The turbulent world of compact galaxy groups

No longer astronomy's freaks, compact groups of galaxies have become laboratories for studying how galaxies evolve, interact, and grow. /// BY MARCIA BARTUSIAK

In 1864, atop France's Plateau Longchamp near the Mediterranean Sea, the Marseille Observatory installed the largest reflecting telescope then in existence. Designed by Léon Foucault (of pendulum fame), the reflector was a technological marvel. It was the first large telescope with a silver-on-glass mirror, which allowed observers to gather far more light than possible with polished-metal mirrors. Eighty centimeters (31 inches) wide, the silvered mirror helped the observatory's director, Edouard Stephan, discover a host of faint nebulae never before charted.

Stephan's most captivating find came in 1877. While exploring the northwest corner of the autumn constellation Pegasus, he noticed an unusual collection of five nebulae huddling close like a scout troop around a campfire on a cold night. In honor of its discoverer, this striking assembly of "nebulae" (actually galaxies) is called Stephan's Quintet. With brightnesses ranging from 13th to 15th magnitude, the group is a favorite target for amateur astronomers with large telescopes. Film buffs may also know these five galaxies from the Christmas holiday classic *It's a Wonderful Life*. The movie opens with an image of the quintet depicting angels engaged in conversation.

THE WHIRLING HEART OF STEPHAN'S QUINTET, the first compact galaxy group ever found, reveals a violent past. Millions of years ago, a quintet member not visible in this image barreled past these galaxies and ripped a 100,000 light-year-long trail of gas from NGC 7319 (upper right). Compact groups are defined by a tightly knit band of a few galaxies.

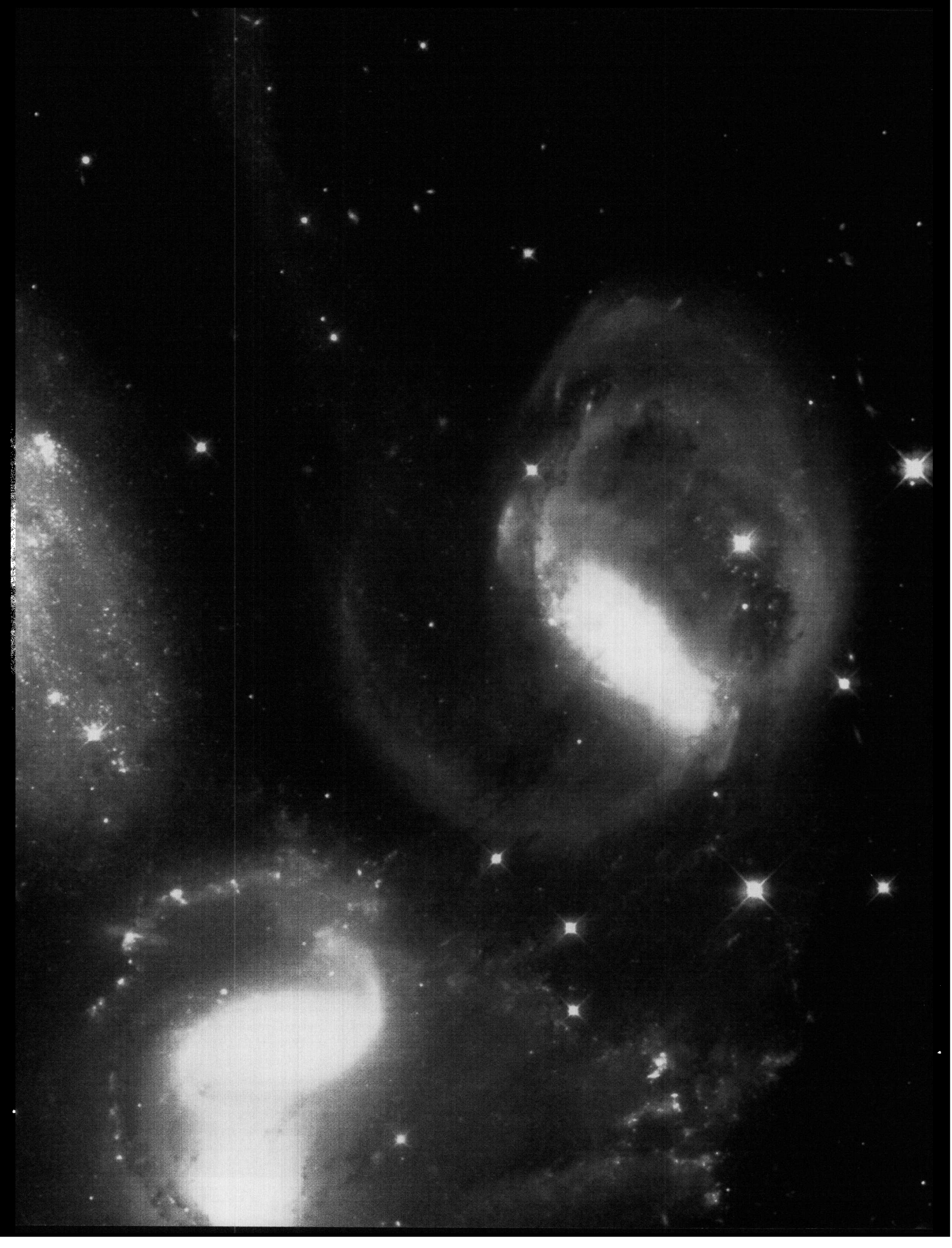
NASA, JAYANNE ENGLISH (UNIVERSITY OF MANITOBA), SALLY HUNSBERGER (PENNSYLVANIA STATE UNIVERSITY), ZOLT LEVAY (SPACE TELESCOPE SCIENCE INSTITUTE), SARAH GALLAGHER (PENNSYLVANIA STATE UNIVERSITY), AND JANE CHARLTON (PENNSYLVANIA STATE UNIVERSITY)

