To create a Death Star laser cannon that can destroy an entire planet and terrorize a galaxy, such as that described in *Star Wars*, one would need to create the most powerful laser ever conceived. At present some of the most powerful lasers on Earth are being used to unleash temperatures found only in the center of stars. In the form of fusion reactors, they might one day harness the power of the stars on Earth.

Fusion machines try to mimic what happens in outer space when a star first forms. A star begins as a huge ball of formless hydrogen gas, until gravity compresses the gas and thereby heats it up; temperatures eventually reach astronomical levels. Deep inside a star's core, for example, temperatures can soar to between 50 million and 100 million degrees centigrade, hot enough to cause hydrogen nuclei to slam into each other, creating helium nuclei and a burst of energy. The fusion of hydrogen into helium, whereby a small amount of mass is converted into the explosive energy of a star via Einstein's famous equation $E = mc^2$, is the energy source of the stars.

There are two ways in which scientists are currently attempting to harness fusion on the Earth. Both have proven to be much more difficult to develop than expected.

Inertial Confinement for Fusion

The first method is called "inertial confinement." It uses the most powerful lasers on Earth to create a piece of the sun in the laboratory. A neodymium glass solid-state laser is ideally suited to duplicate the blistering temperatures found only in the core of a star. These laser systems are the size of a large factory and contain a battery of lasers that shoot a series of parallel laser beams down a long tunnel. These high-power laser beams then strike a series of small mirrors arranged around a sphere; the mirrors carefully focus the laser beams uniformly onto a tiny, hydrogen-rich pellet (made of substances such as

lithium deuteride, the active ingredient of a hydrogen bomb). The pellet is usually the size of a pinhead and weighs only 10 milligrams.

The blast of laser light incinerates the surface of the pellet, causing the surface to vaporize and compress the pellet. As the pellet collapses, a shock wave is created that reaches the core of the pellet, sending temperatures soaring to millions of degrees, sufficient to fuse hydrogen nuclei into helium. The temperatures and pressures are so astronomical that "Lawson's criterion" is satisfied, the same criterion that is satisfied in hydrogen bombs and in the core of stars. (Lawson's criterion states that a specific range of temperatures, density, and time of confinement must be attained in order to unleash the fusion process in a hydrogen bomb, in a star, or in a fusion machine.)

In the inertial confinement process vast amounts of energy are released, including neutrons. (The lithium deuteride can hit temperatures of 100 million degrees centigrade and a density twenty times that of lead.) A burst of neutrons is then emitted from the pellet, and the neutrons strike a spherical blanket of material surrounding the chamber, and the blanket is heated up. The heated blanket then boils water, and the steam can be used to power a turbine and produce electricity.

The problem, however, lies in being able to focus such intense power evenly onto a tiny spherical pellet. The first serious attempt at creating laser fusion was the Shiva laser, a twenty-beam laser system built at the Lawrence Livermore National Laboratory (LLNL) in California that began operation in 1978. (Shiva is the Hindu goddess with multiple arms, which the laser system design mimics.) The performance of the Shiva laser system was disappointing, but it was sufficient to prove that laser fusion can technically work. The Shiva laser system was later replaced by the Nova laser, with ten times the energy of Shiva. But the Nova laser also failed to achieve proper ignition of the pellets. Nonetheless, it paved the way for the current research in the National Ignition Facility (NIF), which began construction in 1997 at the LLNL.

The NIF, which is supposed to be operational in 2009, is a monstrous machine, consisting of a battery of 192 laser beams, packing an enormous output of 700 trillion watts of power (the output of about

700,000 large nuclear power plants concentrated in a single burst of energy). It is a state-of-the-art laser system designed to achieve full ignition of the hydrogen-rich pellets. (Critics have also pointed out its obvious military use, since it can simulate the detonation of a hydrogen bomb and perhaps make possible the creation of a new nuclear weapon, the pure fusion bomb, which does not require a uranium or plutonium atomic bomb to kick-start the fusion process.)

But even the NIF laser fusion machine, containing the most powerful lasers on Earth, cannot begin to approximate the devastating power of the *Star Wars* Death Star. To build such a device we must look to other sources of power.

Magnetic Confinement for Fusion

The second method scientists could potentially use to energize a Death Star is called "magnetic confinement," a process in which a hot plasma of hydrogen gas is contained within a magnetic field. In fact, this method could actually provide the prototype for the first commercial fusion reactors. Currently the most advanced fusion project of this type is the International Thermonuclear Experimental Reactor (ITER). In 2006 a coalition of nations (including the European Union, the United States, China, Japan, Korea, Russia, and India) decided to build the ITER in Cadarache, in southern France. It is designed to heat hydrogen gas to 100 million degrees centigrade. It could become the first fusion reactor in history to generate more energy than it consumes. It is designed to generate 500 megawatts of power for 500 seconds (the current record is 16 megawatts of power for 1 second). The ITER should generate its first plasma by 2016 and be fully operational in 2022. At a cost of $12 billion, it is the third most expensive scientific project in history (after the Manhattan Project and the International Space Station).

The ITER looks like a large doughnut, with hydrogen gas circulating inside and huge coils of wire winding around the surface. The coils are cooled down until they become superconducting, and then a huge amount of electrical energy is pumped into them, creating a magnetic

physics, has said, "We say that we will put the sun into a box. The idea is pretty. The problem is, we don't know how to make the box." But if all goes well, researchers are hopeful that within forty years the ITER may pave the way for commercialization of fusion energy, energy that can provide electricity for our homes. One day, fusion reactors may alleviate our energy problem, safely releasing the power of the sun on the Earth.

