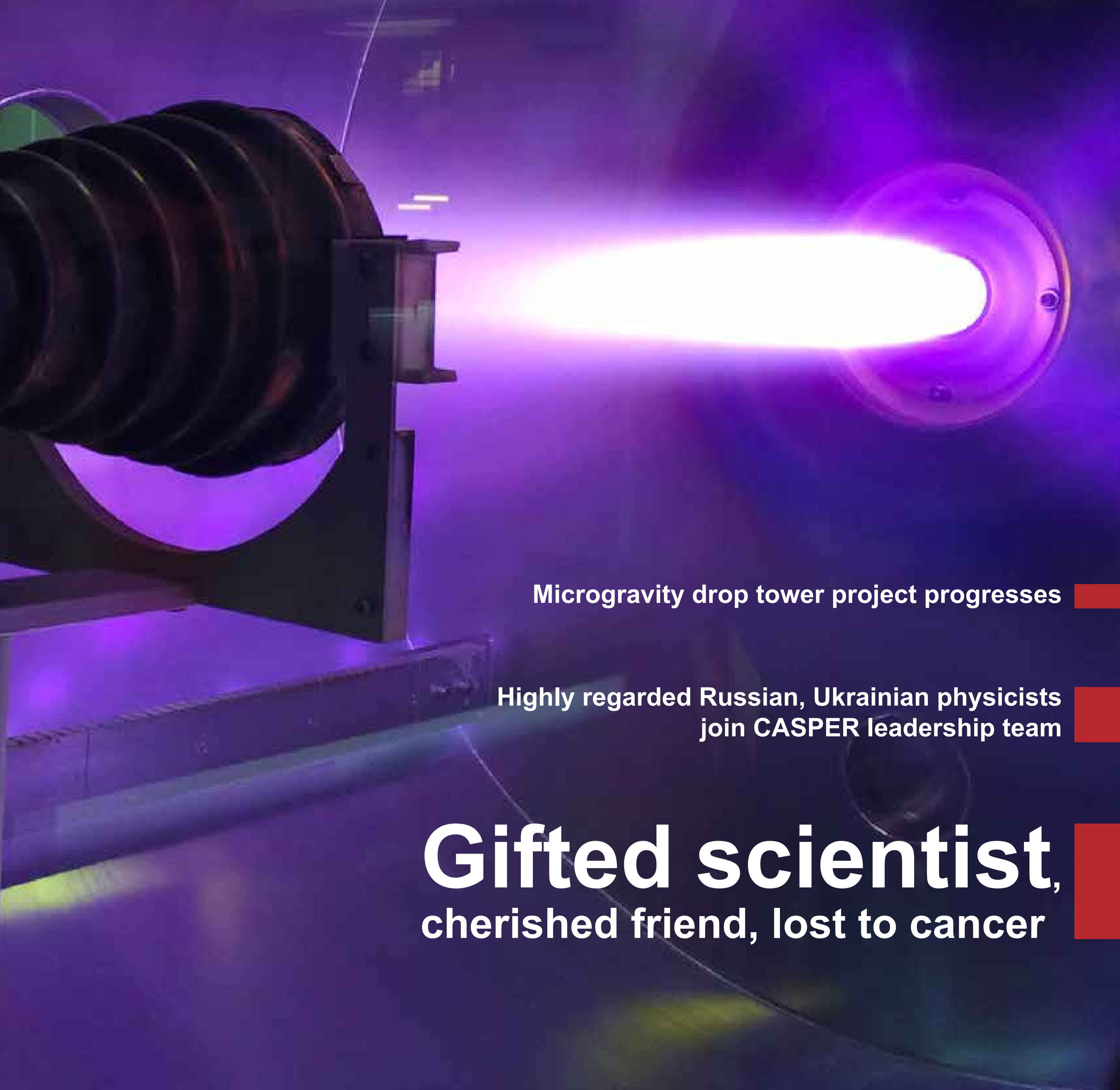
2016 • Volume XVI

CASPER

CENTER FOR ASTROPHYSICS, SPACE PHYSICS & ENGINEERING RESEARCH

Astrophysics & Space Science Theory Group • Early Universe Cosmology & Strings Group
Gravity, Cosmology & Astroparticle Physics Group • Hypervelocity Impacts & Dusty Plasmas Lab
Space Science Lab • Paul and Jane Meyer Observatory



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Cover photo: Magnetic Dusty Plasma Experiment (MDPX) instrument at Auburn University.

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2015 Intellectual Contributions

- 23 Papers
- 41 Presentations
- 75 Articles
- 9 Datasets

2015 Proposals / Grants

- 21 Active Grants

$15.2 million - Total Funding

CASPER News is an annual publication of the Office of Vice Provost for Research at Baylor University. *CASPER News* highlights the work of faculty and staff of the Center for Astrophysics, Space Physics & Engineering Research, Dr. Truell Hyde, director.

CASPER is located in the Baylor Research and Innovation Collaborative in Waco, Texas.

For more information, go to: http://www.baylor.edu/casper. Send comments to: research@baylor.edu.

CASPER loses gifted scientist, cherished friend, to cancer

Dr. Hans-Peter Röser, longtime director and manager of the Space Systems Institute (IRS) at the University of Stuttgart and adjunct researcher at CASPER, died 8 December 2015 at his home in Aachen, Germany, following a long battle with cancer.

In 2007, Röser traveled to Baylor University to finalize and help implement a now long-standing memorandum of understanding between CASPER and IRS. The relationship he fostered initiated a continuous stream of Stuttgart faculty and graduate students to Baylor for study and research, and established an ongoing dusty plasma research collaboration that employs sophisticated inductive plasma generators at both institutions, as well as GEC rf reference cells at Baylor. Under the agreement, the two institutions also exchange information relating to design and construction of student-built satellites and other projects.

Röser managed IRS from 2002 until February 2014. An energetic and forward-thinking scientist, in 2011 he established the Stuttgart-based Baden-Wuerttemberg Space Center. Earlier, he was a founder of the SOFIA Institute which, with NASA, co-sponsored development of the Stratospheric Observatory for Infrared Astronomy, an advanced and powerful infrared telescope that is taken to high altitudes aboard a highly modified Boeing 747.

Born in 1949 in Polch, Germany, Röser studied physics at the Rheinische Friedrich-Wilhelms University in Bonn, receiving his Ph.D. in 1979. Appointments followed at the Max Planck Institute for Radio Astronomy in Bonn and at the Technical University of Berlin, where he held a professorship in space sensor technology. He also simultaneously held a position as director of the Institute of Space Sensor Technology of the German Center for Aerospace (DLR) in Berlin-Adlershof. There he worked chiefly on the SOFIA project, but also initiated numerous innovative small satellite projects.

As a tribute to Dr. Röser, last February the University of Stuttgart hosted a gathering of internationally prominent space scientists and physicists who attended to present their latest research and celebrate their colleague's 65th birthday.

Upon receiving the news of Röser's death, IRS colleague, Dr. Stefanos Fasoulas, offered:

> We are deeply grieved. With Professor Hans-Peter Röser's passing we have lost an outstanding scientist, teacher, mentor and friend. His precise and critical analyses were invaluable to our research and teaching. His enthusiasm and dedication were exemplary and students found his lectures transformative. He was attentive to everyone he met and his advice was always welcome.

Professor Wolfram Ressel, Chancellor of the University of Stuttgart, added the following:

> The news of the death of Professor Hans-Peter Röser has caused deep sadness at the University of Stuttgart. All who had the great good fortune to know this charismatic personality have suffered a great loss. The University, its students and alumni have lost not only an outstanding teacher, scientist and science-manager, but we have especially lost a great man possessed of uncommon openness, humanity and shining strength of personality.

Through his years of association with CASPER, many at Baylor forged close and lasting bonds with Röser. For them, his passing leaves both professional and deeply personal voids.

"Hans-Peter was a truly rare individual — he was both brilliant, placing him at the top of his field, but also truly gifted in his ability to encourage those around him," recalls CASPER director, Dr. Truell Hyde. "His passing is a great loss to us all. He will be sorely missed."

Highly regarded Russian, Ukrainian physicists join CASPER leadership team

Dr. Oleg Petrov and Dr. Vladimir Nosenko join Hungarian scientist Dr. Peter Hartmann as assistant directors of research, further enhancing CASPER's reputation for international collaboration.

Last August, internationally esteemed plasma physicist, Dr. Oleg Petrov, accepted an appointment as an assistant director of research at CASPER. Elected to the Russian Academy of Sciences (RAS) in 2008 and recipient of the 2010 State Prize of the Russian Federation in education, Dr. Petrov serves as Deputy Director for Science at the Academy's Joint Institute for High Temperatures (JHIT) in Moscow. He is a key figure in microgravity plasma research, including the Plasma Kristall-3 project aboard the International Space Station and in the adaptation of plasma science to medicine.

He and CASPER director, Dr. Truell Hyde, first exchanged business cards at a 2004 conference in Paris, but years passed before the two began serious talks about working together.

"The next time I met him was at the 2012 (European Physical Society) conference in Stockholm," Petrov recalled. "That was the starting point for the active phase of our collaboration.

