Distinguishing Cold, Warm, and Self-Interacting Dark Matter Based on FIRE Simulations

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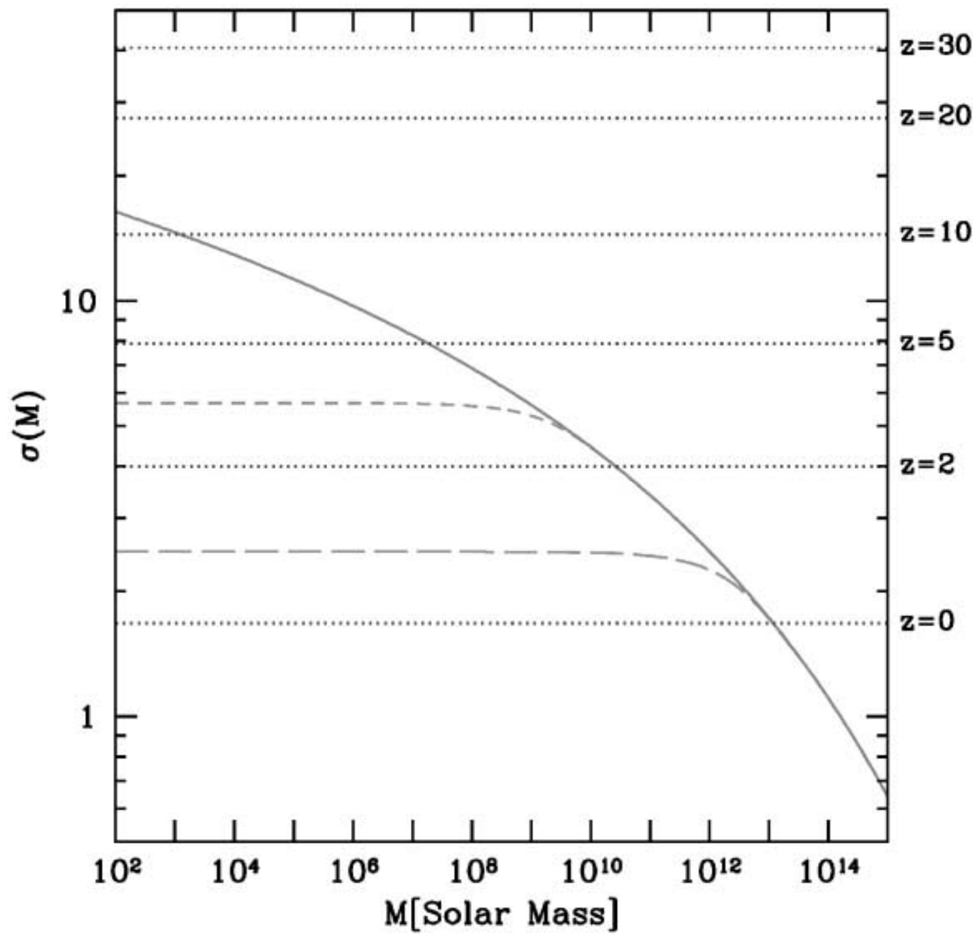
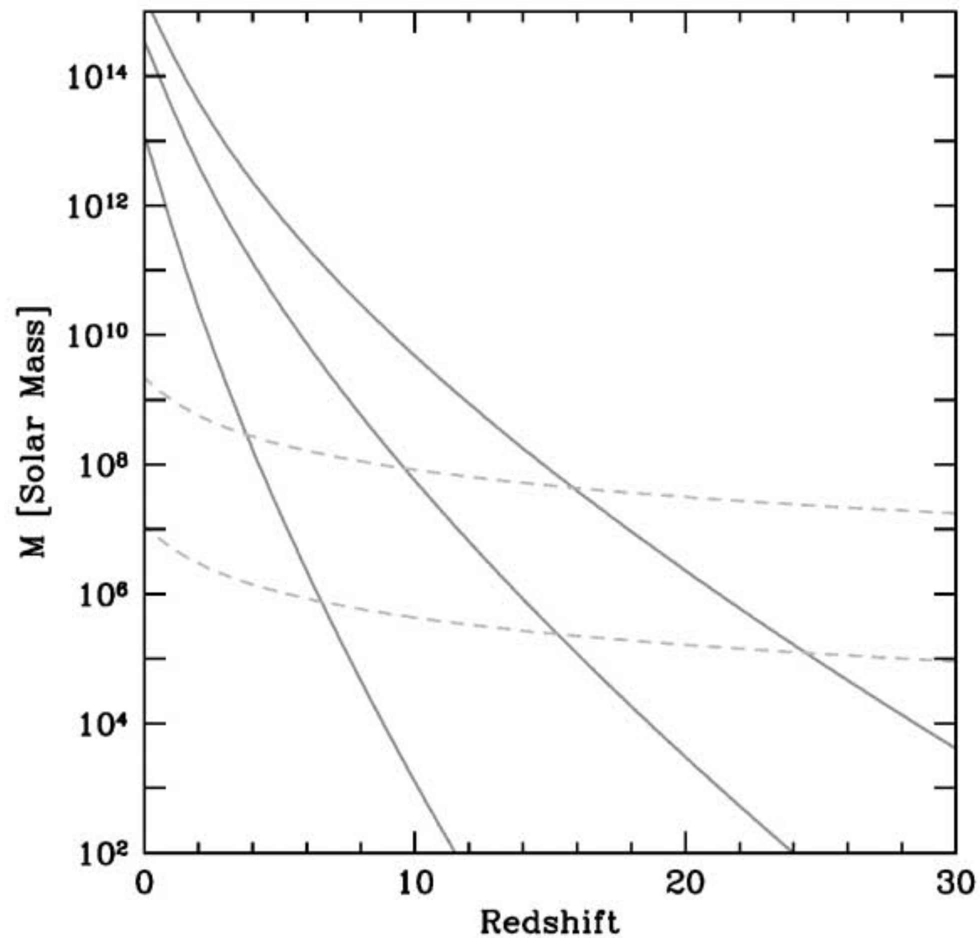
N3AS Network for Neutrinos, Nuclear Astrophysics, and Symmetries
PHYSICS FRONTIER CENTER

