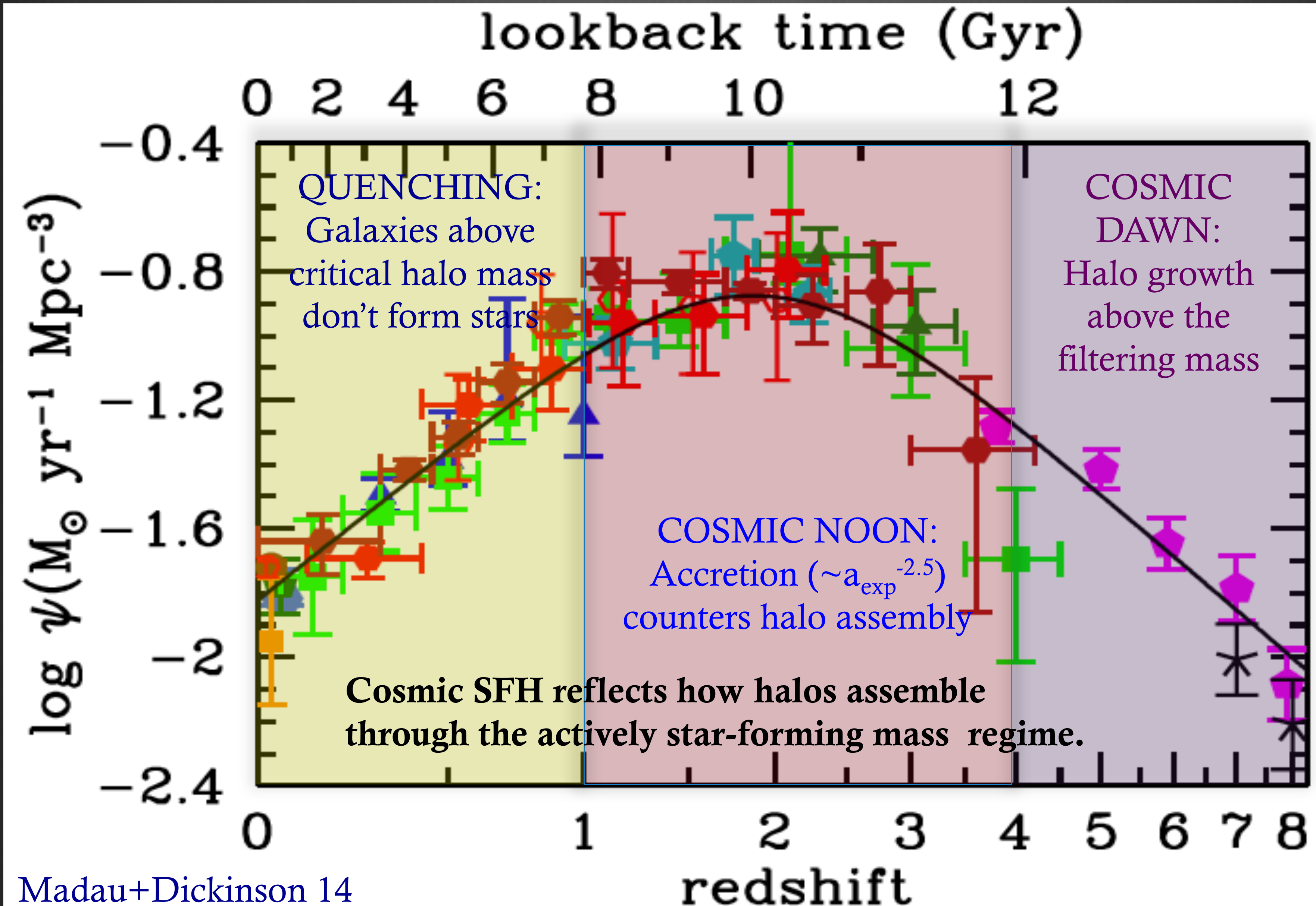
Models for the Cosmic Evolution of Star Formation in Galaxies

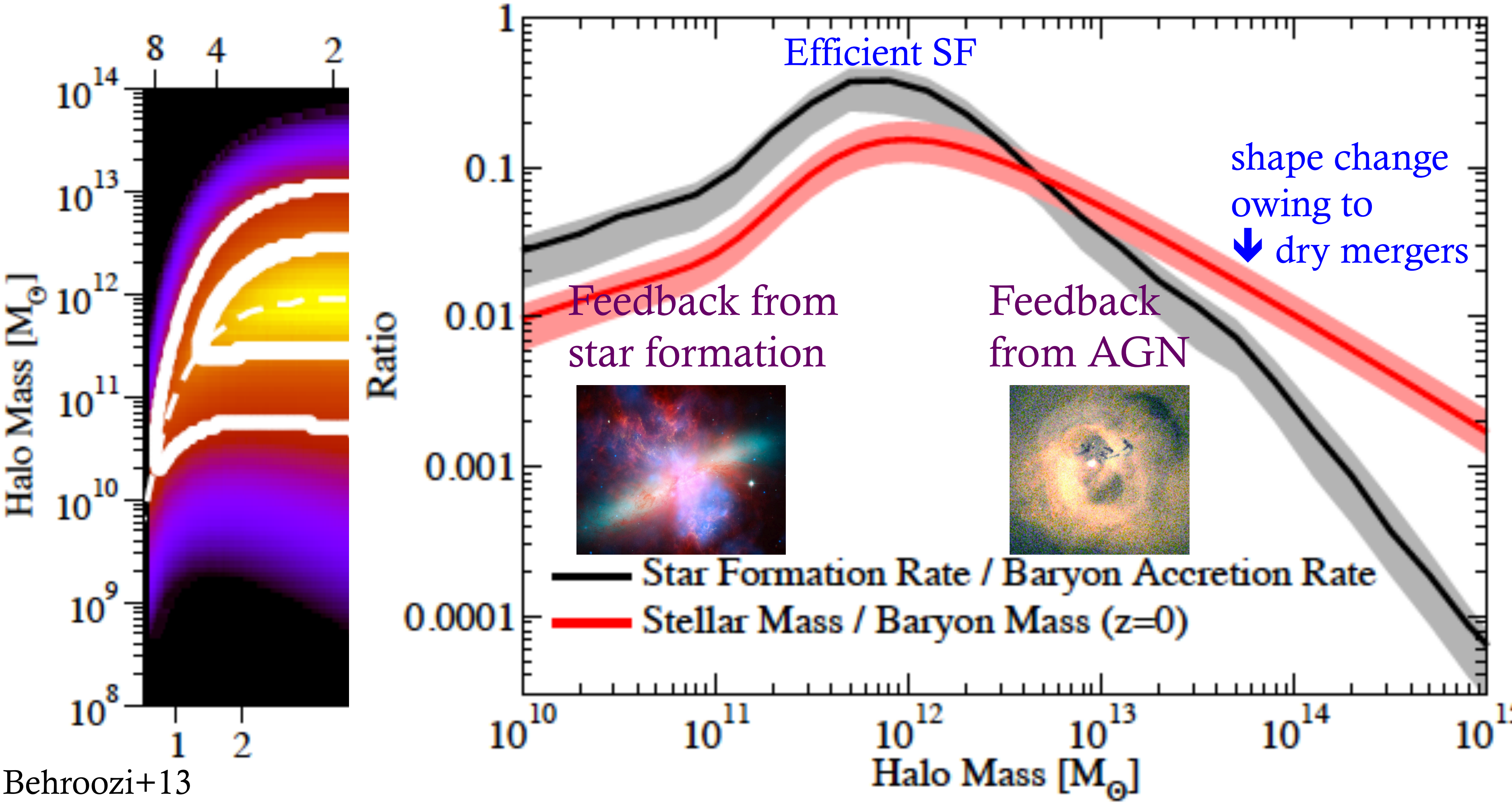
Romeel Davé (Edinburgh)

