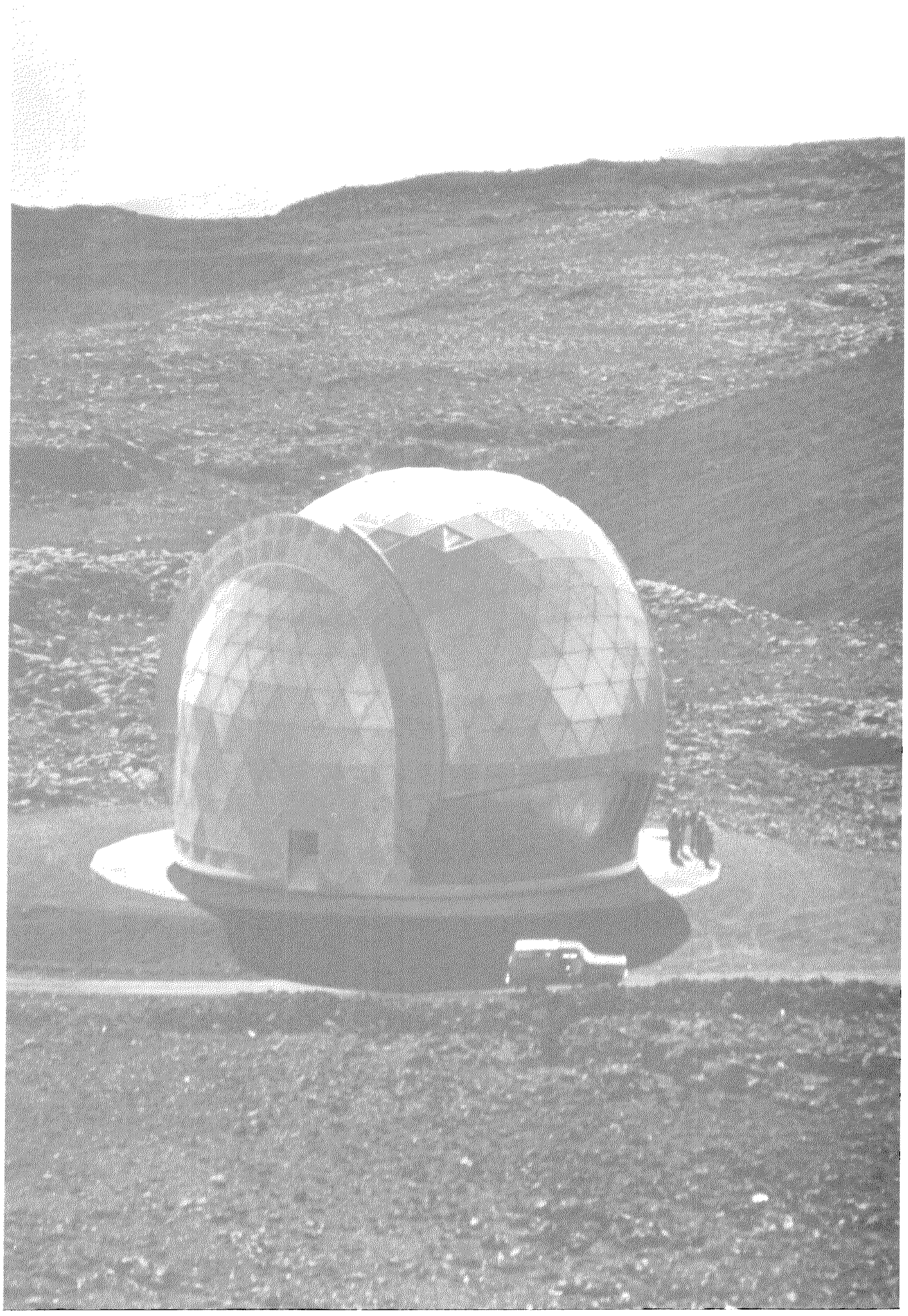


Life on Mauna Kea: The Fascination of What's Difficult

"Being at Mauna Kea is a kind of rite of passage for astronomers."

