Dark Matter and Galaxy Formation

Section 4: Semi-Analytic Models of Galaxy Formation

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Overview

- Success of modern semi-analytic models (SAMs)
- Getting the star formation rate (SFR) correct
- Narrow halo mass range for efficient star formation
- Evolution of galaxies
- Extragalactic background light (EBL) predictions

Modern SAMs

Processes: Extended Press-Schechter theory of halo merging

Gas cooling by radiation

Gas heating by gravitational collapse

Stellar feedback

Assumptions: Most star formation occurs in galactic discs

Galactic spheroids form only in major mergers

Gas cools only onto the central galaxy in any halo

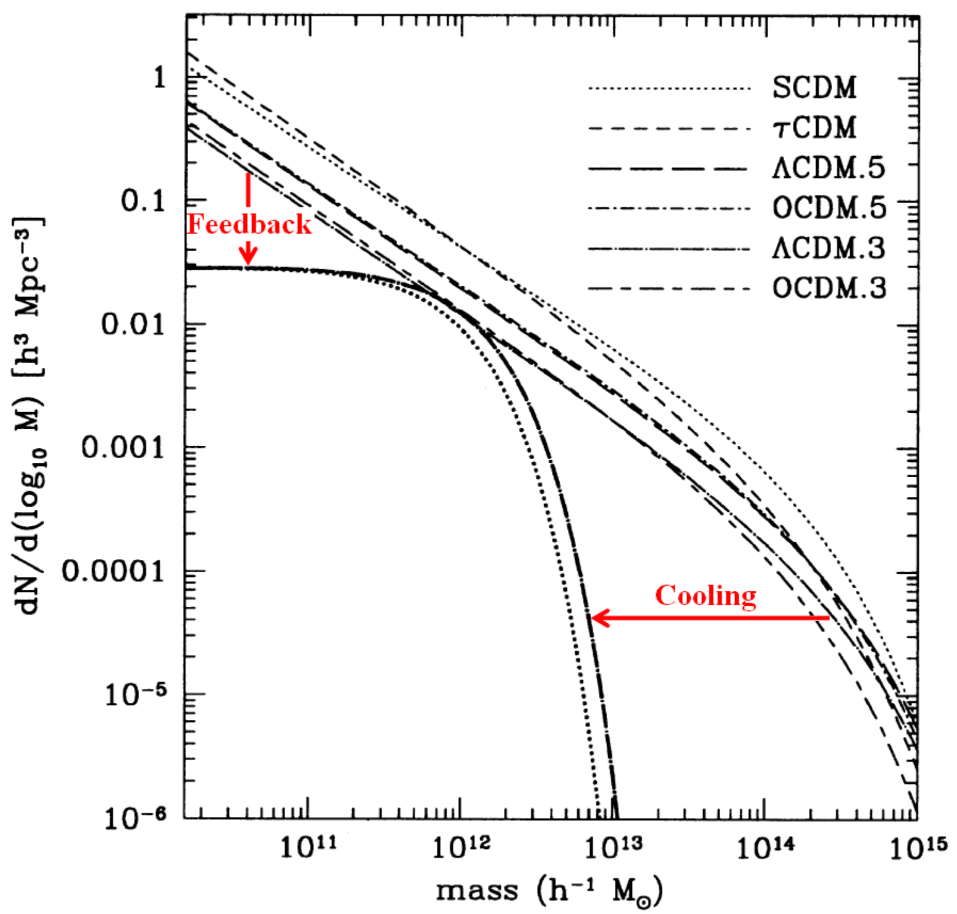
Star formation and feedback parameters set by local data

Reproduced Observations:

