Probing Leptogenesis with the Cosmological Collider

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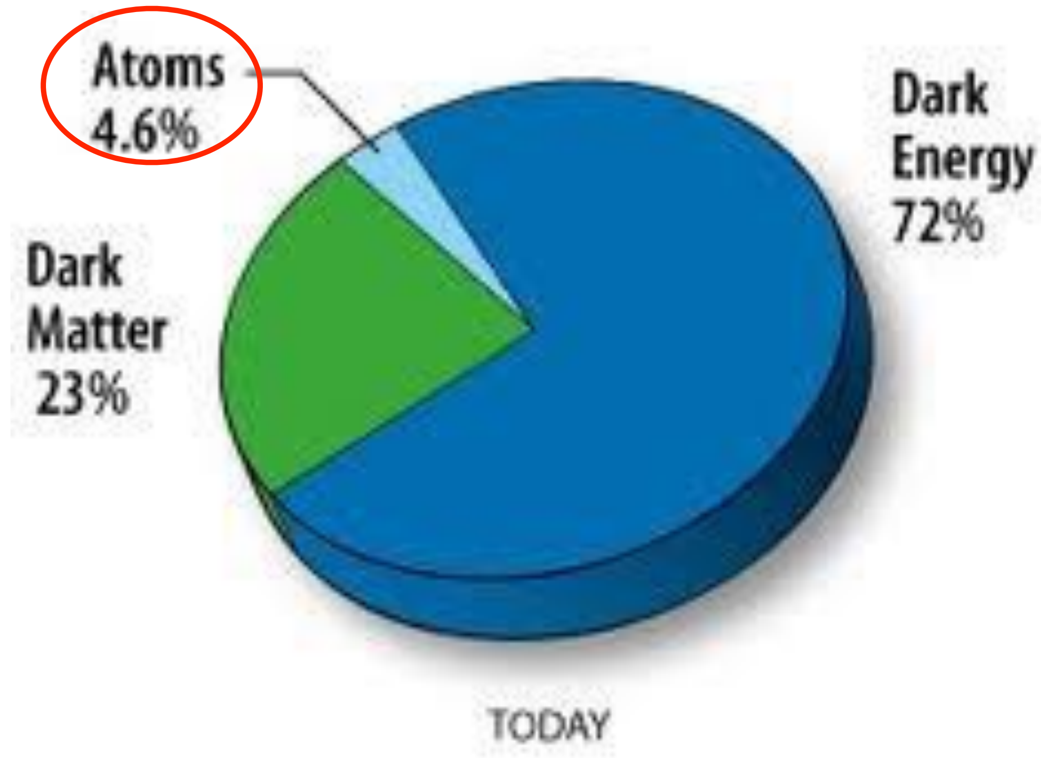
The Cosmic Puzzle of Ω_B

—**Dark** secret of the visible matter

- **Baryon (atomic matter):** $\Omega_B \approx 4\%$
- **Dark Matter:** $\Omega_{DM} \approx 23\%$



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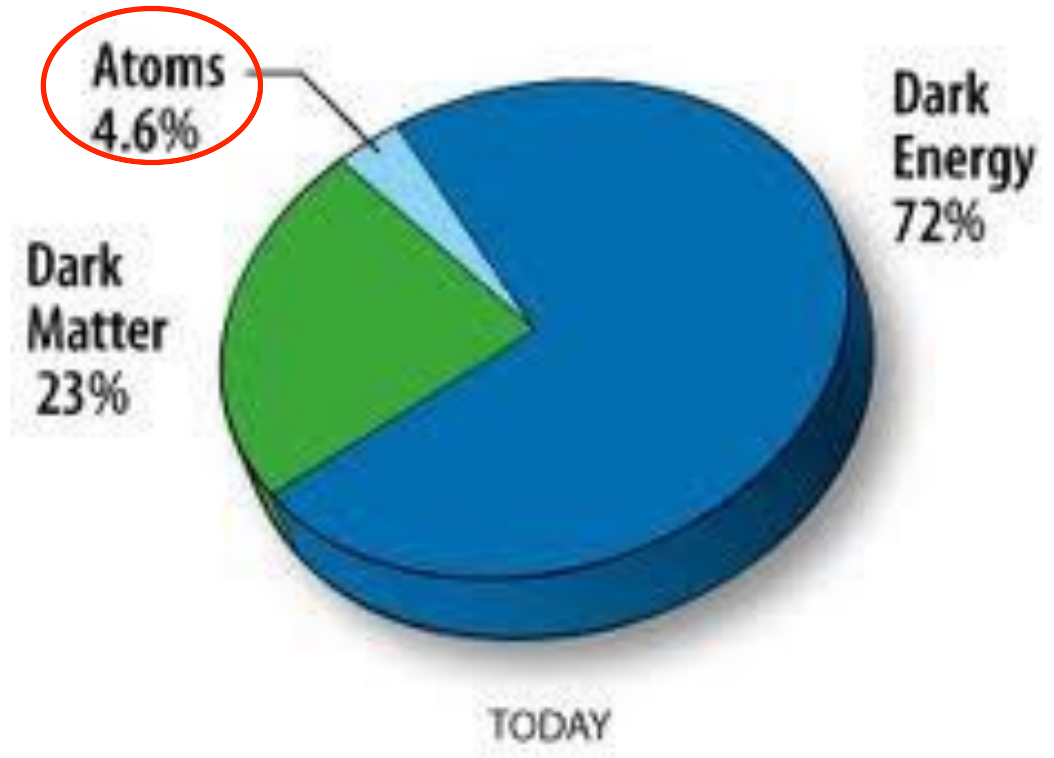
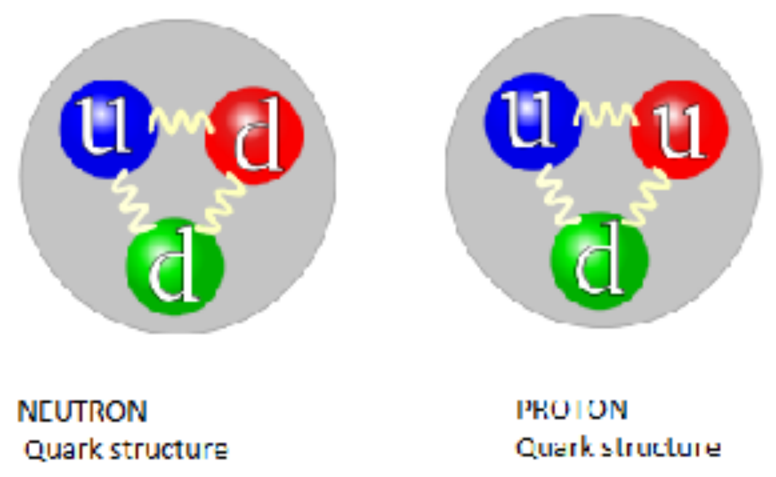


Ω_B: the unknown of the known



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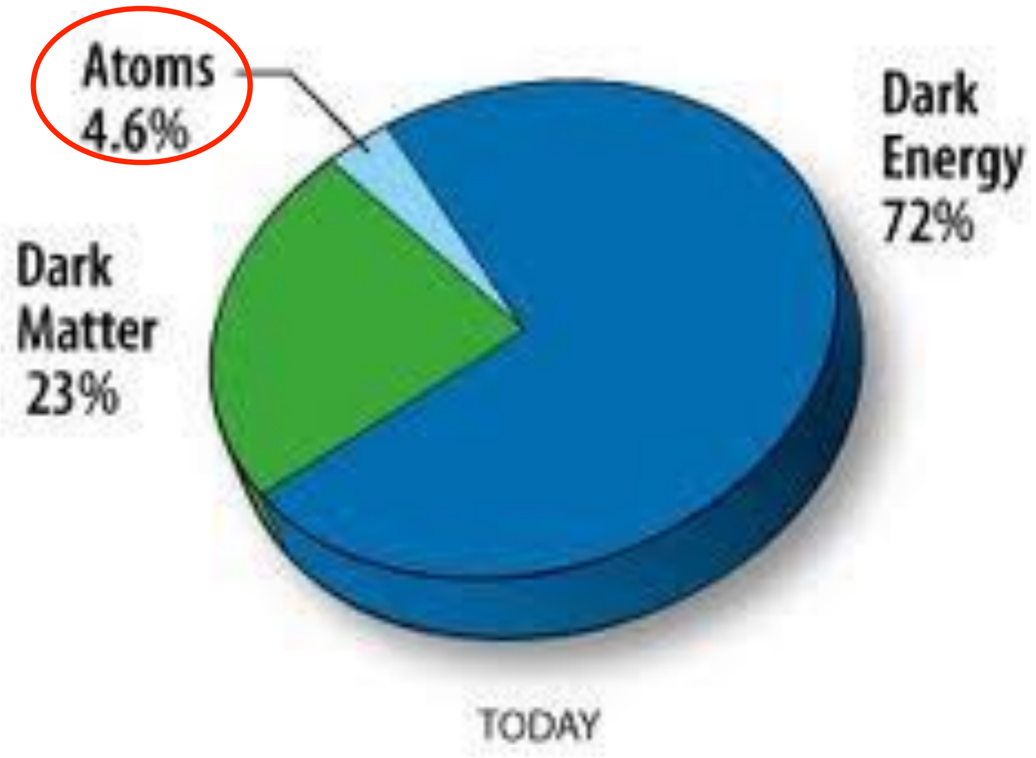

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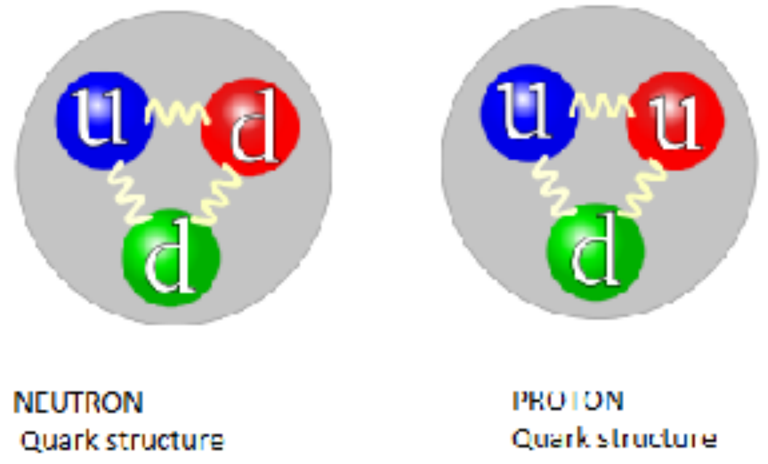
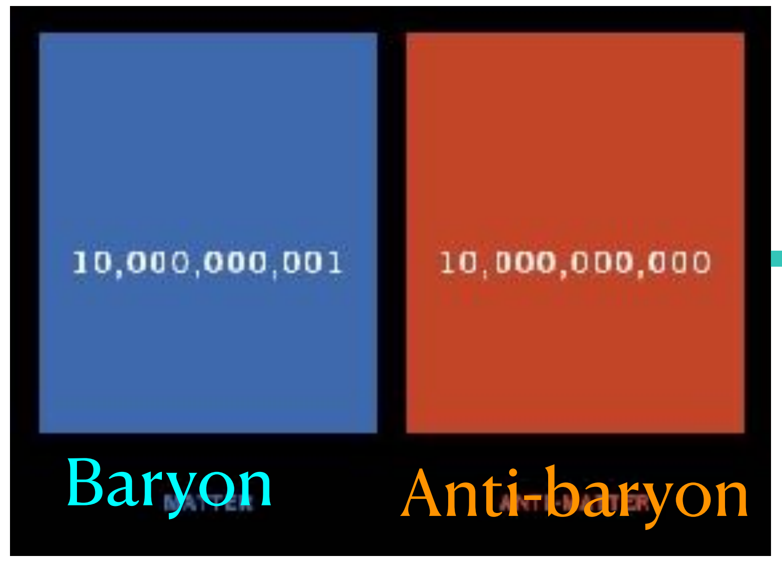


Initial $B - \bar{B}$ asymmetry

$\eta_B = (n_B - n_{\bar{B}})/n_\gamma \sim 10^{-10}$



symmetric annihilation

Today

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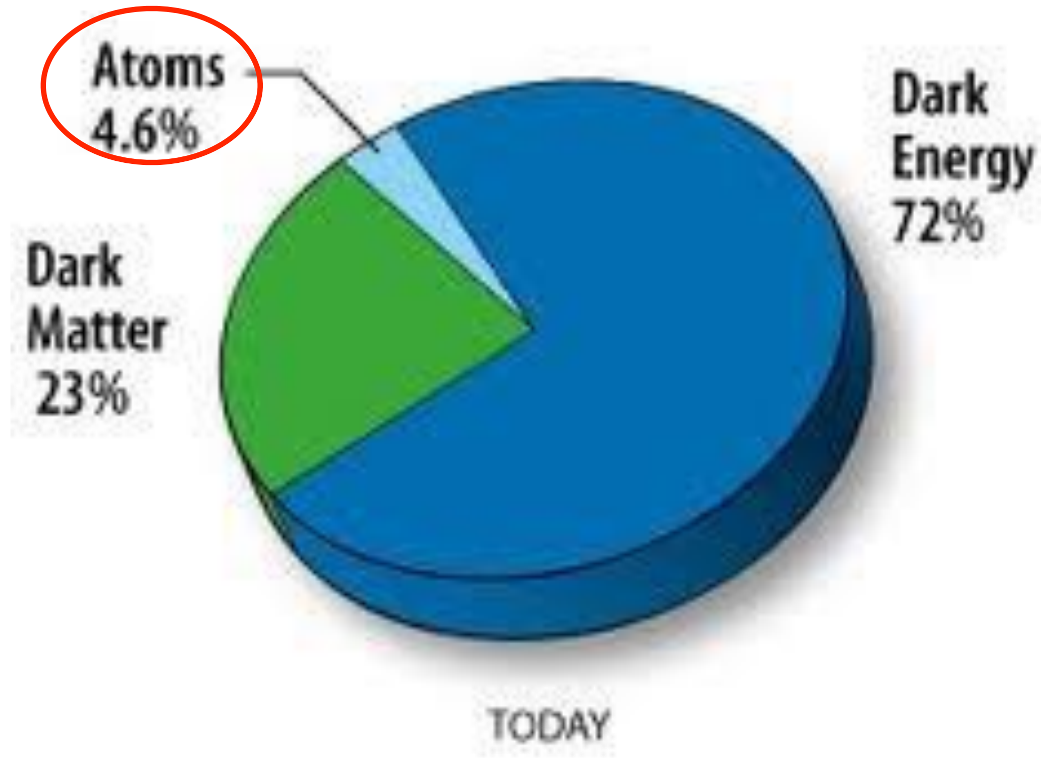

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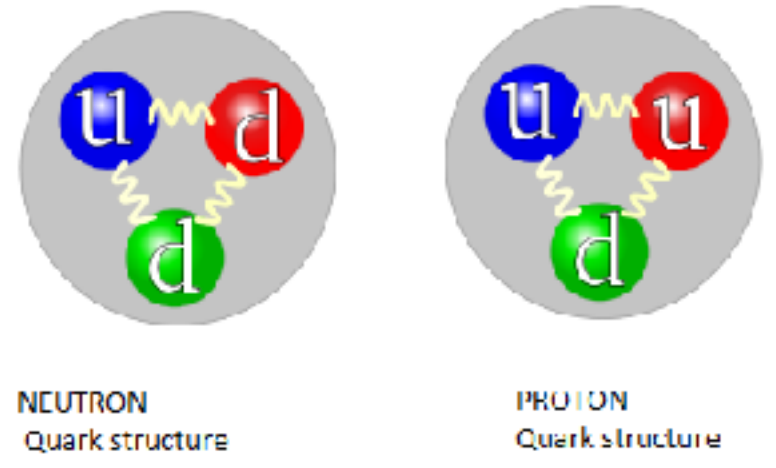

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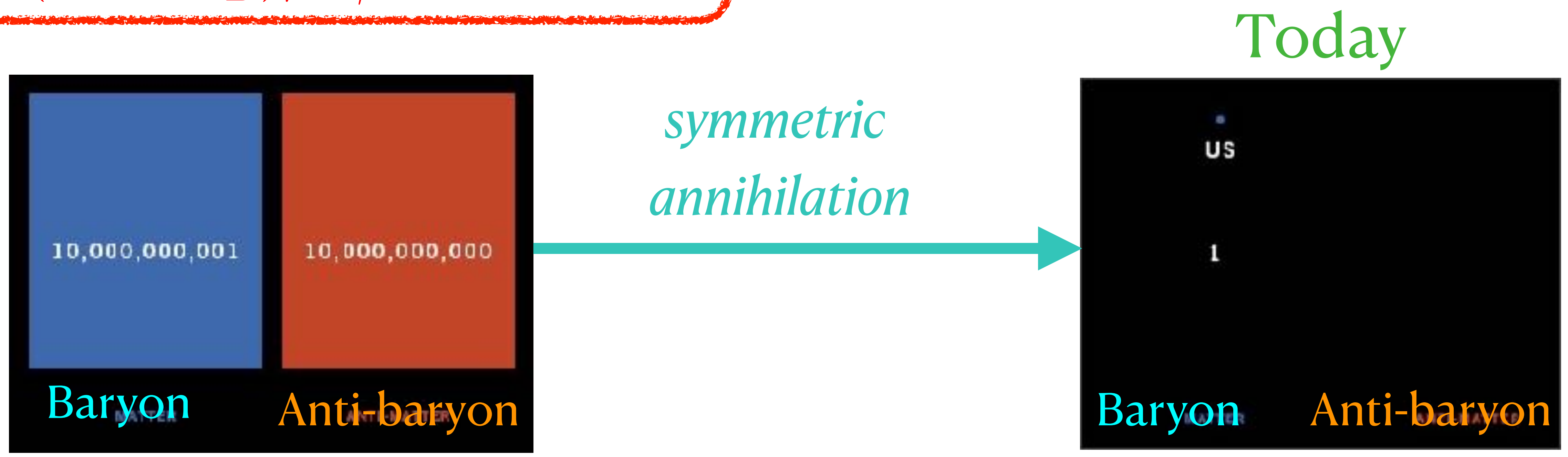

Where does Ω_B come from? =Where do we come from?