The Caltech Submillimeter Observatory, a 10-meter radio dish under a sheltering dome, sits on an outcropping of volcanic rock close to 14,000 feet above sea level on Mauna Kea, Hawaii. One of eight telescopes now operating at the extinct volcano's summit, the CSO is the first Caltech facility to open there.

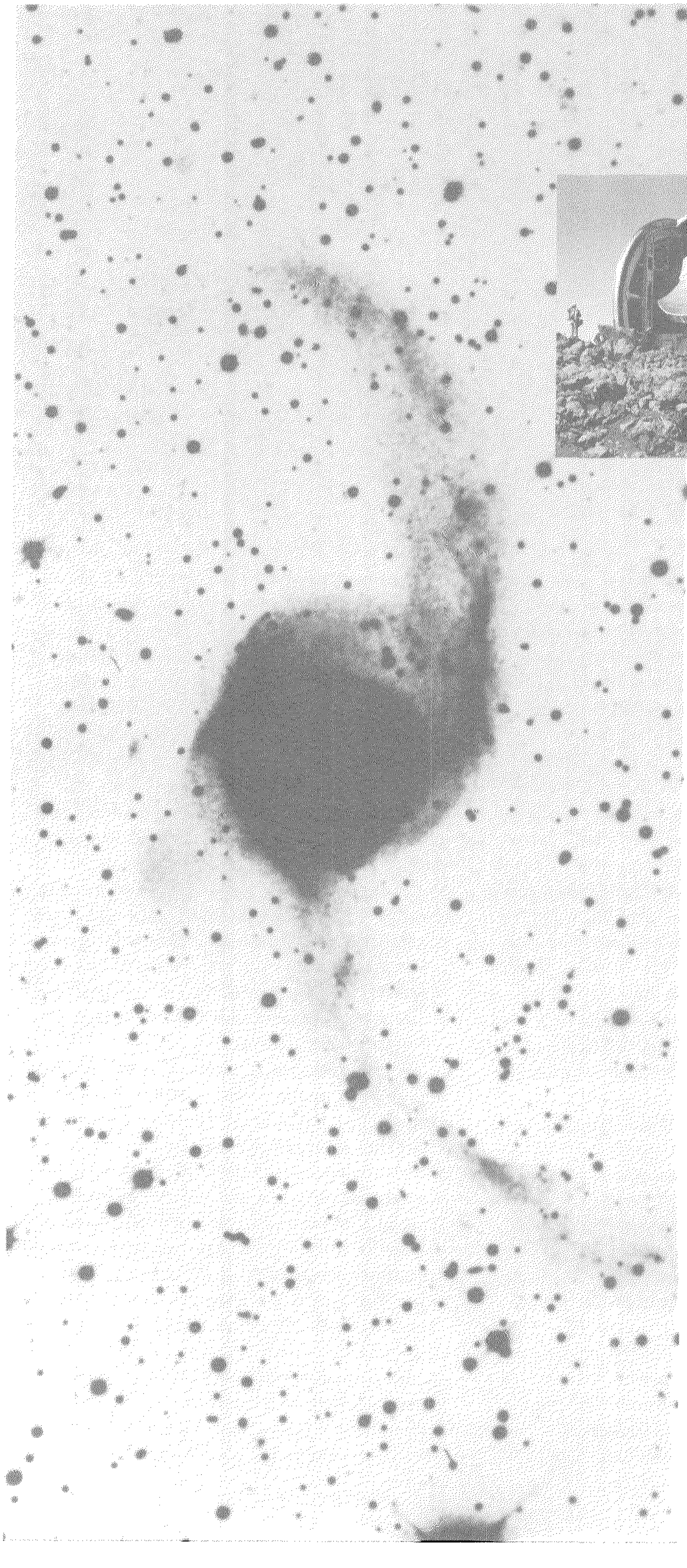
It is 4:30 in the afternoon at Hale (pronounced Hahlee) Pohaku, the picturesque astronomers' residence that the University of Hawaii maintains on the slopes of Mauna Kea—the extinct volcano on the Big Island of Hawaii whose summit is rapidly becoming the world's single largest preserve of astronomers. With eight telescopes representing six nations now operating on Mauna Kea, and a ninth—the W. M. Keck Observatory—currently under construction by Caltech and the University of California, up to 50 scientists, engineers, and technicians may be eating and sleeping at Hale Pohaku, for periods ranging from a few days to several weeks. At 9,500 feet above sea level, the complex is situated in an almost Alpine setting, ringed by fir trees, shrubs and ancient mounds of black and red volcanic ash called cinder cones. In the distance is a view of the blue slope of Mauna Loa, Mauna Kea's still-active sister volcano, as late-afternoon clouds stream toward its peak.