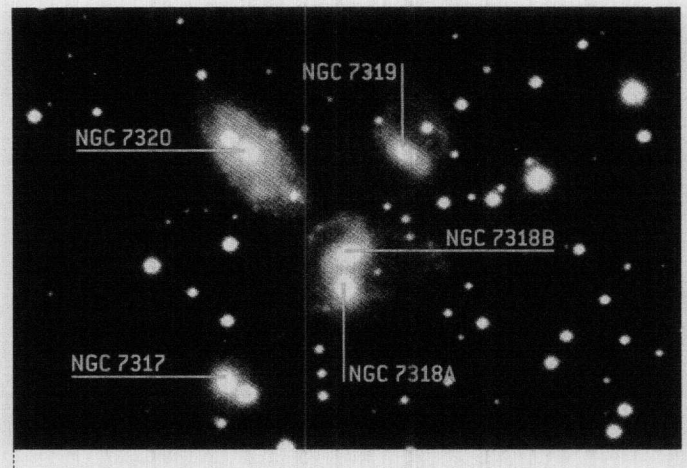
Not your ordinary cluster

Cosmologists have long known that galaxies form loose groups, clusters, and superclusters that weave a bubbly, filamentary network throughout the universe. But groups like Stephan's Quintet are distinctive. They typically consist of just four or five galaxies gathered closely in a region where galaxies are usually sparse. According to Jane Charlton, an astronomer at Pennsylvania State University, a compact group is defined as having no other galaxies around it for at least three times the angular diameter of the group. In normal clusters, there's no such clear-cut border. Like a handful of skyscrapers rising from a rural cornfield, a compact group of galaxies resembles the core of a rich cluster — minus the cluster.

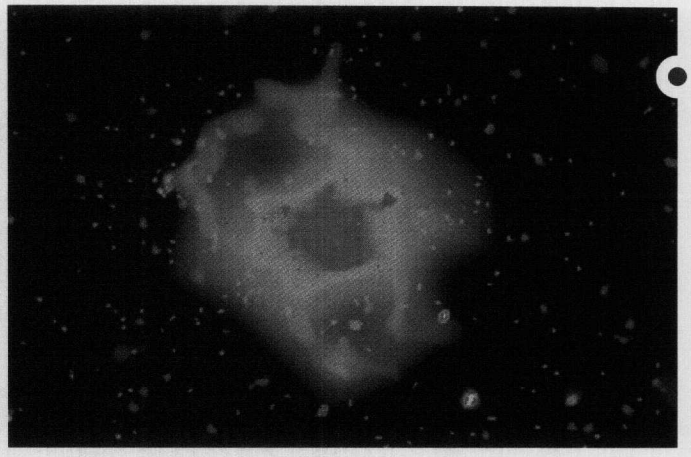
Such collections are rare. After Stephan's Quintet, the next one was not discovered until 1948, when Carl Seyfert of Vanderbilt University noticed six bright objects crowded together on a deep-field photograph. Although recent research has shown that only four galaxies are actually bound to the group, Seyfert's Sextet was one of the densest compact groups known, with its six members apparently squeezed into two arcminutes, barely 1/15 the width of the Moon.