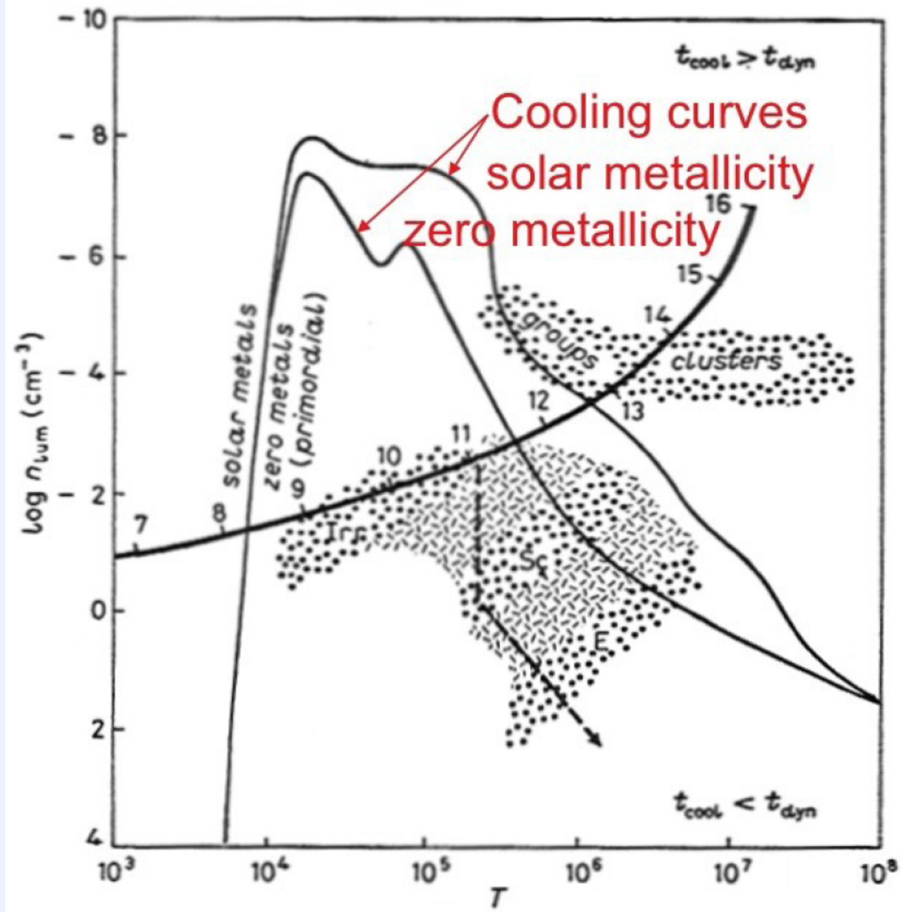
Trends in galaxy luminosity , gas content , morphology

Early-type galaxies populate higher density environments

Most halos do not host galaxies



Somerville and Primack (1999)



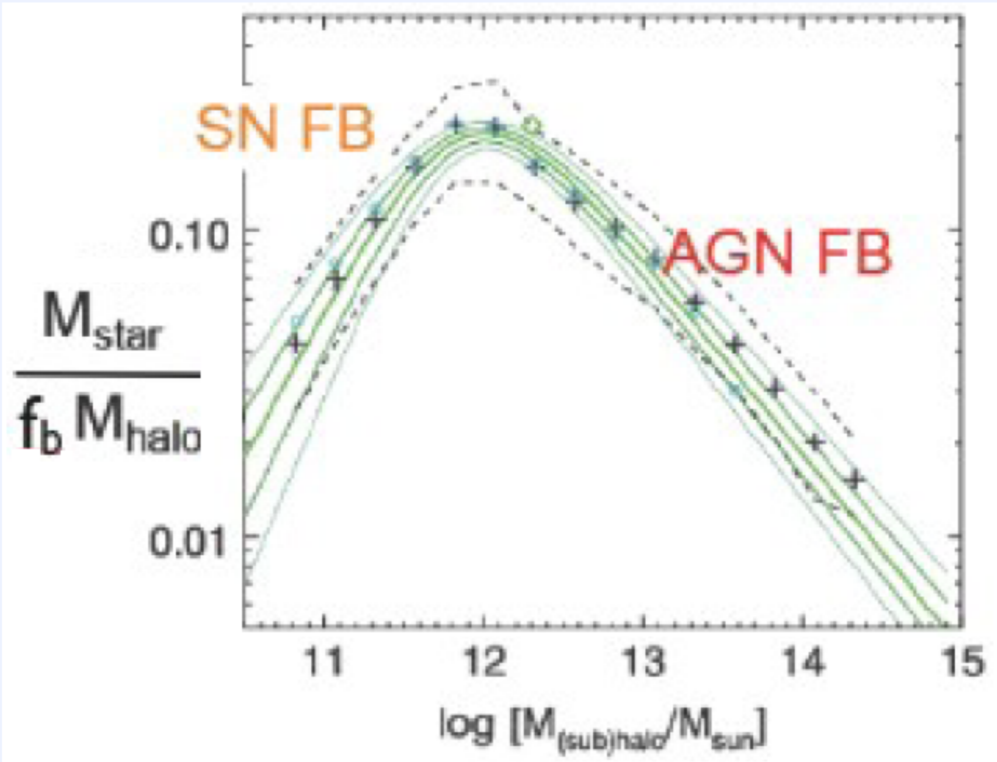
Galaxy formation is efficient only for halos roughly in the mass range $10^8 - 10^{12}\ M_\odot$

