Week 6:
Quenching Part 1:
So-called “mass-quenching”

Introduction by S. Lilly

Questions from the high z SFRD last week:

- **What causes the cosmic SFRD to rapidly rise up to the peak at z ~ 2?**

At high redshifts, the halo mass at which haloes efficiently make stars (10^{12} $M_\odot$) is well above the Press-Schechter M* of the halo mass function. The exponential decline at high masses means that the number density of haloes (N per cubic comoving volume) increases rapidly as the M* increases.

The "cosmic noon" peak at z ~ 2 is when M* ~ 10^{12} $M_\odot$. At later times, the number of 10^{12} $M_\odot$ haloes does not increase much, because we are on the flatter part f the mass function below M*, and the SFRD is dominated by the slow down in the specific growth rate of the haloes, which drives the slow down of the sSFR in galaxies via the gas-regulator model.

Questions from Reionization last week:

- **What is the observational evidence for "reionization", and when did it occur?**

(a) Dark "Gunn-Peterson" troughs in the spectra of $z > 6$ quasars due to Lya absorption by neutral gas.

(b) Significant foreground scattering of CMB photons ($\tau \sim 0.1$) indicating free electrons.

(c) Not yet, 21-cm emission from neutral H.

Reionization occurred probably in an extended period $10 > z > 6$.

- **What sources caused the reionization, and can we identify them?**

Sources of ultraviolet radiation with $\lambda < 91.2$ nm. Known galaxies at $6 < z < 8$ are probably enough given uncertainties in the number of low mass galaxies and the fraction of uv photons that can escape the galaxy.

- **What might reionization of the Universe have as an affect on the development of galaxies?**

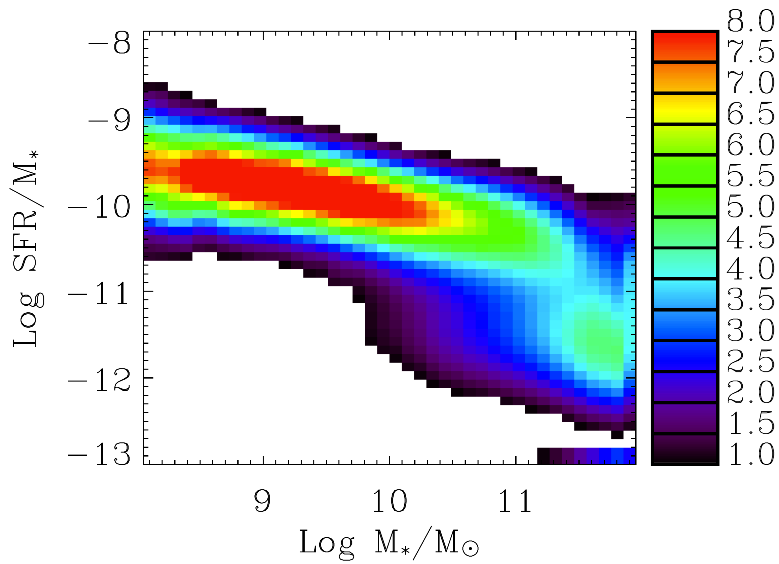
It may prevent the warm gas from collapsing into low mass haloes, but the mass threshold is very low (of order 10^{7-9} $M_{\odot}$ depending on z).

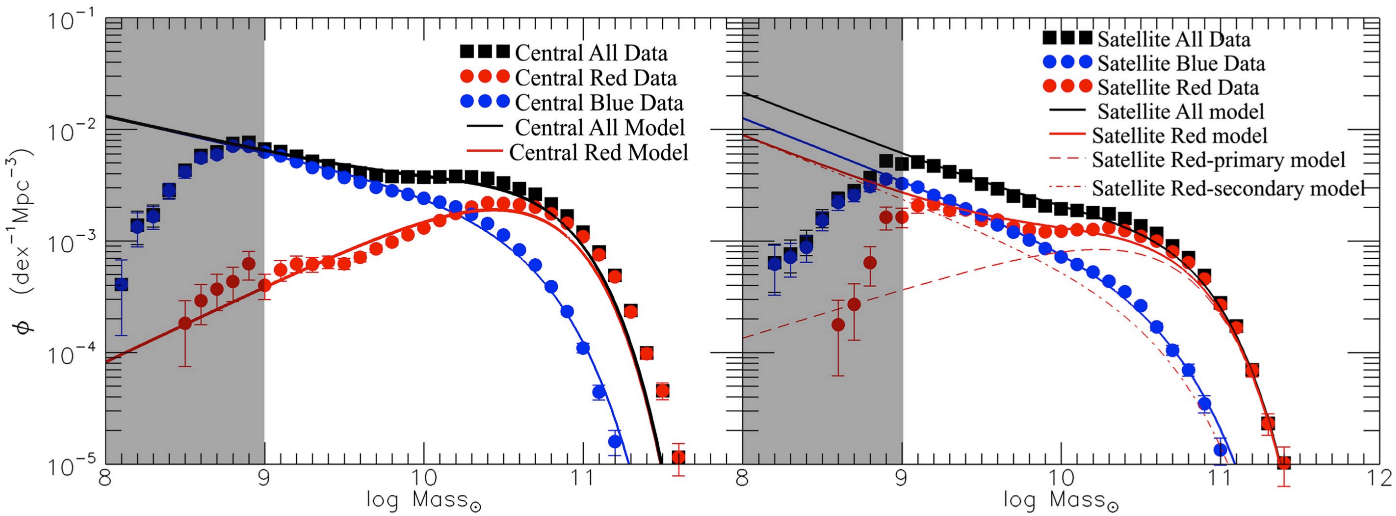
Quenching (Part 1): mass-quenching

First, what do we mean by "quenching"?

