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NIF achieves new fusion output milestone

The latest experiments put laser fusion "at the threshold" of a burning plasma, though ignition remains elusive.

David Kramer

https://physicstoday.scitation.org/do/10.1063/PT.6.2.20180615b/full/

Researchers at the National Ignition Facility (NIF) have taken another step toward their long-overdue goal of using lasers to attain a self-sustaining nuclear fusion reaction. On 14 June in*Physical Review Letters*, researchers described experiments that doubled previous records both for neutron yield (now at 1.9×10^{16}) and fusion energy output (now at 54 kilojoules) generated from capsules containing cryogenic deuterium–tritium fusion fuel. The progress was due largely to changes to both the capsules and the hohlraums—cylinders in which the capsules are suspended—that helped maintain the symmetry of the fuel's implosion.

"This is a critical step forward in the quest for achieving laboratory ignition," says Richard Petrasso, a senior scientist with MIT's Plasma Science and Fusion Center who was not involved in the research. Ignition—the point at which the heating provided by nuclei in the plasma exceeds the heat lost from the system—has been pursued primarily for its relevance to nuclear weapons physics, since it would mimic on a laboratory scale the dynamics in a weapon's fusion stages. Laser fusion is also considered a possible future energy source.

When NIF was completed at Lawrence Livermore National Laboratory in 2009 at a cost of $3.5 billion, researchers were confident they would attain ignition by 2012. But hydrodynamic instabilities and laser–plasma interactions that weren't foreseen in computer simulations have kept experimenters from achieving the uniform implosions that are required for the reaction. Since that time, slow but steady improvements have been made by adjusting various parameters in hohlraums and capsules and by fine-tuning the timing of laser pulses. Hohlraums convert the laser's UV light to x rays that drive capsule implosion.

In the latest round of experiments, the capsule shells consisted of diamond doped with a thin layer of tungsten, and the hohlraums were made of depleted uranium. Earlier experiments had used plastic shells and gold hohlraums. Sebastien Le Pape, lead author of the paper, says the uranium hohlraum boosted the peak energy deposited on the capsule by 25 terawatts, for a total of about 450 TW.

The D–T fusion reaction produces neutrons and alpha particles, or helium nuclei. Though the neutrons can’t be contained, trapping enough alpha particles in a compressed plasma will add heat and thereby boost the fusion yield.

Omar Hurricane, the chief scientist for inertial confinement fusion at Livermore, says the experiments put NIF “at the threshold of achieving a burning plasma state,” in which alpha-particle deposition surpasses compression to become the main source of plasma heating. The latest shots have achieved 360 gigabars of pressure—exceeding that at the center of the Sun—which is around 70% of what’s needed for ignition, says E. Michael Campbell, the director of the University of Rochester’s Laboratory for Laser Energetics who was not involved in the NIF experiments. He says about 10 times as much alpha heating will be needed.

“Not too many more doublings” will be required for ignition, Hurricane says, although he and Le Pape caution that scaling from the results isn’t linear. Ignition won’t be indicated simply by having surpassed some number of neutrons or other single benchmark. Researchers use the Lawson criterion, which defines the minimum values for plasma temperature, confinement time, and density in determining the conditions at which ignition will occur.

Hurricane says the ignition program continues its quest to improve both the quality and the scale of implosions. Scaling up didn't make sense until now because implosion symmetry couldn't be controlled. Over the past two years, scientists were able to discern a "relatively simple" underlying pattern in symmetry control that should allow larger implosions. Further advances will unfold over the next year or two, he says. "Things don't go quickly in this business."

Whether NIF's 1.8 megajoule peak energy capacity is sufficient to achieve ignition remains unknown.

The new results were achieved before the Trump administration proposed cutting funding for NIF by $57 million, to $287 million in fiscal year 2019. That would have forced a 30% reduction in the number of experimental shots of the 192-beam laser. Lawmakers instead added to NIF's funding next year: The final appropriation will likely end up between the $330 million included in a House-passed bill and $344 million included in a Senate measure.

2.

14/06/2018 19:52	**Large batch of equipment delivered from Russia to France** http://www.akm.ru/eng/news/2018/june/14/ns6046451.htm

Another batch of electrical equipment for future installation at the ITER (International Thermonuclear Experimental Reactor), the largest batch to date, was successfully delivered from Russia to France on June 13, according to the press service of the Institution Project Center ITER (operating as part of Rosatom Group).

This consignment was made up of 22 km of coaxial cable lines made by Sevkabel Group of Companies LLC to the order of JSC NIIEFA, the general contractor under this system.

The 38 drums with the cable lines with a total weight of more than 225 tonnes were delivered using 13 specially equipped cargo trailers.

Rosatom was established on December 18, 2007, its core is state-owned holding JSC Atomenergoprom consolidating all the non-military assets of Russia's nuclear industry. Besides, the state-owned corporation operates the nuclear icebreaker fleet.

Rosatom is the largest power generating company in Russia accounting for over 40% of electric power in the European part of the country. Rosatom is a global nuclear technologies market leader ranking first worldwide in the number of simultaneously constructed nuclear power plants abroad, second in the uranium reserves and third in its extraction; in terms of nuclear electric power generation, Rosatom stands second worldwide, accounting for 36% of the global market of uranium enrichment services and 17% of the nuclear fuel market.

"AK&M", 14.06.2018 12:44

3. India to host world's largest IAEA fusion energy conference

Preparations for the event is in full swing with scientific papers being called for from over 1,000 fusion energy scientists from across the world.

Paul John | TNN | June 15, 2018, 07:02 IST

https://energy.economictimes.indiatimes.com/news/power/india-to-host-worlds-largest-iaea-fusion-energy-conference/64594991

Ahmedabad: India will host the world's largest International Atomic Energy Agency (IAEA) fusion energy conference (FEC) at the Institute of Plasma Research (IPR) in Bhat in Ahmedabad. The five-day event will begin from October 22.

Preparations for the event is in full swing with scientific papers being called for from over 1,000 fusion energy scientists from across the world. It is for the first time that India has been chosen to host the prestigious IAEA fusion conference owing to it's ongoing Steady State Tokamak (SST-1) and India's role at providing a tenth of the components for the massive nuclear complex ITER unfolding at Cadarache in France.

For last six years, IPR's founder director, late Padma Shri Predhiman Kaw and later his successor D Bora had tried hard to convince the IAEA for holding the conference in India. This year the present director Shashank Chaturvedi will be hosting the event at IPR.

The conference will be a forum for discussing key physics and technology issues. It will also dwell on innovative concepts of direct relevance to the use of nuclear fusion as an eventual source of energy. The conference will address emerging challenges faced by fusion energy community — technological feasibility of fusion power plants and the economic considerations related to the introduction of fusion energy. The visiting scientists will also review the latest developments in nuclear fusion research and consider these results together with the requirements for a fusion power plant. Sources in IPR say that technologies developed at the Facilitation Centre for Industrial Plasma Technologies (FCIPT) will also be displayed during the conference

“In previous years the conference gathered significant contributions on progress and innovation in the field of fusion research,” says Sehila González de Vicente, the Scientific Secretary of the FEC in a press release. “We look forward to making tangible and documented outcomes once again.”

She also informs that the number of scientific papers submitted to the conference has increased significantly, from the initially 100-150 papers submitted in the 1960s, to more than 800 in 2016. The number of participants has doubled over the years from 500 to over 1000. A senior Department of Atomic Energy (DAE) official from Mumbai told TOI that the FEC is an opportunity for the country to encourage fusion research.

4. Amy Wendt envisions a bright renewable energy future for burning plasma

June 12, 2018

// ELECTRICAL & COMPUTER ENGINEERING

https://www.engr.wisc.edu/amy-wendt-envisions-bright-renewable-energy-future-burning-plasma/

Imagine an abundant energy source that could power the world without harming the environment.

Fusion energy—the same powerful reactions that keep stars burning—could provide a completely renewable alternative to fossil fuels while being much more reliable than solar or wind. What's more, fusion power plants will not emit greenhouse gasses nor produce long-lived radioactive waste.

"Fusion energy as a clean and viable energy source will have a huge impact on our society," says Amy Wendt, a professor of electrical and computer engineering at the University of Wisconsin-Madison.

Wendt is shaping the future of fusion energy research in the United States as one of 19 leaders of a National Academies of Science, Engineering and Medicine committee to develop a strategic plan for U.S. burning plasma research. Since 2017, the university researchers, government scientists and industry representatives have been attending meetings and gathering information for recommendations on U.S. strategy to realize fusion energy for electricity production by mid-century. UW-Madison is well-represented on the committee, as Wendt is joined by Cary Forest, a professor of physics.

To eventually achieve fusion energy, scientists have set their sights on burning plasmas, similar to the hot ionized gases found in stars. The most promising approach to harnessing burning plasmas is known as magnetic confinement fusion, where tremendously high temperatures combined with enormous amounts of compression causes atoms to start fusing, so that the energy released from those fusion reactions is enough to sustain the plasma without further external energy input.

