Simulations of dwarfs formed in WDM halos at the filtering scale

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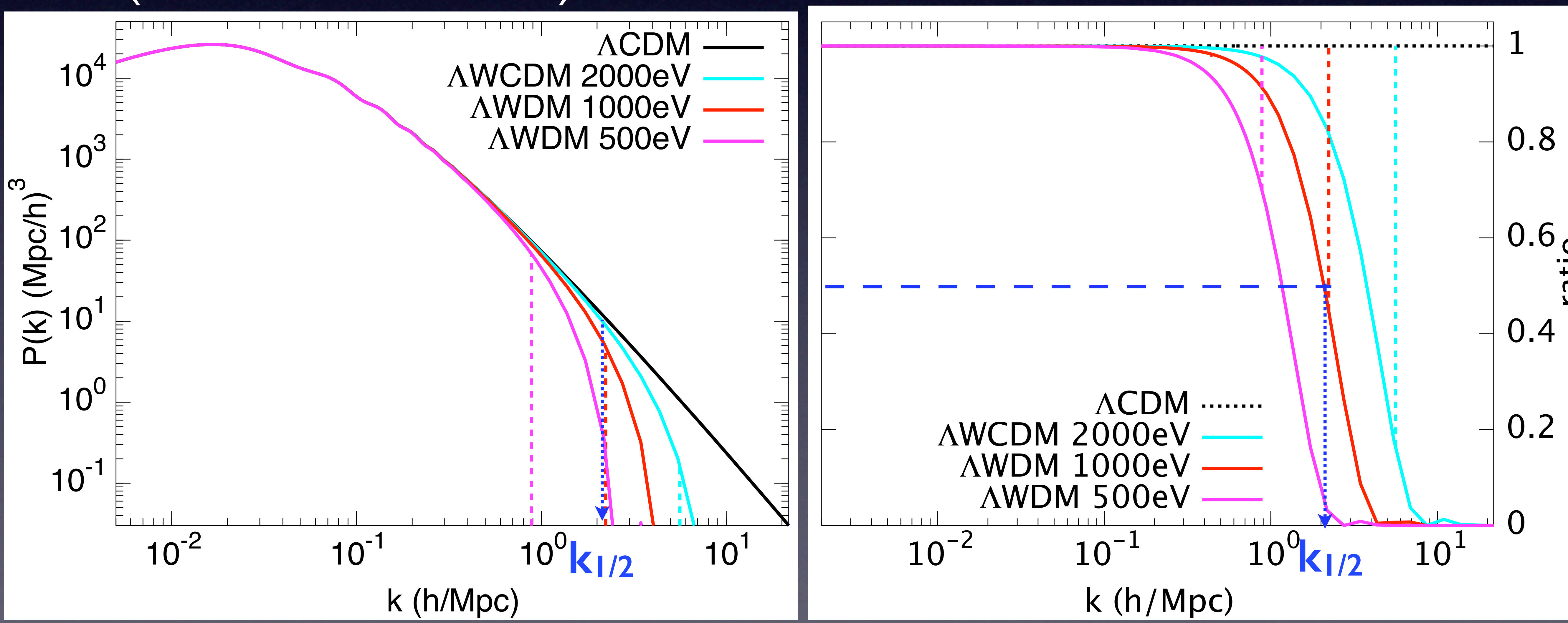
Relevant scales

Free-streaming scale (function of m_{WDM})

below it, no structure formation

Half-mode scale: where $P_{WDM}(k)=0.5\ P_{CDM}(k)$ (function of m_{WDM})

start to be notable the differences with CDM in halo properties and abundance (e.g., Avila-Reese+01; Schneider+12; Benson+13; Angulo+13)



Relevant scales

Free-streaming scale (function of m_{WDM}).

Half-mode scale: where $P_{WDM}(k)=0.5\ P_{CDM}(k)$ (function of m_{WDM}.)

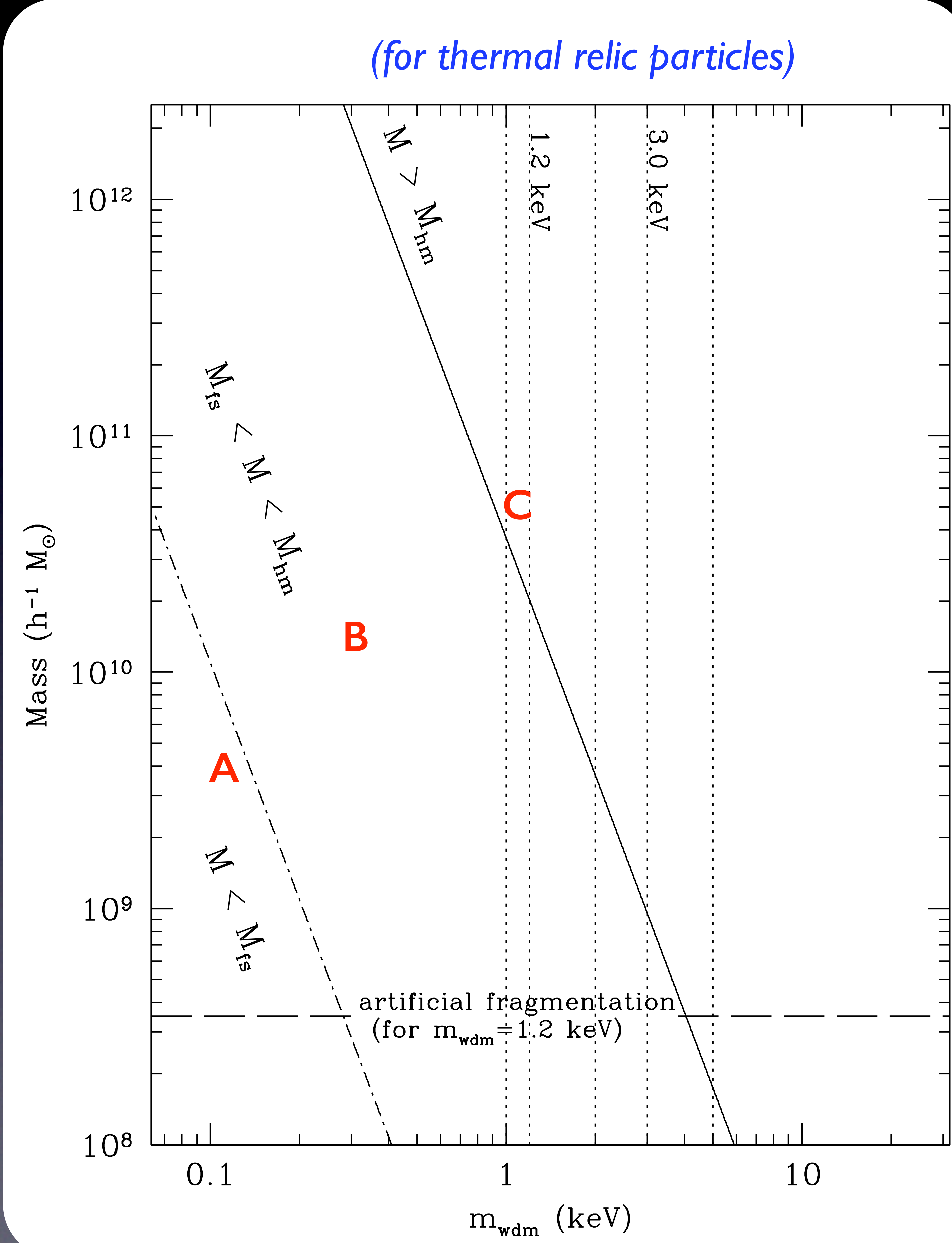
Viel+ 05 $$T_{WDM}(k) = \left[1 + (\alpha k)^{2.0\nu}\right]^{-5.0/\nu}, \quad (3)$$

where $\nu = 1.12$ and the parameter α is related to $m_{\rm WDM}$, Ω_{WDM}, and h through

$$\alpha = a \left(\frac{m_{\rm WDM}}{1{\rm keV}}\right)^{b} \left(\frac{\Omega_{WDM}}{0.25}\right)^{c} \left(\frac{h}{0.7}\right)^{d} h^{-1}{\rm Mpc}, \quad (4)$$

