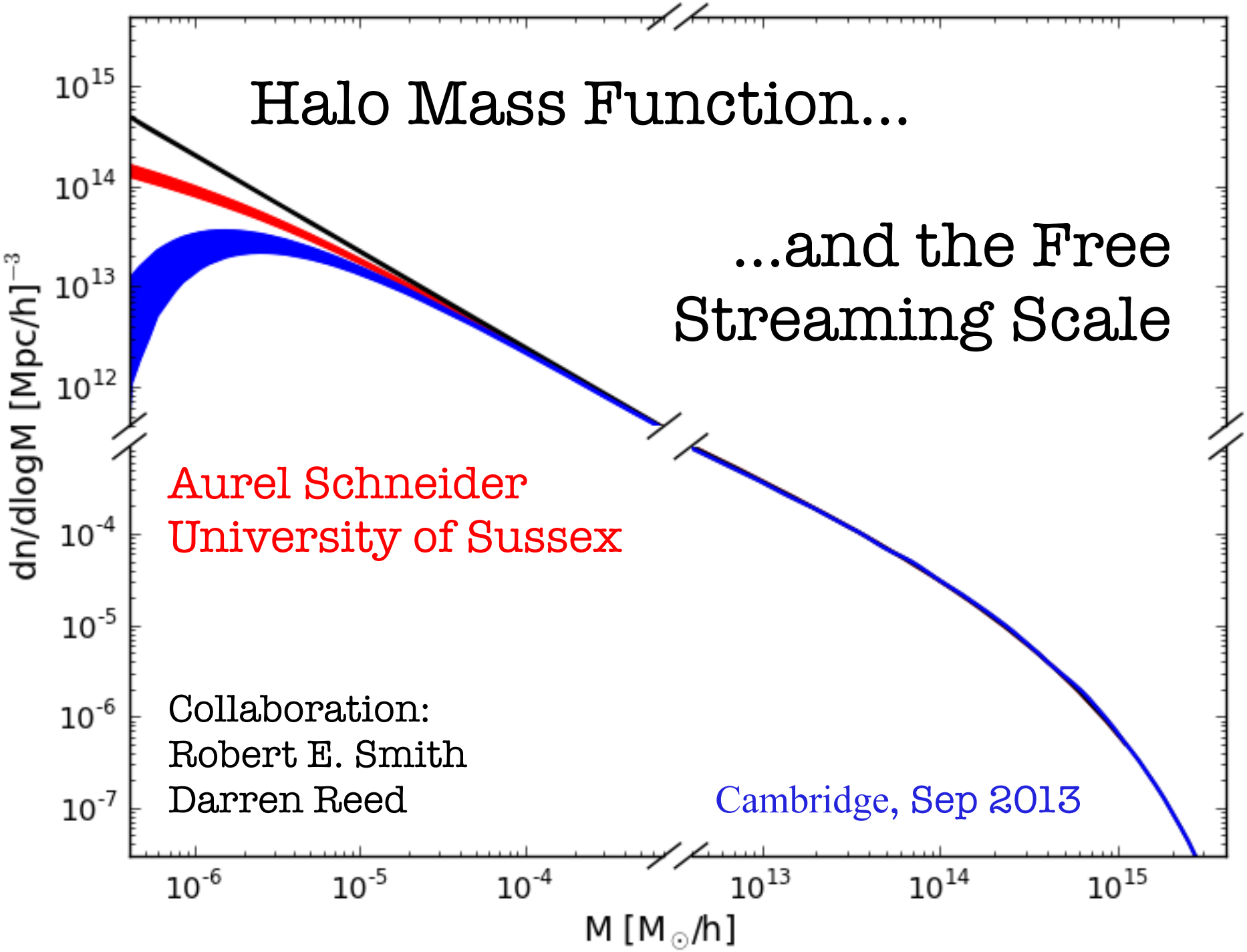

Halo Mass Function...
...and the Free Streaming Scale
Aurel Schneider
University of Sussex
Collaboration:
Robert E. Smith
Darren Reed
Cambridge, Sep 2013
dn/dlogM [Mpc/h]$^{-3}$
M [M$_\odot$/h]
10^{15}
10^{14}
10^{13}
10^{12}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{13}
10^{14}
10^{15}

