PPPL PRINCETON PLASMA PHYSICS LABORATORY
A Collaborative National Center for Fusion & Plasma Research
U.S. DEPARTMENT OF ENERGY
WEEKLY
September 19, 2016

Calendar of Events

THIS WEEK

WEDNESDAY, SEPT. 21

PPPL Colloquium
4:15 p.m. ◆ MBG Auditorium
Superintelligence, Artificial General Intelligence (AGI), and Existential Risk
Susan Schneider, University of Connecticut

UPCOMING

TUESDAY, SEPT. 27

Tour Guide Meeting
9:30–10:30 a.m. ◆ MBG Auditorium
Tour Guide Training
10:30–11:30 a.m. ◆ MBG Auditorium
See page 3 for details.

FRIDAY, OCT. 7

American Red Cross Blood Drive
8 a.m.–1 p.m. ◆ American Red Cross Bloodmobile, Lower End Parking Lot

WEDNESDAY, OCT. 12

PPPL Colloquium
4:15 p.m. ◆ MBG Auditorium
Estimating the Age of Life Using Moore's Law
Alexei Sharov, National Institutes of Health

INSIDE

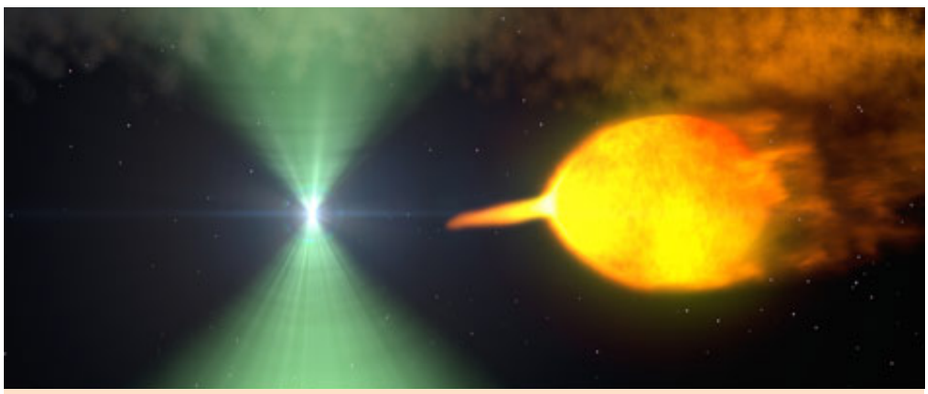
Solving plasma puzzles using Einstein and quantum mechanics

By John Greenwald

Among the intriguing issues in plasma physics are those surrounding X-ray pulsars — collapsed stars that orbit around a cosmic companion and beam light at regular intervals, like lighthouses in the sky. Physicists want to know the strength of the magnetic field and density of the plasma that surrounds these pulsars, which can be millions of times greater than the density of plasma in stars like the sun.

Researchers at PPPL have developed a theory of plasma waves that can infer these properties in greater detail than in standard approaches. The new research analyzes the plasma surrounding the pulsar by coupling Einstein's theory of relativity with quantum mechanics, which describes the motion of subatomic particles such as the atomic nuclei — or ions — and electrons in plasma. Supporting this work is the DOE Office of Science.

The key insight comes from quantum field theory, which describes charged particles that are relativistic, meaning that they travel at near the speed of light. "Quantum theory can describe certain details of the propagation of waves in plasma," said Yuan Shi, a graduate student in the Princeton Program in Plasma Physics and lead author of a paper published July 29 in the journal Physical Review A. Understanding the interactions behind the propagation can then reveal the composition of the plasma.



Sketch of a pulsar, center, in binary star system. (Photo courtesy of NASA Goddard Space Flight Center)

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Successful tests on new device analyzing tokamak materials within a vacuum

By Raphael Rosen

Physicists at PPPL have successfully tested a new measurement device that will lead to a better understanding of the interactions between ultrahot plasma within fusion facilities and the materials of the components inside those facilities. The measurement tool, known as the Materials Analysis Particle Probe (MAPP), was built by a consortium that includes the University of Illinois and Princeton University.

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PPPL internship inspires grad student intern to pursue plasma physics

By Jeanne Jackson DeVoe

When Hanna Schamis packed her bags for graduate school this summer, she already had two summers of hands-on research under her belt as an intern at PPPL and had decided on a career in plasma physics.