with: Sourav Mitra, Kristian Finlator, Robert Thompson, Mika Rafieferantsoa

Cosmic SFRD in ΛCDM



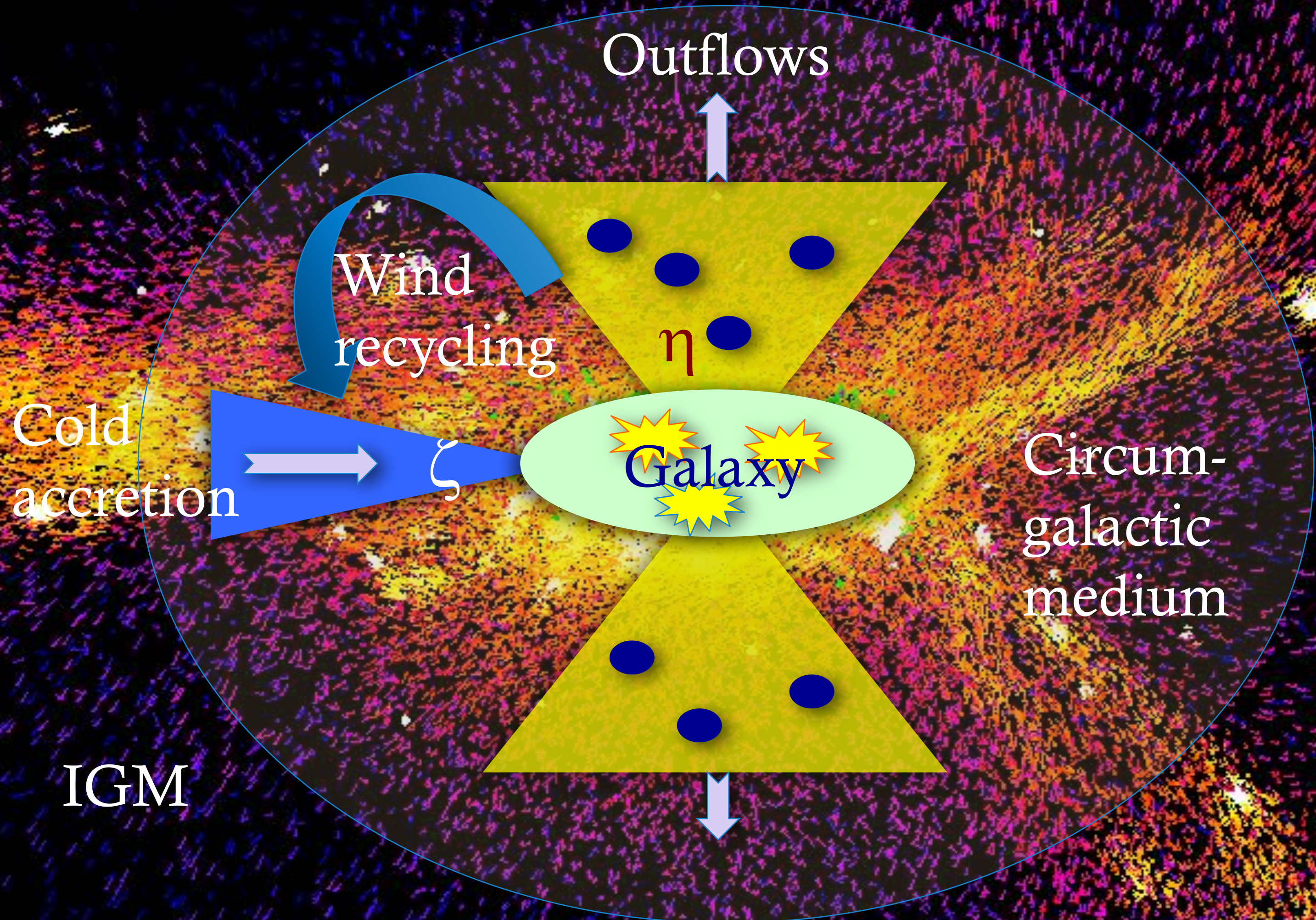
Halo mass range for active SF



Behroozi+13

What is the physics that picks out this mass range?

Growing galaxies via the baryon cycle



define: η = outflow rate / SFR

ζ = Fraction of inflow at R_{vir} that gets into ISM

t_{rec} = typical time for outflow to recycle into ISM

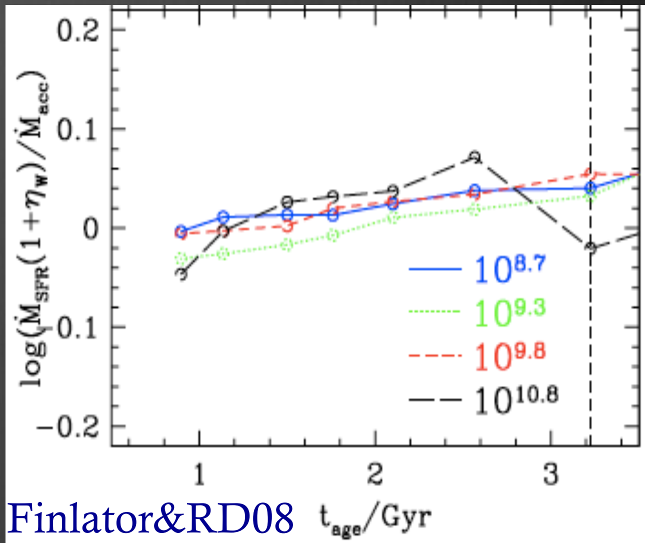
Keres+05

The Equilibrium Model

Inflow = SFR + Outflow + $\underbrace{\text{dReservoir/dt}}_{\approx 0 \text{ (equilibrium)}}$

Finlator,RD 08
RD+12
Mitra+14

- SFR = $(\zeta\, \dot{M}_{grav} + \dot{M}_{recyc})/(1+\eta)$
- $Z = y\, \mathrm{SFR} \,/\, \zeta\, \dot{M}_{grav}$
- $f_{gas} = (t_{dep}\, \mathrm{sSFR})$



Finlator&RD08

$$\frac{\dot{M}_{\cancel{in}\,grav}}{M_{\rm halo}} = 0.47 f_b \left(\frac{M_{\rm halo}}{10^{12} M_\odot}\right)^{0.15} \left(\frac{1+z}{3}\right)^{2.25} \mathrm{Gyr}^{-1}$$

Dekel+09

Baryon cycling parameters

- *Ejective feedback*
  η = Outflow/SFR
- *Preventive feedback*
  $\zeta = \dot{M}_{ISM}/\dot{M}_{gas,halo}$
- *Wind recycling time*
  t_{rec} = time for outflow to return.

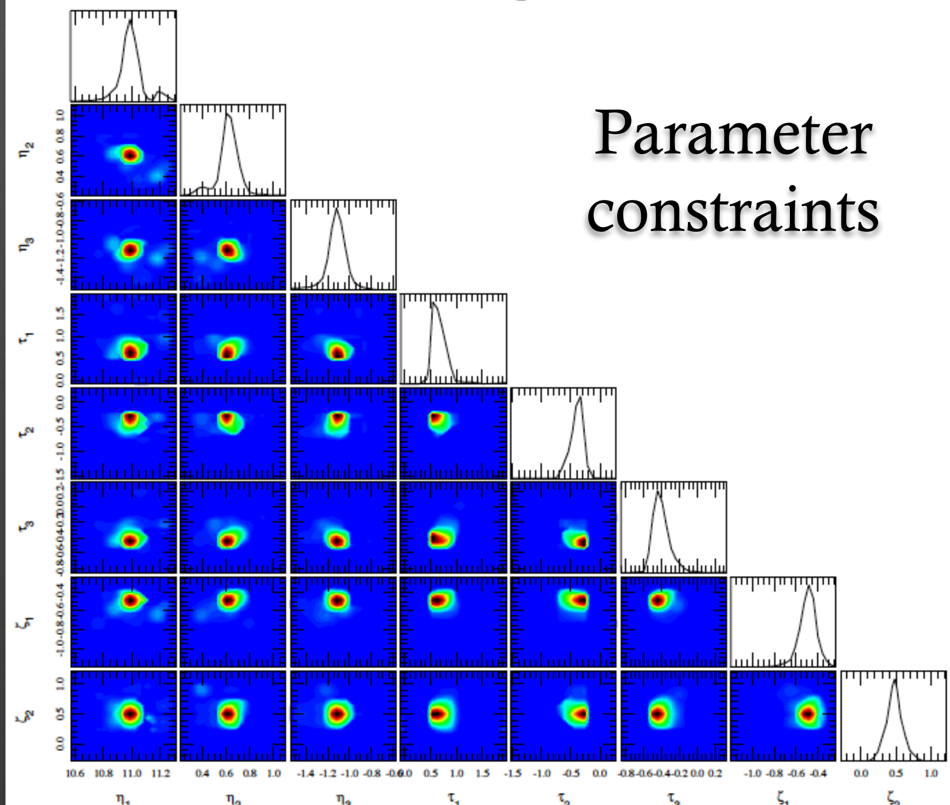
Each depends on M_{halo}, z: 8 free parameters (after model selection).

