THE HUNT FOR BROWN DWARFS

Not quite planet and not quite star, the brown dwarf may explain some of the most persistent puzzles of the cosmos. Or it may not exist at all.

BY MARCIA BARTUSIAK

Donald McCarthy has had better weeks. A few days ago the University of Arizona astronomer was hard at work at the Multiple Mirror Telescope on Mount Hopkins when his infrared detector up and quit, disrupting a critical observing run. Just this morning he was on his way to work when he was involved in a minor car accident that snapped off the right stem of his glasses and strained his back. Now, as he and graduate student Todd Henry prepare for the 50-mile drive to the mile-high Kitt Peak National Observatory, there is the threat of sky-obscuring clouds and rain in the forecast.

"Good luck," a colleague calls as McCarthy wheels a cart full of computer and electronic equipment onto the elevator at the university. "I *used* to have good luck," the beleaguered McCarthy replies.

The drive to Kitt Peak is uneventful. Although the weather is still not cooperating, McCarthy and Henry set to work, attaching enough equipment to the university's telescope there to furnish a small laboratory; a river of cables runs into the control room a few feet away. The heart of their system—enclosed in a metal container cooled to near absolute zero with liquid helium—is a tiny detector chip just four millimeters wide that acts like an electronic photographic plate. The chip gathers not photons of visible light but photons of heat—invisible infrared radiation that has journeyed dozens of light-years through space. The detector is so sensitive that the heat of buzzing moths and gnats around the telescope in the summer can sometimes cause interference.

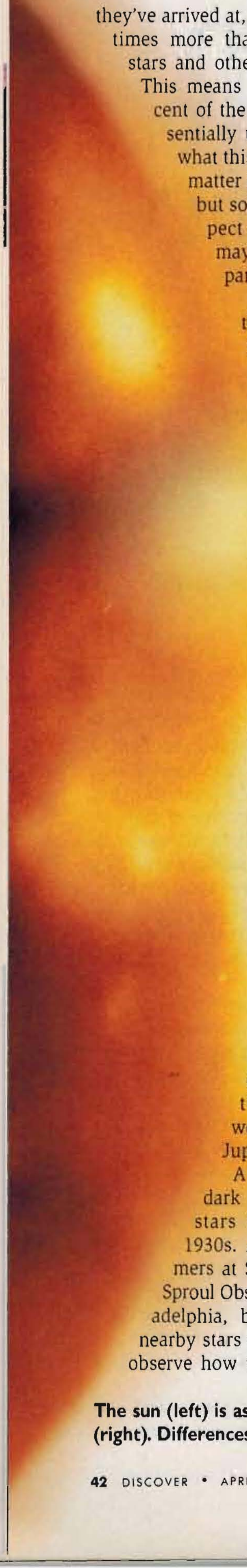
After the hardware is all hooked up, McCarthy and Henry wait, hoping for a break in the clouds that will allow them to switch on the 90-inch telescope and begin scanning the sky. Even if the weather obliges, though, there will probably not be any cause for celebration tonight—or tomorrow night or for many nights to follow. The researchers here, like researchers in numerous observatories around the world, are looking for one of the last stellar objects not yet seen with certainty. They're looking for brown dwarfs, theorized balls of celestial matter that are too small to be stars, too big to be planets, and, so far, too elusive to be seen by even the most sensitive telescopes.

Our sun is about 1,000 times more massive than Jupiter and about 10 times its diameter. A brown dwarf, so the theories go, would match Jupiter in size but be 10 to 80 times more massive. This would be just short of the enormous density and gravity necessary to sustain a nuclear fire. Caught in this celestial middle ground, brown dwarfs would be the underachievers of the cosmos, something more than a planet, but something decidedly less than a star. Brown dwarfs may not exist at all, or if they do, may exist in such small numbers as to be no more than an obscure cosmic curiosity. If, however, the odd little bodies are out there in appreciable numbers, they could answer one of astronomy's most tantalizing mysteries.

