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Gravitational waves from superheavy dark matter

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"Dark matter as a portal to new physics"
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Asian Pacific Center for Theoretical Physics.

Based on work with Joseph Bramante, Ningqiang Song, and Simran Nerval
(arxiv:2008.12306)

apctp 아시아태평양이론물리센터 asia pacific center for theoretical physics

Overview

1. **Introduction & Challenges for Superheavy dark matter (SHDM).**

2. **Relic Abundance for SHDM.**

3. **Superheavy dark matter SHDM from Higgs Mechanism.**

4. **Dark first order phase transitions & Gravitational Waves.**

Introduction

Can dark matter be a fundamental particle heavier than 10^{14} GeV?

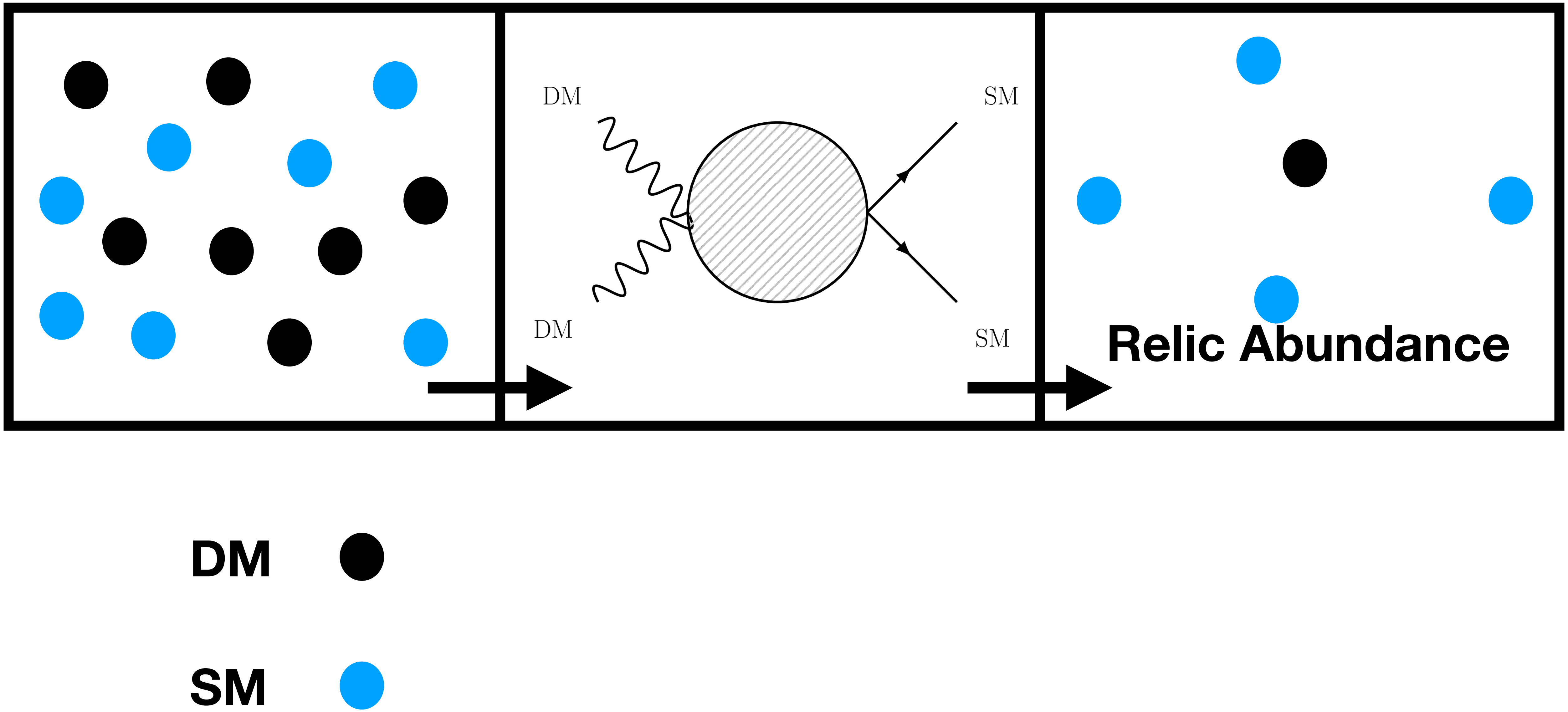
Challenges:

1) Relic abundance

2) Mechanism for generating masses >> 10^{14} GeV

Introduction: Relic Abundance

Freeze - Out: DM as a thermal relic



Introduction: Relic Abundance

Griest-Kamionkowski bound: Freeze-out DM cannot be heavier than O(100) TeV. Not viable for SHDM

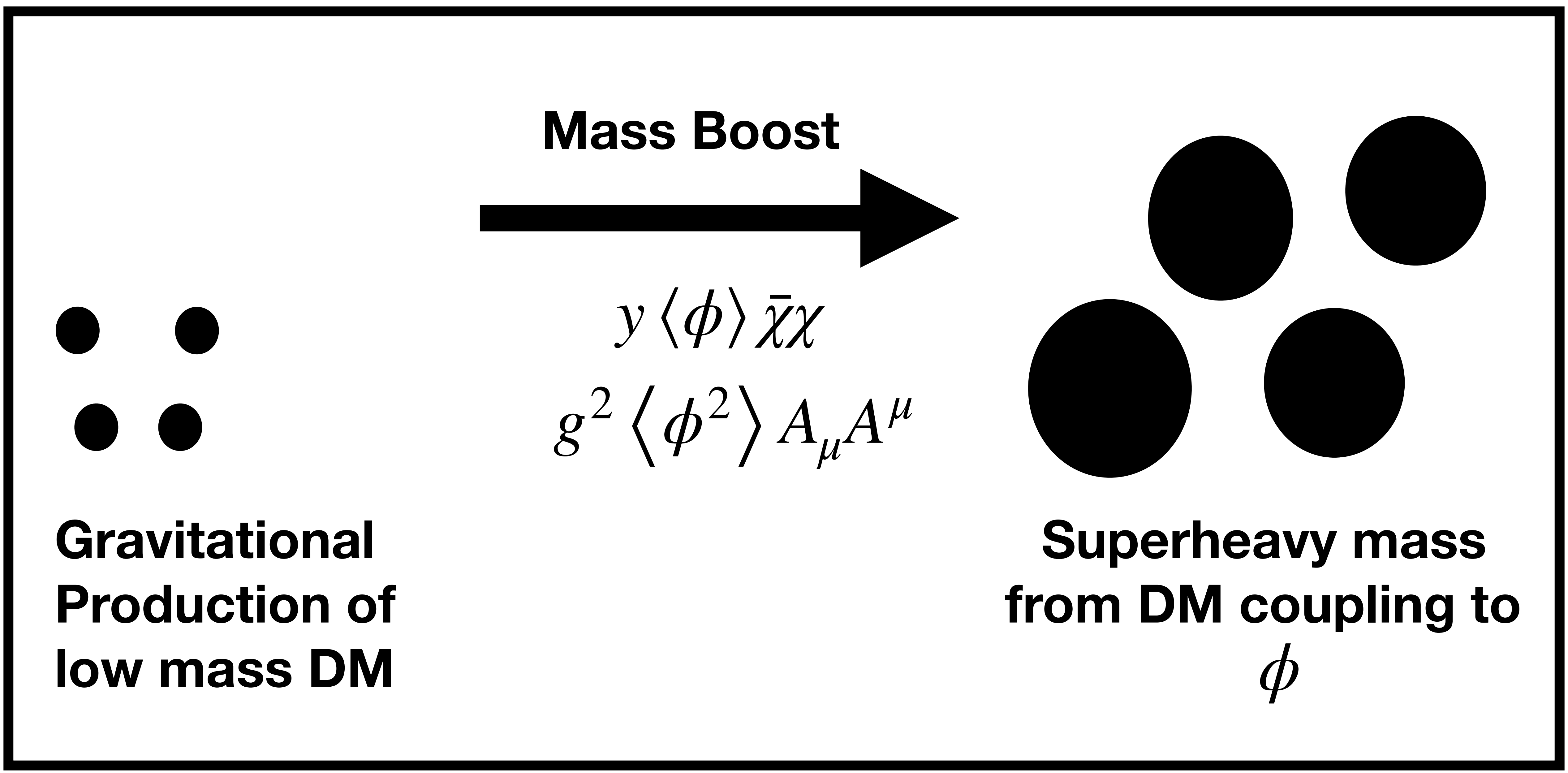
Alternative: Gravitational production at the end of inflation.

Highly suppressed for SHDM.

