PPPL PRINCETON PLASMA PHYSICS LABORATORY
A Collaborative National Center for Fusion & Plasma Research
U.S. DEPARTMENT OF ENERGY
WEEKLY
March 19, 2018

THIS WEEK

WEDNESDAY, MARCH 21

Council Café Lunch
12 p.m. ◆ Cafeteria
Valeria Riccardo
Head of Engineering

Colloquium
4:15 p.m. ◆ MBG Auditorium
High Power Electric Propulsion for the Next Generation of Space Exploration
Benjamin Jorns, University of Michigan, Dept. of Aerospace Engineering

THURSDAY, MARCH 22

Young Women's Conference
8 a.m.–2 p.m. ◆ Princeton University
See page 6 to volunteer.

UPCOMING

WEDNESDAY, MARCH 28

Council Café Lunch
12 p.m. ◆ Cafeteria
Scott Weidner
Princeton University assistant vice president for engineering

WEDNESDAY, APRIL 4

Council Café Lunch
12 p.m. ◆ Cafeteria
Jon Menard
Director of the NSTX-U Recovery Project

Colloquium
4:15 p.m. ◆ MBG Auditorium
Paths to low-carbon energy
Robert Socolow, Princeton University

INSIDE

Big steps toward control of production of tiny building blocks

By John Greenwald

Nanoparticles, superstrong and flexible structures such as carbon nanotubes that are measured in billionths of a meter — a diameter thousands of times thinner than a human hair — are used in everything from microchips to sporting goods to pharmaceutical products. But large-scale production of high-quality particles faces challenges ranging from improving the selectivity of the synthesis that creates them and the quality of the synthesized material to the development of economical and reliable synthesis processes.

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Team wins Innovation prize for PPPL-developed device

By Jeanne Jackson DeVoe

The inventors display the flowmeter at the Innovation Forum. Front left, Adam Fisher; back, Daniel Dudt; right, Michael Hvasta. *(Photo by Aileen Pritch)*

A team of Princeton University inventors won first place at the 13th Annual Innovation Forum for its invention of a unique type of device called a "flowmeter." The instrument was developed at PPPL and offers a simple, inexpensive, and contactless method of measuring fluids in industrial applications.

"It's a very practical invention," said Laurie Bagley, PPPL's head of Technology Transfer. "I think people got that it's simple and useful in a lot of different industries and solves a lot of industrial problems."

The inventors will receive $15,000 to develop the project further after winning the award at a March 14 Innovation Forum at the Princeton University Carl A. Fields Center. The event was sponsored by the Keller Center, Princeton's Office of Technology Licensing and Wise and Company, LLP. Venture capitalists attending the event have already expressed some interest in the device, the inventors said.

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Celebrating the first plasma on FLARE

Physicists, technicians and leaders from PPPL and the Princeton Department of Astrophysical Sciences gathered in McDonnell Hall at Princeton University on Friday, March 16 to celebrate production of the first plasma on FLARE. The new device is a more powerful version of the Magnetic Reconnection Experiment (MRX) at PPPL, which studies the breaking apart and explosive recombination of the magnetic field lines in hot plasma that occurs throughout the universe and gives rise to Northern Lights, solar flares and geomagnetic storms that can disrupt cell phone service.

Achievement of first plasma marked completion of four years of collaborative construction of the device, which is twice the diameter of the sport utility-sized MRX, at 8:13 p.m. on Sunday, March 4, in Jadwin Hall on the Princeton campus. "The collaboration came together beautifully," said Geoffrey Gettlefinger of the Princeton Department of Physics who helped coordinate purchasing, fabrication and modification of building systems during the project. "This demonstrated people from Princeton working together for an outstanding outcome."

Hosting the afternoon event was James Stone, chairman of the Department of Astrophysical Sciences, in recognition of the work of Hantao Ji, a professor in the department and a PPPL physicist and principal investigator of the construction project. Ji is now proposing the subsequent research on FLARE, whose future is to be decided.

