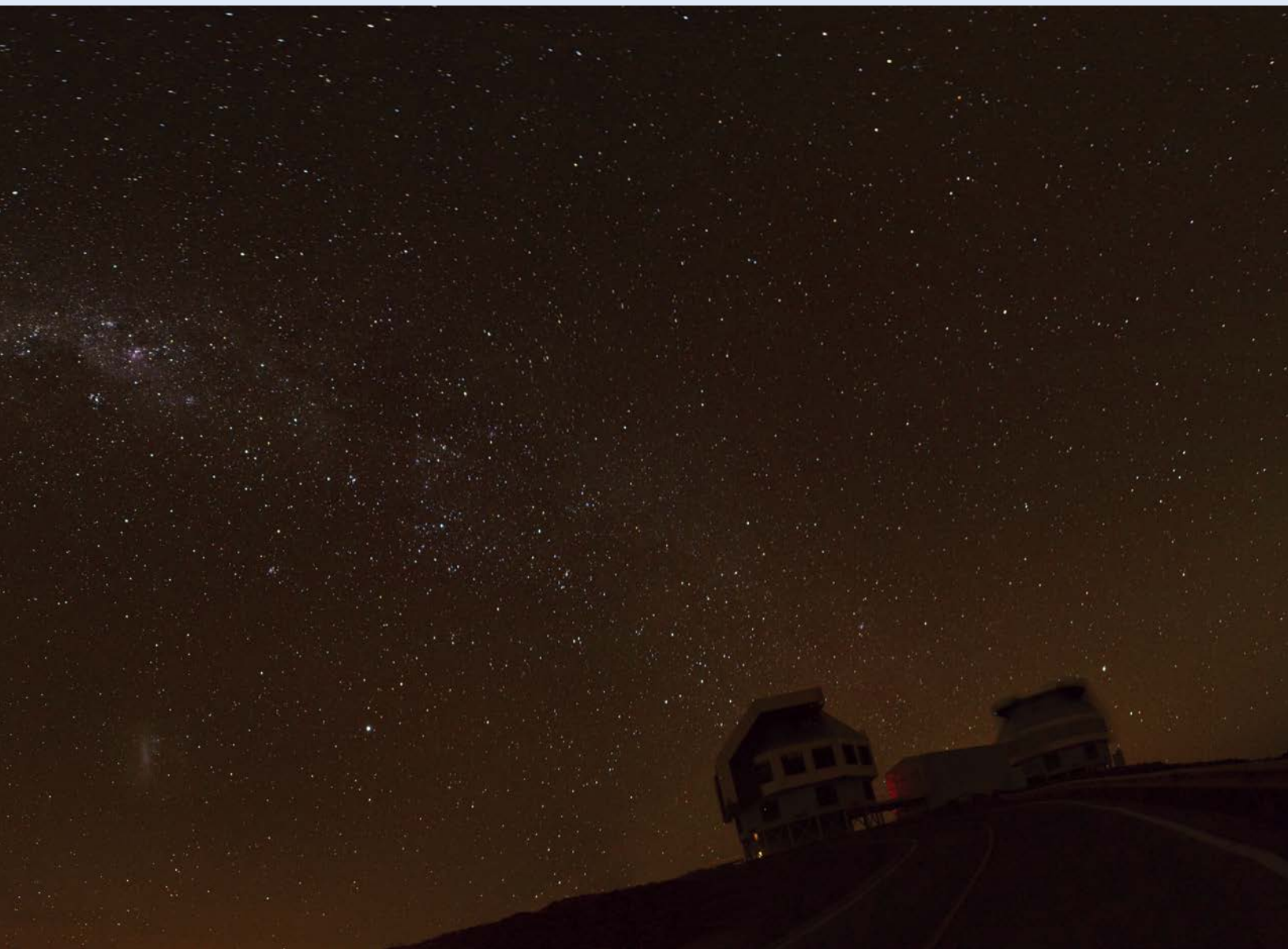


UNIVERSITY OF MICHIGAN

Fall 2013

Michigan Astronomy News

FOR ALUMNI & FRIENDS OF THE UNIVERSITY OF MICHIGAN ASTRONOMY DEPARTMENT





Letter From The Chair

I am very excited about this inaugural edition of the Department's yearly newsletter, which will let us share with you some of the things that have been going on during the past year. We continue to be passionate about teaching and the numbers of non-majors in our

introductory classes has grown so much that half of every entering class will take at least one astronomy class before graduating. Many of these classes make use of our planetarium and campus telescopes on Angell Hall, providing engaging experiences beyond the classroom. Innovation in the classroom is being furthered through a grant from the Provost under the "Transforming Learning for The Third Century", where we will expand our inquiry-based learning in introductory classes.

Our undergraduate major and minor program continues to expand and develop. In addition to our Astrophysics track, we began a new Interdisciplinary Astronomy major and minor, designed for students who want to develop the kind of broad understanding of astronomical principles and practice ideal for technical positions in astronomy or for careers like teaching, science writing, and outreach.

Within our Astrophysics undergraduate program, students perform research that they often present at national scientific meetings, such as the Winter meeting of the American Astronomical Society. They now have the opportunity for an immersion course in observing, where they spend the Spring Semester at Kitt Peak, working at the MDM Observatory. This course, given by Professor Sally Oey for the first time this year, is the only one of its kind (see p. 3).

