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SU(2,CMB), the nature of light and accelerated cosmological expansion

Ralf Hofmann*

Institut für Theoretische Physik, Universität Frankfurt, Johann Wolfgang Goethe - Universität, 60054 Frankfurt, Germany

E-mail: r.hofmann@thphys.uni-heidelberg.de

We present quantitative and qualitative arguments in favor of the claim that, within the present cosmological epoch, the $U(1)_Y$ factor in the Standard Model is an effective manifestation of SU(2) pure gauge dynamics of Yang-Mills scale $\Lambda \sim 10^{-4}$ eV. Results for the pressure and the energy density in the deconfining phase of this theory, obtained in a nonperturbative and analytical way, support this connection in view of large-angle features inherent in the map of the CMB temperature fluctuations and temperature-polarization cross correlations.

Dedicated to Pierre van Baal with best wishes for a soon recuperation.

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*Speaker.

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The principle of relativity and the constancy of the velocity of light are the two empirical facts Special Relativity is built on. For the electrodynamics of moving bodies they imply the nonexistence of a singled-out inertial frame of reference: all inertial frames are connected by Lorentz transformations under which electric and magnetic fields behave like the components of a second-rank tensor. As a consequence, the long-nurtured idea of a world ether, allegedly enabling the propagation of electromagnetic waves and thus defining a preferred rest frame, is abandoned [1]. At first sight this seems to clash wih the observation of an almost perfect black-body spectrum in the cosmic microwave background (CMB) since one is tempted to tie the temperature of the latter to the existence of the rest frame of a heat bath. This apparent contradiction can, however, be avoided if todays CMB and tiny deviations in its Planck spectrum by photon emission from localized sources (stars), are shown to *decouple* from an existing, overall rest frame of a heat bath.

Conventionally, the decoupling of the CMB from its heat bath is thought to occur when the Universe becomes transparent through the capture of electrons by ions and the subsequent formation of neutral atoms. That is, at redshift $z \sim 1100$ or temperatures in the eV range. This point of view, however, is likely to be overly simplistic. As we will argue below, the existence of the CMB is tied to the existence of a ground state (or heat bath) which only within the *present* cosmological epoch happens to be undetectable in the properties of its (photon) excitations. (Gravity, however, is sensitive to the existence of such an invisible ground state.) In other words, the observed decoupling of the background radiation from its heat bath (ground state) today, implying the exact Lorentz covariance of the laws of electromagnetism, could be a singled out situation in the cosmological evolution. If that is to be the case then there must be a good, that is, a dynamical reason.

The purpose of this presentation is to propose a scenario where today's Lorentz invariance and certain properties of the CMB, as observed in its power spectra at large angles, *emerge* due to strongly interacting SU(2) Yang-Mills dynamics of scale $\Lambda \sim 10^{-4}$ eV. We will show why the (finite) temperature, where the thermalized SU(2) Yang-Mills theory dynamically restores Lorentz invariance, happens to be that of the cosmic microwave background $T_{\text{CMB}} = 2.18 \times 10^{-4}$ eV. Because the scale Λ of this Yang-Mills theory essentially is T_{CMB} we adopt the name SU(2)$_{\text{CMB}}$.

We would like to remark at this point that besides the particular situation at T_{CMB} and for $T \ll T_{\text{CMB}}$ [2] the Lorentz invariance of the fundamental Lagrangian of the SU(2) Yang-Mills theory is an exact symmetry of Nature only in the limit of an asymptotically large temperature: In this limit all excitations are massless, and the ground state, although far from being trivial, neither is visible in the spectrum of excitations nor directly contributes to any thermodynamical quantity [2].

The outline of the presentation is as follows: First, we list a number of motivations for the claim that $SU(2)_{\text{CMB}} \stackrel{\text{today}}{=} U(1)_Y$. Before we discuss some of the physics of the CMB, as it follows from that claim, we need to provide prerequisites on a number of results, obtained in a nonperturbative and analytical way, for the thermodynamics of an SU(2) Yang-Mills theory [2, 3, 4]. Subsequently, we discuss this theory at a particular point $T_{c,E}$ of its phase diagram: the boundary between the deconfining and preconfining phase. While the ground state of the former phase emerges as a spatial average over interacting, topology changing quantum fluctuations (calorons and anticalorons subject to gluon exchanges between and radiative corrections within them which manifest themselves in terms of an inert adjoint Higgs field with T-dependent modulus on the one hand and a pure-gauge configuration on the other hand) the ground state of the preconfining phase is a condensate of magnetically charged monopoles.

The point $T_{c,E}$ is remarkable because a coincidence between an electric and magnetic description takes place. (To avoid confusion: A magnetic charge emerging as a result of the apparent gauge-symmetry breaking SU(2)→U(1) in the deconfining phase is interpreted as an electric charge with respect to U(1)$_Y$. Nevertheless we will in the following refer to electric and magnetic charges as if the F_{0i} components of the field strength in the underlying SU(2) theory defined the color *electric* field.) While electrically charged gauge modes decouple thermodynamically at $T_{c,E}$ because their mass diverges there the charge and the mass of a magnetic monopole vanishes at $T_{c,E}$. Thus the photon is precisely massless and unscreened at $T_{c,E} = T_{\text{CMB}}$: a result which is in agreement with our daily experience. This situation is singled-out in the cosmological evolution. As a function of temperature a dynamically emerging Lorentz invariance is stabilized at T_{CMB} by an infinitely sharp dip in the energy density. Next we investigate to what extent the energy density of the ground state at T_{CMB} and the associated (negative) pressure contribute to the Universe's present equation of state.

