Cosmic Star Formation History in ΛCDM Cosmology

Metal cooling & SF model

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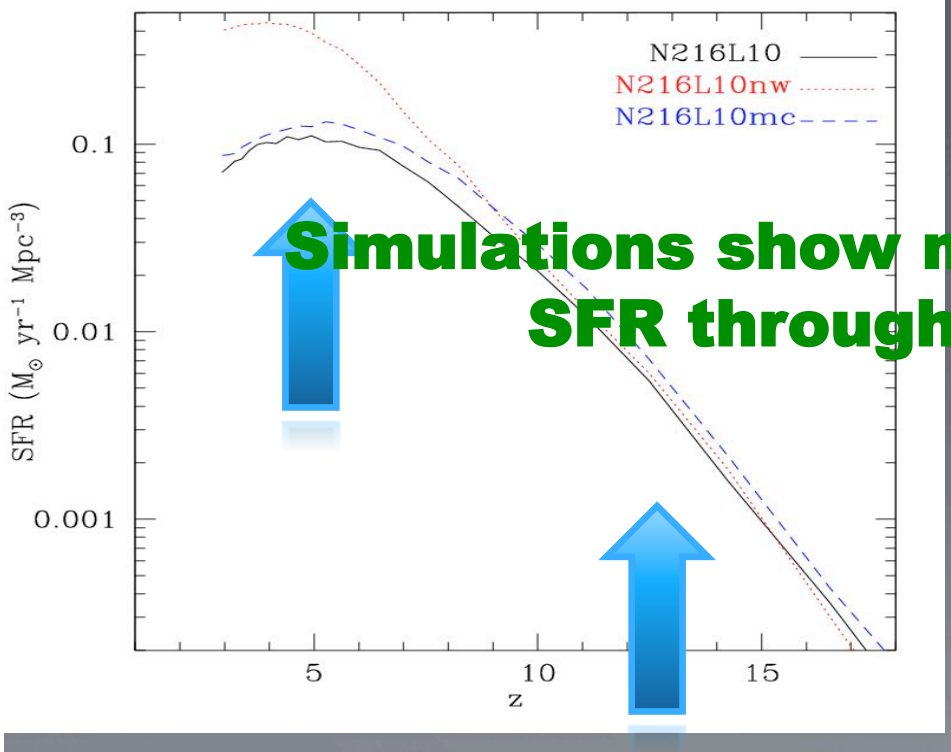
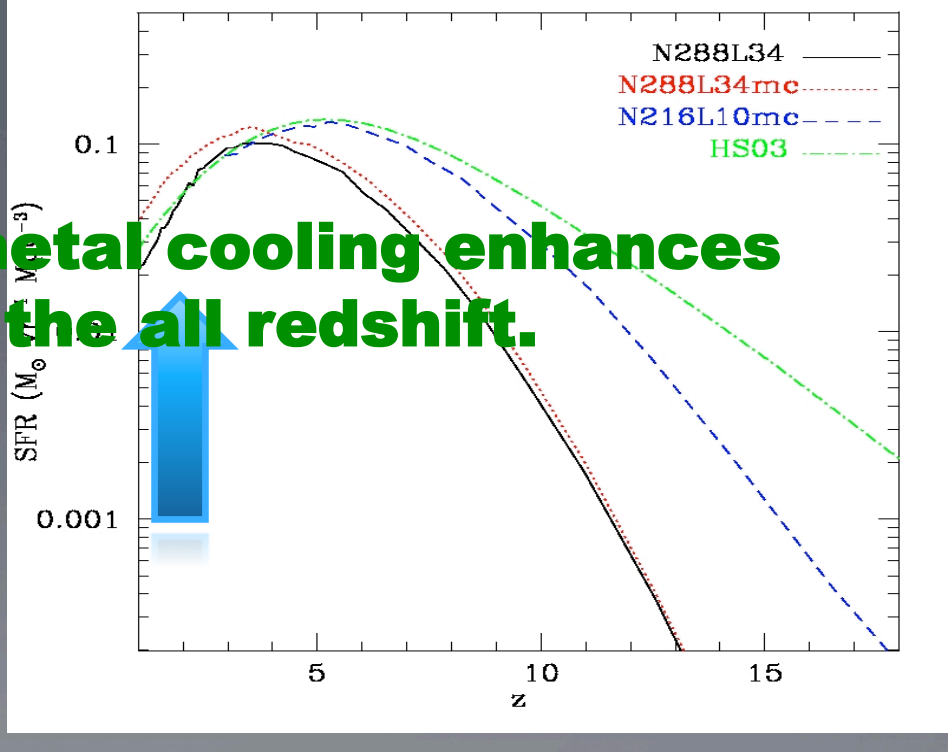
Metal cooling effect on cosmic SFR

