

# The *SPS Observer*

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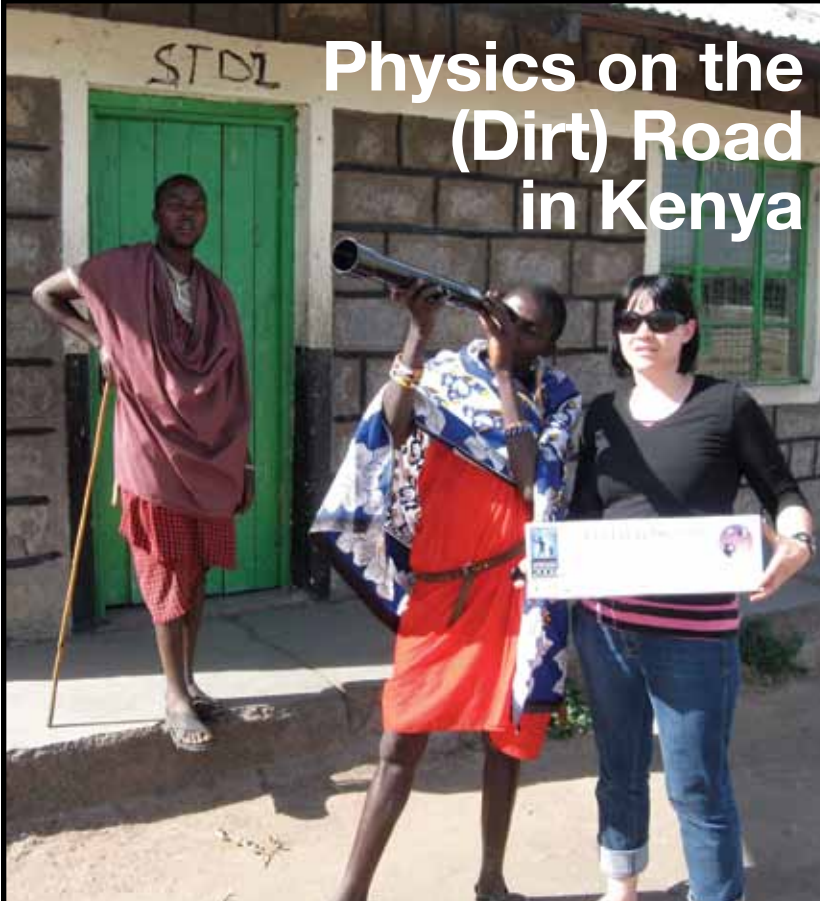
## A Universe of Wonder



## LRO Takes Flight



## Physics on the (Dirt) Road in Kenya




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About the Cover

In this issue we pay homage to "A Universe of Wonder," the 2009 SPS theme, aligned with the International Year of Astronomy 2009. Upper left: SPS member Jodie Barker-Tvedtnes (Utah State University) and daughter Kallia marvel at the wonders of the night sky (see <http://url2it.com/bgpep>). Right: NASA's LRO launches from the Kennedy Space Center (page 2). Lower left: Students peer through a Galileoscope during an outreach event in Kenya (page 5).



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# My Story of LRO

## How the Lunar Reconnaissance Orbiter Will Change Our View of the Moon

By Daniel McNeel, 2008 & 2009 SPS-NASA Goddard Intern, New Mexico State University



LRO. The Lunar Reconnaissance Orbiter or LRO. Chances are you heard about this satellite a few weeks ago, when part of it became a probe and crashed into the Moon. Launched from Cape Canaveral, Florida, I know a great deal about it, because I was there for the launch. This spacecraft and I go way back together, even further back than you might imagine. This is the story of how I came to become involved with this chunk of metal currently circling the moon.

It has been 7 years since I first stood on the steps of the gantry, a mock-up rocket tower that the Kennedy Space Center built to display one of the space shuttle engines. In eighth grade my class took a field trip to Florida and visited Kennedy as an afterthought. For me, it was the main attraction. I was interested even while my classmates were running up and down the steps looking for something *really* interesting, like an alligator. The rockets were by far the most fascinating part of the experience for me. That's probably why, 6 years later, I wound up working at NASA Goddard. That was the summer of 2008, and my first internship. It was there that I saw the spacecraft, came to understand its mission, and learned why NASA is so interested in the moon. This year I returned to NASA to complete my work and to pass on what I learned. Hopefully I can manage that, in part through this article.

The spacecraft that I will be referring to throughout this article is the LRO, a bundle of instruments that was launched aboard an Atlas V rocket at Cape Canaveral. The launch was June 18th, 2009. LRO will explore the surface of the entire moon during a mission up to 5 years long. It observed the top phase of the Atlas V rocket as it impacted the surface of the moon. Interesting, yes, but what do we have to gain from this undertaking?

At first, it may seem that there is no benefit to sending a satellite back to the moon. However, the first and foremost mission of the spacecraft is to gather information on the resources and topography of the moon so that when people go back, we know exactly what to look for and where. The spacecraft is a scout going ahead to look for water on the moon, as well as safe places to land. Humans will return to the moon, perhaps as early as 2020. When we do, we need to know much more about the moon than we do now.

### Water on the Moon

Why would water on the moon be important? How do we find water on the moon? Why



On June 18, 2009, the Lunar Reconnaissance Orbiter and Lunar Crater Observation and Sensing Satellite took off for the moon aboard an Atlas V rocket.  
Credit: NASA

would we even expect to see water on the moon? And really, don't we have enough of it here on earth? I should say we do, judging from my recent trip to Florida.

We are interested because NASA wants to go back to the moon. I think that if you have read this far into my article, you also may have some interest in going back to the moon. The last time we attempted such a feat we had to bring everything we needed with us. It would be nice, when returning to the moon, if we could find a little piece of home waiting for us. It would be nicer still if we could harvest ice to use for rocket fuel and drinking water for the journey home. It would make development of the moon much easier and more cost effective. Indeed, such a discovery could even mean that commercial ventures on the moon, such as the mining of very precious materials, could become plausible.

Neutrons are a crucial tool for finding water on the moon. There are very few neutrons in deep space, because neutrons are unstable particles. This means that any neutrons observed in space were most likely knocked off of a nearby atom. Any atom will do, including the atoms in Earth's



Artist concept of the Lunar Reconnaissance Orbiter with Apollo mission imagery in the background.  
Credit: NASA

atmosphere, atoms in the spacecraft, and atoms in the moon. The neutrons are knocked out of nuclei by high-energy particles known as cosmic rays. On earth, cosmic rays interact mostly with the atmosphere. On the moon, where there is no atmosphere, cosmic rays are stopped in the first meter of soil. Here they smash into the nuclei of atoms, causing a cascade of particles and pieces. Some of the particles that are released are neutrons which can then escape to a detector on the LRO.

Now for the crucial part: linking neutrons to water. Unfortunately, I can't do that. What I can



Daniel (L) relaxing at the test site for Goddard's Pulsed Neutron Generator-Gamma-Ray and Neutron Detector with fellow SPS interns Jose Castellano (New Mexico State University) and Ian Dougherty (Rowan University).  
(Photo courtesy Ian Dougherty).

## Five Things About the Lunar Reconnaissance Orbiter

NASA. "Lunar Reconnaissance Orbiter, NASA's First Step Back to the Moon."  
[www.nasa.gov/mission\\_pages/LRO/news/LROfivethings.html](http://www.nasa.gov/mission_pages/LRO/news/LROfivethings.html) Public domain.

Here are five quick things you should know:

- LRO is leading NASA's way back to the moon.
- The primary objective of LRO is to conduct investigations preparing for future exploration of the moon. Specifically, LRO will scout for safe and compelling lunar landing sites, locate potential resources with special attention to the possibility of water ice, and characterize the effects of prolonged exposure to the lunar radiation environment. In addition to its exploration mission, LRO will also return rich scientific data that will help us to better understand the moon's topography and composition.
- The instrument payload of LRO consists of seven scientific instruments from partner institutions around the nation and globe, including one instrument contributed by the Institute for Space Research in Moscow. These instruments will return lunar imagery, topography, temperatures, and more.
- Launching along with LRO is the Lunar Crater Observation and Sensing Satellite (LCROSS), a partner mission that searched for water ice on the moon by sending an SUV-sized rocket stage into the permanent shadows of a polar crater. LCROSS flew into the plume of dust left by the impact and took measurements of its properties before also colliding with the lunar surface.
- In response to LRO's "Send Your Name to the Moon" web site, the spacecraft carries a microchip with nearly 1.6 million names that were submitted by the public.

To find out more about the LRO mission, visit the NASA website at [www.nasa.gov/mission\\_pages/LRO/main/](http://www.nasa.gov/mission_pages/LRO/main/).

do is link neutrons to hydrogen. The link between neutrons and hydrogen is very simple and therefore, very reliable. Neutrons have about the same mass as hydrogen, so when a neutron collides with hydrogen it loses a lot of energy. That means all we have to do to find the hydrogen is look for areas on the moon that have fewer neutrons. This is very significant, since water is two parts hydrogen to one part oxygen. If the observed hydrogen concentration is high enough, it is very likely that it is in the form of water.

We expect to find water on the moon in the polar regions, where some craters are deep enough to permanently block out the sun. Here on Earth, the sun lights the eastern slopes of a mountain at first light, leaving the western side in darkness for much longer. In the polar regions of the moon, craters can cast shadows over their interiors all day. These shielded craters are cold; this makes them the best places to find water ice.

Finding water on the moon would mean a lot to our future in space and to the future of our space program. President Kennedy said, "We choose to do these things not because they are easy, but because they are hard." Finding water on the moon would make space travel easier, so that we might test ourselves against greater challenges that even President Kennedy did not foresee.

