Planetary Science Institute

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Russian Skyfall *by Natasha Artemieva*

The "smoke train" — the trail left by the Chelyabinsk meteorite as it rushed through the atmosphere — was spectacularly caught on film by Russian photographer Marat Ahmetvaleev, who was fortunate enough to be photographing the sunrise that day.
More at http://marateaman.livejournal.com/27910.html

This is from an article by PSI Senior Scientist Natasha Artemieva that was published as "News and Views" in the Nov. 13, 2013, issue of Nature.

The Feb. 15, 2013, entry of a 65-foot-wide celestial rock into Earth's atmosphere above the Ural Mountains in Russia offered both a spectacular show and invaluable information that advances our understanding of high-velocity impacts. It was the largest impact event on Earth since the Tunguska blast in 1908.

In his letter to *Nature* in 1908, renowned amateur astronomer W. F. Denning described the night of 30 June in Bristol: "The firmament was abnormally luminous, with a very strong glow all over the north at midnight." Other letter writers in that issue of *Nature* and the next issue also reported seeing bright lights in Berlin, London, and Prague that night. And atmospheric disturbances and seismic signals were registered across Eurasia, with the strongest reported in Russian Siberia.

Then in 1927, a huge area of devastated forest was discovered near the Podkamennaya Tunguska River, also in Siberia. It took decades to connect all of these observations with a cosmic-body impact, now known as the Tunguska event of 1908, which carried a total energy of 10–15 megatons of TNT, equal to 1000 times the Hiroshima bomb. Taken together with the hypothesis that an asteroid impact caused the mass extinction at the Cretaceous–Palaeogene geological boundary 66 million years ago, the Tunguska event highlighted a new threat to the human race and a challenge for astronomers: to predict the next asteroid impacts.

There are three fundamental physical processes involved as meteoroids —asteroids' smaller counterparts — enter the atmosphere. First, atmospheric drag decelerates meteoroids from their initial velocity of about 12 miles per second to a free-fall velocity ranging from inches to hundreds of feet per second, depending on size. Second, atmospheric shock waves heat the air sur-

Continued on page 2

This half-ton rock, the largest piece of the Chelyabinsk meteorite, was located in Lake Chebarkul at the time of the fall and pulled from the water months later. *Anton Melnikov/Reuters/Corbis*

Inside this issue:

Russian Skyfall *by Natasha Artemieva (continued)*

Nov. 13, 2013, issue of Nature featuring the Chelyabinsk impact event that occurred on Feb. 15, 2013. *(Credit: Nature)*

rounding the meteoroid and make the body visible as a fireball. Thermal radiation evaporates the meteoroid, which may lose more than 90% of its initial mass before it hits the ground. Third, extremely high dynamic pressure breaks the meteoroid into smaller fragments, which in turn are subjected to even higher degrees of deceleration and evaporation.

So far, approximately 90% of near-Earth objects, such as comets and asteroids larger than a half-mile in diameter, have been monitored. Smaller, Tunguska-like bodies are much more difficult to detect. However, the DA14 near-Earth asteroid, which is about 100 ft wide, was discovered in February 2012. A year later in Tucson, AZ, I was watching NASA TV about the asteroid's expected closest approach (approximately 17,000 miles above Earth) coming the next day, when breaking news from a Russian radio station announced that a superbolide had exploded over Chelyabinsk.

My first thought was that the Russian media had misinterpreted NASA TV. But it was not a mistake. Thousands of people observed a bright flash in the sky followed by a powerful sonic boom that destroyed windows across an area of about 3,000 miles. More than 1,500 people were injured, mainly by broken glass. Amateur video recordings of the event allowed scientists to reconstruct the body's trajectory and its fragmentation history: the entry angle was unusually low (17° above the horizon), the observed trajectory in the atmosphere exceeded 155 miles in length, several light flashes occurred below an altitude of 25 miles, and hundreds of fragments were dispersed along the trajectory.

According to video records and calculations of a "dark flight" (part of its path not visible due to low speed and absence of light) the largest fragment would have touched down in Lake Chebarkul. The recovery of this fragment in October 2013 (see front page photo), which weighed about 1,300 lbs, was the best prize for the scientists. Most probably the Chelyabinsk meteoroid is part of the 86039 near-Earth asteroid, not the 2012 DA14 asteroid, which passed by Earth almost unnoticed, thanks to its loud precursor. Analyses of infrasound and seismic signals and the brightness of the light flash allowed us to estimate the pre-atmospheric diameter of the asteroid to be in the range of 55-65 ft, with a total mass of about 10,000 tons. Only a tiny fraction of this mass, less than 0.01%, has been recovered. The rest formed a spectacular smoke train 125 miles in length (see photos on front and back page) which could be seen for a half-hour as a huge contrail and was then seen as a giant dust belt in the stratosphere by NASA satellites until mid-April.

