Chapter 3: Some key things about stars and star-formation in galaxies

Some key ideas about stars and star formation in galaxies

1. There appears to be a dichotomy between "actively star-forming galaxies", which have $sSFR = SFR/M \sim \boldsymbol{\tau}_H^{-1}$ and those which are not forming stars at a cosmologically significant rate: $sSFR \leq 0.1\ \boldsymbol{\tau}_H^{-1}$.

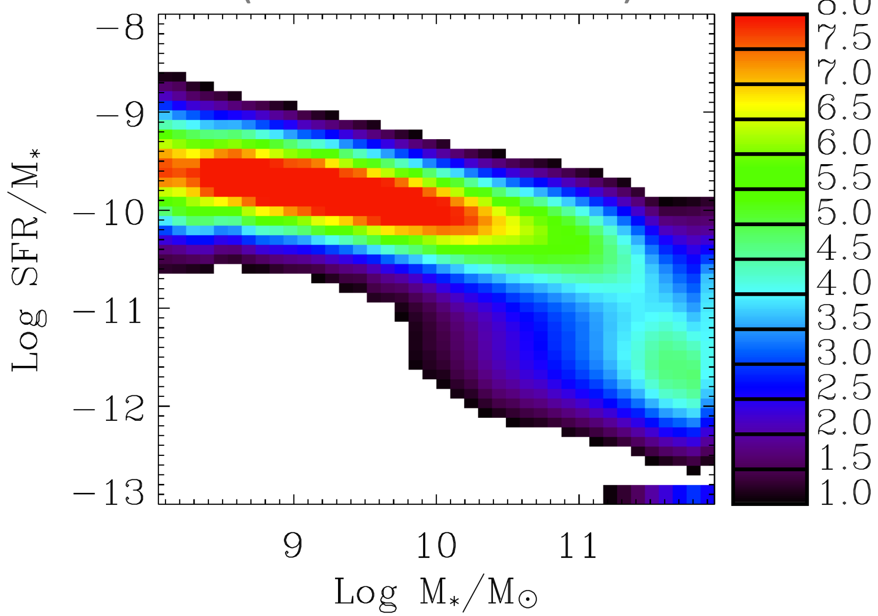
The specific star-formation rate of galaxies in the Universe today

This tight relation (σ ~ 0.3 dex) is called the "Main Sequence" of galaxies, not to be confused with Main Sequence of stars

$$sSFR = \frac{SFR}{m} \propto m_{star}^{\beta} \quad \text{with } \beta \sim 0.1 - 0.2$$

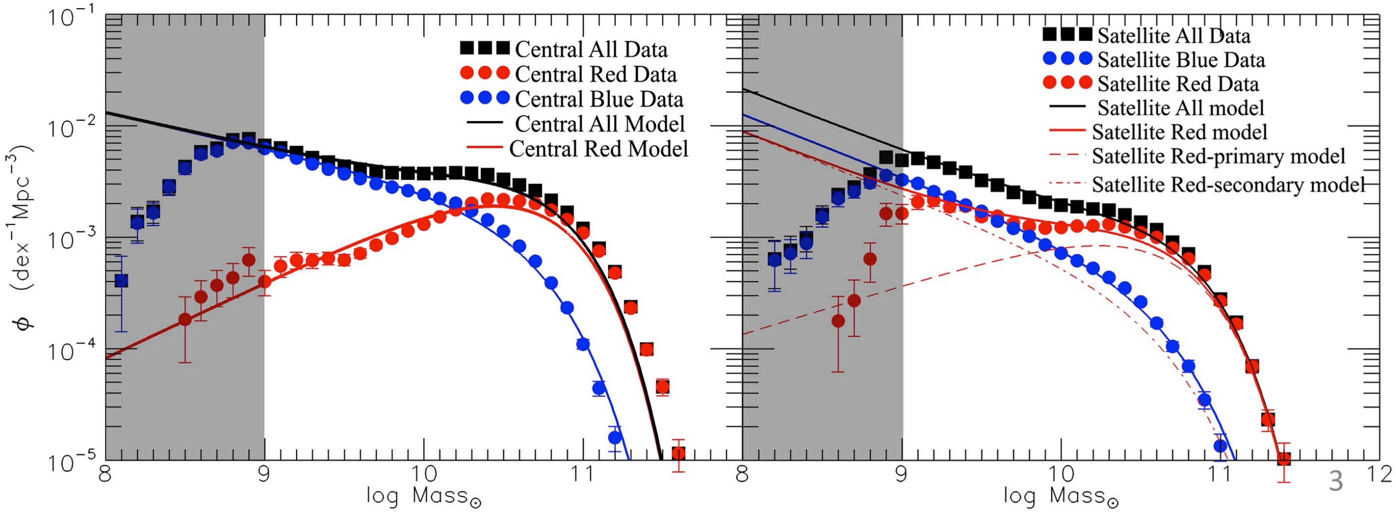
The objects with much lower sSFR are variously called "passive", or "quenched" or "quiescent"….

(Brinchmann+ 2004)