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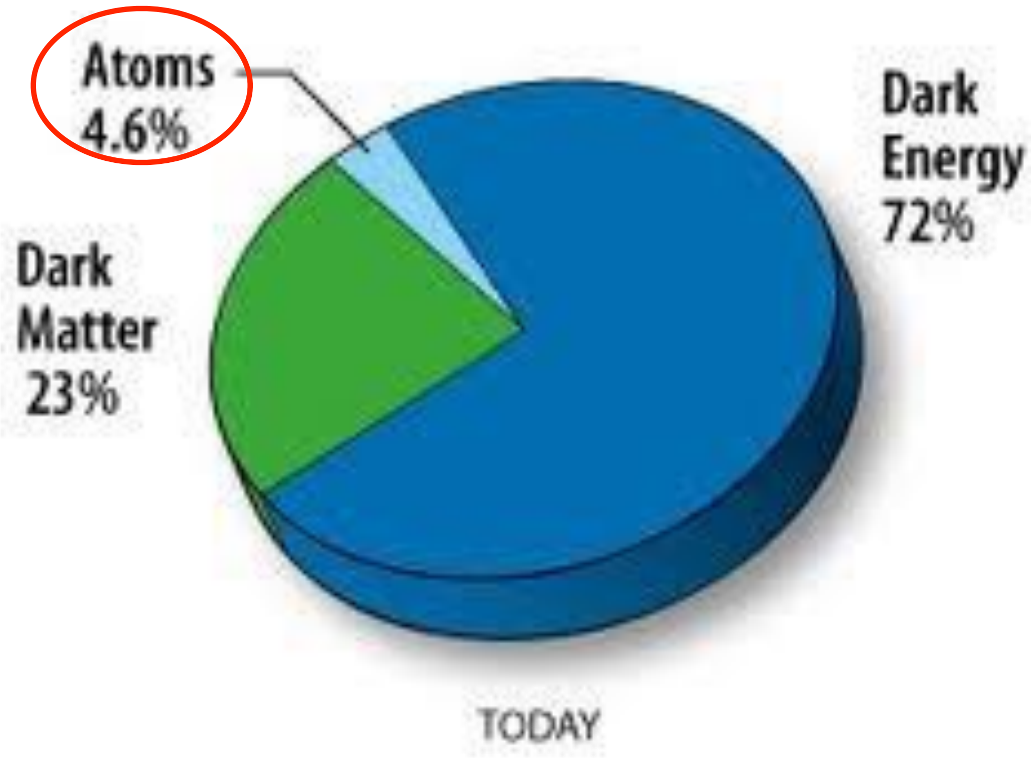

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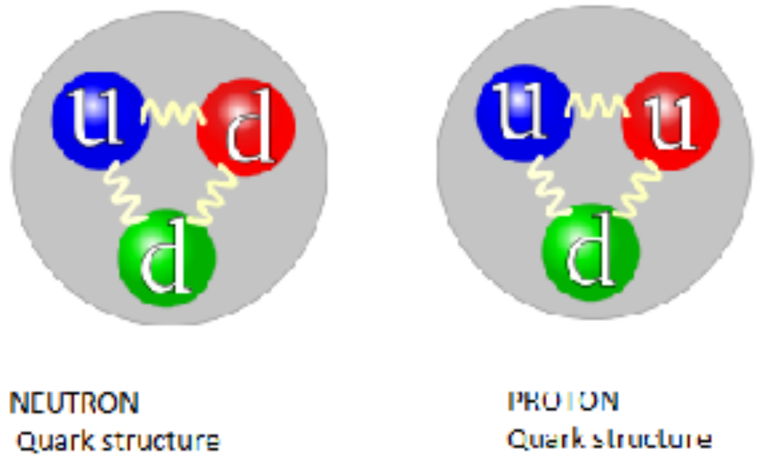

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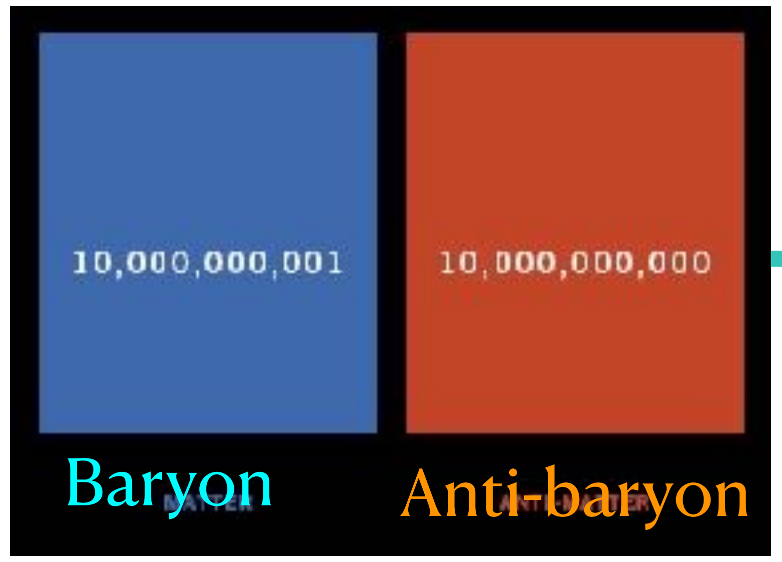


symmetric annihilation

Today

Where does Ω_B come from? =Where do we come from?

We do not know!

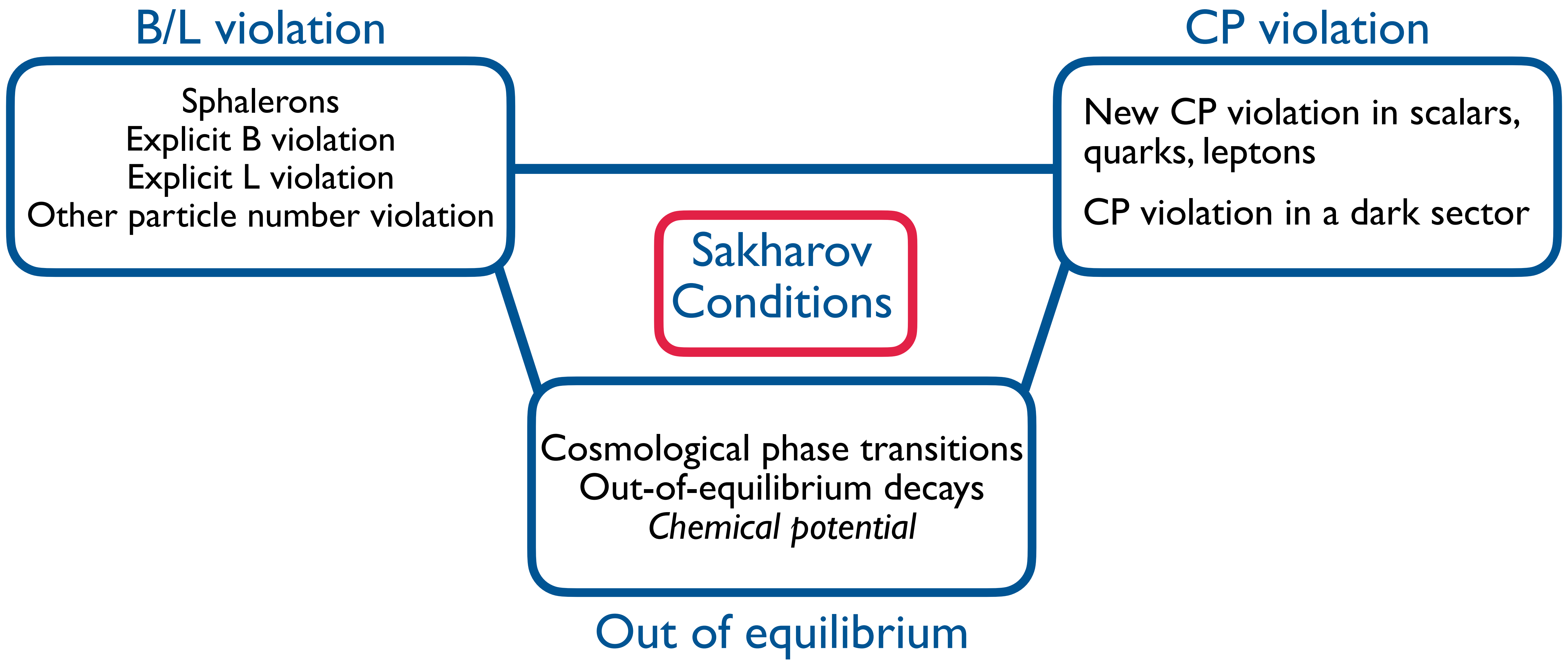
Baryogenesis

- **What is origin of the matter-antimatter asymmetry? (Baryogenesis)**

— the Universe starts with $B = 0$ *(inflation)* $\xrightarrow{?} B \neq 0$

- **Sakharov conditions for BG (1967):** B violation, CP violation, out of equilibrium

Requires BSM new physics to explain $\Omega_B \approx 4\,\%$!



Examples of BSM ingredients evoked to satisfy Sakharov conditions and explain Ω_B (arxiv: 2203.05010)

Traditional Baryogenesis

— Model and Pheno

A general summary of representative BG mechanisms developed in the past decades

(Not a complete list!)

- **GUT baryogenesis:** decay of GUT scale massive particles; challenged by constraints on inflation scale and subsequent T_{RH} ; direct test challenging (high scale)
- **Electroweak baryogenesis**: EW sphaleron + bubble collisions during 1st order PT; minimal models ruled out (SM+MSSM) with LHC data *(extensions being investigated)*

★**Leptogenesis :** decay of heavy RH neutrinos; intriguing connection to neutrino physics (Seesaw); direct test challenging (high scale) (this talk)

- **Affleck-Dine baryogenesis:** evolution/decay of the VEV of scalar condensates in SUSY models; direct test challenging (high scale)

— Well-studied, well-motivated, attractive models; yet some challenged by recent data, others are yet challenging to test

☞ Further pursuits are required!

New Developments on Baryogenesis

Recent progress in solving the Ω_B puzzle, driven by:

- **Big question persists:** Ω_B no less important than Ω_{DM} !
- **Some of the paradigms challenged/constrained by recent data:** e.g. GUT BG, minimal EWBG; new theoretical ideas beyond the known: worthy intellectual pursuit
- Traditional mechanisms typically assume high scale: BG at T_{EW} (100 GeV) or much higher; In reality, BG can occur as late as just before BBN (MeV)!
  ☞ The uncharted/under-explored low-scale BG landscape (theory and observables)!

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- Traditional mechanisms generally involve very high energy physics ($\gg \Lambda_{EW}$): challenging/impossible to directly test with terrestrial probes
  ★ Imprints from the very early/high energy Universe? New opportunity with the era of precision cosmology/astrophysics observatories (CMB, LSS…) + gravitational wave astronomy! *(E.g. This talk)*

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  ★ Imprints from the very early/high energy Universe? New opportunity with the era of precision cosmology/astrophysics observatories (CMB, LSS…) + gravitational wave astronomy! *(E.g. This talk)*
- Increasing attention on **the coincidence problem**: $\Omega_B \sim \Omega_{DM}$ (e.g. asymmetric DM), connection/inspiration/synergy with recent developments in dark matter studies?

A Snowmass White Paper (arxiv: 2203.05010)

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

New Ideas in Baryogenesis: A Snowmass White Paper

Editors: Gilly Elor,[1] Julia Harz,[2] Seyda Ipek,[3] Bibhushan Shakya.[4]

Authors: Nikita Blinov,[5] Raymond T. Co,[6] Yanou Cui,[7] Arnab Dasgupta,[8] Hooman Davoudiasl,[9] Fatemeh Elahi,[1] Gilly Elor,[1] Kåre Fridell,[2] Akshay Ghalsasi,[8] Keisuke Harigaya,[10] Julia Harz,[2] Chandan Hati,[2] Peisi Huang,[11] Seyda Ipek,[3] Azadeh Maleknejad,[10] Robert McGehee,[12] David E. Morrissey,[13] Kai Schmitz,[10] Bibhushan Shakya,[4] Michael Shamma,[13] Brian Shuve,[14] David Tucker-Smith,[15] Jorinde van de Vis,[4] Graham White.[16]

- **New ideas in BG models**
- **New ideas in testing traditional BG models (This talk)**

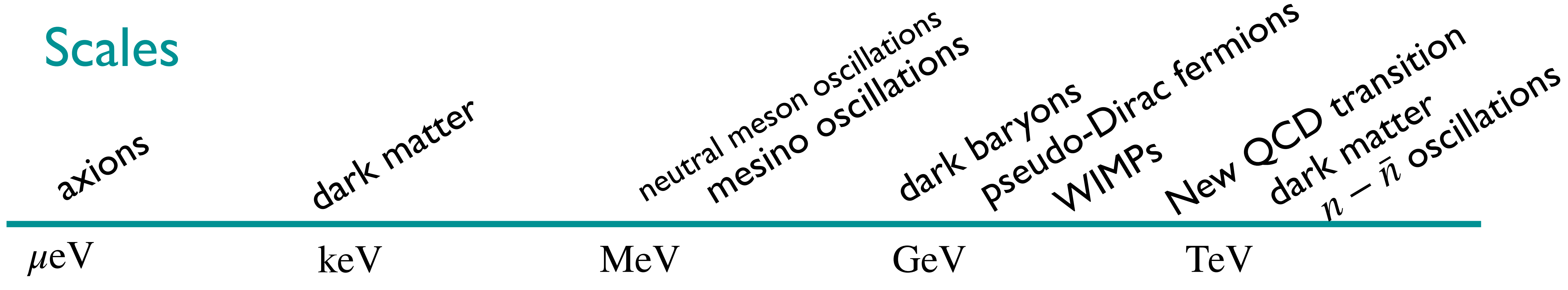
New physics ingredients

B/L violation	*CP* violation	Out-of-equilibrium conditions
Dark baryons RPV terms Sphalerons Direct B/L violation	Axions CKM phase Oscillations DM oscillations DM chemical potential CPV couplings	Freeze-in processes Long-lived particles QCD phase transition EW phase transition Particle decays

Observables

LLP searches · exotic hadron decays · same-sign dilepton asymmetry · new SU(3)-charged particles · new scalar-Higgs mixing · same-sign tops · $0\nu\beta\beta$ decay · missing momentum · induced nucleon decays · Higgs triple coupling · lepton flavor violation · multijet signals · CPV observables at B factories + LHCb · gravitational waves · structure formation · X-ray signals · $n-\bar{n}$ oscillations

Scales



Early Universe Probes for High Scale Baryogenesis?

- **Opportunity for probing high scale BG:**

Early universe *(e.g. inflationary epoch)* naturally provides a very high energy environment

☞ Imprints in cosmological observables? (CMB, LSS, 21 cm, GW…)

— Timely! In light of the rich precision data in coming years

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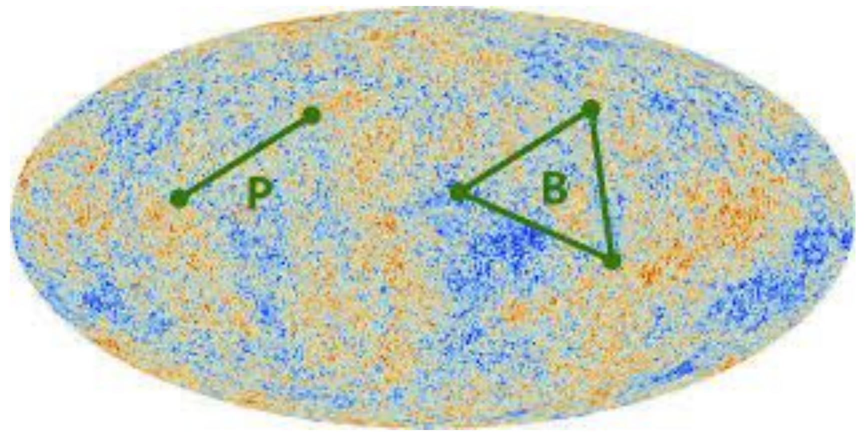
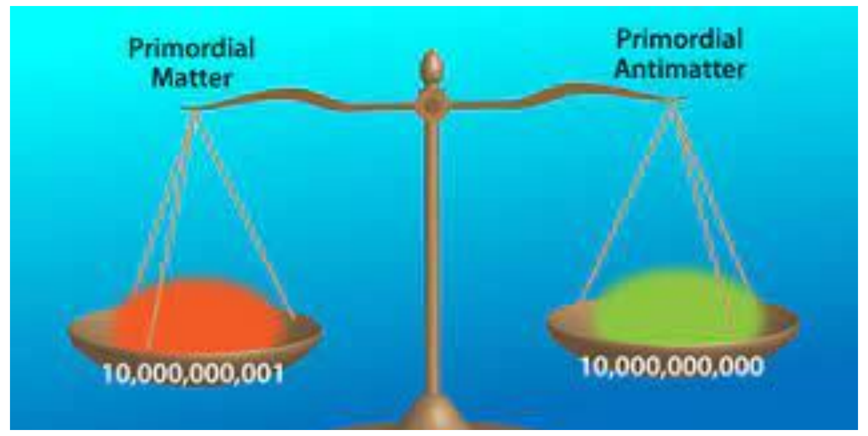
- **A particular focus of this talk (an intriguing/inspiring example):**

⭐ **Cosmological Collider as a Novel Probe for Leptogenesis** ⭐

Observables: detectable, distinct patterns in primordial non-Gaussianity (bispectrum)



(CMB, LSS, 21 cm)



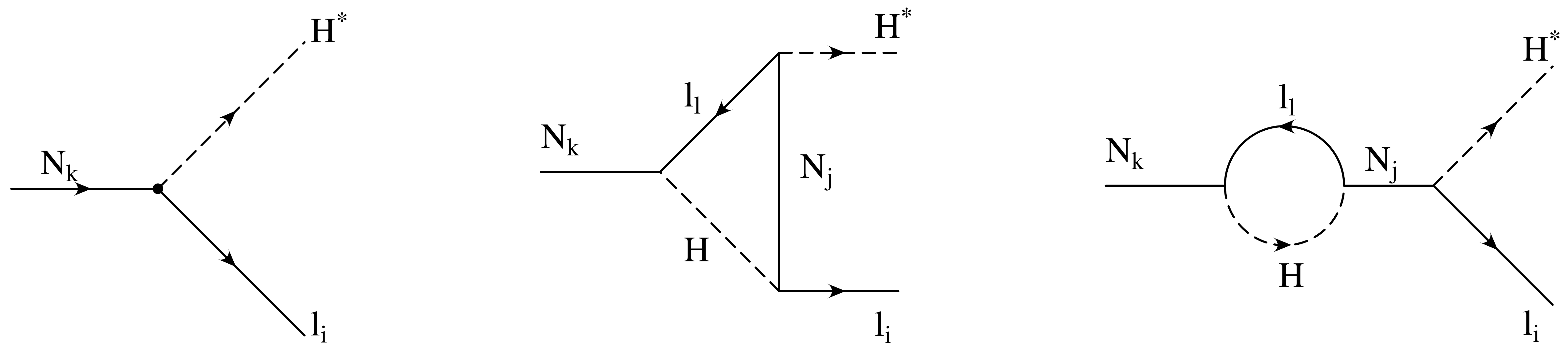
Underlying physics: L-violating interactions, mass of massive RH Majorana neutrino, CP violating phases (essentials for LG)

