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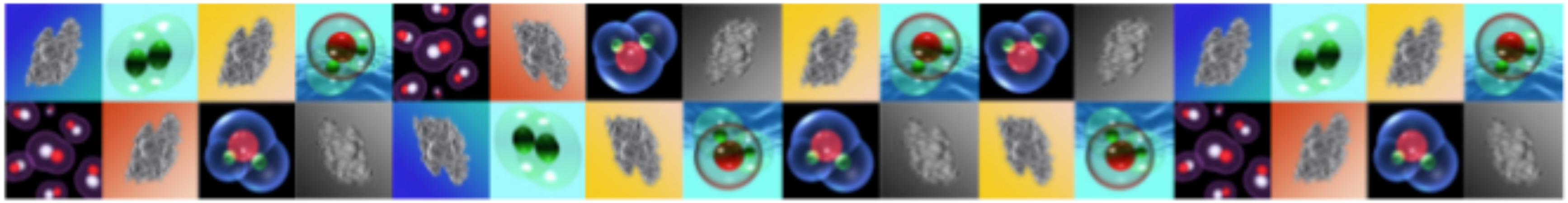
MODULO
MOlecules and DUst at LOw metallicity



updates on chemical evolution models

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+

Leslie Hunt, Laura Magrini, Daniele Galli

Modeling chemical evolution

Valiante, Schneider, Salvadori & Bianchi, in prep

$$\frac{dM_*(t)}{dt} = \mathrm{SFR}(t) - \frac{dR(t)}{dt}$$

$$\frac{dM_{\mathrm{ISM}}(t)}{dt} = -\mathrm{SFR}(t) + \frac{dR(t)}{dt} + \frac{dM_{\mathrm{inf}}}{dt} - \frac{dM_{ej}}{dt}$$

$$\frac{dM_Z(t)}{dt} = -Z_{\mathrm{ISM}}(t)\mathrm{SFR}(t) + \frac{dY_Z(t)}{dt} - Z_{ISM}(t)\frac{dM_{ej}}{dt}$$

$$\frac{dM_d(t)}{dt} = -Z_d(t)\mathrm{SFR}(t) + \frac{dY_d(t)}{dt} - \frac{M_d(t)}{\tau_d} - Z_d(t)\frac{dM_{ej}}{dt}$$

$$\frac{\mathrm{d}M_{\mathrm{inf}}}{\mathrm{d}t} = A\left(\frac{t}{t_{\mathrm{inf}}}\right)^2 \exp\left(-\frac{t}{t_{\mathrm{inf}}}\right).$$

$t_{inf} = t_{ff}/4$

$A = M_{gas,in}/2\ t_{inf}$

Keres et al. (2005); Salvadori et al. (2009)

$$\frac{dR(t)}{dt} = \int_{m_*(t)}^{100M_\odot} (m - \omega_m(m, Z_{\mathrm{ISM}}))\phi(m)\mathrm{SFR}(t-\tau_m)dm$$

$$\frac{dY_Z(t)}{dt} = \int_{m_*(t)}^{100M_\odot} m_Z(m, Z_{\mathrm{ISM}})\phi(m)\mathrm{SFR}(t-\tau_m)dm$$

$$\frac{dY_d(t)}{dt} = \int_{m_*(t)}^{100M_\odot} m_d(m, Z_{\mathrm{ISM}})\phi(m)\mathrm{SFR}(t-\tau_m)dm$$

Mechanical feedback

Mass ejection rate:

$$\frac{dM_{ej}}{dt} = \frac{2\epsilon_w \langle E_{SN} \rangle}{v_e^2} \frac{dN_{SN}}{dt}.$$

kinetic energy by SN-driven winds

$$E_{SN} = \epsilon_w N_{SN} \langle E_{SN} \rangle$$

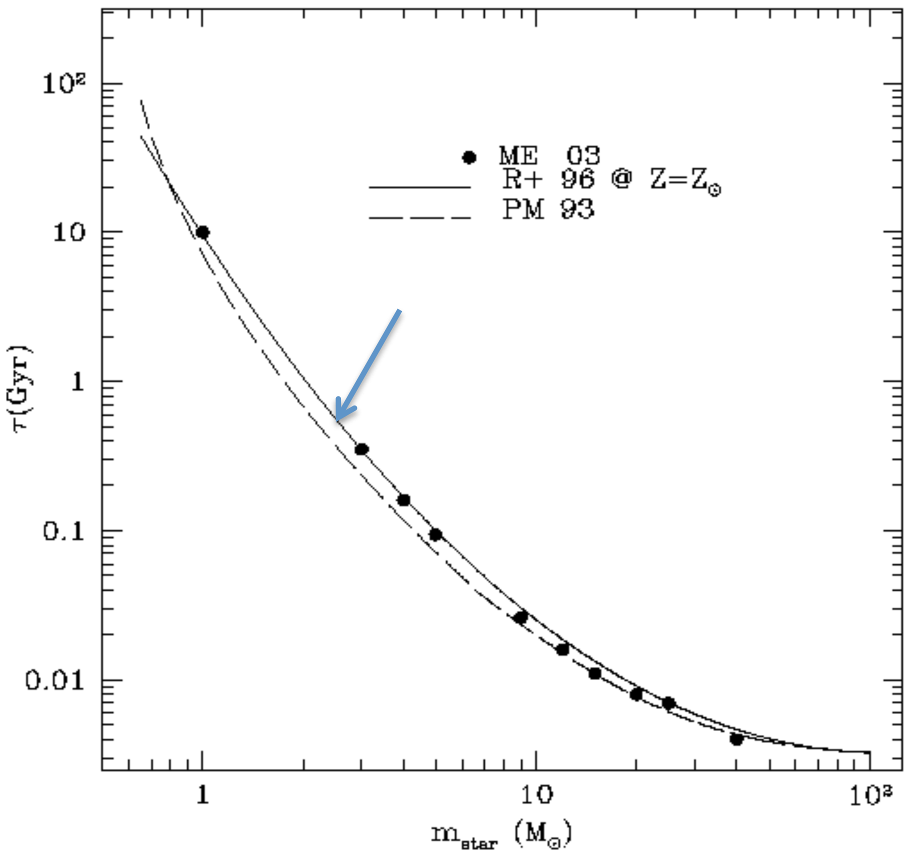
conversion efficiency: 0.002

10^{51}erg

escape velocity

$$v_e^2 = GM/r$$

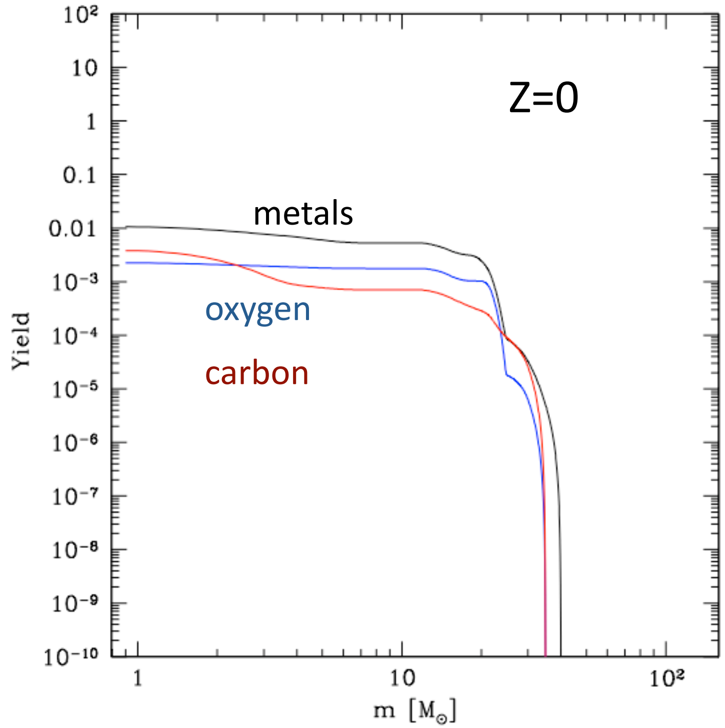
stellar lifetimes and IMF

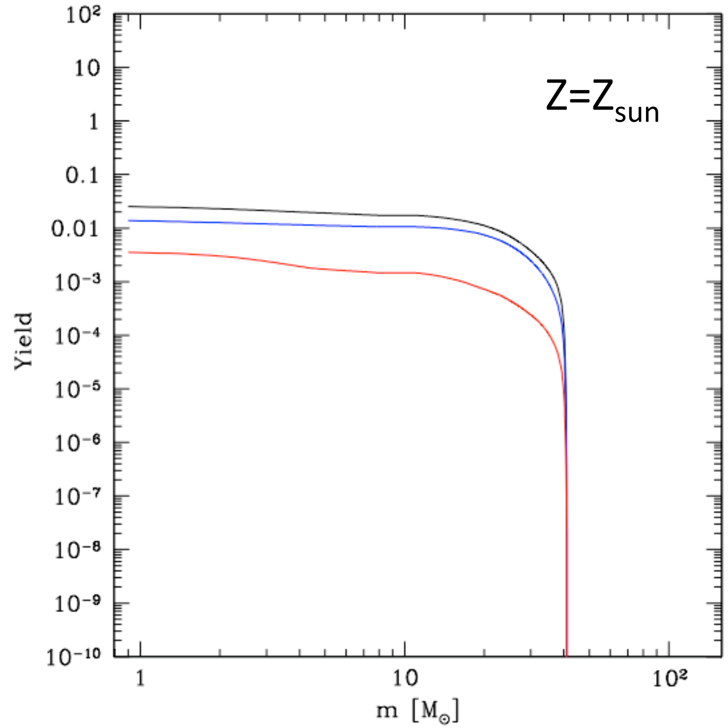


$$\Phi(m) = \frac{\mathrm{d}N}{\mathrm{d}m} \propto m^{-1+x} \exp(-m_{\mathrm{cut}}/m), \qquad (2)$$

with $x = -1.35$, $m_{\mathrm{cut}} = 0.35\,\mathrm{M}_\odot$ and m in the range [0.1–100] $\mathrm{M}_\odot$

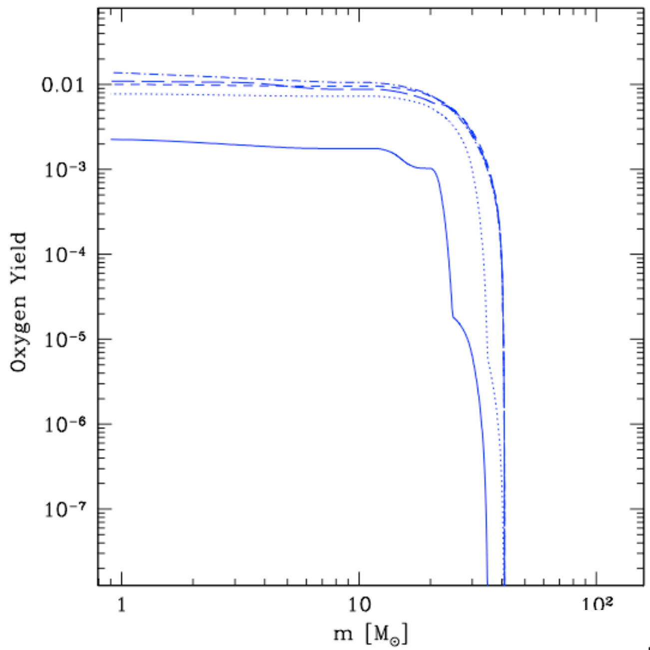
metal yields

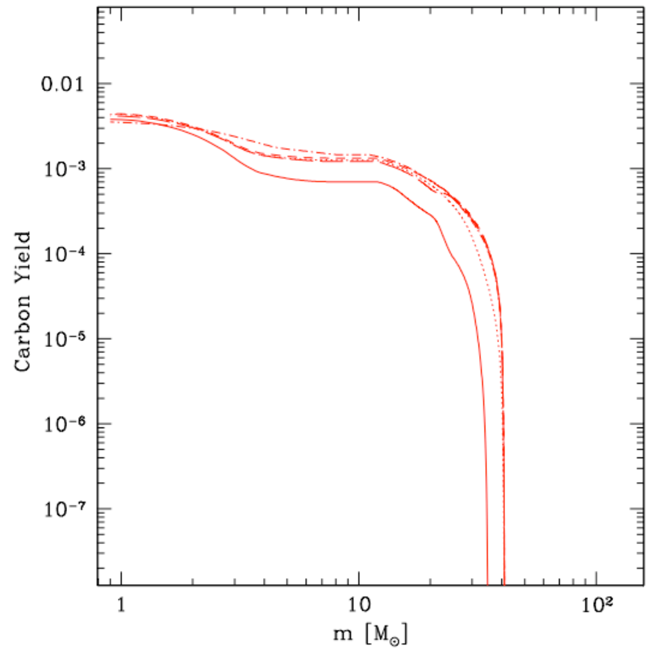


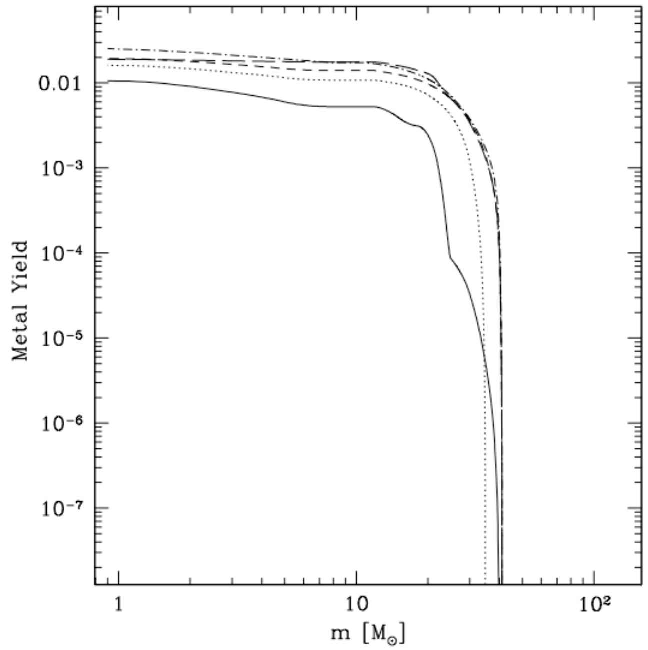


Woosley & Weaver (1995)
Van den Hoek & Groenewegen (1997)

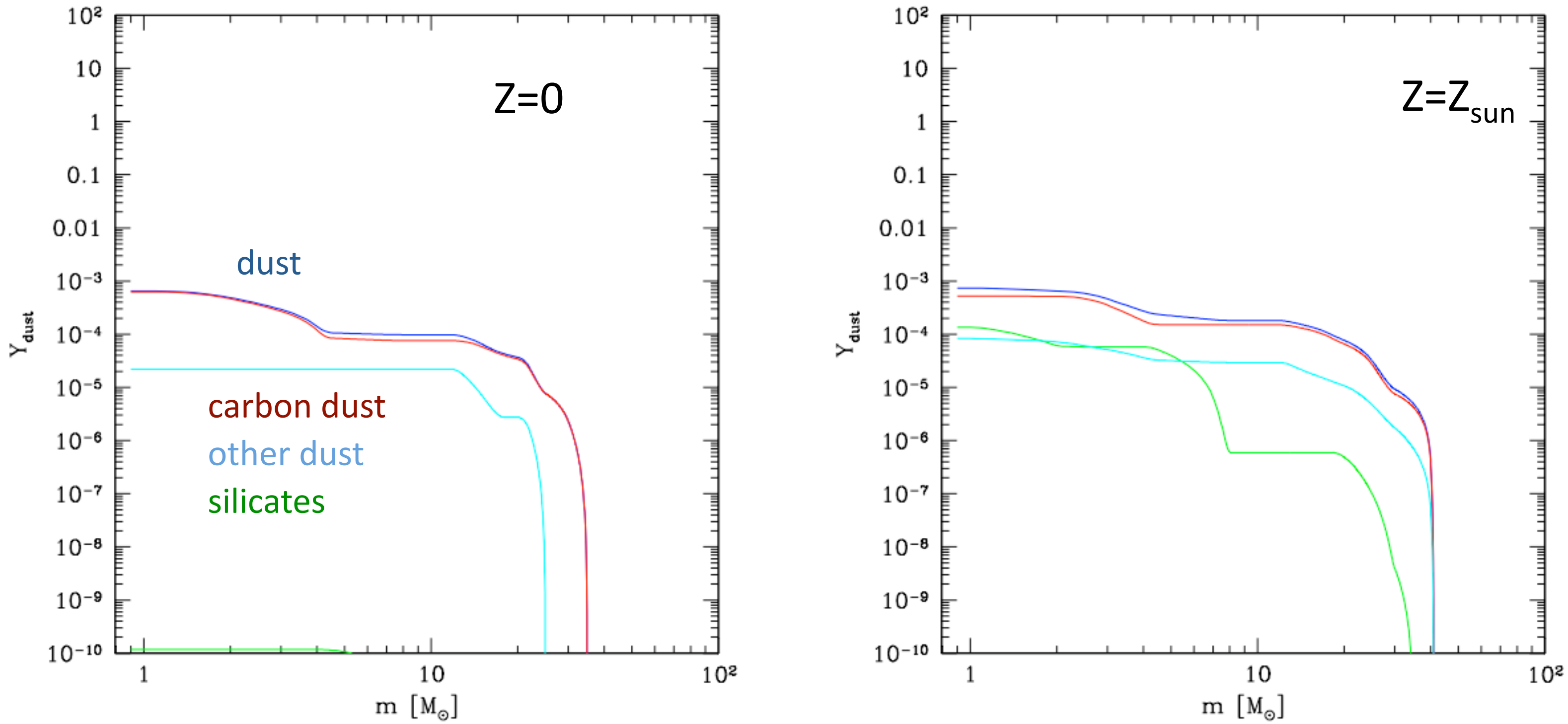
metal yields







dust yields



Bianchi & Schneider (2007)
Zhukovska et al. (2008)