- Motivation
  - Metal cooling can enhance SFR. But it has not yet been rigorously and quantitatively tested.
  - Hernquist & Springel 2003 claimed that metal cooling enhances SFR ~10% at low z (z<3): By increase IGM accretion
- Simulations (N-body/SPH simulation; Gadget-3)
  - (Ω_m, Ω_Λ, Ω_b, σ_8, h)= (0.3 , 0.7, 0.04 , 0.85, 0.7)
  - Metal enrichment due to star formation and SNe II
  - Metal cooling uses Sutherland & Dopita 1993.
  - Runs
    - N216L10 : 10 h^{-1}Mpc with 2×216^3 particles up to z=3
    - N288L34 : 33.5 h^{-1}Mpc with 2×288^3 particles up to z=1

Cosmic Star Formation History

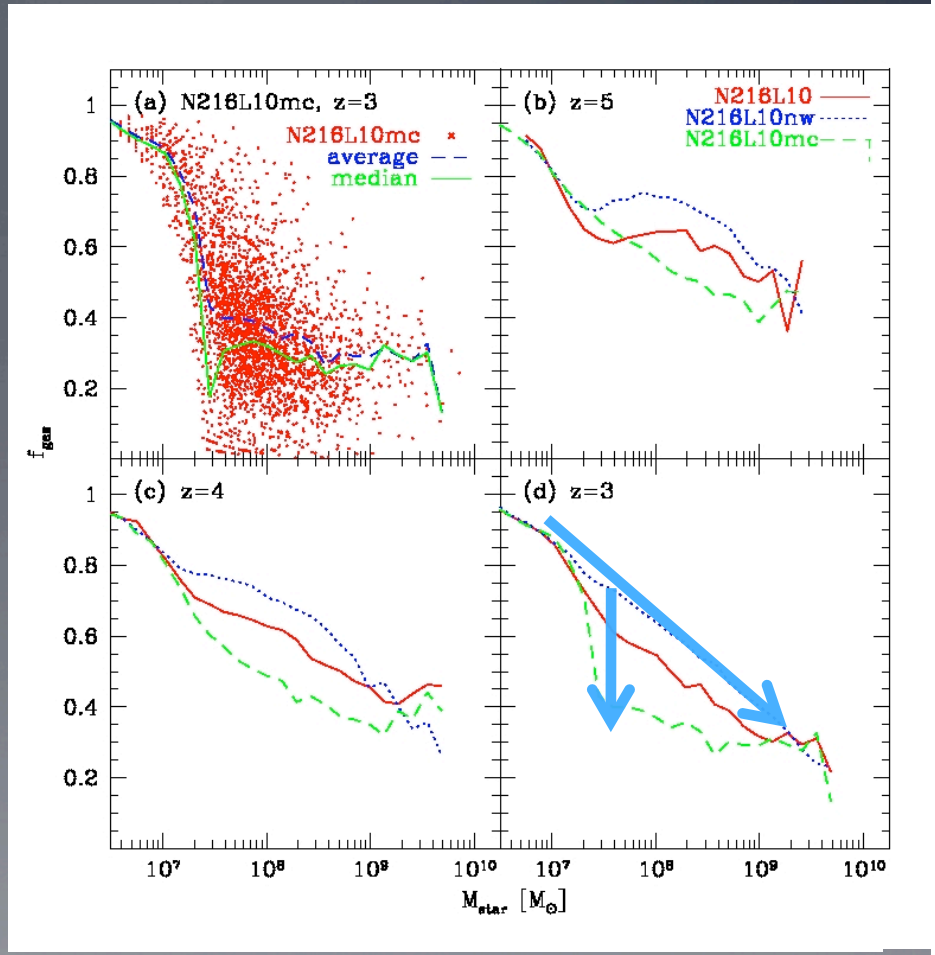




Simulations show metal cooling enhances SFR through the all redshift.

