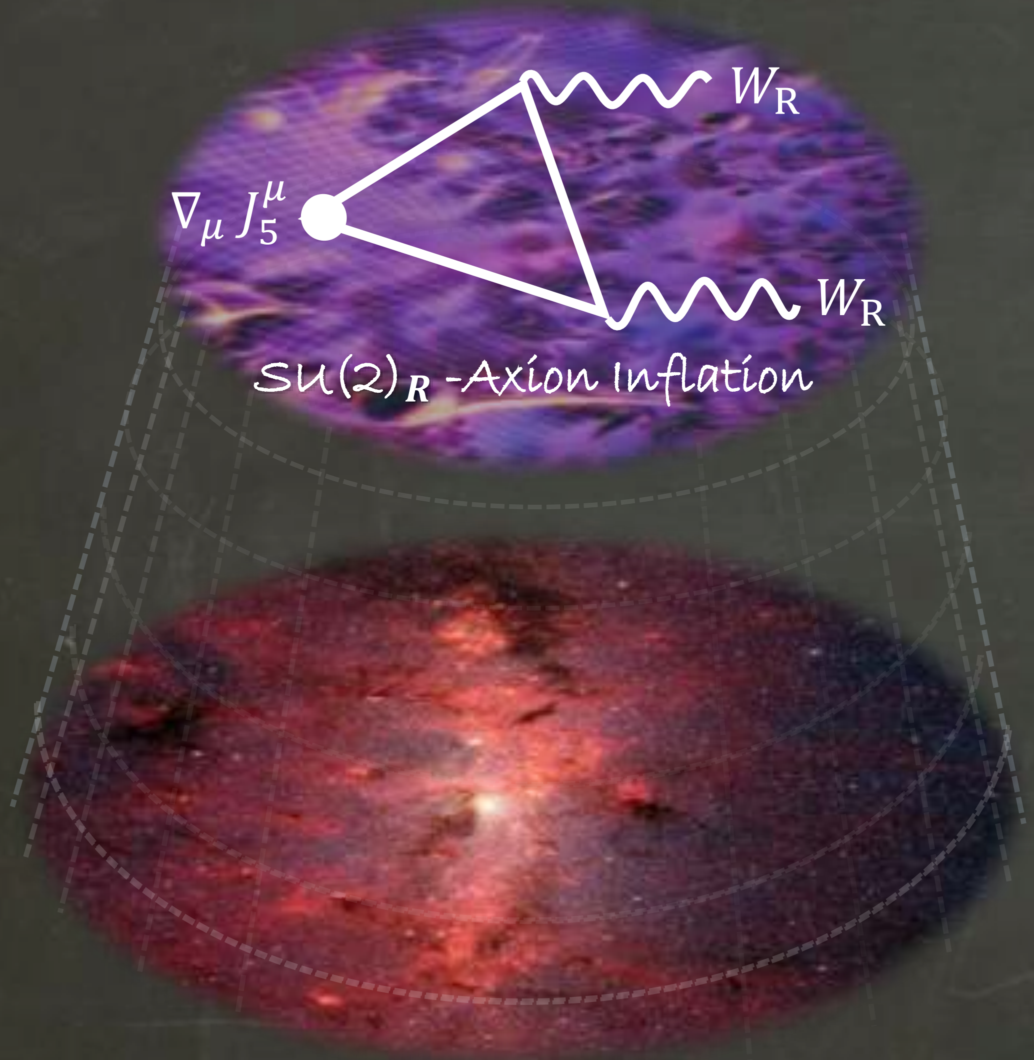


Is our Universe Remnant of Chiral Anomaly in Inflation?

Based on
arXiv:2012.11516 & arXiv:2103.14611

Azadeh Malek-Nejad
CERN

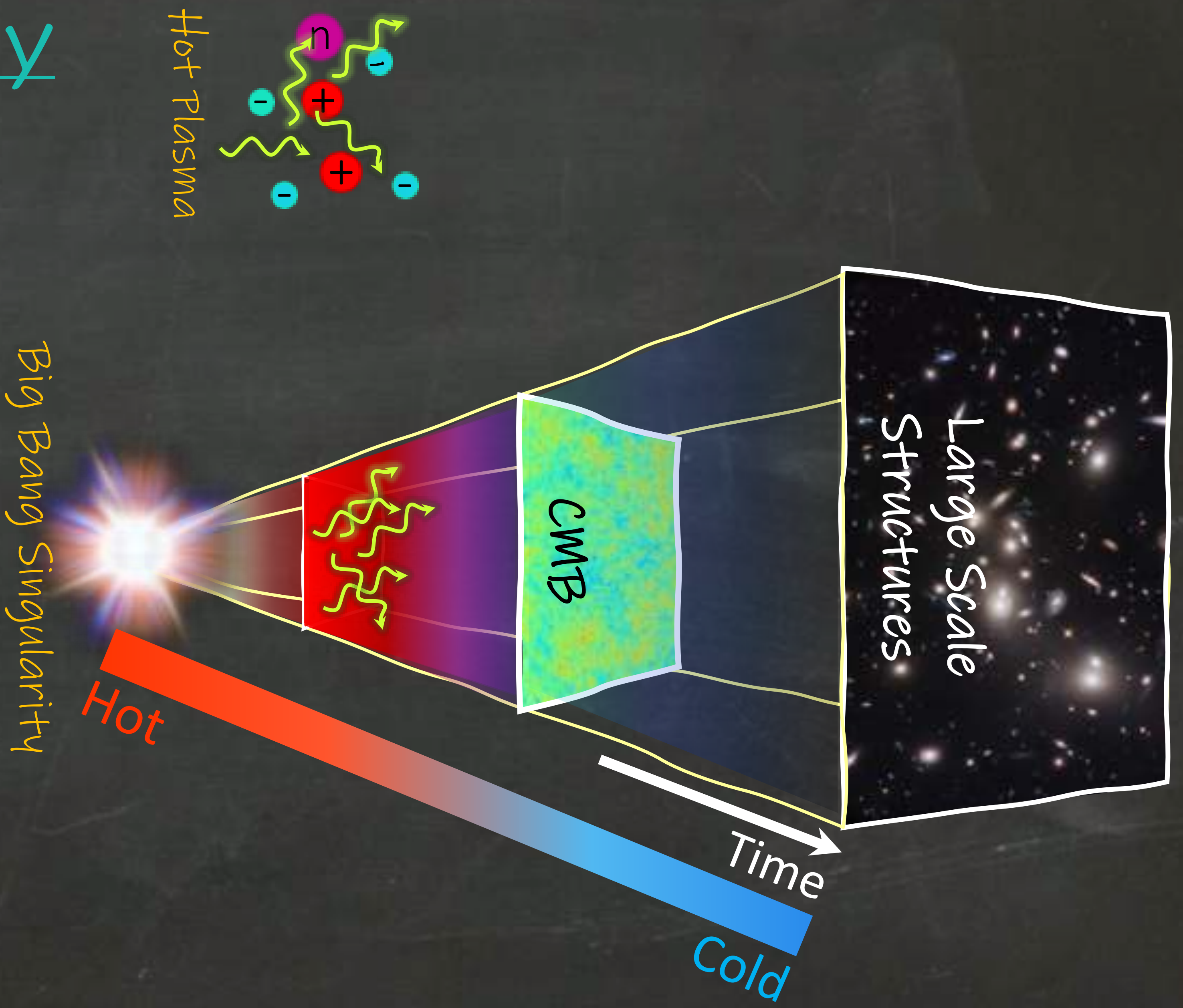
Cosmic History

Cosmic History

Our Universe is expanding.

For many it was filled with a hot plasma.

As it expands it becomes colder and colder.



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When temperature got below 1 eV, neutral atoms &

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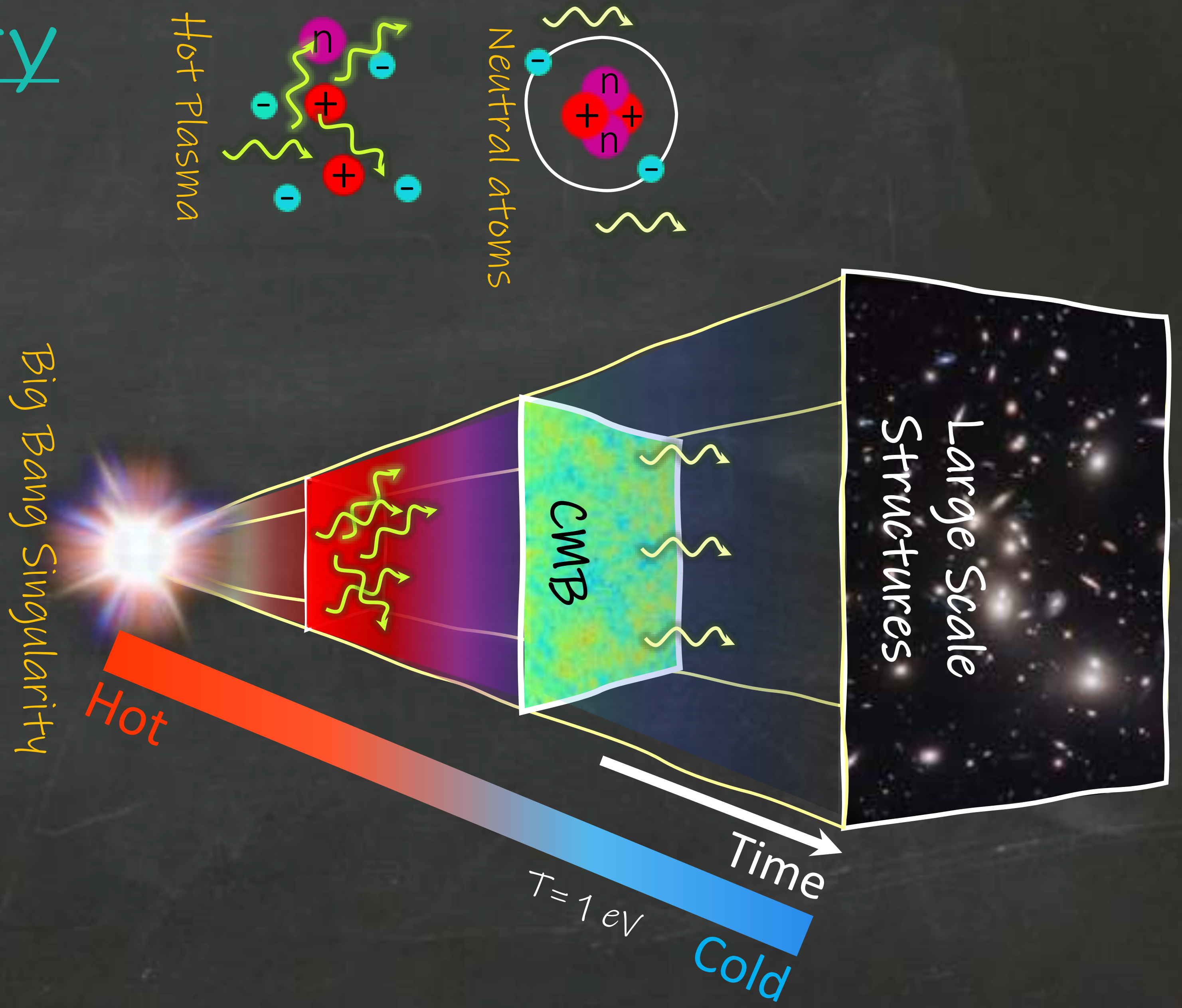

Cosmic History

Our Universe is expanding.

For many it was filled with a **hot** plasma.

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When temperature got below 1 eV, neutral atoms &

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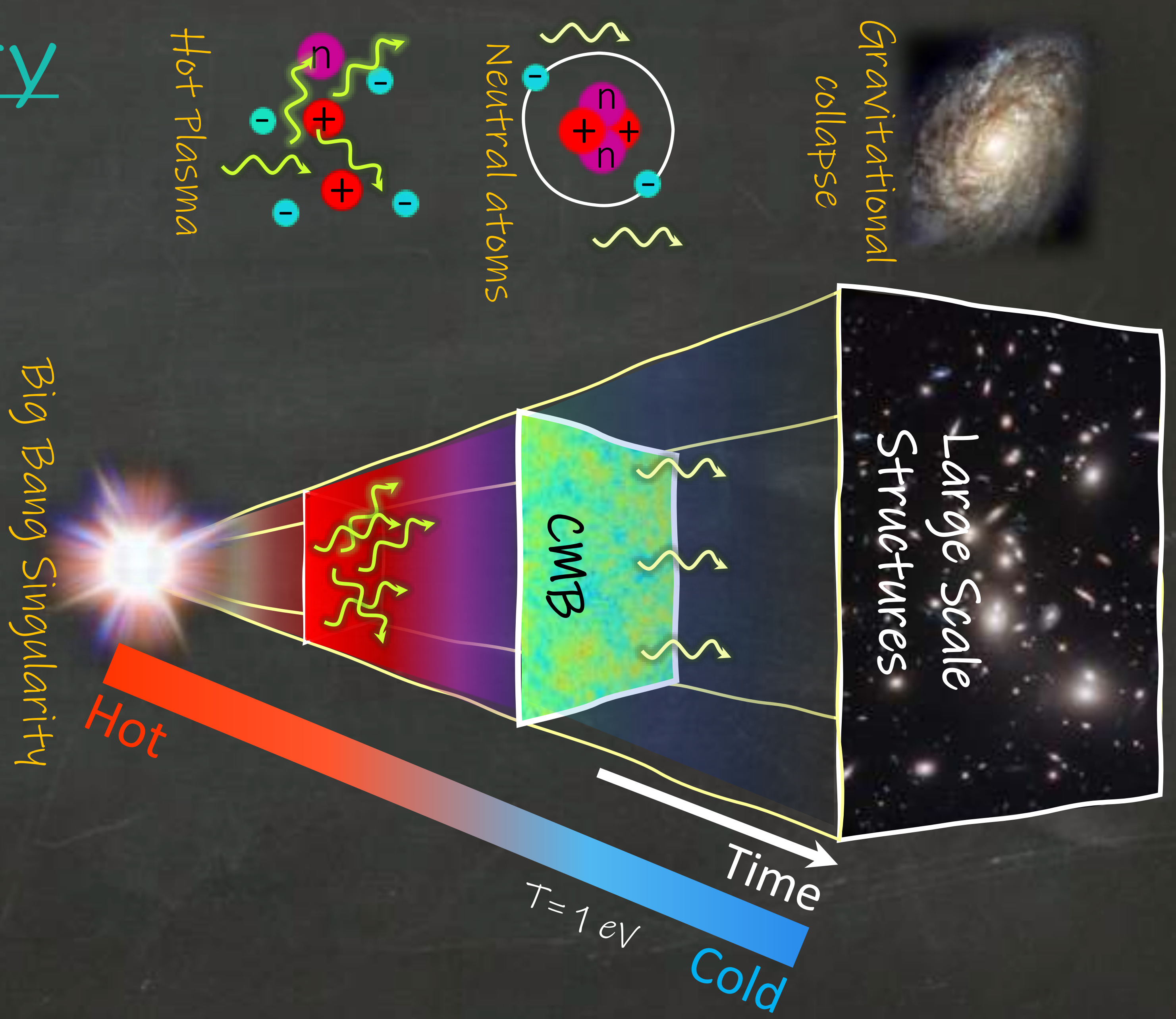
Those initially hot atoms slowly assembled & cooled into Large Scale Structures.



Cosmic History

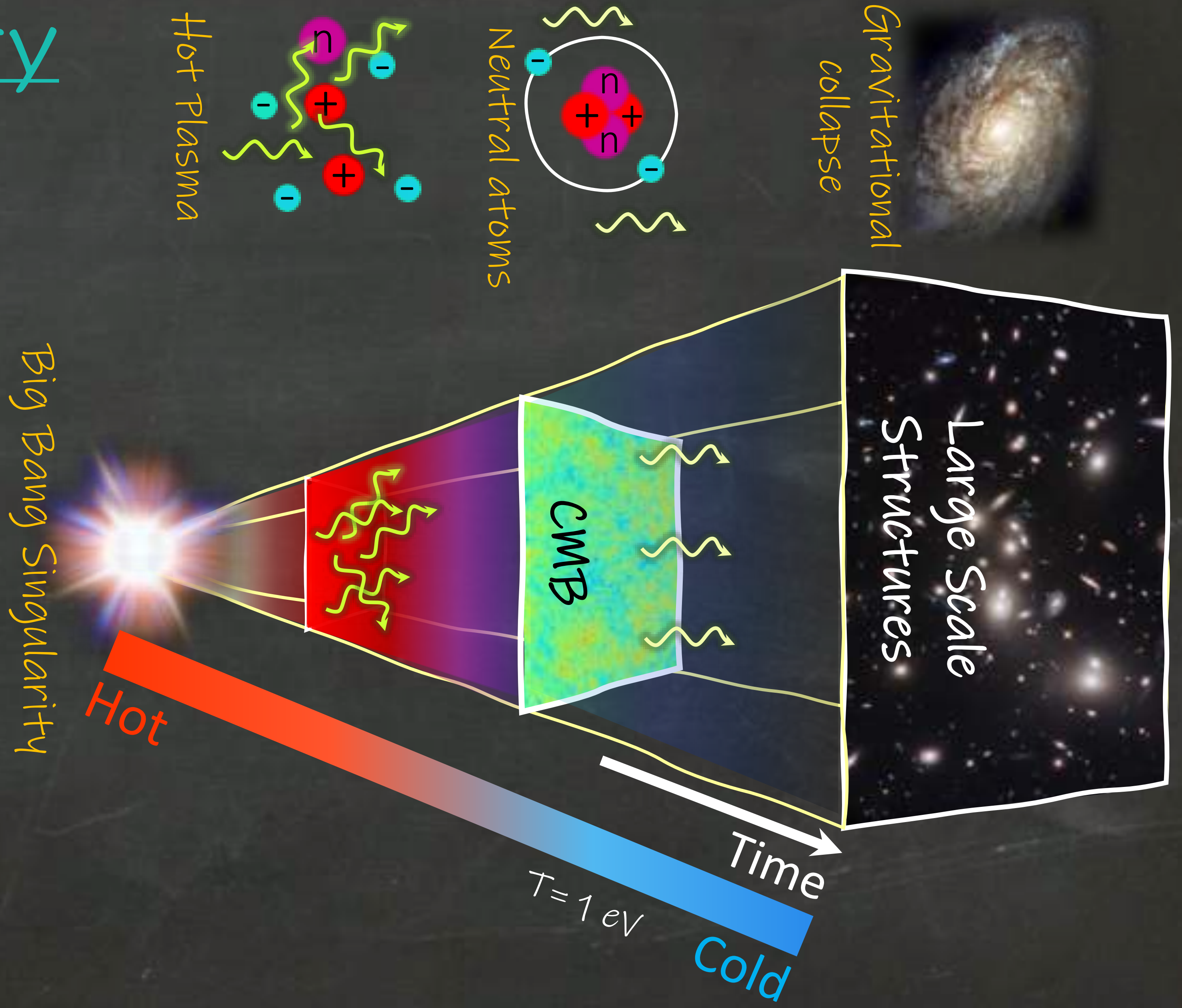
Our Universe is too simple,
too symmetric at
very large scales!

CMB is nearly
homogenous & isotropic!

