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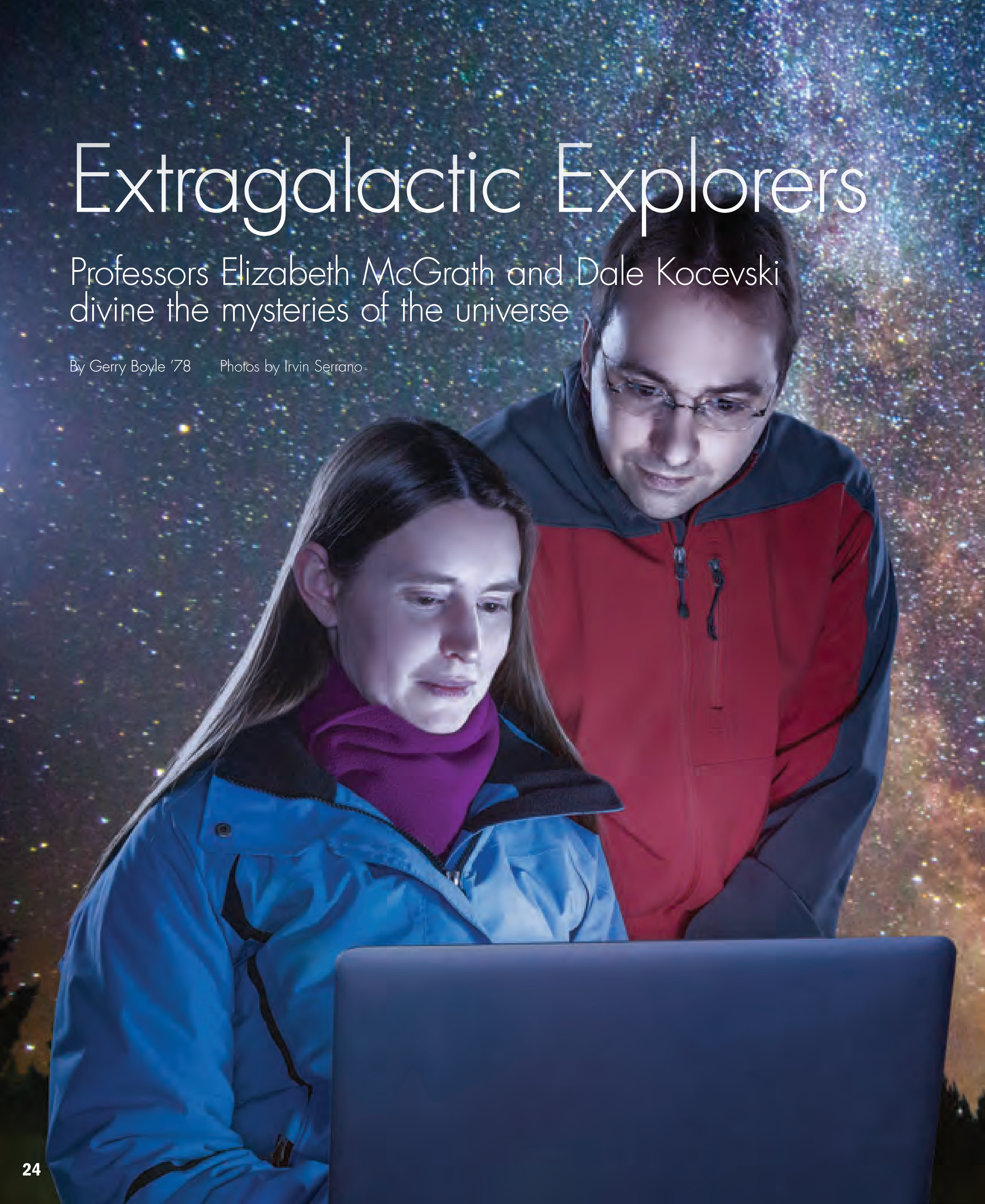
Extragalactic Explorers: Professors Elizabeth McGrath and Dale Kocevski Divine the Mysteries of the Universe

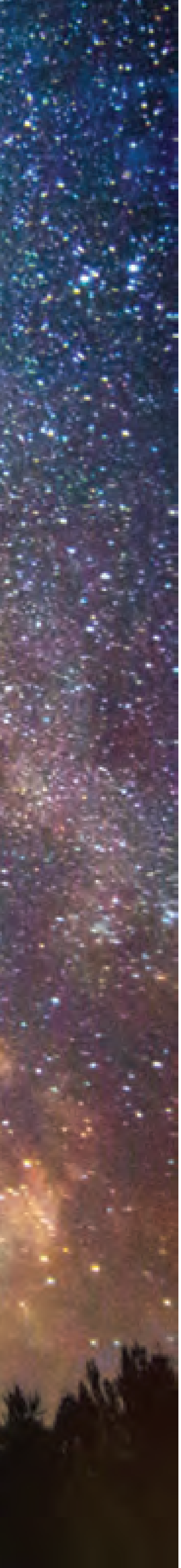
Gerry Boyle
Colby College

Extragalactic Explorers

Professors Elizabeth McGrath and Dale Kocevski divine the mysteries of the universe

By Gerry Boyle '78   Photos by Irvin Serrano





From their offices on the fourth floor of the Mudd Science Building, Elizabeth McGrath and Dale Kocevski enjoy a view that takes in the terraced lawn of the academic quad, the rooftops of Lovejoy and Cotter Union—and distant galaxies as they appeared when the universe was young.