Researchers studying galactic motion have estimated the amount of cosmic matter that must exist for all the billions of known galaxies to hang together gravitationally. The figure

PHOTOGRAPH BY ROGER RESSMEYER/STARLIGHT

The square dome of the observatory on Mount Hopkins, in Arizona, opens to reveal its multiple mirrors. Combined, the six mirrors provide the resolution of a single mirror 21 feet across. Such sensitivity is indispensable for hunting brown dwarfs.



they've arrived at, however, is about ten times more than the total mass of stars and other bodies we can see. This means that roughly 90 percent of the entire universe is essentially unaccounted for. Just what this vast mass of missing matter is made of is unclear, but some theorists now suspect that brown dwarfs may account for at least part of it.

"I am intrigued by the connection between brown dwarfs and missing mass," says McCarthy. "Astronomers are always looking for discoveries, and here is a potential treasure box."

So far the hunt for brown dwarfs has been burdened by a lot of maybes and plenty of dashed hopes. In the astronomical journals any hint that a brown dwarf has been found is always hedged with question marks. "It's a volatile subject," says Henry. "First we hear, 'Yes, we've found one,' but then shortly afterward, 'No, we didn't.' There are at least ten good candidates, and some of them probably do weigh less than eighty Jupiters."

A dedicated search for dark companions around stars started in the late 1930s. At that time astronomers at Swarthmore College's Sproul Observatory, outside Philadelphia, began to photograph nearby stars at regular intervals to observe how they shifted their positions in the nighttime sky in their journey around the Milky Way. It's a specialty known as astrometry. Examining data taken over many years, the Sproul observers reported that certain stars deviated ever so slightly from a smooth, straight path. These stars traveled through space in a wiggly manner, like an unbalanced tire. The periodic jiggles suggested that each star might be accompanied by an invisible companion, whose gravitational tugs on the visible star would produce the minute but perceptible wobble.

These special double-star systems—with one member visible and the other hidden—are called astrometric binaries, and a few dozen have been found. Rhythmic changes in a star's light can also indicate that a dark companion is circling it: when the companion pulls the visible star away from Earth, its wavelengths will stretch out, or redden, a bit; when the star is tugged toward Earth, its light will get a tad bluer.

Astronomers suspected that some hidden companions could be balls of gas that just missed being stars. In 1975 astronomer Jill Tarter christened these objects brown dwarfs because they were one notch below a red dwarf, the least massive star there is, yet not completely black. But there was no great rush to the telescopes to try to view these bodies; the technology of the time was not up to unmasking such dim objects. Not until McCarthy stumbled into the field did the situation at last change, and change dramatically.

More than a decade ago McCarthy began toying with an observing technique called speckle interferometry, which is a means of filtering out the distortions—the twinkle—in a stellar image, caused by the turbulence of the atmosphere. A speckle interferometer, mounted on a telescope, takes thousands of snapshots of its target, each snap lasting no longer than a third of a second. A computer then merges all these separate but faint freeze-frames to create a single, distinct portrait of the celestial object.

For years speckle interferometers were used to capture only visible light. But in the late 1970s McCarthy and other astronomers began adapting the technique to capture photons of infrared light. Infrared interferometers essentially collect stellar heat rather than visible stellar light—a tricky business because the ambient heat of Earth can swamp infrared waves coming in from space. The key to spotting infrared objects is to build more-discriminating hardware that can filter out the interference.

When McCarthy first started working with infrared interferometry, he was using it to detect young stars in nearby gas clouds, stars whose light is often dimmed and blurred by dust in the clouds. One day in 1982, however, while he and his colleagues were aiming their interferometer at the double-star system Zeta Aquarii to carry out a routine calibration, they unexpectedly saw not two stars but three. Astrometrists had already noticed a tiny, unexplained wobble in Zeta Aquarii's motion, the classic sign of a hidden companion. But McCarthy's team was the first to actually see this celestial sibling, a small, cool star a quarter the mass of our sun.

