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LSA ASTRONOMY
UNIVERSITY OF MICHIGAN

WHY MICHIGAN?

UNIVERSITY OF MICHIGAN

#3	US public institution *The Times of London 2015 Higher Education Supplement*
#4	*national public university US News & World Report 2016*
#1	ranked U.S. public research university by the National Science Foundation
$1.3B	in research expenditures

OUR DEPARTMENT

~1:1	ratio of advisors and students
21	active astrophysics faculty
20	research scientists and postdocs
~50%	of Michigan Astronomy graduate students are women

THE GRADUATE EXPERIENCE

- Research from day one
- Guaranteed support for five years
- You get to choose your advisor
- Exclusive access to facilities and telescopes
- Ample centralized travel support

WHAT'S INSIDE

EXCELLENCE. OPPORTUNITY. SUCCESS.

Welcome to Michigan Astronomy — where graduate students experience the full spectrum of expertise, guidance, and resources throughout their program.

EXCELLENCE

Being part of a major research university has many advantages. The University of Michigan ranks first among public universities for its total research budget of $1.3 billion. This has allowed us to hire exceptional faculty, invest in world-class facilities, and create a thriving learning environment for graduate students.

OPPORTUNITY

All of our students begin research from day one. Our broad departmental support allows you to choose your advisor based on science, not on financial considerations. You will be encouraged to write your own proposals and lead research teams under the close guidance and mentorship of faculty.

SUCCESS

Of our 19 graduates over the last five years, nine have won international competitions for prized fellowships (*Einstein, Hubble,* and *Sagan*) that frequently lead to faculty positions. Our alumni have also taken postdoctoral research positions at Cambridge, Princeton, Harvard, Caltech, Max Planck Institute for Astrophysics, UCSB, UCSC, UCSD, and MIT.

OUR RESEARCH SPANS EVERY IMPORTANT AND EMERGING AREA IN ASTROPHYSICS; WE ARE HELPING DESIGN MAJOR SKY SURVEYS, BUILDING ADVANCED INSTRUMENTS FOR MAGELLAN AND CHARA, WRITING ANNUAL REVIEW ARTICLES, CONDUCTING STATE-OF-THE-ART MODELING, AND PLANNING THE NEXT GENERATION OF OBSERVATORIES.

Where could the full spectrum of Michigan Astronomy take you? We encourage you to apply and discover your possibilities.

Elena Gallo
Graduate Chair and Advisor

Ted Bergin
Department Chair

"MY ADVISOR NOT ONLY SERVES AS A SUPERB ACADEMIC RESOURCE FOR BOTH RESEARCH AND TEACHING BUT ALSO AS A CARING AND UNDERSTANDING MENTOR EVERY STEP OF THE WAY."

BRYAN TERRAZAS
PHD STUDENT

FACULTY: EXPERTISE & ACCESS

"MY ADVISOR NOT ONLY SERVES AS A SUPERB ACADEMIC RESOURCE FOR BOTH RESEARCH AND TEACHING BUT ALSO AS A CARING AND UNDERSTANDING MENTOR EVERY STEP OF THE WAY."

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PHD STUDENT

OUR FACULTY BY PRIMARY AREA

STARS, STAR FORMATION, AND EXOPLANETS

FRED ADAMS
TED BERGIN
NURIA CALVET
LEE HARTMANN
MICHAEL MEYER
JOHN MONNIER
EMILY RAUSCHER

EXTREME ASTROPHYSICS

HUGH ALLER
JOEL BREGMAN
ELENA GALLO
KAYHAN GÜLTEKIN
RUDI LINDNER
JON MILLER
MATEUSZ RUSZKOWSKI

EXTRAGALACTIC ASTRONOMY AND COSMOLOGY

ERIC BELL
GUS EVRARD
OLEG GNEDIN
MARIO MATEO
TIM MCKAY
KEREN SHARON

CHRIS MILLER
SALLY OEY
DOUGLAS RICHSTONE
PATRICK SEITZER
MONICA VALLURI

Several professors span multiple areas; they are listed in the area that represents the largest portion of their work.

OVER THE LAST 10 YEARS OUR DEPARTMENT HAS BROUGHT IN AN INFUSION OF FORWARD-LOOKING RESEARCHERS, ALL EAGER TO MENTOR THE NEXT GENERATION OF SCHOLARS.

Their observational and theoretical research spans important and emerging areas in astrophysics, including cosmology, galaxy evolution, dark energy, dark matter, black holes, star and planet formation, exoplanet searches/characterization/theory, stellar feedback/galactic energy budgets, large-scale surveys, and instrumentation, among others.

Our faculty are helping design major sky surveys, building advanced instruments for Magellan and CHARA, writing annual review articles, conducting state-of-the-art modeling, and planning the next generation of observatories.

Their scope is broad enough that you can change your focus while you're here and know there'll be expertise to match. And it's deep enough that you can form a thesis committee with whom you can push boundaries and challenge conventional thinking.

Best of all, you'll have access to this expertise. All our faculty advise and mentor students. In addition, each advisor generally works with only one or two graduate students at a time. This means that students are able to work closely with their mentors and benefit from sustained and direct interaction.

The following pages profile four faculty members who have recently joined our department.

KAYHAN GÜLTEKIN

SPECIALTIES: BLACK HOLES AND ACCRETION ASTROPHYSICS

WHAT HE DOES: Kayhan Gültekin is interested in the accretion physics, evolution, and feedback from black holes across the mass scale, from stellar-mass to supermassive. His research addresses questions such as: What is the relative population of black holes by mass and location? How do black holes and galaxies affect each other's formation, growth, and evolution? Are the smallest galaxies and black holes governed by the same processes as larger ones? If not (as current data imply), what differing physical processes are at play? And to what extent are accretion and outflow relationships similar across the mass scales? Can we find binary pairs of supermassive black holes? Gültekin's work is both theoretical and multi-wavelength observational.

DATA HE'S USING: Hubble Space Telescope, Chandra, EVLA, Gemini, NOEMA, MDM, and Magellan.

HIS BACKGROUND: BA, University of Pennsylvania; MS, PhD, University of Maryland.

NOTABLE RESULTS: Based on Hubble Space Telescope data, he found that in NGC 3706, there is a well-defined edge-on ring of stars at the center of the galaxy, but the stars in it are orbiting in both directions, which is very unexpected. In a separate work, he made predictions for how to find active galactic nuclei with gaps in their accretion disk caused by a secondary black hole. One candidate has been found, and he is hoping to find more.

WHY MICHIGAN?

CUTTING-EDGE RESEARCH

"The Michigan Astronomy Department has such a great variety of expertise in cutting-edge astrophysics research. It's wonderful to be among so many people who are doing such amazing things in different areas whether in theory, observations, or instrumentation."

