

High-Power LASERS

How lasers
push the limits of
physical and
scientific
research.



UK Research
and Innovation



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<https://stfccareers.co.uk/students/>



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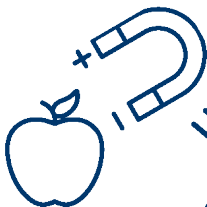
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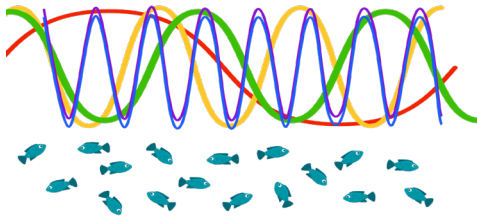
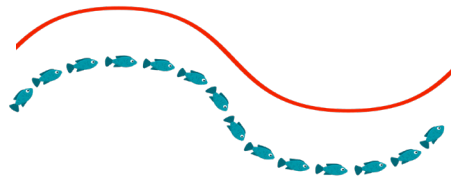
What is a Laser?



LASER stands for 'Light Amplification by Stimulated Emission of Radiation'

Lasers produce a special light with amazing properties. The first laser was called the Ruby laser, built in 1960.

Light is made up of particles called photons. In laser light they move together in a formation...



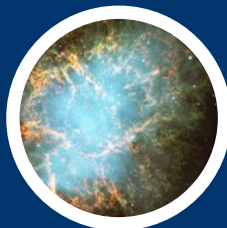
...while a lot of the light around you is much more jumbled up with very different colours!

Some lasers are great at helping us test what materials do in very extreme conditions! We can:



Explore how matter interacts

Replicate stellar explosions



Accelerate particles

The *Central Laser Facility* has multiple high-power lasers...

Vulcan is our oldest laser, and it is now undergoing an upgrade set to make it the most powerful laser in the world! Extreme conditions

Gemini has two powerful beams, creating sources of X-rays or particle beams.

EPAC is our new facility opening in 2026, featuring a laser beam firing ten times a second! This will allow applications including rapid and high resolution X-ray imaging.

DiPOLE is a series of compact but repetitive lasers developed at the CLF. These systems are great for material testing and creating the extreme states of matter found at the centre of planets!



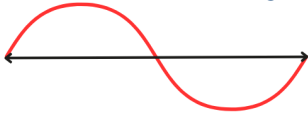
Now let's get into the science.
Introducing...

The ELECTROMAGNETIC SPECTRUM

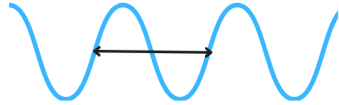
We may think of 'light' as what we can see, but light is an electromagnetic wave, with oscillating electric and magnetic fields. A huge range of different wavelengths and colours of light exist.

Different colours have different waves.

Red waves are longer

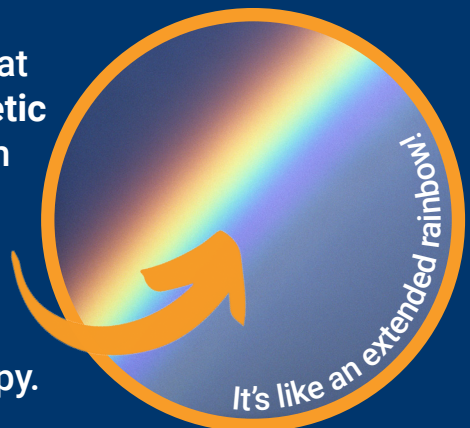


Blue waves are shorter



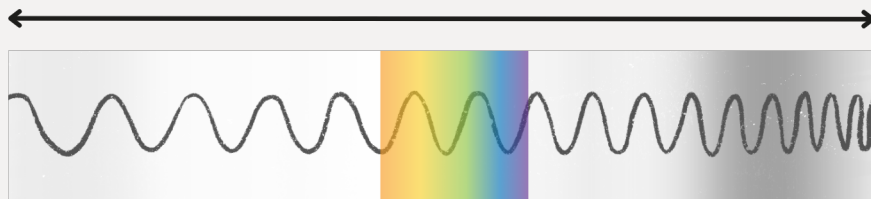
We call this measurement a wavelength.

Visible light is only part of what is known as the electromagnetic spectrum, which extends from radio signals that we use for communications around the world, to gamma rays that are emitted from radioactive samples used in cancer therapy.



