Project title: Protecting the Final Optic: Experimental Approaches to Debris Characterization and control for Next-Generation Inertial Fusion Energy Reactors

Supervisor(s):	**Dr. Charlotte Palmer (QUB) and Dr. Phil Bradford (STFC)**
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Helpful existing knowledge:	Experimental physics experience working with optics or cameras, programming skills in python or similar.
Funding status:	Awaiting confirmation of funding
Closing date:	Friday 6th February 2026

Project Description:

Inertial confinement fusion (ICF) reactors must ultimately operate at multi-hertz repetition rates with minimal downtime to deliver viable energy output. For laser-driven ICF, this places extreme demands on the final optical components, which are continuously exposed to target debris and shrapnel travelling at velocities exceeding 2.5 km/s [1], as well as radiation from energetic neutrons, x-rays, and back-reflected laser light. Current disposable debris shields, typically 3.3 mm thick, are expected to survive fewer than 20 laser shots equivalent to only two seconds of operation at the 10 Hz repetition rate anticipated for fusion reactors.

Although promising new approaches such as plasma-based [2] and neutral-gas [3] optics may eventually offer high-damage-threshold, time-gated solutions, these concepts have yet to demonstrate the required optical quality and transmission efficiency at reactor scales. Consequently, a detailed understanding of debris generation, transport, and accumulation at multi-Hz repetition rates remains a critical challenge for inertial fusion energy (IFE) development.

This PhD project will experimentally characterise debris production [4,5] and deposition under repeated laser-plasma interactions, providing essential data to validate large-scale multi-physics, multi-material simulations [1]. Experiments will be performed at sub-scale facilities such as EPAC and DiPOLE, exploring a wide range of interaction conditions from femtosecond to nanosecond drivers relevant to fusion, fast-ignition, and high-intensity backlighter applications.

The project aims to:

1. **Characterise laser-produce debris over large range of laser and target parameters:** Develop in-situ diagnostics for monitoring debris accumulation and optic damage at multi-Hz rates and use these to build large self-consistent data sets that can be used to benchmark modelling of laser ablation and target fragmentation.
2. **Develop and evaluate debris-mitigation strategies:** including novel refreshing debris shields [6], controlled low-pressure gas fills for ion slowing [7], use of magnetic force fields to deflect charge particles [8].

The resulting experimental database will benchmark predictive debris-transport models, informing the design of robust optical protection schemes for future high-repetition-rate IFE reactors and benefiting the broader high-intensity laser community.

The student will develop advanced proficiency in three key technical areas providing a highly transferable skill set valued across research and industry:

- **high-power laser operation:** Experience with state-of-the-art laser systems will build a deep understanding of precision alignment, control, and safety in high-energy experiments.
- **design of practical engineering components using CAD:** CAD design will provide practical engineering and prototyping skills.
- **high-performance computing for modelling and data analysis:** high-performance computing will enable efficient handling of complex, multi-physics simulations.

Useful references:

[1] Eder et al., Nucl. Fusion, 53, 113037 (2025)

[2] Singh et al., arXiv 2510.02659v1 (2025)

[3] Schrödel et al., Nat. Photonics, 18, 54-59 (2024)

[4] Koniges et al., J. Phys. Conf. Ser. 112 032072 (2008)

[5] Booth et al., Proc. Radiation Detectors in Medicine, Industry, and National Security XIX 19-23 Aug (2018)

[6] Kojima et al., Rev. Sci. Instrum., 96, 083001 (2025)

[7] Amano et al., Rev. Sci. Instr., 81, 023104 (2010)

[8] Mima et al., Matt. Rad. Extremes, 3, 127-134 (2018)