McGrath and Kocevski are extragalactic astronomers, tied to the far reaches and earliest epochs of the universe via computer links to the Hubble Space Telescope, and they are key members of teams made up of some of the world's most highly accomplished scientists in their field.

From high atop Mayflower Hill, Clare Boothe Luce Assistant Professor of Physics and Astronomy McGrath is studying how galaxies form and evolve. "It's exciting to try to understand where we came from. Yeah, you can do that in other sciences, but this is the grand picture."

Assistant Professor of Physics and Astronomy Kocevski studies black holes and how they may regulate a galaxy's life and death. "This is probably the biggest question in astronomy," he said. "What quenches the star formation activity of a galaxy?"

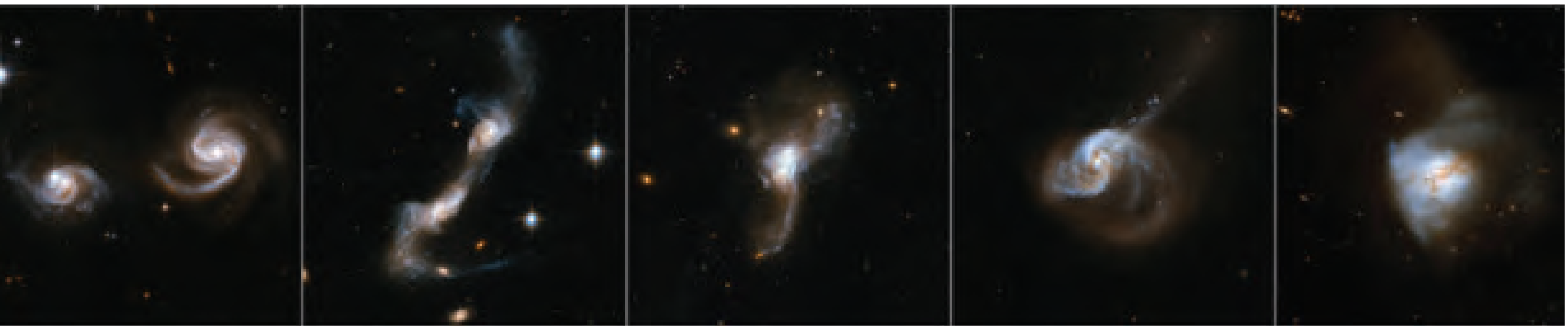
Answering that question is the goal of two NASA grants that awarded $400,000 to Kocevski in July. The first will enable the Colby astronomer and others to use newly available X-ray imaging from the Chandra Space Telescope. The second funds observations on the Hubble Space Telescope that capture images of the black holes of colliding galaxies.

McGrath, meanwhile, will expand her groundbreaking research, which contradicts a long-held explanation of how the most massive galaxies are formed. She made the startling discovery as a graduate student at the University of Hawaii in 2008, and now her team has additional data to consider.

Colby student researchers will be actively involved in both projects, McGrath and Kocevski said, attempting to answer what McGrath describes as "this big-picture question. How did we get from the very beginning to the present day?"

It's important scholarship involving cutting-edge research by elite astronomers, including a large team at the University of California, Santa Cruz. Both McGrath and Kocevski—they are married— did postdoctoral research fellowships there after receiving their doctorates at the University of Hawaii at Manoa. (Both universities' observational astronomy programs are among the best in the world.) McGrath arrived at Colby from UC Santa Cruz in 2012, Kocevski in 2014 after a stint at the University of Kentucky. Their addition to the Colby faculty has connected the College to astronomy work more typically confined to the largest and most prestigious research universities.

It's no accident. McGrath did her undergraduate work—including astronomy—at Vassar, and she longed to teach in a similar system and setting. "I really like the environment at liberal arts schools," she said. "I feel like it's more nurturing, not just for the students but for the faculty as well."



A collection of Hubble Space Telescope images of interacting galaxies. One of the ways galaxies and their central black holes grow over cosmic time is by colliding and merging with their neighbors. Although astronomers cannot watch such an interaction occur in real time (the process takes roughly a billion years to complete), they can piece together the details by imaging galaxies in various stages of such an interaction, as is in the above mosaic.

AURORA KESELLI ’13 STUDIES WITH THE STARS

Aurora Keselli ’13 just needed a course to fulfill her physics major requirement. She ended up with a potential career.

The course was Introduction to Astrophysics, taught by Murray Campbell, the William A. Rogers Professor of Physics, now emeritus. “That really opened my eyes,” Kesseli said. “Everybody has this interest in outer space and the way the universe was formed, and you can answer those questions with physics you’re learning in college physics class.”

