High-gain laser fusion targets demonstrated

While technological hurdles must be overcome before the full potentials of laser fusion can be realized, the question is not "whether," but when. By Charles B. Stevens.

In a front-page article on March 21, 1988 the *New York Times* confirmed in detail reports published by *EIR* last fall, when we wrote in our Oct. 2, 1987 issue that "researchers at the California-based Lawrence Livermore National Laboratory . . . have experimentally demonstrated the science for harnessing the 'internal combustion engine' of the 21st century—the thermonuclear-powered laser fusion reactor." And just as the Wright brothers' first demonstration of powered flight in 1903 was, at the time, hardly noticed, though later widely acclaimed, this event will be celebrated by many generations to come as the dawn of the fusion age.

The data revealed in the *New York Times* article confirms that the essential scientific prerequisites for harnessing laser fusion have been experimentally demonstrated. And while significant technological hurdles remain to be overcome before the full potentials of laser fusion can be realized, the only real question is not "whether," but when. In scientific and technological terms, the experimental results revealed by the *New York Times* mean that the U.S. effort to harness laser fusion is at the same point that the Manhattan Project of World War II reached in 1942 with the successful operation of the first nuclear fission pile. That is, given sufficient resources, within less than a decade the program could demonstrate major laser fusion applications.

And these first-generation applications are truly mind-boggling. First of all, the fuel for thermonuclear fusion is plentiful and readily available. Every gallon of seawater contains a few grams of hydrogen fusion fuel which has the energy equivalent of up to 300 gallons of gasoline. Designs for laser fusion power reactors already exist which can deliver electricity at up to one-half the cost of existing fossil and nuclear fission power plants. But, just as in the case of nuclear fission, the probable, first application of laser fusion will be to provide a means of propulsion for ships. The ships in this case, though, will be terawatt interplanetary spaceships, which will provide the essential means for making the colonization of Mars over the next four decades eminently feasible. Scientifically, the mastery of laser fusion will revolutionize virtually every field of research, as is now being demonstrated in the Livermore effort to make x-ray laser microholograms of living cells—atomic-scale motion pictures of living processes—for the first time.

New York Times revelations

The *New York Times* article reveals for the first time top secret data from the Halite-Centurion program and the overwhelming success of the Lawrence Livermore Laser Fusion Program: "In top-secret experiments, federal researchers have achieved one of the nation's most costly and elusive scientific goals: to ignite a nuclear fusion reaction in tiny pellets of hydrogen, producing powerful bursts of energy. The success was achieved in unorthodox experiments some two years ago at the government's underground nuclear test site in the Nevada desert. . . . In a tantalizing, little-noticed statement last September, Sheldon Kahalas, director of the nation's microfusion effort, run by the federal Department of Energy, told a Princeton University conference that a top-secret effort code-named Centurion-Halite, had achieved results that marked a 'historical turning point' for the fusion program . . . the energy needed for a laboratory laser to mimic the classified achievement would be in the range of 100 million joules."

In summary: " 'There's a new sense of excitement,' William J. Hogan, a microfusion official at the Lawrence Livermore National Laboratory in California, said in an interview. 'In the last two years, we've gotten almost all the data we wanted. That's remarkable. We kind of startled ourselves.' "

Making stars on Earth

Thermonuclear fusion reactions power the stars and provide the means through which the chemical elements, which make up our biosphere, are generated. Deep within the cores of stars, such as our Sun, tremendous gravitational forces are generated by their huge masses. This produces the pressures and temperatures needed to ignite thermonuclear fusion reactions. In general, thermonuclear reactions consist of the "fusing" of the nuclei of lighter elements to form the nuclei of heavier chemical elements. (In our Sun, four ordinary hydrogen nuclei are fused to form helium, the next heavier element.)