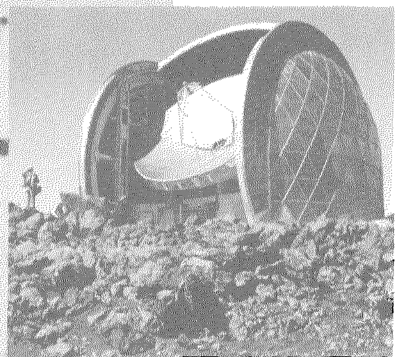
Inside the communal dining room, where Elvis blasts from the kitchen stereo, keeping some of the blearier astronomers alert, the view is equally pleasant: flowers on every table; large, framed pictures of white telescopes on cinder cones that resemble hills of cinnamon; and native Hawaiian plants curving over a circular staircase that leads to the facility's research offices and library.

These graceful reminders of the bright everyday are important because days on Mauna Kea have a tendency to run backward. For most of the people gathered for the evening meal, the day has just started. Their previous day ended at dawn, when a jolting, eight-mile ride down an unpaved dirt road brought them back to Hale Pohaku after a night of observing the sky from Mauna Kea's summit—a rocky wasteland perched almost 14,000 feet above the ocean. The air is thin, the plant-life nonexistent, the temperatures near-freezing, and the ability to concentrate—and sometimes even to walk and talk—for long periods under conditions of reduced oxygen is so valued that the first question a new arrival usually hears from summit veterans is "How did you do at altitude?"

"Being at Mauna Kea," says Caltech senior research fellow Anneila Sargent, who has made several visits to conduct observations at the first Institute facility to open there—the Caltech Submillimeter Observatory (CSO)—"is a kind of rite of passage for astronomers. It's the toughest astronomy work there is."

The Caltech people working at the CSO do not claim to be particularly tough. But they can claim to have established the world's first submillimeter observatory at one of the few places on earth where this demanding form of astronomy can be practiced and to have pioneered some of the most advanced technology available to practice it. At lower, less dry altitudes, most submillimeter radiation is absorbed by water vapor in the earth's atmosphere before it has a chance to reach telescopes. This is not the case at Mauna Kea, where one look at the arid, lunar landscape adds a new level of meaning to the cliche "frontiers of astronomy." "To get good access to these waves, you have to go to this highly inaccessible spot," says CSO director and