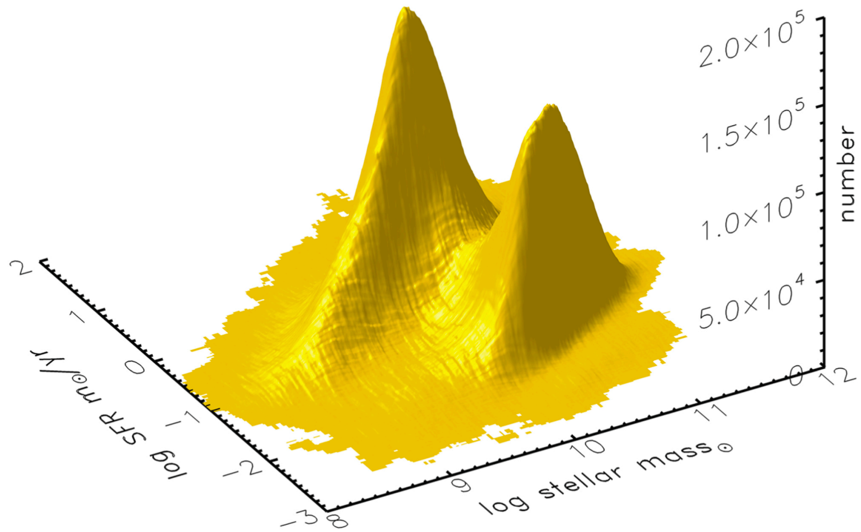


These two populations have different mass functions

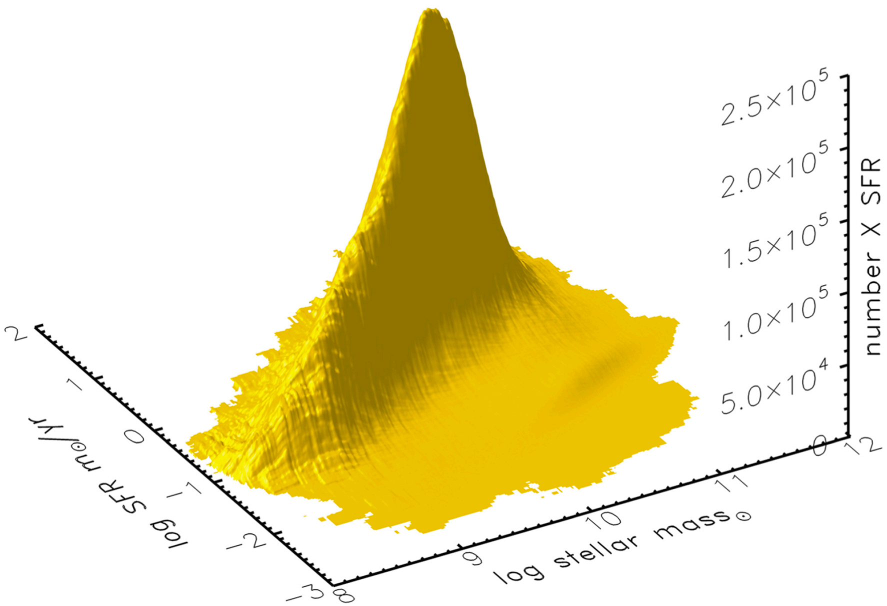
centrals satellites (Peng+ 2012)



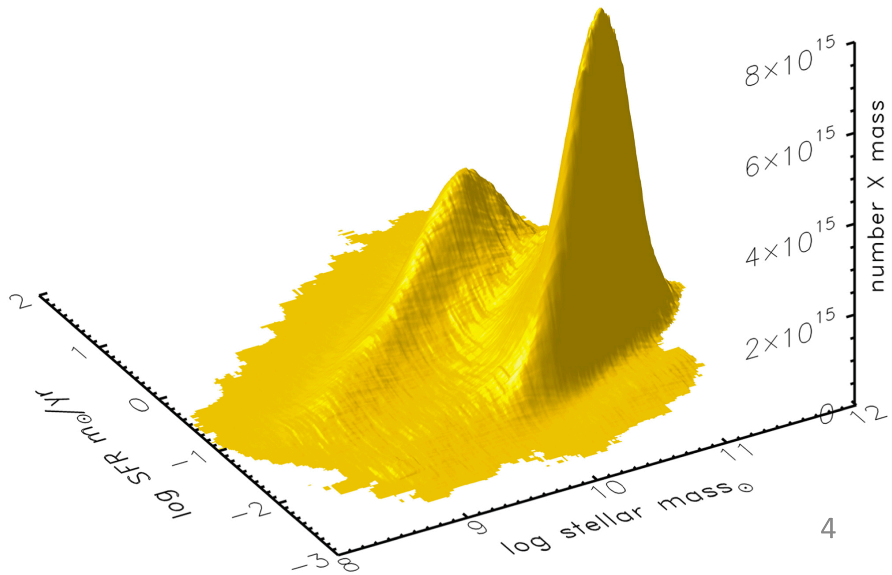
The "Main Sequence" and "passive populations" seen in 3-d (from Renzini & Peng 2015)



Where's the star-formation?



Where's the stellar mass?



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2. There appears to be a less pronounced dichotomy in structure, with some galaxies dominated by a flat uniformly rotating "disk" of stars and gas, and some dominated by a 3-d "spheroid" distribution of stars in which random velocities σ play a large role in support, with a full range in between.

