An Analytic Model for Galaxy Growth

Romeel Davé, Arizona

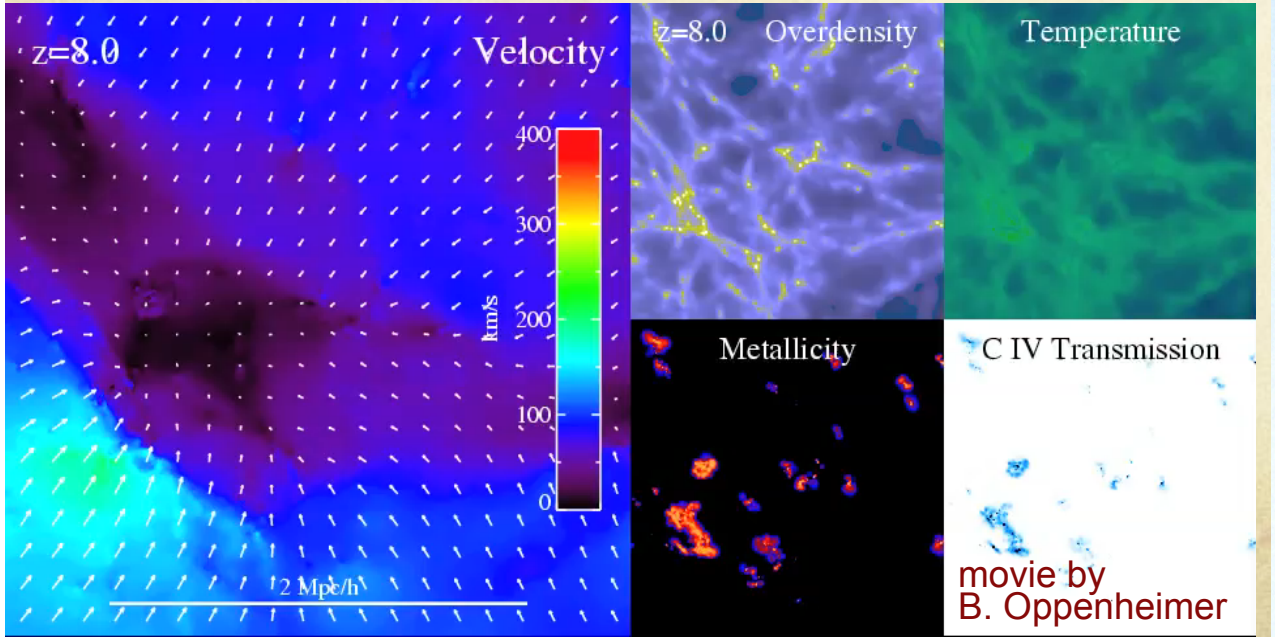
with Kristian Finlator (UCSB), Ben Oppenheimer (Leiden)

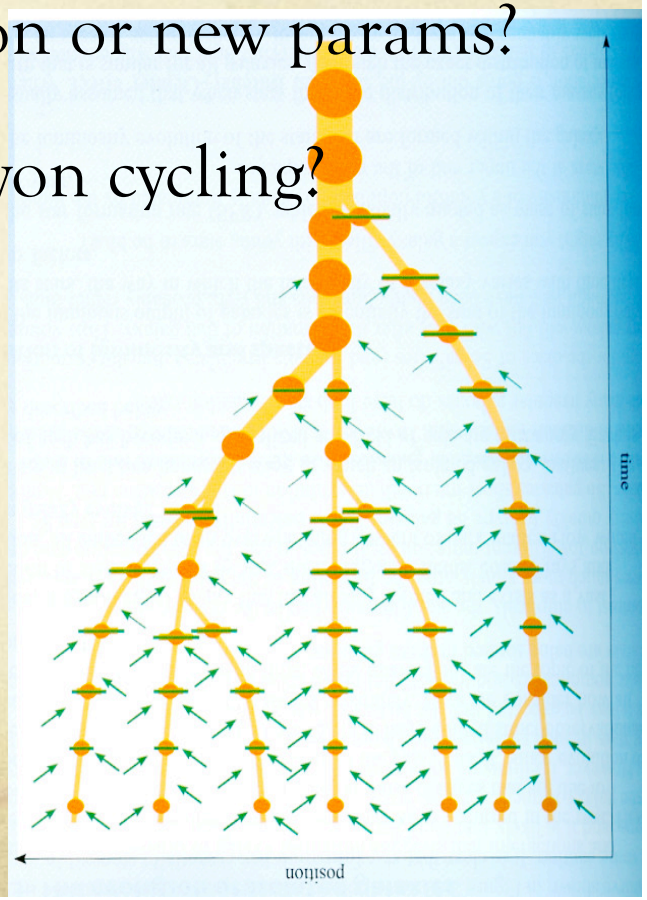
Baryon Cycling

A continual cycle of inflows and outflows is increasingly believed to modulate galaxies' growth.

