Week 6:
Quenching Part 2:
So-called “environment-quenching”

Introduction by S. Lilly

Questions from last week:

1. Why is quenching of star-formation not very easy to achieve?

Gas in the surrounding halo will cool quite easily and fall onto the galaxy, potentially fuelling star-formation.

2. What are some ways that it might be achieved?

Several ideas: Ejection of gas by SN winds or AGN (perhaps in merger-nduced star-bursts), suppression of star-formation by galaxy structure (bulges etc), heating of the halo gas by AGN.

Questions from last week:

3. If we need energy to overcome cooling in the halo, what are the available sources of energy?

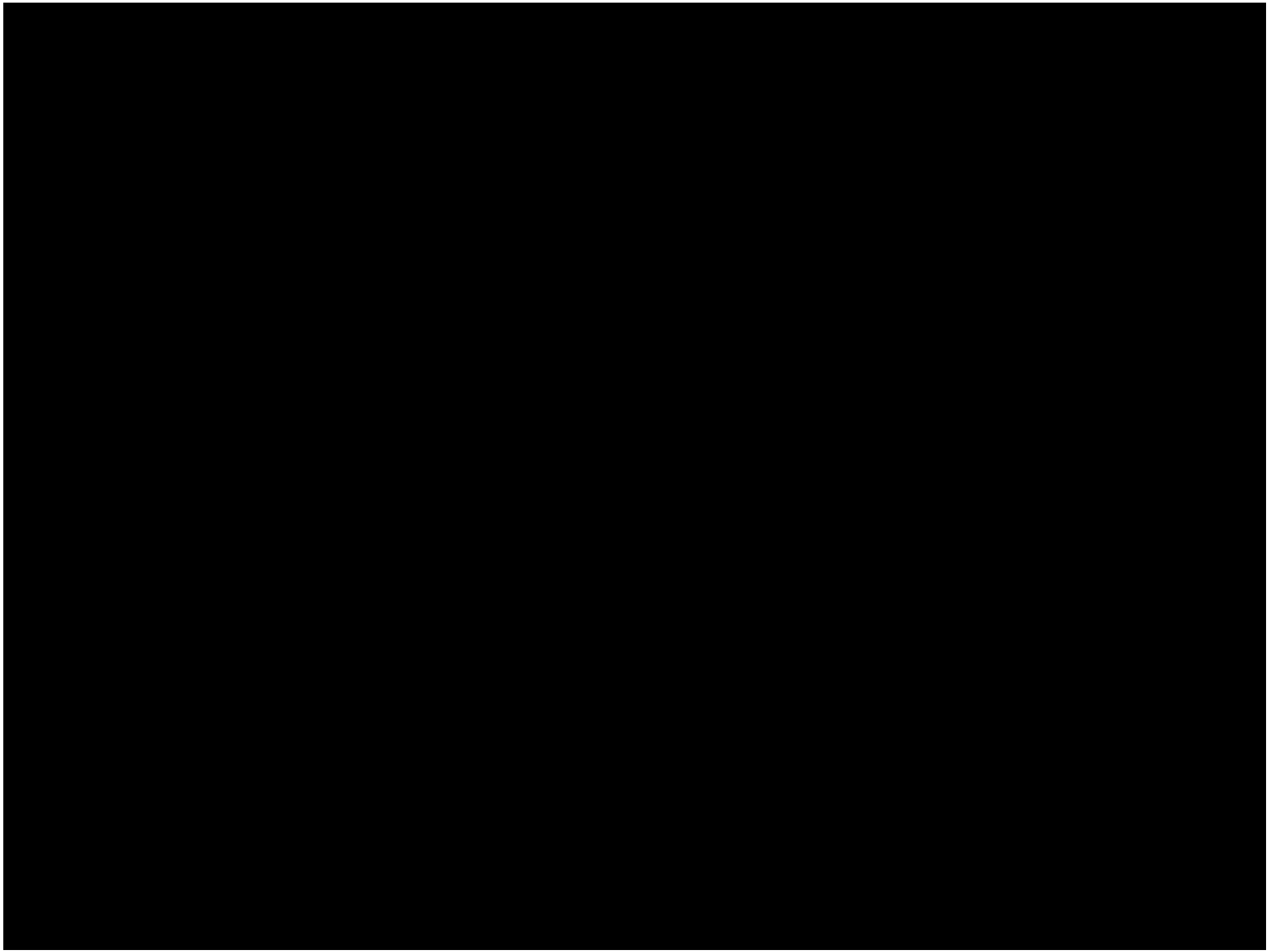
Extreme P.E. of material falling onto a supermassive black hole is very attractive (and enough)