### Final Thoughts

As I stood on the Kennedy Space Center gantry 7 years later, I took some time to think about all that has happened here and how much there is still to be done at NASA. I find myself embarrassed to be part of a generation of so much technological sophistication that hasn't

surpassed the Saturn V rocket from the 1960s. Those of us that are students are too young to remember the moon landings. We hear stories about them, of how brave the astronauts were, of how the flourishing space program created uncountable new discoveries, of how the whole nation watched. I hear these stories and think to myself: We can do better. We can get farther. We can be the generation that remembers the first Mars landing. Certainly the undertaking is monumental. Certainly the risks are still there. But we have better tools now than we did then, and this spacecraft will help point the way. Because of LRO, our generation will leap farther into space than ever before.

## Be an SPS Intern!

SPS internships are 9-week, broad-based learning opportunities for undergraduate physics majors in the areas of scientific research, outreach and policy.

Interns are placed in organizations such as NIST, NASA, AIP, AAS, AAPT, and APS in the Washington, DC area.

These organizations utilize the energy and diversity of aspiring students and contribute to their professional development through meaningful assignments. For more information, visit [www.spsnational.org/programs/internships/](http://www.spsnational.org/programs/internships/).

# For Those Who Care

*It has often been observed that one should let others do the bragging for you. The SPS Awards Committee recently read a thick stack of nominations for the 2009 Outstanding Chapter Advisor Award. Every year the Committee members are humbled and inspired by these letters. We thought that the Society as a whole would benefit from seeing their examples. Here we display, with minimal editing, sample quotations from letters of recommendation written for Award nominees. Most of the letters are written by students. Some are written by the chapter advisor's faculty colleagues or by local community leaders.*

*The rules of the Award allow the Committee to select only one recipient each year. The selection can therefore be excruciating, although the view offered by the letters is uplifting.*

*In sharing excerpts from the letters, I have tried to preserve anonymity of nominees, nominators, and their institutions so that chapters can say, "Oh, that could be us!" Thus, where the advisor's name appeared in the passage, I have substituted the names of "Marie Curie" for female advisors and "Pierre Curie" for male advisors. Where the name of the chapter's college or university appeared in the letter, I have substituted "Sorbonne University" after the institution that was important to both Marie Sklodowska Curie and Pierre Curie.*

*I hope you enjoy this glimpse into the lives of our exemplary chapter advisors.*

*By Dwight E. Neuenschwander*

"...She was my first college professor and through her love of physics convinced me to become a physics major..."

"...While at the time I had never had a class with her, I could tell she was serious about the discipline of physics and the cultivation of all the students within the physics curriculum. Later, I decided to join SPS as a member and ran for an officer position because Dr. Curie encouraged me....I learned that Dr. Curie has given nearly 30 years of her life to the orchestration of the SPS activities and to the support of its students."

"I'm very excited to recommend Dr. Curie—he's the definition of what an outstanding advisor should be. He's an enthusiastic mentor for we students and we can't help but catch the excitement of physics when we are with him. He encourages projects at SPS meetings and helps us build lots of fun things (like Nerf-style bazooka vacuum cannons, small radios, Hero's fountains, mini-spud guns, motors, etc.). He's hosted a number of competitions in SPS such as bridge building and trebuchet building competitions. He plans and participates...in a large number of outreach events...He also helped arrange our visit to the



*SPS President Toni Saucy won the SPS Outstanding Advisor Award in 2007. She's shown here at the Sigma Pi Sigma 2008 Congress with her students from Angelo State University, Meagan Saldua, Logan Hancock, and Kunal Bhatnagar.*

*Photo By Phillip Payette*

Argonne National Lab in Chicago last fall..."  
"Upon hearing about the Sigma Pi Sigma Quadrennial Congress, Dr. Curie already had the idea that our SPS chapter was attending that event...She made it possible for the members of Sorbonne's SPS chapter to reserve a hotel room, using her credit card, found a way to etch out meeting times to plan travel logistics to Illinois... She even...found someone to silkscreen t-shirts for our SPS chapter so we could wear them to the Congress meeting..."

"...Dr. Curie worked with me 1 or 2 days a week on my calculus homework, even though he is not part of the math department...Outside of the classroom, Dr. Curie is always there when you need him..."

"Our physics majors are scattered about the area in its schools and industry. I would boldly put forth that there is not one who wouldn't name Dr. Curie as a significant guiding force in their preparation. Go ahead and ask them..."

"...In 200X, [Sorbonne SPS] took the first ever road trip—they visited nine schools in 4 days, doing two to three demonstration shows each day. They interacted with approximately 900 or so students, teachers and parents over the course of the week...Since the grant expired these trips are [now] paid for by funds generated from sales of the physical science lab manual that Marie pioneered at Sorbonne..."

"...A new tradition-in-the-making is the Edible Car Contest, again initiated by Dr. Curie. In this competition several teams enter homemade cars which are built *completely* out of edible materials. The winners are selected based on appearance, creativity of materials, and distance rolled down a ramp, and all contestants are required to CONSUME their vehicles once the competition is complete..."

"Dr. Curie has not only been one of the most active and enthusiastic faculty advisors for any club on our campus, he has also been inspirational to many students...Dr. Curie helped motivate and mobilize students to build a "human-sized hamster wheel." All the planning, designing, and building were done by students, but without Dr. Curie's encouragement and helpfulness, this project would not have been a success...The human-sized hamster wheel still stands in our physics lab; with a fast enough person running on it, one could power several light bulbs..."

*From a director of a Research Division of a well-known corporation, who teaches physics and astronomy at Sorbonne University as an adjunct: "Although I could identify Dr. Curie as passionate in his work with students early in my association with Sorbonne University, it became clear to me that I have never met or witnessed an individual, at any level in education or in business, that is as committed to the nurturing of young adults in leadership, research excellence, organization, and giving back to the community."*

In reflecting over these letters, some patterns emerge. Their characteristics include:

- Caring
- Involvement
- Connection
- Community
- Outward-directed vision
- Engaged
- Identity
- Relationships...

Parker J. Palmer elaborated in *The Courage to Teach* (1998),

*"But in every story I have heard, good teachers share one trait: a strong sense of personal identity infused their work. [However,] bad teachers... were all the same: 'Their words float somewhere in front of their faces, like the balloon speech in cartoons.'*

*With this one remarkable image [this student] said it all...'Bad teachers distance themselves from the subject they are teaching—and in the process, from their students. Good teachers join self and subject and students in the fabric of life.'*

*Good teachers possess a capacity for connect- edness..."*

These advisors never sought the nomination for the award; the nomination came to them. These chapter advisors, and many more like them, obviously see themselves in the service of students. They are engaged in something that is larger than themselves.

We join their students in thanking them, with admiration.

*By Dwight E. Neuenschwander*

# Physics on the (Dirt) Road in Kenya

By Chris Discenza

American Physical Society (APS)



We approached the school cautiously over the thick dirt road. The Ontulili High School is located in the forest that rests in the shadow of Mt. Kenya. Although this wasn't the rainy season, there were scattered afternoon showers that flirted with the current drought. We knew that if it rained we would be stranded in the thick soil that formed the only road back into town. During our presentation to the students, rain started and continued to pour in an ironic response to our weather science demonstrations.

In July I traveled to Kenya with two colleagues: Sherri Heck, a research scientist from the National Center for Atmospheric Research (NCAR), and Christina Pease from Pima Community College. Sherri was the mastermind behind the whole operation. She measures the carbon dioxide levels in rural areas around the world and Mt. Kenya, on the equator, is an ideal spot to collect data valuable for modeling the climate.

The trip to Kenya was funded by NCAR in support of Sherri's research and included a science outreach component. Christina, who traveled with me on a physics bus around the US in previous years, and I led the outreach program. We were also accompanied by Peter Bundi, Associate Director at the Kenyan Meteorological Department. He escorted us to different schools and enlightened us on current political events and cultural subtleties in Kenya.

We gave presentations on physics and weather science to students and teachers at eight schools around Mt. Kenya. The presentations for the students were motivational demonstration



Students were intrigued by the PhysicsQuest comic book and experiments, donated by the American Physical Society (APS).

Credit: National Center for Atmospheric Research (NCAR)

shows, while the meetings with the teachers functioned as workshops to demonstrate and explain experiments. Since many of these schools lack a budget for science materials, we brought a kit of sustainable materials to each school. Each kit consisted of reusable experiments, rechargeable batteries, and solar chargers for the batteries. Not only did this promote sustainability and alternative energy, it was a functional requirement for the

rural schools. Many of the schools did not have electricity or running water.

We also brought Galileoscopes to each school, and many students and teachers saw the details of the moon for the first time. I imagine this might have been similar to the reaction Galileo received when he demonstrated the telescope 400 years ago. In addition, we were able to point to celestial objects with a green laser pointer, to their amazement.

Our school visits were extremely formal, a cultural influence remaining from British rule. It was also unusual for them to have American visitors and we were treated as ambassadors. The formality followed the same rituals at every school. We were always invited to the principal's office for tea and lunch. Kenyan tea is one of the drinks of which they are most proud, and it is always steeped in hot milk. The lunch typically consisted of rice with a beef stew—flavorful, but not as exotic as an American might imagine.

The schools lacked computer labs and advanced equipment. The average classroom contained only desks and a blackboard. Often the walls were not even painted. Interestingly enough, the level of education at these schools was extremely high—the students were very focused and the teachers were highly educated. The students' bright matching uniforms were a beautiful contrast with the muted colors of unfinished walls.

At the end of our presentation we always took a moment for questions. An awkward silence would pass and then a student would casually emerge from the crowd and give me a handful of



(L-R) Christina, Chris, and Peter meet with students.