From left: Hantao Ji, professor of astrophysical sciences, PPPL physicist, and principal investigator of the FLARE construction project, Russell Kulsrud, emeritus professor of astrophysical sciences, and physicist Masaaki Yamada. *(Photo by John Greenwald)*

James Stone, chairman of the Department of Astrophysical Sciences, center, with Deborah Prentice, provost of Princeton University, and A.J. Stewart Smith, former Princeton vice president for PPPL. *(Photo by John Greenwald)*

Nat Fisch, professor of astrophysical sciences and director of the graduate program in plasma physics, left, chats with David McComas, Princeton vice president for PPPL. Behind them from left: Philip Efthimion, head of the Plasma Science and Technology Department, with physicists Masaaki Yamada and Greg Hammett. *(Photo by John Greenwald)*

From left: Susan Duncan, Department of Astrophysical Sciences manager; Brenda Zanghi, Department of Physics grant manager; Mami Akiyama, Department of Astrophysical Sciences executive assistant. *(Photo by John Greenwald)*

Thank you for participating in the March 14 blood drive!

The March 14 blood drive at PPPL was a success, with 15 participants contributing blood that will provide for 29 hospital patients.

Mark your calendars: the Fall Blood Drive is scheduled for Friday, Oct. 5!

Nanoparticles

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However, this situation could change as a result of research at PPPL, where scientists have developed the diagnostic tools that are being used to advance an improved and integrated understanding of plasma-based synthesis — a widely used but poorly understood tool for creating nanostructures. PPPL scientists and collaborators outline, in several published papers, recent research that could help to develop controllable and selective fabrication of nanomaterials with prescribed structures. Such basic research could pave the way toward manufacturing advances in a variety of industries.

Unique observations

The papers report unique observations of the synthesis in carbon plasma generated by an electric arc *in situ*, or as the process unfolds. Researchers create the plasma arc between two carbon electrodes, producing a hot carbon vapor composed of atomic nuclei and molecules that cool and synthesize — or condense — into particles that grow into nanostructures by bunching together.

Direct observation has produced "a big step forward in understanding how carbon nanoparticles grow in plasma generated by arc," said physicist Yevgeny Raitses, head of the Laboratory for Plasma Nanosynthesis at PPPL. "The idea now is to combine experimental results with computer modeling for improved control of the process and to apply what we learn to other types of nanomaterials and nanomaterial synthesis."

Following is a look at three papers that break new ground in unraveling the poorly understood arc synthesis process. Support for this work comes from the DOE Office of Science.

Spotting precursors that become nanotubes. Missing from today's knowledge is a detailed understanding of the precursors of nanotubes that are formed from the vapor during synthesis. This poses a key challenge for predicting the mechanism for nanosynthesis with a carbon plasma arc.

Shedding light on this process are new discoveries at PPPL. Research led by physicist Vladislav Vekselman and reported in the journal *Plasma Sources Science and Technology* shows that what governs the synthesis of carbon nanotubes in a purely carbon electric arc are molecular precursors that include "dimers" — molecules formed by two carbon atoms.

This finding opens the door to improved predictive modeling of nanosynthesis in carbon arcs. "This is the first time that a laser-induced diagnostic technique has been applied to this type of synthesis," Vekselman said. "We now know where and how much precursor is formed in carbon arc material."

Supporting these findings are simulations of carbon arc synthesis conducted by PPPL physicist Alexander Khrabry. "Our models are based on the underlying physics of vaporization, condensation and the formation of nanostructures," said physicist Igor Kaganovich, deputy head of the PPPL Theory Department. "We apply this to results of the *in situ* experiments to develop predictions that can be tested with further experiments."

Such predictive models have begun to make progress. "Having *in situ* measurements while synthesis takes place is a very valuable aid to understanding and modeling," said Brent Stratton, head of the diagnostics division of PPPL and deputy director of the Plasma Science and Technology (PS&T) Department that houses the nanosynthesis laboratory. "What this project shows is the combined value of experiments and modeling for deepening understanding of plasma arc synthesis."

