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IN
PHYSICS OF THE EARLY UNIVERSE

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PROGRESS REPORT

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Abstract

Since June 1989 most of my research has been devoted to early Universe cosmology. The four focal points have been:

- 1) Galaxy and large-scale structure formation with cosmic strings.
- 2) Quantum field theoretical effects near cosmic strings and their observational signatures.
- 3) Dynamics of inflationary Universe models.
- 4) Quantum particle production and formation of topological defects during phase transitions.

Report

In my research on galaxy and large-scale structure formation I have this year focused on a model in which cosmic strings give the initial density perturbations and in which the dark matter which makes up 90% of the mass of the Universe consists of 25eV neutrinos (called hot dark matter by cosmologists). In collaboration with my student Leandros Perivolaropoulos and with Albert Stebbins (CITA, Toronto), I have studied the formation of structure on large scales in this model [4, 8, 13]. We discovered that wakes, planar density enhancements which form behind long moving cosmic strings, dominate the structure on these scales (distances larger than about 40Mpc, the comoving horizon at the time of equal matter and radiation). Most of the mass of the Universe which condenses into bound objects collapses in wakes. By studying the accretion of neutrinos onto wakes we determined the thickness of the sheets and determined the minimal mass per unit length of the strings in order that any nonlinear objects form by the present time. We concluded that in a cosmic string model with hot dark matter, the large-scale structure will be dominated by planar concentrations of galaxies with length and width of about 40Mpc and thickness

of about 4Mpc. These predictions are in encouraging agreement with the recent redshift surveys which show a *Great Wall* of galaxies with similar dimensions (J. Huchra and M. Geller, *Science* **246**, 897 (1989)).

Currently, we are continuing the development of the cosmic string model with hot dark matter. James Gerber (a Brown undergraduate) and I have worked out the topology of large-scale structure by computing the genus statistic which measures the genus of isodensity surfaces as a function of the density. This statistic is a good discriminator between different theoretical models.

The most exciting result of my research on quantum field theoretical effects near cosmic strings has been the discovery of a direct channel by which nonabelian cosmic strings can catalyze proton decay [16]. We noticed that the long range gauge fields of a non-abelian cosmic string can turn a beam of baryons into a mixed beam of baryons and leptons by the Aharonov-Bohm effect. This process is specific to cosmic strings and does not occur for grand unified monopoles. This work was done in collaboration with Leandros Perivolaropoulos, Andrew Matheson (postdoc at Brown), and Anne-Christine Davis (DAMTP, Univ. of Cambridge) who spent the fall of 1989 on sabbatical leave at Brown, supported in part by Task K. We also performed a more detailed analysis of scattering of fermions by cosmic strings and the proton decay catalysis cross sections due to core interactions. We discovered that in spite of the absence of classical long range forces which attract the fermions to the cosmic string, the scattering and catalysis cross sections are in general larger than the geometric cross section if the flux in the string is fractional [21]. We also investigated finite temperature effects on scattering cross sections and discovered that the enhancement is reduced at high temperature [20]. In collaboration with Ruth Gregory (Fermilab), Anne-Christine Davis and I also discussed catalysis using a skyrmion picture for the protons [1]. We were invited to write a review of this work [10].

Related work on quantum field theoretical effects near strings includes a computation of the predicted ultra-high energy neutrino flux from cosmic strings, work performed in collaboration with Jane MacGibbon (Harvard- Smithsonian Center for Astrophysics and Goddard Space Flight Center) [3].

My third main area of research has been the study of the dynamics of inflationary Universe models. We considered models in which a scalar field is responsible for generating inflation. However, in order to obtain inflation, the scalar field must be homogeneous and almost static. My student Jong Kung and I studied the evolution of scalar field configurations in the early Universe in order to discover whether generic initial conditions

will lead to inflation. We discovered that initial conditions which give chaotic inflation are an attractor in initial condition space [5, 19]. This puts chaotic inflation on a much firmer ground. In previous work, my former student Hume Feldman (CITA, Toronto) and I had shown that chaotic inflation is stable to both matter and metric perturbations [6].

My fourth main area of research has been a study of the formation of topological defects and of quantum particle production during cosmological phase transitions. My graduate student Jinwu Ye and I studied the formation of global and local vortices in an expanding Universe [11, 17]. We considered non-equilibrium initial conditions for the fields and discovered that the density of topological defects formed agrees with the predictions based on the Kibble mechanism. Jennie Traschen (Univ. of Massachusetts, Amherst) and I developed techniques to calculate quantum particle production during second order phase transitions [12]. We applied the formalism to study reheating in the New Inflationary Universe. We showed that most of the energy produced is transferred by parametric resonance.

Other projects I have worked on include a study of cosmological implications of dynamical symmetry breaking versus spontaneous symmetry breaking [2], a more detailed study of gravitational radiation from cosmic strings [15] and a study of how classical density perturbations emerge in the early Universe using methods of quantum cosmology [18].

I have reported on my research as an invited speaker at several conferences [7, 9, 22, 23]. I also gave a lecture series on 'Physics of the Very Early Universe' at the Scottish Universities Summer School in Physics [14].

ROBERT H. BRANDENBERGER: LIST OF PUBLICATIONS SINCE JUNE 1989

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