Three's Company

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Probing the dynamics of multistar systems

By RON COWEN

For nearly half a century, astronomers have studied the fireworks that can happen when one star flirts with another. This celestial pas de deux—which can trigger a burst of X-rays, a stellar explosion, or a catastrophic collapse — has been well documented.

But what happens when the gravitational embrace involves not two, but three or even four companions?

Charles Bailyn thinks it's high time astronomers found out.

Except in rare cases, the tangled adventures of stellar trios or quartets defy precise mathematical modeling. Even an approximate sketch of the dynamics of a multiple-star system requires long hours of computer time. But Bailyn, an astrophysicist at Yale University, maintains that the added complexity shouldn't deter astronomers. Studies of these groups, he says, could offer important new insights into a wide variety of celestial systems.

For one thing, he notes, stellar trios are probably common in globular clusters, the dense groupings of stars scattered throughout the Milky Way and other galaxies. Moreover, the interactions among multistar systems might explain several puzzling phenomena: the persistence of massive stars that look as if they should have expired long ago, the rapid rotation of some superdense stars, and the runaway motion of certain newborn stars.

At an April meeting of the American Physical Society in Washington, D.C., Bailyn reviewed the latest studies of multistar systems and tried to drum up new interest in this field of research. And in several recent journal articles, other scientists have extolled the virtues of studying stars that come in threes or fours.

"Our models [of multistar systems] are more like ideas than theories," says Melvyn B. Davies of the California Institute of Technology in Pasadena. "At this point, we're just trying to see what might work."

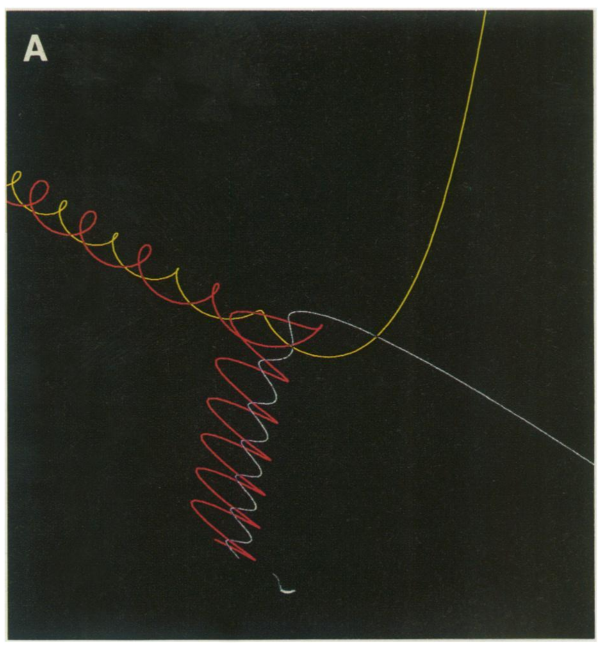
Bailyn limits his own studies to simulations of triple-star systems in which two stars orbit each other closely while a third orbits the pair at a distance at least five times as great as the separation between its two partners. In his computer model, this stable configuration leads to intricate and beautiful patterns for the orbit of the two inner stars as they oscillate in a nearly circular path. But Bailyn says the behavior of *unstable* groups of stars may have more immediate application in astrophysics.

In one model of an unstable trio, he notes, an interloper has a brief but irrevocable encounter with an existing pair of stars. If this interloper stays relatively remote from the pair, it will simply bring the two stars closer together as it robs them of energy. However, if the interloper comes nearer, it may trade places with one member of the binary system. In other cases, a close encounter might induce the paired stars to merge.