The easiest path to fusion makes use of isotopic forms of hydrogen as the fuel, with helium formed as the fusion product. Magnetic fields produced by currents in the plasma and in exquisitely designed external magnet coils contain and compress the plasma until fusion begins.

But containing and compressing those hot ionized gases is anything but easy.

“It’s like taking a lump of Jello and trying to compress it with your hands—it wants to squirt out between your fingers,” says Wendt.

And that lump of Jello is at a temperature roughly 10 times hotter than the core of the sun.

Burning plasmas have not yet been sustained long enough to be a viable power source here on Earth. Even though plasma scientists have identified clear pathways to achieve that goal, a cost-effective power plant requires better understanding of how burning plasmas behave, as well as further development and testing of new technologies needed to fuel the sustained plasma and to collect the excess energy it produces.

Efforts are currently underway to build a burning plasma facility in the south of France, under the auspices of an international collaboration called the ITER organization. When completed, the ITER machine will weigh more than 23,000 tons, and the donut-shaped burning plasma confinement chamber will be more than six stories tall.

“It’s hard to convey the enormity of this construction project. It’s fantastically huge and complex and there’s a lot of new technology,” says Wendt. “When you’re standing in the room where the plasma chamber will be located, it’s like you’re in a Roman coliseum.”

The United states contributes machine components and financial support to the endeavor, and UW-Madison faculty, including engineering physics professors Ray Fonck, Paul Wilson and Oliver Schmitz, among others, have devoted their expertise to ITER over the decades.

Wilson, for example, was instrumental in developing software tools to measure radiation levels in the facility and Schmitz performed sophisticated modeling experiments to predict how the burning plasma will behave once ITER turns on.

ITER marked a major milestone in 2017 when it reached the halfway point for its construction. The facility should be up and running by 2025.

The National Academies committee issued a preliminary report in December 2017 that identified burning plasma experiments as necessary steps toward fusion power. Wendt, along with the other committee members, visited the ITER construction site in February 2018 as part of their evaluation of whether the United States should continue participating in the international collaboration or consider launching an independent burning plasma research effort.

The committee's preliminary report emphasized the potential benefits to the U.S. of combining scientific and engineering expertise through international collaboration if it remains a full partner. For example, supporting burning plasma experiments can help boost our country's overall industrial capabilities by advancing research in materials science, superconducting magnets, cryogenic cooling systems, ultra-precise construction, and robotic manufacturing.

The committee will make detailed recommendations a final report to be released in September 2018.

Even after the ITER burning plasma facility switches on in 2025, advances in many disciplines will be necessary to build a full-fledged fusion power plant. which is another reason why Wendt and the committee were invited to make recommendations on a long-term strategic plan for the United States.

“Fusion power on the electric grid is something that I will not see in my lifetime, but the potential benefit to humanity is incalculable. I think there’s a human drive to create these things that are bigger than ourselves, and in this case it is to meet a societal need,” says Wendt.

While visiting the ITER construction site, Wendt took a side trip to Paris where she marveled at the beauty and history of the Notre Dame Cathedral. Although French Gothic architecture shares few construction materials in common with burning plasma confinement chambers, Wendt was struck by connections between the labor of medieval artisans and that of present-day fusion researchers.

“The cathedrals were conceived by people with a vision powerful enough to sustain the construction over the lifetimes of many generations of contributors,” says Wendt.

Author: Sam Million-Weaver

5. Project *cuts turbulence to boost output from fusion reactors*

By **Helen Knight** 22nd June 2018 9:57 am

https://www.theengineer.co.uk/fusion-turbulence/

Fusion, the process that powers the sun, has long been seen as a potential means of generating abundant, clean energy.

However, despite years of research into the process, challenges remain about how to create and maintain the extremely high temperatures and pressures needed for sustained fusion.

One important factor is turbulence, which can decrease the temperature and pressure of the plasma inside the reactor, reducing the amount of fusion power that can be generated.

Now researchers at York University are investigating ways to suppress this turbulence, in the hope of increasing the amount of fusion power that can be produced by reactors such as the ITER Tokamak project in southern France.

The EPSRC-funded project, which also includes the UK Atomic Energy Authority as well as researchers from the Universities of Oxford, Strathclyde and Warwick, is also aiming to investigate ways in which the same amount of fusion power can be generated from smaller reactors, which would be cheaper and quicker to build and commercialise.

To generate thermonuclear fusion, a plasma of deuterium and tritium contained within a magnetic field must be heated to 100 million degrees Kelvin – ten times the temperature at the centre of the sun. This causes the nuclei to fuse together to form a heavier nucleus, helium, releasing large amounts of energy in the process.

As the plasma is heated, the pressure at the centre increases towards fusion conditions, while that at the edges remains low, to be compatible with the material surfaces of the vessel, according to Professor Howard Wilson at York, who is leading the project. “The steeper you can make your pressure gradient, the higher you can make your central pressure, and the more fusion power you’ll get out,” he said.

However, as the pressure gradient increases, it causes the plasma to begin churning, generating turbulence. This turbulence then pushes heat and charged particles out from the centre of the plasma to the edges, reducing the pressure gradient, and the amount of fusion power that can be produced.

“If this churning didn’t happen, then you wouldn’t get this loss of heat and particles across the magnetic field lines,” said Wilson.

“In this way, you could support a very big plasma pressure gradient, and achieve a high pressure in the centre and lots of fusion power,” he said.

Alternatively, you could achieve the same amount of fusion power, but from a smaller reactor, he said.

To investigate ways of suppressing this turbulence, the researchers plan to use advanced simulation, alongside experiments at the newly upgraded MAST-U reactor at the Culham Centre for Fusion Energy.

The researchers are developing models for how the plasma behaves, and how the turbulence is generated, but the process is an extremely complex one to simulate, said Wilson.

“Turbulence in a fluid like water usually only depends on what we call the fluid variables, parameters like pressure and flow,” he said. “But in a plasma, there are a whole range of new waves that don’t exist in neutral fluids like water or gas, as well as certain characteristic drifts of the particles that can resonate with those waves, amplify them, and cause them to crash and churn up the plasma, driving the turbulence.”

So the researchers are aiming to develop models that simplify this process while keeping as much of the plasma physics as possible. They will then compare their predictions with data from real tokamak reactors, such as MAST-U, he said.

“Then we can use our simulation codes to predict the level of turbulence that we’d expect to see in a real fusion reactor, like ITER, and how we should optimise the plasma scenarios to give us the lowest turbulence state.”

6. India to Reboot Rs 235 Cr Superconducting Fusion Tokamak: 7 Things to Know

The Steady State Superconducting Tokamak or SST-1 is an experimental fusion reactor in the Institute for Plasma Research (IPR), Gujarat.

by **Ahmed Sherrif**June 21, 2018, 2:26 pm

https://www.thebetterindia.com/146867/steady-state-superconducting-tokamak-reactor-india/

The need for clean, renewable and limitless energy has taken humanity from burning wood to obtaining energy from the sun via photovoltaic cells. And next in the line of clean energy are fusion reactors which are touted to be “mini suns” on earth.

Fusion reactions occur when two light atomic nuclei fuse together to form a heavier nucleus and release energy. Devices designed to harness this energy are called fusion reactors.

As simple as that sounds, it is the exact opposite when it comes to executing it. But that won’t deter experimentation.

The Steady State Superconducting Tokamak or SST-1 is one such experimental fusion reactor in the Institute for Plasma Research (IPR), Gujarat.

With just four months to go, the 27th International Atomic Energy Agency (IAEA) Fusion Energy Conference will be held in Gandhinagar, Gujarat. The conference aims to demonstrate the technological feasibility of fusion power plants as well as their economic viability.

Scientists at IPR are currently under the process of rebooting the experiment to meet the deadline of the IAEA Fusion Energy Conference. And the SST-1 will be one of the prime experiments to be showcased because of its unique capabilities.

Tokamaks are a type of fusion reactors which use magnetic force to manipulate plasma. Plasma is a type of matter where electrons are separated from neutrons, and this separation is usually achieved by heat. And India is a select few countries to own a Tokamak reactor.

So here are few things to know about the SST-1 fusion reactor that may be the answer to clean and limitless energy.

- The 235 crore SST mission started way back in 1994 and was conceptualised by 2005. But it was only fully commissioned by 2013. And until December of 2017, it has conducted about 20 experiments.
- By 2015, the SST produced repeatable plasma discharges up to ~ 500 ms with plasma currents more than 75,000 A. This gave incredible insights on how to stabilise the fusion for future experiments.

- One of the great things about fusion reactors is that they use hydrogen and isotopes of hydrogen. This means energy could even be extracted from a glass of water with no harmful byproducts.
- Routine experimentation in December 2017 revealed that the SST suffered some damage in its toroidal magnet system. “The damage is minimum. We will revive the reactor soon,” a senior IPR scientist, now part of the SST-1 team, told The Times of India.

