My Line of Research in the Past

String theory, at present, is the most promising theory of quantum gravity, accommodating possibility of GUTs and demanding supersymmetry. Therefore, understanding dynamics of the theory in various corners of its moduli space of parameters is of great importance. In particular since 1995 we have learned that D-branes would dominate the string theory path integral in various sectors of the theory. Studying dynamics of D-branes have been the main theme of my research work in the first ten years or so of my research career. I have been among the first string theorists initiated and pioneered studying D-brane worldvolume theory in an NSNS B-field background and showed that it leads to the novel noncommutative (NC) effects. That is, a D-brane in the B-field background probed by open strings looks like a NC plane. I was among the first people addressed the renormalizability of NC gauge theories and also contributed to the study of many other aspects of NC gauge theories, such as their gravity duals. Apart from their string theory origin I have been interested in possible phenomenological effects resulting from noncommutativity which started with the observation that in the noncommutative version of QED C and CP are naturally violated, while CPT is always preserved. The important and interesting question in this phenomenological NC models is putting (lower) bounds on the noncommutativity scale. For that matter we have studied Lamb-shift effect in NC Hydrogen atom, NC contributions to anomalous electric and magnetic dipole moments of electron, NC Aharanov-Bohm and Casimir effects and (Schwinger) pair production in NCQED in the constant electric field background. Another challenge in this direction which we have tried to build a model for, is formulating a NC version of Standard Model, which we called NCSM. We have used that model and the precision tests of the Standard Model to put bounds on the noncommutativity scale and the bound obtained in this way is $\Lambda_{NC}\gtrsim 1-10 TeV$. We have continued the same line of research by putting it in a new perspective through the recently proposed theory of Cohen-Glashow Very Special Relativity (VSR). We have shown that [see \# 66 in my publication list] the NC Moyal plane with light-like noncommutativity is providing a robust mathematical framework for realizing VSR invariant theories. During 2002-2007 I had a return to more theoretical issues and mainly focused on the AdS/CFT duality, though in the so-called BMN sector, i.e. Plane-wave/SYM duality. I have studied Penrose limits of various AdS orbifolds and their gravity/string theory duals. In a thorough and detailed study with Mark Van Raamsdonk and Keshav Dasgupta (and also Juan Maldacena) we have analyzed the Matrix model proposed by Bernstein-Maldacena-Nastase (BMN) describing DLCQ of M-theory on the maximally supersymmetric background and shown compelling evidence for the existence of transverse fivebranes in the Matrix model. As a continuation of my studies on the BMN Matrix model, we analyzed (\# 46 in the publication list) orientifold version of the BMN Matrix model describes the strong coupling dynamics of Heterotic E_8 theory on plane-wave background and shown that the E_8 gauge fields in this Matrix model would gain a finite size, which we called giant gluons. During 2002-2004 a huge number of papers have been devote to study of plane-waves from string or supergravity point of view or their gauge theory duals, so I felt that it would be useful for the community to have a review article on the issue. Preparing the review article on plane-wave/SYM duality for Reviews of Modern Physics (\# 47 in the publication list) has been among valuable experiences in my research career. As a part of my studies on various aspects of string theory on the plane-wave and AdS backgrounds, I have focused on giant gravitons. I have proposed a non-perturbative formulation for the light-cone quantization of type IIB string theory on the $AdS_5\times S^5$ background, the {\it Tiny Graviton Matrix Theory} (\# 51 in the publication list). The hope is that through the study of this model, which is a $(0+1)$ dimensional supersymmetric gauge theory, we can learn something about the standard four dimensional SYM theories. In a sense the tiny graviton matrix theory is providing us with yet another dual description for either of four dimensional SYM and/or type IIB strings on $AdS_5\times S^5$. In the process of quantization of the D3-branes in the light-cone gauge we face the problem of ``quantizing Nambu three brackets'', to which a recipe was proposed in \# 51 of the publication list. The same problem arises in formulating multi M2-brane theory motivated by the activities \textit{a la} Bagger and Lambert. During 2006-2009 I worked on various aspects of the multi M2-brane BLG theory and/or the ABJM theory. I have also been thinking about the areas in string theory inspired inflationary cosmology which would become testable in the next generation of CMB observations. In particular, we have proposed and studied various aspects of a novel inflationary model, M(atrix) Inflation, or M-flation for short, in which inflaton field(s) are in the form of hermitian matrices. I am still continuing some projects on this line of research.