Which is just what she did, in two National Science Foundation-funded summer internships at the University of Wisconsin and in a senior honors thesis project overseen by Clare Boothe Luce Assistant Professor of Physics and Astronomy Elizabeth McGrath. Kesseli expanded research done by McGrath earlier, looking for correlations between the shape of galaxies and their age. The senior project concluded that there were more disk-shaped galaxies in the early universe than in galaxies formed later, a finding that challenges what had been conventional wisdom on galaxy creation.

“It was great,” Kesseli said, “at the college level to feel I was contributing to a field.”

She’s continuing to contribute as a graduate student at Boston University, where she is working on a project that considers the initial mass of stars, whether every galaxy is formed with a similar number of stars, and whether the environment can cause variations in that mass.

Kesseli said the work pulls from research she did at Colby and at Wisconsin, creating model galaxies and applying templates of stellar data. “It’s really cool,” she said.

In fact, Kesseli was well prepared by her undergraduate astronomy, though one challenge came early on, she said. She hears all the time that her first name is perfect for an astronomer. But until she got to graduate school, the name wasn’t a distraction.

> **“Everybody has this interest in outer space and the way the universe was formed, and you can answer those questions with physics you’re learning in college physics class.”**
>
> **—Aurora Kesseli ’13**

“At BU the program is space physics and astrophysics together,” Kesseli said. “I never work with the aurora [borealis and/or australis] but a lot of my friends who do space physics specifically study the aurora. I have to desensitize myself from hearing the name ‘aurora’ and responding.”

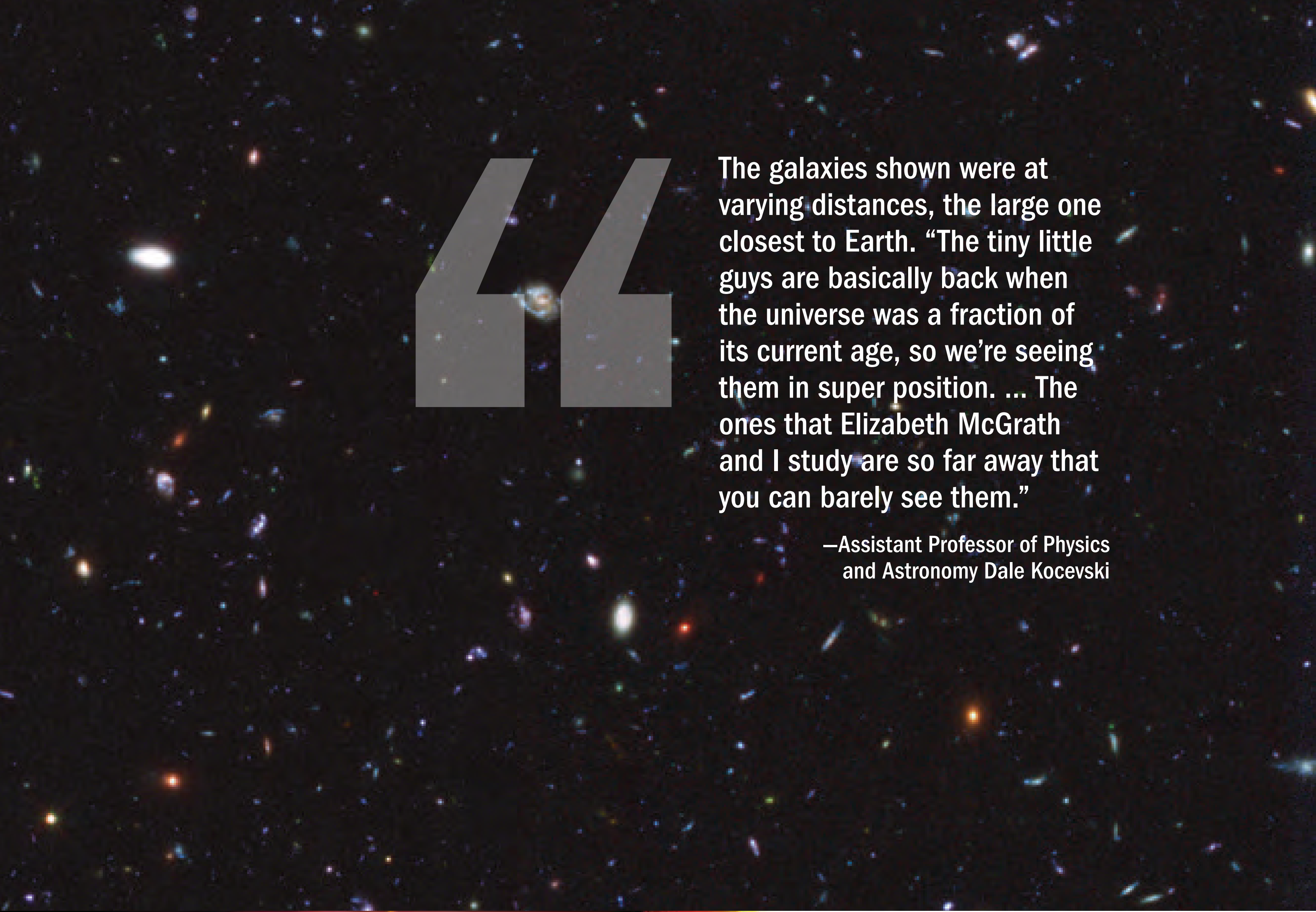
—Gerry Boyle ’78

"There are still two-thirds of the lifetime of the universe where we don't know what happens. We only know what this galaxy was doing seven billion years ago."

