What Makes Galaxies Change?

Conflicting evidence suggests galaxies are driven either by their own character or the environment that surrounds them.

by Marcia Bartusiak

About two-thirds of all large, regular galaxies in the universe are stately spirals, like this one — M100 in Coma Berenices.

The Big Bang gets all the press, but a much larger story remains to be told. How did we get to here (the Milky Way) from there (a vast primordial explosion)? How did those vast collections of stars we call galaxies evolve into the universe we currently behold? Why did some galaxies become spiraling disks of gas, while others turned into bulbous ellipticals? And how did the populations of each galactic type change over the eons?

Edwin Hubble first pondered these questions more than 60 years ago, soon after he confirmed that the Milky Way was but one of billions of other galaxies roaming the vast gulfs of space. A few hardy souls, the most patient and persistent observers in extragalactic astronomy, eventually joined the pursuit, including Augustus Oemler, who has been wrestling with these mysteries for more than two decades. "Very few things in astronomy, from discovery to understanding, happen quickly," notes Oemler, who is director of the Observatories of the Carnegie Institution in Pasadena, California.

Answers have remained elusive for good reason: The deeper astronomers peer into extragalactic space (and consequently back into time), the more they must strain their telescopic "eyes." Even with the largest telescopes, galaxies that reside more than a couple billion light-years away appear dim, small, and indistinct. A fundamental quest in astronomy, determining how galaxies originated and evolved, seemed an impossible endeavor.

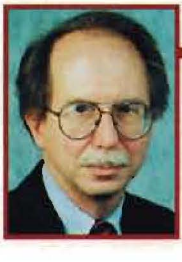
All galaxy photos on this spread: Anglo-Australian Telescope Board

About 10 percent of large galaxies are neither spirals nor ellipticals, but are known as S0 galaxies, or lenticular galaxies, which have characteristics of both types. This lenticular is NGC 5102.

Elliptical galaxies like M87 in Virgo comprise about one quarter of the cosmos' large galaxies. Their dominant population of old stars gives them their characteristic reddish color.

But now there is a palpable excitement in the air. Oemler and a loose confederation — five other astronomers hailing from England, the Netherlands, Australia, and California — have joined forces in recent years to interpret a blizzard of data from the Hubble Space Telescope. Based on the group's proposal, the space telescope had intermittently focused on 10 rich clusters of galaxies scattered about the celestial hemisphere, each cluster situated from 4 to 5 billion light-years away, nearly halfway back to the moment of creation. Distant galaxies that were mere smudges could at last be viewed with impressive clarity. And what the Hubble search revealed was a universe far different from the one observed today.

Five billion years ago, an age when our solar system was just starting to form, there were simply more spiral galaxies around. Oemler and his fellow cosmic evolutionists want to know how the universe got from that vibrant state several billion years ago to the more settled, tidy version we now see around us. More than that, they'd like to find out what happened to those extra galaxies.