$$\eta = \left(\frac{M_h}{10^{10.98+0.62\sqrt{z}}}\right)^{-1.16},$$

$$t_{\rm rec} = 0.52\times10^9{\rm yr}\times(1+z)^{-0.32}\left(\frac{M_h}{10^{12}}\right)^{-0.45}$$

$$\zeta_{\rm quench} = {\rm MIN}\left[1, \left(\frac{M_h}{M_q}\right)^{-0.49}\right],$$

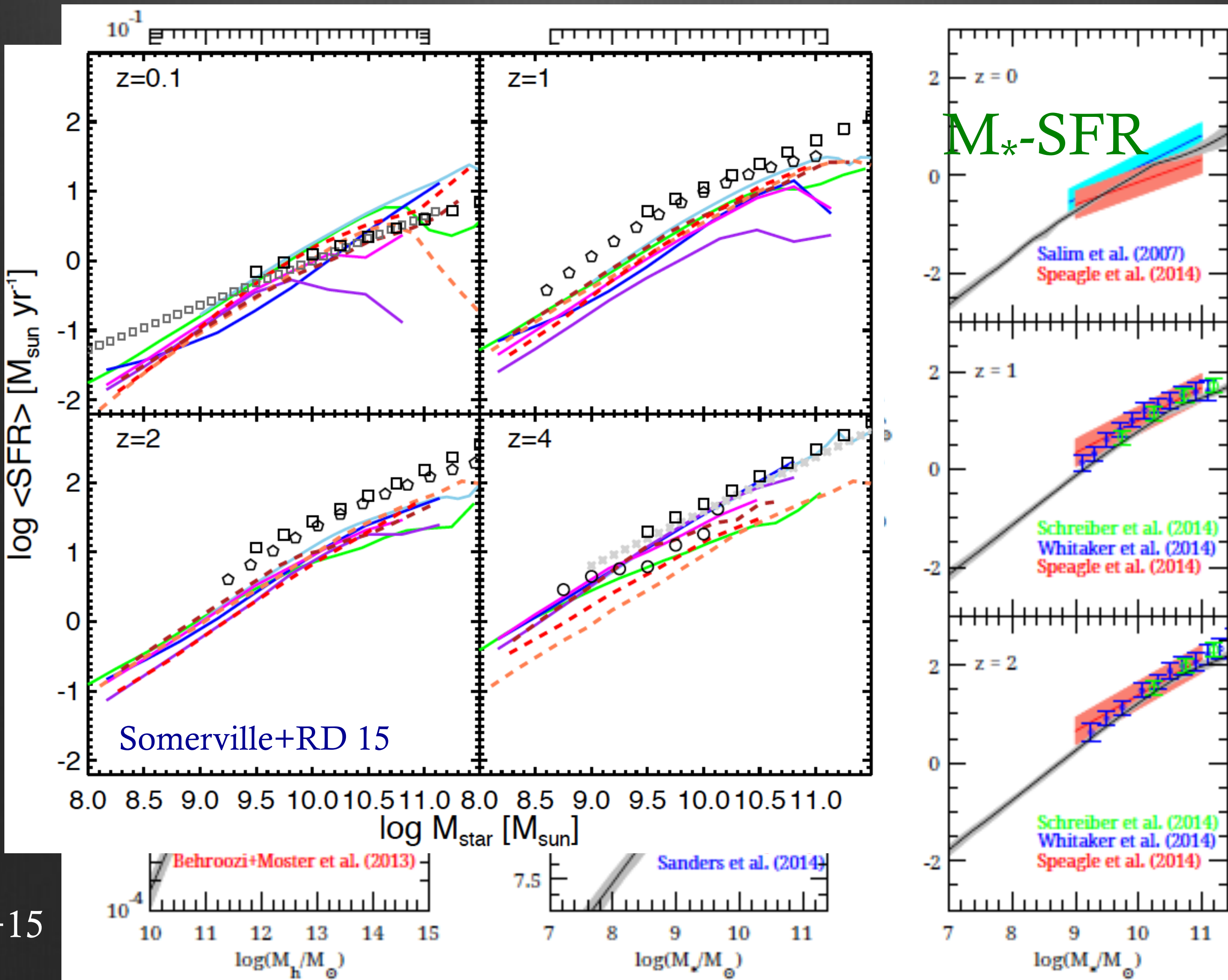
$$\text{where} \quad \frac{M_q}{10^{12}M_\odot} = (0.96+0.48z).$$



Parameter constraints

Mitra+15

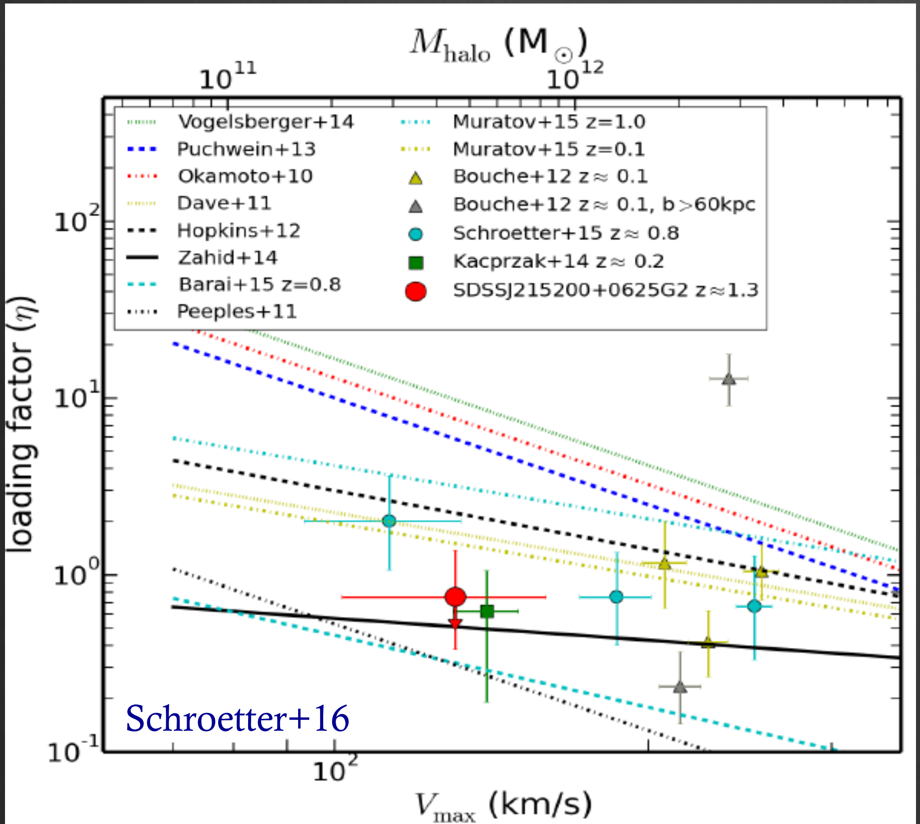
The Best-Fit Equilibrium Model ($\chi^2 \sim 1.6$)