initial conditions

(1) Spherical extragalactic HII regions

Initial available gas mass, $M_{gas} = 10^7 M_{sun}$

dense = 1e5 cm^{-3}
compact = 3e3 cm^{-3}
diffuse = 1e2 cm^{-3}

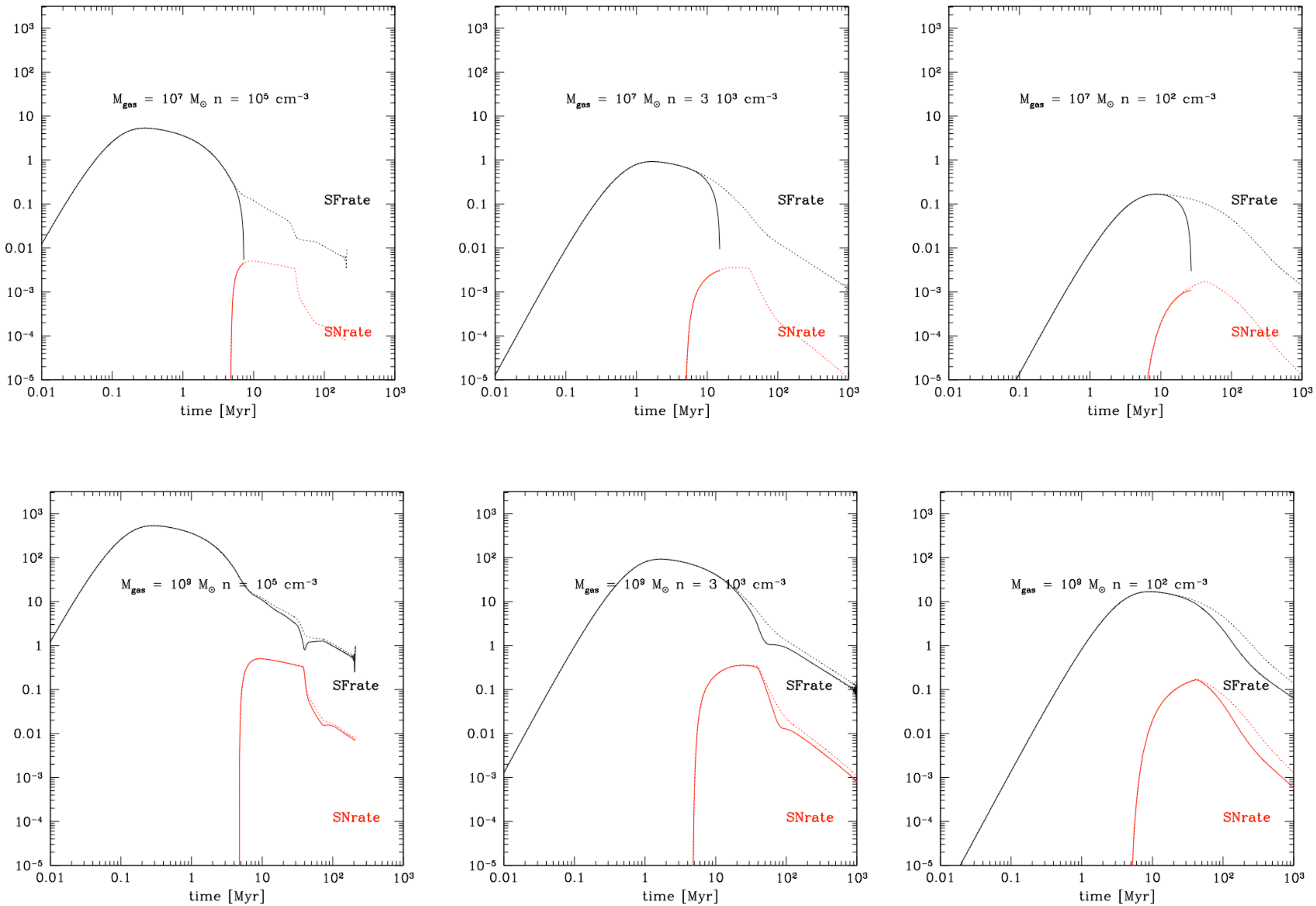
(2) Ultra-luminous-like spherical scaled-up extragalactic HII regions:

Initial available gas mass, $M_{gas} = 10^9 M_{sun}$

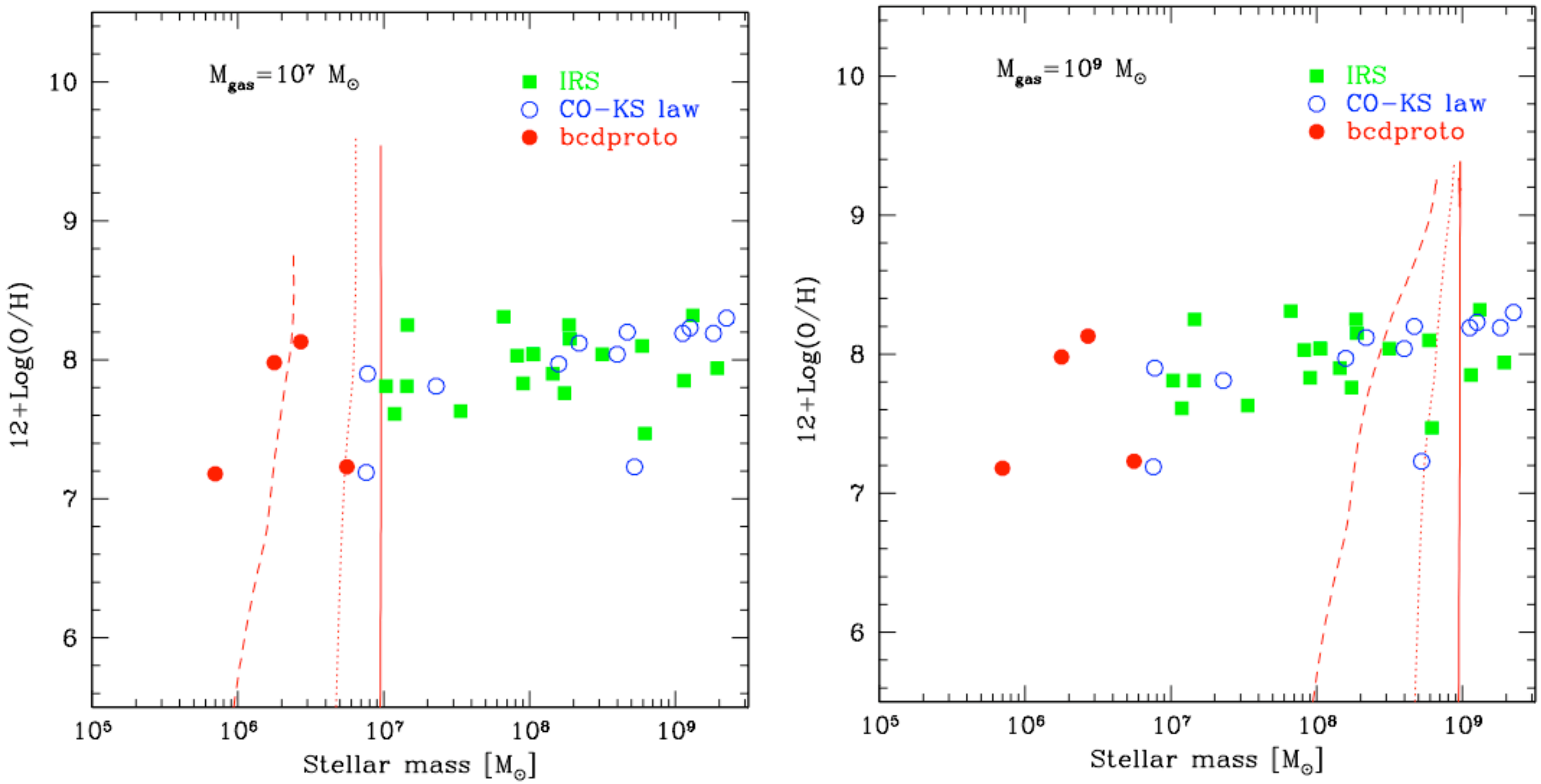
dense = 1e5 cm^{-3}
compact = 3e3 cm^{-3}
diffuse = 1e2 cm^{-3}

