Living on the Edge:
Why the early Universe prefers the non-supersymmetric vacuum

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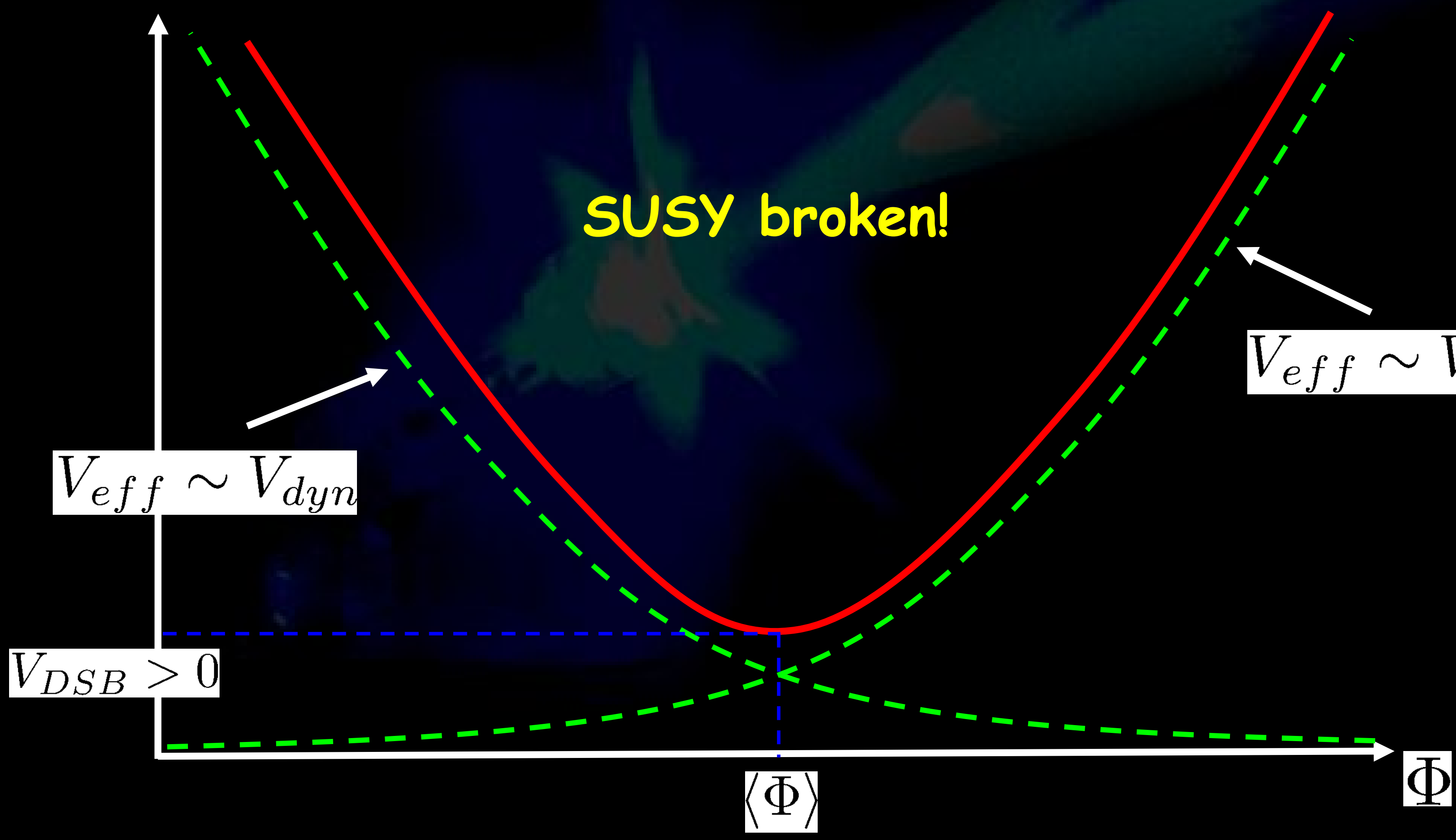
1. Introduction

Conventional picture of DSB



ISS picture of meta-stable SUSY breaking

Advantages of Metastability

- Simplifies models
  (Avoids constraints on R-Symmetry.)

