Foreword

John Collier Director, Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK | Email address: john.collier@stfc.ac.uk | Website: www.clf.stfc.ac.uk

The Central Laser Facility has long thrived on ideas, novelty and creativity, that are most often the product of face-to-face interaction, collaboration and sharing. Many great ideas have arisen through chance encounters or casual remarks. After the challenges we all faced through lockdowns, it has been wonderful to see staff and users returning in numbers to our facilities in 2021/22, once again fermenting that unique collective spirit that has been so successful for us. Interactions matter – they matter a great deal. They are a vital source of motivation and inspiration.

Based at the STFC Rutherford Appleton Laboratory in Oxfordshire, the CLF is the UK's national laser facility and supports curiosity-driven and applied research across a wide range of areas from fundamental physics to the life sciences. Our laser facilities – **Vulcan, Gemini, Artemis, Ultra** and **Octopus** – provide scientists with an unparalleled range of cutting-edge laser technology. We also offer a comprehensive support package for facility users, including custom experiment design and construction, computational **plasma physics, target micro-fabrication** and **engineering**, intended to help our user community to maintain their world-leading position.

We remain committed to advancing the technologies available to our user community and a number of new facilities and facility upgrades are either under construction or at the planning stage. Significant progress has been made on the new **Extreme Photonics Applications Centre (EPAC)** with the building fully complete and plans in place to begin installation of the services. Designs for the laser systems are progressing well. This is an exciting partnership between UKRI, MoD, academia and industry to develop and apply novel, laser-based, non-conventional accelerators and particle sources, delivering new opportunities for engineering, materials, and life sciences research, as well as having a large range of applications for industry and defence. A business case is being developed for **Vulcan 20-20**, an upgrade to the Vulcan facility that will increase its peak power by 20 times to deliver the highest power laser facility in the world. This will enable new areas of research, for example potentially allowing researchers to study the physics of materials under the most extreme conditions, delivering cutting-edge science in a hitherto unexplored regime, and supporting the development of laser inertial confinement fusion. **HiLUX** is a major transformation of the CLF's ultrafast laser and infrared, Raman and XUV spectrometer infrastructure and upgrades the Artemis and Ultra facilities.

In addition to its user facilities, the CLF is home to the **Centre for Advanced Laser Technology and Applications (CALTA),** which aims to deliver societal, scientific and economic impact from developments in the CLF. Alongside supporting the EPAC project, CALTA is developing the next generation of 100 Hz DIPOLE lasers as part of a Widespread Teaming project funded by the EU and the Czech Ministry of Science, with ground-breaking results expected in the coming year. The commissioning work of the DiPOLE-100X system at the European XFEL continues, and the system will be ready for user experiments in 2023. CALTA and the CLF's **Industry Partnerships and Innovation (IPI) group** also work with industrial partners to facilitate solutions to real-world problems. Embedded staff in the IPI group, who are experienced in delivering industry experiments across the facilities, drive the largest growth for the facilities with strategically aligned impact.

Our **Engineering and Technology Centre (ETC)** is almost complete. The vibrant and space-efficient working area offered by new building will allow us to co-locate all the different engineering disciplines, which will have a huge impact on the overall effectiveness of the teams in their delivery of experiments and projects, as well as in their general training and development. EPIC, the joint innovation centre with India, is proving to be essential for the CLF's ongoing facility development projects. Along with developing the control system modules and targetry solutions for our future facilities, EPIC is now exploring options for extremely cost-effective engineering manufacturing in India.

This annual report for the CLF offers an insight into some of the scientific and technical research that has been carried out by users of the CLF and its staff over the financial year 2021/22. As you will see, this research spans a broad range of science areas, and supports wide-reaching efforts to solve major scientific, economic and societal challenges. I do hope that, like me, you enjoy reading this selection of abstracts, and feel inspired by the achievements of all those involved.

