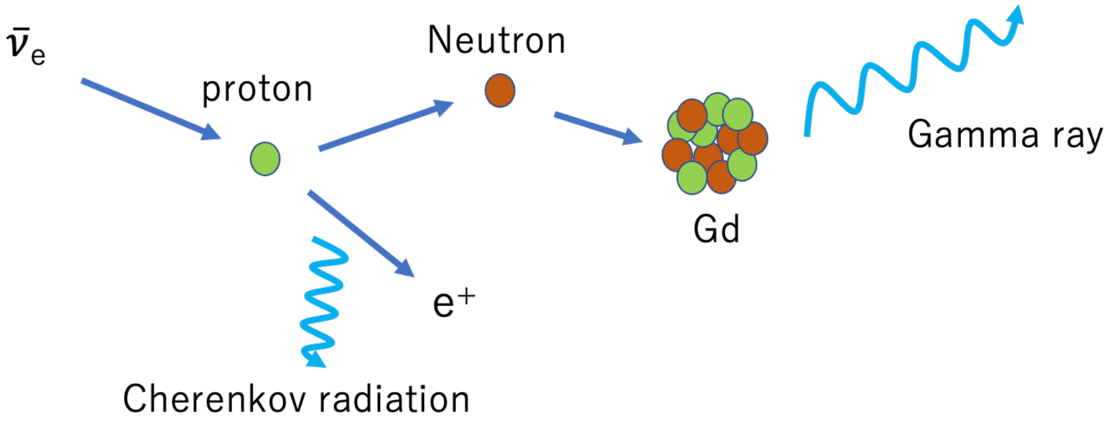
Neutrino astronomy reveals the nature of the universe

Since ancient times, humans have gained knowledge of the universe by looking up at the sky. This was the beginning of astronomy. And in the 20th century, astronomy has evolved dramatically. Our astronomical observation methods have quickly expanded. The development of observational equipment has made it possible to capture electromagnetic waves, not only visible light, ranging from high-energy gamma rays to radio waves. In addition to electromagnetic waves, we can now observe cosmic rays such as protons and neutrinos and even gravitational waves. This is the so-called multi-messenger astronomy. I would like to introduce one of them, neutrino astronomy. How much do you know about the elementary particle called neutrino? Many people, especially Japanese, may have heard of it when Dr. Masatoshi Koshiba and Dr. Takaaki Kajita won the Nobel Prizes in 2002 and 2015. Observing this elementary particle has opened a new window to the universe, so-called Neutrino astronomy, a part of multi-messenger astronomy. And observations of the neutrino can provide some insights into the mechanism of a supernova explosion and the origin of very high-energy cosmic rays or the nature of Dark Matter.

Let me briefly explain the nature of neutrino here. This elementary particle is electrically neutral and has a very small mass compared to other elementary particles. Also, this particle interacts via only weak interaction and gravity. Because of these fundamental natures, the neutrino is very difficult to detect. However, these natures also make the neutrino a good messenger of our universe. Neutrinos are of particular interest in high-energy astronomy. As mentioned earlier, neutrinos are electrically neutral, so unlike charged particles, they cannot be bent by magnetic fields. However, you may think the same is true for high-energy gamma rays. High energy gamma-ray is attenuated via the electron-positron pair production process. So, the observable distance of gamma-ray is limited. Furthermore, Electromagnetic waves, gravitational waves, neutrinos, and cosmic rays have different generation mechanisms. Some information can only be obtained from neutrino observations.

Next, let’s see how we observe neutrinos using the Super-Kamiokande as an example. As mentioned earlier, the neutrino has high transparency, which means that it is much more challenging to observe. Therefore, in order to increase the frequency of neutrino collisions, neutrino observations need a substantial amount of detectors. More groundbreaking experiments called GADZOOKS! are underway at Super-Kamiokande and are also planned in other experiments. One of the main targets of neutrino observations is to observe the neutrinos originating from supernova explosions and clarify the detailed mechanism of supernova explosions. Still, only a handful of neutrinos that were created by supernova have been recorded, neutrinos originating from SN 1987A supernova, which was recorded at the Kamiokande and the IMB experiment. The reason why it is difficult to detect the supernova originating neutrino is that the frequency of supernova explosions in our Milky Way Galaxy is believed to be approximately one per century. However, on average, a supernova explodes once per second in the entire universe, and neutrinos emitted from these past supernova explosions fill the universe (called Diffuse Supernova Neutrino Background). If we can observe this DSNB, we will be able to understand the mechanism of supernova explosions, nucleosynthesis, and many other things. To make this possible, a project called SK-Gd is currently underway to add gadolinium to the Super-Kamiokande water tank. The added gadolinium is known to absorb neutrons and emit gamma rays. The particles emitted when neutrinos interact with nuclei depend on the type of neutrino. This makes it possible to distinguish the events of neutrinos, especially those called electron-antineutrinos, from those of other neutrinos. And we can distinguish supernova-originating neutrinos from other background events.



Finally, I will introduce some expected future discoveries in neutrino astronomy based on these neutrino observations. First is the origin of high-energy cosmic rays. High energy cosmic rays whose energy is up to 10^{20} eV have been observed. However, where it comes from or how it is accelerated is still unknown. As mentioned above, detecting the high-energy neutrino is one of the most promising ways to determine the source of high-energy cosmic rays. Actually, the Ice Cube experiment which places the detector in the Antarctic Ice has observed two events with energetic neutrinos as high as Peta-electron volts, and further upgrades to the experiment are planned. Second, supernova originating neutrino or DSNB neutrino will be observed, and this will lead to a clarification of the mechanism of supernova, nucleosynthesis, or so on. Not only the Super-Kamiokande, but other water Cherenkov detector also now plans to add gadolinium to the water tank as an option. Third, we can gain a more profound understanding of the early universe by investigating the cosmic neutrino background, which travels space just about two seconds after the universe's birth (earlier than the Cosmic Microwave Background!).

References

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