Hierarchical Structure Formation & Chemical Evolution of Galaxies

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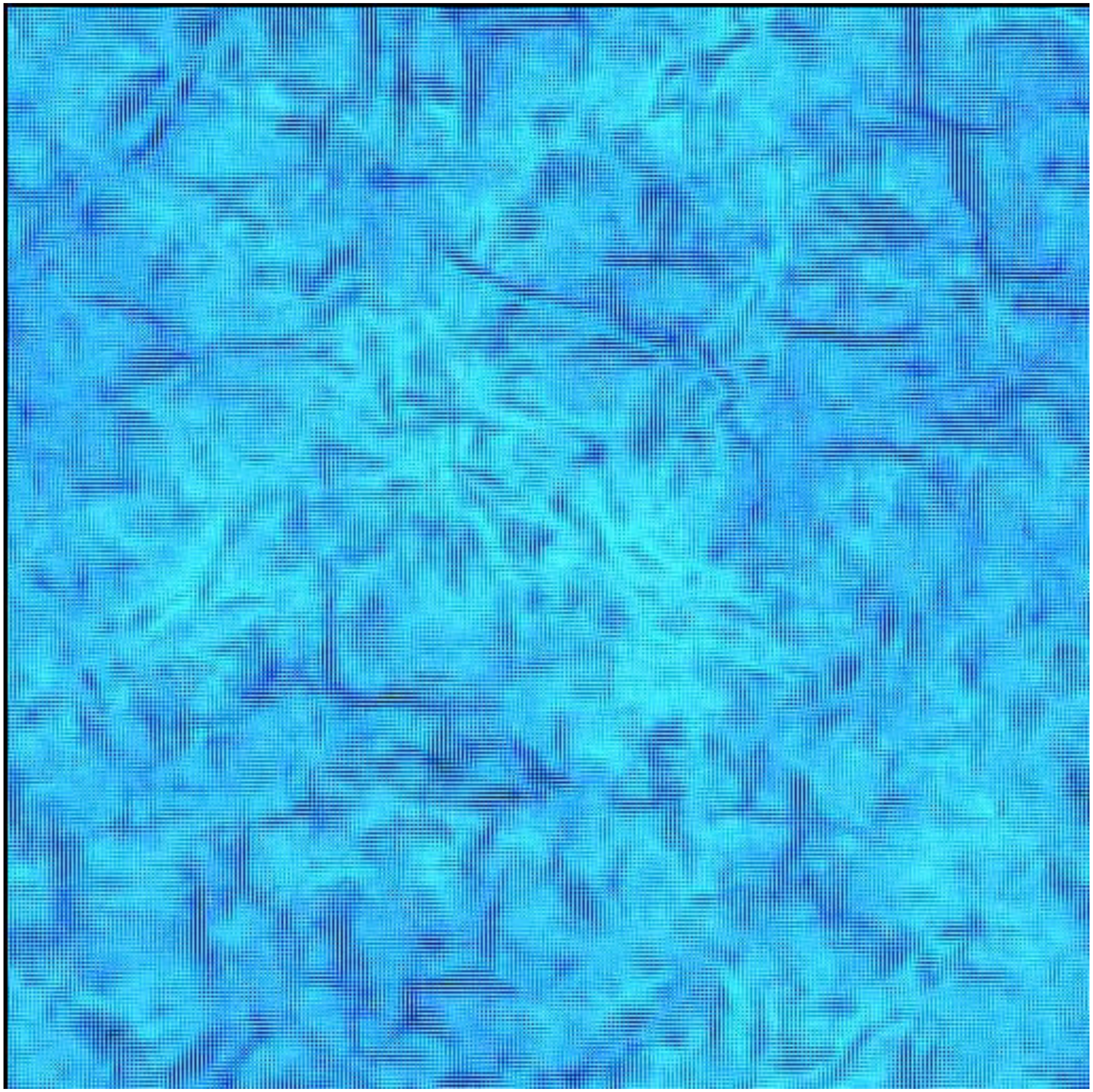
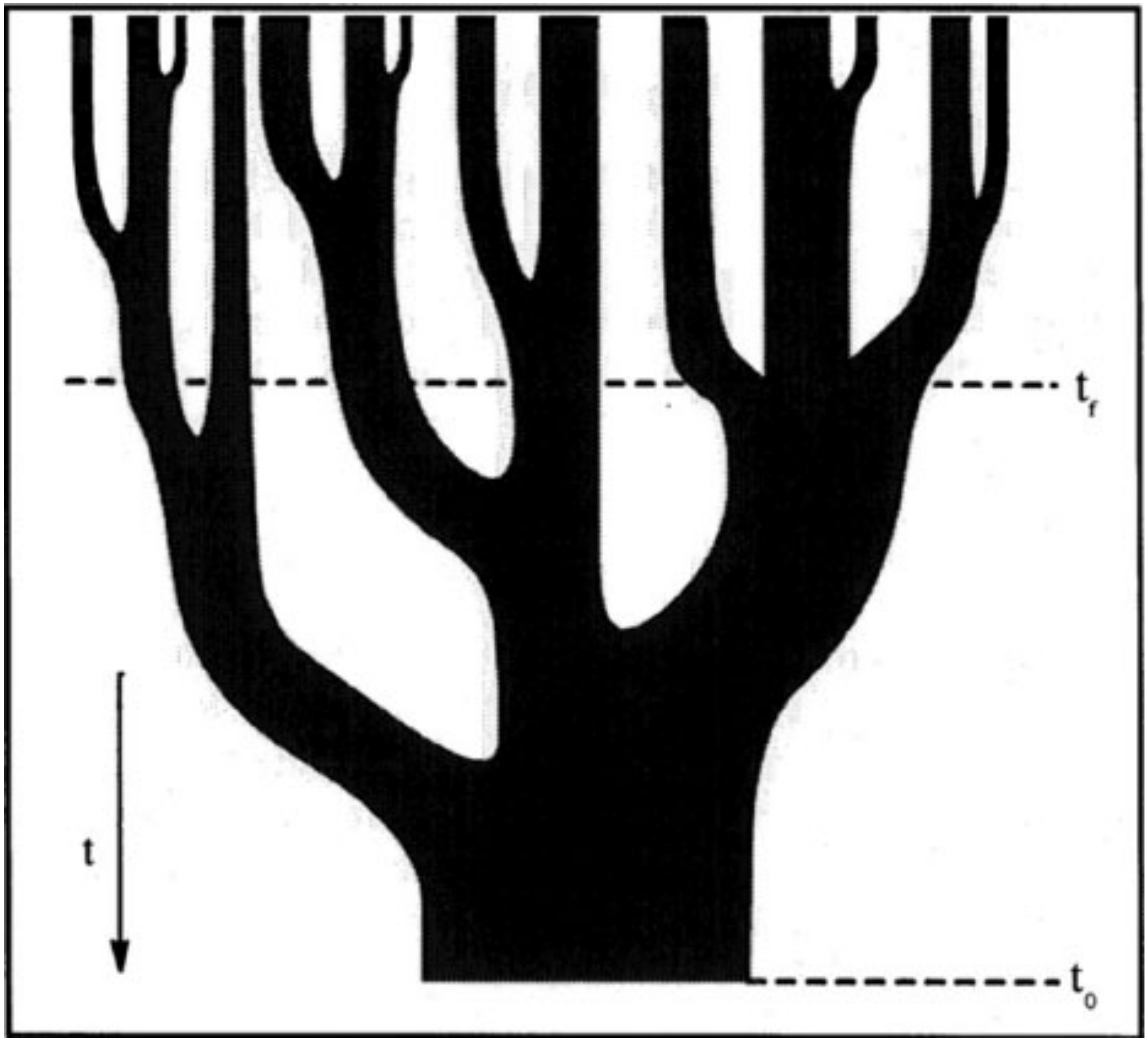
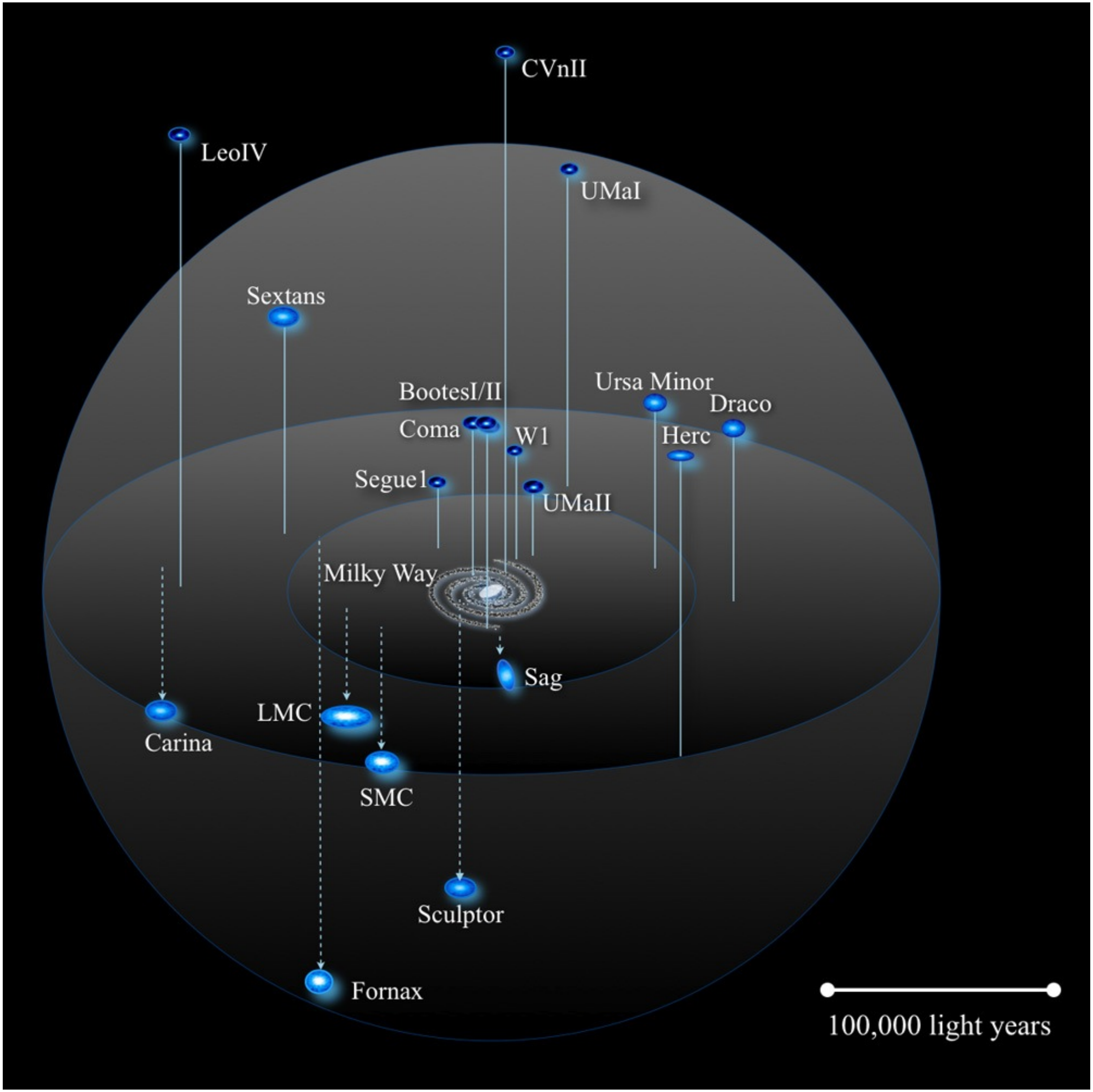
Hierarchical Structure Formation



