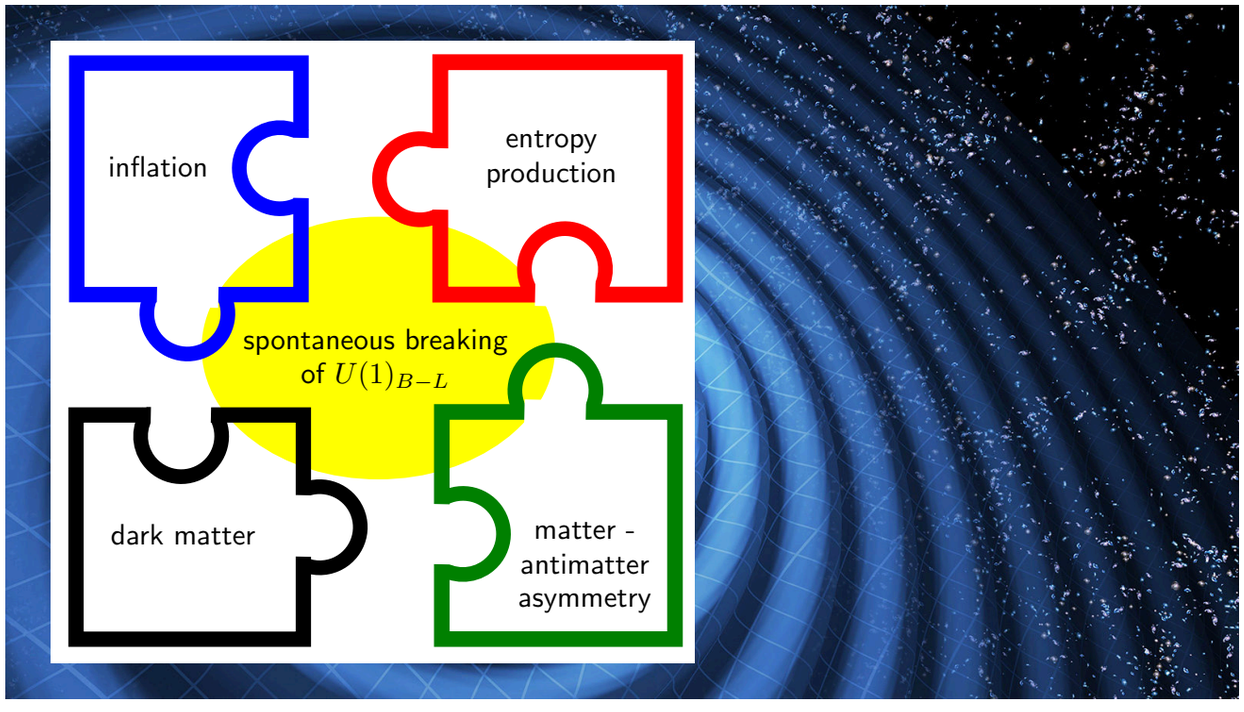
Probing the scale of grand unification with gravitational waves



Valerie Domcke
DESY Hamburg

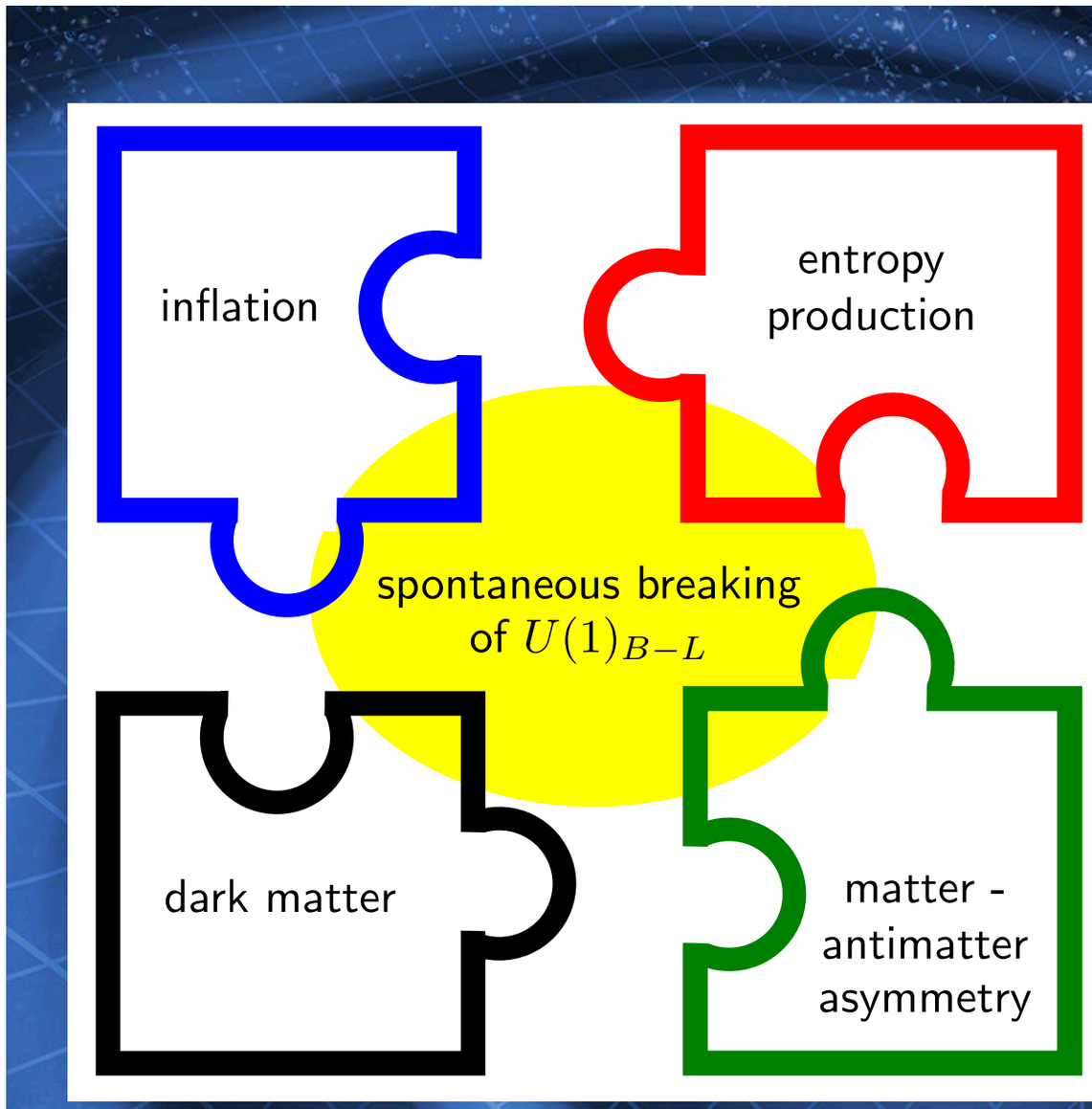
On-Line “Newton 1665” seminar
23.03.2020

based on arxiv:1912.03695
in collaboration with
Wilfried Buchmüller, Hitoshi Murayama and Kai Schmitz

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

DESY.

Outline



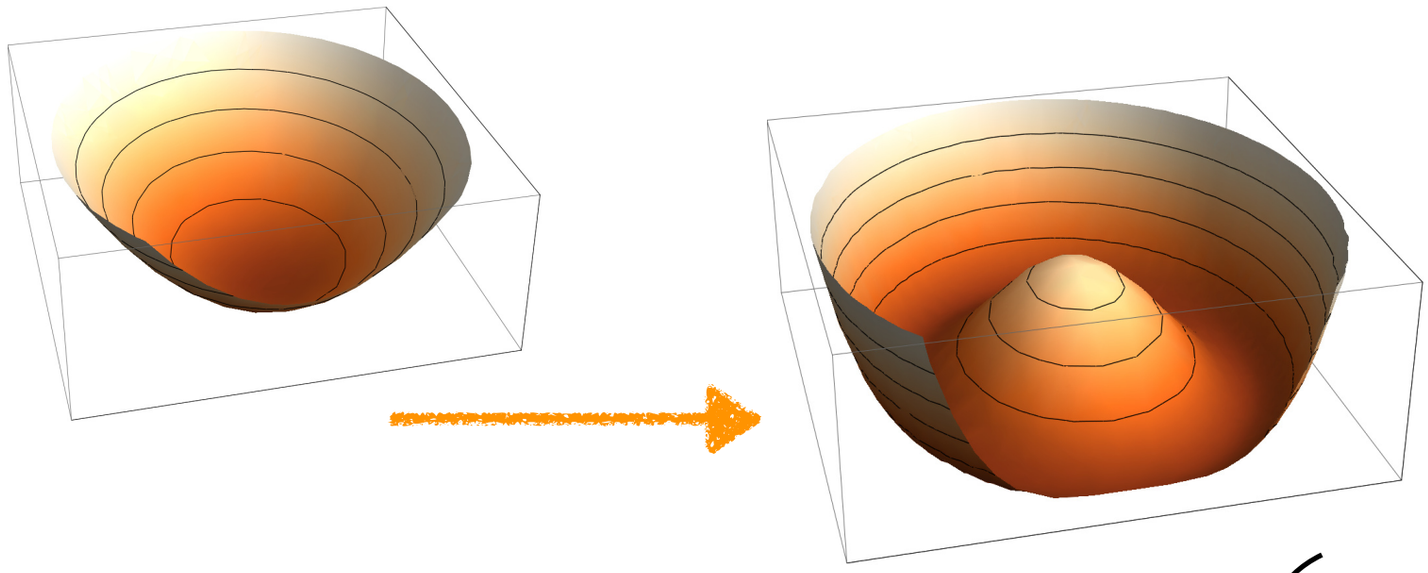
1) gravitational waves from metastable comic strings

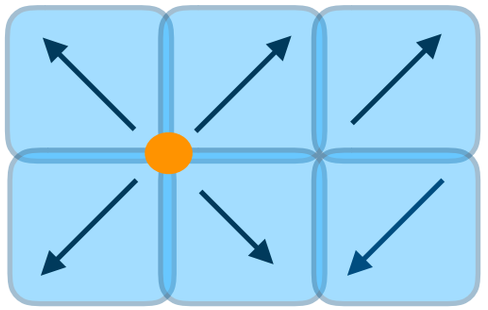
2) Spontaneous B-L breaking as the origin of the hot early Universe

cosmic strings in a nutshell

Cosmic strings : one-dimensional topological objects formed in a early Universe phase transition

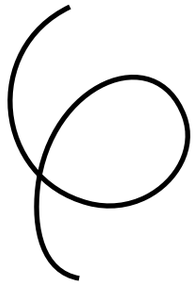
symmetry breaking pattern $G \to H$ produces cosmic strings if $\Pi_1(G/H) \neq 0$.