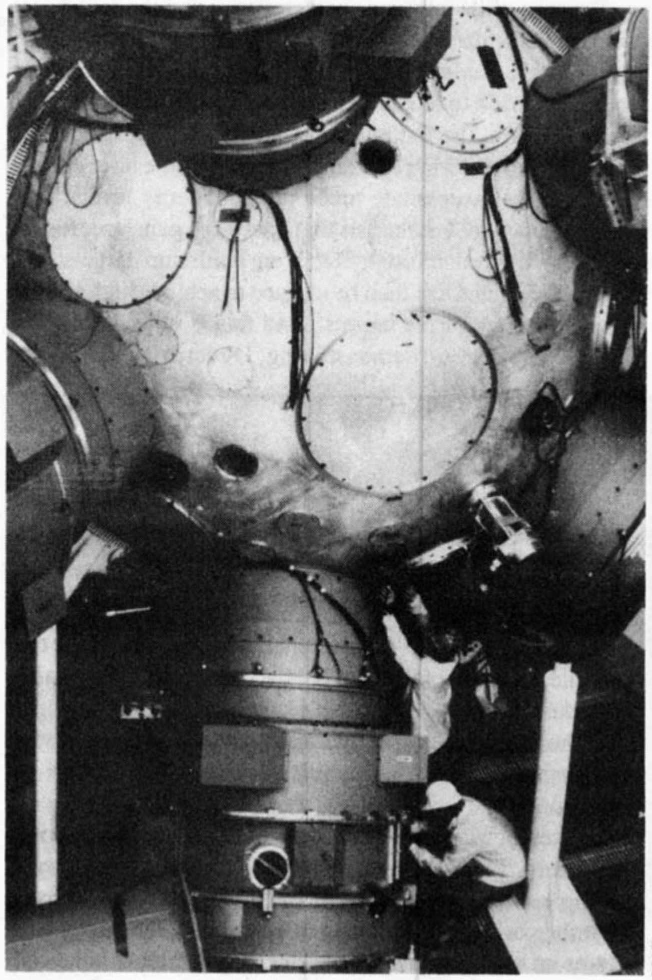
Besides generating most of the chemical elements, nuclear fusion also produces net energy. This is the energy source which lights up the stars, including our Sun. Nuclear fusion generates upwards of four times the energy per unit mass of reactants than nuclear fission of uranium or plutonium, and tens of millions of times more than that of fossil and other chemical fuels.

One gallon of seawater contains enough "heavy" hydrogen fusion fuel to produce the equivalent energy of 300 gallons of gasoline (see box). And while the actual fusion fuel is only a minute part of this seawater gallon, it is readily and cheaply extracted today at a cost of few cents.

Fusion energy generation was first demonstrated with the successful detonation of hydrogen bombs in the 1950s. With the advent of the laser in 1961, research efforts were initiated throughout the world to explore the possibilities of generating a "micro"-hydrogen bomb, a laser-produced fusion microexplosion.

A large nuclear fission powered atomic explosive is utilized to ignite a hydrogen bomb. In the H-bomb, both the fission explosive and hydrogen fusion fuel are placed inside a small chamber called a hohlraum. When the fission explosive is detonated its initial output primarily consists of x-rays. The hohlraum chamber acts to both momentarily contain and transform these atomic bomb generated x-rays. During the few billionths of a second that the hohlraum does this, the atomic bomb x-rays are absorbed and re-emitted as soft x-rays within the chamber. The geometry of the hohlraum is such that the soft x-rays are then directed onto the fusion fuel.

This intense burst of x-rays then drives the fusion fuel to the pressures and temperatures needed to ignite thermonuclear reactions. This is accomplished through ablative implosion and shock heating of the fusion fuel. The hydrogen fusion fuel literally "burns up" before it blows up. And while it is "burning," that is, undergoing thermonuclear fusion, the only force containing the fuel is that of its own inertia. For this reason, this general approach to fusion, as opposed to magnetic fusion where magnetic fields are utilized to contain hydrogen plasmas, is called inertial confinement fusion (ICF).



LLNL

Laser technicians install diagnostic instruments on the Nova target chamber. Nova, at Lawrence Livermore National Laboratory, is the world's most powerful laser, and is helping scientists to harness fusion energy.

There are two general routes to achieving ICF. The first consists of direct drive in which lasers or high energy particle beams are used to compress and heat a small pellet of fusion fuel. The second is that of indirect drive in which the same lasers or high energy particle beams are used to generate soft x-rays which are then used to compress the small fusion fuel pellet. The second indirect drive, or what is termed hohlraum approach, is of the same general characteristics that are utilized in the design of H-bombs. Most details of this indirect drive approach are therefore kept highly secret.