Carnegie Institution

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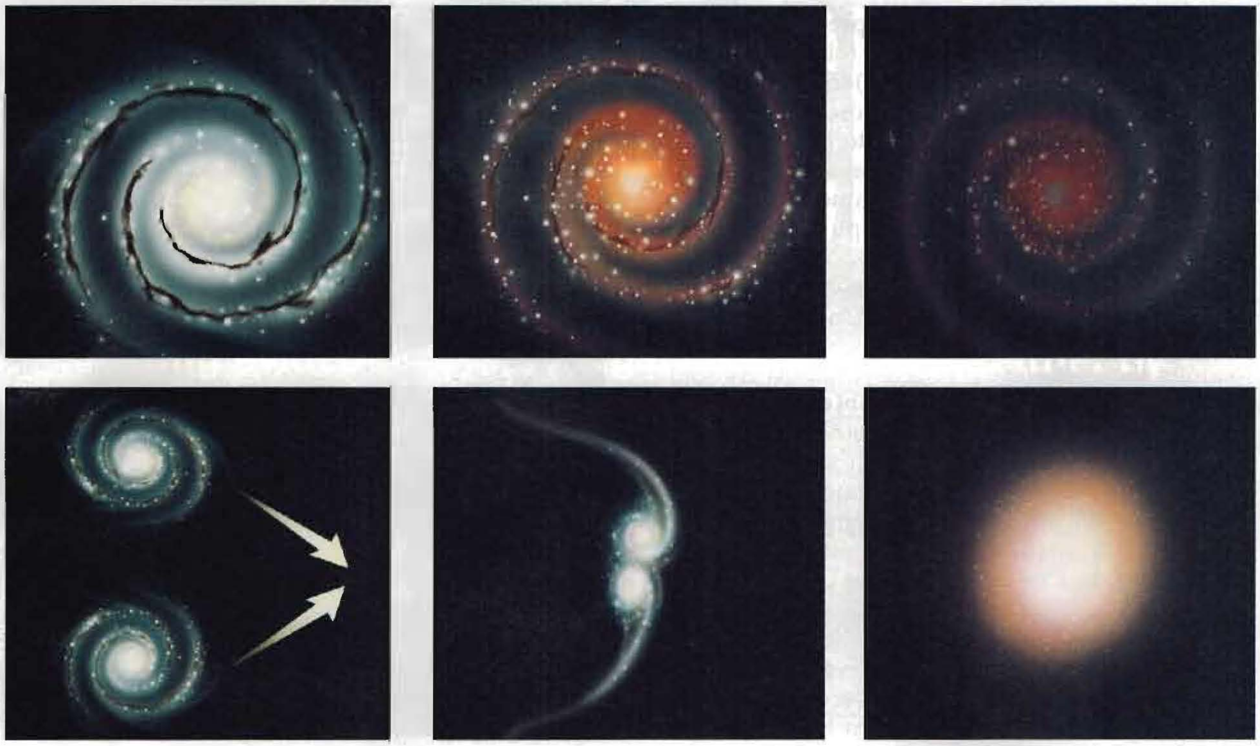


ASTRONOMY: Elisabeth Rowan

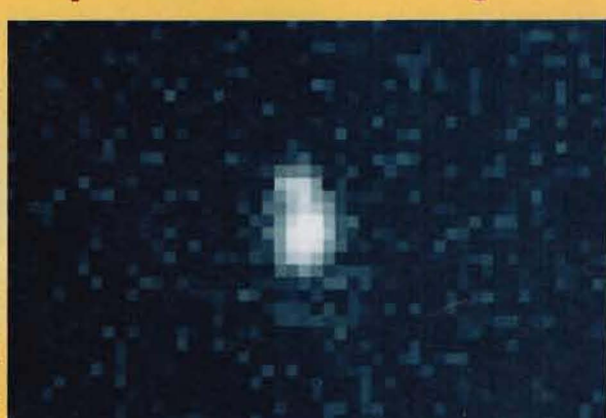
Is galaxy evolution due to nature or nurture? Do galaxies change because of internal processes, or do they change due to outside influences? It's probably a little of both. On the top, we see an example of nature. A spiral galaxy gradually converts its gas into stars. Over time, the stars fade and die. Today, the galaxy is a dim shadow of its former self. On the bottom, we see the forces of nurture at work. Two spiral galaxies in a cluster collide, forming long tidal tails. Eventually the pair merge to form an elliptical galaxy.

Formerly competitors, these extragalactic astronomers teamed up to use the Hubble Space Telescope more efficiently as an international resource. Richard Ellis of Cambridge University, Alan Dressler of the Observatories of the Carnegie Institution, Warrick Couch of the University of New South Wales in Australia, and Harvey Butcher of the Netherlands Foundation for Research in Astronomy, as well as Oemler, have been independently classifying galaxies in the Hubble images. As a cross-check for accuracy, they separately assessed each galaxy's size, type, and magnitude — many thousands of objects in all. "Hubble finally allows us to sort these far galaxies into categories," explains Ellis. "We can now tell the spirals from the ellipticals. Previously, from the ground, we could only say that something was red or blue, big or small."

