Gas and Galaxies: Ins and Outs

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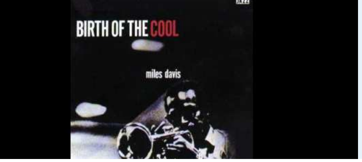
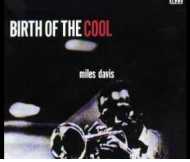


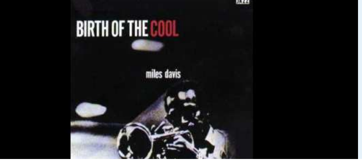
Galaxy Formation Orthodoxy

- Gas falling into a dark matter potential well is shock heated to approximately the halo virial temperature.
- Gas in the dense, inner regions of this shock heated halo radiates its thermal energy, settles into a centrifugally supported disk, and forms stars.
- Mergers of disks can scatter stars onto disordered orbits, producing spheroidal systems, which may regrow disks if they experience subsequent gas accretion.
- Merging dominates over smooth accretion in hierarchical models of galaxy formation.



There are two of ways a galaxy can grow in this world . . .

- Merging with smaller galaxies.
  - Can add both stars and gas.
- Smooth accretion of gas.



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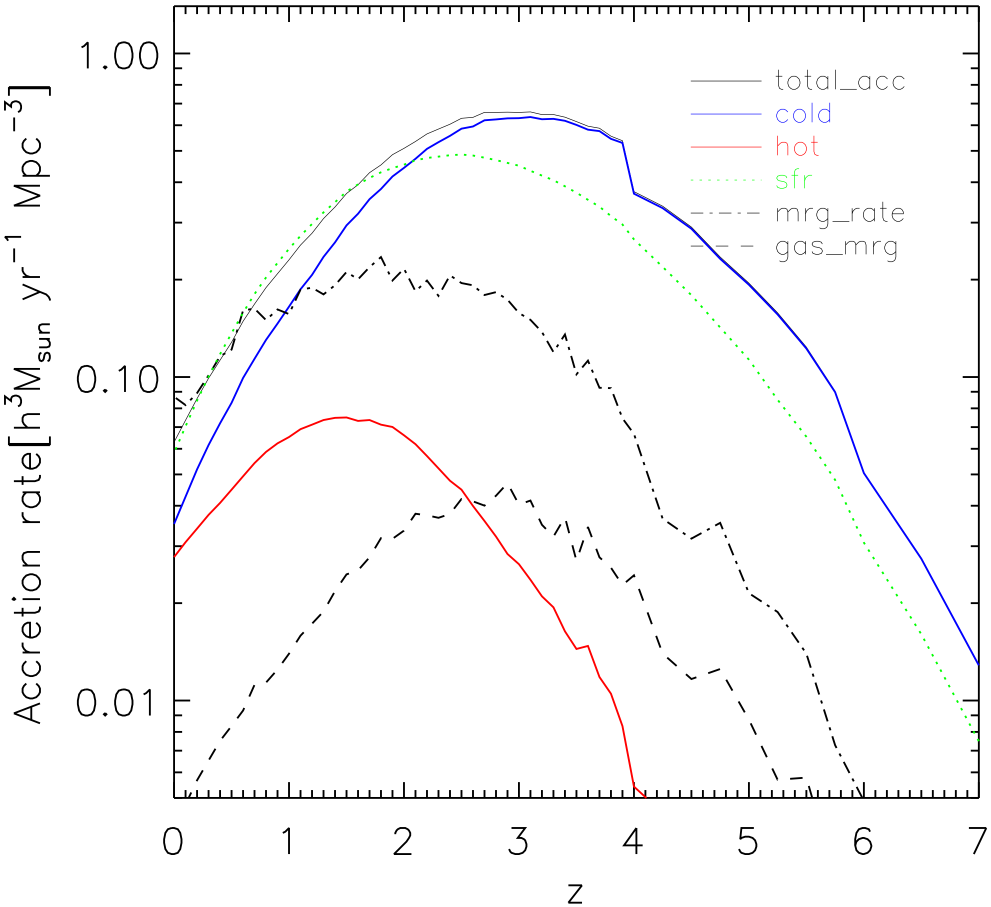
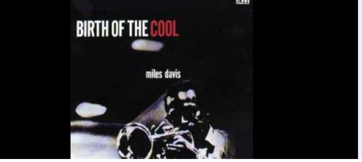
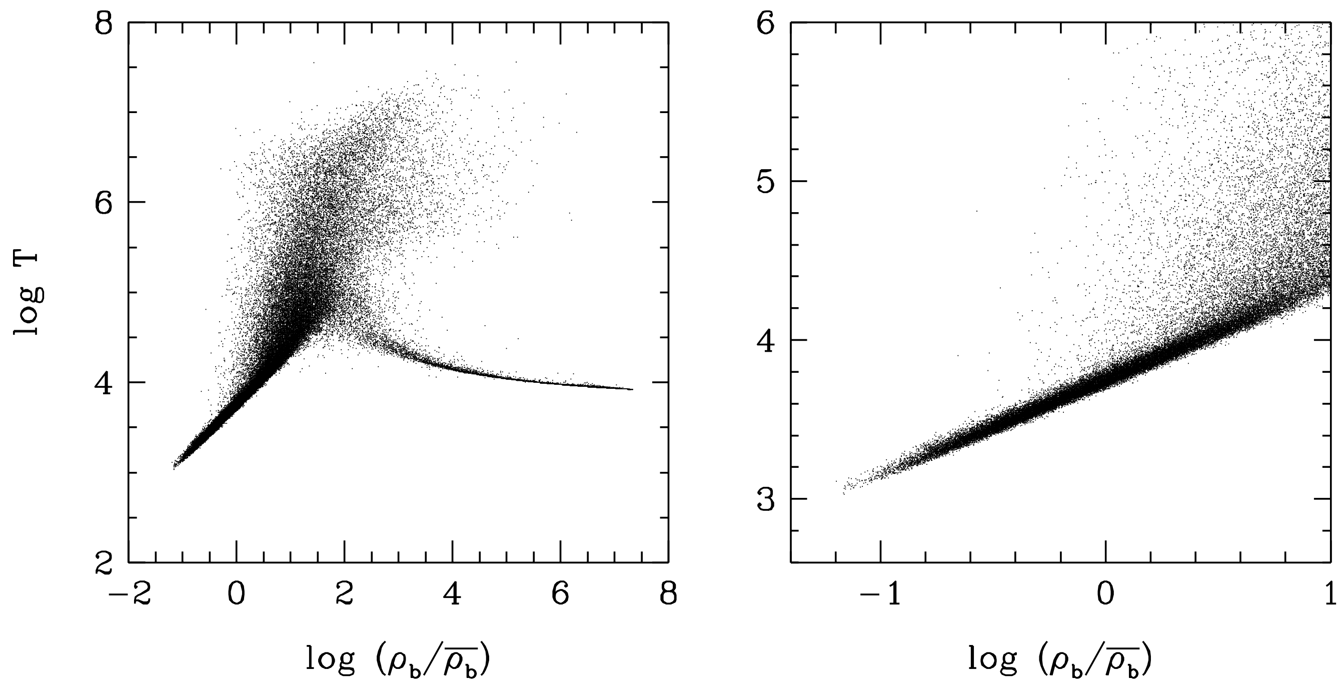
- Merging with smaller galaxies.
  - Can add both stars and gas.
- Smooth accretion of gas.
  - Dominates gas accretion at all redshifts.
  - Dominates total accretion at $z > 1$.

