Modeling Galaxy Formation

living with the degeneracy

Eyal Neistein, MPA Garching

Neistein & **Weinmann** (MNRAS, 2010)
Weinmann, Neistein & Dekel (in prep, 2010)
Neistein, Li, **Weinmann** & Boylan-Kolchin (in prep, 2010)

Max Planck Institute
for Astrophysics

Semi-Analytical Models (SAMs)

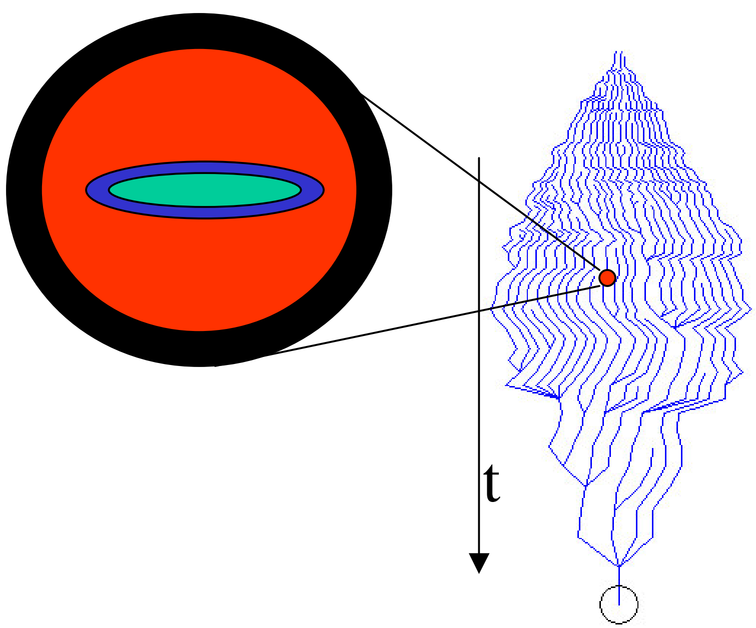
1. Define a Galaxy

- hot gas
- cold gas
- stars
- Others:

BH, metals, ejected gas

2. Quiescent Physical processes

- accretion of new gas
- cooling: hot→cold
- SF: cold →stars
- feedback (SN & AGN): cold →hot



3. Merger trees

- merger trees of subhalos
- dynamical friction
- stripping/accretion by satellites
- merger-induced bursts

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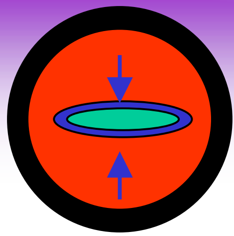
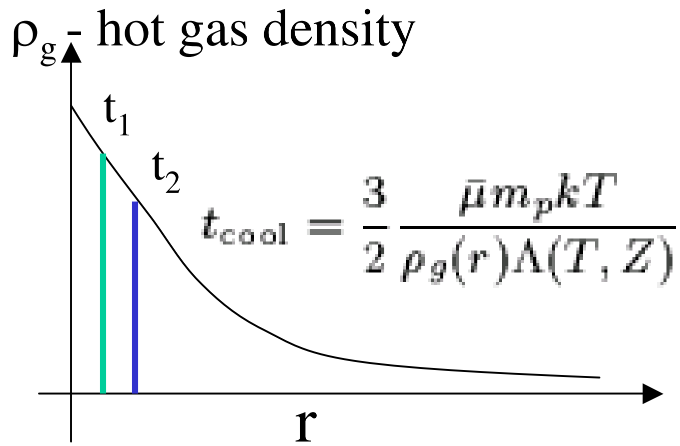
Cooling



Most SAMs follow White & Frenk (1991)

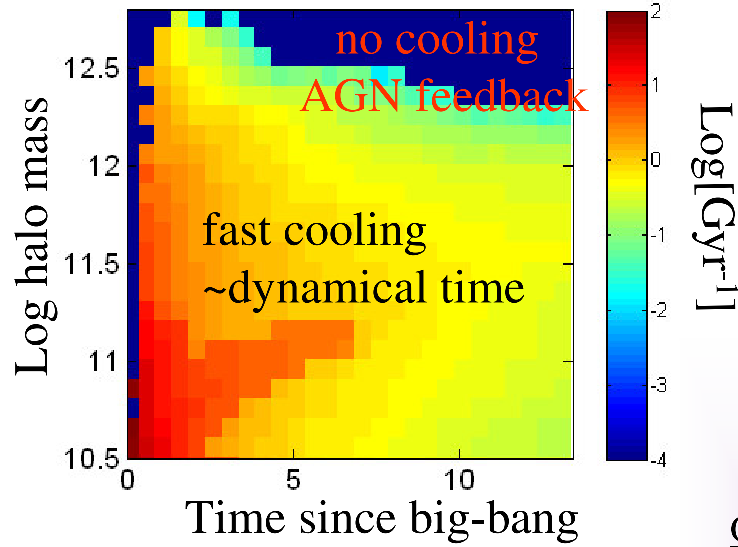


$$t_{cool} = \frac{3}{2} \frac{\bar{\mu} m_p k T}{\rho_g(r) \Lambda(T, Z)} .$$

$\Lambda(T, Z)$: Sutherland & Dopita (1993)

cooling efficiency:

$$[\, \dot{m}_{cold} \,]_{cooling} = f_c \cdot m_{hot}$$



De Lucia & Blaizot (2007)

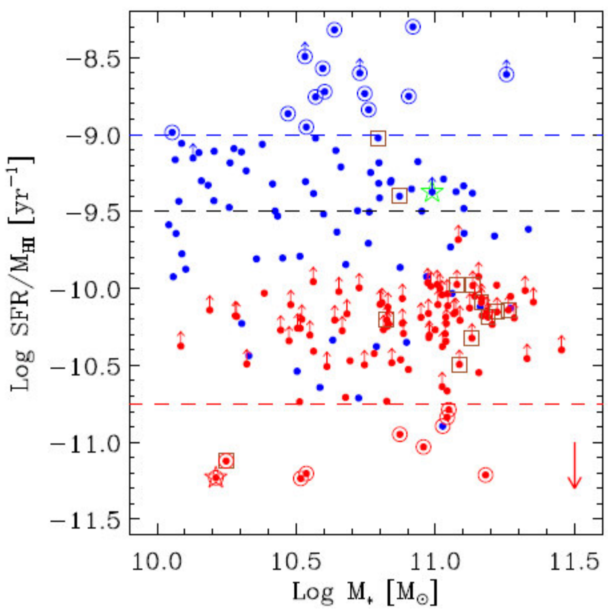
Uncertainties

- Gas density profile, 3D effects (filaments)
- Assuming collisional ionization equilibrium
- Metals: non-solar abundance ratios
- Different implementations of White & Frenk concept.