—Clare Boothe Luce Assistant Professor of Physics and Astronomy Elizabeth McGrath

The Hubble Ultra Deep Field is the deepest image ever taken by the Hubble Space Telescope. It is a compilation of 10 years of observations studying the same region of the sky, equivalent to a continuous exposure of two million seconds. This image shows large galaxies that are relatively nearby, including spiral galaxies, similar to our own Milky Way, and large yellow-orange galaxies whose star formation ceased long ago. In addition, there are thousands of faint galaxies imaged in the very distant reaches of the universe. The new infrared imaging obtained by the CANDELS (Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey) team, of which McGrath and Kocevski are members, is instrumental in detecting these distant galaxies and aiding studies of how galaxies form and evolve through cosmic time.

Image credit: NASA, D. Kocevski and E. McGrath



> The galaxies shown were at varying distances, the large one closest to Earth. "The tiny little guys are basically back when the universe was a fraction of its current age, so we're seeing them in super position. ... The ones that Elizabeth McGrath and I study are so far away that you can barely see them."
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> —Assistant Professor of Physics and Astronomy Dale Kocevski

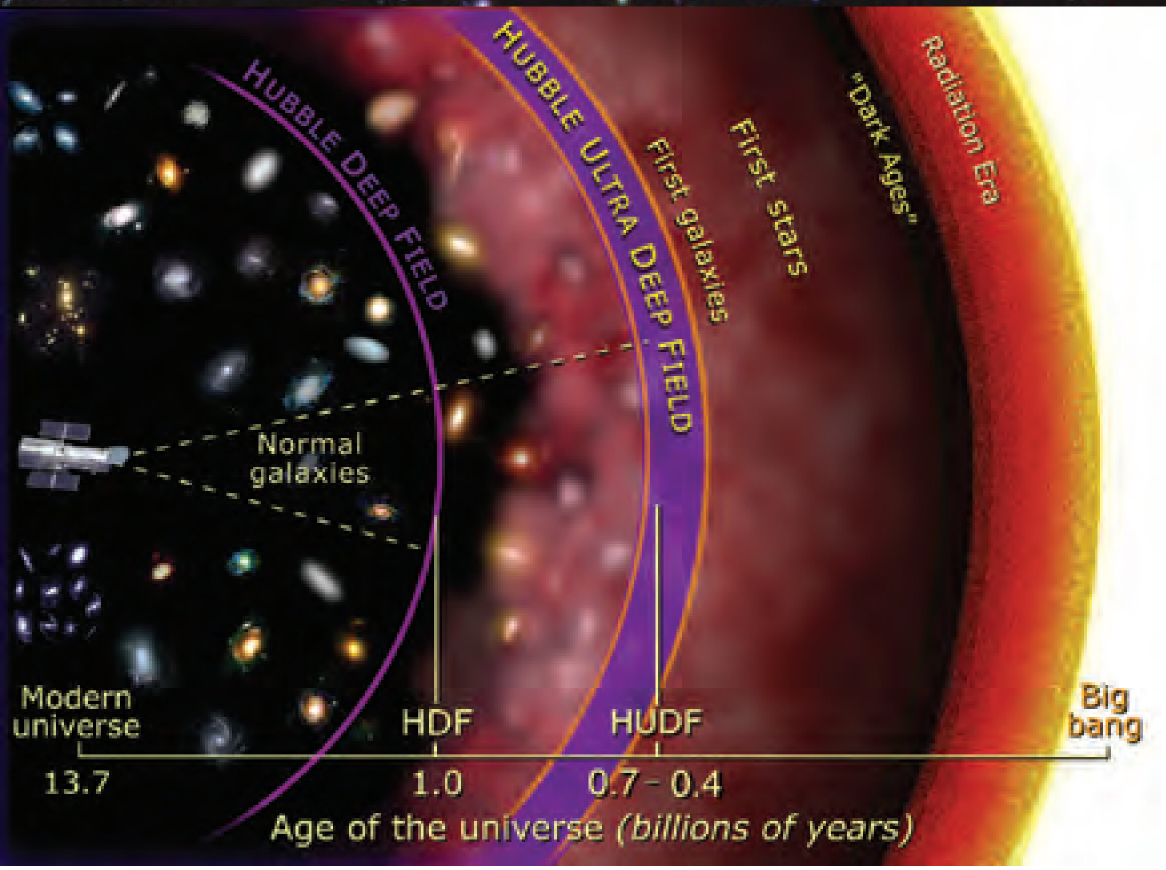
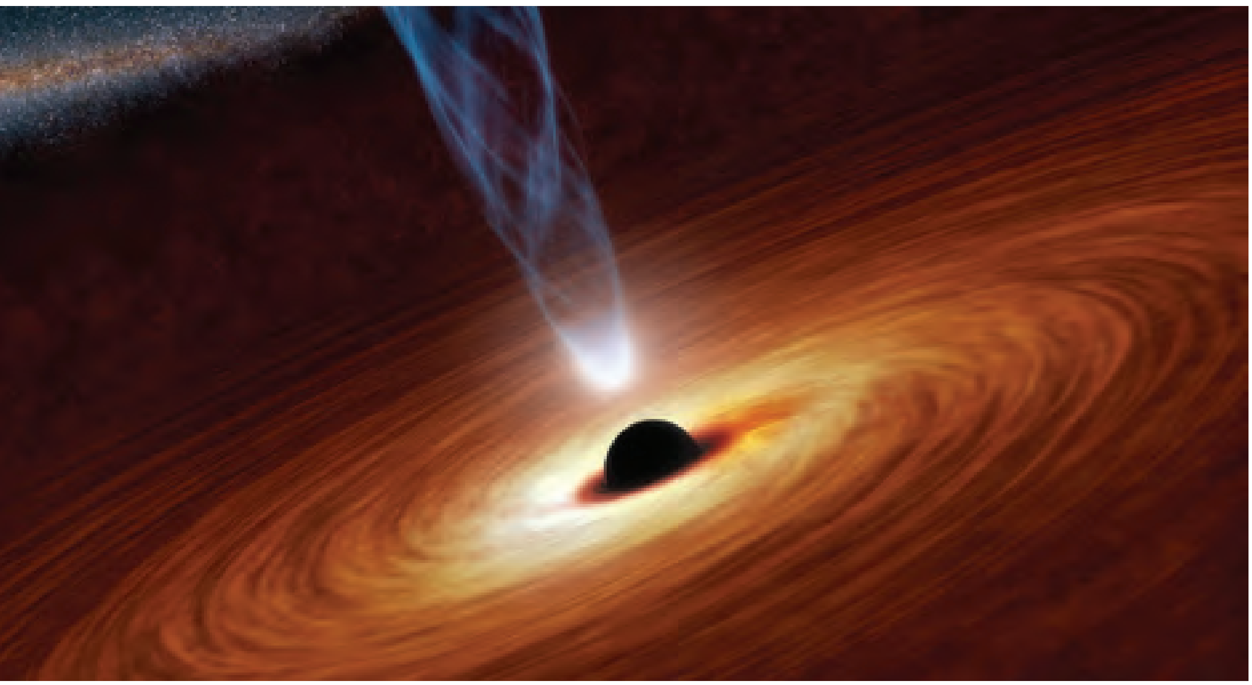