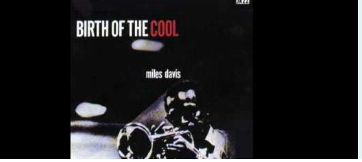




Where's the Gas?

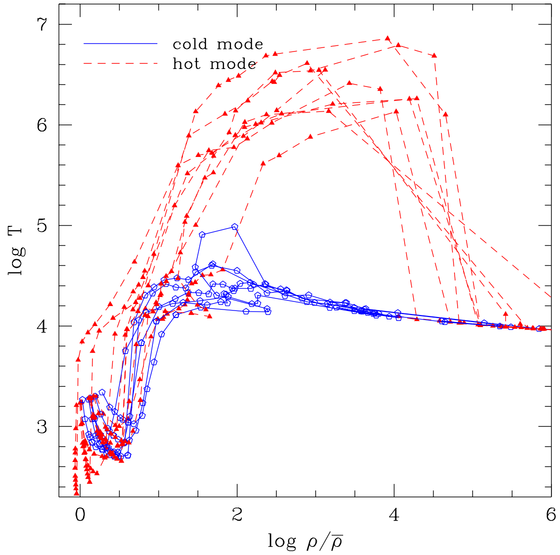


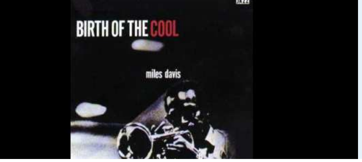
- The gas ends up in three components:
  - Shock heated gas with typical overdensity $\rho/\bar{\rho} \sim 10$–10^4 and $T \sim 10^5$–$10^7 K$.
  - Radiatively cooled, dense gas with $\rho/\bar{\rho} \gtrsim 1000$ and $T \sim 10^4$ K.
  - Low density, highly ionized gas with $\rho/\bar{\rho} \lesssim 10$ and $T \lesssim 10^5$ K.



There are two types of smooth accretion in this world . . .

- Hot: Classic (Rees & Ostriker, White & Rees)
  - Gas is heated to the virial temperature in an accretion shock at the virial radius.
  - The gas accretion rate is determined by the cooling time from this high temperature.





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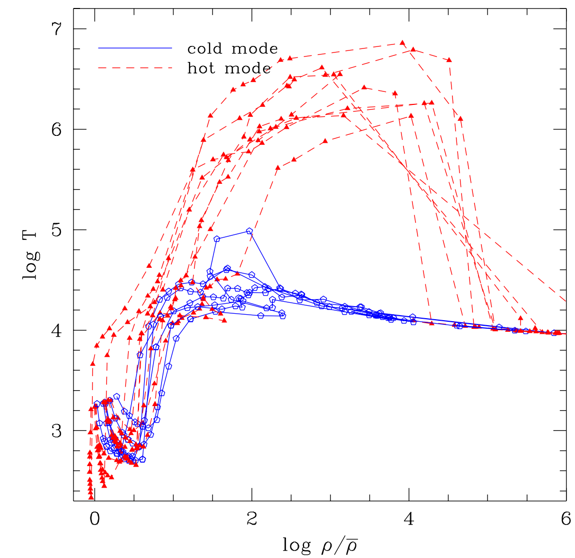
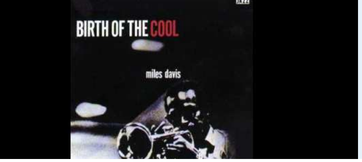
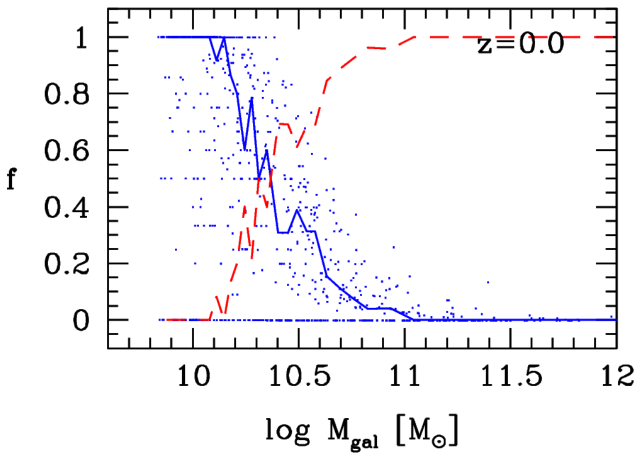


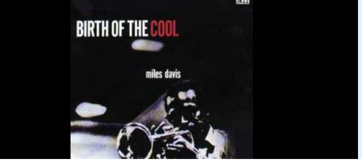
- Cold: Modern (Keres et al, Birnboim & Dekel)
  - The gas is never heated but remains cold as it enters the galaxy.
  - The gas accretion rate is determined by large scale dynamical flows.



There are two types of smooth accretion in this world ...

- At low z cold mode dominates in low mass galaxies and hot mode dominates in high mass galaxies.
- Transition between modes at $\sim 2 \times 10^{10} M_{\odot}$; same mass where SDDS finds a marked shift in galaxy properties.
- At high z cold mode dominates at all masses.