This will be the inaugural year for the Michigan Institute for Research in Astrophysics (MIRA), a new institute that will enhance both research and teaching on campus.

Some of the most exciting scientific problems in astronomy and astrophysics require expertise that crosses departmental boundaries. This institute will focus on the most vibrant astrophysical challenges and bring together faculty from Astronomy, Physics, AOSS (Atmospheric, Oceanic, and Space Sciences) and other relevant departments to work on forefront issues. Associate Professor Eric Bell will be the first director of MIRA.

The Department has been in the Dennison Building since the early 1960s but next year we leave this brick and cinder block palace for a new home, West Hall, formerly known as West Engineering. It is a beautiful old building that is being renovated on the 3rd and 4th floors of the southern part, and if the renovation stays on schedule, we will move in Summer 2014 (see p. 10).

There are a variety of events available to you if you are nearby. We have open houses at our telescope and planetarium every month, with the dates posted at our website. If Comet ISON continues to brighten through November 2013, it will become a naked eye comet and we will have a special viewing, so stay-tuned. Also, there are public lectures from exceptional speakers a few times per year in the evening (distinguished alumnus Prof. Stacy McGaugh on Friday, December 6, 2013; Prof. Martha Haynes on either February 20 or 21, 2014). If you don't live near but can drop by when you are in the neighborhood, please do so and let us know you are coming. Also, we try to stay connected through our web presence and Facebook. Check the back cover for contact information.

Alumni of all stripes — please let us know what you are doing now. We often ask 'What are Joni or Ray up to these days? Does Brian still play the sax?'. So help us fill in the gaps and become more connected. Email contact information, news (you can attach images) and links to astro.alumni@umich.edu. We anticipate a substantial section in future editions of the newsletter on your activities. Best wishes for the coming year.

—Joel Bregman

Department of Astronomy Fast-Facts

People

- 19 Tenure-track Faculty (3 are within Physics)
- 7 Research Science Faculty
- 2 Emeritus Faculty
- 18 Postdoctoral Fellows and Research Associates
- 25 Graduate Students
- 3 Administrative and Technical Staff
- 25-30 Undergraduate majors and minors

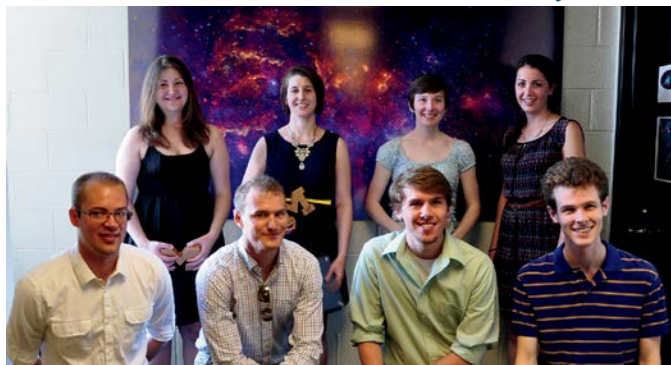
Computing

- University-wide Flux cluster, with 632 multi-core nodes, InfiniBand network, and 640 TB storage.

Observatories

- Magellan Telescopes: 2 x 6.5m telescopes at the Las Campanas Observatory, Chile
- MDM Observatory: a 1.3 m and 2.4 m telescope on Kitt Peak, Arizona
- Curtis-Schmidt telescope at the Cerro Tololo Inter-American Observatory, Chile
- CHARA optical/infrared interferometer on Mount Wilson, California
- Angell Hall student telescopes and planetarium on Main Campus

Undergraduate Postcards



Last winter 11 majors and 3 minors graduated with a degree from the department. Present at the reception for students and their parents were, left to right, Britney Blankenship, Samantha Chappell, Mary Holt, Amelia Bell; Matthew Anderson, Warren Morningstar, Ben Coughenour, and Andrew Burkhardt. (Photo Credit: S. Murphy)

In May, Prof. Sally Oey inaugurated Astro 461, a 4-week course held in residence at Kitt Peak National Observatory. Students studied all aspects of ground-based observatories, and completed their own science projects using the MDM

telescopes. a: (L to R) Prof.

Sally Oey, GSI Anne Jaskot, Hui Li, Jill Moreau, Sierra Grant, Keith Johnson, Talor Henderson, and Evan Kasal; b: opening the instrument hatch of the CCDS spectrograph on the MDM Hiltner 2.4-m tele-

scope; c: engineer Charles Corson demonstrates the 3.5-m WIYN telescope; d: inside the Cassegrain cage of the Mayall 4-m with Darryl Willmarth; e: filling the dewar at the MDM 2.4-m. (Photo Credits: upper pair, H. Li; others, S. Oey.)



Department Visitors

The year saw Drs **Kathy Vivas** and **César Briceño** (Centro de Investigaciones de Astronomía, Venezuela) take their sabbatical leave in the department.

Kathy worked with Prof. Mario Mateo in a wide-field study of pulsating variable stars in the Carina dwarf spheroidal galaxy. Their main interest was to detect dwarf Cepheids. More than 300 such stars were discovered in the galaxy, and were used to study the extended structure and stellar populations of Carina. In addition, she joined the SMASH collaboration, headed by McLaughlin Fellow David Nidever, that will make a deep and extended survey of

the Magellanic Clouds using the new Dark Energy Camera (DECam) at the Blanco 4m telescope at CTIO.

