NEWS

The Runts of the Cosmic Litter

Brown dwarfs and other substellar bodies behave like giant planets, but most of them may form like stars

It takes a lot of cold gas to make a hot star. A cloud of gas and dust must start out cold for gravity to overcome the cloud's thermal unrest. Once it collapses, the gas must get hot and dense enough to ignite hydrogen fusion at its core. The newborn star then throws off its blanket with a gusty wind, having gathered enough gas to ensure a warm and stable life.

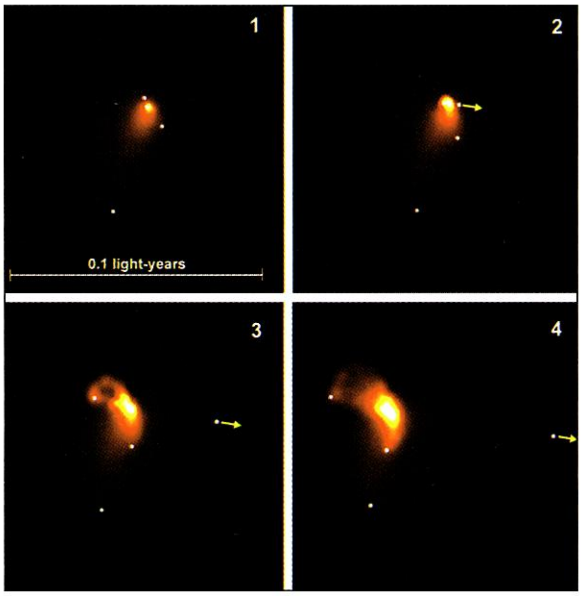
But plenty of objects never reach that critical phase. Lighting the fires of fusion requires a ball of gas at least 75 times the mass of Jupiter, or about 7% of our sun's heft. Anything below that threshold simply cools down for billions of years, like an ember on the hearth, until it vanishes from sight.

These cosmic castoffs, called brown dwarfs, eluded detection for years. But now, searches have turned up so many—more than 200 by the latest count—that astronomers expect brown dwarfs to fill gaps in their theories about the origins of the smallest stars. "Brown dwarfs straddle the realm between stars and giant planets," says astrophysicist Adam Burrows of the University of Arizona in Tucson. "It's the last great chapter of stellar astronomy."

Here on the fringes of planetary science, astronomers see signs that brown dwarfs arise by means of surprisingly puny versions of the processes that create stars like our sun. Surveys reveal a smooth distribution of the numbers of brown dwarfs from 75 Jupiter masses down to about 10 Jupiter masses, suggesting that kernels of gas collapse into a range of substellar sizes. Some young dwarfs seem shrouded by dusty disks as are their stellar cousins, pointing to similar origins. In other cases, protostellar clouds appear to split into smaller chunks, making multiple embryos that compete for infalling gas like chicks in a nest. Gravitational skirmishes among these siblings may eject the smallest ones before they collect enough gas to fledge as bona fide stars.

On the other hand, a few of the scores of known planets outside our solar system look more like brown dwarfs than planets. For example, two titans circle the star HD168443, tipping the scales at a minimum of 7 and 17 Jupiter masses. Some free-floating "planetary-mass objects" as light as 5 Jupiter masses have surfaced in surveys of young star clusters. At the moment, the birthplaces of these nomadic gas giants are impossible to trace.

"It's a confusing picture," says astronomer J. Davy Kirkpatrick of the California Institute of Technology in Pasadena. "It could be that things we think of as brown dwarfs can form by either process, at the high-end tail of planet formation or at the low-end tail of star formation." Those distinctions are crucial to theorists grappling with the extremes of both scenarios. As astronomer Bo Reipurth of the University of Hawaii, Manoa, puts it: "Brown dwarfs do not represent a few pathological objects that form under rare circumstances. They must be integrated within a general understanding of star birth."



Dwarf toss. Simulations of prestellar clumps within a collapsing cloud of gas suggest that the runtiest ones get flung into space, dooming them to lives as brown dwarfs.

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Additions to the alphabet

That integration won't come quickly, for it wasn't many years ago that brown dwarfs existed only in theory. Searches in the 1980s and early 1990s unveiled candidates, but on closer examination they all morphed into stars or observational glitches. "It was frustrating," recalls astronomer Sandy Leggett of the United Kingdom Infrared Telescope on Mauna Kea, Hawaii. "People began to say that star formation must know about the hydrogen-burning mass limit, because we weren't finding anything smaller."

But in 1995, astronomers confirmed the first brown dwarfs by spying the telltale imprints of fragile substances in their faint spectra of light. The gases, either lithium or methane, are destroyed by the heat of genuine stars but can persist in the cooler confines of brown-dwarf atmospheres. At the same time, other teams found the first giant planets circling sunlike stars. "It was suddenly very clear that nature has no problem manufacturing substellar objects," says astronomer Gibor Basri of the University of California, Berkeley.

