$SU(2)_{CMB} \stackrel{today}{=} U(1)_Y$ and the nature of light

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Outline

- motivation
- nonperturbative SU(2) Yang-Mills thermodynamics:

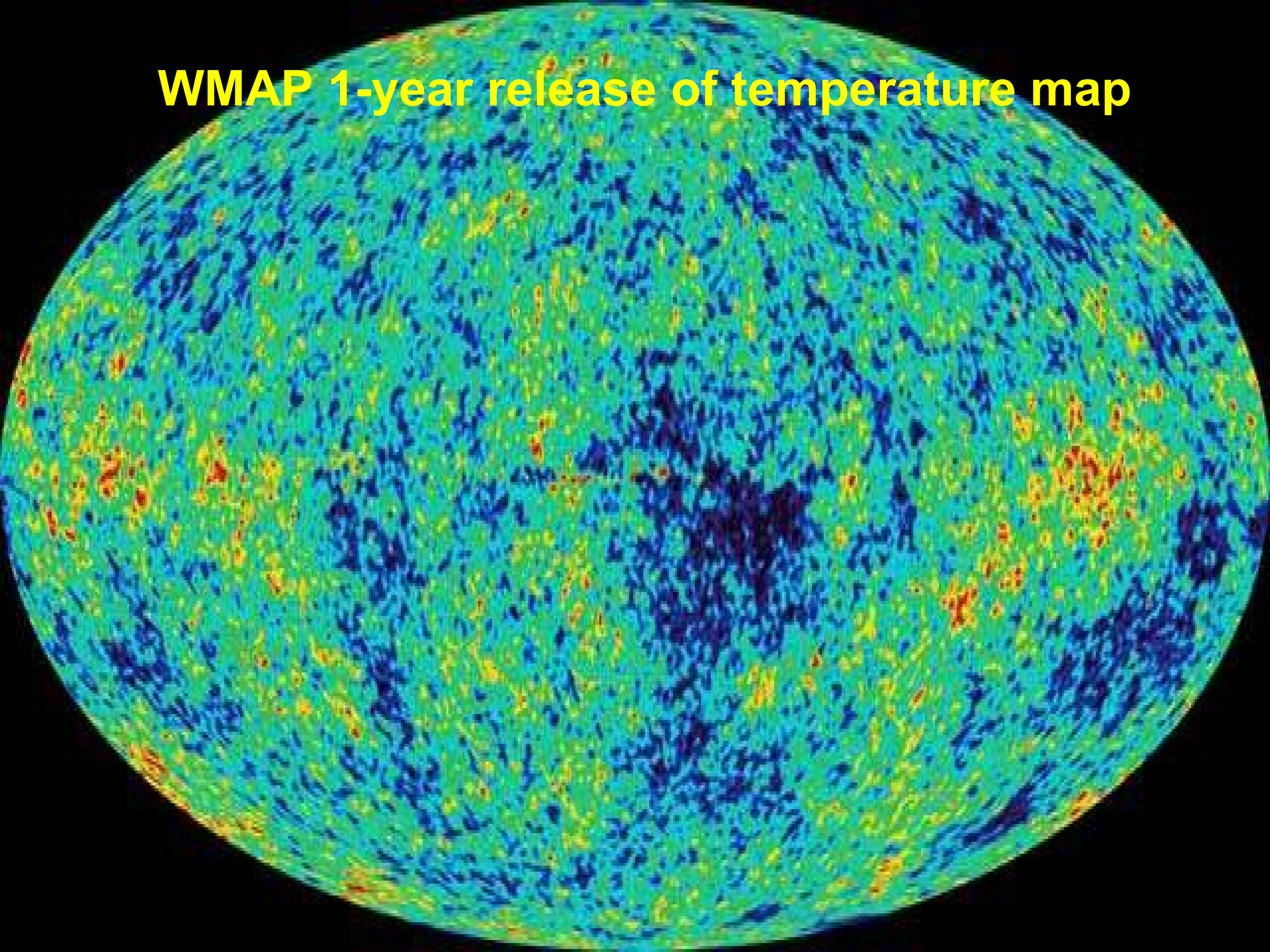
  A very brief introduction
- electric-magnetic coincidence and $U(1)_Y$
- CMB fluctuations at large angles as radiative corrections
- Summary and Outlook

