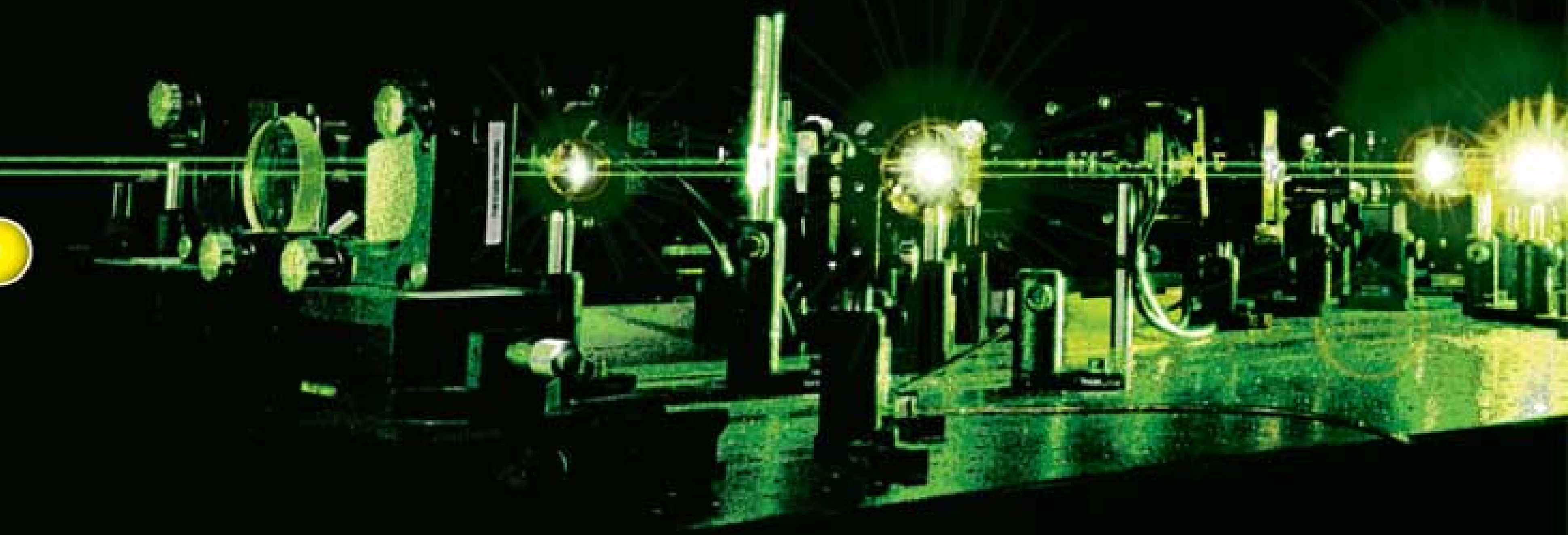
# LASERS

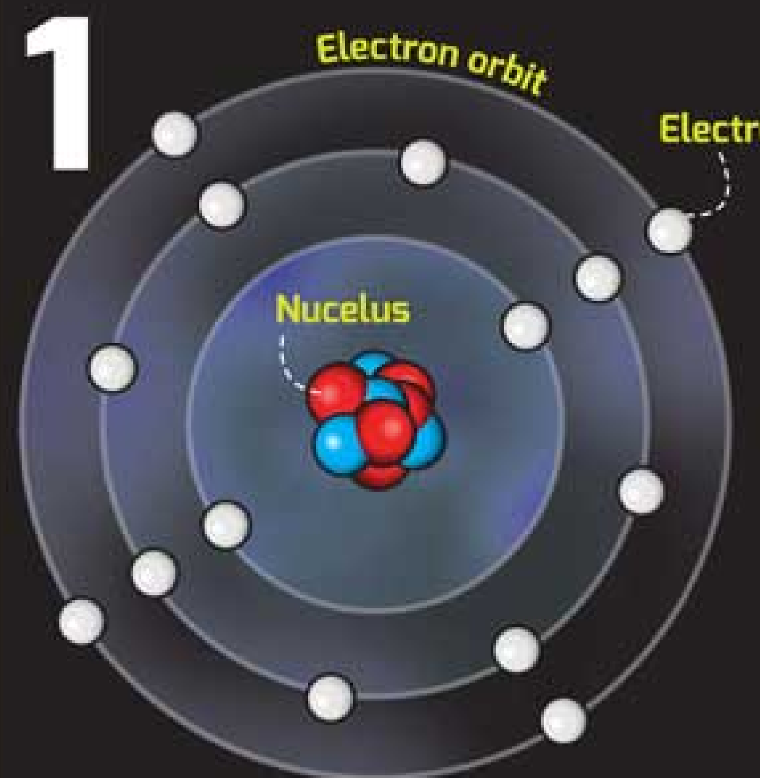


LASER light is a very special form of man-made light that doesn't exist in nature.
Laser devices generate an intense beam of highly-focused light that can be used for anything from drilling and cutting, delicate surgery, reading barcodes and DVDs to probing the atomic building blocks of nature

