

Neutrino Long-Range Self-Interaction and its Impact on Cosmic Structure Formation

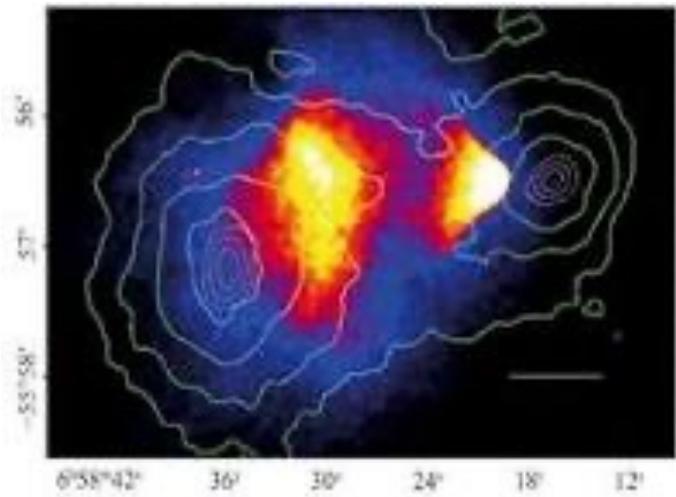
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in collab. with David Kaplan and Surjeet Rajendran



Motivation

- Why light particle
 - Dark Matter
 - Hubble Tension (EDE), DE
- Why Neutrino
 - “Neutrino Portal”
 - Cosmic Neutrino Background (C ν B)
- How to Probe Light Particles?
 - Measure the fifth force (torsion balance)
 - Measure mass variation (measure atomic level)
 - Can we do the same for neutrinos?

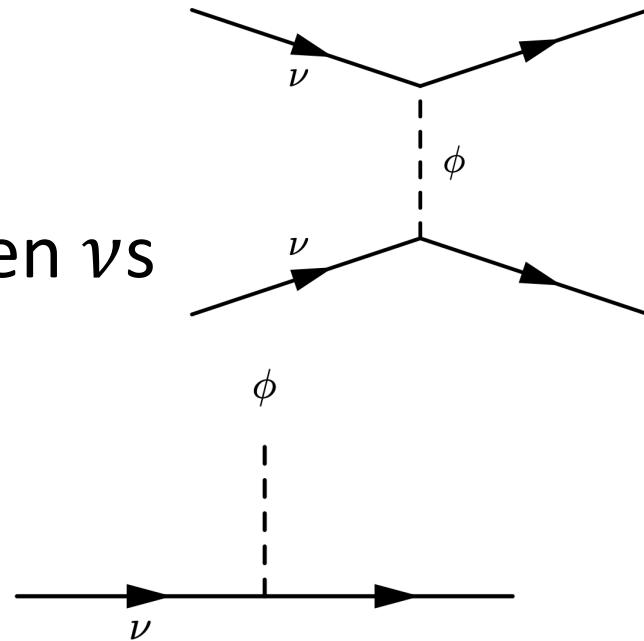


Neutrino Coupled with Light Scalar

- Lab Experiment
 - Fifth Force 
 - Hard to trace the neutrinos
 - Can not put neutrinos in a box
- Mass Variation 
 - MSW effect (require scalar is dm or sourced independently)
- Structure Formation
 - Fifth Force 
 - Structure formation relies on only gravitational interaction
- Mass Variation 
 - The mass of neutrino play an important role in structure formation

