Quenching & Quiescence

...and introductory overview...

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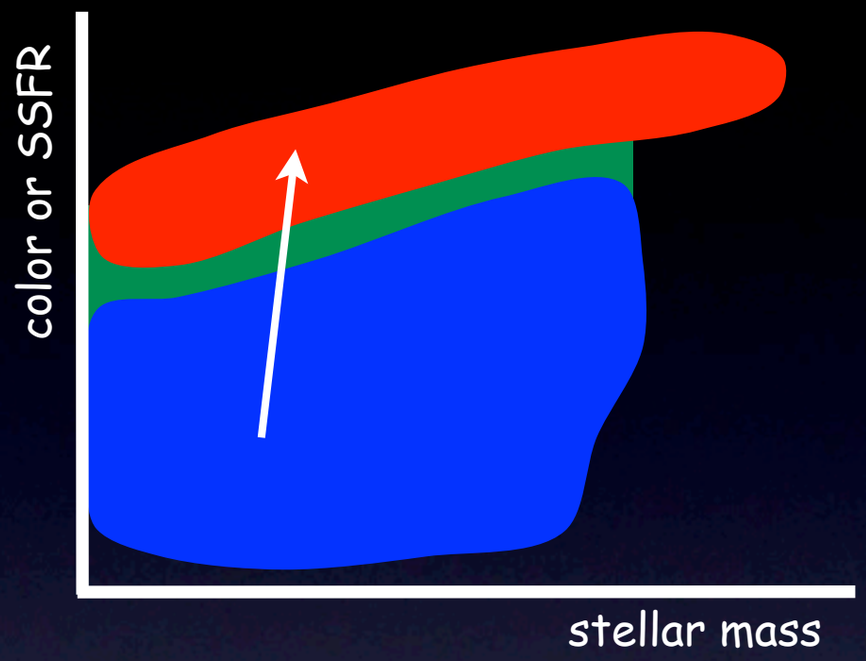
Yale University

Quenching + Quiescence



Quench

\kwench\ *transitive verb*

"to put out or extinguish"

Merriam-Webster Dictionary

"to transit from blue cloud to red sequence"

vdBosch Dictionary & this talk

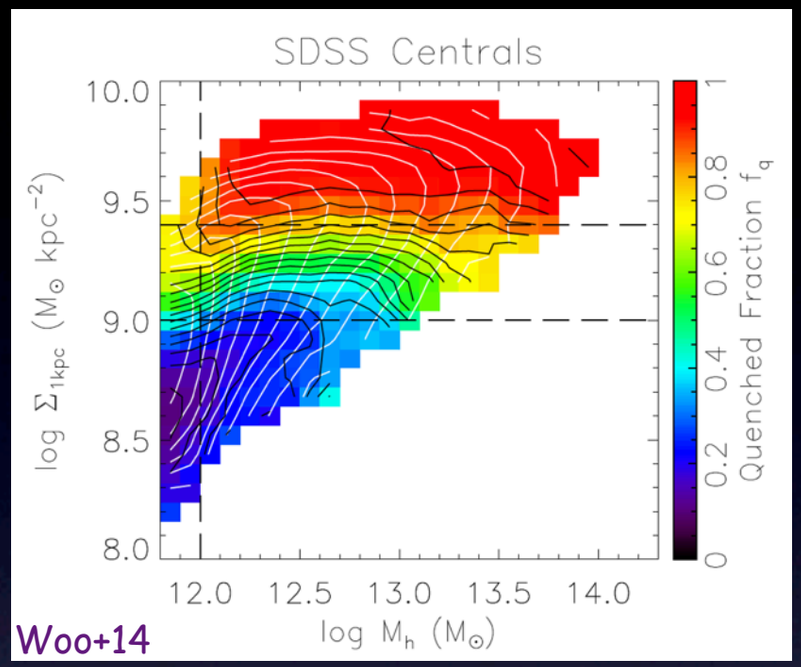
OUTLINE:

Quenching Demographics [who/where/when]

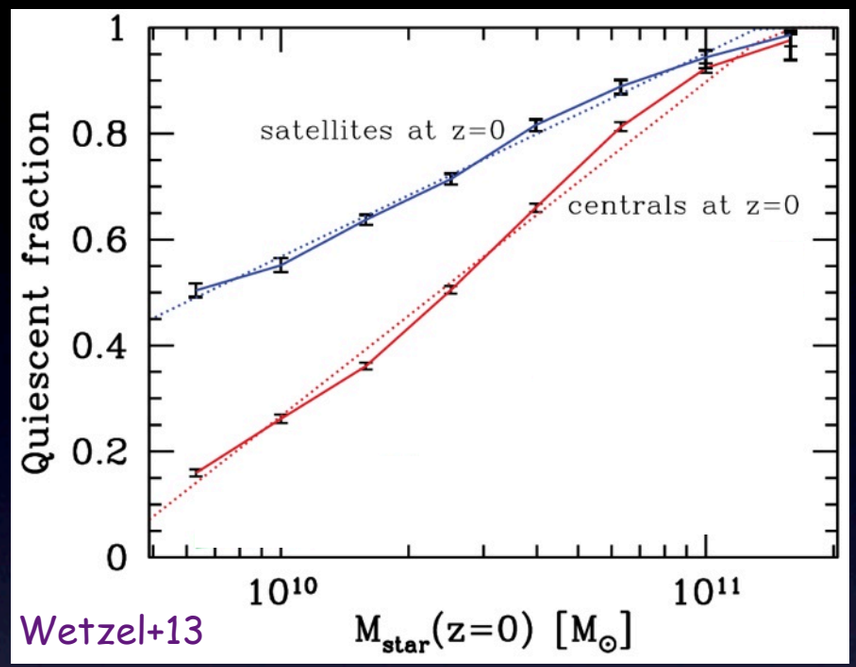
Quenching Mechanisms [how to quench]