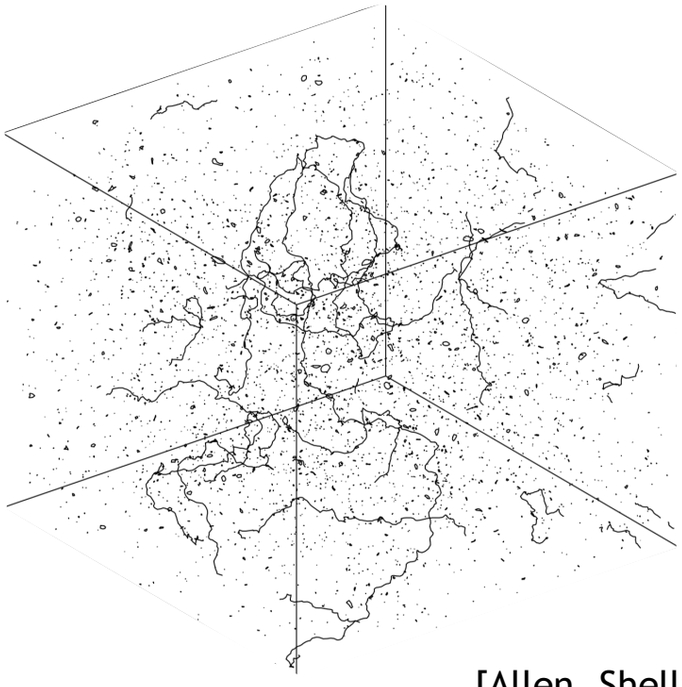


form a cosmic string network, evolves through

- string (self-)intersection → loop formation



- emission of particles and gravitational waves (GWs)



enter scaling regime (constant fraction of total energy density)

[Allen, Shellard 1990]

metastable cosmic strings

consider $SO(10) \to G_{SM} \times U(1)_{B-L} \to G_{SM}$

[Vilenkin '82, Leblond, Shlaer; Siemens '09; Monin, Voloshin '08+'09; Dror et al '19]

$\Pi_1(G_{SM} \times U(1)/G_{SM}) = \Pi_1(U(1)) \neq 0$ → cosmic strings

$\Pi_1(SO(10)/G_{SM}) = 0$ → no cosmic strings

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resolution: no stable cosmic strings

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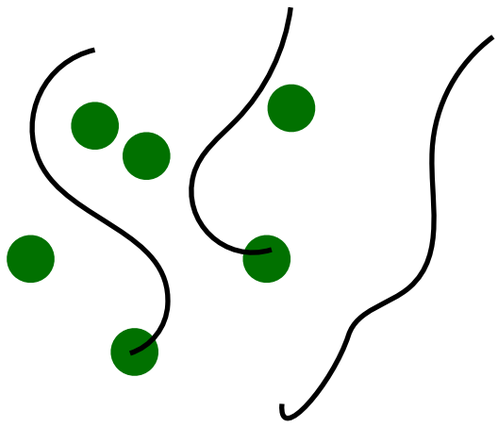

string - monopole gas
-> decays fast

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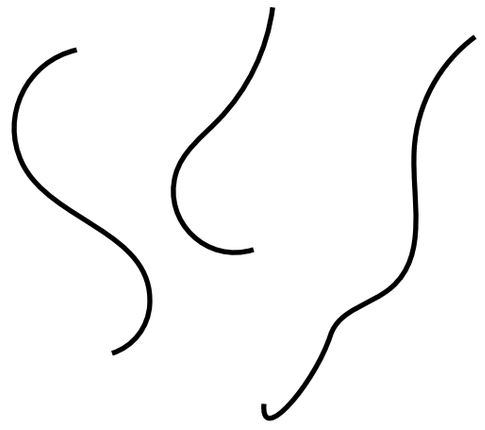

string - monopole gas
-> decays fast

-> metastable cosmic string network,
decays through Schwinger production of monopoles

$$\Gamma_d = \frac{\mu}{2\pi} \exp(-\pi m^2/\mu)$$

$\mu \sim v_{B-L}^2$ string tension,
$m \sim v_{\text{GUT}}$ monopole mass

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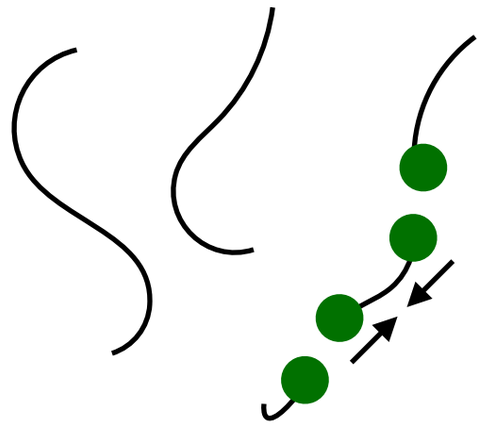

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gravitational wave signal

[see eg. Auclair, Blanco-Pillado, Figueroa et al '19]

gravitational wave emission from integration over loop distribution function:

$$\Omega_{GW}(f) = \frac{\partial \rho_{GW}(f)}{\rho_c \, \partial \ln f} = \frac{8\pi f (G\mu)^2}{3H_0^2} \sum_{n=1}^{\infty} C_n(f) P_n$$

GW power spectrum of a single loop

# of loops emitting GWs observed at frequency f today

$$C_n(f) = \frac{2n}{f^2} \int_{z_{min}}^{z_{max}} dz \frac{\mathcal{N}(\ell(z), t(z))}{H(z)(1+z)^6}$$

# of loops with length ℓ at time t

$$\mathcal{N}_r(\ell, t) = \frac{0.18}{t^{3/2}(\ell + 50\, G\mu t)^{5/2}}$$

decay of cosmic string network at

$$\bar{\ell}\, \Gamma_d = H$$

cosmological history

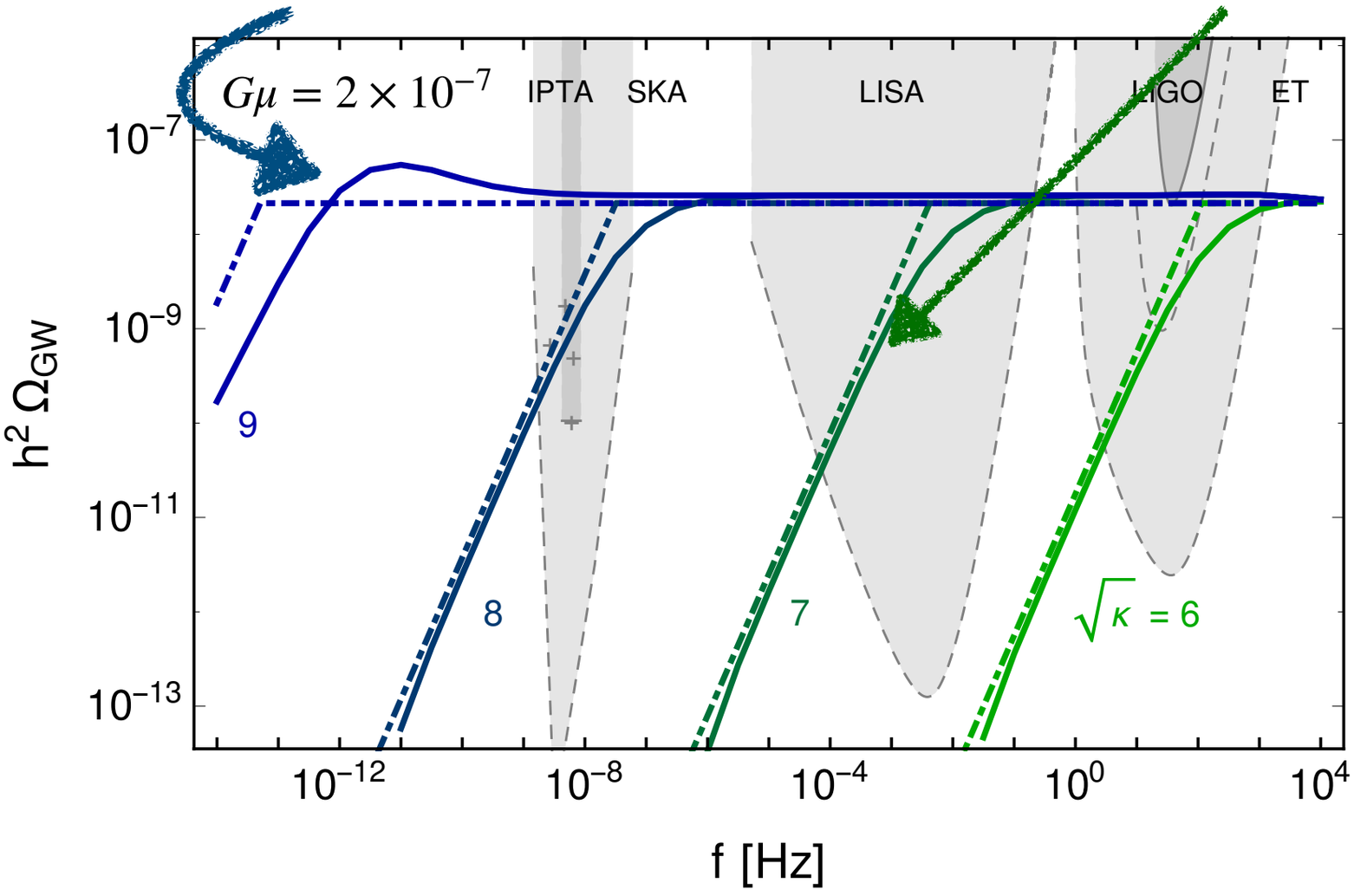
evaluated analytically for $\ell \ll 50\, G\mu\, t$ and $\ell \gg 50\, G\mu\, t$:

$$\Omega_{GW}(f) = 8.04\, \Omega_r \left(\frac{G\mu}{50}\right)^{1/2} \textbf{min}\left[(f/f_*)^{3/2}, 1\right], \quad f_* = 3.0 \times 10^{14}\ \textbf{Hz}\ e^{-\pi\kappa/4} \left(\frac{10^{-7}}{G\mu}\right)^{1/2}$$

gravitational wave signal

standard prediction for stable cosmic strings:
highly constrained by PTAs, $G\mu \lesssim 10^{-11}$

metastable cosmic strings:
discovery space for LIGO, LISA and ET

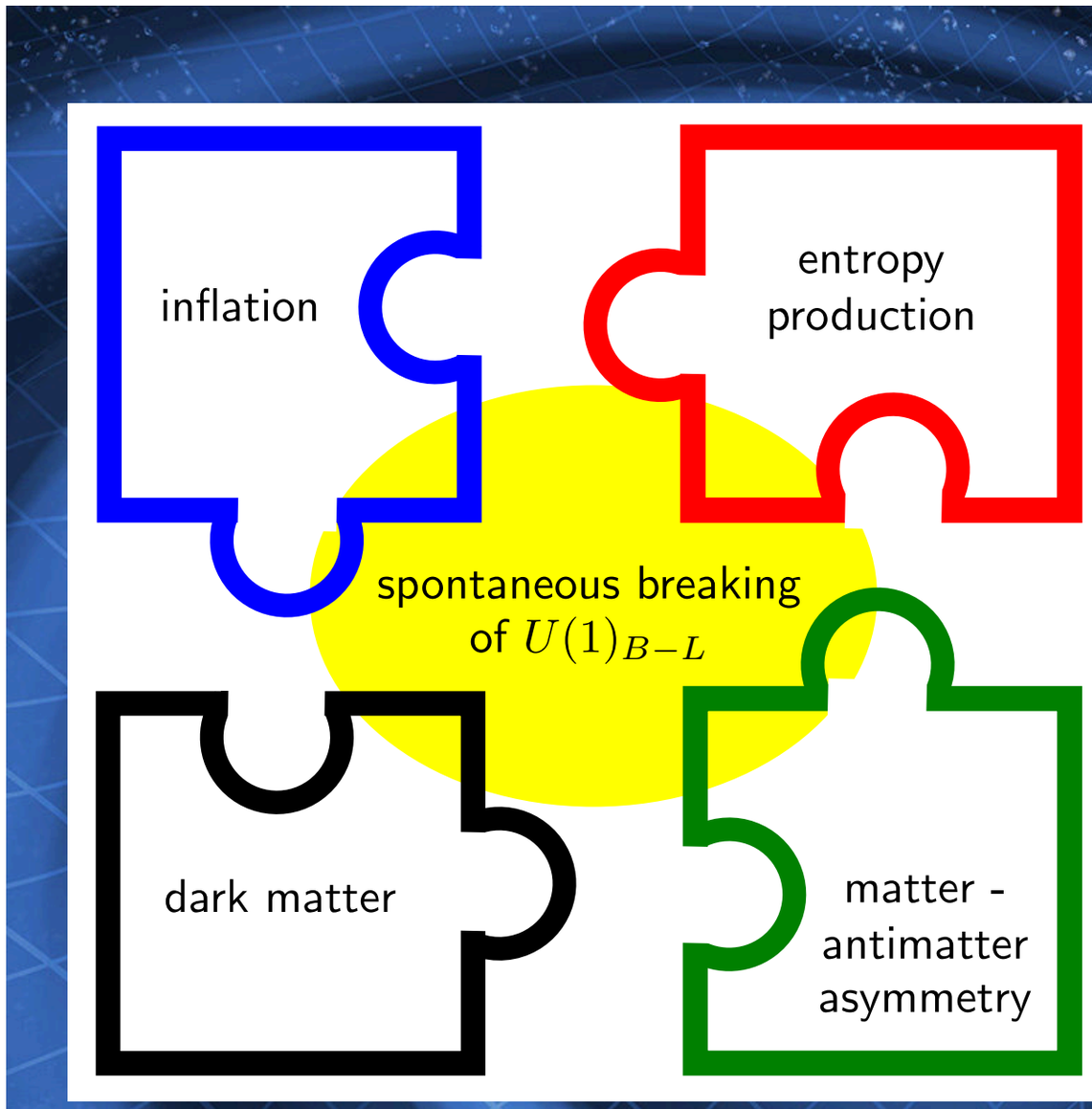


solid: numerical
dashed: analytical

$\sqrt{\kappa} = m/\sqrt{\mu} \sim v_{GUT}/v_{B-L}$

$SO(10) \to G_{SM} \times U(1)_{B-L} \to G_{SM}$ with $v_{B-L} \lesssim v_{GUT}$ can be tested with GWs !

Outline



1) gravitational waves from metastable comic strings

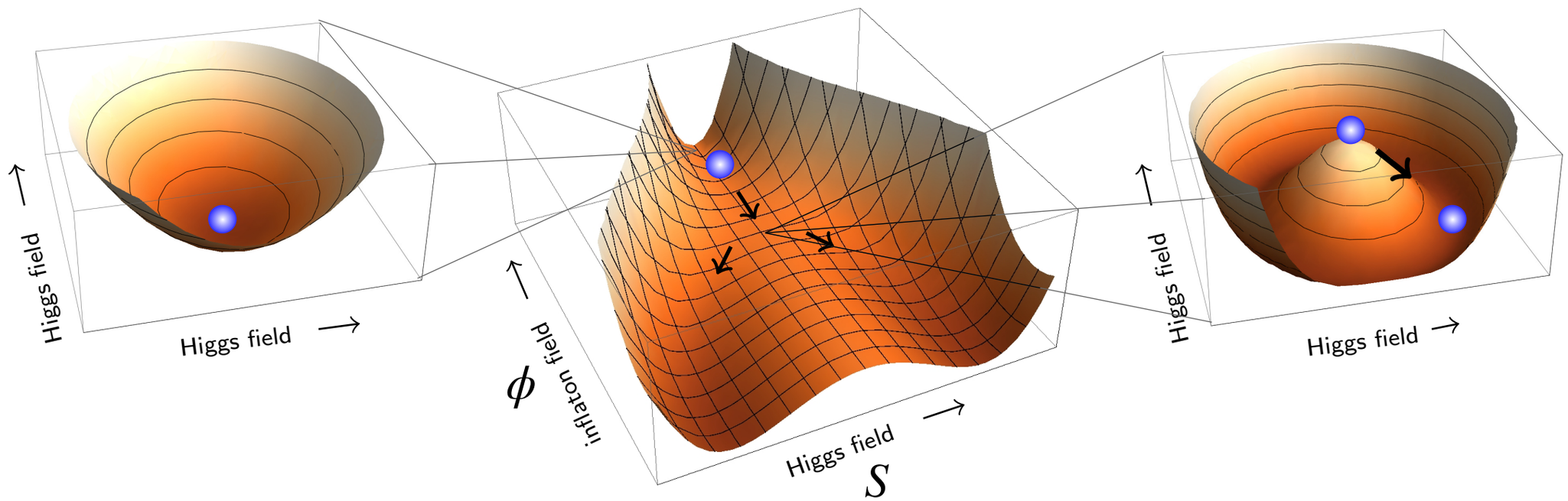
2) Spontaneous B-L breaking as the origin of the hot early Universe