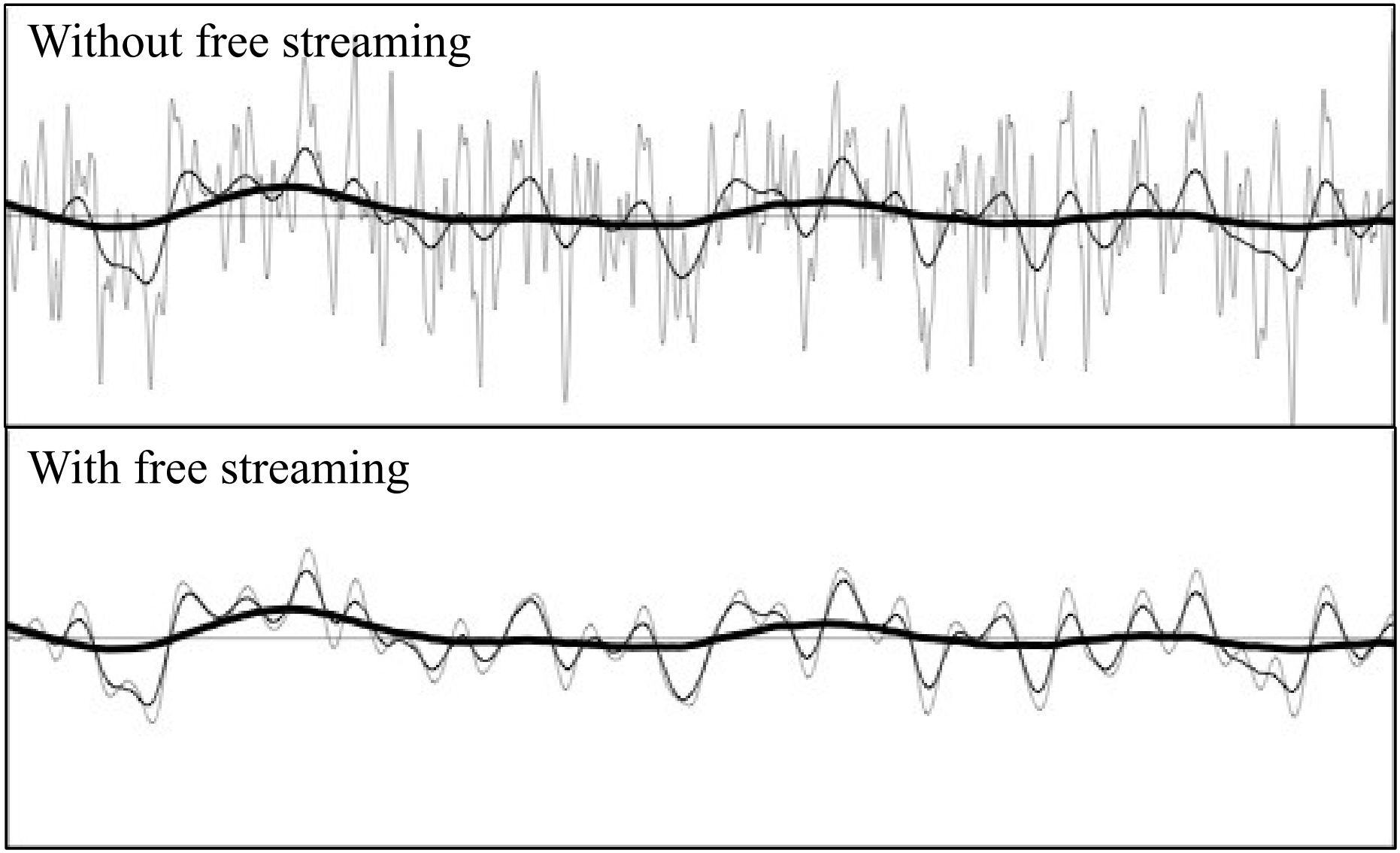
Outline

Structure Formation and Free Streaming

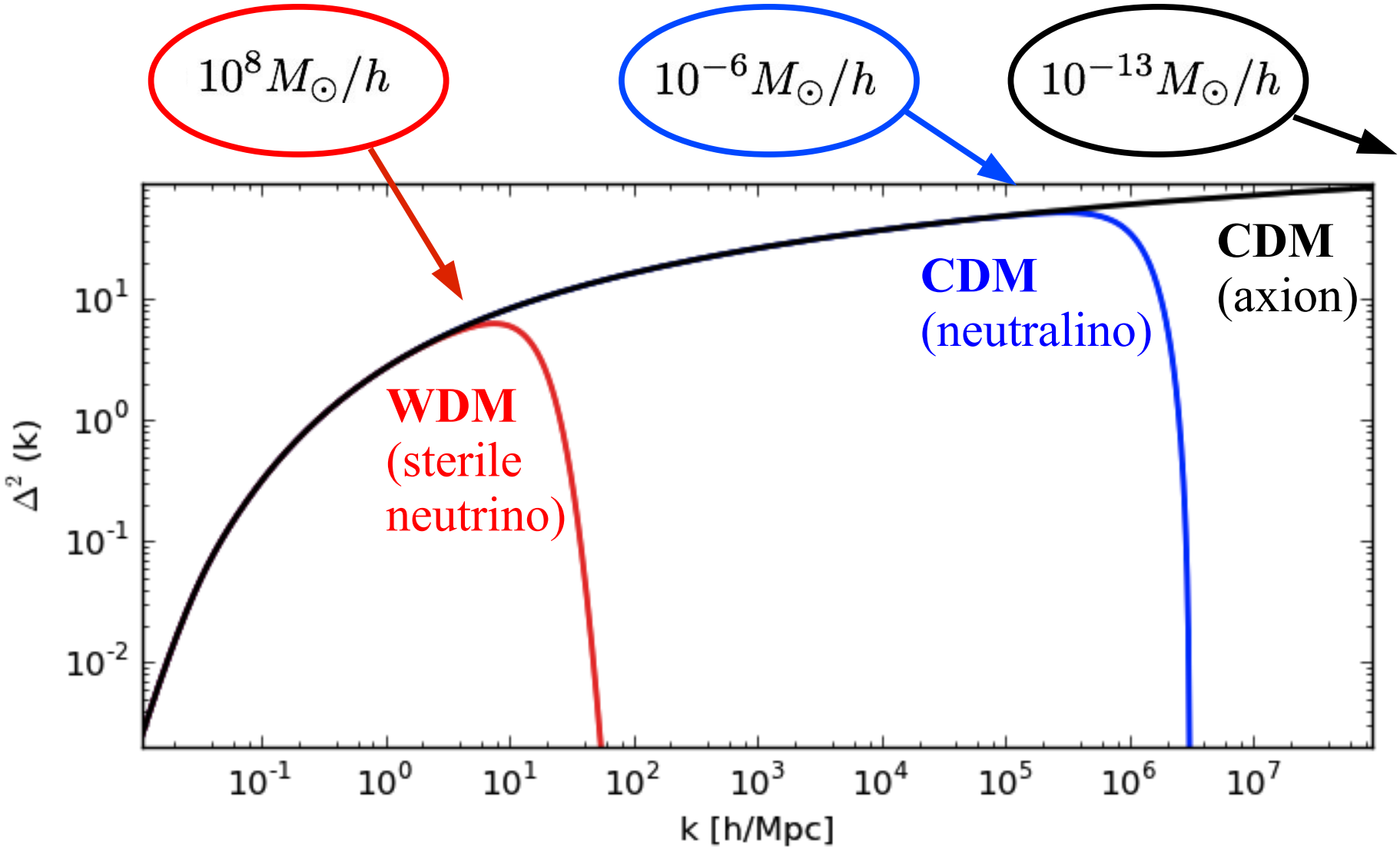
Modeling the Halo Mass Function with WDM

Predictions for CDM

Structure formation: linear density field



Structure formation: linear density field



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Structure Formation and Free Streaming

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Predictions for CDM

Mass Function: Sheth-Tormen model

$$\boxed{\frac{dn}{d\log M} = -\frac{1}{2}\frac{\bar{\rho}}{M} f(\nu) \frac{d\log\sigma^2}{d\log M}} \qquad \nu = \frac{\delta_c^2}{\sigma^2(M)}$$