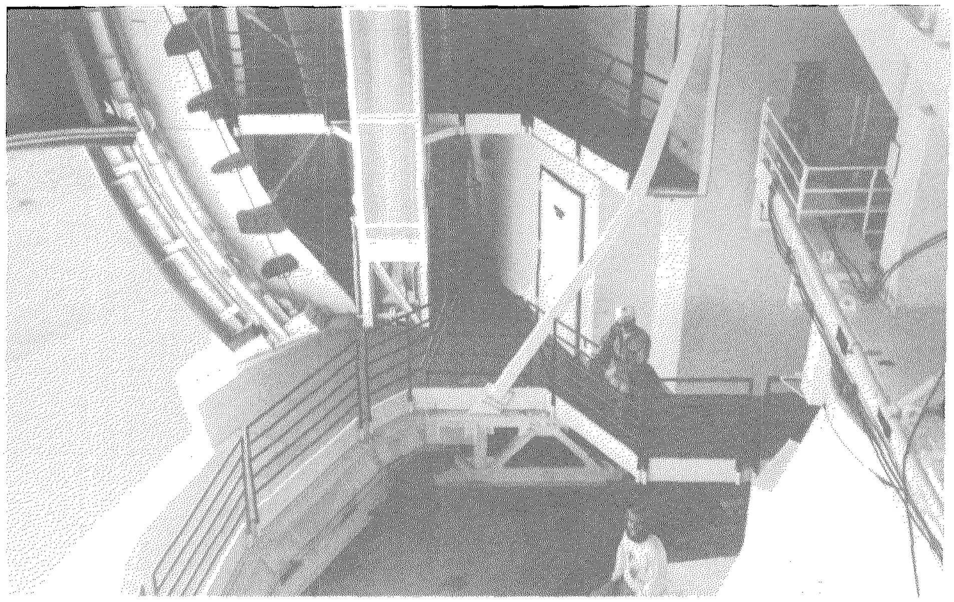


This optical photo of the starburst galaxy NGC 3256, a colliding system under study at the CSO, clearly shows the tidal tails— streamers of stars thousands of light years long—that are the signature of a galactic merger. (Opposite) On-site staffers Randy Hennings (top) and Jeff DeKok (below) wrap up an eight-hour day at the observatory. (Inset) The CSO dome and radio dish.

Professor of Physics Tom Phillips. He currently spends about one week out of four there, overseeing an operation whose dimensions range from detecting galaxies hundreds of millions of light years away to rehabilitating four-wheel-drive vehicles whose engines are repeatedly demolished by exposure to volcanic ash and grit.

While research at the CSO has been under way for 18 months, the project itself dates back to the late 1970s, when Caltech physicist Robert Leighton (now the Valentine Professor of Physics, Emeritus) designed and built one of the first radio dishes accurate enough to focus these very short radio waves. Phillips arrived in 1980, after a decade of advancing the science of millimeter- and submillimeter-wave detection at Bell Labs, research he has continued at Caltech. Work on an observatory dome to shelter Phillips's detectors, or receivers, and Leighton's 10.4-meter radio dish began in the early 1980s, supported by grants from the National Science Foundation, the Kresge Foundation, and NASA. In an effort to expedite construction at the site, the dome and telescope mount were initially assembled at the edge of Caltech's athletic field, taken apart, shipped to Hawaii, hauled piece by piece up the mountain to the summit, and reassembled there.

One Caltech employee who played a major role in this undertaking is senior mechanical engineer Walter Schaal, who designed the hydraulic systems that rotate the CSO dome and radio dish and move the automatic doors that enfold the dish to protect it from the snow, winds, and ultraviolet light at the summit. Another is David Vail, supervisor of mechanical



Refinements will ultimately enable the CSO dish and receivers to detect radiation extending from the millimeter-wave band to the far infrared, a capacity unmatched by any astronomy facility in the world.