- May be calculable

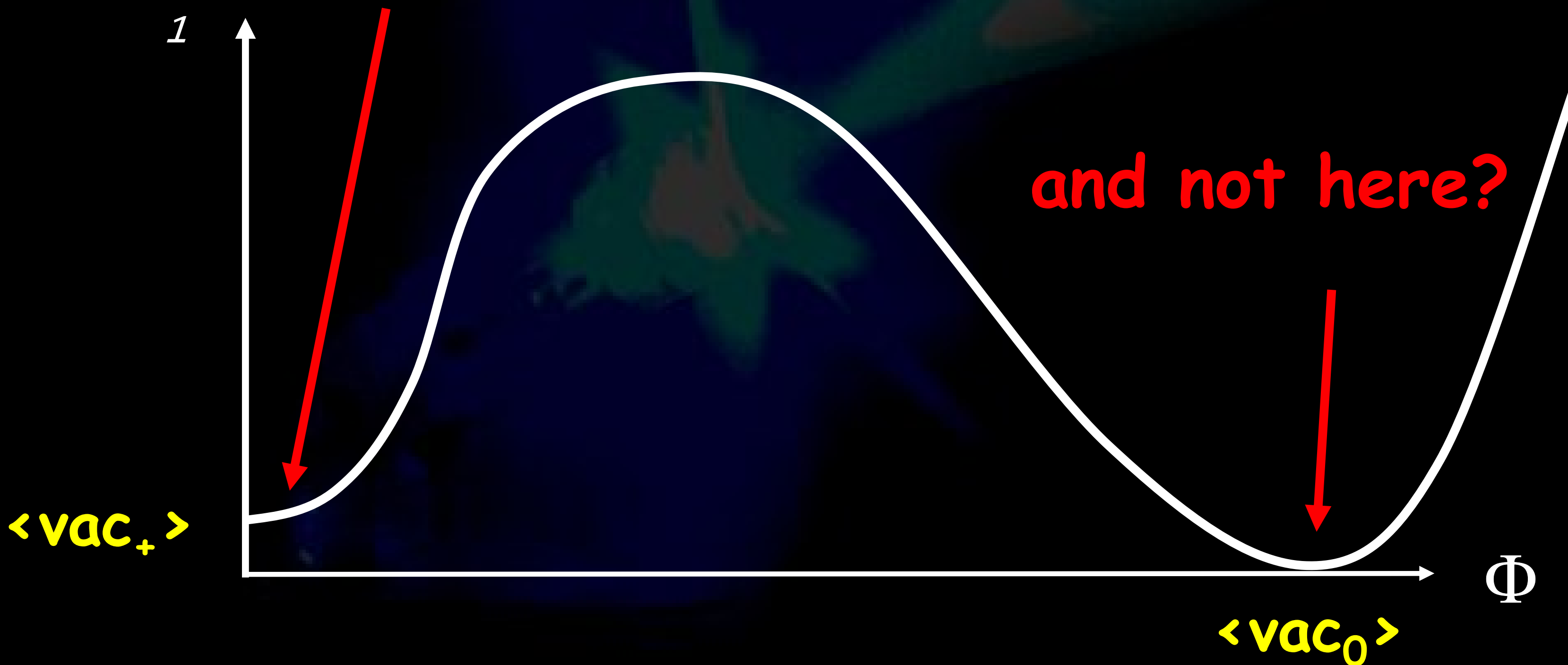
⬇

New Opportunities for Model Building!

(Valya Khoze)

Question of this talk

Why are we here?



Message of the Day

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Why is the Universe in the non-supersymmetric vacuum?

Our answer: thermal effects drive the Universe to the susy-breaking vacuum even if it starts after inflation in the susy-preserving one.

This happens for a large class of models that satisfy:

1. All fields of the theory (MSB, MSSM, messengers) are in thermal equilibrium. True for gauge mediation, direct mediation, and visible sector breaking.
   (Excludes gravity-mediation.)
2. SUSY preserving $\langle vac_0 \rangle$ contains fewer light fields than the meta-stable $\langle vac_+ \rangle$.

