Low frequency and low temperature black-body anomaly

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plan

- Maxwell's equations in vacuum:
  U(1) gauge symmetry
- black-body radiation: Planck's radiation law
- exp. and theor. problems with U(1) gauge symmetry
- What if SU(2) $\longrightarrow$ U(1)?
  (mod. black-body rad. at low temp. $\longrightarrow$ implications)
- Subleties in falsifying/confirming low-T BB anomaly
  (thermal ground state: external fields)
- Proposed principal experimental set-up

Maxwell's equations in vacuum

(units: $c = 1$)

$$\partial_\mu F_{\mu\nu} = 0\,, \quad \partial_\mu \epsilon_{\mu\nu\kappa\lambda} F_{\kappa\lambda} = 0 \;\; (\text{Bianchi})\,, \qquad (1)$$

where $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$, $F_{ij} = \epsilon_{ijk} B_k$, $F_{0i} = E_i$.

– (1) possesses gauge symmetry: $A_\mu \rightarrow A_\mu + \partial_\mu \phi$, real-valued scalar function ϕ parameterizes U(1) group element

$$U = \exp(i\phi) \Rightarrow A_\mu \rightarrow A_\mu - iU^\dagger \partial_\mu U$$

$\Rightarrow$ U(1) gauge group of electromagnetism. **Really?**

Black-body Radiation

– Planck's radiation law (SI units):

$$I_{\mathrm{U(1)}}(\omega) = \frac{\hbar}{2\pi^2 c^2} \frac{\omega^3}{\exp((\hbar\omega)/(k_B T) - 1} \,. \qquad (2)$$

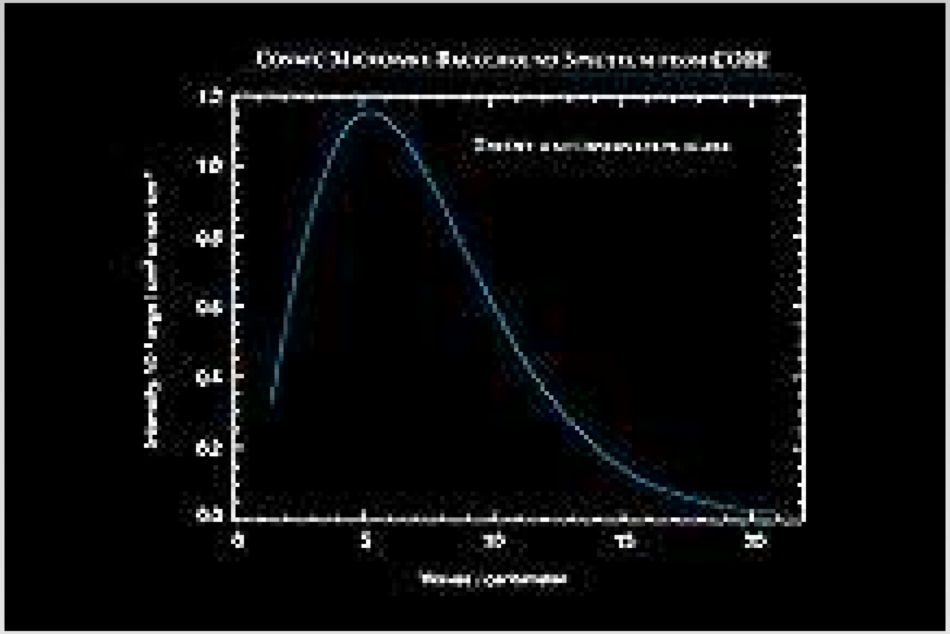
– total radiated power P:

$$P \propto T^4 \;\; \text{(Stefan-Boltzmann)}\,. \qquad (3)$$

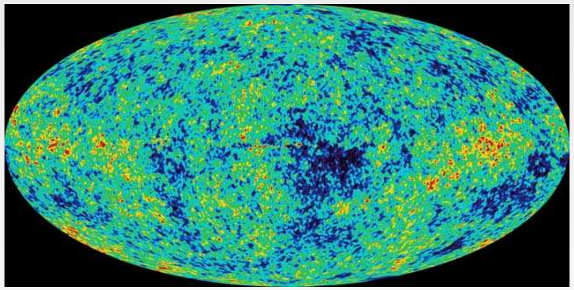
– discovery of new constant of Nature

$h = 6.6260693 \times 10^{-34}$ Js$= 4.13566743 \times 10^{-15}$ eV s.

Cosmic Microwave Background

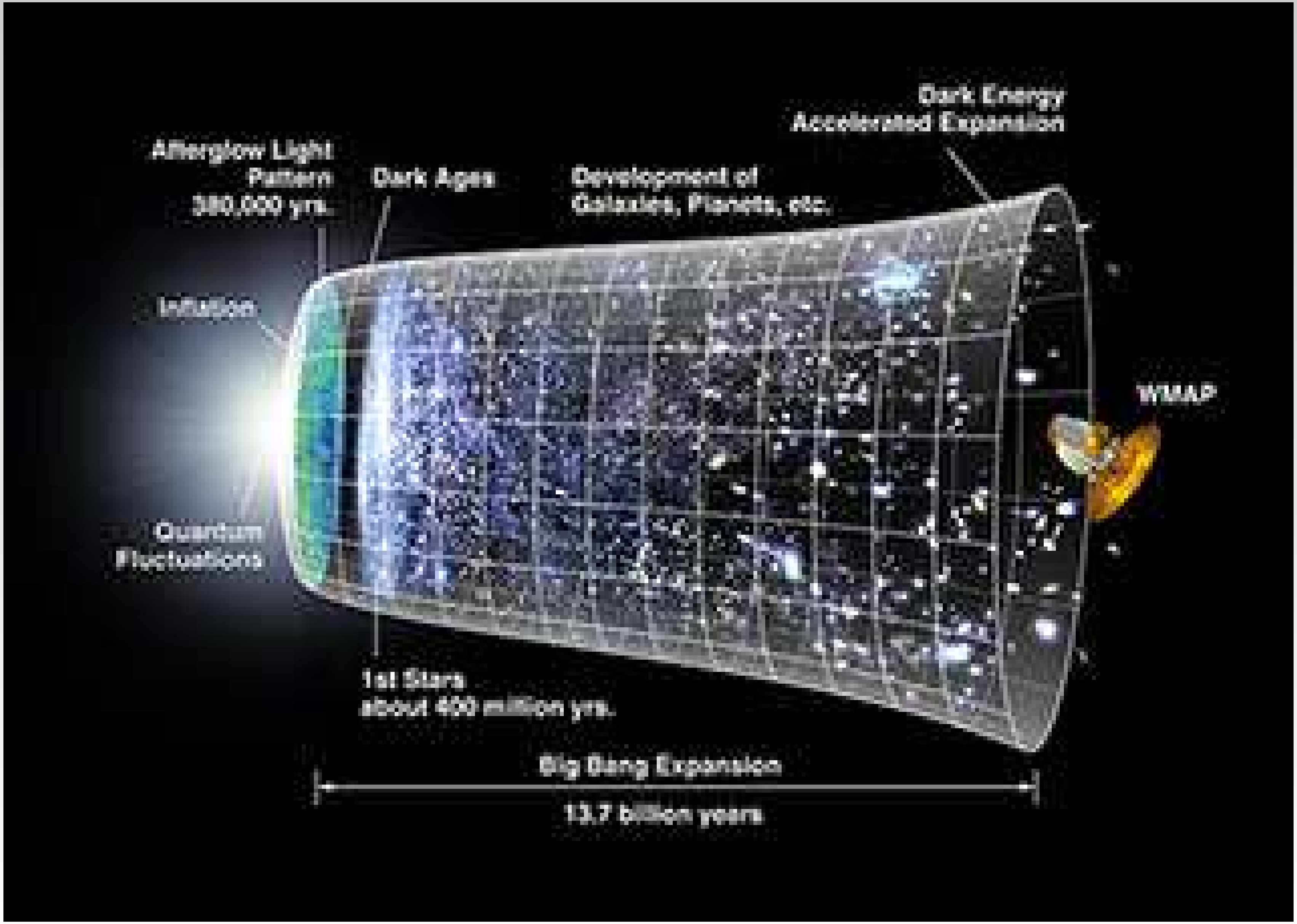


– black-body shape ($\omega > 1\,\mathrm{cm}^{-1}$, COBE-FIRAS 1992-94):