How Does Metal Cooling Enhance SFR?

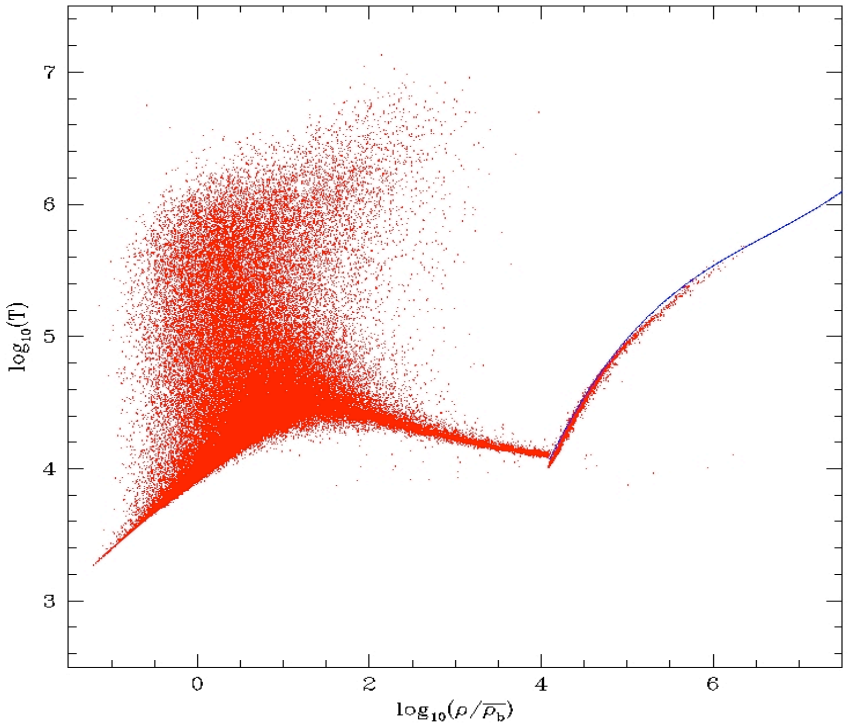
- Metal cooling enhances gas cooling.
- Increase IGM accretion to galaxy
  - Only in low z (z < 3) → Need time to mix
- Increases SF efficiency (ISM to star conversion in a galaxy)
  - Short mixing time
  - All redshifts