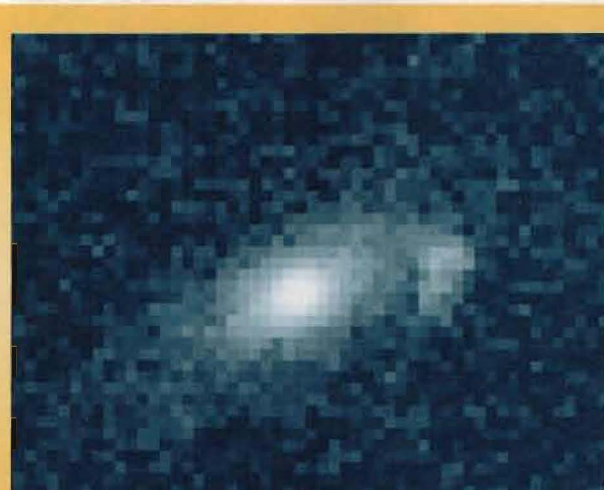
Another group member, Ian Smail of the University of Durham in England, is attempting to measure the total mass of each distant cluster. Rich clusters of galaxies, with their huge gravitational fields, can act as lenses. Like a stream of water that comes upon a rock

Elliptical Galaxies Through Time

A. Dressler, M. Dickinson, D. Macchetto, M. Giavalisco, and NASA



12 billion years ago



9 billion years ago

and gets diverted to either side of the stone, the light from a distant galaxy caught behind a cluster can be split up. This gravitational lensing — an effect rooted in Einstein's general theory of relativity — also magnifies the light. Smail observes how massive clusters bend the beams of light passing by from more distant galaxies. That will give him a handle on the clusters' assorted environments.

Each of these researchers has been pursuing the same goal; they want to know whether a galaxy is shaped primarily by "nature" — the celestial "genes" it inherits at birth, such as its size, mass, and rotation rate — or by "nurture" — the galaxy's later encounters with its environment, such as neighboring galaxies or intergalactic gas.

Such questions were not being discussed when Oemler first started out in astronomy. "If you asked the average astronomer in the 1950s or 1960s, 'Do galaxies change?' they would have said no," recalls Oemler. They were being swayed by the theories of the day; then-current models of our galaxy's construction suggested that it collapsed rather quickly out of a spherical blob of gas. Most astronomers assumed this happened for all types of galaxies, each system forming during a brief, galaxy-forming epoch shortly after the Big Bang. These galaxies, as the story went, then coasted along in the ensuing years, remaining serene and immutable.

The largest number, about two-thirds, emerged as spiral galaxies, with bright round or barred cores surrounded by lush pinwheels of dust and gas. Others became ellipticals: egg-shaped conglomerations that are populated with old, red stars and largely exhausted of the gaseous resources needed to make stars. About 10 percent ended up in a state known as S0s, or lenticular galaxies, which have characteristics of both spirals and ellipticals. Lenticulars consist of a sizable bulge enwreathed with completely smooth disks of stars devoid of spiral arms.

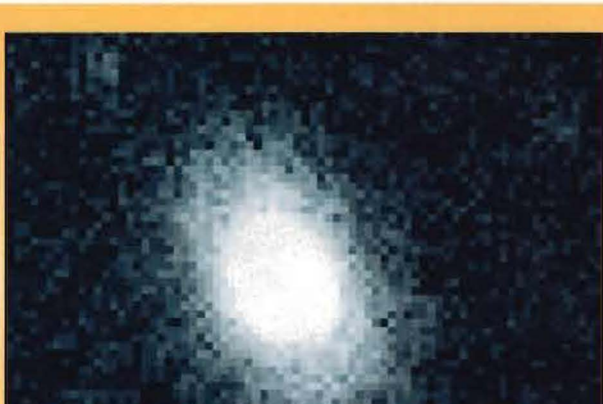
Yet clues were scattered throughout the heavens that a galaxy's life is not that simple — that galaxies have not drifted through space in tranquillity since the Big Bang. Even Hubble noticed that gas-depleted ellipticals and lenticulars were predominant in the universe's "urban areas," the centers of rich, packed clusters, where hundreds to thousands of individual galaxies huddle together. Spirals are more commonly found in the "field," the more sparsely populated or rural regions of space.

