

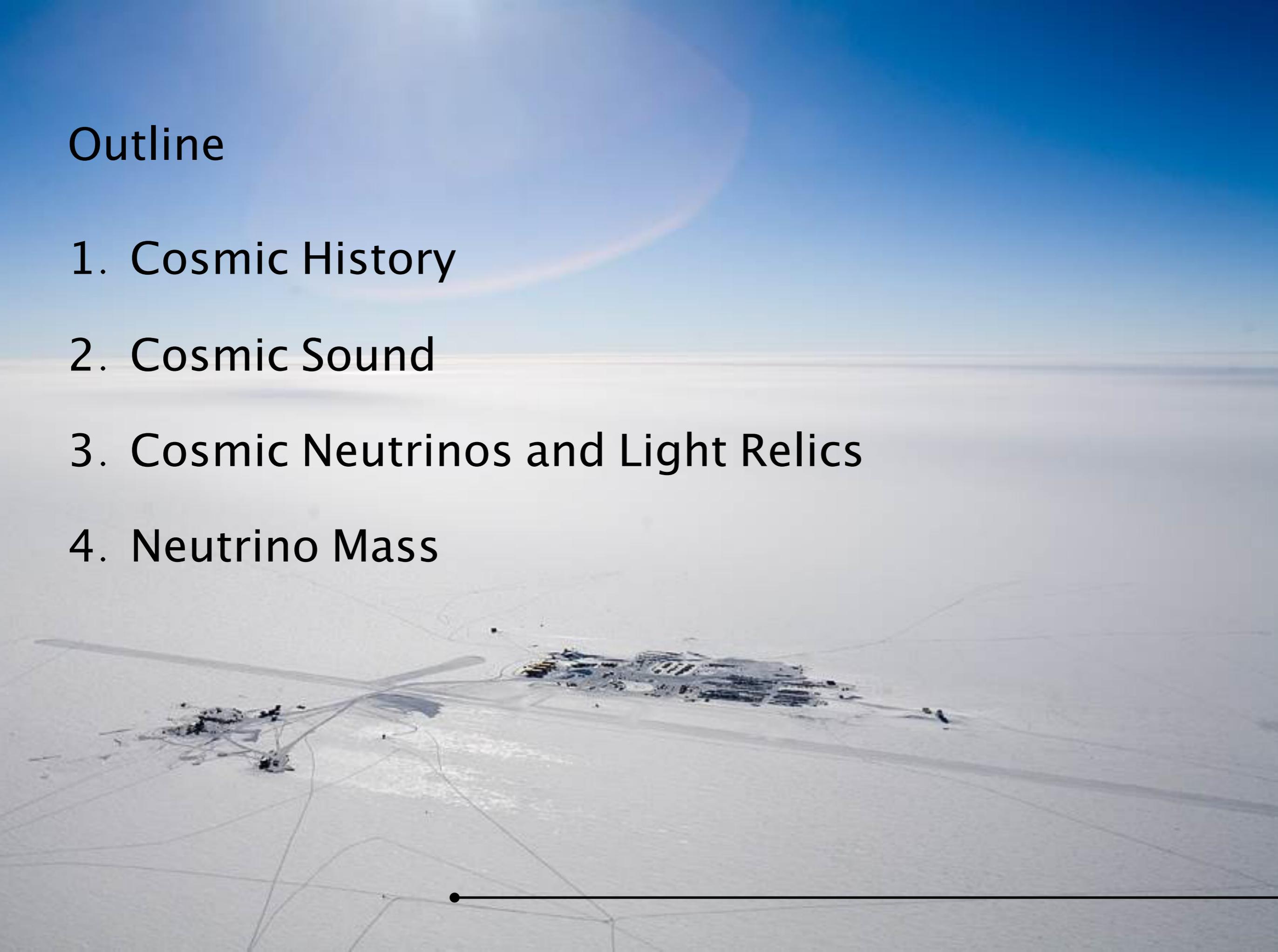
An aerial photograph of a vast, flat, light-colored desert landscape. In the upper left, a large, faint, circular feature is visible in the sky, possibly a lens flare or a celestial object. In the lower center, there is a small cluster of buildings and structures, likely a research facility or a small town. The overall scene is desolate and open.

# Messengers from the Early Universe

Daniel Green  
UC San Diego

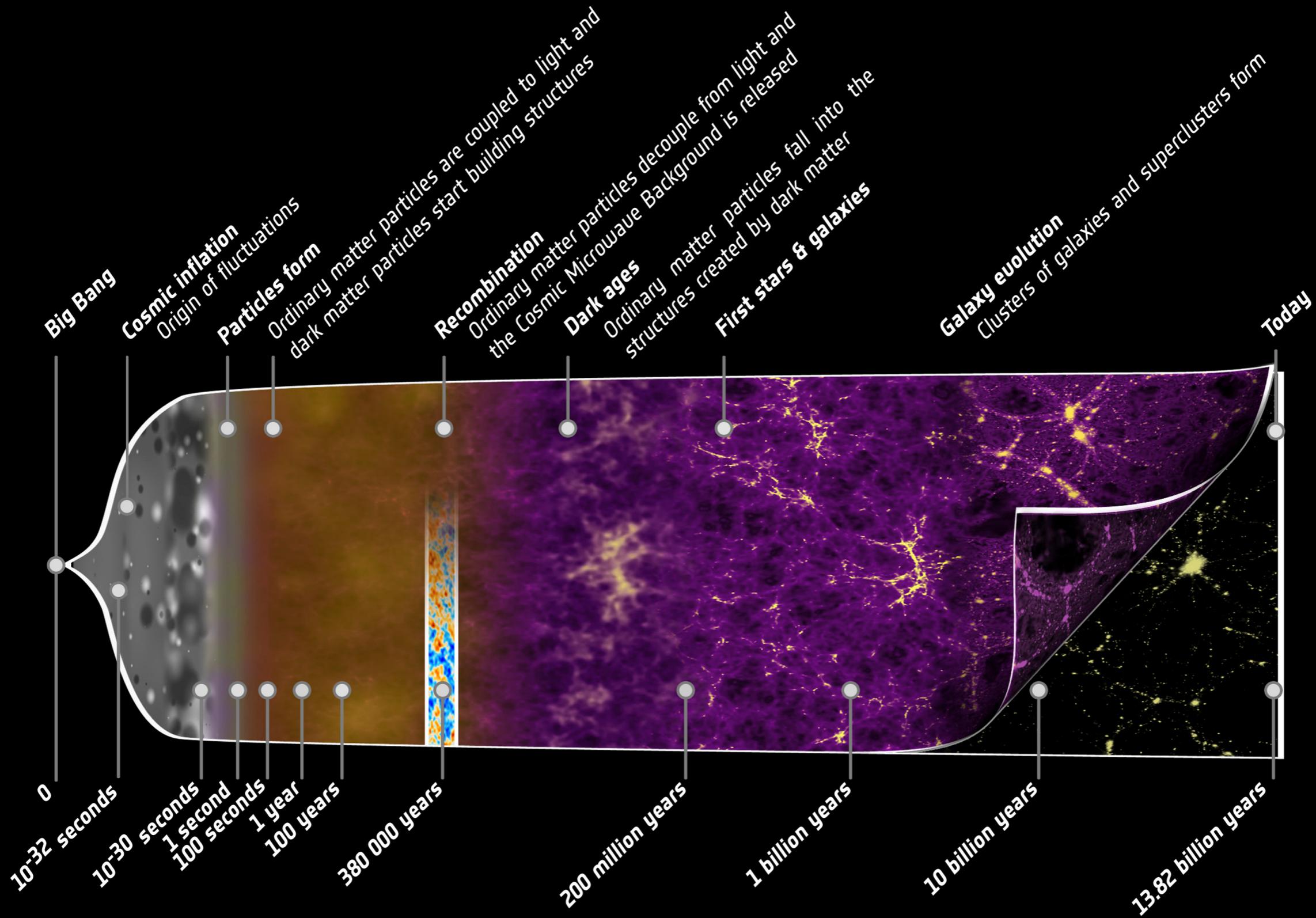
# Outline

1. Cosmic History
2. Cosmic Sound
3. Cosmic Neutrinos and Light Relics
4. Neutrino Mass



An aerial photograph of a vast, flat, snow-covered landscape. In the center, there is a small cluster of dark, rectangular structures, possibly a small settlement or a research station. The sky is a clear, pale blue, and a large, faint, circular structure is visible in the upper left quadrant. The overall scene is desolate and expansive.

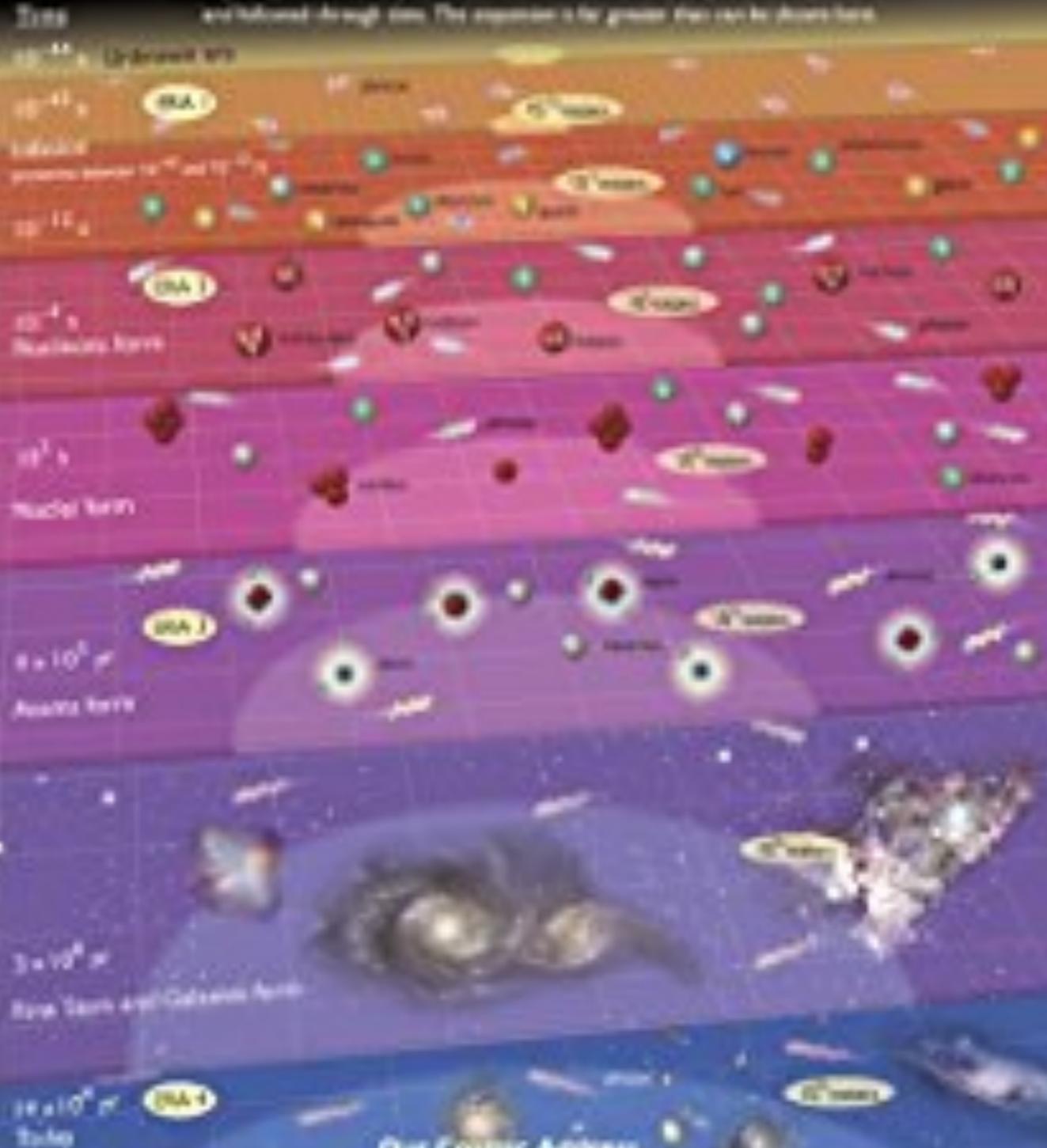
# Cosmic History



# THE HISTORY AND FATE OF THE UNIVERSE

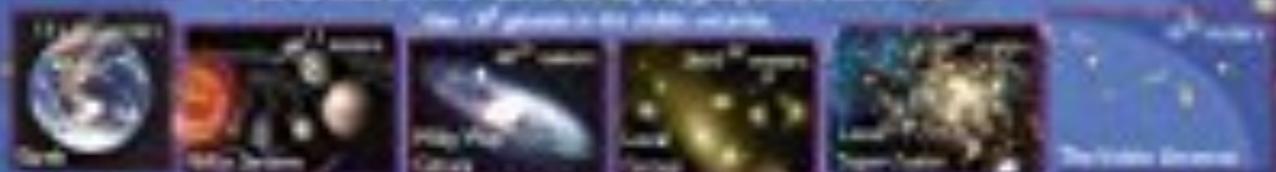
## Four eras and eight major stages in the evolution of the universe

The Big Bang occurred everywhere in the universe. Here and regions has been illustrated and followed through time. The expansion is far greater than can be shown here.



### Our Cosmic Address

Our solar system is 16 x 10<sup>21</sup> years old. The galaxy which is one of more than 10<sup>11</sup> galaxies in the visible universe.



## The Big Bang and Expanding Universe

Space is expanding from an initial moment called the Big Bang. As it expands, the universe becomes less dense and cools. All distant galaxies are moving away from each other, and the space between them is stretching. The universe is both the cause and the effect of its own expansion. There is no center, but a common understanding of the early universe is called the Big Bang model. We are continuing to learn from astronomical observations and theoretical calculations.

## History of the Universe

Two eras are in the expansion history.

### Era 1 - Acceleration: Inflation, Quark Separation

Observations show us that the early universe underwent an extremely rapid, accelerating expansion, called inflation. In a tiny fraction of a second, inflation expanded each part of space by a factor of a billion. Before inflation, the particles of the universe could be so close that a smooth, well-mixed fluid, such as a proton. As inflation ended, the visible universe had grown, and approximately 10<sup>-35</sup> seconds of time.

### Era 2 - Deceleration: Expansion Slows and Structure Forms

After inflation, the universe was a soup of fundamental particles, called a quark-gluon plasma. Forces and the moving particles gradually cooled, allowing particles to group together. In the universe expanded, the energy came from the expansion. Eventually, the cooling matter became dominant over radiation. Our sun, stars, and other structures grew from plasma in clouds of gas in local clusters.

Structure of the universe is not uniform. The universe is filled with galaxies and galaxy clusters.



### Era 3 - Acceleration: Dark Energy Speeds Expansion

Acceleration has occurred for the entire universe. Dark energy is a form of energy that causes the universe to expand at an accelerating rate. It is the dominant force in the universe, and it is causing the universe to expand at an ever-increasing rate. The result is the accelerating expansion of the universe, which is the "accelerating universe" phase. The result is the accelerating expansion of the universe, which is the "accelerating universe" phase.

Learn more at [UniverseAdventure.org](http://UniverseAdventure.org) and at [CPEPphysics.org](http://CPEPphysics.org)

## The Accelerating Universe

As matter and radiation expand, their density decreases. As the universe expands, the density of matter and radiation decreases. The expansion of the universe is accelerating, and the rate of expansion is increasing. The universe is expanding at an ever-increasing rate, and the rate of expansion is increasing. The universe is expanding at an ever-increasing rate, and the rate of expansion is increasing.



When the expansion begins, the universe is very dense and hot. As the universe expands, the density and temperature decrease. The expansion of the universe is accelerating, and the rate of expansion is increasing. The universe is expanding at an ever-increasing rate, and the rate of expansion is increasing.

## The Fate of the Universe

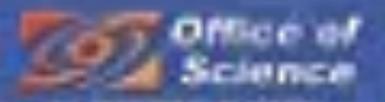
Whether the expansion of the universe will stop or continue indefinitely depends on the amount of matter and energy in it. The universe is expanding at an ever-increasing rate, and the rate of expansion is increasing. The universe is expanding at an ever-increasing rate, and the rate of expansion is increasing.



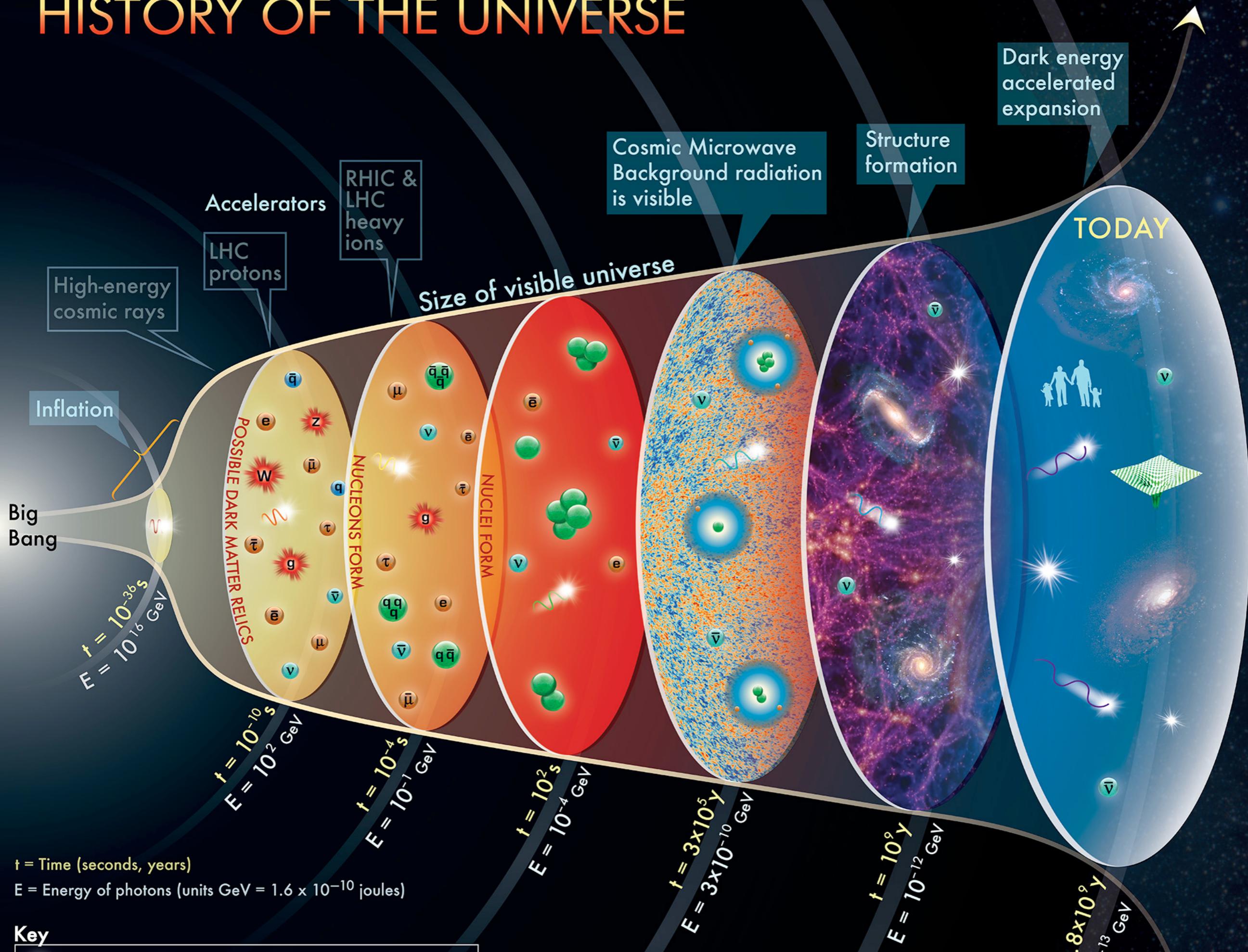
The universe is expanding at an ever-increasing rate, and the rate of expansion is increasing. The universe is expanding at an ever-increasing rate, and the rate of expansion is increasing. The universe is expanding at an ever-increasing rate, and the rate of expansion is increasing.

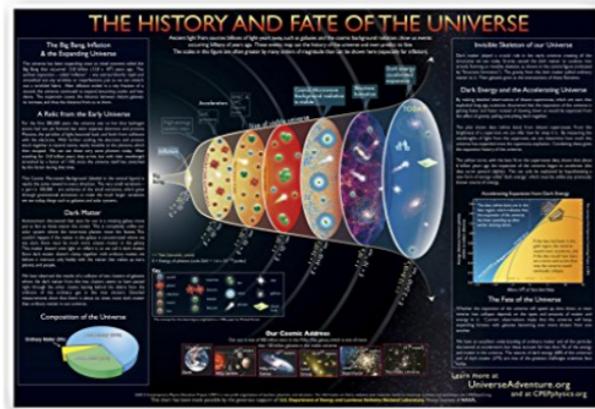
Two things could happen. If the expansion of the universe continues to accelerate, the universe will expand forever. If the expansion of the universe slows down, the universe will eventually stop expanding and collapse back into a dense state. The universe is expanding at an ever-increasing rate, and the rate of expansion is increasing.

Learn more at [UniverseAdventure.org](http://UniverseAdventure.org) and at [CPEPphysics.org](http://CPEPphysics.org)



# HISTORY OF THE UNIVERSE





by Contemporary Physics Education Project (CPEP)

Share

## History and Fate of the Universe II Laminated Placemat

Available in multiple versions

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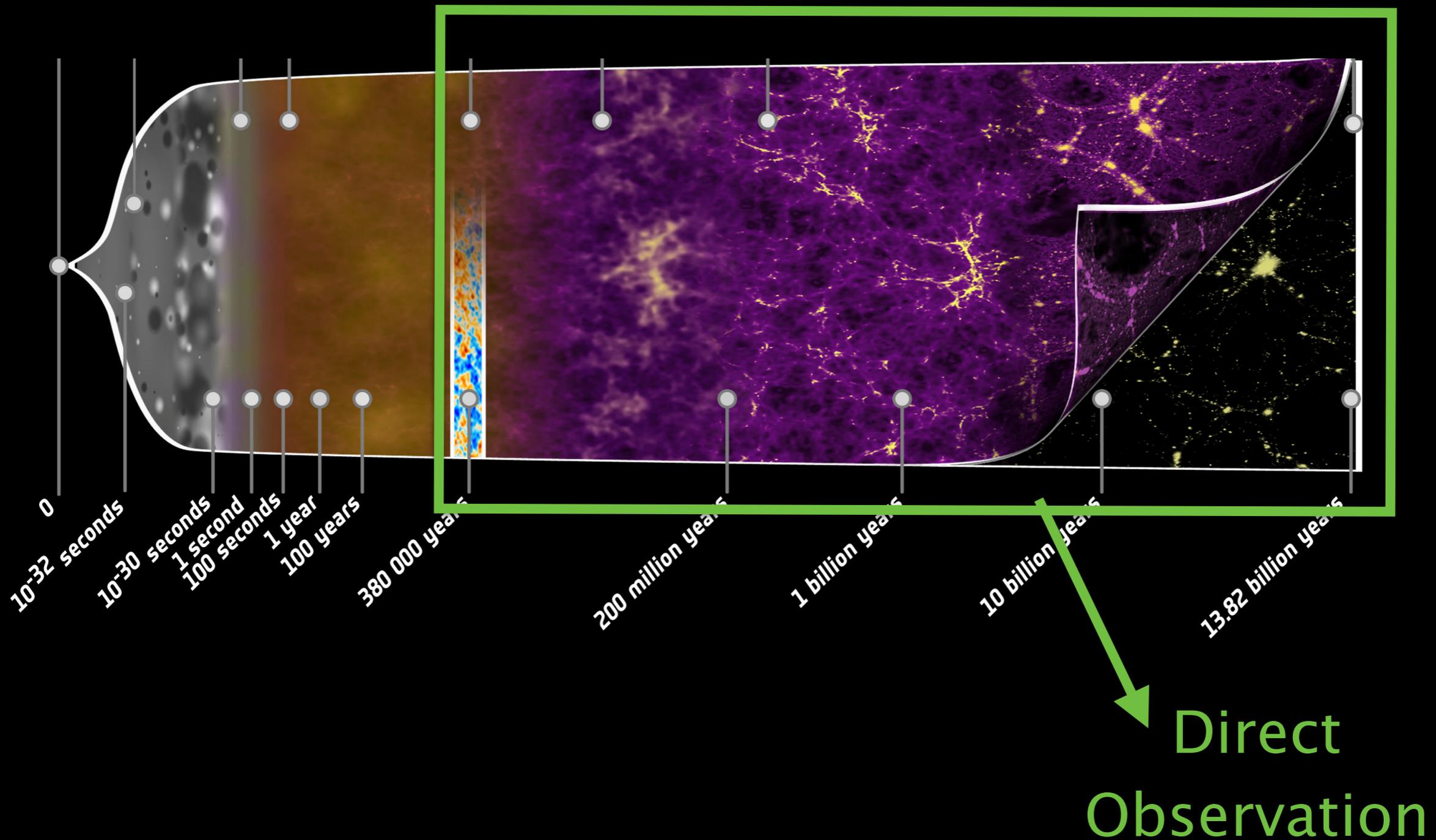
Roll over image to zoom in

# History of the Universe

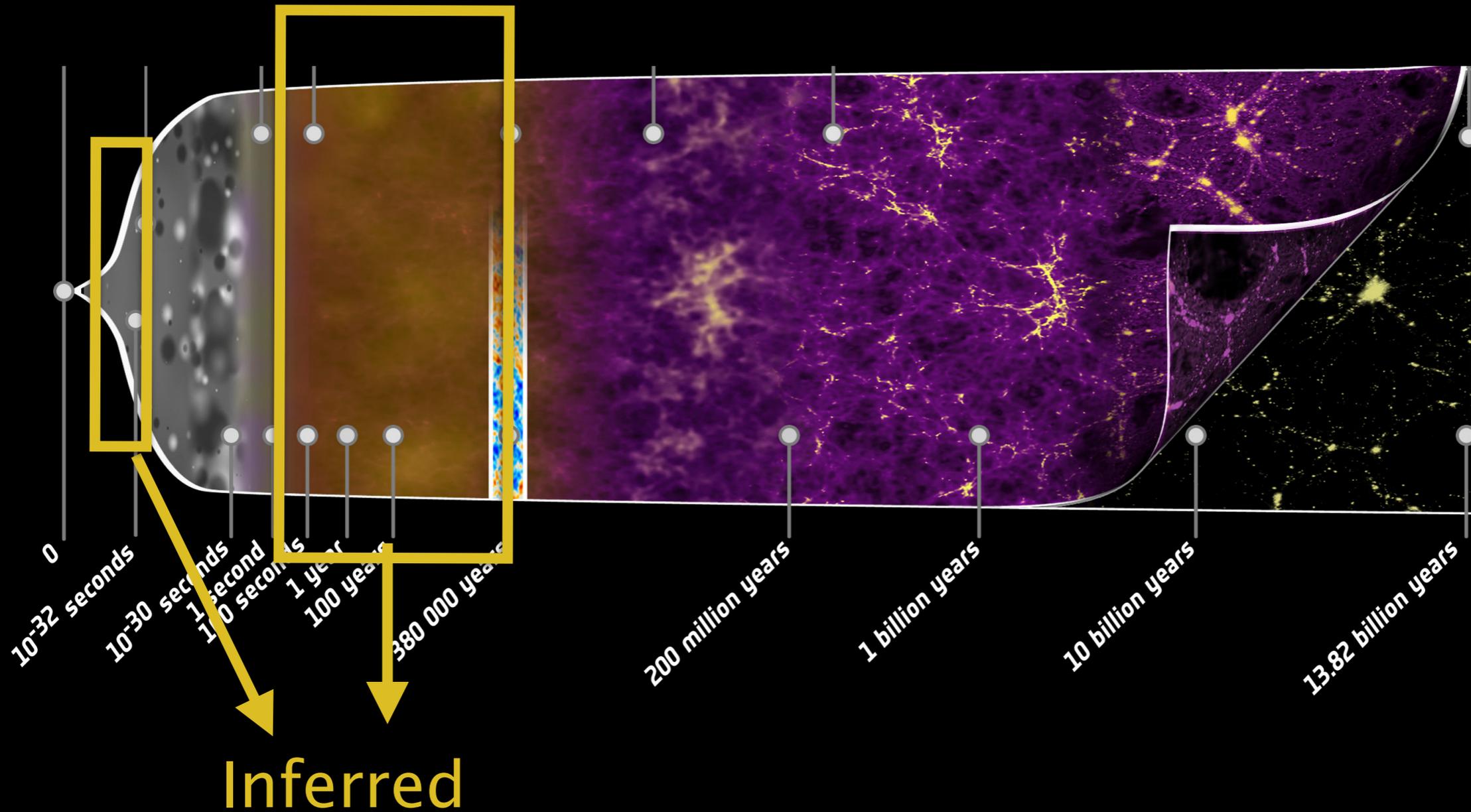
Suggests a complete story

1. Early phase of inflation
  2. Reheating up to  $T \gg 1 \text{ TeV}$
  3. Standard model cools through expansion
  4. (Perhaps) WIMP Dark Matter freeze-out
-

