cortex, he says—because they have no cortex on that side at all. Oxford University psychologist (and codiscoverer of blindsight) Lawrence Weiskrantz adds that monkeys show blindsight even when they have had both halves of their primary visual cortex completely removed.

Gazzaniga is not convinced by either argument. First of all, he insists, "you absolutely cannot cross-reference monkey and human work." As evidence of the difference between the species, he notes that all monkeys that lack a primary visual cortex show blindsight, while the phenomenon is rare in humans with similar damage. As for the hemispherectomized patients, all those that have been studied had their surgery as children, and so he argues that they constitute special cases, because young brains have a great ability to reorganize and compensate for lost functions. Test someone who had a hemisphere removed as an adult, he posits, and you won't find blindsight.

Indeed, Gazzaniga's hypothesis makes many predictions like that, which can be tested with further experiments. And those experiments are proceeding. Ptito says he is about to begin testing a group of patients who had hemispherectomies as adults. And psychophysicist Keith Ruddock of Imperial College, London, and his colleagues recently found that magnetic resonance imaging of a much-studied patient known as "GY" revealed no spared regions in primary visual cortex—a result that would seem to contradict Gazzaniga's hypothesis.

Gazzaniga is reluctant to comment on work he hasn't seen, but he says he would like to test GY in his blindsight set-up to make the experiment complete. Such subject-swapping, many agree, would also help to standardize such important parameters as what kinds of tests are used for blindsight, how the questions are asked, and how the images are presented to the patients, all of which have been shown to be critical to the phenomenon.

Whatever the outcome of the subject swapping, most agree that Gazzaniga's study is an important contribution to the field. "When you claim there is blindsight [in the absence of any primary visual cortex] there is a chance that it may not actually be the case," says MIT's Andersen. "It raises a caution for anyone doing this research."

–**Marcia Barinaga**

Additional Reading

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L. Weiskrantz, "Unconscious Vision: The Strange Phenomenon of Blindsight," *Sciences*, **32**, 22 (1992)

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ASTRONOMY

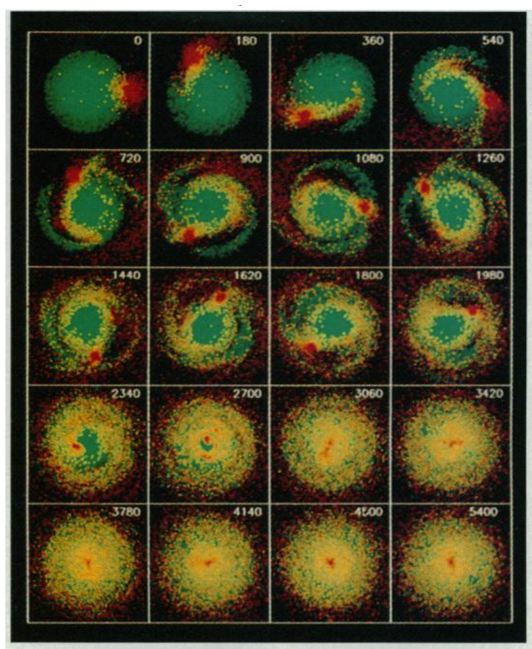
Tracing the Milky Way's Rough-and-Tumble Youth

Our galaxy's graceful spiral form seems the very picture of serenity. For decades, astronomers have thought it had a history to match: an uneventful progression from a primordial gas cloud to an orderly swirl of stars. But as observers take a closer look at the ages, chemistry, and motions of the stars that make up the Milky Way, they are seeing subtle signs of turmoil. And now several groups have concluded that our galaxy had a violent youth, tangling with and gobbling up one or several smaller galaxies in its neighborhood.