Illustration of the depth by which the Hubble Space Telescope has imaged galaxies in its deep field surveys, in units of the age of the universe. Due to the finite speed of light, looking at distant galaxies provides a glimpse back in time, when galaxies and the universe itself were substantially younger. The goal of surveys such as CANDELS (Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey) is to peer back further and get a wealth of images of galaxies as they existed when the universe was a quarter of its current age. Illustration credit: NASA and A. Feild (STScI).

And working with researchers around the country?

"With weekly telecoms, I'm in constant contact with all of these people," said McGrath, who wrote a blog post for her professional research team's site about the experience and rewards of teaching astronomy at a liberal arts college. "Here I feel like what I do matters. The teaching—people appreciate that."

McGrath and Kocevski teach physics and astronomy and already have seen students go on to graduate work in astronomy [see sidebar P. 26]. At Colby, McGrath said, advanced students help upcoming students, a dynamic similar to that found in a consortium of postdocs and graduate students. And, she said, interesting and surprising observations come from students in introductory classes as well. "They'll ask a question about something, like black-hole physics, that I never really thought of before. And it turns out to be a really insightful question."



An artist's impression of a supermassive black hole surrounded by an accretion disk of infalling gas and a jet of high energy plasma. As gas spirals into a black hole, it rapidly heats up and emits immense amounts of energy, making the system visible at a variety of wavelengths. The outflowing jet is thought to be created by the twisting of magnetic fields in the accretion disk, but the precise mechanism responsible is still unknown.
Illustration credit: NASA/JPL-Caltech

There are more questions than answers in a subject that McGrath describes as "a big unknown" despite astounding advances in technology in recent years. It was one of those technological leaps—the Hubble—that enabled the then graduate student to poke a hole in accepted theory of how the most massive galaxies in the universe were formed.

