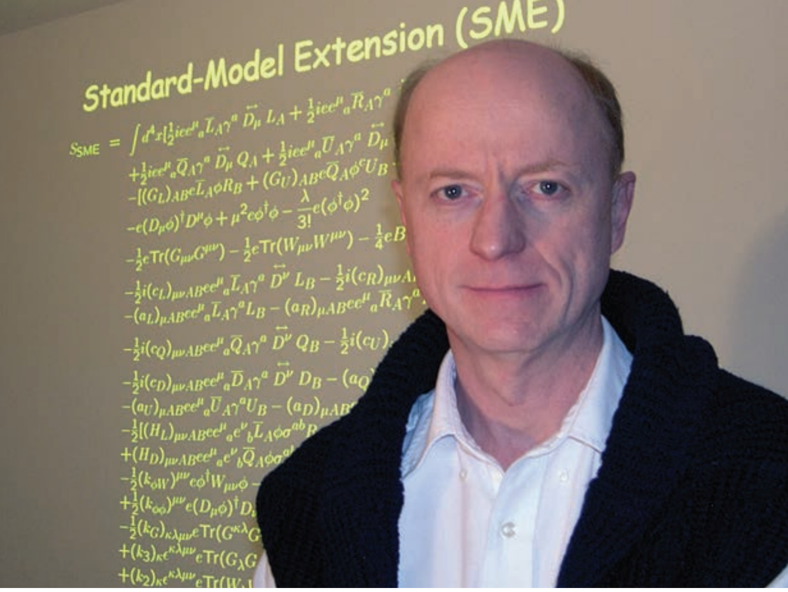
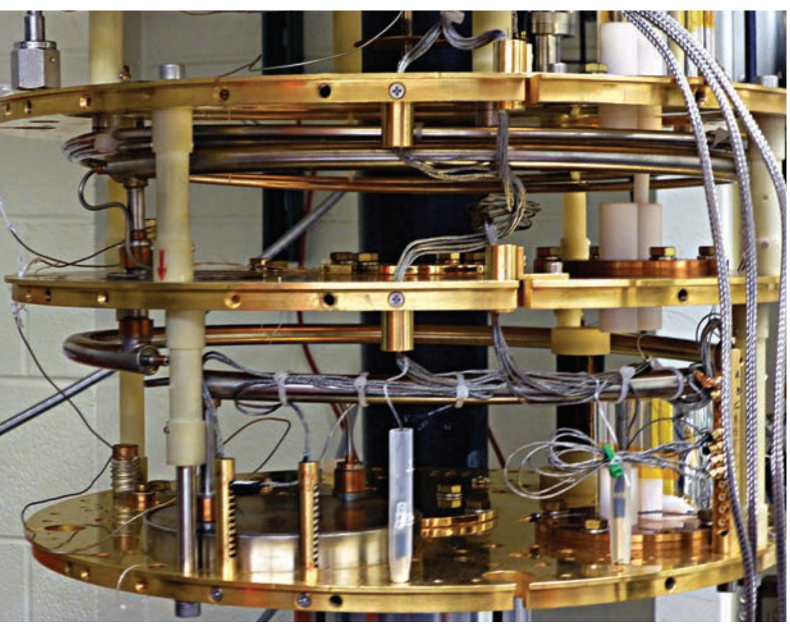


Spacetime
and International Science

Science is the least international and the most international of disciplines. Least because scientists work to exclude the effect of culture and language on their experiments and results. Most because scientific knowledge is the same all over the world. Scientists may not share a common language or background, but they share a common understanding of the scientific problems they are trying to solve. As those problems demand ever-increasing sophistication of precision, speed, and resources, the need for global cooperation increases. Scientists are among the busiest of international travelers, and major advances are rarely made in isolation.