- The SST-1 makes use of extreme heat and strong magnetic field to fuse hydrogen isotopes and perform thermo-nuclear fusion. This results in temperatures 20 times greater than the sun's core and a magnetic field equivalent to 1,000 times that of the earth's normal magnetic field.
- The SST-1 is the only Tokamak in the world to operate the toroidal magnets in a two-phase flow. This gives diversified results for a fusion study.
- Former IPR Director D Bora told the publication how the SST-1 achievements had brought India at par with China and South Korea as one of the eight participants in the International Thermonuclear Experimental Reactor (ITER).

The SST-1 promises to hold some clues and to be insightful for future fusion projects that can yield clean energy without depending on conventional methods like coal.

(Edited by Shruti Singhal)

7. Knighthood in hand, astrophysicist prepares to lead U.S. fusion lab

By Daniel Clery Jun. 19, 2018 , 2:20 PM

http://www.sciencemag.org/news/2018/06/knighthood-hand-astrophysicist-prepares-lead-us-fusion-lab

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It’s been quite a few weeks for Steven Cowley, the British astrophysicist who formerly headed the United Kingdom’s Culham Centre for Fusion Energy (CCFE). Last month, he was named as the new director of the Princeton Plasma Physics Laboratory (PPPL) in New Jersey, the United States’s premier fusion research lab. Then, last week he **received a knighthood** from the United Kingdom’s Queen Elizabeth II “for services to science and the development of nuclear fusion.”

Cowley, or Sir Steven, is now president of Corpus Christi College at the University of Oxford in the United Kingdom. He will take over his PPPL role on 1 July. He has a long track record in fusion research, having served as head of CCFE from 2008 to 2016 and as a staff scientist at PPPL from 1987 to 1993. PPPL is a Department of Energy (DOE)-funded national laboratory with a staff of more than 500 and an annual budget of $100 million. But in 2016, the lab took a knock when its main facility, the National Spherical Torus Experiment (NSTX), developed a series of disabling faults shortly after a $94 million upgrade. PPPL's then-director, Stewart Prager, **resigned soon after**. DOE is now considering a recovery plan for the NSTX, which is expected to cost tens of millions of dollars.

During Cowley's tenure at CCFE, that lab also started an upgrade of its rival to the NSTX, the Mega Amp Spherical Tokamak (MAST). Spherical tokamaks are a variation on the traditional doughnut-shaped tokamak design whose ultimate expression, the giant ITER device in France, is now under construction. The plan is for ITER to demonstrate a burning plasma, one where the fusion reactions themselves generate all or most of the heat required to sustain the burn. But once that is done, researchers hope spherical tokamaks, or some other variation, will provide a route to commercial reactors that are smaller, simpler, and cheaper than ITER. By upgrading the NSTX and the MAST, the labs hope to show that this type of compact reactor can achieve the same sort of performance as CCFE's Joint European Torus (JET), the world's largest tokamak right now and the record holder on fusion performance.

“We have to push down the cost and scale of fusion reactors,” Cowley told *Science*Insider shortly after the 16 May announcement of his PPPL appointment. “I fully support ITER because we have to do a burning plasma. But commercial reactors will need to be smaller and cheaper. A JET-sized machine would be so much more appealing. MAST and NSTX will be a dynamic team going forward.”

Despite the good food and well-stocked cellar on the Corpus Christi campus, Cowley says he is eager to return to the cut and thrust of laboratory life. “It’s too much fun. I was really feeling I missed the everyday discussions about physics and what was going on. I’m a fusion nut. We’re going to crack it one of these days and I want to be part of it,” he says. And PPPL, he adds, will be central to that effort. “Princeton is the place where much of what we know now was figured out. It’s a legendary lab in plasma physics. It’ll be fun to go and work with these people.”

His first job there will be to get the NSTX back on track. “I’m confident we can solve this problem. They’ve understood how the faults arose and they’ve understood how to fix them. If the money comes through, we will get NSTX back online," he says.

Cowley says the key goal for spherical tokamaks and other variants is to reduce turbulent transport, the process that allows swirling plasma to move heat from the core of the device to the edge where it can escape. If designers can figure out how to retain the heat more effectively, the reactor doesn't need to be so large. Spherical tokamaks do this by seeking to hold the plasma in the center of the device, close to the central column.

Another way to solve the heat problem is to increase a device's magnetic field strength overall by using superconducting magnets, an **approach being followed by researchers at the Massachusetts Institute of Technology** in Cambridge. "That can push the scale down," Cowley says, "but high field is not enough on its own. If there is a disruption [a sudden loss of confinement], that can be very damaging" to the machine.

Cowley thinks future machines may take elements from more then one type of reactor—including stellarators, a reactor type that has a doughnut shape that is similar to tokamaks, but with bizarrely twisted magnets that can confine plasma without needing the flow of current around the loop that tokamaks rely on. "There are beautiful ideas coming from the stellarators community," he says. Wendelstein 7-X, a **"phenomenal" new stellarator in Germany**, has been a major driver, he says.

What has changed dramatically in the past couple of decades has been "the ability to calculate what's going on," Cowley says. Advances in both theory and computing power means "we have all these new ideas and can explore the spaces in silicon. The field is driven more by science and less by intuition," he says. "It's quite a revolution."

Meanwhile, ITER construction trundles on despite numerous **delays and price hikes**. Cowley acknowledges that things have improved since the **current director, Bernard Bigot, took over**. "Bigot is an extremely good leader. He's steadied the ship; he makes decisions," Cowley says. "And they've got their team. It took time to find the right set of people." Building ITER is "an amazingly tough thing to do. Assembly [of the tokamak] will be quite challenging and hard to stay on schedule. But when it is finished it will be a technological wonder."

But perhaps the biggest obstacle to progress is a shortage of funding, which has been stagnant in the United States for many years. President Donald Trump has requested $340 million for DOE's fusion research programs in the 2019 fiscal year that begins 1 October, a 36% cut from current levels, but Congress is unlikely to approve that cut. "There's real hope [the 2019 budget] will move up, but it's not energizing the field," Cowley says. "If we can get NSTX to produce spectacular physics results—on a par with the performance of JET—we will energize the community with science."

Posted in:

People & Events

Scientific Community

doi:10.1126/science.aau5277

8. Atomic Movie of Melting Gold Could Aid in Fusion Reactor Design

Scientists from SLAC National Accelerator Laboratory used ultrafast electron diffraction to examine gold melting after being blasted by laser light.

https://interestingengineering.com/atomic-movie-of-melting-gold-could-aid-in-fusion-reactor-design

A study published this week in *Science* saw researchers from the Department of Energy's SLAC National Accelerator Laboratory use ultrafast electron diffraction to examine gold melting after being blasted by laser light. The experiment resulted in a movie featuring never-before-seen atomic details of the melting process that could lead to breakthroughs in fusion power reactor designs and all other applications requiring materials to withstand extreme conditions.

SLAC's high-speed electron camera

The film was shot with SLAC's high-speed electron camera which has a shutter speed of about 100 millionths of a billionth of a second, or 100 femtoseconds. The camera can actually capture the movements of electrons and atomic nuclei within molecules that occur in less than a tenth of a trillionth of a second.

"Our study is an important step toward better predictions of the effects extreme conditions have on reactor materials, including heavy metals such as gold," said SLAC postdoctoral researcher Mianzhen Mo, one of the lead authors of the study, in a statement. "The atomic-level description of the melting process will help us make better models of the short- and long-term damage in those materials, such as crack formation and material failure."

The team witnessed an essentially heterogeneous melting on time scales of 100 to 1000 picoseconds that led to a catastrophic homogeneous melting within 10 to 20 picoseconds at higher energy densities. They also discovered evidence of solid and liquid coexistence, determined the Debye temperature, evaluated the melting sensitivity to nucleation seeds and more.

"About 7 to 8 trillionths of a second after the laser flash, we saw the solid begin turning into a liquid," explained SLAC postdoctoral researcher Zhijang Chen, one of the lead authors. "But the solid didn't liquefy everywhere at the same time. Instead, we observed the formation of pockets of liquid surrounded by solid gold. This mix evolved over time until only liquid was left after about a billionth of a second."

Building fusion reactors

The researchers hope that their new data will be useful in building fusion reactors that require materials resilient enough to withstand extreme radiation and temperatures of as much as hundreds of millions of degrees Fahrenheit. "Our method allows us to examine the behavior of any material in extreme environments in atomic detail, which is key to understanding and predicting material properties and could open up new avenues for the design of future

materials," said Siegfried Glenzer, head of SLAC's High Energy Density Science Division and the study's principal investigator.
SLAC is a multi-program laboratory operated by Stanford University experimenting in photon science, astrophysics, particle physics, and accelerator research. The study's SLAC team was supported by scientists from DOE's Los Alamos National Laboratory; the University of British Columbia and the University of Alberta in Canada; and the University of Rostock and the University of Duisburg-Essen in Germany.

