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Physics Letters B 625 (2005) 171–176

PHYSICS LETTERS B

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The holographic principle and the early universe

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Received 19 May 2005; received in revised form 15 August 2005; accepted 22 August 2005

Available online 31 August 2005

Editor: N. Glover

Abstract

A scenario is proposed in which the matter–antimatter asymmetry behaves like a seed for the inflationary phase of the universe. The mechanism which makes this scenario plausible is the holographic principle: this scheme is supported by a good prediction of the number of e-folds. It seems that such a mechanism can only work in the presence of a Hagedorn-like phase transition. The issue of the "graceful exit" can be also naturally accounted for.

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PACS: 04.70.Dy; 98.80.Cq; 98.80.Es; 11.30.Er

Keywords: Holographic principle; Inflation; Matter–antimatter asymmetry

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1. Introduction

The inflationary scenario [2,14,19,20] has been one of the main achievement in theoretical cosmology of the last decades. It provided many fundamental questions (such as why our universe is flat, homogeneous and isotropic to a very high degree, why we do not observe monopoles or other topological defects, why the primordial perturbations have a flat spectrum and so on; detailed reviews are, for example, [15,21]) with a natural explanation. All the above questions could be answered in a standard FRW model only assuming very special initial conditions and fine tunings of many kinds. The mechanism which allows to solve such problems is mainly based on a very fast initial expansion of the scale factor of the universe which, in a sense, "washes out" the inhomogeneities. The standard engine which drives such an expansion is a scalar field, called *inflaton*, which slowly rolls towards the minimum of its potential. During the slow roll of the inflaton one gets a period of exponential expansion of the universe. It is worth to stress here that, in the inflationary scenario, what is really needed is the very fast initial expansion (from which it is possible to deduce all the wanted physical predictions by analyzing the evolution of the various kinds of perturbations), the scalar field is the easier way to get it but there is

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doi:10.1016/j.physletb.2005.08.079

no compelling physical reason which tells that it is a scalar field, and not a vector or a tensor field or a different kind of mechanism, to drive the inflation (see, for example, [15,21]). Actually, despite its striking successes, the inflationary paradigm still has some problems which can be traced back to the assumption that it is a scalar field to be responsible for the inflationary phase. In particular, it is still not completely clear what is the mechanism which allows a "graceful exit" from the inflationary phase, there is not a commonly accepted potential for the inflaton, the physical origin of the inflaton itself is still unknown and, a priori, it is not lawful to use the classical Einstein equations coupled to the inflaton field, as it is usually done, to study the evolution of the universe in a highly curved regime in which quantum corrections should be expected.

Besides the still unsolved problems of the inflationary scenario (which, on the other hand, do not overshadow its great merits), theoretical cosmology is affected by many unsolved problems. One of the most noticeable is the matter–antimatter asymmetry (detailed reviews are, for example, [9,11,17]). At a first glance, the Lagrangian of the Standard Model seems to be unable to explain why in the actual universe there is such an amount of asymmetry between matter and antimatter which enter symmetrically in the interactions. In a seminal paper [24], Sakharov showed that this asymmetry could be the consequence of the presence of baryon number violating processes, CP violations and departure from thermal equilibrium. In fact, the first two conditions can be fulfilled in the Standard Model: the effects are very small but, in the early universe when the temperature was very high, they are significantly enhanced and the third condition could also be met. There is still not a commonly accepted explanation of this asymmetry; at the moment the two most popular models seem to be the leptogenesis (according to which the weak interactions, converting some lepton number into baryon number, could generate a net baryon and lepton number) and the Affleck–Dine mechanism based on supersymmetry (according to which the scalar supersymmetric partners of quarks and leptons could be responsible for the processes which should give rise to a fulfillment of the Sakharov conditions).

Here, a scenario is proposed in which the matter–antimatter asymmetry is the driving force of the inflationary phase of expansion of the universe. The mechanism which makes this possible is the *holographic principle* (up to now, the most promising available open window on quantum gravity). From the inflationary point of view, this mechanism also has the advantage of providing a natural explanation of the "graceful exit".

In the first section we will briefly review the physical basis of the holographic principle. In the second section we will describe a statistical argument which, together with the holographic principle, makes plausible the proposed scenario. Eventually, some conclusions will be drawn.

2. The holographic principle

Even if the quantum theory of the gravitational field has not been found yet, in the few examples (such as the AdS/CFT correspondence [23]), in which one can carry on quantum computations in the presence of a gravitational field, the effective number of degrees of freedom is much smaller than the number which one would naively expect on purely quantum field theoretic grounds: the number of degrees of freedom in a space-like region turns out to be proportional to the area of that region. The holographic principle heightens this phenomenon to a basic principle of the would be quantum theory of gravity (see, for example, [7]); the physical basis of such a principle were given in [3,13,26,27]. Elegant refinements of the original ideas [3,13,26,27] can be found in [5,8]. Even if we still have not the final theory of quantum gravity, nevertheless it is possible to argue that the holographic principle could have a prominent role in understanding why the observed value of the cosmological constant is so smaller than the one computed in quantum field theory[1] (henceforth QFT). An intuitive explanation could be that in QFT pairs of degrees of freedom, which are coupled by gravitational interaction to form "bound states" behaving as single effective degrees of freedom, are counted as distinct. This overcounting could be responsible of the too large cosmological constant obtained in QFT. In a simple classical model [10] it is also possible to find, without using CFT, a direct

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[1] Of about 120 orders of magnitude in standard quantum field theory which become 60 orders of magnitude in supersymmetric QFT.

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