A discussion of radiative corrections to the pressure at the two-loop level is performed subsequently. We observe that within an error of about 50% the corresponding maximal deviation from the pressure of a free photon gas at $T \sim 3\,T_{\text{CMB}}$ matches the strength of the dipole temperature fluctuation extracted from the CMB map by WMAP and COBE. We subsequently discuss this result.

Finally, we present a summary and an outlook on future research. We stress the necessity to observationally and theoretically investigate the cross correlation between electric/magnetic polarization and temperature fluctuation at large angles: Information about both correlations would allow to identify CP violation in the CMB. The identification of CP violation, in turn, would support the claim that cosmic coincidence, namely the approximate equality of today's energy densities in dark matter and dark energy, is explained by the slow-roll of a Planck-scale axion [2, 6]. The latter field also would have played an important role in the generation of the lepton and baryon asymmetries as we observe them today [2].

1. Why $SU(2)_{\text{CMB}} \stackrel{\text{today}}{=} U(1)_Y$?

There are several reasons to consider the possibility that a larger gauge symmetry masquerades as the U(1)$_Y$ factor of the standard model within the present cosmological epoch. On the theoretical side, Quantum Electrodynamics exhibits ultraviolet slavery as opposed to asymptotic freedom - an esthetically not overly appealing property. On the observational side there are a number of puzzling large-angle anomalies in the one-year data on the cosmic microwave sky as released by the WMAP collaboration which, however, have to be viewed with a healthy scepticism [24]. Decisive results are expected within the near future. If the $U(1)_Y$ factor of the standard model is, indeed, an effective manifestation of strongly interacting SU(2) gauge dynamics then the radiation history of the Universe needs some rewriting in the low redshift regime. This opens up the potential to explain the puzzling anomalies occurring for $z \leq 20$. In addition, a near coincidence for the densities of cosmological dark matter ($\rho_{\text{DM}} \sim 0.3\rho_{\text{crit}}$) and dark energy ($\rho_{\text{DE}} \sim 0.7\rho_{\text{crit}}$) is observed - a fact which, as we will argue below and have argued in [2], may be tightly related to strongly interacting, nonabelian gauge dynamics. (A slowly rolling Planck-scale axion receiving its mass through the topologically nontrivial fluctuations of SU(2)$_{\text{CMB}}$ - calorons, see [5].) The obvious

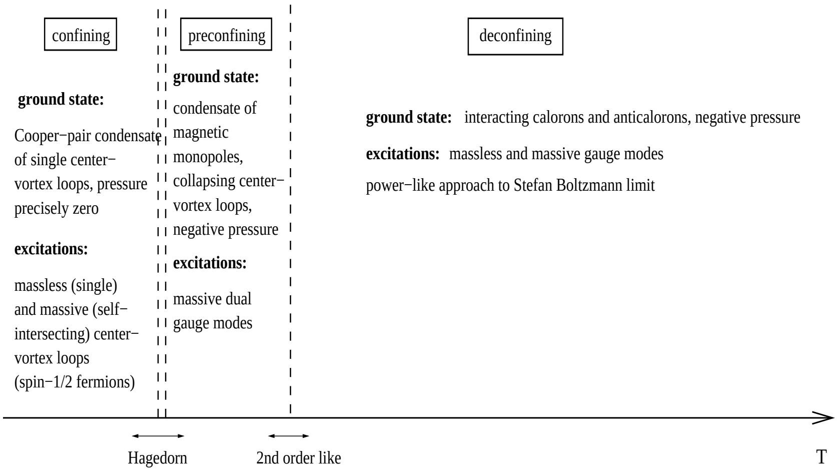

Figure 1: The phase diagram of an SU(2) Yang-Mills theory.

because minimal candidate for such a scenario is a dynamical breaking of an SU(2) Yang-Mills theory down to its Abelian subgroup U(1).

2. SU(2) Yang-Mills thermodynamics

A nonperturbative approach to SU(2) and SU(3) Yang-Mills thermodynamics was worked out recently in [2, 3, 4]. This approach benefits from strong research efforts in SU(N) Yang-Mills theory performed both within the perturbative [7, 8] and within the nonperturbative [9, 10, 11, 12, 13, 14, 15, 16, 17, 18] realm. In [2] we have derived the phase structure of an SU(2) and an SU(3) Yang-Mills theory. Each theory comes in three phases: a deconfining, a preconfing, and a confining one, see Fig. 1. While the transition between the deconfining and the preconfining phase is of a second-order like nature the transition towards the confining phase is genuinely nonthermal and of the Hagedorn type. The latter transition goes with a change of statistics: The excitation in the preconfining phase are massive spin-1 bosons while they are massless and massive spin-1/2 fermions (single and selfintersecting center-vortex loops, respectively) in the confining phase. For our discussion of the CMB power spectra a large angles it is sufficient to resort to deconfining dynamics of the SU(2) theory. Therefore we will elucidate (but not derive) the dynamical facts for this phase only.