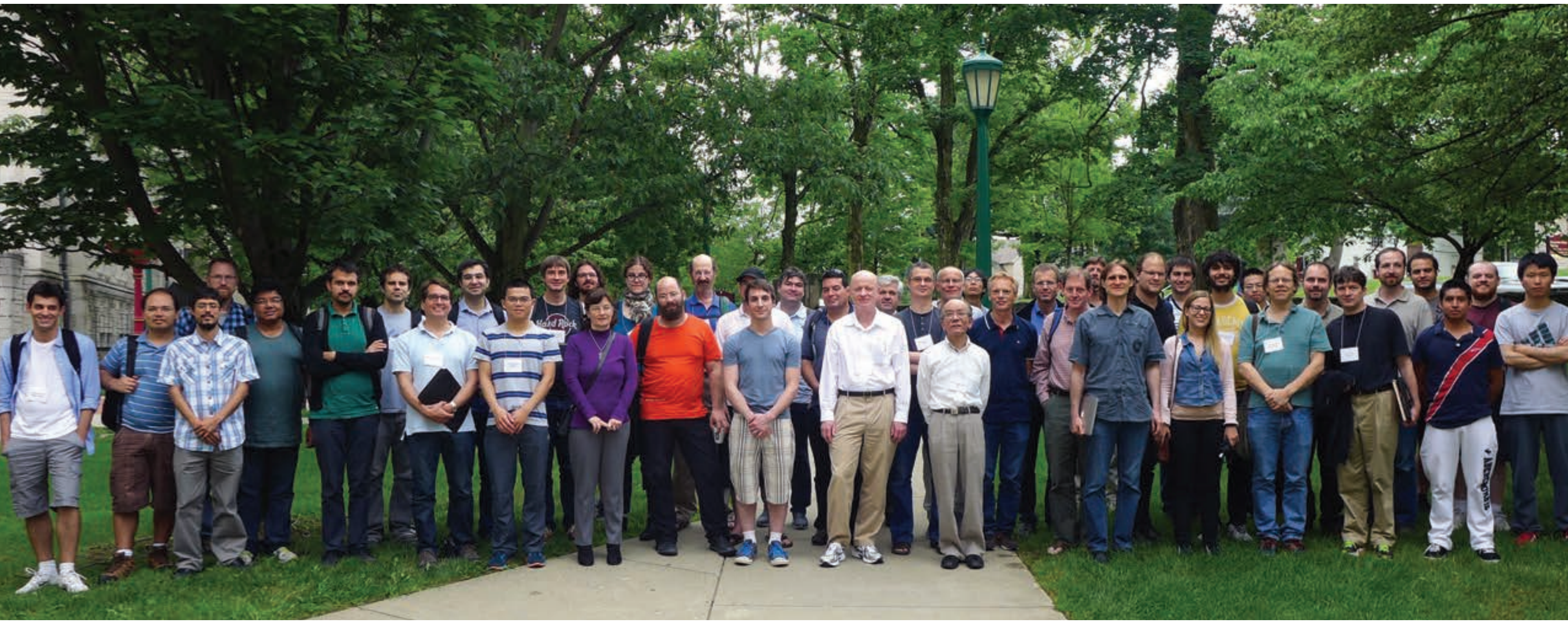


One of the challenges is designing equipment that can produce the extreme environments that are most likely to produce evidence of symmetry violations. Pictured above is part of a device that chills nuclei to temperatures close to absolute zero.

No field of science depends more on international collaboration than particle physics. Major advances—resulting in the Standard Model articulated in the 1970s—fail to provide physicists' holy grail, the "theory of everything." Decades of experiments have proved the soundness of the Standard Model, but problems for that model remain, among them gravity, dark matter, dark energy, and the baffling habit of the universe of expanding at an ever faster rate. "Once you have a theory that works, you attack it," explains IU Professor of Physics Michael Snow. "If it continues to work, you won't learn anything new. If it fails, you learn something new." Physicists are trying to find a chink in the armor of spacetime, as Einstein and others defined it, with the hope that the chink might lead to a theory that can encompass these unknowns.

Far left: *Alan Kostelecky explains his formula that shows how symmetries underlying our understanding of spacetime can be violated.*

Left: *Participants at the 2015 conference: From the left, Arnaldo Vargas, IU grad student from Puerto Rico; Yasuhiro Ueno, grad student at the University of Tokyo; Professor Koichiro Shimomura from KEK (the Japanese High Energy Accelerator Research Organization); and IU Distinguished Professor Alan Kostelecky. They discuss a recent paper by Kostelecky and Vargas that proposes an experiment that can be done by Shimomura and Ueno at KEK.*