Credit: National Center for Atmospheric Research (NCAR)



Chris and crew being rescued from the mud by primary school students.

Credit: National Center for Atmospheric Research (NCAR)

torn paper slips. Each slip had a question.

- Is the physics here and in the USA the same?
- Do US students do quantum physics?
- What is the function of a Galileoscope?
- Can a photo-electric cell be used to measure the threshold wavelength of the infrared and ultraviolet rays?
- What were you demonstrating when you used the yo-yo?

After reading the last question, I realized that this was the first time these students had seen a yo-yo. In fact, they all laughed at the name. I worried that the word “yo-yo” was Swahili or slang for something other than physics. I had a similar experience when I demonstrated the right-hand rule for the Lorentz force. Luckily, my gesture was not perceived as lewd, but they thought I was joking. They learn what is called “Flemming’s left-hand rule” for the same phenomenon. Many students and teachers also asked what happened to Pluto as if it was destroyed or had disappeared. This made me realize some of the challenges of communicating science internationally and the benefits of having face-to-face discussions about science.

*After our presentation to the students, the rain continued to pour. We decided to try our luck with the bus on the muddy road in hopes that the rain had not yet penetrated the soil. We drove at a walking pace as the bus occasionally drifted in the mud. Our luck lasted for half a mile before the bus gently slid into the embankment like a kiss on the cheek. We were stuck. The rain promptly ended but the mud remained. We called for backup. Backup was a land rover used to shuttle Sherri and her instrument up the mountain. It would take over an hour to rescue us. Of the many problems that arise from getting stuck in the middle of the forest, making a call was not one of them. Ironically there is cell phone service everywhere in Kenya: the forest, the city, on safari, and even on Mt. Kenya. As we waited for backup, a group of primary school students were making their way home. Many of them were barefoot. (I have to admit I did fantasize squishing my toes into the soft mud.) The students gathered around our curious predicament. Since they had not studied English, Christina had difficulty communicating*

*with them. However, I could understand that they were making fun of the mud caked on my nice shoes. They told Peter that they could push the bus out of the mud. At first he was reluctant, but they quickly crowded behind the bus and demonstrated their power. Sure enough, they pushed the bus from the embankment and onto the road. In the meantime, many of the girls were inspecting Christina’s odd black dyed hair. I decided to teach the kids how to high five. I’m not sure if a high five will inspire the youth in Kenya, but it is a successful method of communication while stuck in the mud.*



## Chris Discenza

Growing up in the arid, cactus and coyote-filled deserts of Tucson, Arizona, Chris developed a love for math and physics early in life.

He then taught physics and mathematics for several years, during which time it was mentioned that if Socrates corrupted the youth, then Chris has certainly tortured them. He cofounded a nonprofit organization called the Physics Factory that brings the enthusiasm of physics to kids across the nation. He spent several summers roaming the country from coast to coast and from the southwest to Canada, sleeping on beaches, in forests, and on top of the vegetable-oil-powered physics bus, on a mission to bring the excitement of physics to as many students as possible. When not speaking in a weird, vaguely Arizonian accent about transfinite numbers, he manages the PhysicsCentral website for the American Physical Society and podcasts with his glamorous co-podcaster, Nadia Ramlagan. In his spare time he enjoys sticking his finger in dog’s mouths, scratching on his turntables, and reading books about math in cafes.



Students convene around their posters and explain experiments to onlookers.

## The First Annual Trinity College Physics Fair

By Lynda C. Ikejimba  
Trinity College,  
Hartford, CT

On May 2, 2009, the Trinity College chapter of the Society of Physics Students (SPS) hosted the first annual Trinity College Physics Fair. The event, lasting 3 hours, was an opportunity for almost 30 students from the Hartford Magnet Middle School (HMMS) to showcase their endeavors in semester-long physical science experiments. The amount of work put into the projects was as great as the topics were varied. Experimental research ranged from bridge forces, to cosmic rays, to combustion.

Projects were judged by the SPS members and faculty adviser based on a point system as well as overall impressiveness. Six students selected for honorable mention received goodie bags containing physics toys, star gazing guides, and literature donated by the SPS national office. The three top winners of the fair received prizes paid for by the Trinity College SPS. Third place received two season passes to the newly opened Connecticut Science Center, second place won a kite dynamics kit, and first place was awarded an Orion optical telescope. In addition, all participants received customized certificates.

This was the first such event our SPS chapter has hosted: thus, it was limited to participation from just one school for logistics purposes. Like most charter projects, this first instance had plenty of surprises. The excitement and level of commitment evident in the projects far exceeded our expectations. Moreover, students who had not previously registered showed up at the door with projects in hand! Last minute runs for extra materials and food were certainly part

of the experience. The Physics Fair was a complete success. We intend to expand the fair in subsequent years to include more schools in Hartford and to ultimately include both high school and middle school divisions, with appropriate prizes given out to top contenders.

The Physics Fair is an initiative of the Trinity College SPS chapter to foster and ultimately facilitate an enthusiasm for learning physics among students. Whereas many may view physics as one of the most difficult fields of human endeavor and may be dissuaded from its inquiry, SPS recognizes that physics is a foundational science. Thus, we find it necessary to actively engage in community service in the Hartford area in order to promote interest in the physical sciences.

## Competition Unites Science, Art

By Caitlin Sellers

*(Reprinted from the Daily Collegian, Penn State University, University Park, PA, and used with permission.)*

The author describes below the event that was first proposed in her chapter's winning Sigma Pi Sigma Project Award application, one of five project ideas funded in 2009. If you have an idea for an event to bring alumni back to your campus and enhance your Sigma Pi Sigma induction experience, submit a proposal before the deadline, December 15, 2009.

Astronomy and physics met acrylic paint, clay, LED lights, and Sharpies Monday night in an art competition that challenged popular conceptions of art and science.

True to its name, the Universal Art Competition features astronomy art represented through a wide variety of mediums and created by students from diverse academic backgrounds, said Zach Fifer, vice president of the Society of Physics Students.

"It was pretty mixed," he said. "We had art majors, science majors, and a librarian submit pieces."

Submissions were placed in representational, photography, mythology/history, and miscellaneous categories. Attendees of the reception were asked to fill out a ballot indicating their favorite work from each, as well as their favorite piece overall.

Jeremy White, a senior at the University of Southern Florida majoring in computer science, was awarded the grand prize.

The contest was developed by students in response to the United Nations' declaration of 2009 as the International Year of Astronomy, Therese Jones, president of the Society of Physics Students, said.

Jones (senior-astronomy) said one of the



Trinity College SPSers (L-R) Matthew Bermudez, vice president; Justin Hallquist; John Bower; Holly Maykow; Lorenzo Sewanan, secretary; Lynda Ikejimba, president; Joe Lim; Young Ho Shin.



Physics professor Paul Sommers kneels to look at a piece of art in the Universal Art Competition in the Gateway of the Sciences overpass.  
Photo by Peter Tesoriero

missions of the program is to place astronomy art in unexpected locations. She said the pieces submitted to the competition would be on display in the Gateway to the Sciences overpass through Wednesday, and would move to the Sparks Gallery from there.

The competition, sponsored by Sigma Pi Sigma and the Society of Physics Students, was designed to expose students to experiences outside of their usual interests, Fifer (senior-physics and mathematics) said.

"We're hoping to get scientists more interested in art, and artists more interested in science," he said.

Jane Charlton, professor of astronomy and

astrophysics, said she felt the event highlighted the necessary link between art and science.

"Scientists are a creative bunch, and I think they sometimes feel quite stifled," she said. "This gives them an opportunity to explore that side of themselves."

Paintings and sculptures included subjects such as Stonehenge, stars, and volcanoes. Shawn Sinawa (freshman-astronomy and physics) used a makeshift, darkened room and glow-in-the-dark paint to model the Local Group of galaxies, which is the highest order of organization in the universe, he said.

One submission, labeled "sharpie on dry-wall," featured existential poetry involving technical scientific terms.

An excerpt from the piece reads "I start to talk about thermonuclear fusion, but you laugh at the absurdity. -- yours and mine."

## Money for Outreach: The Marsh White Award

From an EcoPhysics program to a Superhero Training Academy, 14 SPS chapters received Marsh W. White Outreach Awards from SPS to help fund their outreach projects during the 2008–2009 academic year. Now it's your turn!

Marsh W. White Awards are made to SPS chapters "to support projects designed to promote interest in physics among students and the general public." To learn more about the award and to apply, visit [www.spsnational.org/programs/awards/2009/mw\\_recipients.htm](http://www.spsnational.org/programs/awards/2009/mw_recipients.htm).

Deadline: November 15<sup>1</sup>

# Art, Sculpture, and Holography Intersect with Science at Fermilab

By Tracy M. Schwab  
SPS Communications Coordinator

More than 600 physics students, faculty, and Sigma Pi Sigma alumni convened at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, IL, Nov. 6–8, 2008, for the 2008 Sigma Pi Sigma Congress. They spent a packed weekend making new connections, interacting with Fermilab scientists and distinguished speakers, debating common concerns for science and society, and touring Fermilab's unique experiments and grounds.

One of the cross-disciplinary themes explored during this gathering was "Art and Science." Fermilab's rich history as a center for culture and art, as well as a center for science, inspired Sigma Pi Sigma to host the honor society's first nationwide art competition during the Congress. The main meeting venue, Fermilab's iconic Wilson Hall, houses a soaring 16-story atrium that provided a spectacular setting for 33 works of art submitted by meeting participants for this event, the majority of which were created by undergraduate members of SPS.



A ground-floor view of Wilson Hall's 16-story atrium.

