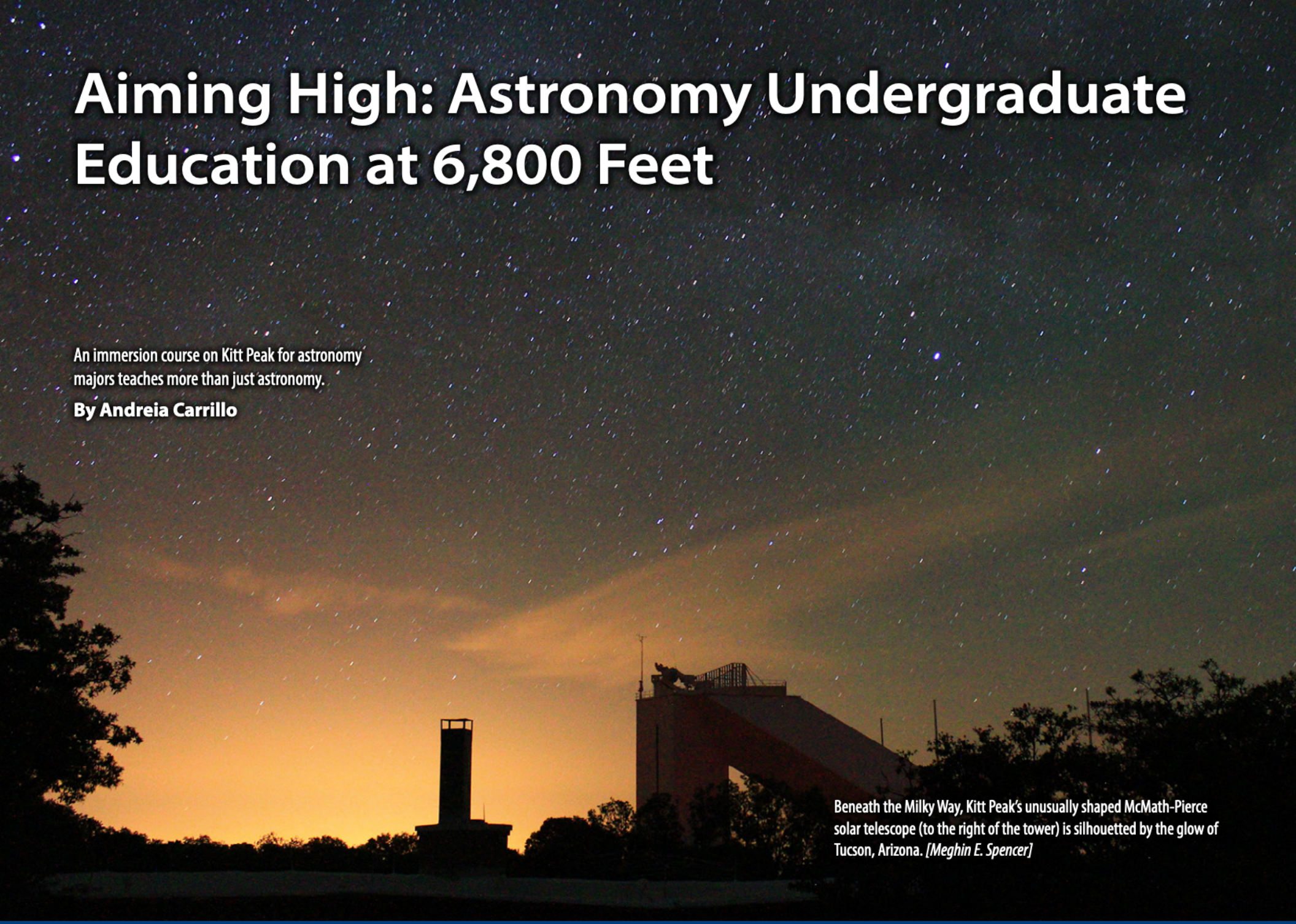
Aiming High: Astronomy Undergraduate Education at 6,800 Feet

An immersion course on Kitt Peak for astronomy majors teaches more than just astronomy.

