

Outsmarting the

Chuck Steidel, one of the nation's top young astronomers, has pioneered a new way to study the distant universe.

by Marcia Bartusiak

AS THE AFTERNOON SHADOWS LENGTHEN, PUFFS OF CLOUDS MOVE DOWN THE mountain like ghostly apparitions. Ever so slowly, this cool autumnal day, the summit of Hawaii's Mauna Kea clears. And just in time.

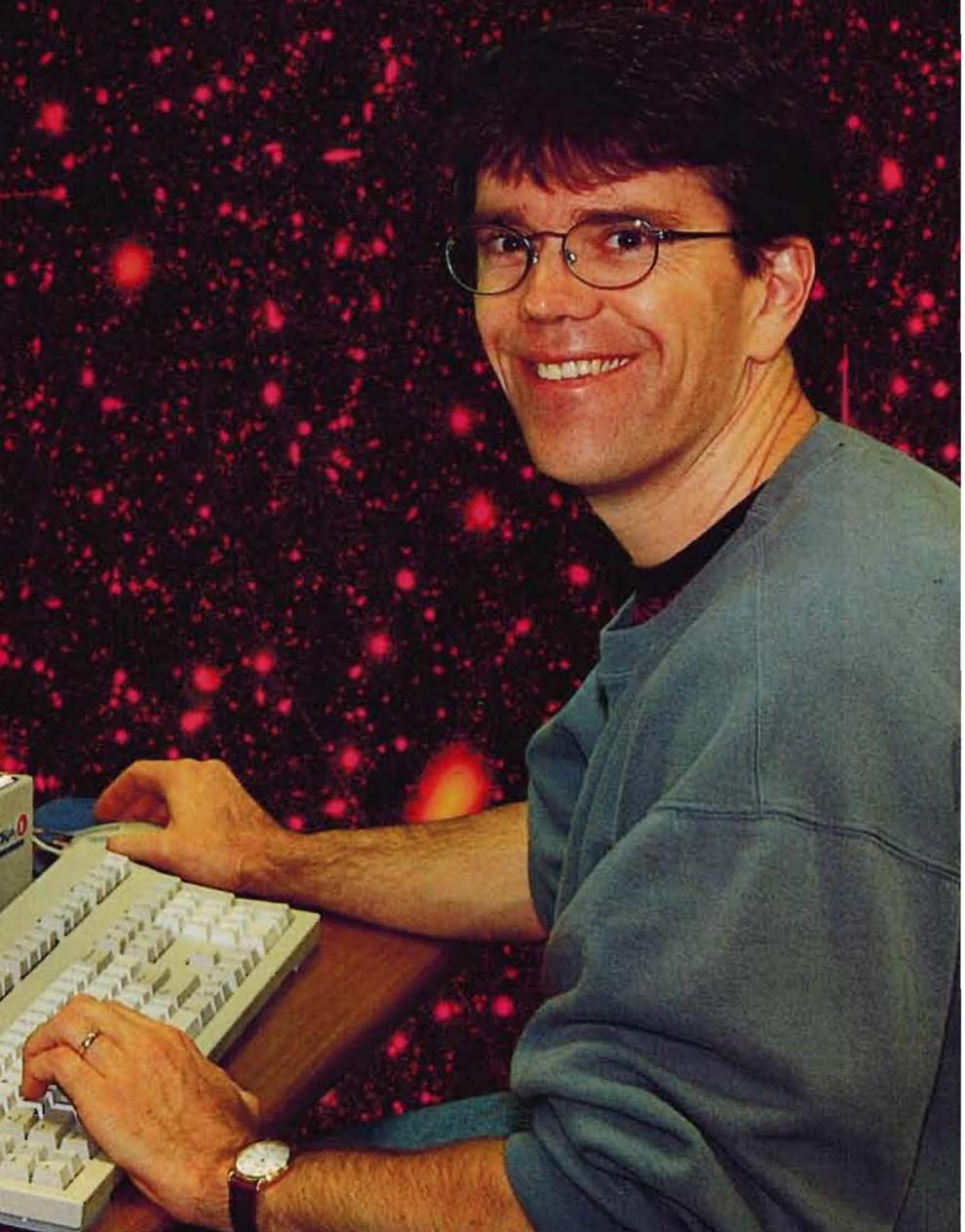
Twelve minutes after nightfall, Charles Steidel directs one of the twin Keck telescopes to its first target, a deep field in the constellation Aquarius. Steidel is actually conducting his run remotely from the observatory's ranch-like headquarters, situated in the quaint town of Waimea lower down on the mountain. Steidel loves this set-up. He can fly in quickly from Caltech, where he is a professor, no longer losing time acclimating to a two-mile-high site. Known as Chuck to his friends, Steidel has a formal demeanor, polite and low-key. His clothes are casual, the requisite uniform for observing: green sweat-shirt and jeans. Tonight, he and his graduate student Kurt Adelberger are attempting to map the distribution of young galaxies in the early universe. They want to know how the galaxies congregate into giant clusters.