Paradigm shift or epicycle? New intuition or new params?

Is there a way to formally represent baryon cycling?



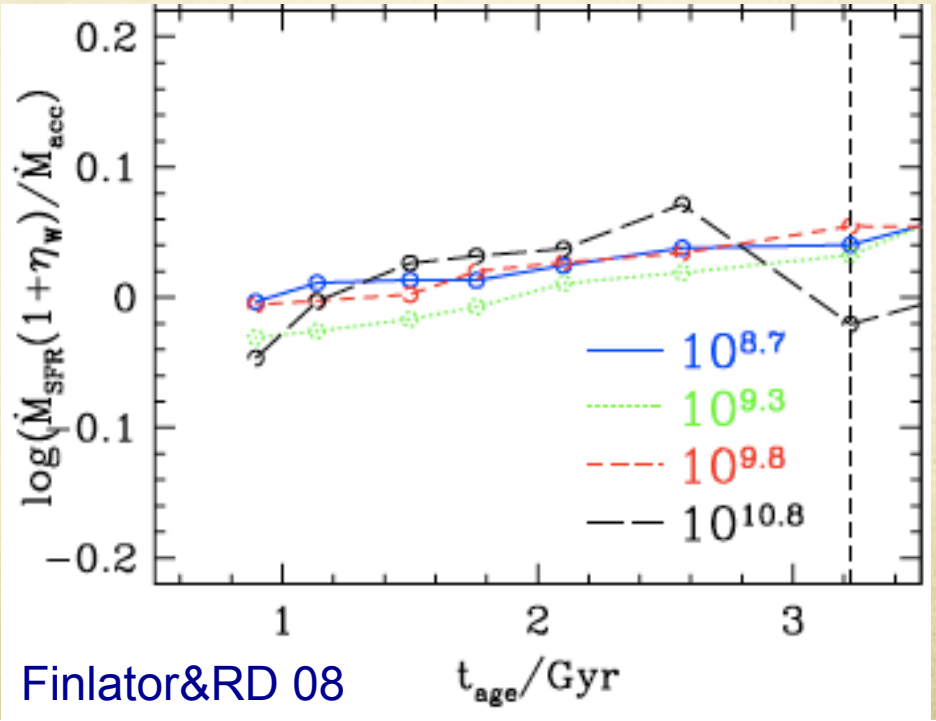


The Equilibrium Condition

Inflow = Star formation + Outflow

SFR = Inflow/(1+η)

η = Outflow/SFR = mass loading factor



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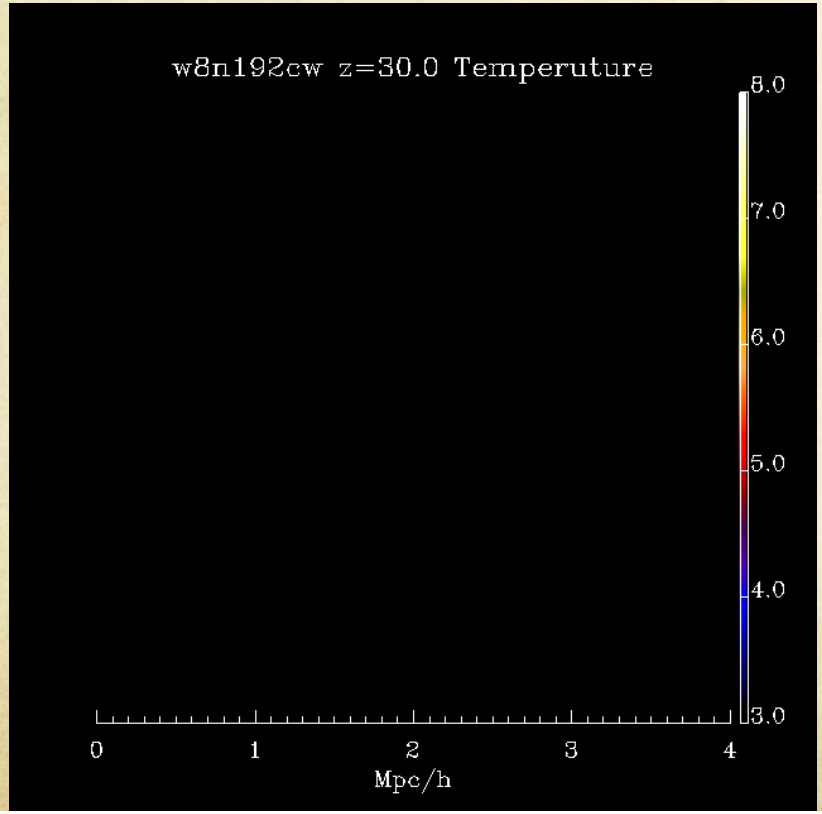
Inflow terms

