【Grant-in-Aid for Scientific Research (S)】

Broad Section B

Title of Project : Early identification of supernovae using neutrino observations at Super-Kamiokande

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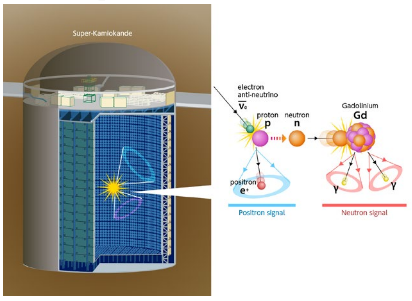
【Purpose and Background of the Research】

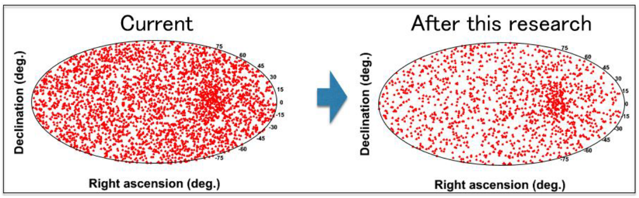
Massive stars are with more than eight solar masses thought to undergo gravitational collapse at the final stage of their evolution, causing a supernova explosion. At that time, an enormous amount of energy of 10^{46} joules is generated in about 10 seconds, and it is thought that 99% of it is released to the outside of the star by neutrinos. In fact, in the 1987 supernova explosion at the Large Magellanic Cloud, Kamiokande, IMB and Baksan detected 24 neutrino events, demonstrating that the scenario is basically correct. However, the detailed mechanism of the explosion was not elucidated due to the small number of events. On the other hand, even simulations that make full use of the latest theories do not answer yet "why they explode?"

Super-Kamiokande (SK) is a 50,000 ton water Chrenkov detector with about 11,000 50 cm photomultiplier tubes, and if a supernova explosion occurs in our galaxy, thousands to 10,000 neutrino events are expected. SK can determine the direction of supernovae from observations. Only SK can do this in the world. In 2020, SK introduced 0.01% gadolinium (Gd) into the tank in order to identify the neutrino reaction. In this research, the concentration of Gd will be increased to 0.03%, the ability to identify neutrino reactions will be improved, and the accuracy of supernova direction will be significantly improved. In addition, we will build multi-messenger astronomy in supernova explosions by promptly reporting neutrino detection to the world.

【Research Methods】

In the energy region of supernova neutrinos, the reaction probability of the inverse beta decay reaction (IBD) in which anti-electron neutrinos react with protons in water is the highest. However, the positrons generated by this reaction do not retain the original neutrino arrival direction. On the other hand, scattered electrons due to elastic scattering of neutrinos (ES) have a strong correlation with the direction of original neutrinos, but ES is only about 5% of that of IBD. Therefore, in this study we identify IBD using Gd signals as shown in the upper-right figure. The lower-right figure is a simulation of a supernova explosion in the galaxy, and the direction of each event is plotted on celestial coordinates. The left is the current situation, and the right is the case where Gd concentration is increased by this research to improve the neutron capture efficiency. In this way, it can be seen that the ES event is easier to see. In fact, the accuracy of supernova orientation can be improved to within 3 degrees. In this research, we will develop a method to calculate the direction of a supernova using machine learning technology and build a system to determine the direction within a few minutes. By using the socket communication of GCN (Gamma-ray Coordinates Network) operated by NASA, it is possible to notify observatories around the world without any time lag.





【Expected Research Achievements and Scientific Significance】

In order to elucidate the mechanism of a supernova explosion, it is necessary to detect many neutrino events during the explosion and observe the explosion process in detail. High-statistical observations of SK will make this possible if a supernova explosion occurs in our galaxy. It is also important to observe by various methods that are tied up with optical telescopes, such as the delay time from the neutrino emission time to the observation of light and the change in luminosity after the explosion. If this research enables early identification of supernovae, they can be realized. In addition, in the case of super-neighborhood supernovae such as Betelgeuse and Antares, the explosion can be predicted in advance using the Gd signal.

【Publications Relevant to the Project】

・ "Real-Time Supernova Neutrino Burst Monitor at Super-Kamiokande", Astropart. Phys. 81 (2016) 39-48.
・ "Sensitivity of Super-Kamiokande with Gadolinium to Low Energy Antineutrinos from Pre-supernova Emission", Astrophys. J. 885, 2 (2019).

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