Since the early 1960s there has been significant progress in the design and construction of high energy lasers. Livermore began its laser fusion R&D with a one-joule, billion-watt laser. Today, the 10-beam Nova glass laser system generates up to 100 thousand joules at a power level greater than 100 trillion watts. Nova is currently the world's most powerful high energy laser. Other lasers operating in Japan, the Soviet Union, and France generate tens of thousands of joules at tens of trillions of watts power levels.

Because of its intrinsic characteristics and the fact that it has been researched intensively for almost four decades, the indirect drive hohlraum approach is currently considered the easiest approach to ICF to demonstrate scientifically. But for power reactors, the indirect drive approach would, because of energy losses during the transformation of the laser energy to soft x-rays, necessitate much greater energy levels. It is hoped by many ICF scientists that once high gain laser fusion has been realized through R&D on hohlraum targets, the knowledge gained can then be utilized to achieve high energy gains with direct drive targets. And this is indeed what the Livermore results are demonstrating. Direct drive ICF power reactors could operate with lasers 100 times smaller than those required for indirect drive.

Halite-Centurion

According to the National Academy of Sciences' 1985 review of ICF, released in 1986, Halite-Centurion is a top secret project that would demonstrate full-scale reactor grade ICF targets within "five years." In 1986 *Science* magazine reported that inadvertently released, top secret congressional testimony showed that Halite-Centurion consisted of a special underground nuclear weapon test facility. During the early 1970s, R&D Associates, a West Coast defense company, developed detailed designs for harnessing in a practical

Nuclear fusion

All matter in nature, solid, liquid, or gas, is made up of one or more of some 92 different elements. An atom is the smallest portion of an element that can exist, while retaining the characteristics of that element. The lightest atoms are those of the element hydrogen, and the heaviest atoms occurring naturally in significant quantity are those of uranium.

Atoms, although extremely small, have an internal structure. Every atom consists of a central nucleus, carrying nearly all the mass of the atom, surrounded by a number of negatively charged electrons. The nucleus of an atom has a positive electrical charge which is balanced by the negative charge of the electrons. Consequently, in its normal state, the atom as a whole is electrically neutral.

All atomic nuclei contain even smaller particles called protons and all except one form of hydrogen also contain neutrons. The protons have a positive electric charge, and the neutrons have no charge. The protons are thus responsible for the electric charge of the nucleus. Each atomic species is characterized by the number of protons and neutrons in the nucleus.

Fusion reactions

There are many different nuclear fusion reactions which occur in the Sun and other stars, but only a few such reactions are of immediate practical value for energy production on earth. These primarily involve forms (isotopes) of the element hydrogen. Three isotopes of hydrogen are known: They are hydrogen (H), deuterium (D), and tritium (T). The nuclei of all three isotopes contain one proton, which characterizes them as forms of the element hydrogen; in addition, the deuterium nucleus has one neutron and the tritium nucleus has two neutrons. In each case, the neutral atom has one electron outside the nucleus to balance the charge of the single proton. (See **Figure 1.**)

To produce net energy, fusion reactions must take place at high temperatures. The power production process which can occur at the lowest temperature and, hence, the most readily attainable fusion process on earth is the combination of a deuterium nucleus with one of tritium.

The products are energetic helium-4 (He-4) the common isotope of helium (which is also called an alpha particle), and a more highly energetic free neutron (n). The helium nucleus carries one-fifth of the total energy released and the neutron carries the remaining four-fifths.

This D-T reaction and some other possible candidates are listed below:

$$D + D \rightarrow He\text{-}3 + n + 3.2\,MeV^*$$
$$D + D \rightarrow T + p + 4.0\,MeV$$
$$D + T \rightarrow He\text{-}4 + n + 17.6\,MeV$$
(See Figure 1 for illustration of D-T reaction)
$$D + He\text{-}3 \rightarrow He\text{-}4 + p + 18.5\,MeV$$

Conditions for fusion

Since nuclei carry positive charges, they normally repel one another. The higher the temperature, the faster the atoms or nuclei move. When they collide at these high speeds, they overcome the force of repulsion of the positive charges, and the nuclei fuse. In such collisions resulting in fusion, energy is released.

