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# COSMIC STRINGS – DEAD AGAIN?*

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**Abstract**

I report on recent numerical simulations of the simplest field theory with cosmic string solutions, the Abelian Higgs model. We find that random networks of string quickly converge to a scaling solution in which the network scale length $\xi$ increases linearly with time. There are very few loops with sizes less than $\xi$, and the strings are smooth, showing no signs of "small scale structure". We claim that particle production is the dominant energy-loss mechanism, not gravitational radiation as previously thought. For strings in Grand Unified Models, stringent constraints can be placed from cosmic ray observations on the string tension $\mu$: we estimate $G\mu < 10^{-9}$, three orders of magnitude lower than the constraint from Cosmic Microwave Background fluctuations.

The reason for studying cosmic strings and other topological defects [1, 2] is that they are possible relics from phase transitions in the hot Big Bang model, and as such provide one of the few ways of gaining information about the very early Universe. The study of cosmic strings has been built up into a scenario, based on the notion that a tangled network of strings would have been formed at a phase transition, and subsequently would have evolved in a scale-invariant manner to the present day. Strings and other defects can leave observable signals in the Cosmic Microwave Background fluctuations. Recent work however [3] tends to discount defects as the source of the fluctuations, and limits the string tension $\mu$ in combination with Newton's constant $G$ to $G\mu < 10^{-6}$.

Recent numerical work on cosmic strings [4] threatens a radical revision of the traditional scenario. We claim that in the string network loses a big (and constant) fraction of its energy into super-massive particles in every expansion

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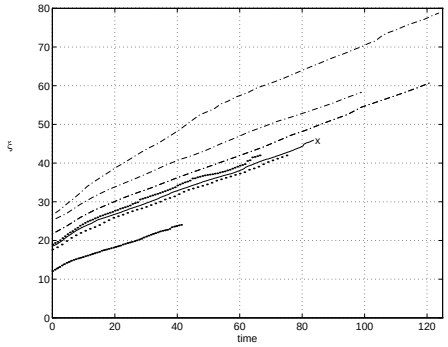


Figure 1: Plots of $\xi_{\rm p}$ for a series of $336^3$ simulations with different lattice spacings $a$. From top to botttom $a$ =0.75, 0.65, 0.75, 0.4, 0.5, 0.45 and 0.25. $\xi_{\rm p}$ is given in units of the inverse scalar mass $m_s^{-1}$ =.

time, which for strings in Grand Unified Theories (GUTs) would decay into extremely energetic electrons, protons, $\gamma$-rays and neutrinos. The observed flux of cosmic rays at above $10^{19}$ eV constrains the allowed injection rate of such particles [5, 6, 7], which is dependent on the mass of the GUT particles, and hence the string tension is constrained. We also claim that there is negligible energy loss to gravitational radiation, at odds with current belief.

Our simulations use the lattice formulation of the Abelian Higgs model due to Moriarty, Myers and Rebbi [10], which is essentially Hamiltonian lattice gauge theory. The random initial conditions appropriate to the high temperature phase of the early Universe are created by drawing the scalar field $\phi$ from a Gaussian random field distribution. In the first part of the simulation then allowed to evolve dissipatively to cool the system and eliminate the spurious high-frequency modes.

We are principally interested in how the length of the network of string $L(t)$ decays with time: the scaling scenario demands that it be a power law with exponent -2. An alternative way of phrasing this is to define a length scale $\xi_{\rm p}(t) = \sqrt{V/L(t)}$, which then should increase linearly. (The subscript "p" reminds us that we measure the physical length of string by tracing the zeros, not the invariant length, which is more usually considered.) The results are shown in Figure (1). Note that by "network" we mean those strings whose length is greater than $\xi_{\rm p}$; the rest we count as loops.

It is clear that the behaviour of $\xi_{\rm p}$ is extremely linear in the second half of the simulations. We find $\xi_{\rm p} = xt^p$, with $x \simeq 0.3$ and $p = 1.00 \pm 0.03$. We also find that the strings are very smooth: there is no sign of any scale in the fractal dimension of the string network other than $\xi_{\rm p}$. This is to be contrasted with numerical simulations in which relativistic strings are simulated directly and there is a lower cut-off on the allowed loop size [8]. We have argued elsewhere [11] that small-scale structure is a numerical artifact caused by this cut-off. The

last of our main results is that in our simulations less than 3% of the string was in loops.

The real question here is how is the network scaling, and scaling so accurately? Somehow, it is losing energy, and it must be losing energy into radiative modes of the field, as it is not losing it into loops. In the traditional string scenario this should not happen. Perturbative calculations [9] indicate that the string must be accelerating faster than the mass of the radiated particle, although these calculations strictly apply only when there is no back-reaction on the string as a result of the particle emission, i.e. when the emitted particle is much lighter than the mass scale of the string. This does not turn out to give the right scaling law. The mechanism must therefore be non-perturbative.

The implications of this result for the cosmic string scenario are profound. If more than $10^{-3}$ of the energy density of a scaling network go into GUT mass bosons, all decaying into Standard Model particles, then the bounds from the observed flux of cosmic rays of energy above $10^{19}$ eV are violated [5]. Using more detailed calculations [6, 7], we derive a limit

$$G\mu < 10^{-9} f_X^{-1.3}, \tag{1}$$

where $f_X$ is the fraction of the energy ending up as quarks and leptons. In the likely case $f_x \sim 1$, this limit is three orders of magnitude stronger than that from CMB observations.

*Note added.* It has been pointed out [12] that one cannot use UHE cosmic rays to bound strings in this way, as the range of gamma rays of this energy is not more than about 20 Mpc, due to pair production on the microwave background photons. However, there are equally strong bounds from lower energy gamma rays, in the range 1-10 GeV, which are produced copiously in a cascade process [6, 7]. Using these data, one still arrives at a bound of about $G\mu < 10^{-9}$ [13].

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