Motivation

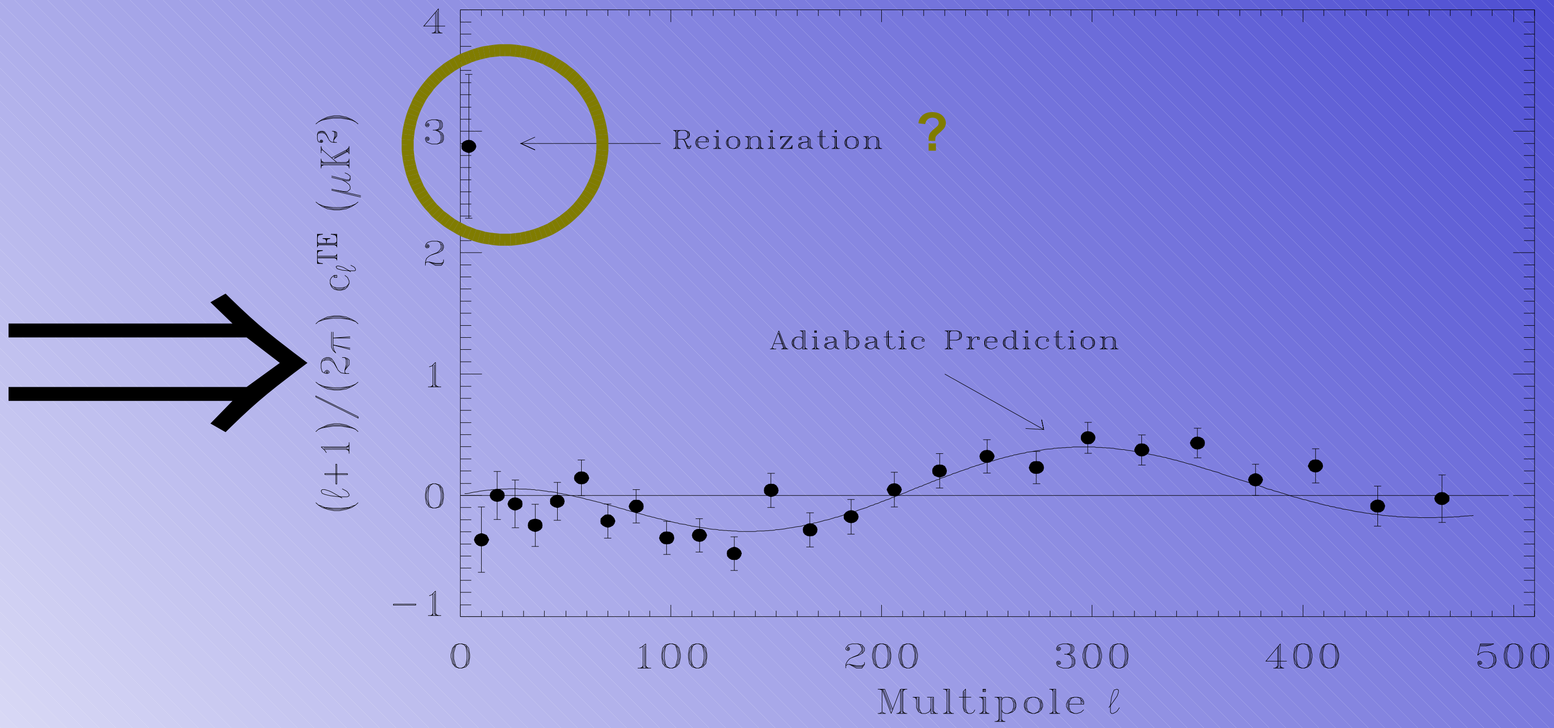
for

$$\mathrm{SU(2)}_{CMB} \overset{today}{=} \mathrm{U(1)}_{Y}$$

WMAP 1-year release of temperature map



temperature-polarization cross correlation at large angles



power spectrum of TE cross correlation:

excess compared to primordial prediction !

(reionization versus mobile electric monopoles at $z = 10...20$)

more motivation

- **Universe´s equation of state:**

$$\Omega = \Omega_{crit}, \Omega_{\Lambda} = 0.7\Omega_{crit}, \Omega_{DM} = 0.3\Omega_{crit}$$

(slowly rolling Planck-scale axion)

- **nontrivial ground state physics related to physics of photon propagation?**

(invisible ether)

- **intergalactic magnetic fields** $B \leq 10^{-9}G$**?**

(condensed, electrically charged monopoles)

SU(2) Yang-Mills thermodynamics, nonperturbatively

SU(2) Yang-Mills thermodynamics

at large temperatures:

spatial coarse-graining over both

plane-wave fluctuations

(small quantum fluctuations, perturbation theory)

1. induce magnetic monopole constituents in calorons
2. induce interactions between monopoles
3. after coarse-graining:

   pure-gauge configuration

topological fluctuations

(large, topology changing quantum fluctuations, calorons)

1. provide spatial correlations to resolve the infrared catastrophe
2. after coarse-graining:

   inert adjoint scalar with T dependent modulus

   $\Rightarrow$ quasiparticle masses by Higgs mechanism

[Nahm 1980, Lee & Lu 1998, Kraan & van Baal 1998, Brower et al. 1998, Diakonov et a. 2004, Ilgenfritz et al. 2005, Polyakov 1974]

SU(2) Yang-Mills thermodynamics: phase diagram

confining

ground state:

CVL condensate

(spin-1/2) excitation:

single and self-intersecting CVLs

preconfining

ground state:

monopole condensate

$\Rightarrow P^{gs} = -\pi T \Lambda^3{}_M$

plus collapsing, closed magnetic flux lines (CVL)

(spin-1) excitation:

massive, dual mode

apparent gauge-symmetry breaking:

$$U_D(1) \rightarrow 1$$

deconfining

ground state:

short-lived (attracting) BPS monopoles and antimonopoles

($\Rightarrow P^{gs} = -4\pi T \Lambda^3{}_E$)

plus dilute, screened BPS monopoles and antimonopoles

(spin-1) excitations:

two massive modes

$$m_{W_\pm} = 2e\sqrt{\frac{\Lambda^3{}_E}{2\pi T}}$$

one massless mode

apparent gauge-symmetry breaking:

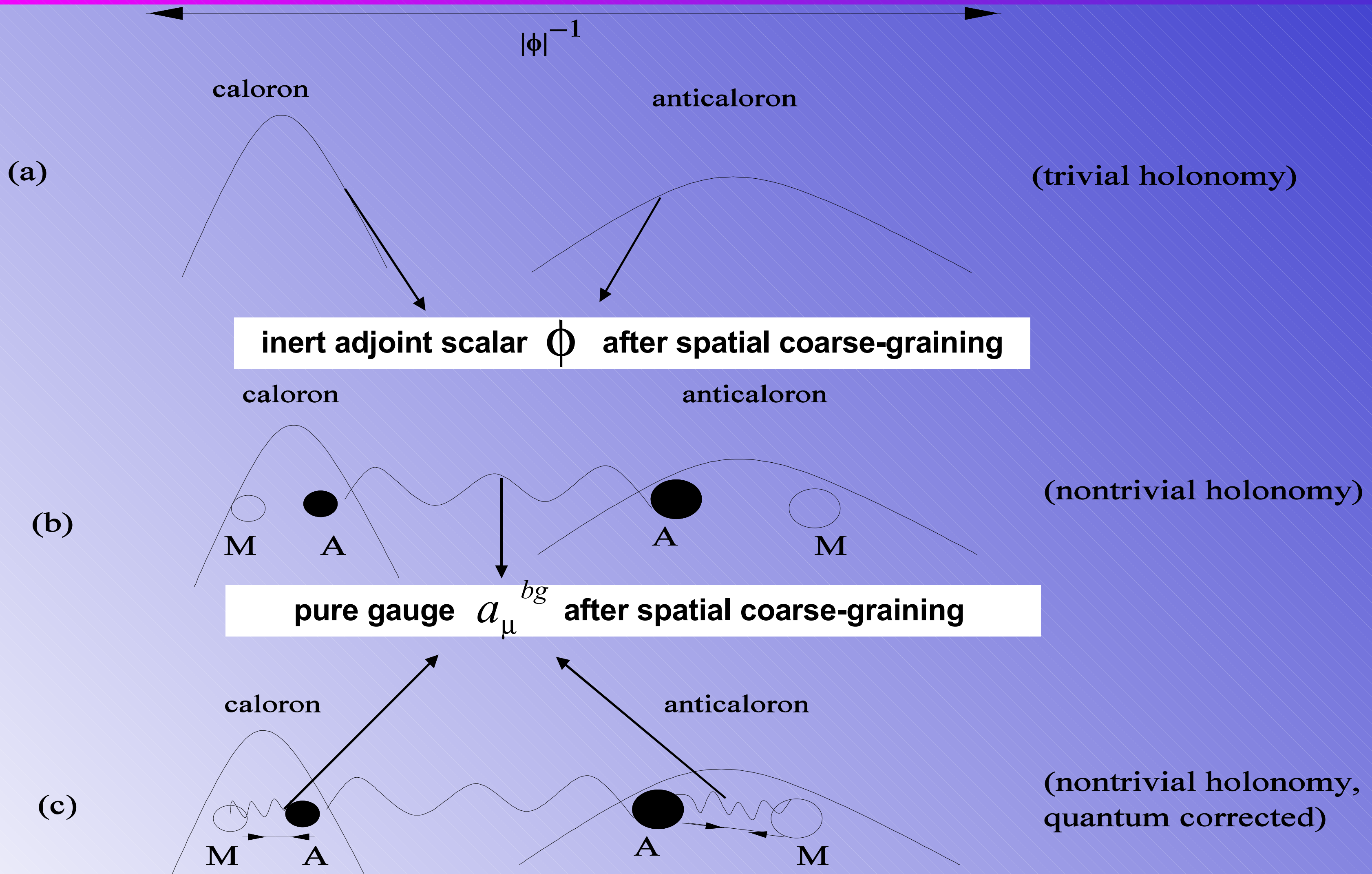
$$SU(2) \rightarrow U(1)$$

Hage-dorn

2nd order

T

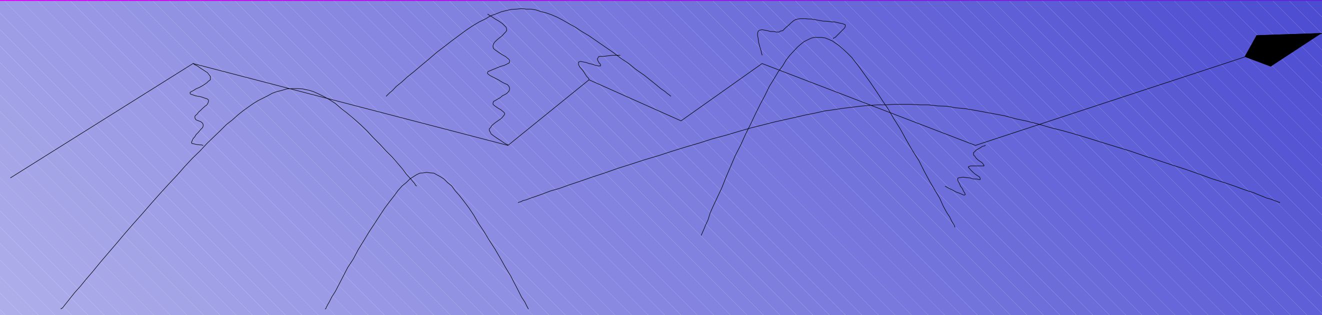
microscopics of ground-state dynamics: deconfining phase



attraction extremely likely => negative pressure macroscopically
repulsion extremely unlikely => isolated and screened magnetic monopoles

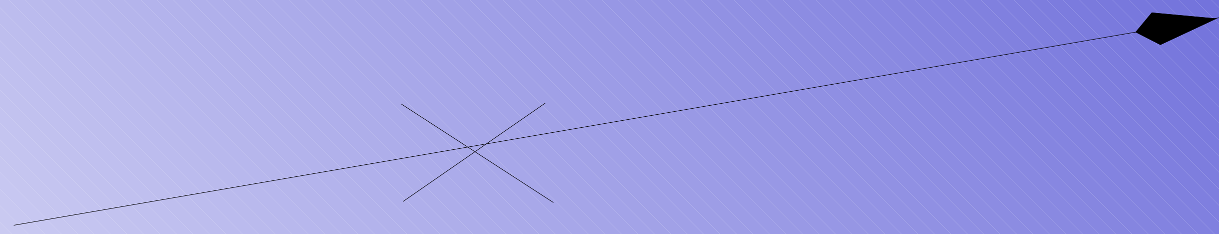
quasiparticle excitations after spatial coarse-graining

(a)



microscopic situation

(b)



after spatial coarse-graining

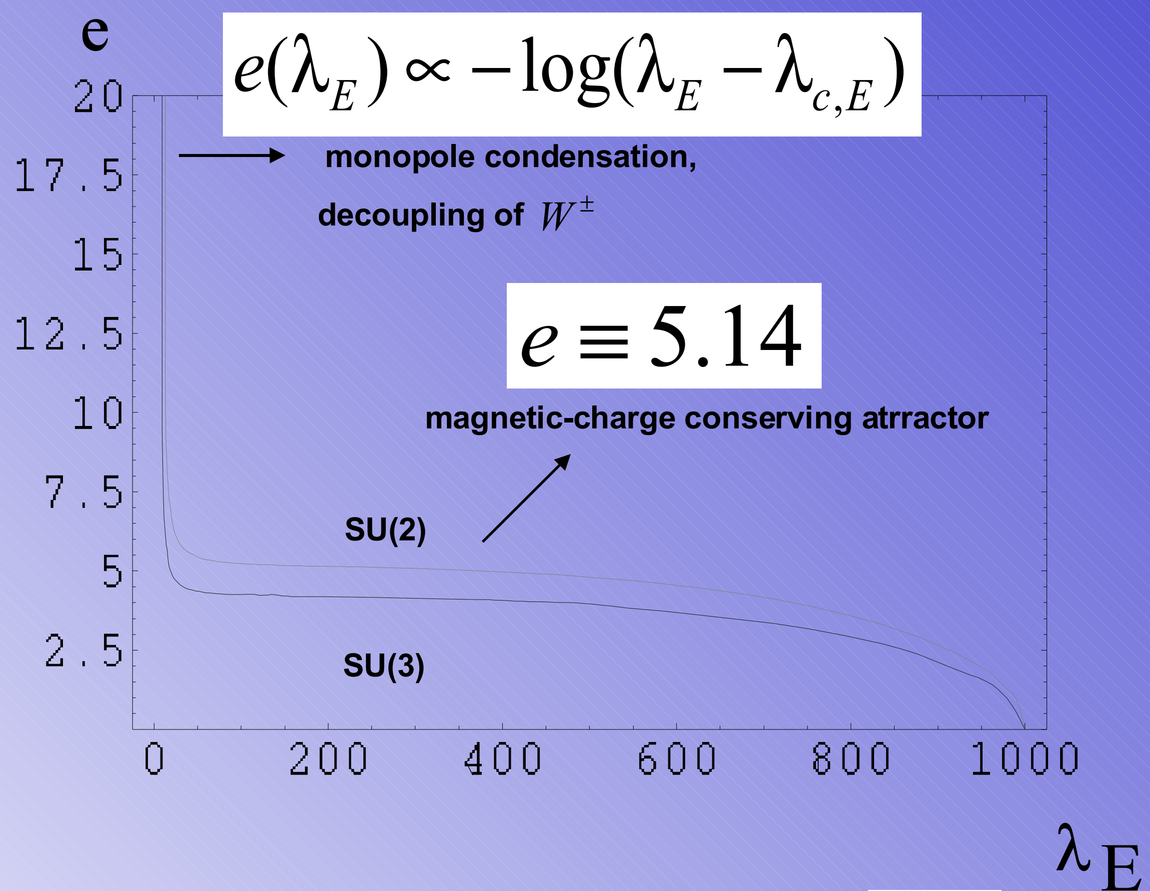
quasiparticle mass:

$$m_{w_\pm} = 2e\sqrt{\frac{\Lambda^3_E}{2\pi T}}$$

Yang-Mills scale

effective gauge coupling

one-loop evolution of e with temperature



$$e(\lambda_E) \propto -\log(\lambda_E - \lambda_{c,E})$$

$$e \equiv 5.14$$

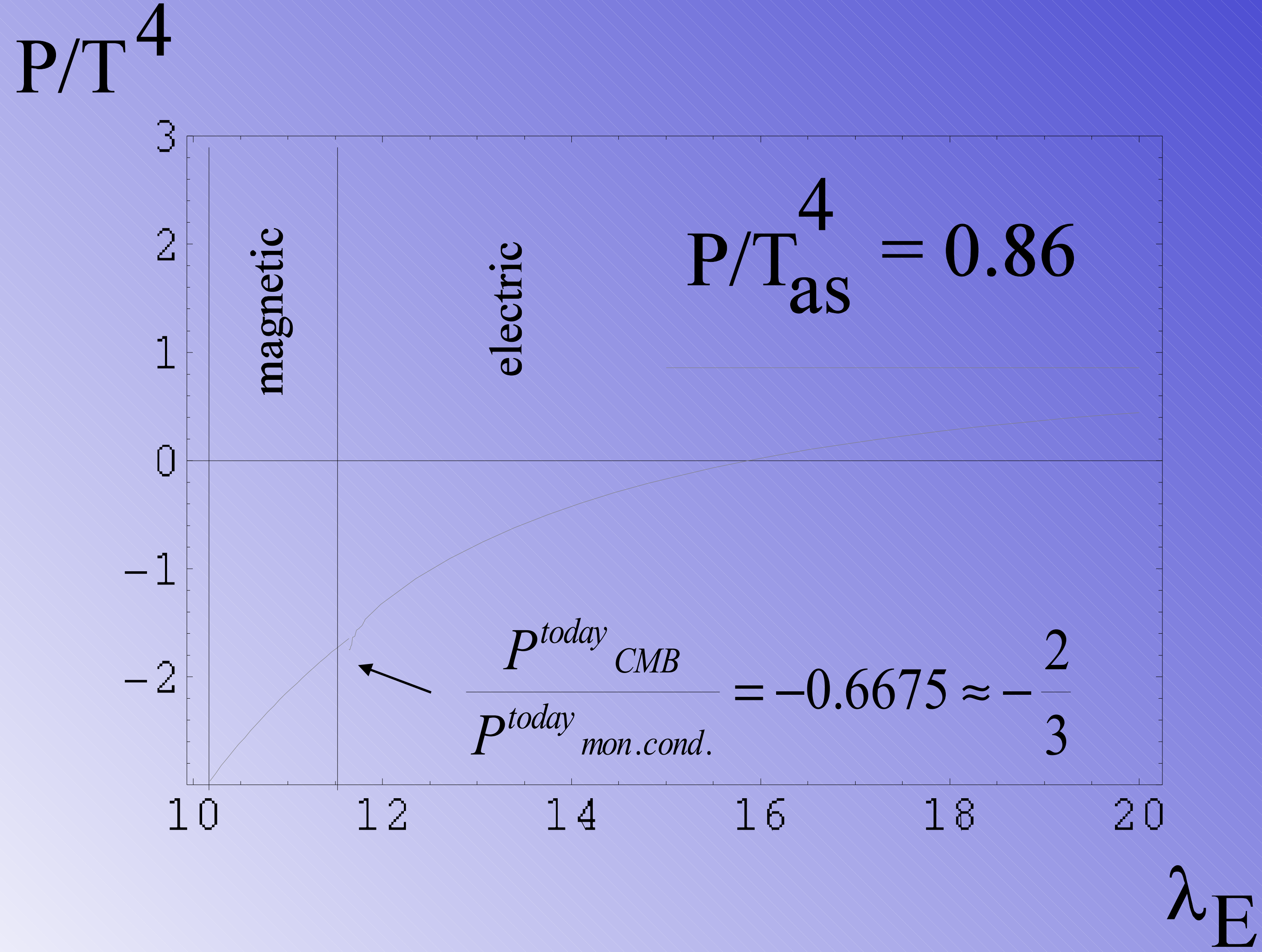
magnetic charge of isolated monopole after screening: $g = \frac{4\pi}{e}$

mass of isolated monopole after screening: $M = 2\pi^2 \frac{T}{e}$ $\Longrightarrow$

