CONFORMAL SYMMETRY BREAKING: DARK MATTER PRODUCTION AND RENORMALIZATION SCALE DEPENDENCE

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University of Warsaw

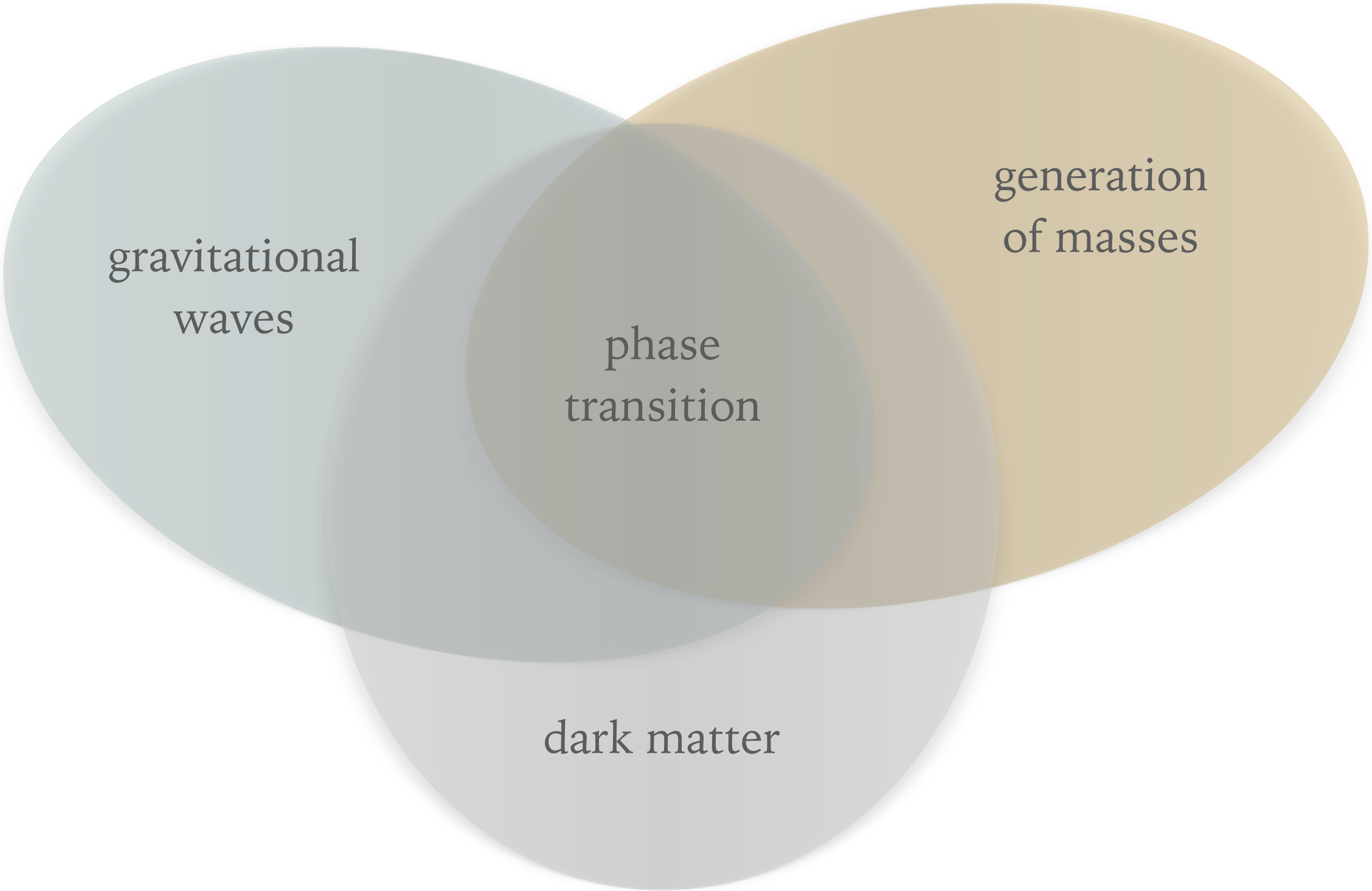
in collaboration with
Maciej Kierkla and Alexandros Karam,

based on
arXiv:22xx.xxxx

Planck 2022, 30.05.2022

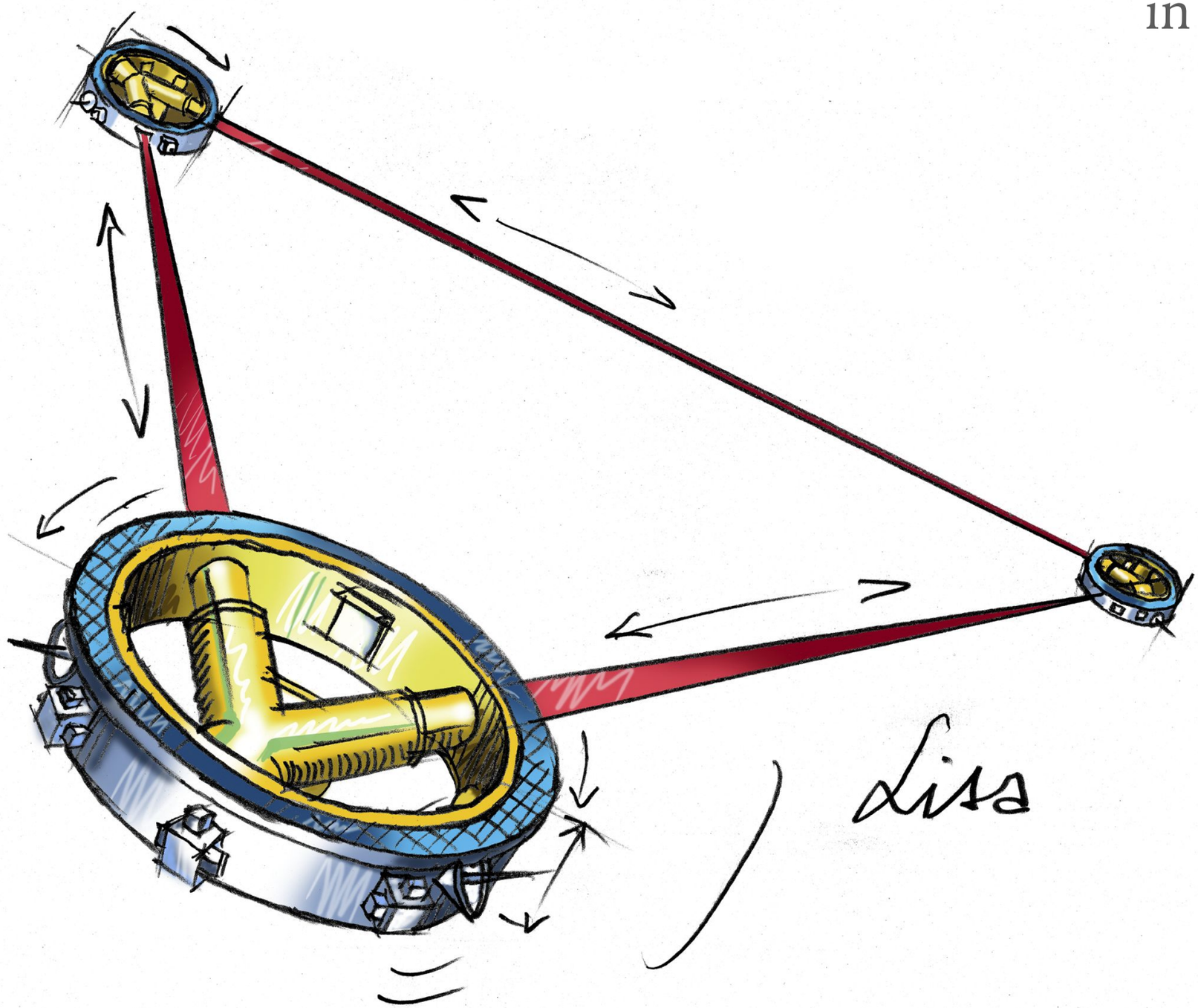
MOTIVATION

PT - A LINK BETWEEN DIFFERENT OBSERVABLES



LISA IS COMING!

in the 2030's

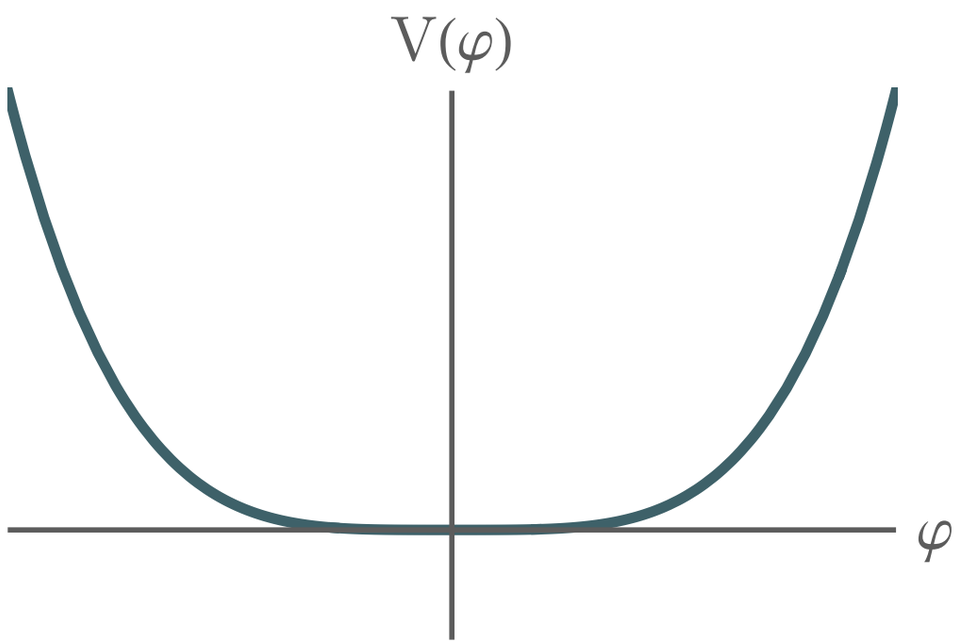


[Image credit: ESA-C. Vijoux]

CLASSICAL CONFORMAL SYMMETRY

CLASSICAL CONFORMAL SYMMETRY

No dimensionful parameters at tree level



[S. R. Coleman, E. J. Weinberg, Phys.Rev. D7 (1973) 1888]

CLASSICAL CONFORMAL SYMMETRY

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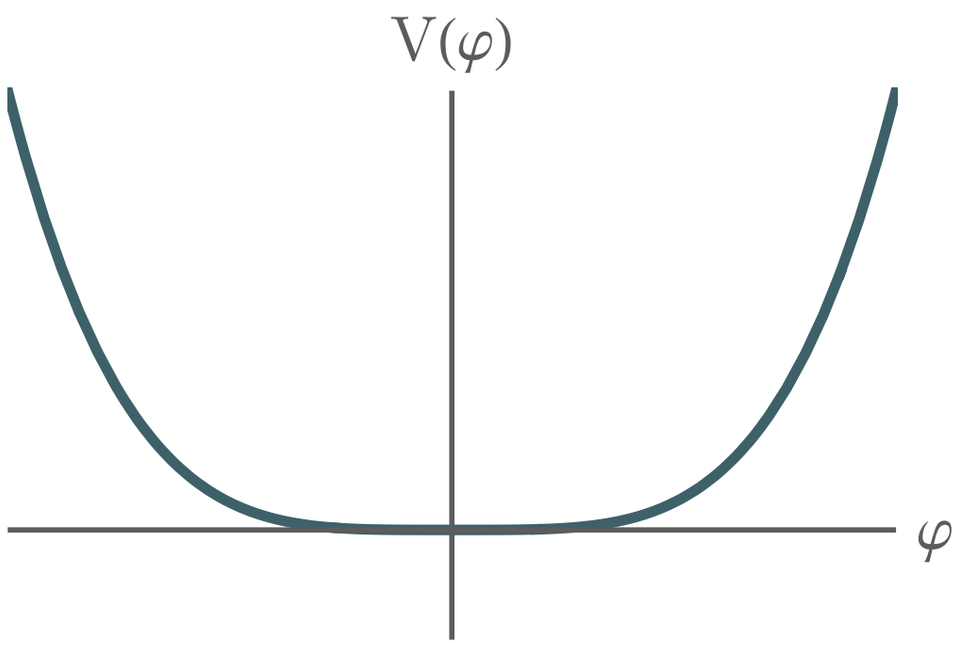
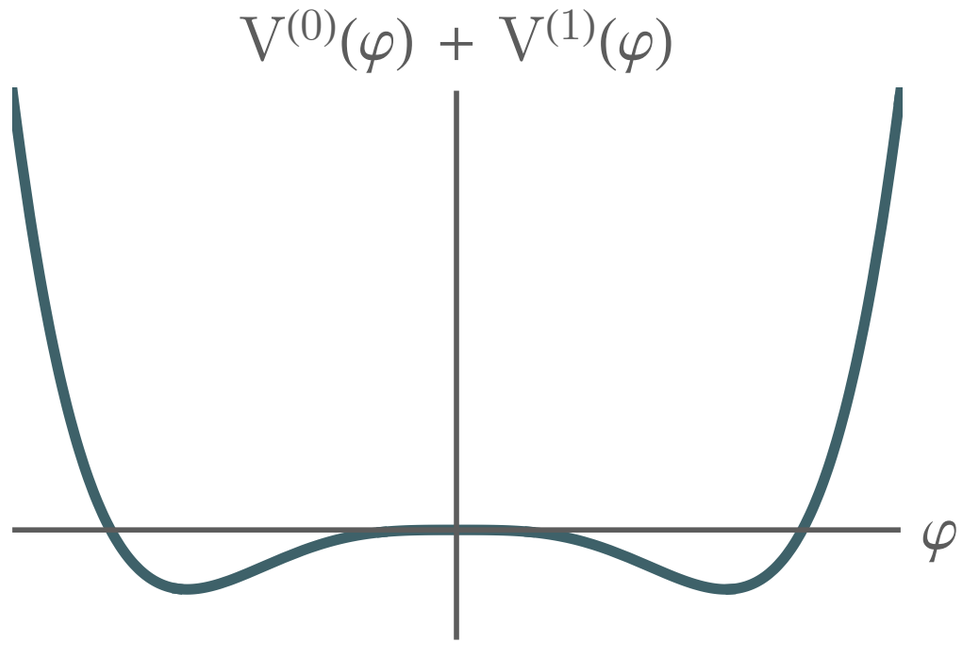




