We present results of a cosmological hydrodynamical study of gravitational accretion in cosmic string wakes and filaments. Cosmic string wakes are formed by fast moving ($v \sim c$) strings. A conical deficit angle in the string spacetime induces a velocity perturbation in the background matter and a two-dimensional wake accretes in the path of the string. Filaments are formed by slow moving strings with a large amount of small scale structure. The major gravitational perturbation from slow moving strings is due to the Newtonian field induced by the effective mass of the wiggles. In cosmic string wakes, cool streams of baryons collide and are trapped at the center of the wake causing an enhancement of baryons versus dark matter by a factor of 2.4. In filaments, a high pressure is induced at the filament core and baryonic matter is expelled leading to a baryon deficit in the center of the filament.

1 Introduction

Strings are an inevitable result of symmetry breaking in many theories in particle physics as well as in numerous condensed matter systems. Once the temperature decreases below the symmetry breaking scale, the field undergoes a phase transition and a string network forms. In an expanding universe, the string distribution quickly approaches a scaling solution in which there are (statistically) the same number of strings per horizon volume at all times. Numerical simulations show that the number of strings per horizon volume is in the range $10^{-30}$. Potential systematic errors due to coarse graining in simulations may tend to favor a lower number of strings per horizon volume.

If symmetry breaking occurs at the GUT scale, the strings are massive enough to be responsible for large-scale structure in the universe. In this case, the scaling solution leads to a Harrison-Zel’dovich spectrum consistent with that observed by COBE. Calculations of the power spectrum give good agreement with the observed power spectrum with a bias factor around 2. Normalization of the spectrum with COBE gives a value of $G\mu \sim 10^{-6}$, a
dimensionless quantity proportional to the mass per length of the string \( \mu \). This value is within observational bounds, the most restrictive being that from timing analyses of the millisecond pulsar.

2 Large-Scale Structure Formation

Large-scale structure in the cosmic string model is due to the growth of density perturbations resulting from the gravitational field of the string network. The gravitational field of a string can conceptually be broken into two parts. The first part is due to purely general relativistic effects: the string leads to a conical spacetime. Geodesics in such a spacetime converge after passing the string. This means that a moving string will cause a velocity perturbation as it passes through matter. For strings with little small-scale structure such as waves and kinks moving along the string, the velocity perturbation from the conical spacetime is the predominant perturbing mechanism. Large-scale structure formed by fast moving strings will thus be in large sheet-like objects called wakes.

Strings with a large amount of small-scale structure move slowly. The predominant perturbation mechanism for these strings is the Newtonian field resulting from the effective mass of the waves and kinks on the string. These strings move slowly accreting long cylindrically shaped overdensities called filaments.

3 Non-linear Matter Evolution (Our Study)

What has been missing in the study of large-scale structure in the context of the cosmic string model is an understanding of non-linear evolution of matter accretion in wakes and filaments. In particular, what is the detailed distribution of the baryonic and dark matter?

To answer this question, we have developed a high-resolution PPM/PIC cosmological hydrodynamical numerical code for investigating the formation and evolution of baryonic and dark matter as they accrete in cosmic string wakes and filaments.

4 Results

We have investigated the matter distribution in the case of wakes and filaments. The matter distribution in the wake is markedly dissimilar to that of the filament.

First, we investigated the matter distribution in a wake caused by a long straight string. As the string passes through matter, its conical spacetime
gives a velocity kick to the matter on either side of its path and a wake forms. Two cool coherent streams of matter flow toward the center of the wake. The baryonic matter in the streams collides at the center forming an overdensity bounded by a shock. The dark matter streams flow through each other giving rise to an overdensity bounded by caustics. The baryonic matter is more concentrated at the center of the wake than the dark matter leading to an enhancement of baryonic matter to dark matter of about 2.4. Temperatures at the wake center are of the order of 100 degrees Kelvin.

Next, we examined the evolution of a filament caused by a slowly moving string. Here, the matter distribution was quite different than that of the wake. In the filament, the kinetic energy of the inflow is higher than that of the wake leading to high post-thermalization temperatures at the filament core. The associated high pressures force the baryons out of the filament core resulting in a net baryon deficit inside the filament. Temperatures at the filament core are of the order a few times $10^6$ degrees Kelvin.

5 Conclusions

From our results we conclude that biasing in the cosmic string model is perturbation dependent. In wakes, biasing of a factor of 2 to 3 can be expected, while in filaments, antibiasing is expected. The amount of biasing in wakes is consistent with calculations of the amount of biasing required by power spectrum calculations.

We find wakes to be relatively cool, with temperatures of the order 100 degrees Kelvin. Filaments are hotter, with temperatures of the order $10^6$ degrees Kelvin.

The baryon enhancement that we find in wakes is a possible mechanism for explaining baryon overabundances in objects such as the Coma cluster. It has been suggested that clusters will form at triple wake intersections. If this is the case, the enhancement will be tripled to a factor of 7, giving a measured baryon fraction of 0.35.

References

1. All references may be found in: A. Sornborger, R. Brandenberger, B. Fryxell & K. Olson, ‘The Structure of Cosmic String Wakes’, accepted for publication in the Astrophysical Journal, June 10, 1997, also in the archives at Los Alamos: [http://xxx.lanl.gov/ps/astro-ph/9608020](http://xxx.lanl.gov/ps/astro-ph/9608020)