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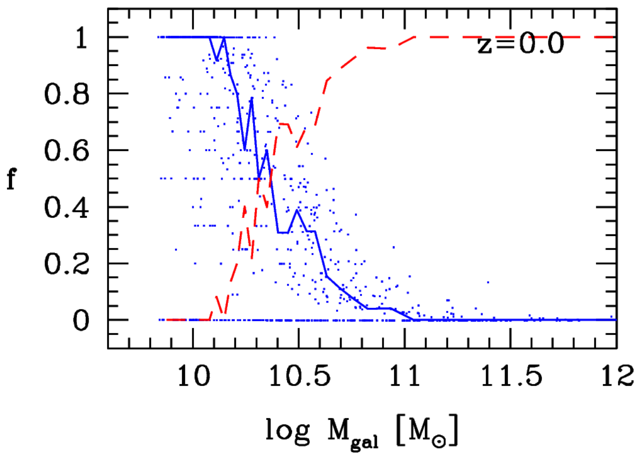
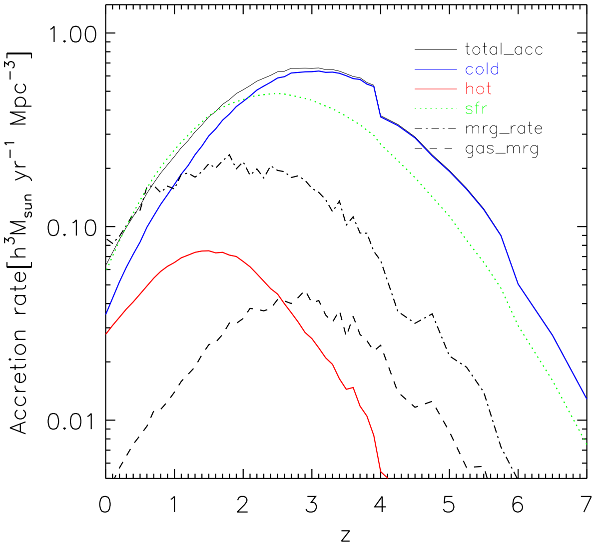
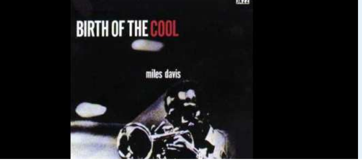
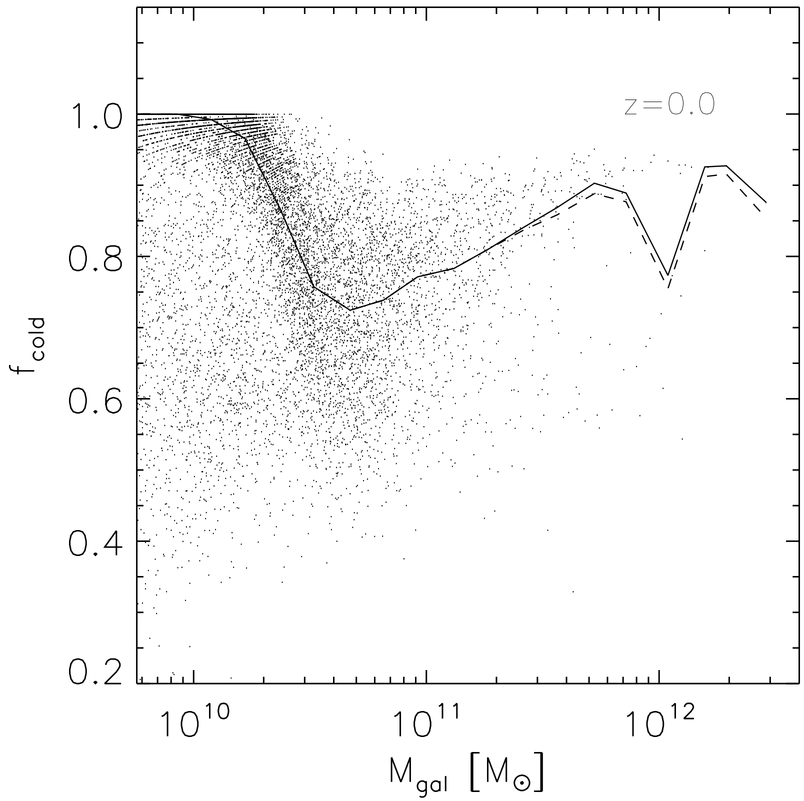


- Cold mode dominates at all z.
- Global SFR follows smooth accretion.

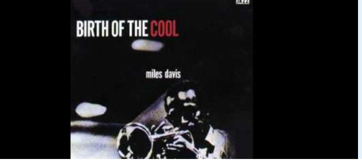




Cold mode rules, hot mode's for fools

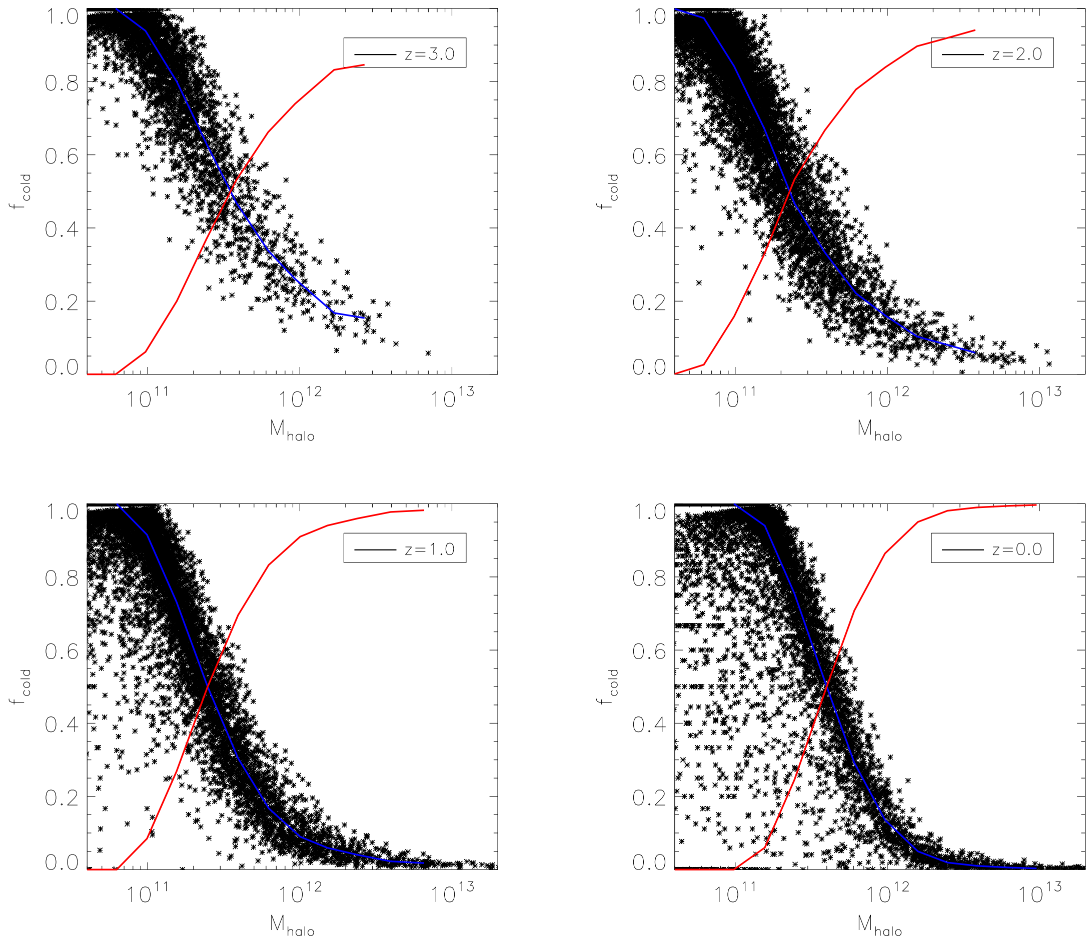


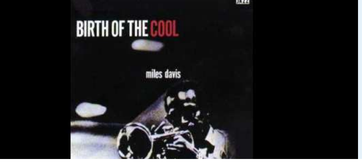
- Cold mode dominates total accreted mass at all galaxy masses.
- Hot mode is only a detail of galaxy formation.



There are two types of halo gas in this world ...

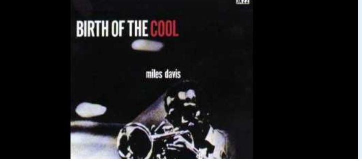
- Halo mass transition at $\sim 3 \times 10^{11} M_{\odot}$
- Almost no redshift dependence.
- At low z:
  - Cold mode ⇒ cold halo gas
  - Hot mode ⇒hot halo gas.
- At high z cold flows penetrate hot halo gas.