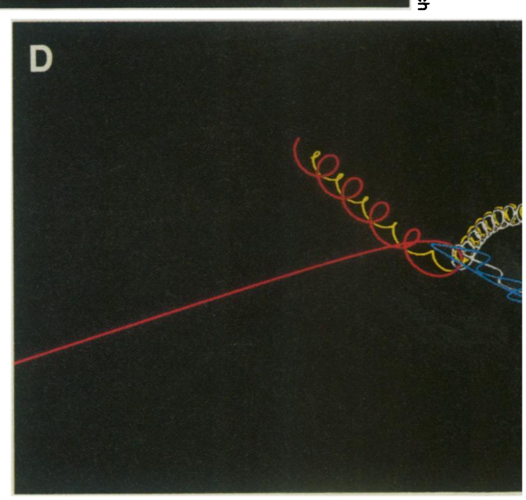
As an example of such a merger, consider the oddball stars known as blue stragglers. Hotter and more massive than the sun, these stars would normally burn out in a few billion years. Yet many blue stragglers reside in globular clusters that are some 15 billion years old.

Why didn't the stragglers die out long ago?

Many researchers believe the typical blue straggler arises from two elderly, lower-mass stars that collided and merged to form a massive, hotter star. This could explain how massive, rapidly burning stars can persist in ancient star clusters.



Images: Sigurdsson, E. Sterl Phinney/Caltech



These computer simulations describe some of the myriad encounters among three or four stars. Figure A depicts an exchange: Two paired stars (orbits in red and yellow) enter from the left and encounter a "white" star entering from the right. The white star, the most massive, ejects the yellow and grabs the red to form a new partnership that moves downward. In Figure B, a binary (red-yellow) enters lower right and steals enough energy from the single white star entering from upper left to prevent it from escaping. This ensures a second encounter, in which the red star is ejected (lower left), leaving the white and yellow stars to form a new binary. Figure C shows an encounter among four stars, a purple-cyan binary (left) and a red-yellow binary (right). The red star is ejected promptly, followed by the cyan star, leaving only one binary. Figure D shows another four-star interaction: A red-yellow binary meets a cyan-white binary. Again the red star quickly exits, but this time the remaining trio has a prolonged union that eventually decays.

But Peter J.T. Leonard thinks a likelier explanation for the plethora of blue stragglers — in low-density clusters at least — involves multistar systems. Leonard, an astrophysicist at the Los Alamos (N.M.) National Laboratory, calculates that mergers between single stars occur too infrequently in such clusters to account for the stragglers seen there. It's more likely, he suggests, that a pair of stars already bound by their mutual gravity would encounter a third star or another binary system. That's because two stars present a larger target for an interloper star. And once this new trio forms, the close encounters between the stars could prompt any two to merge into a blue straggler, Leonard calculates.

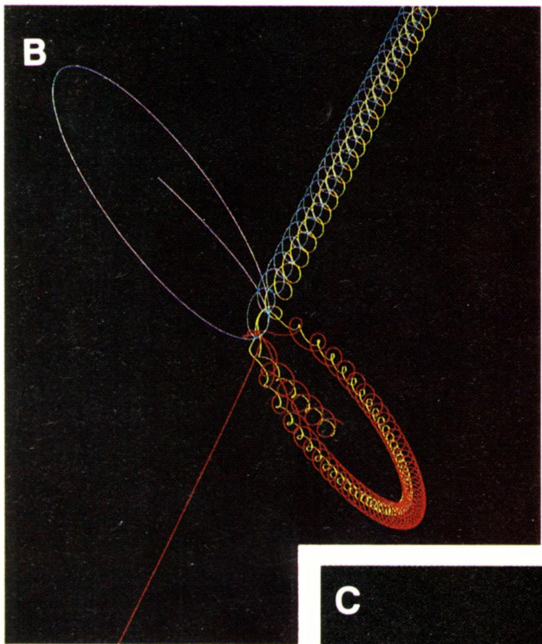
Not all researchers agree with this model. Mario L. Mateo of the University of Michigan in Ann Arbor suggests that interactions between single stars, as well as group encounters, may serve to create blue stragglers. But Leonard asserts that interactions among three or four stars may be needed to form blue stragglers in low-density clusters. That model leads to a definite prediction: If a blue straggler arises from a group process, it should have a distant companion.