KEREN SHARON

SPECIALTIES: GRAVITATIONAL LENSING

WHAT SHE DOES: Keren Sharon's research centers on strong gravitational lensing — a phenomenon in which the gravitational field of a massive structure bends light from objects behind it, allowing it to serve as a natural telescope. Her group studies the massive structures themselves, analyzing the gravitational lensing signal from groups and clusters of galaxies to model their mass distribution. Sharon's team also uses the exceptional magnification provided by these lensing clusters to probe the physical properties of the background galaxies. This technique has allowed them to examine distant galaxies with unprecedented resolution and detail.

DATA SHE USES: Hubble Space Telescope, Magellan, Gemini, and MMT.

NOTABLE RESULTS: Her group's discovery of the largest multiplicity high-redshift lensed quasar was reported in 2013. They were awarded seven orbits of the Hubble Space Telescope (HST) in 2014 to observe this unique system. The group also recently completed a 107-orbit HST program to observe a sample of lensing clusters; results are in preparation. Sharon's team was selected as one of five groups to provide preliminary lens models for the Hubble Frontier Fields; the models were computed by her student, Traci Johnson (see page 28).

HER BACKGOUND: BS, MSc, & PhD, Tel Aviv University/Israel; Kavli Postdoctoral Fellow, Kavli Institute for Cosmological Physics/University of Chicago; University of Michigan's President's Postdoctoral Fellow, U-M.

WHY MICHIGAN?
THE EXCITEMENT

"It's exciting. There are always new observations and discoveries being made. We recently observed a supernova that had exploded in a distant spiral galaxy 9.2 billion years ago. Several teams of astronomers, including myself, predicted where and when this supernova was going to appear. And in December 2015, the Hubble Space Telescope was pointed at this location in the sky and discovered it — confirming our prediction!"

EMILY RAUSCHER

SPECIALTIES: EXOPLANET ATMOSPHERIC DYNAMICS

WHAT SHE DOES: Emily Rauscher is a theoretical astrophysicist who studies exoplanets, particularly hot Jupiters. She develops 3D atmospheric circulation models that explore features such as wind and temperature patterns, the structure of the deep atmosphere, and magnetic effects—and how these might shape the planets' global properties. She's recently used her models to shed light on the conditions under which magnetic fields may profoundly impact hot Jupiters' temperature patterns, a line of inquiry that may help explain why some become "puffy planets"—larger, lower-density versions of Jupiter. Rauscher also works to identify observational methods capable of providing the data needed to test and refine these models. She's demonstrated the potential of eclipse mapping and orbital phase curves to provide information on hot Jupiters' temperature patterns based on specific changes in light detected when these planets orbit their star.

NOTABLE RESULTS: Rauscher and a colleague were the first to propose that spectral Doppler shifts could be used to gain useful data about the atmospheric motion of hot Jupiters. While most of a transiting planet's Doppler shift is accounted for by its orbit, a small part reflects a combination of how its winds are blowing and how the atmosphere is rotating along with the planet. Using Rauscher's 3D simulations and her colleagues' detailed radiative transfer model, the pair calculated hot Jupiters' expected Doppler shifts under various conditions. They showed that with just slightly improved observations, this measurement could help distinguish which planets' winds were being slowed by magnetic drag. They also found that it might be useful, when paired with supplemental measurements, in constraining planets' rotation rates.

HER BACKGROUND: BA, University of California, Berkeley; PhD, Columbia University; Graduate Fellow, Kavli Institute for Theoretical Physics, Santa Barbara; NASA Sagan Postdoctoral Fellow, University of Arizona and Princeton University; Spitzer Postdoctoral Fellow, Princeton University.

WHY MICHIGAN?

INVESTED IN STUDENT SUCCESS

"The department is invested in the students' success. This means that the faculty try to support the grad students, but also hold them to a high standard, making sure they're on a trajectory for success after graduation. For example, the requirement that students submit a paper by the end of their second year can be a challenging effort, but it does help jump-start their publication record."

MICHAEL MEYER

SPECIALTIES: ORIGINS OF STARS, PLANETS, AND LIFE; GALACTIC AND INFRARED ASTRONOMY

WHAT HE DOES: Michael Meyer is an expert on the evolution of planetary systems both in terms of formation and observational characterization. He has more than 20 years of international scientific research experience, in the fields of galactic and infrared astronomy, as well as the formation, evolution, and characterization of planetary systems (and associated implications on the prospects for life in the Universe). He has experience participating in the development of ground- and space-based instrumentation, including both the NIRCam and NIRISS for JWST as well as high contrast imaging systems/spectrographs for 6-10 meter telescopes and ELTs.

HIS BACKGROUND: MS, University of Missouri; PhD, University of Massachusetts; Postdoc at the Max-Planck-Institute for Astronomie; Hubble Fellow at the University of Arizona; Professor/Astronomer at the Department of Astronomy/Steward Observatory of the University of Arizona; head of the planet and star formation group at the ETH in Zürich.

RECENT WORK: Meyer is known for his work on the evolution of circumstellar disks around young sun-like stars, observational constraints on theories of planet formation, and lack of success in searching for significant variations in the initial mass function of stars. His recent work has focused on direct imaging searches for extrasolar planets, particularly at infrared wavelengths, and helping to develop the next generation of high resolution imagers for the world's largest telescopes.

NOTABLE RESULTS: Meyer's group is responsible for two of the three known candidate protoplanets detected while still embedded in the circumstellar disks of gas and dust from which they formed.

WHY MICHIGAN?

EXCELLENCE

"When presented with the opportunity to join a terrific department at a top university with excellent access to the MDM and Magellan telescopes and opportunities for interdisciplinary collaboration in astrophysics, you have to say YES!"

INSIGHT

FACILITIES: RESOURCES & INSIGHT

“BEING INVOLVED IN ALL THE NEW LARGE SURVEYS, THE INTERDISCIPLINARY COLLABORATION, AND STUDENTS’ PRIVILEGED ACCESS TO RESOURCES LIKE MAGELLAN—THAT’S WHAT’S HELPING OUR STUDENTS PUSH THE BOUNDARIES OF SCIENCE AND BE COMPETITIVE IN THE TOP RANKS OF THE FIELD.”

PROFESSOR CHRIS MILLER

RESOURC

"BEING INVOLVED IN ALL THE NEW LARGE SURVEYS, THE INTERDISCIPLINARY COLLABORATION, AND STUDENTS' PRIVILEGED ACCESS TO RESOURCES LIKE MAGELLAN—THAT'S WHAT'S HELPING OUR STUDENTS PUSH THE BOUNDARIES OF SCIENCE AND BE COMPETITIVE IN THE TOP RANKS OF THE FIELD."

