Galaxy Quenching and AGN Feedback

or, why the green valley is a red herring

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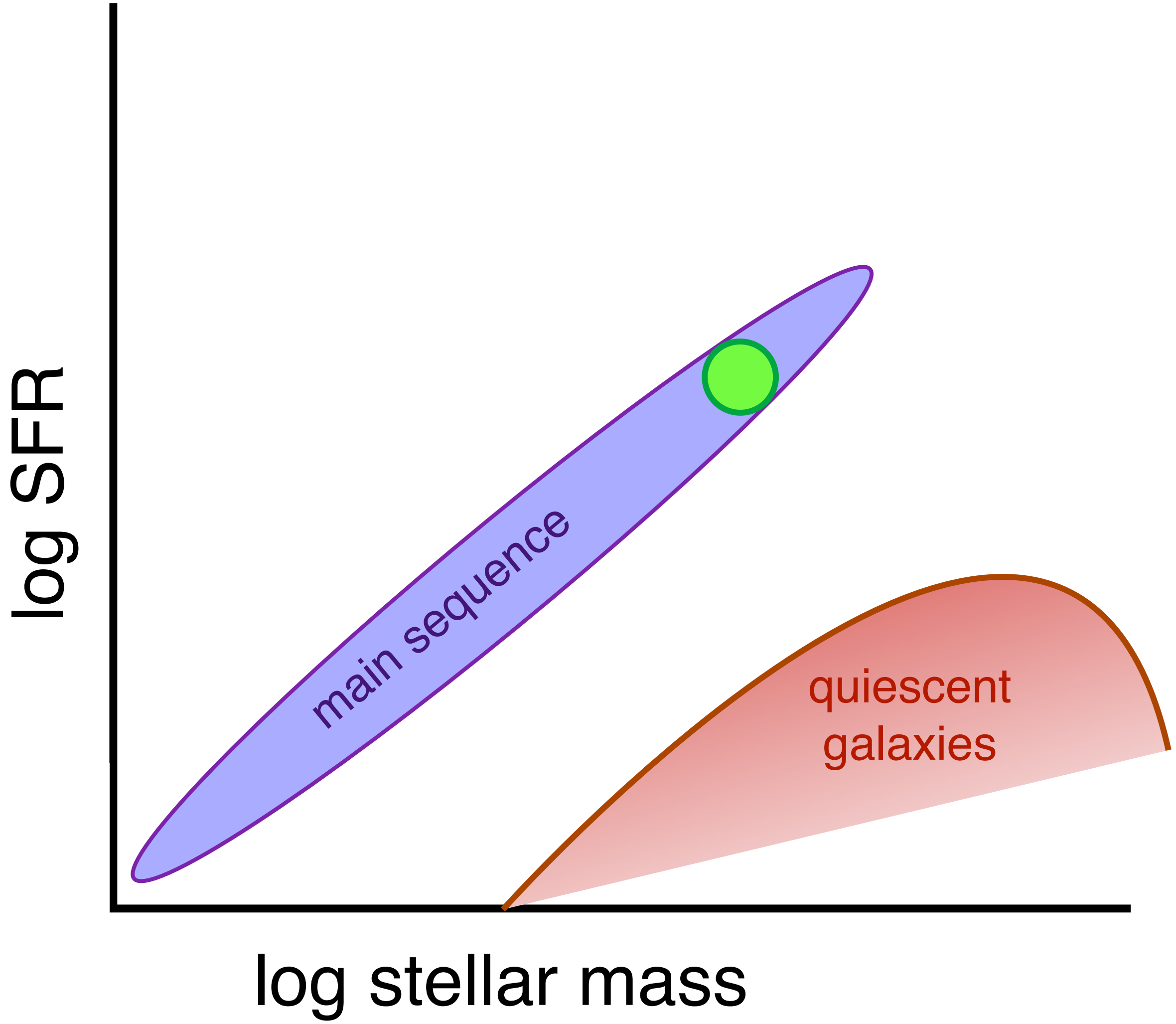
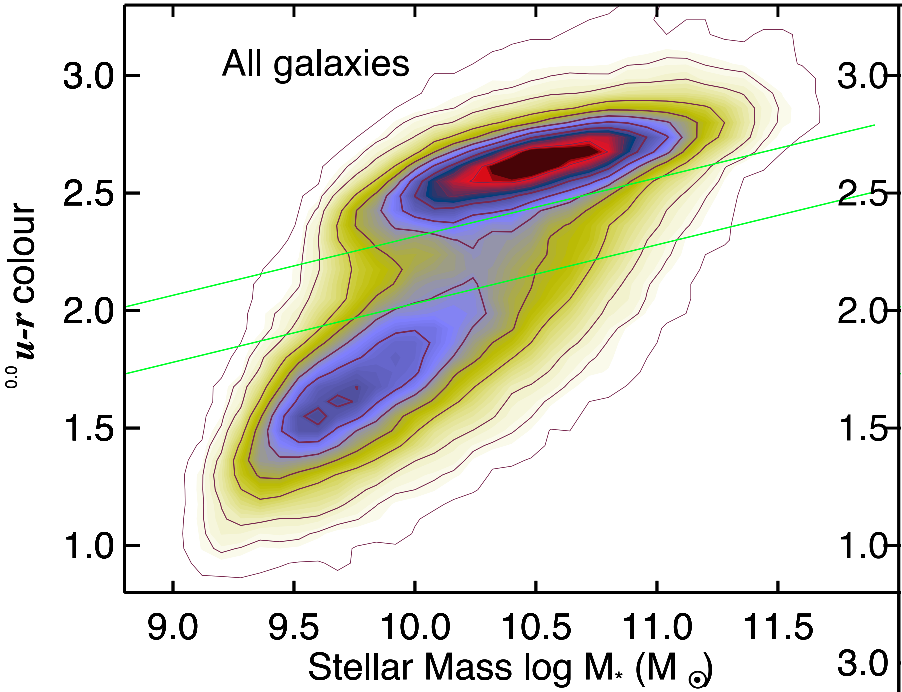
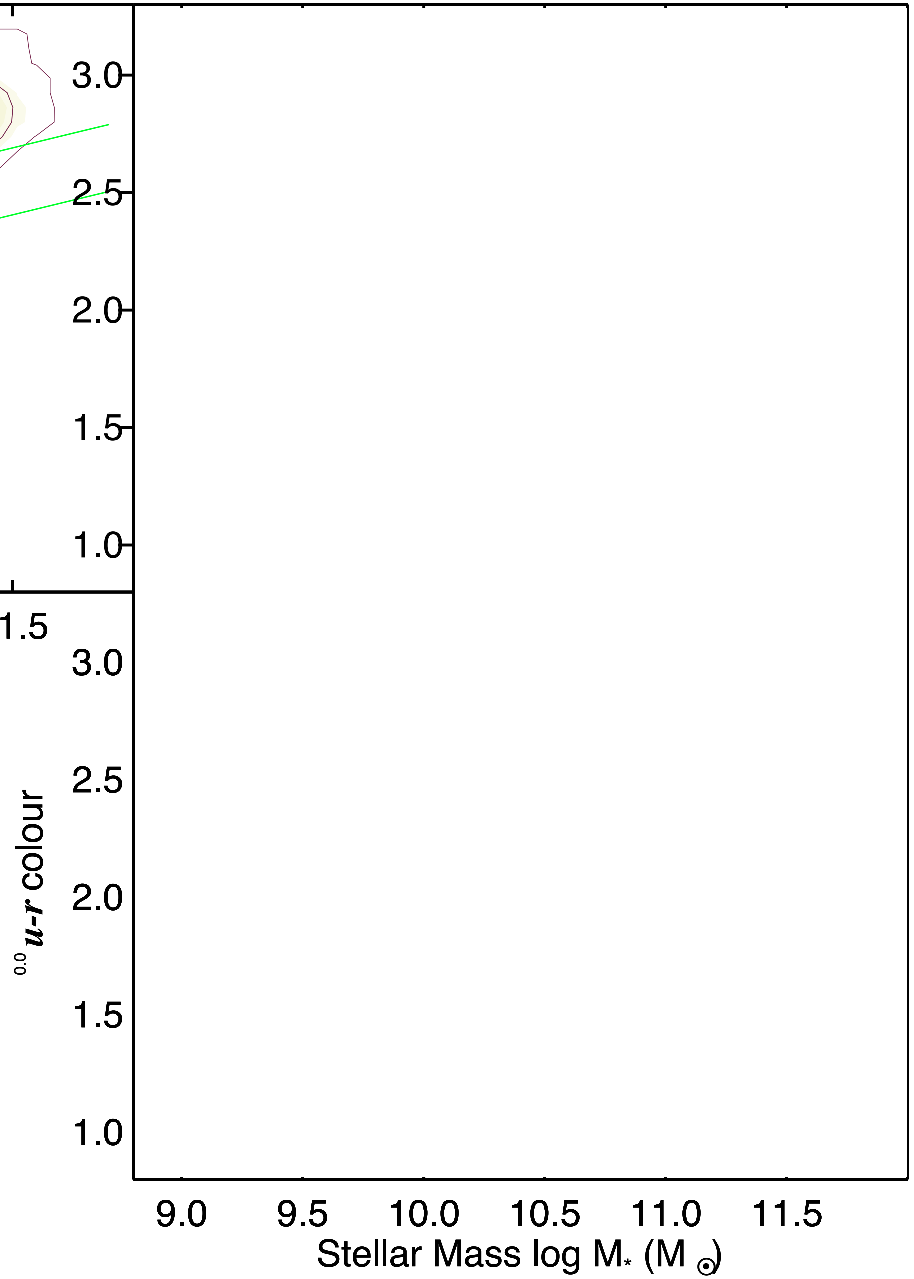
Context: the main sequence

(of star formation, don't throw things at me!)