Mass Boost

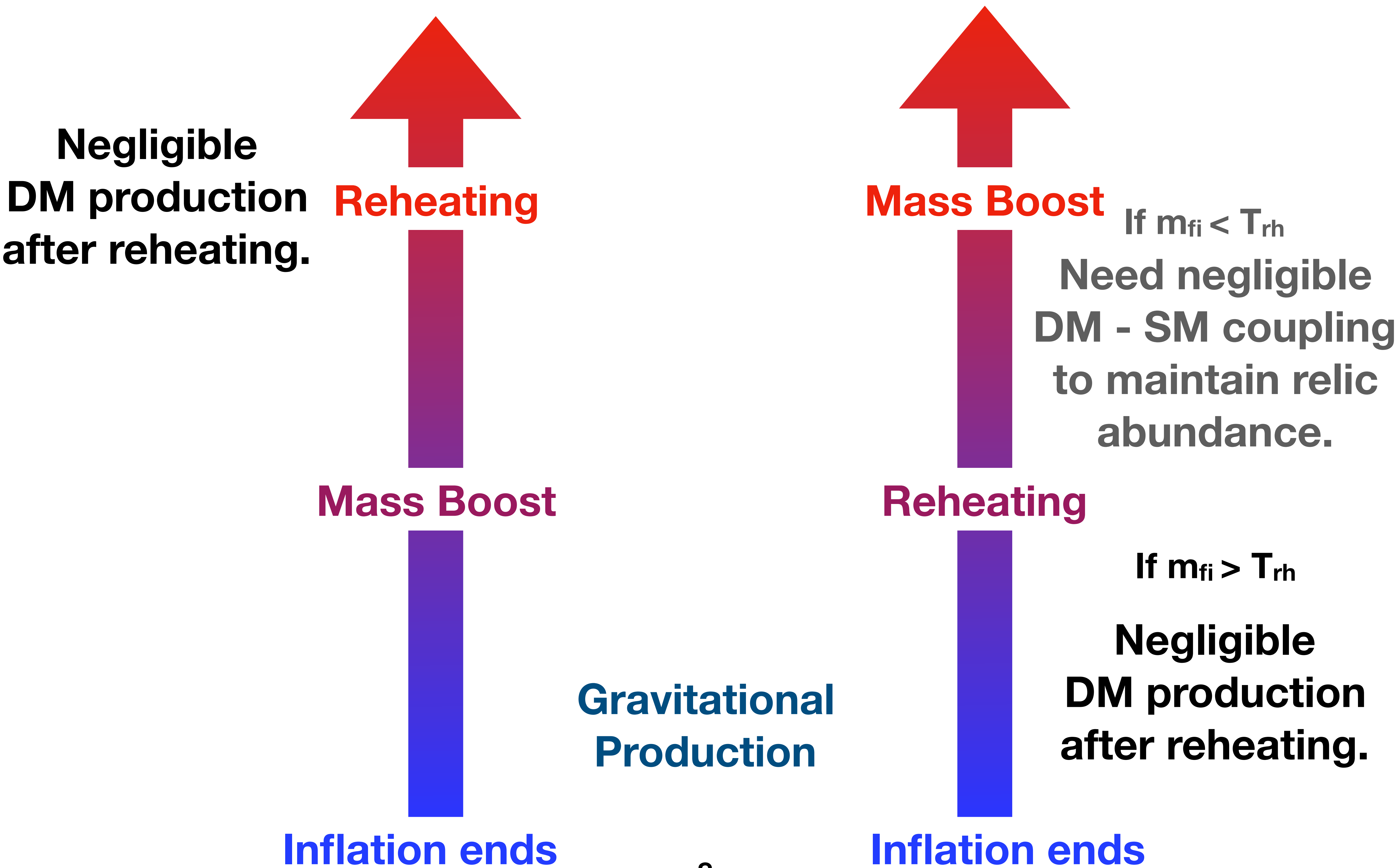
Mass Boost

$$\mathscr{L}_{int} = g^2\phi^2 A_\mu A^\mu + y\phi\bar{\chi}\chi - V\left(\phi\right)$$