But even magnetic confinement fusion reactors would not provide enough energy to energize a Death Star weapon. For that we would need an entirely new design.

Nuclear-Fired X-ray Lasers

There is one other possibility for simulating a Death Star laser cannon with today's known technology, and that is with a hydrogen bomb. A battery of X-ray lasers harnessing and focusing the power of nuclear weapons could in theory generate enough energy to operate a device that could incinerate an entire planet.

The nuclear force, pound for pound, releases about 100 million times more energy than a chemical reaction. A piece of enriched uranium no bigger than a baseball is enough to incinerate an entire city in a fiery ball—even though only 1 percent of its mass has been converted to energy. As we discussed, there are a number of ways of injecting energy into a laser beam. By far the most powerful of all is to use the force unleashed by a nuclear bomb.

X-ray lasers have enormous scientific as well as military value. Because of their very short wavelength they can be used to probe atomic distances and decipher the atomic structure of complicated molecules, a feat that is extraordinarily difficult using ordinary methods. A whole new window on chemical reactions opens up when you can "see" the atoms themselves in motion and in their proper arrangement inside a molecule.

Because a hydrogen bomb emits a huge amount of energy in the

X-ray range, X-ray lasers can also be energized by nuclear weapons. The person most closely associated with the X-ray laser is the physicist Edward Teller, father of the hydrogen bomb.

Teller, of course, was the physicist who testified before Congress in the 1950s that Robert Oppenheimer, who had headed the Manhattan Project, could not be trusted to continue work on the hydrogen bomb because of his politics. Teller's testimony led to Oppenheimer's being disgraced and having his security clearance revoked; many prominent physicists never forgave Teller for what he did.

(My own contact with Teller dates from when I was in high school. I conducted a series of experiments on the nature of antimatter and won the grand prize in the San Francisco science fair and a trip to the National Science Fair in Albuquerque, New Mexico. I appeared on local TV with Teller, who was interested in bright young physicists. Eventually I was awarded Teller's Hertz Engineering Scholarship, which paid for my college education at Harvard. I got to know his family fairly well through visits to the Teller household in Berkeley several times a year.)

Basically, Teller's X-ray laser is a small nuclear bomb surrounded by copper rods. The detonation of the nuclear weapon releases a spherical shock wave of intense X-rays. These energetic rays then pass through copper rods, which act as the lasing material, focusing the power of the X-rays into intense beams. These beams of X-rays could then be directed at enemy warheads. Of course, such a device could be used only once, since the nuclear detonation causes the X-ray laser to self-destruct.

The initial test of the nuclear-powered X-ray laser was called the Cabra test, and it took place in 1983 in an underground shaft. A hydrogen bomb was detonated whose flood of incoherent X-rays was then focused into a coherent X-ray laser beam. Initially, the test was deemed a success, and in fact in 1983 it helped to inspire President Ronald Reagan to announce, in a historic speech, his intent to build a "Star Wars" defensive shield. Thus was set in motion a multibillion-dollar effort that continues even to this day to build an array of devices like the nuclear-powered X-ray laser to shoot down enemy ICBMs. (Later investigation showed that the detector used to perform the measurements during the Cabra test was destroyed; hence its readings could not be trusted.)

Can such a controversial device in fact be used today to shoot down ICBM warheads? Perhaps. But an enemy could use a variety of simple, inexpensive methods to nullify such weapons (for example, the enemy could release millions of cheap decoys to fool radar, or spin its warheads to disperse the X-rays, or emit a chemical coating to protect against the X-ray beam). Or an enemy might simply mass-produce warheads to penetrate a Star Wars defensive shield.

So a nuclear-powered X-ray laser today is impractical as a missile defense system. But would it be possible to create a Death Star to use against an approaching asteroid, or to annihilate an entire planet?

Can weapons be created that could destroy an entire planet, as in *Star Wars*? In theory, the answer is yes. There are several ways in which they might be created.

First, there is no physical limit to the energy that can be released by a hydrogen bomb. Here's how this works. (The precise outlines of the hydrogen bomb are top secret and classified even today by the U.S. government, but the broad outlines are well known.) A hydrogen bomb is actually built in many stages. By properly stacking these stages in sequence, one could produce a nuclear bomb of almost arbitrary magnitude.

The first stage is a standard fission bomb, using the power of uranium-235 to release a burst of X-rays, as was done in the Hiroshima bomb. In the fraction of a second before the blast from the atomic bomb blows everything apart, the expanding sphere of X-rays outraces the blast (since it travels at the speed of light) and is then refocused onto a container of lithium deuteride, the active substance of a hydrogen bomb. (Precisely how this is done is still classified.) The X-rays striking the lithium deuteride causes it to collapse and heat up to millions of degrees, causing a second explosion, much larger than the first. The burst of X-rays from this hydrogen bomb can then be refocused onto a second piece of lithium deuteride, creating a third explosion. In this way, one could stack lithium deuteride side by side and create a hydrogen bomb of unimaginable magnitude. In fact, the largest hydrogen bomb ever built was a two-stage bomb detonated by the Soviet Union back in 1961, packing the energy of 50 million tons of TNT, although it was theoretically capable of a blast of over 100 million tons of TNT (or about five thousand times the power of the Hiroshima bomb).

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