Merger Tree




CVnII
LeoIV
UMaI
Sextans
BootesI/II
Ursa Minor
Draco
Coma
W1
Herc
Segue1
UMaII
Milky Way
Sag
LMC
Carina
SMC
Sculptor
Fornax
100,000 light years

Properties of a Dark Matter Halo
(Bryan & Norman 1998)

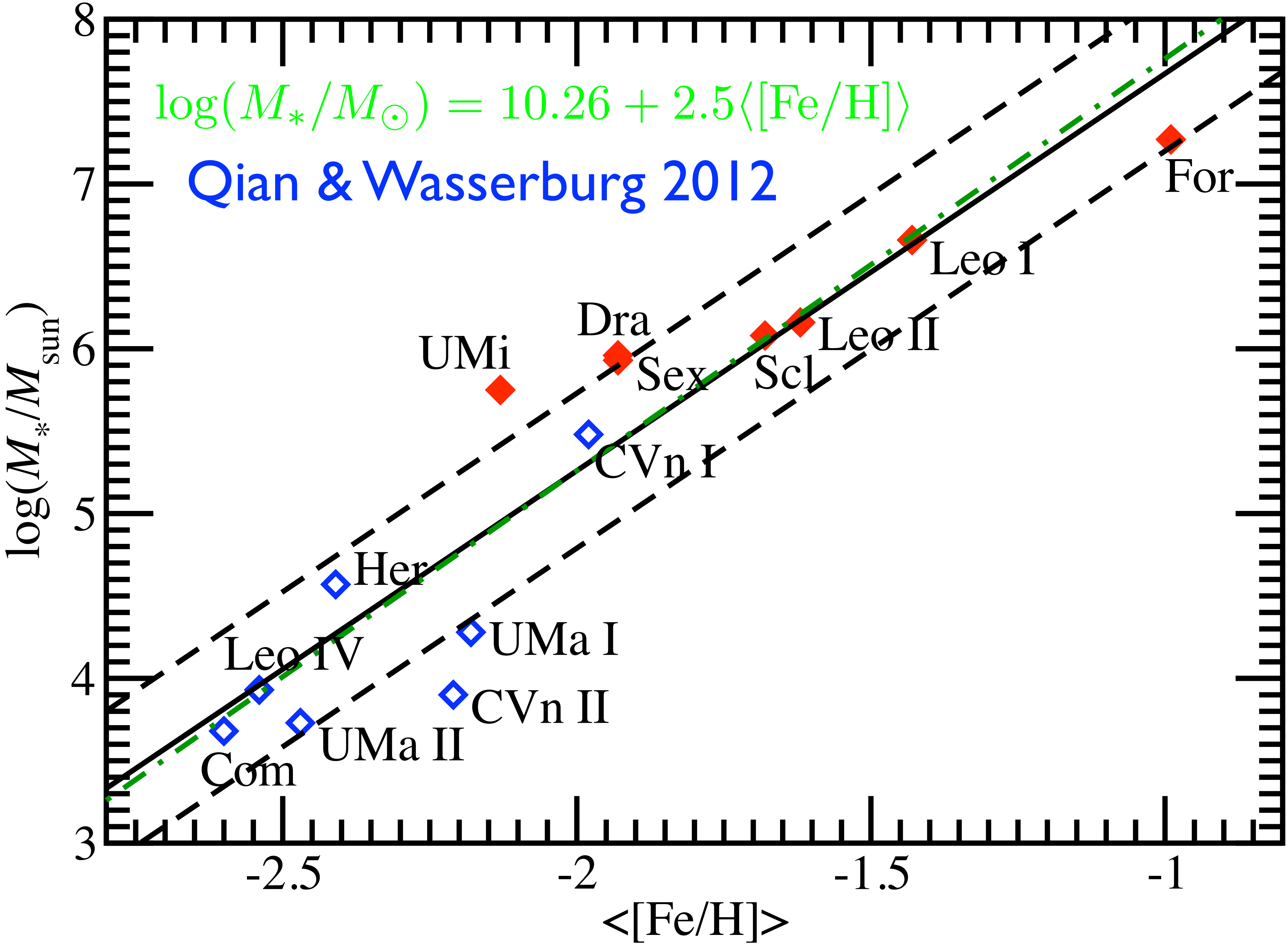
$$\rho_{\rm crit}(z) = \frac{3H(z)^2}{8\pi G}, \;\; \rho_h = \Delta_c(z)\rho_{\rm crit}(z)$$