"We have a really unique situation: we are working in the same direction in dusty plasma research, but we are using different facilities and techniques to trap and transform the (plasma) structures. During my visit to CASPER this summer we were able to successfully combine the (CASPER and JHIT) approaches, giving some exciting results," Petrov said.

At home in Moscow, Petrov spends time with his interior designer wife Elena, their two university student children, Igor and Maria, two pet cats and dog. He also enjoys scuba diving and underwater photography.

Ukraine-born plasma physicist Vladimir Nosenko lends his extensive expertise to CASPER while serving as a full-time research scientist at the German aerospace center, DLR, Germany's equivalent of NASA. A graduate of the Moscow Institute of Physics and Technology, Nosenko earned a Ph.D. at the Ukraine National Academy of Science's Institute for Metal Physics in Kiev before leaving his home country for a position at the Plasma Physics Research Centre at Lausanne, Switzerland.

Nosenko came to the United States in 2002 to study and teach at the University of Iowa, where legendary astrophysicist Dr. James Van Allen was still researching and teaching into his late eighties. The Van Allen radiation belts that are responsible for polar auroras bear his name.

Nosenko returned to Europe in 2006 and conducted research at the Max Planck Institute for Extraterrestrial Physics in Garching, Germany until joining DLR in 2014. An author or contributor to numerous influential scientific papers, Nosenko co-authored a 2007 paper with Drs. Sergey Zhdanov and Gregor Morfill that documented the first experimental proof that the rate of particle dislocation in a solid can at times actually exceed the speed of sheer waves associated with the dislocation. Scientific orthodoxy at the time held that this "speed-of-sheer sound" constituted an absolute speed limit not unlike the speed of light. It was a discovery with potentially significant implications for material sciences and engineering.

Nosenko first came to Baylor in 2011 after a fellow professor at Iowa told him about CASPER. "I visited and came back and said, 'very interesting labs, nice people, lots of nice equipment,'" Nosenko recalls. "Later I began building some ties with (CASPER founder and director Dr. Truell Hyde) and these advanced to the point that I have become an assistant director of research here."

Nosenko's appointment is yet another product of the culture of international collaboration that has been a CASPER hallmark since its founding in 1999. Nosenko says he finds pooling talent in this way to be especially useful and rewarding. "We have an old, wise saying that if you have two people who each have an idea, then as a group you have two ideas. In this way we can have ideas and creatively exchange them. That benefits everyone."

Nosenko finds the field of complex plasmas especially attractive because he sees it as still in its infancy. "I think that many human activities have become commodities like water from a tap – you open it, you get it. That includes certain branches of science where everything is pretty much set. But studying dusty plasmas is not yet a commodity, it is still very early in its development. This is where you can contribute the most toward advancing the field," he says. "In fact, I would call it 'building the field.'"

Nosenko and his wife, a biology researcher, have one daughter who is studying biology at Ludwig Maximilian University of Munich.

New CASPER Faculty

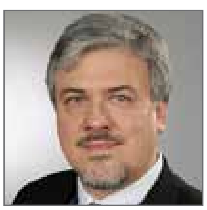
Augusto Carballido, Ph.D. joins CASPER as an assistant research professor in theoretical physics whose primary field of study is solar system and planetary formation with a focus on proto-planetary disks. A native of Oaxaca, Mexico, he received his Ph.D. in astronomy in 2006 from the University of Cambridge, United Kingdom. Until recently he was a postdoctoral scholar in the department of astronomy at the University of Texas, Austin. He is a member of both the American Geophysical Union and the Geological Society of America.

Carballido is fluent in Spanish and English and is reading-proficient in French. He serves as a referee for the Monthly Notices of the Royal Astronomical Society and for the Mexican Journal of Geological Sciences. Among other interests, he enjoys science writing for popular markets and is an avid scuba diver.

Conni Liaw, Ph.D. accepted an appointment at Baylor in 2012 as assistant professor of mathematics after a three-year stint as a visiting assistant professor at Texas A&M. She received her Ph.D. in mathematics in 2009 from Brown University after earning her master's at that institution and a Bachelor of Science (equivalent) degree from the Universität Stuttgart in her native Germany.

A common thread running through her research is developing mathematical analyses to investigate certain problems deriving from mathematical physics. A particular area of expertise lies within several subfields of analysis and includes rank-one perturbations, singular integral operators, model spaces, cyclic vectors, Anderson-type Hamiltonians and exceptional orthogonal polynomials.

Personal Updates



Dr. René Laufer, associate research professor and head of CASPER's Space Science Laboratory, recently was appointed an honorary associate professor at the University of Cape Town, South Africa, where he has been a visiting faculty member since 2014. Laufer also holds visiting faculty status at the Technical Universities of Dresden and Berlin and at the Universities of Stuttgart and Naples. He is a faculty member of the International Space University in Strasbourg, France, and is co-chair of the International Academy of Astronautics' permanent committee on small satellite missions.

Babies

Joy Anxin Vasut

7 lbs. 6 oz., 20 ½ in.
Born at 7:13 a.m., August 1, 2015
to John and Maggie Vasut. She joins sisters Jane, 10, Jennifer, 5, and brother Joseph, 7

Ashley Zhang

6 lbs. 12 oz., 20 in.
Born at 12:18 a.m.,
February 9, 2016
to Bo Zhang and wife Grace Huang

Graduations

Ph.D. student Yanbin Deng received his physics degree in August. His dissertation is *Reflections on General Relativity from Perspectives of Black Hole Physics and Horava-Lifshitz Gravity.*

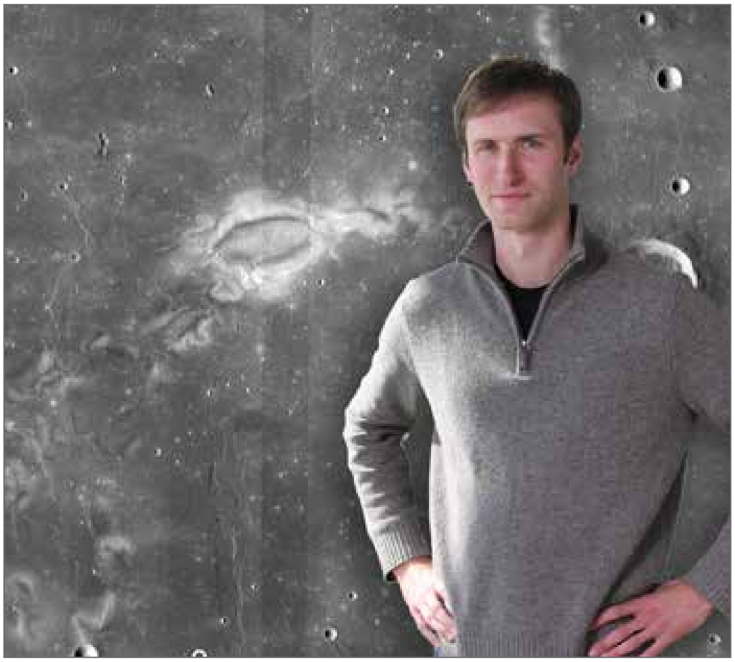
Ph.D. student Curtis Graham received his mathematics degree in August. His dissertation: *Boundary Condition Dependence of Spectral Zeta Functions.*

Ph.D. student Raziyeh Yousefi received her physics degree in December. Her dissertation: *An Investigation of Electrostatic Properties of Dust Grains in a Complex Plasma.*

Undergraduate Drake Gates
graduated in May and is now a Ph.D. candidate in the nuclear engineering program at Syracuse University. Drake's undergraduate thesis is *Investigations on the String Landscape.*

CASPER researchers probe a lunar enigma

Team of CASPER researchers working to explain unusual features on the lunar surface.



Plasma researcher Michael Dropmann with Reiner Gamma lunar swirl

Although lifeless, airless and barren, Earth's moon continues to supply scientists with an endless assortment of mysteries and enigmas to ponder and probe. One of these is the phenomenon of *lunar swirls*, dozens of large, winding patterns with dark and bright lanes on the lunar surface that distinctly contrast with the surrounding soil. In the absence of the eroding effects of weather and apparently unconnected to craters or any other topographical feature, the swirls' bright presence has ignited fires of conjecture in many scientific minds, including several at CASPER.

Michael Dropmann is a research assistant from the University of Stuttgart who is in his fifth year at CASPER. He and a team of colleagues that includes Dr. Lorin Matthews, Dr. Truell Hyde and fellow German researcher Dr. René Laufer, are using one of the lab's plasma generators to create an environment that may help explain the mysterious formations.

Fortunately, investigators are not without clues: the swirls have thus far only been found in regions where the moon's weak magnetic field is somewhat stronger. It's thought that these "mini-magnetospheres" may interact with the lunar plasma environment in a way that produces strong electric fields. The fields might impart an electrical charge to dust particles, causing them to move and form the swirls.

"It's called the 'dust transport theory' because we suspect the dust particles are charging up in the lunar environment; consequently they can be transported by electric fields," Dropmann says.

