Visualization of cosmic perturbation

(Dated: September 26, 2016)

I. METHOD

We use the transfer function $\delta(k)$ obtained from CAMB to calculate the perturbation evolution in real space (to see the evolution of an initial δ function perturbation in real space). The first step is re-set the initial condition (use baryons as an expample)

$$\delta_{\rm b}(k,z) = \frac{\delta_{\rm b}(k,z)}{\delta_{\rm b}^{(\rm ini)}(k)} \tag{1}$$

where $\delta_{\rm b}^{(\rm ini)}(k)$ is the initial transfer function for baryons, we choose $z = 10^6$. Then do an interpolation to the new $\delta_{\rm b}(k,z)$ (interpolate k), this could help us kill the oscillation of the final result. Then delete a pure Dirac function in real space (corresponds a constant $\delta(k)$ in Fourier sapce)

$$\delta_{\rm b}(k,z) = \delta_{\rm b}(k,z) - \delta_{\rm b}(k_{\rm max},z) \tag{2}$$

this process is also used to kill the collision of the final result. Then do a Fourier transformation

$$\begin{aligned}\delta_{\rm b}(r,z) &= \int \frac{{\rm d}^3k}{(2\pi)^3} e^{i\mathbf{k}\cdot\mathbf{x}} \delta_{\rm b}(\mathbf{k},z) \\ &= \frac{1}{2\pi^2}\int_0^{+\infty} \frac{k}{r}\sin(kr)\delta_{\rm b}(k,z){\rm d}k\end{aligned} \tag{3}$$

Then take a Gauss blur process to $\delta_{\rm b}(r,z)$ to kill the rest oscillation of the final result.

For cold dark matter, photon, neutrinos, take the same process. Default setting of CAMB is

$$\Omega_{\rm b}h^2 = 0.0226 \quad \Omega_{\rm C}h^2 = 0.112 \quad \Omega_\nu h^2 = 0.00064 \quad \Omega_{\rm K} = 0 \quad H_0 = 70 \tag{4}$$

II. RESULT

main feature:

1. CDM(see FIG.1(a) and FIG.2(a)): compare with baryon, there is no propagation of the peak when $z > 1000$; but the $\delta_{\rm CDM}(r)$ is also increased at small r when $z > 1000$, this should be caused by gravitational instability(because inhomogeneous baryon etc has already reached here, etc). After $z = 100$(not 1000), the peak growth as baryon did.

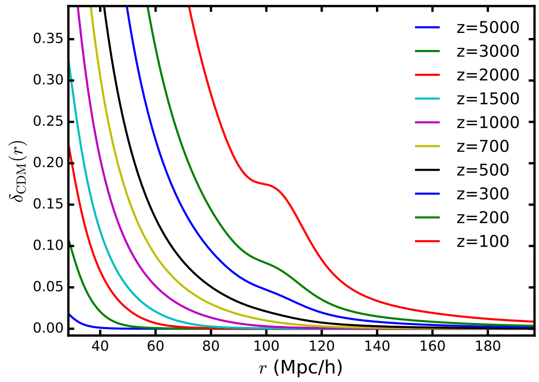
2. baryon(see FIG.1(b) and FIG.2(b)): the peak/perturbation propagate to outside when $z > 1000$, and then growth after $z = 1000$ at $r \approx 103$Mpc/h.

3. photon(see FIG.1(c) and FIG.2(c)) and massless neutrino(see FIG.1(d) and FIG.2(d)): the peak propagate when $z > 1000$ (corresponds to baryon), and there is no peak growth when $z < 1000$. The profile of neutrino is more slope than photon. And the propagation speed of neutrino is faster than photon, the reason should be, when the perturbation propagate to outside, photon acting with baryon, but neutrino don't.