A few decades ago, only one or two papers were published each year on compact groups; today, a couple dozen appear annually. While normal clusters may host the same number of galactic interactions and mergers, which occurred quite frequently in the first few billion years after the Big Bang (when the universe was smaller and denser), compact groups are easier to study because of their size. By examining bursts of star formation and galactic activity within compact groups,





THE FIVE GALAXIES THAT MAKE UP STEPHAN'S QUINTET are not obvious at first glance. Members include NGC 7317, NGC 7318A and B, and NGC 7319. Surprisingly, NGC 7320 is not a true group member, while galaxy NGC 7320C, lying outside of this image, is. Backyard astronomers can glimpse the group in Pegasus glowing dimly at magnitude 14. CHUCK VAUGHN



X-RAY EMISSION from compact groups lends credence to their status as gravitationally bound objects. The gas between galaxies in a cluster often heats to millions of degrees, radiating x rays that can be detected by observatories such as Chandra, which took this false-color image of HCG 62. Black and green denote low x-ray intensities, red and purple high. J. VRTILEK ET AL./CFA/NASA

astronomers have a grand opportunity to see how galaxies may have evolved through the eons.

"We can learn how galaxies interact and how fuel can be funneled into an active galactic nucleus," says Paul Hickson, an astrophysicist at the University of British Columbia. "It will help us answer why some galaxies have active black holes in their centers and others don't."

Discordant redshifts

Astronomers began to look closer at these uncommon galaxy groups a generation ago, thanks to a rancorous controversy. In the early 1960s, redshifts were obtained for members of Stephan's Quintet and Seyfert's Sextet. (Such observations determine the displacement of a galaxy's spectral lines toward the red, a measurement that indicates how fast a galaxy is receding as the cosmos balloons outward. It also gives the galaxy's distance.) In both groups, one galaxy had a very different redshift from the rest of the group. Another "discordant redshift" was found among a remarkable chain of five galaxies called VV 172.

At first it seemed unlikely that a foreground or background galaxy would so often appear to lie near a rare compact group. And for years this perception gave ammunition to a camp (led by maverick astronomer Halton Arp) that argued redshifts were not necessarily due to an expanding universe, but to some yet-undiscovered physics.

Misfit redshifts weren't the only puzzle. The galaxies within each compact collection all had high velocities relative to one another, suggesting they were in the process of coming apart. Astronomers now realize that dark, invisible matter was enveloping the systems and acting as gravitational glue to keep the galaxies bound together despite their speedy motions, which were themselves a result of gravitational interactions.

The redshift debate has also died down. More recent statistical studies that use larger samples of compact groups concluded the discordant galaxies are simply fortuitous, line-of-sight projections. They really are unconnected to the compact groups they appear to lie within.

"Our results confirm that projection alone can account for the high incidence of discordant redshifts," reported Hickson and Angela Iovino of Italy's Brera Observatory in 1997.

Surveying the field

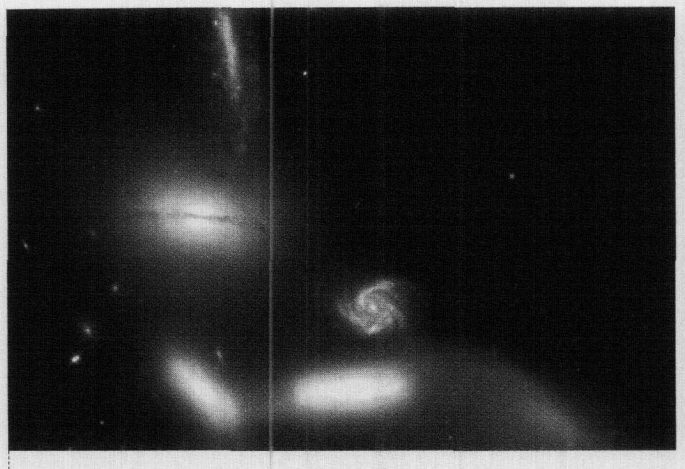
The study of compact groups took a decisive step forward in 1982 when Paul Hickson compiled a catalog of these unusual systems. Up until then, only a dozen or so were known, mostly accidental finds. To understand the properties of these special objects, Hickson knew that astronomers needed a larger sample, selected systematically. He chose specific membership criteria: a certain number in the group (four or more); densely packed (separated by just a few galactic widths); and fairly isolated (no other galaxies within a certain distance). To hunt for them, he spent months poring over prints from the original Palomar Observatory Sky Survey conducted in the 1950s, about a thousand plates in all.