César worked with Prof. Nuria Calvet's group on an ongoing large scale survey of low-mass pre-main sequence stars in the Orion OB1 association. They assembled spectra and multiwavelength photometry for ~2000 objects, finding several young (~5-10 Myr old) stellar aggregates. This is the largest sample of well characterized young stars in this age range, an ideal testing ground for studies of cluster dispersal and protoplanetary disk evolution.

Kathy and César's visit was a fruitful time for the study of star formation in the department.

Cover Photograph:

The 6.5-meter Baade and Clay telescopes at Las Campanas Observatory in Chile. (Photo Credit: A. Aarnio)

Newsletter Production: P. Hughes

Advisory Panel: E. Gallo, M. McClure S. Murphy, K. Sharon

In Memoriam: George Latimer



George Latimer at the controls of the 26m radio telescope on Peach Mountain (Photo Credit: D. Boprie)

Dr Margo Aller writes that **George Edward Latimer** 75, passed away unexpectedly on March 2, 2013. While his official title was Research Project Engineer at the University of Michigan Radio Observatory (the facility known as UMRAO on Peach Mountain in Dexter), his many roles ranged from microwave engineer to mechanical expert to operating and maintaining the dish as the only on-site staff member for the past several decades. He joined the staff of the Radio Observatory as a student assistant in the late 1950s when the telescope was in the construction phase, and he remained a vital member of the Observatory staff until his retirement in 2012. George was passionate about his work at UMRAO, and the round-the-clock operation of the radio telescope remained the focus of his life during his 53-year career at the University of Michigan. He was an avid fisherman and golfer, and he loved all forms of nature including the many birds and animals which reside in the forest surrounding the facility. He is survived by two sons, Tim and Scott, and his long-time companion Mary Gray. Donations in his memory can be made to the Humane Society of Huron Valley, 3100 Cherry Hill Road, Ann Arbor.

New Faces

Jan Malaikal is our new Key Administrator.

She joined the Department of Astronomy in April 2013, after a 21-year career of traveling the world with the United States Army. Her favorite assignment in the Army was to Johnston Atoll, USA, where she got hands-on experience with facilities and contract management, but more importantly, learned how to SCUBA dive so as to enjoy all

the unique wildlife that Johnston Atoll is home to. Her final assignment in the Army was to a coalition headquarters in Kabul, Afghanistan, where she got to work with interesting people from around the globe.



She is an engineer by degree and training, and a certified Project Management Professional. She hopes to leverage her experience in leadership and project management

to help students, faculty and staff of the Department of Astronomy.

Dr **Keren Sharon** joins the department as Assistant



Professor this September. She is currently University of Michigan President's Postdoctoral Fellow, and her research focuses on the observational study of strong lensing galaxy clusters, determining their mass distributions, and using them as cosmic telescopes to study the background Universe.

The "Doc" Losh Fund

The Department is honoring legendary Astronomy Professor Hazel "Doc" Losh for her commitment to undergraduate education with the Losh Undergraduate Student Support Fund. Gifts to the fund will honor a beloved teacher, alumna, and sports fan who devoted some 42 years to teaching at U-M. See the department web page for details on how to contribute.



"Doc" Losh inside the dome at the Old Detroit Observatory. (Photo Credit: Hazel Marie Losh papers, Bentley Historical Library, University of Michigan.)

Graduate Student News

It's been a bumper year for graduate student thesis defenses, with newly minted PhDs spreading out across the country, and the globe. In August 2012 **Laura Ingleby** (Advisor: Nuria Calvet) completed her thesis on *Emission from Hot Gas in Pre-Main Sequence Objects: The Accretion Shock and the Inner Circumstellar Disk*, while **Joel Lamb** (Advisor: Sally Oey) followed with a study of *Massive Star Formation in Sparse Environments*. Both took up Postdoctoral Researcher positions within the department. Joel is the 2013 Ralph B. Baldwin prize recipient.

Working jointly within the department and the School of Education, **Shannon Schmoll** (Advisor: Marta Volonteri) combined her enthusiasm for both astronomy and teaching with a thesis *Toward a Framework for Integrating Planetarium and Classroom Learning*. After defending in February 2013 she took up a position as Stem Education Specialist at the Field Museum in Chicago.

Palantir Technologies of Palo Alto were the beneficiaries of the software development skills that **Sandor van Wassenhove** developed during his work on *Massive Black Hole Dynamics in Unequal Mass Galaxy Mergers* (Advisor: Marta Volonteri), which was defended in March. This sounds like the beginning of a successful Silicon Valley career!

A cluster of defenses over the Spring and Summer was led in April by **Wen-hsin (Tina) Hsu** (Advisor: Lee Hartmann) who studied the *Environmental Dependence of the Stellar Initial Mass Function*. Tina is moving to New York.

With back-to-back defenses and their associated celebrations, **Jordan Zastrow** (Advisor: Sally Oey) who has been studying *Radiative Feedback from Massive Stars: Ionizing Radiation and Its Fate in Starburst Galaxies*, and **Nathan Crockett** (Advisor: Ted Bergin) who presented an *Analysis of the Herschel/HIFI 1.2 THz Wide Spectral Survey Toward Orion KL*, provided the department with festivities fit for the summer solstice! Jordan is moving to the Washington, DC area, with the expectation of a job with the government or a think tank, while Nathan will take up a postdoc at Caltech.