Photo by Phillip Payette

At the time of the Congress, Fermilab hosted a special exhibit titled "Intersections: The Art and Science of Light." Holography artist Lori Napoleon [see article on page 9], one of the guest exhibitors, was invited by Sigma Pi Sigma to talk about art and science and her work, and she joined Fermilab art curator Georgia Schwender and several members of the congress planning committee in judging the art contest.

Aligned with the Congress theme "Scientific Citizenship: Connecting Physics and Society," entries were received for judging or display in three categories: The Citizen Scientist, Future Faces of Physics, and General Science. Artwork was judged on the following criteria: artistic merit, originality, category-specific attributes, the accompanying abstract, and adherence to contest rules. This article features the works presented with the Best in Show, Curator's Choice, Artist's Choice and People's Choice Awards. To view a slide show of all the award-winning art, as well as abstracts of all the entries, visit [www.sigmapisigma.org/congress/2008/art.htm](http://www.sigmapisigma.org/congress/2008/art.htm).



Photo by Aaron Paden

## Best in Show

*Selected by the panel of judges. \$100 cash prize, and a trip to the American Association of Physics Teachers (AAPT) 2009 Summer Meeting. Abstract Kristal Feldt, Undergraduate, University of Kansas, for "The Particle Decay Series," a set of jewelry.*

The goal I wish to achieve in the art field is not to go the average route of replicating organics, but instead bring light to the beauty of science. I seek to design sophisticated art jewelry and small-scale sculpture that brings the elegance of scientific phenomena and concepts, particularly in the realm of physics, to the everyday person. I intend to accomplish this by taking my understanding of the literal and conceptual views of different topics (on which I do personal research to understand to the best of my ability) and creating something beautiful out of it. In The Particle Decay Series, I created a line of artistic jewelry to express the nature of particle decay through its collision patterns. The set includes a hairpin, necklace, bracelet, earrings, brooch, and ring.

**Also of interest:** *The art of physics: KU junior's jewelry, sculpture designs win national prizes*, by Erin Curtis-Dierks, University of Kansas News, Dec. 5, 2008. [www.news.ku.edu/2008/december/5/physicsart.shtml](http://www.news.ku.edu/2008/december/5/physicsart.shtml)



Photo by Phillip Payette

## Curator's Choice

*Selected by Fermilab curator Georgia Schwender.*

*\$50 cash prize. Abstract Jeanette Powers, Undergraduate, Rockhurst University, for "Fractalline Fluids," a painting.*

This painting represents a dynamic system of the movement of fluid and the drying rate and interactions of acrylic pigment. The fractured surface is created by crumpling cellophane over a wet surface of paint. Pigment is then forced into the channels of the cellophane while the canvas is tilted at an angle, to allow gravity to pull the pigment down through the fractured system. This technique I have developed allows the artist to use the natural mixing that fluid dynamics creates along with the control of the artist to create an art piece which exists on the boundary between order and chaos. The result is a chaotic landscape reminiscent of leaves, cells, rivulets, the cracked dirt of arid land: all chaotic processes which leave a recognizable mark. The pattern is not exact but exhibits self-similarity at different scales. In my experience, the struggle with creating science-based art is to keep the technical details while still creating art which is warm, human, and ultimately relates to people from all walks of life.

## Artist's Choice

*Selected by Guest Artist and Speaker Lori Ann Napoleon.*

*\$50 cash prize. Abstract Kristal Feldt, Undergraduate, University of Kansas, for "The Bubble Chamber Reliquary," a sculpture.*

The Bubble Chamber Reliquary was a project for my introductory course to metalsmithing. A previous course in astronomy at the university and further research introduced me to the beauty of neutrinos and particle collisions, which have become recurring themes in both my sculpture and



Photo by Aaron Paden

art jewelry. So I created a spherical container to place symbols of my sister (a more logical mind, symbolized by a Feynman diagram) and myself (a more creative mind, symbolized by the visual representation of particle collision). The reliquary itself is sealed shut (a symbol of the inescapable blood bond between the two of us). The holes, or bubbles, help represent the bubble chamber in which the particle collision occurs and give the observer a peek at the symbols inside. The bubbles might appear to be random at first glance, but a look at the side shows that they actually are symmetrical to the bubbles on the other side.

### People's Choice

*Selected by a majority of Congress attendees. \$50 cash prize. Abstract Douglas Parsons, Undergraduate, Angelo State University, for "Jovian Marbles," a digital painting.*

Recently, the New Horizons probe, on its way to explore Pluto, passed by the Jovian System and took some rather nice snapshots of the system. This is not a representation of Jupiter, but rather just a simple gas giant system in orbit around some far-off star system.



Photo by Phillip Payette

## Lori Ann Napoleon: Light As a Medium Unto Itself

Why do makers make things? What are we saying here, attempting to do? To reveal or transform, to show alternatives, to make ignored or "mundane" phenomena comprehensible and evocative, to play and inspire others to do the same!

I was initially attracted to holography for its haunting realism and reconstruction of depth; the "magic" of an ethereal, simulated image ("suspending the real" as French philosopher Jean Baudrillard would say). But it was the process of learning how they actually work which led to a fascination with optics and, subsequently, physical phenomena on every scale. As I began to look at the world through a diffraction grating, I was compelled to shift my artistic focus from my original training in painting, to explorations in light as a medium unto itself.

Nearly all of my work involves a component of light. Issues of light and color relate to so many fields, from aspects of particles, detectors, and the electromagnetic spectrum, to psychological moods and social associations. Beyond its countless behaviors, light is an extremely powerful communications vehicle which exudes emotion, helps us navigate and conveys information. The multiple disciplines that this medium crosses provides numerous models of viewing "reality"; always present is this simultaneity between our sensing of the physical world and our interpretation of it. I strive to place my work on the cusp of these two types of experience by bringing out the physicality of the material while making aesthetic decisions that still leave space for mystery and wonder. Engaging the immediacy of our sensory perceptions—the passage of time, light, shadow, transparency—just to be able to grab someone's attention and make them deeply look at something in order to inspire wonder and curiosity in the viewer is my goal. I see light as a delicate interplay of serene to quirky physical attributes coupled with the emotional content of moods, dreams, and mythologies.

Understanding the nature of light has led, of course, to scientific innovations and countless applications which have affected the world immeasurably—from revealing the contents and motions of stars to extending our working hours well past sundown. But it

also inspires appreciation of structure and our own perception in a way that can be observed in the everyday lives of anyone with two healthy retinas, our own biological interface.

My interests in the "nature of nature" are what led me to my frequent visits to Fermilab's Ask-A-Scientist program, on the suggestion of Ed Wesly. His description of the bubble chamber fueled my initial visit, which led to many others and secured the influence of physics in my own works to come. I have an immense amount of gratitude to the many people I've met at Fermilab whose tireless explanations and generosity toward me will have a lasting impact on my work and perspective. As a Master's candidate at New York University's interdisciplinary interactive telecommunications program, I am constantly exposed to the effectiveness of a cross-curricular dialogue between the arts, science, and technology. As all of these develop within our shared societal and cultural framework, all disciplines benefit from such a discourse. It is for this reason that I feel that what both art and science have to offer can be used in tandem to elucidate, educate, and inspire.

I can be contacted at [lori.napoleon@gmail.com](mailto:lori.napoleon@gmail.com).



Lori Ann Napoleon holds the completed hologram of herself. Photo by Patrick Boyd, Spatial Imaging (UK)



Holography artist Lori Ann Napoleon works on a self-portrait. Photo by Patrick Boyd, Spatial Imaging (UK)

## History of Big Bang Cosmology, Part 7: The “Great Light”

Dwight E. Neuenschwander



As you know, the main empirical evidence supporting the big bang includes the dark sky, the Hubble expansion, the element abundances, and the cosmic microwave background radiation (CMBR). Parts 1–6 of this series offered overviews on the first three of these points.[1–6] Here we say a few words about the CMBR.

In 1983 the late medical pathologist and science essayist Lewis Thomas wrote “*The world began with what it is now the fashion to call the ‘Big Bang.’ Characteristically, we have assigned the wrong words for the very beginning of the earth and ourselves...It could not, of course, have been a bang of any sort, with no atmosphere to conduct the waves of sound, and no ears. It was something else, occurring in the most absolute silence we can imagine. It was the Great Light.*”[7]

Thomas rightly noted the inadequacy of the term “big bang.”[8] “Great Light” is more dignified—and relevant. But the big bang itself was not Thomas’ subject; he mentioned it merely to illustrate how ambiguity in language enriches concept diversity. As a specialist who followed developments in other fields, no doubt Thomas would have been intrigued to learn that astronomers today are busy measuring sound waves from the early universe, a story intimately connected to the Great Light.

Suppose someone thrusts this into your face for you to read: “*The degree angular scale interferometer (DASI) has measured the power spectrum of the cosmic microwave background anisotropy over the range of spherical harmonic multipoles  $100 < l < 900$ . We compare this data, in combination with the COBE-DMR results, to a seven-dimensional grid of adiabatic CDM models...* [9] I hope this article helps translate such jargon into familiar physics vocabulary. Because the CMBR’s story grew out of the Hubble expansion and element abundances, let us review those ideas.

The universe expands according to Hubble’s law. At the cosmic scale the relative velocity  $v$  between a pair of galaxies is proportional to the distance  $D$  between them,  $v = HD$ , where Hubble’s parameter  $H$  today has been measured at  $70.1 \pm 1.3$  (km/s)/Mpc[10] although it varies throughout cosmic history. In a familiar analogy, the velocities in Hubble’s law are *not* like walking across a rubber sheet, but instead are like being carried on a stretching rubber sheet. Such “carried-along” motion is called *comoving*. Ignite your rocket’s engines, or fall into orbit around a black hole, and you acquire a “peculiar velocity.”