The difficulty in producing fusion energy has been to develop a means which can heat the deuterium-tritium fuel to a sufficiently high temperature and then confine the fuel for a long enough time so that more energy is released through fusion reactions than is utilized for heating and confining the fuel.

Temperature. In order to release energy at a level of practical use for production of electricity, the gaseous deuterium-tritium fuel must be heated to about 100 million

* MeV = Million electron volts. An electron volt is a unit of energy equal to the energy acquired by an electron passing through a potential difference of one volt. 1 MeV = 1.52×10^{16} BTU = 4.45×10^{20} kilowatt-hours = $1.6 \times$ 10-13 Joules.

fashion the energy output of hydrogen bomb explosions. The system was called Project Pacer. The basic idea was to create large chambers in salt-dome geological deposits. The salt-dome chamber could contain and withstand many large H-bomb detonations. Water would be injected into the chamber and steam would be extracted for electricity generation. Breeding of fuel for fission reactors was also included in the design.

In the late 1970s, R&D Associates began designing smaller metal chambers for containing much smaller nuclear weapon explosions than those envisioned by Project Pacer. This has evidently led to the successful Halite-Centurion facility.

The successful containment of nuclear weapon explosions has many defense, scientific, and technological applications. Previously, the most important and expensive nuclear weapon underground tests were carried out for x-ray lasers and electromagnetic pulse (EMP) testing of various defense systems, such as satellites, aircraft, and land vehicles. The tests consisted of constructing a one-time, kilometer long vacuum chamber. Heavy doors would be used to siphon off x-rays and gamma rays from nuclear explosions in order to carry out these tests. A single test could cost upwards of tens of millions of dollars.

By fully containing a nuclear explosion in a reusable facility, the same EMP tests and even more advanced scien-

degrees Celsius. This temperature is more than six times hotter than the interior of the Sun.

Confinement. High as these temperatures are, they are readily attainable; the problem is how to confine the deuterium and tritium under such extreme conditions. One general approach is to utilize magnetic fields to confine the hot fuel. This approach is based on the fact that at multimillion-degree temperatures, hydrogen becomes ionized. That is, it becomes a plasma in which the electrons are separated from the nuclei. Because of this, the electrically charged electrons and nuclei can become trapped along magnetic "force field" lines. By using the appropriate geometry of magnetic fields, the plasma can be confined and insulated with a "magnetic bottle."

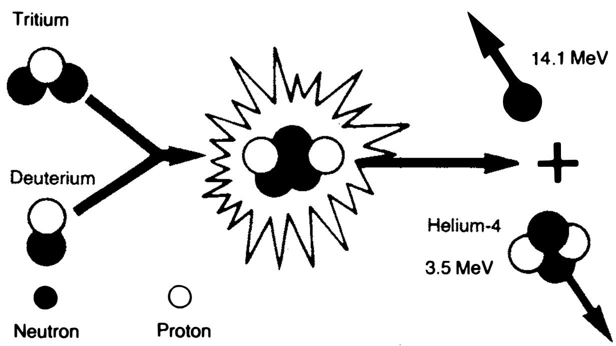
The second major approach to fusion is that of inertial confinement fusion. In this approach the fusion fuel is driven to high densities so that it will "burn up" before it blows up. The object here is to generate gigantic pressures, like those found in the center of stars, in order to compress the fuel to high densities.

In both types of fusion, magnetic and inertial, the measure of the net energy output is given by the Lawson product of the fuel density and the energy confinement time—the time during which the temperature of the plasma must be maintained. For D-T magnetic fusion this product must be about 100 trillion nuclei per cubic centimeter (cc) times one second. That is if the fuel density is 100 trillion nuclei per cc, then it must maintain its 100 million degree Celsius temperature for one second on the average. These are parameters characteristic of magnetic fusion.

For inertial fusion the densities are almost a trillion times greater. But because inertial confinement fusion (ICF) involves a dynamic burn, it must obtain a higher Lawson product—10 to 100 times greater.