Schamis recently began graduate school at the University of Illinois at Urbana-Champaign (UIUC) after completing her second Science Undergraduate Laboratory Internship (SULI) at PPPL. She plans to study in the Department of Nuclear, Plasma, and Radiological Engineering, and continue the research she started at PPPL on the effect of plasmas on materials that could be used for the walls of fusion devices. The materials would protect the device from the intense heat and high flux of particles that emanate from plasmas, which can reach temperatures up to 100 million degrees – hotter than the sun.

A change in career path

Schamis' first summer at PPPL changed her career path, and the current project is more in line with her research interests. "When I first arrived at SULI last year I wasn't very aware of everything going on in plasma research," Schamis said. "Through the lectures and seminars, I started getting really interested in plasma-material interactions so I ended up choosing that path."

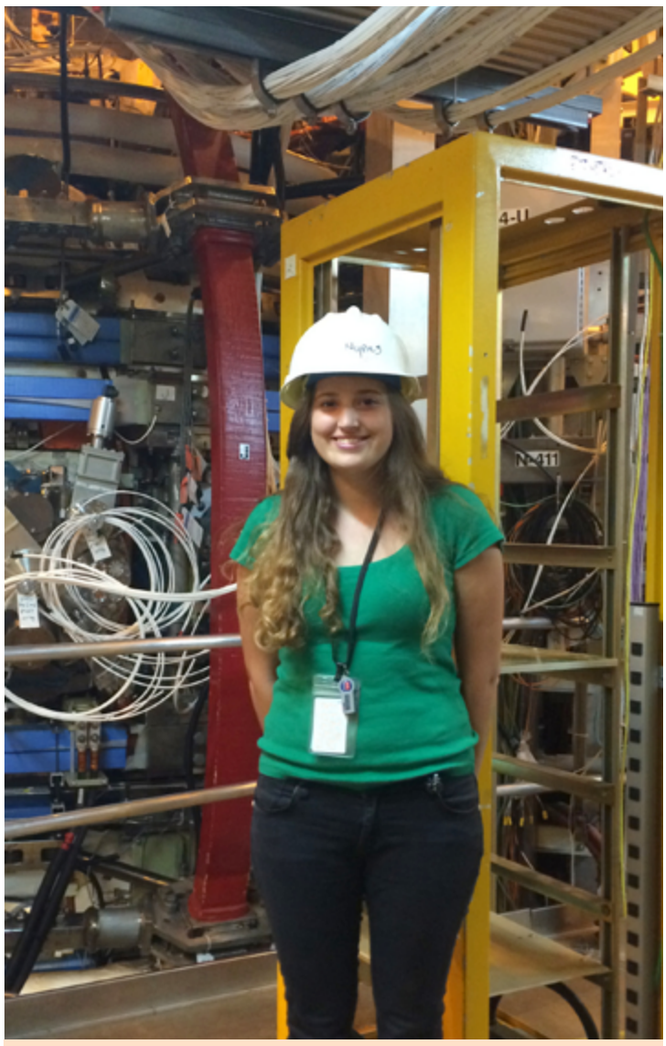
She may have chosen wisely, as finding a wall material that is long lasting and won't affect the behavior of the ultra-hot plasma inside a reactor is one of the greatest challenges of fusion energy research. Such research, on the National Spherical Torus Experiment-Upgrade (NSTX-U) at PPPL and on other tokamaks, can help in understanding how once a burning plasma is achieved – such as that planned at the international fusion experiment under construction in France, ITER – a fusion reactor can be built with a durable wall.

A physics major as an undergraduate at the University of Michigan-Ann Arbor, Schamis was one of 23 students participating in SULI at PPPL this summer. The program is funded by the DOE Office of Science's Office of Workforce Development for Teachers and Scientists. Schamis said she liked the hands-on nature of the SULI program. "I like that it's applied research and it has applications in the real world," she said.

Schamis' research this summer focused on an alloy of molybdenum (TZM), a substance that will be used to line the divertor, a part of the machine that collects heat and particles from the plasma. TZM could eventually be used to line the walls of the NSTX-U. TZM is a strong, heat-resistant material. It would avoid the problem of the plasma eroding the carbon that makes up graphite walls like those presently in the NSTX-U. This would be a serious problem in a reactor that runs for long periods of time like ITER.