T_{CMB} =2.7 K

with
tiny fluctuation

$$\frac{\Delta T}{T_{CMB}} = 10^{-5}!$$



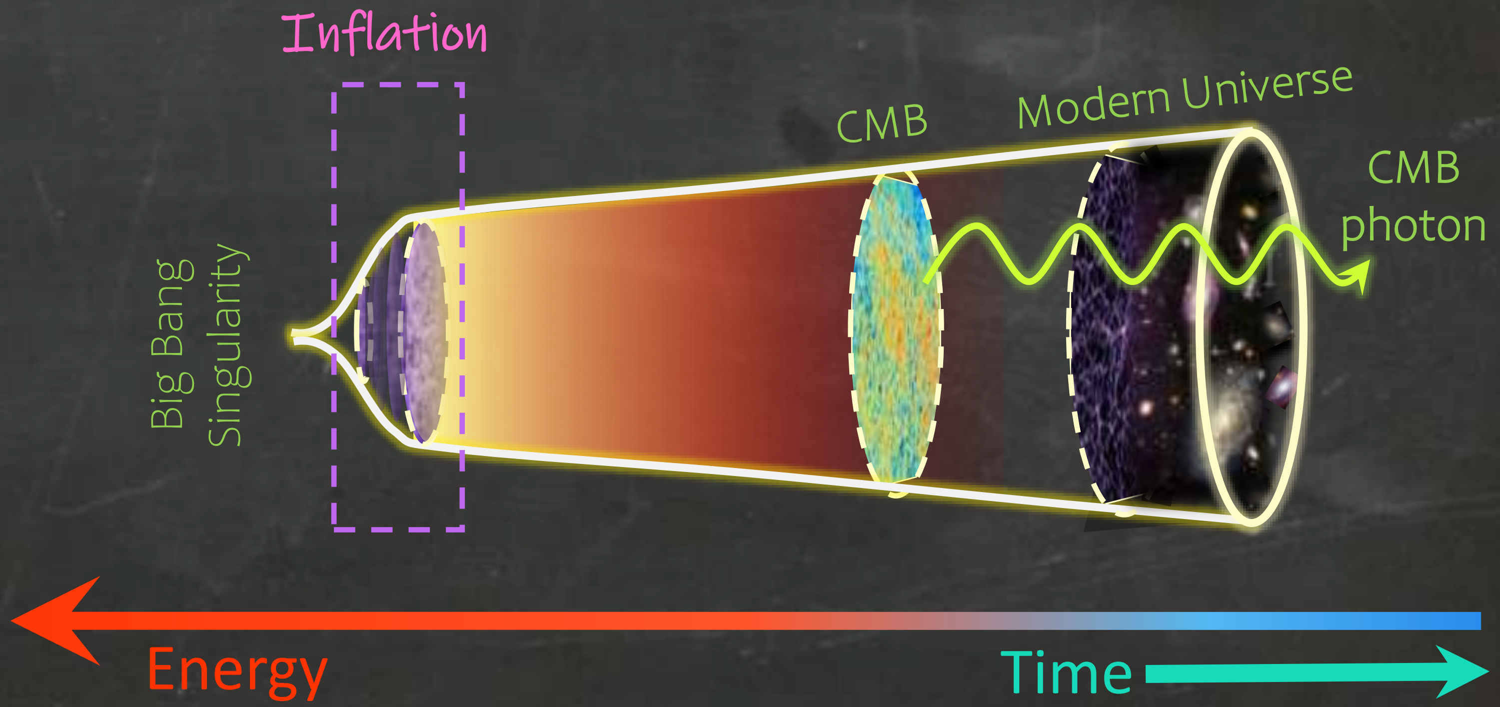
Cosmic Inflation

Guth Phys. Rev. D23 (1981)

Linde Phys. Lett. B 108 (1982)

A period of exponential expansion of space shortly after the Big Bang

$$\frac{a_f}{a_i} = e^{60} \approx 10^{26}!$$



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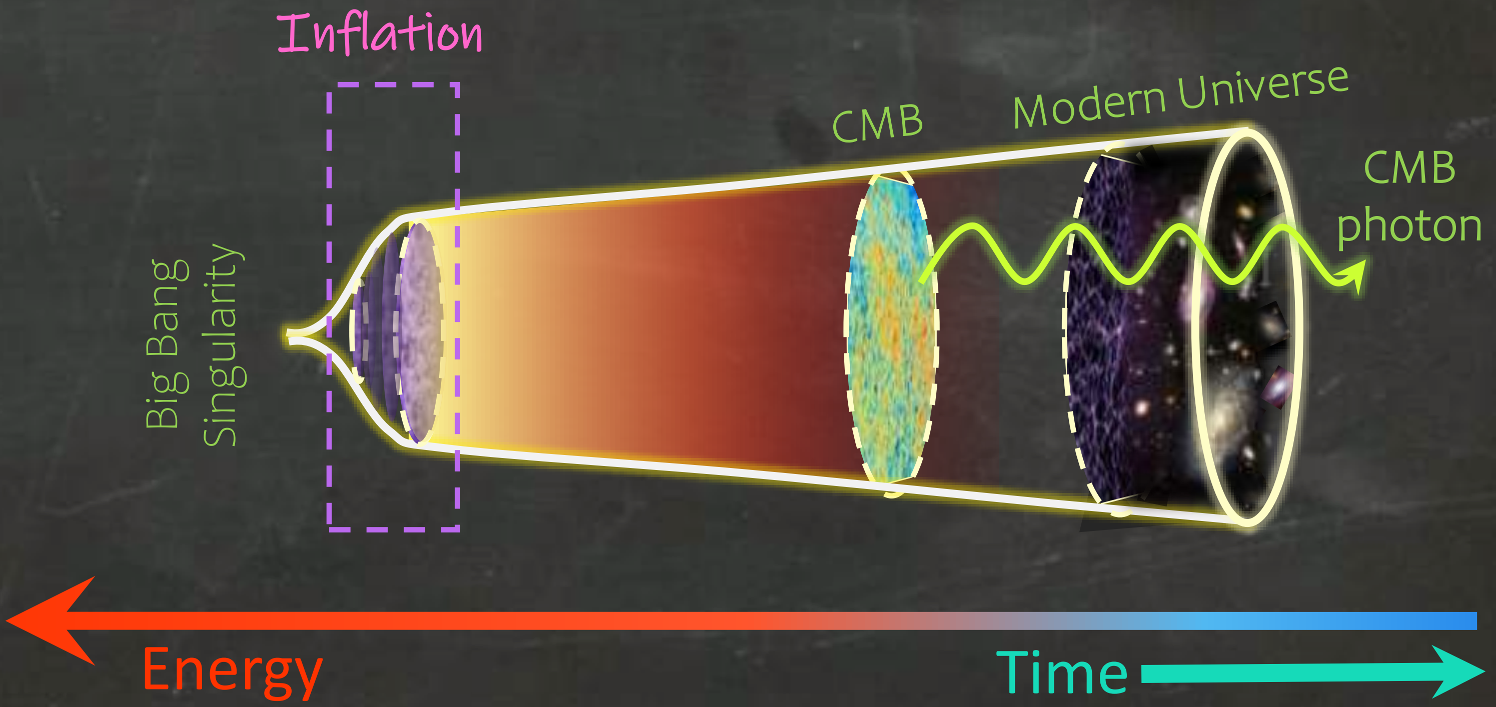
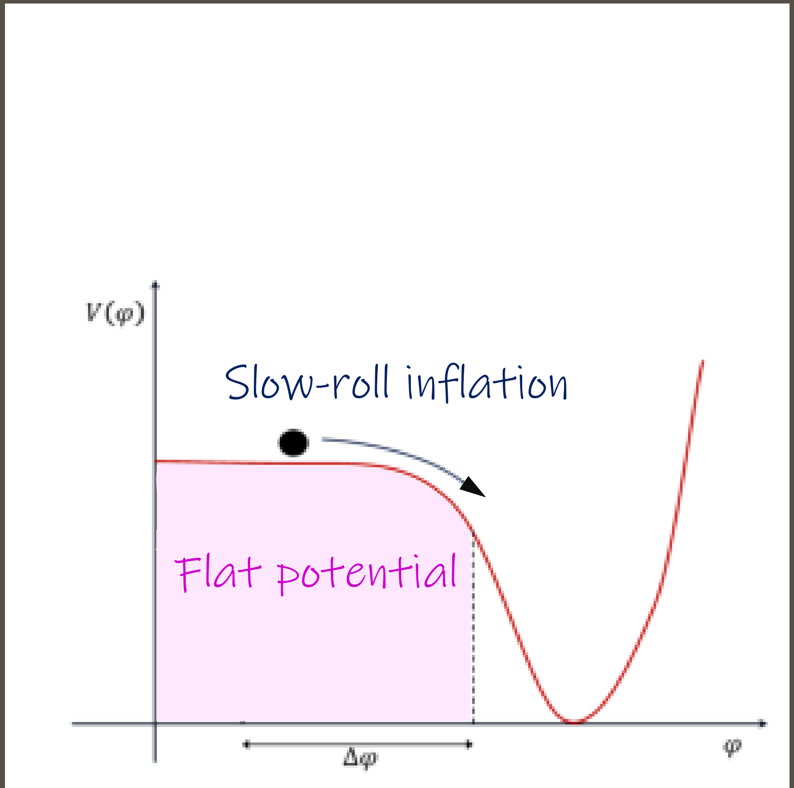
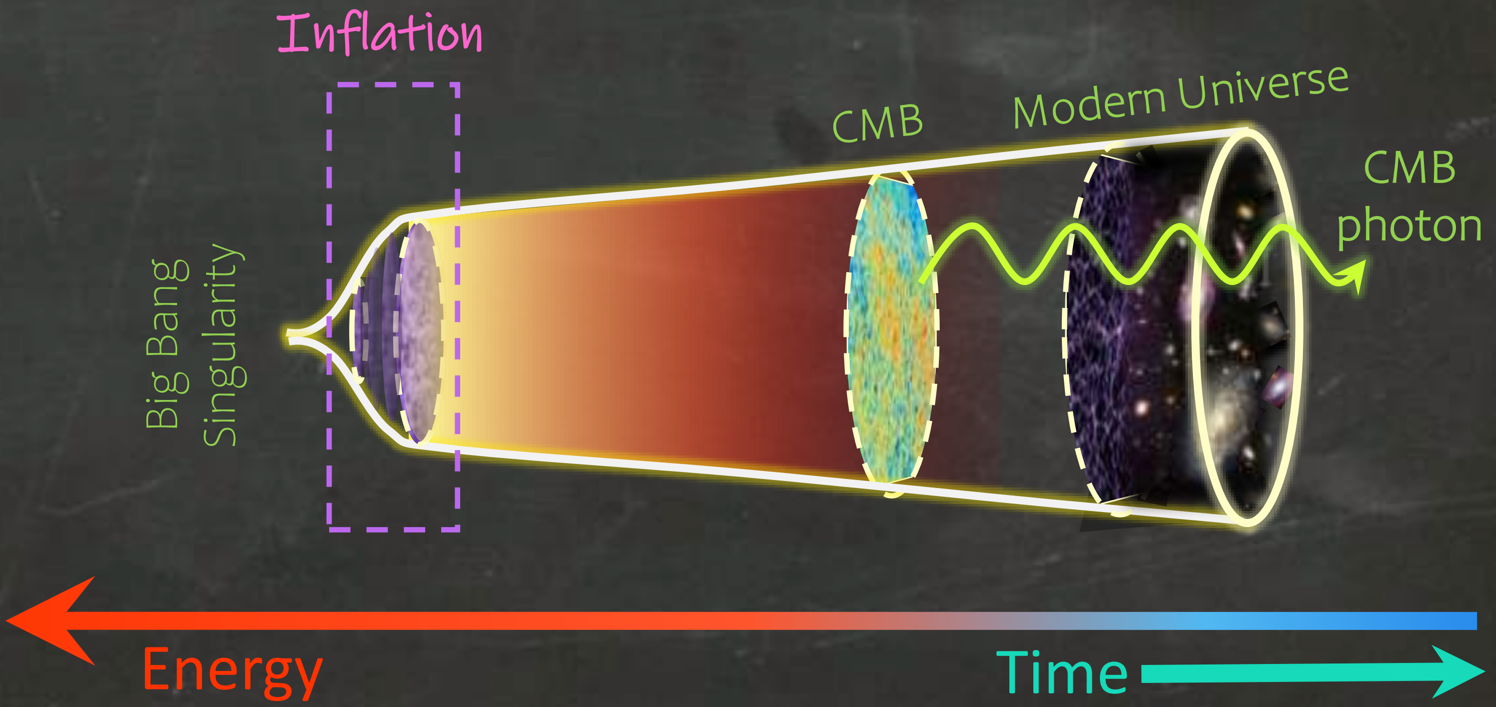


What caused inflation?

A scalar field "slow-rolling" toward its true vacuum provides a simple model for inflation.



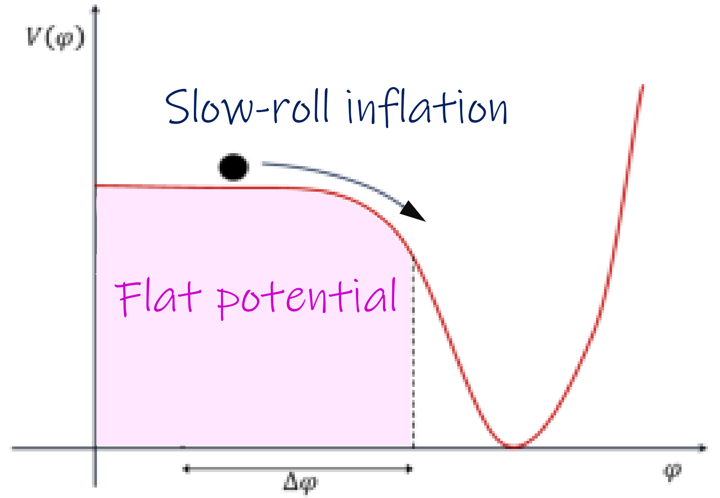


What caused inflation?

A scalar field "slow-rolling" toward its true vacuum provides a simple model for inflation.

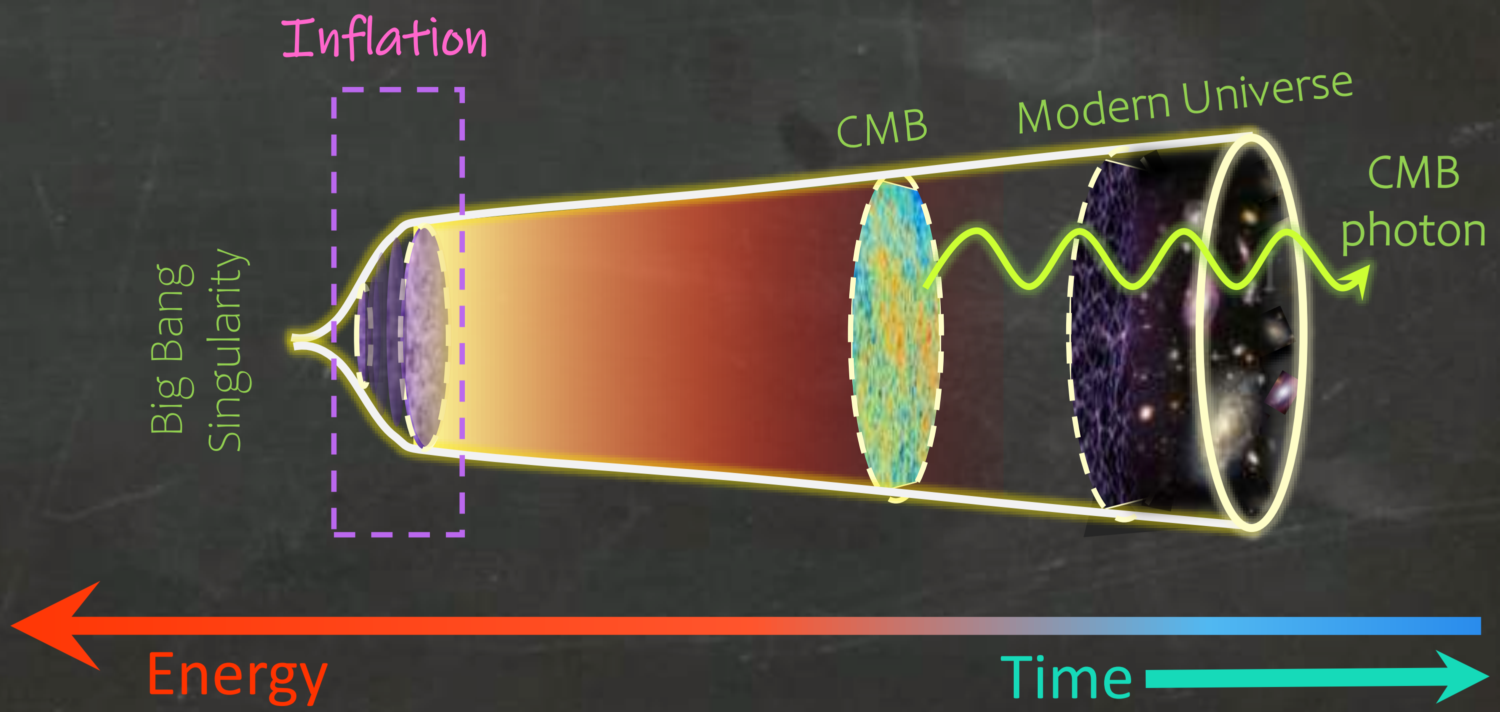
$$\rho = \frac{1}{2}\dot{\phi}^2 + V(\phi)$$

$$P = \frac{1}{2}\dot{\phi}^2 - V(\phi)$$



It is assumed that the cosmos was filled with a homogenous scalar field beyond the SM in inflation

$$\phi(t, \vec{x}) = \phi(t)$$



Quantum Fluctuations

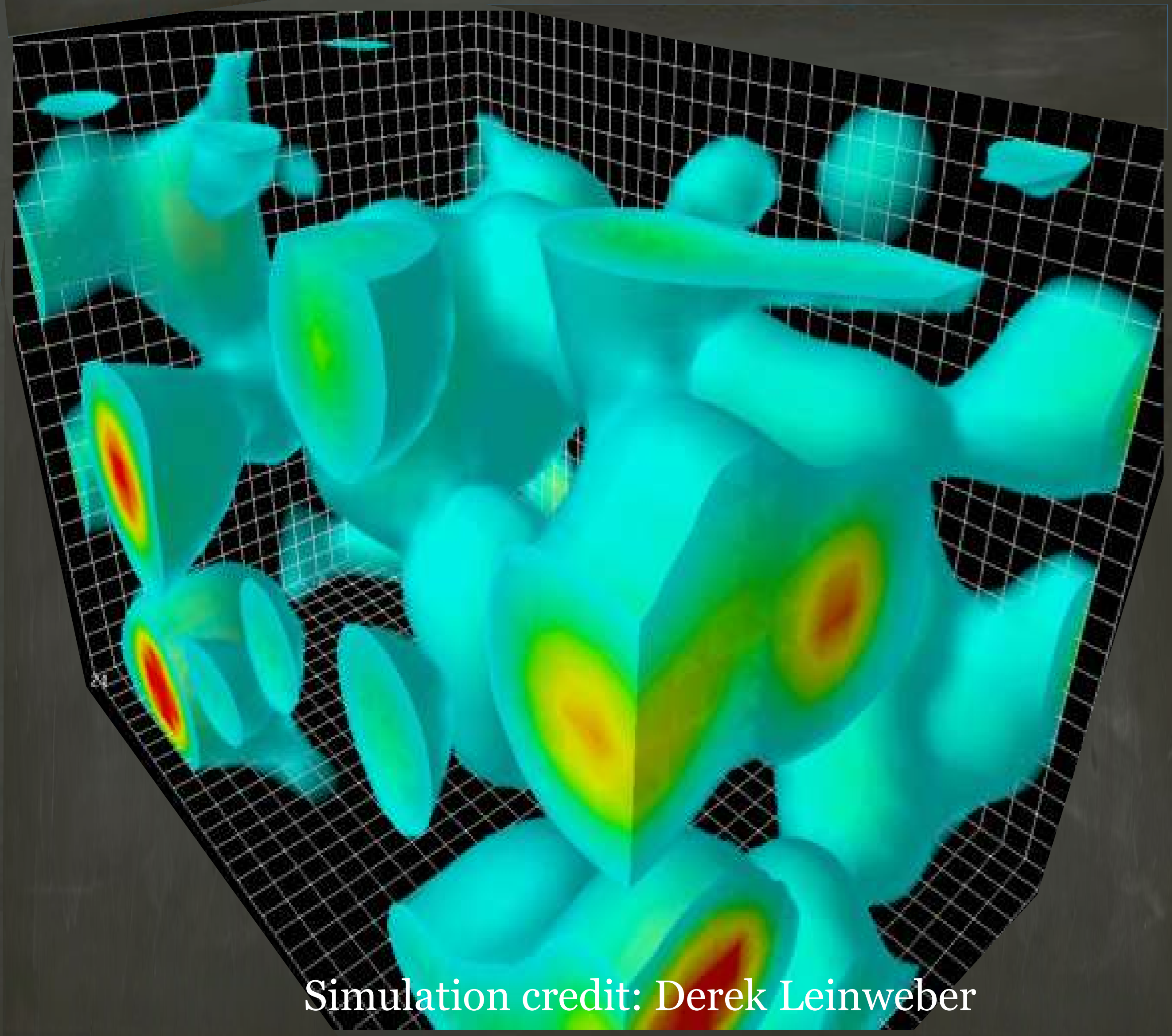
$$\hbar \neq 0$$

Quantum Vacuum $\hbar \neq 0$

Due to Uncertainty Principle

$$\Delta x \, \Delta p \geq \hbar/2$$

quantum vacuum is NOT nothing!



Simulation credit: Derek Leinweber

Quantum Vacuum $\hbar \neq 0$

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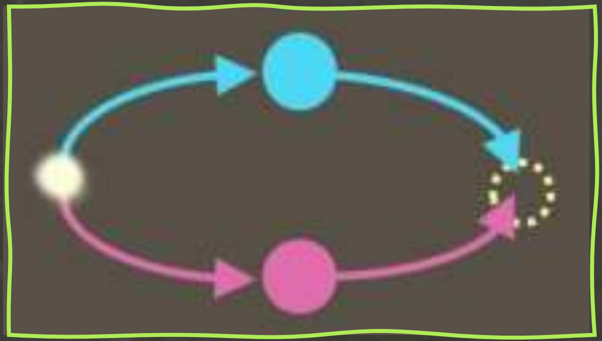
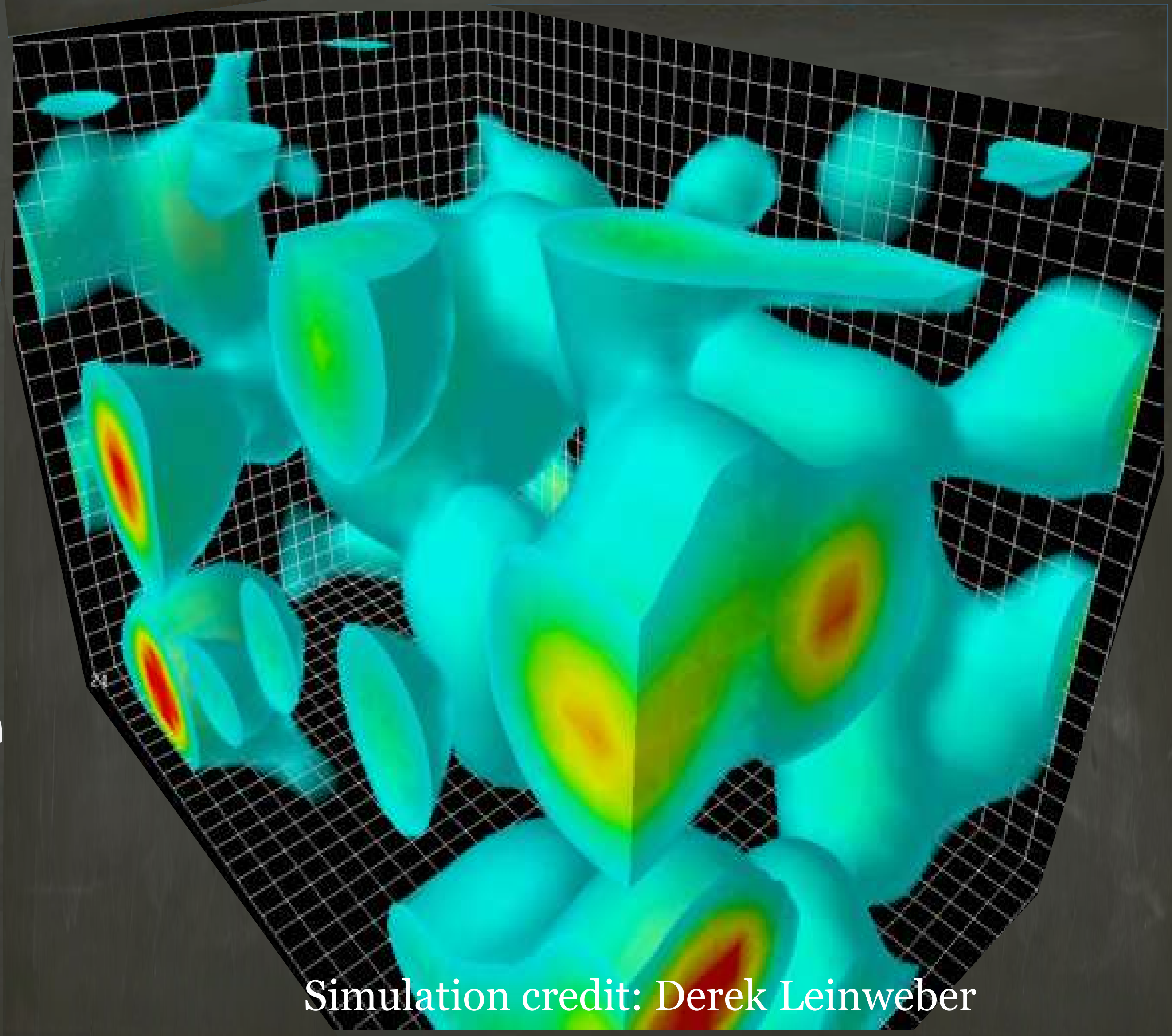
But, a vast ocean made of

Virtual particles

vacuum  vacuum



Simulation credit: Derek Leinweber

Quantum Vacuum → Particle Production

Due to Uncertainty Principle

$$\Delta x \, \Delta p \geq \hbar/2$$

the quantum vacuum is NOT nothing!

