Grappling with the Globulars

A tale of cosmic eggbeaters and born-again pulsars

By RON COWEN

Globular clusters rank among the oldest residents of the Milky Way. Viewed through a telescope, these ancient objects take the breath away: Glowing with the fire of thousands of optically bright stars, they bathe the galaxy in a halo of light.

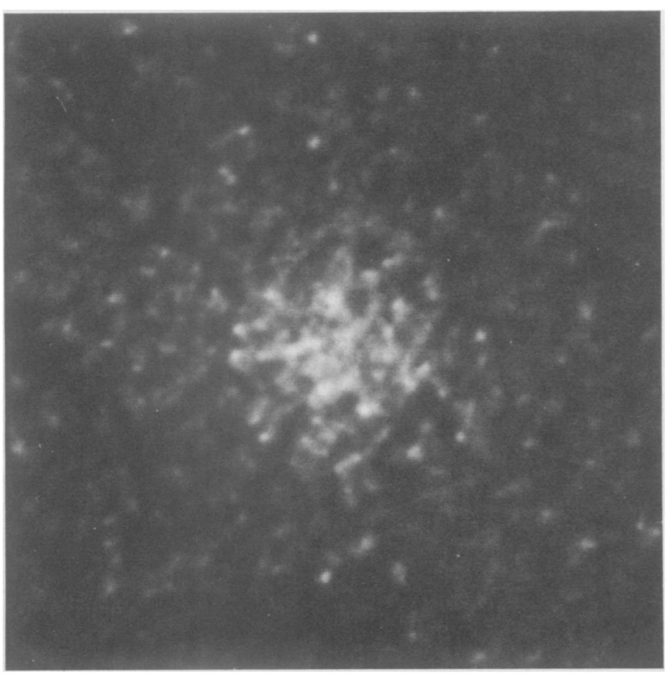
Astronomers have puzzled for years over the evolution of these "mini-galaxies," an estimated 150 of which surround the core and periphery of the Milky Way. (Globular clusters also accompany many other galaxies.) Each packs as many as 1 million stars into a spherical space about 200 light-years across, or 1/500 the diameter of the Milky Way's disk.

Understanding the formation and composition of globular clusters may provide vital information about the evolution of our galaxy, more distant star systems and, perhaps, the universe as a whole, scientists assert. Now investigators may be closer to unlocking the gravitational secrets bound inside these star-packed objects, thanks to new images from the Hubble Space Telescope, as well as recent ground-based observations at radio and visible wavelengths.

Many of the new observations focus on M15, a dense globular cluster located about 42,000 light-years from Earth in the constellation Pegasus. For nearly 30 years, researchers have debated about what lies at the heart of this object. Some have maintained that a black hole lurks there, while others have argued that the core contains a myriad of compact, burned-out stellar objects called neutron stars.

M15 drew special attention in the 1970s when astronomers found that the intensity of light it emits increases steadily from its edge to its core. In fact, ground-based images indicated that a brilliant "spike" of light radiated from the cluster's center. Although these images could not fully resolve M15's tiny core, they suggested that the region contains an unusually dense clump of luminous stars – similar to what would surround a supermassive black hole. Moreover, by 1975, researchers had discovered that the cores of 10 globular clusters orbiting the Milky Way emit intense X-rays – radiation that could be generated by matter falling onto a black hole fixed at the precise center of each cluster. The reports prompted several researchers, including John N. Bahcall of the Institute for Advanced Study in Princeton, N.J., and Jeremiah P. Ostriker of Princeton University, to propose that a black hole more massive than 1,000 suns resides at the core of each cluster.

But in the early 1980s, results from the Earth-orbiting Einstein X-ray Observatory contradicted that interpretation. The observatory found that M15's intermittent X-ray emissions originate from sources a small distance from the center, a discovery at odds with the black hole scenario.



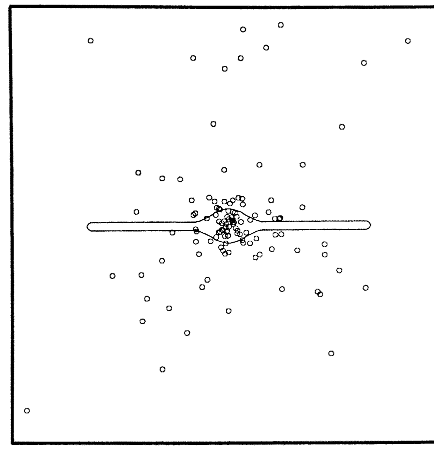
Hubble image of M15's core. Computer processing has removed obscuring bright light from red giant stars, revealing the distribution of the dimmer, more numerous stars at the center. The absence of a bright "spike" of light indicates that a supermassive black hole does not lurk there.