Maintenance Mechanisms [how to remain quenched]

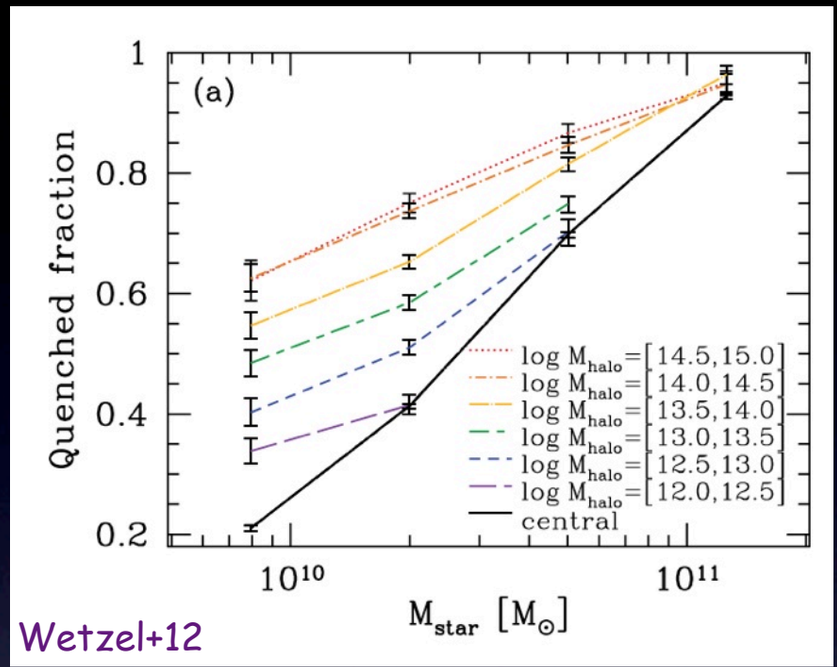
Quenching Demographics



Woo+14



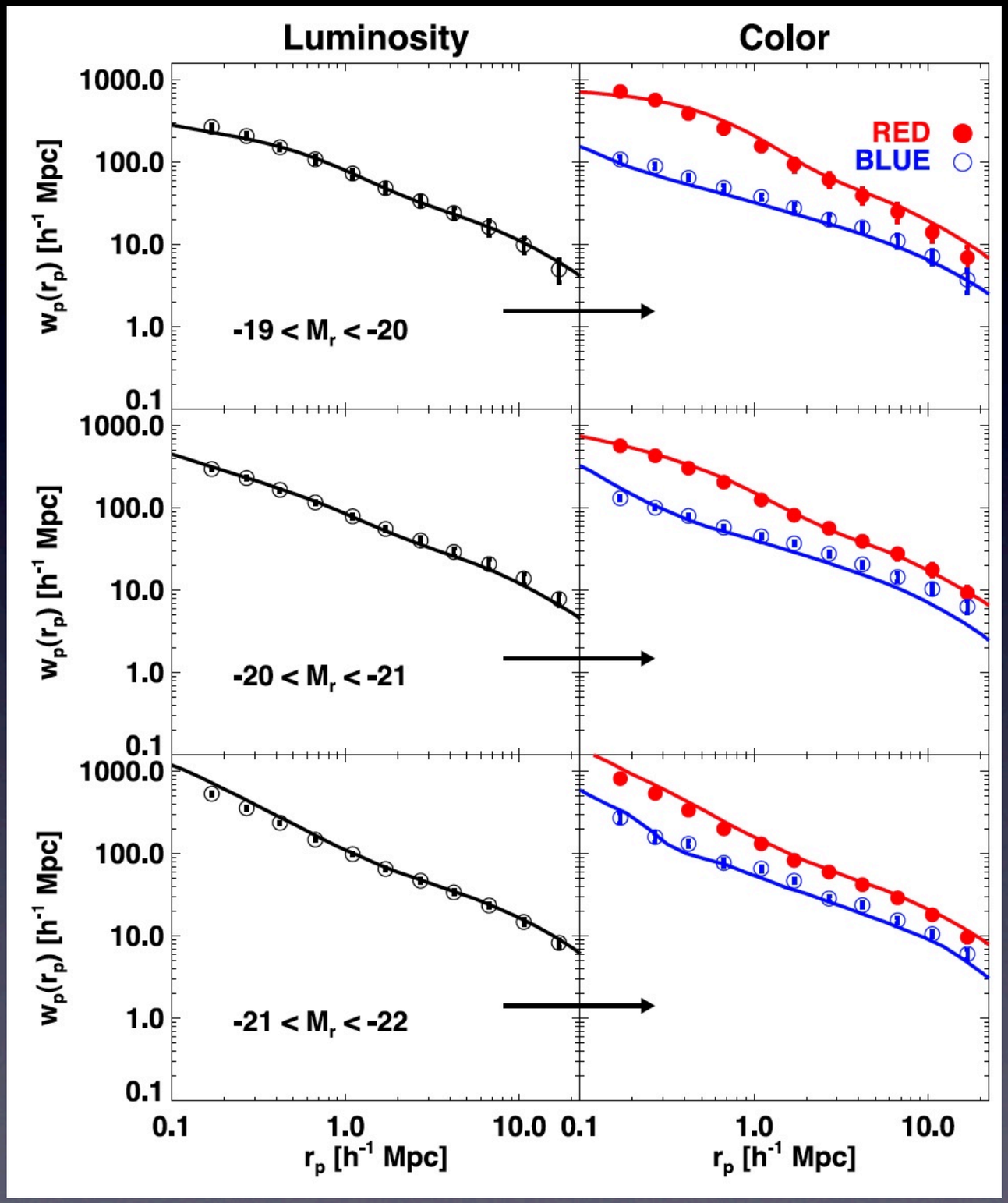
Wetzel+13



Wetzel+12

- The best indicator of being quenched is the central stellar surface density or the B/D ratio (Kauffmann+06; Bell 08; Lang+14; Woo+14)
- A satellite of given stellar mass is more likely quenched than a central (vdB+08; Peng+12; Wetzel+12)
- Quenched fraction of satllites increases with mass of host halo (Wetzel+12)
- Quenched fraction of centrals increases with stellar mass and halo mass (causality not implied) (Weinmann+06; vdB+08;Peng+10; Wetzel+13)

The Age-Matching Miracle



Hearin & Watson 2013

Step 1: run N-body simulation (DM only), and identify haloes.