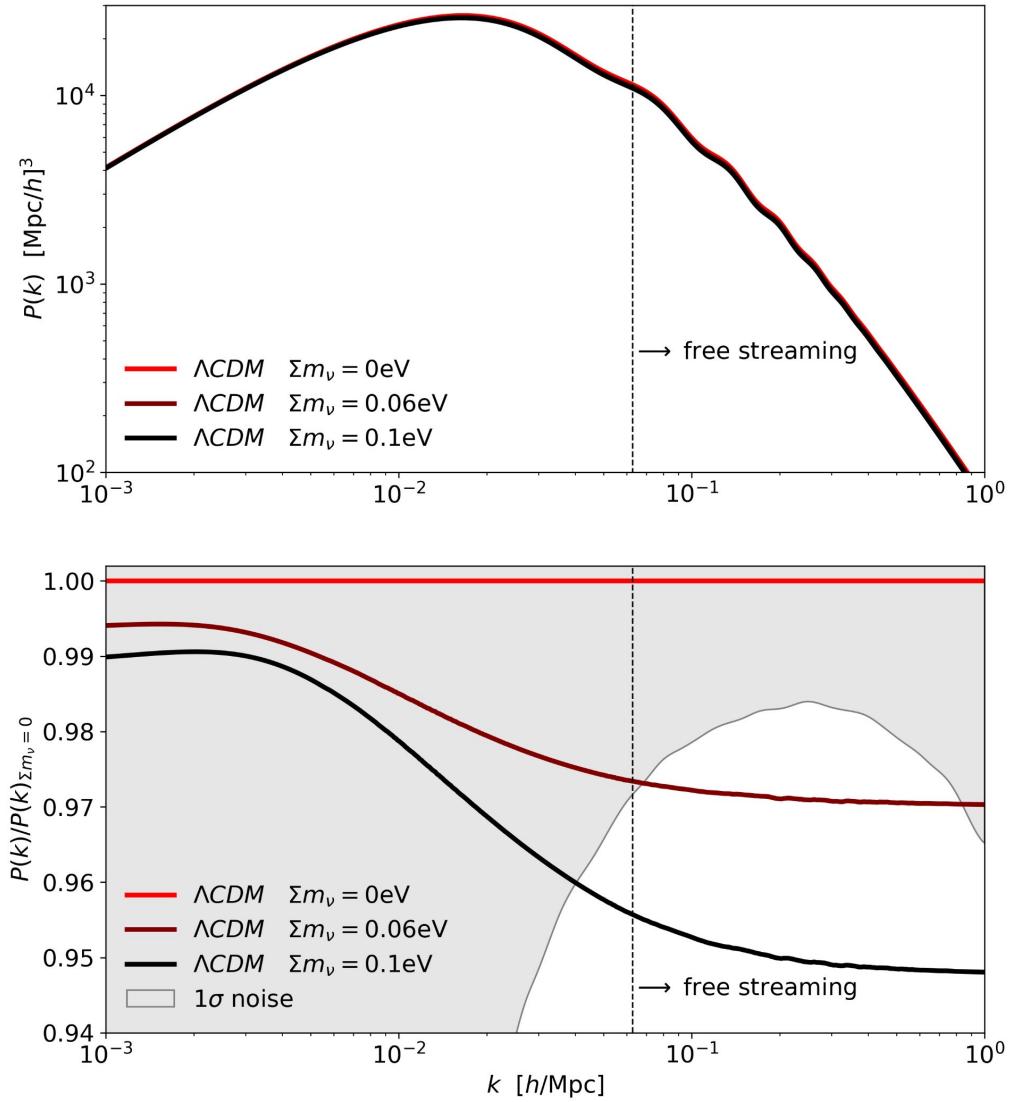
Neutrino Coupled with Light Scalar

- $\mathcal{L} \supset (m_\nu + g\phi)\bar{\nu}\nu$
- ϕ mediate Yukawa force between ν s
 - $r \sim m_\phi^{-1}$
- ϕ vev changes neutrino mass
- How much to mess up the large scale structure?
 - Stronger than gravity, $g \gg \frac{m_\nu}{M_{pl}} \sim 10^{-29}$ ($\eta \equiv \frac{g M_{pl}}{\sqrt{4\pi} m_\nu} \gg 1$)
 - Observed LSS scale Mpc, $m_\phi \sim 10^{-30}$ eV
 - CMB is $\sim 1\%$ matter, expect $\sim O(1)\%$ deviation on matter power spectrum



Massive neutrino in Λ CDM cosmology

- Neutrino become non-relativistic at $z_{nr} \sim 200$.
- Neutrino evolve together with CDM
- Neutrino has pressure to fight gravity
- Up to free-streaming scale, structure formation is suppressed