B-L phase transition

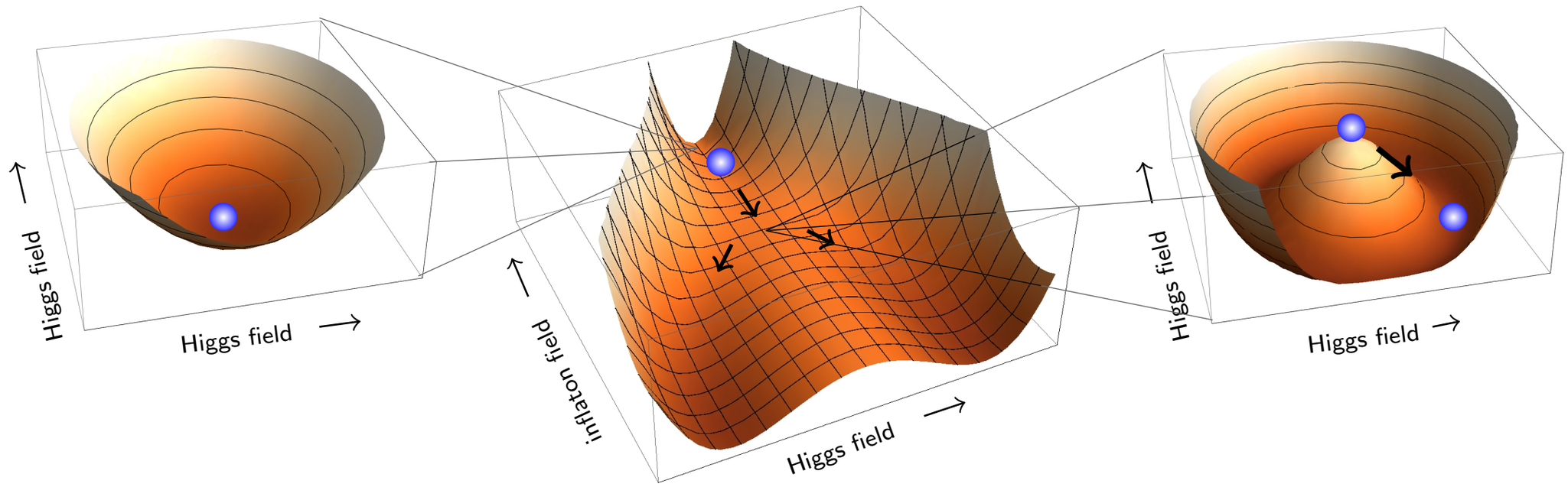
gauging $U(1)_{B-L}$

- global (accidental) symmetry of the SM, subgroup of GUT groups, eg SO(10)
- anomaly cancellation requires introduction of 3 right-handed neutrinos n_i^c
- B-L dynamically broken by B-L Higgs field S $\rightarrow$ neutrino masses via seesaw mechanism

$$W = W_{MSSM} + h_{ij}^{\nu} \mathbf{5}_i^* n_j^c H_u + \frac{1}{\sqrt{2}} h_i^n n_i^c n_i^c S_1 + \lambda \Phi \left(\frac{v_{B-L}^2}{2} - S_1 S_2 \right) + W_0$$



cosmological B-L phase transition



$$W = W_{MSSM} + h^{\nu}_{ij}\mathbf{5}^{*}_{i} n^{c}_{j} H_u + \frac{1}{\sqrt{2}} h^{n}_{i} n^{c}_{i} n^{c}_{i} S_1 + \lambda\Phi\left(\frac{v^2_{B-L}}{2} - S_1 S_2\right) + W_0$$

Before

- hybrid inflation

Phase transition

- tachyonic preheating
- cosmic strings

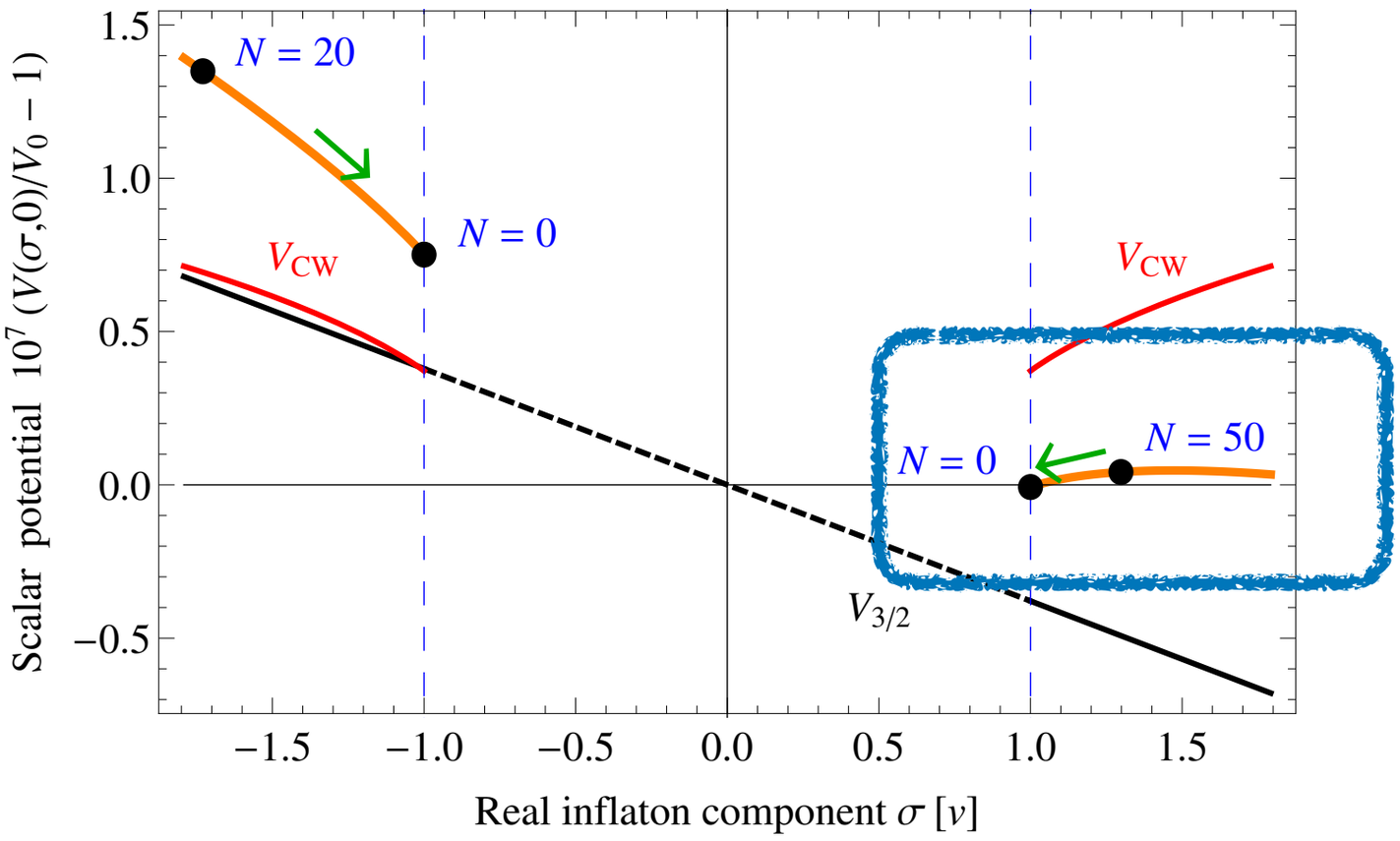
After

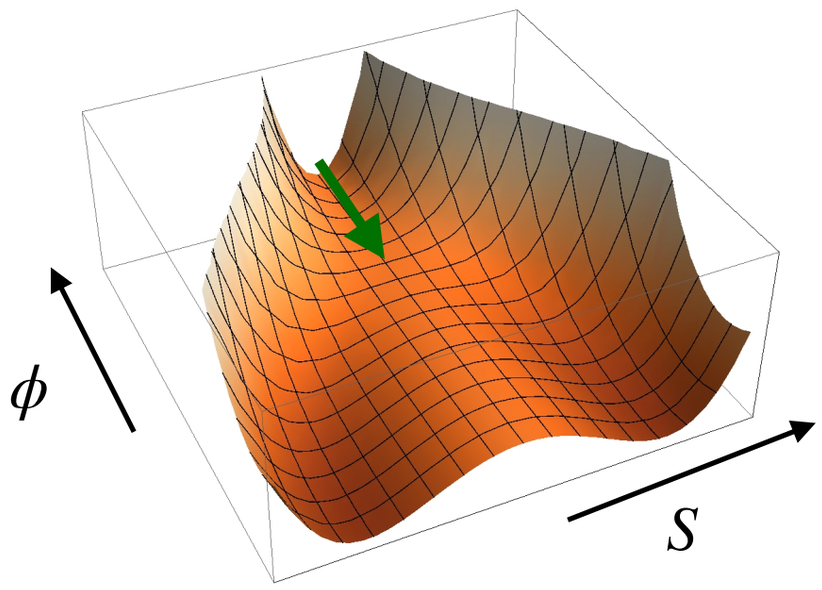
- reheating
- leptogenesis
- dark matter

hybrid inflation

$$W \supset \lambda \Phi \left(\frac{v_{B-L}^2}{2} - S_1 S_2 \right) + W_0 , \quad W_0 \sim m_{3/2} M_P$$

