Observational constraints on the types of cosmic strings

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Abstract

The paper is devoted to put observational limits on the number of one dimensional cosmological objects cosmic strings and other topological defects. Using the methods to search for solitary string there were obtained the upper restrictions on individual string tension depending on string model. It was shown that string can only be semilocal in the range of 1 up to 5. The texure model is also legal. There are no strings with $G\mu/c^2 > 7.36 \cdot 10^{-7}$.

Cosmic string as possible astronomical objects have been intoduced by T.W.B. Kibble [1] and became a hot issue in both theoretical physics and cosmology [2] – [3]. Cosmic string formation appears to be very important in GUT theories and in fundamental superstring theory. Therefore, the models with non-topological defects, called semilocal strings, have become quite popular, [4]. Active search for observational manifestations of cosmic strings, as well as probailistic estimations of their number, [5], showed that, whether or not they exist, cosmic strings should be very few.

The most promising methods to search for cosmic string candidates is to recognize their traces in CMB anisotropy data, [6] - [8]. Due to the specific discontinuity structure of cosmic string anisotropy and its low amplitude we searched its traces with a special step-like set of modified Haar functions, [9].

According the generic theorems for Euclidean spaces, in space L_2 there are complete orthogonal systems of functions. Let us introduce the modified Haar functions $\{\psi_{n\,i}\}$ with cyclic shift. For simplicity we will take them on the compact set $[0, 1]$ with real cyclic shift $a \in [0, 1/2]$. Depending on the parameter a the functions $\{\psi_{n\,i}\}$ can be divided into similar four groups for $0 < a < 1 - i/2^n$, $1 - i/2^n < a < 1 - i/2^n + 1/2^{n+1}$, $1 - i/2^n + 1/2^{n+1} < a < 1 - i/2^n + 1/2^n$, and $1 - (i - 1)/2^n < a < 1/2$. For the first case we have:

$$\psi_{n\,i}^{(a)} = \begin{cases} 2^{\frac{n}{2}}, \dfrac{i-1}{2^n} + a < x < \dfrac{i-1}{2^n} + a + \dfrac{1}{2^{n+1}}, \\ -2^{\frac{n}{2}}, \dfrac{i-1}{2^n} + a + \dfrac{1}{2^{n+1}} < x < \dfrac{i}{2^n} + a, \\ 0, x \notin \left[\dfrac{i-1}{2^n} + a; \dfrac{i}{2^n} + a\right]. \end{cases}$$

For fixed a the set of modified Haar functions is full and orthonormal, as well as the system of classical Haar functions. Therefore it can be correctly used in searching of signals.

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CS candidate number	CS tension	Sky coverage
3	5.52	97
2	5.66	99
2	6.15	90
2	6.32	70
1	7.07	99
1	7.36	97

Table 1: The result of cosmic strings candidates search by the modified Haar function algorithm applied to Planck CMB data is shown for filter 143 GHz. The first column gives the number of cosmic string candidates with given tension $G\mu/c^2$ (second column, in 10^7) for different sky coverage (third column, in percents). The sky coverage characterizes the type of Galactic mask.

We use modified Haar functions as convolution kernel for the processing of the WMAP and Planck CMB data. The entire power of the cosmic string anisotropy is concetrated in a single Haar harmonic, so that an optimal marginal filter is realized. For our purpose this function is equal to one in the rotation angle $[0, \pi)$, and it is equal to -1 in the rotation angle $[\pi, 2\pi)$. Since a cosmic string could be oriented arbitrarily with respect to a grid of lines of longitude and latitude, the search for a cosmic string at each point requires multiple convolutions with a rotation of the circle, which corresponds to a shift (parameter a) in the "jump" in the Haar function.

Before the modified Haar function algorithm was applied on real data we estimated its efficiency. The analysis of 50 simulated maps[1] gives the expected number of false cosmic string candidates in the whole sky as 2.3 with low dispersion. If we use the Galactic filter, 70% and 90%, we obtain 0.69 and 0.23 averages numbers of false cosmic string candidates, respectively. Analysis of the original observational WMAP and Planck data shows the presence of one up to five cosmic string candidates (see Table 1) when using 70% of the Galactic filter (recommended by [10]). The significance level is 3σ. If in the data (using 70% Galactic filter) is found only one cosmic string candidate, then the probability that this is a false candidate is 26%. If there are two cosmic string candidates in the data (using the same 70% Galactic filter), the statistics on false candidates cannot explain this excess. Those statistics strongly support the efficiency of the modified Haar function algorithm.

Of course, in this procedure of cosmic string candidate search we can miss some candidates lying in the equatorial Galactic region. We used all available filters to compare the positions of the candidates and filter out those which are not present at all frequencies, as the appearance of a real cosmic string shall not depend on the observation frequency. It should be emphasized that we found cosmic string candidates in two independent data sets: WMAP and Planck.

The tensions of solitary cosmic string candidates (see Table 1) can be compared with upper bounds of cosmic string tensions found by Planck team, [10], based on cosmic string network simulations (see Table 2).

Let us suppose, without loss of generality, the homogenious distribution of cosmic strings

[1] We applied the algorithm of modified Haar functions to process a map that was a sum of two model maps. The first map was a simulated map of the primordial CMB anisotropy that arose at the surface of last scattering. We generated such maps starting from a simulated power spectrum, generated by CMBEASY, a lighter and faster version of CMBFAST. The second map was a pure anisotropy generated by a straight, moving cosmic string. The maps of the primordial CMB anisotropy and the anisotropy generated by the moving string were summed with a coefficient to characterize the signal-to-noise ratio.

