Star Formation at Cosmic Noon

Perspectives from hydro simulations

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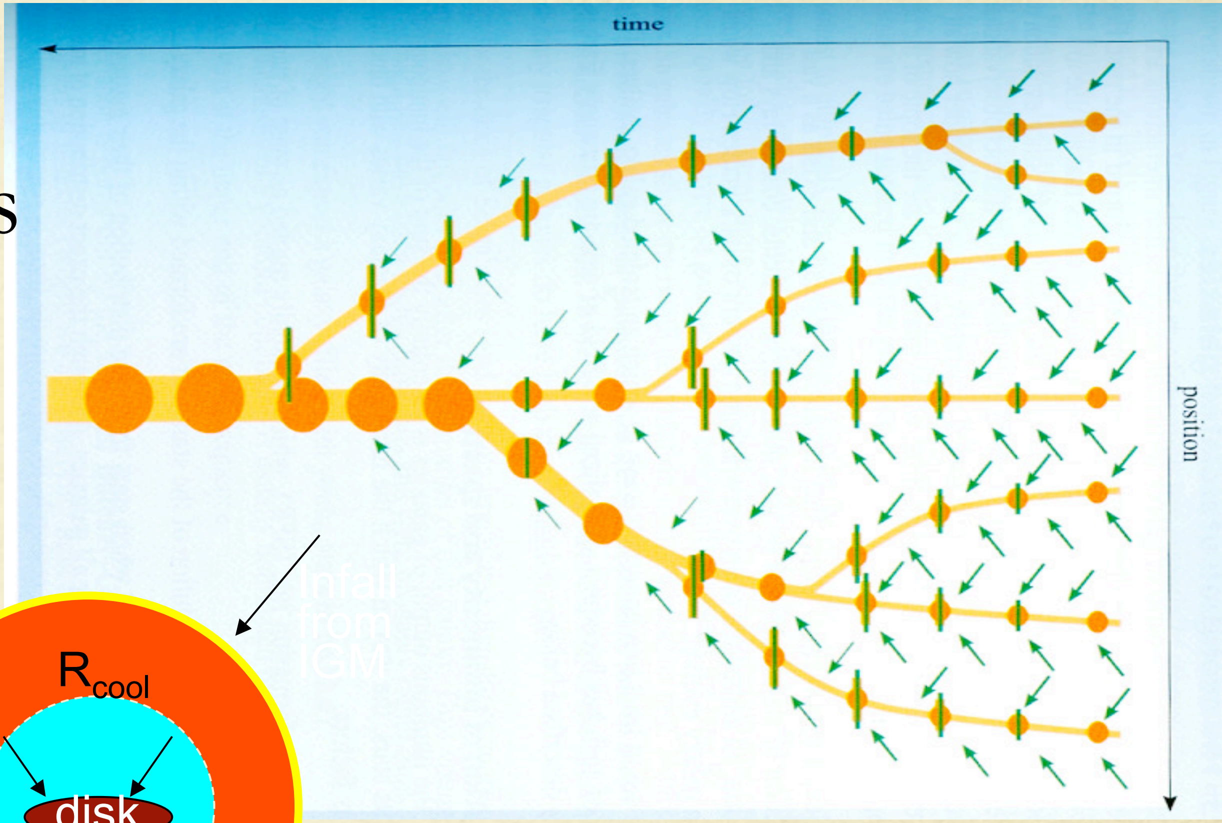
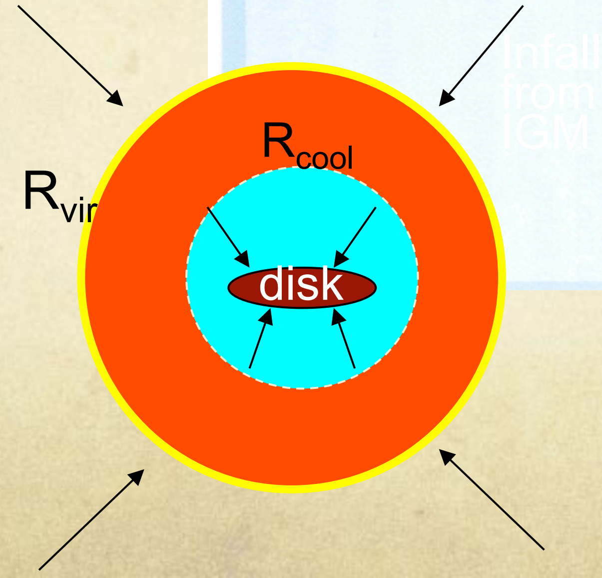
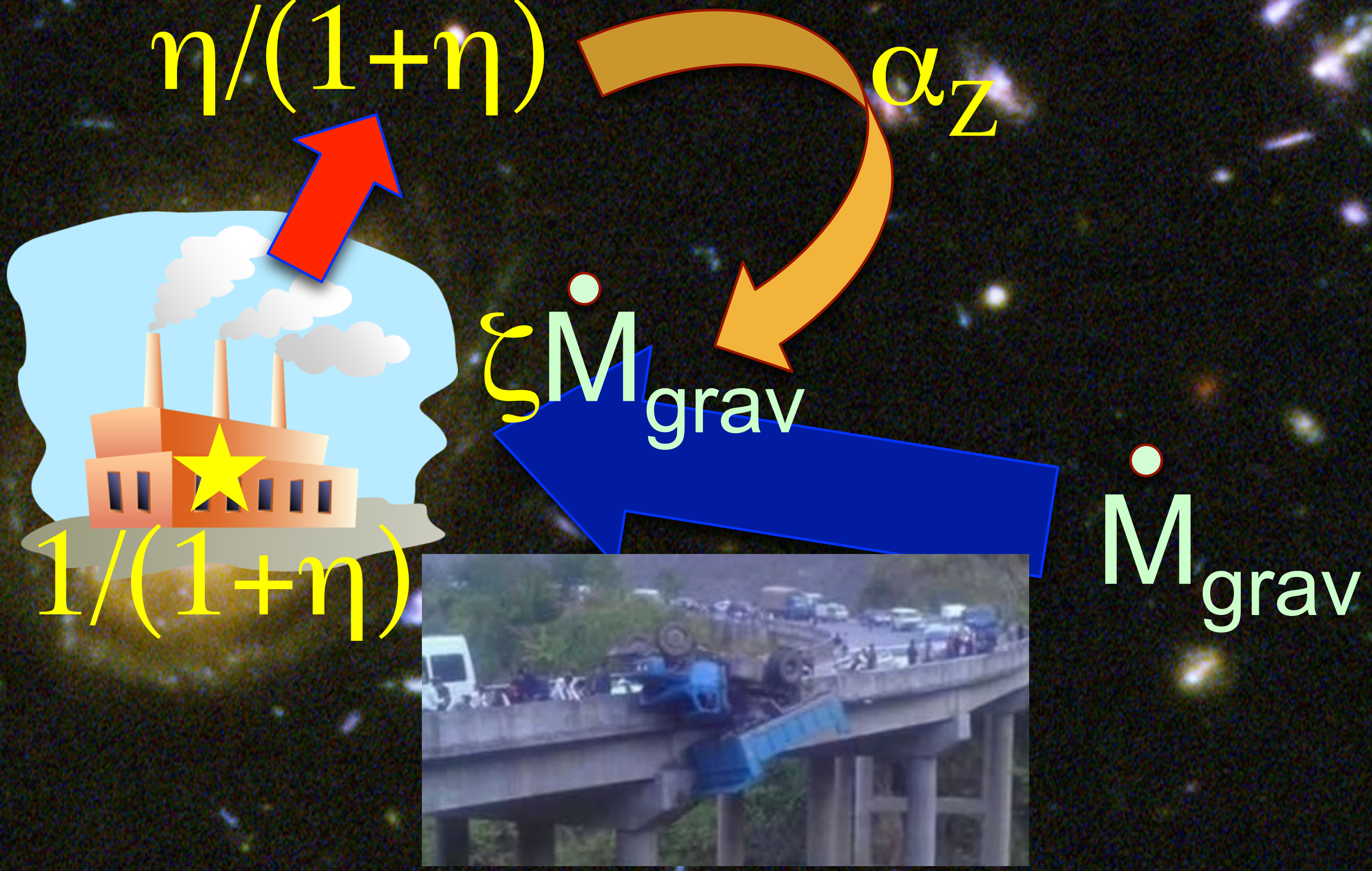
Old School: It's All About the Halos