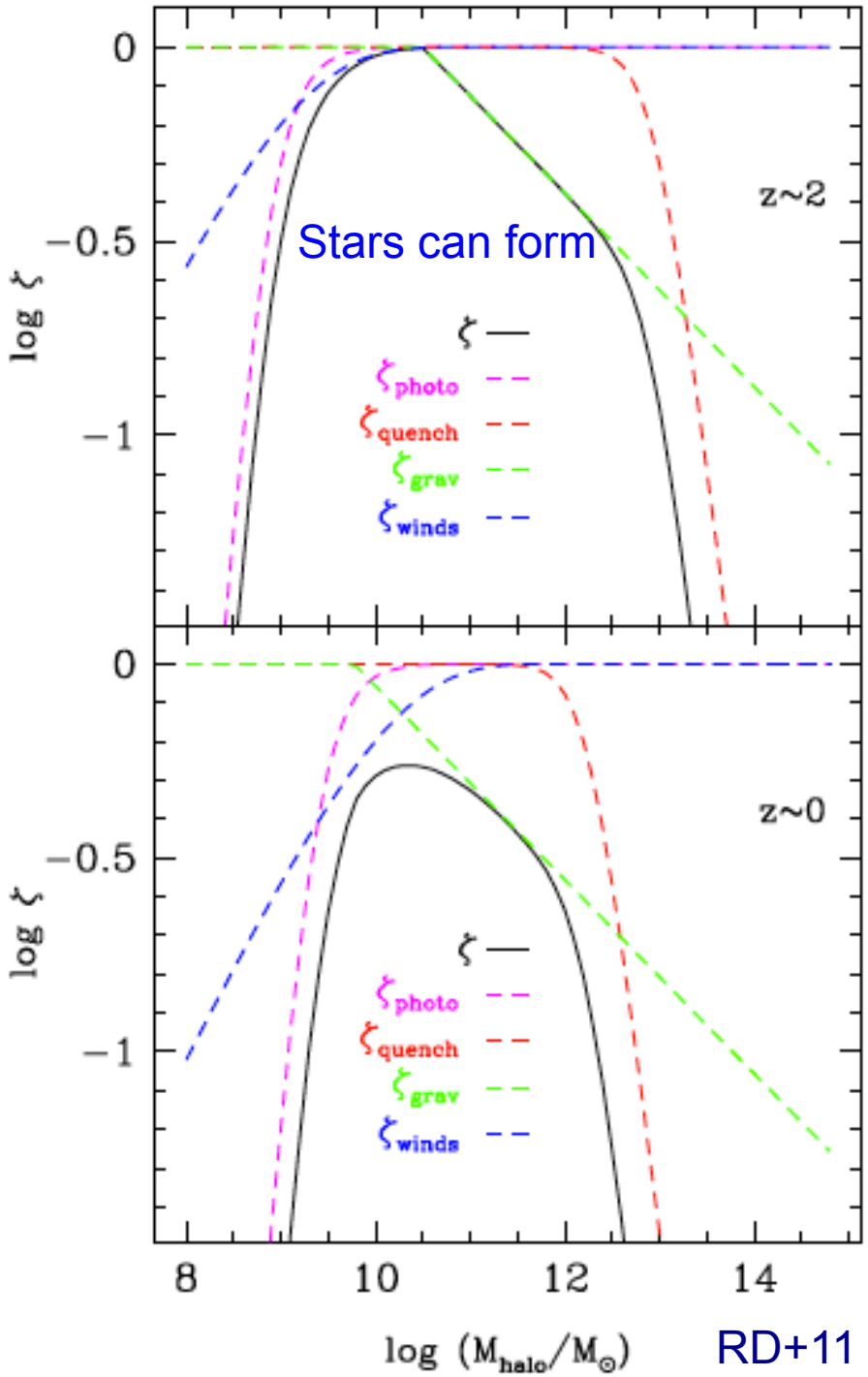
- $\dot{M}_{grav}$ = Gravitational infall of baryons into halo
  - ΛCDM: $\dot{M}_{grav} \propto f_b M_{halo}^{1.1} (1+z)^{2\text{-}2.5}$
- $\dot{M}_{prev}$ = Mass rate into halo gas (not ISM).
  - $\zeta \equiv 1 - \dot{M}_{prev}/\dot{M}_{grav}$
- $\dot{M}_{recyc}$ = Recycled winds

$$\text{Inflow} = \zeta \dot{M}_{grav} + \dot{M}_{recyc}$$

Preventive Feedback:

Photo-ionization, AGN, gravity, winds, ...?