## HOW DO YOU MAKE LASER LIGHT?

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

**Lasers rely on a quantum process that causes an atom to absorb and emit photons**

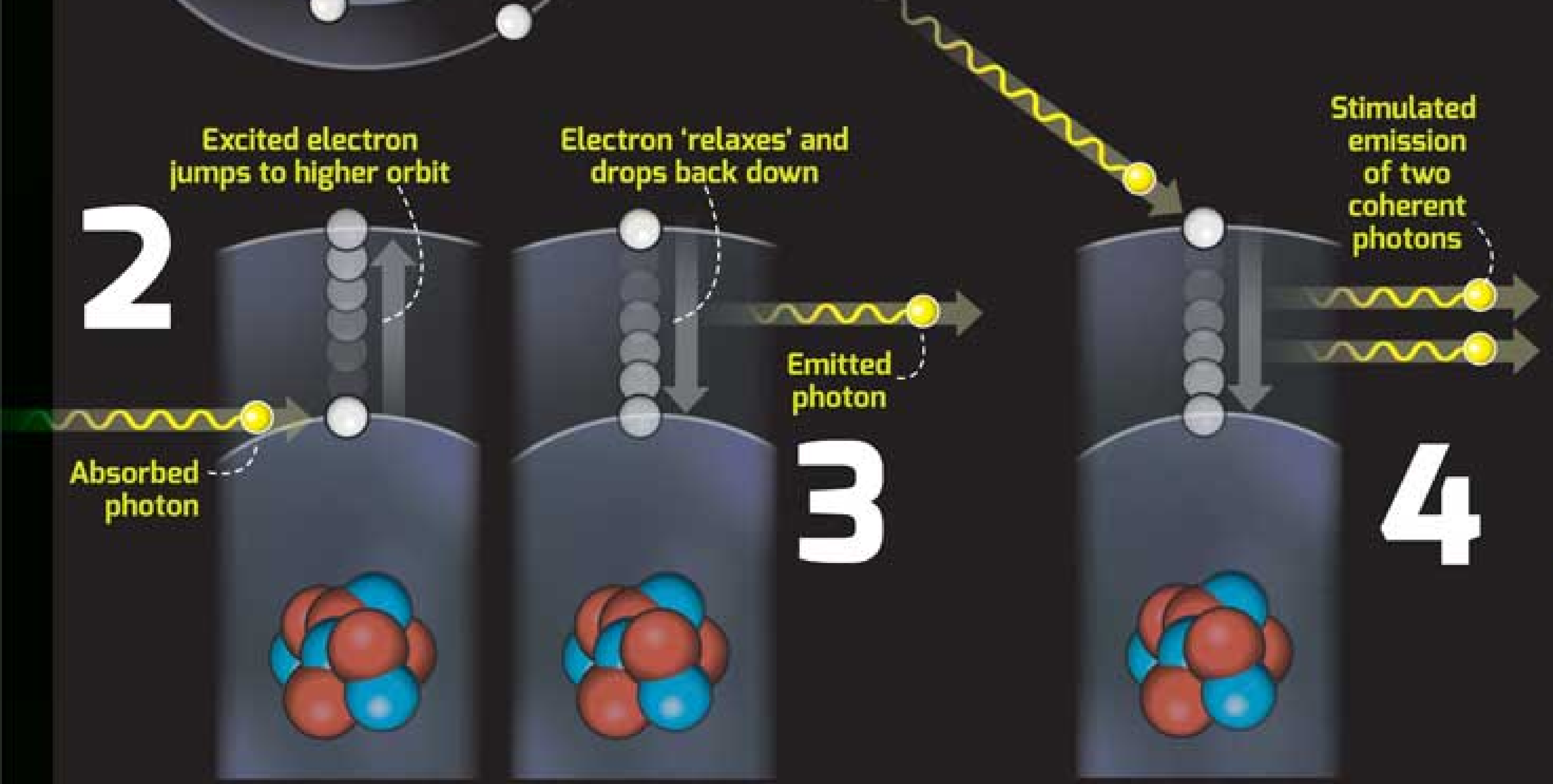



**1.** Atoms are made up of a nucelus surrounded by electrons that move in orbits that occupy different energy levels. Electrons can change their orbit by gaining or losing energy.

**2.** An electron can gain energy by absorbing a photon. When it does so, it gets 'excited' and leaps up to a higher-energy orbit (a quantum leap).

**3.** But the electron wants to return to its original orbit, so it emits a photon and drops back down. This process is called **spontaneous emission**.

