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FERMION INDUCED MONOPOLE - ANTIMONOPOLE ANNIHILATION

A.F. Grillo and Y. Srivastava
Laboratori Nazionali dell'INFN di Frascati, Frascati (Italy

ABSTRACT

Monopole - Antimonopole annihilation is reconsidered taking into account the peculiar behaviour of the Baryon Number violating monopole interactions. We review the problem of cosmological monopole abundance, which can be (almost) solved without reference to inflation or more radical alternatives.

It has recently been discovered[1,2] that magnetic monopoles, necessary consequences of any Grand Unified Theory, have quite peculiar interactions. That is, apart from purely electromagnetic interactions, monopoles appear to be surrounded by a cloud of fermion condensates, of typical radius $\sim 1/m_f$ (m_f being a light fermion mass), which mediate $\Delta B \neq 0$ interactions with cross sections which are characteristic of strong processes.

In this letter we propose that such a large interaction radius manifest itself also in the monopole - antimonopole channel, which would then be strong ($\sim m_f^{-2}$), rather than e.m. (which is $\sim M^{-2}$), much in the same was as $P\bar{P}$ annihilation goes mainly through pions (and not photons) with a typical cross section $(\beta\sigma) \sim m_\pi^{-2}$.

Our intuitive argument goes as follows. The usual picture of the monopole-antimonopole bound state formation assumes that the incoming (anti-) monopole is deflected from its initial trajectory by e.m. interactions in order to be (Coulomb) captured by its partner. For this to happen the two need to be at a relative distance $\lesssim 1/M$, which is very small.

On the other hand, when we visualize a monopole as an extended object due to its surrounding condensate cloud, we find that they can be deflected at large angles for capture even for an impact parameter as large as $1/m_f$. In the Rubakov[1] approach monopoles are essentially classical objects, whereas for a proper discussion of the annihilation channel a priori a quantum theory is required. However it has been shown quantum corrections are small (of order M^{-1}).

While we defer to more detailed calculations for a further justification of our Ansatz, we note that, with this annihilation cross section, the monopole cosmology can drastically change. In the standard picture monopoles are created in the very early Universe ($T \sim M_x$) when the original G.U. group breaks down to a group containing a U(1) factor. Simple arguments suggest that there is essentially one monopole per causal horizon at the temperature of the phase transition, which if annihilation is neglected, is a number by far bigger than the bound deduced from primordial nucleosynthesis ($r = n_M/n_\gamma < 10^{-19}$) or from the mean density of the present Universe ($r < 10^{-24}$)[3]. Due the (presumed) smallness of the annihilation cross section, it has been shown (3) that annihilation cannot alleviate the problem (4). If, however, the annihilation cross sections are as large as $(\beta\sigma_{ann}) \sim m_f^{-2}$, the above result changes dramatically.

Using the notation of Ref. (3), the evolution equation for the number density of monopoles (per comoving volume) can be written as

$$\frac{dn}{dt} = - \langle \beta\sigma \rangle \; n^2 - 3 \left(\frac{\dot{R}}{R} \right) n \tag{1}$$

where (in a radiation dominated Universe)

$$\frac{\dot{R}}{R} = t^{-1} = \left(\frac{0.6 \, m_p \, N^{-1/2}}{T^2} \right)^{-1}, \tag{2}$$

$m_p = 10^{19}$ GeV being the Planck mass and $N \sim 100$ is the number of the light degrees of freedom at the temperature T.

Even if we neglect finite temperature effect the annihilation cross section cannot be, in the early Universe, as large as $1/m_f^2$, since this would imply an interaction radius $(1/m_f)$ larger than the size of the causal horizon. Then the cross section is causality bounded until $t > (m_f)^{-1}$ i.e. (for current algebra $m_q \simeq 5$ MeV)

$$T < 10^9 \text{ GeV}$$

$$(\beta\sigma) \sim \pi t^2 \sim 10^{-2} \; \frac{m_p^2}{T^4} \tag{3}$$

As noted by Preskill[3], for annihilation cross sections which increase faster than $1/T$ as temperature decreases, the final monopole to photon ratio does not depend on its initial value. Thus we get

$$r(T = 10^9 \text{ GeV}) \simeq 10^3 \left(\frac{T}{m_p} \right)^3 \simeq 10^{-30} \text{ ,(4)}$$

to be compared with the present value, as estimated from the deceleration parameter of the Universe

$$r \text{ (now)} \quad \lesssim \quad 10^{-24} \tag{5}$$

Then the cosmological monopole problem, (i.e. its over abundance), would no longer be there.