virial radius: $r_{\rm vir} = \left(\frac{3M_h}{4\pi\rho_h}\right)^{1/3}$

circular velocity: $v_{\rm circ} = \left(\frac{GM_h}{r_{\rm vir}}\right)^{1/2}$

virial temperature: $T_{\rm vir} = \frac{GM_h\mu m_p}{2k_B r_{\rm vir}}$

gravitational binding energy: $E_G = \frac{GM_h^2}{2r_{\rm vir}}$



$\log(M_*/M_\odot) = 10.26 + 2.5\langle[\mathrm{Fe/H}]\rangle$
Qian & Wasserburg 2012
UMi
Dra
Sex
Scl
Leo II
Leo I
For
CVn I
Her
UMa I
Leo IV
CVn II
UMa II
Com
8
7
6
5
4
3
-2.5
-2
-1.5
-1
$\log(M_*/M_{\mathrm{sun}})$
<[Fe/H]>

$$\frac{dM_{\rm Fe}}{dt} = P_{\rm Fe}(t) - X_{\rm Fe}(t)[\psi(t) + F_{\rm out}(t)]$$

$$\int P_{\rm Fe}(t)dt = \int X_{\rm Fe}(t)[\psi(t) + F_{\rm out}(t)]dt$$

$$P_{\rm Fe}(t) \propto \langle Y_{\rm Fe}\rangle \psi(t),\;\; F_{\rm out}(t) \propto \langle E_{\rm expl}\rangle \psi(t) r_{\rm vir}/M_h$$

$$\langle X_{\rm Fe}\rangle = \frac{\int X_{\rm Fe}(t)\psi(t)dt}{\int \psi(t)dt} \propto \frac{M_h}{r_{\rm vir}} \propto M_h^{2/3}$$

$$\frac{dM_g}{dt} = F_{\rm in}(t) - \psi(t) - F_{\rm out}(t)$$

$$\int F_{\rm in}(t)dt = \int [\psi(t) + F_{\rm out}(t)]dt$$

$$M_h \propto M_* r_{\rm vir}/M_h \Rightarrow M_* \propto M_h^2/r_{\rm vir} \propto M_h^{5/3} \propto \langle X_{\rm Fe}\rangle^{5/2}$$