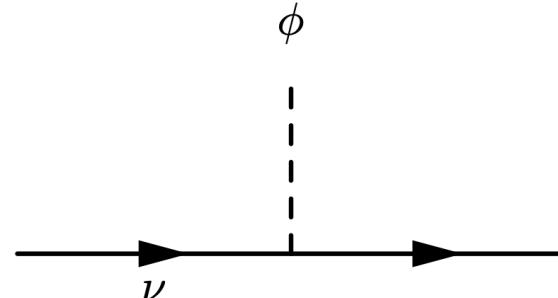


Background: mass variation

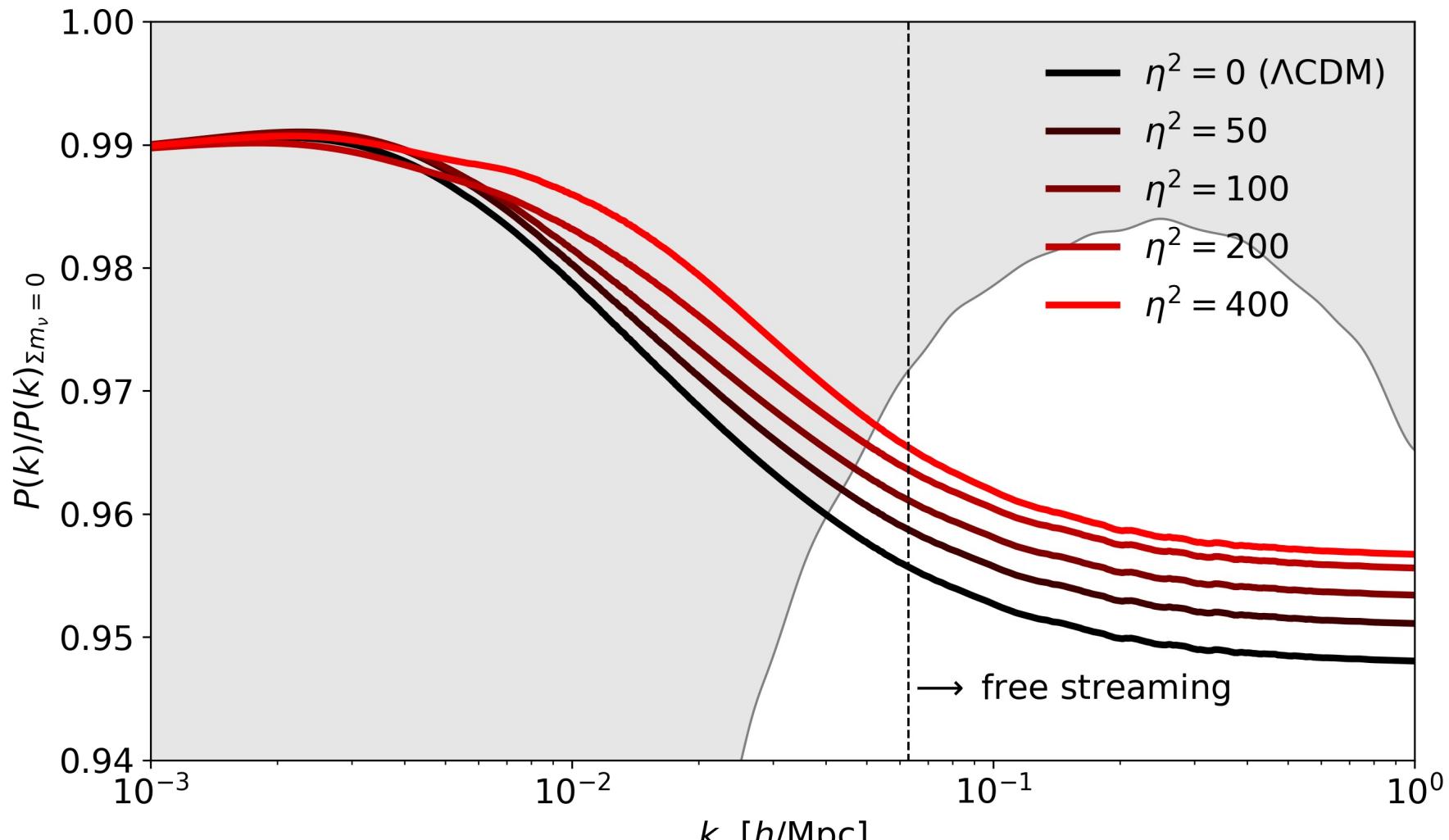
$$\mathcal{L} \supset (m_\nu + g\phi)\bar{\nu}\nu$$

- CvB sources ϕ vev
 - $\phi \sim -\frac{gn_\nu}{m_\phi^2} \sim (1+z)^3$
 - negative means ϕ decrease neutrino mass
- At z_{nr} , $m_\nu + g\phi(z_{nr}) = 0$, neutrino become massless
 - Massless neutrino is an attractor solution
- **Neutrino stay relativistic until smaller redshifts**