Research on device attached to NSTX-U

Schamis used a device called the Material Analysis and Particle Probe (MAPP), built by a consortium that includes Princeton University and the University of Illinois at Urbana-Champaign, to conduct her experiment and analyze the results. MAPP is attached to the bottom of NSTX-U in the divertor, and inserts samples of plasma into the machine during experiments. The samples can then be retracted into a vacuum chamber that is part of MAPP. This chamber is fitted with an apparatus for X-ray photoelectron spectroscopy (XPS). XPS is performed by shooting X-rays at the sample, and measuring the energies of the electrons emitted by the elements on the surface. This allowed Schamis to analyze the effect of the plasma on the chemical composition of the TZM over time.



Hanna Schamis, a Science Undergraduate Laboratory student at PPPL, in front of the National Spherical Torus Experiment-Upgrade (NSTX-U). (Photo courtesy of Hanna Schamis)

"This is the first time measurements of this kind have been performed on a large fusion device like NSTX-U. Since they were made while the samples were still in a chamber that was connected to NSTX-U, changes of the chemistry of the wall could be more readily correlated to changes in the plasma itself," said PPPL physicist Robert Kaita, Schamis' mentor on the project.

The TZM samples exposed to plasma were first coated with boron in a process called "boronization." The process prevents oxygen, which is an impurity in the graphite walls of NSTX-U, from entering the plasma and cooling it. Schamis found that boronization worked for TZM as well. Boronization succeeded in binding the oxygen to the surface of the sample. But as with graphite, the boron wore off with plasma exposure over time.

While Schamis was analyzing the TZM sample, Felipe Bedoya, a graduate student at UIUC, was investigating the effects of boronization and exposure to the plasma on a graphite sample. Studies of graphite continue to be important as the wall material of NSTX-U, and they are being conducted for the first time with MAPP. The two graduate students will continue analyzing the MAPP samples as part of their graduate work at the university. "Felipe is trying to understand the present NSTX-U wall in more detail, and Hanna's job was to do the analysis to predict what would happen with a new material that we want to use in NSTX-U in the future," Kaita said.

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Intern

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An exceptional intern

Kaita, who has mentored more than 70 students from high school through graduate school over his long career at PPPL, said Schamis was an exceptional intern. "Hanna was very interested and engaged. She really took ownership of her project," he said. "She wanted to do a very good job in doing the detailed analysis and trying to look for answers to questions she didn't understand. This made advising Hanna challenging and rewarding. I would tell her how to get started, and she would come back with tough questions."

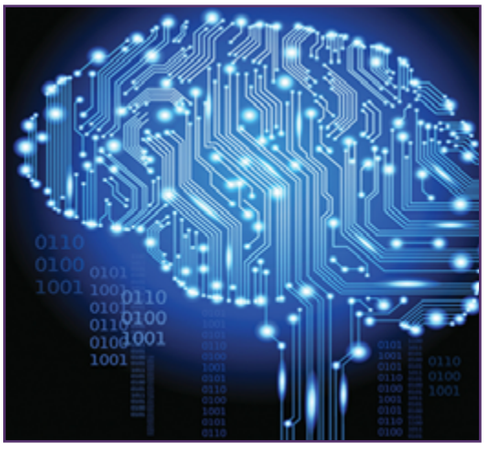
In her first summer as a SULI student, Schamis worked with physicist Igor Kaganovich on a simulation of a type of instability that could potentially disrupt a plasma experiment. She adopted an existing software code to create the simulation.

Schamis credits Kaganovich, deputy head of the PPPL Theory Department, with introducing her to graduate students and physicists who offered advice on graduate school. Kaganovich said one of the main points of the SULI program is to spark an interest in plasma physics research that could lead students like Schamis to pursue a career in the field. "That's the whole point of the program, to get students experience with research," Kaganovich said. "It's important that they enjoy the project. I look at the students: what they can do and what they are interested in and try to match the project to them."

That effort was not wasted on Schamis. "I feel like everyone helped a lot," she said. "The main thing is I found what field of physics I wanted to be in and that's really important."