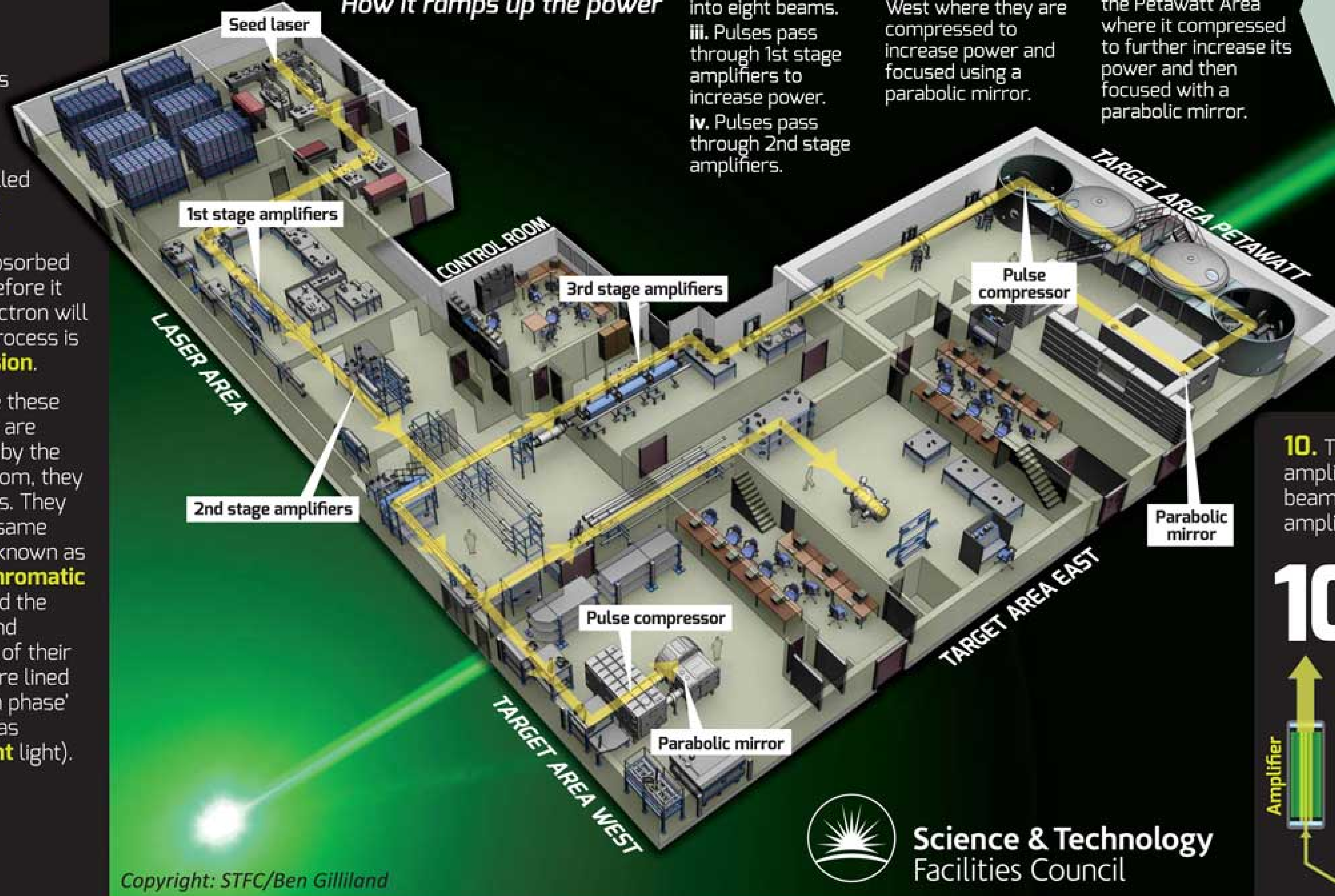
**4.** If another photon is absorbed by the excited electron before it can drop its orbit, the electron will emit two photons. This process is called **stimulated emission**.




Because these photons are emitted by the same atom, they are twins. They are the same colour (known as **monochromatic** light) and the peaks and troughs of their waves are lined up, or 'in phase' (known as **coherent** light).

