outflow from it: It contains many forbidden emission lines (*15*, *16*), which are usually associated with young stars in which a fraction of the inflowing material is ejected perpendicular to the disk. If confirmed through future observations, this finding would further strengthen the analogy between nascent brown dwarfs and their stellar counterparts.

The mounting evidence thus points to a similar infancy for Sun-like stars and brown dwarfs. Does this mean that the two kinds of objects are born in the same way? Many observers tend to think so (*7–12*), but it may be too early to rule out the ejection scenario for at least some brown dwarfs. Far-infrared observations with the Spitzer Space Telescope (launched in August 2003) and millimeter observations with ground-based radio telescopes may reveal the sizes and masses of brown dwarf disks, allowing us to determine whether most disks are truncated. Better statistics of the frequency of binary brown dwarfs could provide another observational test. Infrared studies of even younger "proto-brown dwarfs," which are still embedded in a dusty womb, may also provide clues to their origin.

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ASTRONOMY

Brown Dwarfs—Faint at Heart, Rich in Chemistry

Katharina Lodders

A decade ago, brown dwarfs were not much more than a theoretical curiosity in astronomy textbooks. It was unclear whether such objects, with masses and temperatures between the giant planets and the coolest known dwarf stars, even existed. Today, the problem is how to tell all the different low-mass objects apart. In a recent paper in *Astrophysical Journal*, McLean *et al.* (*1*) propose a unified classification scheme for brown dwarfs on the basis of near-infrared spectra. The scheme also provides insights into the chemistry of these cool, dense objects. [For a discussion of brown dwarf origins, see (*2*).]

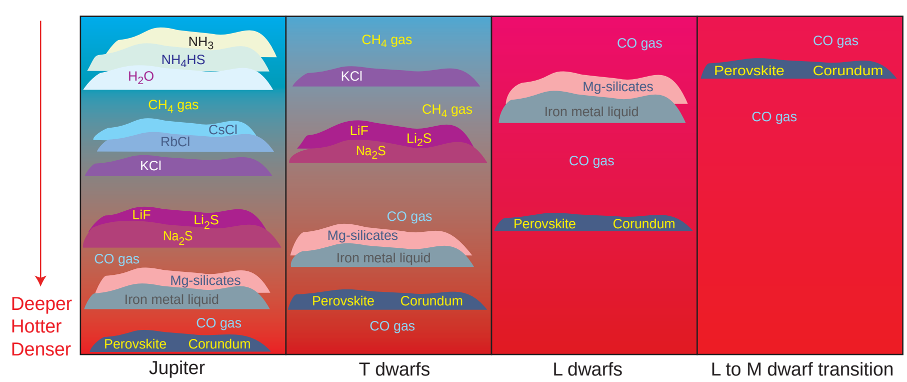
The first brown dwarf, prosaically called Gl229 B, was discovered in 1995 (*3*, *4*). It was clearly substellar, sharing more characteristics with giant planets like Jupiter than with red M dwarfs, the coolest and lowest mass stars known at the time. Many more brown dwarfs were discovered in the late 1990s thanks to large-scale infrared sky searches [Two Micron All Sky Survey (2MASS), Deep Survey of the Southern Sky (DENIS), and Sloan Digital Sky Survey (SDSS)].

Brown dwarfs fall in two spectral classes, L and T (*5–8*). L dwarfs, which are closer to M dwarfs than to giant planets in spectral appearance, include the lightest real stars and the heaviest substellar objects. T dwarfs have spectra that are more similar to those of giant planets, but are much more massive. Brown dwarfs are further divided into subtypes from zero for the hottest (L0, T0) to eight for the coolest (L8, T8), depending on whether certain spectral features assumed to be a proxy of temperature are present. Today, ~250 L dwarfs and ~50 T dwarfs are known (*9*).

Initially, subtyping of L dwarfs was based on red optical spectra, whereas T dwarfs were sorted by near-infrared spectral features (*5–8*). McLean *et al.* (*1*) have now advanced a unified classification scheme for L and T dwarfs based on ~50 objects analyzed with the Keck II Near-Infrared Spectrometer. They have used the high-quality near-infrared spectra to categorize brown dwarfs by the relative strengths of the atomic lines of Na, K, Fe, Ca, Al, and Mg and bands of water, carbon monoxide, methane, and FeH. The observations establish a firm reference frame for the spectral classification of L and T dwarfs.

Such observations represent major progress, because small sizes (roughly the radius of Jupiter) and low masses hamper the detection of brown dwarfs. Their masses only reach up to ~7% that of the Sun (for comparison, Jupiter's mass is ~0.1%), not enough to initiate and sustain the hydrogen burning that powers real stars. Brown dwarfs may burn deuterium if they exceed 13 Jupiter masses. However, the energy released by this deuterium burning is a small fire compared to the inferno of hydrogen burning in stars and lasts less than 100 million years for the most massive brown dwarfs. In contrast, hydrogen can burn for several billion years in dwarf stars (*10*). Much of the energy released by a brown dwarf over its lifetime is from gravitational energy gained during its formation and contraction. A brown dwarf's main fate is to sit and cool in space.

Deprived of a nuclear engine, brown dwarfs never exceed ~3000 K near their surfaces. The more a brown dwarf cools, the less it is visible at optical wavelengths. M dwarf stars emit most strongly at red wavelengths (~0.75 µm), but maximum emissions of the cooler L dwarfs (1200 to 2000



A cloudy picture. Cloud layers for Jupiter, T dwarfs, L dwarfs, and objects near the transition from L to M dwarfs. The layers are progressively stripped off as the temperature of the object increases.