The year wrapped in July with **Alexander (Sasha) Muratov** (Advisor: Oleg Gnedin) defending *Cosmological Small-Scale Structure: The Formation of the First Stars, Galaxies, and Globular Clusters*, and **Michael Anderson** (Advisor: Joel Bregman) defending *Hot Gaseous Halos Around Galaxies*. They are leaving Ann Arbor to take up postdocs at UC San Diego and the Max Planck Institute in Garching, Germany, respectively.

Faculty News

Professor **Nuria Calvet** was named Helen Dodson Prince Collegiate Professor of Astronomy effective 1



October 2012. She joined the department as a professor in 2005, and has a worldwide reputation for her work in the field of star and planet formation.

Her studies focus on the first stages of the life of stars and of the planets around them, specifically on protoplanetary disks and their evolution from primordial disks formed in the collapse of molecular cloud cores to debris disks. Her group has developed modeling tools to interpret observations of protoplanetary disks to understand how their dust and gas composition change with time, using observations from ground-based observatories, especially Magellan, and space missions as HST, Chandra, Spitzer, and Herschel.

She has still found time to be on the organizing committees of numerous scientific conferences, as well as time allocation committees and user panels for facilities such as Herschel and Spitzer!

She is much admired as a teacher and mentor, serving on many thesis committees, and had a lasting impact on the department's graduate program when as graduate chair (2006-2010) she instituted changes that significantly improved faculty advising of graduate student work.

Alumni News

After a postdoc at the Harvard-Smithsonian Center for Astrophysics, former department postdoc Dr. **Stefan Kraus** has joined the faculty of the University of Exeter as Lecturer in Astrophysics. His contributions in star and planet formation, and in high-angular resolution imaging, make him a great catch for the Exeter group.

Former UM postdoc Dr **Fabien Baron** has joined the faculty at Georgia State University as Assistant Professor. His expertise in the field of image reconstruction from interferometry will be put to good use at the home of the Center for High Angular Resolution Astronomy.

Former UM undergraduate Dr **Philip Muirhead** has accepted a faculty position at Boston University. Phil's interests while at Cornell and Caltech have included dwarf stars with small planets, infrared instrumentation, and the precise measurement of radial velocities.

Former UM graduate student Dr **Catherine Espaillat**, currently a NASA Carl Sagan Fellow at the Harvard-Smithsonian Center for Astrophysics, is also to join the faculty at Boston University. Catherine's work has been in the field of planet formation: the structure and evolution of circumstellar disks around T Tauri stars, dust grain growth, and gas dissipation.

Former UM graduate students Dr **Jessica Werk** (IMPS Postdoctoral Fellow, UC Santa Cruz) and Dr **Zhaohuan Zhu** (postdoctoral researcher, Princeton) have just been awarded Hubble Fellowships.



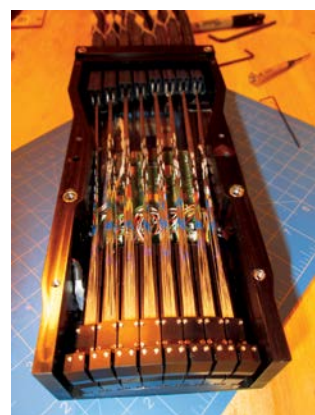
M2FS: The Michigan-Magellan Fiber System

Graduate Student Jeb Bailey reflects on starting his research with Professor Mario Mateo, and explains why fiber is good for you.



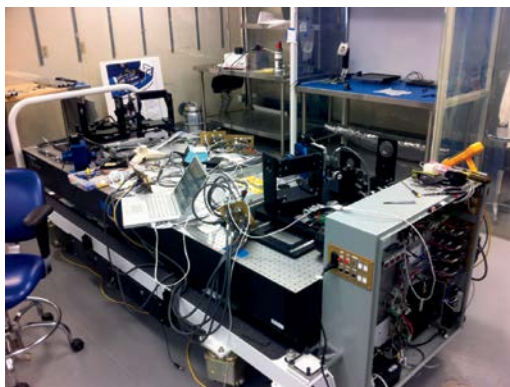
When I entered the doctoral program here four years ago I was thrilled to find that Professor Mario Mateo was just starting to work on the Michigan Magellan Fiber System (M2FS), a new instrument for the Magellan Clay telescope. I spent my undergraduate studies searching for periodicity in the radial velocity measurements of young stars, which consists predominately of writing software to analyze scientific data. Being the sort of person who spent his childhood building computers and taking apart household appliances, I welcomed the switch to instrumentation. Over these past few years I have been fortunate to learn just how much effort (and head-scratching) goes into making a new instrument live, and to play a small role in building what is sure to be a scientific workhorse for years to come.