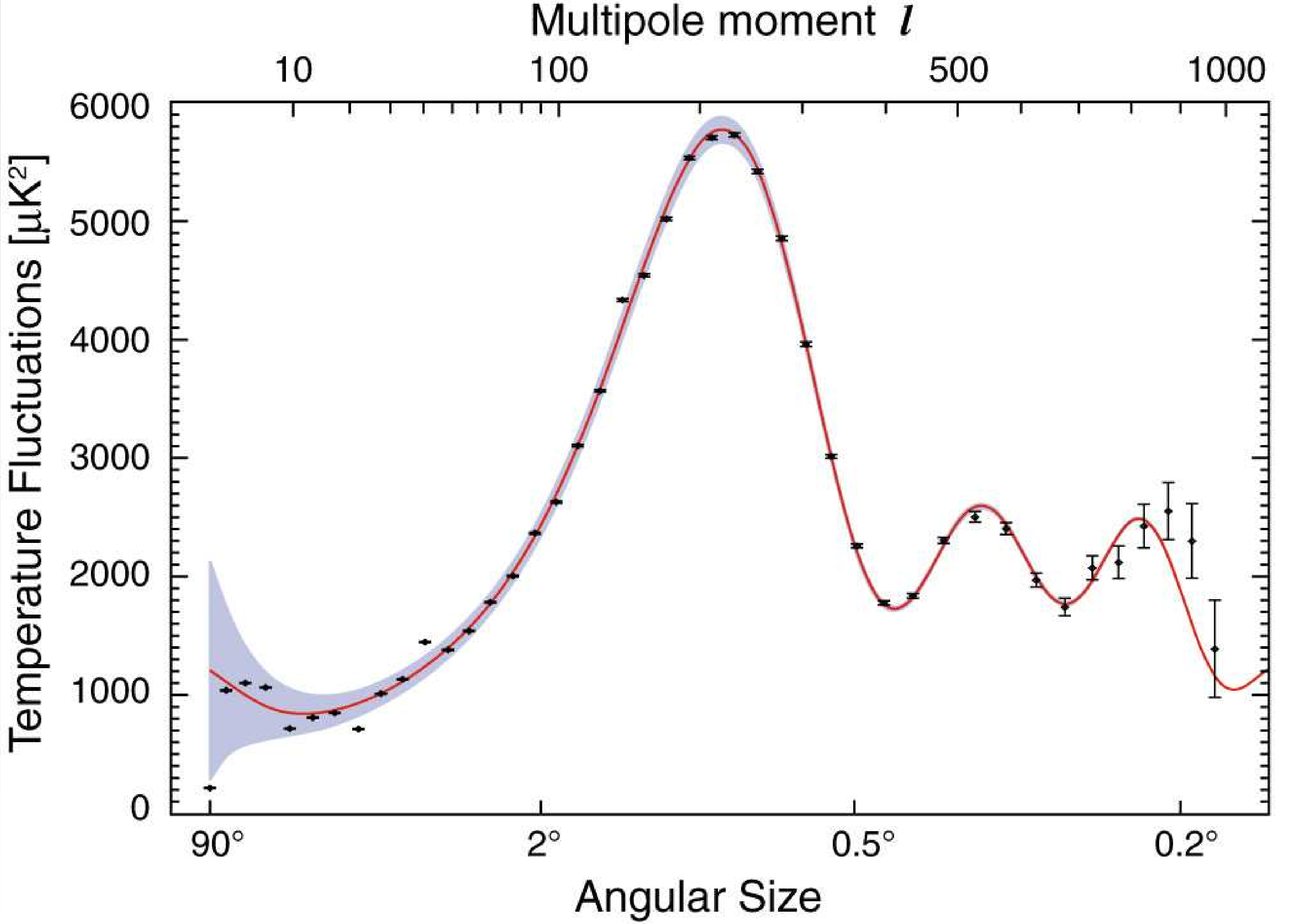


modulo $\delta T/T \sim 10^{-2}$: $\bar{T} = 2.725\,\mathrm{Kelvin}$

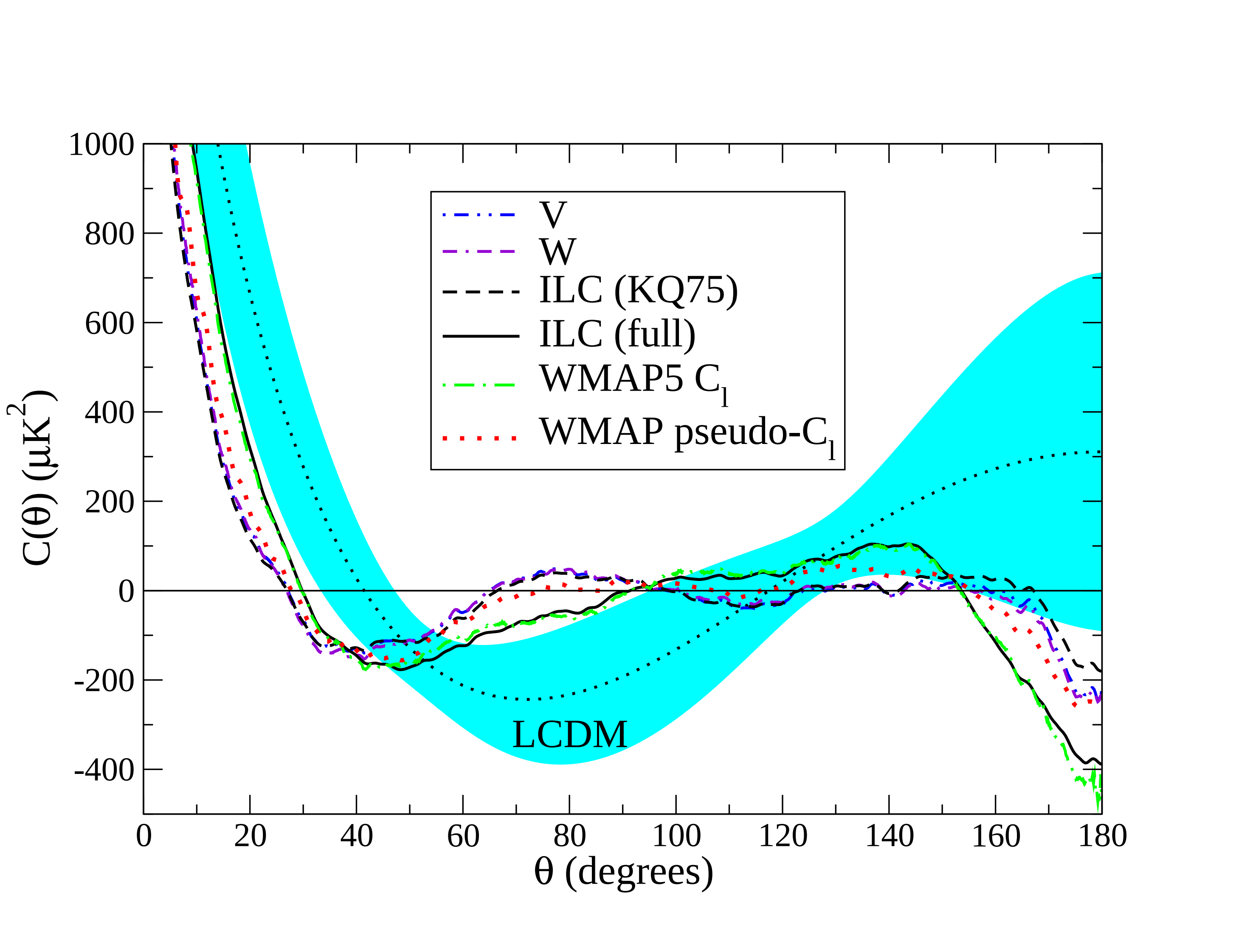
Universe's radiation history



Angular power spectrum



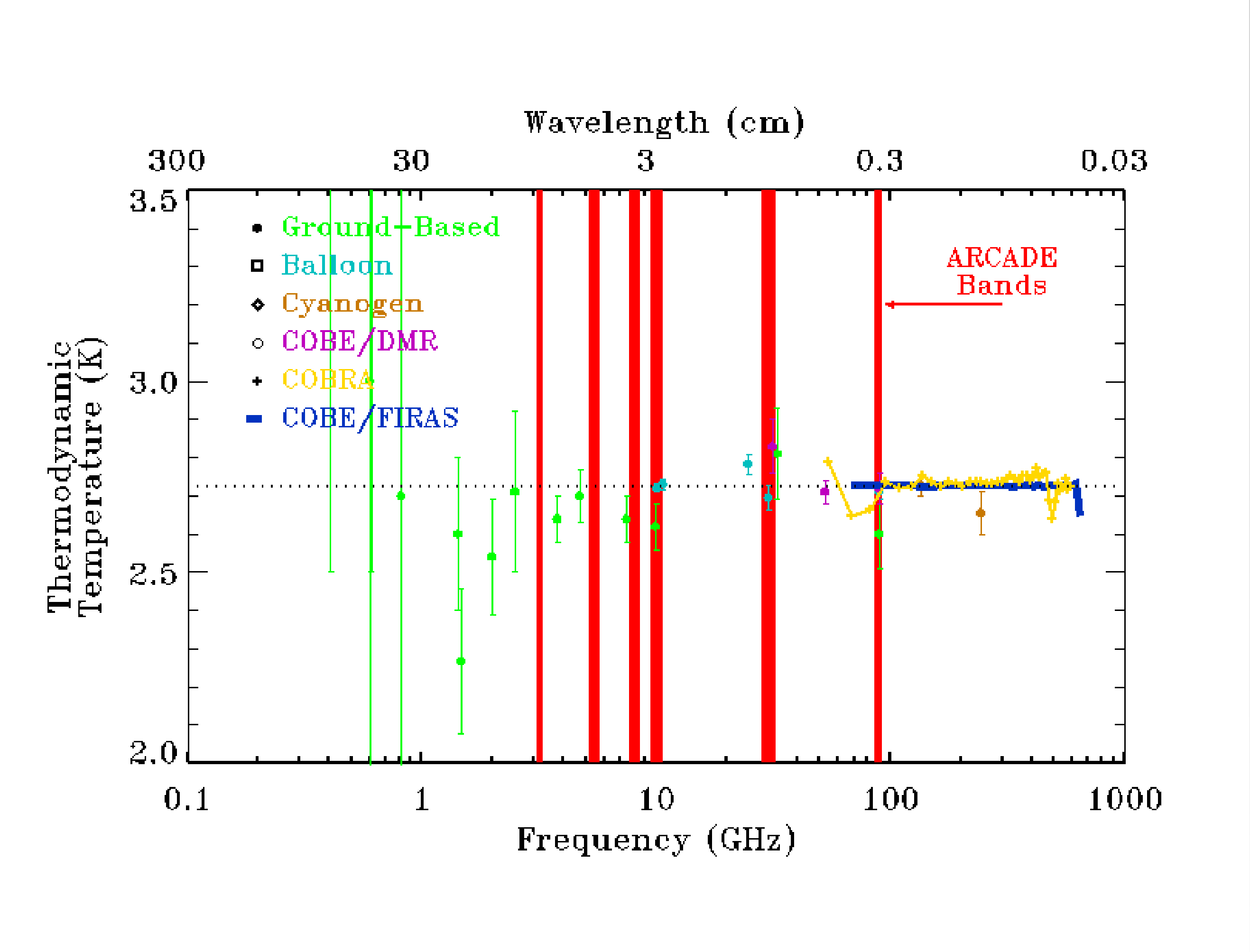
Angular correlation anomaly



[Copi, Huterer, Schwarz, and Starkman, MNRAS 2008]

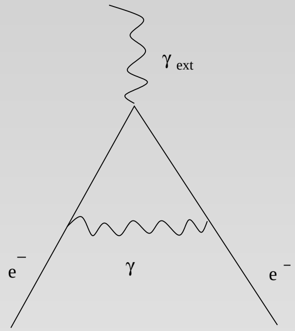
CMB line temperatures

– balloon-borne and ground-based measurements of CMB line temperatures at low frequencies
⇒ UEGE



Theor. problem with U(1):

– quantum electrodynamics (QED) predicts rise of the coupling with increasing momentum transfer Q^2



