Warm Dark Matter, Reionization and 21cm Signal

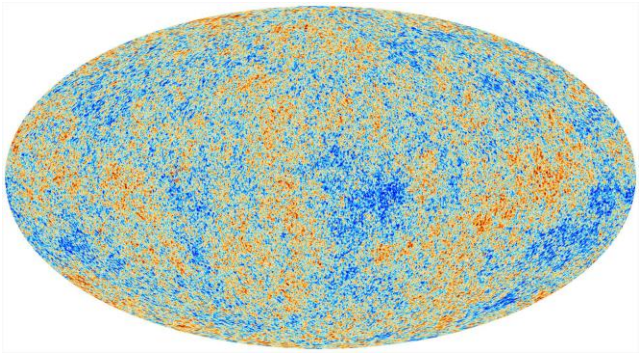
Yin-Zhe MA

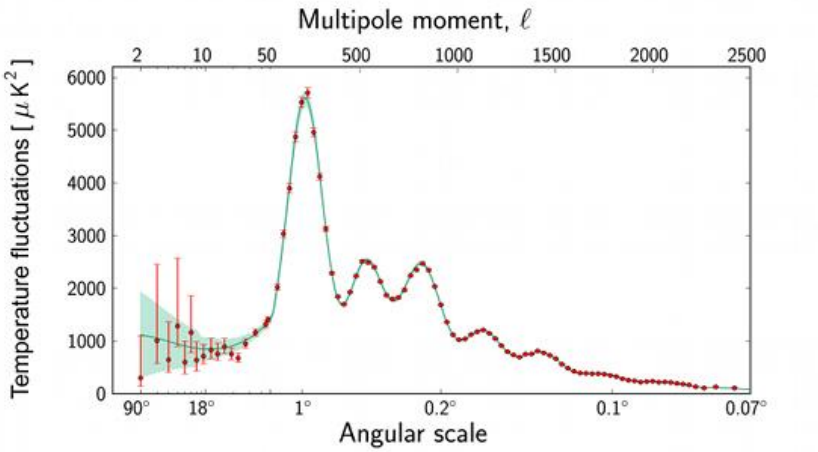
University of British Columbia
Canadian Institute for Theoretical Astrophysics

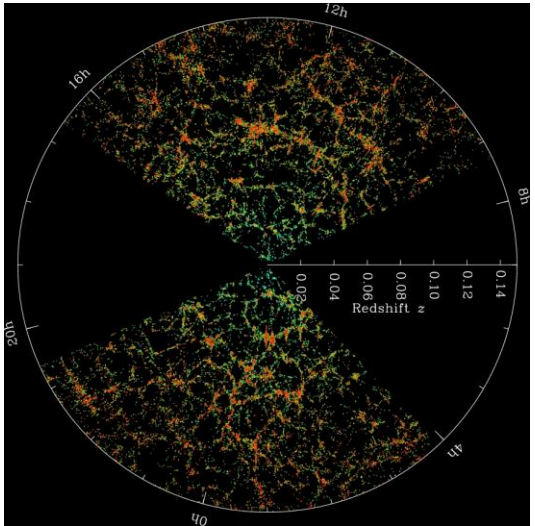
Based on: M. Sitwell, Y.Z. Ma, A. Mesinger, K. Sigurdson, in preparation

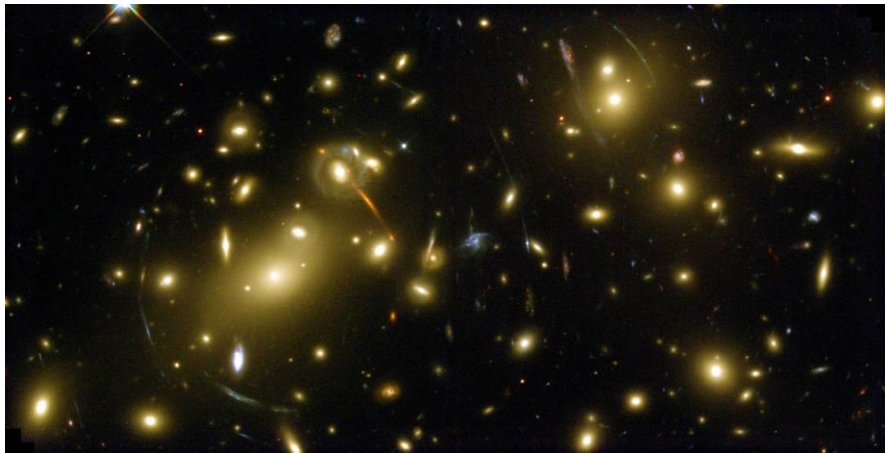
Standard LCDM cosmology has been very successful on large scale cosmology

CMB, large-scale structures through galaxy surveys, cluster abundance, cosmic web



