"Searching for the source of very high energy neutrinos"

Kosuke Nishiwaki

Neutrinos are somewhat mysterious, but they are playing a very important role in the universe. Neutrinos are tiny particles that rarely interact with other materials, so they are referred to as "ghost particles." However, thanks to recent progress in neutrino observations, we have learned a lot about the physical property of this kind of invisible particle. Surprisingly, they are the second most abundant particles in the universe, next to photons. They are almost everywhere. Some of them are born in the Earth's atmosphere, some are from the sun or other stars, some are created at the beginning of the universe, and some others are from other energetic phenomena. While our understanding of neutrino has improved, a new problem has appeared.

IceCube is a big neutrino detector built within the ice of South Pole. It is as big as one cubic kilometer and designed to observe very high energy neutrinos. For about ten years after construction, IceCube has detected almost 100 very high energy neutrino events. IceCube revealed that these neutrinos fill the universe as a diffuse background radiation. However, no one knows where such very high energy ones are born. This is one of the hottest dark problems in high energy astrophysics today: what is the source of very high energy neutrinos?

Though the birthplace of these neutrinos is unknown, their “parents” are well-known. Such neutrinos must be originated from the nuclear interactions between accelerated protons and other particles. When high energy proton collides with other protons or photons, some part of the energy is consumed to create other particles including neutrinos. The same process is happening in the particle accelerators on the Earth, though the energy is a thousand times as small as that is necessary for the creation of very high energy neutrinos. The point is that if high energy neutrinos are created somewhere, there must also be very high energy protons. In other words, the detection of very high energy neutrinos is a “smoking-gun” signal of the particle acceleration in the universe.

Astrophysicists have proposed some candidates for the birthplace of such neutrinos. In the sources of neutrinos, protons have to be accelerated to extremely high energy, so it is natural to assume that they are from very energetic burst phenomena. However,

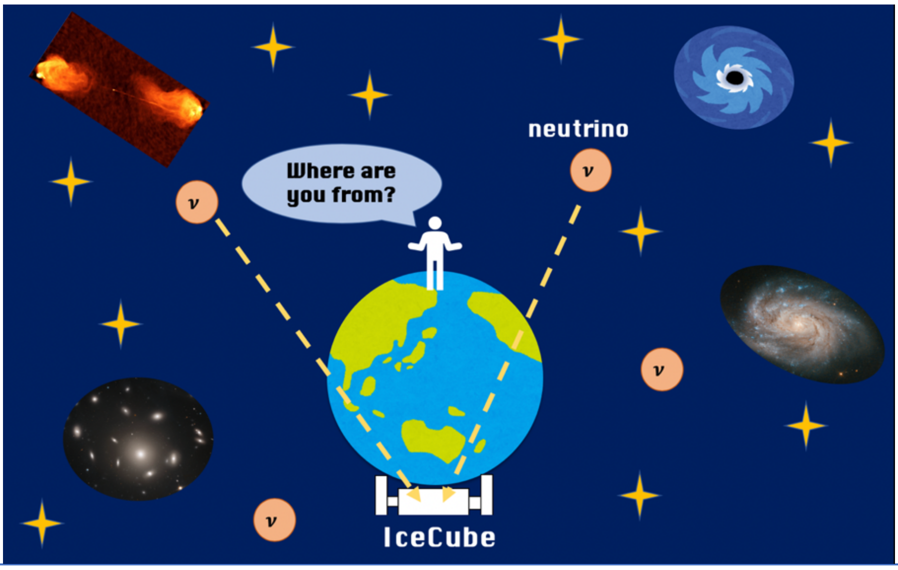

Figure: Wondering where very high energy neutrinos come from
“Sources: Earth and black hole (https://www.irasutoya.com),
Astral bodies (NASA: https://www.nasa.gov/multimedia/imagegallery/index.html)"

some suggest that static objects such as galaxies or galaxy clusters could also be the source of neutrinos. For example, lots of stars are continuously born and dying inside the galaxies. At the end of its activity, a massive star causes a catastrophic explosion called a supernova and release a substantial amount of energy into interstellar space. Some parts of its energy must be used to accelerate particles. Some galaxies seem to be launching collimated flows of accelerated particles. Such kind of galaxy is called blazer, and the flow is usually called "jet." Though the mechanism of jet acceleration is another big mystery, the existence of jets suggests that blazers could be the sources of neutrinos. For another example, galaxy clusters are thought to be the big containers of high energy particles. Thanks to their extremely large volume, particles are accelerated up to extremely high energy before escaping out them. Today, these static objects are gathering more and more attention as sources of very high energy neutrinos. One neutrino event has found to correlate with the flaring of a blazer in 2018[1]. As the operation of IceCube goes on, we can expect more and more clues to the origin of neutrino background radiation.

Many other observations also suggest the existence of high energy particles. For example, electromagnetic wave observations, especially gamma-ray observation,

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[1] https://science.sciencemag.org/content/361/6398/147

have discovered the gamma-ray background radiation; high energy photons also fill the universe. A certain amount of gamma rays must correlate with neutrinos since they are emitted via similar processes. For another example, we can directly observe the signals of cosmic rays. Pierre Auger observatory, one of the biggest cosmic ray observatories located at Argentina, has been detected cosmic rays with ultra-high energy. While traveling the space, cosmic rays are subjected to the collision with photons. Besides, their trajectories may bend due to the magnetic field in our galaxy. Thus, how and where these cosmic rays are from are still poorly understood. Interestingly, we can get different kinds of information from a neutrino, photon, and cosmic ray observations respectively. In other words, these observations compensate each other. Combining these "multi-messenger" information, we can deeply investigate one of the missing parts in our understanding of the universe: the physics of particle acceleration.

What do those high energy particles have to do with us? It may be surprising that the physics of particle acceleration is the key to the existence of life on Earth. Almost 100 years ago, scientists found that there is a rain of charged particles coming from the universe. These particles are called "cosmic rays." Cosmic rays consist of accelerated subatomic particles that travel the space nearly the speed of light. Some scientists think these cosmic rays could have created the very first life on Earth in the following way. When cosmic rays come into Earth's atmosphere, they collide with the gas molecules and ionize them. The ions in the clouds can be the seeds of the lightening and this lightning might have brought the energy to cause chemical reactions that are necessary to create the building blocks of life. Thus, studying the origin of neutrinos may provide us insights into the origin of ourselves!