4. What clues can we get by looking at the big picture and an intriguing coincidence that exists?

The fact that quenching occurs just when SN-driven winds become inefficient suggests that they may be linked.

5. Can we tie together in some way mass-quenching and the changing efficiency of star-formation in haloes?

Nice idea: when SN winds stop being able to eject gas, maybe the conditions for growth of BH are established.



Quenching (Part 2): environment-quenching

Then, what do we mean by "mass-quenching"?

In Peng et al (2010) we noticed that quenched fraction was separable in stellar mass and an "environment" variable.

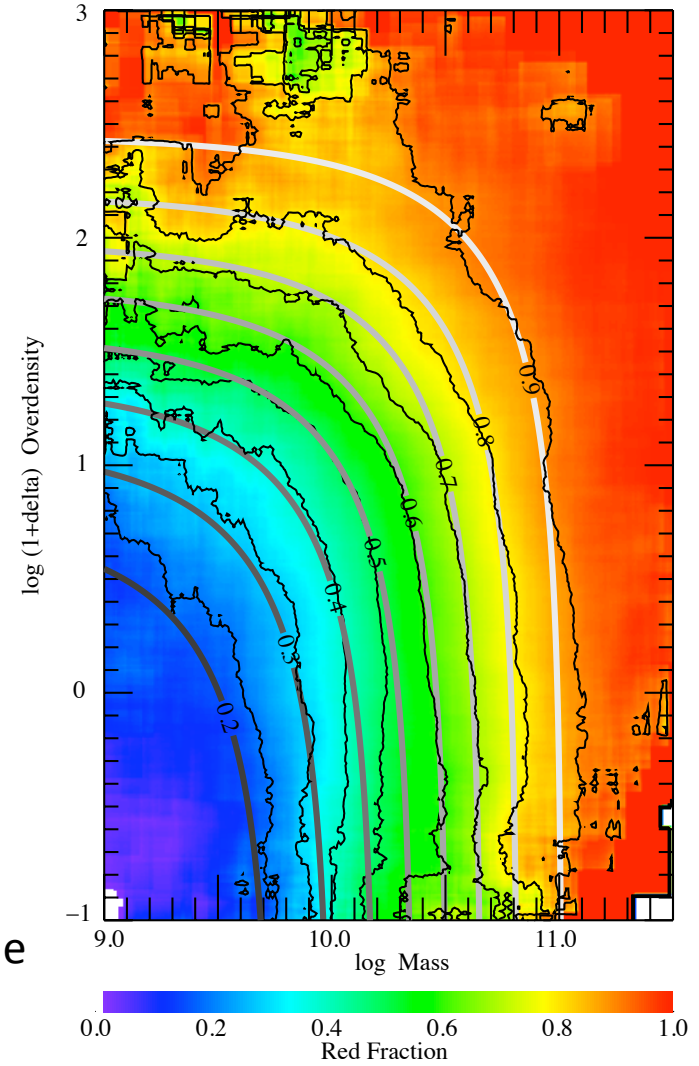
mass quenching

$$f_{blue}(m,\rho) = \left(1-\varepsilon_m(m)\right) \times \left(1-\varepsilon_\rho(\rho)\right)$$

Fraction of surviving SF galaxies

environment quenching

This suggested it might be useful to think of two separate channels to quenching: one dependent on mass but not environment ("mass-quenching") and the other dependent on environment but not mass ("environment quenching").