But there are other theories: one holds that the soil around the swirls may 'age' or turn darker with continued exposure to the intense solar wind, and that the magnetic fields may somehow shield the swirls from the solar wind's effects, maintaining the soil's original bright color. Another speculates that the swirls might be the result of comets that smashed into the moon during the last 100 to 300 million years. Such impacts can imprint an intense magnetic field into the lunar surface. At the same time, the gas cloud surrounding the comet – called its "coma" – can change the lunar surface structure, leaving the impact area brighter. The dark lanes may result from deposition of comet material vaporized by the force of impact. The team's theory could explain parts of either theory.

The CASPER researchers are using one of the lab's GEC rf reference cells in the investigation. These machines use radio frequency power to produce gas plasma in a vacuum chamber into which micrometer-sized spherical particles can be introduced. In a typical swirl experiment, the team uses a glass plate to simulate the moon's electrically nonconductive surface and an array of small magnets beneath it to produce a magnetic field above the glass plate that is very similar to that measured at a swirl, though vastly scaled down.

To serve as a surrogate solar wind, they inject non-reactive argon gas into the chamber where the radio frequency power strips electrons from the gas atoms, producing an ionized plasma cloud that interacts with the magnetic field. This interaction creates a complex pattern of electrical fields; to make them visible the researchers add micro-particles to the plasma cloud. A high-speed camera captures the results.

"When we introduce the particles into the plasma they sort of float around and get pushed in certain directions by the electric fields," says Dropmann. "Just by looking at the trajectories of the particles we can see what the forces on the dust particles are and can trace that back to the electric force."

The team then compares the data from experiments done with and without the magnetic field applied to identify which effects were actually caused by interaction between the plasma and the magnetic field. It's a meticulous process that yields hundreds of gigabytes of data to be analyzed.

Early findings seem to indicate that the team is likely on to something, but Dropmann is cautious. "There are still some other factors that may be having an influence. We think they are negligible but we won't know until we look at it in more detail."

Pondering the origins of planets

Theoretical astrophysicist brings new insights on formation of planets to CASPER.

Astrophysicist Augusto Carballido

The question of how planets form is a field of astrophysics long hampered by the inability of researchers to see deep into the cosmos where new stars and planets are being born, and by the lack of computers powerful enough to handle the vastly complex calculations needed to model the processes at work there.

But the advent of revolutionary instruments like NASA's Hubble Space Telescope and the European Space Agency's Herschel Space Observatory have made imaging of extremely remote objects possible, even routine. Today over 1,900 planets have been found orbiting neighboring star systems and nearly 5,000 more candidate objects await further examination. Likewise, quantum leaps in computing power over the last few decades have enabled researchers in many fields to create dynamic mathematical models of complex phenomena that were previously unfathomable.

Joining CASPER just last year, assistant research professor Dr. Augusto Carballido makes use of all these resources in his study of protoplanetary disks — dense rings of dust and gas that encircle many newborn stars.

His goal and that of his colleagues is to unravel the dizzying assortment of forces and processes involved in planet formation. Ultimately they hope to be able to predict the kinds of planets and systems that will form given the conditions within a protoplanetary disk. Depending on the content of any given region of a disk, rocky, Earth- or Mars-like planets may form, or gaseous giants like Jupiter and Saturn may coalesce instead. But the key to all of them is dust, and lots of it.

"At first, tiny dust particles smaller than the diameter of a human hair are swept along by turbulence in the gas in the disk. Through a molecular-scale force called the *van der Waals interaction*, they clump to one another, first into grains, then pebble-sized aggregations," Carballido explains. "But when they reach small boulder size – about a meter in diameter – other forces like gravity take over and things get more complicated."

Lots more complicated.

In theory, the boulders should succumb to the star's gravity, fall inward and burn up like a meteor. But if that happened there would be no raw materials to make planets, asteroids or moons. Scientists know that's not the case, so it's a bit of a puzzle.

Right now the thinking is that the boulders collide to form larger, kilometer-sized objects called "planetesimals." At that point their gravity becomes the dominant force in planetary formation. But the difficulty of producing computer models that can track millions of planetesimals while accounting for all the forces at play is just one of the many challenges that make the study of protoplanetary disks a task fraught with challenges, but full of opportunities for discovery.

"We are only beginning to fathom the complex mechanisms that are responsible for the origin of planets," Carballido writes. "One thing is certain, though: unraveling the mysteries of planet formation will give us a better idea of how life arose on our own planet."

Microgravity drop tower project progresses

Design draws on innovative European concept.

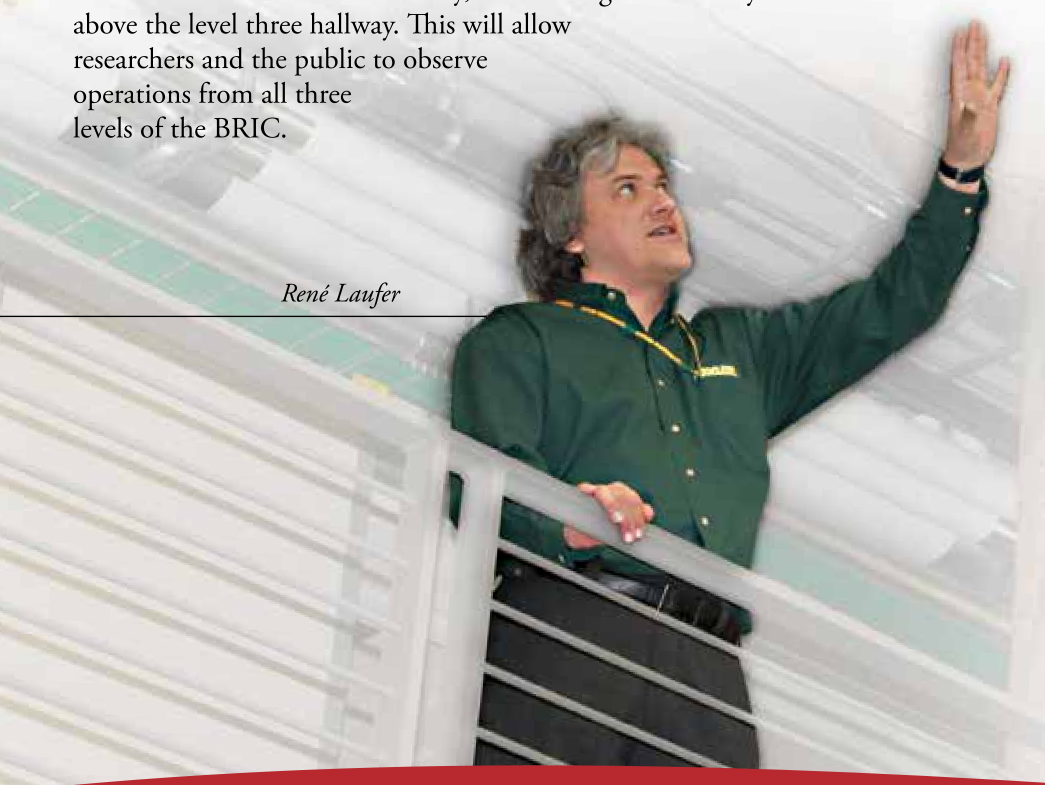
Designers and manufacturers of aerospace electrical and mechanical components need to know how new component prototypes will stand up to the extreme conditions present in airborne and space environments. The ability to perform tests and experiments in simulated microgravity is crucial to space science research. To address that need, a three-story indoor microgravity drop tower has been under development since the BRIC opened three years ago.

There are fewer than ten microgravity drop towers in the world and each is in high demand. When completed, the drop tower will provide an affordable and repeatable method to conduct experiments and tests in near-zero gravity, and will have the potential to make Baylor and Waco a destination for microgravity research in industry, science and education. Dr. René Laufer is head of CASPER's Space Science Laboratory and serves as the technical advisor for the drop tower project.