Subsequent hunts within young stellar clusters have flushed out droves of brown dwarfs. Prime targets are the Pleiades cluster and star-forming regions in Orion and Taurus, where substellar bodies rival stars in number. Other teams have pored over data from broad surveys of the sky to find lone dwarfs among the stars. The most fruitful projects are the Sloan Digital Sky Survey in optical light and two ambitious projects in infrared wavelengths: the Deep Near Infrared Survey in southern skies and the 2-Micron All-Sky Survey in both hemispheres.

Spectra of these objects show that as brown dwarfs age, they look like hot planets rather than cool stars. For a few million years, bodies with at least 13 times the mass of Jupiter can fuse deuterium, an isotope of hydrogen, at their cores. (This nuclear capability led an international panel* to declare last year, after prickly debate, that objects heftier than 13 Jupiter masses are "brown dwarfs" no matter where they are, whereas smaller objects are "planets" if they circle stars and "sub–brown dwarfs" if they drift through space.) The deuterium glow is temporary, however. When it expires, the dwarf bleeds heat as it contracts. Ultimately, it slowly cools like a desert rock after sunset.

The slow chill alters brown dwarfs' atmospheres, strange molecular stews in which compounds form and "rain" downward as the dwarf evolves. Clouds of condensed silicate minerals dominate at 2000 kelvin, about 4000 degrees cooler than the sun. By 1400 K, those solid grains settle deep in the atmosphere, leaving clearer layers ripe with methane, water vapor, and alkali metals such as sodium and potassium. The sodium absorbs most of a dwarf's yellow light. Be-

* Working Group on Extrasolar Planets: www.ciw.edu/boss/IAU/div3/wgesp

cause yellow is a key part of the color we perceive as "brown," Burrows observes that the objects are woefully misnamed. "They're actually purple or magenta," he says. "You can't get them to be brown."

More exotica await below 800 K, the temperature of the coolest dwarf yet seen. Water clouds condense at about 500 K, and ammonia droplets appear at 300 K. This should sound familiar, because planetary scientists probe the coolest of those layers within the closest dwarf wannabe: Jupiter. "In brown dwarfs, we're seeing the early phases of Jupiter's evolution and its interior today," Burrows says.

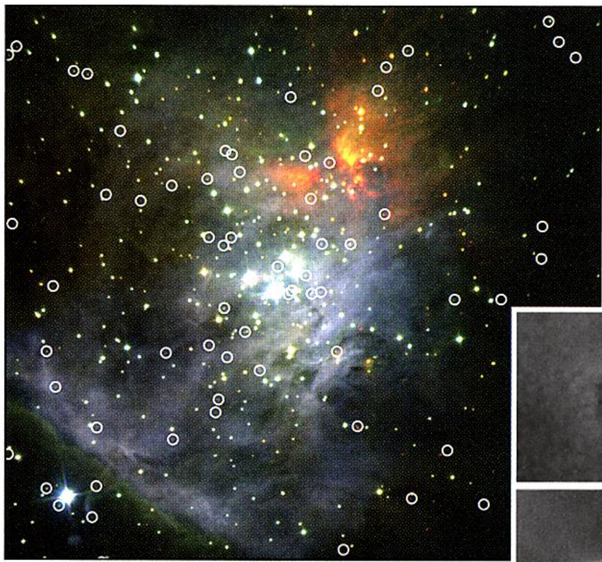
This changing cast of compounds produces spectra utterly different from those of stars, forcing astronomers to amend the "O B A F G K M" spectral classifications devised by Annie Jump Cannon at the Harvard College Observatory in 1901. So far, the new entries are "L" for warmer dwarfs and "T" for cooler ones—spoiling the famed mnemonic, "O Be A Fine Girl, Kiss Me." "Here I am 100 years after my heroines classified stars, and I'm getting a chance to do what they did," Leggett says. "It's such a thrill."

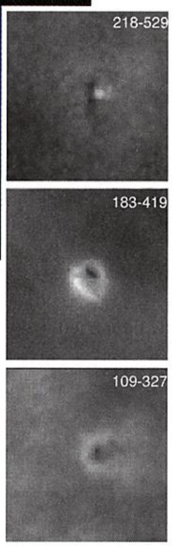
As astronomers continue to scan the heavens, their censuses are bound to turn up many more substellar objects in our galaxy. "There could be several hundred unknown brown dwarfs within 25 parsecs [80 light-years] of the sun," says astronomer Eduardo Martín of the University of Hawaii, Manoa. Contrary to earlier hopes, however, those hidden neighbors probably don't carry enough weight to account for much of the galaxy's missing dark matter. In clusters and star-forming regions, brown dwarfs probably make up just a few percent of the total mass, Martín notes, although untold numbers of them may orbit through the Milky Way's extended halo of stars.