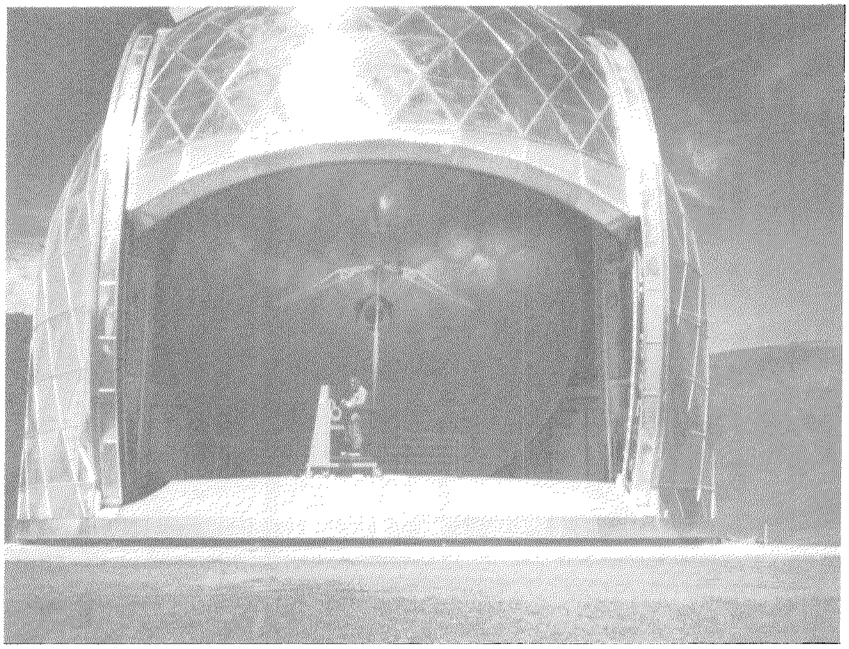
construction in space physics, who machined and modified many of the components for the dome and dish. As their handiwork went up the mountain, Vail, Schaal, Phillips, and Leighton often went with it, encountering such unforeseen problems as a blizzard that filled the exposed dome structure with snow, a subcontractor who walked out in the middle of assembly, and, in the case of Schaal, a broken ankle from slipping on ice at the site. "For about a year," recalls Vail, "Hoggan [the consulting engineer who worked with Phillips on the CSO's design] and I used to pass each other in the air going back and forth from Hawaii."

Today, on the wall of Dave Vail's machine shop in East Bridge, hangs a testament to the happy outcome of this extraordinary effort—a photo of the silver orb of the CSO, taken two days before its dedication in November 1986, with a bright rainbow arching overhead. "Yes, it's a beautiful picture," says Vail. "What makes it a bit odd is that there aren't supposed to be rainbows up there. It's supposed to be a totally dry site."

The CSO is not the world's only submillimeter observatory, a fact that is hard to overlook, since a second such facility, the James Clerk Maxwell Telescope (JCMT), a joint venture of the United Kingdom, the Netherlands, and Canada, sits only a few hundred yards away from the CSO site on Millimeter Ridge. At a time when budget cutbacks have severely curtailed federal support for U.S. astronomy, the JCMT has both a larger staff and larger budget than the CSO, another fact that is difficult to ignore. "We can't compete in terms of money or personnel, but we can try to maintain an edge in certain areas of research," says Phillips. The center of this effort is Downs Laboratory on campus, where Phillips, Leighton, staff physicist Brian Ellison, senior research associate Colin Masson, senior research fellow Jocelyn Keene, research fellow Gene Serabyn, and graduate students Thomas Buettgenbach and Ken Young are working on refinements that will ultimately enable the CSO dish and receivers to detect radiation extending from the millimeter-wave band to the far-infrared, a capacity unmatched by any astronomy facility in the world.

The majority of these refinements are developed and tested at Caltech, then retested at the observatory, a procedure that has its drawbacks. "You get up to the summit with equipment that you designed and that worked beautifully in the lab, and then breakdowns occur," says Buettgenbach, whose new receiver recently had its first on-site test-run. "A cable breaks or a component doesn't work, and you discover that some vital part you need is miles down the mountain or even back in Pasadena. You develop strategies to cope, and one of them is simply accepting the fact that some things are going to take longer."