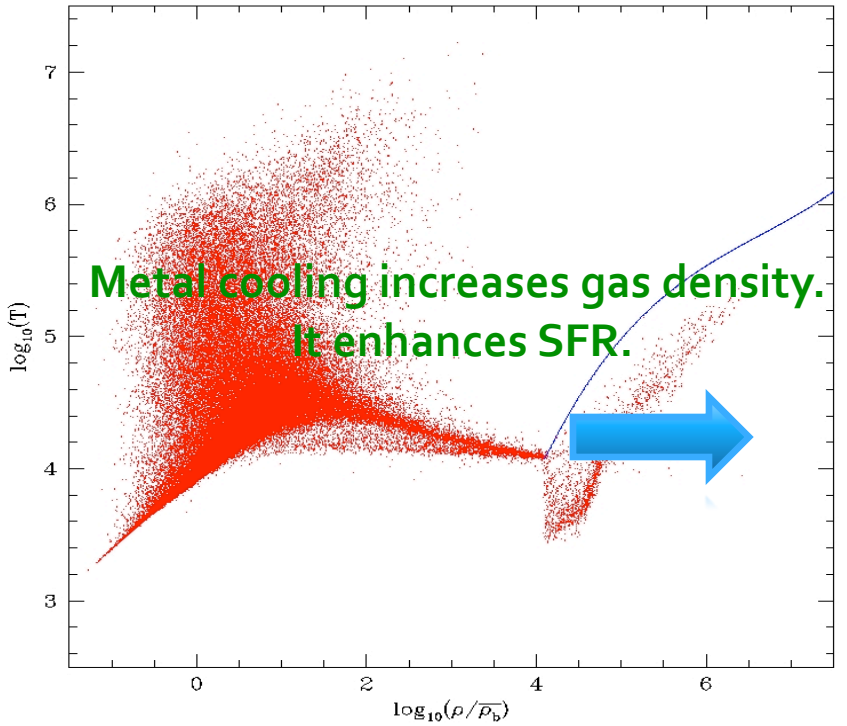


Increased SF efficiency reduces f_{gas} for given galaxies (z > 3)

How to increase SF efficiency?

Gas Phase Diagram at z=3

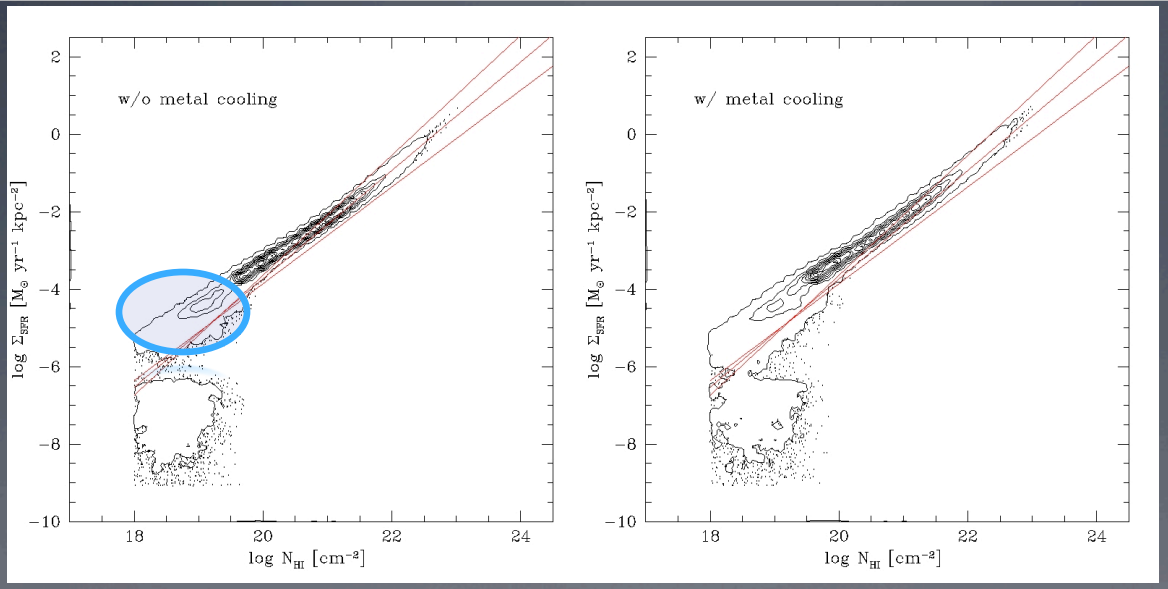




w/o Metal cooling

w/ Metal cooling

Kennicutt-Schmidt Law



- Metal cooling enhances SFR without violating Kennicutt law.
- Metal cooling increases gas density and denser gas causes enhanced SF.
- Over prediction in low density
- Low density threshold (10^{20}cm^{-2} ~ 1 $M_\odot$ pc^{-2})
- Need to test SF model