PROFESSOR CHRIS MILLER

HANDS-ON EXPERIENCE: During their time here, students average more than eight refereed publications, four conference trips, and two Magellan visits.

TELESCOPES

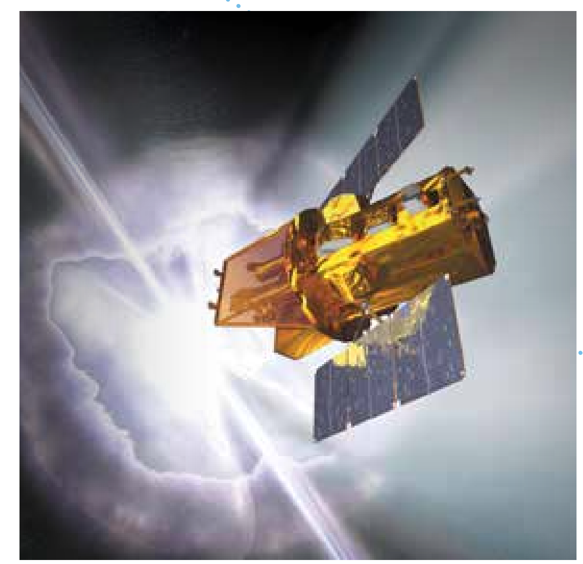
PRIVILEGED ACCESS THAT SPANS THE FULL SPECTRUM

Graduate students often can't believe they receive "privileged access" to the world-class telescopes in which U-M is a partner. This means PhD students have priority over faculty, postdocs, and research scientists in observing for their thesis.

U-M's access to the Southern Sky is through our partnership in the twin 6.5-meter **Magellan Telescopes** in Chile. U-M's 10 percent share in this premier facility means students can undertake projects with long timelines and numerous targets. More than half of our PhD students from the last 15 years have done work here. The University of Michigan-built and -supported Michigan/Magellan Fiber System (M2FS) mounted on the Clay telescope offers unprecedented flexibility and coverage for multi-object spectroscopy.

We are also a partner in the **MDM Observatory** at Kitt Peak, Arizona. Its 2.4- and 1.3-meter telescopes are equipped with an array of optical and infrared instruments, making it useful as both a research and training platform. U-M's portal to the Northern Sky, MDM offers a strong complement to research at Magellan in areas from galaxy clusters to star formation.

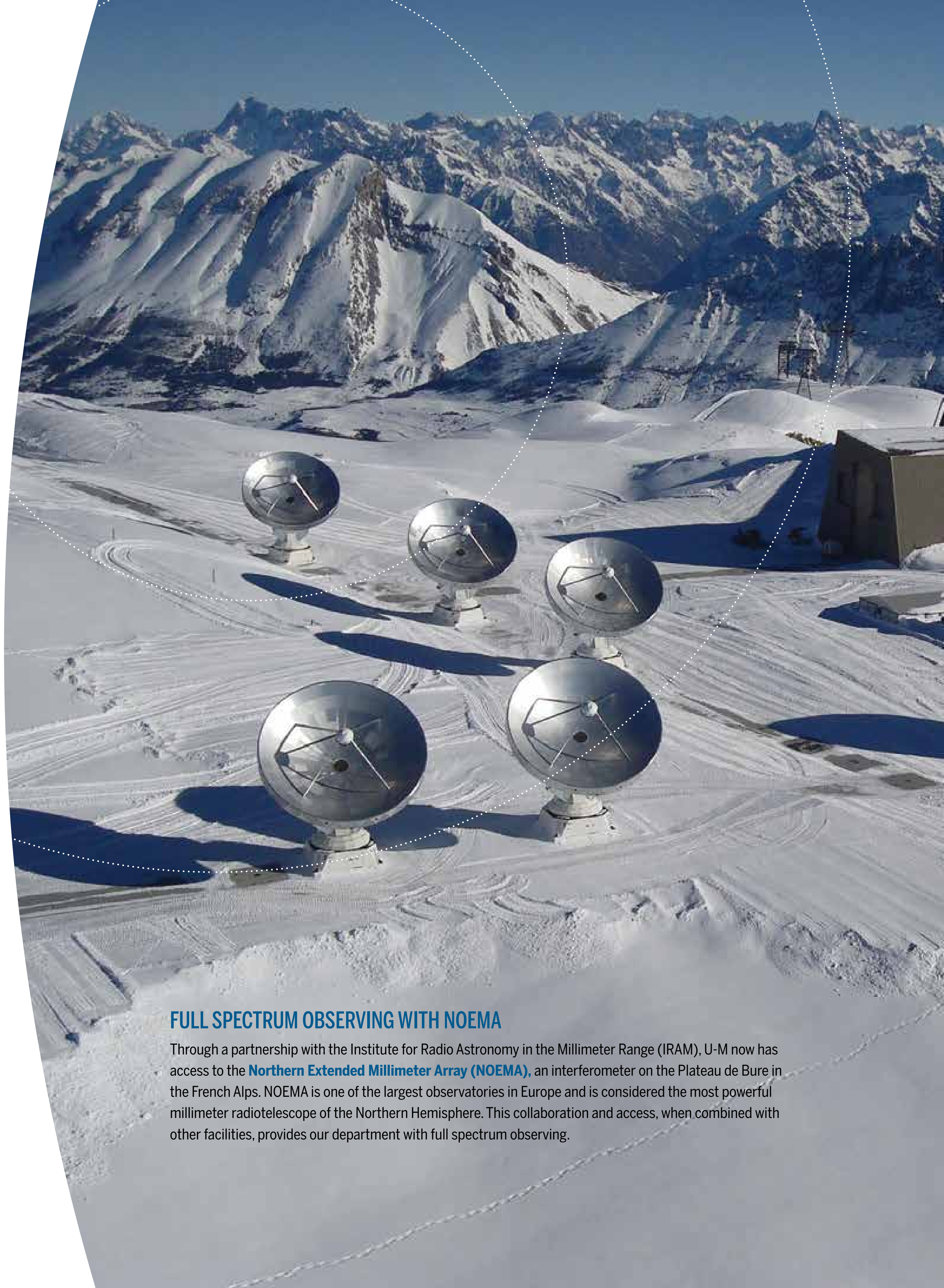
U-M also recently partnered with **Swift,** NASA's high-impact, multi-wavelength orbital telescope. Its instruments are capable of observing simultaneously in the gamma-ray, X-ray, ultraviolet, and optical wavebands. With a million seconds of dedicated observing time, we have a thousand Swift exposures at our disposal every year.



Artists's concept of NASA's Swift orbital telescope.

