DEPARTMENT OF ASTRONOMY

First Image of a **Black Hole!**

In April, astronomers working with the Event Horizon Telescope (EHT) collaboration released the first image of a black hole. The image (right) is the highest angular resolution image ever made, and Illinois astronomers played a key role in the discovery.

The image does not show the black hole itself, since the very definition of a black hole is that no light can escape. The dark area in the middle of the image is the "shadow" of the black hole, and corresponds to lines of sight that end on the black hole's event horizon. The bright orange donut is light that originates in a hot, translucent gas surrounding the black hole. This gas is spiraling around the black hole before making a final plunge through the event horizon.

The imaged black hole is in the middle of the galaxy M87, which is 50 million light years away, in the center of the nearest cluster of galaxies. The black hole has a mass of 6.5 billion times the mass of the Sun. The EHT results made possible the first precise measurement of the black hole mass, using a result from Einstein's theory of general relativity that the size of the black hole shadow is proportional to the black hole mass. This measurement resolved a controversy between two earlier mass estimates that differed by a factor of 2; had the smaller of the 2 estimates been correct, the EHT would have only seen an unresolved smudge of light.

It took years of effort and a large team of astronomers to produce this image and understand its implications. Illinois Professor **Charles Gammie** and his group were key members of the team. They developed computer simulations of the hot gas around the black hole, and the team used these simulations to understand what they were seeing and to estimate the mass and spin of the black hole. One of Professor Gammie's simulations is shown (right).

But Illinois involvement with the EHT goes back even further to an Illinois partnership in two radio telescope arrays: the Berkeley-Illinois-Maryland Association (BIMA) and the Combined Array for Research in Millimeter-wave Astronomy (CARMA). Experiments using these telescopes showed that imaging a black hole was feasible, and the EHT collaboration consisting of more than two hundred astronomers at 59



(Above) Actual black hole image. (Left) Simulation of a black hole image.

institutions in 18 countries, and eight telescopes at six sites—was assembled to make the image.

Four terabytes of data were taken in April of 2017, and it took two years to analyze the data and write the papers. Professor Gammie recalled, "I knew that the observation would see either a large or a small black hole. When I saw the very first plot I knew that the black hole was huge." His team spent many months simulating the luminous gas falling into the black hole, and found that the simulations match the observations and confirm that the black hole is spinning and launching a jet.

"This black hole image is only the first result of many to come," Professor Gammie said. "The April 2017 campaign produced data on the black hole in the center of our galaxy, the Milky Way. In addition, future EHT campaigns will include more antennas to produce better images: in Greenland, in the Alps, and at Kitt Peak in Arizona. We also hope that within the decade we can place an antenna in orbit around the Earth that will bring even higher resolution images of black holes."

Breaking News: The EHT collaboration has just won the **2020 Breakthrough Prize in Fundamental Physics** for this work. The team included many people with Illinois connections. Congratulations to Charles Gammie, George Wong (Phys grad student), Ben Prather (Phys grad student), Andrew Nadolski (Astro grad student), Ben Ryan (former Astro grad student), Monika Moscibrodzka (former Phys postdoc), Roman Gold (former Phys postdoc), Hotaka Shiokawa (former Astro grad student), and Dimitrios Psaltis (former Astro grad student). They will all share in the prize money.

From the department chair



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I am happy to present the Department of Astronomy's second newsletter. We heard so many encouraging words from our alumni and friends after the first one that we had to continue. I only wish we had the personnel to publish these twice a year since there are so many exciting results and Illinois accomplishments.

As we begin our 98th year as a department, we have the largest number of undergraduate majors in our history—more than 150 starting this fall. At the same time, our faculty, research staff, graduate students, and many of our undergraduate students continue to produce amazing lines of research. This year, the most exciting science result was the beautiful image of the black hole in M87, for which Illinois faculty Professor Charles Gammie played a critical role. My jaw dropped when I saw the image, and I hope yours did too. It exemplifies astronomy research and the reasons why we study the universe: those moments of discovery that expand our knowledge. And Illinois Astronomy will continue to push the envelope of research with exciting science projects like the Large Synoptic Survey Telescope, where we are in the midst of establishing a new science center that is already supporting four graduate students over this academic year. Undergraduate and graduate students are critical for engaging faculty and moving science results forward. This year was our first departmental "AstroFest," a half day symposium of our students' research results, shared the Illinois astronomy community, and our first department-wide awards ceremony.