9. CRACKING NUCLEAR FUSION WITH SUPERCOMPUTERS AND SMART CODE

June 27, 2018 Brid-Aine Parnell

https://www.nextplatform.com/2018/06/27/cracking-nuclear-fusion-with-supercomputers-and-smart-code/

Nuclear fusion, the opportunity to harness the power of the stars, has been a dream of humanity from around the time of the Manhattan Project. But while making bombs has been readily achieved, controlling the process for thermonuclear fusion for civilian use has been frustratingly elusive.

Nuclear fusion could be a clean, safe and practically limitless energy source, but despite decades of research, it’s difficult to sustain in any meaningful kind of way. Put simply, the challenge is to confine the particles involved, control the temperature and harvest the energy in a process where even the smallest change can have huge consequences. The amount of energy that goes into making a nuclear fusion reaction far outweighs the energy produced – for now.

There’s only one way to model the kind of nonlinear interactions produced by magnetically confined burning plasmas – including processes like microturbulence, mesoscale energetic particle instabilities, radio frequency waves, macroscopic magnetohydrodynamic modes and collisional transport. And that way involves supercomputers and some very cool coding.

The Gyrokinetic Toroidal Code (GTC), is one such scientific code and happens to be one of 13 projects chosen by the Center for Accelerated Application Readiness (CAAR) to run on the brand-new “Summit” supercomputer at Oak Ridge National Laboratory, one of the key supercomputer centers controlled by the US Department of Energy.

Summit is the new jewel in the crown for US supercomputing, succeeding the

Titan supercomputer that was the most powerful machine in the world five years ago, with 27 peak petaflops and currently ranked seventh in the world. But Summit is targeting 200 peak petaflops of performance at 13 megawatts of power for traditional HPC simulations and more than 3 exaflops for machine learning codes, which should make it the fastest and smartest supercomputer in the world. It's the US answer to China's Sunway TaihuLight.

Summit is being built by IBM, Nvidia, and Mellanox Technologies for the DoE's Oak Ridge Leadership Computing Facility (OLCF). Just like Titan, Summit is a hybrid CPU-GPU system, with 4,608 nodes with two IBM Power9 processors and six Nvidia Volta V100 GPU accelerators per node – you can see the performance benchmarks in the chart below. The supercomputer will have a large coherent memory of over 512 GB DDR4 and 96 GB HBM per node, all directly addressable from the CPUs and GPUs, and an additional 1600 GB of NVRAM, which can be configured as either burst buffer or as extended memory.

Summit will be a powerhouse machine for scientific supercomputing, with projects underway to use machine learning to help select the best treatment for cancer in a given patient and to help classify the types of neutrino tracks seen in experiments. Porting GTC over to the new supercomputer was also an easy choice.

“We look at different things when we make these decisions and a very important one is the science domain that the application supports,” says Tjerk Straatsma, the OLCF’s Scientific Computing Group leader, explaining why GTC was chosen for Summit.

There’s also the fact that the DoE is one partner in the huge international consortium that is building the ITER fusion reactor in France, a multi-billion pound hope for the first large scale fusion reactor to generate a sustained, burning plasma that will produce more energy than it consumes. GTC plays an integral role in getting that hope off the ground by simulating plasma turbulence within Tokamak fusion devices.

The Tokamak device generates a magnetic field that confines the plasma within a donut-shaped cavity and accelerates the plasma particles around the torus. GTC simulates the motions of the particles through the donut using a particle-in-cell (PIC) algorithm. During each PIC time-step, the charge distribution of the particles is interpolated onto a grid, the electric fields are interpolated from the grid to the particles, and the phase-space coordinates of the particles are updated according to the electric field.

That’s a lot of moving parts, which is why massively parallel systems are so instrumental in advancing this science. And Summit will represent a huge step-change in how accurately GTC can simulate plasma turbulence.

“The confinement of the alpha particles involves many physical processes and each process involves different spatial scales and timescales,” explains Zhihong Lin, professor of physics and astronomy at UCI and the creator of that smart GTC code.

“In the past, we could only simulate one process at a time in order to resolve both spatial scale and timescale for that particular process. Now with more powerful computers, we can use more particles, have higher resolution and run a longer time simulation,” he says.

All this modelling should help researchers understand the turbulence of the alpha particle in the Tokamak and how it is ultimately driven out of the fusion device – a result nobody wants. With that understanding, engineers can develop the technology necessary to confine the alpha particles over extended periods.

GTC has been kicking around for more than 20 years and is used by a variety of researchers on different systems across the world. Originally written in Fortran 90/95, porting it to new hybrid supercomputers while maintaining as few versions of the source code as possible has been challenging. To run on Summit, OLCF and the GTC team chose PGI compilers and OpenACC to offload the work to the GPUs without changing the original code.

“They decided to go with OpenACC, which is a directive-based method to offload work to GPUs. You can actually use your original code but tell the compiler that certain loops should be offloaded to the GPU to make it faster,” says Straatsma.

“The advantage to this is that it can run on machines that have these GPU accelerators, but also still runs on machines without. You would get a slightly better performance out of it if you recoded everything in CUDA, but it would only run on NVIDIA GPUs, so it would be harder to port it from one machine to the other. In order to be portable, they use OpenACC.”

With the help of GTC, ITER aims to create its first plasma in 2025 and scale up to maximum power output by 2035. Its success would revolutionize world energy production and make the price tag of over £16 billion well worth it to the international consortium of the US, the EU, India, Russia, China, South Korea, and Japan. But it's not the only group with skin in the game.

Late in 2015, a €1 billion reactor in Germany **produced its first helium plasma** for a duration of one tenth of a second at a temperature of around one million degrees. The reactor uses a stellarator in which the plasma ring is shaped like a Mobius strip instead of a donut.

Even Google is in on the action, **having developed a new algorithm** with leading fusion firm Tri Alpha Energy, backed by Microsoft co-founder Paul Allen. The Optometrist algorithm aims to combine HPC with human judgment to find better solutions for the problems of controlling plasma reactions.

But every attempt to make the dream of clean, usable fusion energy a reality has something in common. We are going to need next-generation supercomputers and portable coding to make it so.

10. German Nuclear Fusion Experiment Sets Records for Stellarator Reactor

http://www.popularmechanics.co.za/science/german-nuclear-fusion-experiment-sets-records-stellarator-reactor/

The stellarator fell out of favor in the late 1960s. The device, a magnetic-confinement fusion reactor named for the sun, was shoved to the side after Soviet scientists revealed their tokamak design to the world in 1968. The tokamak has been the preferred design for fusion reactors ever since, but the stellarator might be making a comeback.

German scientists at the Max Planck Institute for Plasma Physics (IPP) built a stellarator called the Wendelstein 7-X that was switched on for the first time in 2015. Previous tests pushed the plasma in the reactor to higher temperatures and densities than ever before achieved in a stellarator, and now the IPP reports that it has broken its old records in a new test with upgraded components on the Wendelstein 7-X.

A stellarator is similar to a tokamak in that both devices use large superconducting magnets to suspend hydrogen plasma and heat it to the temperatures and pressures required to fuse the material into helium. (The Wendelstein 7-X consists of 50 superconducting magnet coils about 3.5 meters high.) The stellarator, however, traps the plasma in a twisting and spiraling shape, rather than the torus (doughnut shape) of a tokamak. The twisting path of a stellarator is designed to cancel out instabilities present in the suspended hydrogen plasma.

In a recent test, IPP researchers pushed the Wendelstein 7-X to a record stellarator "fusion product," which is a measure of the ion temperature, density of the plasma, and energy confinement time. This value provides an indication of how close the device is to hitting sustainable nuclear fusion (generating more energy than is initially required to start the reaction). The Wendelstein 7-X reached an ion temperature of about 40 million degrees and a density of 0.8 x 10^{20} particles per cubic meter, producing a fusion product of 6 x 10^{26} degrees x second per cubic meter—a new world record for stellarators

"This is an excellent value for a device of this size, achieved, moreover, under realistic conditions, i.e. at a high temperature of the plasma ions," said Thomas Sunn Pederse, director of the Stellarator Edge and Divertor Physics Division at the IPP, in a press release.

To achieve improved efficiency, the Wendelstein 7-X was outfitted with a new interior wall of graphite tiles, allowing higher temperatures to be reached. This interior lining, known as a divertor, protects the twisting chamber walls and allows technicians to pump more plasma in at higher temperatures, providing more control over the density and purity of the hydrogen plasma as well. "First experience with the new wall elements are highly positive," Sunn Pedersen says.