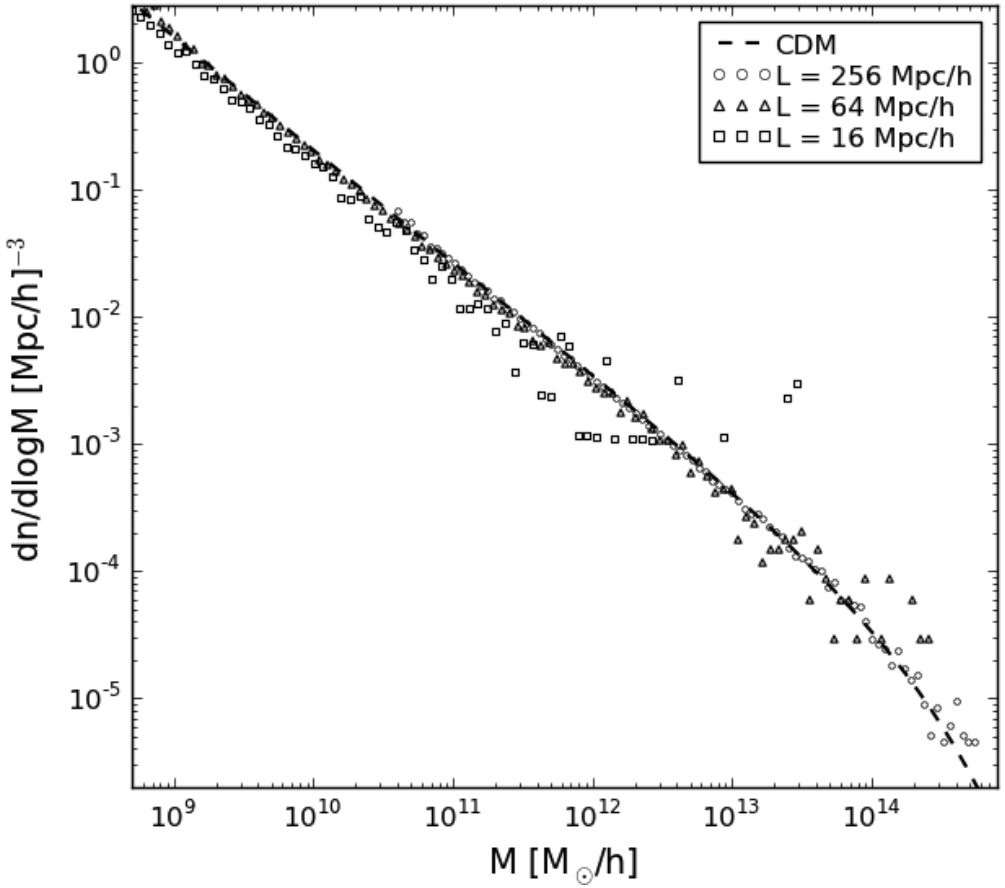
$$\sigma^2(R) = \int \frac{d\mathbf{k}^3}{(2\pi)^3} P_{\rm Lin}(k) W_{\rm TH}^2(kR)$$

$$W_{\rm TH} = 3\left[\sin y - y\cos y\right]/y$$

$$f(\nu) = A\sqrt{\frac{2q\nu}{\pi}}\left[1 + (q\nu)^{-p}\right] e^{-q\nu/2},$$

$$A = 0.322, \quad p = 0.3, \quad q = 0.707.$$

$$M = \frac{4\pi}{3}\bar{\rho}R^3$$



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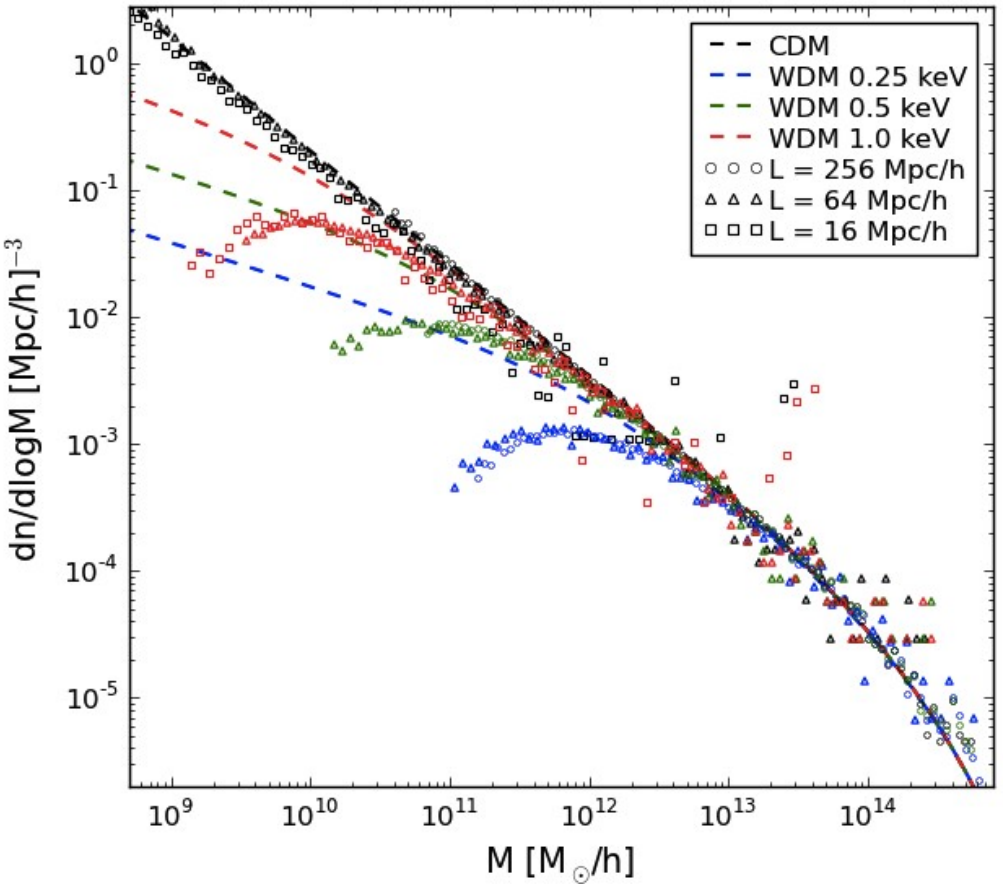

WDM limit: $\lim_{M\to 0}\frac{dn}{d\log M} \propto M^{-1/3} = \infty$

Mass Function: Sharp-k model

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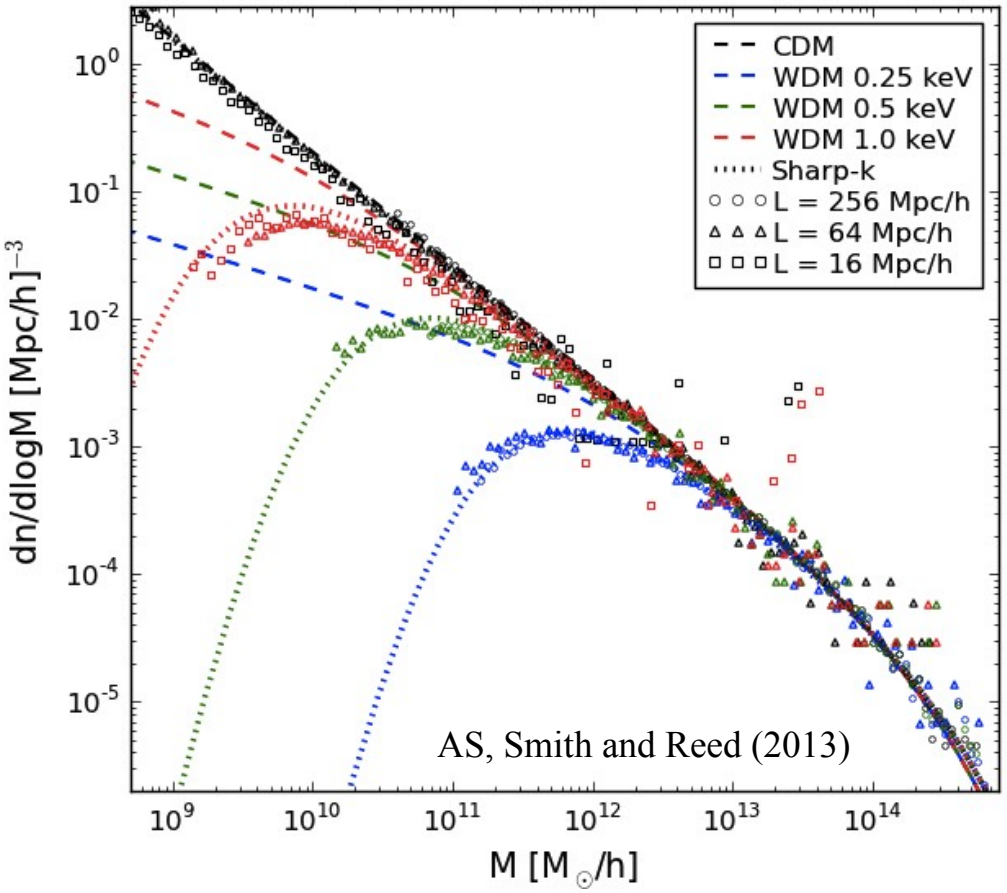
$$\sigma^2(R) = \int \frac{d\mathbf{k}^3}{(2\pi)^3} P_{\rm Lin}(k) W_{\rm SK}^2(kR)$$

