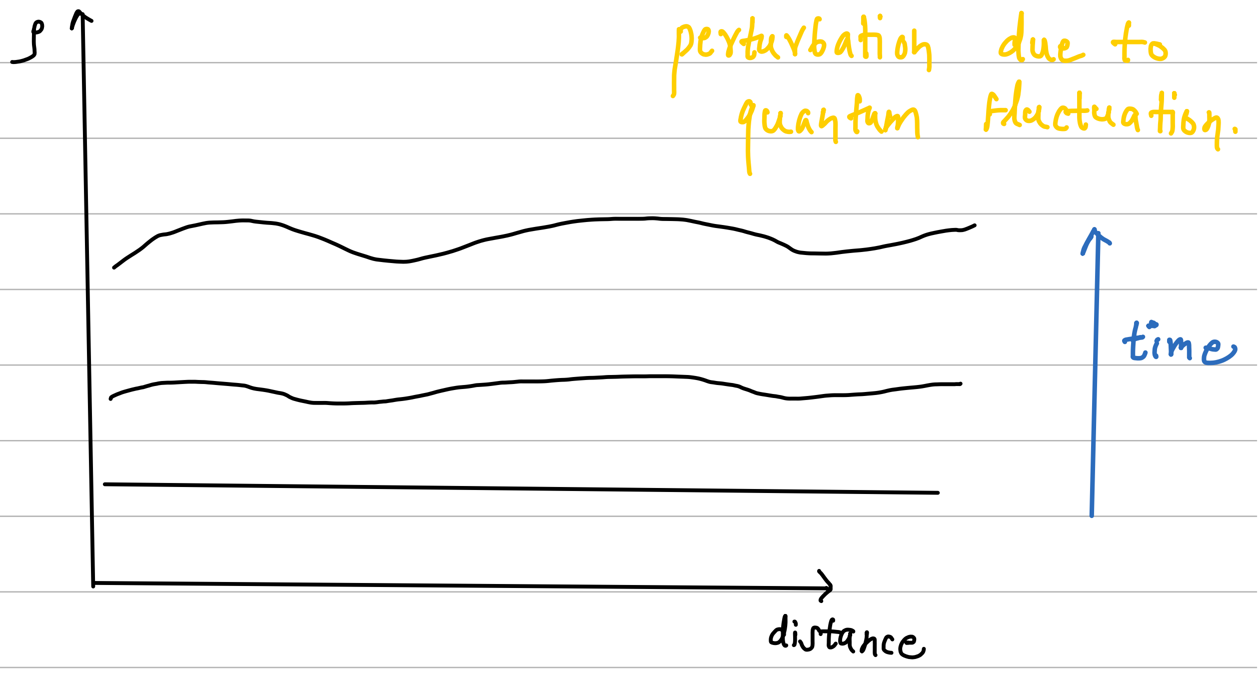
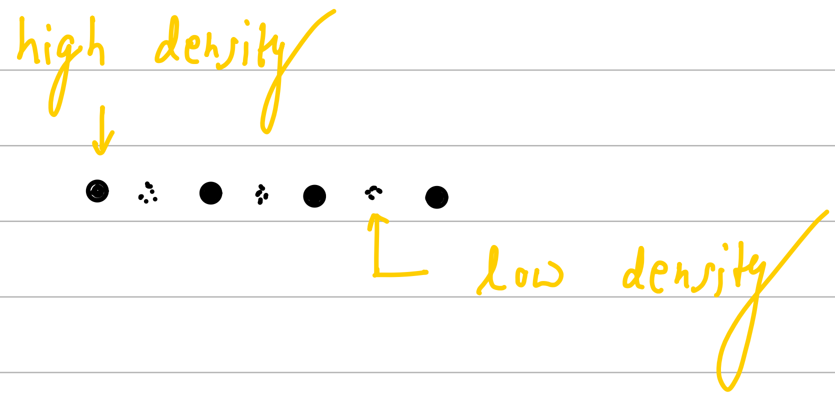
→ Baryon Acoustic Oscillations (BAO)

- Fluctuation in the density of the visible baryonic matter of the universe.