Detecting nanoparticle growth. To further such understanding, researchers must monitor the production of particles in sizes ranging from nanometers all the way down to the atomic scale. PPPL research has now built and demonstrated a unique table-top laser technique for *in situ* detection of nanoparticle growth. "This custom-made diagnostic helps piece together the puzzle of plasma arc nanosynthesis," said physicist Alexandros Gerakis of PPPL, who designed the technique and is lead author of its description in the journal *Physical Review Applied*. "There had previously been no good way to monitor the process."

Members of the nanosynthesis team. Front row from left: Alexandros Gerakis, Vladimir Vekselman, Shurik Yatom. Back row from left: Yevgeny Raitses, Bruce Koel, Igor Kaganovich, Alexander Khrabry, Brent Stratton, Rachel Selinsky, Andrei Khodak. *(Photo by Elle Starkman)*

The novel method, derived from a prediction by Mikhail Shneider of Princeton University, detects particles that flow within and from the electric arc. The technique observes particles some five nanometers in size and could be used to measure materials created by other forms of nanosynthesis as well. Such *in situ* measurement of nanoparticles during large-volume synthesis could advance understanding of the mechanisms behind nanoparticle growth.

Why some synthesis goes wrong. Among the most promising types of nanomaterials are single-wall carbon nanotubes that carbon arc discharges can produce on an industrial scale. But a key drawback to this method is the impurity of much of the synthesized nanomaterial, which includes a mix of nanotubes, carbon soot and random carbon particles.

A chief source of these drawbacks is the unstable behavior of carbon arcs, PPPL has found. Such behavior creates two modes of production, which the laboratory calls "synthesis-on," for pure nanotube fabrication, and "synthesis-off," for impure results. "The synthesis in plasma arcs is 20 percent on and 80 percent off," said physicist Shurik Yatom, lead author of the results published in the journal *Carbon*.

In these experiments, Yatom used a conventional arc synthesis technique and filled one of the two electrodes — called an "anode" — with graphite powder and a catalyst and found that the synthesis was erratic, switching between the dominant synthesis-off mode and the far less common synthesis-on mode. Fast-camera images, electric characteristics and emission spectra showed that the arc engaged the contents of the anode directly in the synthesis-on mode, but oscillated around the hollow anode in the synthesis-off mode and was unable to interact with the powdered graphite and catalyst inside.

The team also constructed a probing device to selectively collect the synthesized product between the two modes. Evaluating the synthesized nanomaterials was Rachel Selinsky of Princeton University, who found that the vast majority of nanotubes were collected during the "synthesis-on" mode.

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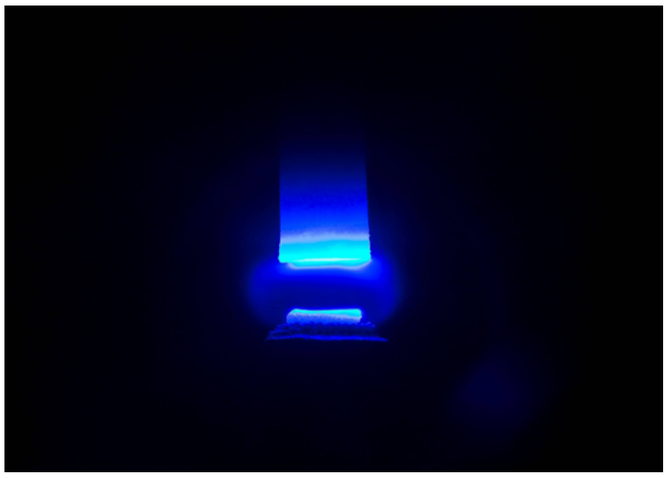
PPPL photo on display in "Art of Science" exhibit

A photo by PPPL photographer Elle Starkman, along with physicists Yevgeny Raitses and Vlad Vekselman, was chosen from more than 170 submissions, for the "Art of Science" exhibit currently on display at the Friend Center, 65 Olden St. The exhibit is free and open to the public during Friend Center hours, 9 a.m. to 5 p.m. or go here.