$$\bullet z_{nr} \sim 200 \left(\frac{gm_\nu}{m_\phi} \right)^{-\frac{2}{3}}$$

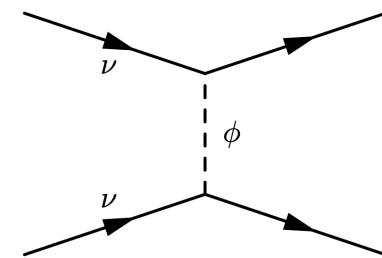


Background: mass variation

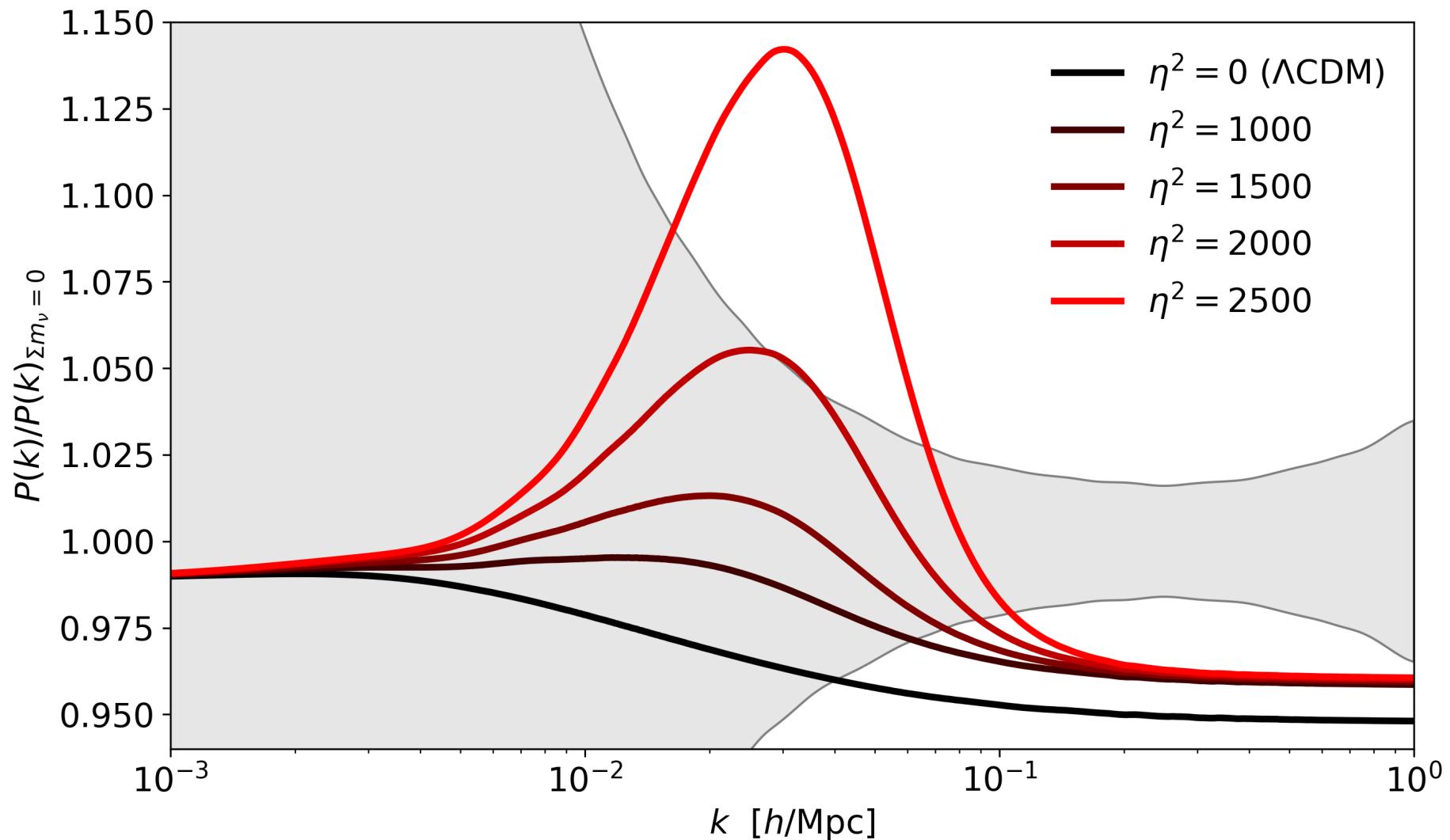


Perturbation: enhanced δ_ν growth

- Yukawa force enhances the growth of neutrino matter perturbation δ_ν at $k/a \sim m_\phi$
 - Growth factor $D \sim \left(\frac{gm_\nu}{m_\phi}\right)^{\eta\sqrt{\frac{2}{3}\Omega_\nu}} \gg 1$
 - Structure growth is suppressed when relativistic
- Nontrivial gravitational influence on cdm
 - even though $\rho_\nu/\rho_m \sim 1\%$, $\delta_m \ll \delta_\nu$, $\rho_\nu \delta_\nu \sim \rho_m \delta_m$
- **Can induce ~10% increase in mps**
- If the coupling is strong enough, neutrino form non-linear structure