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K) and T dwarfs (800 to 1200 K) are shifted to the near-infrared (1 to 2 μm), which also makes brown dwarfs intrinsically faint. Moreover, their outer atmospheres are loaded with molecules such as water, carbon monoxide, methane, and ammonia that absorb light emitted from the interior, further dimming the flux of light. These considerations explain why finding brown dwarfs was such an observational challenge.

The dense, cool atmospheres of brown dwarfs are an ideal environment for producing molecules, rather than the monatomic ions and neutral atoms so prominent in normal stars. Which gases are present at a given depth in brown dwarf atmospheres depends on temperature, pressure, and overall elemental composition. Like Jupiter and the Sun, brown dwarfs mainly consist of hydrogen and helium, but molecules made of less abundant elements make all the difference. Water and carbon monoxide absorption shape the near-infrared spectra of L dwarfs, whereas the near-infrared spectra of T dwarfs are dominated by methane absorption (*1*, *5–8*). Indeed, methane absorption was the proof of the brown dwarf status of Gl229 B. Methane is more abundant than CO only below 1200 to 1500 K and at total pressures characteristic of brown dwarf atmospheres (*11*). Such low temperatures are only reached at substellar masses.

Perhaps the most unusual aspect of brown dwarf atmospheres is the presence of clouds. Refractory oxides, silicates, and liquid iron metal can form cloud layers even in the hottest L dwarfs (*11*, *12*). Cloud formation on brown dwarfs is similar to that on giant planets and did not come as a surprise to planetary scientists, who have modeled cloud layer formation at different atmospheric levels by gravitational settling of condensates from overlying cooler atmospheric regions (*13–16*). However, what distinguishes giant planets, T dwarfs, and L dwarfs is the number of different cloud layers.

Jupiter has top-level clouds of water, ammonia hydrogen sulfide (NH_4HS), and ammonia (see the figure). Deeper inside, there are alkali halide and sulfide clouds followed by silicate and iron cloud layers. The deepest cloud layer on Jupiter is made of refractory ceramics such as corundum and perovskite. In the hotter T and L dwarfs, the cloud layer structure shown for Jupiter is successively stripped at the top. In the hottest L dwarfs, only the layer with the most refractory condensates may be left (see the figure). Thus, looking at hotter brown dwarfs is like looking at deeper and deeper regions of Jupiter's atmosphere.

The atmosphere above a cloud is depleted in the gases that contain the elements trapped in the cloud. For example, molecular absorption of TiO and VO is the trademark of the coolest M dwarfs but disappears in L dwarfs (*1, 5–8*), where both molecules enter a perovskite cloud. Calcium and aluminum lines and CaH bands disappear near the transition from L to M dwarfs, because clouds made of corundum and calcium aluminates take up Ca and Al. FeH absorption fades away in cooler L dwarfs when metallic iron clouds remove iron gases from the observable atmosphere. Atomic alkali lines are prominent in all L dwarfs and detectable in the hottest T dwarfs, but not in cooler T dwarfs, where the alkali atoms form halide gases that condense into clouds.

Drastic compositional changes in their atmospheres thus alter the observable spectral characteristics of brown dwarfs. In addition, clouds can block light emitted by the brown dwarf, depending on how close they are to the observable atmosphere. The effects of clouds on brown dwarf spectra are just beginning to be understood (*17–20*).

Despite the complexity of the brown dwarf spectra, the underlying chemistry can be identified and used as a "thermometer" to sort brown dwarfs (*1*, *16*). No direct observations have yet been made of objects with even lower mass and temperature than T8 dwarfs (effective temperature ~800 K) to complete the bridge to Jupiter (~125 K). But with the Spitzer Space Telescope in orbit ready to gather mid-infrared spectra, such ultralight brown dwarfs may finally come into view.

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MOLECULAR BIOLOGY

Breaking the Silence

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The genomes of eukaryotic cells are not composed of free DNA but exist as chromatin in which the DNA is associated with octamers of histone proteins called nucleosomes. The structure of chromatin varies throughout the genome, providing a means to regulate access of the transcriptional machinery to the underlying genes. In an extreme case, chromatin adopts a condensed structure termed heterochromatin in which genes are less accessible and frequently transcriptionally silent. Uncondensed chromatin (euchromatin) is much more accessible than heterochromatin and contains the majority of actively expressed genes. To regulate gene expression, cells adopt several different strategies to alter chromatin structure. These include the posttranslational modification of histones (for example, by acetylation), the incorporation of variant histone proteins into nucleosomes, and adenosine triphosphate (ATP)–dependent chromatin remodeling by protein complexes related to the yeast Swi2/Snf2 ATPase. Three recent reports, including one by Mizuguchi *et al.* (*1*) on page 343 of this issue, indicate that these different strategies may be more intimately related than previously appreciated.

Mizuguchi and co-workers report their purification from yeast extracts of a protein complex containing Swr1, a previously uncharacterized Swi2/Snf2-related ATPase (*1*). The authors identified 12 proteins in the Swr1 complex, some of which are shared by other chromatin-associated complexes. The same 12 proteins were identified in two complementary reports published elsewhere (*2, 3*). Histones including a significant proportion of Htz1, the yeast histone H2A.Z variant, were found to associate with the Swr1 complex (*1–3*). The investigators then compared the genome-wide transcription profiles of *swr1* and *htz1* yeast mutants. They found that many genes that are either activated or

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