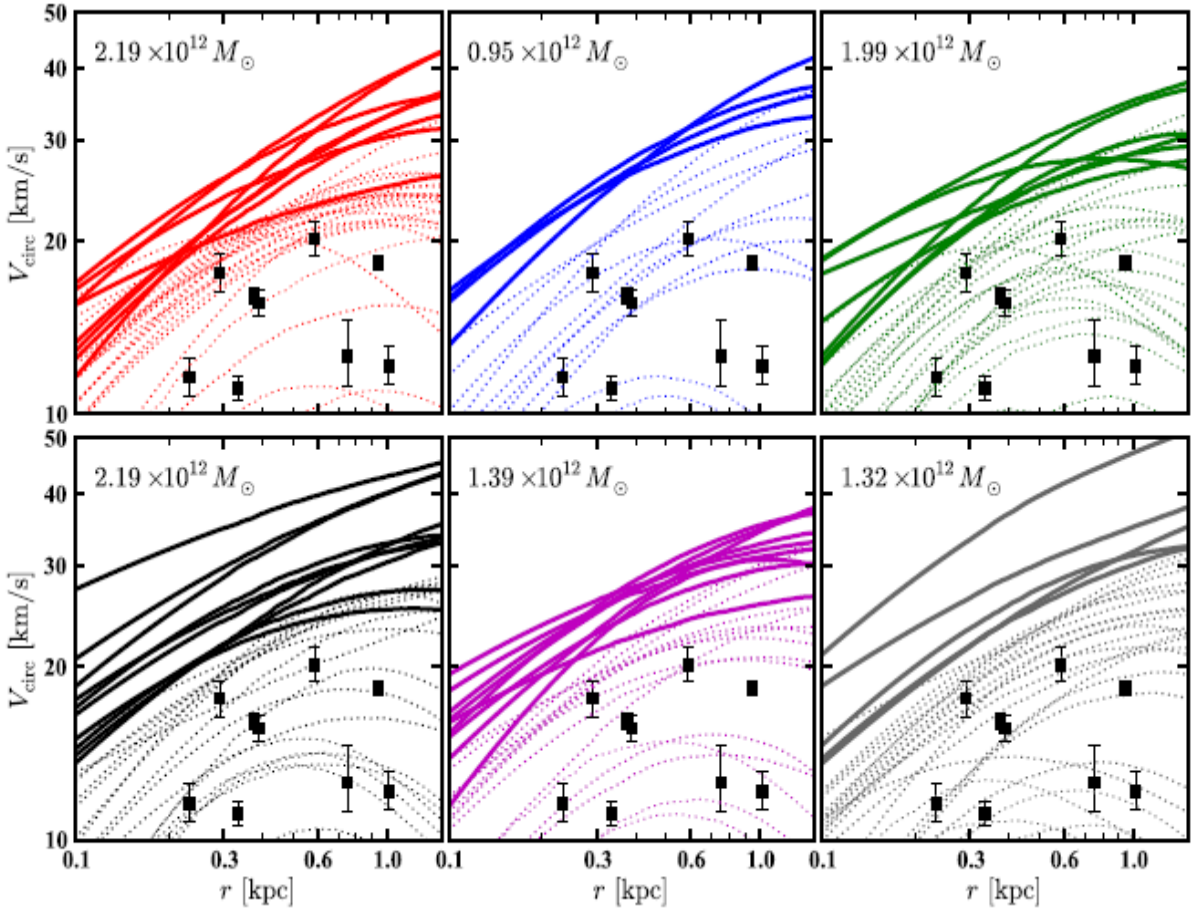






Interestingly, CDM seemingly doesn't do so well on small-scales

- Galactic halos are kinematically inconsistent with CDM: missing population of dense, massive satellites (Boylan-Kolchin+ 2012)



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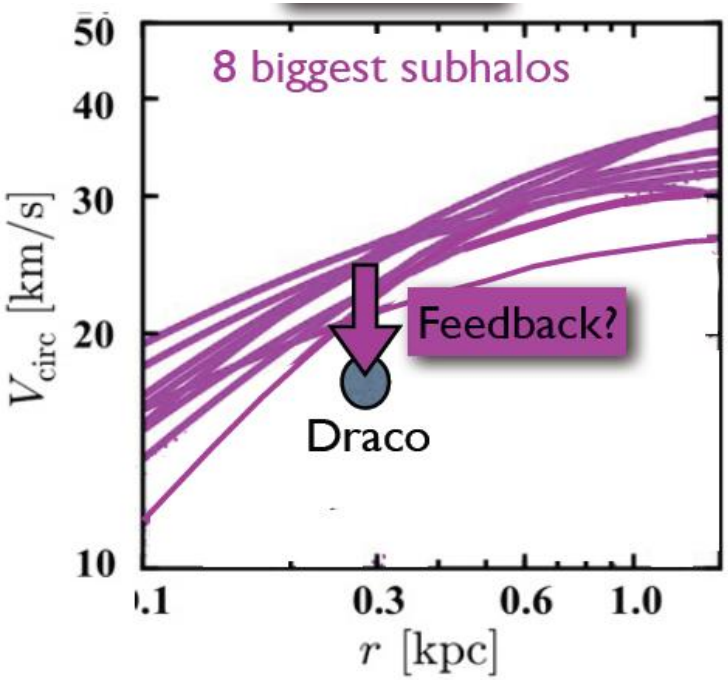
- Galactic halos are kinematically inconsistent with CDM: missing population of dense, massive satellites (Boylan-Kolchin+ 2012)
- Inner profiles of individual dwarf galaxies are too shallow (Moore+1994; de Blok+2001; Maccio+2012; Governato+2012)
- Number of satellite galaxies in Milky Way (Moore+1999; Klypin+1999) and in the field (ALFALFA survey; Papastergis+2011; Ferrero+2012) is too low

Is this due to baryonic effect?