Outline

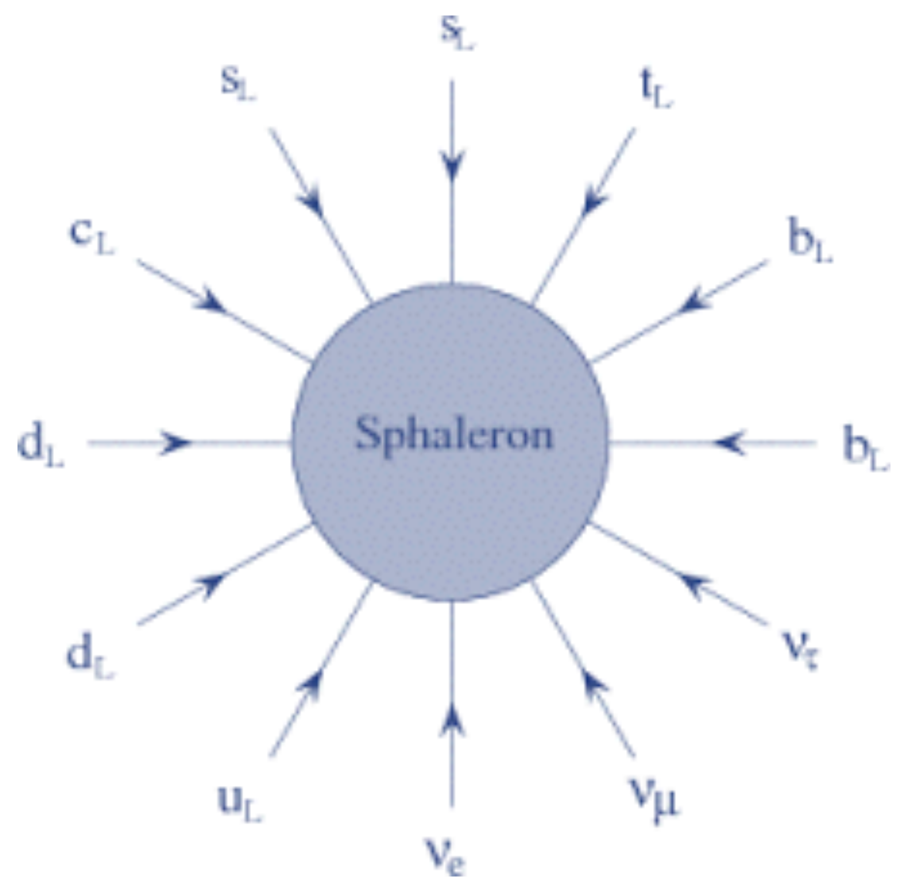
- A brief review of leptogenesis
- Basics of cosmological (Higgs) collider physics
- Leptogenesis, neutrino masses and CP phases during inflation
- Cosmological (Higgs) collider signals of leptogenesis
- Conclusion

A Review of Leptogenesis - I

- **Essentials for generating an lepton asymmetry:**



(a) (b) (c)



- ΔL generated by out-of-equilibrium decay of heavy Majorana neutrinos N_i (tree+loop interference), couplings are L- and CP-violating (phases)

  Realistic models: 3 generations of N_i , $M_1 \gtrsim 10^9$GeV (Davidson-Ibarra bound);
  At least 2 generations for non-zero interference

- Conversion to ΔB via sphaleron process

Close connection to Seesaw mechanism for SM neutrino masses (heavy N_i)

A Review of Leptogenesis - II

- **Washout effects: potential reduction of produced ΔL**

Inverse decay ($\Delta L = 1$) and $2 \to 2$ $\Delta L = 2$ scattering may erase the produced asymmetry

Parametrization of washout: $r = \Gamma_1 / H(T = m_1)$ m_1: mass of the lightest RH neutrino N_1

$$r = \frac{M_{\rm Pl}}{32\pi \times 1.7\sqrt{g_*}} \frac{(y_\nu y_\nu^\dagger)_{11}}{m_1}$$

Note: dependence on couplings
(Potential tension with detectable CC signal, later...)

$r \ll 1$: weak washout; $r \gg 1$: strong washout

- **Prediction for baryon asymmetry:**

$$Y_B = \frac{c_s}{c_s - 1} \kappa \frac{\epsilon_1}{g_*},$$

c_s: sphaleron conversion factor
$c_s = 28/79 \simeq 0.35$ for $N_f = 3$

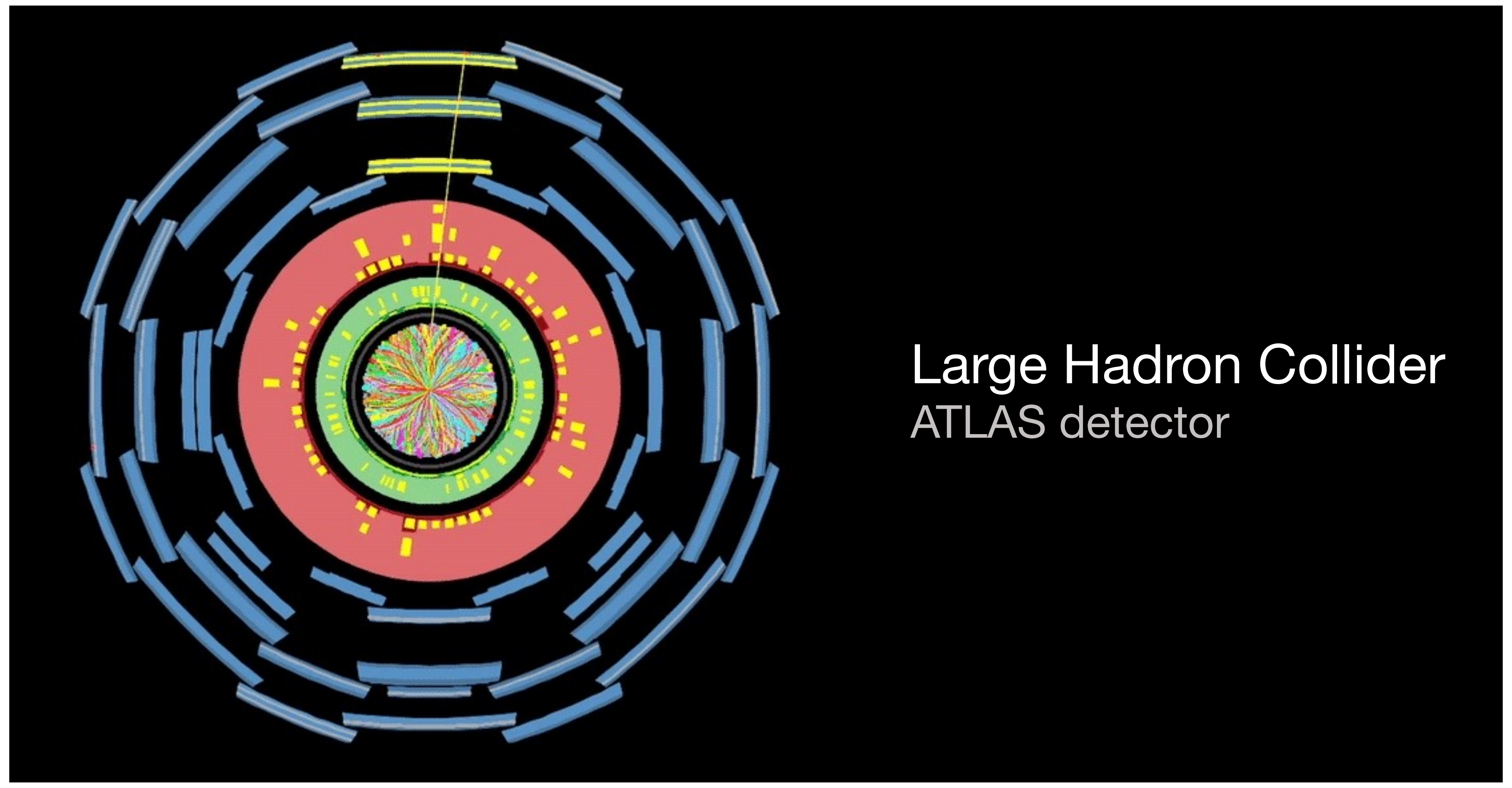
ϵ_1: asymmetry from N_1 decay

$$\epsilon_1 \simeq -\frac{3}{8\pi} \frac{1}{(y_\nu y_\nu^\dagger)_{11}} \sum_{i=2,3} \mathrm{Im}\left[(y_\nu y_\nu^\dagger)^2_{1i}\right] \frac{m_1}{m_i}$$

κ: washout efficiency, relates to r by solving Boltzmann eq. , e.g. $\kappa \simeq 0.3/(r \log r)^{0.6}$ in the range $10 < r < 10^6$ (moderate washout, applies to param range we consider for CC signals)

Cosmological Collider (CC) Physics 101

- **CC physics** (Chen, Wang 2009; Baumann, Green 2011 Arkani-Hamed; Maldacena 2015...)



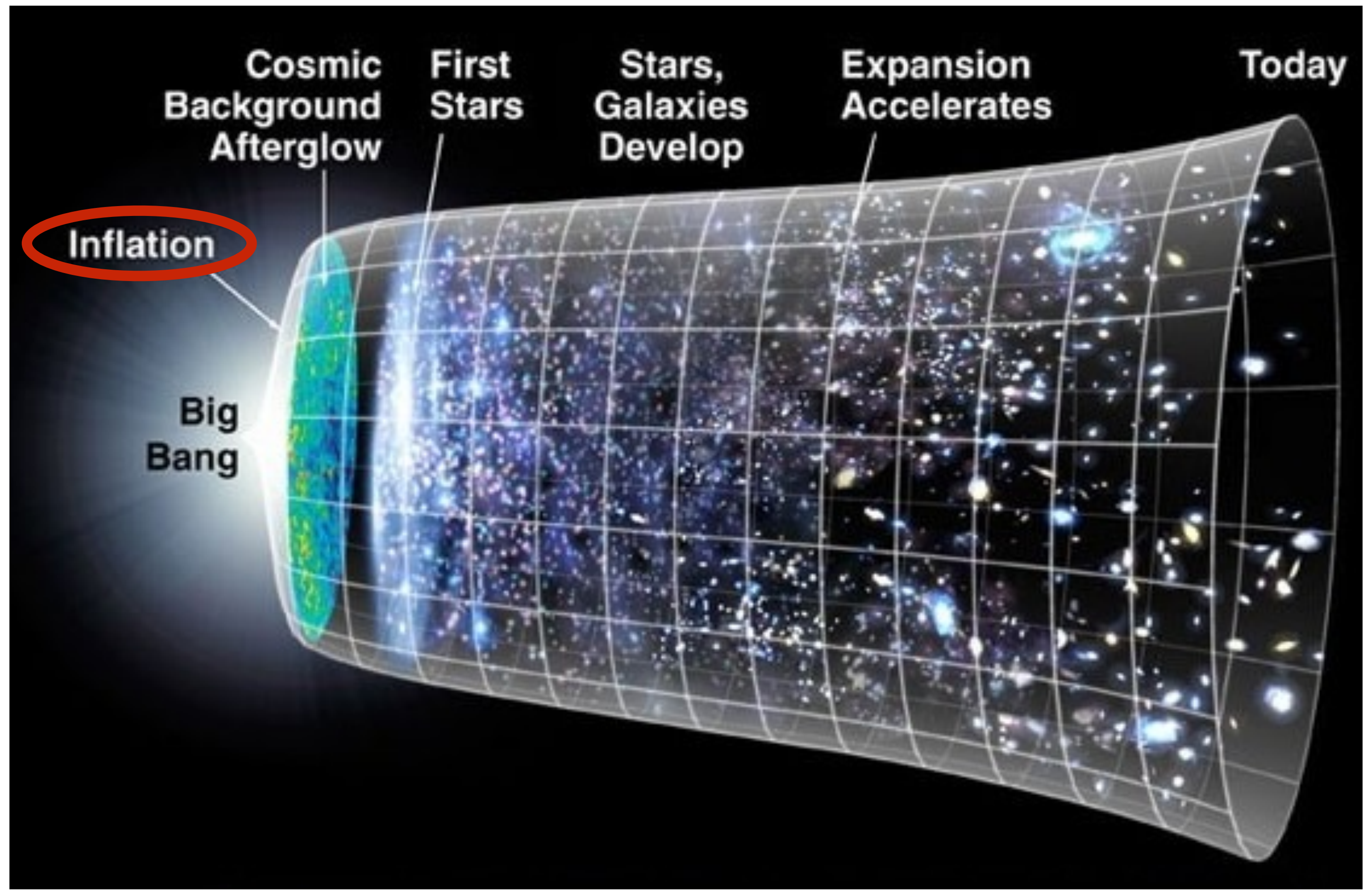
- **Man-made, terrestrial collider physics:**

2D map of energy deposition in calorimeters→ physics of high energy collision (short distance): interactions, masses of new particles

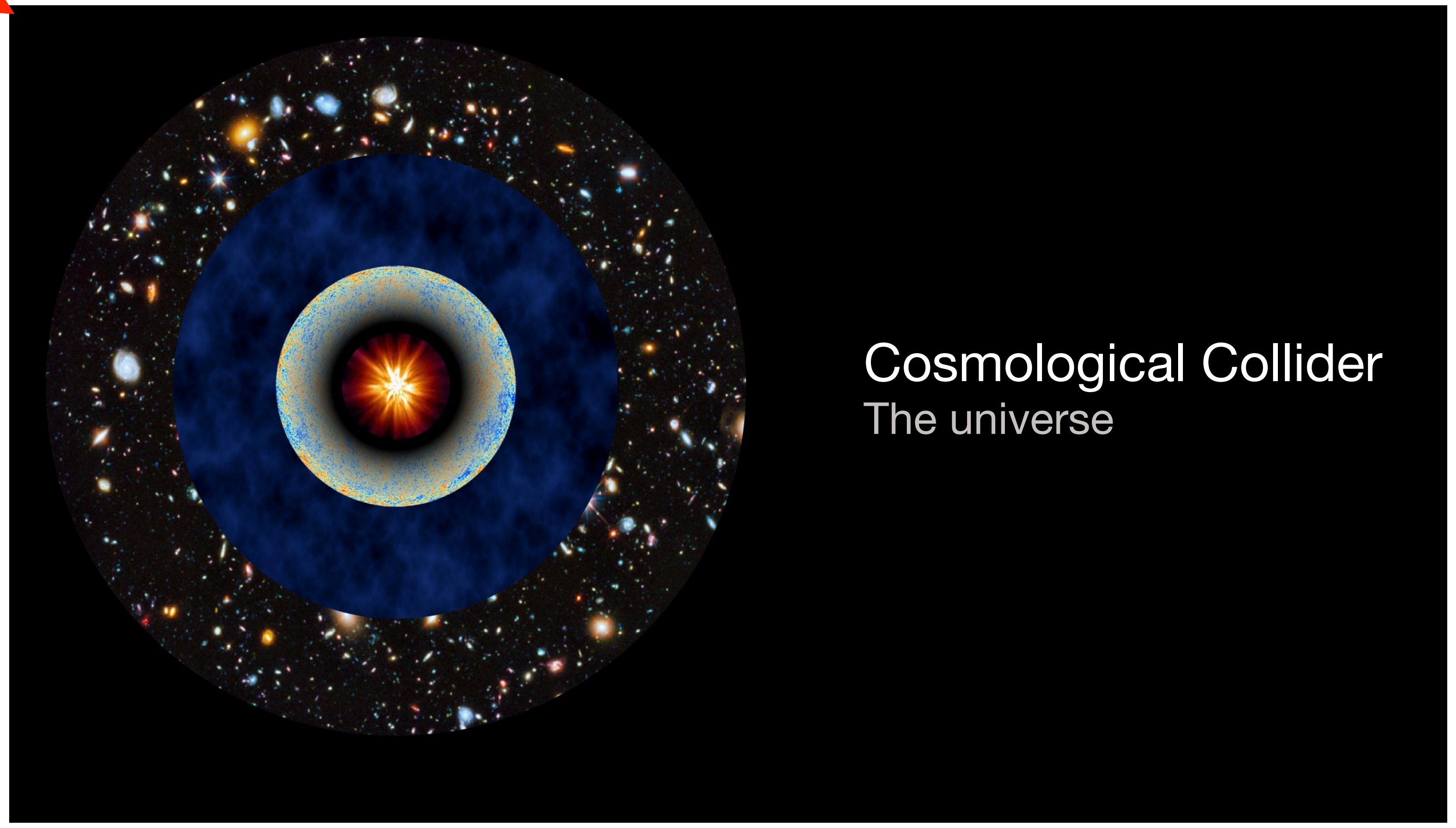
- **Cosmological collider physics:**

2D map of CMB or galaxy distribution (sourced by primordial fluctuation)→ physics of high energy inflationary Universe (new heavy particles, interactions...)

Cosmic history:



2D map



$E = mc^2$

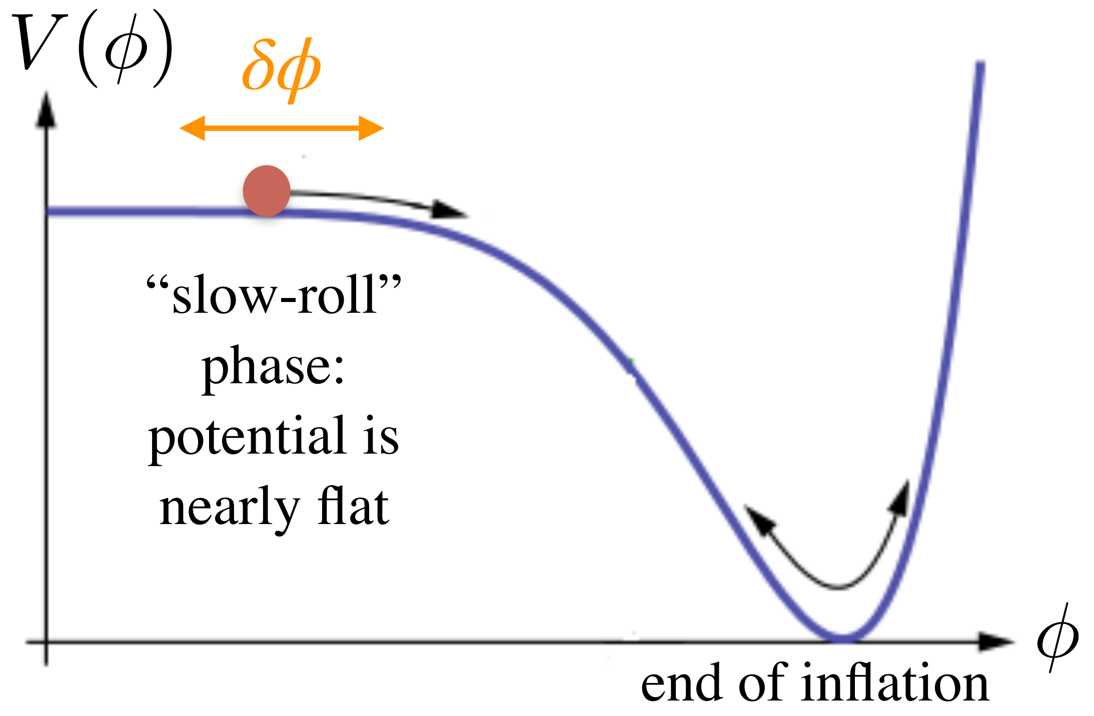
Hubble expansion energy (H) during inflation: up to $O(10^{13})$ GeV!