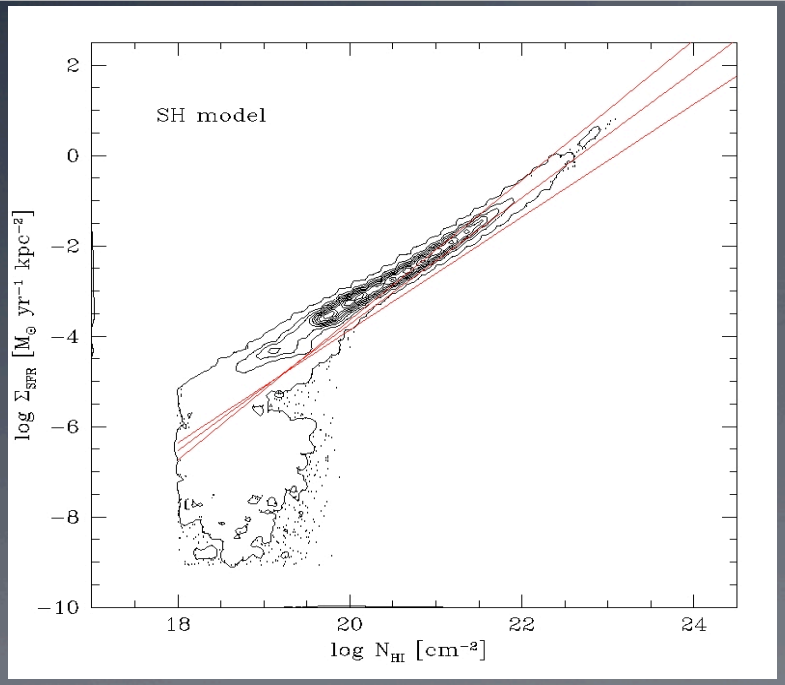
Star formation model

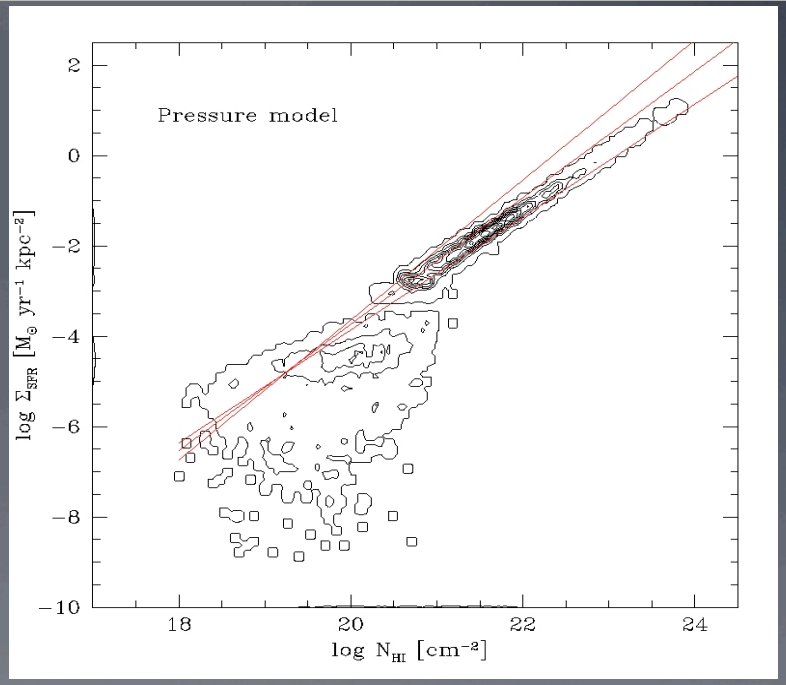
- Previous model (Springel & Hernquist 2003 : SH model)
  - Based on Kennicutt-Schmidt law: $t_{sfr} = t_0 (\rho/\rho_{th})^{1.5}$, where t_0 is 2.1 Gyr
  - Multiphase SPH particle : Hot phase and cold phase
- Issues of star formation in cosmological simulation
  - Predict large population of high z stars
    - Peak of the Madua plot z~5 in simulations (z~3 in observations)
  - The Σ_{SFR} is a function of Σ_{H_2} instead of Σ_{gas}
  - Assuming the constant disk scale height $\Sigma_{gas} / \Sigma_{SF} = \rho_{gas} / \rho_{SF}$
  - More issues in KS law

Testing New Star formation model

- Pressure model
  - Σ to ρ : using Jeans column density from Schaye & Dalla Vecchia 2008
    - $\Sigma_{gas} = \rho L_J$
    - Including a scale height dependence
    - Including the disk instability
    - May capture contribution of Σ_{H_2}
  - Using the polytrophic EOS for cold gas with $\gamma_{eff} = 4/3$
    - Reduce artificial collapse around Jeans equilibrium
- Simulations:
  - $(h, \Omega_\Lambda, \Omega_m, \Omega_b h^2, n_s, \sigma_8) = (0.72, 0.74, 0.26, 0.022, 0.96, 0.8)$
  - N216L10 : 10 h-1Mpc with 2×216^3 particles up to z=3
  - N400L100 : 100 h-1Mpc with 2×400^3 particles up to z=0

