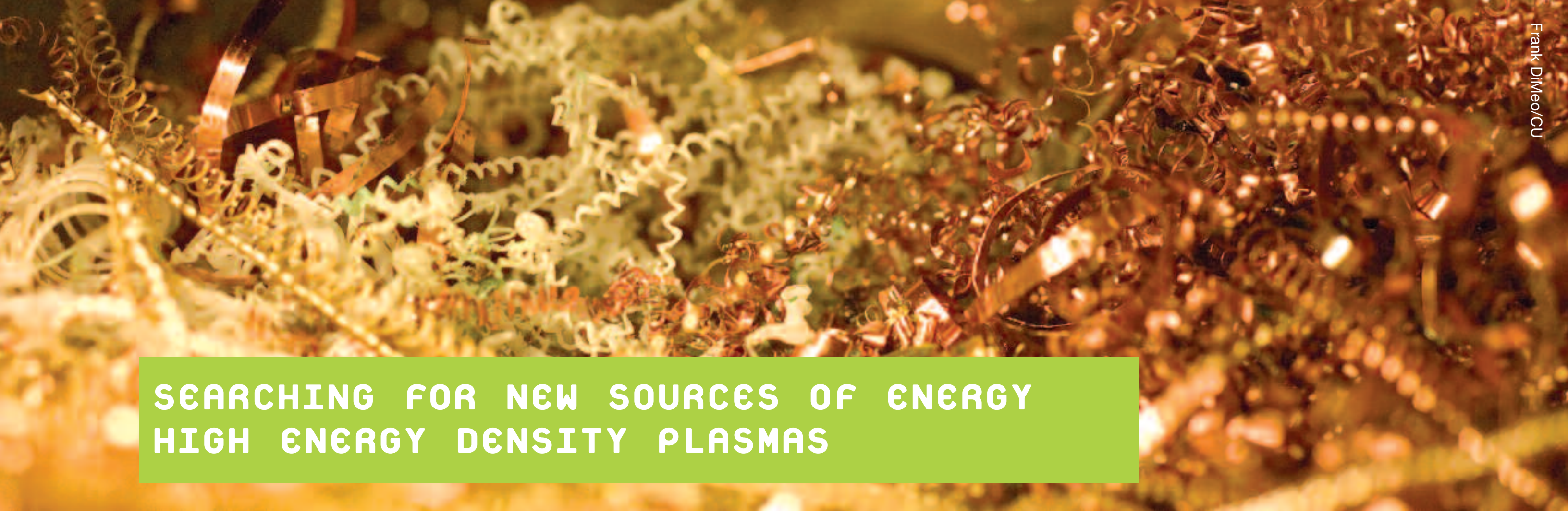

Frank DiMeo/CU

SEARCHING FOR NEW SOURCES OF ENERGY
HIGH ENERGY DENSITY PLASMAS

The Center for the Study of Pulsed-Power-Driven High Energy Density Plasmas

At temperatures of 10 thousand to 10 million degrees, researchers study matter with ordinary solid densities in laboratories. At these high temperatures, the components of the atoms break apart into electrons and ions that can move freely among each other, forming a dense plasma (ionized gas). This is not easy to study. The difficulty lies with both making the hot, dense plasma and measuring its properties. For these reasons, studies of "high energy density" matter have only recently become of great interest to the research community.

New tools developed for controlled fusion research, nuclear weapons science, and astrophysical observation only now enable researchers to investigate, at close range, the high energy density regime like that at the center of the sun or an exploding star forming a supernova.

Interest in HED physics has been stimulated by research in plasma physics, astrophysics, inertial confinement fusion, and the fundamental properties of solid-density matter at high temperature. A recent publication of the *National Research Council, Frontiers in High Energy Density Physics—The X-Games of Contemporary Science* (National Academies Press, 2003), makes clear that new research tools developed for controlled fusion research, nuclear weapons science, and astrophysical observation only now enable researchers to investigate, at close range, the high energy density regime like that at the center of the Sun or in a star that is in the process of exploding to form a supernova.

One method of producing high energy density plasmas is to use extremely powerful laser pulses. A second approach, the one Cornell uses, employs high current electrical pulses that last fractions of a microsecond. These pulses are produced by the technique referred to as pulsed power technology. The main difference in the physics of the two methods is that in the pulsed power approach, magnetic fields are dominant in both the production and compression processes while magnetic fields are not as important in the laser approach. For some experiments, high energy density matter can be produced at a much lower cost with the pulsed power approach.