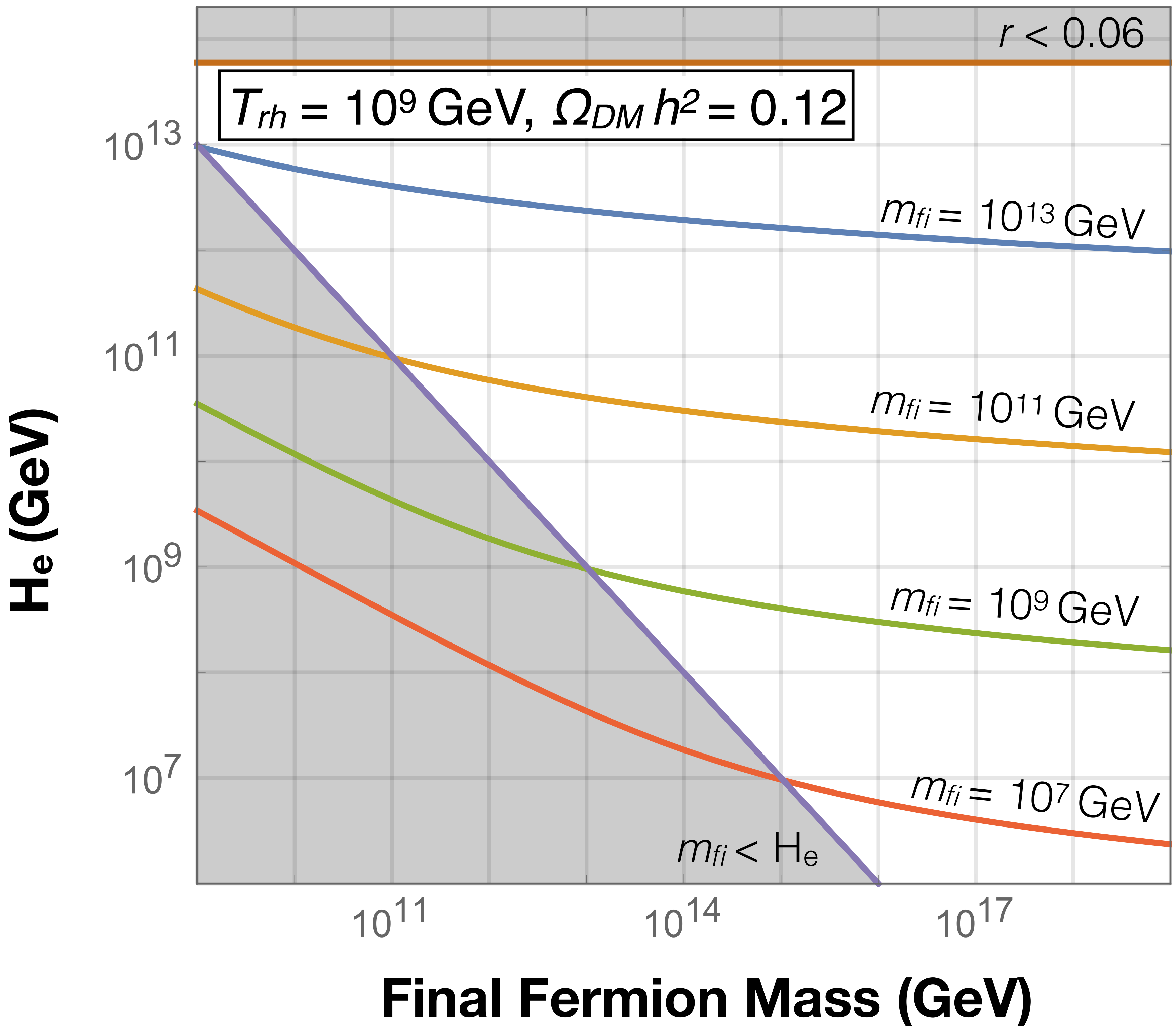


Mass Boost

Two Possibilities



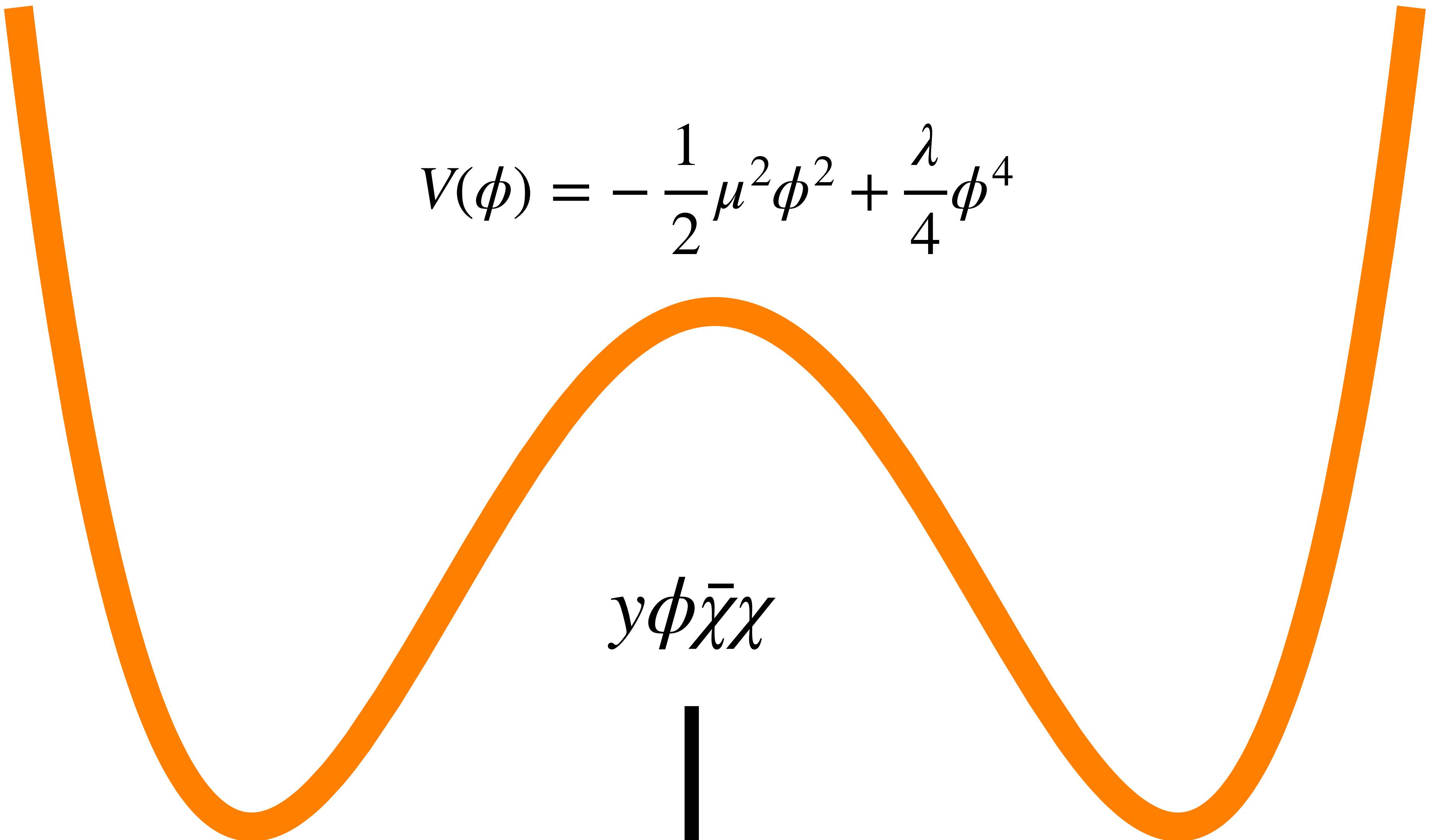
Mass Boost



$r < 0.06$
$T_{rh} = 10^9$ GeV, $\Omega_{DM} h^2 = 0.12$
$m_{fi} = 10^{13}$ GeV
$m_{fi} = 10^{11}$ GeV
$m_{fi} = 10^{9}$ GeV
$m_{fi} = 10^{7}$ GeV
$m_{fi} < H_e$
10^{13}
10^{11}
10^{9}
10^{7}
10^{11}
10^{14}
10^{17}
H_e (GeV)
Final Fermion Mass (GeV)

SHDM from Large VEVs

SHDM from Higgs-like Mechanism



$$V(\phi) = -\frac{1}{2}\mu^2\phi^2 + \frac{\lambda}{4}\phi^4$$

$$y\phi\bar{\chi}\chi$$

↓

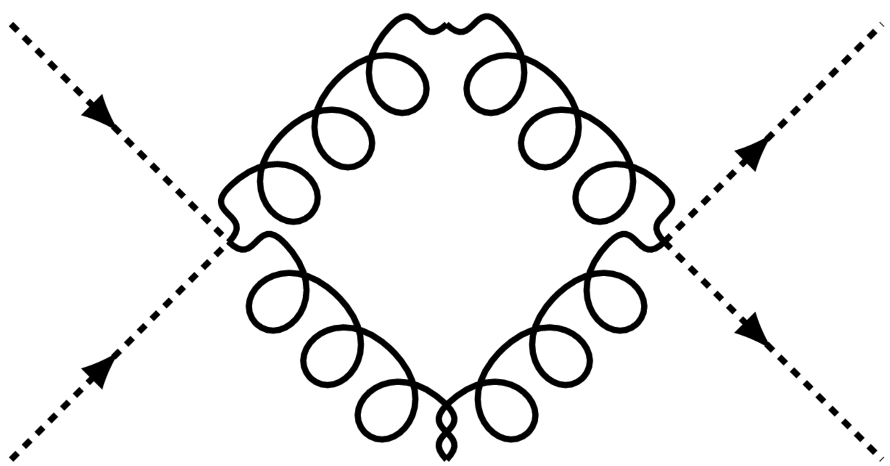
$$m_\chi = y\langle\phi\rangle$$

$$\langle\phi\rangle = \frac{\mu}{\sqrt{\lambda}}$$

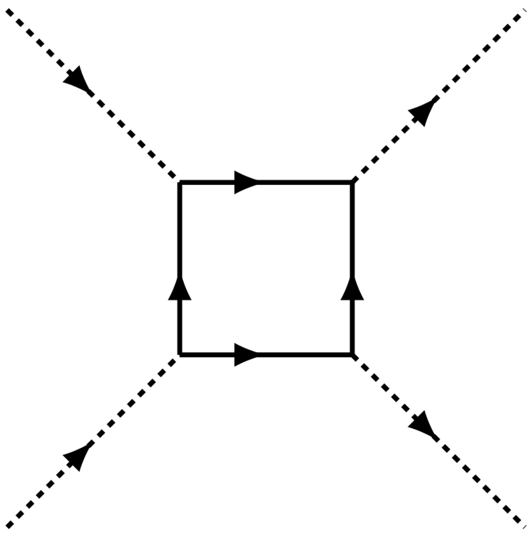
Very small λ **makes** $\langle\phi\rangle$ **large**

SHDM from Higgs-like Mechanism

λ **not arbitrarily small. Receives loop corrections.**



$$\sim g^4 \qquad - \qquad \sim y^4$$



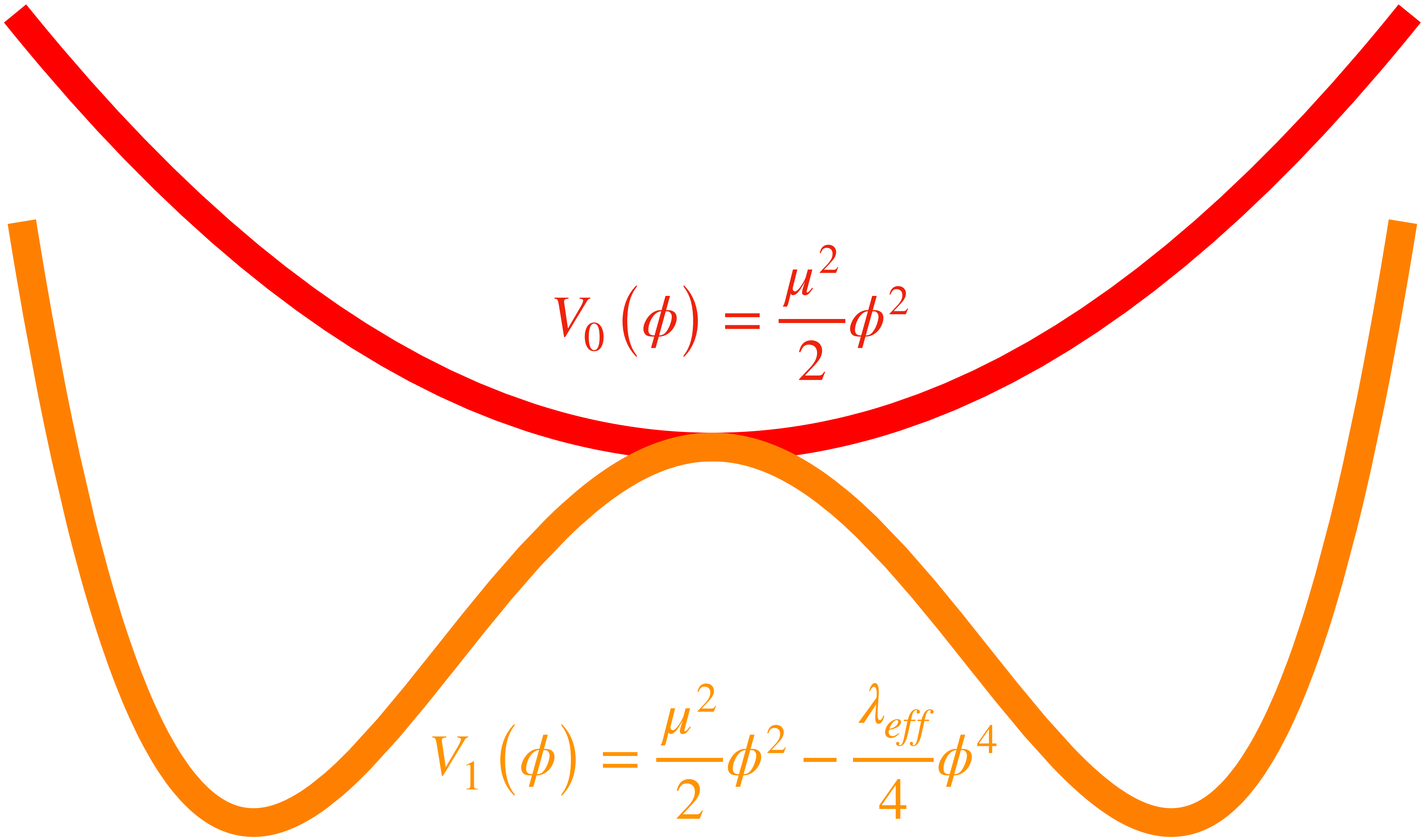
$$\lambda_{eff} \sim \frac{1}{16\pi^2}\left(4y^4 - 3g^4\right)$$