Previous experiments achieved pulses of plasma lasting about six seconds. The new divertor lining has allowed the researchers to jack up the plasma pulse time to 26 seconds. Heating energies introduced to the system were also increased to about 18 times those of previous experiments, up to 75 megajoules of energy.

In addition to introducing the new graphite interior lining, the Wendelstein 7-X team was able to optimize the reactor based on data from the previous experiments, which were analyzed in a recent paper published in *Nature Physics.* Plasma experiments will resume with the reactor in July, and in the future, the IPP plans to replace the graphite tiles of the divertor with water-cooled carbon-reinforced carbon components, allowing plasma pulses of up to 30 seconds.

The Wendelstein 7-X, which is an experimental reactor not designed to generate power, continues to get closer to its fusion optimization goals. Along with stellarator experiments in the U.S. and Japan, the work is bringing this unique and complex fusion reactor design back from the dead. And with experiments at places like MIT and Google using new helium-3 fuelsand eddy current plasma confinement, the world continues to inch closer and closer to the promise of half a century ago: virtually limitless energy generated by the same method that powers the sun.

Previously Published by: *Popular Mechanics USA*

11. **Fusion energy: Making history**

June 27, 2018

https://www.openaccessgovernment.org/fusion-energy-making-history/47060/

Laban Coblentz, Head of Communication at ITER explains his thoughts on how history is being made when it comes to the exciting world of fusion energy

Last November, the ITER fusion project – 35 countries collaboratively building the most world's most complex machine – reached the 50% mark in "total construction work scope through First Plasma." Nearly 800 publications and media outlets in more than 40 countries hailed this milestone. Scientists, government ministers and industry CEOs congratulated each other on the joint progress to date.

Which feature captures the significance of this accomplishment? Is it ITER's ground-breaking science and engineering? The multinational project management required? The potential impact of fusion energy on society? Perhaps it is a combination of the three?

Part one: The science and engineering

The physics of magnetic confinement fusion is well understood. A few grammes of hydrogen in two forms – deuterium and tritium – are injected into a large, doughnut-shaped vacuum chamber. The hydrogen gas is superheated to form an ionized plasma, its atoms separated into positively charged nuclei and negatively charged electrons. At temperatures approaching 150 million °C, the charged particles are moving fast enough that when they collide, they overcome their natural repulsion and fuse. Adhering to E=mc2, a miniscule portion of mass is converted to a massive release of energy. ITER's engineering has also been largely validated in past tokamak reactors. Multiple sets of superconducting electromagnets – cylindrical, round, D-shaped and more – create an invisible magnetic cage that confines the charged particles of the plasma away from the metal chamber walls. Only the neutrons, which have no charge, escape the plasma to convert their immense kinetic energy into heat. These behaviours have been demonstrated in smaller machines, as have most of the cryogenics, vacuum systems, robotics and power electronics in the ITER design.

What sets ITER apart is the combination of scale and precision required. Each of ITER's main magnets weighs several hundred tonnes; some have dimensions as large as 25 metres; yet the intense magnetic fields they generate must be cross-woven so intricately that charged hydrogen nuclei – sized at roughly 10^{-15} metres – cannot escape. Components so large they must be fabricated in shipyards will be positioned with the delicacy of a watchmaker.

These extremes are driving a host of innovations and firsts, from fabrication techniques to new materials, instrumentation and tools. They are required by ITER's mission: to demonstrate the feasibility of fusion energy on a commercial scale, by creating for the first time on Earth the conditions necessary for a "burning plasma," in which the plasma heating is largely self-generated: in brief, to create a star on earth.

Part two: Multinational project management

As if the complexity of a full-scale tokamak were not demanding enough, the ITER Agreement stipulates that each member will contribute most of its financial support "in-kind," in the form of hardware. In other words, the million-plus ITER components being manufactured across the globe, in Japanese factories, American laboratories, Indian foundries, Korean industrial plants, Chinese workshops, Russian shipyards, European innovation centres – must be fitted together into a single, functional device: a sort of reverse Tower of Babel that begins with no one speaking the same language, connecting through the common vocabulary of mathematics, physics and three-dimensional CAD drawings.

Yet this is not lunacy. As the ITER Director-General, Bernard Bigot, said recently: “No country or organisation could do this alone. By choosing to build this machine in an integrated way, we have made our success interdependent. Our project is built on this condition: if our partnerships perform well, each partner contributes its expertise, we all learn from each other, the interfaces are well-managed, the project succeeds, and everyone wins.” Multinational project management at ITER – systems engineering, risk management, configuration control – is a herculean effort; but in this crucible, new models for cross-border collaboration are being forged.

Consider one example: In December 2017, Japan celebrated the completion of ITER’s first toroidal magnet case: at first glance, merely an oddly shaped, giant piece of steel. But the devil is in the details: the 16-meter case, fabricated in sections by Mitsubishi and Hyundai, successfully achieved tolerances of less than 1 millimetre. In January it was shipped to Italy, where a 310-tonne magnet, containing more than 5 kilometres of niobium-tin superconductor manufactured in China, Europe, Russia and the United States, will fit snugly into the case. When finished, the component will be received at the ITER worksite in southern France, where an 800-tonne, Korean-made assembly tool – standing 10 stories tall, arms outstretched like a mechanical angel's wings – will cradle it gently, together with a European-made sector of vacuum vessel and a Korean-made ultra-thin silver-plated thermal shield; and will slowly, ponderously merge the pieces together to form a single, unified tokamak section.

To quote Bigot again: "The future of fusion – like the future of science – is partnership." Almost from its inception, magnetic confinement fusion has been uniquely collaborative. In 1968, when Russian scientists announced that their T-3 Tokamak had achieved plasma temperatures of 10 million degrees, their next action defied precedent: they invited a team from the United Kingdom, their Cold War enemies, to work with them at the Kurchatov Institute to verify and build together on this breakthrough. From that point forward, fusion has been a globally collaborative R&D effort.

This is the genius of ITER: the study of a controlled burning plasma is the convergent next step in the fusion roadmap of every country involved.

Gargantuan, audacious, hellishly complex, yet elegant in the simplicity of its civilisation-changing goal: ITER seeks to enable the human animal to harness the power of the heavens. Safe, environmentally friendly and with abundant supplies of fuel available to every country, fusion energy aims to transform the socio-political landscape.

The stakes are high for humankind.

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12. Wendelstein 7-X achieves world record

Stellarator record for fusion product / First confirmation for optimisation

June 25, 2018

http://www.ipp.mpg.de/4413312/04_18

In the past experimentation round Wendelstein 7-X achieved higher temperatures and densities of the plasma, longer pulses and the stellarator world record for the fusion product. Moreover, first confirmation for the optimisation concept on which Wendelstein 7-X is based, was obtained. Wendelstein 7-X at Max Planck Institute for Plasma Physics (IPP) in Greifswald, the world's largest fusion device of the stellarator type, is investigating the suitability of this concept for application in power plants.

Unlike in the first experimentation phase 2015/16, the plasma vessel of Wendelstein 7-X has been fitted with interior cladding since September last year (see **PI 8/2017**). The vessel walls are now covered with graphite tiles, thus allowing higher temperatures and longer plasma discharges. With the so-called divertor it is also possible to control the purity and density of the plasma: The divertor tiles follow the twisted contour of the plasma edge in the form of ten broad strips along the wall of the plasma vessel. In this way, they protect particularly the wall areas onto which the particles escaping from the edge of the plasma ring are made to impinge. Along with impurities, the impinging particles are here neutralised and pumped off.

“First experience with the new wall elements are highly positive”, states Professor Dr. Thomas Sunn Pedersen. While by the end of the first campaign pulse lengths of six seconds were being attained, plasmas lasting up to 26 seconds are now being produced. A heating energy of up to 75 megajoules could be fed into the plasma, this being 18 times as much as in the first operation phase without divertor. The heating power could also be increased, this being a prerequisite to high plasma density. In this way a record value for the fusion product was attained. This product of the ion temperature, plasma density and energy confinement time specifies how close one is getting to the reactor values needed to ignite a plasma. At an ion temperature of about 40 million degrees and a density of 0.8 x 10^{20} particles per cubic metre Wendelstein 7-X has attained a fusion product affording a good 6 x 10^{26} degrees x second per cubic metre, the world’s stellarator record. “This is an excellent value for a device of this size, achieved, moreover, under realistic conditions, i.e. at a high temperature of the plasma ions”, says Professor Sunn Pedersen. The energy confinement time attained, this being a measure of the quality of the thermal insulation of the magnetically confined plasma, indicates with an imposing 200 milliseconds that the numerical optimisation on which Wendelstein 7-X is based might work: “This makes us optimistic for our further work.”

