June 6th 2011, Nice "Star Formation in Galaxy Clusters"

Star formation properties of cluster galaxies in the SDSS & in semi-analytical models

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Outline

Star Formation of cluster galaxies in the SDSS

Group and cluster catalogues

Results: sSFR / colour

Comparison to semi-analytical models

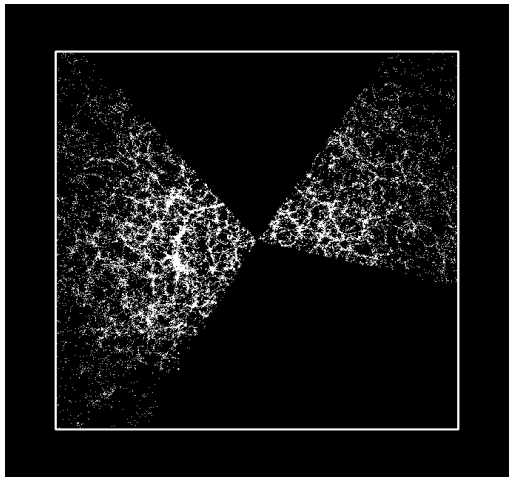
Status 2006 / 2011

Physical implications

SDSS Group and Cluster Catalogues

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
Publicly available



Von der Linden et al. 2007 cluster catalogue

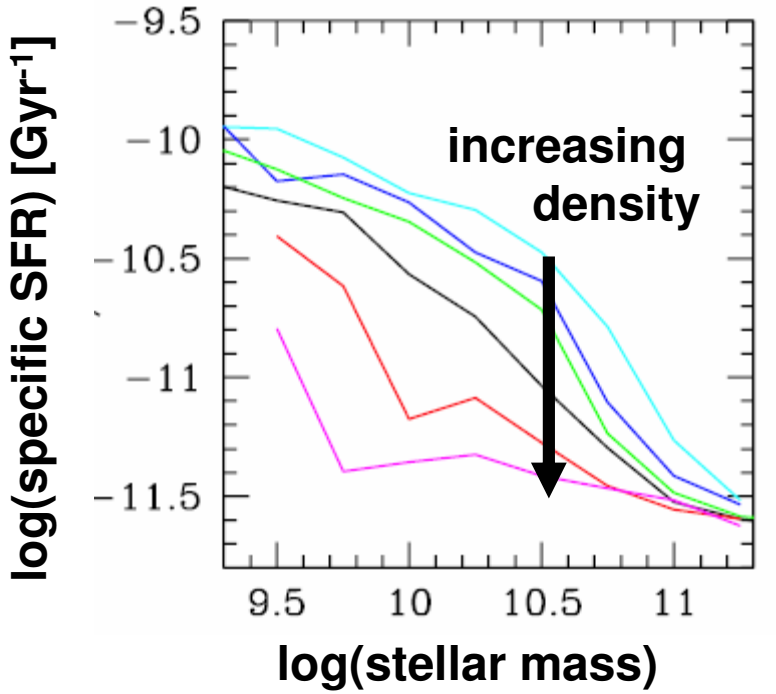
Based on clustering in *z*, RA, Dec, colour
Mass estimated from velocity dispersion
521 clusters

Other SDSS cat's:

Berlind et al. 2006
Miller et al. 2004
Aguerri et al. 2007
Koester et al. 2007
....

Environment vs. stellar mass

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



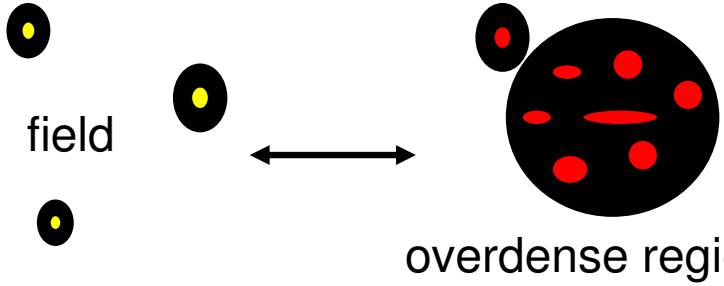
Kauffmann et al. 2004

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

Quantifying environment

traditional approach:

local galaxy density



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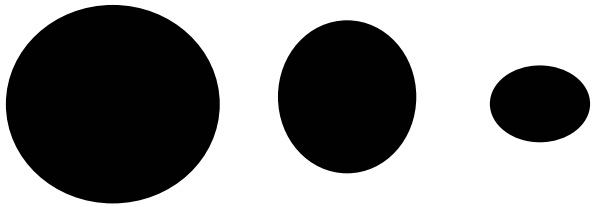
new approach with group catalogues: fix stellar mass of galaxies, then:

distinction satellite - central

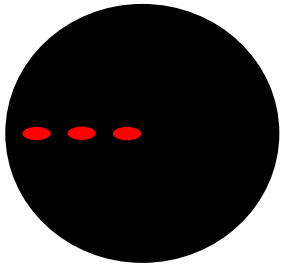


for satellites:

host halo mass



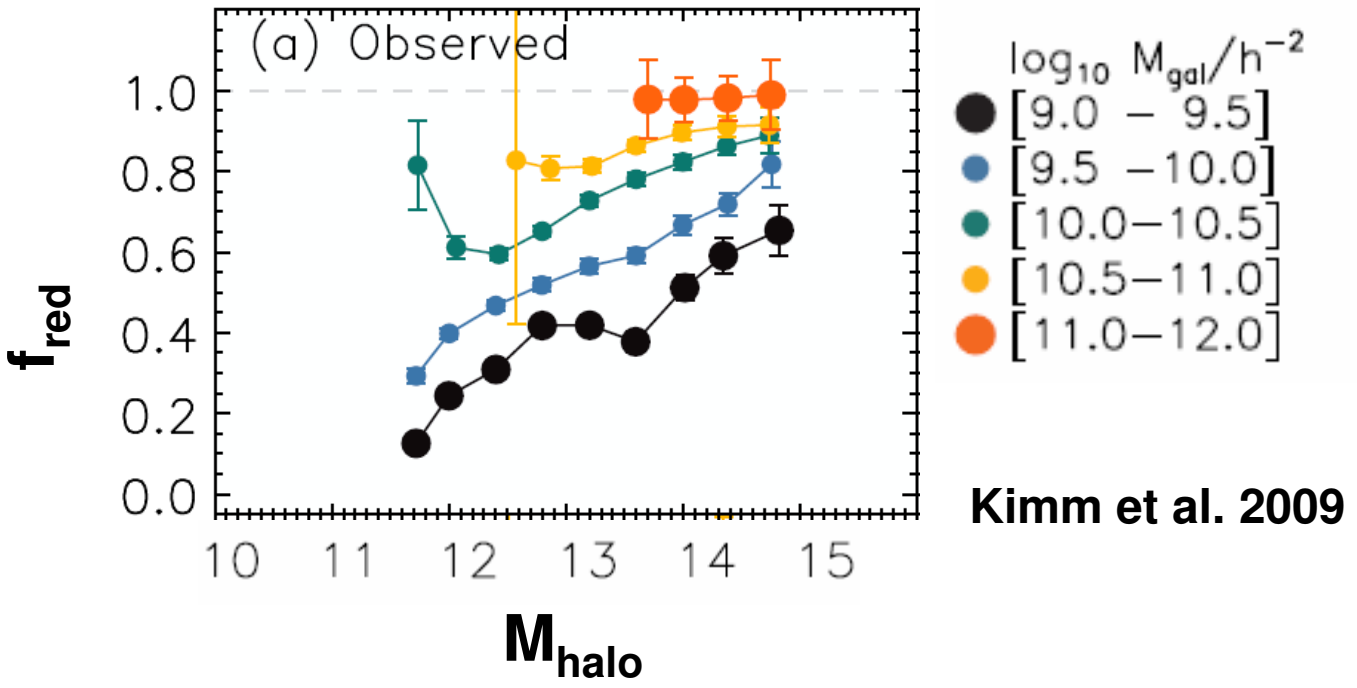
group-centric distance



Dependence of star formation rates and colours on environment

at fixed stellar mass

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

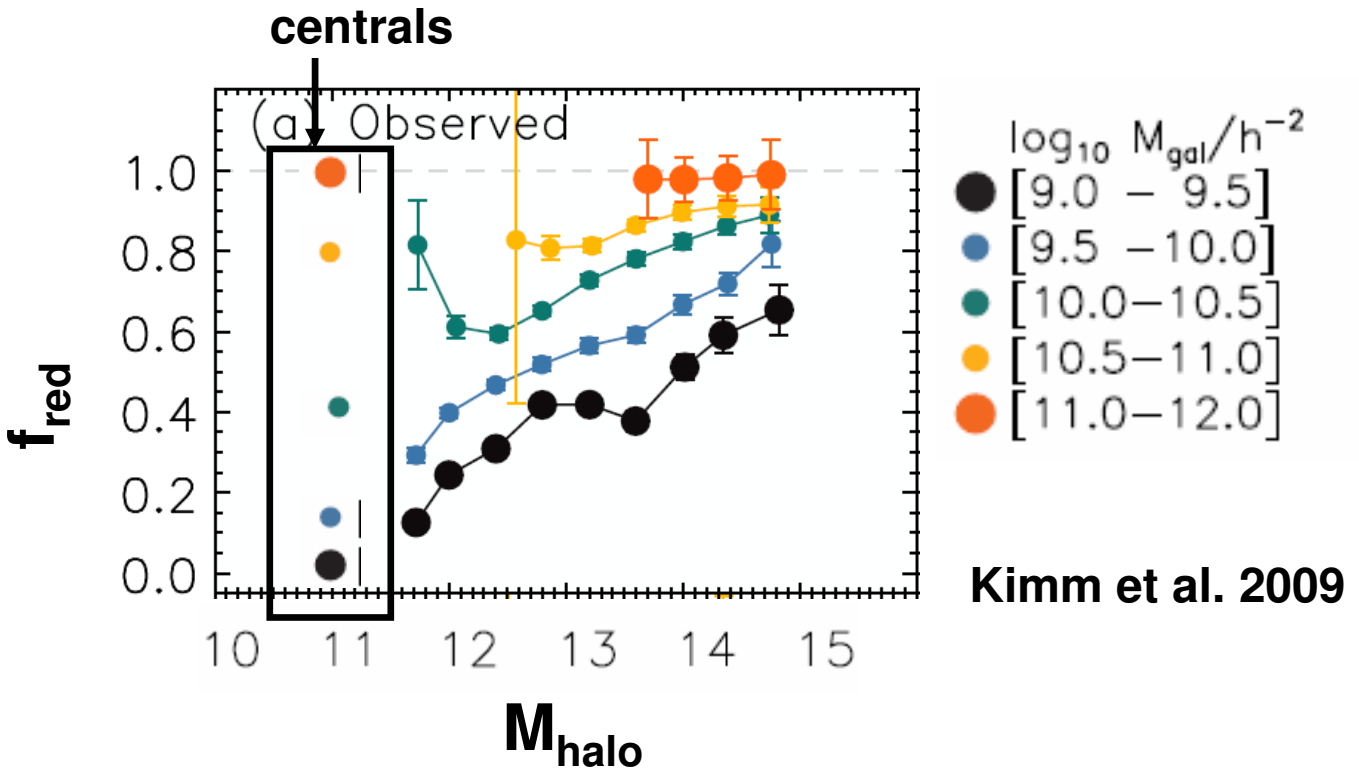


Kimm et al. 2009

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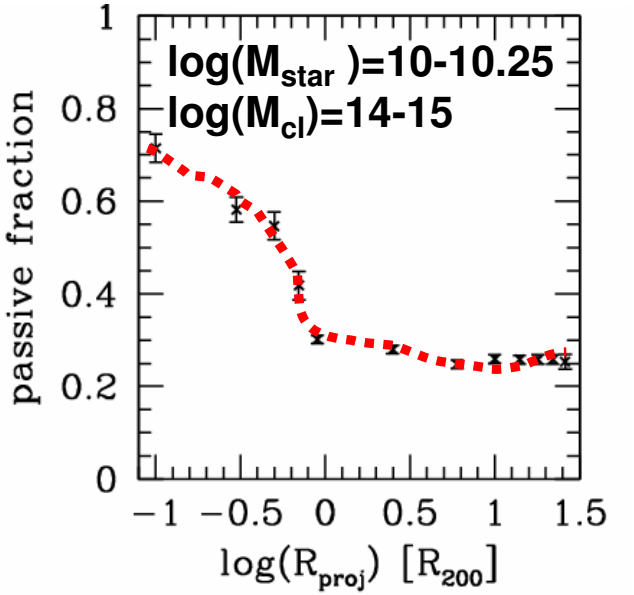


