XVI LATIN AMERICAN SYMPOSIUM ON HIGH ENERGY PHYSICS
November 30th - December 4th, 2026

Contribution ID: **29**   Type: **Parallel Talk**

Phase Transition Effects on the Deleptonization of Proto-Magnetars

t has been theorized that proto-magnetars are born possesing high temperatures (around 50 to 100 MeV), rich in leptons (electrons and neutrinos out of beta equilibrium with a fraction of 0.4 per baryon), and with extremely intense magnetic fields (around 10^18 Gauss). This makes them unique astrophysical laboratories to investigate the properties of dense nuclear matter under extreme conditions. During their early evolution, deleptonization progressively reduces the lepton fraction of around 0.4 while heating the stellar core. Interestingly, it is expected from effective nuclear and quark models that a hadron-quark phase transition might be triggered due to the amount of trapped neutrinos at the inner core along this initial stage of evolutionary process. In this work, we investigate the influence of deleptonization on the phase transition of highly magnetized proto-magnetars assuming that the magnetic field is not constant in the bulk but density dependent as required by the Einstein-Maxwell equations. One fundamental ingredient is the computation of the so-called Landau levels when computing the pressure, energy density and entropy density which allow us to obtain equation of state useful to compute the masses, radii and tidal deformabilities trough the Tolman-Oppenheimer-Volkoff and Hinderer equations, respectively, assuming the system evolves keeping spherical symmetry. Besides, we analyze the evolution of the particle population, chemical potentials, and the onset of deconfined quark matter for different magnetic field strengths. Our calculations indicate that such large magnetic fields significantly modify the composition of dense matter and alter the density at which the phase transition occurs assuming it is highly discontinuous. We found a time-dependent reduction of the lepton fraction during the deleptonization process where the protostar reduces its volume while being heating. These results can qualitatively compared against upcoming data from the neutrino luminosity inferred from multimessenger data expected to be detected from kilonovas in neutron star mergers or even directly from supernovae in the Cosmic Explorer and Einstein Telescope Observatories.

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Session Classification: Parallel Talks

Track Classification: Astroparticle physics