The POLAR project: Experimental simulation of radiative accretion shocks in magnetic cataclysmic variables

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INTRODUCTION

Accretion processes are among the most important phenomena in high-energy astrophysics since they are widely believed to provide the power supply in several astrophysical objects and they are the main source of radiation in several binary systems\(^1\). Understanding the complex physical processes that allow to release the gravitational energy in the form of radiation energy is fundamental to interpret the high-energy astronomical observations. Among the different X-ray binary systems, the cataclysmic variable stars provide a unique insight to study the accretion processes in extreme astrophysical regimes. They are close binary systems containing a white dwarf that accretes matter from a late type Roche-lobe filling secondary star\(^2\). They provide the best opportunity to study accretion processes in isolation, since sources of luminosity other than the accretion region are relatively weak. A broad research program has been developed since 2008: the POLAR project\(^3,4\). We have specifically studied the accretion processes in high-magnetized white dwarfs, known as Polars stars. Its main objective is to improve the modelling and the understanding of accretion phenomena occurring in Polars stars by coupling astronomical observations to theoretical, numerical and experimental studies.

In these astrophysical systems, the magnetic field is strong enough to prevent the formation of an accretion disk and to channel the accreting plasmas up to the compact object magnetic poles, leading to the formation of an accretion column. In this context, we focused on the study on the radiation hydrodynamic region near the photosphere of the compact objects that is responsible for the emission of high-energy radiation. This high-energy environment presents a fascinating complex radiation hydrodynamics where theory and modelling are still not well known. The impact of the supersonic free-fall ($v \approx 1000$ km/s) accreting matter on the white dwarf photosphere leads to the formation of a radiative reverse shock which heats the infalling plasma up to 10-50 keV. The structure of this high-energy environment depends on multi-scale physics introducing issues for theoretical and numerical modelling. Moreover the scales involved in these zones are of the order of the white dwarf radius or smaller\(^5\), which induce severe difficulties to direct observations and therefore to infer the physics of the impact zone. Recent comparisons between observational properties\(^6\) of polars and numerical simulations\(^7\) of accretion shock dynamics have shown many disagreements between theory and observations. Thus, every alternative approach that can provide direct insight of these objects is of primary importance.

Thanks to recent works on the scalability of radiation magnetohydrodynamics flows\(^4,8\), we proved that exact scaling laws exist for different accretion column regimes and specifically for the radiation-dominated cases, i.e. in the case where the magnetic field only channels the flows\(^9\). We have proved that an adapted scaling law can be constructed to reproduce these phenomena at measurable scales in laboratory with high-energy lasers. In this GEKKO XII experiment, a new target design has been tested to produce relevant accretion shock regime.
TARGET DESIGN AND EXPERIMENTAL SETUP

The target design is presented on Fig. 1. The target is composed of an ablator in CH, a Sn foil which plays the role of the accreted flows and an obstacle in aluminium which plays the role of the white dwarf photosphere. The set of the target parts is fixed on plastic support.

![Target design](image)

**Fig. 1.** Target design

Transverse Streaked optical pyrometry (SOP) has been used. These diagnostic image the self-emission from the incoming flow and the reverse shock onto a streak camera, and record the incoming flow velocity, radial velocity, and the temperature of post-shocked region information as a function of time. In addition, gated optical imagers (GOI) have been used to give ‘snapshot’ images of the self-emission at different times. An optical probe has been installed in the perpendicular direction to the incoming flow propagation direction.

Different shadowgraphy diagnostics, which are sensitive to the curvature of the electron density, have been implemented. These diagnostics show the incoming flow as well as the post-shocked region, and are particularly well suited to diagnose sharp density features – such as shock waves – and are able to image structures in the post-shock region with high resolution. This comprehensive set of diagnostics has been successfully demonstrated on several experiments performed at ILE in the last few years producing high quality, time-resolved data on a shot-to-shot basis.

EXPERIMENTAL RESULTS

The high-quality of the experimental results obtained during this GEKKO XII experiment allows us to characterize the radiation hydrodynamic regime of the produced plasmas. The great laser energy produced on GEKKO XII allowed to produce high-velocity flows which are interesting radiation hydrodynamic regimes (cooling parameter $\gamma_{\text{cool}}=\text{thyd} <1$). Indeed the velocity regime of the different flows produced with GEKKO XII laser is between 110-180 km/s for the different types of target designs (Fig. 2). Thus GEKKO XII facility allows us to produce new and interesting radiation hydrodynamic regimes. Thanks to the 2D diagnostics (SOP and shadowgraphy), the structure of the incoming flow and the post-shock region after the collision with the obstacle are characterized (Fig 3).

CONCLUSION

During this GEKKO XII experiment, a new target design has been tested and validated. These very promising results will be presented at the next HEDLA conference. This experiment is the first step to prepare the next generation of experiments with external magnetic fields which are proposed for this year on GEKKO XII facility.

REFERENCE(S)