$$\alpha(Q^2) = \frac{\alpha_0}{1 - \frac{\alpha_0}{3\pi}\log\frac{Q^2}{Q_0^2}} \,. \qquad (4)$$

(more of naked charge is seen for larger Q^2;

Landau unhappy: asymptotic slavery)

Observ. problem with U(1):

– naive estimate of ground-state energy density ρ^{gs}
$\Rightarrow 10^{120}$ times the measured value of

$$\rho^{gs}_{exp} \sim (10^{-3}\,\mathrm{eV})^4\,. \tag{5}$$

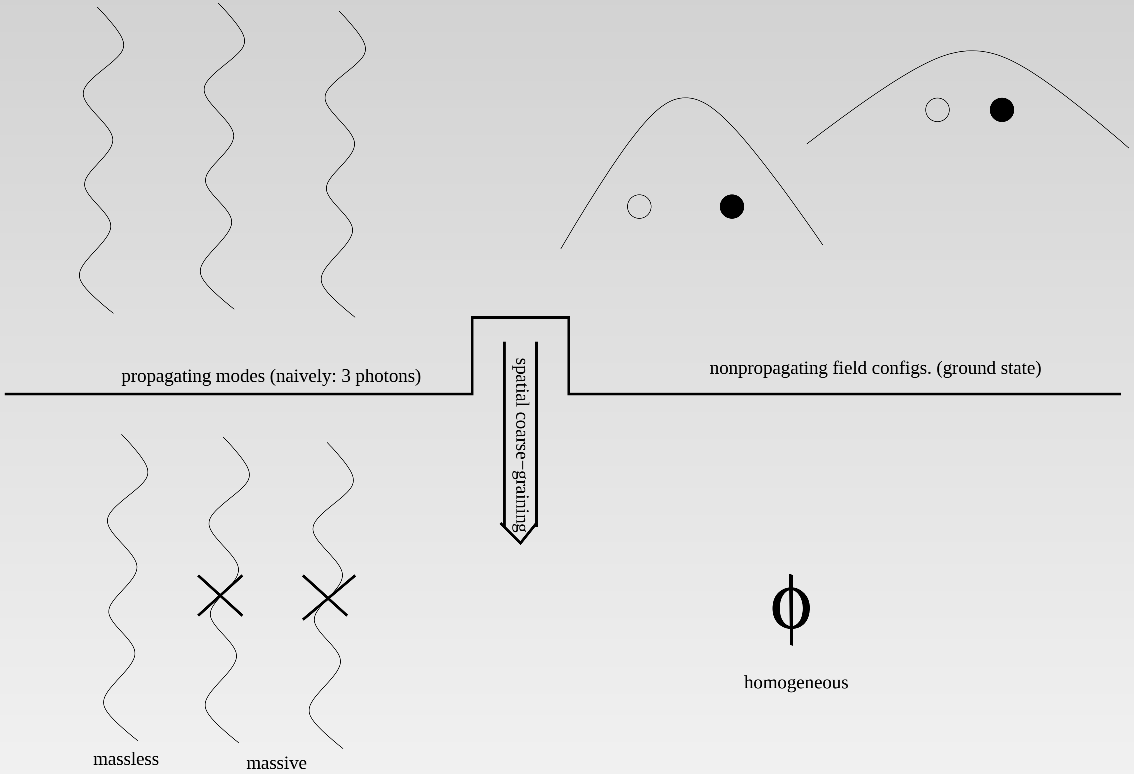
$\Rightarrow$ U(1) based QED represents both:

biggest success (e^- anomalous magnetic moment) and
biggest failure (cosmological constant)

of a scientific theory.

What if SU(2)$\longrightarrow$ U(1)?