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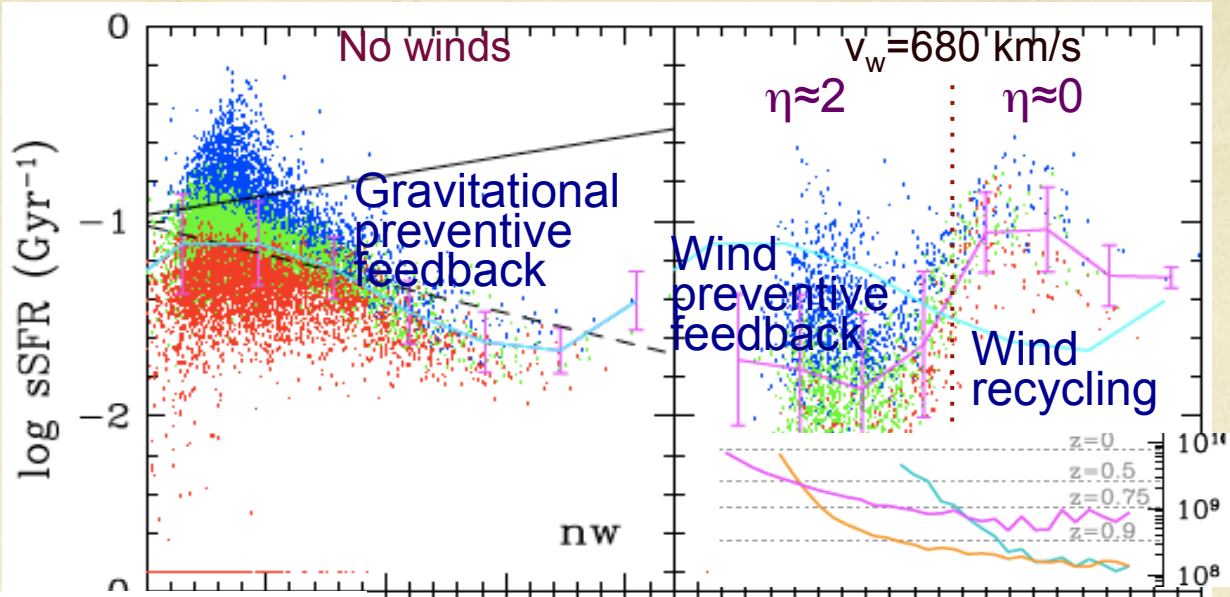
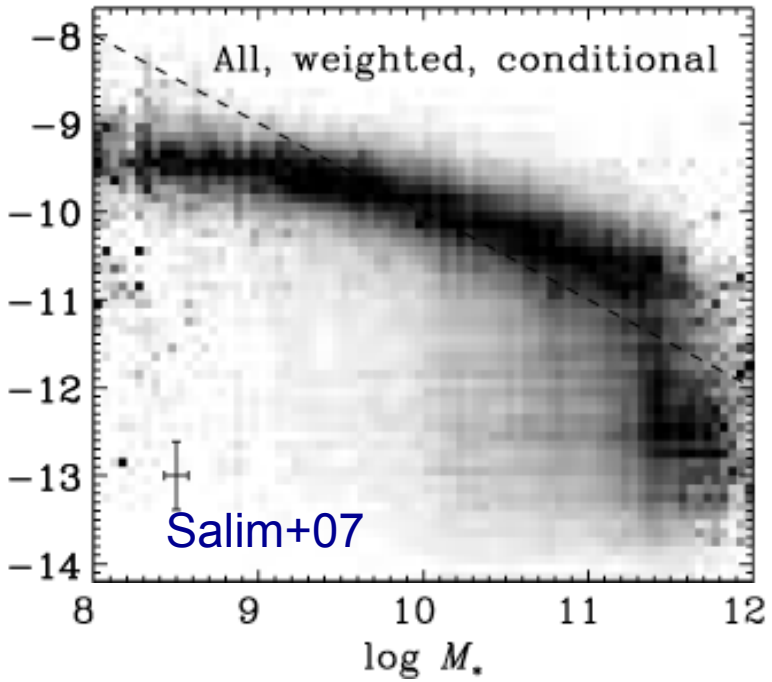
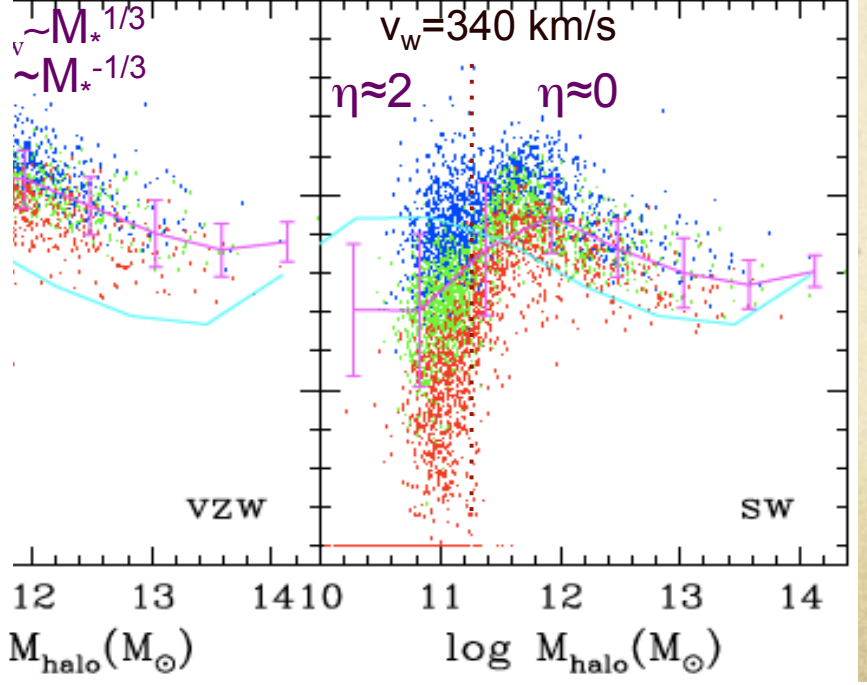
Specific SFR & Recycling

