Binary Births

Astronomers investigate the secret lives of paired young stars

By IVARS PETERSON

On a clear night, the sky seems filled with stars. But the naked eye detects only a fraction of what's really there. About half of those visible stars whirl through space with a hidden partner — a second star too close or too faint to be readily visible by itself.

Astronomers have discovered that stars are as likely to exist in binary systems, in which two stars orbit each other, as they are to live out their lives in splendid isolation. Nevertheless, many questions concerning the formation and early history of such stars remain unanswered. Among the more intriguing: Are binaries equally common among newly formed stars? If so, what happens within star nurseries that leads so often to the birth of star pairs?

How binary stars materialize out of the collapse of vast, spinning clouds of dust is one of the most fundamental questions in astronomy. Understanding that process could lead to deeper insights into the formation of planetary systems and other features of our galaxy.

In the last few years, astronomers have made a concerted effort to search for binary systems among young, low-mass stars. Such stars, perhaps only a million or so years old and comparable in mass to the sun, are too young to have core temperatures high enough to fuse hydrogen into helium and thus have not yet entered the main sequence of stellar evolution. Often swathed in clouds of gas and dust, they are difficult to observe.

"Up until now, there have been very few such systems known," says Robert D. Mathieu of the University of Wisconsin-Madison. "Only recently has technology permitted extensive, systematic observation of young binary stars."

Several teams of astronomers are now exploring a number of star-forming regions within our galaxy. Their observations of pairs of relatively close, low-mass stars are providing important clues useful to theorists trying to understand how binary stars form. At the same time, theorists are developing increasingly sophisticated computer models simulating the star-formation process.

"For the first time, theoretical and observational work on the formation of binaries seems to be on the right track," says Bohdan Paczynski of Princeton (N.J.) University.

Astronomers have long studied binary systems in which the stars are far enough apart and bright enough to be seen as separate individuals. Such easily observed systems allow astronomers to plot orbits, measure how long it takes the companions to circle their center of mass, and calculate how much heavier one star is than the other.

The latest binary-star surveys focus on young stars with companions too close or too faint to be resolved even with telescopes. Mathieu and his collaborators are interested in coupled stars so close together that they complete orbits within days. The shortest-period systems represent the equivalent of putting a second sun well within the orbit of Mercury.

To detect such close companions, researchers measure the positions of lines in the spectrum of light emitted by these stars. Those lines shift to shorter wavelengths when the star is moving toward the observer and to longer wavelengths when the star is moving away from the observer.

Astronomers use this shift in line position to identify binaries. Sometimes they can detect two sets of lines, one for each star in the pair. In fact, the first "spectroscopic" binary among young stars was discovered in 1983 by accident, when an astronomer noticed pairs of lines where only single lines had been expected. By measuring how long it takes a line to shift from one extreme in wavelength to the other, researchers can calculate the binary's orbital period.

Mathieu and his team group the young stars they study into two populations. Classical T Tauri stars are often surrounded by dust and gas. Near the stars, this material likely arranges itself into a disk. These stars still carry with them remnants of the material out of which they were born. Naked T Tauri stars, only recently discovered, apparently emerge without any circumstellar material.

So far, Mathieu's group has identified a total of seven close binaries among both classes of stars and determined the period and shape, or eccentricity, of their orbits. Among naked T Tauri stars, the fraction of stars that turn out to be close binary systems is roughly the same as the fraction of binaries found among comparable older stars elsewhere. "We're finding about what you would expect [for naked T Tauri stars]," Mathieu says. "The odd thing is that it's been remarkably difficult to find spectroscopic binaries among the classical T Tauri stars."

It's easy to jump to the conclusion that a close companion may somehow sweep away circumstellar material. That could explain why some naked T Tauri stars have companions but no circumstellar material, whereas classical T Tauri stars, with their accompanying dust clouds, appear rarely to have companions.

But it's also possible the obscuring clouds make it much more difficult to detect spectral lines from classical T Tauri stars. "It's a common situation in astronomy," Mathieu says. "The fact is we don't see many, but that does not necessarily imply there aren't many. At present, the data show only an intriguing hint of a deficiency, and I would not be the least surprised if the classical T Tauri binary frequency turned out to be normal with the acquisition of more data."