But, a vast ocean made of

Background field can upgrade them into **actual particles**!

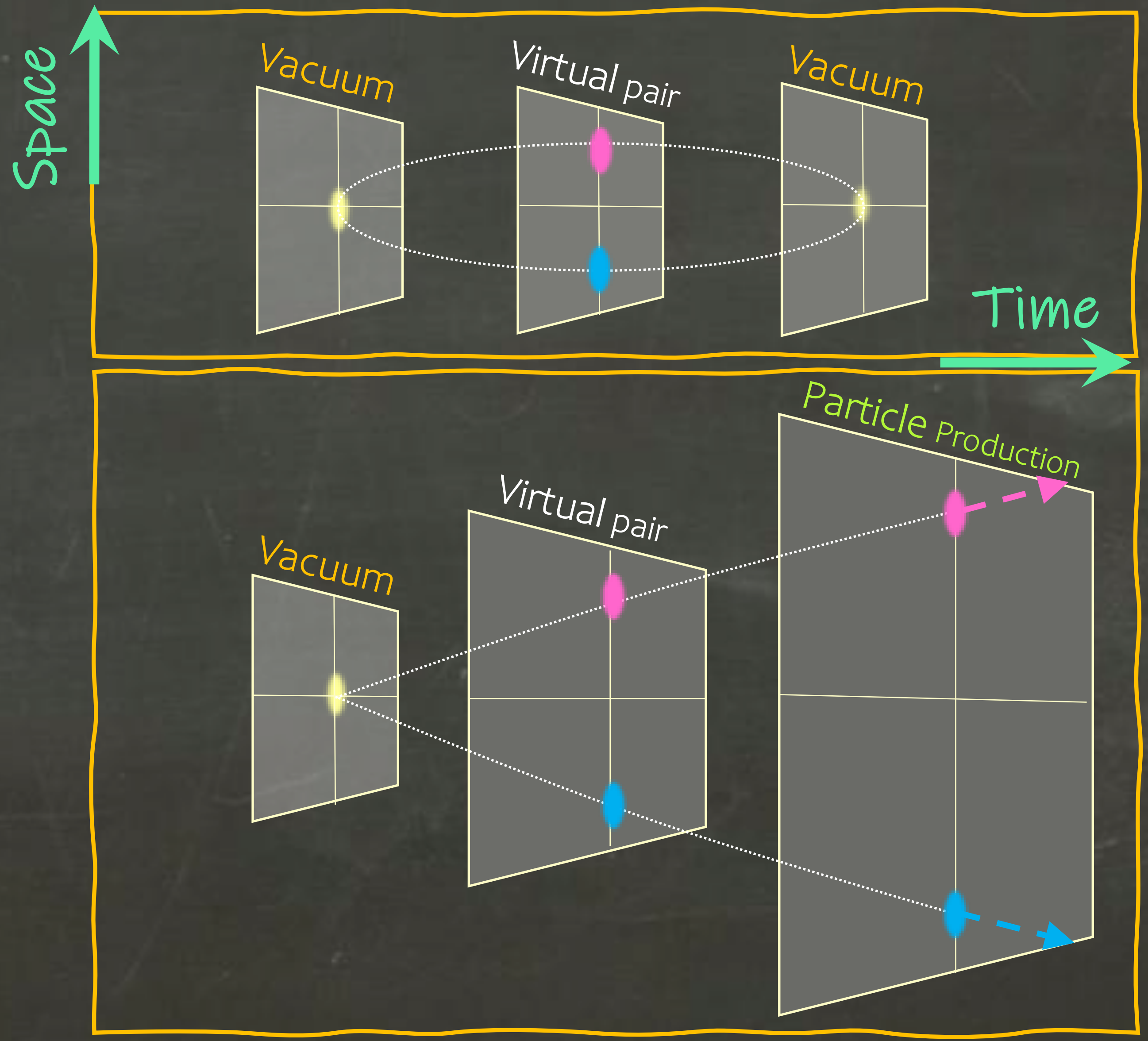
Examples of such BG fields:

1) Electric (*Schwinger effect*)
2) Gravitational (*Gravitational production*)

Inflation Produces Particles!

Flat Space:

Expanding space:

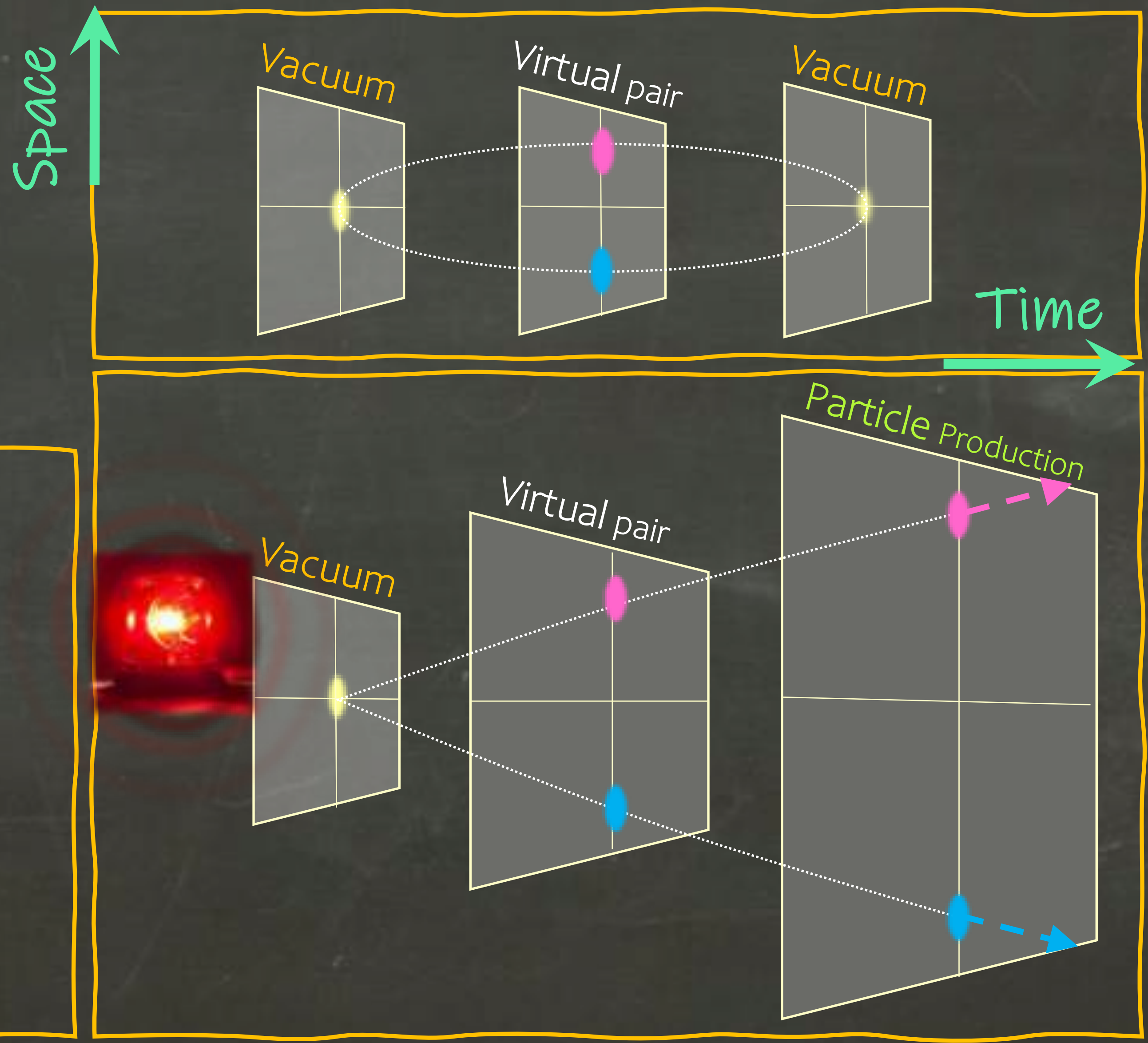


Vacuum

Particle Production

Inflation Produces Particles!

Flat Space:



Vacuum

Expanding space:

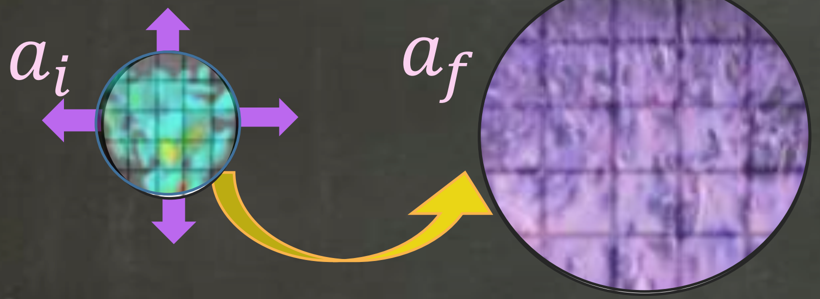
Edwin Schrödinger
(1939)

Shocked by his discovery,
Schrödinger found it
an alarming phenomenon!

Particle
Production

Cosmic Perturbations

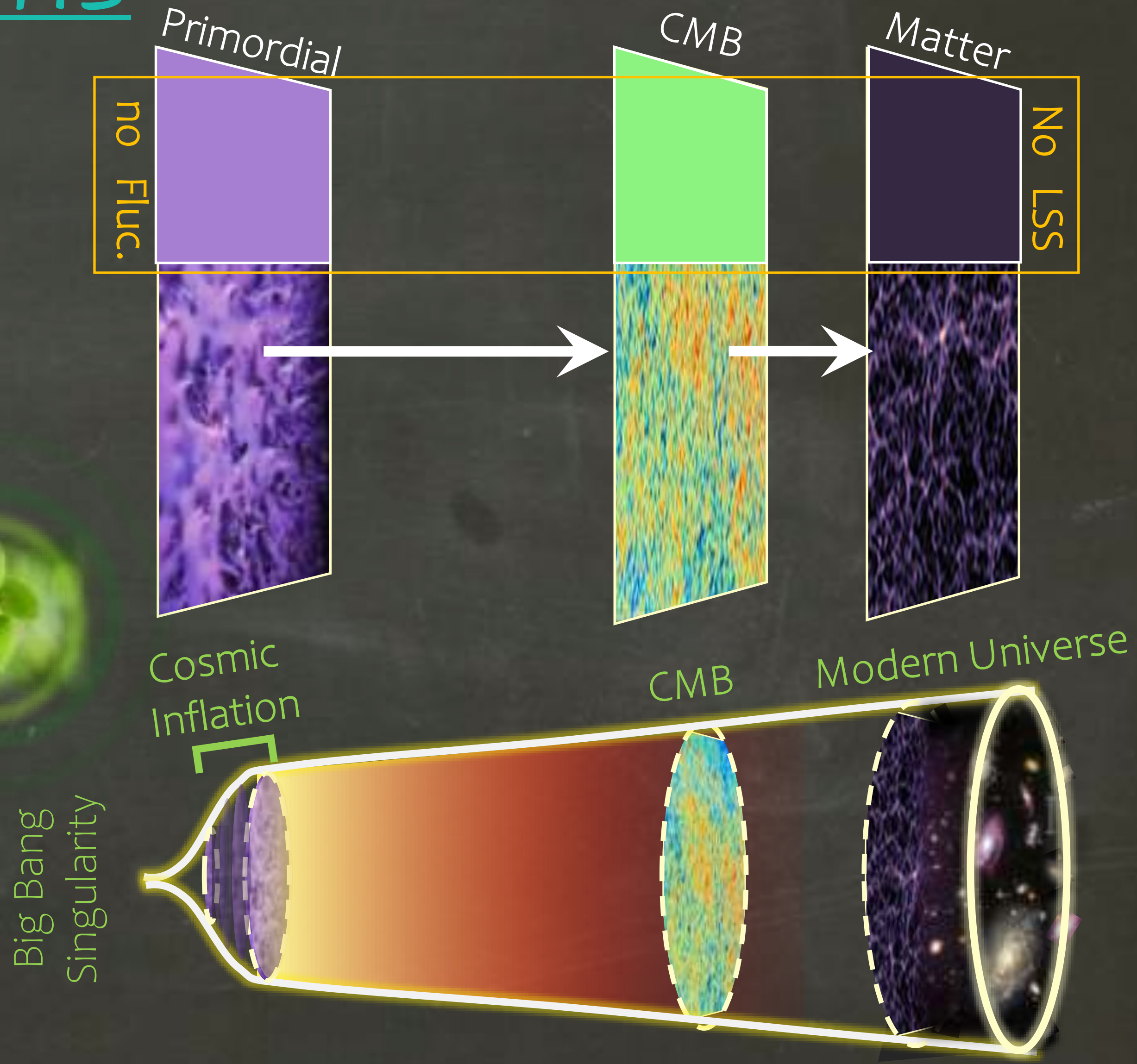
Exponential expansion turns initial quantum vacuum fluctuations into



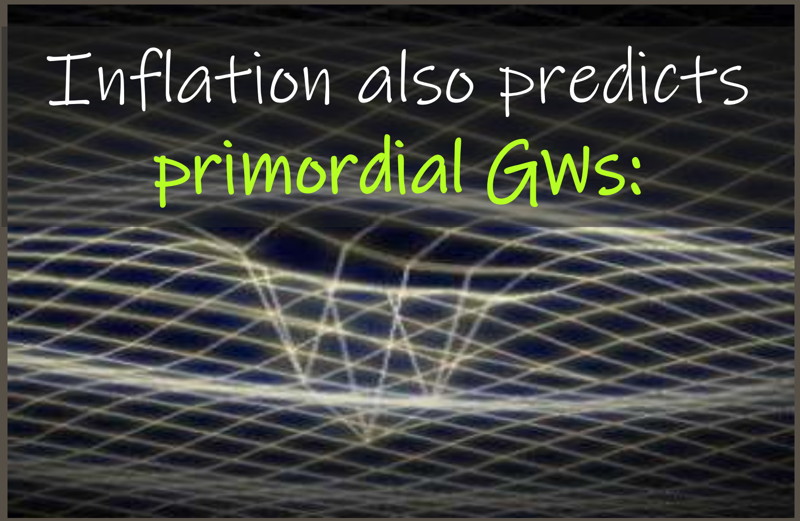
actual cosmic perturbations!

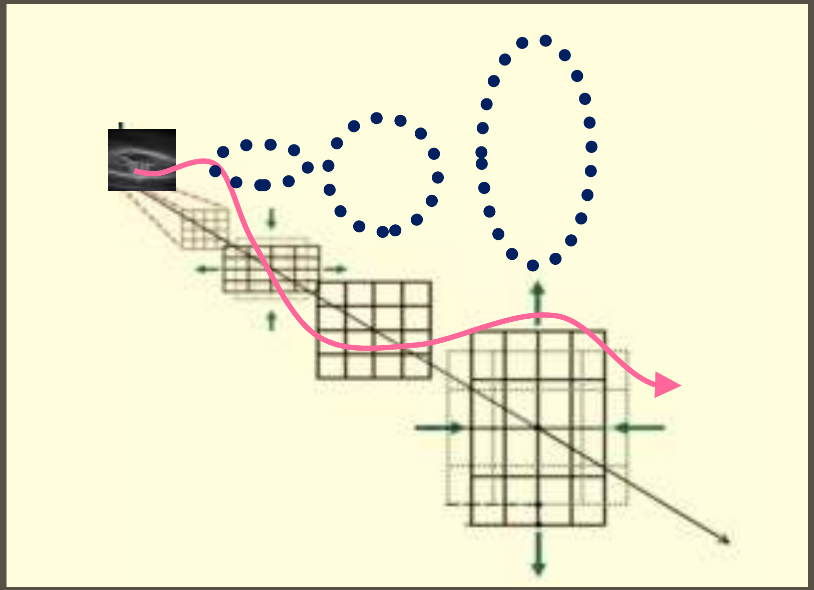
We are the product of quantum fluctuations in the very early universe!

(Stephen Hawking)

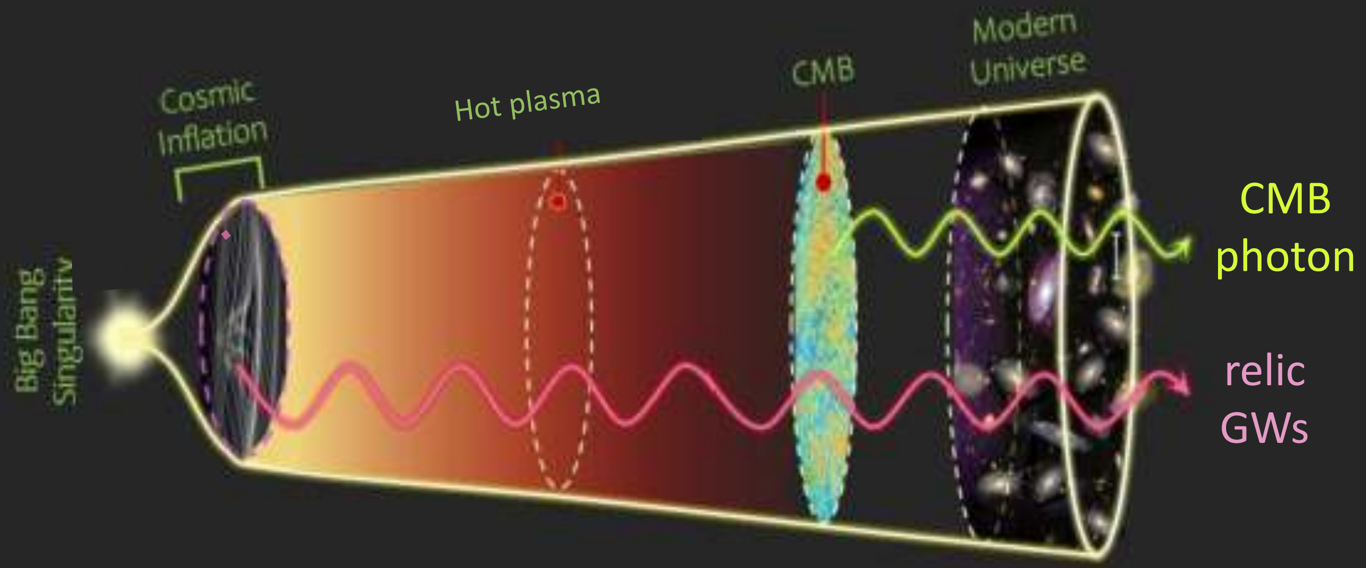


Primordial Gravitational Waves





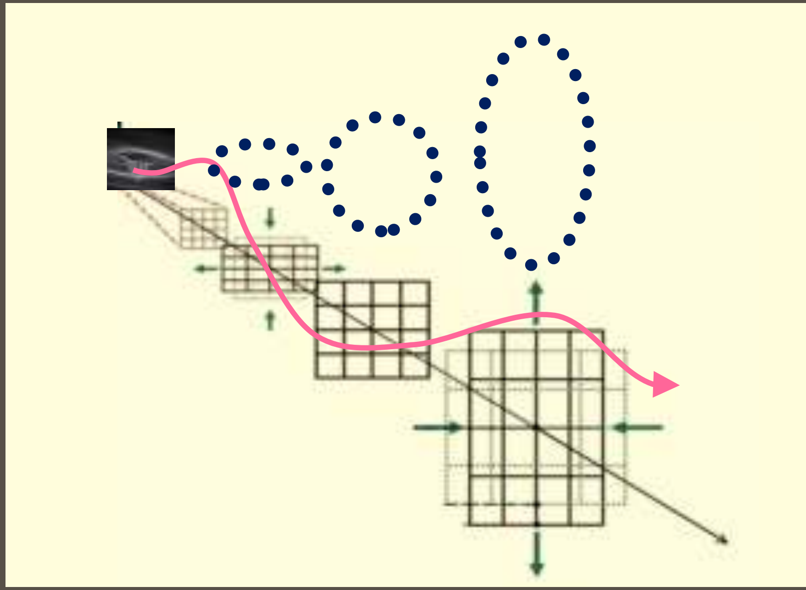
Primordial GWs: tiny waves in the fabrics of the space-time that squeeze and stretch anything in their path as they pass by.

