The evolution of satellite galaxy quenching

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Traditional environmental gas picture

This ball of gas and stars falls into a group/cluster and is stripped.

If the hot gas is removed, it’s **starvation/strangulation**.

If the cold gas is removed, it’s **ram pressure stripping**.
Timescales of gas consumption

Hot Gas

Cold Gas

Stellar Mass

\[
\text{Time} = \frac{M_{\text{res}}}{SFR}
\]

Ram pressure stripping $< 1$ Gyr

$10$ Gyr $> \text{Starvation} > 1$ Gyr

Are these models successful because they are seemingly unfalsifiable?

Isn't this treatment/picture inconsistent with our understanding of how galaxies form?
Theoretical and ‘central’ galaxy gas picture

Cosmological models of galaxy growth are not static balls of gas.

Equilibrium model has current star formation rate and outflows being balanced by cosmological infall.

Outflow rates can be several times the star formation rate.
In this picture, the cutting off of cosmological infall will have drastic effects on the galaxy.

\[
\text{Time} = \frac{M_{\text{res}}}{SFR + \text{outflow}}
\]
Orbit-based timescale

Timescale of ram pressure stripping

Dynamical Time $\propto \frac{R}{V}$

$M \propto RV^2$

$M \propto R^3 \rho$

Dynamical Time $\propto \rho^{-1/2} \propto (1+z)^{-3/2}$

(McGee et al. 2014b)
Outflow Timescale

Cosmological Infall = 0

\[ T_{\text{delay}} = \frac{M_{\text{res}}}{M_{\text{res}}} \]

\[ M_{\text{res}} = M_{\text{baryon}} - M_{\text{cold}} - M_{\text{stel}} - M_{\text{ej}} - M_{\text{strip}} \]

\[ T_{\text{delay}} = \frac{M_{\text{baryon}} - M_{\text{cold}} - M_{\text{stel}} - M_{\text{ej}} - M_{\text{strip}}}{M_{\text{stel}}(1 - R + \eta)sSFR} \]

\[ T_{\text{delay}} = \frac{f_{\text{baryon}} - f_{\text{stel}}(0.1 \ast (1 + z)^2 + \eta(1 + R) + 1) - f_{\text{strip}}}{f_{\text{stel}}(1 - R + \eta)sSFR} \]

(McGee et al. 2014b)
The satellite experiment

**GEEC: 0.3 < z < 0.55**
- extensive spectroscopic follow-up of 30 galaxy groups found by CNOC2
- GALEX UV, HST ACS, Spitzer, Chandra, XMM

**GEEC2: 0.8 < z < 1**
- combination of COSMOS and x-ray galaxy groups
- extensive spectroscopic follow-up of 12 galaxy groups

### Stellar mass and star formation rates estimates
- Done consistently for all surveys using McGee et al. 2011 procedure
- Marginalize over metallicity, dust, star formation history and age
- Use full range of far UV to IR imaging
- Consistent answers with Bruzual-Charlot 2003, 2007 and Conroy 2010 models
- Good match to independent estimates from spectroscopic indicators and dust obscured estimates
How can we derive a quenching time?

1. Make observations of the passive fractions of group and field galaxies.

(McGee et al. 2011)
How can we derive a quenching time?

2. Determine the distribution of infall times of satellite galaxies from numerical simulations.

3. Assume the passive fraction model for the central galaxies, and that excess quenching in satellites happens as a function of time.

(McGee et al. 2009)
How can we derive a quenching time?

Observations of the passive fractions of group and field galaxies.

\[ z = 0 \quad z = 0.4 \quad z = 0.9 \]

(McGee et al. 2011) (Mok et al. 2014)
Timescales

(McGee et al. 2014b)
Strong evolution in the quenching timescales of satellites, but not strong evolution in the quenching efficiency.

Potentially satellites are quenched by outflows prior to ram pressure stripping, strangulation or any of the other usual suspects.

We call this process “overconsumption”.

(McGee et al. 2014b)
Satellites are “canaries in the coal mine” for our galaxy formation models.

Outflow rates of greater than 2.5 times the star formation rate will never get satellite properties right. Even without any stripping mechanisms.

(McGee et al. 2014b)
Other evidence for overconsumption

HI gas masses in similar in star forming satellite and centrals. (McGee et al. in prep)

Similar Stellar Mass-Metallicity- HI mass relations (McGee et al. in prep)

Simulations show, even without AGN feedback and at z=0, 50% of stripping is actually outflow driven (Bahe & McCarthy 2015)
Conclusions

We need to update our picture of environment specific gas removal processes.

The cutting off of cosmological accretion alone can have dramatic consequences for the satellites.

Orbit-based stripping removal and overconsumption predict different evolutions in the quenching time.

A compilation of quenching times may suggest that satellites are quenched via overconsumption.