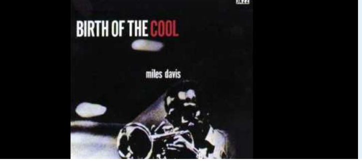
There are two types of feedback in this world . . .

- Bouncer Feedback: gas comes in but gets thrown out
  - Supernova winds
  - AGN: quasar mode?



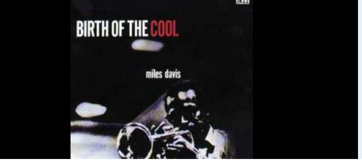
There are two types of feedback in this world . . .

- Bouncer Feedback: gas comes in but gets thrown out
  - Supernova winds
  - AGN: quasar mode?
- Velvet Rope Feedback: the gas never makes it in
  - AGN: radio mode
  - Preheating



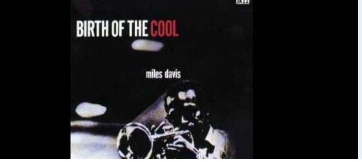
Halo gas vs. feedback type

- "Bouncer" Feedback should mostly affect low mass halos.
  - At low z these are all the cold mode halos.
  - Only energetics determine whether or not winds escape cold mode halos.
  - Quasi-spherical hot halo makes winds hard to escape.

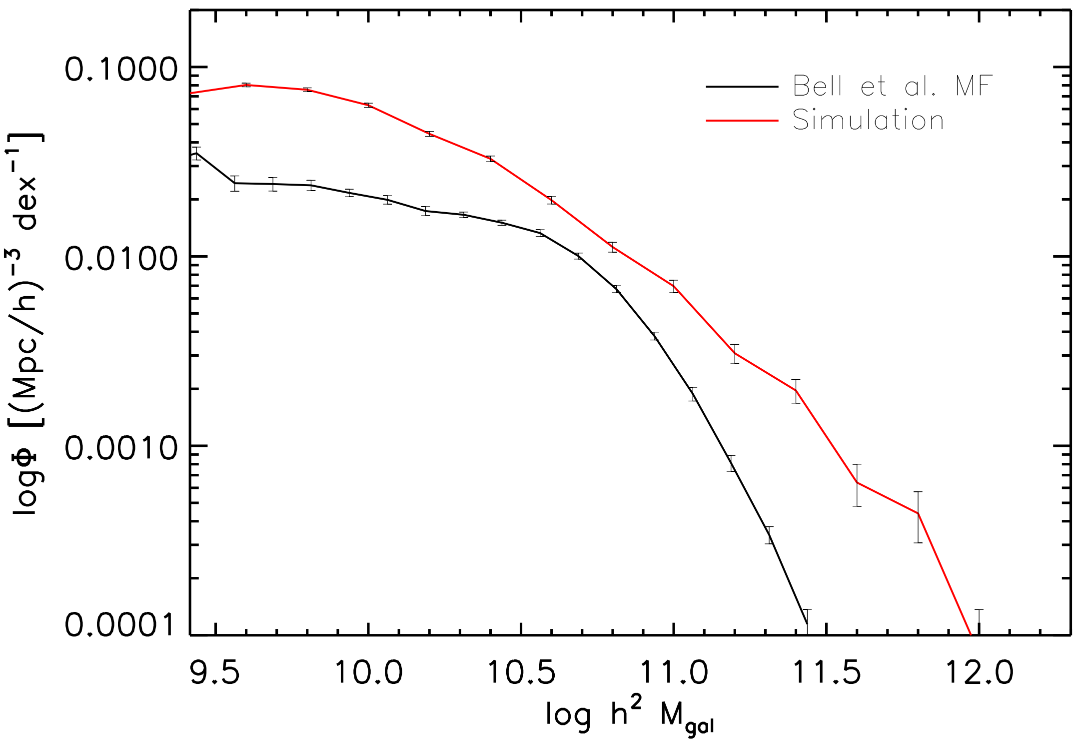


Halo gas vs. feedback type

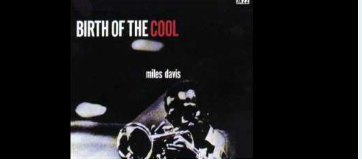
- "Bouncer" Feedback should mostly affect low mass halos.
  - At low *z* these are all the cold mode halos.
  - Only energetics determine whether or not winds escape cold mode halos.
  - Quasi-spherical hot halo makes winds hard to escape.
- At low *z* "Velvet Rope" Feedback should mostly affect hot mode galaxies.
  - Easier to prevent quasi-spherical gas from cooling.
- At high *z*, "Velvet Rope" Feedback will not operate efficiently.
  - Hard to prevent cold mode from entering except perhaps by preheating.



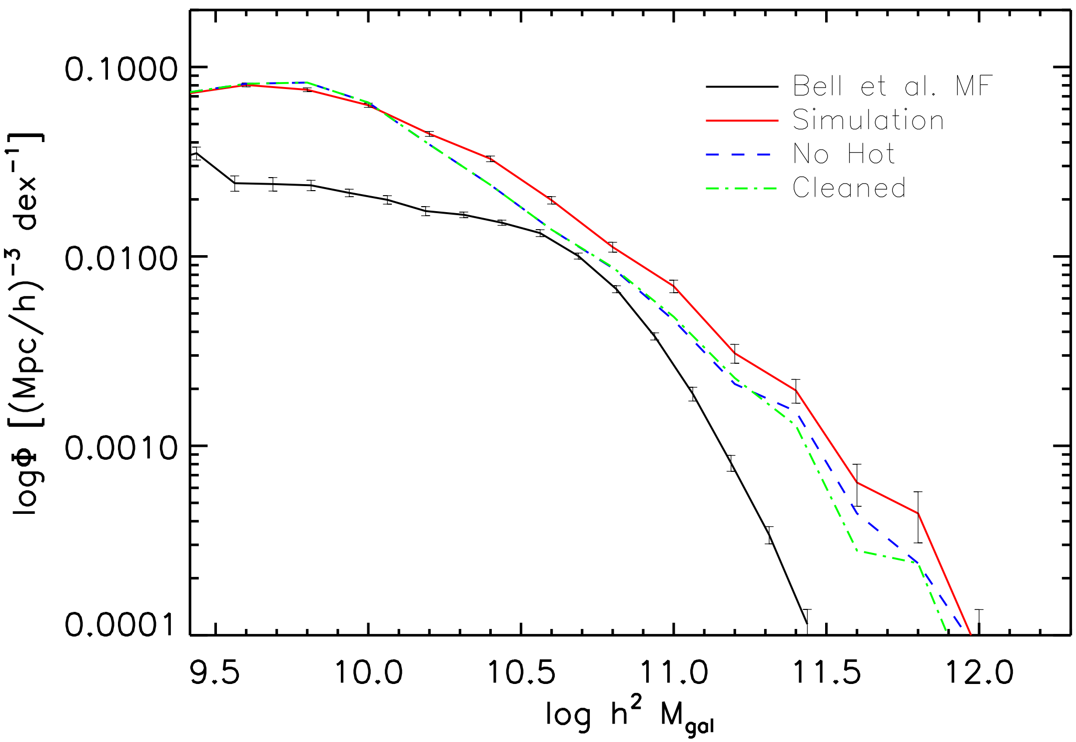
Stellar Mass Function



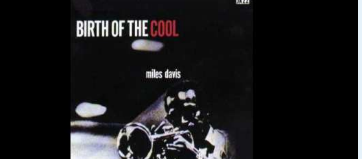
- Terrible match at all masses!
- Need to lower masses at both the high and low mass ends.
- Typically: SN winds for low mass end and AGN radio mode for high mass end.