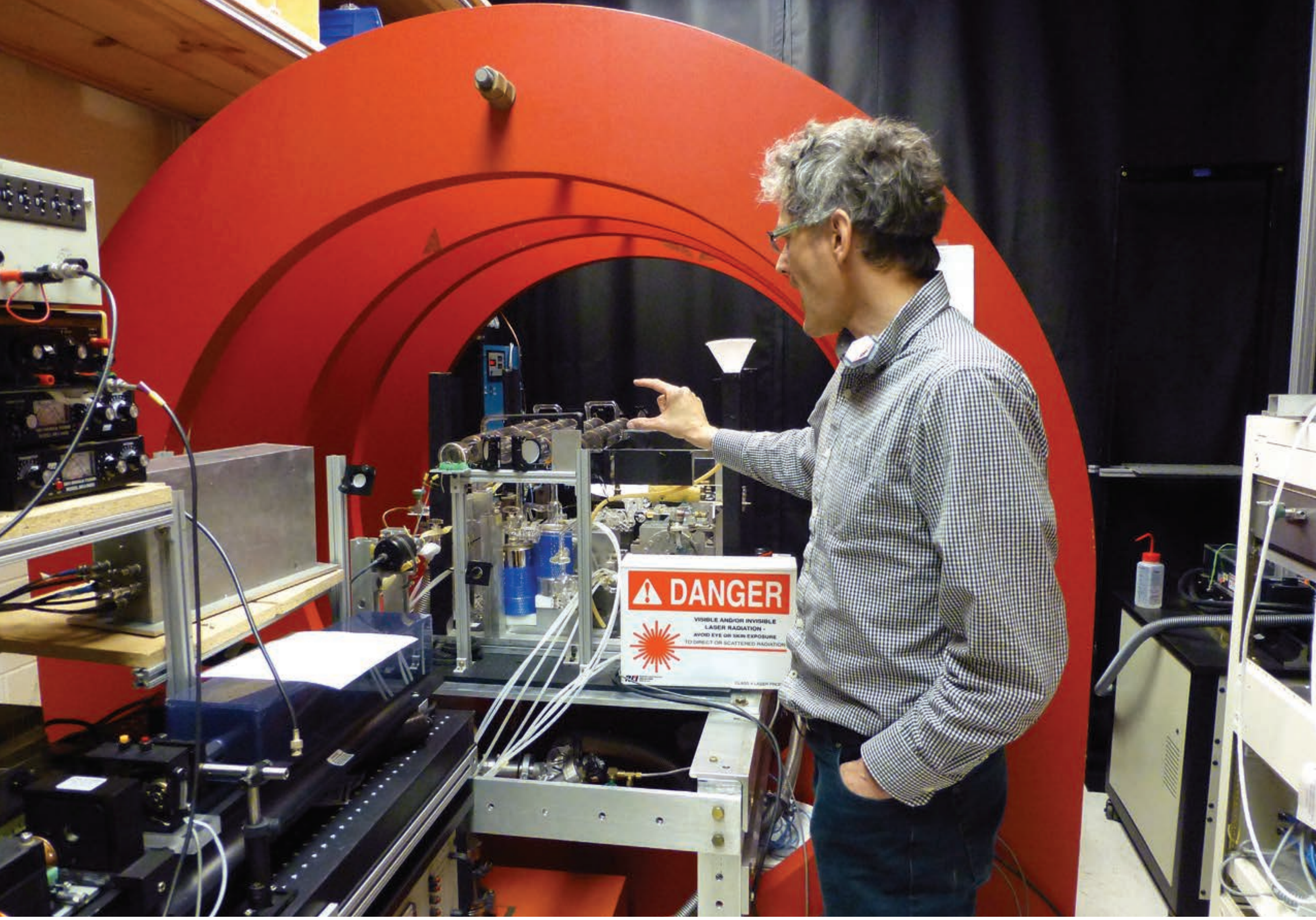
Participants in the June 2015 conference at the IU Center for Spacetime Symmetries

One of the pillars of the Standard Model is symmetry. If you find a spot in deep space, conduct an experiment, and gather results, and then find a different spot in deep space and do the experiment in the same way again, you will get the same results. This symmetry holds even in the most fantastic of circumstances. IU Distinguished Professor Alan Kostelecky explains: "Change matter to anti-matter. Do the experiment in a mirror. Make time go backwards. If you could do all three things, the Standard Model says the symmetry will still hold; the experimental results would be the same."

In 1989, Kostelecky and his colleagues demonstrated theoretically ways that spacetime symmetry might be violated. If such violations could be shown experimentally, physics would be a step closer to a more unified theory. The proposed Standard Model Extension "got a horse laugh at the beginning," Kostelecky admits. "It took a long time to figure out how an experiment might be done. Now I would be hard pressed to name a country where someone is not working on this idea."

As yet, no one has produced experimental results of a violation of the kind Kostelecky predicted, but the IU Center for Spacetime Symmetries, founded in 2010, is committed to trying. Director Mike Snow said, "We have people coming from atomic physics, astrophysics, gravitational physics, almost every subfield. They each have some special angle their measurements can bring to bear on the question."

It is most likely that violations will be found at extremes—extreme speed, extreme temperature, extremely small spaces. Many assume that experiments require the speed



Mike Snow explains a device that produces and manipulates atoms of helium with spinning nuclei inside.