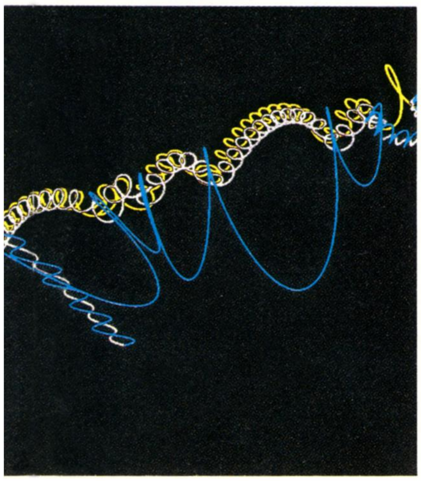
Recent observations of blue stragglers in a Milky Way open cluster — a loosely packed agglomeration of stars — appear to support this. Studies conducted by David W. Latham of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass., indicate that many of the blue stragglers in the open cluster M67 do have a distant companion.

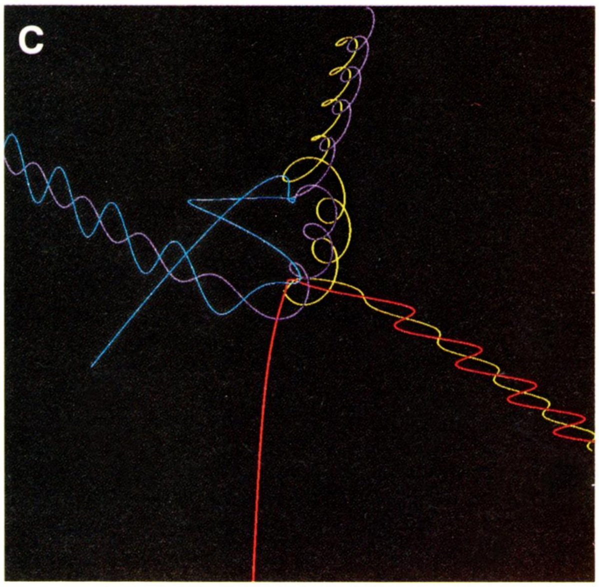
"These observations could be a kind of Rosetta stone" for multistar systems, Leonard says.

Encounters among several stars might also explain how millisecond pulsars rev up their spin. A pulsar is a rotating star so dense that its electrons and protons have fused to form neutrons. Like celestial lighthouses, pulsars beam radio waves as they spin, in some cases rotating several thousand times a second. Many astronomers theorize that these millisecond pulsars consist of ancient, slowly rotating neutron stars that a lower-mass companion has spun up to high speed. The companion does so by hurling material onto a disk surrounding the neutron star.

But according to several researchers, this recipe for "born-again" millisecond pulsars may have a fatal flaw. When a companion dumps material onto a neutron star, the binary system emits intense X-rays that telescopes such as ROSAT should easily observe (SN: 6/29/91, p.408). Alas, astronomers find that globular clusters contain far more millisecond pulsars than X-ray sources to produce them. This apparent mismatch has prompted some to propose alternative explanations.







Two of the leading models involve interactions among groups of three or four stars.

One of these scenarios begins with the collision of two pairs of stars. Each pair consists of a white dwarf — an ancient, compact star — gravitationally bound to a lower-density, lower-mass star. As a result of the collision, the gaseous remains of the lower-mass star are soon expelled and the two white dwarfs spiral toward each other. The less massive member of this new partnership dumps mass onto its companion. The companion collapses explosively, forming a rapidly rotating neutron star: A millisecond pulsar is born.

Although hurling mass from one white dwarf to another still creates X-rays, Leonard notes that this radiation has lower energy, less intensity, and shorter duration than the X-rays produced by dumping material on a neutron star. These X-rays are more difficult to detect. Thus, a collapsing white dwarf might account for the mismatch between millisecond pulsars and the number of X-ray-emitting star systems that create them.

Leonard and his Los Alamos colleague, Kaiyou Chen, review several variations of this model in the July 10 ASTROPHYSICAL JOURNAL LETTERS.