- A: no cosmic structures form
- B: 3D enhancements and "proto-halos"
- C: classical halos *(Angulo+ 2013)*

At M_{hm}, the WDM halo MF is close to its maximum



Previous and our hydro WDM simulations

- Libeskind+13: galaxy group simulation
- Herpich+14: *halos at z=0 ≳10xM_{hm}.*
- *Governato+14: 1 halo at z=0, 2xM_{hm}.*

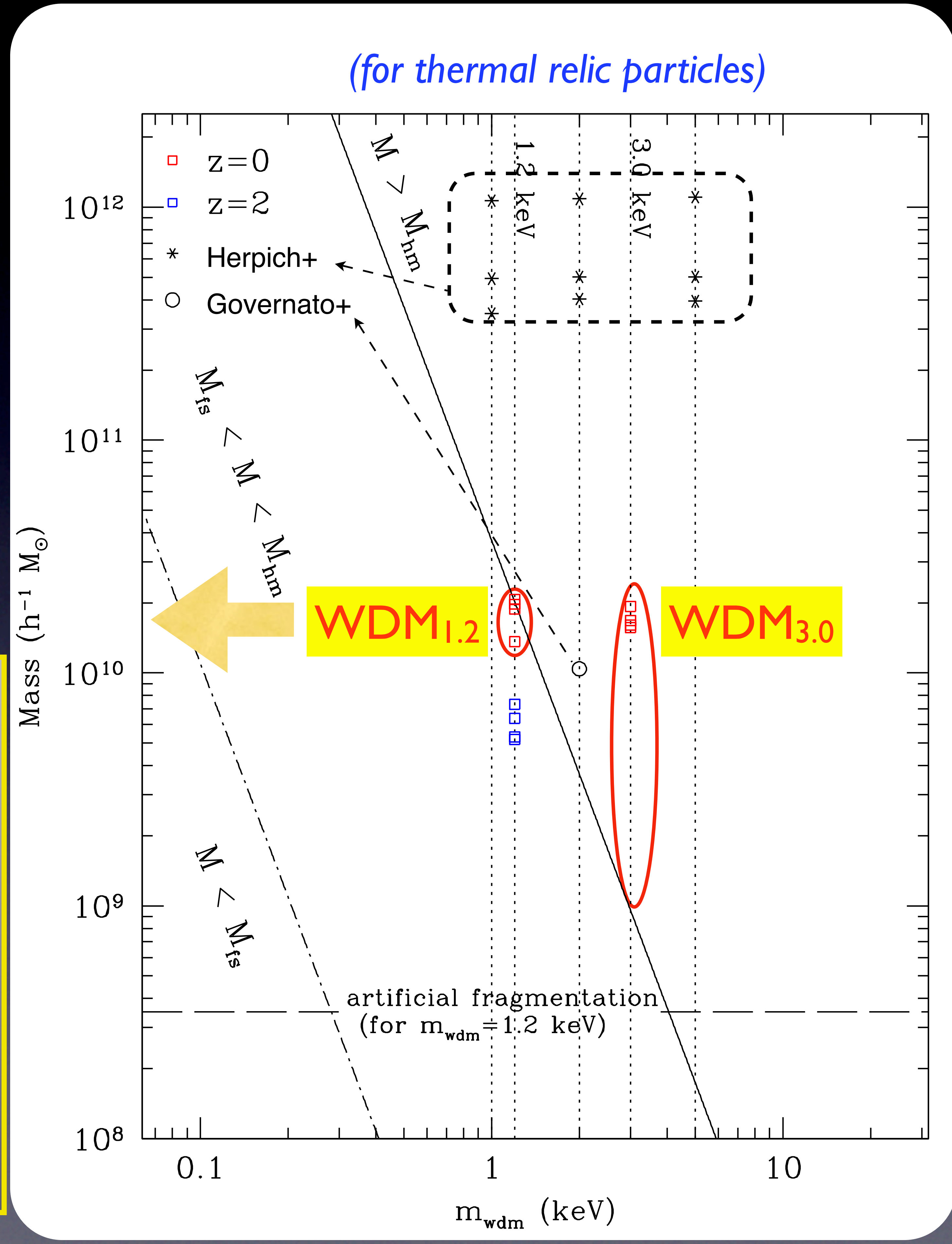
Colín+ 14: halos at z=0 ≲M_{hm} *and ~20xM_{hm} (M_v=2-3x10^{10} $M_\odot$/h)*

Well above the artificial fragmentation limit given in Wang&White 07, even at high z's.

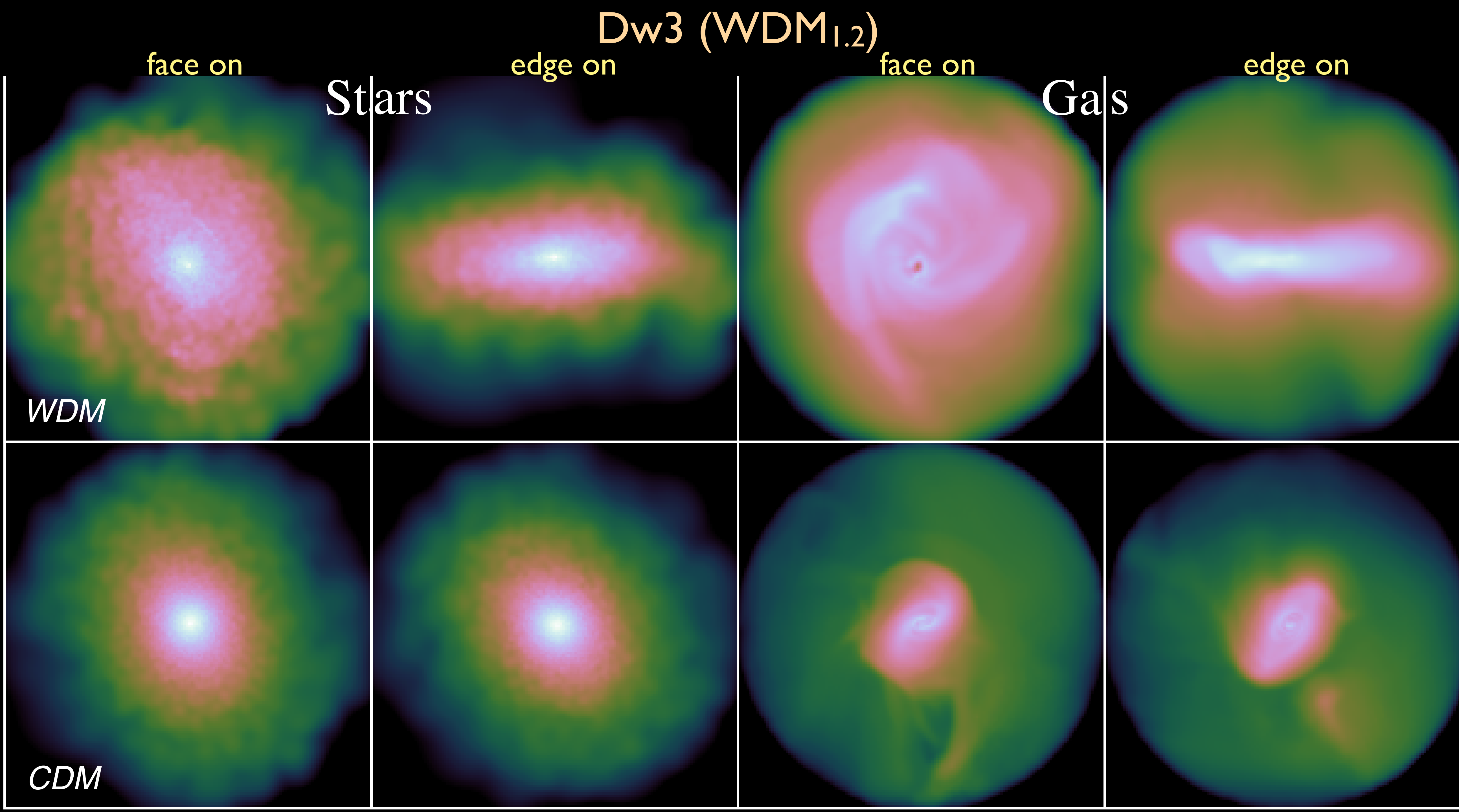
H+ART code *(Kravtsov+ 97,03)*: cooling, advection of metals, cosmological UV heating. "Standard" SF and stellar (thermal) feedback implementation *(see Colín +10; Avila-Reese+11; Gonzalez-Samaniego +14)*