Symmetry broken by loop corrections (dimensional transmutation)

[S. R. Coleman, E. J. Weinberg, Phys.Rev. D7 (1973) 1888]

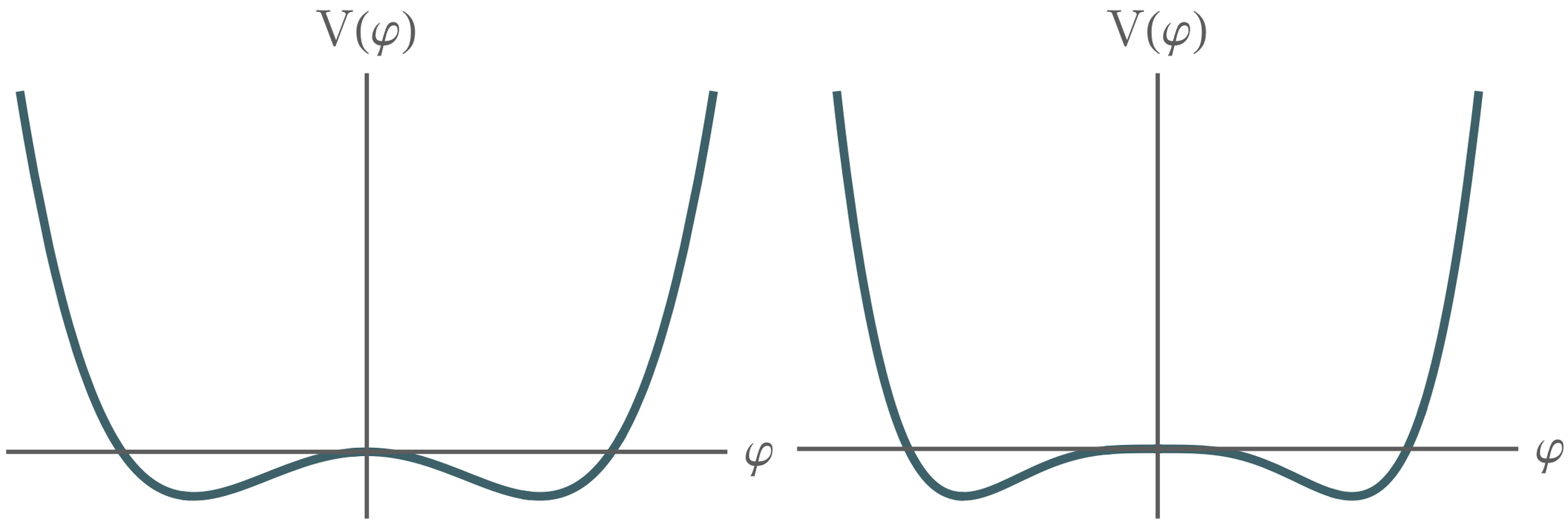
WHY CLASSICAL CONFORMAL SYMMETRY?

dynamical generation of all mass scales

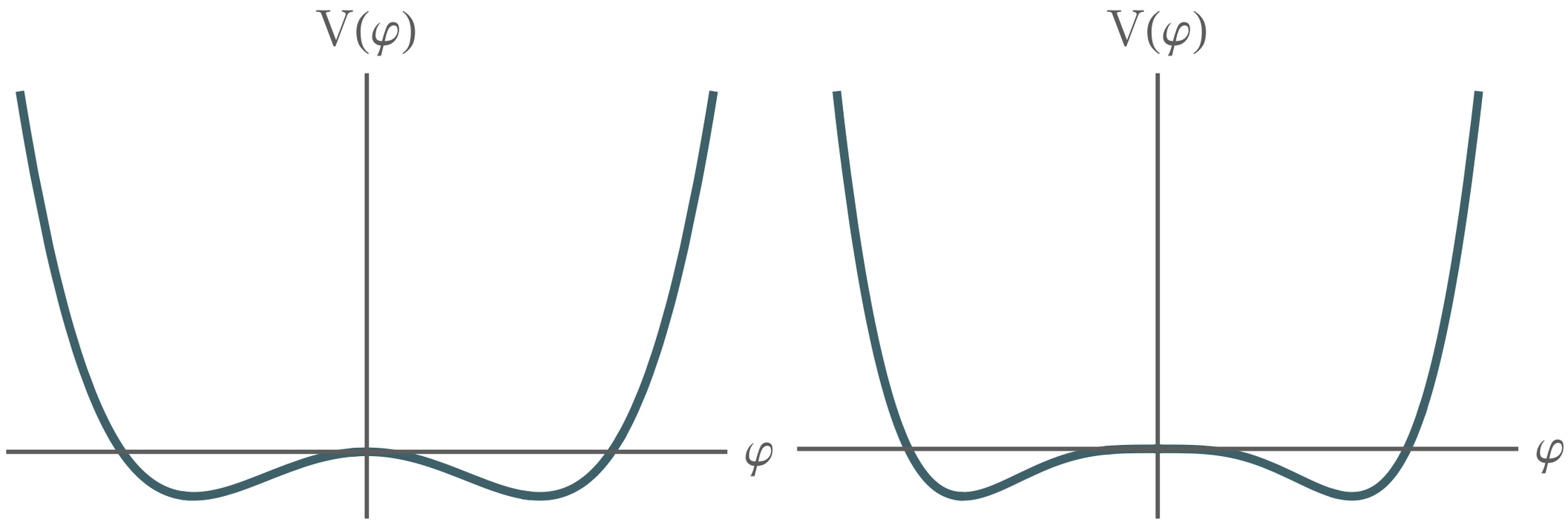
predictivity - few free parameters

Generically strong GW signal testable with LISA

CONFORMAL VS "NORMAL" POTENTIAL



CONFORMAL VS "NORMAL" POTENTIAL



The thermal barrier can last until low temperatures

↓

Potential for supercooling and strong transition

SU(2)CSM

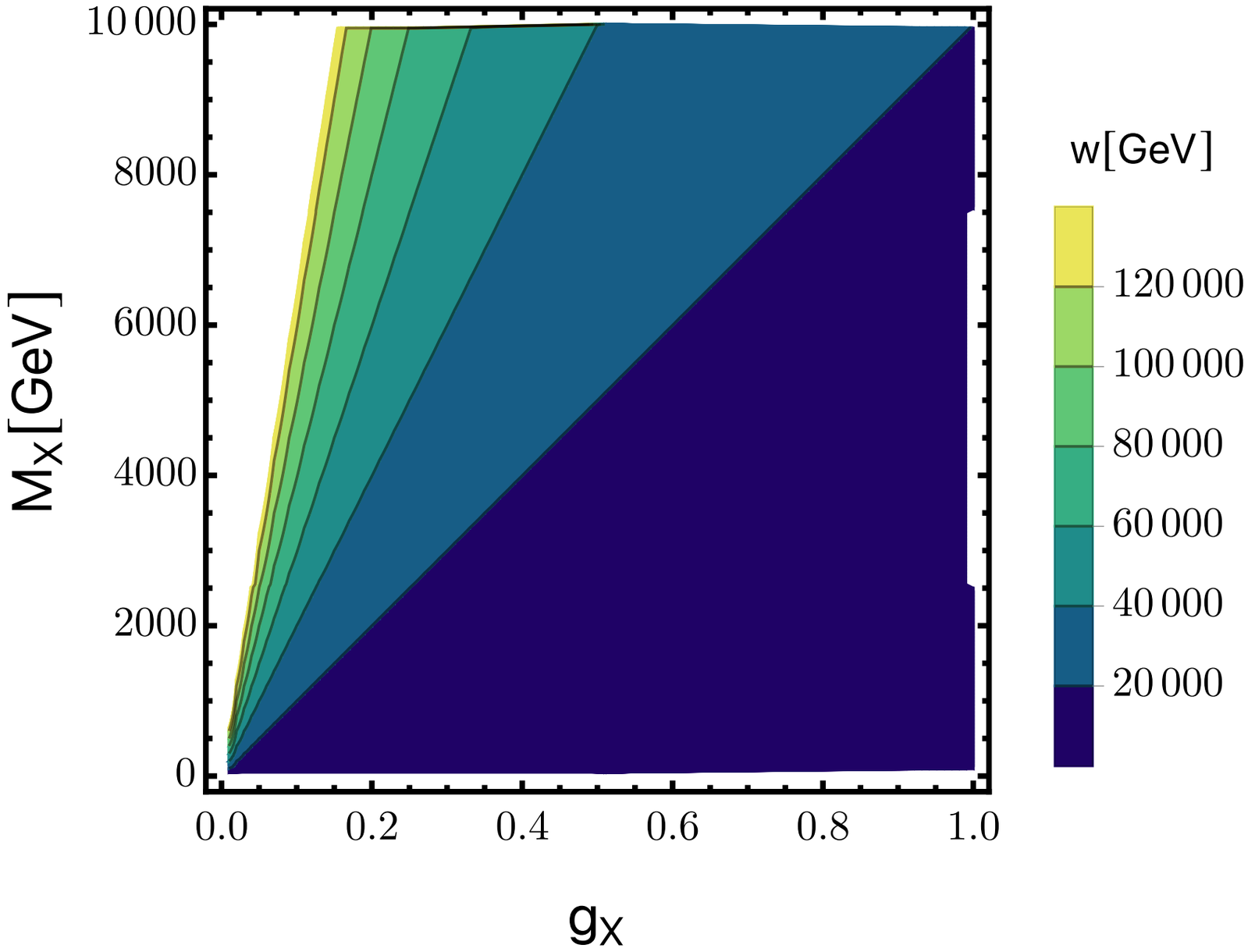
cSM:
$SU(2)_L \times U(1)_Y$
Φ

Hidden sector:
$SU(2)_X$
Ψ

$$V^{(0)}(\Phi,\Psi) = \lambda_1 \left(\Phi^\dagger\Phi\right)^2 + \lambda_2 \left(\Phi^\dagger\Phi\right)\left(\Psi^\dagger\Psi\right) + \lambda_3 \left(\Psi^\dagger\Psi\right)^2,$$

[See also: T.Hambye, A.Strumia, PRD88 (2013) 055022, C.Carone, R.Ramos, PRD88 (2013) 055020, V.V.Khoze, C.McCabe, G.Ro, JHEP 08 (2014) 026, T. Hambye, A.Strumia, D.Teresi, JHEP 1808 (2018) 188, I.Baldes, C. Garcia-Cely, JHEP 05 (2019) 190, T.Prokopec, J.Rezacek, BS, JCAP02(2019)009, D. Marfaria, P. Tseng, JHEP 02 (2021) 022]