The fact that optimisation is taking effect not only in respect of the thermal insulation is testified to by the now completed evaluation of experimental data from the first experimentation phase from December 2015 to March 2016, which has just been reported in Nature Physics (see below). This shows that also the bootstrap current behaves as expected. This electric current is induced by pressure differences in the plasma and could distort the tailored magnetic field. Particles from the plasma edge would then no longer impinge on the right area of the divertor. The bootstrap current in stellarators should therefore be kept as low as possible. Analysis has now confirmed that this has actually been accomplished in the optimised field geometry. “Thus, already during the first experimentation phase important aspects of the optimisation could be verified”, states first author Dr. Andreas Dinklage. “More exact and systematic evaluation will ensue in further experiments at much higher heating power and higher plasma pressure.”

Since the end of 2017 Wendelstein 7-X has undergone further extensions: These include new measuring equipment and heating systems. Plasma experiments are to be resumed in July. Major extension is planned as of autumn 2018: The present graphite tiles of the divertor are to be replaced by carbon-reinforced carbon components that are additionally water-cooled. They are to make discharges lasting up to 30 minutes possible, during which it can be checked whether Wendelstein 7-X permanently meets its optimisation objectives as well.

Background

The objective of fusion research is to develop a power plant favourable to the climate and environment. Like the sun, it is to derive energy from fusion of atomic nuclei. Because the fusion fire needs temperatures exceeding 100 million degrees to ignite, the fuel, viz. a low-density hydrogen plasma, ought not to come into contact with cold vessel walls. Confined by magnetic fields, it is suspended inside a vacuum chamber with almost no contact.

The magnetic cage of Wendelstein 7-X is produced by a ring of 50 superconducting magnet coils about 3.5 metres high. Their special shapes are the result of elaborate optimisation calculations. Although Wendelstein 7-X will not produce energy, it hopes to prove that stellarators are suitable for application in power plants.

Its aim is to achieve for the first time in a stellarator the quality of confinement afforded by competing devices of the tokamak type. In particular, the device is to demonstrate the essential advantage of stellarators, viz. their capability to operate in continuous mode.

Isabella Milch

Publication:

Andreas Dinklage et al.
Magnetic configuration effects on the Wendelstein 7-X stellarator.
In: Nature Physics, 21 May 2018, https://doi.org/10.1038/s41567-018-0141-9

13. The mysterious fourth state of matter

FROM aeon

Luca Comisso

http://theweek.com/articles/782745/mysterious-fourth-state-matter

July 7, 2018

When I was at elementary school, my teacher told me that matter exists in three possible states: solid, liquid, and gas. She neglected to mention plasma, a special kind of electrified gas that's a state unto itself. We rarely encounter natural plasma, unless we're lucky enough to see the Northern lights, or if we look at the sun through a special filter, or if we poke our head out the window during a lightning storm, as I liked to do when I was a kid. Yet plasma, for all its scarcity in our daily lives, makes up more than 99 percent of the observable matter in the universe (that is, if we discount dark matter).

Plasma physics is a rich and diverse field of inquiry, with its own special twist. In some areas of science, intellectual vitality comes from the beauty of grand theories and the search for deep underlying laws — as shown by Albert Einstein's account of gravity in general relativity, or string theorists' attempt to replace the Standard Model of subatomic particles with tiny oscillating strands of energy. The study of plasmas also enjoys some remarkably elegant mathematical constructions, but unlike its scientific cousins, it's mostly been driven by its applications to the real world.

First, though, how do you make a plasma? Imagine heating up a container full of ice, and watching it pass from solid, to liquid, to gas. As the temperature climbs, the water molecules get more energetic and excitable, and move around more and more freely. If you keep going, at something like 12,000 degrees Celsius the atoms themselves will begin to break apart. Electrons will be stripped from their nuclei, leaving behind charged particles known as *ions* that swirl about in the resulting soup of electrons. This is the plasma state.

The connection between blood and "physical" plasma is more than mere coincidence. In 1927, the American chemist Irving Langmuir observed that the way plasmas carried electrons, ions, molecules, and other impurities was similar to how blood plasma ferries around red and white blood cells and germs. Langmuir was a pioneer in the study of plasmas; with his colleague Lewi Tonks, he also discovered that plasmas are characterized by rapid oscillations of their electrons due to the collective behavior of the particles.

Another interesting property of plasmas is their capacity to support so-called *hydromagnetic waves* — bulges that move through the plasma along magnetic field lines, similar to how vibrations travel along a guitar string. When Hannes Alfvén, the Swedish scientist and eventual Nobel prizewinner, first proposed the existence of these waves in 1942, the physics community was skeptical. But after Alfvén delivered a lecture at the University of Chicago, the renowned physicist and faculty member Enrico Fermi came up to him to discuss the theory, conceding that: "Of course such waves could exist!" From that moment on, the scientific consensus was that Alfvén was absolutely correct.

One of the biggest motivators of contemporary plasma science is the promise of controlled thermonuclear fusion, where atoms merge together and release intense but manageable bursts of energy. This would provide an almost limitless source of safe, "green" power, but it's not an easy task. Before fusion can occur here on Earth, the plasma must be heated to more than 100 million degrees Celsius — about 10 times hotter than the center of the sun! But that's not even the most complicated bit; we managed to reach those temperatures and beyond in the 1990s. What's worse is that hot plasma is very unstable and doesn't like to stay at a fixed volume, which means that it's hard to contain and make useful.

Attempts to achieve controlled thermonuclear fusion date back to the early 1950s. At the time, research was done secretly by the U.S. as well as the Soviet Union and Great Britain. In the U.S., Princeton University was the fulcrum for this research. There, the physicist Lyman Spitzer started Project Matterhorn, where a secret coterie of scientists tried to spark and contain fusion in a figure-8-shaped device called a "stellarator." They didn't have computers, and had to rely only on pen and pencil calculations. While they didn't solve the puzzle, they ended up developing "the energy principle," which remains a powerful method for testing the ideal stability of a plasma.

Meanwhile, scientists in the Soviet Union were developing a different device: the "tokamak." This machine, designed by the physicists Andrei Sakharov and Igor Tamm, employed a strong magnetic field to corral hot plasma into the shape of a donut. The tokamak was better at keeping the plasma hot and stable, and to this day most of the fusion research programs rely on a tokamak design. To that end, a consortium of China, the EU, India, Japan, Korea, Russia, and the U.S. has joined together to construct the world's largest tokamak reactor, expected to open in 2025. However, in recent years there's also been a renewed enthusiasm for stellarators, and the world's largest opened in Germany in 2015. Investing in both routes to fusion probably gives us our best chance of ultimately attaining success.

Plasma is also entangled with the physics of the space around Earth, where the stuff gets carried through the void on the winds generated in the upper atmosphere of the sun. We're lucky that the Earth's magnetic field shields us from the charged plasma particles and damaging radiation of such solar wind, but our satellites, spacecraft, and astronauts are all exposed. Their capacity to survive in this hostile environment relies on understanding and accommodating ourselves to the quirks of plasma.

In a new field known as "space weather," plasma physics plays a role similar to that of fluid dynamics in terrestrial, atmospheric conditions. I've devoted much of my research to something called *magnetic reconnection*, where the magnetic field lines in the plasma can tear and reconnect, leading to a rapid release of energy. This process is believed to power the sun's eruptive events, such as solar flares, although detailed comprehension remains elusive. In the future, we might be able to predict solar storms the way that we can forecast bad weather in cities.

Looking backward, not forward, in space and time, my hope is that plasma physics will offer insights into how stars, galaxies, and galaxy clusters first formed. According to the standard cosmological model, plasma was pervasive in the early universe; then everything began to cool, and charged electrons and protons bound together to make electrically neutral hydrogen atoms. This state lasted until the first stars and black holes formed and began emitting radiation, at which point the universe "re-ionized" and returned to a mostly plasma state.

Finally, plasmas help to explain some of the most spectacular phenomena we've observed in the remotest regions of the cosmos. Take black holes, massive objects so dense that even light can't escape them. They're practically invisible to direct observation. However, black holes are typically encircled by a rotating disk of plasma matter, which orbits within the black hole's gravitational pull, and emits high-energy photons that can be observed in the X-ray spectrum, revealing something about this extreme environment.

It's been an exciting journey for me since the days I thought that solids, liquids, and gases were the only kinds of matter that mattered. Plasmas still seem rather exotic, but as we learn to exploit their potential, and widen our view of the cosmos, one day they might seem as normal to us as ice and water. And if we ever achieve controlled nuclear fusion, plasmas might be something we can no longer live without.

This article was originally published by Aeon, a digital magazine for ideas and culture. Follow them on Twitter at @aeonmag.

14. European Master of Science Nuclear Fusion and Engineering Physics topranked by El Mundo

http://www.fusenet.eu/node/1336

The spanish newspaper El Mundo has ranked the European Master of Science in Nuclear Fusion and Engineering Physics at the top in the category "Experimental and Technological Sciences".

They have created a guide of the best master programs of 2018. See the (spanish) website here.

This guide compiles the 250 best graduate programs. The ranking includes 50 specialties and the five best entities where they are taught after a detailed study. The classification is the result of the analysis of 25 criteria, the opinion of 800 professors and experts, alumni and collaborating companies.

