Progress and perspectives for magnetized high energy-density plasma experiments

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Abstract

Magnetic fields (B-fields) are ubiquitous in the Universe, ruling the structure and the dynamics of many astrophysical settings. The generation of high-energy particles (cosmic rays) and radiation in e.g. supernovae remnants is believed to take place in colliding flows through particle scattering off self-induced B-field fluctuations. In certain objects such as compact stars, B-fields are so strong that they determine the star's structure and composition, as well as its radiation properties. Efforts in understanding these settings have been restricted to a combination of observations and theoretical modelling. Yet, powerful laser-matter interactions are now revealing their potential to recreate mechanisms of high-energy phenomena at the laboratory scale, where observations and theoretical models can be quantitively compared with experimental data and where tests can be repeated and iterated. Besides astrophysical applications, there has been a growing interest in past years in laser-driven, high energy-density (HED) systems embedded in strong magnetic fields. A challenge is to deliver to the experiments B-fields enough strong to reach scale-equivalent magnetized plasma conditions.

We will first discuss different strategies to drive strong quasi-static magnetic fields in laser-plasma experiments:

i) By using intense, kJ-energy, ns laser pulses interacting with coil targets: the laser pulse induces a high potential in a plate (electrode), which drives a strong discharge current through a connected coil-shaped wire. The nanosecond time-scale for the discharge is set by the laser pulse duration and the target impedance. With mm-size coils this corresponds to a “slow”, quasi-stationary regime of B-field generation.

ii) In similar experiments with ps laser pulses of relativistic intensity, the discharge current propagates across the target as a pulse, resulting in fast transient fields. In order to obtain a quasi-static magnetic field, the target size needed to be reduced. As the laser pulse undergoes multiple reflections, relativistic electrons are accelerated and guided along the curved target surface. Their interplay with the inductive surface return current leads to strong B-fields embedded into the plasma progressively filling in the inside of the target.

iii) Extreme B-fields can also be reached through plasma compression and field advection within the compression.

We will then illustrate how these B-fields can contribute to breakthrough advances in inertial confinement fusion (ICF), in laser-driven particle sources and in laboratory astrophysics investigations.

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