Particle Theory at UNSW

Dark matter depopulation in the early Universe

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NUW Alliance

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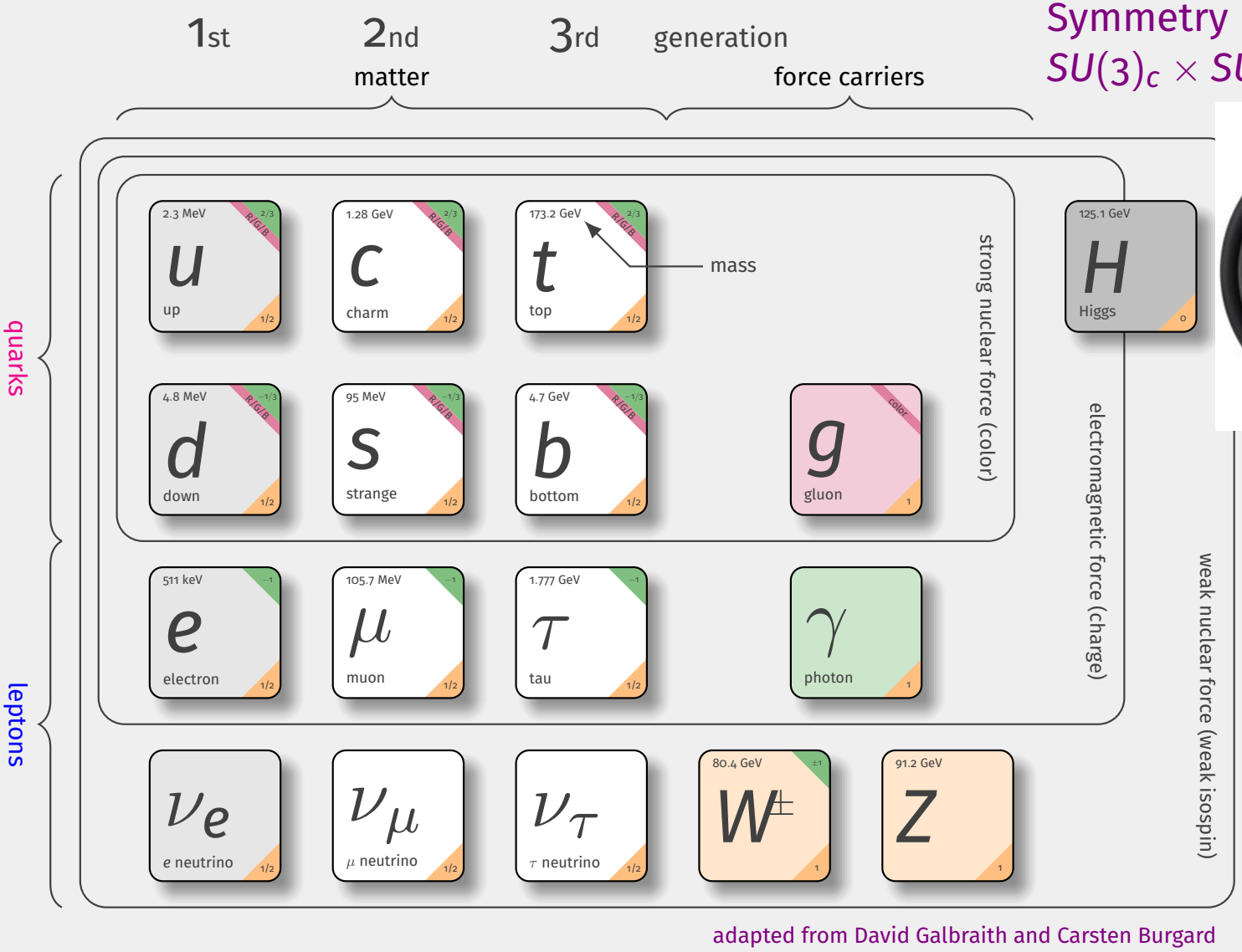
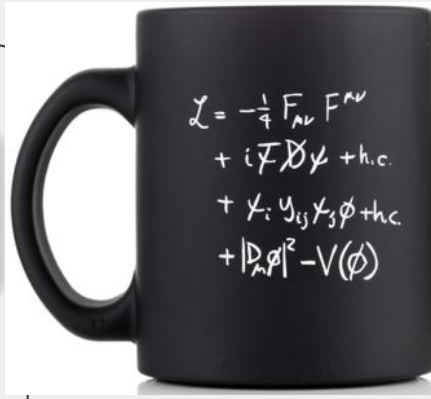
UNSW
SYDNEY

Standard Model of Particle Physics



Symmetry

$SU(3)_c \times SU(2)_L \times U(1)_Y$



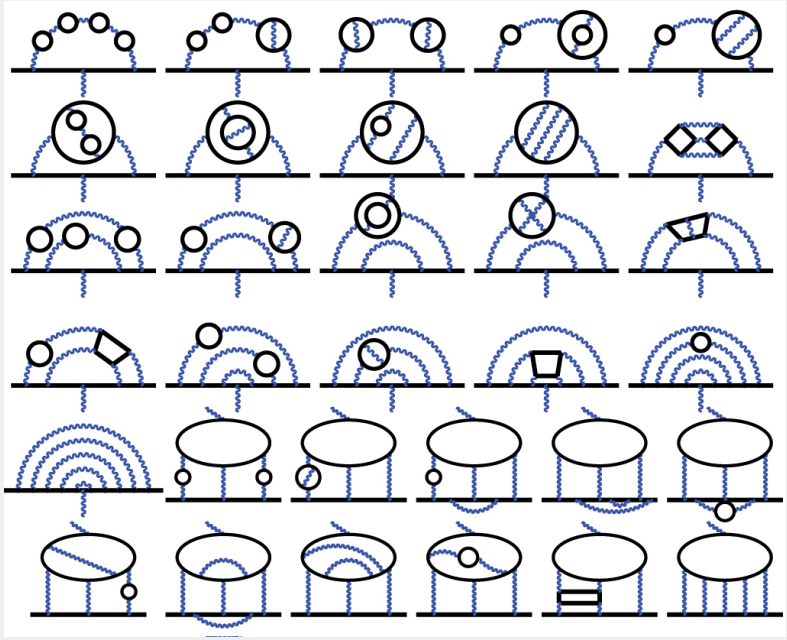
adapted from David Galbraith and Carsten Burgard

Masses measured in GeV

proton mass $m_p = 1$ GeV

Triumph of the Standard Model

- Extremely precise prediction:
  e^- magnetic moment $\mathcal{O}(10^{-12})$
- CKM unitarity
- S, T, U parameters
- Excluded 4th gen. at $> 5\sigma$
- ...



