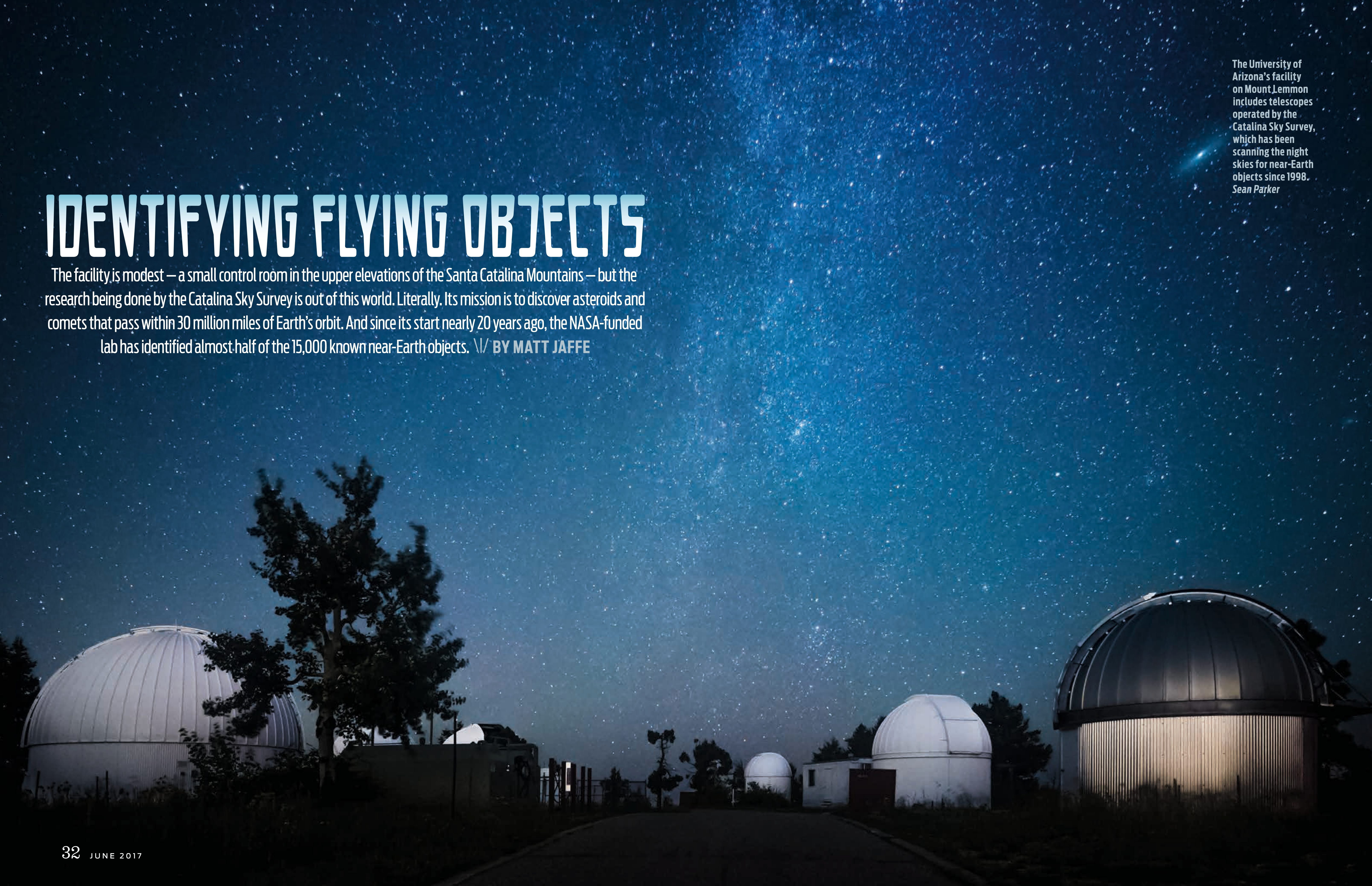
IDENTIFYING FLYING OBJECTS

The facility is modest — a small control room in the upper elevations of the Santa Catalina Mountains — but the research being done by the Catalina Sky Survey is out of this world. Literally. Its mission is to discover asteroids and comets that pass within 30 million miles of Earth's orbit. And since its start nearly 20 years ago, the NASA-funded lab has identified almost half of the 15,000 known near-Earth objects. \|/ **BY MATT JAFFE**