By Andreia Carrillo



Beneath the Milky Way, Kitt Peak's unusually shaped McMath-Pierce solar telescope (to the right of the tower) is silhouetted by the glow of Tucson, Arizona. *[Meghin E. Spencer]*

How often can you attend a class at 6,800 feet, surrounded by 26 telescopes? When I heard that "Astronomy 461: Ground-Based Observatories" would be offered by the University of Michigan this year, I was so excited that I started recruiting some of my peers. Astro 461, taught by Professor Sally Oey, is a unique immersion class held at Kitt Peak National Observatory (KPNO) in Arizona. It is designed to educate students about the scientific, technical, and political aspects of doing research with ground-based observatories.

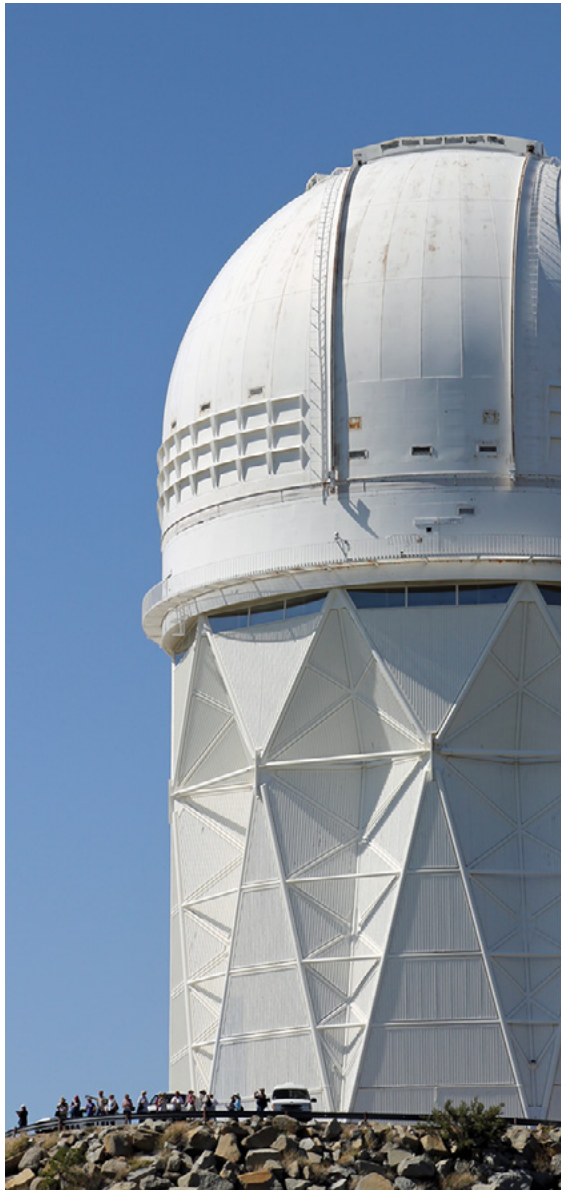
In this four-week class, students visit telescopes and regional observatories to learn about the instruments and their technical properties, supported by lectures from the professor, our Graduate Student Instructor Meghin Spencer, observatory staff, and guest speakers. Also studied is the sociopolitical significance of these scientific facilities, with field trips to other observatories, regional institutions, and museums to help us understand the local environment. Students also conduct research projects based on their own observations, data reduction, and interpretation.

I really wanted to experience these activities for myself. There were nine others, mostly majors in Astronomy and Astrophysics, accepted into the Spring 2015 program. After meeting everyone, I couldn't wait to spend a month working alongside this group of amazing and driven minds!

Starting Out

Stepping out of the Tucson airport, we were greeted by cacti as far as the eye could see and by the intense sun overhead — so different from Michigan. It seemed like a long drive from the airport to Kitt Peak, but eventually we glimpsed the Mayall 4-meter telescope dome. It looked like a little white speck on top of the mountain, but it turned out to be anything *but* little. It's a colossal structure, 18-stories high! After dropping off our baggage in the astronomers' dormitory, we visited the 1.3-meter McGraw-Hill and 2.4-meter Hiltner telescopes of the Michigan-Dartmouth-MIT (MDM) Observatory, which we'd use for our projects. Back in Michigan, we have an excellent 0.4-meter telescope, and I knew that we have bigger telescopes at Kitt Peak and the Magellan Telescopes in Chile. But *seeing* the MDM telescopes myself for the first time was exceptional.