RADIATIVE SYMMETRY BREAKING IN SU(2)CSM



[See also: L. Chataignier, T. Prokopec, M.G. Schmidt, BS, JHEP 08 (2018) 083]

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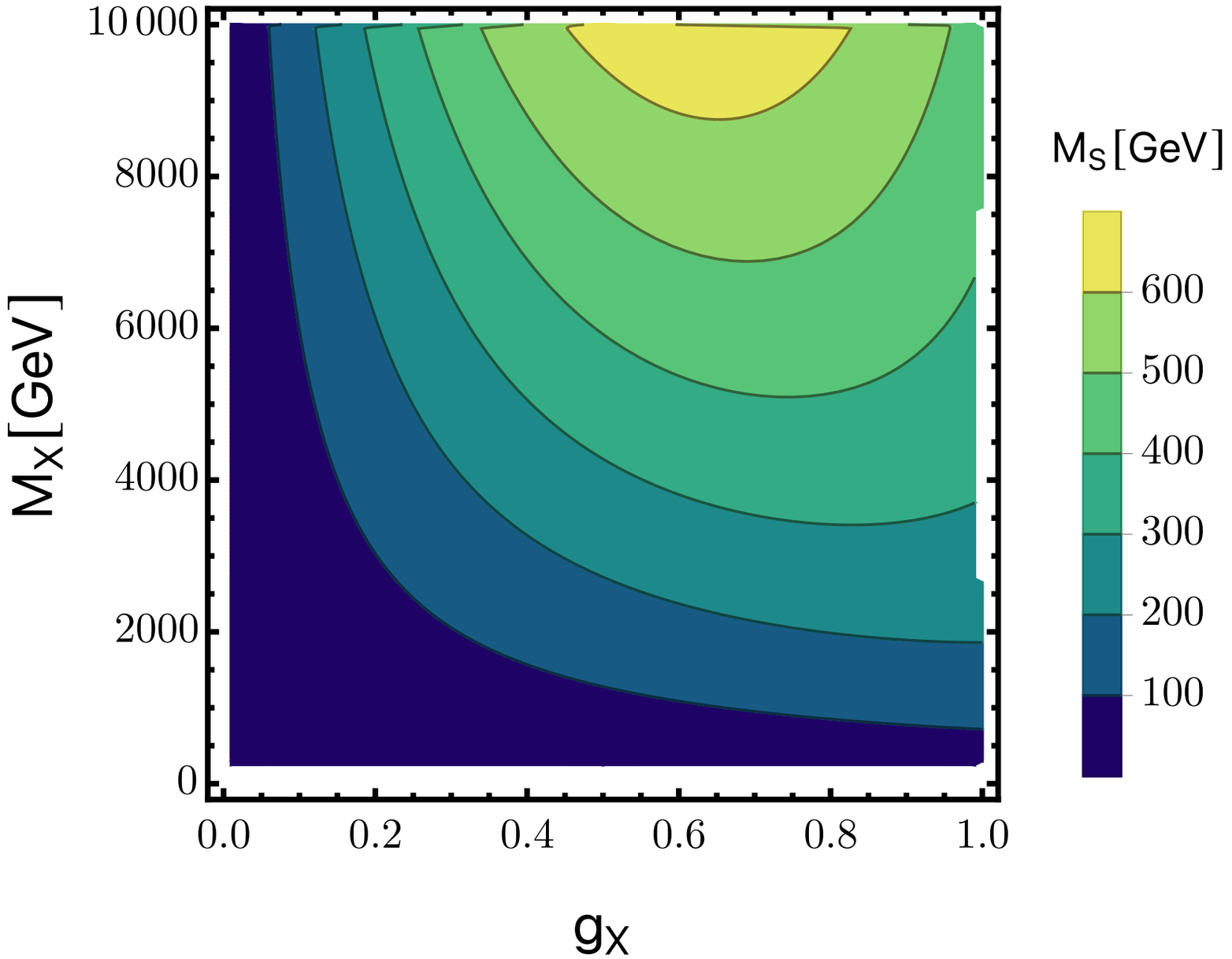

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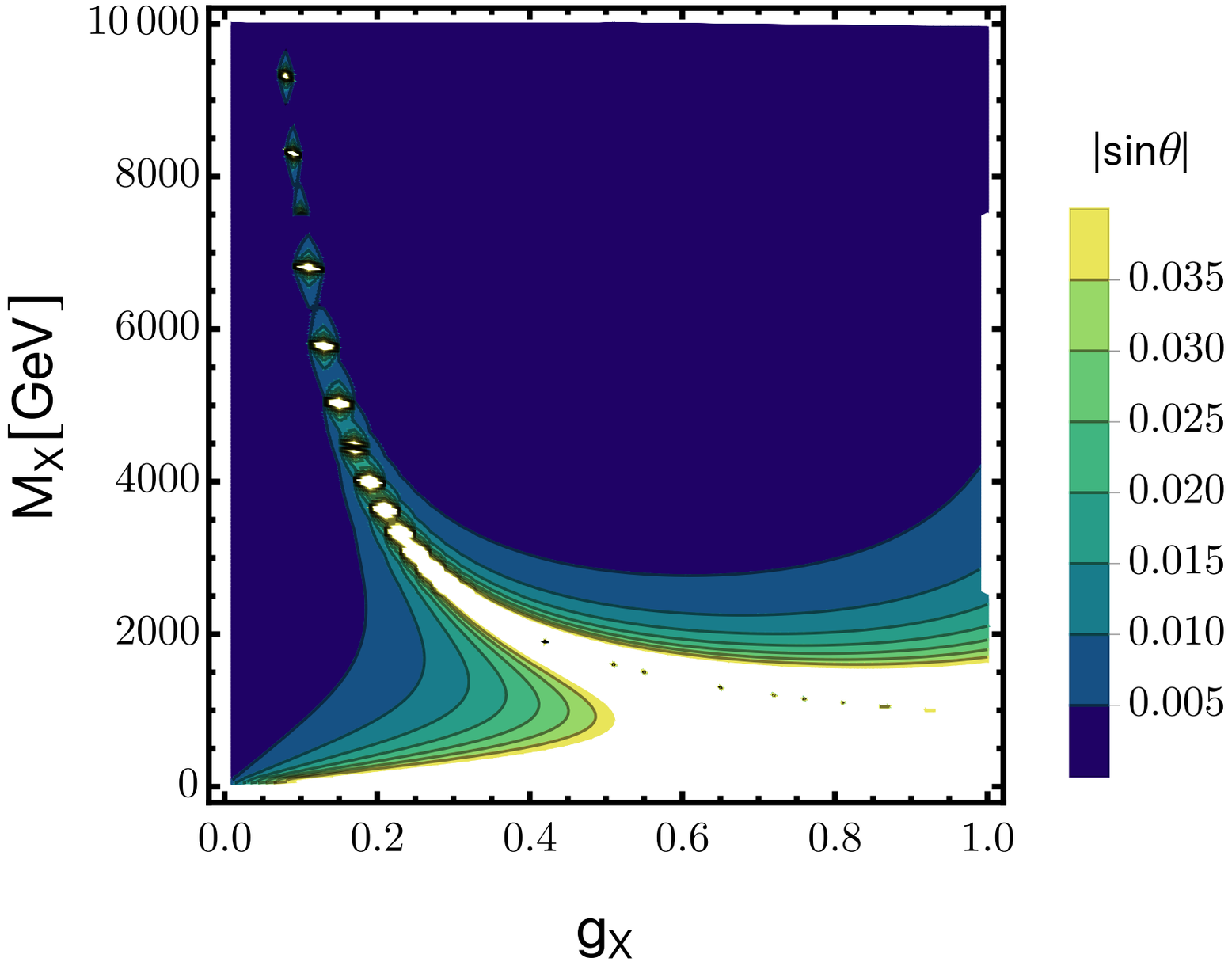


[See also: L. Chataignier, T. Prokopec, M.G. Schmidt, BS, JHEP 08 (2018) 083]

PHASE TRANSITION AND DM PRODUCTION

For details of the PT computations and GW signal see the talk by Maciej Kierkla

SU(2)CSM

cSM:
$SU(2)_L \times U(1)_Y$
Φ

Hidden sector:
$SU(2)_X$
Ψ

$$V^{(0)}(\Phi,\Psi) = \lambda_1 \left(\Phi^\dagger\Phi\right)^2 + \lambda_2 \left(\Phi^\dagger\Phi\right)\left(\Psi^\dagger\Psi\right) + \lambda_3 \left(\Psi^\dagger\Psi\right)^2,$$

$$\mathrm{SU}(2) \to \mathbb{Z}_2 \times \mathbb{Z}_2$$

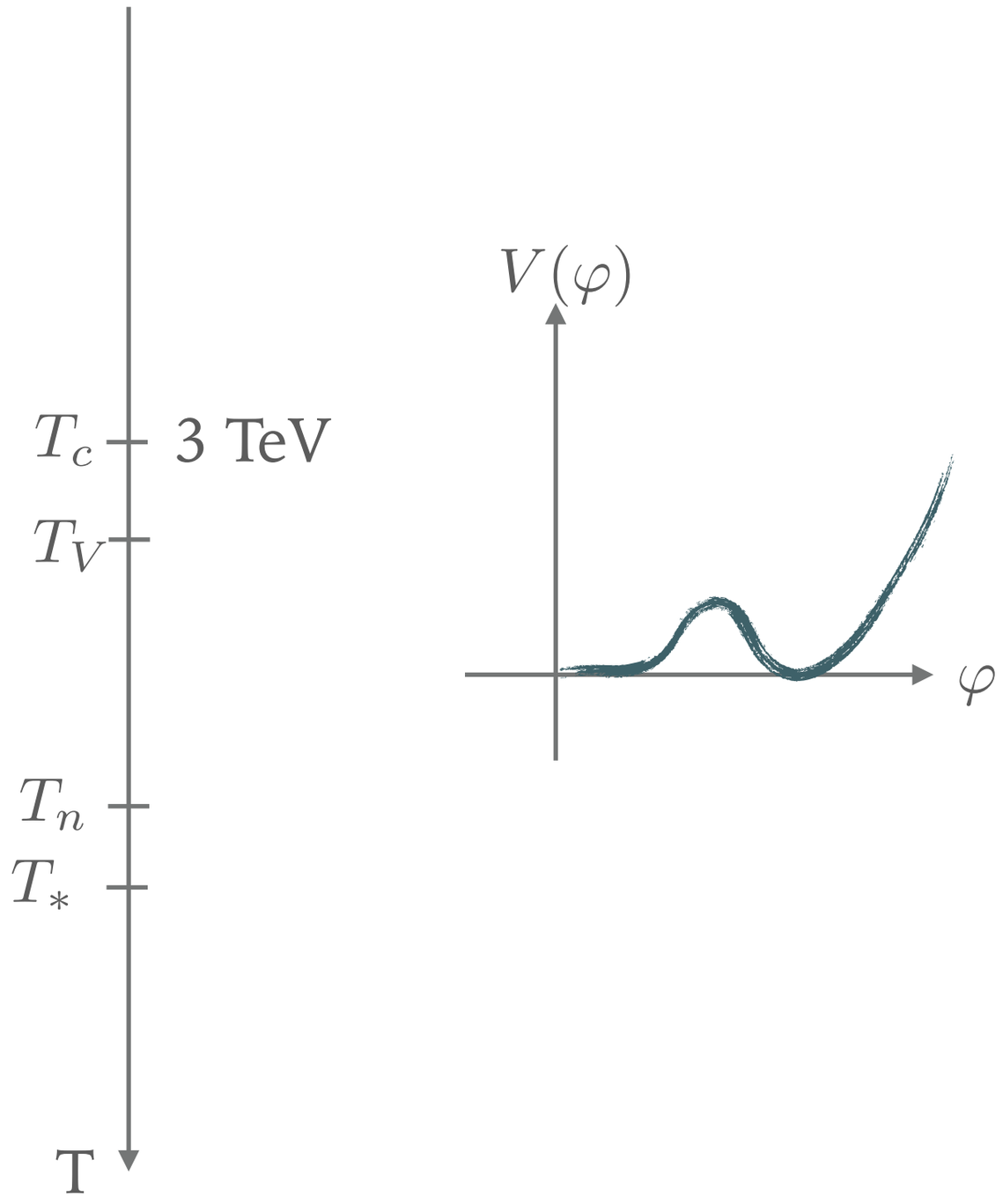
DM stability protected by a symmetry

[See also: T.Hambye, A.Strumia, PRD88 (2013) 055022, C.Carone, R.Ramos, PRD88 (2013) 055020, V.V.Khoze, C.McCabe, G.Ro, JHEP 08 (2014) 026, T. Hambye, A.Strumia, D.Teresi, JHEP 1808 (2018) 188, I.Baldes, C. Garcia-Cely, JHEP 05 (2019) 190, T.Prokopec, J.Rezacek, BS, JCAP02(2019)009, D. Marfaria, P. Tseng, JHEP 02 (2021) 022]