"I can't think of a time when I wasn't international in my perspective. I was interested in physics, and you quickly discover that everybody contributes from everywhere in the world. You never know where good ideas are going to come from." —Mike Snow

and high energy of a particle accelerator like the Large Hadron Collider in Europe. "As an alternative to building an ever bigger collider, we can rely on the precision of measurements," Snow said. "If you measure precisely enough, you can address questions that no accelerator can reach. That is some of what we do here." Snow's own research involves experiments inside nuclei at temperatures near absolute zero.

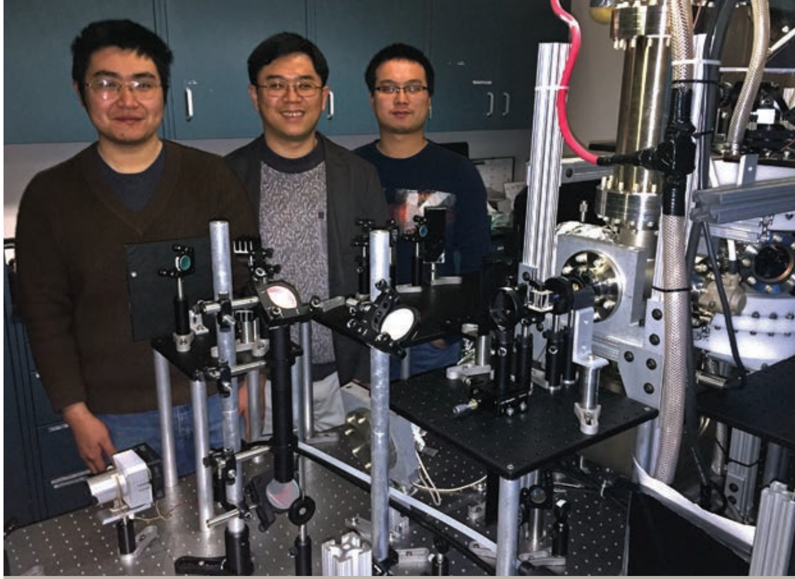
Although such experiments are being conducted around the world, "research in physics is much more efficient if you can discuss it with somebody in their physical presence," Snow said. "Email or Skype manages bits and pieces of the intellectual engagement; often that's too inefficient. What people especially need for effective theoretical research are elements conducive to concentration: isolation, time, and focus. Researchers and students come to the center from all over. They hang out here for a month or so. We give

Physicists are trying to pierce the armor of spacetime, as Einstein and others defined it, with the hope that the discovery might lead to a theory that can encompass these unknowns.

them space and opportunities to work together. They discuss, hash out ideas, do calculation, talk to each other, and get a collaborative scientific result."

Every other year, the IU Center for Spacetime Symmetry center convenes a conference, "the only one in the world" according to Snow, on progress towards finding something that violates spacetime symmetries demanded by the Standard Model. The June 2015 meeting brought scientists from 17 countries—including a strong representation from Brazil, and from Hungary, Mexico, Japan, Australia, Azerbaijan, India, and China—to discuss "signals for nonminimal Lorentz and CPT violation" and preceded it with a weeklong training session for scientists wishing to begin research into the problem.

IUPUI Assistant Professor of Physics Le Luo was part of the conference. He explains the importance of having such a variety of eyes on the problem. "The evidence of a violation of symmetry cannot be a single event. You need different experiments from different systems—solid state physics, astronomy, atomic and nuclear physics. You need different expertise, different resources. It cannot be done in a single group or a single place. You need the collaboration from physicists all over the world."



Luo (left) in his IUPUI lab with students. Jiaming Li (center) is an exchange student from Sun Yat-sen University. Ji Liu (right) completed his bachelor's degree at Sun Yat-sen University and is working on his Ph.D. at IUPUI.

LE LUO

Le Luo grew up in Guangzhou, China. His father, Zhenzhong Luo, was a professor of physics at Sun Yat-sen University. Luo followed in his father's footsteps and earned his bachelor's degree in physics from Sun Yat-sen. The senior Luo studied semiconductors and applied physics. The son was more interested in in experimental physics for fundamental studies, and for that he came to the United States. After completing his advanced degrees at Duke and postdoc work at the University of Maryland, he accepted a position in the physics department at IUPUI. His lab, which has attracted undergraduate and graduate students from Sun Yat-sen University to IUPUI, has been dedicated to studying the behavior of atoms at temperatures close to absolute zero. At the conference in June 2015, he explored with other researchers a new experimental direction, testing whether light propagation in a vacuum might provide evidence of a violation of symmetry.