Quenching causes galaxies to lower their SFR by a factor of 10-100 relative to Main Sequence galaxies.

Mostly at high stellar masses, but with tail extending to lower masses.





(Peng+ 2012)

Quenching (Part 1): mass-quenching

Then, what do we mean by “mass-quenching”?

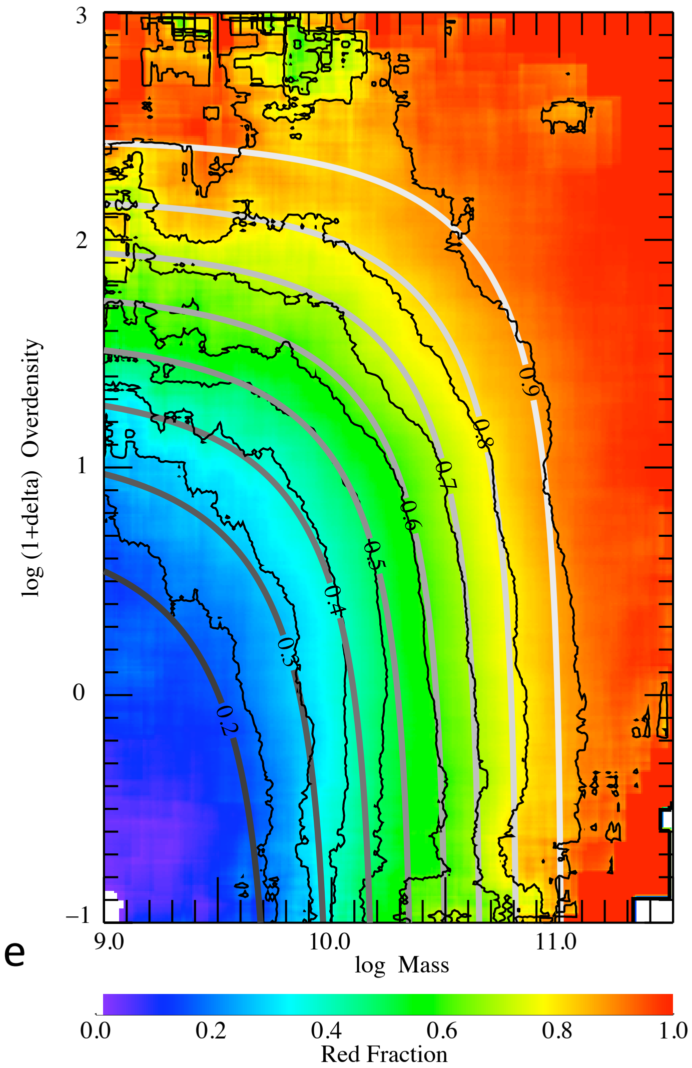
In Peng et al (2010) we noticed that quenched fraction was separable in stellar mass and an “environment” variable.