SFR = eff * M_{gas} / t_{ff} with eff = 0.1

star formation histories & SN rate



Mass-metallicity relation

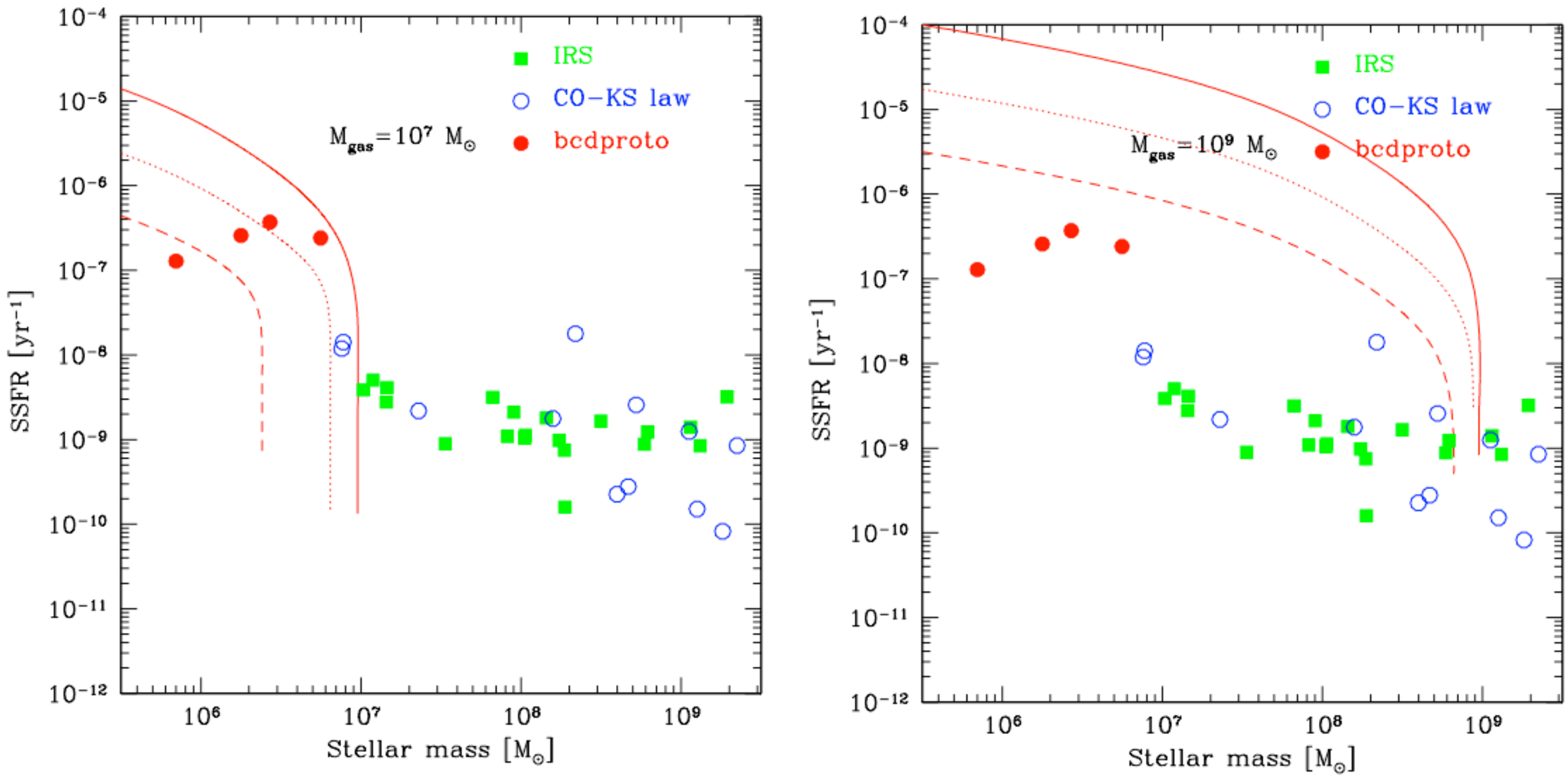


compact

dense

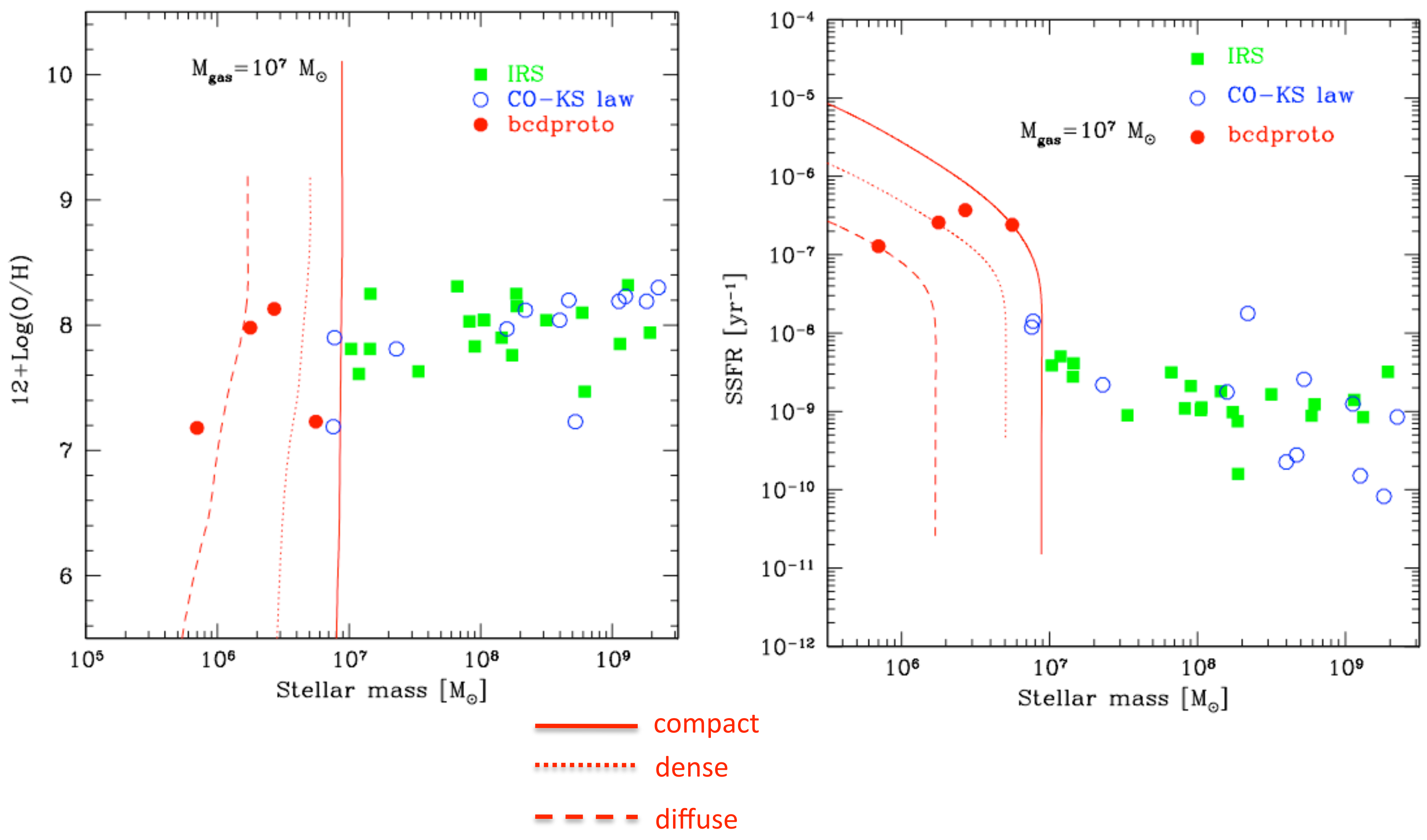
diffuse

Specific star formation rate

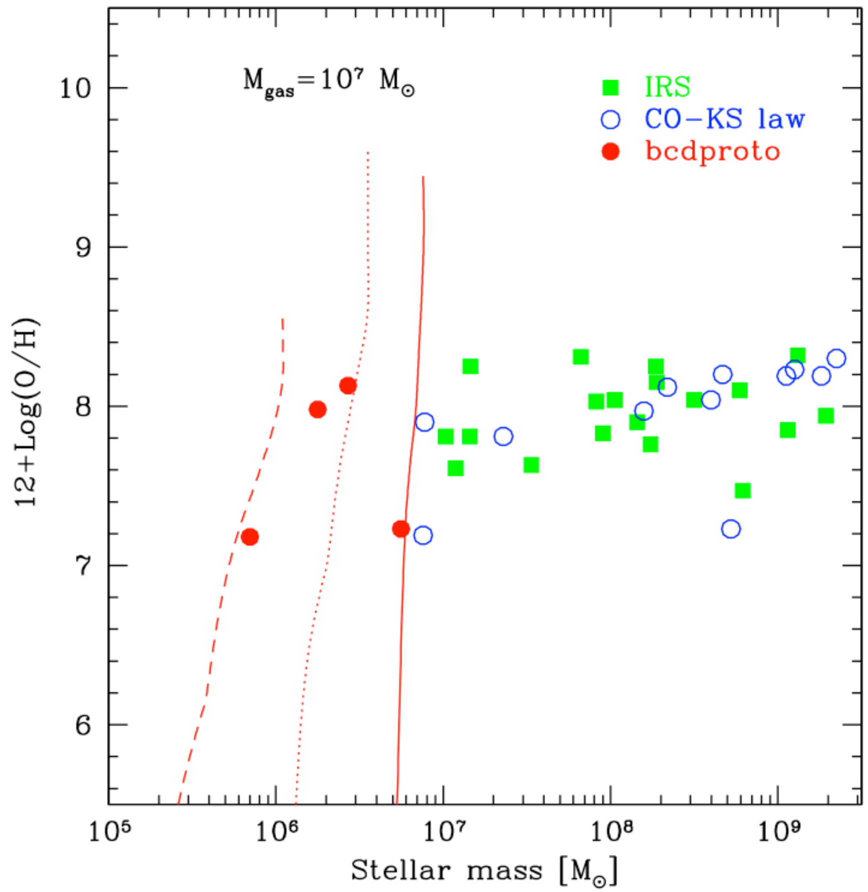


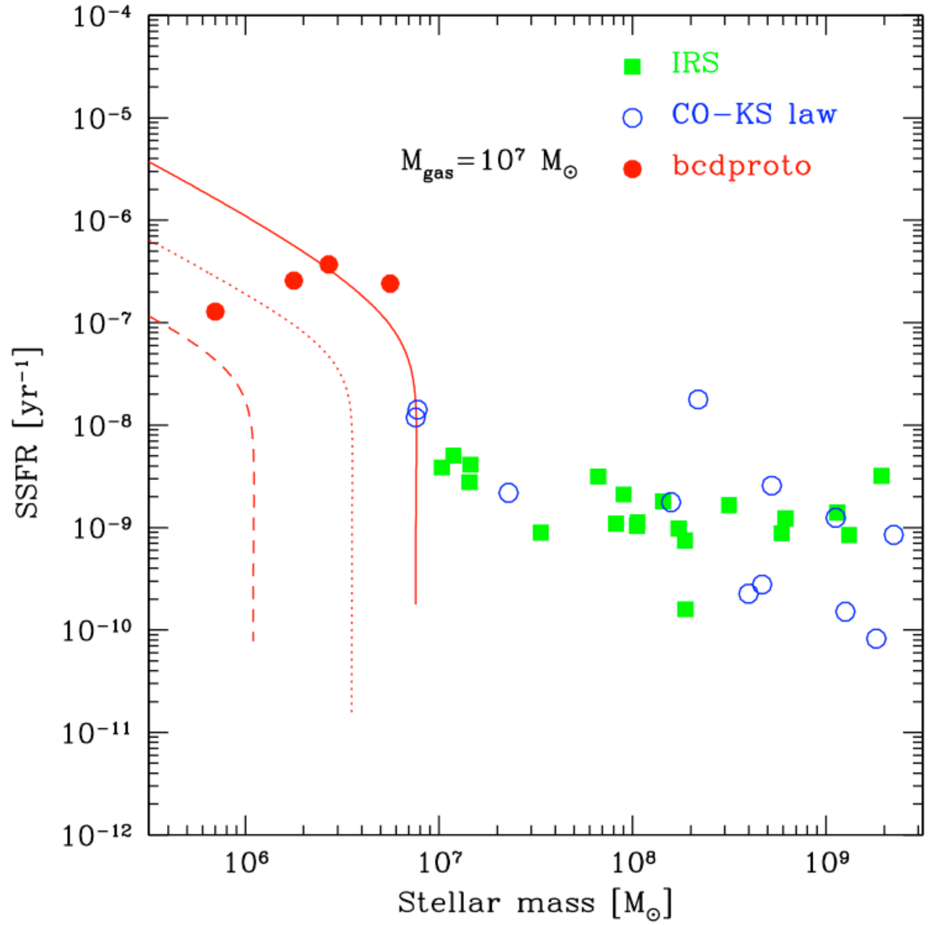
compact
dense
diffuse

With reduced efficiency (0.05)



With reduced efficiency (0.02)





compact
dense
diffuse

New SFR prescription

Stars form out of molecular gas $SFR = \varepsilon f_{H2} M_{gas}/t_{ff}$ $\varepsilon = 0.01$

fraction of molecular gas:
depends on physical conditions

free-fall time within the molecular cloud

$f_{H2} = f_{H2}(Z_{met}, \Sigma_{gas})$ Krumholz, McKee & Tumlinson (2009)

surface density of the atomic/molecular complex

$\Sigma_{gas} = \Sigma_{H2} + \Sigma_{HI}$

$\Sigma_{H2} = N_{cl}\,\Sigma_{cl}$ $\Sigma_{cl} = 85\ M_{sun}/pc^2$

$N_{cl} = M_{H2}/M_{cl}$

$M_{cl} = M_{jeans}(n_{HI}, T_{HI}) = 1660\ M_{sun}\ (T_{HI}/25K)^{3/2}\ n_{HI}^{-1/2}$

Initial Conditions

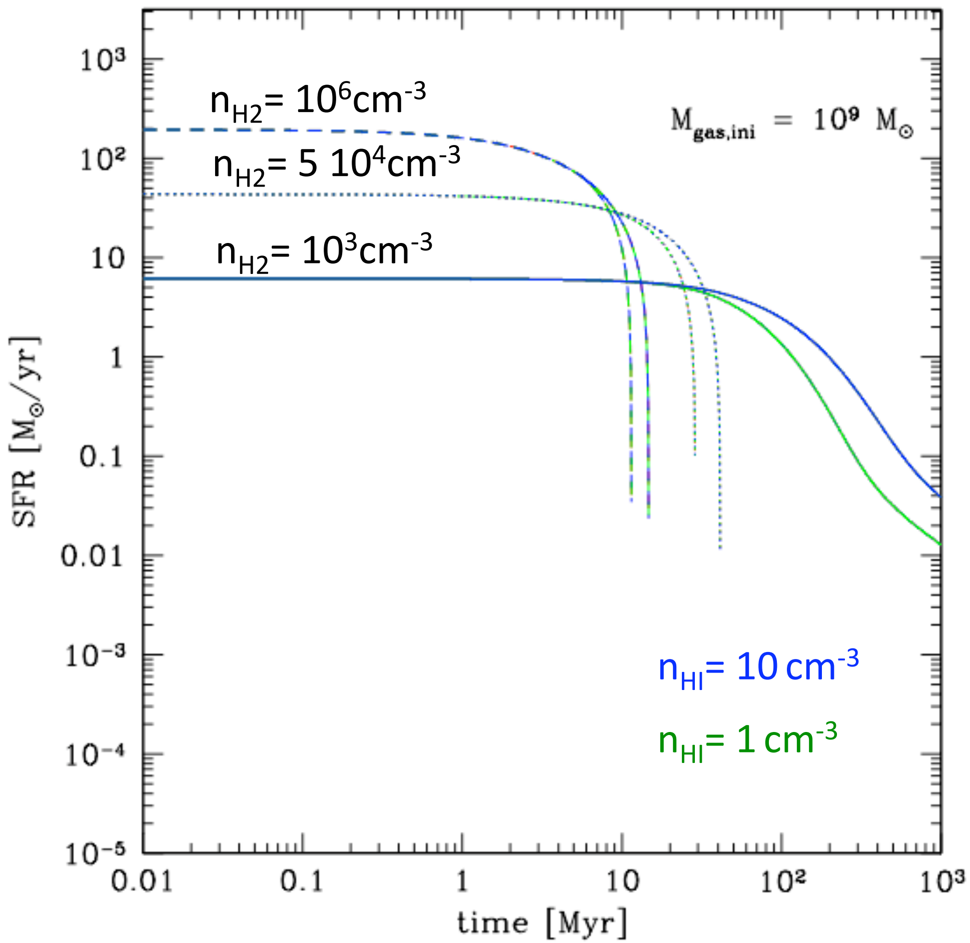
$M_{gas} = 10^9, 10^{11}\ M_{sun}$

$T_{HI} = 20, 25, 30$ K

$n_{HI} = 1, 10\ cm^{-3}$

$n_{H2} = 10^3, 5\ 10^4, 10^6\ cm^{-3}$

star formation histories (no infall)

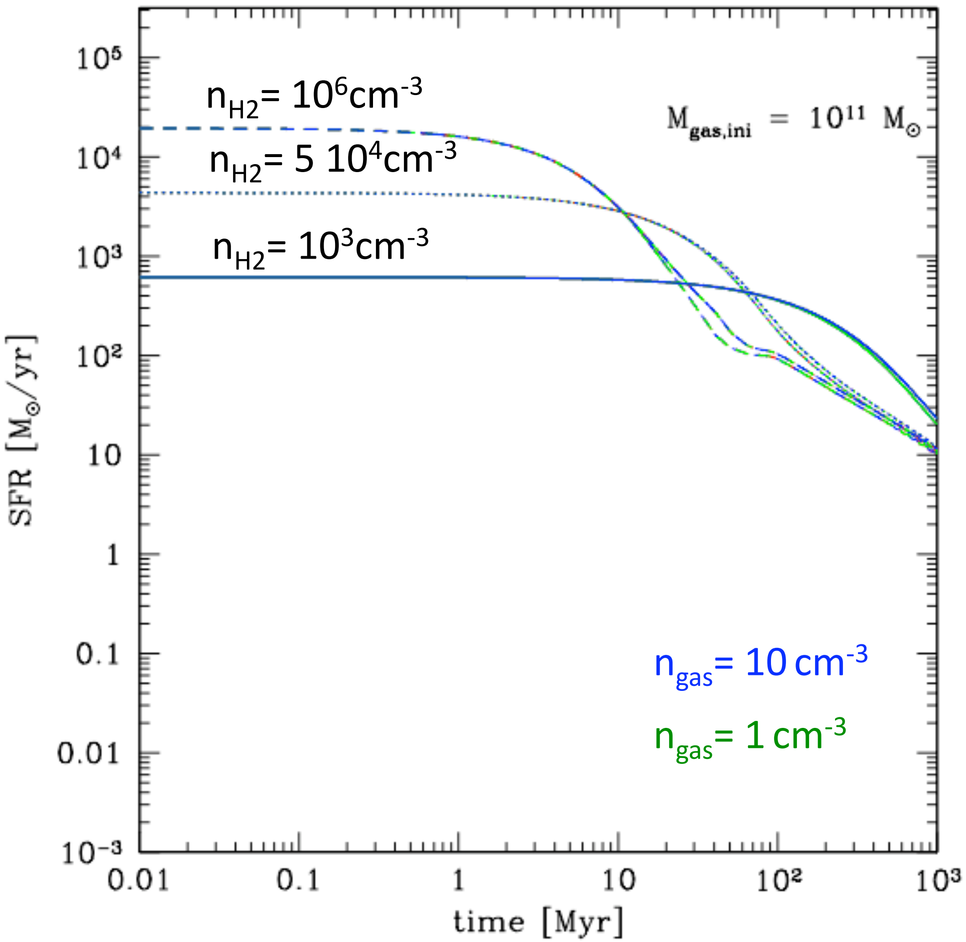


$M_{gas,ini}$ = 10^9 M_{sun}

SFR = ε f_{H2} M_{gas}/t_{ff}

SFR depends on n_{HI} only through the strength of SN feedback (fix E_b and v_{esc})

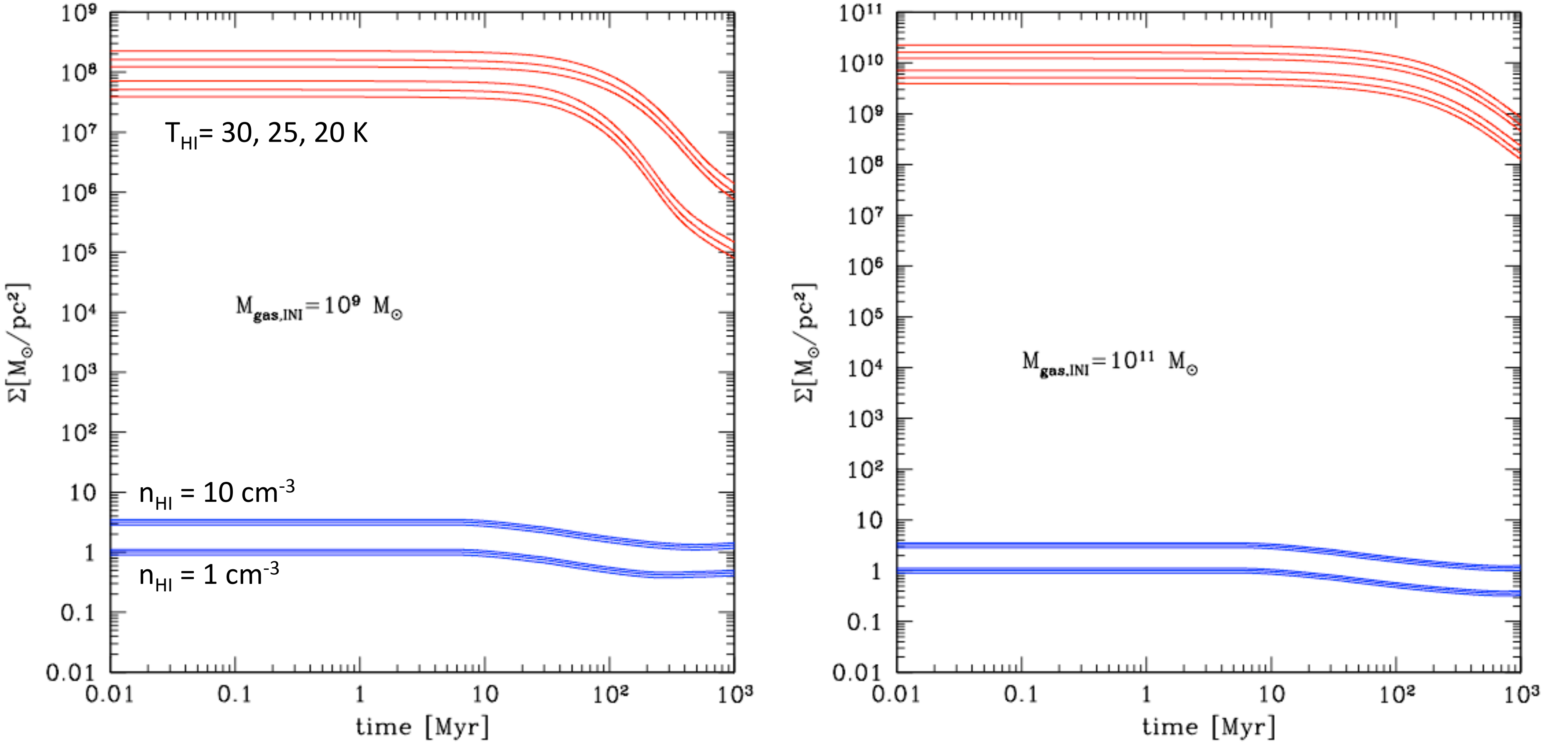
star formation histories (no infall)