Thinking back, I see Mario sitting for hundreds of hours polishing fiber optics with a rickety polishing



One of two fiber “shoes” which terminates the fibers at MSpec’s injection plane. Each mechanism in the foreground is used to maneuver one of six slits in front of sixteen fibers. (All Photos: J. Bailey & M. Mateo.)

robot I cobbled together in my first year and then sitting for many hundreds more assembling and testing each fiber optic assembly. I remember the months I spent designing a mechanism no bigger than a pinky finger, which would, for the first time, allow the use of different slit widths in a fiber-fed spectrograph. I lose count (honestly) of the number of flights between Michigan and Carnegie Observatories in Pasadena Mario and I have made over the



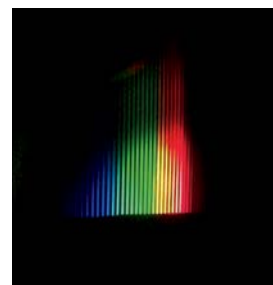
The evolution of MSpec over the course of 14 months. The bottom photo shows Mario Mateo, Jeb Bailey, and Jeff Crane (OCIW).

past two years, slowly putting the instrument together. I feel the callouses on my hands from stripping all of the wires that went into making the instrument’s control system. I hear the thoughtful insights of our collaborator Jeff Crane asking me something to the effect of “Why not this way?”. I recall taking the first spectrum with the camera on my phone. I grin at the picture of Mario’s soaked T-shirt from Splash Mountain, where we went to celebrate shipping the instrument to Chile. Most of all I know many, many people without whom this instrument would not be possible.

M2FS is the successor to the Michigan/MIKE Fiber System (MMFS) that Mario constructed as a multi-object fiber front end for the MIKE spectrograph back in 2003. Although MMFS proved to be critical in multiple theses, the MIKE spectrograph was not designed as a multi-object instrument and thus MMFS suffered from a number of limitations, perhaps the most notable being a significant reduction in the available spectral coverage. By designing a spectrograph tailored to the needs of a multi-object fiber feed, Mario was able to overcome these limitations. The new instrument is a system of four major components: MSpec, a pair of identical, versatile spectrographs; MFib, the fiber optic front end to the spectrograph which will enable observers to obtain spectra of many stars simultaneously; MWFC, a wide-field corrector which allows M2FS to utilize Magellan Clay’s full half-degree field of view; and MCal, the instrument calibration unit which will live just below (and to the side of) the telescope’s secondary mirror.

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The first cross-dispersed spectrum. Since it was taken with a cell phone we can see the actual colors.



Charlie Hull (OCIW), Mario & Nancy Mateo, Jeb & Brittany Bailey, shortly after a trip down Splash Mountain.

dispersed high resolution ($R \sim 18,000 - 34,000$) mode. The spectral orders are captured by two E2V 4096² CCDs with 2.5 e⁻ read noise. We anticipate the total system throughput to be between 20 and 45% depending on the mode utilized.

Personally, I will be using M2FS for a multi-epoch, sub-20 m/s precision radial velocity survey of a few nearby open clusters. The idea is to canvas all the F-K stars in a few nearby cluster cores and put hard statistical constraints on massive, close planetary companions in the cluster environment: all but six known extrasolar planets orbit field stars. To date such studies have not been performed on sufficient scale, in part due to the large time commitment which would be demanded for single object spectroscopy.

Mario and Matt Walker (CfA) will continue pushing the limits of our understanding of dwarf spheroidal kinematics by measuring the motions of stars on the outskirts of the Milky Way's dwarf satellites, enabling them to estimate the masses of the smallest dark matter halos. Graduate student Marina Kounkel and Professor Lee Hartman plan to use M2FS to measure radial velocities for the Orion Molecular Clouds which, when combined with VLBA parallax measurements, will provide a complete three-dimensional understanding of the positions and velocities for all of the stars in that region. McLaughlin Fellow David Nidever will be using M2FS to look at stars in the outskirts of two nearby dwarf galaxies, the Large and Small Magellanic Clouds, to search for possible relics of their early violent formation and evolution. Professor Joel Bregman and Jimmy Irwin (Alabama) find M2FS ideal for obtaining a large number of spectra of extragalactic globular clusters harboring luminous X-ray sources. In particular, they hope to find additional examples of exotic emission line

Technically speaking, the instrument offers 256 1.2" fibers which are positionable anywhere within the field of view and which may be packed to 12" fiber to fiber separations. Each spectrograph services 128 fibers and is capable of operating in either a low resolution ($R \sim 500$ to a few 1000s) or a cross-dis-



Juan Carrasco, Jeff Crane, Mario Mateo working on MSpec at Magellan this July. MFib is positioned just behind Mario and MCal is the small black cylindrical object behind Juan. The MWFC lenses are in the lower left.

objects that may signal the presence of tidal disruption events by large black holes. And Professor Sally Oey looks forward to surveying all the field OB stars in the Small Magellanic Clouds to set constraints on star formation processes, runaway ejection mechanisms, and the Oe/Be disk formation mechanism.

With so much future research riding on M2FS's success it seems fitting to close with where we stand at present. I have spent the past week working in the Magellan Telescope auxiliary building, reassembling M2FS with Mario and Jeff Crane. As I type this Mario is taking calibration data to fine tune the grating angles and focus. Although we will wrap this trip up in two days, barely a week later we will return to Magellan for the commissioning run in the last week of August. I leave you with a picture of M2FS in the Andes.



A reasonably complete group photo taken just after packing M2FS into its 40 foot shipping container. Back row: Jeff Crane, Steve Schectman, Jeb Bailey, Jerson Castillo. Middle row: Tyson Hare, Ian Thompson, Vince Kowal, Steve Wilson, Christoph Birk, Ian Roederer, Alan Uomoto, Greg Burley. Front row: Jorge Estrada, Robert Storts, Scott Rubel, Mario Mateo.





Galactic Center Fireworks!