The early universe was a hot, dense gas of elementary particles—the “ylem”—from which bound structures precipitated as the universe

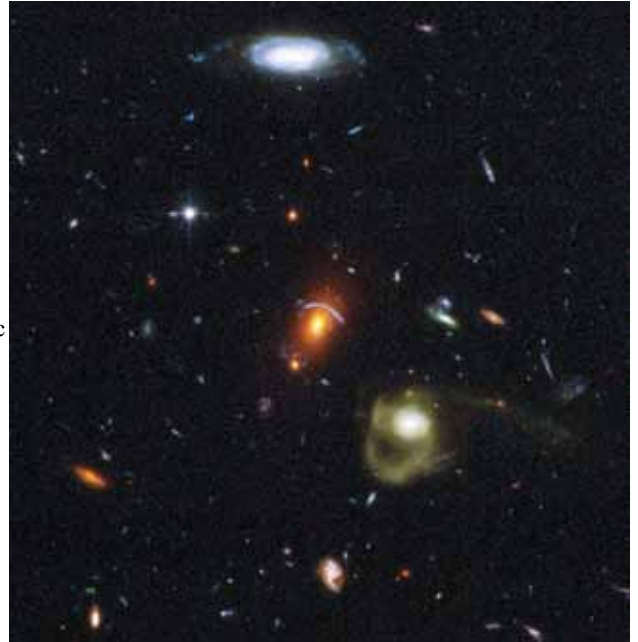
expanded and cooled. Among the first structures to form were nuclei. An understanding of isotope abundances began with the 1948 calculations of Ralph Alpher and George Gamow.[11] Elements such as deuterium and helium were produced when the temperature dropped to where nuclear fusion products could survive photofission. Alpher and Robert Herman also realized in 1948 that electromagnetic radiation left over from that hot early environment should survive today. They predicted its present temperature to be about 5 K, putting its spectrum in the microwave band. [12]

For nucleosynthesis calculations to achieve ~0.1% agreement with observations, it was necessary to assume a billion-to-one ratio of photons to baryons. The source of a preponderance of photons occurred well within the first 0.01 s, when the rates of spontaneous decay of certain antiparticle species exceeded the decay rates of their corresponding particles. When photon energies dropped below  $mc^2$  for that species, their pair production was quenched. Then the antiparticles were annihilated with particles, leaving a residue of matter.

Following helium synthesis, the ylem consisted of hydrogen and helium nuclei, electrons, and photons (neutrinos survived but no longer interacted, having already “decoupled”). The radiation and matter maintained thermal equilibrium, thanks to Thompson scattering (the low-energy Compton effect) between the photons and charged particles.[13] The photon spectrum would be a Planck distribution, or “blackbody radiation.”

Some 380,000 years after the big bang, the plasma temperature had fallen to about 3000 K, cool enough to quench photoionization, allowing electrons and nuclei to bind into neutral atoms, as photons decoupled from matter. As that light bounced off the “surface of last scattering” it carried its Planck distribution. After decoupling its temperature continued to drop as the wavelengths stretched with the universe itself. Those abundant photons must be detectable today, with their cooled-down Planck distribution.

As mentioned in earlier installments, the CMBR was observed by A. McKellar in 1940–1941 but not recognized;[14] it was observed and recognized by Tigran Shmaonov (he reported  $T = 4 \pm 3$  K), the subject of his 1957 doctoral thesis and published in a Soviet journal, but not widely noticed.[15] Despite their efforts to



“How can the CMBR be so smooth when matter is so lumpy?”

Credit: NASA

convince radio astronomers to look for it, Alpher and Herman had to wait until the mid-1960s for the CMBR to be observed *and* correctly interpreted *and* the news widely disseminated. Apparently unaware of prior predictions and measurements, in 1964 Arno Penzias and Robert Wilson of Bell Laboratories, while calibrating an antenna to receive microwaves bounced off the Echo satellite, found anomalous radio noise with a temperature of 2.7 K. Their finding was immediately understood by Robert Dicke and his colleagues at Princeton to be the CMBR. They had been building an antenna to search for this cosmic radiation. The two groups’ papers appeared together in 1965.[16,17]

The uniformity found initially in the CMBR affirmed the big bang model, because the assumption of cosmic isotropy and homogeneity was built into the fundamental equations. But this success, like all successes, allowed deeper questions to be raised, including the problem of structure formation. Although we can get away with modeling the universe as uniform at the largest scale, the *real* universe shows a hierarchy of structures with galaxies, clusters of galaxies, and superclusters separated by vast voids. How can the CMBR be so smooth when matter is so lumpy? This question raised a major challenge to the big bang model.

In a 1967 paper by R.K. Sachs and A.M. Wolfe we overhear how far this conversation had already come: “*The actual universe is quite lumpy, but the usual cosmological models assume a uniform distribution of matter. One simple method for making somewhat more*

realistic cosmological models is to consider linear perturbations away from spatially homogeneous isotropic models [citations dating back to 1946]. In this paper we shall integrate the equations governing perturbations of an expanding Friedmann model... We shall then use our model to estimate the temperature variations in angle produced by the gravitational effects of the perturbations on the microwave background radiation.”[18]

Similarly, in 1970, P.J.E. Peebles and J.T. Yu remarked, “The possible discovery of radiation from the primeval fireball opens a promising lead toward a theory of the origin of galaxies. This primeval radiation would serve, first, to fix an epoch at which nonrelativistic bound systems like galaxies can start to develop, and second, to impress on the power spectrum of initial density fluctuations characteristic lengths and masses.... A more direct observational test of these processes might be provided by the residual small-scale fluctuations in the microwave background, if we assume that this radiation has not been further scattered.”[19]

### Perturbation Expansions

The “standard model,” based on the Friedmann–Lemaître–Robertson–Walker metric, describes the unperturbed cosmology.[4] With energy density as the source of gravitation, this metric in Einstein’s equations yields the Friedmann equation,

$$H^2 = \kappa \rho \quad (1)$$

where  $H$  denotes Hubble’s parameter,  $\kappa = 8\pi G/3c^2$ ,  $G =$  Newton’s constant,  $c =$  speed of light, and  $\rho$  denotes the energy density of all the universe’s constituents, and

$$\rho = \rho_{\text{matter}} + \rho_{\text{radiation}} + \dots, \quad (2)$$

where possible cosmological constant and curvature terms may be written as effective densities. To this system we add perturbations.

Because gravity relentlessly attracts, structure formation would be initiated if, for whatever reason, matter density fluctuations existed in the ylem,

$$\rho_m = \rho_0 [1 + \delta_m(\mathbf{r}, t)], \quad (3)$$

where  $|\delta_m| \ll 1$ , and henceforth “sub-o” denotes unperturbed background values. The  $\mathbf{r}$  reminds us that these fluctuations vary with location. Nearby matter would be gravitationally attracted to regions where  $\delta_m > 0$ , draining matter from regions where  $\delta_m < 0$ , giving positive feedback to the fluctuations. Such inhomogeneities would leave their imprint on the CMBR, because photons that last scattered from overdense regions had to climb out of gravity potential wells slightly deeper than average. Such photons reaching us today would be slightly *extra* redshifted compared to the ambient redshift of the overall background. Photons from underdense regions should be slightly less

redshifted than average. With the perturbation in the gravitational potential denoted as  $\epsilon$ , we may say that

$$\Delta v/v_0 = \epsilon/c^2 = 3 \Delta T/T_0, \quad (4)$$

where  $v$  denotes the frequency of the light, and where  $T_0 = 2.7$  K. The first equality merely restates gravitational redshift; [20] the second holds if the density fluctuations compress the plasma adiabatically (the factor of 3 would take us farther afield; see Eq. (21.23) of Ref. 24). If the big bang model is consistent with theories of galaxy formation, the CMBR field today *must* show temperature fluctuations.

Given matter fluctuations, structure formation could efficiently begin, even before photon decoupling, if some kind of matter exists that could be attracted into the over dense regions despite the Thompson scattering going on all around them. Such matter would have to be electrically neutral, heavy, and relatively slow, the “cold dark matter” (CDM) that boasts a compelling case for its existence even though nobody yet knows the identity of the CDM particles themselves! [21] To complicate this puzzle, the CDM must be nonbaryonic. Nucleosynthesis calculations place tight restrictions on the number of baryons in the universe, and they’re already accounted for. CDM leads to a “bottom-up” scenario of subsequent galaxy formation, where galaxy clusters grow by accretion. Growing galaxies take billions of years; here we are speaking of nurturing the *seeds* of galaxy formation.

Those seeds first reveal their presence as *acoustical waves* in the ylem. Before photon decoupling, as matter falls into an over dense region the photons get squeezed. Their pressure and temperature shoot above ambient values. The overpressure pushes back on the surrounding plasma like a spring, opposing the compression. With a period determined by the size of the region being compressed, these compressions and rebounds produce driven oscillations—sound waves—before decoupling, forming a harmonic series of standing wave modes. At photon decoupling, the adiabatic compressions and rarefactions of those sound waves must be imprinted on the CMBR temperature field. We construct here a simplified version of the essential ideas.