→production of heavy particles well beyond the reach of LHC!

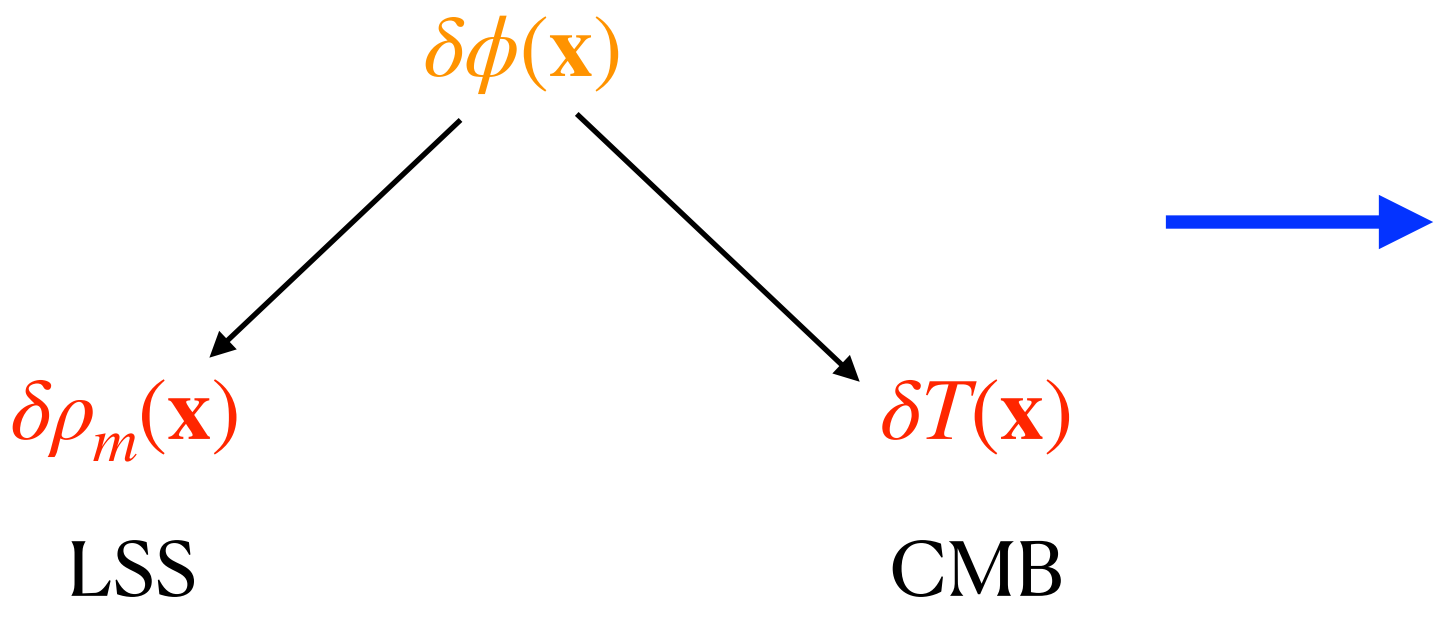
Cosmological Collider (CC) Physics 101

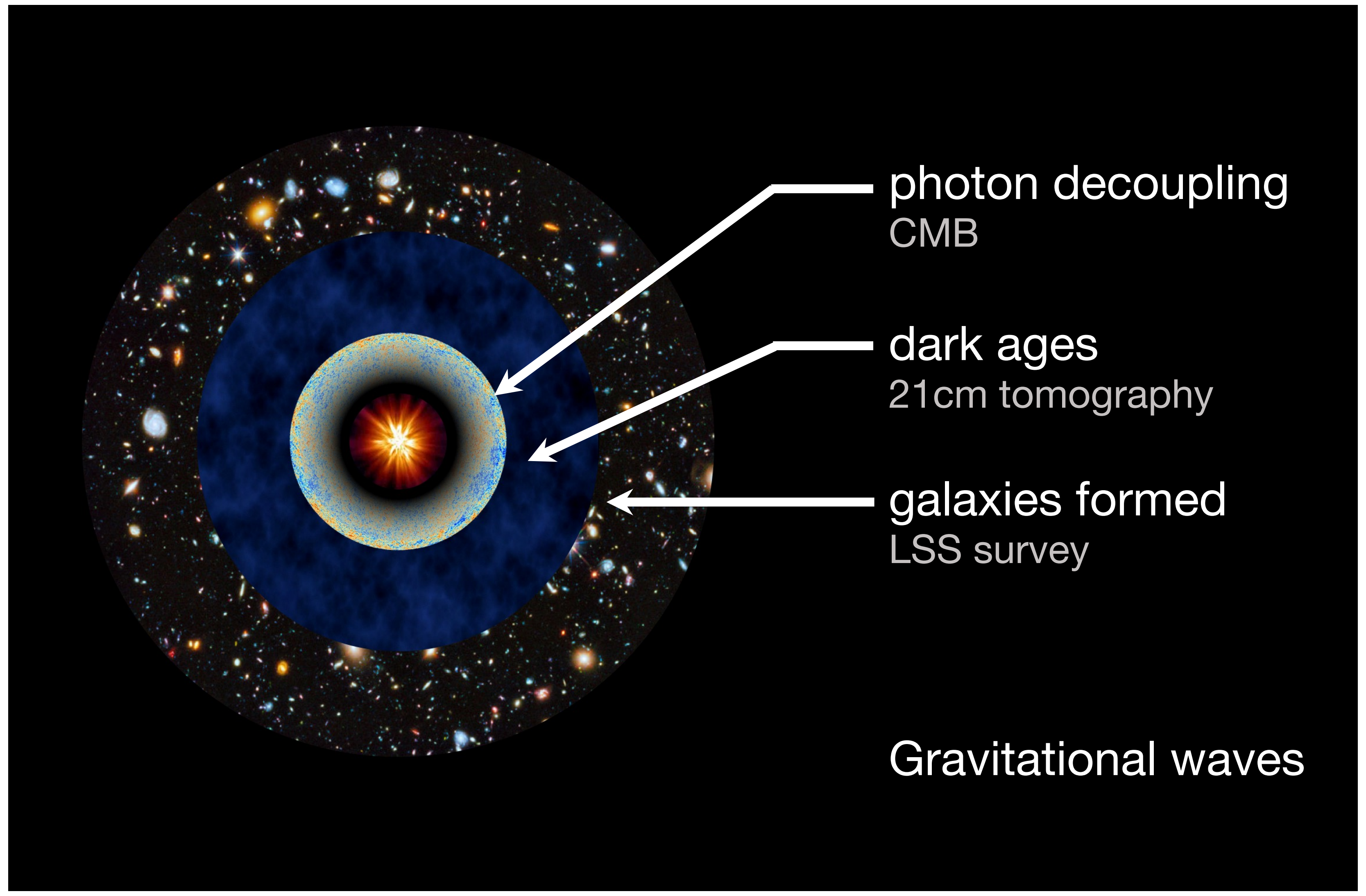
-Primordial Fluctuations

- **Inflation**: era of exponential expansion after the BB, address large scale homogeneity of the Universe
- Primordial quantum fluctuation of a scalar field(s) ϕ during inflation (e.g. inflaton), $\delta\phi$: seeds CMB anisotropies, structure formation (inhomogeneities)



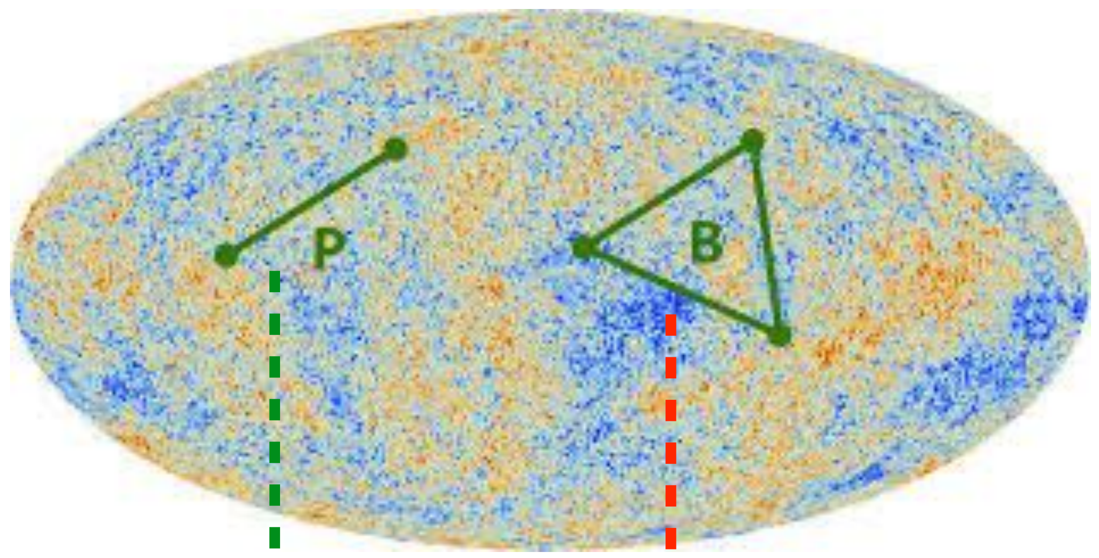
Single field slow-roll inflation





Cosmological Collider (CC) Physics 101

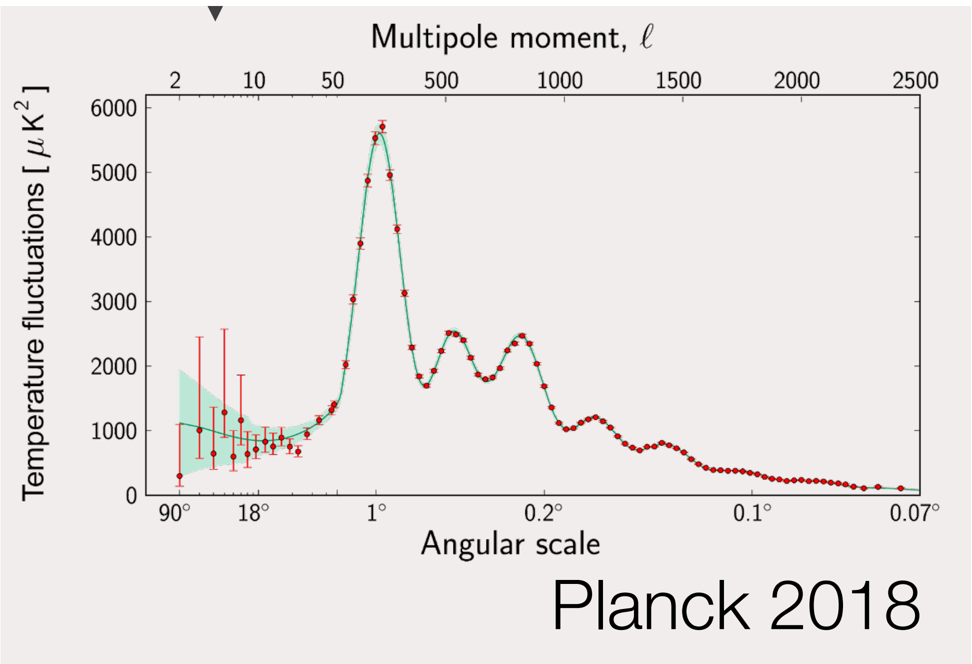
- How we extract information from the CMB



$\langle \delta T(x_1) \cdots \delta T(x_n) \rangle \rightarrow \langle \zeta(x_1) \ldots \zeta(x_n) \rangle$ *Fourier transform* $\langle \delta T(k_1) \ldots \delta T(k_n) \rangle$

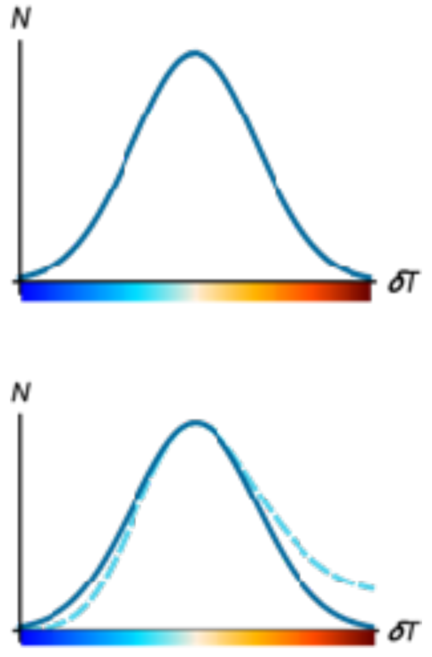
$\langle \zeta(k_1) \ldots \zeta(k_n) \rangle$

$\zeta(x)$: curvature perturbation due to $\delta\phi$



- n=2: 2-point correlator ☞ power spectrum
- n>2: Higher order correlations, bispectrum (3-pt), trispectrum (4-pt) ☞ Non-Gaussianity!

★ Reveal info about **interactions** of the field(s) contributing to primordial fluctuation *(inflaton+...)*



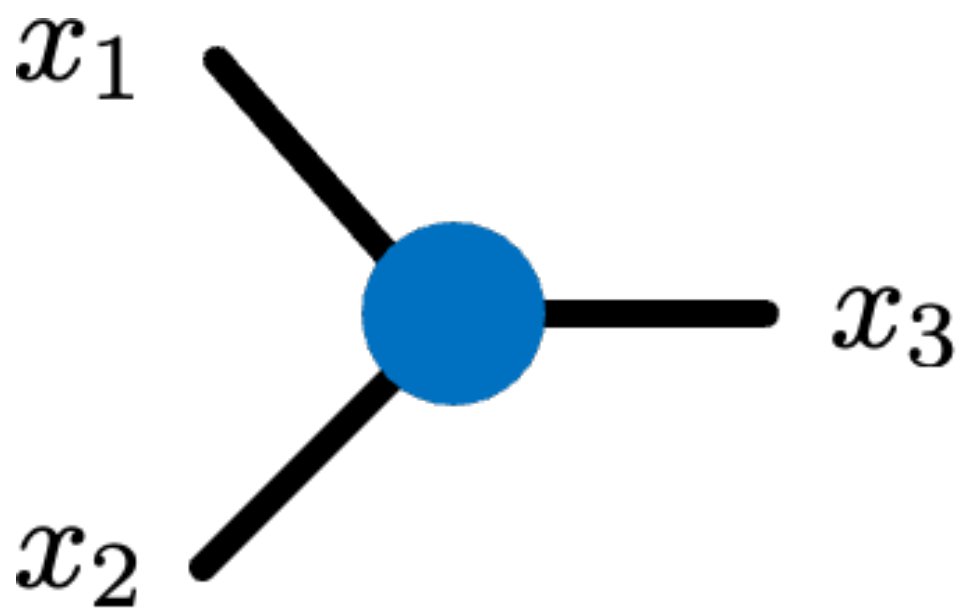
Propagation

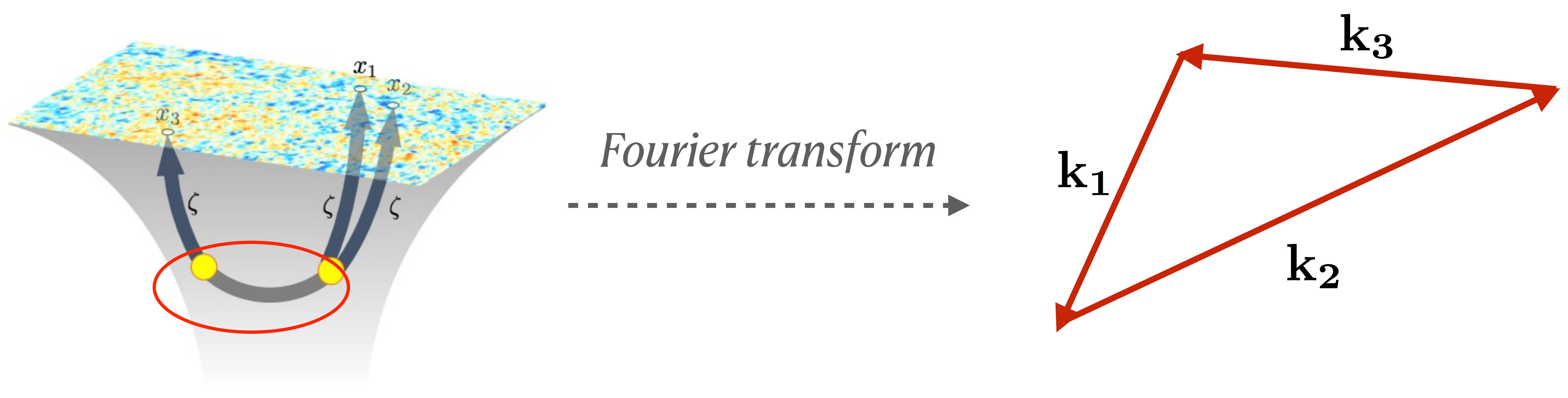
Collision (interactions!)