At 250 Jupiters, the body was much too massive to be a brown dwarf, but it got McCarthy thinking: since red and brown dwarfs are far more luminous in the infrared portion of the spectrum than in the visible, an infrared interferometer might be able to spot these and other faint bodies. "You could take the astrometry that people had worked on for decades," says McCarthy, "and at last measure these previously unseen objects. I started going on this kick to look at every astrometric binary that I could."

One of the stars McCarthy surveyed was called VB 8, a close neighbor of Earth's, just 21 light-years away. In 1984 McCarthy used his speckle interferometer to generate a picture of VB 8 that appeared to include a smaller, fainter companion. The brightness and orbital position of the companion allowed McCarthy to estimate its mass at 30 to 60 times that of Jupiter. McCarthy dubbed the modest body VB 8B and released a very carefully worded statement to the

SUN PHOTOGRAPH COURTESY NASA; BROWN DWARF PAINTING BY MICHAEL CARROLL; JUPITER PHOTOGRAPH COURTESY NASA

The sun (left) is as much as 100 times more massive than a brown dwarf (center) and 1,000 times more massive than Jupiter (right). Differences in density between the two smaller bodies give them the same diameter—a tenth that of the sun.

press, describing VB 8B as a substellar object, possibly a brown dwarf.

The media picked up on the story but, to McCarthy's dismay, sensationalized it. To the popular press something smaller than a star that orbits around a star could be only one thing: a planet. "We got the text of our statement exactly right," says McCarthy, "but we couldn't control the headlines that would be attached to it." EXTRASOLAR PLANET FOUND, the papers trumpeted. The cautious "substellar" and "brown dwarf" got lost in the excitement.

The uproar caused by McCarthy's work was short-lived. Other groups tried to confirm the existence of VB 8B but were never able to get a fix on it. Most astronomers now see it as just another brown-dwarf dead end.

But McCarthy did not come out of the VB 8B episode empty-handed. During the initial ballyhoo, he delivered a lecture at Cornell before an audience that included Todd Henry, then a senior at the university. From childhood Henry had wanted to look for other planets. Upon graduation from Cornell, he enrolled at the University of Arizona, dropped in on McCarthy on the first day of classes, and asked to become part of his team. McCarthy agreed, and Henry soon joined in the brown-dwarf hunt. It was a pivotal moment for the young Ph.D. candidate. "We know what stars are, and we know what planets are," says Henry. "But we don't know what's in between. Searching for brown dwarfs is the closest I can come to looking for planets."

Henry's current work—which will form the basis of his thesis—involves conducting a systematic search for brown dwarfs around 77 faint red dwarfs within 26 light-years of Earth. Although our sun is a loner, about two-thirds of all stars come in pairs. Since both members in a binary system are usually close in size, a good place to look for brown dwarfs is next to small red dwarfs, which are typically smaller than 250 Jupiters. Nearby red dwarfs are just bright enough to be seen through large telescopes.

The first stage of Henry's survey, out to 17 light-years, started simply as a student project, meant to convince his Arizona professors that he could handle the research. But after 20 to 30 nights of telescope time over two and a half years, the study ballooned into a 14-page paper published in *The Astrophysical Journal*, the world's premier astronomical journal. Although Henry will not earn his doctorate until the fall of this year, his publication record—which includes six other papers—rivals those of some tenured professors. "Todd was willing to do something that had a big risk factor, and now he's reaping some of the benefits," says McCarthy with more than a little pride.

McCarthy and Henry's visit to Kitt Peak marks the seventh time the grad student has worked at the facility on this survey. The clouds never broke that first night of the run, but now, on the second night, conditions are better: the atmosphere is very jittery, but at least it's clear. Henry's first target is Wolf 922, an astrometric binary located in the constellation of Capricorn. The visible star is a red dwarf, one-quarter the mass of our sun. "It's awfully faint," says Henry, shaking his head worriedly.