Just a decade ago the far universe was a dim mirage. Now, thanks to new technologies and clever strategies, astronomers are pushing outward billions of light-years, to nearly the edge of the visible universe and the beginning of time, given the amount of time it takes light to travel those great distances. Steidel's triumph in this endeavor was mastering a technique for detecting young galaxies. He might be called the Henry Ford of galaxy hunting: He began finding infant galaxies wholesale, in assembly-like fashion. "I think Chuck's work is one of the most important developments in observational astronomy in the last 10 or 20 years," says Caltech astronomer Wallace Sargent.

Sargent is not alone in his assessment. Last year the American Astronomical Society awarded Steidel the Helen B. Warner Prize, given annually to an astronomer no older than 36 who makes a significant contribution to the field. Looking over the list of past

Chuck Steidel operates the giant Keck I Telescope from the Remote Operating Center.

Early Universe



Chuck Steidel pioneered a method for finding galaxies more than 10 billion light-years away. Such galaxies will appear in both red and green light, but their ultraviolet light will be absorbed en route to Earth, rendering them invisible through an ultraviolet filter.



Chuck Steidel (Caltech)

winners, one sees a veritable who's who of astronomy, such as Margaret and Geoffrey Burbidge, who helped unravel how elements are made in stars, and Riccardo Giacconi, a founder of x-ray astronomy.

Steidel, in turn, is now fashioning a new history of the universe. All galaxies did not emerge in one great burst of fireworks as once thought. Rather, they seem to have arisen more like an ever-growing roaring fire. Steidel's work suggests that the largest galaxies, the ones destined to be the massive ellipticals and the bulges of major spirals like our own Milky Way galaxy, were in place fairly early, when the universe was less than a quarter of its present age. Such early births were a surprise to many. Star formation rates, though, seemed to have peaked later as smaller galaxies continued to coalesce, interact, and evolve over several more eons. Moreover, Steidel is also gathering hints that the universe's structure — the tendency for galaxies to align themselves into sheets and bubble-like walls — can be seen early on as well.

None of this information arrives quickly. "We do a lot of work before we ever get to the Keck," notes Steidel. First, pictures of the deep fields are taken with the 200-inch Hale Telescope on Palomar Mountain in California. Each picture, covering a region of the sky about the size of a quarter moon, contains some 3,500 objects, mostly stars and nearby galaxies. But some of the objects, usually around 100, look different. They could be young galaxies caught at the farthest edge of the visible universe.

To know for sure requires the power of the Keck. A set of "masks" is constructed before an observing run, each a rectangular plate of aluminum with a couple dozen narrow slits, much like the holes in an old computer punch card. Each slit has been carefully machined to align with a target galaxy, blocking out the rest of the field. Thus, with the mask in place at the focus, only the light from the target galaxies enters the telescope's spectrograph, which then separates the light into a rainbow of colors for analysis. In this way, observers can confirm the distances to many galaxies at once, not one at a time as in the old days. Distances are pegged by noting how much the light has been stretched and reddened ("redshifted" in astronomers' jargon) by the universe's expansion.