Professor John Collier FLSW
Director, Central Laser Facility

Highlights of 2021/22 include:

For many cutting-edge research areas in laser-matter interactions there is a desire to increase the intensity to which high power lasers can be focused. Higher laser intensities can open up new approaches to laser-driven particle beams as well as allow us to study fundamental physics such as high field quantum electrodynamics. One method to achieve this new intensity regime is focusing the laser to an ever smaller spot size. Researchers from the University of Strathclyde have used the **Vulcan** Petawatt laser to demonstrate that the spatially-varying intensity profile of the laser focal spot strongly affects the fundamental physics of how these high power lasers are absorbed at the target interface. The research points the way to future methods of optimising (and improving the reproducibility) of laser-driven secondary sources relevant to upcoming facilities like EPAC.

An international collaboration, led by Queen's University Belfast, used **Gemini** to study plasma acceleration in solid density interactions at extreme intensity. The radiation pressure of the laser pulse produced ions with energy of 10s MeV emitted from the rear surface of the targets. In this work, the team optimised the mechanism to preferentially accelerate carbon ions over contaminant hydrogen – an important result for the use of heavy ions for radiobiology applications.

The CLF successfully held its first ever hybrid **High Power Laser** Christmas scientific meeting, with a series of talks dotted between networking and poster sessions. The meeting went very well, with 60 people attending in person and a further 40 people online.

Artemis user experiments with XUV pulses re-started in the new labs in the Research Complex at Harwell. Artemis commissioned its new 100 kHz laser system, and completed engineering work on the new XUV beamline designed to exploit it for studies of ultrafast dynamics in materials.

Octopus continues to be strong in the fields of atmospheric science, through optical trapping of aerosols to assess their morphology and composition, and life sciences, through correlative and super-resolution microscopy of mammalian and plant samples. The group contributed to the characterisation of new probes for lipids and DNA, as well as being involved in an international project uncovering the mechanisms of SARS-CoV-2 coronavirus infection.

Ultra has been developing its support for energy sciences, such as research into new catalysts. Ultra's ability to study chemistry across multiple steps of a catalytic cycle was highlighted by the Royal Society of Chemistry, for sustainable catalytic chemistry work with the University of York (Fairlamb and Lynam).

Most current laser shock peening (LSP) techniques require a confinement layer, typically water, which puts a major limitation on its accessibility to industry. **CALTA**'s in-house DiPOLE laser was used to demonstrate the ability to peen without the need for the water confinement layer, opening up LSP as a technique for real-world applications.

The **EPIC** partnership with India is developing a talent pool of control and software engineers from which we could potentially recruit. We had the first such recruit in this reporting year, for developing the data management solutions for EPAC. We have also explored cost-effective engineering manufacturing in India through EPIC; the first turning chamber for EA1 will shortly be shipped to the UK.

The CLF's **IPI group** continues to scan for innovative concepts and technology transfer opportunities, to capture and drive forward the most impactful ideas and inventions. A new patent family was filed, giving a current total of 25 active patent families, with 11 invention disclosure forms submitted for future consideration.

The **Plasma Physics Group** has continued to provide CLF users with theory and simulation support, including access to the PRISM suite and help with use of the CLF's SCARF resources. In the wake of the announcement of net gain on the NIF (USA) in 2022, Dr Robbie Scott also helped inform national media outlets of the importance of this seminal result.

The CLF's **Target Fabrication Group** has continued its support for the user community with delivery to the Vulcan and Gemini laser systems, and further developments in tape drive technology to enable direct laser irradiation for high rep rate ion acceleration experiments. It has also supported academic access to the Orion laser system and CLF-led experimental campaigns on Omega in the US.

The CLF's **Engineering Division** will shortly be moving into its purpose-built Engineering and Technology Centre. This new space will include an upgraded mechanical machine shop with a range of new CNC machines for faster and more accurate production of components, a flexible ground floor space to maintain and build large items, and a first floor space to build racks and modules.