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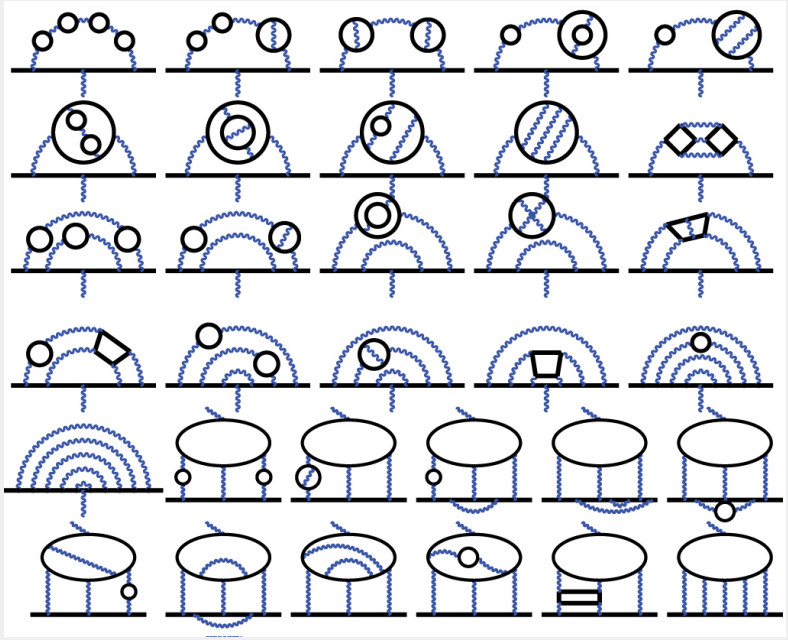

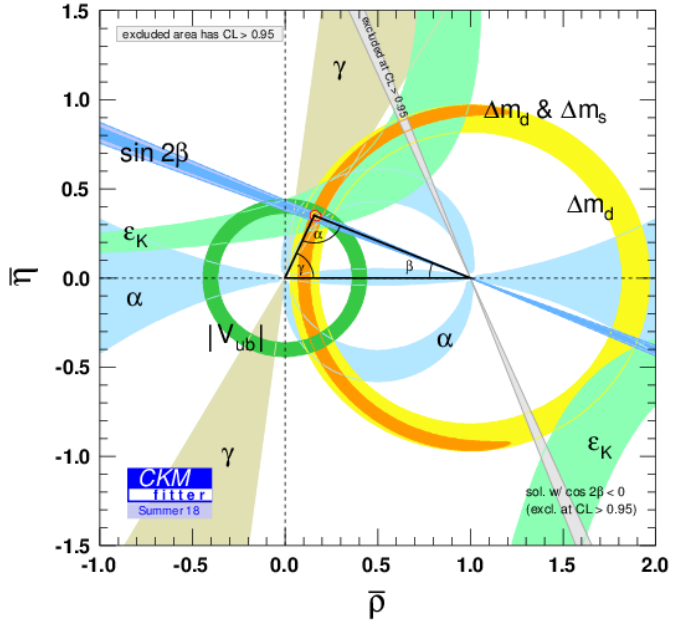

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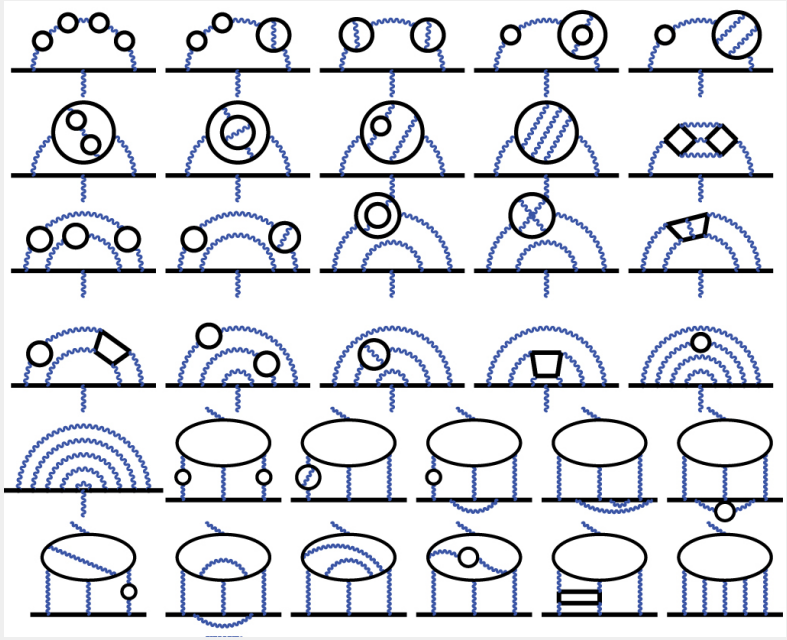