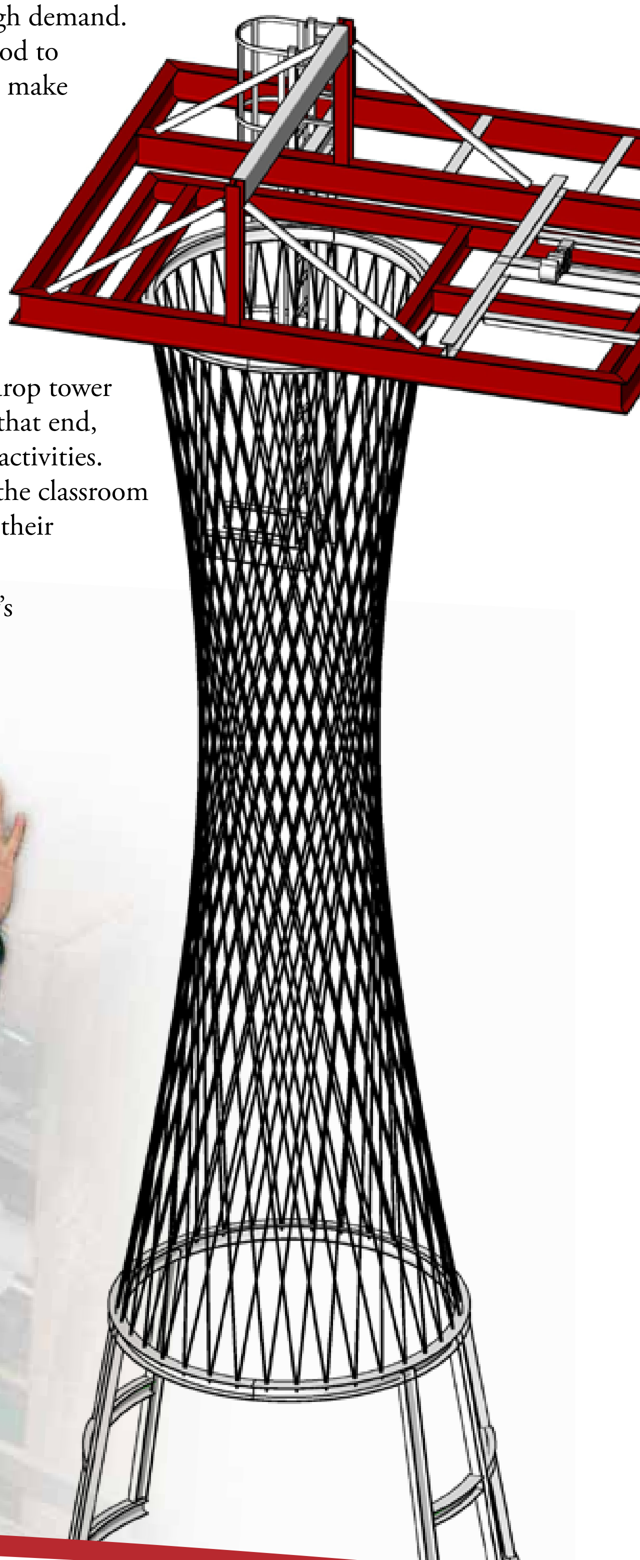
"A high-quality microgravity drop tower will enable research capabilities in many fields — from fundamental physics, material sciences and chemistry to medical applications and combustion motor engineering — for Baylor scientists, academic partners and industrial customers," Laufer says.

Due to the educational research efforts already underway within the BRIC, the drop tower will also become the centerpiece for K-12 STEM student research programs. To that end, work has already begun on STEM-based curriculum associated with drop tower activities. The goal is for teachers to introduce the drop tower concept to their students in the classroom so that the students can write a research plan, build a drop package, then deploy their experiment in a drop tower payload package at the BRIC.

The BRIC's microgravity drop tower is patterned on the European Space Agency's outreach/exhibition drop tower located in the Netherlands. That facility utilizes an advanced, tension cable construction concept. The BRIC drop tower will be much larger than the ESA tower, and will be anchored in the level one circulation hallway, terminating immediately above the level three hallway. This will allow researchers and the public to observe operations from all three levels of the BRIC.



René Laufer



Federal grant supports fundamental plasma research

Fundamental charging processes in dusty plasmas studied in NSF/DOE-funded collaboration.

A team of CASPER and University of Alabama – Huntsville researchers are delving into the intricate patterns of electrical charges present in dusty plasmas, with the aim of discovering and understanding the processes that produce them.

Plasmas — gaseous clouds of positive ions and unbound electrons — constitute the fourth state of matter and are the most abundant form of ordinary matter in the universe. Dusty or *complex* plasmas, are plasmas that contain nano- to micron-scale particles of cosmic dust or other substances.

Awarded in August of 2014, the three-year, $345,000 grant provides Baylor with $115,000 annually for basic research into a phenomenon that most scientists feel has been understudied, yet is important to many scientific and engineering fields. In high-energy physics, an understanding of the dynamics of dusty plasmas is key to fusion research. In the fields of astrophysics and astronomy, dusty plasma research promises to yield new insights into the formation of planets, space weather, and countless other cosmic phenomena. Discoveries made as a result of this work also have the potential to give engineers expanded practical understanding that will enable them to refine the many manufacturing processes that employ plasmas, a field known as *industrial plasma processing*.

While the overall charge of a "pure" plasma is roughly neutral, the presence of dust particles in plasma greatly increases the complexity of the system, as each dust particle carries its own unique charge. When individual particles interact with other particles and the plasma itself, the result is a constantly changing swarm of electrical charges.

"The physics behind the charging and formation of dust structures in the plasma has proven to require a highly nuanced understanding," said Dr. Lorin Matthews who, along with CASPER director Dr. Truell Hyde and Dr. Babak Shotorban of the University of Alabama – Huntsville, serves as co-principal investigator on the project.

"The charge acquired by the dust grains is determined by the plasma environment, but the charged particles in turn influence the plasma," Matthews said. "This makes the charge very difficult to calculate, and the dust charge is extremely difficult to determine in experiments."

Difficult as the work may be, in just the first year of the grant the team's work has yielded four published journal papers and over twenty conference presentations. These early results attest to the potential wealth of discoveries yet to be made in this relatively young field of investigation.

Astrophysics & Space Science Theory Group (ASSTG)
Space Science Lab (SSL)
Hypervelocity Impacts & Dusty Plasma Lab (HIDPL)

46th Lunar and Planetary Science Conference

CASPER researchers attended the 46th Lunar and Planetary Science Conference March 16-20, 2015 in The Woodlands, Texas. This conference brings together international specialists in petrology, geochemistry, geophysics, geology, and astronomy to present the latest results of research in planetary science. The five-day conference is organized into topical symposia and problem-oriented sessions.

The CASPER group included Michael Dropmann, Valentin Belser, Christoph Montag and Jeremy Smallwood. The group displayed five poster presentations at the conference:

Aerodynamic and Engineering Design of a 1.5-seconds High Quality Microgravity Drop Tower Facility. V. Belser, J. Breuninger, R. Laufer, K. Boehm, A. Carballido, M. Dropmann, G. Herdrich, T. W. Hyde & H.-P. Röser.

Dust Transport in Plasmas Interacting with Complex Magnetic Fields Close to Non-Conductive Surface. M. Dropmann, R. Laufer, G. Herdrich, L. S. Matthews & T. W. Hyde.

Integration of a Dust Accelerator into the IPG-B Test Facility for Material Impact Tests. C. Montag, R. Laufer, R. Srama, G. Herdrich, O. Przybilski & T. W. Hyde.

Piezoelectric Dust Detector Design and Calibration for the ARMADILLO Program. F. Odom III, G. Richter, J. Brown, B. Martinsen, R. Cai, M. Fellows, A. Wolf, C. Montag, P. Young, J. A. Carmona-Reyes, J. Schmoke, M. Cook, B. Garner, I. Gravagne, K. Pin, L. Shedd, T. Groskreutz, T. Hegle, N. Mulenos, J. Stone, C. Wiley, V. Yanga, D. Eustice, K. Flachsbart, N. Steele, C. Tilley, P. Friudenberg, D. Penshorn, L. Henderson, E. Cavazos, A. Nabili, E. Cox, A. Cox, J. Wood, L. Devine, J. Curran, A. Mendiola, C. Falkner, R. Laufer, R. Srama, K. E. Schubert, L. S. Matthews, G. Lightsey & T. W. Hyde.

Photophoresis: Potential Sorting Mechanism in a Proto-Planetary Disk. J. L. Smallwood, L. S. Matthews, and T. W. Hyde.

Astrophysics & Space Science Theory Group
Space Science Lab
Hypervelocity Impacts & Dusty Plasma Lab

Faculty and Staff

Truell W. Hyde
Lorin S. Matthews
Jie Kong
Ke Qiao
René Laufer
Michael Dropmann
Augusto Carballido
Connie Liaw
Oleg Petrov
Peter Hartmann
Vladimir Nosenko
Ray Nazzario
Jorge Carmona-Reyes
Michael Cook
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John Fitch
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Rainer Sandau
Ralf Srama
Sean Casey
David Lary
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Yungui Gong
Jianxin Lu
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Bo Zhang
Indra Ghimire
Chuchu Xing
Eva Kostadinova
Zhiyue Ding

Interns

Thomas Abernathy
Ian Anderson
Jesse Cadenhead
Kyle Carter
David Ferrell
Wendy George
Jeff Lam
Tyrell McSpadden
Nicole Sohns

57th Annual Meeting of the APS Division of Plasma Physics

As is their yearly custom, a sizeable contingent of CASPER researchers attended the 57th annual meeting of the American Physical Society's Division of Plasma Physics November 16-20 in Savannah, Georgia. Among the dozen CASPER attendees this year was Lori Scott, a participant in the lab's NSF-funded Research Experiences for Undergraduates program. Four other REU students — Kyle Busse, Josh Edgren, Kate Clements, Rebecca Kaplan — were among co-authors listed on several of the 12 paper/poster presentations made at the conference by CASPER participants.

The group included three female attendees which, at 25 percent, is a larger portion than is typical for representation at a physics conference. The group also included two of CASPER's assistant directors of research, Peter Hartmann of the Wigner Research Institute for Physics in Hungary, and Oleg Petrov, deputy director of the Joint Institute for High Temperatures in Moscow, and five other Baylor researchers — Lorin Matthews, Jie Kong, Ke Qiao, Jorge Carmona-Reyes, and Conni Liaw. Rounding out the group were four graduate students: Mudi Chen, Michael Dropmann, Zhiyue Ding, and Bo Zhang.