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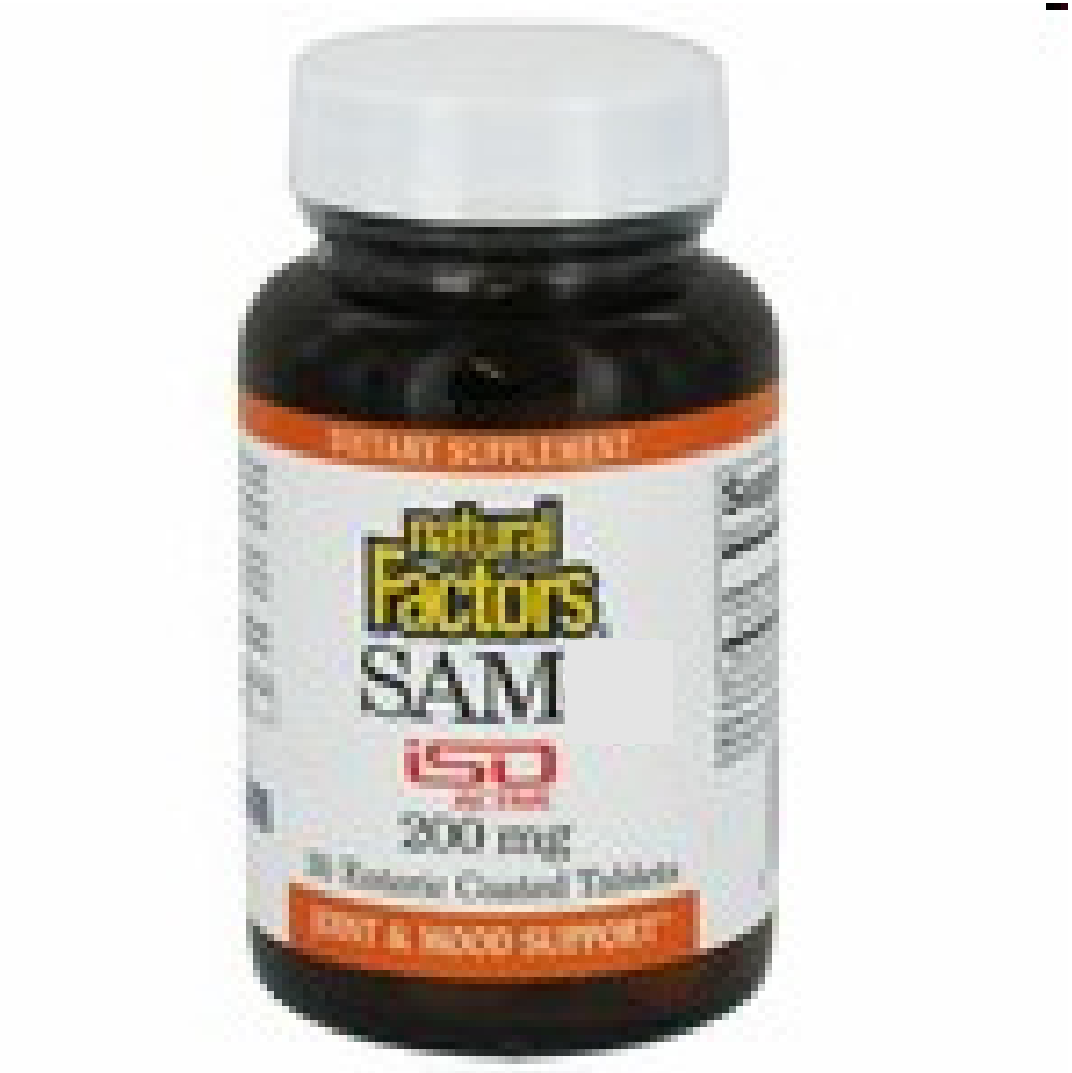
Weinmann et al. 2010

Dependence of star formation rates and colours on environment
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Why?

Semi-analytical models (SAM)



Semi-Analytical Models (SAM)



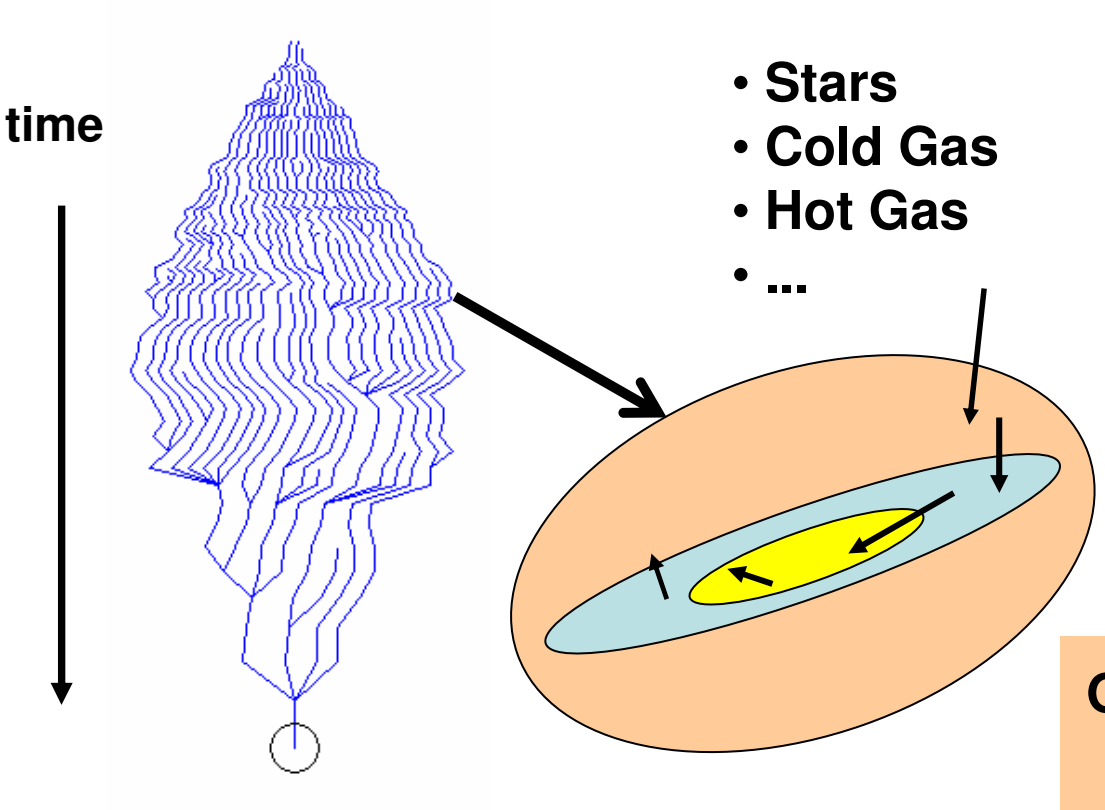
DM merger trees:

Galaxies:

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

Physical processes:

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



widely used SAMs: e.g. Croton et al. 06, De Lucia & Blaizot 07, Bower et al. 06, Font et al. 08, Guo et al. 10