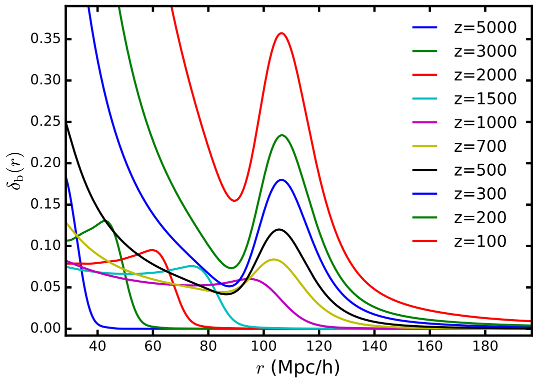
4. massive neutrino(see FIG.1(e) and FIG.2(e)): when $z > 1000$(or $\sim$200, see the animate in section III for details), massive neutrino acting as massless neutrino(the "peak" propagate to outside). when $z < 100$, the difference between this two kind of neutrinos appeared: massless neutrino acting as photon, massive neutrino acting as baryon(the perturbation of massive neutrino growth, and we can see a small peak around $r = 100$ if Ω_ν big enough).

If we increase the value of Ω_ν (set $\Omega_\nu = 0.022$, corresponds to $\sum m_\nu = 1.00$eV, for FIG.4), the growth of massive neutrinos at late time become faster, and there is a quasi-peak arise near $r = 100$, see FIG.4. This means the massive neutrinos acting as baryons in the late time.

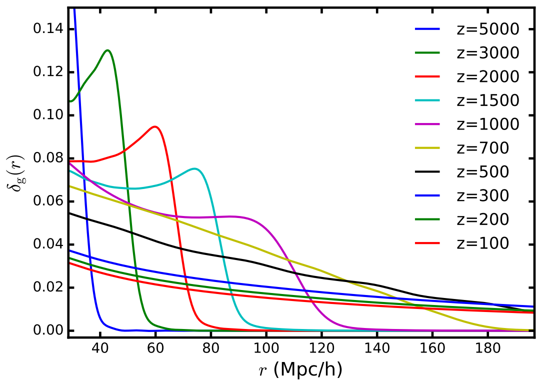
FIG.3 plot $\delta(r)$ in one figure for all component at some redshift section. The animate in section III is also useful to show the evolution of the initial δ function perturbation in real space.