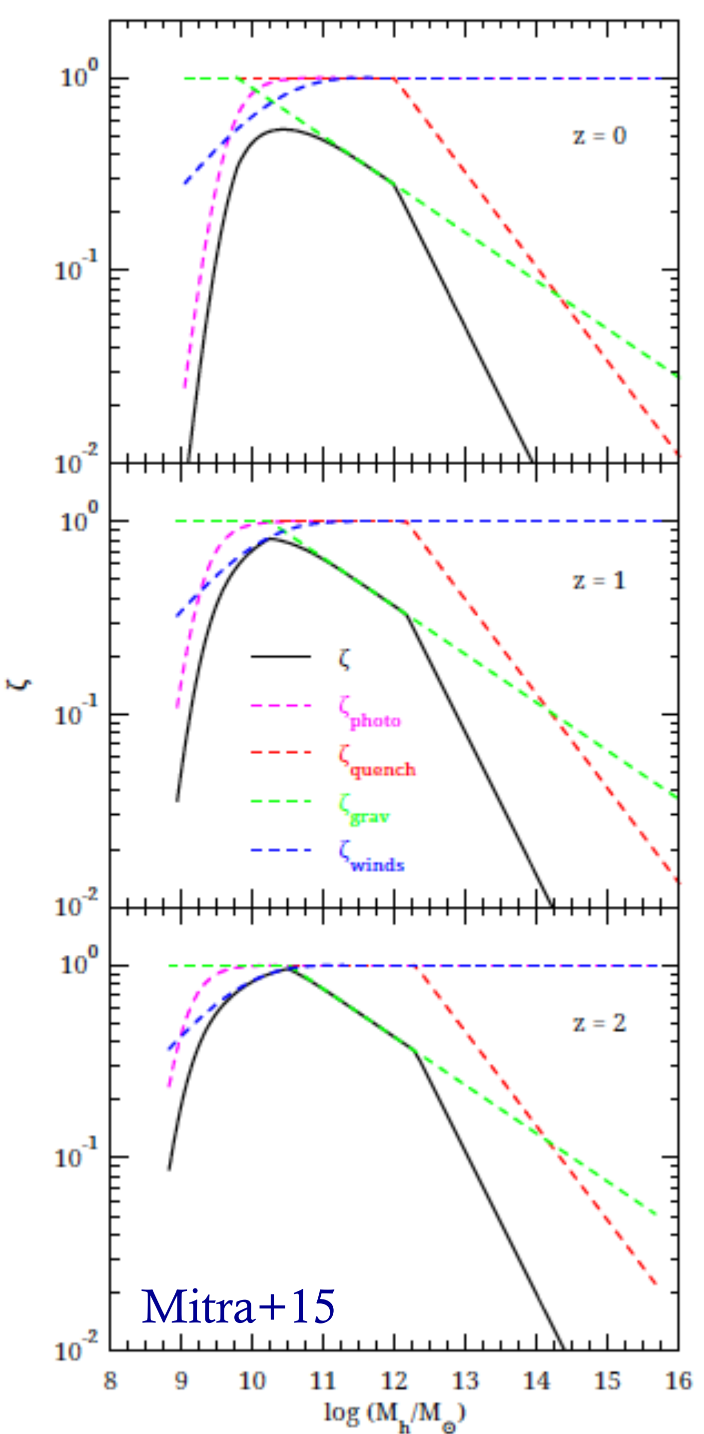


Mitra+15

Constraints on feedback

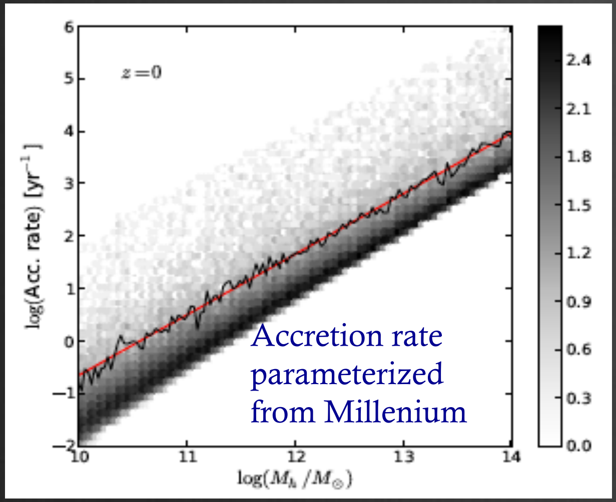
- Preventive feedback effective at $M_h<10^{10}$ and $M_h>10^{12}M_\odot$.
- Ejective feedback stronger at low mass, high redshift(?).



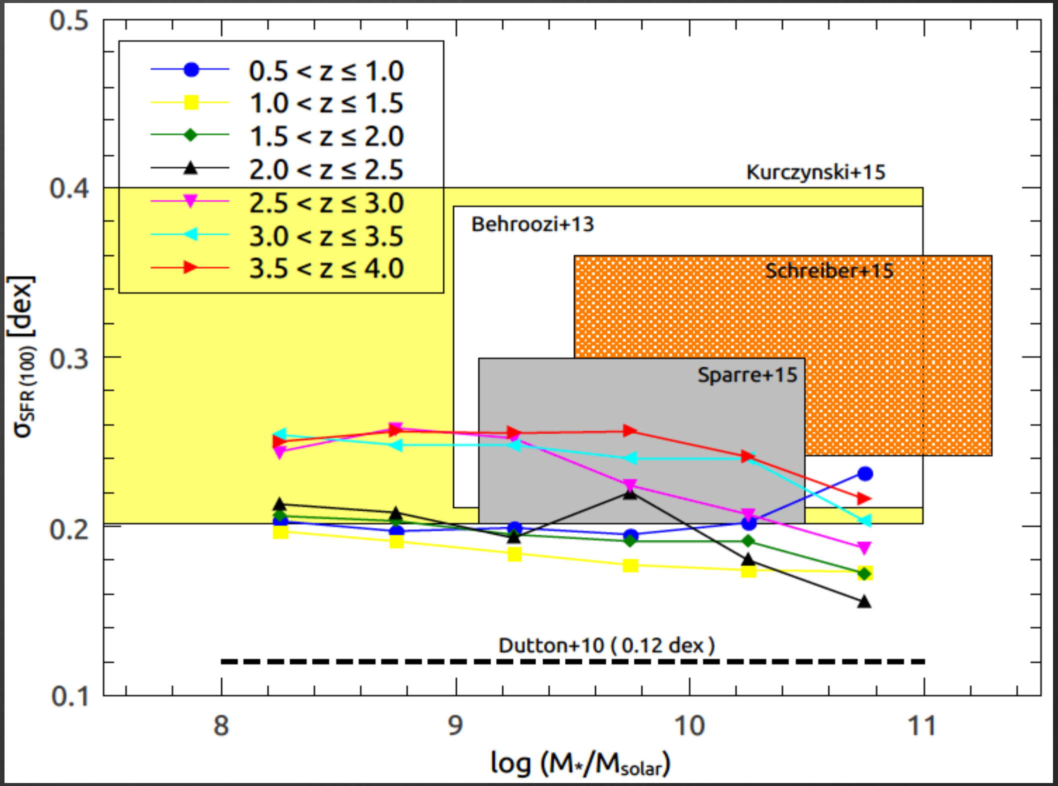


Scatter from inflow stochasticity

- If we assume scatter in halo inflow translates to scatter in SFR, then we get σ~0.2-0.25 dex, approx indep of M_* and z.
- Simulations also predict σ~0.25 dex (RD+11, Sparre+15, …), though larger at low-M* where feedback creates burstiness.