Cosmological Collider (CC) Physics 101

- How we discover new heavy particles with CC

3-pt correlation function:





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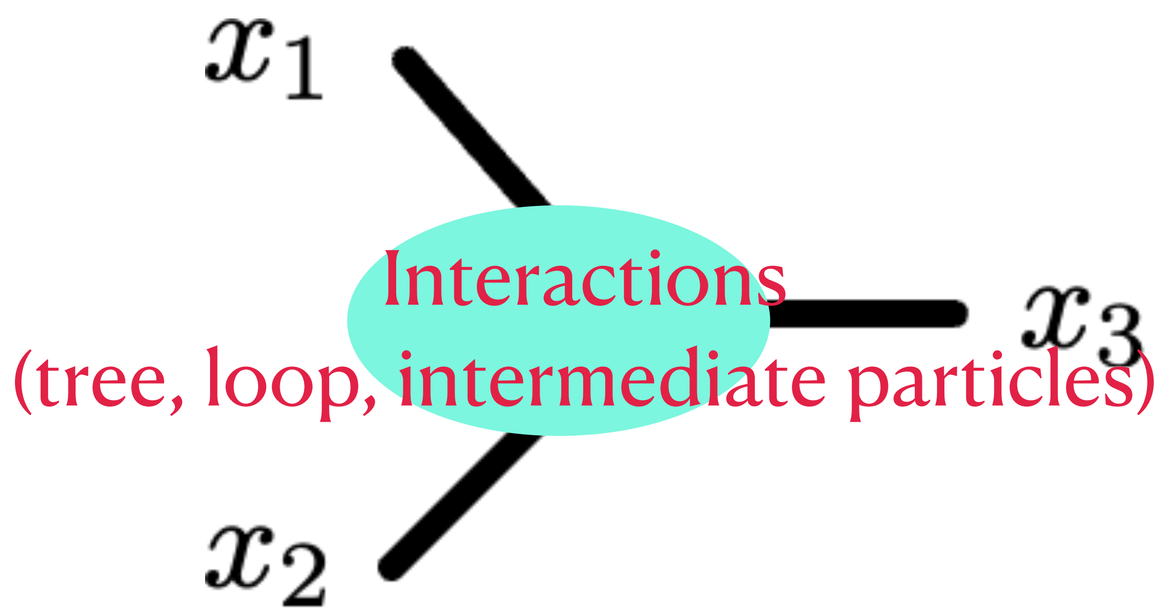
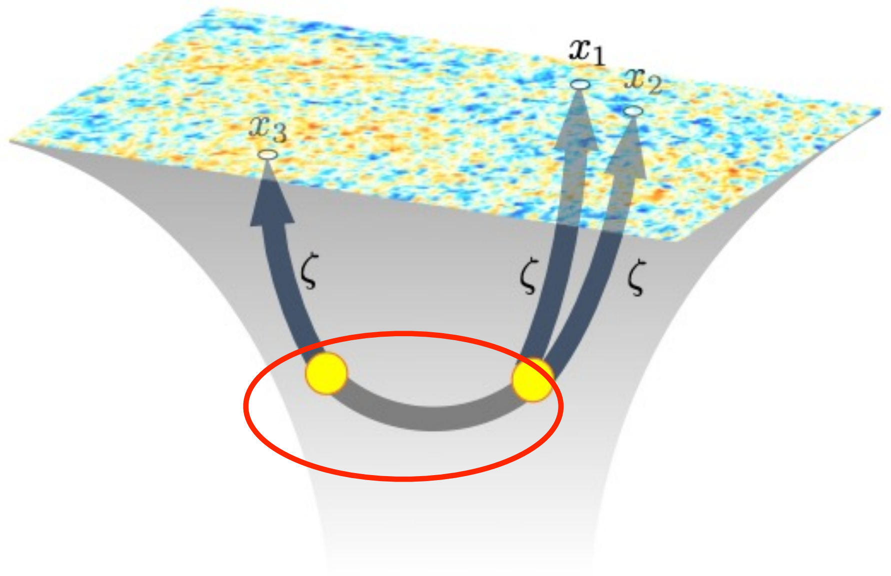
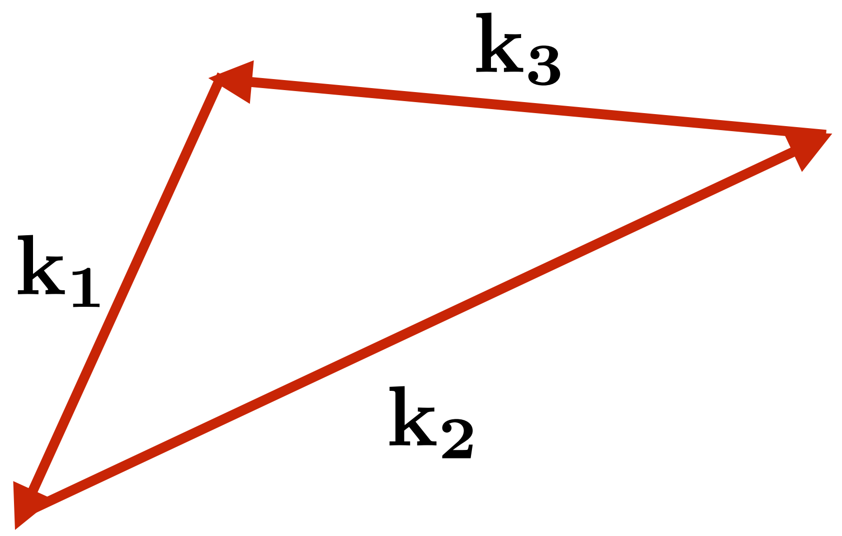




Fourier transform



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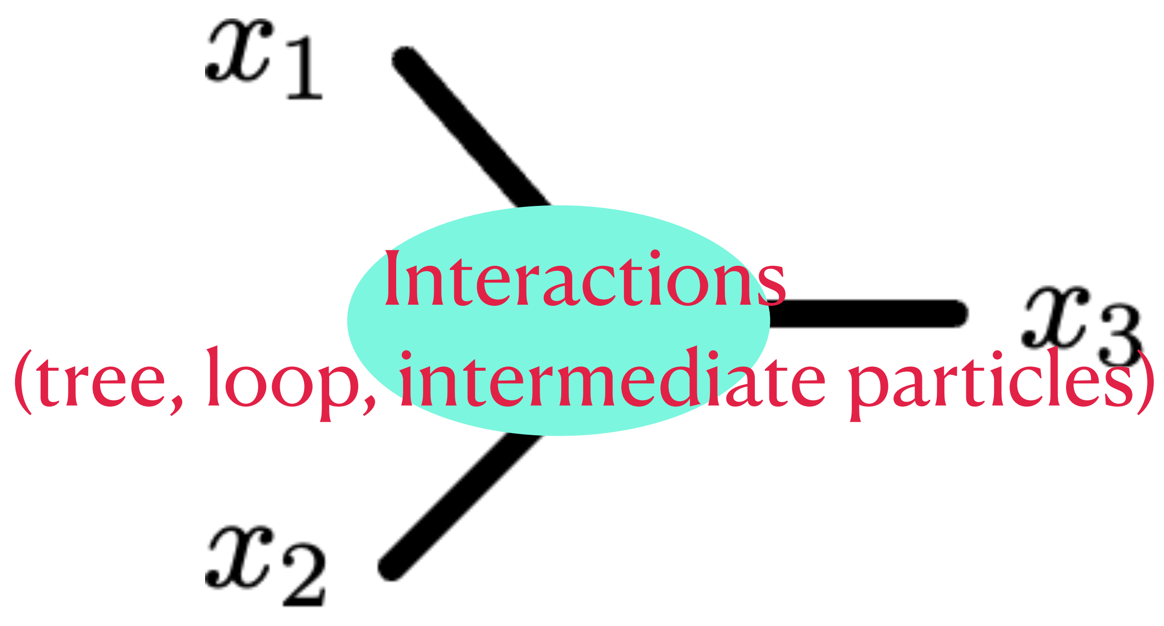
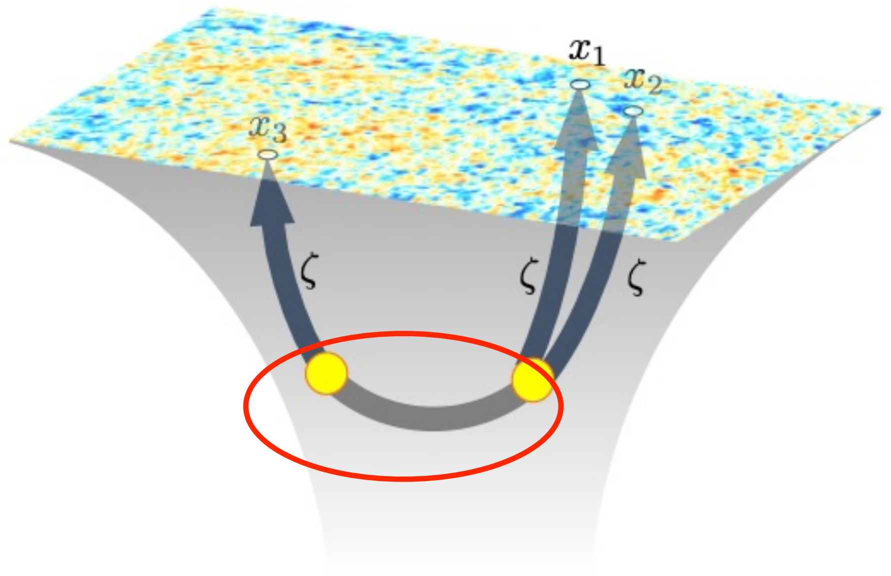
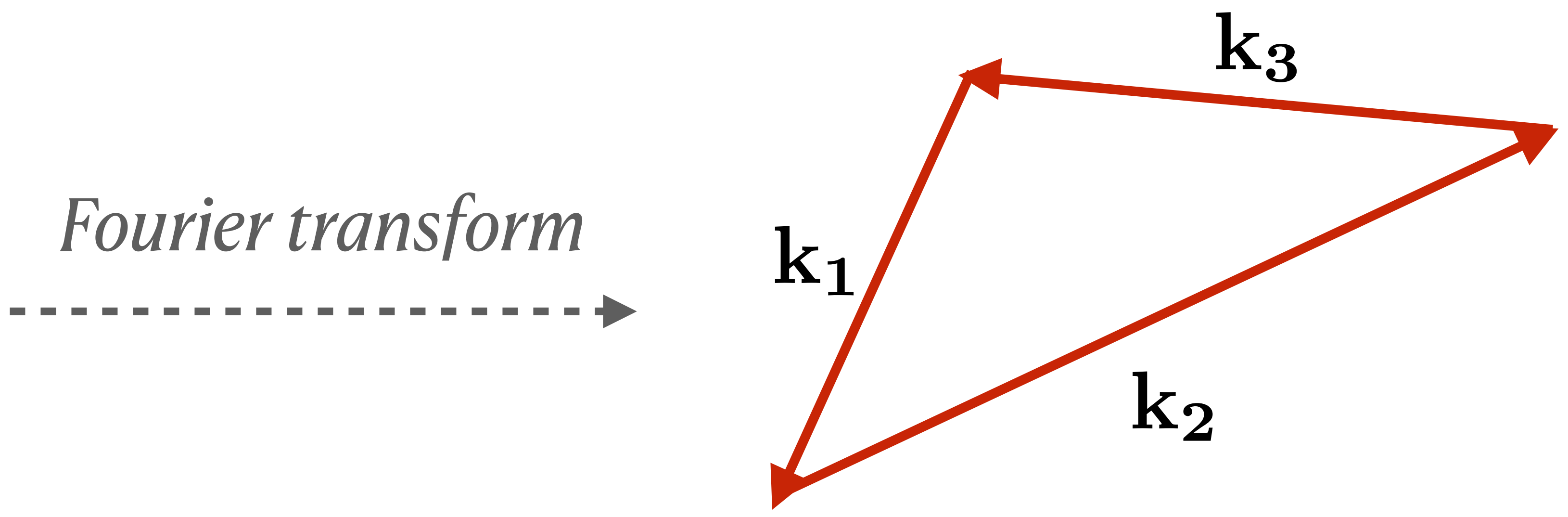






$$\langle \zeta_{\mathbf{k}_1} \zeta_{\mathbf{k}_2} \zeta_{\mathbf{k}_3} \rangle' \equiv (2\pi)^4 P_\zeta^2 \frac{1}{(k_1 k_2 k_3)^2} S(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3)$$

$S(k_1, k_2, k_3)$: shape function

★**Amplitude** of non-G: $f_{\rm NL} \simeq |S(\mathbf{k}, \mathbf{k}, \mathbf{k})|$

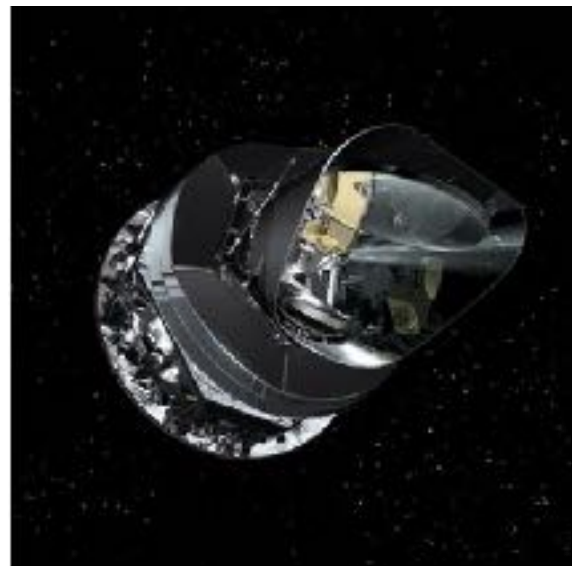
Cosmological Collider (CC) Physics 101

- How we discover new heavy particles with CC

Observational prospect for $f_{\rm NL}$:

Now

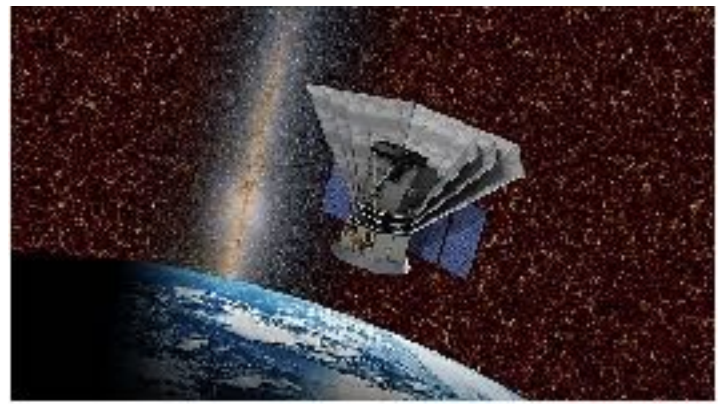
Planck 2018:

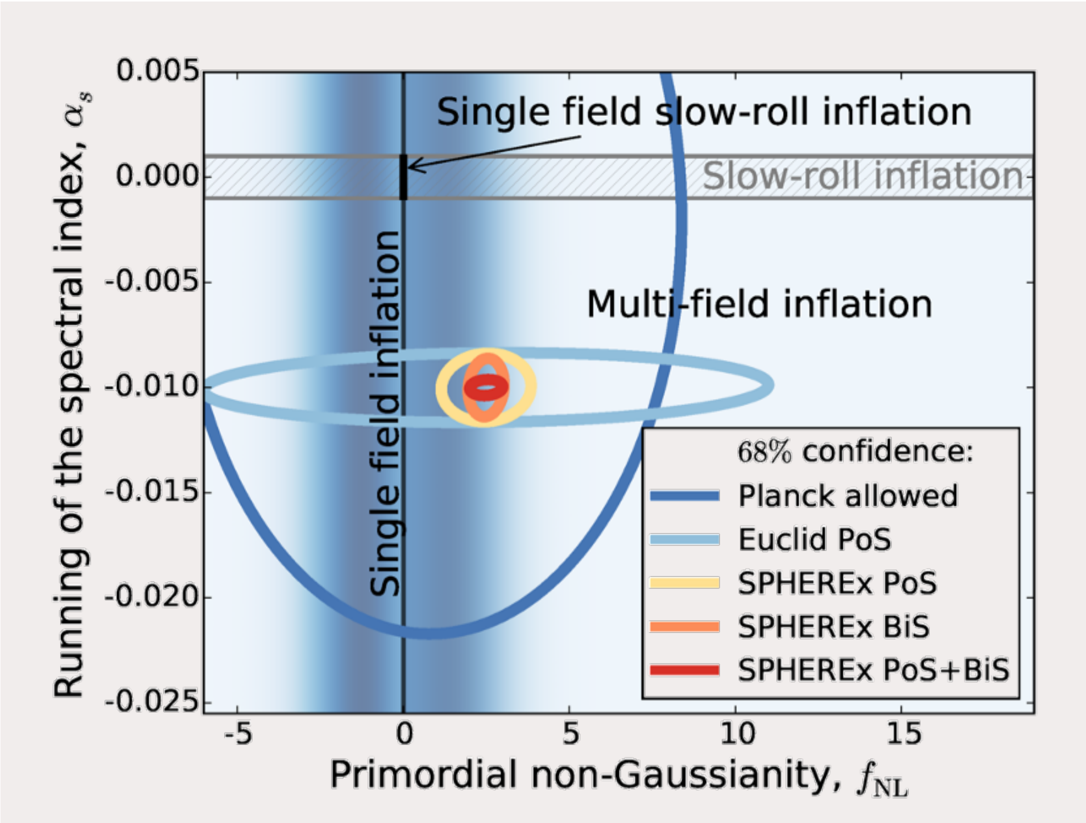


$$f_{\rm NL}^{\rm (local)} = -0.9 \pm 5.1$$
$$f_{\rm NL}^{\rm (equil)} = -26 \pm 47$$
$$f_{\rm NL}^{\rm (ortho)} = -38 \pm 24$$

O(1) in 10 yrs?

