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Megalasers to pulse in several new EU countries

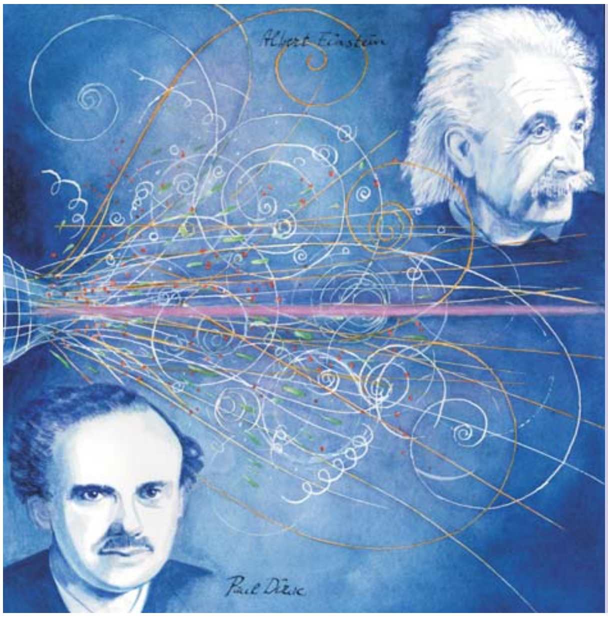
As the world celebrates 50 years since the invention of the laser, a European facility approaching exawatt power is expected to stimulate new research areas and communities.

"You are bound to find new physics," says Wolfgang Sandner, referring to the Extreme Light Infrastructure, a multisite project in the works in Europe that will start off with several 10-petawatt-class lasers and aims to build a 200-PW laser. "Some of it can be identified, but there will be lots more that we don't even think about at the moment. ELI would be two orders of magnitude beyond today's state of the art in laser intensities," says Sandner, a project steering committee member, director of the Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy in Berlin, and coordinator of a network of 26 European national laser physics laboratories. Research topics planned for ELI include attosecond (10^{-18} s) science, nuclear physics, laser particle accelerators, and the structure of the vacuum.

"ELI is the first truly international laser research project in the world," claims Sandner, who puts free-electron lasers in a different category because "from a physics point of view, they are accelerators. They grew out of a different community." Based on population inversion and stimulated emissions, ELI evolved out of the tabletop lasers invented 50 years ago. "The laser community is a bottom-up community," Sandner says. "It grew from individual labs to national labs—we are there now—and we are making the next step toward international facilities." Thirteen countries are involved in ELI's preparatory phase, which goes through November. After that, countries will have to buy in to join the collaboration.

Sites have so far been selected in Szeged, Hungary; outside of Prague in the Czech Republic; and in Măgurele, Romania. Each will be the biggest investment in science to date in those new European Union (EU) member states. "The whole ELI project is very significant for the three host countries," says Gábor Szabó, a physicist at the University of Szeged and science adviser for ELI's Hungarian site. "It's the first time such large-scale infrastructure will be built in the former socialist countries. It's something we have been waiting for for a long time." Regardless of whether it's a neutron source—Hungary had vied to host the European Spallation Source, which is to be built in Sweden (see PHYSICS TODAY, March 2010, page 24)—a tokamak, or other machine, "a big scientific facility brings a culture inherent to these investments," says Szabó.

GÉRARD MOUROU AND LOU GIESEN



Boiling Vacuum, a painting by Gérard Mourou and Lou Giesen, represents the breakdown of a vacuum by the electric fields that the Extreme Light Infrastructure's most powerful laser will produce. Particles and their antiparticle counterparts swirl around, and some of Albert Einstein's theories may be tested by experiments with ELI; Paul Dirac is present in this painting in recognition of his prediction of the existence of antimatter.

Basic research and applications

Each site will have high-power lasers and attending equipment optimized for a distinct area of research (see table). In Hungary, the focus is attosecond science. Twenty-femtosecond pulses from a 1-PW optical laser will shoot into a gas or solid target and be compressed via a Doppler shift into attosecond pulses of x rays. One plan, says Szabó, is to do pump–probe experiments. A 10- or 20-PW laser will vaporize a target into plasma. "Then you study it with the attosecond probe. You don't want the prepulse to preheat or destroy the target."

The attosecond regime is "where you can see electrons going around the atom in an almost instantaneous, stroboscopic way. Until now, electrons have been seen only as a blur," says Toshiki Tajima, ELI scientific committee chair and a physicist at Ludwig-Maximilians University in Garching, Germany. The high repetition rate is a bonus, he adds. "And because the photons are coherent, you can also manipulate the electrons. You might see how quantum mechanics works. The Hungarian pillar of ELI will advance attosecond science in a very deep way." (See also the article by Henry Kapteyn, Margaret Murnane, and Ivan Christov in PHYSICS TODAY, March 2005, page 39.)