In an ICF system the energy confinement time is proportional to the radius of the compressed fusion fuel. The Lawson product can then be given in terms of the product of the fuel density and radius. This is termed the "rho-R" of the fuel. For high gain ICF, where 100 times more fusion energy is generated than the energy of the laser input, rho-R's of about 3 grams per centimeter squared are required. Densities would be several hundred grams per cc—an order of magnitude greater than that of lead. At such densities, only a couple of milligrams of fusion fuel would be utilized, as compared to several hundred thousand grams needed in hydrogen bombs. The compressed radius of the fuel would be about 30 microns.

FIGURE 1
The fusion process



To attain fusion, two nuclei of hydrogen, the basic fusion fuel, must join together. This generates one helium nucleus from every two nuclei of hydrogen and liberates energy in the process.

In the deuterium-tritium fusion process shown here, a deuterium nucleus (one neutron and one proton) fuses with a tritium nucleus (one proton and two neutrons). The two protons and two neutrons combine to form a stable helium nucleus, with the extra free neutron flying off with four-fifths of the energy released, in the form of kinetic energy. (The stable helium atom has the remaining one-fifth of the energy.) This kinetic energy can then be converted to heat or electricity.

The minimal energy needed to start the deuterium-tritium reaction is 10 thousand electron volts (kilovolts), while the energy produced is 17.6 million electron volts.

Why ICF requires high density

In thermonuclear fusion the net energy output is a function of the Lawson product, the product of the fuel density and the "confinement" time during which it is kept at this density. In inertial confinement fusion (ICF), the confinement time is simply the time that the compressed pellet takes to blow up. This is approximately given by dividing the radius of the compressed pellet by the speed of sound. That is, the confinement time is approximately equal to the time it takes a sound wave to propagate from the compressed pellet core to its surface. Taking the speed of sound as being relatively constant, the confinement time is then proportional to the radius (R) of the compressed pellet. Therefore, in ICF the confinement time can be replaced by the compressed pellet radius in the confinement time-density product, which gives the product "rho-R," measured in grams per square centimeter. (That is, density in grams per cubic centimeter times radius in centimeters equals grams per square centimeter.)

Another way to see this ICF "Lawson" product is that the average time it takes for the fuel to burn up—be consumed by nuclear fusion reactions—is inversely proportional to the fuel density. The confinement time is proportional to the compressed pellet radius. Therefore, the ratio of the confinement time to the burn time is simply given by the product "rho-R." And in order for there to be significant fuel "burn-up," the ratio of the confinement time to the burn time should be greater than one, and this directly gives "rho-R" as being greater than one gram per square centimeter. More detailed calculations show that "rho-R" should be equal to about 3 grams per square centimeter for optimum energy outputs.

Energy gain

Given the above requirements for significant fusion fuel burn-up, it now remains to estimate the input energy required to achieve these conditions and the resulting fusion energy output. This will provide the basis for determining the energy gain, G, which is defined as the fusion energy generated F, divided by the input laser energy L:

tific studies could be carried out at costs many times less than the old single-shot vacuum tunnel. The containment of nuclear weapon-scale outputs also makes any type of verification for a test ban treaty virtually impossible.

The application to ICF would consist of siphoning off x-rays from the nuclear weapon plasma and utilizing them for imploding laser fusion scale pellets. And the *New York Times* now confirms that this facility has permitted the testing of full-scale, high-gain ICF targets before the construction of a full-scale laser or particle beam driver.

Scientific implications

The most significant implication of the Halite-Centurion results is simply the fact that high density compressions can be generated. For decades, compression to superdensities has been a major goal of the U.S. ICF effort—both for peaceful and weapons applications. In fact, during the 1970s, reports surfaced that the U.S. nuclear weapons program had failed to generate such high densities. Concomitant with this apparent failure, was the fact that physical interactions which characterize matter at high densities were not understood. In other words, scientists could not predict the "equation of state" for matter at superdensities. Therefore, there existed neither a theoretical nor an experimental foundation for assuring that compressions to superdensities could be achieved with existing technological capabilities—until this success of the Halite-Centurion experiments.