quasiparticle mass: $m_{w_\pm} = 2e\sqrt{\frac{\Lambda^3{}_E}{2\pi T}}$

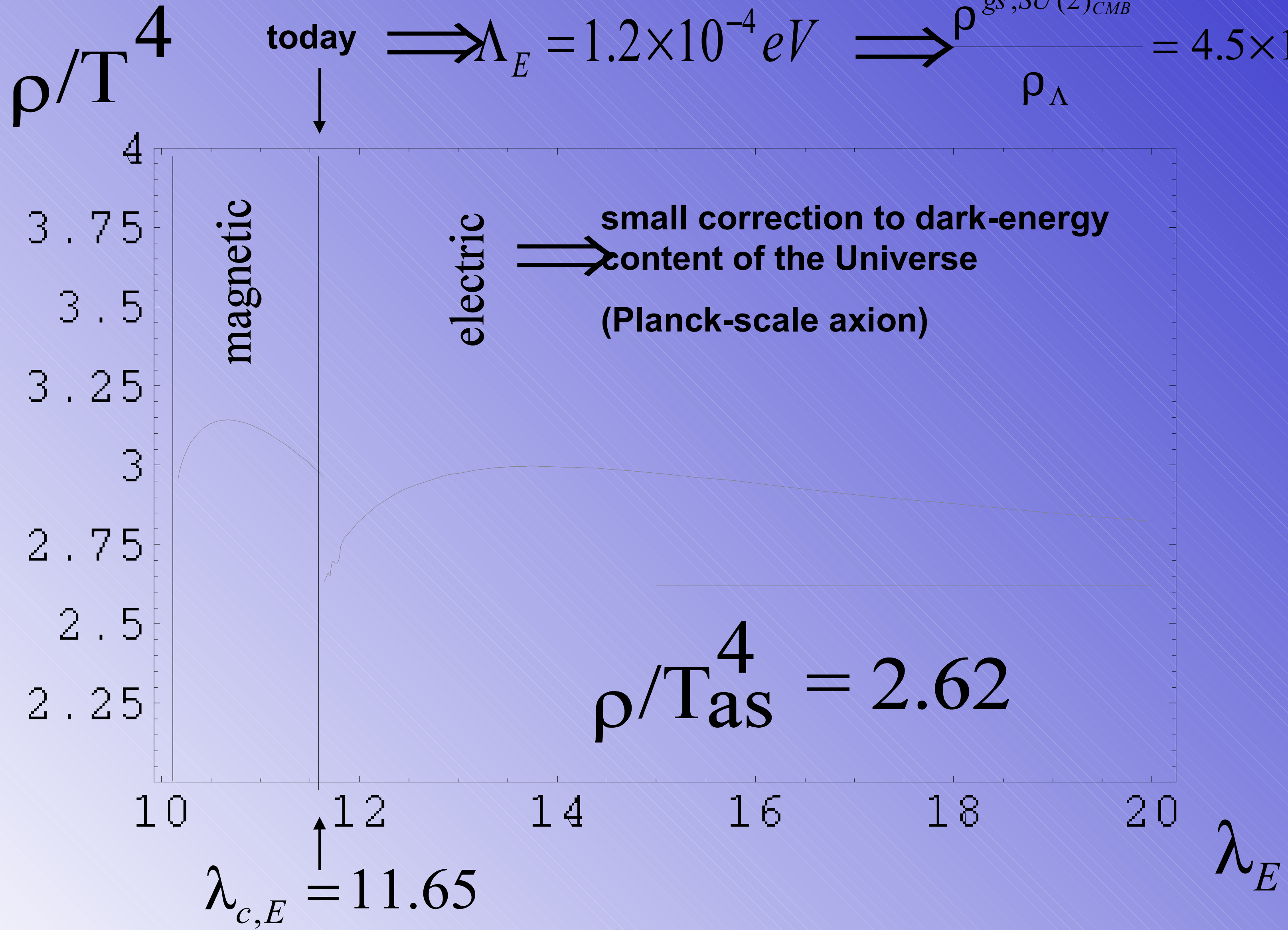
monopoles mobile close to phase transition $\Longrightarrow$ **CMB gets polarized at large angles !**

pressure at one-loop



energy density at one-loop

today $\Longrightarrow \Lambda_E = 1.2\times10^{-4}\,eV \Longrightarrow \frac{\rho^{gs,SU(2)_{CMB}}}{\rho_\Lambda} = 4.5\times10^{-3}$



electric-magnetic coincidence

at $\lambda_{c,E}$: electric coupling $e = \infty$, **magnetic coupling** $g = 0$

(dynamically stabilized)

$\Longrightarrow$

1. free photon gas (no screening, $W^{\pm}$ decoupled)

2. (i) not yet a coupling of the photon to the monopole condensate:

   (ii) photon massless,

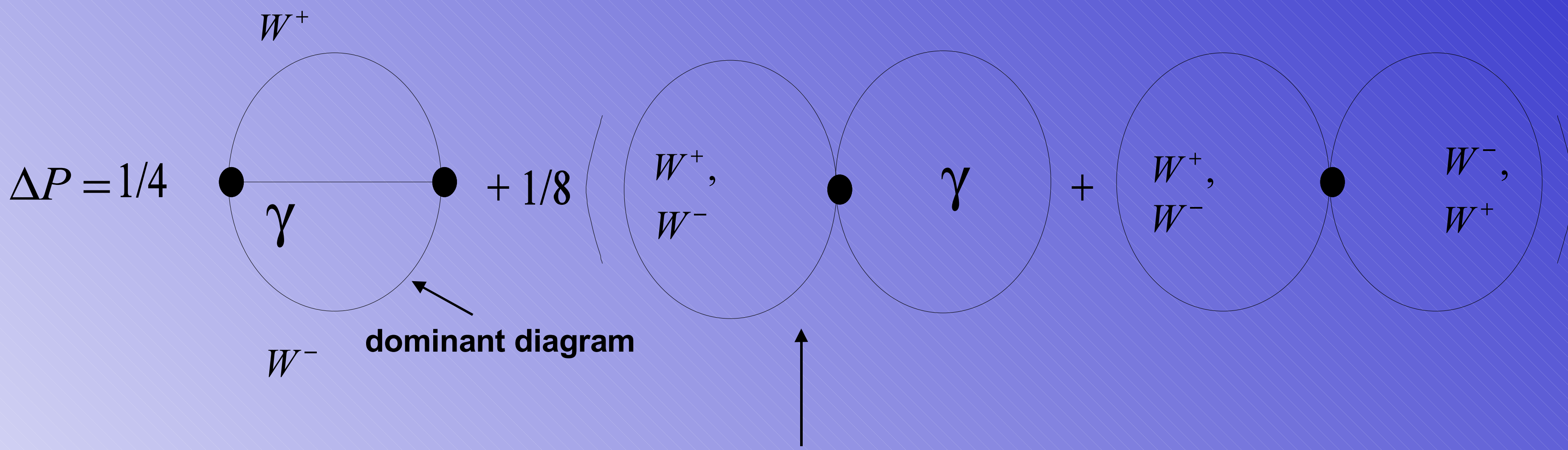
   (iii) rest-frame of heat bath not visible in single photon propagation (invisible ether),

   (iv) superconductivity of ground state (intergalactic magnetic fields ?) barely visible

$\Longrightarrow$ $SU(2) \rightarrow U(1)$ / $SU(2) \rightarrow U(1)_D$ coincide!