Star forming galaxies are on main sequence: $M_{stellar} \sim SFR^{\beta}$, with small scatter.
Scatter small, holds out to at least z~2, perhaps higher.
See: Brinchmann+04; Elbaz+07,11, Noeske+07; Salim+07; Peng+10; Lee+12





Data

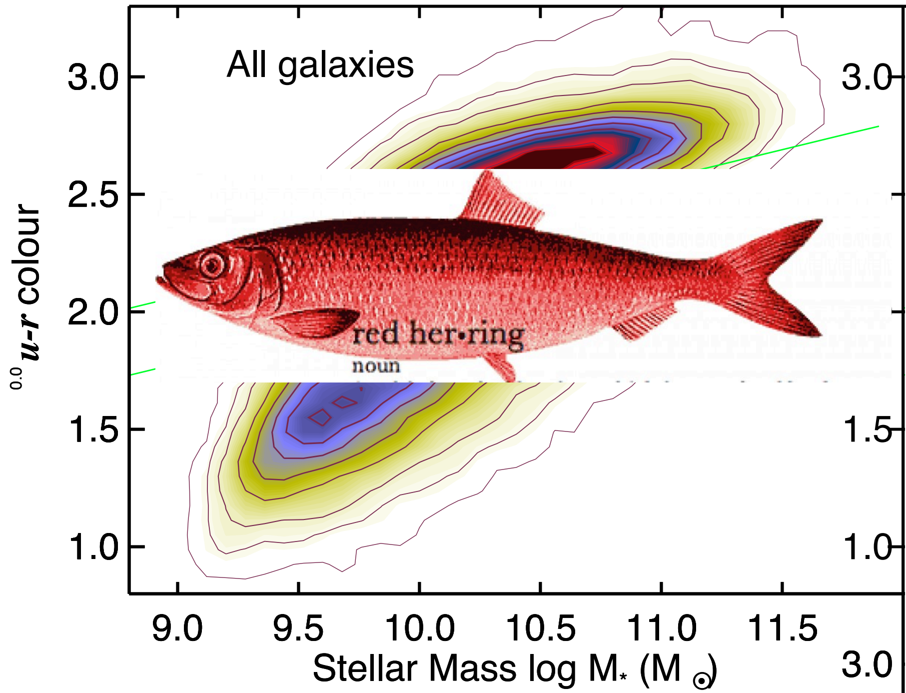
SDSS DR7

Galaxy Zoo 1 morphologies

GALEX GR6

MPA-JHU masses & SFRs

OSSY emission lines



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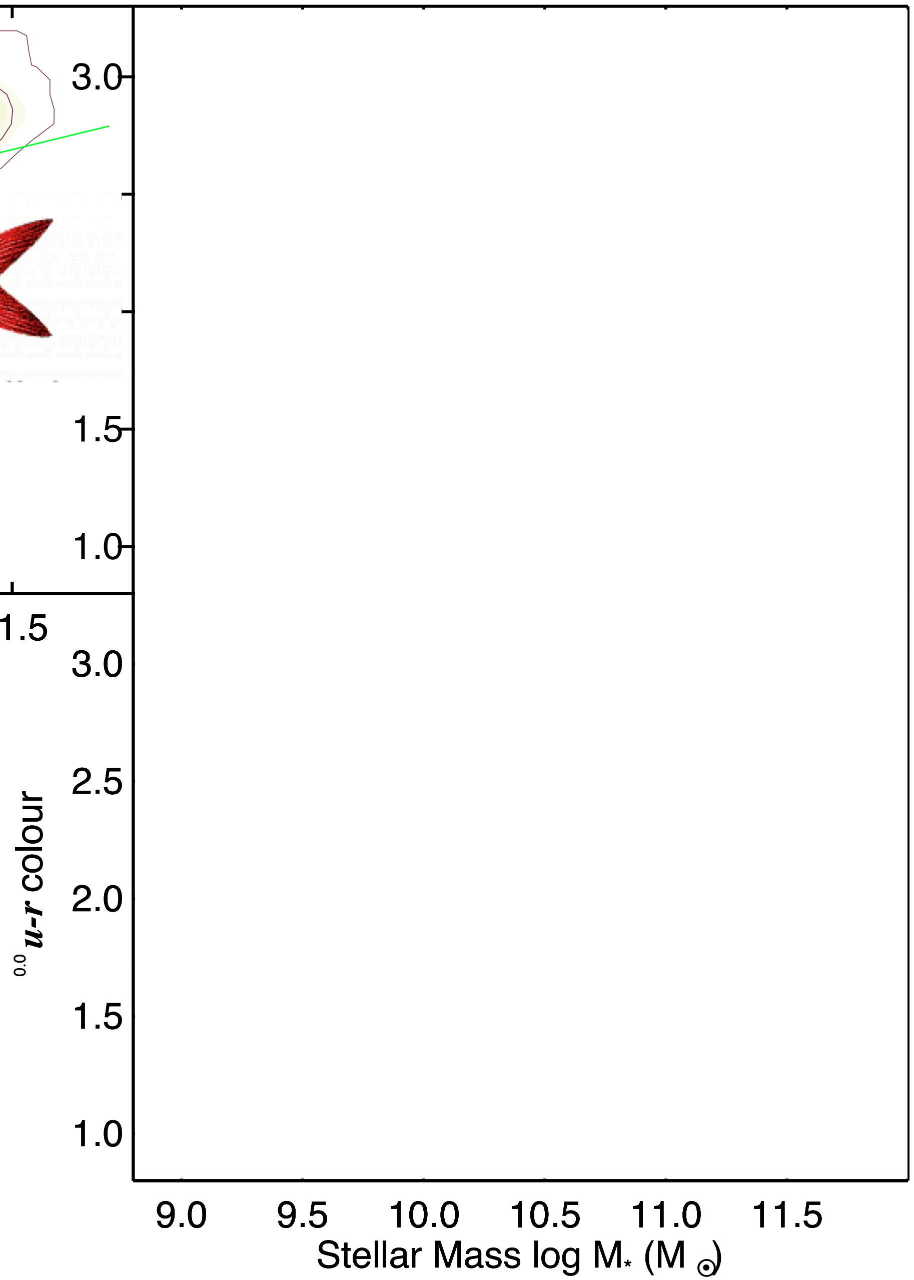
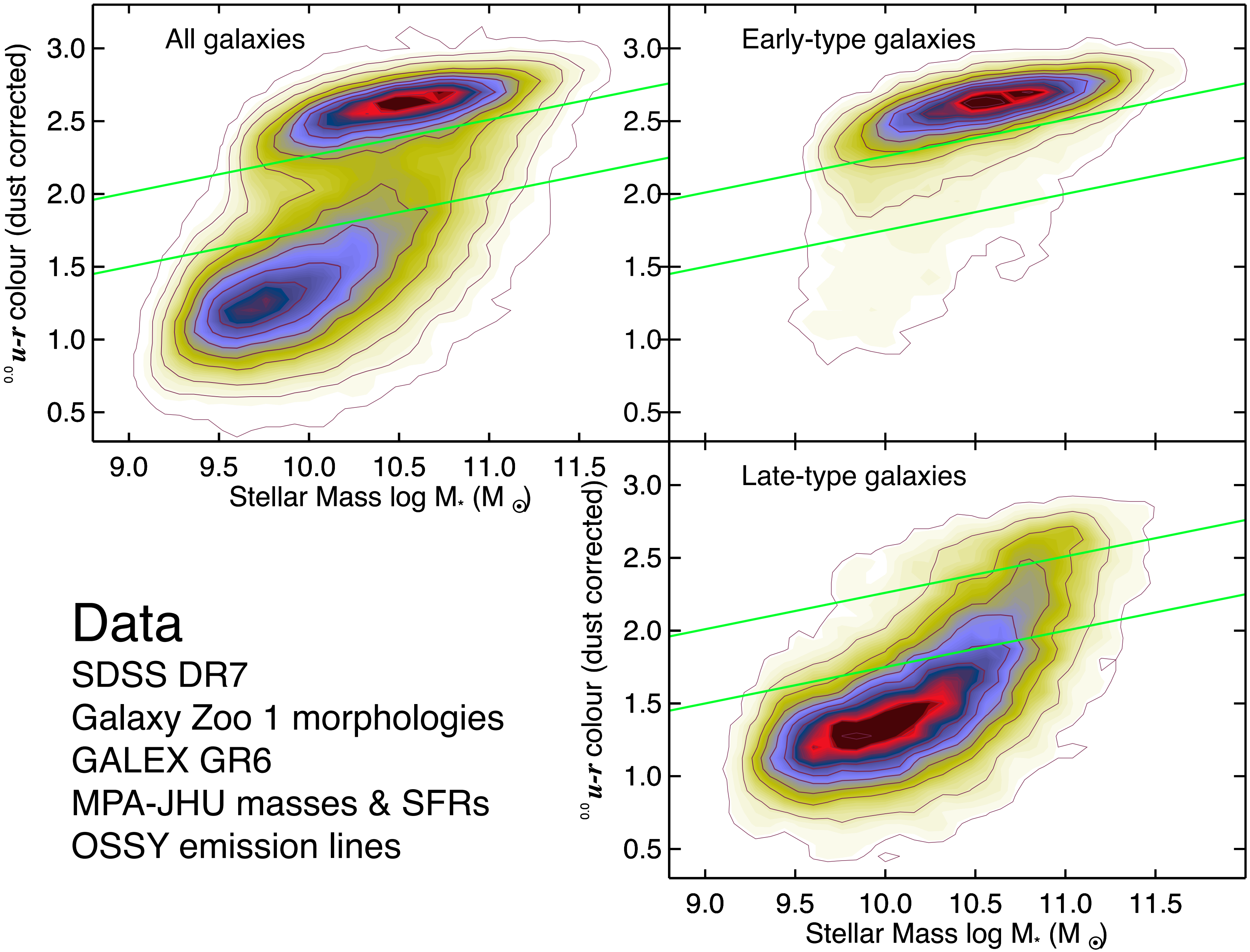


dust-corrected colours!