Our typical day started in the morning with a lecture, then a break for lunch prepared by classmates on an assigned rotation. It was a good bonding experience, and I also picked up a few easy recipes! In the afternoon session we toured the telescope facilities that were pertinent to the morning's



The Mayall telescope building; the 4-meter scope is housed in the dome atop the support structure. For scale, note the people and cars at the base of the building. *[Paul Deans]*

TABLE OF CONTENTS

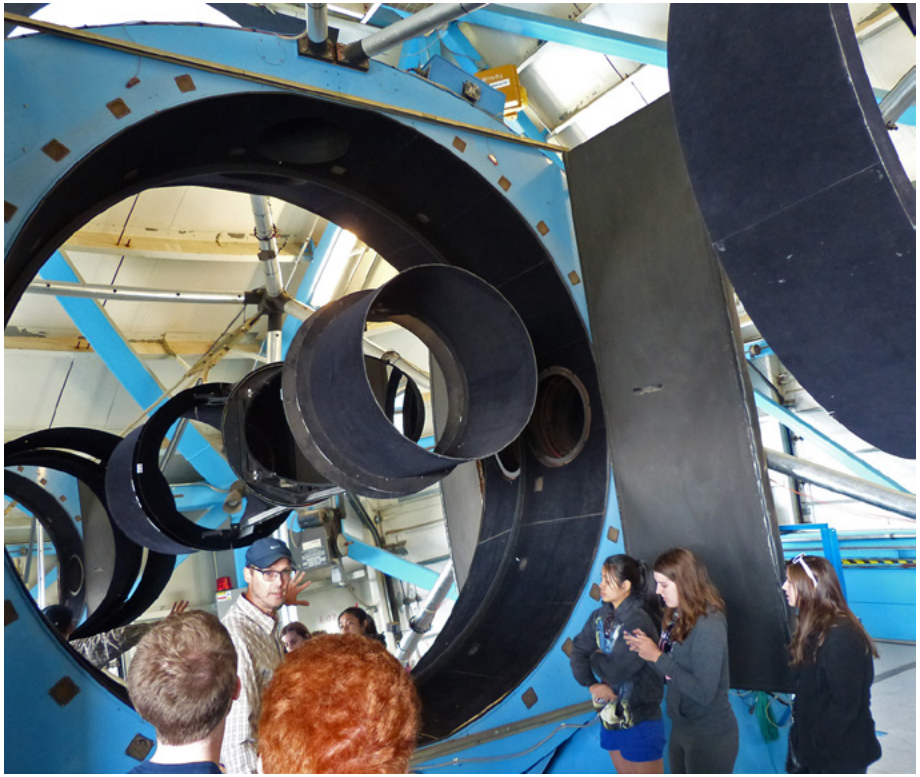
discussions. I found this class structure extremely helpful, because we saw the direct application of what we had just learned. The ideas were still fresh in our minds, and we could ask relevant questions to the observatory staff showing us around. We even shadowed astronomers observing at the 4-meter telescope, and they graciously gave us tips on how to stay awake during observing: if you can, catch up on sleep while on the plane. And of course, we had the usual assignments and quizzes — it was still a class, after all.

A Research Project of Our Own

Astro 461 truly lived up to its reputation as an immersion course by having the students carry out research projects from start to finish. Working in pairs, we created our own research topic and wrote a proposal based on its scientific significance and technical feasibility. We took our own data with the MDM telescopes and reduced them ourselves, after which we presented our findings in talks and posters on our last day of class.

Katie Murray (my research partner) and I made a bubbly duo, but we knew when to get serious, especially before deadlines! Since there are so many topics to explore in astronomy, it was hard for us to choose. There's also a lot to consider when writing a successful observing proposal for your given instrumentation. After many hurdles during the brainstorming process, we finally settled on our research project: supernova remnants (SNRs), the remains of stellar explosions that occur when massive stars die. This process — stars exploding and expelling material into their surroundings — is the source of elements heavier than hydrogen and helium. These blasts can even compress interstellar gas to trigger star formation. Studying SNRs ultimately gets us closer to understanding the life cycle of stars.

So for our project, we decided to observe the spectra of three SNRs to estimate the abundance of expelled elements and confirm their shockwaves. We also wanted to measure their expansion velocities, based on the differences between actual and observed wavelengths of emission features. Lastly, we wanted to image the SNRs to give us insight into the morphology and distribution of materials. Combined with other existing images in different wavelengths such as radio or x-ray, we would get a complete picture of how they have been expanding and affecting their surroundings.