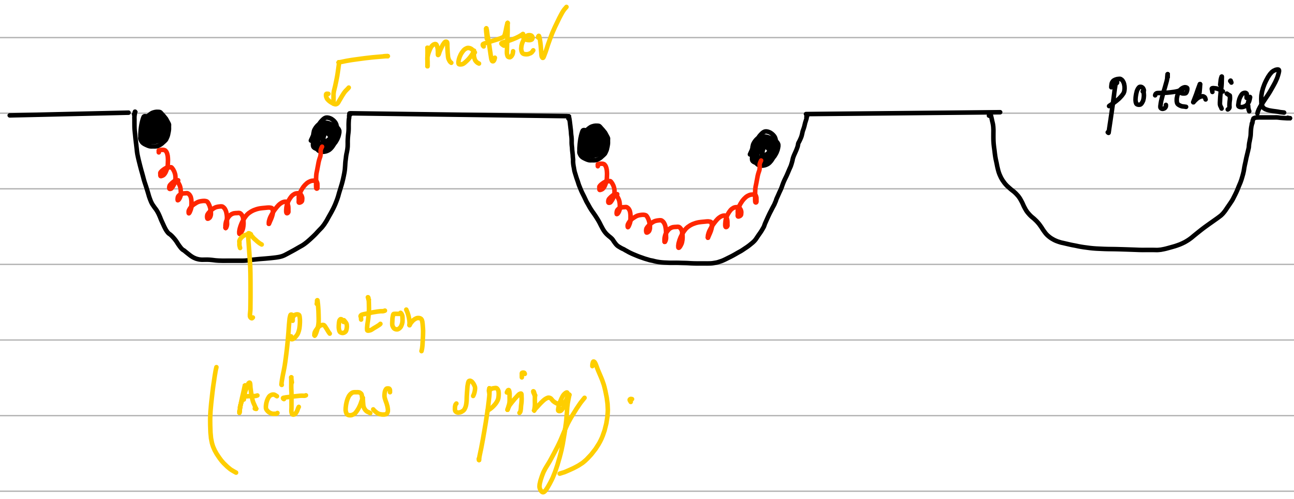
i) Baryon - photon plasma Opaque.

ii)





iii) This can be viewed as



- Matter try to accumulate due to high density but photon coupling to Baryonic matter makes oscillation

iv) As universe expands, due to recombination photon decouples & escapes. NO further oscillations.

This ripple froze at $z = 1100$ (CMB).

This imprint of oscillation can be seen in galaxy clusters today.

Summary : "Information in matter & radiation".

[photon + Baryonic fluid] [z = 1100]

CMB [photon]

BAO (matter).

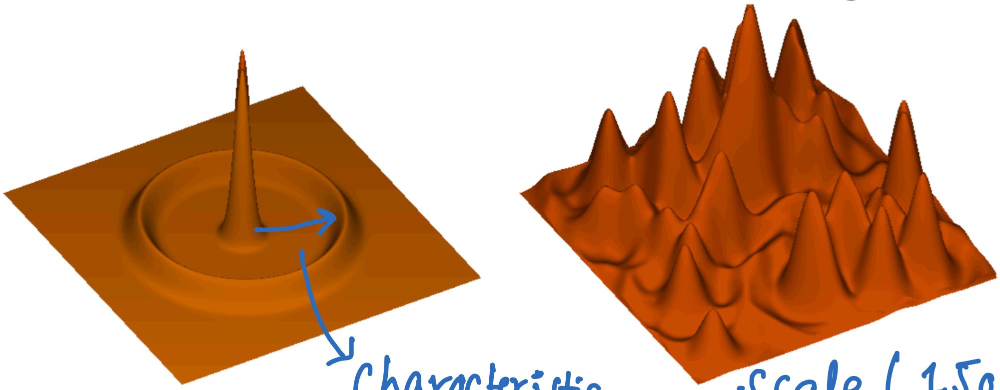
Background Noise of radiation in microwave range.

Galaxy clusters. (0 < z < 3).

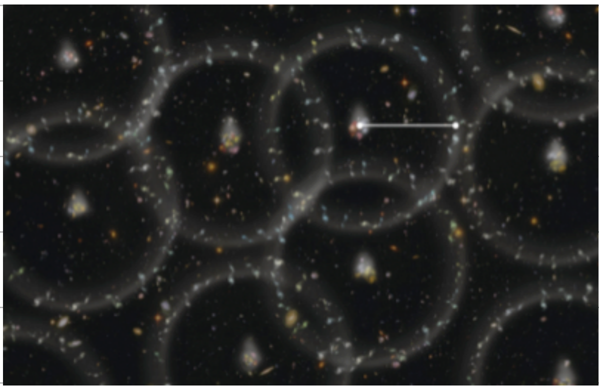
• perturbation on Cosmic Fluid.

Fluctuation at every point.