Hubble Fellow Nathalie Degenaar and Research Scientist Mark Reynolds preview the possible collision of a gas cloud with the supermassive black hole in our Galactic Center.



Supermassive black holes lurk at the centers of every Galaxy. Our own Milky Way harbors a black hole of approximately 4 million Solar masses, whose electromagnetic counterpart is known as Sagittarius A* (Sgr A*). Most surprisingly, its radiative output is about 9 orders of magnitude lower than the maximum level for a black hole of this mass. Nevertheless, observational features such as the “Fermi Bubbles” (see p. 9) and light echoes from molecular clouds near the Galactic center suggest that Sgr A* has not always been dormant, but instead evidences a wild and glorious past.

We may now find ourselves at the dawn of a reactivation phase of our supermassive black hole, which is foreshadowed by the discovery of a cold gas cloud (a.k.a “G2”) that is on a collision course with Sgr A* and is predicted to impact in the coming months. The cloud may become disrupted due to tidal forces and parts of the shredded gas could then be accreted onto the black hole. However, whether this interaction leads to fireworks remains to be seen. Right from the start of G2’s reported discovery in early 2012, there has been ongoing discussion regarding the nature, origin, and hence the faith of this tantalizing gas cloud that seems to have come out of nowhere. It remains uncertain as to whether G2 harbors a central object (e.g., a young star or a binary) that is keeping the cloud gravitationally bound. If so, G2 may survive its doom-trail, keeping any observable effects on the emission of Sgr A* to a bare minimum.

Astronomers all over the world are at the ready should Sgr A* become revived, armed with monitoring campaigns utilizing ground-based and space-based facilities, and target-of-opportunity programs covering the entire electromagnetic spectrum. And so they should: this has the potential to be a unique, once-in-a-lifetime opportunity to observe a disruption event in our own backyard and have an unprecedented view of the feeding process of our Galactic nucleus. In the Astronomy department we occupy a front seat and are in place to follow this historic event at infrared and X-ray wavelengths.

Joining forces across different institutes of the Magellan consortium (UMich, Carnegie and Harvard), we have recently embarked on a monitoring program employing the infrared-imager FourStar mounted on Magellan-Baade. Starting in mid-July, the Galactic center is observed nearly weekly using the J, H and Ks filters. This

allows us to promptly detect any possible changes in the infrared emission of Sgr A*, which might signal enhancement of the accretion flow due to the shredded gas cloud.

Our Magellan infrared campaign is complemented by intensive X-ray monitoring. Utilizing the unique flexibility of the Swift satellite, we observe the center of our Galaxy every day

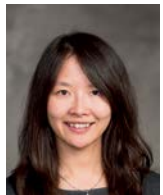
with the onboard X-ray telescope. This program has been running since 2006, providing us with valuable insight into the long-term X-ray behavior of the supermassive black hole. This serves as an important calibration point to assess if, and how, the X-ray

properties of Sgr A* change as a result of its interaction with G2. Moreover, Swift is the only observatory that can accommodate daily X-ray observations and could well turn out to be the first to detect any action and thereby serve as a trigger for other observatories.

Given the uniqueness of this astronomical event and the broad scientific and public interest, we have set up an automated reduction and analysis pipeline for the daily X-ray observations obtained with Swift. New data is downloaded the instant that it becomes available; generally this is within a mere 3 hours after an observation was taken. Quick-look images and light curves are then produced and immediately uploaded onto a website (swift-sgra.com), followed by an instant e-mail notice distributed to subscribers. This allows the scientific community to optimally benefit and promptly respond, in case our Galactic nucleus awakens.



Stacked X-ray image of the Galactic center region ($\sim 25' \times 25'$) using data obtained with the Swift/XRT between 2006 and 2011. The colors of red, green, and blue are mapped to low (0.3-1.5 keV), medium (1.5-3.0 keV), and high-energy (3.0-10.0 keV) X-rays.



Galactic Archeology With Fermi Bubbles

Postdoctoral Fellow Hsiang-Yi (Karen) Yang describes a study of earlier Galactic Center activity with Professor Mateusz Ruszkowski.



Recent observations by the Fermi Gamma-ray Space Telescope have revealed a pair of giant bubbles extending about 3000 light years above and below the center of the Milky Way galaxy. The vast amount of energy required to inflate these ‘Fermi bubbles’ implies that the Galactic center was in an active state sometime in the past. The Fermi bubbles as observed today thus provide archaeological records that allow one to study the history of the Galactic center environment. A past starburst event or relativistic jets from the supermassive black hole (SMBH) residing at the Galactic center are the two most promising hypotheses proposed to explain the origin of the bubbles. Which of these two scenarios is true remains a hotly debated issue.

We have been investigating the possibility that the Fermi bubbles are created by past jet activity from the central SMBH. This is of particular interest to the astronomical community because it suggests that the SMBH in our Galaxy, though currently in a quiescent phase, was once an active galactic nucleus like many other currently active galactic nuclei. Because of their proximity, the Fermi bubbles are great laboratories for studying how the relativistic jets from active galaxies interact with their surroundings. This process is significantly more difficult to observe in other galaxies because of limited instrumental resolution and sensitivity.