$M_{gas,ini} = 10^{11}\ M_{sun}$

$SFR = \varepsilon\ f_{H2}\ M_{gas}/t_{ff}$

Problem: after 1 step $f_{H2}=1$



$\Sigma_{gas} = \Sigma_{H2} + \Sigma_{HI}$

$\Sigma_{H2} = N_{cl}\ \Sigma_{cl}$

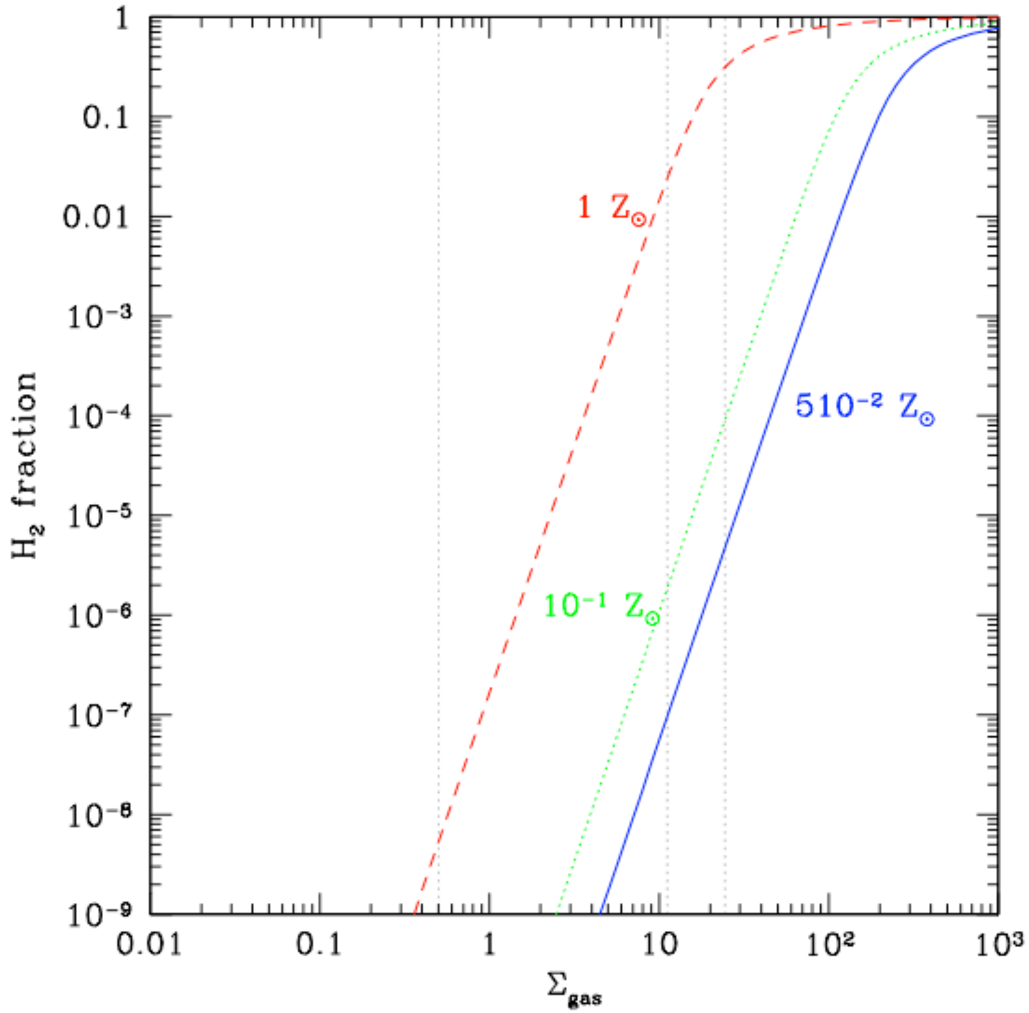
$M_{H2} = f_{h2}(\Sigma_{gas}, Z_{gas})$

$N_{cl} = M_{H2}/M_{cl}$

$M_{cl} = M_{jeans}(n_{HI}, T_{HI}) = 1660\ M_{sun}\ (T_{HI}/25K)^{3/2}\ n_{HI}^{-1/2}$

$f_{H2}(\Sigma_{gas}, Z)$

Krumholz, McKee, Tumlinson 2009



@ t_{ini}, M_{H2}=0 and $\Sigma_{gas} = \Sigma_{HI}$ $f_{H2} \approx 10^{-4}$

@ $t_{ini} + \Delta t$, $M_{H2} \approx 10^5$ M_{sun} and $N_{cl} >> 1$

$\Sigma_{gas} = \Sigma_{H2} >> 10^2$ M_{sun}/pc^2 $f_{H2} \approx 1$ thereafter

2 problems

1. we are giving the system all the row material at the first step → we have to re-introduce the infall term (easy!)

2. we are computing f_{H2} using the ***total*** gas column density; KMT09 say that f_{H2} depends on the column density of the atomic/molecular complex averaged over 100 pc

   $\Sigma_{compl} = c\,\Sigma_{gas}$ with c = clumping factor (> 1 for r > 100 pc, ≈ 1 for r → 100 pc)

   $\Sigma_{cl} = 85\ M_{sun}/pc^2$ if $\Sigma_{gas} < 85\ M_{sun}/pc^2$

   $\Sigma_{cl} = \Sigma_{gas}$ if $\Sigma_{gas} > 85\ M_{sun}/pc^2$

   What is the typical "size" of a molecular cloud? $R_{cl} \approx \Sigma_{cl}/(2\ m_H\, n_{H2})$

n_{H2} [cm^{-3}]	10^3	$5\ 10^4$	10^6
R_{cl} [pc]	1.7	$3.4\ 10^{-2}$	$1.7\ 10^{-3}$

and the "size" of the HI region? $R_{HI} = \{3\ M_{HI}/4\ \pi\rho_{HI}\}^{1/3}$

$M_{gas,ini} = 10^9\ M_{sun}$	$n_{HI} = 1/10$ [cm^{-3}]	$M_{gas,ini} = 10^{11}\ M_{sun}$	$n_{HI} = 1/10$ [cm^{-3}]
R_{HI} [kpc]	1.99/0.93	R_{HI} [kpc]	9.3/4.3

Re-introducing the Infall term

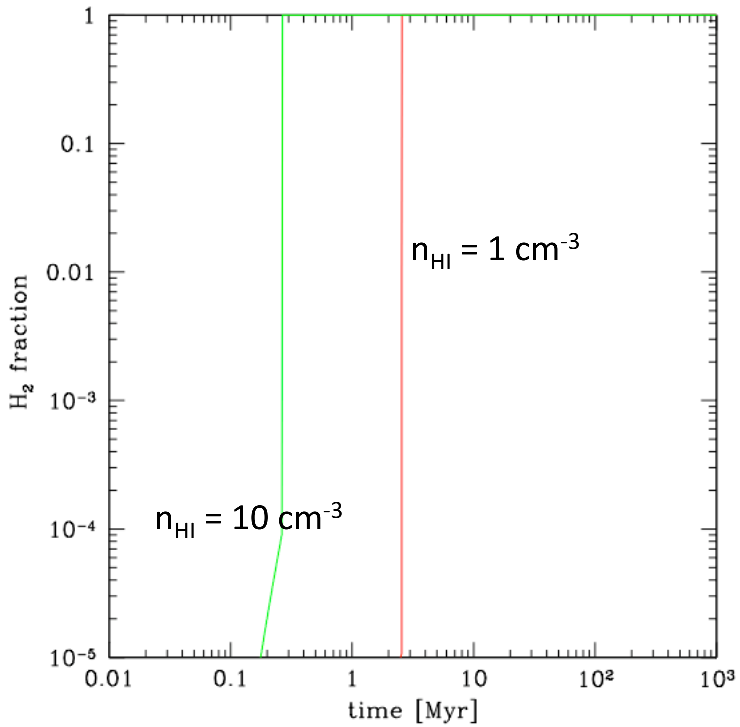
$$\frac{dM_{\rm inf}}{dt} = A\left(\frac{t}{t_{\rm inf}}\right)^2 \exp\left(-\frac{t}{t_{\rm inf}}\right).$$

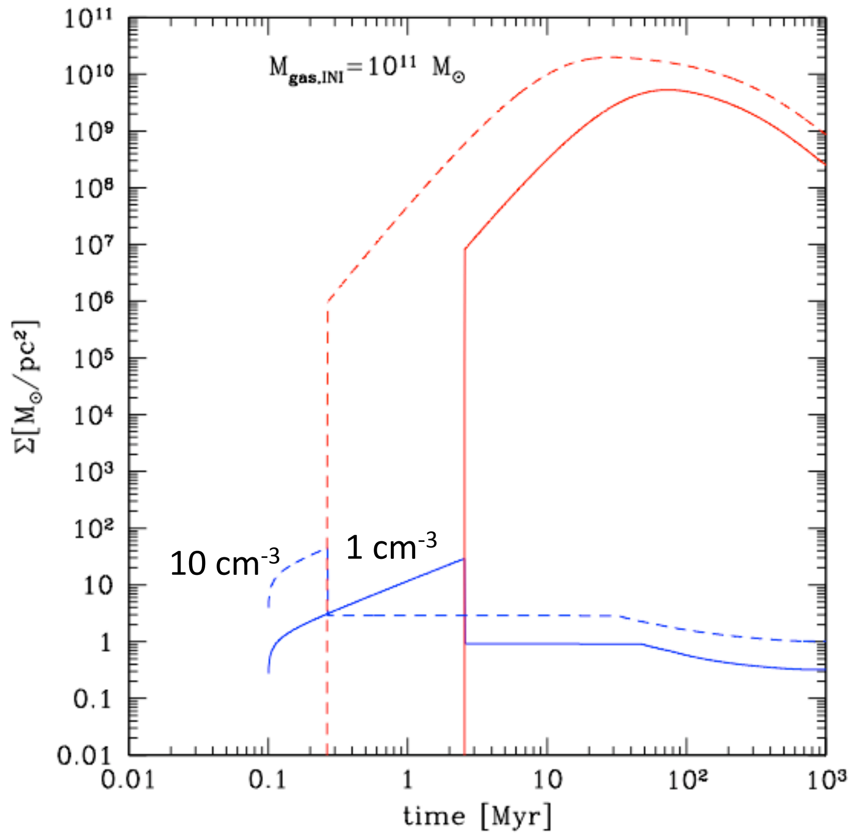
$t_{inf} = t_{ff}/4$
$A = M_{gas,in}/2\ t_{inf}$

Keres et al. (2005); Salvadori et al. (2009)

Infall-time depends on the adopted HI density: $n_{HI} = 1/10\ cm^{-3}$ $t_{inf} = 12.8/4.1$ Myr