- SNe, reionization and ram pressure stripping can reduce baryon content, smearing out some DM along with them
- But simulations have difficulties in reproducing all properties with single feedback mechanism (e.g. Boylan-Kolchin+2012; Garrison-Kimmel et al. 2013; Teyssier et al. 2013)

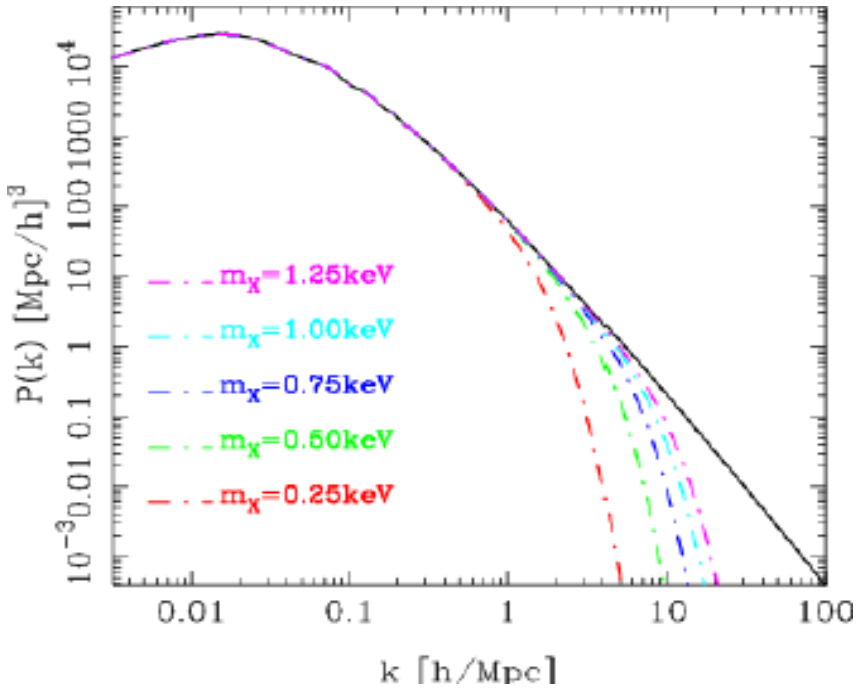


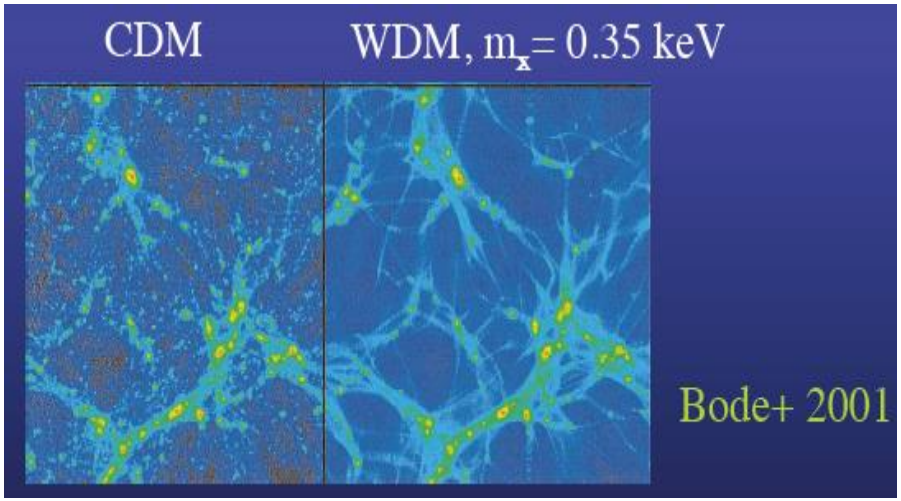
Galaxies with M~10^(7) M_sun need to have removed ~10^(7) M_sun of dark matter to make this work.

What about suppressing primordial power, e.g. warm dark matter

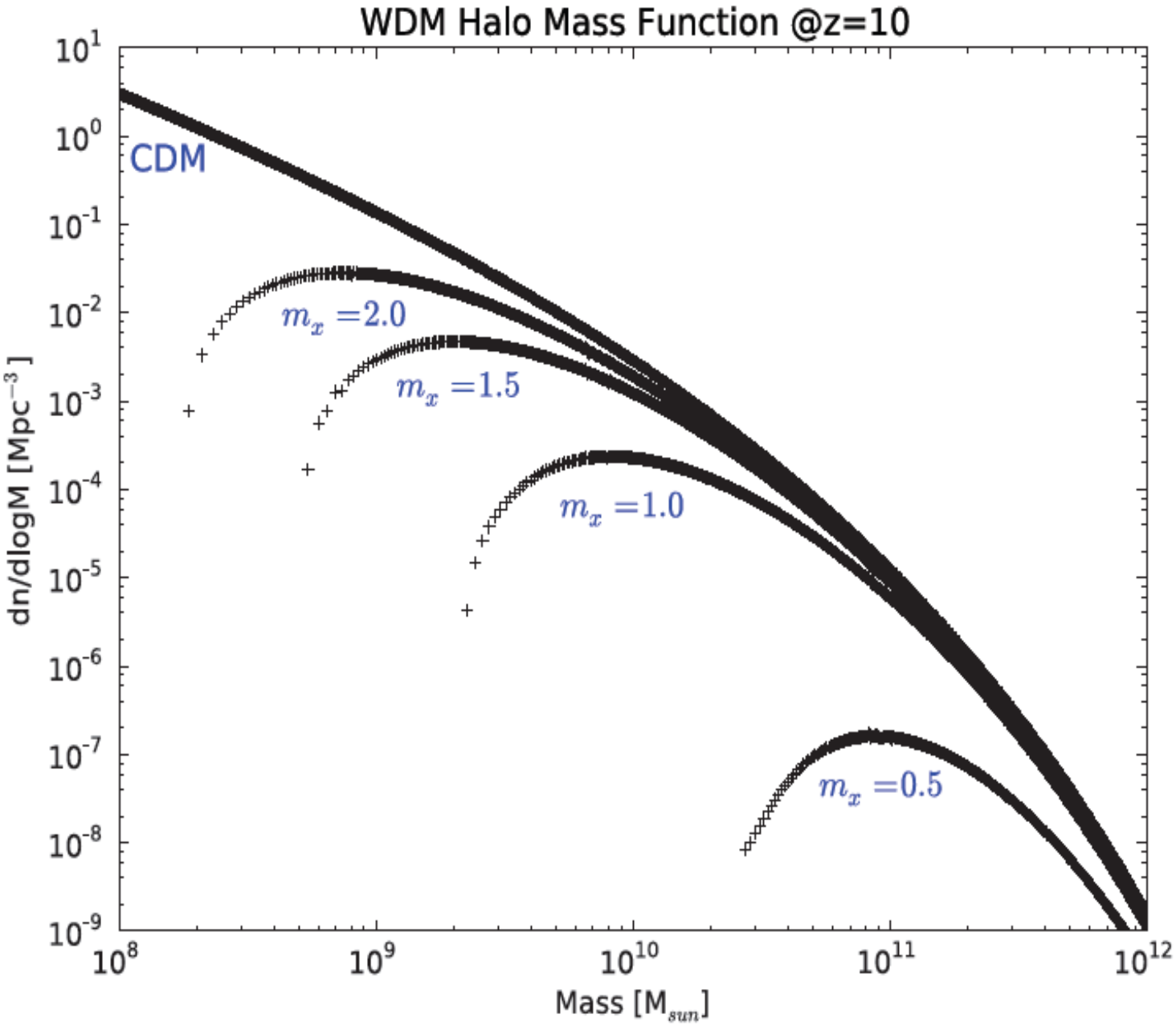
- Free-streaming effect: particles stream out of the primordial potential wells, and truncate powers on scales on distance up to radiation-matter equality