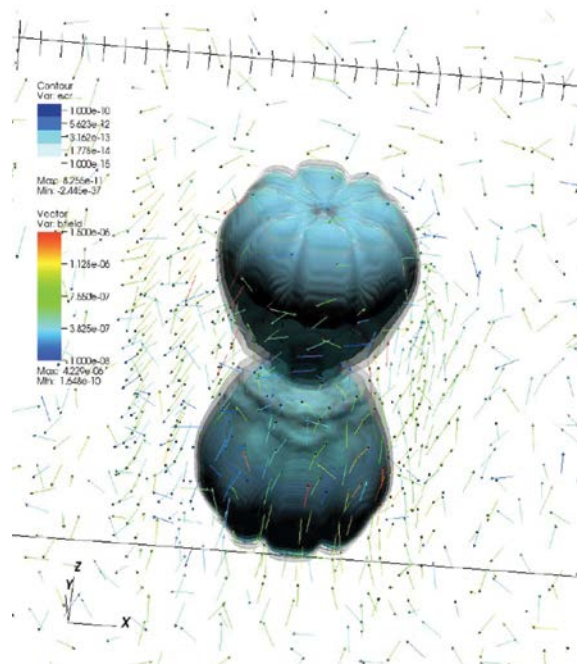
We have performed detailed numerical simulations of the propagation of relativistic particles (or cosmic rays) from jets into the interstellar medium of the Galaxy. These highly energetic cosmic rays collide with photons from stars and cause the radiation to appear as gamma rays — a viable mechanism to produce the Fermi bubble emission. In order to make accurate predictions for the properties of the bubbles, the simulations take into account several critical model elements that were not included in previous studies. Firstly, the initial conditions of the interstellar medium, such as the density and temperature, are adopted from X-ray observations analyzed by Prof. Joel Bregman and graduate student Matt Miller. Secondly, the effects of the Galactic magnetic fields on the trajectories of the cosmic rays are included. Since the cosmic rays are charged particles, they gyrate along magnetic field lines while their diffusion across the field lines is limited. Furthermore, the simulations were carried out in three dimensions (3D), allowing one to study the spatial distribution and evolution of this powerful event, as well as to do proper projections onto the sky to directly compare simulations with observa-

tions.

By matching the morphology of the simulated Fermi bubbles to what is observed, we obtained constraints on the time when the jets were launched, bubble age, initial jet speed, and the amount of mass and

energy released in this catastrophic event. The Fermi bubbles are very likely formed by powerful jets from the central SMBH that started about one million years ago and lasted for three hundred thousand years. The SMBH may have consumed large amounts of ‘fossil’ fuel in the form of stars and gas weighing about ten thousand times the mass of the Sun, estimated from the power of the jets and a typical efficiency to convert mass into energy. The simulations reproduced many properties of the observed bubbles, such as the gamma-ray surface brightness distribution, electromagnetic spectrum, and the sharp contrast between the bubbles and the background. These successes provide strong support for the scenario in which the Fermi bubbles originate from an episode of SMBH jet activity at the center of our Galaxy.

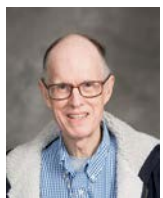
As more and more observational data become available in the near future in the gamma-ray, microwave, radio, and X-ray bands, more sophisticated physical mechanisms for modeling the cosmic ray spectra will need to be included in the simulations. Parts of the simulation code have been developed by graduate students Sinh Trung and Hui Li and will be incorporated into the FLASH code. Future simulations will enable investigation of the properties of the Fermi bubbles in multiple wavebands and will provide a much clearer picture of the formation process of the Fermi bubbles and past history of the Milky Way center.



A snapshot of the simulated 3D distribution of cosmic rays and magnetic field.

On The Move

Fifty years after the opening of Dennison Building, we are soon to move to a new home in West Hall.



Professor (Emeritus) Charles Cowley reflects on the early years in Dennison.

In the late 1950s the Astronomy Department was overflowing its quarters in the old Observatory building. Of that structure, a small portion remains, as the historical Detroit Observatory. The Director at that time, Leo Goldberg, had made a special plea for a building that would comfortably accommodate his people. Both Dr Goldberg and the radio astronomer Fred Haddock had begun serious programs of space research, and they complained that one of the biggest problems was finding office space for the researchers.

Anne Cowley and I were among the last of the Michigan PhDs to work entirely in the old Observatory on Ann Street. Before we left town, many people had already moved to the new offices in Dennison, which was then called the Physics-Astronomy (P&A) Building. When we returned after 4 years at Yerkes (Chicago), the department was well settled in the new quarters. The redoubtable Professor Hazel Losh had managed in just a few years to accumulate sufficient old exams and papers that her new office looked as 'lived in' as the famous one she had at the old Observatory.

The lower floors of P&A were used for labs and undergraduate classes, but some physics professors had offices on the 7th floor. Among those was David Dennison, an outstanding figure among the glorious ones of mid-20th century physics. Professor Dennison was one of the pioneer physicists who developed the quantum theory of molecular spectra. It is just one of those ironies of history that it was half a century after Dennison's time that astronomers began to study the same kind of molecules — in interstellar space. After Dennison's death in 1976, the P&A Building was renamed in his honor.

The old Observatory had a sizable machine shop — I was told with the largest lathe on the campus. At the end of the 1960s, Orren Mohler, who was then the astronomy chairman, decided to move the shop to the P&A building — a large room at the west end of the tenth floor, which had been used as a coffee room — where it remained for the next several decades. It was moved, and combined into a general shop for the science departments in 2011.