Small y, g

Avoid tuning between y and g.

SHDM from Higgs-like Mechanism

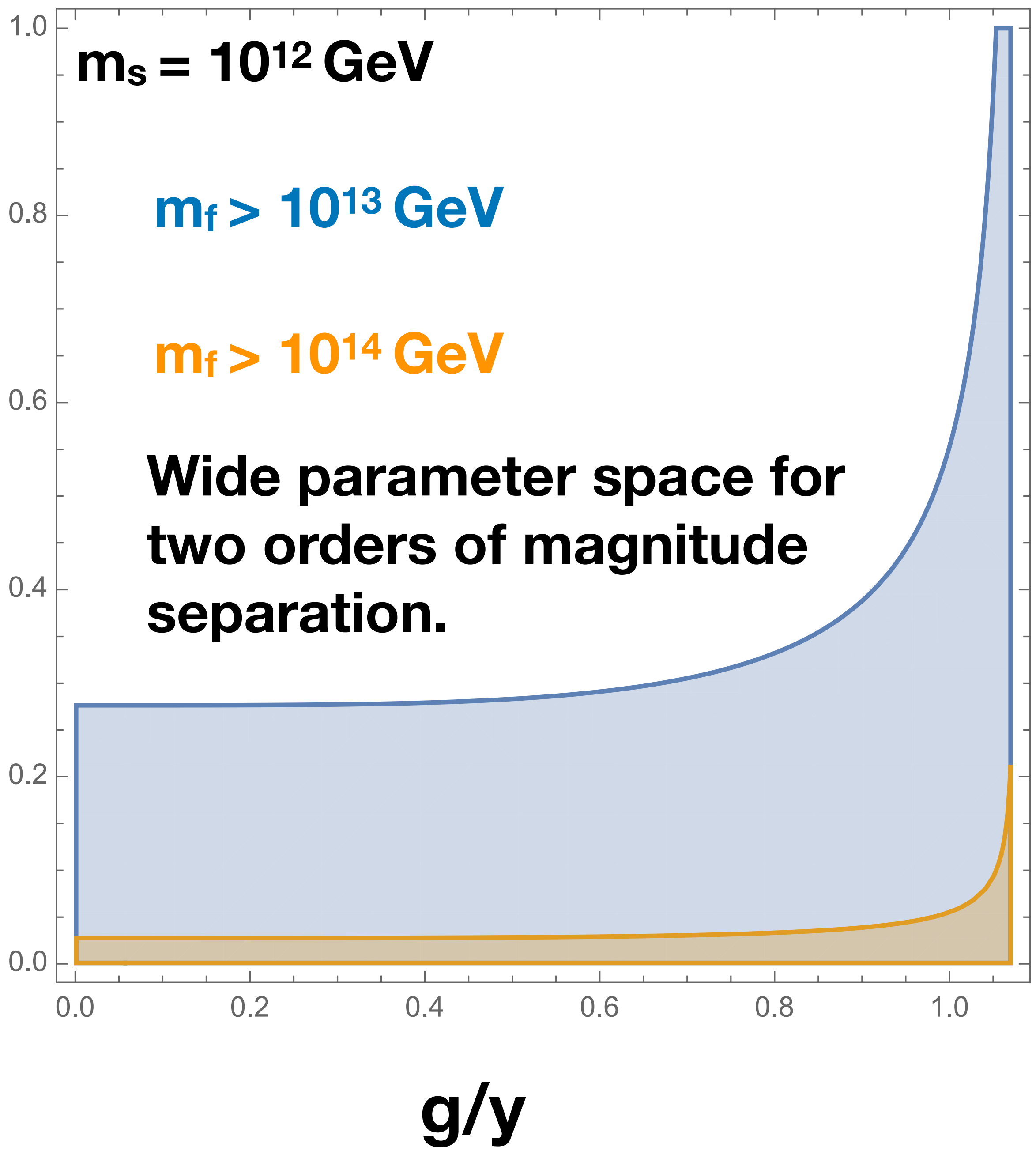
$$\mathscr{L}_{int} = g^2\phi^2 A_\mu A^\mu + y\phi\bar{\chi}\chi + \frac{\mu^2}{2}\phi^2$$

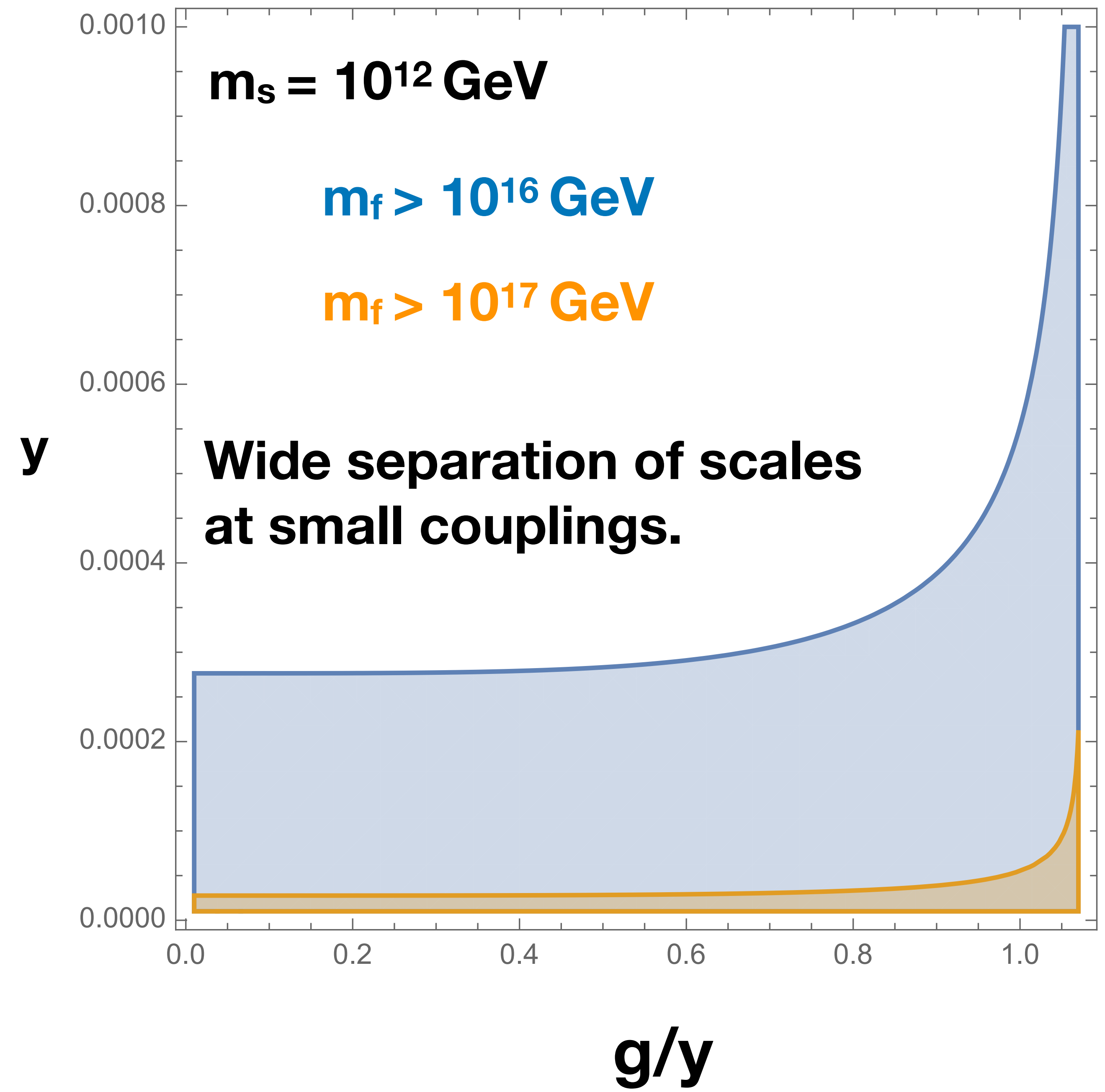


$$\langle\phi\rangle \sim \frac{\mu}{\sqrt{4y^4 - 3g^4}}$$

Loop corrections generate a VEV.