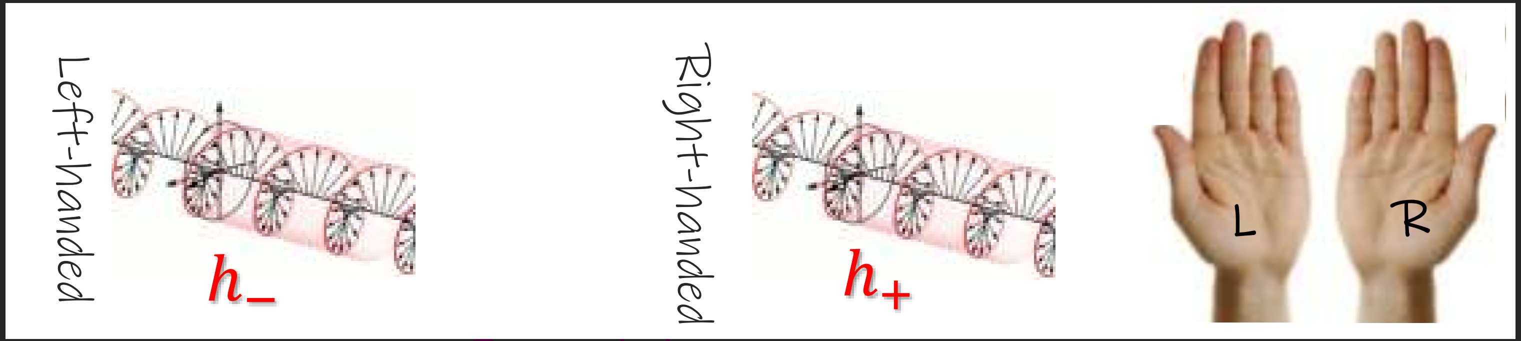


Primordial Gravitational Waves

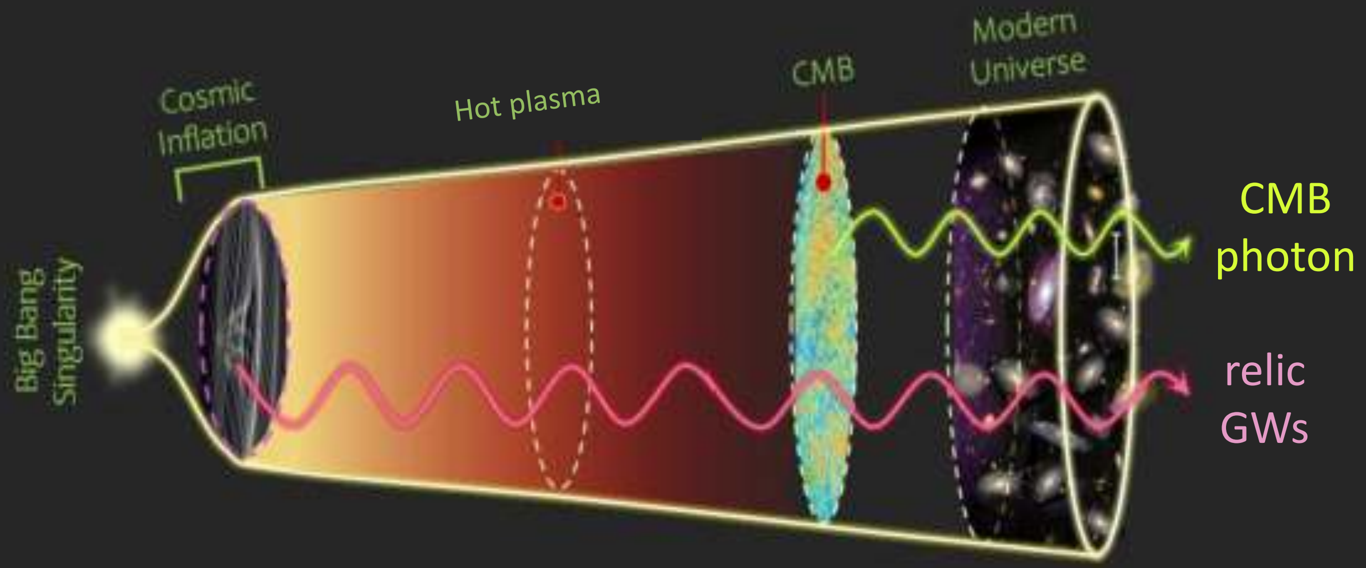
- Vacuum GWs

$\Box h_{ij}=0 \rightarrow h_\pm = h_\pm^{vac}$





Circular polarizations



Primordial Gravitational Waves

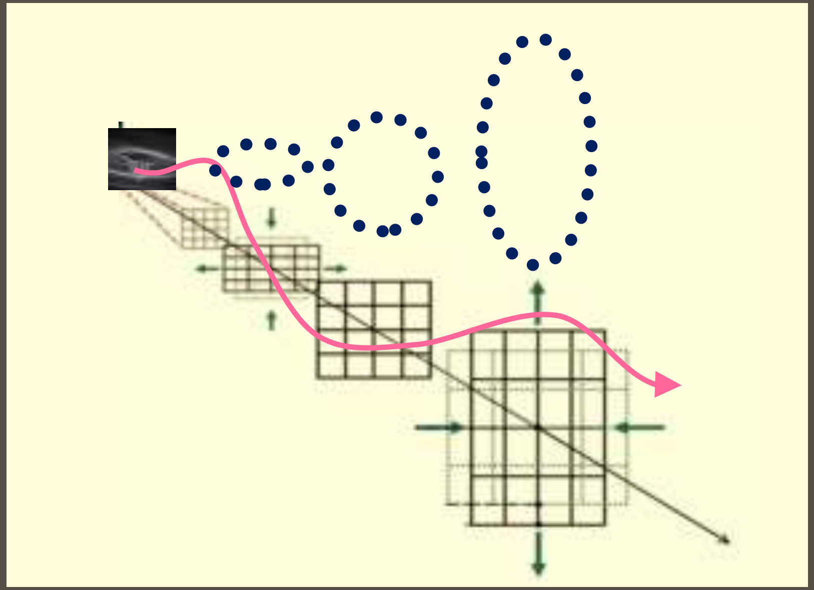
- Vacuum GWs

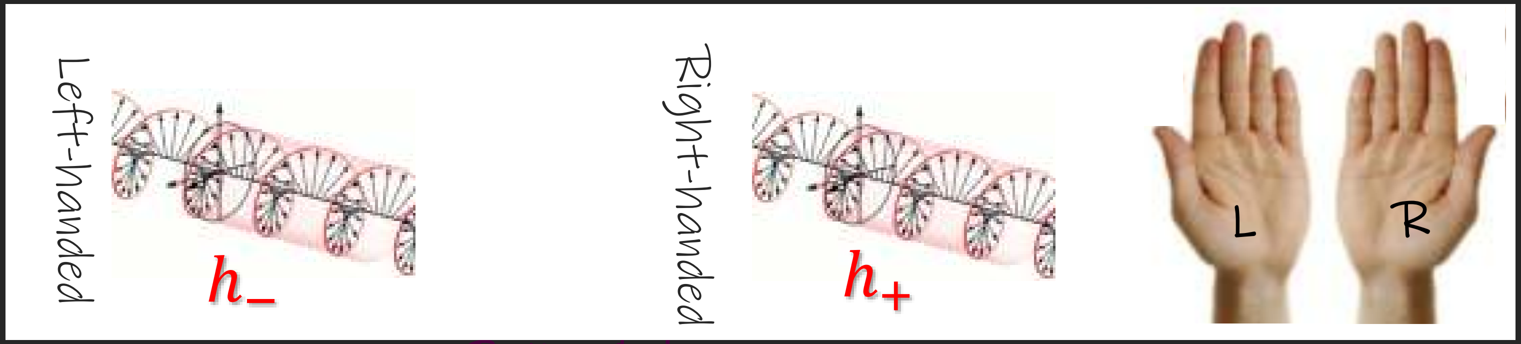
$\Box h_{ij}=0 \rightarrow h_{\pm}= h_{\pm}^{vac}$

- Unpolarizaed

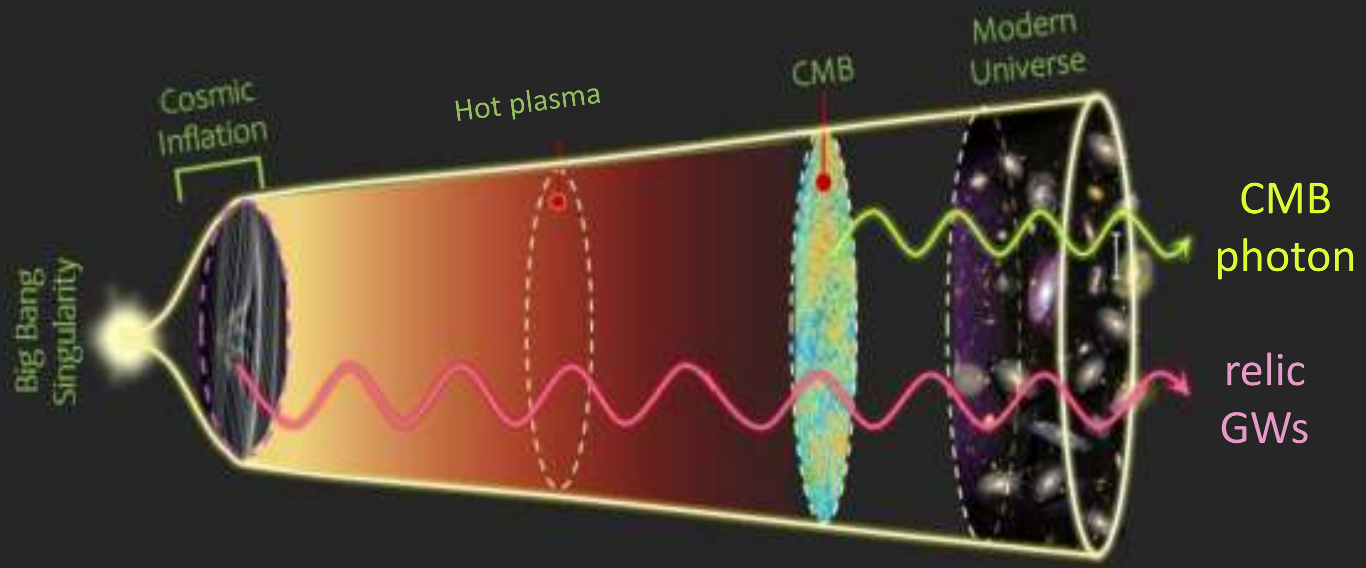
$<|h_{+}^{vac}|^2>=<|h_{-}^{vac}|^2>$

- Nearly Gaussian





Circular polarizations



Cosmic Perturbations-Gravitational Waves

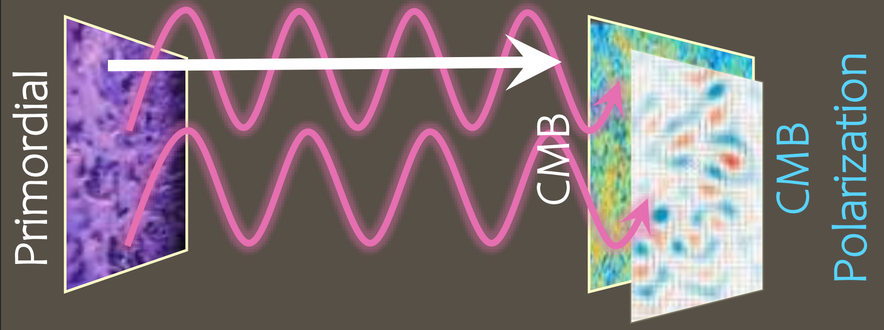
- Inflation also redicts primordial GWs:

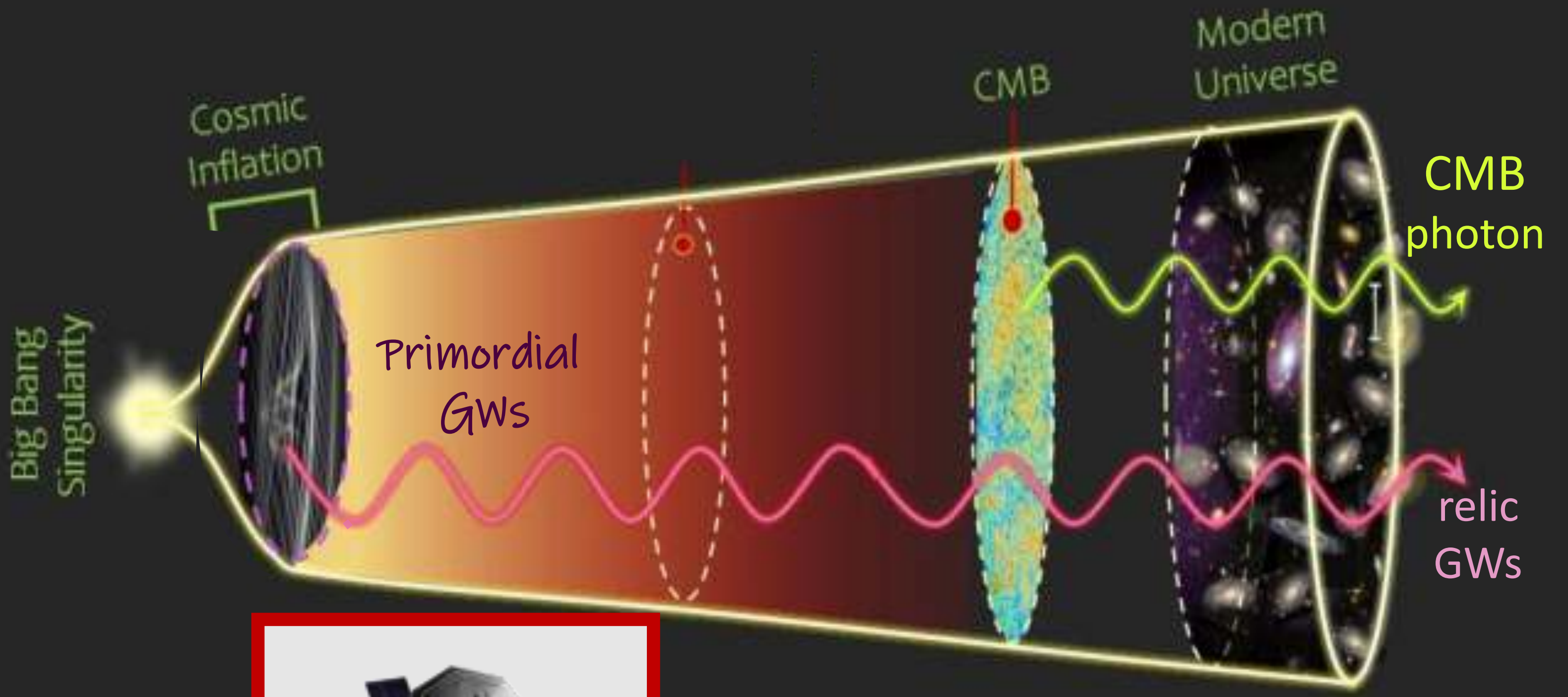
$\Box h_{ij}=0 \rightarrow h_{\pm}= h_{\pm}^{vac}$

- Unpolarizaed

$<|h_{+}^{vac}|^2>=<|h_{-}^{vac}|^2>$

- Nearly Gaussian
- CMB polarization





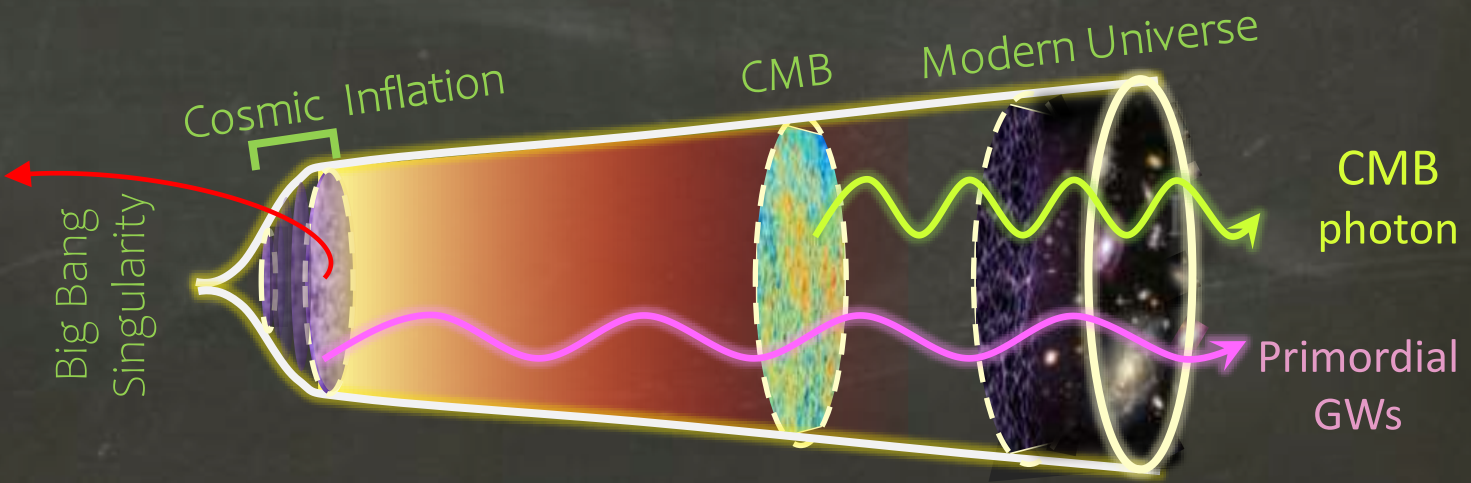
CMB-S4
Next Generation CMB Experiment

As Yet

- Observations are in perfect agreement with Inflation.
- The Particle Physics of Inflation is still unknown.
- The Standard models of inflation are based on Scalars.

Inflation Particle Physics:
- a scalar singlet BSM

-Unpolarized, Gaussian GW



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What about Gauge Fields?!

Inflation Particle Physics:
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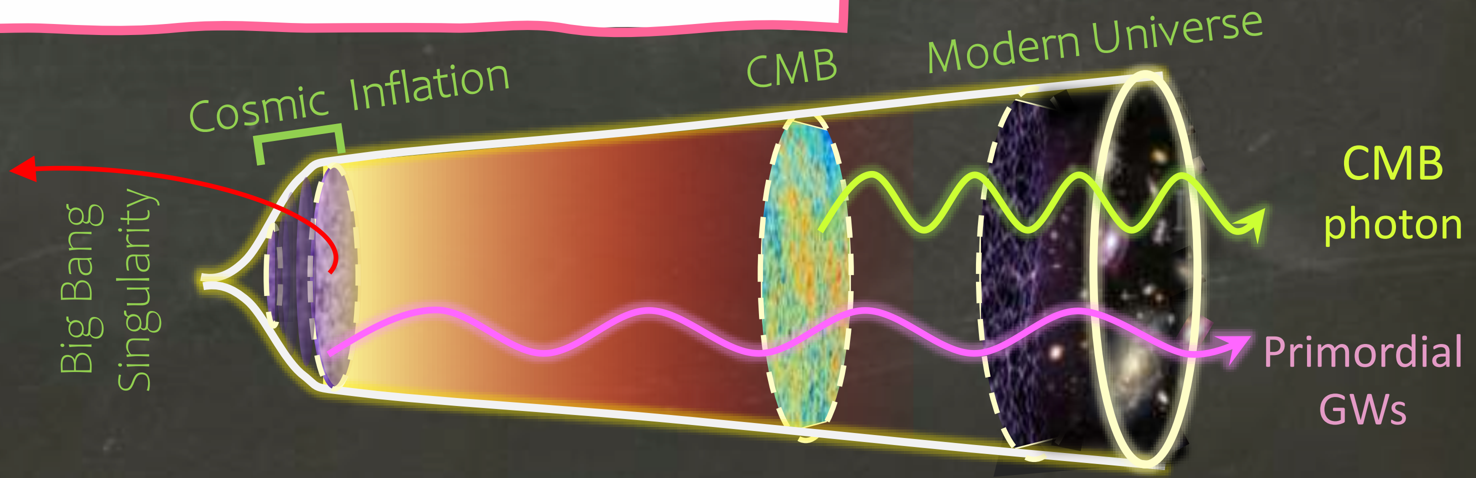


Puzzles of SM & Cosmology

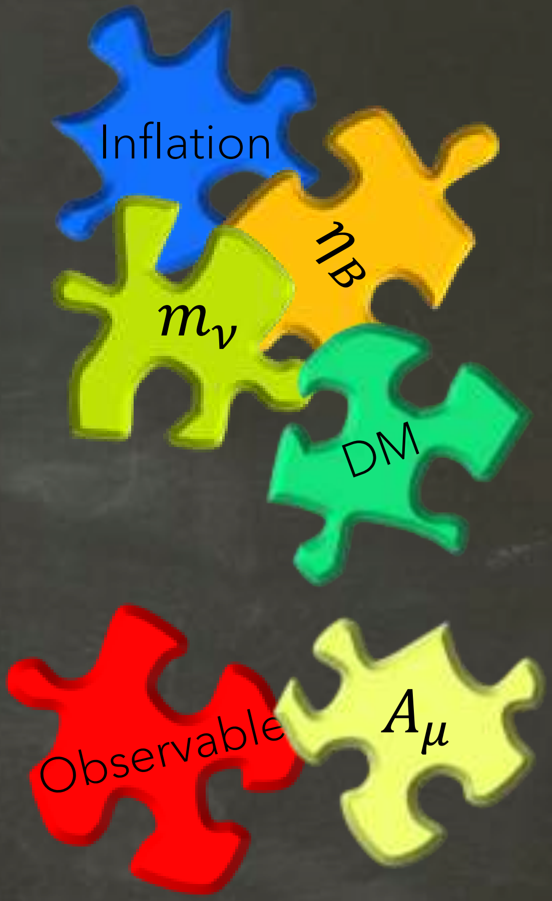
I) Particle physics of Inflation

II) Origin of matter asymmetry

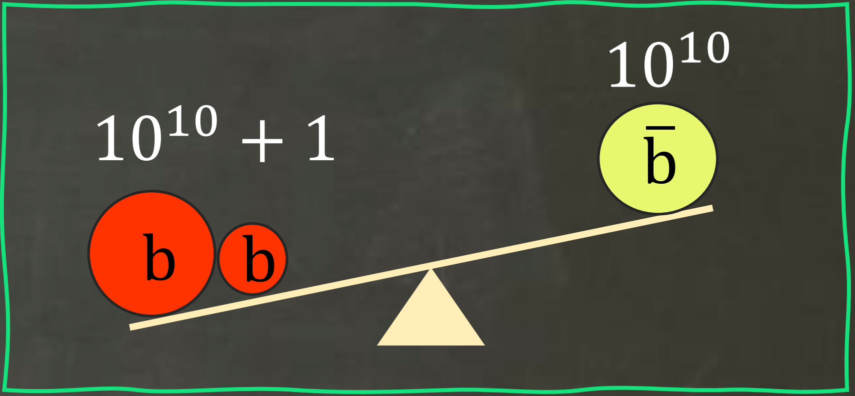
III) Origin of Neutrino mass

IV) Particle nature of DM

Puzzles of
Standard Model of Particle Physics (SM)
& Cosmology which need
Physics Beyond SM



