SUPERSTARS

With supercomputers astronomers can see things they can't see through telescopes. And they don't have to work nights.

BY MARCIA BARTUSIAK

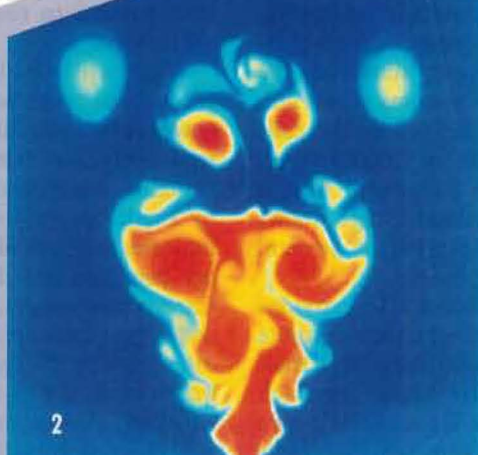
In the early part of this century astronomers were essentially celestial librarians who patiently cataloged the sizes and colors of various stars. "When I began working in astronomy in 1933," Leo Goldberg of Harvard has written, "astronomy was almost strictly an observational science with very little understanding of the physical meaning of observations." But now that has changed. Today astronomers hope to unmask the universe's most intimate secrets: how galaxies were born; how exploding supernovas spew the stuff of future stars and planets into space; how matter was forged in the first microsecond of creation. Once limited to studying static pictures of the night sky, astronomers now focus on the dynamic processes that have made the universe what it is.

In so doing they face a problem. Most astronomical events take a long time—too long for them to be observed in their entirety. The sun, a typical star, has a life span roughly 100 million times longer than our own; an individual human (such as an astronomer), who is born, grows old, and dies in less than a century, is like a mayfly to the cosmic clock.

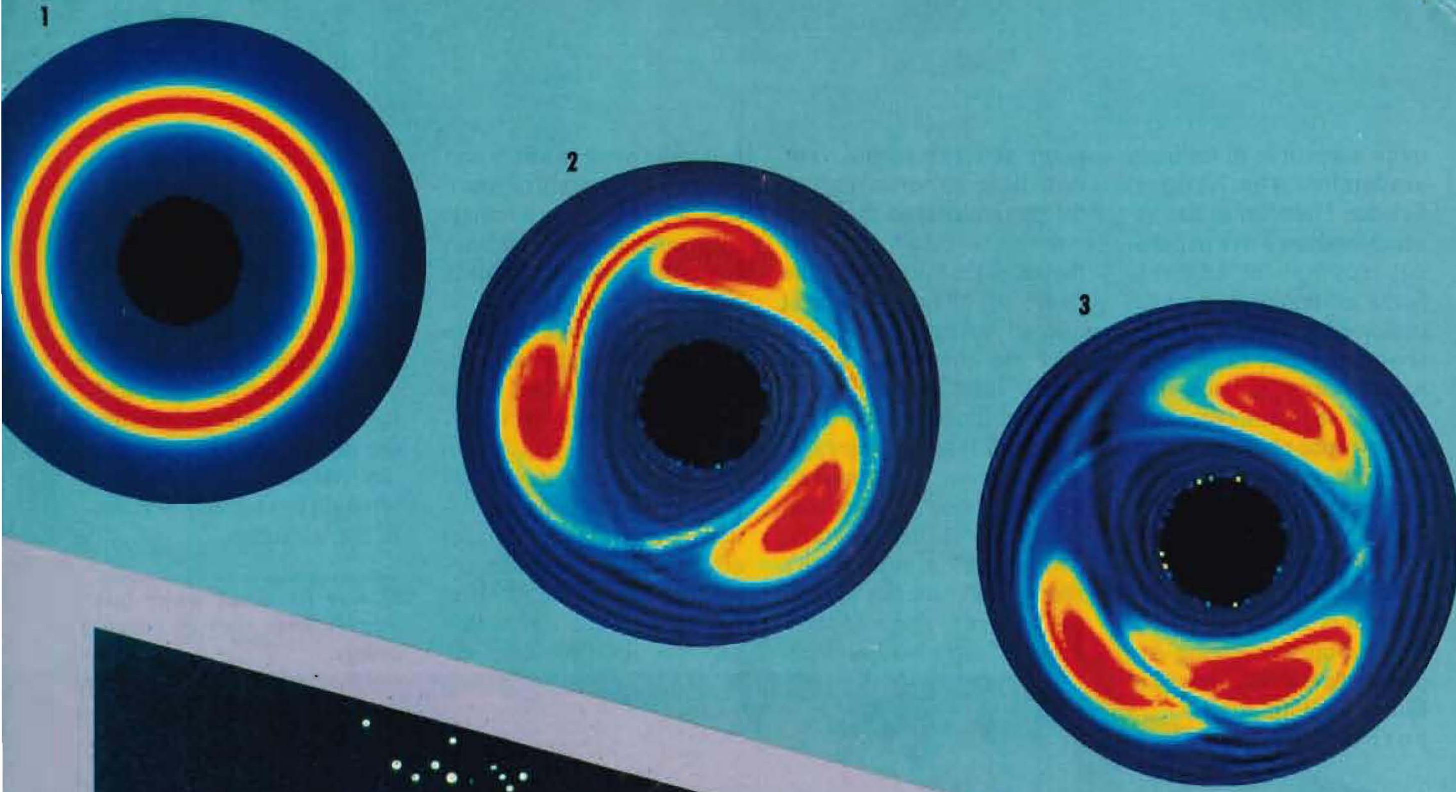
Supercomputers—machines that make several hundred million calculations a second—have begun to offer a solution to this problem. By running mathematical models on a supercomputer, astronomers can compress the celestial time scale and simulate long-lived astronomical processes. They can re-create cosmic events, such as the formation of galaxies, that happened billions of years ago. In short, they can mimic realms that will remain forever out of their reach.