Step 2: populate haloes with galaxies using standard subhalo abundance matching ($M_h \leftrightarrow M_\star$)

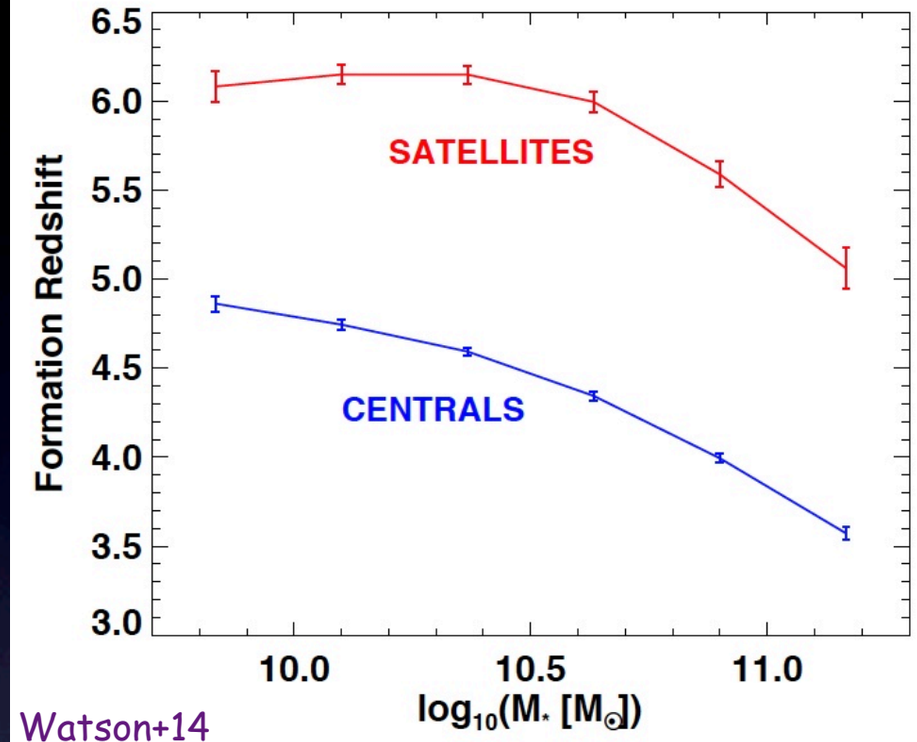
Step 3: For given (narrow) bin in $M_\star$, sort haloes according to formation time.

Step 4: Use observed color distribution of those galaxies, and assign reddest colors to oldest haloes..

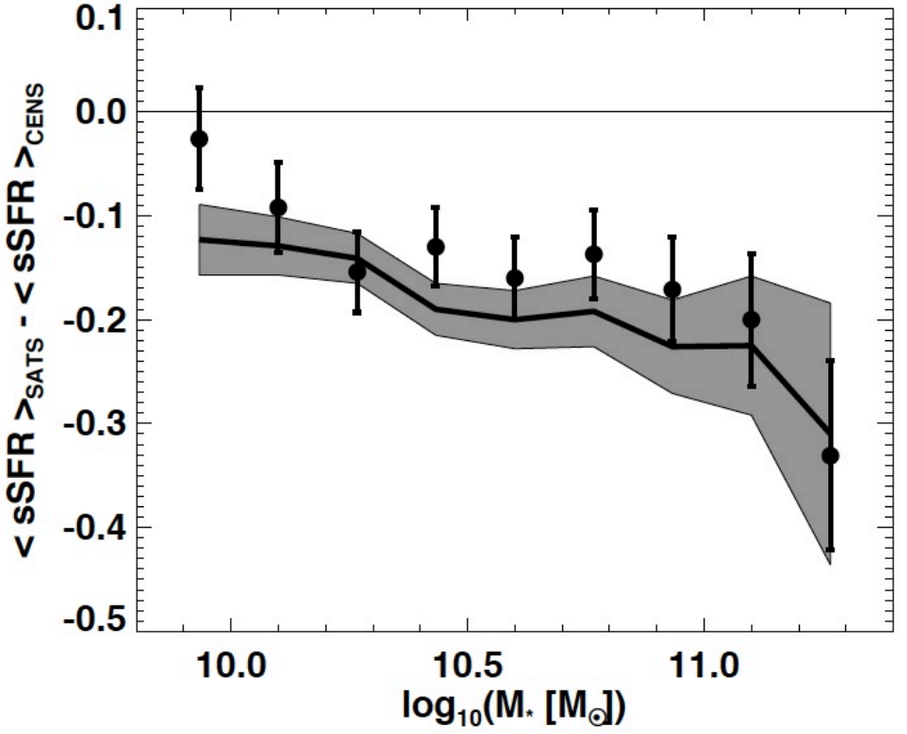
clustering of red and blue galaxies in excellent agreement with observations

For details, see Hearin & Watson (2013) and Watson+14

The Age-Matching Miracle



Watson+14



Age Matching also perfectly reproduces

- Radial profiles of red/blue galaxies in groups & clusters
- Differences between centrals & satellites w/o satellite-specific treatment!!
- Galactic Conformity (Weinmann+06, Kauffmann+13

Cosmic Coincidence or Physical Insight?