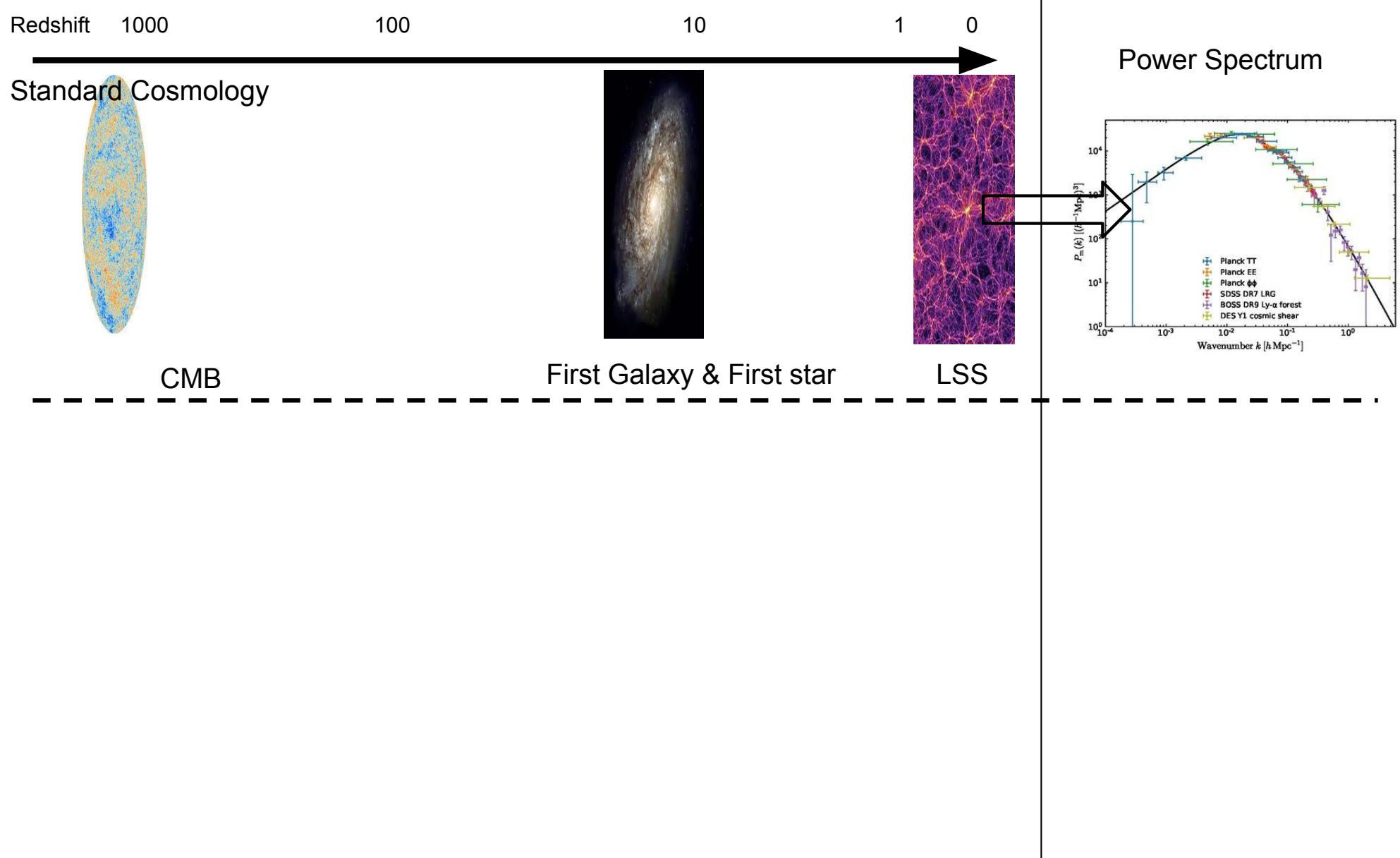
Perturbation: enhanced δ_ν growth

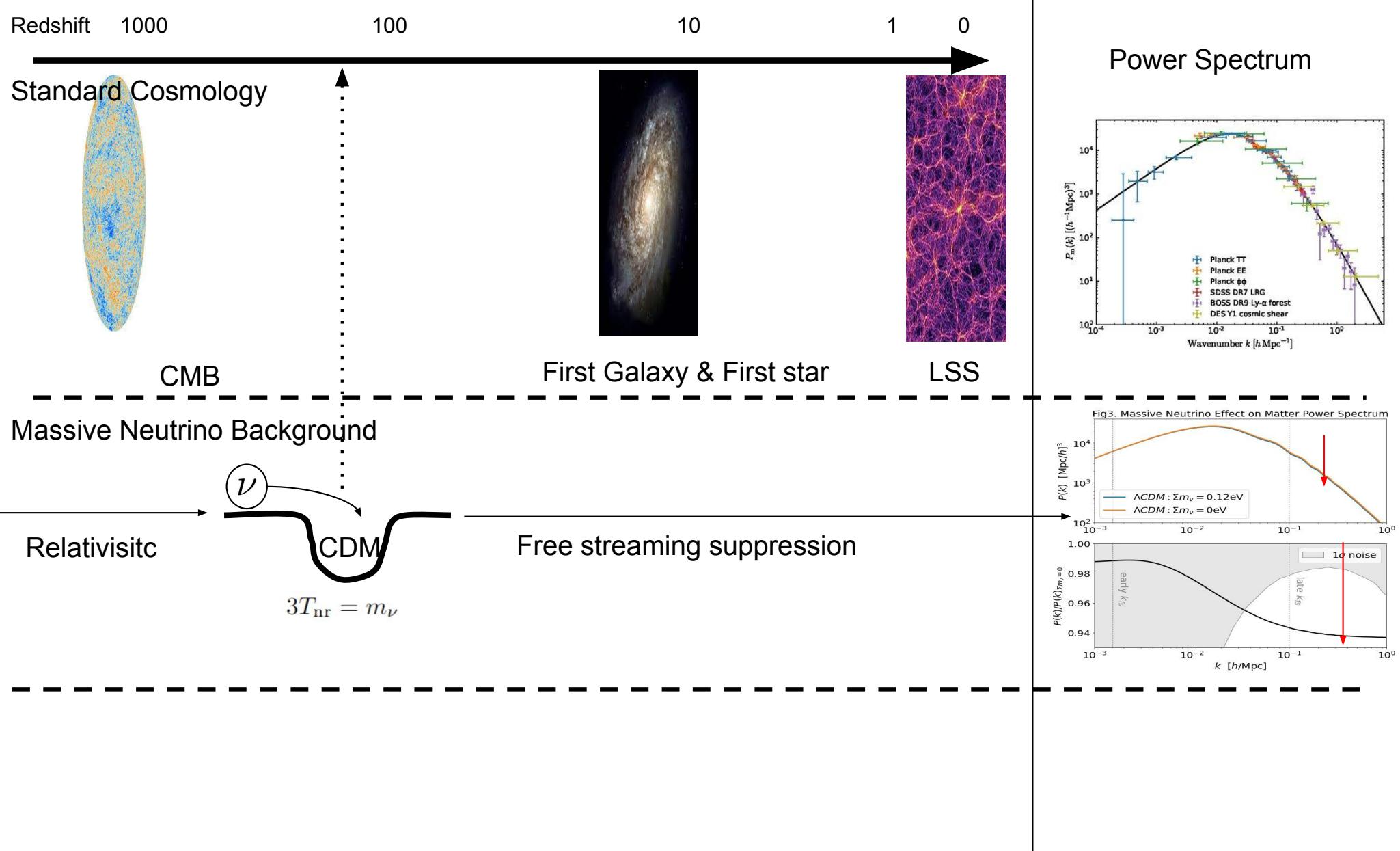


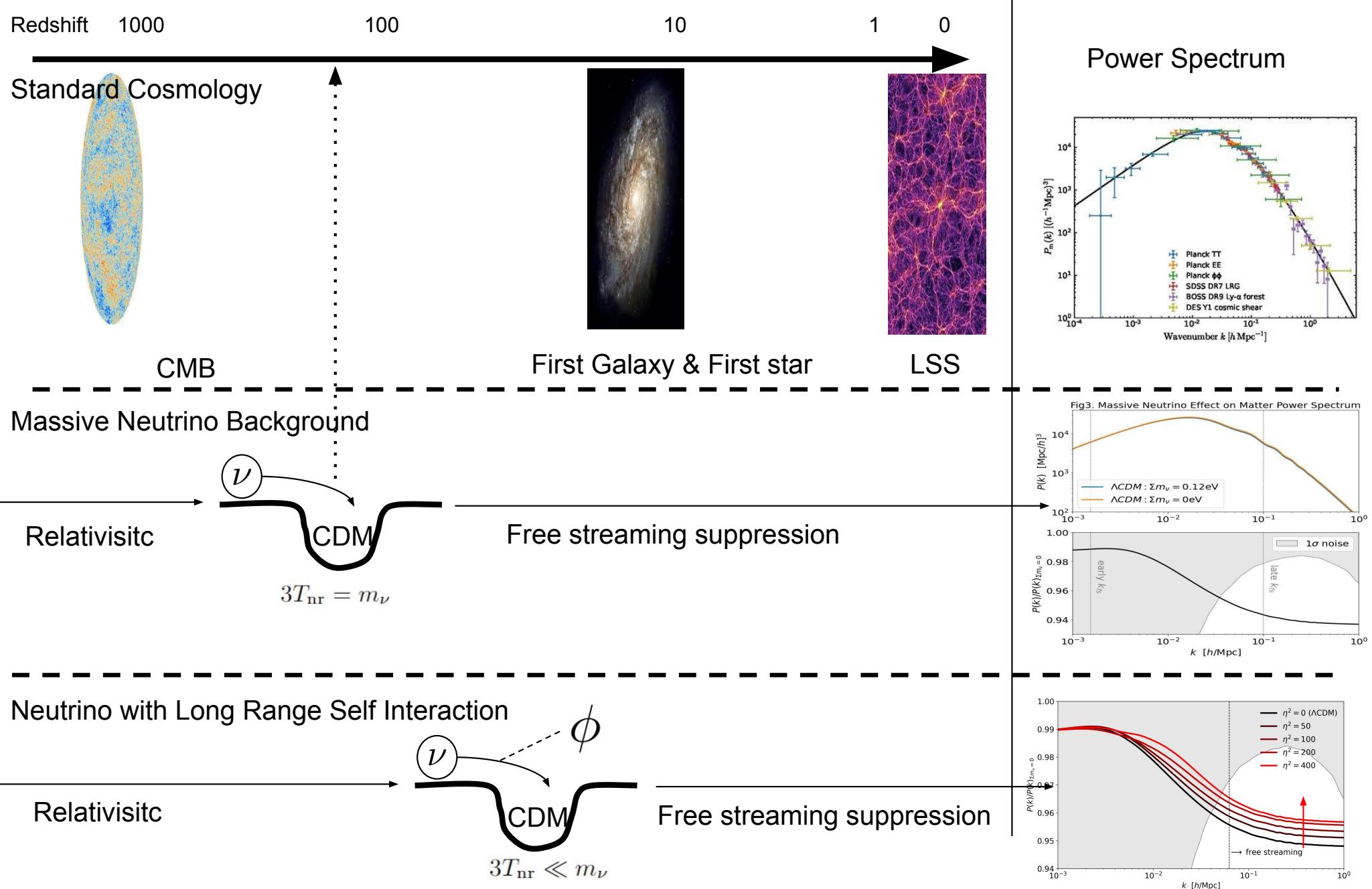
Summary

- We studied the evolution of CvB with coupling to a light scalar
- The system has a significant impact on cosmic structure growth
 - For the background evolution, CvB appears more massless, resulting $\sim 1\%$ increase in mps
 - For the perturbation evolution, CvB clusters quicker, resulting $\sim 10\%$ increase in mps

Thank you!