CS network	Data	CS tension
Nambu-Goto model	Planck + WP	1.5
Abelian-Higgs field theory model	Planck + WP	3.2
Abelian-Higgs mimic model	Planck + WP	3.6
Semilocal CS model	Planck + WP	11.0
Global texture model	Planck + WP	10.6

Table 2: The upper bounds on cosmic strings and textures tension $G\mu/c^2$ (third column, in 10^7) for different types of cosmic string network and texture simulations (first column) using combined CMB data from Planck and WMAP polarization, [10].

in the network. In this case for solitary cosmic strings the restriction on tension becomes[2]:

$$\left(G\mu/c^2\right)|_{solitary}\sqrt{N} = \left(G\mu/c^2\right)|_{network},$$

where N is cosmic string number.

Values from Table 2 give the inequalities for each cosmic string types:

$$\left(G\mu/c^2\right)\sqrt{N} < c, \tag{1}$$

where "c" is the corresponding upper limit on the cosmic string tension (Table 2).

The method of modified Haar function allow us to try to find individual, single strings. Therefore we can compare the tension from network simulations with tension of individual cosmic strins, see Fig. 1. The closed black contour is from Planck CMB data analysis by modified Haar functions. One can see the only semilocal cosmic strings (and textures) models are consistent with estimation of solitary cosmic string number. Therefore, the main result is that in modified Haar function analysis there are no cosmic string candidates of Nambu-Goto, Abelian-Higgs field theory, and Abelian-Higgs mimic models. The region at the left side of the vertical dash line is where the modified Haar function method is ineffective, because of unverifiable spurious string candidates. Thus the existence of semilocal cosmic strings with tensions $G\mu/c^2 \leq 4.83 \cdot 10^{-7}$ is not forbidden but it is beyond the Planck data scope.

In conclusion, our modified Haar function algorithm can clarify the preferred cosmic string types in the Universe. The most preferable types of cosmic strings are semilocal ones, described by the model with complex scalar doublet, [13]. If its imaginary part is equal to 0, the semilocal cosmic strings becomes the Abelian-Higgs strings. The main difference between these two types is that the semilocal strings can have ends (monopoles) and can be unstable under certain conditions. The topological ("ordinary") strings have no ends. Formally they break on the surface of last scattering. It means that if our string candidates are topological defects, then they have to be very far from the observer, up to $z = 7$ (because their length is much less than 100^0, [8]). In this case we have no possibility to observe their effects in the optical data by looking through gravitational lensing events, and we will never confirm our candidates by independent optical observation. But the situation substantially changes if we are dealing with semilocal strings. They can be closer to us, being not very long. Therefore our strategy is

[2]To estimate the contribution of the energy of the cosmic string network on the total energy of the Universe it is usually used the unequal time correlator (UETC) of the CS stress energy tensor, [11]. The cosmic string tension is usually quantified in terms of the dimensionless ratio $G\mu/c^2$. This ratio is not a tension of one string. This is only normalization of power spectrum produced by cosmic string network to be consistent with CMB data, [12]. In other words this value gives us the upper limit to estimate the fraction of energy in string with respect to the total energy of the Universe. Planck (and WMAP) cannot mark out single strings. They are dealing with the network in a whole.

now to find suitable optical fields to search for the chains of gravitational lenses, produced by candidates to semilocal strings. The structure of the strings candidates found by the method of modified Haar function confirms the view of semilocal strings as a collection of segments, [14].

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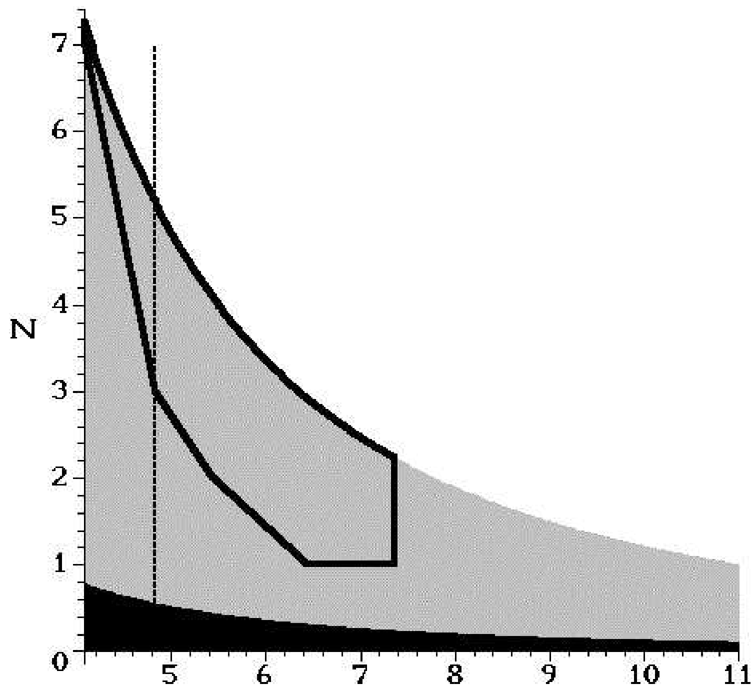

Figure 1: *The permitted region for cosmic strings to exist. The vertical axis is cosmic string number N. The horizontal axis is cosmic string tension (in $G\mu/c^2 \cdot 10^7$). The gray region is that permitted for semilocal cosmic strings and textures model. The black region is that permitted for Nambu-Goto, Abelian-Higgs field theory, and Abelian-Higgs mimic cosmic string models. The areas were obtained from the inequality (1).*