How Does Metallicity-Dependent Star Formation Affect Galaxy Formation?

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UCSC Galaxy Workshop 2011

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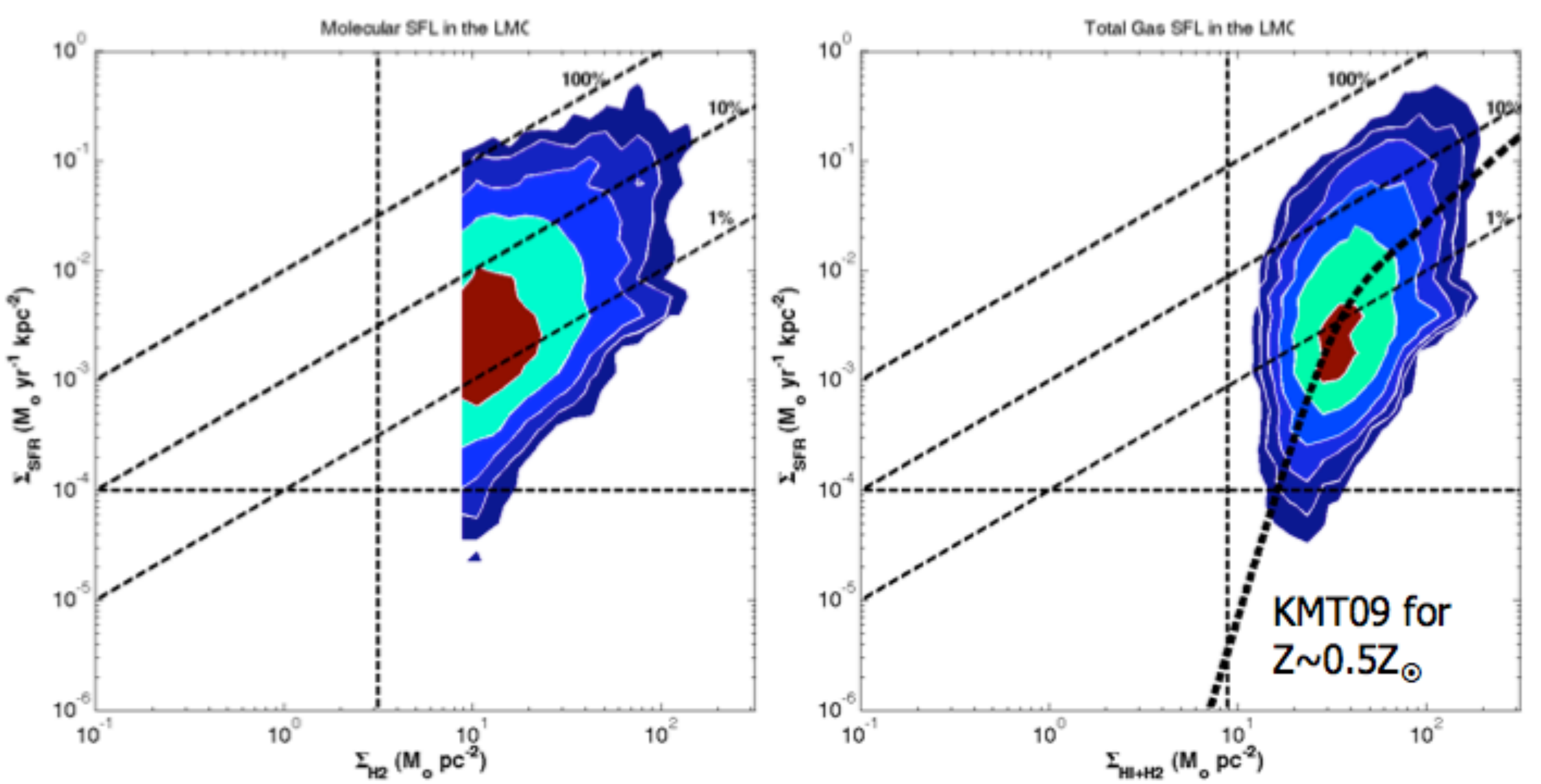
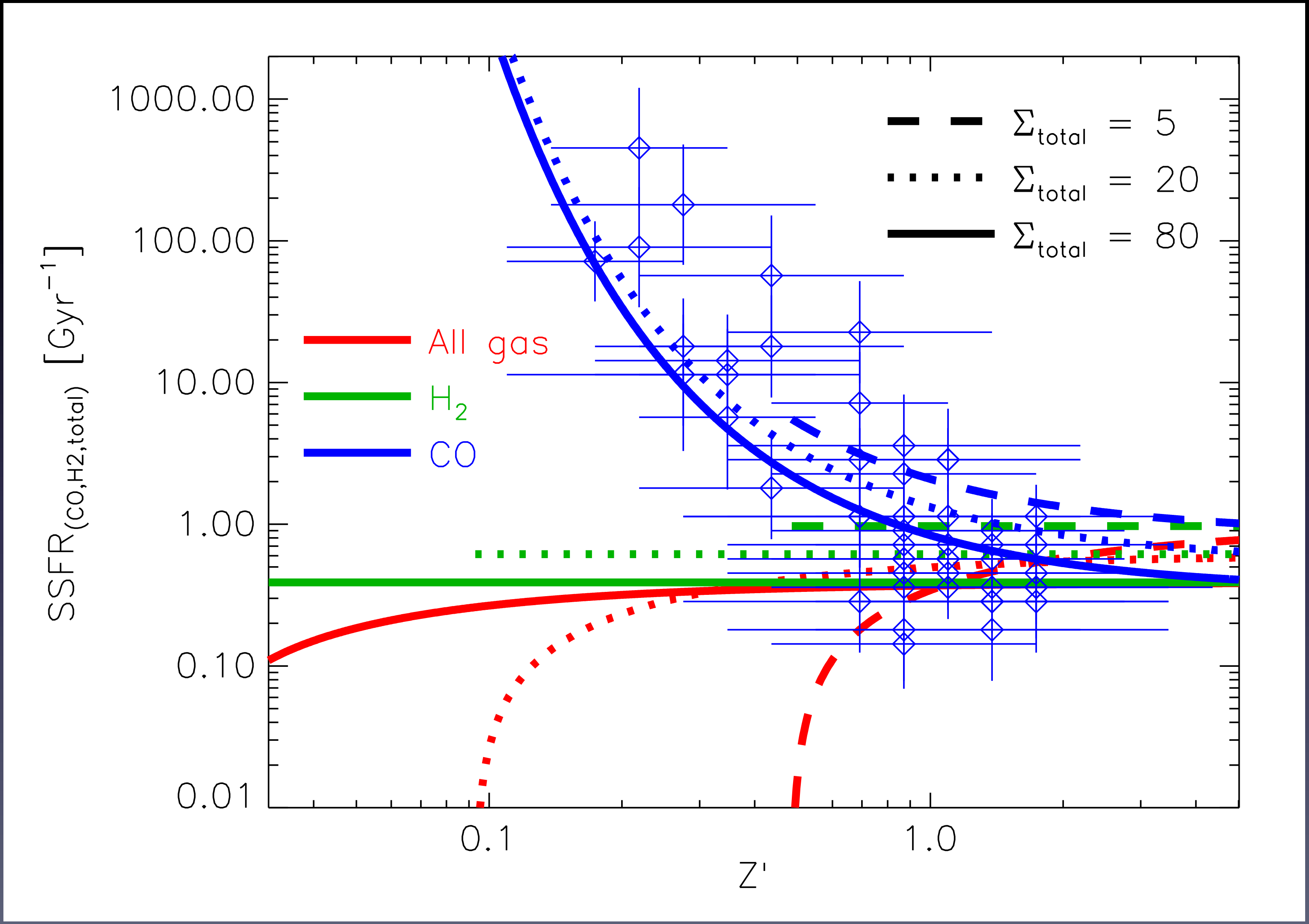
A Reminder Why This Matters

