Agenda for Ast 309N, Oct. 9

- Results of class poll, 10/02
- Brown dwarfs: formation; observed properties
- Video on exoplanet discoveries, circa 2008
- Card activity: exoplanets around red dwarfs

What's Interesting about Low-Mass Stars?

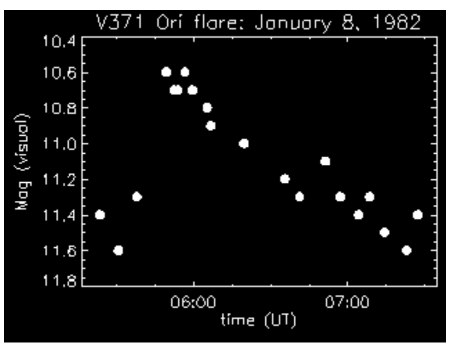
- They are much more numerous than massive stars
- They have very long lifetimes; there could be stars still out there that formed very early in the universe
- They have a tendency to be very 'active' – in the sense of solar activity: giant starspots, intense magnetic fields, mass ejections, and flares

  …. *especially when they are young; this activity dies down over billions of years, which enables us to estimate ages*
- This "activity" is driven by a combination of fast rotation and strong convection; the fact that it goes away is related to the rotation speed slowing down

Evidence for Activity in Low-Mass Stars

Starspots and outbursts are detected mainly by the dimming or sudden brightening of the star's light

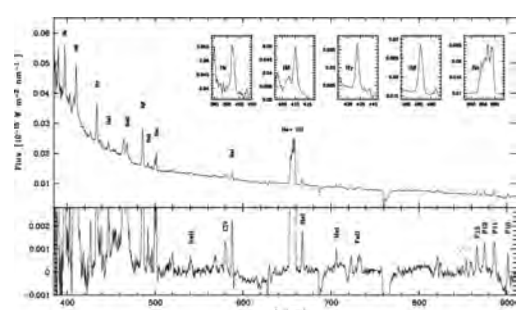
A "light curve" traces how a star's brightness varies over time



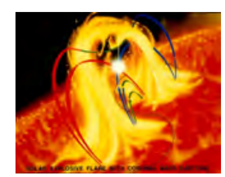
More Evidence for Activity

Such stars often show emission lines in their spectra.

Here's what we see:

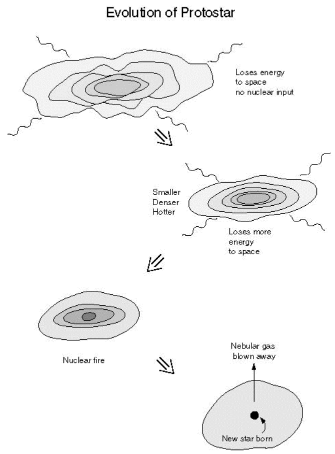


We interpret these as indicators of strong flare or CME-like activity



How the Sun became a Star

- The Sun began as a cloud of gas, contracting under gravity.
- This converted gravitational energy into kinetic then thermal energy, and heated up the central regions.
- The center eventually became hot and dense enough for thermonuclear reactions to begin: H fusion into He.
- Contraction stopped and fusion became the energy source.



Wheeler, Fig. 1.5

Why do Some Protostars "Fail"?

As a star is forming through contraction of a cool low-density cloud, the inside heats up. However, hot objects radiate, so some of the created energy is lost due to radiation, cooling the protostar. This causes gravity to overcome thermal pressure. The protostar continues contracting, so the core gets even hotter. Eventually it's hot enough for nuclear fusion to start.

If the cloud starts out with less than 0.08 solar masses (80 times Jupiter's mass), it becomes a brown dwarf, or a "failed star." Why does this happen; why doesn't it just keep contracting, going through the loop described above, until it gets hot enough?

Hint: This scenario is based on thermal pressure. Is there any other kind? For example, what supports a white dwarf?

Why is there a Minimum Possible Mass for Main Sequence Stars?