This was in 2008, when some astronomy theories were still just theories because scientists had no way to see the most distant parts of the universe up close. The theory was that massive galaxies (10 times the size of our Milky Way galaxy) formed by absorbing smaller galaxies, a process that continued for billions of years. Scientist believed that small disk-shaped galaxies collided with other disk-shaped galaxies, disrupting the galaxies' rotations and transforming them to a rounder, spherical shape.

Enter McGrath and her colleagues—and the fresh images from Hubble.

She studied the new evidence from the early universe and found that there were massive disk-shaped galaxies that had gone through their life and death cycle ("death" occurs when a galaxy is no longer forming stars). They had grown to massive size and hadn't gone through the structural changes expected in the merging theory.

"We weren't expecting to see this at all," McGrath said. In fact, "it took a long time to actually get traction in the theoretical community. These results were at such odds with the merger picture, and people were sort of holding onto the merger picture. And I was just one grad student saying this."

McGrath wasn't entirely dispelling the merger theory, but the evidence did suggest other processes were at work that could be just as important. The knock on her conclusion was that she'd only studied six galaxies—that maybe they were just some weird anomaly? It is, after all, a big universe out there.

So now McGrath and Kocevski are involved in a project that widens the field of observations for studies like this. CANDELS (Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey) is a massive effort that uses images gleaned by a new camera installed on Hubble in 2009. Like handing someone the first pair of binoculars, the near-infrared camera enables scientists to see farther into space, nearer to the Big Bang than ever before.

And the new information has produced more evidence that backs McGrath's original observations, so much so that theorists are developing new models to reproduce that reality that we now see. That reality, she points out, is already dated,

representing a period in the evolution of the universe that is long over. Observations made of the state of the universe when it was a third of its current age (an estimated 14 billion years) leave a big part of the story still untold.

"There are still two-thirds of the lifetime of the universe where we don't know what happens," McGrath said, gesturing toward an image on her computer screen. "We only know what this galaxy was doing seven billion years ago."

So little time and, for extragalactic astronomers, so many billions of years to cover.

But with each passing week, each new image from deep space, more mysteries of the universe are being discovered. Kocevski continues to study data from the Hubble that is the fruit of a NASA grant he received while at UC Santa Cruz in 2009, while new data from last summer's grant pours in.

"Actually, I just got observations," he said, in his Colby office recently. "They're relayed to the ground today and then processed. I'll get an e-mail probably tomorrow or the next day. Pull it, download it, analyze away."

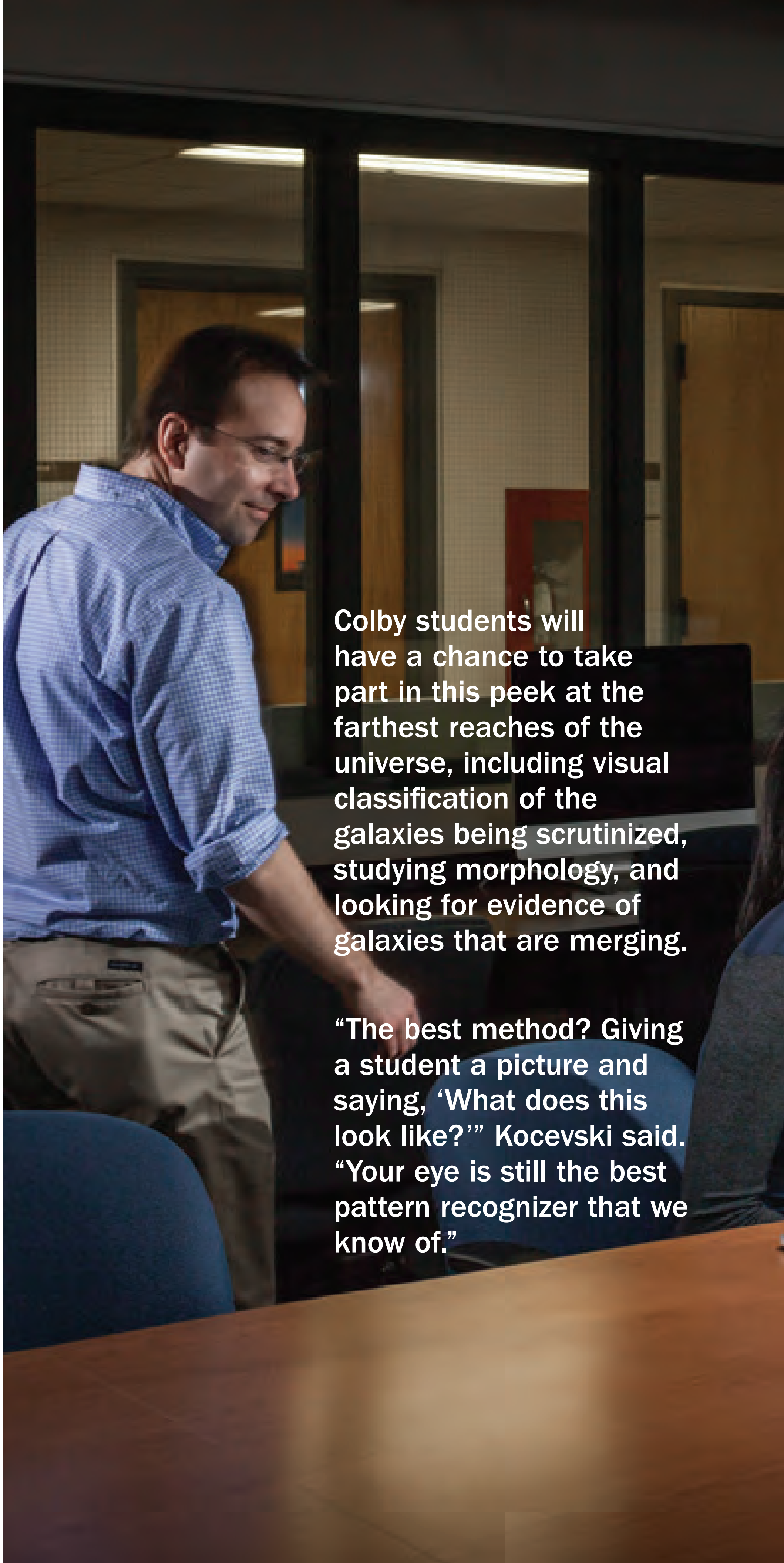
Observational astronomers like McGrath and Kocevski are wholly dependent on what is referred to as "Hubble time," the use of the Hubble's cameras, which are so in demand that grant awards are measured, not only in dollars, but in seconds.