14th Workshop on the Physics of Dusty Plasmas at Auburn University

CASPER WPDP attendees examine Magnetic Dusty Plasma Experiment

In May, CASPER founder and director Dr. Truell Hyde led a group of 10 researchers to the 14th Workshop on the Physics of Dusty Plasmas at Auburn University. The most recent previous session of the triennial event was held at Baylor in May of 2012.

Co-sponsored by Wittenberg University, the Auburn event attracted more than 70 plasma physicists and researchers who discussed topics ranging from basic dusty plasma physics to theoretical and computational studies of dusty plasmas, to industrial applications.

The workshop was hosted by Dr. Edward Thomas, Jr., director of the Auburn University Plasma Sciences Laboratory and Lawrence C. Wit Professor in the College of Sciences and Mathematics. Thomas is a longtime colleague and friend of Hyde's. Theirs is a relationship recently enhanced by Baylor's collaboration on the Magnetic Dusty Plasma Experiment, an Auburn-based, multi-institutional initiative of which Thomas is principal investigator.

"I've always enjoyed working with (Dr. Thomas) and Baylor is one of the MDPX project's founding members," Hyde says. "One of the real highlights of the workshop was getting a close-up look at the device."

Dusty plasmas — also known as complex plasmas — consist of electrons, ions and neutral atoms interspersed with tiny, nanometer- and micrometer-sized "dust" particles. The particles bear an electrical charge that collectively affects the dynamics of a plasma cloud in ways that are only now becoming understood; a magnetic field complicates those dynamics even further.

Auburn's MDPX is a unique instrument that employs superconducting magnets to "saturate" a dusty plasma cloud with a magnetic field. Before development of the MDPX, magnetizing a dusty plasma cloud to the extent that the magnetic force was closely equivalent to other forces present — a condition necessary for thorough study of the phenomenon — was not possible.

Funded through grants from the Department of Energy and the National Science Foundation, the MDPX project benefits from a resource-rich, multiple-institutional network that, in addition to Baylor and CASPER, includes The Princeton Plasma Physics Laboratory, Los Alamos National Laboratory and Naval Research Lab, along with the universities of Iowa, Colorado, California San Diego. Also sponsoring are Wittenberg, Ouachita, Middle Georgia, and West Virginia Universities and MIT. International partners include Kiel University, the MPE-Complex Plasma Group in Germany, and the University of Delhi and Institute for Plasma Research, both in India.

Dr. Robert L. Merlino of the University of Iowa, Dr. Marlene Rosenberg of UC-San Diego, and Dr. Uwe Kokopka of Auburn serve as co-PIs on the project.

Experimental Astronomy Group

Under the mentorship of Experimental Astronomy Group director, Dr. Dwight Russell, senior astrophysics student Thayer Walmsley from Baytown, Texas, is using the Paul and Jane Meyer Observatory's 24-inch telescope to study asteroids. Walmsley has been watching the asteroid, 2004 Lexell, over a four-month period in an effort to determine its size and shape. As it rotates and tumbles along its path around the sun, irregular surfaces of the asteroid reflect varying amounts of sunlight toward Earth. By observing and recording the asteroid's brightness over time, an impressively detailed idea of its motion and form comes into view.

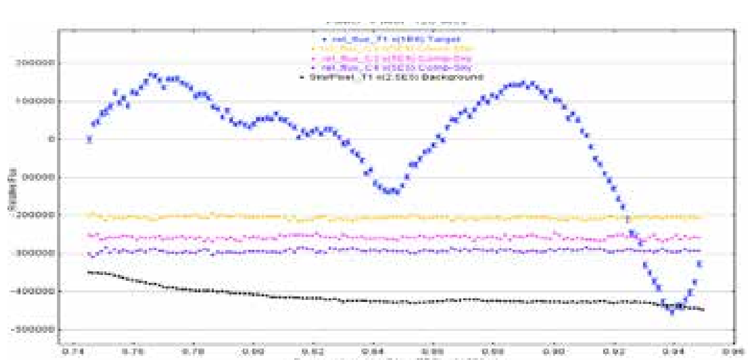
"A typical individual observation lasts about four hours," Russell says. "(Walmsley) records the asteroid's relative brightness during each observation and enters it into a graph called a 'light curve.'"

The light curves from all the observations are then used to flesh out information about the asteroid. Results so far appear to agree with a previously determined period of rotation of five hours for the object. With these encouraging results, Walmsley is preparing for the more intricate analysis needed to determine 2004 Lexell's size and shape.

Experimental Astronomy Group

Faculty

Dwight Russell
Dick Campbell



Asteroid 2004 Lexell Light Curve (blue), November 18, 2015 Observation

Gravity, Cosmology & Astroparticle Physics Group (GCAP)

During 2015, GCAP director Dr. Anzhong Wang served as chair of the local organizational committee for the *2015 Annual Meeting of the Chinese Physical Society, Division of Gravitation and Relativistic Astrophysics* held June 21-26 in Hangzhou, China.

In addition, Dr. Wang published five papers and had three others either submitted or in press. He gave three plenary talks at scientific conferences and workshops and is scheduled to give a presentation at the *2nd Mini-Workshop on Gravity and Cosmology* in Paris this October. Additionally, he delivered invited talks at seven other conferences.

This past July, CASPER GCAP researcher Dr. Tim Sheng was honored to give the keynote address at the *15th International Conference on Computational and Mathematical Methods in Science and Engineering* in Rota, Spain. The annual CMMSE conference is among the world's most influential events in the fields of engineering and computational mathematics. His address, titled "The Legacy of ADI and LOD Methods, and Recent Applications for Solving Singular and Highly Oscillatory Partial Differential Equations," was very well received.

In December, Sheng traveled to Delhi, India, to address the *2015 International Conference on Modern Mathematical Methods and High Performance Computing in Science and Technology*, also known as "M_3HPCST." His lecture was titled, "The legacy of ADI and LOD methods and an operator splitting algorithm for solving highly oscillatory wave problems."

Gravity, Cosmology & Astroparticle Physics Group

Faculty and Adjunct Faculty

Anzhong Wang
Klaus Kirsten
Qin (Tim) Sheng
Yumei Wu
Nilton Oscar Santos
Tao Zhu
Rong-Gen Cai
Yungui Gong
Jianxin Lu

Graduate Students

Bao-Fei Li
Xinwen Wang
Madhurima Bhattacharjee
Jared Fier
Jacob Oost

Visiting Scholar

Chikun Ding

Early Universe Cosmology & Strings Group (EUCOS)

Researchers in CASPER's EUCOS group wrote or co-authored four papers in 2015, three of which were joint GCAP/EUCOS papers; the fourth paper was authored by Jeff Lee and Gerald Cleaver. The two researchers also had a pair of papers accepted for publication, with six additional papers under review for publication.

Lee's and Cleaver's Cosmic Cryptography paper was reviewed in the New Scientist article, "How to encrypt a message in the afterglow of the Big Bang," appearing in the 30 November 2015 edition.

EUCOS Ph.D. student Yanbin Deng was graduated in August 2015 on the merits of his dissertation, "Reflections on General Relativity from Perspectives of Black Hole Physics and Horava-Lifshitz Gravity." EUCOS undergraduate Drake Gates was graduated in May and has begun a Ph.D. candidacy in nuclear engineering at Syracuse University. His undergraduate thesis is "Investigations on the String Landscape."

Two other physics undergraduates, Robert Gill and Kameron Scott, participated in string landscape research over the summer with Cleaver under a combination of grants from Baylor's Summer Undergraduate Research in Physics program and University Research Committee.

In July, Cleaver presented "Matter-Antimatter Propulsion from Parallel Electric and Magnetic Fields" at the Army Research Lab's Modern Topics on Energy and Power Meeting in Washington, D.C., and "Multiverse: God's Indeterminacy in Action," at the American Scientific Affiliation annual conference in Tulsa, OK. During September Cleaver attended the Defense Advanced Research Projects Agency's (DARPA's) *Wait, What?* workshop in St. Louis, Missouri. This important, invitation-only event is held to provide key academic and corporate researchers with insight into DARPA's funding foci for the next decade. At the 2015 workshop, DARPA announced plans to "push frontiers" in harnessing quantum physics for national security applications, a specific area of interest to Cleaver.

The three-year, "Randomness as Indeterminism in Nature: Scientific Warrants and Theological Assessments" project, of which Cleaver was a participant, concluded in 2015. Funded through a $200,000 John Templeton Foundation grant, the project was coordinated by the Center for Theology and the Natural Sciences.