NSF

hierarchical evolution of DM halos

Barkana & Loeb 2001

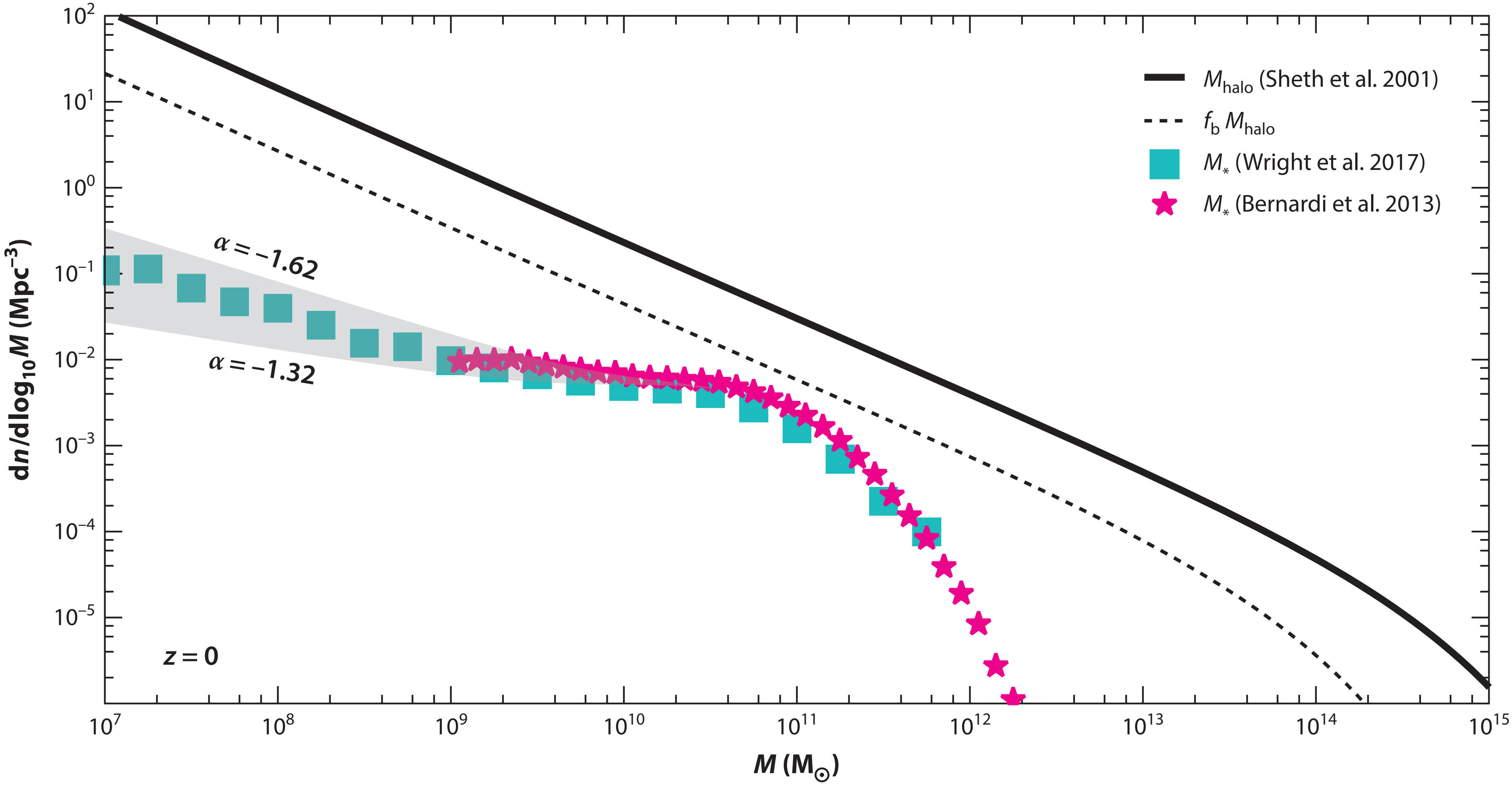




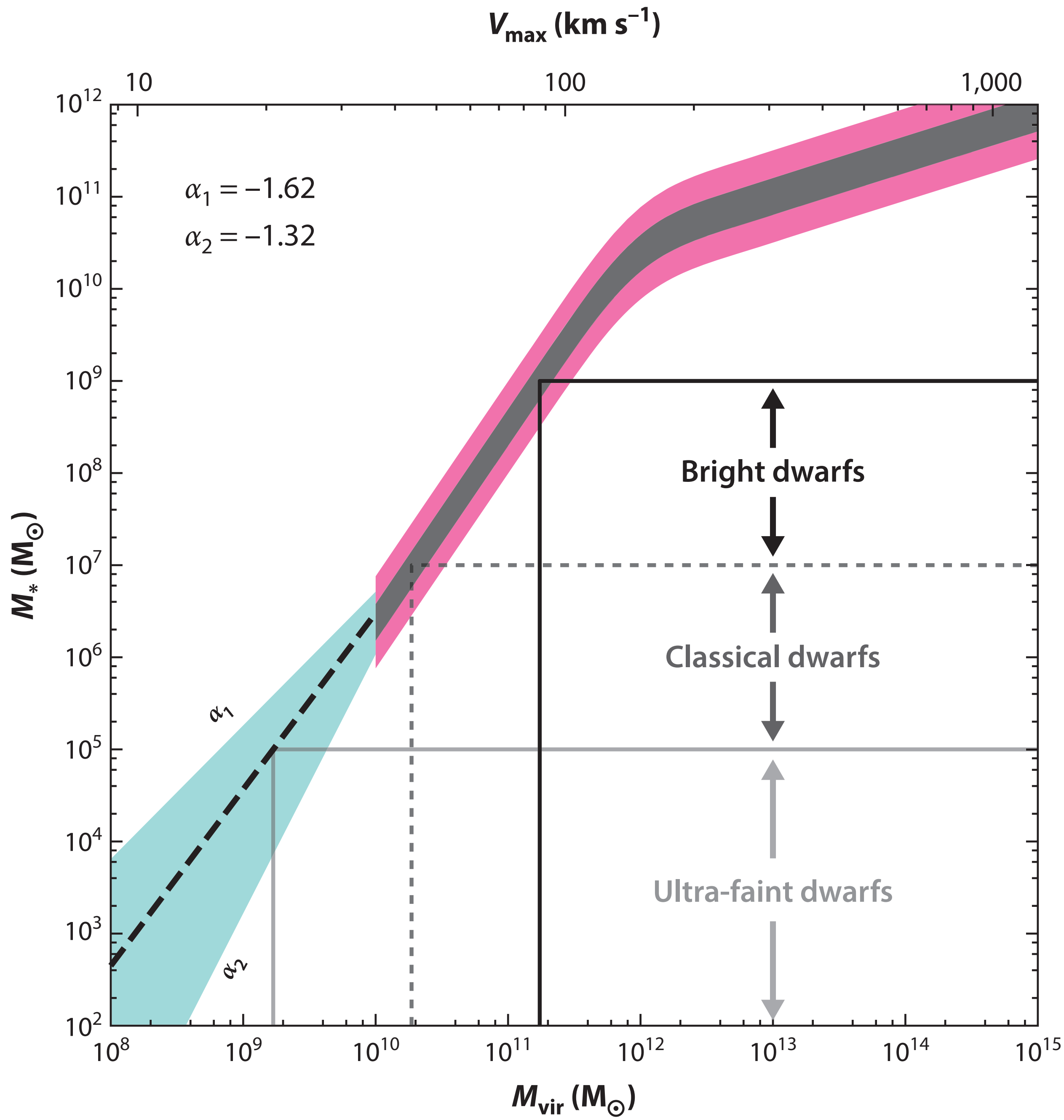
$$\delta_{\rm crit}(z) = \frac{1.686}{D(z)},\ D(z=0) = 1$$