(data from Bolatto+ 2011)

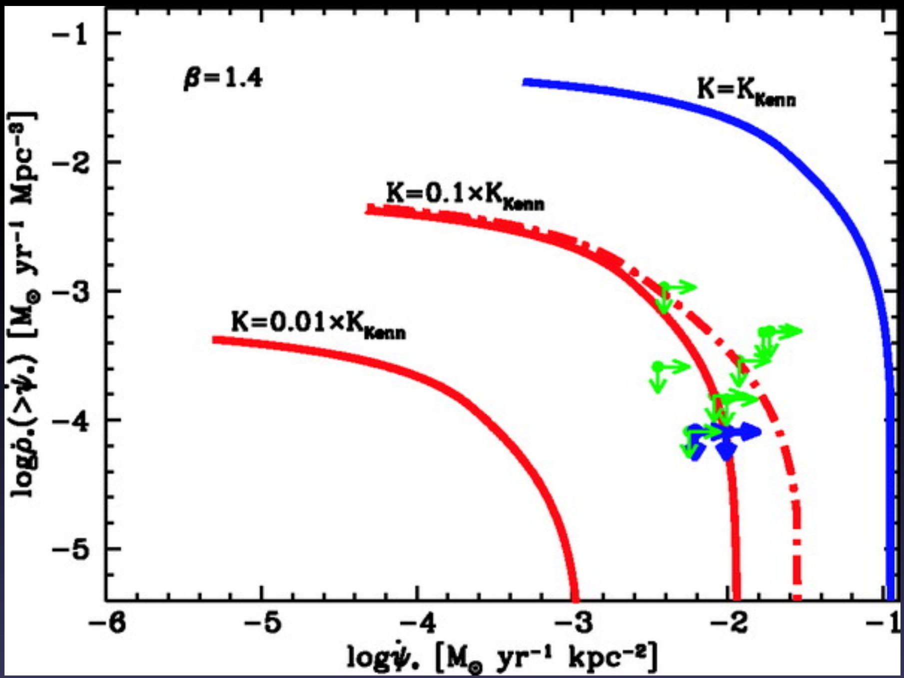


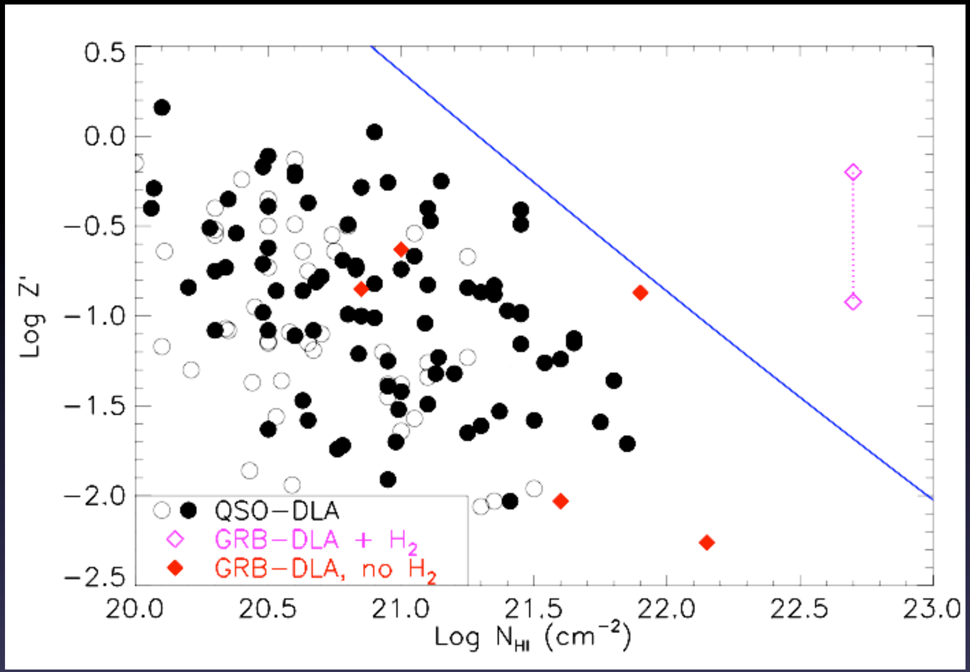
sSFR Depends on Phase

(Krumholz, Leroy, & McKee 2011)



DLAs Don’t Obey Local KS Law





Left: z ~ 3 galaxy density if the DLAs follow the Kennicutt (1998) SF law; data plus expectations (Wolfe & Chen 2006)

Right: DLA column density and metallicity distribution, plus line showing HI - H_2 transition (Krumholz+ 2009; also see Schaye 2001, Gnedin & Kravtsov 2010)

So how does all of this change our picture of galaxy formation?

Two approaches:

1) Simulations (M. Kuhlen's talk)
2) SAMs / toy models (this talk)

Our Main Tool: an Analytic Model for HI / H_2 Balance

(Krumholz, McKee, & Tumlinson 2008, 2009; McKee & Krumholz 2010)

Approximate the system as being in approximate chemical equilibrium:

Formation on grains = Photodissociation