⇓

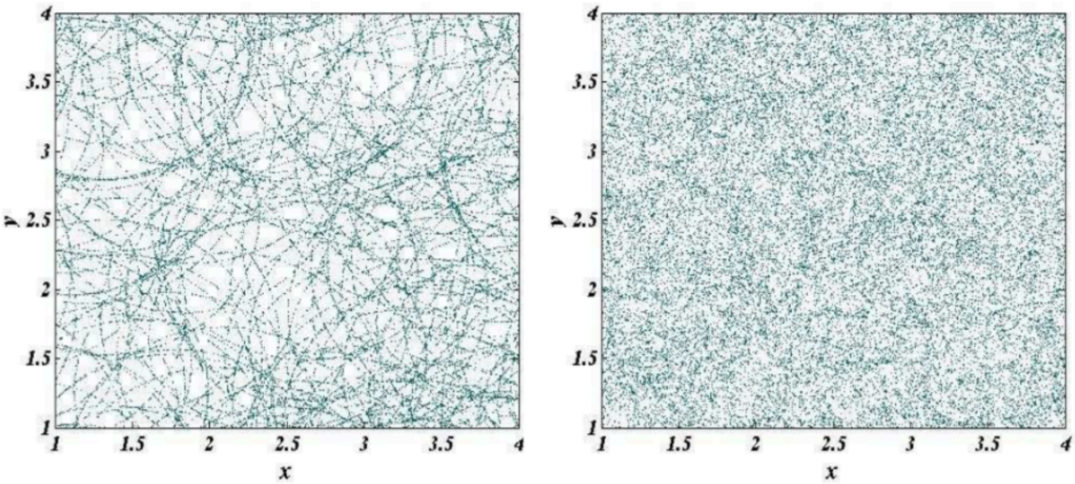


Characteristic scale (150Mpc)



(Artistic) oscillation imprinted on the galaxy clusters.

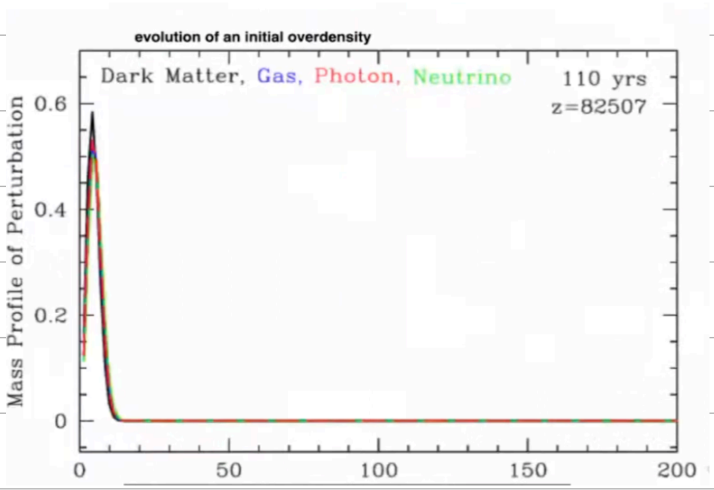
↓

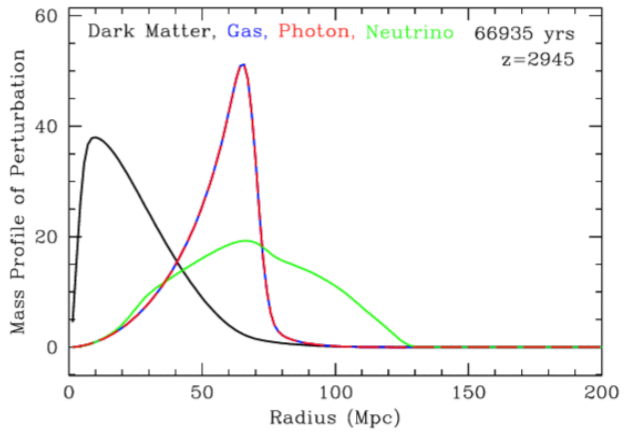


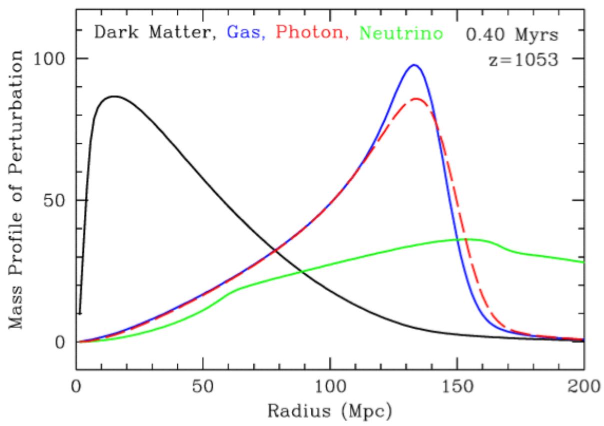
Statistically infer from 2 point correlation function.