$$W_{\rm SK} = \Theta(1 - kR)$$

$$f(\nu) = A\sqrt{\frac{2q\nu}{\pi}}\left[1 + (q\nu)^{-p}\right] e^{-q\nu/2},$$

$$A = 0.322, \quad p = 0.3, \quad q = 1.0.$$

$$M = \frac{4\pi}{3}\bar{\rho}[cR]^3, \quad c = 2.7$$



WDM limit: $\lim_{M\to 0} \frac{dn}{d\log M} \propto M^{6-n/3} = 0$

Mass Function: Sharp-k model

Problem solved ?

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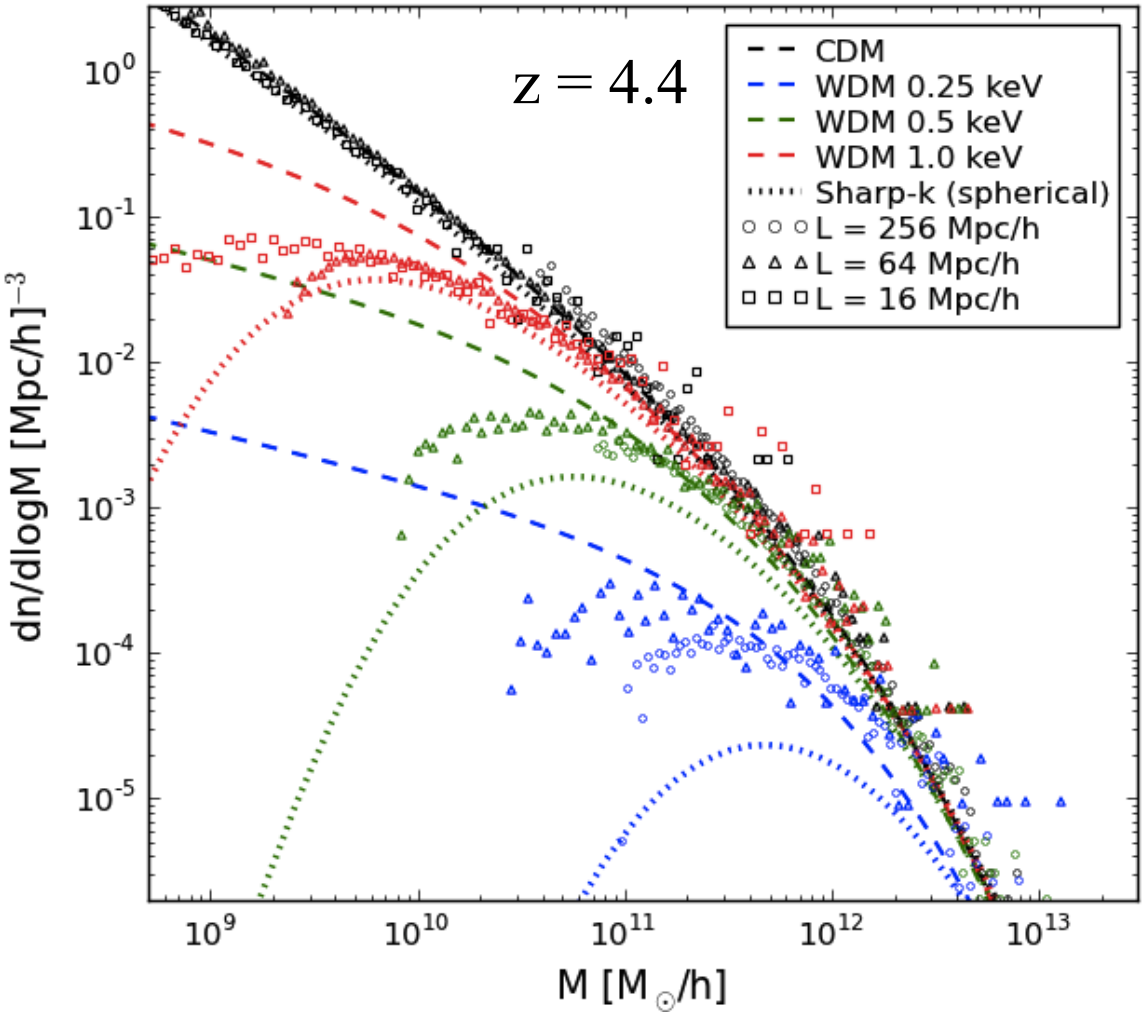
Problem solved ?



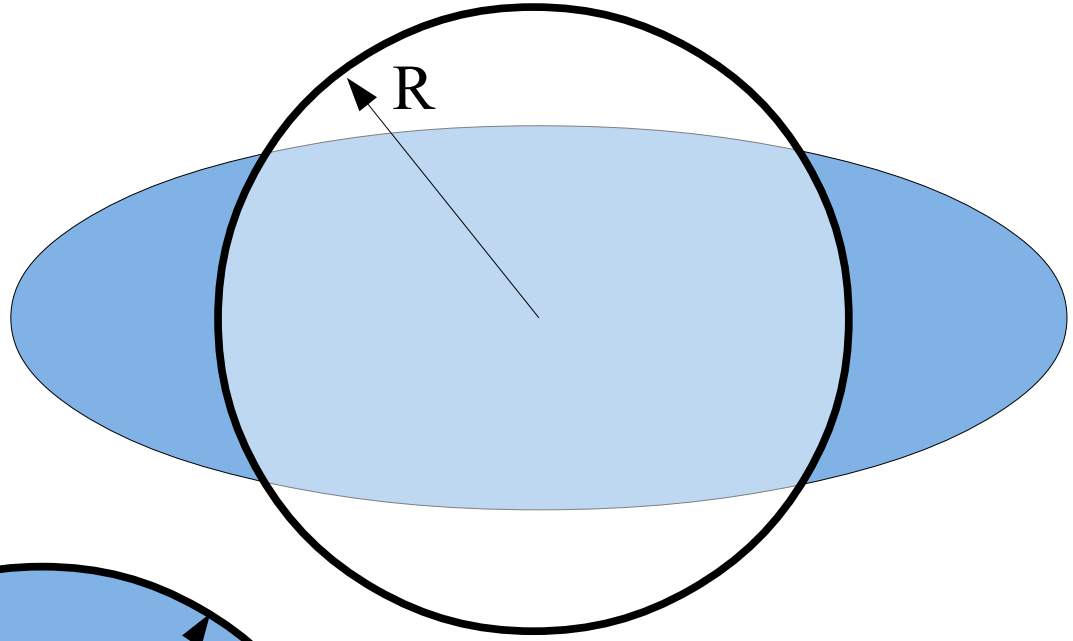
...not at high redshift!