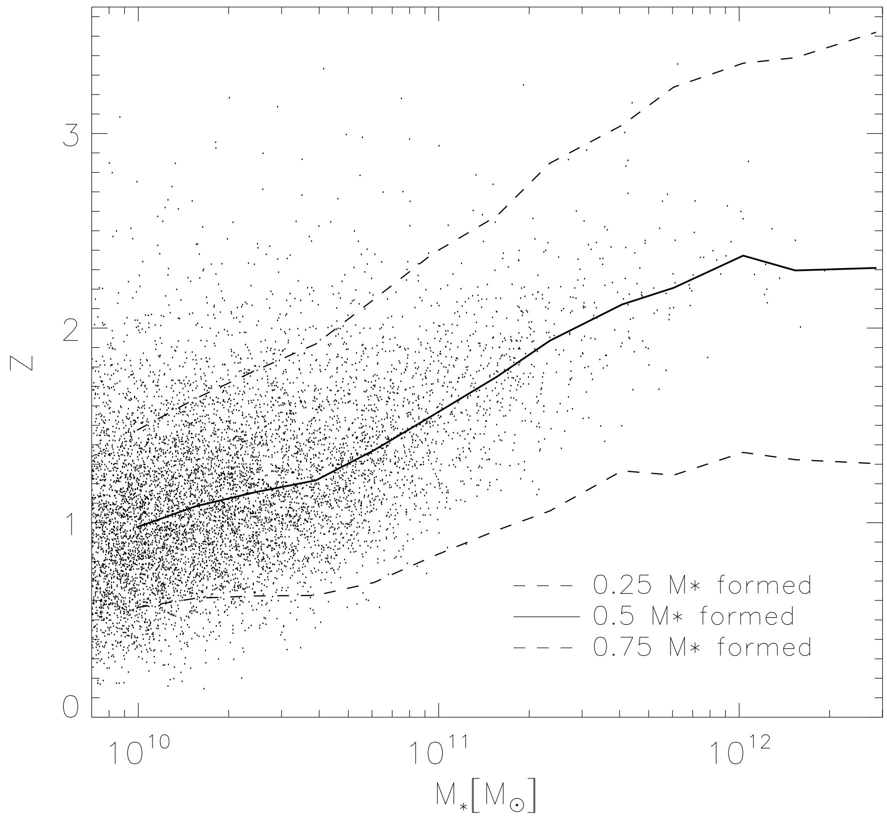
Stellar Mass Function: No hot mode



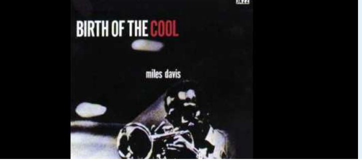
- Remove hot mode accretion to approximate maximum AGN feedback.
- Lowers mass function at the high end but not enough.
- High mass galaxies grow through merging, not through accretion.



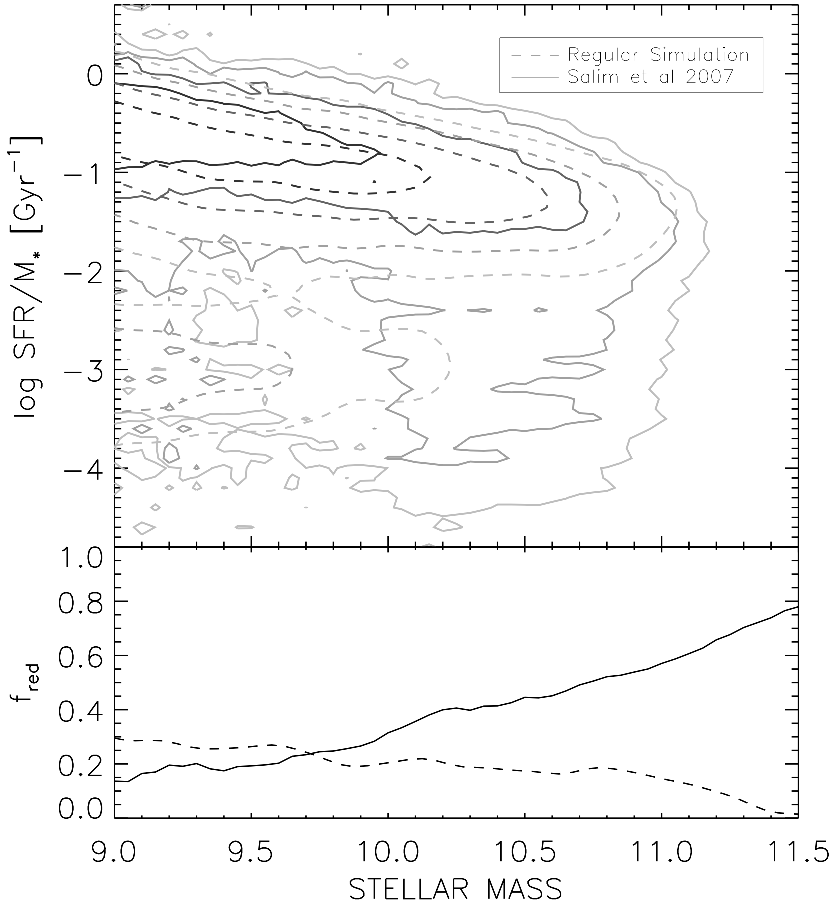
We can downsize too!



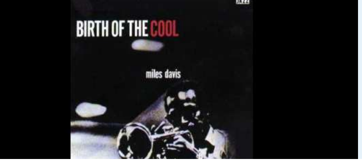
- Massive galaxies form most of their stars at high redshift.
- Need to remove or prevent cold mode accretion to match massive end.
- Cold mode removal should probably happen more at high *z* and not too much at low *z* to fix high mass end.