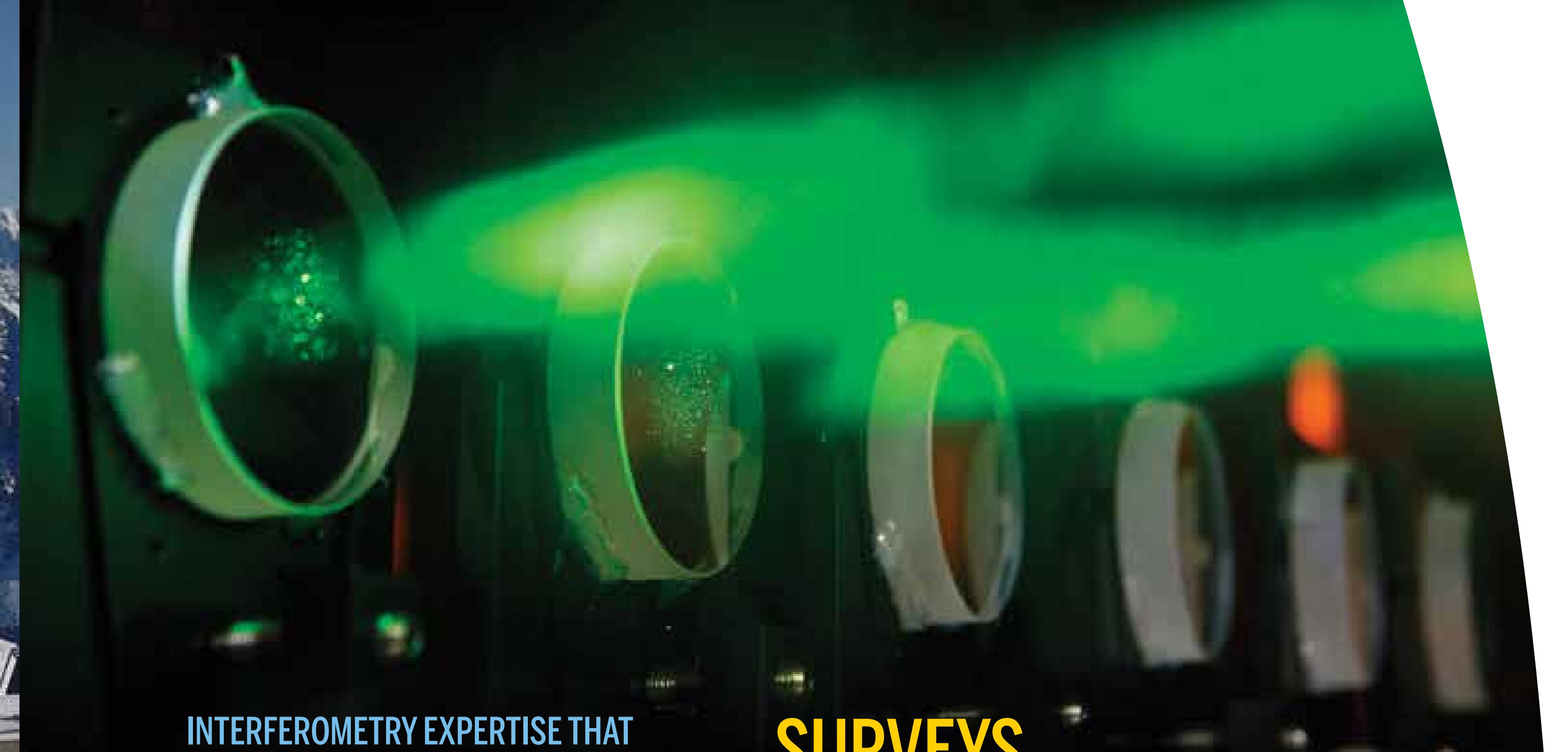
"If we see something interesting with another instrument, we can ask Swift to lock onto it at a moment's notice. That's utterly unique in space-based astronomy."

—PROFESSOR JON MILLER



FULL SPECTRUM OBSERVING WITH NOEMA

Through a partnership with the Institute for Radio Astronomy in the Millimeter Range (IRAM), U-M now has access to the **Northern Extended Millimeter Array (NOEMA),** an interferometer on the Plateau de Bure in the French Alps. NOEMA is one of the largest observatories in Europe and is considered the most powerful millimeter radiotelescope of the Northern Hemisphere. This collaboration and access, when combined with other facilities, provides our department with full spectrum observing.



INTERFEROMETRY EXPERTISE THAT OPENS DOORS AT CHARA

In addition, students have special access to the world's top facility for optical/infrared interferometry, Georgia State University's **CHARA Array** on Mount Wilson, California. U-M is one of only a handful of institutions worldwide with this level of access, thanks to Professor John Monnier's work developing cutting-edge instruments for this facility. These include:

- MIRC (THE MICHIGAN INFRARED COMBINER): Monnier's newest update allows all six of CHARA's telescopes to work together, making it the most powerful combiner for infrared interferometry in the world. He and his students have used MIRC to image the surfaces of a variety of stars for the first time.
- FRINGE-TRACKER: This instrument boosts MIRC's performance, correcting for atmospheric turbulence and helping to image faint objects like the planet-forming disks around young stars.
- ADAPTIVE OPTICS: Monnier and one of his graduate students are building a wavefront sensor for CHARA's adaptive optics upgrade. This will allow a nearly six-fold increase in the number of young stars that can be imaged.

"U-M is a great place for students interested in instrumentation," says Monnier. "This is because we work on instruments that are technologically advanced but at the scale of a single group. A lot of instrumentation projects in astronomy today involve big contracts that are not accessible to students. But here, we're able to come up with an idea, design it, build it, and carry out experiments with it. You get hands-on experience at every step in the process."

SURVEYS

U-M has made a strong commitment to the future of astronomy by investing in preferred access to major sky surveys like the **Dark Energy Survey** and the **Dark Energy Spectroscopic Instrument.** This means our faculty have been involved in building the surveys, giving them unique insight into how to make best use of the data.

CLOUD COMPUTING

The department's instrumentation, theoretical, data-mining, and image-analysis projects place high demands on computing resources. That's why we access the University's new cloud environment, where the infrastructure is continuously updated to stay ahead of demand—even from the data-intensive sky surveys.

KEY FEATURES:

- The new Flux high-performance computing facility
- Direct connection to the NSF's Teragrid/XSEDE open scientific-discovery infrastructure with petaflop computing capabilities
- Campus-wide Value Storage with multi-terabyte data volumes
- Internal bandwidth within the Flux environment up to 25 Gbps (25x faster than Ethernet)
- External connectivity to the National LambdaRail backbone at 10 Gbps

ALUMNI: PREPARED TO SOAR

MANY OF OUR GRADUATES AND CURRENT POSTDOCS ARE RECIPIENTS OF THE FIELD'S MOST PRESTIGIOUS AWARDS LIKE NASA'S HUBBLE, EINSTEIN, AND SAGAN FELLOWSHIPS.