As our major gets larger, we are also changing the curriculum of courses to maintain students at the cutting edge of modern research. One of the largest changes over the last year, is the addition of a new computational course first taught by Professor Matthew Turk, then taught last spring semester by Professor Paul Ricker. This course will now be a required course for our undergrads. At the same time, there was a new graduate seminar course taught in data science and machine learning by Professor Xin Liu.

Our department's mission, as part of a land grant University, is not only to play critical roles in exciting research and outstanding teaching but to also engage the public. I am proud of how our department continues to increase our already impressive public outreach. For example, as part of the AstroIllini group, graduate students have increased their engagement with the Education Justice Project, presenting astronomical topic seminars at the Danville Correctional Center. Also this academic year, our Icko Iben Jr. Distinguished Lecture Series in Astronomy ("The Universe Continues to Reveal Surprises" by University of Chicago Professor Wendy Freedman), was highly successful, and exposed students and the community on what to expect with the planned giant telescopes under construction. We are also grateful to the Friends of the Observatory, who have continued to support the Observatory, providing more access to its history and enhancing operations, thereby improving the Observatory Open House experience for everyone.

Thank you for your support. We continue to raise funds to name our classroom the James B. Kaler Astronomy Classroom in honor of one of our most beloved educators, and we have nearly met the limit needed to make this happen. That is wonderful.

I'm honored to have the opportunity of being the Department Chair during the next year, pursuing our shared goals of Illinois Astronomy excellence and positively impacting all aspects of the Department's mission.

Sincerely, Leslie Looney

Newsletter credits

Melanie Archipley — editor Rebecca Bare — contributor Leslie Looney — editor, writer

GRADUATE STUDENT SPOTLIGHT: Water in the Early Universe



ater is one of the most important molecules for life, and it is abundant even in the distant Universe. Fifth year graduate student **Sreevani Jarugula**, in collaboration with Professor **Joaquin Vieira** and the South Pole Telescope Submillimeter Galaxy group, detected water in three

distant galaxies when the Universe was only 2 billion years old. The light from these galaxies is magnified 10-20 times due to a phenomenon called gravitational lensing, where a massive galaxy curves the space around it, acting like a magnifying glass for a more distant galaxy. With a certain orientation, the light from the distant galaxy will look like a ring, often called an Einstein ring. With the galaxy light being magnified, Jarugula and her team were able to detect faint molecular lines while also increasing the spatial resolution. Jarugula used the world's most sensitive radio telescope, the Atacama Large Millimeter/ submillimeter Array (ALMA). With these state-of-the-art observations, the team showed that the water emission is mainly arising from the star



ALMA image of water emission from SPT0538-50, a distant gravitationally lensed galaxy that is actively forming stars.

forming regions of the galaxy and can be used to estimate the rate of star formation. With more such water observations, they hope to better understand the physical and chemical processes within galaxies.

NEW EVENT: AstroFest

Y e have kicked off a new tradition in the department: Illinois Astrofest, a symposium that aims to bring together groups on campus whose research touches on astronomy and astrophysics. The first Astrofest was held this April at NCSA, with help from your donations. Two 45-minute oral sessions straddled an hour-long poster session (with refreshments!). The presentations spanned the breadth of astronomical research taking place at Illinois, from machine learning to active galactic nuclei, and from gravitational waves to exoplanet formation. Appropriately, most of the talks were given by both undergraduate and graduate students! We also had a guest alumna speaker, Coralie Adam (2010 minor in Astronomy and Lalya Ryan awardee), provide insight via webcam into her career path as a Lead Deep Space Optical Navigation Engineer at KinetX (working on NASA space missions such as OSIRIS-REx). The poster session was undoubtedly one of the highlights,



with animated discussions and dedicated poster judges making sure that everyone had a chance to show off their work. We look forward to the next Astrofest in 2020.