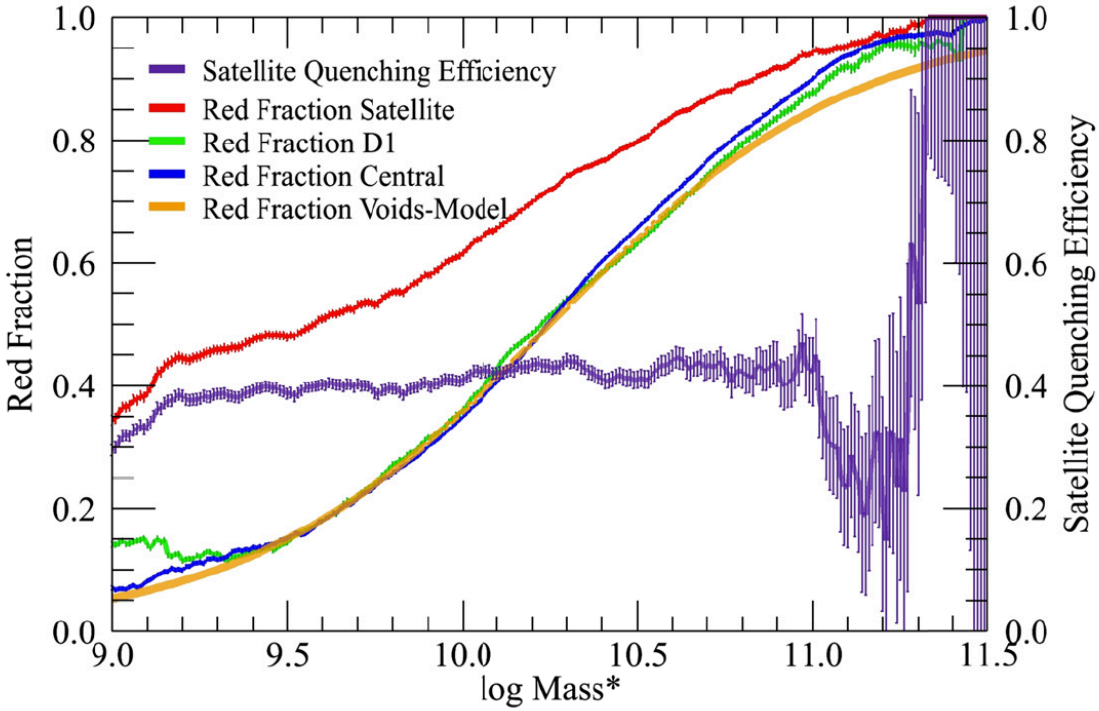
Satellite-quenching

40-50% of satellites are quenched relative to what they would have been as centrals, independent of stellar mass and the same fraction at z = 1 as locally

- Van den Bosch et al 2008, arXiv0805.0002
- Weinmann et al, 2009, MNRAS 394, 1213
- Peng et al, 2012,, Ap 757, 4

What does this tell us about the physical process?

- Strangulation
- Stripping
- Harrassment
- Mergers ?



Interestingly, the fraction of galaxies that are satellites is more or less independent of their stellar mass.

Also, the distributions of environment-related parameters that may be relevant for quenching (halo mass, overdensity, stellar mass of your central, radial position in your halo) are also very largely independent of the stellar mass of the satellite.

i.e. the “drivers” of satellite quenching (~ environment quenching) are independent of mass. Therefore, separability then implies that the response to these drivers is also independent of stellar mass.