COLLOQUIUM

Superintelligence, Artificial General Intelligence (AGI), and Existential Risk



Susan Schneider
University of Connecticut

Wednesday, Sept. 21
4:15 p.m., M.B.G Auditorium, Lyman Spitzer Building

Tour Guide Meeting

Please come to a tour meeting on Sept. 27 from 9:30–10:30 a.m. in the MBG Auditorium. Both experienced and new tour guides are welcome.

After a general meeting, experienced tour guides will be free to leave at 10:30 a.m. New tour guides will stay for a tour training session from 10:30–11:30 a.m.

Quantum mechanics

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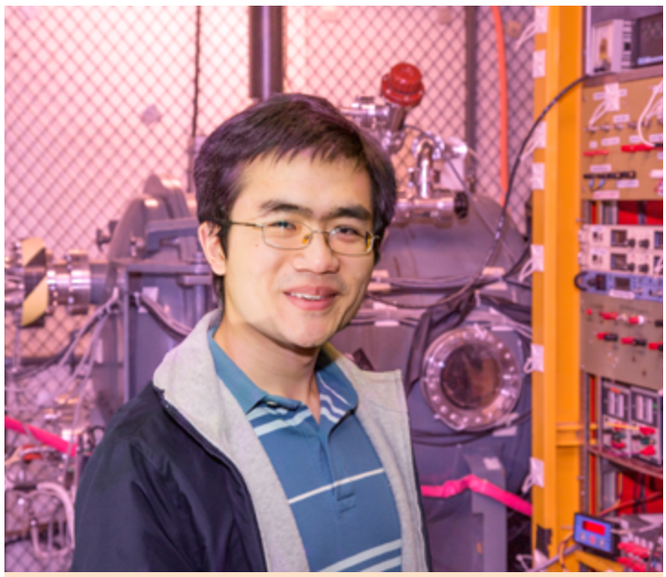
Shi developed the paper with assistance from co-authors Nat Fisch, director of the Program in Plasma Physics and professor and associate chair of astrophysical sciences at Princeton University, and Hong Qin, a physicist at PPPL and executive dean of the School of Nuclear Science and Technology at the University of Science and Technology of China. "When I worked out the mathematics they showed me how to apply it," said Shi.

In pulsars, relativistic particles in the magnetosphere, the magnetized atmosphere that surrounds the body, absorb light waves, and this absorption displays peaks against a blackbody background. "The question is, what do these peaks mean?" asks Shi. Analysis of the peaks with equations from special relativity and quantum field theory, he found, can determine the density and field strength of the magnetosphere.

The process combines the techniques of high-energy physics, condensed matter physics, and plasma physics. In high-energy physics, researchers use quantum field theory to describe the interaction of a handful of particles. In condensed matter physics, people use quantum mechanics to describe the states of a large collection of particles. Plasma physics uses model equations to explain the collective movement of millions of particles. The new method utilizes aspects of all three techniques to analyze the plasma waves in pulsars.

The same technique can be used to infer the density of the plasma and strength of the magnetic field created by inertial confinement fusion experiments. Such experiments use lasers to ablate — or vaporize —a target that contains plasma fuel. The ablation then causes an implosion that compresses the fuel into plasma and produces fusion reactions.

Researchers want to know the precise density, temperature and field strength of the plasma that this process creates.



Graduate student Yuan Shi (Photo by Elle Starkman)

Standard mathematical formulas give inconsistent answers when lasers of different color are used to measure the plasma parameters. This is because the extreme density of the plasma gives rise to quantum effects, while the high energy density of the magnetic field gives rise to relativistic effects, says Shi. So formulations that draw upon both fields are needed to reconcile the results.

For Shi, the new technique shows the benefits of combining physics disciplines that don't often interact. Says he: "Putting fields together gives tremendous power to explain things that we couldn't understand before."

Wanted: Undergraduate women interested in physics for January conference

What: Apply now for the 2017 Conference for Undergraduate Women in Physics.

When: Oct. 14 deadline for the Jan. 13–15 conference.

Where: Princeton University

Cost: The conference, lodging and meals are covered. Students pay $45 registration fee and transportation.