Globally: anti-correlation between stellar age and halo assembly time

At fixed $M_\star$: tight correlation between stellar age and halo assembly time

Quenching Mechanisms

	Centrals	Satellites
Fuel Exhaustion	Halo Quenching Preheating	Strangulation
Fuel Removal	Quasar Mode Feedback Stellar feedback	Ram-Pressure Stripping Tidal Stripping
Fuel Pollution	Morphological quenching	-

Disclaimer: this list is not exhaustive; apologies if your favorite mechanism is not listed here..

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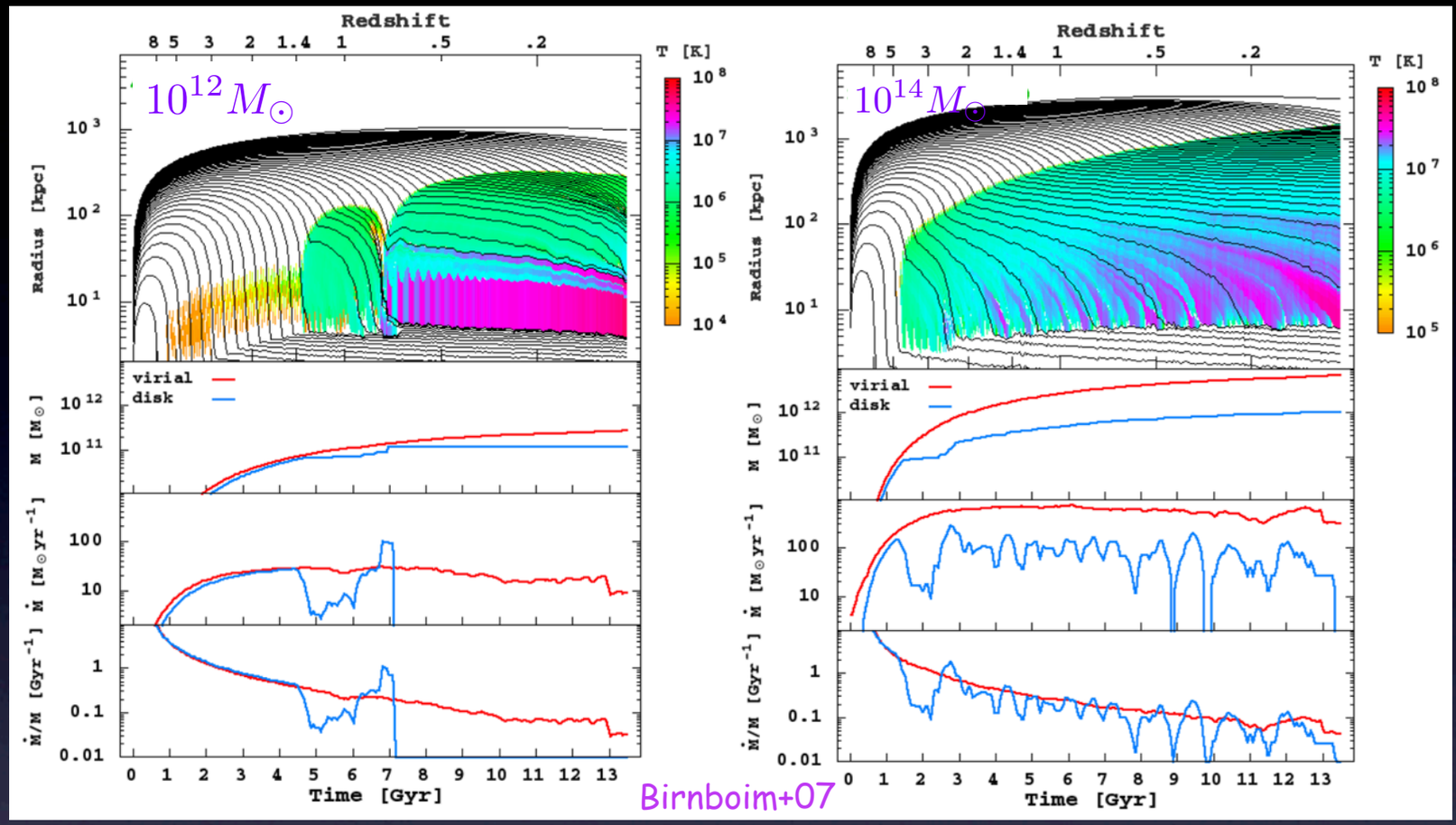
Quenching Mechanisms