Years of experience allow Steidel to detect crucial spectral lines amidst the noise. Right off, he finds a galaxy at a redshift of 3.45. That number is a gauge of cosmic distance. The higher the redshift, the more distant the galaxy. A redshift of 1, for example, is roughly halfway back to the Big Bang. A galaxy at

a redshift of 3, on the other hand, resides at a distance of about 10 billion light-years, when the universe was only one-sixth its current age. "It's great what you can do when the mask is in place," says Steidel.

STEIDEL DOESN'T FIT THE STEREOTYPE OF AN astronomer. As a child, he never gazed at the stars, never read science fiction, never watched *Star Trek*. He was born in Ithaca, New York, in 1962, when his parents were graduate students at Cornell University, his father studying material science, his mother English literature. The family, including a younger sister, eventually settled in Allentown, Pennsylvania, where Steidel grew up. He recalls a rather lonely childhood, spending a lot of time reading. He was interested in science, building the occasional model rocket, but he was also attracted to literature. The reclusive Thomas Pynchon is a favorite author, which is a telling clue about Steidel, a very private man. Pynchon's novels, dense and allegorical, often require a second reading. His latest book, *Mason & Dixon*, was reviewed as being "about the follies of the Age of Reason and the ... misguided imperatives of straight lines."

Steidel, too, dislikes answers arrived at straight-away, preferring problems that engage the mind and require interpretation. That's what attracted him to the distant universe. "I like the nebulous, the far away things where you get only glimpses," he says. "Many are starting to claim that we're about to find out all of cosmology's holy grails, such as the Hubble constant, the fate of the universe, as well as its size and age. But I'd be disappointed for the quest to be over. Just filling in the details is so much less interesting."

Indeed, upon entering Princeton University in 1980, he at first feared that adopting a science major would provide no more than vocational training, simply acquiring the tools of a trade. But he eventually learned that the astronomy department offered the opportunity to do research.

The shy teenager began to socialize by both organizing a band that played at college parties and working as a disk jockey at the campus radio station, where his taste in music ran from blues to alterative rock. That's where he first met Mark Dickinson, now an astronomer at Johns Hopkins University and one of Steidel's closest colleagues. "We shared a common interest in obscure garage bands of the sixties, the noisier the better. We tortured the New Jersey public," recalls Dickinson. Working

from the basement control room over summer breaks, the two friends rarely saw sunlight for weeks at a time, surviving on beer and tuna fish sandwiches. "Not much different from astronomy in a way," notes Dickinson. Around this same time, Steidel also met his future wife Sarah, a history major, at one of Princeton's eating clubs.

While his social life was booming, he feared failure in his studies. His senior thesis put limits on identifying galaxies at great distances, work "reduced to rubble by Princeton's top faculty members, Jerry Ostriker, James Gunn, and Ed Turner. The worst experience I've ever had in astronomy," he says. But sheer inertia kept him in the game. Although theory is stressed at Princeton, he eventually chose Caltech, a haven for observers, for graduate school. "A visit to the 200-inch at Palomar in the spring of 1984