We start by considering a Euclidean formulation of the thermalized SU(2) theory where time is constrained to a circle, $0 \leq \tau \leq \beta \equiv \frac{1}{T}$ (periodicity of gauge-field configurations). From a unique, nonlocal definition involving a pair of a noninteracting trivial-holonomy caloron and its anticaloron (Harrington-Shepard solution) [12] the computation of the τ dependence of the phase of a spatially homogeneous, quantum mechanically and statistically inert, adjoint scalar field ϕ is the first step in deriving a spatially coarse-grained action. Notice that it is consistent to determine the phase in terms of classical (Euclidean) field configurations since the periodic dependence in τ is solely determined by T, that is, dimensional transmutation is irrelevant for ϕ's phase. (To explain the term holonomy: A nontrivial holonomy is the feature of a finite-temperature gauge-field configuration that its Polyakov loop, evaluated at spatial infinity, is different from an element of the center Z_2 of SU(2). The Harrington-Shepard solution [12], which is (anti)selfdual and thus energy-

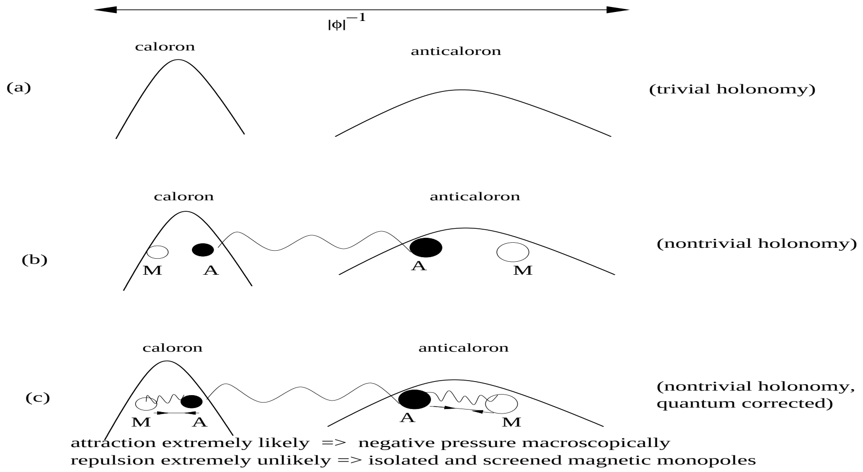

Figure 2: Stepwise and selfconsistent derivation of a thermal ground state upon spatial coarse-graining. (a) A homogeneous and inert adjoint scalar field ϕ emerges from a pair of trivial-holonomy caloron and anticaloron upon spatial coarse-graining down to a resolution given by $|\phi|$. (b) Interactions between caloron and anticaloron, mediated by plane-waves of a resolution not much larger than $|\phi|$, induce a nontrivial holonomy and thus a BPS monopole-antimonopole pair in each configuration. (c) plane-wave fluctuations of resolution considerably larger than $|\phi|$ induce a potential between monopole and antimonopole which is attractive (repulsive) for a small (large) holonomy.