The spatial variation of the acoustical field may be written as a superposition of plane waves, a Fourier series normalized to standing wave modes in a large volume. Identify various modes with their wavenumbers  $\mathbf{k}$ : [22]

$$\delta_m(\mathbf{r}, t) = \sum_{\mathbf{k}} \delta_{\mathbf{k}}(t) e^{i\mathbf{k}\cdot\mathbf{r}}. \quad (5)$$

Because the matter density perturbations are *very* weak sources of gravity, their effects can be approximated with Poisson’s equation for the gravitational potential, so that  $\epsilon$  gets produced by  $\delta_m$  according to

$$\nabla^2 \epsilon = 4\pi G \rho_0 \delta_m. \quad (6)$$

Perform a plane-wave expansion also on the potential’s perturbation with Fourier amplitudes  $\epsilon_{\mathbf{k}}$ , insert this and the perturbed density of Eq. (5) into Eq. (6), and use Eq. (1) to obtain a form of the “Sachs–Wolfe relation,”

$$\epsilon_{\mathbf{k}} = -(3/2) (cH/k)^2 \delta_{\mathbf{k}}. \quad (7)$$

From Eqs. (4), (5), and (7) the temperature fluctuations correspond to matter density fluctuations as [23–25]

$$\Delta T/T_0 = -\frac{1}{2} H^2 \sum_{\mathbf{k}} k^{-2} \delta_{\mathbf{k}} e^{i\mathbf{k}\cdot\mathbf{r}}. \quad (8)$$

Any function of latitude and longitude mapped on a spherical surface (such as the celestial sphere) can be expanded as a superposition of the *spherical harmonics*  $Y_l^m(\theta, \phi)$ , where  $l = 0, 1, 2, \dots$  and  $m = l, l-1, \dots, -l$ . [26] Thus we may also write

$$\Delta T/T_0 = \sum_{l=0}^{\infty} \sum_{m=-l}^l A_{lm} Y_l^m(\theta, \phi). \quad (9)$$

The  $l = 0, 1, 2, \dots$  terms describe monopole, dipole, quadrupole, ... terms, respectively. The amplitudes  $A_{lm}$  can, on one hand, be predicted from a model; on the other hand, they can be measured—or rather their power spectrum can be measured. The power carried by a mode goes as the square of its amplitude.

To relate the  $\delta_{\mathbf{k}}$  to the  $A_{lm}$  we deploy in Eq. (8) a spherical-coordinate expansion of plane waves that expresses the  $r$ -dependence through spherical Bessel functions  $j_l(kr)$ :

$$e^{i\mathbf{k}\cdot\mathbf{r}} = 4\pi \sum_{l=0}^{\infty} \sum_{m=-l}^l i^l j_l(kr) Y_l^{*m}(\mathbf{k}) Y_l^m(\mathbf{r}) \quad (10)$$

where \* indicates a complex conjugate, and the vectors in the arguments of the spherical harmonics point in the direction of their  $\theta$  and  $\phi$  coordinates. We compare the result of Eq. (10)-into-(8) with Eq. (9) and read off the  $A_{lm}$  in terms of  $\delta_{\mathbf{k}}$ :

$$A_{lm} = -2\pi i^l H^2 \sum_{\mathbf{k}} k^{-2} \delta_{\mathbf{k}} j_l(kr) Y_l^{*m}(\mathbf{k}). \quad (11)$$

To connect these amplitudes with the power spectrum, we borrow a page from statistics and use the *autocorrelation function*  $\langle \delta_{\mathbf{k}} \delta_{\mathbf{k}'} \rangle$ , which averages over the normalization volume the product of density fluctuations for different wavenumbers. In addition, each multipole  $l$  has  $2l+1$  components, and we average over these, too, to define the  $l$ th multipole’s contribution to the *power spectrum*,

$$C_l = (2l+1)^{-1} \sum_{m=-l}^l \langle |A_{lm}|^2 \rangle. \quad (12)$$

Because we are interested in the power spectrum of temperature *fluctuations*, the  $l = 0$  and  $l = 1$  terms are omitted because  $l = 0$  gives a *constant* and  $l = 1$  gives the *systematic* dipole shift due to

Earth's peculiar motion relative to the CMBR.

When inserting Eq. (11) into (12), we write a double sum that distinguishes the mode sum over  $\mathbf{k}$  from another over  $\mathbf{k}'$ . However, by virtue of the periodic boundary conditions on the Fourier standing waves, the cross-terms for which  $\mathbf{k} \neq \mathbf{k}'$  all average to zero. Also, with the assistance of the spherical harmonics "addition theorem,"

$$\sum_{m=-l}^l Y_l^m(\mathbf{k}) Y_l^m(\mathbf{k}') = (2l+1)/4\pi, \quad (13)$$

we bring Eq. (12) into a form relating the temperature fluctuation power spectrum to the original matter density fluctuations:

$$C_l = \pi H^4 \sum_{\mathbf{k}} k^4 \langle |\delta_{\mathbf{k}}|^2 j_l^2(kr) \rangle. \quad (14)$$

Write the sum over  $\mathbf{k}$  as an integral, where with spherical symmetry  $d^3k = 4\pi k^2 dk$ , so that

$$C_l = 4 \pi^2 H^4 \int_0^\infty k^{-2} \langle |\delta_{\mathbf{k}}|^2 j_l^2(kr) \rangle dk. \quad (15)$$

Without knowing the  $k$ -dependence of the density fluctuations, the pioneers in this business, notably E.R. Harrison and Ya. B. Zel'dovich,[27] made the simplest assumption they could. As Peebles and Yu put it, if the "initial perturbation contains no built-in characteristic lengths [then the] perturbation looks the same on each scale of size." [19] Such a spectrum of density fluctuations came to be called "scale invariant," and requires  $|\delta_{\mathbf{k}}|^2 \approx k$ . More generally, one introduces the "spectral density index"  $n$  via  $|\delta_{\mathbf{k}}|^2 \approx k^n$ . But with  $n = 1$  in Eq. (15), a "scale-invariant" spectrum results,

$$C_l \approx 4\pi^2 H^4 / l(l+1). \quad (16)$$

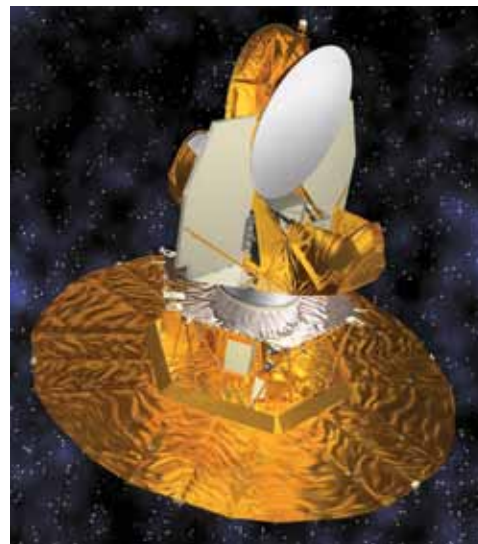
Power spectrum data usually gets presented as a plot of  $l(l+1)C_l$  vs.  $l$ . From Eqs. (16), (1), and (2) we see how the observed power spectrum can be related to multiparameter models of the early universe. The  $l$ th term of a multipole expansion of the right-hand side of Eq. (16), which goes as  $\kappa^2 \rho^{-2} = \kappa H^2 \rho$ , is made model-sensitive by integrating numerically a large set of coupled equations: equations of state for various constituents (baryonic matter, CDM, radiation,...), their reaction rates, thermal physics, and the cosmological expansion equations. In such a manner one makes a model-dependent prediction of the power spectrum and then compares various models to the observed spectrum. The observed spectrum goes on the left of Eq. (16) and the model predictions on the right.

### Relating the Sky Map to $l$

In the early universe, the speed of adiabatic compressional waves in the plasma-photon medium was  $c/\sqrt{3}$ . The photon decoupling, which happened at about  $t_D = 380,000$  yr, determined the half-wavelength distance  $L_D$  of the fundamental acoustical mode:  $L_D = c t_D / \sqrt{3} \approx 2 \times 10^5$  c-yr. The radiation from the surface

of last scattering reaches us today redshifted to  $z \approx 1000$ . Therefore a fundamental mode region will have expanded to a size  $L_D z \approx 2 \times 10^8$  c-yr. The photons reaching us today from those regions have been traveling about 14 Gyr. A region originally of size  $L_D$  will appear to us—assuming Euclidean geometry—to subtend an angle on the sky of  $\Delta\theta = (2 \times 10^8 \text{ c yr}) / (14 \text{ Gc yr}) \approx 0.014 \text{ rad} \approx 1^\circ$ . The overtone wavelengths are  $1/n$  of the fundamental, where  $n = 2, 3, 4, \dots$ , so their antinodes today should be separated by about  $1/2, 1/3, 1/4, \dots$ . Sound waves that existed at decoupling should therefore reveal themselves in a graph of the power spectrum vs. angular resolution. To relate values of  $l$  to angles, consider the angles subtended by the zeroes of  $Y_l^0(\theta, \phi)$ . They occur, roughly, at about  $180^\circ/l$ . Angles of  $1^\circ, 1/2^\circ, 1/3^\circ, 1/4^\circ, \dots$  correspond in the multipole expansion to  $l = 180, 360, 540, 720, \dots$

The peak at  $\Delta\theta \approx 1^\circ$  reaches us today from the chorus of places in the early universe where the infalling matter had just reached the first maximum photon compression at the time of decoupling. The first overtone at  $\Delta\theta \approx 1/2^\circ$  comes from regions that went through one compression and bounced back to the maximum rarefaction. The third harmonic corresponds to regions of size  $L_D/3$  at decoupling, where there was just enough time for one squeeze followed by one rarefaction and a second squeeze.