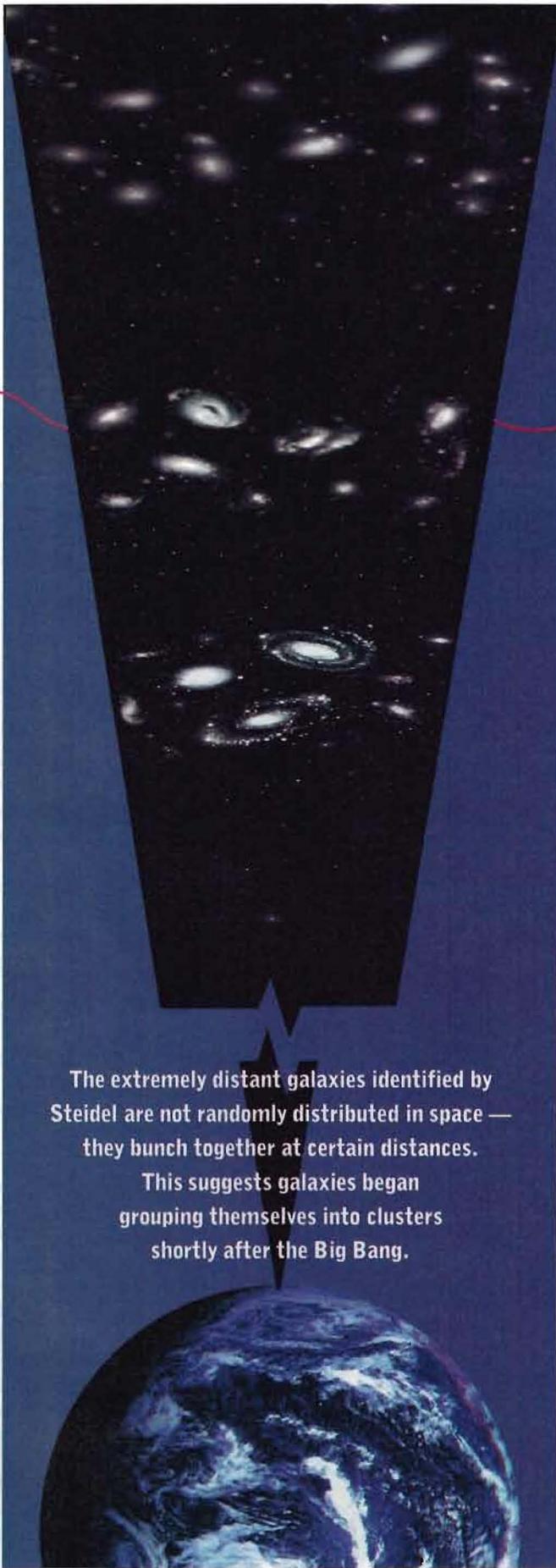
clinched it for me," he explains. "Keck is high-tech, but it has no personality like the 200-inch has. Palomar's dome has a classical beauty. It was then that I decided to be an observer."

Once at Caltech, he sought out Sargent to be his thesis advisor, a 33-year astronomy veteran known for his work at the far frontier. "He was the faculty member I found the most intimidating, and that attracted me," says Steidel. Sargent remembers it a bit differently: "At the start of a semester, each faculty member gives a talk to 'advertise their wares.' For mine, though, the students usually fall asleep. I took Chuck on because he was the only one who asked."

Steidel's research strongly suggests that major galaxies such as M81 formed when the universe was quite young.



Hale Observatories



The extremely distant galaxies identified by Steidel are not randomly distributed in space — they bunch together at certain distances. This suggests galaxies began grouping themselves into clusters shortly after the Big Bang.

Astronomy: Elisabeth Rowan

STEIDEL RECALLS HIS GRADUATE-SCHOOL DAYS WITH fondness. He married Sarah and developed a collegial relationship with Sargent, working on one of Sargent's specialties, quasar absorption lines. A quasar is believed to be an extraordinarily bright young galactic center powered by a supermassive black hole. As this distant beacon shines through the cosmos, some of its rays are selectively absorbed by intervening material, leaving distinctive lines in the quasar's spectrum. These absorption lines enable astronomers to examine the universe's evolution over billions of light-years. It is a means of gauging exactly when stars began cooking up carbon, oxygen, and other higher elements from the hydrogen and helium spewed from the Big Bang.