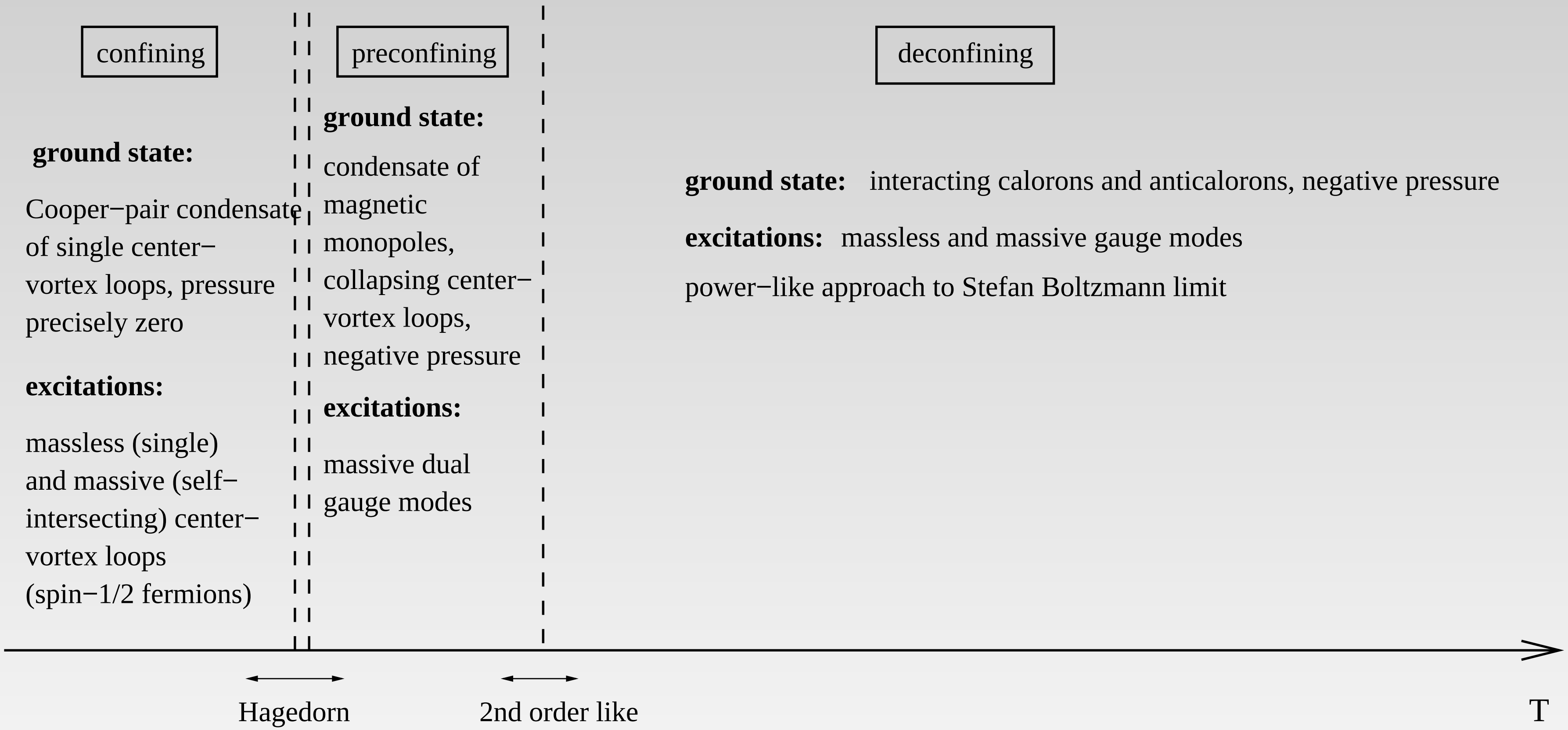
– consider pure gauge theory subject to **nonabelian** gauge symmetry SU(2) $\Rightarrow$



– SU(2) **dynamically broken** to U(1) (thermal ground state)

[RH, IJMPA 2005]

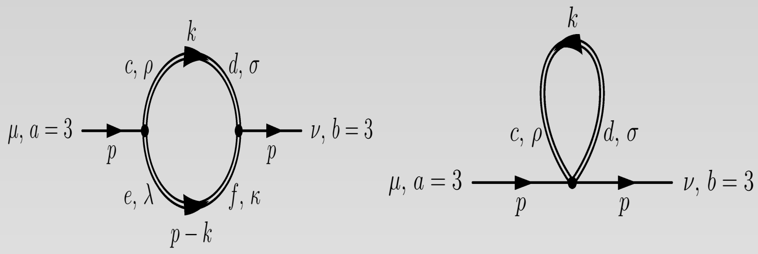
SU(2): Phase diagram



Modified γ dispersion law

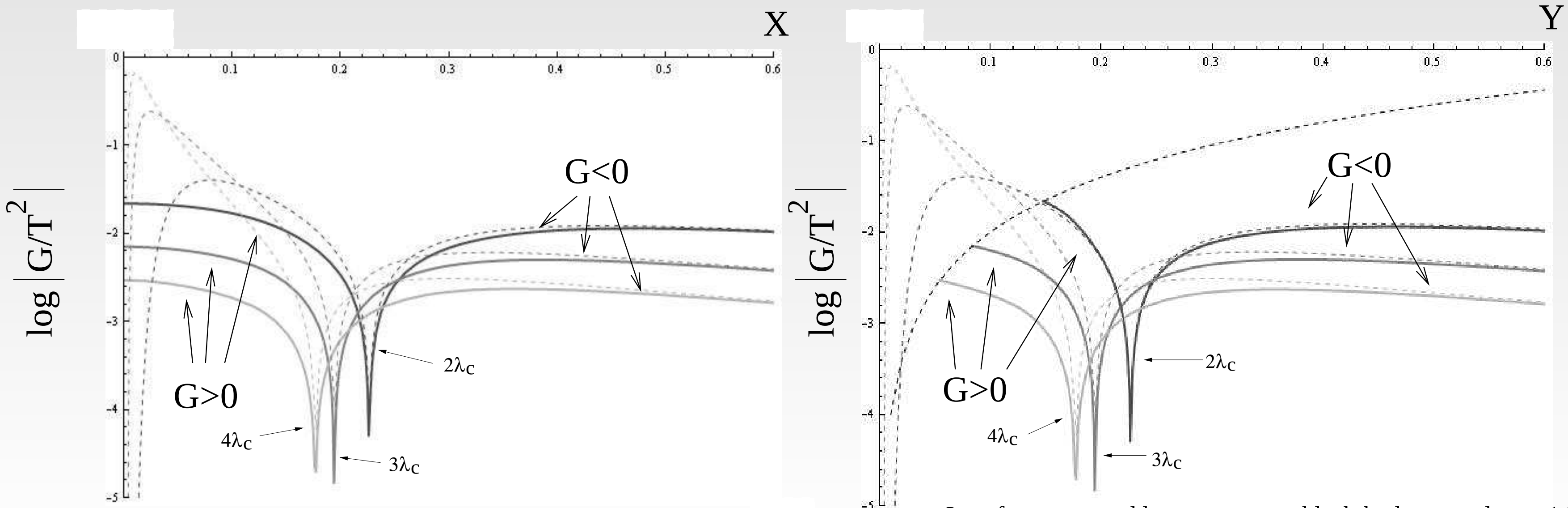
$$(c = \hbar = k_B = 1)$$

– $\omega^2 = |\vec{p}|^2 \longrightarrow \omega^2 = |\vec{p}|^2 + G(|\vec{p}|, T)$; G computable as:



A B

– result for G[IJMPA 2007, AdP 2008]:



What is T_c?