Applications and more information: cuwip.princeton.edu
or contact Shannon Swilley Greco, sgreco@pppl.gov, ext. 2208

MAPP

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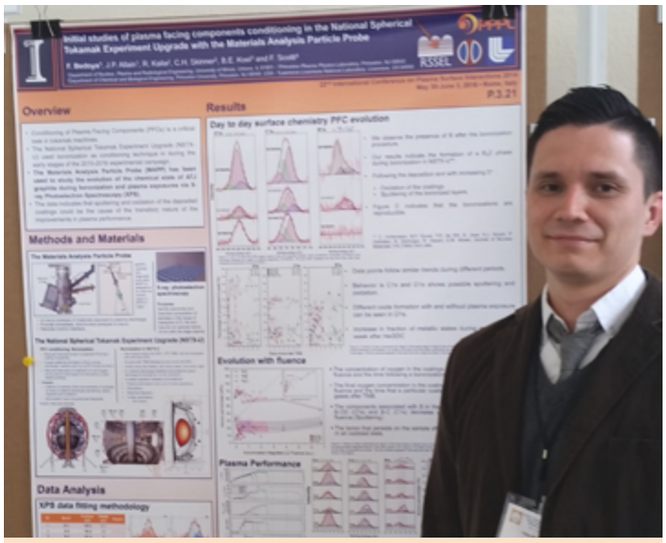
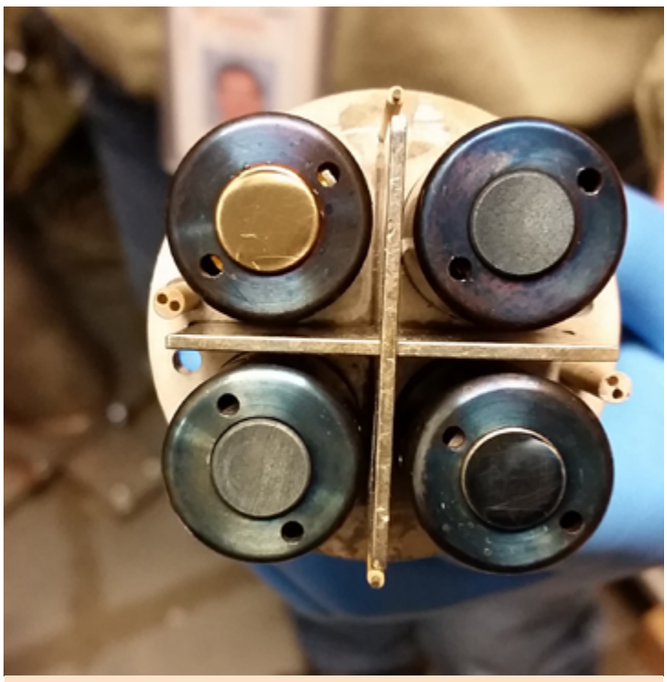
MAPP's leading developer is Professor Jean Paul Allain, now at the University of Illinois, who began the project in 2011. Collaborators at PPPL include physicists Robert Kaita, Charles Skinner, and Bruce Koel, of Princeton University.

The device lets scientists test the chemical make-up of the surface of materials exposed to plasma, while keeping the materials in a vacuum. The research was published in the July issue of *Review of Scientific Instruments*, and was funded by the DOE Office of Science and the Francisco José de Caldas Fellowship Program.

"Using MAPP, we are seeing for the first time the evolution of the materials when they interact with the plasma, and how the conditioning and other procedures modify the chemistry of the materials," said lead author Felipe Bedoya, a graduate student in the Department of Nuclear, Plasma and Radiological Engineering at the University of Illinois at Urbana-Champaign. Bedoya spent a semester at PPPL investigating the relationship between the conditioning of plasma-facing components (PFCs) and the behavior of plasma in the



Felipe Bedoya, a graduate student in the Department of Nuclear, Plasma and Radiological Engineering at the University of Illinois at Urbana-Champaign, with a poster on his research at a poster session at PPPL in August. (Courtesy of Felipe Bedoya)



A holder of wall material samples containing gold and molybdenum. (Photo by Felipe Bedoya)

National Spherical Torus Experiment-Upgrade (NSTX-U), the flagship fusion facility at PPPL.