## VULCAN

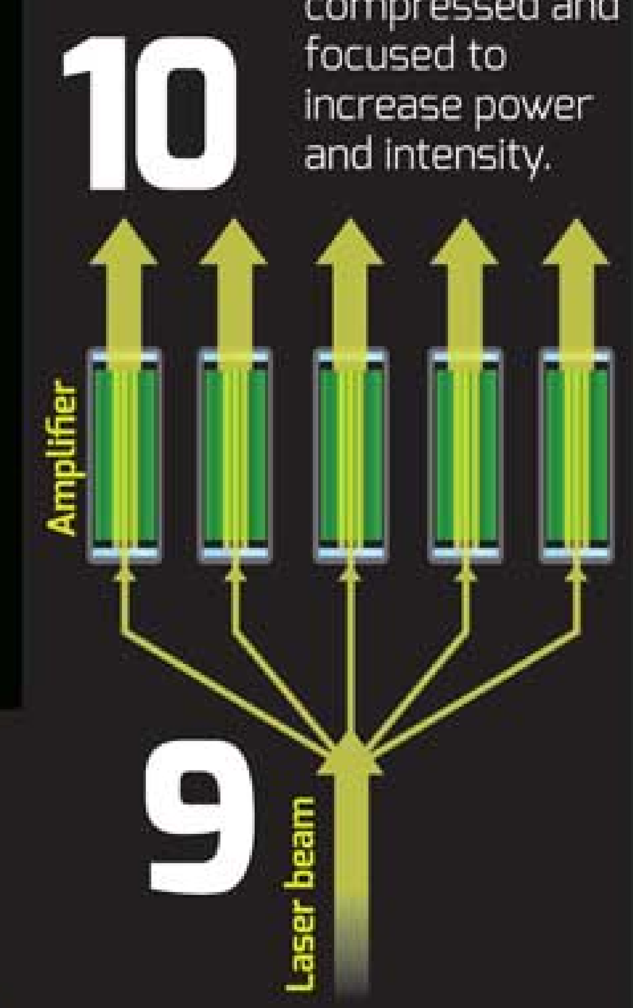
*How it ramps up the power*

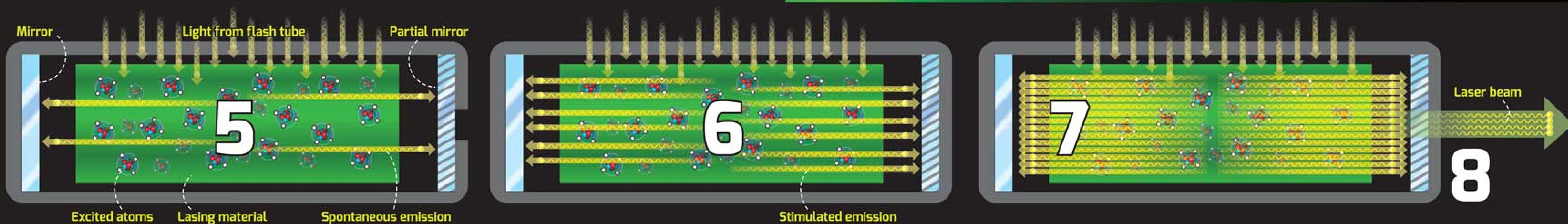



**i.** A 'seed' laser pulse is generated.
**ii.** The pulse is amplified and split into eight beams.
**iii.** Pulses pass through 1st stage amplifiers to increase power.
**iv.** Pulses pass through 2nd stage amplifiers.
**v.** Six pulses are sent to Target Area West to increase power and focused using a parabolic mirror.
**vi.** Two pulses can be sent to Target Area West where they are compressed to increase power and focused using a parabolic mirror.
**vii.** Or, one of the pulses can be sent to the 3rd stage amplifiers and on to the Petawatt Area where it compressed to further increase its power and then focused with a parabolic mirror.

The **Vulcan laser** at the STFC's Central Laser Facility at the Rutherford Appleton Lab is capable of producing laser pulses that, for a fraction of a second, can deliver 10,000 times more power than the whole of the UK's National Grid. To achieve this power, the seed laser undergoes many stages of amplification.

**10.** These can be further amplified or split into more beams, or pulses, to be amplified. Pulses can be compressed and focused to increase power and intensity.




**9.** To make a more powerful laser, the initial 'seed laser' beam can be split into narrower beams (or short pulses), which are then individually amplified.

**5.** At its most simple, a laser consists of a crystal (the '**lasing material**'), two mirrors and a flash bulb. The flash bulb pumps energy (photons) into the lasing material and excites the crystal's atoms, which spontaneously emit photons of their own.

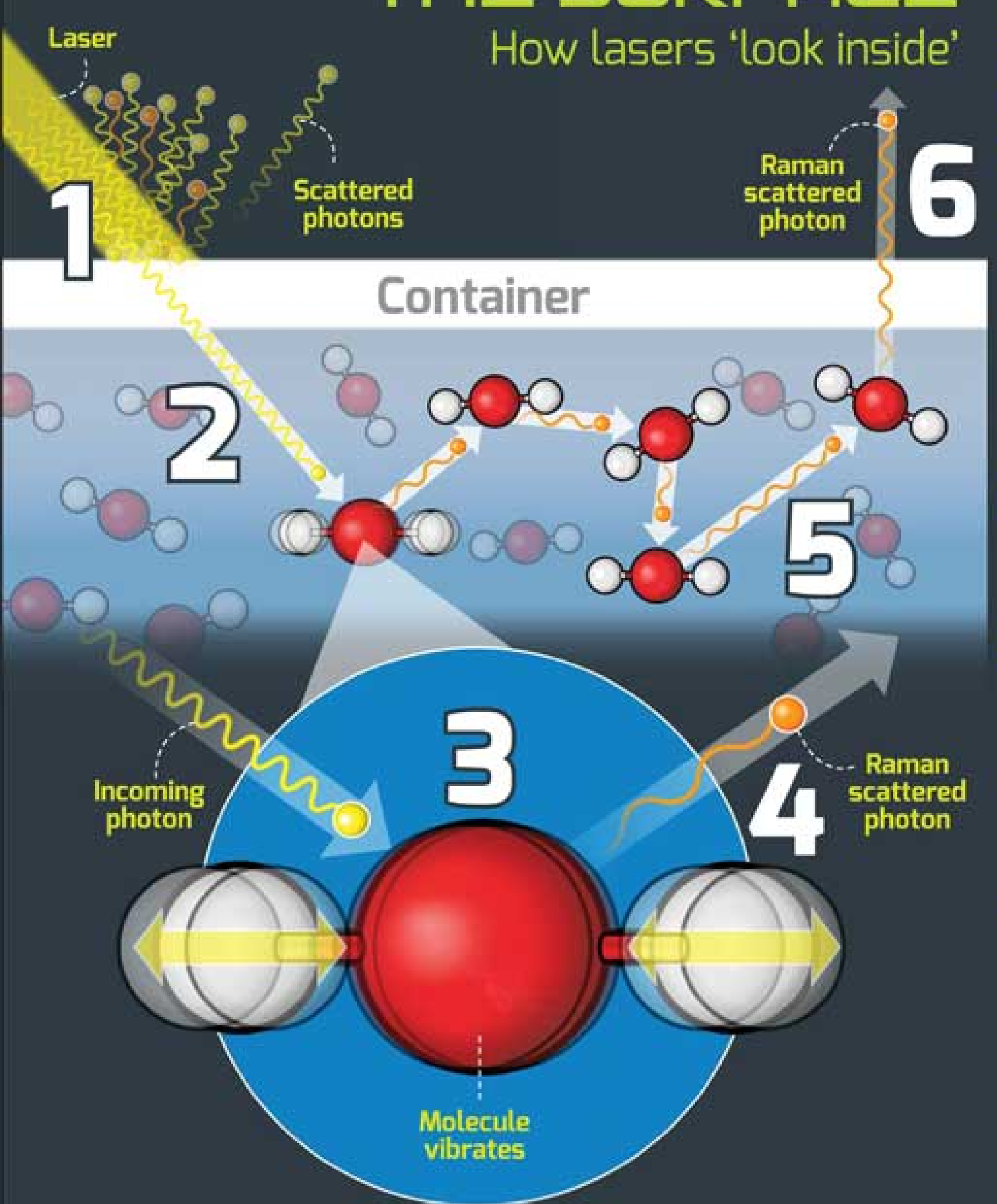
**6.** The emitted photons reflect off the mirrors and travel back and forth through the lasing material. As they do so, they stimulate the already excited atoms to emit more photons. As each individual photon stimulates the emission of two photons and the light is amplified.