The University of Arizona's facility on Mount Lemmon includes telescopes operated by the Catalina Sky Survey, which has been scanning the night skies for near-Earth objects since 1998. *Sean Parker*

IT CAME FROM OUTER SPACE. A LONG TIME AGO. Bright gold and shedding glowing debris, a small asteroid surged across the violet afternoon sky. I was hiking near Northern New Mexico's Brazos Cliffs, and I remember the tail as a mix of pink and green light in those long seconds that it etched a nearly horizontal streak above the granite ridge. Then, nothing. Gone.

This was a time before smartphone cameras. There were no dashcams to record the moment in living color, no social media to tweet my wonder in 140 characters or fewer. Hiking alone, I didn't even bother with a "Did you see that?" after witnessing the daylight fireball.

I'm in the Santa Catalina Mountains, describing this moment to Eric Christensen, director of the University of Arizona's Catalina Sky Survey (CSS), one of a handful of NASA-funded programs with the mission of discovering asteroids and comets that pass within 30 million miles of Earth's orbit.

We're in the chilly control room for the survey's Schmidt telescope, up an icy forest road off the Catalina Highway, at 8,200 feet, on Mount Bigelow. Senior research specialist Gregory Leonard sits at a bank of monitors where, just the night before, he found 10 new near-Earth objects (NEOs). Since its start nearly 20 years ago, the survey has identified 45 percent of the 15,000 known NEOs, including a record 930 in 2016.

The CSS is part of the university's esteemed Lunar and Planetary Laboratory (LPL), founded in 1960 by Gerard P. Kuiper — for whom the Kuiper Belt, the vast area of frozen objects and rocks on the edge of the solar system, is named. The LPL is also leading the OSIRIS-REx project, which in September 2016, at Florida's Cape Canaveral Air Force Station, launched a satellite that in 2020 will intercept and later gather rock from the asteroid Bennu.

Christensen grew up in Boise, Idaho, and came to the university as a fine arts major specializing in ceramics. Growing up, he also had a deep interest in astronomy, and after first working on infrastructure and telescope maintenance on Mount Lemmon, Christensen began observing for the survey in 2003. That May, he made his first discovery: a comet that now bears his name. Since then, he's found 23 more.

Christensen tells me he's never seen a daylight fireball, then puts my sighting into perspective. Asteroids like the one I observed, probably the size of a baseball or basketball, are nothing unusual. Ten-foot asteroids strike Earth monthly. Nor was Chicken Little just crying wolf: According to NASA, 100 tons of space material reaches Earth every day. The sky really *is* falling.

But this chunk of rock was big enough and bright enough to be visible during daylight. And Christensen says it briefly connected me, over an almost unfathomable chasm of time and events, to the very origins of the solar system.

"Your history and its history converged," he says. "You were born when and where you were born, then led a life that brought you to that place at that specific time. Meanwhile, on the other side, back at the beginning of the solar system, this object was created or came off another object in a collision. Its orbit evolved over time, or changed; then, it maybe suffered more collisions.

"We think of the solar system as infinite. But any given rock, any given asteroid, often has an end state. On that day, at that moment, you were able to witness the end of this particular asteroid. After maybe four and a half billion years."

INDEED, THEY'RE OUT THERE: comets and asteroids. Some are tiny, while others are large enough that in the unlikely scenario of striking Earth, they could trigger extinction-level events, such as 65 million years ago, when a roughly 6-mile-wide asteroid gouged the 110-mile-wide Chicxulub Crater along Mexico's Yucatán Peninsula.

A fireball spread out hundreds of miles, as did a towering tsunami. A massive earthquake rocked the planet. Ash and debris from the impact, roughly equal to 100 million megatons of TNT, eventually obstructed sunlight and led to a global winter that killed off the dinosaurs, as well as most life on Earth. Talk about your terrible, horrible, no good, very bad days.