The interactions between the plasma and the inner walls of the tokamak are crucially important to the production of fusion energy because they profoundly affect the condition of the plasma. If hot hydrogen ions in the plasma touch the walls, the ions are absorbed and cool down. And if the cool hydrogen re-enters the plasma, it lowers the temperature of the plasma's edge and fusion reactions within the plasma occur less often.

In addition, the interior of a tokamak can be eroded by the bombardment of the plasma ions. The amount of plasma-wall interactions can also determine how long a tokamak's plasma-facing components can last before being replaced. Understanding the behavior of materials when exposed to plasma is therefore critical for the design of future fusion machines.

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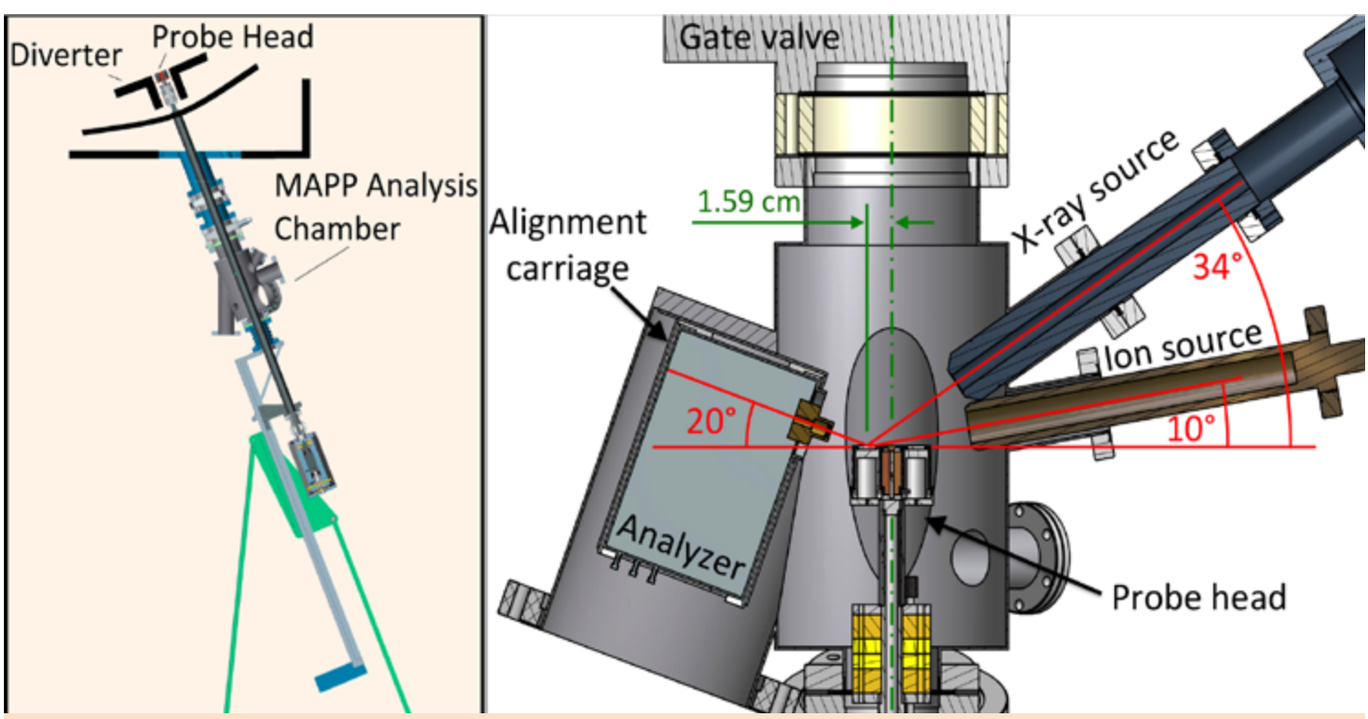

Diagrams of the MAPP experiment. (Courtesy of University of Illinois at Urbana-Champaign)