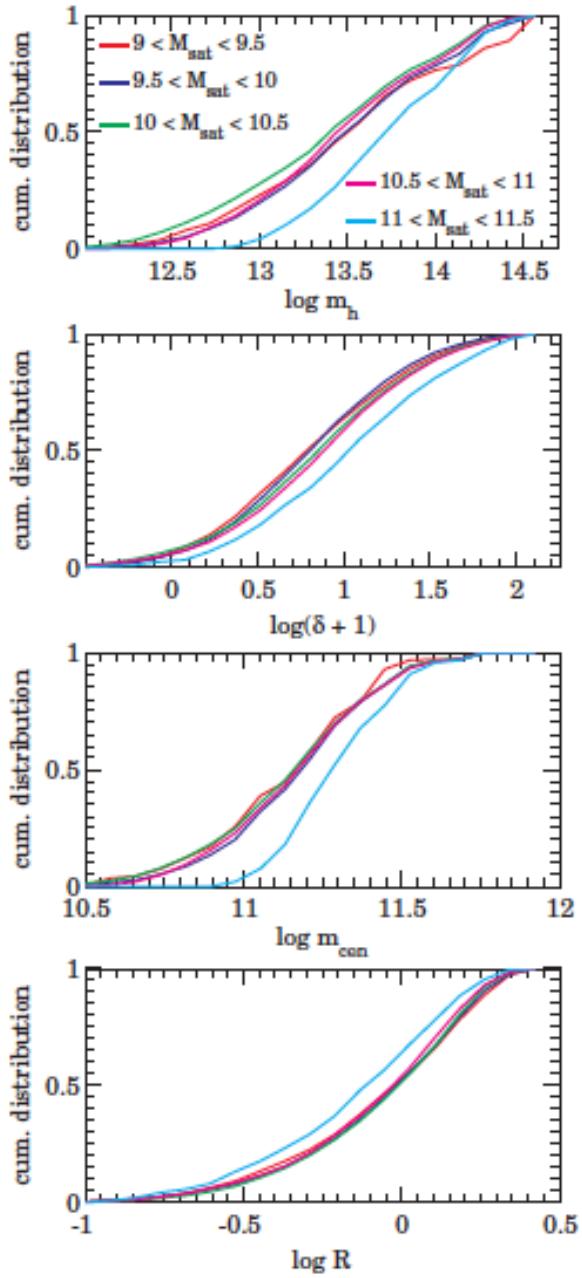