zoom-in simulations of *distinct* halos

m_{DM}=6.6x10^4 $M_\odot$/h

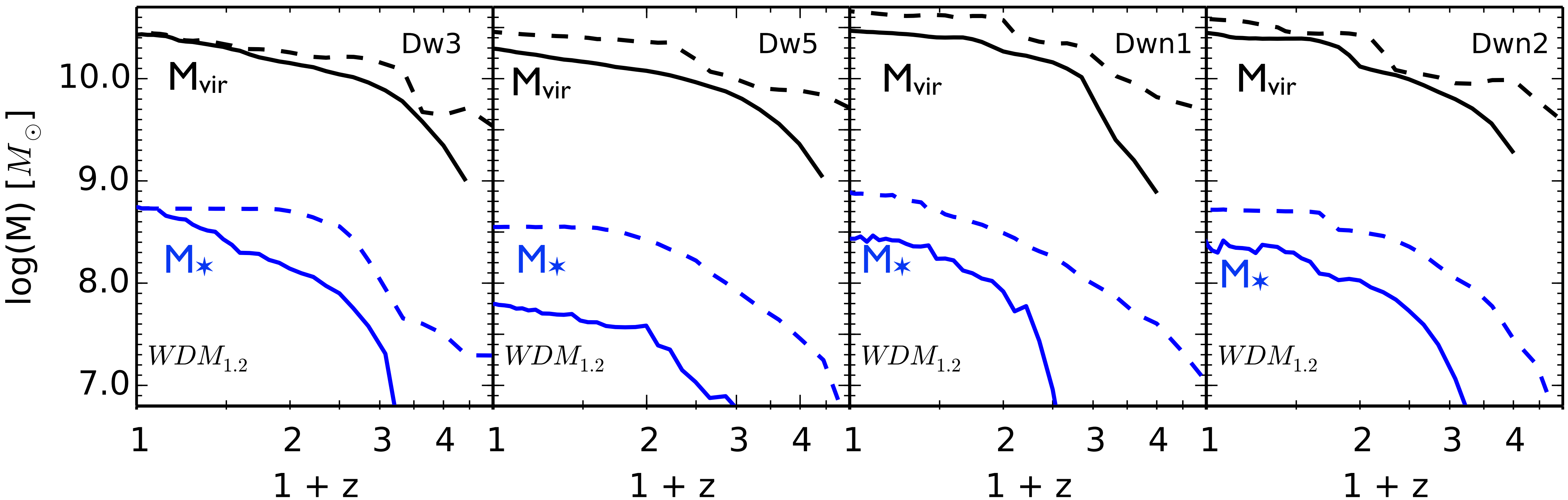


All the $WDM_{1.2}$ and $WDM_{3.0}$ zoom-in simulations have their CDM counterparts *(presented in González-Samaniego+14)*.



The WDM galaxies at the M_{hm} scale are more disky, extended, and less centrally concentrated than their CDM counterparts.