MAPP

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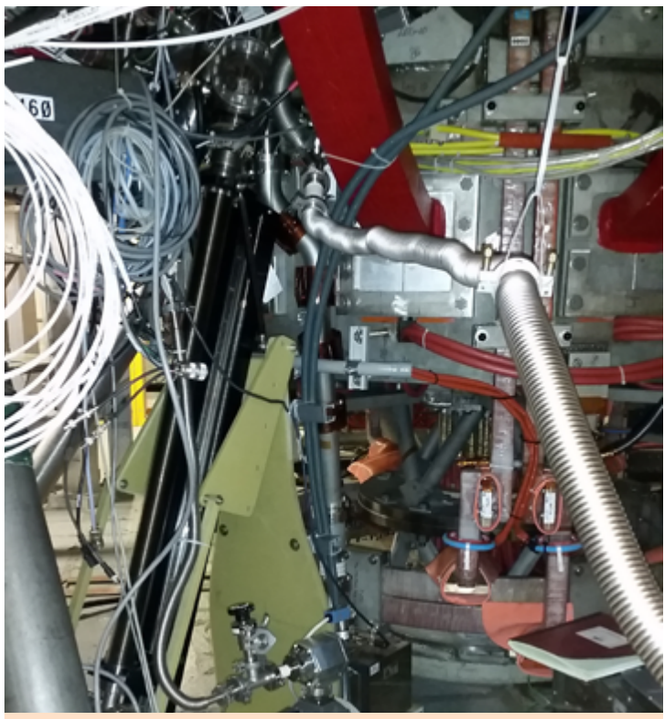
Before MAPP, scientists had to wait for the completion of a long series of fusion experiments before analyzing materials within a tokamak. That kept researchers from confidently correlating fusion experiments with their effect on the materials. And because samples of the material had to be exposed to air when they were brought to a laboratory, scientists couldn't be sure that the chemistry of the samples had not changed.

MAPP enables material samples to be measured under vacuum conditions after each experiment. "People used to wait until the end of an experiment campaign to take out a tile, bring it to a lab, and examine it," said Bedoya. "What we're doing right now is bringing the lab to the machine."

MAPP has been in operation on the NSTX-U for the last 10 months. While using MAPP, researchers expose a set of material samples conditioned with boron to the NSTX-U plasma and retract the samples into a vacuum chamber without any exposure to air. They then use a technique called "X-ray photoelectron spectroscopy" to strike the samples with X-rays and study the electrons the process emits. The emissions provide information about the surface chemistry of the samples, revealing how the boron coating changes when exposed to the plasma.

In the paper, Bedoya and the other physicists report that they successfully tested a method to analyze data produced by MAPP. They used a sophisticated computer program called CasaXPS to obtain the proper interpretation. Results appear to have matched both controlled laboratory experiments and computer simulations, suggesting that the technique's analysis is correct.

"Many people have seen a strong correlation between the conditioning of the plasma-facing components and the performance of the plasma," said Bedoya. "So if you can diagnose how the conditioning changes, you can do it better and better each time and ultimately figure out the optimum conditioning."



A view of the analysis chamber of MAPP installed on NSTX-U. (Photo by Felipe Bedoya)

Scientists believe that MAPP will become an integral part of plasma physics research. "MAPP is a step towards uncovering the mysteries of what's happening at tokamak walls, shot by shot, as the wall changes the plasma's conditions," said Charles Skinner, PPPL physicist and co-author of the paper. "Using this device could help us see exactly what's going on at the wall, and how that correlates or even explains what's going on with the plasma."

Tour Guides and Tour Hosts Wanted!

We are looking for engineers and physicists who are willing to donate a couple of hours of their time each month to show off the Laboratory to students, clubs, and local people who are interested in science. Our growing tour program is a great way to educate the community about fusion energy and the Lab's mission and to let them know about the cutting-edge research taking place at PPPL.

Please plan to come to our tour meeting. **See page 3 for details.**

Please email Jeanne Jackson DeVoe, jjackson@pppl.gov, to volunteer.

New central campus parking option available for PPPL staff

Do you have business or meetings on Princeton University's central campus? PPPL staff members now have use of a limited number of "Official Business Cards" (OBC) that allow two-hour parking in many locations on campus. The locations are:

- **Numbered Lots (except restricted lots 8, 9, & 18)**
- **Front of Dillon Gym**
- **Brown Hall OBC spaces**
- **Rear of Edwards Hall**
- **Visitor spaces behind Baker Rink, Lot 12 (close to MacMillan)**

The parking cards can be checked out from Carol Ann Austin in the Director's Office, who will administer the cards.