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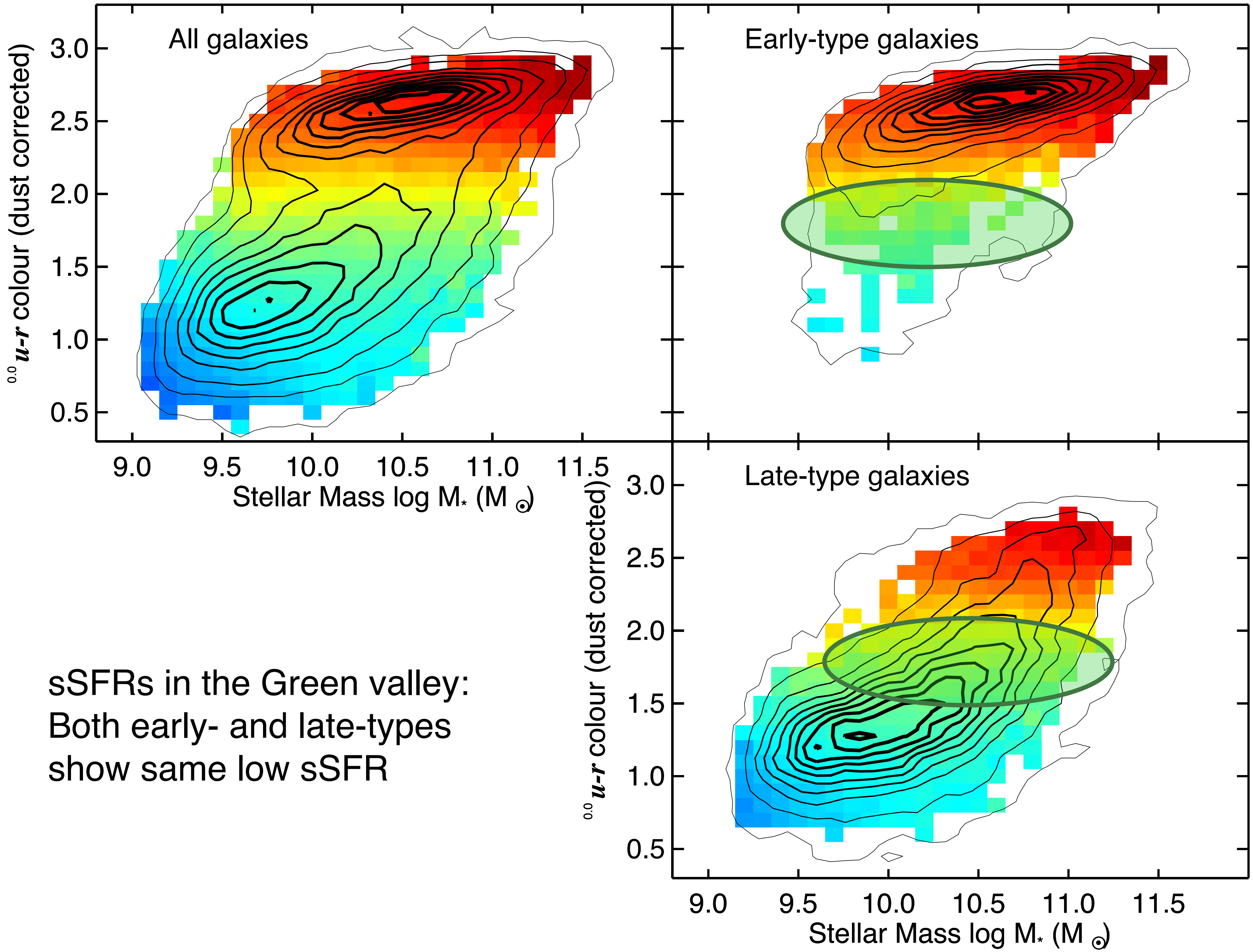
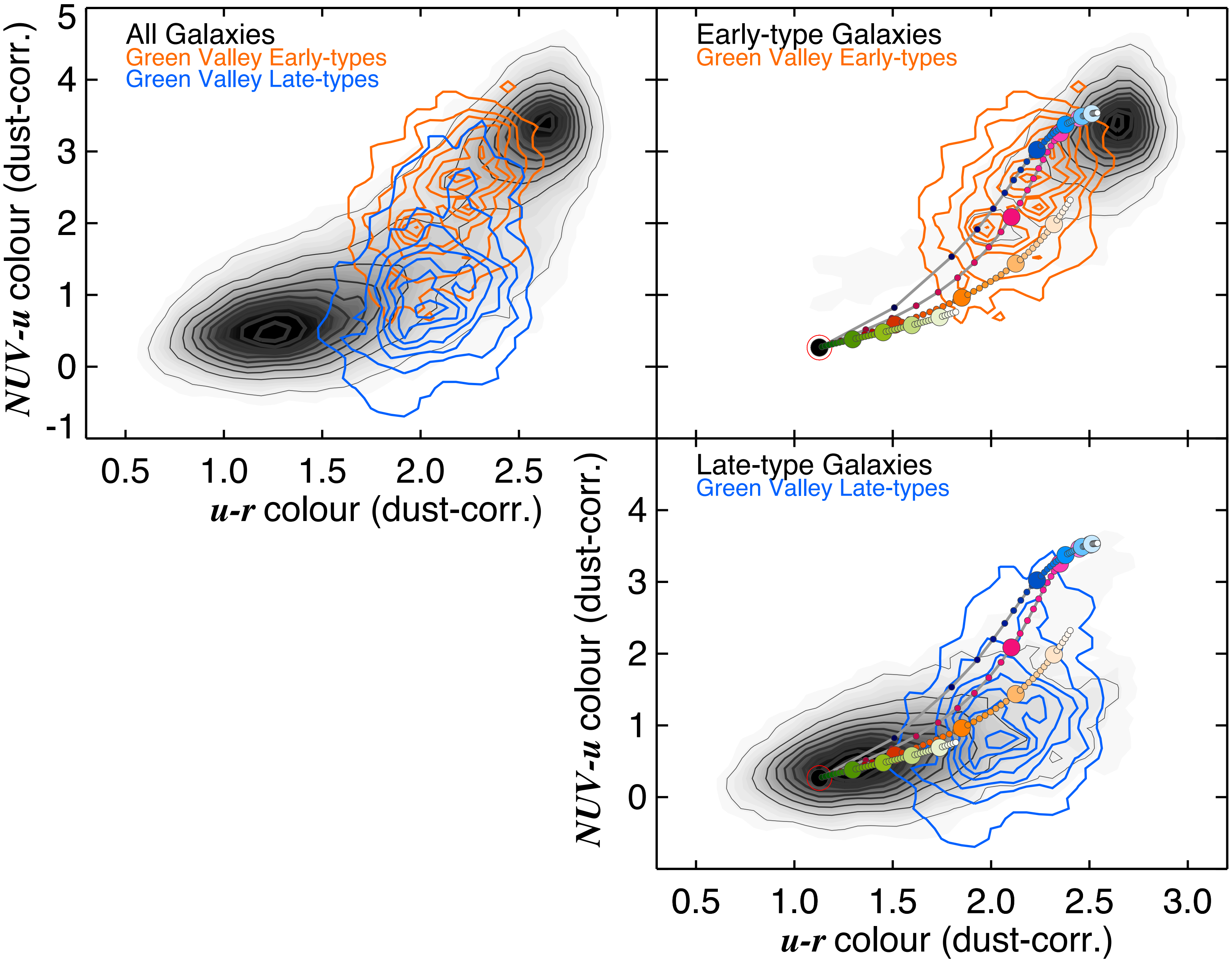


sSFRs in the Green valley:
Both early- and late-types
show same low sSFR

Measure* d/dt sSFR(t) of green valley galaxies

* really, broadly constrain for now

UV-optical colours constrain d/dt sSFR(t)