ASHLEY KING, PHD '14

DEMYSTIFYING BLACK HOLE OUTBURSTS

CURRENT POSITION: Einstein & Kavli Fellow, Stanford University

PREVIOUS POSITION: Postdoctoral Fellow, University of Cambridge

PHD RESEARCH: Ashley King and Professor Jon Miller used a unique sample to shed light on how accretion onto black holes affects the production of jets and winds. By looking at black holes across the mass scale, they found that 95 percent of the material in accretion disks may be lost through wide-angle winds. They also found a relationship between the power of these winds and the black holes' X-ray luminosities across a range of masses.

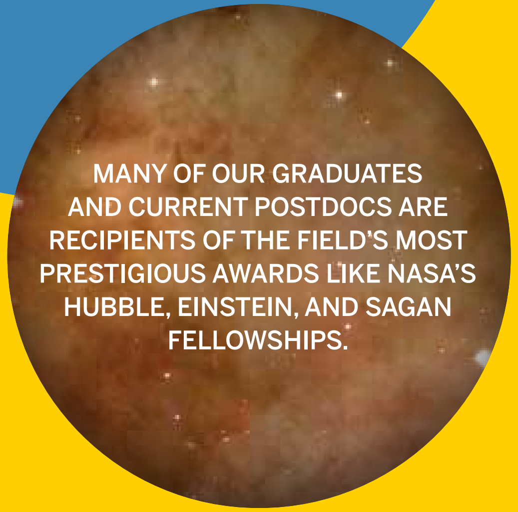
HIGHLIGHT: Ashley won the 2016 American Astronomical Society HEAD Dissertation Prize, which recognizes an outstanding doctoral dissertation in high-energy astrophysics.

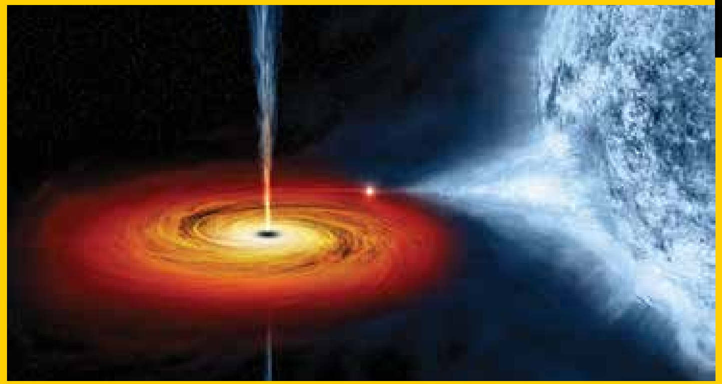
CURRENT RESEARCH: King recently led Chandra observations of a rare outburst of V404 Cygni, a stellar-mass black hole in a binary system. Her team found several unusual features: combination jet-wind outflows more typical of a supermassive black hole and winds powerful enough to disrupt the black hole's accretion disk and quench its own outburst. Her team is now modeling the mechanisms at play.

WHY MICHIGAN?

LEADERSHIP SUPPORT

"I was competitive for these fellowships because I had a number of first-author publications and 10 accepted telescope proposals. It showed that I could get time on instruments across the spectrum, in X-ray from Chandra and Swift, and radio from VLA and VLBA."





▲ Artist's illustration of a binary black hole system. Image: NASA/CXC/M.Weiss.

ILSE CLEEVES, PHD '15

TRACING THE PHYSICAL AND CHEMICAL ORIGINS OF SOLAR SYSTEMS

CURRENT POSITION: Hubble/ITC/SMA Fellow, Harvard-Smithsonian Center for Astrophysics (CfA)

PHD RESEARCH: Combining modeling and observation, Ilse Cleeves worked with Professor Ted Bergin to examine the physical and chemical properties of young circumstellar disks in order to understand what sets the stage for solar systems like our own to form. This work has contributed to our understanding of how much water and organics might be available to developing planetary systems, and has shed light on both the mechanisms and consequences of high-energy processes, such as ionization, in these disks.

HIGHLIGHT: Cleeves' research on the origins of water in the universe, published in *Science*, has received national press coverage from *TIME* magazine to NPR's Science Friday.

▲ Cleeves' work suggests that up to half of Earth's water is older than the sun. It likely formed in the cold molecular cloud that spawned our solar system. Image: Bill Saxton, NSF/AUI/NRAO.

WHY MICHIGAN?

WORLD-CLASS EDUCATION

"Michigan has one of the strongest star- and planet-formation departments in the U.S., with faculty who are invested in providing a world-class graduate education. Students have access to powerful optical, radio, X-ray, and UV facilities, and high-performance supercomputers to conduct cutting-edge research."

CATHERINE ESPAILLAT, PHD '09

UNVEILING THE PROCESS OF PLANET FORMATION

WHY MICHIGAN?

PROFESSIONAL CREDIBILITY

"U-M is a well-recognized and respected leader on several research fronts. Whatever field you choose, it gives you the credibility of having been trained by some of the best astronomers around."

CURRENT POSITION: Assistant Professor of Astronomy, Boston University

PREVIOUS POSITIONS: Sagan Fellow, NSF Postdoctoral Fellow, Harvard CfA

PHD RESEARCH: Catherine Espaillat was the first to identify pretransitional disks around low-mass, pre-main sequence T Tauri stars (below). These disks, in which a central region is cleared between an inner and outer dust ring, lent strong evidence for dust clearing due to planet formation vs. the competing photoevaporation theory. Espaillat identified these pre-transitional structures using original observations from Spitzer and NASA's Infrared Telescope Facility with models of disk evolution co-developed by her advisor, Professor Nuria Calvet.

Espaillat's predictions were subsequently confirmed by the observation of a young planet in the pre-transitional disk of star LKCa 15.

CURRENT RESEARCH: Espaillat recently received an NSF CAREER award to fill two persistent gaps in astronomy: the gap between theoretical models of disk evolution and observable properties of disk structure, and the gap between postdoc and faculty positions when women are most likely to leave STEM fields. Her team will bridge these gaps by extracting the most detailed observational constraints to date for theoretical disk models and creating postdoctoral mentoring programs to retain women in STEM.

▲ Prior to Espaillat's thesis, researchers had identified stars surrounded by both full and transitional disks. Espaillat was the first to identify pre-transitional disks by modeling detailed data from Spitzer and other sources. Image: NASA/JPL-CALTECH.