TEMPERATURE EVOLUTION

$M_X = 9$ TeV, $g_X = 0.9$

critical temperature: two degenerate minima



TEMPERATURE EVOLUTION

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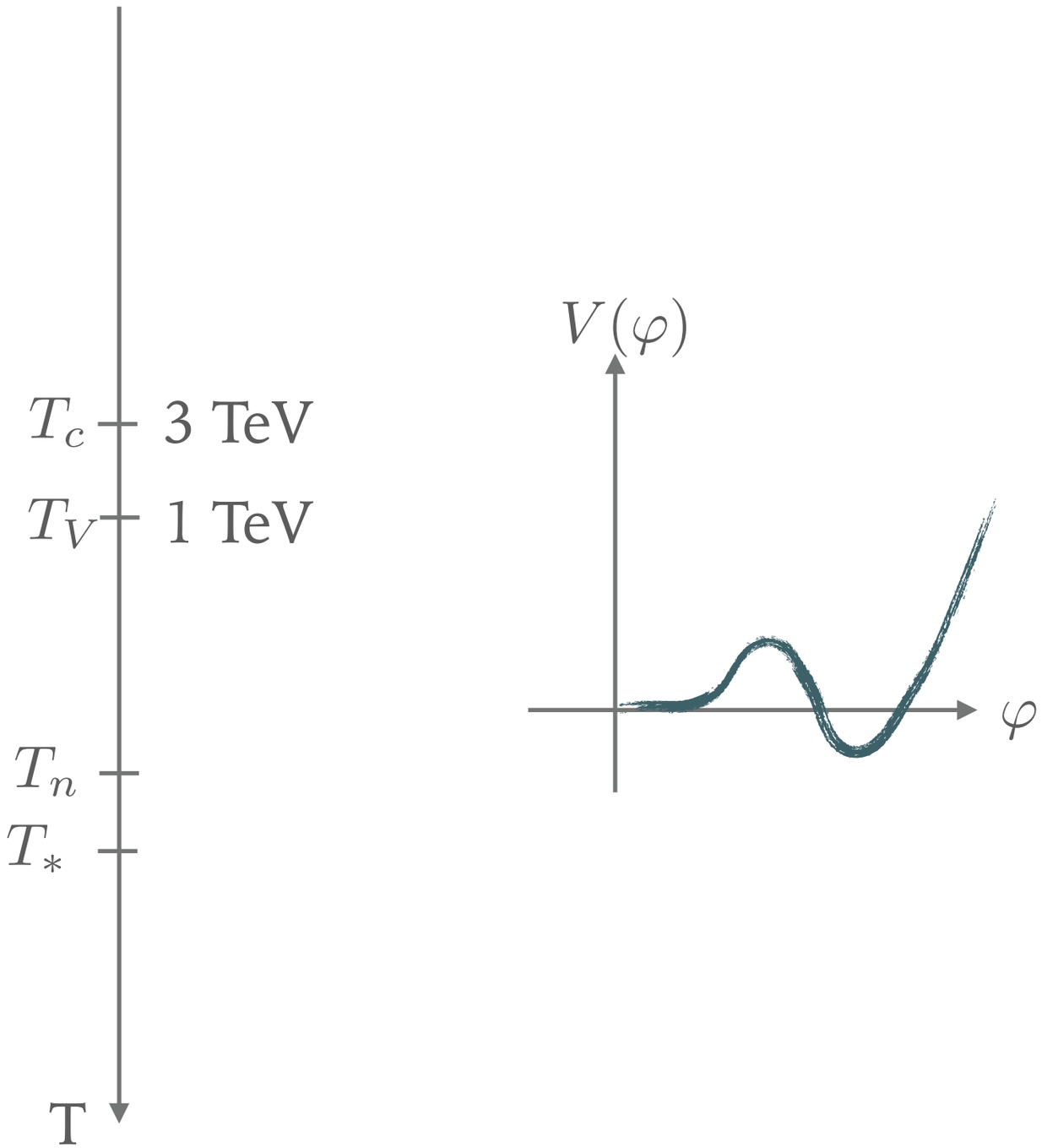
vacuum domination begins



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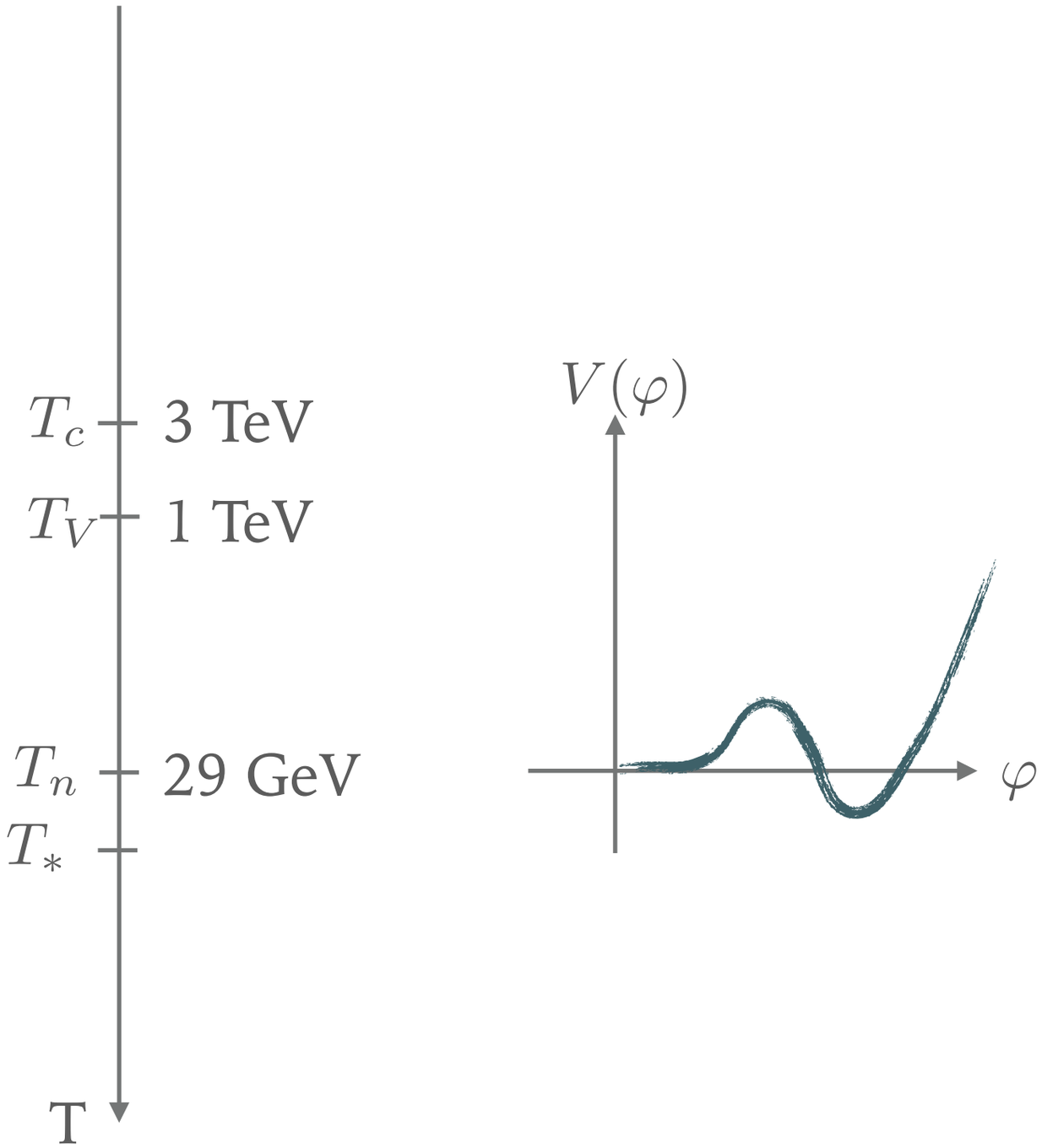
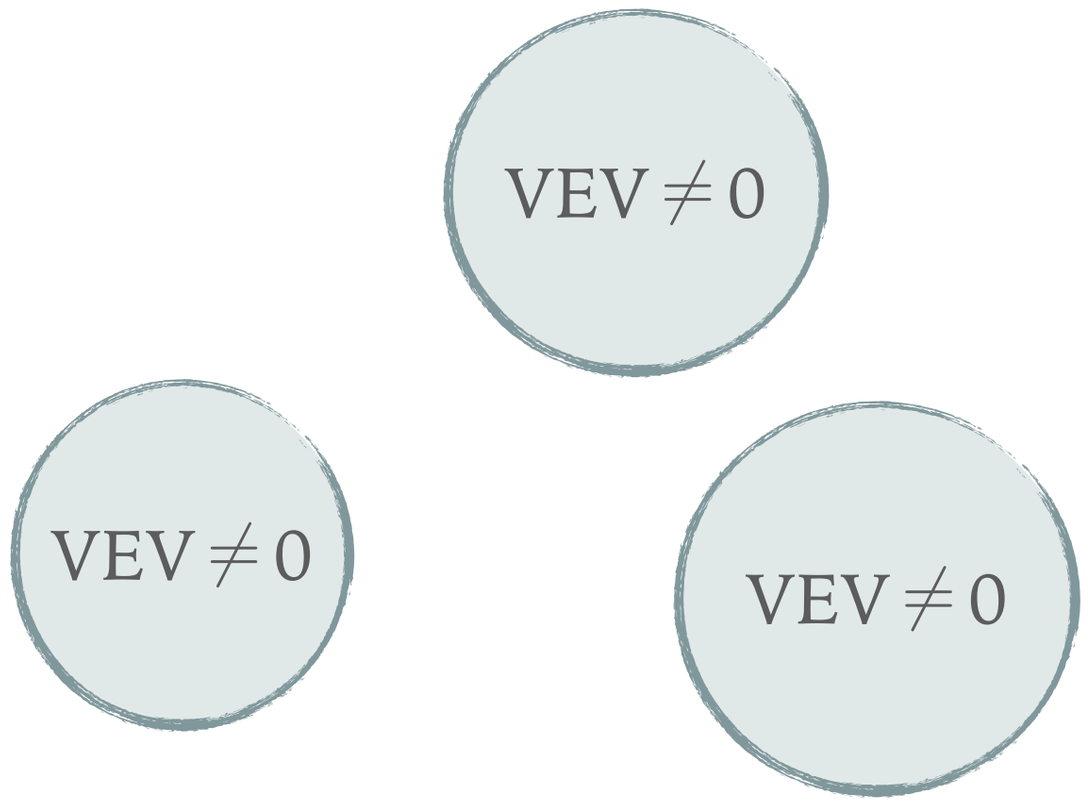