$$n_{\mathrm{HI}} n \mathcal{R} = n_{\mathrm{H}_2} \int d\Omega \int d\nu \, \sigma_{\mathrm{H}_2} f_{\mathrm{diss}} I_\nu / (h\nu)$$

$$\hat{e} \cdot \nabla I_\nu = -(n_{\mathrm{H}_2} \sigma_{\mathrm{H}_2} + n \sigma_{\mathrm{d}}) I_\nu$$

Decrease in radiation intensity = Absorptions by H_2 molecules + dust grains

Idealized problem: spherical cloud of radius *R*, density *n*, dust opacity σ_d, H_2 formation rate coefficient $\mathcal{R}$, immersed in radiation field with LW photon number density E_0^*, find fraction of mass in HI and H_2.

Predictions for H_2 Content

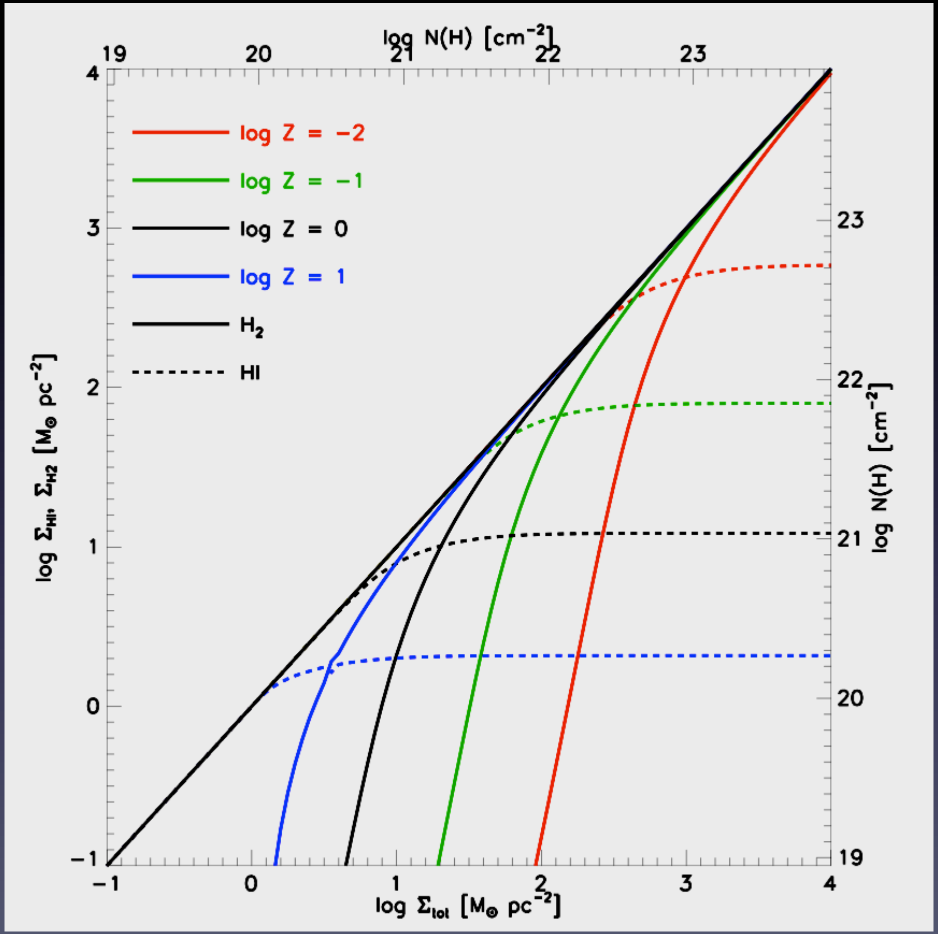
- Bottom line

$$f_{\mathrm{H}_2} \approx 1 - \frac{3}{4}\left(\frac{s}{1+0.25s}\right)$$

$$s \approx \frac{\ln(1+0.6\chi+0.01\chi^2)}{0.04\left(\frac{Z}{Z_\odot}\right)\left(\frac{\Sigma}{M_\odot\ \mathrm{pc}^{-2}}\right)}$$