How a close companion affects circumstellar material is an important issue. "We have to understand what one does to the other if we're going to understand how solar systems form," Mathieu says. "It's an issue regardless of what we find, but what we find may provide some guidance to the theorists."

Stars start out as large, gaseous globs that contract to a more compact form. Mathieu and his team have observed orbital periods as short as two days among young binaries. Such a period corresponds to a separation between two stars actually smaller than the size of a single, very young star.

"One naturally has to ask: How did those two stars get so close?" Mathieu says. "Did they form in wider orbits, and did the orbits evolve to a smaller system? Or did these stars form by a different route than that followed by an isolated star?" The answers aren't known yet.

Mathieu and his collaborators also observe that within a million or so years after their birth, young binary systems appear almost indistinguishable from their more mature brethren. The only systematic difference noted so far is in the shape of certain orbits. When young binaries have a period of less than four days, their orbits are circular. Binaries with longer periods have highly elliptical, or eccentric, orbits. In old binary systems, the dividing line between circular and eccentric orbits is roughly 10 days.

"That's telling us something about the evolution of the orbits," Mathieu says. "Something has to be making that happen."

Whereas Mathieu and his collaborators can observe binary stars no farther apart than roughly the distance from the Earth to the sun, other researchers, using different techniques, study more widely separated binaries, ranging out to 100 times the Earth-sun distance. In particular, the lunar occultation method offers a powerful means of identifying binaries among obscured, dust-enshrouded young stars.

The idea is to watch the infrared light of a star as the moon passes in front of it. If the star is by itself, the light blinks out almost immediately. Sometimes, however, the light first drops by a half and then goes out. That indicates the presence of two stars. Because young stars radiate most of their light in the infrared region of the spectrum, observers monitor changes in the intensity of infrared rather than visible light.

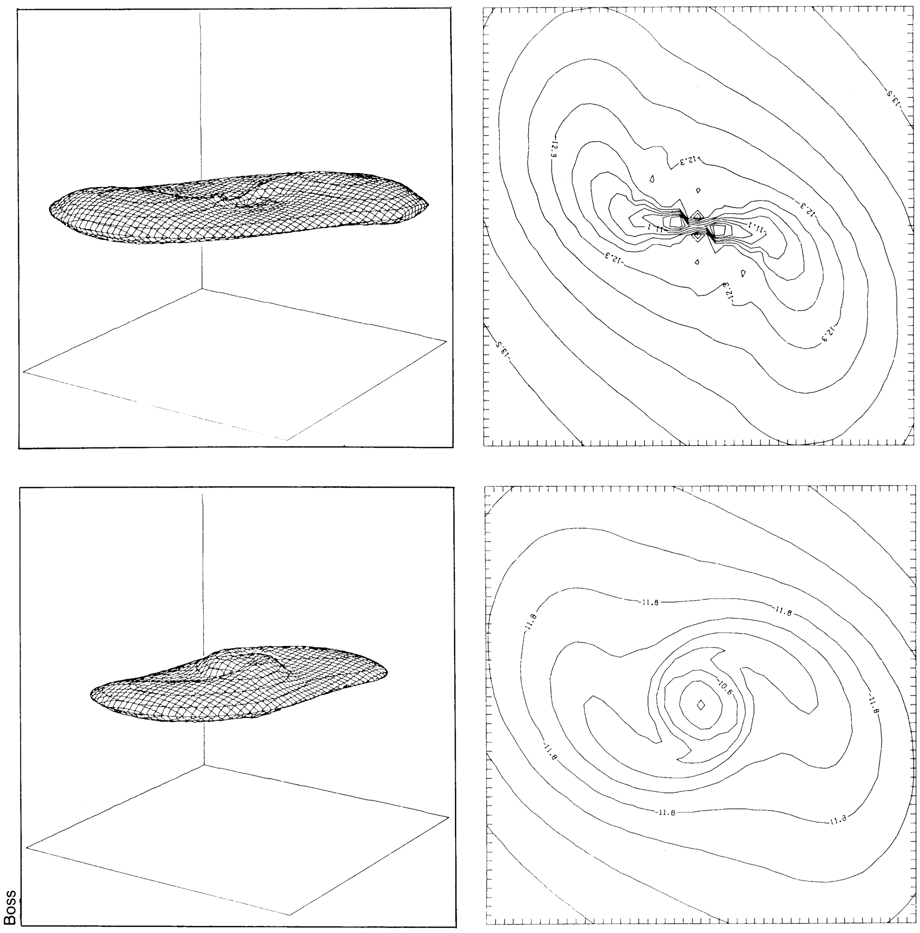
"It's information about young stars one can't get by other means," says Michal Simon of the State University of New York at Stony Brook. Luckily, Taurus Aurigae and Ophiuchus, two nearby star-forming regions, lie in the path of the moon. Because the Taurus star-forming region is rather wide, occultations of young stars within that cloud occur every year. The Ophiuchus cloud is more concentrated, limiting the number of observations to the few times the moon happens to pass across the cloud – roughly every five or six years.