Did this segregation happen from the start, based on the initial conditions of galaxy formation? Perhaps ellipticals and lenticulars were selectively born where the primordial gas was densest. Dressler long championed that idea. Or possibly those ellipticals were created later on, when an initial population of gas-rich spirals fell into a cluster and merged. Oemler favored that scenario. "I used to insist that everything was due to evolution in clusters," says Oemler. "Alan and I argued these points in journal papers for more than a decade." Today, they are coming to believe it's probably a little of both.

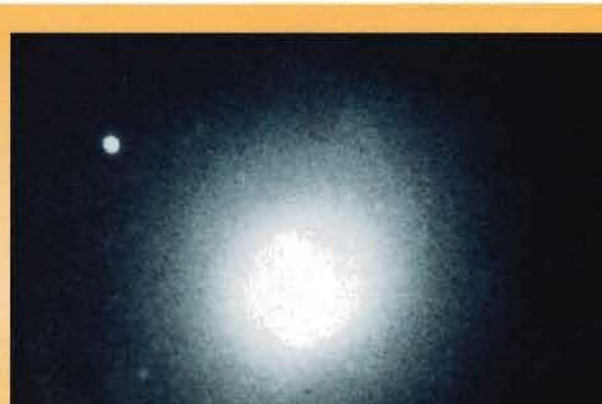
Alan Dressler

"Galaxies just don't look like that today, I hardly know how to classify them."
— Alan Dressler

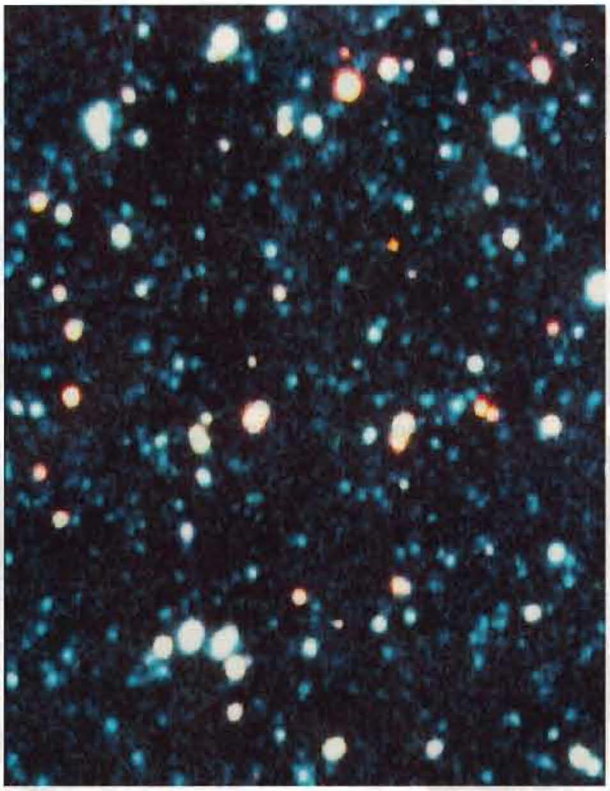
The roots of this debate can be traced back to 1978, the year that astronomers obtained the first direct evidence that galaxies were indeed evolving over time. Using the 84-inch telescope on Kitt Peak in southern Arizona, Oemler and his longtime collaborator Harvey Butcher analyzed the colors emanating from two galaxy clusters situated some 5 billion light-years away (hence 5 billion years back in time). And what they saw was somewhat unexpected: Both clusters' galaxies were radiating more blue light than the clusters seen near us today, which tend to be