Clues to the womb

Instead of focusing on the galaxy's "missing mass," astronomers now view brown dwarfs as missing links in low-mass star formation. Recent studies offer intriguing hints about their role.

One clue is the prevalence of dusty disks around brown dwarfs. Such remnants of protostellar nurseries often linger around infant stars. A team led by graduate student August Muench of the University of Florida, Gainesville, studied dozens of candidate brown dwarfs in the Trapezium, a crowded star-forming swarm in Orion. Although the team members didn't see disks directly, excesses of infrared emission suggest that dust clouds around most of the dwarfs absorb energy from the newborn objects and reradiate it as heat. The ubiquity of disks indicates that small stars and substellar pygmies are born in the same way, Muench and his colleagues maintain.





Starlets. The Trapezium, a star-forming region in Orion, is studded with probable brown dwarfs (circled). Hubble Space Telescope images show that some have dusty disks (*insets*).

CREDITS: (LEFT TO RIGHT) AUGUST MUENCH *ET AL.*/ESO; JOHN BALLY *ET AL.*/HUBBLE SPACE TELESCOPE

Basri of Berkeley agrees that the births of brown dwarfs probably cut handily across the mass bins into which astronomers have placed them. His team's studies of newborn dwarfs in Orion and Taurus bear that out. Emissions from substellar objects have the same spectral patterns as those from low-mass stars, just at a smaller scale. "They look very much like wimpier versions of stars forming," Basri says. "It's nothing weird at all."

Muench draws the same conclusion from the statistics of the ongoing tally of brown dwarfs and extrasolar planets. Astronomers presume that giant planets arise in disks of gas around their parent stars, a process quite distinct from star formation. The planets may accumulate mass by adding gas onto seeds of ice and rock, or they may collapse gravitationally within their own dense vortices of gas. However, if many substellar objects formed in those planetlike ways, one might expect a notable hump in the numbers of low-mass brown dwarfs, Muench says. Instead, the parsing of masses seems evenly spread, down to the range of 10 to 20 Jupiter masses. "There's no evidence for multiple mechanisms," he says. "It's a consistent picture: Brown dwarfs form from protosubstellar cores."

Surveys aren't as clear about bodies weighing in at a few Jupiters, whose masses are hard to determine. If deeper images expose many more, it would bolster the views of some theorists that chaotic interactions within young planetary systems fling such bodies into interstellar space. Simulations do suggest that gravitational whiplash can expel planets, but the most common victims are smaller objects such as Saturn and Earth. For that reason, theorist Alan Boss of the Carnegie Institution of Washington, D.C., thinks planetary ejection goes only so far. "The masses don't quite agree," Boss says. "If you're trying to explain free floaters as big as 5 to 10 Jupiters, you'd need stars with companions of 20 to 50 Jupiter masses to kick them out. We just don't see those."

Rather, Boss favors another scenario to cast most lone dwarfs into space: expulsions from nests of substellar embryos. This provocative idea belongs to Hawaii's Reipurth, who believes that most brown dwarfs are losers in battles for food among many siblings. If such events occur, they would inject randomness into a process that most astronomers have viewed as smoothly evolving.

Reipurth bases his hypothesis on observations of 14 "giant Herbig-Haro flows," great outpourings of gas from certain newborn stars. The Hubble Space Telescope pinpointed the apexes of the long, energetic jets. With help from ground-based radio images, Reipurth and others determined that 12 of them had two or more stars embedded inside. "These flows are a fossil record of small, unstable systems, which eject low-mass objects," Reipurth says. "If an embryo is ejected before it has accumulated enough mass to burn hydrogen, it will forever remain a brown dwarf."

One snag is that models of star-forming regions have strained to produce anything resembling a tightly clumped nest of small gaseous cores. It seemed that a single object—or at most, a binary—would condense from the infalling deluge. However, research conducted last year by Boss may provide an answer. Magnetic fields lacing through a protostellar cloud may fracture a disk of gas into at least four pieces, Boss says. The initial core of each fragment might be as small as 1 Jupiter mass—about 1/10 the size that previous nonmagnetic simulations had predicted. "For now, it's a hand-waving idea," Boss admits.

Observations of stellar cradles with the Space Infrared Telescope Facility, due for launch in July 2002, may discriminate among these and other notions. In the dim, magenta-tinged realm of brown dwarfs, astronomers will need a bright red flag to rule anything out.

–ROBERT IRION