So far, Simon and his colleagues have observed 29 stars, six of which turn out to be binaries, with periods ranging from 100 to 1 million days. Spectroscopic binaries generally have shorter periods because the partners are much closer. "Our sample is still small, but it seems that we are detecting a smaller number of binaries than expected," Simon says. "The observed binary frequency is about half that expected from the binary statistics of a comparable sample of field stars."

With a larger, more thoroughly studied sample of young stars, the statistics may improve, Simon says. Furthermore, the lunar occultation technique isn't sensitive enough to pick up binary systems in which one star is significantly dimmer than the other. "I know we're missing some of the faint companions," he says. "That may account for many of the missing binaries."

Observational astronomers have their work cut out for them. While studies of individual young binaries are interesting in themselves, it is the statistical analysis of a large number of binaries that allows comparison between observation and theory, says Bo Reipurth of the European Southern Observatory in Chile. "This situation is still several years into the future."

The discovery of close binaries among young stars is reassuring to astronomers. They had suspected the binaries ought to be there, and the recent observations confirm these suspicions. "Binaries are where they belong," Princeton's Paczynski says. "It seems that among these very young stars, the fre-



Boss

Each pair of computer-generated diagrams shows a three-dimensional view (left) and a density-contour plot (right) of one stage in the collapse of a rotating gas cloud. In the upper pair, the initial gas cloud has a mass one-fourth that of the sun; in the lower pair, one-tenth the mass of the sun. Whether such clouds fragment to form binary systems depends on their temperatures, masses and rotation rates.

quency of binaries is just as high as among all stars."

Moreover, young binary systems appear to have properties very similar to those of older systems. "Everything seems to fit together pretty well," says Alan P. Boss of the Carnegie Institution of Washington, D.C.

The growing catalog of young-star binaries provides valuable clues for theorists trying to determine how binary star systems form. Are they created through a process of cloud collapse and fragmentation? Or do they result from the splitting, or fission, of rapidly rotating objects? The evidence now points toward collapse and fragmentation as the preferred mechanism for the formation of close, low-mass binaries.

The new observations and computer simulations have forced a major shift in the way astronomers picture the formation of binaries. For decades, astronomers thought fission was the more likely possibility for producing close binaries: a large glob of stellar material – a protostar – spinning so rapidly that it breaks up into two pieces. "The problem is that it doesn't work," says Boss.

Recent computer simulations show that when a spinning glob begins breaking up, it kicks out streams of material that form graceful spiral arms. The gravitational force exerted by the spiral arms on the incipient binary robs the binary of the spin it needs to keep on forming. The result is not a low-mass binary but a single, rapidly rotating object surrounded by a disk or ring.

Furthermore, no one has detected the protostars needed for the fission scenario. Binaries are present among even the youngest stars observed, indicating that breakup probably occurs before the formation of a large central object, or protostar.

That leaves cloud collapse and fragmentation as the more promising theoretical model. Theorists suspect that for a cloud to contract and form any star, it must go through a very rapid collapse. Such a process, in which the density of matter increases dramatically by 20 orders of magnitude, inevitably leads to the breakup of the cloud. "People who have studied fragmentation have found that it is actually almost hard to find clouds that will not fragment," Boss says.

Computer calculations show that fragmentation, depending on the cloud's initial geometry and motion, can lead to binary systems with a wide range of separations between the partners. In some cases, binaries start to form but don't quite make it. They end up merging together again to form a single star. In other instances, the newborn pair of stars survives as a binary.