– at T_c : γ starts to acquire a **Meissner mass** m_γ (monopole condensate) $\Rightarrow$

for $\omega \leq m_\gamma$: γ is **evanescent.**

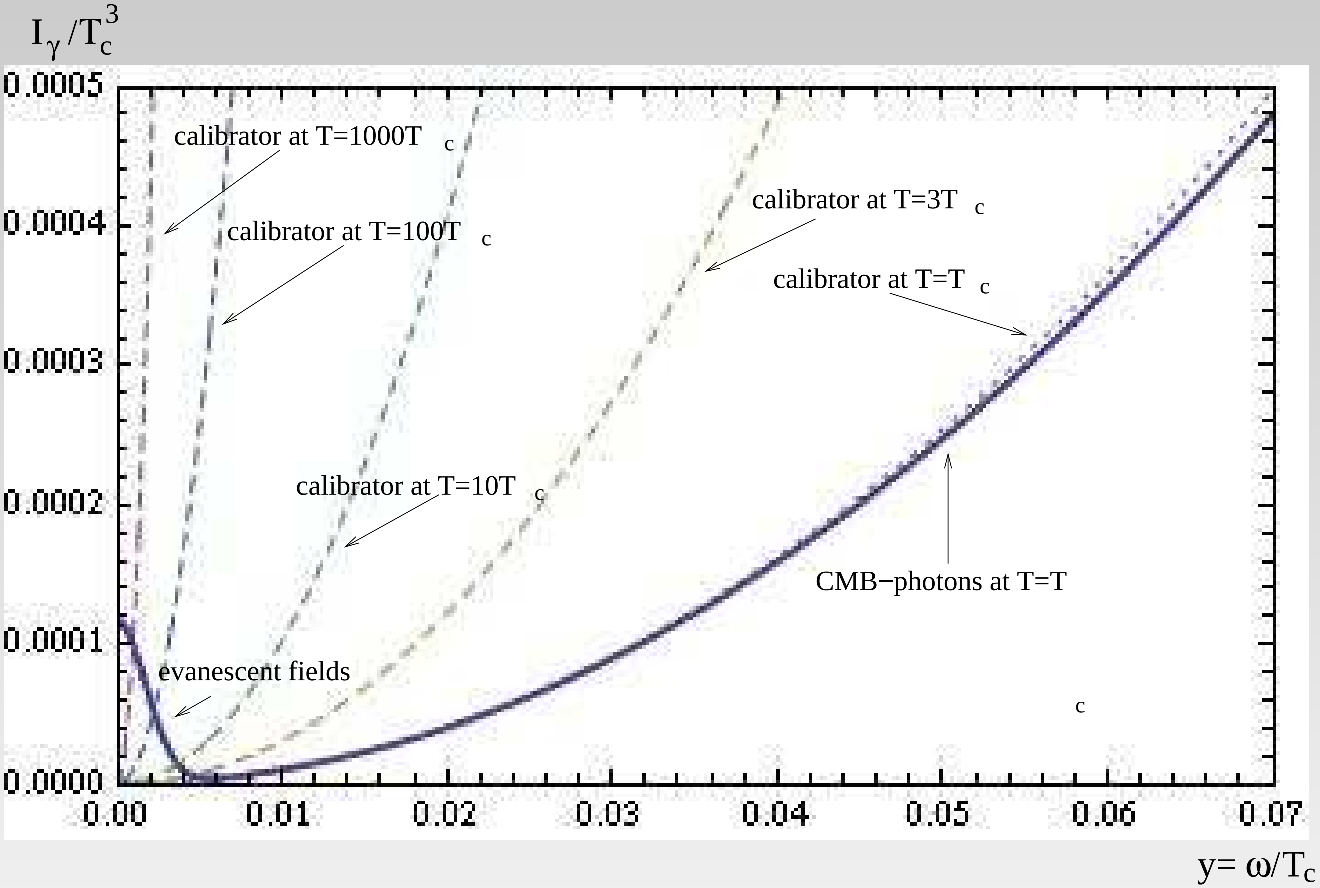
– CMB observational situation at low ω

(ground based: radiofrequency surveys 1980ies;

balloon-borne: Arcade2 2004-2008):

$$T(\omega) = 2.725\,\mathrm{K} + 1.19\,\mathrm{K}\left(\frac{\omega}{1\,\mathrm{GHz}}\right)^{-2.62}\,. \tag{6}$$

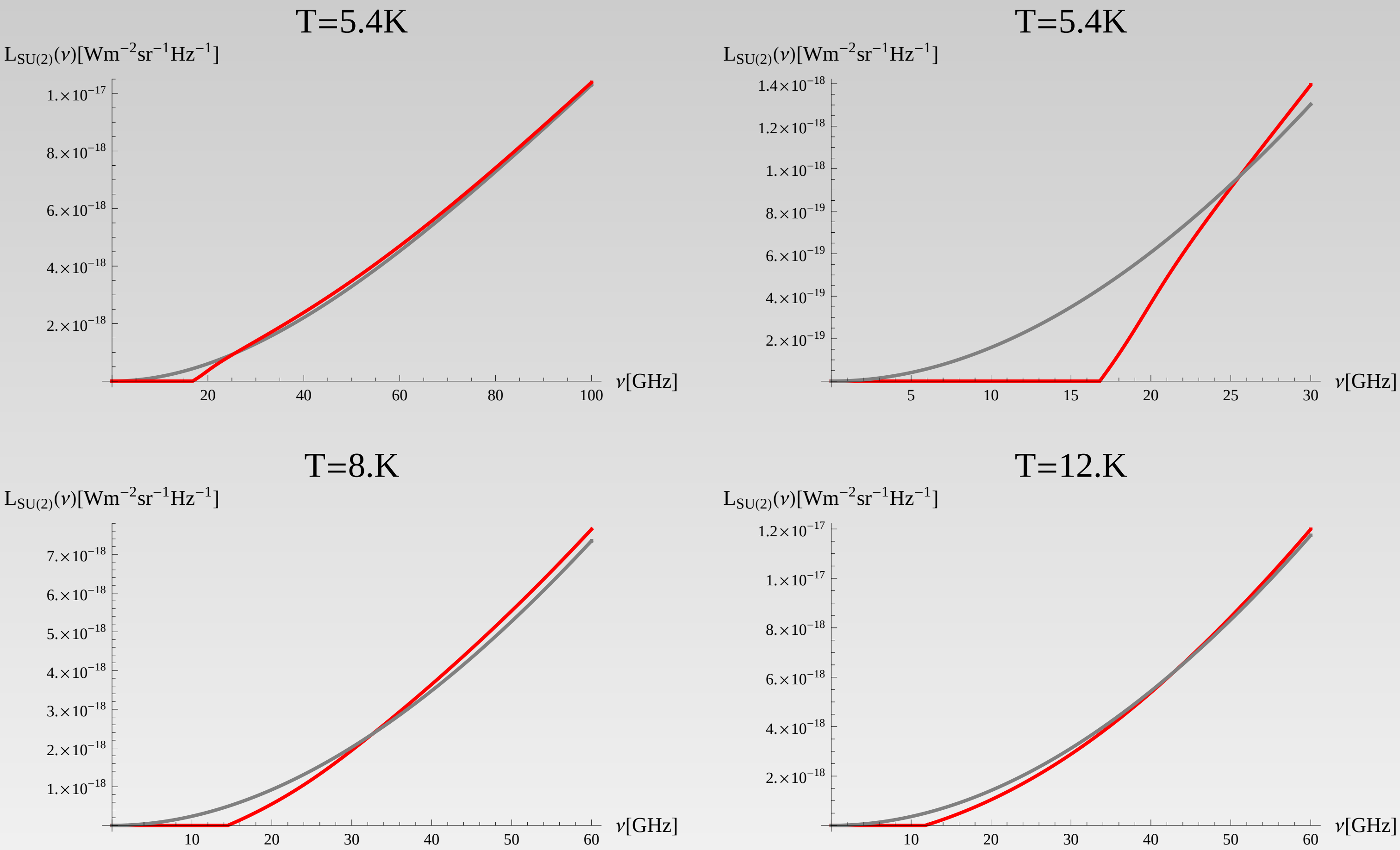
Unexpl. Extragal. Emission



(extracted value: $m_\gamma \sim 100\,\mathrm{MHz}$)

[RH, AdP 2009]