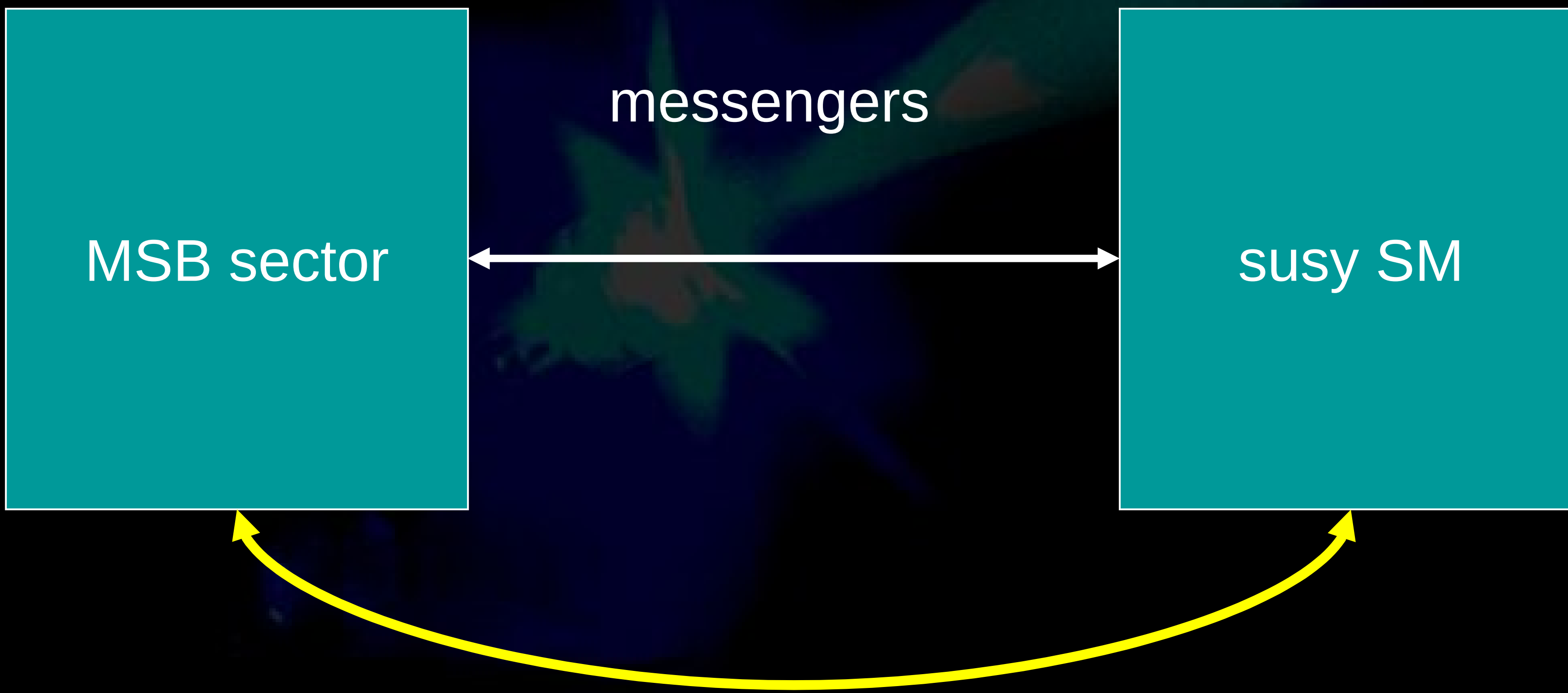
2. Setup

Full Theory

- Full Theory

Full Theory

- Full Theory



Thermal Equilibrium!

3. Getting to the metastable vacuum

Free Energy

- In a thermal environment systems try to minimize Free Energy:

$$F = E - TS$$

Wins at high T!

Expect negative contribution!