Early Universe Cosmology and Strings Group

Faculty and Adjunct Faculty

Gerald B. Cleaver
Jeff S. Lee

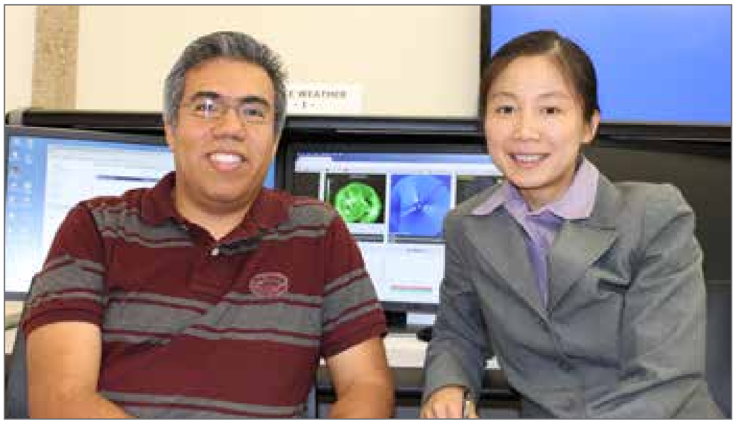
Graduate Students

Yanbin Deng
Brandon Mattingly
Andrew Lawler
Lesley Vestal

Undergraduate Students

Robert Gill
Kameron Scott
Andrew Bass

Education Research Group



Jorge Carmona-Reyes and Li Wang

Educational research and outreach have been top priorities at CASPER for as long as the center has been in existence; that's especially true with regard to STEM disciplines. It is a focus exemplified by CASPER's popular NSF-sponsored REU and RET programs (see p. 13).

Early on, the lab's director, Dr. Truell Hyde, accentuated this aspect of the lab's mission by forming CASPER's Education Research Group. The group's responsibilities include conducting CASPER's various outreach programs and assisting in preparing grant proposals that have an educational outreach mandate. But primarily, the group works with other organizations engaged in STEM education research. Today the group's functions are carried out by two experienced researchers with highly complementary credentials.

Education Research Group

Faculty and Staff

Jorge Carmona-Reyes	Truell Hyde
Li Wang	Lorin Matthews

Jorge Carmona-Reyes is CASPER's assistant director of educational outreach and research, and a former graduate student in physics who is now pursuing a master's in Baylor's School of Education. In addition to conducting plasma research, Carmona-Reyes was deeply involved in developing CASPER's physics circus. A candid conversation with a young student visiting the physics circus jarred his world view and began shifting his passion away from physics research toward becoming an educator.

"I had this conversation with a student and I asked him what he wanted to be when he grew up. Without even stopping to think about it he said he wanted to be a drug dealer," Carmona-Reyes recalled. "I talked to some of the teachers about it and they said it was very common for kids to say that. But to me it was heartbreaking to think that this kid saw dealing drugs as something to aspire to, that it's the only hope he has of getting out of whatever needful situation he was in. If what we're doing here can excite students and help them get out of that mindset, I think it's well worth our time."

Carmona-Reyes is teamed with Li Wang, Ph.D., M.Ed., an experienced instructional designer and specialist in professional development for educators. Having worked primarily in higher education before coming to CASPER, Wang finds her new job interesting on several levels.

"In the past most of my time was spent designing and conducting professional development for university professors," she said. "But what makes this job so interesting is working with teachers directly, helping them make a difference in learning for their students. Teachers have to be constantly engaged in professional development. Working with K-12 teachers might be little bit different, but from some of the initial data I'm seeing, professional development needs are really quite universal."

The data Wang refers to comes from surveys taken from nearly a hundred teachers who participated in professional development workshops over the summer. The workshops were designed and conducted by Education Resource Center Region 12, which has teamed with Huckabee, Inc., a top Texas architectural firm, to form LexLab, an education research collaboration. From its suite in the Baylor Research and Innovation Collaborative, LexLab educators and Huckabee architects research and test new, advanced learning environments and write curricula tailored to take advantage of them. In one successful project, participants in CASPER's National Science Foundation-funded Research Experience for Teachers program developed lesson plans for middle and high-school teachers to use in better integrating computing into their physics and chemistry curricula.

Carmona-Reyes currently is investigating how a change from traditional classrooms to newer, open and flexible learning spaces alters the way in which teachers move about the classroom and how student engagement is affected. In a concurrent collaboration, the two are working with Region 12 researchers to establish a student engagement baseline by observing how attentive students are before any changes to instruction are made.

The group will later reassess teacher effectiveness and student performance after the newly designed lesson plans have been implemented. Ultimately those classroom configurations and lesson plans found to be most successful in raising student interest and performance will find their way into classrooms across Texas and beyond.

Rockwall senior wins top prize at plasma physics workshop

Workshop award winner, Lori Scott

Senior physics major Lori Scott earned top honors in the undergraduate category at the 14th Workshop on the Physics of Dusty Plasmas held May 26-29th at Auburn University. Her project, titled "A Consistent Model of Plasma-Dust Interactions in a Glass Box," was prepared under the mentorship of Dr. Lorin Matthews and CASPER director, Dr. Truell Hyde.

The presentation described numerical modeling of complex (dusty) plasmas and focused specifically on dust particle interactions within an electric field. The goal of her work was to "better understand the effects of plasma on the dust particles without having to further change the interior conditions of an experimental setup." She continued working on her project during the summer as a participant in CASPER's NSF-sponsored Research Experiences for Undergraduate program.

The daughter of musician parents — her father heads the music department at Texas A&M University-Commerce and her mother directs a middle school orchestra — Lori jokes that her talent for science and mathematics amounts to something of a family mystery.

"In high school I always liked math but didn't see where it could take me," she explained. "When I took physics my junior year I realized I really liked how it used math in the real world. Once I came to Baylor, I started looking at the specific areas of research that the physics professors were involved in and Dr. Matthews' research really sounded intriguing. Complex plasmas have a lot of applications that were interesting to me and numerical modeling was an area I wanted to learn more about and gain some experience in."

Lori plans to enter graduate school in physics after receiving her undergraduate degree.

Baylor freshman delivers presentation at national mathematics conference, assists CASPER researchers

Last August, then-freshman mathematics major Kyle Busse traveled to Washington, D.C. to speak at MathFest 2015, an annual summer conference sponsored by the Mathematics Association of America. Last year's 4-day event drew more than 2,500 students, teachers and mathematicians to celebrate the Association's 100th anniversary.

The Austin, Texas, native is the product of a high-tech family—his mother is a database engineer and his father works as an electrical engineer. The invitation to speak at the conference was a bit unusual, as freshmen are seldom selected to present.

"In order to be accepted to talk at MathFest, I submitted a preliminary abstract summarizing the content of my talk," Busse says. "The submitted abstracts were then reviewed by MathFest officials and mine was accepted!"

Busse's presentation, *Anderson (De)localization in a Complex Plasma Crystal at Weak Disorder*, stemmed from work done with CASPER researchers Conni Liaw, Lorin Matthews and director Truell Hyde. He said his attendance at the event was an invaluable experience that provided insight into what makes a good presentation, and was also an opportunity to get comfortable with what he hopes will become a career-long experience.

While his CASPER work reveals a capacity for applied math, Busse says his primary interest lies in pure mathematics. "I've always thought of math as the deepest and purest form of thinking - it operates under very few unquestioned assumptions and therefore, the results obtained in that broad field are solid in reasoning, not to mention insightful," he says.

Recently, Busse co-founded the Baylor chapter of the Association of Women in Mathematics and has taken on a second major in physics. Though he is unsure whether he will focus on math or physics in graduate school, one thing is certain: "At this point I know that I'd love to work in academia."

2015 CASPER REU/RET Fellows

For the twenty-first consecutive year, high-achieving undergraduate science students came to Baylor from across the nation to participate in CASPER's National Science Foundation's Research Experience for Undergraduates (REU) program. It was also the sixteenth year that Baylor hosted teachers in the REU's companion, Research Experience for Teachers program (RET). This year, twelve students and four teachers participated in the programs. And again this year, women participants outnumbered the men, boding well for the future of women in the sciences.

REU participants conducted research in mathematics, astronomy and theoretical and experimental physics under the direction of Baylor faculty from the departments of physics, mathematics and mechanical engineering. RET participants collaborated with CASPER's Education Resource Group in developing curriculum the teachers were to use in the upcoming school year.

Activities

As in previous years, participants took time off from their intensive research schedules to feast on pizza, barbecue, submarine sandwiches and other fare at regular Wednesday Lunch Bunch seminars. Each seminar began with the group singing a physics-themed parody of a well-known tune, followed by an informative and entertaining technical presentation by faculty. In addition to presentations on such topics as electromagnetism, solar science and cosmic acoustics, practical talks instructed participants on how to conduct searches of scientific literature, write technical papers, prepare project posters and create effective PowerPoint presentations, and gave them tips on applying to graduate schools.

On Fridays, participants put their presentation training to good use by updating faculty and fellow participants on the progress of their research. The REU fellows themselves prepared the refreshments served at the update sessions.

NSF REU and RET Mentors

Astronomy

Dick Campbell
Dwight Russell

Complex Plasma & Space Science

Truell Hyde
Lorin Matthews
René Laufer
Jorge Carmona-Reyes
Augusto Carballido
Conni Liaw
Michael Dropmann
Mudi Chen
Mike Cook
Jimmy Schmoke

Condensed Matter Surface Physics

Zhenrong Zhang

Education

Li Wang
Jorge Carmona-Reyes

Sponsored by
the National Science Foundation and CASPER

To conclude their projects, each student prepared a project poster and wrote a paper detailing the research and findings. Then, each participant delivered a twelve-minute PowerPoint summation and took questions from faculty and other fellows.