By the time Steidel completed his Ph.D. in 1989, he was determined to link those shadowy lines with specific entities, possibly newborn galaxies in the distant universe. To do this, he moved on to the University of California at Berkeley, a mecca for far-galaxy work, for four years of post-doctoral work. First-time fatherhood arrived as well, when daughter Emily was born in 1991.

At Berkeley, Steidel met back up with Dickinson. Still a graduate student, Dickinson was one of the few astronomers at the time who were attempting to detect faraway galaxies. Back then, their only hope to spy something in the distant universe was to look for extraordinary activity, which meant he and his colleagues ended up with a few radio galaxies here or unusually bright galaxies there. "But what did the average galaxy look like at those far distances?" asked Steidel when he arrived. Distant galaxies, so dim and obscure, simply got lost amidst the crowded celestial sky.

Using telescopes at both Lick Observatory in California and Kitt Peak National Observatory in Arizona, Steidel and Dickinson took deep exposures of the sky around selected quasars. After perusing the images and picking out any faint galaxy-like objects near quasars, they'd go back to the telescope to laboriously take spectra of each and every one. In this way, they found some 70 normal, run-of-the-mill galaxies out to a redshift of 1, some 6 billion to 7 billion light-years distant.

Working with others, Steidel decided to go out even farther, which was quite a challenge. How could he pick out fainter and fainter baby galaxies? There was a trick: Newborn galaxies are awash in hydrogen gas, which absorbs much of the ultraviolet radiation generated by its many young stars. The galaxy freely emits its red, yellow, and green light but holds on to its ultraviolet radiation. It never gets out. This effect is known as the ultraviolet dropout. This means such a far galaxy could be seen through a red filter, as well as a green, but would disappear when observed through an ultraviolet filter.

In 1991, using the 4-meter Cerro-Tololo Inter-American Observatory telescope in Chile, Steidel and his colleagues examined a far quasar with three different filters to see if it had any close companions. They found more than a dozen fuzzy blobs that fit the bill: All vanished in the ultraviolet, which suggested they were fairly far-off. "But just finding the dropouts didn't set people on fire," notes Dickinson.

What Steidel needed were spectra, which would determine the distances exactly. And the only telescope on Earth that

could do that was the Keck. After a brief professorship at MIT, Steidel moved to Caltech so he would have regular access to the giant instrument. His breakthrough came in the fall of 1995, just a month after his return to the West Coast. Going out to Keck with Dickinson for two nights of observing, Steidel came home with 15 galaxies past a redshift of 3. "And that was 15 more than astronomers had at the time," notes Steidel. People had even been speculating that average galaxies wouldn't be found at that distance, but that hypothesis was quickly demolished. "Everywhere you looked in the sky, there were tons of these things," says Dickinson.

In his usual self-deprecating fashion, Steidel credits his success to sheer luck. That did play a role: He was in the right place, at the right time, using the right instrument for the

problem at hand. But as the famed French chemist Louis Pasteur long ago noted, "In fields of observation, chance favors only the mind that is prepared." Steidel's discovery was the culmination of a well-conceived program. He had taken a technique and applied it across the heavens. He enabled astronomers to begin strip-mining the far universe.

"His accomplishment is all the more miraculous because in April 1996, Sarah gave birth to twins three months premature," points out Sargent. For nearly three months, in the midst of analyzing his blizzard of data, he spent half of his time helping care for his wife and children, until the twins could be safely released from the hospital. (Nicholas and Elizabeth are now healthy and energetic toddlers.)

AT FIRST, JUST FINDING THESE YOUNG GALAXIES WAS an end in itself. But now, Steidel has built up quite a large catalog of distant galaxies. He and his colleagues have found more than 600 already and have well over 1,500 candidates awaiting confirmation. With such a large sample in hand, they can begin to answer questions about the cosmology of the early universe. How many of these galaxies are there? When did they form? How are they clustered? Just setting a record for finding the most distant galaxy doesn't interest Steidel. "We're not after a *Guinness Book* world record," he stresses. "There's a difference between making headlines and advancing our knowledge."