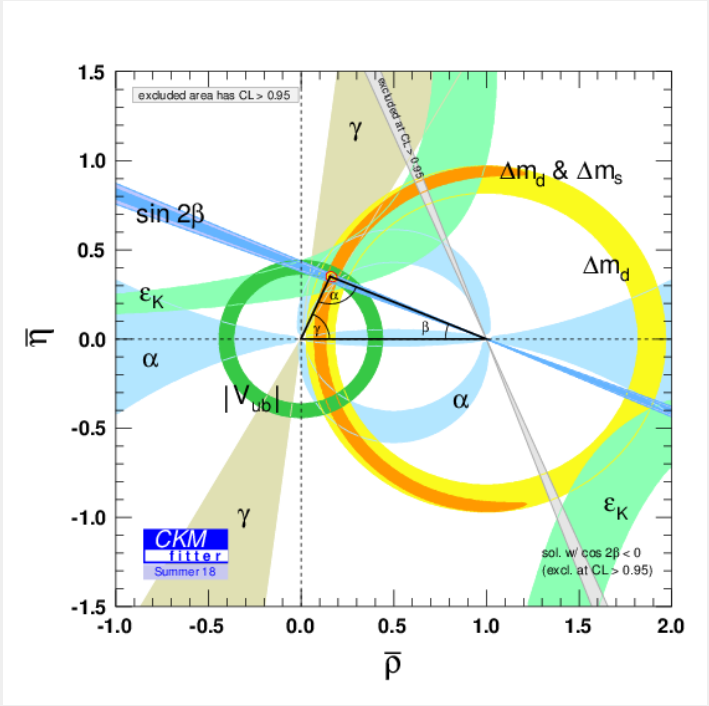

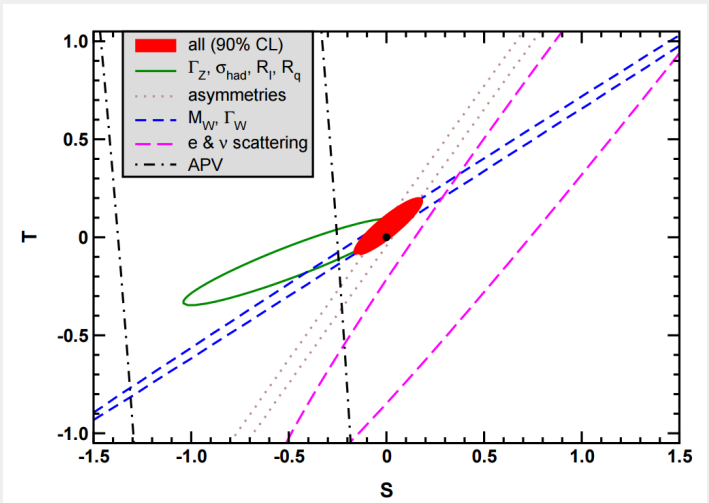

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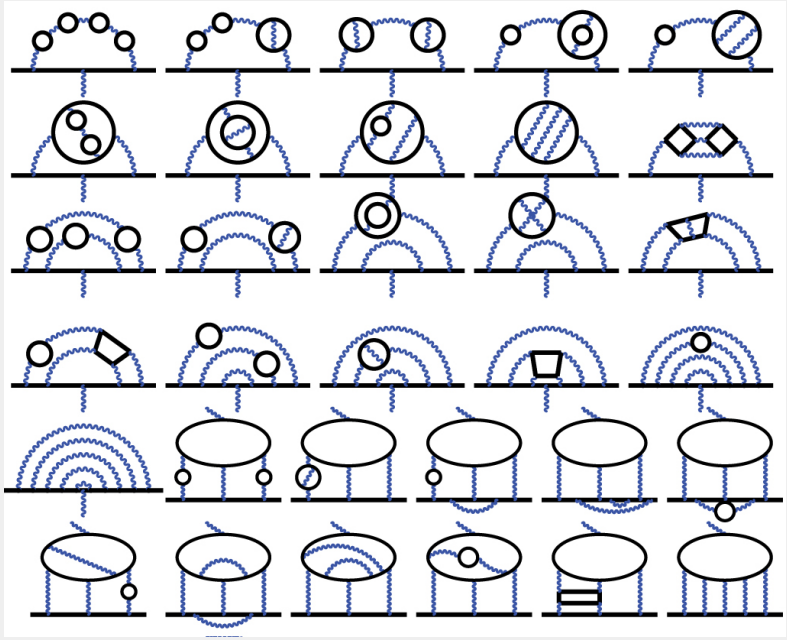
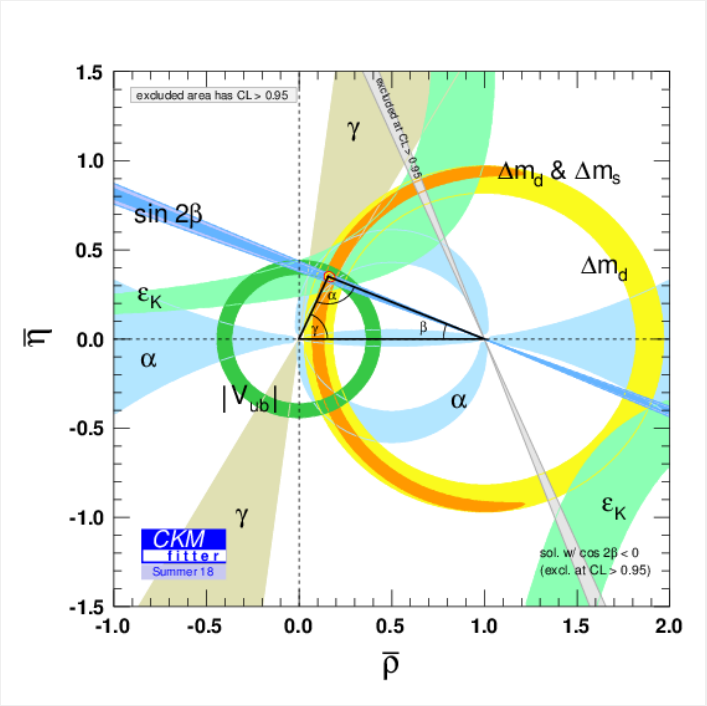
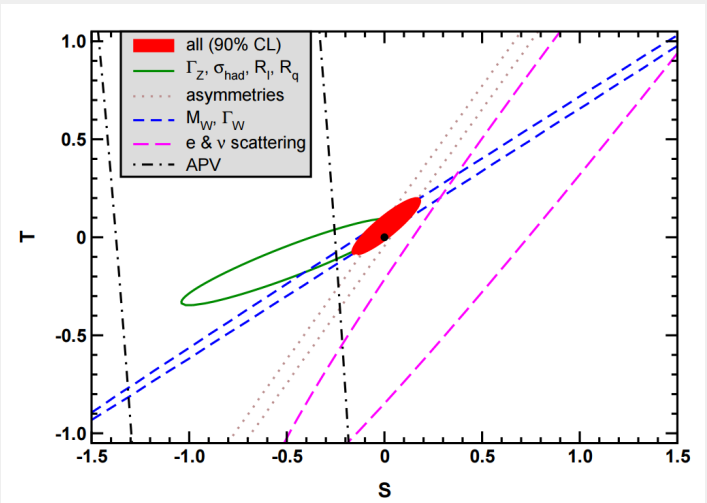






Incomplete Standard Model

Theoretical concerns

- Gravity is not incorporated.
- Why 3 generations? Any explanation of fermion masses?
- Why P and CP violation? Strong CP problem? ...