Here is the description of the photo from the exhibit:

The Princeton Plasma Physics Laboratory's photograph "Nano Plasma Arc" shows evaporated carbon atoms in a plasma between two graphite electrodes with a surface temperature measuring approximately 4000 degrees Kelvin, according to Elle Starkman, multimedia specialist, Yevgeny Raitses, principal research physicist and lecturer in astrophysical sciences, and Vlad Vekselman, associate research physicist.



Nanoparticles

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The findings revealed the need for stabilizing the arc so that it constantly engaged the graphite and catalyst for the continuous production of single-wall carbon nanotubes. The paper proposes several pathways going forward, ranging from the use of thinner-walled to solid composite anodes for producing nanotubes in a continuous manner with fewer unwanted byproducts.

Finally, understanding the cause of such impurities is crucial for future research at PPPL and elsewhere. As scientists continue to develop methods of *in situ* characterization for nanostructures, they must monitor the arc behavior and distinguish between results obtained in the synthesis-on and synthesis-off modes.

Going forward, PPPL conducts *in situ* measurements of plasma nanotubes synthesized from boron nitride, a promising material with aerospace and electronics applications. Collaborating on this work are professors Roberto Car of Princeton University, Predrag Kristic of the State University of New York at Stony Brook, and Bruce Koel of Princeton.

Overseeing PPPL nanosynthesis projects is Phil Efthimion, head of the PS&T Department. Following are coauthors of the papers. Nanoparticle precursors: Vladislav Vekselman, Alexander Khrabry, Igor Kaganovich, Brent Stratton and Yevgeny Raitses of PPPL, and Rachel Selinsky of Princeton University. Detecting nanoparticle growth: Alexandros Gerakis, James Mitrani, Brent Stratton, and Yevgeny Raitses of PPPL, Yao-Wen Yeh and Mikhail Schneider of Princeton University. Synthesis on and synthesis off: Shurik Yatom and Yevgeny Raitses of PPPL, Rachel Selinsky and Bruce Koel of Princeton University.

What is the number one reason for unsafe behaviors at PPPL?

Doing what is easy over what is correct ("convenience over safety") is the number one reason behind observed unsafe behaviors at PPPL, according to STOP program findings.

Take the time you need to work safely!

Safety first:
Use the STOP program!

Innovation Forum

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First prize winners Daniel Dudt, second from right, and Michael Hvasta, far right, with other award winners, from left: second place winner graduate student Kurt Ristroph; third place winners: graduate students Evan Zhao, Agnieszka Gil, and Alex Goglia, a graduate student and MD candidate. *(Photo by Laurie Bagley)*

"We'd like to thank PPPL for offering the infrastructure, opportunity and expertise for this technology," said lead inventor Michael Hvasta, an associate professional specialist in the Department of Mechanical and Aerospace Engineering at Princeton University. Hvasta works on liquid metal research with Egemen Kolemen, an assistant professor in the Department of Mechanical and Aerospace Engineering at Princeton, jointly appointed by PPPL and the Andlinger Center for Energy and the Environment.

When Hvasta learned that the invention had won first place, his co-inventor Daniel Dudt, a graduate student in the Department of Mechanical and Aerospace Engineering at Princeton, was still out in the Fields Center lobby. Hvasta ran into the lobby shouting, "We won first place!" and the two took the stage to accept the award.

A long history with PPPL

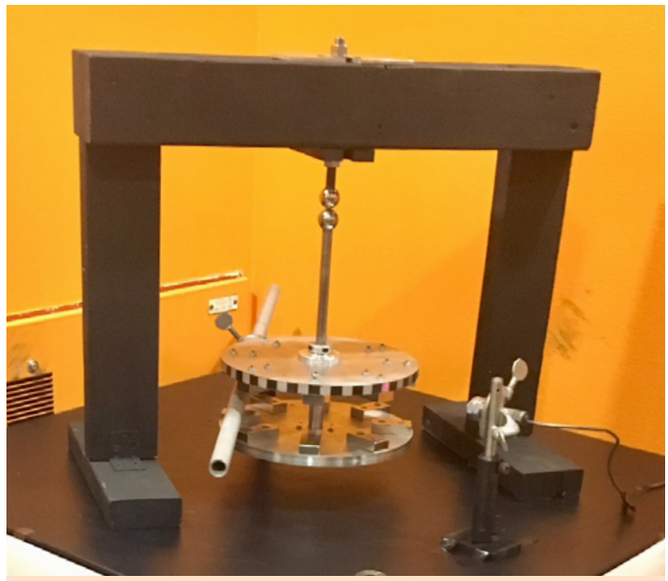
Hvasta, who received a Ph.D. in nuclear engineering and engineering physics from the University of Wisconsin in 2013, has a long history with PPPL. He was a research intern at PPPL as a physics major at The College of New Jersey in 2007 and 2008. He was first part of the Princeton Plasma Physics Laboratory's research internship program and then worked on dusty plasma research with Andrew Zwicker, then head of Science Education and now also head of Communications and Public Outreach.