0th-order links between star-formation and structure

Star-forming galaxies

Flattened disks with ordered rotation of stars and gas

Passive galaxies

3-d structures supported by randomly oriented velocities of stars

Structure and morphology

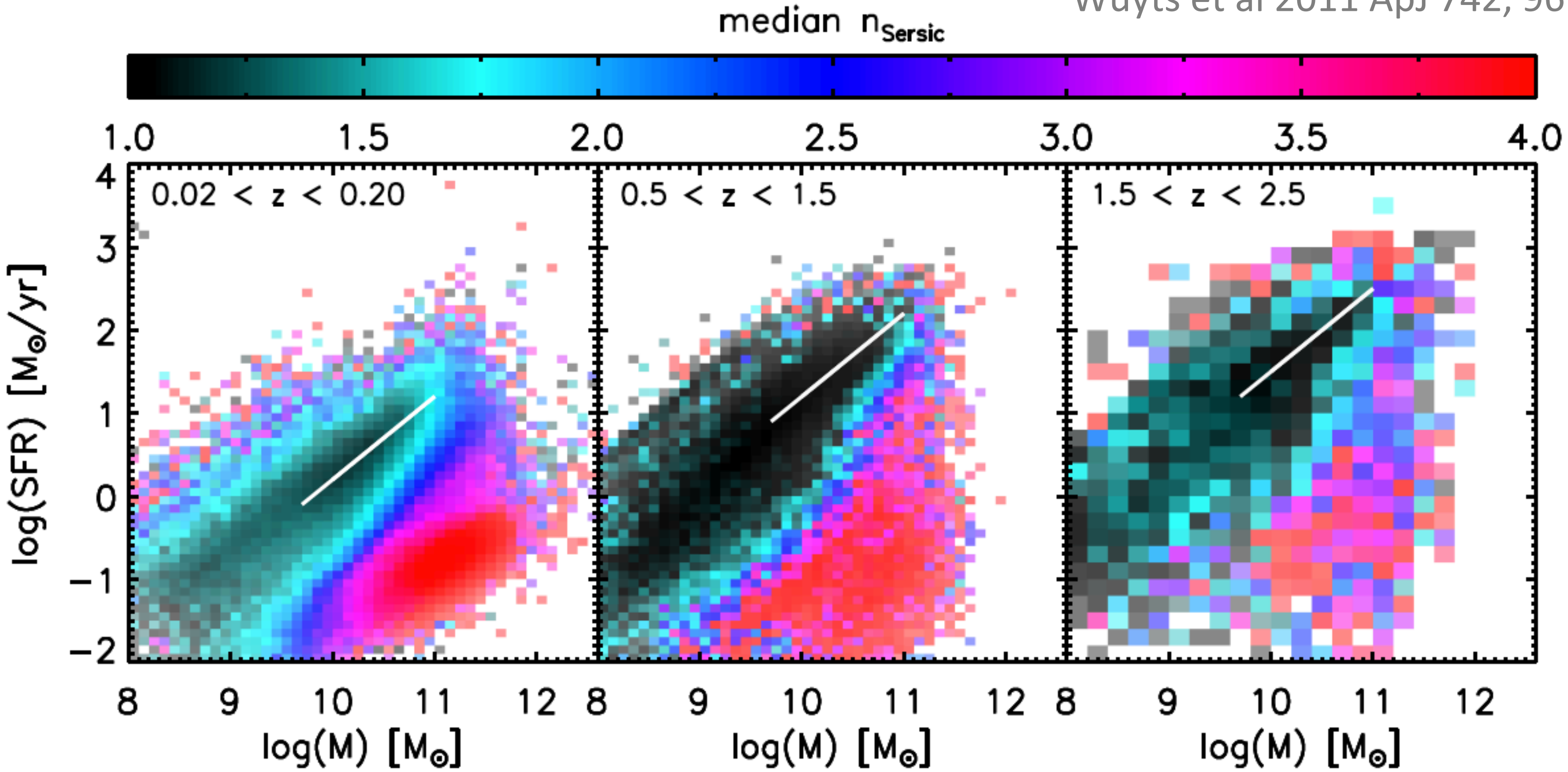
Sersic surface brightness formula

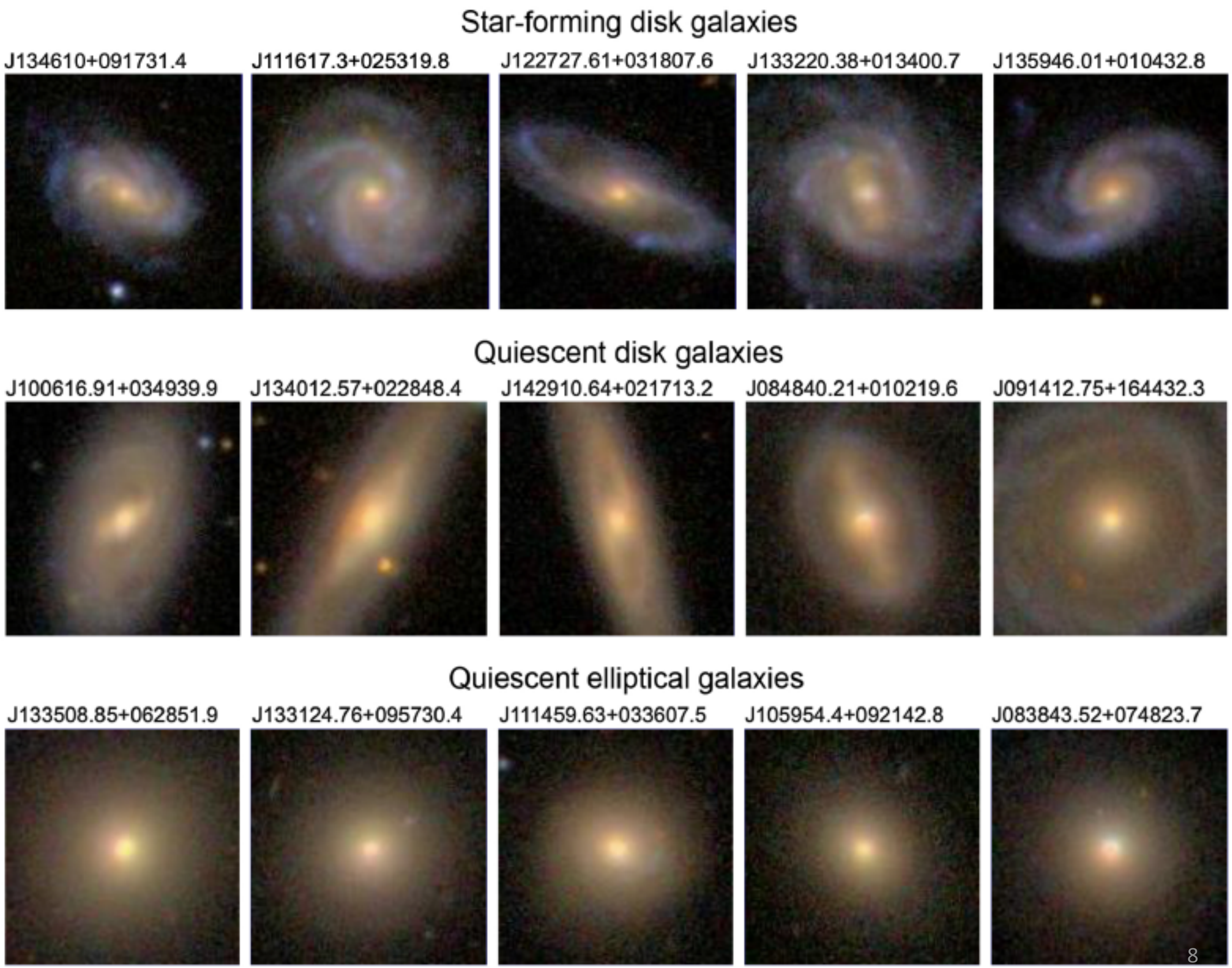
- Exponential disk has $n = 1$
- Most spheroid dominated galaxies have $n \sim 4$

$$\mu = \mu_0 e^{-kr^{1/n}}$$

There is a clear correlation between n and sSFR but it is not exact

Wuyts et al 2011 ApJ 742, 96




Star-forming disk galaxies
J134610+091731.4
J111617.3+025319.8
J122727.61+031807.6
J133220.38+013400.7
J135946.01+010432.8
Quiescent disk galaxies
J100616.91+034939.9
J134012.57+022848.4
J142910.64+021713.2
J084840.21+010219.6
J091412.75+164432.3
Quiescent elliptical galaxies
J133508.85+062851.9
J133124.76+095730.4
J111459.63+033607.5
J105954.4+092142.8
J083843.52+074823.7

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3. If we define a "star-formation efficiency" ε or "gas-depletion timescale" τ_{dep}, based on the formation of stars from gas, then most galaxies have more or less the same value.

