June 9th 2011, Trieste, INAF/OATS UNI/TS Seminar

Properties of satellite & central galaxies in observations & in semi-analytical models

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Leiden Observatory

Collaborators: Frank van den Bosch, Xiaohu Yang, Houjun Mo, Guinevere Kauffmann, Gabriella De Lucia, Anja von der Linden, Thorsten Lisker...

Outline

Observations of environmental trends

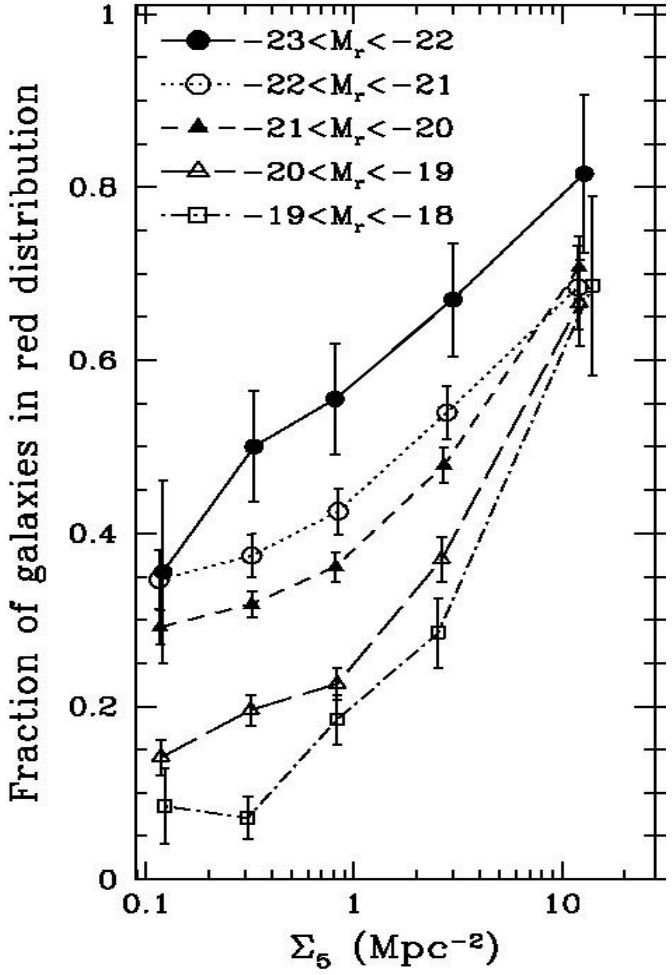
Comparison to semi-analytical models

2006 vs. 2011

Implications

A more fundamental problem?

Environmental Dependencies



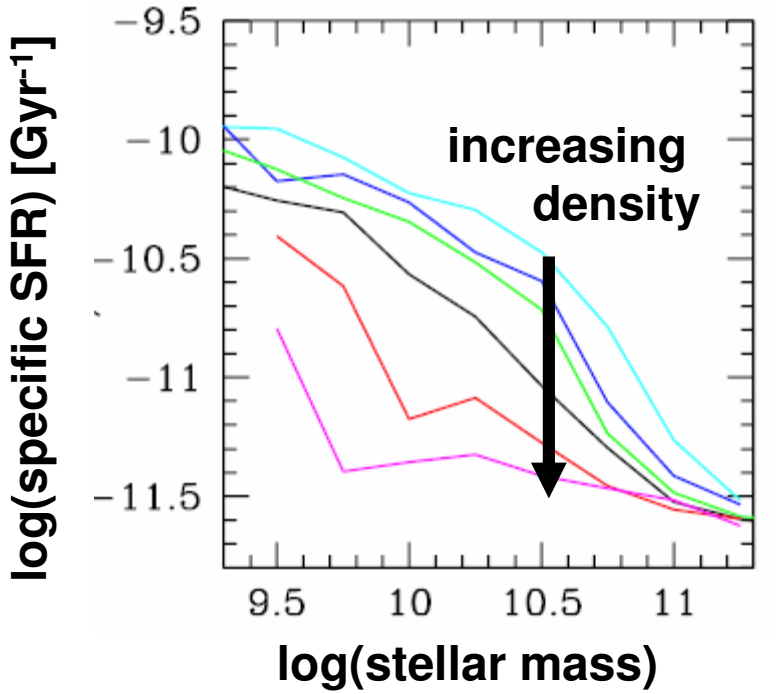
Red/passive galaxies more often found in dense regions

Balogh et al. 04

low density ⟷ **high density**

Environment vs. stellar mass

Galaxy properties depend even more on stellar mass than on environment:

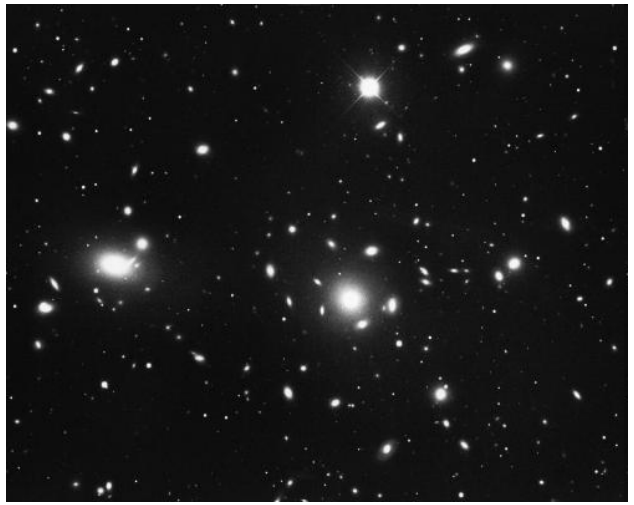


Kauffmann et al. 2004

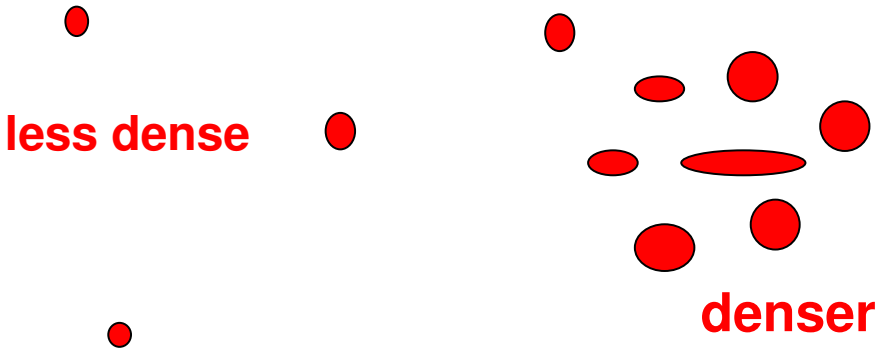
→ **It is important to take out stellar mass dependence when studying environmental effects**

Group and Cluster Catalogues

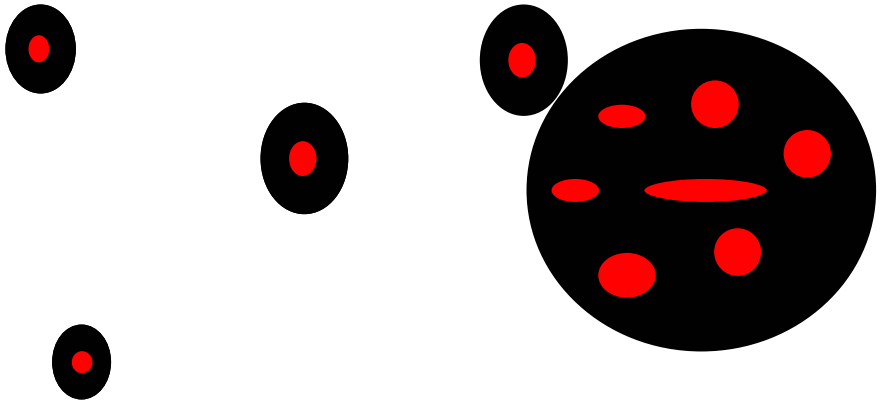
Coma cluster



what we see: galaxies



what (we think) is really there: lots of DM

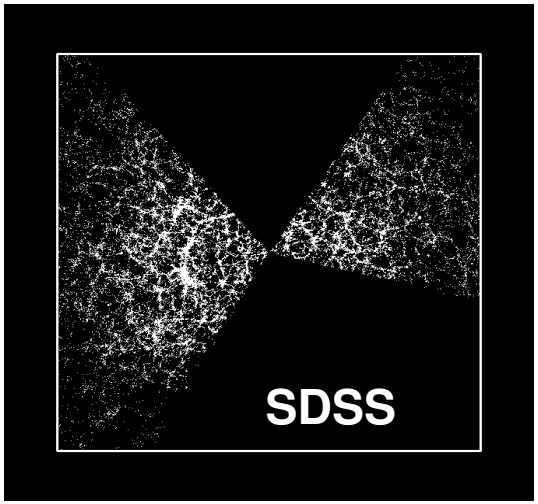


Goal:
relate galaxies to their
host dark matter haloes

group & cluster catalogues

Group and Cluster Catalogues

SDSS $0.01 < z < 0.2$
$M_{star} > 10^{9.5}$



Yang et al. 2007 group catalogue
Iterative group finder, based on halo model
Mass estimated from total stellar mass
~ 200,000 groups with ~ 280,000 galaxies

Von der Linden et al. 2007 cluster catalogue
Clustering in z, ra, dec, colour
Mass estimated from velocity dispersion
521 clusters

$z < 0.02$, $M_{star} > 10^{7}$

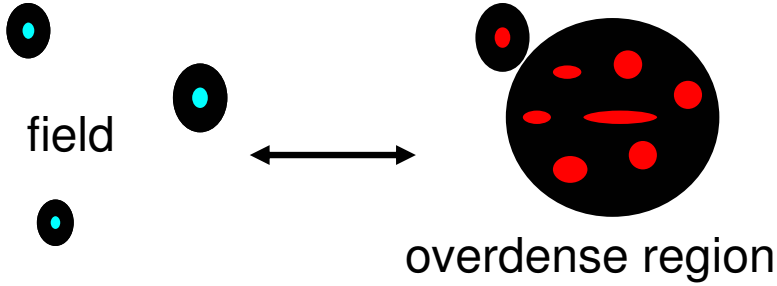
$z < 0.02$
$M_{star} > 10^{7} – 10^{8}$
Perseus / Coma / Virgo / Fornax
from various sources, background-correction

Coma cluster

Quantifying environment

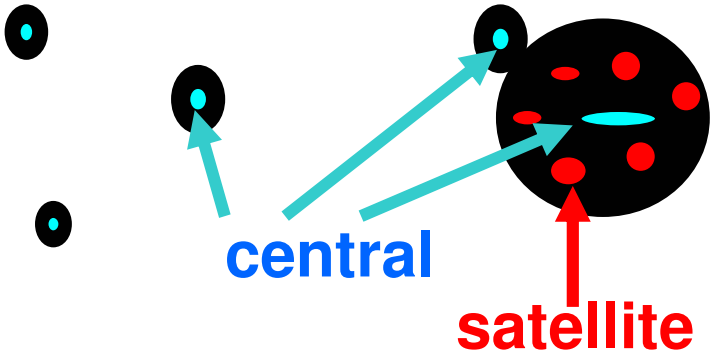
traditional approach:

local galaxy density



new approach with group catalogues: fix stellar mass of galaxies, then:

distinction satellite - central

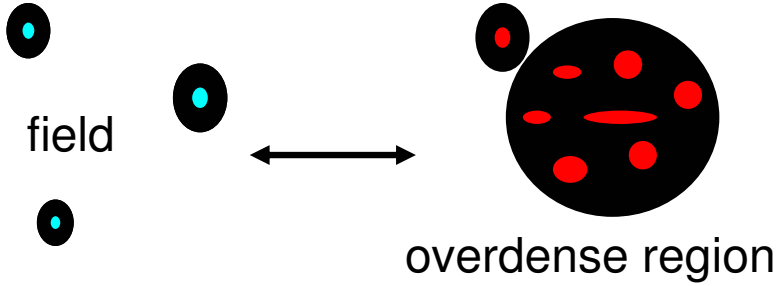


"centrals" : most massive galaxy in their dark matter halo
"satellites" : all other galaxies
Fundamentally different, since
only central galaxies can accrete new gas!

Quantifying environment

traditional approach:

local galaxy density



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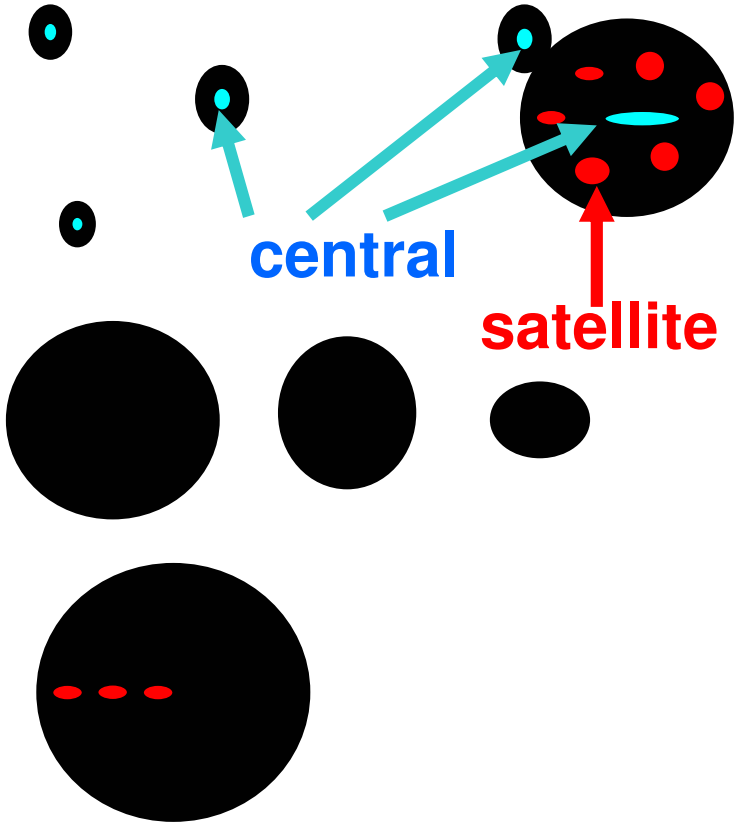


for satellites:

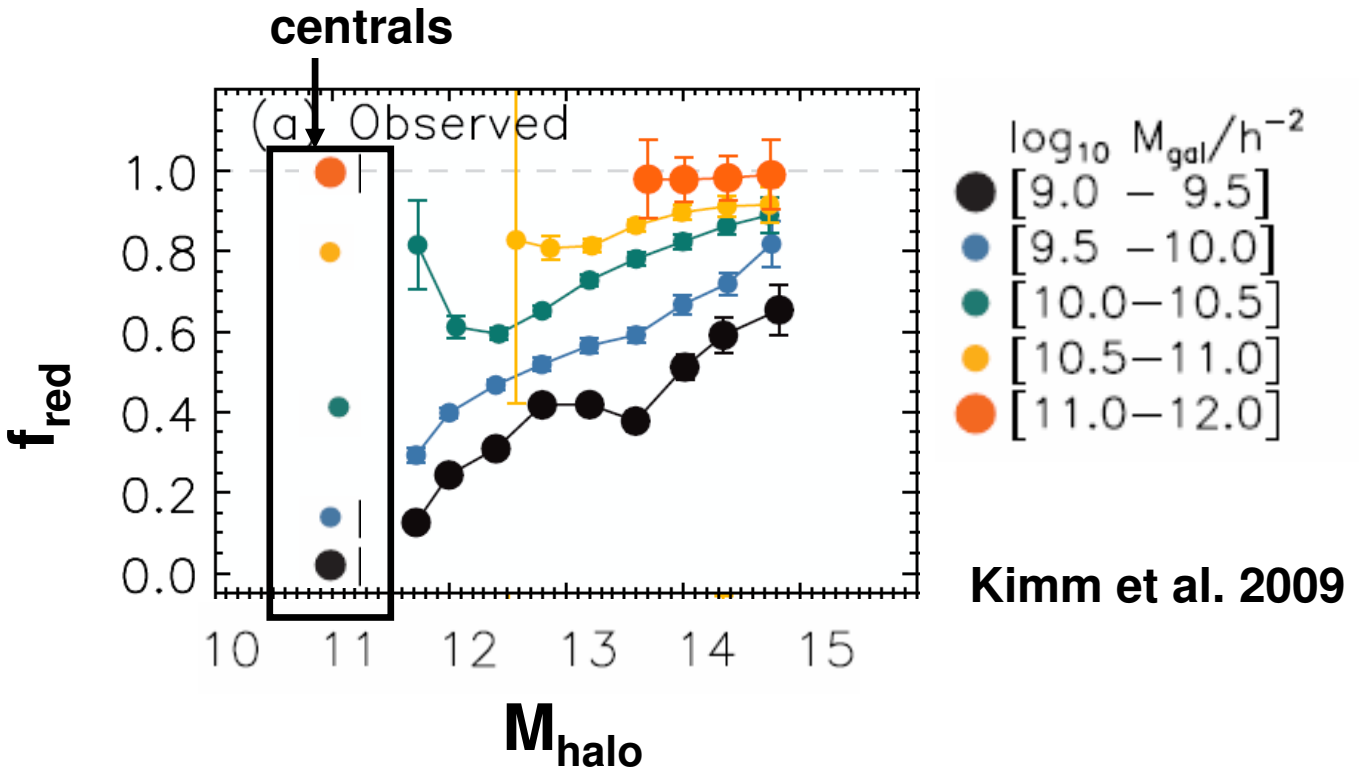
host halo mass

group-centric distance

Dependence of star formation rates and colours on environment

at fixed stellar mass

- Satellite galaxies are redder & less star forming than centrals
- Satellite galaxies are redder & less star forming if they reside in higher mass groups and clusters

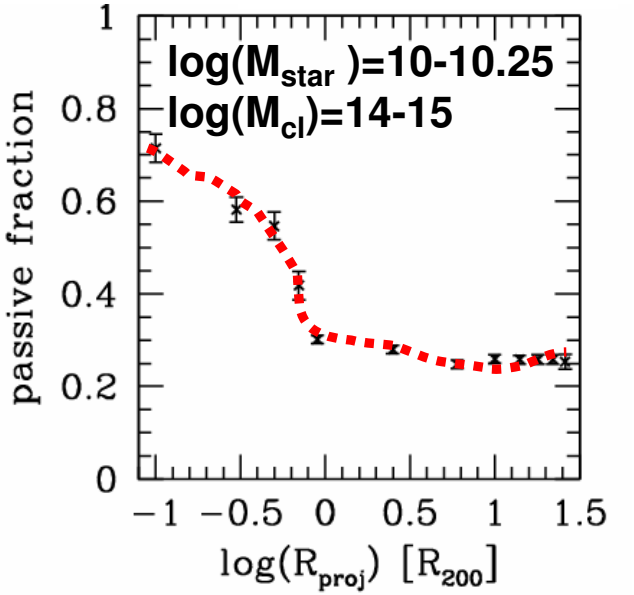


Kimm et al. 2009

Dependence of star formation rates and colours on environment

at fixed stellar mass

- Satellite galaxies are redder & less star forming than centrals
- Satellite galaxies are redder & less star forming if they reside in higher mass groups and clusters
- Satellite galaxies are redder & less star forming if they reside closer to the center of the cluster



Weinmann et al. 2010

Dependence of star formation rates and colours on environment
at fixed stellar mass

- Satellite galaxies are redder & less star forming than centrals
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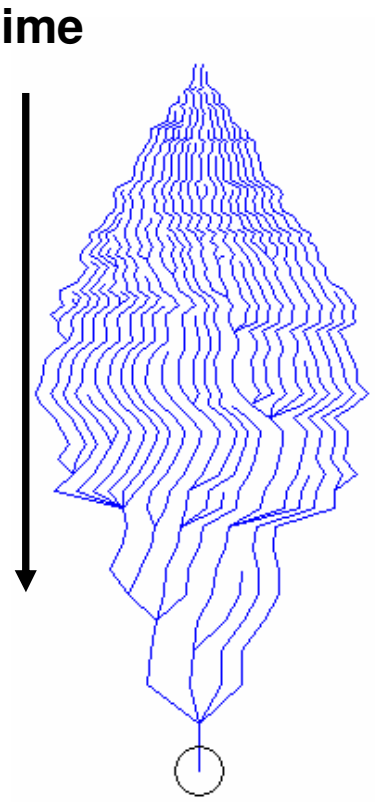
Why?

Dependence of star formation rates and colours on environment
at fixed stellar mass

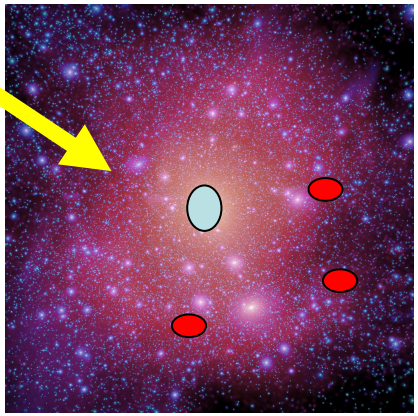
- Satellite galaxies are redder & less star forming **than centrals**
- Satellite galaxies are redder & less star forming **if they reside in higher mass groups and clusters**
- Satellite galaxies are redder & less star forming if they **reside closer to the center of the cluster**

Semi-Analytical Models (SAM)

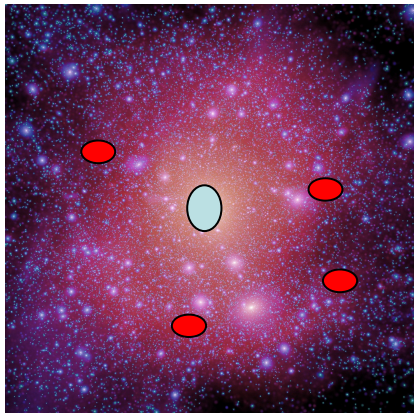
Start from a dark matter simulation (like Millennium) that gives evolution of DM subhaloes



example "merger tree": is populated with galaxies



t_1

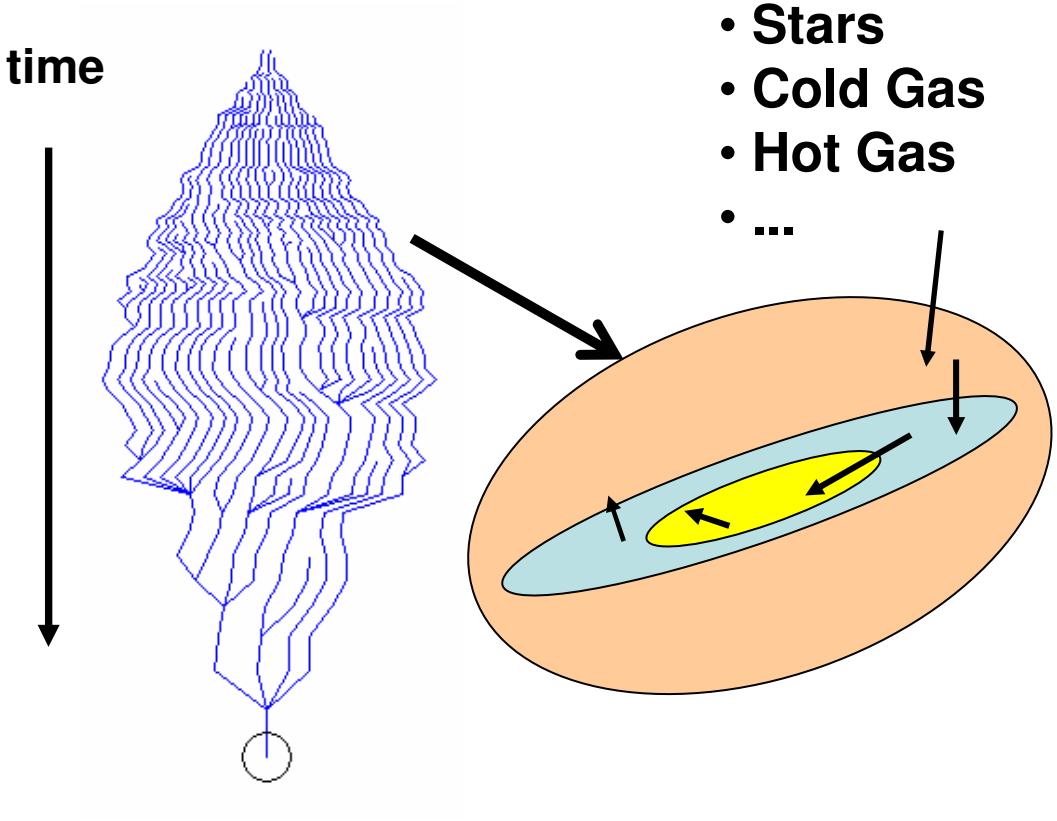


t_2

also follows centrals becoming satellites, and their orbit in their host cluster

Semi-Analytical Models (SAM)

DM merger trees:

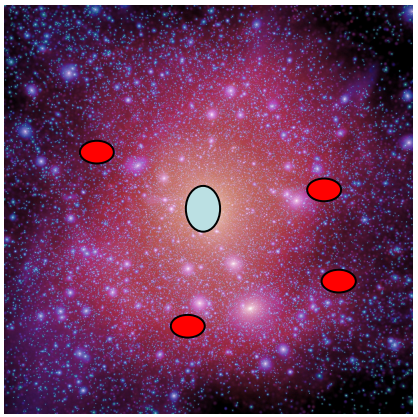


Galaxies:

- Stars
- Cold Gas
- Hot Gas
- ...

Physical processes:

- Accretion
- Cooling
- Star Formation
- SN feedback
- mergers
- environmental effects on satellites



Semi-Analytical Models (SAM)

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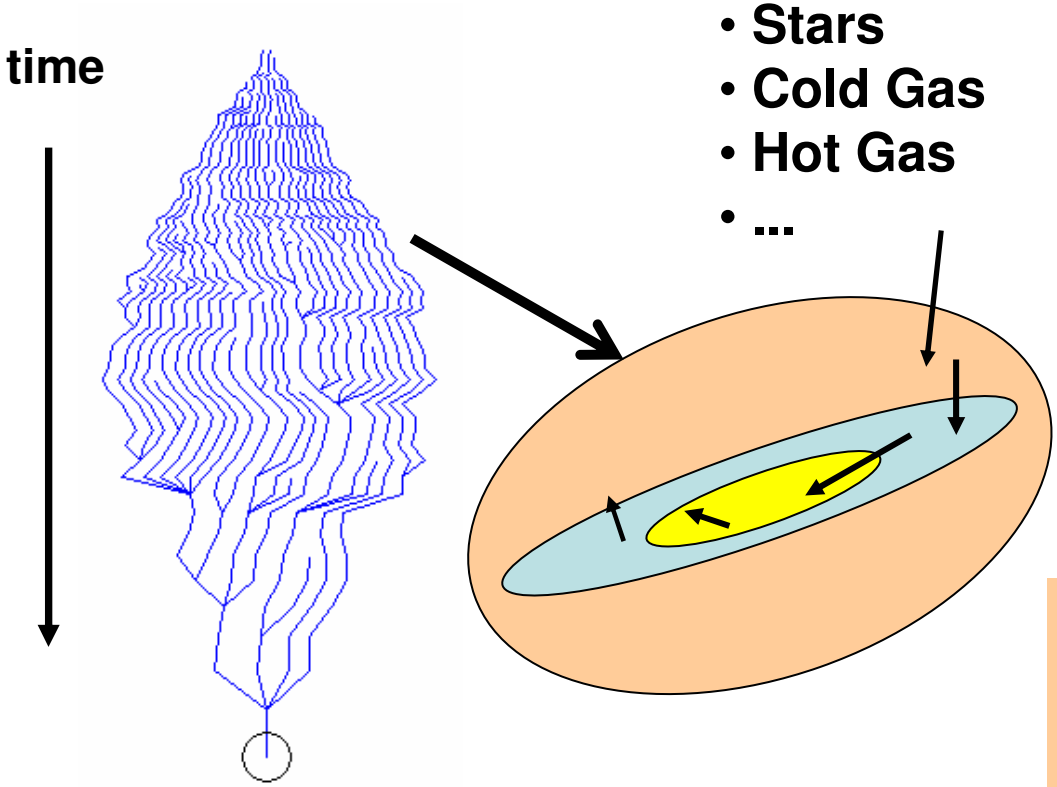

Galaxies:

- Stars
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Physical processes:

- Accretion
- Cooling
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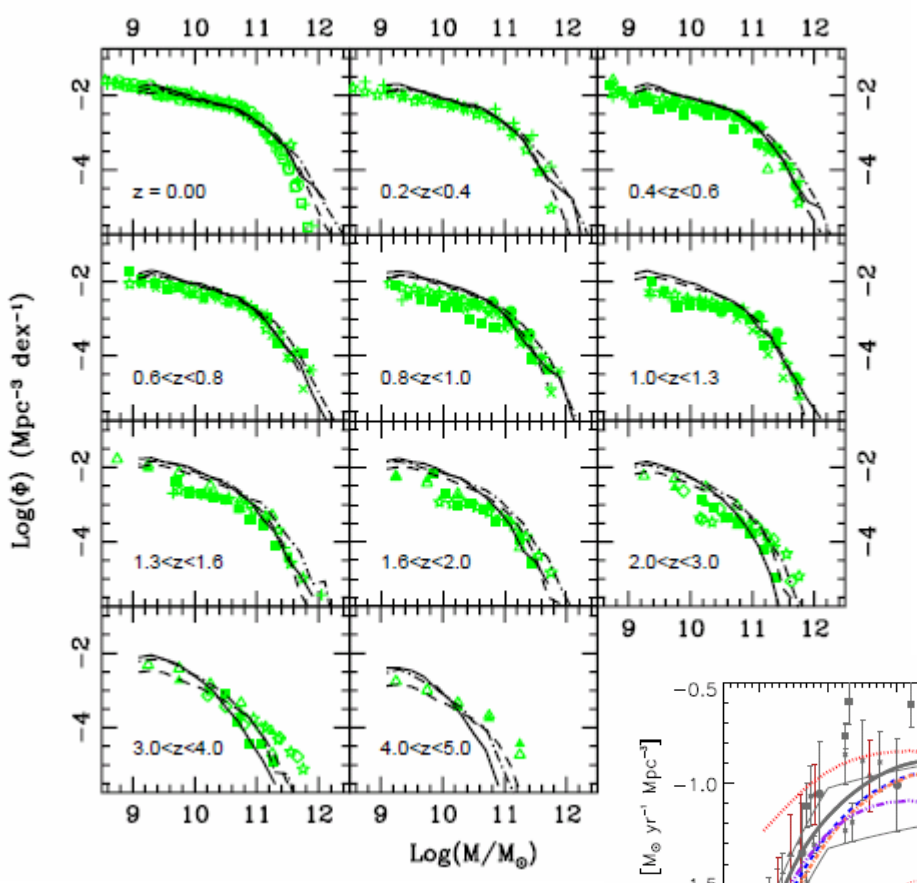
- environmental effects on satellites

Only one environmental effect is explicitely included in current SAMs, namely:

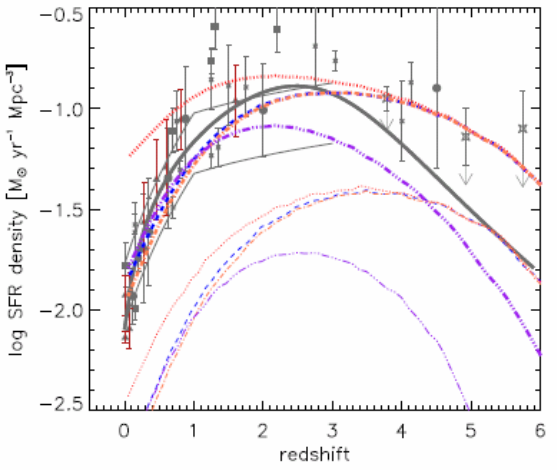
starvation

Semi-Analytical Models

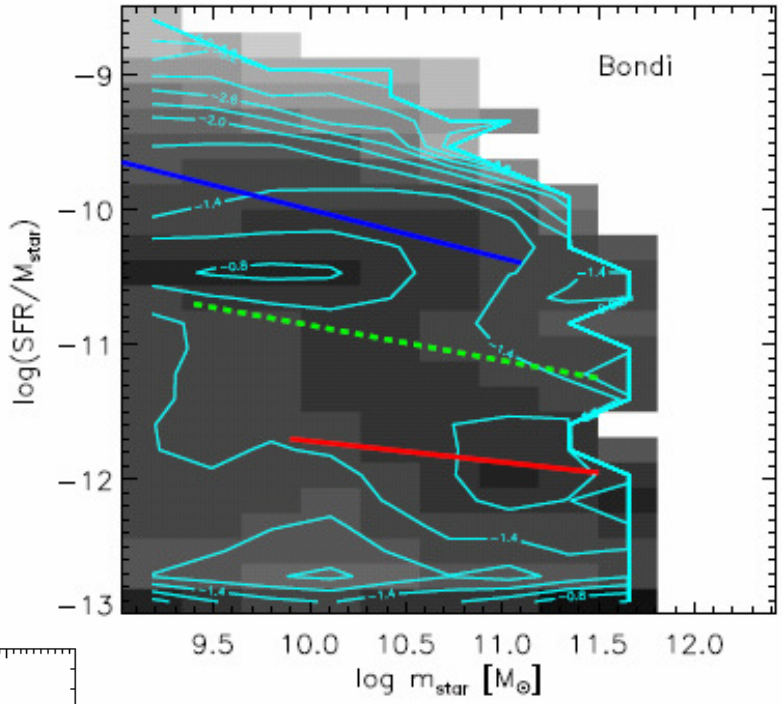
Can reproduce many important properties of the global galaxy population:



stellar mass functions over time (Fontanot et al. 09)



Universal SFR density (Somerville et al. 08)

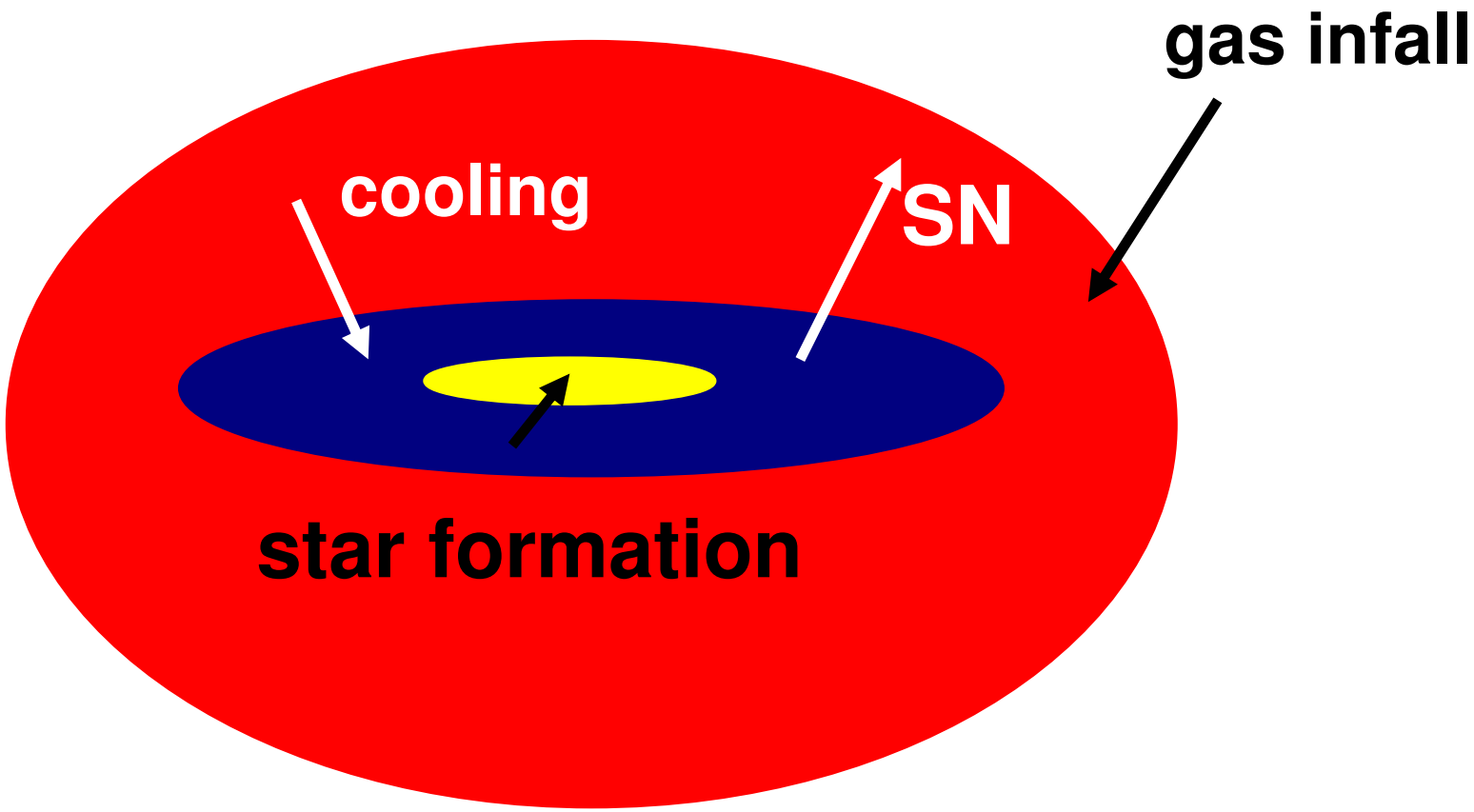


Specific star formation rates at z=0 (Somerville et al. 08)

"Starvation" in standard SAM:

Simple prescription:

All *hot halo gas* is removed when a galaxy falls into a group or cluster.



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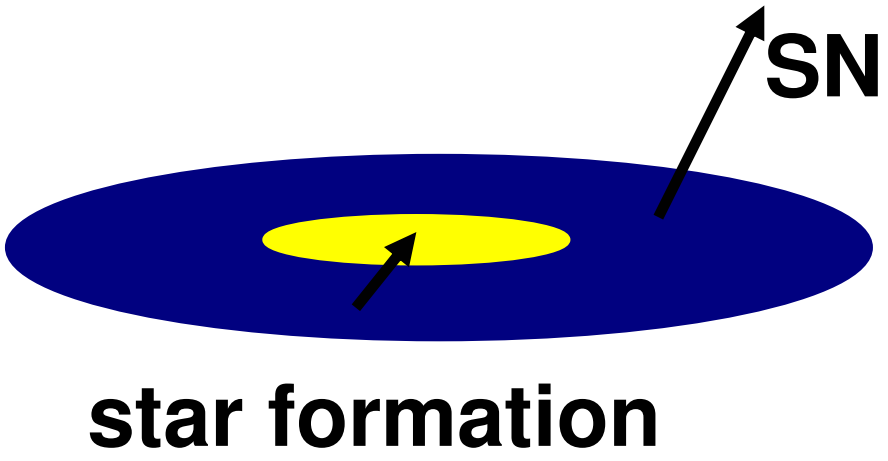

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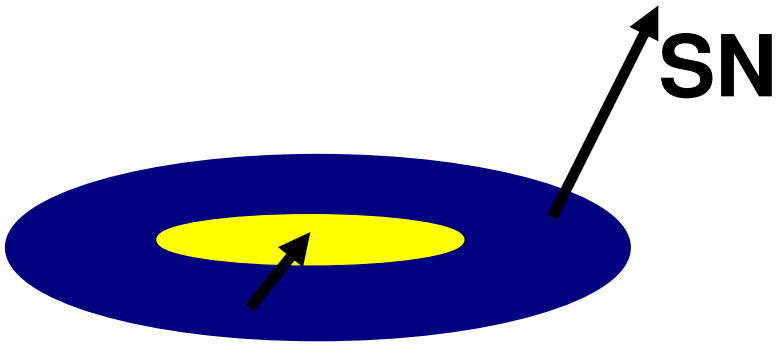


star formation declines exponentially...

"Starvation" in SAM:

Simple prescription:

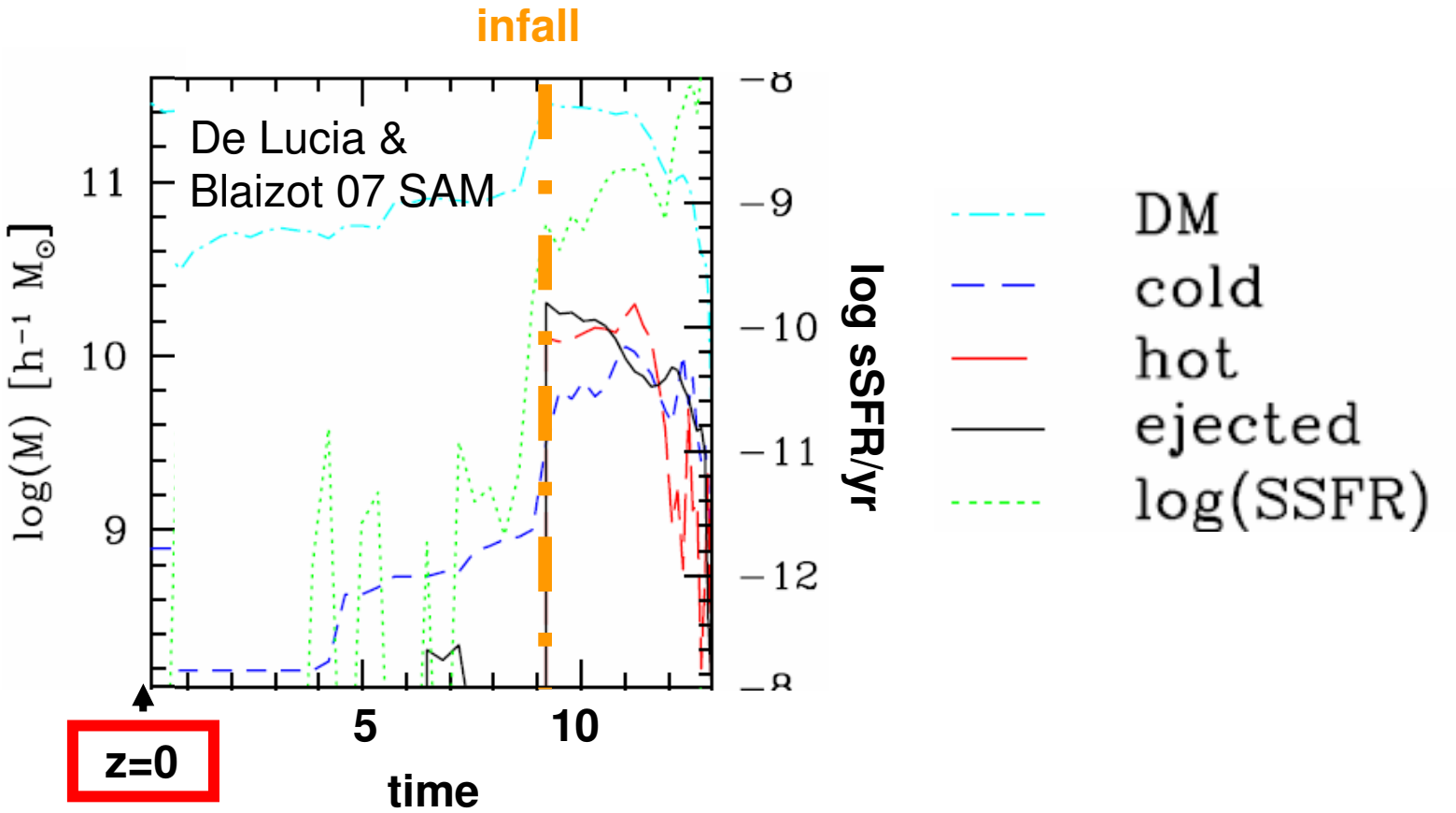
All *hot halo gas* is removed when a galaxy falls into a group or cluster.

.. and stops completely

"Starvation" in SAM:

Simple prescription:

All *hot halo gas* is removed when a galaxy falls into a group or cluster.