Additional SAM processes

Process or Assumption	Helps to
Dust extinction	Reproduce observed luminosity functions
AGN feedback	Not overproduce very luminous galaxies
Radio-mode AGN feedback Supernova feedback	Quench star formation Reproduce galaxy color bimodality
Critical halo mass $M_{shock} \sim 10^{12}\ M_{\odot}$	Quench star formation

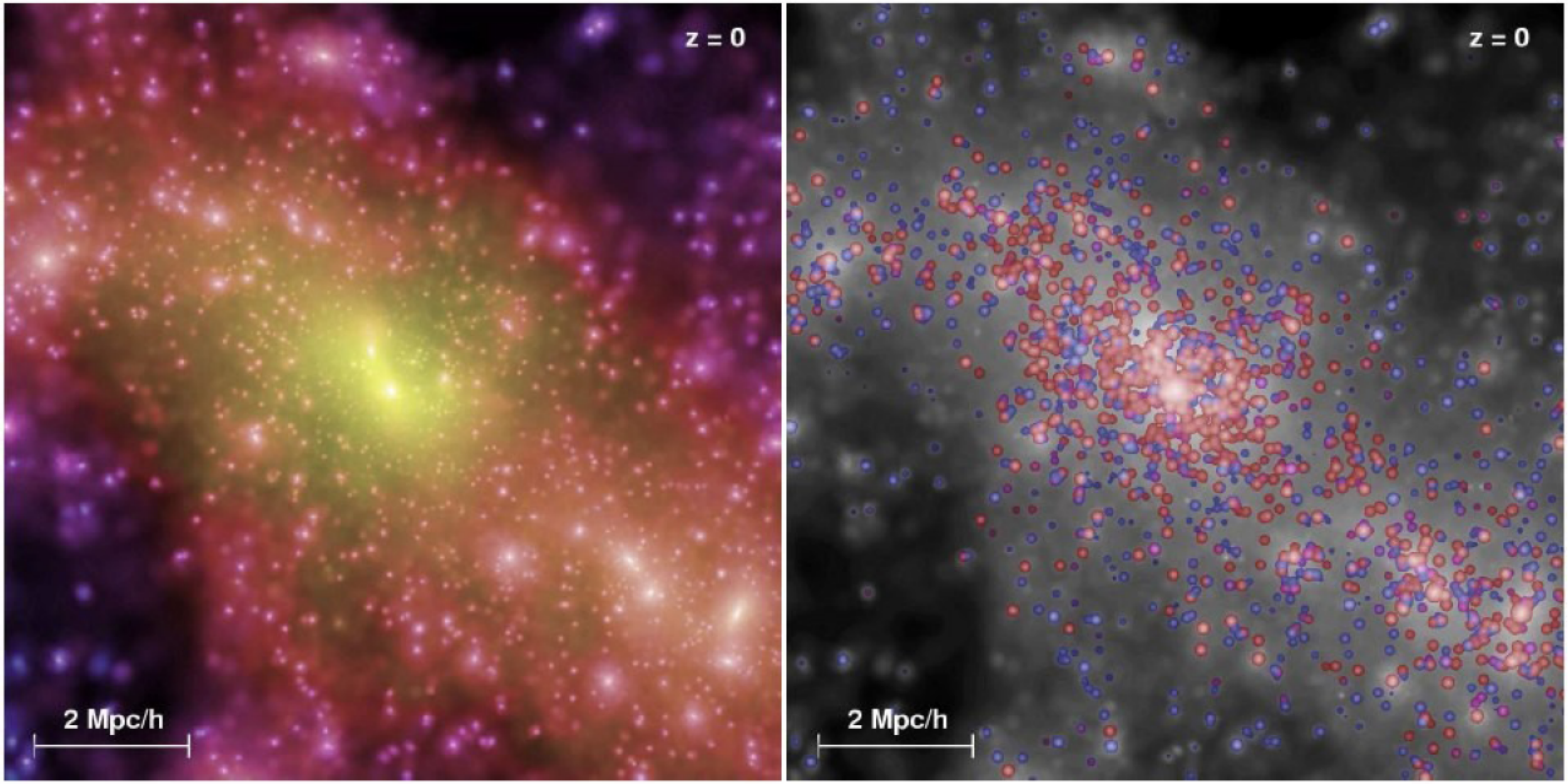
$M_h < M_{shock}$ halos
Gas can enter in cold streams and form stars efficiently