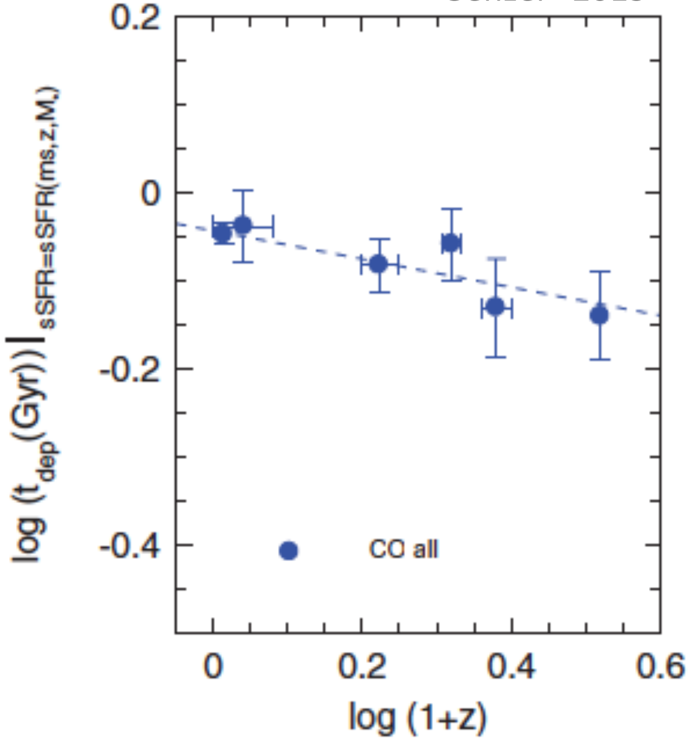
Star-formation efficiency and gas depletion ("Kennicutt-Schmidt")

$$\varepsilon = \frac{SFR}{M_{gas}} = \tau_{dep}^{-1}$$

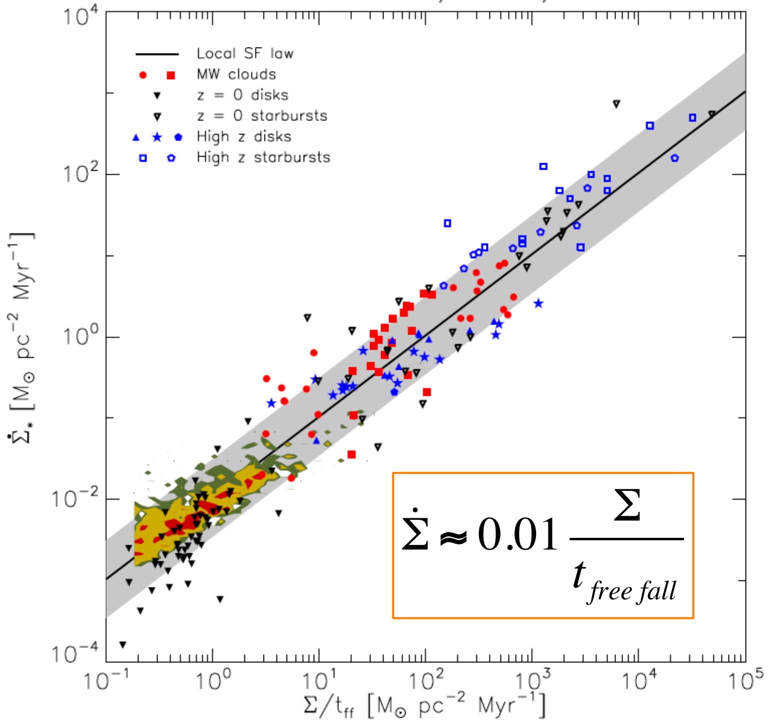
Gas-depletion timescale τ_{dep} is typically ~ few Gyr

- ~ 100 times longer than free-fall time
- ~ several times shorter than τ_H
- apparently varies little with redshift (or galactic mass)

Genzel+ 2015



Krumholz, Dekel, McKee 2011



This is presumably telling us something about the physics of how stars form, rather than how galaxies as a whole evolve.

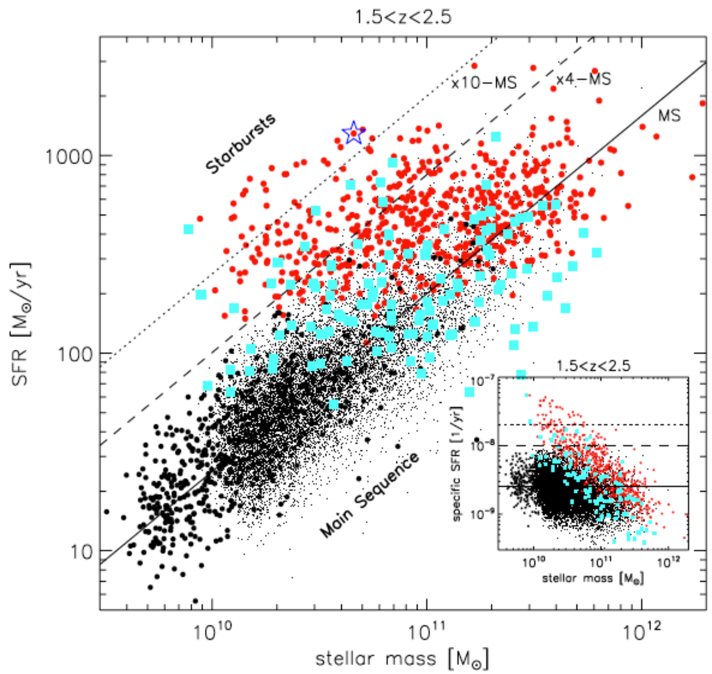
Aside: galaxies above the Main Sequence

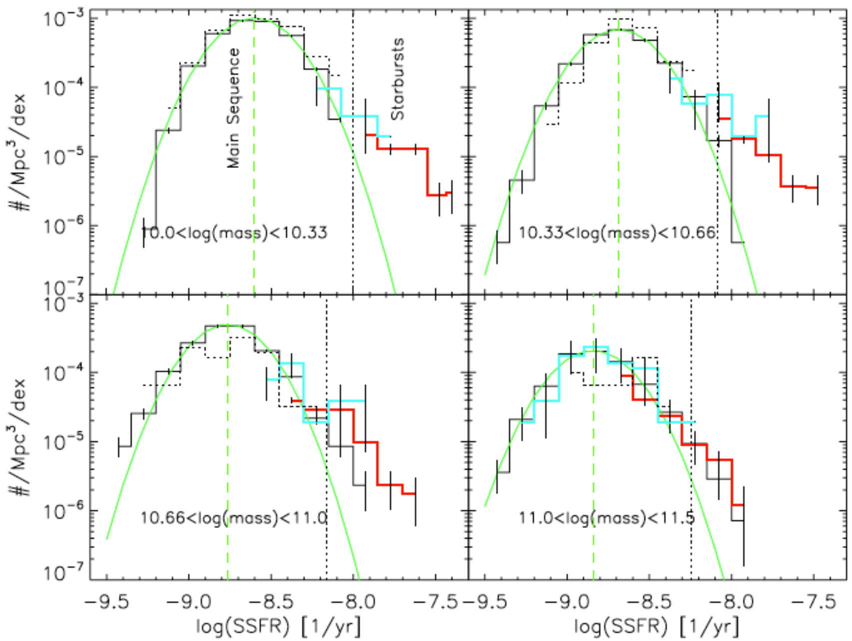
About 2% of galaxies at all redshifts lie significantly above MS, with sSFR more than 4× <sSFR>$_{MS.}$

