Mergers and Mass Assembly of Dark Matter Halos & Galaxies

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Millennium I + II Simulations

Springel et al (2005)   Boylan-Kolchin et al (2009)

	Millennium I	Millennium II	
Particle number:	**2160^3**	**2160^3**	
Particle mass:	**8.6×10^8**	**6.9×10^6**	**$h^{-1} M_{sun}$**
Box size:	**500**	**100**	**h^{-1} Mpc**

DM subhalos: **760 million** **590 million** **(from z=127 to 0)**

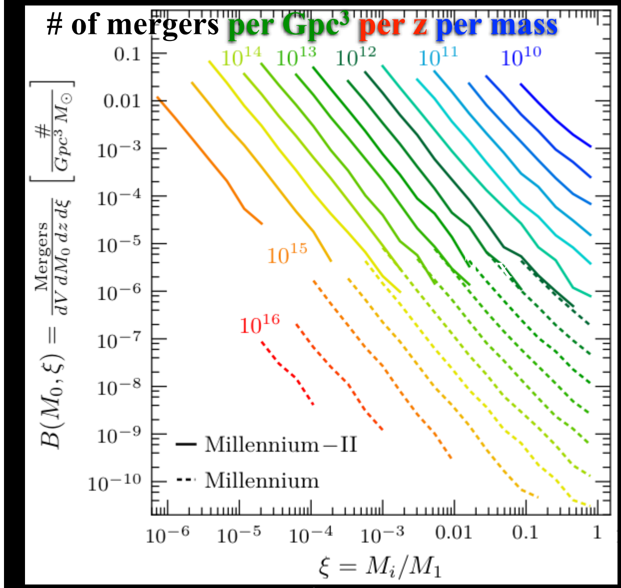
DM halos:

- **~ 18 million total**
- **~ 500,000 with $M > 10^{12} M_{sun}$ at z=0**

Halo merger trees:

constructed from 46 (57) outputs from z=6.2 (15) to 0 (Δz=0.02 at low z)

Millennium I + II (z=0)