In another model, proposed by Davies and his colleagues, the cast of characters differs, but the theme — the extraordinary influence that companion stars can have on one another — remains the same. Davies and his co-workers, Willy Benz of the University of Arizona in Tucson and Jack G. Hills of Los Alamos, consider the trials and tribulations of a trio of stars: an isolated, elderly neutron star that encounters a white dwarf bound to a star of ordinary density and average mass.

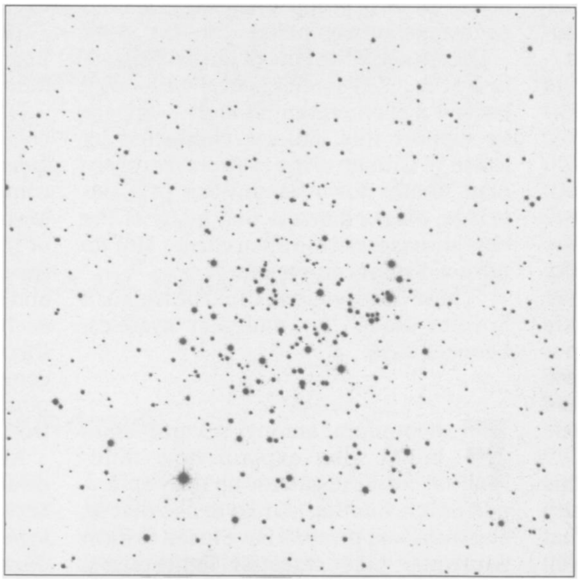
The white dwarf and the neutron star initially keep their distance from each other, with a separation greater than 7 million kilometers. But over time, the gaseous, ordinary star engulfs the other two, pulling them closer together — to about one-third their initial separation. As they expend energy to blow off the gas that has smothered them, the white dwarf and the neutron star move even nearer to each other. The paired stars spiral around each other as they emit gravitational radiation. Ultimately, the white dwarf dumps its material onto the elderly neutron star, recycling the oldster into a fresh, young millisecond pulsar.

This process, notes Davies, might still generate lots of intense radiation, including X-rays. But the emission is brief, making detection extremely unlikely. Thus, this scenario might also explain the mismatch between the relatively large number of millisecond pulsars and the relatively few X-ray-emitting binaries that have been observed.

Davies and his co-workers detail their theoretical musings in the July 1 ASTROPHYSICAL JOURNAL.

Not all astronomers agree that millisecond pulsars have their roots in multistar systems. But there may be a way to discern the influence of such systems. In the May 1 ASTROPHYSICAL JOURNAL, Chen and Malvin Ruderman of Columbia University in New York City suggest that variations in the patterns of radio waves emitted by millisecond pulsars may betray their different origins. If a revved-up neutron star forms a millisecond pulsar, the orientation of its magnetic field, and thus the character of its radio emissions, will reflect that. Similarly, if a collapsing white dwarf forms a pulsar, its magnetic field, and thus its radio emissions, will show a different pattern.

In analyzing radio emissions from a small sample of millisecond pulsars, Chen and Ruderman turned up an intriguing finding. Pulsars in globular clusters tend to have an emission pattern indicating that they originated as white dwarfs. In contrast, pulsars in the spiral disk of our galaxy have an emission pattern suggesting that they evolved from old neutron stars.



Kent Montgomery, Kenneth James/Boston Univ.

The open cluster M67, a low-density cluster of stars in the Milky Way, contains many blue stragglers. Interactions among three or four stars may account for the stragglers.

Why should pulsars have different types of parents depending on their place of birth? Chen and Leonard suggest that white dwarfs may collide more often in the star-packed globular clusters than in the galactic disk. Thus, multiple-star interactions involving white dwarfs may prove more significant in globular clusters.

Interactions among groups of stars may play another, more fundamental role in globular clusters, notes Bailyn. In a fleeting encounter between a pair of stars and an interloper, the interloper steals energy from the orbiting duo. The interloper's increased energy "heats" the surrounding cluster, preventing the dense core of the cluster from succumbing to gravity and collapsing — much as heat from the sun's nuclear furnace keeps this star from imploding.