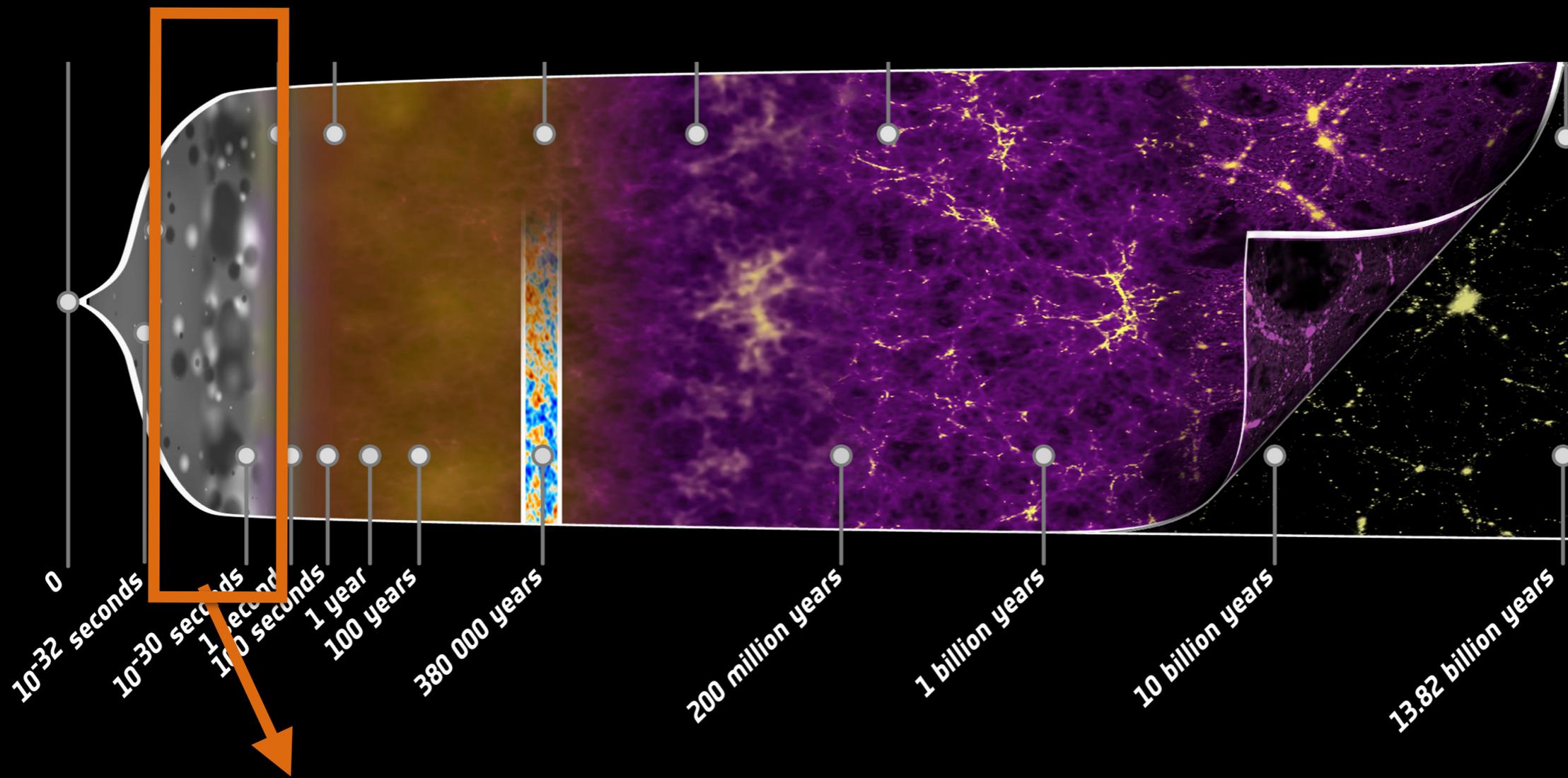
This story is plausible but hardly proven



This story is plausible but hardly proven



This story is plausible but hardly proven

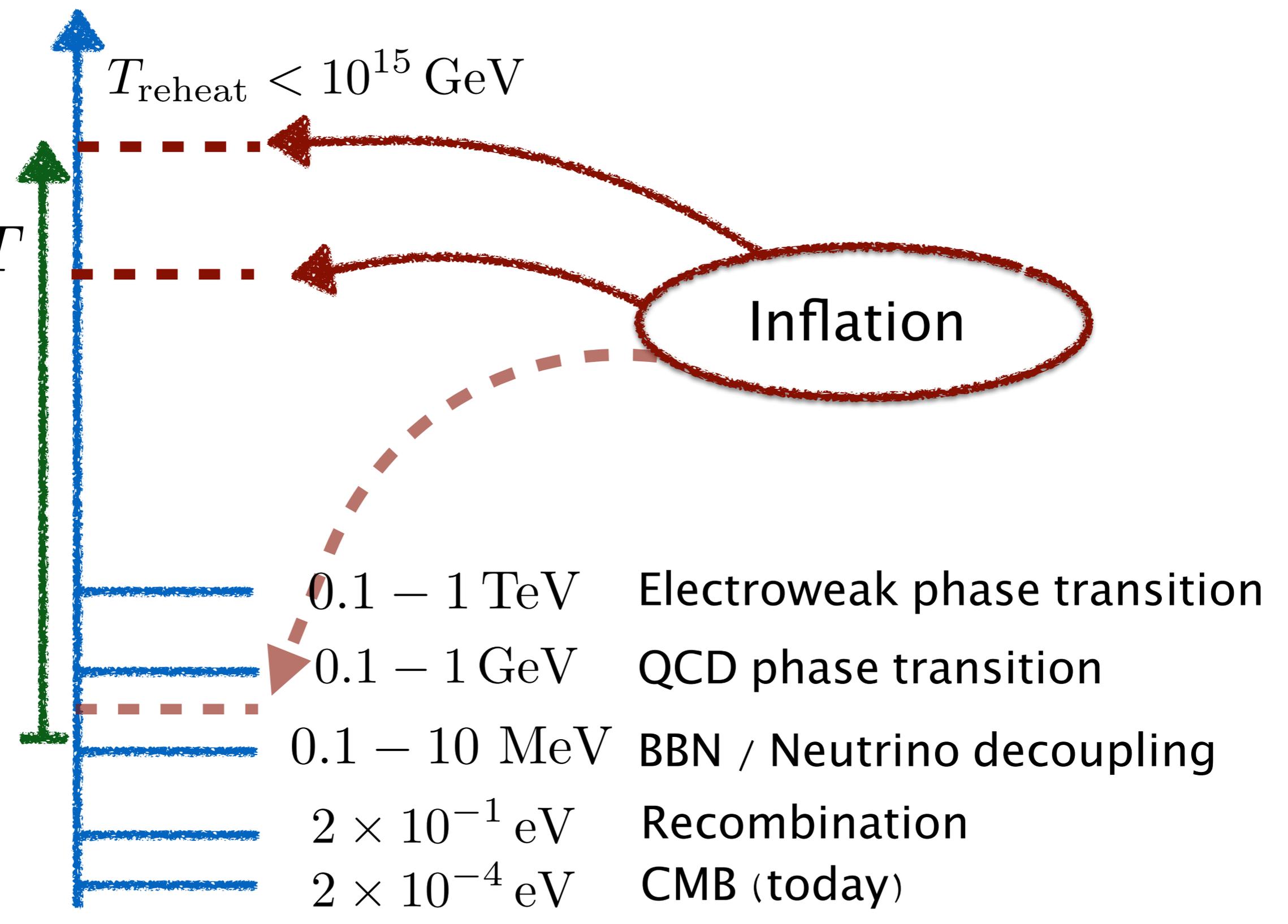


$T_{\text{reheat}} < 10^{15} \text{ GeV}$

$T$

Inflation

Can we probe this regime?



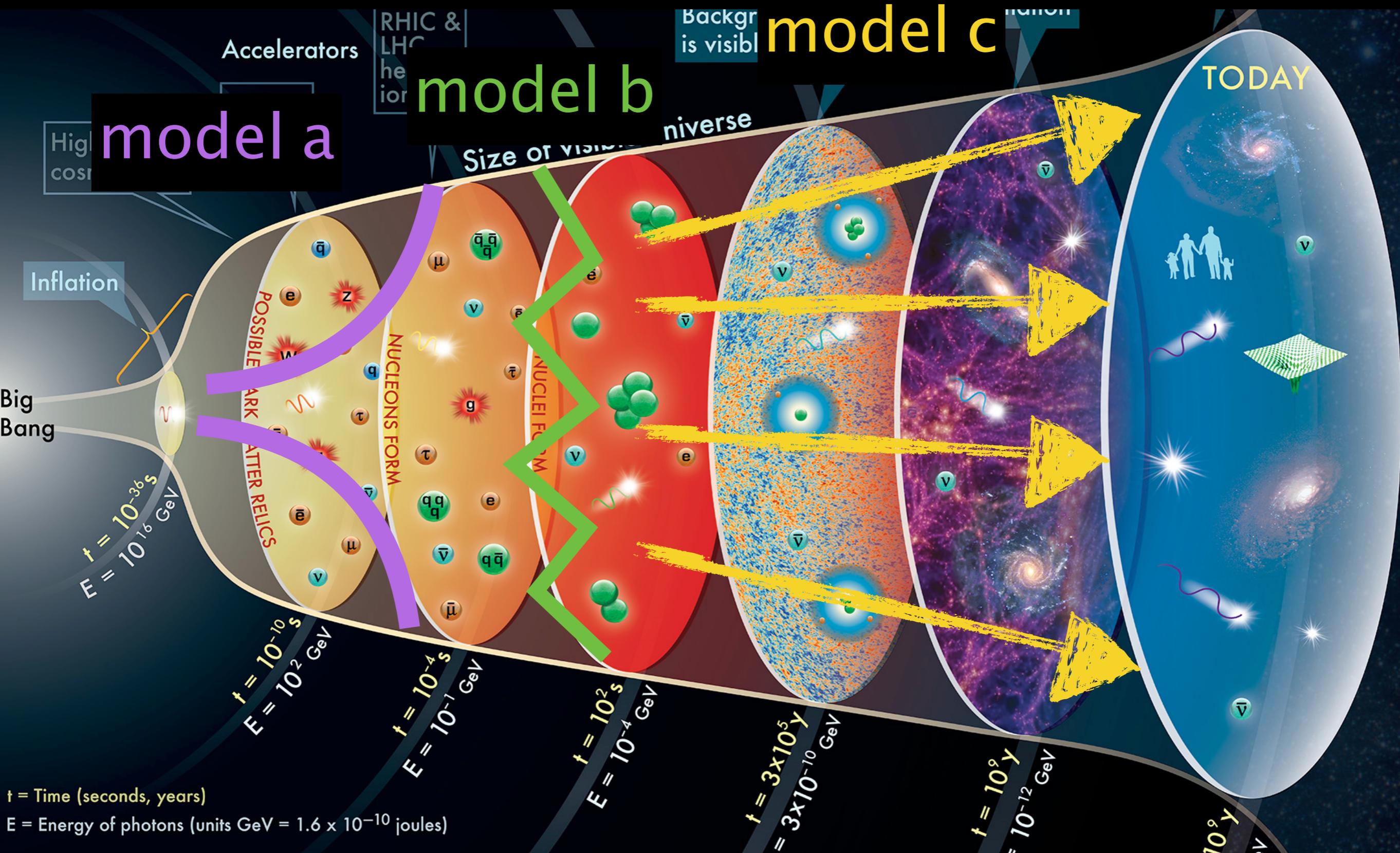
# Does it matter?

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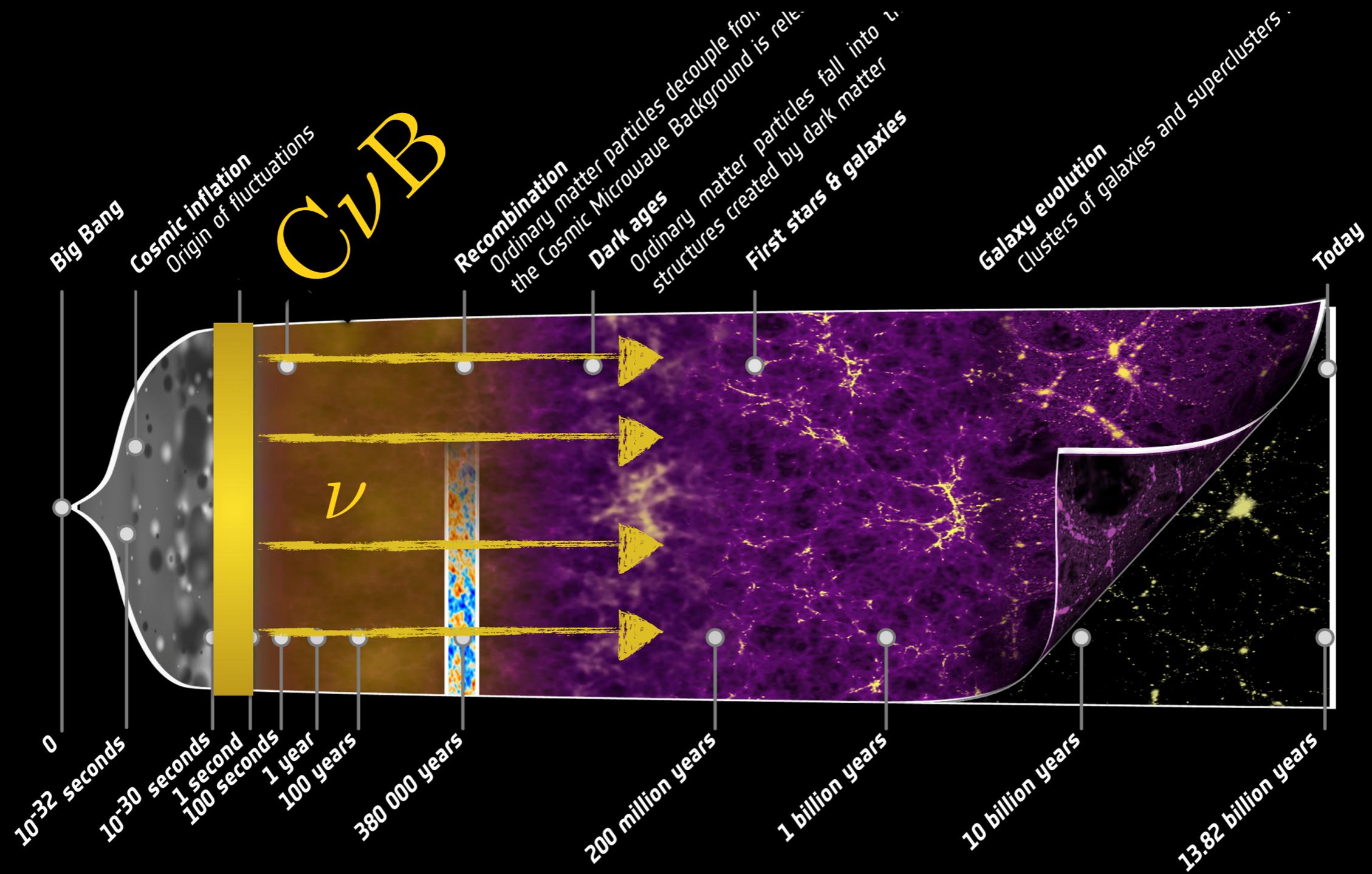
Cosmology is tied to every basic problem

- Cosmological Constant
  - Dark Matter / Dark Sectors
  - Solution to strong CP problem (axion)
  - Cosmological solutions to Hierarchy Problem
  - Relics from new symmetries (e.g. gravitino)
  - Origin of structure, baryogenesis, B-fields, ...
-

# Ideas are not consistent with a single cosmic history

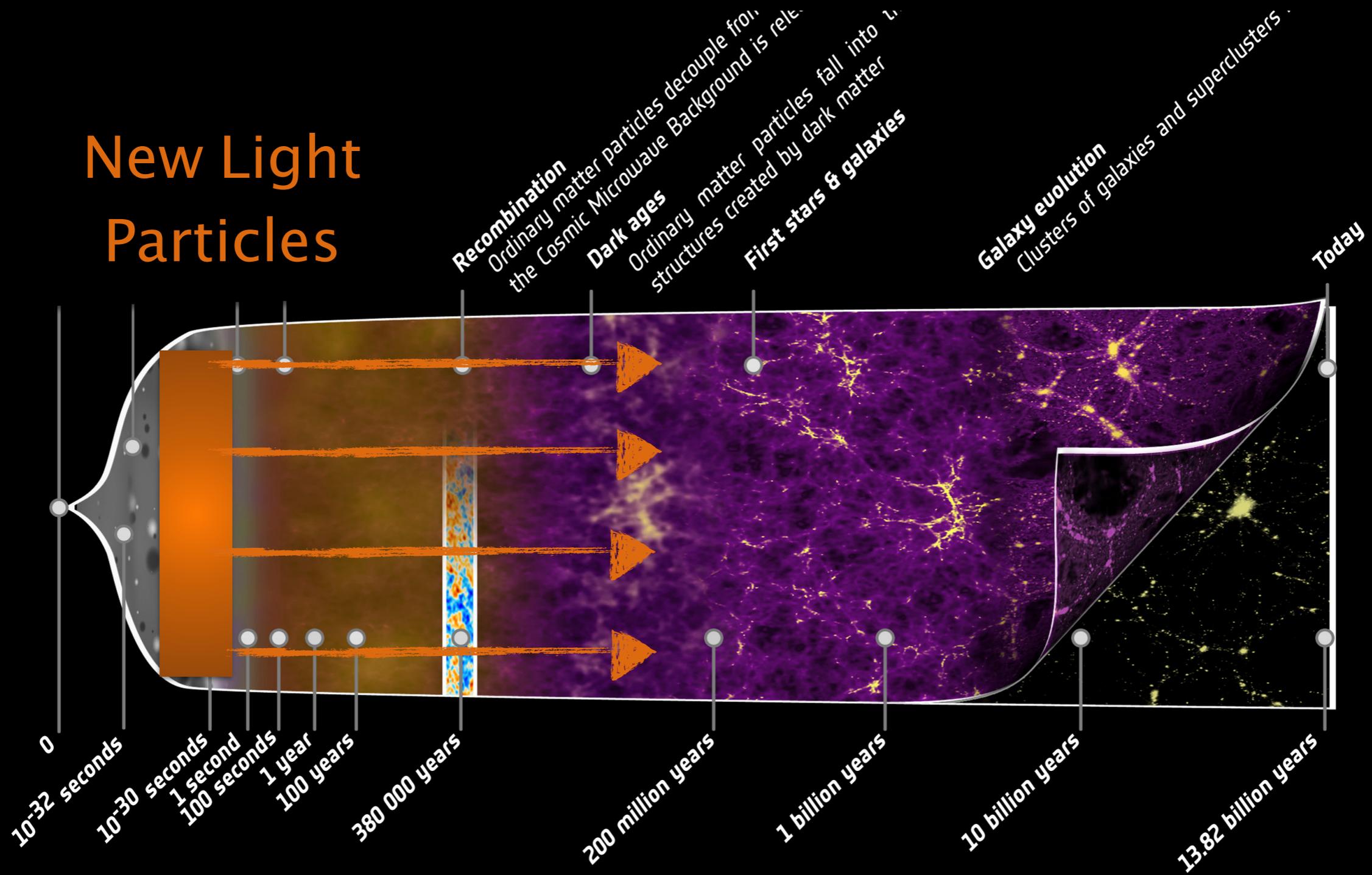


# I will focus on two related goals:



# I will focus on two related goals:

## New Light Particles



# Does it matter?

Observations will be relevant to:

- Cosmological Constant
- Dark Matter / Dark Sectors 
- Solution to strong CP problem (axion) 
- Cosmological solutions to Hierarchy Problem 
- Relics from new symmetries (e.g gravitino) 
- Origin of structure, baryogenesis, B-fields, ...

An aerial photograph of a vast, flat, snow-covered landscape. In the center, there is a small cluster of dark, rectangular structures, possibly a small settlement or a research station. The sky is a clear, pale blue, and a large, faint, circular feature is visible in the upper left quadrant. The overall scene is desolate and expansive.