Halo and stellar mass assembly histories



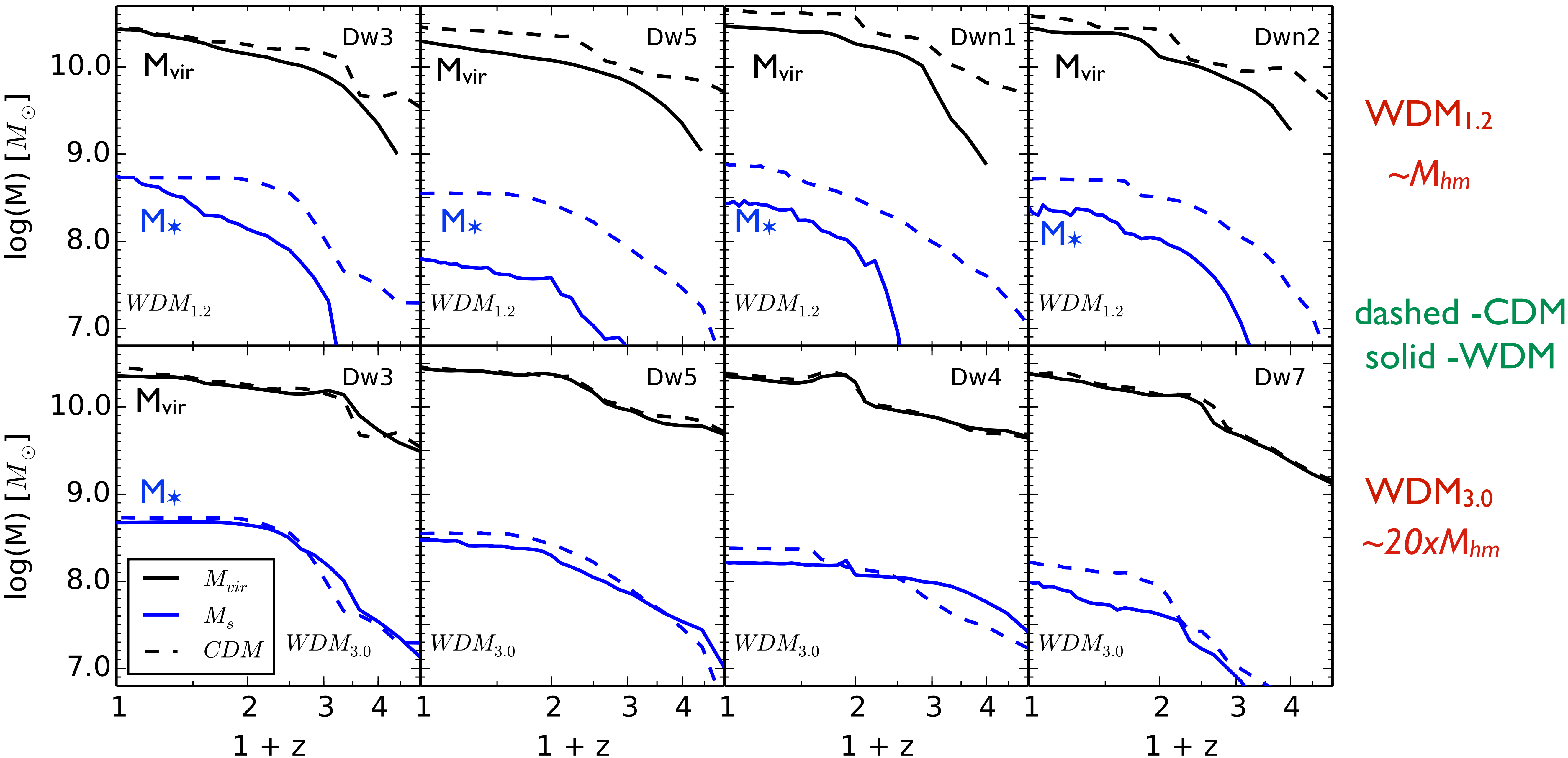
WDM1.2
~Mhm

dashed -CDM
solid -WDM

-Halos at the filtering scale start to assemble later than the CDM ones.

-The stellar mass assembly is delayed and today $M_\star$ is smaller than in the CDM runs (⇒lower $M_\star/M_{vir}$ ratio)

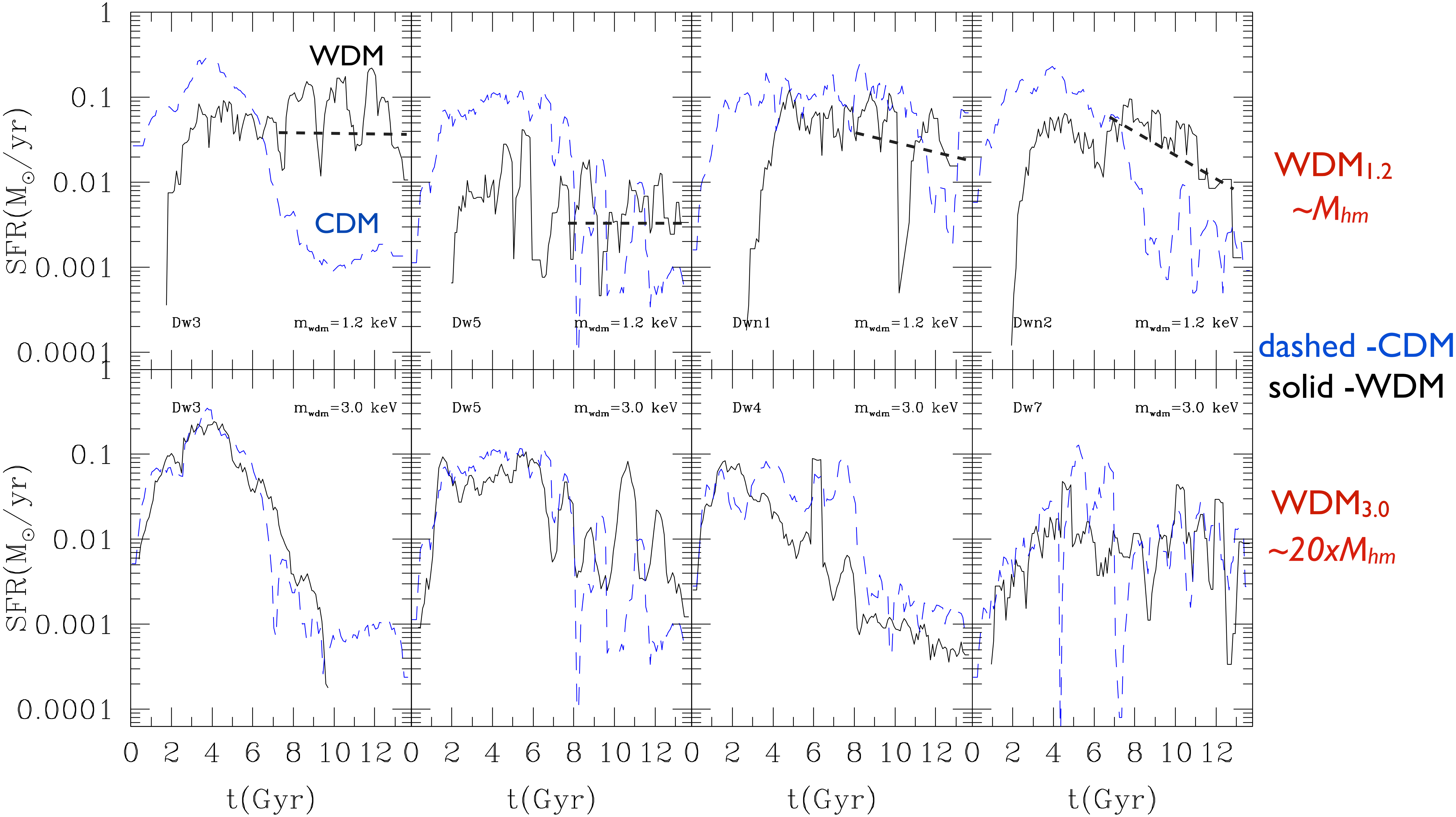
Halo and stellar mass assembly histories



-For halos ~$20xM_{hm}$, the differences are minimal (*see also Herpich+14*)