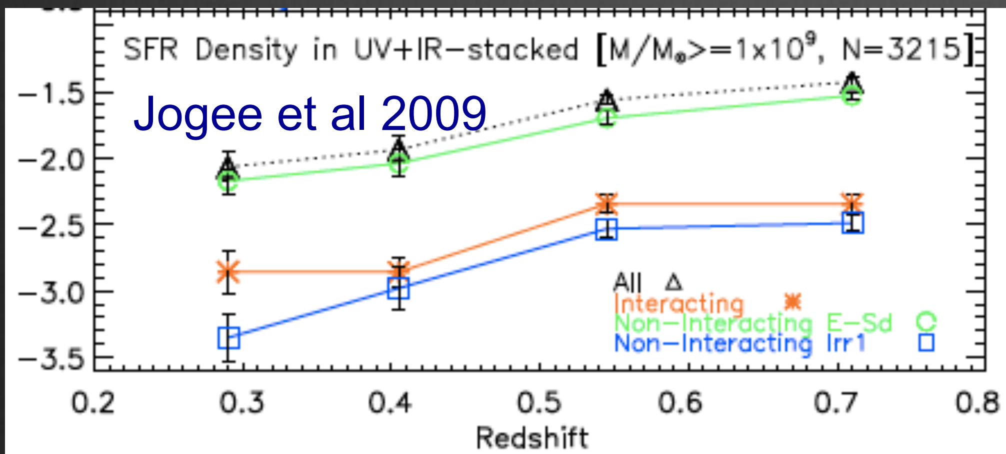


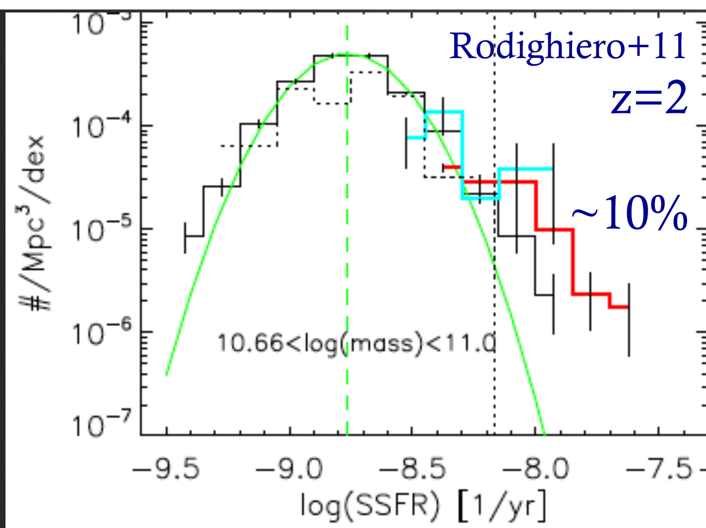
Mitra+16
see also Forbes+14

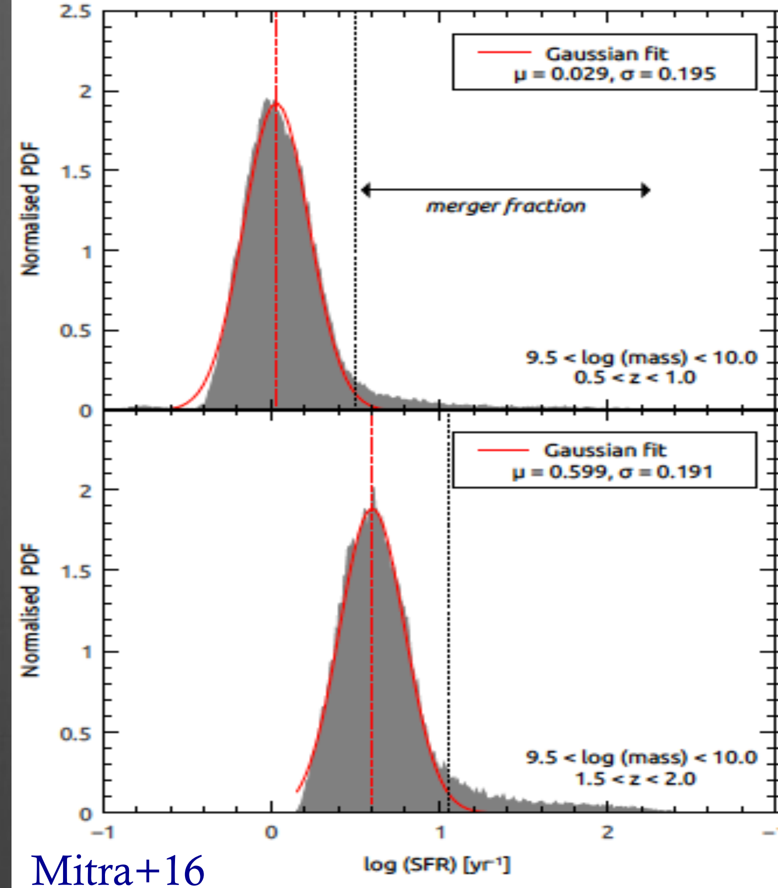


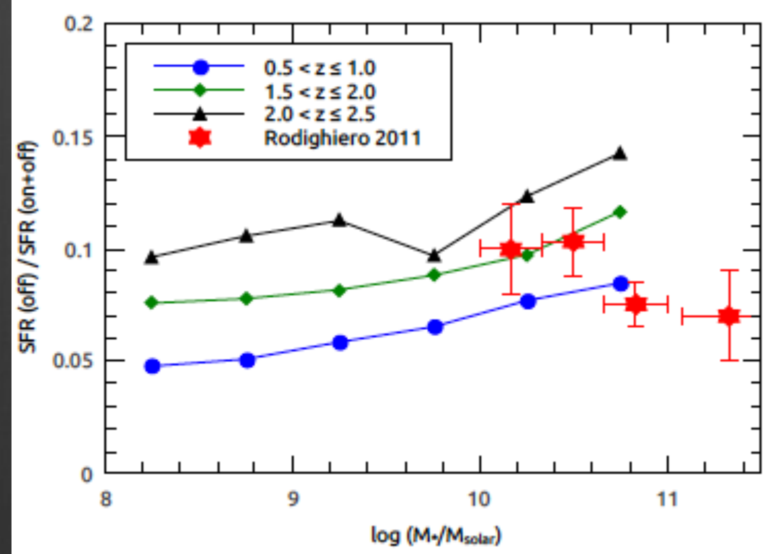
Outliers (starbursts)

- Accretion fluctuations are not pure lognormal – tail to high SFR (~10%)



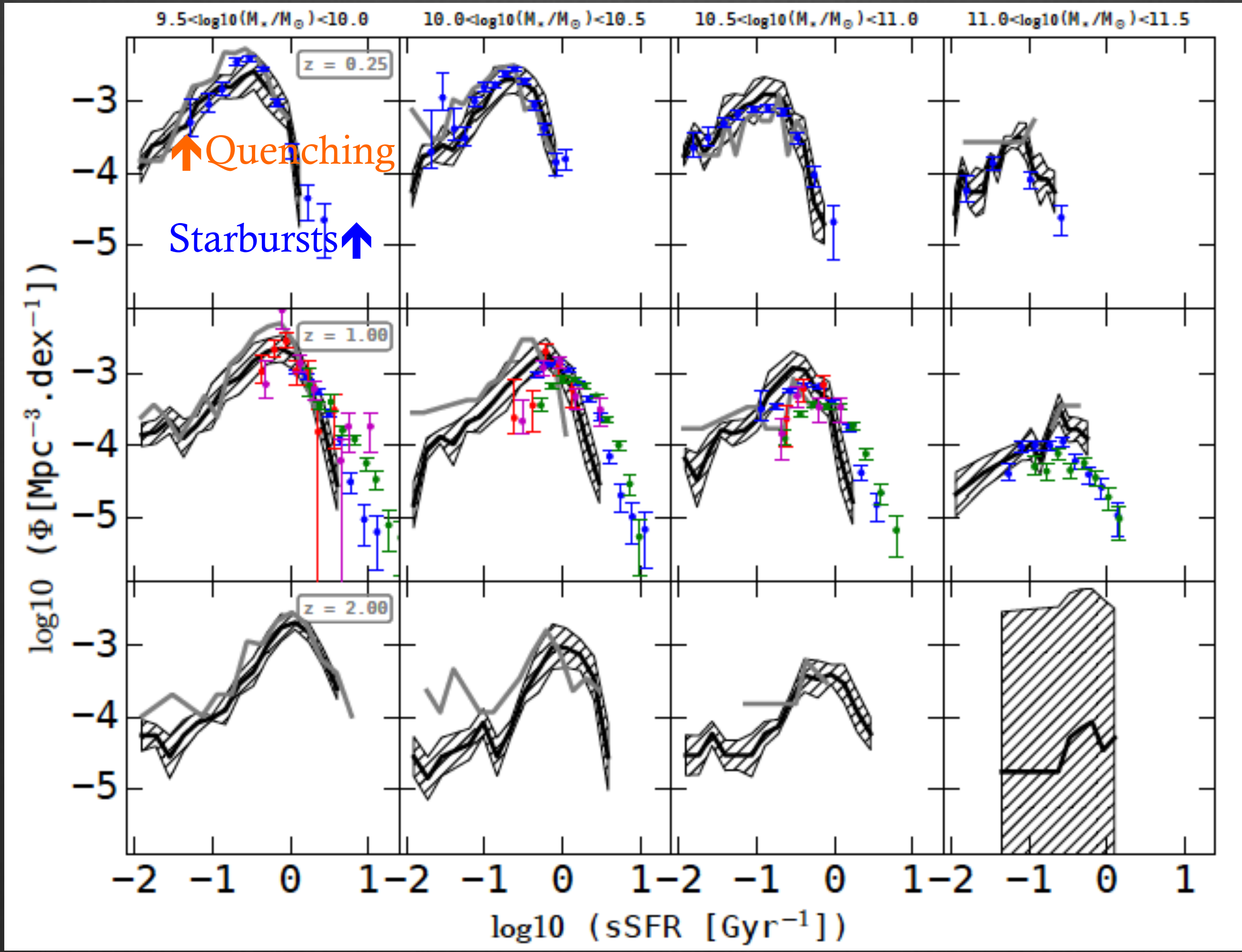






MS scatter via the sSFRF

- Specific SFR function in bins of stellar mass shows more detail than just σ: e.g. rapidity of quenching, starburst fraction, …

