

McGill High Energy Theory and Cosmology



Robert Brandenberger



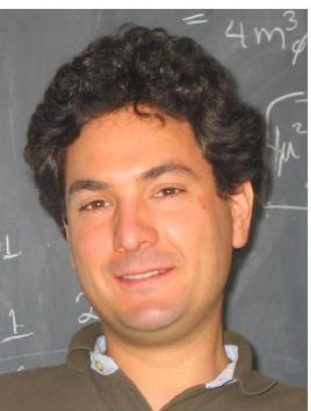
Jim Cline



Keshav Dasgupta



Alex Maloney



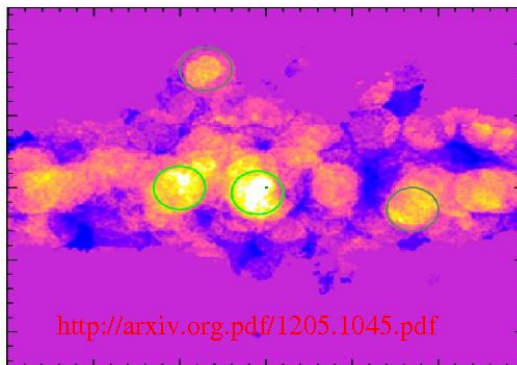
Guy Moore



Johannes Walcher

The Ultimate Search

What are the laws of nature at their most fundamental level? Is there an ultimate unified theory of elementary particles and gravity? This is the “holy grail” of theoretical physicists. At McGill, our quest takes three different but related directions: a bottom-up approach (phenomenology) of trying to deduce the new laws from the latest experimental observations; the top-down approach, using the mathematical consistency of string theory to understand quantum gravity; and cosmology, which through the big bang can give us complementary information about physics at very high energies.

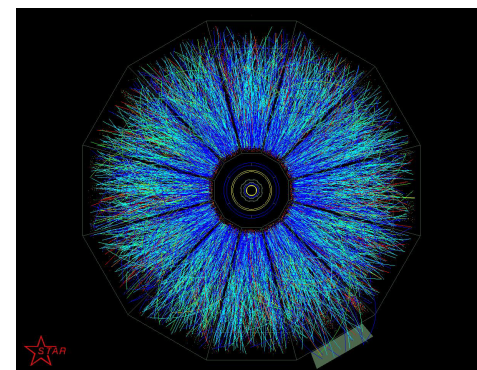


The first observation of dark matter annihilations?

Phenomenology and extreme matter

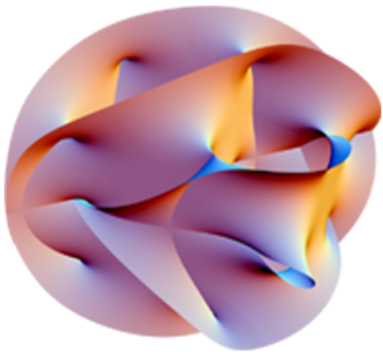
Jim Cline is currently focusing on the quest for theoretical explanations of dark matter, which comprises 80% of the mass density of the universe, but whose identity remains a mystery. There are several experimental hints that dark matter might be manifesting itself non-gravitationally: in excess 511 keV and 130 GeV gamma rays from the galactic center, and unexplained events in underground detectors searching for dark matter colliding with nuclei. It is also possible that the Large Hadron Collider (LHC) will produce dark matter directly, or see

indirect effects of its interactions with other particles. The decays of the recently discovered Higgs boson into photons can be changed as a result of such interactions. Dark matter can also be entwined with the mechanism for producing the normal (baryonic) matter of the universe.



Collision at the Relativistic Heavy Ion Collider

Guy Moore's work studies matter under the extremely hot and dense conditions that existed in the early Universe and in modern heavy ion collisions. One direction is to better understand perturbation theory, which at high temperatures is more complex and intricate, and less convergent, than for conventional particle physics situations. The McGill group is taking a leading role in extending perturbation theory to higher orders and better understanding its physics and its limitations. This includes computing higher-order corrections to dynamical properties of the quark-gluon plasma, and clarifying the associated physical effects and technical methods. Ongoing work includes studying how such ultra-dense matter first forms and approaches equilibrium, which may be crucial to understanding data from heavy ion collisions. A very general tool, hydrodynamics, depends only on the plasma being nearly isotropic. But relativistic hydrodynamics is not fully understood, and work is ongoing to fathom this theory more completely.