These should be regarded as “star-bursts” (on duty-cycle arguments)

These are generally more highly dust-obscured. They are probably merger-induced, producing short-lived enhancement in the star-formation efficiency (SFR/m_{gas}). They represent only about 10% of the total SFR at any epoch.

from Rodighiero et al 2012 ApJL 739, L40





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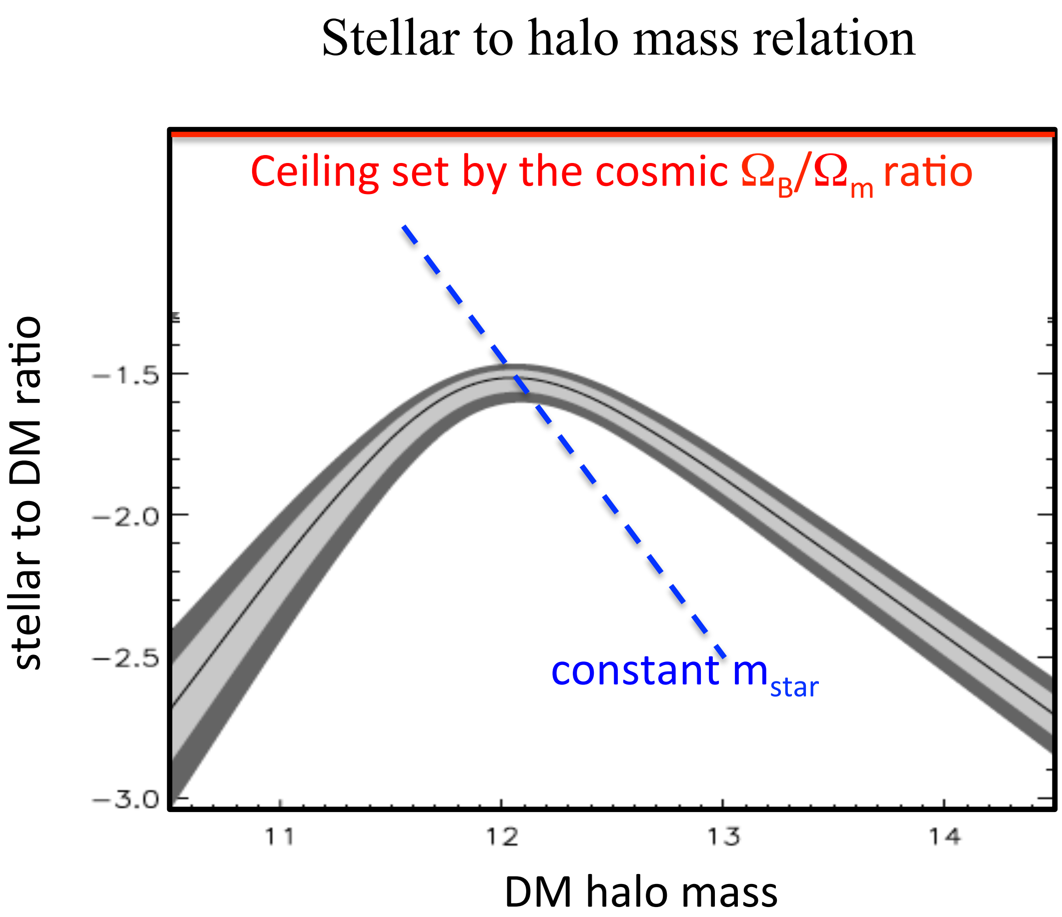
4. The ratio of stellar mass to DM halo mass varies strongly with halo mass (also sometimes confusingly called "star-formation efficiency" of a halo), peaking around $10^{12}\ M_\odot$.

The relation between stellar mass and halo mass



Moster+ (2010)

Estimated via extensive statistical analysis based on assumption of a simple monotonic relationship between the two, plus input of data on number density, spatial clustering, etc.

Then, checked with observational estimates of DM halo masses from weak lensing, X-ray gas data and dynamical mass estimates.

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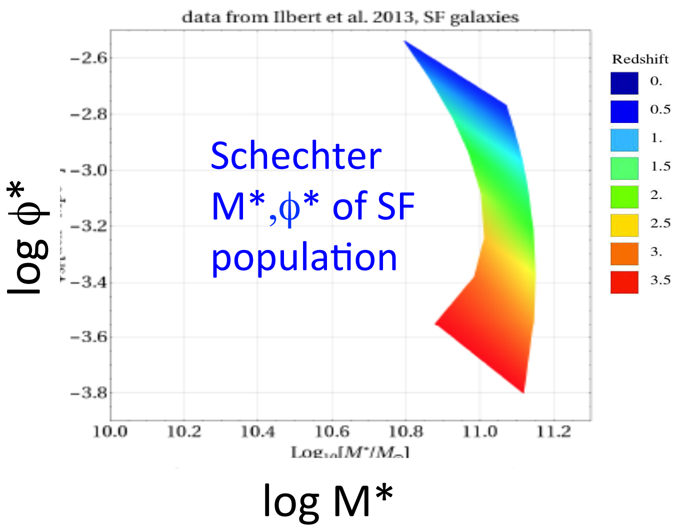
5. The mass function of star-forming and passive galaxies, the sSFR of the Main Sequence and the overall star-formation rate of the Universe all evolve with cosmic epoch.