- Merger rates
- Mass functions
- Disk growth
- SF law
- …





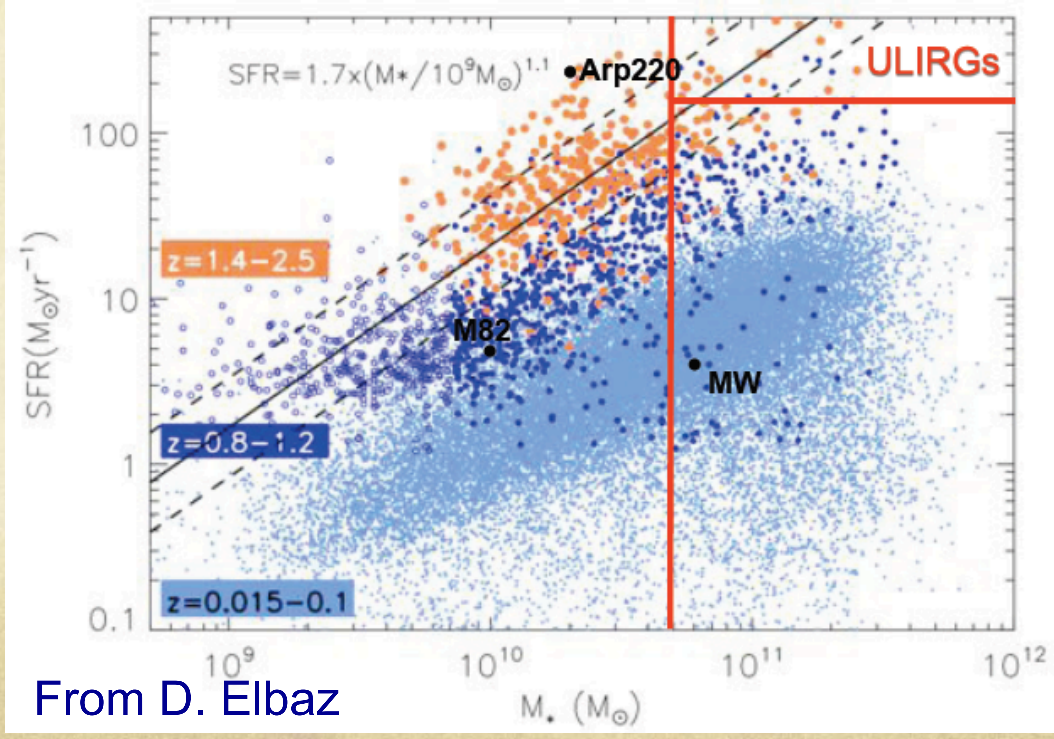


Gas Processing Factories

$$SFR = \zeta\dot{M}_{grav}/(1+\eta)(1-\alpha_Z)$$

Scaling relations: SFR-M_*

- Driven by $\dot{M}_{grav} \sim f_b\, M_{halo}^{1.1}\,(1+z)^{2.25}$
  - Relation should be close to linear
  - At given M* (M_{halo}), SFR should grow with z.



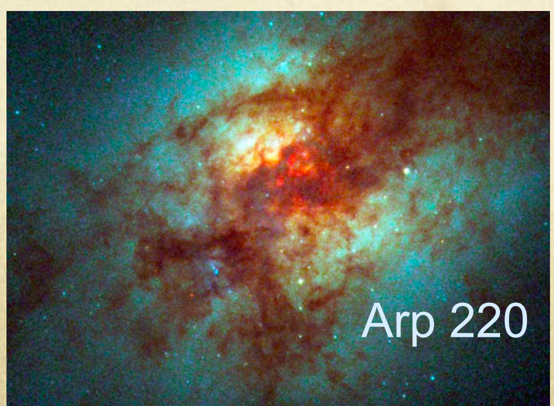
A 100 $M_\odot$/yr star-forming galaxy…

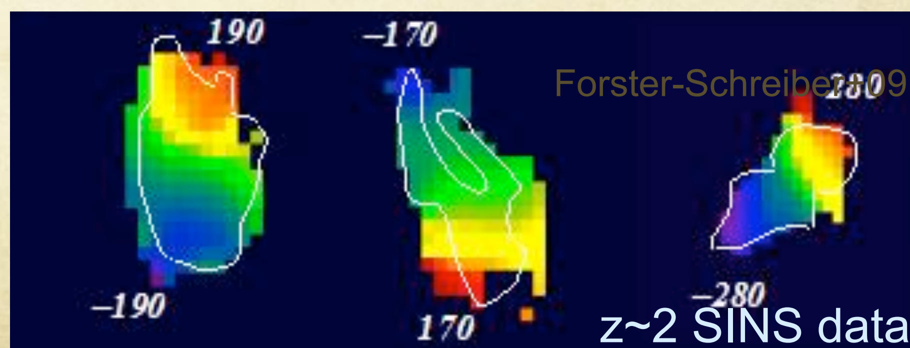
at z=0:

- M_*~few x 10^{10} $M_\odot$
- Major merger
- Nucleated SF
- Bursting: $t_{double} << t_{gal}$
- Strong AGN activity
- *Main sequence* outlier

at z=2:

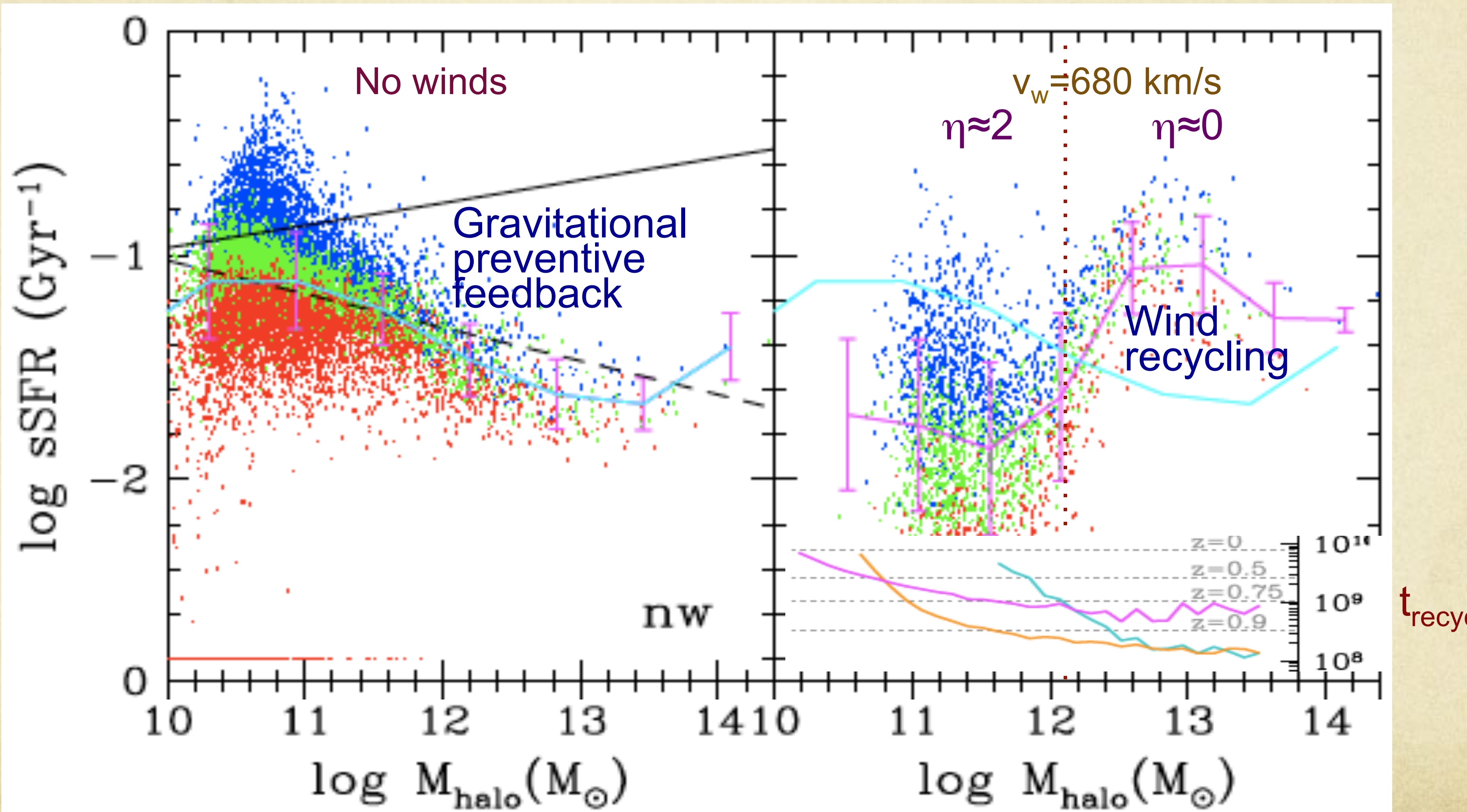
- M_*~few x 10^{10} $M_\odot$
- Thick, clumpy disk
- Distributed SF
- Quiescent: $t_{double} \sim t_{gal}$
- Little AGN activity
- *Main sequence* member