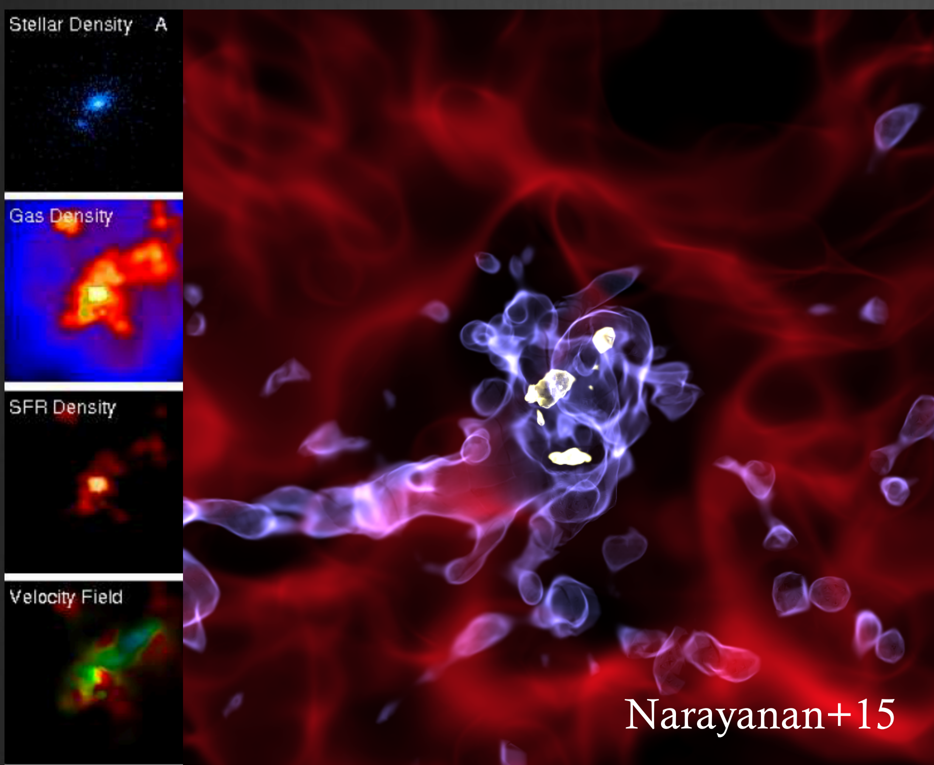


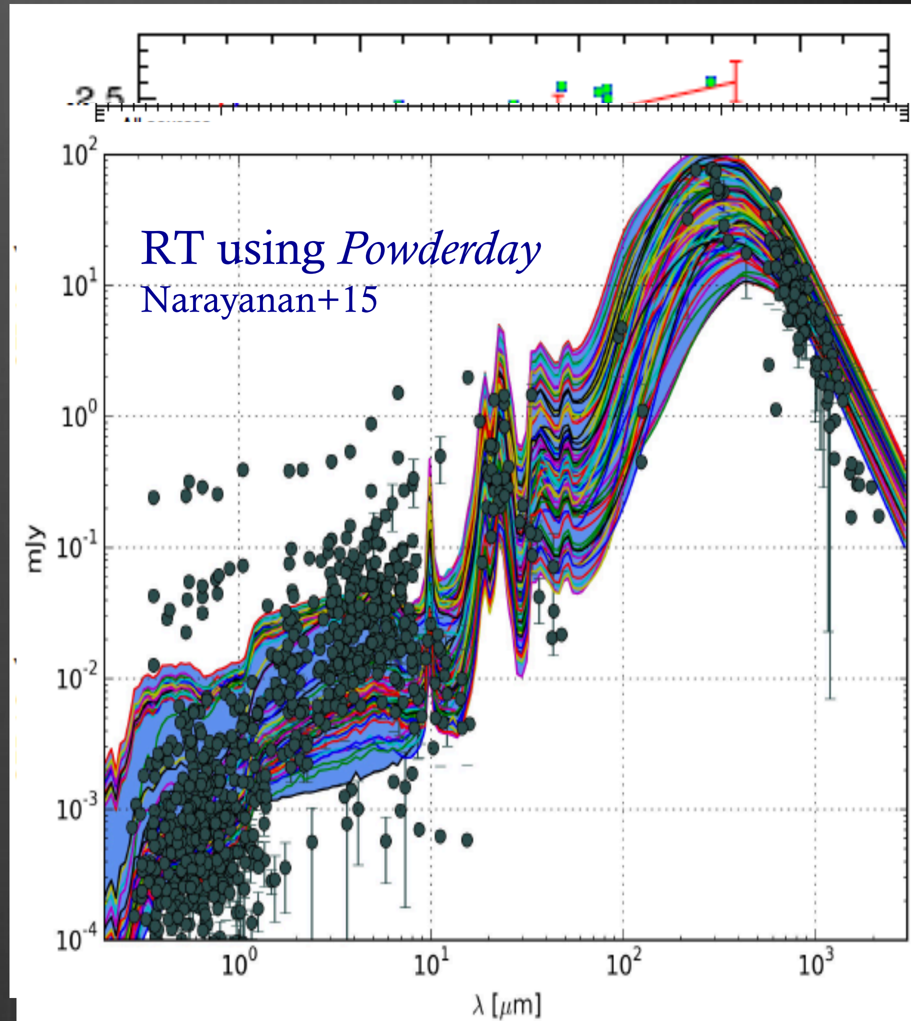
Lines: MUFASA
Points: Ilbert+15

RD+17a

Extreme star-formers at high-z

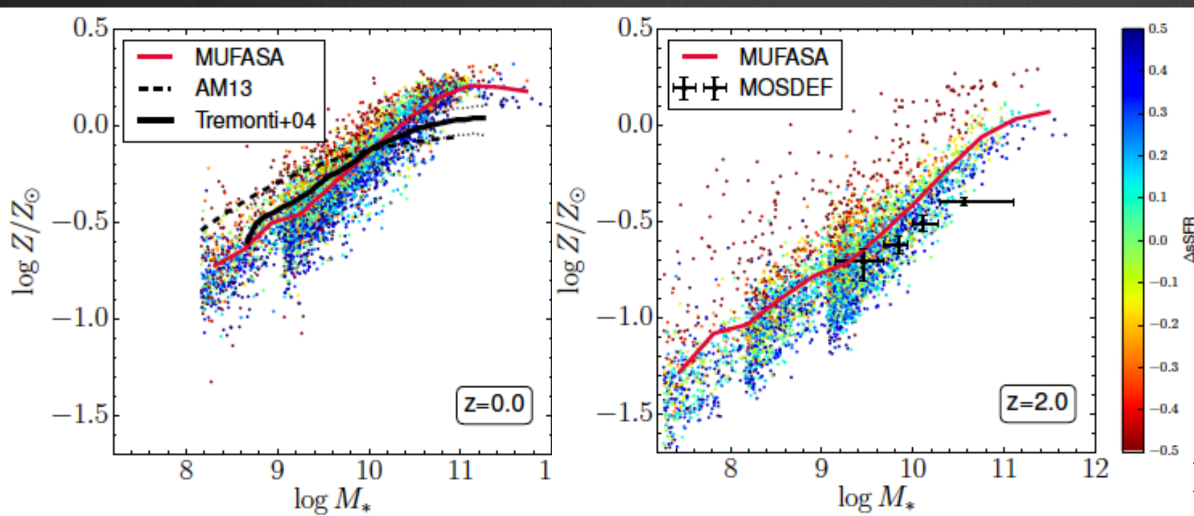
- Most SMGs consistent with top end of main sequence; not in a burst phase. Still often inter-acting in dense environment.