The evolution of the mass-function of galaxies

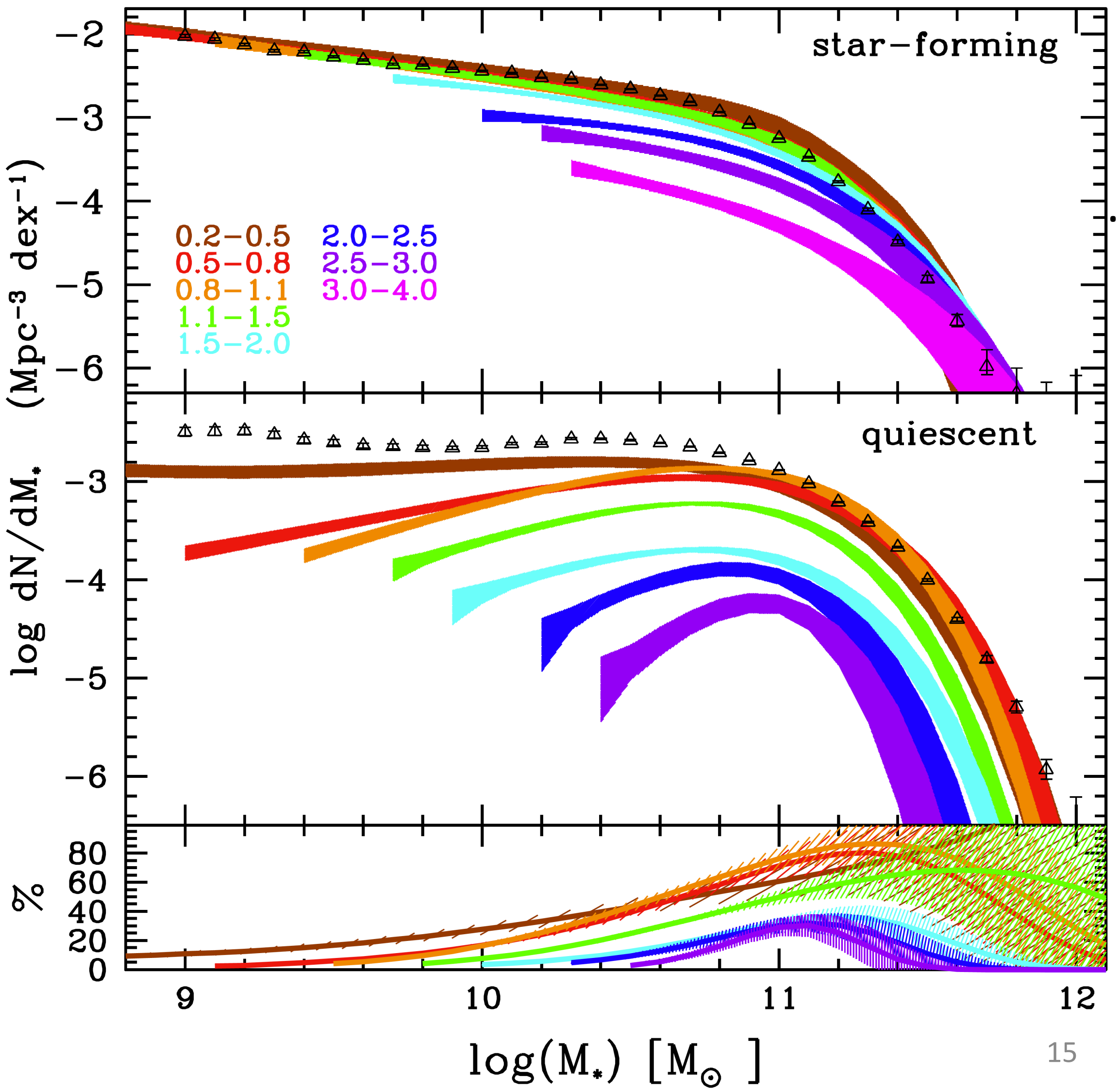
The mass function of both star-forming and passive galaxies changes with epoch, but in a possibly *surprising* way:

Not evolution in M* as in the Press-Schechter mass function of haloes, but rather evolution in density ϕ* with constant M*