The focus in the Czech Republic will be creating tabletop particle accelerators. "We have the goal of producing secondary sources of x rays, gamma rays, and particles for fundamental research and applications in materials science and biomedical research," says Bedřich Rus, scientific manager of the Czech effort.

New methods to transform transverse oscillating electromagnetic fields into forward-directed electric DC fields make it possible to accelerate electrons or ions with a laser, as Sandner explains. For electrons, ultrashort laser pulses plow through a gas-filled capillary. The electrons in the resulting plasma are accelerated by riding the wake fields behind the laser pulses (see the article by Wim Leemans and Eric Esarey, PHYSICS TODAY, March 2009, page 44). Ions can be accelerated by pushing an electron cloud through a thin foil into a vacuum. The field cre-

Lasers planned for the Extreme Light Infrastructure*

Country	Facility focus	Power (PW)	Pulse energy (J)	Pulse width (fs)	Rep rate (Hz)
Romania	Nuclear physics	10 (×2)	200	20	0.1
Hungary	Attosecond physics	1	5	5	1000
		20	400	20	0.1
Czech Republic	Secondary beam radiation, high-energy particles	1	10	10	10
		5	50	10	10
		10 (×2)	200	20	0.1
To be determined	High intensity	10 beams of 10–20 PW each, phased and combined to create total power of 100–200 PW			

*Laser parameters still subject to change.

ated by those electrons pulls ions from the foil, forming a collimated beam ready for applications. Lasers have the advantage of strong fields and therefore compact acceleration: Meters, rather than kilometers with conventional accelerators, would be needed to reach a given energy. In principle, says Sandner, lasers could accelerate electrons well above TeV energies.

"The duration and luminosity is unique to these sources because lasers produce incredible concentrations of energy in spacetime," says Rus. "The new thing is that you can produce femtosecond flashes of gamma rays and electrons of 50–100 GeV." One application could be to treat tumors. By forming the proton or ion beam near the patient, the cost and bulk of large magnets could be circumvented. For that, high rep rate is crucial, says Gérard Mourou, director of the Institute of Extreme Light at Paris's École Nationale Supérieure de Techniques Avancées and the initiator and coordinator of ELI. "You can't expect a patient to keep absolutely still for an hour."

Nuclear physics is the focus of ELI in Romania. The site will have two 10-PW lasers and a 600-MeV electron accelerator to produce gamma rays. The gamma rays will be used to excite nuclei, and then the lasers will probe how long it takes the nuclei to relax back. "Atomic physics was revolutionized by lasers. The nucleus is more tightly bound [than an atom], and 1- to 10-MeV gamma-ray beams could revolutionize nuclear physics," says Tajima. With ELI, adds Mourou, "the power is such that you can start doing nuclear spectroscopy to see how protons and neutrons interact with light and with each other. This is completely new."

One likely application at the Romanian site is to study aging of materials, such as reactor and tokamak walls that get bombarded with neutrons. "We would like to slow down aging," says Mourou. Another application will be to treat nuclear waste by transmuting long-lived isotopes into shorter-lived ones.

Extreme power

The fourth pillar, which would consist of a 100- to 200-PW laser, "gave the name to the project," says Mourou. "We want to shoot the laser into vacuum, with an electric field so high that it dissociates particles and antiparticles. We want to study the structure of the vacuum. This is extremely important. Everything comes from the vacuum. The vacuum is the mother of all particles." For example, he notes, all the fundamental constants in physics are dictated by the vacuum.

The electric fields of ELI's lasers "will shake charged particles much harder than what is currently available," says Tajima. "If we get intense enough fields to shake even where there is no matter, the laser can shake the nothingness—the vacuum. This could make a qualitative difference in physics." In fact, he says, ELI's lasers may not be intense enough, "but even below breaking down the vacuum, with clever ideas we could begin to see nonlinear interactions. We are thinking about how to become clever enough to do this new physics even at 10 PW." One trick, he says, would be to combine laser light and gamma rays to break down vacuum more easily. And, he says, with a 200-PW laser "it may finally be possible to test Einstein's equivalence principle—gravity is equivalent to acceleration—in an extreme limit. We could study the general relativistic effect and see how the theory pans out."

"We are starting to tickle the tail of the dragon with relativistic plasmas. Going up 100 times in intensity will lead to plasma found only in exotic places in astrophysics," says Todd Ditmire, who heads a 1-PW laser facility at the University of Texas at Austin and is considering collaborating with the Romanian branch of ELI. "We are not going to let the grass grow under our feet just because the Europeans are going ahead with ELI." He notes UT's involvement in a US university-industry-national lab team that is talking about an exawatt (10^{18} W) laser.

Paul Drake of the University of Michigan, whose article on high-energy-density physics appears on page 28 of this issue, says, "The ELI project is trying to push up by a significant amount in intensity and an awful lot in rep rate. I would note that Gérard Mourou is one of the greatest developers in technology around. If it can be done, that team ought to be able to do it."