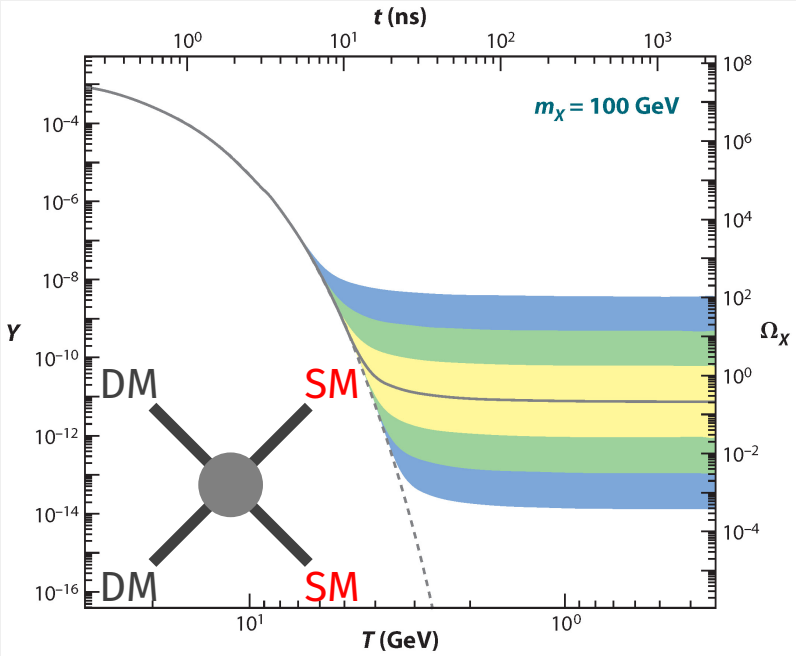
Unexplained observations

- What is dark matter ?
- Neutrino masses and oscillations
- Baryon asymmetry of the Universe ...

Hints for new physics

- 3.7σ (2.4σ) deviation in muon (electron) magnetic moment
- Anomalous measurements in semileptonic B meson decays
- LSND/MiniBooNE: sterile neutrinos? ...

Dark matter: The WIMP Miracle



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- weak-scale interaction strength
  $\sim \mathcal{O}(10^{-26})\mathrm{cm}^3/\mathrm{s}$

- DM in thermal equilibrium with SM particles at high T
- *freeze-out* when the Universe cools down and $\Gamma \lesssim H$
- relic abundance approx equals to the freeze-out abundance

$$\Omega_{\mathrm{DM}} \propto \langle \sigma v \rangle^{-1}$$

- Note: If cross section too small, DM overabundant

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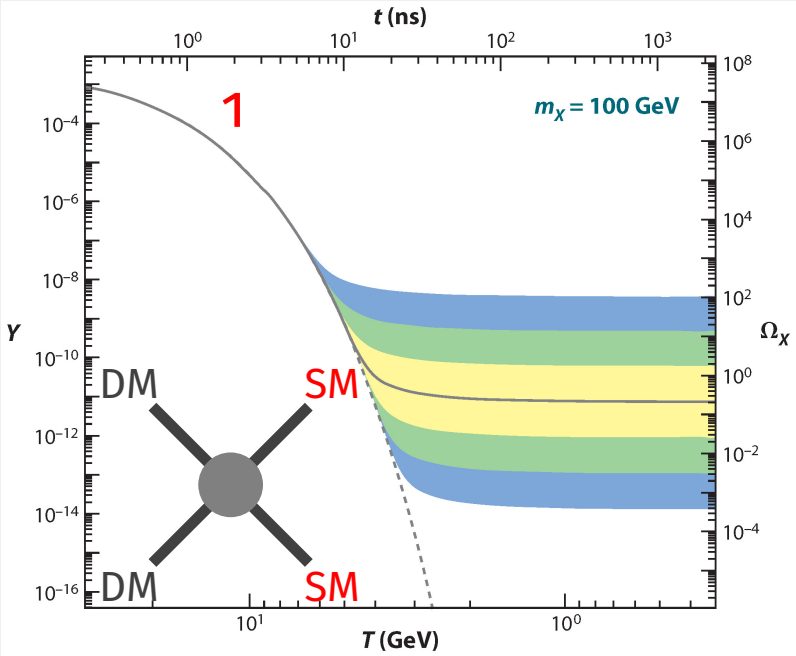

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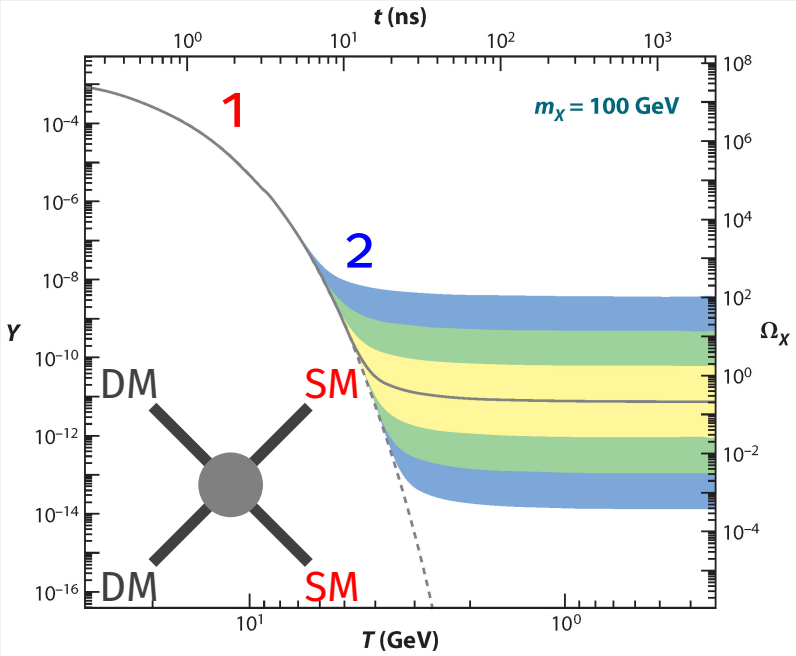