$M_h > M_{shock}$ halos at $z < 2$
Entering gas is shock-heated and cannot form stars efficiently



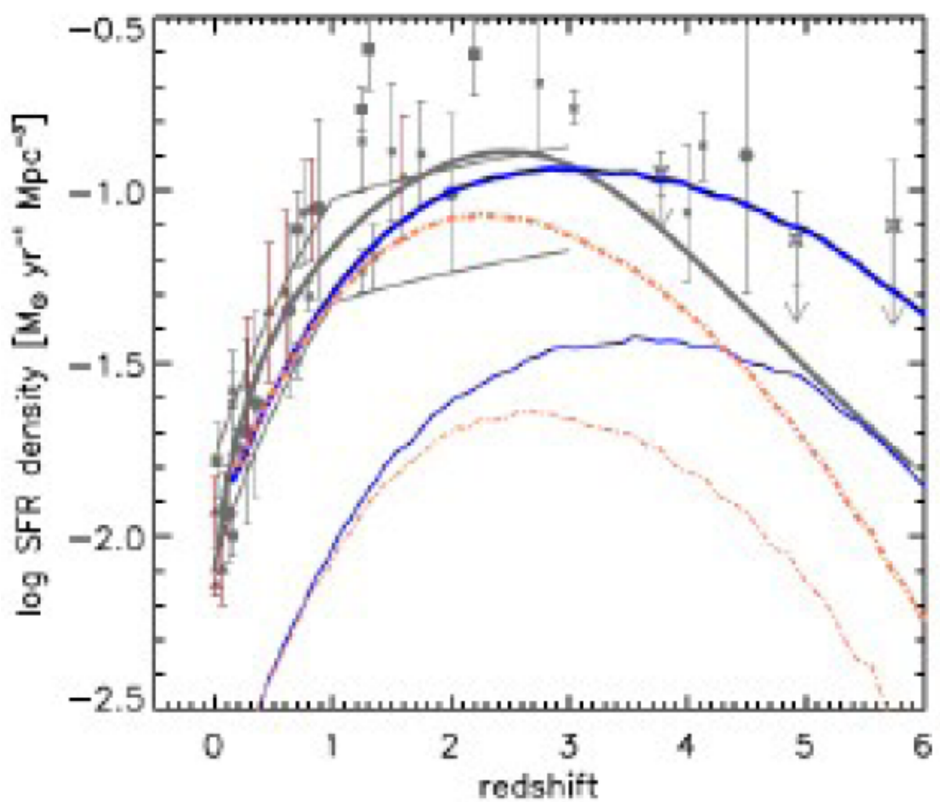
Somerville et al. (2008)