Standing in front of the WIYN's 3.5-meter-diameter mirror, engineer Charles Corson explains the operation of the telescope. *[Sally Oey/U. Michigan]*

As a Time Allocation Committee, we reviewed all the proposals. We all critiqued and ranked them based on their importance, creativity,

TABLE OF CONTENTS

and feasibility. It was one of my favorite activities, because not only was I able to read about the other groups' ideas, but it also stimulated me to think critically about them — even if they weren't in my field of expertise. Professor Oey provided guidance on what to consider when evaluating the proposals, and I'm happy with the feedback and suggestions we received for making our proposal more robust (e.g., aside from pretty pictures of SNRs, why else do we need six hours on the imager?). Our taste of the real world of astronomy research was just getting started, and I was already totally hooked.

Joy and Tears

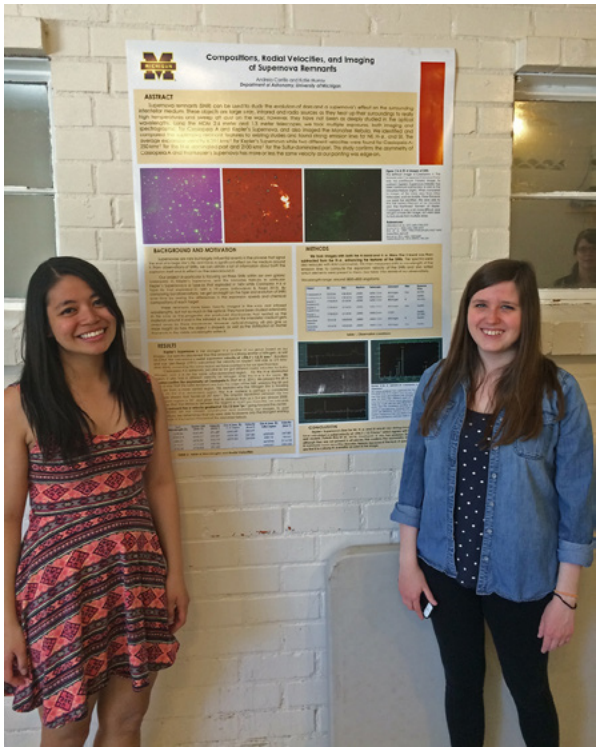
In the days leading up to our observing run, we tried to prepare our biological clocks by staying up later every night. My preparation also involved a lot of coffee. Finally, the day (or I should say night) came to get our feet wet. It was my first time on an observing run, so I felt a lot of pressure! Katie and I took images of Kepler's SNR in R-band (a red-light band). It was a bit underwhelming, because this filter passes a broad range of wavelengths. Thus, light from stars in the same field overwhelms the light from the SNR, which produces line emission only at specific wavelengths, particularly the Hα emission line (emitted as the expanding shell of material cools).

The following night, I obtained images using an Hα narrow-band filter. Seeing them for the first time was like seeing my newborn child. There it was, that wispy concentration of an optically visible shell! Meanwhile, Katie, in the other dome, was finally able to get a spectrum of it, which was so dramatic that it brought her close to tears.

We used IRAF and DS9 software to reduce the data, and some teams even used additional software such as MATLAB and Python. To be honest, it was exhausting at times, especially after doing lot of work only to realize that I was going about it incorrectly. There were so many instances when I wanted to give up, because the best approach is not always clear. So I constantly needed to think of different ways to accomplish my goal. This is something I will never forget, and it will ultimately help me in my career as I go to graduate school and beyond.

By the end of class, we were ready with our research presentations. It was amazing how different our projects were, especially given that we thought of them ourselves. It was so unlike a typical "search on Google and summarize" paper. One team worked on Jupiter's Galilean moons and measured their masses. Another imaged Saturn and looked at its chemical abundances. A third studied newly formed stars with circumstellar disks and compared them to their counterparts on the main sequence. The last team observed merging and non-merging galaxies and studied their star formation. Everyone gave superb presentations, and we also displayed posters of our research to the KPNO staff.