# Cosmic Sound

# Cosmic Microwave Background (CMB)

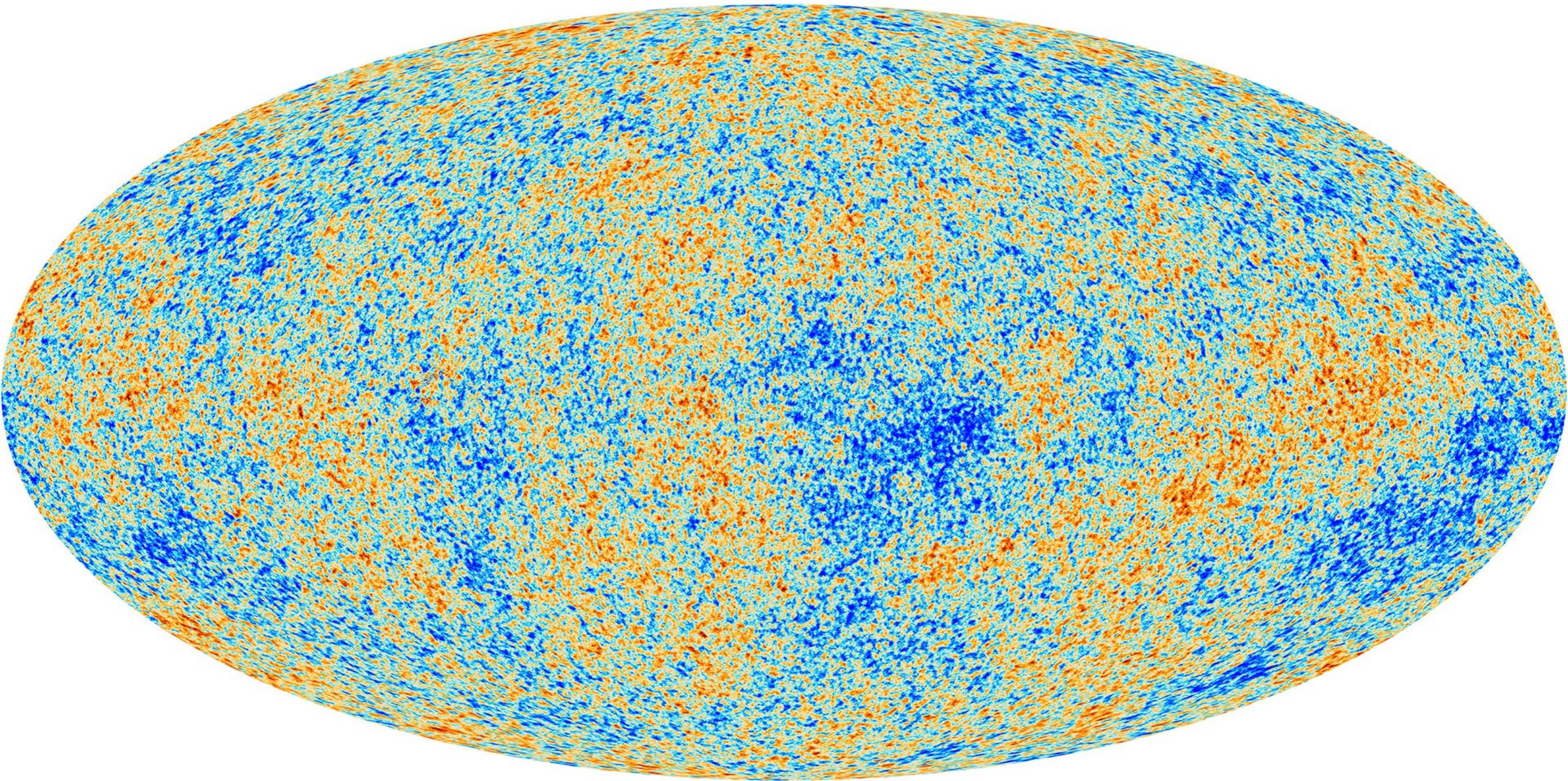


Image from Planck

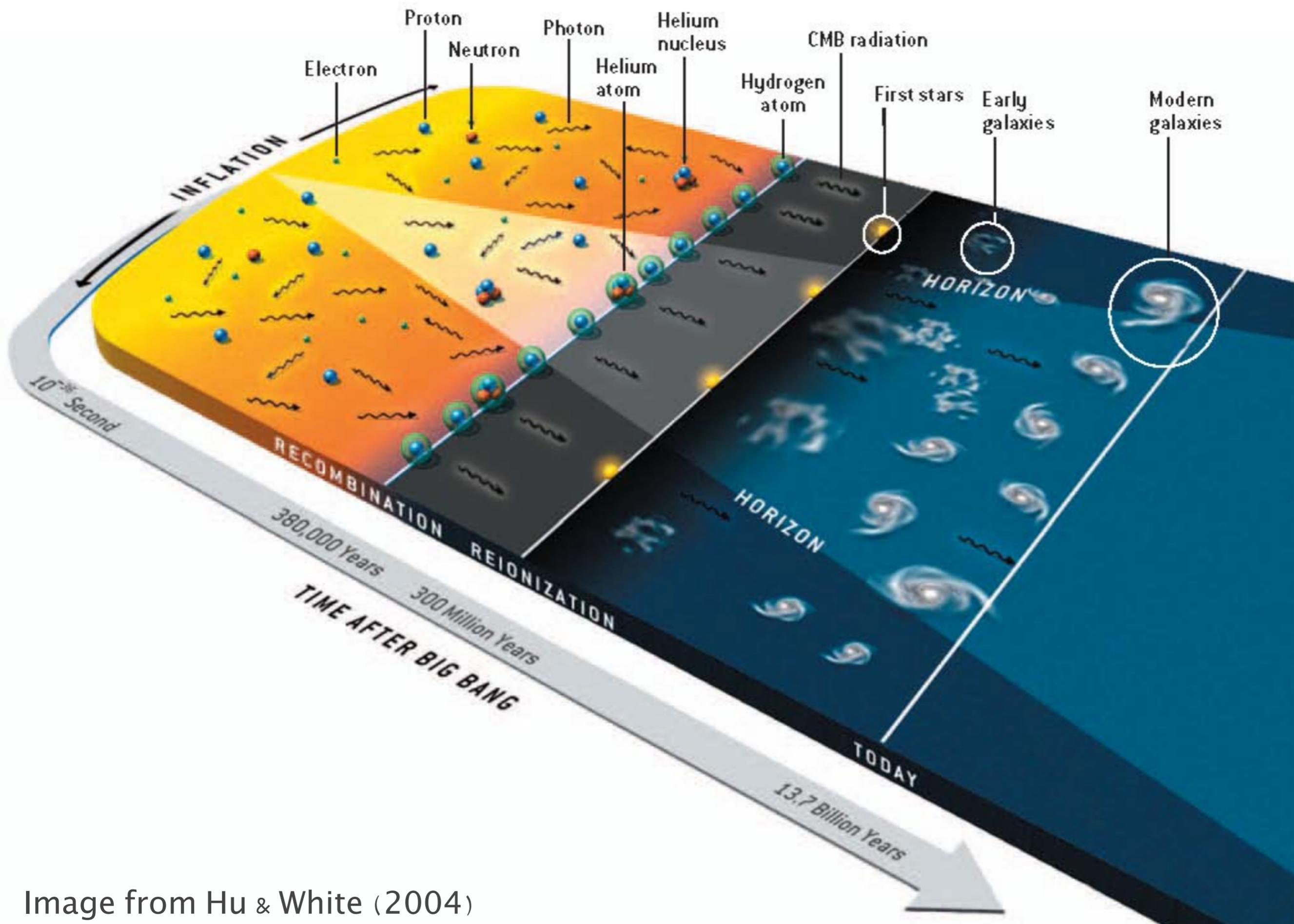
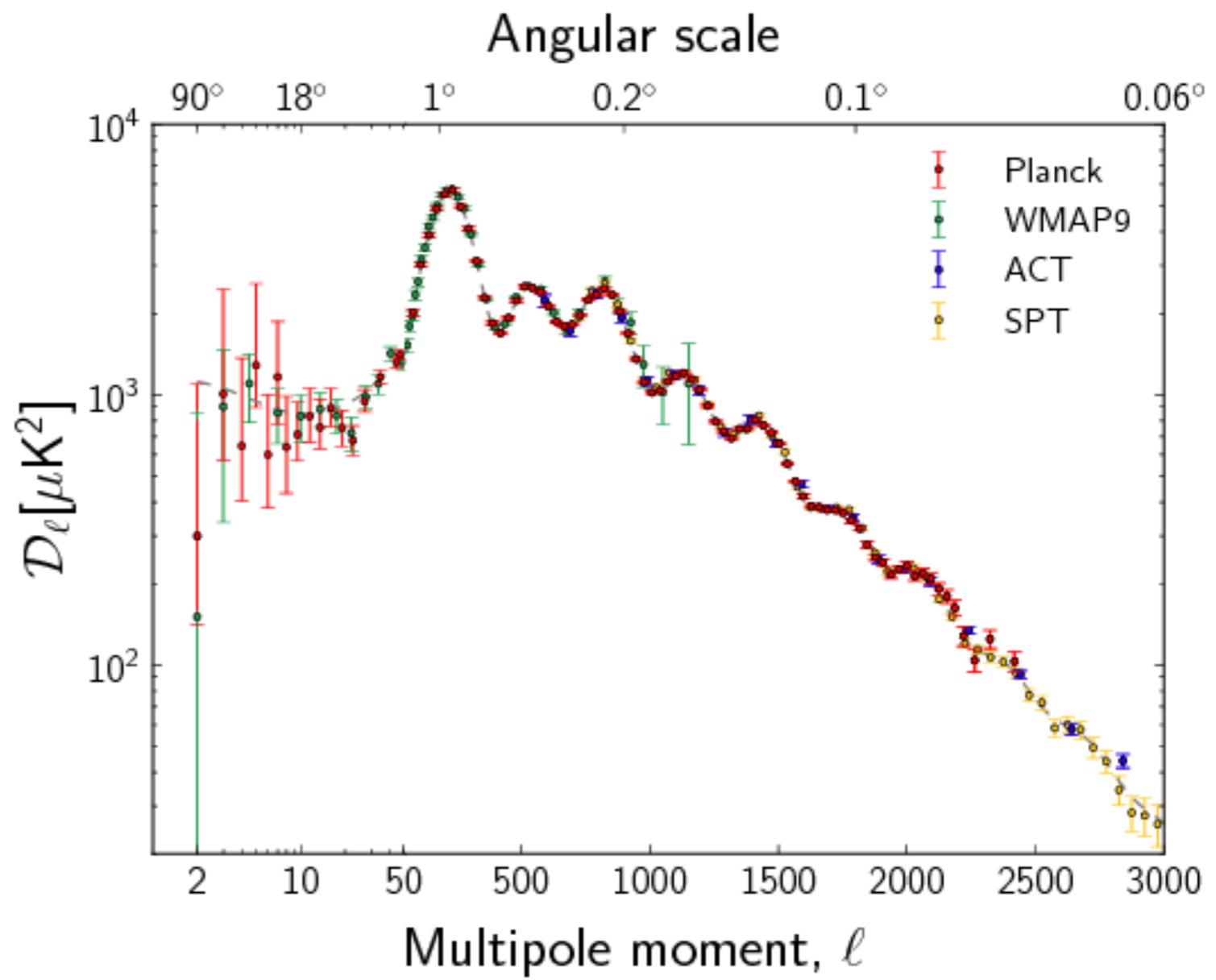
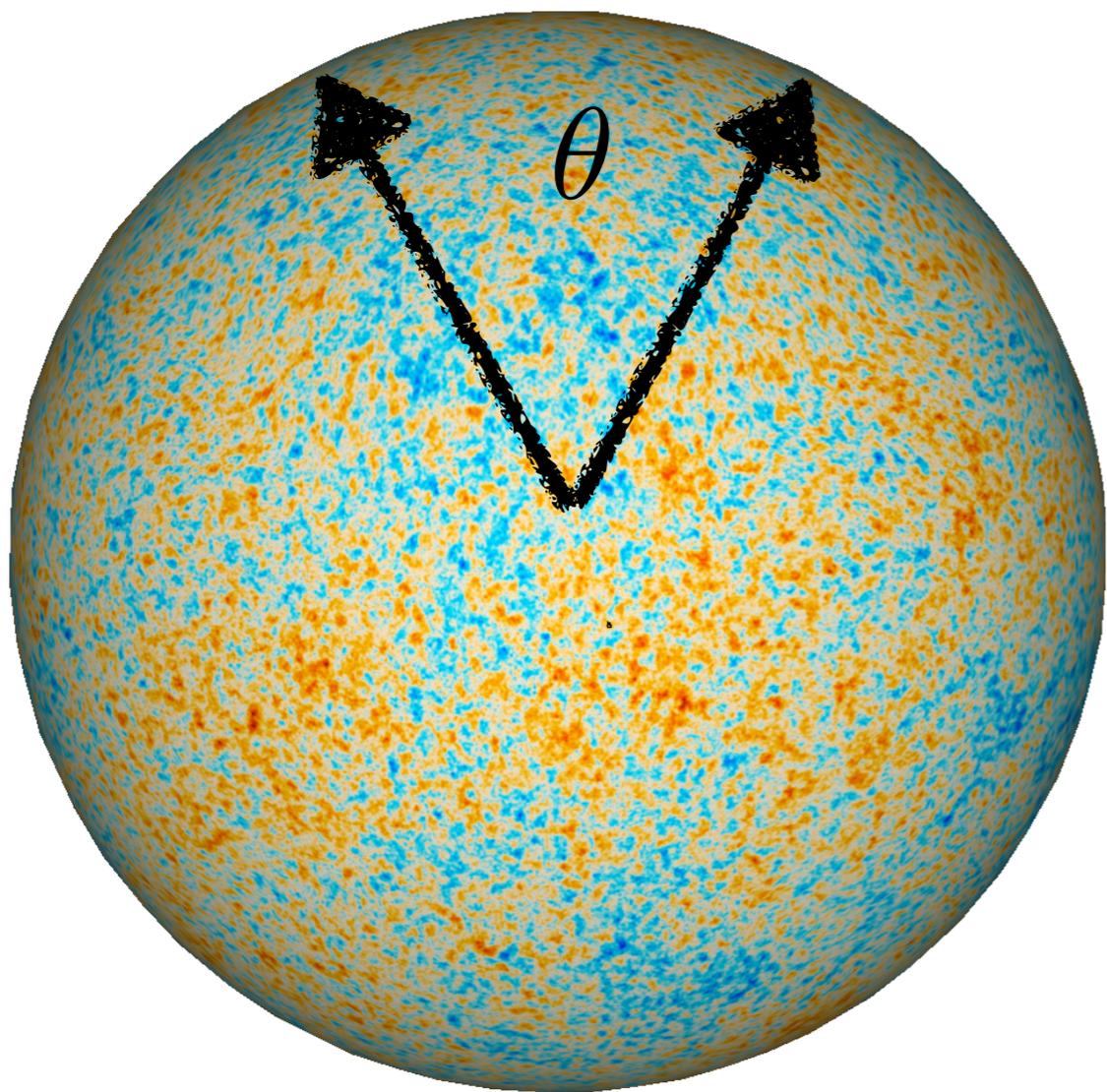
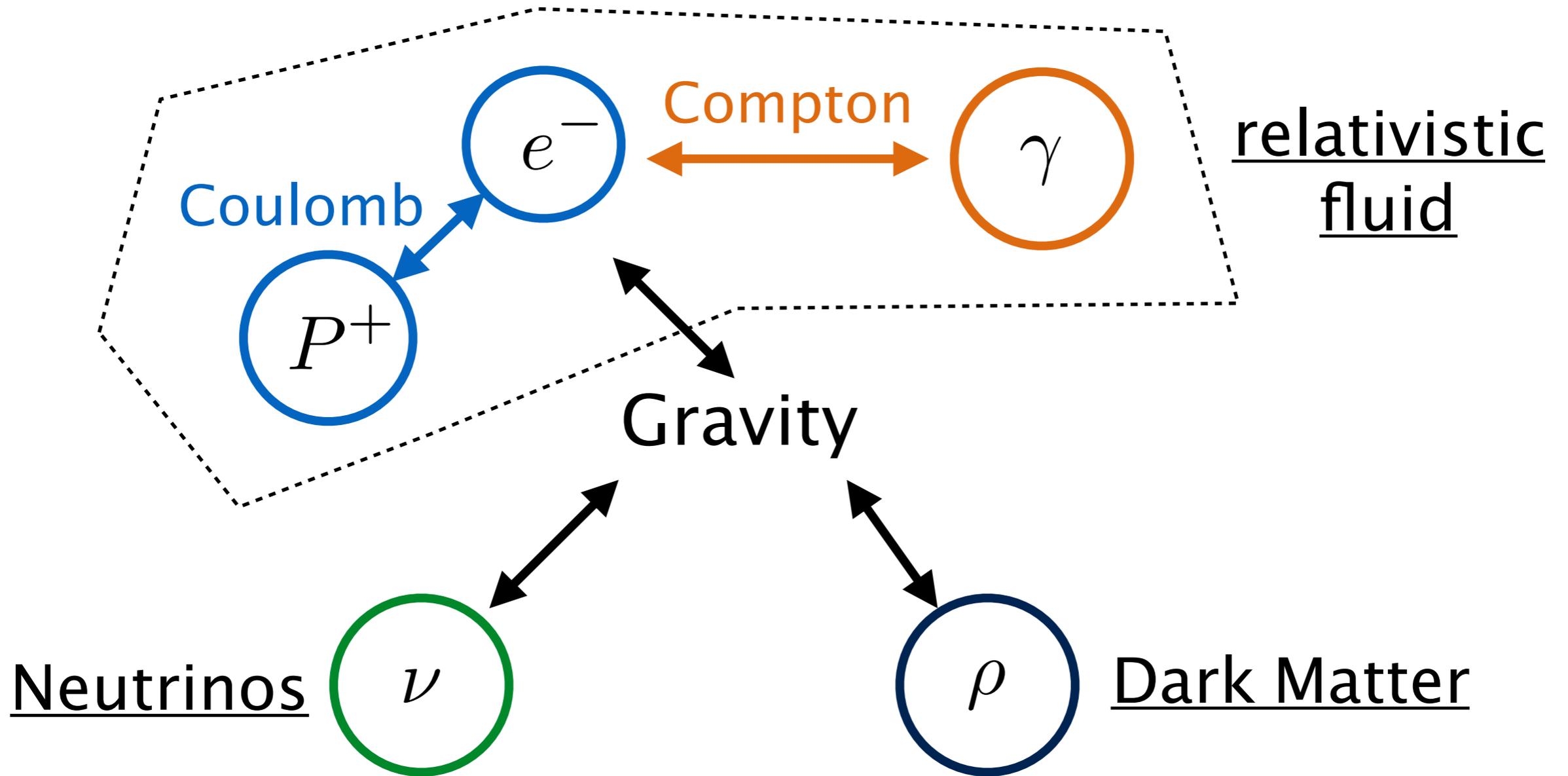
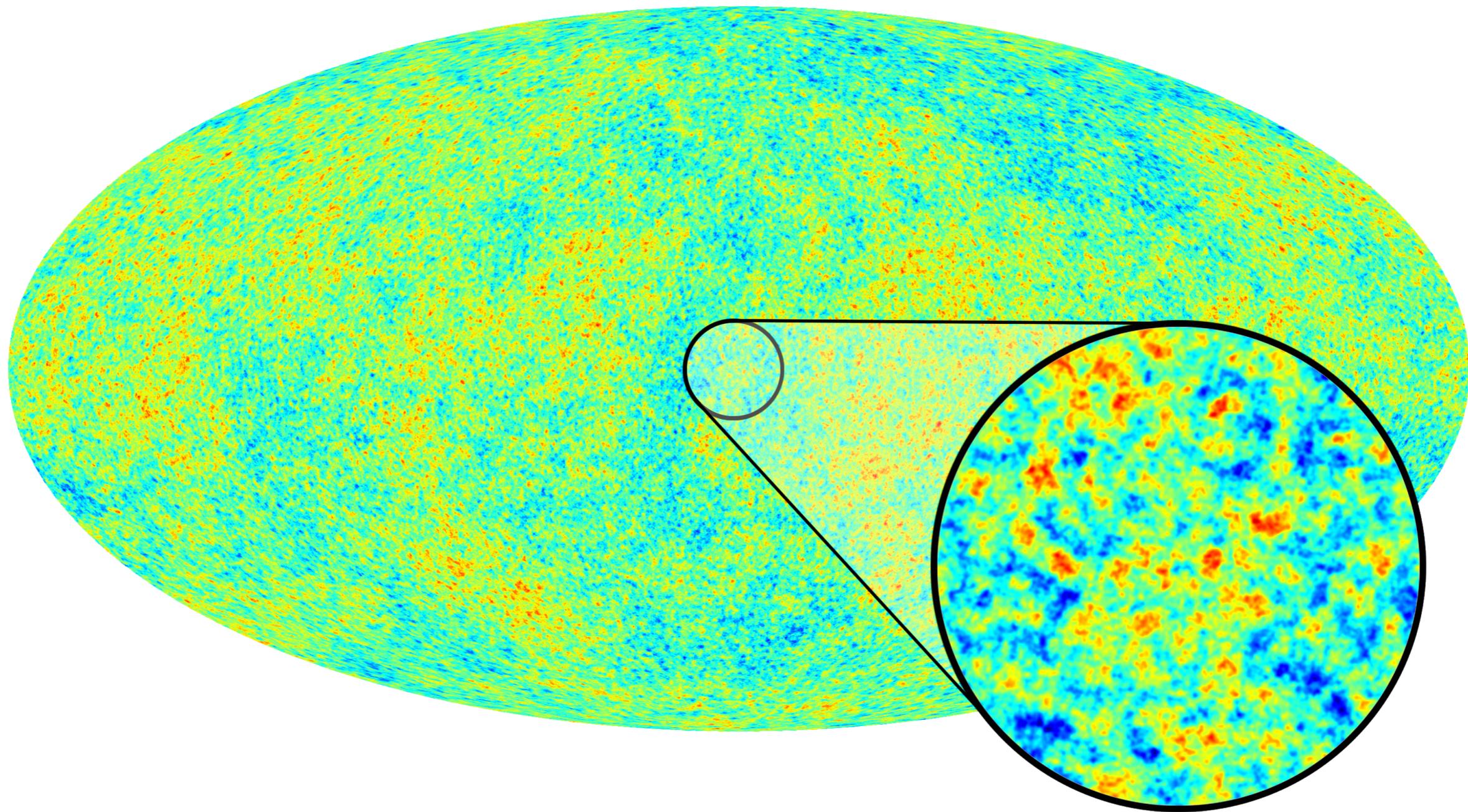
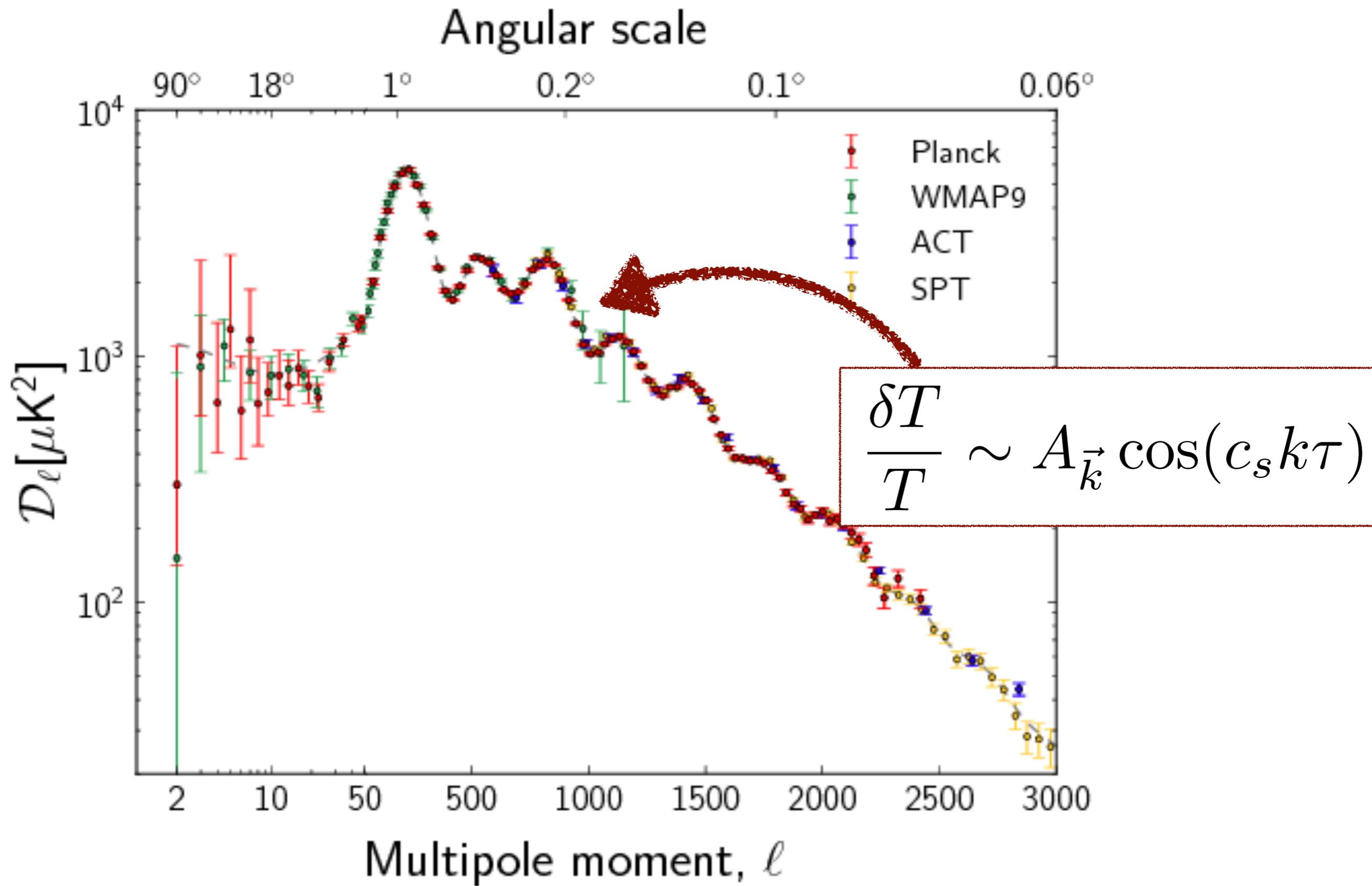


Image from Hu & White (2004)









# Cosmic Sound

$$\ddot{d}_\gamma - c_s^2 \nabla^2 d_\gamma \approx \nabla^2 \Phi$$

$$d_\gamma \approx A_{\vec{k}} \cos c_s k \tau + \cancel{B_{\vec{k}} \sin c_s k \tau}$$

# Cosmic Sound

But we have to Match to long wavelength

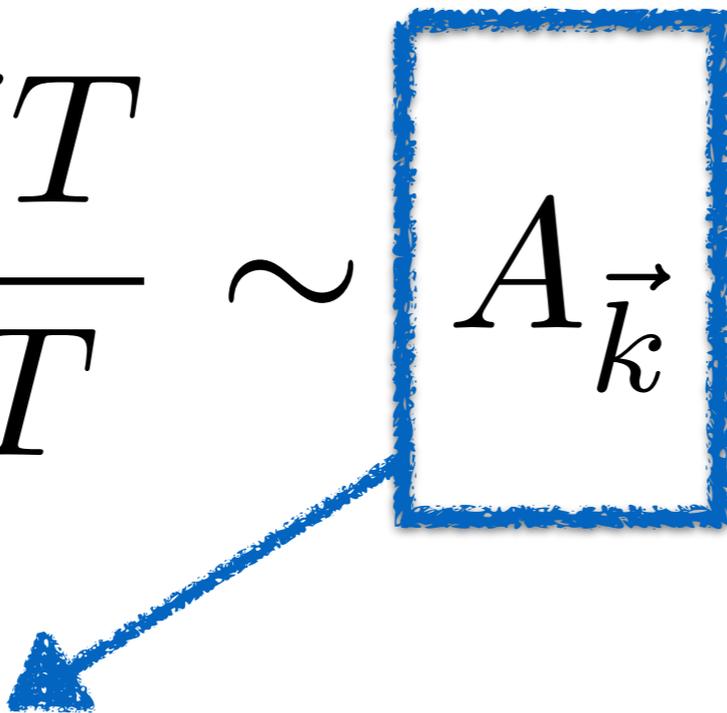
$$k_{\text{physical}} \propto a^{-1} \quad H \propto a^{-2}$$

In the past

$$k_{\text{physical}} \ll H$$

$$d_{\gamma} \approx a_{\vec{k}} + b_{\vec{k}} a^{-3}$$

$$B_{\vec{k}} \sim b_{\vec{k}} a^{-3} \rightarrow 0$$

$$\frac{\delta T}{T} \sim \boxed{A_{\vec{k}}} \cos(c_s k \tau)$$


“Inflation” : source of initial conditions

$$\langle A_{\vec{k}} A_{\vec{k}'} \rangle = \frac{\Delta^2}{k^{4-n_s}} (2\pi)^3 \delta(\vec{k} + \vec{k}')$$

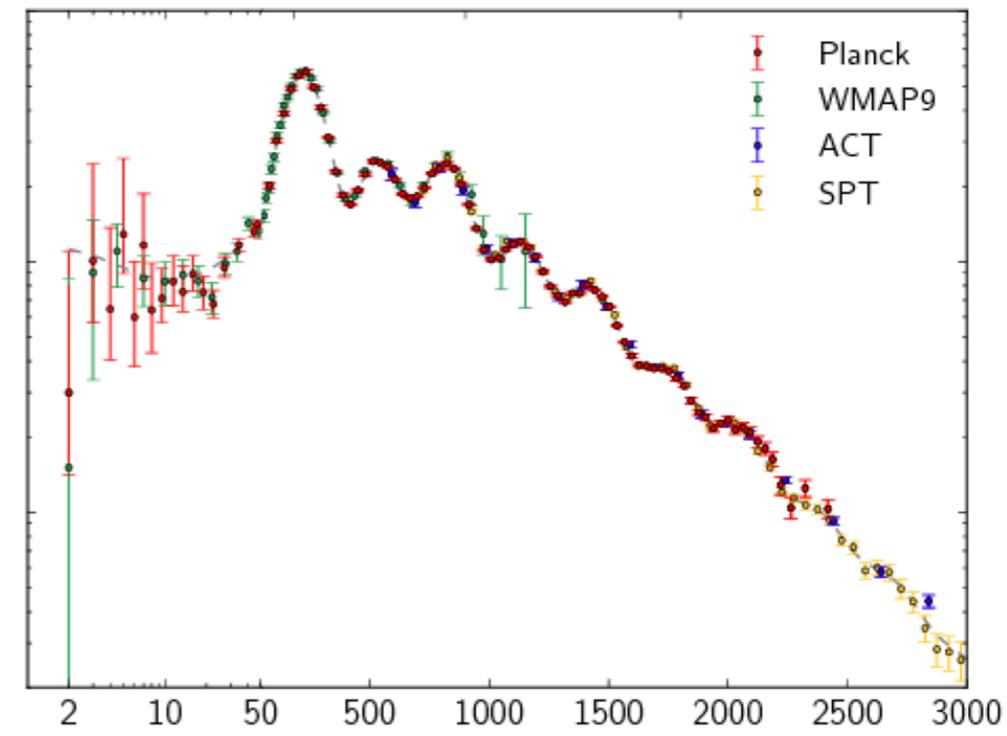
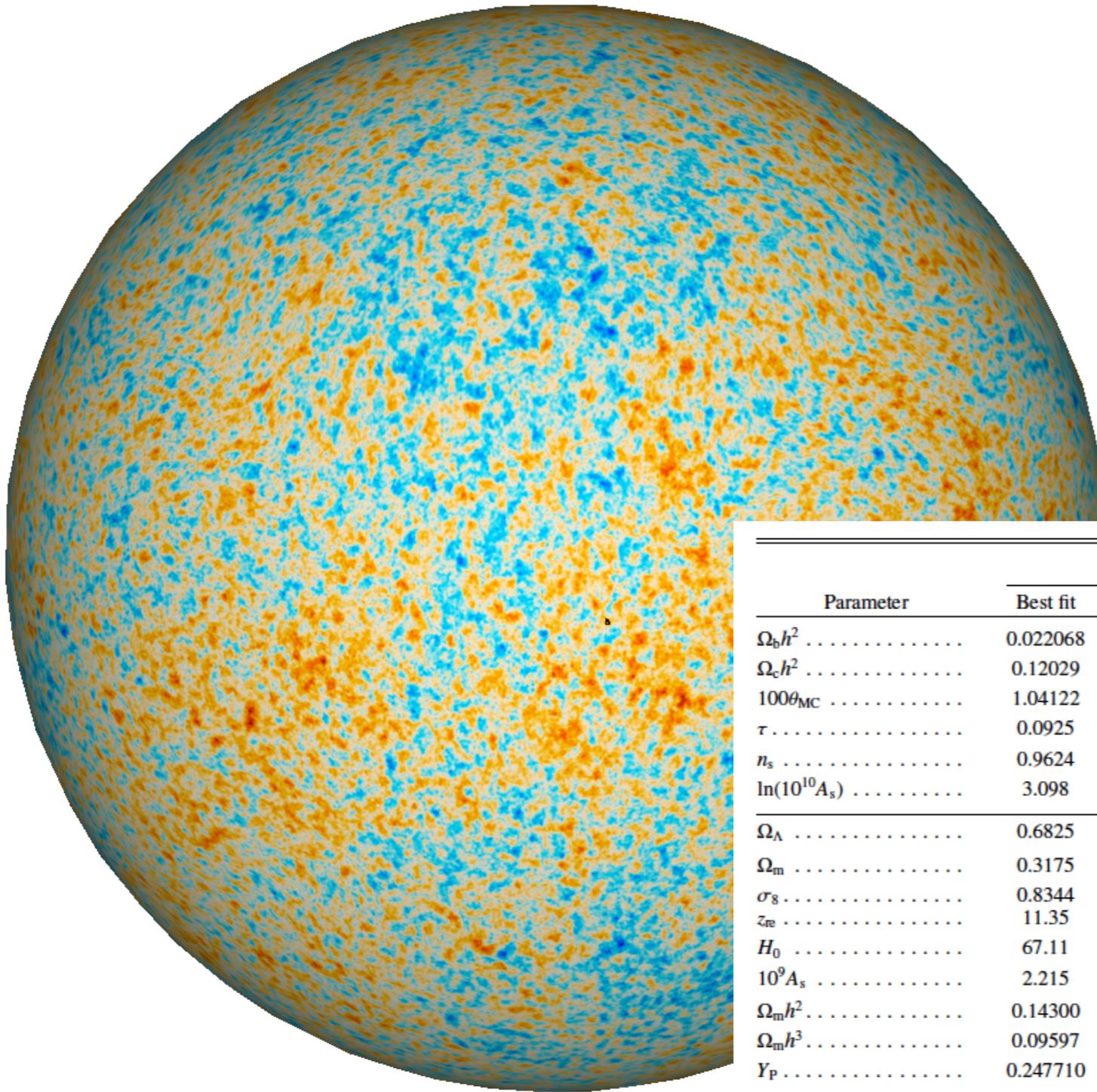
$$\langle A_{\vec{k}_1} A_{\vec{k}_2} \cdots \rangle = ?$$

$$\frac{\delta T}{T} \sim A_{\vec{k}} \cos(c_s k \tau)$$

Recombination:

$$c_s \sim \frac{1}{\sqrt{3(1 + R_b)}}$$

+ diffusion, gravitational forces / redshift, etc.

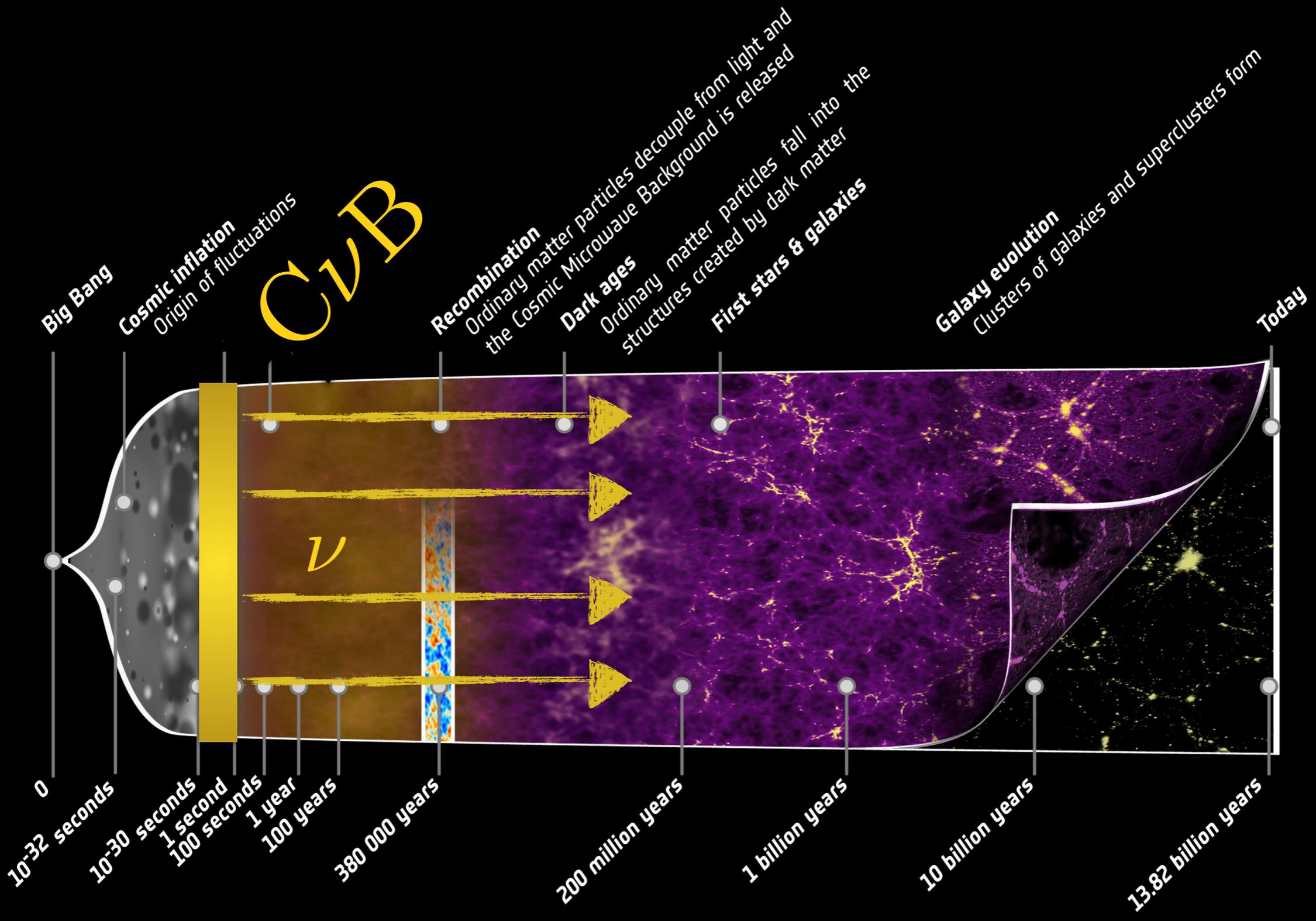


Parameter	Planck		Planck+lensing		Planck+WP	
	Best fit	68% limits	Best fit	68% limits	Best fit	68% limits
$\Omega_b h^2$	0.022068	$0.02207 \pm 0.00033$	0.022242	$0.02217 \pm 0.00033$	0.022032	$0.02205 \pm 0.00028$
$\Omega_c h^2$	0.12029	$0.1196 \pm 0.0031$	0.11805	$0.1186 \pm 0.0031$	0.12038	$0.1199 \pm 0.0027$
$100\theta_{MC}$	1.04122	$1.04132 \pm 0.00068$	1.04150	$1.04141 \pm 0.00067$	1.04119	$1.04131 \pm 0.00063$
$\tau$	0.0925	$0.097 \pm 0.038$	0.0949	$0.089 \pm 0.032$	0.0925	$0.089^{+0.012}_{-0.014}$
$n_s$	0.9624	$0.9616 \pm 0.0094$	0.9675	$0.9635 \pm 0.0094$	0.9619	$0.9603 \pm 0.0073$
$\ln(10^{10} A_s)$	3.098	$3.103 \pm 0.072$	3.098	$3.085 \pm 0.057$	3.0980	$3.089^{+0.024}_{-0.027}$
$\Omega_\Lambda$	0.6825	$0.686 \pm 0.020$	0.6964	$0.693 \pm 0.019$	0.6817	$0.685^{+0.018}_{-0.016}$
$\Omega_m$	0.3175	$0.314 \pm 0.020$	0.3036	$0.307 \pm 0.019$	0.3183	$0.315^{+0.016}_{-0.018}$
$\sigma_8$	0.8344	$0.834 \pm 0.027$	0.8285	$0.823 \pm 0.018$	0.8347	$0.829 \pm 0.012$
$z_{re}$	11.35	$11.4^{+4.0}_{-2.8}$	11.45	$10.8^{+3.1}_{-2.5}$	11.37	$11.1 \pm 1.1$
$H_0$	67.11	$67.4 \pm 1.4$	68.14	$67.9 \pm 1.5$	67.04	$67.3 \pm 1.2$
$10^9 A_s$	2.215	$2.23 \pm 0.16$	2.215	$2.19^{+0.12}_{-0.14}$	2.215	$2.196^{+0.051}_{-0.060}$
$\Omega_m h^2$	0.14300	$0.1423 \pm 0.0029$	0.14094	$0.1414 \pm 0.0029$	0.14305	$0.1426 \pm 0.0025$
$\Omega_m h^3$	0.09597	$0.09590 \pm 0.00059$	0.09603	$0.09593 \pm 0.00058$	0.09591	$0.09589 \pm 0.00057$
$Y_p$	0.247710	$0.24771 \pm 0.00014$	0.247785	$0.24775 \pm 0.00014$	0.247695	$0.24770 \pm 0.00012$
Age/Gyr	13.819	$13.813 \pm 0.058$	13.784	$13.796 \pm 0.058$	13.8242	$13.817 \pm 0.048$
$z_*$	1090.43	$1090.37 \pm 0.65$	1090.01	$1090.16 \pm 0.65$	1090.48	$1090.43 \pm 0.54$
$r_*$	144.58	$144.75 \pm 0.66$	145.02	$144.96 \pm 0.66$	144.58	$144.71 \pm 0.60$
$100\theta_*$	1.04139	$1.04148 \pm 0.00066$	1.04164	$1.04156 \pm 0.00066$	1.04136	$1.04147 \pm 0.00062$
$z_{drag}$	1059.32	$1059.29 \pm 0.65$	1059.59	$1059.43 \pm 0.64$	1059.25	$1059.25 \pm 0.58$
$r_{drag}$	147.34	$147.53 \pm 0.64$	147.74	$147.70 \pm 0.63$	147.36	$147.49 \pm 0.59$
$k_D$	0.14026	$0.14007 \pm 0.00064$	0.13998	$0.13996 \pm 0.00062$	0.14022	$0.14009 \pm 0.00063$
$100\theta_D$	0.161332	$0.16137 \pm 0.00037$	0.161196	$0.16129 \pm 0.00036$	0.161375	$0.16140 \pm 0.00034$
$z_{eq}$	3402	$3386 \pm 69$	3352	$3362 \pm 69$	3403	$3391 \pm 60$
$100\theta_{eq}$	0.8128	$0.816 \pm 0.013$	0.8224	$0.821 \pm 0.013$	0.8125	$0.815 \pm 0.011$
$r_{drag}/D_V(0.57)$	0.07130	$0.0716 \pm 0.0011$	0.07207	$0.0719 \pm 0.0011$	0.07126	$0.07147 \pm 0.00091$