Participants enjoyed a catered Mexican buffet farewell dinner and awards presentation at The Palladium, a popular downtown Waco events venue.

NASA astronaut delivers CASPER seminar on space suit design and enthralls audiences with descriptions of launches, spacewalks and life aboard the International Space Station.

In a CASPER seminar on December 4, 2015, at the Paul Foster Campus for Business and Innovation, veteran NASA astronaut Rick Mastracchio discussed the technical requirements and tradeoffs for space suit design with an audience composed largely of Baylor science and engineering students and faculty.

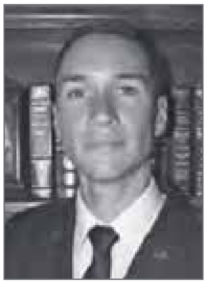
He dramatized his presentation with a description of the near-drowning of an Italian astronaut in 2013 due to a water leak in his space suit. Mastracchio also related how, during a spacewalk, his own space suit once was accidently covered in poisonous, highly corrosive ammonia jettisoned from the ISS. He was forced to remain outside to allow the ammonia crystals to evaporate before entering the airlock.

The previous day in a BRIC lecture hall packed with a cross section of the Waco community, Mastracchio related his experiences as a veteran of four orbital space missions, including flights aboard three separate Space Shuttles and a Russian Soyuz spacecraft. During his most recent mission in 2013, he lived aboard the International Space Station for 188 days.

Mastracchio said a spacewalk is the one activity everyone who gets into orbit wants to experience. Over the course of his four missions, he performed nine spacewalks, logging more than 50 hours outside the spacecraft; many of those were spent assembling the International Space Station. He used a video clip from the movie *Gravity* of an astronaut cavorting at the end of his safety tether as a textbook example of how not to do a spacewalk.

During the question and answer session that followed, he advised aspiring astronauts to "find something (they) enjoy and get good at it," and to earn an advanced degree, preferably a Ph.D. He also counseled them to persevere in applying for the job — Mastracchio applied nine times before being accepted into the astronaut corps.

Mastracchio appeared as a public service of NASA.



Dr. F. Anthony Eckel

Microsoft Corp. /University of Washington

To %, or Not to %

Abstract: People seek knowledge of future weather conditions in order to make good decisions. Today's weather forecasts are predominantly deterministic (single-value), which, while skillful, are fundamentally limited by the omission of forecast uncertainty information. Knowledge of forecast uncertainty (or confidence) enables weighing of weather risks and potential consequences, and, when used properly, can optimize decision making.

Most operational weather prediction centers can now produce a comprehensive view of the forecast distribution, rather than just the traditional deterministic prediction generated via numerical weather prediction (NWP). An ensemble prediction system (EPS) generates a suite of possible future states of the atmosphere by not only modeling the atmosphere, but also by simulating the error growth in the NWP model. The resulting probabilistic forecasts are underutilized today due to many factors – some being justifiable due to challenges of practical application, but most being baseless and due to poor understanding.

Mr. Nans Kunz

NASA Engineering Safety Committee Chief Engineer

SOFIA (Stratospheric Observatory for Infrared Astronomy)

Abstract: Mr. Kunz has over 38 years of engineering experience at NASA, most as an Engineering Leader/Manager or Project Chief Engineer, and has been responsible for and contributed to the success of many important NASA projects and programs. A couple of the larger projects in which Mr. Kunz held significant roles include the National Full Scale Aerodynamic Complex (NFAC) modification project and the Stratospheric Observatory for Infrared Astronomy (SOFIA). SOFIA is relevant in several ways to the Waco area: The SOFIA 747 aircraft modifications were completed by L-3 Waco over an eight year period and included installation of a 54,000 lb. astronomical infrared telescope in the aircraft, just aft of the wings. It is a joint NASA-German Space Agency project. The door assembly, which is designed to open at 40,000 feet, is a one-of-a-kind, two piece composite structure. The flat pressure bulkhead (typically concave) between the telescope area and the pressurized cabin was another "engineering first", as was the bearing assembly and the woven composite shaft connecting the telescope through the pressure bulkhead to the counterweight assembly in the cabin. All assembly and preparation for first flight, which occurred here in Waco, was completed by L-3 and German engineering firms.

In particular for SOFIA, Mr. Kunz served as engineering lead during the early feasibility studies and when the project was approved as a new start development in 1995, he was selected as the Chief Engineer for this $90M per year international development. He served as Chief Engineer for the SOFIA Program from the beginning of development through completion of the first flight series in 2007. He joined the NESC team as the NESC Chief Engineer at Ames in September 2009.

Patrick E. Rodi, Ph.D.

Lockheed Martin Fellow

Orion – America's Deep Space Human Exploration Spacecraft

Abstract: The Orion spacecraft is NASA's new manned vehicle for deep space exploration. Orion is being developed to take humans farther than they've ever gone before — to deep space destinations such as the Moon, an asteroid and eventually Mars.

Designed and built by Lockheed Martin, the Orion program recently evaluated the design on a two orbit flight test called Exploration Flight Test-1 (EFT-1). Launched by a Delta-IV Heavy rocket from Cape Canaveral Air Force Station's Space Launch Complex 37, the flight evaluated the spacecraft's launch, orbital, and high speed re-entry systems such as avionics, flight controls, parachutes, and the heat shield. Dr. Patrick Rodi, LM Fellow and Aerosciences Lead for the Orion program, discussed the vehicle, the role of the EFT-1 flight test, and the future for the program.

Olufisayo Jejelowo, Ph.D.

Director and Chief Research Officer, Global Progressive Network, Houston, TX

Activation of Inflammatory Pathways and miRNA Expression following exposure to High Energy Particle Radiation

Abstract: Space radiation comprises galactic cosmic rays and solar particle events that are capable of causing cellular damage. Exposure to ionizing radiation (IR) causes increased ionization in the cells and tissues that severely affects the central nervous system, gastrointestinal tract, and bone marrow. Chronic irradiation causes cancer, birth anomalies, erythema, and dysfunctions to almost all organs of the body depending on the total dose and site of irradiation. Understanding the mechanism of cellular response to proton-derived IR is vital for determining health risks to astronauts during space missions. To study the effect of high-energy particle radiation on NF-κ B activation, numerous tissues were dissected from Balb/c mice after exposure to high-energy particle radiation at 0.1, 1, and 2 Gy and frozen in liquid nitrogen. The tissue samples were analyzed for the activation of NF-κ B and its regulated gene products by Western blot. Results demonstrated that 1 and 2 Gy exposures to high-energy radiation induced the activation of matrix metalloproteinase 9 and cyclooxygenase-2 through the activation of NF-κ B. The effect of proton radiation on microRNAs in testis, brain and liver tissues was also investigated. Results suggest tissue specific changes in the pattern of RNA expression in response to proton radiation. Results are discussed in terms the role of miRNAs in cellular defense against exogenous stress and their involvement in the generalized cellular response to oxidative stress.

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CASPER's New Educational Research Group: The Physical Environment and Educational Interventions, **J. Carmona-Reyes, L. Wang, L. Matthews & T. Hyde**, poster presented at the 57th Annual Meeting of the APS Division of Plasma Physics, Savannah, Georgia, November 16-20, 2015.

Critical Point Transitions between Dust Particle "Phases" in a Complex Plasma, **T. Hyde, L. Matthews, J. Kong, K. Qiao, M. Chen, B. Zhang & Z. Ding**, paper presented at the 57th Annual Meeting of the APS Division of Plasma Physics, Savannah, Georgia, November 16-20, 2015.

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Investigation of plasma particle interactions with variable particle sizes, **M. Dropmann, R. Laufer, G. Herdrich, L. Matthews & T. Hyde**, paper presented at the 57th Annual Meeting of the APS Division of Plasma Physics, Savannah, Georgia, November 16-20, 2015.

Externally and self-excited nonlinear waves in a dusty plasma, **B. Zhang, K. Qiao, J. Kong, L. Matthews & T. Hyde**, poster presented at the 57th Annual Meeting of the APS Division of Plasma Physics, Savannah, Georgia, November 16-20, 2015.

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A Consistent Model of Plasma — The Potential in a Glass Box, **L. Scott, L. Matthews & T. Hyde**, poster presented at the 57th Annual Meeting of the APS Division of Plasma Physics, Savannah, Georgia, November 16-20, 2015.

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Experimental Investigation of the Wake-Mediated Interaction Forces Between Dust Particles in a Flowing Plasma, **O. Petrov, E. Lisin, K. Statsenko, T. Hyde & J. Carmona-Reyes**, poster presented at the 57th Annual Meeting of the APS Division of Plasma Physics, Savannah, Georgia, November 16-20, 2015.

