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High Energy Density Physics Research in the United Kingdom

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I will describe the large-scale laser facilities that are available to the academic community for research into high energy density physics in the United Kingdom, i.e. the Vulcan and Astra-Gemini laser facilities at the Central Laser Facility, Rutherford Appleton Laboratory and the ORION laser facility at AWE Aldermaston. I will discuss their current performance and planned upgrades. I will discuss potential new routes to generate even greater ultra-high peak power laser pulses as well as petawatt laser pulses that contain enough energy to fully explore the parameter space for fast ignition inertial confinement fusion.

1. The Vulcan laser facility

The Central Laser Facility (CLF), STFC Rutherford Appleton Laboratory, is one of Europe's premier research establishments in laser science. The laboratory provides state of the art laser technology for a wide range of investigations into intense laser-plasma interactions. There are two high power lasers – the Nd:glass laser Vulcan and the TiS laser ASTRA-GEMINI.

The Vulcan laser is an eight beam facility that comprises rod and disk amplifiers up to 20cm in diameter (Figure 1). They provide 2.5 kJ in 1 nanosecond pulses at a wavelength of 1.053 μm. The laser has two independent rod amplifier chains that allow a wide range of pulse duration and colours to be delivered to target for different experimental configurations.

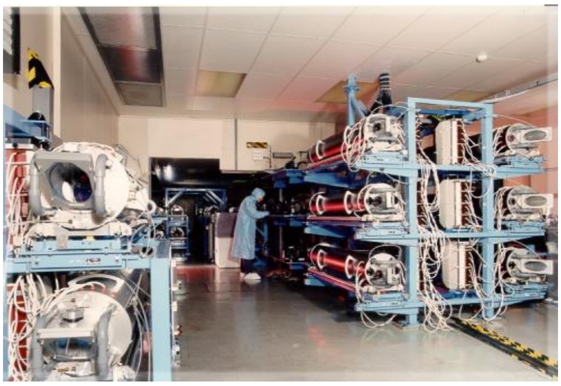

Fig. 1. The Vulcan disk amplifier area.

At present, there are two targets areas. The first allows combinations of 100TW (100J/1ps) 50TW (500J/10ps) and pulses ranging from 80ps – 1ns. The second provides a petawatt laser pulse (500J/0.5ps) to target, as shown in Fig. 2. Typical experiments include equation of state studies, fundamental laser-plasma interactions, laboratory astrophysics and particle acceleration.

Fig. 2. The Vulcan PW target area.

2. The ASTRA GEMINI laser facility

This laser was commissioned in September 2007. It is also a petawatt facility and provides two beams to target, each capable of delivering 15J/30fs pulses to target. The operating wavelength is 0.800 μm. The repetition rate is substantially higher than Vulcan – it is capable of firing every 20 seconds, compared with Vulcan's 20-minutes. The laser provides a second target area with 12TW (0.5J/40fs) pulses to target. It has been used for electron and ion acceleration studies and was the first laser on which mono-energetic electron bunches were observed.

3. The ORION laser facility

The ORION laser facility at AWE plc, Aldermaston is also a ND:glass laser, similar in architecture to Vulcan. It is capable of delivering 5.0 kJ of 0.351 μm light to target in precisely shaped nanosecond duration laser pulses. Shown in Fig. 3 is one half of the nanosecond beam-lines delivered to target. The laser also has two petawatt beamlines, capable of delivering 500J/500fs pulses to target in orthogonal directions for pulse/probe experiments.

Fig. 3. The long-pulse beam-lines for ORION

While the primary mission of the ORION laser is nuclear stockpile stewardship, 15% of the available laser energy is given to academic research into high energy density physics.

4. Multi-PW laser pulse amplification

A long laser pulse (pump) in plasma will spontaneously scatter off Langmuir waves – commonly known as Raman scattering. This process can be stimulated by sending in a short, counter propagating pulse at the frequency of the scattered light (probe pulse). Most of the energy of the long pump will go into the short probe because scattering happens mainly at the location of the probe pulse. This leads to efficient pulse compression.

My team have studied the conditions under which one can get efficient pulse compression [1]. The process is highly non-linear and can only be realised in a narrow parameter space of density, intensity of both pump and probe pulses and propagation length. We found that it is possible to compress 30ps pulses to 25fs, and that the process is transversely scalable [1]. That is to say, to realise larger peak powers, one has only to increase the size of the pump and probe pulses, keeping all other factors the same. This means that one can potentially compress pulses to 400 – 500 PW, making this process a true contender to explore the intensity frontier.

We have extended this study to the compression of nanosecond-duration laser pulses to the picosecond regime [2]. Self-similar scaling indicates that the use of lower intensity laser pulses allows efficient energy transfer of up to 60% to occur. This was confirmed by state of the art particle-in-cell simulations. These results mean that one ought to be able to convert large fractions of nanosecond laser energy to picoseconds-duration petawatt pulses. This has wide ranging applications in high energy density physics research, including exploring the full parameter space for fast ignition inertial fusion using existing facilities.

References.

[1] R. Trines, F. Fiuza, R. Bingham, R.A. Fonseca, L.O.Silva, R.A. Cairns and P.A. Norreys, Nature Phys. **7**, 87 (2011).

[2] R. Trines, F. Fiuza, R. Bingham, R.A. Fonseca, L.O.Silva, R.A. Cairns and P.A. Norreys, Phys. Rev. Lett. **107**, 105002 (2011)