

Citation of the 2018 Nishina Memorial Prize

1) Awardee:

Dr. Masaru Shibata

Director, Max Planck Institute for Gravitational Physics

Professor, Yukawa Institute for Theoretical Physics,

Kyoto University



Title of Research Achievement

“Study of Binary Neutron Star Mergers by Numerical Relativity Simulations”

Abstract of Research Achievement

Mergers of close binary neutron stars are important events not just to verify general relativity involving very strong gravitational fields, but also to provide information on the internal structure of neutron stars and the astrophysical origin of heavy elements.

Devoted to theoretical research on relativistic merger events for more than 20 years, Dr. Shibata has established the canonical scenario of the merger, and has characterized model predictions of various observables to be seen in the merger events. His research started with extensive studies on numerical relativity where the Einstein equation and the relativistic hydrodynamics equations are solved simultaneously. He developed a wide array of approaches such as the choice of relevant gauge conditions, establishment of stable numerical hydrodynamics codes, the numerical method to define the gravitational collapse into a black hole, and the method to extract gravitational-wave signals. In 1999, Dr. Shibata successfully performed the world's first numerical simulations of merging binary neutron stars by integrating those approaches [1].

This work was highly praised by the community for ushering in the practical application of numerical relativity simulations. Later, as the lead of his team of young researchers, Dr. Shibata enhanced the precision of physical processes as well as the computational resolution, and performed a series of simulations of various merger models under realistic conditions [2,3,4,5]; he founded standard theories on dynamical merger processes, gravitational waveforms, mass ejection and neutrino emission, among others, and progressed with theoretical predictions of the behavior of gravitational waves and electromagnetic radiation in binary neutron star mergers.

Coinciding with his scientific achievement, the gravitational wave detectors, Advanced LIGO and Advanced Virgo, recorded for the first time the gravitational waves (GW170817) from a merger of binary neutron stars in August 2017. Furthermore, simultaneous observation of electromagnetic waves, ranging from gamma rays to infrared radiation, marked the herald of "multi-messenger astronomy". Dr. Shibata's theoretical research has become a fundamental key to elucidating physical phenomena behind these observations [6].

Dr. Shibata is certainly the pioneer and the front runner in the research of binary neutron star mergers based on numerical relativity simulations. Coupled with expected further advancements in observations of gravitational waves and electromagnetic counterparts, Dr. Shibata's work will undoubtedly gain increasing importance.

- [1] "Fully general relativistic simulation of coalescing binary neutron stars: Preparatory test", M. Shibata, Phys. Rev. D **60**, 104052-1-25 (1999).
- [2] "Simulation of merging binary neutron stars in full general relativity: $\Gamma=2$ case", M. Shibata and K. Uryu, Phys. Rev. D **61**, 064001-1-18 (2000).
- [3] "Merger of binary neutron stars with realistic equations of state in full general relativity", M. Shibata, K. Taniguchi, and K. Uryu, Phys. Rev. D **71**, 084021-1-26 (2005).
- [4] "The mass ejection from the merger of binary neutron stars", K. Hotokezaka, K. Kiuchi, K. Kyutoku, H. Okawa, Y. Sekiguchi, M. Shibata, and K. Taniguchi, Phys. Rev. D **87**, 024001-1-27 (2013).
- [5] "Remnant massive neutron stars of binary neutron star mergers: Evolution process and gravitational waveform", K. Hotokezaka, K. Kiuchi, K. Kyutoku, T. Muranushi, Y. Sekiguchi, M. Shibata, and K. Taniguchi, Phys. Rev. D **88**, 044026-1-30 (2013).
- [6] "Modeling GW170817 based on numerical relativity and its implications", M. Shibata, S. Fujibayashi, K. Hotokezaka, K. Kiuchi, K. Kyutoku, Y. Sekiguchi, and M. Tanaka, Phys. Rev. D **96**, 123012-1-22 (2017).

2) Awardee:

Dr. Koichiro Tanaka

Professor, Graduate School of Science, Kyoto University

Title of Research Achievement

“Development of Extreme-nonlinear Terahertz Optics in Solids”



Abstract of Research Achievement

Extreme-nonlinear optical phenomena are induced when the interaction energy of an electron system in matter with incident light gets close to or exceeds the characteristic energy scale of the electron system (such as ionization or band-gap energy). In the 1990's it was experimentally discovered that higher-order harmonic light waves are generated when atoms are irradiated with high-intensity visible light pulses. For the description of such optical phenomena, perturbation theory is no longer appropriate, and the development of a novel theoretical framework, including the case when matter and light highly interact with each other, was strongly called for. Subsequently, the proposal of a successful phenomenological model triggered the theoretical understanding. At the same time, technologies for generating soft X rays from visible and attosecond light sources were developed by employing extreme-nonlinear optical effects. On the other hand, a solid is damaged when it is irradiated with high-intensity visible light pulses such as those used for atoms, so that a profound understanding of extreme-nonlinear optical phenomena in solids had not been achieved yet. In solids consisting of a periodic crystal lattice, the electron system is well described by the band picture, but to what extent this band picture is applicable when the intensity of incoming light is causing extreme-nonlinear optical phenomena and also what kind of optical phenomena appear, remained unknown.

Dr. Tanaka has successfully developed a high-intensity terahertz light source based on the pulse-front-tilting method, according to his idea that extreme-nonlinear optical phenomena in solids can be observed without damaging them by reducing the light frequency to the terahertz region. As a result, he has realized the world's first terahertz light source where the pulse peak electric field exceeds 1.2 MV/cm (peak magnetic field is 0.4 T) [1]. This has triggered studies on terahertz extreme-nonlinear optics in solids all over the world with great momentum in both experiment and theory, leading to a sheer endless series of discoveries. Dr. Tanaka himself used this

light source to realize a 1000-times amplification of charge carriers in GaAs quantum wells [2], a giant modulation of the magnetization in the canted ferromagnet HoFeO₃ [3], ultrafast terahertz optical switching [4], and the generation of higher-order high-harmonic light in graphene for the first time in the world [5].

- [1] "Single-cycle terahertz pulses with amplitudes exceeding 1 MV/cm generated by optical rectification in LiNbO₃", H. Hirori, A. Doi, F. Blanchard, and K. Tanaka, *Appl. Phys. Lett.* **98**, 091106 (2011).
- [2] "Extraordinary Carrier Multiplication Gated by a Picosecond Electric Field Pulse", H. Hirori, K. Shinokita, M. Shirai, S. Tani, Y. Kadoya, and K. Tanaka, *Nature Communications* **2**, 594 (2011).
- [3] "Nonlinear magnetization dynamics of antiferromagnetic spin resonance induced by intense terahertz magnetic field", Y. Mukai, H. Hirori, T. Yamamoto, H. Kageyama and K. Tanaka, *New J. Phys.* **18** 013045 (2016).
- [4] "Ultrafast Carrier Dynamics Under High Electric Field in Graphene", S. Tani, F. Blanchard, and K. Tanaka *Phys. Rev. Lett.* **109**, 166603 (2012).
- [5] "High-harmonic generation in graphene enhanced by elliptically polarized light excitation", N. Yoshikawa, T. Tamaya, and K. Tanaka, *Science* **356**, 736-738 (2017).