Centrals

Halo Quenching
Preheating

Quasar Mode Feedback
Stellar feedback

Morphological quenching

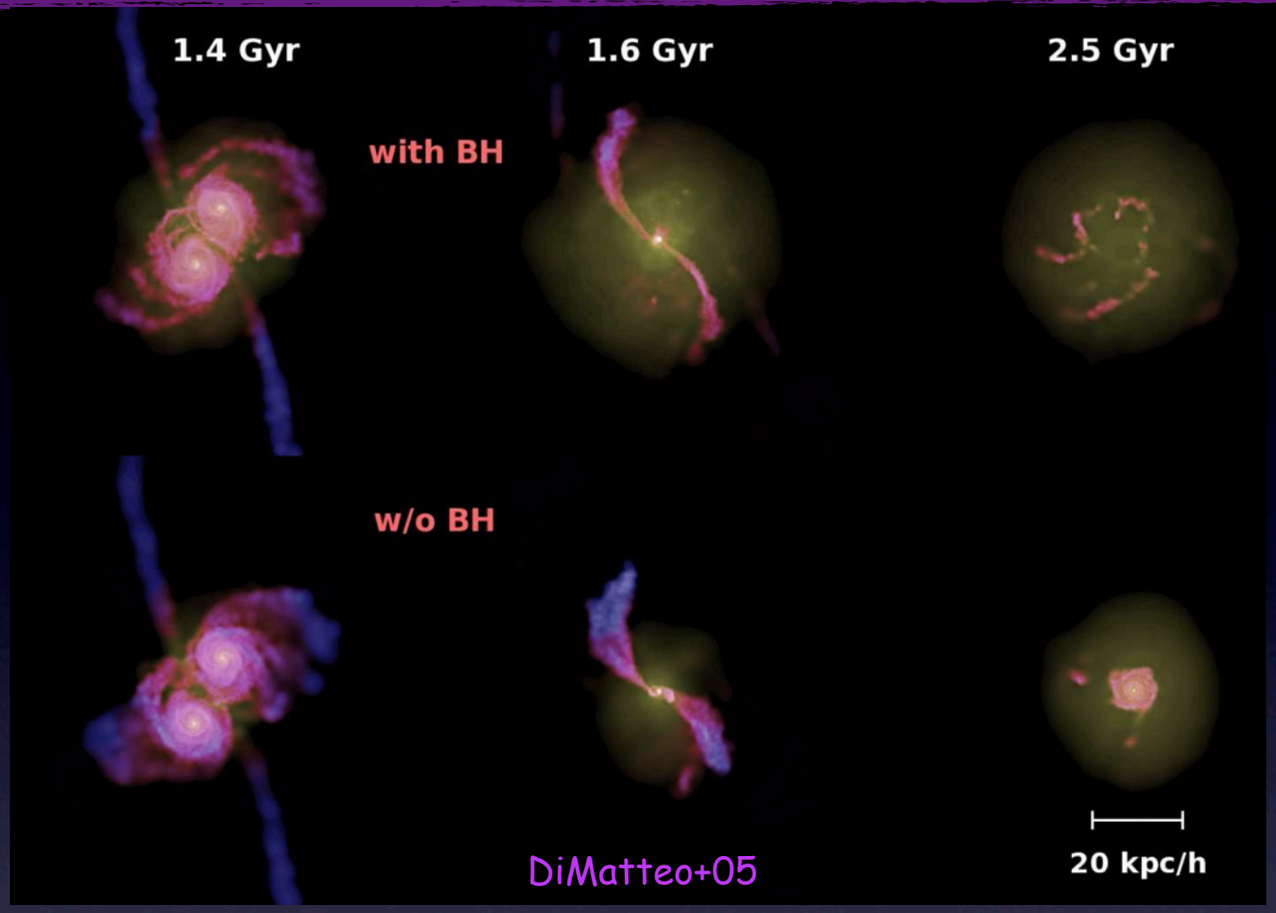


Halo Quenching: quenching related to the halo mass transitting from cold-mode to hot-mode accretion (Birnboim & Dekel 2003; Cattaneo+08)

- Does not explain, by itself, correlation of quenching with bulge mass
- For massive halos (>10^{13} Msun) requires efficient maintenance mode

Quenching Mechanisms

Centrals
Halo Quenching Preheating
Quasar Mode Feedback Stellar feedback
Morphological quenching



Quasar Mode: form of AGN feedback (radiative) which operates during high accretion rates (close to Eddington) at high radiative efficiency.
(Silk & Reese 98; Fabian 99; DiMatteo+05)

- natural link to merging --> bulge/spheroid creation (Hopkins+05,06,07a,b,..z)
- energetically feasible & observational support (quasar winds)
- actual process poorly understood (are winds driven by pressure or radiation)
- favorite mechanisms in most models & simulations