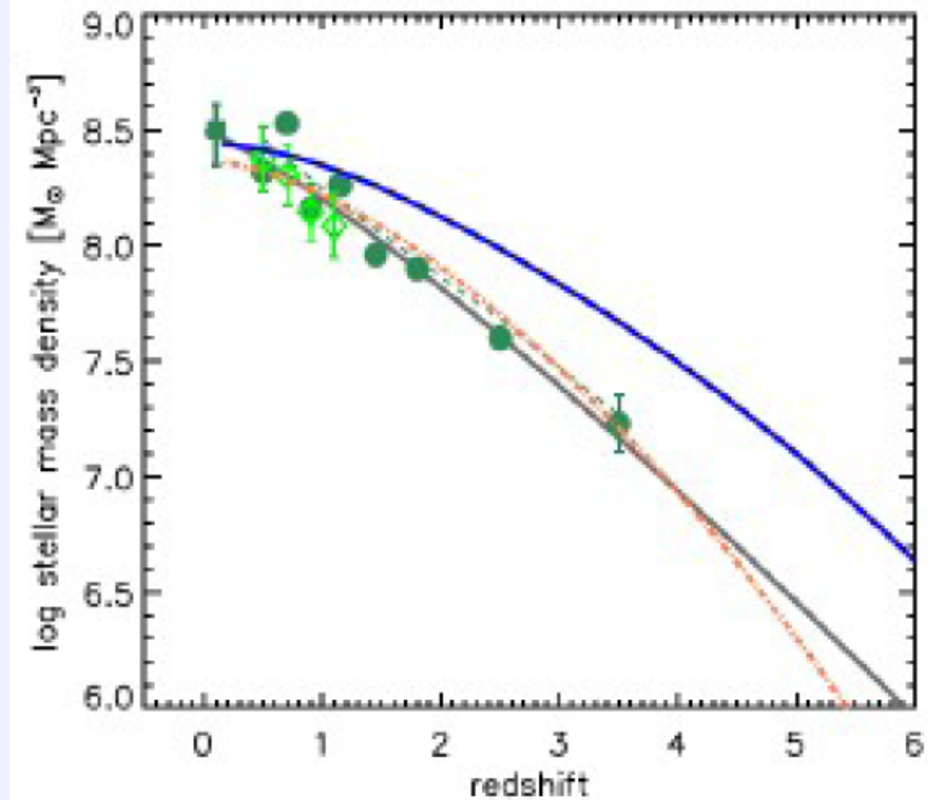
Importance of quenched star formation



The central galaxies are all red, which is consistent with observations.

Inconsistency between SFR and stellar mass densities





Possible Solutions

- Stellar initial mass function (IMF) could be evolving:

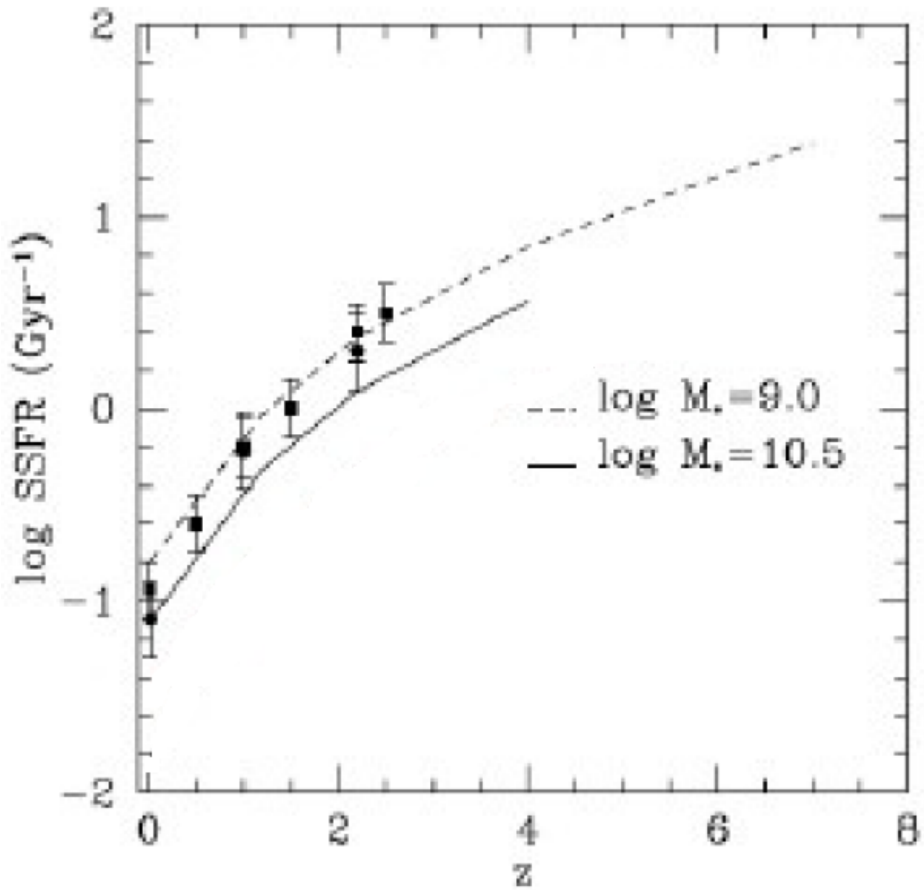
  Producing a higher fraction of high-mass stars with increasing z
- SFR in the left plot might have been overestimated for higher z