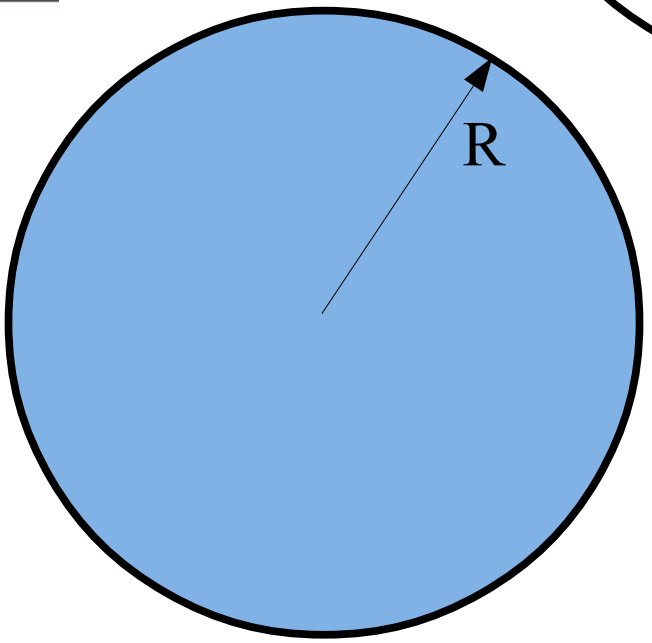
Mass Function: ellipsoidal correction

$$\boxed{\frac{dn}{d\log M} = -\frac{1}{2}\frac{\bar{\rho}}{M} f(\nu) \frac{d\log\sigma^2}{d\log M}}$$

$$\frac{d\log\sigma^2}{d\log M} = \frac{1}{6\pi^2\sigma^2}\frac{P_{\rm Lin}(1/R)}{R^3}$$

$$M = \frac{4\pi}{3}\bar{\rho}[cR]^3$$





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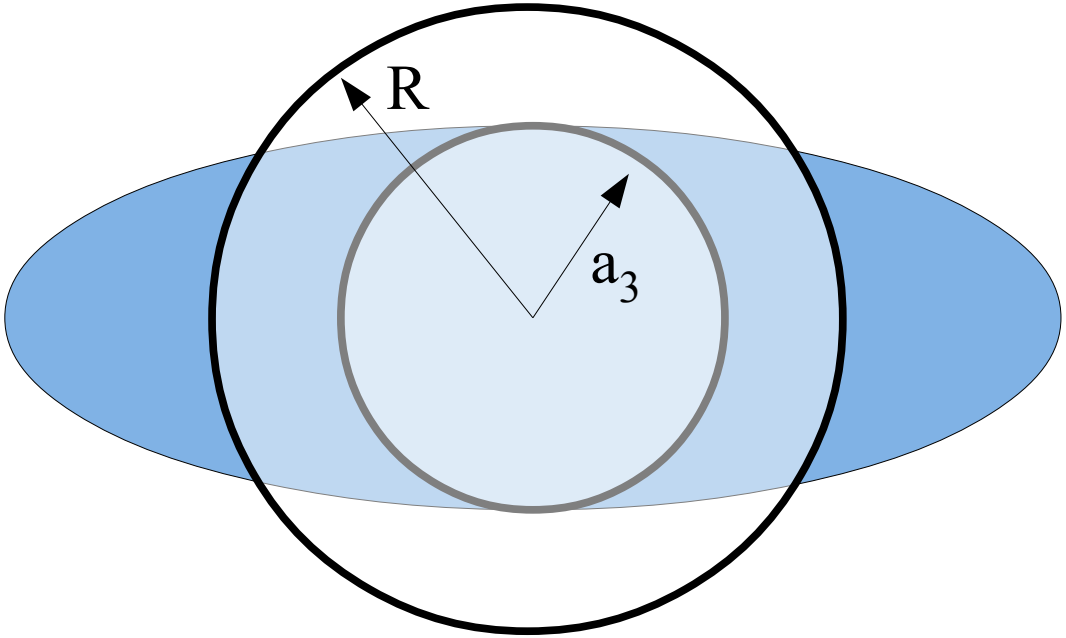
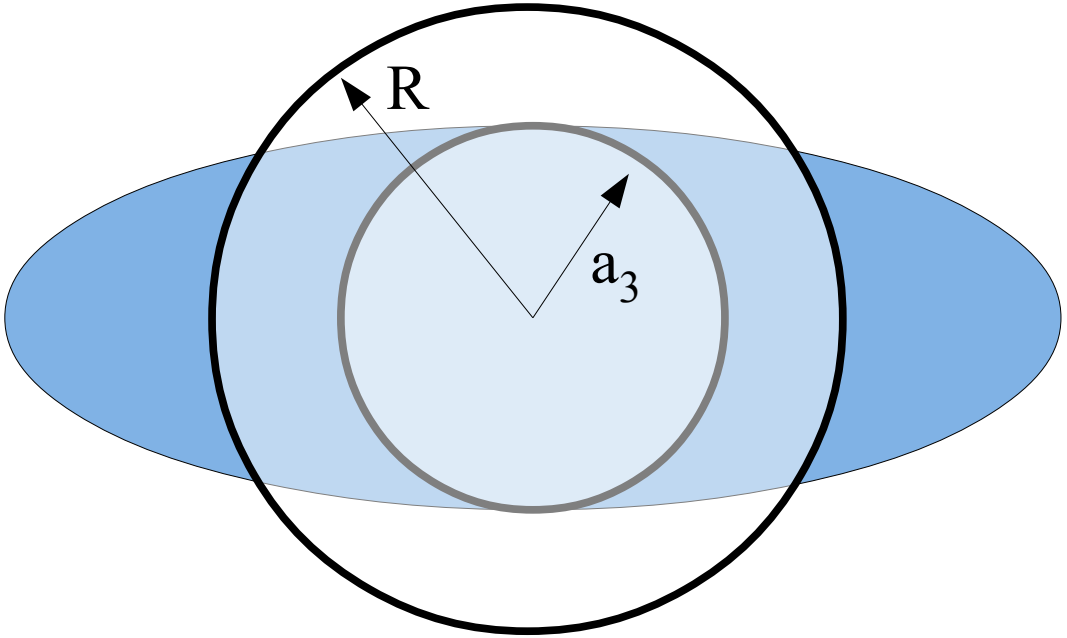