Matter asymmetric



Universe is highly matter asymmetric

$$\eta_B = \frac{n_B - n_{\bar{B}}}{n_\gamma} \approx 6 \times 10^{-10}$$

- Statistical fluctuations ✖ (Too small)
- Initial condition ✖ (due to inflation)

Must be produced dynamically, i.e. Baryogenesis by

Sakharov Conditions:
- Baryon number violation,
- C and CP violation,
- Out of thermal equilibrium

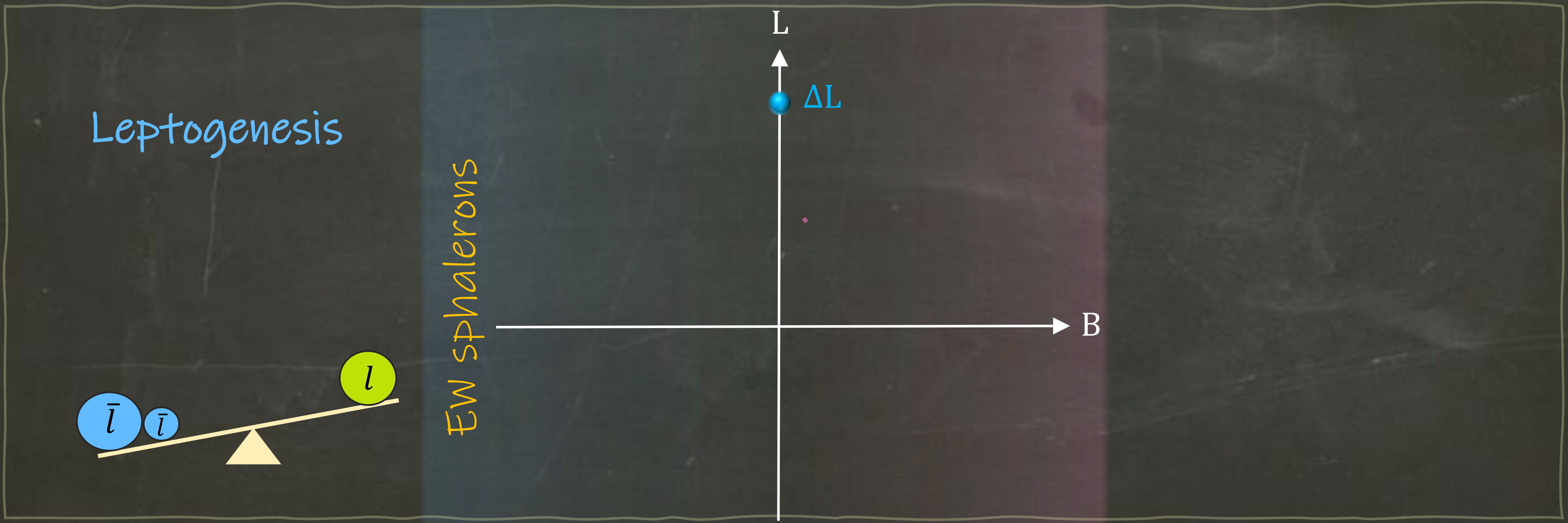
SM Has All, But Too Tiny! ✖

Physics Beyond the Standard Model!

Baryogenesis via Leptogenesis

Lepton asymmetry → EW sphalerons → Baryon asymmetry

ΔL → ΔB



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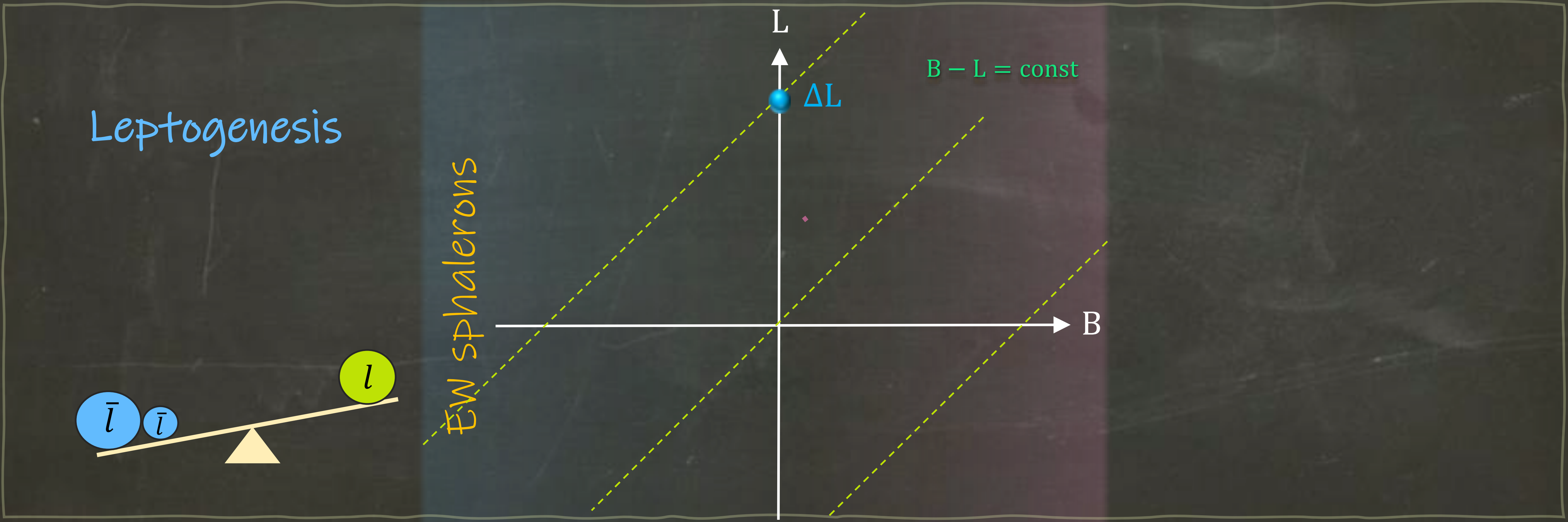
ΔL ΔB

Sphaleron transitions: - Conserve **B-L**



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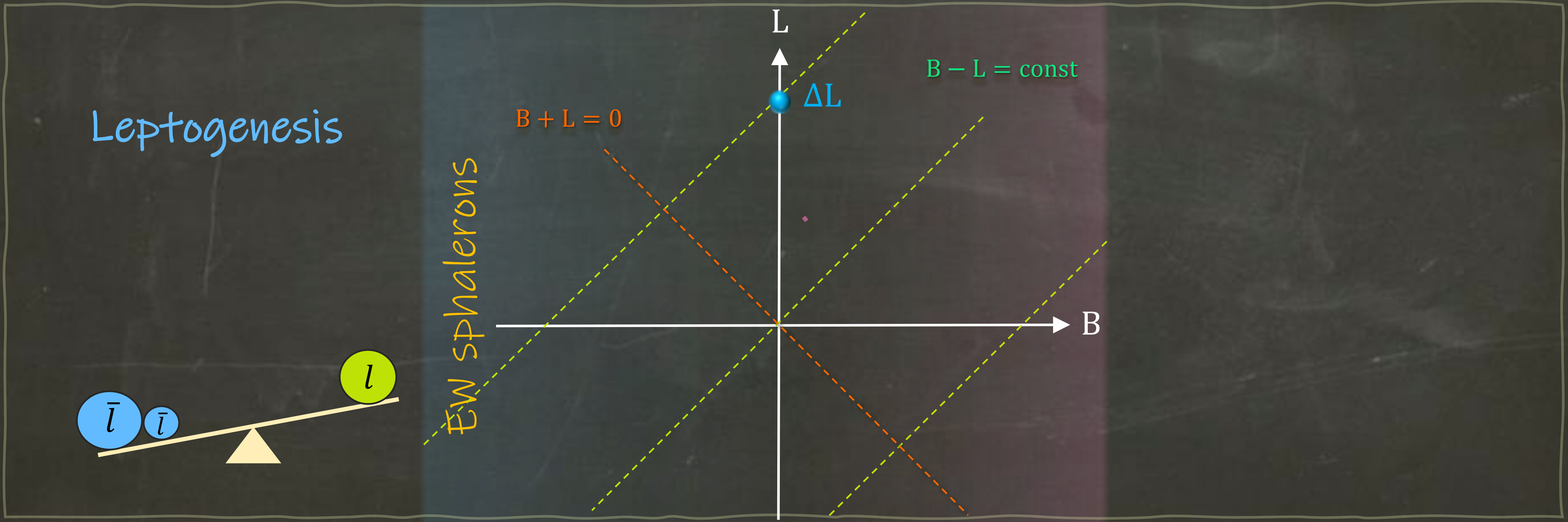
ΔL ΔB

Sphaleron transitions:
- Conserve **B-L**,
- Wash out **B+L**! ------> B+L=0



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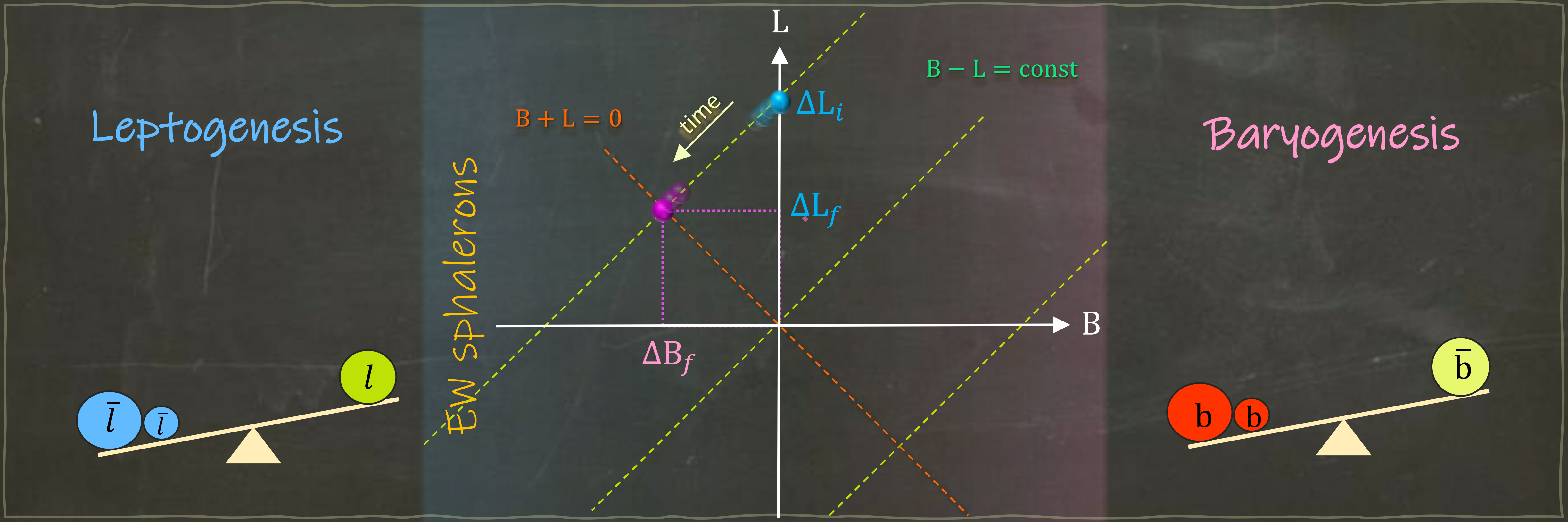
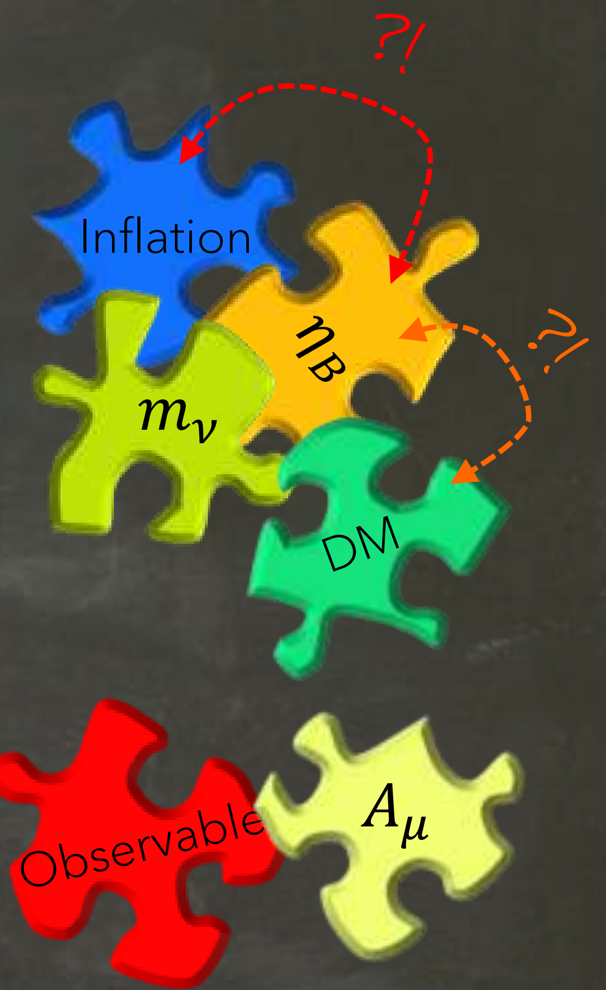


Puzzles of SM & Cosmology

I) Particle physics of Inflation
II) Origin of matter asymmetry
III) Origin of Neutrino mass
IV) Particle nature of DM

Puzzles of Standard Model of Particle Physics (SM) & Cosmology which need **Physics Beyond SM**



- Curious cosmological coincidences $\eta_B \simeq 0.3\, P_\zeta$ and $\Omega_{DM} \simeq 5\Omega_B$!

$$\eta_B = \frac{n_B - n_{\bar{B}}}{n_\gamma} \approx 6 \times 10^{-10}$$

Baryon to Photon Ratio Today

$$P_\zeta = \frac{1}{2\epsilon}\left(\frac{1}{2\pi}\frac{H}{M_{pl}}\right)^2 \approx 2 \times 10^{-9}$$

Curvature Power Spectrum in Inflation

Puzzles of SM & Cosmology

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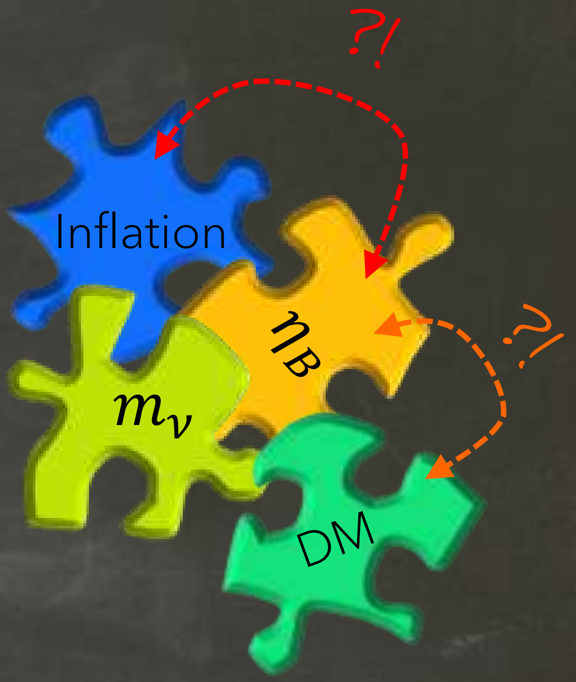
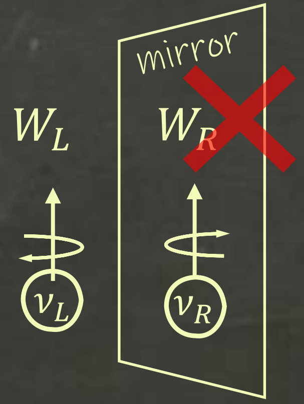
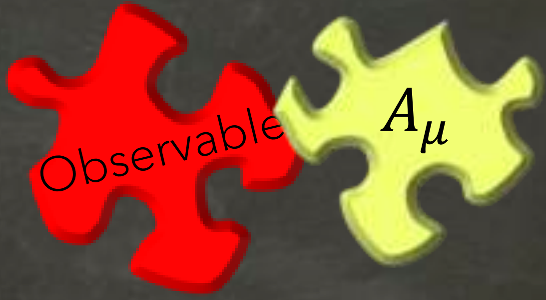


- Curious cosmological coincidences $\eta_B \simeq 0.3\,\mathrm{P}_\zeta$ and $\Omega_{DM} \simeq 5\Omega_B$!

1. Ad hoc parity violation
2. Accidental B-L global symmetry
3. Vacuum Stability problem
4. Strong CP problem

SM as a particle physics model
also faces some ***conceptual issues***





Gauge Fields & Inflation

Why Gauge Fields in Inflation?!

- Why not?
  - Inflation happened at highest energy scales observable!
  - Gauge fields are ubiquitous, building blocks of SM & beyond.
- What do they do in inflation?

$E_{Inf} < 10^{14} GeV$

Comparing to LHC

$\frac{E_{Inf}}{E_{LHC}} \lesssim 10^{11}$!!!!

Why Gauge Fields in Inflation?!

- Why not?
  - Inflation happened at highest energy scales observable!
  - Gauge fields are ubiquitous, building blocks of SM & beyond.
- What do they do in inflation?

I. Can Gauge Fields Contribute to Physics of Inflation?
   Yes!

II. Do they leave an observable signature?
   Yes! Robust prediction for GW background.

III. How much they can change the cosmic history?
   A lot! Novel mechanisms for Baryo- and Dark-genesis.

$E_{Inf} < 10^{14} GeV$

Comparing to LHC

$\frac{E_{Inf}}{E_{LHC}} \lesssim 10^{11}$!!!!

Challenges:

1) Conformal symmetry of Yang-Mills

   gauge field dilutes like $A_\mu \sim 1/a$

2) Respecting gauge symmetry

   Not to break gauge symmetry explicitly

A.M. & Sheikh-Jabbari, 2011

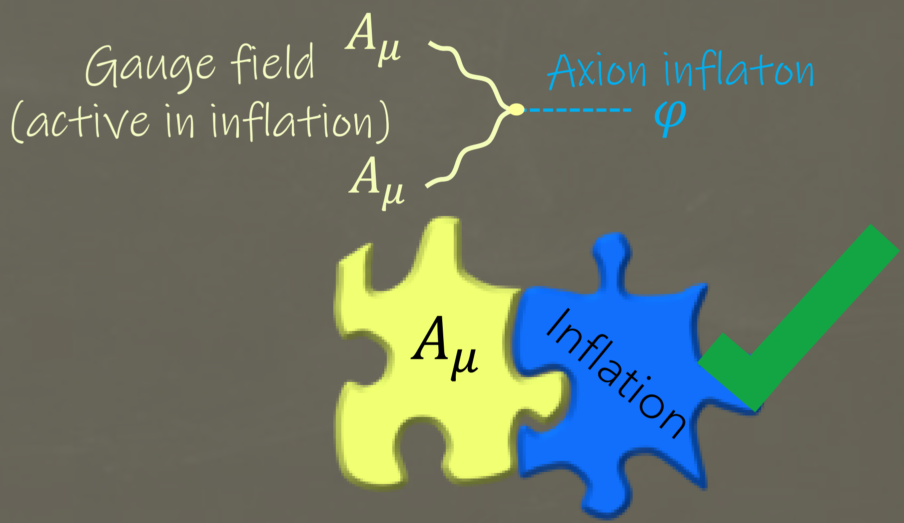
Adding new terms
to the gauge theory

$$\frac{\kappa}{384}(F\tilde{F})^2$$

or

$$\frac{\lambda}{8f}\, F\tilde{F}\, \varphi$$

Axion



Challenges:

1) Conformal symmetry of Yang-Mills

   gauge field dilutes like $A_\mu \sim 1/a$

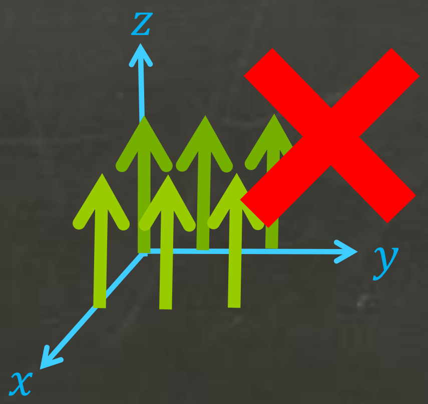
2) Respecting gauge symmetry

   Not to break gauge symmetry explicitly

3) Spatial isotropy & homogeneity

   U(1) vacuum $\boldsymbol{A_\mu}$

$$\boldsymbol{A_i = Q(t)\delta_i^3}$$



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$$\frac{\kappa}{384}(F\tilde{F})^2$$

or

$$\frac{\lambda}{8f}F\tilde{F}\,\varphi$$

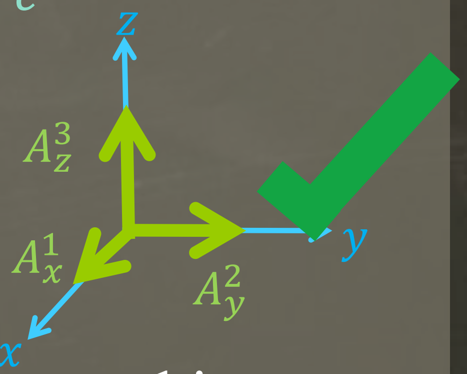
Axion

SU(2) vacuum $\boldsymbol{A_\mu = A_\mu^a\, T_a}$

$$[\boldsymbol{T}_a, \boldsymbol{T}_b] = i\,\varepsilon^{abc}\,\boldsymbol{T}_c$$

Spatially isotropic

$$\boldsymbol{A_i^a = Q(t)\delta_i^a}$$



so(3) & su(2) are isomorphic

SU(2)-Axion Model Building

- Gauge-flation **A. M.**, & Sheikh-Jabbari, **2011**

$$S_{Gf} = \int d^4x \sqrt{-g}\left(-\frac{R}{2} - \frac{1}{4}F^2 + \frac{\kappa}{384}(F\tilde{F})^2\right)$$

- Chromo-natural P. Adshead, M. Wyman, 2012

$$S_{Cn} = \int d^4x \sqrt{-g}\left(-\frac{R}{2} - \frac{1}{4}F^2 - \frac{1}{2}\left((\partial_\mu\varphi)^2 - \mu^4\left(1 + \cos(\frac{\varphi}{f})\right)\right) - \frac{\lambda}{8f}\varphi F\tilde{F}\right)$$

SU(2)-Axion Model Building

- Gauge-flation **A. M.**, & Sheikh-Jabbari, **2011**

$$S_{Gf} = \int d^4x \sqrt{-g}\left(-\frac{R}{2} - \frac{1}{4}F^2 + \frac{\kappa}{384}(F\tilde{F})^2\right)$$

Ruled-out by the data

R. Namba, E. Dimastrogiovanni, M. Peloso 2013

P. Adshead, E. Martinec, M. Wyman 2013

+ Theoretical issue:

Very large $\lambda \sim 100$!