The COBE satellite  
Credit: NASA

### COBE Measures Smoothness and Lumpiness

In the mid-1970s NASA invited proposals for astronomical research instruments to be carried aboard satellites. To cut short a long and fascinating story,[28,29] John Mather of the Goddard Space Flight Center and George Smoot of UC-Berkeley became the principal investigators in the design, construction, and

use of the Cosmic Background Explorer (COBE) satellite. Over a thousand people worked on COBE. It carried three main instruments. The two that concern us here are the far infrared absolute spectrophotometer (FIRAS) and the differential microwave radiometer (DMR). FIRAS tested the CMBR's smoothness. The DMR tested its lumpiness farther out in the decimal places. After the tragic *Challenger* explosion in 1986 grounded the space shuttle fleet, COBE had to be redesigned to fit into a Delta rocket. It was launched in November 1989.

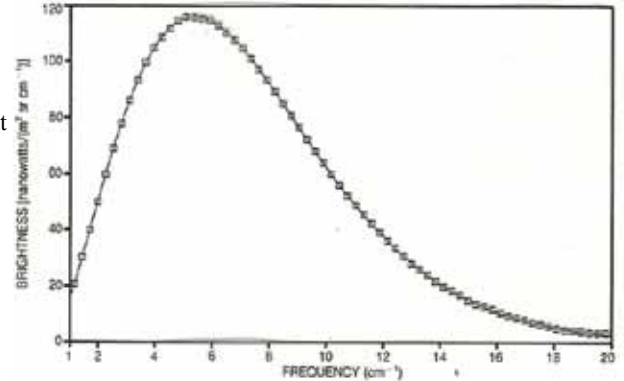


Fig. 1. The 1990 COBE-FIRAS spectrum fit to a Planck distribution at  $T = 2.735 \pm 0.06$  K. The tiny boxes are experimental uncertainties. From Mather et al., Ref. 30. Used by permission.

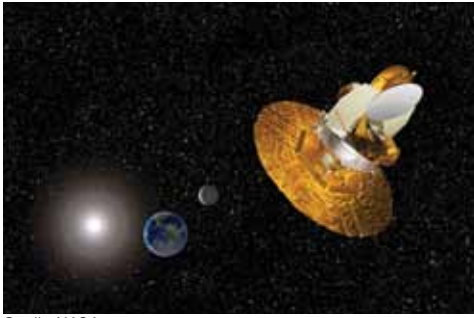
Ralph Alpher and Robert Herman attended.

Mather led the FIRAS experiment. It measured the CMBR spectrum in wavelengths from 0.5 to 1 cm, the range that includes all the active CMBR modes. This measurement was essential to nail down conclusively the big bang nativity of the CMBR. Before FIRAS, only fragments of the CMBR spectrum had been fit to a Planck curve.

Within a few weeks of launch, the FIRAS team had collected enough data to announce a "preliminary measurement" of the CMBR spectrum. Mather made the announcement at the January 1990 meeting of the American Astronomical Society. Subtracting out our galaxy's background and the dipole from our local system's peculiar motion, Mather reported  $T = 2.735 \text{ K} \pm 0.06 \text{ K}$ [30] and presented the graph shown in Fig. 1, which the audience greeted with a standing ovation.

The astonishing feature of Fig. 1 is the error boxes: they are amazingly small, and the fitted Planck curve passes through *every single one* of them. This measurement is very likely one of the tightest agreements between theory and observation in the history of physics. To its level of precision, the FIRAS data showed the CMBR temperature to be uniform across the sky. The unperturbed "standard model" of cosmology was vindicated!

Vindicating the perturbations on the standard model would take more decimal places, out to the microkelvin level of precision, and thus more data. Toward that end, Smoot led the



Credit: NASA

DMR experiment. The DMR design, pioneered by Robert Dicke in the 1940s, features dual receiver horns to measure the temperature difference between two points of sky. By early 1993 the data was in. At the April meeting of the American Physical Society that year, Smoot presented the DMR results to an expectant crowd, many hoping for a report on the presence of perhaps the quadrupole term. Smoot and his colleagues dramatically presented the  $C_l$  values one at a time, beginning with  $l = 2$  quadrupole, then proceeded on up to  $l = 20$ . [31]

The COBE efforts have since been beautifully extended by other groups, filling in higher multipoles of the CMBR power spectrum. These collaborations include the DASI interferometer stationed in Antarctica, the balloon-borne Boomerang instruments, MAXIMA, the Wilkerson Microwave Anisotropy Probe (WMAP), and others underway or being planned. A recent WMAP update presented this power spectrum

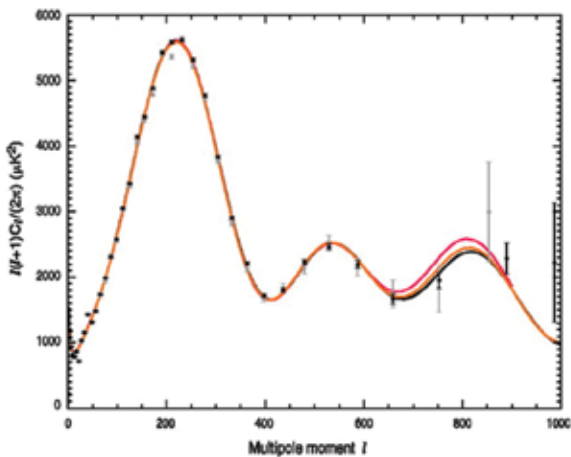


Fig. 2. The CMBR power spectrum, showing fits of cosmological parameters to 1- and 3-year data. From Spergel, Ref. 32. Used by permission.

(Fig. 2): [32]

With the FIRAS and DMR results in hand, the big bang stands as affirmed today as a scientific model can be. Now the problem gets turned around: The spectrum of the CMBR temperature fluctuations has become a tool for studying the early universe.

When the possibility of density fluctuations triggering cosmic structure was first contemplated, a serious puzzle was identifying a mechanism

that could produce the original fluctuations in the first place, without having to postulate them as initial conditions. Peebles and Yu closed their 1970 paper worrying about this point: [19] "It is well to bear in mind that this calculation of the initial density fluctuations are invoked in an ad hoc manner because we do not have a believable theory of how they may have originated..."

Random quantum fluctuations are an essential part of quantum theory. But how could microscopic quantum noise grow into a cluster of galaxies? To answer that we must go back deep into the very early universe—about  $t \approx 10^{-35}$  s and examine the plausibility of a temporary but potent mechanism called "inflation" that was originally invented to solve other cosmological puzzles. Inflation swells the inhomogeneities to macroscopic size, so they could attract CDM, imprint the Great Light, and eventually bind baryonic matter to produce another great light: the stars. Inflation is the subject of Part 8.

### Acknowledgment

Thanks to Thomas Olsen for thoughtfully reading manuscript drafts and offering many helpful suggestions.

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- the latter best reveals itself with gamma rays, and when  $T \approx 3000 \text{ K}$  the ambient energy is  $k_b T \approx 0.3 \text{ eV}$ , "low energy" by the standards of elementary particle physics.
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## Fermi's First Results and the April Meeting of the American Physical Society (APS)

**APS April Meeting 2009**

By Scott Vaughn Burger

Western Washington University

Denver, CO, May 2-5, 2009,

To read the entire report, visit

[http://www.spsnational.org/meetings/reports/2009/aps\\_april.pdf](http://www.spsnational.org/meetings/reports/2009/aps_april.pdf).

Almost within minutes of my arrival into this new world of science journalism, I was bombarded with physicists antsy to talk to journalists. Having a press badge at a conference like this was a lightning rod for attracting scientists. I had never talked to an academic outside of my own Department of Physics and Astronomy at Western Washington University, and now here I was, neck-deep in a conversation about fusion with someone who had gotten a doctorate under Werner Heisenberg, one of the most famous physicists in history.

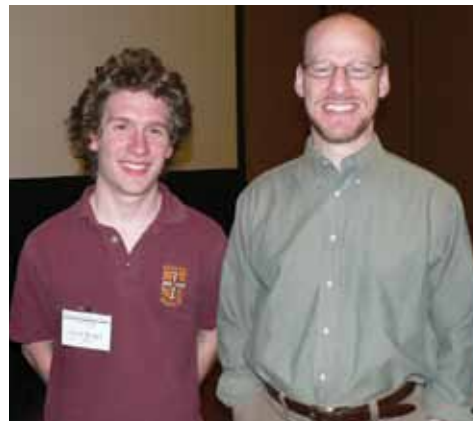
There were many notable high energy physics community members at the meeting and many bigwigs to boot, but perhaps the largest wig of them all was Dr. Makoto Kobayashi, the 2008 Nobel laureate in physics for his work on spontaneous symmetry breaking. An easy way of explaining symmetry breaking is to think of a pencil standing on its point. The slightest nudge from anything is going to make the pencil fall over, thus breaking its symmetry by the direction it falls compared to all the other directions it could have fallen.

Kobayashi's work is key to understanding the universe as we know it. Most of the universe is made of matter as opposed to antimatter today, but early in the universe's history the numbers were much closer. In the end, matter survived, but I asked Dr. Kobayashi, if symmetry breaking could have anything to do with this initial imbalance? "The difference between the particle and the antiparticle," said Kobayashi, "must be caused by CP violation. But we have not yet understood the concrete mechanism of CP violation's interaction, so this is a present subject to attack."

One session I attended was a fast-paced seminar on dark matter searches. There were eight speakers, each given about 10 minutes to present their research to a room so jam-packed with physicists that there was standing room only. These talks were largely focused on the Fermi telescope's first results, future results, and how they pertain to dark matter, but there were also talks about detecting dark matter from ground-based observatories like the Very Energetic Radiation Imaging Telescope Array System (VERITAS). In fact, one talk covered how to measure a magnetic moment of a dark matter particle, should it even have one! For someone who thought they were ensconced in the world of dark matter research, I



Makoto Kobayashi preparing for a talk on his Nobel Prize winning work at the April APS meeting.