Competing technologies

Two different technologies for chirped-pulse amplification (CPA; first demonstrated 25 years ago by Mourou) will be used for ELI's 10-PW lasers, and tests getting under way in the UK and France will narrow the choice for the 100-PW-class laser, which will be the sum of 10 beams of 10–20 PW each.

The pros of optical parametric CPA, says Mourou, "are that the material is transparent, so no energy is deposited. The amplifier does not heat up. And it has high gain." One con is that it uses a very short pulse pump, on the order of 1 ns.

The other candidate is titanium:sapphire CPA. It uses a longer pulse pump (roughly 30 ns), but growing large enough titanium:sapphire crystals is slow and tricky. "The devil is in the details," says Mourou. "Only when you understand the technologies fully can you make the decision."

"It's a binary decision between two competing technologies," says Sandner. "We are confident both would work, and we have the luxury to develop both to 10 PW in the context of the first three pillars. We don't lose time—we gain security to have the best available technology without having to make a premature decision." The specifications and the site for ELI's highest-power laser will be set in 2012.

More sites, more impact

Originally planned for a single site, ELI was spread by politics over at least three countries. The former Soviet bloc countries are eager to take part in the pan-European project, but will contribute significantly only if they can host it. Each site will cost an estimated €280 million ($350 million) to construct and €30 million a year to run. So making the more than €1 billion ELI a multisite project eases the fundraising process. Money for the first three pillars is close to certain, but must still be found for the 100-PW site.

Most of the money will come from EU structural funds to new members. "This money is foreseen for social cohesion, and it's basically devoted to less-developed regions," says Szabó. So far, he adds, such monies have been used mostly for roads, sewage systems, and the like. "But now the idea is that social cohesion could be supported by investing in science." That money is the good news, although some bureaucratic hoops still have to be jumped through before it is finalized. The bad news, says Szabó, "is that these funds have to be used very quickly. The money is not available beyond 2015. If we cannot make ELI quickly enough, we may face problems at the end of the story." In Hungary, soil mechanics studies are under way, and construction is slated to start next year.

Because of additional buildings, lasers, and other redundancies, splitting the project boosts ELI's tab by about €300 million, says Mourou. It will also be more complex to run. But each country is committing €250 million to €300 million. Mourou, who initially opposed splitting the project, says that in giving talks he "started to feel the impact. You could see the excitement of people in these countries. I started to see that we are broadening the community. You have to weigh things. The pros are much bigger than the cons." Among the pros, Mourou lists the solid commitment from three countries, a larger workforce and more lasers total, and more opportunities for students. All told, he says, "the impact will be much bigger."

ELI "will be an example of a distributed facility," says Rus. "We have one mission, coordinated goals, one governing body, and one user community."

The project is also a good marketing tool, Szabó says. "We have to work hard to produce the necessary human resources. The whole European laser community is not enough to build and run ELI. We need to get new young talent into the business." One effort is a master's program being launched jointly by three Hungarian universities to train students in laser physics. Educational programs that link the three pillars are also in the works. Says Szabó, "We are also trying to attract people from other countries. It is generally perceived that we need people available in the next five to seven years. This is not unrealistic. We hope they will want to come here. These places will be the top places in laser physics." **Toni Feder**

DOE begins rationing helium-3

As the extent of the shortage becomes clear, an interagency task force is giving scientific users priority, but some say the material is not available at any price.

Casting about for new sources of helium-3 to alleviate what one Department of Energy (DOE) official has called "a critical shortage in the global supply," a federal interagency task force is seeking to strike deals with Canada and is exploring other avenues to obtain additional supplies. In the meantime, some scientific users of ^{3}He have reported having to pay more than $2100 per liter of the gas for an isotope that cost them less than $100 a couple of years ago.

On the heels of a broad ^{3}He crisis (see PHYSICS TODAY, October 2009, page 21) and with DOE's inventory of the gas now well below a single year's demand, the task force instituted a rationing system this year that gives first priority to applications that have no known substitute. Topping the list are cryogenics needed for physics below 1 K, ring lasers used for missile guidance and space navigational systems, and magnetic resonance imaging of the lungs. The interagency group suspended all distributions in 2009 and curtailed releases this year to less than 12 000 liters of world demand, estimated at 70 000 to 76 000 liters, while it seeks ways to address the shortage of ^{3}He for use in radiation monitors at ports, airports, and border crossings—which had been the largest ^{3}He consumer by far. A warning by DOE officials that scientists at neutron scattering facilities abroad need to look elsewhere for their requirements has set off a scramble to find alternative neutron-detection technologies.

In addition, the International Atomic Energy Agency has been informed by the US, long the IAEA's major supplier of ^{3}He for nuclear safeguards inspections, that future shipments are unlikely. The US provided just 1800 of the 2800 liters that the IAEA had requested for this year.