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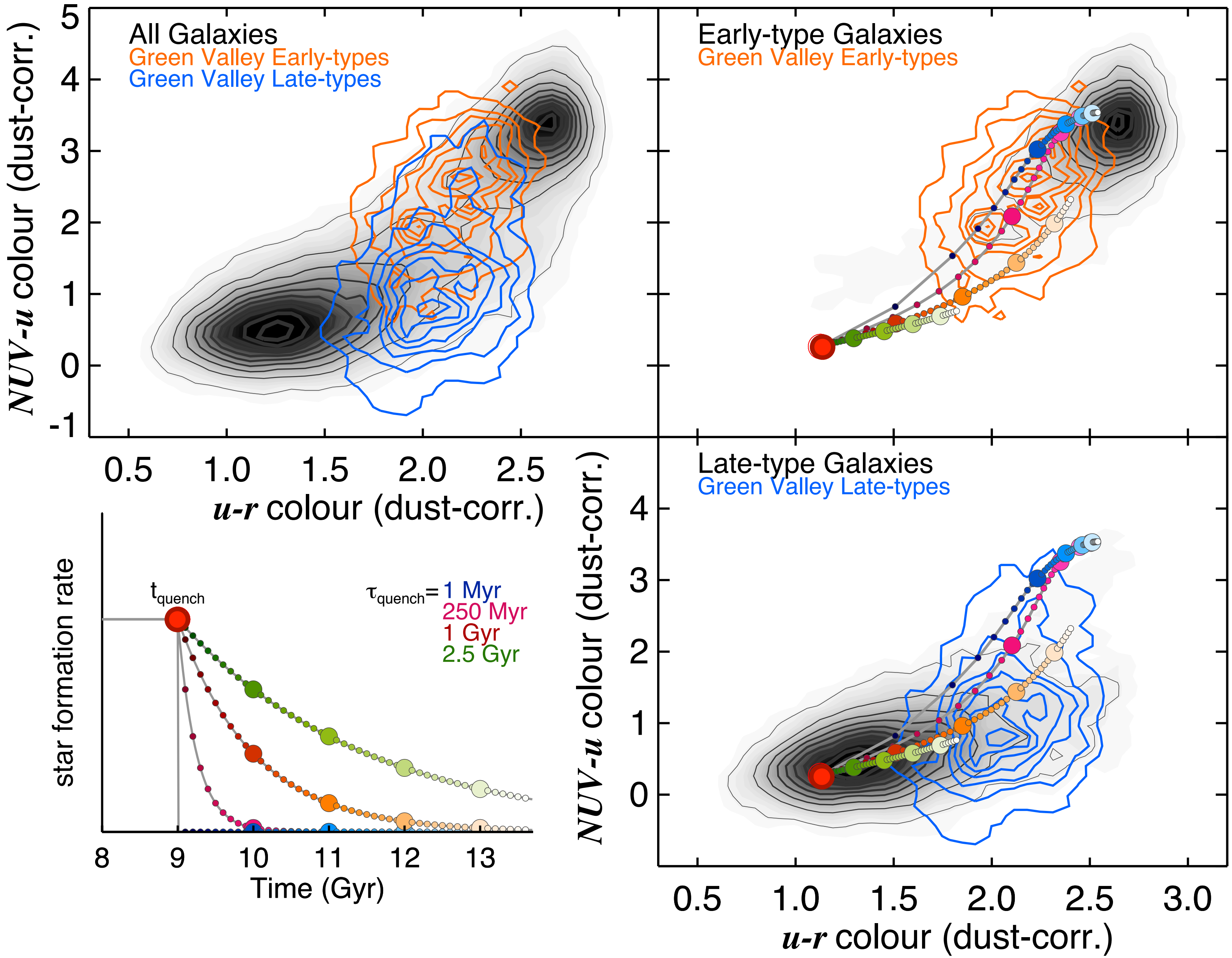

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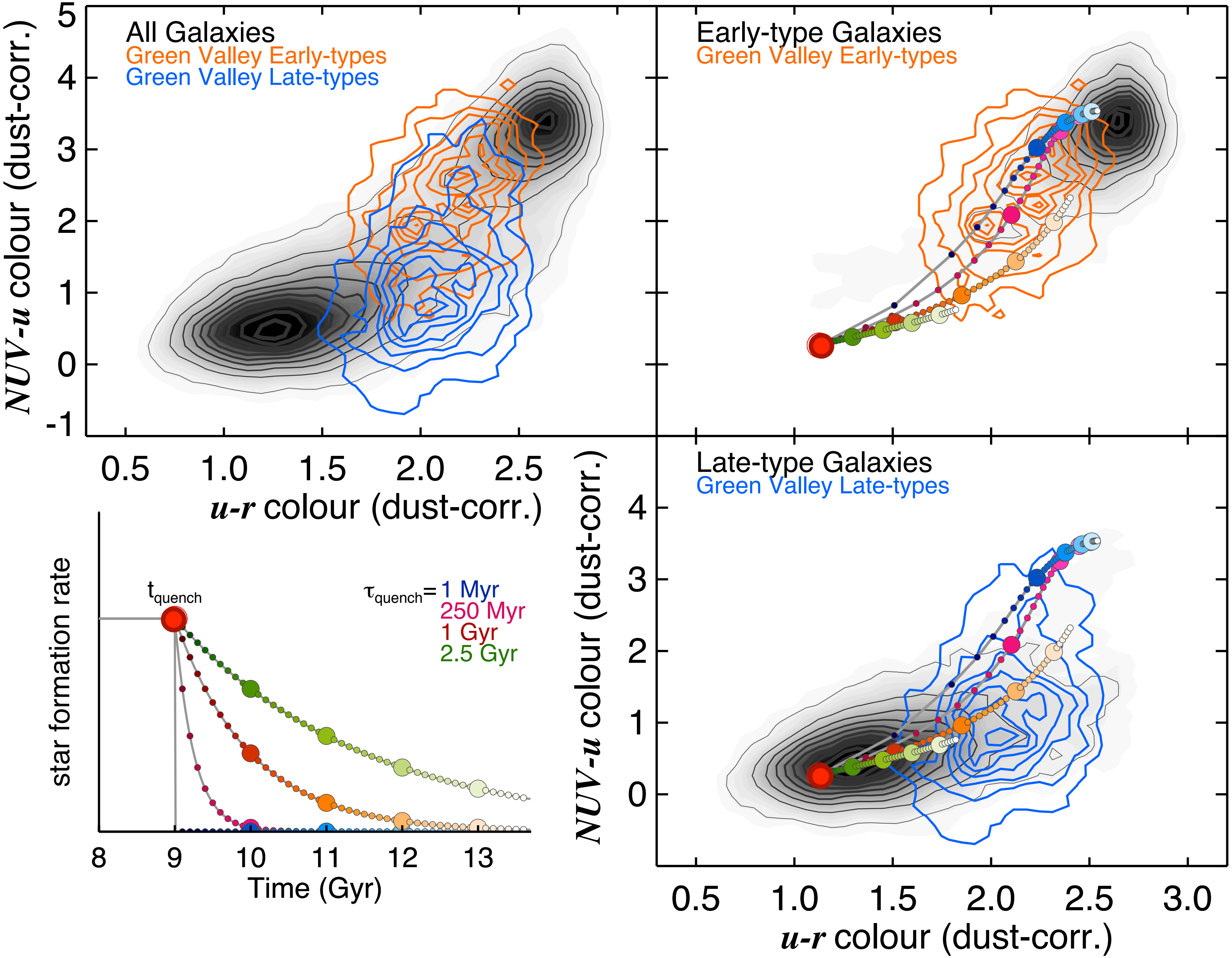
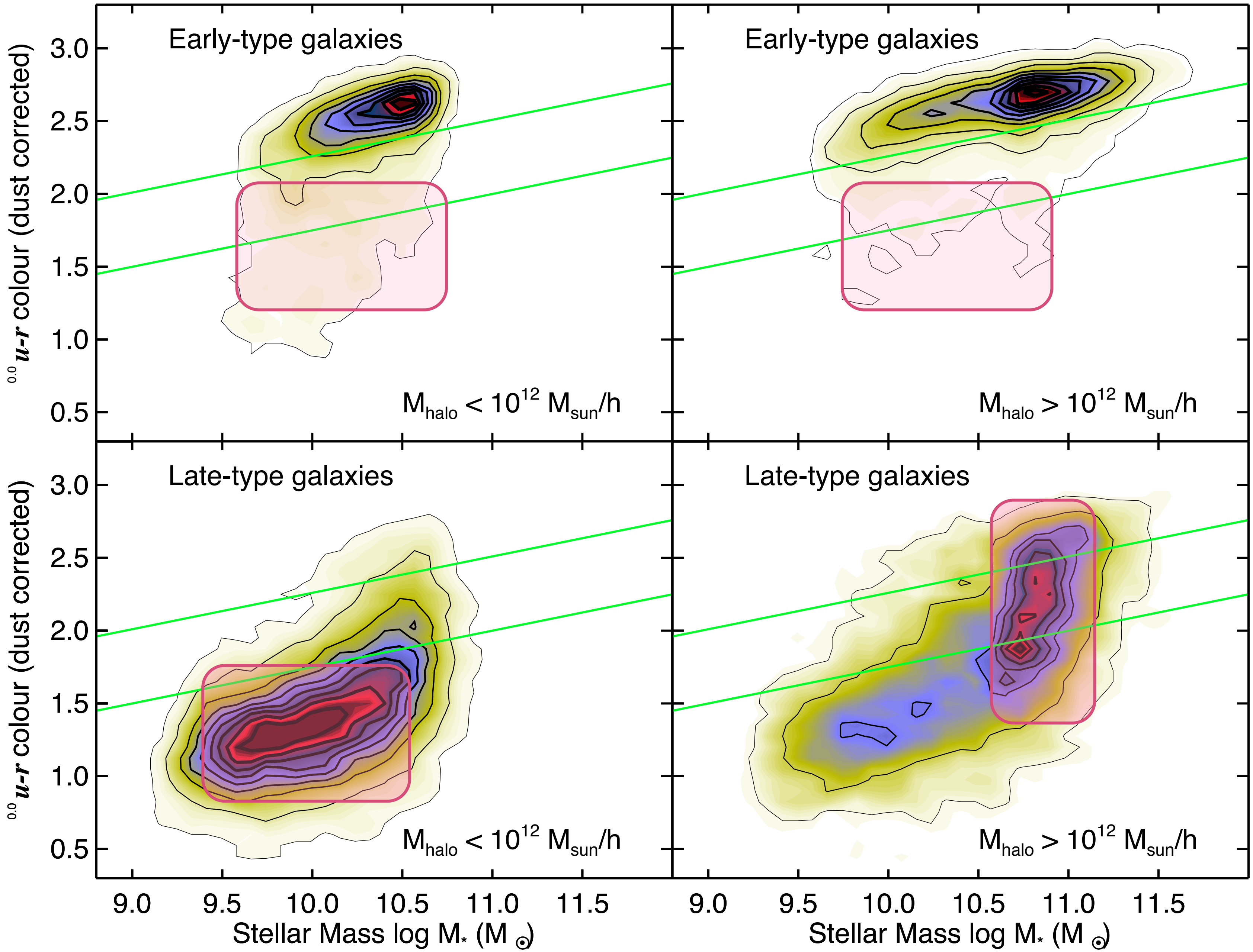


What about environment?

