Gamma Ray Bursts From Ordinary Cosmic Strings

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Abstract

We give an upper estimate for the number of gamma ray bursts from ordinary (non-superconducting) cosmic strings expected to be observed at terrestrial detectors. Assuming that cusp annihilation is the mechanism responsible for the bursts we consider strings arising at a GUT phase transition and compare our estimate with the recent BATSE results. Further we give a lower limit for the effective area of future detectors designed to detect the cosmic string induced flux of gamma ray bursts.
1 Introduction

This work is an attempt to extend recent efforts to propose methods to detect direct evidence for the existence of cosmic strings\[1\],\[2\]. Since, after the COBE results\[3\], the cosmic string scenario for large scale structure continues to be in agreement with observation\[4\],\[5\], we may hope that such methods can provide us with independent verification (or rejection) of the theory. This will certainly be necessary if we are to trust our theoretical predictions. This work concerns only the behaviour of so called ‘ordinary’ cosmic strings, ie. non-superconducting strings. Superconducting cosmic strings\[6\] have additional phenomena associated with them\[7\],\[8\] with which we do not concern ourselves here. Motivated by the recent BATSE results from the Gamma Ray Observatory (GRO) satellite\[9\] and the need for suggestions for further experimental techniques, we consider a cosmic string based mechanism with the potential to account for the observed data and give an upper estimate for the number of gamma ray burst events which we may expect to observe at a terrestrial detector due to cosmic strings.

There are several reasons for believing that cosmic strings may be responsible for gamma ray burst events. Firstly there is the isotropic distribution of the data which seems to imply an extragalactic origin for the bursters. Any source at these distances, therefore, needs to have the power to produce gamma rays of extraordinarily high energy in order that they be observable by the time that they reach the Earth. Cosmic string mechanisms could naturally account for this due to the isotropic distribution of the string network and the combined energy of the mass per unit length of the string ($\sim 10^{15}$ tonnes/cm) coupled with its relativistic motion. We may also consider the timescale of the bursts; the mechanism which we investigate, cusp annihilation, may be expected to produce short, highly directional pulses of radiation in agreement with the burst observations so far. Further, the spectrum and precise form of the bursts appears to vary considerably from event to event with no common features. Cusp annihilations might be expected to produce such signatures since different cusps may be formed on strings of different radii and the extent to which we intercept a beam from such an event would cause the length of the burst to vary. Both these effects could give rise to results taking a continuum of values in a random manner.

Although there are a number of methods by which a cosmic string may produce high energy gamma radiation we consider only contributions from
cusp annihilations from oscillating string loops \cite{10,11}. We neglect contributions from cusps formed at string intersections due to intercommuting and also ignore high energy bursts from string loops emitting their last energy as particles at the end of their lifetimes. In addition we neglect the contribution due to particle-antiparticle pairs produced in the background of a moving string loop. These effects are expected to be small compared with the dominant contribution from cusp annihilation.

These considerations aside, we consider our result to be an upper estimate because of our main assumption that at the formation of a cusp all the energy in the cusp region is released as a burst of high energy particles. In reality we expect that when the Nambu action breaks down as a cusp is being formed, back-reaction effects may become important and lead to the release of only a fraction of the total cusp energy.

2 Cusp Formation and Annihilation

The Nambu action for a string of infinitesimal width leads to time periodic solutions containing at least one cusp per oscillation; ie. parametrizing the string trajectories as $\mathbf{x}(s, \tau)$ where $\tau$ is coordinate time and $s$ parameterizes the length along the string we expect the periodic formation of points at which $|\dot{\mathbf{x}}| = 1$ and $\mathbf{x}' = 0$ \cite{13}. As these points begin to form we expect the Nambu action to break down and strong microphysical forces to counteract the cusp formation by particle emission.

Initially the energy released by the string will be in the form of false vacuum quanta of the gauge fields associated with the symmetry breaking giving rise to the string network. In this work we primarily concentrate on strings produced at GUT symmetry breakings since it is these that may be responsible for structure formation. These products will then decay into lower mass particles and at some stage to quanta to which we may apply the empirical QCD multiplicity functions to predict the energy spectrum of the final decay products of the initial particles. In this way we arrive at an expression for the number of photons expected from cusp annihilation on a string of a given radius at a given time after the symmetry breaking.