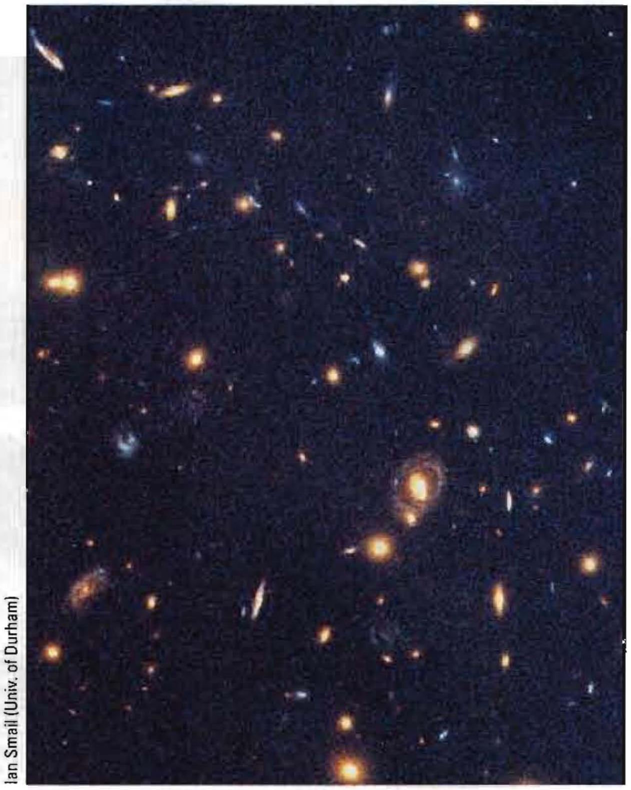
5 billion years ago



A few million years ago


J. Anthony Tyson (AT&T Bell Labs)

Ground-based telescopes show distant blue galaxies as smudges of light devoid of shape. To understand how galaxies change with time, astronomers needed the Hubble Space Telescope.


Ian Smail (Univ. of Durham)

Hubble reveals distant galaxies in all their glory. By comparing the shapes of distant galaxies to their nearby counterparts, astronomers can piece together the story of galactic evolution.

red. This bluish characteristic of populations of galaxies in distant clusters was soon dubbed the Butcher-Oemler effect.

Even as Butcher and Oemler were gathering their data, Yale theorist Beatrice Tinsley was modeling how entire populations of stars age within a galaxy. She concluded that galaxies can undergo substantial internal evolution through time, more than previously assumed. A young galaxy can start out bright and blue, when the gaseous resources needed to form stars are at their peak, and then gently redden with age and fade away over the eons as the stars age and die.

But others wondered whether the Butcher-Oemler effect was a sign that great upheavals were taking place in that far-off time: Could galaxies be dimmed, brightened, or altered owing to influences from outside the galaxy? Perhaps the galaxies were colliding, merging, and consequently "starbursting," vigorously forming stars at hyper-accelerated rates. Theory was on their side. At MIT in the 1970s, mathematician Alar Toomre was beginning to conduct his groundbreaking computer simulations that showed how two spiral

Spiral Galaxies Through Time


A. Dressler, M. Dickinson, D. Macchetto, M. Giavalisco, and NASA

12 billion years ago

9 billion years ago

Harvey Butcher

Harvey Butcher and his colleagues have been independently classifying galaxies in the Hubble images.

galaxies can merge to form an elliptical galaxy.

Something was obviously happening in these clusters. Following up on Butcher and Oemler's finding, first Dressler in California and later Couch in Australia obtained spectra of the distant galaxies and saw evidence of heightened star formation. "A spectrum can tell you a lot," explains Couch. "We found emission lines, which means that star formation is definitely going on. But we also found lots of hydrogen absorption lines from A-type stars, which hang around for only a billion years or so. So, we were seeing galaxies within a billion years of a starburst."

Obtaining additional information over the next 15 years, though, was a struggle. Astronomers switched from photographic plates to CCDs — digital imaging — which offered a better look at the clusters. But not good enough. The blue objects in Oemler and Butcher's far clusters were still indistinguishable, no more than faint blobs.