$$R_S \approx 0.31 \left(\frac{\Omega_X}{0.3}\right)^{0.15} \left(\frac{h}{0.65}\right)^{1.3} \left(\frac{\mathrm{keV}}{m_X}\right)^{1.15} h^{-1}\ \mathrm{Mpc}\,.$$





Pacucci, Mesinger, Haiman, 2013

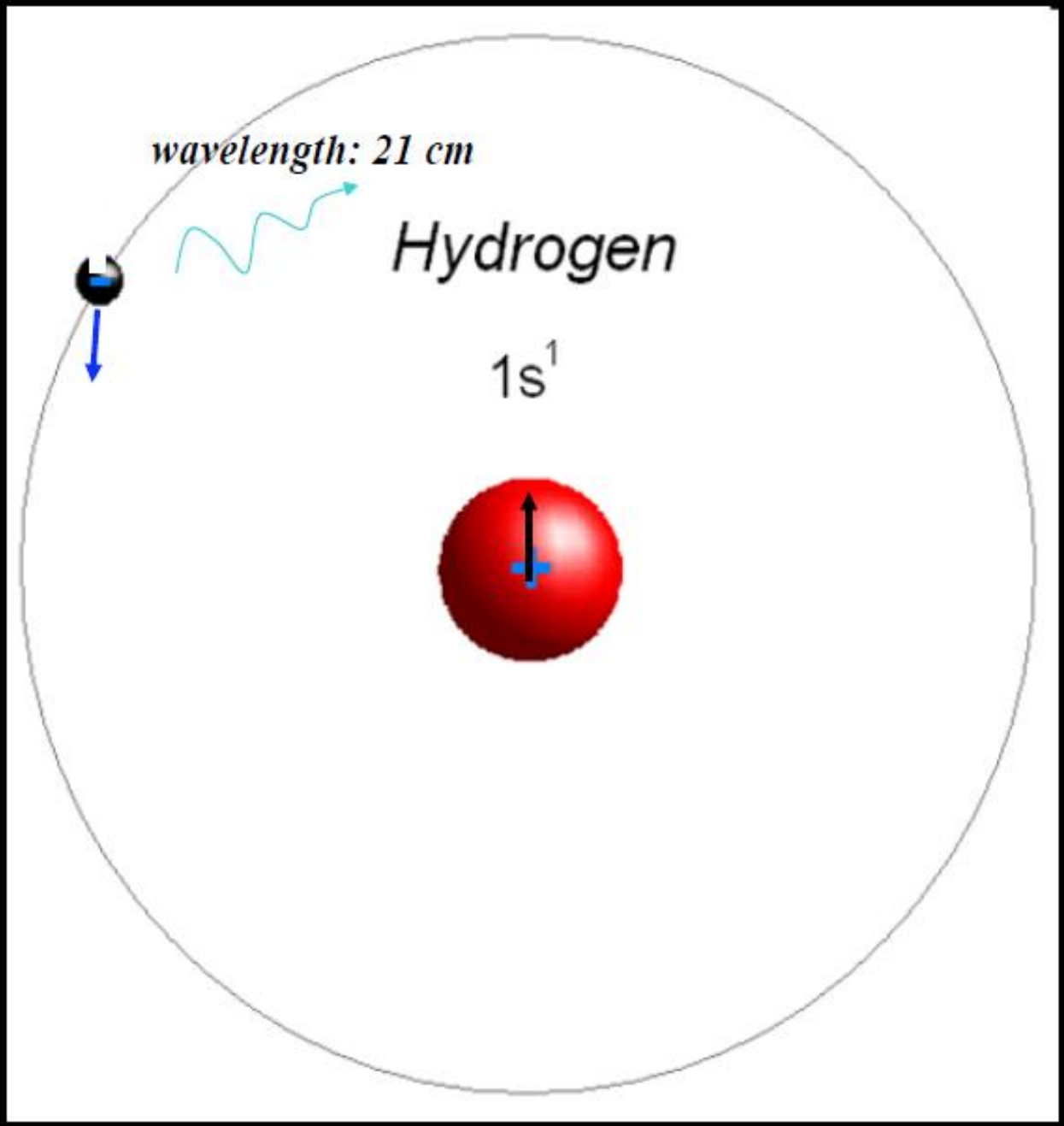


What is the current constraint on warm dark matter mass?