The experimental demonstration of compression to superdensities is of truly astronomical proportions, beyond its application to ICF. According to our present scientific data, the only place that such superdensities are currently found in the universe are in the cores of large stars and other superdense objects such as neutron stars and so-called black holes.

In his famous 1854 paper on geometry, Bernhard Riemann suggested that the most crucial area for physical science was the experimental exploration of the curvature of space-time—particularly in terms of curvature in the small. The ability to experimentally achieve compressions to superdensities provides the essential means to carry out such explorations within the laboratory. And these laboratory results will permit us to better understand the data from observations of astrophysical phenomena.

Take for example the possible effects of gravitational lenses. It has been fairly well established that objects with large masses, such as our Sun, have sufficiently intense gravitational fields to literally "bend" light. Extending this phenomena to even denser and larger objects and groups of astrophysical objects, it is not difficult to see that they could act like very complex optical lenses. For example, such a hypothesized, super-gravitational lens could refractively compress and reorder incoming light waves. That is, light beams which could be incident upon the gravitational lens for billions of years, could be re-emitted over a period of time lasting a few million years. Therefore, to observers on the opposite side of the gravitational lens, time would appear to be compressed several thousand-fold—from billions to millions of years. (Alternatively, time could be dilated.)

Hypothetically, such gravitational lenses could also reorder the incoming light. That is, for example, the lens could

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$$G = F/L$$

Combining the above "rho-R" requirements with several other factors, such as the efficiency of coupling the laser energy into the pellet surface, a multiplier effect results due to the thermonuclear burn wave propagation and, lastly, the compression factor, *n*, which is given by the ratio of the compressed pellet density divided by the ordinary solid density of hydrogen. With these it can be shown that the required laser energy is roughly given as follows:

$$L = G^3(\times)1.6\ MJ/(n^2)$$

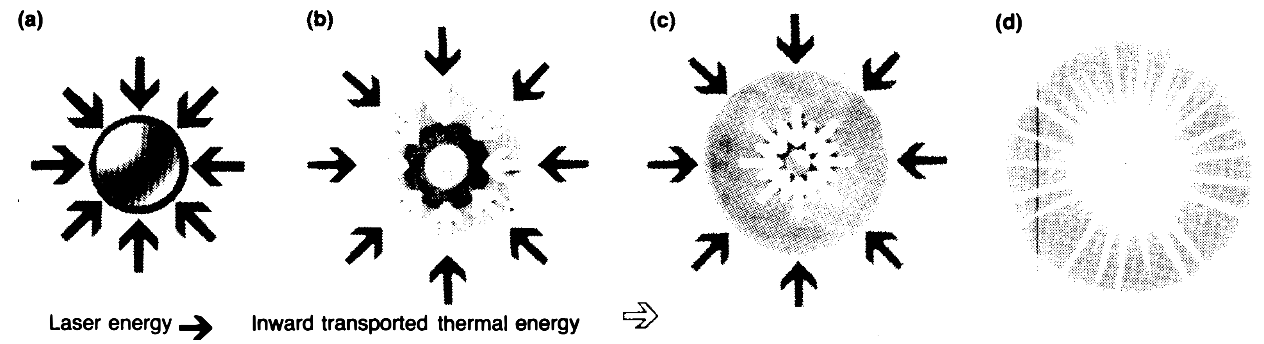
Therefore, to reach energy breakeven (G = 1) at ordinary solid densities (n = 1) requires a laser energy of about 1.6 MJ (MJ = millions of joules). For reactor applications the gain must be above 100 to compensate for power plant inefficiencies. Thus for simple solid densities, G = 100 would require a laser input of 1.6 million MJ—a million times more than in the case of G = 1. This required laser energy input is about equal to the energy output of a small nuclear weapon, with a yield of a third of a kiloton. This is millions of times larger than any existing high-power laser. Furthermore, the fusion energy output, F, given that there is a 100-fold gain, would be 160 million MJ or equivalent to a 40 kiloton nuclear explosive. This level of energy output would be technologically difficult to contain and utilize economically.

However, if the density of the fuel is raised through isentropic compression to 10,000 times solid density (n = 10,000), then the required laser energy for a gain of 100 is only 16 thousand joules—one hundred million times less. The total fusion energy output would also be 100 million times less, which constitutes, therefore, a microexplosive impulse far easier to economically contain and utilize.