[Buchmüller, VD, Kamada, Schmitz '14; Schmitz, Yanagida '18]





reproducing CMB observables (A_s, n_s)

eliminates two parameters

out of three (λ, v_{B-L}, $m_{3/2}$)

hybrid inflation

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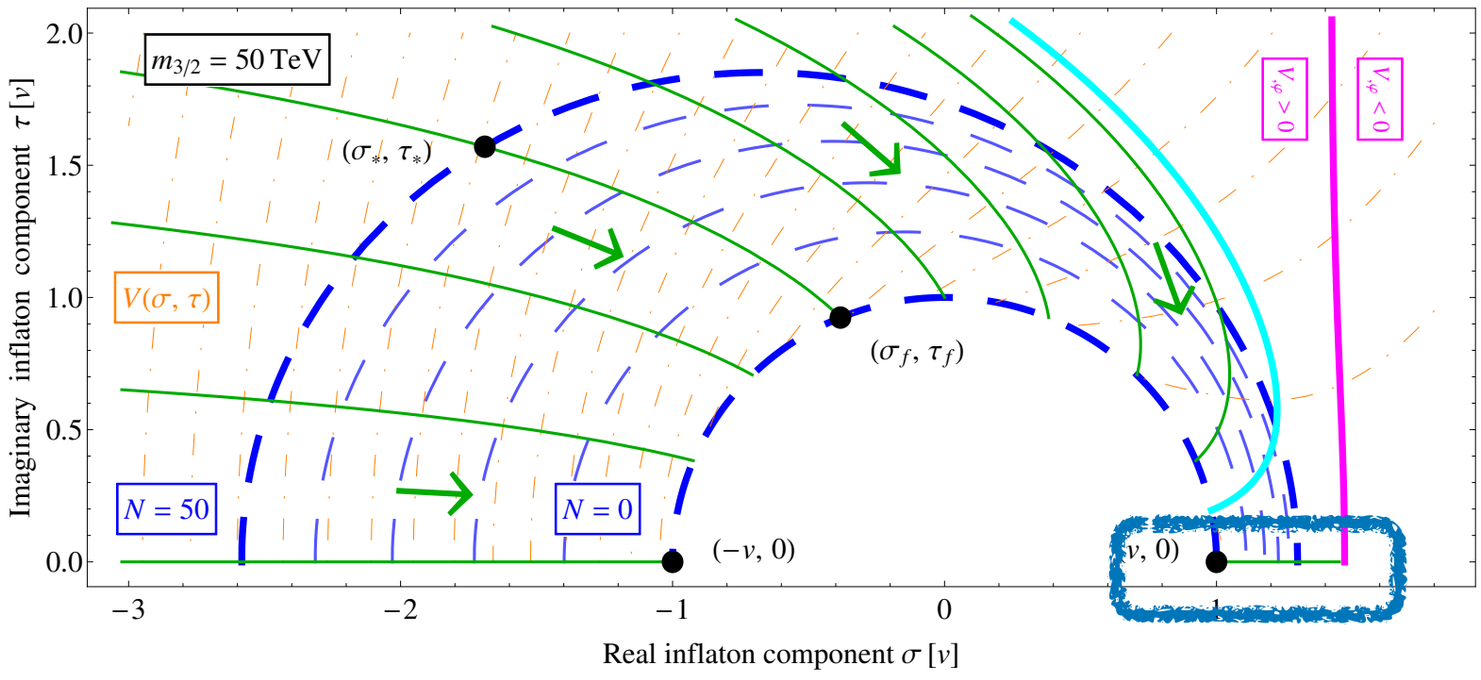

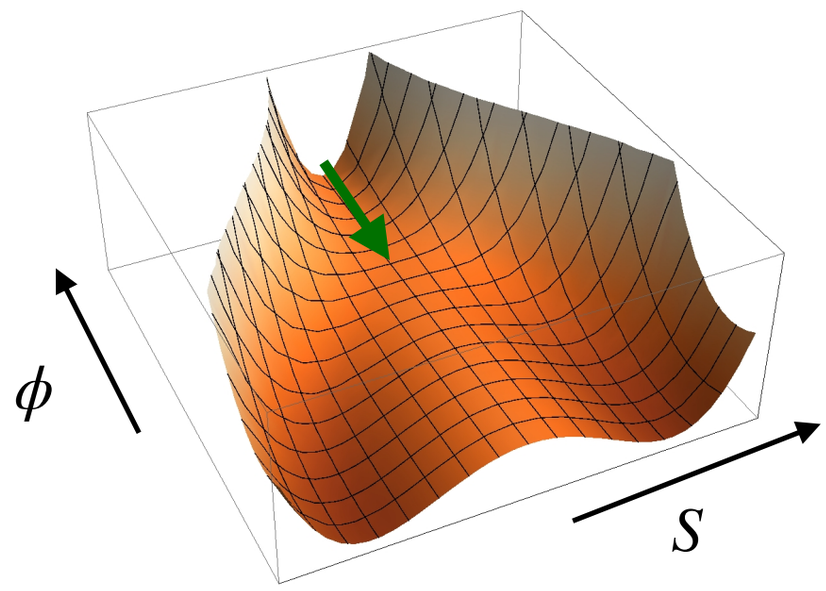

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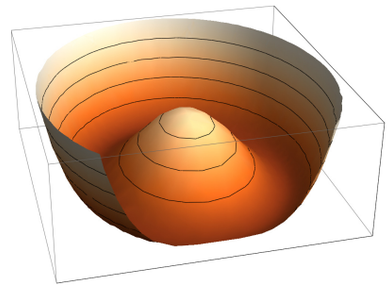
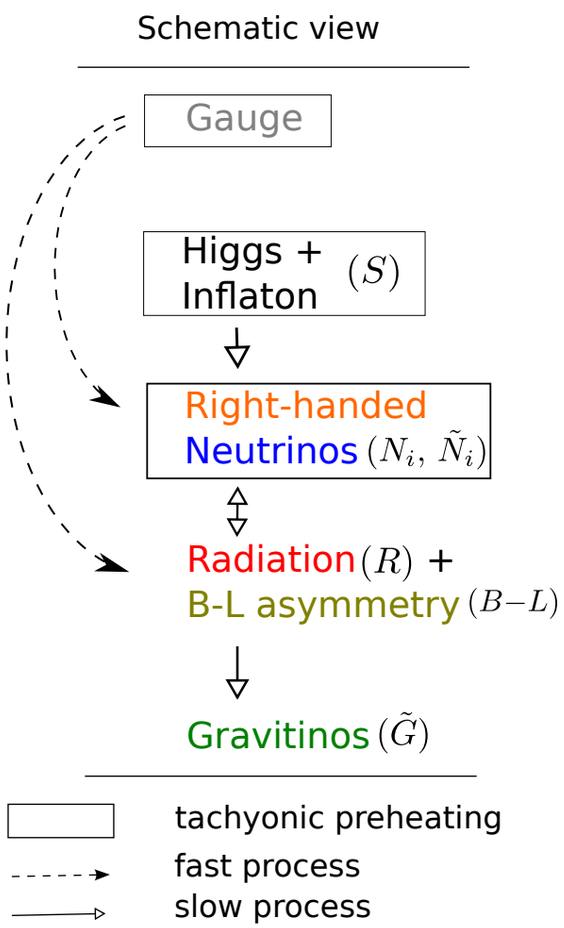
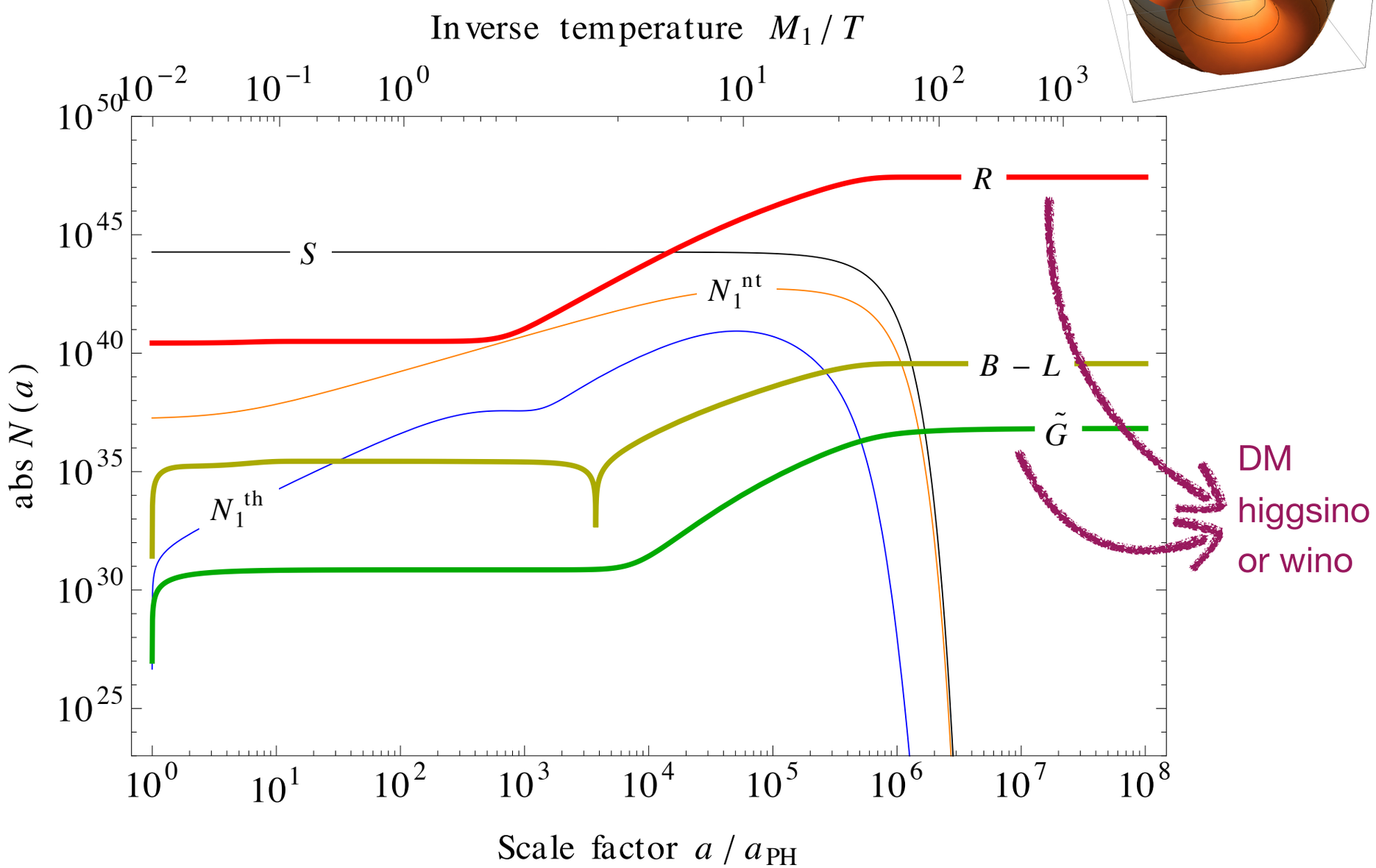
(p)reheating and leptogenesis

solving coupled Boltzmann equations:

[Buchmüller, VD, Schmitz '12]







parameters: $\widetilde{m}_1 = \dfrac{(m_D^\dagger m_D)_{11}}{M_1}, \varepsilon_1 \lesssim 2\times 10^{-6}\dfrac{M_1}{10^{10}\,GeV}, M_1, m_S$ $\qquad T_{rh}, m_S, m_{3/2}, m_{LSP}$

(p)reheating and leptogenesis

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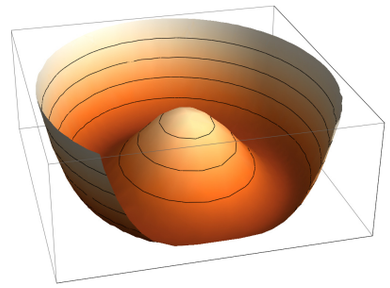
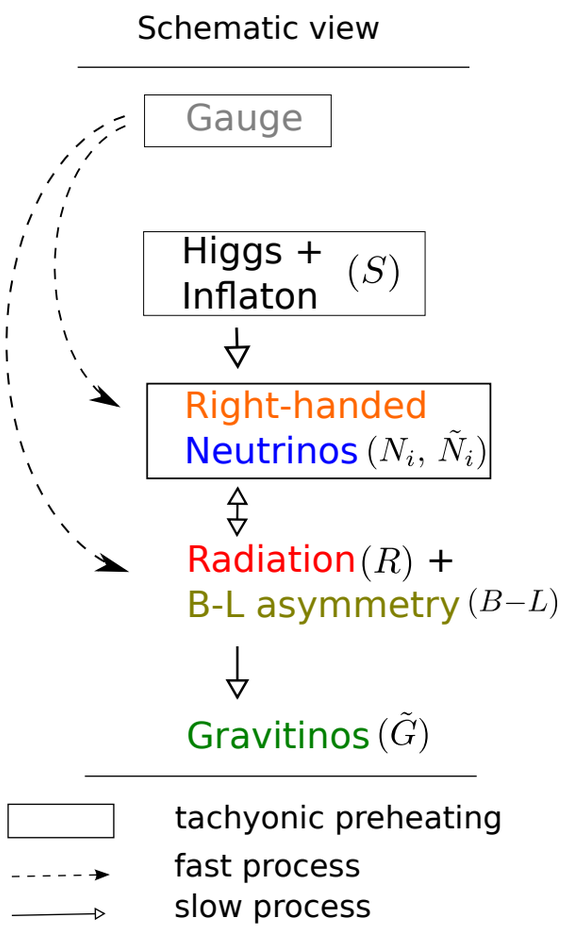
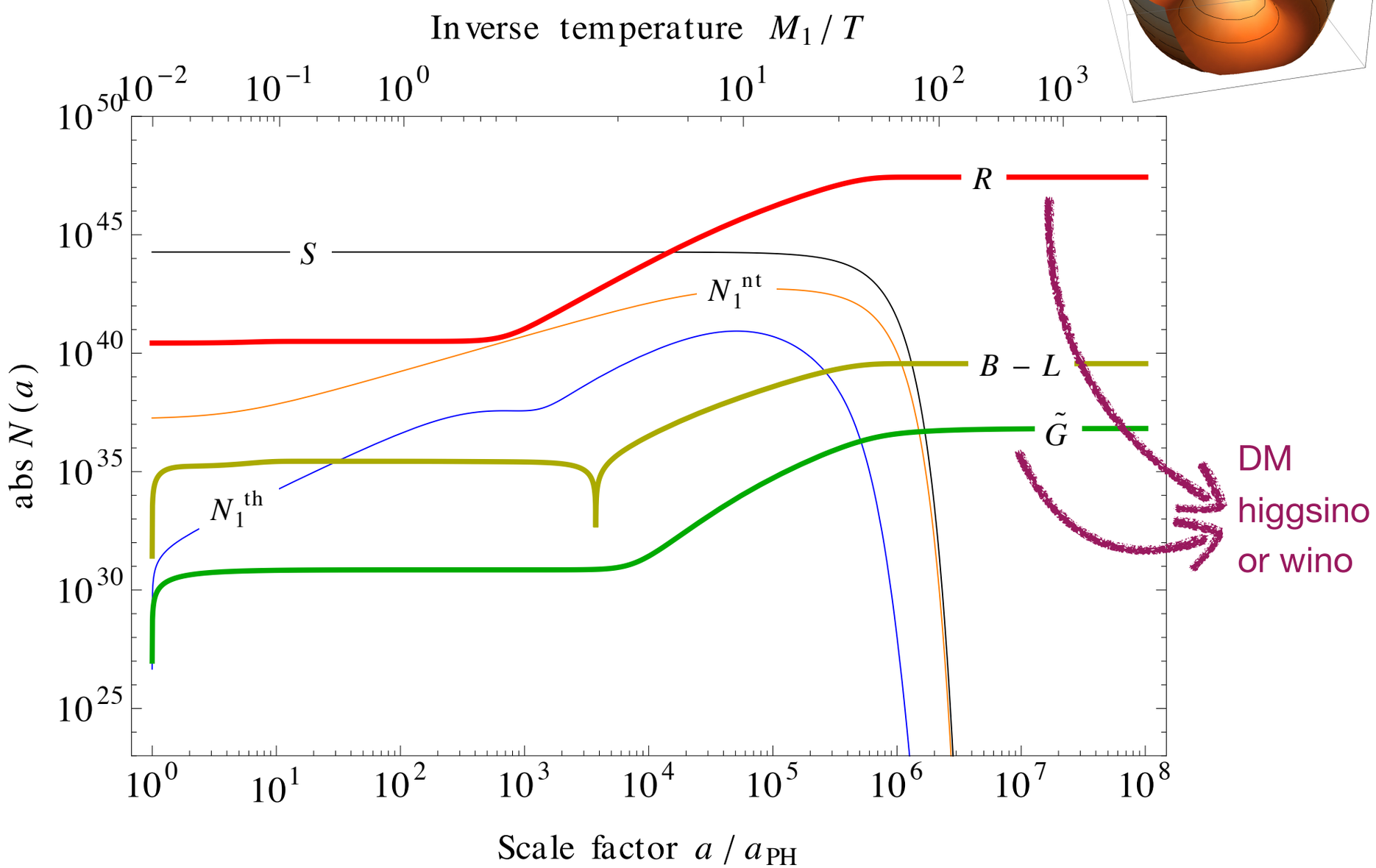
[Buchmüller, VD, Schmitz '12]