**7.** The mirrors only reflect photons with a specific wavelength and phase. The parallel mirrors also ensure that only photons travelling perfectly parallel to each other (called '**collimated light**') are reflected back into the crystal to be amplified.

**8.** One of the mirrors is only partly reflective and it lets some photons escape. The monochromatic, coherent, collimated light that leaves the mirror is the **laser beam**.

# SEEING BENEATH THE SURFACE

## How lasers 'look inside'




An ingenious laser technique called spatially-offset Raman Spectroscopy (SORS), developed at the STFC's Central Laser Facility (CLF), allows us to 'see' through opaque objects.

It can be used at airports to detect hidden explosives and is also being developed to scan for breast cancer and bone disease.

**1.** A laser beam is directed at a container, such as a bottle. Most of the photons interact with the container's molecules and scatter off its surface.

**2.** But some photons make it through and penetrate the contents.

**3.** A small percentage of those photons will be absorbed by molecules inside the container. The photon excites the molecule and makes it vibrate.

**4.** When a photon does this, it loses energy to the molecule – so when it scatters (emitted by the molecule) the photon's wavelength has shifted and it changes colour. This is called Raman scattering.

**5.** The Raman scattered photon 'bounces' around inside until it finally exists the container – where it is picked up by a detector.

**6.** From the amount of energy the photon has lost, scientists can identify the chemical properties of the molecule it scattered from – and so Identify the contents of the bottle without ever opening it.