pressure free, is a periodic instanton in singular gauge with trivial holonomy (no substructure) and topological charge ± 1. The Lee-Lu-Kraan-van-Baal solution [15, 16] is (anti)selfdual with nontrivial holonomy and topological charge ± 1. Because the nonvanishing $a_4(\vec{x} \to \infty, \tau)$ sets a mass scale proportional to temperature the solution exhibits a substructure in terms of a BPS magnetic monopole-antimonopole pair whose combined mass $M_m + M_a$ is $8\pi^2 T$. By computing the one-loop quantum weight for a nontrivial-holonomy caloron, which is a heroic deed, it can be shown that there is an attractive (repulsive), quantum-induced potential between monopole and antimonopole if the holonomy is small (large) [18].) Assuming the existence of a Yang-Mills scale Λ_E, which is strongly supported by one-loop perturbation theory [7], the modulus $|\phi|$ follows. (At this level the scale Λ_E only enters into a constraint for the finite size of the spatial volume that saturates the infinite-volume average.) Since ϕ, describing averaged-over noninteracting trivial holonomy calorons and anticalorons at a spatial resolution $|\phi|$, turns out to be nondeformable it represents a fixed source to the coarse-grained Yang-Mills equations for the trivial-topology sector of the theory. Thus it turns out to be selfconsistent to consider (anti)caloron interactions, which are mediated by the topologically trivial sector, *after* the spatial coarse-graining has been performed. These interactions manifest thermselves in terms of a pure-gauge configuration a_μ^{bg} solving the coarse-grained Yang-Mills equations. As a consequence, the pressure and the energy density of the ground state is shifted by (anti)caloron interactions from zero to $\mp 4\pi T \Lambda_E^3$. (The concept of a thermal ground state thus emerges in view of the average effect of interacting quantum fluctuations of trivial and nontrivial topology.) How this shift comes about on the microscopic level is depicted in Fig. 2. On length scales not much smaller than $|\phi|^{-1}$ a gluon exchange between a trivial-holonomy caloron and its anticaloron essentially shifts the holonomy only, thereby creating a monopole-antimonopole pair in both the caloron and the anticaloron. Fluctuations of much higher resolution induce a potential between the monopole and its antimonopole. Since the latter attract for a small holonomy monopole and antimonopole eventually annihilate. Thus the quantum weight for the process of monopole-antimonopole creation and their subsequent annihilation essentially is given by that for a trivial-holonomy caloron [13]. Depending on the scale parameter of the caloron this quantum weight can be sizable. In the opposite case of monopole-antimonopole repulsion (large holonomy) the (anti)caloron dissociates into an isolated but screened monopole and antimonopole. (The screening of magnetic charge is facilitated by intermediate, small-holonomy (anti)caloron fluctuations which generate short-lived magnetic dipoles.) The weight for such a process essentially is given by $\exp\left[-\frac{M_m+M_a}{T}\right]=\exp[-8\pi^2]$ which is an extremely small number. We thus conclude that the dissociation of (anti)calorons is an extremely rare process as compared to the fall-back process of a small-holonomy caloron onto trivial holonomy by monopole-antimonopole annihilation. The latter process involves *attraction* between the (anti)caloron constituents: a situation which is responsible for the negative and spatially homogeneous ground-state pressure $P^{gs}=-4\pi T\Lambda_E^3$ emerging upon spatial coarse-graining.

What about propagating excitations? Depending on the direction in color space an excitation either gets scattered off caloron or anticalorons (off-Cartan directions in a gauge where the spatial projection of an (anti)caloron is ‘combed’ into a given color-space direction) or it propagates in an unadulterated way through the caloron-anticaloron ’forrest’ (Cartan direction). In the former case an excitations describes a zig-zag like trajectory while there is straight-line propagation in the latter case. Upon spatial coarse-graining a zig-zag like propagation is converted into straight-line propagation but now subject to a mass term, see Fig. 3. Straight-line propagation on the microscopic level is left untouched by spatial coarse-graining. After spatial coarse-graining the situation is summarized by the adjoint Higgs mechanism: two out of three directions in adjoint color space become massive ($m_{W^\pm}=2e|\phi|=2e\sqrt{\frac{\Lambda_E}{2\pi T}}$ where e denotes the *effective* gauge coupling, the subscript $W^\pm$ solely indicates the massiveness and the electric charge of the excitation and is not to be associated with the massive bosons in the electroweak unification) due to coarse-grained, interacting (anti)calorons while the third direction remains massless ($m_\gamma=0$). Interactions between coarse-grained excitations are mediated by plane-wave fluctuations which, however, can not be further off their mass shell than $|\phi|^2$ since all fluctuations of resolution larger than $|\phi|$ are integrated into the pure-gauge configuration a_μ^{bg} already. This renders the effect of explicit interactions very small after spatial coarse-graining [2, 4]. As far as large-angle signatures in the fluctuation map for the cosmic microwave background are concerned they do, however, play an important role.

The invariance of the Legendre transformations between thermodynamical quantities (thermodynamical selfconsistency [19]) demands a first-order evolution equation for the *effective* gauge coupling e [2]. The solution of this equation is depicted in Fig. 4 for both SU(2) (grey line) and SU(3) (black line). A number of comments are in order (only discussing the SU(2) case). First, there is an attractor to the evolution being a plateau $e=5.1$ and a logarithmic divergence $e\propto-\log(\lambda_E-\lambda_{c,E})$ where $\lambda_{c,E}=11.65$. That is, the low-temperature behavior in the evolution of e is independent of the boundary condition set at high temperatures. This is the celebrated ultraviolet-infrared decoupling property of the SU(2) Yang-Mills theory, which, in a logarithmic fashion, is already observed in perturbation theory. Second, the plateau value signals the conservation of the magnetic charge $g=\frac{4\pi}{e}$ of an isolated and screened magnetic monopole: Even

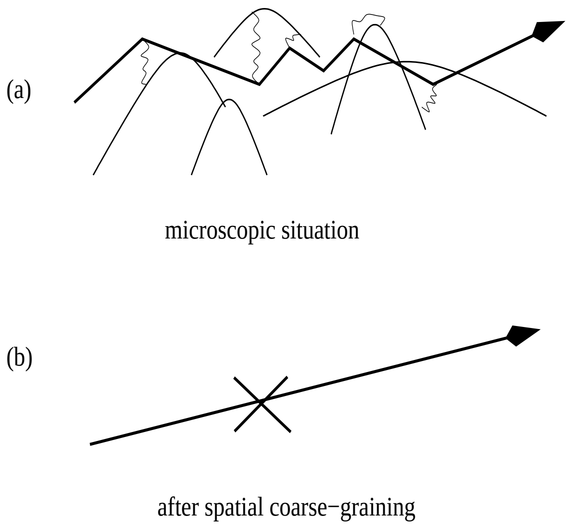

Figure 3: Consecutive scattering of off-Cartan modes off calorons and anticalorons (a) and the emergence of mass by optimized spatial coarse-graining (b).