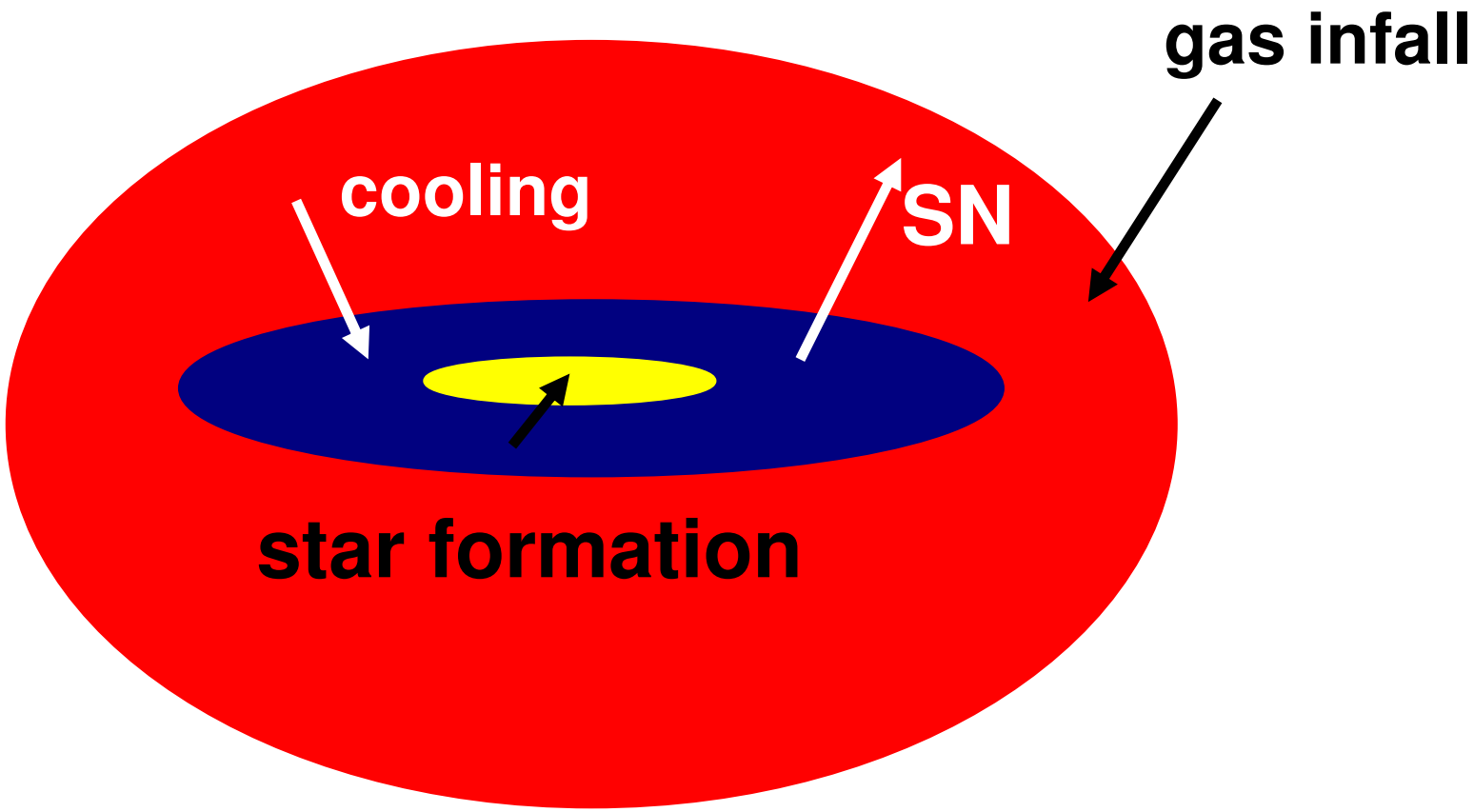
Only one environmental effect is explicitely included in current SAMs, namely:

starvation

"Starvation" in standard SAM:

Simple prescription:

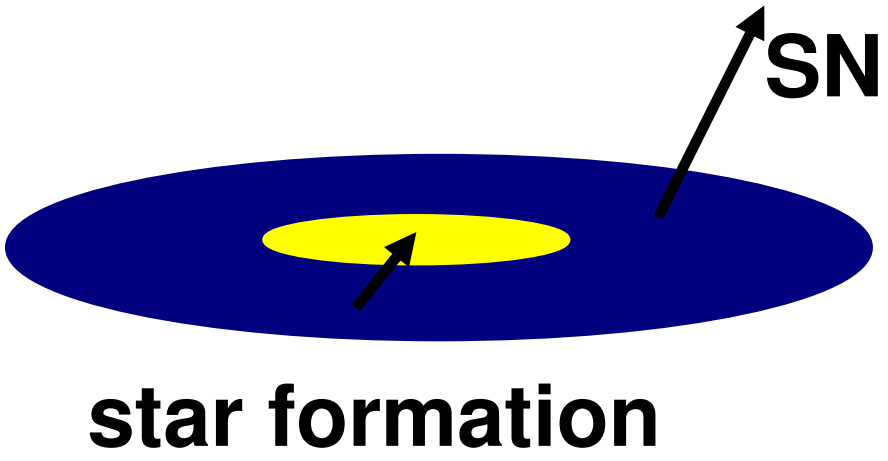
All *hot halo gas* is removed when a galaxy falls into a group or cluster.



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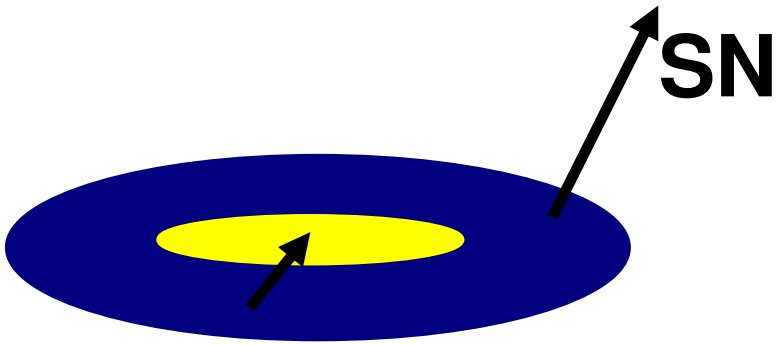
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star formation declines exponentially...

"Starvation" in SAM:

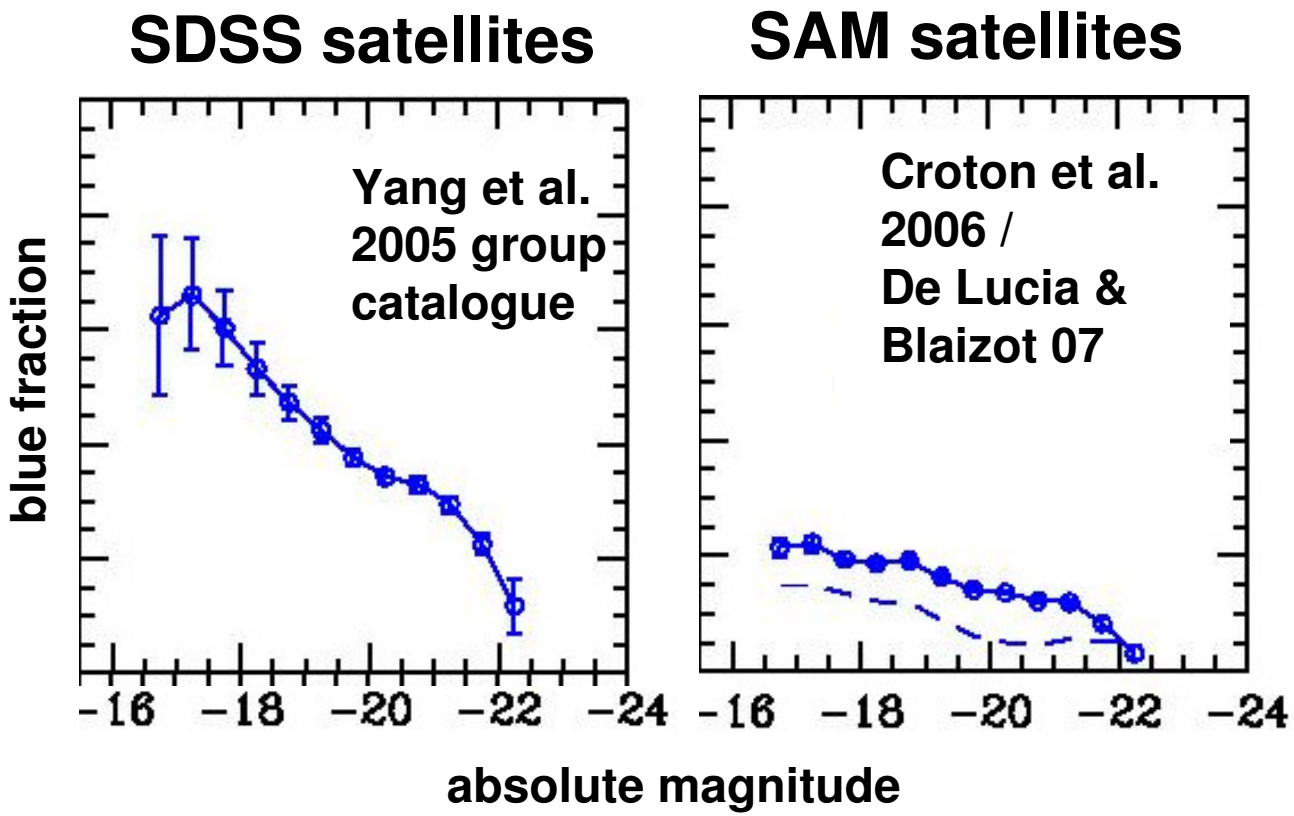
Simple prescription:

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



.. and stops completely

Compare properties of group galaxies in SAM and observations 2006



Blue satellite fraction in SAM much too low

Weinmann et al. 2006

⟶ **only including starvation already overpredicts quenching....**

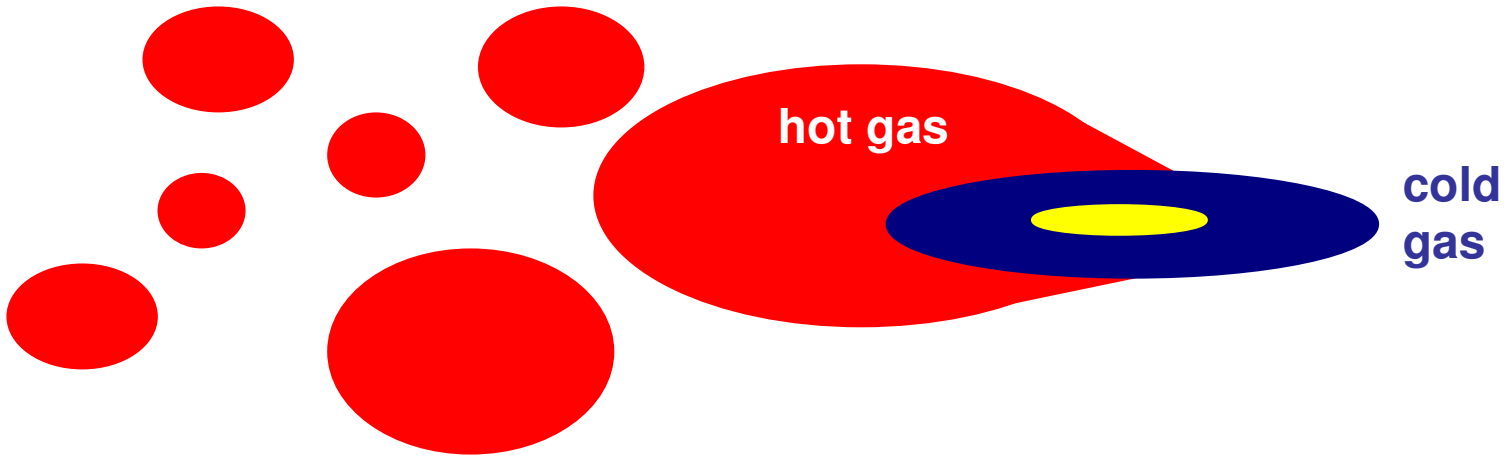
Compare properties of group galaxies in SAM and observations 2011

Several attempts for slowing down of "starvation" in SAMs:

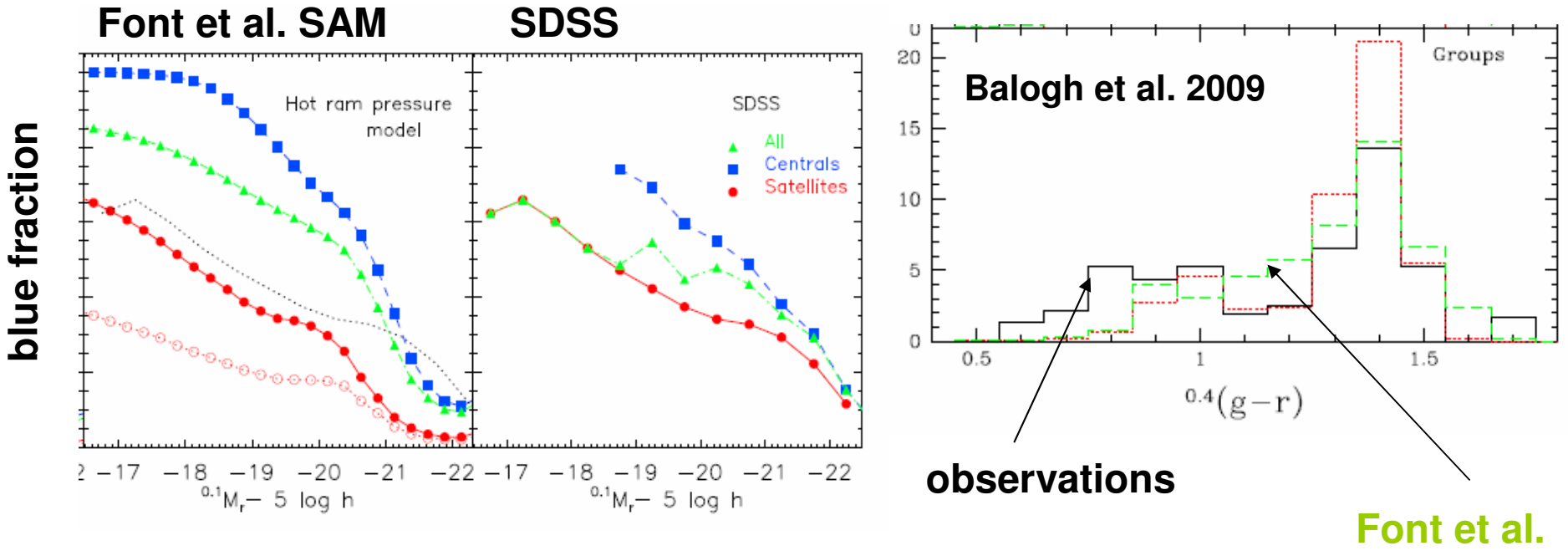
Font et al. 2008 – strip hot gas halo via ram-pressure stripping