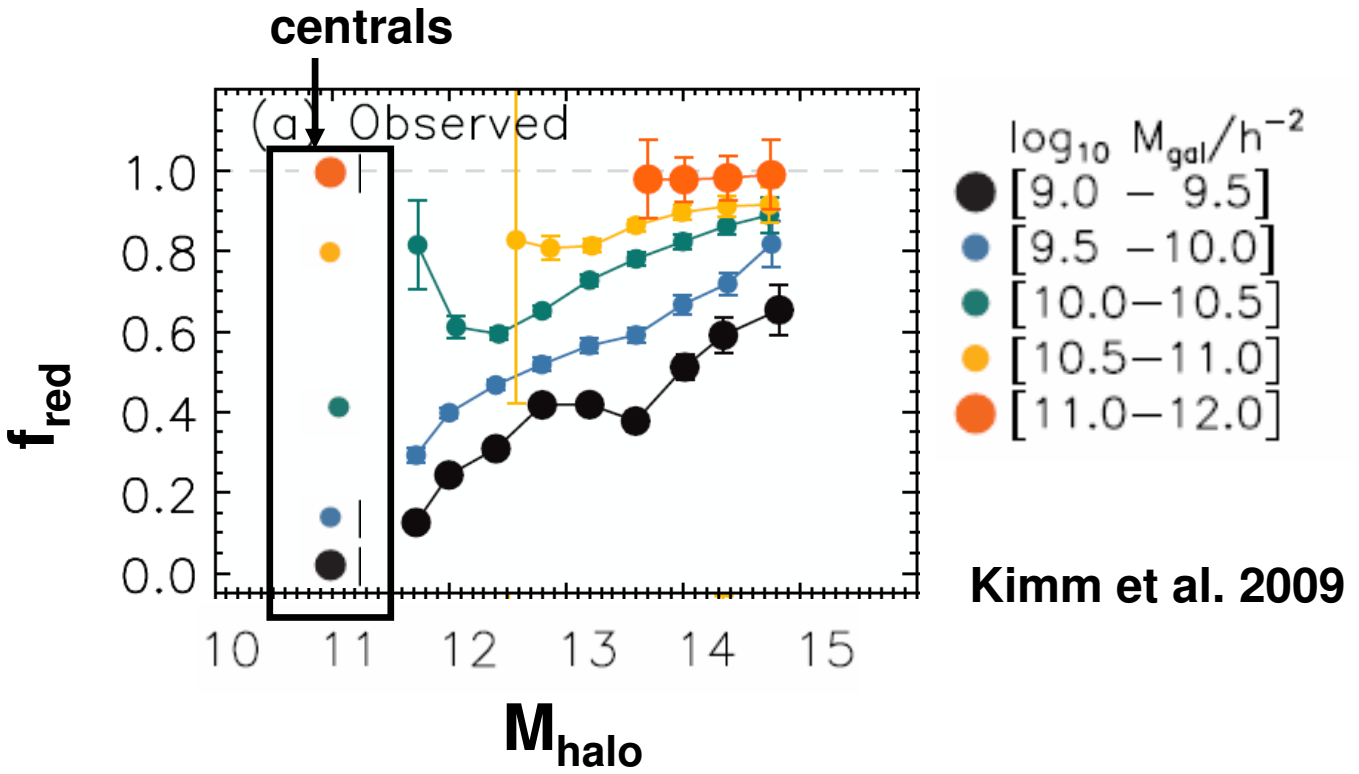


Weinmann et al. 2010

Dependence of star formation rates and colours on environment

in observations

- Satellite galaxies are redder & less star forming than centrals
- Satellite galaxies are redder & less star forming if they reside in higher mass groups and clusters

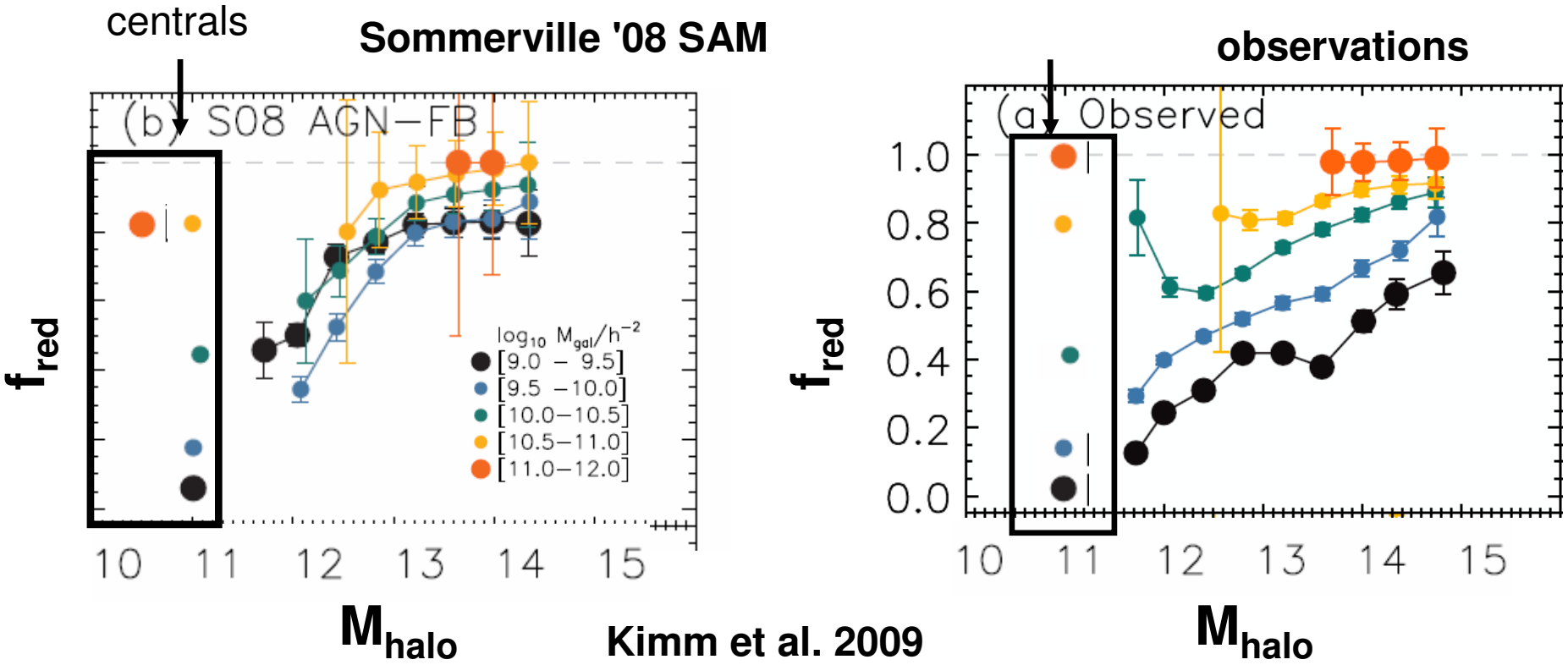


Kimm et al. 2009

Dependence of star formation rates and colours on environment

in semi-analytical models

- **Satellite galaxies are redder & less star forming than centrals**
- **Satellite galaxies are redder & less star forming if they reside in higher mass groups and clusters**



Kimm et al. 2009

Dependence of star formation rates and colours on environment

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- **Satellite galaxies are redder & less star forming than centrals OK**
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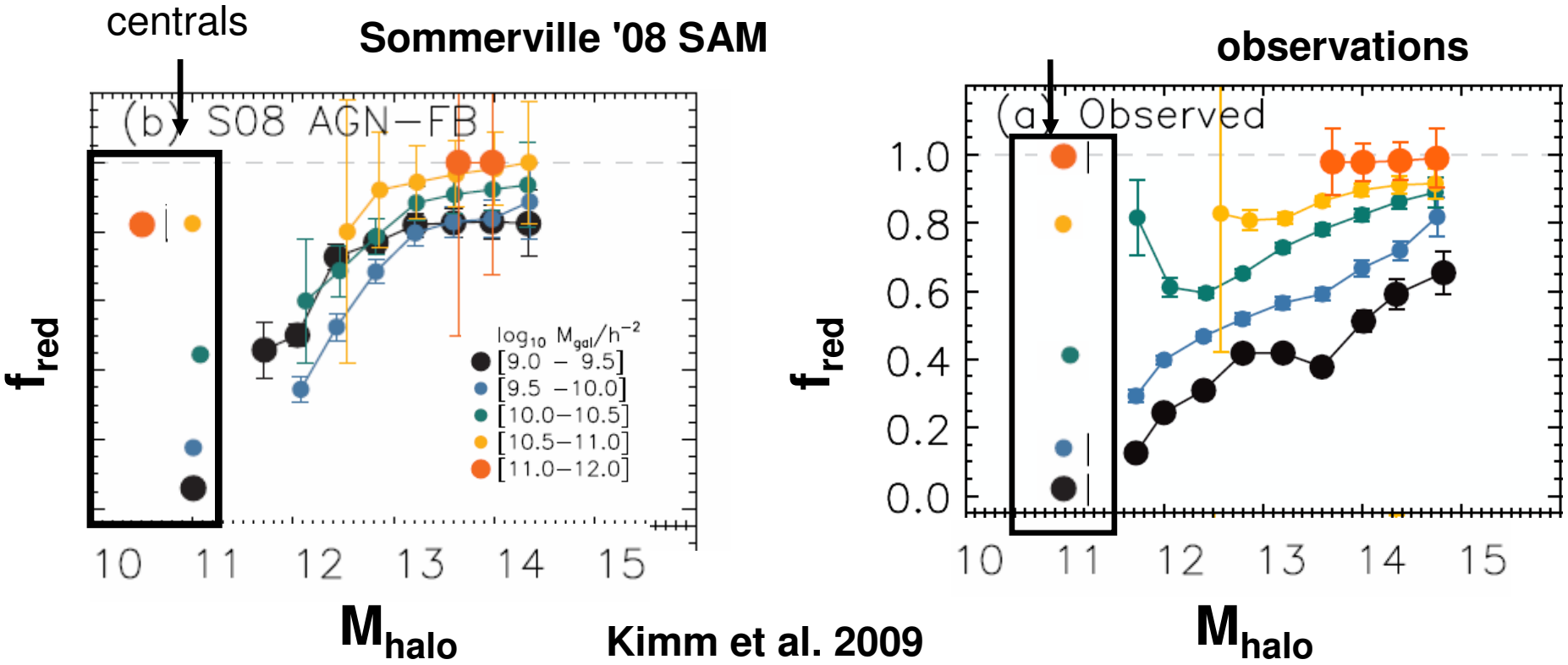

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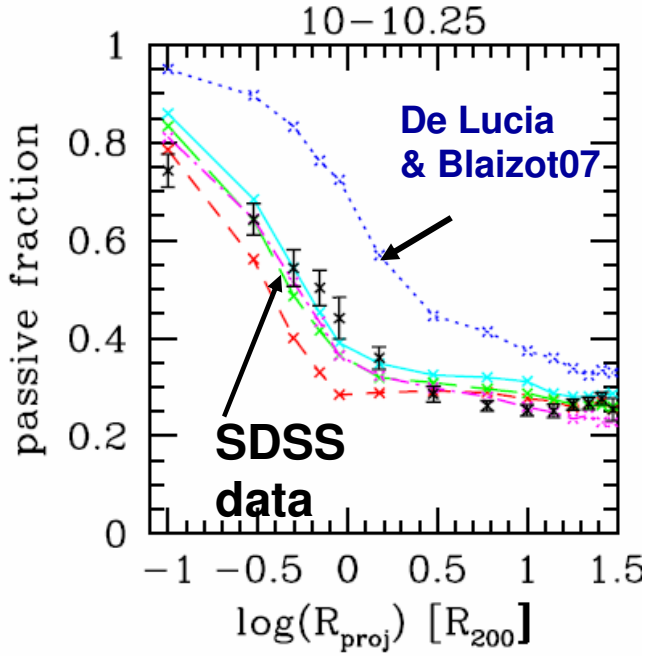
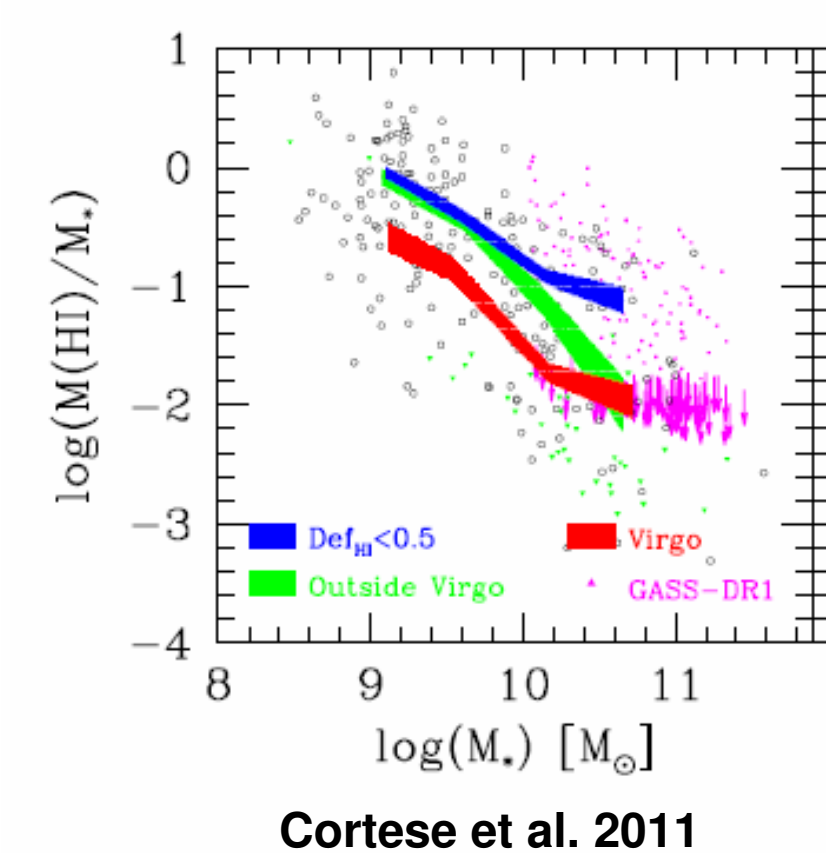