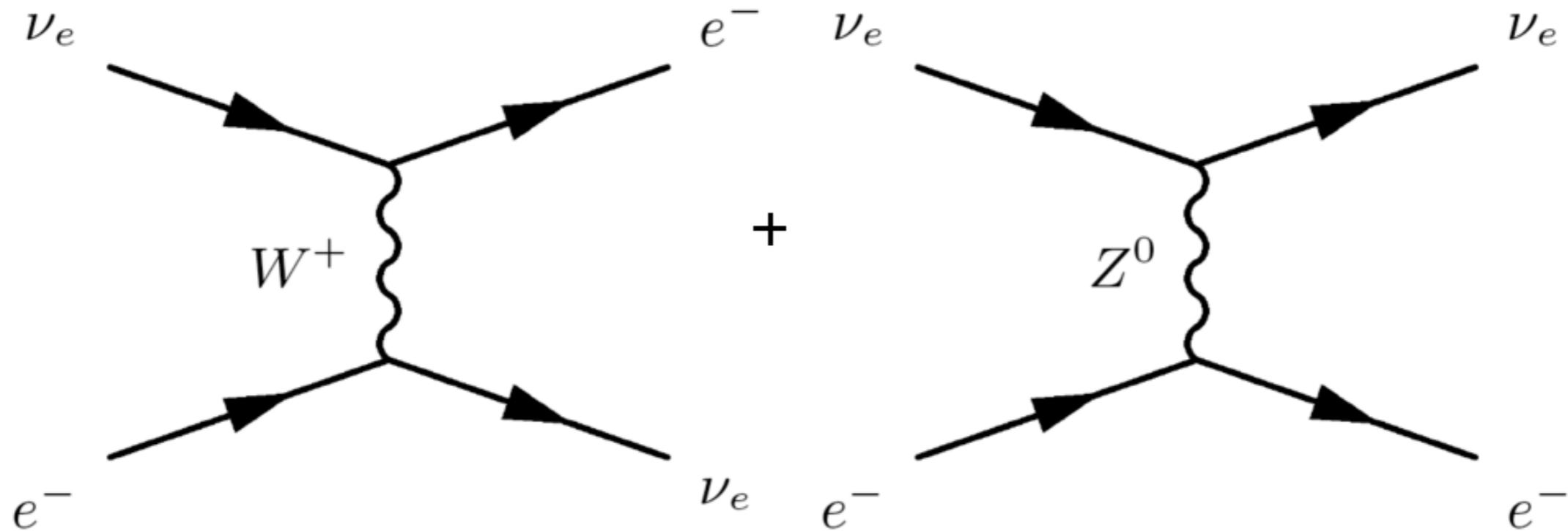
Courtesy of thecmb.org

# Cosmic Neutrinos





# Cosmic Neutrino Background



Equilibrium :

$$\Gamma \sim G_F^2 T^5 > H \sim \frac{T^2}{M_{\text{pl}}}$$

Decoupling:  $T^3 \sim G_F^{-2} / M_{\text{pl}} = \mathcal{O}(1 \text{ MeV})$

# Cosmic Neutrino Background

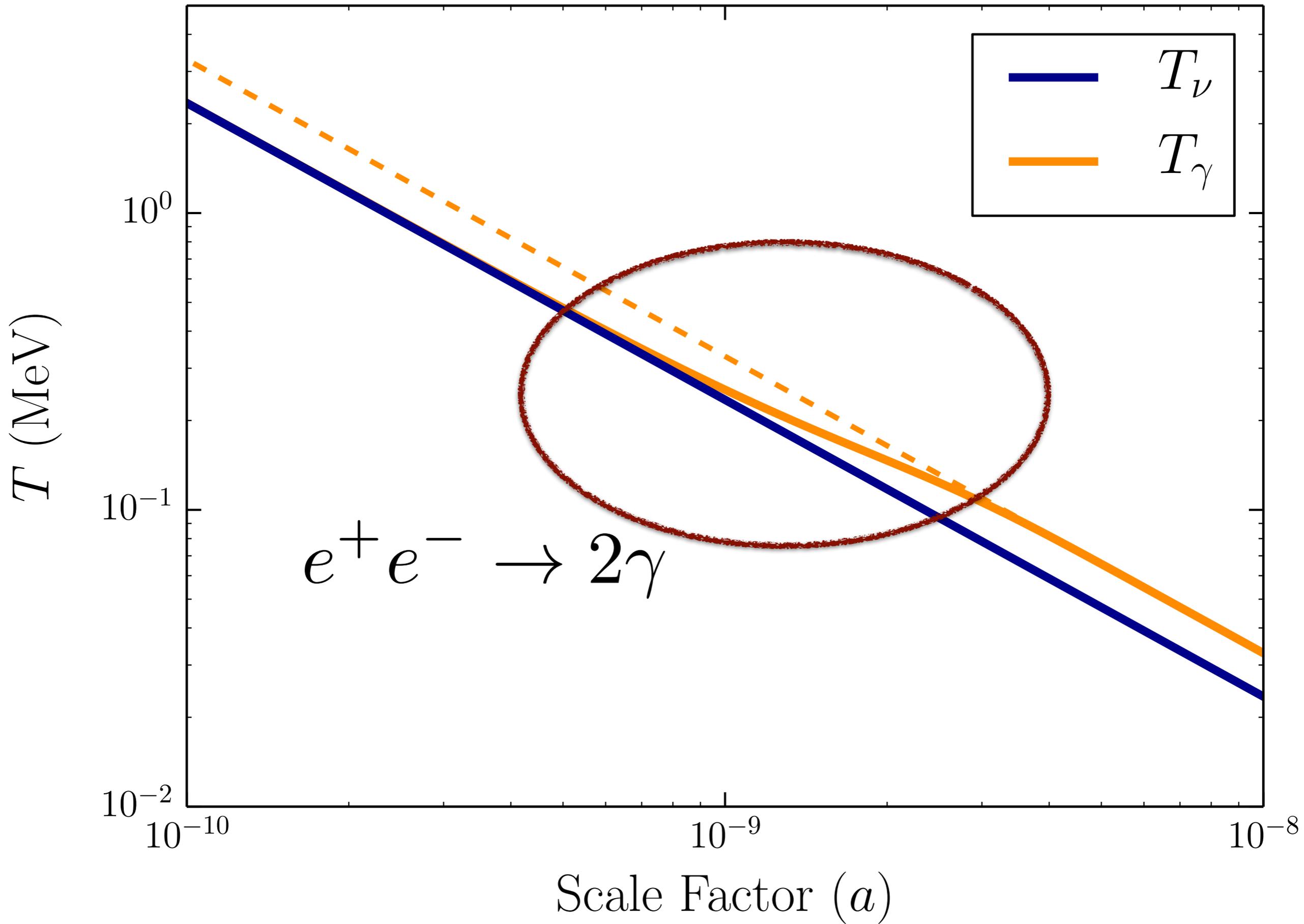
In equilibrium, light fields share entropy evenly

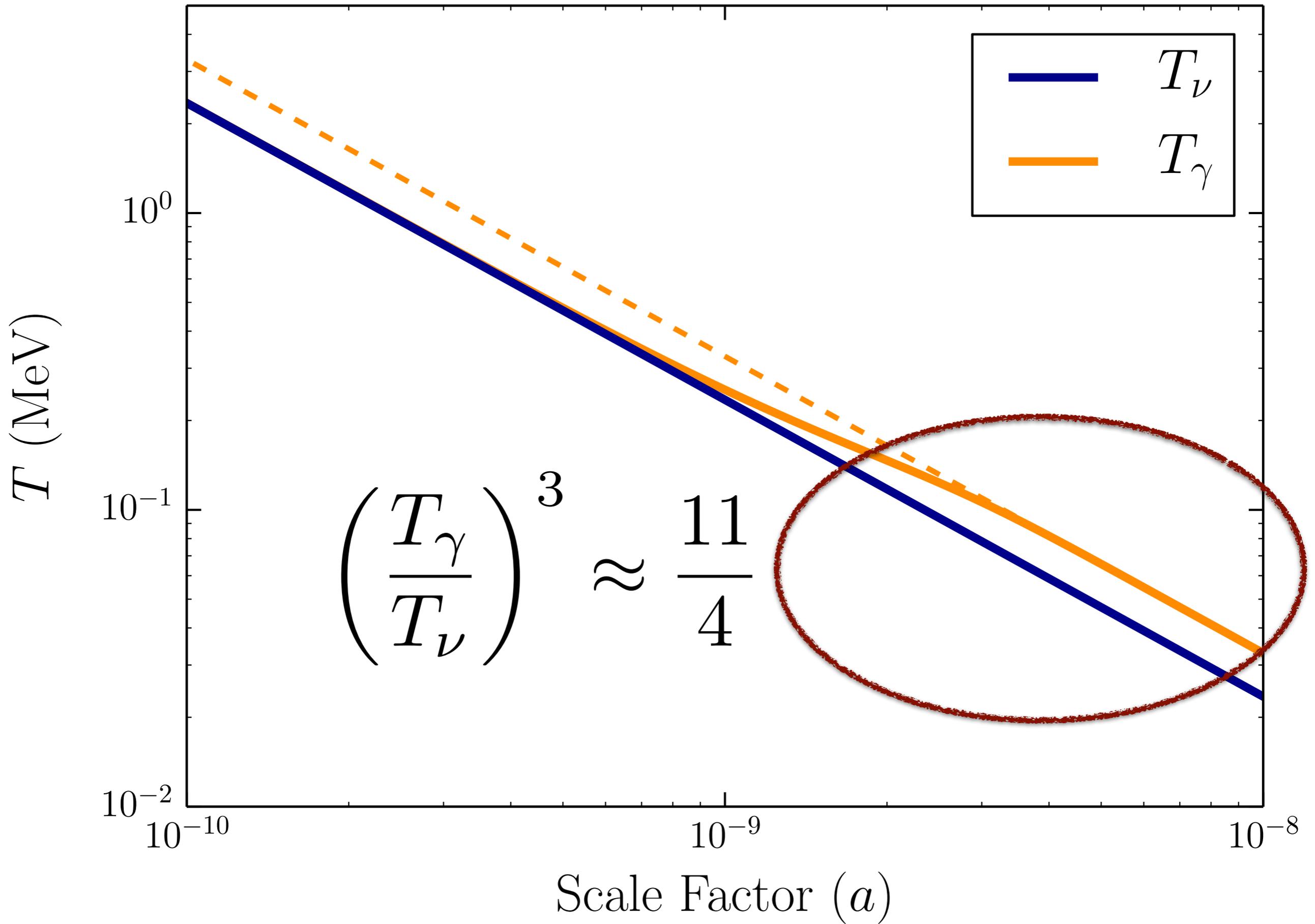
$$s \propto g_{\star}(T)T^3 \quad g_{\star} \approx N_{\text{bosons}} + \frac{7}{8}N_{\text{fermions}}$$

Neutrino number density  $\approx$  photon number density

All the power of cosmology starts here

The Universe prepares for us a pristine, high-density state of neutrinos





# Cosmic Neutrino Background

Cosmology sensitive to the neutrino energy density

Conventional to define

$$N_{\text{eff}} \equiv \frac{8}{7} \left( \frac{11}{4} \right)^{4/3} \frac{\rho_\nu}{\rho_\gamma}$$

Perfect decoupling :  $N_{\text{eff}} = 3.$

Imperfect decoupling + QED :  $N_{\text{eff}} = 3.045$

Salas & Pastor (2016);  
Mangano et al. (2005)

# Cosmic Neutrino Background

After decoupling the state doesn't change

$$f(p, t) = \frac{1}{e^{p/T_\nu} + 1}$$

where  $T_\nu, p \propto a^{-1}$

Neutrino temperature redshifts like CMB

$$T_{\text{CMB}} = 2.72 \text{ K} \quad \rightarrow \quad T_\nu = 1.95 \text{ K}$$

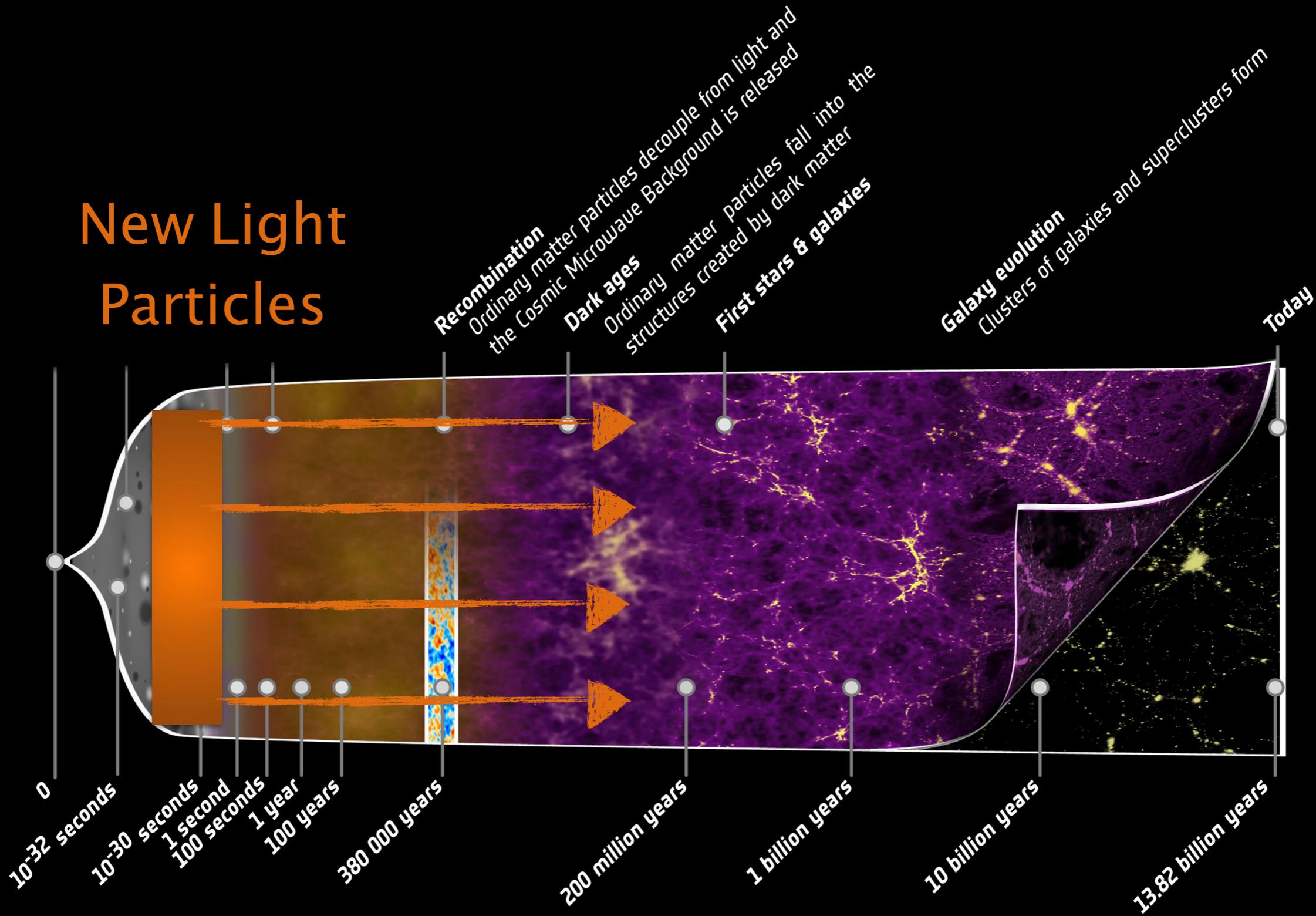
Today, these are very low energy neutrinos

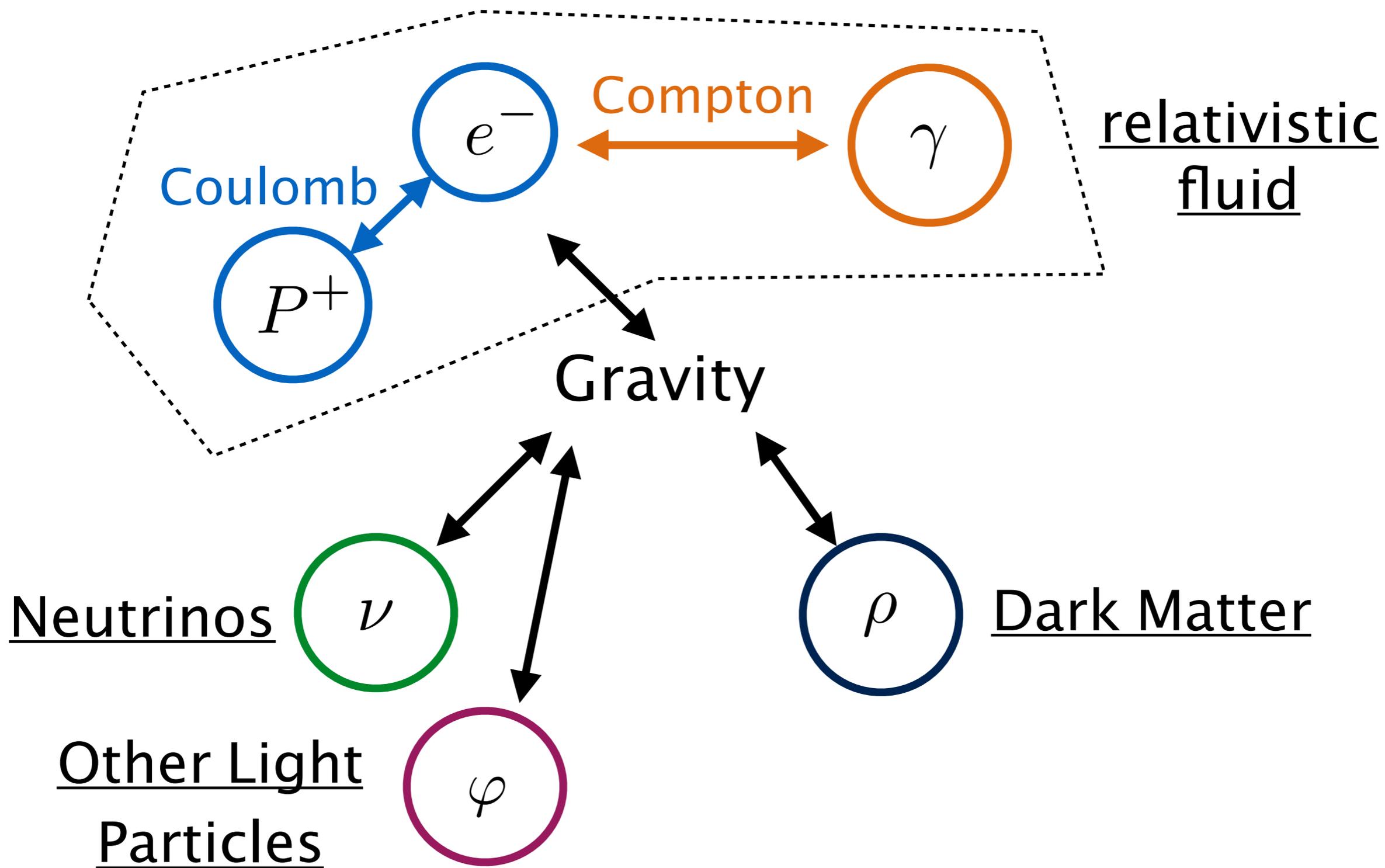
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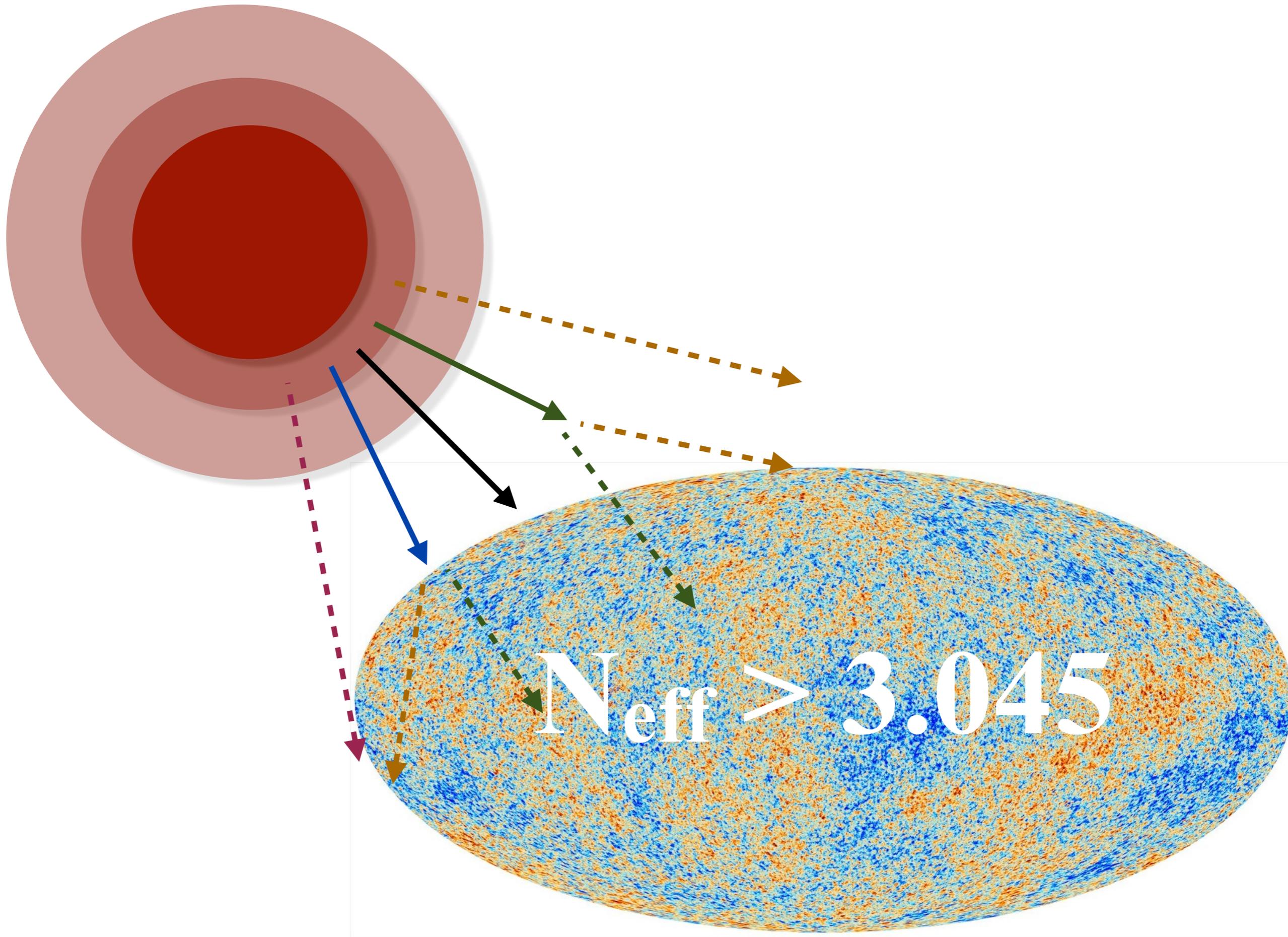
# Light Relics



# New Light Particles







# Light Relics

Any light thermalized particle looks like a neutrino

If a light particle decouples at temperature  $T_F$

Only diluted by annihilation after decoupling

$$\Delta N_{\text{eff}} = N_{\text{eff}} - 3.045 = \boxed{g_s} \frac{4}{7} \left( \frac{43}{\boxed{4g_*(T_F)}} \right)^{4/3}$$

Light relics degrees of freedom

Standard Model degrees of freedom

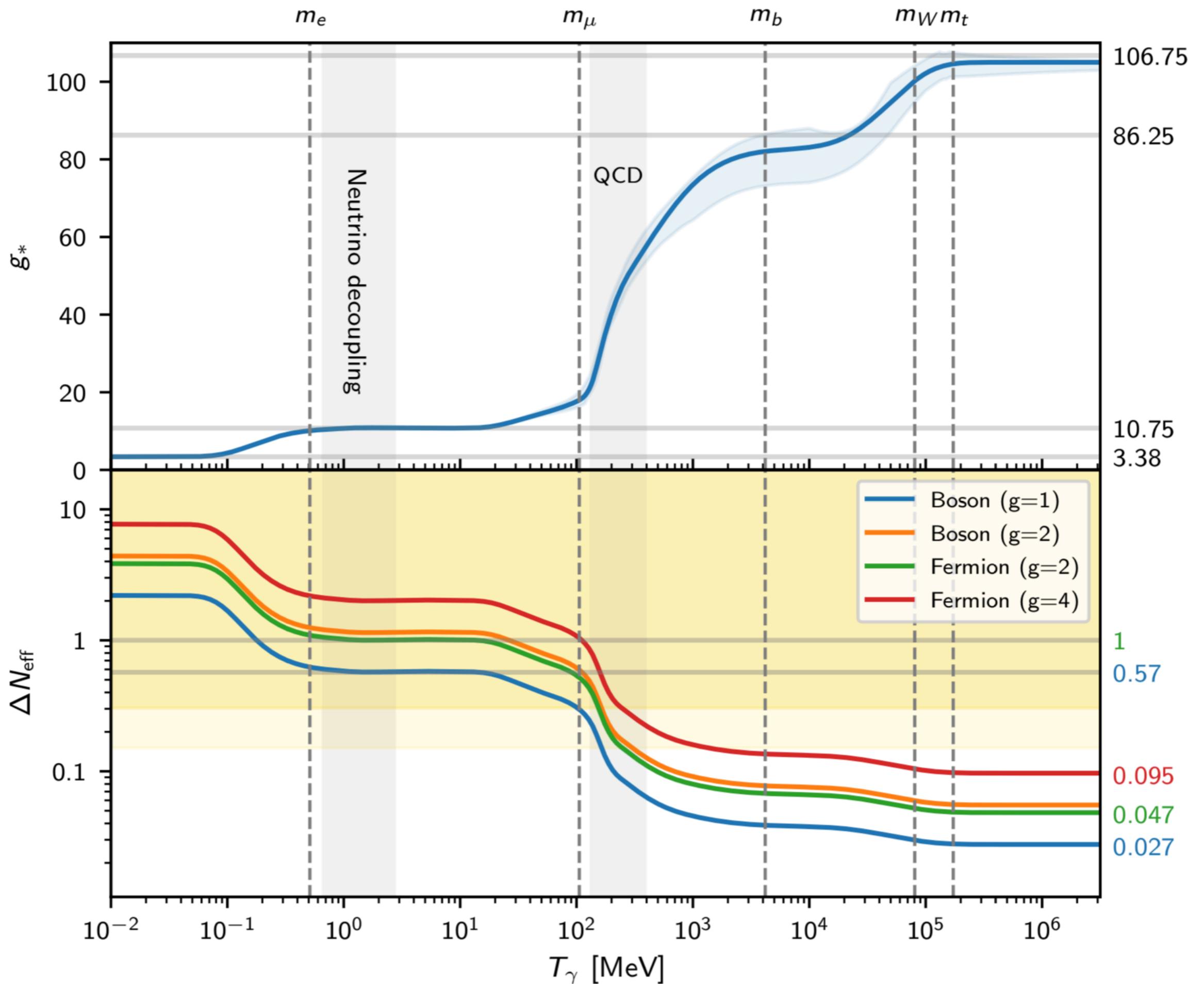
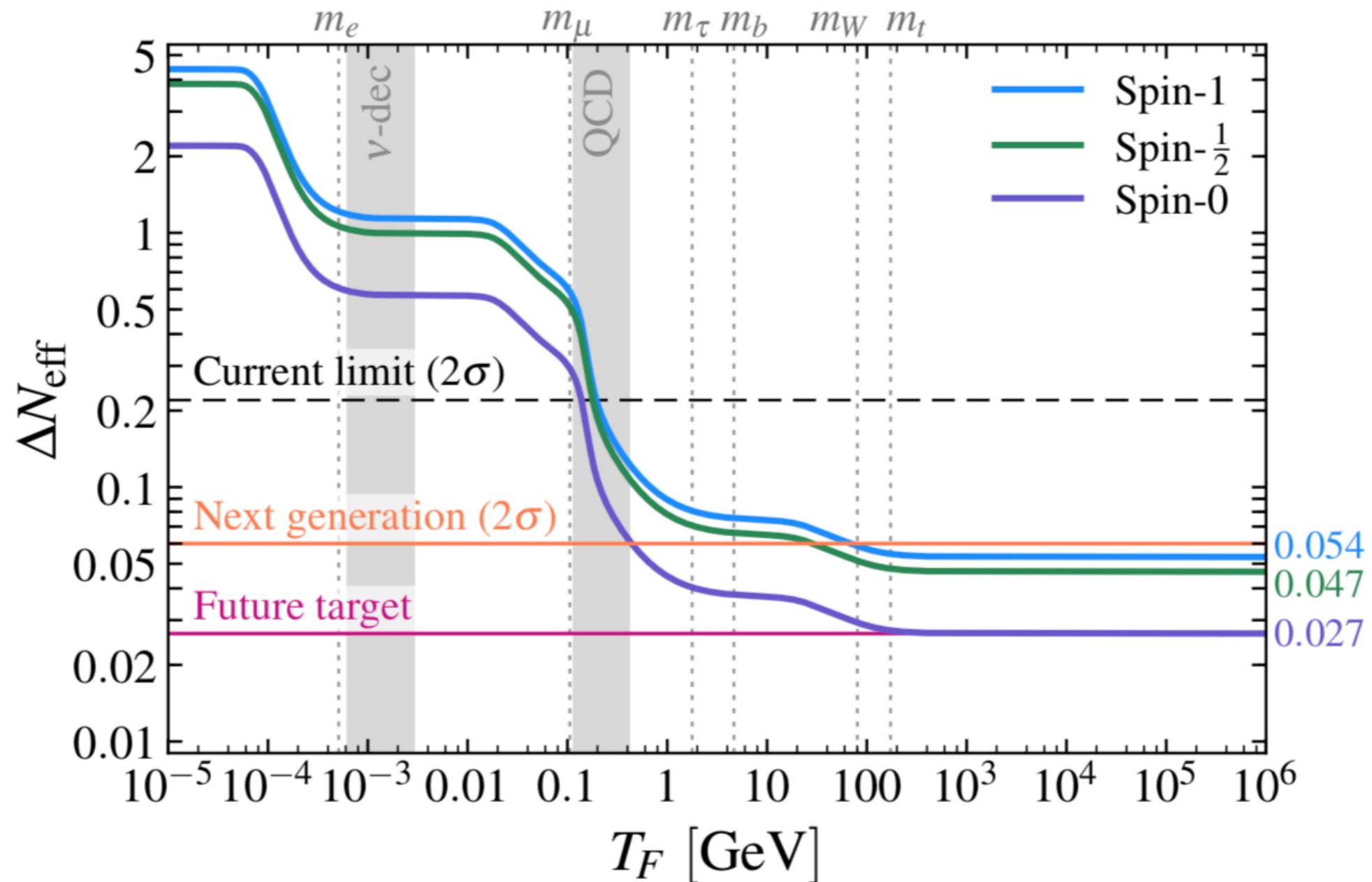