Increasing
wavelength
(redder)

Decreasing
wavelength
(bluer)



Radio
waves

Infrared

Ultraviolet

Gamma
rays

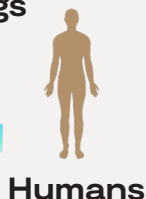
Microwaves

Visible
light

X-rays

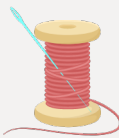
wave size

Buildings



Humans

Honey
bee



Needle
point

Cells



Molecules



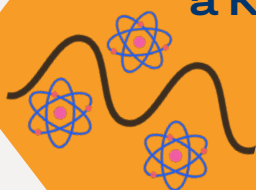
Atoms



Atomic
nuclei



Radio wavelengths can be
a KILOMETRE long...



...while those of gamma rays may
be 1 TRILLIONTH of a metre!

How to Add Power to a Laser

Energy in the form of light

To increase the power of a laser we put it through a process called amplification. This gradually makes the beam of light more and more energetic.

Mirrors and lenses help us direct light while we amplify it. The mirrors in Vulcan are up to 1m wide and can weigh more than a grand piano!



Laser beams travel through a long set-up of equipment with fragile objects made from glass or crystals. These come in all shapes and sizes, like rods, disks, or slabs!



To extract energy out of an amplifier, we direct white light onto the crystal or glass inside. When the laser beam passes through, a part of the energy transfers from the glass or crystal to the beam itself, adding more photons and making it incredibly energetic! This is what we call 'stimulated emission'.



Using this method we can reach intensities similar to squeezing all of the sunlight hitting the surface of the Earth onto the head of a pin!

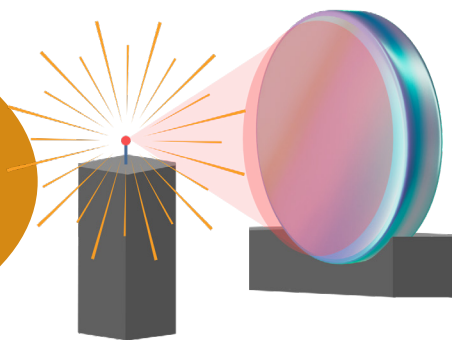
How do the optics not break?

With such high amounts of power, it's hard to believe all these delicate optics can tolerate it. To understand this, it's important to recognise the difference between power and energy.

$$\text{POWER} = \frac{\text{ENERGY}}{\text{TIME}}$$

You get more power out if you transfer the same amount of energy faster rather than slower.

Our lasers are so powerful because all the energy is thrown at the target in a time quicker than you can blink!



Lasers are fired in bursts known as 'pulses'. If we stretch out these pulses, making them longer, we keep the same energy, but reduce the peak power. This protects our equipment during the amplification stages.

We compress the pulses to a tiny moment in time and focus the beam onto the target for maximum impact.

Particle Acceleration

Using light to speed up matter

Conventional particle accelerators can move particles close to the speed of light, and they can be several kilometres in length! These long accelerators have been used for studying some serious physics. We have been trying to use lasers as tools to accelerate particles.



Lasers could be used to accelerate particles in just a matter of centimetres!

How does it work?

You may have heard of the three states of matter; solids, liquids, and gases. Laser-driven accelerators rely on a special *fourth* state of matter called plasma.



SOLID



LIQUID

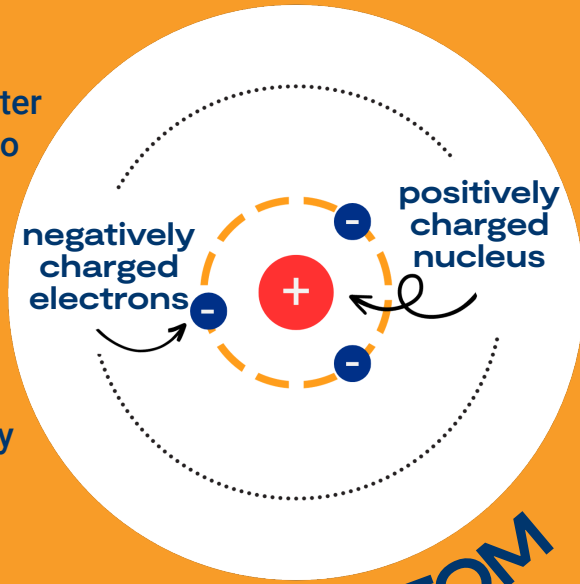


GAS



PLASMA

Plasma is a state of matter beyond a gas. A plasma is so hot that the negative electrons in the material break away from the positive atomic centres to which they were bonded, forming positive ions. This creates a soup of electrically charged particles!



Neon lights use plasma!