inefficient star formation

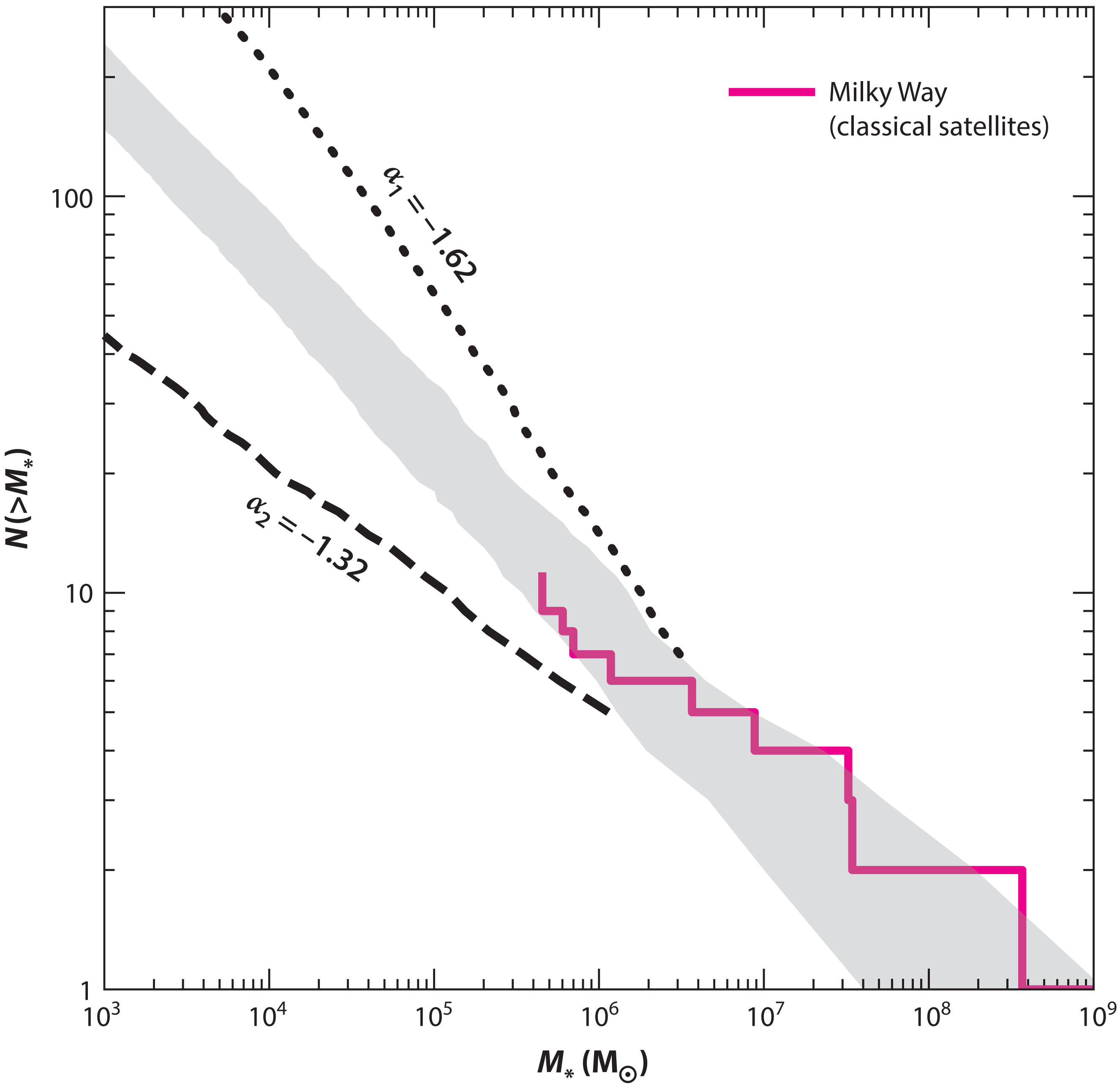
Bullock & Boylan-Kolchin 2017



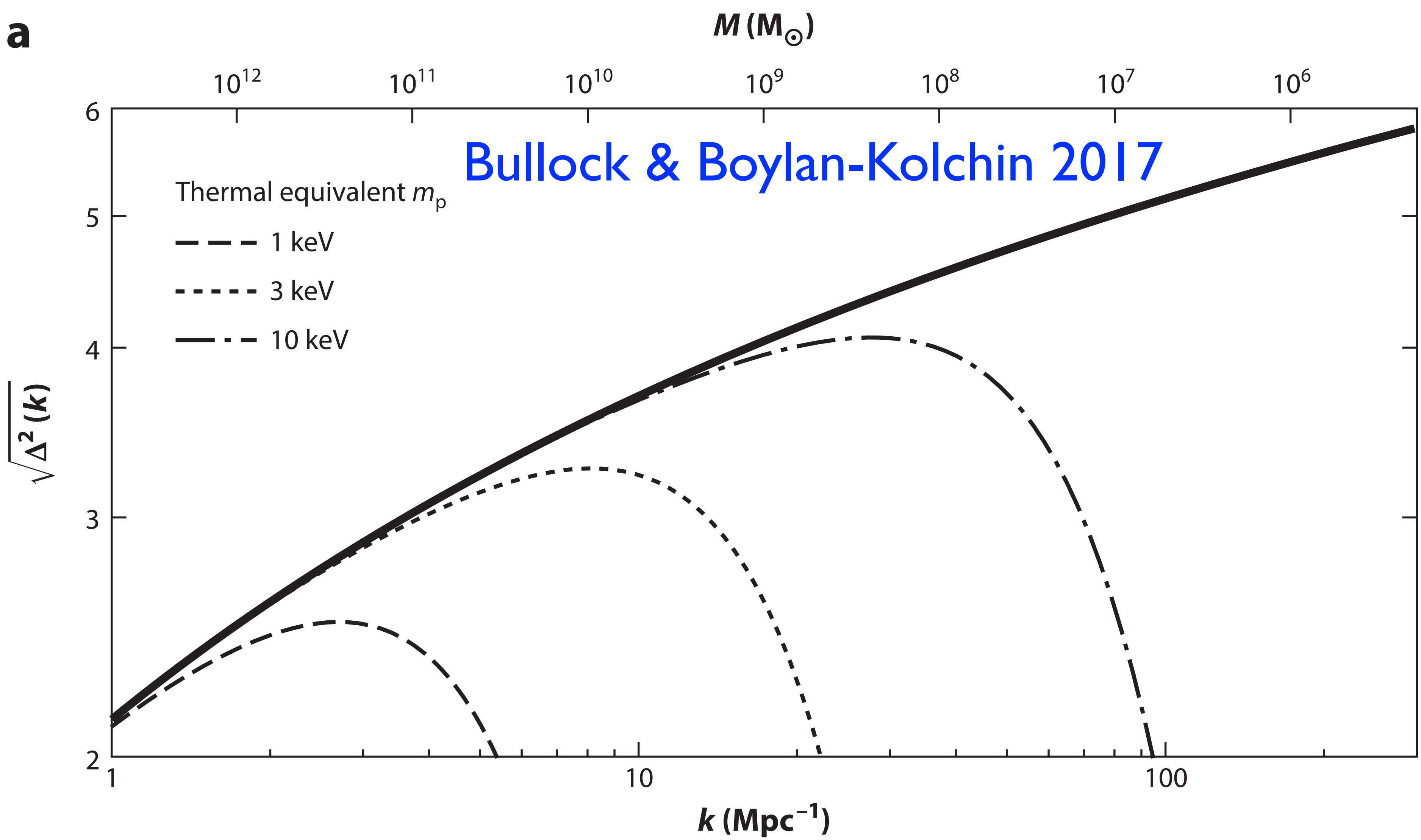
abundance matching by Behroozi (Bullock & Boylan-Kolchin 2017)



missing satellites? (Bullock & Boylan-Kolchin 2017)



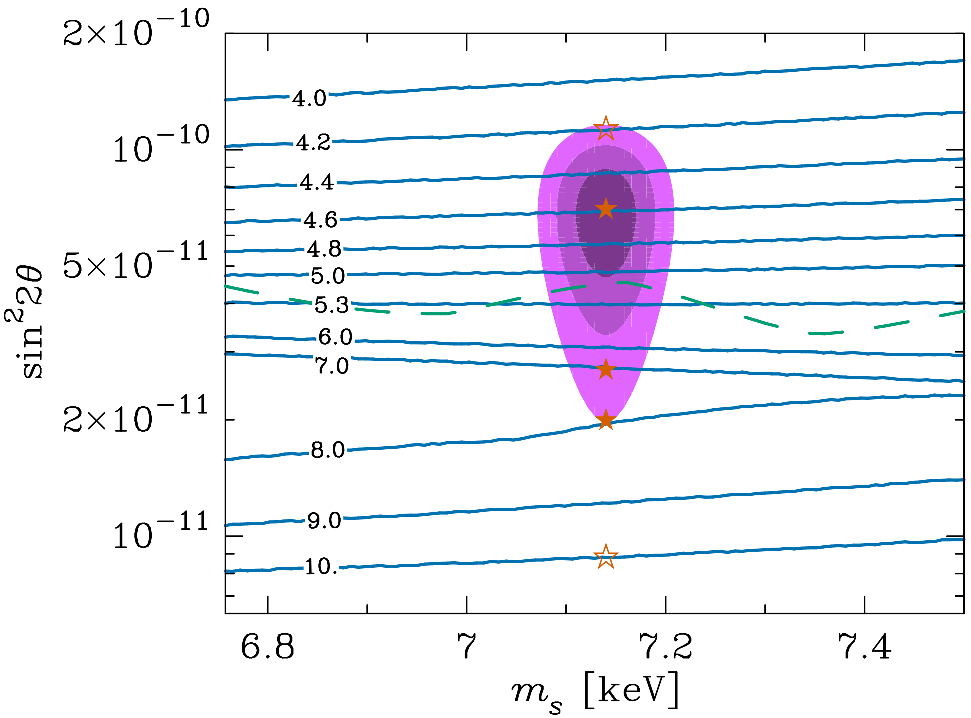
warm DM suppress structure formation on small scales

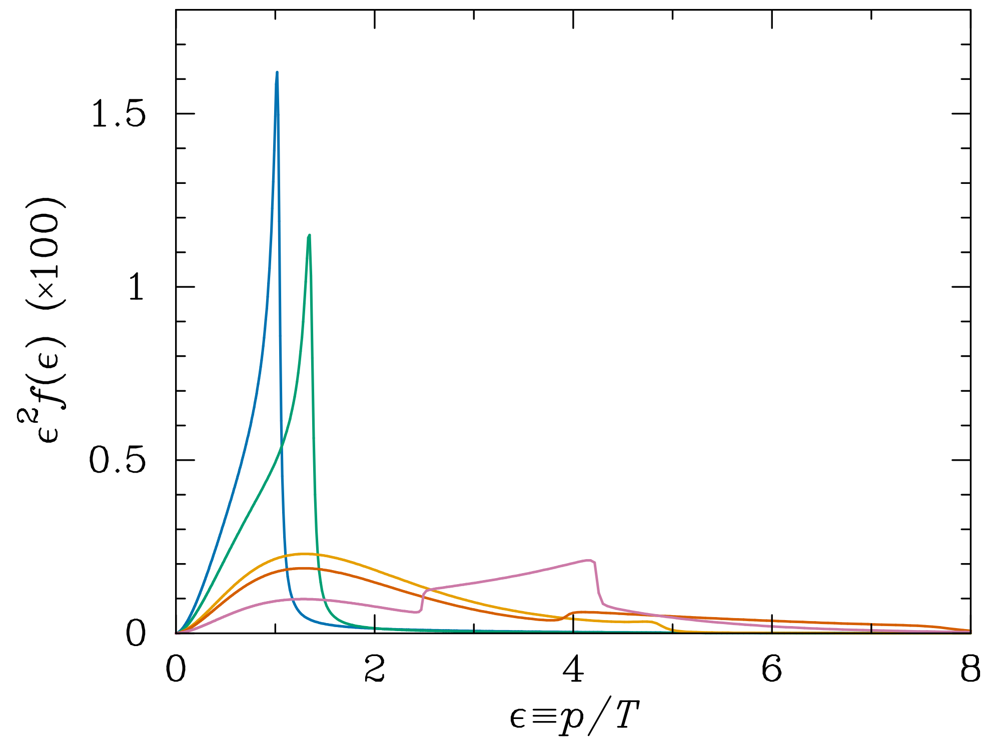


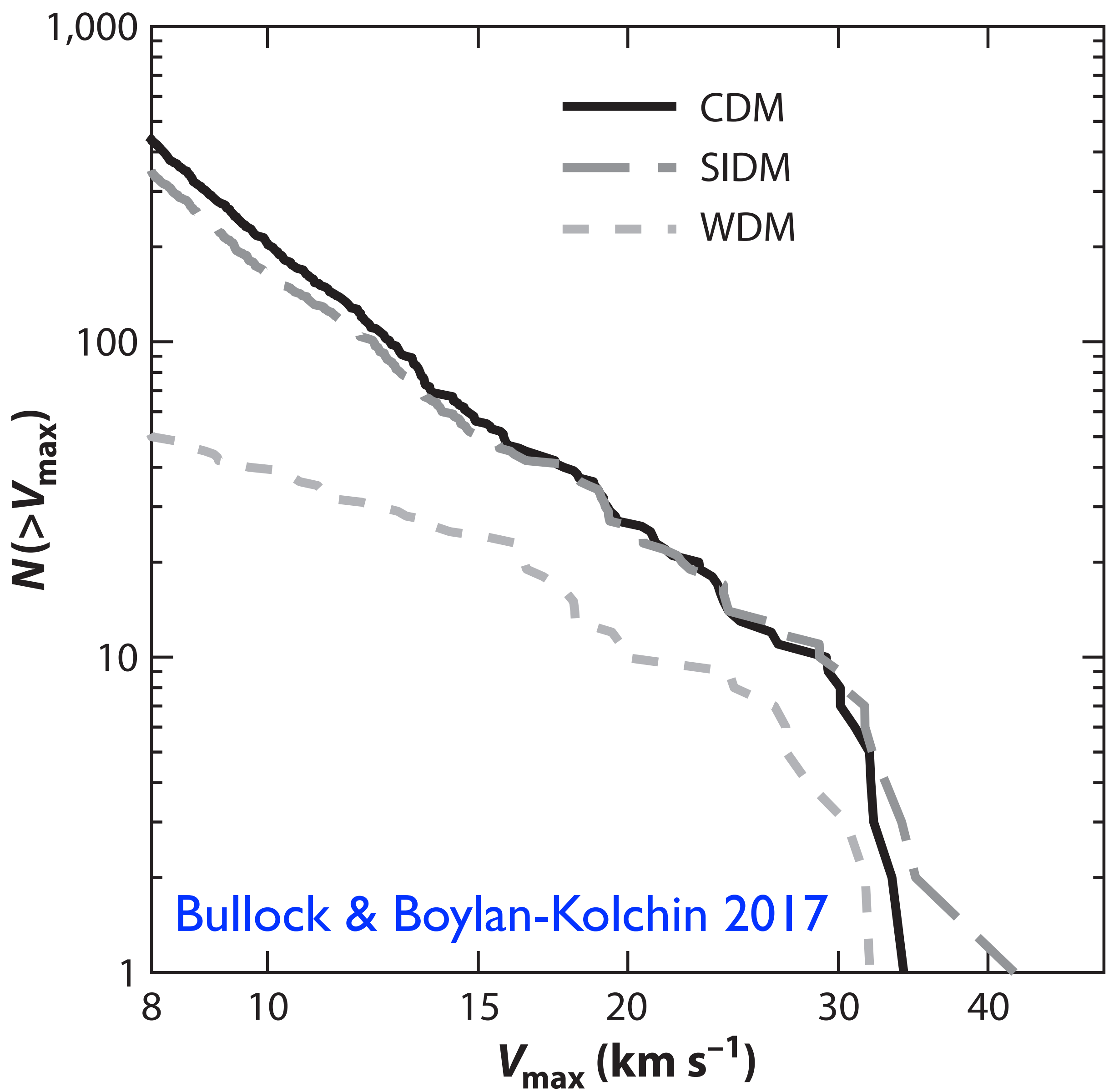
to account for observed number of satellites: $m_p \gtrsim 2 \text{ keV}$