Redshift 1000

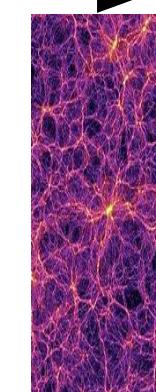
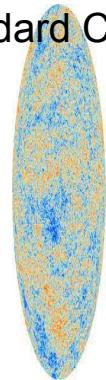
100

10

1

0

Standard Cosmology



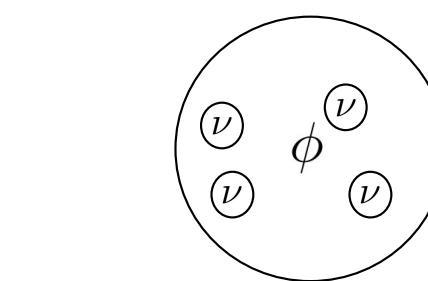
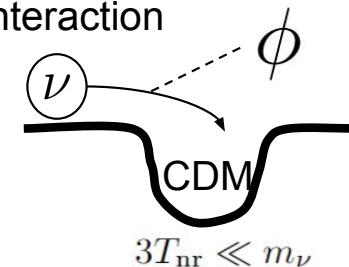
CMB

First Galaxy & First star

LSS

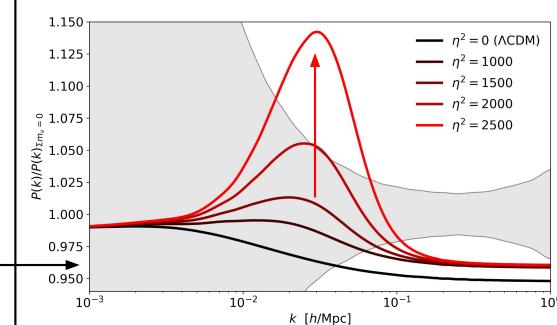
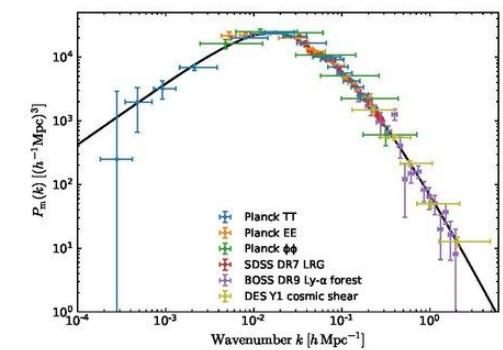
Neutrino with Long Range Self Interaction