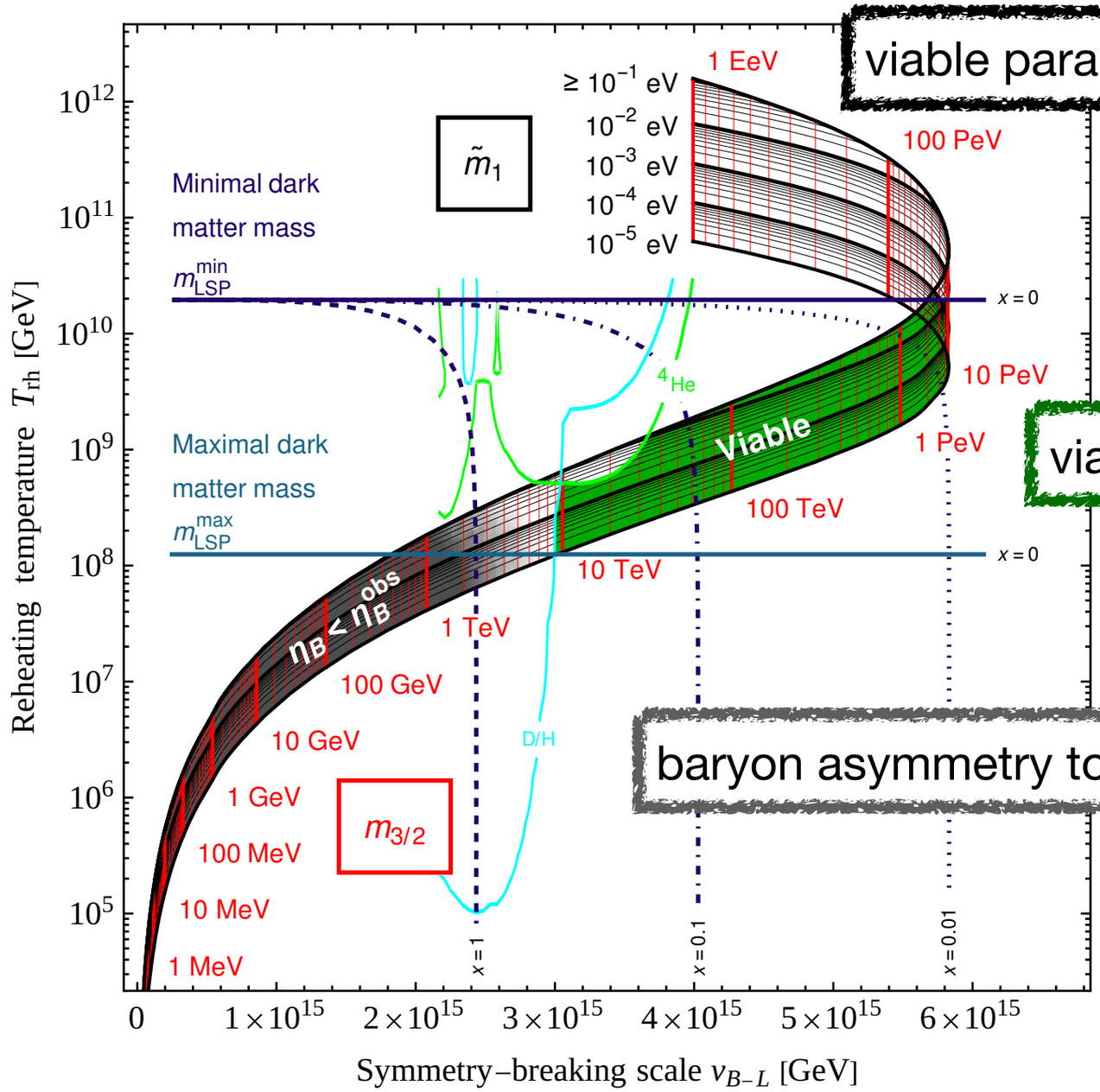


yields reheating temperature, baryon asymmetry (thermal + nonthermal), dark matter

inflation, reheating, leptogenesis and dark matter

5D parameter space: $v_{B-L}, T_{rh}, m_{3/2}, \widetilde{m}_1, m_{LSP}$

observables: $A_s, n_s, \Omega_{DM}, \eta_B^{obs}$

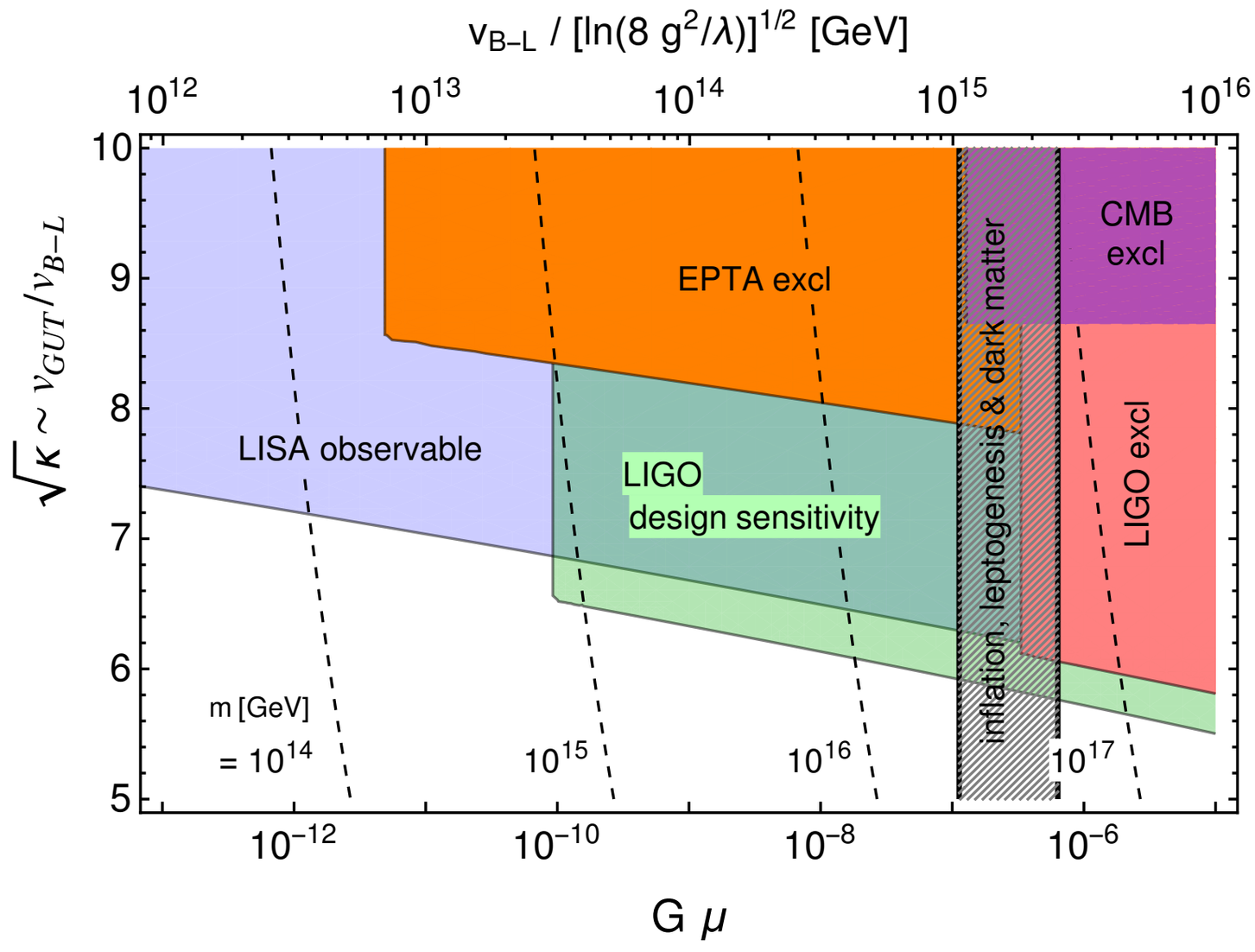


Frogatt-Nielson model to parametrize all Yukawa couplings

[Buchmüller, VD, Schmitz '12, Asaka '03]

Can be tested with LIGO !

embedding in SO(10) : gravitational wave signal from metastable cosmic strings



Cosmological B-L breaking as common origin of inflation, leptogenesis & DM will be tested by LIGO

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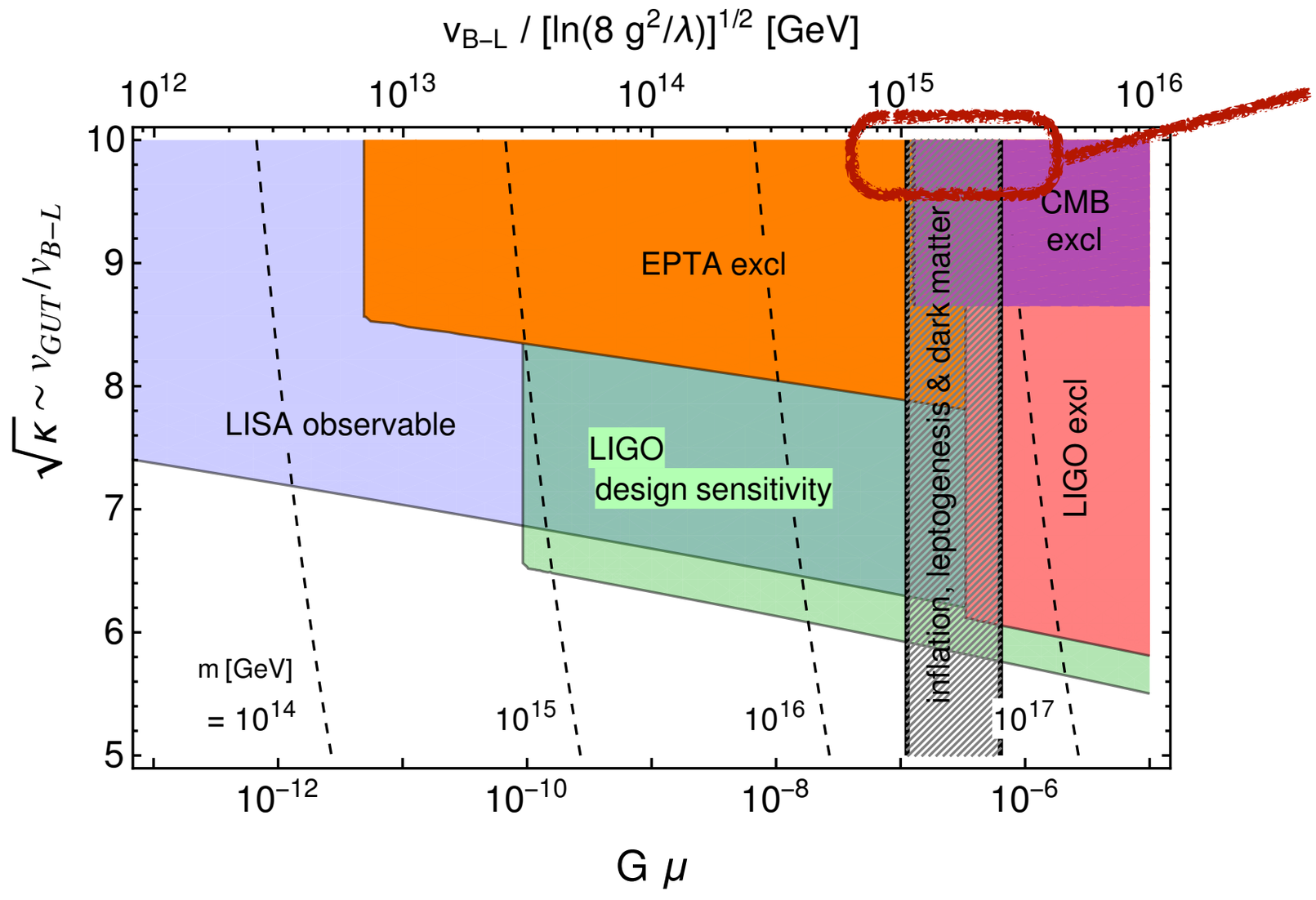