nucleation:
one bubble nucleates
per Hubble volume



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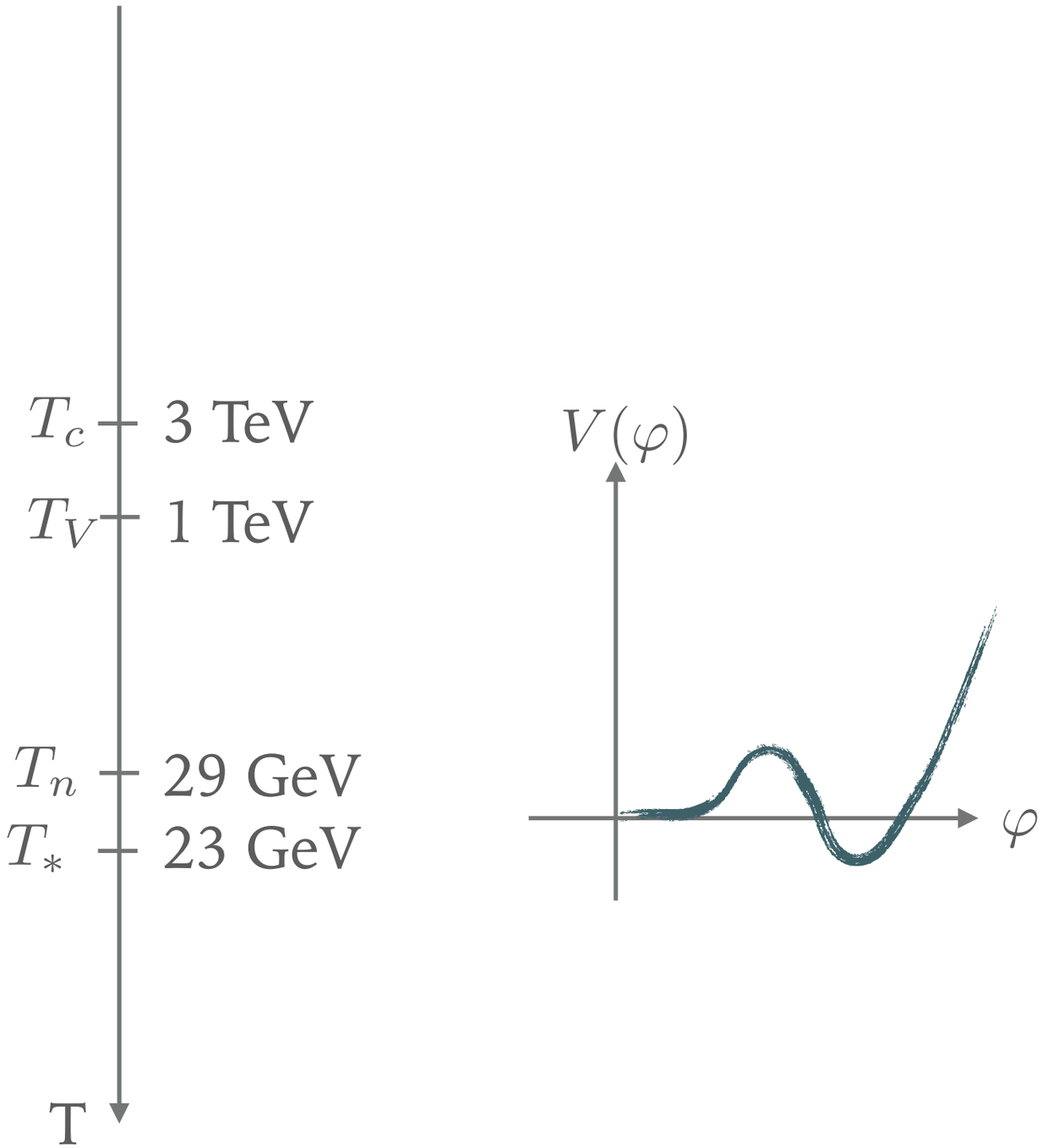
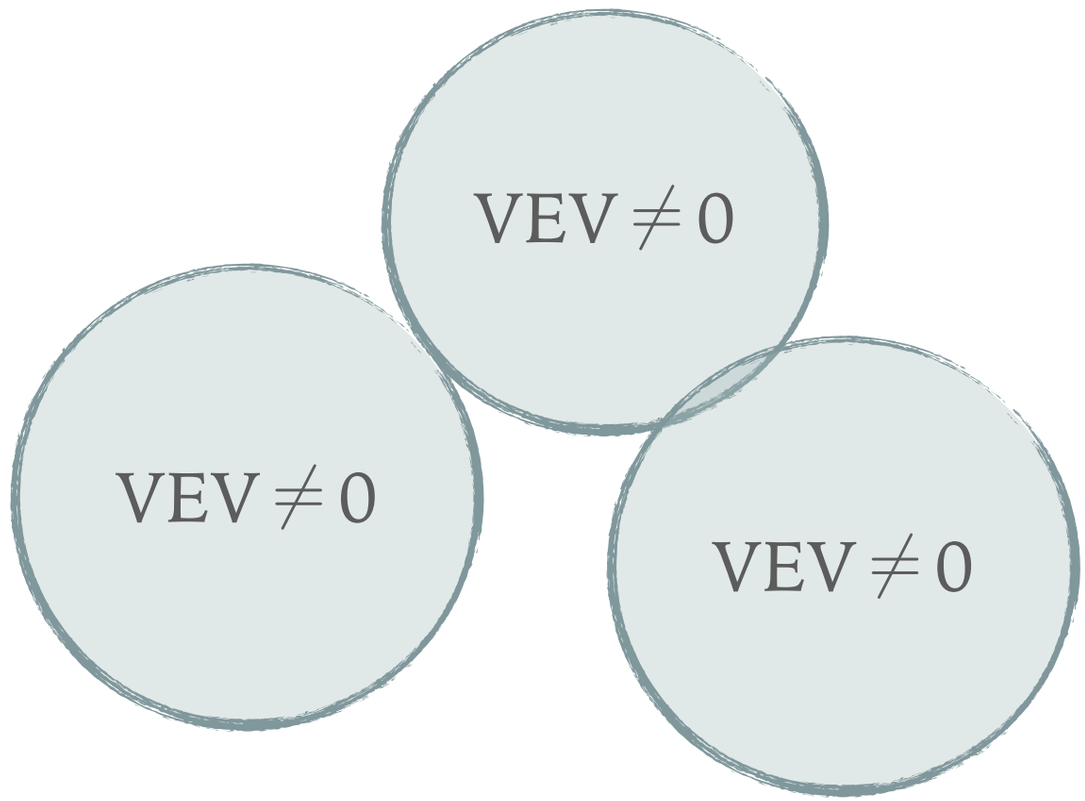


Percolation: phase transition completes



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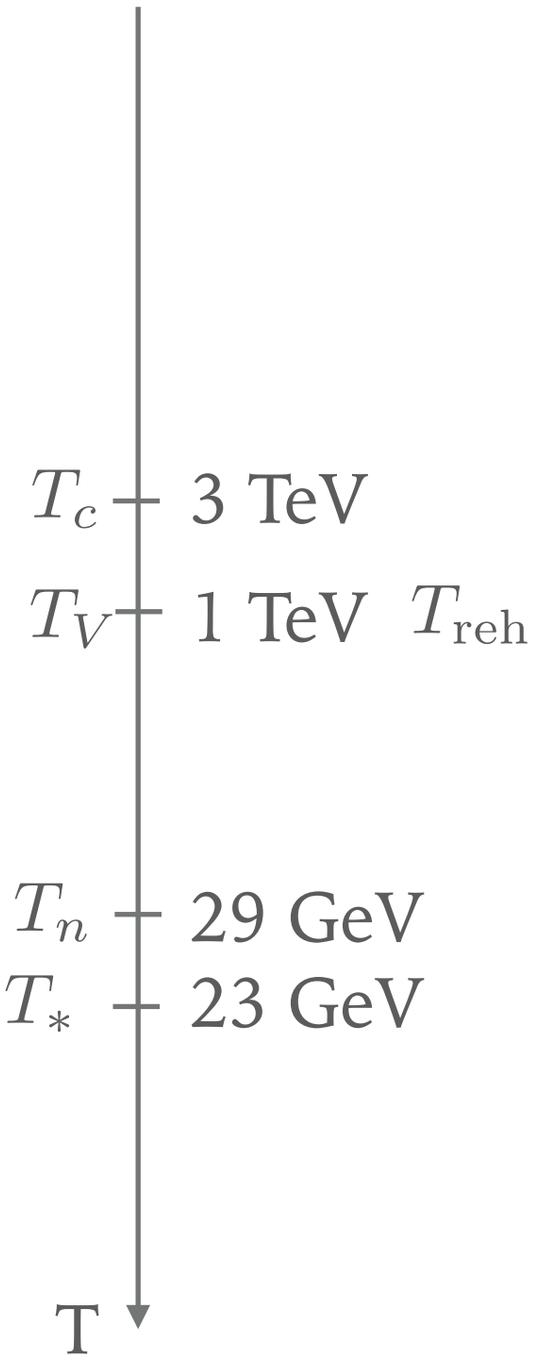
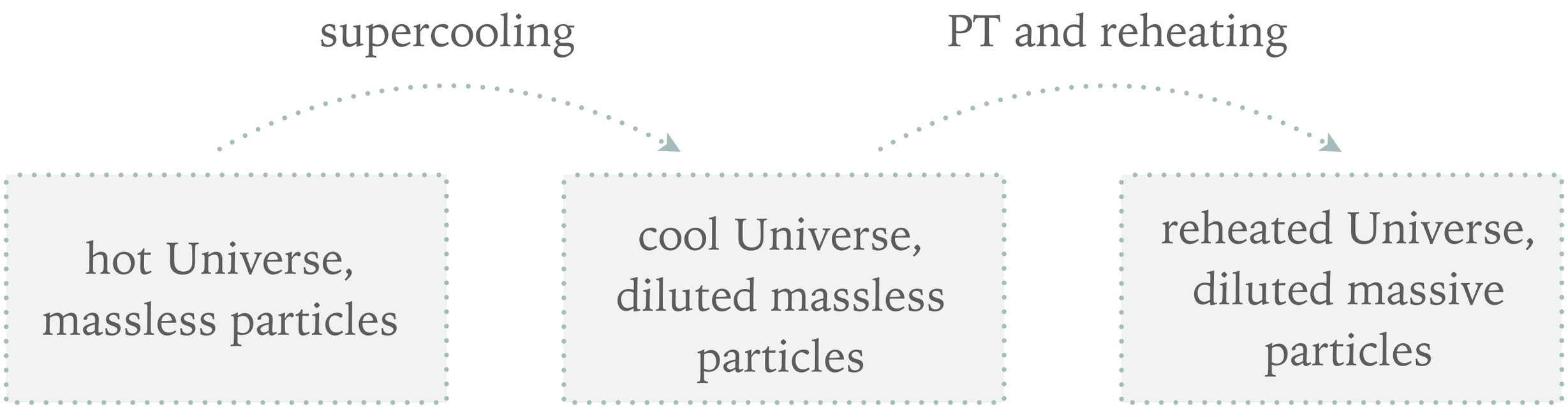
$M_X = 9$ TeV, $g_X = 0.9$



reheating

$$\alpha = \frac{\Delta V}{\text{energy of radiation}} \approx 4 \cdot 10^6$$

NON-STANDARD DM PRODUCTION



NON-STANDARD DM PRODUCTION

supercooling

PT and reheating

hot Universe, massless particles

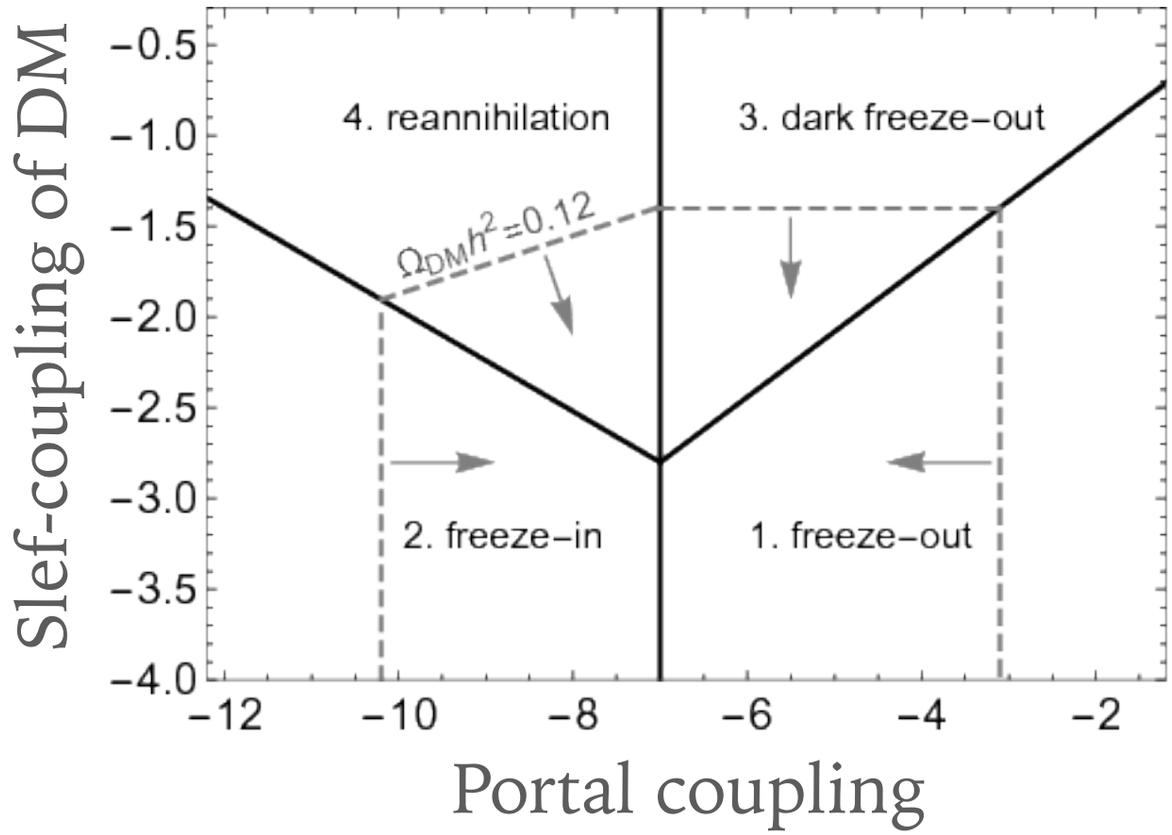
cool Universe, diluted massless particles

reheated Universe, diluted massive particles

- Abundance of DM after PT?
- Relation between reheating and decoupling temperatures?
- Self-coupling and coupling to the visible sector

