Toward the discovery of the Diffuse Supernova Neutrinos Background in the Super-Kamiokande detector: a probe of the early universe

Ph.D. 2019-2022

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PHENIICS doctoral school PhD **Thesis subject proposal 2019**

Laboratory/research team

Laboratoire Leprince-Ringuet, École polytechnique / Neutrinos group

Title:

Toward the discovery of the Diffuse Supernova Neutrinos Background in the Super-Kamiokande detector: a probe of the early universe.

Overview of the research:

In February of 1987, the Kamiokande detector detected the world's first neutrinos emitted by a supernova burst. Since then, no supernova burst has occurred in or near our galaxy. Supernovae produce and disperse elements heavier than Helium and are vital to understand many aspects of the present Universe. They provide a huge source of neutrino flux, neutrinos carrying about 99 % of the binding energy released during the collapse of the star. The study of neutrinos from supernovae leads to a wide field of physics researches: neutrino's properties, mechanism of supernova or black-hole formation, cosmology and recently it becomes a complementary tool with gravitational waves to study core collapses of massive objects.

Even if in our galaxy, supernovae may be fairly rare (current estimation is about three per century), it is estimated that about 10^{17} supernovae have occurred over the entire history of the universe, yielding about one supernova every second somewhere in the universe. The neutrinos emitted from these past and present events must have suffused the universe but their flux remains un-observed so far. The detection of this neutrinos flux usually referred as the Diffuse Supernova Neutrino Background (**DSNB**) would provide important insights into cosmology, the history of star formation, nucleosynthesis, and stellar evolution.

The detection of the supernova relic neutrinos and supernova burst neutrinos constitutes a major challenge for the Super-Kamiokande (**Super-K**) experiment. Even if supernova bursts generate all types of neutrinos, because of its larger cross section, electron anti-neutrinos are the most copiously detected neutrinos in a water Cherenkov detector like Super-K. About 88 % of the detectable supernova neutrino events are inverse beta interactions (IBD), ending up with a positron and a neutron in the final state. Super-K has previously carried out searches for DNSB from the expected positrons detection (through the emission of the Cherenkov light) without requiring the detection of a delayed neutron and only an integral flux upper limit was set (current best limit) for neutrinos energy threshold above 17.3 MeV. Since the detector cannot directly differentiate electrons from positrons, these searches suffer from background of electrons and positrons explaining such a large threshold. However, many background channels do not produce neutrons and therefore, the detection of both the positron and the neutron in coincidence, would improve the obtained limit by lowering down the threshold. Therefore, Super-K is going to dope the water with a water-soluble chemical compound of Gadolinium which benefits from a large cross-section of neutron capture yielding a gamma cascade easily detectable. The coincident detection of a positron's Cherenkov light, followed shortly thereafter in roughly the same place by a shower of gamma rays, will serve to positively identify the anti-neutrinos from IBD in the detector strongly suppressing the backgrounds and making the DSNB signal visible. The schedule of the project is such that by the beginning of 2020, the Gd will be progressively dissolved into the water of Super-K tank, paving the way to **the world's first observation of the DSNB.**

Thesis project

This thesis offers the unique opportunity to participate to some outstanding project in the field of high energy **at the frontier between cosmology and elementary particle physics,** in addition to the discovery of the Japanese culture.

The future Ph.D. student might participate in the final stage of operation of adding gadolinium in the Super-K detector, and she/he is expected to participate in Monte Carlo simulations and in the analysis of the DSNB with the first data after the Gd upgrade. The different sources of backgrounds and the detection efficiencies of the DSNB will have to be optimized, the Ph.D. student being expected to play a leading role in the analysis. First estimates with the next generation of water Cherenkov detector, Hyper-Kamiokande, might be also envisaged.

The student is expected to spend some significant fraction of his time in Japan. In particular, he/she will collaborate with the Okayama university team expert of the DSNB physics.

The defense of the thesis is foreseen by summer 2022.

Master and doctoral school

- Master 2 in particle physics

- PHENIICS doctoral school – Université Paris-Saclay or NewUni doctoral school

Local teams

The neutrino group[1] of the LLR consists of 5 researchers (staff members), 2 post-doctoral students and 3 Ph.D. students and they contribute to several neutrino experiments. Six of them are members of the Super-K experiment.

Contact

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Super-Kamiokande: http://www-sk.icrr.u-tokyo.ac.jp/sk/sk/srn-e.html

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[1] http://llr.in2p3.fr/-physique-des-neutrinos-