mass quenching

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

Fraction of surviving SF galaxies

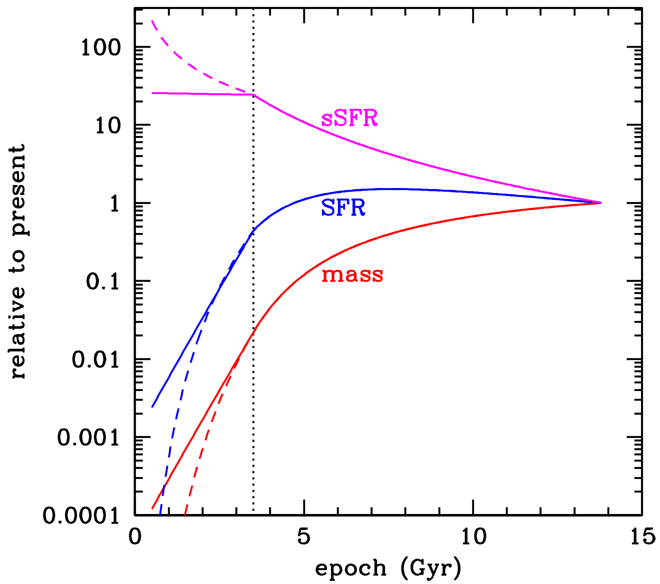
environment quenching



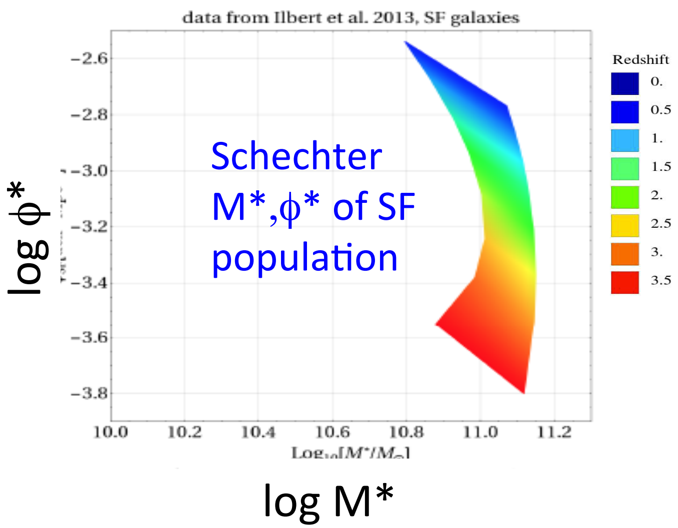
This suggested it might be useful to think of two separate channels to quenching: one dependent on mass but not environment (“mass-quenching”) and the other dependent on environment but not mass (“environment quenching”).

Therefore, only mass-quenching will affect the stellar- mass-function of galaxies.

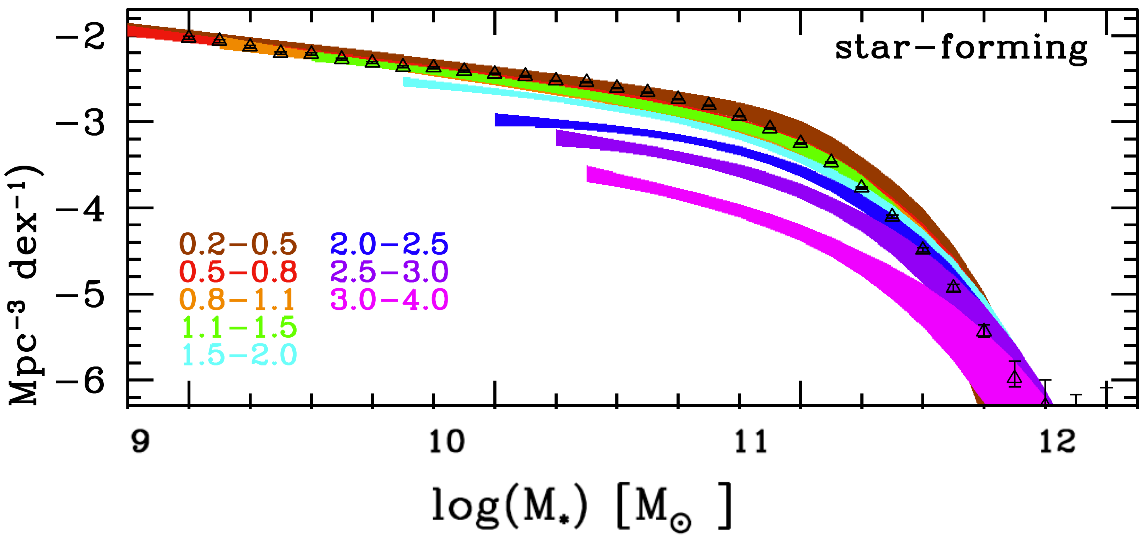
The evolution of the mass-function of star-forming galaxies (Peng+ 2010)



A galaxy that stays on the Main Sequence increases its mass x20 since z ~ 2, and even more since z ~ 4 …



… yet the shape of the mass function stays the same with constant M*.



from Ilbert+ 2013

The evolution of $\phi(m)$ of star-forming galaxies (Peng+ 2010)

What is mass-quenching?

Only mass quenching depends on mass, and therefore mass quenching is "that process that controls the shape of the mass function of the surviving star-forming galaxies"

Phenomenological quenching law:

In order to preserve the Schechter function with constant M*:

- the chance η for a star-forming galaxy to quench in unit time is simply given by it's SFR.
- equivalently, the probability that it survives to reach mass m is given by $P(m)$, a simple exponential survival.

$$\eta = \frac{1}{M*} \cdot SFR = sSFR \cdot \frac{m}{M*} \quad \Leftrightarrow \quad P(m) = \exp\left({}^{m}\!/_{M*} \right)$$

Important note: This doesn't mean that SFR is necessarily doing the quenching. Only that quenching is caused by something that is somehow related to stellar mass. Is it really stellar mass, or halo mass, or central BH mass (all of which are correlated) or something else that is related to these ? That is the question to answer!

Questions for today:

1. Why is quenching of star-formation not very easy to achieve?
2. What are some ways that it might be achieved?
3. If we need energy to overcome cooling in the halo, what are the available sources of energy?
4. What clues can we get by looking at the big picture and an intriguing coincidence that exists?
5. Can we tie together in some way mass-quenching and the changing efficiency of star-formation in haloes?