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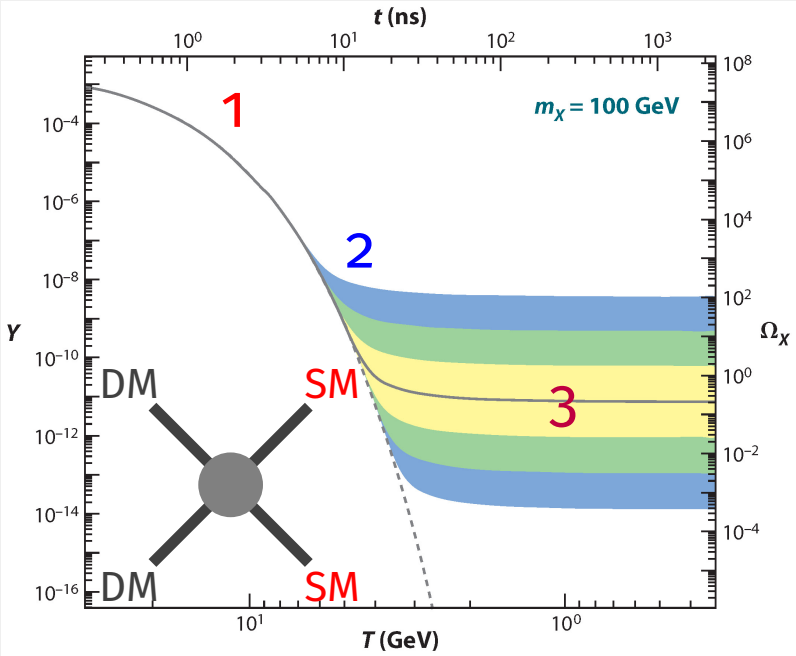

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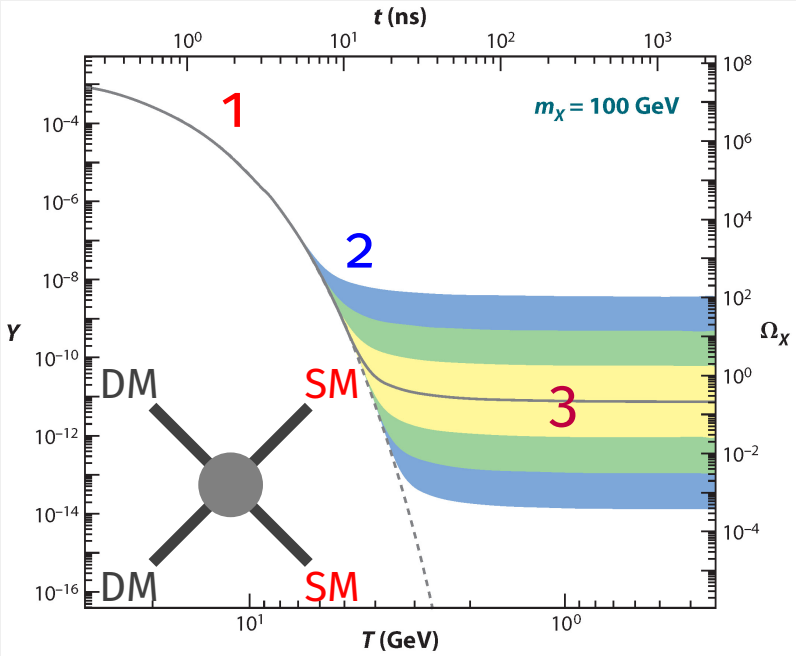