Of all the hardships of life at the top, coping with the reduced-oxygen environment is one of the toughest. The air at the summit contains about 60 percent of the oxygen at sea level, and the effects on some people can be devastating. At one extreme is the experience of a renowned British astronomer and dynamic science popularizer who went up the mountain with a documen-



CSO technician Allen Guyer under the half-open dome. The devices and software that position dish, dome, and observatory doors were largely designed at Caltech. "There's no other building in the world like this one," says site manager Walt Steiger. "It's a marvel of engineering."

tary team and had become incoherent by the time he was scheduled to perform his part of the program. A similar fate overtook the chief aide to a Senate appropriations subcommittee who led a delegation to Mauna Kea and passed out during his fact-finding tour of the telescopes.

Most Mauna Kea astronomers do not have such dramatic reactions. Staying at Hale Pohaku, where the oxygen depletion is relatively slight, helps prepare people for the more strenuous conditions at the peak. So do repeated visits to the summit. But nobody is entirely immune to the effects of diminished oxygen.

According to Leighton, "The primary effect is that the lack of oxygen makes me feel very confident. Once I come back down to Hale Pohaku, I begin to wonder if some of my judgments at the summit haven't been too optimistic."

"More than anything else, it's exhausting," says Keene. "When I'm at work there I don't notice it so much, but a week of activity can wear you out to the point where it takes another week to recover."

"You know when you've been up there too long because you begin to feel a bit senile," says Masson. "After several hours, you find that you lose your concentration and become confused. If two people get confused in opposite directions, things can become quite argumentative."

"It doesn't bother me all that much because I'm pretty absent-minded at sea level as it is," says Serabyn. "It does provide a great excuse to go skiing the weekend before a trip to Hawaii. 'I'm going to the mountain,' you say. 'It's time to go skiing to get acclimated.' "

If research at submillimeter wavelengths is so arduous, why do astronomers go to such lengths to pursue it? A large part of the answer is that while this radiation does not easily get through the earth's atmosphere, it does easily penetrate a medium that is far more prevalent in the rest of the universe—interstellar gas and dust clouds. Hidden within these clouds, beyond the reach of optical telescopes, is an array of intriguing phenomena: the centers of galaxies; aging stars returning their outer layers of gas and dust to the interstellar medium, where the material is recycled into new stars; and cool gas clouds that are collapsing to form young stars and, possibly, planetary systems.

"By the time these stars have formed and turned on so that optical telescopes can see them, the excitement's all over," comments Phillips. He anticipates that within a year or two, the CSO will be operating at frequencies high enough to probe the most energetic portions of these gas clouds of the interstellar medium. Several such clouds lying within 1,000 light years of earth are major sites of star formation, and studies of conditions in these "stellar nurseries" may finally enable astronomers to understand how the sun and its planets were formed.

But before astronomers can begin exploring the far reaches of space, they have to make it to the top of the mountain. The road to Mauna Kea starts at Caltech, continues with a five-hour flight over the Pacific to Hilo Airport, followed by a 90-minute drive to Hale Pohaku along "Saddle Road," a windy, treacherous stretch

Mauna Kea's summit is rapidly becoming the world's single largest preserve of astronomers.

Aerial view of Mauna Kea, taken in 1987, shows (clockwise from left): the foundations of the Keck Observatory; the NASA Infrared Telescope Facility; the Canada-France-Hawaii Telescope; the University of Hawaii Telescope; the UK Infrared Telescope; the Caltech Submillimeter Observatory; the James Clerk Maxwell Observatory. (Inset) Caltech astronomer Anneila Sargent takes a break from observations.

whose twists and turns have convinced most rental-car agencies to declare it off-limits to their customers. Saddle Road was built by the U.S. Army during World War II, and legend has it that the military expressly designed the route to thwart progress across the island by a possible invader. Now that an army of astronomers is advancing on Saddle Road, the military has been called in to improve it.