Specific SFR: Feedback Effects

$$SFR = \zeta \dot{M}_{grav}/(1+\eta)(1-\alpha_Z)$$



RD+11

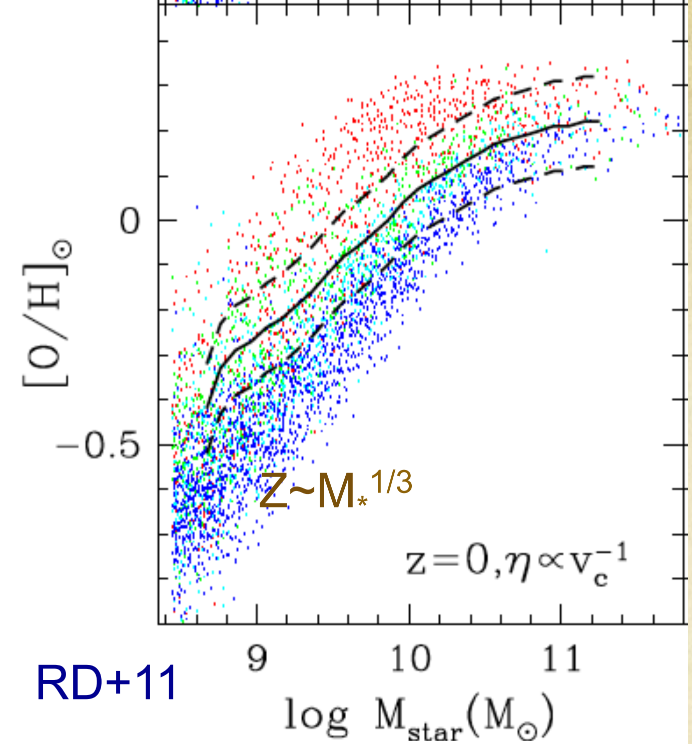
The role of Merging: Scatter

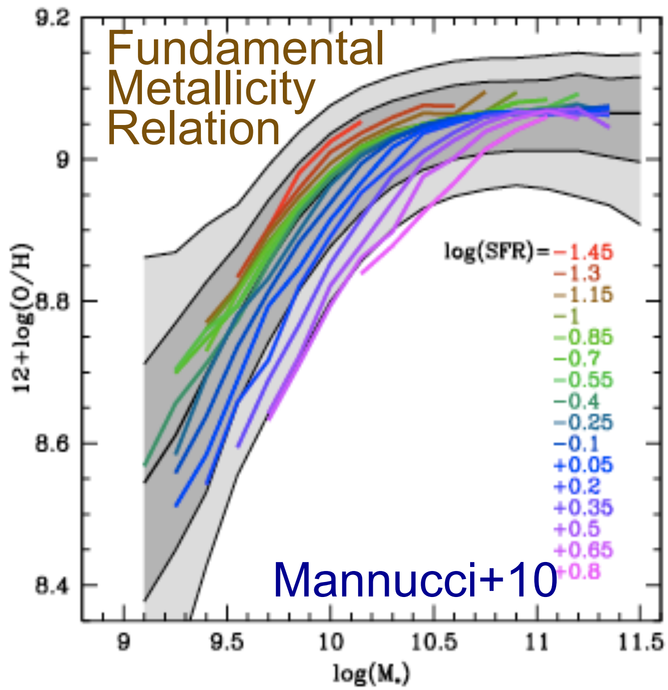
- *First order: Smooth accretion*

  Overall smooth accretion sets the form of scaling relations.

  $$Z = y/(1+\eta)(1-\alpha_Z)$$

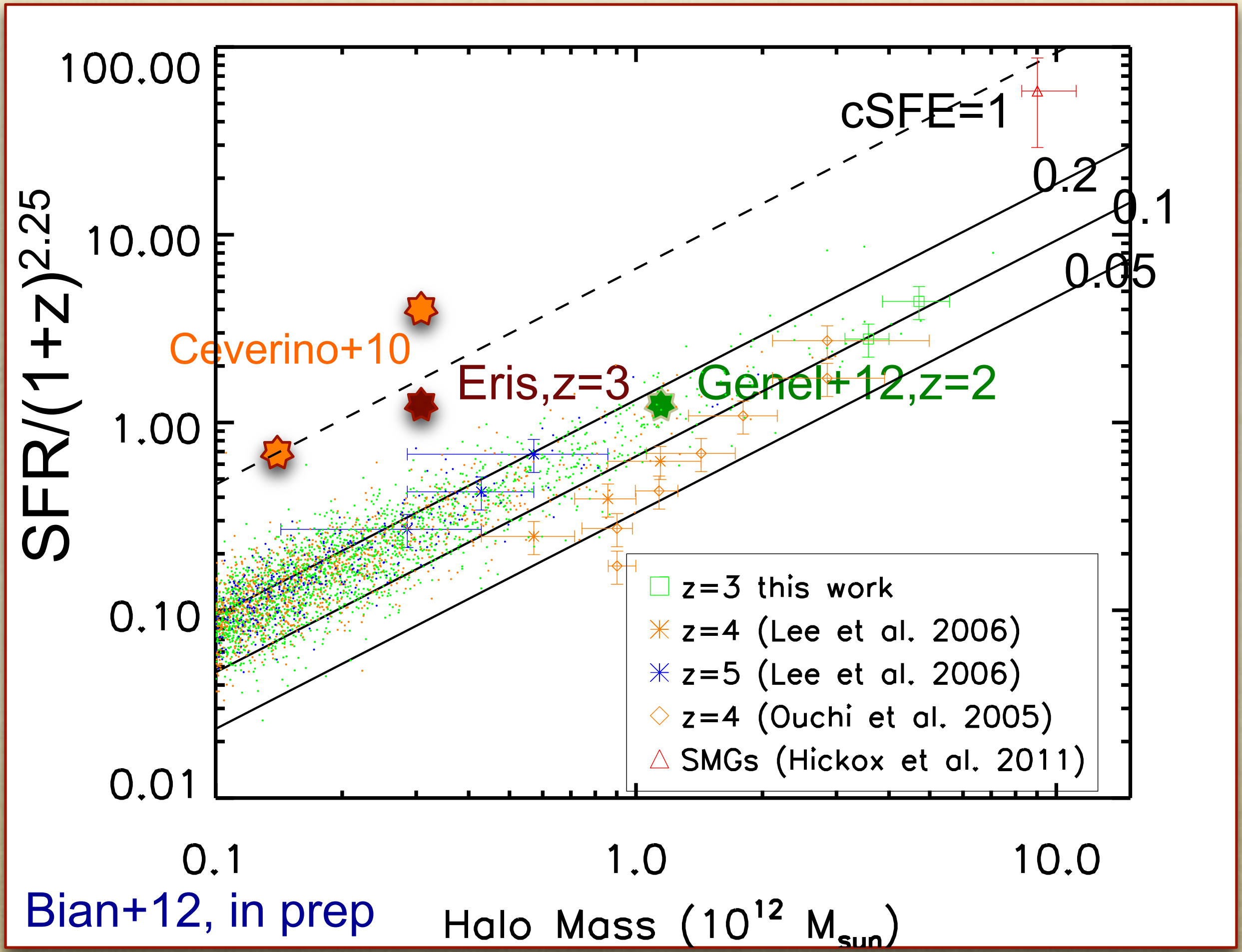
- *Second order: Stochasticity*
  - Mergers, environment, etc. are 2nd order effects.
  - Accrete a “lump” (merger) ➔ higher SFR (&f_{gas}), lower Z.