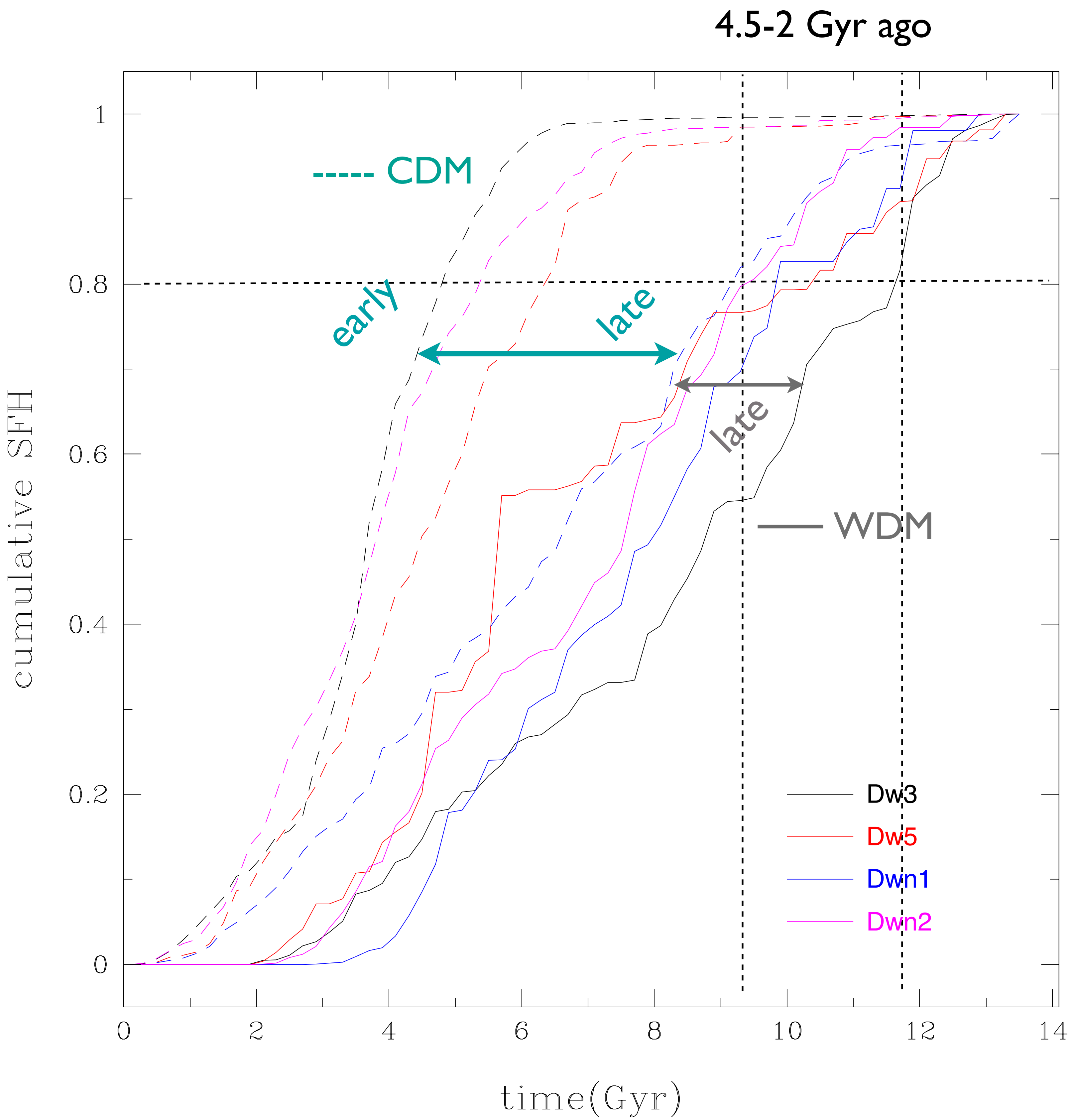
Star formation histories

-Bursty SFHs in the CDM *(see Gonzalez-Samaniego+14)* and in the WDM cases



-For halos at the filtering scale, the *starting* of SF is delayed by ~2 Gyr and it keeps more active until z~0 than in the CDM counterparts.

Cumulative SFHs *(WDM$_{1.2}$ vs CDM)*



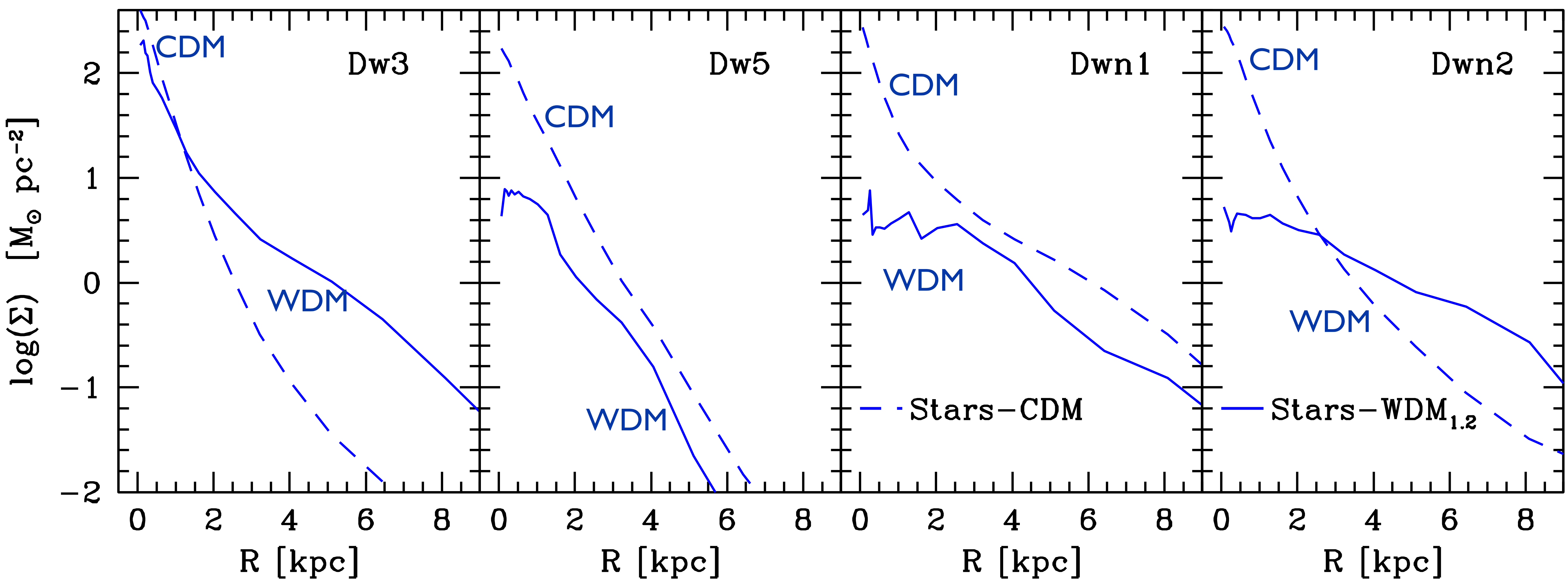
-WDM: 20% of stars assembled in the last ~2-4.5 Gyr CDM (all the SFHs are late)

-CDM: large scatter (early and late SFHs; see also Maccio's and Bullock's talks);
80% of stars in place already ~5-9 Gyr ago.

Archaeological mass-weighted ages: WDM dwarfs are 1-5.5 Gyr younger than their CDM counterparts

Stellar and gas surface density profiles (z=0)