MATT WALKER, PHD '07

ILLUMINATING THE ELUSIVE NATURE OF DARK MATTER

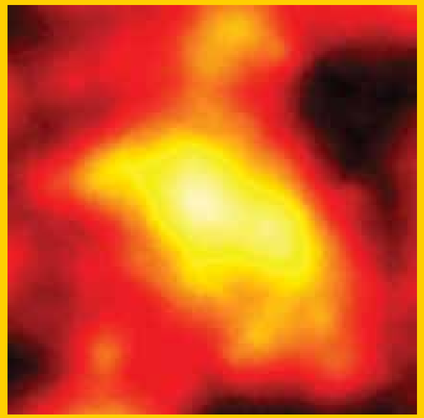
CURRENT POSITION: Assistant Professor of Physics, Carnegie Mellon University

PREVIOUS POSITIONS: Hubble Fellow, Harvard CfA; Postdoc, Cambridge Institute of Astronomy/UK

PHD RESEARCH: Matt Walker worked with advisor Professor Mario Mateo to collect a data set of unprecedented size that provided insight into how dark matter is distributed in dwarf galaxies based on its gravitational influence on nearby stars. They used Mateo's custom-built fiber spectrograph to increase the available sample from 100 to nearly 3,000 stars in four galaxies. They also collaborated with the U-M Statistics Department to develop a method for moving beyond mass measure-ments of dark matter to assessing its distribution.

Walker and Mateo provided the first direct observational challenge to models' predictions that dark matter forms centrally concentrated "cusps" in the smallest dwarf galaxies. Their evidence for homogeneously "cored" dark matter halos has motivated theorists and simulators to examine how star formation might alter the structure of cold dark matter halos.

CURRENT RESEARCH: Most recently, Walker has been looking for astrophysical signatures of dark matter from non-gravitational interactions – such as gamma rays emitted by colliding particles. He and his collaborators at CMU are scouring the gamma-ray sky for hints of dark matter annihilation from the nearest and densest dwarf galaxies.



◀ Bright areas are gamma rays from the direction of a galaxy ~100,000 light-years away. Image: Geringer-Sameth & Walker/CMU.

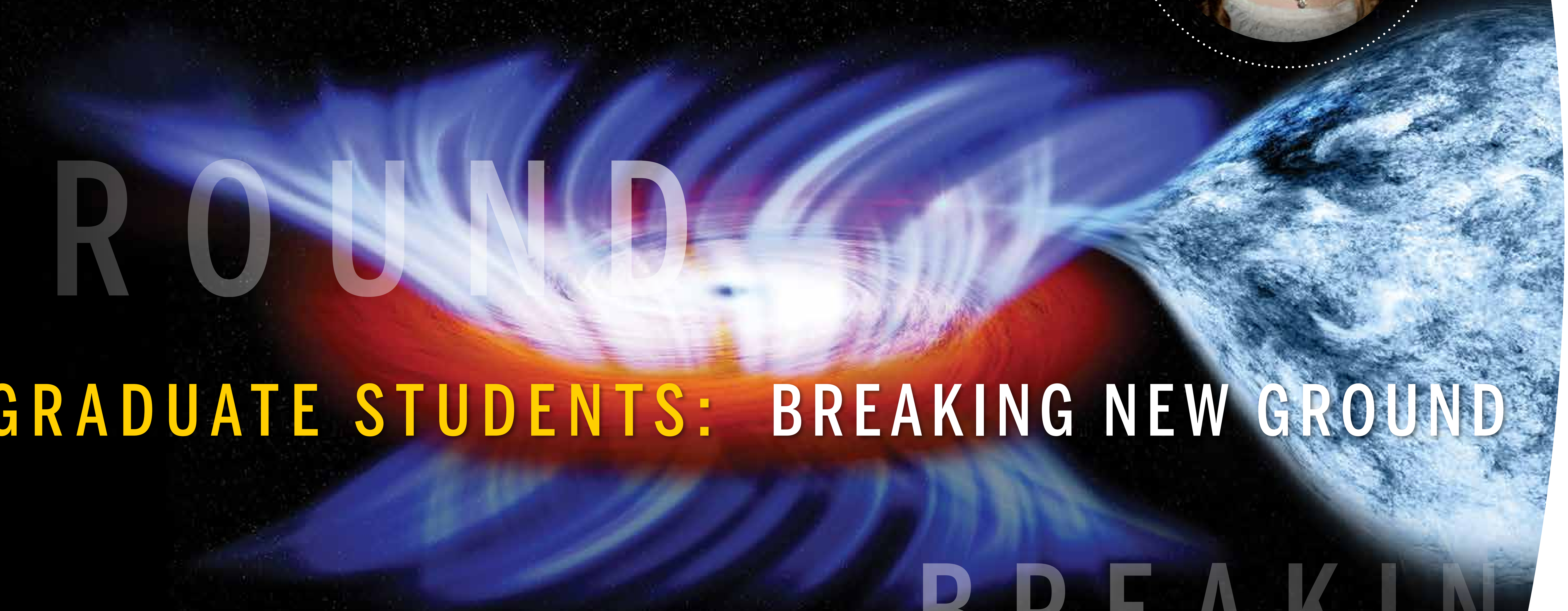
WHY MICHIGAN?

RESEARCH CALIBER

"By the end of my time at Michigan, I remember thinking I could walk into a conference and know I had the world's best data set for the galaxies we were looking at. Ultimately that's why I was an attractive candidate on the job market; I was sitting on data from which, even years later, we're continuing to extract new information."

"THIS DEPARTMENT IS VERY STUDENT-FOCUSED. YOU REALLY DO START WORKING ON PROJECTS FROM DAY ONE. YOU'RE EXPECTED TO SHOW PROFICIENCY IN RESEARCH. YOU'RE EVEN AUTHORING PAPERS BY THE END OF YOUR SECOND YEAR."

TRACI JOHNSON
PHD STUDENT



GRADUATE STUDENTS: BREAKING NEW GROUND

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TRACI JOHNSON
PHD STUDENT

TRACI JOHNSON

PHD STUDENT

ADVISOR: Keren Sharon

SPECIALTY: Strong lensing in galaxy clusters

PHD RESEARCH: Traci Johnson models strong gravitational lensing in galaxy clusters, the most massive structures in the universe and natural telescopes to the distant universe. The dark matter halos occupied by these clusters are massive enough to bend and deflect light from the background toward our line-of-sight, allowing us to see highly magnified, distorted, multiple images of the same background galaxies. Johnson uses the configurations of these lensed images to model the cluster mass. These models are used to derive the magnification of the source and to reconstruct the shape of the galaxy as it would be seen if not lensed. All of this information is needed to study the physical properties of the lensed galaxies, such as luminosity, morphology, substructure, and star formation rate. Strong lensing allows us to gain detailed insight into the star formation history of the universe around the time when galaxies were producing their stars most efficiently.