Scientific teams in Russia, the U.S., and Czech Republic used standard models of impacts to make their calculations. Although these models are valid for small meteoroids, they may fail for meteoroids that are over 30 ft in diameter. For these, the collective behavior of fragments plays a crucial part: evaporation could be more intense and account for the small final mass, whereas dynamic pressure could be much lower, explaining why large fragments survive. It is hoped that the Chelyabinsk event will prompt researchers to refine their models.

Continued on back page

About the Author, Natasha Artemieva

Natasha (short for Natalia) Artemieva grew up in Russia not far from Chelyabinsk and moved to Moscow to study physics and math at the Institute (University) of Physics and Technology in 1976. She joined PSI in 2006 and splits her time among Tucson, Berlin, and Moscow.

Her interest in space science followed the 60's zeitgeist. Human space travel began in 1961 when Yuri Gagarin, a Soviet pilot and cosmonaut, became the first person to orbit Earth. Gagarin, with his winning smile and celebrity status, made becoming a cosmonaut a popular, new goal for young people in Russia and everywhere. Natasha shared that ambition.

After a short excursion into plasma physics and the births of three children, her girlhood dream of space exploration turned into the adult reality of being a scientist studying high-velocity impacts in the Solar System. She earned her Ph.D. in 1996 at the Institute of Geosphere Dynamics, Russian Academy of Sciences.

Her main focus is studying impact craters and related phenomena on the Moon, Mars, and Earth using numerical models. Her main instrument is the hydrocode SOVA (meaning "owl" in Russian) created with her Ph.D. supervisor during her graduate years. Natasha's current projects include the study of ejecta from the Chicxulub crater in Mexico and global fires at the K-Pg boundary, transfer of meteorites from the Moon, and formation of double ejecta layers around martian craters. Meteoroids (such as Chelyabinsk and Tunguska) were the main subject of her Ph.D. and remain her prime interest.

Outside of science, she tries to find time for cycling, dancing, and flower gardening. We are delighted to have Natasha back in Tucson every winter and spring.

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Chris Holmberg, *Editor and Writer*

Alan Fischer, *Writer and Photographer*

Special thanks to Gil Esquerdo, Dianne Janis, Emily Joseph, Victoria Klocko, Carol Neese, and Elaine Owens

Introducing Amanda Hendrix

In 2012, Amanda Hendrix joined PSI as a Senior Scientist. Her science investigations focus almost exclusively on UV spectroscopy. She is keenly interested in what this wavelength regime reveals about the surfaces of small bodies in the Solar System, including the Moon, asteroids, and the icy moons of the outer Solar System.

Amanda knew as early as the 2nd grade, when learning about the Solar System, that she was especially drawn to the planets. However, not realizing there was a career in it, she decided she would be an astronaut. Once she discovered that she could have a career doing planetary science — "the most satisfying, creative, stimulating career she could imagine" — that did it for her. (All that being said, if given the opportunity, she confesses, she would fly in space in a heartbeat. Once she did fly in the "Vomit Comet" and proclaimed it "out-of-this-world fun!")

Amanda attended California Polytechnic State University, San Luis Obispo, for her undergraduate education (graduating in 1991), studying physics and aeronautical engineering. She also spent a year abroad in Heidelberg, Germany. She went to graduate school at the University of Colorado (CU) in Boulder to study aerospace engineering. She found her way into planetary science when she joined the Galileo Ultraviolet Spectrometer team to analyze the data from lunar flybys for her Ph.D. thesis with her advisor Charles Barth. From then on, studying UV spectra of surfaces has been her specialty. After getting her Ph.D. in 1996, as a post-doctoral student at CU Boulder, Amanda was the UVS Co-Investigator, leading the effort on analysis of data of the icy Galilean moons and investigating the chemical and photometric effects of plasma bombardment on the surfaces of these moons. She was also interested in extending her UV spectroscopy interests to asteroids, so she contacted (future PSI-er) Faith Vilas and weasled her way into a summer research project with her at Johnson Space Center. They eventually learned about the important effects of space weathering on S-class asteroids in the UV, a topic on which they continue to collaborate.