(quick detour)

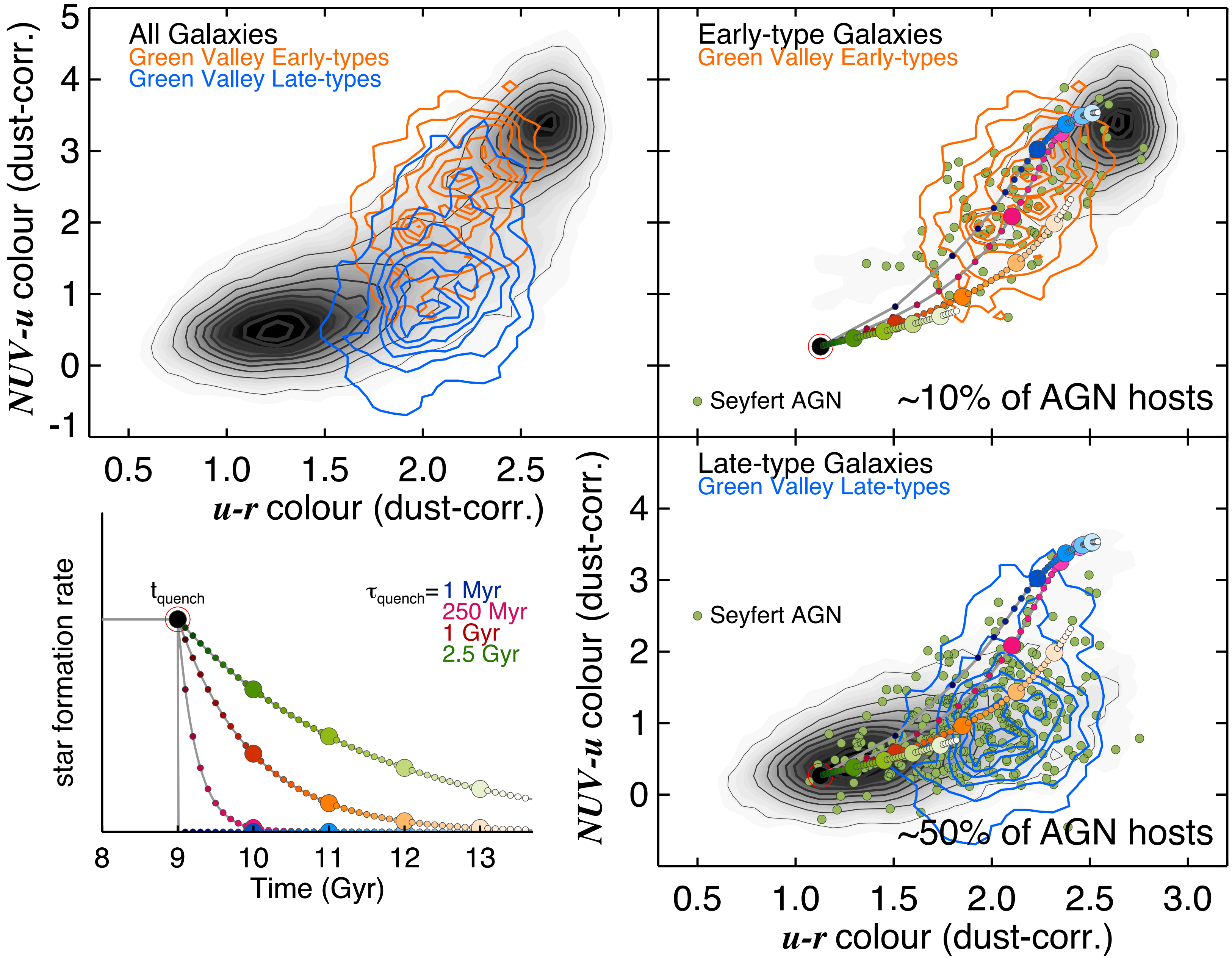
Environment



Halo masses from DR7 catalogue of Yang+

What about AGN?
Is there feedback?

Black Hole Growth



BPT AGN classification from Oh+12

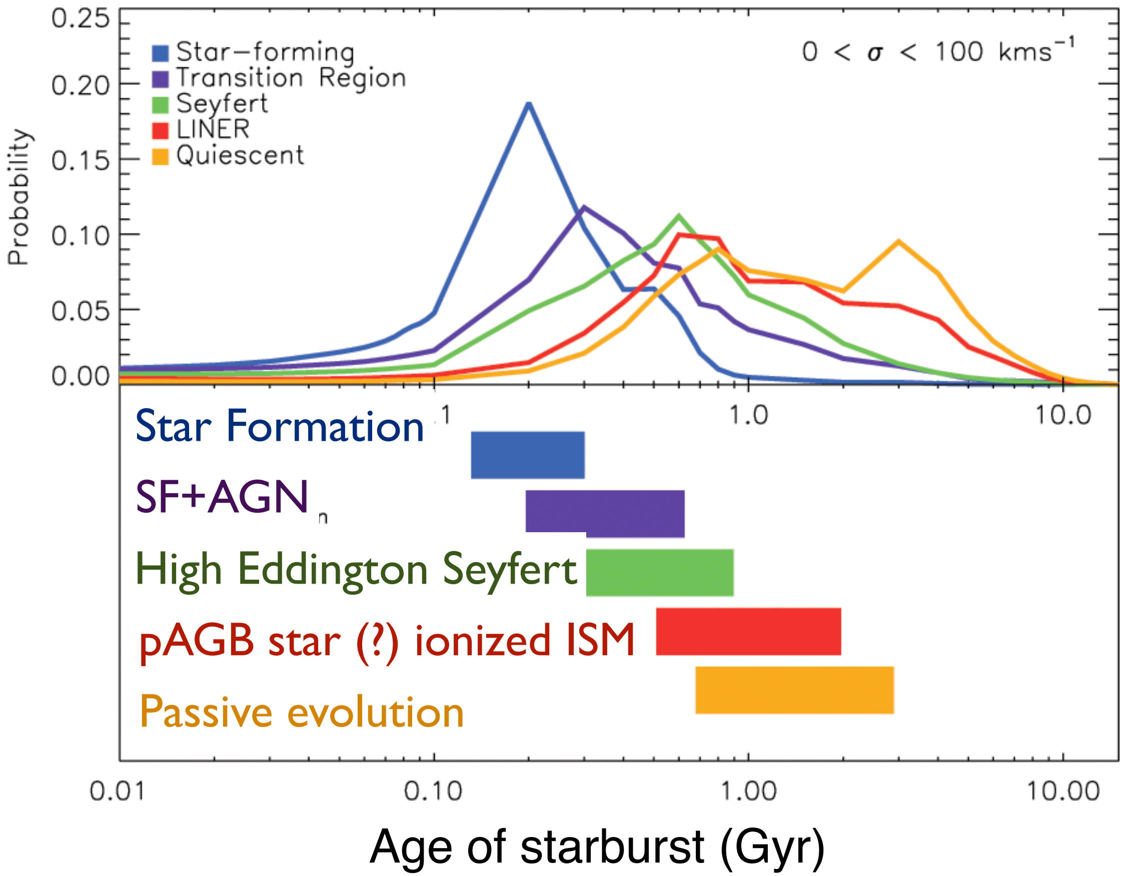
$$SFR = \varepsilon M_{gas}/\tau_{dyn}$$

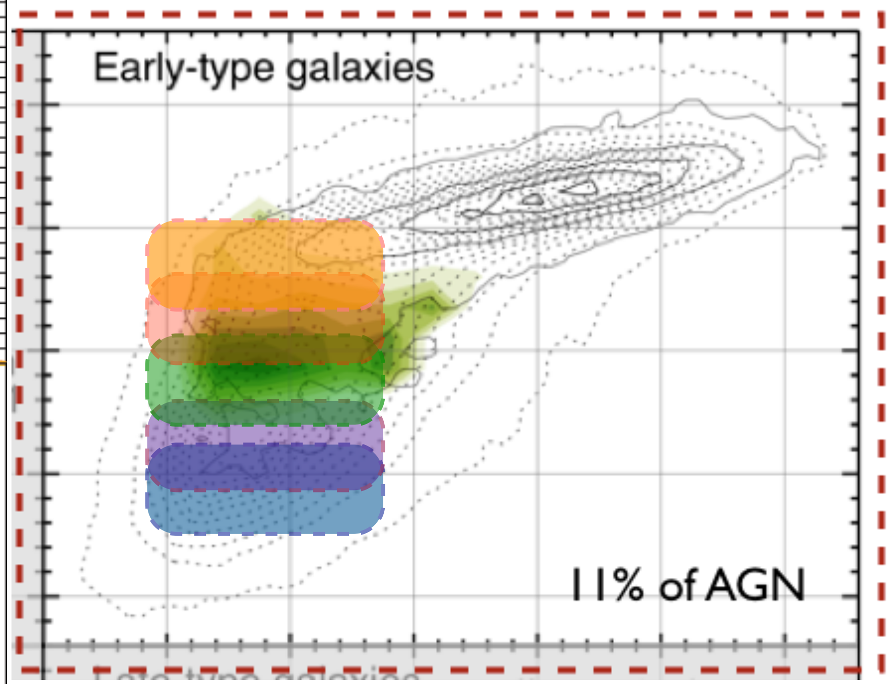
> SFR(t) ~ exponential

$\varepsilon \sim 2\%$
$\tau_{dyn} \sim$ few 100 Myr
(see Kaviraj+10!)