Star formation density relation

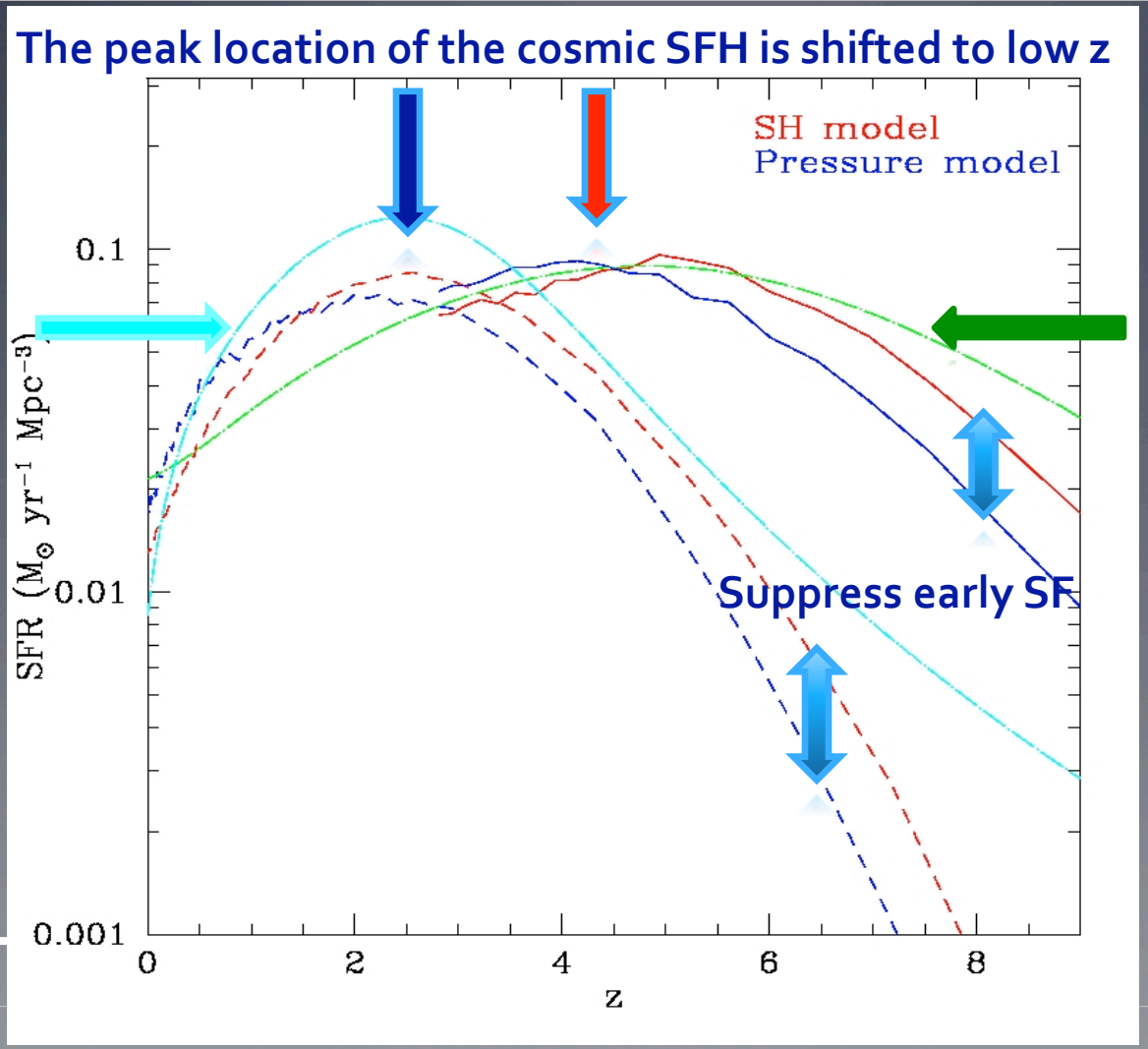




- Pressure model suppresses over-prediction at low density
- Pressure model reproduces proper SF density threshold
- Slop depends on n and EOS