It was the amazing resolution of the Hubble Space Telescope that provided a quantum leap in this endeavor. "It really hits you when you look at these Hubble images, just how beautiful the galaxies are," says Couch. "Exquisite detail." Astronomers could at last see directly what was only guessed at or suspected. The bluer objects in the far clusters were definitely spiral galaxies and, more important, they existed in numbers greater than in clusters today. "That's a big step forward," says Oemler. "It could have been that the blue things we saw had nothing to do with normal galaxies. We always suspected they were spirals, but we couldn't prove that until we had the Hubble Space Telescope."

The appearance of these distant galaxies, though, is making astronomers redefine the term "normal." They are spirals, but very strange-looking spirals indeed. Oemler brings up the image on a computer workstation of one particular cluster under study. Scanning over the picture, he points to many galaxies in the cluster that are ragged and asymmetric. "You also see all these rings," he notes. "Galaxies just don't look like that today." Dressler adds, "It's full of twisted, funny spiral galaxies. I hardly know how to classify them." One of the group's tasks is gauging the degree of "blobbiness" in each galaxy — in other words, how much the galaxy is distorted compared to

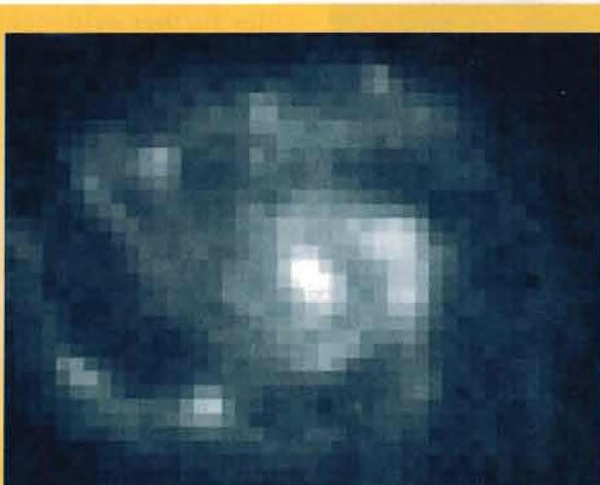
Warrick Couch

"It really hits you when you look at the Hubble images, just how beautiful the galaxies are."
— Warrick Couch

a more normal disk galaxy. In this way, they hope to glean clues on the origins of those distortions.

At first, the group was tempted to conclude that mergers explained it all — that these unusual spirals, types no longer seen today, simply paired up to become something else, most likely elliptical galaxies. Interactions are certainly occurring; some of the galaxies are elongated and have tidal bridges between them (see "Galaxies Colliding in the Night," November 1996). But that simple scenario no longer explains all that they are seeing.

For one, there are problems with mergers within a cluster: Galaxy velocities are so fast within a cluster, up to 1,000 kilometers per second, and stars are spaced so far apart, that the stars would merely pass



5 billion years ago

A few million years ago

by one another with hardly a fare-thee-well. Even if the spirals did somehow merge, the newly formed ellipticals would be rich in blue, star-forming light because the colliding clouds of gas and dust would trigger a new round of star formation. But all the big elliptical galaxies in these clusters appear red and long settled. Ellis is checking to see if any of the ellipticals display a smidgen of residual blue light, a sign of prior merging and star formation. "But so far," he says, "the bulk of the luminous ellipticals in these clusters look very old." Their births seemed to have occurred much further in the past. This seems to bear out Dressler's long-cherished belief that ellipticals are a product of "nature" more than "nurture."

But the spirals may be another matter entirely. The group is now considering whether the bizarre-looking spirals were, instead, altered in some way. A spiral's gas and dust could have been be stripped away as it zoomed through the relatively dense gases hovering throughout the cluster. Maybe in that way, suggests Couch, the spirals turned into lenticulars. "The fraction of lenticulars in nearby clusters is very high," he notes, "but it is low in these younger clusters."