NEW PROJECTS: Sloan Digital Sky Survey, 5th Generation

Ilinois Astronomy is one of the partners in the Sloan Digital Sky Survey, Generation 5 (also known as SDSS-V). Over the last two decades, SDSS has been arguably the most influential project in astronomy, setting new standards for the wide dissemination of astronomical survey data. SDSS-V, beginning in Fall 2020 and finishing in 2025, will open new windows into our understanding of the Milky Way galaxy and extragalactic supermassive black holes. SDSS-V will use two 2.5-meter telescopes: one in the northern hemisphere at the Apache Point Observatory in New Mexico, and one in the southern hemisphere at the Las Campanas Observatory in Chile. "These two telescopes in both hemispheres allow an all-sky survey," said Illinois Professor Yue Shen, one of the key players in the project. "In addition, the survey operates at both optical and infrared wavelengths. Previous surveys relied solely on the optical regime, or what we can see with our eyes through the telescope."

SDSS-V has three research focuses. First, the infrared observations will be used to peer through the cosmic dust to reveal the stars in our Milky Way galaxy. Astronomers will be able to measure the properties of stars, such as their composition, size, and type, aiding the study of the emergence of chemical elements and the origin of planets. The second focus is the study of supermassive black holes residing in the center of most galaxies. Luminous, active supermassive black holes, known as quasars, are among the most exotic objects in the universe. Quasars swallow massive amounts of material and then radiate the energy away quickly. The survey will track their flickers, flares, and radical transformations, which are linked to the mass of the black hole. "With these observations, we will be able to measure the masses of thousands of supermassive black holes and begin to understand their evolution with time," said Professor Shen. The third focus is the study of the interstellar medium, the gas and dust between stars in a galaxy, from which new stars are born. SDSS-V will observe the "local volume" of the interstellar medium of the Milky Way and our closest neighboring galaxies using a system of smaller telescopes in both hemispheres.

In all three areas, astronomers hope to create a spectroscopic gallery of stars, gas, and black holes many times larger than previous surveys. In addition, the survey will revisit the same region of the sky repeatedly, capturing the dynamic changes of these objects on timescales from days to years. Robots will increase the observing efficiency of the project by rapidly positioning the targets in optical fibers to collect the light. Five hundred robotic fibers will be placed to observe the same field



How the survey will collect the data from multiple telescopes in both hemispheres: at Apache Point Observatory (APO) in the USA and Las Campanas Observatory (LCO) in Chile. Multi-object fiber spectroscopy will be obtained with the two 2.5m telescopes for the Milky Way Mapper and Black Hole Mapper programs. The Local Volume Mapper will make use of smaller telescopes at APO and LCO to perform its optical integral-field spectroscopy.

at the same time, allowing the simultaneous observations of 500 objects, which greatly speeds up the sky survey.

Several professors and researchers at Illinois are already doing the groundwork in preparation for this five-year survey. Professor Shen is working on the design of key components of the quasar survey, such as what objects to observe and how frequently. Dr. **Hector Ibarra Medel**, research scientist, is working on the software needed to reduce and calibrate the data taken by the telescope. Professors **Xin Liu** and **Tony Wong** are also involved with the testing and science verification of new instruments. They will use the data from SDSS-V to study massive black holes, stars, and the interstellar medium in the Milky Way and other galaxies, in order to understand the physics in the formation and evolution of these objects.

"The participation of U of I in SDSS-V adds to the longstanding strength in survey science in Illinois astronomy and complements the upcoming Large Synoptic Sky Survey project that Illinois is also heavily invested in," said Professor Liu.

DEPARTMENT FRIEND SPOTLIGHT: Observatory Curator

Illinois alumnus Craig Sutter has been a friend of Illinois Astronomy for decades. Since retiring from teaching and moving back to Urbana-Champaign, he has been playing an even larger role: Observator Curator. Craig has quickly become an indispensable member of the Illinois Astronomy family. He is now the de facto face of the Observatory, improving the overall experience for everyone. He interfaces with the department, the Astronomy Club (UIAS), the Friends of the Observatory, and anyone who wants to schedule an observatory tour. The department owes Craig deep gratitude for his diligence in curating the Observatory, ensuring everything runs smoothly, and stewarding the building into the future. Craig has other non-astronomy adventures too. He has worked in Antarctica on ozone hole research, was an aerobatic flight instructor, was for twenty years involved in auto racing both as a driver and an engineer/mechanic, and has been climbing mountains since age sixteen. We are privileged that he donates so much of his valuable time to the department and the 12 inch refractor. In addition, he has also donated funds over



the last two years to support a graduate student who assists the Observatory Curator with telescope operations and our outreach mission. Thank you Craig for all of your support to the department.