D. Baumann & L. McAllister 2014

- Chromo-natural P. Adshead, M. Wyman, 2012

$$S_{Cn} = \int d^4x \sqrt{-g}\left(-\frac{R}{2} - \frac{1}{4}F^2 - \frac{1}{2}\left((\partial_\mu\varphi)^2 - \mu^4\left(1 + \cos(\frac{\varphi}{f})\right)\right) - \frac{\lambda}{8f}\varphi F\tilde{F}\right)$$

Inspired by them, several different models with SU(2) fields have been proposed and studied.

An incomplete list of Different Realizations of the SU(2)-Axion Inflation:

1. **A. M.** and M. M. Sheikh-Jabbari, Phys. Rev. D 84:043515, 2011 [*arXiv:1102.1513*]
2. P. Adshead, M. Wyman, Phys. Rev. Lett.(2012) [*arXiv:1202.2366*]
3. **A. M.** JHEP 07 (2016) 104 [arXiv:1604.03327]
4. C. M. Nieto and Y. Rodriguez Mod. Phys. Lett. A31 (2016) [arXiv:1602.07197]
5. E. Dimastrogiovanni, M. Fasiello, and T. Fujita JCAP 1701 (2017) [arXiv:1608.04216]
6. P. Adshead, E. Martinec, E. I. Sfakianakis, and M. Wyman JHEP 12 (2016) 137 [arXiv:1609.04025]
7. P. Adshead and E. I. Sfakianakis JHEP 08 (2017) 130 [arXiv:1705.03024]
8. R. R. Caldwell and C. Devulder Phys. Rev. D97 (2018) [arXiv:1706.03765]
9. E. McDonough, S. Alexander, JCAP11 (2018) 030 [arXiv:1806.05684]
10. L. Mirzagholi, E. Komatsu, K. D. Lozanov, and Y. Watanabe, [arXiv:2003.04350]
11. Y. Watanabe, E. Komatsu, [arXiv:2004.04350]
12. J. Holland, I. Zavala, G. Tasinato, [arXiv:2009.00653]
13. ....

A. M. , **SU(2)R –axion inflation** [arXiv:2012.11516]

SU(2)-Axion Model Building

- Gauge-flation **A. M.**, & Sheikh-Jabbari, **2011**

$$S_{Gf} = \int d^4x \sqrt{-g}\left(-\frac{R}{2} - \frac{1}{4}F^2 + \frac{\kappa}{384}(F\tilde{F})^2\right)$$

- Chromo-natural P. Adshead, M. Wyman, 2012

$$S_{Cn} = \int d^4x \sqrt{-g}\left(-\frac{R}{2} - \frac{1}{4}F^2 - \frac{1}{2}\left((\partial_\mu\varphi)^2 - \mu^4\left(1+\cos(\frac{\varphi}{f})\right)\right) - \frac{\lambda}{8f}\varphi F\tilde{F}\right)$$

Ruled-out by the data

R. Namba, E. Dimastrogiovanni, M. Peloso 2013
P. Adshead, E. Martinec, M. Wyman 2013

+ Theoretical issue:
Very large $\lambda \sim 100$!

D. Baumann & L. McAllister 2014

SU(2)-Axion inflation has a very rich phenomenology:

- A new mechanism for generation of Primordial Gravitational Waves — P. Adshead et. al 2013; Dimastrogiovanni et. al 2013; **A. M.** et. al, 2013
- All Sakharov conditions are satisfied in inflation: a new baryogenesis mechanism — **A. M. 2014 & A.M. 2016**; R. Caldwell et. al 2017
- Particle Production in inflation by Schwinger effect and chiral anomaly — **A. M.** et. al **2017 & 2018**; **A.M. 2019**

SU(2)-Axion Model Building

- Gauge-flation A. M., & Sheikh-Jabbari, **2011**

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- Minimal Scenario of SU(2)-axion inflation **A. M.**, 2016 $f<0.1$ Mpl & $\lambda<0.1$

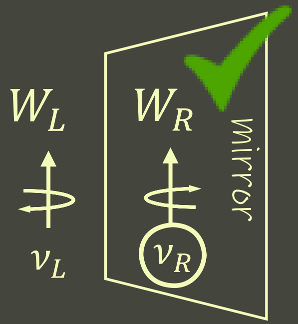
$$S_{AM} = \int d^4x \sqrt{-g}\left(-\frac{R}{2} - \frac{1}{4}F^2 - \frac{1}{2}\left((\partial_\mu\varphi)^2 - V(\varphi)\right) - \frac{\lambda}{8f}\varphi F\tilde{F}\right)$$

Axion Monodromy

How to Connect them with the SM?

Let us Extend SM Gauge Symmetry by an $SU(2)_R$ and couple it to Axion Inflaton!

- Left-Right Symmetric Model + axion!



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Axion Monodromy

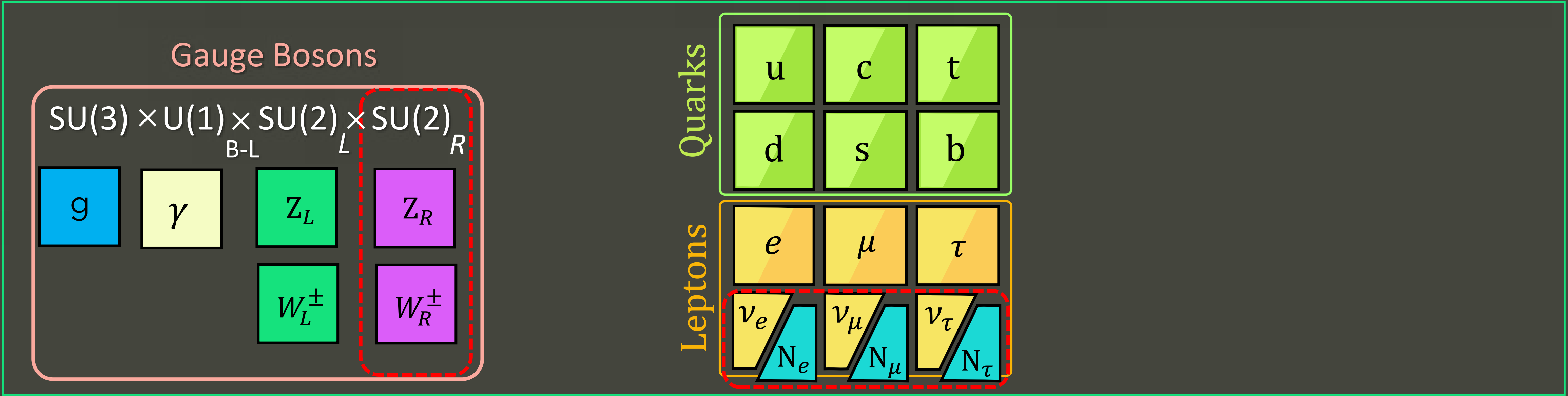
Gauge field is $su(2)_R$

A. M. arXiv: 2012.11516

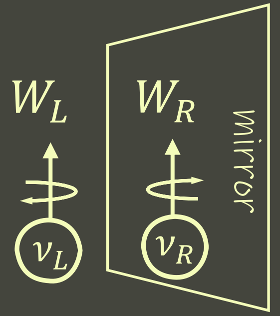
Minimal Left-Right Symmetric model

Left-Right Symmetric Model

- An SU(2) gauge extension of SM with 3 Right-handed Neutrinos coupled to it.



J. C. Pati and A. Salam, Phys. Rev. D 10, 275-289 (1974) R. N. Mohapatra and J. C. Pati, Phys. Rev. D 11, 2558 (1975) G. Senjanovic and R. N. Mohapatra, Phys. Rev. D 12, 1502 (1975)



$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

↓ Spontaneous Symmetry Breaking

$SU(2)_L \times U(1)_Y$

Minimal Left-Right Symmetric model

Left-Right Symmetric Model

- An SU(2) gauge extension of SM with 3 Right-handed Neutrinos coupled to it.

Gauge Bosons

$SU(3) \times U(1)_{B\text{-}L} \times SU(2)_L \times SU(2)_R$

g γ Z_L Z_R

$W_L^{\pm}$ $W_R^{\pm}$

Quarks

u c t

d s b

Leptons

e μ τ

ν_e N_e ν_μ N_μ ν_τ N_τ

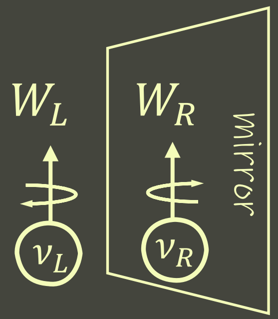
Higgs sector

ϕ bi-doublet $SU(2)_L \times SU(2)_R$

Δ_R $SU(2)_R$ triplet

Δ_L $SU(2)_L$ triplet

J. C. Pati and A. Salam, Phys. Rev. D 10, 275-289 (1974) R. N. Mohapatra and J. C. Pati, Phys. Rev. D 11, 2558 (1975) G. Senjanovic and R. N. Mohapatra, Phys. Rev. D 12, 1502 (1975)



$SU(2)_L \times SU(2)_R \times U(1)_{B\text{-}L}$

↓ Spontaneous Symmetry Breaking

$SU(2)_L \times U(1)_Y$

$\langle \Delta_R \rangle \neq 0$

Massive

N_i $W_R^{\pm}$ Z_R

Minimal Left-Right Symmetric model

Left-Right Symmetric Model

- An SU(2) gauge extension of SM with 3 Right-handed Neutrinos coupled to it.

Gauge Bosons

$SU(3) \times U(1)_{B-L} \times SU(2)_L \times SU(2)_R$

g, γ, Z_L, $W_L^{\pm}$, Z_R, $W_R^{\pm}$

Quarks

u	c	t
d	s	b

Leptons

e	μ	τ
ν_e / N_e	ν_μ / N_μ	ν_τ / N_τ

Higgs sector

- ϕ — bi-doublet $SU(2)_L \times SU(2)_R$
- Δ_R — $SU(2)_R$ triplet
- Δ_L — $SU(2)_L$ triplet

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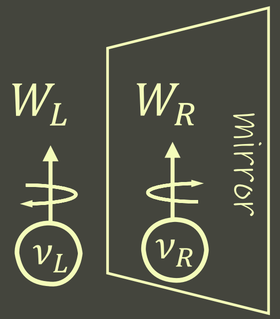


$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

↓ Spontaneous Symmetry Breaking

$SU(2)_L \times U(1)_Y$

$\langle \Delta_R \rangle \neq 0$

Massive

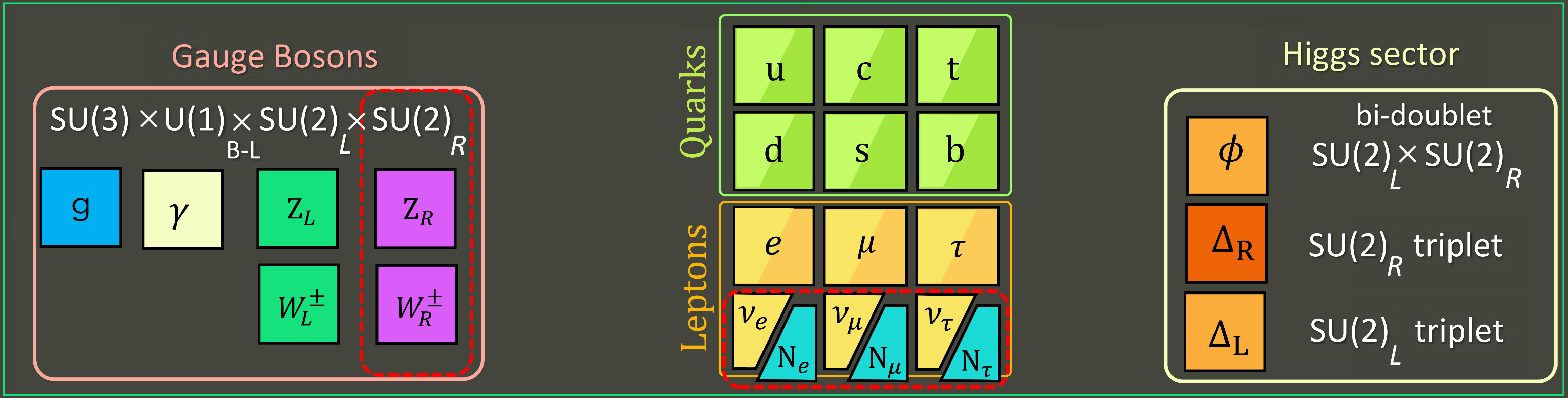
N_i $W_R^{\pm}$ Z_R

1. Ad hoc parity violation ✔
2. Accidental B-L global symmetry
3. Vacuum Stability problem
4. Strong CP problem

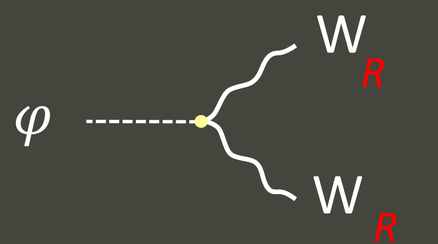
Minimal Left-Right Symmetric model

Left-Right Symmetric Model

- An SU(2) gauge extension of SM with 3 Right-handed Neutrinos coupled to it.



- Axion is the inflaton which is coupled to $SU(2)_R$

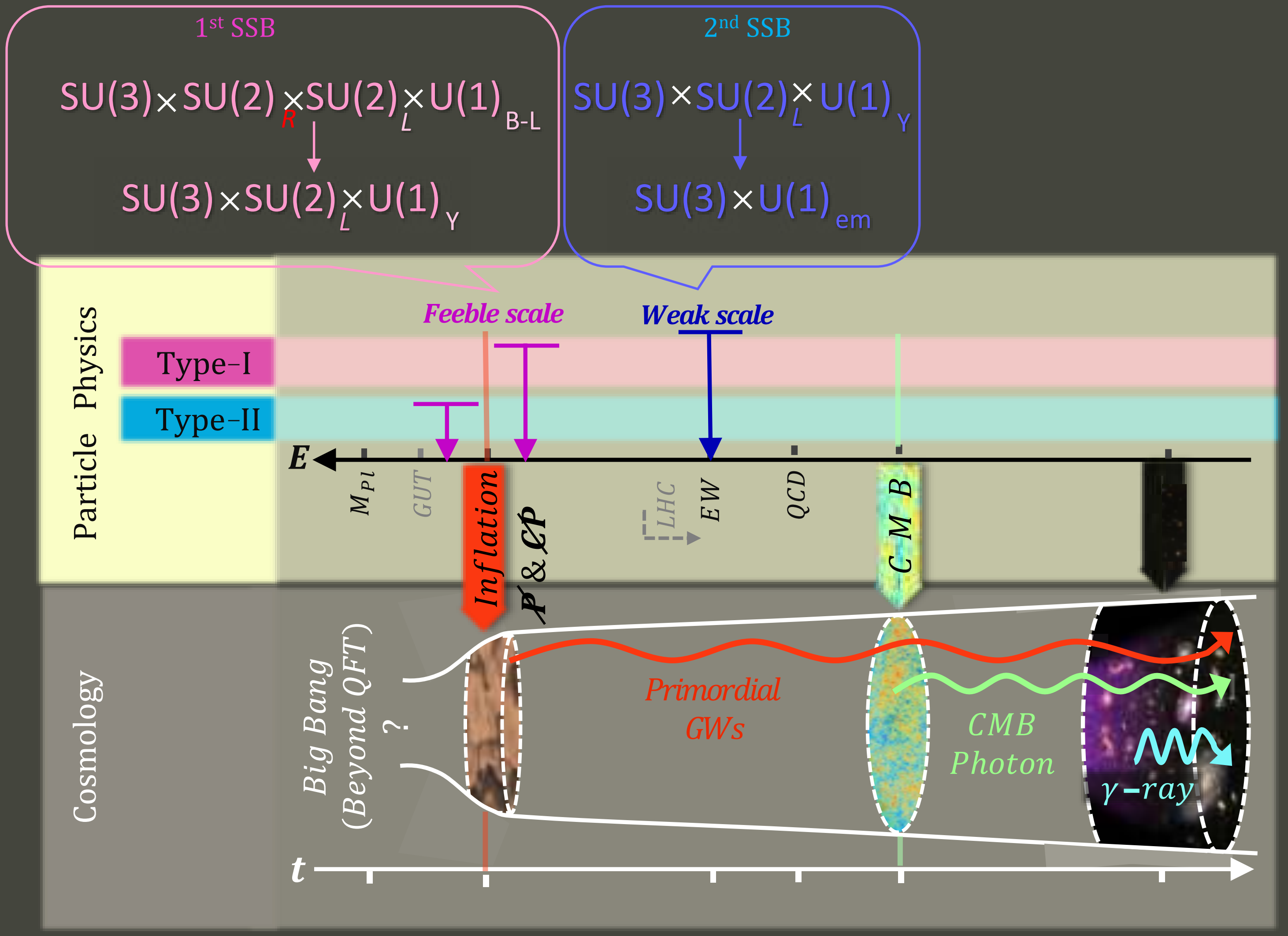


A. M. arXiv: 2012.11516

$SU(2)_R$-axion Inflation

A. M. arXiv: 2012.11516

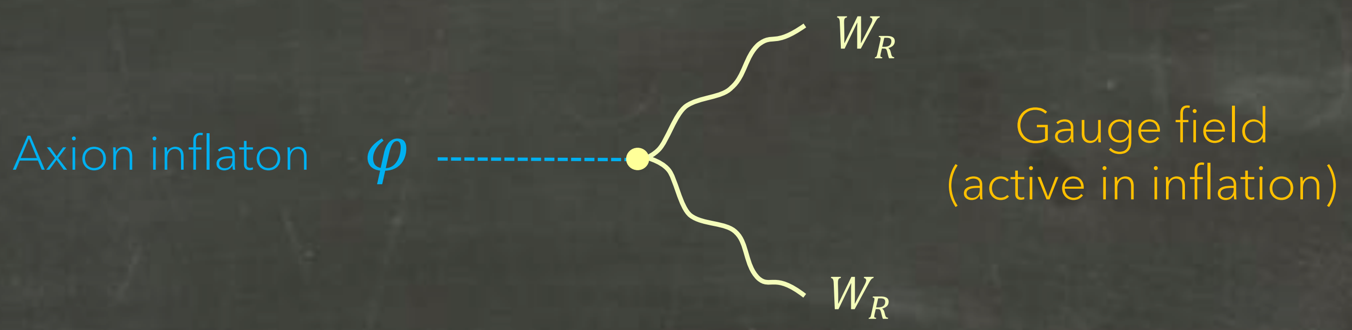
Gauge symmetry



Gauge field Production by Axion

Gauge field Production in Inflation

- SM Gauge fields are diluted by inflation & unimportant , BUT $SU(2)_R$:



$SU(2)_R$ Gauge Field

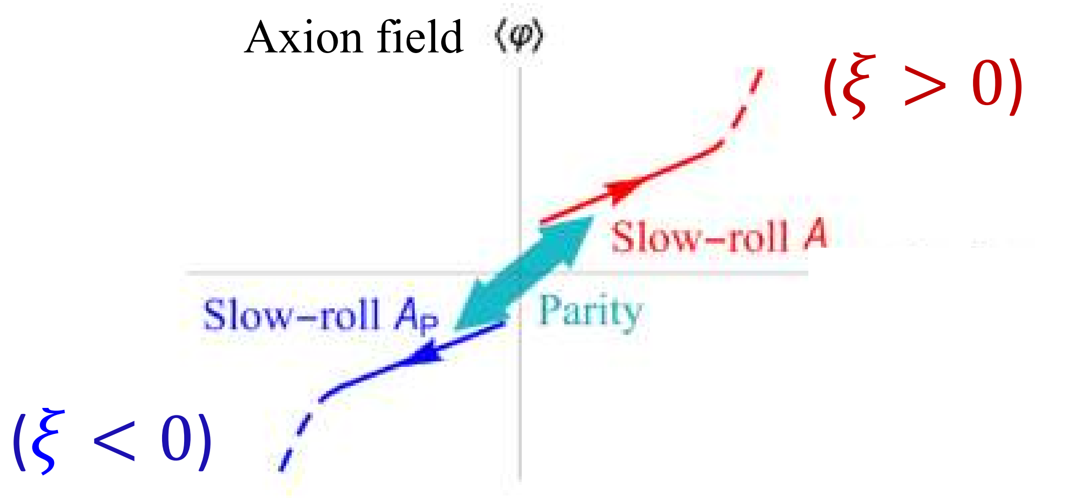
- $\delta A_i^a = B_\pm^a(t,k)e_i^\pm\left(\vec{k}\right)$

$$B_\pm'' + \underbrace{[k^2 \mp \xi\, k\mathcal{H}]}_{} B_\pm \approx 0$$

effective frequency

Given by the BG ($\xi = \frac{2\lambda\partial_t\varphi}{fH}$)