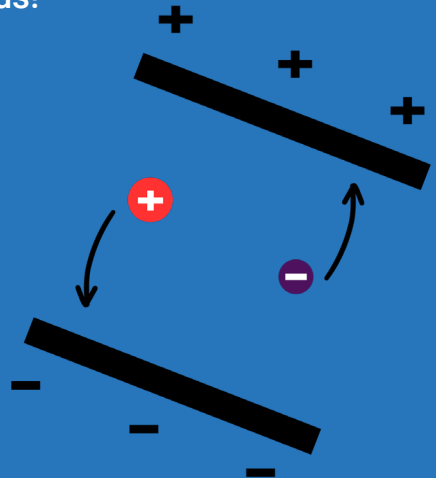


The ATOM

Why lasers?

Powerful lasers can create plasma by breaking the electrons away from atoms. In the electro-magnetic field of the laser, the lighter, negatively charged electrons move away from the positively charged ions. This creates a huge electric field in the plasma. Particles caught in this field can be accelerated to near light-speeds!

These table-top accelerators are an exciting new option for scientists studying particle physics!

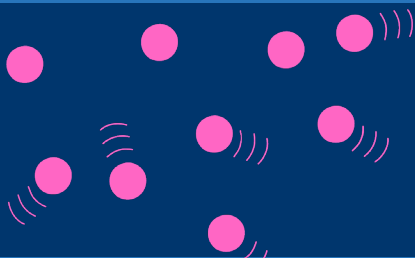


Laser Targets

What do we fire our lasers at?

High power laser experiments require specially made, tiny targets on which the laser deposits all its energy.

Particles emerge from the laser-target interaction, and we can use different types of target to produce different types of particles.



Producing a range of particles means we can perform a huge variety of experiments!

We use special tools to make these targets for our facilities, like this!





Our target fabrication team makes targets out of materials like metals and plastics. High-power lasers are focused down to a tiny spot, and so the targets they hit need to be smaller than a human hair!

Copper Tape Targets



Some targets are 2D films just a few atoms thick! These targets must be measured very precisely as even a speck of dust can affect the results.

3D targets are carefully put together from lots of pieces, a bit like flat-pack furniture! Our team does this intricate work by hand - no machine could be as versatile.



Complex Target

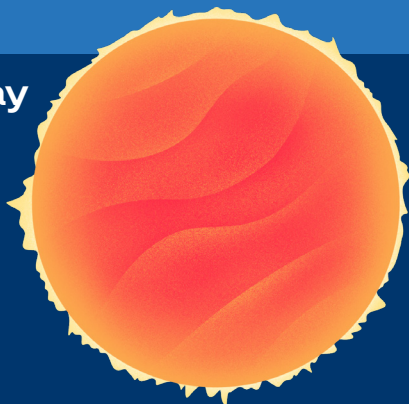
We have to measure our targets
BEFORE our experiments...because they're
destroyed upon impact!

Astrophysics in the Lab

How we make stars here in Oxfordshire

Scientists are fascinated by what lies beyond the Earth, from the Solar System to the wider Universe. However, it's incredibly hard to study outer space from the safety of our atmosphere.

Events in space are so far away the light from them can take, thousands of years to reach us... meaning they actually happened a long time ago!



We saw Cassiopeia A explode around 300 years ago – but it exploded over 11,000 years ago!

If we can't physically measure what we see in space, our other option is to recreate it in the lab. This might sound like fiction, but it is possible to simulate space and stars if we get the science just right.

What are we studying?

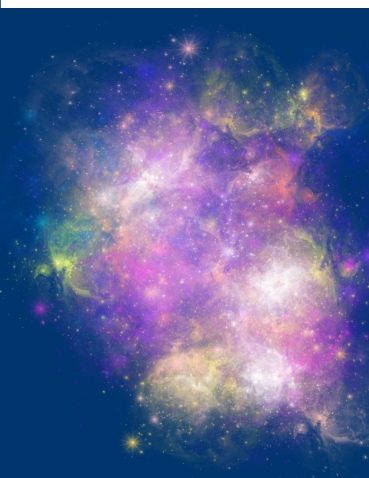


HEAVY PLANETS!

Large planets can have huge internal pressures completely unlike anything we see on Earth! We can use lasers to achieve and measure these conditions.

SPACE SUPERNOVAS!

Stars require fuel to burn, which comes in the form of light elements like hydrogen and helium. When massive stars run out of this fuel, their lives end in a huge explosion called a supernova! Lasers help us mimic what these explosions might be like.



<

>

We use computers to ‘scale-up’ our lab astro data. This lets us apply results from laser targets less than millimetres across to real, large scale events across the Galaxy.