Thermal effective potential

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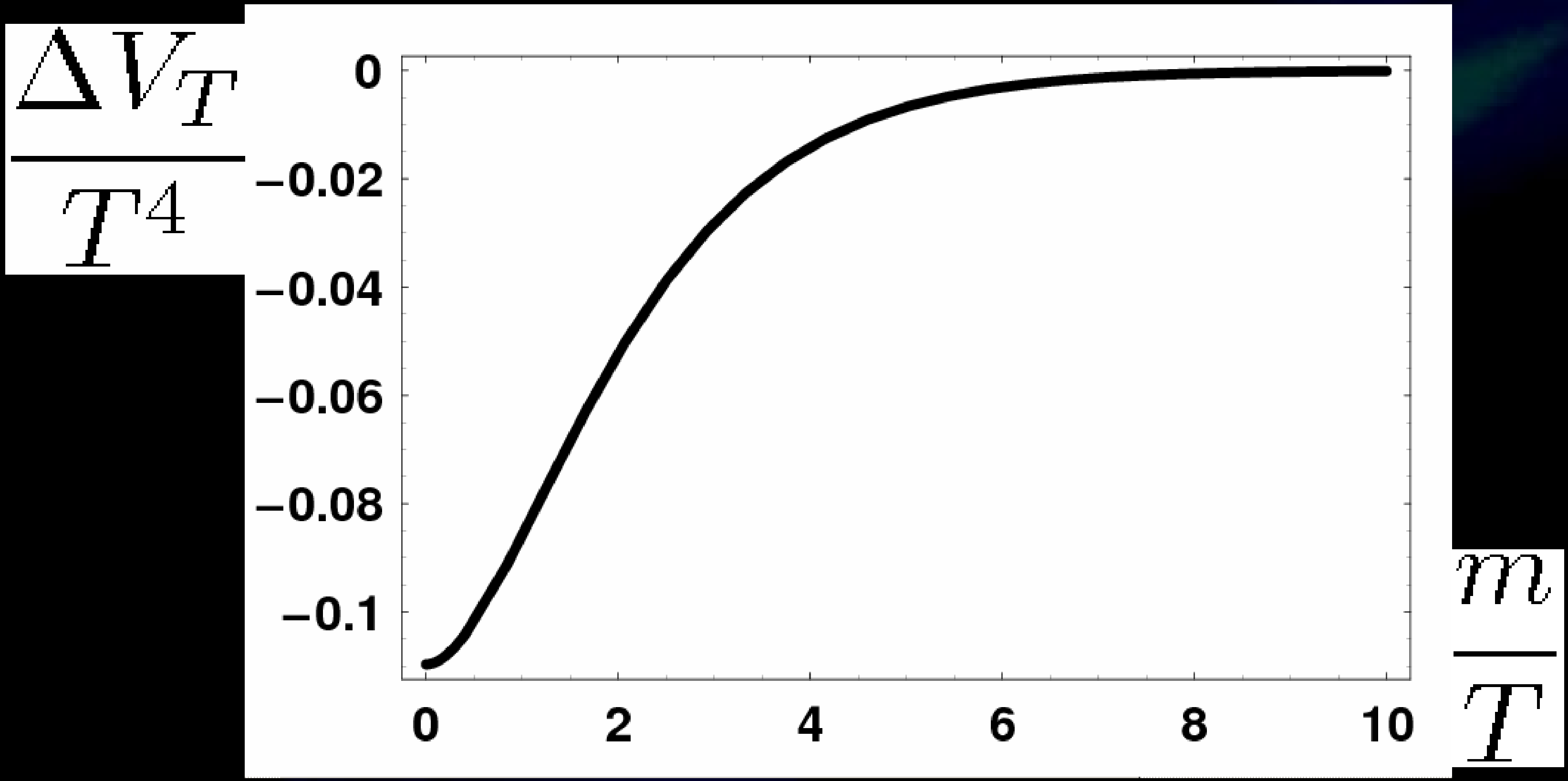
$$V_T(\Phi) = V_{T=0}(\Phi) + \frac{T^4}{2\pi^2}\sum_i \pm n_i \int_0^\infty \mathrm{d}q\, q^2 \ln\left(1 \mp \exp(-\sqrt{q^2 + m_i^2(\Phi)/T^2})\right)$$

- 1-loop expression.
- n_i are the numbers of degrees of freedom (+ corresponds to bosons; - to fermions.)
- $m_i^2(\Phi)$ are their masses as functions of $\langle\Phi\rangle$.
- Φ-dependence in the thermal correction is only through $m_i^2(\Phi)$