The Center for the Study of Pulsed-Power-Driven High Energy Density Plasmas—established at Cornell in October 2002 by an agreement between Cornell and the Department of Energy's National Nuclear Security Administration—exploits the benefits of the pulsed power technology relative to the laser technique. With Bruce R. Kusse, Applied and Engineering Physics, as director, and David Hammer, Electrical and Computer Engineering, as associate director, this is a natural for Cornell with its long-standing experience in the application of pulsed power technology conducted in Cornell's Laboratory of Plasma Studies.

The Center for the Study of Pulsed-Power-Driven High Energy Density Plasmas exploits the benefits of the pulsed power technology, which is one way of producing high energy density plasmas.

Robert Barker/CU

Graduate student David Chalenski inserts an array into the COBRA pulsed power generator.

HED studies have practical applications like the development of new energy sources and the study of basic physical phenomena under extreme conditions of high density and temperature.

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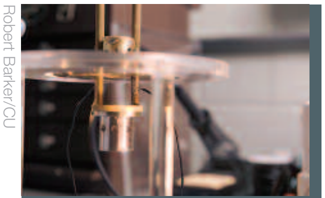

An array of 8 Tungsten 15 micron wires

Other participants in the Center for the Study of Pulsed-Power-Driven High Energy Density Plasmas, in addition to Cornell, include the University of Rochester, the University of Nevada, Reno, Imperial College (London), the Weizmann Institute of Science (Israel), and the Lebedev Physical Institute (Moscow).

The center is positioned to carry out high quality, experimental, high energy density (HED) plasma physics research and to train graduate and undergraduate students in HED studies. The center conducts supporting theoretical work, such as computer simulations of phenomena in order to help understand the experiments. The research portfolio of the center consists of studies of laboratory plasmas for their own sake, as well as laboratory experiments intended to simulate astrophysical phenomena. HED studies have practical applications, like the development of new energy sources, in addition to the study of basic physical phenomena under extreme conditions of high density and temperature.

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Graduate student Katherine Chandler at COBRA

The center is uniquely positioned to investigate this newly emerging field—high energy density physics using pulsed power technology—and to train students in it.

For more information:

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The Laboratory Instrumentation and Regime

The HED regime can be characterized by an energy density at least a million times higher than ordinary atmospheric pressure (a pressure greater than 1 million atmospheres, or an energy density greater than 100 billion Joules per cubic meter). This is the energy density at which the strongest materials lose their structural integrity and ordinary solid matter starts to turn into plasma.

The center's concentration—generating HED material using pulsed power technology—entails a laboratory regime that is accessed only for short times, on a pulsed basis. A major effort for the first year and a half has been the construction of a unique experimental user facility called COBRA. This pulsed power machine is capable of generating 100-200 nanosecond pulses of current in excess of 1 million amperes. The HED plasmas are produced by current-driven explosions followed by implosions of arrays of very fine wires. The implosions are driven by the magnetic fields associated with the high current pulses.

COBRA, commissioned on July 2, 2004, is now available for users including scientists from other universities and laboratories and Cornell's own graduate and undergraduate students. In addition to COBRA, other experimental facilities of the center include a similar high current generator at Imperial College called MAGPIE, several smaller pulsed power machines, and many diagnostic instruments.

Starting from fine metal wires, typically ≤ microns in diameter, the scientists study the initiation phase of the current-driven wire explosion process with currents ranging from 1 kiloampere (kA) to a few hundred kA per wire. The latter implosion phases when the plasmas become very hot and dense, emitting copious quantities of x-rays. Work includes single wire experiments, linear wire array experiments with from two to four wires, multiwire cylindrical configurations, and the X-pinch configuration (a novel point x-ray source and diagnostic). The center's diagnostic instruments include visible, ultraviolet, and x-ray detectors—including spectrometers and imaging devices—and current and voltage monitors for the pulsed power machines.

When cylindrical wire arrays are exploded by large current pulses, magnetically driven implosions of the plasma occur, compressing the wire material onto the cylindrical axis and establishing a configuration known as a z-pinch. This magnetic implosion produces extremely large bursts of x-rays. The Sandia National Laboratories in Albuquerque, New Mexico (SNLA), uses a 20 million ampere pulsed power generator called Z to generate imploding z-pinch plasmas that produce

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Beam splitting prism

for some experiments, high energy density matter can be produced at a much lower cost with the pulsed power approach.

up to two million Joules of x-rays with peak powers up to 200 trillion Watts.