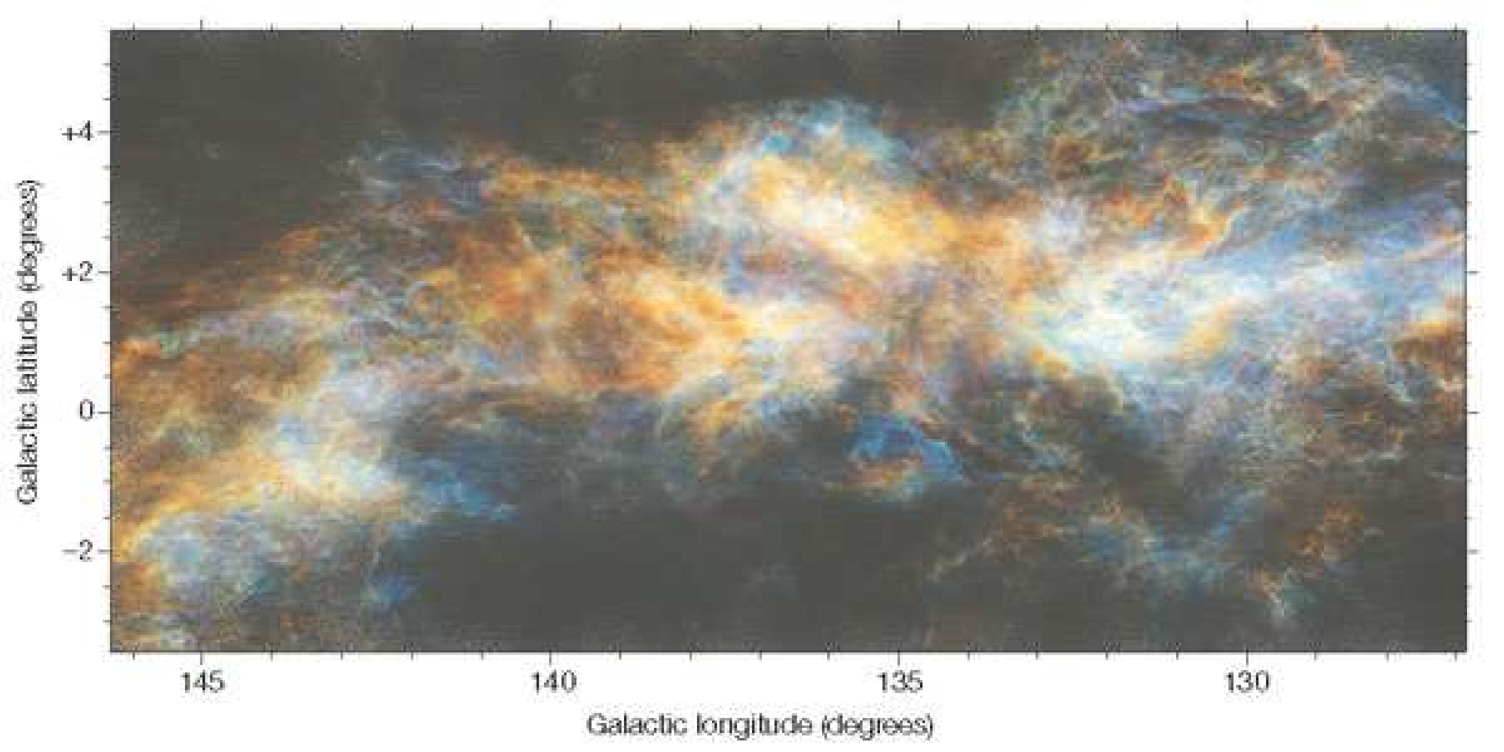
Modified BB spectrum



[Schwarz, RH, Giacosa; Ludescher and RH; Falquez, RH, Baumbach (prep.)]

Implication I:

– **Cold, dilute, old, and stable H1 clouds:**

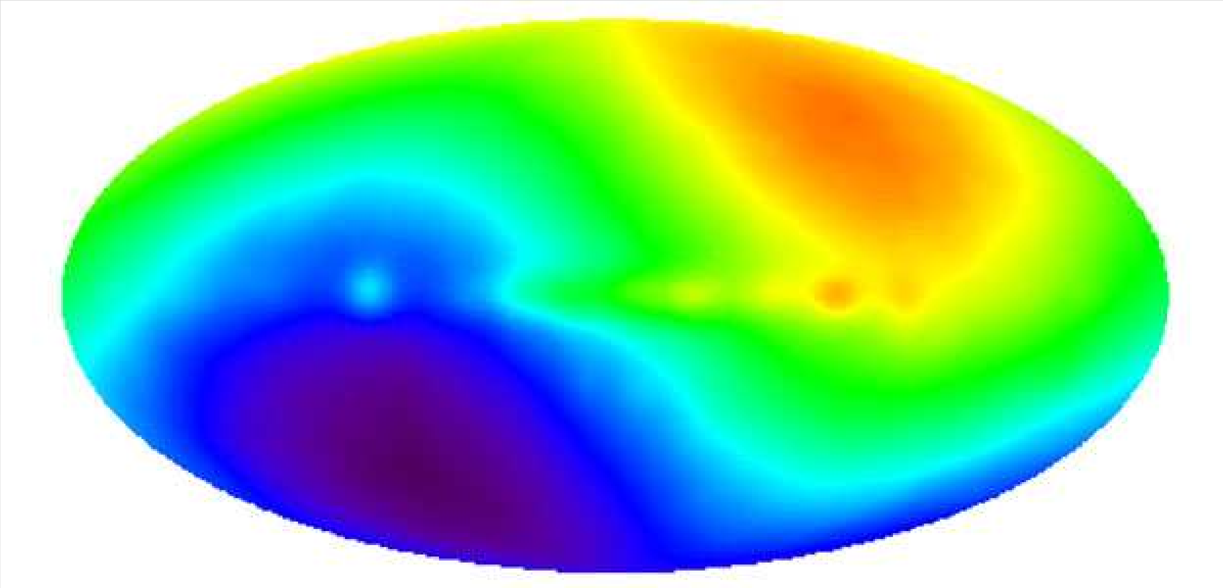


location, long. extent: outer edge of Milky way, 10 kPc
age: 5×10^7 y; **composition:** mainly H1;
density: $\sim 1\,\mathrm{cm}^{-3}$

[Brunt and Knee, Nature 2001]

Implication II:

– dynamical component to CMB dipole:



puzzle: rel. Doppler effect ⇒ $v_{\text{rel-CMB}}$ in contradiction to gravitationally inferred infall velocity of Local Group towards Virgo Cluster

discrepancy: gradient to CMB T profile ⇒ Dipole possesses dynamic component (BB anomaly)

[Szopa and RH, JCAP 2008; Ludescher and RH, arXiv 2009]

Implication III:

– Primordial nucleosynthesis:

$n^0 \longrightarrow p^+ + e^- + \bar{\nu}_e$	$p^+ + n^0 \longrightarrow {}^2_1\mathrm{D} + \gamma$
${}^2_1\mathrm{D} + p^+ \longrightarrow {}^3_2\mathrm{He} + \gamma$	${}^2_1\mathrm{D} + {}^2_1\mathrm{D} \longrightarrow {}^3_2\mathrm{He} + n^0$
${}^2_1\mathrm{D} + {}^2_1\mathrm{D} \longrightarrow {}^3_1\mathrm{T} + p^+$	${}^3_1\mathrm{T} + {}^2_1\mathrm{D} \longrightarrow {}^4_2\mathrm{He} + n^0$
${}^3_2\mathrm{He} + {}^4_2\mathrm{He} \longrightarrow {}^7_3\mathrm{Li} + \gamma$	${}^3_2\mathrm{He} + n^0 \longrightarrow {}^3_1\mathrm{T} + p^+$
${}^3_2\mathrm{He} + {}^2_1\mathrm{D} \longrightarrow {}^4_2\mathrm{He} + p^+$	${}^3_2\mathrm{He} + {}^4_2\mathrm{He} \longrightarrow {}^7_4\mathrm{Be} + \gamma$
${}^7_3\mathrm{Li} + p^+ \longrightarrow {}^4_2\mathrm{He} + {}^4_2\mathrm{He}$	${}^7_4\mathrm{Be} + n^0 \longrightarrow {}^7_3\mathrm{Li} + p^+$

at $T_{\text{freeze-out}} \sim 1\,\text{MeV}$ for fixed ratio neutrons/protons:

$$H = \Gamma_{\text{weak}}\,. \tag{7}$$

SU(2) $\Rightarrow$ 6 add. rel. dof's $\Rightarrow$ G_F 10% larger $\Rightarrow$
EW symmetry not broken by Higgs sector in SM!