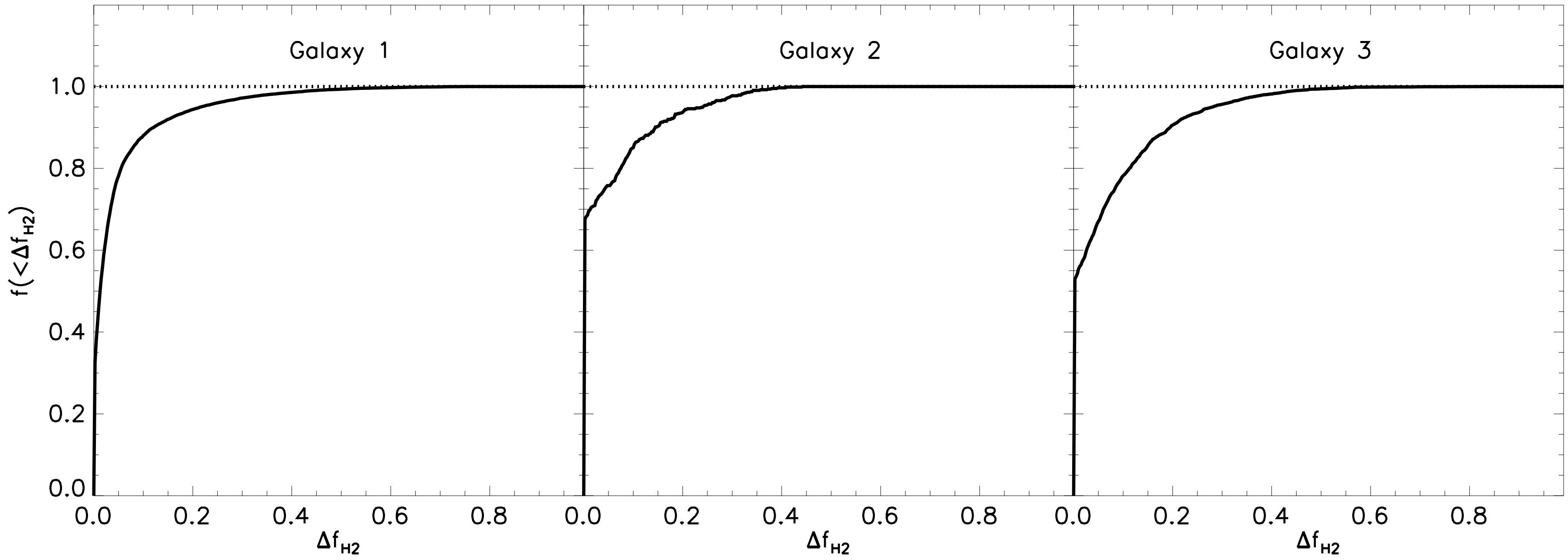
$$\chi \approx 3.1\,\frac{1+3.1\left(\frac{Z}{Z_\odot}\right)^{0.365}}{4.1}$$

- Qualitative effect: f_{H_2} goes from ~0 to ~1 when $\Sigma Z \sim 10\ M_\odot\ \mathrm{pc}^{-2}$



Model vs. simulations with full H_2 chemistry

(Krumholz & Gnedin 2011)



