Nishina Memorial Prize 2018

Every year since 1955, the Nishina Memorial Prize has been awarded to young physicists for their achievements in the field of atomic and sub-atomic physics. This prize* is regarded to the most prestigious prize in physics in Japan. From this year, the recipient shall be introduced in the Bulletin.

Dr. MASARU SHIBATA

Director, Max Planck Institute for Gravitational Physics
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Title of Research Achievements:
"The Study of Binary Neutron Star Mergers by Numerical Relativity Simulations"

Abstract of Research Achievements:
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.

With work dedicated 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, the establishment of stable numerical hydrodynamics codes, the numerical method to define 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 a 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).

* http://www.nishina-mf.or.jp/NishinaMemorialPrize-E.html

[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).

Dr. KOICHIRO TANAKA

Professor, Graduate School of Science, Kyoto University

Title of Research Achievements:
“Development of Extreme-nonlinear Terahertz Optics in Solids”

Abstract of Research Achievements:

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 an electron system (such as ionization or band-gap energy). In the 1990’s, researchers 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 was no longer appropriate, and the development of a novel theoretical framework, which would include the case when matter and light highly interact with each other, was strongly called for. Subsequently, the proposal of a successful phenomenological model triggered further 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. However, solids were damaged when they were irradiated with high-intensity visible light pulses such as those used for atoms, indicating that a profound understanding of extreme-nonlinear optical phenomena in solids had not yet been achieved. In solids consisting of a periodic crystal lattice, the electron system is well described by the band picture; however, the extent to which this band picture is applicable when the intensity of incoming light causes 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 realized the world's first terahertz light source where the pulse peak electric field exceeded 1.2 MV/cm (peak magnetic field is 0.4 T) [1]. This work has triggered, with great momentum, both experimental and theoretical studies on terahertz extreme-nonlinear optics in solids all over the world, leading to a substantial series of discoveries. Dr. Tanaka himself used this light source to realize the 1000-times amplification of charge carriers in GaAs quantum wells [2], giant modulation of the magnetization in the canted ferromagnet $HoFeO_3$ [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 $LiNbO_3$”, 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).