stable cosmic strings excluded

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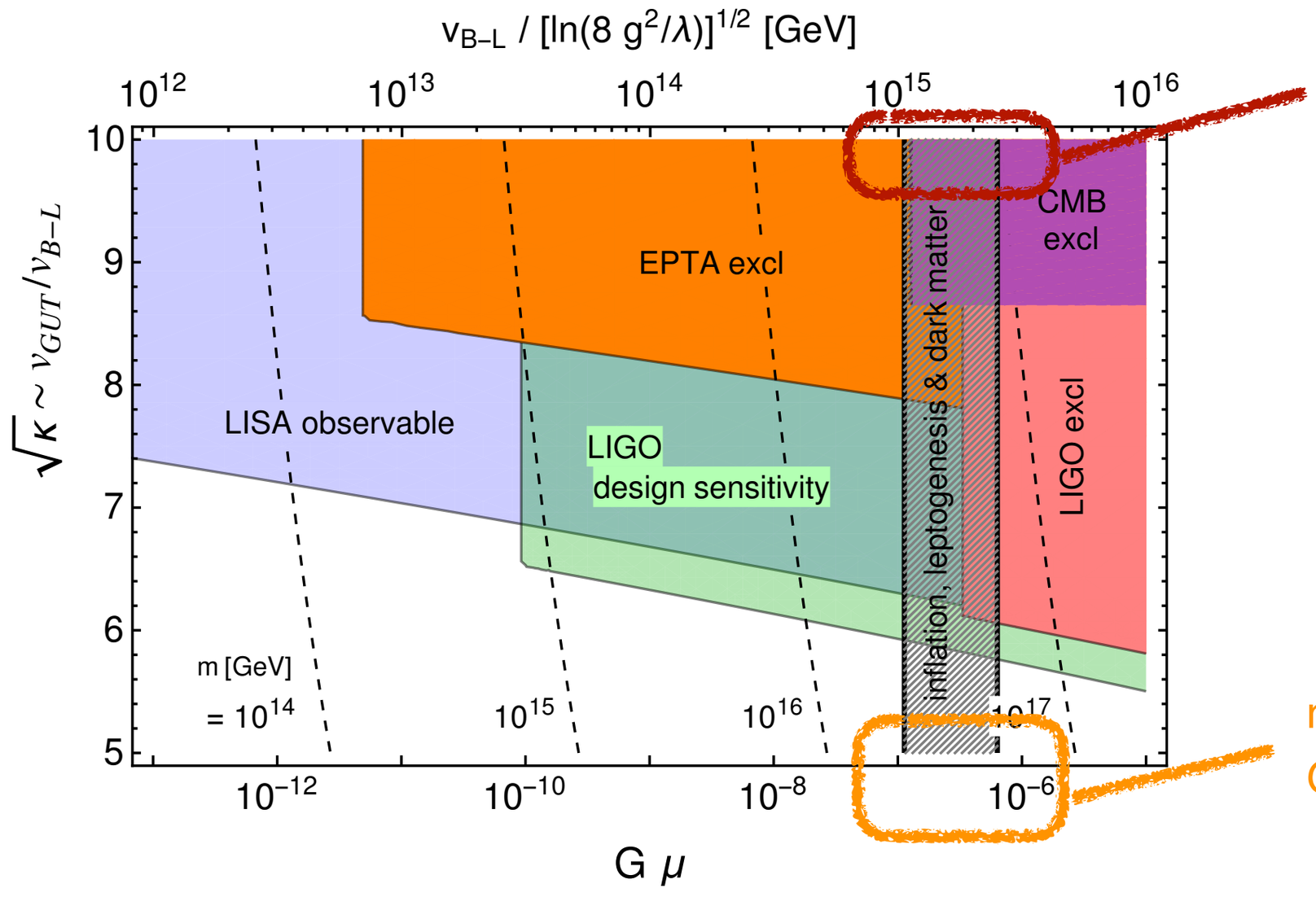

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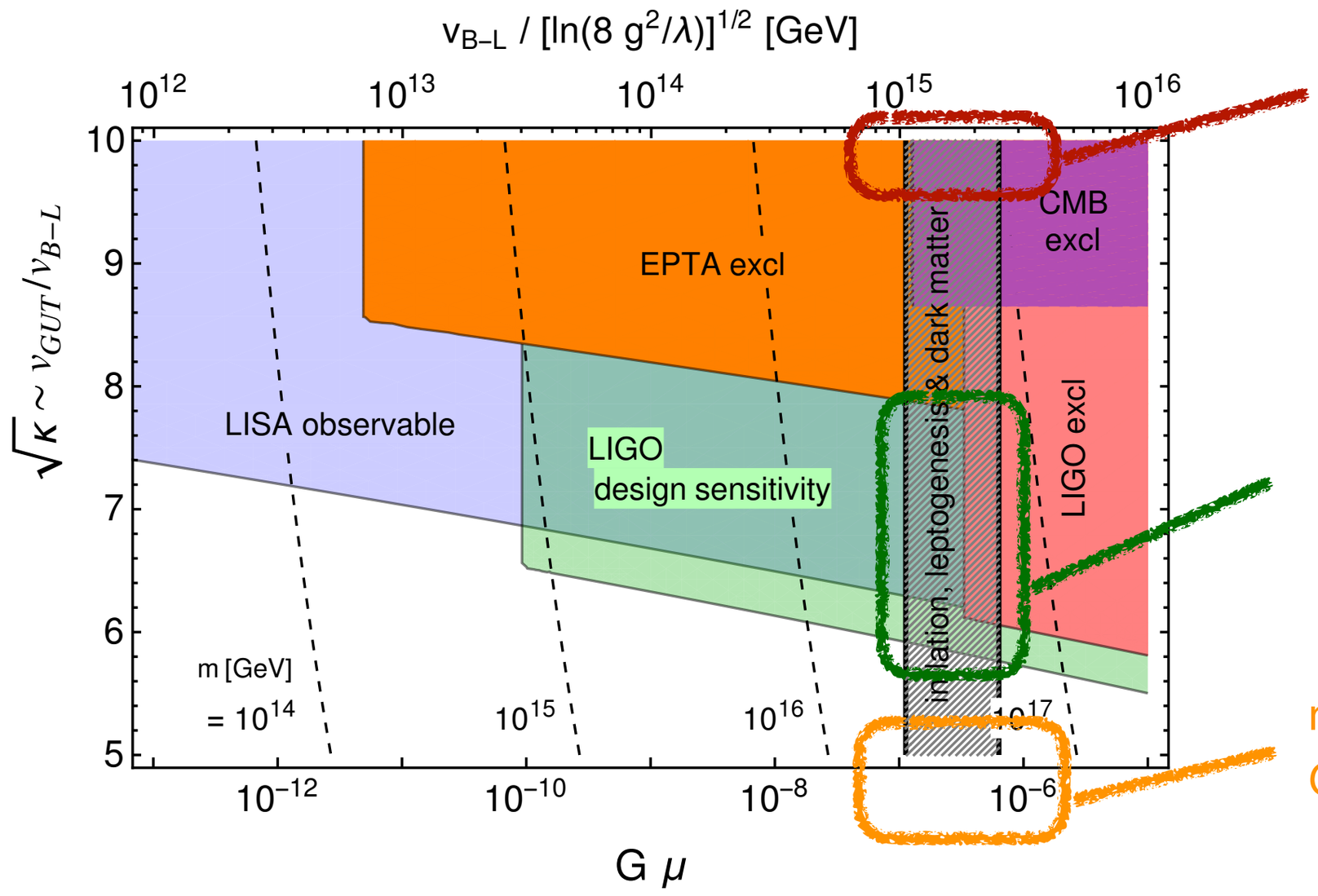

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Cosmological B-L breaking as common origin of inflation, leptogenesis & DM will be tested by LIGO

Conclusion

Spontaneous B-L breaking at $v_{B-L} \sim 10^{15}$ GeV explains

- cosmic inflation in the unbroken phase
- reheating and leptogenesis through decay of B-L Higgs and RH neutrinos
- dark matter as neutralino LSP

Symmetry breaking $SO(10) \to G_{SM} \times U(1)_{B-L} \to G_{SM}$ results in metastable cosmic strings

- avoid low-frequency bounds (pulsar timing arrays)
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Thank you!