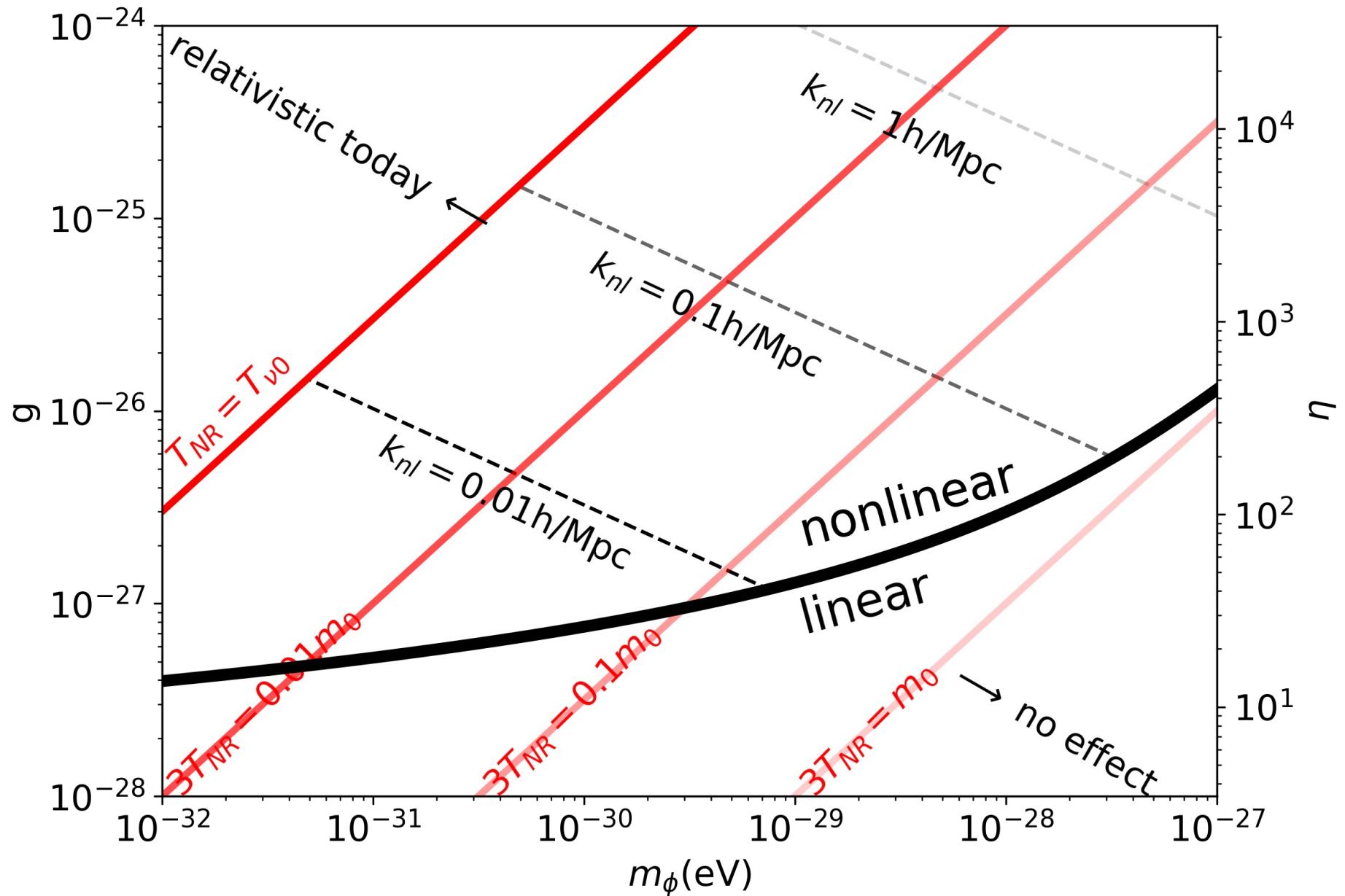
Relativistic



Enhanced Structure Growth

Power Spectrum





Background Effect

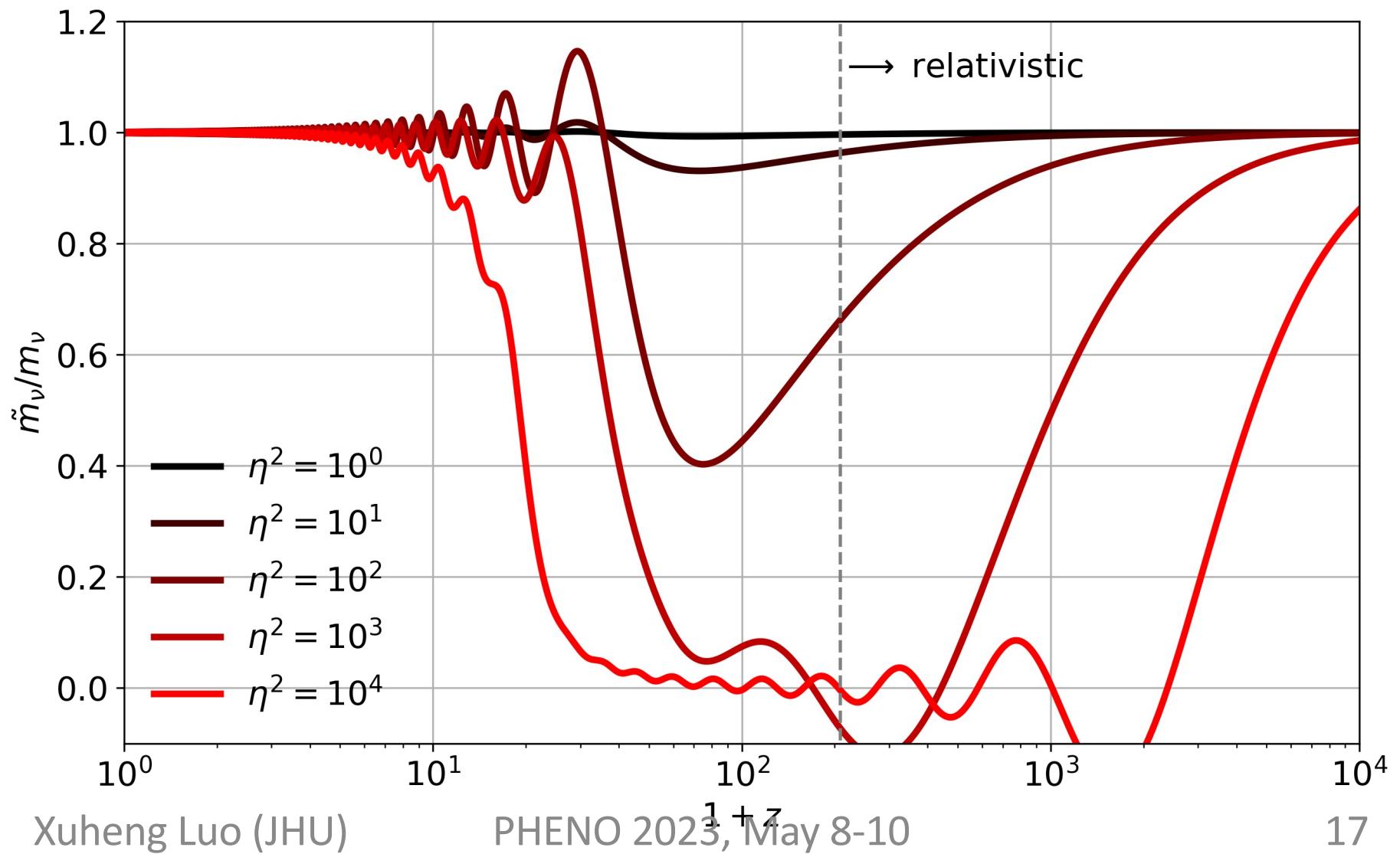


Fig2. CMB power spectrum compare with fiducial cosmology