The Master degree is a European cooperation coordinated by the University of Ghent (Belgium) and organized in Madrid by the Carlos III University of Madrid (UC3M) and the Complutense University of Madrid (UCM). It has an important collaboration of the Fusion Division of CIEMAT, an institution associated with the master's degree, as well as the participation of personnel from various institutions and universities such as the Autonomous University of Madrid, the Polytechnic University of Madrid, the University of Córdoba or the CSIC.

15. Nuclear Fusion Reactor in France 55 Percent Complete

*Posted by **News Editor** in **Energy**, **Latest News**, **RSS** on July 3, 2018 5:35 pm / **no comments***

Nuclear Fusion Reactor in France 55 Percent Complete

*Posted by **News Editor** in **Energy**, **Latest News**, **RSS** on July 3, 2018 5:35 pm /*

SAINT PAUL-LEZ-DURANCE, France, July 3, 2018 (ENS) – There may be lingering disagreements among China, the European Union, India, Japan, South Korea, Russia and the United States, but there is one complex project these seven

entities have in common that is on track for success – the world's largest nuclear fusion facility.
This first global collaboration on building a nuclear fusion reactor is taking place at Cadarache in the south of France.

Construction of the reactor began in 2017 and is now more than 50 percent complete. It is scheduled to achieve first plasma in December 2025. This means that the reactor will be able to generate a molten mass of electrically-charged gas, known as plasma, inside its core.

Deuterium-tritium fusion experiments are scheduled to begin in 2035.

Director-General Bernard Bigot of France said the passing of the 50 percent milestone reflects "the collective contribution and commitment of ITER's seven members."

The seven participants in the International Thermonuclear Experimental Reactor, ITER, are building the 500 megawatt tokamak fusion device designed to prove the feasibility of fusion as a large-scale and carbon-free source of energy that is safe, abundant and environmentally responsible.

Fusion is the process that powers the Sun and the stars; when light atomic nuclei fuse together to form heavier ones, a large amount of energy is released.

At its 22nd meeting on June 20 and 21, the ITER Council reviewed in detail the latest reports and indicators covering organizational and technical performance.

ITER Council Members jointly reaffirmed the importance of the mission and vision of the project.

The ITER Council evaluated the most recent reports of manufacturing, construction and installation progress for the fusion reactor, including the latest measures of performance.

The Council approved refinements to the construction strategy proposed by the ITER Organization to optimize equipment installation in the Tokamak Complex Building.

With this strategy in place, the project remains on track for first plasma in 2025.

The Council agreed that substantial progress has been made on the fabrication of technologically challenging components such as vacuum vessel sectors and toroidal field magnets, as well as on installation of the cryoplant, site service building and magnet power supply and conversion. Based on the latest performance metrics, project execution to achieve first plasma is over 55 percent complete.

Since January 2016, ITER has achieved 33 scheduled project milestones, including the recent commissioning of the first experiment of the SPIDER Neutral Beam Test Facility in Padua, Italy.

The specialized components – some 10 million parts in total – are being manufactured in industrial facilities all over the world. Then they are sent to the Cadarache worksite to be assembled into the final machine.

Europe is contributing almost half of the costs of construction, while the other six members: China, India, Japan, South Korea, Russia and the United States, are contributing equally to the rest.

Construction costs are expected to be around €20 billion (US$22 billion), with components contributed by the ITER members on an “in-kind” basis.

Summit, the world’s fastest supercomputer, recently launched at the Oak Ridge National Laboratory in the United States, will be instrumental in accelerating fusion research.

The new supercomputer takes computing powers to new heights. Summit can perform 200,000 trillion calculations per second – or 200 petaflops – that is 200 quadrillion calculations, eight times more than the previous record-holder at the Oak Ridge National

Lab, Titan.

The massive machine, weighing more than a commercial aircraft, is also the world’s largest computer equipped with artificial intelligence – a machine whose software will write new software.

Harnessing Summit’s capabilities in machine learning and simulation as well as in artificial intelligence and deep learning will allow researchers to accelerate scientific discovery in nuclear fusion.

At the close of its June meeting, the ITER Council stated, “The ITER Project is sustaining its strong performance and rapid pace; the ITER Organization and Domestic Agencies continue to work as an integrated team to meet the challenging schedule and demanding technical requirements, anticipating and mitigating risks to stay on track for success.”

16. Printing the parts for nuclear fusion

3 July 2018

https://www.materialstoday.com/additive-manufacturing/news/printing-the-parts-for-nuclear-fusion/

3D printing is branching into an unlikely domain—nuclear fusion. The sun uses nuclear fusion to produce energy, and now researchers are exploring how 3D printing can contribute to making **nuclear fusion reactors** on Earth.

The engineering challenges are immense. “Our 3D printing technology could fabricate complex components of a fusion reactor that are difficult to make by conventional methods,” says **Shaojun Liu** of the research team at the **Institute of Nuclear Energy Safety Technology**, Chinese Academy of Sciences, in Hefai, China.

The researchers report on the development of their method in the ***Journal of Nuclear Materials***. They also discuss significant technical insights into the metal structures that the fabrication process creates.

The work uses a specific form of 3D printing called **selective laser melting** (SLM). A high-powered laser is targeted at selected regions of a substrate material, causing those regions to melt and then solidify to form the desired component. The structure is built up layer by layer through repeated scans by the laser.

The procedure was used to create scaled-down metal samples suitable for the internal wall of a fusion reactor. The reactors are donut shaped structures known as **tokamaks**. This "**first wall**" surrounds the high energy nuclear **plasma** in which the fusion occurs. It is therefore exposed to significant physical challenges, including bombardment by neutrons released during the fusion reactions. This unique environment imposes specific demands on any material used as a first wall. To meet these demands, the researchers create their parts from a special type of steel, developed in China, that is particularly resistant to high energy neutron irradiation.

"The structure of the first wall is very complex," Liu explains, but he says that the 3D printing was able to create it quickly and with highly efficient use of the basic raw materials. Another key advantage in building the material layer by layer is that it allows microstructural features of the orientation of the metallic grains to be analysed and controlled. Liu says that further work required to optimise the process and scale it up is now underway.

The type of steel the researchers are producing is likely to be used in the **International Thermonuclear Experimental Reactor (ITER)** project, of which China is a founding member. The ITER project management currently hopes to have their first plasma fusion reactor working by 2025, but the assembly of the reactor is scheduled to begin in 2018.
“ITER will be the first fusion device to maintain fusion for long periods of time,” the project website declares. If that hope is fulfilled, the hot and seething heart of the process may well be surrounded by 3D printed steel.

Read the full article: Liu, S. et al.: "**Microstructure anisotropy and its effect on mechanical properties of reduced activation ferritic/martensitic steel fabricated by selective laser melting**," *Journal of Nuclear Materials* (2018)

17. 10 Questions for Steven Cowley, New Director of the Princeton Plasma Physics Laboratory

By
Larry Bernard
July 2, 2018
https://www.pppl.gov/news/2018/07/10-questions-steven-cowley-new-director-princeton-plasma-physics-laboratory

10 Questions for Steven Cowley, New Director of the Princeton Plasma Physics Laboratory

Steven Cowley, a theoretical physicist and international authority on fusion energy, became the seventh Director of the Princeton Plasma Physics Laboratory (PPPL) on July 1 and will be Princeton professor of astrophysical sciences on September 1. Most recently president of Corpus Christi College and professor of physics at the University of Oxford in the United Kingdom since 2016, Cowley previously was chief executive officer of the United Kingdom Atomic Energy Authority (UKAEA) and head of the Culham Centre for Fusion Energy. He earned his doctorate at Princeton University in astrophysical sciences in 1985 and was a staff scientist at PPPL from 1987 to 1993. He is a Fellow of the Royal Society and *of the Royal Academy of Engineering, and was knighted by the Queen of England in June 2018 for his role in fusion science.*

1. Why are you returning to the Princeton Plasma Physics Laboratory?

The short answer is because I think it will be fun. The science and technology at PPPL is world-leading and I am looking forward to being part of that capability. I am also deeply committed to making fusion power a reality, and PPPL is central to that mission.

2. What do you hope to accomplish?

Although it is clear that fusion is possible, we do not yet have all the knowledge to make fusion cost-effective. Specifically, we need to create innovations that will bring down the cost and scale of future fusion facilities. The National Spherical Torus Experiment-Upgrade (NSTX-U) at PPPL is critical to exploring the promise of compact and cost-effective spherical devices that can deliver such innovation. We are going to finish the reconstruction of the NSTX-U and bring the device back as the world's strongest spherical tokamak, to fulfill its mission in fusion energy research.