By meticulously monitoring Wolf 922's motions over a 15-year period, from 1963 to 1978, astronomers from the Sproul Observatory had seen evidence of a wobble; on their photographic plates the movement measured less than .001 inch. From this they were able to infer the presence of a dark companion and to make an educated guess of its mass as one-tenth that of the sun, or 100 Jupiters. Henry is gathering further data, hoping that figure might come down to the realm of brown dwarfs.

The observing procedure is a tedious one. A herd of white dots jump and flicker on the computer monitor as Henry brings Wolf 922 into focus. Each flicker represents an individual picture snapped by the interferometer every quarter-second. It's a herky-jerky movie that, by chance, stays in sync with the beat of a rock tune playing on the control-room radio.

"This is definitely not the type of work that lets you see anything right away," says Henry. "I may have data already showing a brown dwarf orbiting a nearby star, but I just haven't gotten them through the computer pipeline yet."

To the popular press something smaller than a star that orbits around a star could be only one thing: a planet.

Getting the data into the pipeline involves first pointing the telescope at a well-known bright star to measure the atmospheric jitter at that moment. Then the telescope is moved to the binary target to snap thousands of freeze-frames, removing much of the atmospheric twinkle. Both sets of data are then fed into a computer, where the split-second freeze-frame exposures are combined. The amount of distortion measured in the reference star is then subtracted from the pictures to clarify them even further. The image left behind is, or should be, a relatively blur-free portrait of both members of the binary system. Astronomers can then analyze the brightness and relative position of the two bodies in order to estimate the mass of both. Henry figures he spends 5 percent of his research time at the telescope and 95 percent back at the university analyzing his data. As it would turn out, on this night Henry has data showing that Wolf 922's companion is not a brown dwarf but a red dwarf, but it will be months before he knows that.

Henry and McCarthy are not alone in stalking brown dwarfs. Research teams at Harvard, UCLA, the University of Hawaii, the University of Rochester, and the U.S. Naval Observatory have also joined the search. Along with nearby stars, young star clusters and nebulas in the throes of stellar birth are popular hunting grounds. A newborn brown dwarf, hotter and brighter than an older one, has a better chance to be seen. "We can then catch them before they cool and drop out of sight," says low-mass star expert Conard Dahn of the U.S. Naval Observatory in Flagstaff, Arizona.

In 1989 Rochester astronomer Wil-

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liam Forrest thought he saw a bevy of brown dwarfs in a rich star-forming cloud in Taurus. But a year later it looked as if the suspects were simply background stars made redder by the intervening dust cloud. More promising is a find by Harvard astronomer John Stauffer and four colleagues. They discovered some brown-dwarf candidates in the famous Pleiades cluster, a group of young stars known since antiquity as the Seven Sisters. Infrared images of the Pleiades have resolved a handful of objects that may match the expected color and brightness of brown dwarfs. But these candidates are not part of any binary system, so orbital motion and position cannot be studied to determine their mass.

Even without a confirmed brown-dwarf sighting, researchers like astrophysicist Adam Burrows, also of the University of Arizona, have a fair idea of what the object might be like. He and his colleagues have been modeling its properties for several years. At birth an average brown dwarf would have a surface temperature of about 6000 degrees, largely caused by the gravitational heat built up as the original cloud of dust and gas coalesced into a ball. It would glow a deep orange-red. "It might even be mistaken for a red-dwarf star," says Burrows.

After 100 million years the brown dwarf's surface would cool to nearly 4000 degrees, the temperature of a blast furnace; by 10 billion years it would be down to 1000 degrees—quite cool, though still hot enough to melt lead. "A brown dwarf continues to cool over the eons like the embers of a dying fire," says Burrows. Eventually, it would cool to complete blackness.