For the past two years, Kocevski has served on the selection committee for guest-observer grants for the Hubble. Of the thousand proposals received, only about 10 percent are selected to receive Hubble time, he said.

And what does that get you?

"I'll show you," Kocevski said.

He pulled up an image of a field of about 50,000 galaxies. Each galaxy looked like a fuzzy star, and like stars they showed different colors. The galaxies shown were at varying distances, the large one closest to Earth. "The tiny little guys are basically back when the universe was a fraction of its current age," Kocevski said, "so we're seeing them in super position. … The ones that Elizabeth McGrath and I study are so far away that you can barely see them."



Colby students will have a chance to take part in this peek at the farthest reaches of the universe, including visual classification of the galaxies being scrutinized, studying morphology, and looking for evidence of galaxies that are merging.

"The best method? Giving a student a picture and saying, 'What does this look like?'" Kocevski said. "Your eye is still the best pattern recognizer that we know of."

Professors Elizabeth McGrath, right, and Dale Kocevski, left, confer with, from left, Jianing Yang '18, Ryan Cole '15, and Max Jennings '15.

Kocevski studies the massive black holes that are at the center of most galaxies, typically a billion times more massive than individual stars like our sun. Some of the black holes are more than just supermassive. They are absorbing gases and even stars, emitting vast amounts of energy and becoming what astronomers call an active galactic nucleus.

How active? Some AGNs outshine the starlight of their entire host galaxy. And if an AGN really gets going, it can actually suppress the galaxy's star formation and halt its growth, Kocevski explained. "We think that one of the outcomes of having these black holes at the center of the galaxies is that they regulate the life and death of a galaxy," he said.

Stop a galaxy's star power and it's dead.

But in a science of unknowns, more questions remain about the connection between the evolution of galaxies and their central black holes. Kocevski's two NASA grants should help to get closer to the answers.

One grant allots observing time on the Chandra Space Telescope, which, along with the Hubble, is one of what are called the four "Great Observatories." It uses X-rays to survey deep space, which, it is hoped, will allow the team to detect gas from growing black holes—at a time when black hole growth was at its peak. The observations are expected to provide a glimpse of the earliest black hole ever detected, Kocevski said.

Data from a second NASA grant provides additional observing time on Hubble, now equipped with an infrared camera. Kocevski and his colleagues want to find evidence of galaxies that have "just" collided, creating black holes still shrouded by gas and dust. Doing this means examining images of galaxies back when the universe was just three billion years old, sort of in its cosmic adolescence. "This is the first time that we can actually study galaxies at those distances," he said.

McGrath's and Kocevski's work is full of "firsts" and "farthests," as technology peels back the layers that lie

between us and the birth of the universe. Colby students will have a chance to take part in this peek at the farthest reaches of the universe, including visual classification of the galaxies being scrutinized, studying morphology, and looking for evidence of galaxies that are merging.

This, Kocevski said, is a task they will perform at Colby with one of the most sophisticated pieces of optical equipment ever produced: the human eye.

"The best method? Giving a student a picture and saying, 'What does this look like?'" Kocevski said. "Your eye is still the best pattern recognizer that we know of."

The recent grant awarded Kocevski's project 30 orbits of the Hubble. That data will be sent back to Earth by this spring, he said, and a Colby student researcher will study and classify the images.

Both Kocevski and McGrath exude excitement as they talk about their work, the formation of galaxies, the unknowns that remain out of reach of human technology, if not the human imagination.