Same problem: transition is only delayed

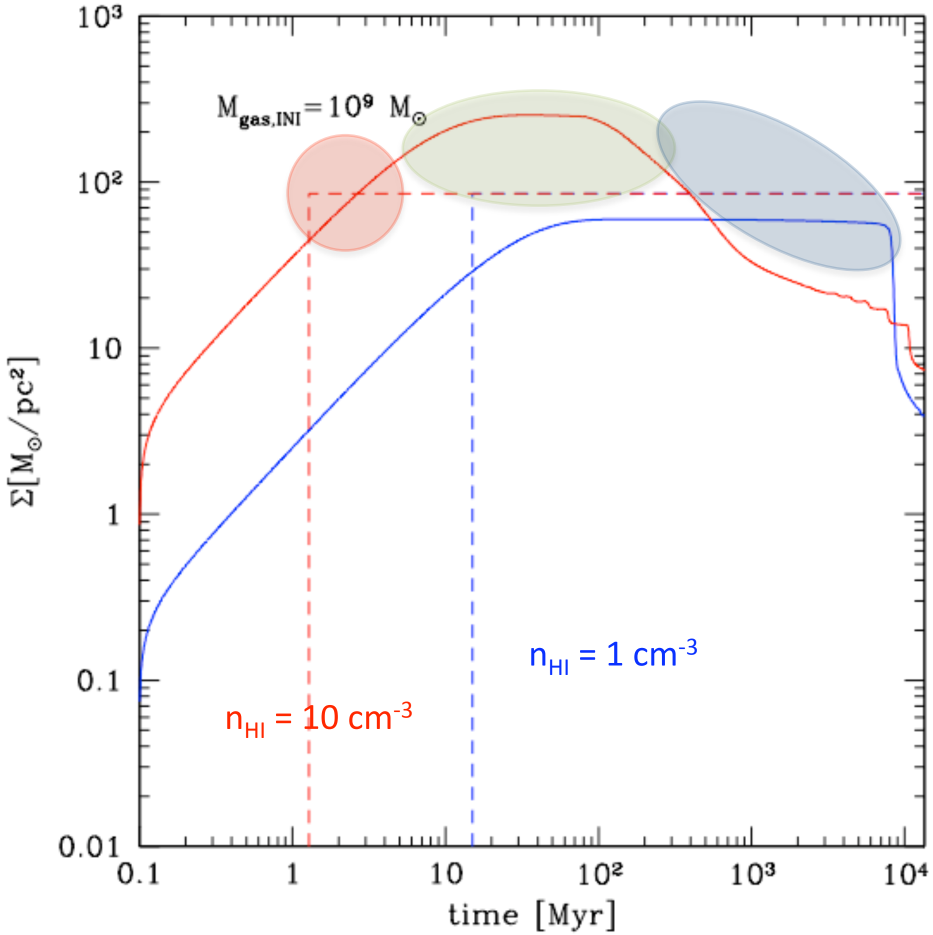


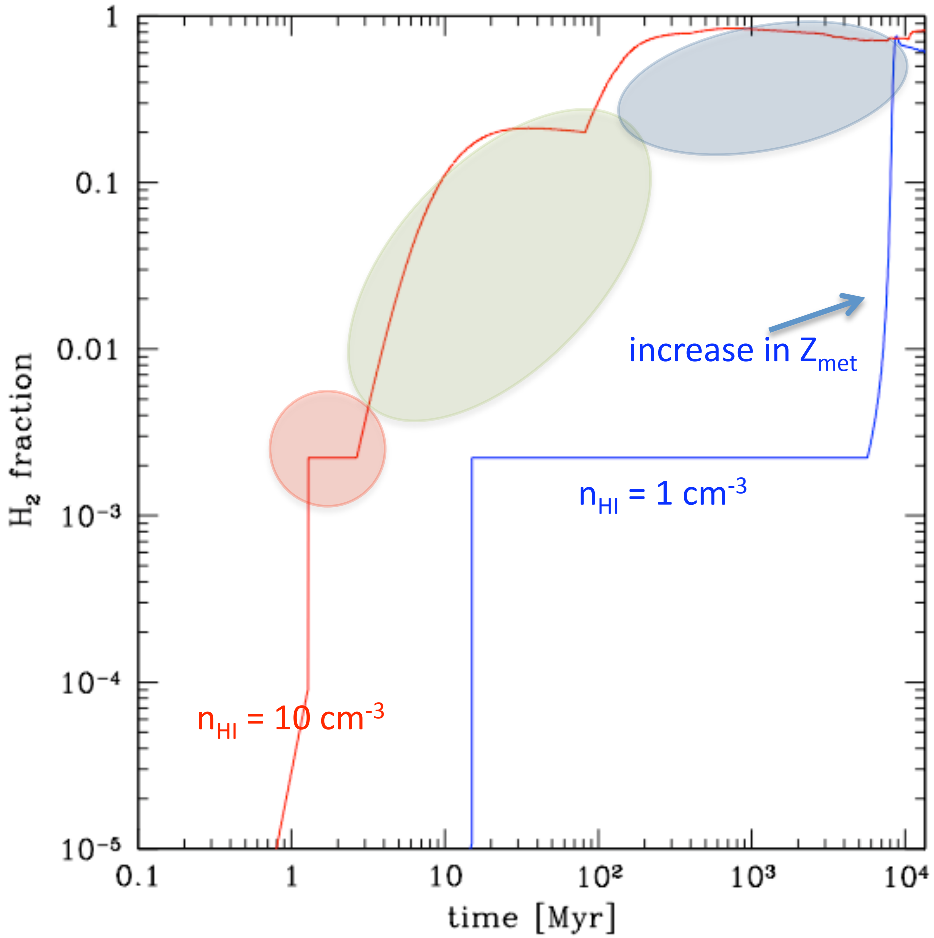


Changing from $f_{H2}(\Sigma_{gas})$ to $f_{H2}(\Sigma_{comp})$

$\Sigma_{comp} = \Sigma_{HI}$ when $N_{cl} = 0$

$\Sigma_{comp} = \max(\Sigma_{HI}, \Sigma_{cl})$ when $N_{cl} \geq 1$





Changing from $f_{H2}(\Sigma_{gas})$ to $f_{H2}(\Sigma_{comp})$

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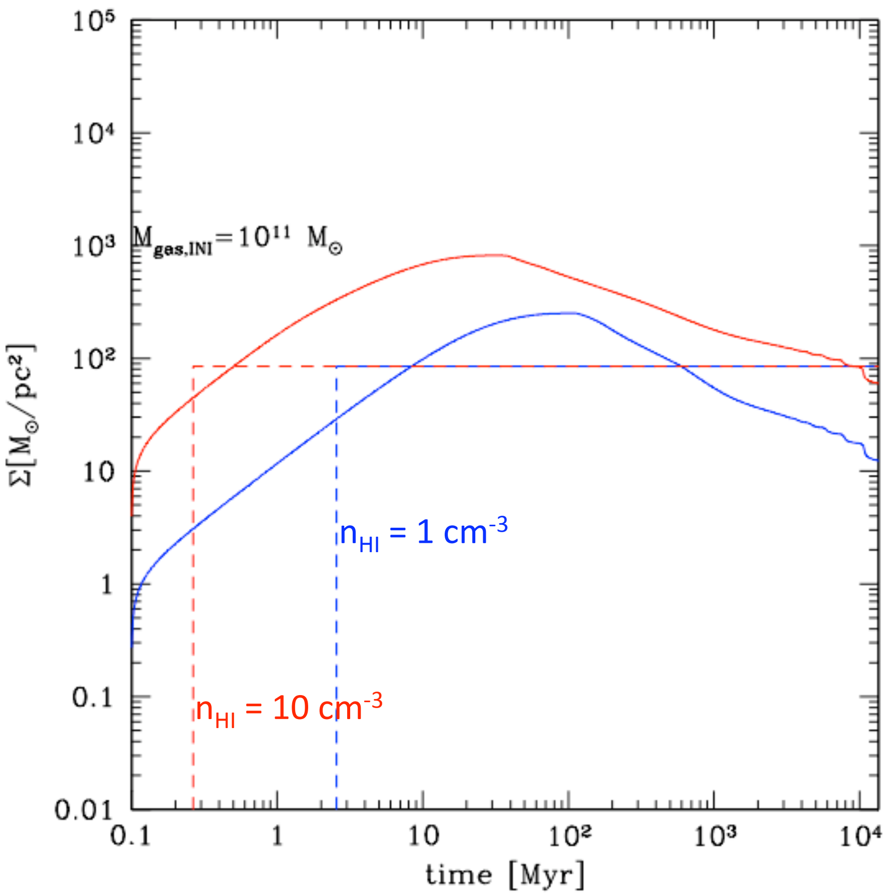
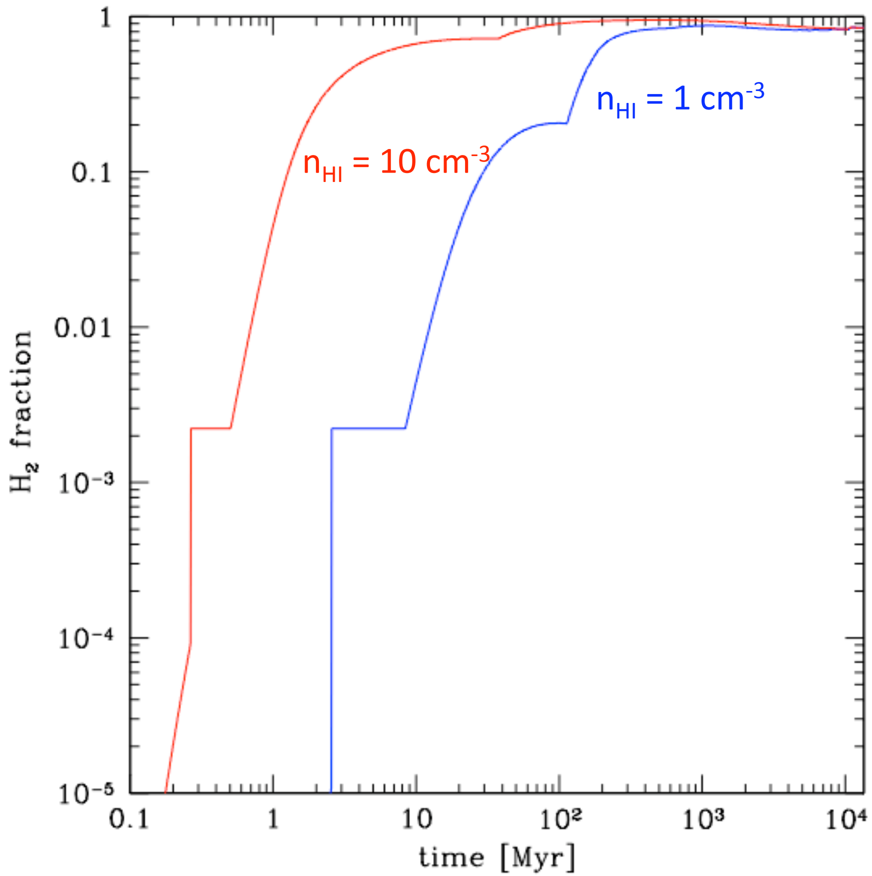
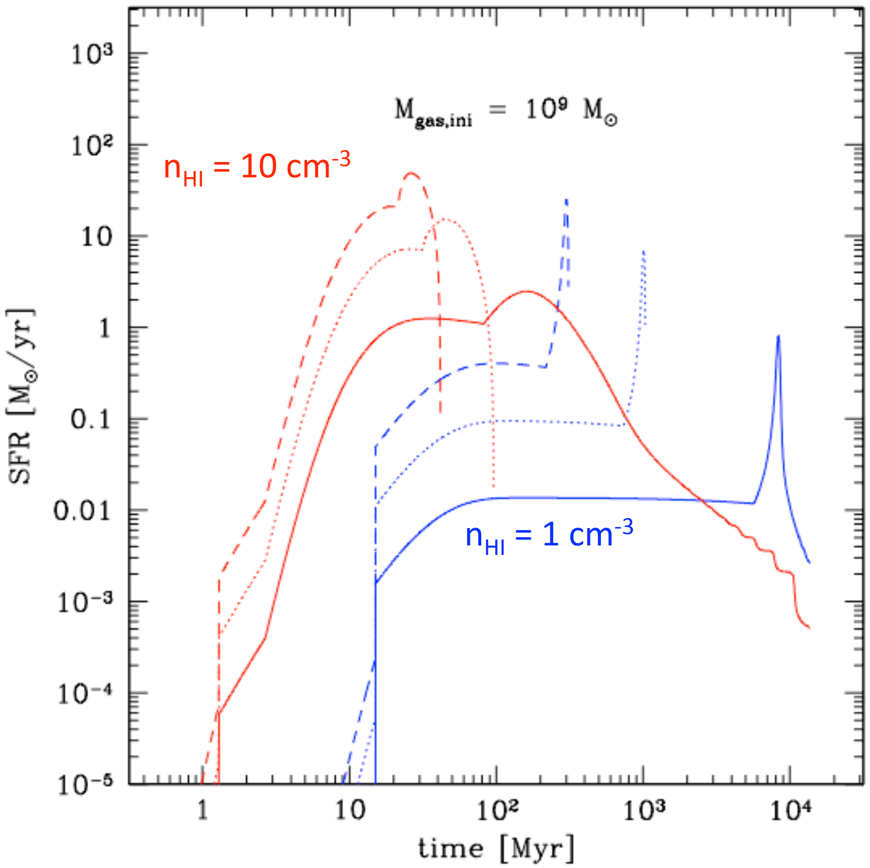
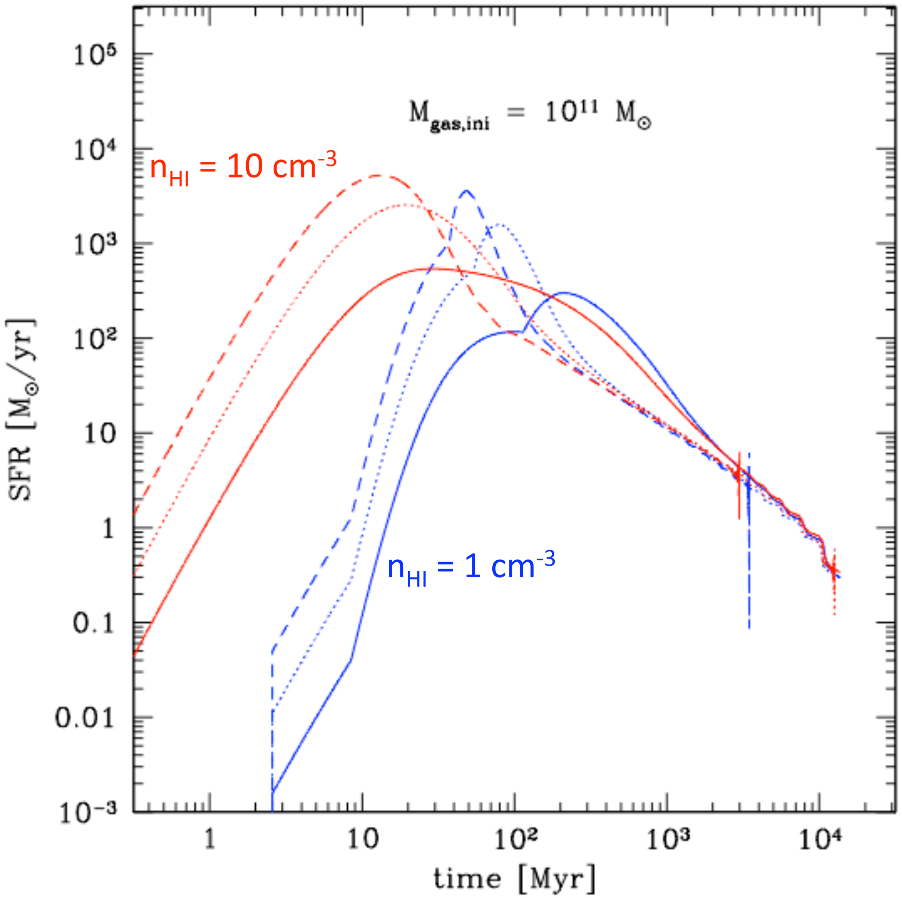




How is the SFR affected?

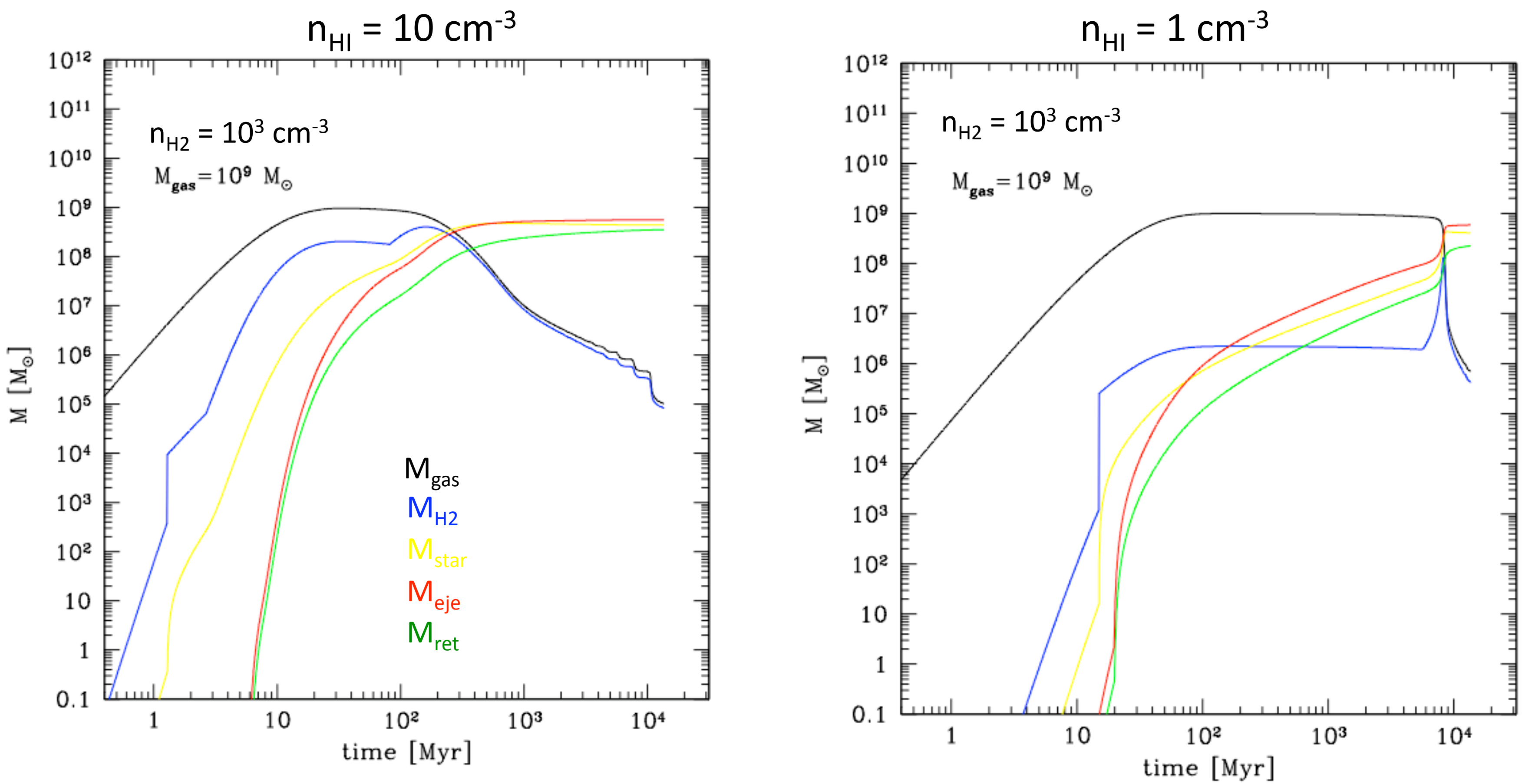
The star formation histories are very sensitive to M_{gas} and n_{HI}



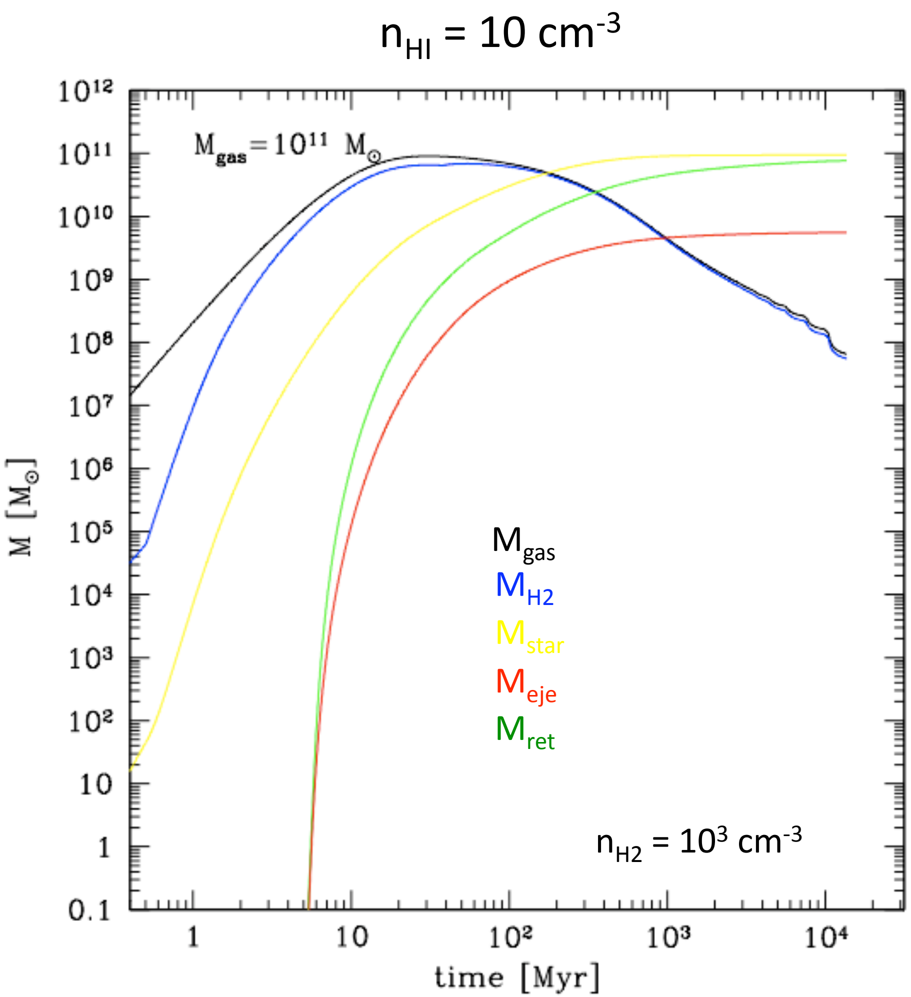


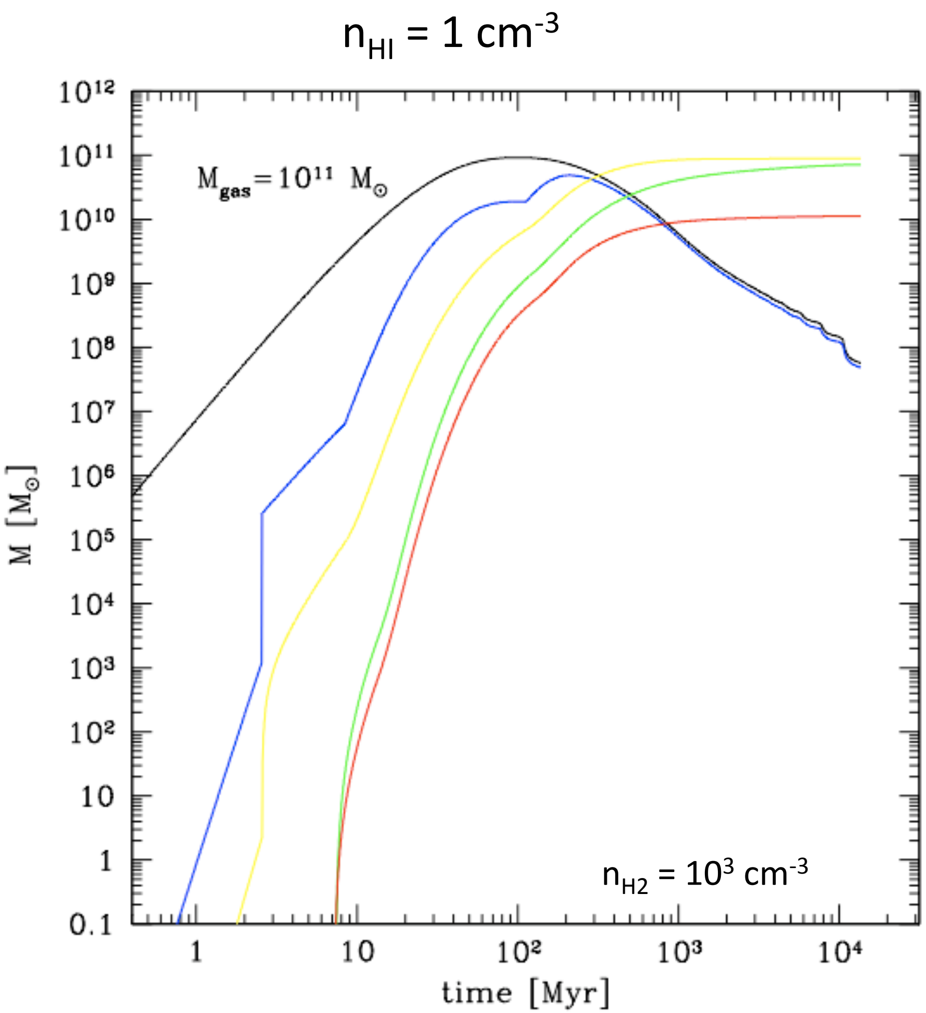
- - - - $n_{H2} = 10^6\ cm^{-3}$
.... $n_{H2} = 5\ 10^4\ cm^{-3}$
—— $n_{H2} = 10^3\ cm^{-3}$