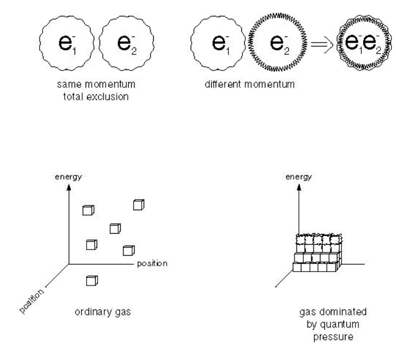
- A cloud with a smaller initial mass has less gravitational potential energy available during the contraction phase,
- … providing less thermal energy to heat the core
- … so the central temperature doesn't rise high enough to start fusion of H into He as quickly as it does for a more massive protostellar cloud.
- Why doesn't it just keep on contracting and heating until it *does* get hot enough, even if that takes longer to happen?
- Because something stops the collapse; a new form of pressure, electron degeneracy pressure or, as Wheeler calls it, "quantum pressure" (start on p. 11).

Degeneracy or "Quantum" Pressure

Heisenberg Uncertainty Principle: one cannot exactly specify the location and momentum of an electron simultaneously. If you "sharpen" your view of one quantity, the other gets "fuzzy."

Pauli Exclusion Principle: two electrons cannot have identical momenta → Electrons possess "personal space." They resist compression at high densities.

"Stacking" electrons: to pack in more e's, they must have higher momenta/energies



Wheeler, Fig. 1.4

Protostellar Contraction and Heating

What breaks the "cycle," and keeps the star from continuing to contract and heat?

Thermal pressure, if fusion supplies energy and keeps the gas hot

OR

Electron degeneracy or "quantum" pressure"

Main Sequence star

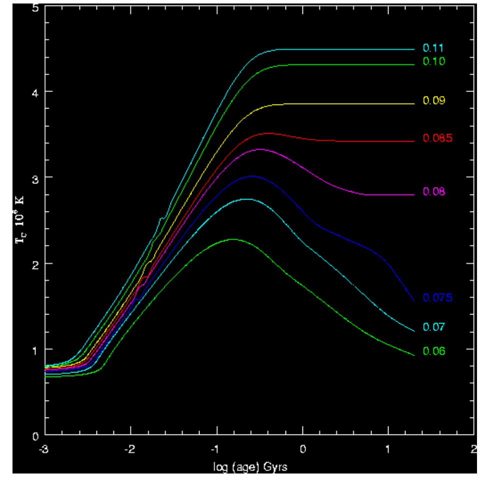
More than $0.08\ M_\odot$ (or 80 times Jupiter)

Brown dwarf

Less than $0.08\ M_\odot$ (or 80 times Jupiter)

Central Temperatures of Protostars

The plot shows the central temperatures of contracting clouds, in units of thousands of degrees. Each line is labeled by the mass in solar masses. The higher-mass ones "flatten out" when fusion turns on; the lower-mass ones reach maximum T, stop contracting, and then just cool off.



Introducing Brown Dwarfs

Objects with mass too small for H-fusion were named "brown dwarfs" by Jill Tarter (brown is not a [spectral wavelength] color).

Correspond to masses < 0.08 (8%) solar masses = 80 Jupiter masses, radius ≈ $0.1\ R_\odot$

$M_{Jup} = .001\ M_\odot = 10^{-3}\ M_\odot$

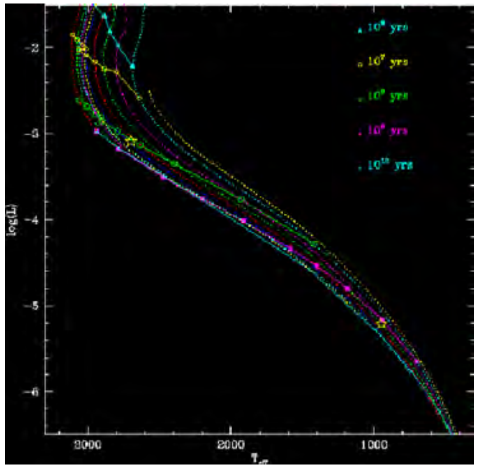
How Degenerate Stars Behave

Degeneracy pressure depends on density alone, *not* on temperature. Degenerate stars do not behave like ordinary stars which are supported by thermal pressure.