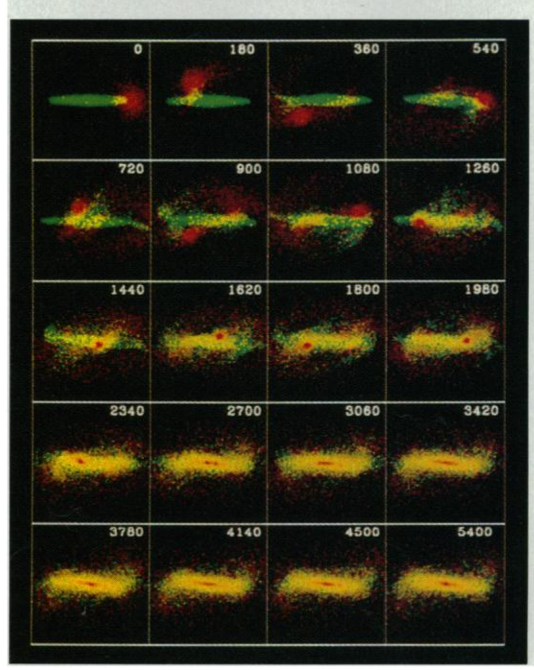
One line of evidence comes from studies of globular clusters, dense knots of stars that are scattered in a vast spherical halo around the familiar disk of the galaxy. Some of them, say Robert Zinn of Yale University and Sidney van den Bergh of the Dominion Astrophysical Observatory in Canada, show every sign of being stolen goods, wrested away from other galaxies as the Milky Way collided with them. Meanwhile, other investigators are reporting signs that these ancient collisions have left their mark on stars within the disk of the Milky Way itself.

If these findings are confirmed, they would add to the challenge facing the classical picture of how the galaxy took shape. Proposed 30 years ago by Olin Eggen of Cerro Tololo Interamerican Observatories, Donald Lynden-Bell of Cambridge University, and Allan Sandage of the Carnegie Institution, that picture holds that the galaxy formed from a single cloud of gas that collapsed in isolation. First born, in this picture, was a spherical halo of stars—precursors of today's globular clusters. The galaxy's flat disk and its central bulge came later, in the last stages of the collapse. Earlier this year, Yale astronomer Young-Wook Lee cast doubt on this "outside-in" picture when he reported that the oldest stars in the galaxy reside in the bulge, not in the halo (*Science*, 7 August, p. 746). Similarly, notes astronomer Peter Quinn of the Mount Stromlo and Siding Spring Observatories in Australia, "a subdivision of globular clusters is not what you would expect from a monolithic collapse." Instead it suggests that at least some of the clusters were added by collisions well after the core of the galaxy formed.

As a theoretical possibility, "inside-out" formation isn't new to astronomers; they've been debating it since 1978, when the scenario was proposed by Zinn himself and by Carnegie's Leonard Searle. And in 1984, Alexander Rodgers of the Australian National University and George Paltoglou of the University of Maryland presented some



QUINN, HERNQUIST, AND FULLAGAR



Milk shake. In a computer simulation, top and side views show in million-year intervals how a collision inflates the Milky Way's disk.

of the first supporting evidence: They noticed that a few globular clusters are circling the galactic center "backward," compared to the orbits of the sun and most other stars. They also noted that the "horizontal-branch" stars—a special breed of low-mass stars—in these contrary clusters are much redder, and hence younger according to a widely accepted theory, than similar stars in other clusters. Rodgers and Paltoglou speculated that the unusual clusters are interlopers, which fell into the proto-Milky Way when it tangled with one or more smaller galaxies.

The evidence wasn't conclusive enough to draw wide attention, but Zinn and van den Bergh have now built a more detailed case. Zinn, who first announced his findings at a conference in Santa Cruz last July, concluded from studies of horizontal branch stars that globular clusters in the inner part of the halo have more or less the same age—perhaps 15 billion years—while clusters at greater distances can be as much as 2 billion years younger. And Zinn found that the younger clusters are set apart by their motions as well, tending to move at random or even backward, as Rodgers and Paltoglou had reported. Van den Bergh, who worked independently, says he will soon be publishing similar conclusions.

The signs, say both Zinn and van den Bergh, point to a two-stage scenario for the formation of the galaxy. The older inner halo and the disk could still have formed in the rapid collapse of a vast gas cloud, as the classical scenario holds. But the outer halo was annexed in a collision, in which a nearby galaxy merged with the Milky Way. Or maybe several nearby galaxies; from the observations, it's impossible to tell, though that has not stopped van den Bergh from speculating about the source of the anomalous clusters. The more massive a galaxy, astronomers have learned, the richer its globular clusters are in "metals"—the heavy elements that are gradually forged in stars from their primordial hydrogen and helium. The reason: Metals, which are strewn through interstellar space in supernova explosions, are more likely to be trapped by the stronger gravity of larger galaxies. Because the metal content of the anomalous clusters is higher than that of the Milky Way's largest satellite galaxy, the Large Magellanic Cloud, van den Bergh concludes that the ancestor or ancestors must have been still more massive.