Nor do asteroids have to be nearly that big to leave their mark. Just detour off Interstate 40 west of Winslow, to Meteor Crater. The object that created that 1-mile-diameter, 550-foot-deep impact crater was only about 130 feet wide. Then again, it weighed 300,000 tons and slammed into the ground at 26,000 mph.

So the prospect of a collision with an asteroid or comet stirs a certain morbid fascination — if not apocalypse now, then apocalypse maybe, someday. Hollywood, for one, loves a good end-of-the-world scenario, and in 1998, two hit movies — *Deep Impact* (the better of the two) and *Armageddon* (the more profitable) — explored the idea of an NEO clobbering us.

That was also the year that the Catalina Sky Survey began operations. Four years earlier, the world watched with a measure of planetary schadenfreude as Comet Shoemaker-Levy 9 smashed into Jupiter. Inspired by that event and hoping to identify threats to Earth, the LPL's Steven Larson wrote a proposal to launch the survey, then received NASA funding. The CSS joined Spacewatch, the LPL's existing NEO project; it observes from Kitt Peak National Observatory, which is located southwest of Tucson.

Although the CSS expanded from its modest beginnings and now operates three telescopes on Mount Lemmon, the Mount Bigelow control room feels a bit like a basement where my geeky buddies and I played Risk in junior high, albeit with a bank of powerful computers humming in the background. Posted on the cheap wall paneling, there's a *National Geographic* Milky Way map and a photo of Comet Skunk, the survey's mascot. According to the caption, this Western spotted skunk earned the name for his comet-like traits: fuzzy white tail, occasional outgassing and tendency to stir panic during close encounters. Larson arrives in the control room and further explains that Comet Skunk, forever seeking warmth, had an uncanny ability to find ways into the observatory before settling contentedly on the control-room couch. Yet no outgassing incidents occurred prior to Comet Skunk's successful relocation to nearby Bear Canyon.

If the control room looks like a clubhouse, then the domed

Star trails form over a creek in the Santa Catalina Mountains' Sabino Canyon in a long-exposure photograph. *Jeff Maltzman* telescope room currently resembles a do-it-yourselfer's garage. Maxwell House coffee cans, filled with washers, screws and bolts, are lined up on a table. Across the room, a red Sears Craftsman workbench stashes drill bits, sandpaper, wire and socket wrenches.

As part of ongoing improvements designed to allow observers to both cast a wider galactic net and observe the sky in greater detail, the survey is upgrading the Schmidt telescope's camera and optics. While a crew from the university performs more complicated work, survey astronomers handle much of the upgrade, as well as ongoing maintenance.

"If it's out of alignment, you get to align it," Christensen says. "The telescope needs grease? Then you grease it. We're all involved at more than one level, with observing, writing software and adjusting the optics. We wear different hats on different nights."

Observers typically drive up the mountain for three-night shifts. After choosing a section of the sky, telescopes make pictures of that area every five to 10 minutes. Typically, 200 different fields are photographed, generating as many as 1,000 images some nights.

Computers conduct an initial screening to identify potential NEOs, which range from 1 yard to more than 2 miles across. Christensen says even though the computers rapidly process massive amounts of data, astronomers still must filter out false detections — sometimes hundreds of them. Then, Christensen and Leonard show me an actual NEO discovered the previous night. Seen in a sequence of photos, the object's trajectory is unmistakable as it races against a fixed backdrop of stars.

This is astronomy for the rest of us. Deep-space astronomy observes an incomprehensibly distant past, the light from events that took place billions of years ago. The collected data might not be analyzed for months, or even years. But the survey's work is near Earth and virtually in real time. "We're often analyzing within five minutes of the last image being taken," says Christensen. "It's an unusual way to run a telescope."

One morning in October 2008, survey observer Richard Kowalski identified a small NEO, maybe 10 feet in diameter, and reported it to the Minor Planet Center in Cambridge, Massachusetts. Researchers calculated that the object would enter the Earth's atmosphere above northern Sudan the next day.