Quenching Mechanisms

Centrals

Halo Quenching
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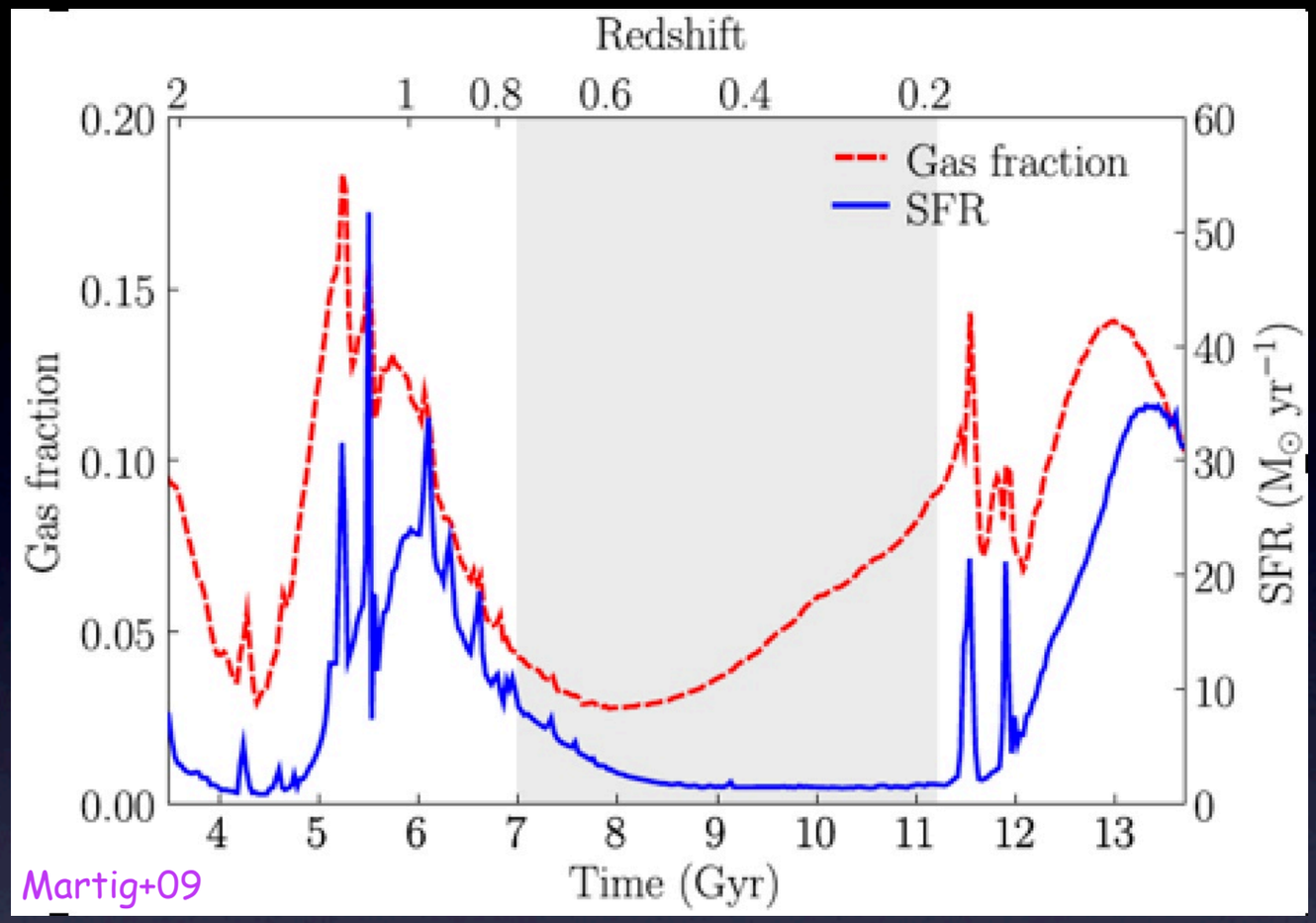


Morphological Quenching: Bulge formation via secular evolution can stabilize the disk against star formation (Martig+09)

- natural link between quenching and bulge dominance
- maintenance required (quenching is only temporarily)
- might be dominant quenching mode in low mass haloes (< 10^{12} Msun)

Maintenance Mechanisms

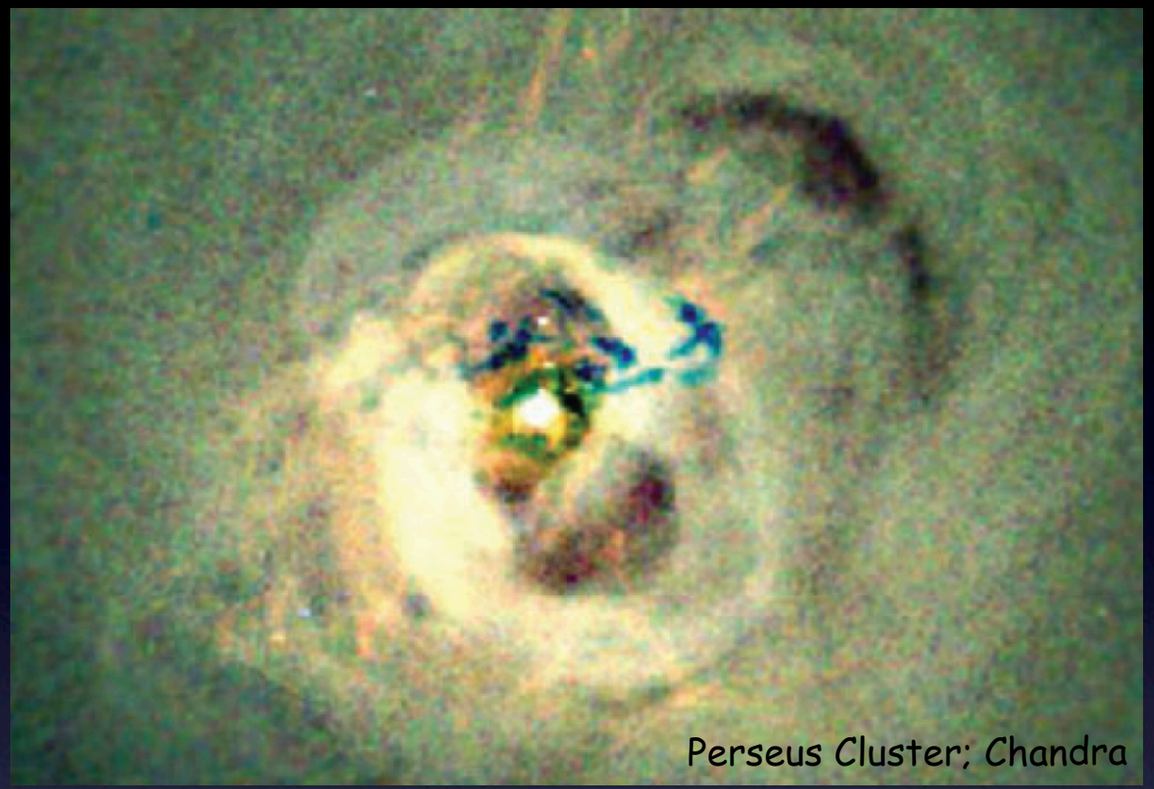
Overcooling problem, aka Cooling Flow Problem, demands that some mechanism offsets the cooling in the hot atmospheres of massive haloes.
This is also required to maintain quiescence in their central galaxies.