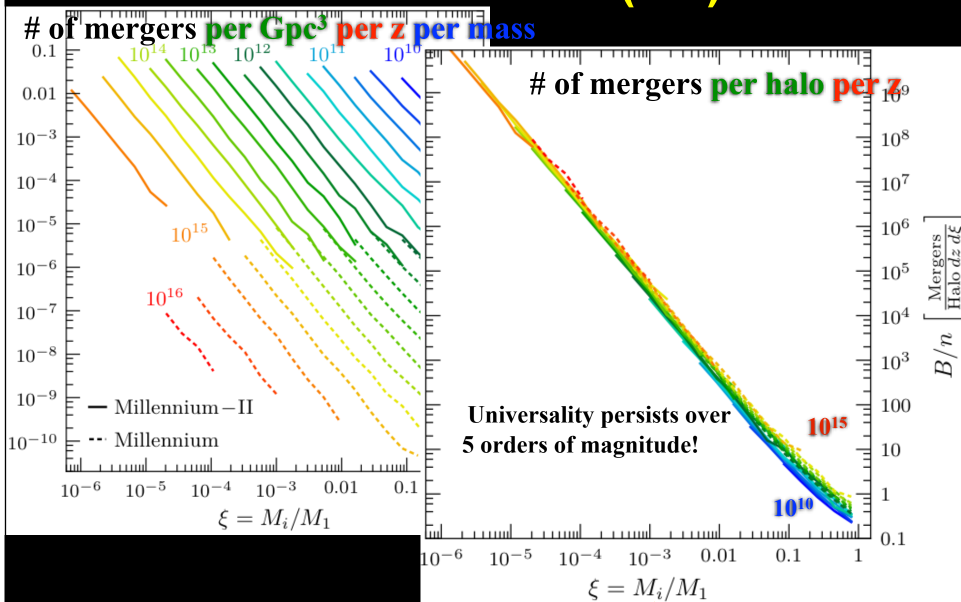


Solid: Millennium II
Dashed: Millennium

minor → major mergers

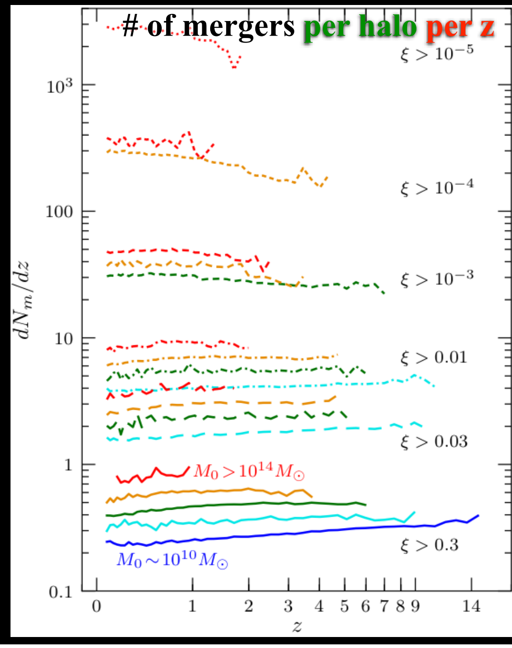
Fakhouri, Ma, Boylan-Kolchin (2010)

Millennium I + II (z=0)



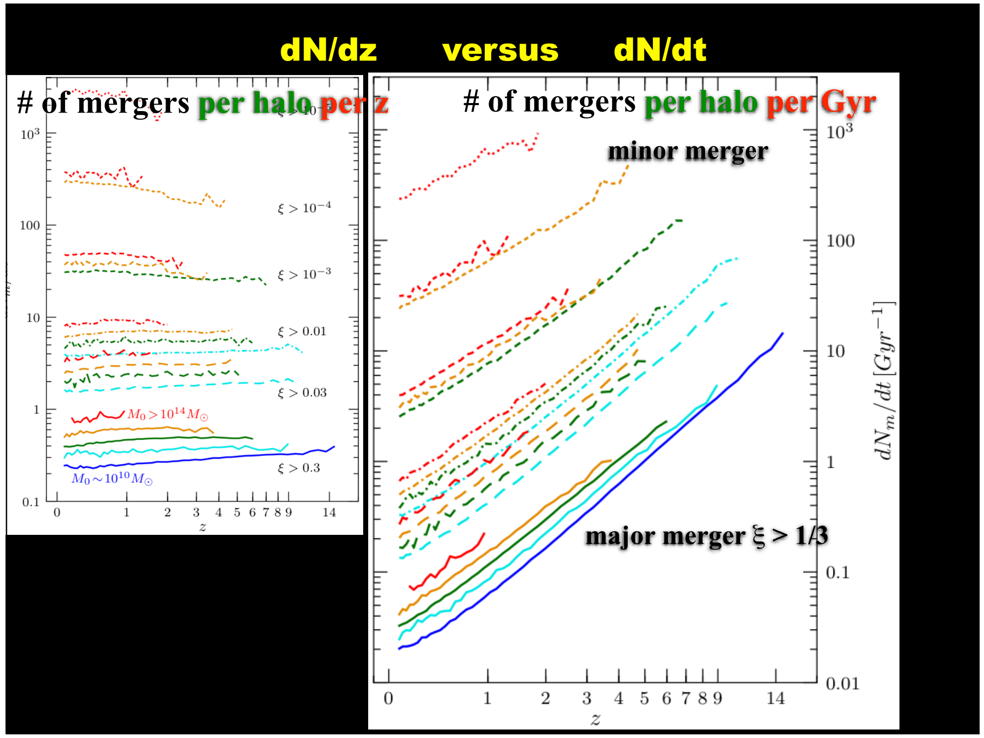
minor → major mergers

dN/dz: Weak Redshift Dependence



minor merger

major merger



dN/dz versus dN/dt
# of mergers per halo per z
# of mergers per halo per Gyr
minor merger
major merger ξ > 1/3
$\xi > 10^{-4}$
$\xi > 10^{-3}$
$\xi > 0.01$
$\xi > 0.03$
$\xi > 0.3$
$M_0 > 10^{14} M_\odot$
$M_0 \sim 10^{10} M_\odot$
$dN_m/dt\ [Gyr^{-1}]$
z

