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To the working groups: ”Fundamental interactions” and ”Astroparticle physics and Cosmology”

NEUTRINOS: **from the discovery of the diffuse supernova neutrino background to quantum information theory**

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Dense environments – core-collapse supernovae, binary neutron star mergers, early universe - are powerful sources of low energy neutrinos. In astrophysical environments, shock waves, turbulence, neutrino-neutrino interactions and unknown neutrino properties influence the neutrino time signal and energy spectra when neutrinos propagate in the medium. How neutrinos change flavor, in a dense gas of weakly interacting neutrinos and matter, is a quantum many-body problem. This question, and its interplay with neutrino properties, has triggered an intense activity worldwide in the last fifteen years. While many aspects have been unravelled, because of its complexity, this constitutes one of the main open problems and will remain at the center of significant theoretical developments in the coming decade.

Besides its theoretical interest, this domain is observationally important because neutrino flavor evolution impacts future observations of supernova neutrinos from an (extra)galactic explosion (a rare phenomenon) and of diffuse supernova neutrino background whose discovery is expected in a few years. Moreover neutrinos properties and flavor evolution are tightly linked to the longstanding open questions of how massive stars explode and necessary to uncover the site(s) for r-process nucleosynthesis. Importantly, GW170817 gave evidence that r-process elements are produced in kilonovae. In their (dynamical, viscous, neutrino-driven) winds, neutrinos modify the electron-fraction, a key parameter for r-process nucleosynthesis. Therefore the current and future progress in this domain is essential to answer these longstanding open issues. As for the early universe, the advances in the description of neutrinos go hand in hand with those in neutrino physics and astrophysics. Notably, neutrino quantum kinetic equations are necessary and non-standard physics, such as sterile neutrinos or neutrino non-radiative decay, impact cosmological observables.

Concerning supernovae, the precise measurements of the neutrino luminosity curve and spectra from a future supernova will give key information on the explosion mechanism and on key unknown neutrino properties such as the neutrino magnetic moment. Complementary to this, the upcoming detection of the diffuse supernova neutrino background will open a new observational window in neutrino astrophysics, since it is sensitive to the debated fraction of failed supernovae (supernovae that turn into a black hole), the still uncertain core-collapse supernova rate as a function of redshift, and unknown neutrino properties including flavor mechanisms in media and neutrino decay (e.g. neutrino decay with the emission of Majorons).

In the coming years, theoretical developments will be crucial to answer these fundamental open questions and to support the coming decade of unique measurements. Moreover, connections between many-body systems of weakly interacting neutrinos in dense matter and quantum information theory are currently being explored and will be central in the future. This theoretical activity at the interface of astrophysics, cosmology, many-body theories, quantum information theory and computing will be crucial to push the frontiers.