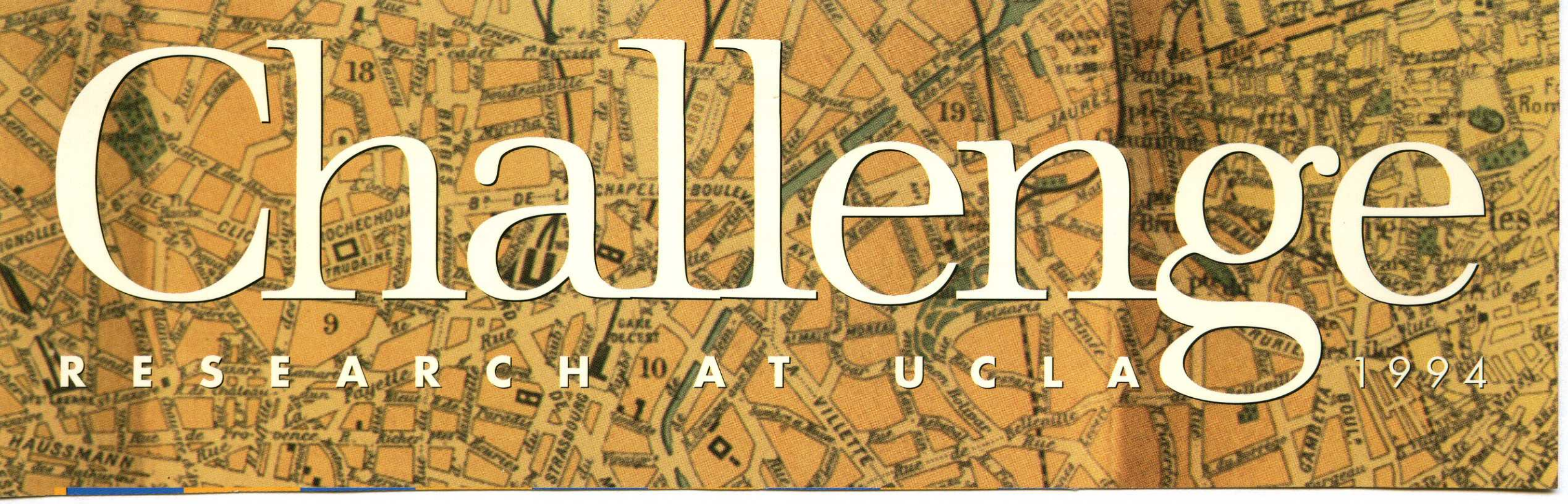


Challenge

RESEARCH AT UCLA 1994

Riding a 'Beat Wave' of Progress

In their insatiable quest for ever-higher energies in the machines they use to study the fundamental forces of nature, physicists have run up against the decidedly un-cosmic constraints of their wallets—as accelerators become more powerful, they grow larger and prohibitively expensive. Now, UCLA researchers have demonstrated that a new method of accelerating electrons, employing a pair of lasers to create a plasma "beat wave," can propel the particles on a far more rapid pace than has been achieved by conventional, radiofrequency-powered accelerators.

Culminating more than a decade of experiments, the UCLA researchers, led by Dr. Chan Joshi, professor of electrical engineering, reported the first conclusive evidence of significant acceleration of electrons by plasmas. Their technique beams in two lasers of different frequencies designed to cause peaks or "beats" in intensity at regular intervals, which excites strong plasma waves. Once injected, electrons ride the crest of the wave—much as a surfer would—picking up energy.

Joshi and colleagues (Drs. Chris Clayton and Ken Marsh, both from the Department of Electrical Engineering at UCLA) reported accelerations 50-100 times that achieved by modern radiofrequency machines—albeit over a small distance. "We've shown we can build a very fast car," Joshi told the New York Times. "But we don't know if it will go very far." Expanding the length of the acceleration region is next on the researchers' list.