resonant production of non-thermal sterile neutrinos

Shi & Fuller 1999; Abazajian 2014



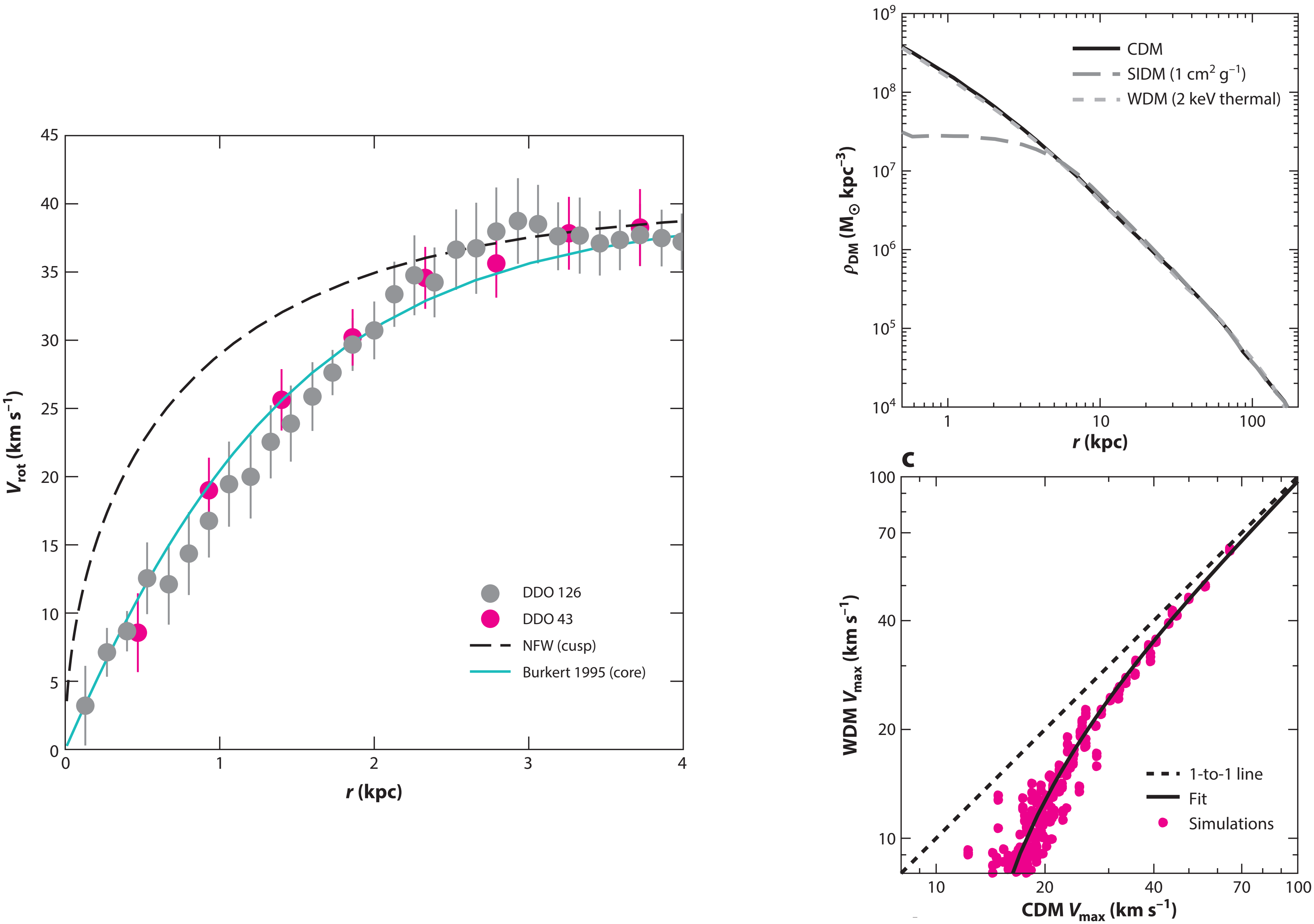




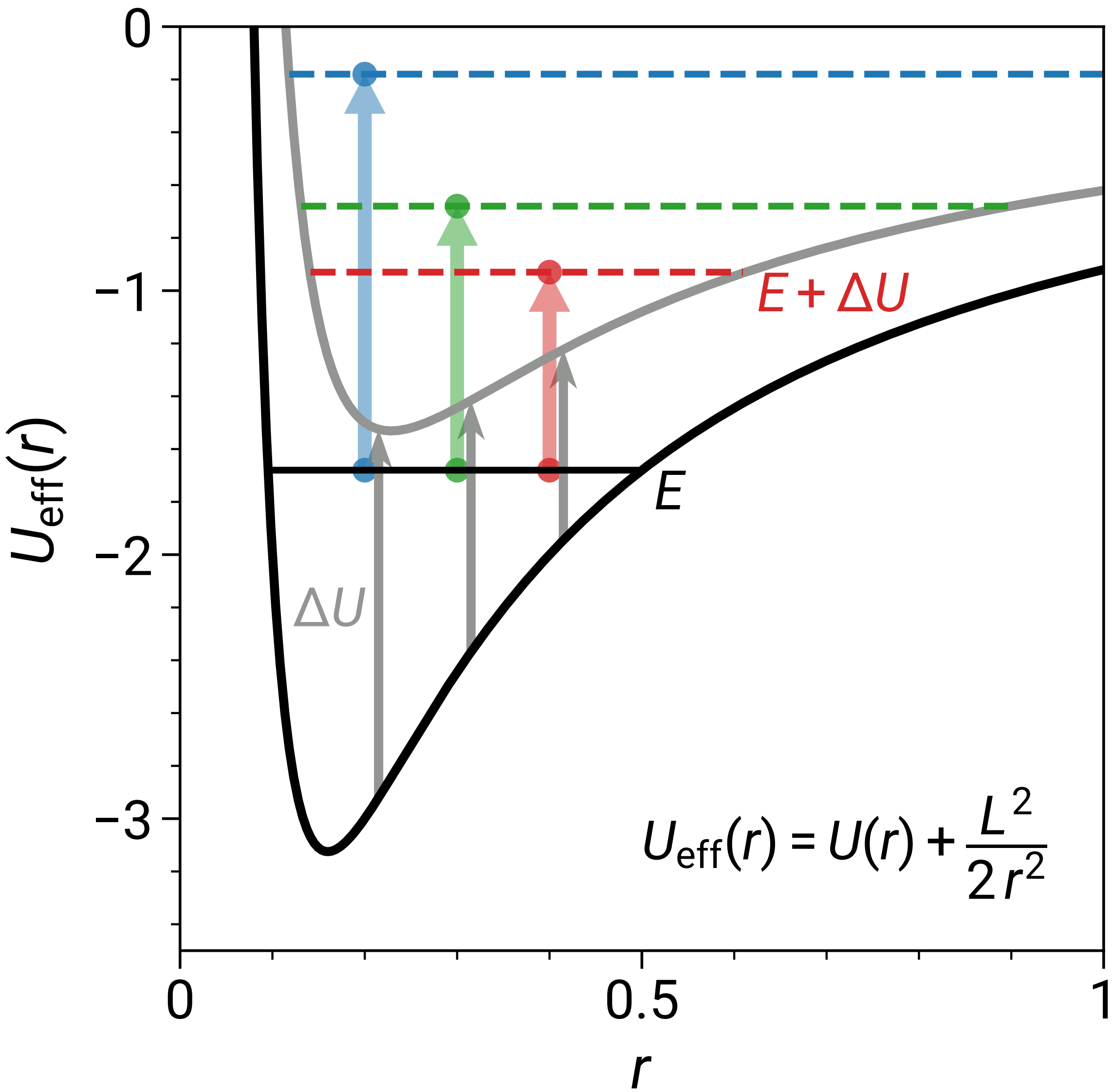
but star formation in UFDs suppressed due to reionization, etc.

