

Curriculum Vitae

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Personal

Born in Hamamatsu, Shizuoka Prefecture, Japan, October 16, 1971.
Japanese, Married.

Title

Associate Professor, University of Tokyo

Education

Ph.D. in Physics, 1999/03, Kyoto University
M.S. in Physics, 1996/03, Kyoto University
B.S. in Physics, 1994/03, Kyoto University

Employment

2008/04-Present: Associate Professor, University of Tokyo
2004/10-2008/03: Assistant Professor, University of Tokyo
2003/09-2004/09: Postdoctoral Fellow, Harvard University
2001/09-2003/08: JSPS Fellow, Harvard University
1999/11-2001/08: CITA National Fellow, University of Victoria
1998/04-1999/10: JSPS Fellow, YITP, Kyoto University
1997/04-1998/03: Research Assistant, YITP, Kyoto University

Awards

Young Scientist Award of the Physical Society of Japan, 2007/09

Research Statement

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Modern cosmology has been ever developing, based on precision observational data. It is fair to say that many among those parameters describing our universe were determined, or at least are being determined, with good precision. However, physics behind the values of those parameters are still covered by a veil of mystery. For example, we do not know what dark energy and dark matter really are, although our universe is thought to be filled mostly with them. What made our universe so big? This question can be addressed by cosmic inflation, but again we do not know the physical origin of vacuum energy driving inflation. Three big mysteries, dark energy, dark matter and inflation, are standing in the way of cosmology which boasts precision observational data.

I have been working on research subjects such as braneworld cosmology, string cosmology, Higgs phase of gravity and horizon thermodynamics to tackle the mysteries of the universe. I will continue to challenge by using every possible means such as general relativity, particle physics and superstring theory.

Research Experiences

I have been doing research in cosmology and gravitation. Recently I am working on (i) braneworld cosmology, (ii) IR modification of gravity, and (iii) black hole entropy. In the following, I will explain my main contribution to each field.

(i) Braneworld cosmology:

In many theories including superstring theories and M-theory, the number of spacetime dimensions is assumed to be larger than 4. Since our observed universe is 4-dimensional, the number of dimensions must be reduced so that extra-dimensions cannot be seen at low energy. In the so-called braneworld scenario our 4-dimensional universe is supposed to be a 4-dimensional timelike surface, or the world-volume of a 3-brane, in a higher dimensional spacetime.

In a braneworld scenario proposed by Randall and Sundrum, I obtained a new exact solution of braneworld cosmology representing a general homogeneous, isotropic universe on the brane, and explicitly wrote down effect of the 5th dimension [35]. I called this effect dark radiation, which is now a standard technical term in this field.

After finding the exact solution, the next step would be to analyze perturbations around it [32, 30, 26, 25]. Indeed, this is a very important subject since observational data of the cosmic microwave background radiation is ever growing and comparison between observation and theory requires careful analysis of perturbations around a homogeneous, isotropic universe. However, in the braneworld scenario the number of metric components is significantly larger than the conventional 4-dimensional cosmology, and we have to solve a set of partial differential equations for those components simultaneously. I developed a gauge-invariant formalism of cosmological perturbations in the braneworld and discovered that all gauge-invariant variables can be obtained

by differentiating a single master variable [32]. I also obtained a master wave equation which the master variable follows. This formalism has been used by many researchers to investigate cosmological perturbations in the braneworld scenario.

I have also been investigating various other aspects of the braneworld scenario, including cosmology driven by rolling tachyon [22, 20], linearized gravity [24, 23], quantum effects [29, 27], extension to higher co-dimensions [11, 9, 5, 3], and so on. For research in braneworld cosmology I recently received Young Scientist Award of the Physical Society of Japan.

(ii) IR modification of gravity:

Recent observations of supernovae and cosmic microwave background radiation suggest current accelerated expansion of our universe, and the existence of invisible cosmological energy with negative pressure. In order for galaxies not to be torn apart by its rotation, invisible matter is believed to exist. Those invisible energy and matter are called dark energy and dark matter, but we do not know what they really are ... even though they are believed to fill most of our universe.

With this situation, one obvious question is “Do we really need dark energy and dark matter?” When the perihelion shift of Mercury was discovered, some people introduced an invisible planet called Valcan, so to speak dark planet, to explain the anomalous behavior of Mercury. However, as we all know, the dark planet was not real and the right answer was to change gravity, from Newton to general relativity. Knowing this historical fact, it is probably natural to ask whether it is possible to change general relativity in the infrared (IR) to address the mystery of dark energy and dark matter. This is, however, a very difficult question. People previously proposed many ideas, but all of them had problems. For example, in the massive gravity theory and the Dvali-Gabadadze-Porrati (DGP) braneworld model, it has been known that quantum effects become significant at macroscopic scales, say at $\sim 1000km$ if the IR scale is the current Hubble scale, and that predictability is completely lost. My collaborators and I discovered a scenario to modify gravity in the IR without this problem [16]. This scenario, called ghost condensation, is an analog of the Higgs mechanism for gravity and attracted considerable attention, including a feature article in the British scientific magazine “New Scientist” and more than 200 citation by academic papers.