Universal Merger Rate

Fakhouri & Ma (2008)
Fakhouri et al (2010)

Mean merger rate per halo

$$\frac{dN_m}{d\xi dz}(M,\xi,z) = A\left(\frac{M}{10^{12}}\right)^{\alpha} \xi^{\beta} \exp\left[\left(\frac{\xi}{\tilde{\xi}}\right)^{\gamma}\right](1+z)^{\eta}$$

Descendent halo mass — **Progenitor mass ratio** — **Redshift dependence**

$$\alpha \approx 0.13 \quad \beta \approx -1.995 \quad \eta \approx 0.099$$

See also: Stewart et al (2009), Genel et al (2009)

Dark Matter Accretion Rate

$$M(z) = M_0(1+z)^\beta e^{-\gamma z}$$

McBride et al. (2009)

Fakhouri et al. (2010)

$$\frac{\dot{M}}{M} = [\gamma(1+z) - \beta]H_0[\Omega_m(1+z)^3 + \Omega_\Lambda]^{1/2}$$

$$\dot{M}_{\rm mean} = 46.1\frac{M_\odot}{\rm yr}\left(\frac{M}{10^{12}}\right)^{1.1}(1+1.11z)[\Omega_m(1+z)^3+\Omega_\Lambda]^{1/2}$$

$$\dot{M}_{\rm med} = 25.3\frac{M_\odot}{\rm yr}\left(\frac{M}{10^{12}}\right)^{1.1}(1+1.65z)[\Omega_m(1+z)^3+\Omega_\Lambda]^{1/2}$$

General trends: (1) Specific accretion rate depends weakly on M

(2) Rate increases with redshift as $\sim(1+z)^{1.5}$ at z >~ 1

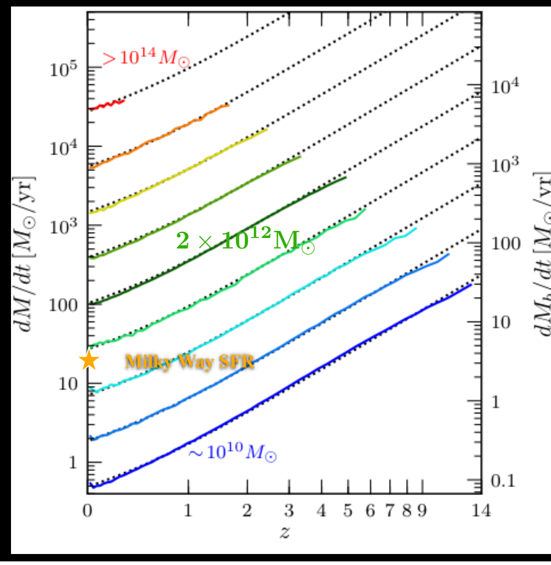
Zero-point mean value is similar to Neistein et al (2008), Genel et al (2008)

Dark Matter Mean Accretion Rates

(across virial radius)