mass distribution: core vs. cusp

Bullock & Boylan-Kolchin 2017



response of DM to sudden change of potential by gas removal



shallower potential results in wider radial range of orbits

relaxation to cored density profile

Li et al. 2022

① Initial equilibrium

$$U_0 = U_{\rm g,i} + U_{\rm dm,i}$$

$$f_0(E) = \frac{1}{\sqrt{8}\pi^2} \int_E^0 \frac{d^2 \rho_{\rm dm,i}}{dU_0^2} \frac{dU_0}{\sqrt{U_0 - E}}$$

② Sudden gas removal

$$U_1 = U_{\rm g,f} + U_{\rm dm,i}$$

$$\Delta U(r) = U_1(r) - U_0(r)$$

③ Relaxation to new equilibrium

New distribution function for $E \to E + \Delta U(r)$

$$f_k(E) = \frac{\int_0^{r_E} f_{k-1}(E - \Delta U(r))\sqrt{E - U_k(r)}r^2\,dr}{\int_0^{r_E} \sqrt{E - U_k(r)}r^2\,dr}$$

Equilibrium density in *static* U_k

$$\rho'_{{\rm dm},k}(r) = 4\sqrt{2}\pi \int_{U_k(r)}^0 f_k(E)\sqrt{E - U_k(r)}dE$$

Evolve $\rho_{\rm dm}$ towards $\rho'_{{\rm dm},k}$ with a finite step

$$\rho_{{\rm dm},k}(r) = \mu\rho'_{{\rm dm},k}(r) + (1-\mu)\rho_{{\rm dm},k-1}(r)$$

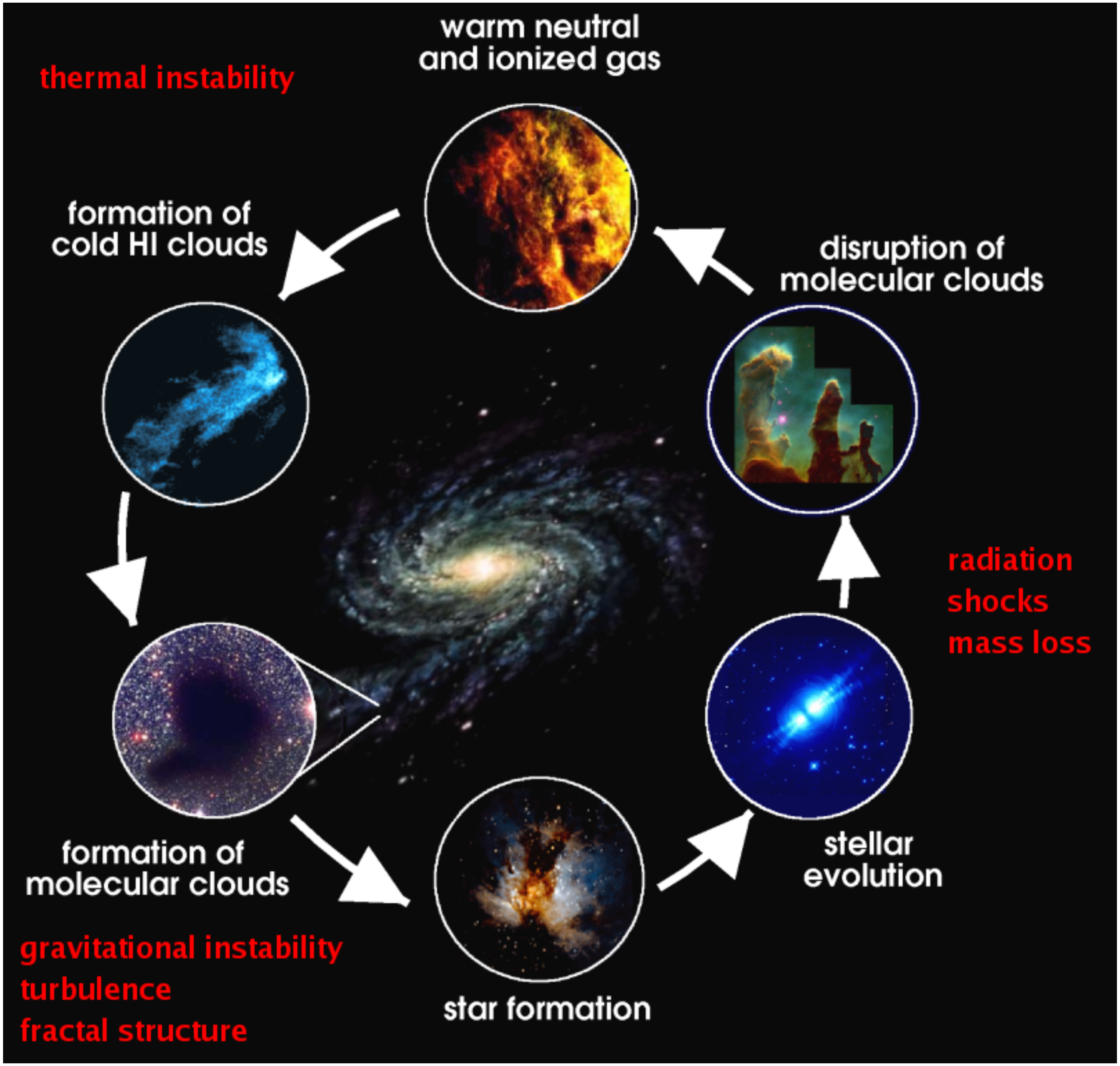
Update potential

$$U_{k+1}(r) = U_{\rm g,f}(r) - 4\pi G \int_r^\infty \frac{dy}{y^2} \int_0^y \rho_{{\rm dm},k}(x)x^2\,dx$$