Cosmic Star Formation History

Hopkins & Beacon 2006

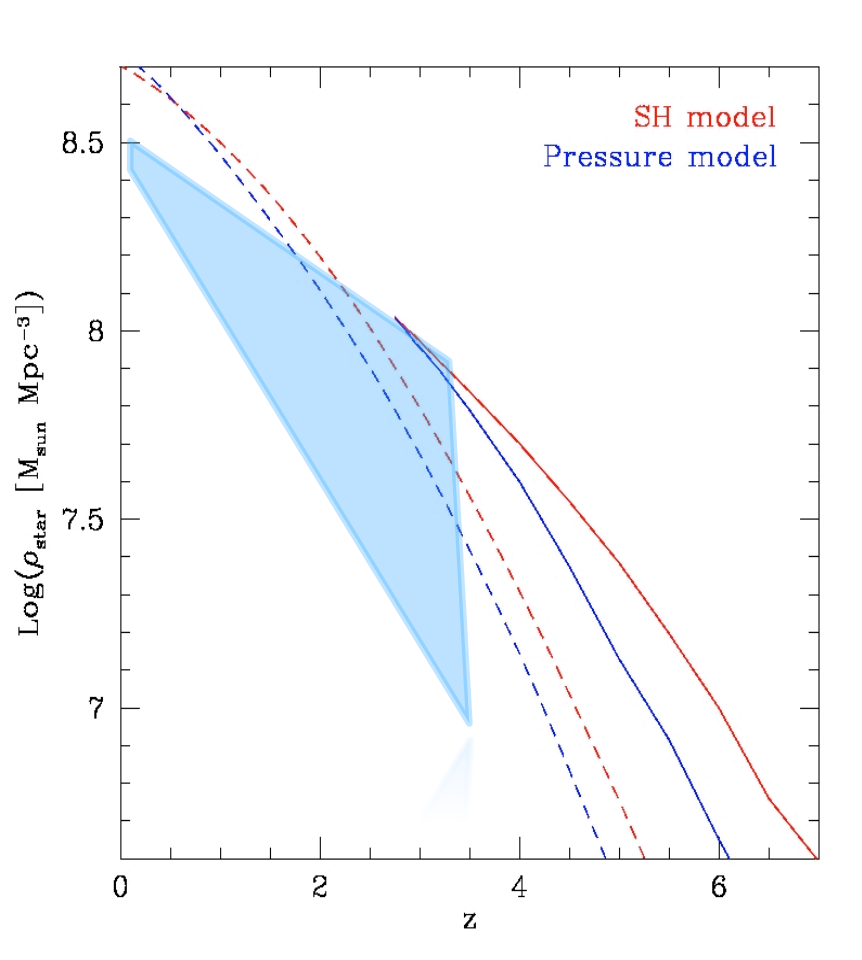


Hernquist & Springel 2003
with metal cooling effect

N216L10 ——

N400L100 - - - -

Evolution of Global Stellar Mass Density



- The stellar mass from integrating SMFs over $M_{star}/M_{\odot} > 10^8$
- The Pressure model shows low stellar mass density at high redshifts.
- Issues
  - Discrepancy in low z
    - May need better outflow (+BH)
  - Poor Resolution
    - Simulation : difference between N400L100 and N216L10
    - Observation : 10^8 $M_{\odot}$ mass cut-off

Marchesini et al 2008

Summary

- Metal cooling enhances SFR in two ways
  - Increase IGM accretion to galaxies
  - Increase SF efficiency by increase gas density : ISM to star
  - Metal cooling enhance SFR through entire history of galaxy formation (~ 20 % at high z and ~ 50 % at law z)
- New Star formation model
  - Reduction of the over-prediction SFR in low density region and reproduce a correct density threshold
  - Suppression of early star formation
  - The peak location of the cosmic SF history is shifted to lower z
  - Better agreement with observations
  - More refinement in the KS law : Threshold density evolution