The SNLA experiments motivated Cornell's initial studies of individual exploding wires and 2-4 wire linear arrays as well as the cylindrical wire array experiments that will be conducted on COBRA. Cornell's research activities will also involve wire-array z-pinches and X pinches for laboratory simulation and studies of astrophysical phenomena. These experiments will study the interaction of astrophysical-type plasma jets with target plasmas and radiation-dominated dense plasmas. The X pinch can also be used to study the atomic physics of highly stripped high-Z elements.

Underway are parallel efforts involving theory and computer simulations of the experiments to understand the laboratory observation and to optimize the resulting energy density. Computer simulations, in particular, are necessary because HED plasma physics interactions are extremely complex and highly nonlinear.

The Center for the Study of Pulsed-Power-Driven High Energy Density Plasmas is uniquely positioned to investigate this newly emerging field of high energy density physics using pulsed power technology. This regime of work has only recently become possible to study in the laboratory. It provides an invaluable environment for fostering international collaborations and for training students in a developing field.

Bruce R. Kusse
Applied and Engineering Physics

At temperatures of 10 thousand to 10 million degrees, researchers study matter with ordinary solid densities in laboratories.

Bruce Kusse, Applied and Engineering Physics, director of the Center for the Study of Pulsed-Power-Driven High Energy Density Plasmas

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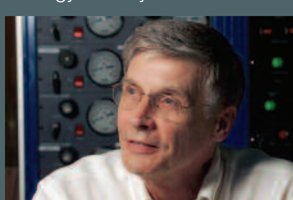

David Hammer, J.C. Ward, Jr. Professor of Nuclear Energy Engineering, associate director of the Center

Frank DiMeo/CU

Daniel Lundberg '05, undergraduate researcher, at COBRA

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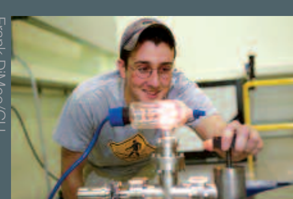

Katherine Chandler, graduate student, in an RF isolating screen room

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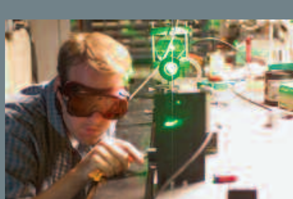
Marc Mitchell, graduate student, adjusts a laser diagnostic

Frank DiMeo/CU



Christopher Morris (r.), undergraduate researcher, with Professor David Hammer (l.)

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Installation of a cylindrical array at COBRA

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Jon Douglas, graduate student, constructs cylindrical array of Tungsten 15 Micron wires

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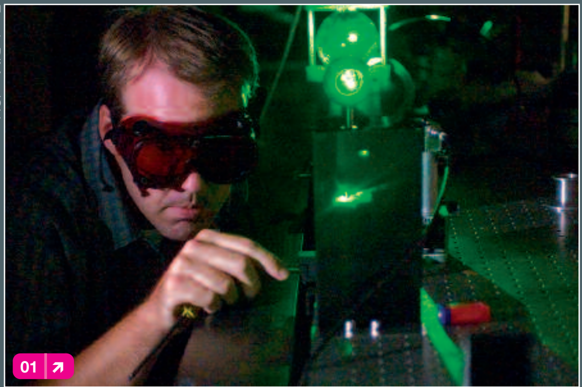

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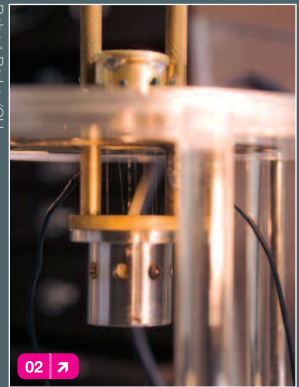