SDSS reveals an evolutionary sequence:

Low-mass early-types migrate to the red sequence

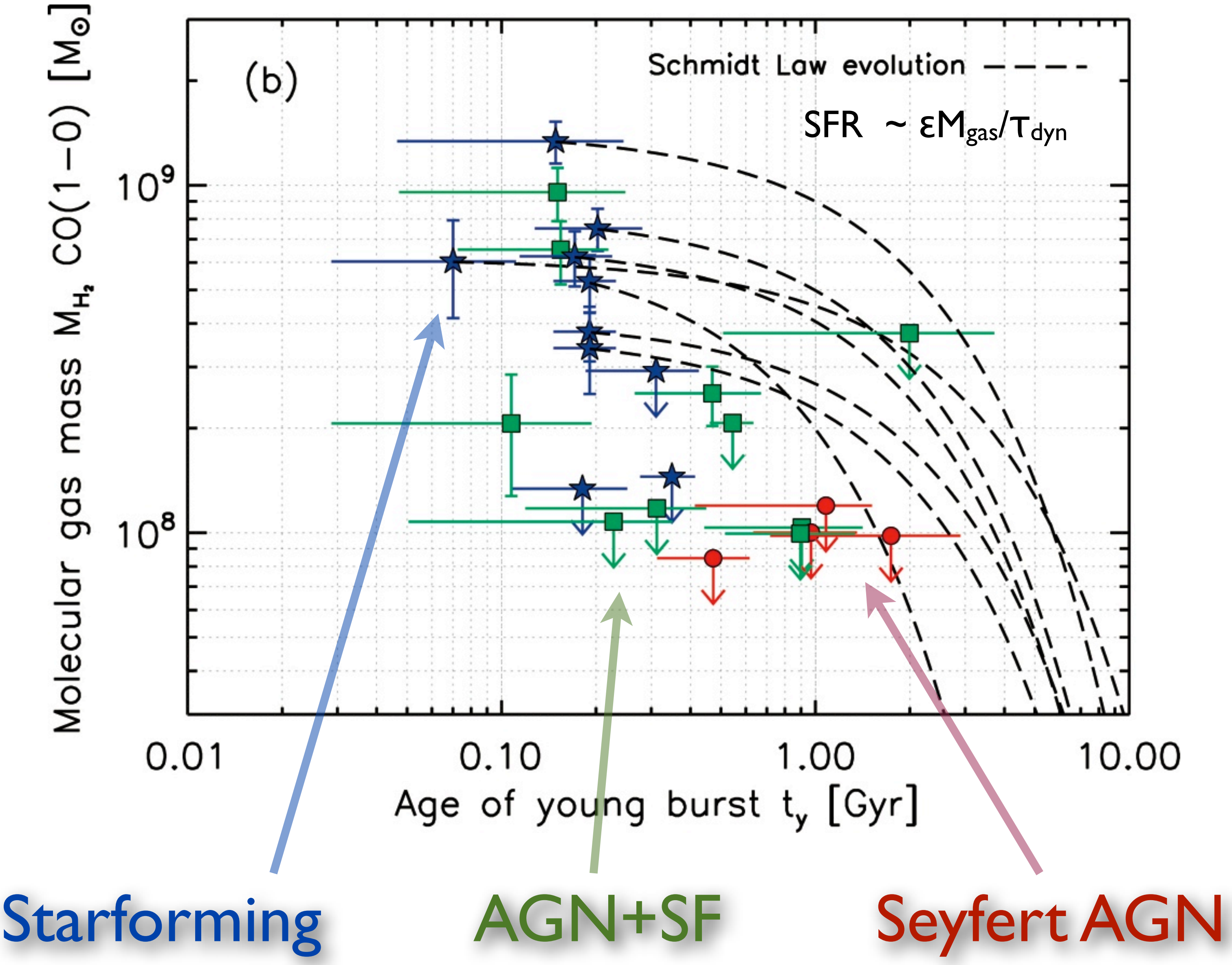




Schawinski+07

Input: GALEX+SDSS+2MASS photometry, SDSS spectroscopy (Lick indices)
Result: **1-10% of stellar mass** formed in most recent burst; leads to **rapid quenching** on ~100 Myr timescale and **migration to red sequence**

Deviations from the Schmidt Law: Clues to Feedback



Schawinski+09a, Kaviraj, Schawinski, Silk & Shabala 2010

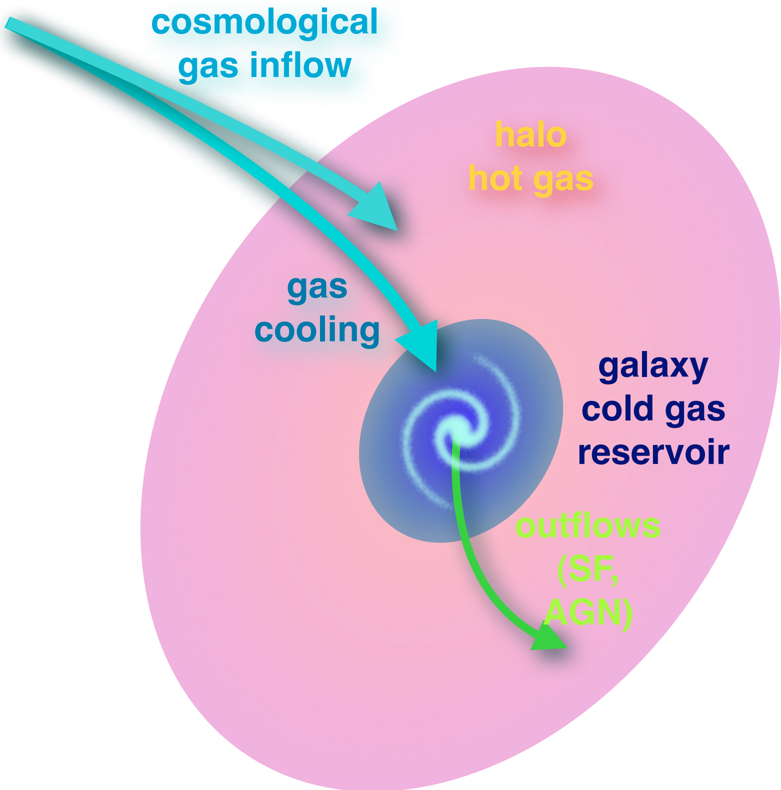
Can we model* these two quenching pathways?

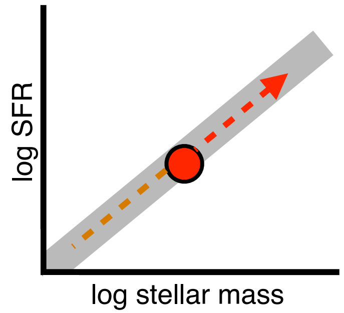
* really, very roughly

1. Late-type galaxies

Late-type galaxies quench star formation slowly

(1) prior to t_{quench}





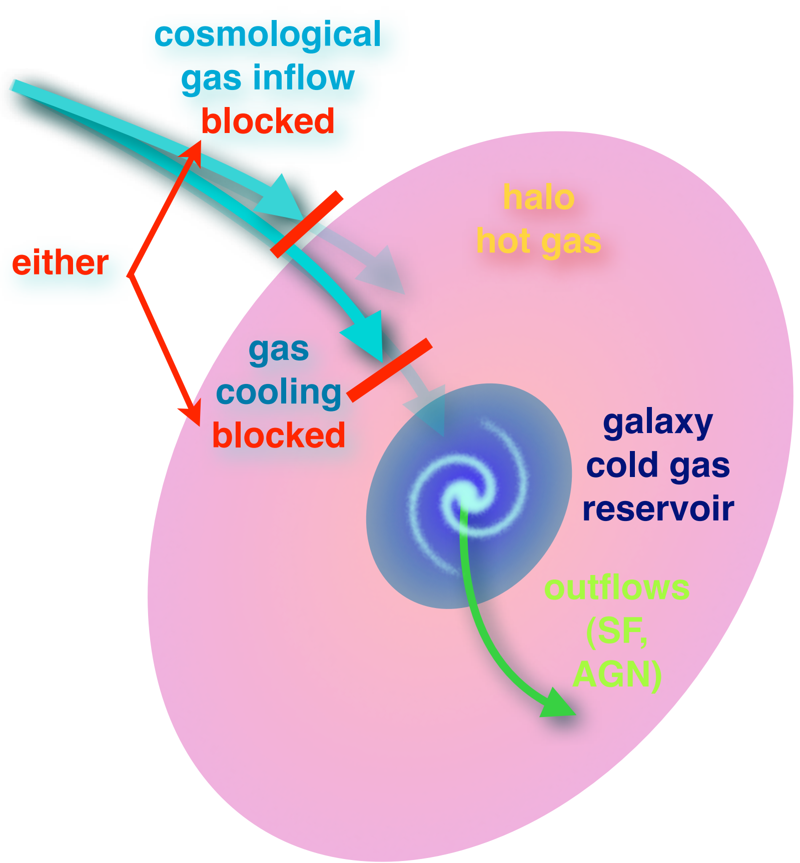
Galaxy is on main sequence
$M_{stellar} \sim SFR^{\beta}$

Inflows balance outflows:
system in quasi-equilibrium
(Bouche+10; Lilly+13)

could correspond to classical environmental mechanisms (strangulation, harassment, starvartion).