Research Statement

For the next few years, I am planning to continue the line of research I have been doing in the last four-five years. My projects are along two main directions, both of course in the area of high energy physics. 1) Early Universe Inflationary model building, 2) More formal topics in high energy theory, mainly oriented along quantum aspects black holes. \vskip 3mm \noindent\tcdg{{\large{\bf{Inflationary model building proposals}}}} \vskip 2mm With the advancement of cosmological observations, and in particular Cosmic Micorwave Background (CMB), we are able to disentangle information imprinted on the CMB from the early Universe when there was no large scale structure such as galaxies, galaxy clusters or first generation super massive stars. The recent observations indicate a correlation between the large cosmic structures we see today and the fluctuations imprinted on the CMB: both of the two, the seeds of galaxy clusters which are tiny fluctuations in the density of the background usually parameterized by $\delta\rho/\rho$, and the fluctuations of the temperature of the CMB, are coming from a common source. Observations show that $\delta\rho/\rho\sim 10^{-5}$. Current observations also indicate that these fluctuations are ubiquitous, they appear almost uniformly on all scales and they have to a good extent a Gaussian distribution. These are very peculiar features and needs to be explained by cosmic evolution models. Inflation is a paradigm according which the early Universe has undergone an accelerated expansion during which the scale of Universe has grown up to e^{60} times during a period which could be as short as $10^{-32}\ sec$, corresponding to energy scales of order $10^{15}-10^{16}$ GeV (or smaller). Inflation solves a number of theoretical issues facing the standard hot Big Bang scenario, while at the same time contains a mechanism to produce such small, (nearly) scale invariant and uniform fluctuations at cosmic scales. It does so by providing a mechanism to turn \emph{quantum fluctuations} to classical fluctuations which then puts its imprints on the CMB at the surface of last scattering, at a time when inflation is long finished. So far, many many inflationary models have been proposed and studied, however, a satisfactory embedding into particle physics models which are supposed to be operating around the same energy scales is largely missing. One of the general directions in the early Universe cosmology is hence generating inflationary model building ideas within the usual frameworks of beyond standard particle physics models. Recently, together with my former PhD student A. Malaknejad, who is currently a postdoc at physics dept. of IPM, we showed that it is indeed possible to tune inflationary models in the \emph{non-Abelian gauge field theories} setup. We then studied some other aspects of this model. We, together with A. Maleknejad and J. Soda, recently finished a comprehensive review to appear in \textit{Physics Reports}, on \textbf{gauge fields and inflation}. We are currently studying some other aspects of our gauge-flation or other models involving gauge fields, especially given the recent data by Planck satellite which indicate a possible statistical anisotropy in the CMB. In a different line of thought, about four years ago, together with A. Ashoorioon and H. Firouzjahi we proposed, a string and brane theory inflationary model, the Matrix inflation of \emph{M-flation}, an inflationary model in which inflaton fields are three $N\times N$ matrices. With Amjad Ashoorioon, we are now studying some different aspects of the M-flation model (see my recent paper with A. Ashoorioon in the list below) and intending to continue studying non-Gaussianity and preheating in the M-flation model. \vskip 3mm \noindent\tcdg{{\large\bf{Black hole physics projects}}} \vskip 2mm Generic solutions to Einstein gravity theory have singularities, classification and studying properties and characteristics of these singularities has been an important part of the gravity studies. Among these singular solutions there are black holes, the singular locus of which is generically located behind an (event) horizon. The horizon itself, however, is a place where curvature is relatively small and nothing about the classical geometry of horizon is singular. The horizon, on the other hand, is a subspace which has an infinite redshift from the observer sitting asymptotically far from it. In addition, as was first pointed out by Hawking in the early 1970's, horizon is a place where quantum fluctuations of any field in the black hole background geometry becomes very important. This leads to the well-known