"I used a big, long plastic ruler, set it down on the plate, and then scanned along with a magnifying glass," he recalls. "Then I'd move the ruler down and scan another line, continuing this procedure down the plate."

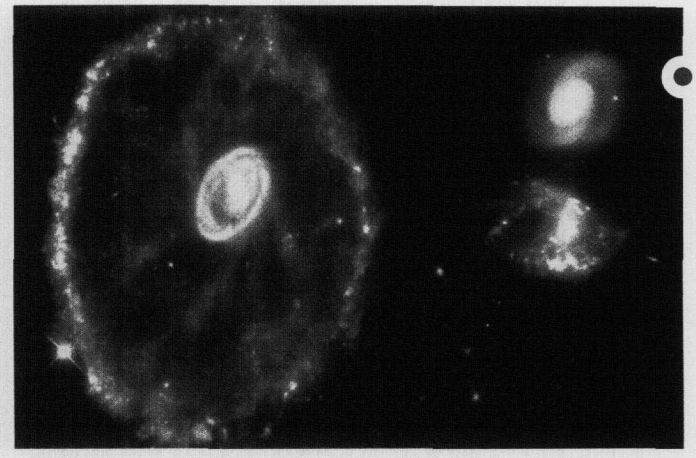
In the end he found exactly 100 compact groups of galaxies, known by the designation HCG, for Hickson Compact Group. (Stephan's Quintet, for example, is HCG 92 and Seyfert's Sextet is HCG 79.) Through the 1980s, Hickson and his graduate students carried out extensive photometry and spectroscopy on each group.

With such a large dataset available at last, other astronomers were soon attracted to these systems as well. Hickson groups have now been studied with infrared, radio, and x-ray telescopes. New digital scans of the sky, as well as redshift surveys, are revealing new groups yearly. As the list of compact groups has swelled, a few members of the Hickson catalog have also been removed. Some have proven to be chance projections of galaxies at varying distances; a few turned out to be the cores of

Marcia Bartusiak, a member of *Astronomy*'s Board of Advisors, is a science writer based in Massachusetts. Her award-winning book, *Einstein's Unfinished Symphony*, was published in paperback this February.



SEYFERT'S SEXTET, in the constellation Serpens, is actually a misnomer. The small face-on spiral at center is about five times farther away than other group members, and the sixth "galaxy" (lower right) is simply a trail of stars ripped from another galaxy. NASA, J. ENGLISH (U. MANITOBA), S. HUNSBERGER, S. ZONAK, J. CHARLTON, S. GALLAGHER (PSU), AND L. FRATTARE (STSCI)



CELESTIAL FIREWORKS hang in the sky in the form of the Cartwheel Galaxy, whose ringed structure is a result of a head-on collision a few hundred million years ago with one of the two galaxies beside it. Such forceful collisions are thought to occur often in compact galaxy groups, seeding millions or billions of new stars in the process. K. BORNE (STSCI)/NASA

larger clusters. "In one case I even mistakenly identified a star as a galaxy," says Hickson.

A few astronomers wondered whether these groups were merely filaments in the universe's bubbly large-scale structure as seen from one end, looking straight into the filament. Indeed some may be, but the majority appear bound together. Almost half of the HCGs, for example, show signs of ongoing interactions between members: Galaxy shapes are distorted, galactic centers are brightened (a sign that gas is flowing in and fueling an active nucleus), and sweeping trails of stars attest to past galactic encounters. Moreover, compact groups appear to be deficient in neutral hydrogen, which was likely stripped away by frequent gravitational interactions. Galaxies in a chance alignment would not share such similar properties.

lifetime of these compact groups should be "disturbingly short." "We recognized there was a severe merging instability," says Hickson. Gravity would draw the close galaxies together quickly to form one large galaxy.