Late-type galaxies quench star formation slowly

(2) t=tquench



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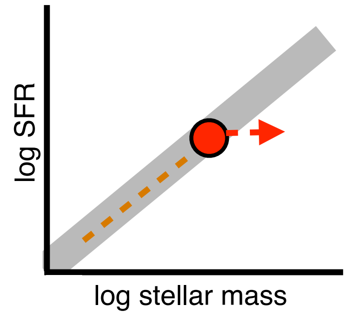


Either cosmological inflows or cooling from halo are stopped, galaxy gas reservoir is now no longer replenished

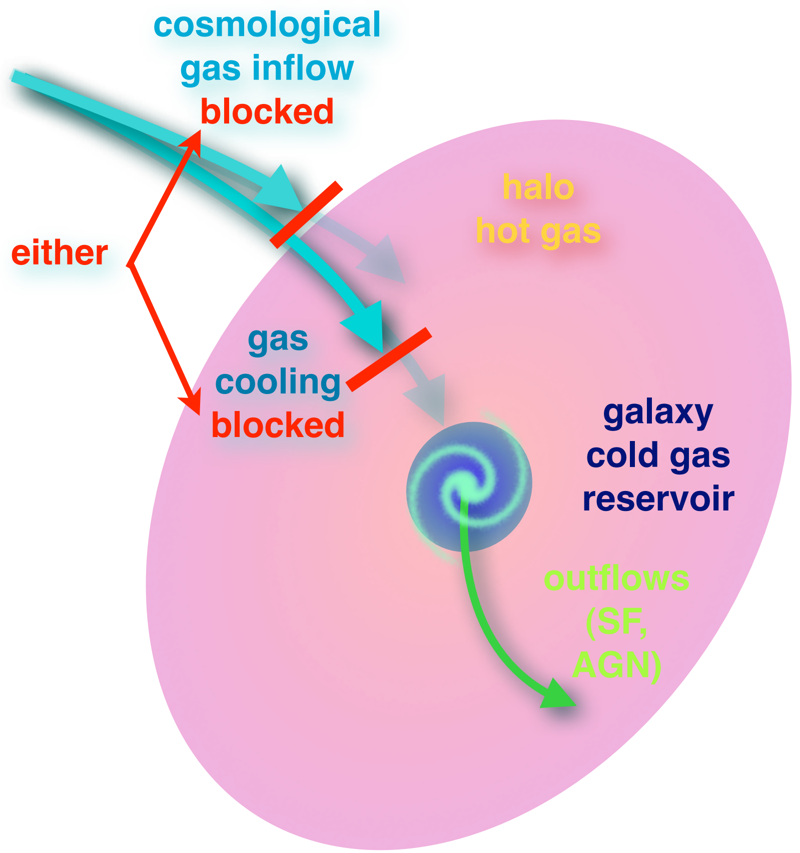
Galaxy leaves main sequence

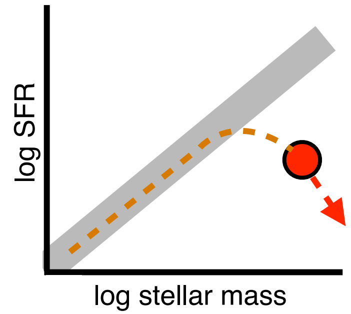
SFR = $\varepsilon M_{gas}/\tau_{dyn}$

> SFR(t) ~ exponential

Late-type galaxies quench star formation slowly

(3) several 100-1000 Myr past tquench





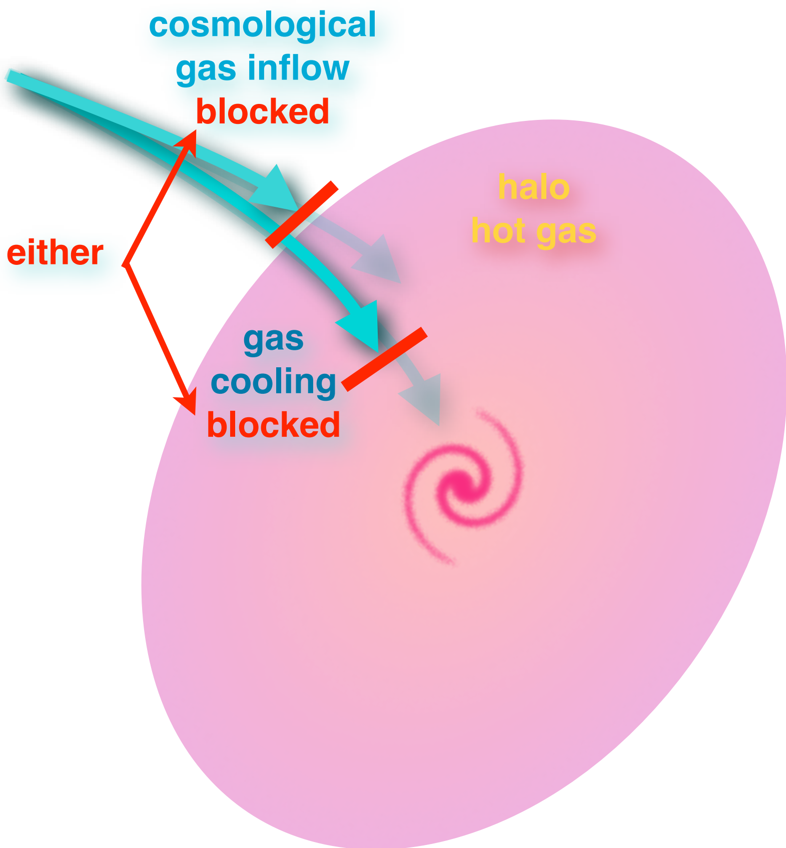
SFR goes into exponential decline, galaxy enters green valley

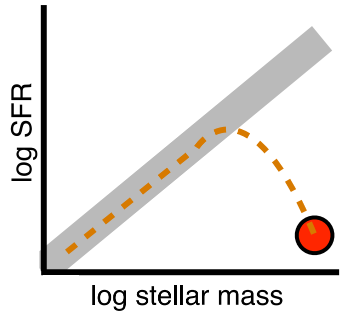
Gas reservoir is slowly used up

could correspond to classical environmental mechanisms (strangulation, harassment, starvartion).

Late-type galaxies quench star formation slowly

(4) several Gyr past tquench





Several Gyr later...

Passive, red spiral galaxy

No morphological transform-
ation > "red spiral"

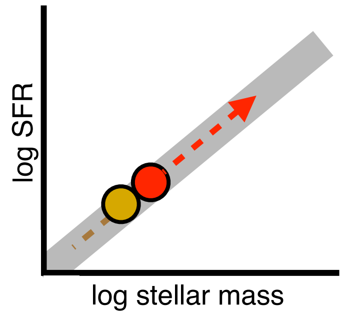
Very low SSFR

could correspond to classical environmental mechanisms (strangulation, harassment, starvartion).

2. Early-type galaxies

Early-type galaxies quench star formation rapidly

(1) ~100s Myr prior to t_{quench}

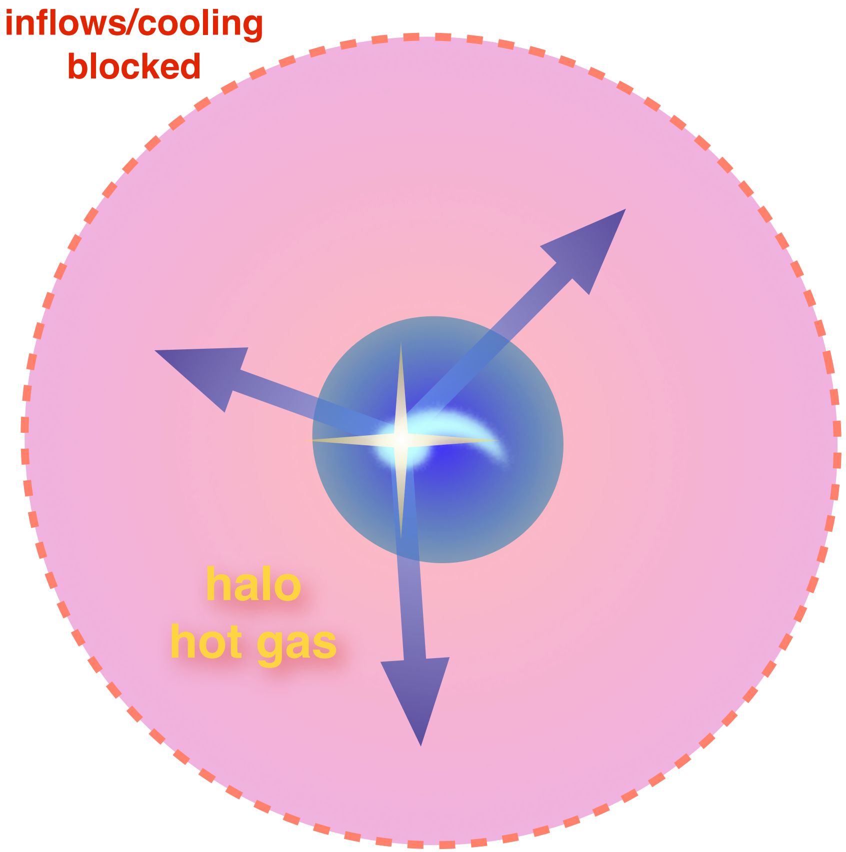


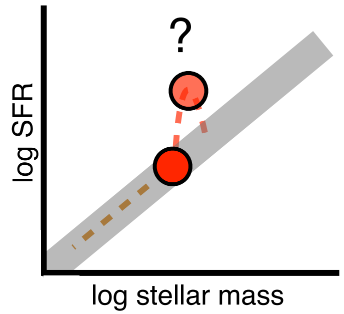
Two galaxies on main sequence are about to merge