"We want to enable and grow the collaborations between PPPL and the central campus and I kept hearing that the parking problem was a barrier. The OBCs should greatly increases our efficiency and productivity when PPPL staff have business on campus," said Dave McComas, Princeton vice president for PPPL who spearheaded the initiative. "Instead of spending unproductive time searching for limited available parking, we now have additional options. I am grateful to Kim Jackson and her staff in Transportation and Parking Services for making this option available to us."

Here is a link to a map indicating the locations suitable for OBC parking.

Boy Scouts STEM Fair, October 22

Volunteers needed

Subject experts in physics and engineering are especially needed to plan workshops.

Please contact Rob Sheneman, rshenema@pppl.gov, ext. 3392, to volunteer.

American Red Cross Blood Drive

Friday, October 7

8 a.m.–1 p.m.

American Red Cross Bloodmobile
Lower Parking Lot

The need for blood is constant and your donation is important for maintaining a healthy and reliable blood supply. One pint of donated blood can save up to three lives.

Please give blood. All blood types are needed.

To schedule a donation appointment, please contact the OMO at extension 3200.

Thank you.
American Red Cross
Occupational Medical Office Staff

BROCK

MARK GAZO
Chef Manager

Café at PPPL

BREAKFAST ..... 7 a.m. • 10 a.m.
CONTINENTAL BREAKFAST ..... 10 a.m. • 11:30 a.m.
LUNCH ..... 11:30 a.m. • 1:30 p.m.
SNACK SERVICE ..... until 2:30 p.m.

	Monday September 19	Tuesday September 20	Wednesday September 21	Thursday September 22	Friday September 23
COMMAND PERFORMANCE Chef's Feature	**OTA-Ya Sushi**	**Ravioli Puttanesca** with Olives, Capers, Red Onion, Garlic & Basil	**Loaded Baked Potato Bar**	**Beef Stroganoff** served over Egg Noodles	**Pub-Style Fish & Chips**
Early Riser	**Potato Skins** with Egg, Bacon & Swiss Cheese	**Steak, Egg & Cheese Quesadilla**	**Ham & Bacon Breakfast Strata**	**Ham Steak** with White Country Gravy, 2 Eggs & Biscuit	**2 Eggs,** Choice of Breakfast Meat & Tater Tots
Country Kettle	**Chicken Gumbo**	**Spinach Tortellini Tomato**	**Italian Wedding Soup**	**Split Pea**	**Manhattan Clam Chowder**
Grille Special	**Corned Beef Reuben** on Rye	**Pork Roll, 2 Eggs & Cheese** on a Kaiser Roll with Tater Tots	**Chicken Cacciatore Sub**	**BBQ Chicken,** Cheddar Cheese, Onion Straws, Lettuce & Tomato on Kaiser Roll	**Crab, Asparagus** & Roasted Pepper Quesadilla
Deli Special	**Tofu Burger**	**Italian Chopped Antipasta Wrap**	**Italian Hot Dog** with Peppers, Onions & Potatoes	**Shrimp Salad** on Multigrain Bread	**Chicken Parmesan Sub**
Panini	**3 Cheese Panini** with Cheddar, Swiss & Blue Cheese with Bacon & Tomatoes on Sourdough	**Andouille Sausage Torpedo** with Peppers & Onions	**Teriyaki Chicken** with Grilled Pineapple, & Swiss Cheese on a Kaiser Roll	**Asparagus,** Sundried Tomatoes, Roasted Peppers & Mozzarella Cheese Wrap	**Teriyaki Chicken Quesadilla** with Peppers & Onions

MENU SUBJECT TO CHANGE WITHOUT NOTICE

HEART HEALTHY VEGETARIAN OPTION

WEEKLY
Editor: **Jeanne Jackson DeVoe** ◆ Layout and graphic design: **Kyle Palmer** ◆ Photography: **Elle Starkman**
Science Editor: **John Greenwald** ◆ Webmaster: **Chris Cane** ◆ Communications Director: **Larry Bernard**

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DEADLINE for calendar item submissions is noon on WEDNESDAY. Other stories should be submitted no later than noon on TUESDAY.
Comments: commteam@pppl.gov ◆ **PPPL WEEKLY** is archived on the web at: http://w3.pppl.gov/communications/weekly/.