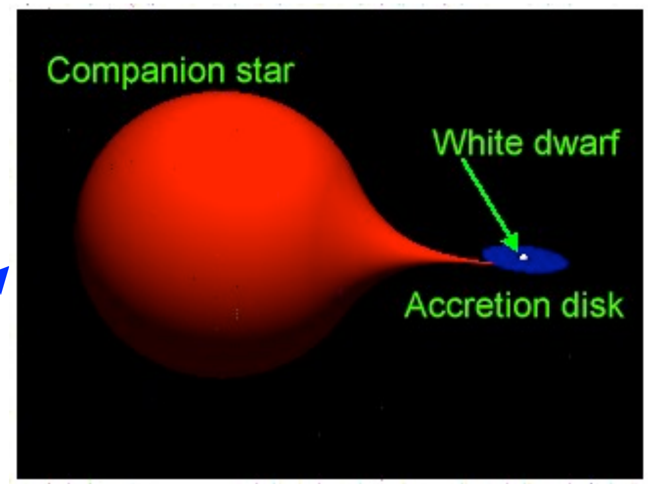
$$k \mathrel{+}= 1$$

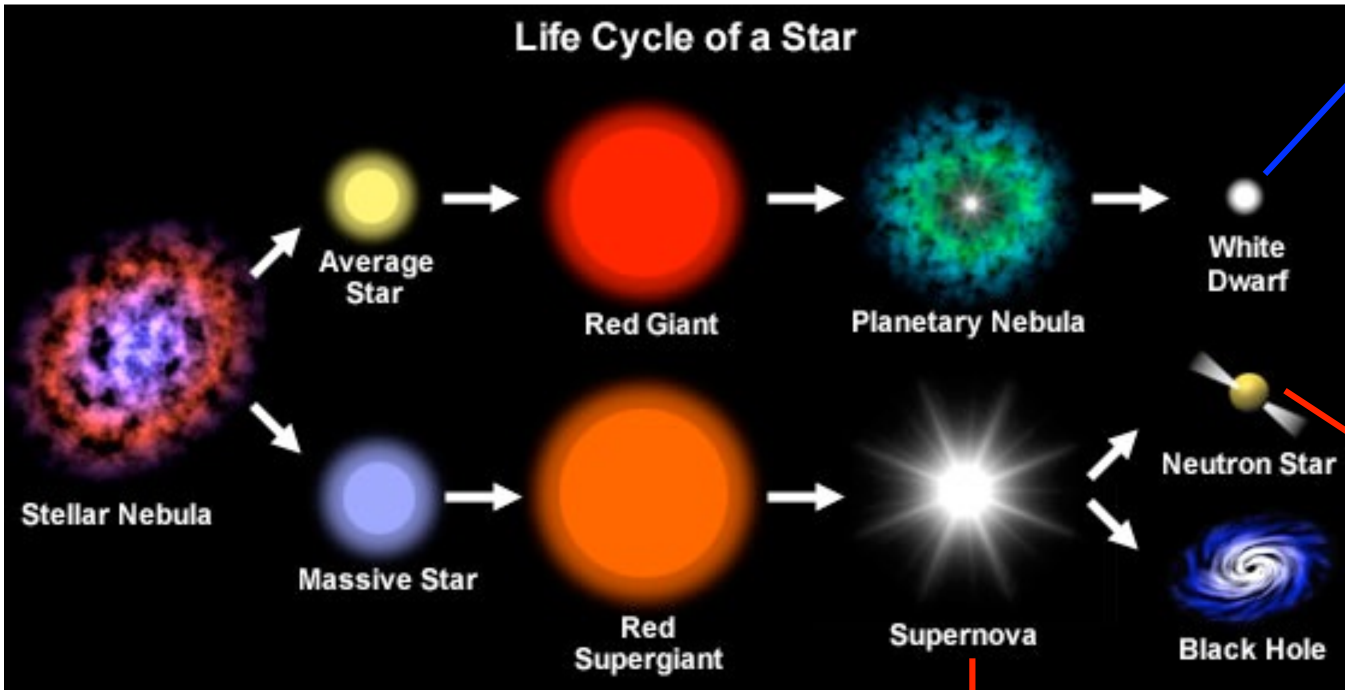
$$\Delta U(r) = U_k(r) - U_{k-1}(r)$$

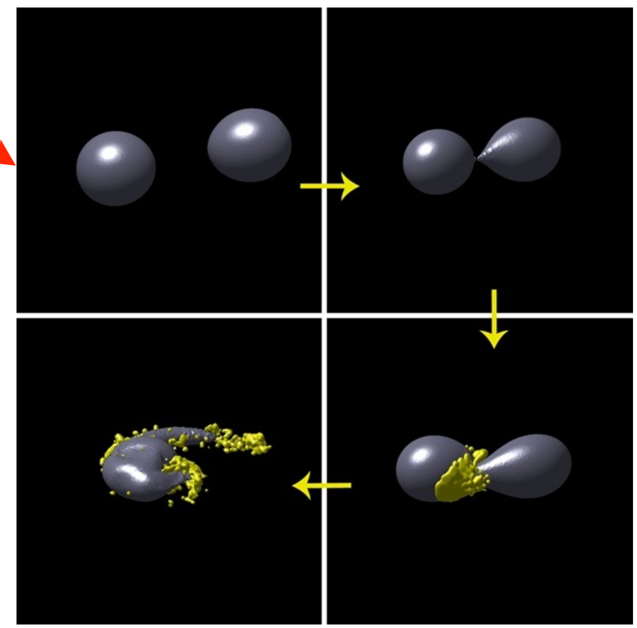
FIRE: Feedback In Realistic Environments (Hopkins et al.)