Vacuum structure



$SU(2)_{\mathbb{R}}$ Gauge Field

- $\delta A_i^a = B_\pm^a(t,k)e_i^\pm\left(\vec{k}\right)$

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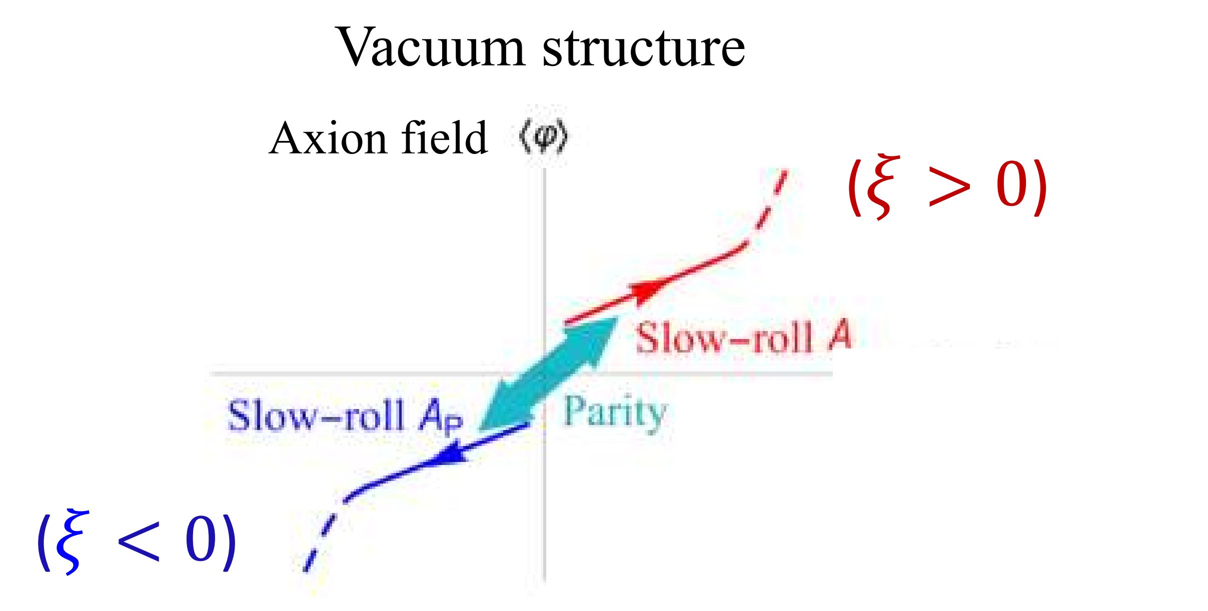


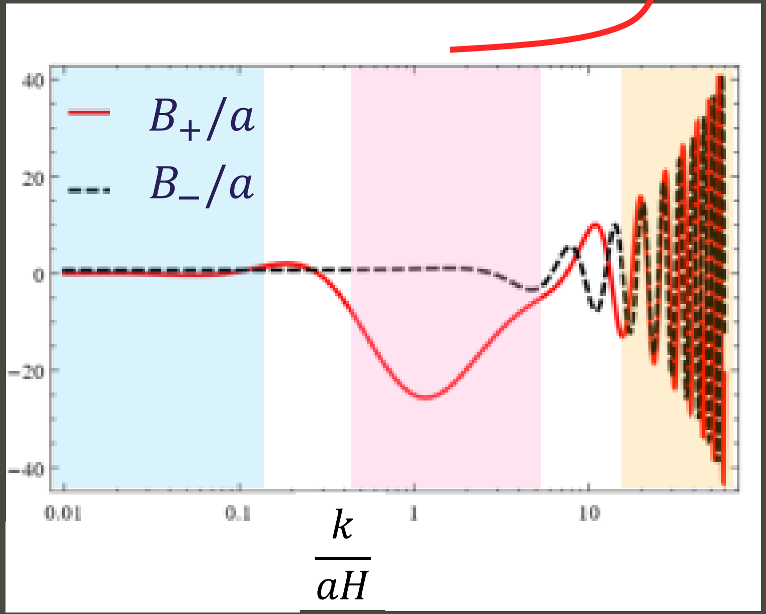
For $\xi > 0$

Short tachyonic growth of B_+

Chiral Field

$$n_B \sim \frac{H^3}{6\pi^2}\xi^3\, e^{\frac{(2-\sqrt{2})\pi}{2}\xi}$$

Particle Production



Gauge Field sources Primordial GWs

- $\delta A_i^a\left(t,\vec{k}\right) = B_{\pm}^a(t,k)e_i^{\pm}\left(\vec{k}\right)$ is governed by

$$B_{\pm}'' + [k^2 \mp \xi\, k\mathcal{H}]\, B_{\pm} \approx 0$$

- That sourced the GWs

$$h_{\pm}'' + [k^2 - \frac{a''}{a}]\, h_{\pm} = \mathcal{H}^2\, \Pi_{\pm}[B_{\pm}]$$

- Gravitational waves have two uncorrelated terms

$$h_{\pm} = \underbrace{h_{\pm}^{vac}}_{} + \underbrace{h_{\pm}^{s}}_{}$$

Vacuum GWs unpolarized $h_+^{vac} = h_-^{vac}$

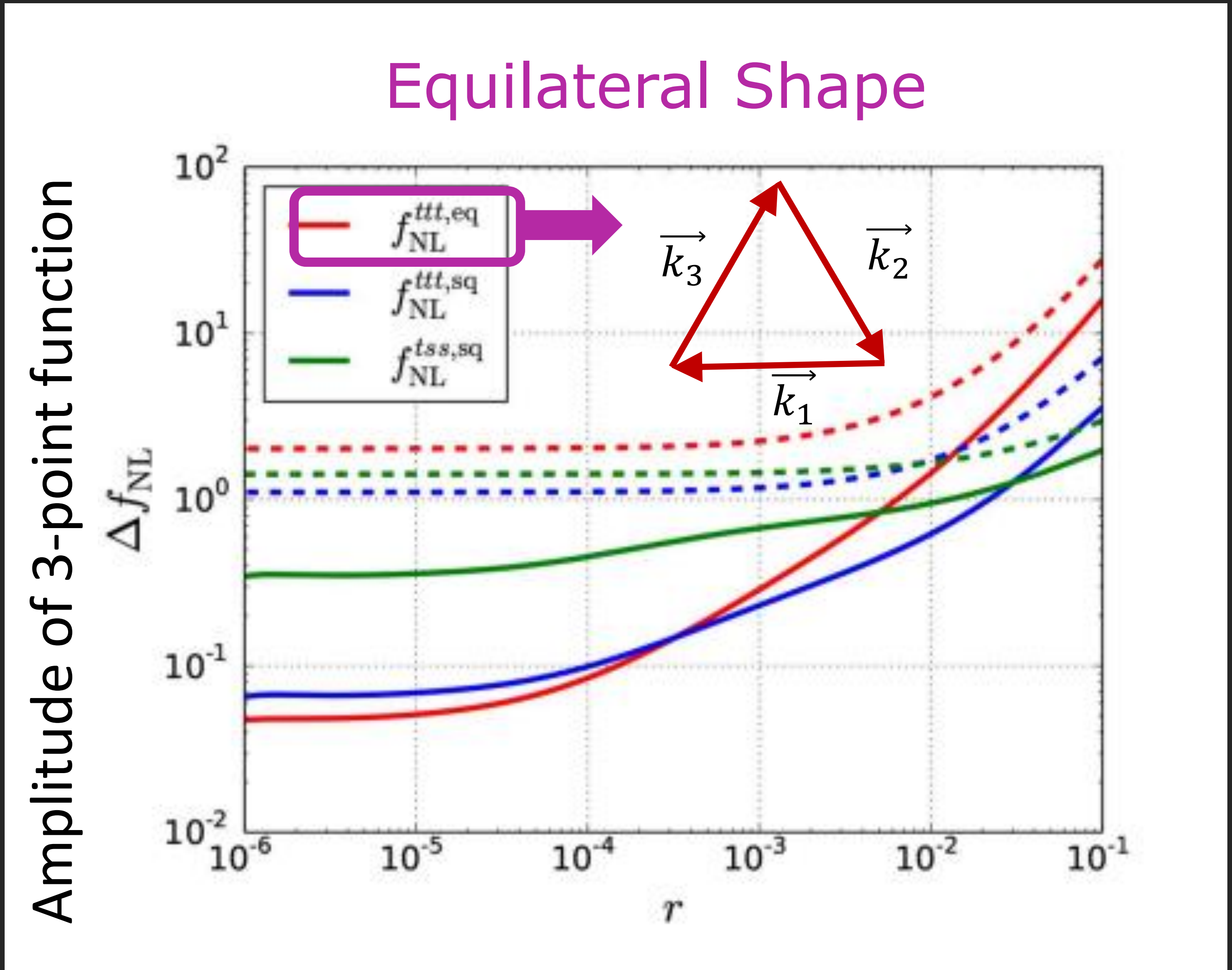
Sourced by $B_{\pm}$ Polarized $h_+^s \neq h_-^s$

Novel Observable Signature: CMB

- The sourced tensor modes is Highly non-Gaussian.

Agrawal, Fujita, Komatsu 2018

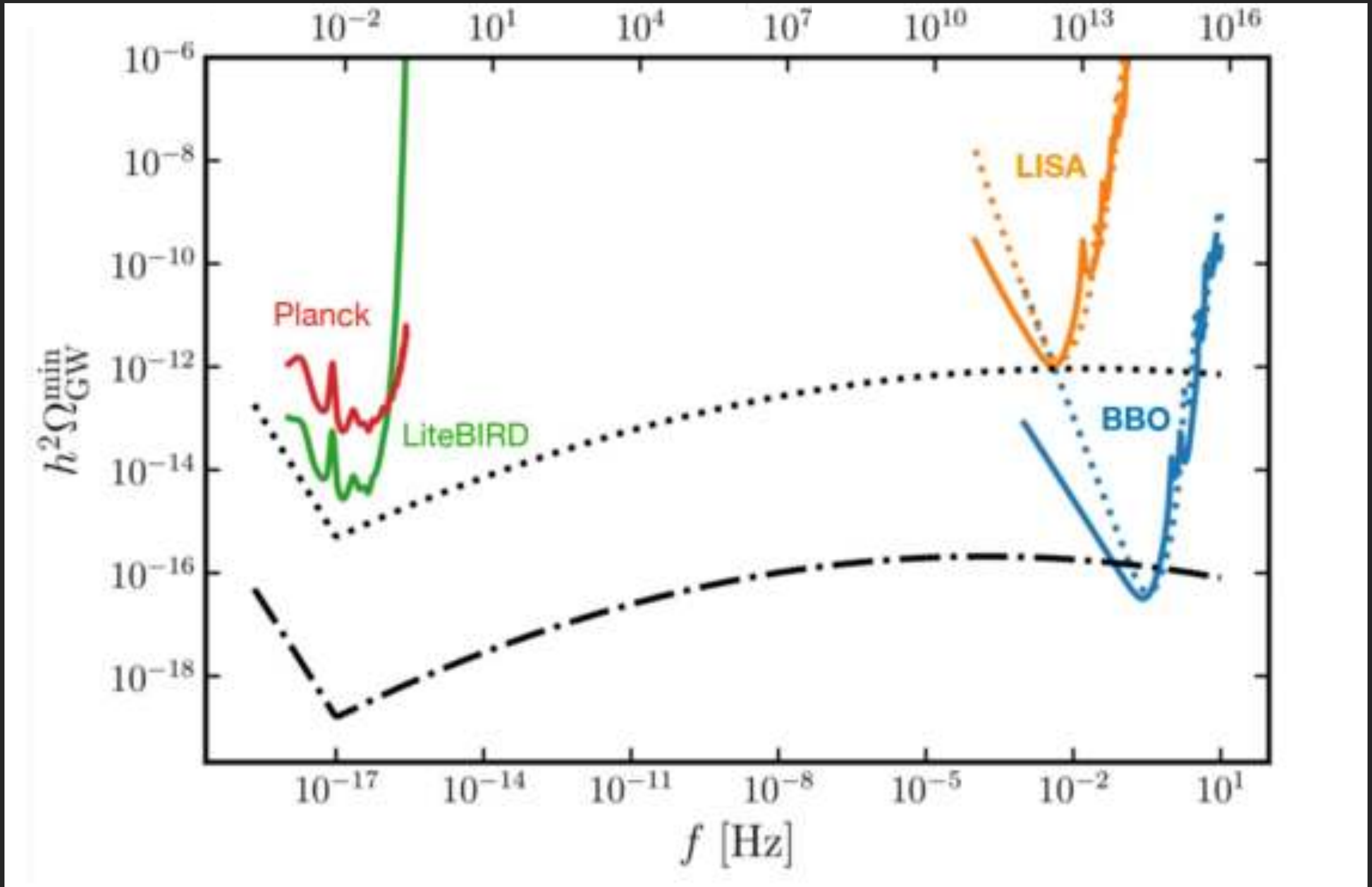
- That can be probe with future CMB missions., e.g. *Litebird* and *CMB-S4*!



Maresuke Shiraishi, Front. Astron. Space Sci. 2019

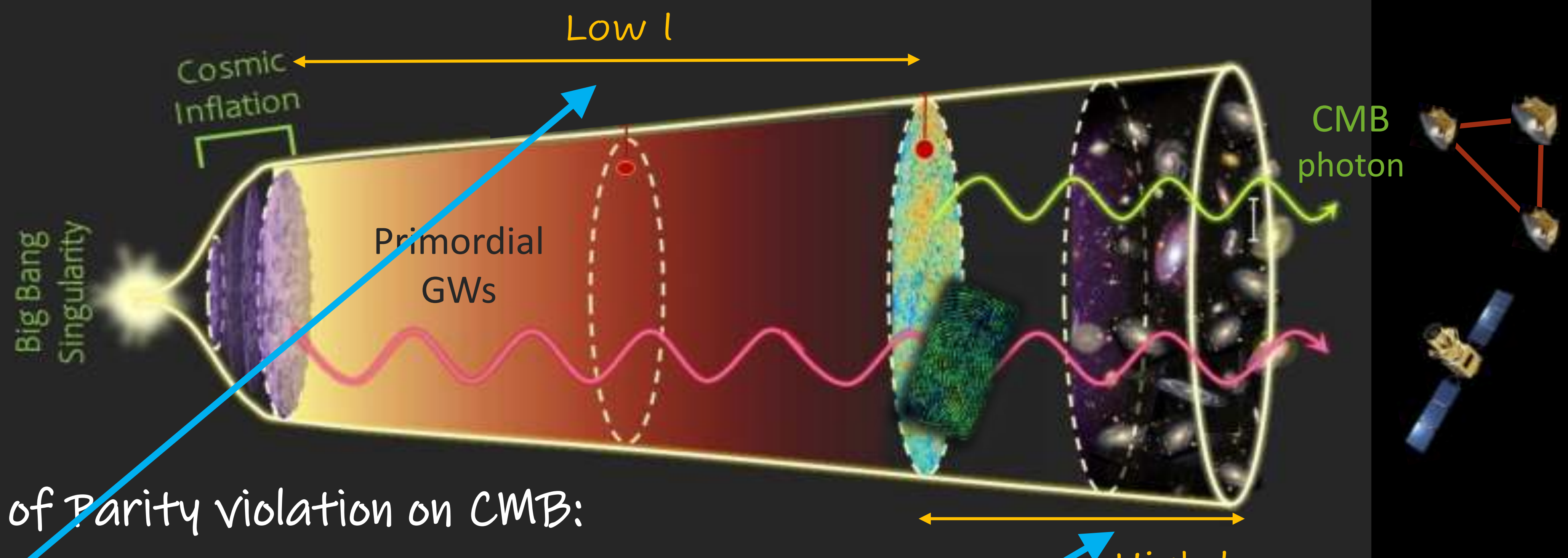
Novel Observable Signature: Beyond CMB

- Comparison of sensitivity curves for LiteBIRD, Planck, LISA & BBO.



Thorne, Fujita, Hazumi, Katayama, Komatsu & Shiraishi, 2018

Parity Odd CMB Correlations: TB & EB $\neq 0$



Sources of Parity violation on CMB:

- Cosmic Birefringence: axion-photon coupling $\varphi F\tilde{F}$
- Gravitational Chern-Simons: axion-graviton coupling $\varphi R\tilde{R}$
- SU(2)-axion Inflation: SU(2) field-Graviton coupling

B. Thorne et. al.2018

Lepton & quark Production by $SU(2)_R$

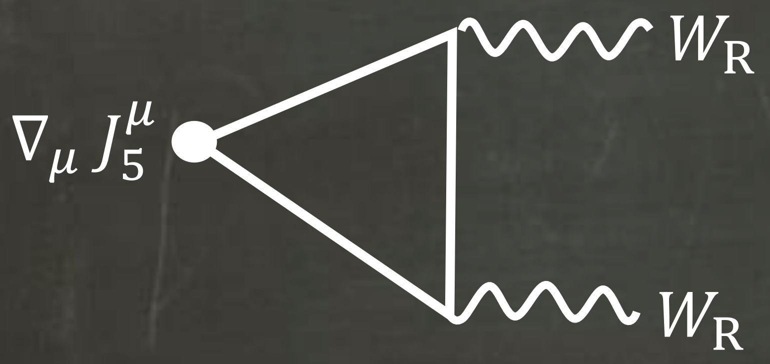
Lepton & quark Production in Inflation

- Left-handed fermions are diluted by inflation, BUT
- Right-handed fermions are generated by $\mathbf{SU(2)_R}$ gauge field:

Lepton & quark Production in Inflation

- Left-handed fermions are diluted by inflation, BUT
- Right-handed fermions are generated by $\mathrm{SU(2)_R}$ gauge field:

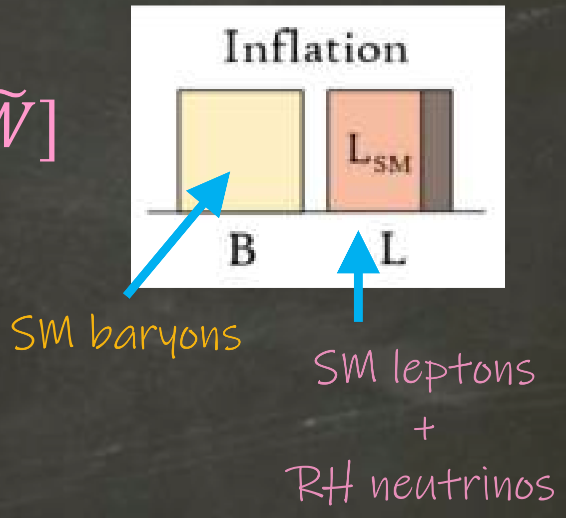
The key ingredient is the Chiral anomaly of $\mathrm{SU(2)_R}$ in inflation:



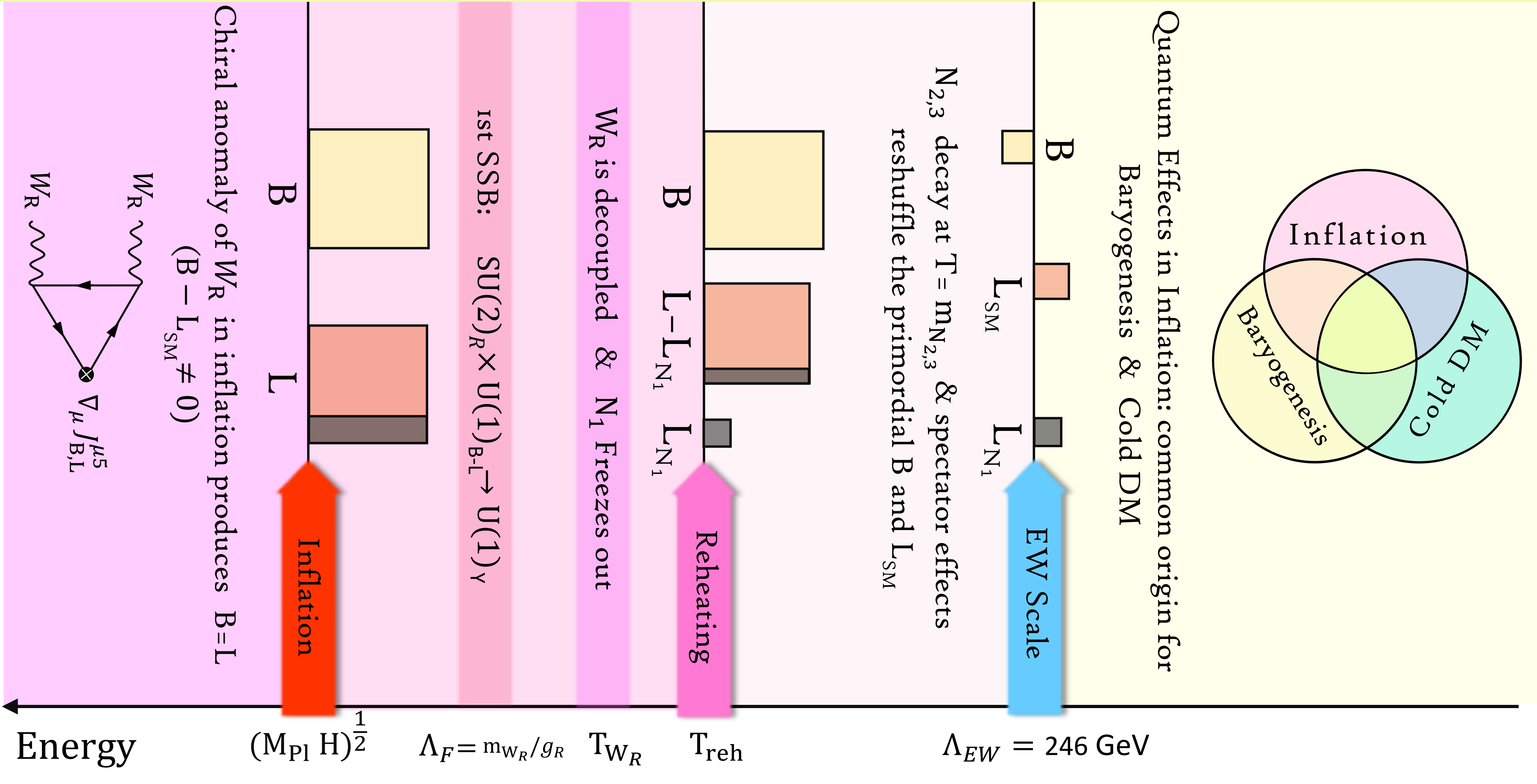
$$\nabla_\mu J^\mu_\mathrm{B} = \nabla_\mu J^\mu_\mathrm{L} = \frac{g^2}{16\pi^2} tr[W\widetilde{W}]$$