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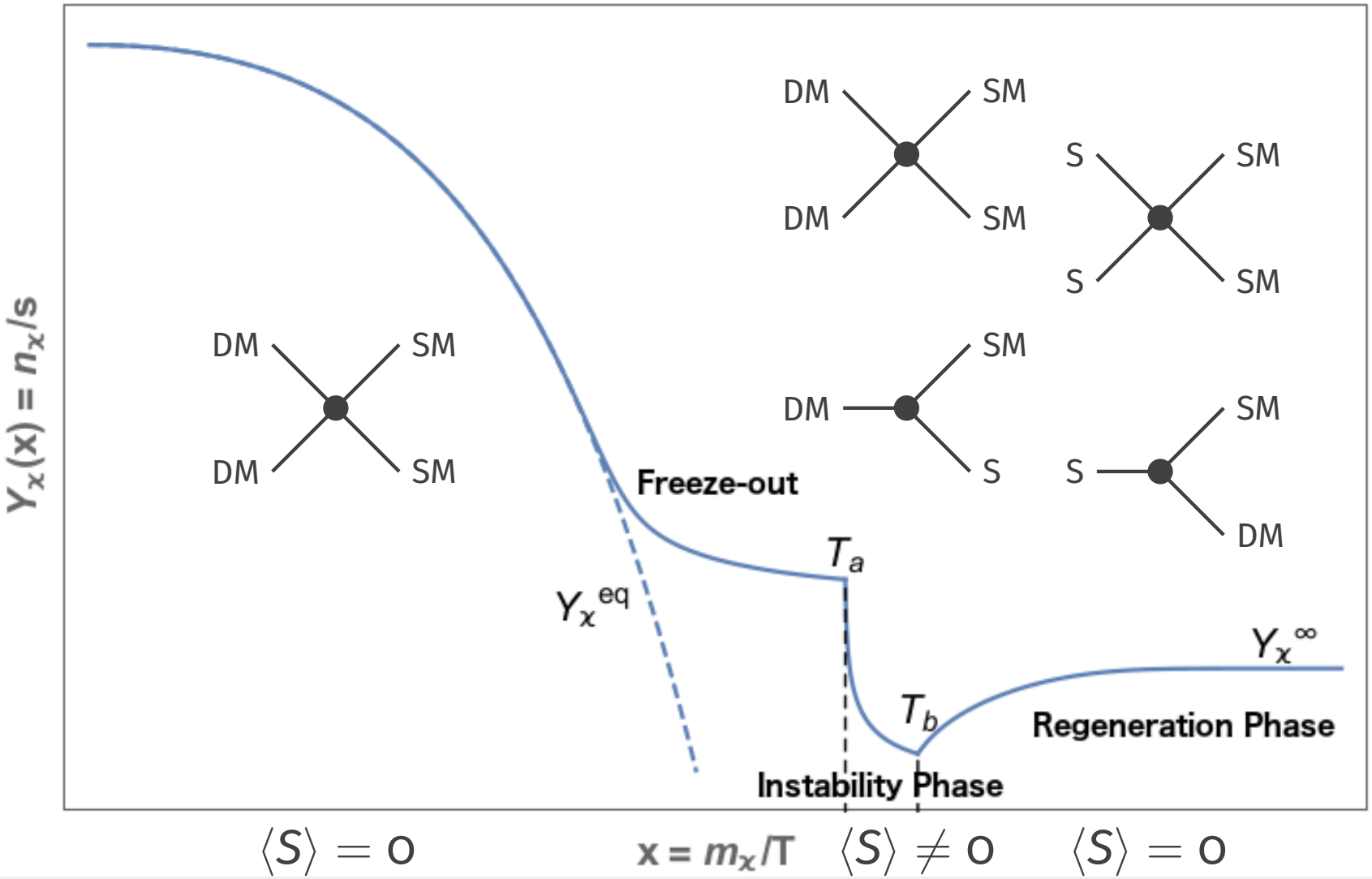
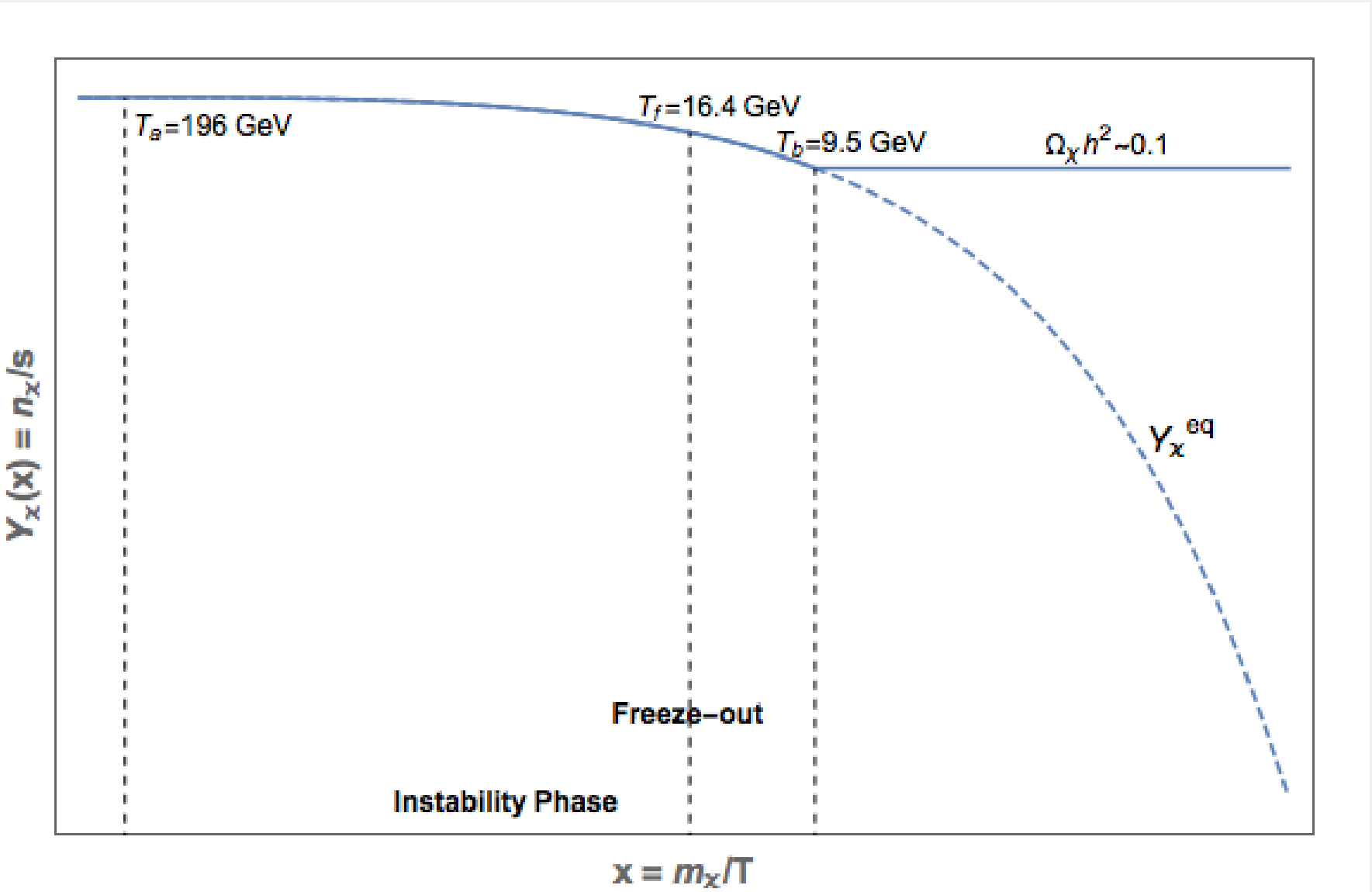
Dark matter depopulation [Kobakhidze,MS,Talia 1712.05170,1910.01433]

Dark matter χ and scalar S odd under Z_2 symmetry: $Z_2 : (\chi, S) \to (-\chi, -S)$