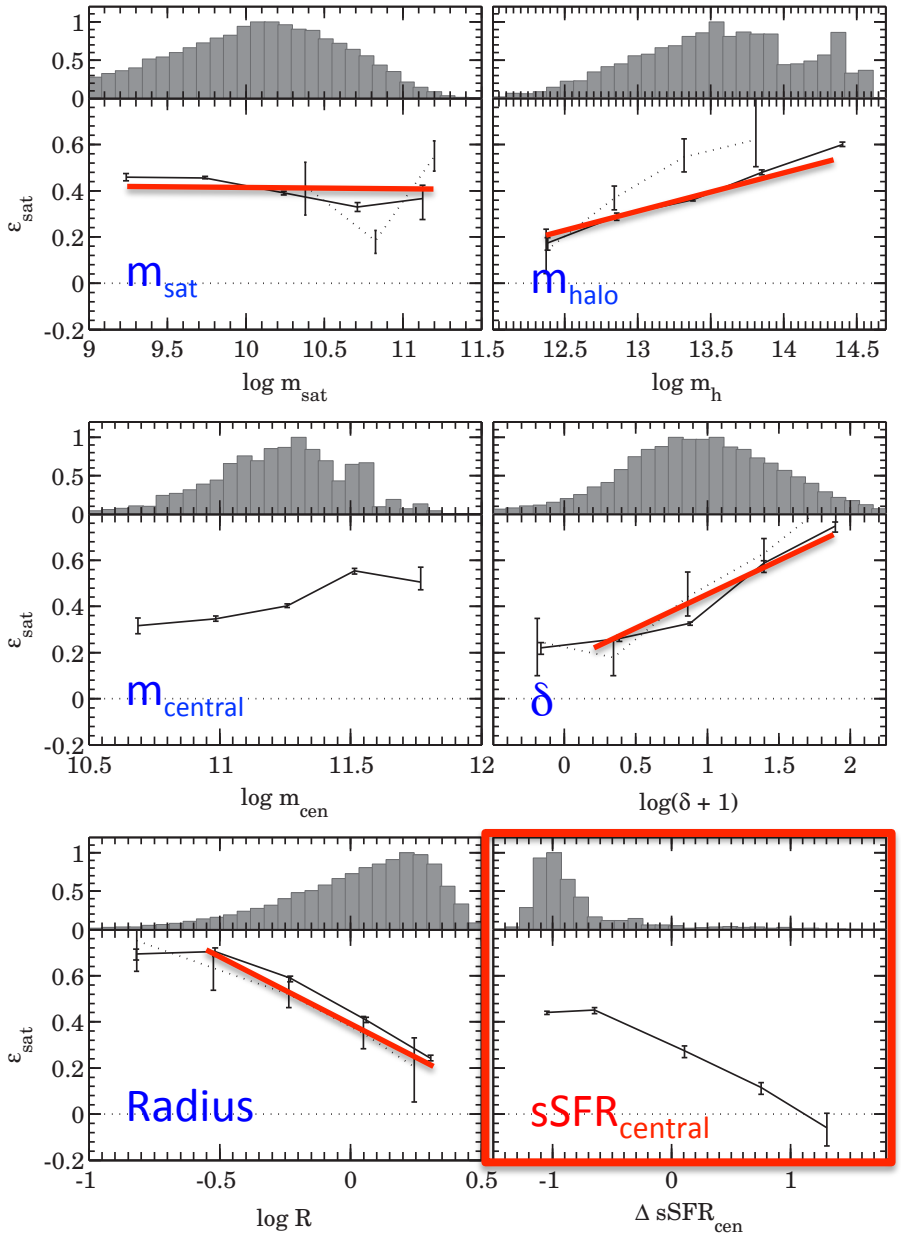