time evolution: M_{gas}, M_{star}, M_{H2}



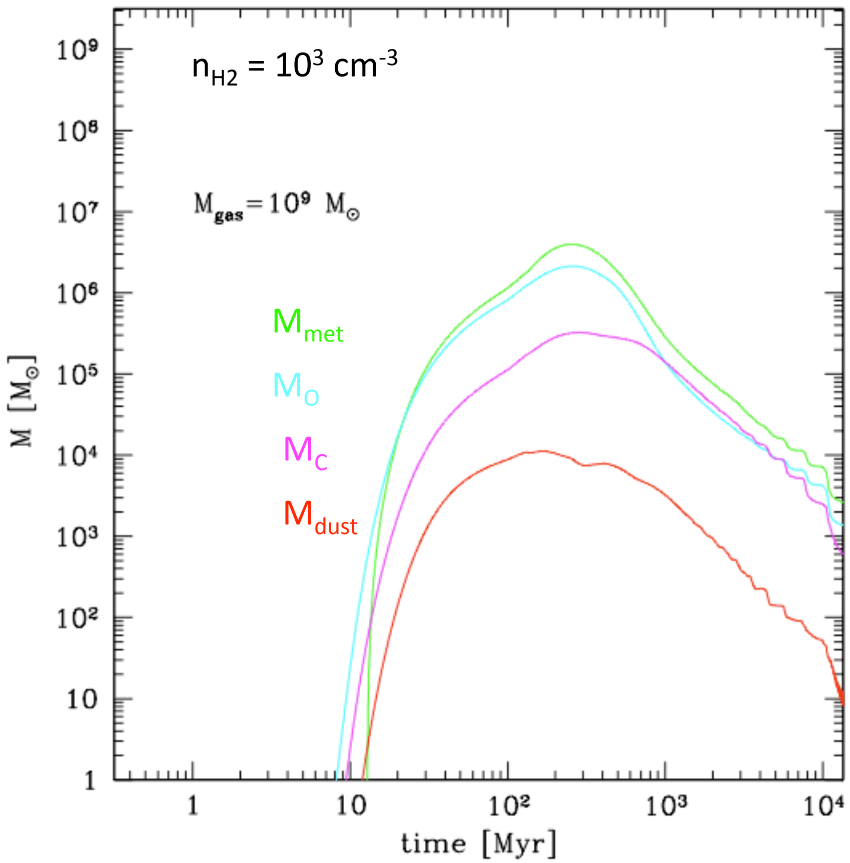
time evolution: M_{gas}, M_{star}, M_{H2}