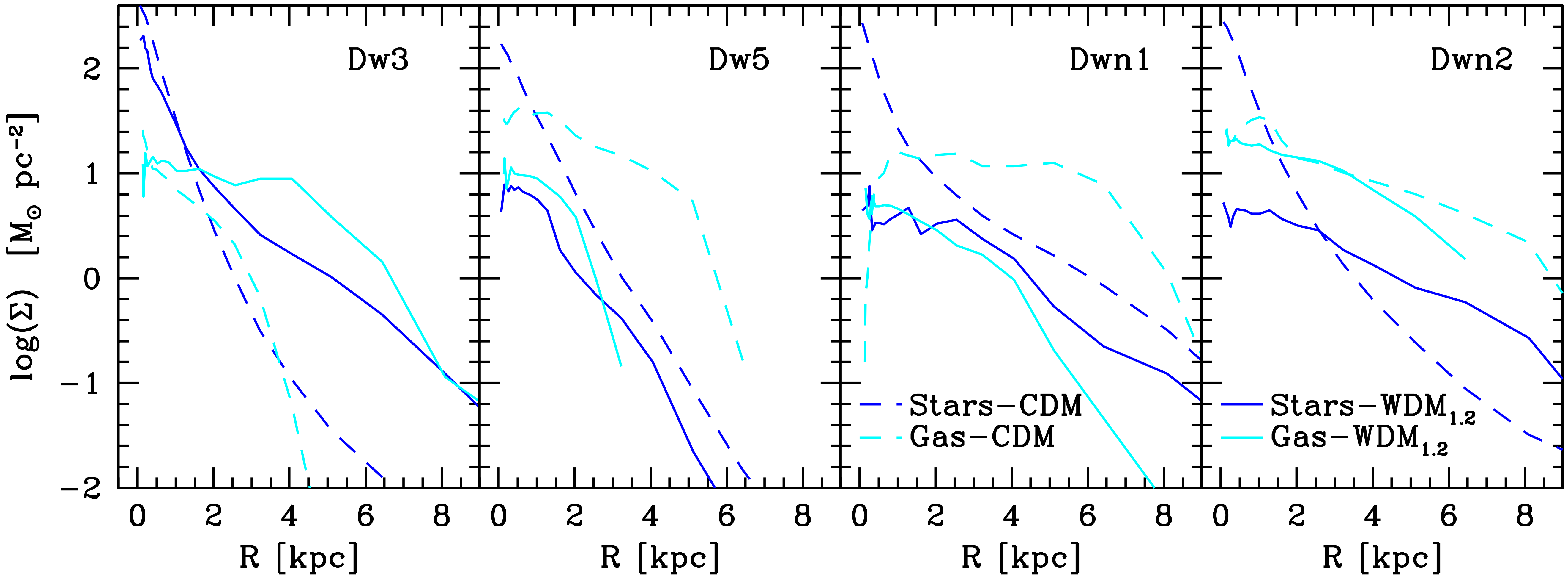
WDM$_{1.2}$ ~M_{hm}



The stellar R_e are *1.3-3x* larger in the WDM$_{1.2}$ galaxies than in the CDM counterparts.

Stellar and gas surface density profiles (z=0)

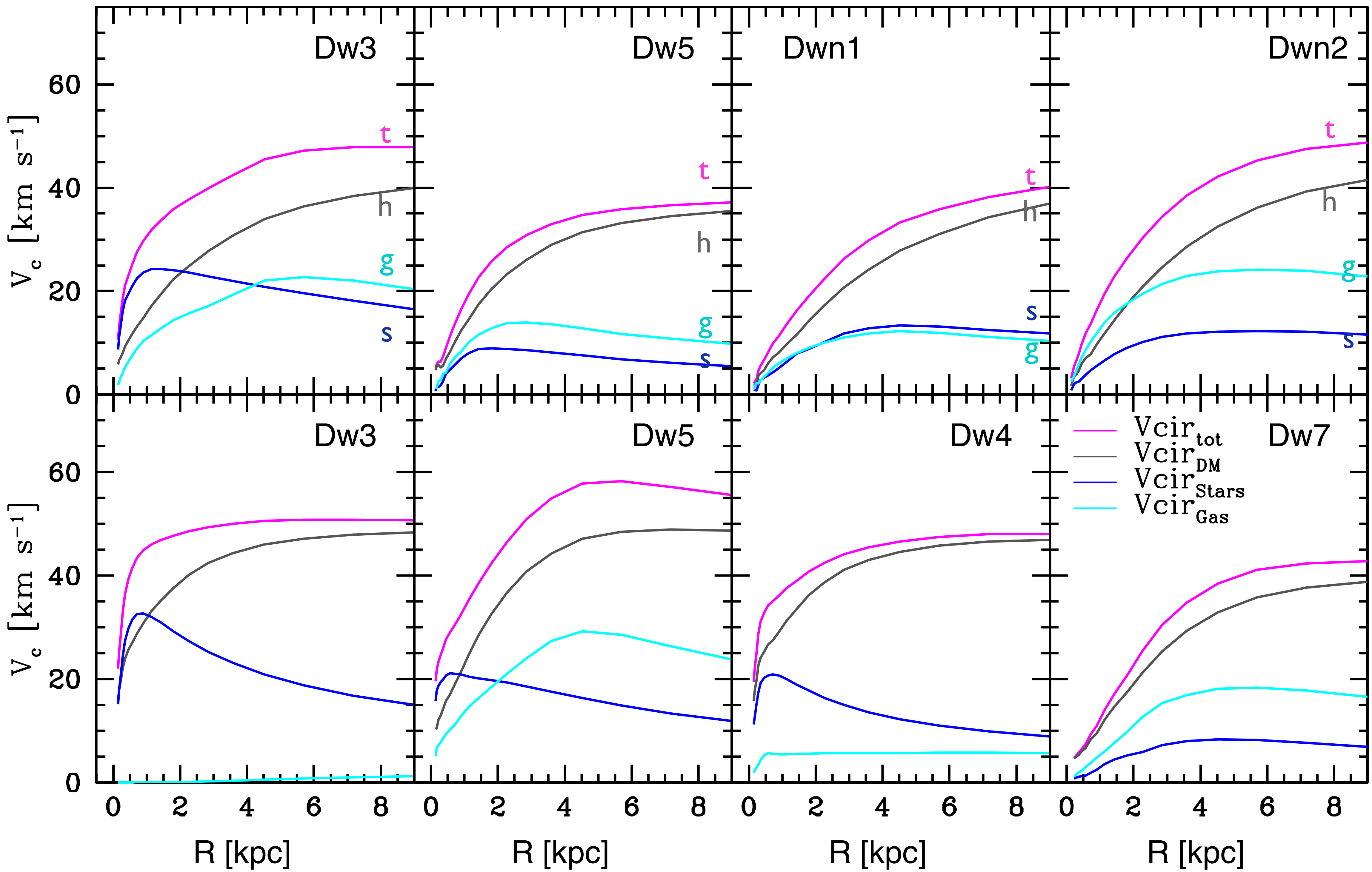
WDM$_{1.2}$ ~M_{hm}



The stellar R_e are *1.3-3x* larger in the WDM$_{1.2}$ galaxies than in the CDM counterparts.

The gas distribution in the WDM$_{1.2}$ galaxies roughly follows the stellar one; in the CDM counterparts.