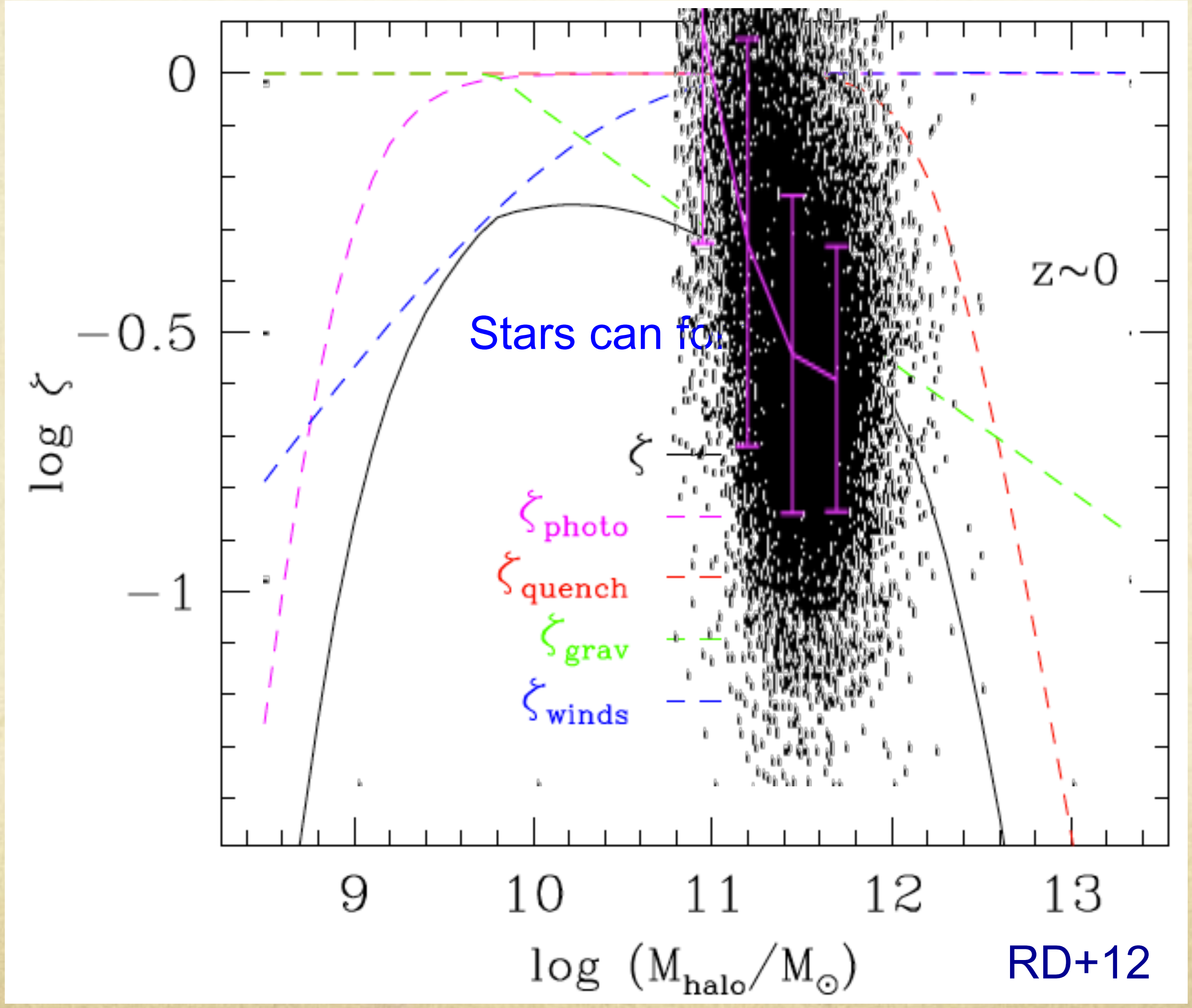


Cosmic Star Formation Efficiency

- $\mathrm{cSFE} = \mathrm{SFR}/\dot{M}_{grav} = \zeta\,(1+\eta)^{-1}\,(1-\alpha_Z)^{-1}$

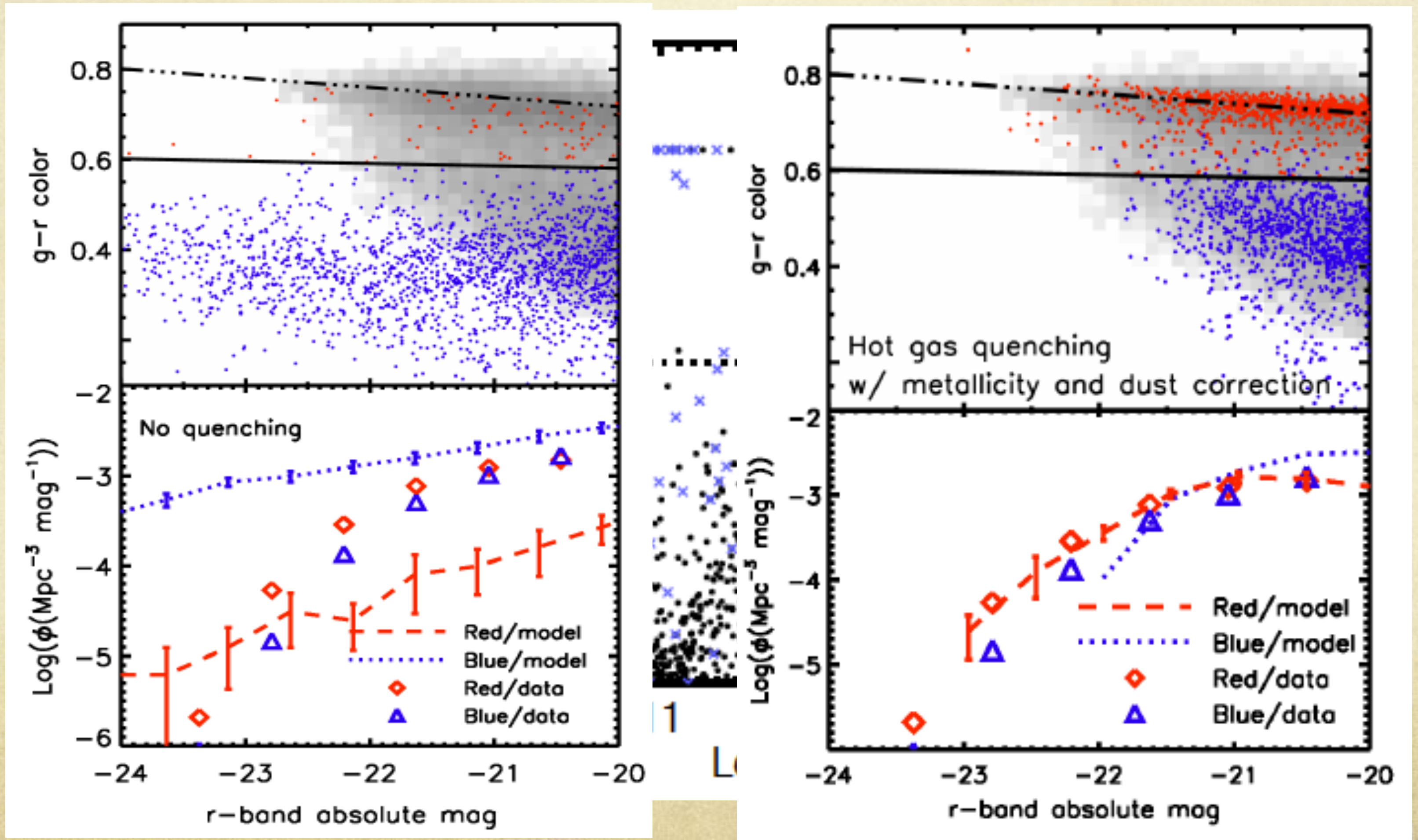


Measuring Preventive Feedback:
$SFR/Z = \zeta\, \dot{M}_{grav}/y$



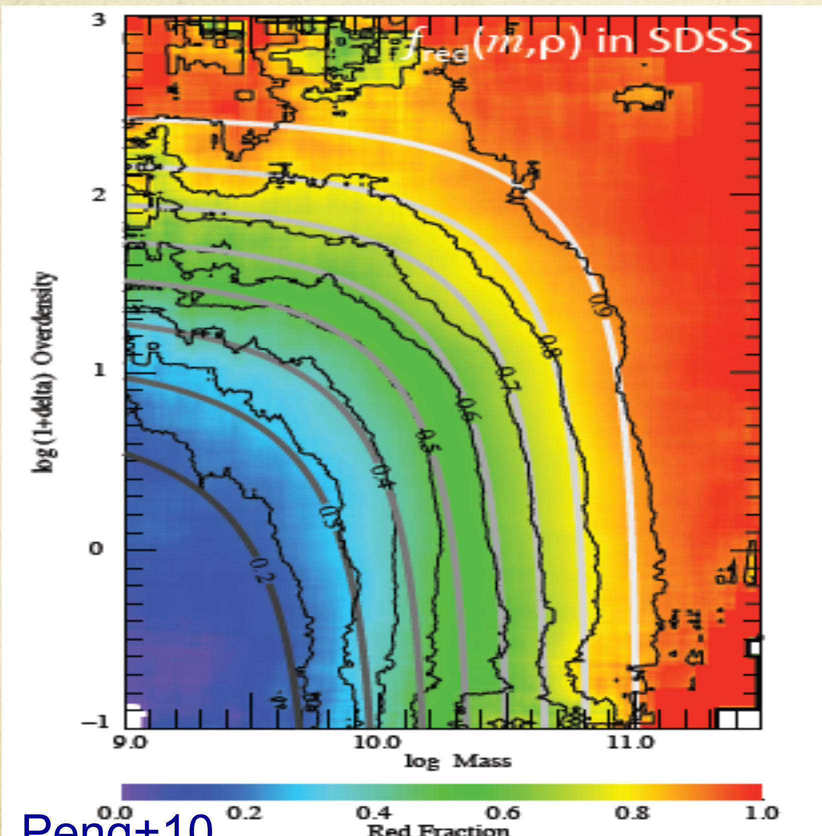
Quenching star formation

- Phenomenological model: Keep hot halos hot
  - Roughly equivalent to quenching when $M_{halo} > 10^{12}\ M_{\odot}$.