SFR = Inflow/(1+η)







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Gas Fractions

- $f_{gas} = M_{gas}/(M_{gas}+M_*) = 1/(1+(t_{dep}sSFR)^{-1})$

  where $t_{dep} = M_{gas}/SFR$.

When $M_{gas} << M_*$, then $f_{gas} \approx t_{dep}\ sSFR$

t_{dep} mostly depends on SF law only!

All feedback info contained in sSFR.

Depletion time

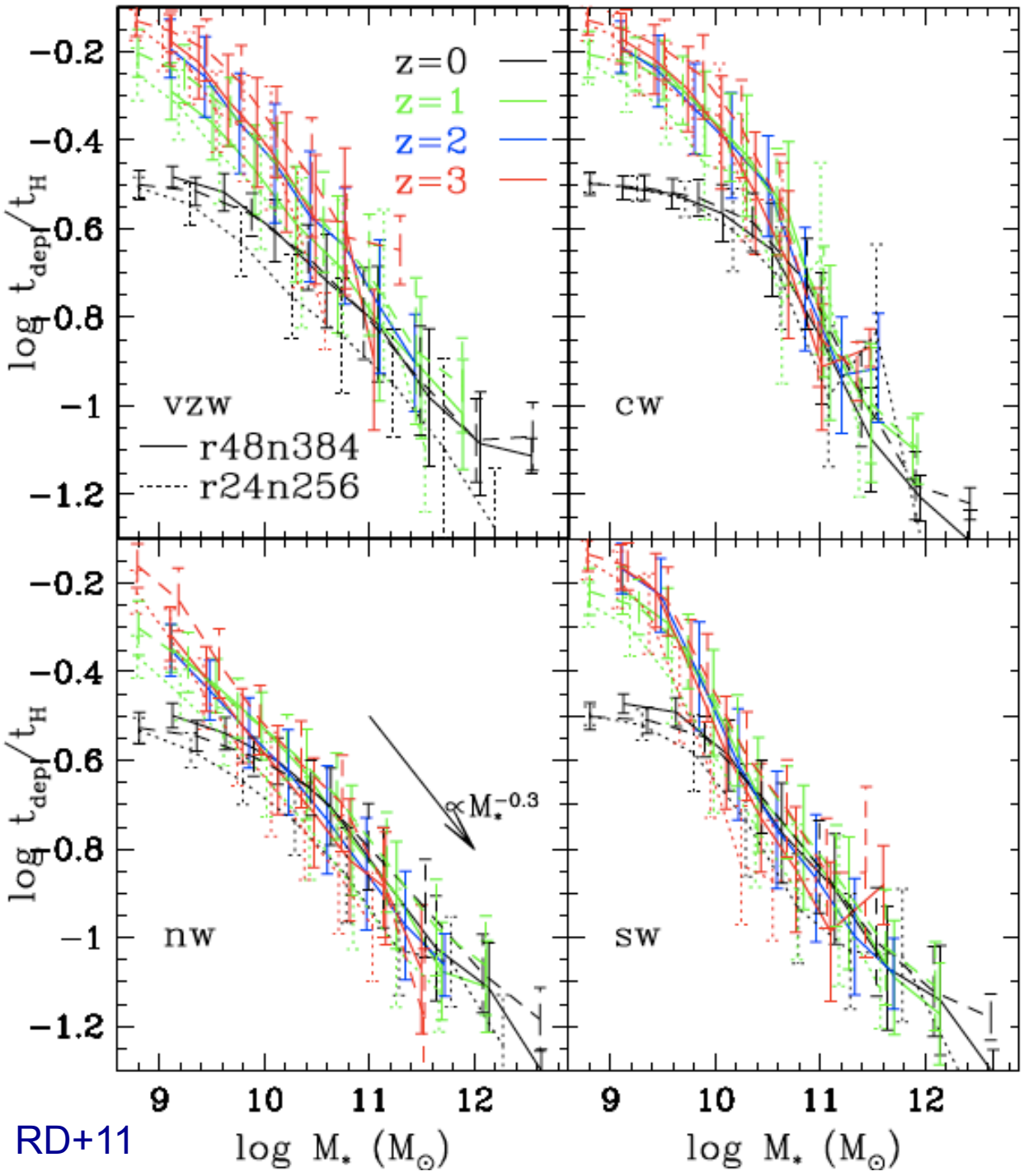
$t_{dep} \sim t_{Hubble}\ M_*^{-0.3}$

Set by *SF law*:

$SFR \sim \varepsilon\ M_{gas}/t_{dyn}$

$t_{dep} \sim t_{dyn} \Sigma_{gas}^{1-N}$