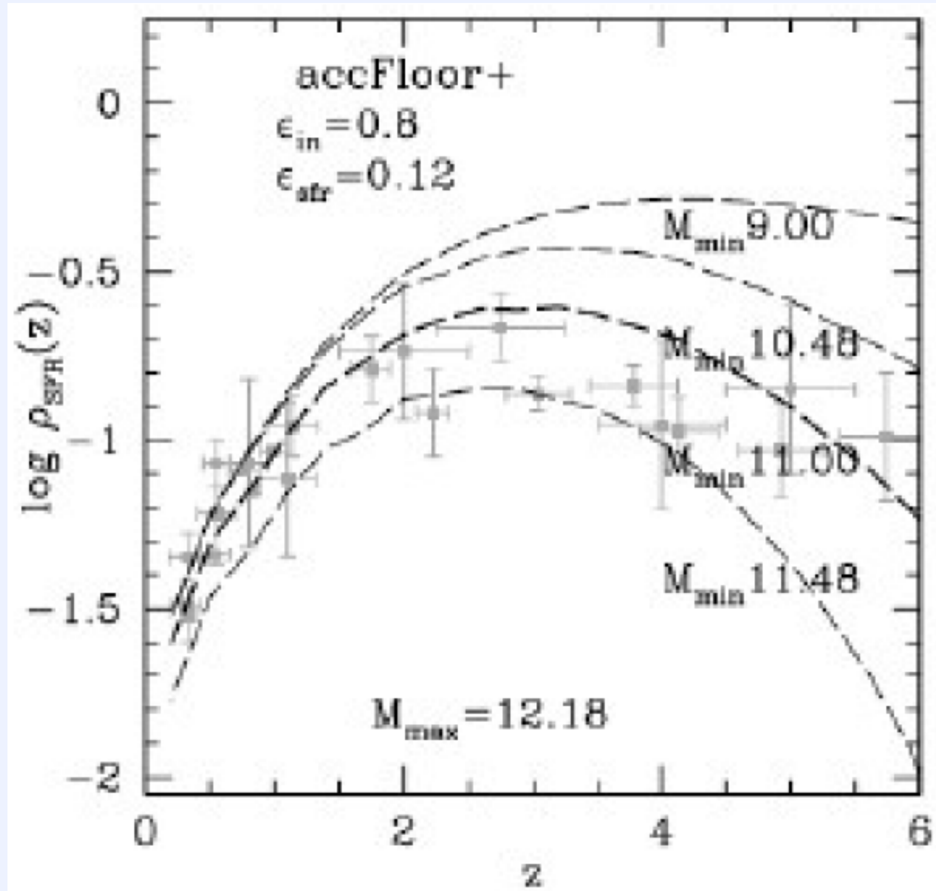
Narrow halo mass range for efficient star formation