Requirements:

- suppress cooling rates by 5-10% of `classic' prediction over Gyr timescales.
- detailed balance (claimed); suggestive of feedback-loop [thermostat]
- heats needs to be distributed over large volume/mass fraction in core

Maintenance Mechanisms

Maintenance Mechanisms
Radio Mode Feedback Gravitational Heating Conduction & Diffusion AGB Heating etc.



Perseus Cluster; Chandra

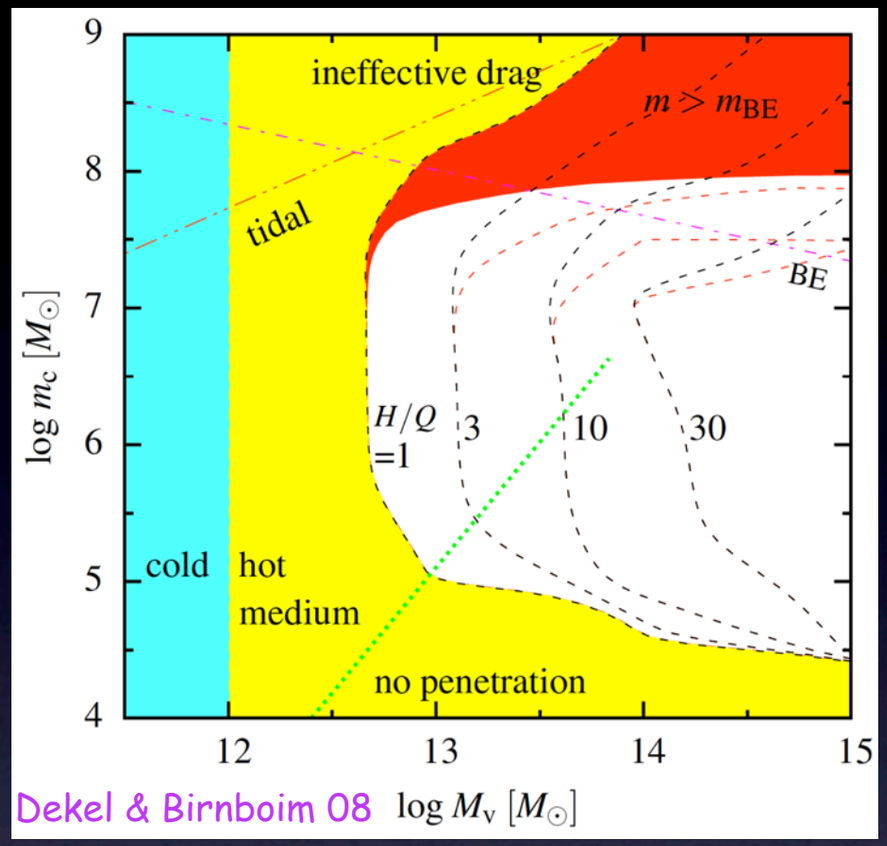
Radio Mode: form of AGN feedback (kinetic) which operates via jets during low BH accretion rates (Binney & Tabor 1995; Ciotti & Ostriker 97; Churazov+02)

- claims advantage of feedback loop, but poorly understood
- energetically feasible & observational support (caveties, shocks, sound waves)
- actual process poorly understood (shocks, sound waves, B-field, CRs, viscosity)
- favorite mechanisms in most models & simulations

Maintenance Mechanisms

Maintenance Mechanisms

Radio Mode Feedback
Gravitational Heating
Conduction & Diffusion
AGB Heating
etc.



Gravitational Heating: release of gravitational energy through deceleration of matter moving wrt hot gas (Fabian 03; Wang & Abel 07; Khochfar & Ostriker 07)

Virial Theorem assures that it is energetically feasible

Different scenarios & energy transfer mechanisms have been proposed:

- Dynamical Friction on satellite galaxies (El Zant 04, 05)
- Drag on gas clumps associated with thermal instability (Fabian 03)
- Drag on gas clumps associated with cosmological accretion (Dekel & Birnboim 08)