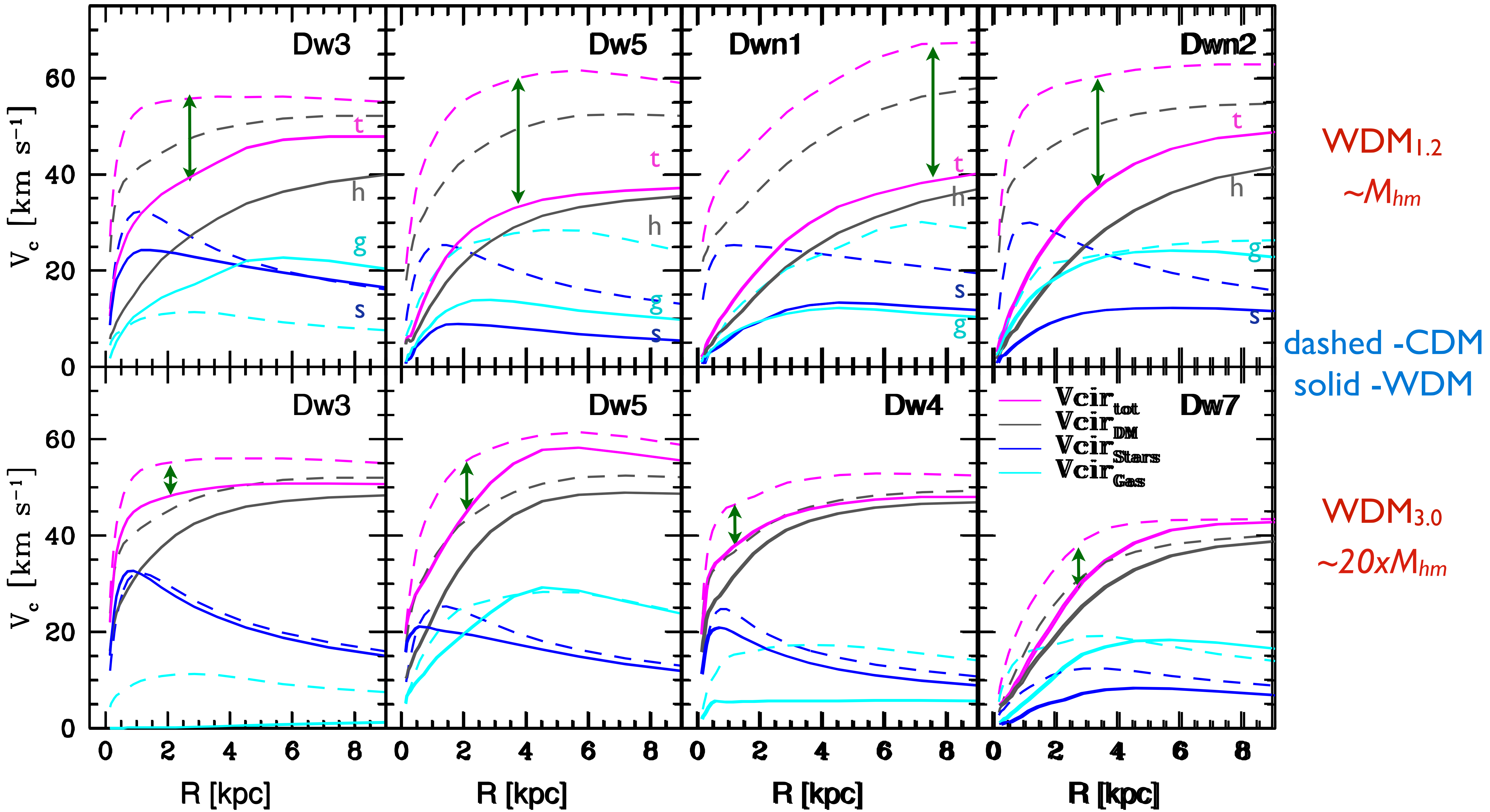
Circular velocity decomposition (z=0)



WDM1.2
~M_{hm}

WDM3.0
~20xM_{hm}

Circular velocity decomposition (z=0)



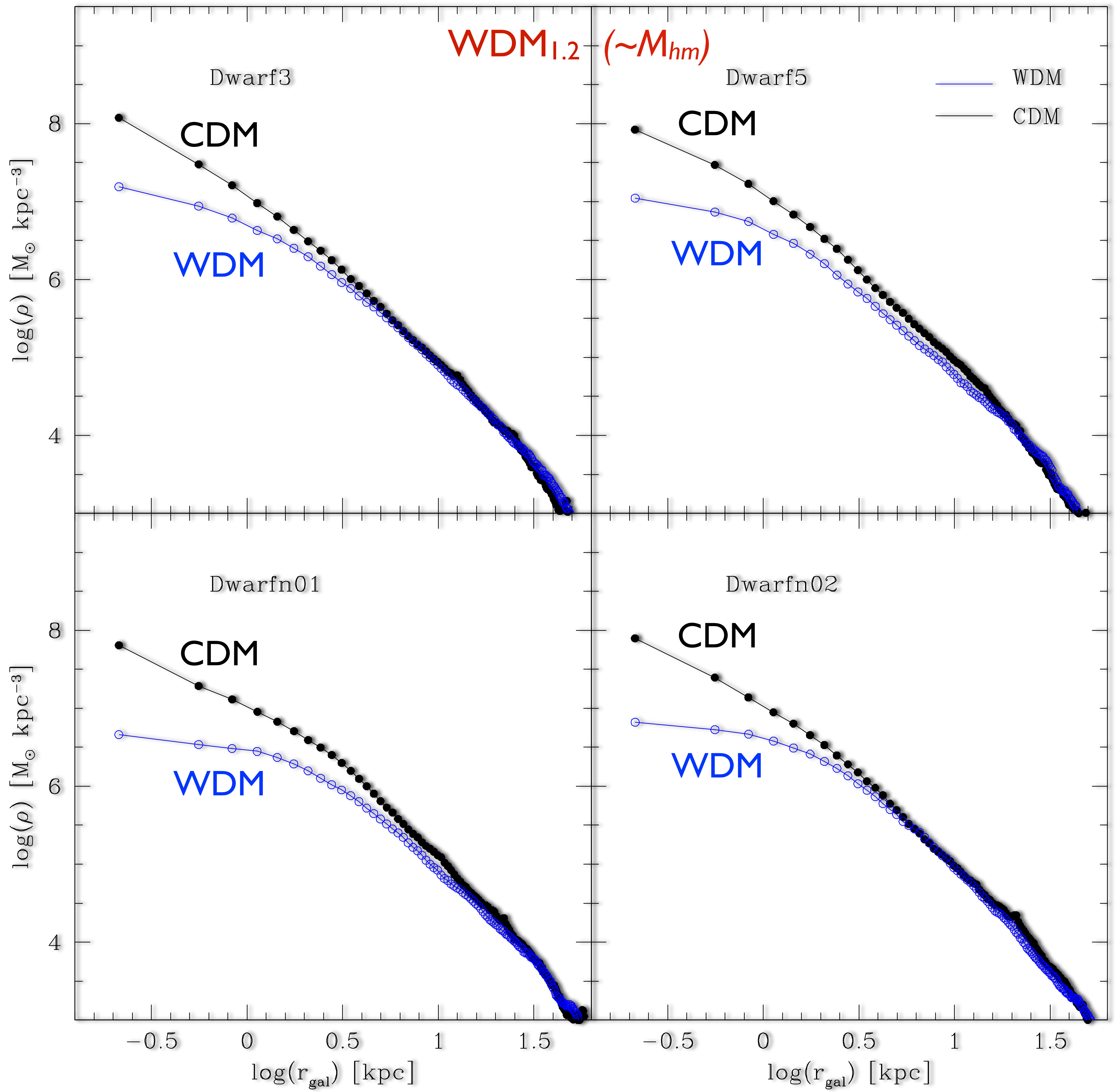
- WDM1.2 dwarfs have V_{max} *1.2-1.6x* lower than CDM ones.
- The V_c profiles of WDM1.2 dwarfs are shallower, mainly because the stars+gas profiles are much less concentrated than the CDM ones.
- For WDM3.0 dwarfs, the differences with CDM dwarfs are small *(see also Herpich+14)*.