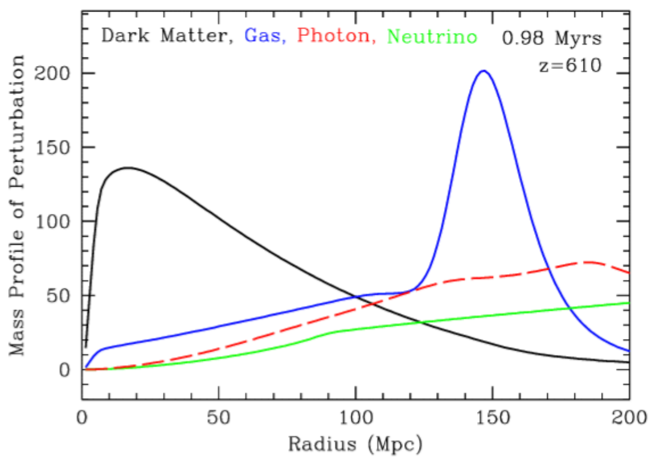
x

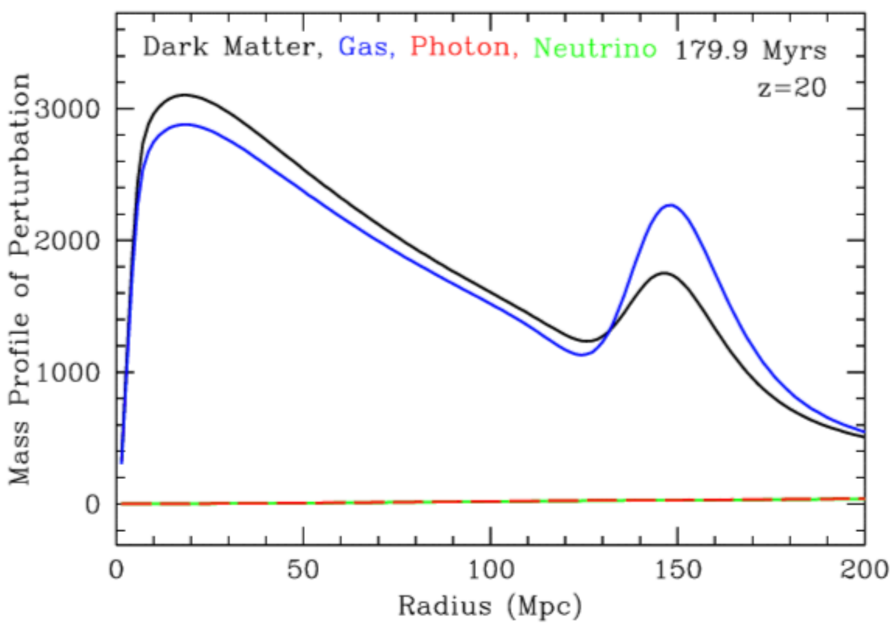
- Ripples in the different constituents.