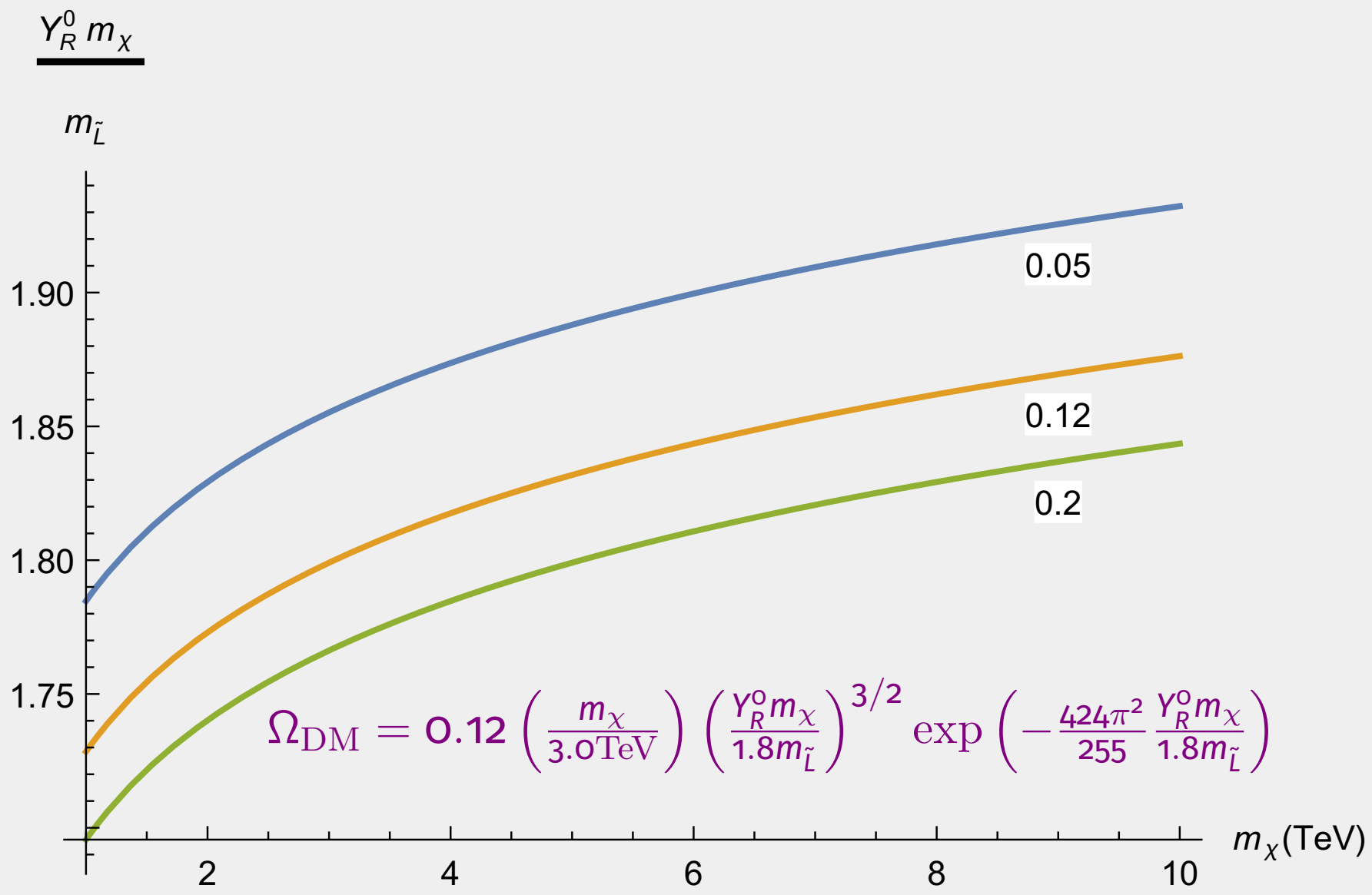


Chronological order may differ from $T_f > T_a > T_b > T_{f,S} > T_i > T_c$

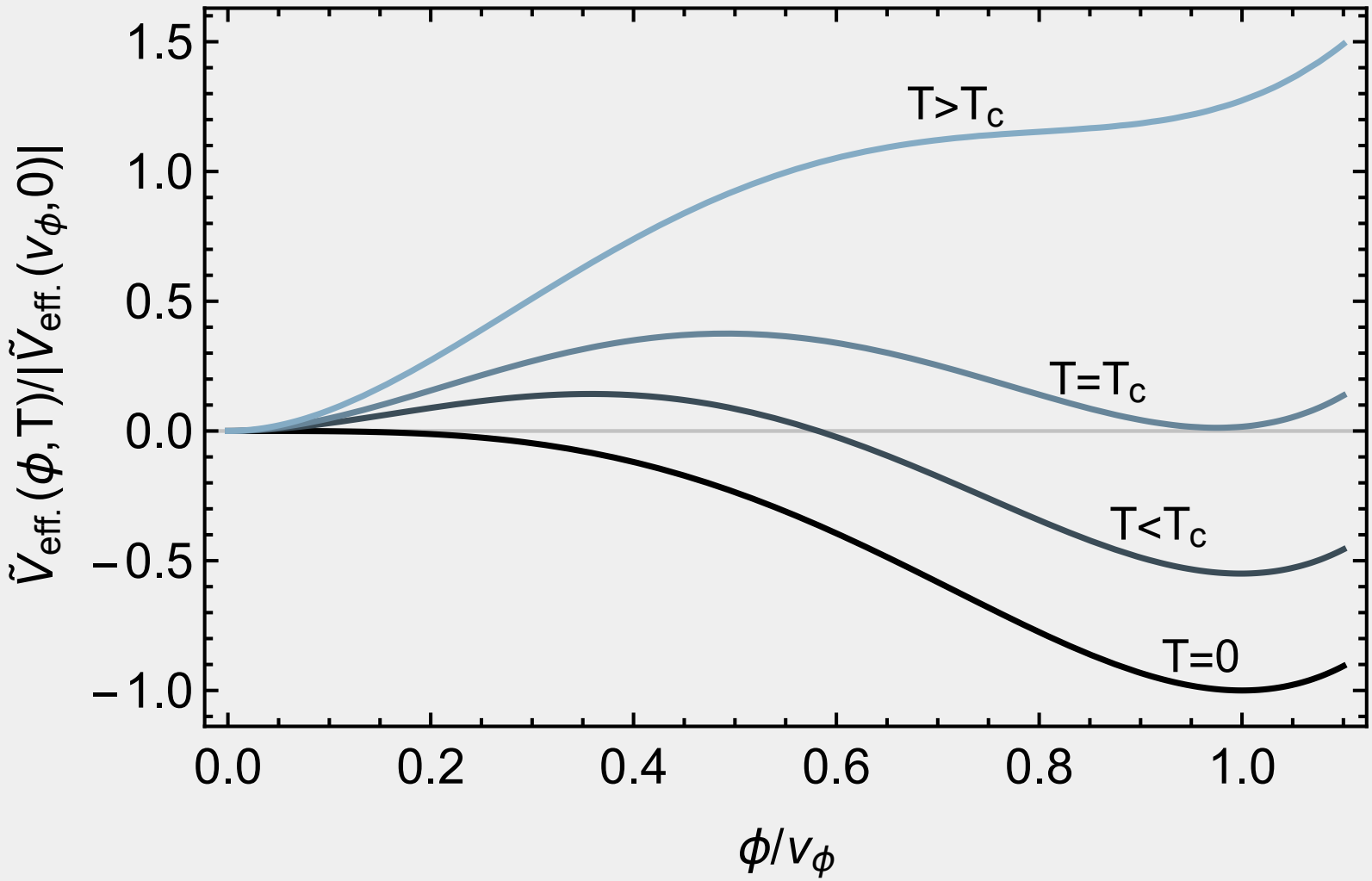
Simplest scenario [Kobakhidze,MS,Talia 1712.05170]