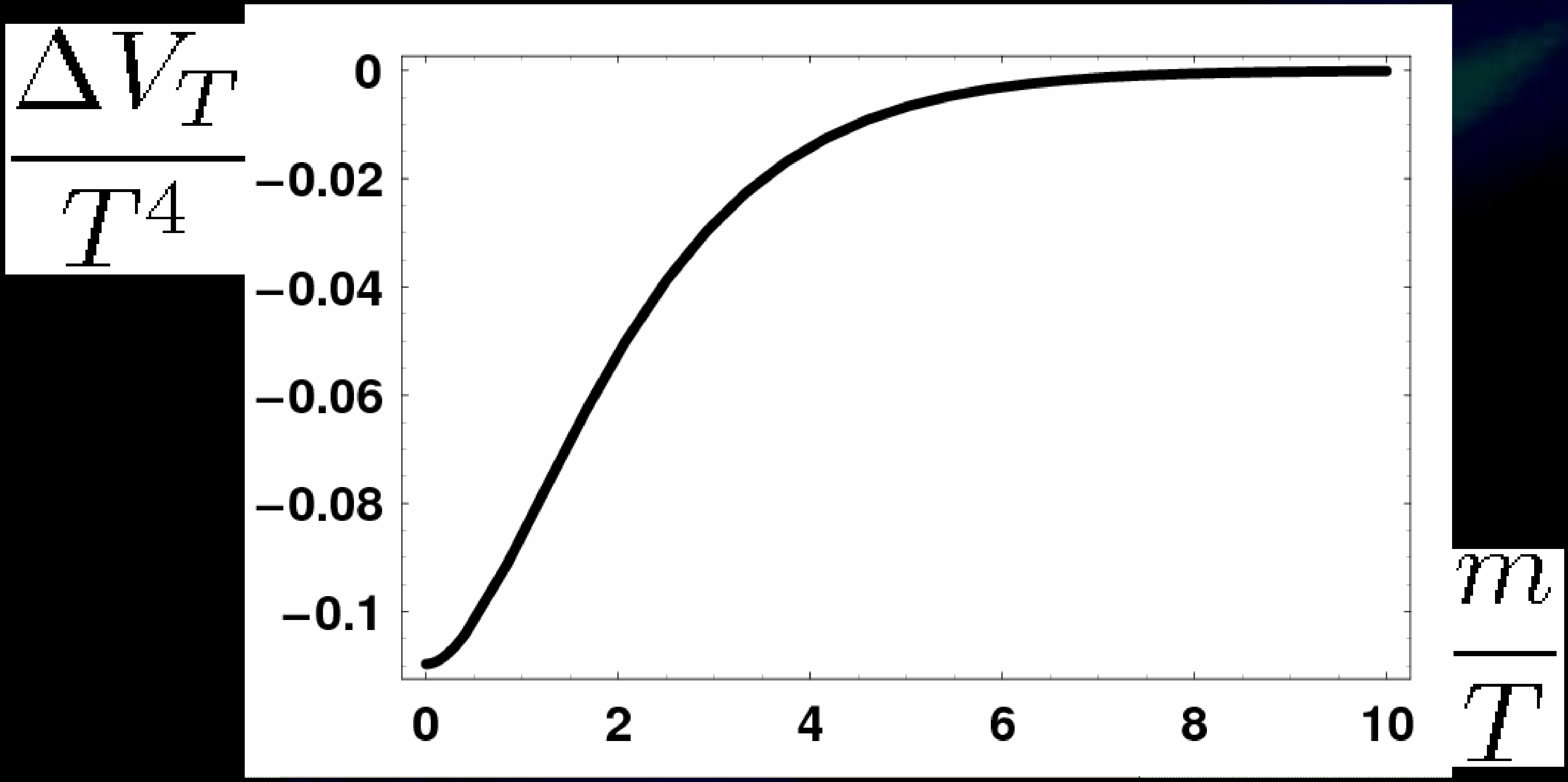
Thermal effective Potential



$$\Delta V_T(m=0) = \frac{\pi^2}{90}\begin{cases} 1 & bosons \\ 7/8 & fermions \end{cases}$$

