Research Highlight

Superstring Theory & the Resolution of the Big Bang Singularity

Prof. Robert Brandenberger *is a Canada Research Chair (Tier 1) and Professor of Physics in the McGill Physics Department and the MSI.* **Guilherme Franzmann is a** *PhD student in Prof. Brandenberger's group and a key member of the team which is developing an understanding of how superstring theory leads to an understanding of what replaces the "Big Bang".*

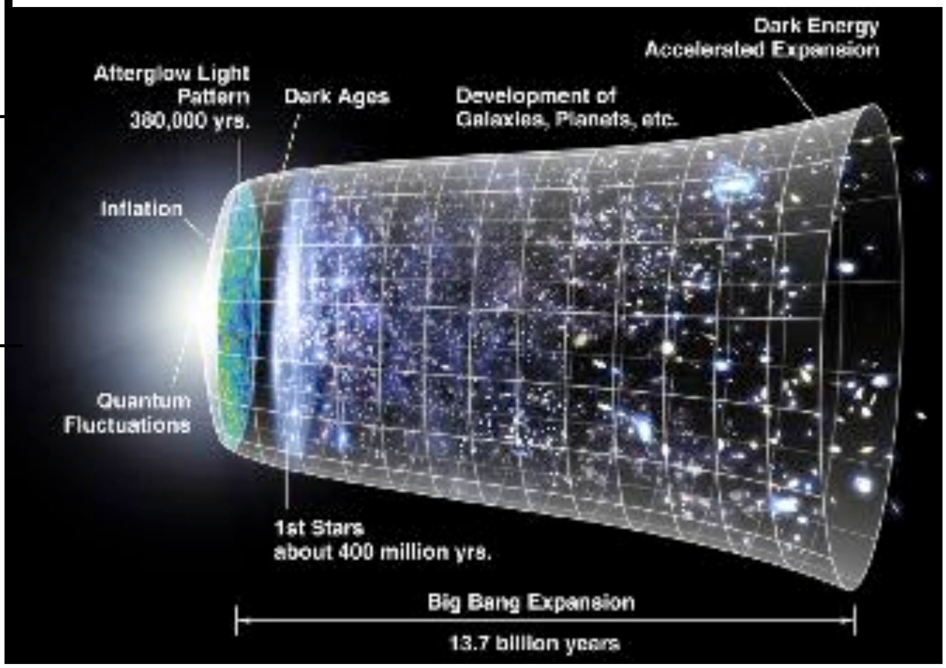
Why this is important

Close to the Big Bang', the usual physical laws based on Einstein's theory of General Relativity break down. Superstring theory holds the promise to be able to replace the Big Bang by an understanding of the earliest moments of the universe which makes physical sense. ``String Gas Cosmology'' is a scenario (based on string theory) which promises to provide a new picture of the early universe.

Brandenberger, R., Costa, R., **Franzmann, G.**, & Weltman, A. (2018). Dual Space-Time and Nonsingular String Cosmology. arXiv preprint arXiv:1805.06321.

The origin and early evolution of the universe remains a mystery. According to the Standard Big Bang scenario, there was a beginning of time at which the temperature of matter was infinite. For a physicist, the presence of such a ``singularity'' indicates the breakdown of the theory which yields such a conclusion. The inflationary universe scenario, the current paradigm of how the early universe evolved, does not resolve this singularity problem. New physics is required if we are to obtain a better picture of how the universe evolved at very high temperatures.

Prof. Brandenberger's group is using tools from superstring theory to attempt to obtain an improved understanding of how space-time evolved at very high densities. Superstring theory is a very ambitious attempt to unify all forces of nature at the quantum level. According to superstring theory, the basic indivisible objects of nature are strings rather than point particles. Strings have many more degrees of freedom than point particles: like violin strings, fundamental strings have oscillatory modes, and they can wind space.



Right: Artist's depiction of the expanding universe according to standard and inflationary cosmology. The horizontal axis is time.The universe is assumed to begin with a "Big Bang" after which the structures which we currently observe with telescopes such as the WMAP satellite (depicted on the right side) form. (Credit: NASA/WMAP Science Team)

A gas of strings has interesting properties: in contrast to a gas of point particles, there is a maximal allowed temperature. If we take a box of strings and shrink its radius, the temperature of the gas of strings will increase then eventually decrease. This conclusion arises from a new symmetry of string theory, the ``T-duality symmetry''. "String Gas Cosmology'' a cosmological scenario based on these fundamental principles of superstring theory, was proposed by Brandenberger and his Harvard colleague Prof. Cumrun Vafa a number of years ago. This scenario can provide an alternative to the inflationary paradigm for explaining the observed large-scale structure of the universe.

Supported in part by a ``twinning'' grant which he has obtained in order to collaborate with South African Research Chair Professor Amanda Weltman from the University of Capetown, Prof. Brandenberger, his PhD student Guilherme Franzmann, postdoctoral fellow Dr. Renato Costa and Professor Weltman have been studying the dynamics of String Gas Cosmology using new tools from superstring theory. Making use of the T-duality symmetry of string theory mentioned above, they were able to show that the resulting cosmology has no beginning of time - it resolves the singularity problem which plagues Standard Big Bang cosmology. Key to this conclusion is the realization that lengths have to be measured with measuring sticks made up of strings, and clocks which reflect the basic symmetries of string theory.

The research team has been able to show that the resulting cosmology has a bounce: it starts with a contracting phase, dissolves into an "emergent" phase where the usual description of space has to be changes (the number of measurable spatial coordinates doubles) and the expands again. So far, the conclusions have been reached using rather restrictive approximations, but the research team is working on an improved understanding

Prof. Alan Guth visits the McGill Physics Department

Dr. Alan Guth, the Victor Weisskopf Professor of Physics in the Massachusetts Institute of Technology, visited the McGill physics department in January 2018 to give a public and a scientific Anna I. McPherson lecture about his work on inflationary cosmology. Dr. Guth, is the physicist who first developed the idea of "cosmic inflation" -- the idea that the Universe underwent a period of rapid growth shortly after the Big Bang.

During his visit, he met with students from MSI and the physics department.