- Lyman alpha forest: (Viel+ 2006; 2008) $m_X > 1\text{-}3 \mathrm{keV}$
- Reionization occurring by z~6 (Barkana+2011) $m_X > 1 \mathrm{keV}$
- Reproducing stellar mass function and Tully-Fisher relation: (Kang+2013) $m_X > 0.75 \mathrm{keV}$

The most powerful probe of this epoch is the redshifted 21cm line!

Probes ionization AND thermal history of the Universe!

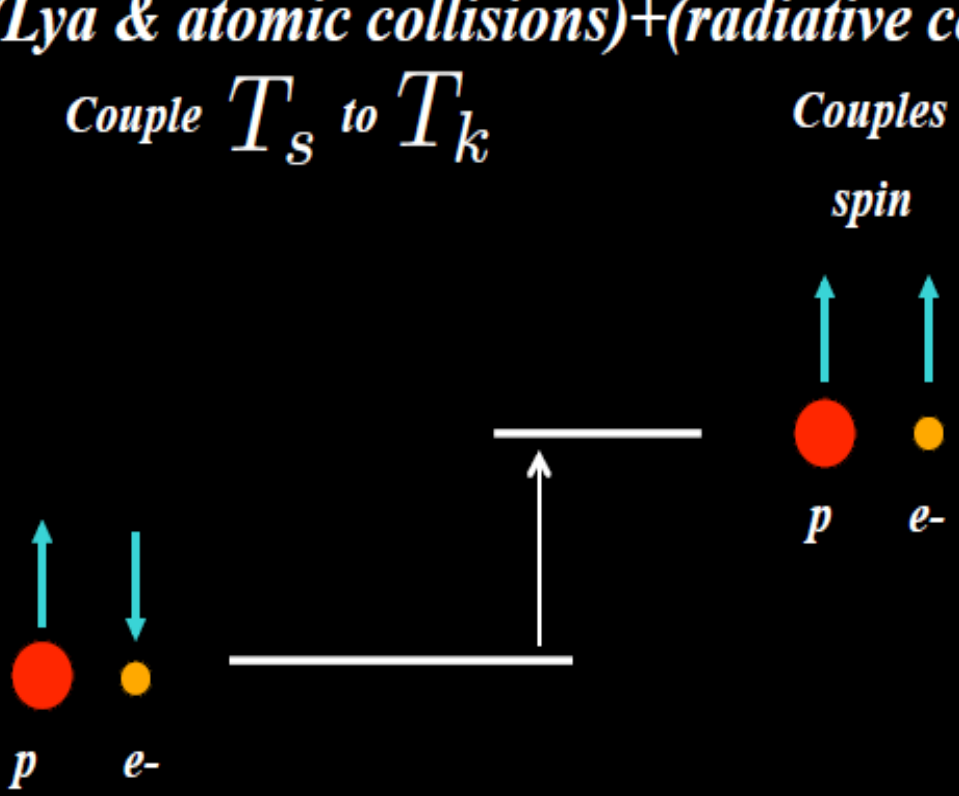

wavelength: 21 cm
Hydrogen
1s1

Hyper-fine transition in the ground state of neutral hydrogen produces 21cm lines

excitation rate= (Lya & atomic collisions)+(radiative coupling to CMB)