SHDM from Higgs-like Mechanism



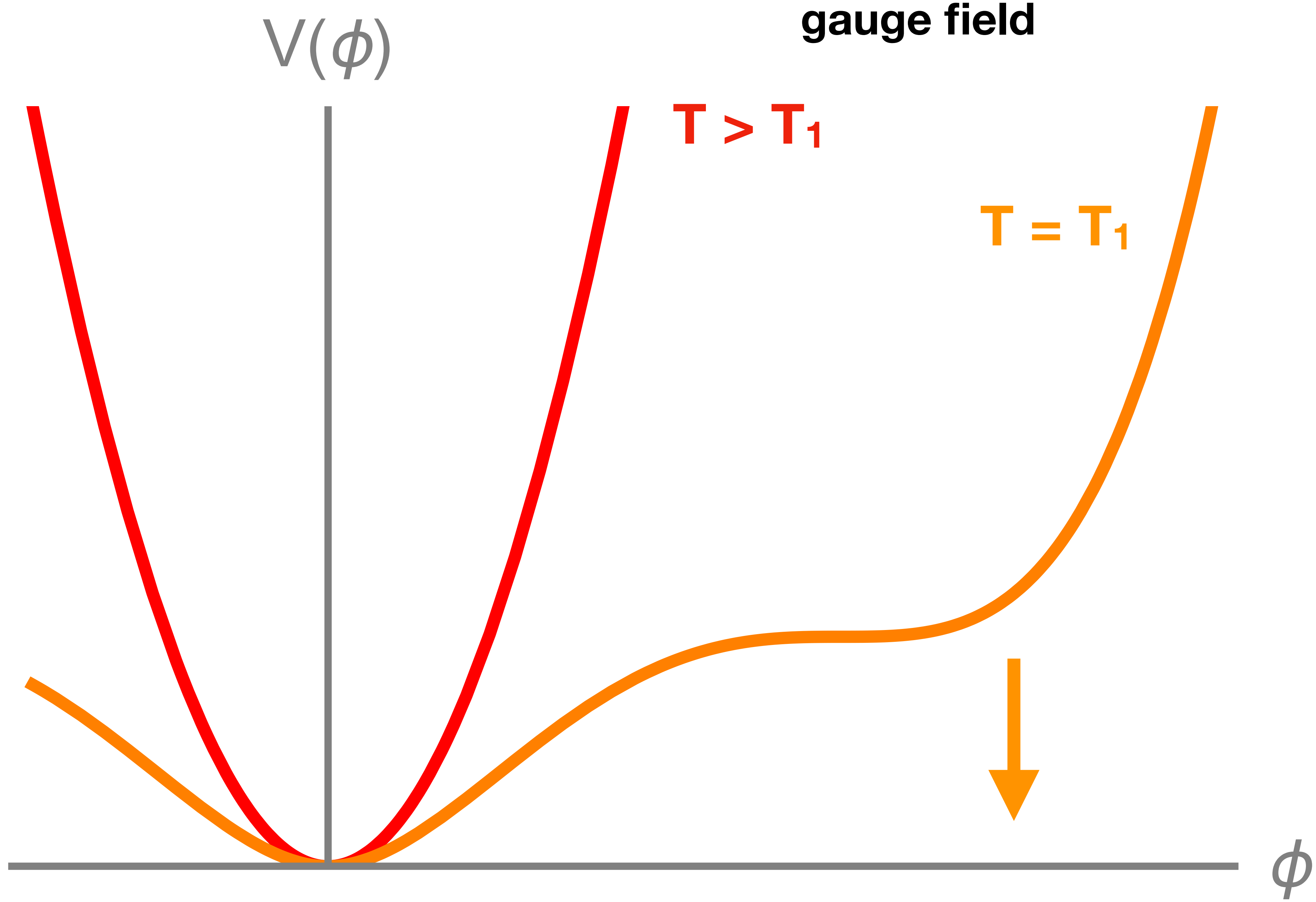


Dark Sector Phase Transitions

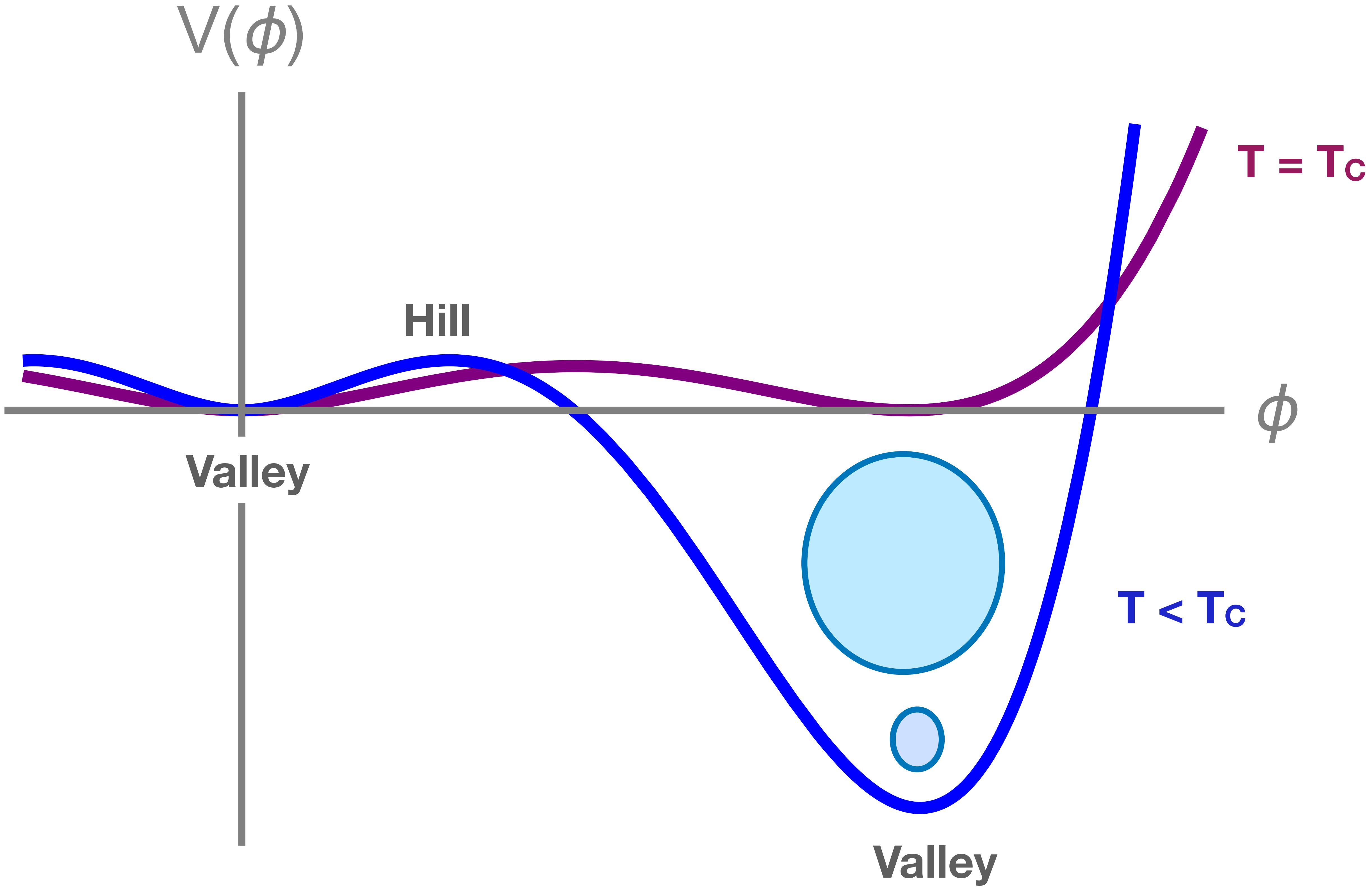
Dark First Order Phase Transitions

$$V\left(\phi, T\right) = D\left(T^2 - T_0^2\right)\phi^2 - ET\phi^3 + \lambda\left(T\right)\phi^4$$