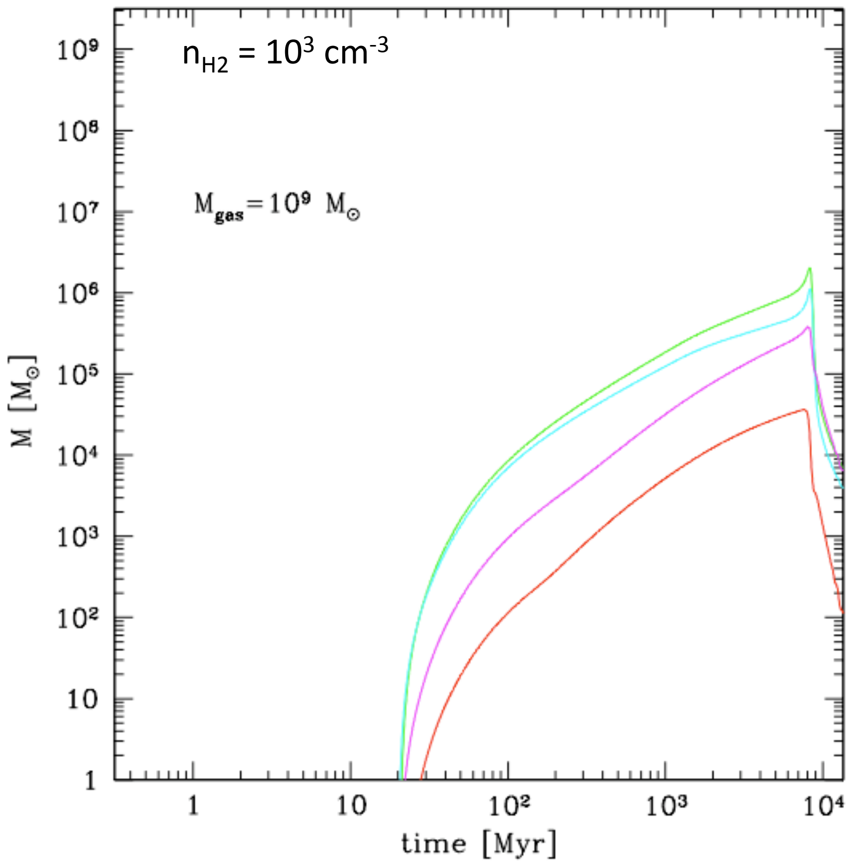


time evolution: M_{met}

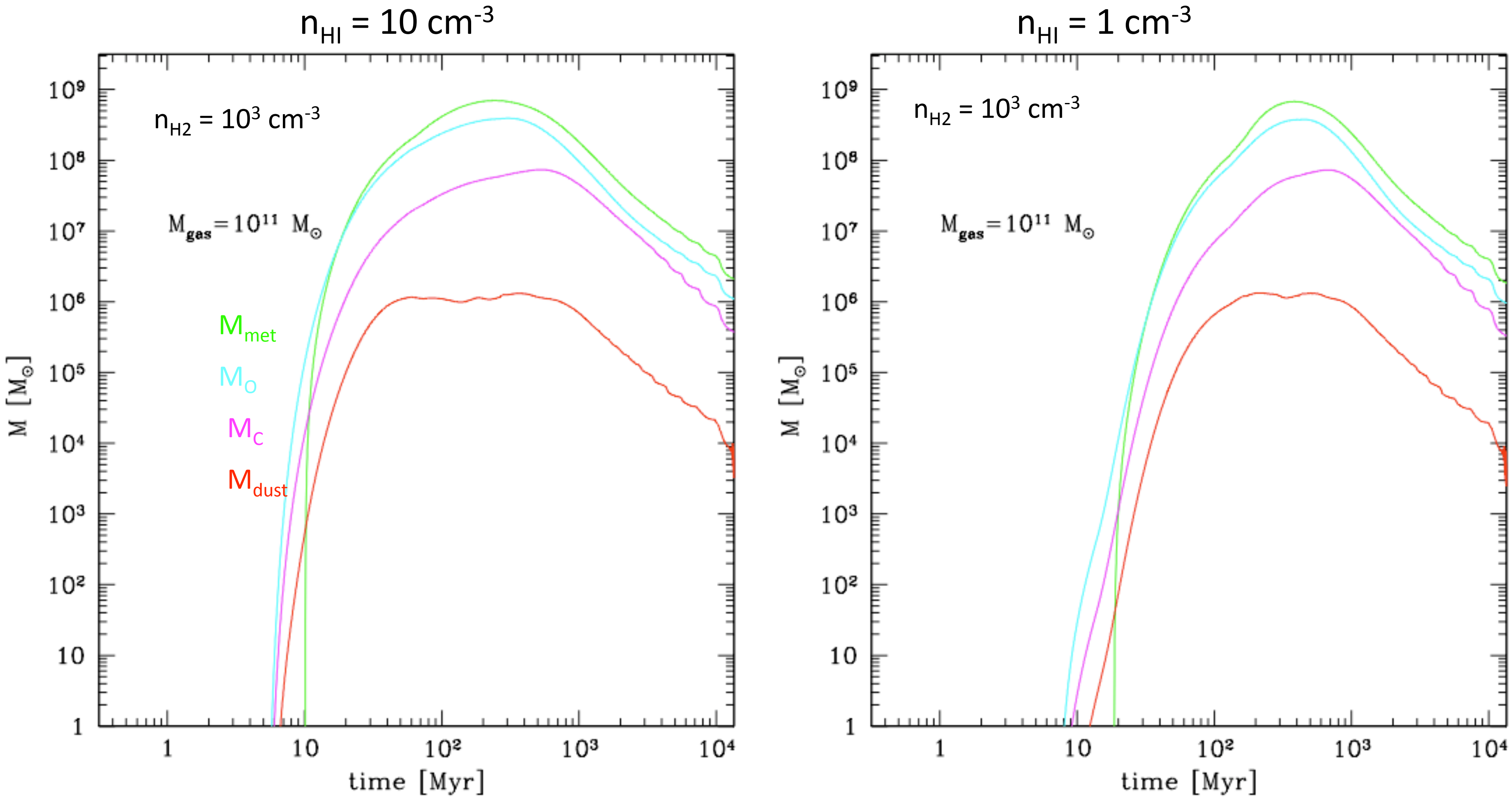
n_{HI} = 10 cm^{-3}



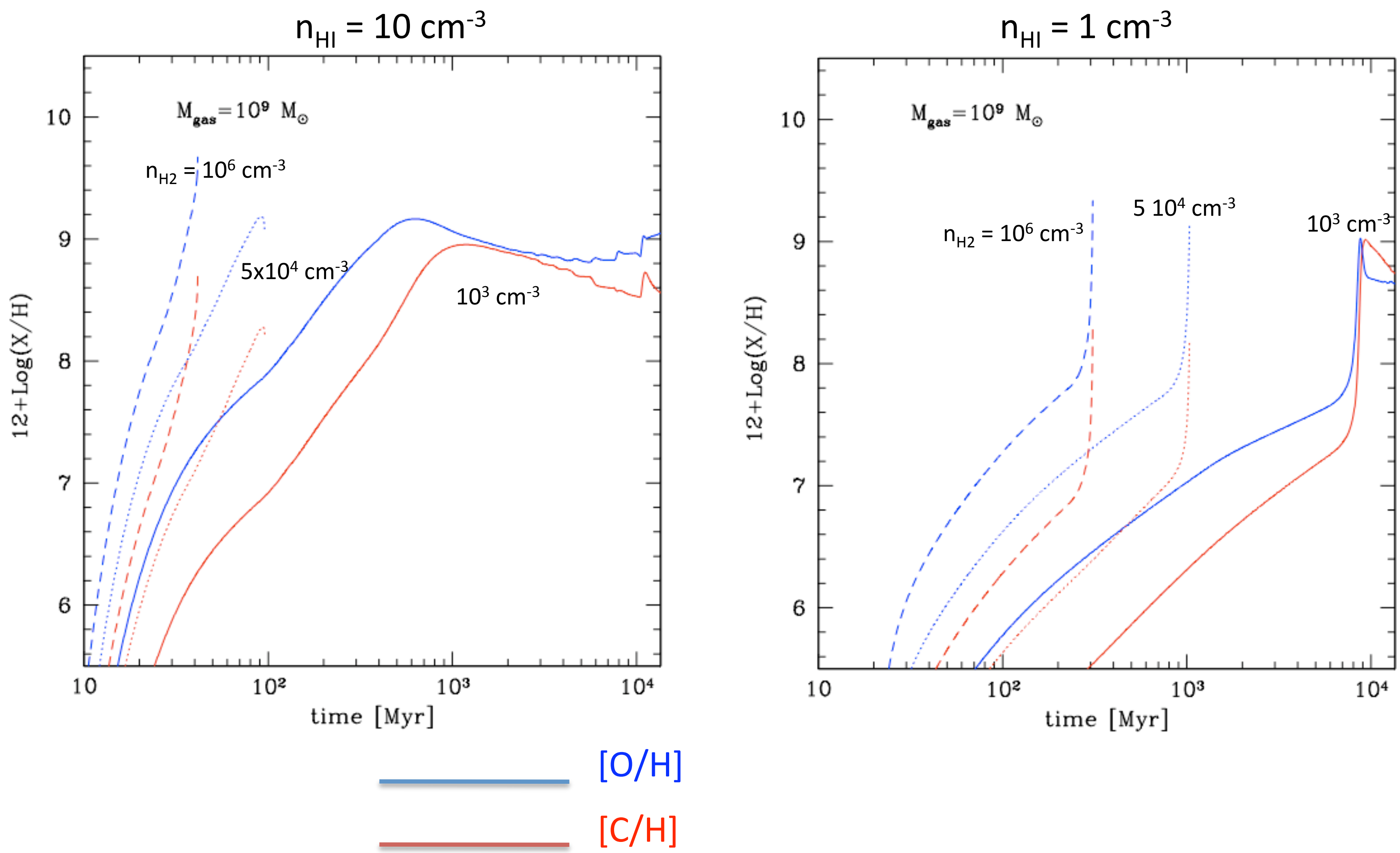
n_{HI} = 1 cm^{-3}



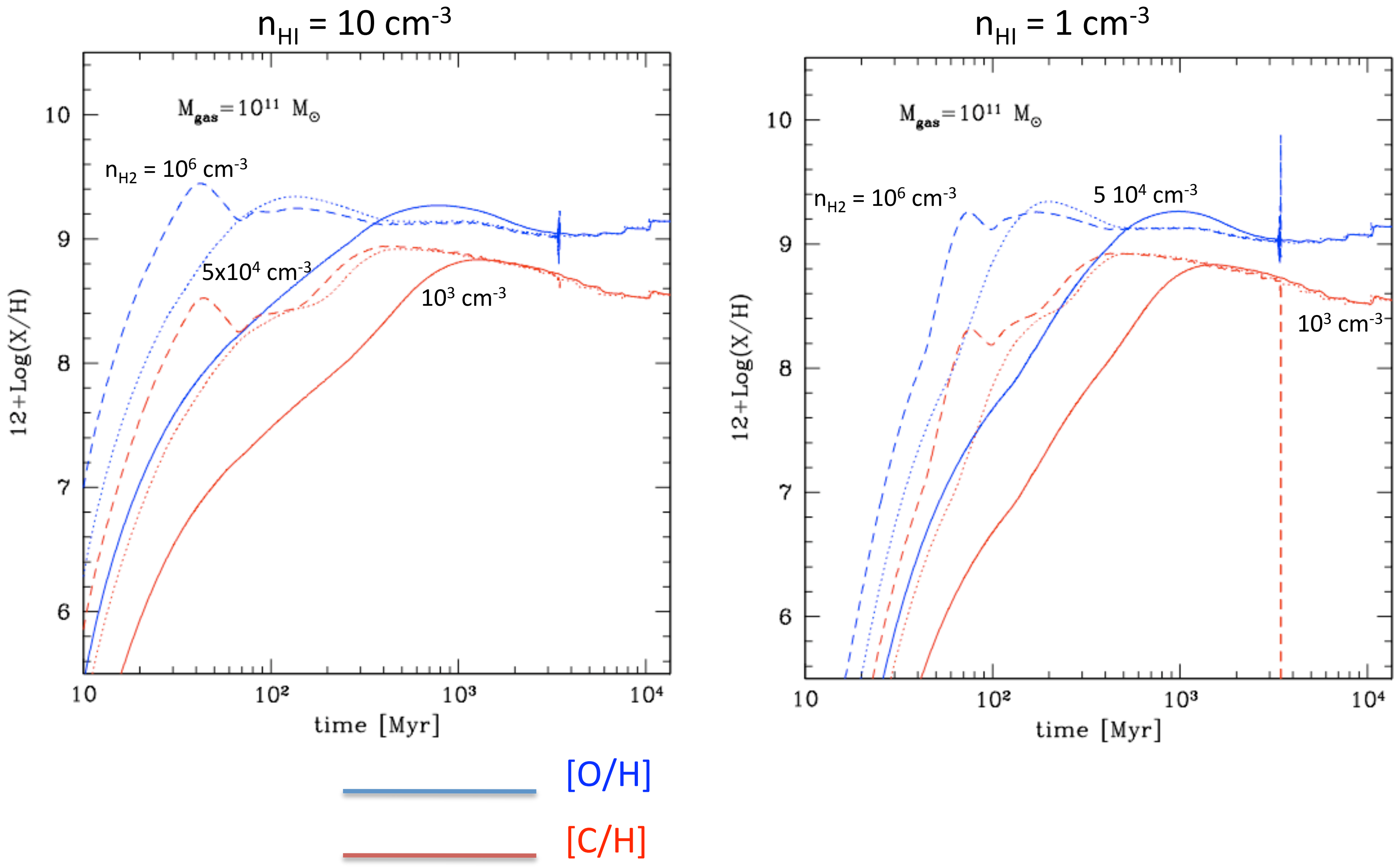
time evolution: M_{met}



Metallicity evolution

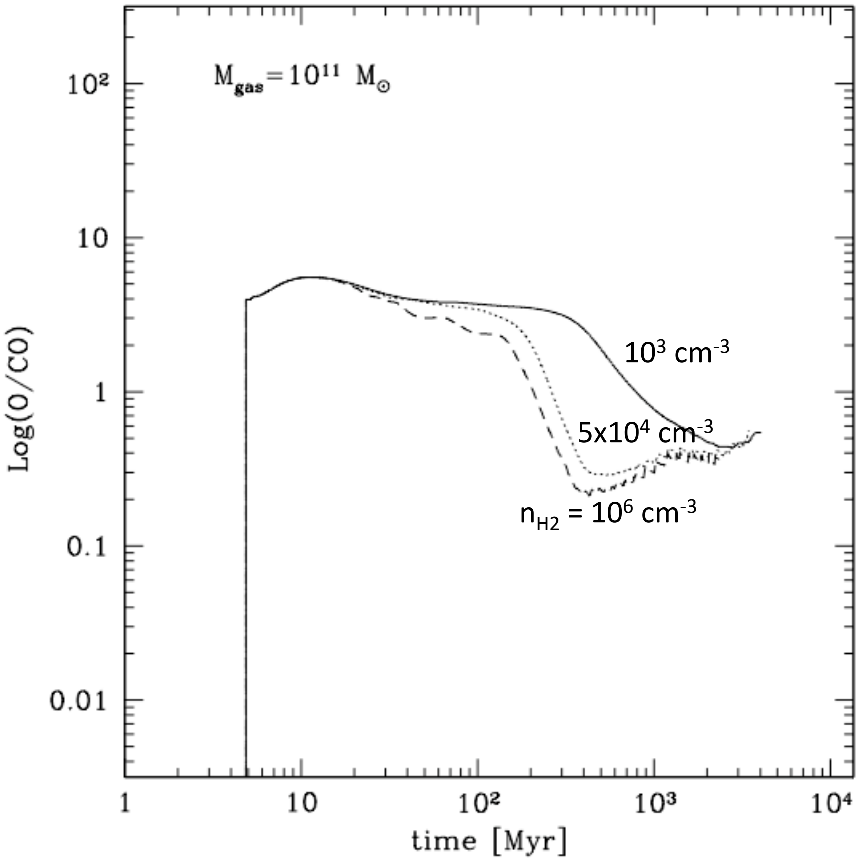


Metallicity evolution

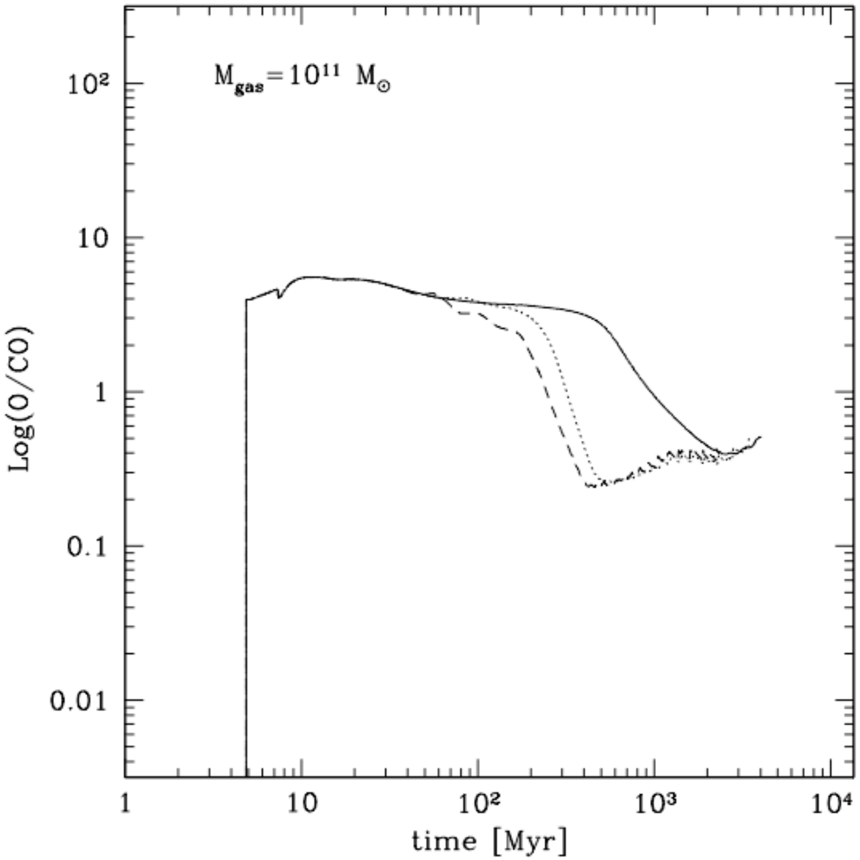


Molecule evolution

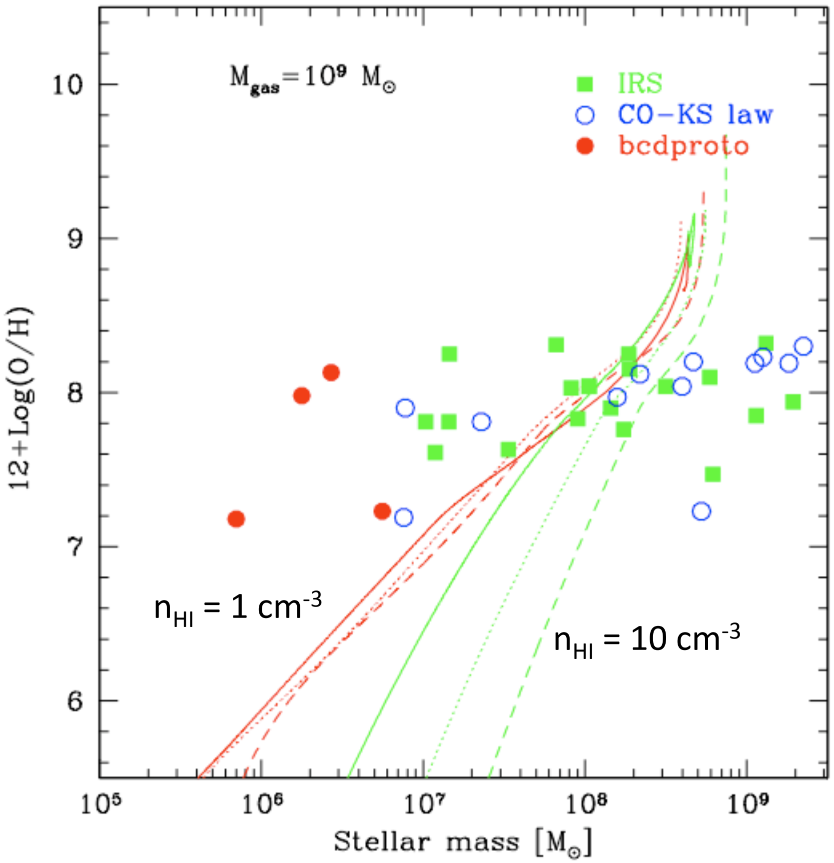
n_{HI} = 10 cm^{-3}

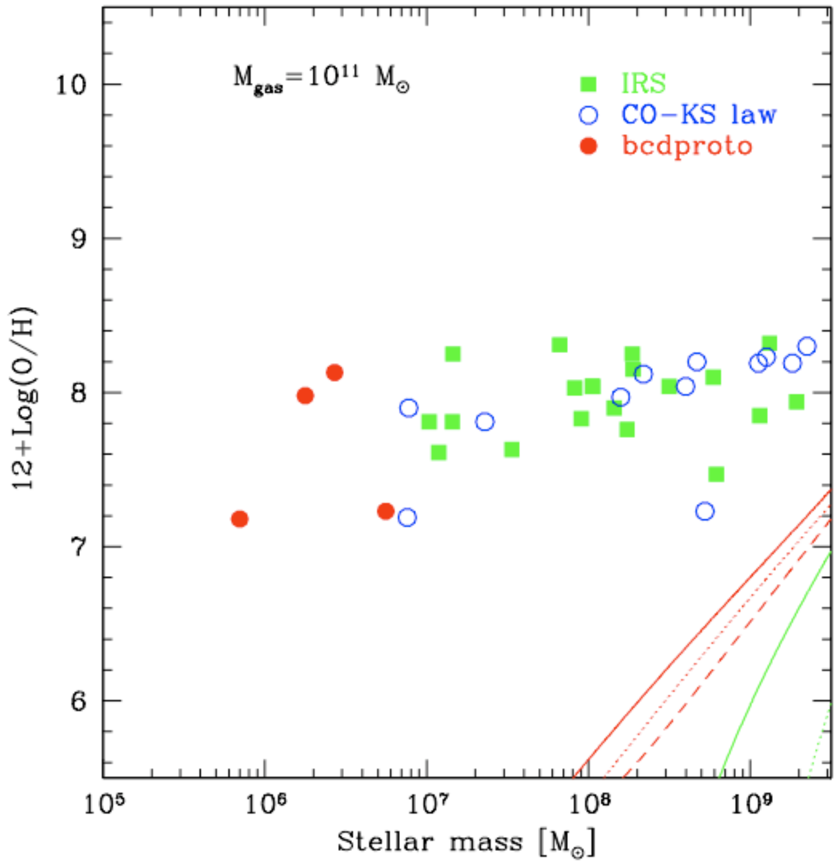


n_{HI} = 1 cm^{-3}

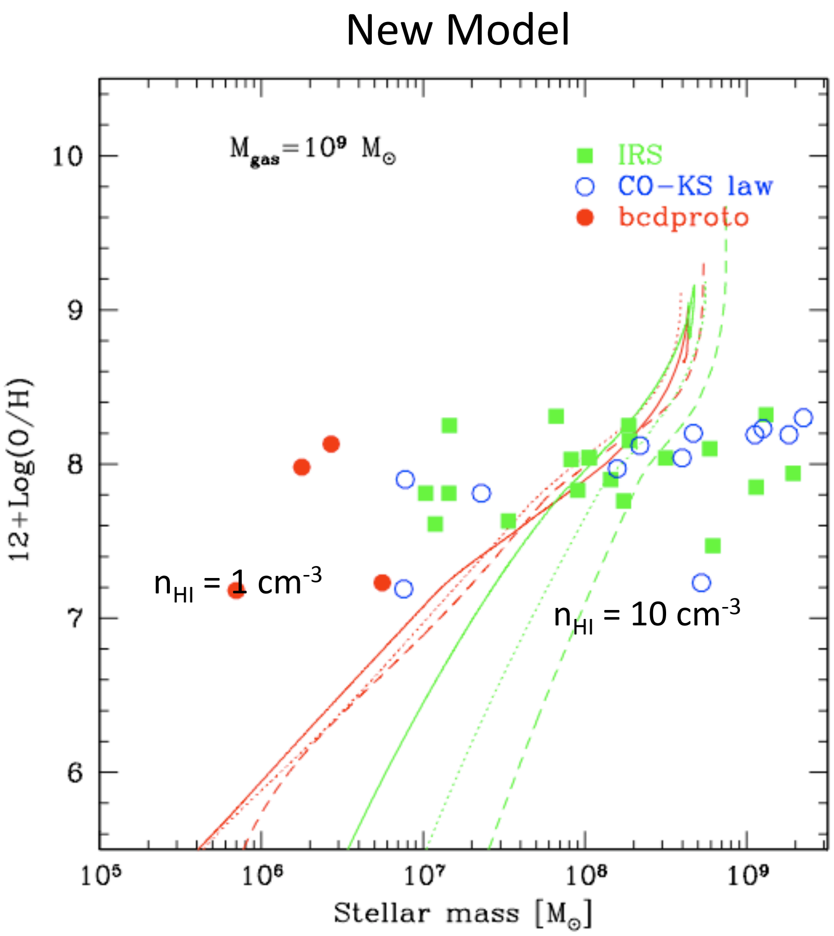


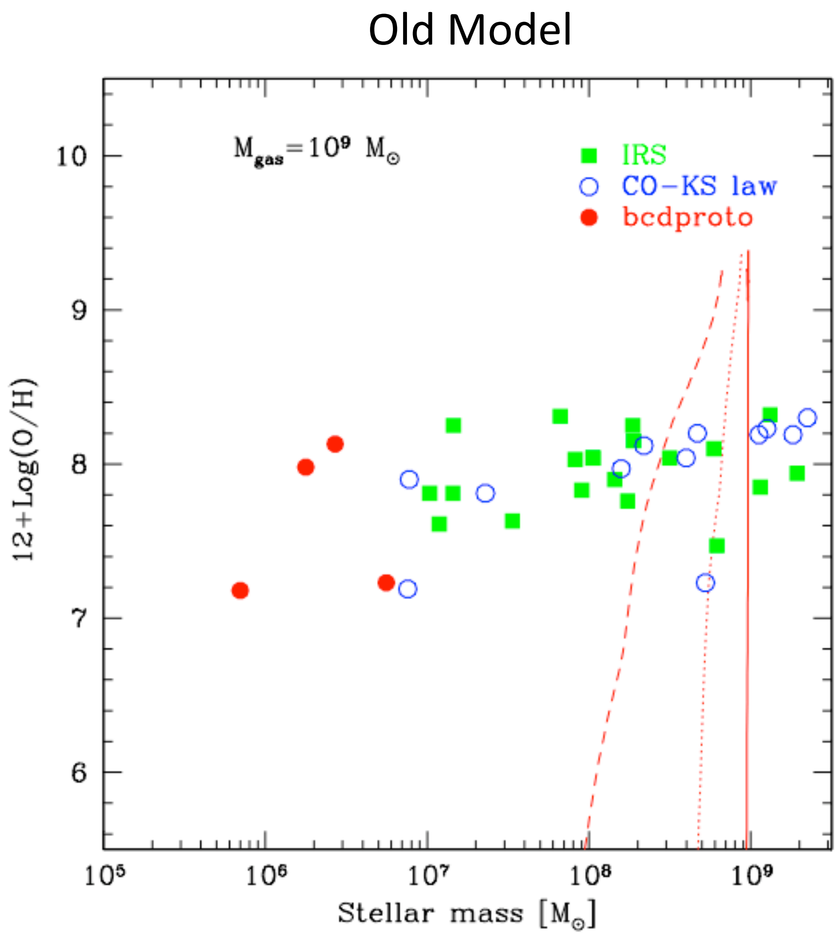
Mass-metallicity relation





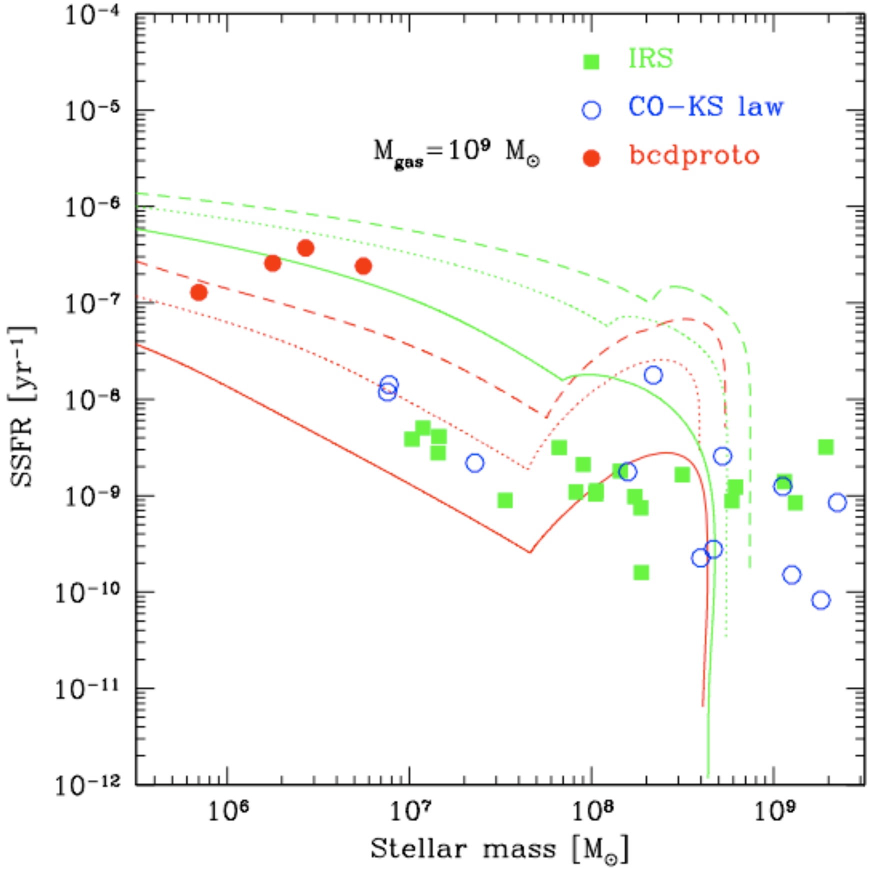
Mass-metallicity relation



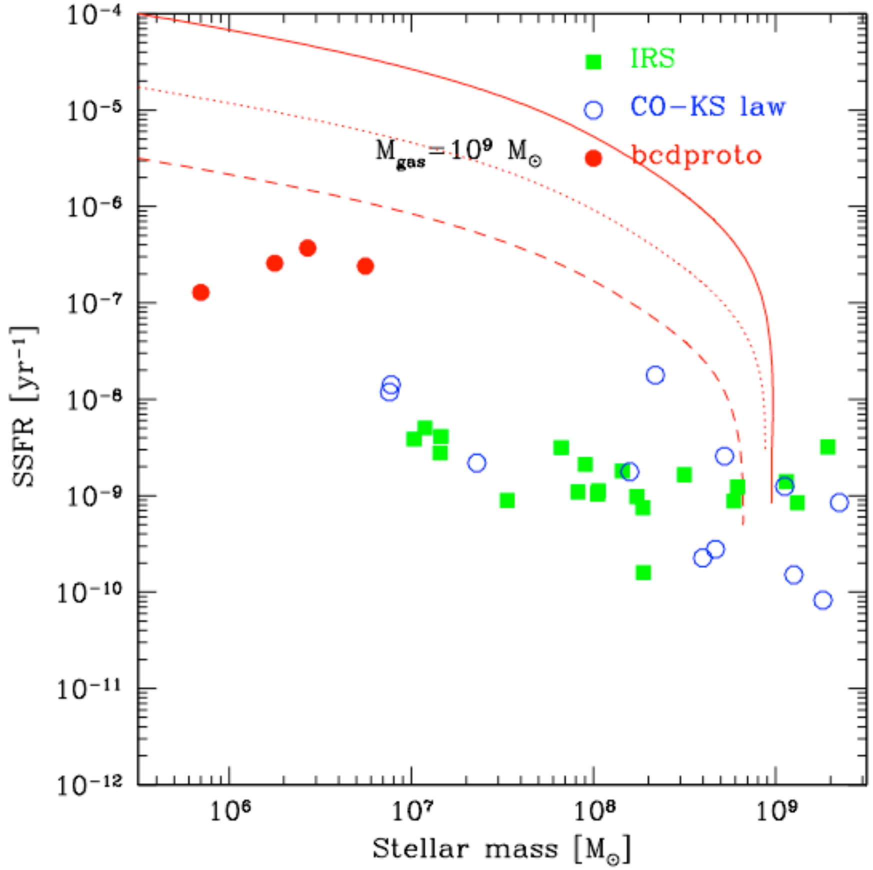


Specific star formation rate

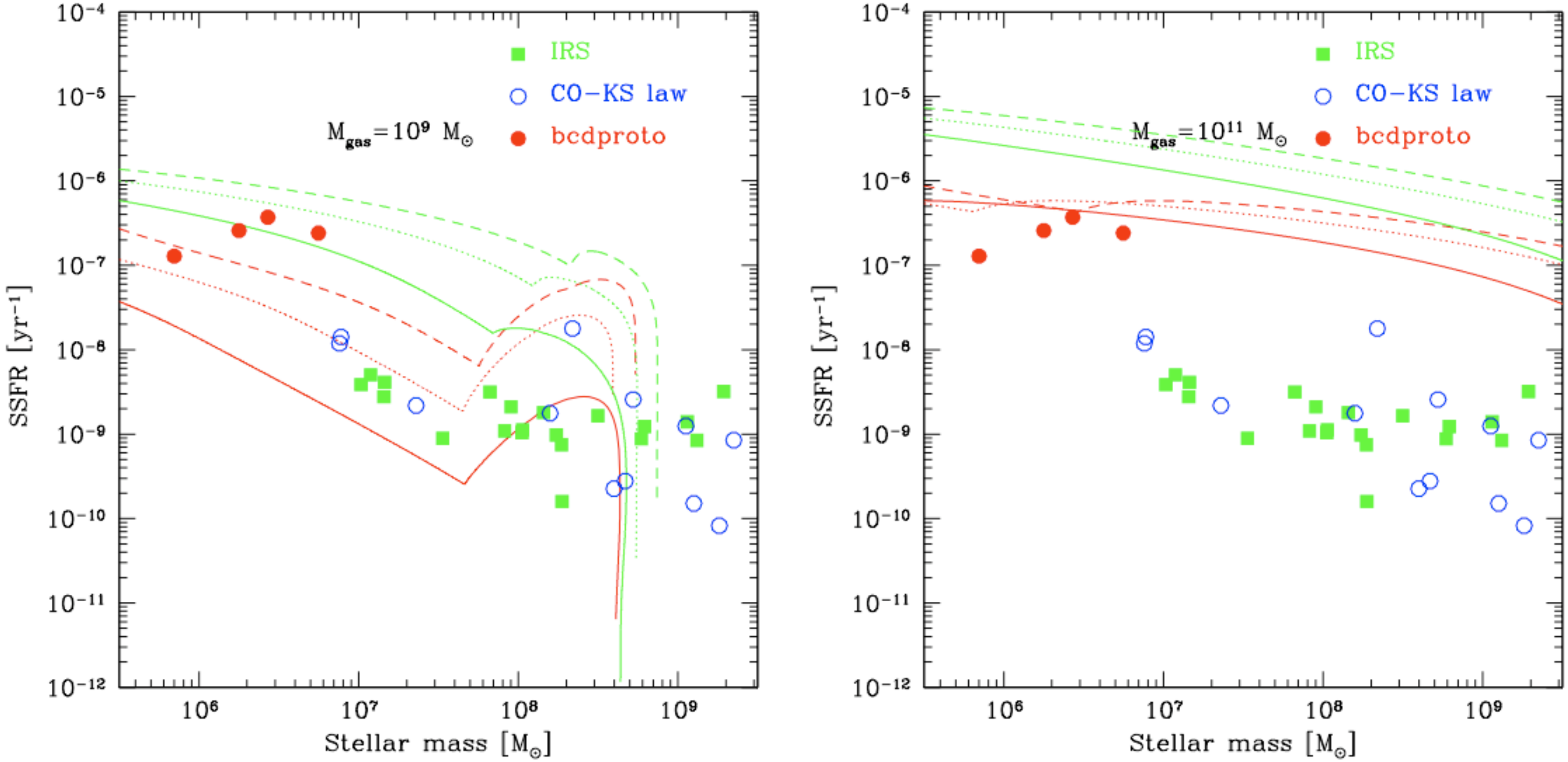
New Model



Old Model

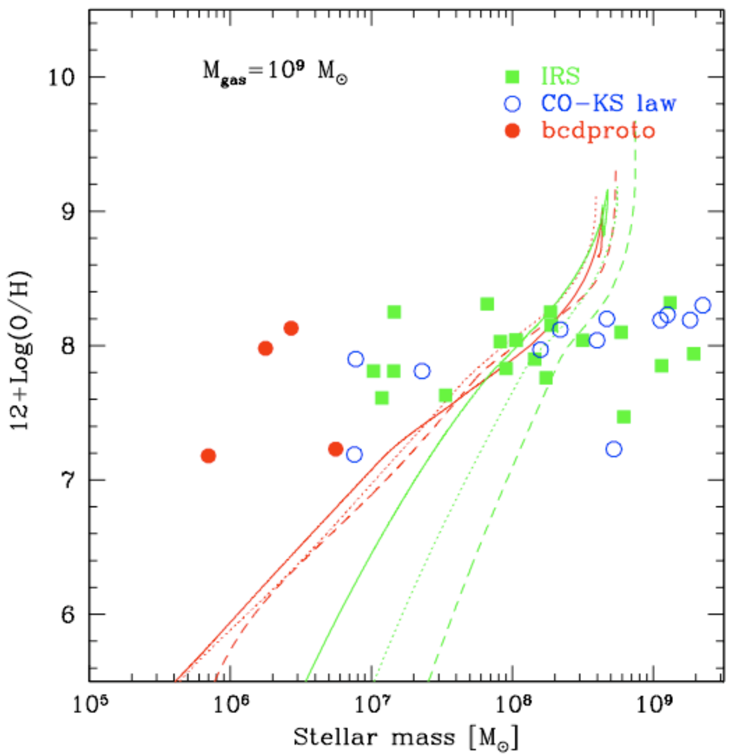


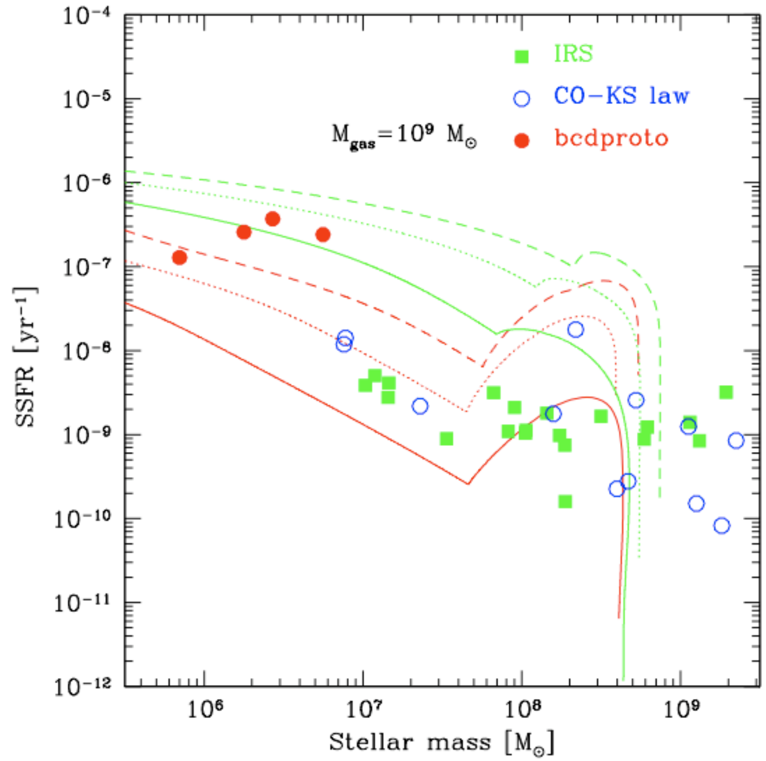
Specific star formation rate



conclusions

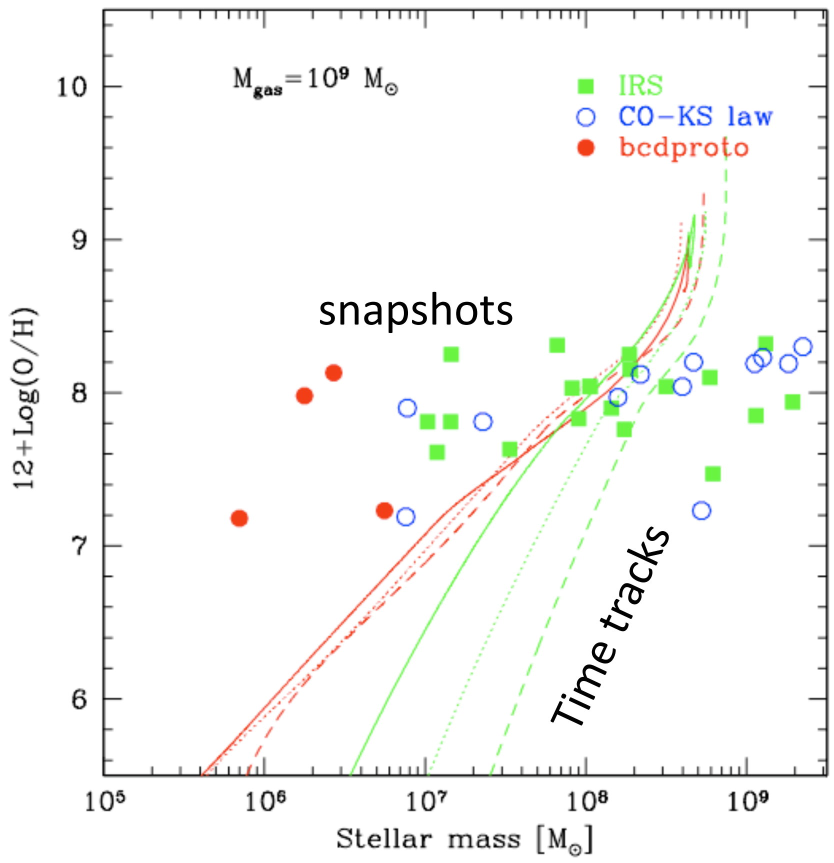
- chemical evolution model is ok
- still need to work on the SFR prescription: are we computing f_{H2} in the right way?