where N≈1.4



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Gas Fraction Scalings

- For massive (low-f_{gas}) galaxies,

  $f_{gas} \sim t_{Hubble}\, M_*^{-0.3}\, (1+z)^{2.25}\, M_*^{\beta}$

Implications:

- $f_{gas}(M_*)$ drops slowly with time: Supply rate drops faster than consumption rate
- Slope of $f_{gas}(M_*)$ at low f_{gas} is β-0.3, when $M_* \sim < M_{gas}$ it flattens.

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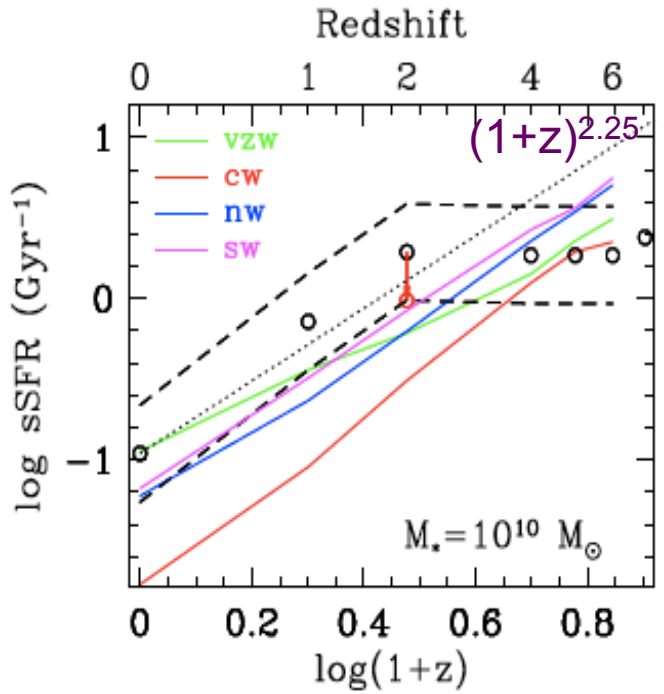
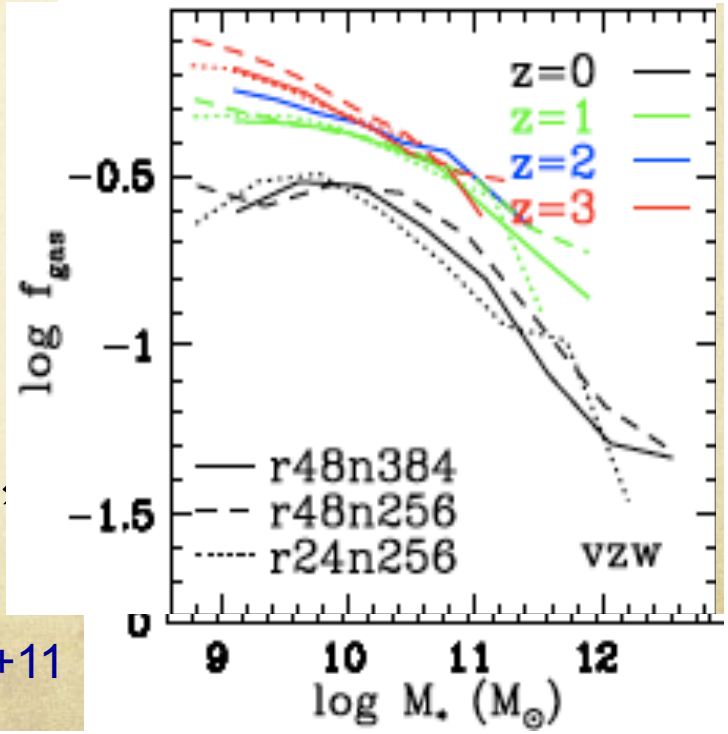