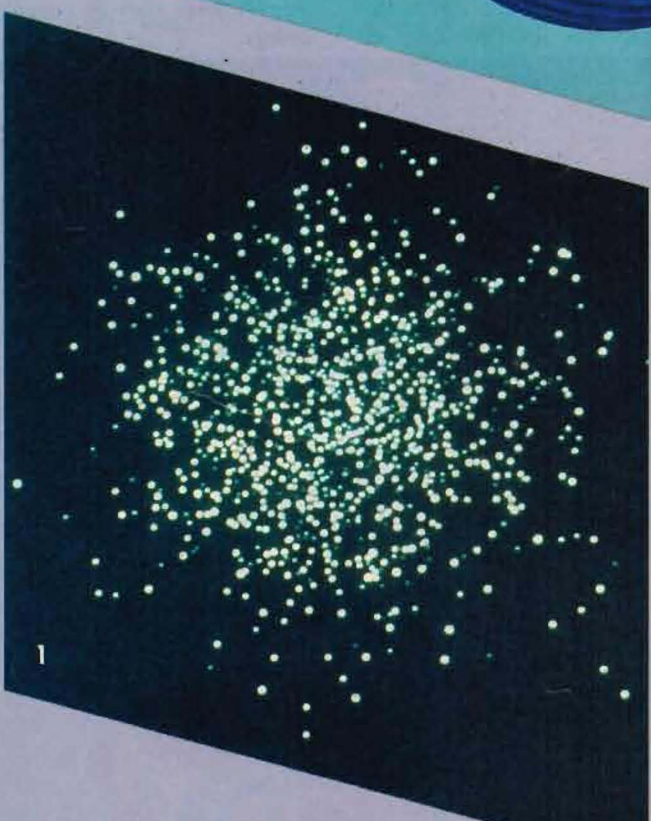
In a sense, the astronomical modelers are just following in the footsteps of Isaac Newton, who realized that physical processes can be expressed as mathematical formulas. But whereas a physics student equipped with pencil, paper, and Newton's law can calculate the gravitational attraction that keeps the Earth revolving around the sun, the mathematical descriptions of most astronomical processes are a good deal more complicated. For example, to describe in detail how thousands of stars plunge into the gravitational pit of a black hole requires a huge number of calculations. Without a supercomputer the job would be impossible.