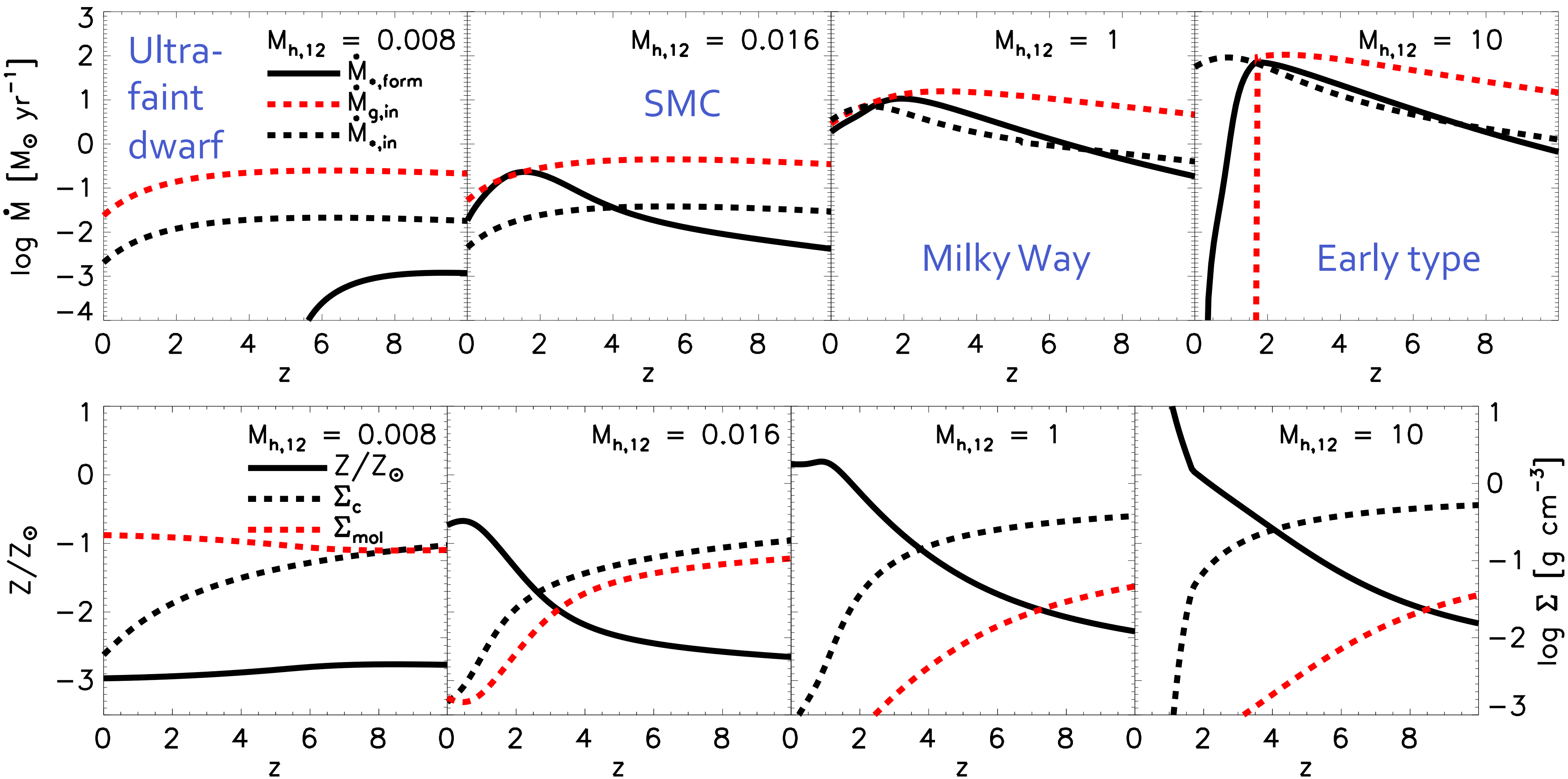
Comparison between model and time-dependent chemistry / radiative transfer code for 3 galaxies with $Z = 0.01 - 0.5\ Z_{\odot}$, UV field 7x – 100x MW value

A Toy PS-Based Model

(Krumholz & Dekel 2011)

- Simple model that follows main halo
- Baryonic accretion rate from PS, with cutoff due to virial shock heating at high masses and late times
- Assume exponential disk with scale length proportional to R_{vir}, compute SFR from KMT model
- Metallicity buildup: instantaneous recycling approximation + mass-dependent ejection