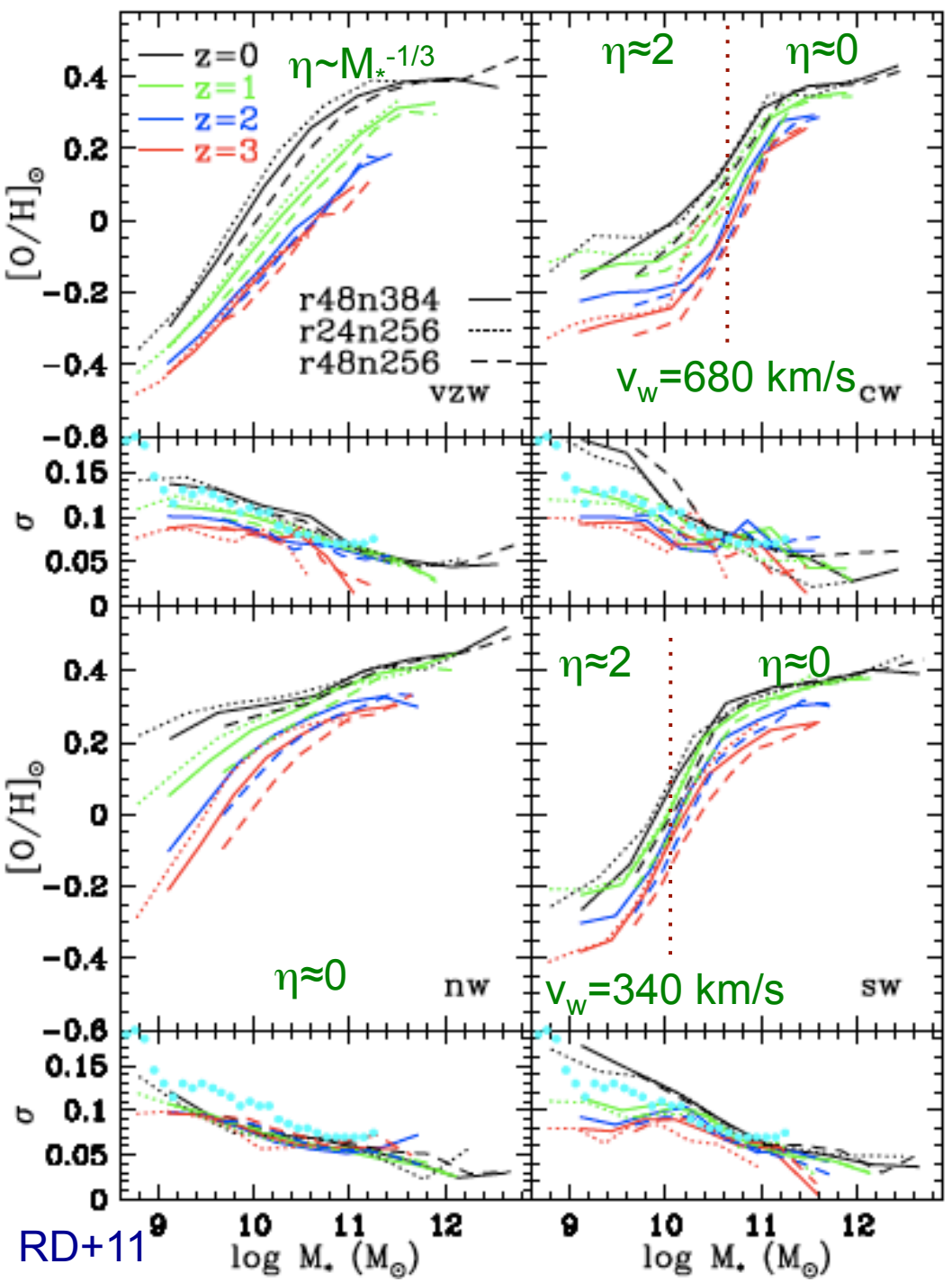


Metallicities

- Z = y SFR / Inflow
  = y/(1+η)

Independent of ζ

Mass-metallicity rel'n reflects η(M*).