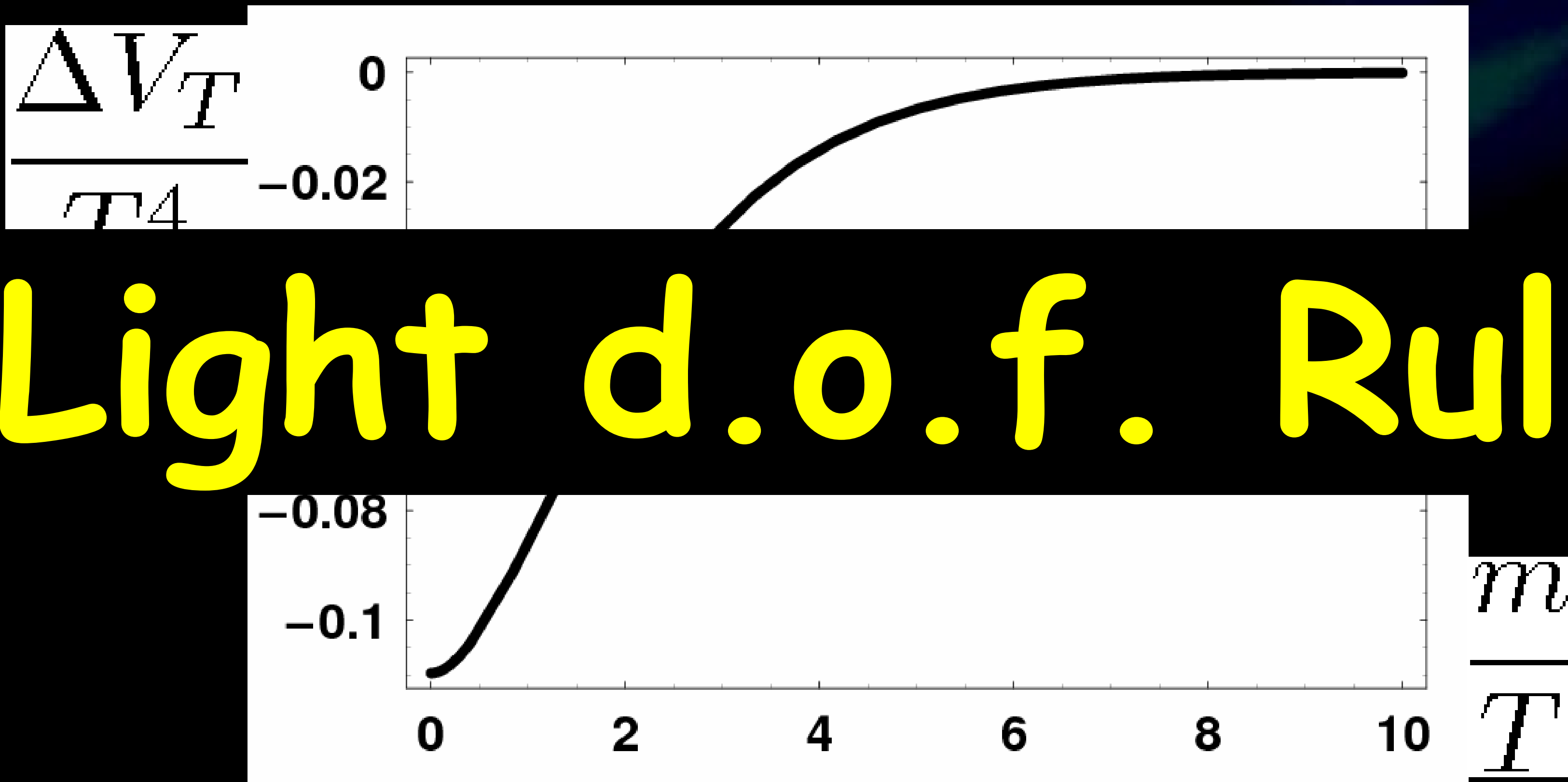
$$\Delta V_T(m >> T) \approx 0$$

Thermal effective Potential



➡ Preference of the SUSY breaking vacuum at high T arises because the SUSY breaking vacuum has more light d.o.f.!

Thermal effective Potential



Light d.o.f. Rule!!

➡ Preference of the SUSY breaking vacuum at high T arises because the SUSY breaking vacuum has more light d.o.f.!

Massive Particles at $\Phi>0$

- Quark masses:

$$m_\varphi = h\Phi$$

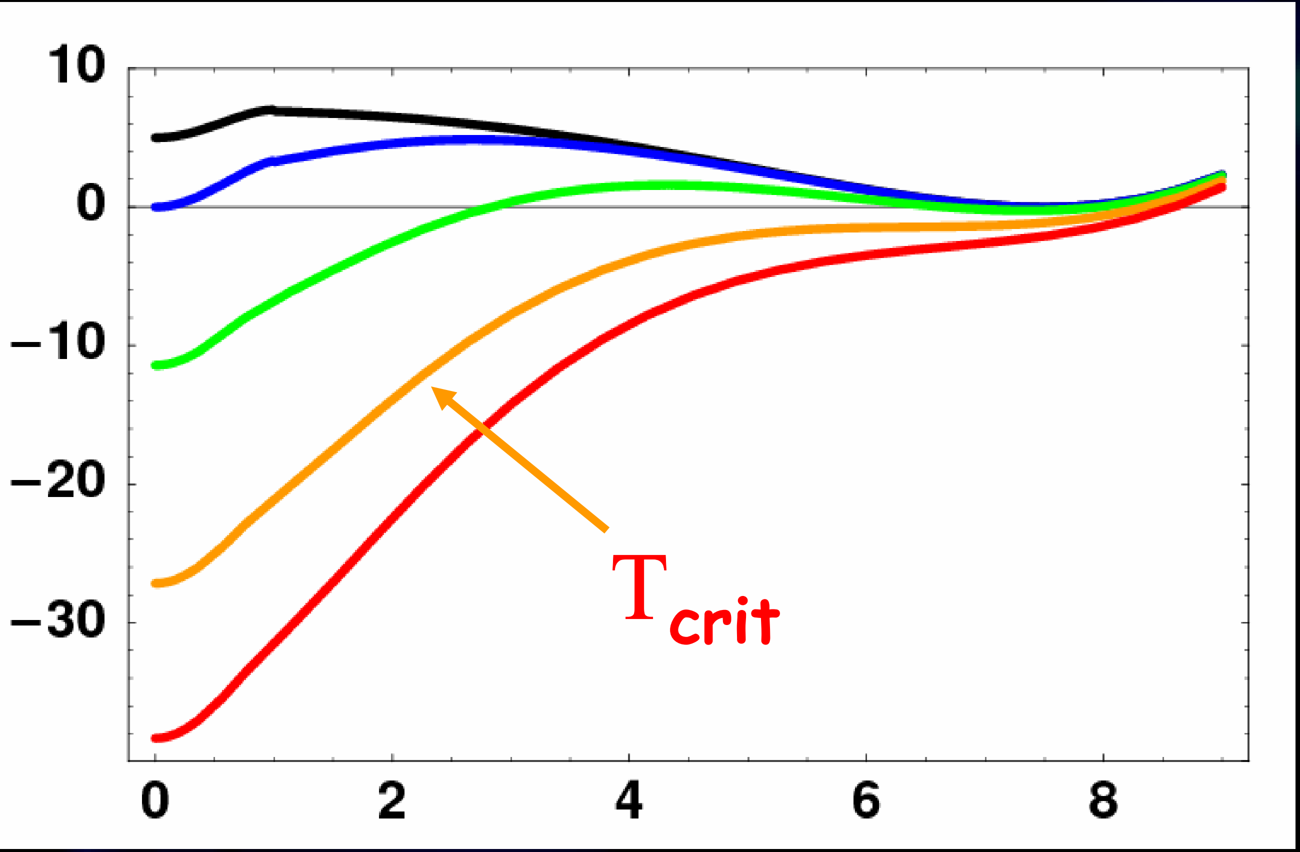
Quarks are heavy in the SUSY breaking minimum Φ^1 0!

- Gluons are

Free at $\Phi=0$ Confined at $\Phi>0$

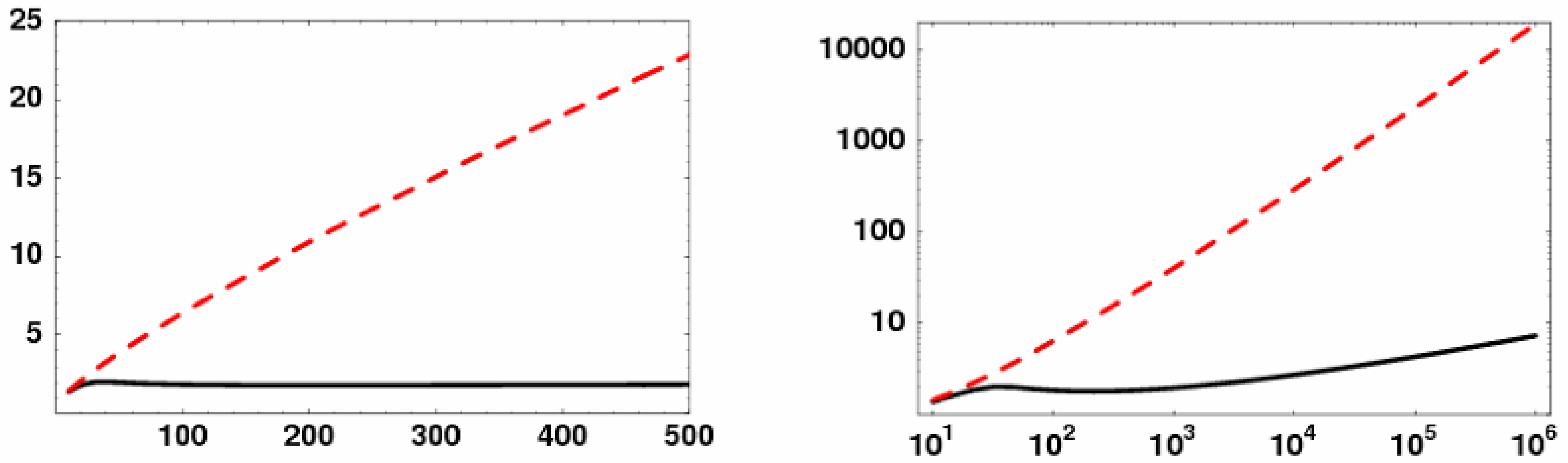
Gauge bosons are heavy in the SUSY breaking minimum Φ^1 0!