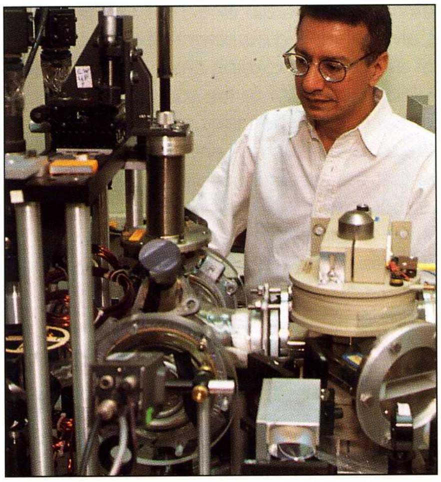
Nonetheless, the news that the UCLA scientists reached an energy of 30 mega-electron volts (MeV) over a distance of 1 centimeter with a "beat wave" form of plasma particle acceleration was greeted with great enthusiasm among physicists, whose demand for increasingly higher-energy accelerators has begun to outstrip their affordability. But the potential for smaller, cheaper accelerators promises to affect not just those already engaged in high-energy research; by cutting the genre down to size, the new technology opens the door to compact X-ray sources for medical therapies, biological studies, materials analysis and semiconductor processing, to name a few possible applications.

"It's a bit like what happened when personal computers became available," says Dr. John Dawson, the UCLA professor of physics whose early laboratory simulations and writings inspired Joshi's work. "The big computers were available for a long time, but when people got PCs, suddenly everyone was able to use them and computers became a much more powerful tool than they were when only huge laboratories with big budgets had them. If we can bring the size and cost of these accelerators down to the point where any researcher could have one in his or her laboratory, a lot more practical applications could be addressed."

The UCLA "beat wave" accelerator is based on the principle that a laser beam fired into a cloud of hydrogen will superheat the gas, stripping the electrons from their nuclei, and create a plasma. The process begins with two laser beams of different frequencies at a power level of a trillion watts. These powerful laser beams are focused by mirrors down to the size of approximately .05 centimeters into a column of two centimeters of hydrogen gas enclosed in a sealed chamber. Plowing through the gas, the laser pulses rip the electrons right off their atoms, creating the plasma—gaseous nuclei with no orbiting electrons.

Through this process, a pulsing wave is created by the overlapping laser frequencies, which alternately add and cancel each other. These alternating peaks of high and low intensity are like the peaks and valleys of a wave. As the hundreds of peaks and valleys in a single laser pulse pass through any given region in the plasma, more and more electrons from that region are recruited into this "beat wave" movement—resulting in a steadily increasing wave of charge, moving through the plasma along with the laser. Once the wave effect is created, a fresh cluster of electrons is shot into the plasma behind the laser beam to "surf" the wave, picking up energy and following the laser beam at near-light-velocity.

Dr. Chan Joshi with "beat wave" accelerator.



For years, physicists have relied on high-energy particle accelerators to glimpse the processes of creation. By smashing charged bits of matter together at nearly the speed of light, they attempt to re-create the conditions that prevailed just after the Big Bang, the explosion from which the universe is believed to have emanated.

Rising to energy levels of 1 MeV, the cyclotron accelerators of the 1930s simulated conditions in the cores of giant stars and produced a laboratory environment for studying nuclear reactions. Next came synchrotrons and linear accelerators, able to reach 1 billion electron volts and simulate the interior of neutron stars, revealing the existence of anti-matter. Most recently, synchrotrons have soared to 1 trillion electron volts, showing the conditions present in the universe within a billionth of a second of its birth. As scientists move closer to the secrets of creation, they demand still higher energies from accelerators. Unfortunately, these machines not only continue to get larger in size, but their cost has soared to the point where few nations can afford them.

"By 30 years from now, physics machines will be getting too costly, too big, and some kind of revolutionary approach will be required," says Joshi.

In 1979, Dawson and postdoctoral student Toshiki Tajima posed such an approach, suggesting from their laboratory simulations that electric fields generated within a neutral plasma could be used to accelerate charged particles to very high energies in a very short distance. Joshi read their paper with great interest, and when he arrived at UCLA the following year he paid Dawson and Tajima a visit. After initially proving that plasma waves could be excited with laser beams, Joshi and colleagues set about demonstrating acceleration. The key to their success? "UCLA has a unique mix of theorists, computer simulationists, and experimenters," Joshi explains. "We went down many wrong paths, but the synergy was there to do it."

With that accomplished, they are now attempting to extrapolate the experiment to see if the same acceleration rate could be maintained over the space of approximately a foot, in which case the device would reach a giga-electron (1 billion) volts. "That would open up many practical possibilities," Joshi says.