# CREATING A STAR ON EARTH

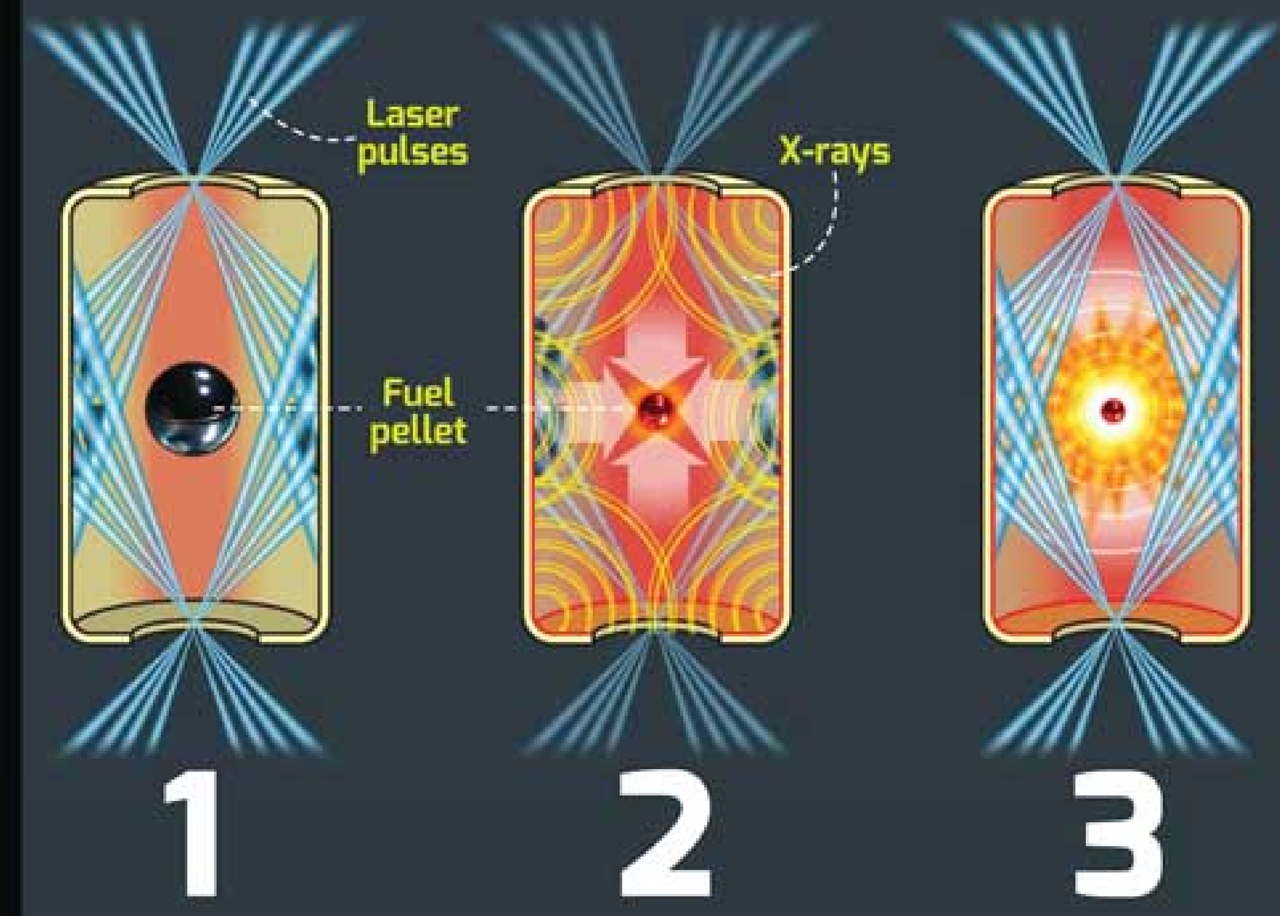
## How lasers recreate a star

Nuclear fusion (the process that makes the stars shine) could provide a near-endless supply of clean, safe energy.

To create fusion on Earth, scientists must recreate the sort of heat and pressure that exists in the heart of a star.

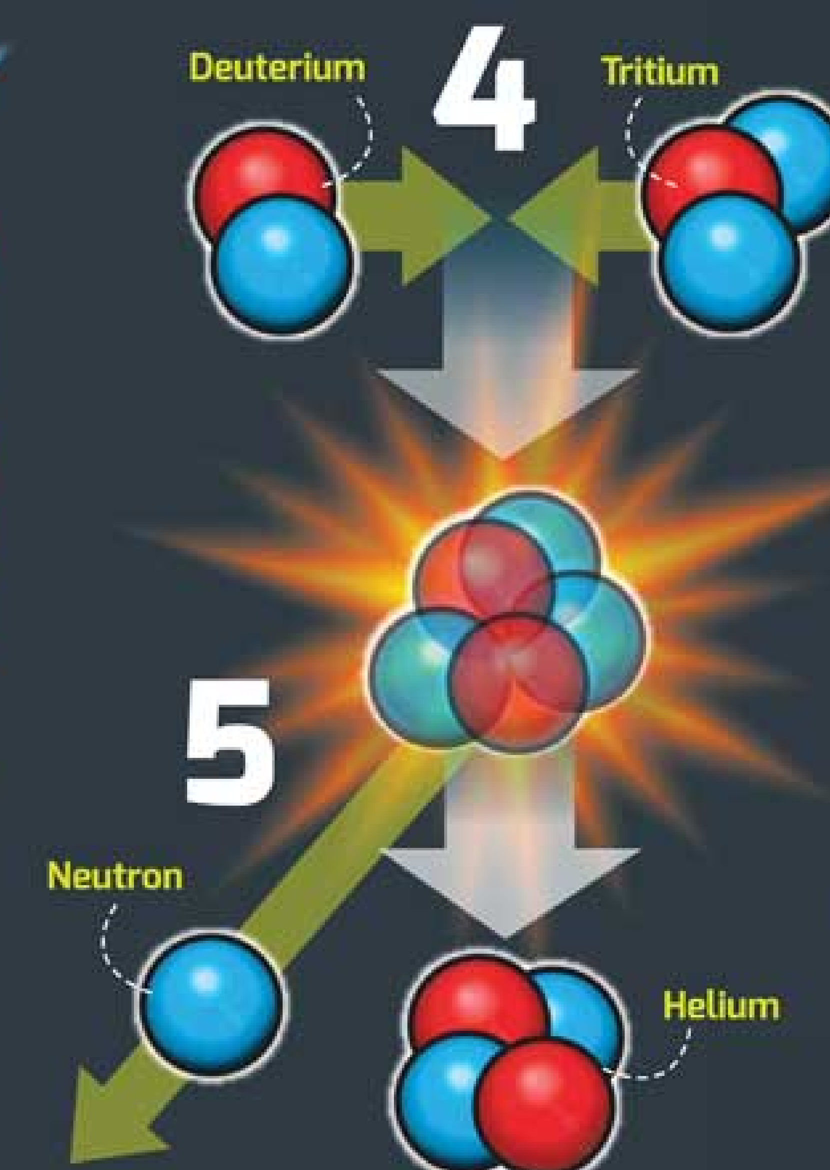
Facilities like the Vulcan laser are exploring ways make this possible.

**1.** A tiny gold capsule, containing a hydrogen fuel pellet, is zapped by high-power laser pulses.




**2.** This super-heats the capsule and creates powerful X-rays that heat the pellet to millions of degrees. The pellet's outer shell vapourises – creating a shockwave that crushes the pellet.

**3.** A final laser pulse heats the pellets to more than 100 million degrees.




**4.** This creates enough heat and pressure to force the atoms within the fuel pellet to fuse together. Two hydrogen atoms fuse to create one helium atom.