Fragmentation may also occur several times during cloud collapse. The contracting cloud breaks into two pieces, then those two pieces break up further, and so on. Boss' calculations show that fragmentation appears to stop when the fragments are smaller than one-hundredth the mass of the sun.

The mass limit on cloud breakup suggests that the fragmentation scenario is an unlikely source of planetary systems, in which planets have masses much less than one-hundredth a solar mass. "As you go to a smaller and smaller mass, it's harder and harder to get the cloud to break up," Boss says.

Theorists still have a long way to go to explain the birth of binary stars. "This is a very young field," says Joel Tohline of Louisiana State University in Baton Rouge. "We are just beginning to understand qualitatively how the process can take place in nature."

"At this point, theorists are dealing primarily with the issue of how you get two stars bound together," Mathieu says. "So far, they haven't really made many specific predictions about what the system will look like after they're made. What will the orbital periods be? What will the eccentricities be? How do the systems evolve to what we see? We need to have predictions by which to test what the theorists are saying." □

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Nobels awarded for physics, chemistry

Electrons, photons, neutrinos and mesons – these subatomic particles form the background for the Nobel prizes this year in physics and chemistry.

In contrast to last year's Nobel prize in physics, awarded for very recent work on superconductivity, the Royal Swedish Academy of Sciences reached back to work done nearly three decades ago to select the 1988 physics prize winners. Three Americans – Leon Lederman, director of the Fermi National Accelerator Laboratory in Batavia, Ill., Melvin Schwartz of Digital Pathways Inc. in Mountain View, Calif., and Jack Steinberger, now at the European physics research center CERN in Geneva, Switzerland – won the prize for work they did in 1960 to 1962 while at Columbia University in New York City.

During that time, they became the first researchers to devise a way to produce a stream of neutrinos in the laboratory. When they did so, the trio found a new type of neutrino, a discovery that helped lead to the creation of the current family tree showing the relationships among all subatomic particles.

The neutrino is a neutral particle with little or no mass and very little interaction with other particles. It is so noninteractive that billions of neutrinos pass unimpeded through each square centimeter of the Earth every second. Until Schwartz suggested a method, no one knew how to create a stream of neutrinos to study in the laboratory.

To produce neutrinos the group used high-energy protons from a particle accelerator to bombard a beryllium target, producing a shower of protons, neutrons and the smaller pi-mesons (pions). As the pions traveled away from the target they disintegrated into mu-mesons (muons) and neutrinos. The researchers filtered out all particles but the neutrinos by passing the beam through a 44-foot-thick barrier of steel. The neutrinos then entered a 10-ton aluminum detection chamber, where a few neutrinos out of the hundreds of billions passing through interacted enough with the aluminum atoms to be detected.

From previous research the scientists knew neutrinos could create either electrons or muons as they interacted with matter. But in the detector the neutrinos from pion disintegration created only muons, indicating there must be two types of neutrinos – one for muons and one for electrons. The academy awarded the 1988 Nobel prize to the three not only for the discovery of the muon neutrino, but also for the method for producing high-energy neutrino streams.

The Nobel prize in chemistry went to three West Germans – Johann Deisenhofer, now working at the Howard Hughes Medical Institute in Dallas, Robert Huber of the Max-Planck Institute for Biochemistry in Martinsried, West Germany, and Hartmut Michel of the Max-Planck Institute for Biophysics in Frankfurt am Main, West Germany – for determining the structure of a bacterial protein that performs simple photosynthesis. The cytochrome protein, which sits astride the bacterial membrane with one part inside the cell and one part outside, uses a specialized molecular architecture to absorb photons of light and uses that light energy to transfer electrons and hydrogen ions across the membrane.

Bacteria use the resulting difference in the concentrations of hydrogen ions (pH) and electrons (voltage) inside and outside the cell to make one of life's most basic chemical energy sources, adenosine triphosphate. This type of photosynthesis is simpler than that in plants, but the German trio's discovery contributes to the understanding of the mechanisms of photosynthesis in general.

Michel solved the biggest technical difficulty of the project in 1982 when he discovered how to purify and crystallize the membrane-bound protein. Deisenhofer and Huber then joined Michel to perform X-ray crystallographic measurements on the purified protein, which allowed the team to elucidate its structure in 1985. – *C. Vaughan*