Couple T_s *to* T_k

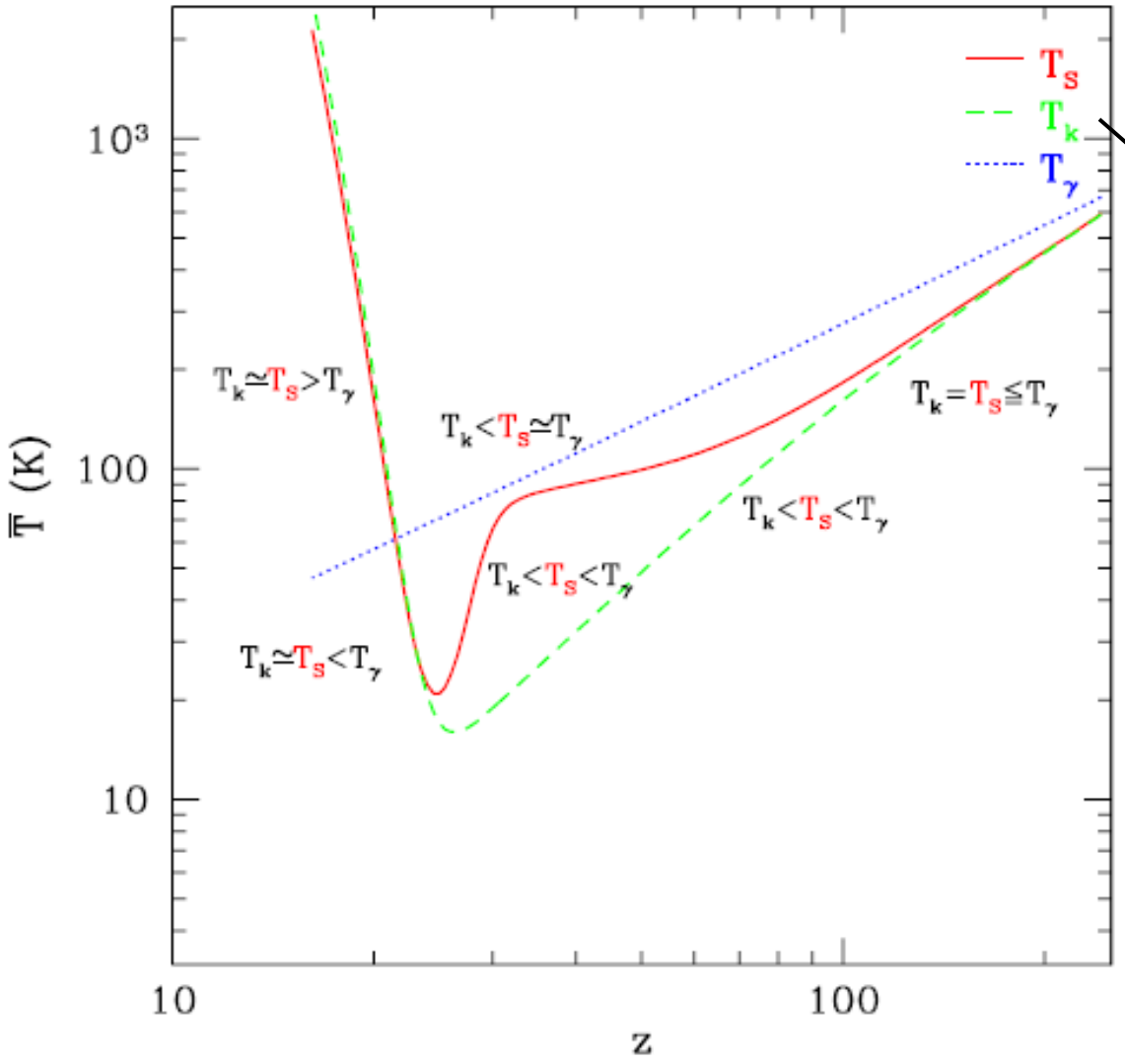
Couples T_s *to* T_γ



Spin Temperature

$$\frac{n_1}{n_0} = 3\exp\left(-\frac{0.07\mathrm{K}}{T_s}\right)$$

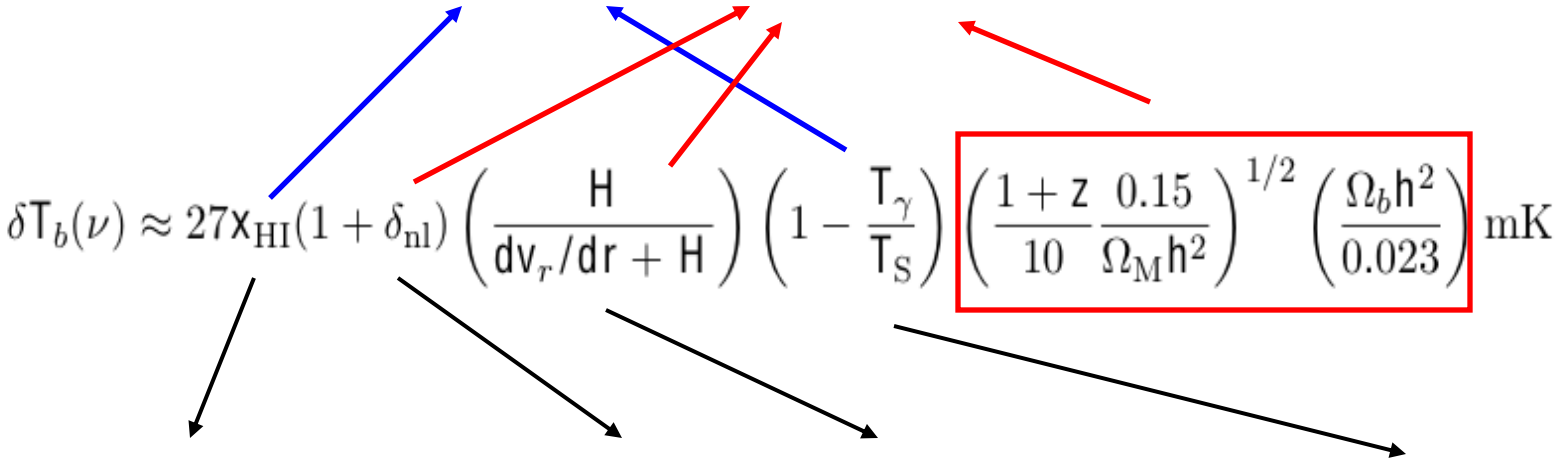
The spin temperature is an interpolation between CMB temperature and gas temperature