Unfortunately, finite temperature effects are likely to invalidate the previous result, as at finite temperature the interaction radius (as given by the condensate extension) grows only as $1/T$[5], so that

$$(\beta\sigma) \sim \pi/T^2 \tag{6}$$

until $T \sim m_f$.

In this case we have

$$r(T \simeq 300 \text{ MeV}) \simeq \frac{T}{m_p} \simeq 10^{-20} . \tag{7}$$

If for $T < m_f$, $(\beta\sigma)$ m_f^{-2} σ_o $(\sigma_o \lesssim 1)$

the final result is

$$r(T \sim 0) \simeq \left\{ r(T \sim 300 \text{ MeV})^{-1} + 10^{-1} \sigma_o \left(\frac{m_p}{m_f} \right) \right\}^{-1}$$
$$\simeq r(T \sim 300 \text{ MeV}) \tag{8}$$

We note that we have not taken into account the fact that, at early times, annihilation is modified by diffusion through the light particle plasma. It is at this point that we differ from earlier estimates[3] for the following reason. Our annihilation cross - section - due to truely quantum effects - goes on increasing as $(1/T^2)$, whereas in the classical analysis there is a much slower increase. As a consequence, in our approach, the final monopole concentration depends essentially on the behaviour at late times, contrary to the earlier results where annihilation effectively ceases when diffusion stops.

For the above case the bound from primordial nucleonsynthesis is easily satisfied. On the contrary, the bound from the deceleration of the Universe appears to be violated. We stress, however, that r(T) depends essentially upon the cross section at lower temperatures, where the simple $(1/T^2)$ behavour is likely to be modified due to heavy flavour production as well as the dynamics of the confining phase transition. For illustration consider the following two schemes:

A. $\beta\sigma \sim 1/T^2$ for $T > m_H$

$\sim 1/m_i^2$ for $m_{i-1} < T < m_i$.

we get $r(\text{now}) \simeq 10^{-20}$

B. $\beta\sigma \sim 1/T^2$ for $T > m_H$

$\sim \left(\frac{m_H}{T^2} \right)^2$ for $T < m_H$,

where m_H is the heavy flavour. In this case we get $r(\text{now}) \simeq 10^{-22}$.

The proximity of the above estimates to the required bound lead us to conclude that a detailed theory of finite temperature effects is needed to obtain precise values of r in order to check whether the cosmological bound is indeed satisfied.

Considerations similar to ours, but without reference to the fermion condensates, have been made by Nussinov[6].

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REFERENCES

(1) V.A. Rubakov, U.S.S.R. Academy of Sciences Institute for Nuclear Research preprint P-0211 (1981); JETP Letters 33 644 (1981); Nuclear Phys. B203, 311 (1982).

(2) C.G. Callan, Phys. Rev. D25, (1982); Princeton University Preprint "Dyon-Fermion dynamics" and "Monopole Catalysis of Baryon Decay" (1982).
F.A. Wilczek, Phys. Rev. Lett. 48, 1146 (1982).

(3) J. Preskill, Phys. Rev. Lett. 43, 1365 (1979); see also, Ya.B. Zeldovich and M.Yu Khlopov, Phys. Lett. 79B, 239 (1978).

(4) For possible way-outs see: A.H. Guth, Phys. Rev. D23, 347 (1981). A.D. Linde, Phys. Lett. 108B, 389 (1982).

(5) F.A. Bais, J. Ellis, D.V. Nanopoulos and K.A. Olive, CERN Preprint TH.3383-CERN.

(6) S. Nussinov, Phys. Lett. 110B, 221 (1982).