The author with Dr. Phil Plait (right), blogger for Discover Magazine. His latest book, "Death From the Skies!" details the ways in which the universe is extremely inhospitable for life. Plait gave a public talk at the APS about both his book and how some movies use lousy science for entertainment, or, as Plait calls it, "bad astronomy."

had my eyes opened but these talks into just how vast is this field of scientific research.

Dr. Lawrence Krauss, one of my physics-world heroes, gave a talk on science and society... I asked Krauss if science journalists, who are well qualified to do their job, are getting the message of scientific understanding out to the general public. "No," he stated flatly, "I mean, it's a difficult task and there are inherent problems... One is that journalism at its very basis has got a fundamental tension with respect to science, namely, journalists are always taught that there are two sides to every story. But in science, one side is usually wrong. ... I actually don't think many good science journalists necessarily think that they are the ones to teach the public. Their job isn't to teach the public, it's to inform the public of the news. I think that scientists have to take that task to hand."

The experience of reporting on the APS meeting has really inspired me to seek a master's program in science journalism after my under-

graduate education. Many at the conference referenced how important it is for young scientists to get involved in their fields. Some stressed the importance of needing younger, skeptically-minded scientific journalists in the field as well.

The meeting came into its full perspective at the end of my journey. Before I landed back in Seattle, the woman sitting next to me asked why I was in Denver. I told her about the APS and she asked me, "What exactly does a physicist do?" It's a valid question to ask, but a very hard one to answer. I leafed through the APS Bulletin that had all the meetings, talks, and colloquia in it and selected the ones that I thought exemplified physics and physicists. I told her about the Large Synoptic Survey Telescope (LSST), the planned successor to the Sloan Digital Sky Survey, and how it would literally change the way we see the cosmos. We talked about ITER (formerly the International Thermonuclear Experimental Reactor, [www.iter.org](http://www.iter.org)) and the promise of nuclear fusion as a viable source of energy in the future. I also told her about Richard Muller's talk on examining the terrorist threat. I referenced her to Muller's recent book, *Physics for Future Presidents* as a fantastic way of learning about physics from a non-scientist perspective.

"I envy you," she said. "You're just beginning your journey. You have so many opportunities, are so young, and have so many great things to accomplish. I wish you the best of luck." That meant a lot to me for many reasons. The compliment was not only personal, but I felt it could be applied to all those beginning their careers in physics, wherever those careers may take them. The young physicists today are the envy of the old. We are all beginning our journeys. We all have so many opportunities and have many great things to accomplish. Best of luck to us all!

*This couldn't have been possible without help from Kendra Rand and James Riordon. I also want to thank Jennifer Siegal-Gaskins, Michael Kuhlen, Nadia Ramlagan, Dr. Hooper, Dr. Curt Callan, Dr. Kobayashi, Dr. Krauss, and Dr. Phil Plait.*

## Physics Teachers Invade Ann Arbor, MI

**American Association of Physics Teachers (AAPT) Summer Meeting 2009**

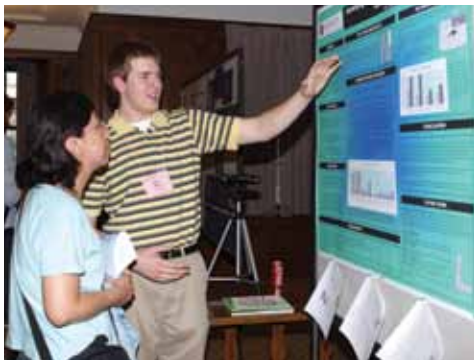
By Raina Khatri

Hope College,

SPS Summer Intern,

Ann Arbor, MI, July 25-29, 2009

*Every summer SPS takes a subset of the SPS summer interns to the summer meeting of AAPT. This year four interns attended: Raina Khatri (Hope College), Mary Mills (The College of Wooster), Scott Stacy (Texas Christian University), and Leslie Watkins (North Carolina State University). To read more about their AAPT experience and their summer in Washington,*



Adam Moyer, a student from Grove City College, presenting his poster during the student poster session.

Photo by Warren Hein, AAPT

DC, visit <http://www.spsnational.org/programs/internships/2009/>.

The AAPT meeting was at the University of Michigan in Ann Arbor, which meant a Northwest flight to Detroit for Mary, Leslie, Scott, and me. We took the Metro to the airport at 7am on Sunday, lugging suitcases and seven poster tubes along. The flight was uneventful (definitely the best kind of flight) and my relatives from Detroit met me at the airport. We had a nice lunch before my aunt dropped me off at the hotel to get ready for the poster session in the evening.

The student poster session was fantastic. The four of us had a lot of traffic. I had a lot of good conversations with students and teachers interested in using *Physics to Go* ([www.physicstogo.org](http://www.physicstogo.org)). A group of students and one faculty member from China were particularly interested in the site. I'm not sure why they liked it so much, but they asked if they could link to it from their university website, which was pretty exciting. I handed out loads of *Physics to Go* bookmarks, so hopefully people will remember the site and visit.

On Monday, Mary and I took the shuttle bus from the hotel to the University of Michigan, getting there just in time for the 7 am "first timer's"



Raina (right) with Bruce Mason, principal investigator for ComPADRE.

Photo by Warren Hein, AAPT

breakfast. It was a good idea to go to that, not just because of the free bagels and fruit, but because I got a sense of the sessions and talks I should attend. After the breakfast we went to a session regarding the teaching of physics laboratories. For lunch, Mary and I went to the Young Physicists Meet and Greet. We sat with the same Chinese students who liked *Physics to Go*. We ended up having a fantastic hour-and-a-half-long conversation about the differences in education and lifestyle between China and the US.

Late in the afternoon I went to my favorite session of the whole conference. The topic was women in physics, and each of the three speakers had been invited to give a 30-minute talk. Each talk was very thoughtful and not overly feminist in any way. Like the hearing I attended a few weeks ago, they gave me a lot to think about.

Tuesday was another full day populated with thought-provoking talks and conversations. The 10:30 am talk was given by the Klopsteg Award winner Lee Smolin. He thinks we ought to teach students quantum mechanics first, before Newtonian mechanics, because potential physics students are bored by the intro classes and go for majors that seem more interesting. I admit I wish I had taken classes in this order, not that it matters now.

After lunch there were more award talks. One high school physics teacher gave an excellent speech on her experience. She advocated all-girl and all-boy groups for lab activities, because that way the girls actually get to touch the equipment and learn something. She also mentioned the story of a troublesome student who one day ran up to her and shouted, "I hate you!" The student elaborated to the poor, confused teacher, "I see physics everywhere now, so I hate you!" Then they handed out the rest of the awards, one of them to Bruce Mason, the director of ComPADRE, so that was pretty neat.

After the award ceremony, a ComPADRE colleague came up to me and said, "So is your poster up?"

"Poster?" I said, a squeak in my voice.

"The poster for the session tonight?"

"Tonight? What session tonight?"

"You're in the program for 8:30."

And so we had to dash back to the hotel so I could retrieve my poster. I ended up enjoying this one more than the first. A lot more physics teachers were around at this one, so I acted more like a used car salesman to promote *Physics to Go* than a student presenting their summer project. I had a lot of good conversations with physics faculty members from across the country.

Wednesday was a fun day. First I went to a plenary about Frank Oppenheimer. Then I went to a session on diversity in physics, where I watched Ted Hodapp of APS and both Gary White and Kendra Rand of the SPS National Office, so that was pretty cool. After that, my aunt picked me up and I spent the rest of the day visiting family before going to the airport.



A screenshot from *Physics To Go*, [www.physicstogo.org](http://www.physicstogo.org), an online biweekly mini-magazine that Raina worked on during her summer as an SPS intern. *Physics To Go* is a collection within ComPADRE, the physics and astronomy digital library.



## Other Highlights

### Mary Mills, SPS Intern

Monday I went to the Physics Instructional Resource Agents (PIRA) session, which turned out to be one of my favorite sessions of the entire conference. I learned a lot about how to handle different age groups. I also saw a demo about gravity and a water bottle that I'm dying to try.



### Scott Stacy, SPS Intern

The highlight of the trip was seeing the Michigan Galileo manuscript, on which Galileo wrote down notes on Jupiter's moons. We also got behind-the-scenes tours of the first edition of Galileo's *Sidereus Nuncius* (*Starry Messenger*), Kepler's response to *Starry Messenger*, *Dissertatio cum Nuncio Sidereo* (*Conversations with the Starry Messenger*), and one of Newton's original manuscripts.

Photos by Phillip Payette

## Going to a meeting?

The Society of Physics Students (SPS) offers travel support at a level of \$200 for SPS chapters or individual students reporting on a national physics meeting for SPS. Interested? See the details at [www.spsnational.org/programs/awards/reporter.htm](http://www.spsnational.org/programs/awards/reporter.htm).

## Looking to the Future

In September the SPS National Council gathered for a packed weekend in Washington, DC, to plan for the 2009–2010 year. An exciting result was the passage of an official statement on the importance of encouraging a diversity of people to excel in physics.

*The Society of Physics Students recognizes that there is a vast untapped intellectual resource in all groups underrepresented in physics. For this reason, the Society of Physics Students is committed to making physics more accessible to everyone. We are committed to providing programs, resources, and opportunities that encourage greater participation in the community of physics from members of all groups.*



*The 2009–2010 SPS National Council.*  
Photo by Phillip Payette

The SPS National Council is the governing body for the Society of Physics Students and Sigma Pi Sigma, the physics honor society. The council is composed of one zone councilor (faculty advisor) and one associate zone council (student) from each of 18 regional zones, along with a small executive committee. Meet your Council members and hear from newly elected SPS President Toni Sauncy (Angelo State University) on the SPS website, [www.spsnational.org/governance/council](http://www.spsnational.org/governance/council).