Thermal effects



No SUSY preserving Minimum $T > T_{crit}$!

Critical Temperature

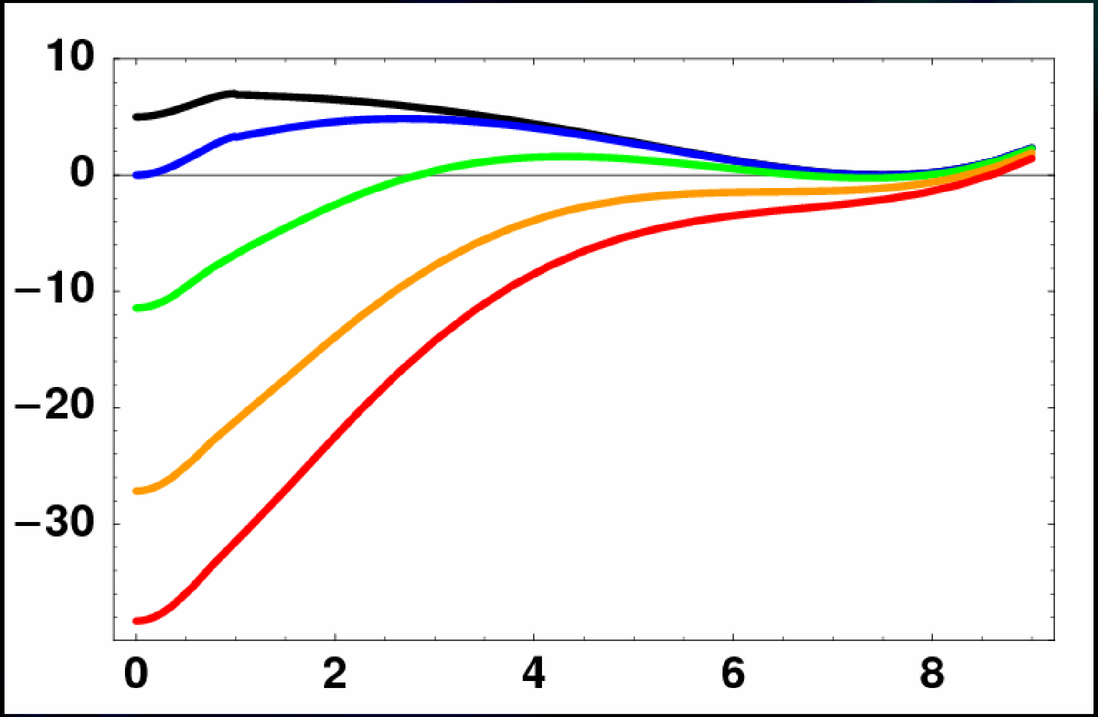


Critical Temperature is surprisingly small!

Critical Temperature=few¤μ!

Dynamical question: Enough Time?

- At $T>T_{crit}$ field is free to roll.



Does it have enough time to get to $\Phi=0$?

Rolling fast...

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- Cooling of the Universe by Expansion
- Typical timescale: $$t_{cool} \sim \frac{1}{H_0} \sim \frac{M_{\rm P}}{T_0^2}$$
- Compare to „Rolling time“:

$$\Delta t = \text{ const}' \; \frac{\Phi_0}{T_0^2} \sim \frac{\Phi_0}{M_{\rm P}} t_{cool} \ll t_{cool}$$

Enough time to complete transition!

... and not overshooting

- Interactions with other fields (e.g. SM fields) provide damping!!!

➡ Field oscillations die out exponentially!

$$\Phi_{max}(T) \sim \Phi_0 \sqrt{\frac{T}{T_0}} \exp\left(-\frac{\Gamma}{2}(t - t_0)\right)$$

$$\Gamma \sim T \Rightarrow \Gamma t_{cool} \sim \frac{M_{\mathrm{P}}}{T} \gg 1$$

4. Conclusions

Conclusions

- More light d.o.f. ➡ preferred

- The Universe is driven to the supersymmetry breaking meta-stable vacuum by thermal effects because it has more light d.o.f.
- Essentially any reheat temperature larger than a few times the supersymmetry breaking scale μ is sufficient to ensure that the Universe ends up in the desired nonsupersymmetric vacuum state.