Press-Schechter Formalism

primordial density fluctuations on various length scales

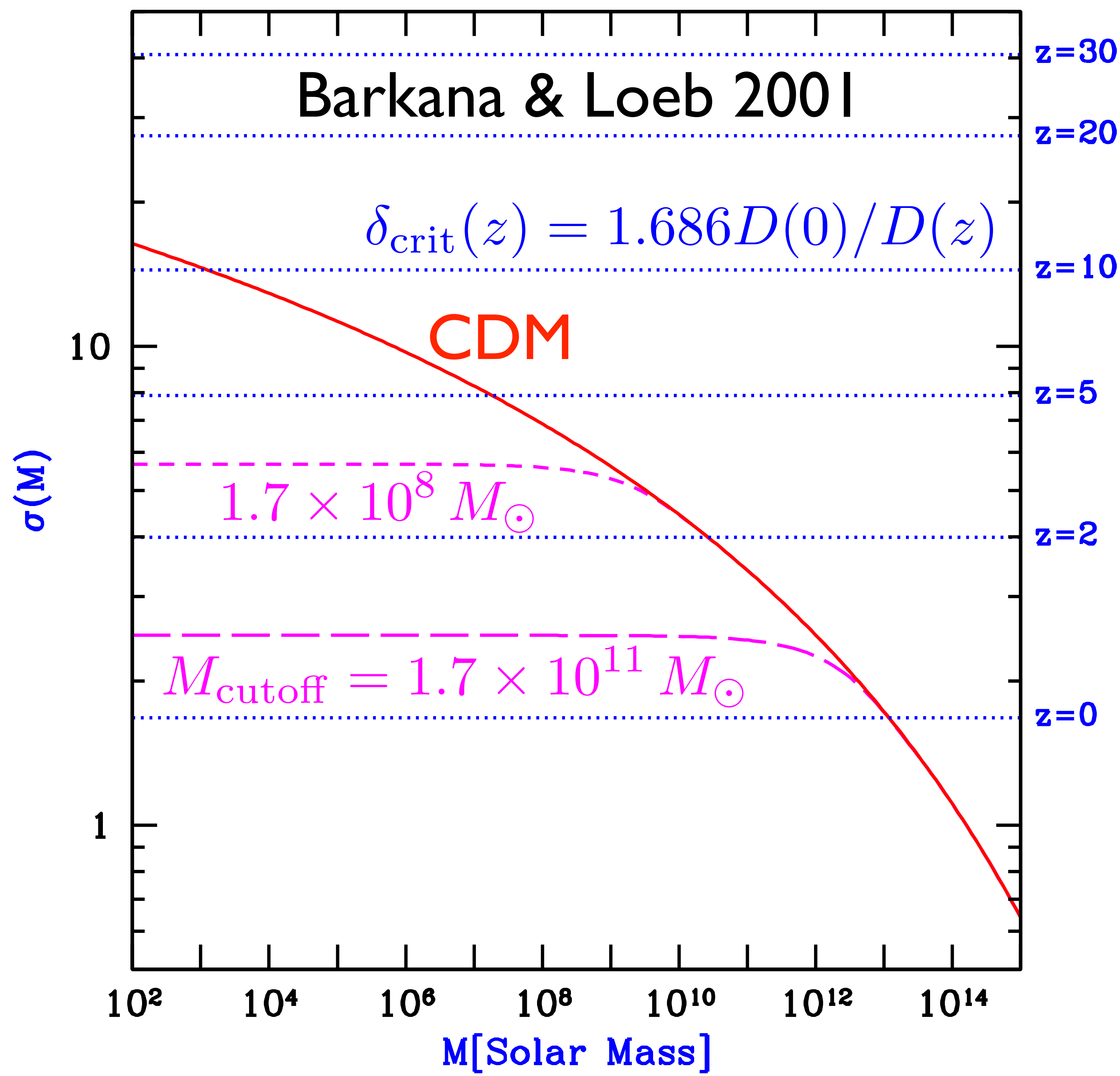
$$\delta(\vec{r}) = \frac{\rho(\vec{r})}{\langle \rho \rangle} - 1$$

linear
growth
theory

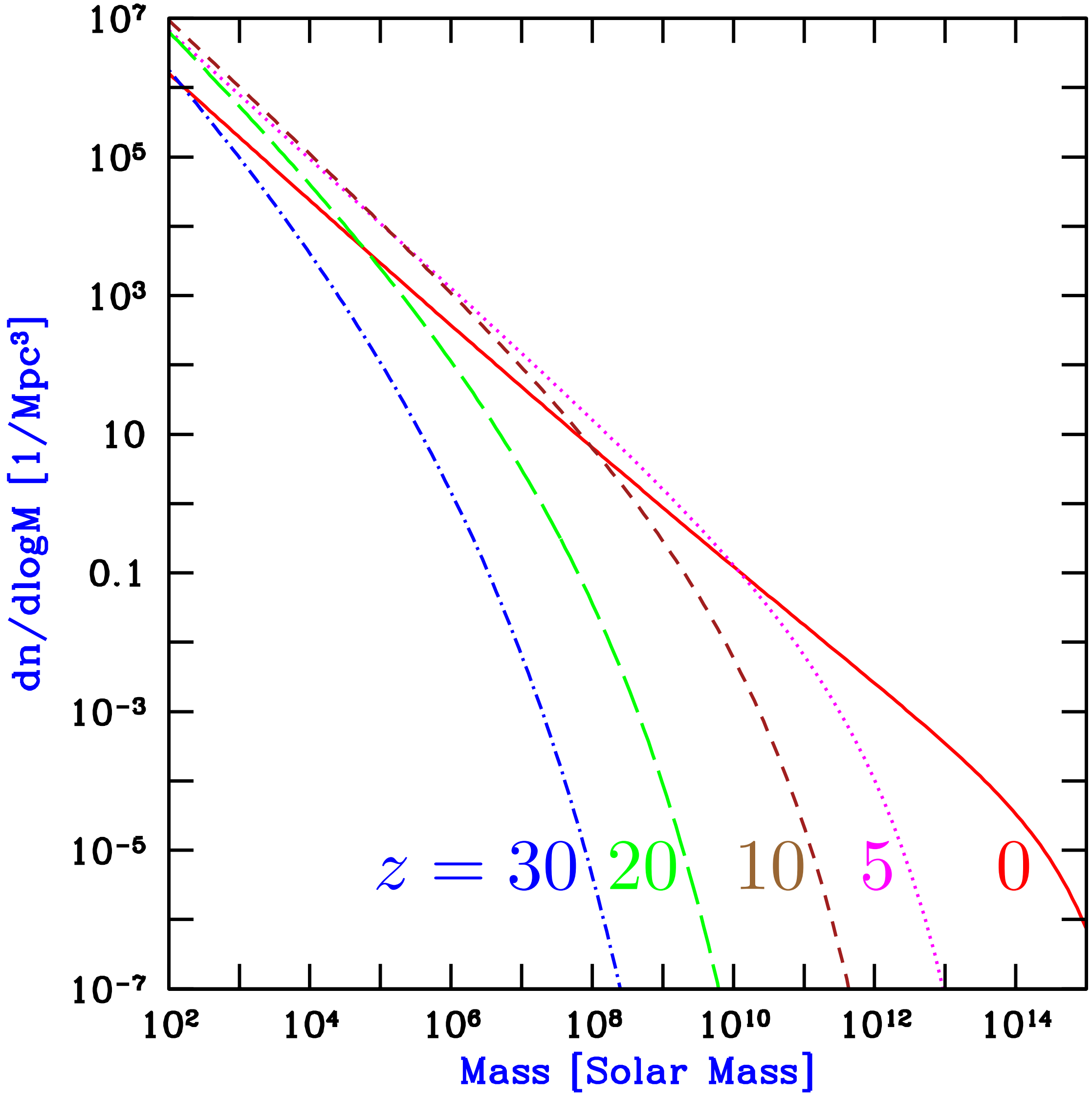
$$\delta_{\rm crit}(z) = 1.686 \frac{D(0)}{D(z)}$$