SN Ia

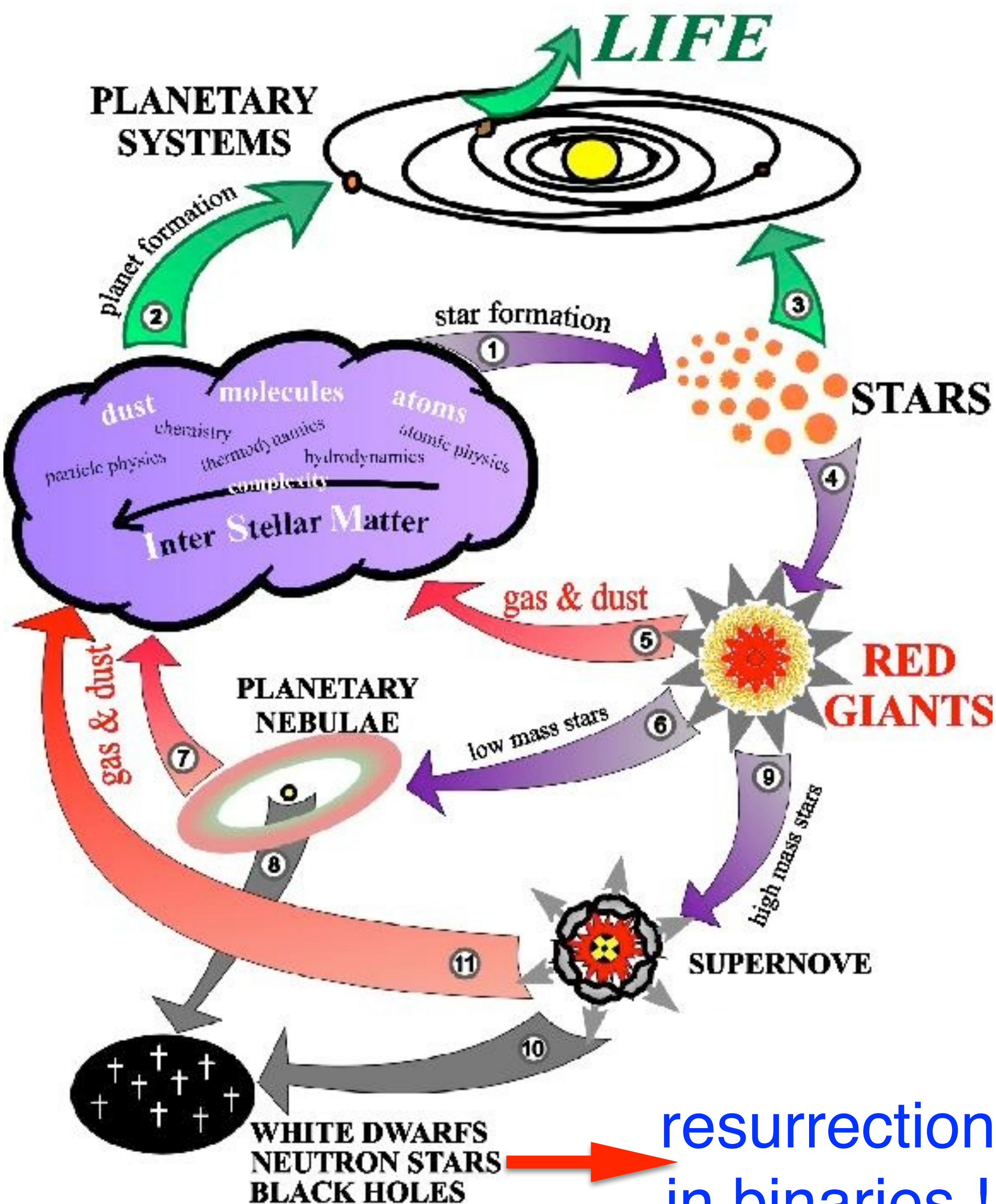






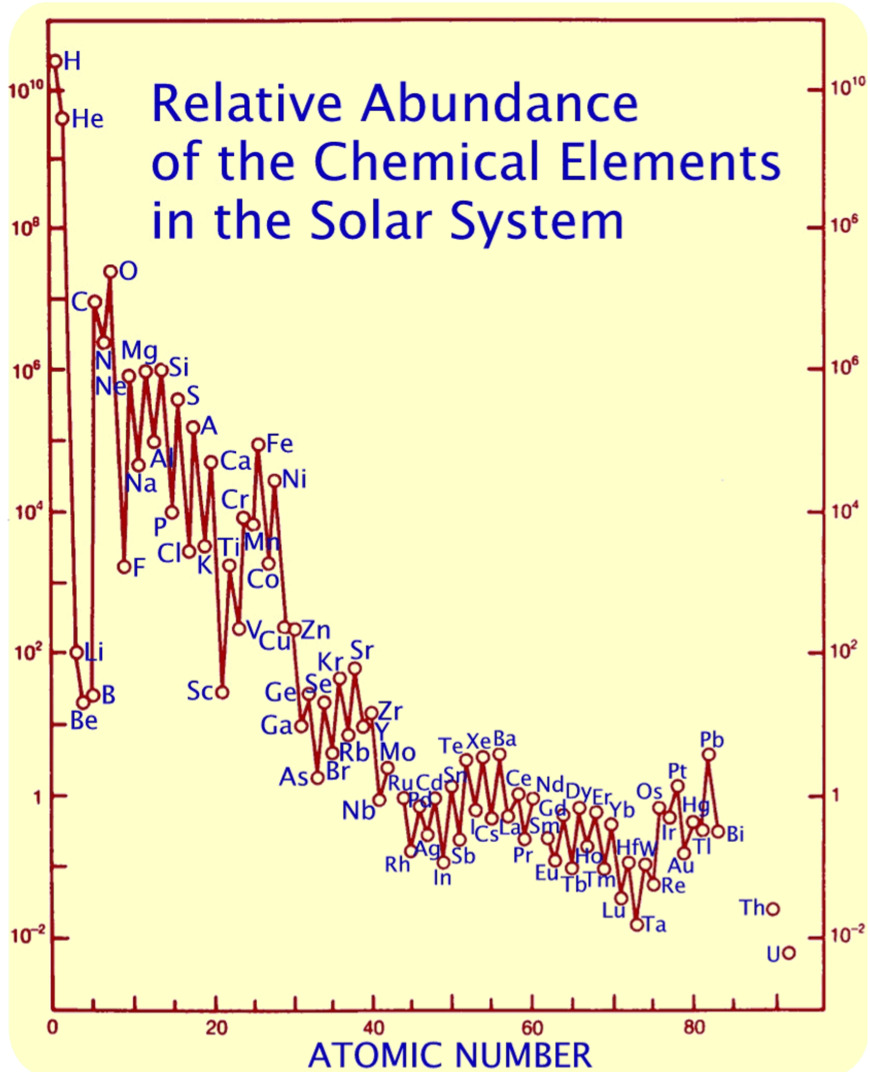
SN II, Ib, Ic

NS merger



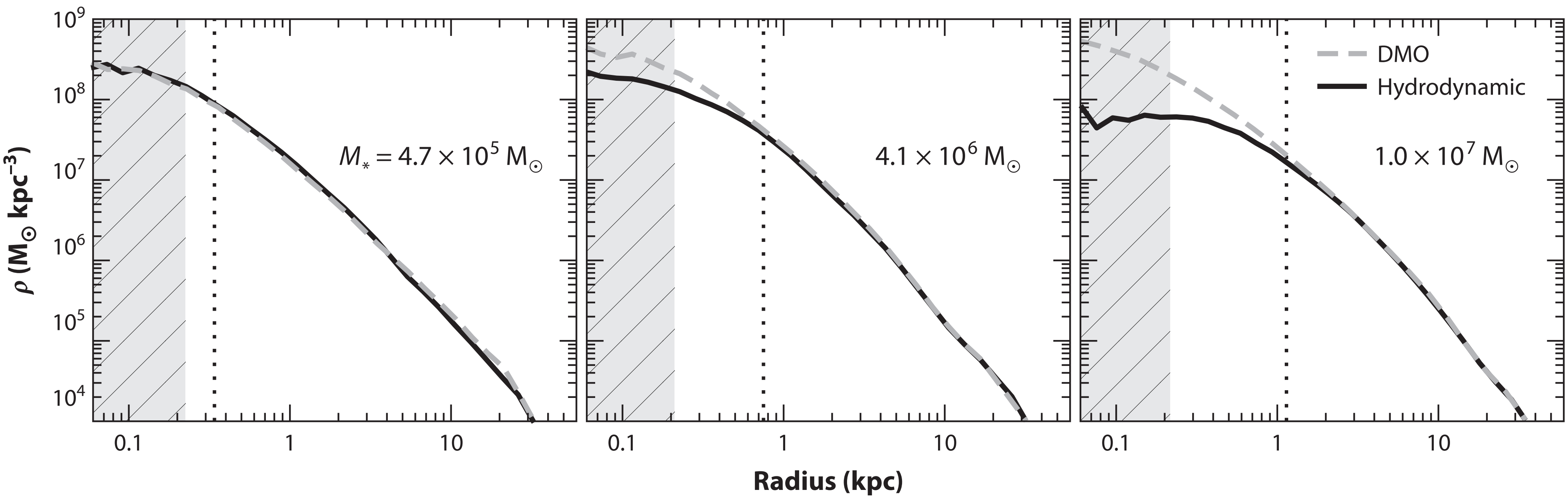
resurrection in binaries !

chemical evolution



baryonic feedback in CDM halos of $M_{\mathrm{vir}} \approx 10^{10}\, M_\odot$

Fitts et al. 2016

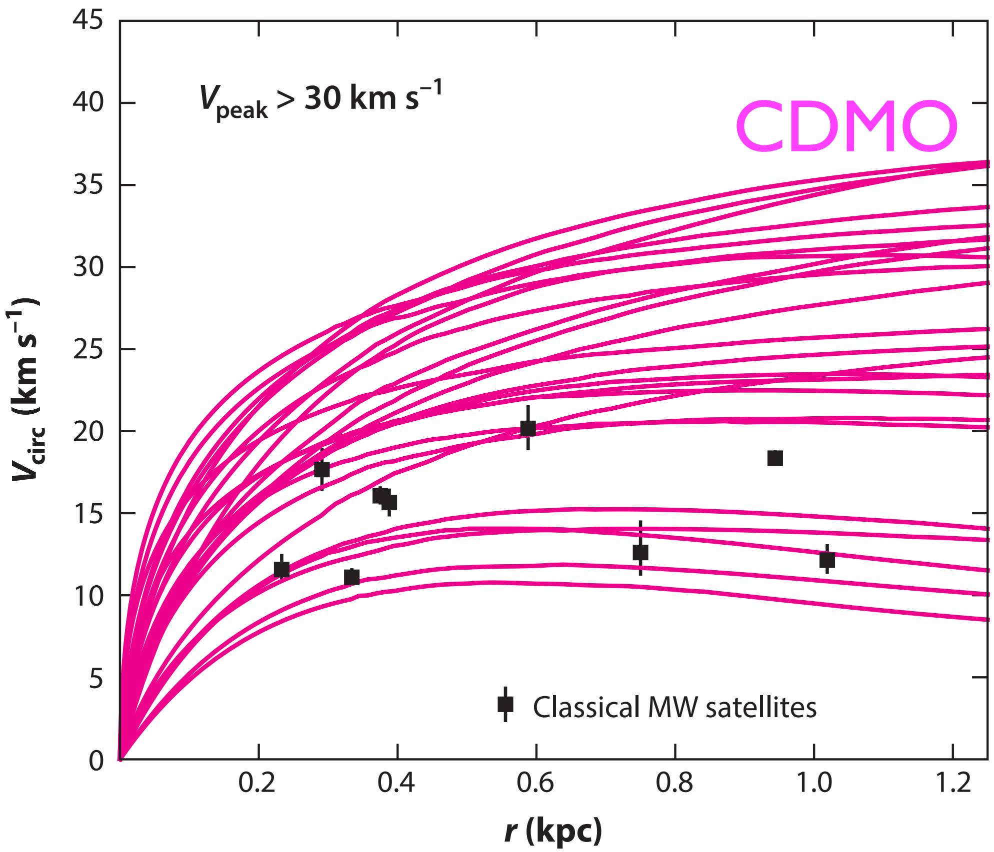


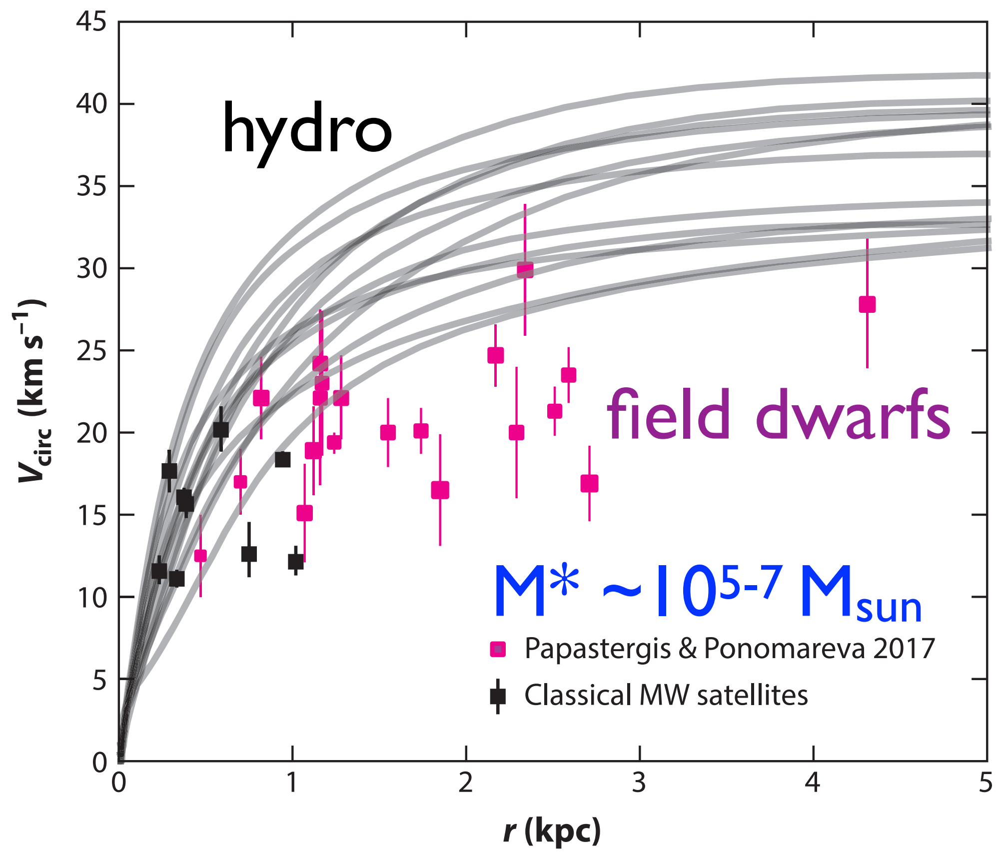
baryonic feedback becomes ineffective for $M_* \lesssim 10^6\, M_\odot$

(effectiveness also depends on star formation history)

too big to fail?