While at CU Boulder, Amanda became involved with the Cassini Ultraviolet Imaging Spectrograph (UVIS) team; at the time, Cassini was en route to Saturn. Fellow UVIS Co-I (and another future PSI-er) Candy Hansen alerted her to an opening on the Cassini science planning team at JPL. She worked at JPL for 12 years, mainly on the Cassini mission, planning science activities during icy satellite flybys and ultimately spending two years as Deputy Project Scientist. Amanda left JPL to join PSI in 2012.

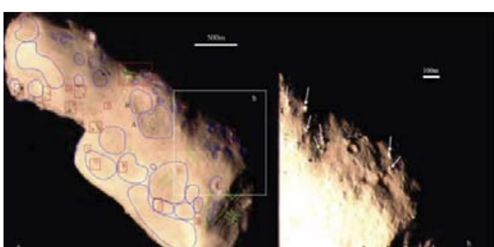
As a Co-Investigator on Cassini UVIS, Amanda analyzes the far-UV spectra of Saturn's icy moons, studying variations in spectral shapes and photometric properties across the surface and what processes could have produced them. As a Participating Scientist on LRO/LAMP (Lunar Reconnaissance Orbiter/Lyman Alpha Mapping Project, a far-UV spectrograph), she is studying far-UV spectra of Earth's Moon to understand composition, hydration, and space weathering effects.

Besides planetary science, the loves of her life are her husband, her 9-year-old stepdaughter, and their dogs! Favorite free time activities include yoga, food and wine, going to the beach and hiking, and exploring new places.

We could not be more pleased to welcome Amanda to PSI!

Closest Ever Asteroid Spacecraft Flyby

by Alan Fischer



PSI Research Scientist Jian-Yang Li was part of a research team that secured high-resolution images of near-Earth asteroid 4197 Toutatis during a close spacecraft flyby. The images were taken by China's Chang'e-2 spacecraft, which passed within about 770 meters of the asteroid and allowed images to be taken with resolution of better than 3 meters.

"This is the smallest flyby distance ever conducted by any spacecraft to a Solar System object," Jian-Yang said. "The images returned are of high quality that reveal a wealth of geologic features of the asteroid, advancing our understanding about the origin and evolution of this asteroid." Jain-Yang is co-author on a *Scientific Reports* paper titled "The Ginger-shaped Asteroid 4179 Toutatis: New Observations from a Successful Flyby of Chang'e-2."

Jian-Yang participated in the definition of the scientific objectives and technical requirements for the flyby mission. After the flyby, he discussed the research and data analysis plan with the research team in China, based on the characteristics of the available imaging data. During the development of the paper, he provided information and helped revise the paper.

Jian-Yang is the only scientist from a U.S. research institution on the project. His contribution to this work is not supported by any NASA funds.

The masthead image on the front page is from the Hubble telescope and shows the large Whirlpool Galaxy M51, at left, known for its sharply-defined spiral arms. Their prominence could be the result of the Whirlpool's gravitational tug-of-war with its smaller companion galaxy, at right. At the Hubble News Center site(Hubblesite.org), find the story behind this image, along with its original news release and all related images. Credit: NASA, ESA, S. Beckwith (STScI), and The Hubble Heritage Team (STScI/AURA)

Face-to-Face with Sugata Tan

Sugata Tan joined PSI in December 2011 as an Associate Research Scientist. He came to us while he was working on Titan's chemistry with Jeffrey Kargel (University of Arizona), who introduced him to planetary science and to PSI. He lives with his wife and two daughters in Laramie, Wyoming. He was a researcher at the Soft Material Laboratory, University of Wyoming, for six years. Before coming to the U.S., he was a senior lecturer teaching engineering, physics and mathematics at the University of Surabaya, Indonesia.

Sugata's science is all about chemical thermodynamics and development of thermodynamic equation-of-states for phase equilibria of various chemical systems: cryogenic chemistry, aqueous systems, petrochemical systems, polymeric systems, etc. In the last few years he has been excited to apply this expertise to planetary science. In his current funded project, he is developing a thermodynamic equation-of-state that can describe phase equilibria at cryogenic conditions relevant to extraterrestrial bodies: solid-liquid-vapor equilibria on Titan and solid-vapor equilibria for applications on cold bodies such as Pluto.