Ordering Processes within Vertically Aligned 3D Dust Clusters, **T. Hyde, L. Matthews, J. Kong, K. Qiao, M. Chen & B. Zhang**, Oral Presentation. Presented at the 14th Workshop on the Physics of Dusty Plasmas, Auburn, AL, 2015.

Intellectual Contributions, continued

Electric Charge and Dipole of Dust Aggregates in the Presence of Ion Flow, **R. Yousefi, L. Matthews & T. Hyde**, Presented at the 14th Workshop on the Physics of Dusty Plasmas, Auburn, AL, 2015.

Interaction of Plasma with Single and Multiple Dipole Magnets in a GEC RF Reference Cell, **M. Dropmann, R. Laufer, G. Herdrich, L. Matthews & T. Hyde**, Presented at the 14th Workshop on the Physics of Dusty Plasmas, Auburn, AL, 2015.

Mode Coupling and Resonance Instabilities in Small Dust Systems, **K. Qiao, J. Kong, L. Matthews & T. Hyde**, Presented at the 14th Workshop on the Physics of Dusty Plasmas, Auburn, AL, 2015.

Dust Particle Thermal Properties in a Glass Box, **J. Kong, K. Qiao, L. Matthews & T. Hyde**, Presented at the 14th Workshop on the Physics of Dusty Plasmas, Auburn, AL, 2015.

Dust Charging and Coagulation Processes in Protoplanetary Environments, **L. Matthews, B. Shotorban & T. Hyde**, Presented at the 14th Workshop on the Physics of Dusty Plasmas, Auburn, AL, 2015.

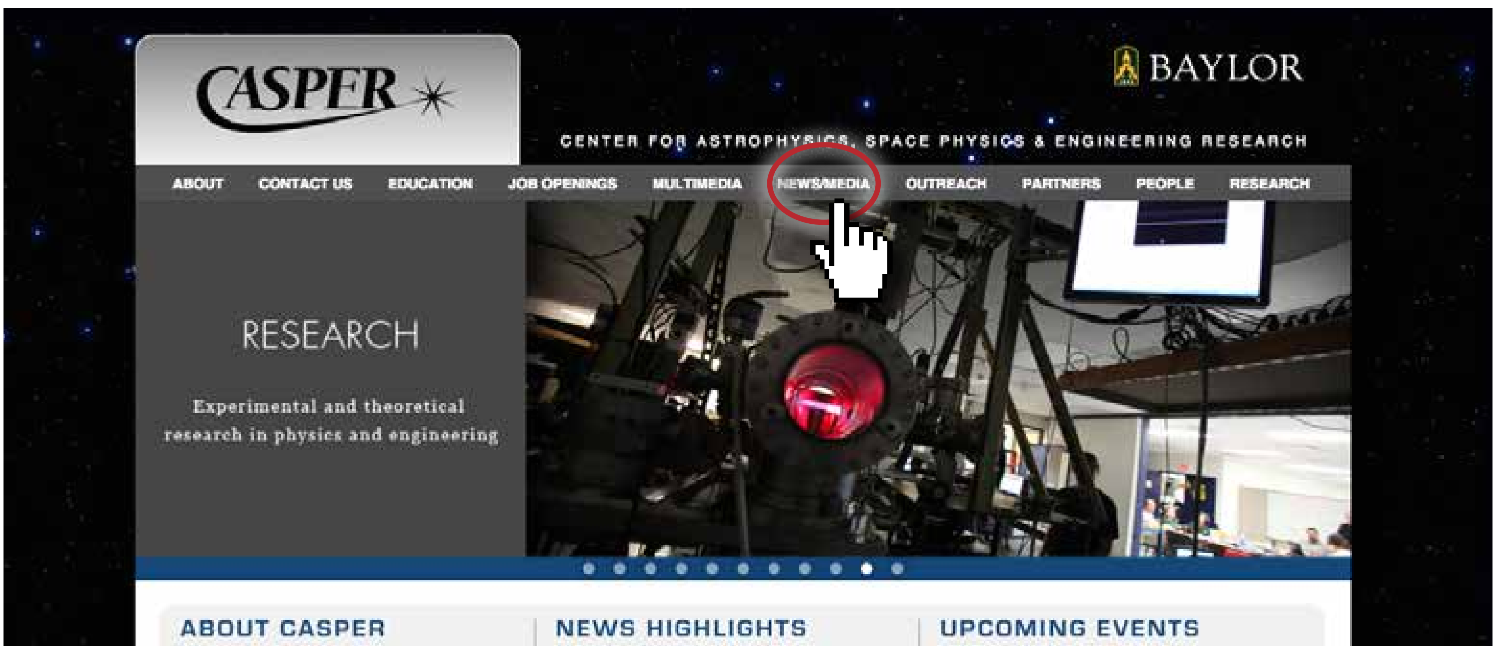
Rotational Dust Clusters in Complex (Dusty) Plasmas, **B. Zhang, L. Matthews & T. Hyde**, Presented at the 14th Workshop on the Physics of Dusty Plasmas, Auburn, AL, 2015 (poster).

Experimental Observations of Vertical Clouds in a Boundary-Controlled Dusty Plasma Environment, **J. Carmona-Reyes, J. Schmoke, M. Cook, L. Matthews & T. Hyde**, Presented at the 14th Workshop on the Physics of Dusty Plasmas, Auburn, AL, 2015 (poster).

A Consistent Model of Plasma-Dust Interactions in a Glass Box, **L. Scott, L. Matthews & T. Hyde**, Presented at the 14th Workshop on the Physics of Dusty Plasmas, Auburn, AL, 2015 (poster).

Dust as Discharge Probe: Single and Two Particle Oscillations, **P. Hartmann, J. Carmona-Reyes, L. Matthews & T. Hyde**, Presented at the 14th Workshop on the Physics of Dusty Plasmas, Auburn, AL, 2015 (poster).

Mapping the Confining Force in a Glass Box, **M. Chen, M. Dropmann, R. Yousefi, J. Kong, K. Qiao, J. Carmona-Reyes, L. Matthews & T. Hyde**, Presented at the 14th Workshop on the Physics of Dusty Plasmas, Auburn, AL, 2015 (poster).



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Arrival of a New Era: Gravitational Wave Astronomy

Anzhong Wang, Theoretical Physicist

The announcement on February 11, 2016 that scientists had at long last detected gravitational waves was widely celebrated in both the scientific and popular media. The discovery ended a century-long search for this elusive phenomenon predicted by Einstein's General Relativity Theory, and in the process created — or at least validated — a whole new branch of astronomy.

Baylor theoretical physicist **Dr. Anzhong Wang**, is director of CASPER's Gravity, Cosmology & Astroparticle Physics group. In that role, the topic of gravitational waves is, as they say, right in his wheelhouse. On February 19, 2016, Dr. Wang spoke at length on gravitational waves to a packed seminar room.

"Gravity results from the curvature of space-time, which is caused by the presence of mass," Wang explained. "As objects with mass move around in space-time, this curvature changes to reflect the changed positions of those objects. Accelerating objects generate changes in this curvature, which propagate outward in a wave-like manner at the speed of light. These propagating phenomena are known as gravitational waves."

Wang described two types of gravitational waves. The first type were produced in an infinitesimally brief instant at the formation of the universe and are called "primordial gravitational waves." Astrophysicists have long sought hints to the presence of this kind of gravitational waves.

Gravitational waves of the second type are generated by collisions between enormously massive objects in the universe. The waves detected last September were generated 1.3 billion years ago when two black holes, each slightly less than a hundred miles in diameter and 30 times more massive than the sun, spiraled into one another at approximately half the speed of light. For a sliver of time, the energy released by that collision was greater than that emitted by all the stars in the visible universe, spawning immensely powerful gravitational waves.

Yet, by the time the waves reached Earth, they were so weak they defied detection. But they rippled through the Earth, leaving a miniscule trace of their passing in two large scientific detectors nearly two thousand miles apart: one in Washington State, the other in Louisiana.

The two detectors comprise LIGO, the **Laser Interferometer Gravitational-Wave Observatory**, funded by the National Science Foundation and operated by the California Institute of Technology and the Massachusetts Institute of Technology. Each of LIGO's detectors has two 2.5-mile-long "arms," which are vacuum chambers set in an "L" arrangement. Up to five laser interferometers are housed in each chamber. Gravitational waves passing through the arms cause one to lengthen, while compressing the other. The detectors' design and the distance between them yields unprecedented sensitivity. LIGO could measure the distance from the sun to the nearest star — about 3.5 light years — to an accuracy the width of a human hair. In this case, the waves produced a difference only a thousandth of the width of a proton along the 2.5-mile length of the arms.

This scientific landmark has been hailed as equivalent to Galileo's telescope that, some four centuries ago, began the age of observational astronomy. Wang expects this discovery to have an equivalent effect on modern astronomy.

"The new era of gravitational wave astronomy has just begun," he said. "The possibilities for discovery are as rich and boundless as they have been with light-based astronomy."

> "The new era of gravitational wave astronomy has just begun."

In each issue of *CASPER News* we present an expert faculty member's perspective on a topic relating to recent or significant advances in the field of physics. If you would like to suggest topics for future issues please contact, gary_stokes@baylor.edu

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