EXCITING DISCOVERY: Along with her advisor and collaborators, Johnson recently used strong gravitational lensing to zoom in on the star formation and morphology of a highly magnified galaxy behind a galaxy cluster. They were able to resolve individual star forming regions in this galaxy as it was 11 billion years ago on physical scales five-to-ten times better than the Hubble Space Telescope can do without lensing.

WHY MICHIGAN? STRONG SUPPORT

"There's great support here. I've had the opportunity to attend conferences around the world. I've never had any issues with finding funding."

WHY MICHIGAN? FACULTY ACCESSS

"It's a very positive, welcoming department. The faculty-to-student ratio is amazing. You can really interact with all of the faculty. They are accessible and actually have time to have discussions and answer questions for you."

JULIETTE BECKER

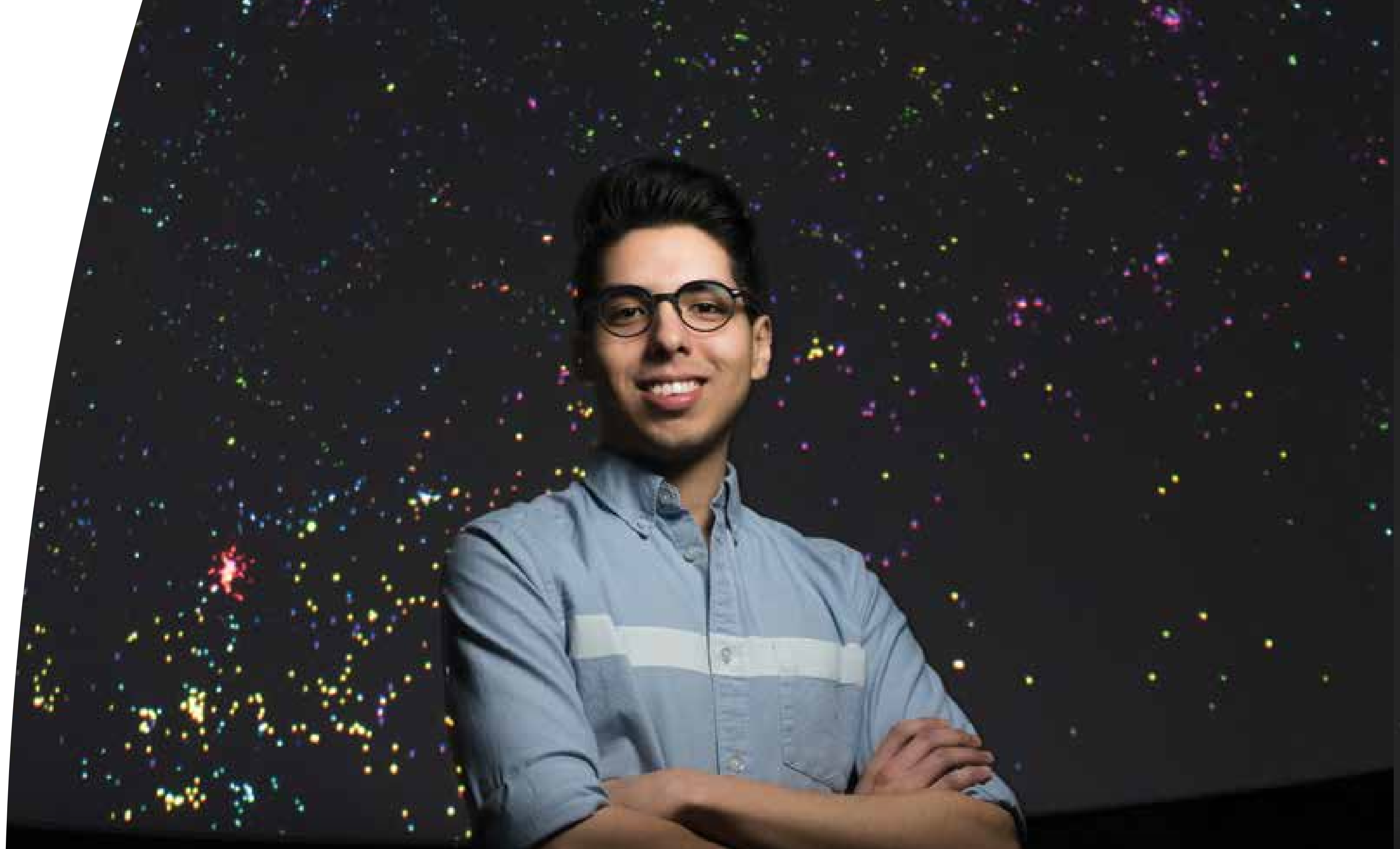
PHD STUDENT | NSF FELLOWSHIP

ADVISOR: Fred Adams

SPECIALTY: Exoplanet dynamics

PHD RESEARCH: The burgeoning field of exoplanets has resulted in the discovery of nearly ten thousand planets around distant stars via a variety of observational methods (radial velocities, transit photometry, microlensing, direct imaging). This growing population of planets presents a statement on the current state of these systems, but it remains a largely open question both how these individual systems formed and what exactly are the specific mechanisms that dictate their evolution. Juliette Becker attacks this problem with a combination of observational and theoretical methods, using data as an inspiration for a more general dynamical analysis of planetary orbits. Currently, Becker is using Laplace-Lagrange secular theory to predict the excitation of inclination in tightly packed, multi-planet systems, with the aim to better understand the multi-planet Kepler sample.

EXCITING DISCOVERY: Along with her advisor, Becker and colleagues recently discovered a hot Jupiter system with two close-in planetary companions using data from the Kepler space telescope. It is the first hot Jupiter found with any close-in planets. This new discovery will help scientists who are trying to understand how planets form and migrate in solar systems.



BRYAN TERRAZAS

PHD STUDENT | NSF & U-M RACKHAM MERIT FELLOWSHIP

ADVISOR: Eric Bell

SPECIALTY: Galaxy evolution

PHD RESEARCH: Bryan Terrazas is studying the evolution of galaxies with stellar masses similar to that of the Milky Way by comparing and analyzing computational simulations and observations. The goal is to better understand what characteristics of high-redshift galaxies can be observed in order to identify progenitors of a subset of galaxies at the current epoch. Specifically, he works on exploring their merger histories, gas accretion rates, star formation rates, as well as their eventual formation into either quiescent or star-forming galaxies in order to understand how these mechanisms affect the resulting descendant galaxy population and the importance of black holes in this paradigm. An understanding of the sources of uncertainty with regard to growth histories will help clarify how to improve the agreement between models and observations. By looking at the evolutionary histories of Milky Way-mass galaxies, he hopes to establish a physical interpretation of observed properties for an important subset of the galaxy population, improving our understanding of how galaxies evolve through cosmic time.

WHY MICHIGAN? COLLABORATION

"The graduate students here really come together, collaborating to make sure our voices are heard and included in the department. As a result, there's a strong community and a healthy academic environment at Michigan."