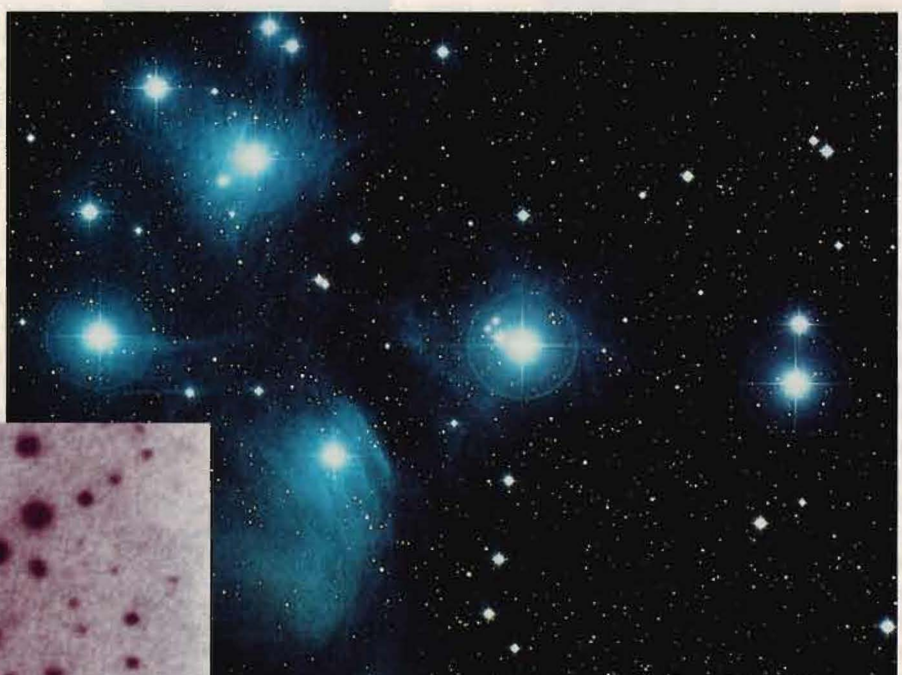
The pressure inside a brown dwarf would be sufficient to convert the predominant elements, hydrogen and helium, into liquid metal. This does not happen in stars because the greater heat generated by their mammoth nuclear engines keeps the stellar materials gaseous. Surrounding the metallic core of a brown dwarf would be an outer atmosphere a few hundred miles thick. The presence of water vapor, carbon monoxide, methane, titanium oxide, and other trace molecules could produce color in this shallow atmosphere, akin to Jupiter's bands and Great Red Spot.

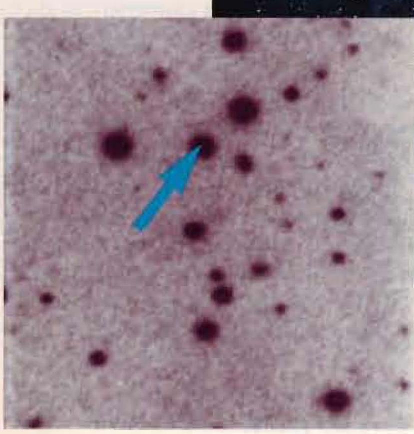
The brown dwarf's atmosphere might also include particles of such heavy elements as silicon, iron, magnesium, and carbon, creating a sort of grainy smog. This light-absorbing pollution might be one of the reasons brown dwarfs are hard to find. But Burrows suggests that a brown dwarf, being the near-star that it is, might also be shooting off solarlike flares and intense bursts of X-rays, which could help signal its presence. As yet, however, no one has tried to test this theory by turning an X-ray detector toward a suspected brown dwarf.

While best described as hotter and denser Jupiters, brown dwarfs are not totally incapable of burning like a star. Theory suggests that many dwarfs may be massive enough to ignite and burn first deuterium for 10 million years, and later hydrogen for a few billion years more. In a body so small, however, the gravitational compression is not high enough to allow these internal fires to burn very hot. Ultimately, the heat that radiated away from the dwarf would exceed the heat generated within, and the little substar would sputter out like a choked engine, never to start up again.

