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On the detection of relativistic magnetic monopoles by deep underwater and underice neutrino telescopes

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Abstract

We present here some reflections and very speculative remarks on the detection of relativistic magnetic monopoles by currently operating deep underwater/ice neutrino telescopes.

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A possible existence of isolated free magnetic charges and their direct detection have been exhilarating many generations of experimental physicists since as early as the beginning of the 19th century. After Dirac's [1,2] introduction of magnetic monopoles (MM) to make Maxwell's equations symmetric and to explain electric charge quantization, a lot of experiments, mainly at accelerators have been carried out to detect MMs, see Refs. [3,4] for extensive reviews of the issue.

The advent of the Grand Unification Theory (GUT) of strong and electroweak interactions in the early 1970s has inhaled new breath into experimental searches for MMs. At that moment the experimental efforts concentrated mostly on searches for super heavy MMs ensued from GUT theories. The Rubakov–Callan effect [5,6] opened up new possibilities for experimentalists to detect slow moving super heavy MMs via nucleon catalyzing effects, see Ref. [7] for a brief review of the detection techniques.

In this short note we would like to draw attention to one peculiar aspect of relativistic MMs detection by deep underwater/ice Cherenkov neutrino telescopes. The detection principle of this kind of MMs is based on the detection of Cherenkov light induced by MMs in water or ice. The number of Cherenkov photons, N, induced by MMs is defined by a well-known formula:

$$\mathrm{d}N/\mathrm{d}\lambda = (2\pi\alpha/\lambda^2)(ng)^2(1 - 1/(n^2\beta^2)), \qquad (1)$$

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where α is the fine structure constant, g is the magnetic charge, n is the refractive index. The magnetic charge is defined by Dirac's electric charge quantization formula:

$$g = 2\pi\xi\_c/e, \quad \xi = 0, \pm 1, \pm 2, \tag{2}$$

$$g = \xi 68.5e. \tag{3}$$

The intensity of Cherenkov radiation due to a relativistic MM with the basic magnetic charge moving in a media with a refractive index n should be $(gn)^2$ times larger than that for a relativistic muon in the same media. The basic strategy of searches for relativistic MMs moving in water or ice boils down to the detection of muon like events with a $\sim$8300 times higher light intensity. It means that one searches for "naked" relativistic MMs. Based on their experimental data the Baikal and AMANDA experiments set rather stringent upper limits on fast MMs with $0.75 \leqslant \beta \leqslant 1$. The upper limits, obtained by both experiments, are shown in Fig. 1 [8,9]. The results are undoubtedly very impressive. The AMANDA experimental limit of $6 \times 10^{-17}\,\mathrm{cm^{-2}\,s^{-1}\,sr^{-1}}$ is actually even lower than the astrophysical limit, the so-called Extended Parker Bound (EPB) of $10^{-16}\,\mathrm{cm^{-2}\,sr^{-1}\,s^{-1}}$ [10]. But a closer look to the limits at $\beta = 1$ reveals explicitly the nonphysical character of the limit at this exact point. Of course, it is a matter of a convention accepted by all the persons involved in

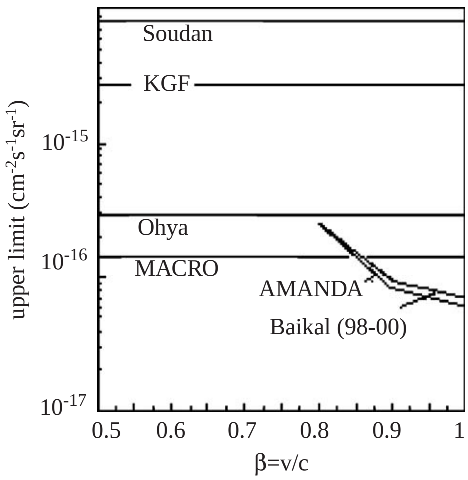

Fig. 1. Experimental upper limits on relativistic magnetic monopoles, from Ref. [9].

the field, but on the other hand, when β gets closer and closer to unity, one can no longer consider just "naked" MMs. In this case they produce more and more accompanying electromagnetic showers and eventually, at high values of the Lorentz factor γ, the electromagnetic showers accompanying such MMs will contribute more to the total Cherenkov light than "naked" MM.

It seems that MMs of light or intermediate masses of 10^7–10^{10} GeV contrary to GUT MMs with masses of 10^{17} GeV or higher, if they exist at all, would be very likely ultra relativistic objects with high values of the Lorentz factor γ. Indeed, they would be very easily accelerated by galactic and extragalactic or galactic cluster magnetic fields up to very high energies [11].

$$E_k \sim g \int_{\text{path}} B\,\mathrm{d}l \tag{4}$$

$$E_k \sim g B \xi \eta^{1/2}, \tag{5}$$

here E_k is MMs kinetic energy, g the magnetic charge, B the magnetic field strength, ξ the magnetic field's coherence length, η the number of coherence field domains along the path. The random walk character is specified by a factor $\eta^{1/2}$. The value of η is roughly estimated to be of the order of 100 [11].

According to Eqs. (4) and (5) MMs can be accelerated up to the highest energies exceeding even 5×10^{23} eV [11]. For MMs with masses of 10^7–10^{10} GeV the Lorentz factor can reach $\gamma \geqslant 10^5$–10^8. MMs with such masses will be ultra relativistic with high values of γ. For MMs above $\gamma = 10^3$, the energy losses due to direct pair and photonuclear productions in water or ice begin to dominate over other ways of losses, and at $\gamma = 10^6$ the number of charged particles accompanying MMs reaches the value of $\sim 2 \times 10^6$ thereby exceeding the direct Cherenkov light intensity due to "naked" MMs by nearly two orders of magnitude. Fig. 2, taken from Ref. [11], shows the dependence of the number of accompanying charged particles on the MMs Lorentz factor. A Lorentz factor of 10^6 can be considered as a limit for searches by neutrino telescopes for MMs that are upward going from the bottom hemisphere