Nishina Memorial Prize 2019

The Nishina Memorial Prize* has been awarded to young physicists for their achievements in the field of atomic and sub-atomic physics. It regards to the most prestigious prize in physics in Japan. The prize this year is awarded to: Dr. Yoshihiro Iwasa of Graduate School of Engineering, University of Tokyo for Discovery of Electric-field Induced Two-dimensional Superconductivity, and Dr. Shigeru Yoshida of Graduate School of Science, Chiba University and Dr. Aya Ishihara of Institute for Global Prominent Research, Chiba University for Discovery of Ultra-High Energy Cosmic Neutrinos.

Dr. Yoshihiro Iwasa

Thin film superconductors have played a central role in the field of superconductivity, from basic physical properties to device applications. Main materials in these superconductors are metal vapor-deposition films such as Nb, Al, and MoGe, and it has been experimentally shown that these superconducting properties are different from those of bulk three-dimensional systems. Furthermore, in this century, nanotechnology such as thin film fabrication and device fabrication has progressed dramatically, and superconductors with thickness of 1 nanometer or less and sometimes consisting of monoatomic layers with high crystallinity have been produced.

Dr. Yoshihiro Iwasa developed a method of high-density carrier-doping by a gate voltage and found superconductivity in two-dimensional systems on oxide insulators and chalcogenide semiconductors [1]. In this method, the carrier doping is achieved by a gate voltage as in the field-effect transistor (FET) consisting of a metal-insulator-semiconductor structure. In the FET structure that constitutes silicon integrated circuits, high carrier concentration sufficient for superconductivity cannot be achieved because of breakdown of the insulator.

Dr. Iwasa realized the high-density carrier-doping by replacing the insulator of an FET structure with an ionic conductor that is an electronic insulator but capable of conducting electricity by ionic motion. This technique enables the control of carrier concentration for a range much wider than FET with less influence of impurities on carriers in comparison with other methods like elemental substitution. His research group discovered, for the first time in the world, the electric-field induced superconductivity, where the electrical resistivity of induced carriers vanishes above a critical carrier concentration when it is increased just by changing a gate voltage. Further, his group obtained an electronic phase diagram ranging from semiconductor to superconductor [2] and a magnetic field-temperature phase diagram with large in-plane and out-of-plane anisotropy of the superconducting transition temperature [3, 4].

This technique of converting an insulator to a superconductor by electric-field induced carrier-doping provides an important experimental method that can eliminate impurity effects in the study of quantum spin liquids, strongly correlated-electron superconductivity, etc. In addition, it has already been applied to many other cutting-edge fields in condensed matter research leading to new developments.

References

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* https://www.nishina-mf.or.jp/project_en/kinen_en/

Dr. Shigeru Yoshida and Dr. Aya Ishihara

Dr. Shigeru Yoshida and Dr. Aya Ishihara have made essential contributions to the discovery of ultra-high-energy cosmic neutrinos with the IceCube Neutrino Observatory, bringing new insights to the fields of cosmic ray physics and high-energy neutrino astronomy. While cosmic rays with energies up to 10^{20} eV have been observed, their production sources and acceleration mechanisms are largely unknown. Due to various collisions and magnetic bending while traveling through space, the origins of protons and nuclei cannot be easily reconstructed. Thus, observation of neutrinos is a powerful means to probe information of cosmic rays immediately after their productions.

The IceCube Neutrino Observatory is an array of 5,160 optical sensors embedded in a 1 km^3 volume of deep ice at the South Pole. The optical sensors capture Cherenkov photons radiated by charged particles in the form of showers and tracks, produced by reactions of cosmic neutrinos inside or nearby the detector array. Dr. Yoshida and Dr. Ishihara established an analysis method capable of reliably detecting ultra-high-energy neutrinos. By using this method, two shower events initiated by PeV-energy neutrinos were found in the 2011-2012 data set [1]. This is the first identification of ultra-high-energy cosmic neutrino candidates, observed with significance of 2.8 sigma (99.71 % confidence level). The extensive analysis following this finding has shown that the strongly evolved classes of astronomical objects such as radio-loud galaxies, vastly more active at the far universe, are unlikely to be a major origin of ultra-high-energy cosmic rays [2]. This was the first meaningful constraint on characteristics of ultra-high-energy cosmic ray origins, realized by neutrino observations.

This very first discovery of PeV-energy neutrinos clarified some characteristics of cosmic neutrino signals, which prompted a follow-up search to find more neutrino-induced showers at lower energies using IceCube. The 37 events in total with energies from 30 TeV to 2 PeV were found in the three year data set taken during 2010-2013 [3]. This observation clearly shows the existence of a neutrino population beyond atmospheric backgrounds of neutrinos and muons. It brought strong evidence of astrophysical neutrinos to a statistical significance of 5.7 sigma. (99.9999994 % confidence level)

After this achievement, the IceCube Collaboration began identification of cosmic neutrino candidates in real-time and a new online data processing flow where alerts of the observational information, such as their energy and arrival direction, are sent to the global astronomical community starting in 2016. Using this system, the high-energy cosmic neutrino event called "IceCube-170922A" was detected and immediately followed by an alert to the world astronomical facilities on September 23, 2017 (Japan Time). Rapid follow-up observations, based on the neutrino direction, discovered that the blazar galaxy housing a massive black hole called "TXS 0506+056" was found to be more luminous than usual in the visible spectrum. It prompted the rapid analysis by the Fermi-LAT team finding that this galaxy was undergoing a giant gamma-ray flare [4]. The MAGIC atmospheric Cherenkov gamma-ray telescope also detected very high-energy gamma rays extending above 100 GeV. The identification of neutrino sources through observations with gamma rays and neutrinos has opened up a new era of multi-messenger astronomy led by neutrinos. Dr. Yoshida and Dr. Ishihara both played important roles in the IceCube neutrino alert system and the analyses of IceCube-170922A.

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