Weinmann et al. 2010 – strip hot gas halo via tidal stripping

Guo et al. 2011, Kimm et al. 2011 – strip hot gas halo via both tidal & ram pressure stripping



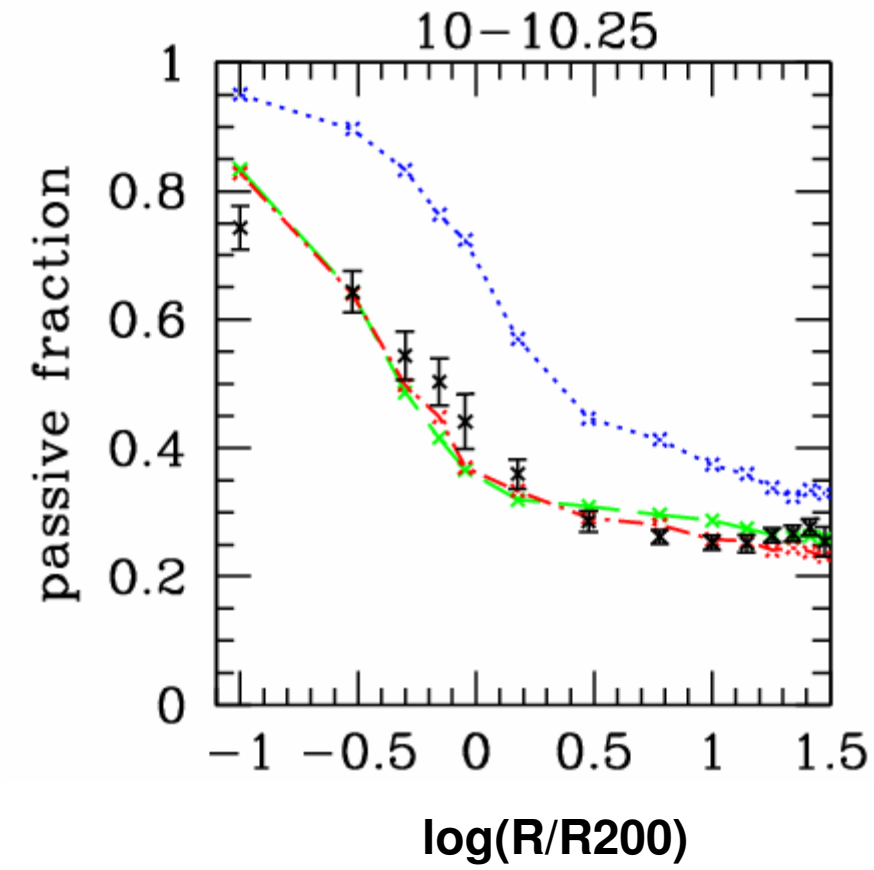
Compare properties of group galaxies in SAM and observations 2011



Font et al. 2008 – strip hot gas halo via ram-pressure stripping

Reproduce blue fraction of satellites better – but observed bimodal colour distribution of satellites is not reproduced by ram-pressure stripping...

Compare properties of group galaxies in SAM and observations 2011



: observations from von der Linden et al. cluster cat.

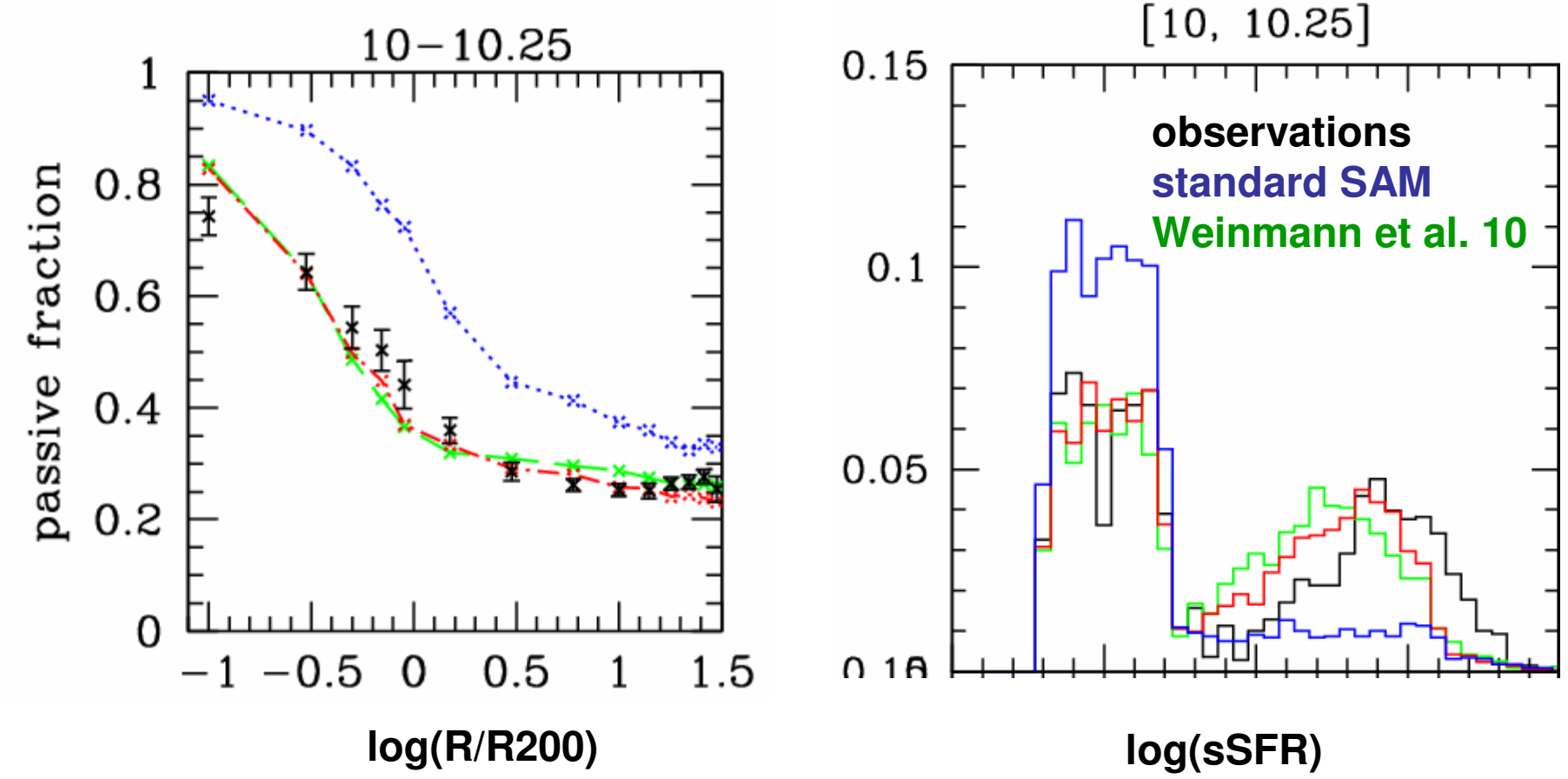
blue: standard SAM

green: tidal stripping of hot gas halo

red: simplified recipe

Weinmann et al. 2010 – strip hot gas halo via tidal stripping – reproduces observed passive fraction in clusters and colour bimodality