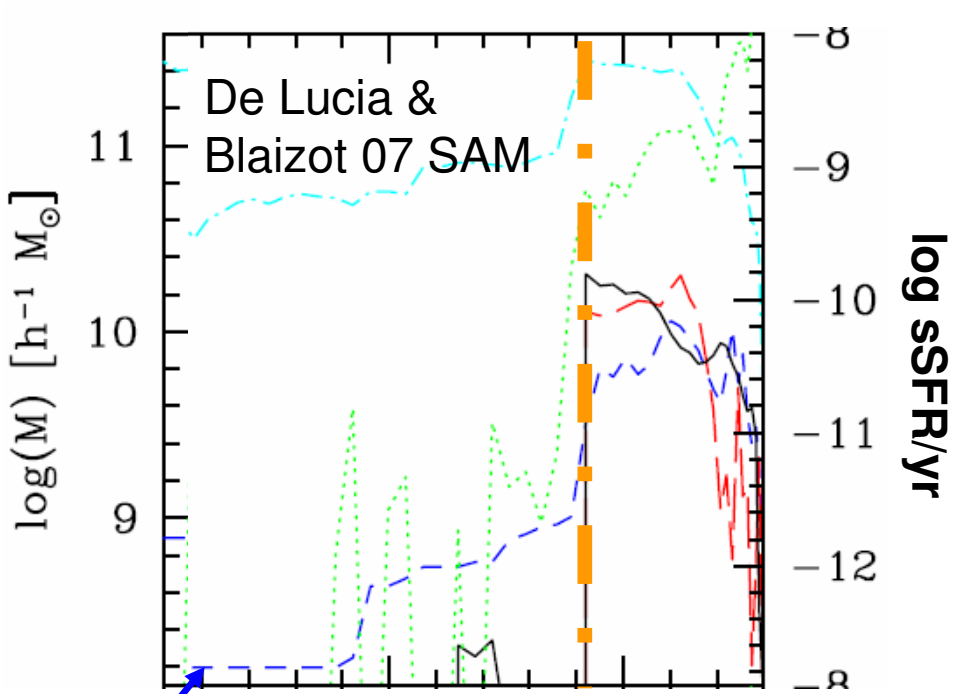
Weinmann et al. 2010

Starvation explains HI deficiency in cluster galaxies



Cortese et al. 2011

infall



Weinmann et al. 2010

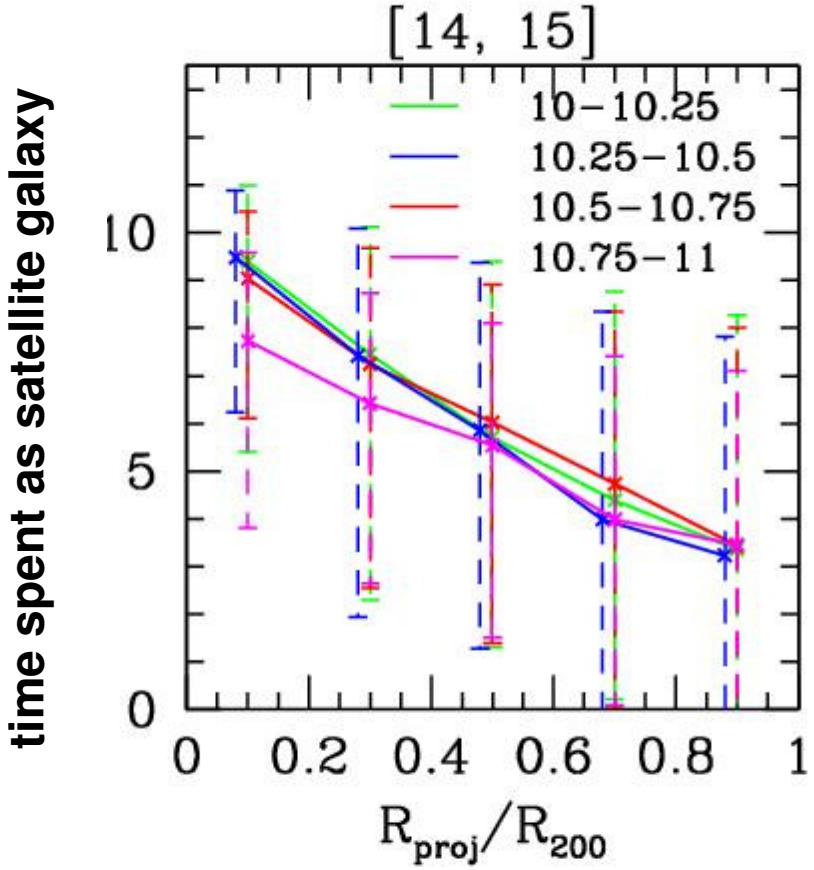
nearly no cold gas left – with starvation alone

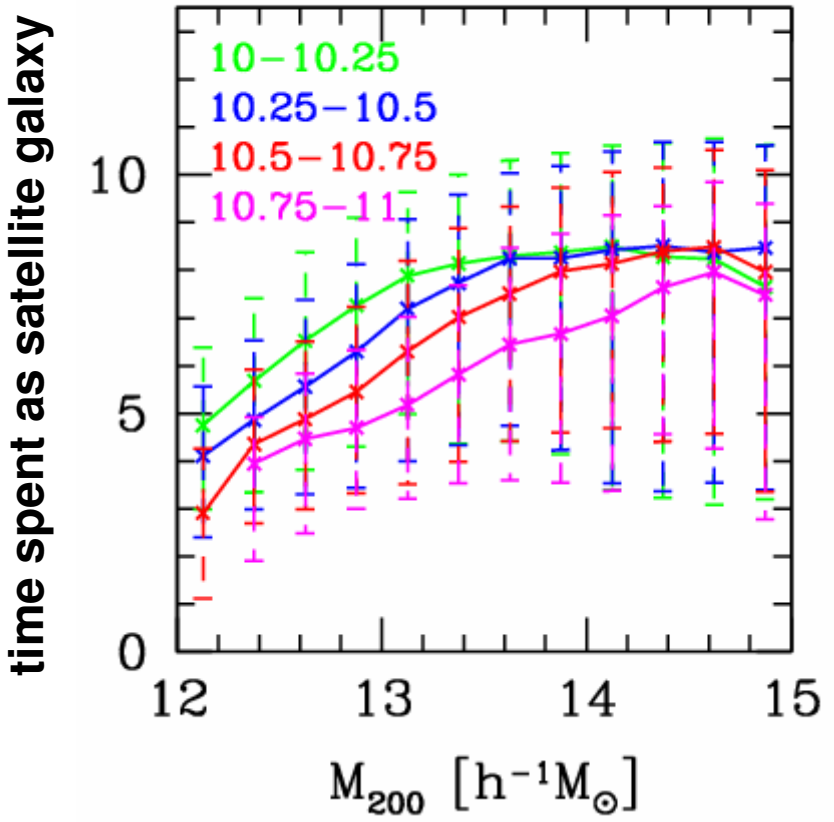
Dependence of star formation rates and colours on environment
in SAMs

- Satellite galaxies are redder & less star forming than centrals OK
- Satellite galaxies are redder & less star forming if they reside in higher mass groups and clusters OK
- Satellite galaxies are redder & less star forming if they reside closer to the center of the cluster OK
- Cluster galaxies are HI deficient OK

all these fundemental trends are qualitatively reproduced by SAMs using a very simple treatment of environmental effects (only starvation)!

Reason for this success is very simple:
the star formation is satellites is going down
galaxies in higher mass groups and closer
to the cluster center have been satellites for longer:





Weinmann et al. 2011

Dependence of star formation rates and colours on environment
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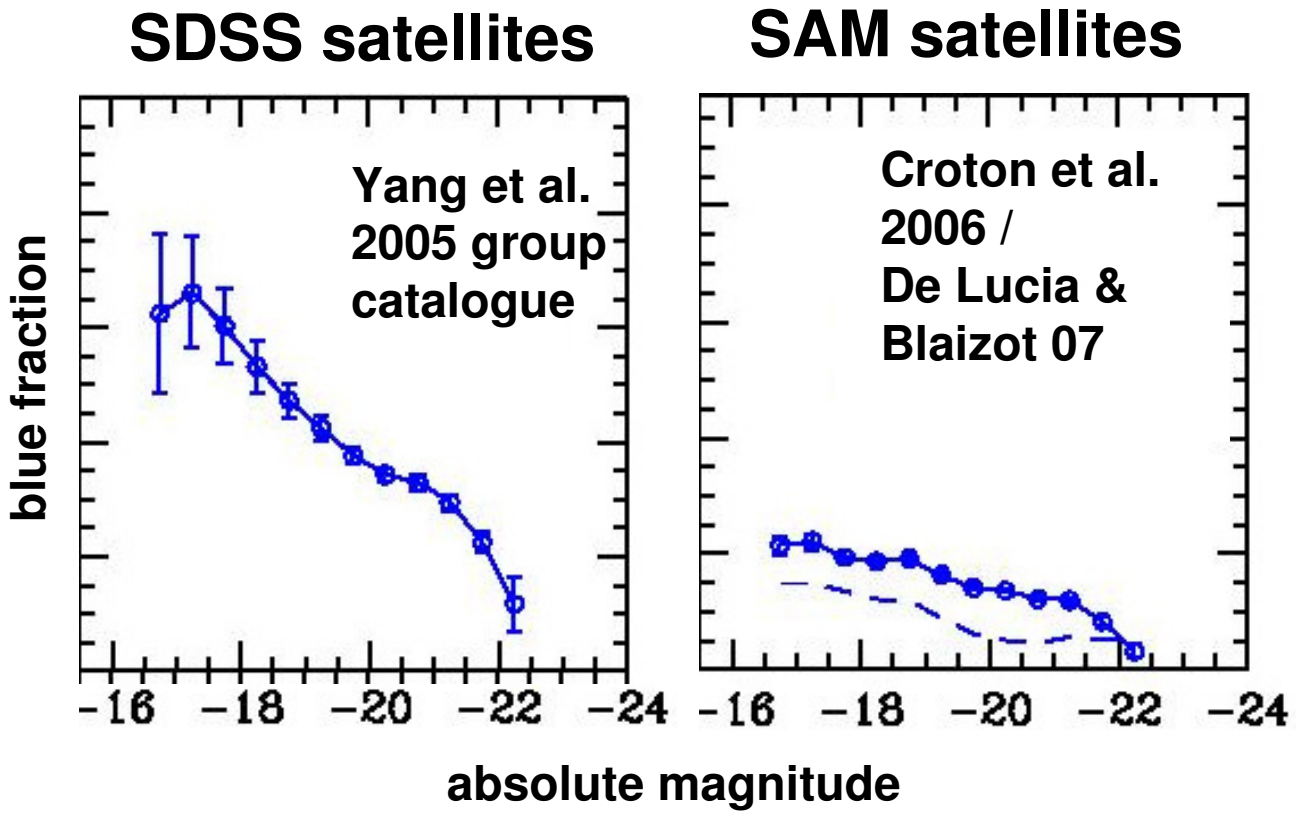
all these fundemental trends are qualitatively reproduced by SAMs using a very simple treatment of environmental effects (only starvation)! → but not yet quantitatively

Compare properties of group galaxies in SAM and observations (2006)



Blue satellite fraction in SAM much too low

Weinmann et al. 2006

⟶ **means that 'starvation' is too efficient**

Compare properties of group galaxies in SAM and observations

Blue satellite fraction in SAM much too low

STATUS 2006

Compare properties of group galaxies in SAM and observations

Blue satellite fraction in SAM much too low

STATUS 2006

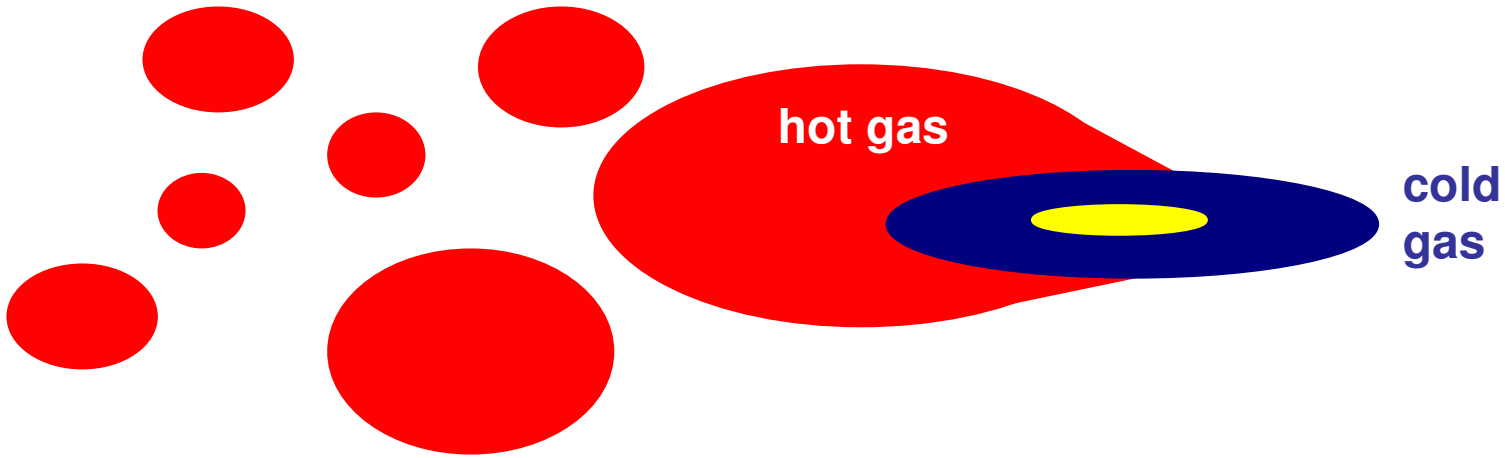
→ environmental effects must be over-efficient

Compare properties of group galaxies in SAM and observations

Blue satellite fraction in SAM much too low

→ environmental effects must be over-efficient

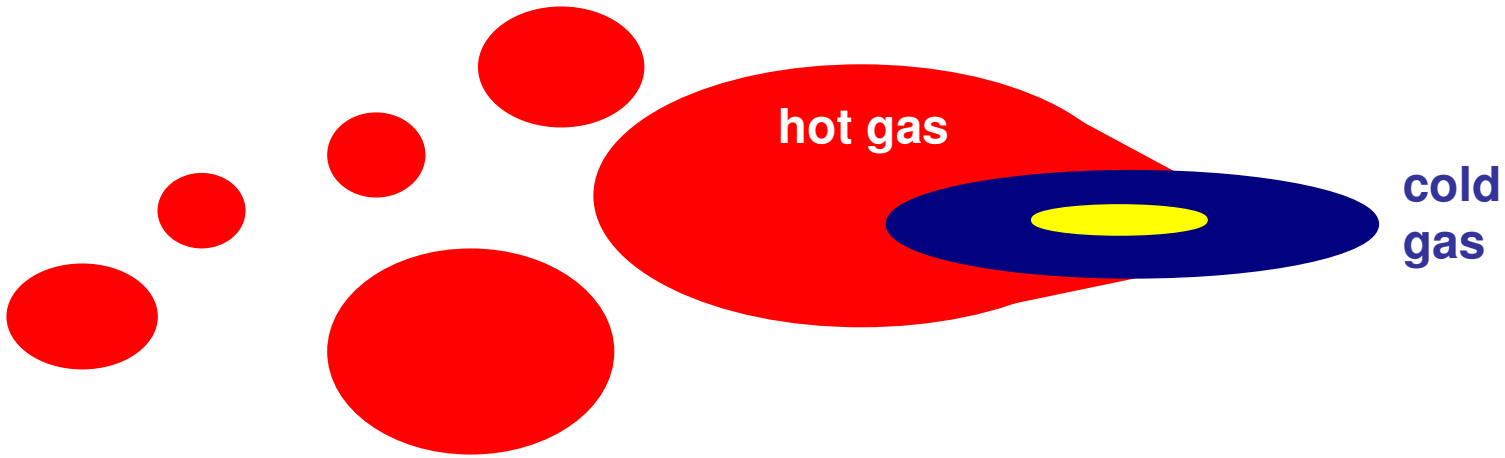
Slower hot gas stripping in SAMs implemented by
Kang & van den Bosch 2008, Font et al. 2008, Weinmann et al. 2010, Guo et al. 2011



Compare properties of group galaxies in SAM and observations

Starvation is expected to be caused by
(i) tidal stripping (interaction with cluster potential, other subhaloes)
(ii) ram-pressure stripping ("wind" caused by moving through hot intracluster gas)

→ more detailed modelling possible!