In the 1980s, astronomer Joshua Barnes, now at the University of Hawaii, carried out computer simulations of interacting spiral galaxies and reached the same conclusion. Dense groups did not last very long in his models — just a fraction of the universe's age. In his simulations, the galaxies merged to form one elliptical galaxy in a billion years or less. This may explain the occasional giant elliptical seen isolated in space, the result of a compact group that eventually coalesced completely. Ellipticals are usually found in the cores of clusters.

Trevor Ponman of the University of Birmingham in Great

Compact groups may dissolve like aspirin in water, evolving slowly from spirals into a single hypergalaxy via persistent tidal stripping.

Living fossils

How can such dense groups form in the first place? The latest evidence suggests that close-knit systems can form as transient associations within looser groupings of galaxies, perhaps inside particularly dense clumps of dark matter. Cosmologists looking at the big picture suspect that if this is true, then such groups offer further proof that the universe's matter-energy content approaches or equals so-called "critical density." This is their term for the knife-edge balance between a cosmos that's completely open (and expanding forever) or closed (wherein the expansion someday stops and reverses toward a cosmic collision, or Big Crunch). Such tight groupings could not form gravitationally if the universe were less dense.

But one mystery remains — how long can compact groups live? Early on, in 1977, Hickson and colleagues Douglas Richstone and Edwin Turner published a paper noting that the

Britain and six colleagues identified a possible fossil compact group using the ROSAT x-ray telescope. They discovered a large elliptical galaxy some 2 billion light-years distant whose x-ray luminosity and properties closely resembled that of a compact group. It was "similar to the giant elliptical galaxies at the centers of clusters, yet . . . apparently isolated," they reported in 1994. "The most natural explanation . . . is that it is the merged remains of the galaxies which previously constituted the group."

Yet if compact groups merge quickly, why then do any still exist? Some astrophysicists suggest that compact groups could be continuing to form as subsystems within larger groups. "From some lines of sight," points out Barnes, "our own Local Group of galaxies — the Milky Way, Andromeda, and Triangulum — probably looks like a compact group. But we're only now starting the process of gravitationally collapsing." A group might also be refreshed and reinvigorated by the periodic infall of new galaxies from their surroundings.

HCG 40'S HIGH-SPEED GALAXIES might have merged long ago were it not for the dark matter that envelops and preserves them, astronomers believe. In computer simulations, dark matter and angular momentum stave off mergers long enough to explain the number of compact groups we see today. CISCO, SUBARU TELESCOPE, NAOJ

THE GALAXIES IN HCG 87, short for Hickson Compact Group 87, revolve around a common center every 100 million years. Insight into these systems and their role in galactic evolution and dynamics has grown by leaps and bounds since 1982, when astronomer Paul Hickson compiled a catalog of 100 such groups. AURA/STSCI/NASA

Other astronomers wonder if the compact groups seen today survive longer and are actually much older than assumed. Members of this camp contend we don't see enough fossils if swift mergers have gone on since the beginning. To test this, researchers at the Marseille Observatory — where Stephan discovered the quintet — recently conducted new computer simulations of mergers within compact groups. When they adopted the simplest initial conditions, the Marseille team ended up, like Barnes, with rapid mergers. But they found they could avoid this fate if they added some angular momentum (spin) to the group and an extensive halo of dark matter enveloping the entire group. The more massive the halo, the slower the merger rate. In this way, a compact group forged in the early universe could still be around. The dark matter serves as a buffer to slow down — or even hold off — a merger.

"They're like flies caught in molasses," says Jack Sulentic, an astronomer at the University of Alabama who worked with Arp as a post-doc during the height of the redshift controversy and leans toward this view. "Seyfert's Sextet is an old group, yet we still see its individual galaxies. This suggests compact groups do not merge violently and swiftly but dissolve like aspirin in water. There's a slow evolution from spirals into a single hypergalaxy via persistent tidal stripping."

