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

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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:

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

Kauffmann et al. 2004
Group and Cluster Catalogues

what we see: galaxies

less dense

denser

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**
  - $M_{\text{star}} > 10^{9.5}$

- **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, $M_{\text{star}} > 10^7$**
  - Perseus / Coma / Virgo / Fornax
  - from various sources, background-correction

- **Coma cluster**
Quantifying environment

traditional approach:

local galaxy density

field

everdense region

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

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 & 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

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

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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.

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)

DM merger trees:  

Galaxies:
- Stars
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- ...

Physical processes:
- Accretion
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- SN feedback
- mergers
- environmental effects on satellites

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

starvation
Semi-Analytical Models

Can reproduce many important properties of the global galaxy population:

- Specific star formation rates at $z=0$ (Somerville et al. 08)
- Universal SFR density (Somerville et al. 08)
- Stellar mass functions over time (Fontanot et al. 09)
"Starvation" in standard SAM:

Simple prescription:
All *hot halo gas* is removed when a galaxy falls into a group or cluster.
"Starvation" in SAM:
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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

De Lucia & Blaizot 07 SAM

"Starvation" in SAM:
Simple prescription:
All _hot halo gas_ is removed when a galaxy falls into a group or cluster.
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

\[ \text{centrals} \]

Sommerville '08 SAM

\[ M_{\text{halo}} \]

\[ f_{\text{red}} \]

Kimm et al. 2009

\[ M_{\text{halo}} \]
Dependence of star formation rates and colours on environment in semi-analytical models

- 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

![Graph showing the relationship between halo mass and the frequency of red galaxies.](image)
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

Weinmann et al. 2010

De Lucia & Blaizot07

SDSS data
Starvation explains HI deficiency in cluster galaxies

Cortese et al. 2011

nearly no cold gas left – with starvation alone

Weinmann et al. 2010

Hubble time in Gyr

De Lucia & Blaizot 07 SAM

log sSFR/yr

log(M(HI)/M_\odot)

log(M_\odot) [M_\odot]

-4 -3 -2 -1 0

8 9 10 11
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 fundamental 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 in SAMs

• Satellite galaxies are redder & less star forming than centrals OK

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all these fundamental 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)

- SDSS satellites
  - Yang et al. 2005 group catalogue

- SAM satellites
  - Croton et al. 2006 / De Lucia & Blaizot 07

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

→ environmental effects must be over-efficient
Compare properties of group galaxies in SAM and observations

Blue satellite fraction in SAM much too low

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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

![Image of galaxy cluster with stars and gas](image)

![Graph showing stripped fraction over gigayears since infall](graph)
Status 2011

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

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

Blue satellite fraction in SAM much too low

McCarthy et al. 2008

ram-pressure of intracluster medium

Agertz et al. 08
Old model: immediate stripping of hot halo gas around satellites

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Status 2011

Blue satellite fraction in SAM much too low

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
  - $\rightarrow$ some sat affected more than others

- **Font et al. 2008:** gradual **ram-pressure stripping** of hot gas
  - Does not reproduce colour bimodality of satellites
  - $\rightarrow$ means that satellites all are similarly [10, 10.25]

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![Figure showing log(sSFR) and 0.4(g-r) distributions for different groups.](image)
Status 2011

Old model: immediate stripping of hot halo gas around satellites

New models:

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

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

Still somewhat too low fraction of blue satellites overall

Reproduces fraction of blue satellites overall

![Graph showing blue fraction versus Mr, 0.1 - 5logh](image1)

![Graph showing hot ram pressure model](image2)
Old model: immediate stripping of hot halo gas around satellites

New models:

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

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

Guo et al. 2011
Kimm et al. 2011
include both processes
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Still overefficient quenching of satellite galaxies in newest SAM?
Status 2011

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Still overefficient quenching of satellite galaxies in newest SAM?

Weinmann et al. 2011
Compare properties of group galaxies in SAM and observations

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?

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Open problems for SAMs:
- too many red satellites
- missing evolution in the MF

see also Fontanot et al. 2009
A more fundamental problem?

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

Open problems for SAM:
• too many red satellites
• missing evolution in the MF
• faint galaxies at z=0 too passive, red?

A serious problem for all galaxies?
A more fundamental problem?

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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 vs. standard SAMs

Weinmann et al. 2011
A more fundamental problem?

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

Open problems for entire galaxy population in SAM:

- too many red galaxies
- 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
- dwarf-to-giant ratio is too high in model

number of faint galaxies per bright galaxy in galaxy clusters

observations $\sim 1.5$

Guo et al. SAM higher

Weinmann et al. 2011
A more fundamental problem?

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• too many red satellite galaxies
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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?

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• too many red galaxies
• missing evolution in the MF
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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?

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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?