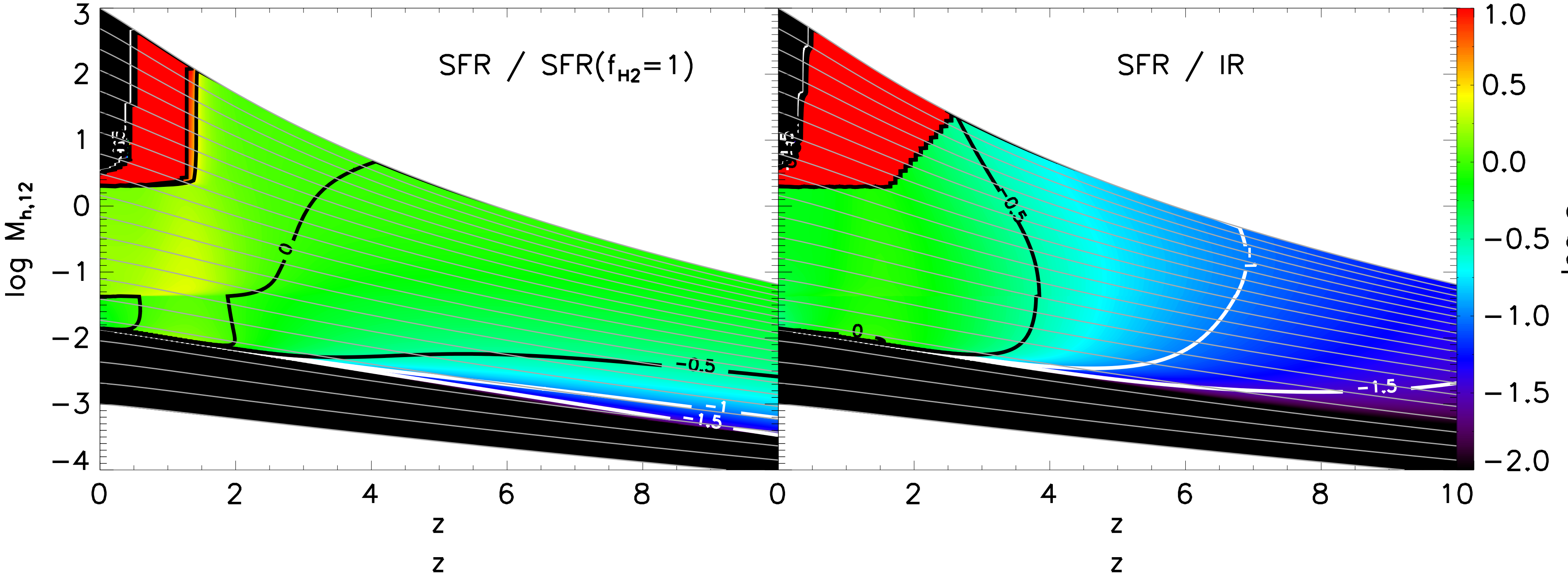
History of Individual Halos



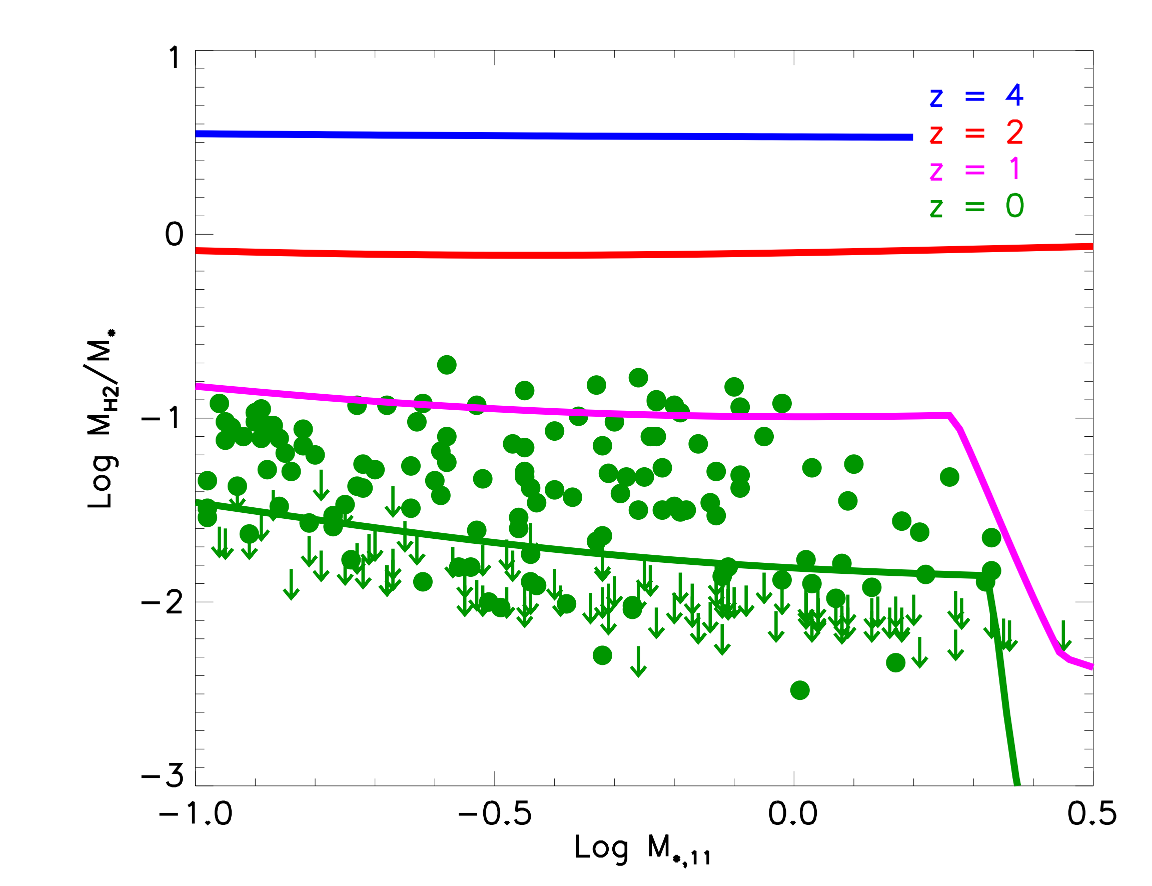
Evolution of total rate and SFR (top)
Evolution of metallicity, surface density (bottom)