In summary, this very approximate analysis is sufficient to show that achieving high fuel density compressions is essential to achieving and economically utilizing ICF. Therefore, the most crucial scientific question facing ICF is whether super compression to high fuel densities is possible. This is what the Halite-Centurion experiments have, indeed, demonstrated.

FIGURE 2

Inertial confinement fusion



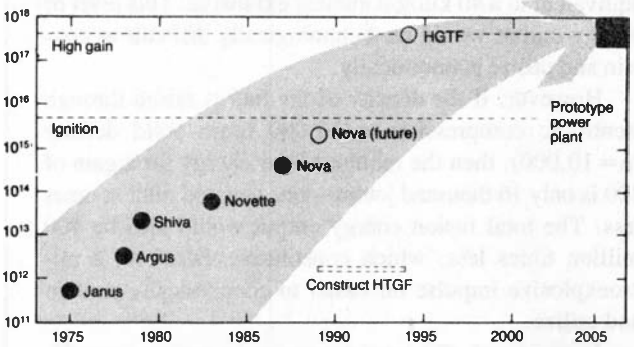
In inertial confinement fusion (ICF), powerful laser or high energy particle beams are focused onto a spherical fusion fuel pellet (a). If these powerful beams are properly tailored and tuned, the surface of the pellet will absorb this incident energy and rapidly heat up to temperatures of tens of millions of degrees. This rapid heating causes a surface layer of the pellet target to expand explosively away from the pellet core. This exploding layer of pellet material acts like a rocket exhaust generating an equal and opposite motion directed toward the center of the pellet target. This ablatively driven rocket drive generates a spherical compression of the remaining pellet material (b). (The outward, spherically directed rocket exhaust is not shown in the figure; only the resulting, inward reaction forces.)

Given the high power of the driving beams, the inward compression takes the form of inwardly directed shock waves. The incident beams are tailored so that a series of "weak" compression shock waves are generated. This permits the pellet material to be efficiently compressed without significant heating. But this series of tailored compression shock waves is arranged so that they all arrive at the center of the pellet at the same time (c). This shock wave convergence heats the compressed pellet core to the 100-million-degrees Celsius temperatures needed to ignite thermonuclear fusion. Once this core region is ignited (d), a significant fraction of the fusion output energy heats the remaining pellet material to fusion ignition temperatures—that is, a thermonuclear burn wave is generated and proceeds through the outer layers of the pellet before the pellet can blow up. In this way, within a few billionths of a second the pellet can generate hundreds of times more energy via nuclear fusion than the energy contained within incident laser or particle beams utilized to drive the implosion.

Source: LLNL

FIGURE 3

Progress in inertial confinement fusion



There has been continuous progress in the inertial confinement fusion program, moving toward the conditions required for commercial fusion energy in the early 21st century. This figure shows (vertical axis) the product of temperature, density and confinement times achieved in experiments at Lawrence Livermore National Laboratory since 1975. The temperature, density, confinement time product is given in units of kilovolts, nuclei per cubic centimeter, and seconds, respectively.

Source: LLNL

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act as a phase conjugation system in which time is reversed—literally like running a motion picture in reverse.

Therefore, it is not difficult to see that gravitational lenses could be both compressing and/or dilating the time of observed astrophysical phenomena, but also reordering the sequence of the "observed" events. Furthermore, since these hypothesized gravitational lenses cannot be assumed to be absolutely independent of events taking place within our solar system and nearby galaxy, the working of these gravitational lenses could be highly nonlinear with regard to local events. More precisely, as indicated by the instantaneous-far action effects of the Bohm-DeBroglie quantum potential and "pilot wave" concepts, local events, such as living processes, which appear to involve small increments of "energy," when only local effects are taken into account, could involve "energy" transformations on a far greater scale than the currently largest astrophysical phenomena (such as exploding supernovas), when their full effects on the universe are taken into account, as mediated, hypothetically in this case, through the nonlinear interaction with gravitational lenses.

Only the exploration of such phenomena in the laboratory and through improved astrophysical observations will provide the essential means for sorting out such processes.