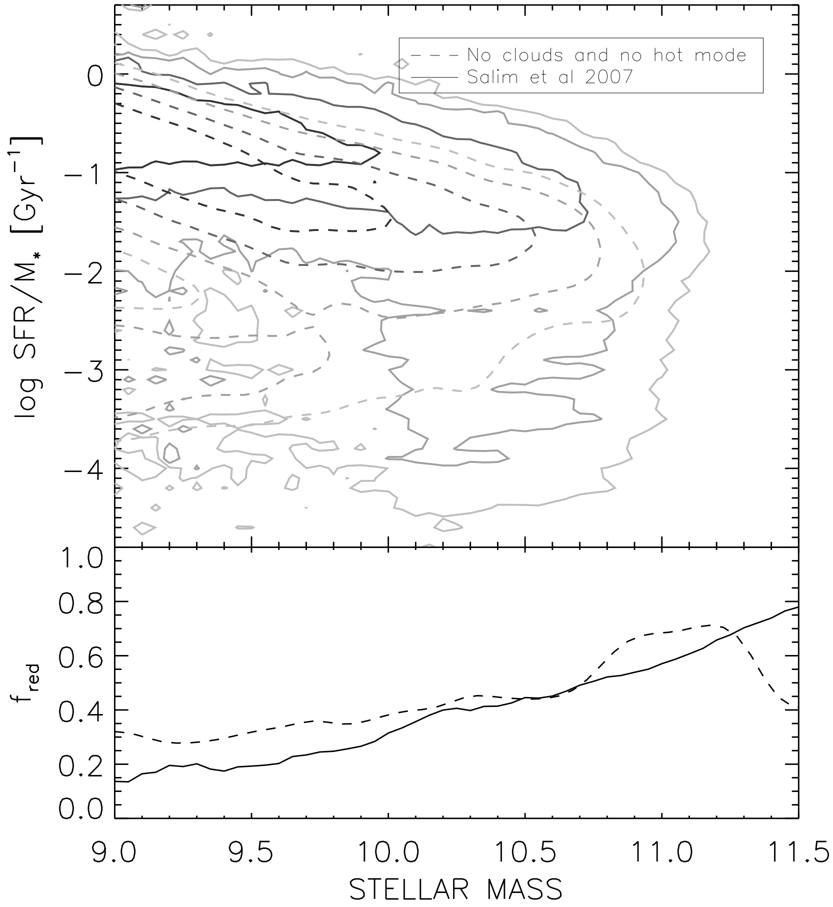
Theorist's color-magnitude diagram



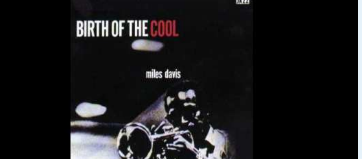
- Rescaled simulated galaxy masses to match observations.
- Simulation does not have enough high mass red galaxies.



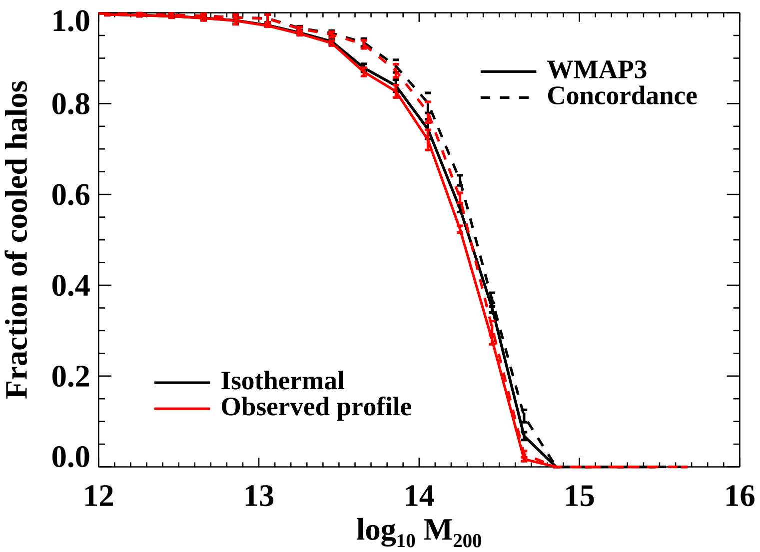
Theorist's color-magnitude diagram: No hot



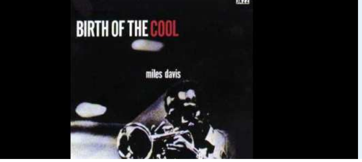
- Remove hot mode accretion to approximate maximum AGN feedback.
- Red enough at all but the highest masses.



Some Like it Hot, Some Not

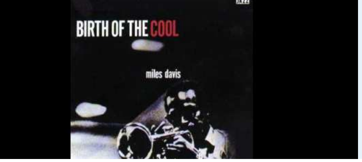


- Assume that halo gas is reheated during its last major merger.
- Sharp transition in mass between cooling and noncooling halos.
- Transition occurs around same mass where x-ray properties change.
- The question is not how to stop cooling flows in clusters but how to start them.
- Velvet rope (AGN) feedback must be efficient in groups not clusters.

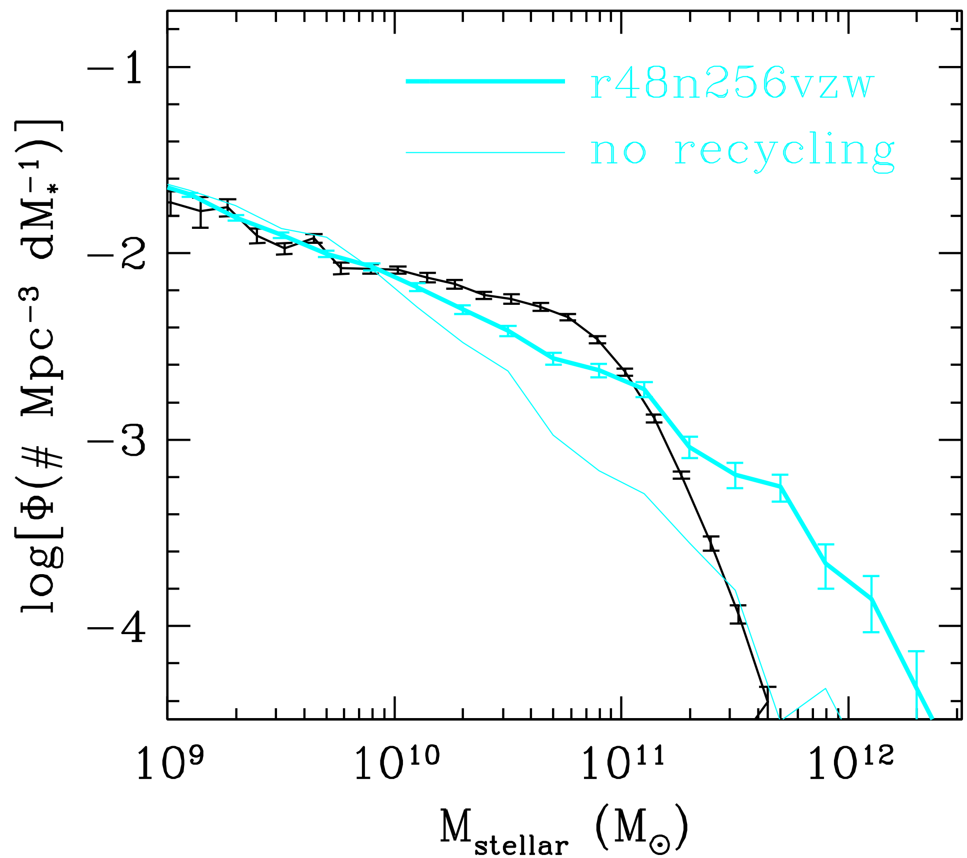


A cold wind blows some good

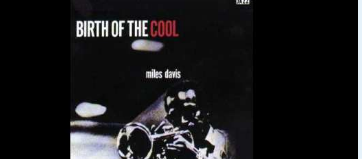
- Use momentum driven wind model.
  - $v_{wind} \sim \sigma$
  - $\eta \sim \sigma^{-1}$
- Successful at matching IGM metal observations at high and low z.
- Reproduces the galaxy mass-metallicity relation.
- Better matches the detailed low ion kinematics of damped lyman alpha systems.