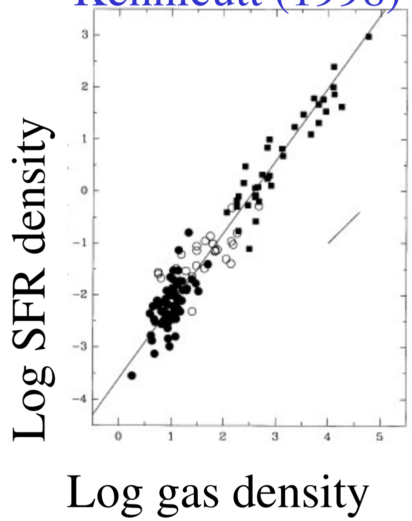
Gnat & Sternberg (2007); Wiersma et al. (2009); Lu et al (2010)

Star-Formation (SF)

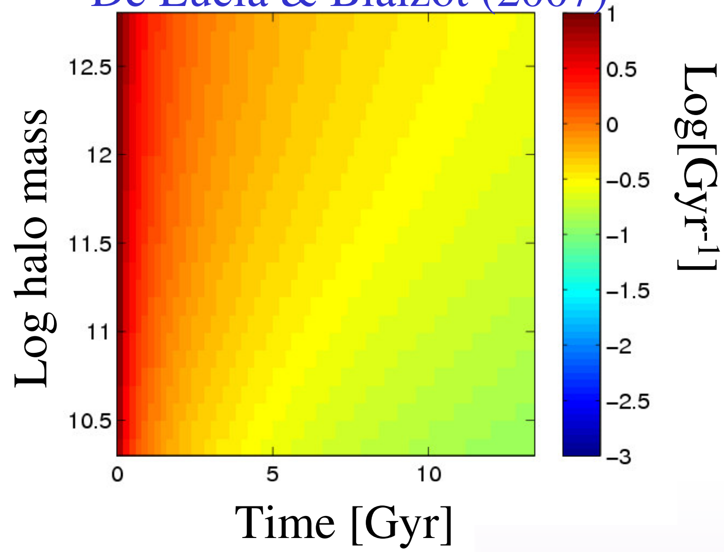
Schiminovich et al (2010)



Kennicutt (1998)



De Lucia & Blaizot (2007)



SAMs: $$\dot{m}_{star} = \frac{m_{cold}}{\tau_{disk}}$$

SF efficiency : $$\frac{\dot{m}_{star}}{m_{cold}}$$

Uncertainties:

- H_2 or HI (SAM use H_2+HI) - Fu et al (2010)
- Density averaged over the whole galaxy or local
- Large scatter observed

Outline:

☞ SAM recipes

SeSAM method

Degeneracy

Abund. match.

High-z SSFR

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08/10, UCSC

Supernova Feedback

- Cold gas is heated back to the hot component

$$\dot{m}_{hot} = \frac{a}{\mathrm{V_h}^{\alpha}} \dot{m}_{star}$$

Kauffmann et al (1999) α=2
Cole et al. (2000) α=5.5
Croton et al (2006) α=0
Khochfar & Ostriker (2008) α=2

- Cold gas is ejected out of the halo

$$\dot{m}_{eject} = \left(\frac{b}{\mathrm{V_h}^{\alpha}} - a \right) \dot{m}_{star}$$

Croton et al (2006) α=2

Open issues:

- High level of uncertainty
- Not enough observational constraints
- Other kinds of feedback: AGN, preheating, SN-Ia, stellar feedback

Our Approach - SeSAM

sesam semmel

Motivation

- include most of the physical processes
  (merger-trees, cooling, SF, feedback, accretion, bursts)
- keep it as simple as possible
  (while not changing the results of SAMs)
- deal with uncertainties within the recipes
- fit the data !

The 'recipes' depend only on halo mass and redshift
(mergers and satellites are treated in a similar way as in SAMs)

cooling: $\dot{m}_{cool} = f_c(M_h, z) \cdot m_{hot}$

SF: $\dot{m}_{star} = f_s(M_h, z) m_{cold}$

SeSAM

The formalism is simple and compact:

$$\mathbf{m} = \begin{pmatrix} m_{\rm star} \\ m_{\rm cold} \\ m_{\rm hot} \end{pmatrix} \quad \mathbf{A} = \begin{pmatrix} 0 & (1-R)f_s & 0 \\ 0 & -(1-R)f_s - f_d f_s & f_c \\ 0 & f_d f_s - f_e f_s & -f_c \end{pmatrix} \quad \mathbf{B} = \begin{pmatrix} 0 \\ f_{ca} \\ f_{ha} \end{pmatrix}$$

recycling, SF, cold accretion, feedback, ejection, cooling, hot accretion

One equation for the quiescent evolution:

$$\dot{\mathbf{m}} = \mathbf{A}\mathbf{m} + \mathbf{B}\dot{M}_h$$

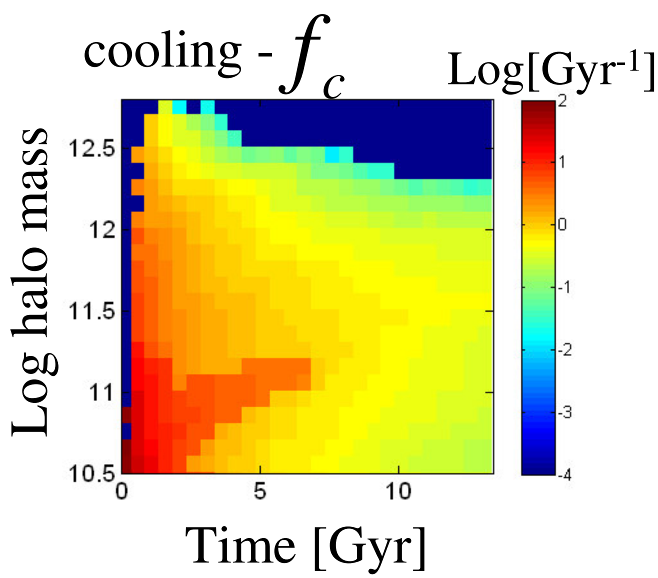
<u>Benefits</u>

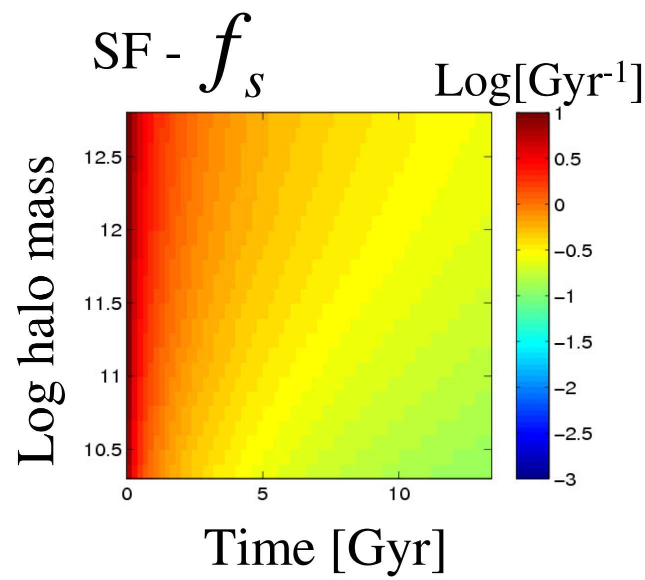
- We don't to parameterize recipes in advance
- Tuning the model is straight forward
- The complex structure or merger-trees is being used

Too simple?

De Lucia & Blaizot SAM → SeSAM

1. We run De Lucia & Blaizot SAM and save all transition rates
2. We average transition rates per halo mass and redshift:

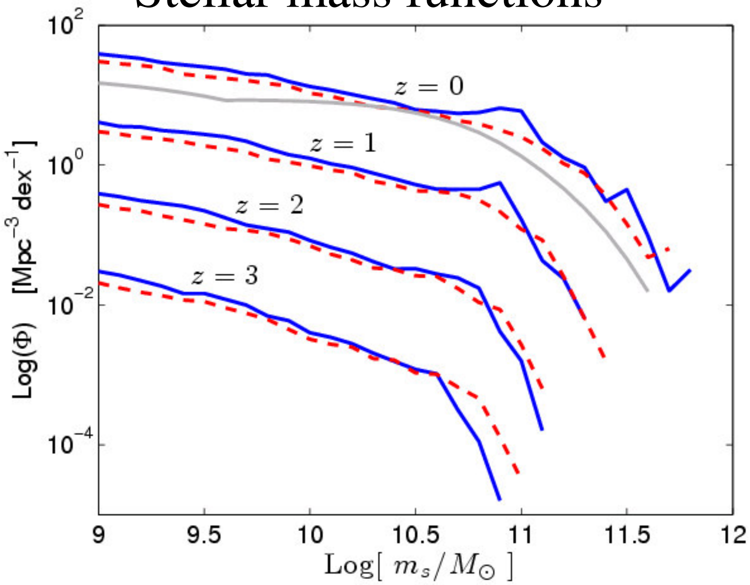




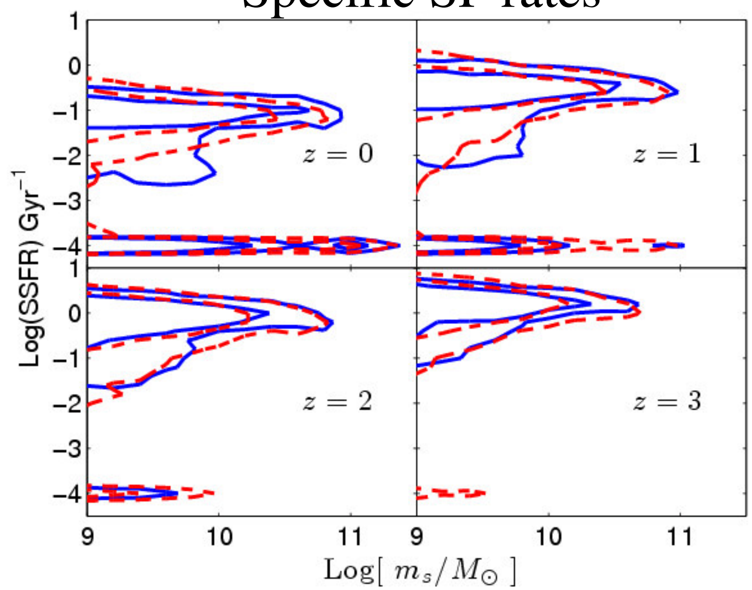
3. We use the averaged recipes within our model, using the same merger-trees as De Lucia & Blaizot

Comparing results

Stellar mass functions



Specific SF rates



Blue – our model

Red – De Lucia & Blaizot (2007)

Gray – observations (Li & White 2009)

Very similar scatter!

The scatter in the properties of galaxies comes mainly from different merger-histories !!

New Models

Motivation

- explore the degeneracy
- span different scenarios
- identify important observ. constraints
- fit the data !