As scientists, it's our duty to make science accessible to the public. Nothing beats the simple sense of wonder conveyed in explanations such as, "This supernova



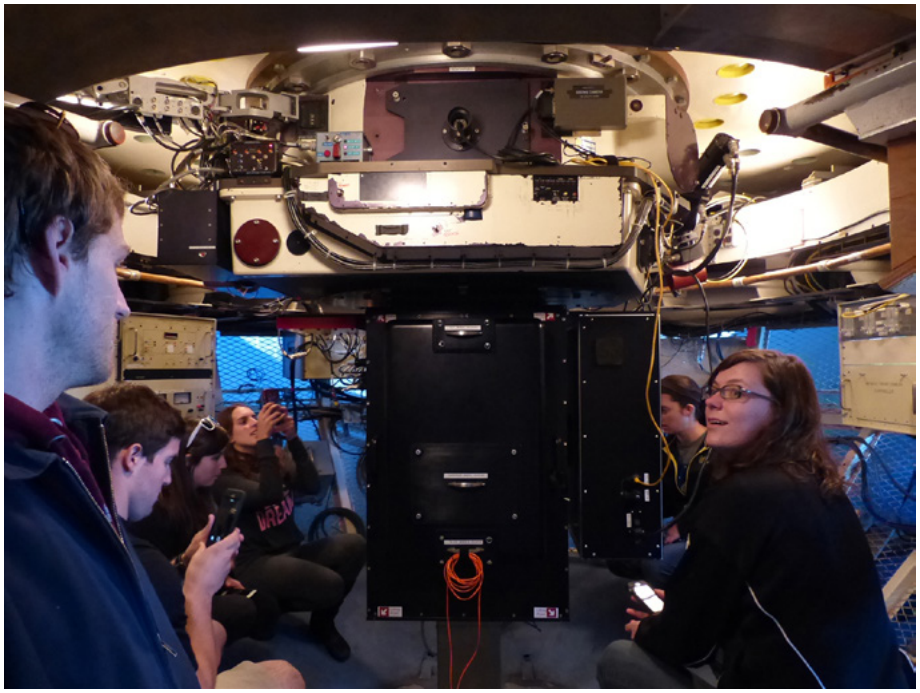
Katie (right) and I present our findings in a poster session for the KPNO staff. *[Andreia Carrillo]*

TABLE OF CONTENTS

remnant is expanding at 2,000 kilometers per second. That's four and a half *million* miles per hour!" These incredible facts are what got me into astronomy in the first place, and it's very fulfilling sharing the same experience with others.

Behind the Scenes

In addition to our research projects, Astro 461 revealed everything involved in ground-based astronomy, from doing science to maintaining the facilities. Of course, we didn't miss the opportunity to visit the telescopes on the mountain. We toured the 4-meter Mayall telescope, the 3.5-meter WIYN telescope, and numerous other facilities to see how their instruments, mounts, domes, and technical specifications differ — and how they ultimately achieve their science goals, based on the technology available when they were constructed.



Engineer Patrick Dunlop (left) takes students into the Cassegrain cage at the 4-meter Mayall telescope. The black box mounted at the focus houses the KOSMOS multi-object spectrograph. *[Sally Oey/U. Michigan]*

The freshly recoated 2.4-meter Hiltner mirror of the Michigan-Dartmouth-MIT Observatory sits, ready to go, at Kitt Peak's realuminization facility. *[Sally Oey/U. Michigan]*

The older telescopes are upgraded as technology evolves. For example, some received dome vents to improve airflow, and some instruments that originally recorded data with photographic plates transitioned to using CCDs. We also had a special chance to visit the aluminization chamber during the realuminization of the MDM 2.4-meter mirror. Tungsten filaments coated with aluminum are heated in a vacuum chamber, and in a flash, the aluminum evaporates and coats the mirror with a reflective surface! The coating is roughly one-

TABLE OF CONTENTS

thousandth the thickness of a human hair and totals only one gram.

There are many important aspects to making everything run smoothly during an observatory's daily operations. For example, we visited the water treatment facility on the mountain. Being in Arizona on a relatively inaccessible mountaintop, the KPNO staff have to be clever to maintain their water supply. The paved surfaces at the summit channel rain water to a large catchment basin, where the water is treated so it's drinkable. Water conservation is taken very seriously here, because in years of drought, they have to transport water from somewhere else, making operations much more expensive.

