論文の内容の要旨

Impacts of Cosmological and Stellar Magnetic Fields on Nucleosynthesis (and related Physical Processes)

（宇宙・恒星磁場が元素合成（および関連する物理過程）に及ぼす影響）

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In this thesis, I mainly discuss the influence of magnetic fields on the nuclear astrophysics in both weak- and strong-strength cases. The transverse momentum components of $e^{\pm}$ inside the astrophysical plasma are quantized in magnetic field, results in a change of the thermodynamic condition of the plasma and further affect the weak interaction rates as well as the screening correction to the Coulomb potential of bare nuclei. On the other hand, nuclear weak reactions strongly depend on the background temperature and density of the reactant nuclei species, these are easily affected by the dynamical evolution of magnetic fields due to the induced energy fluctuations, results in a further change of the nucleosynthesis path.

Specifically, for the weak primordial magnetic field (PMF) in the early universe, I investigate its impacts on the Big Bang Nucleosynthesis (BBN). In Chapter 2, I explore the screening effects arising from the relativistic magnetized plasma in the early universe, and correct the electron capture rates by including the screening potential. By taking into the influence on $e^{\pm}$ momentum phase space during BBN, I constrain the epoch at which the PMF was generated. I also discuss the possibility of solving deuterium abundance underestimation problem from PMF. Considering both screening corrections and Landau quantization effect to the weak interaction rates, and using up-to-date observations of primordial elemental abundances, I find that the predicted D and ^{4}He abundances are both consistent with the observational constraints in the context of PMF.

Then, I investigate the impacts on the BBN from the presence of a stochastic PMF whose strength is spatially inhomogeneous distributed. I assume a uniform total energy density and a Gaussian distribution of field strength. In this case, domains of different temperatures exist in the

BBN epoch due to variations of the local PMF. I show that in such a case, the effective distribution function of particle velocities averaged over domains of different temperatures deviates from the Maxwell–Boltzmann distribution. This deviation is related to the scale-invariant strength of the PMF energy density ρ_{Bc} and the fluctuation parameter σ_B. I perform BBN network calculations by taking into account the PMF strength distribution. I find that the inhomogeneous PMF strength reduce the ^{7}Be production and enhance D production. I analyze the averaged thermonuclear reaction rates compared with those of a single temperature and find that the averaged charged-particle reaction rates are very different. Finally, I constrain the parameters ρ_{Bc} and σ_B from observed abundances of ^{4}He and D and find that the "cosmic Li problem" could be alleviated.

More reliable conclusions could be obtained from a more realistic study on dynamical PMF evolution with BBN, therefore I derive the cosmological relativistic MHD equations that could be applied to "two-fluid" approximation. I also discuss the generation mechanism of inhomogeneous PMF from collisions among different phases of the plasma extensively. I calculate a static multi-zone PMF model with BBN nuclear reaction network encoded, the result show that an inhomogeneous PMF generated from neutrino decoupling could reduce the ^{7}Li abundance dramatically without violating other elemental observations.

In Chapter 3, for the strong astrophysical magnetic field, I investigate the Coulomb screening and weak interactions in magnetized non-degenerate plasma. The characteristic plasma screening lengths at high temperatures and at high magnetic fields is explored. I estimated the screening potential as well as the changes in weak interaction rates at high field, it is found that high fields can result in the increased β-decay rates as the electron and positron spectra are dominated by Landau levels. Finally, the effects studied here are evaluated in a simple r-process model. I find that relativistic Coulomb screening has a small effect on the final abundance distribution. While the changes in weak interaction rates in strong magnetic fields can have an effect on the r-process evolution and abundance distribution, the field strength required to have a significant effect may be larger than what is currently thought to be typical of the r-process environment in collapsar jets or neutron star mergers. If r-process exist in fields $> 10^{14}$ G, effects from fields on weak decays would be significant.

I also study the magnetized degenerate astrophysical plasma. I apply a relativistic Hartree self-consistent field method to calculate the screening potential. A profile from a $15M_{\odot}$ progenitor is applied in order to evaluate the electron capture rates of iron group nuclei ^{54}Fe and ^{70}Zn. I find that the screening potential at high field is enhanced compare with the previous study. For the case that field is high enough and only the lowest Landau level is allowed, I find a two orders of magnitude reduction of the electron capture rates in high density region. Such deviations of the ^{54}Fe and ^{70}Zn electron capture rates are essential since these two isotopes determine the neutron richness of the progenitor model as well as the iron core mass, which are crucial for SNe explosion calculation. The reduction of electron capture rates of heavy nuclei under strongly magnetized degenerated plasma could also potentially deviate the neutrino absorption rate and the neutrino emission spectrum.