Local disturbances

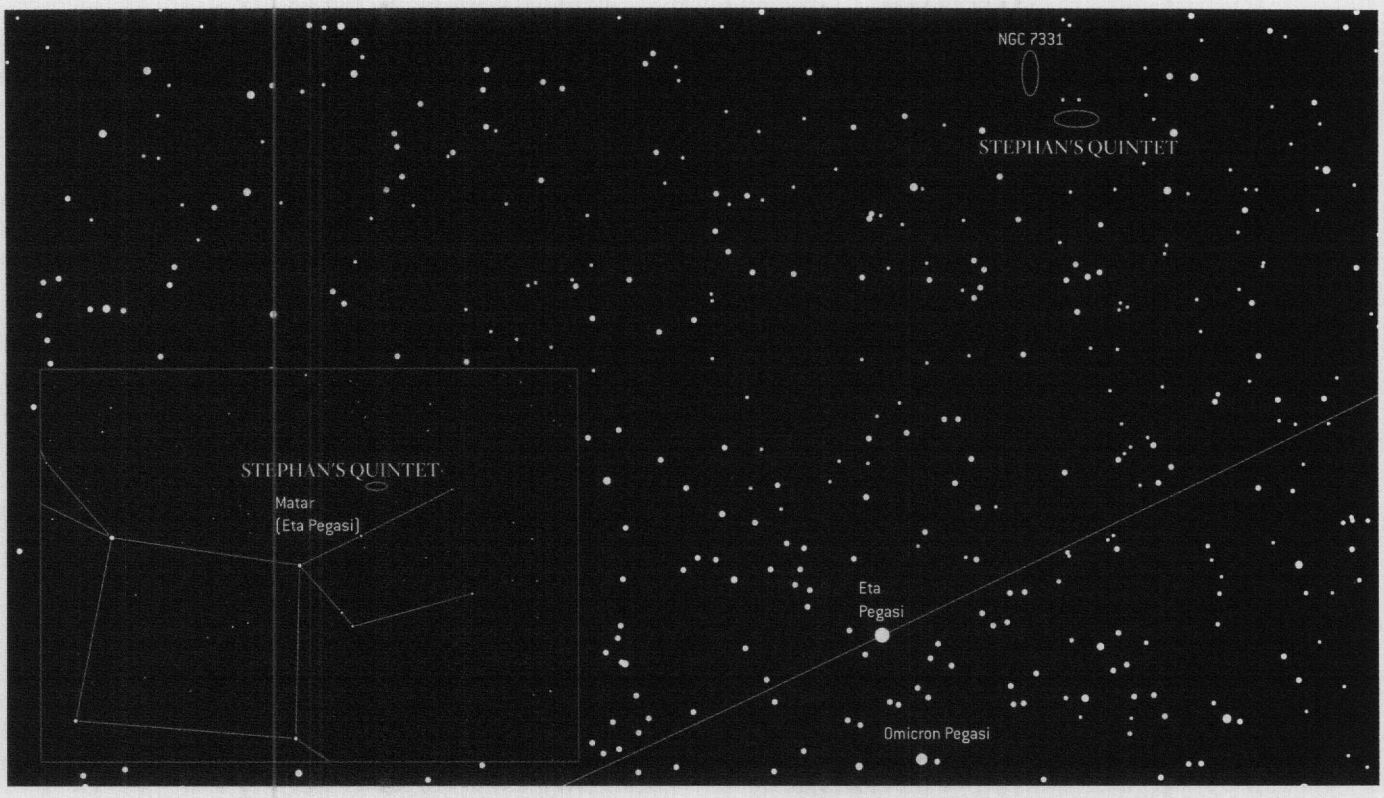
Along with the statistical studies encompassing all known compact groups, astronomers are also zooming in on individual groups to understand their dynamics. Two years ago Sarah Gallagher, Jane Charlton, and Sally Hunsberger from Pennsylvania State University trained the Hubble Space Telescope's keen eye on Stephan's Quintet and revealed breathtaking details within that special environment.

They found galactic distortions, long trains of stars sweeping outward from past interactions, and bursts of star formation. Hubble's high resolution confirmed that NGC 7320, the large spiral galaxy at the southern edge of the quintet, is not a true member of the system but a foreground galaxy situated some 35 million light-years away. The other quintet members — NGC 7317, NGC 7318A and B, and NGC 7319 — lie nearly eight times farther out, at a distance of 270 million light-years.

Just 250 million years ago, the quintet captured the spiral galaxy NGC 7320C (now seen off to the east) as it sprinted through the group, ripping out a wispy trail of gas and stars in its wake. The tidal disruptions of this passage triggered new stars to form. Evidence for an even older tail, aged 750 million years, suggests this might have been the second time NGC 7320C sped through the group. Whoever the culprit was, NGC 7320C is now a member of the quintet and will return again many millions of years from now, yanked back like a ball on an elastic string. In fact, some tidal disturbances are occurring right now. As NGC 7318B races through the quintet at more than 800 kilometers (500 miles) per second, it's wreaking similar havoc on NGC 7318A.

