To be submitted to
Nature

ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF-76/59(P)
29 Novembre 1976

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L. Donazzolo[(x)] and A. F. Grillo: BLACK HOLE EVAPORATION AND THE BARYON NUMBER OF THE UNIVERSE.

The growing interest in the attempt to formulate a quantum field theory in a strongly curved (but not quantized) geometry has recently led to some remarkable results. The most intriguing of them, mainly for its implications of very fundamental nature, is probably the proof, due to Hawking[(1)], that a black hole of mass m would radiate as a black body of temperature $T \simeq 10^{26}\ m^{-1}\ {}^{o}K$ (m in grams), so to loose its mass in an explosive process in a time τ (sec) $\simeq 10^{-28}$ m.

Even if many important advances have been made (see for example ref. (2)), we can say that a detailed model of the emission mechanism is still lacking. However we can hardly escape from the conclusion that the laws of physics are very wildly changed in the collapse and emission mechanism[(3)].

We will consider here the situation from the point of view of baryon number conservation. That the baryon number of a black hole is a quantity which cannot be operatively defined was known since some years: however in the Hawking process one can effectively make a

(x) - Work supported in part by INFN;
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(gedanken) experiment in which a collection of matter of given baryon number B collapses and then, after some (in general long) time t, evaporates leaving a relic of different baryon number B'.

This is because it doesn't seem possible that the information of the black hole baryon number can be (at least not completely) transmitted to the radiation. This conclusion can possibly have some important consequences on the problem of the charge (a)symmetry of the universe.

Let firstly assume, as another ingredient of our discussion, that in the early universe casual fluctuations are strong enough for a significant production of low mass (primordial) black holes[4]. Their evaporation process is much faster than that of non-cosmological objects and primordial black holes of mass less than 10^{15} g have by now evaporated.

We can then imagine a situation in which, in an initially symmetric universe, fluctuations form primordial black holes from regions having $B \neq 0$, so that, after a lapse of time, in a sort of random walk process, the whole universe can acquire a net $B \neq 0$.

In this paper we shall try to examine quantitatively this process, which however seems unavoidable in principle. As a consequence, even if numerically, as we shall see, it is not possible to explain the actual baryon number of the universe, the problem of defining the "initial" state of the universe can acquire a different, more elusive, aspect.

We have estimated the maximum ΔB in various cases, obtaining negative results, so that we conclude that it is not plausible that the baryon number of the universe, came through this process: however various cautions must be used in discussing this result, as we shall see at the end.

We shall follow the description of primordial black hole formation and spectrum given by Carr[5]. There, density fluctuations given by $\delta = \epsilon \left(\frac{m}{m_o}\right)^{-n}$ (m_o is the Planck mass $m_o \sim 10^{-5}$ g, assumed as minimum mass) lead to the formation of primordial black holes when they drive enough matter inside its Schwarzschild radius. Following Carr we shall consider three cases :

a) $n = 2/3$.

In this case the number density of primordial black holes decreases as a power in the mass. Assuming the usual big-bang thermodynamics, the variance of the baryon number "obscured" by a primordial black hole of mass m is $\sigma_B^2 \simeq 10^{-15}\, m^{9/4}$ (m in grams). If for instance N primordial black holes only of a given mass m were formed, then the fluctuation ΔB in the baryon number of the universe would be

$$\Delta B \simeq \sqrt{N \sigma_B^2} \quad .$$

We can argue the orders of magnitude (and plausibility) by noting that if we fix m to be the mass of the observable universe ($\sim 10^{55}$ g), then in order to have the correct ΔB ($\sim 10^{80}$) we must have formed 10^{30} primordial black holes of this mass. This case is clearly unphysical; better estimates however, taking into account the decreasing density spectrum give $\Delta B \approx 10^{32}\ \alpha\, \bar{m}^{3/8}$ where α is an exponentially decreasing function of ε ($\alpha \approx 0.02$ for $\varepsilon = 0.1$) and $\bar{m}$ is the maximum allowed mass of primordial black holes.

b) $n > 2/3$.

This case is even worse than the previous one, since the number density is exponentially faster decreasing.

c) $n < 2/3$.

This case seemed the most favourable one, since the number density increases up to some m^* and then decreases. Values of ΔB have been computed, that are of the order, and even much bigger (as functions of ϵ and n) than the actual one. Unfortunately these values lead to a matter density which is much higher than the observed one.

Let us add a few words of comment to these results. In principle the baryon number obscuration by primordial black holes might explain an actual asymmetry of the universe as a statistical fluctuation; the recognization that indeed this cannot be the case, leaves us with the previous initial value problem: either the universe is symmetric, and a fluctuation stronger than the statistical one occurred (phase transition), or it is asymmetric, and in this case the initial excess of baryons over antibaryons is left unjustified.

However, in order to get numbers, some assumptions had made, which are quite strong and questionable. Thermodynamical equilibrium has been assumed even for times shorter than any possible equilibrium time: note for example that production of primordial black holes with $m < 10^{15}$ g occur at $t < 10^{-23}$ s. This leads to another assumpion made, namely that strong interactions have been neglected in a period in which they are plausibly dominating. As a consequence quantitative results can be drastically changed.

In conclusion, even if the numbers do not seem encouraging enough, we think that a better understanding of this kind of approach can be important and deserves a more precise investigation.

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