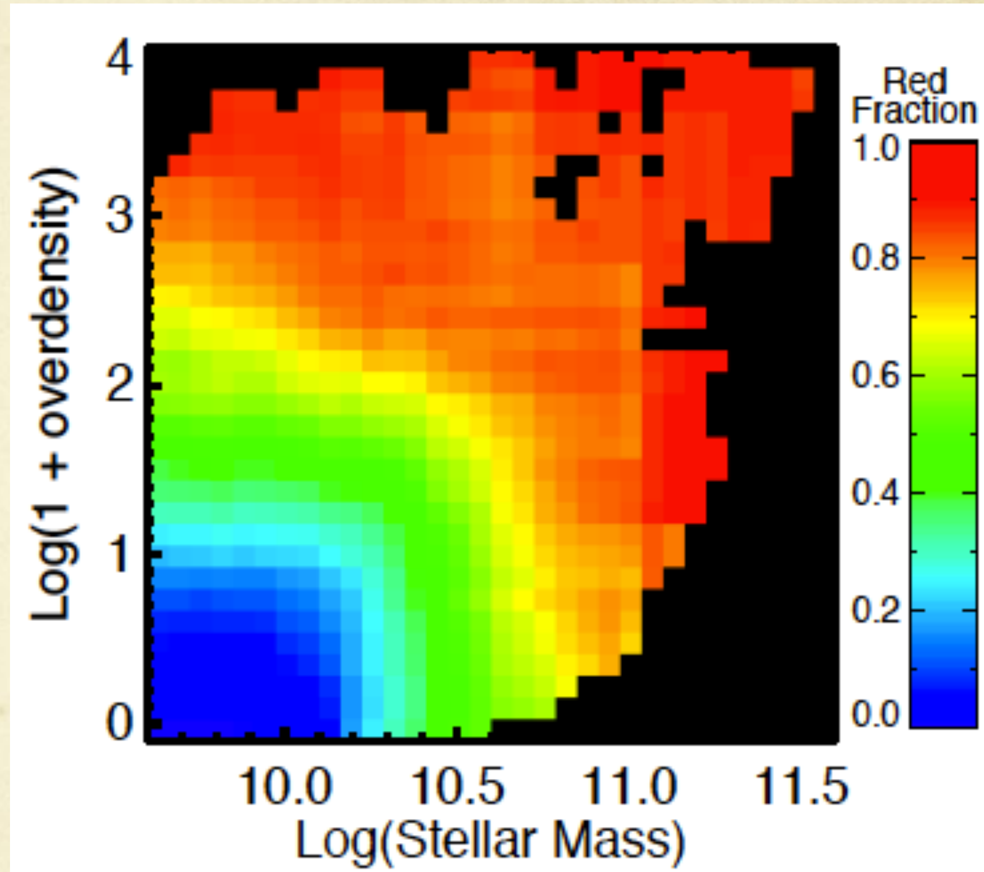


Environment & Mass Quenching

- Quenching separable in environ & mass



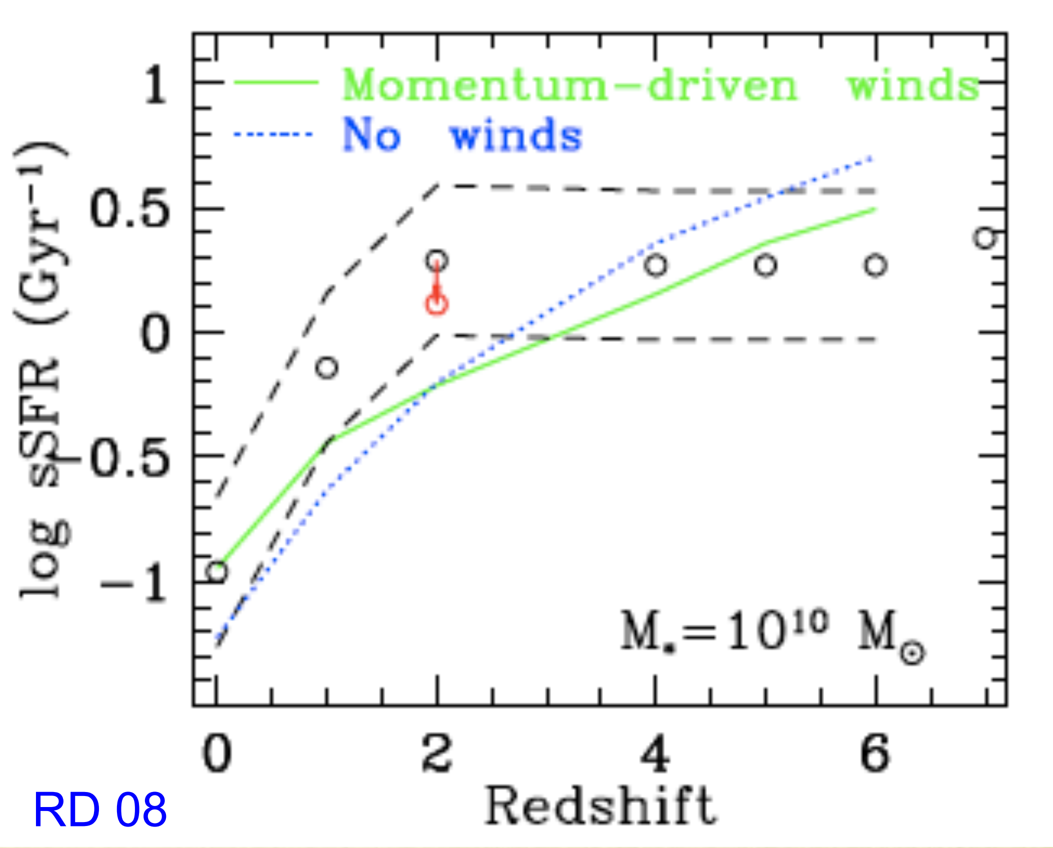
Peng+10



Gabor+RD 12

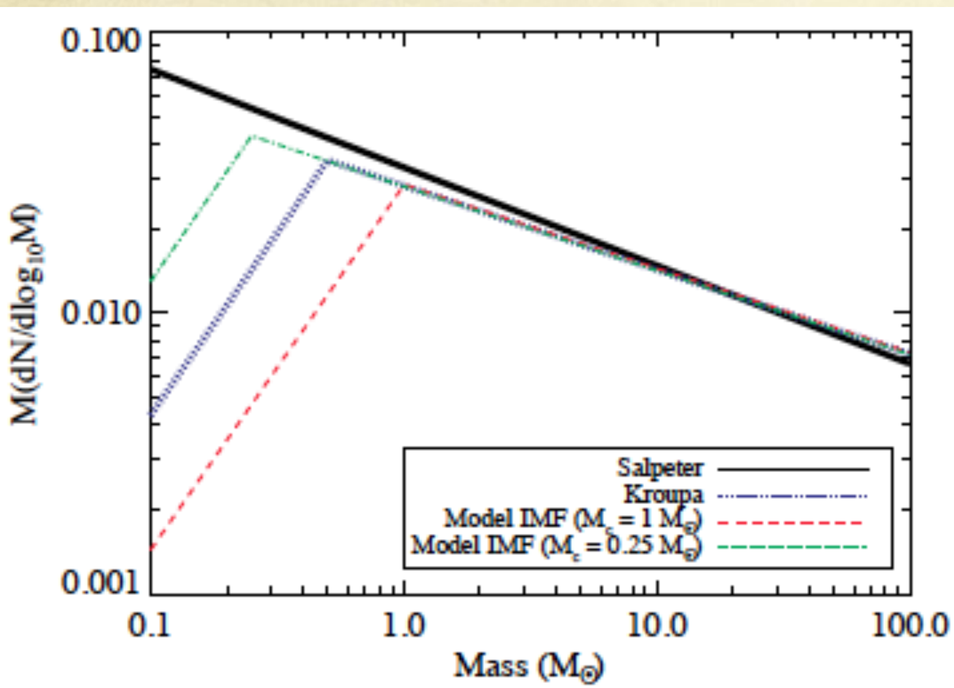
Main seq evolution: Not quite right

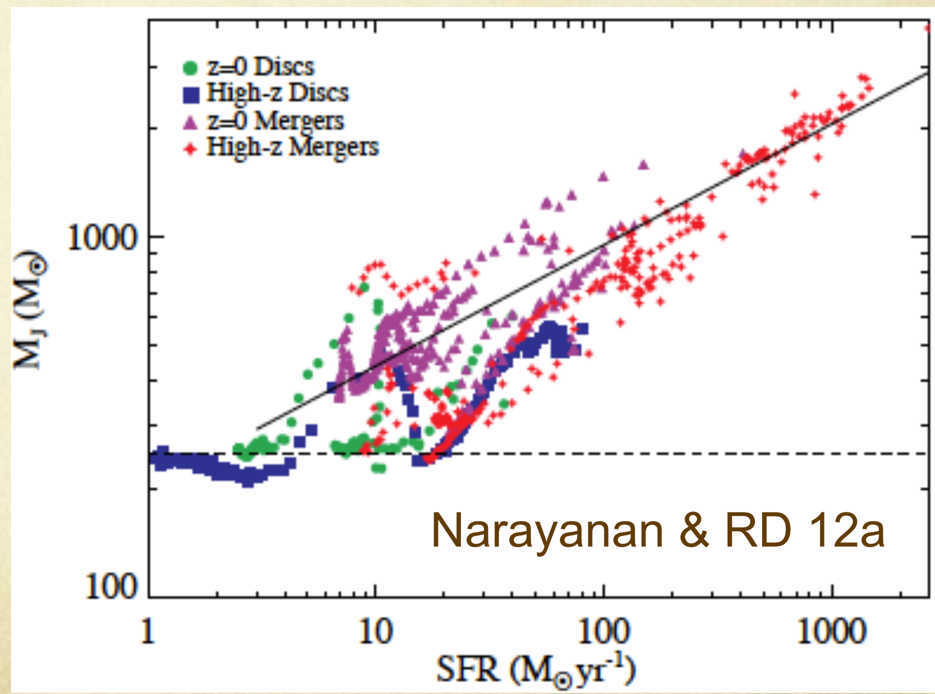
- Models get right:
  - Slope
  - Scatter