$$\frac{d\log\sigma^2}{d\log M} = \frac{1}{6\pi^2\sigma^2}\frac{P_{\rm Lin}(1/a_3)}{a_3^3}\frac{da_3}{dR}\xi(R)$$

$$R^3 = a_1 a_2 a_3 = \left(\frac{a_1}{a_3}\frac{a_2}{a_3}\right) a_3 = (\xi a_3)^3, \qquad a_3(R) = \frac{R}{\xi(R)} \qquad M = \frac{4\pi}{3}\bar{\rho}\left[cR(a_3)\right]^3$$

Mass Function: ellipsoidal correction

$$\frac{dn}{d\log M} = -\frac{1}{2}\frac{\bar{\rho}}{M} f(\nu) \frac{d\log\sigma^2}{d\log M}$$



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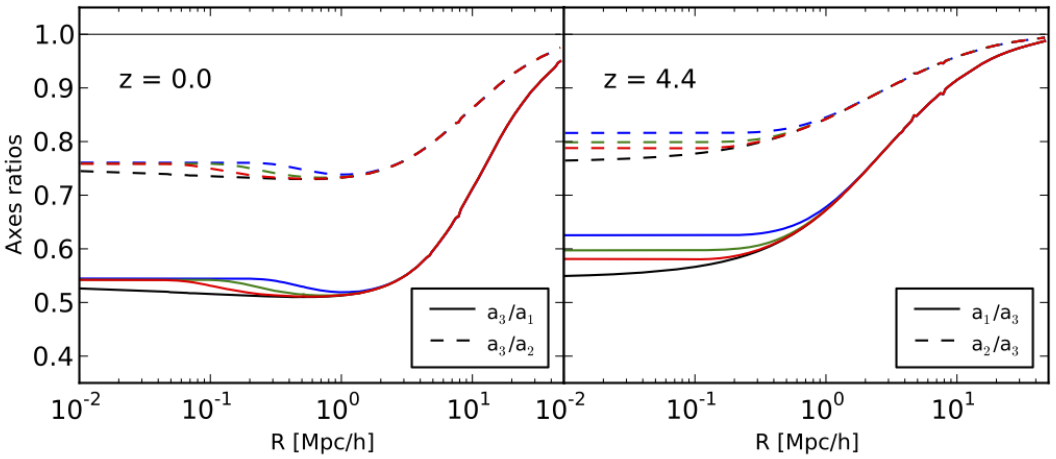
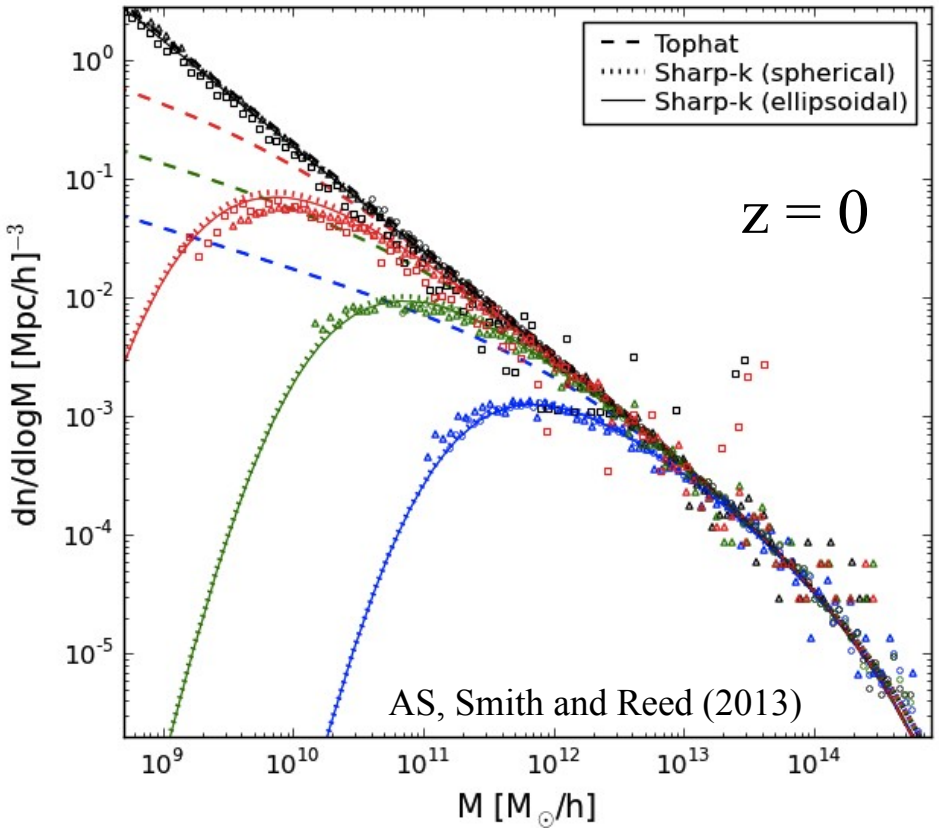
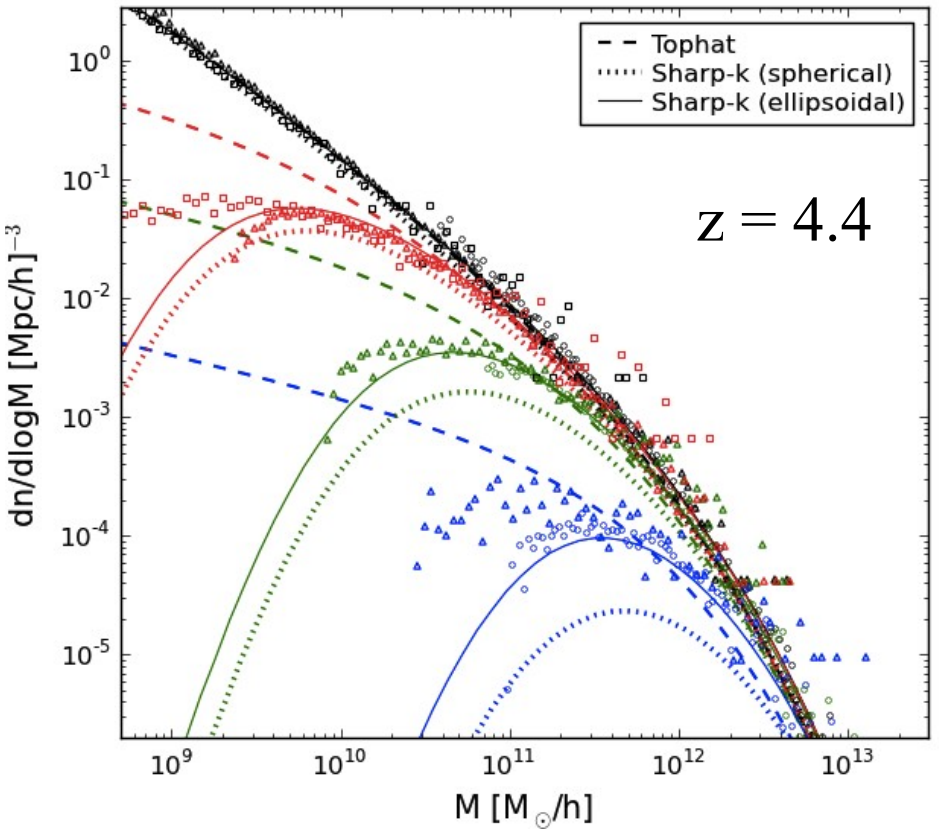
$$R^3 = a_1 a_2 a_3 = \underbrace{\left(\frac{a_1}{a_3}\frac{a_2}{a_3}\right)}\, a_3 = (\xi a_3)^3$$