The new building provided adequate space, at least for the permanent staff. Pairs of graduate students were assigned to somewhat small but adequate rooms. I don't recall loud complaints about space.

The elevators were a constant source of complaint

and amusement. The building had been constructed with four shafts, for three passenger and one freight elevator. However, to save money, a decision was made to only put in two passenger elevators, and to use the freight elevator like the other two. Rumor had it that the elevator company warned that they had designed the system to work with four elevators, and they could not be responsible for the operation of a system that was one elevator short. In spite of the warning a decision was made to go with the three-elevator system. There were always problems, with elevators frozen, and crowds of students, astronomers and physicists waiting for a lift to the upper floors.

The fourth elevator shaft stood empty for some decades before a decision was made to install a model particle detector in that space: part of a large project involving Michigan physicists, to try to detect proton decay. Both the model and a larger detector were built, but had no success in discovering proton decay. However, the project was able to detect, marginally(!) neutrinos from Supernova 1987a. The empty elevator shaft had played its small role. The elevators continued to be troublesome, until a 21st century remodeling of parts of Dennison which included 4 working elevators.

Physicists kept offices on the seventh floor for several decades. Astronomers used the eighth floor for administrative and professors' offices, a large and a small classroom, and a small reading room-library. The main astronomical collection from the Observatory was combined with the physics library and located on the second floor of the low-rise part of Dennison. Eventually, that library was itself moved to become part of the Shapiro Science library, and that happened toward the beginning of the electronic information age which has had such a broad impact on libraries, books, and journals.

The ninth floor was mostly devoted to the offices of radio astronomers, staff, post-docs and students. Both the ninth and tenth floors had a ring of small offices with windows, and an inner space used for storage, dark rooms, and for a while, coffees. Regular 'coffees,' at 10am and 3pm had been a tradition at the old Observatory and they continued in the new quarters. After the shop moved in, the coffees moved to a much smaller (windowless) room in the central part of the 10th floor. A visitor once described it as "that dismal little room." Perhaps the ambiance was one reason the regular coffees were discontinued at some point in the 1970s.

Little has changed in the intervening years!



Professor Douglas Richstone previews our new home.

The Department's new home in West Hall will be on the 3rd and 4th floors above the arch over the south end of the Diag and extending along the wing of the building that parallels South University Street. North facing offices will have views of the Diag, while South facing offices will look across South University toward the School of Social Work. The space was previously occupied by the School of Information, and, briefly, by the English Language Institute. It includes a number of spacious rooms with excellent views, two of which will be retained as meeting rooms in the new design. The roof of the building has functional skylights, but the necessity to run unattractive ductwork through the attic permits exposing these in only a few places. West Hall is a beautiful building — designed by the noted architect Alfred Kahn and built around 1905.

The designers selected at the start of the project were the Quinn-Evans Architects, an Ann Arbor-based team with extensive experience in renovating old buildings. Their portfolio includes the renovation designs of the Kennedy Center, the Colorado State Capital Building, the Grand Rapids Civic Center and Michigan's Hill Auditorium and Dana Building. They have now completed a design for the area and the Regents have given approval for the renovation design to be offered for bidding by contractors.

One feature of the plan is that the laboratory areas assigned to Professors Monnier and Mateo will be relocated to space in Randall — space that was designed from the ground up to serve as a laboratory. This will provide them with more space, and more appropriate space, especially for John's work developing instruments for interferometry.

The offices for the faculty will all be on one floor — an improvement over the current division between two floors. Unfortunately, there will be significantly less space than we currently occupy in Dennison. In order to fit the department into this space, faculty offices will be about ½ of their present sizes. In many respects this is understandable: space near the original 40 acre campus is extremely valuable and under increasing demand. Extensive office space for personal collections of journals used to be critical in Astronomy, but those journals are now always available on the internet. While everyone expects that they will be able to fit themselves and their primary research and teaching materials into the space to be provided, an important

limitation will be the inability of research groups to meet in the faculty offices. Since most departmental research is now carried out in small groups of faculty, research scientists, and students, this limitation is a serious issue.

In order to palliate that issue we were able to work with the architects to develop 4 medium-sized conference rooms within the space. The central core of faculty offices forms an oval around two of these rooms, with a large conference room on one side — all on the third floor.

On the fourth floor, the central showpiece of the offices is a large room, with skylights, where there is space



The open student area. (Photo Credit: Quinn-Evans Architects.)

for all of the department graduate students. Views from this room look north over the Diag. Shared office space for postdoctoral fellows and research scientists runs along the south side of the floor and above the arch, facing north. A particularly large and attractive meeting room looks south from the arch on the fourth floor — although it will remain a College-scheduled room, it is presently under-utilized and we anticipate taking advantage of it.

Some offices will be initially configured for 10 GB internet service and we expect that within 5 years the entire department will operate at 10 GB.

Undergraduates joining the department will have a work area conveniently located on the fourth floor together with an adjoining computer lab. The lab and work area both represent a major upgrade over the current undergraduate space in Dennison. They should make it much easier for undergraduate students to complete projects with faculty.

Overall, the new area represents a compromise. There is less space, and the graduate students will lose some privacy. On the other hand, the space for graduate students will be more interesting, the laboratory space will be much improved, the undergraduate work area will be much better, and network speed will be greater. The challenge for the faculty will be to manage the small meeting rooms effectively to minimize the impact of smaller offices. We should be able to do that.

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