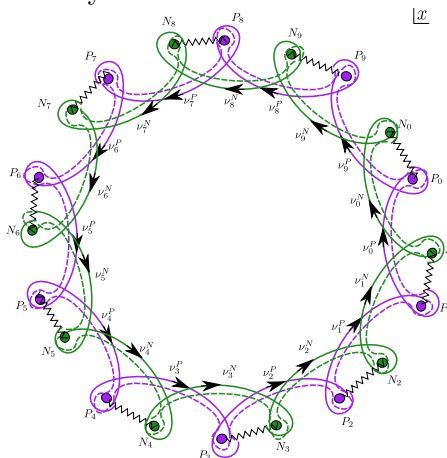
A Calabi-Yau manifold

String Theory

Johannes Walcher's work is built on connections between high-energy physics and modern mathematics that have emerged over the past several decades. Information flows in both directions: areas of mathematics that were long thought to be largely disconnected from physics have proven remarkably useful for addressing foundational questions in string theory. Conversely, and even more surprisingly, physicists working on formal questions in high-energy theory have made stunning conjectures about properties of certain mathematical structures, and even predicted the existence of new ones! String theorists have worked for more than twenty years on compactifying ten-dimensional superstrings to four dimensions to make contact with the real world. During this exploration, they discovered that certain models of quantum physics tie in very naturally with abstract constructions in geometry and algebra. Efforts continue toward developing a physics level intuition about these structures, and to expose new points of view on many problems.

Alex Maloney's research is in quantum field theory, string theory, and quantum gravity. His recent focus is on black holes and cosmology, which may illuminate fundamental ques-

tions involving the quantum structure of space-time. Black holes are an ideal theoretical laboratory for studying quantum gravity, since quantum effects are important near their central singularity. Black holes are intensively studied in string theory, for example via the higher order corrections to Einstein's equations that it predicts, leading to surprising insights into the geometry and thermodynamics of these mysterious objects. On the cosmology side, the study of time-dependent universes in string theory, notably de Sitter space, has been both challenging and fruitful. Work continues toward constructing de Sitter backgrounds of string theory, and on the holographic descriptions of simple time-dependent universes which, while sharing many features of realistic cosmological models, can be solved exactly.



Classical states in a special supersymmetric theory

Keshav Dasgupta works on supersymmetric quantum field theories using tools of string theory. His research focuses on understanding a special class of theories that mimic the well-known theory of strong interactions, quantum chromodynamics (QCD), both at very high and very low energies. While QCD itself is difficult to study, the supersymmetric theories are nice toy models that can be solved exactly, and which

allow one to infer many interesting properties of QCD. One such recent success is the theoretical understanding of the enigmatic phenomenon of “confinement” that is common to QCD and its supersymmetric cousins.

Cosmology

Robert Brandenberger's research interests span a wide range of topics in theoretical cosmology. These include the inflationary universe, notably the search for imprints of Planck-scale physics in observables, and detailed studies of inflationary reheating. Cosmological perturbation theory is foundational to these pursuits since it connects the physics of the very early universe with the present. This includes studying back-reaction of cosmological perturbations on the background spacetime, with a view toward dynamical relaxation of a large underlying cosmological constant to the small remnant presently observed as the dark energy. It also includes pioneering contributions to the emerging field of superstring cosmology, in particular “string gas cosmology”, which might resolve cosmological singularities and replace inflation for generating the seeds of the observed large-scale structure. With members of the Astrophysics Group, broad searches have been initiated for signatures of cosmic strings in new ways, including CMB polarization maps, 21 cm redshift surveys and high redshift galaxy observations. Since cosmic strings are predicted in a large class of particle physics models beyond the “Standard Model,” searching for cosmological signatures of strings may probe new particle physics in ways that are complementary to accelerator searches such as those at the LHC.

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