[Schwarz, RH, Giacosa, JHEP 2008]

Subleties of a measurement

The problem of external fields:

Tada et. al [M. Tada et al, PLA 2006]
measure BB line temperature at:
2.527 GHz for $T = 67 \ldots 1000\,\mathrm{mK}$.

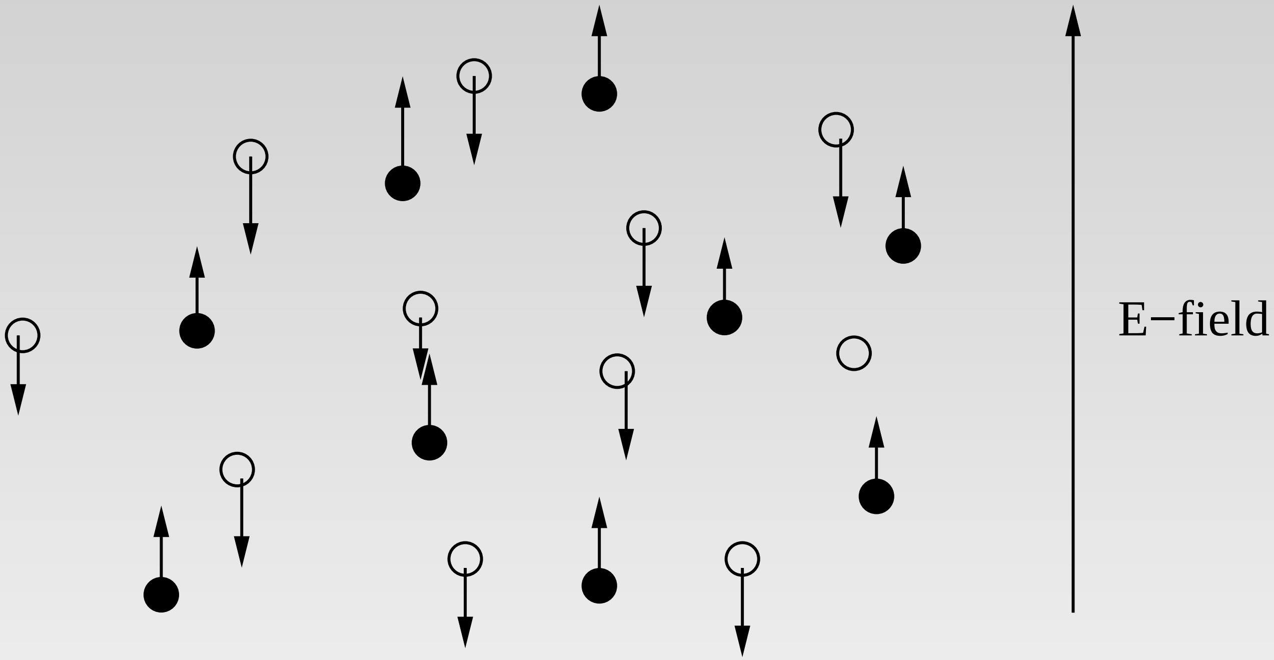
result: no deviation from Planck radiation law ?!

resolution: stray E-field of $|\vec{E}| \sim 25\,\mathrm{mV/cm}$ in cavity
$\Rightarrow$ external energy density $\rho_E = 172\,\mathrm{MeV/m}^3$
but: internal energy density $\rho_{\text{g.s.}} = \frac{T}{T_c} \times 463\,\mathrm{keV/m}^3$.

$\Rightarrow \rho_E \sim 170 \times \rho_{\text{g.s.}}$ for $T \sim 2\,T_c$
$\Rightarrow T_{\text{eff}}$ is $T_{\text{eff}} \sim 350\,T_c$

$\Rightarrow$ SU(2) shows perfect U(1) behavior.

Effect of external E-field on thermal ground state:



(i) monopole−antimonopole acceleration and separation
(ii) by collisions dissipation of external field energy
(iii) virialization generates an effective ground state temperature disparate to temperature of massless excitations

lesson:

– external E-fields screened well below $|\vec{E}| \sim 0.6\,\text{mV/cm}$ (criterion: $\rho_E \leq 0.1\,\rho_{\text{g.s.}}$)

– Rydberg-atom single photon counting experiment by Tada et al. not a valid SU(2) test

– photon mass extractions at external energy densities above $\rho_{\text{g.s.}}$ nothing to do with prediction at T, say, 5 K

– static external B-fields not expected to have a large effect; to be safe, however, screen magnetic energy density to well below $\rho_{\text{g.s.}}$

Proposed experiment

A: fixed frequency, line-temperature difference:

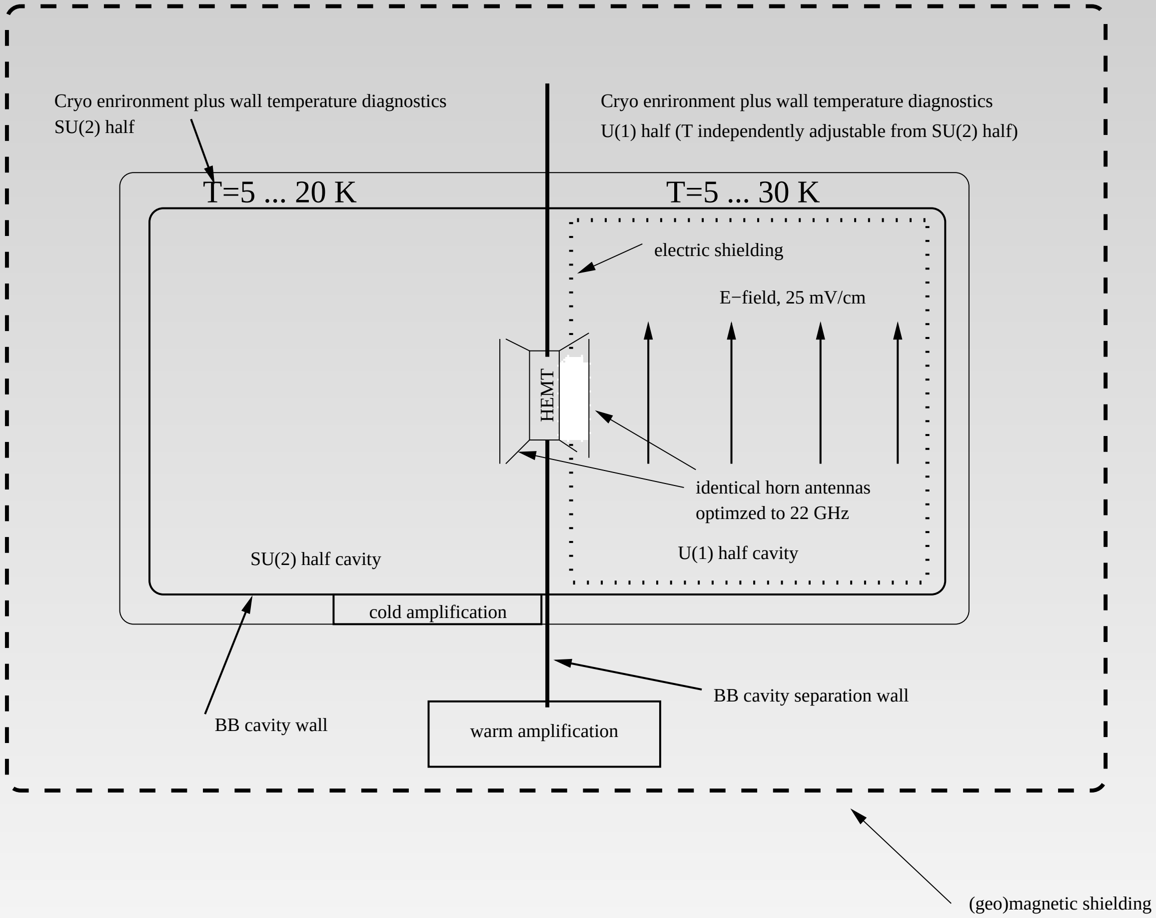
SU(2) nulled by U(1) intensity
in dep. of SU(2) wall temp.

B: fixed frequency, intensity difference:

diff. SU(2) and U(1) intensity

in dep. of common wall temp.