  - General evolution
- But amplitude evolution is wrong!
- Can't easily fix with feedback



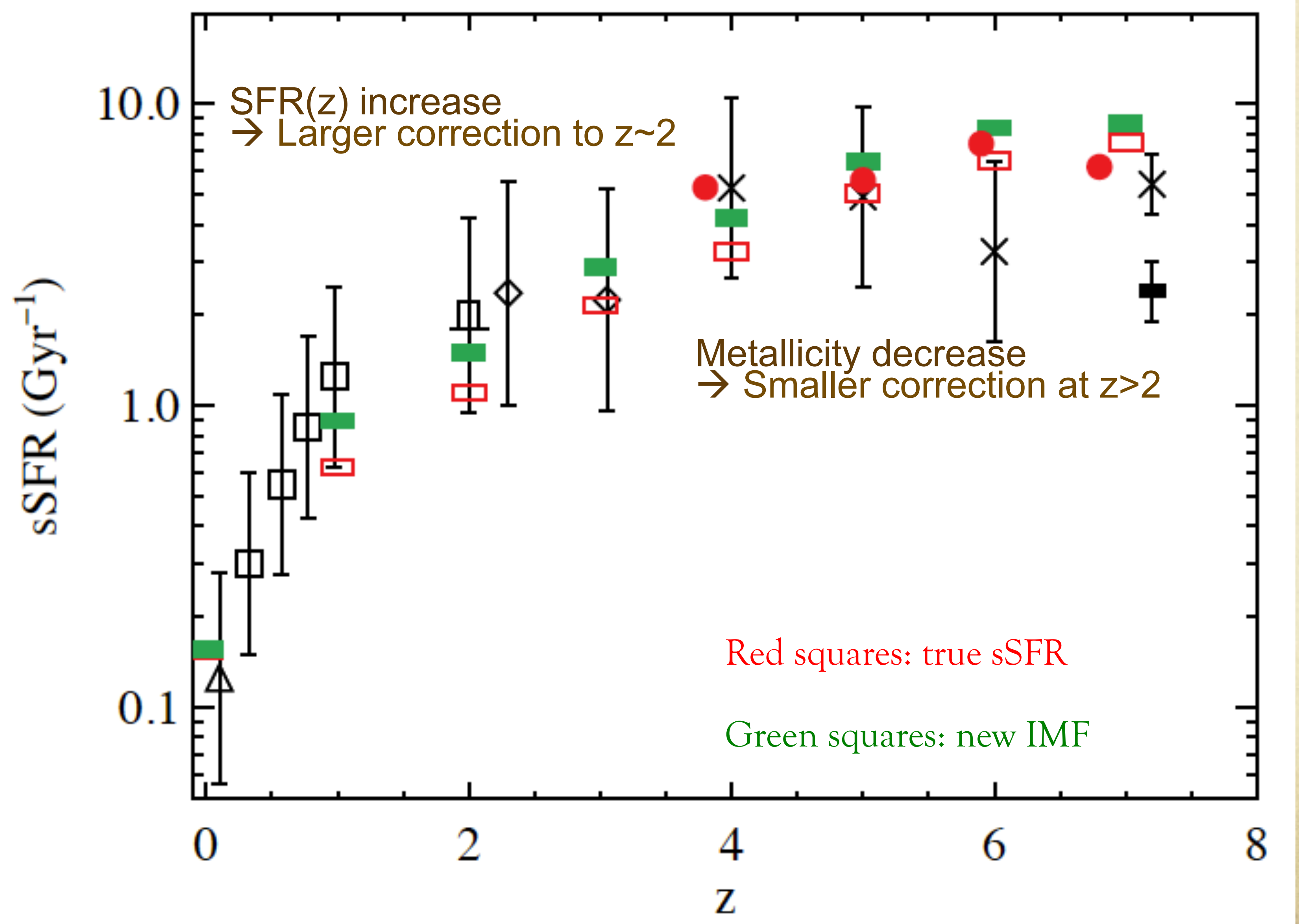
A physical model for a varying IMF

- Assume IMF characteristic mass scales with $\langle M_{jeans} \rangle_{H2\text{-weighted}}$.
- M_{Jeans}(SFR) from isolated disk/merger sims.
- SFR ~ $L_{IR}^{0.92}$ – peak SFR drops!