Vulcan



Here on the Earth, we're lucky to be protected from the harsh and intense conditions we see in outer space and the wider Universe. The downside? This makes those conditions so much harder to study!

Lasers help us bring these environments to the lab by replicating high temperatures, pressures, and magnetic fields for a split-second.



Did you know Vulcan was in the Guinness Book of Records in 2005 and 2006 as the world's highest intensity laser?

It was built back in 1977, but has had lots of modifications and power added to it since!

Lasers like Vulcan can replicate what we think is happening in the centre of stars, or what happens when they explode. Unsurprisingly, it can be very difficult to take actual measurements of these events, so this is ideal for scientists who want to study these phenomena.

VULCAN NEWS

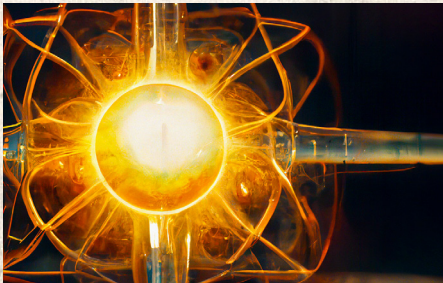
VULCAN 20-20

Exciting news - Vulcan is currently being upgraded! Due to be completed in 2029, this project (called Vulcan 20-20) will increase the facility's power by 20 times, and is set to make Vulcan the most powerful laser in the world once again.

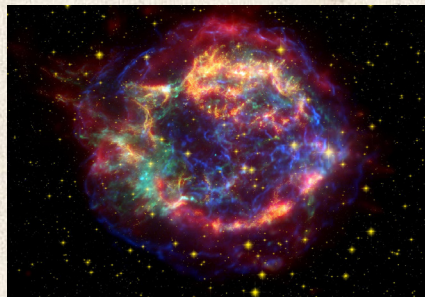


FUTURE FUSION

Scientists are using Vulcan to begin to figure out how we can fuse atoms, like stars do in their cores. This releases huge amounts of energy, which would be a revolutionary source of clean energy here on Earth.



SUPER SPACE



Vulcan was used to mimic an interesting stellar explosion called Cassiopeia A. This helped scientists understand why the explosion had a strange shape - it was caused by turbulence in space.

Gemini

In the scientific world, there is a lot of demand for intense sources of light and particles to help us study materials, atomic physics, and even medicine. Lasers happen to be an ideal way of developing these sources!

Gemini uses its twin lasers to produce bright and intense X-rays, or beams of electrons or protons.

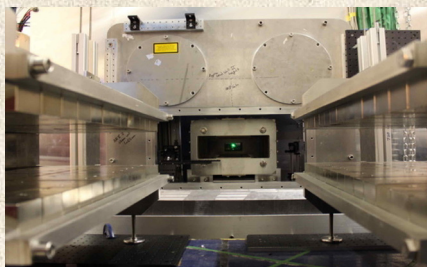


In Gemini, we have also been exploring how we can use lasers to drive small particle accelerators!



Gemini can be used to investigate some of the fundamental aspects of the Universe, including how light and matter are related, and how we can put high amounts of energy to use.

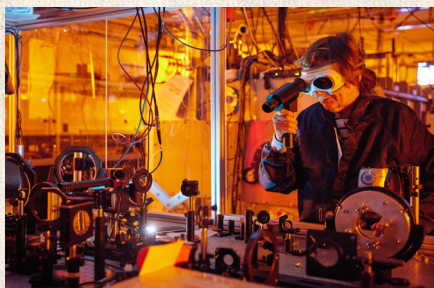
MINI MECHANICS



We could someday find out what the early Universe was like using lasers like Gemini. Researchers have conducted experiments into how matter may have formed from light and why.

LASER TUNNELS

Scientists have recently used Gemini to investigate a new way of accelerating particles. Their method involves creating 'tunnels' inside a strange state of matter called plasma which the particles can then neatly and quickly travel through.



EXPLOSIVE POTENTIAL

Gemini was used to simulate a Gamma Ray Burst, the brightest kind of explosion known to us. These bursts in space are able to outshine an entire galaxy. Lasers can help us uncover how and why these strange and incredible explosions happen.



DiPOLE

High-power lasers are incredible and useful tools - but they often require a lot of space and equipment! Can we ever have the best of both worlds - a compact yet mighty system? The answer is yes!

The DiPOLE concept, created by our brilliant CALTA team, is fast, high in energy, and super efficient.



They've designed and built DiPOLE laser systems for other facilities across Europe!