NEW PRODUCTION MECHANISMS

Figurę from N. Bernal et al, Int.J.Mod.Phys.A 32 (2017) 27, 1730023



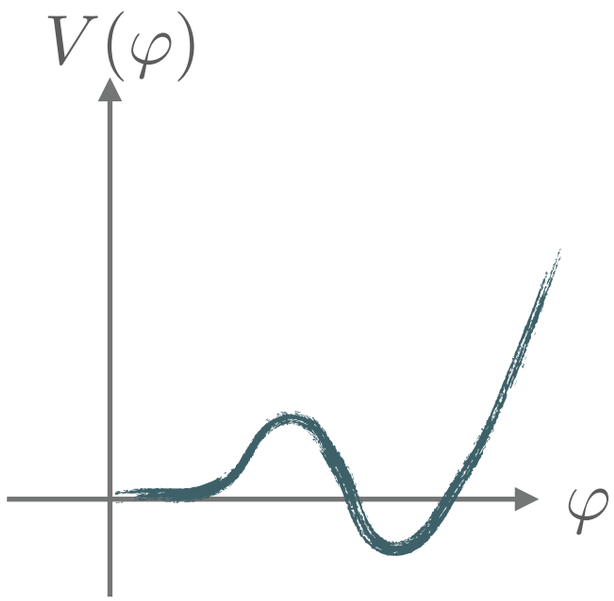
Supercool DM
DM diluted by thermal inflation
$T_{\rm dec} > T_{\rm reh}$

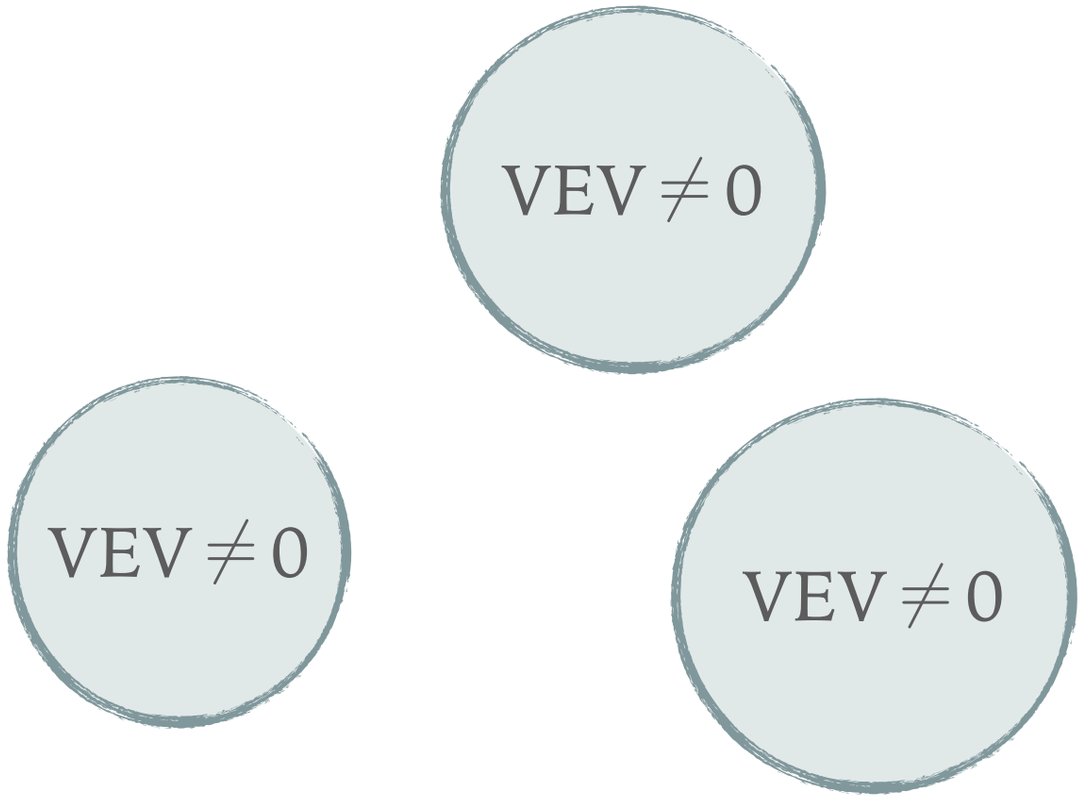
[See also: T.Hambye, A.Strumia, PRD88 (2013) 055022, C.Carone, R.Ramos, PRD88 (2013) 055020, V.V.Khoze, C.McCabe, G.Ro, JHEP 08 (2014) 026, T. Hambye, A.Strumia, D.Teresi, JHEP 1808 (2018) 188, I.Baldes, C. Garcia-Cely, JHEP 05 (2019) 190, D. Marfaria, P. Tseng, JHEP 02 (2021) 022]