Hawking radiation: A black hole, radiates out its mass (and charge or angular momentum) via a \emph{black body radiation} which is specified by just a temperature (and total charge or angular momentum). This creates the very much talked about unitarity problem in black hole physics. Namely, throwing in any matter into a black hole, regardless of the details of the information it is carrying (as viewed by an observer at infinity), once crossed the horizon, only its mass (and charge or angular momentum) is observable and the other information it may have carried is concealed from the outside observer. However, then due to Hawking radiation the black hole can eventually evaporate, leaving behind a black body radiation. Therefore, the evolution of the black hole seems to be non-unitary. On a parallel line of studies in early 1970's Bekenstein argued that one should associate an entropy to the black hole, if the system of black hole and its environment is supposed to be thermodynamically closed. Moreover, it has a temperature which is equal to the temperature associated with the Hawking radiation. The Bekenstein and Hawking analysis has been studied intensively since then and it is now taken as an established fact that a black hole should be viewed like a thermodynamical system, characterized by energy, entropy, temperature and other charges and the corresponding chemical potentials. As pointed out a black hole may be viewed as a thermodynamical system and this provides a hint for solving the black hole unitarity problem: We know that unitarity is broken at \emph{macroscopic} level for any thermodynamical system, however, for all the known examples, the underlying \emph{microscopic} statistical mechanical system is unitary and violation of unitarity is an artifact of taking thermodynamic limit. So, the black hole problem may also be resolved if we can identify its underlying microscopic system, usually known as \emph{black hole microstates}. It is a widely held belief that identification of black hole microstates is ultimately possible in a well understood theory of \emph{quantum gravity}. In lack of such a theory, many ideas have been tried within the existing (not completely understood) quantum gravity frameworks. One such framework which has happily had some successes in this direction is string and brane theory, and in particular AdS/CFT duality. The Bekenstein-Hawking black hole entropy, being proportional to the \emph{area} of horizon (in Planck units), has lead to the holographic principle and that the black hole microstates are residing on the horizon, rather than being distributed in the bulk of the black hole geometry (the region outside the horizon). Therefore, in the study of black holes special attention is paid to the near horizon geometry, e.g. for the generic black hole this geometry looks like a \emph{Rindler space}. For the extermal black holes, the black holes which at the horizon, the radial component of the metric has a double root and hence have vanishing Hawking temperature, the near horizon geometry is different: it has been proved that in the near horizon limit an extremal black hole leads to a geometry involving an AdS$_2$ throat. This observation has prompted the idea of using AdS/CFT as a tool for identifying the microstates of generic extremal black holes. Due to the lack of a thorough understanding of AdS2/CFT1 duality appearance of AdS$_2$ throat is not of great help for this purpose. In the last five years, I together with several oversees colleagues in various groups, and in particular with \textit{Joan Simon and Jan de Boer}, we showed there exist special extremal black holes, \textbf{Extremal Vanishing Horizon (EVH)} black holes, that in the near horizon lead to AdS$_3$ throats. This has lead us to propose \textbf{EVH/CFT} correspondence and use a much better understood AdS3/CFT2 duality for explaining microstates of the EVH black holes and their low energy excitations. I am now working on several problems all related to better understanding of EVH/CFT and Kerr/CFT proposals which will hopefully eventually lead to a coherent picture in black hole physics, at least for some particular black holes.\vskip 3mm \noindent\tcdg{\large{\bf{Other lines of interest}}} \vskip 2mm As in the last ten years, I am also pursuing my other lines of interest, though with a lower pace than the above two major projects. These include \begin{itemize} \item various aspects in quantum field theory on noncommutative space time (mainly together with my collaborators in Helsinki). \item Studying 2d CFT orbifolds and their properties with the motivation of using in AdS3/CFT2 and black hole physics.