- If it is heated, a degenerate star does not expand, causing it to cool off; it has no "relief valve."
- If it radiates and cools, a degenerate star does not contract, which would cause heating due to the release of gravitational energy. (It's like a brick.)
- A fully degenerate star stays at constant volume (radius), so its luminosity falls as it cools.

Brown Dwarfs in the HR Diagram

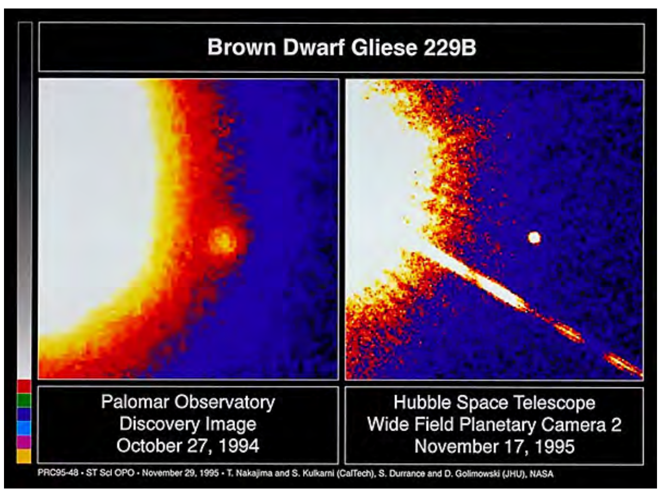
Brown dwarfs “live” in the lower right corner of the diagram, beyond the red dwarfs, though not a continuation of the Main Sequence. At the top, they are still contracting, gaining energy from gravity. Once they stop contracting, they get cooler and dimmer, sliding down along a line of constant radius.



Search Methods for Brown Dwarfs

- Indirect methods: “reflex motion” of companion star: like binary stars, except that one member is very cool and faint
  - What methods? Index card of 9/25!
- Direct methods: see emission directly from the brown dwarfs.
  - What spectral region? Hint: they are cool.

First Confirmed Brown Dwarf: Gl 229B



First Confirmed Brown Dwarf, Gl 229B

Discovered in 1994, as a companion of the low-mass Main Sequence star Gliese 229

Planet-star separation similar to Pluto-Sun

Luminosity only $6 \times 10^{-6}\ L_{\odot}$

Surface less than 1000 K; spectrum has H_2O and CH_4 (methane) - like Jupiter

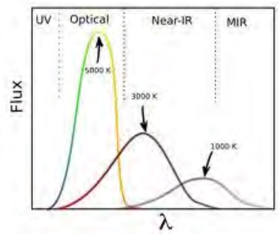
Inferred mass depends on age (why?)