I – no SN feedback

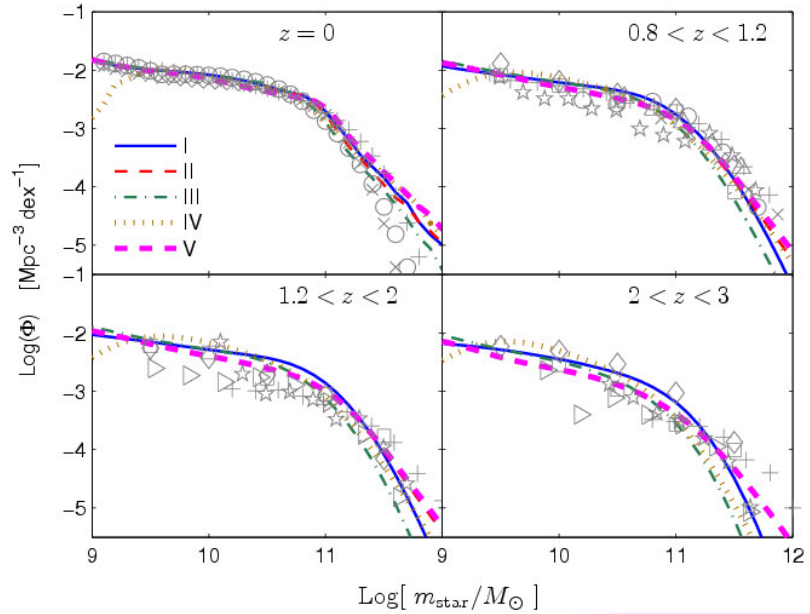
II – no ejection feedback

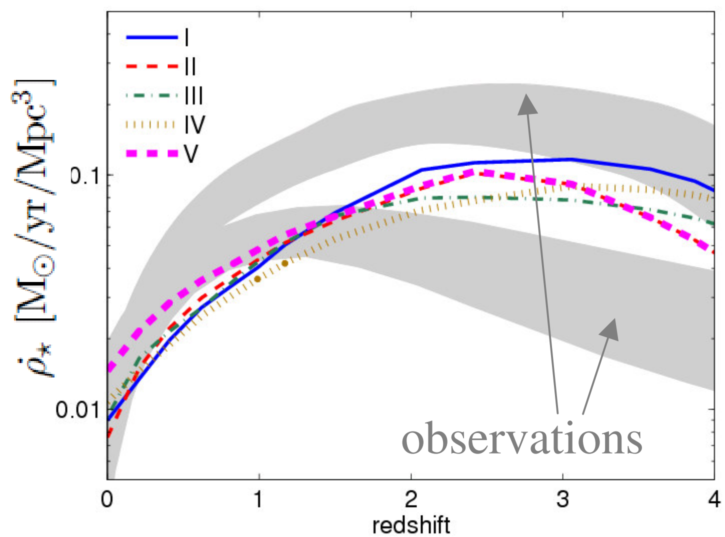
III – cold accretion

IV – only bursts

V – shutdown by mergers

Stellar mass functions





Outline:

SAM recipes

SeSAM method

Degeneracy

Abund. match.

High-z SSFR

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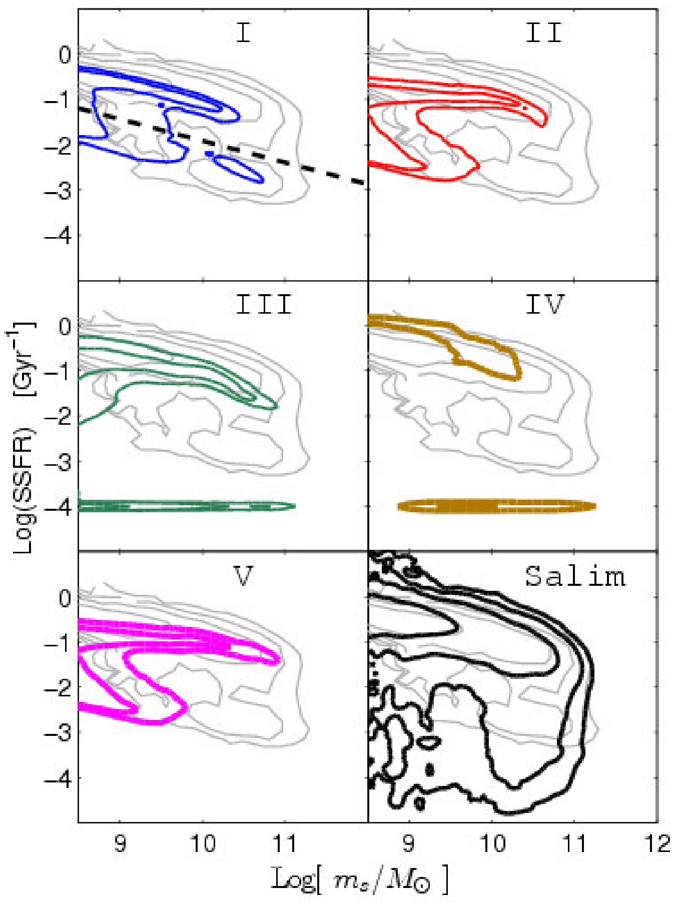
Breaking the degeneracy



I – no SN feedback
II – no ejection feedback
III – cold accretion
IV – only bursts
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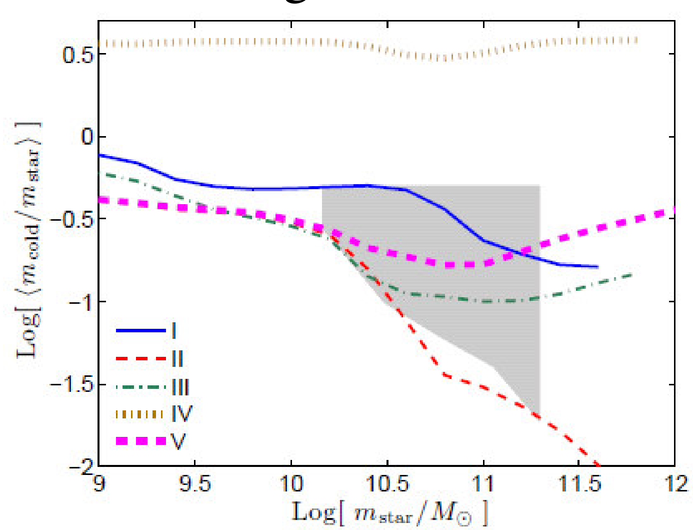
Residual SF in passive galaxies

cold gas fraction



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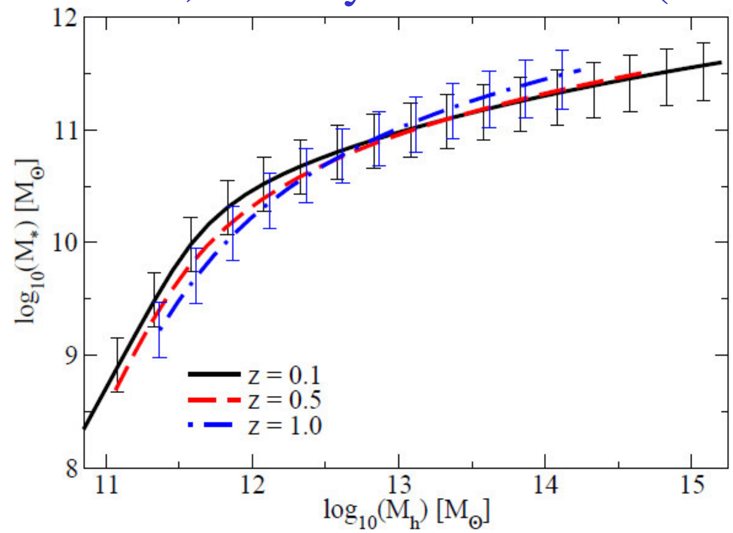
Abundance matching