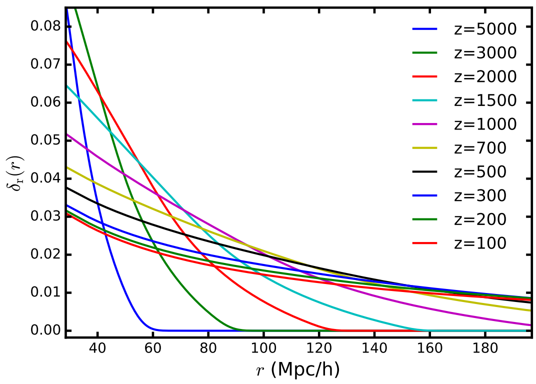
(a)cold dark matter



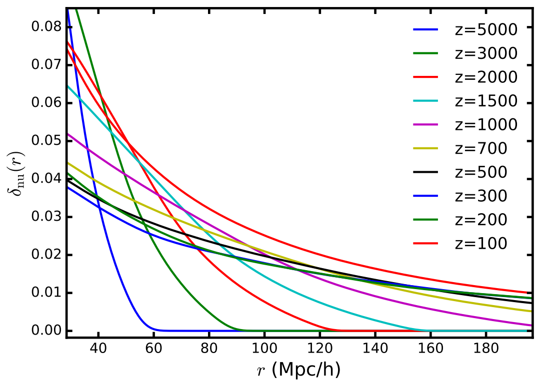
(b)baryons



(c)photons

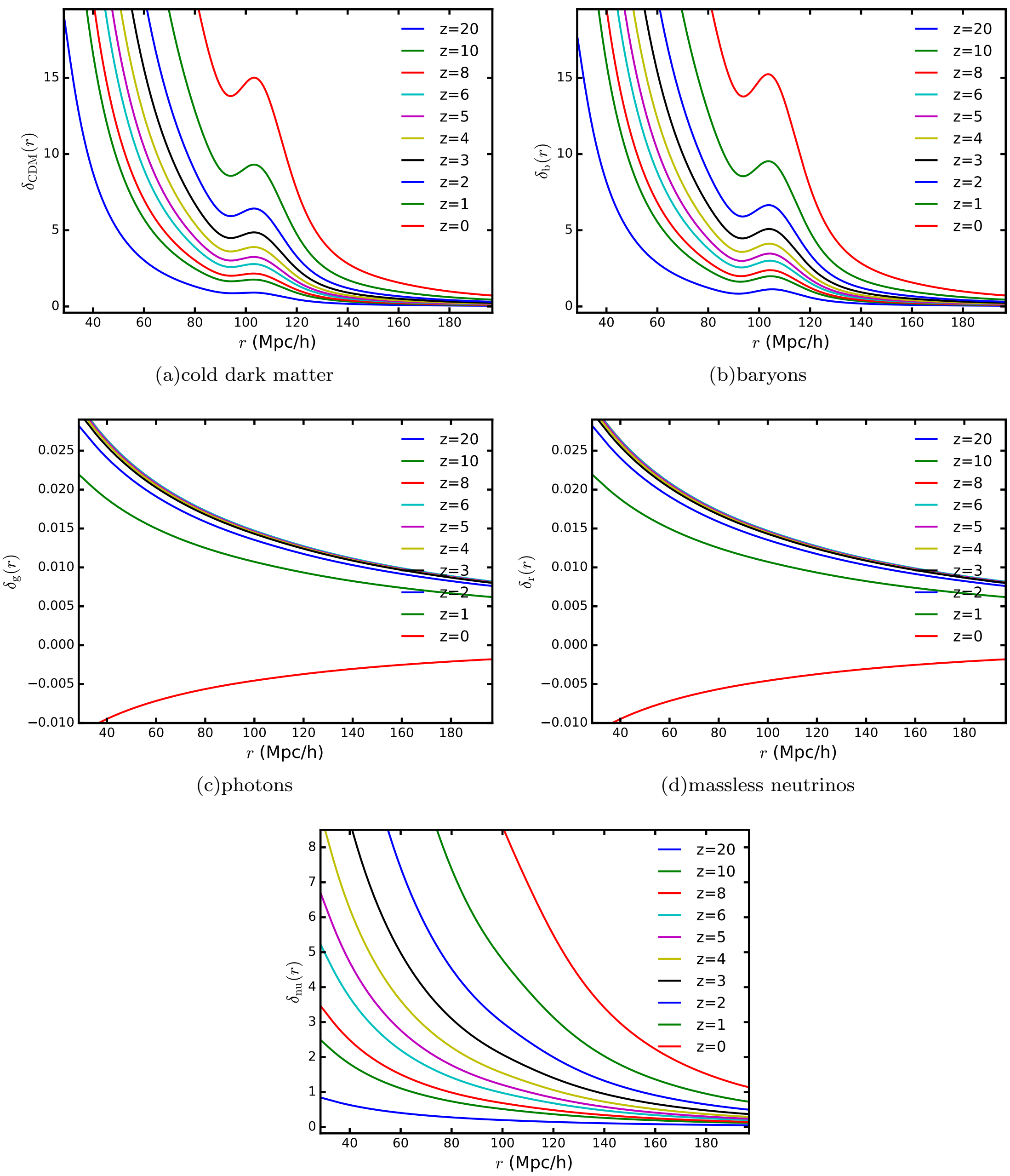


(d)massless neutrinos



(e)massive neutrinos

FIG. 1: Perturbation in real space at early period for each component. Notice the difference between massless and massive neutrinos at $z = 100$. CDM is cold dark matter, b is baryons, g is photons, r is massless neutrinos, nu is massive neutrinos.



(a)cold dark matter

(b)baryons

(c)photons

(d)massless neutrinos

(e)massive neutrinos

FIG. 2: Perturbation in real space at late time for each component. For photons and massless neutrinos at $z = 0$, $\delta(r)$ exhibit bad, this maybe caused by the computational error of CAMB (see $\delta(k)$ in Fourier space could found some clue).