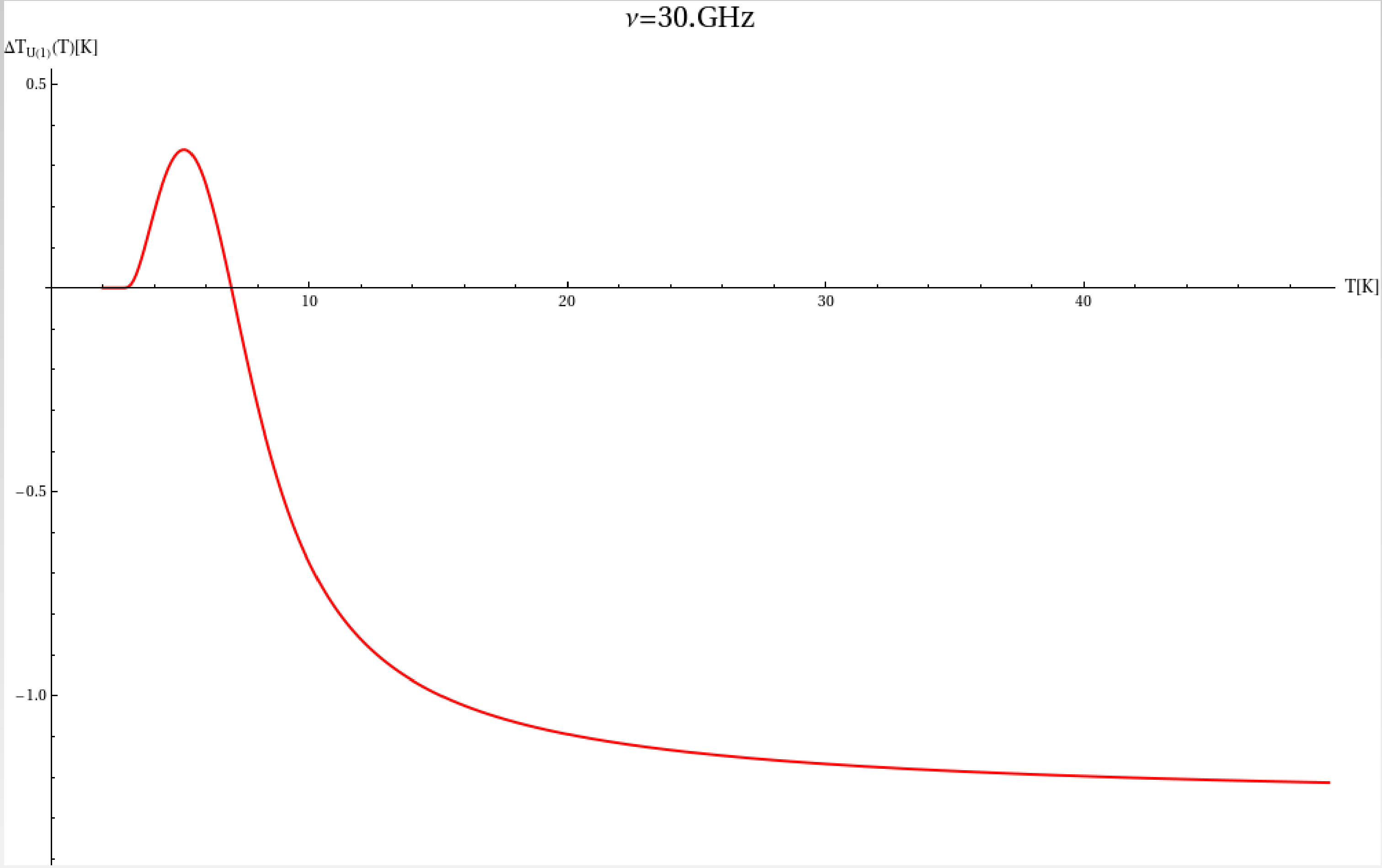
Sketch of set-up



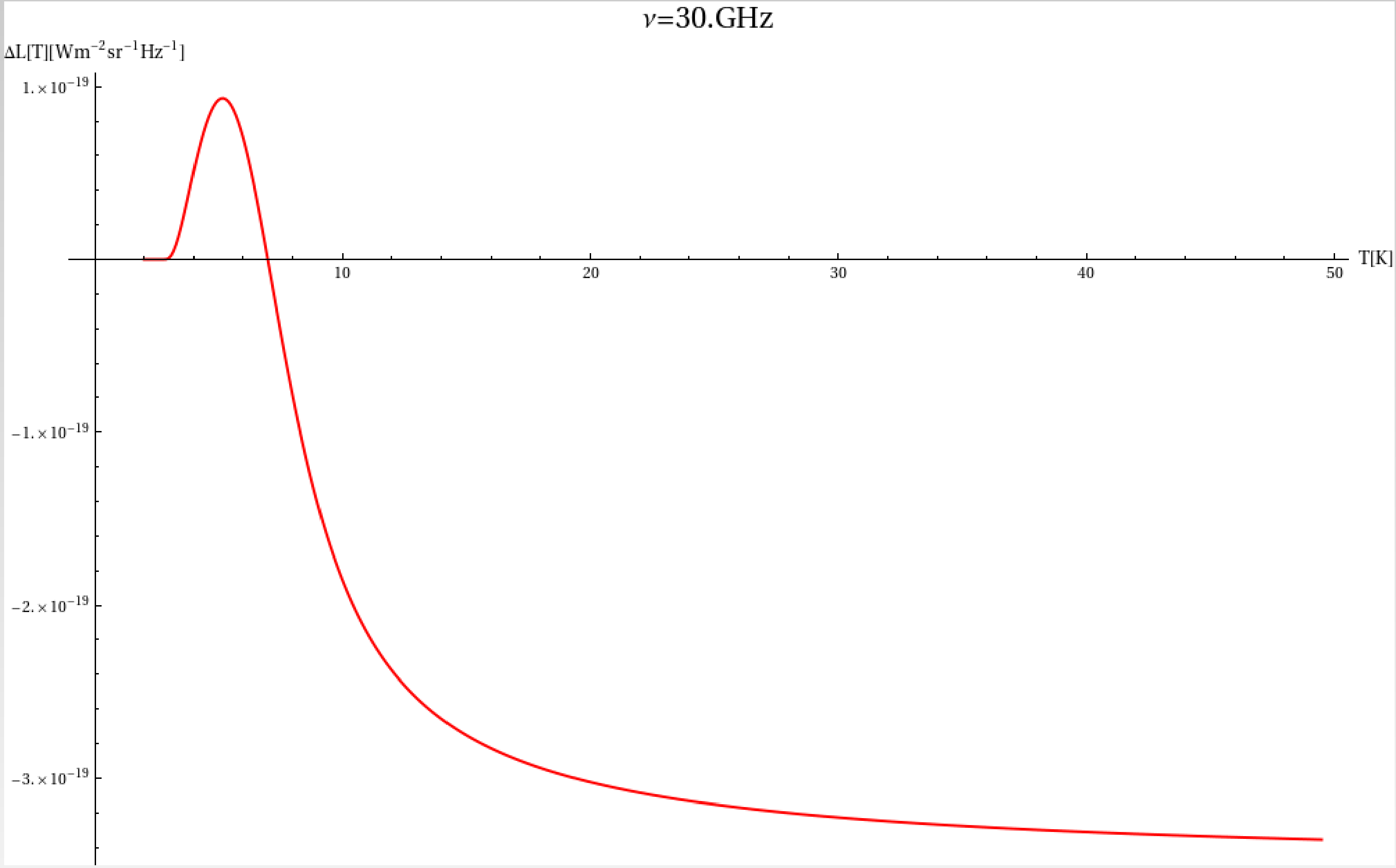
Principal set−up proposed to measure U(1) line temperature of SU(2) intensity at fixed frequency as function of SU(2) temperature.

The static electric field in the U(1) half cavity lifts the thermal ground state to an effective temperature where photons no longer experience SU(2) effects.

Proposed experiment A:



Proposed experiment B:



Summary

– gauge principle for electrodynamics

– problems with U(1)

– nonperturbative SU(2) as alternative

– critical temperature

– prediction of BB anomaly at low T and low ω

– cosm., astroph., and particle-physics implications

– prediction for U(1) line temperature
as function of BB temperature

+ principal proposed experimental set-up

Thank you.