Gas: adiabatic cooling

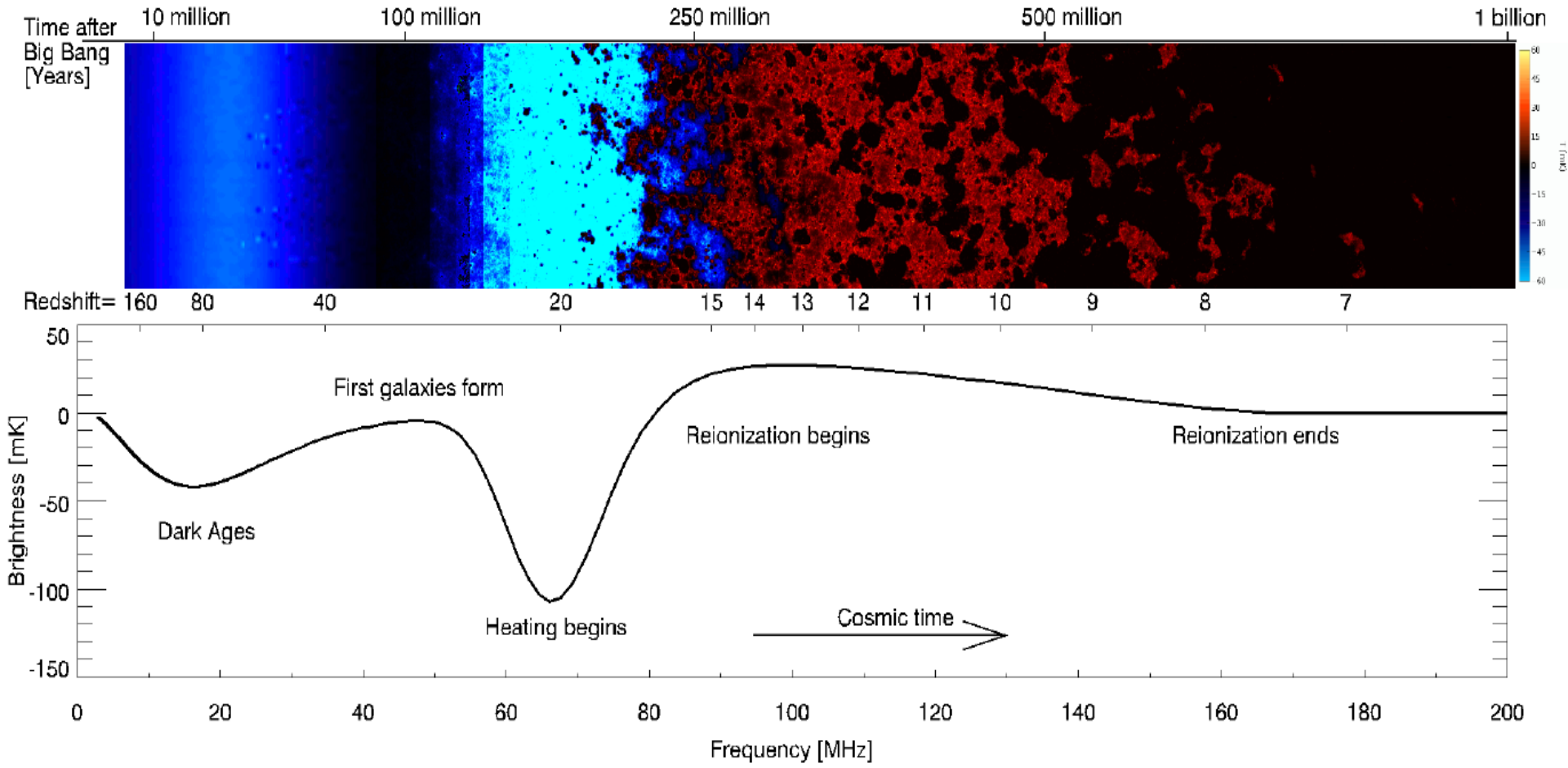
Cosmological 21cm signal

Astrophysics, Cosmology

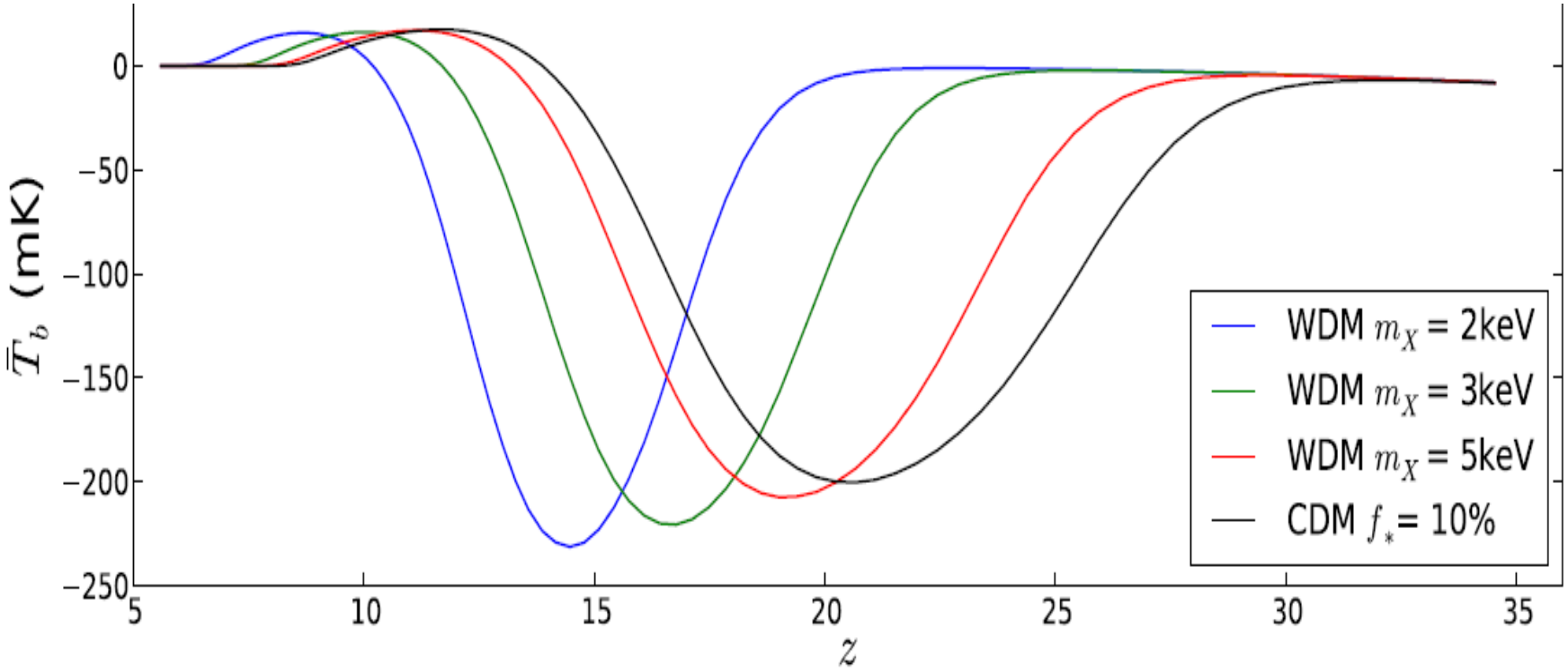


Fraction of neutral hydrogen, gas density, los velocity gradient, spin temperature

