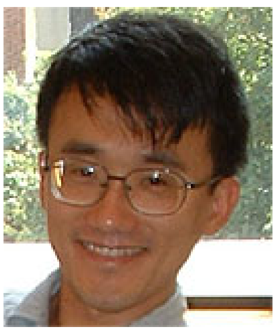
FAST BREAKING PAPERS - 2009

February 2009

PDF

Pei-Ming Ho, Yosuke Imamura, and Yutaka Matsuo talk with *ScienceWatch.com* and answer a few questions about this month's Fast Breaking Paper in the field of Physics.



Article Title: M2 to D2 revisited
Authors: Ho,PM; Imamura, Y; Matsuo, Y
Journal: J HIGH ENERGY PHYS
Volume: (7)
Year: no.-003 JUL 2008
* Natl Taiwan Univ, Dept Phys, Taipei 10617, Taiwan.
* Natl Taiwan Univ, Dept Phys, Taipei 10617, Taiwan.
* Natl Taiwan Univ, Ctr Theoret Sci, Taipei 10617, Taiwan.

SW: Why do you think your paper is highly cited?

Superstring theory is the only candidate for the theory of everything. It is also the only theory that admits a consistent perturbative formulation of quantum gravity. People used to think that there are five different superstring theories, but it was later realized, through a web of dualities, that all superstring theories are unified in a single theory, called M theory.

However, little is known about M theory. Its most important feature is that it is an eleven-dimensional theory with extended objects called "M2-branes" (or just "membranes") and "M5-branes" as its basic ingredients. Understanding how to describe M2-branes and M5-branes is one of the most important problems in the study of string theory.

A breakthrough in this direction was made in 2007 by Bagger and Lambert, and by Gustavsson. They proposed a model (now called the "BLG model") for describing multiple M2-branes. The novelty of their model is that its gauge symmetry is formulated in terms of a Lie 3-algebra, as a generalization of Lie algebra (or Nambu bracket in place of Lie bracket). This is an exciting progression because it has the potential to finally allow us to understand the mysterious M theory (which was named "M theory" for being mysterious), and also because of the appearance of an interesting class of symmetries new to physicists.

The Lie 3-algebra is a special case of the Lie n-algebra defined by Fillipov, as a generalization of the Lie algebra (or Lie 2-algebra). Lie algebra has been largely applied to physics for a long time. It is used to write down the standard model that describes strong, weak, and electromagnetic interactions in particle physics.

On the other hand, the problem with the BLG model is that almost nothing is known about Lie 3-algebra. There are only a handful of examples in the literature, not to mention any classification theorem or representation theory. Without a concrete Lie 3-algebra to work with, the BLG model is practically useless. Hence our understanding of M2-branes crucially relies on our understanding of Lie 3-algebras.

Coauthor
Yosuke Imamura

Our paper, together with the paper by Gomis, Milanesi, and Russo, and another by Benvenuti, Rodriguez-Gomez, Tonni, and Verlinde, proposed a new class of Lie 3-algebras. Given any Lie algebra, we are able to construct a Lie 3-algebra. We also applied the new algebra to the BLG model, and, remarkably, the BLG model becomes a model free of any free parameters, as is required by M theory.

Furthermore, we studied how multiple M2-branes in M theory can reduce to D2-branes in string theory in two different ways. The first approach is to apply the Higgs mechanism to the BLG model equipped with our new 3-algebra. The other approach is to first construct an M5-brane out of infinitely many M2-branes, reduce the M5-brane to a D4-brane by double compactification, and then finally the D4-brane can reduce to a D2-brane via compactification on a torus. Our work provides strong supporting evidences for the BLG model, with many things fitting together almost miraculously.

Coauthor
Yutaka Matsuo

SW: Does it describe a new discovery, methodology, or synthesis of knowledge?