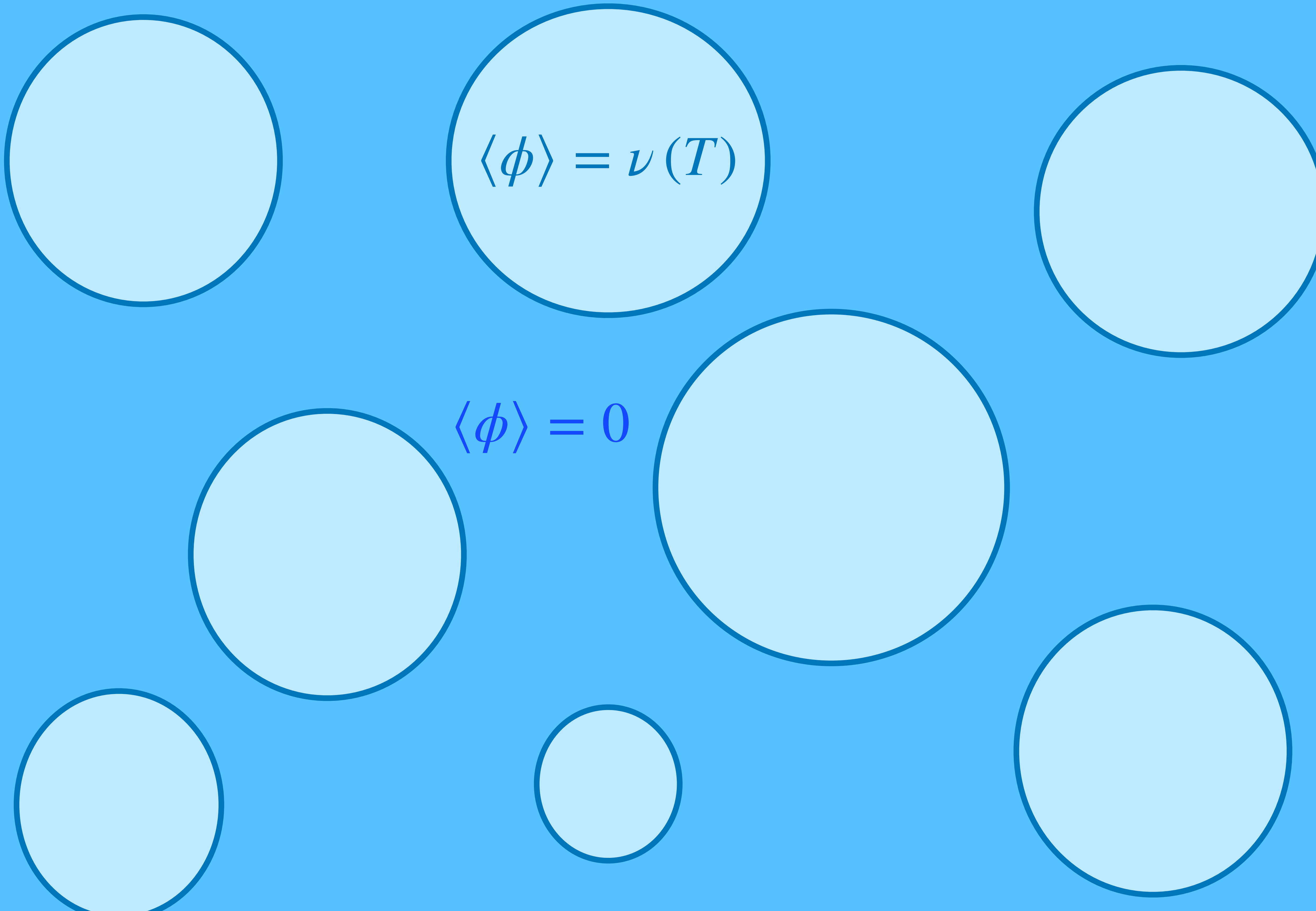
Only from gauge field



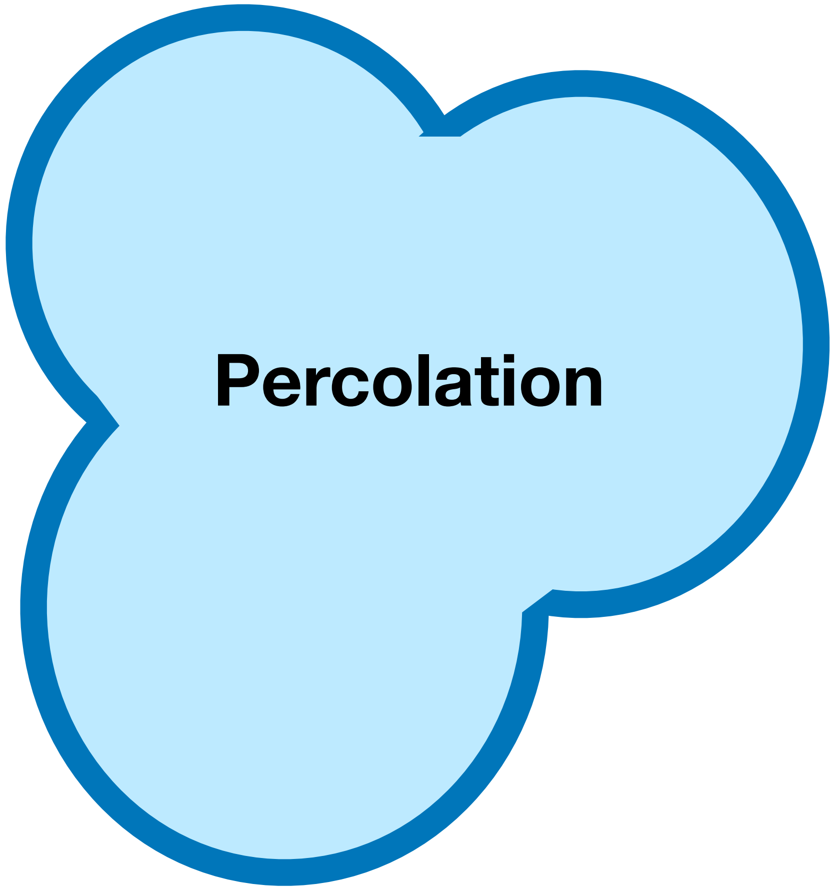
Dark First Order Phase Transitions

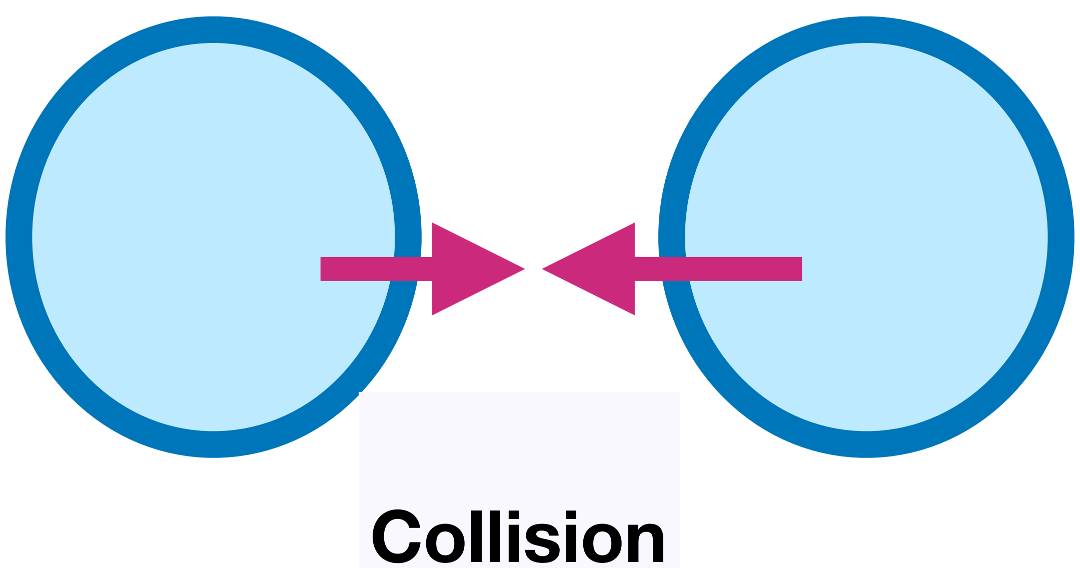


Dark First Order Phase Transitions



Dark First Order Phase Transitions



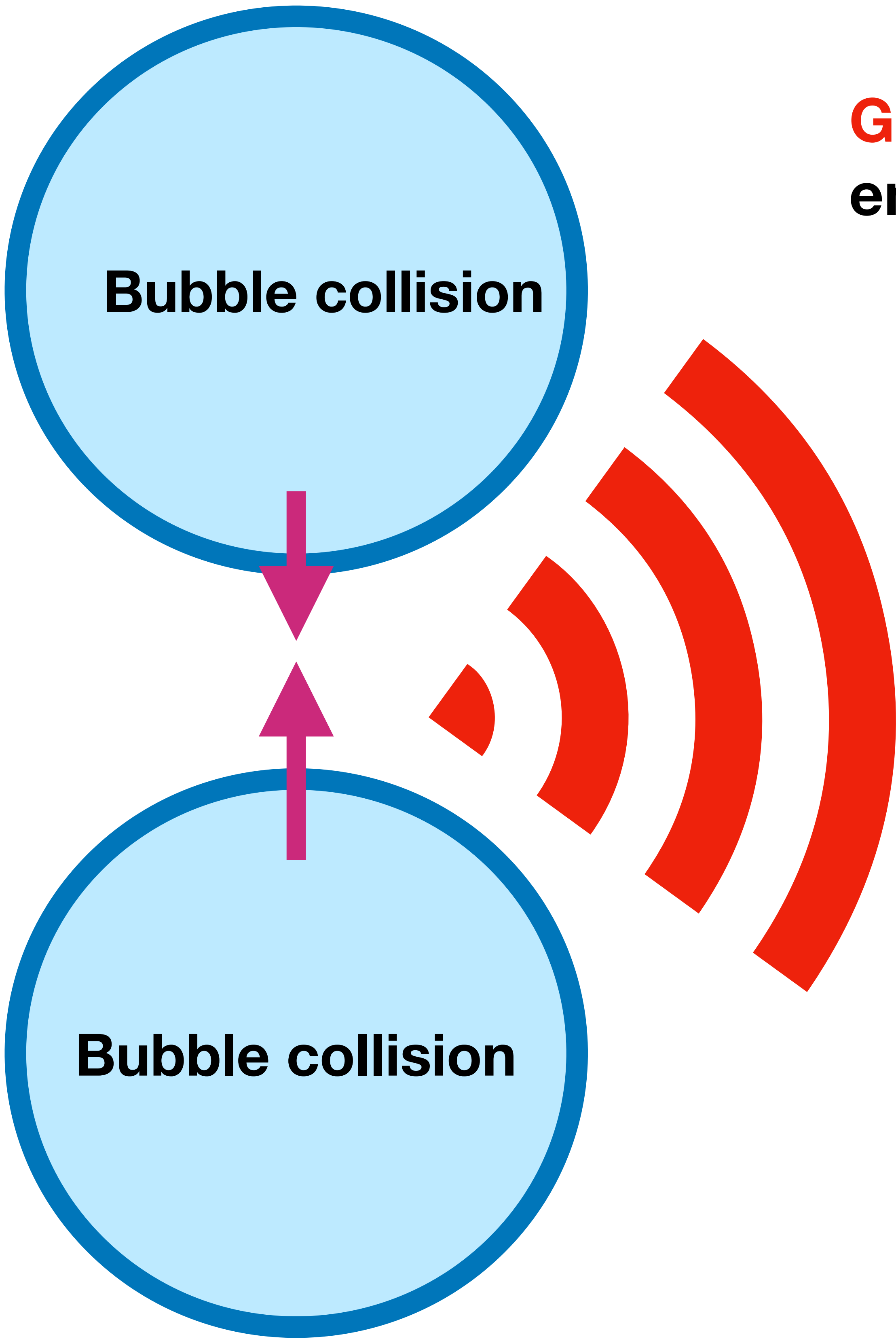


Bubbles grow, collide, and percolate.

PT to complete
bubble nucleation rate
must be fast compared
to Hubble Expansion.

Nucleation temperature T_N :
Temperature when bubble
nucleation rate is one per
Hubble volume.

Dark First Order Phase Transitions



Gravitational Waves (GW) emitted from collisions of bubbles.