Status 2011

Blue satellite fraction in SAM much too low

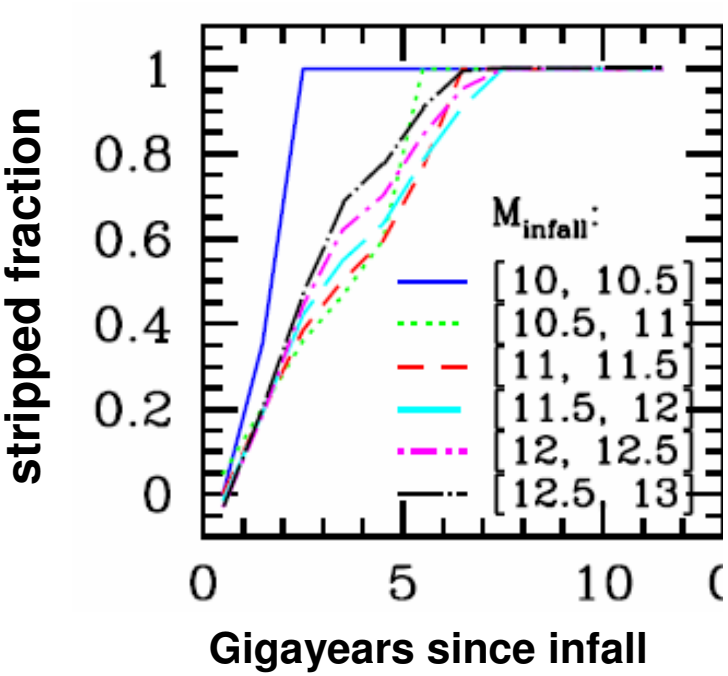
Old model: immediate stripping of hot halo gas around satellites
New models:

Status 2011

Blue satellite fraction in SAM much too low

Old model: immediate stripping of hot halo gas around satellites
New models:

Weinmann et al. 2010:
gradual tidal stripping of hot gas in proportion to dark matter subhalo



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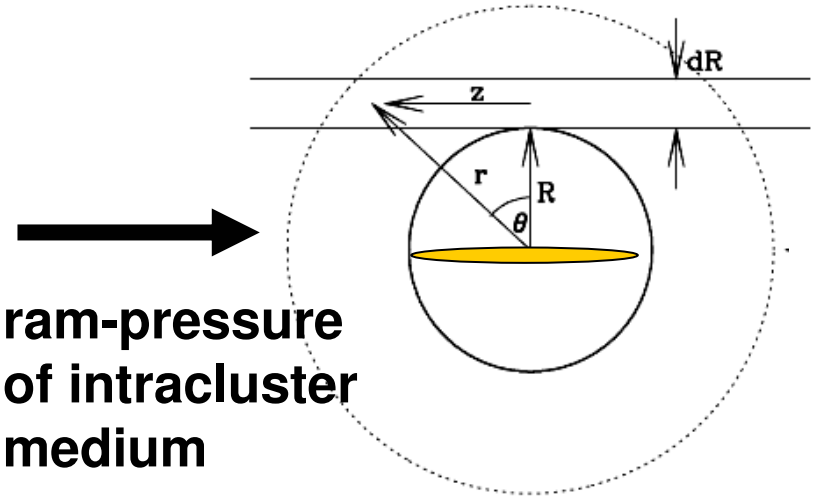
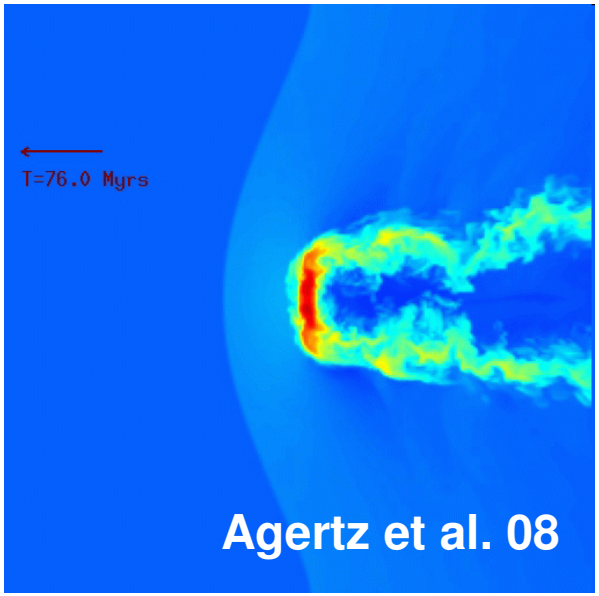
New models:

Font et al. 2008:
gradual ram-pressure stripping of hot gas



ram-pressure of intracluster medium

McCarthy et al. 2008



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Weinmann et al. 2010:
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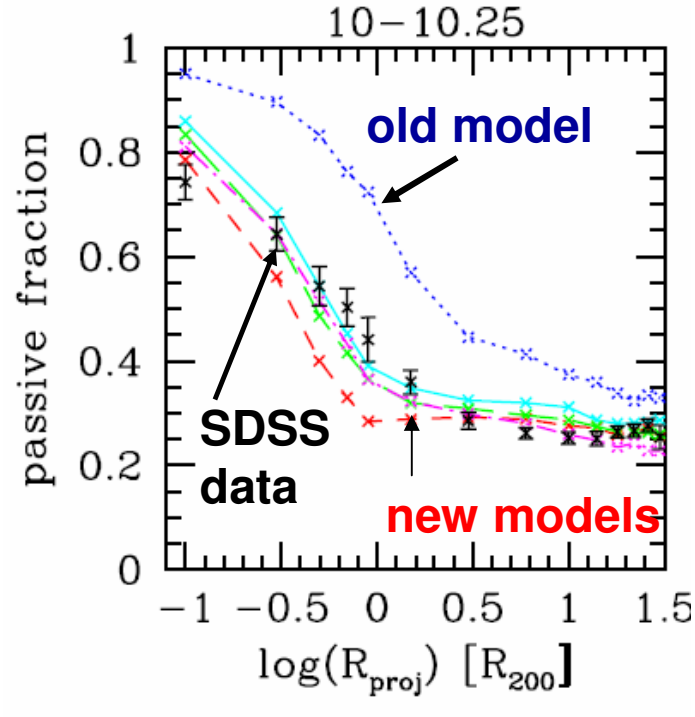

Font et al. 2008:
gradual ram-pressure stripping of hot gas

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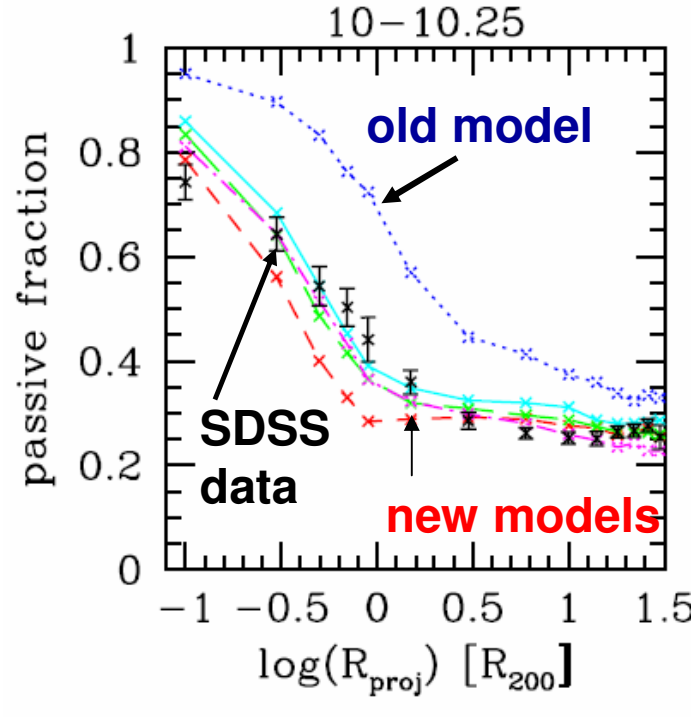

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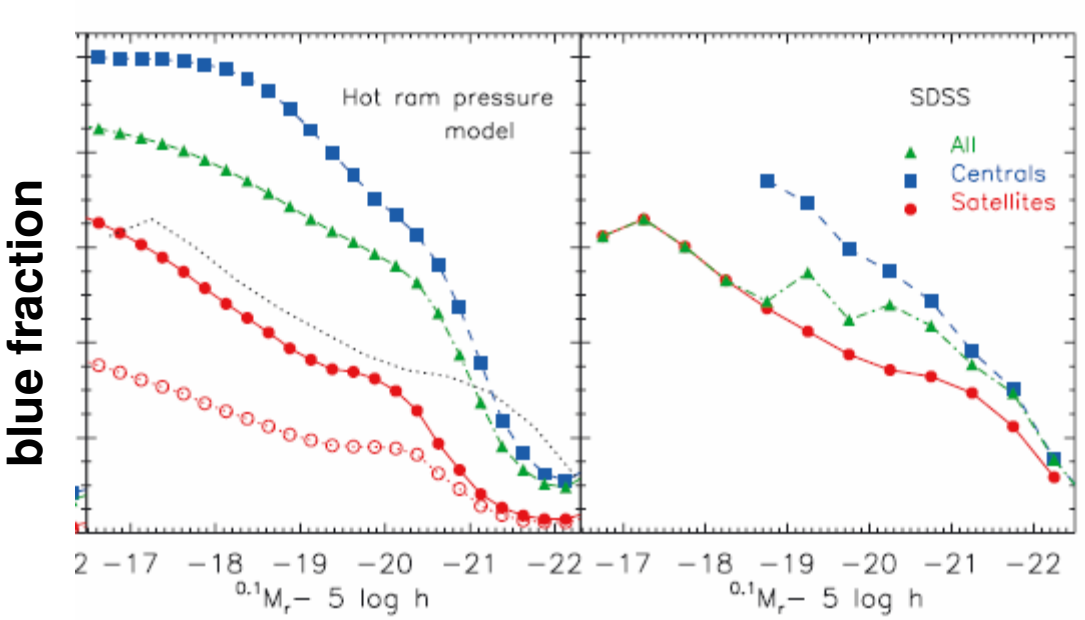


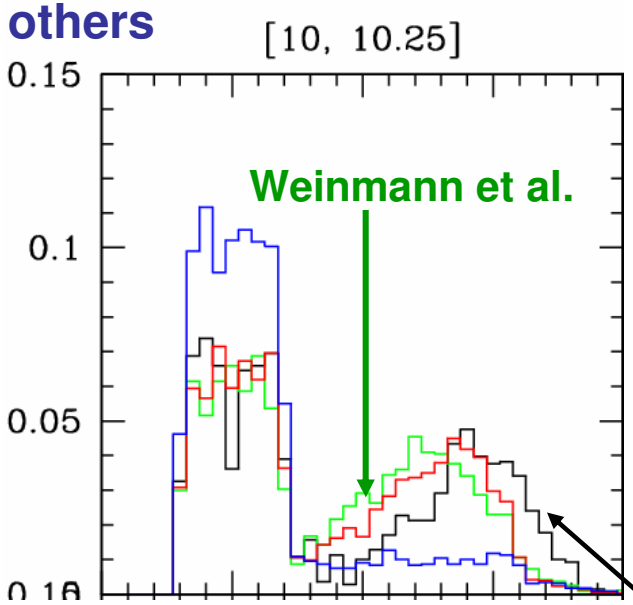
Clear improvement, but....