NEW FACULTY: Gautham Narayan



We are happy to welcome our new Assistant Professor **Gautham Narayan** to the department. He comes to us from the Space Telescope Science Institute, the home institution for NASA's Hubble Space Telescope scientists, where he was the Barry M. Lasker Data Science Fellow. This was

preceded by a postdoctoral fellowship at the National Optical Astronomy Observatory in Tucson, AZ. He received his PhD in physics in 2013 from Harvard University and his BS in physics from Illinois Wesleyan University. Professor Narayan's research is at the intersection of cosmology, astrophysics, and data science. He specializes in the study of exploding stars and other extreme events such as the destruction of stars by supermassive black holes; his work illuminates the properties of transient populations and their environments. He uses these systems to study the expansion history of the Universe and understand the nature of dark energy. He is the current co-chair of the Large Synoptic Survey Telescope (LSST) Dark Energy Science Collaboration (DESC) supernova working group, and we expect he will be one of the main Illinois astronomers taking advantage of LSST opportunities. We look forward to sharing his future research results in upcoming newsletters.

Undergraduate Student News

Astronomy students are in demand after graduation. Based on this year's survey, our graduates have the highest rate of majors continuing to graduate school in the College of LAS, as well as the second-highest starting salaries for new graduates. We are proud of our graduates! We are excited to announce our graduates for 2018/2019. Majors (Astronomy and CS+Astronomy): John Aulabaugh, Brittany Glodowski, Nathan Knipfer, Ashvini Krishnan, Xincheng Lin, Yuanze Luo, Arun Madhavan, Emily Ng, Alexander Novak, Kunal Patnaik, Aaron Smothers, and Jingyao Zhu. Astronomy minors: Isabel Anderson, Gabriela Carreno, Vishnuteja Chavva, Dawn Haken, Zehao Jin, David Krein, Naichen Long, Daniel MacLean, Angela Printzis, and Margaret Winter. The Layla Suzanne Ryan Memorial Scholarship was established to recognize outstanding undergraduates who also exhibit community service. The winner of the 2019 award is junior astronomy major Lina Florez. The Stanley Wyatt Memorial Award is awarded annually to the graduating astronomy major or minor with the most outstanding GPA and track record of undergraduate research. The 2019 winner of the award is Jingyao Zhu. Dawn Haken (2019 Astronomy minor) was the student leader of CubeSail, a CubeSat designed to test a new technique for deploying solar sails; CubeSail launched into orbit from New Zealand in December 2018.

Graduate Student News

Graduate students play a critical and important role in our department. They are students, researchers, teachers, mentors, and leaders, and we acknowledge their achievements in all of these. In the last year, they were on approximately 25 papers whose topics spanned all of astronomy. Attending talks and conferences with our students, we expect some more great results this upcoming year.

One of the first steps for our graduate students is the preliminary exam in which they outline their PhD research. The graduate students who have passed their prelims this academic year are (ordered by date): Monica Huang, Di Wen, Patrick Mullen, Kedar Phadke, and Wei-Ting Liao.

We are happy to announce our graduate students who have graduated with a PhD this academic year (ordered by date): Erin Cox, Xilu Wang, Daniel George, Yixian Cao, and Taylor Tobin. For her dissertation work, Erin Cox won the 2018 Robert Brown Outstanding Doctoral Dissertation Award (sponsored by the National Radio Astronomy Observatory) for her thesis "Probing Planetary Disks: from Birth to Protoplanets."

Every year, we present awards for our graduate students who have an article accepted for publication in a peer-reviewed scientific journal on which they are listed as first author. This year we recognize the following students: Daniel George, Miguel Holgado, and Taylor Tobin. The Mr. and Mrs. Hsiang-Pai and Wen-Hua Chu Department of Astronomy Excellence in Research Graduate Student Award was founded by Professor Emeritus and former Department of Astronomy Chair You-Hua Chu, named in honor of her parents. The 2019 winner of the award is Miguel Holgado, a DOE NNSA Stewardship Science Graduate Fellow researching gravitational-wave astrophysics. Over the course of Miguel's graduate studies, he has joined several collaborations, including the LIGO-Virgo Collaboration, the NANOGrav Collaboration, and the eLISA Consortium, where he has worked on various topics on gravitational-wave astronomy spanning the multi-band frequency spectrum.