after screening by intermediate small-holonomy caloron fluctuations each isolated monopole or antimonopole is a nonrelativistic particle for temperatures not too close to $\lambda_{c,E}$. The very limited mobility of a (anti)monopole then implies that the magnetic charge per unit volume is a conserved quantity. Third, only close to $\lambda_{c,E}$ do (anti)monopoles become mobile due to increased screening leading to the instability of (anti)calorons with respect to a switch to large holonomy (monopole condensation) [18]: local charge conservation does no longer hold. This is the relevant regime for an investigation of polarization-temperature cross correlations in the angular power spectrum of the CMB. At $\lambda_{c,E}$ monopoles become precisely massless and thus Bose condense while the off-Cartan excitations exhibit a diverging mass and thus fall out of thermal equilibrium.

In Fig. 5 a plot of the total pressure P over T^4 as a function of temperature is shown for both the deconfining and the preconfining phases. Notice the rapid (power-like) approach to the Stefan-Boltzmann limit. Notice also that the total pressure is negative shortly above $\lambda_{c,E}$ and even more so in the preconfining phase. This is a consequence of the ever increasing dominance of the ground state when cooling the system in the regime where the temperature is comparable to the Yang-Mills scale and where excitations becoming increasingly massive. (Recall that the ground-state physics in the deconfining phase originates from a spatial average over pairs of *attracting*, *annihilating*, and subsequently *recreated* monopoles and antimonopoles while there are collapsing and recreated center-vortex loops in the preconfining phase making up the *negative* ground-state pressure.) In Fig. 6 we show a plot of the total energy density ρ over T^4 as a function of temperature. Again, there is a power-like approach to the Stefan-Boltzmann limit. Notice the infinite-curvature dip at $\lambda_{c,E}$. The upwards jump toward the preconfining phase is a consequence of the dual gauge mode acquiring an extra polarization by the Abelian Higgs mechanism compared to the Cartan-excitation in the deconfining phase. To excite this additional polarization costs energy, therefore the jump. The steep slope to the right of the dip arises due to the logarithmic decoupling of the off-Cartan excitations when approaching $\lambda_{c,E}$. Because off-Cartan excitations possess infinite mass at $\lambda_{c,E}$ the Cartan excitation (our photon if the theory $SU(2)_{\text{CMB}}$ is considered) propagates in a completely unscreened way. Moreover, the photon is precisely massless because the magnetic coupling $g=\frac{4\pi}{e}$

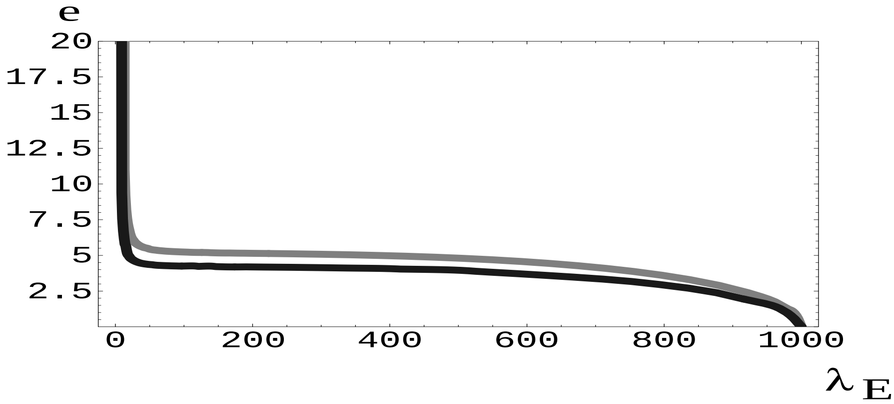

Figure 4: The evolution of the effective gauge coupling e with temperature in the deconfining phase. The grey line depicts the SU(2) case while the black line is for SU(3). We have introduced a dimensionless temperature as $\lambda_E \equiv \frac{2\pi T}{\Lambda_E}$.

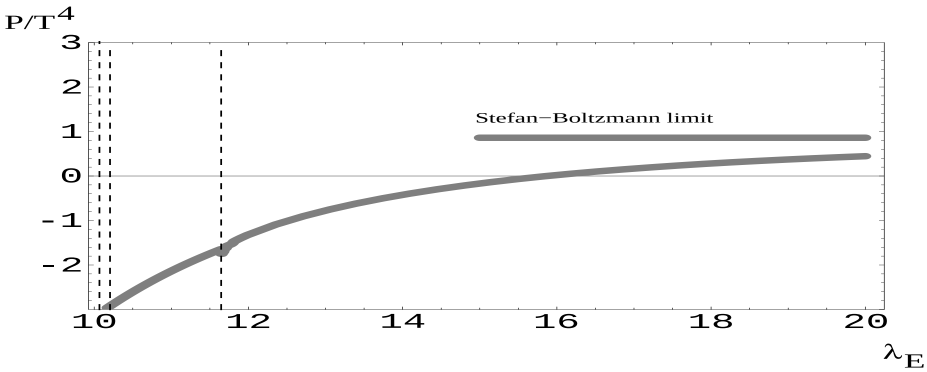

Figure 5: The ratio $\frac{P}{T^4}$ for an SU(2) Yang-Mills theory throughout its deconfining and preconfining phase.

to the monopole condensate vanishes at $\lambda_{c,E}$. This situation is strongly stabilized in terms of the dip in the energy density: Only a departure from thermal equilibrium, which is induced by an external source, will elevate the system into its preconfining phase.