EN, Cheng Li, Simone Weinmann, Michael Boylan-Kolchin

$$m_*(M_h)$$

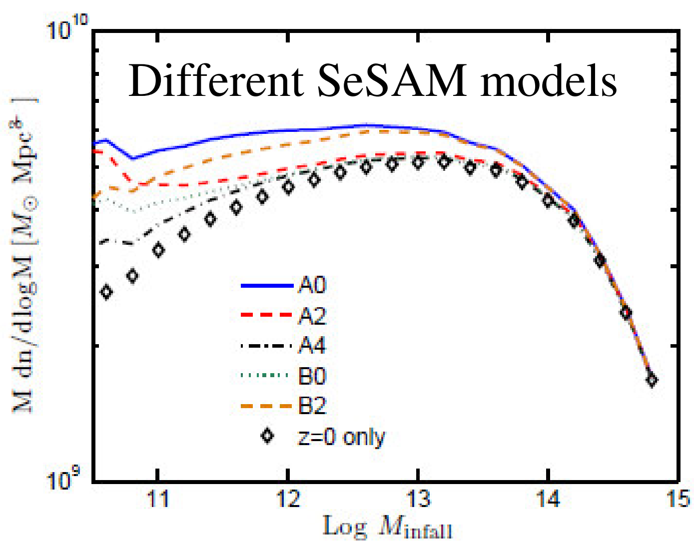
Stellar-mass as a function of the subhalo mass at the time of infall

Behroozi, Conroy & Wechsler (2010)



Assumptions on satellites at z=0:

1. Using only subhalos which survive until z=0
2. No redshift dependence: $m_*(M_h, z)$
3. infalling subhalos are similar to other centrals
4. No mass gained after infall



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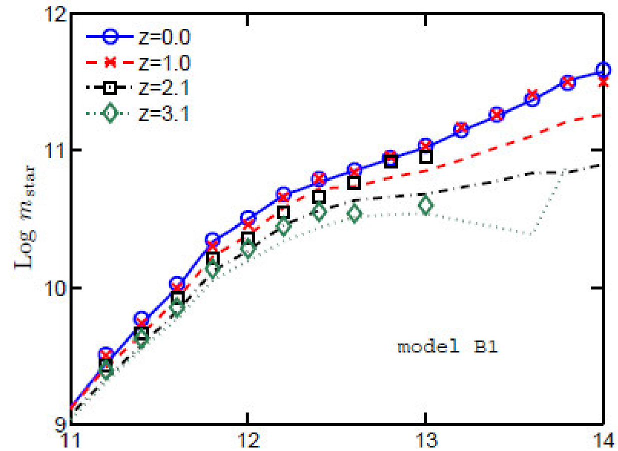
Abundance matching (II)

Lines: central galaxies at each redshift

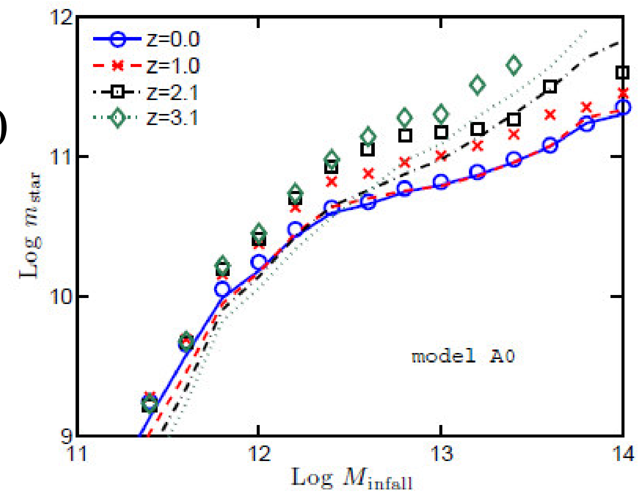
Symbols: satellite galaxies at z=0,

labeled by their infall z,

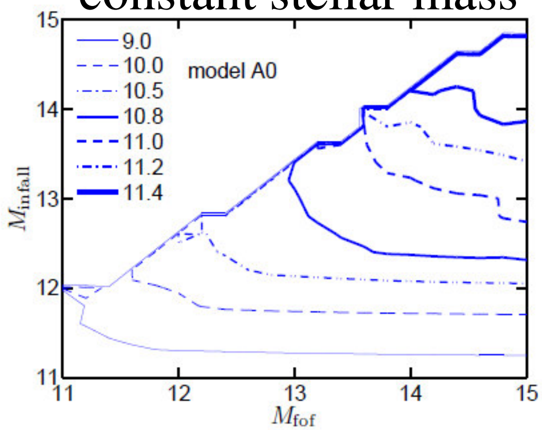
stellar mass at infall



Symbols:
stellar mass at z=0



Contours:
constant stellar mass



All these effects modify the correlation function …

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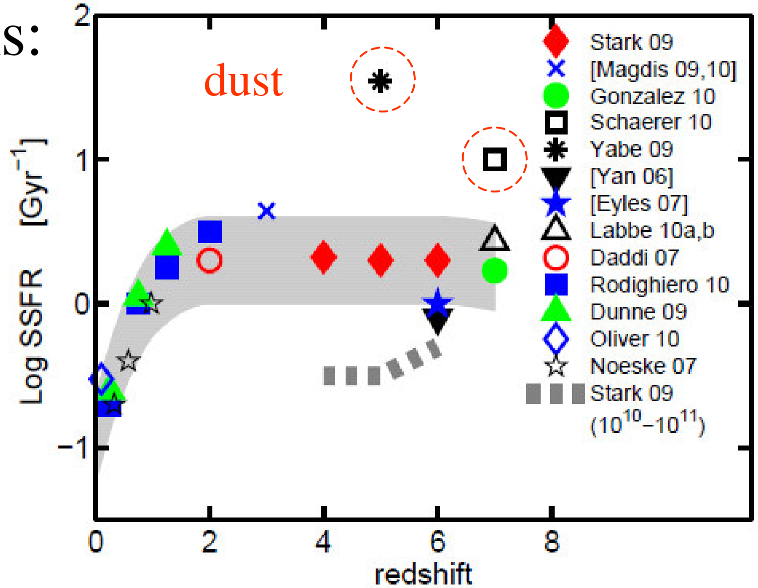
High-z SFR