CALTA (the Centre for Advanced Laser Technology and Applications) focuses on developing new and impressive laser technology for research. The DiPOLE laser is one of the most advanced of its kind in the world!

June 2024

DIPOLE NEWS

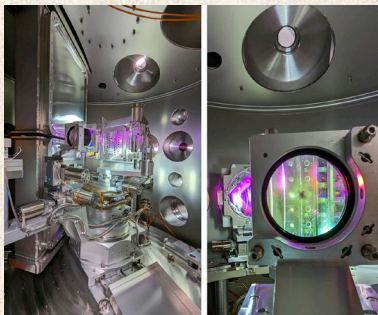
RAPID ENERGY



The newest DiPOLE laser is the DiPOLE100Hz, a more compact version of its predecessor (DiPOLE100). In its first experiment, it fired a massive 1.5 MILLION shots in 4 hours! This high repetition laser can make a huge impact.

CORE PRESSURES

D100-X, another DiPOLE laser, has been installed on the European XFEL in Hamburg, Germany. It's been used to explore how much pressure certain materials can withstand - it can create conditions similar to the pressures felt at the centre of extrasolar planets!



STRONG SOLUTIONS



DiPOLE is helping scientists to understand how we can make materials tougher, so they can be used in turbine blades or aeroplane parts.



EPAC

The CLF's Extreme Photonics Applications Centre (EPAC) will provide a new space in which we can continue our work at the forefront of science. This particular facility will have the capability to conduct both scientific and industrial research, and will enable both high-power laser experiments and precise imaging using laser sources.

EPAC is set to start operations in 2026!

At the heart of the facility is the CLF's DiPOLE technology, which provides a versatile and powerful laser system.



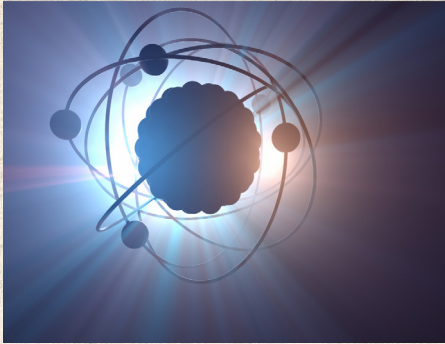
EPAC will give scientists the opportunity to drive beams of X-rays and gamma rays, as well as particles such as electrons, protons, and neutrons. This will enable them to generate extreme states of matter and find out more about them. It will also support 3D imaging and industrial research.

EPAC NEWS

Harwell Campus

June Edition

BIG SCIENCE



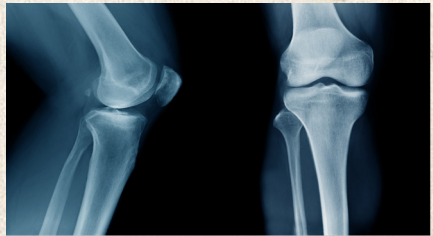
EPAC will be exploring some of the biggest topics in science such as medical research and accelerating particles using lasers. It will be able to do this incredibly quickly, giving us the time to really get into the finer details of these areas!

IN INDUSTRY

EPAC can be used to inspect batteries, engines, and much more! This will help us ensure that they are safe and that they can withstand specialised conditions, like being high in the atmosphere.



NEW HEIGHTS



One of the most exciting parts of EPAC will be its ability to create incredibly detailed 3D images using deep X-rays. This will let us examine objects up close - everything from industrial materials to diseased bones!

**Find the
answers on the
back cover!**

QUIZ!

1. What does LASER stand for?

- a. Light Amplification by Stimulated Emission of Radiation
- b. Light Addition by Spontaneous Electromagnetic Radiation

2. What is the fourth state of matter?

- a. Light
- b. Plasma
- c. Crystal
- d. Heat

3. Which laser simulated Cassiopeia A?

- a. Vulcan
- b. Gemini
- c. EPAC
- d. DiPOLE

4. What type of wavelength can be a kilometre long?

- a. Visible
- b. Infrared
- c. Radio
- d. X-ray

5. How many shots did DiPOLE 100Hz fire in 4 hours?

- a. 1,500
- b. 15,000
- c. 150,000
- d. 1.5 million

6. Do we measure targets before or after experiments?

- a. Before
- b. After

7. Which TWO materials are used to add power to a laser?

- a. Glass
- b. Plastic
- c. Metals
- d. Crystals

8. What can we use lasers for?

- a. Creating 3D images of bones
- b. Simulating explosions in space
- c. Accelerating particles
- d. All of the above

Quiz Answers: 1. a, 2. b, 3. a, 4. c, 5. d, 6. a, 7. a & d, 8. d



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