Image from Planck 2018

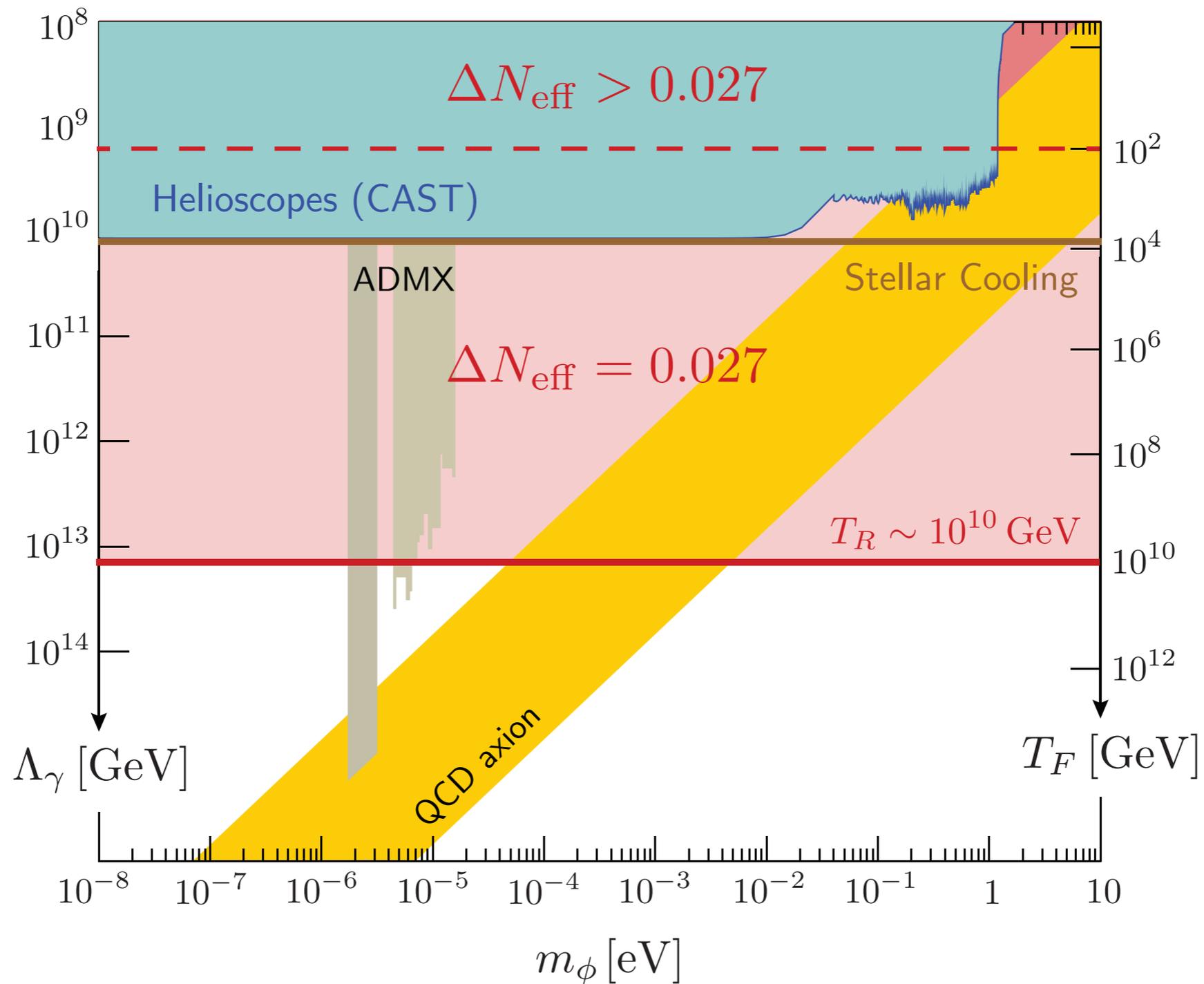
# Light Relics

Coming generations will make a lot of progress



# Implications for Axions

$\Lambda_\gamma$



Baumann, DG & Wallisch (2016)

# Implications for Axions

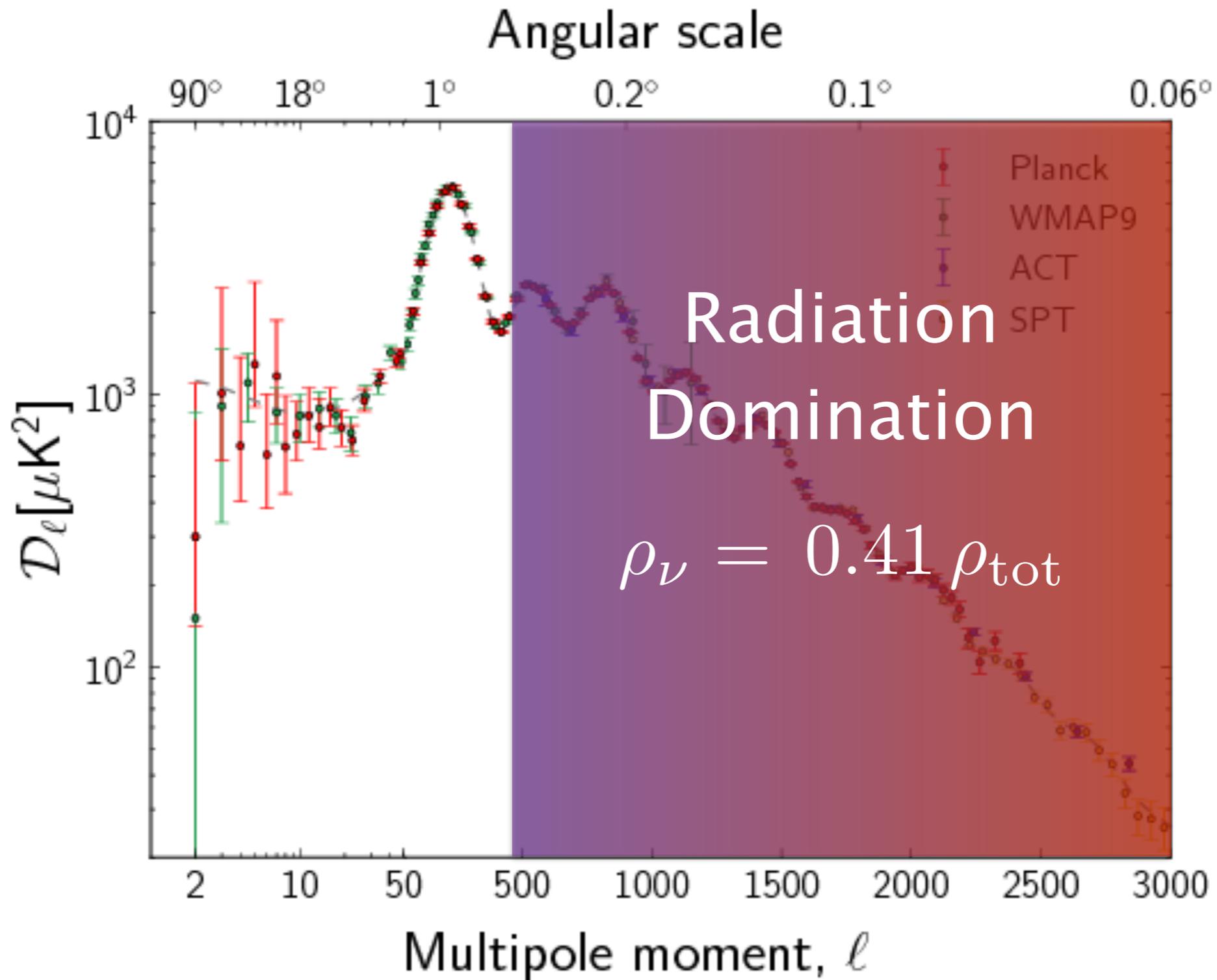
Coupling	Current Constraints		Future CMB Constraints		
	Bound [GeV]	Origin	Freeze-Out [GeV]	Freeze-In [GeV]	$\Delta\tilde{N}_{\text{eff}}$
$\Lambda_{ee}$	$1.2 \times 10^{10}$	White dwarfs	$6.0 \times 10^7$	$2.7 \times 10^6$	1.3
$\Lambda_{\mu\mu}$	$2.0 \times 10^6$	Stellar cooling	$1.2 \times 10^{10}$	$3.4 \times 10^7$	0.5
$\Lambda_{\tau\tau}$	$2.5 \times 10^4$	Stellar cooling	$2.1 \times 10^{11}$	$9.5 \times 10^7$	0.05
$\Lambda_{bb}$	$6.1 \times 10^5$	Stellar cooling	$9.5 \times 10^{11}$	–	0.04
$\Lambda_{tt}$	$1.2 \times 10^9$	Stellar cooling	$3.5 \times 10^{13}$	–	0.03
$\Lambda_{\mu e}^V$	$5.5 \times 10^9$	$\mu^+ \rightarrow e^+ \phi$	$6.2 \times 10^9$	$4.8 \times 10^7$	0.5
$\Lambda_{\mu e}$	$3.1 \times 10^9$	$\mu^+ \rightarrow e^+ \phi \gamma$	$6.2 \times 10^9$	$4.8 \times 10^7$	0.5
$\Lambda_{\tau e}$	$4.4 \times 10^6$	$\tau^- \rightarrow e^- \phi$	$1.0 \times 10^{11}$	$1.3 \times 10^8$	0.05
$\Lambda_{\tau\mu}$	$3.2 \times 10^6$	$\tau^- \rightarrow \mu^- \phi$	$1.0 \times 10^{11}$	$1.3 \times 10^8$	0.05
$\Lambda_{cu}^A$	$6.9 \times 10^5$	$D^0 - \bar{D}^0$	$1.3 \times 10^{11}$	$2.0 \times 10^8$	0.05
$\Lambda_{bd}^A$	$6.4 \times 10^5$	$B^0 - \bar{B}^0$	$4.8 \times 10^{11}$	$3.7 \times 10^8$	0.04
$\Lambda_{bs}$	$6.1 \times 10^7$	$b \rightarrow s\phi$	$4.8 \times 10^{11}$	$3.7 \times 10^8$	0.04
$\Lambda_{tu}$	$6.6 \times 10^9$	Mixing	$1.8 \times 10^{13}$	$2.1 \times 10^9$	0.03
$\Lambda_{tc}$	$2.2 \times 10^9$	Mixing	$1.8 \times 10^{13}$	$2.1 \times 10^9$	0.03

Baumann, DG & Wallisch (2016)



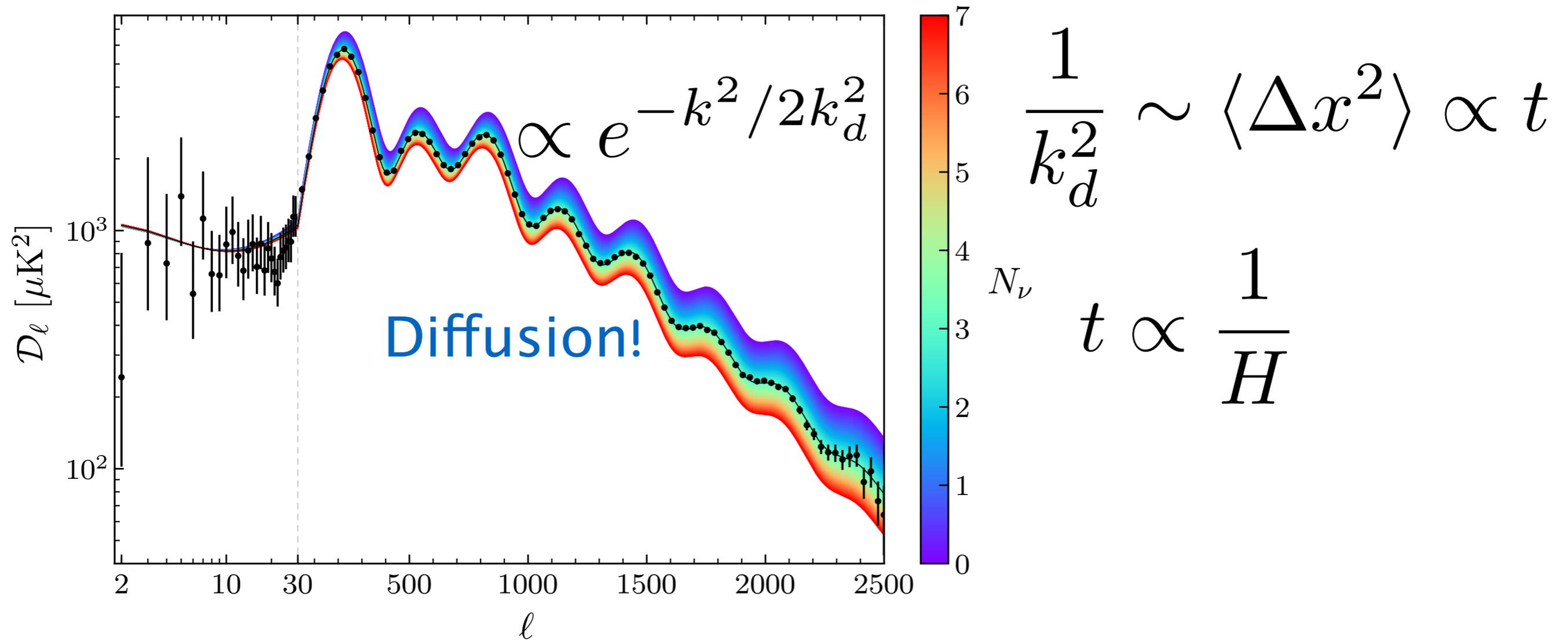
# Signals in the CMB

# Cosmic Microwave Background



# Cosmic Microwave Background

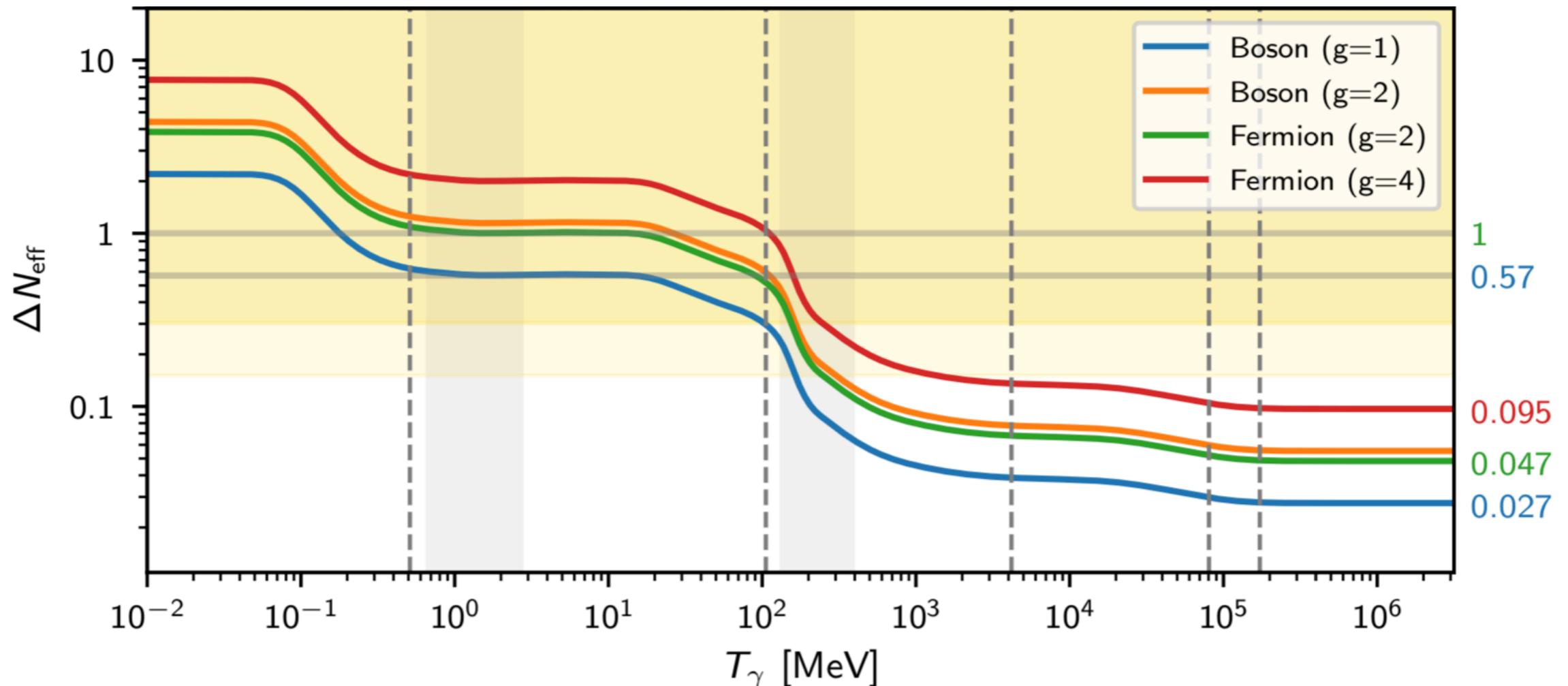
$$3M_{\text{pl}}^2 H^2 = \rho_\gamma + \rho_\nu$$



# Cosmic Microwave Background

Damping drives the constraints for  $\Lambda\text{CDM} + N_{\text{eff}}$

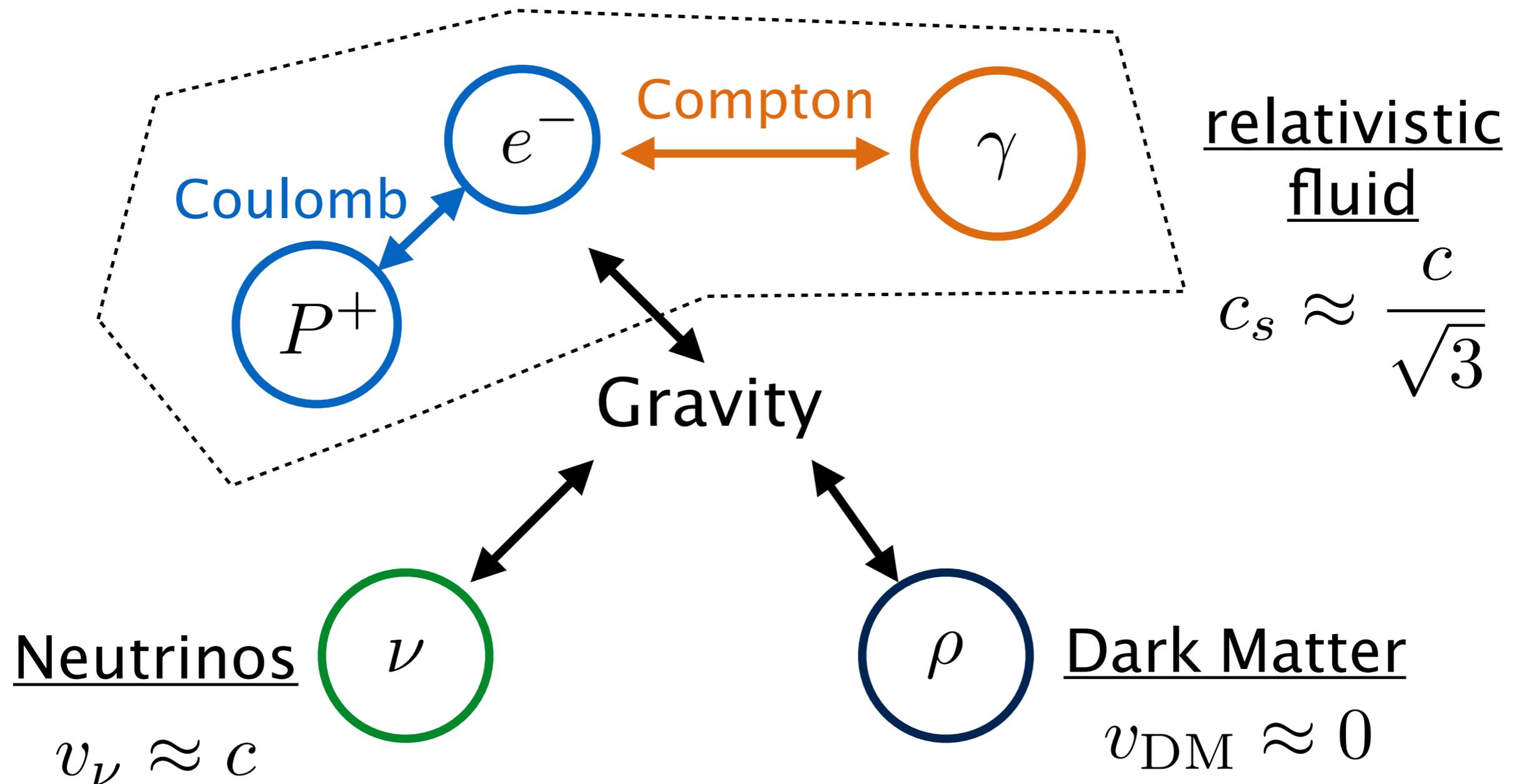
$$N_{\text{eff}} = 2.99 \pm 0.17 \text{ (TTTEEE + BAO + } \kappa\kappa\text{)}$$