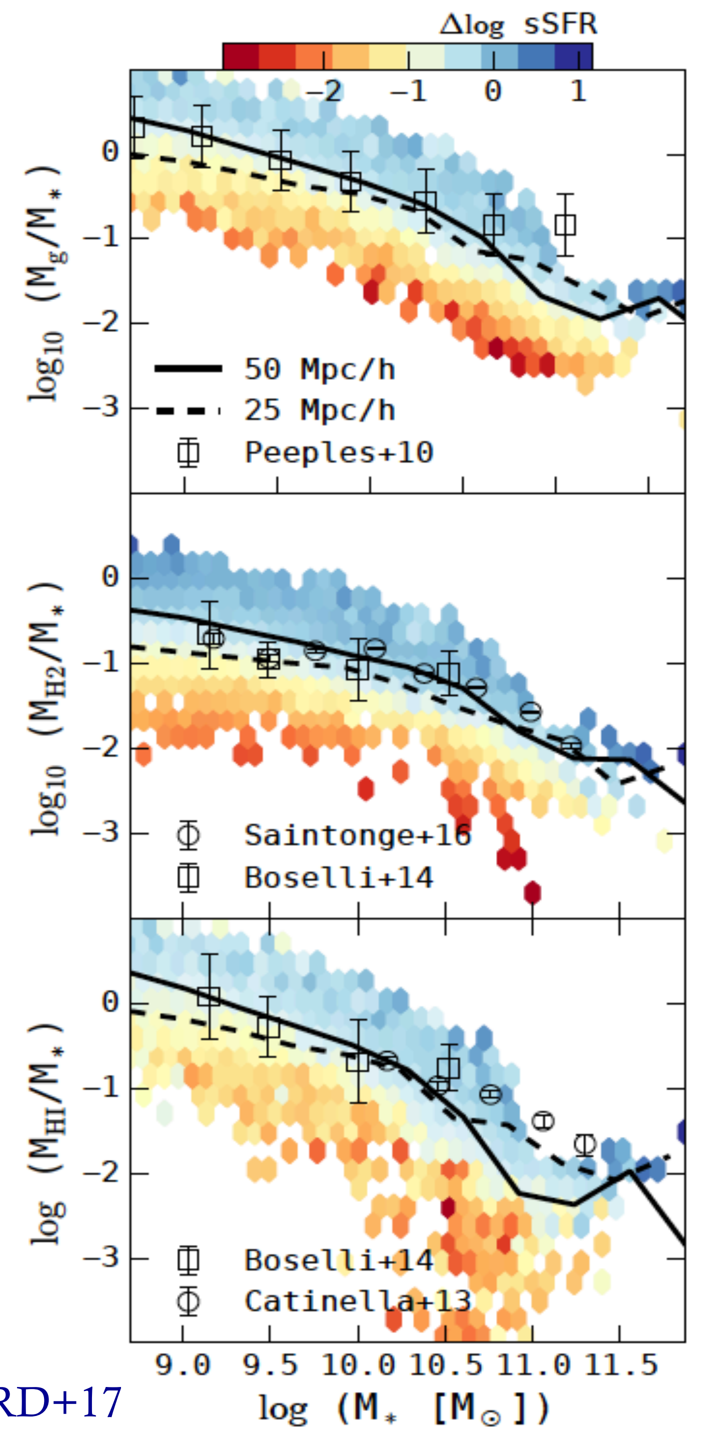




Scatter is correlated!

- Inflow event -> decrease in Z with increase in f_{gas} -> increase in SFR.
- Correlated scatter reflects competition bet. consumption time $M_{gas}/sSFR(1+\eta)$ and accretion time $M_{gas}/(dM_{in}/dt)$.
- Probes response of galaxy to stimulus – new regime to test models.

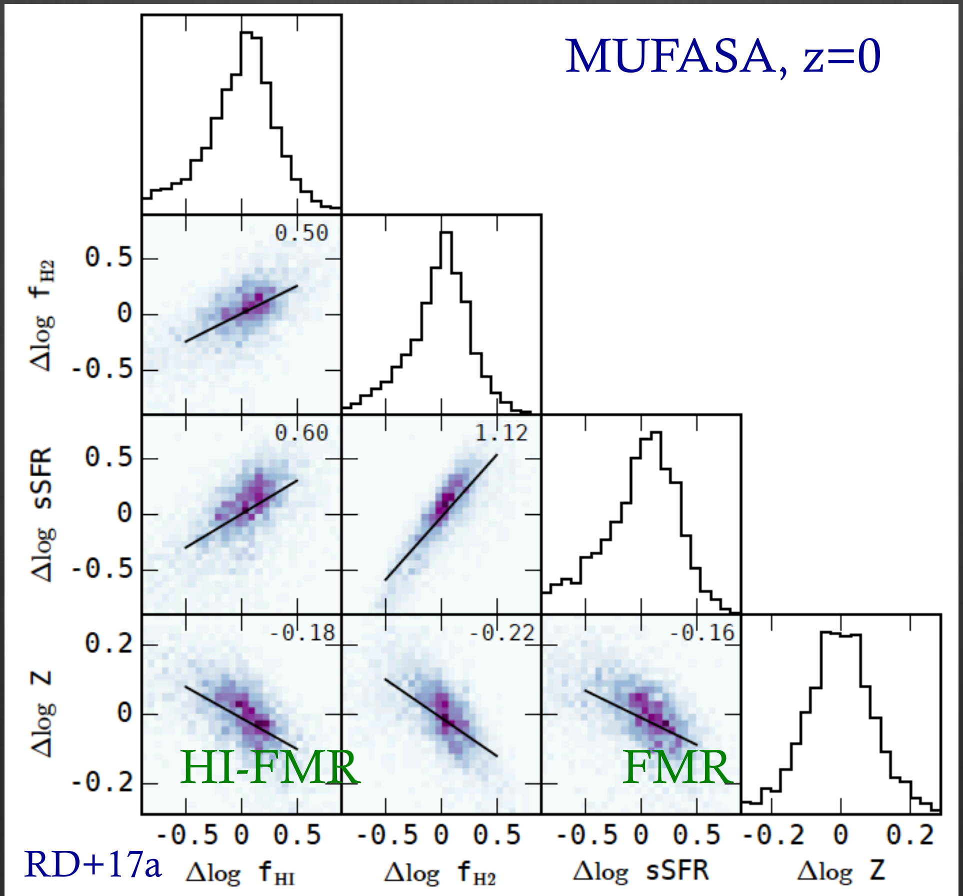




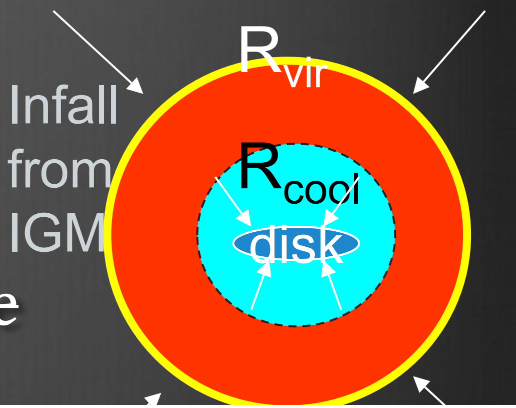
RD+17

Quantifying "second-order" galaxy growth

- *Deviation plots:* Δ[SFR,Z,f_{HI},f_{H2}] from their typical value at a given M_*, plotted against each other.
- Key test of galaxy response to inflow fluctuations; less sensitive to calibration issues.