present fluctuations on various mass scales

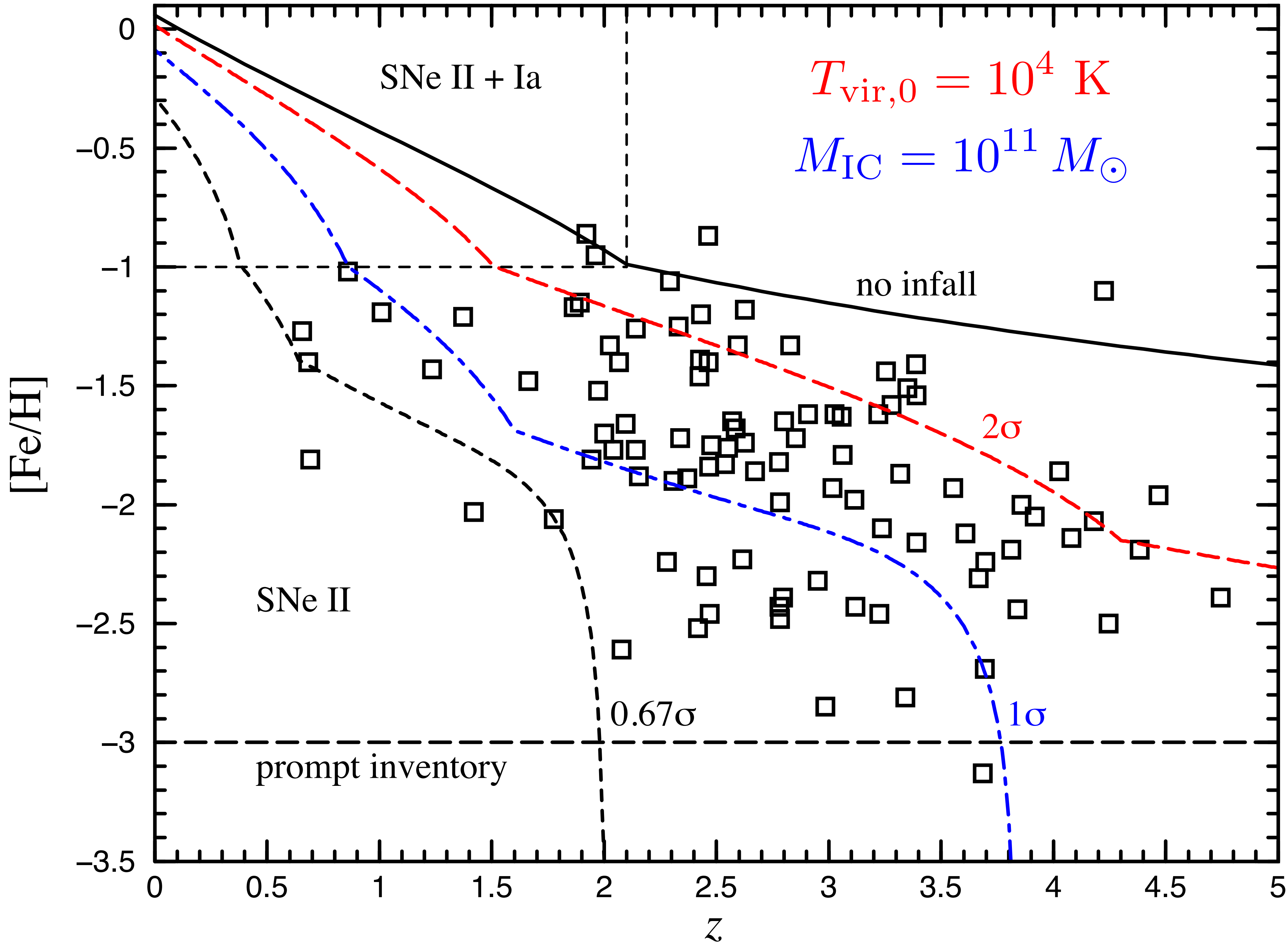
$$\sigma(M)$$



Barkana & Loeb 2001
$\delta_{\rm crit}(z) = 1.686 D(0)/D(z)$
CDM
$1.7 \times 10^8 \, M_\odot$
$M_{\rm cutoff} = 1.7 \times 10^{11} \, M_\odot$
z=30
z=20
z=10
z=5
z=2
z=0
10
1
σ(M)
10^2
10^4
10^6
10^8
10^{10}
10^{12}
10^{14}
M[Solar Mass]



$$F(>M|z) = \sqrt{\frac{2}{\pi}} \int_{\delta_{\mathrm{crit}}(z)}^{\infty} \exp\left[-\frac{\delta^2}{2\sigma(M)^2}\right] \frac{d\delta}{\sigma(M)}$$