Figure 11. Cumulative distributions of the environmental parameters for our satellite sample in different stellar mass bins. Each color corresponds to a stellar mass bin as indicated in the top panel. It is obvious that the distributions are fairly similar for different mass bins except for the highest mass bin (i.e., $\log m_{\rm sat} > 11$). To compute these distributions the satellites are weighed (see Section 2.1).

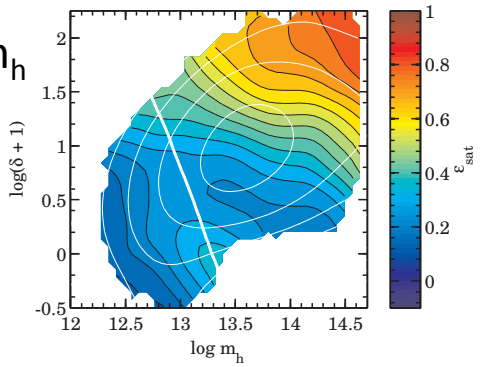
How does ε_{sat} vary with different parameters? Knobel+ 2015



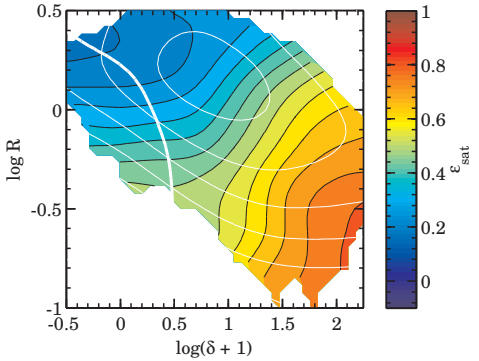
"Conformity"
Weinmann et al 2006

Variation of ε_{sat} in 2-d

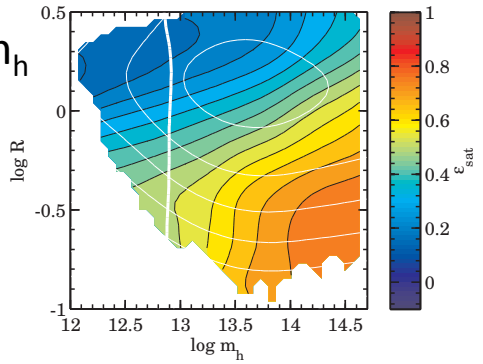
δ and m_h



R and δ



R and m_h

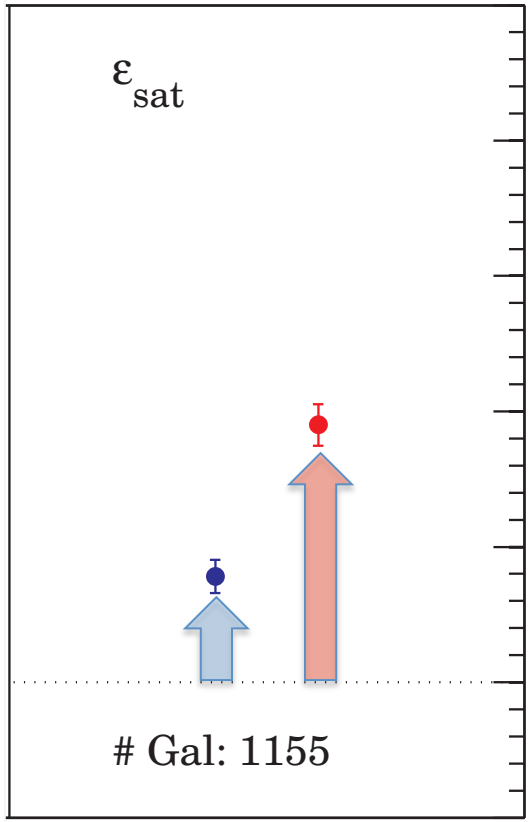


Conformity

Knobel+ (2015)

Conformity-like signals can be produced by independent correlations of central and satellites with e.g. halo mass, but these would disappear when you match satellites in that parameter

Satellite quenching is 2.5 times stronger with quenched centrals even when you match the satellites in all five of M_{halo}, m_{cen}, m_{sat}, R/R_{vir}, δ



The meaning of conformity

Knobel+ (2015)

Conformity suggests that either

- Environmental-quenching is (largely) caused by halo-wide effects that are consequent to mass-quenching of the central, by whatever mechanism, or
- Both mass- and environment-quenching are both caused by halo-wide effects that are causally shared by centrals and satellites of a given halo (and distinct from parameters matched in the analysis)

Note, not by two independent correlations with a matched parameter

Question: Are mass-quenching and satellite-quenching after all closely related?

The meaning of "probability"

Knobel+ (2015)

We talk about the "probability of being quenched" and use the fraction of galaxies of a particular type that have been quenched as a measure of that probability.

But galaxies are not probabilistic systems! On these scales they are deterministic.

The idea of probability masks our ignorance, either or what properties are important, and/or of how those parameters impact the evolution of galaxies (in this case their quenching), i.e. the presence of hidden variables.

Knobel et al (1915): Conformity implies that there are "hidden common variables" involved, or equivalently a variable that is correlated on significant spatial scales

Developing idea: Set q = 1 for quenched and q = 0 for star-forming. Construct $\Delta = (q - f_q(x_i \ldots))$ for each galaxy, where $f_q(x_i \ldots)$ is our best estimate of the quenched fraction based on the known parameters x_i.

The variance of Δ in a population is then a measure of our inability to predict quenching, i.e. our ignorance. The correlation of Δ in space is a measure of conformity.

Questions for today:

1. Why might evolution of centrals and satellites be different?
2. Why do some centrals become satellites of other galaxies?
3. What are some ways that the environment could quench satellite galaxies?
4. What does “separability” of f_Q tell us?
5. What is “conformity” and what does it tell us?