The Dominance of Quenching at All Cosmic Times
(Sometime simplest things come last to mind)

Madau & Dickinson, 2014

Alvio.Renzini@Subaru, Hilo, February 12, 2016
Playing with just two items (and for now, forget all the rest)

- The observed evolution of the SFR density, $SFRD(t) =$
\[
\psi(z) = 0.015 \frac{(1 + z)^{2.7}}{1 + [(1 + z)/2.9]^{5.6}} \, M_\odot \text{year}^{-1} \text{Mpc}^{-3}.
\]

- The observed evolution of the Main Sequence of SF galaxies, $SFR(t, M_*)$ from Peng+10 (P10):
\[
sSFR(t) = \sim 2.5 \, \eta \, (t/3.5 \, \text{Gyr})^{-2.2} \, \text{yr}^{-1} \, \text{Mpc}^{-3} \text{ for } t > 3.5 = \text{flattening, for } t < 3.5 \, \text{Gyr (i.e. } z > \sim 2).}
\]
The 3D SFR-M*-Number Relation for Galaxies in the Local Universe (Renzini & Peng 2015)

The Main Sequence of star-forming galaxies
Where is the SFR and where is the mass

Number x SFR

Number x M*
And its projection on the SFR-M* Plane

Slope of the Main Sequence \( \sim 0.8 \)

Specific Star Formation rate = SFR/M* = sSFR

B/T increases
But not counting the mass of quenched bulges: slope $\sim 1$ (Abramson+2014)
Beyond redshift ~2 sSFR are more uncertain.
Playing with just two items (and for now, forget all the rest)

- The observed evolution of the SFR density, SFRD(t) = \[
\psi(z) = 0.015 \frac{(1+z)^{2.7}}{1 + [(1+z)/2.9]^{5.6}} \ M_\odot \text{year}^{-1} \text{Mpc}^{-3}.
\]

- The observed evolution of the Main Sequence of SF galaxies, SFR(t, M_*) from Peng+10 (P10):

\[sSFR(t) = \sim 2.5 \ \eta \ (t/3.5 \text{ Gyr})^{-2.2} \ \text{yr}^{-1} \text{Mpc}^{-3} \text{ for } t>3.5\]

= flattening, for t<3.5 Gyr (i.e. z~2).
A few trivial relations

- \( \frac{dQ_\ast}{dt} = (1-R) \text{SFRD}(t) \)  \hspace{1cm} \text{Assume} \ R=0.3
- \( \text{SFRD}(t) = s\text{SFR}(t) \ Q_{\ast}^{SF}(t) \)
- \( Q_{SF\ast}(t) = \text{SFRD}(t)/s\text{SFR}(t) \)
- \( Q_{Q\ast}(t) = Q_{\ast}(t) - Q_{SF\ast}(t) \)
- Use \( \eta \) as a fudge factor to absorb possible relative systematics in M* & SFRs used in M&D and P10.
To be clear:

- $\varrho_*(t)$ is the total stellar density ($M_\odot \, \text{Mpc}^{-3}$)
- $\varrho_{SF*}(t)$ is the cosmic stellar density of stars in star-forming environments, i.e., in the star-forming portions of galaxies on/near the MS
- $\varrho_{Q*}(t)$ is the cosmic stellar density of stars in NON-star-forming environments, i.e., in quenched galaxies and in quenched halos & bulges
- Use of a linear SFR-M* relation is justified if the stellar mass refers only to the star-forming regions of galaxies (Abramson+14; Selmi+12), so $SFRD(t) = sSFR(t) \varrho_{SF*}(t)$
The red line is obtained by integrating \[ \frac{d\varrho_*}{dt} = (1-R)sSFR(t) \varrho_*(t) \].

Quenching must set in very early!!!
\[ \rho^{\text{SF}*}(t) = \frac{\text{SFRD}(t)}{s\text{SFR}(t)} \]

\[ \rho^{\text{Q}*}(t) = \rho^{*}(t) - \rho^{\text{SF}*}(t) \]

78% quenched

22% star-form.

At z=0
If All This is (kind of) Right, then ...

- Quenching dominates at (almost) all times
- \( \rho_{Q\star}(t) > \rho_{SF\star}(t) \) from almost the beginning
- We may have missed lots of quenched “mass” at \( z \geq \sim 3 \)
- sSFR unlikely to keep increasing beyond \( z \sim 2 \)
- \( \rho_{SF\star} \) as been almost constant over the last \( \sim 10 \) Gyr
- The fraction of star-forming mass density (\( \sim 22\% \)) at \( z=0 \) nicely agrees with the \( \sim 23\% \) estimated from SDSS by Abramson (private communication)
Thank You!