SNe II + Ia
$T_{\rm vir,0} = 10^4$ K
$M_{\rm IC} = 10^{11}\ M_\odot$
no infall
2σ
SNe II
0.67σ
1σ
prompt inventory
[Fe/H]
z

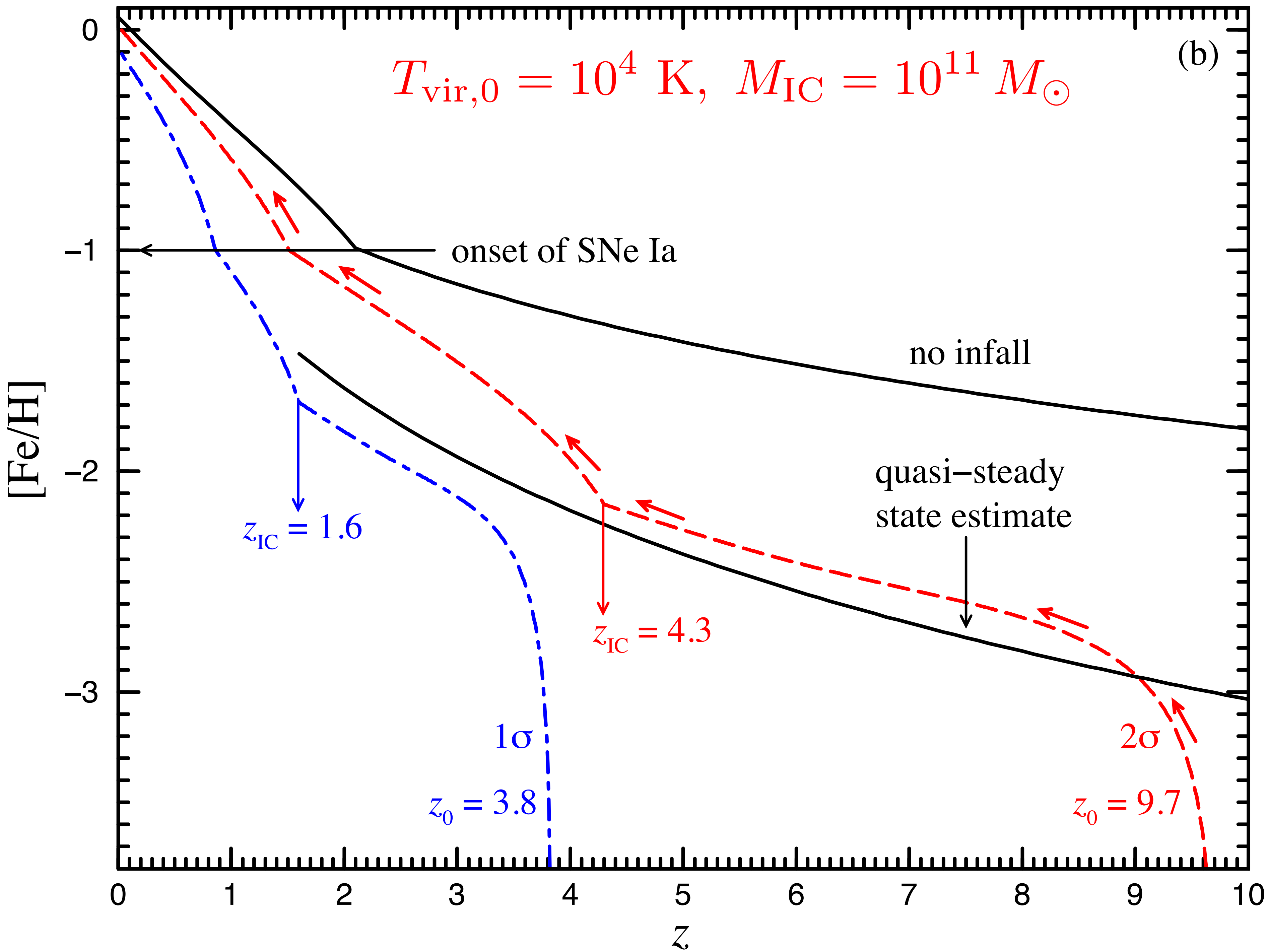
$$\frac{dM_g}{dt} = F_{\rm in}(t) - \psi(t) - F_{\rm out}(t)$$

$$\frac{dM_{\rm Fe}}{dt} = P_{\rm Fe}(t) - X_{\rm Fe}(t)[\psi(t) + F_{\rm out}(t)]$$