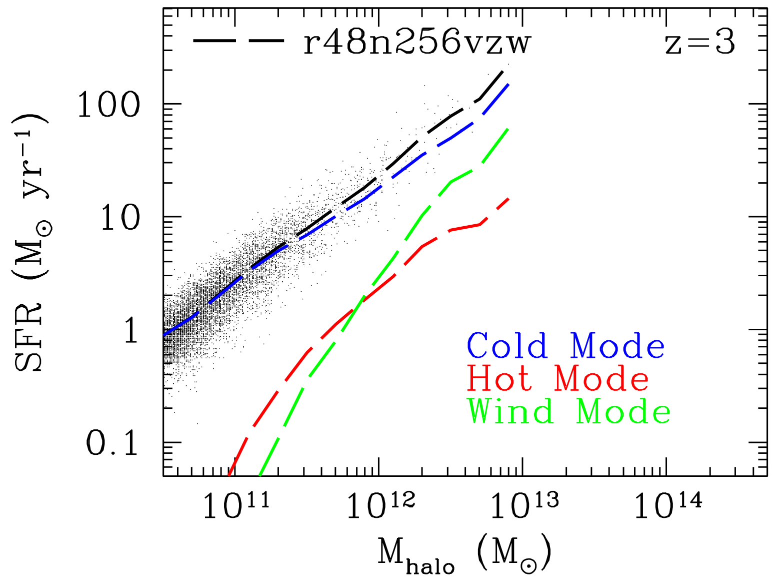
I’ll huff and I’ll puff and I’ll blow your gas out

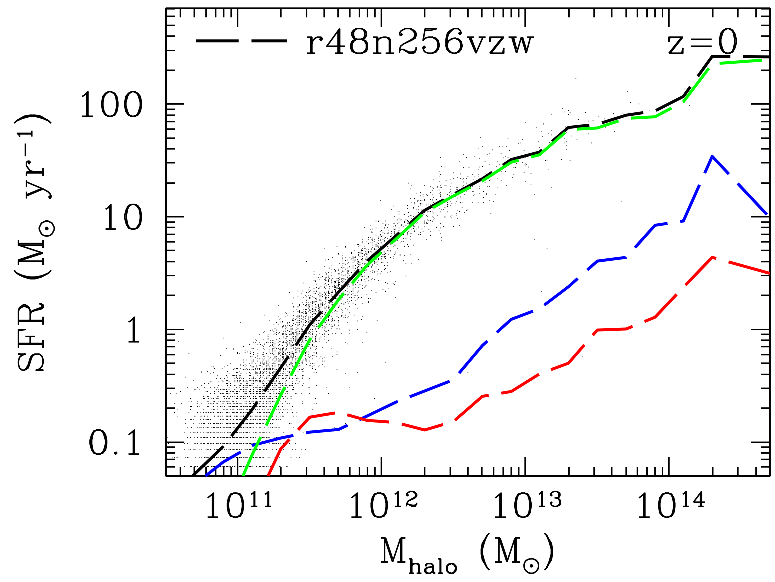


- Winds lower masses at low mass end as desired.
- At high mass end wind recycling negates help from winds.

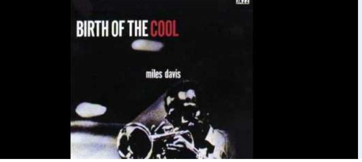


What goes up must come down

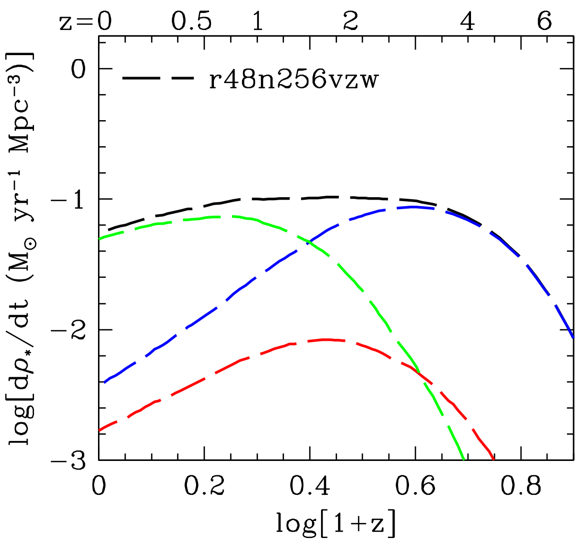


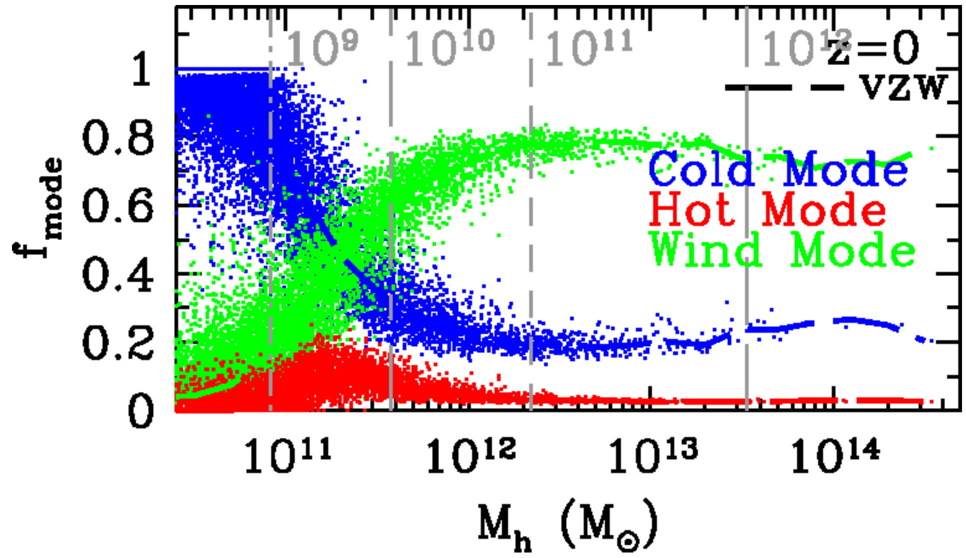


- At high *z*: cold mode accretion dominates star formation.
- At low *z*: reaccreted wind material dominates star formation at all but lowest masses.