Best estimate: 20 – 50 Jupiter masses

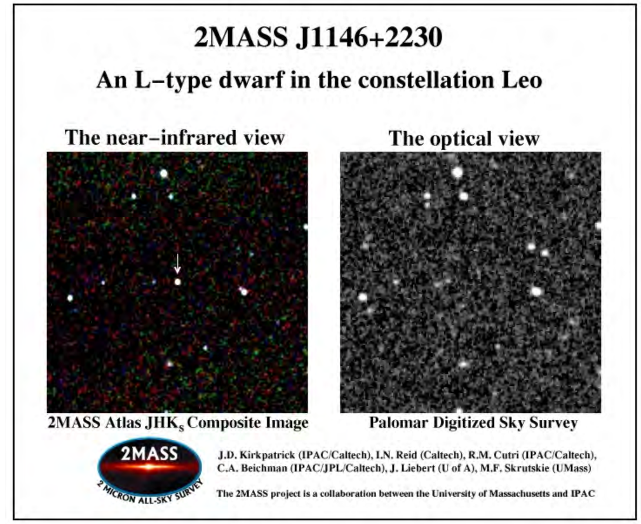
Brown Dwarf Searches: A New Era

Found by infrared surveys: 2-MASS, Spitzer, WISE

Temperatures starting at around **1000 K**, going cooler



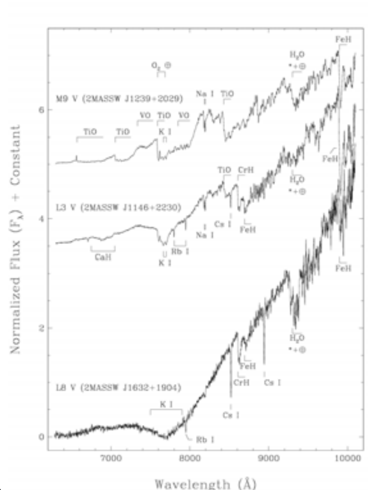
Have to eliminate reddened (by dust) red dwarfs, which requires spectroscopy.



"L" Dwarfs: A New Spectral Class

"L dwarfs": 1500-2000K, follow the M dwarfs in the spectral sequence. Notice steep rise toward the red end.

Spectra different from M stars. Instead of TiO, etc. see molecules that require cooler temperatures, e.g. CaH, FeH, also alkalis like sodium (Na), potassium (K)

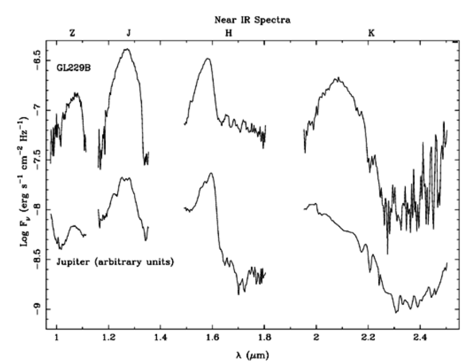


"T" dwarfs": Another New Spectral Class !

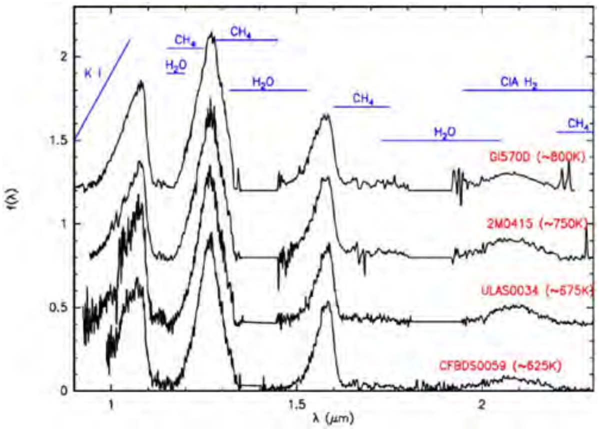
"T-type" also called "methane" dwarfs: < 1500K

Cooler than L dwarfs, so observe in the infrared

Spectrum is full of molecules, especially methane (CH_4), looks like Jupiter

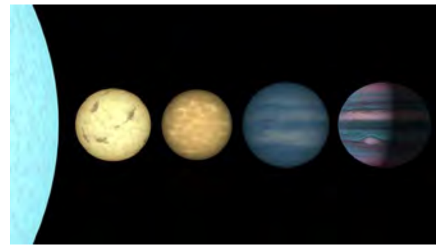


Complex Molecules in Brown Dwarf Spectra



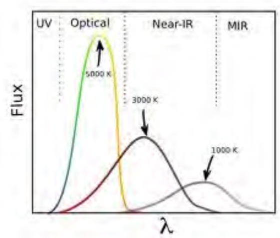
Sun M dwarf L dwarf T dwarf Jupiter

View in visible light (Jupiter seen by reflection)



View in infrared light (blue color - methane)

Yet Another New Spectral Type? "Y" Dwarfs



At least a couple of Y dwarfs have already been found by WISE, a survey in space, observing in the mid-infrared

The Coolest Brown Dwarf Yet

J1458+1013B, a brown dwarf 75 light-years from Earth has a mass of 6-15 times Jupiter, was found in 2011 by Kevin Luhman of Penn State (he was a UT undergraduate!). Its surface temperature is downright chilly, below 100 Celsius (212 F).