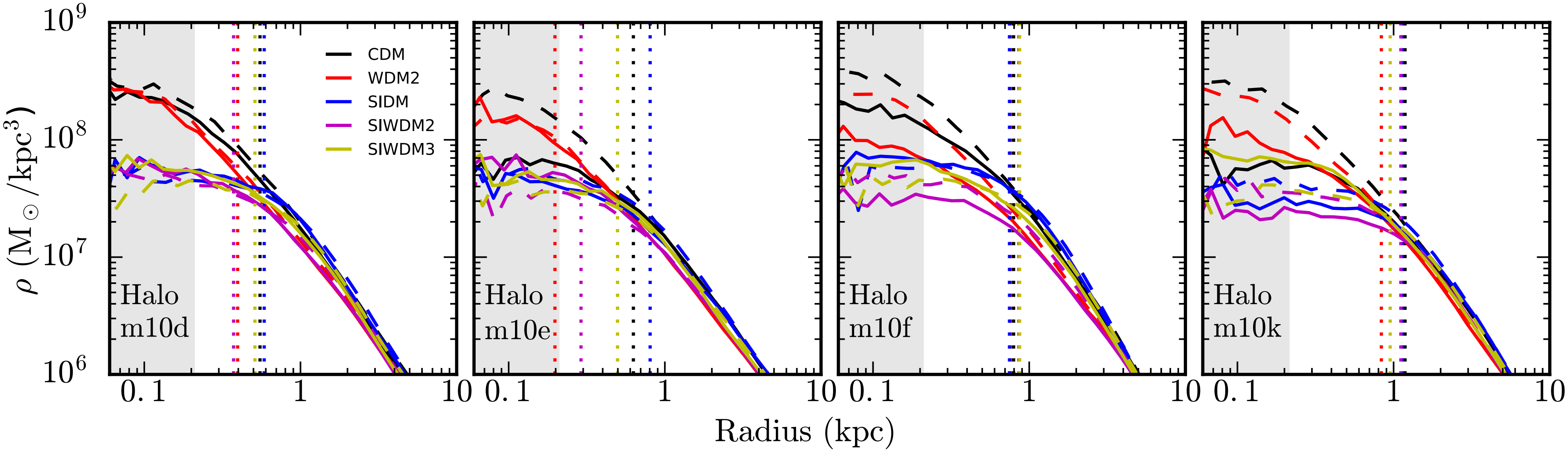
Bullock & Boylan-Kolchin 2017





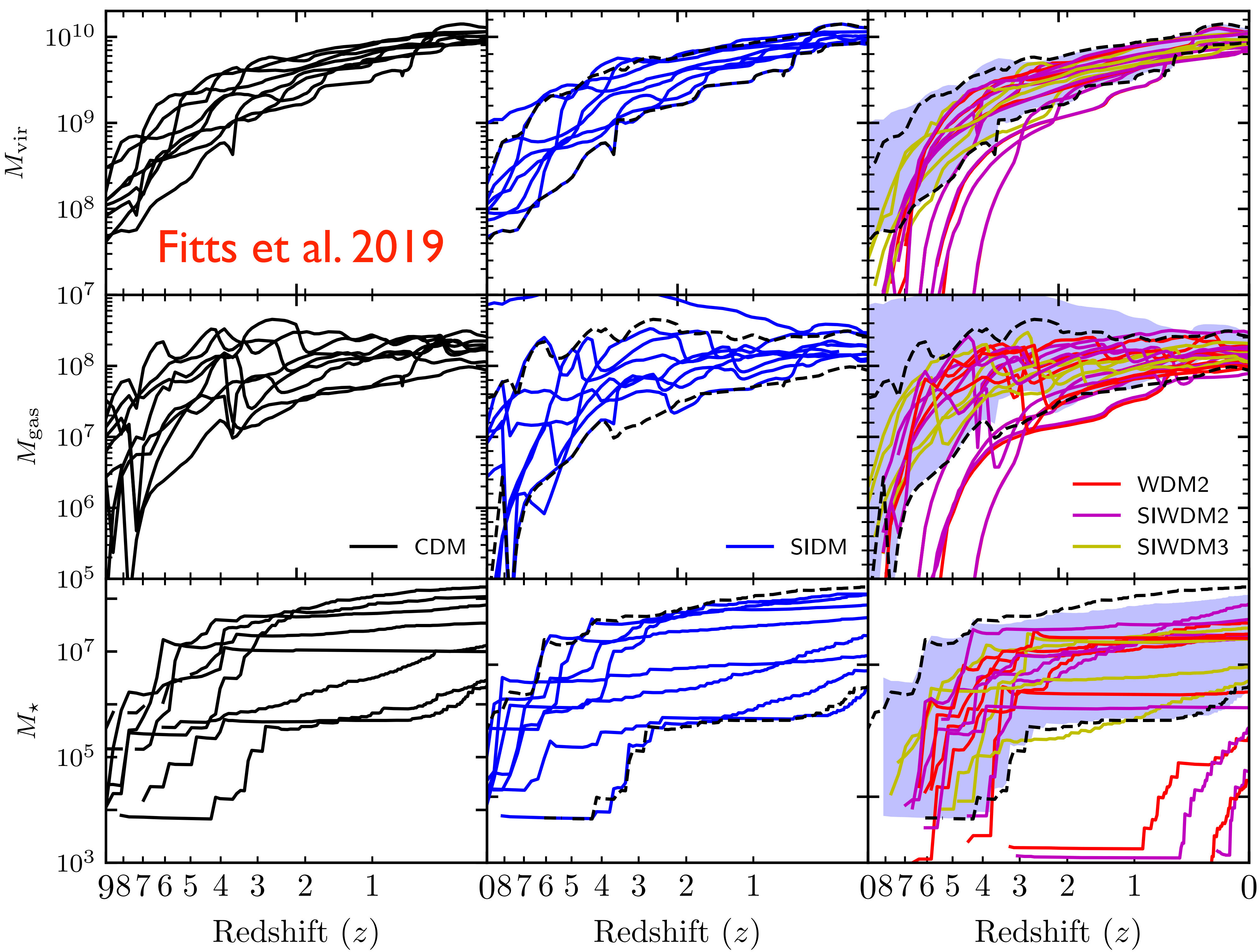
distinguishing CDM, WDM, & SIDM based on FIRE simulations

Fitts et al. 2019

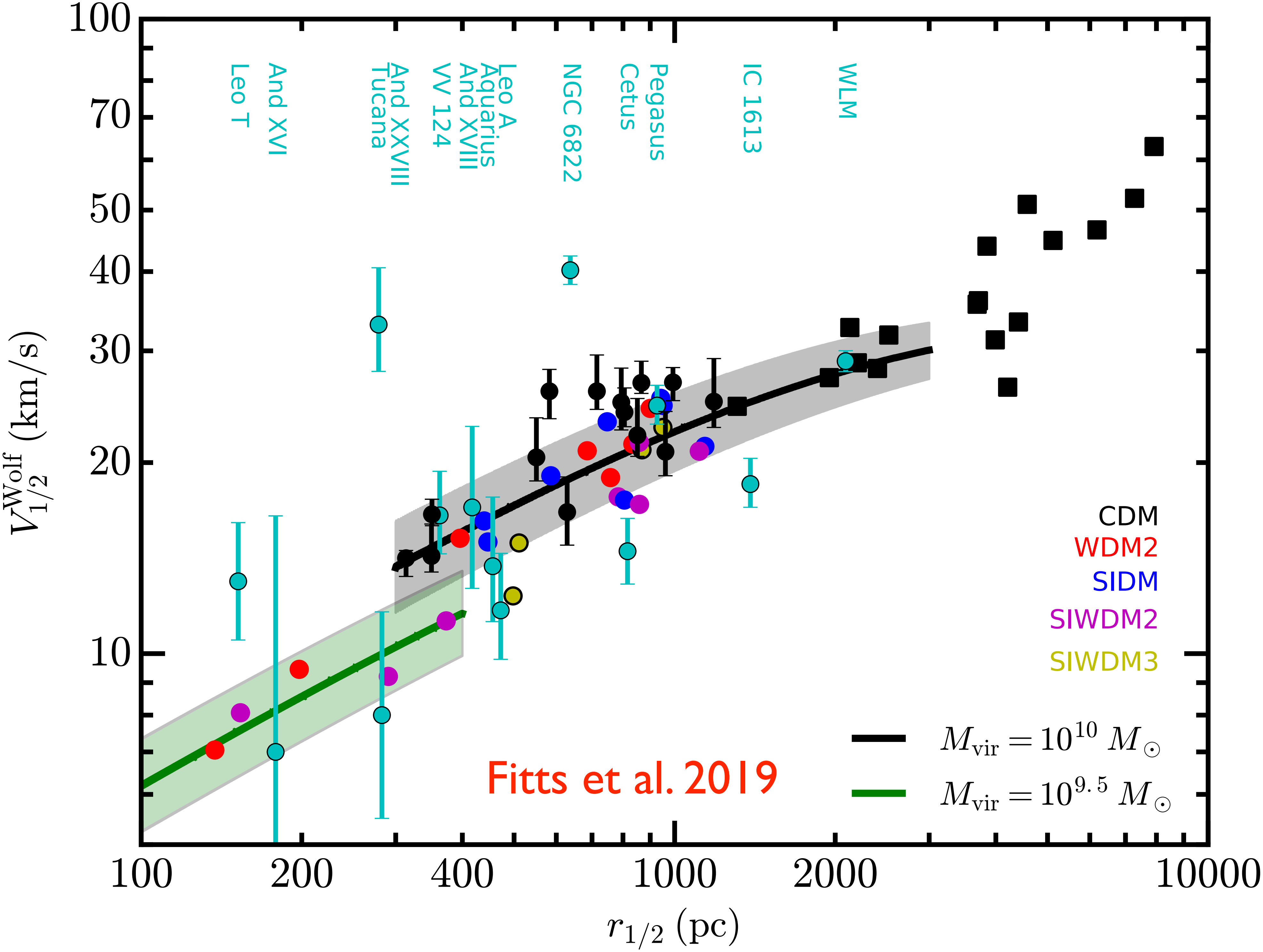


M* →

$$M_{\rm vir} \approx 10^{10}\, M_\odot$$



Fitts et al. 2019
$M_{\rm vir}$
$M_{\rm gas}$
$M_\star$
CDM
SIDM
WDM2
SIWDM2
SIWDM3
Redshift (z)



Leo T
And XVI
And XXVIII
Tucana
VV 124
And XVIII
Aquarius
Leo A
NGC 6822
Cetus
Pegasus
IC 1613
WLM
CDM
WDM2
SIDM
SIWDM2
SIWDM3
$M_{\rm vir} = 10^{10}\, M_\odot$
$M_{\rm vir} = 10^{9.5}\, M_\odot$
Fitts et al. 2019
$V_{1/2}^{\rm Wolf}$ (km/s)
$r_{1/2}$ (pc)
100
70
50
40
30
20
10
100
200
400
1000
2000
10000

summary

galaxies form stars with varying efficiency, perhaps stochastically at & below dwarf mass scales

baryonic feedback for $M^* > 10^6\ M_{sun}$ important, especially for CDM

signature for WDM: UFDs with young stars only
problem for WDM: UFDs with old stars (formed at $z > 7$) only
elemental abundances are important observables

signature for SIDM: cored UFDs with $M^* << 10^6\ M_{sun}$
other effects: gravothermal core collapse?