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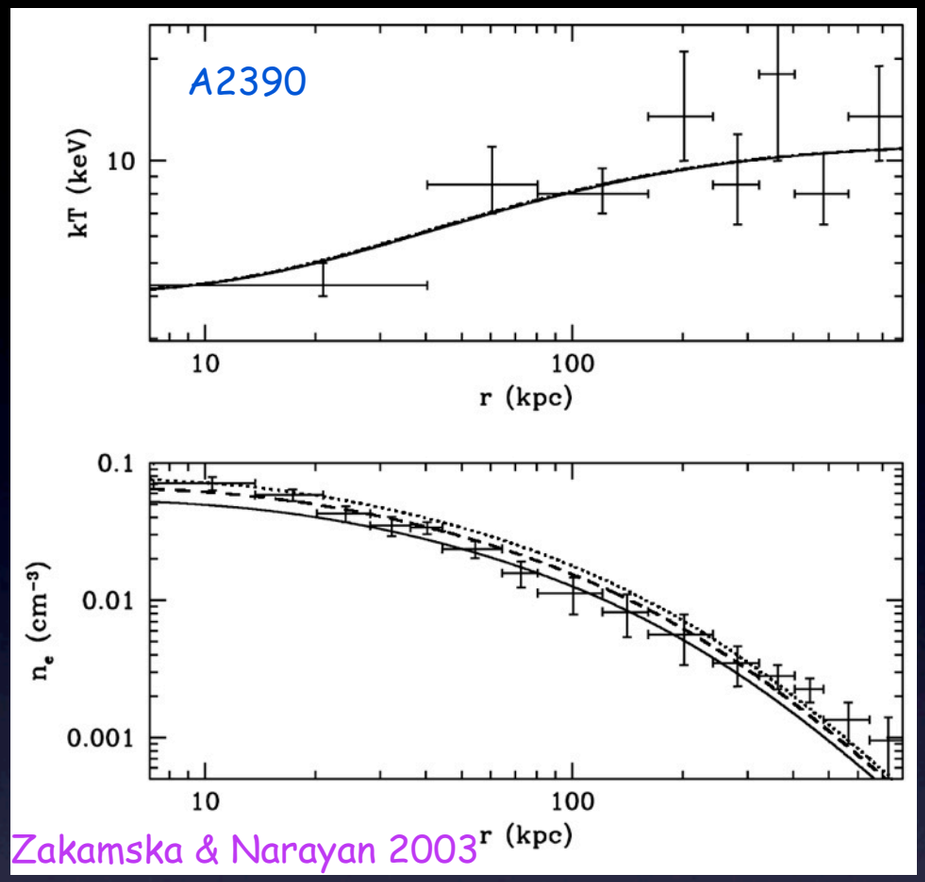

Zakamska & Narayan 2003

Conduction & Diffusion: heating of central atmosopheres due to heat conduction and diffusion from the outer regions (Narayan & Medvedev 2001; Ruszkowski & Oh 2011)

- Conductivity & viscosity can reach values close to Spitzer-Braginskii in presence of tangled magnetized field (Narayan & Medvedev 2001; Gruzinov 2006)
- Turbulence is key! Galaxy motions can be source (Parrish+10; Ruszkowski & Oh 2011)
- Sufficient to explain T and n_e profiles in some clusters if cooling rate = conductive heating rate (Zakamska & Narayan 2003; but see Conroy & Ostriker 2008)

Maintenance Mechanisms

Maintenance Mechanisms

Radio Mode Feedback
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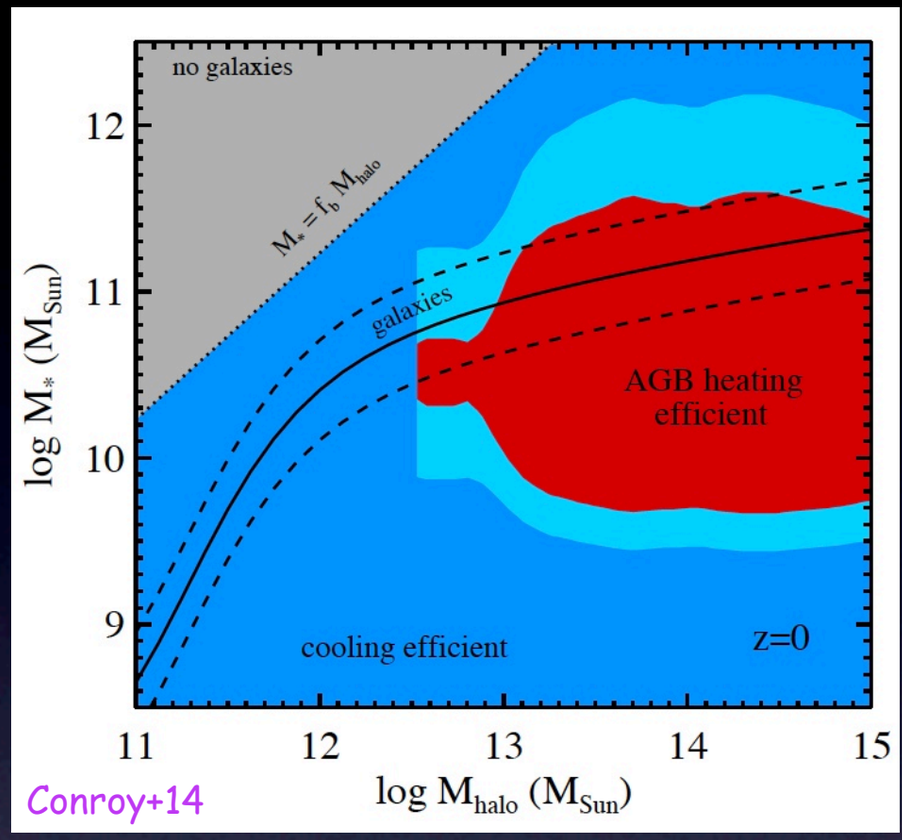

Conroy+14

AGB Heating: heating of hot gas due to drag on ejected envelopes of AGB stars that are in motion wrt hot gas (Conroy+14)

- requires that most kinetic wind energy is converted to thermal energy of ambient gas, but it may also cool ambient gas by mixing (Bregman & Parriott 09)
- can only heat at small radii (where stars are abundant)

Summary

- Quenching of centrals becomes more likely with increasing halo/stellar mass and with increasing bulge mass/central surface density; causalities unclear.
- What does the Age Matching Miracle tell us?
- No shortage of suggested quenching & maintenance mechanisms

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

- AGN feedback (Quasar + Radio mode) is most `popular' but poorly understood. Gives modellers and simulators ample leeway; Anything Goes Now Feedback
- Are any of the alternatives viable? Do they perhaps all contribute?
- Do we really require detailed thermal balance (thermostat) over Gyr time scales?