P 10: High Energy Density Physics I

Time: Wednesday 11:00–12:30 Location: KH 02.016

Invited Talk P 10.1 Wed 11:00 KH 02.016

Laser fusion activities in Germany - applications in planetary and stellar astrophysics and experiments at high-power laser facilities — •Dominik Kraus — University of Rostock, Rostock, Germany — Helmholtz-Zentrum Dresden-Rossendorf

Research in the field of laser-driven inertial fusion ("laser fusion") has gained significant momentum following the achievement of the Lawson criterion for fusion ignition at the National Ignition Facility, triggering substantial public and private investment worldwide, including in Germany.

Despite this progress, a detailed understanding of the complex physical processes along the compression pathway toward inertial fusion plasmas remains essential for the realization of laser fusion as a practical energy source. The most widely pursued laser fusion schemes begin with the compression of the ablator and deuterium*tritium fuel to megabar pressures, corresponding to conditions similar to those found in planetary interiors. This stage is followed by a quasi-isentropic compression to gigabar pressures, reaching regimes comparable to stellar interiors. Both phases fall within the regime of so-called warm dense matter, which remains only partially understood.

This talk will review current developments and key challenges in laser fusion research and outline potential contributions from experimental facilities in Germany. In addition, selected examples will demonstrate how these facilities can be used to advance our understanding of dense astrophysical plasmas.

P 10.2 Wed 11:30 KH 02.016

Recent advances in the operation of nano-accelerators towards IFE applications — •Fabian Batsch[1], Daniel Rivas[1], Marius S. Schollmeier[1], Georg Korn[1], Hartmut Ruhl[1], and our collaborators[2] — [1]Marvel Fusion GmbH, Munich, Germany — [2]LMU Munich, Germany; ELI-NP, Romania; Thales LAS, France

We propose an alternative path towards inertial fusion energy (IFE) involving ultra-short pulse, petawatt-class lasers and nano-fabricated targets. These highly ordered nanowire arrays, or nano-accelerator (NA), can absorb laser pulses with intensities above 10^{20} W/cm^2, leading to a controlled and efficient energy transfer into radiation and kinetic particle energy. Optimal laser-solid interaction without preplasma formation is required for best performance of the NA, which requires ultra-high temporal laser contrast ($< 10^{-12}$ on ps timescales) that can be achieved through the strongly non-linear processes of either plasma mirrors or second-harmonic generation (SHG).

In this presentation we report on recent progress in the validation of the NA concept through experiments at two PW-class laser facilities: the influence of double plasma-mirrors and changes in nanowire parameters on the laser contrast, laser absorption and emitted particle spectra is studied at the Extreme Light Infrastructure for Nuclear Physics (ELI-NP, 800 nm, 10 PW). The scaling with laser wavelength will be evaluated through the second-harmonic of the ATLAS-3000 laser pulses at the Centre for Advanced Laser Applications (CALA, 400 nm, >25 J, 30 fs). First results on SHG conversion efficiency, focus quality and contrast improvements will be presented.

P 10.3 Wed 11:45 KH 02.016

Fusion energy research at the European XFEL: Current capabilities and future perspectives — •Ulf Zastrau — European XFEL, Holzkoppel 4, 22869 Schenefeld, Germany

The European XFEL in Schenefeld near Hamburg provides unprecedented opportunities to study matter under extreme conditions relevant to inertial fusion energy (IFE). Recent workshops and studies have outlined a coordinated strategy to exploit XFEL capabilities for diagnosing high-energy-density (HED) plasmas, characterizing fusion-relevant targets, and benchmarking hydrodynamic and radiation-transport models. In my talk, I will present the current capabilities of the HED-HIBEF instrument together with a roadmap for fusion-energy research at the facility. The program emphasizes precision X-ray probing of laser-driven plasmas, the development of dedicated diagnostics and target platforms, and the integration of a multi-kJ high-power laser at a new XFEL beamline for next-generation fusion experiments. These efforts aim to establish the European XFEL as a central hub for cross-disciplinary fusion-energy research, bridging basic plasma physics and applied energy science.

P 10.4 Wed 12:00 KH 02.016

Toward predictive modeling of Inertial Confinement Fusion plasmas — •Michael Bonitz, Daniels Krimans, Hanno Kählert, and Christopher Makait — Institute of Theoretical Physics and Astrophysics, Christian-Albrechts-Universität zu Kiel, 24098 Kiel, Germany

In Inertial confinement fusion (ICF) hydrogen rapidly undergoes compression, heating and ionization. Simulations have to take into account simultaneously laser-matter interaction, shock propagation, and nuclear reactions. Moreover, the initial phase of the compression is strongly influenced by nonequilibrium carriers, electronic quantum effects, and Coulomb correlations. Despite the rapid recent progress in theory and simulation of dense plasmas and warm dense matter [1], presently, no method exists that reliably captures all these processes, and commonly used radiation-hydrodynamics simulations do not have predictive capability. In Ref. 2 a solution of this dilemma has been proposed: a smart combination of a variety of different simulations, together with a first-principles based downfolding approach. The starting point are quantum Monte Carlo simulations, in equilibrium [3], and quantum kinetic theory [4], in nonequilibrium. This should allow for predictive ICF simulations in the near future.

[1] M. Bonitz et al., Phys. Plasmas **27**, 042710 (2020); [2] M. Bonitz et al., Phys. Plasmas **31**, 110501 (2024); [3] A. Filinov and M. Bonitz, Phys. Rev. E **108**, 055212 (2023); [4] M. Bonitz, "Quantum Kinetic Theory", 2nd ed. Springer 2016

P 10.5 Wed 12:15 KH 02.016

Equation of State and Electronic Transport Properties of Dense Liquid Hydrogen — Armin Bergermann[1], •Uwe Kleinschmidt[2], Siegfried H. Glenzer[1], and Ronald Redmer[2,3] — [1]SLAC National Accelerator Laboratory, Menlo Park CA 94309, USA — [2]Institute of Physics, University of Rostock, D-18051 Rostock, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstr. 400, D-01328 Dresden, Germany

We present extensive first-principles calculations of the equation of state and electronic transport properties of hydrogen across a wide density ($0.2 < \rho < 70$ g/cm^3) and temperature ($10^3 < T < 10^6$ K) regime, encompassing conditions relevant to giant planet interiors, stellar envelopes, and inertial confinement fusion plasmas. The equation of state data recover the ideal-gas and fully ionized plasma limits. Electronic transport coefficients were obtained via the Kubo-Greenwood formalism. The electrical conductivity exhibits an inversion region near $\rho \sim$ 1-10 g/cm^3, where degeneracy and coupling parameters are of order unity, marking the transition from molecular to metallic hydrogen. The thermal conductivity rises monotonically with increasing density and temperature, bridging between the Wiedemann-Franz behavior in the degenerate regime and the Spitzer scaling in the classical limit. Comparisons with analytical models show good agreement within their respective validity regimes. Our data set provides a high-accuracy benchmark for warm dense hydrogen and a reliable reference for applications such as planetary modeling, stellar structure calculations, and ICF design.