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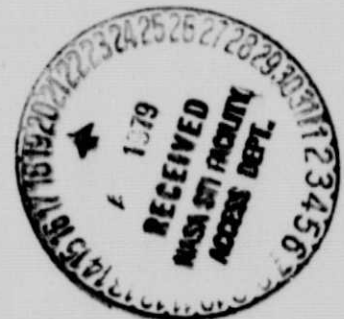
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UNIFIED FIELD THEORIES, THE EARLY BIG BANG AND THE MICROWAVE BACKGROUND PARADOX

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Abstract

It is suggested that a superunified field theory incorporating gravity and possessing asymptotic freedom could provide a solution to the paradox of the isotropy of the universal 3K background radiation. Thermal equilibrium could be established in this context through interactions occurring in a temporally indefinite preplanckian era.

1. Introduction

There is a mystery concerning the evolution of the universe which is of profound and fundamental significance. It goes like this:

When we look out over the sky, we can "see" radiation that was emitted in when the universe was very young and which last scattered off the matter content of the universe some 15×10^9 years ago. At that time, it had a temperature some $\sim 10^3$ times its present temperature of $\sim 3K$, i.e., it last scattered at a redshift $z \approx 10^3$, orders of magnitude higher than the redshift of the furthest quasar. But the ultimate source of the radiation, annihilation of particles and antiparticles with all masses allowable at corresponding temperatures, lies at much earlier, hotter epochs. The 3K microwave background radiation is remarkably isotropic - to within better than one part in a thousand.¹⁾

The paradox comes in when we consider that the universe is expanding at less than the velocity of light. Therefore, as time goes on we see more and more of the universe as distant regions come within our "event horizon", those within distances $X \leq ct_u \sim c/H(z)$ where $H(z)$ is the Hubble "constant" (really a function of z and therefore t) and t_u is the age of the universe. Thus, we are now seeing 3K microwave background radiation from parts of the universe which apparently were never in causal contact, since even radiation travelling at the speed of light never would have time to cross from one region to another. How then could they be in such apparent thermal equilibrium? Or, putting it another way, how could one region have known to adjust its temperature to that of the unknown other region?

2. Grand Unification

The solution may lie with the very earliest stages of the big-bang and may be supplied by concepts now emerging out of the new unified gauge-field theories. The argument may run in outline like this:

It is by now well known that Weinberg²⁾ and Salam³⁾ have succeeded in developing a theory unifying the weak and electromagnetic interactions which led to some predictions now confirmed such as "neutral current" (e.g. $\nu + N \rightarrow \nu + X$) interactions.⁴⁾ The Weinberg-Salam Theory has been

shown by 't Hooft⁵⁾ to be renormalizable and therefore to be just as well defined a theory as quantum electrodynamics, the extremely accurate quantum theory of the electromagnetic field.

A further step toward unification was taken with the proposed grand unified theory of strong, weak, and electromagnetic interactions of Georgi and Glashow.⁶⁾ This theory enabled one to calculate the value of the very important Weinberg angle parameter expressing the ratio of the strength of neutral current to electromagnetic interactions, left undetermined in the Weinberg-Salam model. This is because the SU(5) group upon which the Georgi-Glashow model is based is a simple group involving only one gauge coupling constant whereas the SU(2)⊗U(1) model of Weinberg and Salam admits two apparently independent gauge coupling constants. This is the result of the symmetry breaking SU(5)→SU(3)⊗[SU(2)⊗U(1)]. The calculated value of the Weinberg angle agrees beautifully with recent experimental results as do the predicted masses of the φ and T mesons.⁷⁾

The SU(5) Georgi-Glashow theory incorporates within it the SU(3) gauge theory of strong (or quark-gluon color) interactions known as quantum chromodynamics (QCD). This theory has the peculiar (but for our purposes here essential) property called asymptotic freedom⁸⁾ which is experimentally supported by the observations of Bjorken scaling and certain nucleon structure functions measured in high energy neutrino-nucleon interactions.⁹⁾ Asymptotic freedom, i.e. the weakening of the color force (or "strong force") at small distances (or, equivalently, higher energies), is one side of the mathematical relationship that requires such forces to become strong at "large" distances (of the order of the size of the nucleon), a phenomenon sometimes called "infrared slavery". Indeed, Weinberg has remarked that we would have to postulate asymptotic freedom in order to allow a gauge field to become strong.¹⁰⁾

Work is now progressing on what may be the final unification of the "grand unified theory" with a quantum gauge theory of gravity. Such theories are called "supergravity" theories¹¹⁾ While many problems remain, let us for the moment assume that they can be overcome and that a quantum unified field theory can be constructed. We can then put together an outline of the evolution of the big-bang.