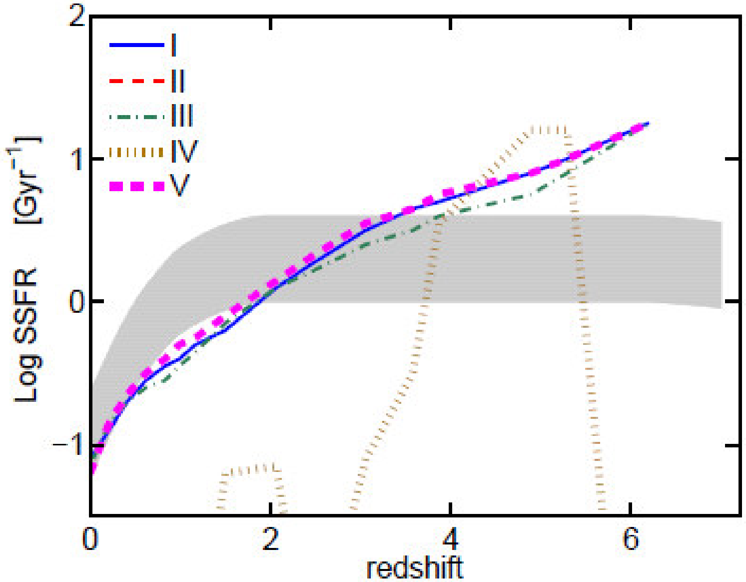
Simone Weinmann, EN & Avishai Dekel

Observations:

10^9-10^{10}



Standard SeSAMs:

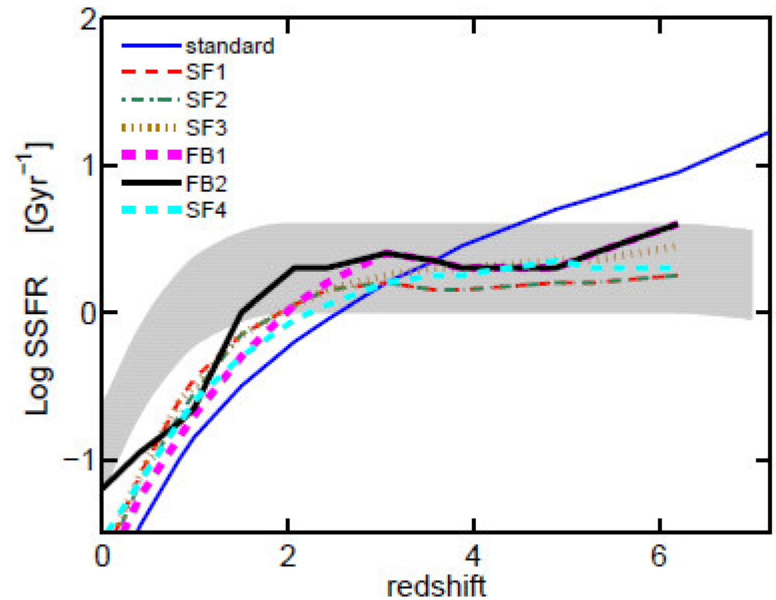


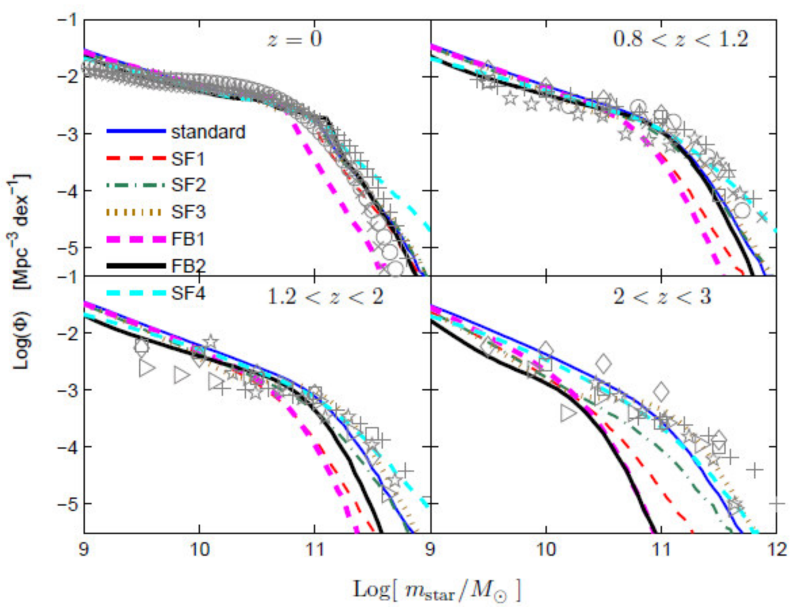
- Is the plateau in conflict with the theory?
- Why most models behave the same (and different from the observ.)?

High-z SFR (II)

Fitting the plateau

- significant changes in SF and feedback efficiencies
- too low stellar mass function





Reproducing both only by changing mergers

- high efficiency of SF bursts
- short dynamical friction times at high-z

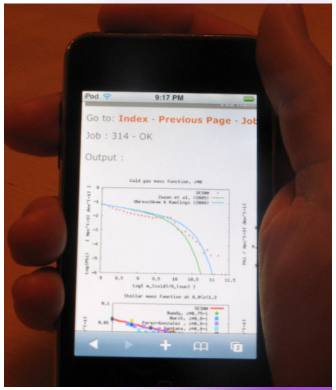
Summary

New 'SeSAM' methodology:
- simple & fast (8 sec for the Milli-MS)
- easy to tune
- no a-priory parameterization of recipes
- 5 very different models