Shape of initial patches depend on scale and redshift (Bardeen et al 1986)



Mass Function: ellipsoidal correction





- Spherical sharp-k: $A = 0.322, \;\; p = 0.3, \;\; q = 1.0.$ $\quad M = \frac{4\pi}{3}\bar{\rho}[cR]^3, \;\; c = 2.7$
- Ellipsoidal sharp-k: $A = 0.322, \;\; p = 0.3, \;\; q = 0.75$ $\quad M = \frac{4\pi}{3}\bar{\rho}\left[cR(a_3)\right]^3, \;\; c = 2.0$

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Cold Dark Matter: comparison

Does model work for neutralino-CDM?

- Free streaming scale: 10^{15} times smaller!
- Different cutoff

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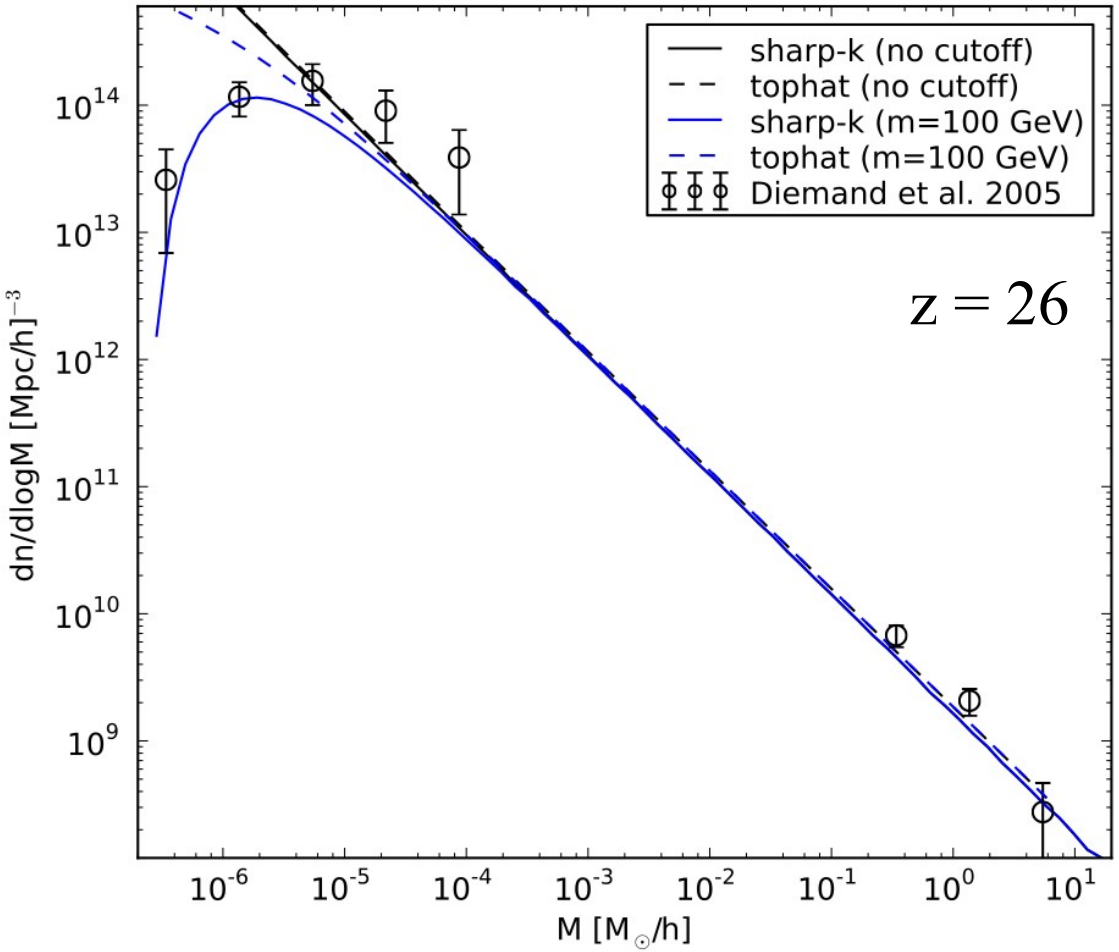