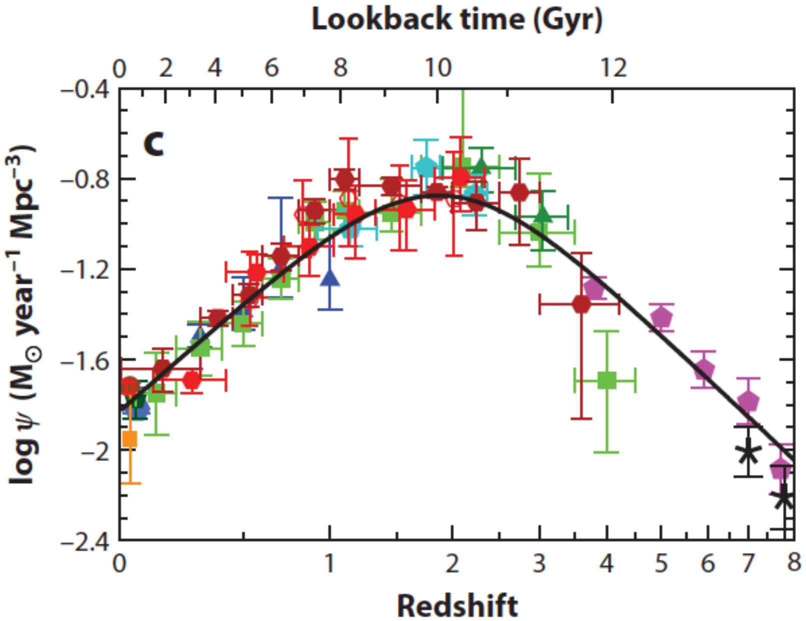
from Caplar+ 2015

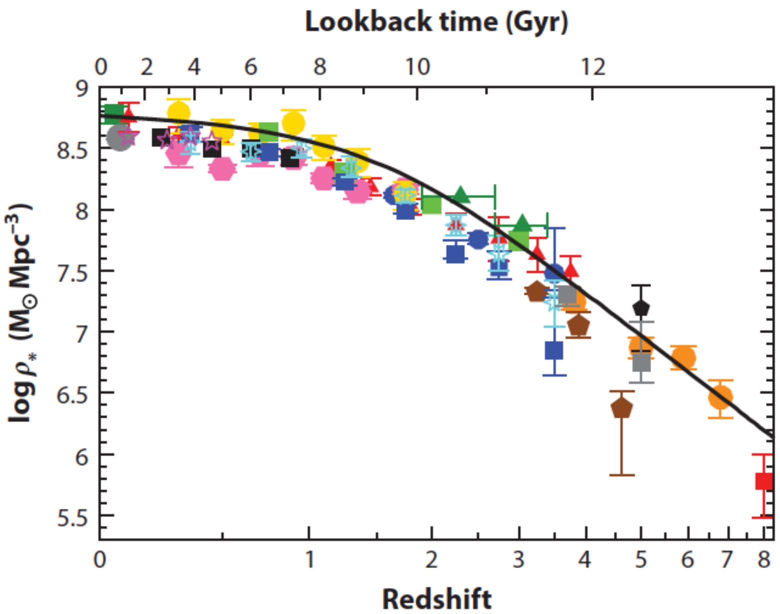


from Ilbert+ 2013

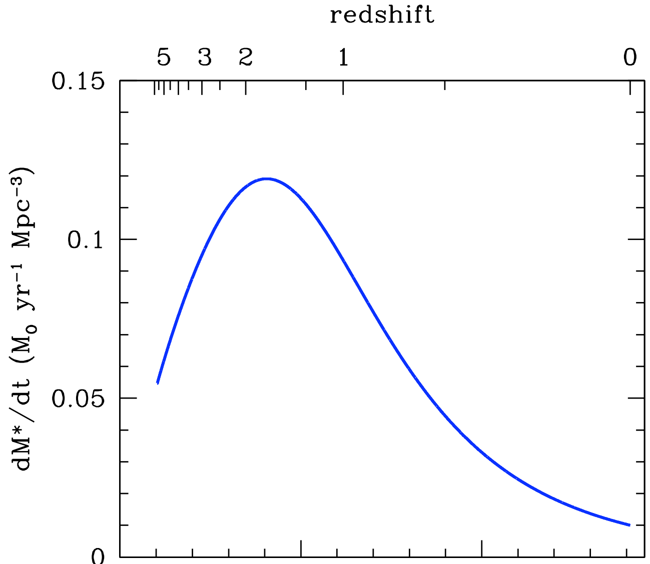


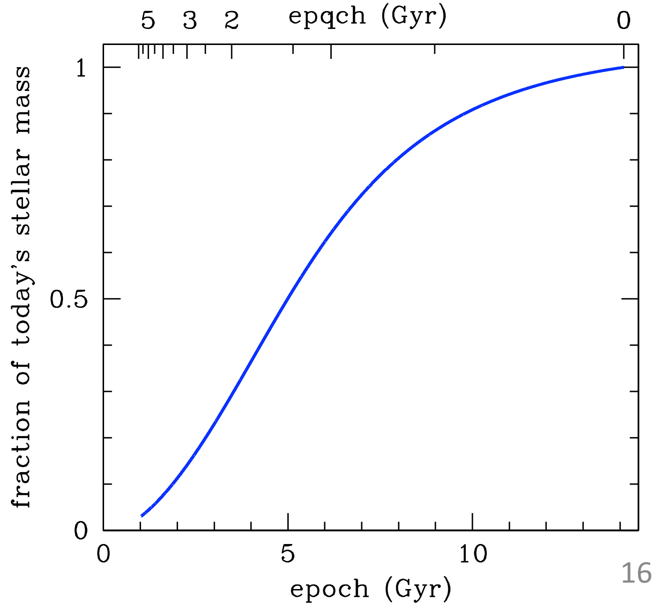
The star-formation rate density of the Universe evolves…





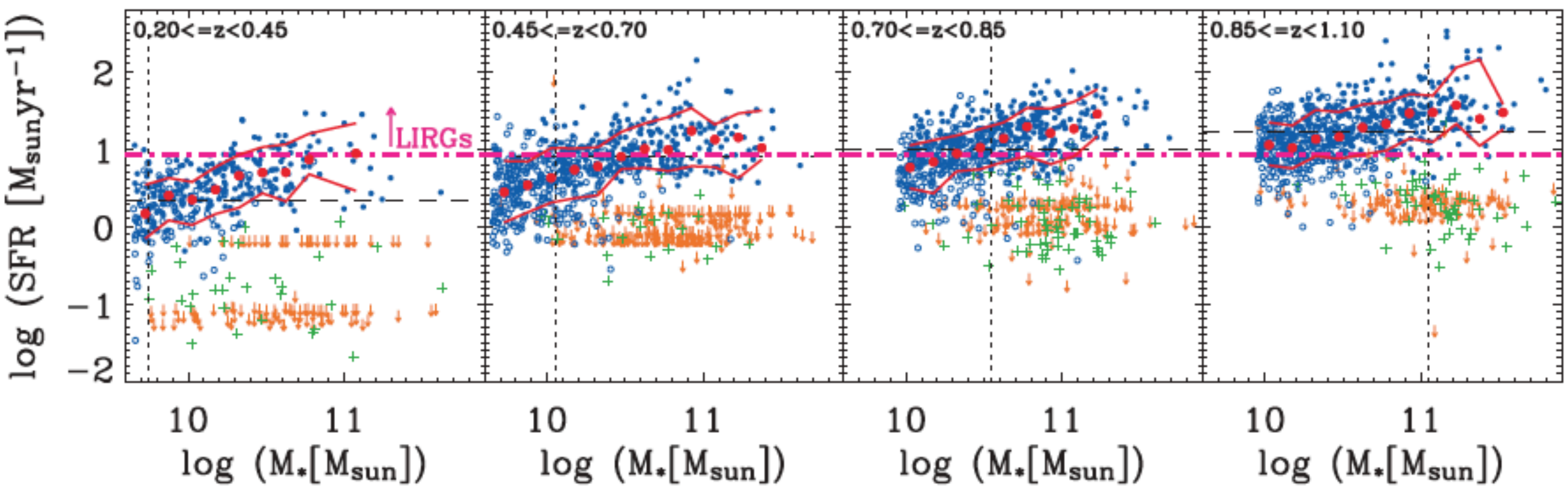
Madau & Dickinson Review (2014)