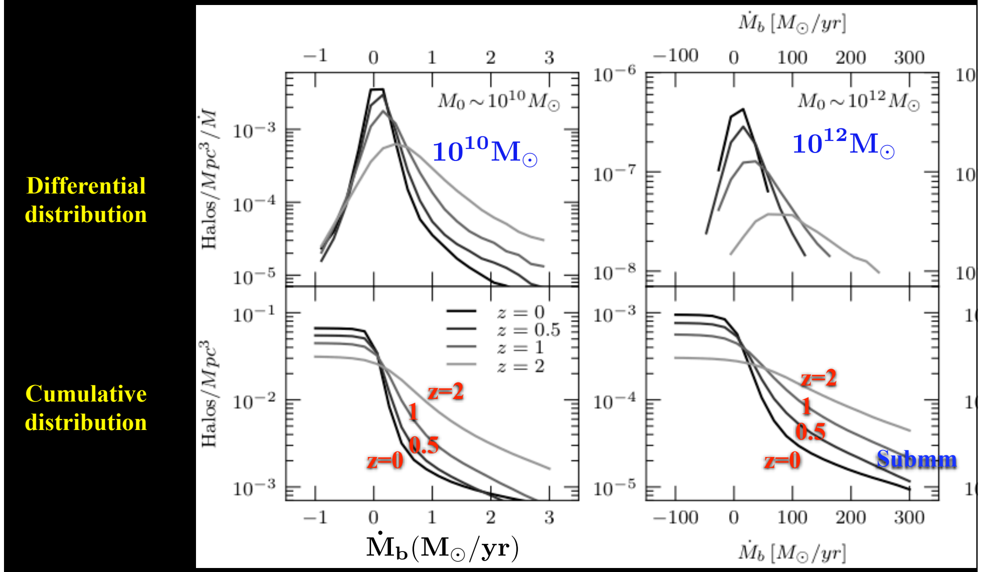
Fakhouri et al (2010)

dark matter accretion rate



(inferred) baryon accretion rate

Distribution of Accretion Rates



Dark Matter vs Baryon Assembly

Faucher-Giguere, Keres, Ma (in prep)

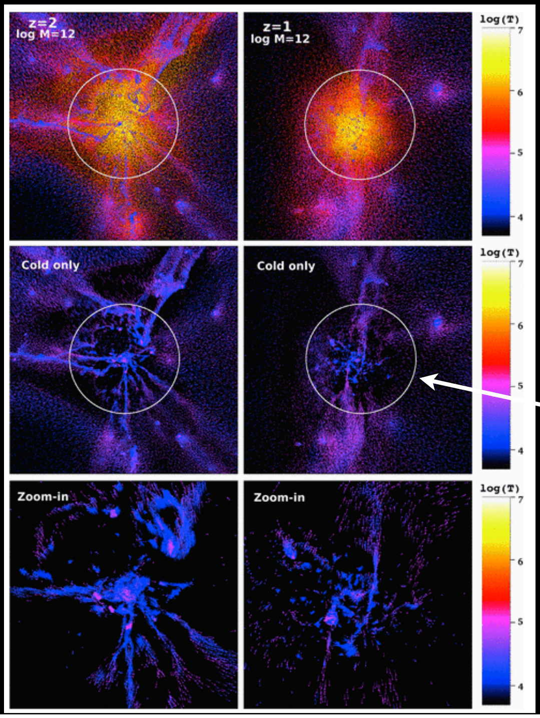
New SPH cosmological simulations

40 Mpc h^{-1} box
2 x 512^3 particles
1.6 kpc h^{-1} resolution

SN-driven galactic winds

$$\dot{M}_{\rm wind} = \eta \dot{M}_* \qquad \frac{1}{2}\dot{M}_{\rm wind} v_{\rm wind}^2 = \chi \epsilon_{\rm SN} \dot{M}_*$$