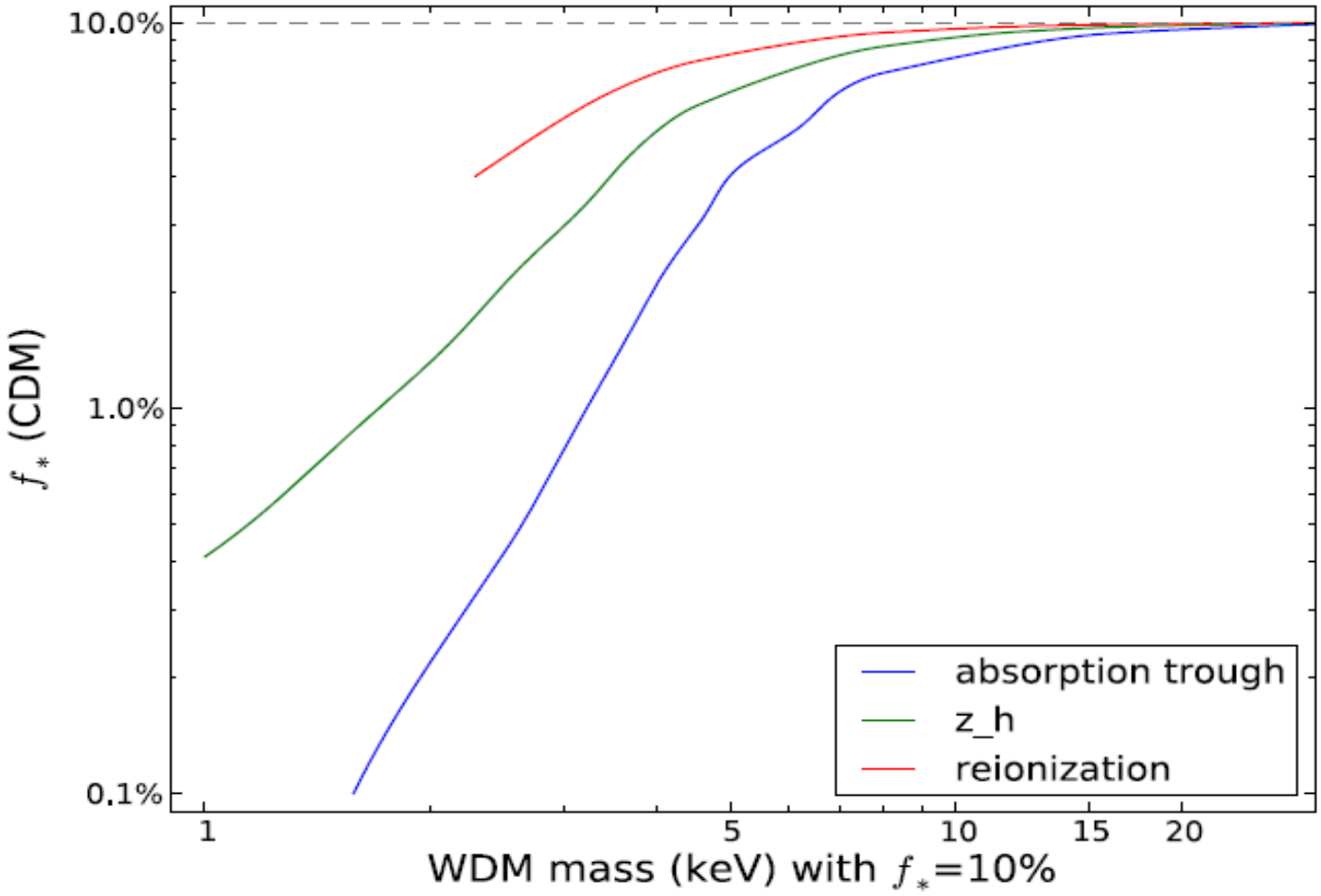
Very rich physics, the trick is to effectively modeling the whole process (21cmFast)


Time after Big Bang [Years]
10 million
100 million
250 million
500 million
1 billion
Redshift= 160 80 40 20 15 14 13 12 11 10 9 8 7
Brightness [mK]
50
0
-50
-100
-150
First galaxies form
Reionization begins
Reionization ends
Dark Ages
Heating begins
Cosmic time
0 20 40 60 80 100 120 140 160 180 200
Frequency [MHz]

How does WDM affect the signal?



Siwell, Ma, Mesinger, Sigurdson, 2013



For m_X > 5keV, star formation efficiency is degenerated with WDM

For low mass, the two are not degenerated.

This is observable by the high-redshift measurement such as square kilometer array (2020).

Conclusion

- Standard CDM model can fit most of the large scale observations quite well, but on small scales it cannot provide a good match of the halo abundance.
- WDM with keV mass is a good candidate for solving these problem.
- It delays the suppression of 1st structure in the Universe, and can be distinguished by the 21cm global signal.

What about suppressing primordial power, e.g. warm dark matter

- Residual particle velocity: like an effective pressure, preventing early structure formation under “Jeans mass”.

$$M_{\rm J} = 3.06 \times 10^8 \left(\frac{1+z_{\rm eq}}{3000}\right)^{1.5} \left(\frac{\Omega_{\rm M} h_0^2}{0.15}\right)^{1/2} \times \left(\frac{g_{\rm X}}{1.5}\right)^{-1} \left(\frac{m_{\rm X}}{1.0\ {\rm keV}}\right)^{-4} {\rm M}_\odot,$$