- are we comparing the models and data in the right way?

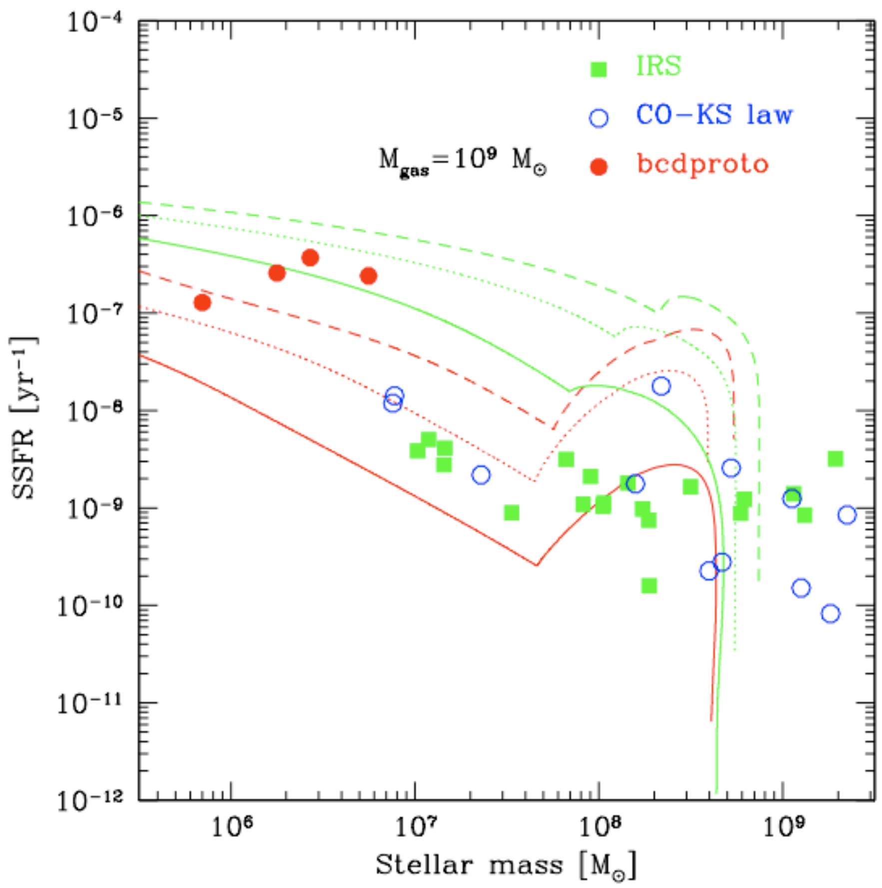




Notes for brain-storming

are we comparing the models and data in the right way?





snapshots = galaxies selected on the basis of specific properties (ex. SFRs)

→Run a grid of models ($M_{gas,in}$, n_{HI}, n_{H2}) and select them in terms of SFRs to populate the plane

To do list

(1) Rileggere bene il paper originale di McKee per capire bene se stiamo considerando la Sigma giusta

(2) Capire cosa conviene fare: evolvere il gas a volume density costante o a raggio costante? Cambia la dipendenza dal tempo della Sigma. Infatti:

Sigma ≅ Mgas(t)^(1/3) se nH=cost
Sigma = Mgas(t) se RH=cost

(3) Intensificare la griglia di modelli per Sigma (eventualmente nH2)

(4) Considerare un infall di gas alla metallicita' Zmin = 5x10^{-2} Zsun e provare ad abbassare la soglia

(5) Selezionare i dati (rivisti da Leslie per essere sicuri che ci sia consistenza) in funzione della SFR,th e fare la stessa cosa per I dati teorici

(6) Cercare di capire le correlazioni osservate (mass-metallicity), (ssfr vs mstar) per poi "calibrare" la Schmidt-Kennicutt law (alpha_CO/X-factor)