Less than 21 hours after the discovery, the asteroid exploded about 25 miles above the Earth as it traveled nearly 8 miles per second. The incident marked the first time the location and time of a potential NEO impact were accurately predicted.

"So we're one up on the dinosaurs," Larson says.

"What we do is like Coast Guard work," Leonard adds. "There's stuff literally falling down on us all the time. Rocks from space. In this job, it's as if we get to touch space."

IF THE SKY SURVEY is our first line of defense against potential space invaders, then the OSIRIS-REx mission is a discovery expedition, the 21st century counterpart to the trailblazing explorations of Lewis and Clark.

It's an audacious effort that will span seven years as the satellite first travels to and then explores the asteroid Bennu, which orbits the sun at 63,000 miles per hour. Nor is Bennu just some random asteroid. Out of 500,000 contenders, only five satisfied the mission's criteria, which included size, distance from Earth and composition. With a diameter of a third of a mile, a thick middle and the stout build of an NFL nose tackle, Bennu consists of carbon-rich material that scientists anticipate is rich in organic compounds present in the solar system 4.5 billion years ago, when Earth was forming. Those compounds could help explain how early life on Earth developed.

After spending two years mapping Bennu's surface and examining its composition, in July 2020, the satellite will deploy an 11-foot robotic arm, known as TAGSAM (Touch-and-Go Sample Acquisition Mechanism), near the asteroid's surface. A five-second blast of nitrogen gas will then dislodge material for collection. If it all works, in 2023, a capsule will deliver to Earth between 2 ounces and 4.5 pounds of dust and gravel — the most material returned from space since the Apollo lunar missions more than 50 years earlier.

So, with only enough nitrogen for three attempts, this seven-year mission, first conceptualized in 2004, comes down to just 15 critical seconds.

For OSIRIS-REx principal investigator Dante Lauretta, the close encounter with Bennu — which he calls "the moment of truth, the moment of terror" — is a culmination not only of the mission, but of a boyhood dream. Growing up in New River north of Phoenix, Lauretta aspired to be an explorer — hardly a promising career path in the waning decades of the 20th century.

Undaunted, Lauretta still hoped to boldly go where no man had gone before. He backpacked in the desert for days, certain he could reach a pristine place, only to notice a beer can on the ground nearby. So Lauretta concluded he would have to explore the solar system instead.

Referring to the fragments of asteroids and other space objects that survive entry into Earth's atmosphere, Lauretta says: "Meteorites were a way for me to be an explorer. Because that's where the true firsts are still available to us. You can have the experience — when you're holding an ancient fossil that's billions of years old and then cut it open — that you're going to see something that nobody has ever seen before. A great scientific discovery."