Sugata's interest in space science began as a Star Trek fan. He was also inspired by great films: Carl Sagan's *Contact*, Steven Spielberg's *Close Encounters of the Third Kind*, Roland Emmerich's *Stargate*, and great books: Stephen Hawking's *A Brief History of Time*, Fritjof Capra's *The Tao of Physics,* and Gary Zukav's *The Dancing Wuli Masters*. He finds enlightening the fact that his engineering tool for petrochemical industries applies well to describing planetary chemical thermodynamics.

Sugata acquired his B.Sc. in physics at Gadjahmada University, Indonesia (1987), an M.Sc. in applied physics at the University of Adelaide, Australia (1995), and his Ph.D. in chemical engineering at the University of Wyoming (2004).

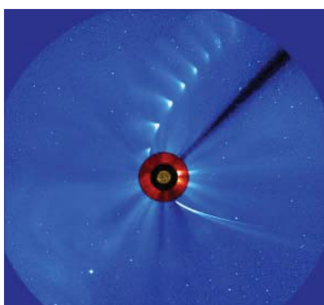
The works of Anthony de Mello and Eckhart Tolle inpire him to challenge his destiny and be a lifelong learner. The Australian outback and Wyoming wilderness have taught him much about nature, and he enjoys hiking when he finds the time.

Sugata is a very welcome addition to our PSI science staff!

Death of Comet ISON Viewed from Kitt Peak

by Emily C. S. Joseph

Comet ISON (named for the survey that discovered it, the **I**nternational **S**cientific **O**ptical **N**etwork) had two characteristics that made it extra exciting for scientists: It was "new" and it was what's called a "Sungrazer."This was the first time it had visited the inner Solar System — it had been traveling from the outskirts, where it was formed, for about 400,000 years. This meant it was unaltered by previous approaches to the Sun. However, once it did get near the Sun, it got extremely close —724,000 miles above the Sun's surface!

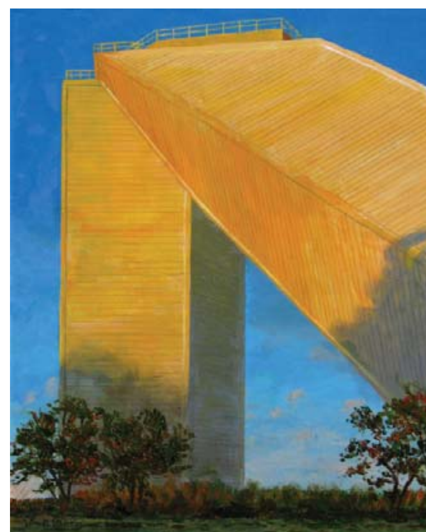


Comet ISON entered the frame from lower right and fled the Sun toward the upper right, falling apart as it went, in this time-lapse Solar & Heliospheric Observatory image from November 28, 2013. *(Credit: ESA/NASA/SOHO/SDO/GSFC)*

This rare event had telescopes around the world turning towards the comet, and PSI Senior Scientist Jeff Morgenthaler led a team that made observations from the McMath-Pierce Solar Telescope on Kitt Peak, 56 miles from Tucson.

Some team members in front of the main spectrograph, l-r: Lori Spalsbury (University of Maine), Jeff Morgenthaler, Principle Investigator (PSI), Carey Lisse (Johns Hopkins Applied Physics Lab), Prof. Emeritus Uwe Fink (UA Lunar and Planetary Laboratory), Matthew Knight (Lowell Observatory). *Photo by Carey Lisse.*

The McMath-Pierce's odd-shaped building actually contains three separate telescopes that focus light down its 300-foot-long optical tunnel. Morgenthaler's team reconfigured the main spectrograph to allow them to observe Comet ISON in the bright daytime sky. The telescope was rearranged several more times in the course of observation, with changes being made as the comet got closer to the Sun.



The outside of the McMath-Pierce Solar Telescope as painted by PSI Co-founder and Senior Scientist William K. Hartmann.

The comet rounded the Sun on November 28, however, the nucleus did not survive its solar close encounter. This deprived backyard observers of what was hoped to be a beautiful naked-eye comet, but this was still a once-in-a-lifetime scientific opportunity. We've never seen anything like ISON before, and its spectacular demise will be talked about for years to come.

A view down the telescope's main, 300-foot-long optical tunnel. *Photo by Carey Lisse.*

Director's Note

PSI continues to expand with the purchase of a building between our east and west wings in Tucson. We were already leasing the southern half of this facility, the "mid-wing", seen in this photo, for the past year, and in executing our option to buy we have added another 3,400 sq ft. This represents an investment in our continuing success, giving us good breathing room and space for more offices and new laboratories.