**5.** Fusion releases a huge amount of energy. Most of this is carried off by a neutron, which can be captured and used to heat water, drive a steam turbine and generate electricity.


Lasers come in all sorts of shapes and sizes. They can be smaller than a microchip and emit tiny amounts of low-energy infrared light, or huge room-filling multi-laser systems that blast out high-energy radiation. Their uses are even more diverse

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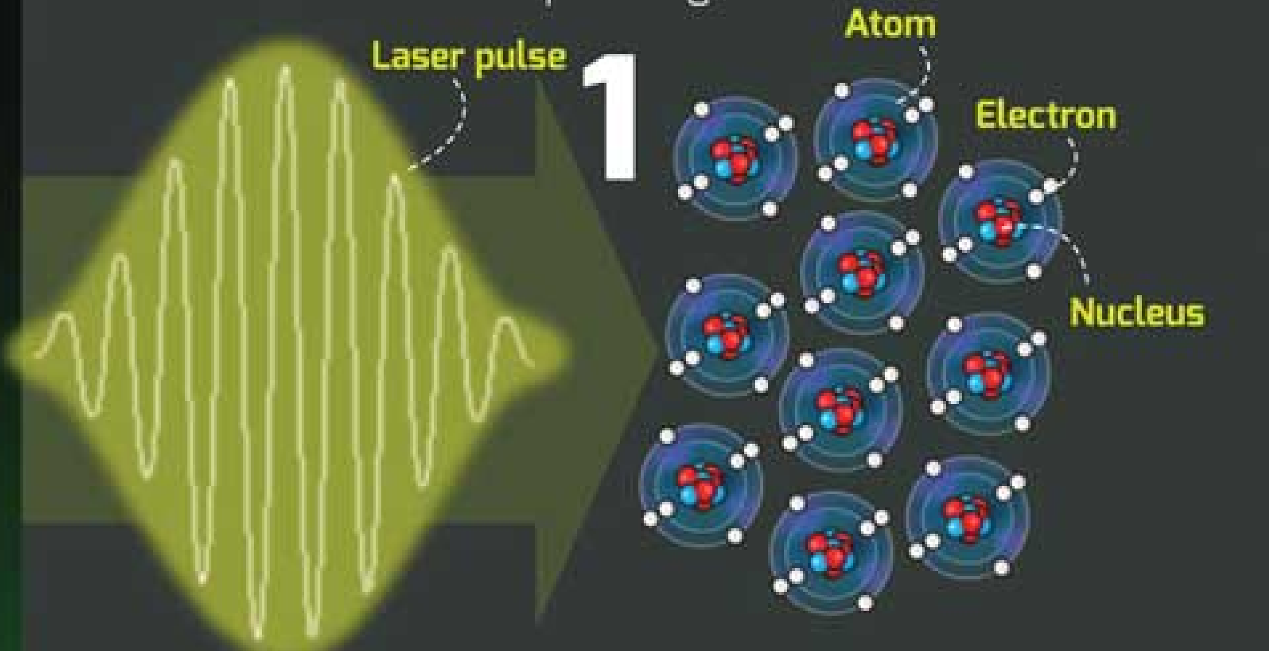
# MINI PARTICLE ACCELERATORS

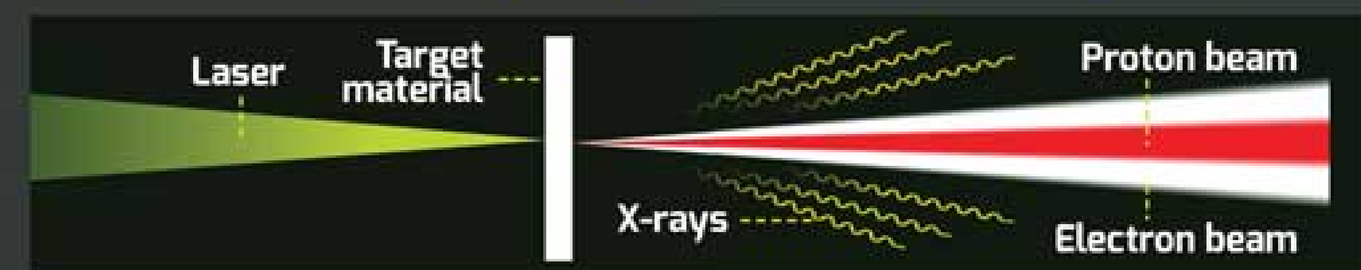
## How lasers accelerate particles

We are used to thinking of particle accelerators as being huge underground rings but scientists are working on accelerators that could fit on a desktop.