VIVIENNE BALDASSARE

PHD STUDENT | NSF FELLOWSHIP

ADVISOR: Elena Gallo

SPECIALTY: Supermassive black holes in dwarf galaxies

PHD RESEARCH: Vivienne Baldassare is studying supermassive black holes at the centers of dwarf galaxies. She uses data from the Magellan telescopes to search for signatures of black holes consuming material at a vigorous rate. By identifying these elusive objects and studying their properties, she hopes to learn more about how black holes and galaxies grow together over cosmic time.

EXCITING DISCOVERY: Baldassare and her advisor recently discovered the smallest black hole ever observed at the center of a galaxy. Every large galaxy, including our own Milky Way, is believed to have a supermassive black hole at its core. The recently discovered object is one of the first to be identified in a dwarf galaxy. The findings illuminate for astronomers important similarities between galaxies of vastly different scales. And because the dwarf galaxy, called RGG 118, is so small, it's unlikely that it has ever merged with other galaxies, so it gives researchers a window to a younger universe.

WHY MICHIGAN? VALUABLE EXPERIENCE

"Grad students are valued and supported at Michigan. You're not only encouraged and given the skills to become an independent researcher, you're given the valuable experiences and access to resources and facilities to really make it happen."

ANN ARBOR

The city of Ann Arbor combines the charm and quality of life of a small town with the range of educational, cultural, and recreational opportunities of a larger city. An array of music, theater, restaurants, shops, museums, parks, and special events make Ann Arbor an eclectic and desirable destination. Highlights include the Ann Arbor Art Fairs, the Summer Festival, and Big Ten athletics.

In addition, the area is served by numerous parks. There is an arboretum/botanical garden right on campus; 13 Metroparks provide a 25,000-acre greenbelt for year-round outdoor activities; and wooded trails like the 17-mile Pinckney-Potawatomi are ideal for hiking, mountain biking, and cross-country skiing.

Ann Arbor regularly receives national attention as one of the best places to live. Recent honors include:

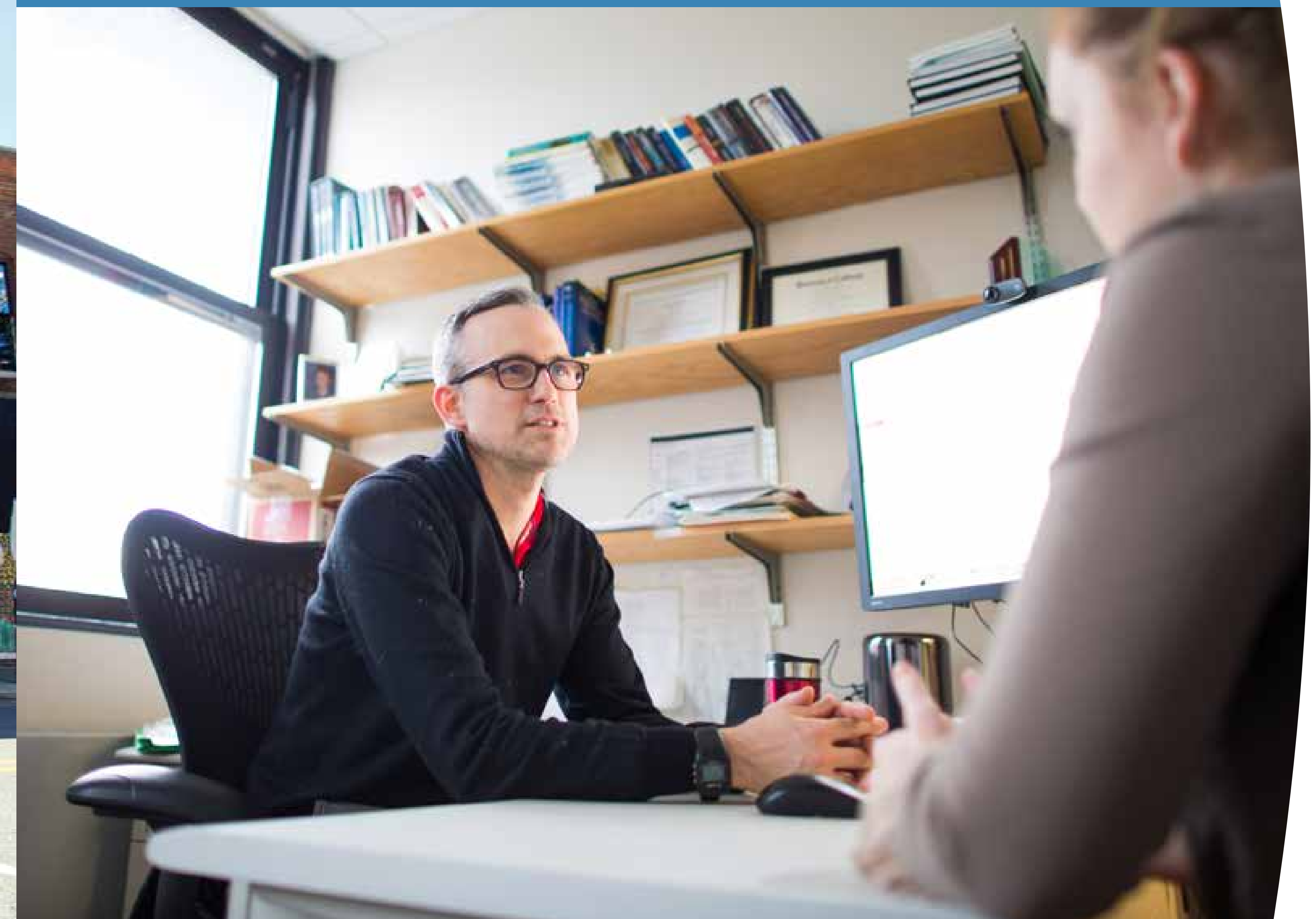
- #1 **College City, *Forbes* magazine**
- #1 **Most Educated City in America, *WalletHub***
- #1 **City for Millennials, *American Institute of Economic Research***

ABOUT THE PROGRAM

APPLICATION DEADLINE: First week of January. We encourage candidates to visit that spring.

FUNDING: Students receive a stipend, plus health and dental coverage. We also support student applications for prestigious external fellowships.

STRUCTURE: Total program length is generally 5 to 6 years. The first two include research projects, classes, and the opportunity to teach. The remaining time is devoted to thesis research.



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TO LEARN MORE OR REQUEST A VIEWBOOK, PLEASE CONTACT US AT:

University of Michigan
Department of Astronomy
311 West Hall
1085 South University Ave.
Ann Arbor, MI 48109-1107

734.764.3440
astro.phd.inquiries@umich.edu
astro.lsa.umich.edu

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