That finding thrust to the fore an alternative theory to explain the character of globular clusters and their spectral emissions: that M15 and other X-ray-emitting clusters contain a large number of neutron stars. Less dense than a black hole, neutron stars nonetheless possess an exceptionally strong gravitational field – one powerful enough to capture another star and form a special type of binary system. Indeed, given the abundant supply of neighboring stars inside M15's core, a neutron star would have ample opportunity to couple with a lower-mass companion. Material slowly stripped from the surface of its companion would form a hot disk around the neutron star, radiating X-rays similar to those detected from M15, notes astronomer Haldan N. Cohn of Indiana University in Bloomington.

The fact that these binaries would reside throughout the core of the cluster could account for the off-center location of the observed radiation, he adds. Helping to clinch that argument, French astronomer Michel Aurière reported in 1984 finding an ultraviolet counterpart to M15's X-ray emissions. While the disk of material surrounding a neutron star would emit both ultraviolet and X-ray light, the matter encircling a black hole should only emit X-rays.

Still, the debate persisted. Some theorists suggested reviving the black hole model in the mid-1980s as improved ground-based, visible-light observations (though still lacking full resolution of the core) continued to indicate an intense spike of light coming from M15's center. In the December 1989 ASTROPHYSICAL JOURNAL, Patrick Seitzer of the Space Telescope Science Institute in Baltimore, along with colleagues from the University of Chicago and the Whipple Observatory near Amado, Ariz., reported additional provocative evidence for the black hole model. Their velocity measurements of stars in M15 indicated that those nearest the core had, on average, significantly higher speeds – an indication that M15 and objects like it might contain a black hole massive enough to pull in surrounding stars at high speed.

Enter the Hubble Space Telescope. For nearly a decade, researchers studying globular clusters pinned their hopes on this long-awaited orbiting observatory. They anticipated that Hubble's images, expected to have unprecedented clarity, would finally resolve the cluster controversy. But shortly after Hubble's long-delayed launch last year, their hopes appeared dashed. The instrument's flawed primary mirror placed a fuzzy halo around every star it tried to sharply image, and the swarm of stars in the core of M15 proved no exception.



Map of globular clusters (circles) superimposed on schematic of the Milky Way. Although many of the clusters reside at the outskirts of the galaxy, more than half lie within 13,000 light-years of the central galactic bulge.

William E. Harris/McMaster University

Scientists analyzing Hubble's images of M15, taken last fall, faced a second hurdle: At the ultraviolet wavelength they chose to study, a handful of stars known as red giants shines as brightly as the thousands of other stars inside the core of M15. In the images Hubble transmitted to Earth, the red giants' blinding light confounded the results, preventing scientists from determining whether an intense spike of light — the hallmark of a hidden black hole — truly existed in the globular cluster.

By using computer techniques, Tod R. Lauer of the National Optical Astronomy Observatories in Tucson, Ariz., Jon A. Holtzman of Lowell Observatory in Flagstaff, Ariz., and Sandra M. Faber of the University of California, Santa Cruz, found a solution. With the help of image processing, the astronomers erased the Hubble-generated fuzzy halos and subtracted the bright red giants from their images, leaving behind a background of less luminous but far more abundant stars.

These processed images — the first to apparently map stars at the core of M15 — proved surprising, Lauer says. They confirmed that M15's central region is indeed dense, containing nearly 7,000 stars in a core only 0.8 light-year in diameter — about one-fifth the distance between our sun and its closest stellar neighbor. But what of the ultimate test? "If there's a [massive] black hole present, then the number of stars per unit area should keep climbing up as you go to the center," says astrophysicist Shrinivas Kulkarni of the California Institute of Technology in Pasadena. Instead, Hubble's images reveal that the density at M15's core plateaus at a density just 1 percent of that expected if a massive black hole were present.

"On a very basic level, this [finding] doesn't support the black hole picture at all," notes Kulkarni.

In fact, says Lauer, the results suggest that M15's core has already reached its point of maximal collapse and has begun to reexpand. He and his colleagues speculate that rapidly orbiting star pairs formed when the cluster's core was denser. Acting like cosmic eggbeaters, they transferred enough kinetic energy to nearby stars to fling them to the outskirts of the core, or even eject them. Thus, temporarily at least, the core is bouncing back, growing less dense. Lauer and his colleagues reported their findings at a meeting in January of the American Astronomical Society in Philadelphia.

While the full interpretation of Hubble's findings remains speculative, Kulkarni and other astronomers note that this new scenario dovetails with recent ground-based observations suggesting M15 and other globular clusters may possess a surprising abundance of single neutron stars and binaries. A series of surprising observational discoveries since 1988 have uncovered at least 40 radio-emitting pulsars in Milky Way globular clusters. Flashing like cosmic lighthouses, the pulsars rotate rapidly enough to beam radio waves at Earth every few hundredths of a second. Astronomers believe that the strong magnetic fields of spinning neutron stars generate such pulses.