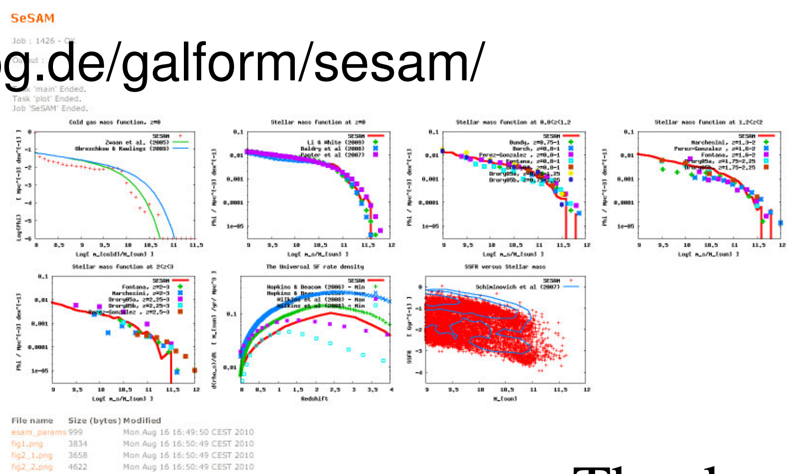
Abundance matching
- more complicated behavior in SeSAM
- dependence on environmental effects
- dynamical friction

High-z SSFR
- different SF/feedback recipes needed
- high efficiency of mergers burst
- shorter accretion times

Run it from your palm:



web page
http://www.mpa-garching.mpg.de/galform/sesam/

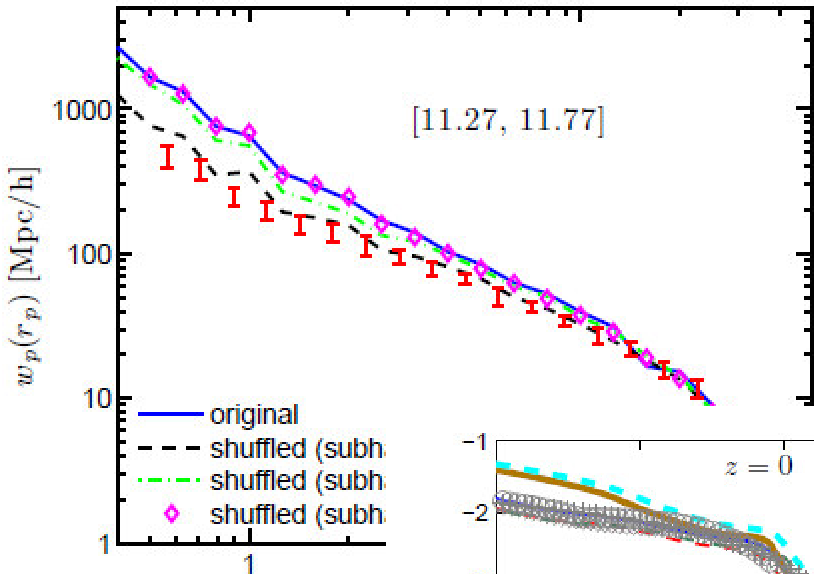


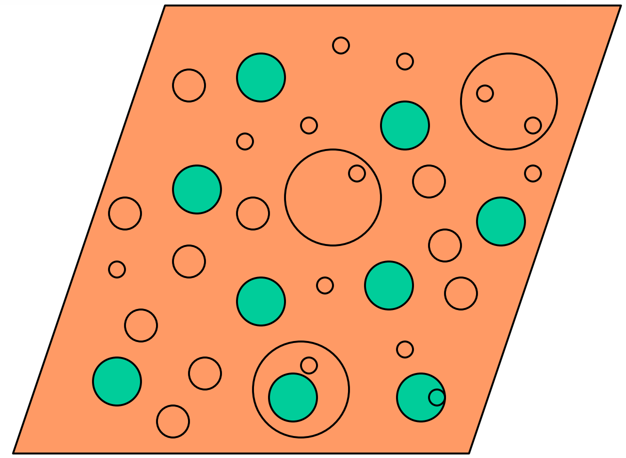
1. **Choose** your parameters
2. **Run** the model (on our server!)
3. **See** comparison
   against observations
4. **Download** catalogs

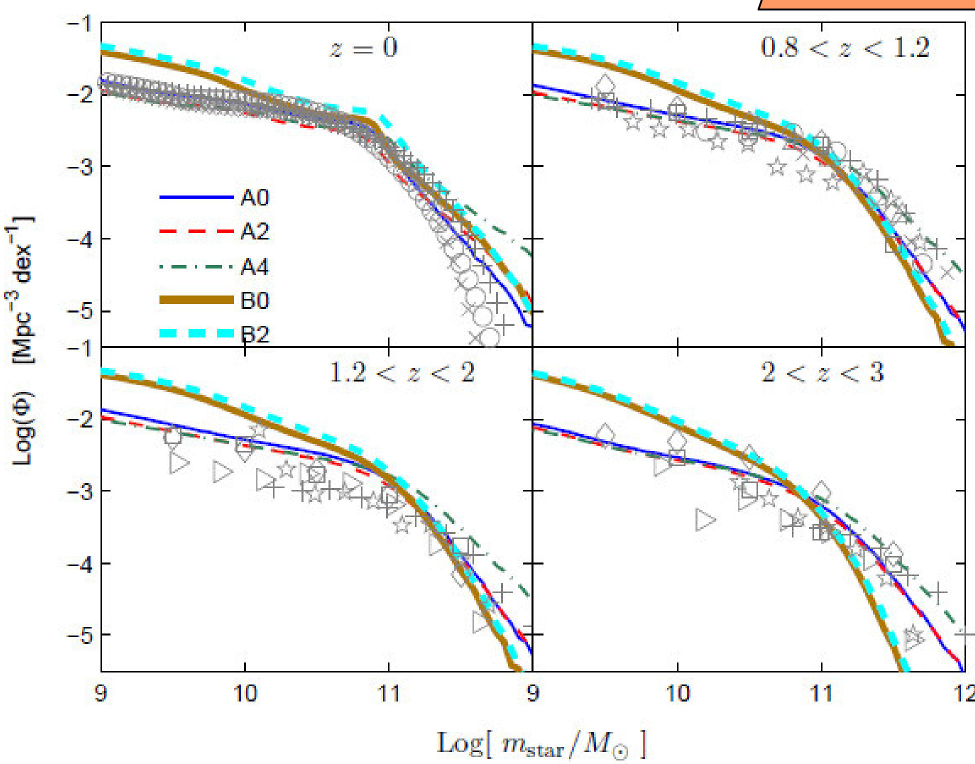
Thank you!