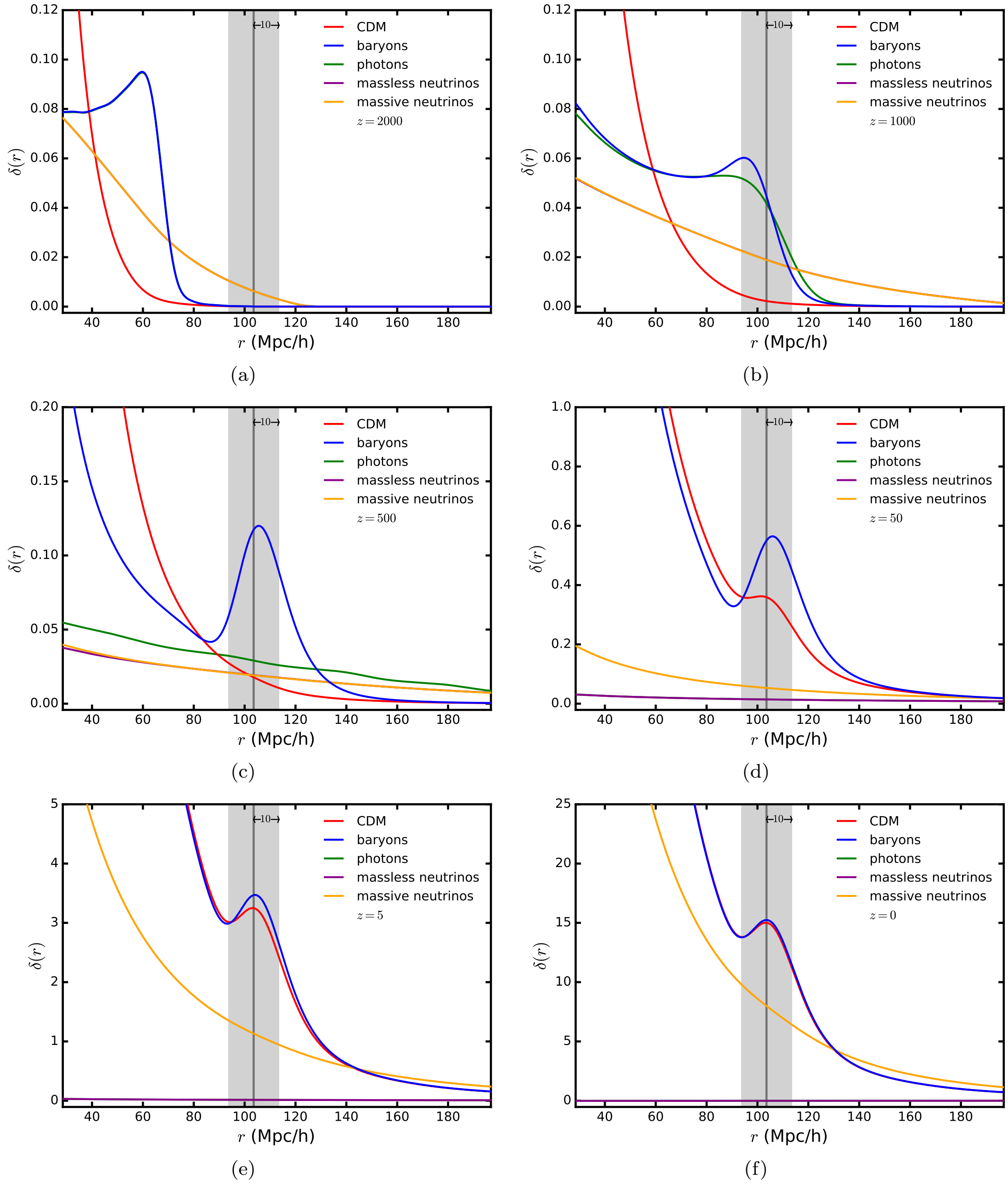


FIG. 3: Perturbation at some redshift section for all component. At early time, baryon is overlap with photon, and massless neutrino is overlap with massive neutrino. At late time, baryon is overlap with cold dark matter, and massless neutrino is overlap with photon.