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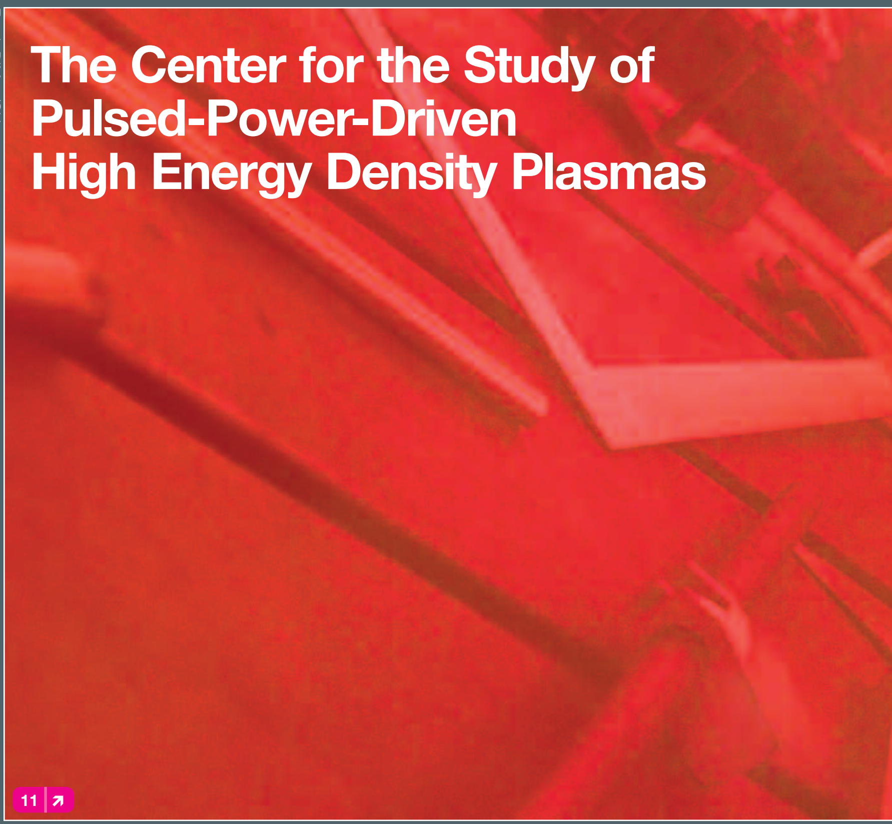

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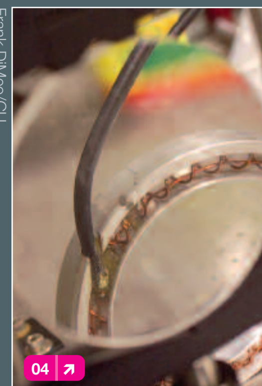

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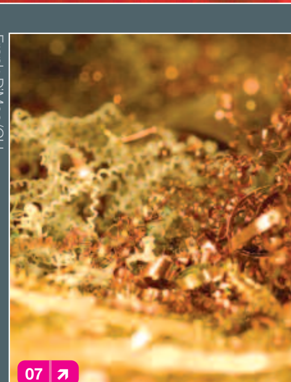

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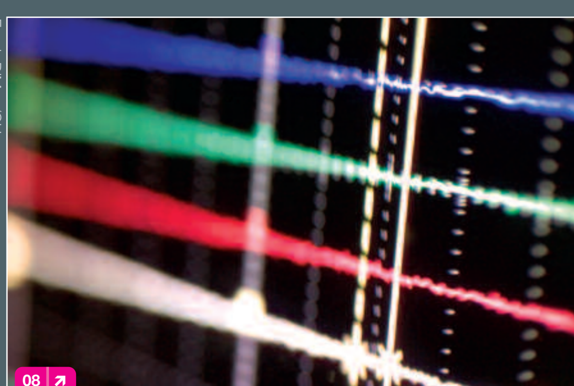

01. Marc Mitchell, graduate student, adjusts a laser diagnostic

02. An array of 8 Tungsten 15 micron wires

03. (l. to r.) Christopher Morris, Professor David Hammer, and Daniel Lundberg '05, Applied and Engineering Physics, at COBRA

04. Ragowski coil for current measurements

05. Oscilloscope connections

06. (l. to r.) Undergraduate student Daniel Lundberg and graduate student Katherine Chandler

07. Scrap metal

08. Digitizing oscilloscopes

09. Welding bench through a UV shield

10. RF shielded screen room where data is collected and recorded; the shield blocks electromagnetic RF pulses to minimize the noise on the data channels.

11. Welding bench through a UV shield