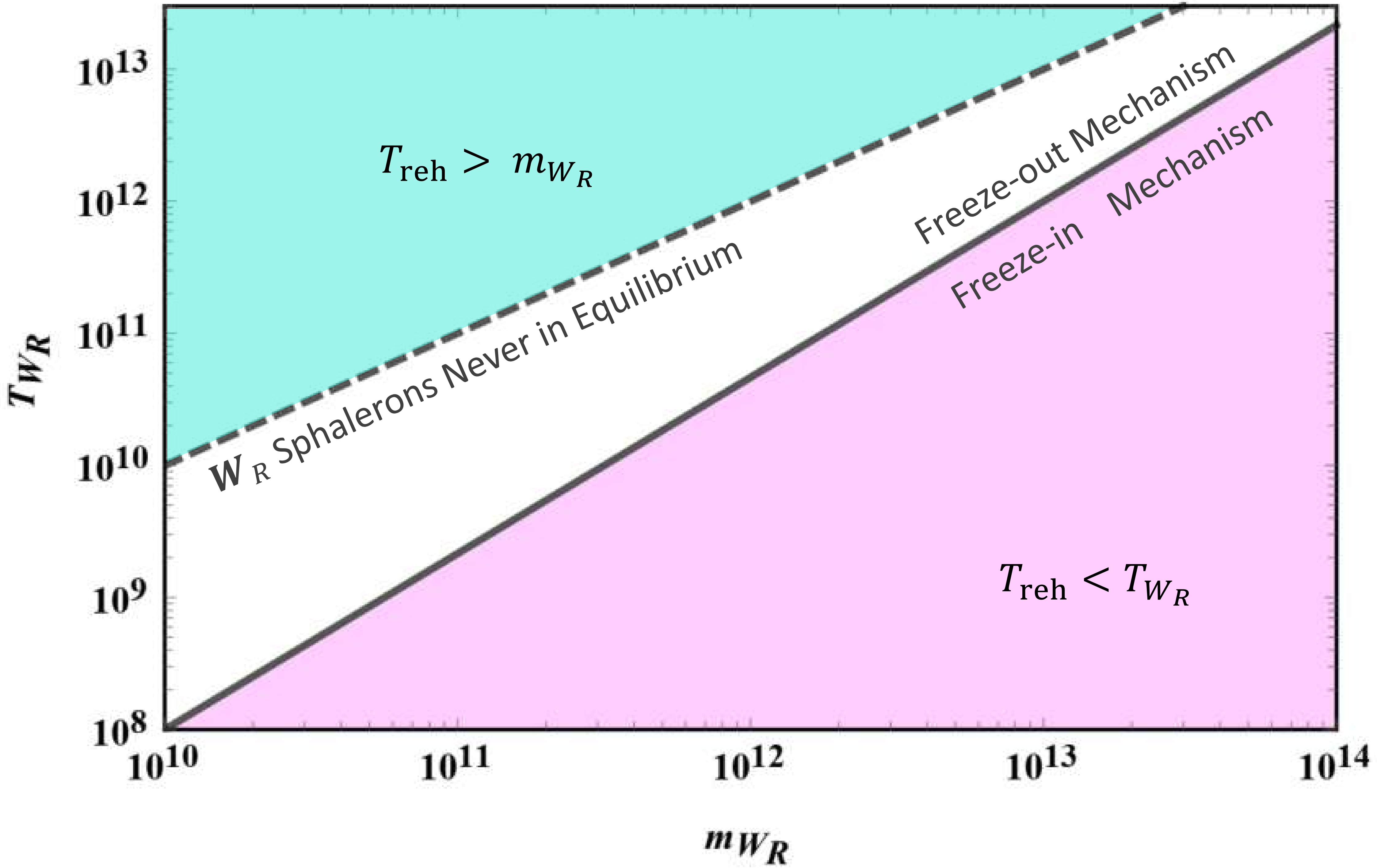
$$\mathrm{n_B} = \mathrm{n_L} = \alpha_{inf}(\xi) H^3$$

$$\alpha_{inf}(\xi) \sim \frac{g^2}{(2\pi)^4} \mathrm{e}^{2\pi\xi}$$



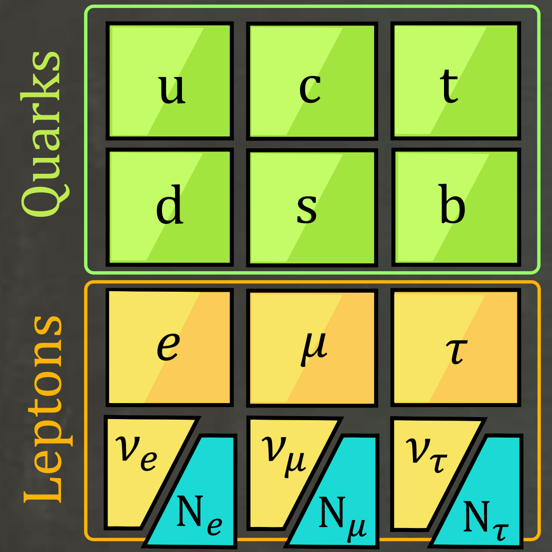
Summary of the mechanism:

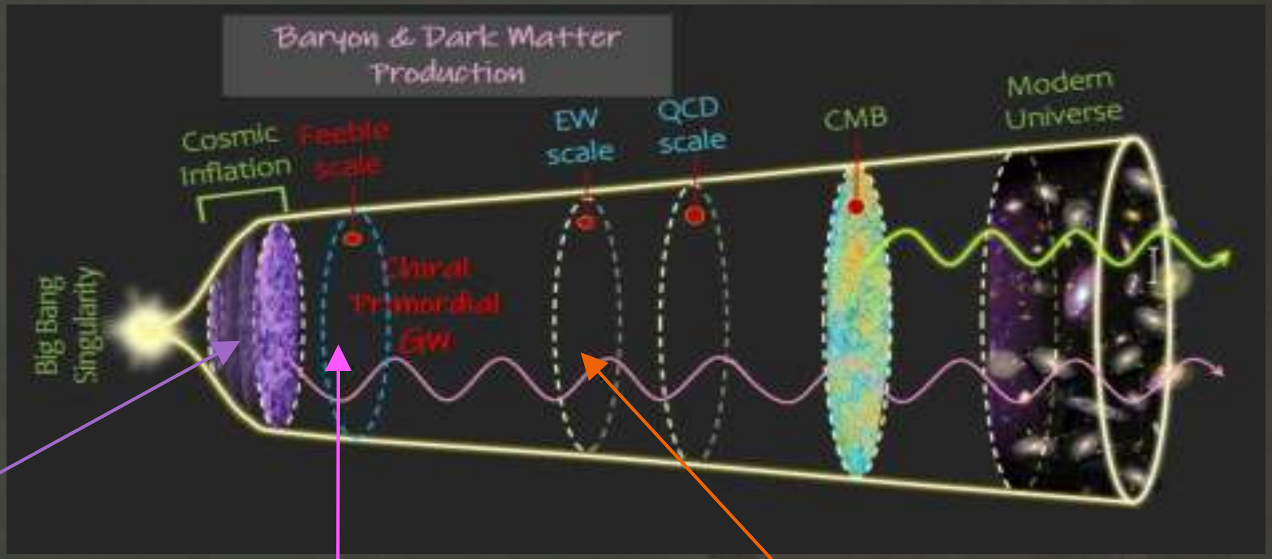




$T_{\rm reh} > m_{W_R}$
W_R Sphalerons Never in Equilibrium
Freeze-out Mechanism
Freeze-in Mechanism
$T_{\rm reh} < T_{W_R}$
T_{W_R}
m_{W_R}
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}

Summary of the mechanism:

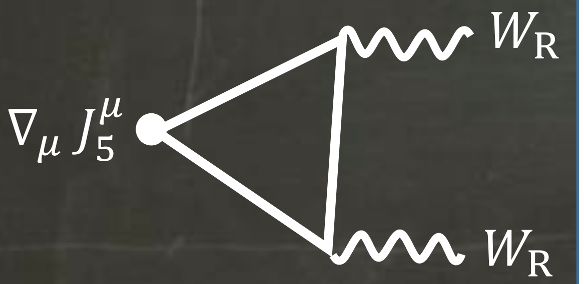


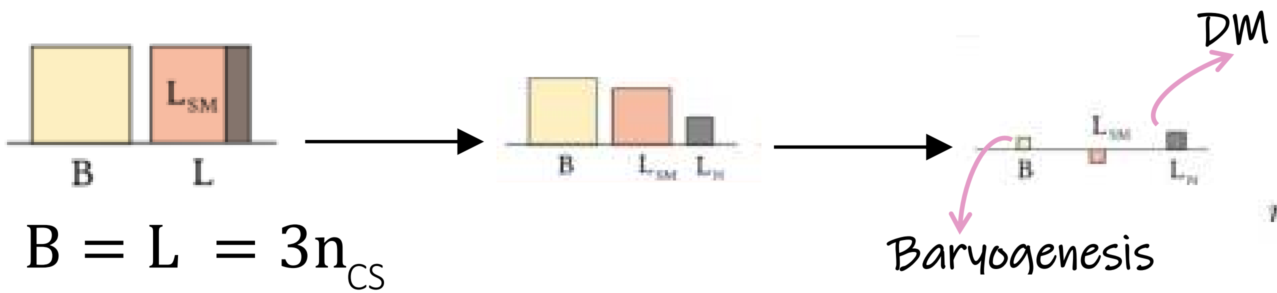


Chiral anomaly of SU(2)R in inflation

Freezeout of Ni

EW scale





$$\Omega_{N_1} \approx 2.8 \frac{m_{N_1}}{m_p} \Omega_B$$

$$m_{N_1} \simeq 1.8\, m_p = 1.7\ GeV.$$

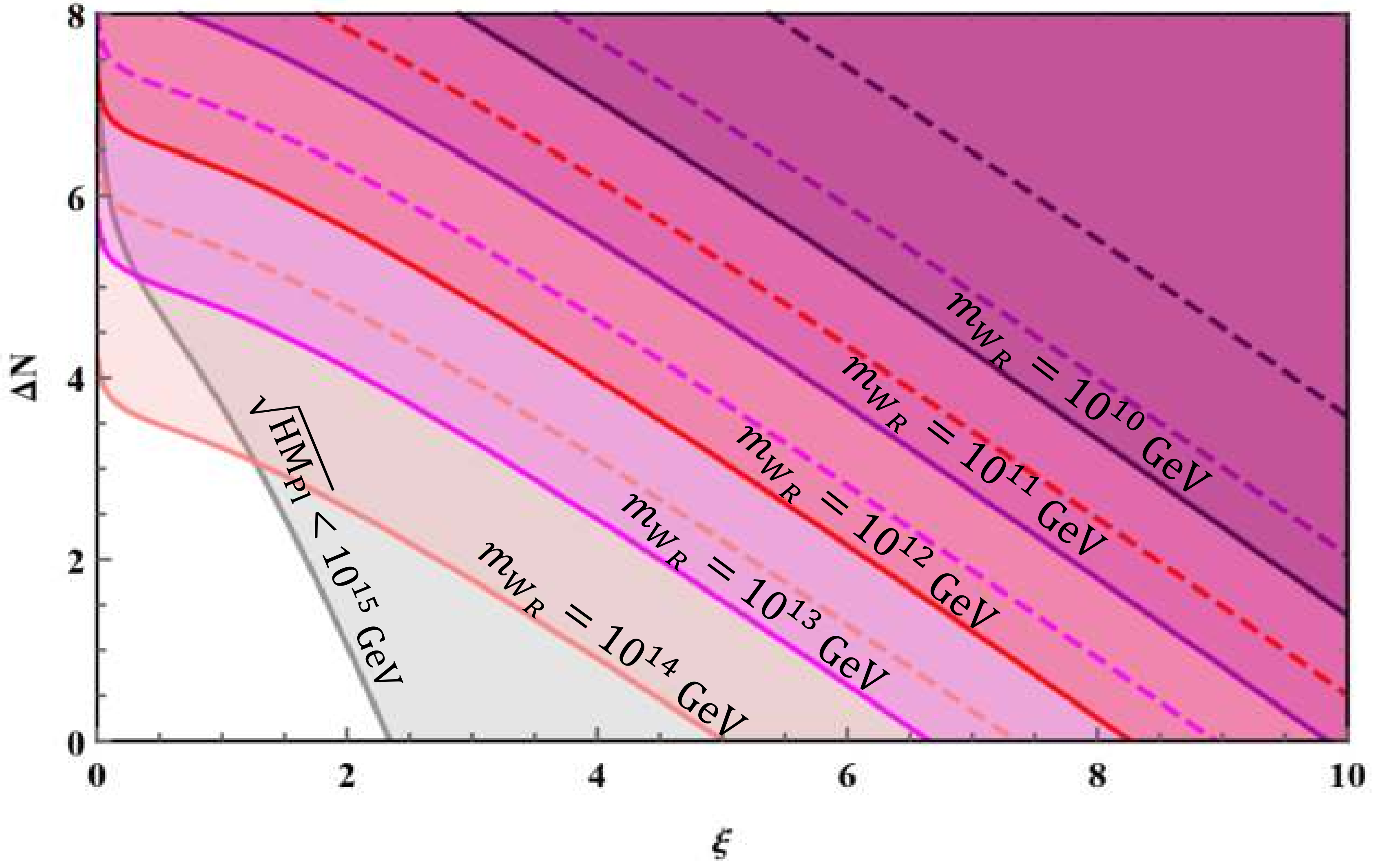
$$B = L = 3n_{CS}$$

$$B - L_{SM} \neq 0$$

$$\eta_B^0 \approx 3 \left(\frac{g_{\rm eff}}{100}\right)^{\frac{3}{4}} \frac{\alpha_{\rm inf}}{(\delta_{\rm reh})^{\frac{3}{4}}} \left(\frac{H}{M_{\rm Pl}}\right)^{\frac{3}{2}}$$

This setup prefers Left-Right symmetry breaking scales above $m_{W_R} = 10^{10}$ GeV !

(same as scales suggested by the non-SUSY SO(10) GUT models with intermediate LR symmetry scale.)



Compelling Consequences:

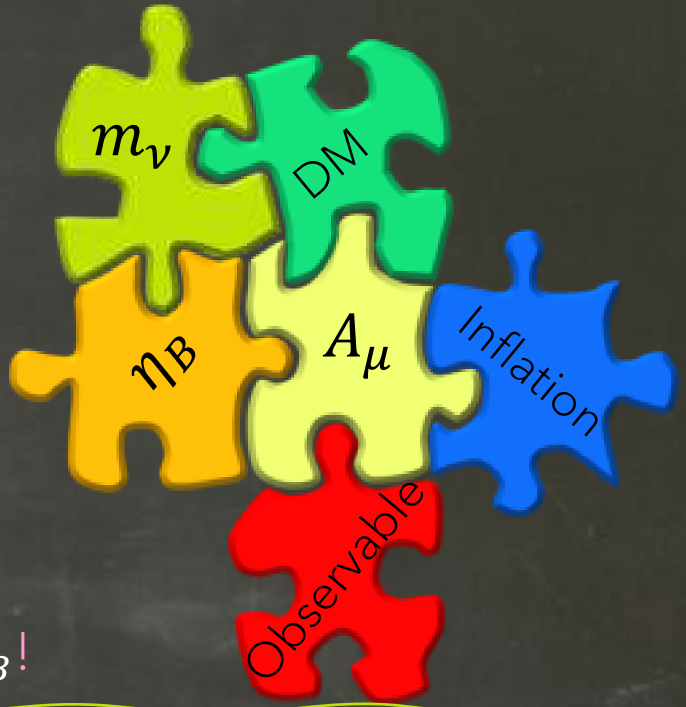
Puzzles of Particle Cosmology

I) Particle physics of Inflation

II) Origin of matter asymmetry

III) Origin of Neutrino mass

IV) Particle nature of DM



⬟ Curious cosmological coincidences $\eta_B \simeq 0.3\, P_\zeta$ and $\Omega_{DM} \simeq 5\Omega_B$!

Questions

- What do Gauge Fields do in Inflation? May be coupled to axion inflaton
- Does it come with a cosmological signature? Yes! Chiral, non-Gaussian GWs.
- How Inflaton & its Gauge Field are connected to the SM? Left-Right Symmetric Model + axion!
- (Is there a simple, elementary & minimal set-up that can solve all the above issues? Yes!)

This Set-up is a complete beyond SM that can solve I-IV & explain ⬟ !

Minimal Set-up:

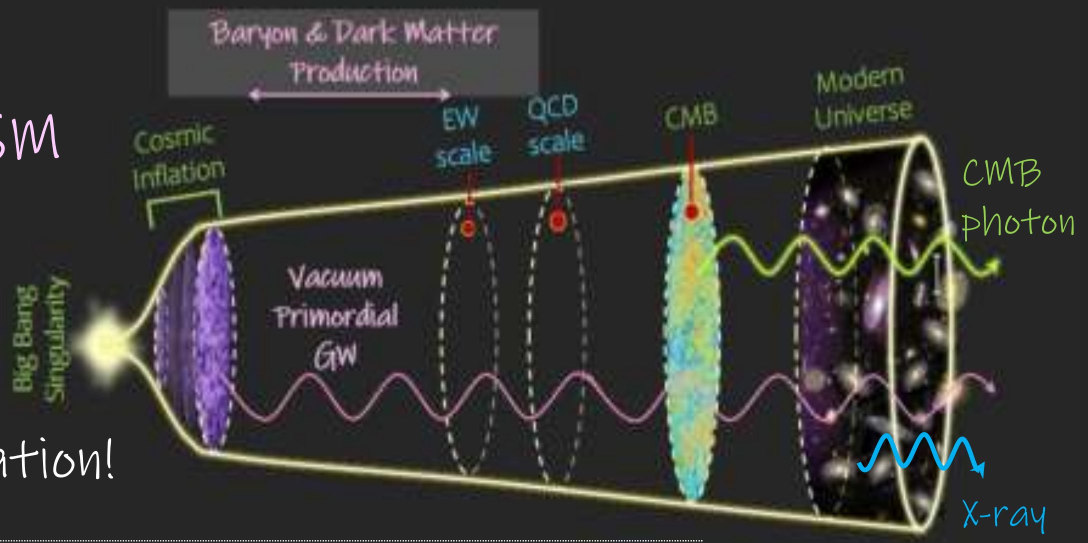
-Inflation Particle Physics: a scalar singlet BSM

-Unpolarized, Gaussian GWs

-Baryon asymmetry (BAU):

CP violating phases in neutrino sector

-Sterile neutrino DM: $m_{N_1} = \mathcal{O}(10) keV$ & X-ray radiation!



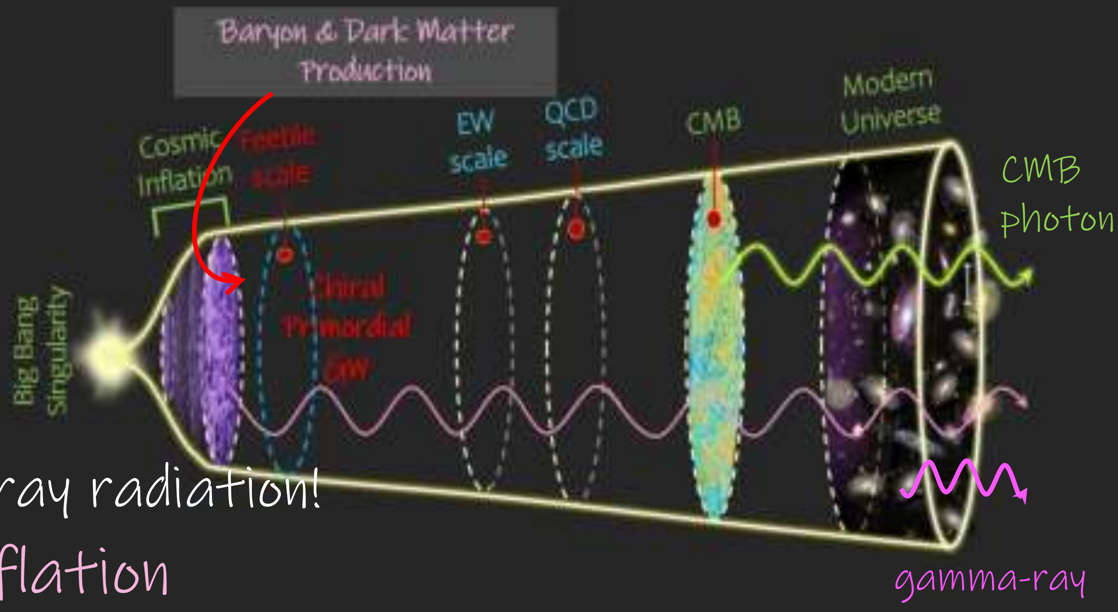
SU(2)$_R$–Axion Inflation:

-Inflation Particle Physics (BSM):

Axion & its SU(2) Gauge Field

-Chiral, non-Gaussian GWs

- BAU: Spontaneous CP violation in inflation
- Right neutrino DM: $m_{N_1} = \mathcal{O}(1) GeV$ & gamma-ray radiation!
- Simultaneous Baryon & DM production in inflation
- Explains coincidences among cosmological parameters ($\eta_B \sim P_R$ & $\Omega_{DM} \simeq 5\Omega_B$)




Questions?!