Let us briefly discuss how this likely happens in the real Universe. A Planck-scale axion field [5], which is spatially homogeneous on cosmological length scales and glued to the slope of its potential by cosmological friction at temperatures well above $\lambda_{c,E}$ (see e.g. [6]), starts to roll for $\lambda \gtrsim \lambda_{c,E}$. At a critical velocity of axion rolling, which is going to be reached eventually because the ratio of axion mass to the Hubble parameter increases with increasing axion velocity and because the bulk of the Universe's energy density is stored in the axion field, thermal equilibrium is sufficiently violated to overcome the discontinuity in the energy density of $\mathrm{SU(2)_{CMB}}$ at $\lambda_{c,E}$. As a consequence, the photon will acquire a Meissner mass (visible superconductivity of the Universe's ground state).

Taking the dual gauge boson mass as an 'order parameter' for the second-order like transition at $\lambda_{c,E}$ (associated with an apparent gauge symmetry breaking $U(1)_D \to 1$ in the preconfining phase) we have determined the critical exponent to $\nu = 0.5$ in [2]. Even though both results, the pressure and the energy density, were obtained by a one-loop calculation they are accurate to within the 0.1% level, see below.

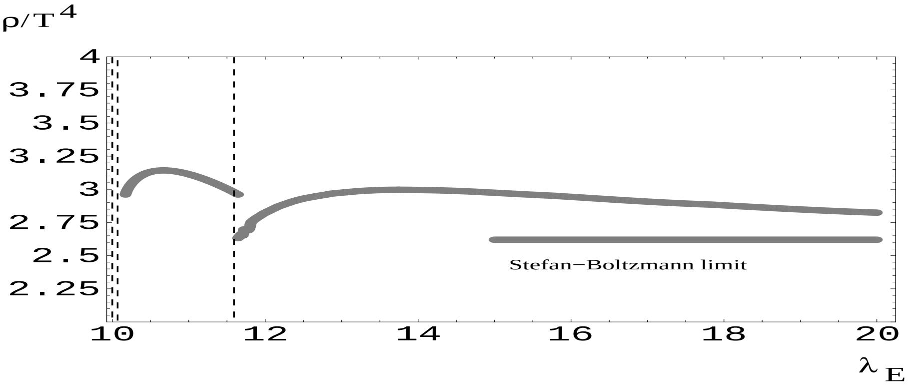

Figure 6: The ratio $\frac{\rho}{T^4}$ for an SU(2) Yang-Mills theory throughout its deconfining and preconfining phase.

3. Electric-magnetic coincidence

At the point $\lambda_{c,E}$ we encounter an exact coincidence in the electric and the magnetic description of the thermalized gauge system. Namely, no dynamical electric charges exist because the off-Cartan modes are decoupled and at the same time magnetic charges are condensed in such a way that they do not influence the properties of the left-over excitations (the magnetic coupling g vanishes precisely at $\lambda_{c,E}$). The dynamical equations of the effective theory, which coincide with Maxwell's equations in the absence of sources, thus are invariant under an electric-magnetic duality transformation at the point $\lambda_{c,E}$. The ground state, although gravitationally detectable by a measurement of the expansion rate of the Universe, is not visible otherwise. To abandon the idea of a world ether, as it was done by Einstein a hundred years ago [1], is correct as far as the electrodynamics of moving bodies is concerned but appears too radical when extending one's perspective by including gravity. This coins the name *invisible ether* for today's $SU(2)_{\text{CMB}}$ monopole condensate not influencing the propagation of photon excitations (including those being excited by accelerated electric charges): At $\lambda_{c,E}$ the photon is massless and unscreened as we observe it today. Thus identifying the point $\lambda_{c,E}$ with the present temperature of the cosmic microwave background $T_{\text{CMB}} = 2.1824 \times 10^{-4}\,\text{eV}$ defines a boundary condition to the thermodynamics of the associated SU(2) Yang-Mills theory. As a result, we determine the scale of the Yang-Mills theory to $\Lambda_E = 1.177 \times 10^{-4}$ eV. Knowing Λ_E yields a prediction for the energy density ρ^{gs} of the invisible ether (a contribution to dark energy). We have $\rho^{gs} = (2.586 \times 10^{-4}\,\text{eV})^4$. If we take the measured value of today's density of dark energy to be $\sim (2 \times 10^{-3}\,\text{eV})^4$ [20, 21, 22] then we derive that only about 0.03% of the Universe's present dark energy density is provided by the ground state of $SU(2)_{\text{CMB}}$. Therefore the bulk of today's dark energy density arises from another source. In [2] we have scetched how a slowly-rolling Planck-scale axion besides generating today's dark energy density also may explain why there is a near coincidence of this value with that of the cosmological dark matter density. In addition, a Planck-scale axion, which becomes mobile whenever an SU(2) or an SU(3) Yang-Mills theory approaches its center (or confining) phase during the Universe's evolution and is frozen-in otherwise, represents a candidate mechanism for the generation of the observed baryon- and lepton asymmetries [2].