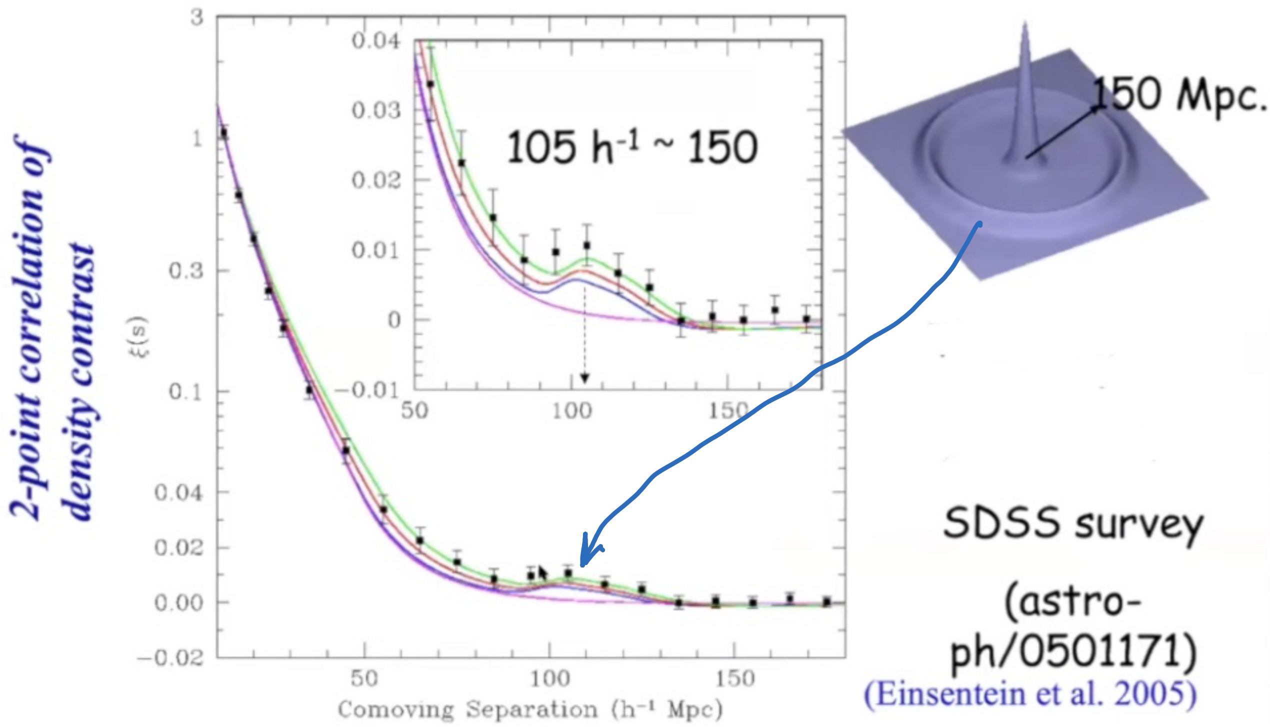
⇒ At very early universe density Fluctuation happend. Assume uniform universe and put density fluctuation on photon, DE, Gas, Neutrinos (same amplitude on each)

⇒ At $z = 2945$, neutrino is decoupled, but baryonic matter is coupled to photons.

⇒ At $z = 1100$, photon decouples from baryon photon fluid.

⇒ At $z = 610$, photons & neutrinos are already decoupled. Slowly, baryons fall back to Dark matter potential well in expanding universe.

Baryon Acoustic oscillations in the matter correlation function !!



→ Detection of ripple in present universe at $105\, h^{-1} \sim 150$.

$$h^{-1} = \left(\frac{H}{100}\right)^{-1}$$

Questions.

1. Figure shows at $z = 10/20$, radius 150.

⇒ If you replay animation, after photon-baryon decouples, baryons is no longer pushed by photons, so the acoustic wave stops propagating.

2. What does sound horizon tell us?

→ It gives you a idea of scale at which imprint of oscillation can be seen in galaxy clusters today due to early universe fluctuation.

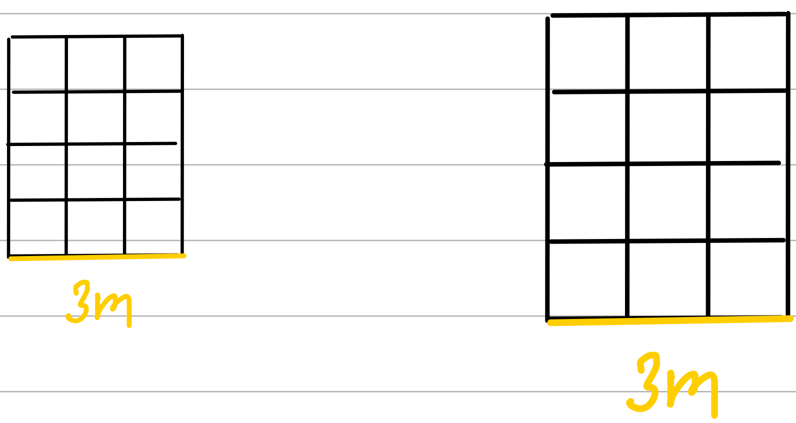
3. Where will bump appear at different z ?

⇒ It appears at 150 Mpc after decoupling.

This is comoving seperation.

· comoving ⇒ you faltor out scaling.

$\Downarrow$



→ Actual size has changed, for this . i.e what you actually measure.

$$r_{physical} = a \cdot r_{comoving}$$

So, if observe bump at $z = 1$

$$a = \frac{1}{1+z}.$$

$$a = \frac{1}{2}.$$

$\Rightarrow$ you will measure physical size of BAO oscillation at 75 Mpc.