Comparison to fiducial model with no
metallicity-dependence

SFR in all Halos

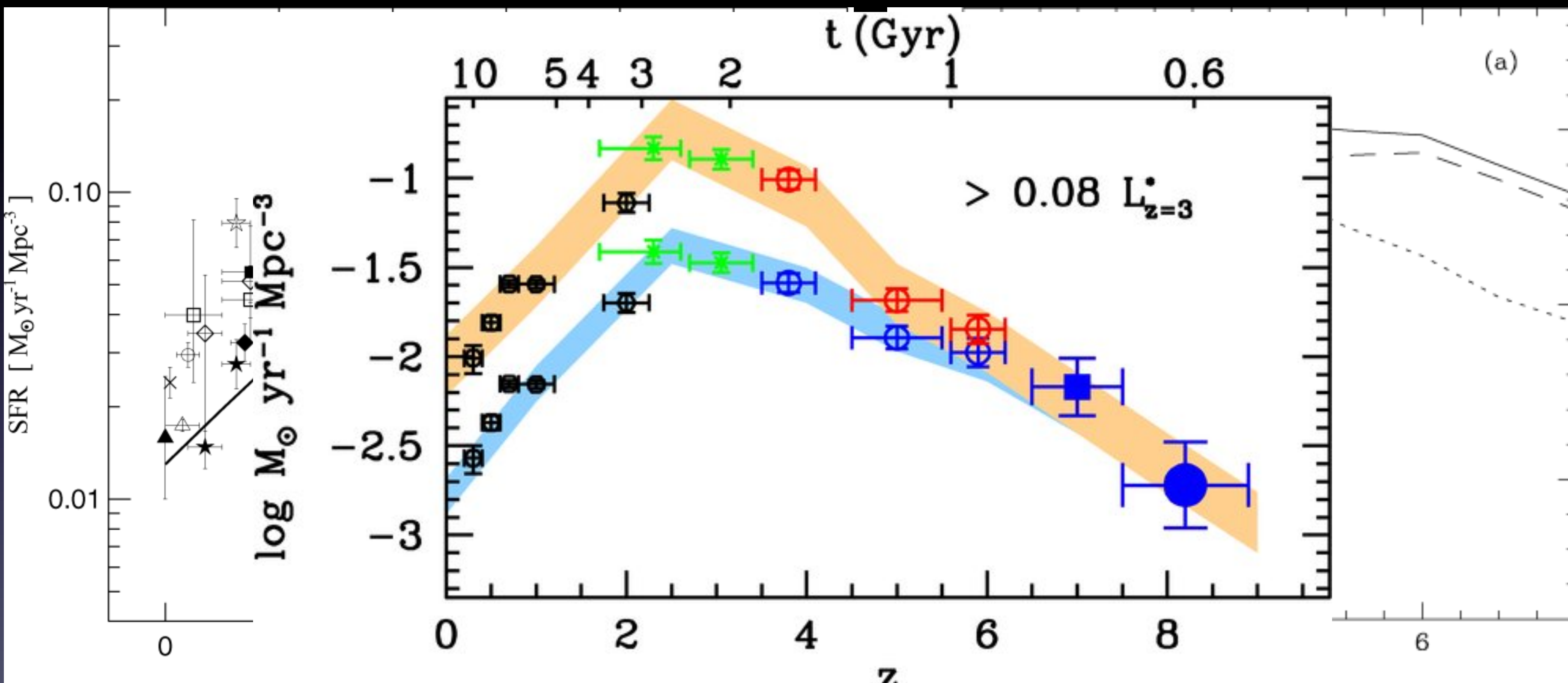


Observational Comparison: H_2 Mass vs. Stellar Mass



H_2 / stellar mass vs. stellar mass as a function of redshift (lines = model, points = nearby galaxies from COLDGASS, Saintonge+ 2011a, 2011b)