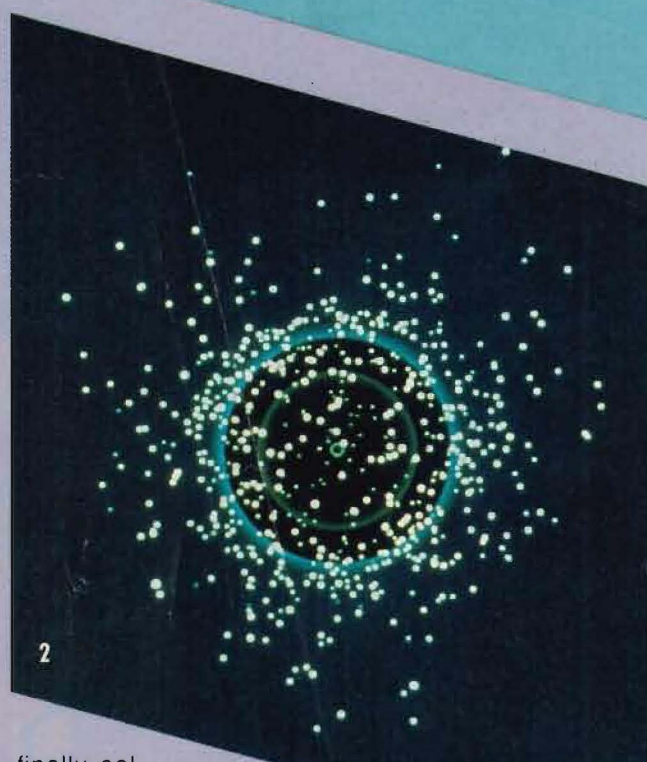
Today's supercomputers can do in a single second calculations that would have taken a full year on the fastest computer of the 1940s. And although just a few years ago these multimillion-dollar machines could only be found at a handful of corporate and government laboratories, they are now becoming



COSMIC JETS are beams of hot, ionized, extremely tenuous gas that erupt from the core of an "active" galaxy. The beams may be hundreds of thousands of light-years long, and they bore through intergalactic space like blowtorches, at speeds of thousands of miles per second. Radio astronomers have discovered many galactic jets; the nearest one to Earth is that of the galaxy Centaurus A. Jack Burns and Martin Sulkanen of the University of New Mexico and Michael Norman of the University of Illinois turned to a supercomputer to find out why some jets, such as Centaurus A's, flare into a wide tail near the edge of the galaxy, whereas others remain concentrated and intact far into space. They found a simple answer: a jet flares when it is disrupted by a crash into a shock wave. (The shock wave







QUASARS are thought to be young, far-off, extremely active galaxies; their explosive luminosity has been attributed to a supermassive black hole in the galactic core. But how could such an object have formed? A supercomputer-generated movie produced by Stuart Shapiro and Saul Teukolsky of Cornell University suggests that the collapse of a dense cluster of ultradense neutron stars could have done the job. At first the cluster appears stable, with each of the thousands of stars orbiting the center of the cluster under the gravitational influence of the other stars (1). (The computer kept track of the stellar motions by repeatedly solving Einstein's equations of general relativity; the 100 billion calculations required ten hours of computer time.) But over billions of years some of the inner stars begin to spiral farther inward at near-light speeds, creating a dense concentration of mass that finally collapses to form a black hole (2): an object whose gravitational field is so intense that neither matter nor light (depicted by the computer as spherical flashes) can escape it (3). At this point the collapse accelerates. Within days the black hole gobbles up much of the inner cluster, sweeping clean the center of the galaxy out to a distance of several light-years (4). Over the succeeding millennia, stars farther out in the cluster are drawn down the celestial drain. Before disappearing, however, the matter is squeezed and heated to a dazzling brilliance—which we see as a quasar.