Planck 2018

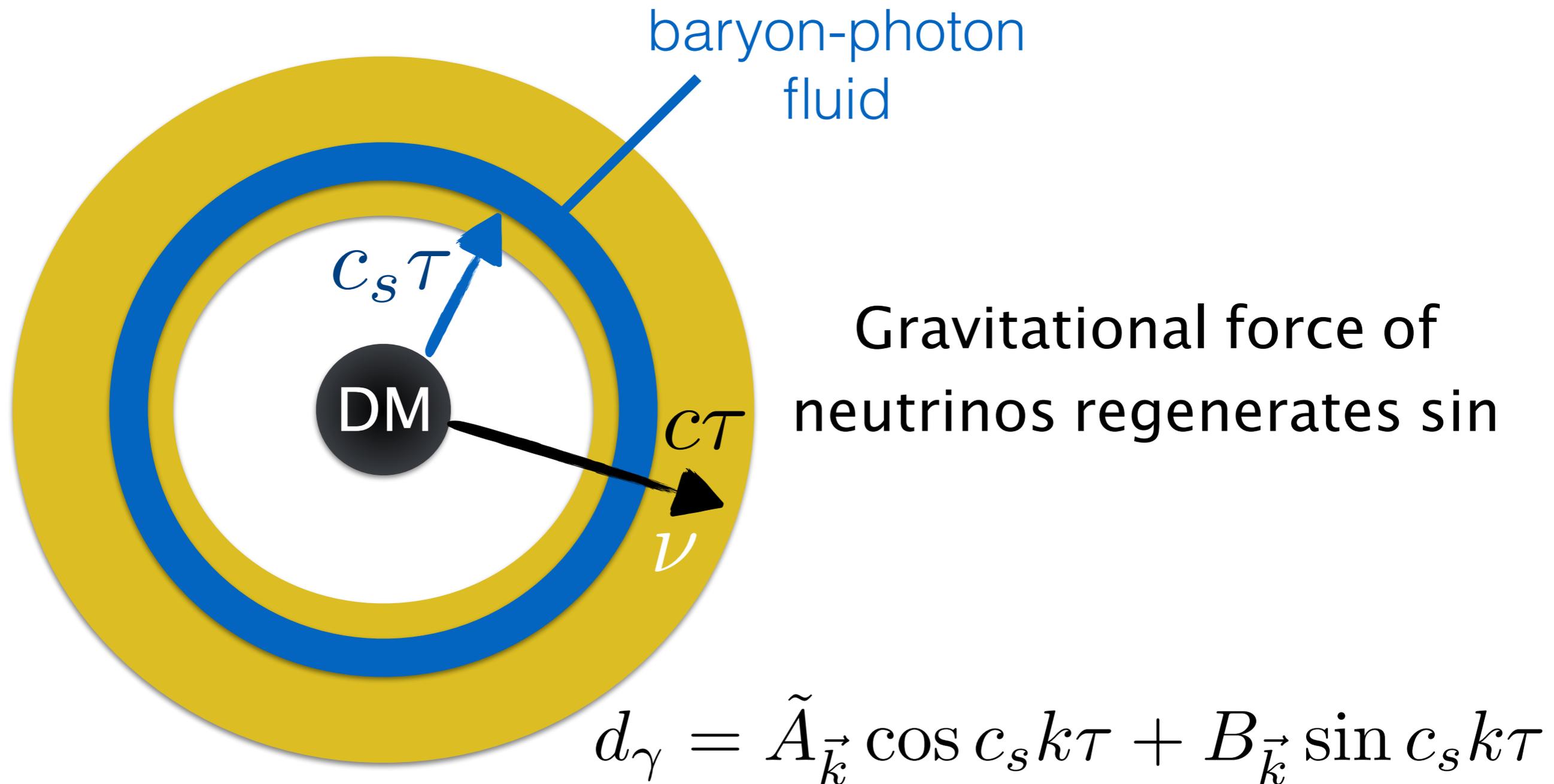
# Phase Shift

Neutrinos fluctuations move faster than sound



# Phase Shift

Information propagates ahead of the sound horizon

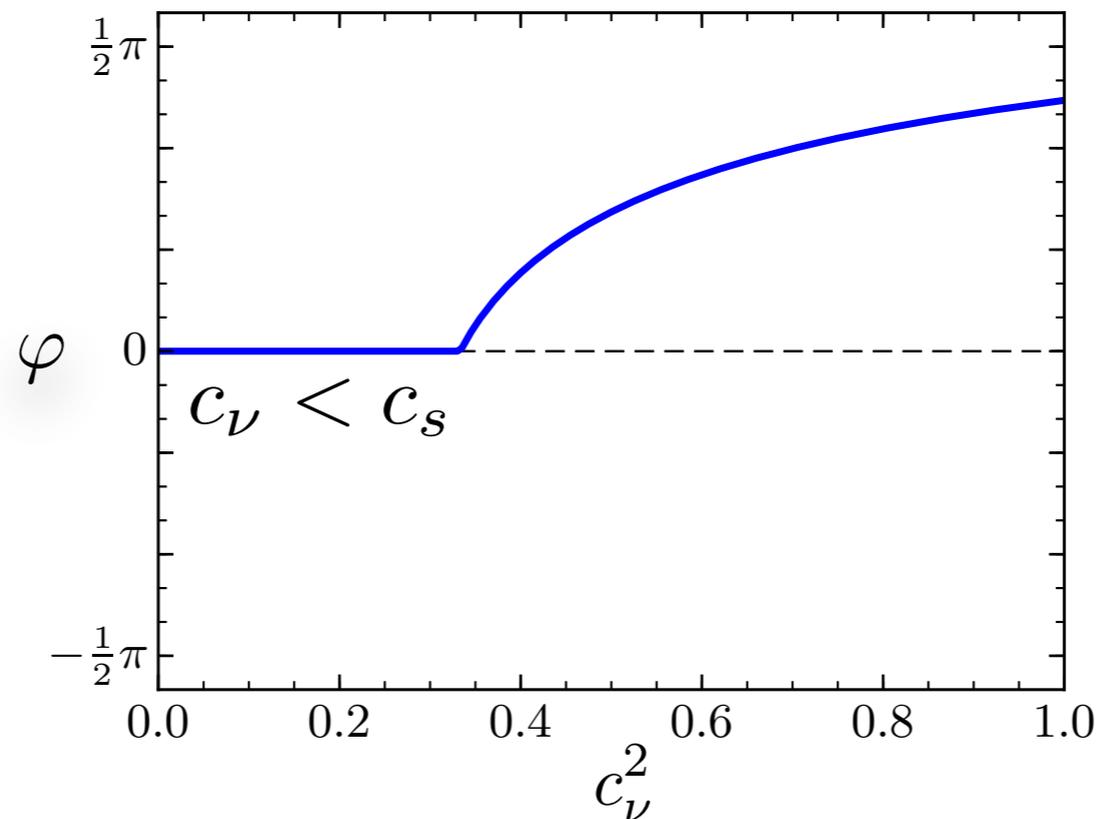


# Phase Shift

The sine is equivalent to a phase shift

$$\cos(kr_s) \rightarrow \cos(kr_s + \varphi) \quad \varphi \sim B/\tilde{A}$$

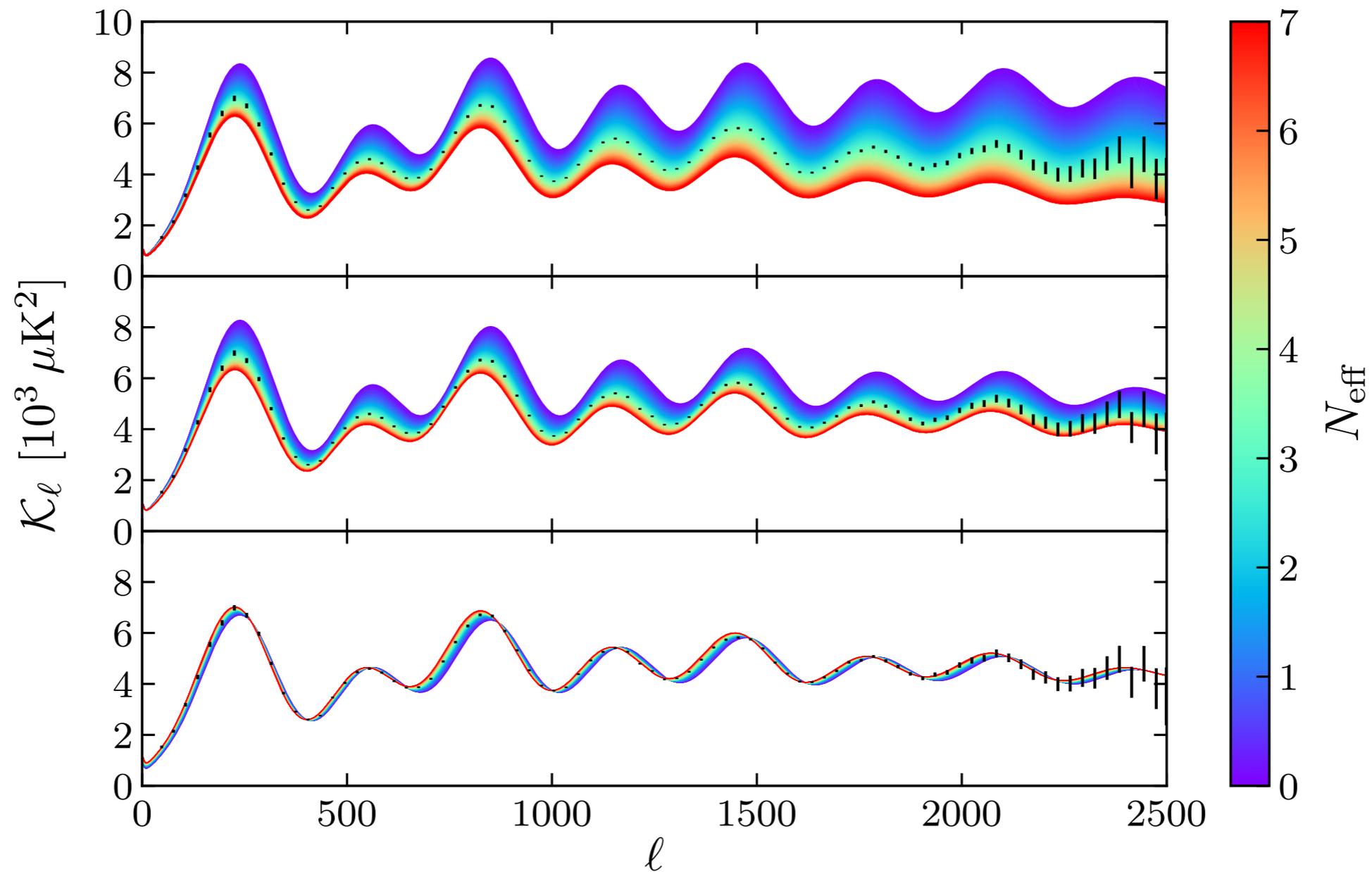
Supersonic fluctuations encoded in phase shift



Bashinsky & Seljak (2003); Baumann, DG, Meyers, Wallisch (2015)

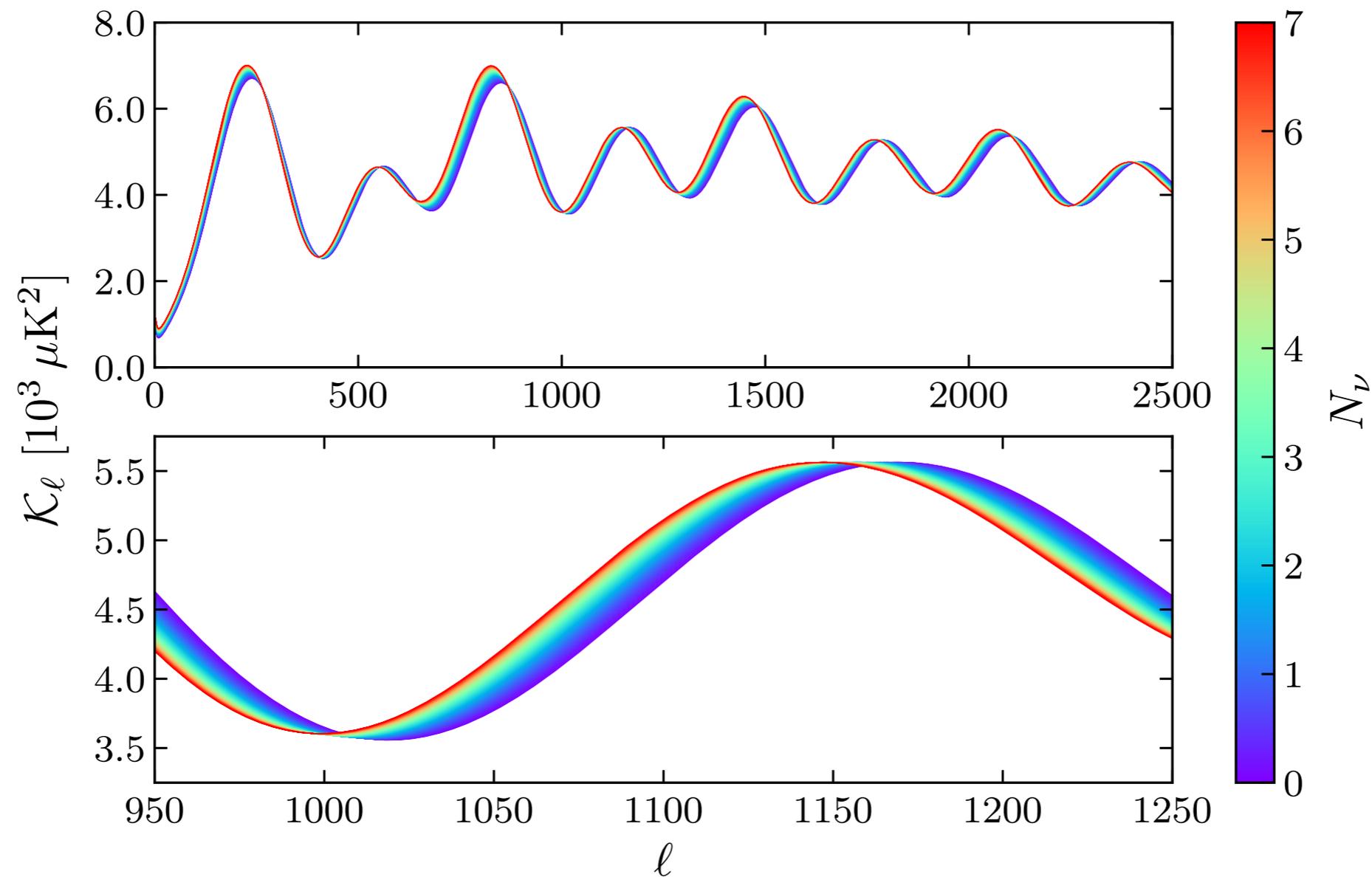
# Phase Shift

Neutrinos produce a unique shift in the CMB



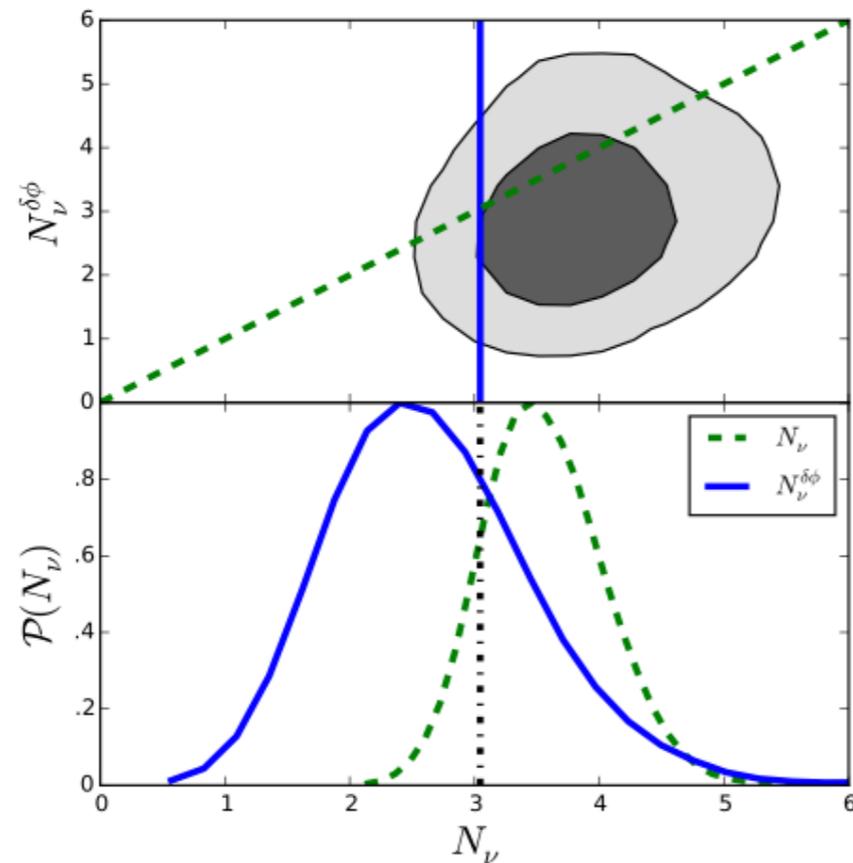
# Phase Shift

Neutrinos produce a unique shift in the CMB



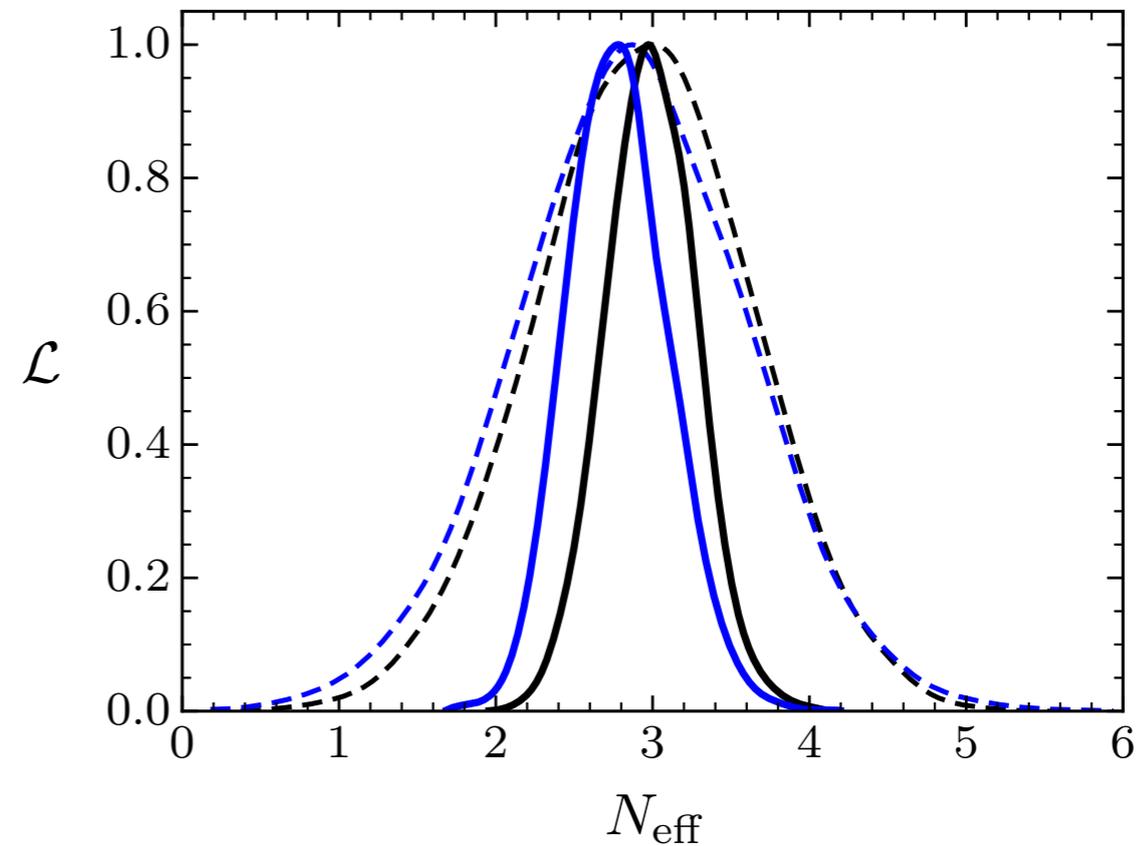
# Phase Shift

This phase shift is detected in the CMB



$$N_{\text{eff}}^{\text{phase}} = 2.3^{+1.1}_{-0.4}$$

Follin et al. (2015)



$$N_{\text{eff}}^{\text{phase}} = 2.68^{+0.29}_{-0.33}$$

Baumann, DG, Meyers, Wallisch (2015);  
Brust, Cui, Sigurdson (2017)

# Baryon Acoustic Oscillations (BAO)

Signal is frozen in distribution of galaxies / matter

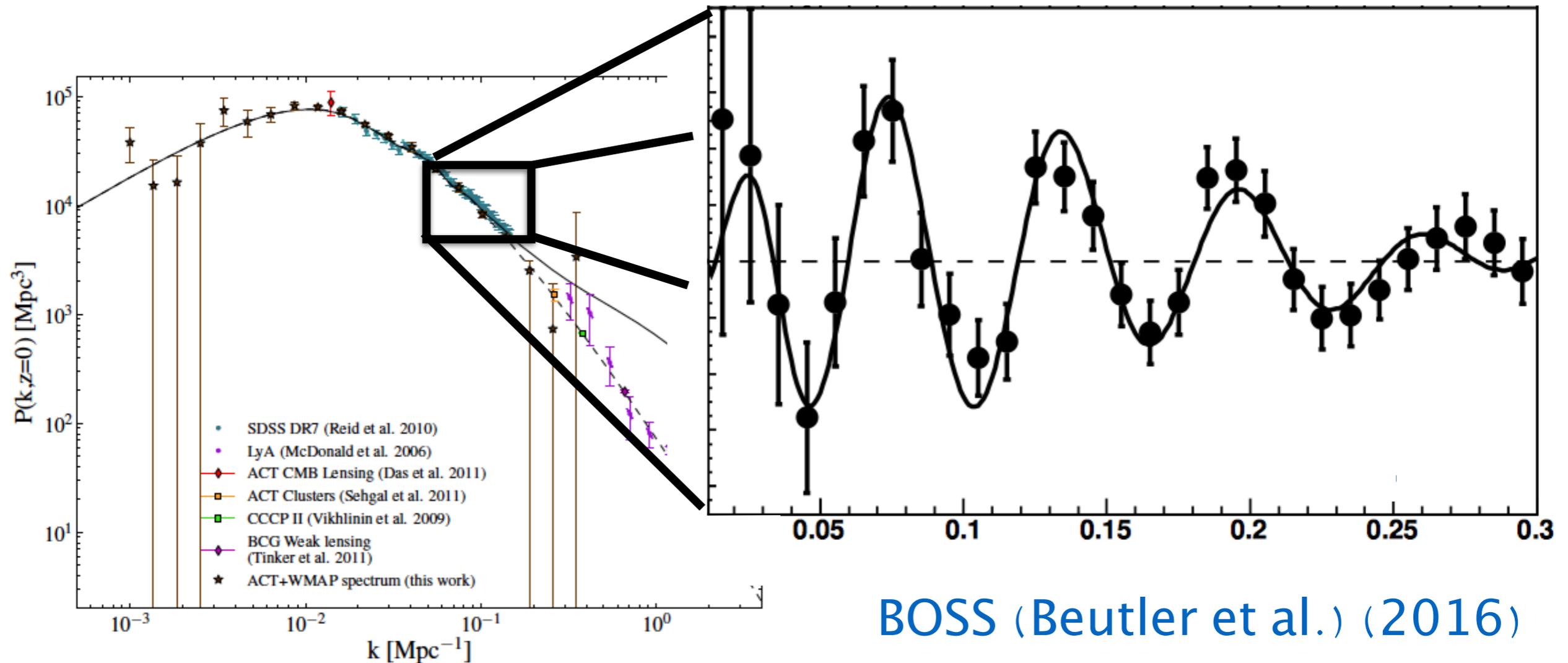
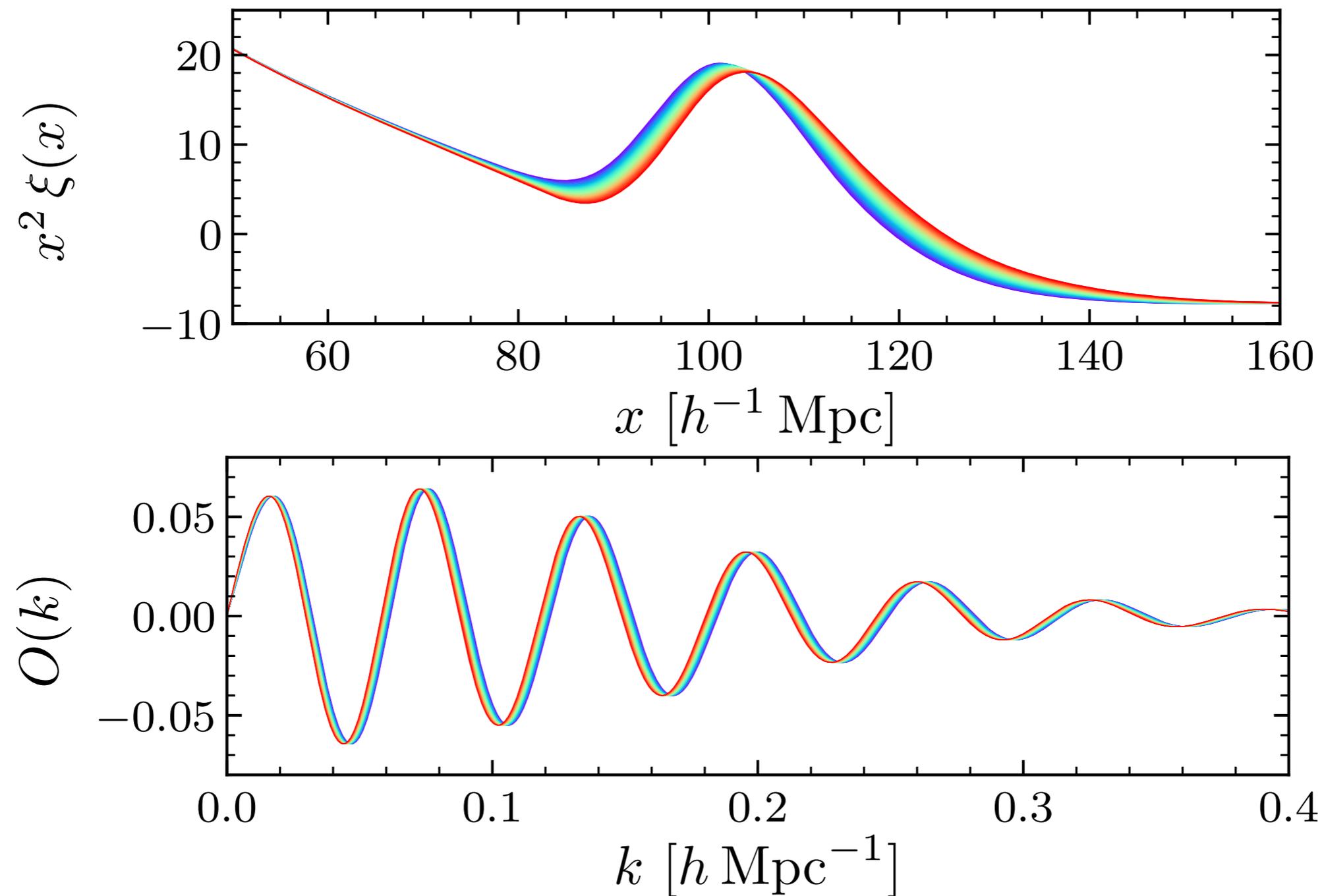


Figure from Hlozek et al.

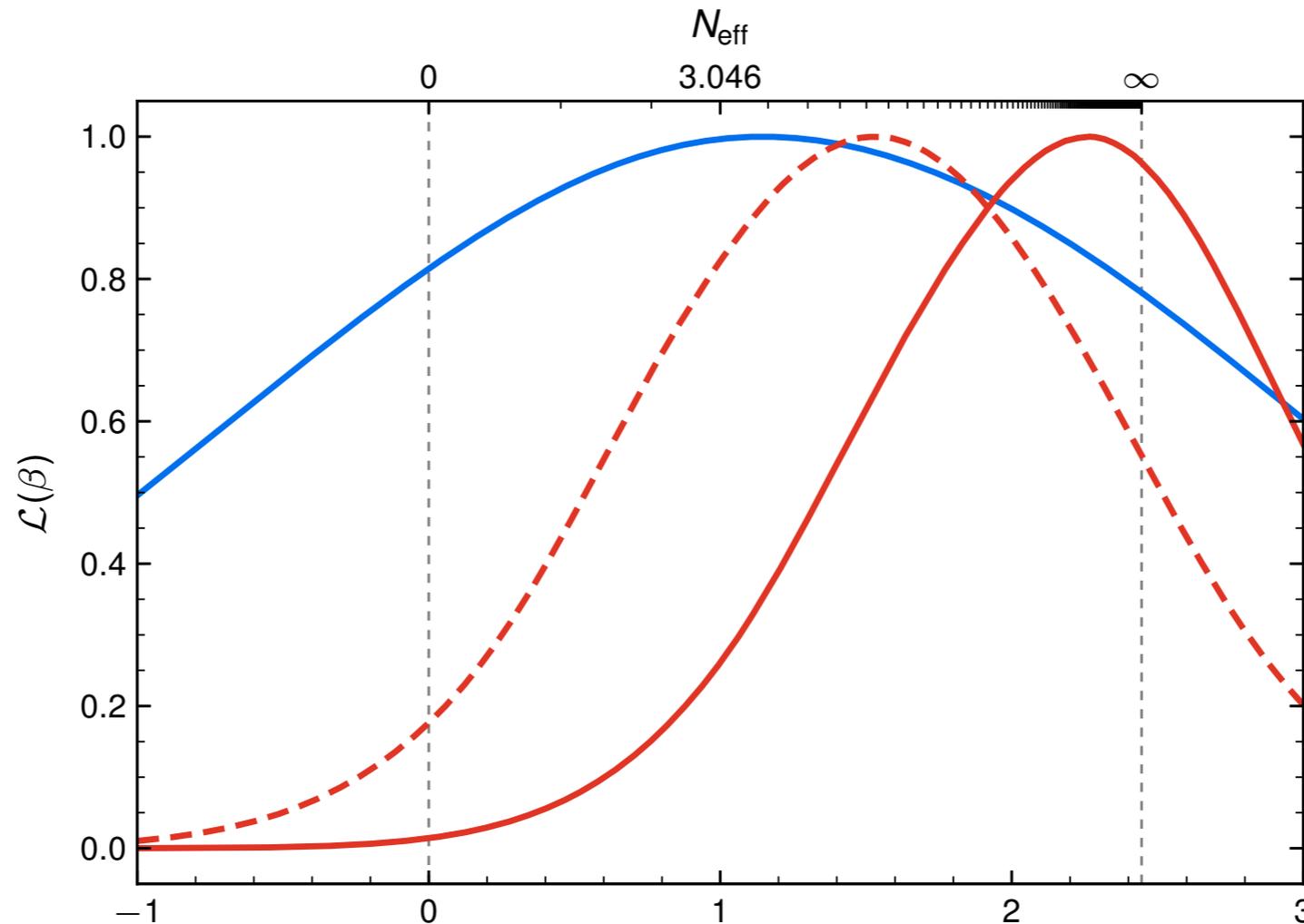
# BAO Phase Shift

Phase shift appears in BAO



# BAO Phase Shift

Applying same idea to BOSS data



Positive phase shift seen with 99.5% confidence

Baumann et al. (2018)