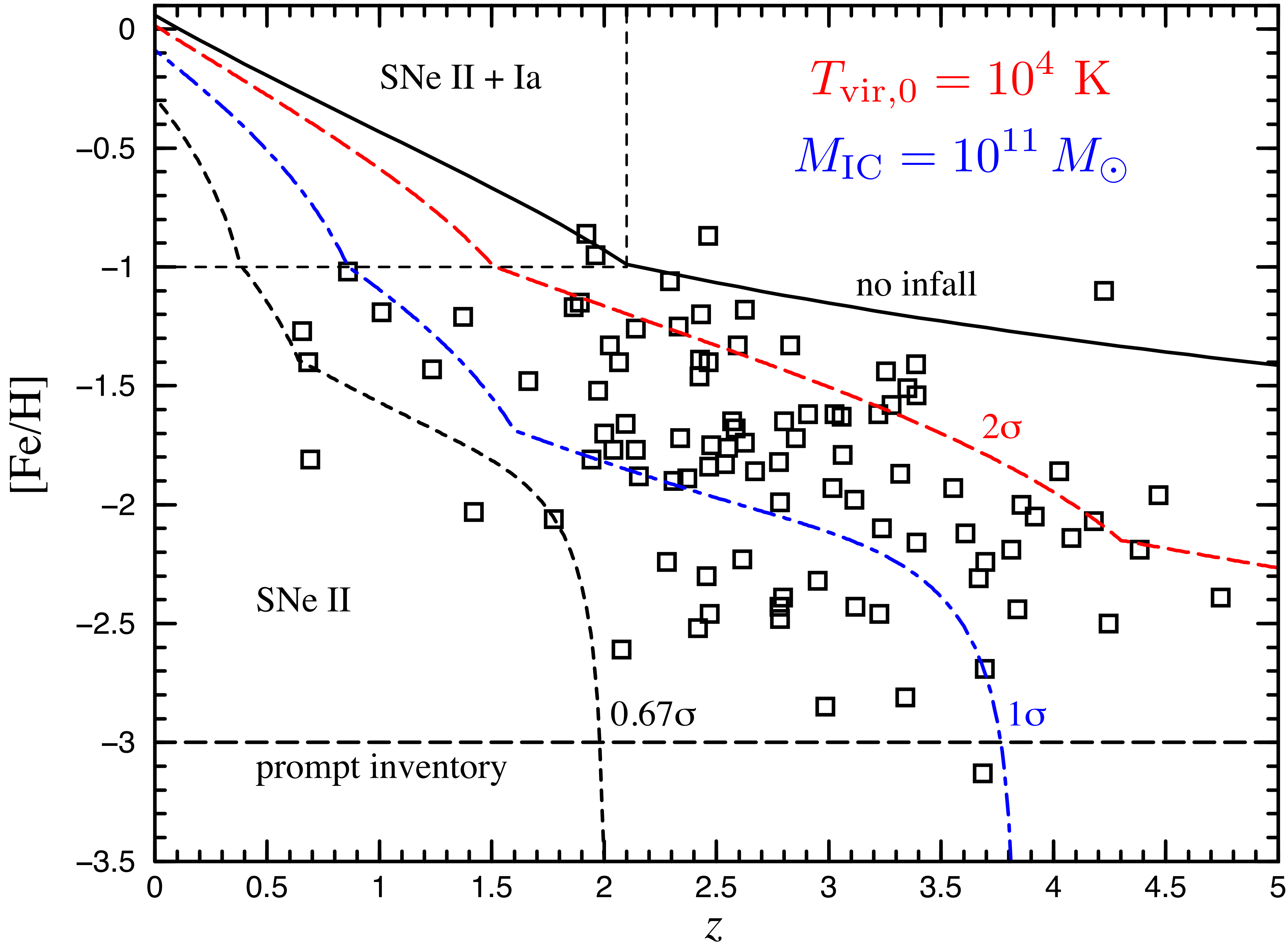
$$\frac{dX_{\rm Fe}}{dt} = \frac{P_{\rm Fe}(t)}{M_g(t)} - X_{\rm Fe}(t)\frac{F_{\rm in}(t)}{M_g(t)}$$

$$\frac{P_{\rm Fe}(t)}{M_g(t)} \sim \lambda_{\rm Fe}, \quad \frac{F_{\rm in}(t)}{M_g(t)} \sim \frac{1}{M_h}\frac{dM_h}{dt} = \lambda_{\rm in}(t)$$

quasi-steady state: $X_{\rm Fe}^{\rm QSS}(t) \sim \dfrac{\lambda_{\rm Fe}}{\lambda_{\rm in}(t)}$



(b)
$T_{\rm vir,0} = 10^4$ K, $M_{\rm IC} = 10^{11}\ M_\odot$
onset of SNe Ia
no infall
quasi−steady
state estimate
$z_{\rm IC} = 1.6$
$z_{\rm IC} = 4.3$
1σ
$z_0 = 3.8$
2σ
$z_0 = 9.7$
[Fe/H]
z



$T_{\rm vir,0} = 10^4$ K
$M_{\rm IC} = 10^{11} M_\odot$
SNe II + Ia
no infall
2σ
1σ
0.67σ
SNe II
prompt inventory
[Fe/H]
z
0
−0.5
−1
−1.5
−2
−2.5
−3
−3.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5