$$\eta = 1 \quad \chi = 0.25 \rightarrow v_{\rm wind} = 340\,{\rm kms}^{-1}$$



Gas Temperature

Two 10^{12} M_{sun} Halos

virial radius

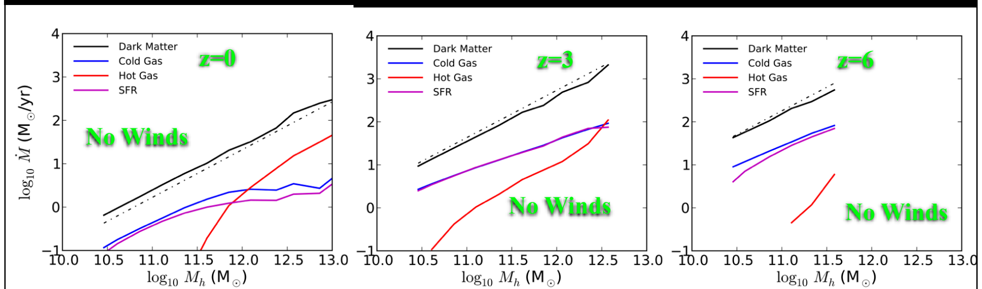
Keres et al (2009)

See also Dekel & Birnboim
Ocvirk et al (2008)

Dark Matter vs Baryon Accretion Rates

(at virial radius)

Faucher-Giguere et al (in prep)

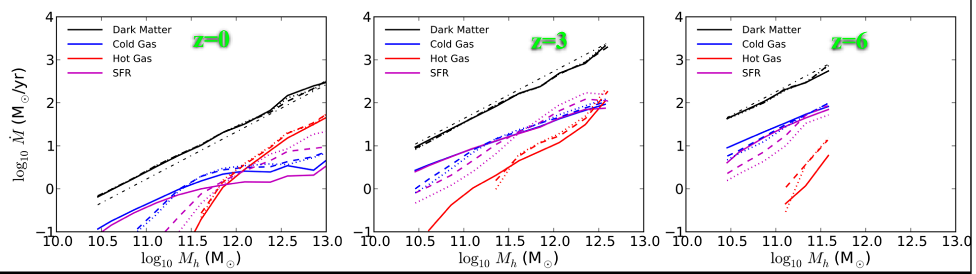


Dark matter accretion rate is similar to Millennium results.
Cold gas (T<250,000K) dominates baryon accretion in low-mass halos.
Hot gas accretion dominates in high-mass halos at lower redshifts.
Star formation rate ~ Cold gas accretion rate

(See also Keres et al 09 - note their rate was for accretion onto galaxies)

Effects of Galactic Winds

Faucher-Giguere et al (in prep)



SFR is strongly suppressed by galactic winds in M < $10^{11.5}$ M_{sun} halos

Hot gas accretion rate is raised only slightly by winds

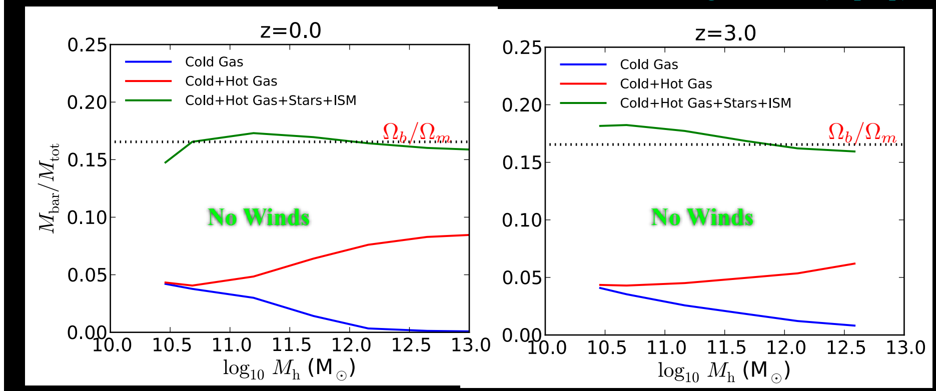
Net cold gas accretion rate is suppressed by winds in < $10^{11}M_{sun}$ halos

BUT......