For PT to complete bubble nucleation rate must be fast compared to Hubble Expansion.

Nucleation temperature T_N : Temperature when bubble nucleation rate is one per Hubble volume.

GW signal strongest T_N. Spectrum a power law peaked at T_N .

Gravitational Waves

$$\Omega_{GW}h^2 = \Omega_{SW}h^2 + \Omega_{BC}h^2 + \Omega_{MT}h^2$$

Dominant

Three sources of GW:

BC - Bubble collisions themselves.

SW - Sound Waves from bubble dumping its energy into the Standard Model plasma.

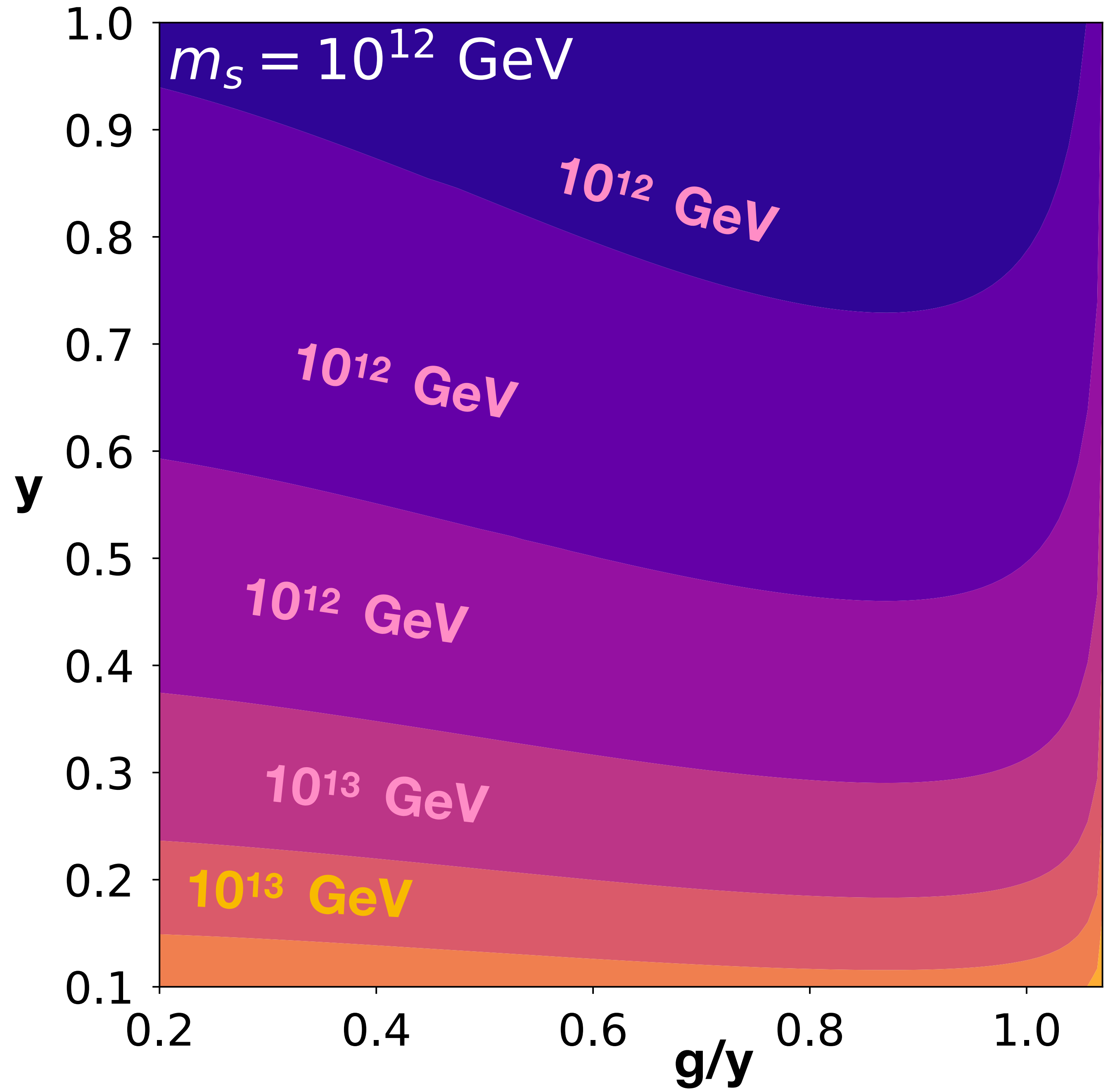
MT - Magnetohydrodynamical turbulence

Gravitational Waves

$T_C \sim T_N$: Indicates when GWs emitted.