# Neutrino Mass



# Neutrino Mass

Neutrinos have mass

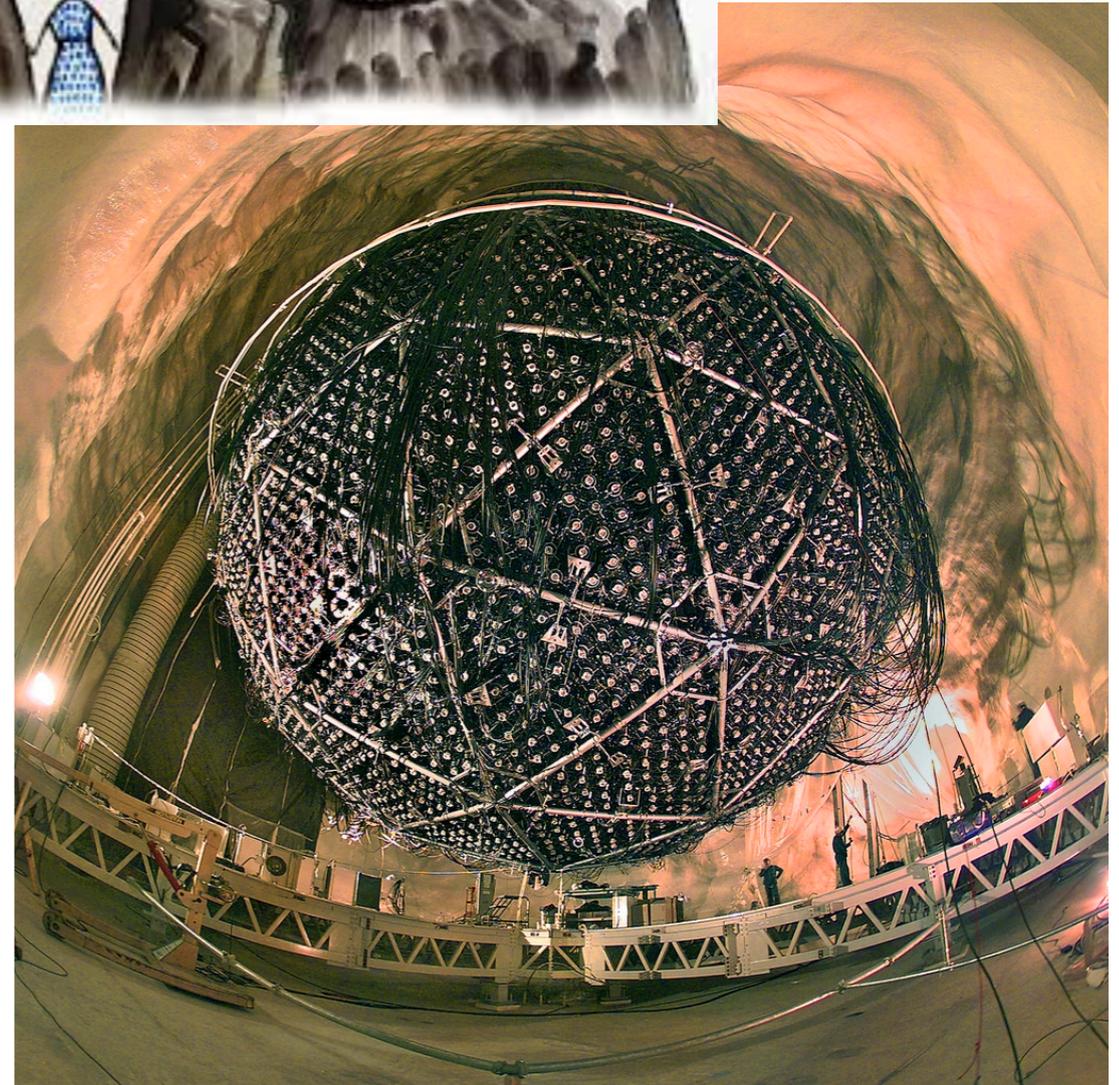
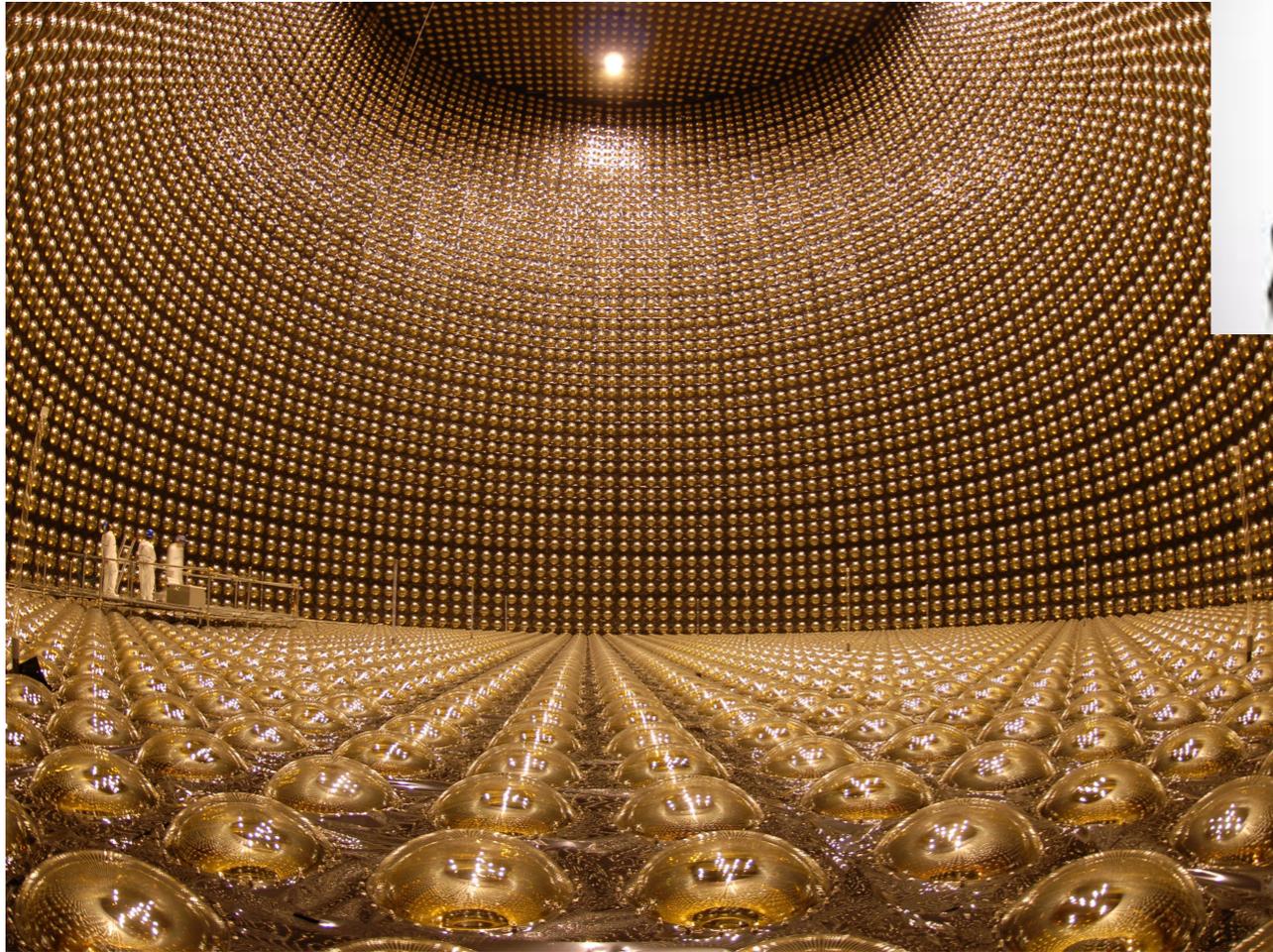
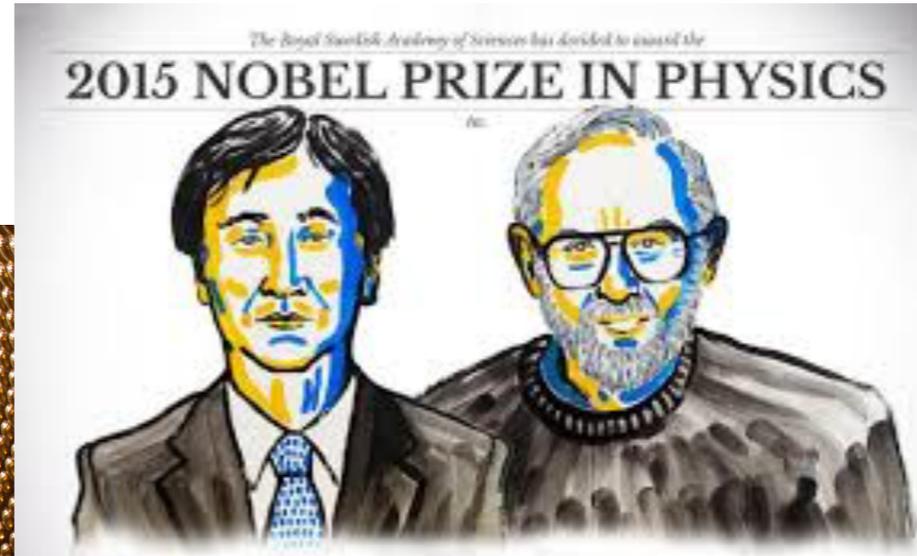
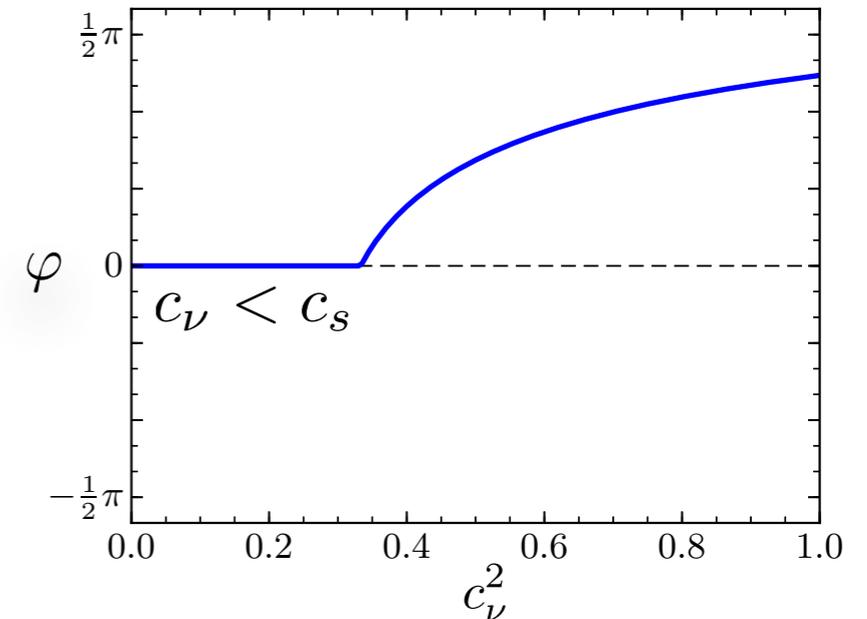


Image from Super-K ; SNO

# Neutrino Mass

We know neutrinos were relativistic at recombination

If it wasn't, then  $c_\nu \approx \frac{3T_\nu}{m_\nu} \ll 1$



Phase shift doesn't arise when non-relativistic

$$T_{\text{CMB}}(z_{\text{recomb.}}) \approx 0.25 \text{ eV} \quad \sum m_\nu < 0.26 \text{ eV (95\%)}$$

Planck TTTEEE (2018)

We can still improve by going to lower redshift

# Neutrino Mass

Massive neutrinos free stream / suppress growth

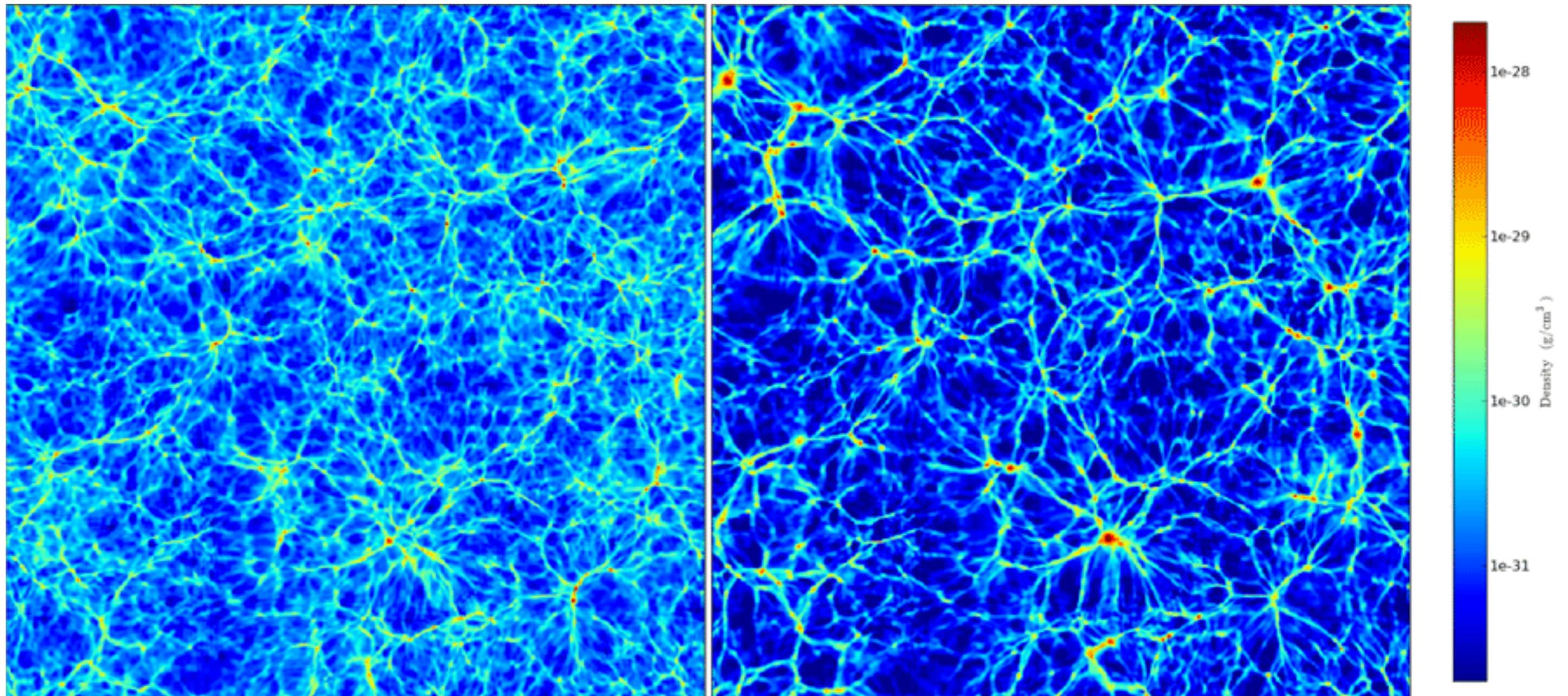
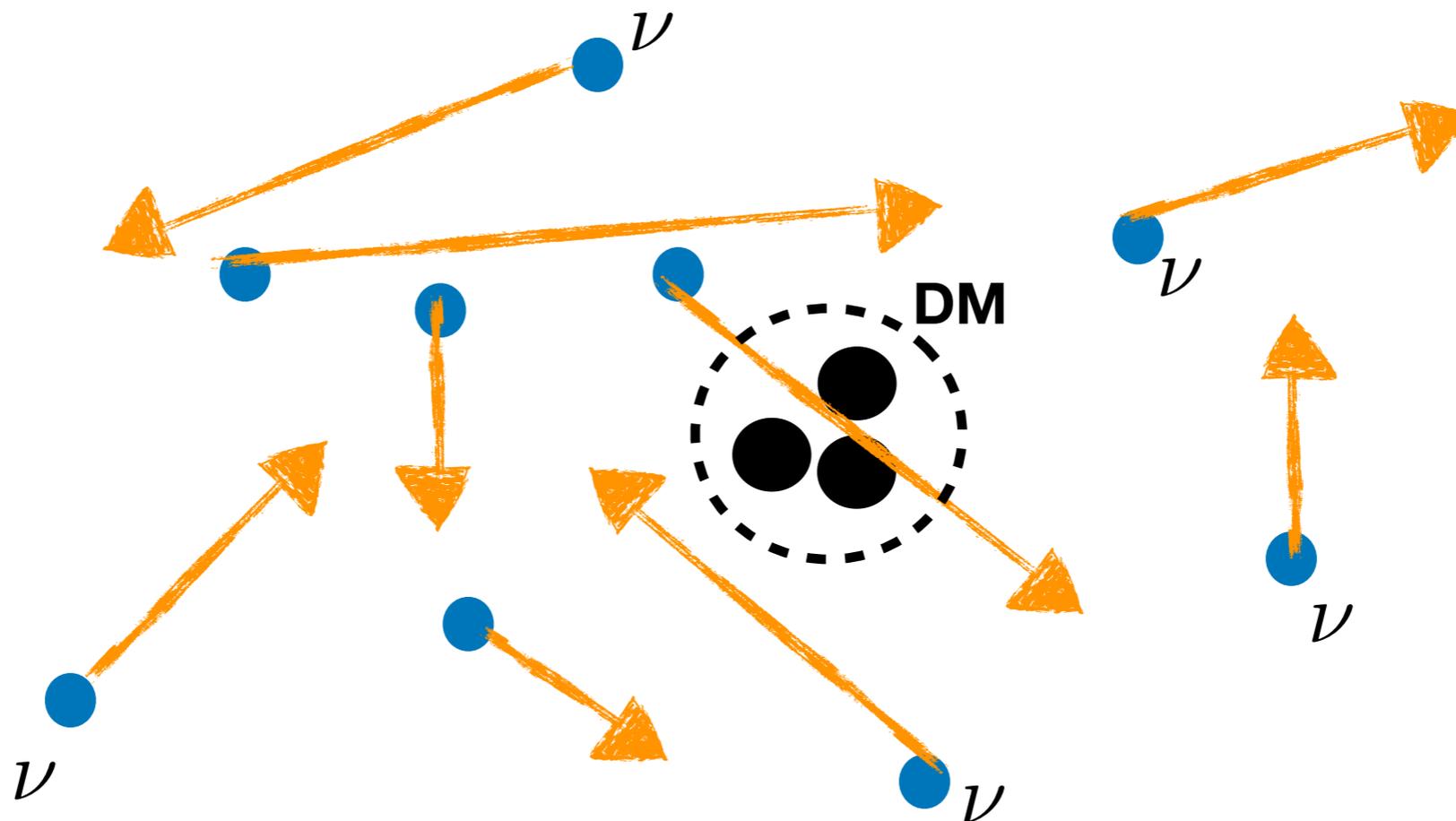


Image from Agarwal & Feldman (2010)

# Neutrino Mass

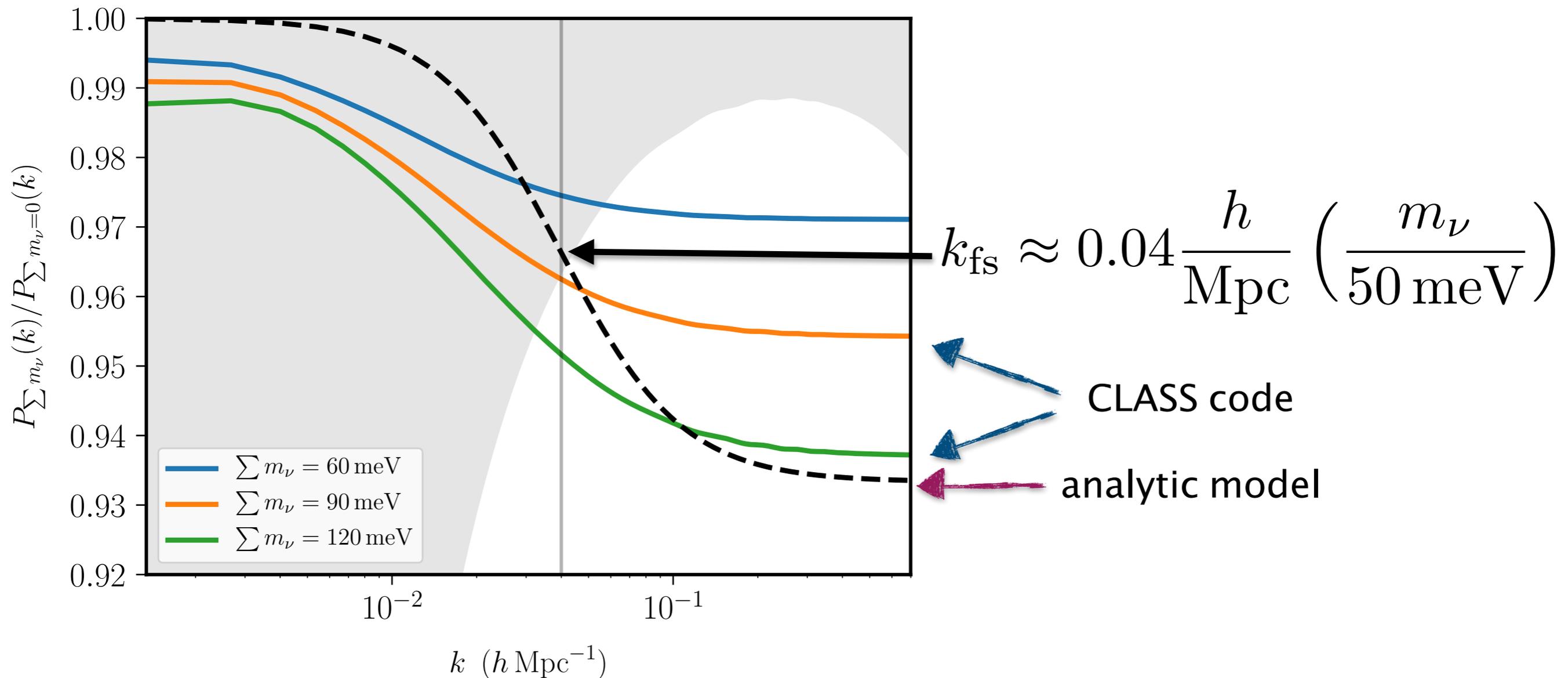
Massive neutrinos free stream / suppress growth

$$c_\nu \approx 8.7 \times 10^{-3} c \frac{1}{1+z} \left( \frac{58 \text{ meV}}{\sum m_\nu} \right) \quad c_{\text{dm}} \approx 0$$



# Neutrino Mass

## Massive neutrinos free stream / suppress growth



# Neutrino Mass

Suppression is really two separate effects:

1. Neutrinos redshift like matter but don't cluster

At fixed, total matter density

$$P_m[m_\nu \neq 0] \approx (1 - 2f_\nu)P_m[m_\nu \neq 0]$$

2. Dark matter clusters more slowly

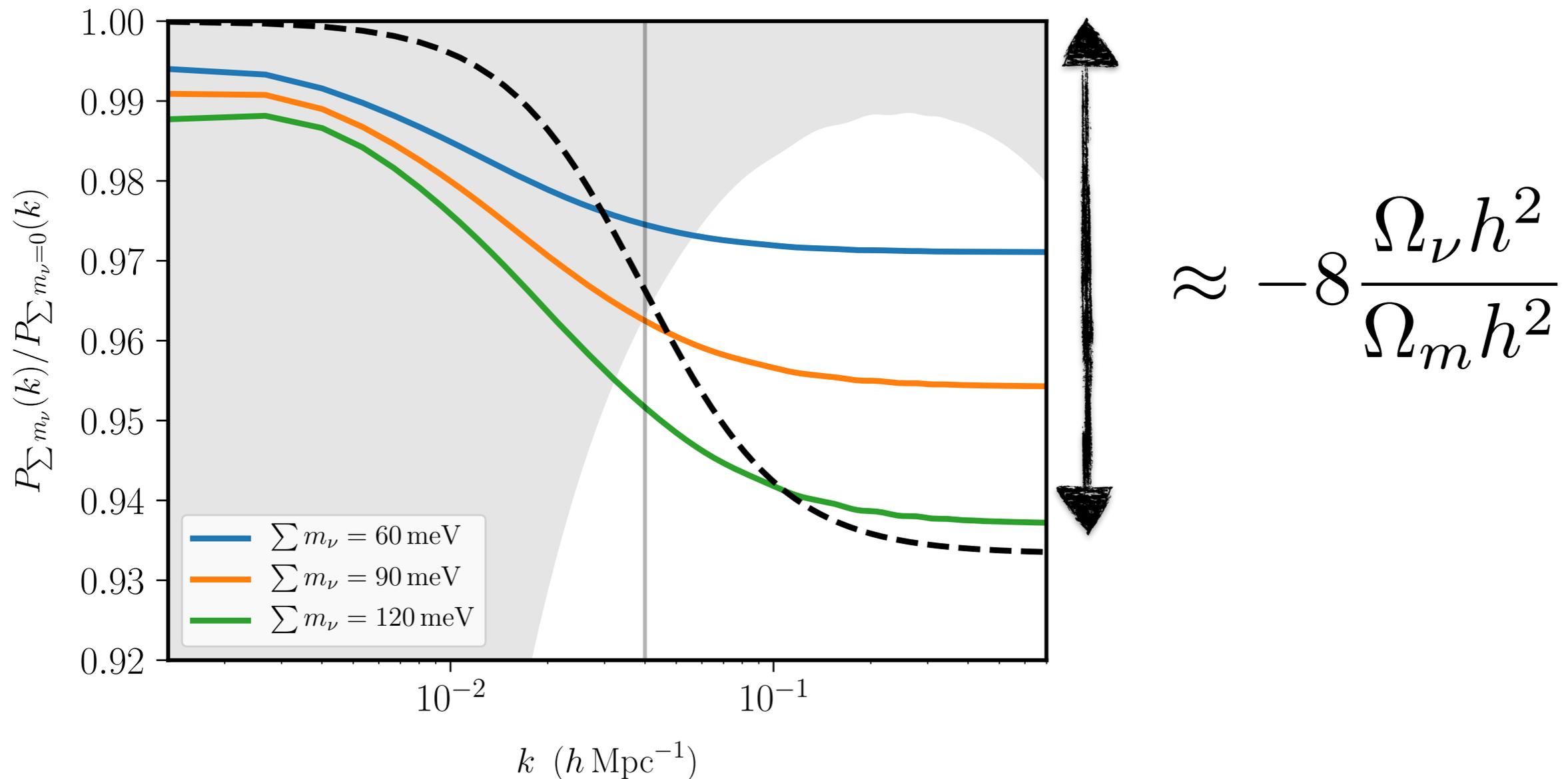
$$P_m[m_\nu \neq 0] \approx \left(1 - \frac{3}{5}f_\nu \log \frac{1 + z_{\text{NR}}}{1 + z}\right)P_m[m_\nu \neq 0]$$

Enhanced by a large log (time of growth)

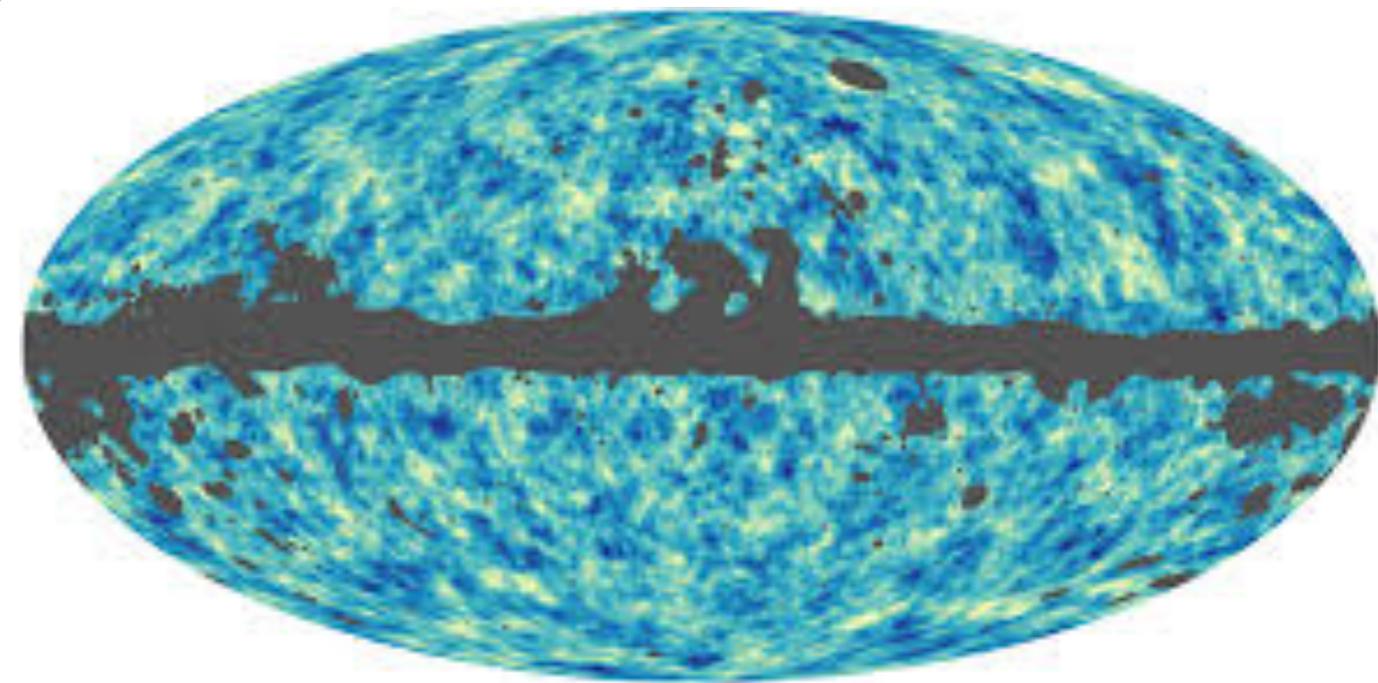
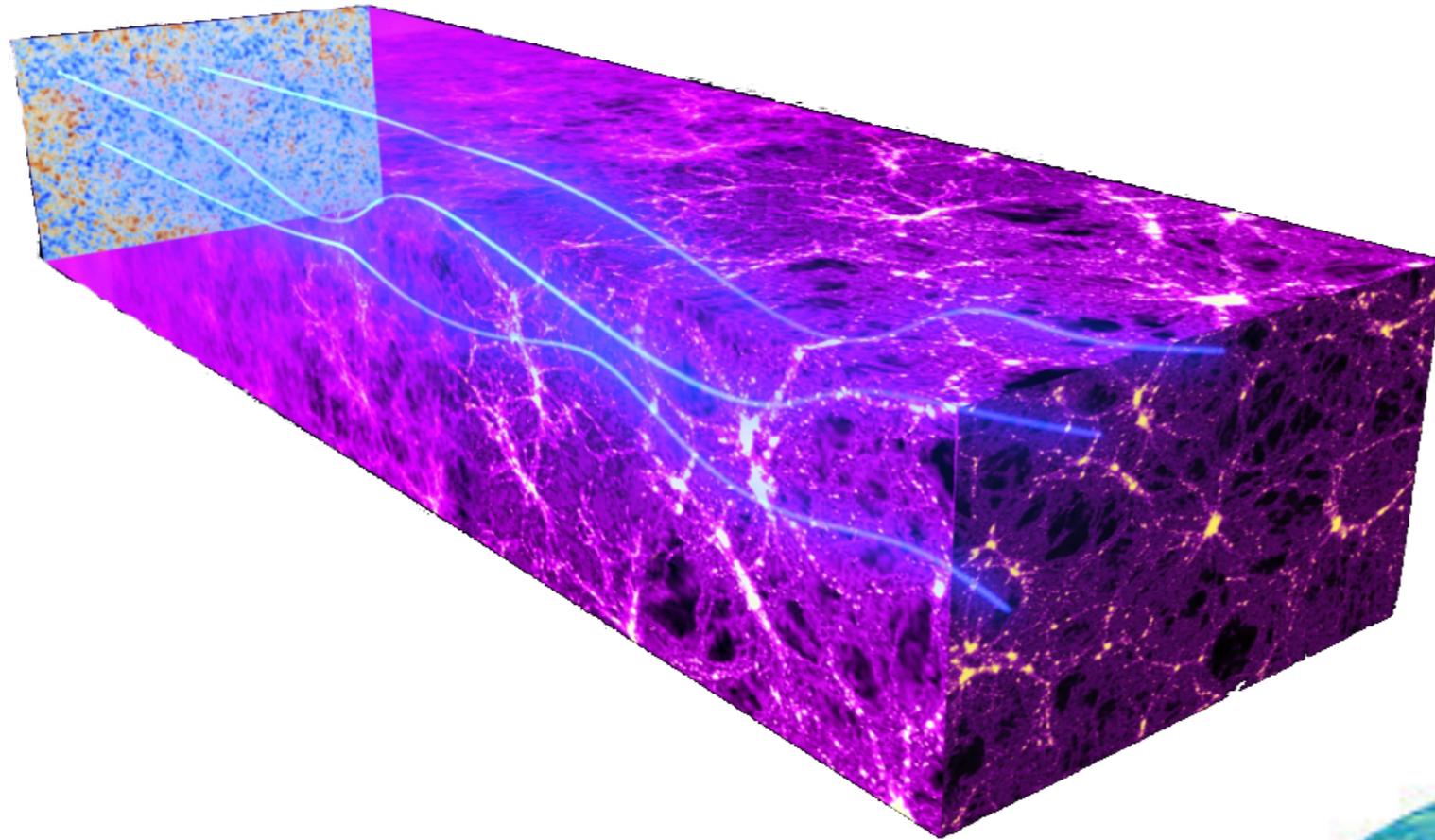
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# Neutrino Mass