(neither dynamical magnetic charges (screening) nor condensed electric charges (photon mass) measureable)

CMB fluctuations at large angles as radiative corrections



subject to compositeness constraints

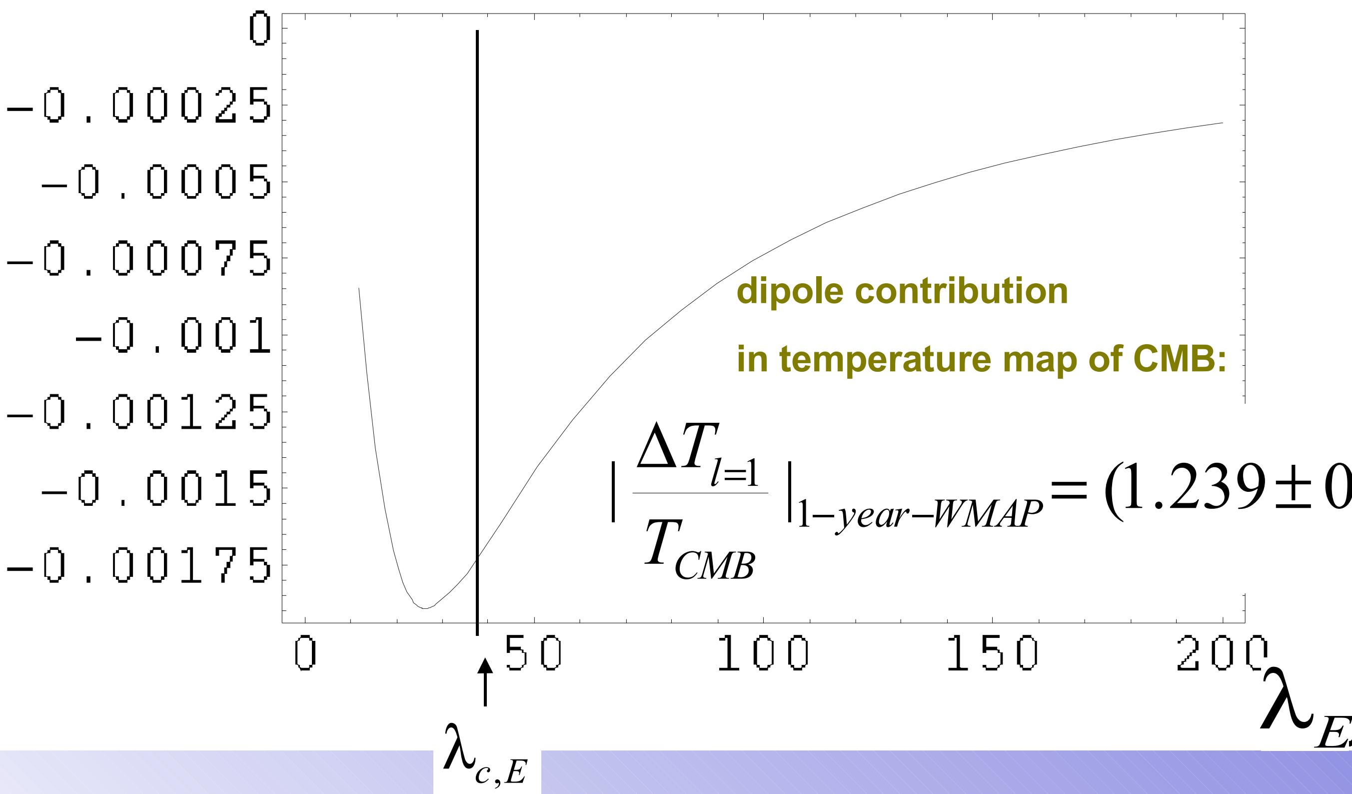
(plane-wave quantum fluctuations softer than $|\phi|$, harder fluctuations integrated out into a_μ^{bg})

$\Longrightarrow$ **radiative corrections to pressure at most 0.2%**

[Herbst, RH, Rohrer 2004]

dominant correction

$$\Delta P^{HHM}_{ttv} / 4\, P_{1\text{-loop}} \approx \frac{3}{4}\frac{\Delta T}{T}$$ **for** $\lambda_E >> \lambda_{c,E}$



dipole contribution

in temperature map of CMB:

$$\left|\frac{\Delta T_{l=1}}{T_{CMB}}\right|_{1-year-WMAP} = (1.239 \pm 0.006)\times 10^{-3}$$

(computed with $e \equiv 5.14$

$\Longrightarrow$ **upper bound for modulus when** $\lambda_E \to \lambda_{c,E}$ **!)**

Summary and Outlook

Universe today possibly dynamically stabilized at boundary between deconfining and preconfining phase of SU(2) Yang-Mills theory of scale

$$\Lambda_E = 1.2 \times 10^{-4}\, eV$$

$\Longrightarrow$ **invisible ether: structureless condensate of electric monopoles (electric-magnetic concidence)**

$\Longrightarrow$ after jump to preconfing phase: Universe's ground state visibly superconducting

$\Longrightarrow$ **monopole condensate: small correction to Universe's dark-energy content**

$\Longrightarrow$ **large-angle part of CMB power spectra: radiative corrections in deconfining phase of** $SU(2)_{CMB}$ **(mobile monopoles)**

Summary and Outlook

future work:

- computation of two-loop correction to pressure in an FRW background

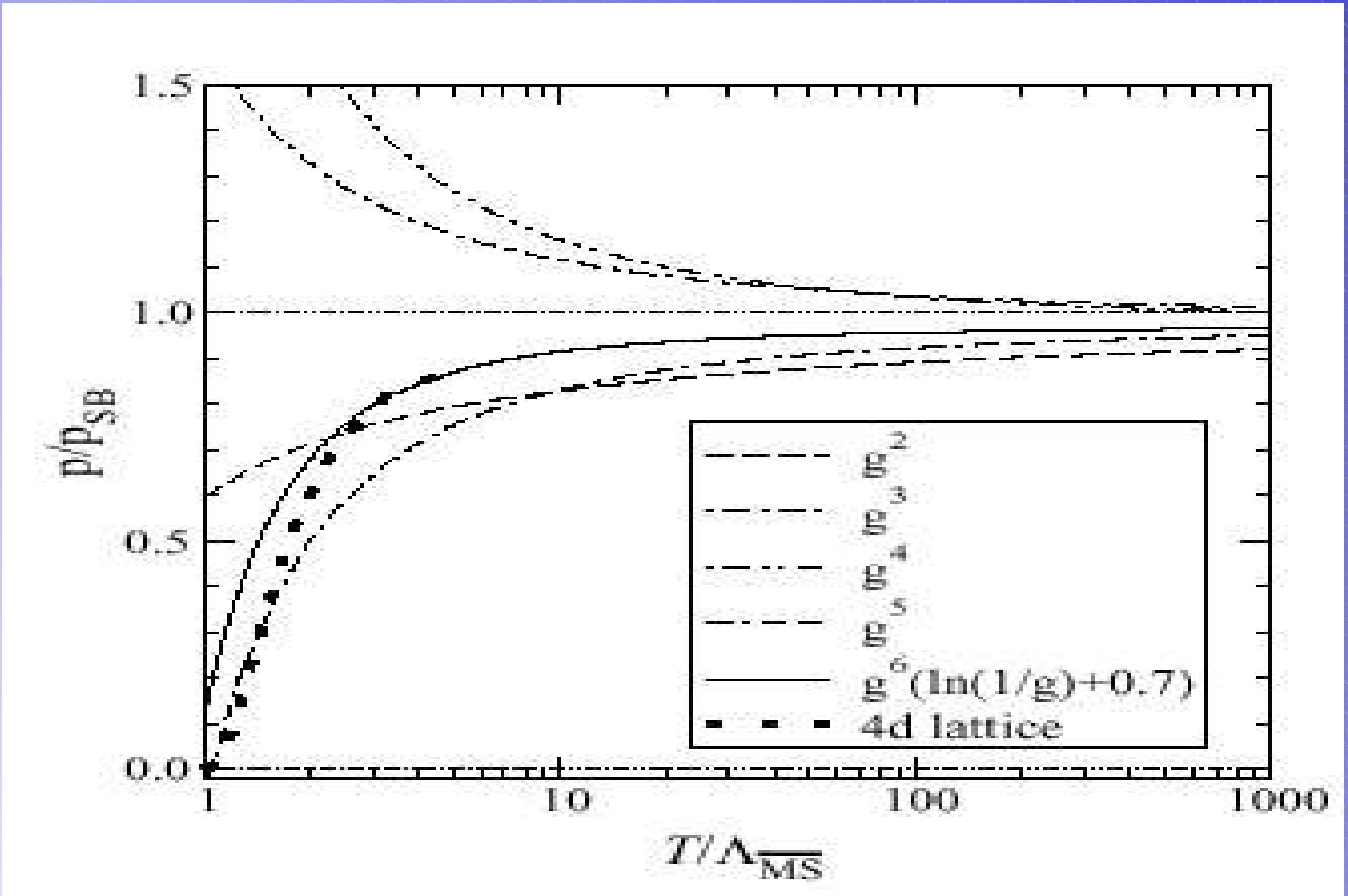
  $\Longrightarrow \frac{\Delta T}{T}(l)$ at low l

- computation of various thermal two-point correlators in Minkowski space and FRW background with or without axion background

  $\Longrightarrow$ polarization power spectra and CP violation

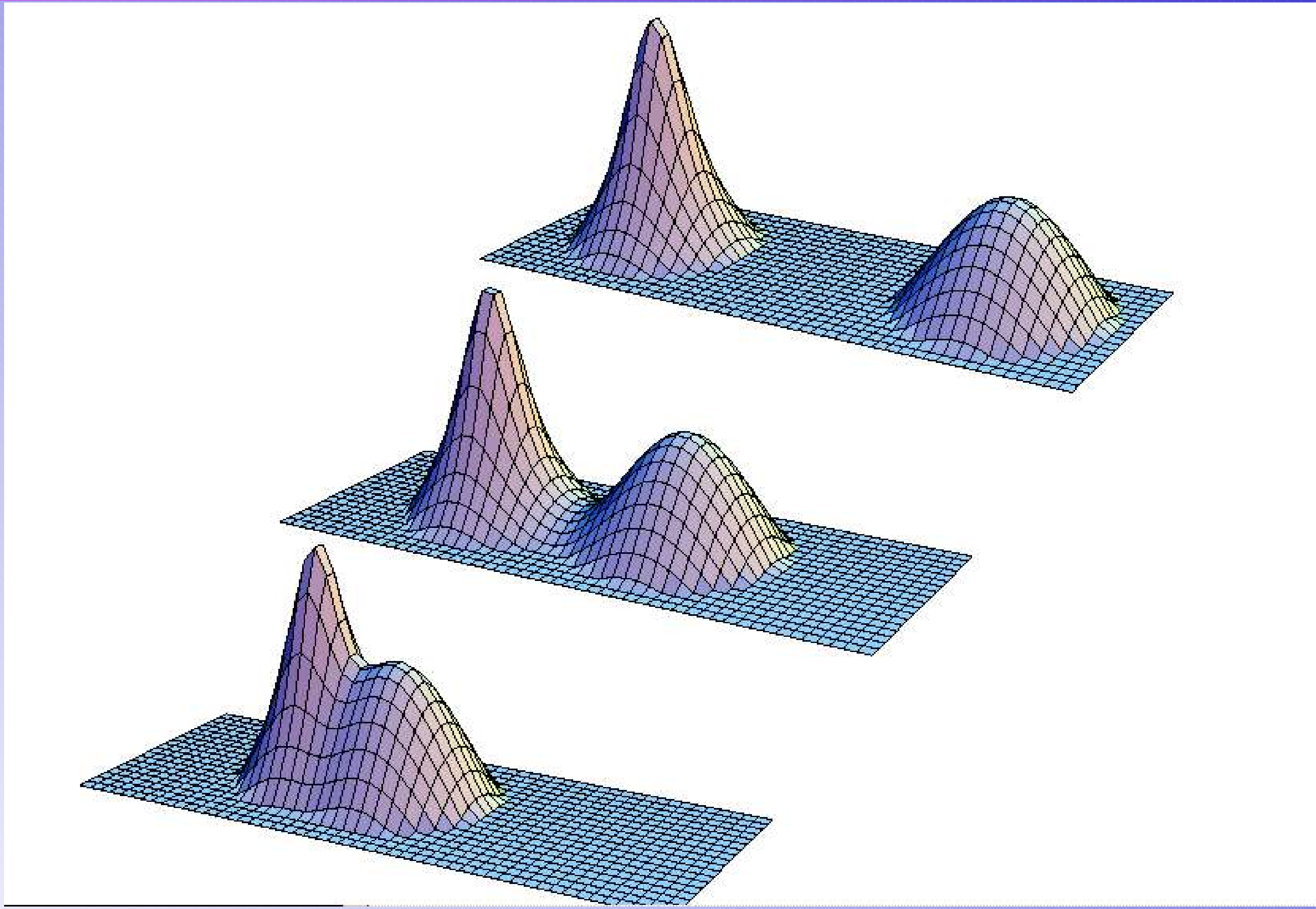
- rate of axion rolling necessary for jump to preconfining phase (violation of thermal equilibrium)