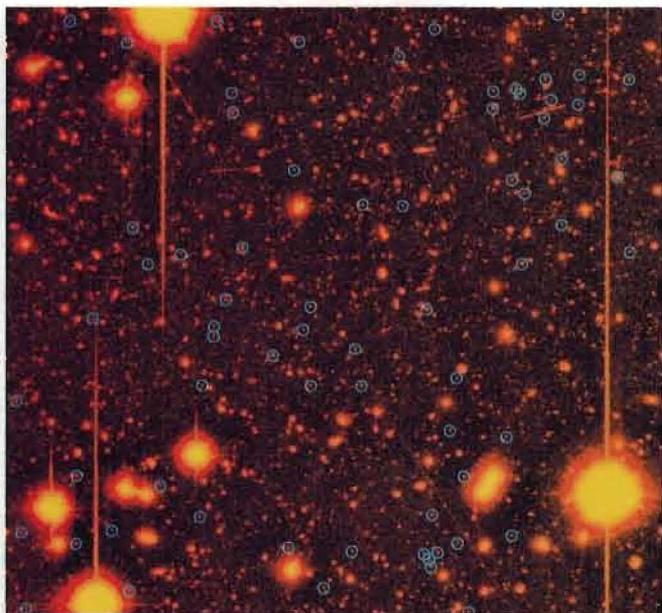
What have they found out so far? For one, these young galaxies are not rare. In fact, the population of objects in that far sector of the universe just about matches the population of bright galaxies — the Milky Way and its kin — that exists today. That seems to suggest that they are the initial cores of ellipticals, as well as the bulges of yet-to-be spirals. What is more surprising is the clustering found in this early cosmic era. In one field, Steidel and his colleagues have observed a collection that resembles one of the great walls of galaxies spread out like a vast maze in the present-day universe. It might be that they are finding the first galaxies that formed in slightly overdense regions, islands with a touch of extra mass in the smooth material spread over space from the Big Bang.

Halfway through the night, Adelberger brings up a rough cut of the data on his computer monitor, a series of spectrums lined up, from top to bottom, like the ribbons on a highly decorated soldier. In one, he spots a bright line, a typical emission line

from energized hydrogen, but shifted quite a bit from its regular position. "That looks promising," says Steidel, bending over the display. A quick calculation pegs it at a redshift of 4.2, that's farther than a record-setting distant quasar Steidel helped find just a decade ago.

By 4:20 a.m., with about an hour left of usable telescope time, Steidel announces that he has "hit the doldrums." He's gone 30 hours without sleep. He had to get up quite early the previous day to fly from Los Angeles to the Big Island in time to set up his observing run. On a scale of 1 to 10, Steidel gives the night a 3.

During the second night a fog settles over the mountain, which cuts off their view. As the hours progress, it's catch as catch can as the moisture comes and goes. "Isn't it a ridicu-



Chuck Steidel (Caltech)

In this image taken with the 5-meter Hale Telescope on Palomar Mountain, the circled galaxies disappear in ultraviolet light — indicating they are very far away. Steidel later takes their spectra with the 10-meter Keck Telescope to determine their redshifts, which yields their distances.

lous science that puts you at the mercy of the weather?" says Steidel.

It is the third night that's the charm. The run moves along like clockwork (well, at least for the first half of the night, before a fog rolls in). "This is more typical of what I usually get at Keck," says Steidel. In the end, they were able to determine some 80 redshifts, half the number they hoped for.

But then, Pynchon-like, Steidel is not expecting definitive answers anytime soon. He suspects that nature will prove to be more complicated than the optimists believe. "I'm not pursuing 'truth,'" he says. "The interesting part is the process. Who wants to get rid of the mystery?" **A**

Award-winning science writer Marcia Bartusiak is a member of Astronomy's editorial advisory board. Her previous article was "A Beast in the Core" in the July 1998 issue.