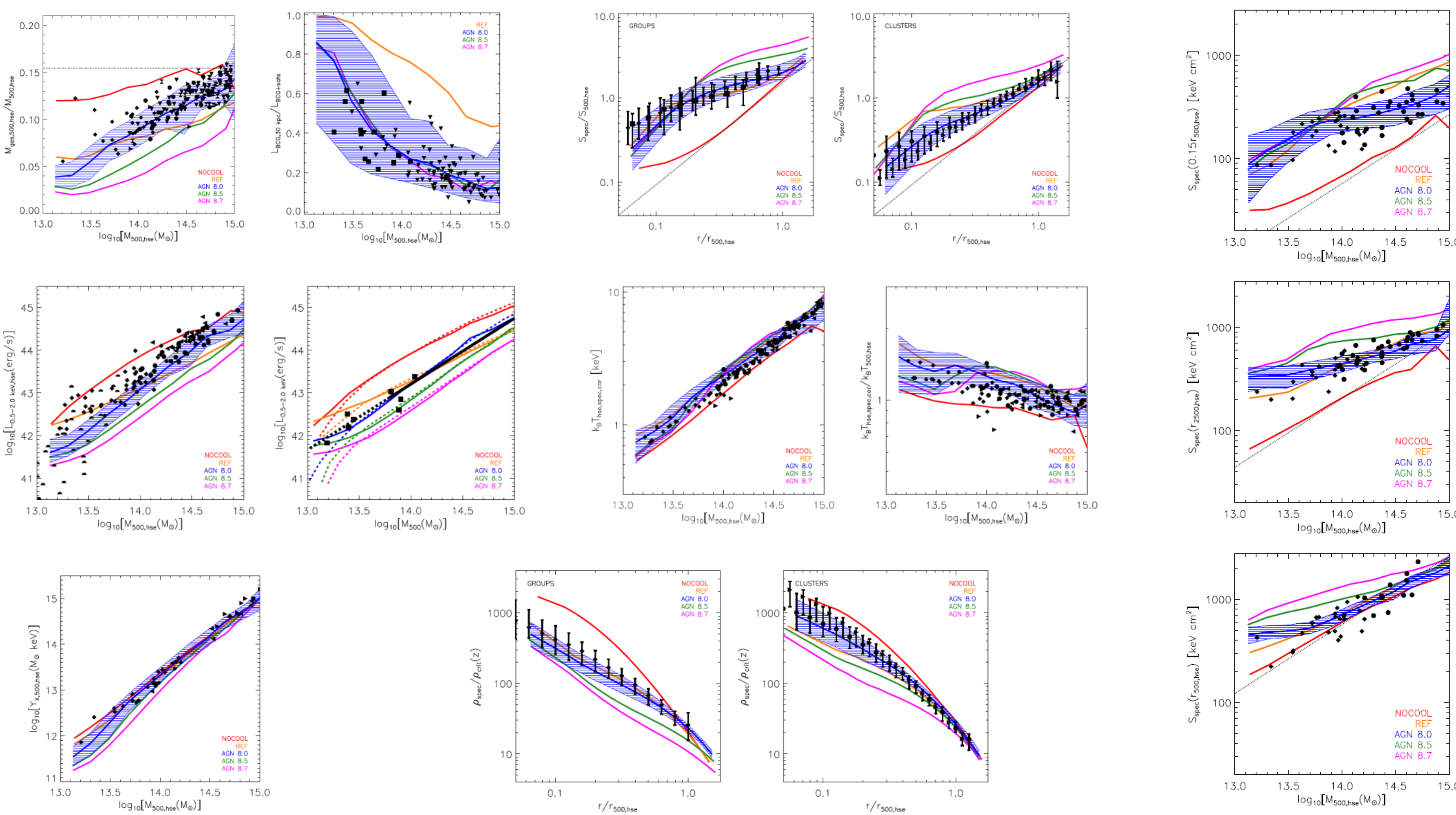




Amount of feedback energy less important than the manner in which it is injected!

(Cosmo-)OWLS: Le Brun+ '14; McCarthy+ '10

Thermal bomb AGN FB works



Stellar metallicities too low, rest works well

(Cosmo-)OWLS: Le Brun+ '14; McCarthy+ '10

How does thermal bomb AGN FB operate in this successful model?

- **Pre-ejection** of low-entropy gas: ejected from progenitors of todays groups/clusters
- Replaced by high-entropy gas that was never heated by the AGN-driven outflow
- Higher entropy → reduced cooling rate
- Nearly all of the action takes places at high z, when the BHs grew and the stars were formed

McCarthy+ '11

Quenching logic (pun intended):

Observations indicate that:

1. Disks are star-forming
2. Bulges are quiescent

From this it follows that:

- Quenched galaxies have very high B/T (and associated properties: e.g. compact, high surface density, high vel. dispersion, high Sersic index)
- Quenched galaxies live in environments that are not conducive to disk growth
  - In orbit around another galaxy; or
  - At the center of a halo w/o cold flows
- Quenching mechanism must be
  - Ineffective in disks, e.g. nuclear outflow
  - Effective during morphological transformation, e.g. nuclear outflow triggered by wet merger or violent disk instability

THANKS TO THE ORGANIZERS!