Combine to give a large suppression



# Cosmological Observables

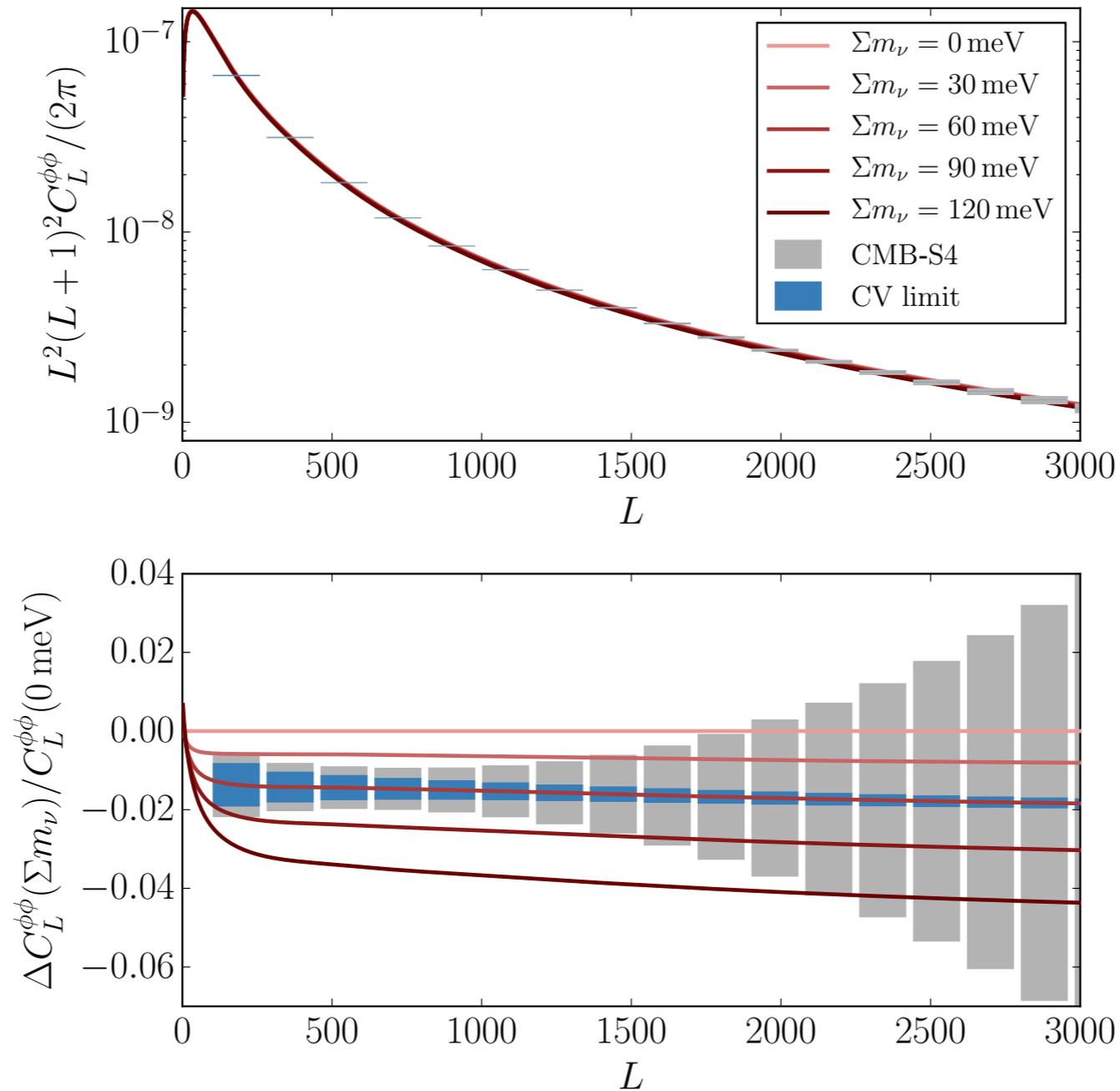


Images from ESA



# Cosmological Observables

Hard because we don't measure  $k_{fs}$



# Cosmological Observables

We need to measure 3 numbers:

(1) (dark) matter power spectrum – lensing

$$P_{\text{lensing}} \propto \Omega_m^2 \times A_s$$

(2) High accuracy matter abundance – BAO

(3) Primordial Amplitude of Fluctuations – CMB

With planned observations: 1–3 are easiest–hardest

# Realistic Goals

Data we have in hand + DESI BAO can reach

$$\sigma\left(\sum m_\nu\right) \approx 30 \text{ meV}$$

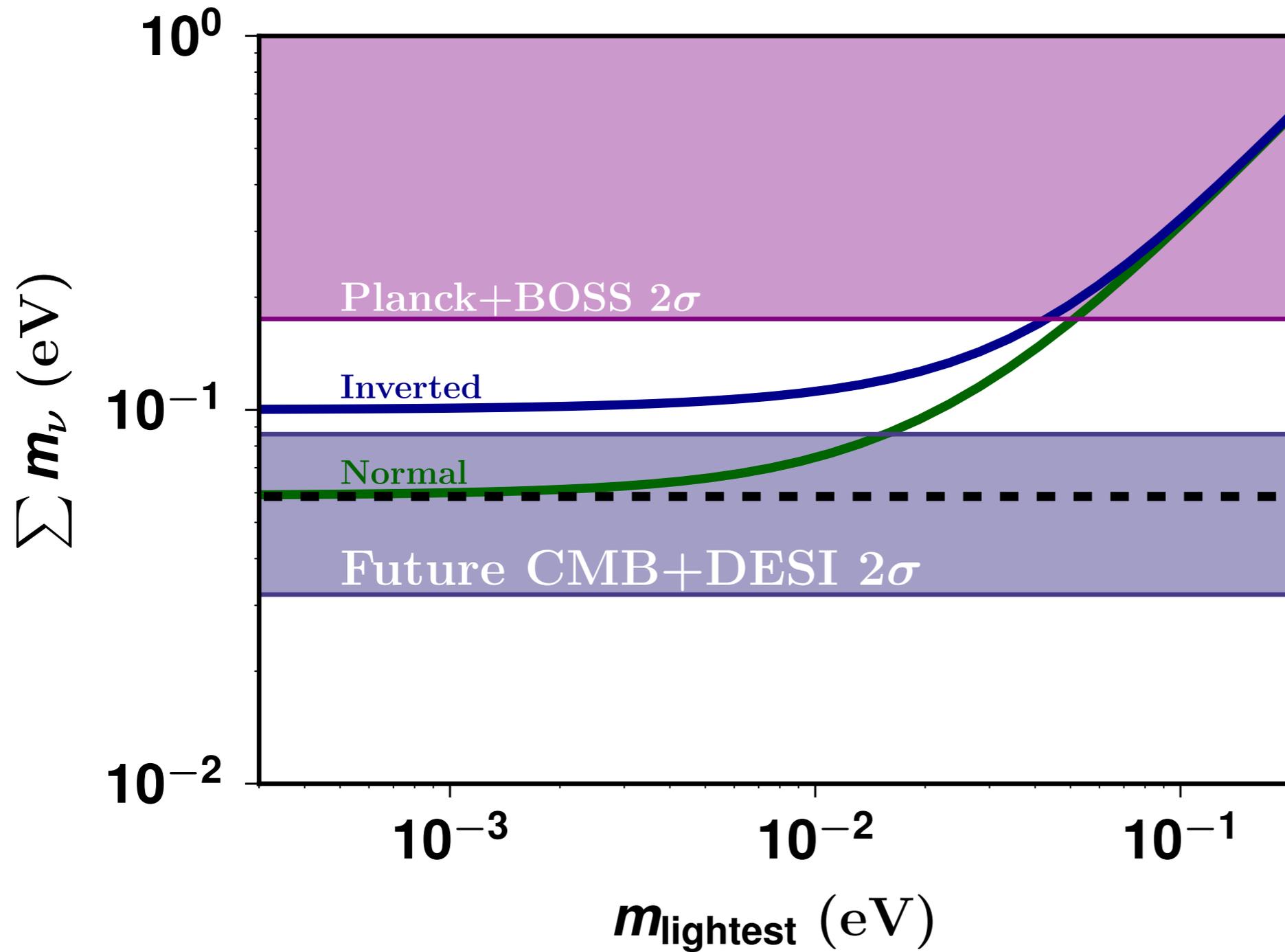
95% exclusion of  $\sum m_\nu = 0$  for minimum mass

With improved measurements of reionization:

$$\sigma\left(\sum m_\nu\right) < 15 \text{ meV}$$

Best bet is a satellite, possible from ground/balloon

# Realistic Goals



$$\sum m_\nu \geq 58 \text{ meV}$$

# Beyond neutrinos

$N_{\text{eff}}$  and  $\sum m_\nu$  are gravitational measurements

Sensitive probes of dark / hidden sectors

From current constraints on  $\sum m_\nu$

$$\Omega_\nu h^2 < 1.2 \times 10^{-3} \text{ (95\%)}$$

Implies the fraction of hot dark matter is

$$f_\chi < 0.0045 \text{ (95\%)}$$

---

An aerial photograph of a vast, flat, snow-covered landscape under a clear blue sky. In the lower center, there is a small, dark, rectangular structure or building. Several thin, dark lines, likely tracks or paths, crisscross the snow around the structure. The horizon is a straight line in the distance. The word "Summary" is written in blue text on the right side of the image.

# Summary

# Summary

---

Cosmic neutrinos background exists

- CMB detects change to expansion rate at  $30\sigma$
- CMB detects phase shift at  $10\sigma$
- Galaxy clustering sees phase shift at 99.5%
- Detection of neutrino expected in 2020s

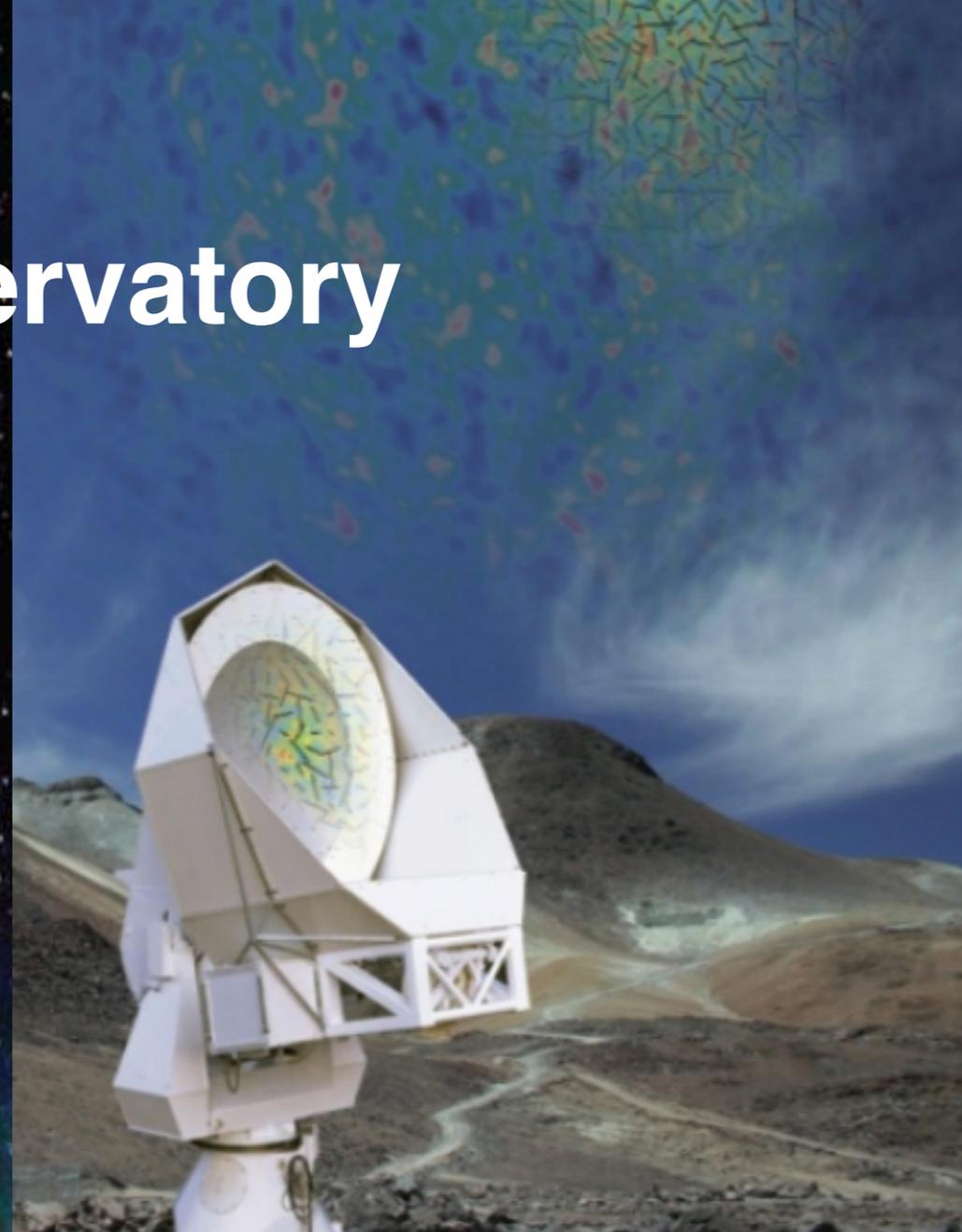
All detections are gravitational

Provides a very sensitive window into new particles

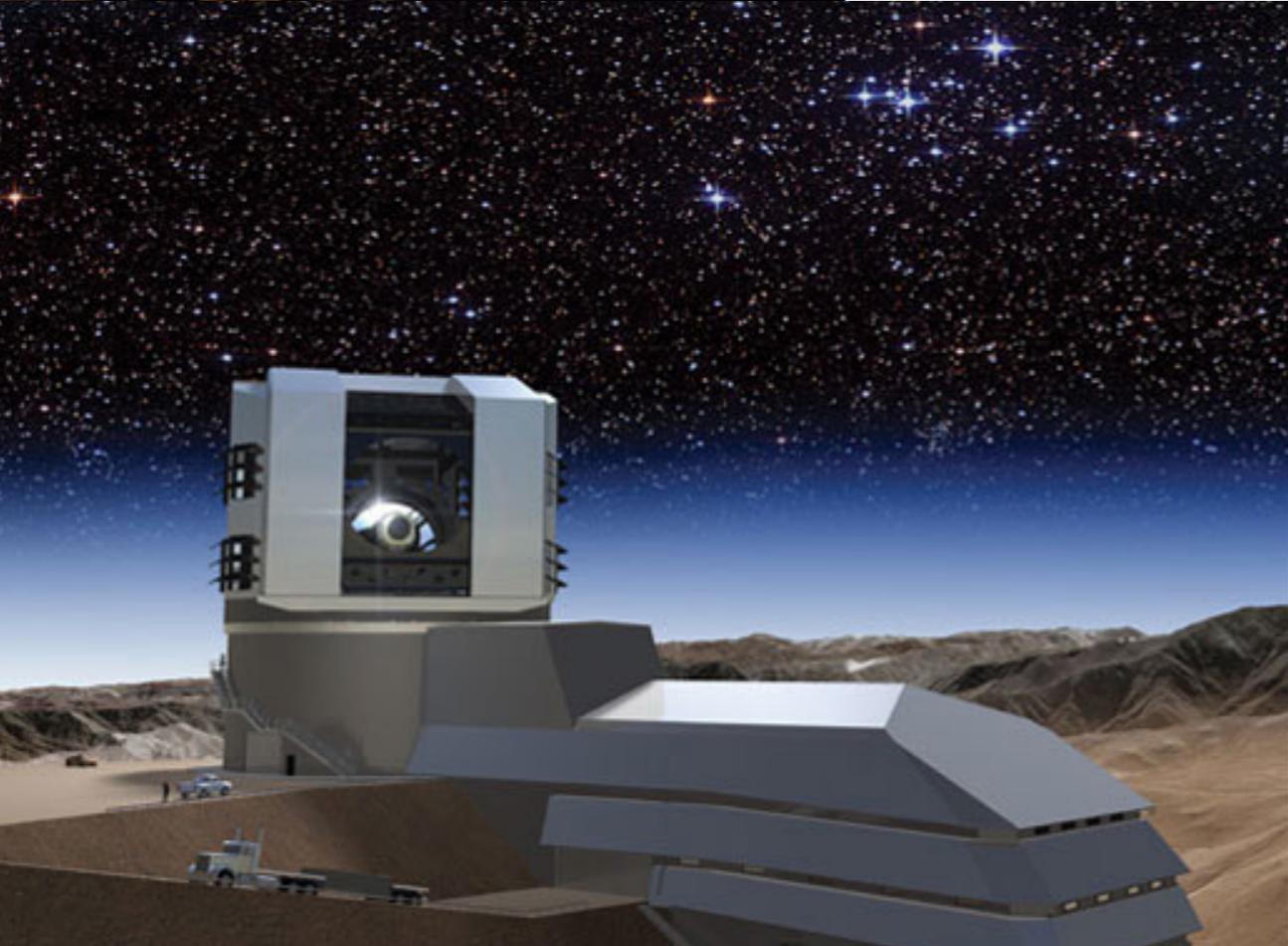
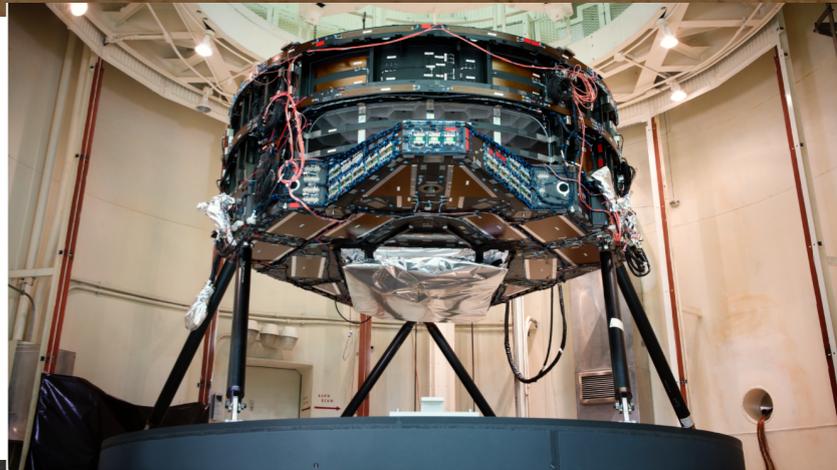
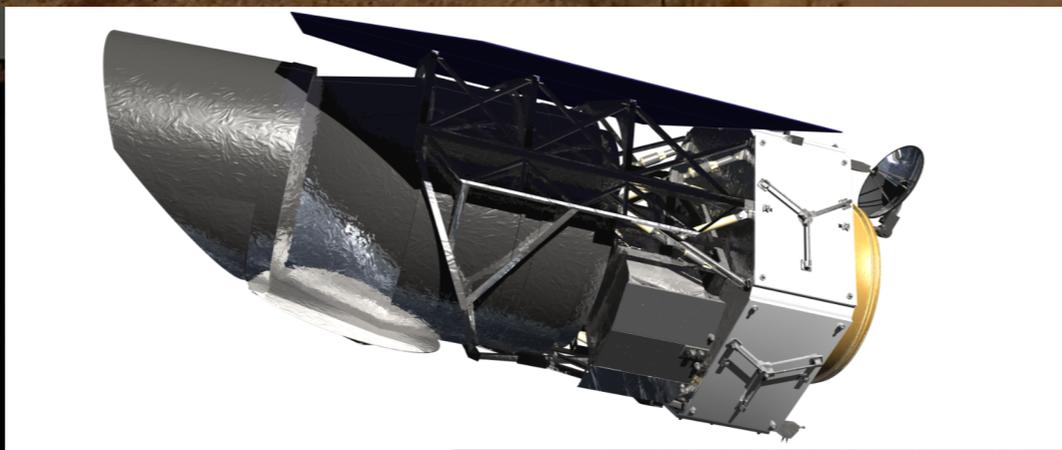
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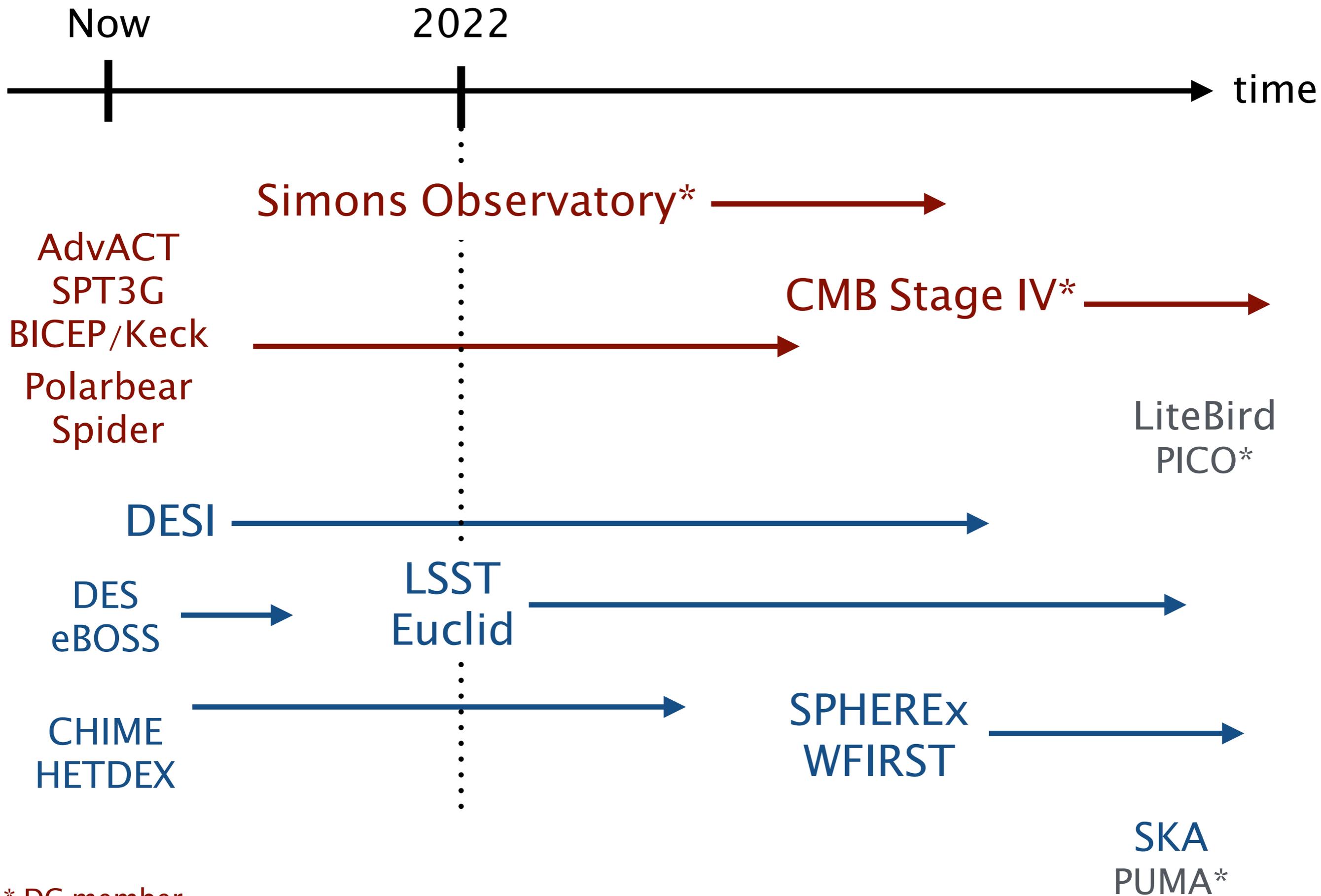


# The Simons Observatory



**CMB-S4**  
Next Generation CMB Experiment

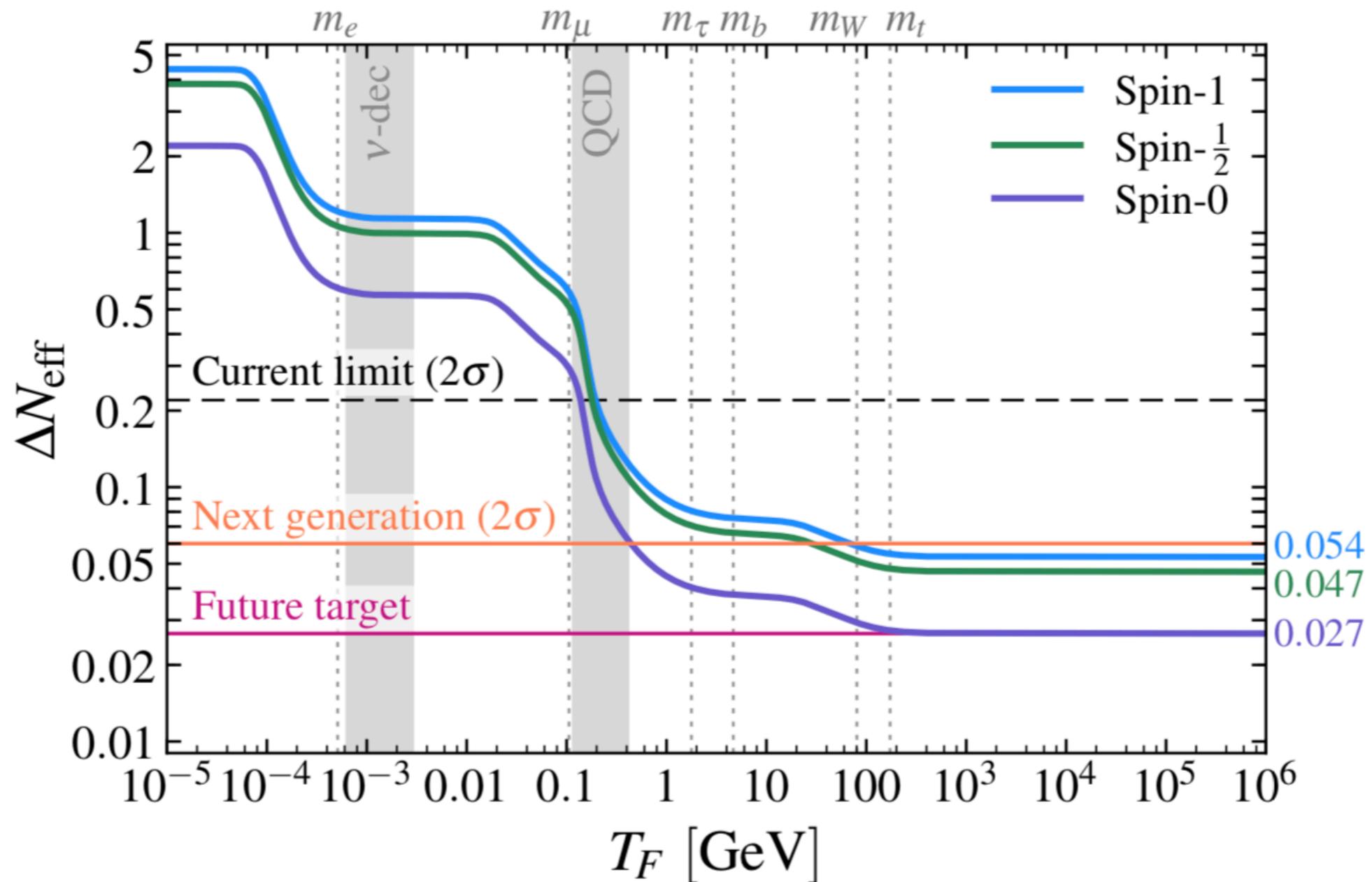




\* DG member

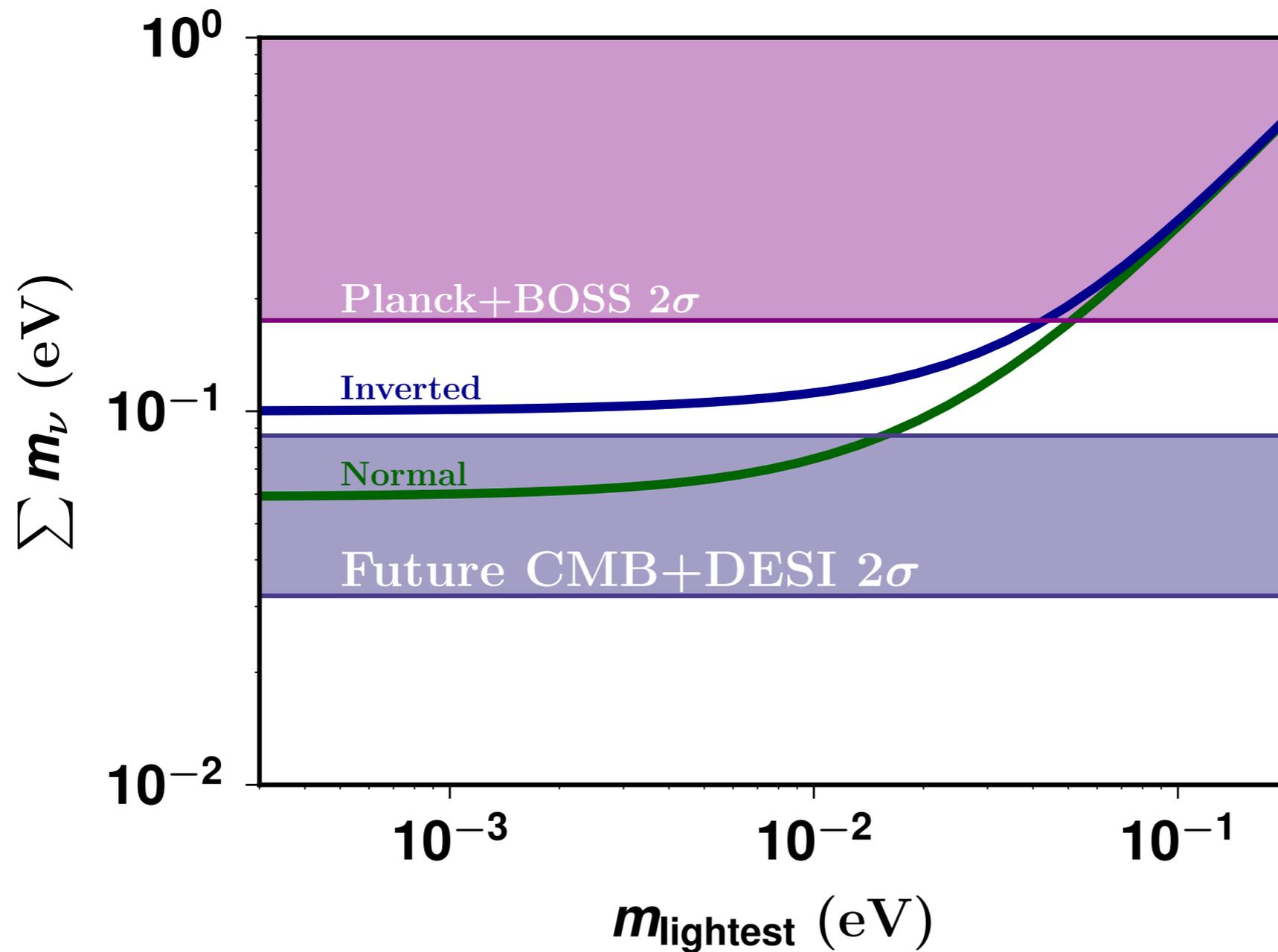
# Summary

Coming generations will make a lot of progress



# Summary

Coming generations will make a lot of progress



A scenic view of a coastline. In the foreground, there are palm trees and other tropical vegetation. A cliffside is visible on the right, with a few people standing on top. The ocean is a deep blue, and the sky is a lighter blue with some white clouds. The text "Thank you" is overlaid in the center in a white, sans-serif font.

Thank you