SCALE DEPENDENCE OF PT PARAMETERS

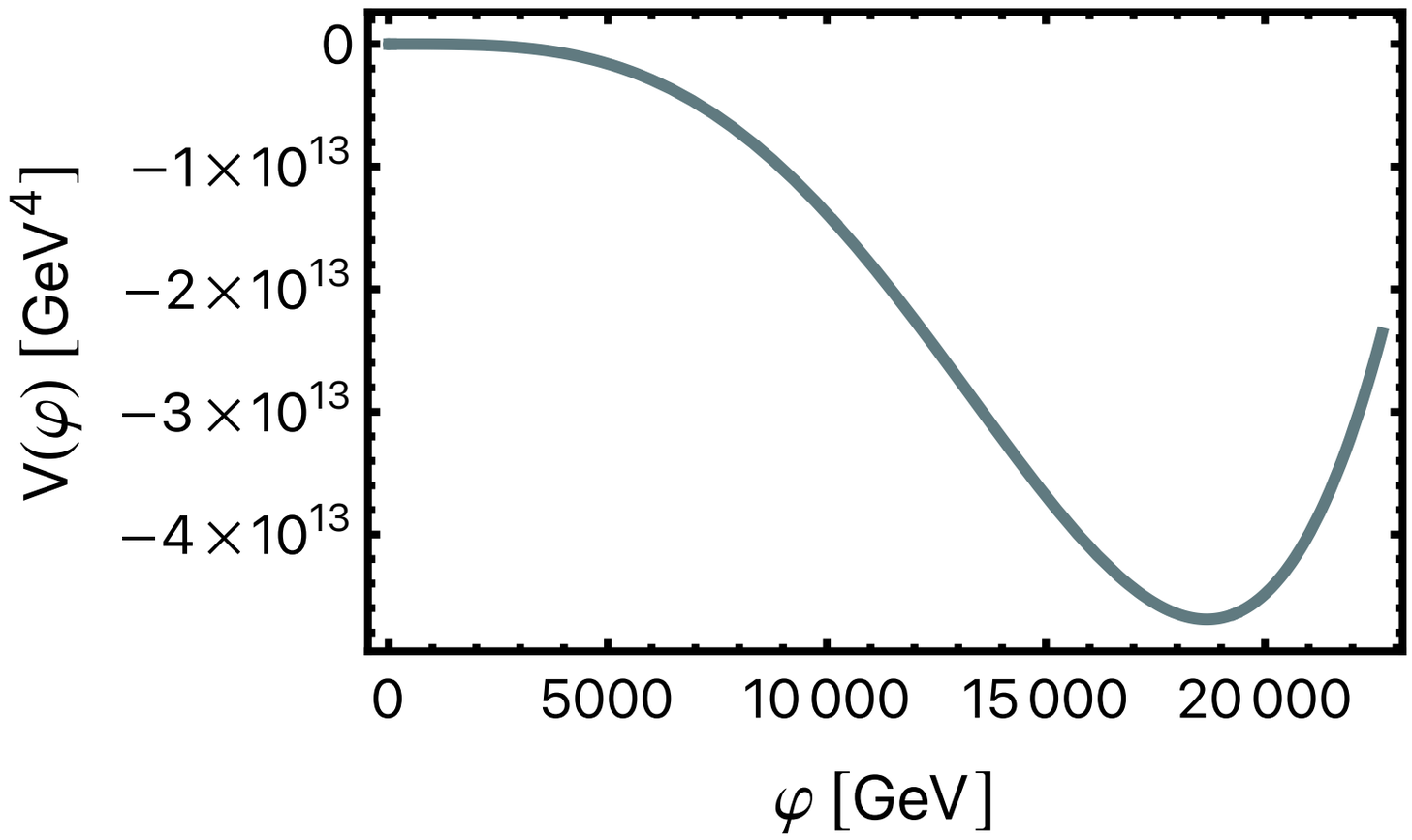
See also the talk of Andreas Ekstedt

PHASE TRANSITION





DIFFERENT SCALES INVOLVED



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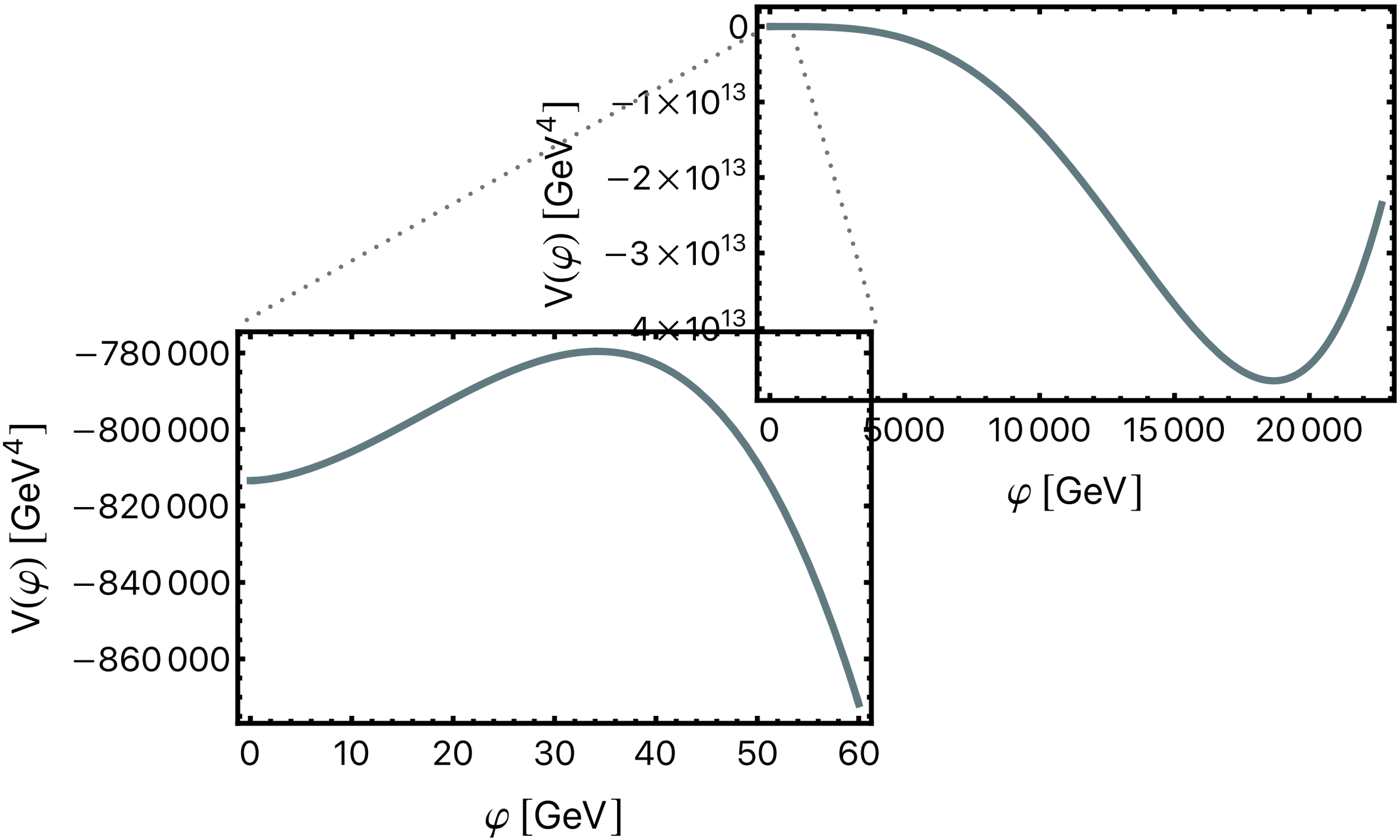
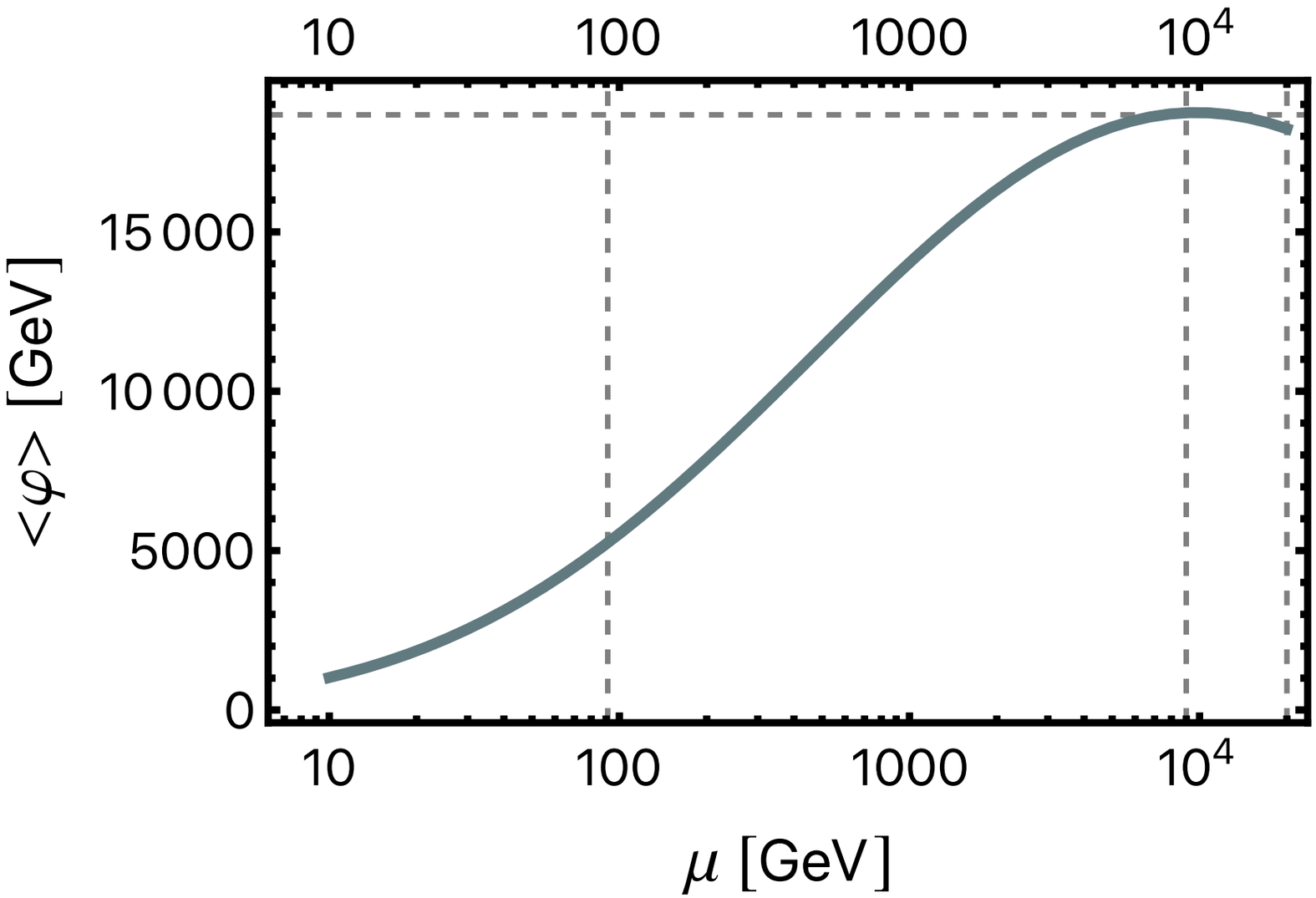


SCALE DEPENDENCE OF THE VEV



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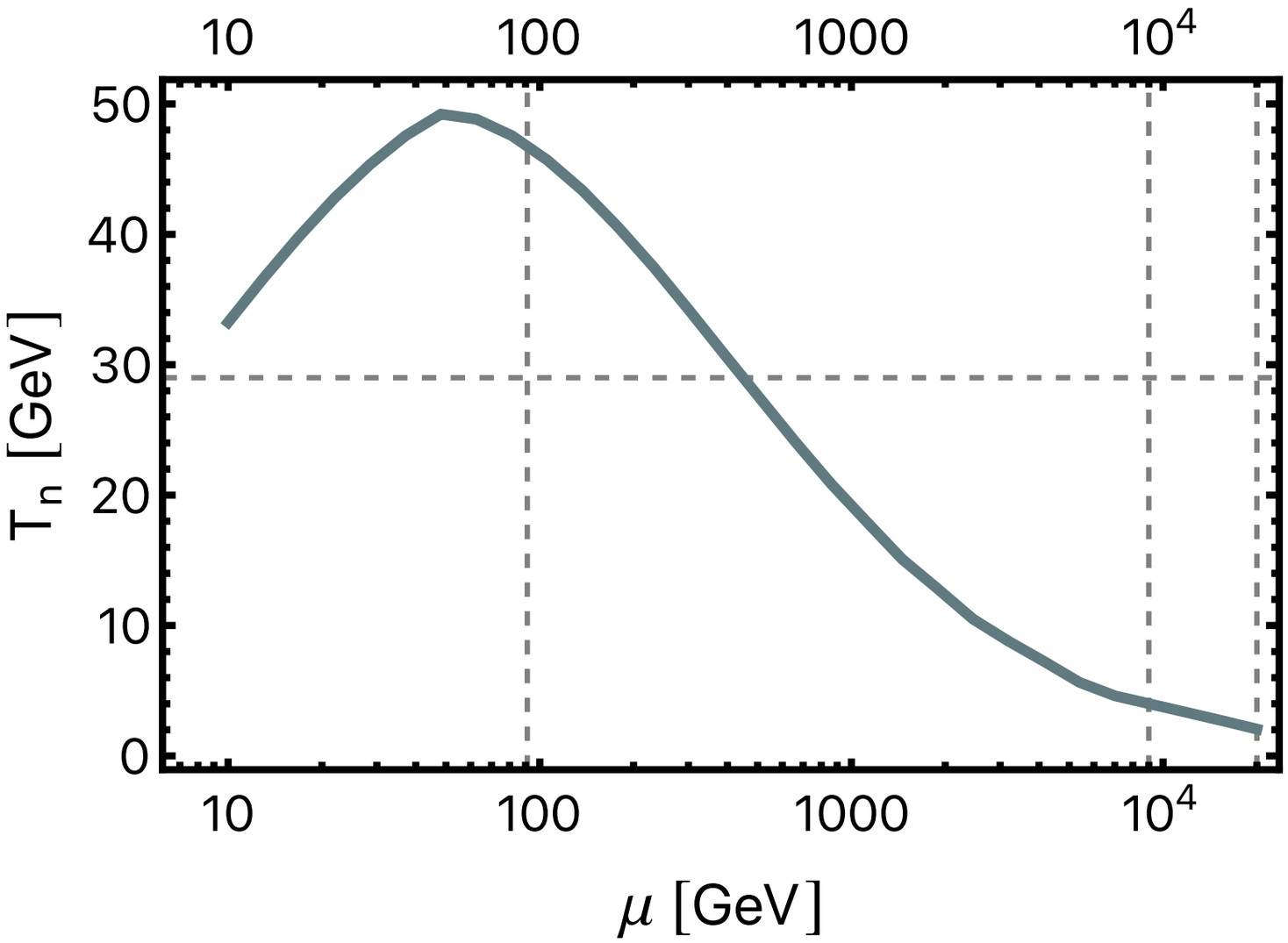
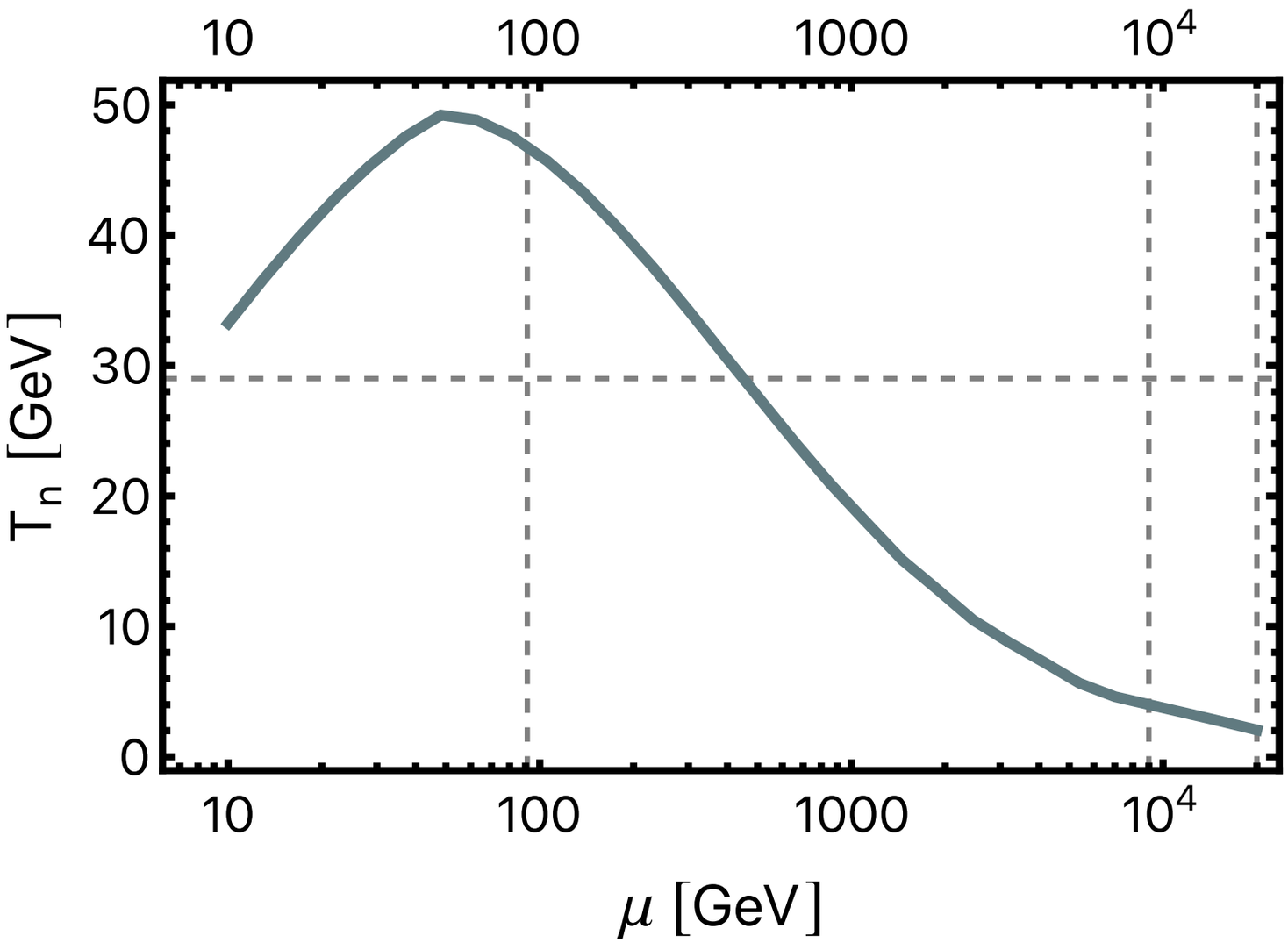