Status 2011

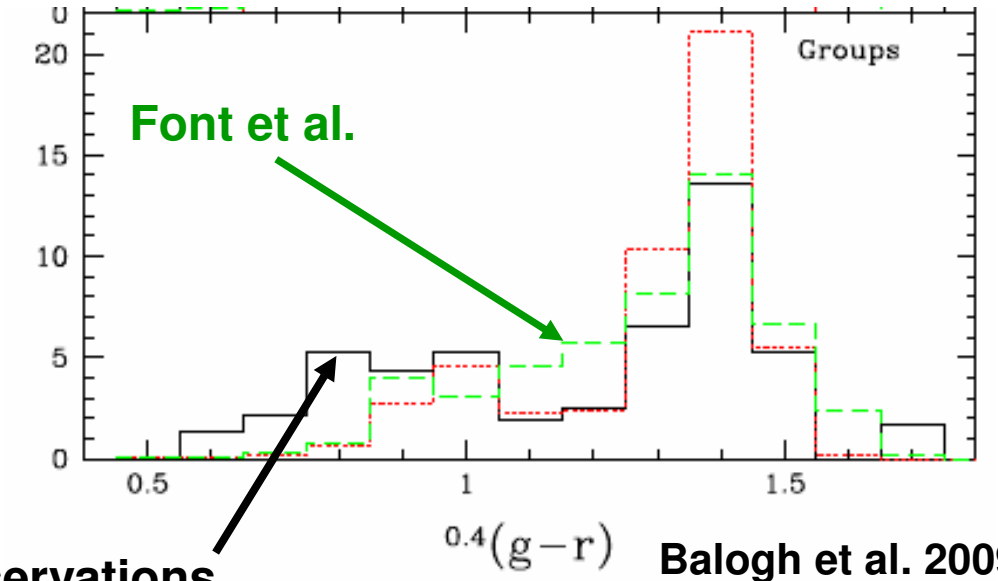
Old model: immediate stripping of hot halo gas around satellites
New models:

Weinmann et al. 2010:
gradual tidal stripping of hot gas

Reproduces colour bimodality of satellites
→ some sat affected more than others



Font et al. 2008:
gradual ram-pressure stripping of hot gas
Does not reproduce colour bimodality of satellites
→ means that satellites all are similarly



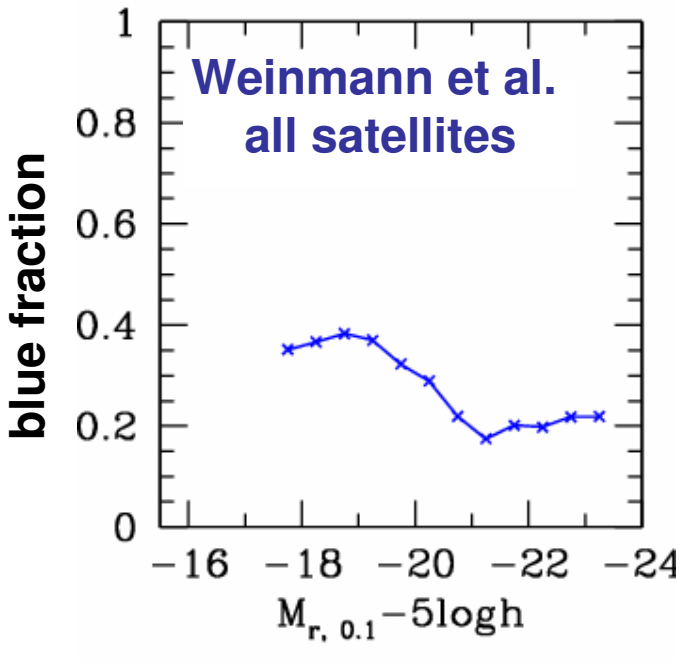
Balogh et al. 2009

Status 2011

Old model: immediate stripping of hot halo gas around satellites
New models:

Weinmann et al. 2010:
gradual tidal stripping of hot gas

Still somewhat too low fraction of blue satellites overall



Font et al. 2008:
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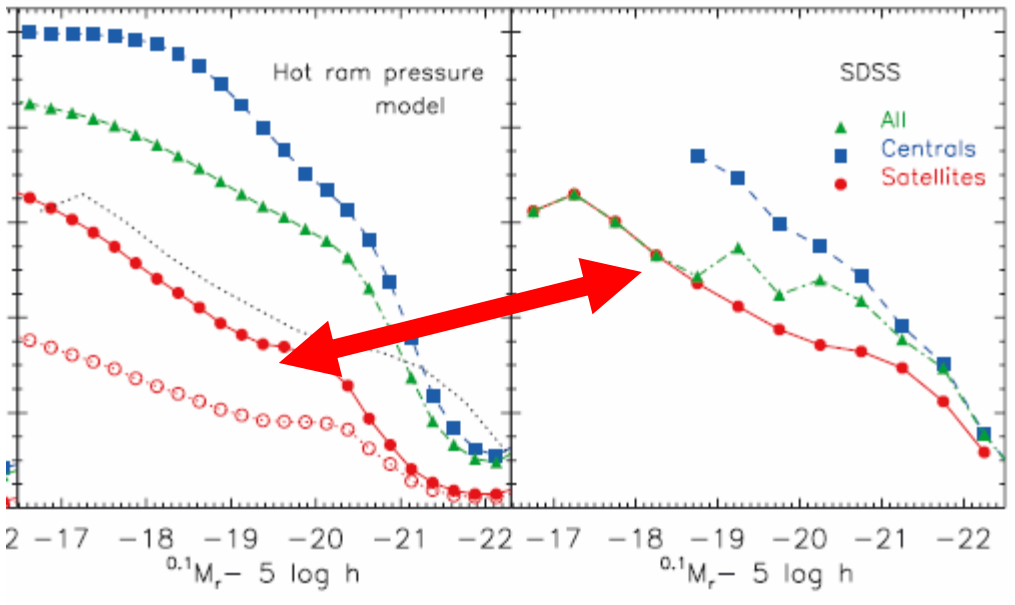
Reproduces fraction of blue satellites overall

Font et al. 2008 **SDSS**



Status 2011

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Guo et al. 2011
Kimm et al. 2011
include both processes

newest MPA SAM

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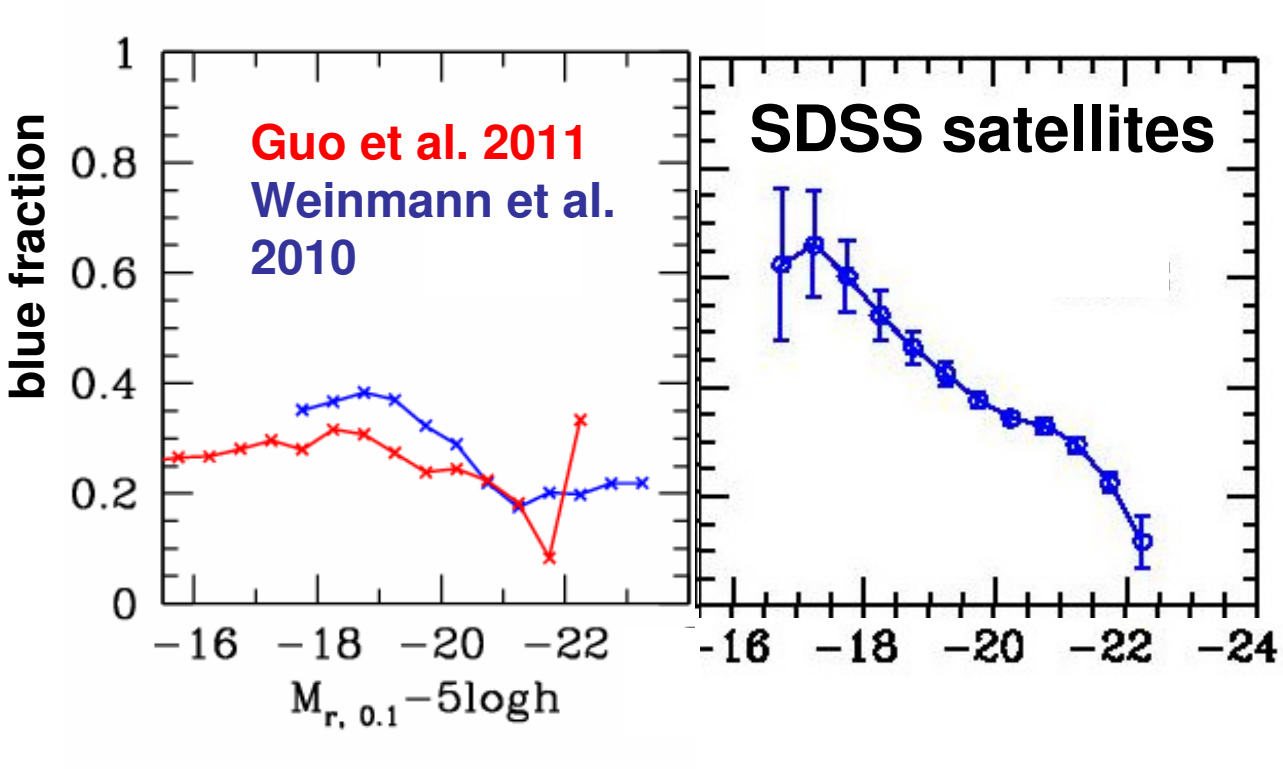

Still overefficient quenching of satellite galaxies in newest SAM?

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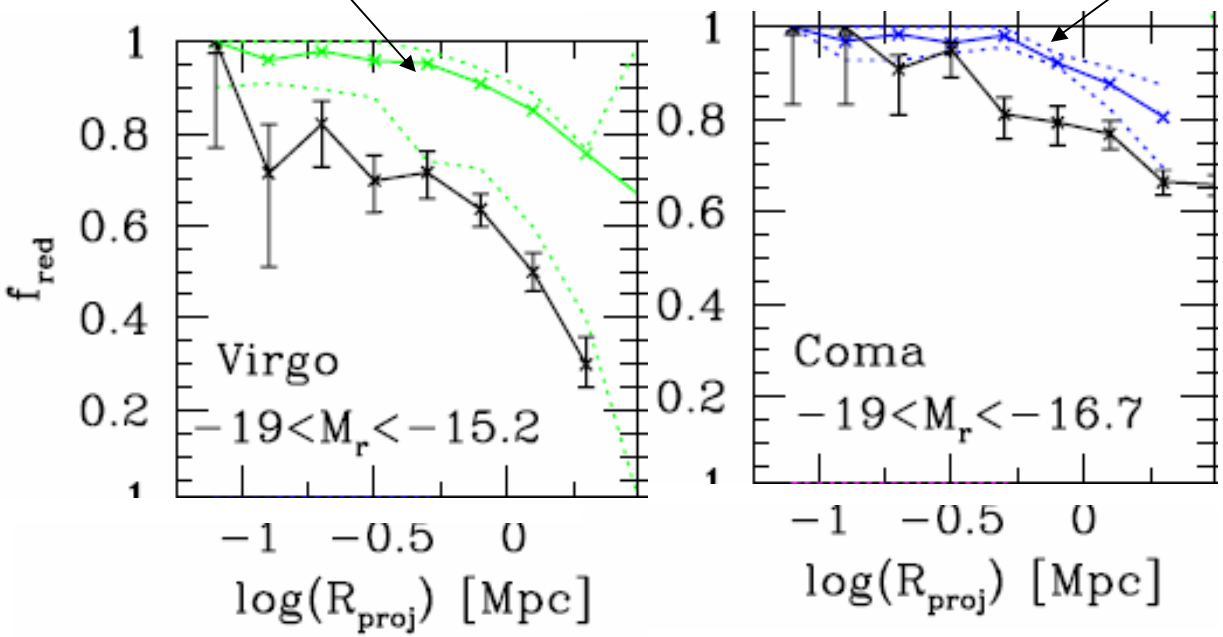
Guo SAM

Guo SAM



Still overefficient quenching of satellite galaxies in newest SAM ?

Weinmann et al. 2011

Compare properties of group galaxies in SAM and observations

STATUS 2011

Agreement has improved, but....

Blue satellite fraction in SAM still too low

Do we need even weaker environmental effects?
More satellite disruption?
Or are we looking in the wrong direction...?

A more fundamental problem?

Do we need even weaker environmental effects?
More satellite disruption?
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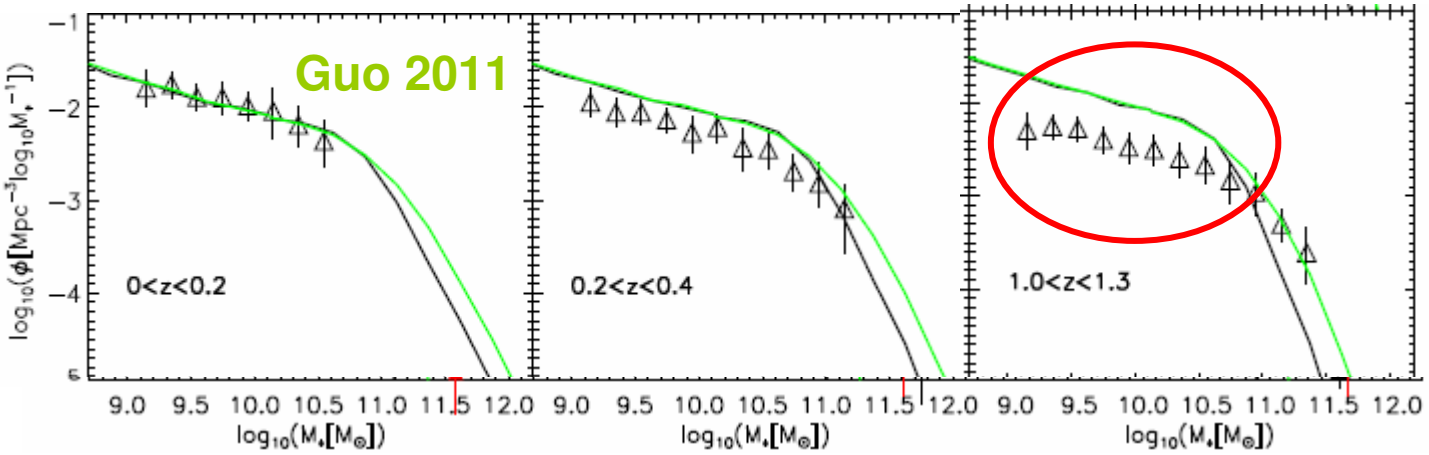
Open problems for SAMs:
- **too many red satellites**
- **missing evolution in the MF**



see also Fontanot et al. 2009

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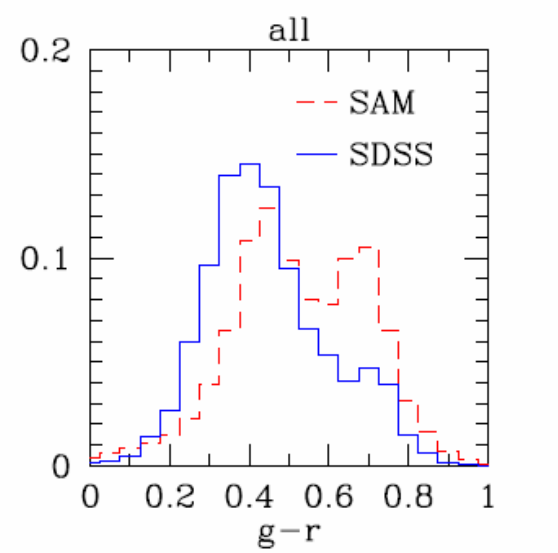

serious problem for all galaxies?

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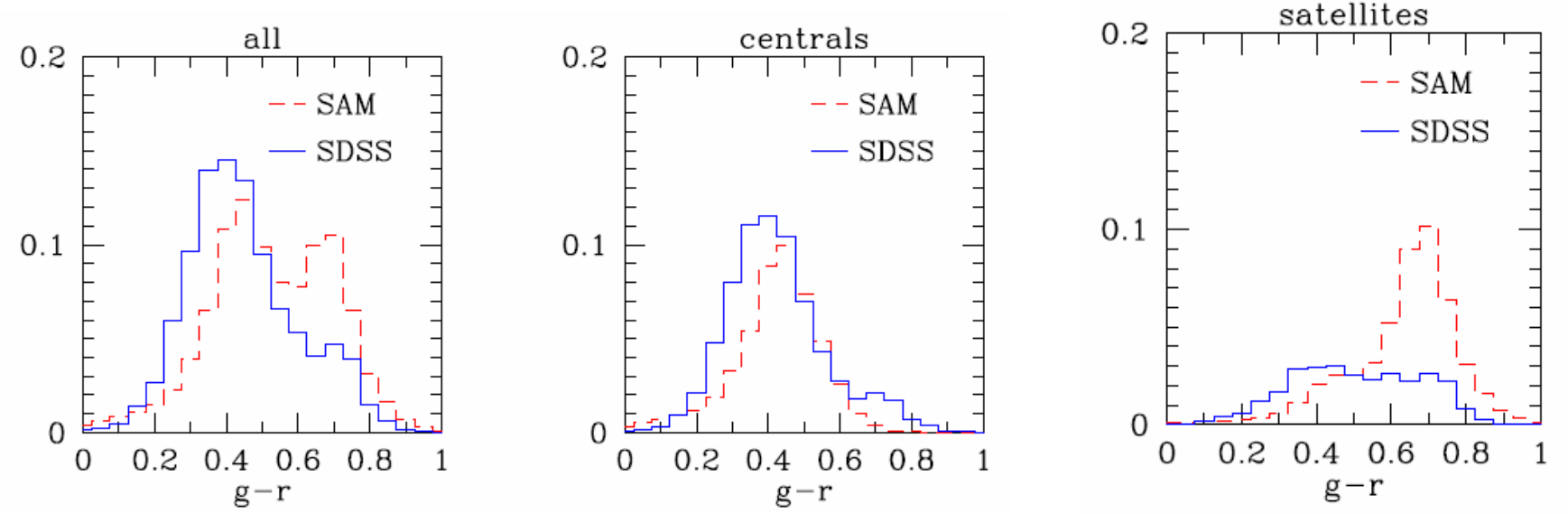

or mainly for satellites?