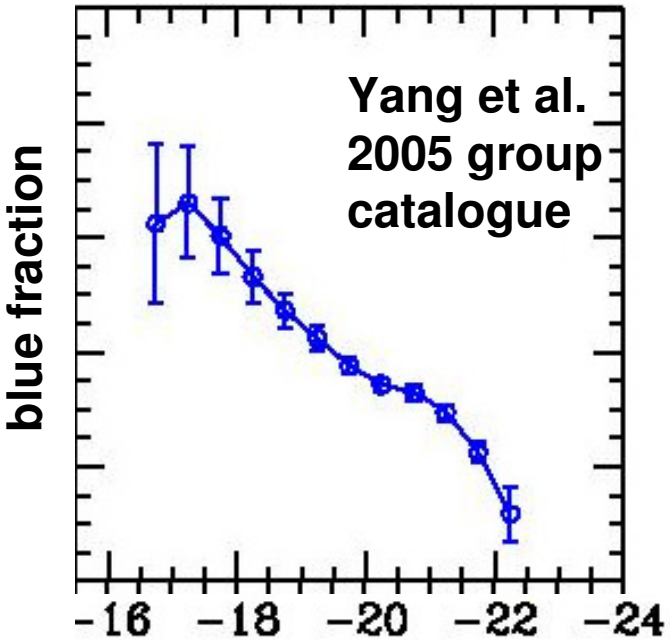
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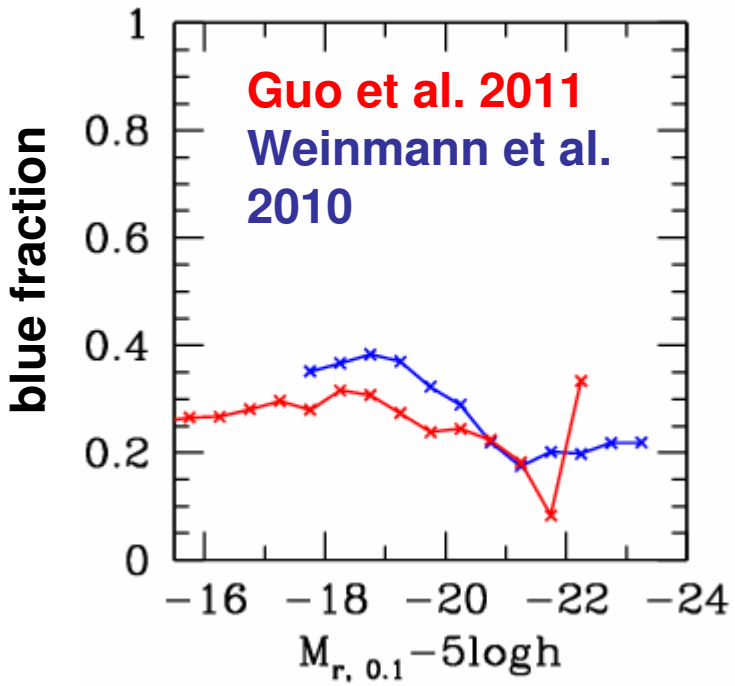
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Compare properties of group galaxies in SAM and observations 2011

SDSS satellites



SAM satellites 2011

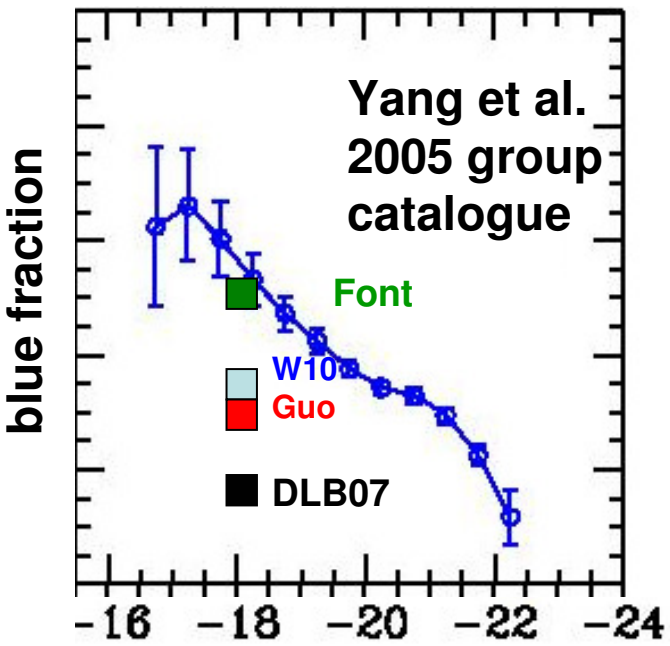


... but not overall blue fraction of satellites. Same problem occurs in Guo et al. 2011 and Kimm et al. 2011 which include both tidal and ram-pressure stripping.

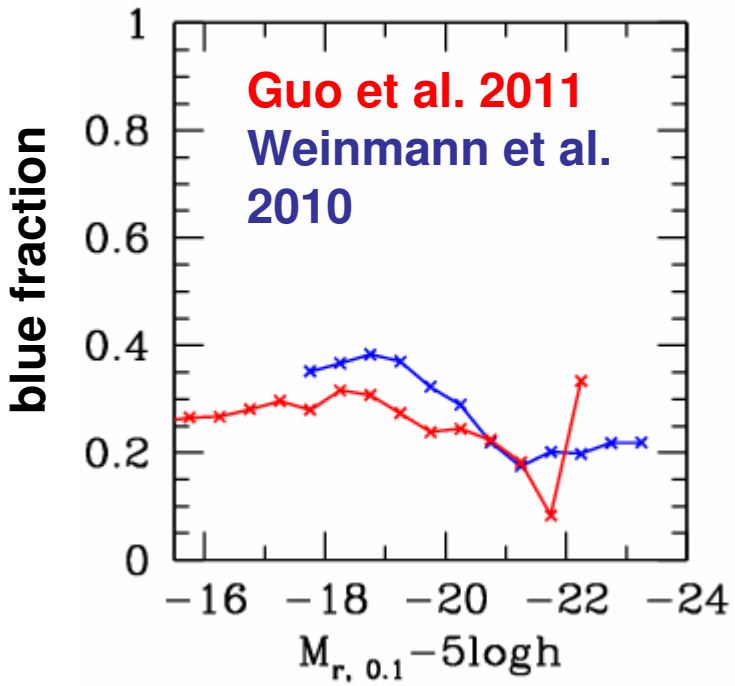
→ no SAM can yet reprouduce SF & colour vs. environment in detail!

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SAM satellites 2011



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What decreases SF in cluster galaxies?