SPHEREx: launch ~2024





O(0.01) ultimately

21 cm tomography

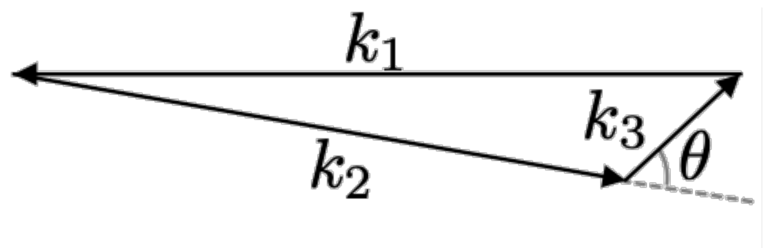
Cosmological Collider (CC) Physics 101

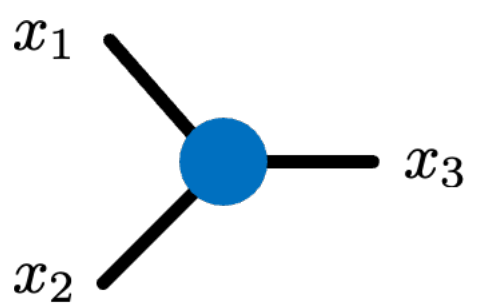
- How we discover new heavy particles with CC

- $S(k_1, k_2, k_3)$: **more information beyond f_{NL}!**

Squeezed limit of bispectrum: $k_1 \simeq k_2 \gg k_3$

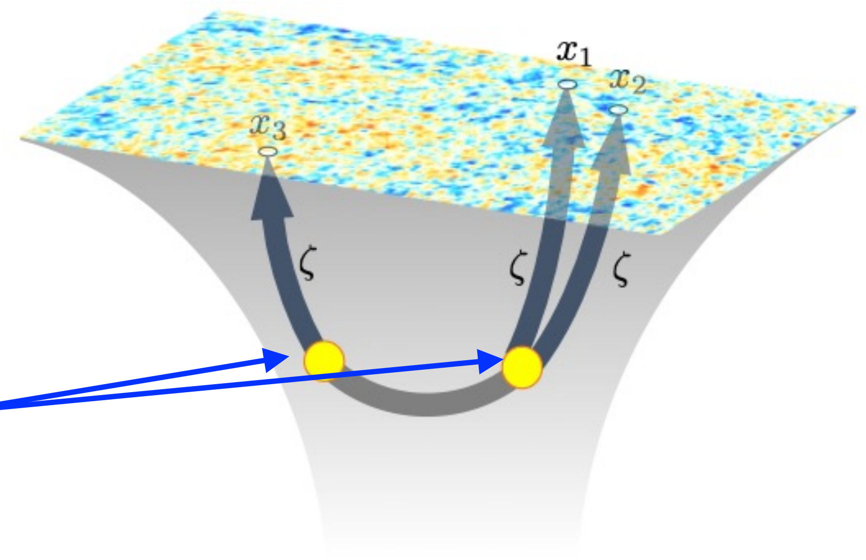
☞ key for revealing new heavy particles



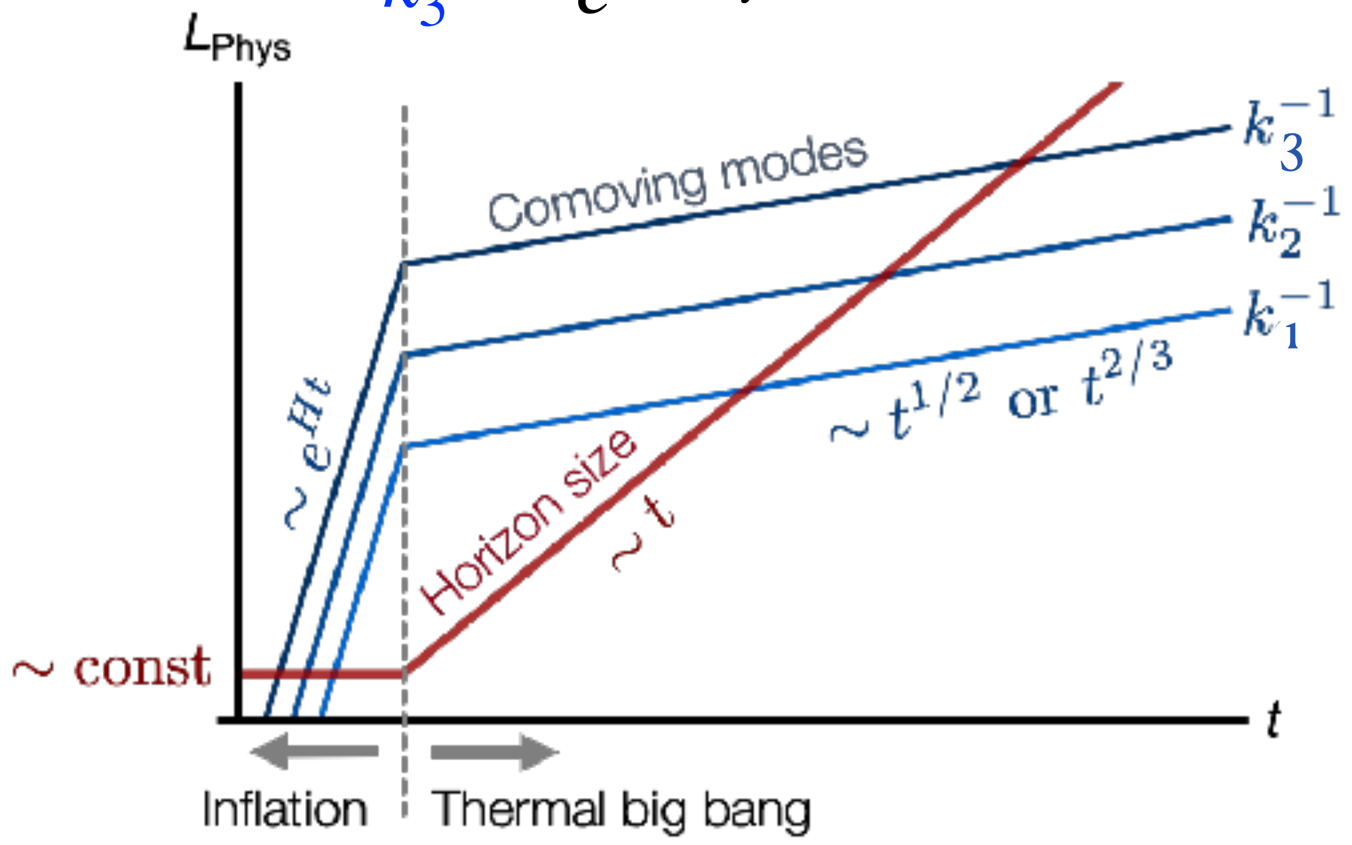


Small-momentum mode exits horizon earlier during inflation

☞ k_1/k_3: measures time difference



$$\frac{k_1}{k_3} = \frac{e^{Ht_{\text{late}}}}{e^{Ht_{\text{early}}}} = e^{H\Delta t}$$

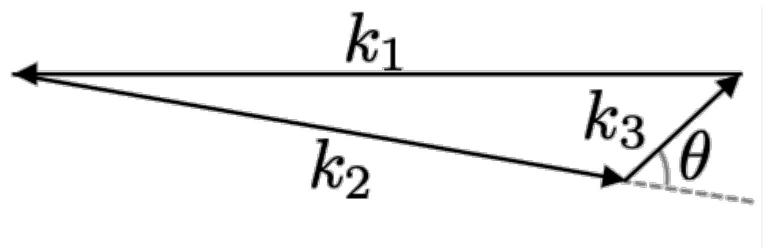


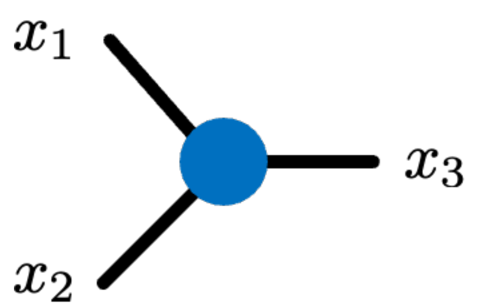
Cosmological Collider (CC) Physics 101
- How we discover new heavy particles with CC

- $S(k_1, k_2, k_3)$: more information beyond f_{NL}!

Squeezed limit of bispectrum: $k_1 \simeq k_2 \gg k_3$

☞ key for revealing new heavy particles





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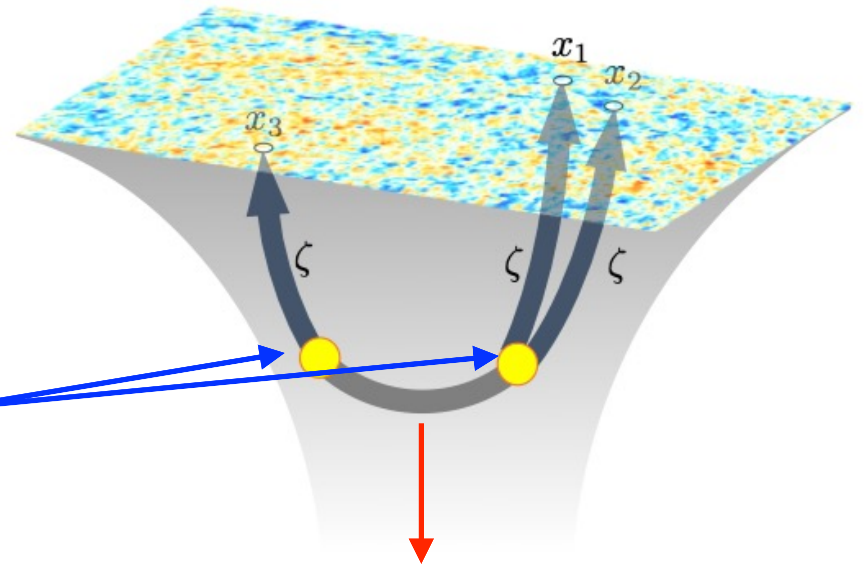
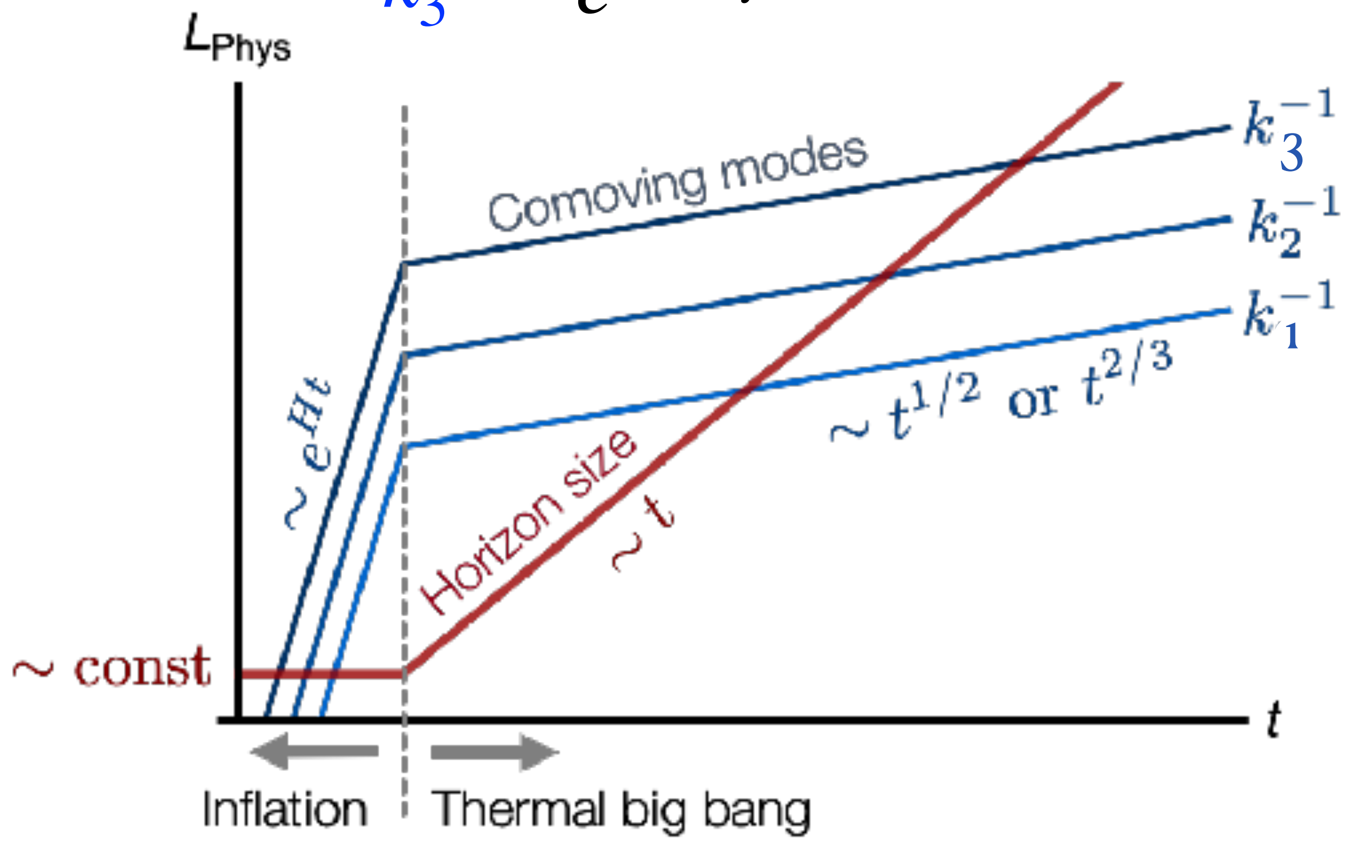


$$\frac{k_1}{k_3} = \frac{e^{Ht_{\rm late}}}{e^{Ht_{\rm early}}} = e^{H\Delta t}$$

Propagating, real intermediate particle!



$$S(k_1, k_3) \propto e^{-\pi m/H} e^{im\Delta t}$$

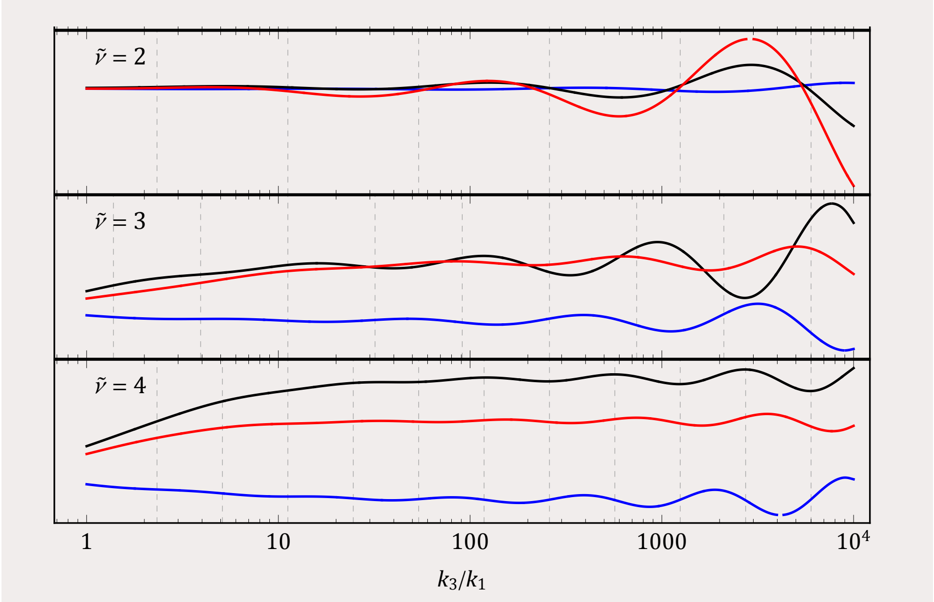
Boltmann factor ($T_{\rm dS} \sim H$) Oscillation (QM)

$$\sim e^{-\pi m/H} (k_1/k_3)^{im/H}$$

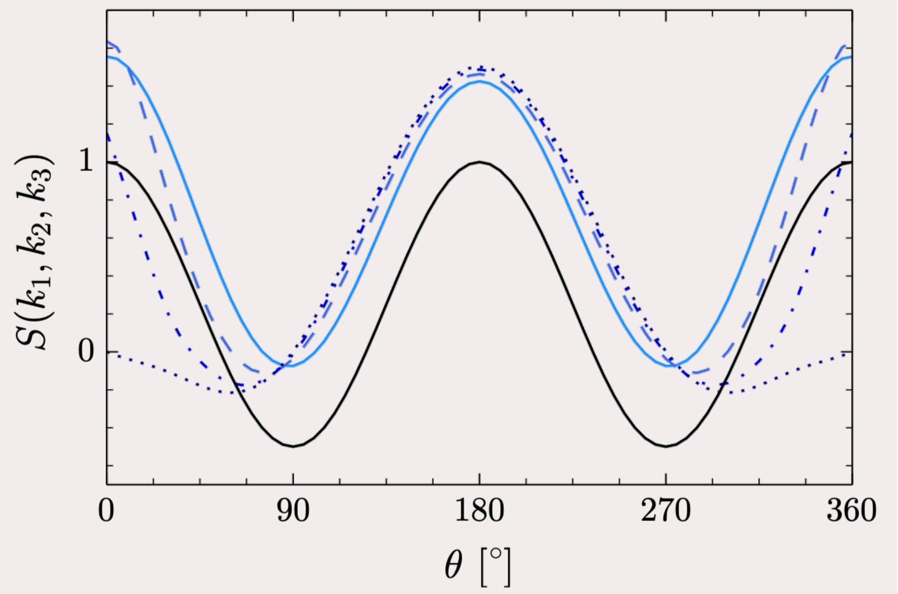
— **Mass measurement!**

(C.f. bump hunting at the LHC)

Examples of $S(k_1, k_3)$:



Chen, Chua, Guo, Wang, ZZX, Xie, 1803.04412

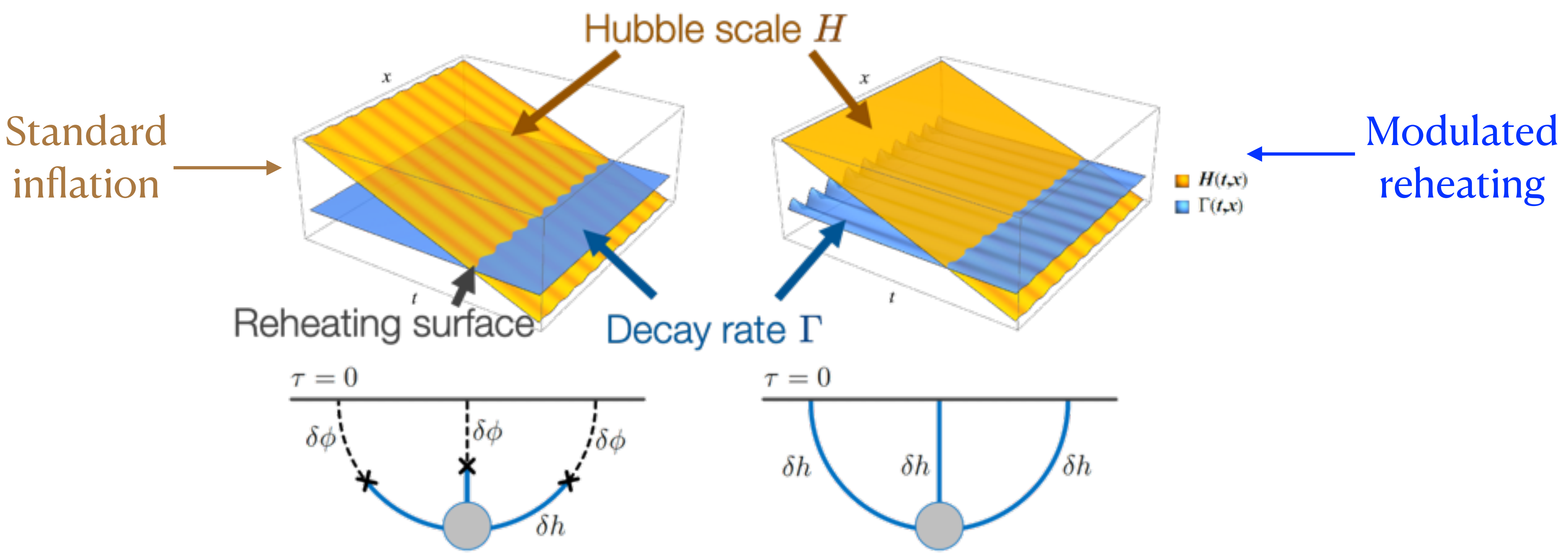


Lee, Baumann, Pimentel, 1607.03735

Cosmological Collider (CC) Physics 101

- Alternatives: Cosmological Higgs Collider

- Original CC: an inflaton collider
  — inflaton fully responsible for both homogeneity (exponential expansion) and inhomogeneity
- Beyond the minimal (yet motivated!): Separate the tasks
  vacuum energy from inflaton, fluctuations from a different source *(partially)*
  ☞**Modulated reheating** *(Dvali, Gruzinov, Zaldarriaga 2003)*, application in CC (fewer params, larger f_{NL}):
  - Cosmological Higgs Collider (CHC): Lu, Wang and Xianyu 2019 (relevant to this talk)
  - Curvaton collider: Kumar, Sundrum 2019



Cosmological Collider (CC) Physics 101

- Apply it for probing high scale leptogenesis?