Weinmann et al. 2011

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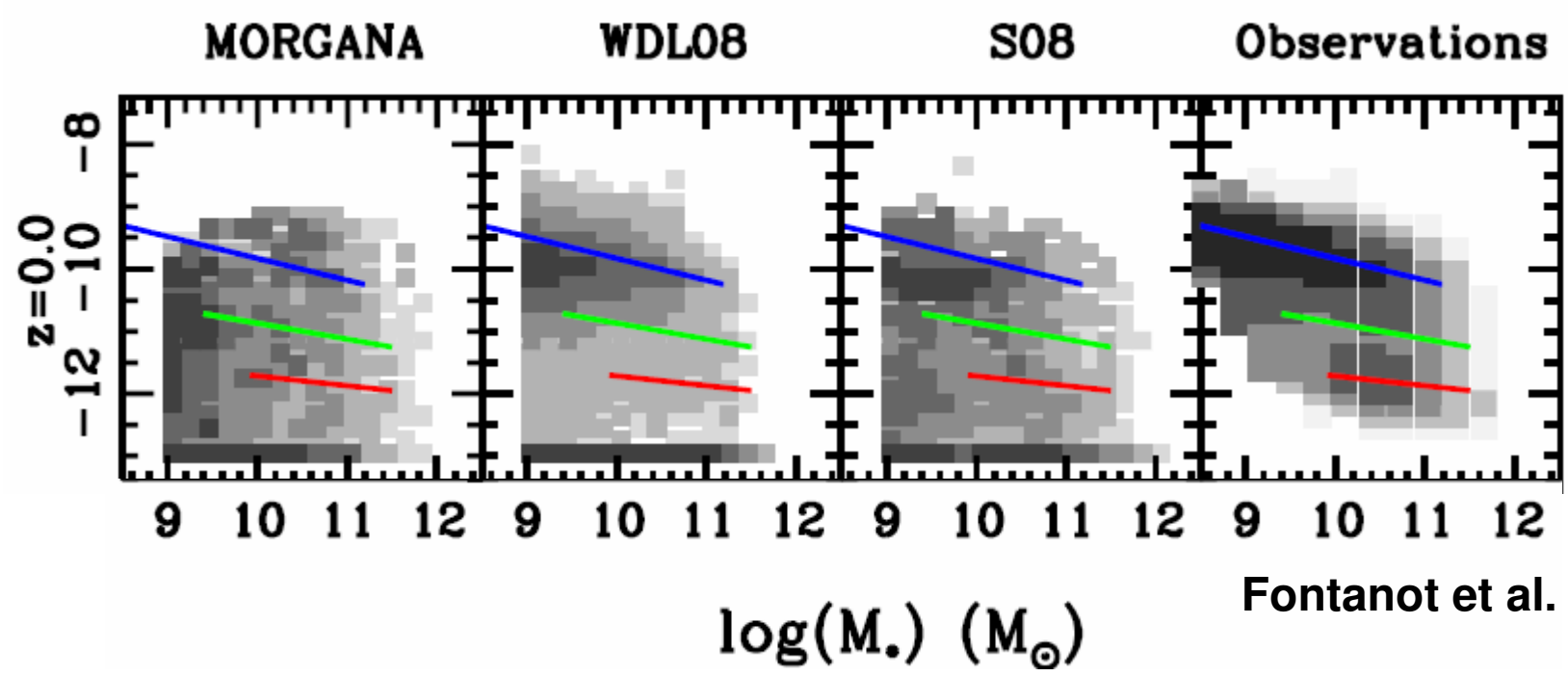

Fontanot et al. 2009

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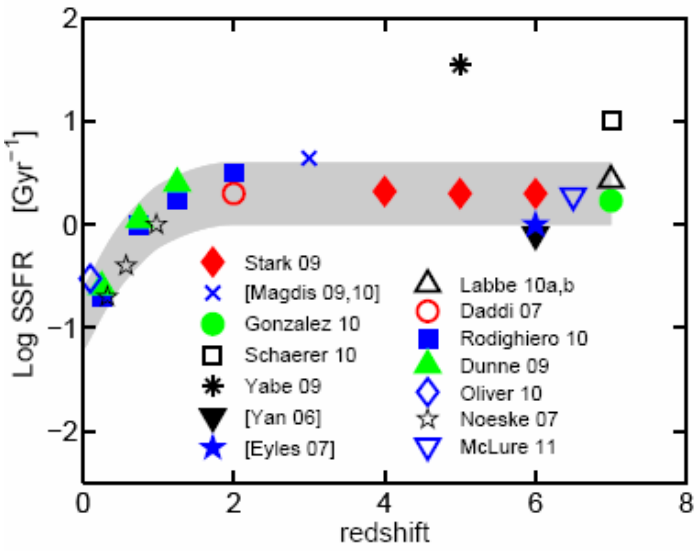
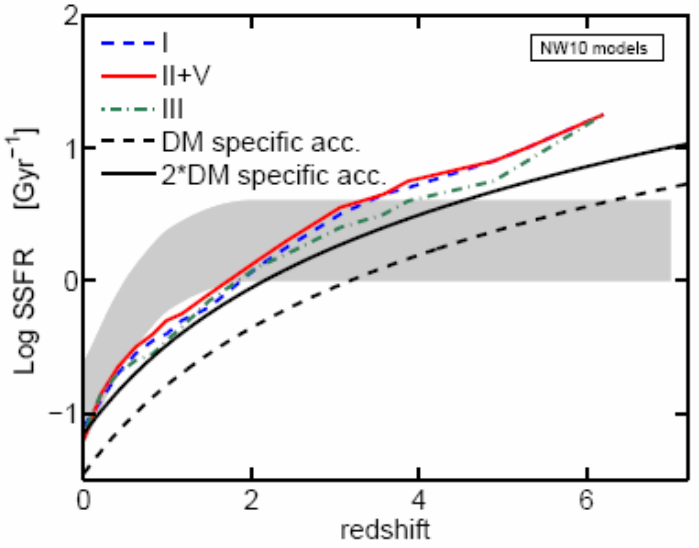
Open problems for entire galaxy population in SAM:

- **predicts too many red satellites**
- **missing evolution in the MF**
- **faint galaxies at z=0 too old, passive, red?**
- **evidence for too little SF at z=2, and too much at z>3**

observations



standard SAMs



Weinmann et al. 2011

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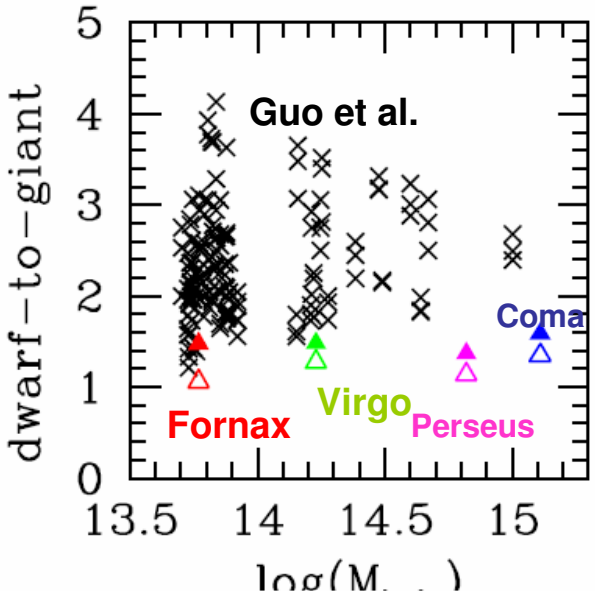

number of faint galaxies per bright galaxy in galaxy clusters

observations ~ 1.5
Guo et al. SAM higher

Weinmann et al. 2011

A more fundamental problem?

Open problems for entire galaxy population in SAM:

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Suspicion:
All these problems related to
too efficient galaxy formation at high z and for low mass dark matter haloes
?
e.g. Fontanot et al. 2009

A more fundamental problem?

Open problems for entire galaxy population in SAM:

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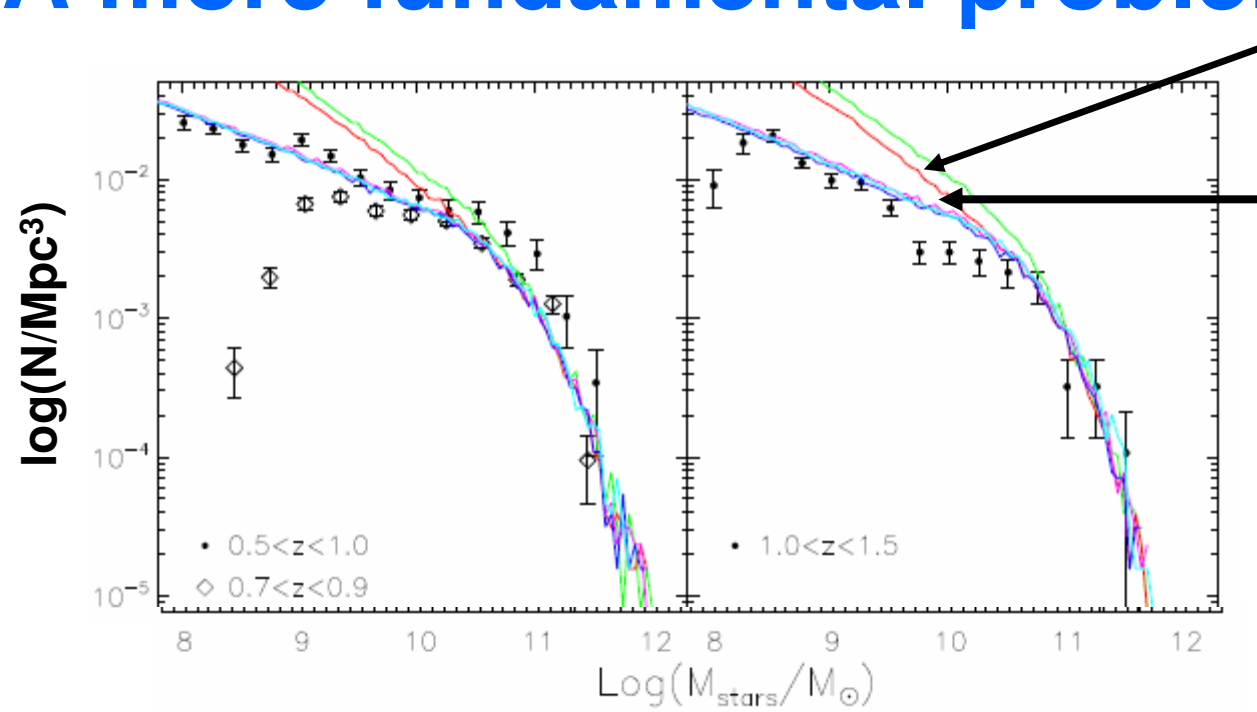
Is there one change to models that can fix all problems at once?
For example:

- **less efficient SF at high redshift? (Weinmann et al. 2011, Krumholz & Dekel 2011, Wang et al. 2011 in prep.)**
- **some sort of 'preheating' mechanism at high redshift ?**
- **warm dark matter?**
- **SN feedback with completely different time-dependence?**

A more fundamental problem?



Wang, Weinmann et al. in prep.

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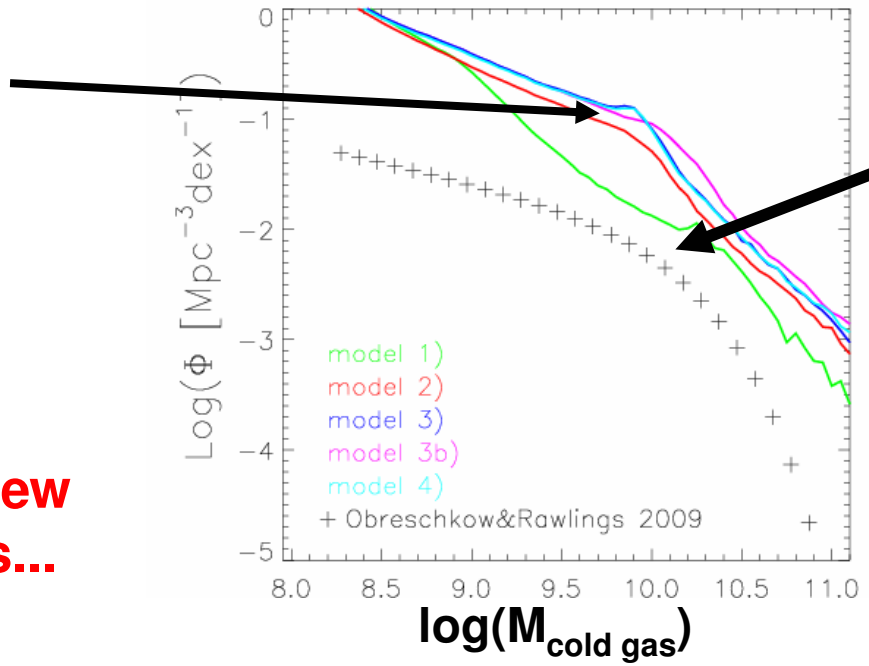
A more fundamental problem?

SAMs with less efficient SF at high z



observations

Wang, Weinmann et al. in prep.

causes new problems...

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At fixed stellar mass, sSFR is lower for

satellites than centrals

satellites in higher mass clusters

satellites in cluster centers

SAMs reproduce many properties of the galaxy population

including basic environmental trends.

However, it is surprisingly difficult to match them in detail, despite recent improvements.

The same is true for other fundamental relations

Can this be fixed by further refining and fine-tuning the models?

Or can it be that many problems are related, and can be solved by a more fundamental change?