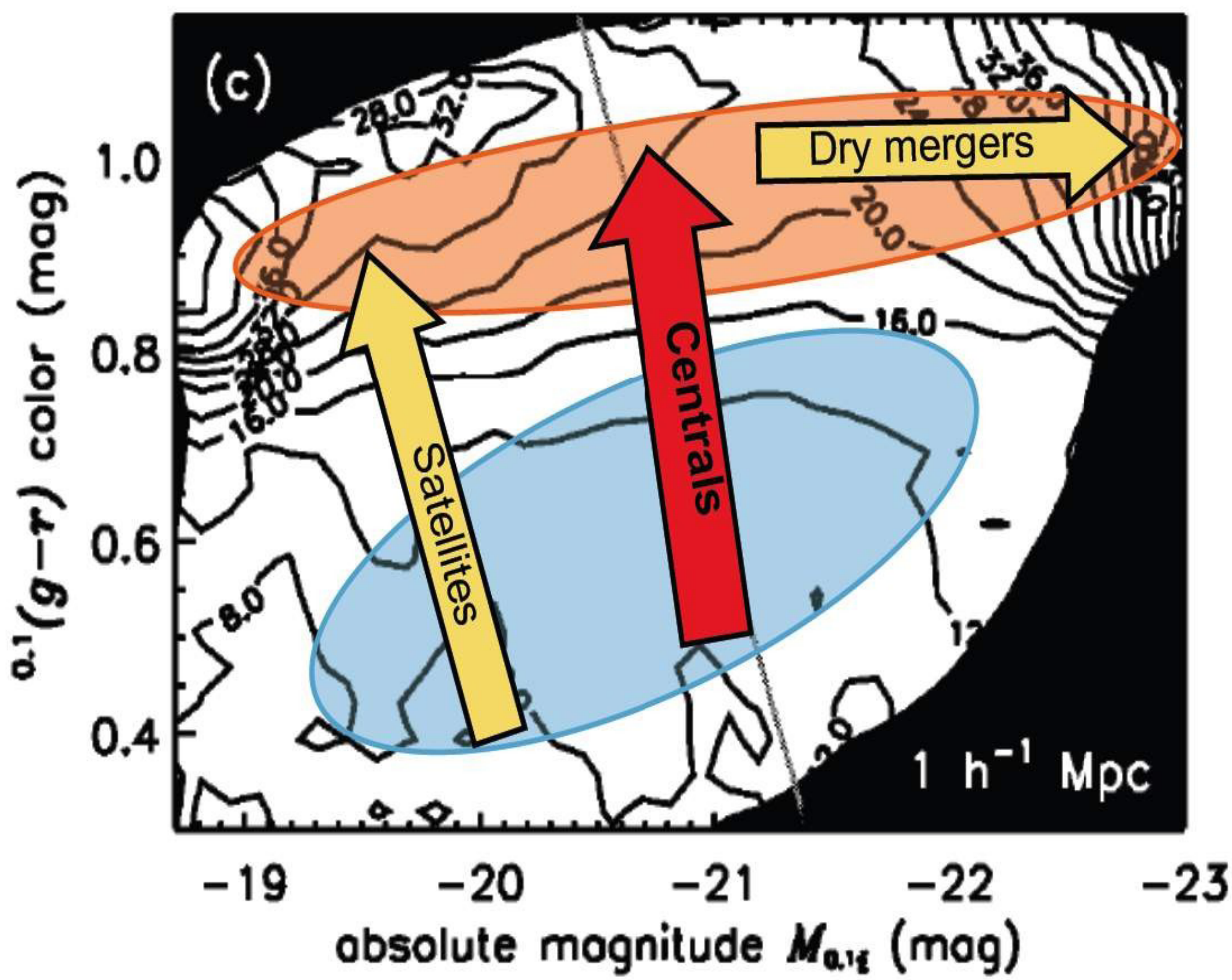
Assumptions

- SF only efficient for ΛCDM halos in M_{min} – $M_{shock} = 1.5\times10^{12}\,M_\odot$
- SSFR ≈ f_b × (halo mass accretion rate)

SSFR (specific SFR): SFR per unit stellar mass







Galaxy Evolution

Satellite galaxies

Star formation quenches

Gas accretion ceases

Become red

Central galaxies

Join the red sequence if either:

- Form a supermassive black hole
- Halo mass exceeds M_{shock}
- Become satellite galaxies in clusters