The conceptually interesting thing is that Lorentz invariance, which is one of the defining features of the underlying Yang-Mills theory in the limit $T \to \infty$ and which is dynamically violated

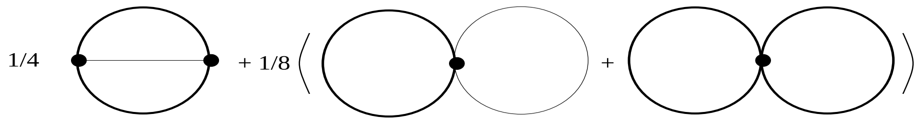

Figure 7: Two-loop corrections to the pressure. The nonlocal diagram is the by-far dominating contribution.

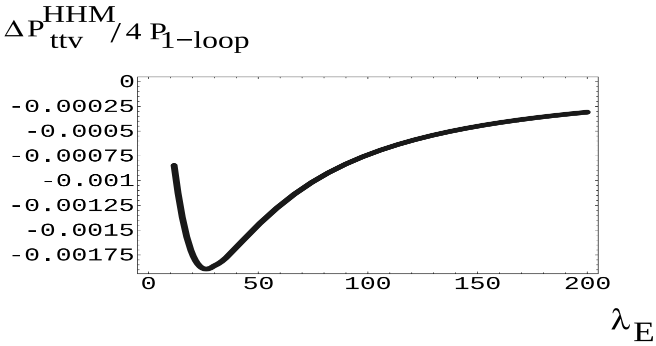

Figure 8: The dominating two-loop correction to the pressure in the deconfining phase of an SU(2) Yang-Mills theory as a function of temperature.

by interactions with a nontrivial, thermal ground state inside the deconfining and the preconfining phase (Higgs mechanism induced, temperature dependent masses), is *dynamically* restored at the point $\lambda_{c,E}$ and in the effective theory at zero temperature (confining phase): A strongly interacting gauge theory restores an asymptotically valid spacetime symmetry at two specific points of its phase diagram.

4. Large-angle fluctuations in the CMB as radiative corrections

We now would like to address how temperature fluctuations and temperature-polarization cross correlations at large angles may be generated in the associated power spectra of the cosmic microwave background. While we have something quantitative to say concerning the former case we need, for the time being, constrain ourselves to a qualitative statement in the latter case. Radiative corrections to the pressure at the two-loop level correspond to the set of diagrams as depicted in Fig. 7. To evaluate these diagrams one has to work in a physical gauge (Coulomb-unitary) for a meaningful implementation of the cutoffs for the off-shellnes of quantum fluctuations. Recall that these cutoffs arise from the spatial coarse-graining inherent in the effective theory. The by-far dominating diagram is the nonlocal one. In Fig. 8 the relative correction to the free-gas pressure asrising from this diagram is shown as a function of temperature. If we interprete the two-loop correction to the pressure in terms of a global temperature fluctuation ΔT of a free photon gas we have $\left|\frac{\Delta P}{P_{\text{1-loop}}}\right| \sim \frac{3}{4}\frac{\Delta T}{T}$. The minimum of the correction in Fig. 8 is at about $\lambda_{m,E} \sim 3 \times \lambda_{c,E}$ and thus corresponds to a redshift of $z \sim 3$. The associated temperature fluctuation is $\frac{\Delta T}{T_{\text{CMB}}} \sim 2.3 \times 10^{-3}$. (We have used the plateau value $e = 5.1$ for the computation of the two-loop correction. Taking into account the logarithmic pole for the temperature dependence of e close to the phase boundary,

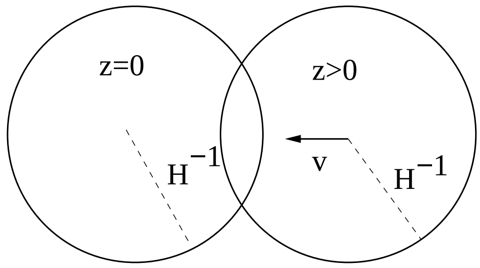

Figure 9: Motion of a Hubble volume from $z \sim 3$ to $z = 0$ in a de Sitter Universe.