Eyal Neistein
08/10, UCSC

More on ABM







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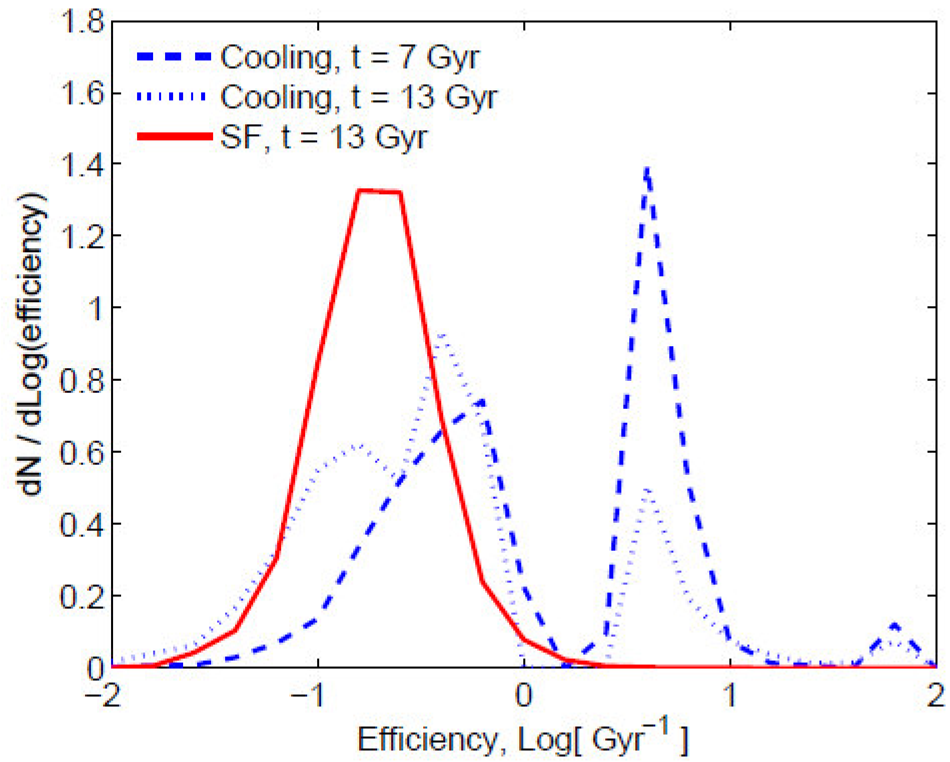
Scatter



SF – halo spin distribution, depends weakly on halo mass

Cooling – numerical behavior for small mass halos

<u>Outline:</u>

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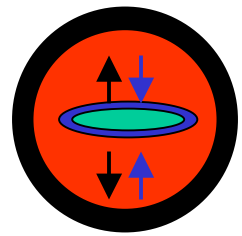
Model I - Minimum Cooling

What are the minimum cooling rates possible?

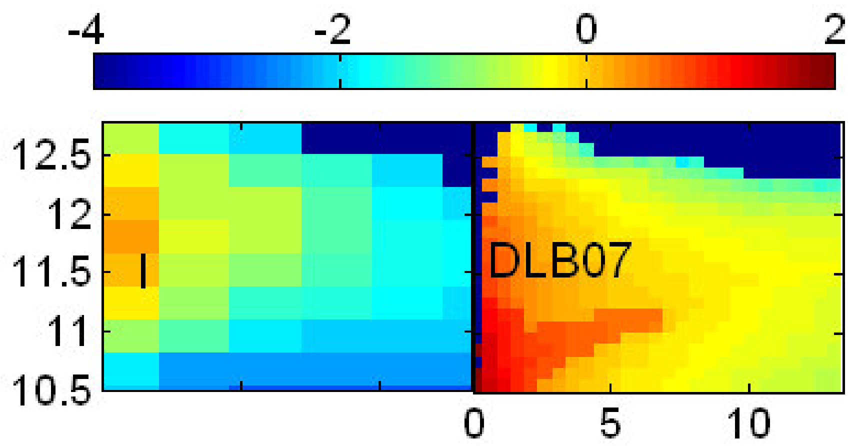
- cooling is balanced by feedback, **(minimum cooling)=(zero feedback)**
- cooling will then control the total amount of mass within stars & cold gas
- ~unique solution for cooling rates



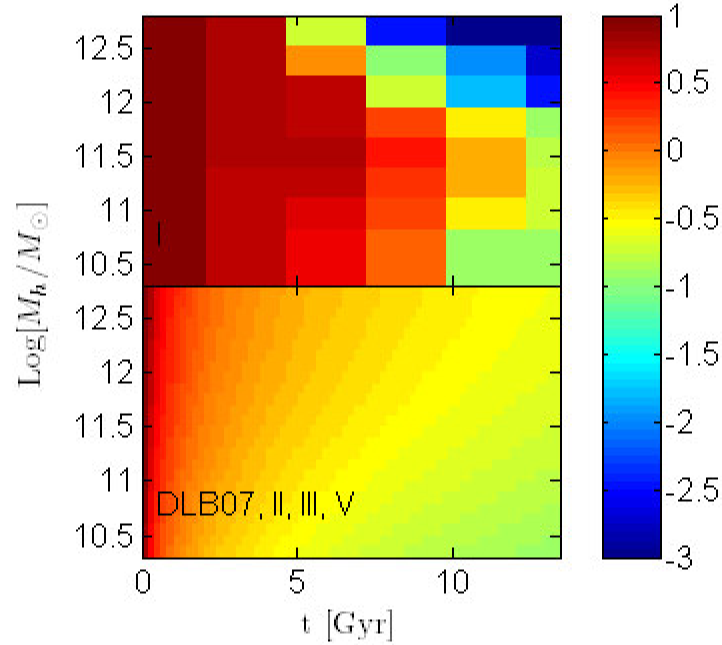
Model ingredients:

- zero SN feedback
- no merger induced SF bursts
- total freedom in cooling and SF:

Log $f_c(M_h, z)$



Log $f_s(M_h, z)$



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