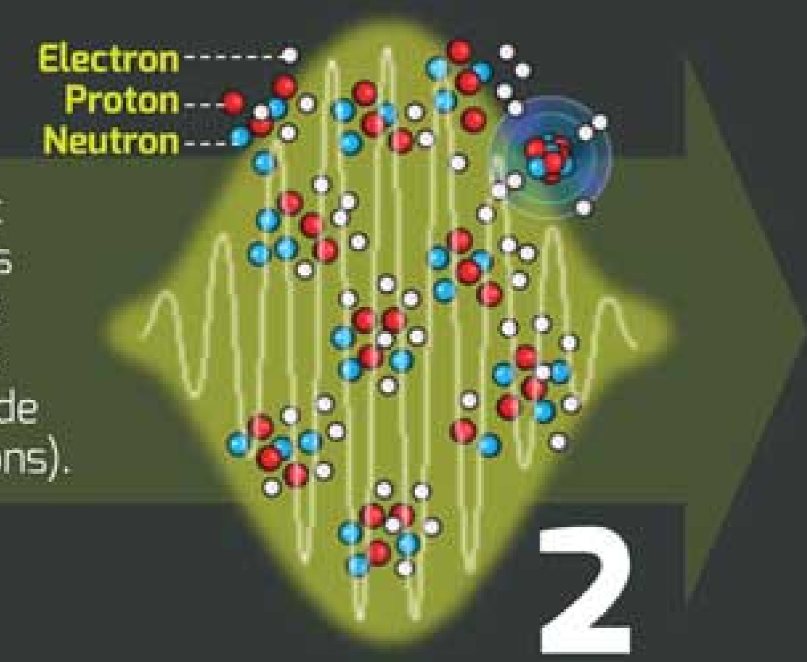
The CLF's high-power lasers are being used to develop the next generation of compact particle accelerators. These laser-driven accelerators could be used in areas such as cancer diagnosis and treatment, security inspection and in industry.

**1.** A powerful laser pulse is fired at a target material – a solid foil or a puff of gas

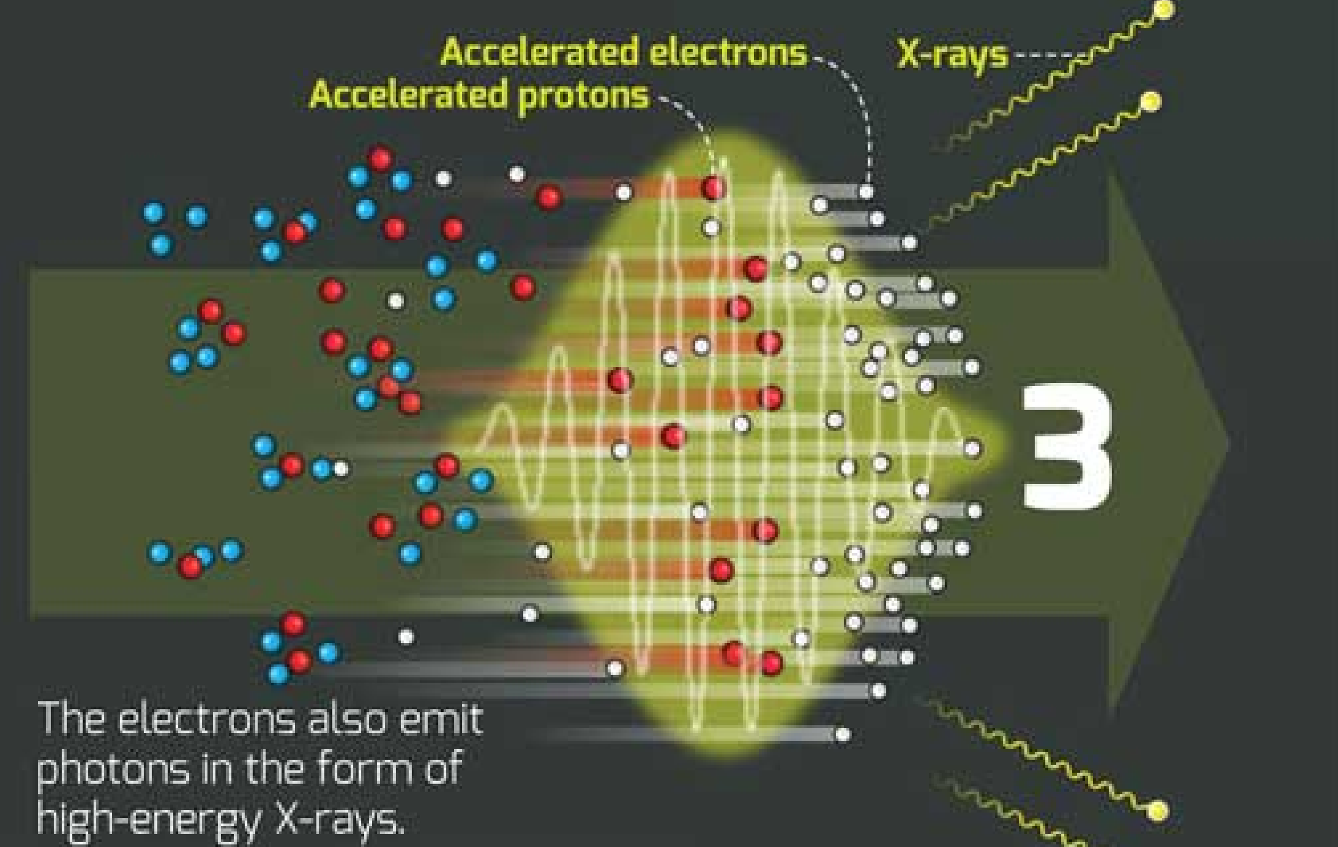



**3.** As it passes through, the laser pulse picks up the electrons and protons and accelerates them to high speeds – creating powerful electron and proton beams.




**2.** The laser's electric field rips the electrons from the orbits of the foil's atoms and tears apart their nuclei (made of protons and neutrons).




The electrons also emit photons in the form of high-energy X-rays.