- **Attempts of probing BSM particle physics with CC physics:**
  - SM particles *(Chen, Wang, Xianyu 2016)*
  - GUT physics *(Kumar, Sundrum 2018)*
  - Higgs potential at high energy *(Hook, Huang, Racco 2019)*

  ...

—Cosmological collider: probe the impossibles for terrestrial colliders!

Opportunities for high scale baryognesis?

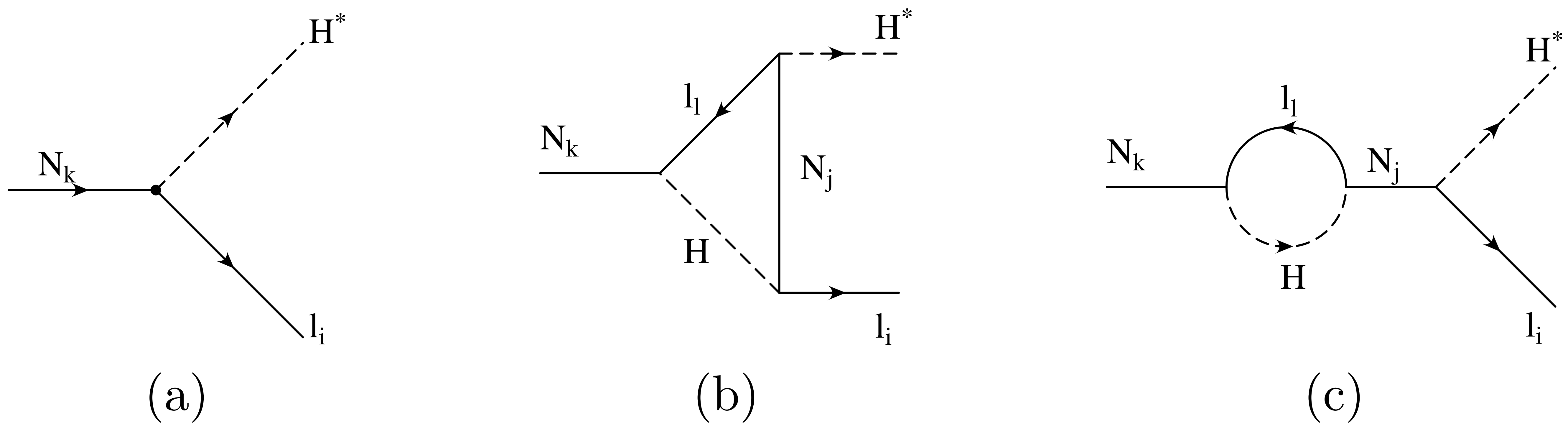
A benchmark: Leptogenesis

Naturally suitable for CHC: heavy RH neutrino, coupling to SM Higgs

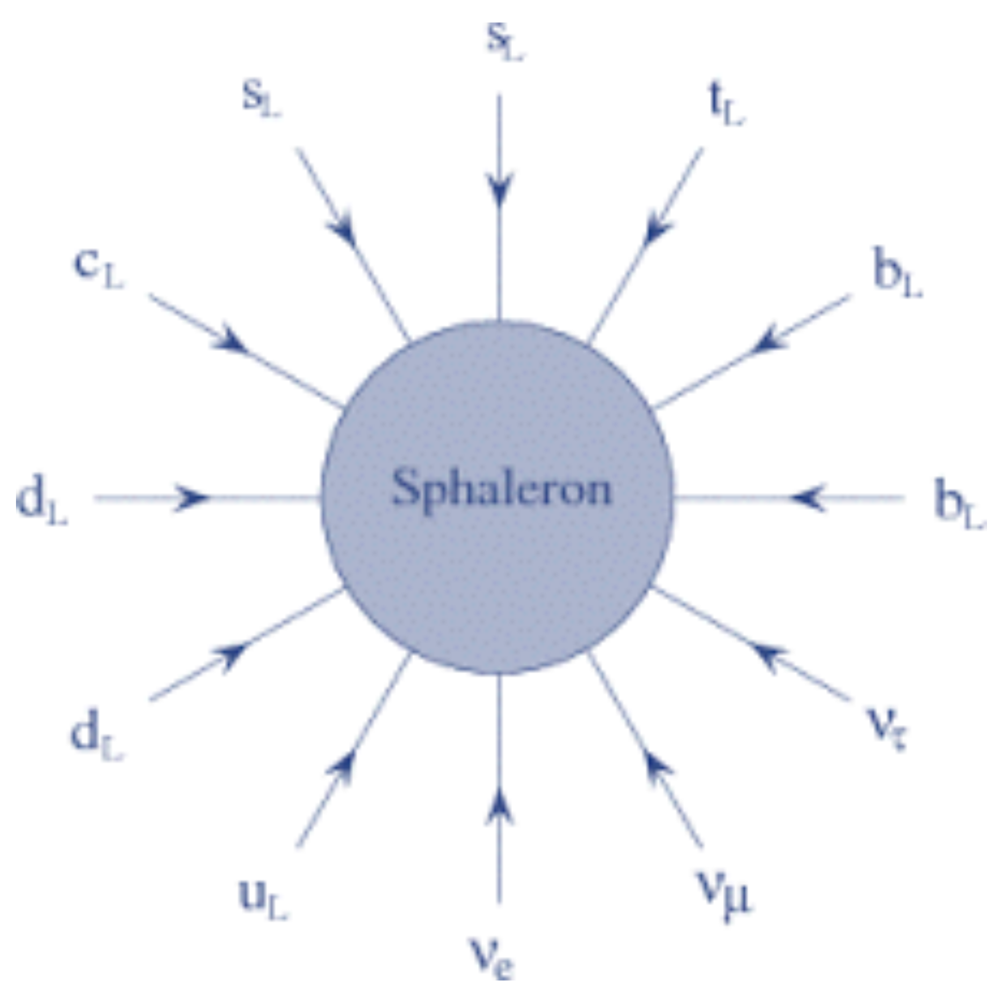
Structure of Leptogenesis Model During Inflation
— Masses, Couplings

- Model for leptogenesis (Type-I Seesaw): heavy RH Majorana neutrino N, SM lepton doublet $L = (\nu, e^-)^T$, couple to the SM Higgs $\mathbf{H}$.

Recall: essential interactions/processes (post-inflationary)



Generate ΔL



ΔL transferred to ΔB before EWPT

Structure of Leptogenesis Model During Inflation
— Masses, Couplings

- **Distinct story when applying to CHC:**

During inflation Higgs gets a large VEV $v \sim H \gg v_{\rm EW}$! quantum fluctuation *(e.g. Bunch, Davies 1978),*

H: Hubble during inflation ➜ Distinct pattern of neutrino mass/mixing

— different from both leptogenesis era ($v = 0$) and today—after EWPT ($v = v_{\rm EW}$)

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Take 1 generation of N as a toy example first: parametrize the Higgs as $\mathbf{H} = (0, (v+h)/\sqrt{2})^T$

$$\Rightarrow \quad \Delta\mathscr{L} = \nu^\dagger i\bar{\sigma}^\mu\partial_\mu\nu + N^\dagger i\bar{\sigma}^\mu\partial_\mu N + \left[m_D\left(1+\frac{h}{v}\right)\nu N - \frac{1}{2}m_N NN + \text{c.c.}\right] \qquad m_D \equiv yv/\sqrt{2}$$

Rotate to mass eigenstates $\psi_\pm$: $\mathscr{L} \supset \frac{m_D h}{v\sqrt{m_N^2+4m_D^2}}\left[m_D(\psi_-^2 - \psi_+^2) + m_N\psi_-\psi_+\right] \quad m_\pm = \frac{1}{2}\left(m_N \pm \sqrt{m_N^2+4m_D^2}\right)$

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★ $m_D \sim m_N \sim H$ during inflation— no Seesaw! $\Rightarrow m_+ \sim m_-$

★ Mass matrix and Higgs Yukawa couplings cannot be simultaneously diagonalized

Sizable Yukawa coupling mixing mass eigenstates!

☞ **Novel pattern of CHC signal**

Structure of Leptogenesis Model During Inflation
— Masses, Couplings

- Generalize to realistic 3 generation N's:
  mixed Yukawa couplings persist, plus CP phases

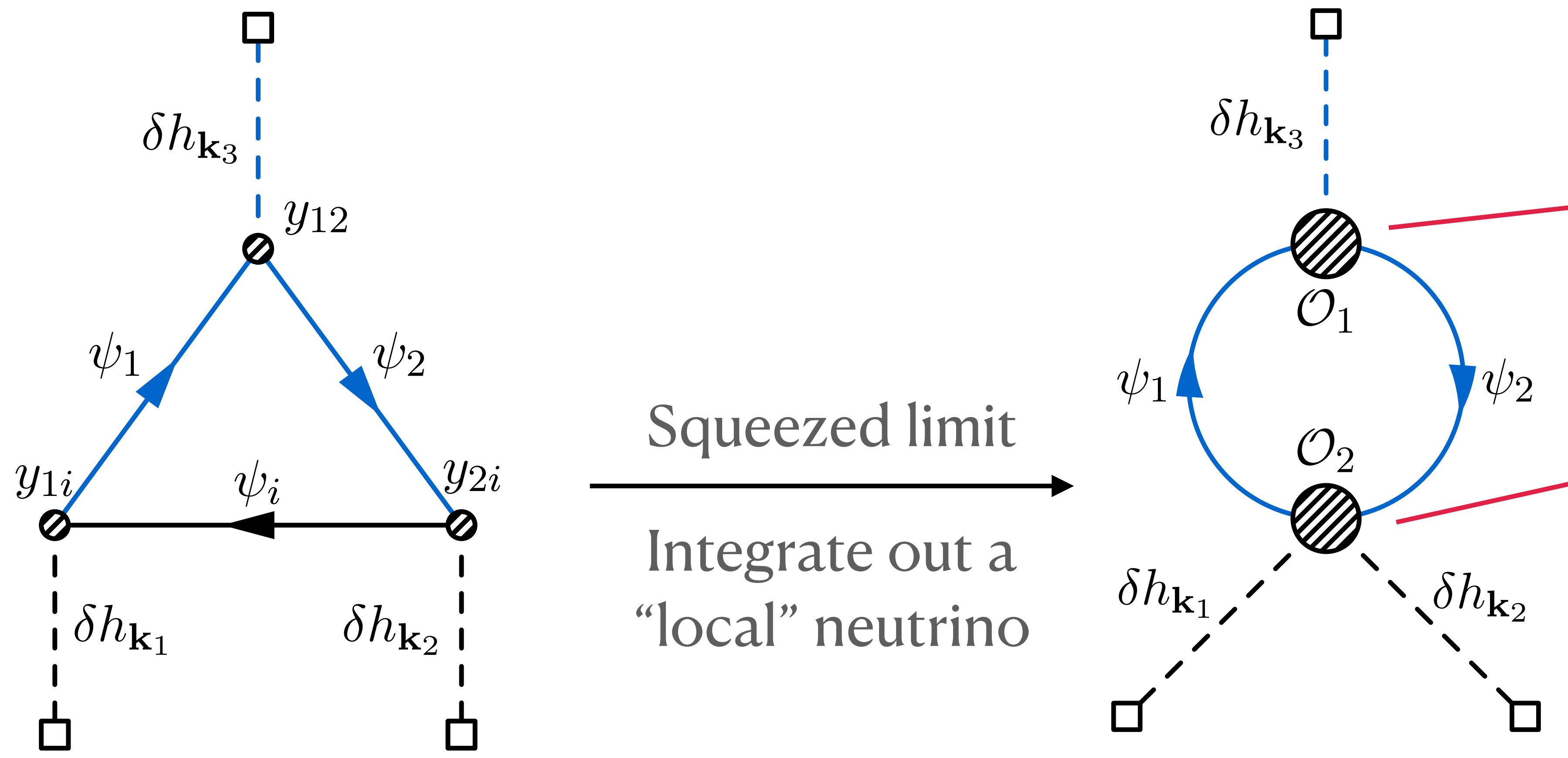
$$\Delta\mathscr{L} = \nu_i^\dagger \mathrm{i}\bar{\sigma}^\mu \partial_\mu \nu_i + N_i^\dagger \mathrm{i}\bar{\sigma}^\mu \partial_\mu N_i + \left[m_{Dij}\left(1 + \frac{h}{v}\right)\nu_i N_j - \frac{1}{2} m_{Nij} N_i N_j + \text{c.c.} \right]$$

Rotate to mass eigenstates:

$$\mathscr{L} \supset \frac{h}{2v}\left(\psi_1, \cdots, \psi_6\right) \begin{pmatrix} M_1 - C^T m_N C & -C^T m_N D \\ -D^T m_N C & M_2 - D^T m_N D \end{pmatrix} \begin{pmatrix} \psi_1 \\ \vdots \\ \psi_6 \end{pmatrix}$$

Cosmological (Higgs) Collider Signals of Leptogenesis

- **Central task for finding CHC signal: calculate the 3-pt correlator of δh**



$$\mathcal{O}_1 \equiv y_{12}(e^{i\varphi_{12}}\psi_1\psi_2 + \text{c.c.})$$

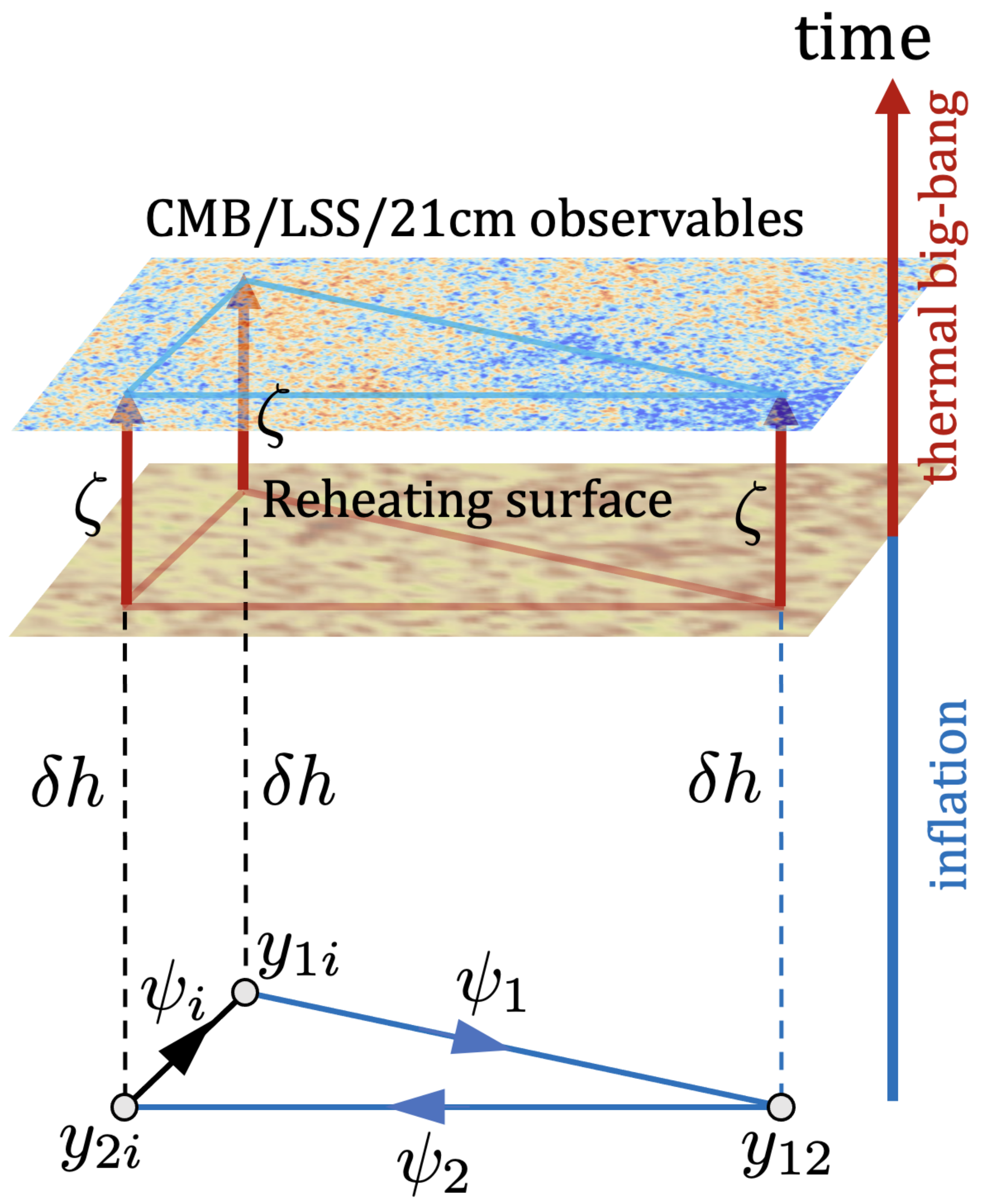
φ_{12}, φ_5: CP phases

$$\mathcal{O}_2 \equiv \frac{1}{\Lambda}(e^{i\varphi_5}\psi_1\psi_2 + \text{c.c.})$$

$$1/\Lambda \sim y_{12}(y_{11}/m_1 + y_{22}/m_2)$$

$$\langle \mathcal{O}_1(x)\mathcal{O}_2(y)\rangle = -\frac{4y_{12}}{\Lambda}\Big[\cos(\varphi_{12}+\varphi_5)g_{m_1}(x,y)g_{m_2}(x,y) + \cos(\varphi_{12}-\varphi_5)f_{m_1}(x,y)f_{m_2}(x,y)\Big]$$