We shared this new space and our many activities with the public at a recent PSI Open House. We attracted a great crowd, including Tucson Mayor Rothschild and some Friends of PSI who drove out from California to attend the event! PSI scientists talked about our efforts to track incoming meteors with weather radar (including last year's fall over Tucson), demonstrated our ability to generate 3-D topographic maps of Mars, explained what we have been learning about Vesta from the Dawn mission illustrated by a 3-D movie of the rotating protoplanet, conducted impact demonstrations with audience participation, and a half-dozen other activities. Bill Hartmann gave a tour of his artwork around our buildings and the scientific thought and perspective that informs it. I was bending people's ears about PSI's range of mission activity and basic research, its business model, continuing growth around the country, and showed a presentation of our efforts to bring human exploration to Tucson through our Atsa Suborbital Observatory program. There is much to be excited about.

We are also pleased to announce the first awardees of the Pierazzo International Student Travel Awards, named in honor of PSI Senior Scientist Betty Pierazzo. At a time of shrinking funds available for international travel, these awards provide support for a U.S. graduate student to attend a planetary related meeting outside the U.S., and a non-U.S. graduate student to attend a planetary-related meeting in the U.S.. This memorializes Betty's commitment to education and building international collaborative relationships. These awards are supported by PSI's Betty Pierazzo Memorial Fund. We look forward to sharing pictures of the presentations that will be made in Vienna and Tucson later this year.

Mark V. Sykes
April 2014

PSI attends LPSC

Above, PSI Director Mark Sykes (center, in green) surrounded by some members of PSI's LPSC contingent who gathered for dinner and conversation at Landry's Seafood restaurant.

Photo by Robert Reedy

PSI scientists attended the 45th annual Lunar and Planetary Science Conference (LPSC) in Houston, March 17-21. More than 50 PSI scientists and educators made over 128 oral and poster presentations at the conference held in The Woodlands, Texas.

Topics included the Mars Science Laboratory rover mission, the Mercury MESSENGER mission, the Dawn mission to the asteroid Vesta, achondrite meteorites, lunar remote sensing, planetary cartography, asteroid analysis, exobiology, lunar impact cratering and many more areas of scientific study.

PSI Staff News

Congratulations to our newest PSI parents!

At right, Noah Bennett Berman, son of PSI Research Scientist Daniel Berman and Desi Berman, was born on Feb. 10. He weighed 8 lbs 1 oz and measured 19 inches long.

Joshua David Benecchi was born March 11 to PSI Research Scientist Susan Benecchi and her husband R.J. Newborn Joshua weighed 6 lbs and was 19.5 inches long.

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Russian Skyfall *(Continued from front page)*

The trail of the Feb. 15th, 2013, fireball formed a spectacular "smoke train" 125 miles in length that could be seen for a half-hour and was observed as a giant dust belt in the stratosphere by NASA satellites until mid-April.

More at http://marateaman.livejournal.com/27910.html

How common are Tunguska- and Chelyabinsk-like events — should we expect other guests from outer space any time soon? Standard methods predict a Tunguska-like event once every millennium, and a Chelyabinsk-like event once a century. However, recent observations allow a tenfold higher probability for both types of event. We may have to wait 100 years to find out.

And are astronomers capable of predicting the impacts of meteoroids several feet in diameter? Probably not: Such objects are too small to be detected in space by modern telescopes. One successful prediction was that of asteroid 2008 TC3, which was discovered by accident a day before it struck Earth's atmosphere, and recovered later in Sudan as the Almahata Sitta meteorite. If the trajectory, size, and composition of a body are known, physicists can predict its behavior: whether it will harmlessly vaporize and fragment in the atmosphere or cause serious damage to the planet's surface, such as shock waves, wildfires, and impact craters.

Finally, can humans minimize the risk of impact-related injuries? Yes they can, by learning a few basic facts about meteoroids and their interaction with the atmosphere — just as people living in seismically active areas are prepared for earthquakes. A meteoroid impact could happen at any time, anywhere on Earth. If you see a bright flash in the sky, do not panic: stay away from the windows and find a secure spot to hide. If possible, use your mobile phone to take pictures and videos, and time the interval between the flash and the sonic boom (it may take up to a few minutes). Without your observations, a future impact event might remain as enigmatic as that at Tunguska.