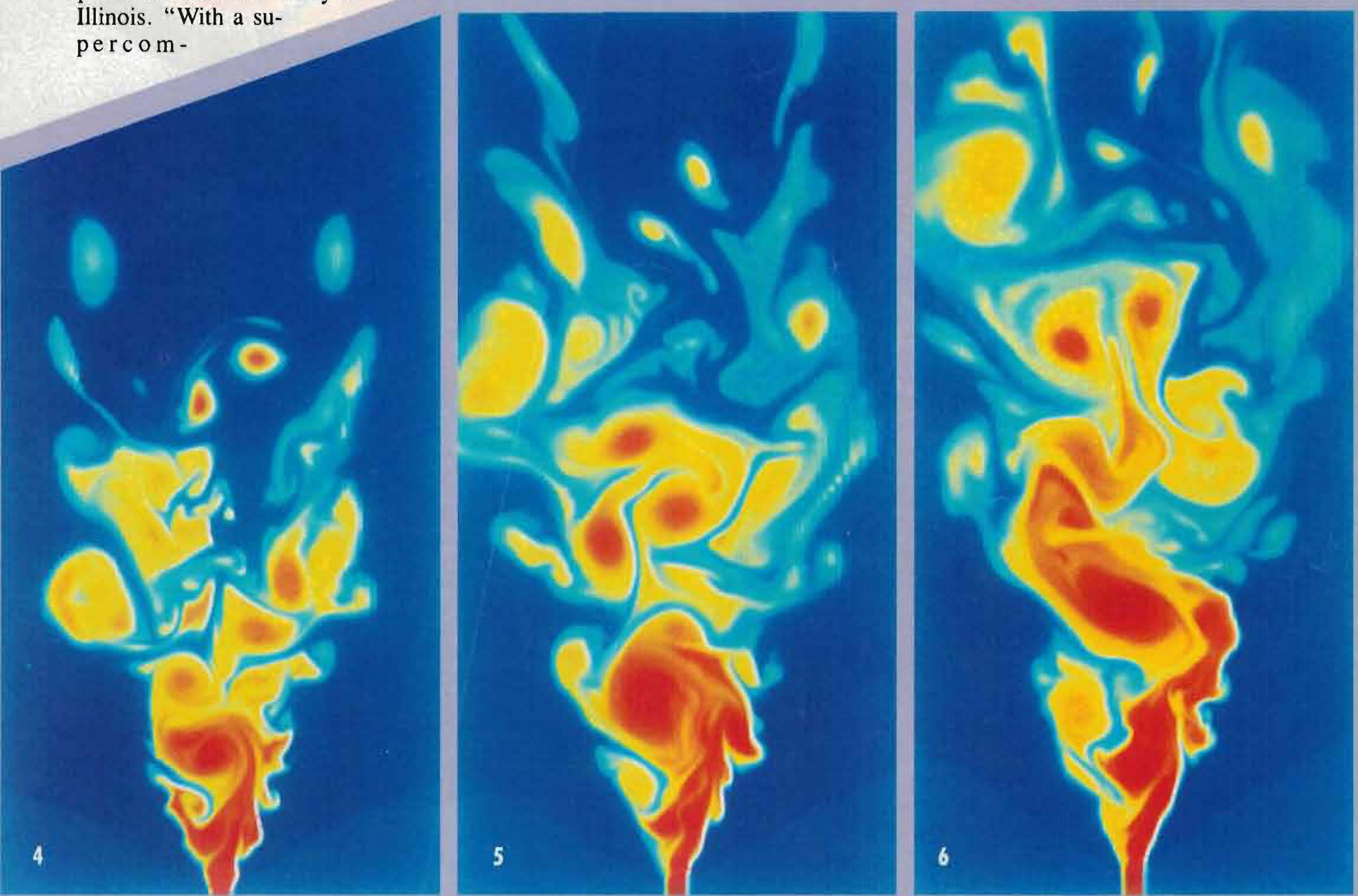
more accessible to ordinary academics. The National Science Foundation has recently endowed five national supercomputer centers. Some astronomers, long accustomed to traveling to telescopes on out-of-the-way mountaintops, are now traveling to supercomputer centers to probe phenomena that have not yet been seen—or are impossible to see—through telescopes.

"The process is almost godlike," says Larry Smarr, director of the National Center for Supercomputing Applications at the University of Illinois. "With a supercomputer you can create your own little universe, choose the particular laws that your universe is going to have that day, and then look into the heart of phenomena that human beings may never have the chance to see directly." In addition to the phenomena illustrated on these and the following pages, researchers are "observing" the collisions of galaxies containing millions of stars; "watching" a supernova's shock front race through interstellar space; and "seeing" how hot gases circulate deep within a fiery star.

The development of supercomputers that can simulate such intricate processes has coincided with a revolution in computer graphics. A good computer image is now worth a thousand equations, transforming piles of digits into recognizable science. It would take a year just to read the millions of numbers produced during one simulation. But computer images offer answers at a glance, enabling astronomers to share results with colleagues in a way they never could before.

Supercomputing in astronomy is neither pure theory nor observation of the sky, the two traditional methods of research. In effect, it is a third route to astronomical discovery, closely akin to laboratory experiment. The astrophysical insights that emerge from the use of this new tool may one day rival the profound changes wrought by Galileo's first use of the telescope.

Marcia Bartusiak wrote last month's cover story on cosmic strings.



itself probably forms where the diffuse wind of particles emanating from the galaxy collides with the intergalactic medium.) In the simulation, which shows the evolution of a jet over hundreds of millions of years, the shock wave is the boundary between the light blue and dark blue areas; the center of the galaxy is offscreen to the bottom. As the jet pushes through the shock, it is slowed to subsonic speed, and turbulent eddies begin to peel off on both sides of the main flow (1). The eddies drag material from the surrounding medium into the jet (2 to 5), until ultimately it looks as wispy as smoke rising from a chimney (6). Why do some cosmic jets escape this fate? Because, the researchers say, those jets are so fast and so energetic that they can blast through a shock front and still retain their integrity.