Encounters among three or more stars may explain other puzzling phenomena. Consider the curious case of massive runaway stars. These youthful stars, born in the spiral arms of our galaxy, emerge from quiescent gas clouds that have little leftover momentum to impart to their progeny. Yet astronomers have observed that some of these newborn stars appear to flee their birthplace at speeds as fast as 150 kilometers per second.

Leonard suspects that the newborns get their unexpected oomph earlier in their young life, when they are members of tightly bound binary star systems. Clustered in the gaseous stellar nursery, these binaries collide wildly. "The binaries are like buzz saws that run into each other. Then all hell breaks loose," Leonard says. The collisions are so forceful, he suggests, that some of the binaries break apart, giving individual stars — the runaways — an energetic kick out of the nursery.

Though sometimes a hotbed of violence, multistar systems may also promote the survival of planets that form around single stars. A case in point might be the millisecond pulsar known as PSR 1620-26, which lies in the nearby globular cluster M4.

Researchers discovered this pulsar in 1987. Soon afterward, they realized it had a stellar companion. An analysis of radio emissions from the pulsar later revealed that an additional companion jerks its orbit. The apparent binary is in fact a trio, according to findings reported last year by Donald C. Backer of the University of California, Berkeley.

In the July 20 ASTROPHYSICAL JOURNAL LETTERS, Stephen E. Thorsett of Caltech and Zaven Arzoumanian and Joseph H. Taylor of Princeton University speculate about the identity of the third component. They suggest two possibilities: It might be a star orbiting the binary pulsar at 50 times the Earth-sun distance, or it might be a nearby planet-like body with the mass of Saturn, orbiting the binary at about the same distance Saturn orbits the sun.

In an upcoming issue of ASTROPHYSICAL JOURNAL LETTERS, Steinn Sigurdsson of the University of California, Santa Cruz, argues for the planetary model and proposes a scenario that would keep the planet intact for several billion years. He suggests that during certain encounters between a binary pulsar (a neutron star paired with a white dwarf) and an ordinary star that has a planet orbiting it, the ordinary star and the white dwarf would trade places. To his surprise, he calculated that about 10 percent of these interactions retain the planet in a stable orbit around the new binary. Thus, the interplay among stars in a group may preserve planets born in the dense, collision-prone environment of globular clusters, Sigurdsson says.

One of the more unusual triple stars, which enjoyed the limelight earlier this year, is now receiving renewed attention.

In the March 20 ASTROPHYSICAL JOURNAL, Benjamin M. Zuckerman and Eric E. Becklin of the University of California, Los Angeles, reported that a nearby star, similar in mass to the sun, appeared on the verge of forming planets. They based their argument on the star's unusually strong infrared emission, an indication that a disk of dust—the raw material for making planets — may surround the star.

Astronomers have long known that this star, designated HD 98800, has a companion visible from Earth. Now, unpublished observations by Latham and Robert P. Stefanik, also at Harvard-Smithsonian, show that the star has a second companion, Latham says.

The presence of the two companions would indeed allow dust to coalesce into planets, he notes. He adds, however, that the newly discovered companion occupies the same region around HD 98800 that the planets in our solar system occupy around the sun. Thus, any planets that form around this star must do so in the frozen, outer reaches of its gravitational influence. "There won't be planets in the region where water would be liquid and life comfortable," says Latham.

He adds that his team plans to report other intriguing features about the planet-making potential of this star and its companions. Moreover, this stellar trio may allow observers to unlock additional secrets about triple systems, he says.

Bailyn, on the other hand, still awaits his Rosetta stone: a stable trio that, as his computer simulations predict, drastically deviates from the behavior of ordinary binary stars.

"Every strange, bizarre star up in the sky turns out to be strange and bizarre because it has a friend," he says. "Now there are strange and unusual binary systems, and I think some of these will turn out to be triples. But we haven't really found one that we can point to and say, 'This is a binary that is strange in this particular way because it actually has a third companion.'" □