2 most popular scenarios:

(i) ram pressure / tidal stripping of gas *currently involved* in SF

→ fast decrease in SF
→ should be most important in the centers of massive clusters, unimportant in groups

(ii) starvation = stripping of gas reservoir for *future* SF

→ slow decrase in SF (order Gyrs for most galaxies, some faster)
→ also occurs in low mass groups

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Arguments for starvation as main process:

- ***Only*** **including starvation already gives too many passive galaxies in SAMs. Adding RPS not necessary to reproduce observations**

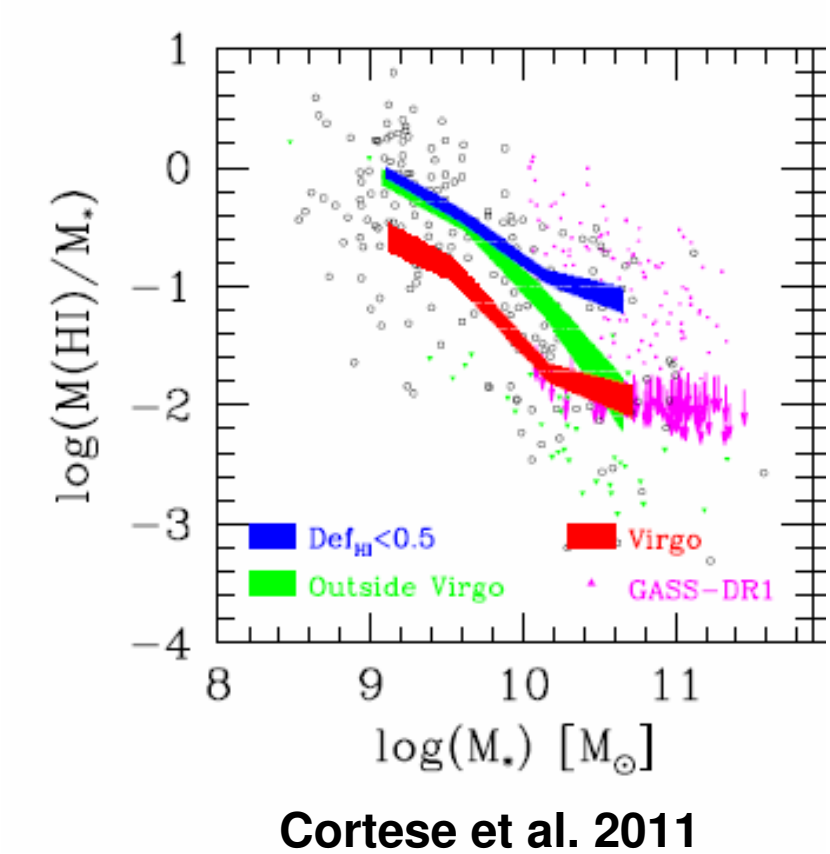
- **Starvation alone can lead to HI deficient galaxies**

- **Hot extended gas envelopes around massive ellipticals in clusters observed (Jeltema et al. 2008)**

- **No increase of galaxies with post-star burst signatures towards center of clusters (von der Linden et al. 2010)**

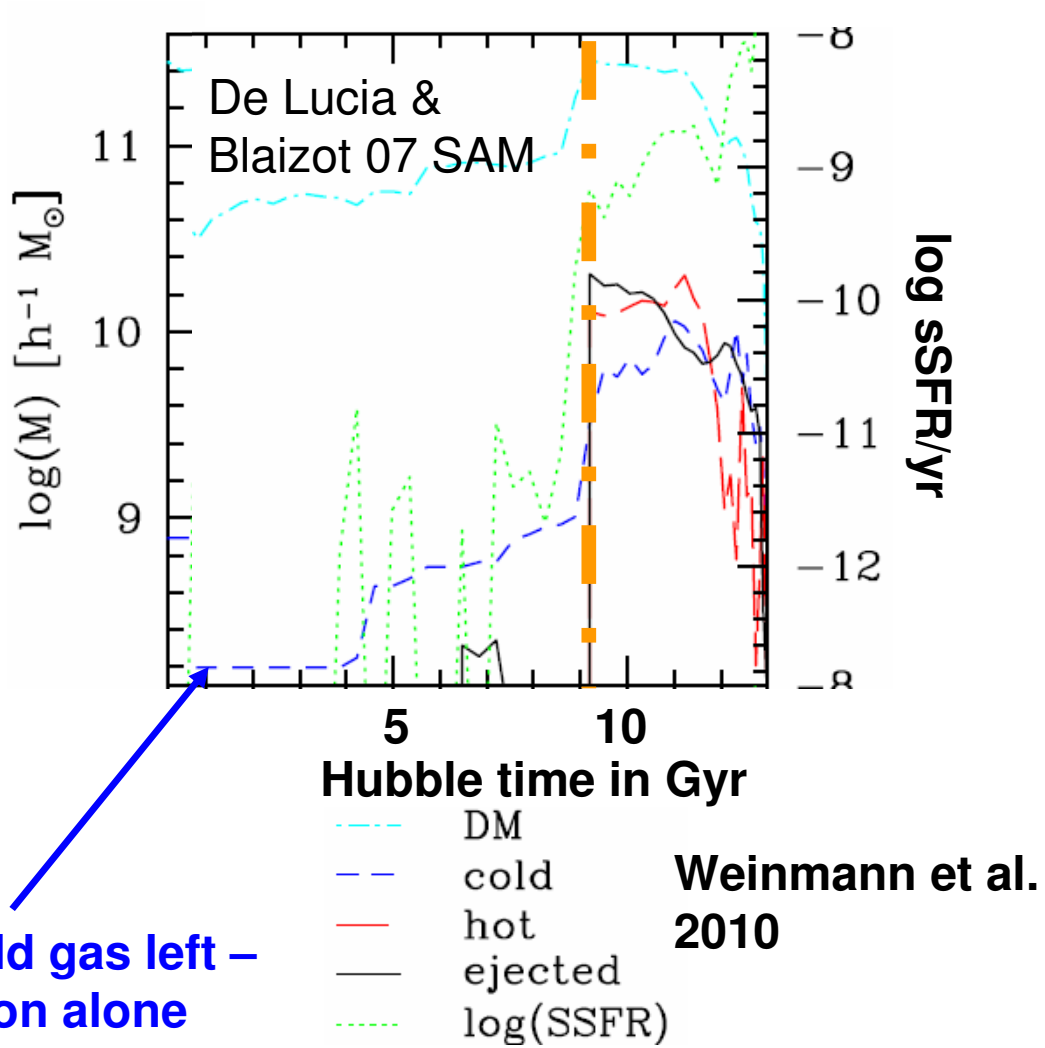
- **Smooth dependence of passive fraction on group mass, no characteristic scale**

Starvation explains HI deficiency in cluster galaxies



Cortese et al. 2011

infall



Weinmann et al. 2010

nearly no cold gas left – with starvation alone

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Conclusions

At fixed stellar mass, sSFR is lower for

- **satellites than centrals**
- **satellies in higher mass clusters**
- **satellites in cluster centers**

Semi-analytical model are slowly making progress towards reproducing observed environmental trends – but not done yet

"Starvation" seems to explain observed trends