"That's an amazing velocity for a group galaxy," says Sulentic. "They usually move at 100 to 200 kilometers per second. It's heating the gas within the group to a million degrees and creating a tremendous shock wave, one of the largest we've ever seen — [as big as] a significant fraction of the diameter of the Milky Way. And all this is happening now. We've caught it 'in flagrante delicto'." Sulentic recently published a multiwavelength study of the quintet with colleagues from Mexico, Spain, Italy, and Germany. In a few million years, he says, the quintet will begin to cool down.

Such encounters may be another reason that certain compact groups condense more slowly than expected. Galaxies periodically passing through can transfer enough energy to the group to prevent members from merging into one giant galaxy. In time, NGC 7318B will shoot completely through the group and leave the system entirely — it's moving too energetically to stop. Its collision began some 20 million years ago, but star clusters are still being born as a result. Like a series of linked fireworks, the explosive death of one generation of stars can trigger the birth of the next, and so on down the line. "So much gas gets stripped out of the galaxies during these encounters and



LOOK FOR STEPHAN'S QUINTET just above the Great Square of Pegasus, which rises in the wee hours of the morning this month. JAY SMITH

thrown into intergalactic space," notes Jane Charlton, "that stars even form in those regions, outside the galaxies."

"Stephan's Quintet is a valuable laboratory," adds Sulentic. "There are many compact groups, but not all are active at the same moment. So we're lucky to see one in action." The last time something like this happened nearby may have been 300 to 400 million years ago, when an intruder punched completely through a spiral galaxy, creating the famous Cartwheel Galaxy, an immense ring-like structure 100,000 light-years wide.

Out of the debris

Charlton and her colleagues continue to sift through the Hubble data, focusing on the dwarf galaxies often sprinkled throughout compact groups. In recent years evidence has been growing that dwarf galaxies can form in the tidal debris left over after two galaxies interact. The Hubble image of Stephan's Quintet displays this very clearly. According to Pennsylvania State University astronomers, some of the material in the quintet's tidal debris has now created 20 or so dwarf galaxies.

The big question, says Penn State astronomer Christopher Palma, is whether the dwarf galaxies are massive enough to keep their stars from drifting apart. Radio observations of neutral hydrogen in Stephan's Quintet from the Very Large Array suggest many might be, depending on their provenance. The observations revealed another tidal tail, not visible in the optical. It stretches due north from the other tails and is likely the remnant of another ancient encounter.

"In searching for dwarf galaxies within Stephan's Quintet, we found dwarfs lined up with this tail of hydrogen, and this is important," says Palma. By being embedded in the gas, which provides additional gravitational glue, they're likely to survive, he argues. And that could mean that a good number of dwarf galaxies in the present-day universe were created in just this way, out of the debris of galactic interactions and mergers during the universe's infancy.

The quintet's image could be a snapshot of events that occurred regularly in the early universe, when galaxies were first forming. Palma estimates that up to a third of dwarf galaxies might have originated as tidal debris, although he stresses this is still speculation. The Penn State team hopes to use the Hubble Space Telescope again to look at 20 additional compact groups and examine dwarf galaxy populations more broadly.

Aside from serving as a special laboratory for observing interactions and mergers, compact groups of galaxies fulfill another service — sheer cosmic pleasure. Take HCG 87. In 1999, members of the public visiting the HST website voted to have Hubble's wide field camera take a special picture of this particular group for its Heritage Image Gallery. Voters were not disappointed. By combining the images taken separately through four different color filters — blue, green, red, and infrared — Hubble astronomers created a full-color portrait of HCG 87. This celestial family of three spirals and one elliptical offers a stunning view of a universe in miniature.

Even though Jane Charlton had a hand in obtaining that vivid image, HCG 87 is not her favorite Hickson compact group. That title goes to the first such group ever found, the sparkling collection of star systems known as Stephan's Quintet. "Not only because it was the first Hubble time I ever got," she says, "but also because of its connection to the movie *It's a Wonderful Life*. When I was young, I always wondered what the galaxies in that movie were. Now, it's a nice way to break the ice with the public when I talk about compact groups." ■