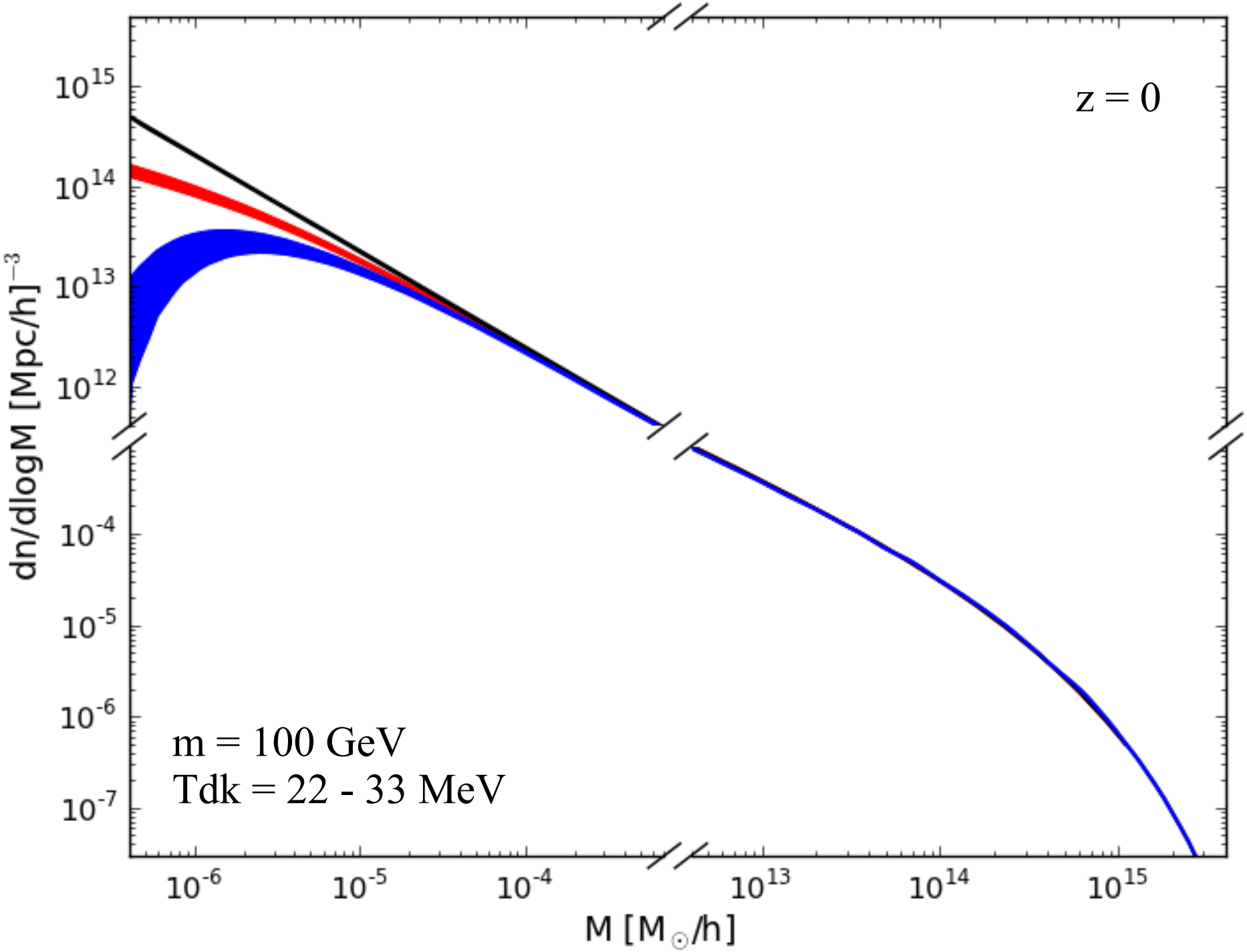
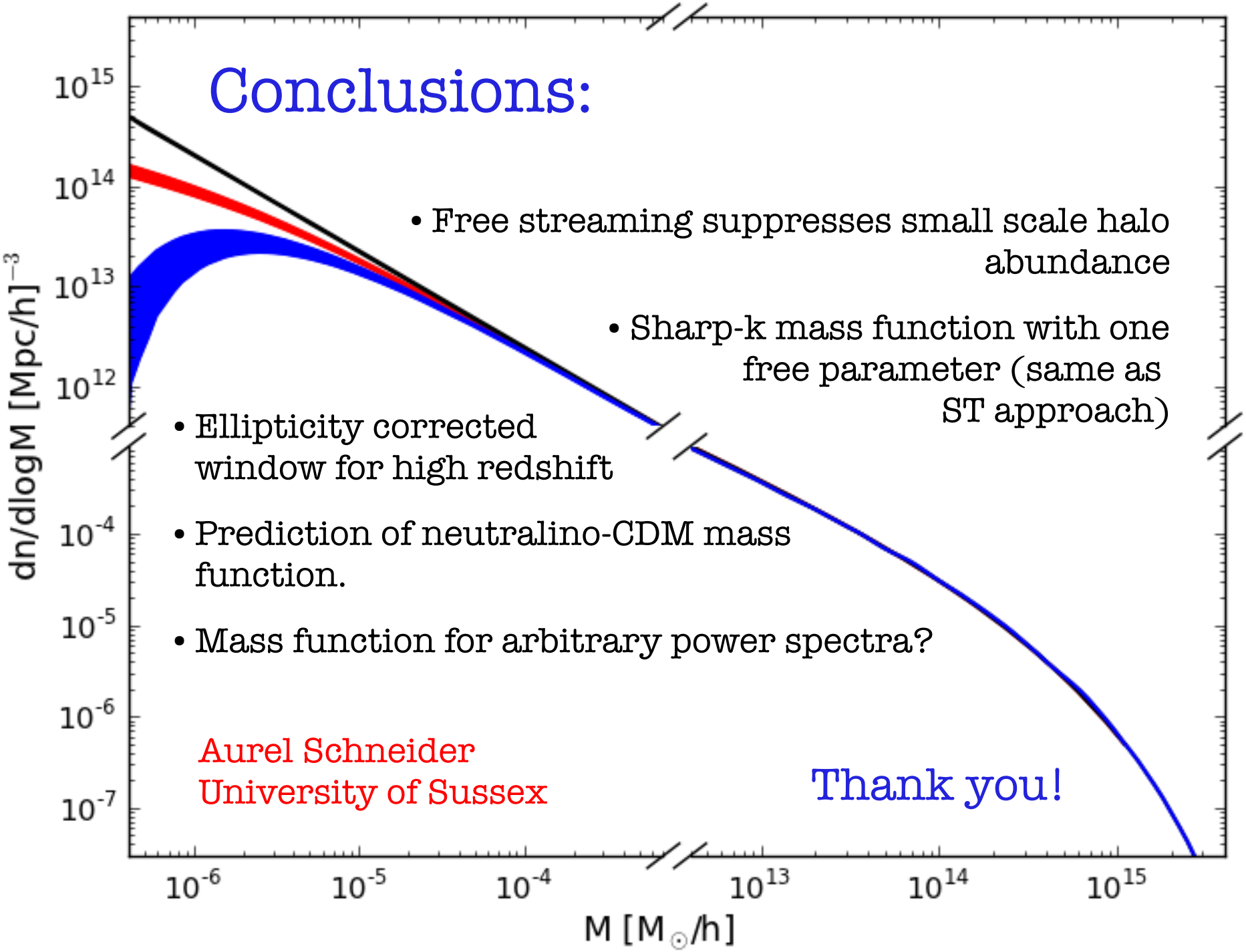


Diemand et al. (2006):
m = 100 GeV, T_{dk} = 28 MeV


z = 0
m = 100 GeV
Tdk = 22 - 33 MeV
dn/dlogM [Mpc/h]$^{-3}$
M [M$_\odot$/h]
10^{15}
10^{14}
10^{13}
10^{12}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{13}
10^{14}
10^{15}

Conclusions:



- Free streaming suppresses small scale halo abundance
- Sharp-k mass function with one free parameter (same as ST approach)
- Ellipticity corrected window for high redshift
- Prediction of neutralino-CDM mass function.
- Mass function for arbitrary power spectra?

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University of Sussex

Thank you!