In addition to these departmental awards and milestones, our students are winning university-wide and external recognition. Some selected highlights: Melanie Archipley (Excellent Teacher List, fall and spring), Colin Burke (Excellent Teacher List, spring), Miguel Holgado (APS Travel Award for Excellence in Graduate Research and the Lindau Young Scientist, 69th Lindau Nobel Laureate Meeting), Jennifer Li (2019/2020 NASA/Illinois Space Grant Fellowship and a 2019 Government Scholarship to Study Abroad in Taiwan), Cail McLean (accepted into the Open Science Grid User School, La Serena School of Data Science), Taylor Tobin (presented with a Teacher Scholar Certificate from the Center for Innovation in Teaching and Learning), and Di Win (Excellent Teacher List, spring).

Faculty News

We are excited to announce the following faculty recognitions. Assistant Professor Xin Liu was awarded the Arnold O. Beckman Research Award by the Campus Research Board for her for her project "A Systematic Search of Binary Supermassive Black Holes in the Dark Energy Survey". Associate Professor Yue Shen was chosen as a 2019 Scialog Fellow by the Research Corporation for Science Advancement and awarded the 2018 NCU-Delta Young Astronomer Lectureship by the National Central University (NCU) and Delta Electronics Foundation (Taiwan). Professor Charles Gammie was selected for a prestigious Associate Research Appointment in the Center for Advanced Study (CAS) during the 2019-2020 academic year for his project to develop the theoretical tools necessary to understand the expected first images of the supermassive black hole at the center of our galaxy. Professor Leslie Looney was part of a team whose magnetic field images of Orion and the Cigar

Galaxy (from the airborne observatory SOFIA) were selected for the Astronomy Picture of the Day on Feb. 27 and March 11, respectively. Emeritus Professor Jim Kaler showed a selection of his sky photographs at the Clark-Lindsey art gallery. Research Assistant Professor (and 2014 PhD alum) Matias Carrasco Kind was awarded the 2019 Trusted CI Open Science Cybersecurity Fellowship 2019 by the Trusted CI, NSF Cybersecurity Center of Excellence. We congratulate Yue Shen on his promotion to Associate Professor. Associate Professor Joaquin Vieira and Assistant Professor Jeffrey Filippini were awarded a NASA grant of \$7.7 million to build a new Antarctica balloon mission called Terahertz Intensity Mapper (TIM), which will map a volume spanning 4.5 billion years of cosmic history with complete spectroscopic information. Stay tuned for more on this in our next newsletter.

James B. Kaler Astronomy Classroom



We are getting close to raising enough funds to rename the Astronomy classroom in honor of one of our most beloved educators, Professor Emeritus **Jim Kaler.** With the help of your donations, the Astronomy classroom has been transformed. We have new flooring, repainted walls, new desks, and new pictures are on the wall. Thanks to everyone who helped with this effort. We only need to raise a little more to complete the room, provide funds for upkeep, and add the name plaque. With sufficient funds, we hope to dedicate the classroom for Fall 2020. For more information go to **astro.illinois.edu/kaler-classroom**.



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We count on the generosity of alumni and friends to support students as they embark on earning a world-class education and to fund faculty members as they conduct world changing research and train students. Your investment makes a big difference!

Yes! I believe in the importance of excellence in astronomy and wish to show my support!

Department of Astronomy Annual Fund. (11334898) Your gift to our department fund will have the widest impact as it supports the full range of our key missions, including undergraduate and graduate student support, distinguished lecturers, the recruitment of excellent faculty, and alumni and outreach events.

Stanley Wyatt Memorial Award Fund. (11775123) Support graduating Astronomy majors/minors with outstanding GPAs and track records of undergraduate research. Help us increase the monetary award, which has not increased in the last 10 years.

Layla Suzanne Ryan Scholarship Fund. (11773536) Support junior or senior majors/minors in Astronomy who exhibit outstanding community service or outreach.

\$______Mr. & Mrs. Hsiang Pai & Wen-Hua Chu Department of Astronomy Excellence in Research Graduate Student Award Fund. (11774227) Support graduate students who exhibit excellence in research. We want to expand this award to have a theory and observational award each year. Your gift can help achieve this.

Lectureship Series Fund. (11772338) Support the Iben Lecture series that brings top researchers to campus to give public talks on their work.

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