Infall cold gas accretion rate is insensitive to winds

Baryon Content
(within virial radius)

Faucher-Giguere et al (in prep)

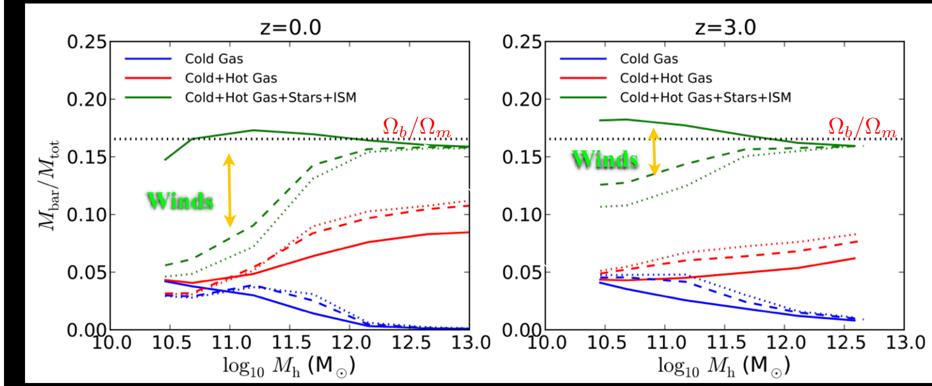


Low mass halos: gas is mostly cold
(median) baryon fraction ~ cosmic mean value without wind

High mass halos: gas is mostly hot
(median) baryon fraction ~ cosmic mean value without wind

Baryon Content
(within virial radius)

Faucher-Giguere et al (in prep)



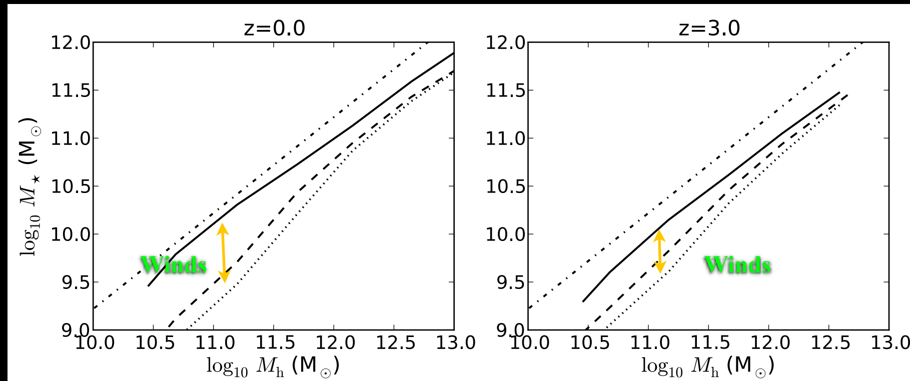
Low mass halos: gas is mostly cold
M* is strongly reduced by galactic winds
baryon fraction is only ~1/3 cosmic when wind is on

High mass halos: gas is mostly hot
baryon fraction = cosmic mean value regardless of wind

Stellar Mass vs Halo Mass

(within virial radius)

Faucher-Giguere et al (in prep)



Without winds: excessive M_* in low mass halos

With winds: M_* - M_{halo} relation is improved. Steep enough?

See also Keres et al (2009), Oppenheimer et al (2010)

Summary

Dark Matter Assembly

The mean rate of halo-halo mergers follows a simple universal form.

dN/dz depends weakly on descendant mass and redshift

dN/dt increases as $(1+z)^n$, $n \sim 2$ to 2.3

Halo mass accretion history M(z) is well fit by a two-parameter function

Median dark matter accretion rate is 54 M_{sun}/yr today for 2×10^{12} M_{sun} halos,

Implied baryon accretion rates are 9, 15, 39, 77 M_{sun}/yr at z=0, 1, 2, and 3.

Distribution of accretion rate is broader at high z.

Baryon Assembly

Without galactic winds, baryon fraction & accretion rate are ~ 1/6 of dark matter , but M* is too high

With galactic winds, baryon fraction, SFR, M* are all much reduced in $M < 10^{11.5}$ M_{sun} halos

In progress:

Find simple analytic approximations for various baryon rates in different wind models