The halo mass density distribution

only-DM sim's:

WDM halos are ~NFW (no shallow cores), though less concentrated *(**Avila-Reese+01; Colín +00,08;** Lovell+12; Schneider +12; Anderhalden+13)*

The halo mass density distribution



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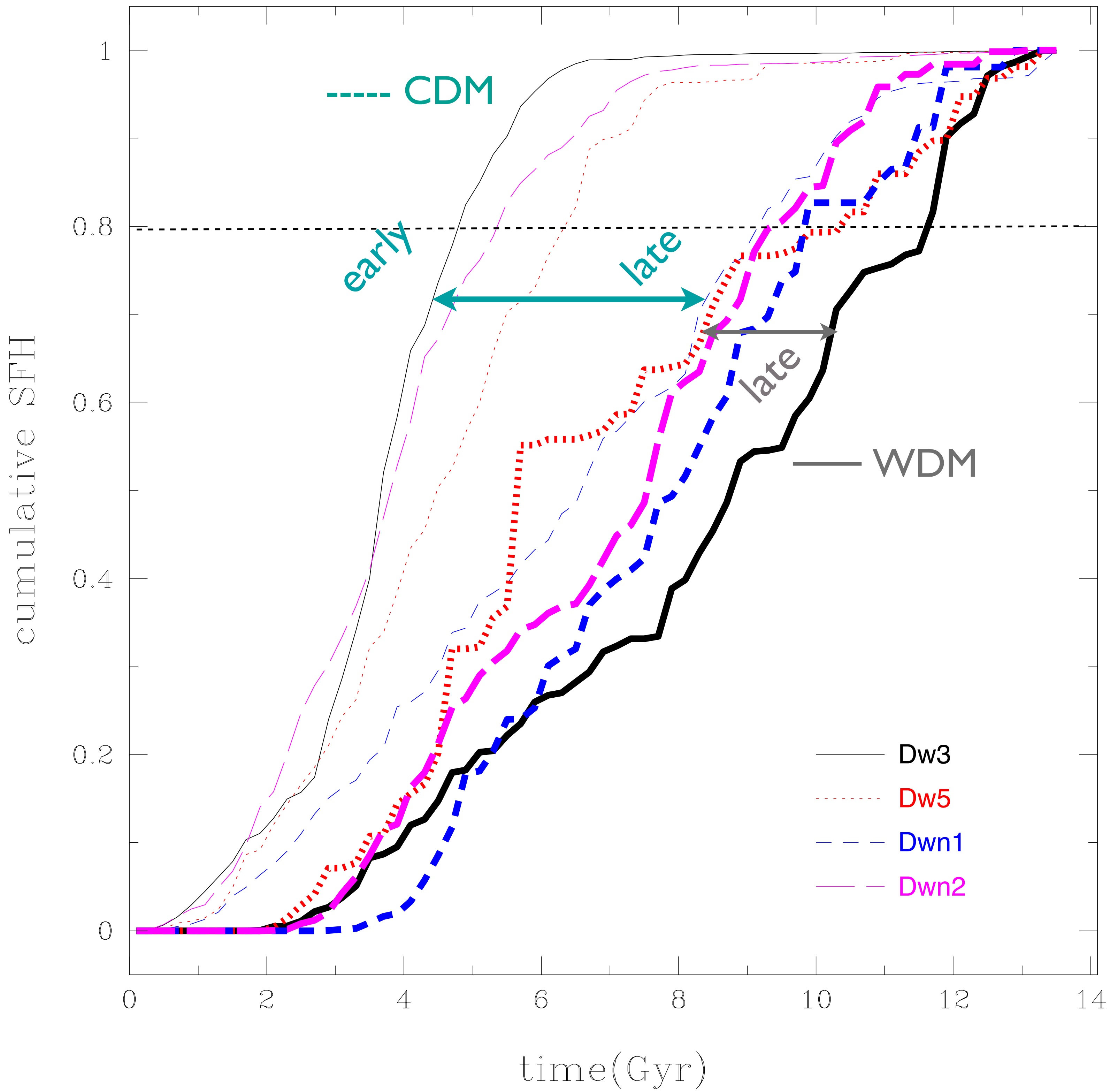
(Avila-Reese+01; Colín +00,08; Lovell+12; Schneider +12; Anderhalden+13)

hydro sim's:

in the $WDM_{1.2}$ runs, the cores are shallower than in the CDM ones!



why do shallow cores form?

- lower concentrations → more efficient effect of outflows
- no mergers to regrow cusps and to increase baryon dens.
- later SFHs → survival of cores *(see also Bullock's talk)*
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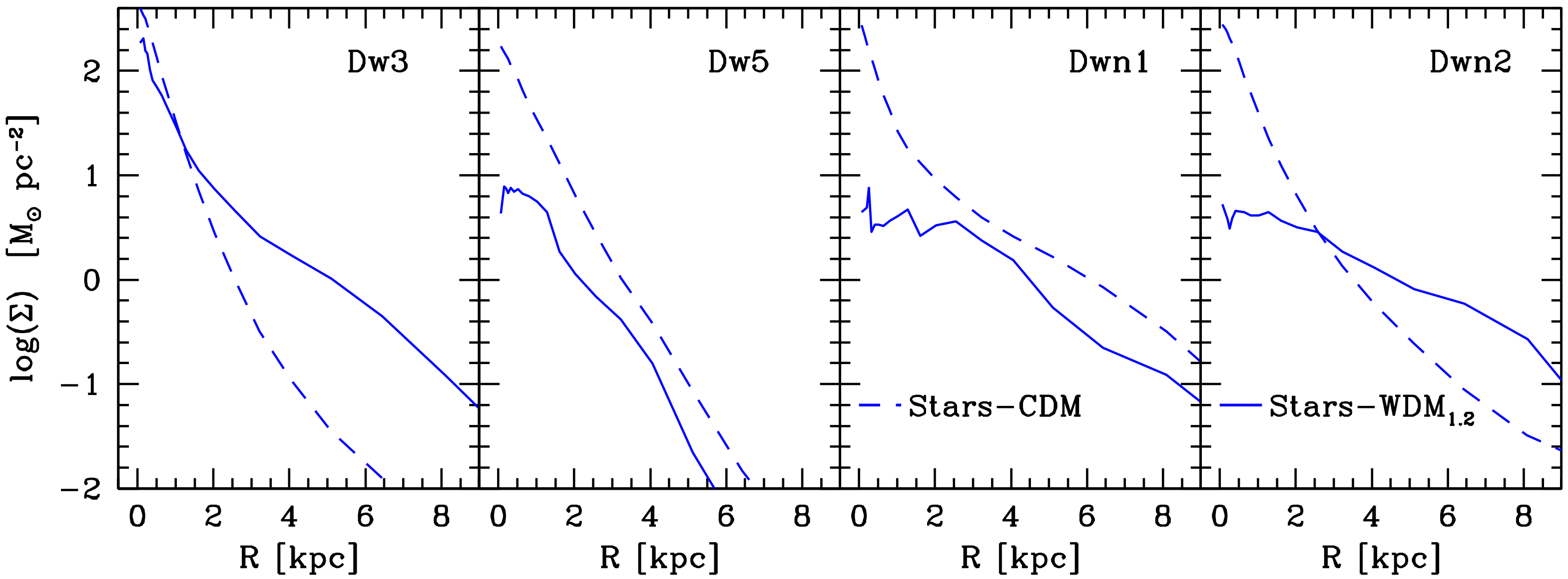

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why the inner stellar SDs are flat?

• lower halo spin parameters?
  -No *(λ can be lower or higher)*
• late stellar assembly → lower densities in general
• no mergers → no central-concentration formation

Conclusive remarks

•First N-body/hydro simulations of galaxies at the filtering scale. The WDM galaxies at this scale differ from their CDM counterparts in that:

- assemble later *(mass-weighted ages younger by ~1.5-5 Gyr)*
- have lower inner stellar SDs and more extended profiles *(R_e larger by 1.3-3x)*
- have lower V_{max} values by 1.2-1.6x, and shallower $V_c(r)$
- have lower $M_\star$ and higher gas fractions

•If m_{WDM}>3 keV, then $M_{hm}<1.5\times10^9 M_\odot$ --> $M_\star<5\times10^6 M_\odot$; field dwarfs of these masses are expected to be more extended, disky and gaseous, with lower V_{max} and shallower cores than their CDM counterparts.

•As the halos are larger than M_{hm}, the galaxies are more similar to the CDM counterparts.