3. The Early Big-Bang

Going back in time to about 10^{-6} s after the big-bang, the weak and electromagnetic forces may have been unified into one force with strength $\sim \alpha$. At this time nucleons and mesons did not exist and in their place was a gas of quarks. These quarks and leptons look like "point particles". For this reason, we can continue talking about particles even for times when the distance to the event horizon was less than $\sim 10^{-13}$ cm, the size of a typical present-day hadron. (Such a situation has been called the "hadron barrier".¹²⁾)

Going further back to $\sim 10^{-36}$ s after the big-bang, according to the Georgi-Glashow theory⁶⁾ all of the forces except gravity may have been unified. At this time, the universal "soup" consisted of unified leptons, quarks and the various gauge bosons - photon, gluons, weak intermediate

vector bosons ($W^{\pm}, Z^0$), leptoquark intermediate vector bosons (X,Y) gravitons and possibly Higgs bosons and gravitinos. The X and Y bosons have masses $\sim 10^{16}$ GeV/c²!

Finally, we arrive back at a time $\sim 5 \times 10^{-44}$ s after the big-bang when gravitation was as strong as the other forces¹³⁾ and may have been unified with them. This is the Planck time $t_{pl} = (\hbar G/c^5)^{1/2}$ at which the full quantum effects of gravity come into play.¹⁴⁾

What happened earlier? It is in this "preplanckian era" that a possible solution to the 3K background isotropy may be found. Two points in the above discussion are crucial.

- (1) All fields at that time could have been unified into one "force."
- (2) The color field exhibits asymptotic freedom. Asymptotic freedom also holds for various classes of grand unified theories of weak, strong and electromagnetic interactions¹⁵⁾, and has also been recently shown to hold for one type of quantum gravity¹⁶⁾.

Combining these points, it is plausible to suppose that the unified force possesses asymptotic freedom, i.e., $\alpha \rightarrow 0$ as $T \rightarrow \infty$. It has hitherto been assumed (although we have no theory of gravity at these energies) that gravitational forces blow up as $t \rightarrow 0$. It is unlikely, however, that such a nonlinear behavior could lead to a truly renormalized quantum theory of gravity¹⁶⁾.

It has been speculated that the Planck time t_{pl} there existed unified gauge bosons having the Planck mass $M_{pl} = (\hbar^3 c/G)^{1/2} \sim 1.2 \times 10^{19}$ GeV/c² existing as their own independent "black holes." At t_{pl} space-time was then discontinuous, assuming its full quantum behavior¹⁷⁾. In this situation we can no longer speak of a topology of a space-time continuum whose properties define the gravitational field¹⁷⁾, or indeed the behavior of a particle in any unified field. Thus, without space-time there is no gravity (or unified gravity). Remaining physical concepts would of necessity be expressed in such pretopological terminology as Borel rings¹⁸⁾. An alternative is that the curvature of space-time actually could have been smaller than the inverse Planck length because of asymptotic freedom. It also may have been that before the breakdown of full symmetry the gauge bosons could have actually been massless, their huge masses being the result of spontaneous symmetry breaking in the post-Planckian era. Such a situation would have resulted in a long-range unified field. We may thus have been, in the preplanckian era, at a stage when quantum effects were important but when physics, as we know it, was still meaningful.

The concept of time ordering, however, might not have been meaningful at this earliest stage in the history of the universe. In a preplanckian stage where the physics does not blow up, owing to the uncertainty principle and the primitive nature of the space-time topology, time fluctuations may have occurred in both temporal directions about $t = 0$ until a fluctuation occurred which was large enough to "set off" the big-bang. Indeed, before spontaneous symmetry breaking it may have been

impossible to define a unique global direction of time. It has been suggested that the big-bang could have arisen as a vacuum fluctuation provided that the universe initially had a vanishing net baryon number.¹⁹⁾ Such a situation arises naturally within the context of baryon symmetric cosmology.²⁰⁾ Thus the preplanckian era could have possessed a very large "effective event horizon" and a type of thermodynamic equilibrium may have occurred, accounting for the ultimate isotropy of the 3K microwave background radiation. Were this the case, the term "Planck radiation" could have more than one meaning!

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