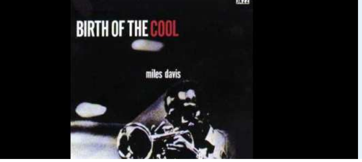


What is old is new again

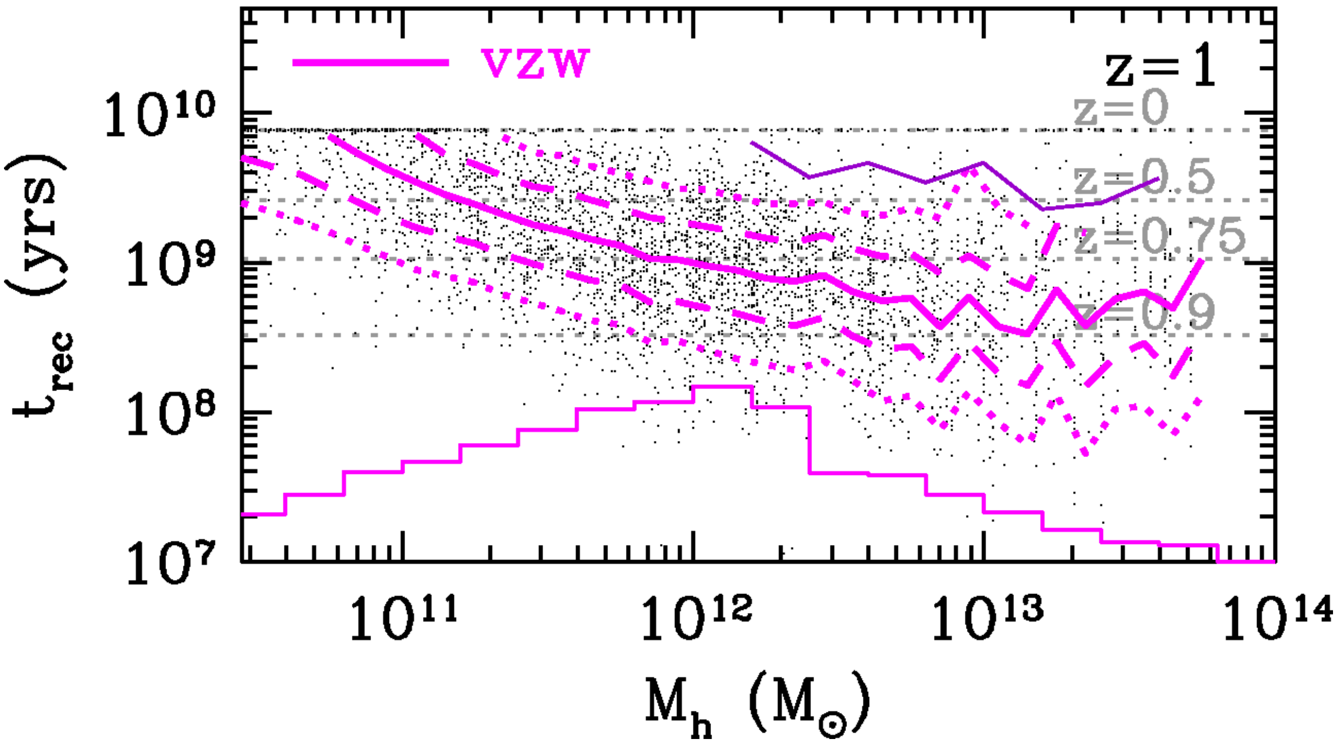




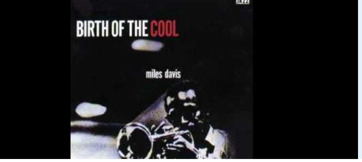
- Globally, reaccreted winds dominate star formation at $z < 1.5$
- Very important for massive galaxies, $M_{\mathrm{stellar}} > 10^{10.5} \mathrm{M}_\odot$



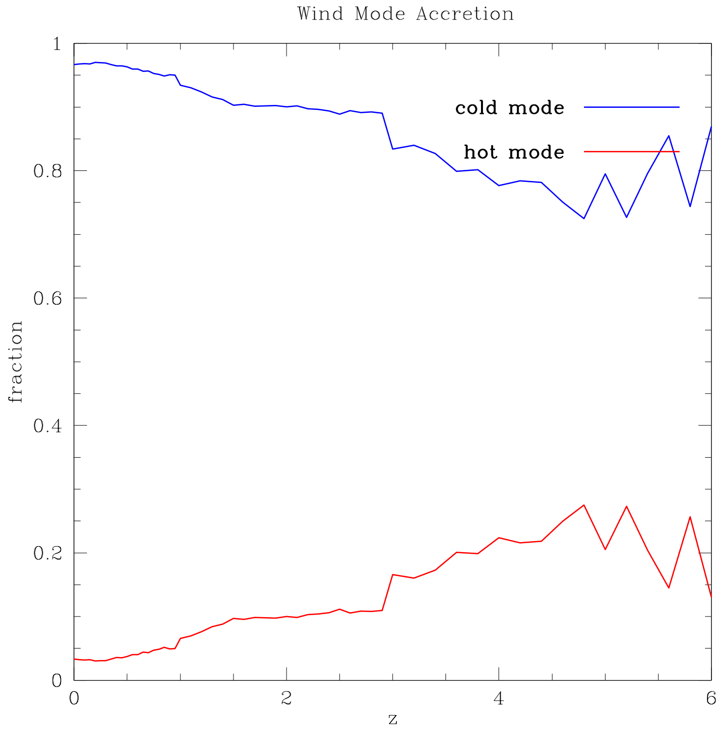
I'll be back



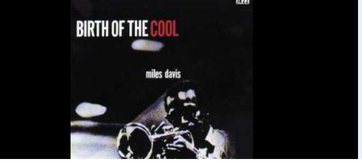
- 83% of wind particles are reaccreted.
- A typical wind particle recycles 3 times.
- Recycle times are shorter in more massive halos.
- Winds interact with hot halo gas.



A cold rain is going to fall

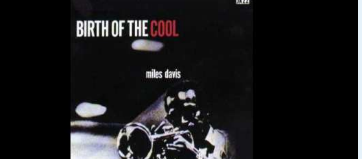


- In simulations, most reaccreted wind material stays cold.
- Need a feedback process to stop this reaccretion.
- Standard AGN feedback is unlikely to work.
- Are the numerics correct?



There are two kinds of dwarfs in this world. . .

- Blue dwarf galaxies vs. red dwarf galaxies in SDSS (Wang et al 2008)
  - For dwarfs with $-13.7 < M_r < -16.3$ ($h = 0.7$) about 33% are red.
  - For blue dwarfs: 21% satellites, 79% centrals.
  - For red dwarfs: 45% satellites, 23% near larger halo, 32% centrals & isolated.
  - For all dwarfs: 11% are red, central, & isolated.
  - Croton SAM predicts 0.4%.



Conclusions

- Smooth accretion is more important than merging and determines the star formation history of the Universe.
- Cold mode accretion dominates the formation of galaxies and standard hot mode accretion is only a detail of galaxy formation.
- AGN feedback alone is unlikely to solve the massive galaxy problem.
- Adding AGN feedback makes massive galaxies red but not red enough especially at the high mass end.
- Need a process to reduce cold mode accretion whenever it occurs, particularly at high redshift in addition to AGN feedback: SN winds?
- Reaccreting wind material dominates star formation at $z < 1.5$ so need a process to stop it.
- Low mass end probably needs an additional process: preheating?
- Much work remains to be done.