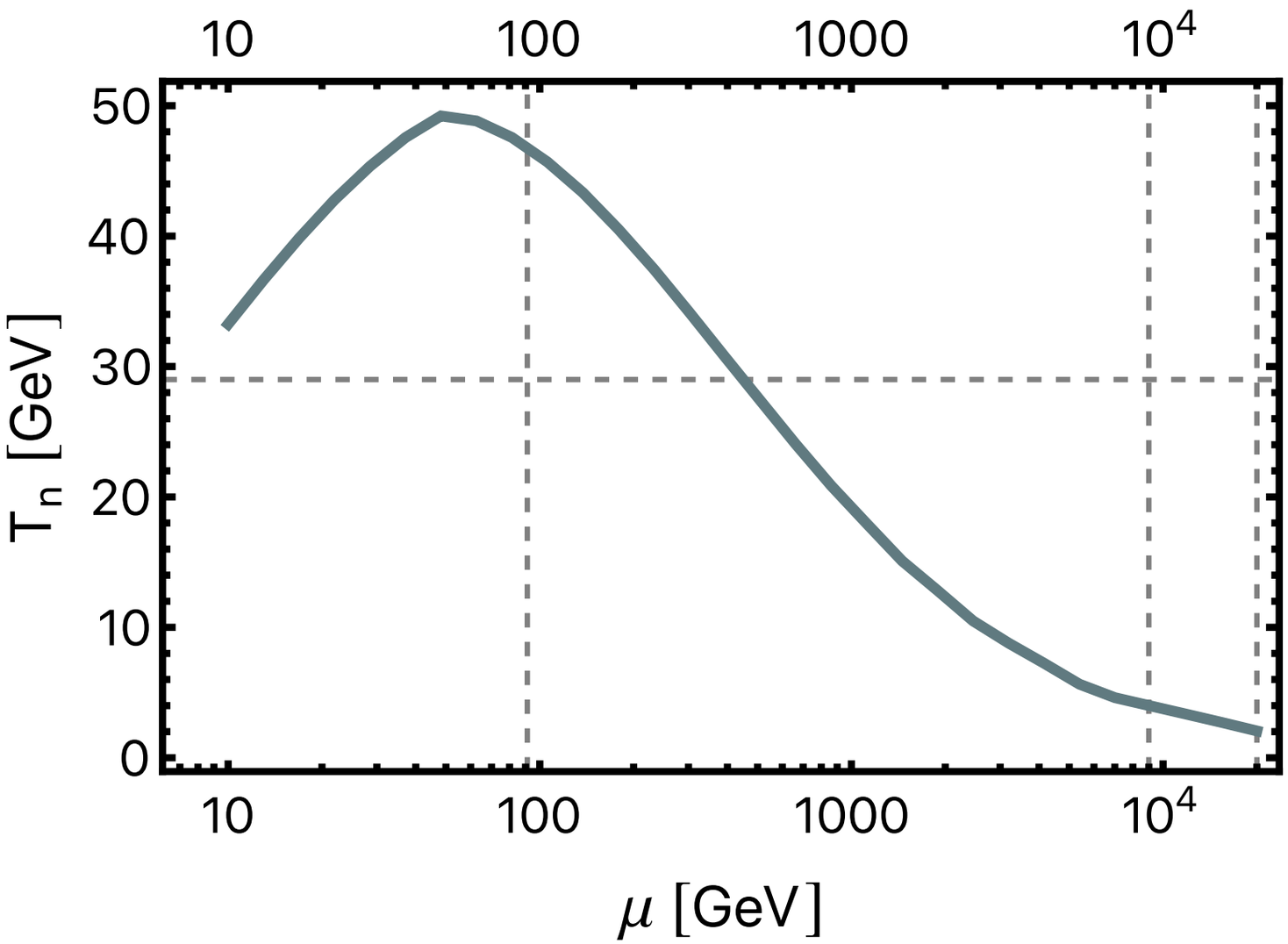
SCALE DEPENDENCE

Remedy: RG improvement



SCALE DEPENDENCE

Still to be improved



SUMMARY

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Conformal symmetry breaking is associated with interesting phenomena: strong GW signal and DM production. They will be testable with future experiments.

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Conformal symmetry breaking is associated with interesting phenomena: strong GW signal and DM production. They will be testable with future experiments.

But if we want to formulate reliable predictions, we can not turn a blind eye to theoretical uncertainties.

THANK YOU FOR YOUR ATTENTION

NATIONAL SCIENCE CENTRE
POLAND

DM PRODUCTION MECHANISMS

Freeze-in

DM not in thermal equilibrium, produced by decays or annihilations in the visible sector

Dark freeze-out

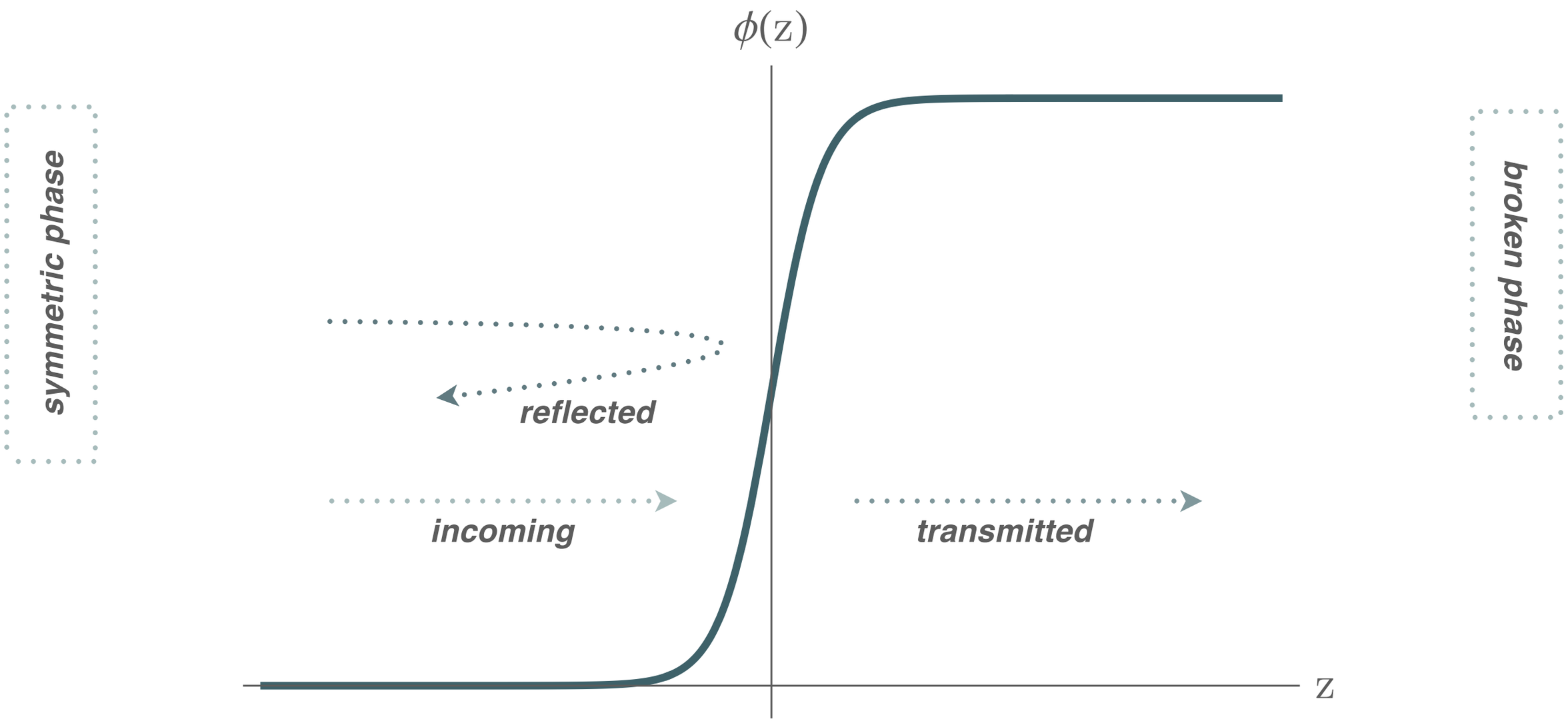
DM not in equilibrium with the visible sector, freeze-out within the dark sector

Reannihillation

DM frozen in the dark sector but produced by the visible sector, final freeze-out when the yield ends

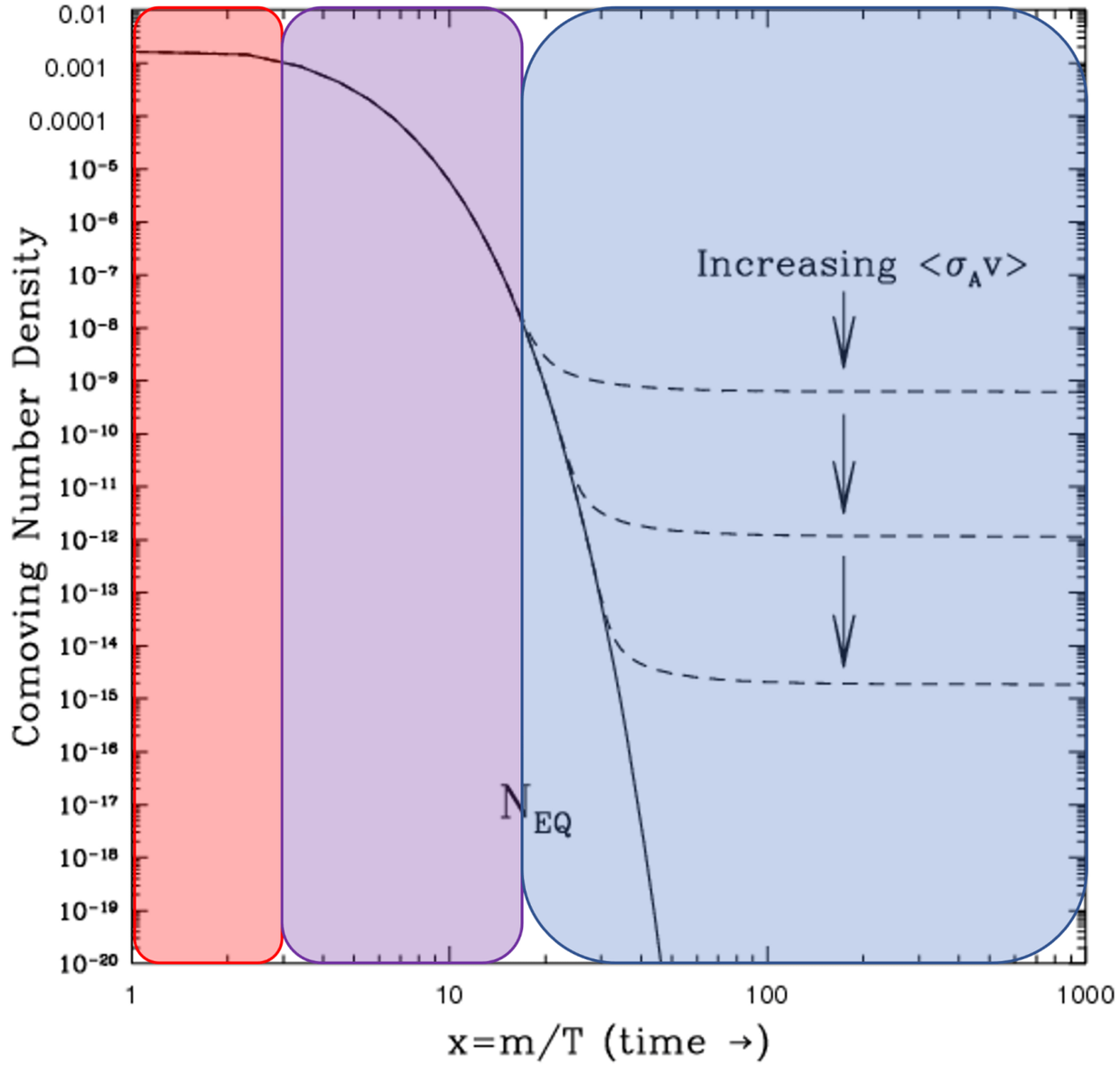
[N. Bernal et al, Int.J.Mod.Phys.A 32 (2017) 27, 1730023]

SOUND WAVES OR BUBBLE COLLISIONS?



[G.D. Moore, T. Prokopec, PRL 75 (1995), PRD 52 (1995), P.B. Arnold, PRD 48 (1993) 1539, D. Bodeker, G.D. Moore, JCAP 0905 (2009) 009; JCAP 1705 (2017) 025, G.C. Dorsch, S. J. Huber and T. Konstandin, JCAP 12 (2018); 2106.06547, T. Konstandin, G. Nardini and I. Rues, JCAP 09 (2014), J.Kozaczuk, JHEP 10 (2015), S. Höche et al, 2007.10343, Y. Gouttenoire, R. Jinno, F. Sala, 2112.07686]

STANDARD FREEZE-OUT



[from Cold and Turner, adapted by particle bites.com]