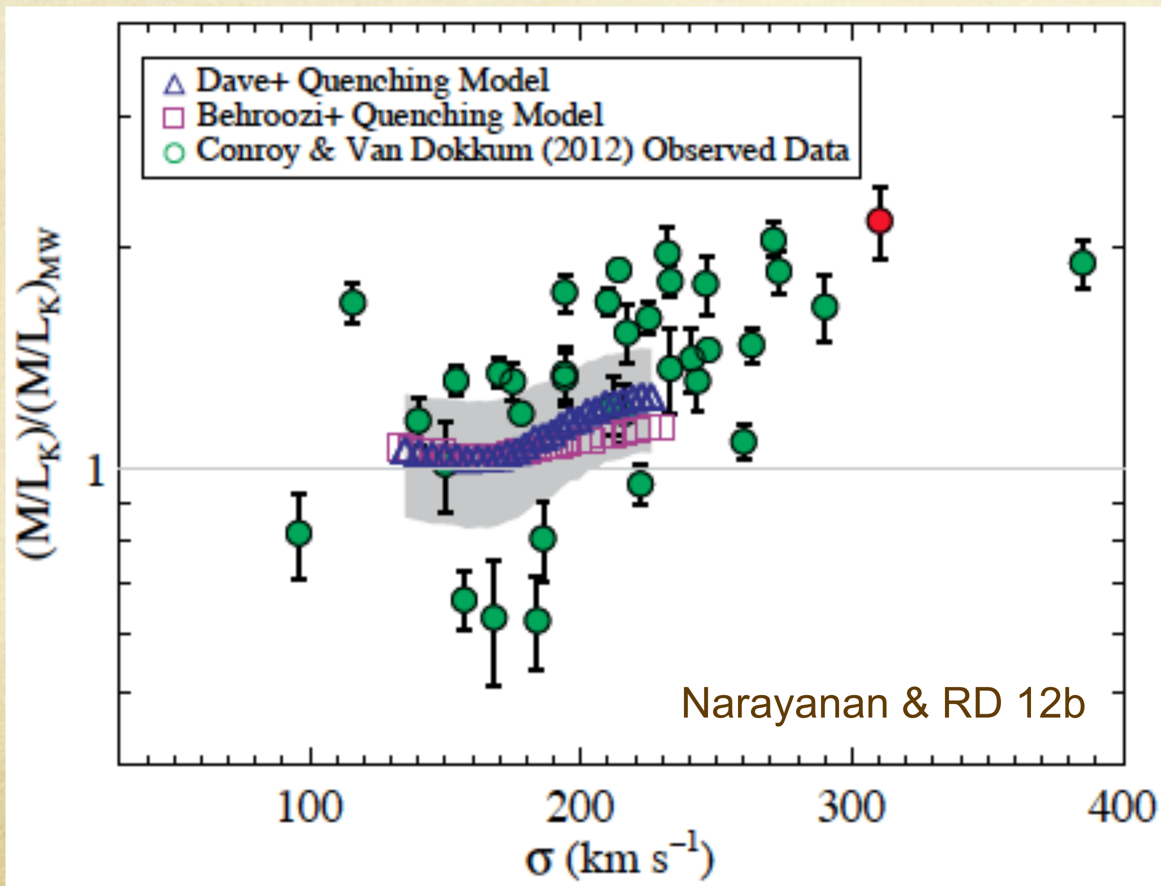


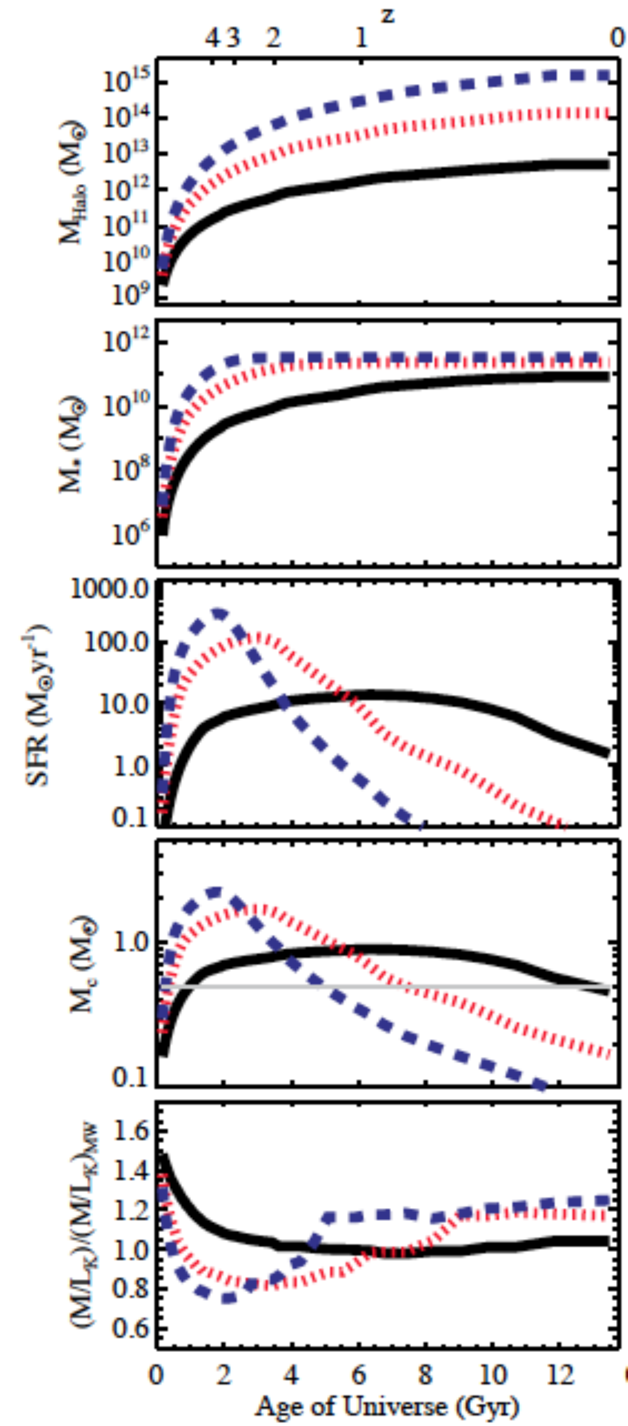
MS evolution with Varying IMF



Wait... isn't the IMF bottom-heavy? Yes!

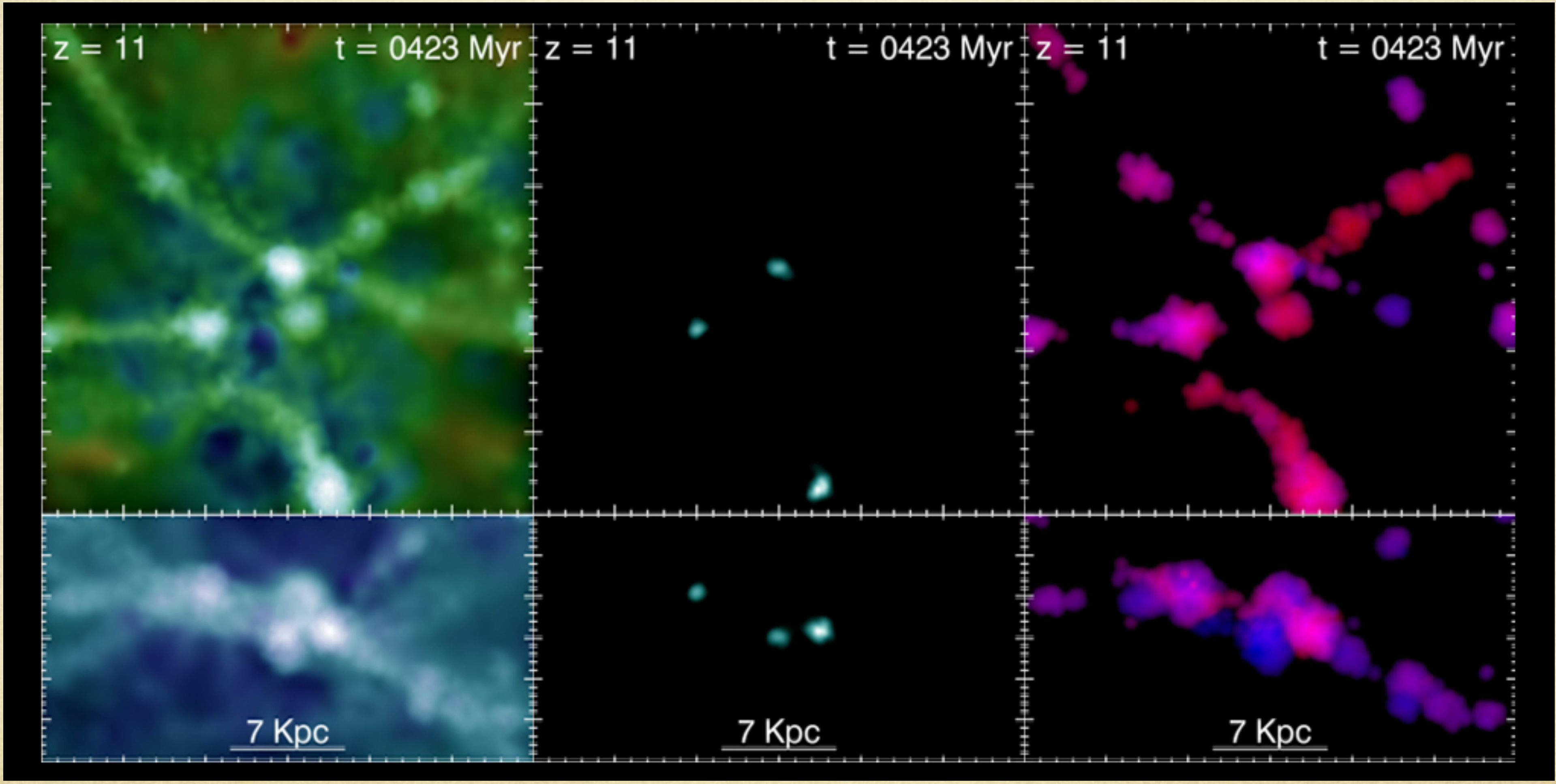
- Take SFH & Z from equilibrium model, get IMF evolution, predict M/L





Zoom disk simulations

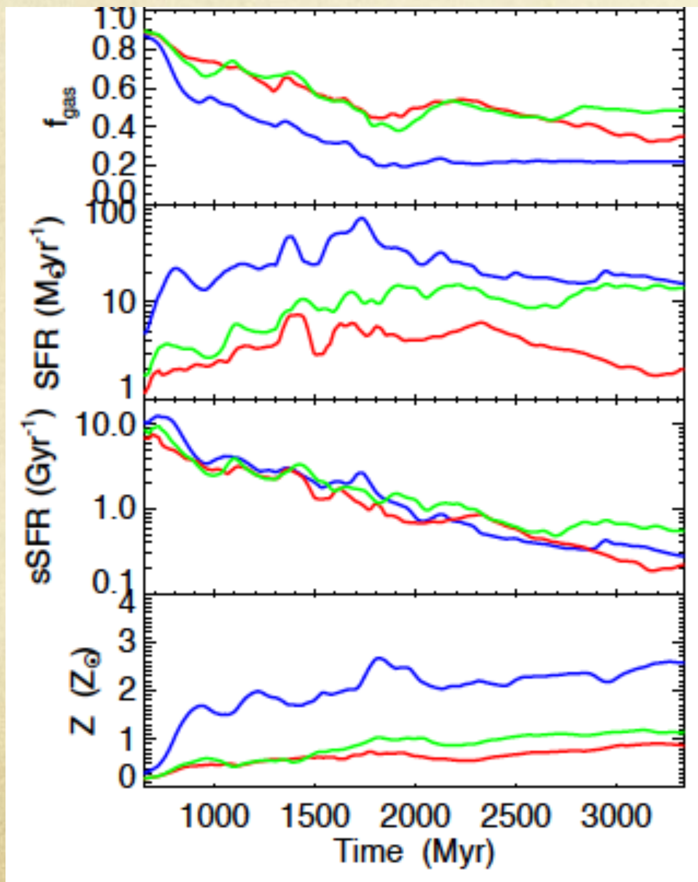
Density (color: T) SFR density LOS velocity