$\frac{\Delta T}{T_{\rm CMB}}$ will be a bit smaller than 2.3×10^{-3}.) Now the power of the dipole fluctuation measured in the CMB is $\left.\frac{\Delta T}{T_{\rm CMB}}\right|_{l=1} = 1.24 \times 10^{-3}$: The measured number deviates from the computed one only by about 50%! The standard explanation for the dipole moment is in terms of a net velocity $v \sim 370\,\text{km s}^{-1}$ of the solar rest frame as compared to the CMB rest frame [23]. This is a purely kinematical explanation of the dipole in terms of the relativistic Doppler effect. It is known for a long time that the inferred velocity v is unexpectedly larger than the relative velocity measured between the center-of-mass frame of galaxies and the solar system, see for example http://apod.gsfc.nasa.gov/apod/ap990627.html. It is well possible that a combination of kinematical and dynamical effects generates the dipole as follows: Let us, for simplicity, imagine a pure de Sitter Universe such that the Hubble radius, which sets the size of the horizon, is constant in time. Assume that the solar system started to move at $z \sim 3$ where global temperature fluctuations peak. Due to its net velocity with respect to the comoving frame the solar system's horizon volume at $z = 0$ is spatially shifted as compared to that at $z \sim 3$. While a temperature fluctuation is of horizon-size at $z \sim 3$ temperature fluctuations no longer are global at $z = 0$ because the latter horizon volume has picked up a sequence of temperature changes along the direction of its motion by diving into formerly causally disconnected regions, see Fig. 9. As a consequence, the pure kinematically inferred $v \sim 370\,\text{km s}^{-1}$ would represent an upper bound only, the actual value may be signifantly lower. In reality there is no pure de Sitter expansion at $0 \le z \lesssim 3$ but this does not alter the qualitative validity of the argument.

Let us now discuss how a large cross correlation between temperature fluctuation and electric field polarization at large angles is likely to be generated without relying on the hypothesis of an early reionization of the Universe. Fig. 8 shows that the dominating radiative correction to the photon-gas pressure starts to become sizable at $\lambda_E \sim 10\,\lambda_{c,E}$. In this regime the isolated magnetic monopoles, which are electrically charged with respect to $U(1)_Y$, become increasingly light by an ever increasing screening by intermediate small-holonomy caloron fluctuations. This renders them explicit and mobile electric charges capable of amplifying a primordially existing cross correlation. At $\lambda_{c,E}$ monopoles condense and therefore are not available as isolated scattering centers anymore.

Finally, we would like to stress that it may be premature to take the observed large-angle anomalies, as suggested by the analysis of the one-year WMAP data, at face value as far as their cosmological origin is concerned [24].

5. Summary, conclusions and future work

We have proposed that a strongly interacting SU(2) pure gauge theory ($SU(2)_{CMB}$) of Yang-Mills scale $\Lambda_E = 1.177 \times 10^{-4}$ eV masquerades as the $U(1)_Y$ factor of the standard model of particle physics within the present cosmological epoch. This proposal looks in so far viable and consistent as (i) there exists a dynamical stabilization mechanism for the exact restoration of Lorentz invariance at a particular point in the phase diagram of the Yang-Mills theory (the boundary between the deconfining and the preconfining phase), (ii) the ground-state energy density of $SU(2)_{CMB}$ (not coupling the Planck-scale axion to it) at this point represents only about 0.03% of the measured density in dark energy of the present Universe, (iii) the dipole strength in the temperature map of the CMB is numerically close to the maximum of a global temperature fluctuation (as a function of temperature) derived in terms of a radiative correction in the deconfining phase of the Yang-Mills theory, (iv) there is a mechanism for providing a large correlation between temperature fluctuation and electric field polarization at large angles in terms of mobile and isolated electrically charged monopoles (the hypothesis of an early reionization may turn out to be redundant), and (v) coupling a (slowly rolling) Planck-scale axion to the theory, possibly explains the observed near coincidence between cosmological dark matter and dark energy. (Notice, however, that this would imply that structure formation would be due to ripples and lumps in the coherent axion field [25].) The increasing rate of rolling of the latter will eventually destroy the present thermal equilibirum and elevate $SU(2)_{CMB}$ into its preconfining phase where the photon is Meissner massive.

Furthermore, the system $SU(2)_{CMB}$ plus Planck-scale axion may provide a future theoretical framework to investigate the overall strength and distribution of intergalactic magnetic fields. (For a slight deviation from thermal equilibrium patches of the Universe's ground state are visibly superconducting by the condensate of electric monopoles coupling to its excitations.)

To substantiate the scenario further we need to investigate various angular two-point correlations by a diagrammatic analysis of the radiative corrections in the deconfining phase of $SU(2)_{CMB}$. On a microscopic level, we also may investigate CMB photon scattering processes off individual, electrically charged monopoles for $T > T_{CMB}$. (At a given temperature $T > T_{CMB}$ the number density, the mass, and the charge radius of the latter can be reliably estimated [2, 18].) This provides a handle on the amount of induced electric polarization. A fluctuating Planck-scale axion should introduce an asymmetry between the electric and the magnetic polarization-temperature cross correlation at large angles. It also should make the expectation in the large-angle fluctuation of electric times magnetic mode nonvanishing. If future observations of the CMB at large angles detect a clear signal for CP violation then this would be another indication that the system $SU(2)_{CMB}$ plus Planck-scale axion is responsible for the ground-state physics of our present Universe.

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