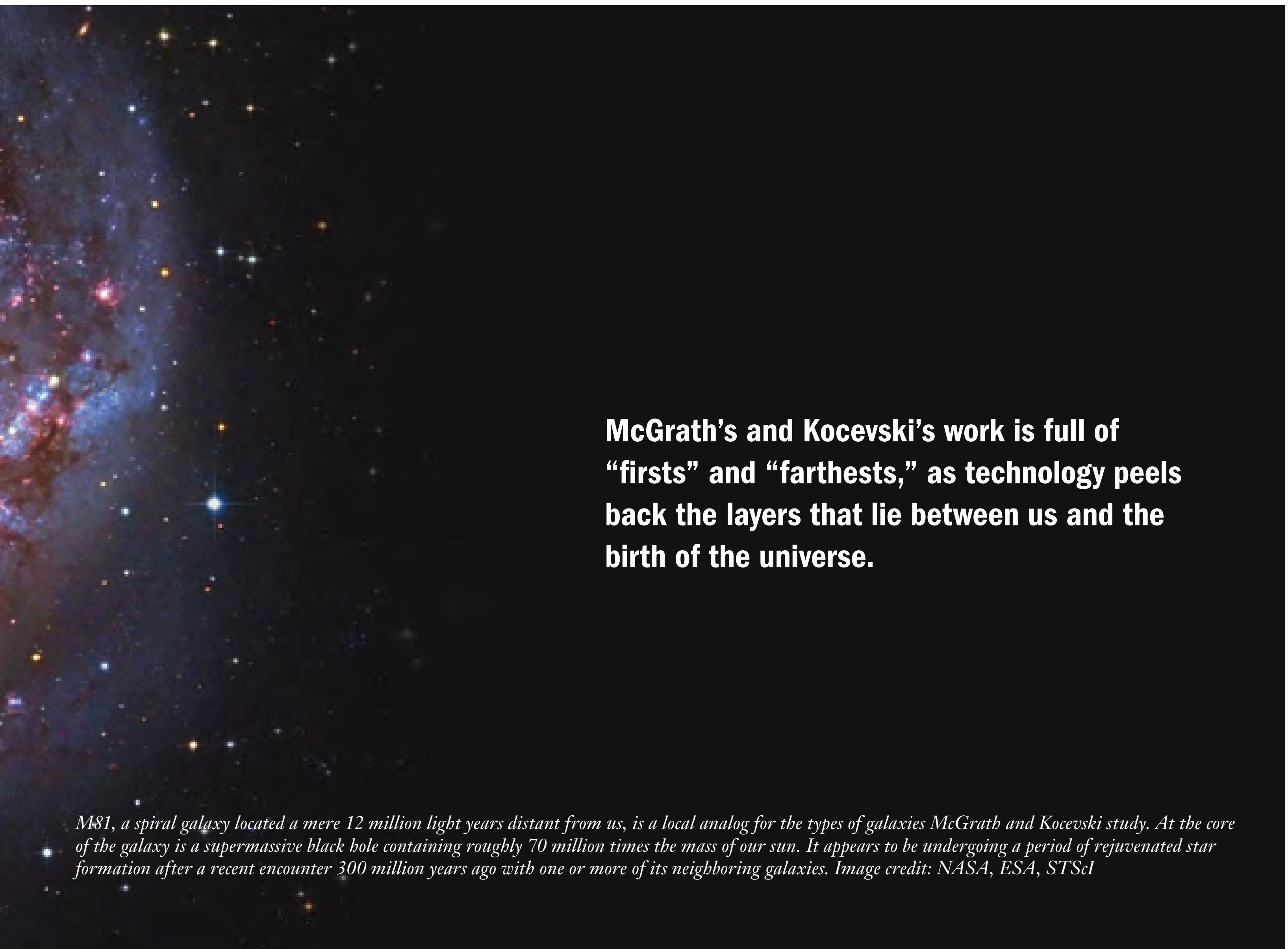
McGrath speaks about the amazement she still feels when she looks up at the Milky Way splashed across the sky, and as she teaches undergraduates she reaches back to her own experience in undergraduate astronomy. "What was exciting to me then?"

But as scientists, both Colby astronomers are fixed on the future and the mysteries it will reveal as technology reaches farther into space and time.

"We definitely know what we want to test," Kocevski said. "We want to see a galaxy right after the Big Bang to see what's happening. We simply can't see that far." Yet.

The next-generation James Webb Space Telescope, he noted, launches in 2018.

High atop Mayflower Hill, astronomers can't wait.



McGrath's and Kocevski's work is full of "firsts" and "farthests," as technology peels back the layers that lie between us and the birth of the universe.

M81, a spiral galaxy located a mere 12 million light years distant from us, is a local analog for the types of galaxies McGrath and Kocevski study. At the core of the galaxy is a supermassive black hole containing roughly 70 million times the mass of our sun. It appears to be undergoing a period of rejuvenated star formation after a recent encounter 300 million years ago with one or more of its neighboring galaxies. Image credit: NASA, ESA, STScI