Or the distant galaxies could have been "harassed" (as astronomers like to call it these days), whittled down by tidal forces as they gravitationally encountered other passing galaxies. This encounter would compress their gases, and new stars would flare up,

Richard Ellis

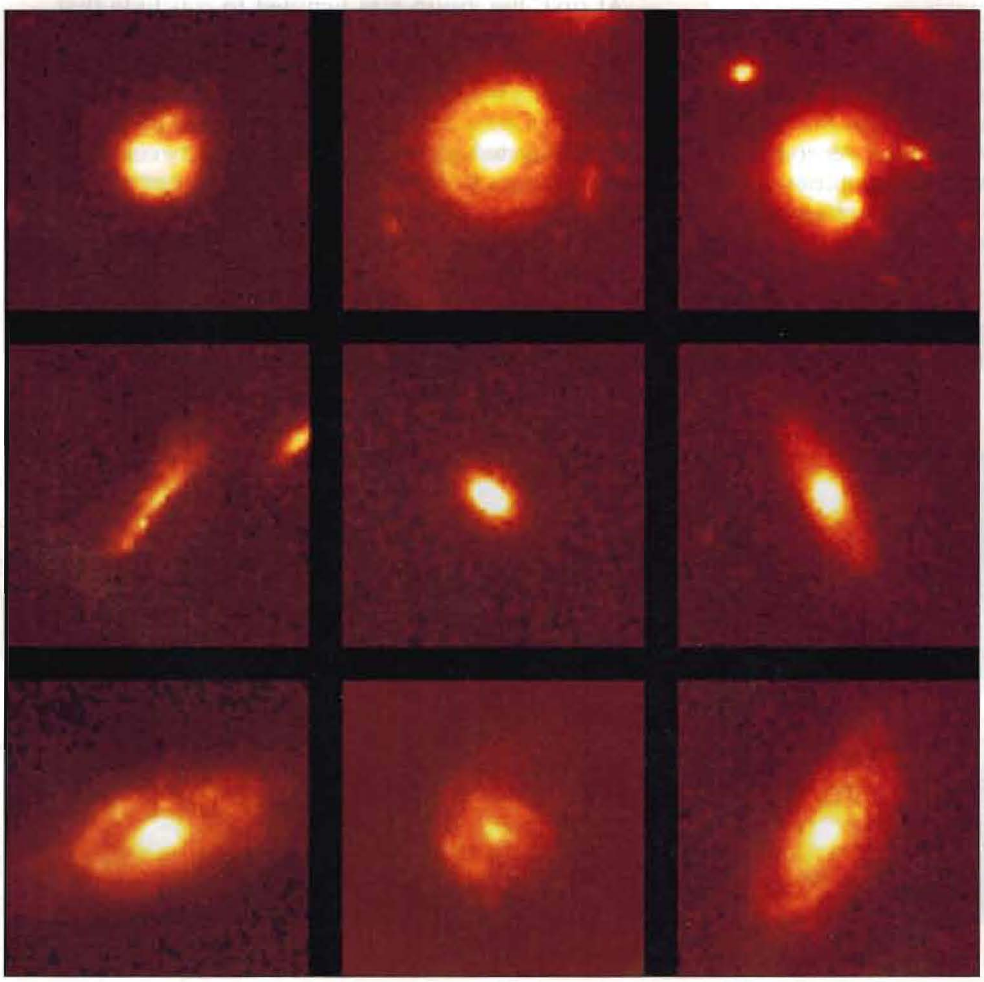
"Hubble finally allows us to sort these far galaxies into categories."
— Richard Ellis

speedily depleting the galaxy's gaseous resources. Today, too dim to be photographed, these spiral galaxies seem to have vanished from the universe. Astronomers have recently begun finding hordes of dim galaxies that contain very few stars (see "Ghost Galaxies of the Cosmos," June 1996). Maybe these are the ghostly remains of these distant blue spirals that once burned brightly many eons ago. But that's only speculation at this point. "I'm not yet convinced that we've found enough dim galaxies nearby to explain what's going on," says Ellis.