Using the 300-meter radio telescope at the Arecibo (Puerto Rico) Observatory, Kulkarni and his colleagues found five such pulsars in M15. The research team, which included Stuart B. Anderson, Aleksander Wolszczan and Thomas A. Prince of Caltech, describes its work in the July 5, 1990 Nature and in an upcoming Astrophysical Journal Letters. Other teams, including scientists at the Parkes (Australia) Radio Observatory, have found radio pulsars in the globular clusters 47 Tucanae, M28 and M4.

These findings strongly indicate that neutron stars — both alone and as part of a binary star system — play a key role in the evolution of globular clusters, say Kulkarni and other researchers.

Without the option of forming a binary, all rotating neutrons stars in the ancient Milky Way clusters — now about 15 billion years old — would have long ago spun down, exhausted by the braking action of their own magnetic fields. Radio emissions would have come to a halt, Kulkarni notes. But just as some of these stars were about to sing their swan song, they paired off with a neighboring, lower-mass star in the cluster's core, he says. Instead of dying, the neutron stars captured material from their new companion and spun back up.

These "born-again" pulsars, says Kulkarni, account for the recently detected radio pulsars. The same tightly bound, spinning binaries could also act as cosmic eggbeaters, he adds, kicking out of the core lower-mass stars that happen to pass by the orbiting duo. Caltech astronomers E.S. Phinney and Steinn Sigurdsson detail this scenario in the June 25, 1990 Nature.

In the June 10, 1990 Astrophysical Journal, Kulkarni and other collaborators from Caltech and the University of Arizona calculate that Milky Way globular clusters likely contain 10,000 pulsars. Since only about 10 percent of neutron stars form these rapid rotators, the Milky Way clusters may contain an astonishing 100,000 of these very compact stars, Kulkarni told Science News.

Though the prevailing wisdom held that only big, dense clusters contained a pulsar, "we're finding pulsars even in clusters that people two years ago would have laughed off as being unimportant for this kind of work," Kulkarni says. "Even the scruffiest [lowest-density] globular cluster seems to have a pulsar." Most important of all, he adds, the abundance of neutron stars inside globular clusters suggests that most of these stars — created in the aftermath of a supernova explosion — formed early in the development of the universe.

At the January meeting of the American Astronomical Society, Brian W. Murphy of the University of Utrecht in the Netherlands reported on optical studies that also indicate an abundance of binaries in globular clusters. Working at La Palma Observatory in the Canary Islands of Spain, he and colleagues from four other institutions detected strong calcium emissions from the center of M15. Murphy says these emissions signify high magnetic activity, either from rapidly rotating single stars or from binary systems.

Since single stars in the aging cluster cannot spin fast, Murphy believes that light from calcium atoms originates in binaries. Paired stars produce the light when their large magnetic field heats the outer layer of the neutron star's partner, he proposes.

Beyond their intrinsic interest for Milky Way astronomers, studies of our galaxy's globular clusters may also shed light on more distant collections of stars, says Cohn. Collaborating with Robert P. Grabhorn and Phyllis M. Lugger at Indiana University, he has designed several computer simulations of the structure and evolution of globular clusters. Their venerable age, he and other astronomers contend, represents a lower limit for the age of the universe as estimated from redshift measurements and the apparent velocity of distant galaxies.

"Any cosmological age of less than 15 billion years runs counter to the age — determined by stellar evolution — of globular clusters," Cohn notes.

Moreover, he says, these clusters provide a laboratory for understanding how densely packed stars interact gravitationally. "It gives us a nearby analog to active galactic nuclei — clusters of 100 million or more stars at the centers of galaxies that very likely *do* have supermassive black holes at their core," he says. "We develop theories similar to the globular cluster theories to explain how stars in active galactic nuclei, which are thousands of times more distant, interact with each other."

"If we can understand the relatively nearby globular clusters, we have a much better basis for understanding what's going on in galactic nuclei and quasars," Cohn says. The newest model developed by Cohn and his collaborators indicates that the core of M15 may have undergone periodic collapse and expansion several times before its latest apparent reexpansion.

Several mysteries about globular clusters continue to perplex astronomers. For instance, Kulkarni notes, no one truly understands why the explosive, supernova birth of so many neutron stars inside clusters did not rip apart these star-packed regions. He speculates that certain stars — "halo" stars orbiting the outskirts of the Milky Way — may in fact represent remnants of globular clusters that didn't survive the violent creation of neutron stars.

"If that is true," Kulkarni concludes, "we have really learned a lot from pulsars and globular clusters." □