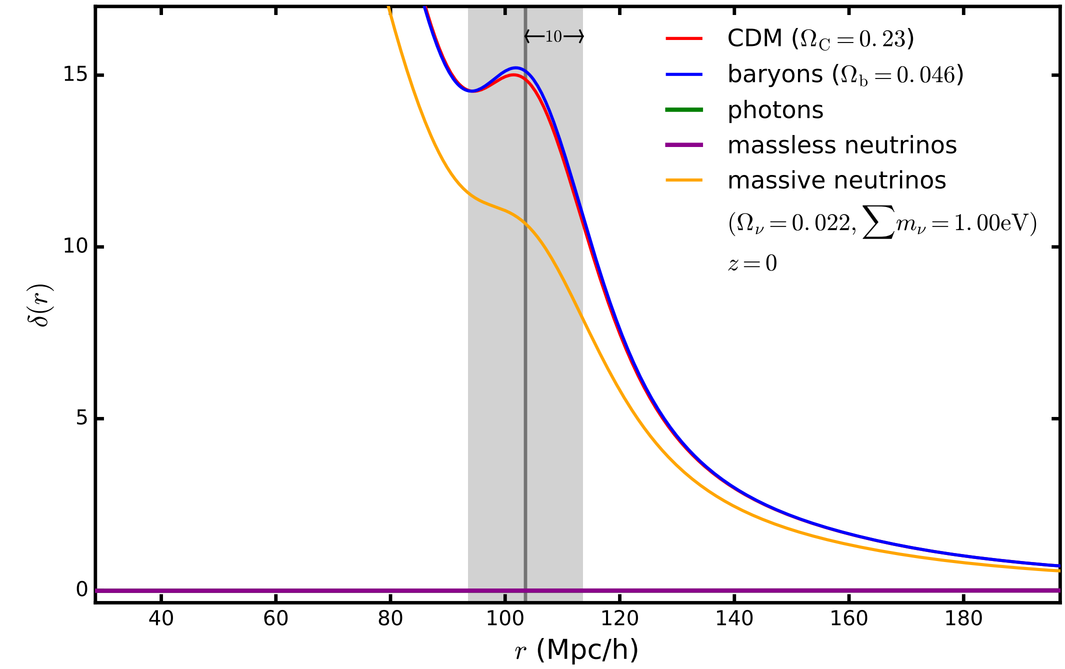
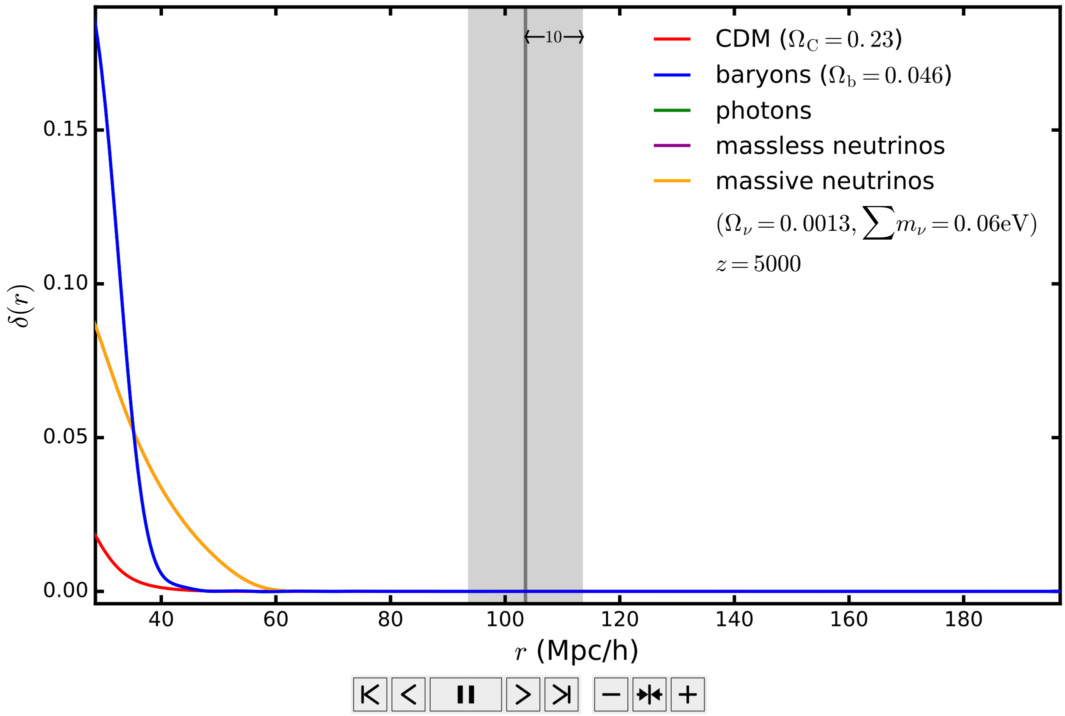


FIG. 4: $\delta(r)$ for much more massive neutrinos.

III. ANIMATE



Form the above animate, we can also see a backward motion of baryons after $z \sim 100$(but not too much), this should be caused by the gravitational attraction of the central cold dark matter. And maybe the same mechanism to slow down baryons (photon carry baryon go outside with high velocity initially).