"We need to find the smoking gun," adds Oemler.

What would help would be to compare what's happening in the urban areas, that is the central area of the clusters, with what's happening in the field. Fortunately, Hubble is also carrying out the Medium Deep Survey, a set of long-term exposures of distant galaxies in the field. And the view there is just as bizarre as in the clusters. Astronomers are seeing many faint, blue, irregular galaxies in deep space, far more than seen today (see "Our Strange, Scrappy Ancestors," December 1995). Either they've stopped forming stars and so have now faded away, or they've come together to form more normal-looking galaxies. Whatever the reason, the change provides further evidence that the universe has indeed evolved over time.

If galaxies both in the field and in the clusters are following the same course, then it would point to nature having the upper hand. Where a galaxy is located doesn't matter; it's just following



Ian Smail (Univ. of Durham)

Nine spiral galaxies as they existed halfway back to the moment of creation. Many spirals in that distant epoch had distorted shapes. These spirals have no counterparts in the modern-day universe.

Robert Williams and the Hubble Deep Field Team/STScI and NASA

Galaxies through time: Last year the Hubble Space Telescope took a 10-day exposure of a tiny patch of sky, revealing galaxies in the local, intermediate, and distant universe.

its own internal life cycle. "In other words, those distant spiral galaxies could be ragged and scruffy simply because that's what galaxies looked like back then," points out Dressler. But if the evolution of a galaxy differs in those disparate environments — field and urban center — then a strong finger is pointed at nurture doing the job. The change a galaxy makes would depend on its surroundings, its encounters with other galaxies over time.

Ian Smail

Ian Smail observes how massive clusters bend the beams of light passing by from more distant galaxies.

Answers will arrive with additional observations, especially spectral measurements from the ground. Only there are the mirrors big enough (particularly on the new 8- and 10-meter-class telescopes) to capture sufficient light from those distant regions to dissect the light into its spectral components. That will help astronomers determine what is causing the bursts of star formation in those far galaxies. Hubble's relatively small 2.4-meter mirror, while superb for imaging because of its position above the atmosphere, cannot gather enough light to do spectroscopy on particularly dim objects.

"We've got a series of snapshots," says Oemler. But they need the see the entire movie, including scenes closer in as well as farther out. A new wider-field camera on Hubble, scheduled for installation in 1999, will help astronomers view nearby clusters, which extend over a broader swath of sky. But getting deeper images will eventually require new instrumentation because Hubble is not optimized for viewing the primeval universe.

Waves of light from distant space stretch out with the universe's expansion, so going deeper into space means peering at longer and longer wavelengths, beyond the visible spectrum — into the infrared. Dressler recently chaired a committee that recommended the construction of a future 4-meter infrared space telescope, nearly twice the size of Hubble, to view the era of galaxy formation some 10 billion light-years distant or more. "In the current competition for financial resources, we're probably talking about something 15 to 20 years from now," says Dressler. But NASA has jumped on the Dressler committee suggestion, and is now looking at the possibility of building an even larger space telescope with a 6- to 8-meter mirror and launching it as early as one decade from now. "The power of such a telescope to look back to the era of galaxy birth would be awesome," adds Dressler.

In the meantime, Smail is working on a clever technique to discern some information on galaxies farther out. As pointed out earlier, rich galaxy clusters can act as lenses. Smail is testing a method of estimating the distance of those far galaxies by the amount their images are distorted — elongated — by the lensing effect.

But, for now, the group is simply relishing the view from Hubble. "That's the most fun of all," notes Oemler, "just staring at these pictures." Dressler muses: "For as long as all of us have been trying to figure out whether nature or nurture is the key to galaxy evolution, it's hard to believe that Hubble and the giant new telescopes like Keck are finally giving us some answers — it's some of both. It's funny how many things turn out that way." □

Marcia Bartusiak is a Massachusetts-based science writer. Her previous article for ASTRONOMY, *"The New Dark Age of Astronomy," appeared in the October 1996 issue.*