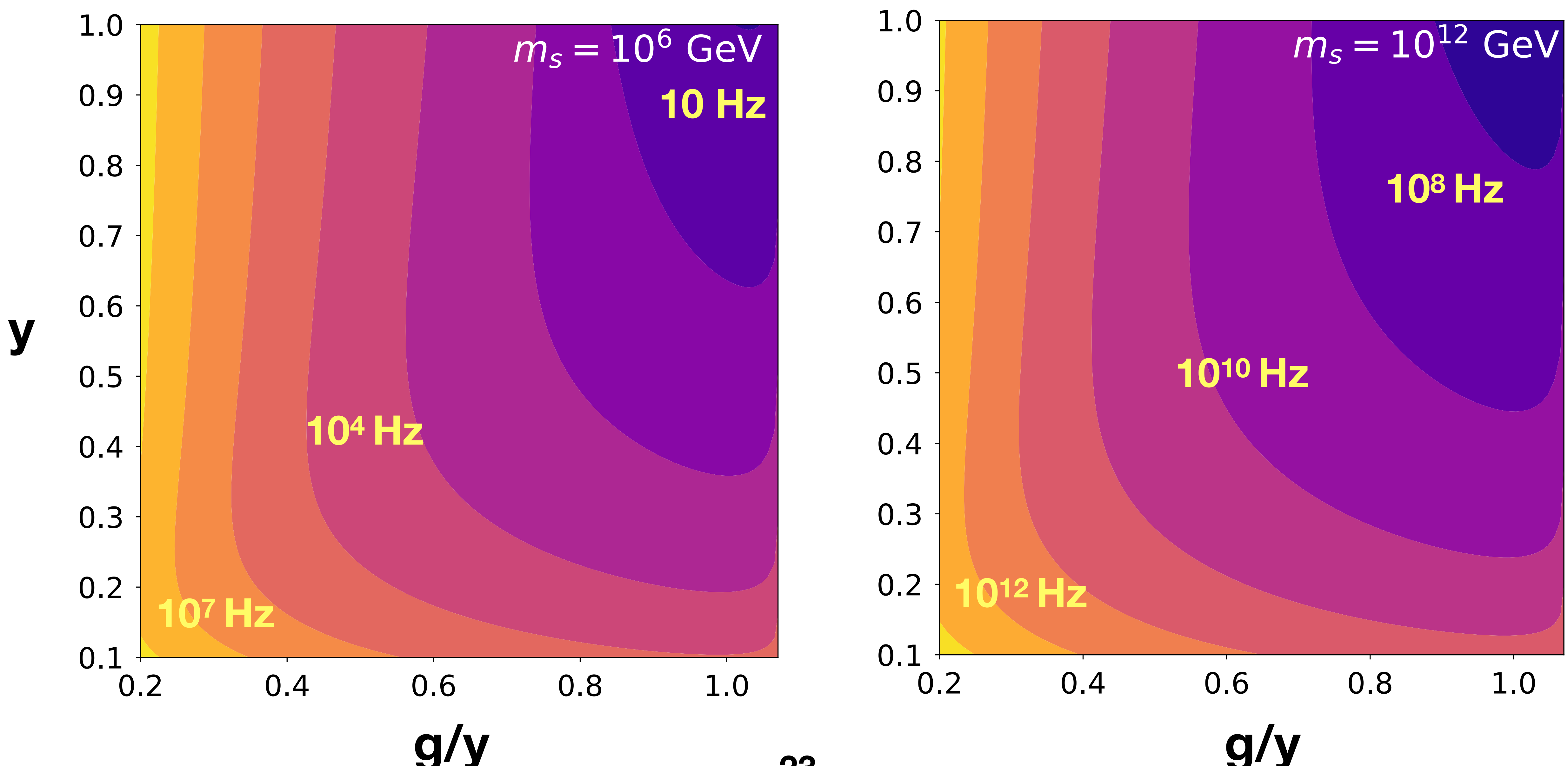
Early GWs are highly redshifted. SHDM induced GWs might be detected at planned future detectors.

T_C

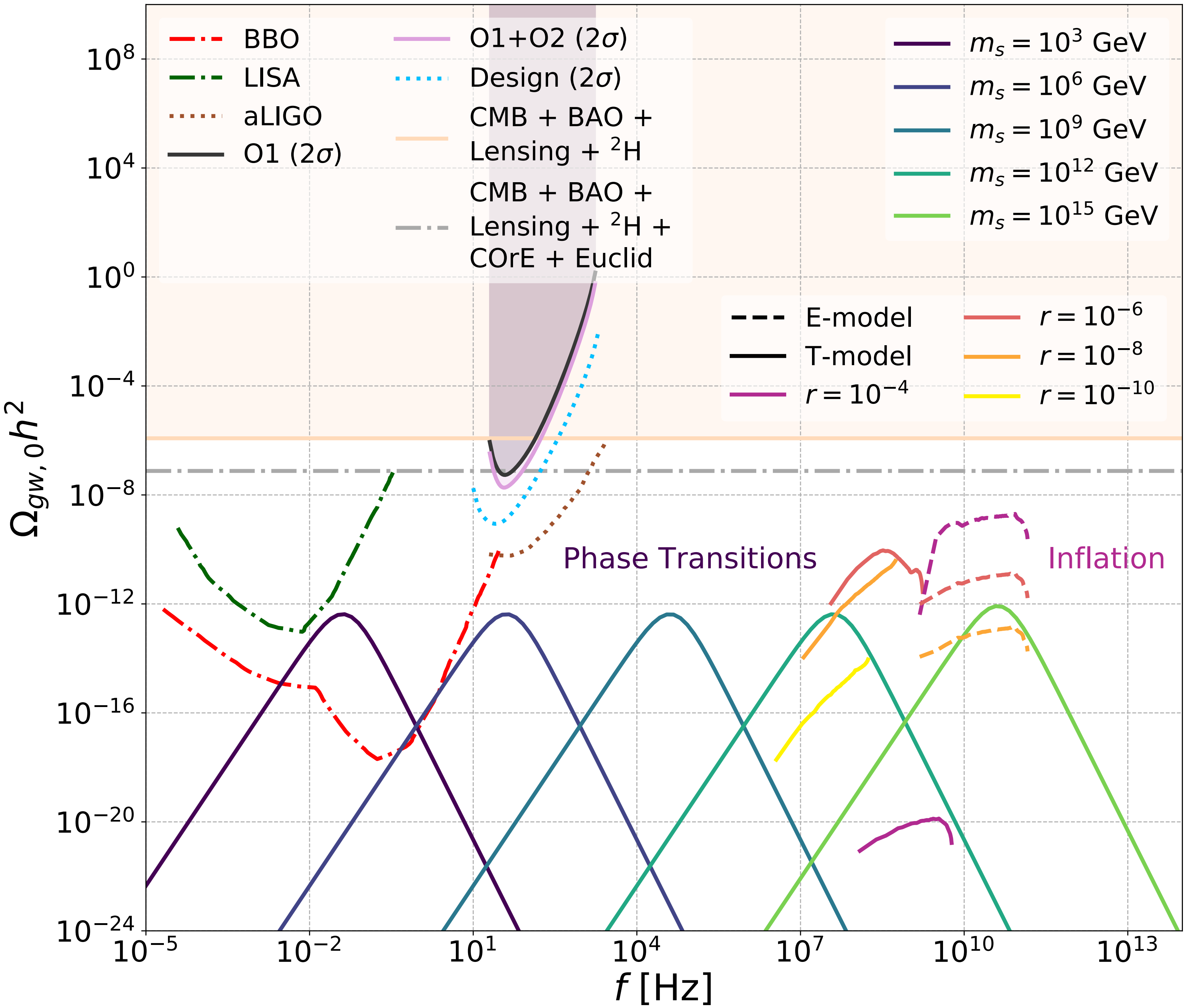


Gravitational Waves

Peak Frequency GW from SHDM



Gravitational Waves



y = 0.8

g/y = 1.05

Conclusion

1) Possible for dark matter to be a fundamental particle heavier than 10^{14} GeV.

2) Mass boost mechanism an excellent way to achieve right dark matter relic abundance.

3) Superheavy dark matter can be generated through the Higgs Mechanism.

4) Superheavy dark matter can produce gravitational wave signals within reach of future experiments.

5) Gravitational wave detectors offer an exciting new probe of dark sector phase transitions.