At least Saddle Road is paved. The eight-mile road from Hale Pohaku to the summit is not, and consequently is open only to four-wheel-drive vehicles. As this last lap of the trip to the top begins, Hale Pohaku is left behind in an eddy of clouds. The road twists higher, the drive becomes steeper, the trees dwindle to shrubs, the shrubs dwindle to gorse, which shrivels to grass, and finally nothing but rocks grow on either side of the road. About two miles from the peak, the jeep passes a lava quarry, where ancient Hawaiians, making the journey on foot, gathered material for stone tools. Ahead are signs of another technology: ridges of rock and dust piled so high by natural forces that they resemble man-made pueblos—and then, nine telescopes.

It's hard to imagine a better spot to view the logistics of the universe. At night, the stars overhead seem about a foot away; during the day, the clouds drift by a few thousand feet below, and the CSO, a 200-ton silver bubble at the edge of an ancient lava flow, enhances this alien landscape. The entire structure can pivot through a full turn like a small planet, greatly simplifying the art of pointing the instrument at objects in the sky. A tour of the three-story interior reveals some refinements that were not in place during the initial assembly at Caltech—a control room, electronics room, and machine shop, a lounge that doubles as a library, a small galley, and a closet holding the canisters of oxygen that are required of all facilities operating at the summit.

One frequent visitor to the site is Walt Steiger, CSO site manager and professor of solar astronomy, emeritus, at the University of Hawaii. He makes the trip from Hilo about once a week, ferrying equipment, scientists, and information, and coordinating activities between a five-man technical crew on the mountaintop and a scientific staff 2,500 miles away in southern California.

"You sit up here in this very high-altitude area—the most severe and barren region you can imagine—and you're surrounded by all this sophisticated, high-powered and computerized technology," says Steiger. "You can pick up the phone from this isolation zone and call anywhere

At one in the morning, the observers are scanning ten million light years out of the Milky Way.

in the world. The contrast is amazing."

During the start-up phase of a telescope, new discoveries are as likely to be about the strengths and weaknesses of the instrumentation as they are about anything in the sky. While this can be frustrating over the short term, the long-term gains in overall performance are worth the effort, something Phillips is occasionally at pains to point out. "With enough patience and persistence, you can get very fine data," he says. "I just keep staying up on the mountain long enough to try to convince people of that fact."

On March 7, Phillips is back on the mountain, accompanied by three Caltech astronomers —senior research fellows Anneila Sargent and Dave Sanders, and Nick Scoville, professor of astronomy and director of Owens Valley Radio Observatory. Over the next several days, the researchers plan to use the CSO to study a group of extremely bright, colliding galaxies whose central regions are undergoing explosions of star formation, or "starbursts," and in the process generating 10 to 100 times the energy of the entire Milky Way. Immense clouds of hydrogen gas and dust in these galaxies are emitting millimeter and submillimeter waves, and by studying this radiation, the group hopes to obtain a clearer picture of what is actually happening in these peculiar cosmic objects.

But first a problem closer to home must be addressed. Arriving at the CSO, the Caltech group discovers that the sky over Mauna Kea, generally one of the clearest in the world, is clouding up, which could force cancellation of the night's run. Weather bulletins from the one radio station whose signals are strong enough to reach the mountain are of no help. "Every time you call and ask for a forecast, they say they have no information," says Phillips. "Ten minutes after you hang up, the broadcaster announces they've just had an exclusive report that things don't look good on Mauna Kea."

Eventually the cloud cover thins out enough for the group to aim the telescope in the direction of the nearby molecular cloud Orion A, and the appropriate directives are entered on the computer. Is the dish now pointing at Orion? Sanders is asked. "*You* are now pointing at Orion," is the reply, as the CSO dome gently swivels its freight of dish and astronomers around to point at the designated coordinates in the sky. Data on the computer screen indicate that Orion A is coming in loud and clear, a signal to Phillips that it is time to subject the receivers to a "cold load" of liquid nitrogen, an exercise that will clarify how much of what the observers are seeing is astronomical data and how much is background noise generated by the receivers.