… as also does the characteristic sSFR of the Main Sequence

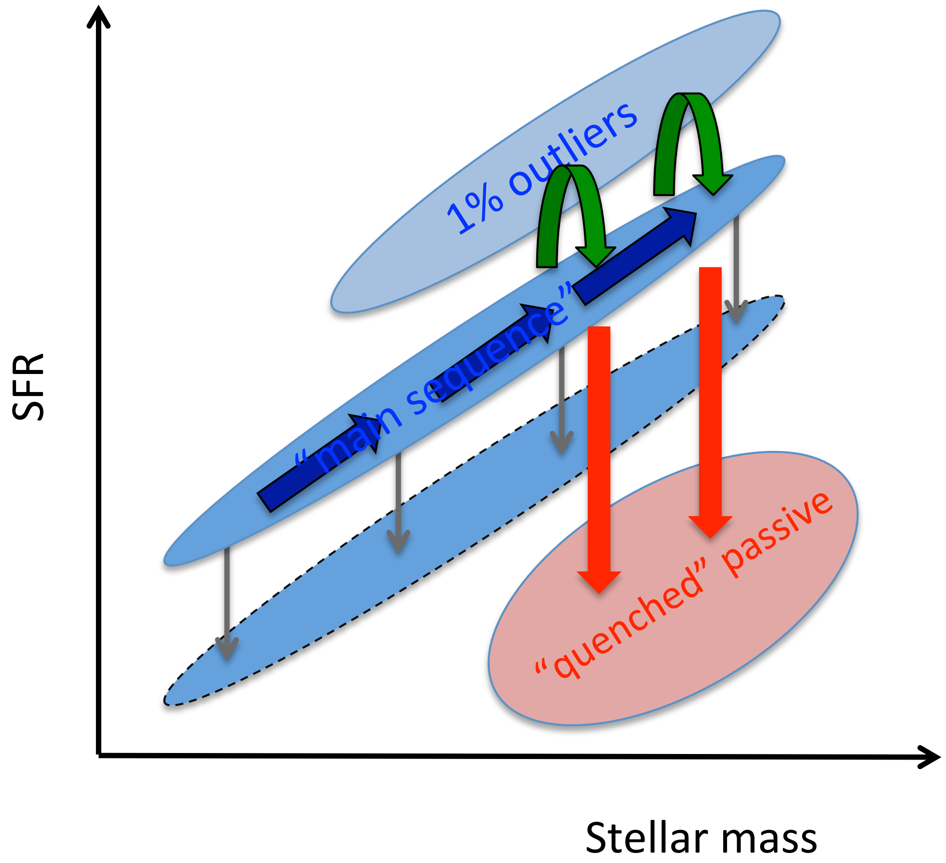
Noeske et al 2007 ApJ 660 L43



This characteristic sSFR of the Main Sequence population increases with redshift as something like $(1+z)^{2.5}$

By $z \sim 2$, the mass doubling timescale has reduced to $sSFR_{MS}^{-1} \sim 0.5$ Gyr, which is considerably less than the age of Universe at that redshift.

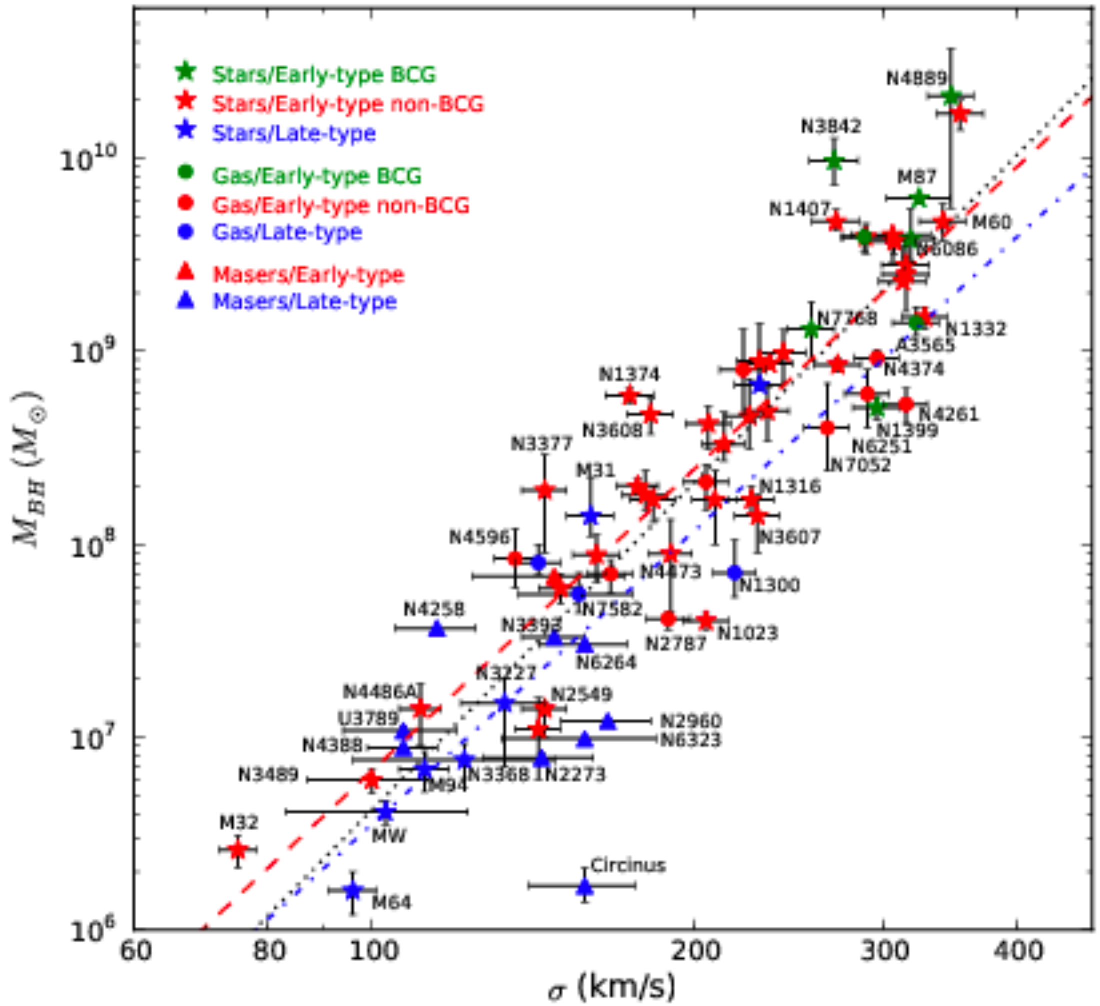
A simple cartoon of galaxy evolution



Finally, what about the black holes?

There are clear correlations between the mass of the central super-massive black holes and the stellar component of galaxies.

e.g. m_{BH} vs. stellar velocity dispersion



Summary: Some obvious questions

- What sets the value and rather small dispersion of the sSFR of typical "Main Sequence" star-forming galaxies and why does this change with time/ redshift, increasing roughly as $(1+z)^{2.5}$?

- Why do lower mass haloes have a lower m_{star}/m_{halo} ratio than those like the Milky Way , at $10^{12} M_{\odot}$, i.e. why are they less effective at forming stars?

- What does the fact that the mass doubling timescale $sSFR^{-1} = m_{star}/SFR$ is much longer than τ_{dep} tell us?

- Why is the characteristic star-formation timescale for most star-forming galaxies $\tau_{dep} \sim m_{gas}/SFR \sim 10^9$ yr, so much longer than the free-fall time in gas clouds $\sim 10^7$ yr.

- What causes some galaxies to stop forming stars altogether, i.e. to quench their star-formation?

- How does galactic structure come in? And what about central black holes?