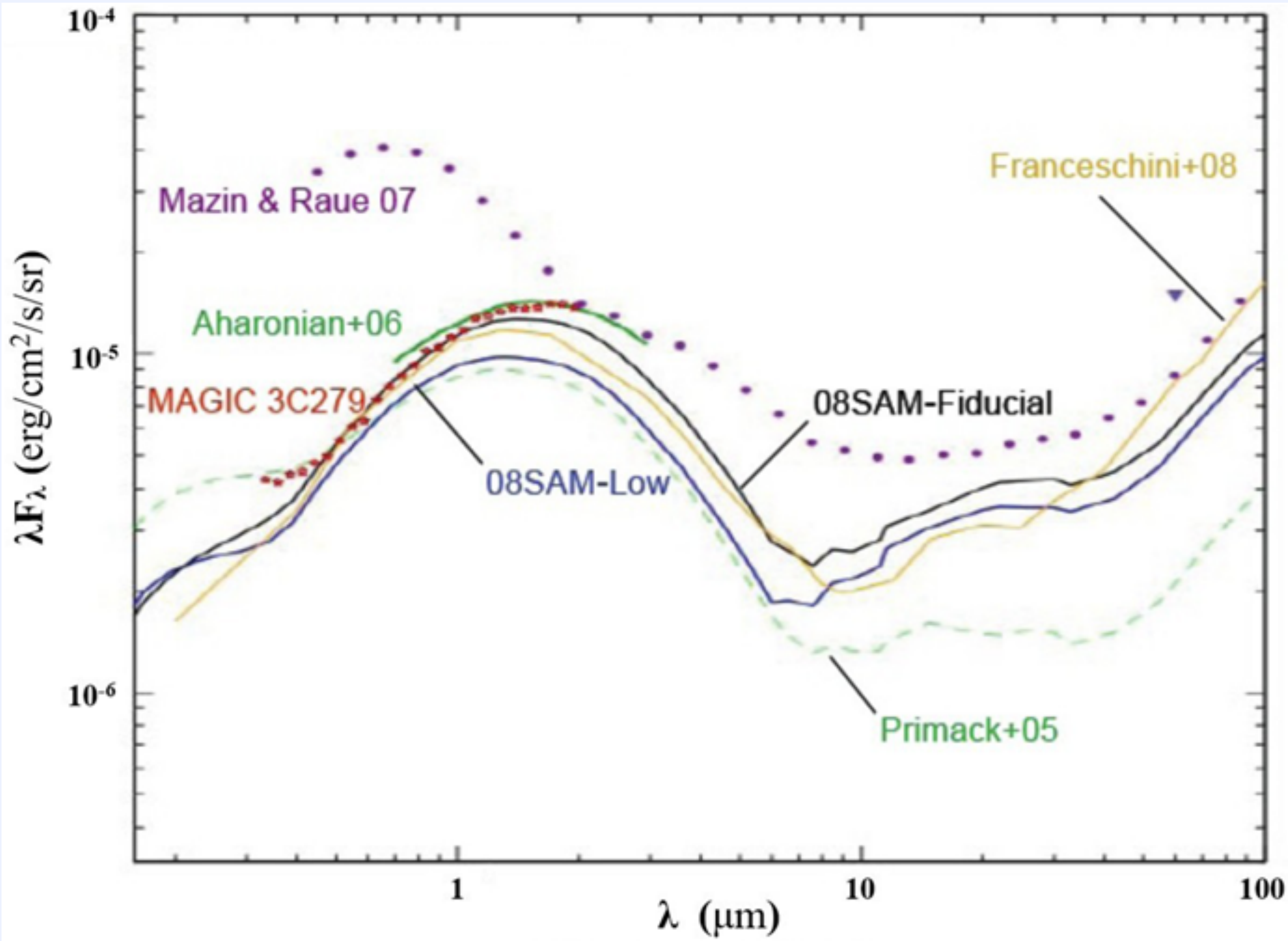
Dry mergers

Most massive reds

Form through mergers of reds

(Blues are not massive enough)

Extragalactic background light predictions



Summary

- Modern SAMs reproduce many observed galactic features
- Remaining problems:
  - Solving the inconsistency between SFR and stellar mass density
  - Getting star formation right in small galaxies
  - Getting black hole accretion history right
- SAMs that assume a narrow halo mass range for efficient star formation are successful
- Upper EBL limits constraint the cosmic SFR history and therefore are a testable prediction of SAMs