The inventors are the second group from PPPL to win an award at the Innovation Forum. Engineer Charlie Gentile, George Ascione, the manager of Health Physics at PPPL, and Adam Cohen, former deputy director for operations, received third place in 2016 for their invention of an on-demand method to create a widely-used medical isotope for medical imaging.

Gentile and Bagley helped coach Hvasta. "Charlie was an excellent resource," Hvasta said. "He provided a lot of insights regarding the competition and really helped us refine our presentation."

Second prize at the Forum went to a team of inventors for "Photo-pharma," which uses light to control bio-engineered proteins for use in pharmaceuticals. The third prize went to Kurt Ristroph, a graduate student in chemical and biological engineering, who invented a method to use nanoparticles to eliminate antibiotic-resistant bacteria known as "superbugs."

Hvasta and his colleagues have already built a demonstration model of the "Rotating Lorentz-Force Flowmeter," which they displayed at the Innovation Forum. They have used



The flow meter on display at the Innovation Forum. *(Photo by Laurie Bagley)*

the device in the laboratory at PPPL to measure the flow of a liquid metal alloy known as "galinstan" as part of a project led by Kolemen to study the use of liquid metals as plasma-facing materials for a torus. Kolemen's team includes Hvasta and co-inventors Dudt and Adam Fisher, also a graduate student in Princeton University's Department of Mechanical and Aerospace Engineering.

Kolemen received $450,000 in Laboratory Directed Research and Development (LDRD) funds from the U.S. Department of Energy for the project in fiscal year 2017. "We were trying to develop a liquid metal flowmeter for fusion reactors and that's how we developed this," Kolemen said.

Plans to test and refine device

What makes the device unique is the use of low-friction bearings that allow the device to respond more quickly and without requiring calibration, the inventors say. This makes it able to measure liquids at low-flow rates. The inventors plan to use the $15,000 award to further test and refine the device, Hvasta said. They plan to demonstrate the technology on a variety of liquids and develop an electromagnetic version of their low-friction bearing that would make the device simpler and improve the performance.

The rotating Lorentz force flowmeter operates by using a spinning array of permanent magnets to measure the flow of electrically conductive fluids. It can be installed outside a piping system and since it doesn't have moving parts or seals touching the fluid, the flowmeter can be used to measure high-temperature or corrosive fluids.

The market for flowmeters is expected to grow by 25 percent over the next four years to become a $9 billion market, Hvasta said. In his presentation, he noted that his device cost under $1,000 to build, a much lower price than most commercial flowmeters, which could cost thousands of dollars.

The inventors outside the Lyman Spitzer Building at PPPL. From left: Adam Fisher, Daniel Dudt, Michael Hvasta, and Egemen Kolemen. *(Photo by Jeanne Jackson DeVoe)*

Deedee Ortiz recognized for contributions to diversity and inclusion

Deedee Ortiz, PPPL's Science Education program manager, was recently recognized by the Latino Princetonians Employee Resource Group for her leadership in managing and implementing programs that promote the University's diversity and inclusion efforts. Ortiz manages several Science Education programs including Science on Saturday, the N.J. Regional Science Bowl, and the Young Women's Conference.

Deedee Ortiz at the Young Women's Conference in 2017. *(Photo by Elle Starkman)*

Benway School Students Tour PPPL on March 14

Students from the Benway School in Wayne, New Jersey, visited PPPL on March 14. They toured the control room and test cell, and the PPPL firehouse, where they learned how emergency responders put out fires.