At times we also visited Tucson, where the Steward Observatory Mirror Lab makes mirrors for next-generation telescopes. This advanced facility uses a rotating oven to naturally shape the melted borosilicate glass into a paraboloid. This allows them to make big mirrors with short focal ratios. Before this technology, people had to precisely grind and polish a huge chunk of solid glass, which isn't practical for a 10-meter telescope! Another cool thing they do is make the mirrors lighter by molding them into a honeycomb structure. This reduces their weight by more than 50% while still giving them stability.

Meeting the people who make it all happen was one of the highlights of the class for me. We met so many engineers, scientists, and facility staff who showed us around and shared their expertise. We talked to people from the International Dark Sky Association and a County Supervisor to learn more about ordinances and efforts to keep Kitt Peak's skies dark, even though it's near Tucson and Phoenix. We met many others, including docents who give tours and keep the public up to date and interested in astronomy.

But the event that stuck with me the most was our lunch with two Tohono O'odham Native Americans, Amy Juan and Capri Childs, who work in the Visitor Center at KPNO. It made me wish that every astronomer could talk with tribe members to hear their perspectives and vision for shared goals of the astronomy and Native communities.

Kitt Peak is the Garden of I'itoi. It's the second-most sacred mountain on the Tohono O'odham Nation, after Baboquivari Peak (located south of Kitt Peak). So it's understandable that Kitt Peak National Observatory was, and still is, a sensitive topic for some, and it is not without its share of controversy. That's why dialog is important, and as clichéd as it sounds, more progress can be made when we work hand in hand. Dr. Katy Garmany, a KPNO astronomer, is working to bridge the gap — to offer more opportunities to the younger

Our group in front of the concrete "donut" that is a double of the 4-meter Mayall mirror. We're flanked by Professor Sally Oey (left) and Meghin Spencer (right). During telescope assembly, the donut acted as a surrogate for the real mirror as it has the same dimensions and weight. *[Sally Oey and Meghin E. Spencer/U. Michigan]*

TABLE OF CONTENTS

O'odham generation to learn about astronomy and the role of Kitt Peak. Amy and Capri sang a beautiful song in their native language about the Garden of I'itoi, filling me with such an overwhelming combination of emotions that I could only let out tears.

The Last Sunset

It felt like time passed so slowly, and then in a snap, it was over. This class went above and beyond my expectations. I came in thinking I'd have mainly a research experience and learn about taking my own data, but I came out with so much more. I think I changed as a person in less than a month. This class made me deeply appreciate everyone's contributions and roles in the field. And my classmates also taught me the value of collaboration and the importance of taking constructive criticism.

But what really stands out for me is how passionate and dedicated everyone was. We were a small group of 10, and it was really up to us to set the tone of the class. Having everyone live together on the mountain was a major factor in this learning process, as we saw each other studying, working on our projects, or reflecting on what we learned by writing blog posts. These reinforced the goals of the class even during our spare time and made us strive for the best — day after day (and night).

It was, for me, starkly different from the other classes I've taken at university — not that I didn't like them, but there was definitely some indifference on my part. I reached a point where I studied and submitted assignments just to pass and get good grades. But my month at Kitt Peak reminded me that I should, and could, study to appreciate and learn. I wanted to have a great research project, because I wanted to know what I am capable of, and actually accomplish it. There's nothing more fulfilling than discovering something on your own. Everyone's engagement in class showed how much they loved studying the material for its own sake — to explore what's beyond our little world, Earth.

Watching our last sunset near the Mayall telescope. *[Meghin E. Spencer]*

After our last, busy day, we walked around the mountain for the final time. That ultimate sunset was very nostalgic. To our right was the 4-meter telescope, the dome rotating as the observer obtained sky flats or perhaps focused on a guide star. Behind us was the WIYN telescope, whose unique silhouette I'll always remember. Below was that snaking road we ascended, full of excitement and wonder and knowledge and passion, the day we arrived. Tomorrow we would descend the same road, armed with so much more than we arrived with. Beside me were the incredible people who inspired me to not give up when I wanted to.

It was definitely one of the most beautiful sunsets I have ever seen. ★

ANDREIA CARRILLO is a senior at University of Michigan majoring in Astronomy and Astrophysics and Interdisciplinary Physics. Along with her classes, research, and graduate school applications, she's also busy with the school's Student Astronomical Society, which educates the public about astronomy with outreach events, public telescope viewing, and planetarium shows.

TABLE OF CONTENTS