Satellite Quenching and Galactic Conformity around Massive Galaxies at $0.3 < z < 2.5$

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In the Footsteps of Galaxies:  
Tracing the Evolution of Environmental Effects  
Soverato-Italy, 7th-11th September 2015
What is Galactic Conformity?

fraction of late-type galaxies

also from SDSS, Wang & White 2012
Kauffmann et al. 2013
Knobel et al. 2014
and UDS at z ~2, Hartley et al. 2015

halo mass

Weinmann et al. 2006
What processes quench galaxies?

What is the physical origin of the conformity?
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What is the physical origin of the conformity?

We explore the correlation between the star-formation activity of central galaxies and their satellites over a large range of stellar mass ($9.3 < \log(M/M_\odot) < 10.1$) and $0.3 < z < 2.5$. 
UKIDSS UDS DR8

- The deepest degree-scale (0.77 deg$^2$) near -IR survey
- The K-band reaches 24.6 mag (5σ AB) (Williams et al. 2009; Quadri et al. 2012)

UltraVISTA

- The catalog covers 1.62 deg$^2$ in the COSMOS field. (Muzzin et al. 2013b)
- 40 nights on 6.5m Magellan Baade telescope at Las Campanas Observatory
- Five Medium-band filters in the near-IR
95% Stellar mass-completeness limit

Relative areas of all three surveys
Quiescent Fraction of Satellite

Isolation criteria: exclude galaxies from central sample, if there is more massive galaxies within 300 ckpc.

\[ f_{\text{sat}} = \frac{\sum (N_{q}^{sc} - N_{q}^{bg})}{\sum (N_{tot}^{sc} - N_{tot}^{bg})} \]


Tal et al. 2014
Quiescent Fraction of Satellite

Satellite selection criteria:

\[ |z_{cen} - z_{sat}| \leq 0.2 \]

\[ M_{lim} \leq M_{sat} < 10^{10.2} \, M_{\odot} \]


Tal et al. 2014
Quenching efficiency

Fraction of satellites that have been quenched in excess of the quenched field galaxy population,

\[ \epsilon_{q, sat} = \frac{f_{q, sat} - f_{q, bg}}{1 - f_{q, bg}} \]
Detection of Galactic Conformity to z \sim 2 in UDS, UltraVISTA, and ZFOURGE

A galaxy is not quenched as it becomes a satellite of a central galaxy.

L. Kawinwanichakij, ZFOURGE/CANDELS, submitted
Detection of Galactic Conformity to $z \sim 2$

Satellites around both *star-forming* and *quiescent* centrals have positive quenching efficiencies.

L. Kawinwanichakij, *ZFOURGE/CANDELS*, submitted
Detection of Galactic Conformity to z ~ 2

Quiescent fraction

Quenching efficiency

Strong conformity signal at 0.6 < z < 0.9 and at 0.9 < z < 1.6 (~3-4 sigma).

L. Kawinwanichakij, ZFOURGE/CANDELS, submitted
At fixed stellar mass, quiescent centrals have a higher number density of satellites (~2x) compared to star-forming.

Kawinwanichakij et al. 2014
At fixed stellar mass, quiescent central galaxies occupy more massive halos than star-forming central galaxies.

Kawinwanichakij et al. 2014

Comparison the Guo et al. SAM: 
The Role of Halo Mass

median halo mass is higher by ~0.3 dex

Kawinwanichakij et al. 2014

(e.g., Mandelbaum et al. 2006, More et al. 2011, Hartley et al. 2013, Phillips et al. 2014)
Does Halo Mass Drive Galactic Conformity?

Assumption: Number of satellites around our centrals scales with halo mass.

L. Kawinwanichakij, ZFOURGE/CANDELS, submitted
Halo mass appears not to account for all of the conformity

L. Kawinwanichakij, ZFOURGE/CANDELS, submitted
Some Possible Origins of Small-Scale Conformity:

- Hot gas content of halo
- Halo conformity with galaxy color-halo age relation (Bray et al. 2015)
- Halo accretion conformity (Hearin et al. 2014, 2015)
Positive quenching efficiency of satellites around star-forming centrals out to z ~ 2 likely requires:

- High-z needs fast-acting quenching (e.g., Weinmann +10, Tinker & Wetzel 2010, Quadri +12)

- Low-z needs slow-acting quenching (e.g., McGee +11, De Lucia +12, Heines +13)
Conclusion

• Satellites have excess quenching above similar galaxies in the field regardless of the activity of their central galaxy.

• **Galactic conformity exists at $0.3 < z < 2.5$:** Higher quiescent fractions for satellites around quiescent centrals compared to satellites around star-forming centrals at fixed stellar mass.

• While the halo mass may be a significant driver of conformity, it is unable to explain all of the conformity signals.
At fixed halo mass, the number density of satellites at $10 < r/kpc < 100$ equal between quiescent and star-forming central.

Kawinwanichakij et al. 2014

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Comparison the Guo et al. SAM: The Role of Halo Mass

Kawinwanichakij et al. 2014
UVJ color selection

Start by defining a generic region of the UVJ diagram for quiescent galaxies as,

\[ U - V > A \times (V - J) + zp \]
\[ U - V > 1.3 \]
\[ V - J < 1.6 \]

where \( A \) is slope of the red sequence
\( zp \) is zeropoint
UVJ color selection: UDS

Step 1. Fit the slope of the red sequence. Set the diagonal of the UVJ selection to this slope.

(U-V)_{rest} vs. (V-J)_{rest}

0.3 < z < 1.6

UDS
slope=1.00
zp=0.35

Normalized number vs. Distance from UVJ diagonal line

23
UVJ color selection: UltraVISTA

Step 2. Measure the distribution of color distance from the diagonal line.

UltraVISTA
slope=1.20
zp=0.35

0.3<z<1.6
UVJ color selection: ZFOURGE

Step 3: Define the zeropoint of the UVJ selection as the local minimum between the red and blue sequences.
1-halo and 2-halo conformity

• **1-halo conformity (intra-halo effect)**
  present amongst the galaxies within a single parent dark matter halo

• **2-halo conformity (inter-halo effect)**
  a separate effect acting on galaxies in neighboring halos
Halo accretion conformity (Hearin et al. 2014, 2015):

No large-scale conformity at $z > 1$? and Large-scale conformity naturally lead to small scale-conformity

No small-scale conformity at $z > 1$?
Observe strong small scale conformity out to z < 1.6 and much weaker at 1.6 < z < 2.5.

- Halo accretion conformity (Hearin et al. 2014, 2015):
  
  Large scale conformity extends to z > 1 than predicted

  or

  Small scale conformity is not simply caused by assembly histories
Observe strong small scale conformity out to $z < 1.6$ and much weaker at $1.6 < z < 2.5$.

- Halo accretion conformity (Hearin et al. 2014, 2015):

  - Large scale conformity extends to $z > 1$ than predicted
  - Small scale conformity is not simply caused by assembly histories

  Require large and deep datasets