Typical situation in thermal perturbation theory



taken from Kajantie et al. 2002

SU(2)



taken from van Baal & Kraan 1998

Does ϕ fluctuate?

quantum mechanically:

$$\frac{\partial^2_{|\phi_l|} V_E}{|\phi_l|^2} = 3l^3\lambda_E{}^3 > 1 \qquad (\lambda_E \equiv \frac{2\pi T}{\Lambda_E})$$

compositeness scale

$\Longrightarrow$ **No !**

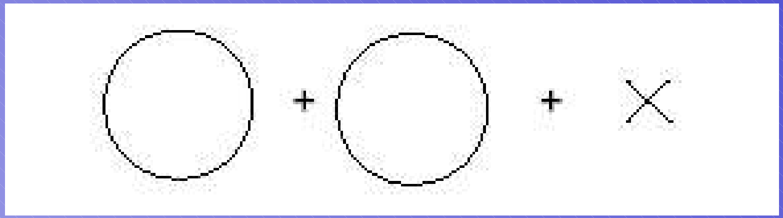
thermodynamically:

$$\frac{\partial^2_{|\phi_l|} V_E}{T^2} = 12\pi^2 l^2 > 1$$

$\Longrightarrow$ **No !**

Thermodynamical self-consistency:

pressure (one-loop):



however:

Higgs-induced masses and ground-state pressure both

T - dependent

$\Longrightarrow$ T - derivatives involve also implicit dependences

$\Longrightarrow$ relations between thermod.quantities violated:

$$\rho \neq T \frac{dP}{dT} - P \quad .$$

Relaxation to the minima

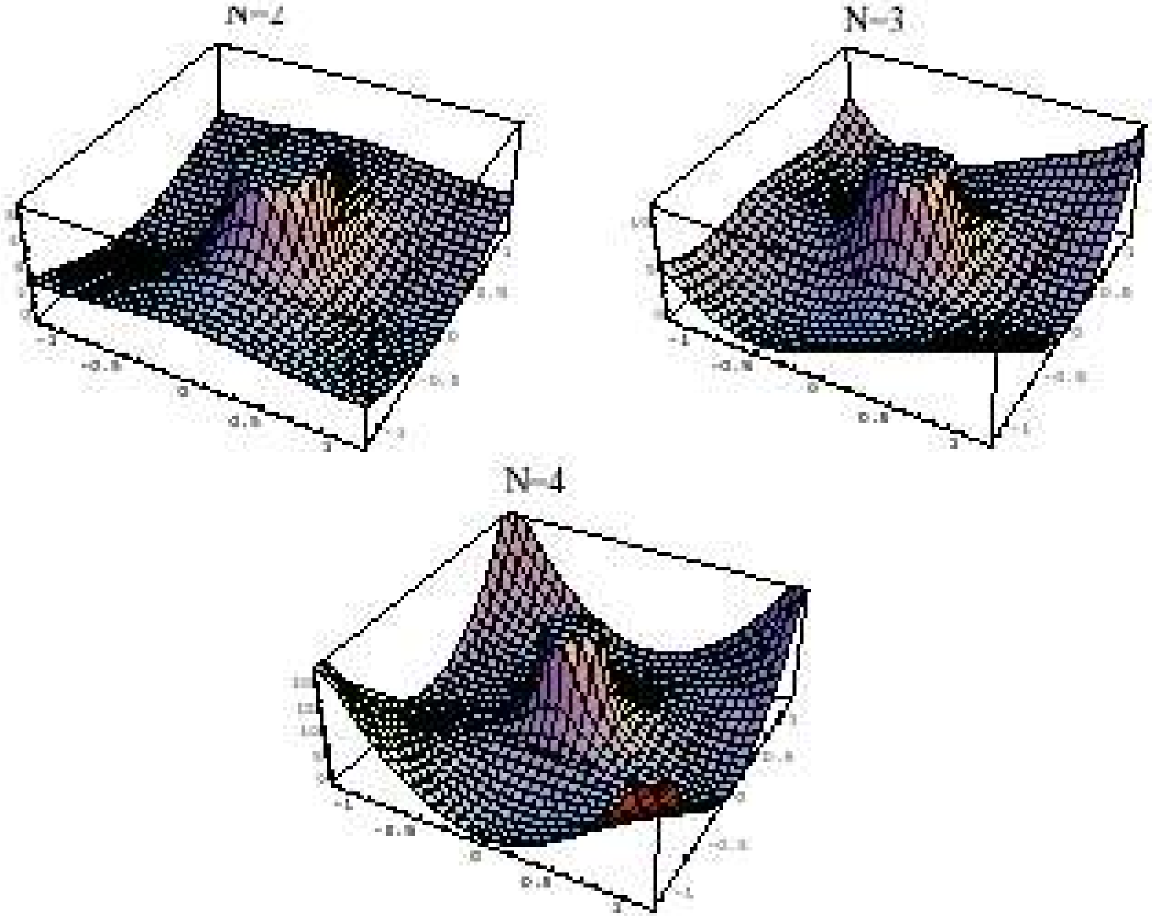


Figure 10: The potential $V_{C^*} = \overline{w_{C^*}(\Phi)}\, w_{C^*}(\Phi)$ corresponding to the definition in Eq. (97) for N=2,3,4 and $\Lambda_{C^*} = \Lambda^1_{C^*}$. $|\Phi|$ is given in units of Λ_{C^*} and V_{C^*} in units of $\Lambda^4_{C^*}$. Notice the minima $V_{C^*} = 0$ at the N^{th} unit roots.