What comes with a kiss?
Spectral Classes

- Oh be a find girl kiss me.
- Main sequence stars
- OBAFGKM
- O0 to O9
- Luminosity class
  - Ia: brightest supergiants
  - Ib: less luminous supergiants
  - II: bright giants
  - III: giants
  - IV: subgiants
  - V: main-sequence stars
New Spectral Types L and T

Yanling Wu
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Kirkpatrick, J.D. 2005, ARAA, 43, 195
What is brown dwarf?

- What is a star?
  - a self-luminous sphere of gas
  - held together by gravity and thermal energy from nuclear reactions held them from collapsing
- Brown dwarfs are low-mass by-products of star formation.
  - first postulated by Kumar (1963) and Hayashi & Nakano (1963)
  - electron degeneracy supports the objects from collapsing further.
First discovery of brown dwarf

- Intrinsically very faint
- Becklin & Zuckerman (1988) discovered a very red companion to the 32-pc distant DA4 white dwarf GD165.
- 6400~9000Å spectrum of the companion, dubbed GD 165B by Kirkpatrick et al. (1993) confirmed the discovery.
  - TiO absorption cannot be distinguished
  - other observed absorption bands do not match the CH₄ or NH₃ features seen in Jupiter and Saturn.
  - Temperature lower than that of known M dwarfs but much higher than the onset on CO-to CH₄ conversion
First discovery of brown dwarf (cont’)

- Another stellar-to planetary link:
  - a common proper motion companion to the 5.7-pc distant M1 dwarf Gl229 (Nakajima et al. 1995)
- Even dimmer than GD165B
  - near infrared spectrum showed clear absorption by CH$_4$ at H and K bands and strongly resembled spectrum of Jupiter.
More on the discovery

• 2MASS (Kirkpatrick, Beichman & Skrutskie 1997)

• DENIS (Delfosse et al. 1997)

• SDSS (Strauss et al. 1999; Tsvetanov et al. 2000, Leggett et al. 2000)
The philosophy of classification

• Which new letters should be chosen? ---L and T.
• What sort of classification methodology would be best applied to these discoveries?
  ---MK system (Morgan, Keenan & Kellman 1943)
  Uses standard reference points on the sky

“These standard reference points do not depend on values of any specific line intensities or ratios of intensities; they have come to be defined by the appearance of the totality of lines, blends, and bands in the ordinary photographic region.”

ease of naming, classification based on the sum of traits, utility for deducing the underlying physics and shoptalk that is constant with time.
How about L and T dwarfs

• Oh boy, a fat girl kicked my left toe.

• Old boring astronomers feel greatly knowledgeable making ludicrous test.

• To find out more, go to:
  http://www.earth.uni.edu/~morgan/astro/course/obafgkmlt.html
The optical

- Early T dwarfs show a melange of atomic and molecular bands (alkali lines: Na I, K I, Rb I, Cs I etc., oxide bands: TiO and VO, hydride bands: CrH, FeH and CaOH)
- Mid-L: ground state Na I and K I lines have grown tremendously in strength, the hydrides MgH, CaH, CrH, and FeH have also strengthened, whereas the oxides TiO and VO have largely disappeared.
- Late-L and early-T: H$_2$O has increased in strength, the neutral alkali lines are still strong, and the hydrides are much reduced in prominence.
- Late-T: H$_2$O is major absorber and the two prominent lines of Na I and K I have grown so wide that they have begun to further suppress the pseudo-continuum between them at ~7000Å.
The Near-Infrared

• Late-M and early-L spectra are characterized by strong bands of $\text{H}_2\text{O}$, bands of FeH and CO, and neutral atomic lines of Na, Fe, K, Al and Ca.

• The hallmark of the T spectral class, $\text{CH}_4$, appears at early-T along with strengthening $\text{H}_2\text{O}$.

• By late-T the near-infrared spectrum has been chewed up into a series of flux peaks near 1.08, 1.27, 1.69 and 2.08 ($\mu$m), each of which has been sculpted on both sides by absorptions of $\text{CH}_4$ and $\text{H}_2\text{O}$.

• By T8 the 2.08 ($\mu$m) peak has been further flattened by overlying collision-included absorption by $\text{H}_2$. 
Normalized flux ($F_\lambda$) + constant

Wavelength (μm)
Beyond 2.5 Micron

- No independent classification owing to the difficulty of securing spectra there.
- The onset of the CH$_4$ fundamental bands at 3.3\(\mu\)m first appears around mid-L. By late-L the P- and R-branches of CH$_4$ also appears. By mid-T, methane has created a huge absorption trough from 3.1 to 4.0\(\mu\)m.
- IRS spectrum from 5 to 15\(\mu\)m.
The physics underlying the spectra

• Is the spectral sequence a temperature sequence?
  -- \( L = 4\pi R^2 \sigma T^4 \)
  -- Optical: A tight monotonic correlation throughout the range of L dwarfs with a broken at early-T and the trend continues from mid-T to late-T.
  -- Near-infrared: temperature and spectral types are well correlated only from early- to mid-L. From mid-L to mid-T, all objects have roughly the same temperature but the scatter is large. At types of T6 and below, the correlation of cooler temperature with later type re-emerges.