A potentially important point about the emission of this radiation is that it is highly anisotropic in the rest frame of the loop. In fact the radiation is beamed into a specific solid angle which we include in our calculation of the
flux expected at terrestrial detectors.

Defining \( n_{\text{burst}} \) to be the number of observable bursts per unit time we therefore have the expression

\[
n_{\text{burst}} = \int_{t_{\text{min}}}^{t_0} dt \int_{t_{\text{min}}}^{t} dR \frac{1}{R} n(R, t) 4\pi d_c^2(t)
\]

where \( n(R, t) \) is the number of strings of radius \( R \) per unit volume at time \( t \), (for this we assume the known scaling solution), \( 1/R \) gives the rate of cusp formation, \( 4\pi d_c^2(t) \) is the comoving area of the past light cone at time \( t \) and \( t_{\text{min}} \) is the lower cut-off of radius and time calculated below and is constrained by our detection capabilities.

## 3 Detection Considerations

The number of photons of energy \( E \) radiated per unit area at a cusp by a loop of cosmic string of radius \( R \) is given by

\[
N_R(E) = \frac{1}{\theta^2 d^2} \frac{\mu l_c c^2}{Q_f^2} \left[ \frac{16}{3} - 2 \left( \frac{E}{Q_f} \right)^{1/2} - 4 \left( \frac{E}{Q_f} \right)^{-1/2} + \frac{2}{3} \left( \frac{E}{Q_f} \right)^{-3/2} \right]
\]

Here \( \theta^2 \) is the solid angle into which the radiation is beamed, \( d \) is the physical distance of the loop from the Earth, \( Q_f \) is the fixed energy of the particles initially emitted by the cusp (we assume a \( \delta \)-function distribution of initial energies) to which we may apply the QCD multiplicity functions and \( l_c \) is the length of the overlap region of the loop at the cusp. Here, as always, \( \mu \) represents the mass per unit length of the string.

Now, it is only possible for a detector to register an event as a burst if sufficient photons are received to distinguish the event from the background of photons in which the detector operates. If we need \( n_0 \) photons detected to give a positive detection then we need the corresponding burst at time \( t \) to produce at least \( n(t) \) photons, given by

\[
n(t) = \frac{4\pi d_c^2(t)n_0\theta^2}{A}
\]
where $A$ is the effective area of our detector. A second constraint on the number of bursts resulting in a detection is the sensitivity range of the detector. Suppose our detector has a range of sensitivity of $(E_{\text{min}}^0, E_{\text{max}}^0)$. Then we may only detect photons which, after being redshifted on their way to us, have energy lying in this range. Thus, given a burst by a cosmic string of radius $R$, we require

$$\int_{E_{\text{min}}^0(1+z(t))}^{E_{\text{max}}^0(1+z(t))} dE \ N_R(E) > n_0$$

(4)

in order that the burst be registered at us (where $z(t)$ is the redshift).

### 4 Calculation

If, as is natural at first, we consider GUT strings then we expect $Q_f \sim 10^{15}\text{GeV}$. Clearly, for a typical burst $E << Q_f$ and so we may approximate (2) by

$$N_R = \frac{2\mu c}{3\theta^2 d(t)Q_f^2} \left( \frac{E}{Q_f} \right)^{-3/2}$$

(5)

We may then perform the integral (4). Using convenient units and noting that the overlap length $l_c \sim w^{1/3}R^{2/3}$, where $w \sim \mu^{-1/2}$ is the width of the string we obtain the inequality

$$\left( \frac{R}{t_{\text{eq}}} \right)^{2/3} > \left( \frac{E_{\text{min}}^0}{Q_f} \right)^{1/2} (1+z)^{1/2}(t) \left( \frac{Q_f}{\mu^{1/2}} \right) \left( \frac{d(t)}{t_{\text{eq}}} \right)^2 \left( \frac{w}{t_{\text{eq}}} \right)^{2/3} \left( \frac{t_{\text{eq}}^2}{A} \right)$$

(6)

where we have used the value $n_0 = 10$ for present detectors. Now, setting $R(t) = t$ in this inequality gives the contribution from the biggest strings at time $t$ and so provides a lower limit on $t$. This gives

$$\left( \frac{d(t)}{t_{\text{eq}}} \right)^2 \left( \frac{t}{t_{\text{eq}}} \right)^{-2/3} (1+z)^{1/2}(t) < \left( \frac{E_{\text{min}}^0}{Q_f} \right)^{-1/2} \left( \frac{Q_f}{\mu^{1/2}} \right)^{-1} \left( \frac{w}{t_{\text{eq}}} \right)^{-2/3} \left( \frac{t_{\text{eq}}^2}{A} \right)^{-1}$$