"The sample of disk stars studied so far is too small to say anything definitive about a galactic merger."
–Heather Morrison

That's further than most of van den Bergh's colleagues would go; many of them are still debating the evidence for two populations of globular clusters, which astronomer Bruce Carney of the University of North Carolina at Chapel Hill calls "pretty strong but not compelling." But advocates of the collision scenario have another card to play. Besides loading the galaxy with additional globular clusters, a trio of computer modelers has found, the collision would have shaken it to its heart. By using a computer to simulate the collision of a satellite galaxy with the young Milky Way, Quinn, his Mount Stromlo colleague David Fullagar, and Lars Hernquist of the Lick Observatory learned that "mergers of satellites, even small ones, are very damaging to the disk," says Quinn. The result of a collision, says Hernquist, is to "inflate the disk and spread it out," even to tilt, warp, or flare it.

Those effects, if they exist, would be hard to see from our vantage point within the galaxy. But several groups of astronomers believe they have indirect evidence that a collision once disrupted the disk. If the collision took place early in the galaxy's history, the stars flung out into a "thick disk" would have been low in metals. Over billions of years, as successive generations of stars forged metals and spread them through interstellar space, metal-rich gas clouds would form in the thick disk—but they would tend to lose energy by colliding with other clouds and would settle into the disk's central plane. The thick disk would remain low in metals, while at the center of the thick disk a new thin disk would take shape from the gas, like the filling in a sandwich.

That's exactly the picture Rosemary Wyse of Johns Hopkins University and Gerard Gilmore of Cambridge University believe they can see. By tracing the motions of stars at various distances from the plane of the galaxy, they found that the stars fall into two groups, with those along the plane following more orderly paths and those farther out moving more randomly. The predicted chemical division is there as well, say Carney, David Latham of the Harvard-Smithsonian Center for Astrophysics, and John Laird of Bowling Green State University, who are now putting together a detailed paper on their results. They looked at the metal content of stars at a range of distances from the galactic plane and found a clear split between the metal content of stars in the plane and those that lie farther away. "This makes me think the thick disk is a merger event," says Carney.

But after billions of years of galaxy evolution, the signs are faint, and other astronomers just don't see the same pattern. Says Heather Morrison of the Kitt Peak National Observatory, "The sample of stars studied so far is too small to say anything definitive." Morrison's own survey of metals in stars far from the disk plane shows, she says, that "a merger is not required for forming the [thick] disk, but I won't rule it out completely." Kavan Ratnatunga, a theorist at the Space Telescope Science Institute in Baltimore, is more emphatic: The evidence for a separate thick disk is "very subjective."

The split in the metal content of disk stars "makes me think the thick disk is a merger event."
–Bruce Carney

Collision proponents admit that their case isn't definitive, and they're looking forward to some further research. Zinn, for example, would like to see if field stars in the halo—stars that don't belong to globular clusters—also fall into two groups, a finding that would strengthen the case for a galactic merger. And other observers are planning further searches for evidence of separate thick and thin disks.

But the collision proponents say their argument is already entirely plausible. Our galaxy, points out Zinn, may be on the verge of a collision even now. Astronomers have known for nearly a decade that the Large and Small Magellanic Clouds are slowly spiraling toward the Milky Way. Indeed, our galaxy already seems to be wresting material from them. Earlier this year Douglas Lin of the Lick Observatory and Harvey Richer of the University of British Columbia argued that the orbits of two of our galaxy's globular clusters can be traced back to the Magellanic Clouds, as if the clusters had recently been captured. If satellite galaxies are slowly merging with the Milky Way now, why not in the past? All told, says Quinn, "the evidence is too compelling" to think otherwise.

–Ray Jayawardhana

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Additional Reading

Peter Quinn, Lars Hernquist, and David Fullagar, "Heating of Galactic Disks by Mergers," to appear in *Astrophysical Journal*, 20 January 1993.

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Robert Zinn, "The Galactic Halo Cluster Systems: Evidence for Accretion," to appear in *Proceedings of the Santa Cruz Workshop on the Globular Cluster-Galaxy Connection, July 1992.*