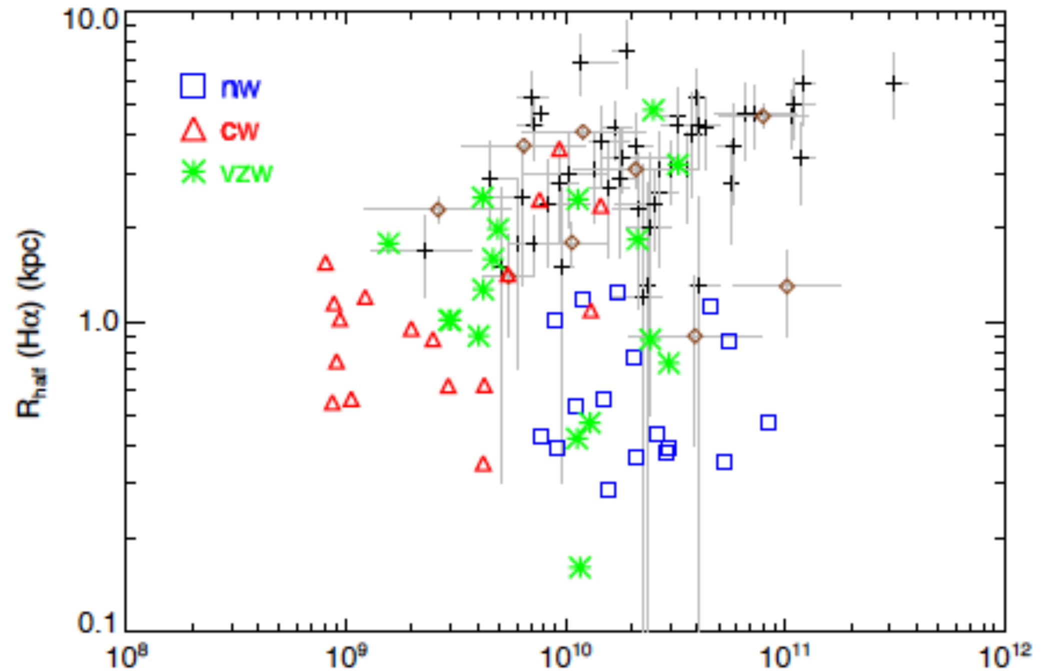


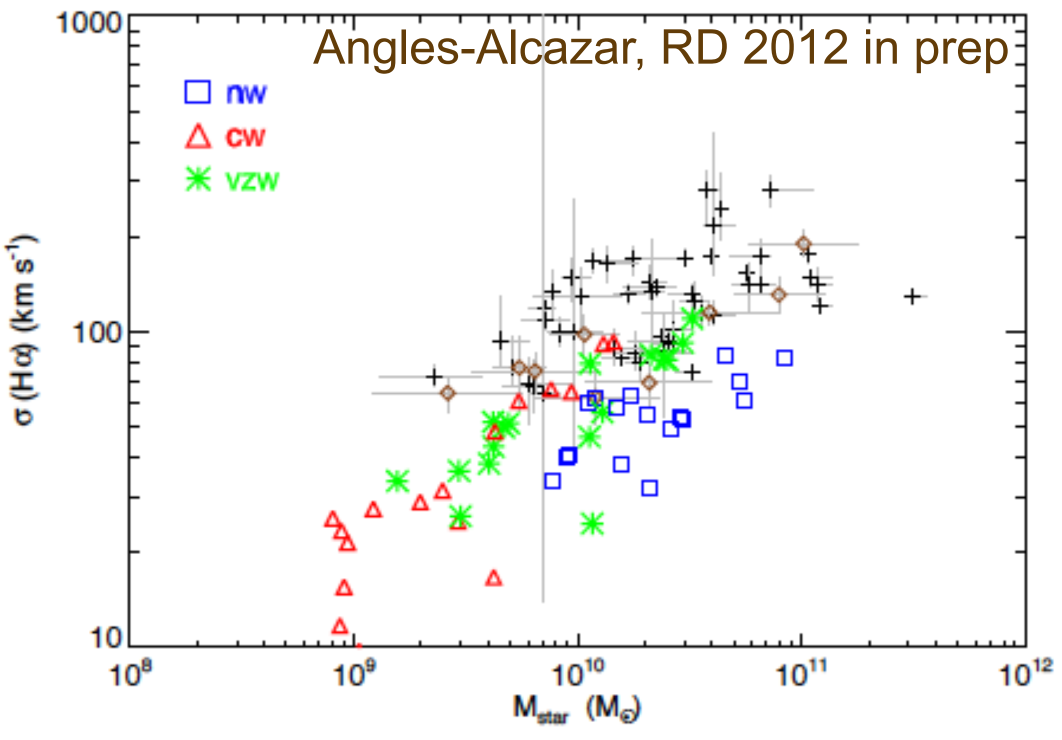
movie by D. Angles

Comparison to z=2 disks

- Winds detail SF and make disks larger & puffier.

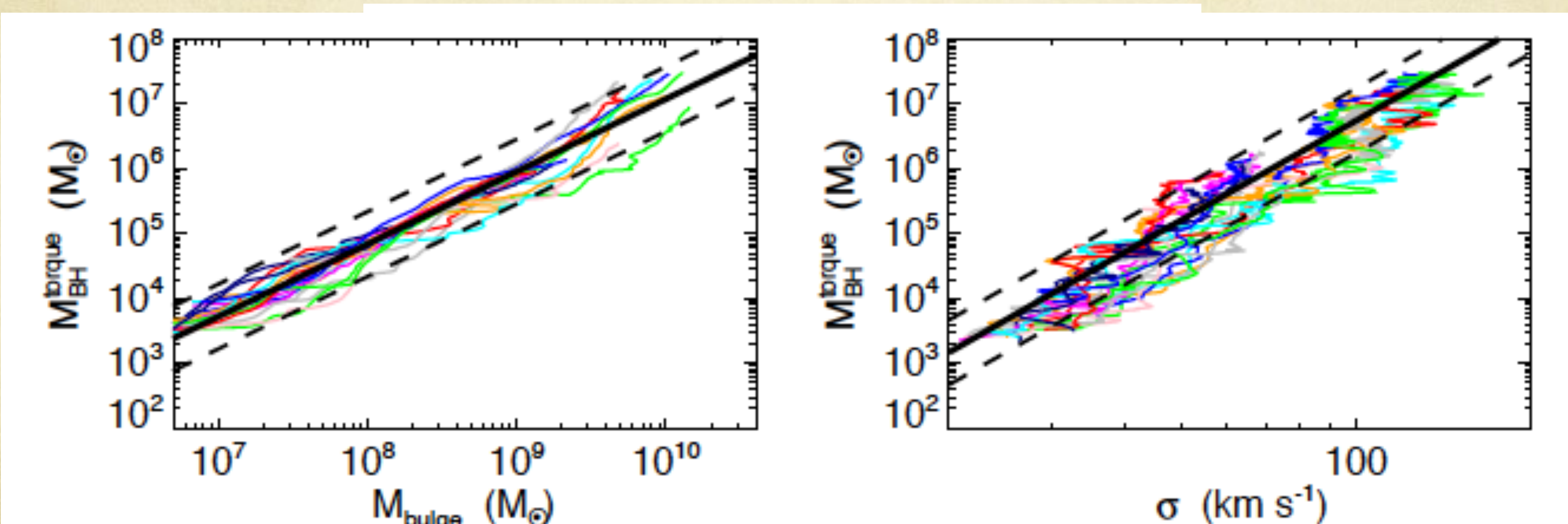






Is black hole growth self-regulated? Not necessarily...

- Bondi accretion: $\dot{M}_{BH} \sim M_{BH}^2$
- Torque-limited accretion: $\dot{M}_{BH} \sim M_{disk}\, M_{BH}^{1/6}$
- Bondi *requires* feedback to lie on M-σ; torque does not.



Angles-Alcazar, Ozel, RD in prep

M_{BH}^{acc} $(M_\odot yr^{-1})$

Summary

- Star formation histories of galaxies are driven by cosmic accretion. Average inflow sets scaling relations, stochasticity (mergers) drives the scatter. Feedback governs galaxy growth: Ejective (η), preventive (ζ), and recycling (α_Z).
- Characteristics of galaxies at various epochs are best understood in relation to main sequence, not by matching up SFR or M_*.
- Mild IMF variations where the M_{IMF}~M_{Jeans} gives top-heavy IMF at hi-z, bottom heavy in present-day massive ETGs.
- Zoom sims of z=2 disks show interesting phenomenology, including spin flips and puffing by wind recycling.