(7)
Now, with $E_{\text{min}}^0$ of order a few MeV and a detector area of $1m^2$ (ie. the energy range and area of the GRO satellite detector) we have the following relations

$$\left( \frac{Q_f}{E_{\text{min}}^0} \right) \sim 10^{18}, \quad \left( \frac{Q_f}{\mu^{1/2}} \right) \sim O(1) \quad (8)$$

$$\left( \frac{A}{t_{eq}^2} \right) \sim 10^{-40}, \quad \left( \frac{t_{eq}}{w} \right) \sim 10^{51} \quad (9)$$

which give us

$$\left( \frac{d(t)}{t_{eq}} \right)^2 \left( \frac{t}{t_{eq}} \right)^{-2/3} (1 + z)^{1/2} (t) < 10^3 \quad (10)$$

Since it is elementary to show that

$$d(t) = 3t^{2/3}(t_0^{1/3} - t^{1/3}) \quad (11)$$

and we know that $(1 + z(t)) = \left( \frac{t}{t_0} \right)^{1/2}$ we arrive at

$$\left( \frac{t_0}{t} \right)^{1/3} \left[ \left( \frac{t_0}{t} \right)^{1/3} - 1 \right]^2 < 10^{-5} \quad (12)$$

Clearly this is only satisfied for $t \in [t_{\text{min}}, t_0]$ where $t_{\text{min}} = t_0(1 - \epsilon)$ and $\epsilon << 1$. Therefore our expression (1) for the number of observable bursts per unit time becomes

$$n_{\text{burst}} = \Delta t \eta(R, t_0) \frac{1}{R} d_c(t_{\text{min}}) \quad (13)$$

where $t_{\text{min}} \sim t_0$. This implies that $n_{\text{burst}} << 1$ and completes our calculation.

5 Conclusions

We have obtained a crude estimate for the expected frequency of gamma ray bursts from cusp annihilations on ordinary GUT cosmic strings. We consider our result to be an upper bound and, since our calculation shows the flux to be negligible, we conclude that cusp annihilations from ordinary GUT cosmic
strings are not responsible for the gamma ray burster events observed by the GRO satellite.

It is easily seen from equations (8)-(12) that if we consider the effective area of the detector to be the sole parameter in the calculation we may hope to detect the flux from GUT strings with a detector of \( A \sim 10^5 m^2 \) ignoring back reaction effects. It is also clear that ordinary strings produced at lower energy phase transitions will give rise to an even lower estimate of the flux.

We have shown, therefore, that cusp annihilation is not a viable method of detection of cosmic strings with foreseeable measurement capabilities. It remains to see whether there exist other phenomena by which we may independently confirm or reject the existence of these objects.

References

[1] J.H. MacGibbon and R.H. Brandenberger, Nucl. Phys. B331 153 (1990).
[2] J.H. MacGibbon and R.H. Brandenberger Phys. Rev. D in press (1993).
[3] G. Smoot et al., Ap. J. Lett. 396, L1, 160 (1992).
[4] D. Bennett, A. Stebbins and F. Bouchet, Ap. J. Lett. 399, L5, 199 (1992).
[5] L. Perivolaropoulos, Phys. Lett. B298, 305 (1993).
[6] E. Witten, Nucl. Phys. B249, 557 (1985).
[7] D. Spergel, T. Piran and J. Goodman, Nucl. Phys. B291, 847 (1987).
[8] J. Ostriker, C. Thompson and E. Witten, Phys. Lett. 180B, 231 (1986).
[9] S. Fishman, NASA Huntsville preprint, 1992.
[10] R. Brandenberger, Nucl. Phys. B293, 812 (1987).
[11] R. Brandenberger and A. Matheson, Mod. Phys. Lett. A2, 461 (1987).
[12] A. Albrecht and N. Turok, Phys. Rev. Lett. 54, 1868 (1985); D. Bennett and F. Bouchet, Phys. Rev. Lett. 60, 257 (1988); B. Allen and E.P.S. Shellard, Phys. Rev. Lett. 64, 119 (1990).
[13] T.W.B. Kibble and N. Turok, Phys. Lett. 116B, 141 (1982).