ESU Capt. Kevin Rhoades greets students at the PPPL firehouse. *(Photo by Raphael Rosen)*

Tour guide Atiba Brereton answers questions in the control room. *(Photo by Raphael Rosen)*

A Benway student puts out a controlled fire using a hose from a PPPL fire engine with help from Capt. Jamie Dunnigan. *(Photo by Raphael Rosen)*

Volunteer for the Young Women's Conference March 22

There will be 750 girls from all over New Jersey at this year's Young Women's Conference March 22 at Princeton University. Volunteers are needed to help out with PPPL and Liberty Science Center tables, registration, and other tasks.

Click here to register to volunteer.

Please contact Deedee Ortiz, dortiz@pppl.gov, ext. 2785, for more information

Young scientists and engineers win PPPL awards at Mercer County Science & Engineering Fair

Charlotte Michaluk, age 11, a sixth grader at Timberlane Middle School in Pennington, received PPPL's Young Engineer and Scientist Award for Challenging Problem Solving and Research at the 2018 Mercer County Science & Engineering Fair.

Kevin Lamb, a senior technician, and Hans Schneider, an engineer, presented the award to Charlotte during the fair on Tuesday night at Rider University.

Charlotte won a plaque for her project "Terrific Tensile Tester: a cost-effective solution for evaluating adhesive systems." All of the award winners receive a certificate and a tour of the Princeton Plasma Physics Laboratory.

Honorable mentions went to:

Jiaqi Lu: "Fighting Irreproducibility in Solar Cell Research"

Daniel Kardhashi: "Where's The Wifi?"

Emma Charlotte Phelan: "The Gauss Rifle… How fast, how far, how many?"

Molly Frascella: "Are you eating nails for breakfast?"

Charlotte Scher: "Where will my rocket land?"

The Mercer County Science and Engineering Club has organized the fair for more than 50 years. It is open to Mercer County students in fourth through twelfth grades.

Kevin Lamb with Charlotte Michaluk holding her award from PPPL. *(Photo by Hans Schneider)*

COLLOQUIUM

High Power Electric Propulsion for the Next Generation of Space Exploration

Benjamin Jorns
University of Michigan, Dept. of Aerospace Engineering

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

Council Café Lunch

This Week:
Valeria Riccardo, Head of Engineering

Wednesday, March 21
12 p.m., PPPL Café

March 28: Scott Weidner

BROCK

NICK PETTI
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 March 19	Tuesday March 20	Wednesday March 21	Thursday March 22	Friday March 23
Early Riser	**Blueberry Pancakes**	**Fried Bologna and Egg Sandwich**	**Tater Tot Breakfast Bake**	**Ham, Egg & Cheese French Toast**	**Biscuits and Sausage Gravy**
Country Kettle	**Chef's Choice**	**Chef's Choice**	**Chef's Choice**	**Chef's Choice**	**Chef's Choice**
Deli Specialty	**Italian Hero**	**Muffaletta**	**Lemon Rosemary Turkey Sandwich**	**Sushi**	**Italian Tuna Salad Wrap**
Grill Specialty	**Taco Cheese Steak**	**Pork Roll and Cheese Sandwich**	**Grilled Fish Cake Sandwich**		**BBQ Turkey Melt**
COMMAND PERFORMANCE **Chef's Feature**	**Beef and Bean Burrito with Yellow Rice**	**Cornmeal Catfish** with Red Beans and Rice and Hush Puppies	**Carved Jerk Seasoned Pork Loin** with Pineapple Rice and Mango Salsa		**Bourbon Chicken** over Rice
Grilled Panini	**Cuban Wrap**	**Grilled Carnegie**	**Meatball Parmigiana Hero**		**NY Street Dog—** 2 Sabrett Hot Dogs with Sauerkraut, Red Onions & Mustard served with Fries

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** ◆ Science Writer: **Raphael Rosen** ◆ Webmaster: **Chris Cane** ◆ Communications Director: **Larry Bernard**

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