Fixing the SF History of the Universe

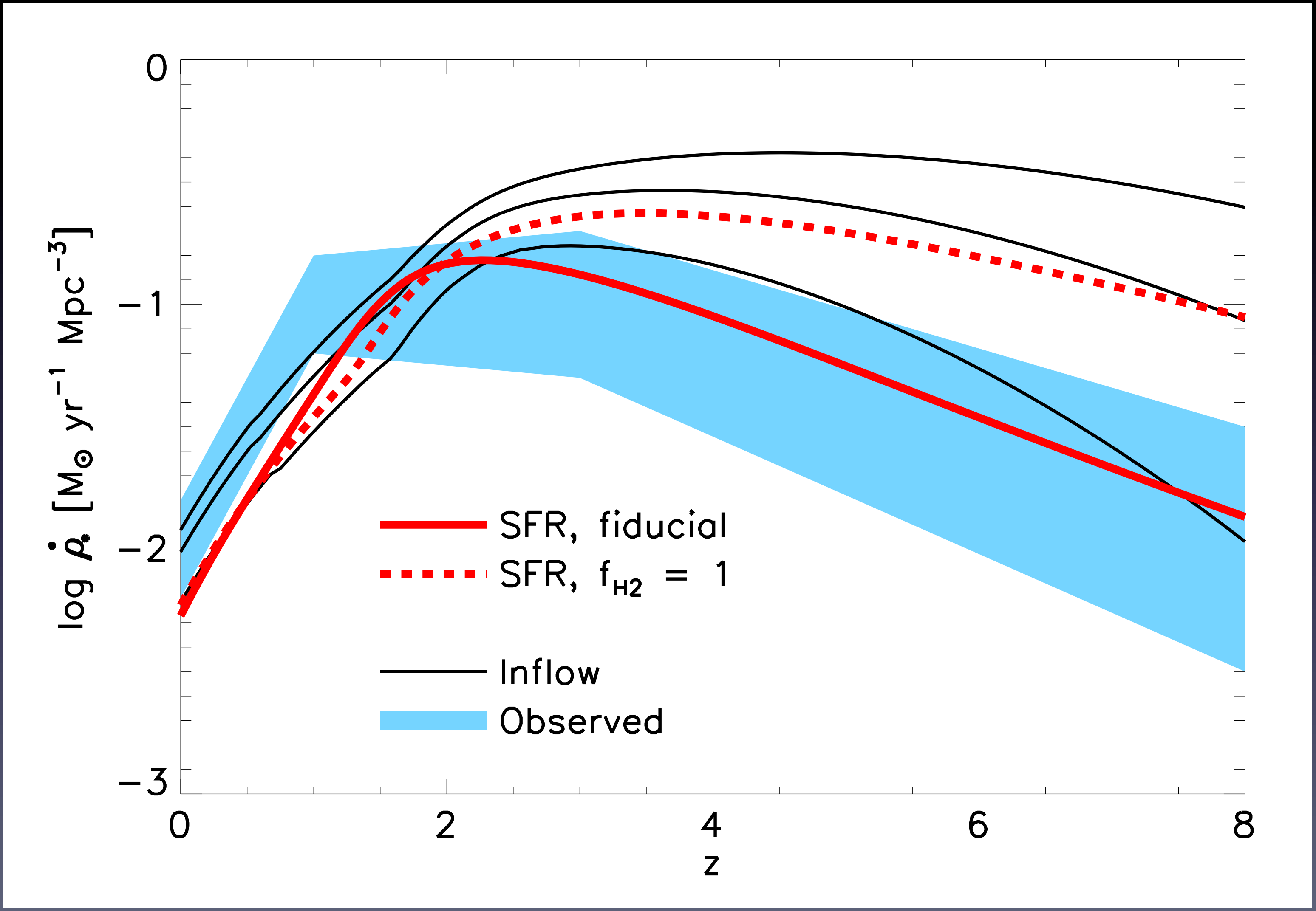


SF history from cosmological simulations (Springel & Hernquist 2003)

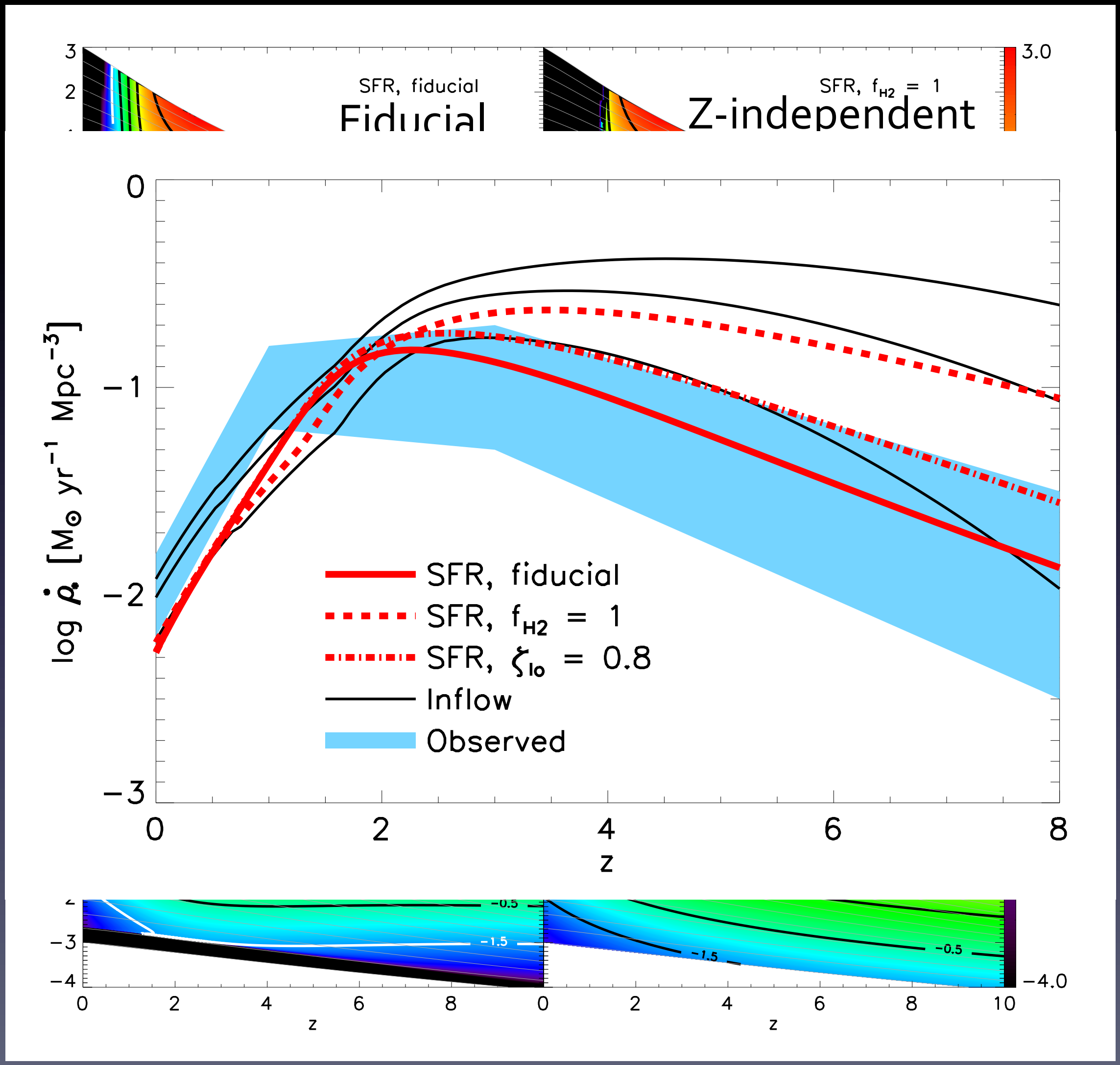
Observed SF history of the universe (Bouwens et al. 2010)

SF history from a SAM (Baugh et al. 2005)

Observed vs. Model SF History



What Matters In These Models?



The results are most sensitive to how well very small galaxies (M_h <~ 10^9 $M_\odot$) are able to retain their metals.

Lessons Learned and Future Work

- Metallicity-dependent star formation makes no difference in MW-sized galaxies, but makes a large difference at SMC scales
- Metal ejection, IGM mixing, re-accretion make a big difference; this needs numerical work
- Cosmological averages that depend on the faint end of the luminosity function needs to be re-evaluated