The appearance of Lie 3-algebra in physics will motivate theorists to construct new models from existing models, replacing Lie algebra with Lie 3-algebra. For instance, Yang-Mills theory, a paradigm of modern physics and the core of the standard model, can be upgraded to a theory with the gauge symmetry described by a Lie 3-algebra. Our invention of the construction of a Lie 3-algebra from any Lie algebra will provide a bridge between the new model and the old, and it will be useful for understanding the physical meaning of these new theories.

Another aspect of our work is that, despite the common lore that negative-norm generators in a Lie algebra lead to violation of unitarity, we showed how unitarity can be saved by certain algebraic properties. It turns out that these algebras with negative-norm generators have interesting applications to D-brane physics.

SW: Would you summarize the significance of your paper in layman's terms?

M theory unifies all superstring theories, which are the only candidates of the theory of everything. However, very little is known about M theory, except that it is equivalent to superstrings under special circumstances.

While the model of Bagger-Lambert-Gustavsson was proposed to describe a system of multiple membranes—the building blocks of M theory—there was not much supporting evidence. Our work serves as a strong support by showing how, under proper conditions, the BLG model can be reinterpreted as a model for a physical system in the superstring theory.

Our work also improved our understanding of the algebraic structure of Lie 3-algebras, which can potentially play an important role in theoretical physics in the future. For instance, it may help us understand how the uncertainty principle is to be generalized in M theory.

SW: How did you become involved in this research, and were there any problems along the way?

We have been interested in M2-branes for a long time, and suspected that the Nambu bracket, which is closely related to Lie 3-algebra, is the suitable mathematical structure for describing M2-branes. Naturally the works of Bagger, Lambert, and Gustavsson attracted our attention. Another work that intrigued us was the paper by Mukhi and Papageorgakis. They proposed a Higgs mechanism for the BLG model, which we have later adopted in our work.

A problem that puzzled us for a while was the fact that there are ghost fields in the BLG model for the 3-algebra we invented. *A priori*, ghost fields correspond to negative-norm states and the theory may be ill-defined. After some struggle we realized that some of the field components can be fixed without losing any symmetry and we believed that this should be how we define the theory.

With this interpretation in mind, it turns out that the ghost fields are naturally decoupled. Further justification of this procedure was later provided by Bandres, Lipstein, and Schwarz, and by Gomis, Rodriguez-Gomez, Van Raamsdonk, and Verlinde.

SW: Where do you see your research leading in the future?

Right now we are continuing research in this direction, trying to better understand the BLG model and general features of Lie 3-algberas. We have learned that the BLG model can also describe M5-branes by putting infinitely many M2-branes together in a specific way. Another long-standing puzzle that the concept of Lie 3-algebra or Nambu bracket shed some light upon is why the entropy of N M2-branes, and that of N M5-branes, scale with N as N^{3/2}, and N^3, respectively. (If the gauge theory for M2-branes and M5-branes are ordinary Yang-Mills theories that we are familiar with, the entropy should scale as N^2.)

It is possible that a lot of knowledge about M theory is still hidden in the BLG model, waiting to be uncovered. We also expect that the Lie 3-algebra will play an important role in other areas of physics once its mathematical structure is better understood.

SW: Do you foresee any social or political implications for your research?

We have to admit that the problems we are working on are purely academic, without any immediate practical application that will change human's material lives in any way. Apart from the intellectual pleasure for us and the readers who find our work interesting, our work is free from benefit as well as hazards to the general public.

Pei-Ming Ho
Professor
Department of Physics and Center for Theoretical Sciences
National Taiwan University
Taipei, Taiwan

Yosuke Imamura
Assistant Professor
Department of Physics
Faculty of Science
Tokyo University
Tokyo, Japan

Yutaka Matsuo
Associate Professor
Department of Physics
Faculty of Science
Tokyo University
Tokyo, Japan

Keywords: NAMBU-MECHANICS; DEFORMATION QUANTIZATION; P-BRANES; POISSON; MANIFOLDS; ALGEBRAS; DYNAMICS.