Bino DM depopulation in MSSM [Kobakhidze,MS,Talia 1910.01433]



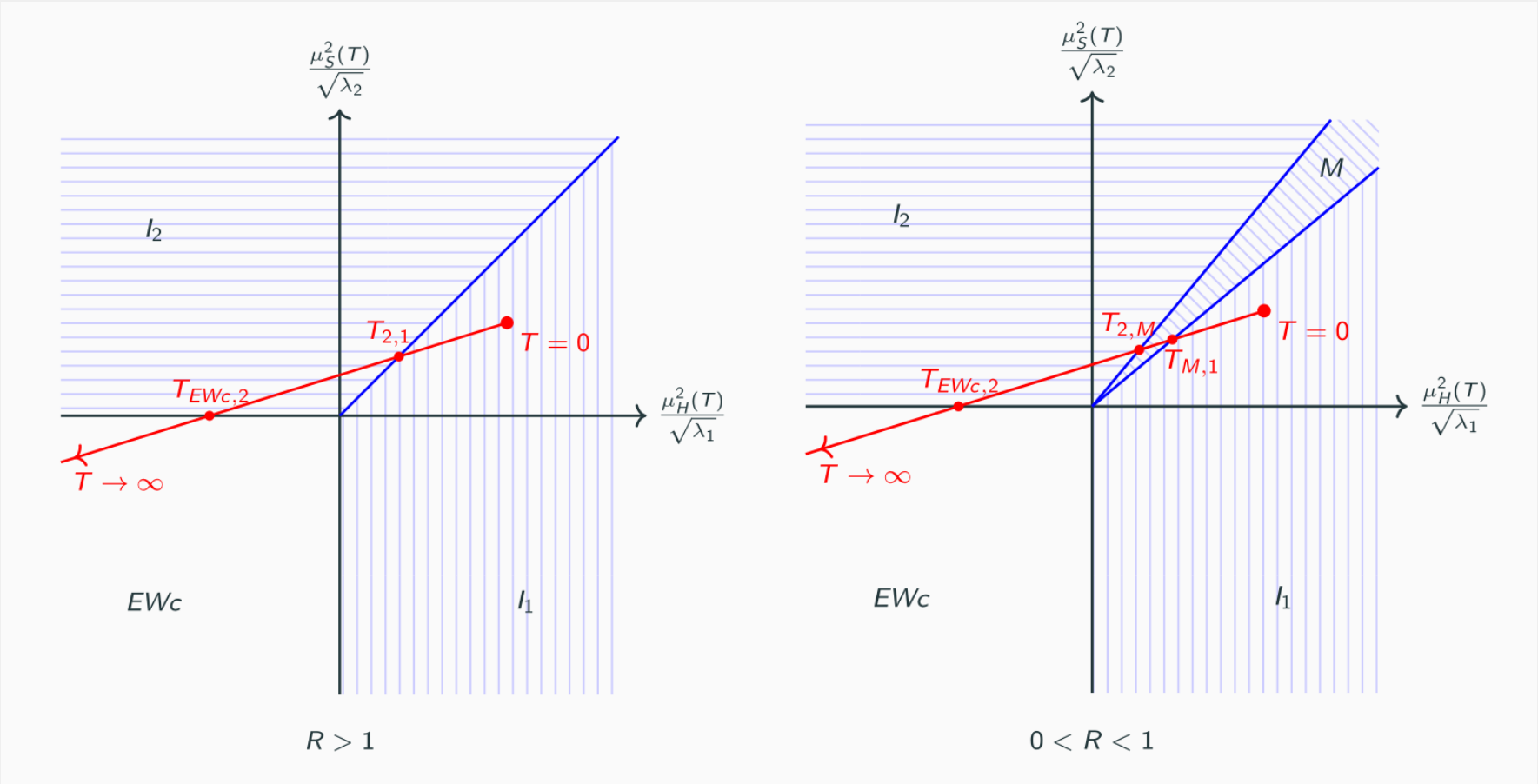
Phase transition



Leading thermal corrections (large T limit): $\delta V(T) = -\mu^2 + c_2 T^2$

Thermal evolution

Four phases: $EWc(\langle S\rangle = \langle H\rangle = 0)$, $I_1(\langle S\rangle = 0)$, $I_2(\langle H\rangle = 0)$, $M(\langle S, H\rangle \neq 0)$



$$R = \frac{\lambda_3 + \lambda_4 - |\lambda_5|}{\sqrt{\lambda_1 \lambda_2}} \simeq \frac{\text{portal coupling}}{\text{self coupling}}$$