I have been investigating various cosmological consequences of this scenario. Those include properties as an alternative to dark energy and dark matter [10], a new inflationary model based on this scenario [15], accretion of the Goldstone boson into a black hole [13], a formulation of cosmological perturbation [6], a partial UV completion by gauging the shift symmetry [8], a proposal towards a stringy UV completion [4], and so on. In particular, a new model of cosmological inflation based on this scenario predicts relatively large non-Gaussianity and, thus, can be checked observationally by near-future experiments [15]. By using the formalism developed in [6], it is also possible to constrain the ghost condensation as an alternative to dark energy and dark matter by combining the geometrical information on the universe and the dynamical information on the large scale structure in the universe. The former includes the supernova distance-redshift relation, and the latter includes the cosmic microwave background anisotropy, weak gravitational lensing and galaxy clustering.

Since ghost condensation is a very new idea, there are many interesting new research subjects associated with it, including inflation, late-time acceleration of the universe, large-scale structure of the universe, galactic dynamics, solar-system dynamics, and so on.

(iii) black hole entropy:

In the theory of black holes, there are many properties analogous to thermodynamics, and are, as a whole, called black hole thermodynamics. I have been interested in black hole thermodynamics and, in particular, the microscopic origin of black hole entropy.

With W. Israel, I revisited a long-debated problem in the brick wall model for the origin of black hole entropy [42]. In this model, black hole entropy is considered to be originated from thermal atmosphere near the black hole horizon. However, many people including 'tHooft, who had proposed this model, pointed out the problem of strong back-reaction due to large positive energy and considered it as a fatal defect of this model. Contrary to the “lore”, by identifying the correct ground state of the system, we showed that the problematic large positive energy is canceled by negative energy of the ground state and that the back-reaction is actually weak enough.

I also investigated various other aspects of black hole entropy. These include validity of the generalized second law [50, 37], other proposals for the origin of black hole entropy such as D-brane description [49] and entanglement entropy [48, 44, 43, 39], extensions of the first law of black-hole thermodynamics to general covariant theory of gravity [41] and to dynamical processes [40, 38], and so on.

Future Research

One of the greatest aims of theoretical physics is to construct the theory of quantum gravity. This is an attempt to unify quantum mechanics and Einstein’s theory of general relativity. I expect that in the process of finding the theory of quantum gravity, research of cosmology and black hole entropy will play important roles. Hence, I will cope with any problems to understand the origin and the dynamics of the universe and black holes with great interest, including all research fields in which I have been working. If we take into account the fact that superstring theory, as a strong candidate for the theory of everything, is gradually revealing its non-perturbative, whole structure and if we compare this exciting situation with the history of the development of quantum mechanics, it is probably very effective to tackle concrete problems like cosmology and black hole entropy. I strongly believe that cosmology and black hole entropy will play as important a role in the development of quantum gravity as the black body radiation and the hydrogen atom did in the development of quantum mechanics.

(iv) String cosmology:

In the forthcoming years I will mainly concentrate on string cosmology as well as the above-mentioned three subjects that I have been working on. Needless to say, however, I will tackle any problems in cosmology and black hole physics, according to circumstances with theories and observations/experiments.

Cosmology has been a rapidly developing, exciting area of science. Precision experimental/observational data strongly suggest that our universe experienced an inflationary epoch soon after its birth and that our universe now is mostly filled with dark energy and dark matter. However, we do not know what the origin of vacuum energy driving inflation nor what dark energy and dark matter really are. In this sense, modern cosmology is facing three major mysteries: inflation, dark energy and dark matter.

String theory is the strongest candidate for the theory of everything and, thus, is supposed to address these cosmological mysteries at least in principle. Thus, I will work on various cosmological issues in string theory, including inflationary model building, investigation of reheating after inflation in multi-throat scenarios, analysis of gravity in braneworlds with co-dimensions more than two, investigation of properties of dark matter candidates, realization of Higgs phases of gravity, and so on. Incidentally, the year 2005 was the 100th anniversary of Einstein’s special theory of relativity and the years 2006-2007 were the centenaries of the birth of Tomonaga and Yukawa. I believe that it is the time to tackle the three mysteries of the universe in the context of string theory, towards the 100th anniversary of general relativity.

Publication List

Shinji Mukohyama

May 7, 2008

Papers Published in Refereed Journals

- [1] L. Kofman and S. Mukohyama, “Rapid roll Inflation with Conformal Coupling,” *Phys. Rev. D* **77**, 043519 (2008) [arXiv:0709.1952 [hep-th]].
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- [3] S. Kinoshita, Y. Sendouda and S. Mukohyama, “Instability of de Sitter brane and horizon entropy in a 6D braneworld,” *JCAP* **0705**, 018 (2007) [arXiv:hep-th/0703271].
- [4] S. Mukohyama, “Towards a Higgs phase of gravity in string theory,” *JHEP* **0705**, 048 (2007) [arXiv:hep-th/0610254].
- [5] Y. Sendouda, S. Kinoshita and S. Mukohyama, “Doubly covariant formula of deficit angle and its application to six-dimensional braneworld,” *Class. Quant. Grav.* **23**, 7199 (2006) [arXiv:hep-th/0607189].
- [6] S. Mukohyama, “Accelerating universe and cosmological perturbation in the ghost condensate,” *JCAP* **0610**, 011 (2006) [arXiv:hep-th/0607181].
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