3. Why is fusion important; what are its benefits?

Fusion is the perfect way to make energy: the fuel is abundant, it has low environmental impact and it is safe. Imagine an energy source that can last millions of years, is widely available, and does not harm the planet — inexhaustible and zero-carbon. Controlled fusion is clearly difficult to do on Earth, but not impossible as the results of 1990s experiments, such as the Tokamak Fusion Test Reactor at PPPL, and the Joint European Torus show. In those experiments we actually created fusion power. This source of energy is simply too important not to pursue.

4. What is plasma and why is it so special?

Plasma is the fourth state of matter where the electrons are separated from the nuclei and move freely. Plasma makes up 99 percent of the visible universe — stars like our sun are giant balls of plasma. But the behavior of plasma is extraordinarily complex, and invariably turbulent. In the last decade, theory and computation have finally become powerful enough that we can simulate the behavior of real turbulent plasmas, creating an understanding that will help us produce controlled fusion on Earth.

5. Are there other advantages to fusion research, besides providing virtually unlimited energy?

The science of plasmas has been developed largely for fusion research. But the understanding that has been achieved has been applied to plasmas in astrophysics, space physics and to numerous industrial applications. PPPL has played a role in all areas of plasma research — that is surely one of the many strengths of the laboratory. Fusion research has also been a driver for technological innovation — from high-powered particle beams to strong magnetic field superconducting coils. So the spinoffs are many.

6. Why is it taking so long? Put another way, what are the current challenges to providing fusion energy and how (and when) will we overcome them?

It has taken longer than expected to make progress in fusion, in large part because we did not expect that confined plasmas would be so turbulent and difficult to control. But the progress has been extraordinary when you consider the extreme complexity of the physics in our experiments. I see four areas that must be improved to overcome the challenges. We must:

Confine the plasma better, or in other words, decrease the energy loss from the plasma;

Increase the pressure of the plasma that we confine (in physics talk, increase the plasma beta) to get the nuclei to fuse more rapidly;

Find a way to handle the huge exhaust heat, and;

Find materials that can withstand the battering of neutrons in the fusion device. It is truly a grand challenge — as much an engineering and materials science problem as it is a physics challenge.

7. There are different types of fusion devices all around the world. Do we need them all?

We certainly need them all. In fact, we need more. There are many unexplored magnetic configurations. For example, the compact stellarator ideas that were developed at Princeton over a decade ago have never been explored — and they are beautiful ideas. There are other types of approaches to fusion in addition to magnetic confinement. The best fusion configuration is not clear and we need to experiment with many different types of machines to determine the best path forward.

8. PPPL has an extensive staff of savvy scientists. What else besides fusion are they working on?

There is so much that I cannot mention it all. I shall only highlight some examples. The growth of astrophysical plasma research at PPPL is of great attraction to me. I have a long-standing interest in the origin of magnetic fields in the universe — so called magneto-genesis (a rather pretentious name!). Some of our smartest young people are thinking deeply about that problem. It is also wonderful to see PPPL's instrument-building capability in the form of the X-ray spectrometer making inroads into other areas of research. The impact of PPPL's industrial research is profound and I hope we can continue to strengthen our impact on the economy.

9. Can commercial fusion energy be a reality?

You bet! It is inevitable that eventually fusion energy will play a significant role in world energy production. Our job is to make it happen soon.

10. What are some of your hobbies or interests besides plasma physics?

I was once a very mediocre trumpet player; I remain a huge jazz fan. The Golden State Warriors play the prettiest basketball I have ever seen. But if I have a spare couple of hours I like to do algebra — once a nerd always a nerd.

18. Paper Reports on NIF Hydrodynamic Instability Studies

In a *Proceedings of the National Academy of Sciences* (PNAS) “Special Feature” paper published online on June 26, LLNL and University of Michigan researchers reported on recent experiments and techniques designed to improve understanding and control of hydrodynamic (fluid) instabilities in high energy density (HED) settings such as those that occur in inertial confinement fusion implosions on NIF.

https://lasers.llnl.gov/news/papers-presentations#instabilities

This paper described four areas of HED research that focus on Rayleigh-Taylor (RT) instabilities, which arise when two fluids or plasmas of different densities are accelerated together, with the lighter (lower density) fluid pushing and accelerating the heavier (higher density) fluid.

These instabilities can degrade NIF implosion performance because they amplify target defects as well as perturbations caused by engineering features like the “tents” used to suspend the target capsule in the hohlraum and the fill tube that injects fusion fuel into the capsule.

Conversely, RT and its shock analog, the Richtmyer-Meshkov instability, are seen when stellar explosions (supernovae) eject their core material, such as titanium, iron, and nickel, into interstellar space. The material penetrates through and outruns the outer envelopes of the lighter elements of silicon, oxygen, carbon, helium, and hydrogen. In addition, a unique regime of HED solid-state plastic flow and hydrodynamic instabilities can occur in the dynamics of planetary formation and asteroid and meteor impacts.

The PNAS paper presents summaries of studies of a wide range of HED RT instabilities that are relevant to astrophysics, planetary science, hypervelocity impact dynamics, and inertial confinement fusion (ICF).

The researchers said the studies, while aimed primarily at improving understanding of stabilization mechanisms in RT growth on NIF implosions, also offer "unique opportunities to study phenomena that typically can be found only in high-energy astrophysics, astronomy, and planetary science," such as the interiors of planets and stars, the dynamics of planetary formation, supernovae, cosmic gamma-ray bursts, and galactic mergers.

NIF HED experiments can generate pressures up to 100 terapascals (one billion atmospheres). These extreme conditions allow research samples to be driven, or compressed, to the kinds of pressures found in planetary interiors and the interiors of brown dwarfs (sometimes called “failed stars”). They also lend themselves to studies of RT evolution ranging from hot, dense plasmas and burning hot spots at the center of ICF implosions to relatively cool, high-pressure materials undergoing solid-state plastic flow at high strain and strain rate.

“We found that the material strength in these high-pressure, solid-state, high-strain-rate plastic flow experiments is large and can significantly reduce the RT growth rates compared with classical values,” the researchers said. “These results are relevant to planetary formation dynamics at high pressures.

“An intriguing consideration,” they added, “is the possibility of using these findings to enhance resistance to hydrodynamic instabilities in advanced designs of ICF capsule implosions.”

Joining lead author Bruce Remington on the paper were LLNL colleagues Hye-Sook Park, Dan Casey, Rob Cavallo, Dan Clark, Channing Huntington, Aaron Miles, Sabrina Nagel, Kumar Raman, and Vladimir Smalyuk, along with Carolyn

Kuranz of the University of Michigan.

19.

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Small three-dimensional magnetic fields lead to big changes in fusion plasma turbulence

New insight into the interaction of magnetic field distortions and turbulence could lead to greater control in fusion devices

https://fusion.gat.com/global/_media/diii-d/highlights/small_three-dimensional_magnetic_fields_lead_to_big_changes_in_fusion_plasma_turbulence.pdf

The Science

Turbulence is a pervasive every day phenomenon and that can be observed in common situations like the roiling of boiling water, the curling of smoke from a candle or the wind buffeting our faces. Similar turbulence is present in high-temperature plasmas used for fusion energy research and is an important means by which a plasma loses its energy. Researchers are trying to expand our understanding of turbulence in an effort to control it in magnetic fusion plasmas, thereby leading to more efficient and sustainable plasmas. In recent experiments at the DIII-D National Fusion Facility in San Diego, scientists made a surprising discovery that small distortions to the large magnetic fields used to contain fusion plasmas produce surprisingly large changes in turbulence.

The Impact

These results provide deeper insight into the structure of outer layers of fusion plasmas as scientists seek to understand the turbulence well enough to predict its effect on the plasma and learn to control it. Theoretical modeling of these experiments indicates that these measured changes in turbulence are related to different responses of the ions and electrons as they move through the very slightly distorted magnetic field.

Improved control of turbulence informed by these insights could lead to improved performance of plasmas that are being developed for fusion energy production.

Summary

The torus-shaped tokamak uses strong two-dimensional magnetic fields to hold the plasma in place for sustained periods of time. In such a magnetic field, the turbulence of the plasma is the same on one side of the tokamak as on the other. However, when scientists applied very small distortions to the magnetic field in the DIII-D tokamak, they discovered a very surprising behavior in the turbulence of the plasma density. Despite the fact that the distortion in the magnetic field was about 1 part in 10,000, the turbulence amplitude changed by about 50 percent. As shown in the figure, the density turbulence on opposite sides of the machine (separated by 180 degrees) showed different behavior. When the turbulent intensity at one measurement location increased, the intensity on the other side of the machine decreased. The researchers determined that the change in turbulence was due to a small change in the density from one side of the machine to another, yet another surprising result for such a small perturbation. Theoretical modeling indicates that these changes in density are related to different responses of the ions and electrons as they move through the very slightly distorted magnetic field. This deeper understanding of how the plasma responds to the magnetic fields may help researchers learn how to control the turbulence and improve plasma performance.

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