Enriched Infl

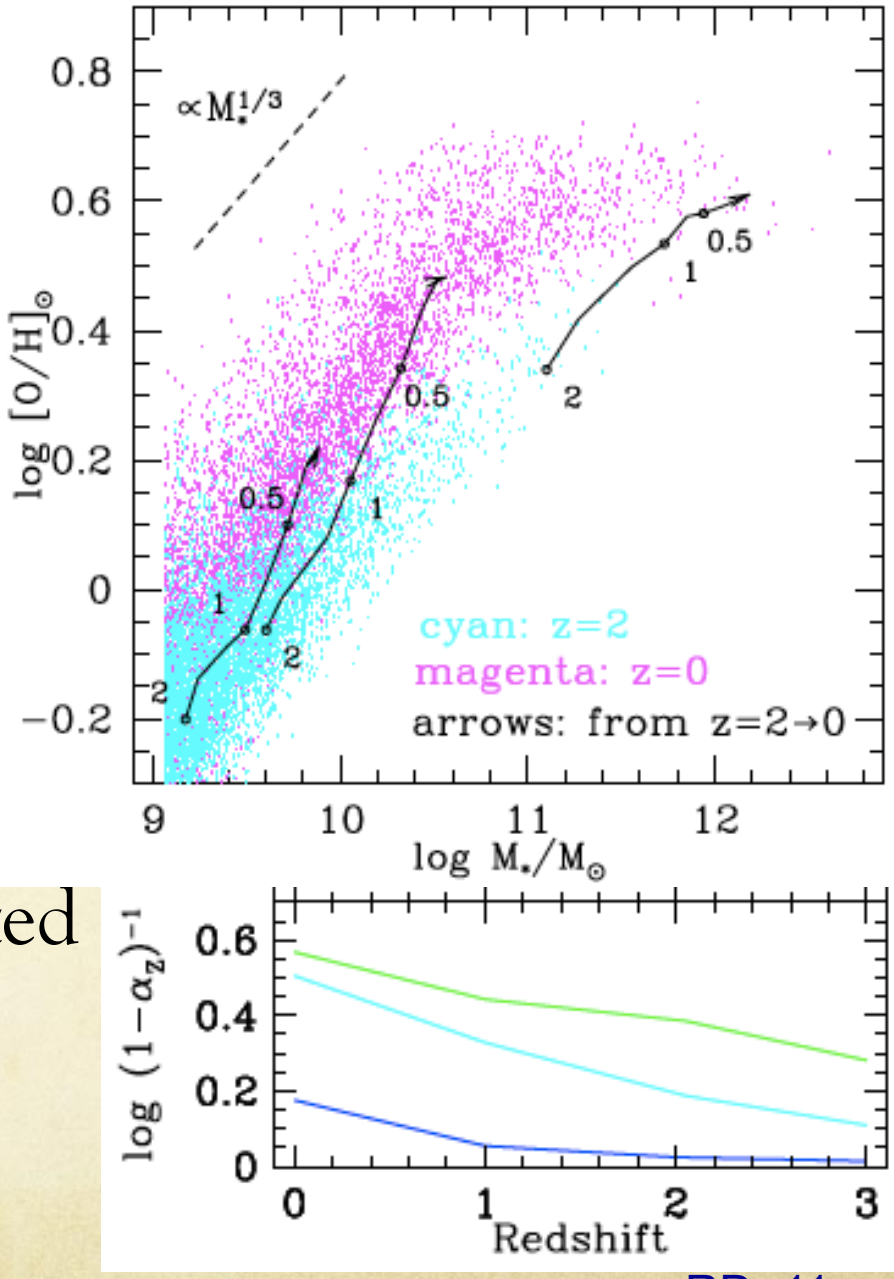
$$Z = y\,(1+\eta)^{-1}\,(1-\alpha_Z)^{-1}$$

where $\alpha_Z = Z_{inflow}/Z_{ISM}$

Increase in α_Z drives MZR evolution.

If all IGM metals deposited by outflows:

$$\dot{M}_{recyc} = \zeta\,\dot{M}_{grav}\,\alpha_Z\,(1-\alpha_Z)^{-1}$$



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Equilibrium Relations

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

Baryon cycling parameters: η, ζ, α_Z.

Examples of intuition from these equations:

- SFR and Z don't depend on SF Law!
- Observed: $Z \sim M_*^{1/3}$ ➔ $\eta(M_*) \sim M_*^{-1/3} \sim v_{circ}^{-1}$

Intuition from the Equilibrium Scenario

- 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. consumption rate

- Mergers ~~fuel galaxy evolution~~

  are subdominant to cold streams for fueling

- Galaxies & IGM ~~evolve independently~~

  are connected by baryon cycling