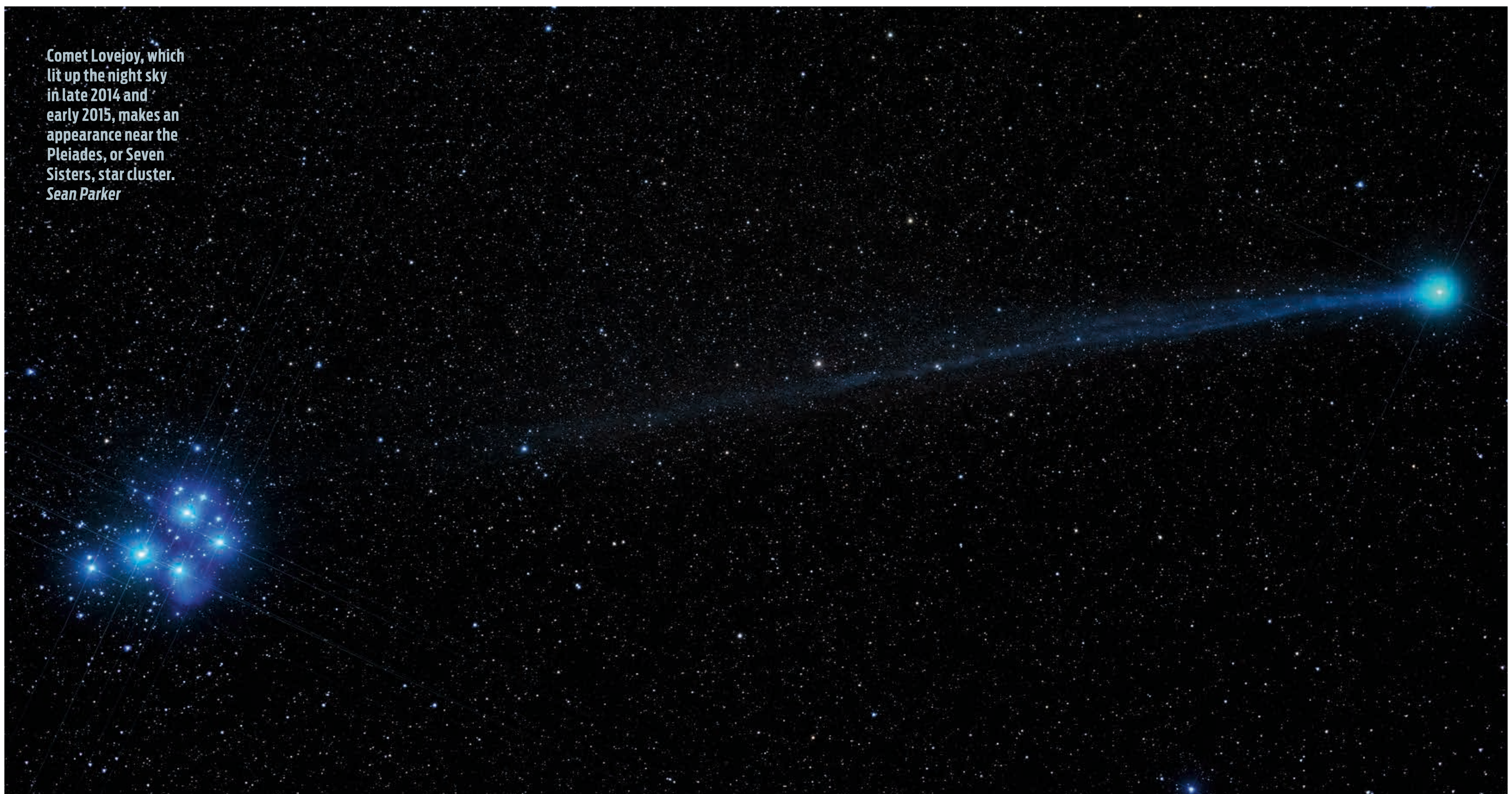
The operations center for OSIRIS-REx is not on campus, but in a low-slung contemporary building west of the university, surrounded by streets of older houses with low stone walls and prickly pear thickets in their yards. The building is named for Michael J. Drake, the late planetary scientist and LPL director who championed OSIRIS-REx and worked on the project until his final days.

Drake was Lauretta's mentor and inspiration. "He was a very big thinker. He asked the big questions, and he went after them," Lauretta says. "He wasn't intimidated. He always said to me, 'If you're going to make an impact in science, you have to ask the right questions. That's where it all starts.'"

Lauretta says asteroids just may offer the big answers to those big questions: Why is the Earth unique? Why is this a habitable planet? How did life begin?

"They tell the story of how our solar system came to be," he says. "I was just fascinated by that whole idea that you could hold a rock in your hand that's older than the Earth itself, that represents the dawn of our solar system. With the organic molecules that may be our ultimate ancestors."

I'll admit to a measure of envy as I listen to Lauretta describe what it might be like to truly touch both space and time. As I think back to the daylight fireball, I'm intrigued by the convergence of the spiritual and the scientific that it and other asteroids represent, as well as their inherent contradictions. They are the deliverers of life and potentially the destroyers of worlds, both solid and ephemeral — objects that have endured forever, only to arrive on Earth and sometimes disappear in a flash. AH



Comet Lovejoy, which lit up the night sky in late 2014 and early 2015, makes an appearance near the Pleiades, or Seven Sisters, star cluster. *Sean Parker*