Both bring in gas reservoir and are connected to cosmic gas inflow

Early-type galaxies quench star formation rapidly

(2) t_{quench}



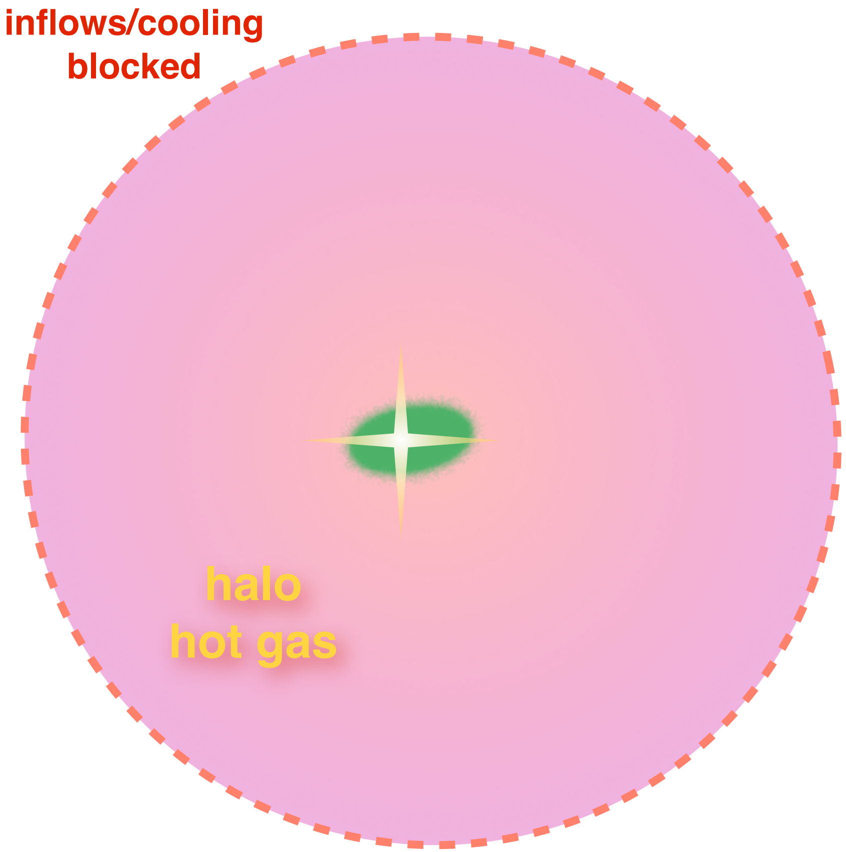


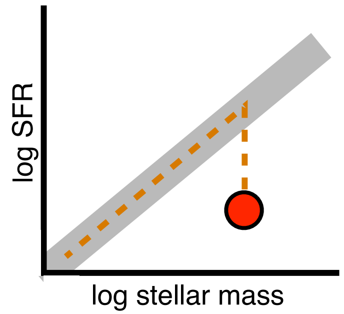
Merger may drive SFR above main sequence, or not. Morphology is transformed to spheroid

Some process drives outflows of gas to rapidly deplete the cold gas reservoir, perhaps AGN feedback?
SFR ≠ εMgas/τdyn
Further cosmological inflows and/or cooling stopped

Early-type galaxies quench star formation rapidly

(3) ~100s Myr post t_{quench}





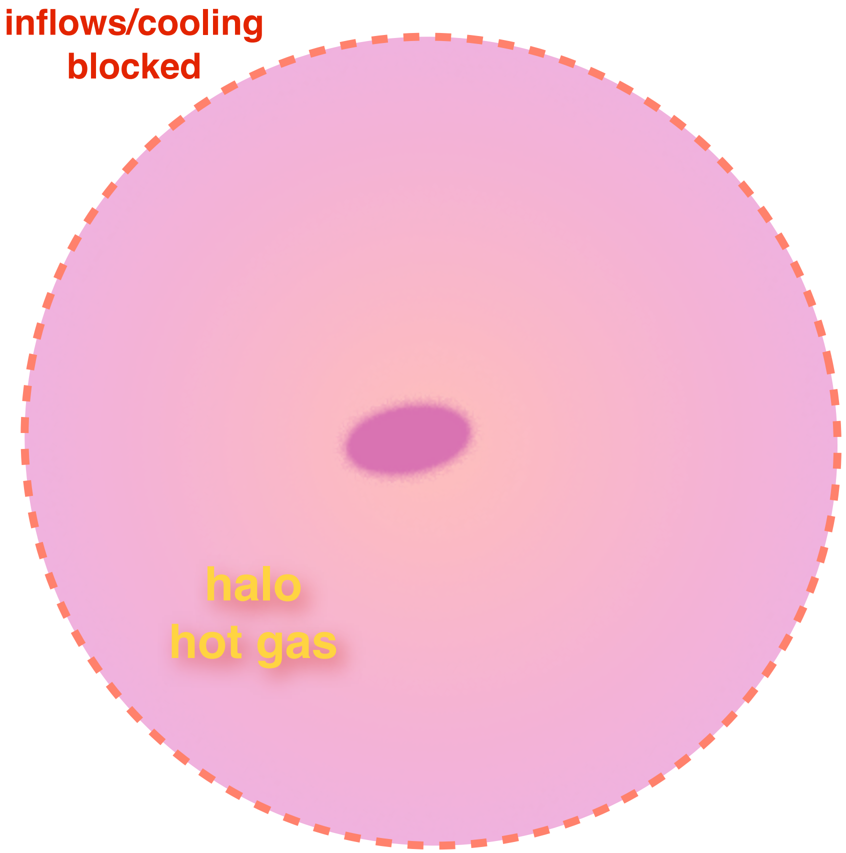
SFR drops rapidly to zero, galaxy moves to green valley

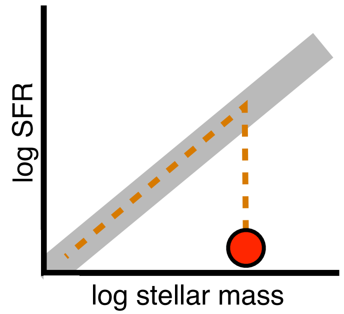
Gas reservoir is destroyed, further inflows not allowed to replenish

AGN active

Early-type galaxies quench star formation rapidly

(4) ~1-2 Gyr post t_{quench}





With no gas reservoir and no further gas inflows, new early-type becomes passive red sequence galaxy.

Summary

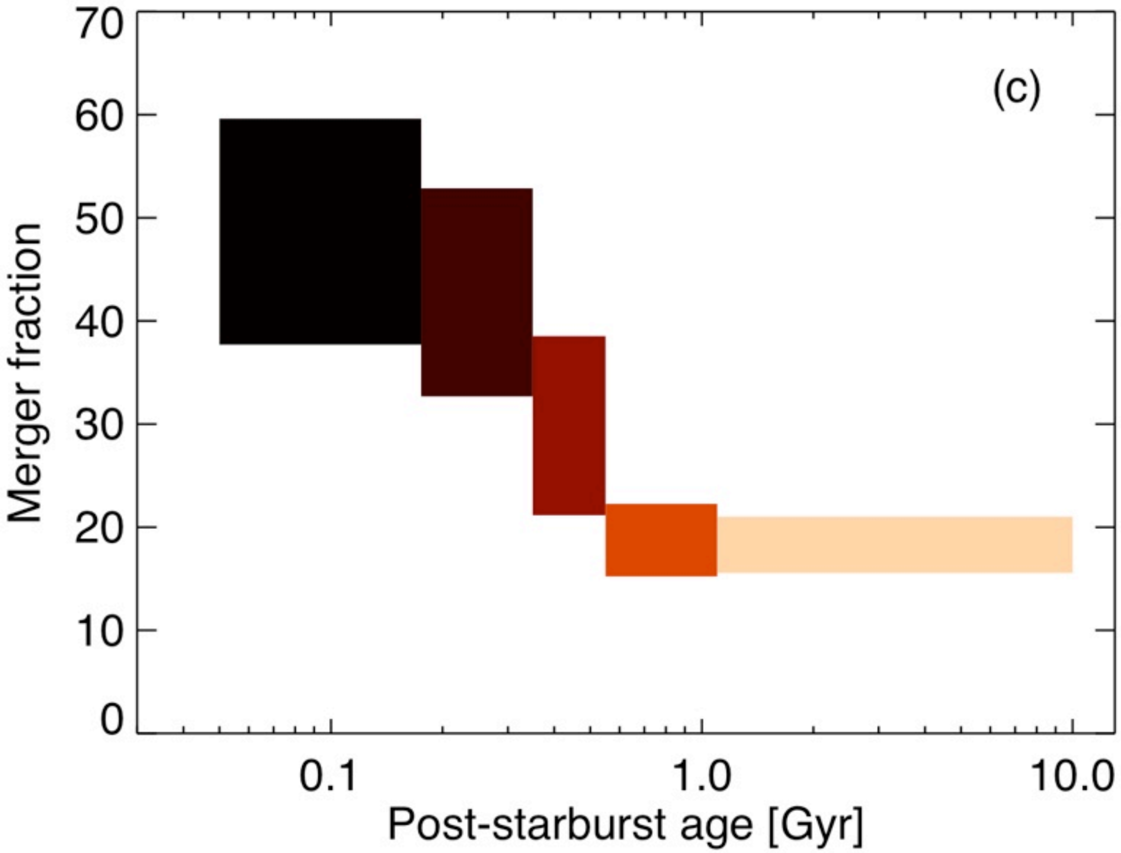
sSFR + UV/optical colours show **two different quenching pathways** though green valley associated with early- and late-type galaxies

Late-type galaxies **quench slowly, without changing morphology** (d/dt sSFR small) due to an external process that stops further inflow/cooling of gas; *could correspond to classical environmental mechanisms*.

Early-type galaxies **quench rapidly, during or after merger-driven change of morphology** (d/dt sSFR large) due to an internal process that destroys the gas reservoir, possibly *AGN feedback*?

@kevinschawinski

Mergers trigger the migration from the blue cloud to the red sequence



Schawinski+10