This is the start of a long night of computer calibrations, adjustments to the receivers, phone calls to computer programmer Ken Young back in Pasadena and, as the hours wear on, of coping with exhaustion brought on by the altitude. The best antidote to creeping fatigue turns out to be the stream of data pouring in over the computer, supplemented by tea and crackers from the galley and the small pile of apples and oranges that Scoville has thoughtfully removed from Hale Pohaku's kitchen. At one in the morning, the

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The starburst galaxy NGC 1614, one of several ultraluminous galaxies being studied at the CSO, radiates 10 to 20 times the energy of the Milky Way. CSO data are shedding light on the dynamics of the hydrogen gas clouds in this system. (Opposite, from left) Phillips, Scoville, Sanders, and Sargent ponder Galaxy M82 in the CSO control room.

dome is turning, the sound system is playing classical music, and the observers are scanning ten million light years out of the Milky Way, a stone's throw by astronomical standards. Their target is Galaxy M82, sometimes known as the "firecracker" galaxy because a collision with its neighbor, M81, has ignited a spectacular starburst in the galactic center. Three hours later, with the gratifying news that the CSO dish has achieved a nearly 50 percent improvement in detection efficiency over all previous runs, it is time to to go down the mountain, get some sleep, and begin thinking about what data from this run will go into the next series of professional papers.

The next day for this group dawns at about three in the afternoon. Phillips is on his way back to Pasadena, where deadlines for funding renewal proposals are fast approaching, and Sargent, Sanders, and Scoville, buoyed by the gains of the night before, are expanding the list of galaxies they plan to study. As on the previous night, evening at the observatory opens with a series of maneuvers to assess the pointing accuracy of the dish. "We want to be sure of where we are," says Sargent, "before we go zooming all over." "Then," adds Scoville, "we can all fight about what galaxies we're going to look at." After some preliminary scans of nearby objects, they beam out 200 million light years to a starburst galaxy known as NGC 1614 and begin an hour of painstaking calibrations at the computer. A series of calculations and recalibrations, punctuated by frequent checks on the performance of the receivers, and the results are worth it. From a distance of almost a quarter billion light years, NGC 1614 announces its presence on Sargent's and Sander's monitors in a broad, clean emission spectrum that looks not unlike the peak of Mauna Kea. Further work produces a double emission peak, and Sanders is jubilant. "We have just detected," he says, "the faintest and weakest object ever seen by this telescope."

This work will go on for two more nights, culminating in the sighting of the ultraluminous galaxy Markarian 231, a colliding system whose core is believed to harbor both a starburst and a quasar.

"The work up there is incredibly rough," says astronomer Keene. "The dust rips apart your clothes and shoes, the dry air chaps your face and body, and a week on the mountain usually means three to four days' downtime just recovering from the experience. What's worthwhile about all this? The prospect of getting observations that are just about impossible to obtain any other way."

Driving down from Mauna Kea, back to sea level, it is indeed a bit hard to shake off the effects of the mountain. The only radio waves are those reaching the car's antenna, and the only messages they carry are from stations in Honolulu whose signals are strong enough to overcome the combined interference of Mauna Kea and Mauna Loa. The scenery has reverted to the tropical display expected of Hawaii, and both oxygen and greenery are abundant. Heading up the north coast, a driver who happened to look out the car window toward the west would see the pinnacle of Mauna Kea gradually sweep back into view. A little effort with the eyes and it becomes clear that the four white caps at the peak are not snow drifts but telescopes. Slightly farther down the road, one can look up again. The late afternoon clouds have ascended Mauna Kea's slope and are about to envelope the summit. For a brief instant, the telescopes shimmer at the edge of the cloud and then the mountain top and its cargo of star-gazers vanish from view. □ — *Heidi Aspaturian*

Heidi Aspaturian is a writer in Caltech's Office of Public Relations and associate editor of On Campus, *where this article first appeared. She visited Mauna Kea in March with a team of CSO observers.*