Laser-Driven Nuclear Astrophysics

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Abstract

Nuclear reactions are the fundamental engines driving stellar evolution, nucleosynthesis, and energy generation in the Universe. The determination of reaction rates at astrophysical energies remains one of the central challenges of nuclear astrophysics, as the relevant cross sections often become exceedingly small within the energy range of stellar interest. Traditionally, these measurements have been performed using accelerator-based experiments, which provide precise control of beam and target properties but are limited in their ability to reproduce the plasma environments in which nuclear reactions actually occur.

In stellar interiors, nuclear reactions take place in ionized media where plasma effects, electron screening, and collective phenomena can modify the effective interaction between reacting nuclei. Understanding the impact of these effects on reaction rates is crucial for improving astrophysical models and reducing uncertainties in predictions related to stellar evolution, nucleosynthesis, and explosive astrophysical scenarios. Despite decades of theoretical and experimental efforts, the quantitative role of plasma environments on nuclear reaction rates remains an open problem.

This seminar will provide an overview of the nuclear astrophysics framework underlying stellar reaction rates, with particular emphasis on electron screening and plasma effects. After introducing the main concepts governing thermonuclear reactions in stars, I will discuss the experimental challenges associated with reproducing and investigating such conditions in the laboratory.

The second part of the talk will focus on a novel experimental approach based on ultra-intense laser interactions with cryogenic gas-cluster targets. In these systems, laser-driven Coulomb explosions generate dense plasmas and accelerated ion populations under conditions that may provide a unique opportunity to investigate nuclear reactions in environments closer to those found in astrophysical plasmas. I will present recent developments in laser-driven plasma nuclear astrophysics, discuss the associated diagnostic and simulation challenges, and outline ongoing efforts aimed at studying fusion reactions of astrophysical interest, including the possibility of probing plasma-modified reaction rates in previously unexplored regimes.