Just how many brown dwarfs could be out there? Usually, the smaller the cosmic body, the more abundant it is in our galaxy. Blue-white supergiants are beautiful but rare; lowly red dwarfs make up most of a galaxy's stellar population. By that measure, brown dwarfs could be the most plentiful of all.

Cosmologists are keen to find out. If the universe's theorized dark matter is made up of ordinary stuff such as





Above: The Pleiades cluster is home to several brown-dwarf candidates. The substars would be hard to spot with conventional telescopes since they are luminous mostly in the infrared. Inset: A picture taken with an infrared filter reveals a potential brown dwarf, indicated by an arrow.

PHOTOGRAPH FROM PHOTO RESEARCHERS; INSET, COURTESY JOHN STAUFFER, SMITHSONIAN ASTROPHYSICAL OBSERVATORY

Kitt Peak National Observatory gives Donald McCarthy a mile-high perch from which to search for the brown dwarf.

brown dwarfs, observers should find a brown dwarf in every 30 or so cubic light-years of space. That means several could be residing within a few light-years of us. Over the entire Milky Way there could be trillions.

So far, there is not much evidence for such an enormous brown-dwarf population. Henry and McCarthy have uncovered only three new brown-dwarf candidates—which go by the unglamorous names of Gliese 623B, G 208-44B, and LHS 1047B. All are paired with red dwarfs located within 25 light-years of Earth. It is not yet clear whether the candidates are true brown dwarfs, or merely lightweight red dwarfs—and it won't be clear until additional data are taken. Other groups have added six or seven potential brown dwarfs to the list, but by cosmic standards that's still next to nothing.

PHOTOGRAPH BY ROGER RESSMEYER/STARLIGHT

George and Marcia Rieke, a husband-and-wife team at the University of Arizona, have found the brown-dwarf pickings equally slim. They took pictures of stars in our local stellar neighborhood using a traditional infrared camera and long exposures. Interferometers have greater resolution than infrared cameras, but cameras—with their shutters left open—can detect fainter levels of incoming radiation. The Riekes, however, found no objects they considered good brown-dwarf candidates. Along with several other colleagues, the Riekes also took a look at the Rho Ophiuchi cloud, a prolific stellar nursery, and found only three likely substellar sources. "Far fewer than expected if brown dwarfs make up a large portion of the missing mass," George Rieke says.

Given these bleak results, McCarthy is not convinced that our galaxy is teeming with brown dwarfs. But Henry is more optimistic. "They could simply be a lot fainter than theorists suspect," he contends. "It depends on how much dust and molecules are in a brown dwarf's atmosphere."

Henry has more opportunities than ever to search. New red dwarfs in our galactic neighborhood continue to be found as more-sensitive optical telescopes come on-line. Over the past 40 years the population of known small red dwarfs has nearly doubled; many of the bodies could be paired with brown dwarfs. "I think that if you add up all the small red dwarfs we can't see, throw in brown dwarfs and dead white dwarfs—maybe a couple black holes, dust, and gas—you might be able to make up all the missing mass without neutrinos or other exotic particles," says Henry. "I like the ordinary junk, probably because I don't understand the extraordinary stuff."

For McCarthy it is not the question of missing mass but rather the search for other planetary systems that keeps him in the thick of the brown-dwarf field. By honing his cosmic detection skills in the hunt for brown dwarfs, he hopes one day to be able to spot even smaller, planet-size bodies.

"I think the most exciting thing, even more than the cosmology," says McCarthy, "is the possibility of finding other solar systems. There are a lot of theories about how ours formed, and they're probably wrong. We need to find other solar systems to compare ours with. That's how science is done. Finding other solar systems might trigger a complete revolution—and a complete revelation—about how we got here." ❑

Contributing editor Marcia Bartusiak wrote about astronomer Vera Rubin in the October 1990 issue.