Self-Regulated Star Formation



- Stellar and metal growth limited by ~~cooling rate and conversion of gas into stars~~

  ejective and preventive feedback

- Gas & metal content reflects ~~"evolutionary state"~~

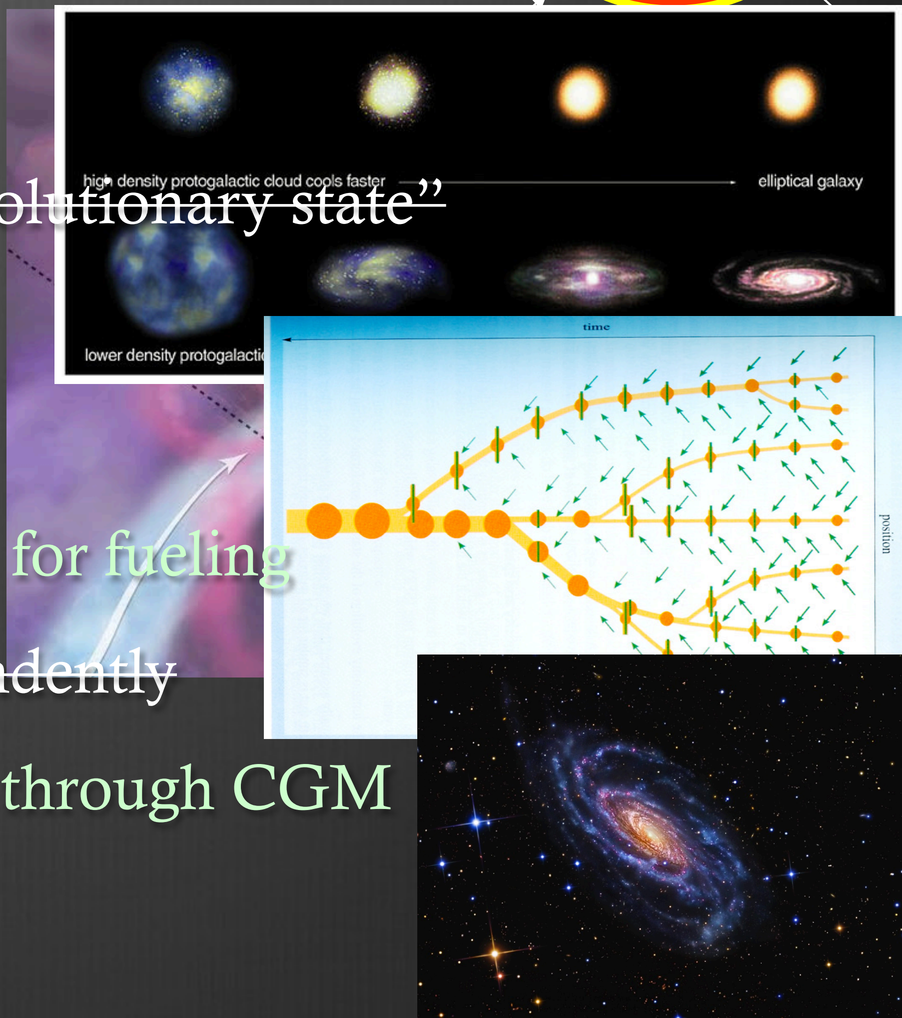
  gas supply vs. processing rate

- Mergers ~~drive galaxy evolution~~

  are subdominant to cold streams for fueling

- Galaxies & IGM ~~evolve independently~~

  are connected by baryon cycling through CGM

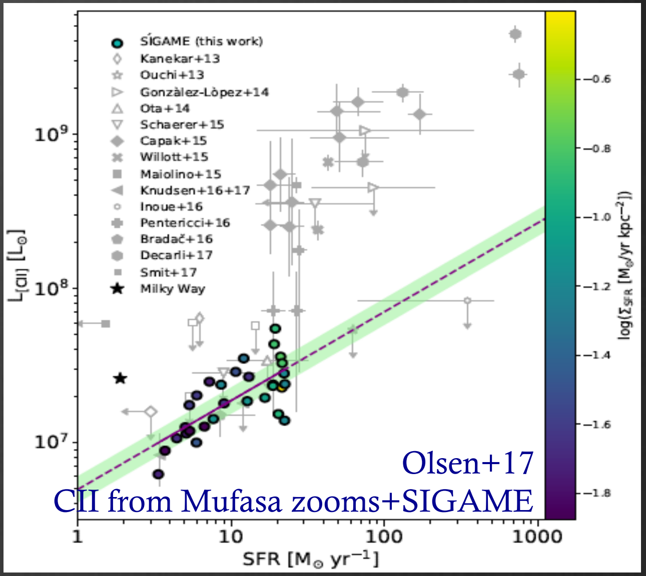


Concluding remarks: Emission line galaxies as probes of the baryon cycle

- Cosmic star formation driven by stochastic halo growth, suppressed by preventive feedback at high & low masses, and modulated by outflows in between. What physics sets this?

- Emission lines provide an optimal way to probe such processes:
  - Balmer lines probe star formation, outflows
  - Metal lines probe metallicity, AGN content
  - CO, CII probe molecular fuel
  - HI-21cm probes gas in outskirts & CGM
  - Lyα probes low-mass early galaxies

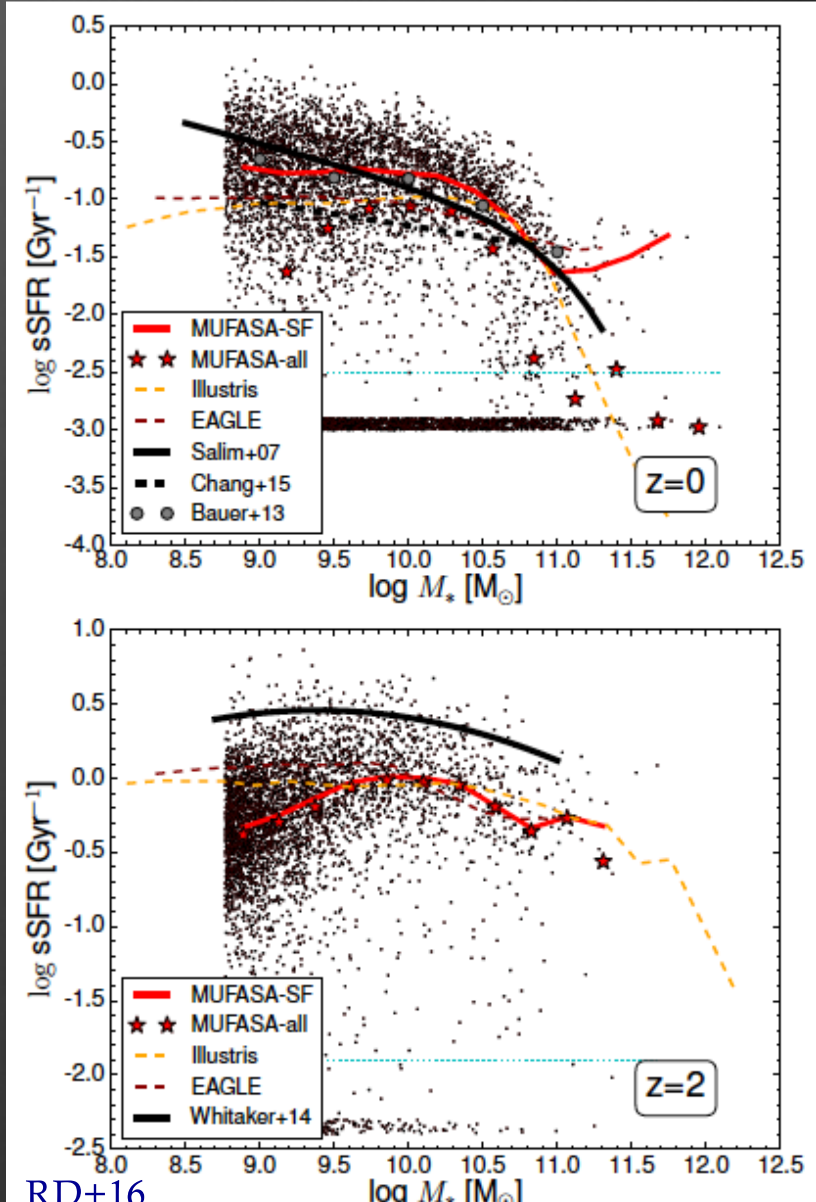
  … all of these can now be directly simulated



- Scatter around mean scaling relations is non-Gaussian and correlated, which offers new ways to test models and gain insights into how galaxies are impacted by baryon cycling.

MS & scatter in simulations

- Main sequence predictions among simulations are similar.
- Cosmological sims predict σ~0.25 dex.
- Still too low at z~2



RD+16