☞ How the CHC signal depends on m_1, m_2, CP phases



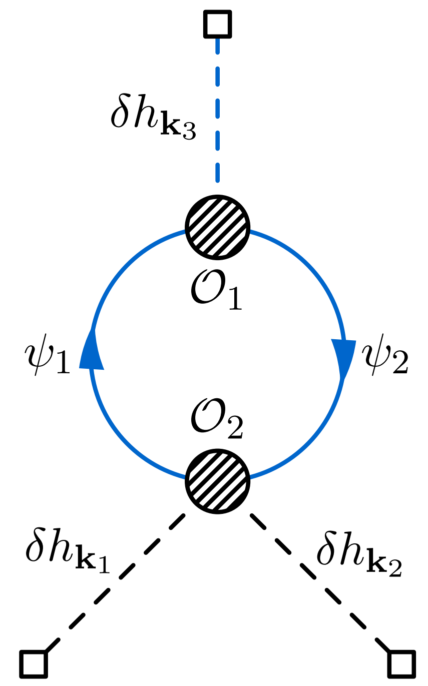
Cosmological (Higgs) Collider Signals of Leptogenesis

$$\langle \mathcal{O}_1(x)\mathcal{O}_2(y)\rangle = -\frac{4y_{12}}{\Lambda}\Big[\cos(\varphi_{12}+\varphi_5)g_{m_1}(x,y)g_{m_2}(x,y)+\cos(\varphi_{12}-\varphi_5)f_{m_1}(x,y)f_{m_2}(x,y)\Big]$$

$$\mathrm{i}f_m(x,y) = 2\mathrm{Re}\Bigg\{\frac{\Gamma(2-\mathrm{i}\widetilde{m})\Gamma(\frac{1}{2}+\mathrm{i}\widetilde{m})}{4\pi^{5/2}}\left(\frac{\tau_1\tau_2}{X^2}\right)^{3/2-\mathrm{i}\widetilde{m}} \times\left[1+\frac{(3-4\widetilde{m}(2\mathrm{i}+\widetilde{m}))(\tau_1^2+\tau_2^2)-6\tau_1\tau_2}{2(1-2\mathrm{i}\widetilde{m})X^2}\right]\Bigg\},$$

$$g_m(x,y) = 2\mathrm{Re}\Bigg\{\frac{\Gamma(2-\mathrm{i}\widetilde{m})\Gamma(\frac{1}{2}+\mathrm{i}\widetilde{m})}{4\pi^{5/2}}\left(\frac{\tau_1\tau_2}{X^2}\right)^{3/2-\mathrm{i}\widetilde{m}} \times\left[1+\frac{(3-4\widetilde{m}(2\mathrm{i}+\widetilde{m}))(\tau_1^2+\tau_2^2)+6\tau_1\tau_2}{2(1-2\mathrm{i}\widetilde{m})X^2}\right]\Bigg\}.$$

$$\widetilde{m} = m/H$$



Three cases:

- Pure Dirac mass: $m_N \to 0, \quad \varphi \to 0$, Yukawa coupling is diagonalizable with real eigenvalues

  $\langle \mathcal{O}_1\mathcal{O}_2\rangle \propto f_{m_i}^2 + g_{m_i}^2$, vanishes at LO $\Rightarrow$ signal decays faster than naively expected

  — restores result known in literature *(e.g. Chen, Wang, Xianyu 2018)*, applies to Dirac ν/Dirac LG

- Majorana mass induced mixed Yukawa but no CP phase: $\langle \mathcal{O}_1\mathcal{O}_2\rangle \propto f_{m_1}f_{m_2} + g_{m_1}g_{m_2}$,

  $\Rightarrow$ at LO oscillating signal with a single frequency $\tilde{m}_1 - \tilde{m}_2$ — new to literature!

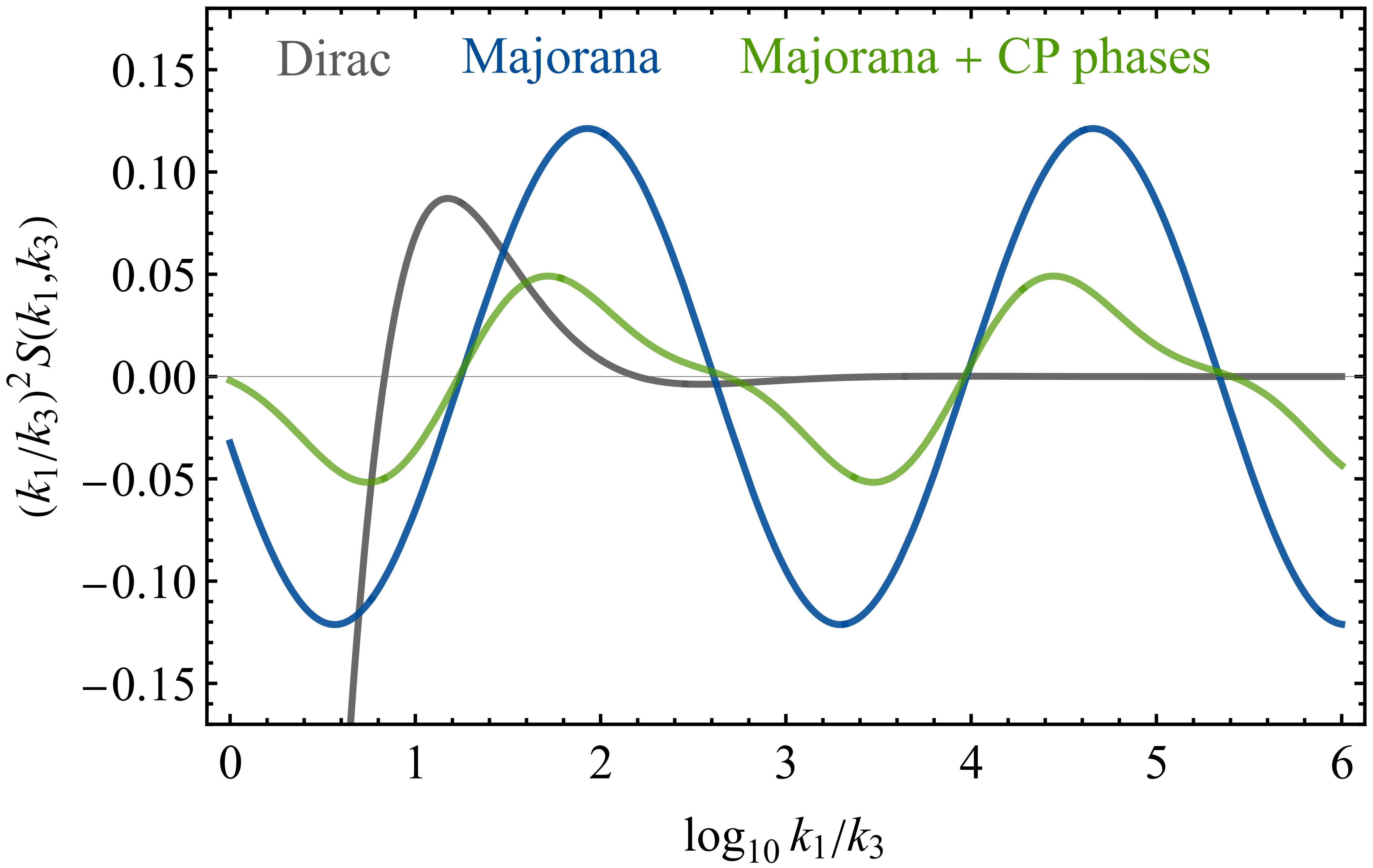
- **Majorana mass plus CP phase (realistic LG):** $\langle \mathcal{O}_1\mathcal{O}_2\rangle \propto \cos(\varphi_{12}+\varphi_5)f_{m_1}f_{m_2} + \cos(\varphi_{12}-\varphi_5)g_{m_1}g_{m_2}$

  $\Rightarrow$ at LO oscillating signal with two distinct frequencies $\tilde{m}_1 - \tilde{m}_2$ and $\tilde{m}_1 + \tilde{m}_2$ — distinct signature of LG!

Cosmological (Higgs) Collider Signals of Leptogenesis

Result-1: Shape function of the primordial bispectrum:

$$\langle \mathcal{O}_1 \mathcal{O}_2 \rangle \to S(k_1, k_3)$$



Three cases:

- Pure Dirac mass: known case, signal dies fast
- Majorana mass w/o CP phases: single mode oscillation
- Majorana mass w/ CP phases (leptogenesis): two distinct modes of lasting oscillation

☞ Information about heavy RH neutrino mass!

With 3 generations, more oscillation modes possible, but generally expect one pair of mass eigenstates dominate the signal

Cosmological (Higgs) Collider Signals of Leptogenesis

Result-2: CHC signal strength $f_{\rm NL}$ VS. Y_B predicted by leptogenesis

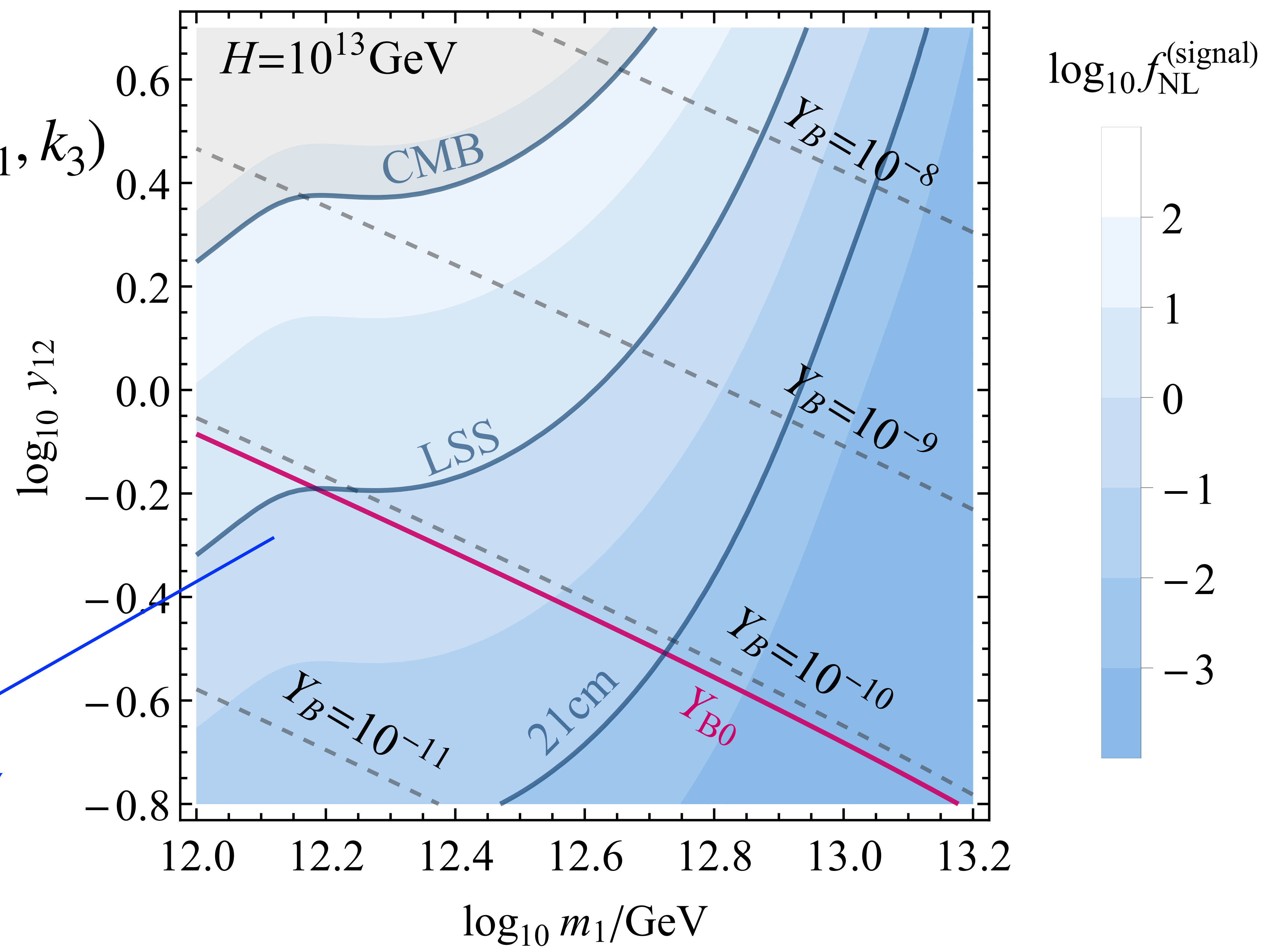
Recall:

$f_{\rm NL}$: amplitude of the shape function $S(k_1, k_3)$

$$Y_B = \frac{c_s}{c_s - 1}\kappa\frac{\epsilon_1}{g_*}$$

- c_s : sphaleron conversion
- ϵ_1 : asymmetry from N_1 decay
- κ: washout efficiency, most sensitive to couplings

Observed Y_B today



Scan over perturbative Yukawa couplings, mass range

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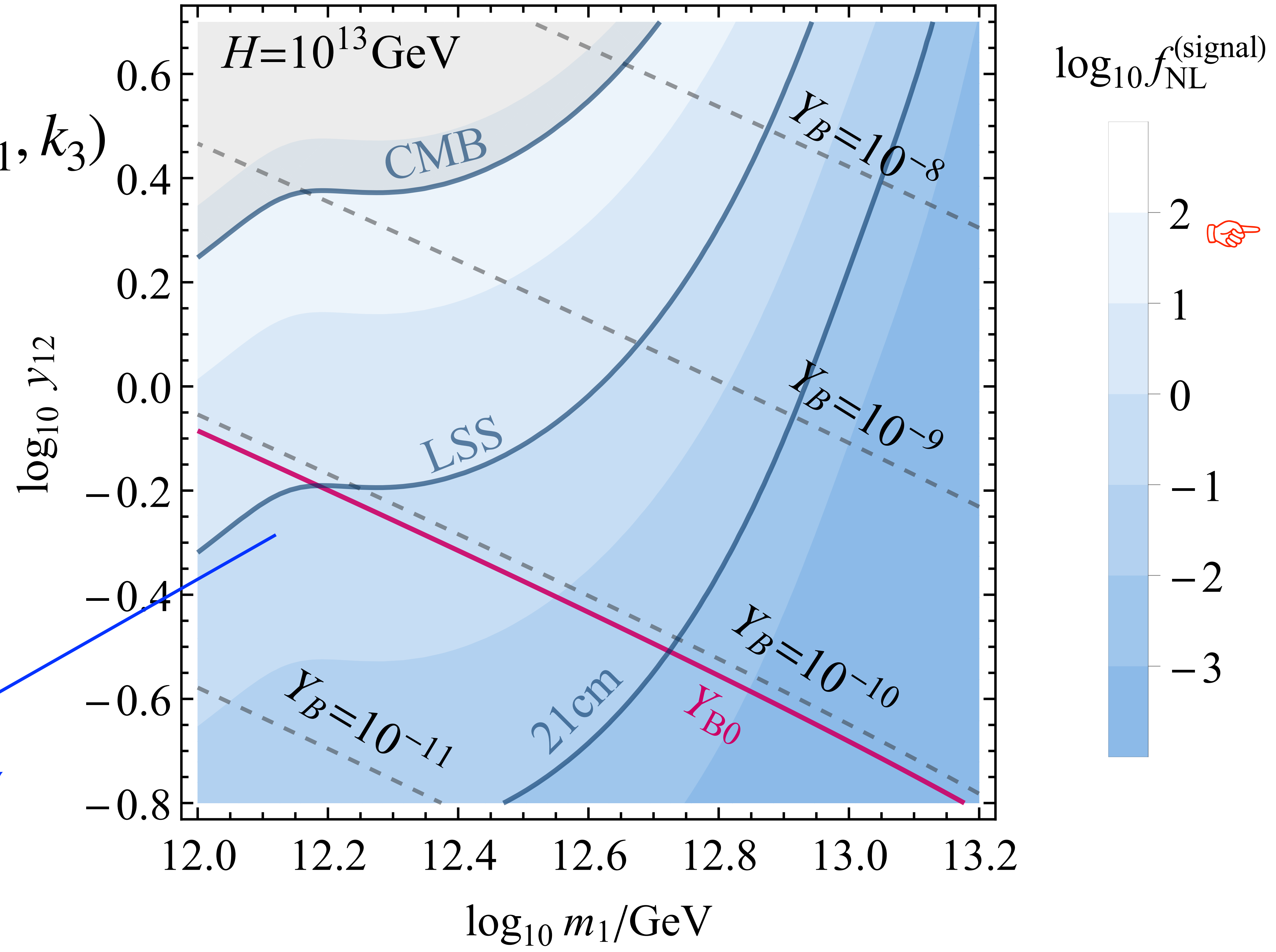


Scan over perturbative Yukawa couplings, mass range

☞ Viable leptogenesis models can lead to signals detectable by future CMB/LSS/21 cm experiments!

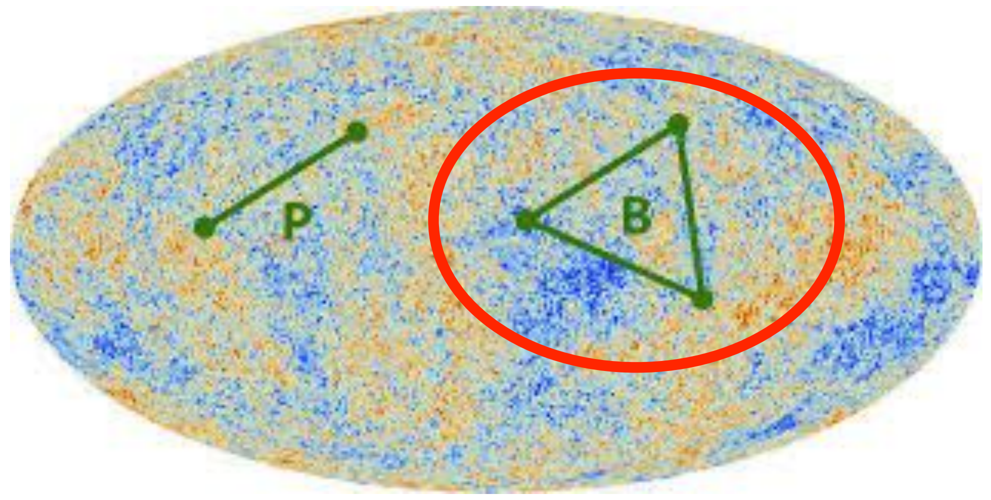
Conclusion

- Matter-antimatter asymmetry remains a profound puzzle
- Cosmological Collider Physics: probe new physics with super-high energy collider—the cosmos during inflation!

- A new method for probing high-scale leptogenesis with CHC
  - Signal strength ($f_{\rm NL}$) from realistic LG models within reach of upcoming experiments
  - Signal shape (oscillation pattern) distinct from known CC signals

☞ Information about $\not{L}$ couplings, CP phases and heavy RH neutrino masses!

Unraveling matter-antimatter asymmetry puzzle by dedicated measurements of primordial non-Gaussianity?



Thank you!