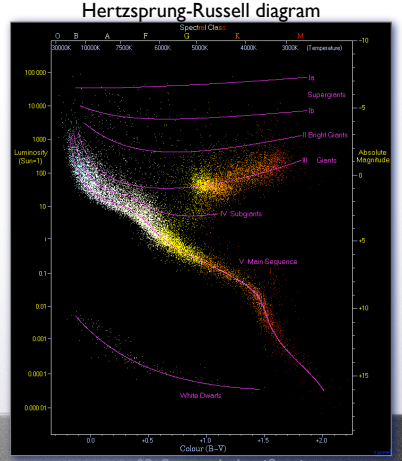
Lecture 2: Spectral classification

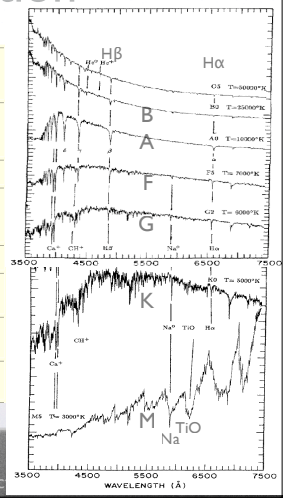
Stellar classification

Hertzsprung-Russell diagram



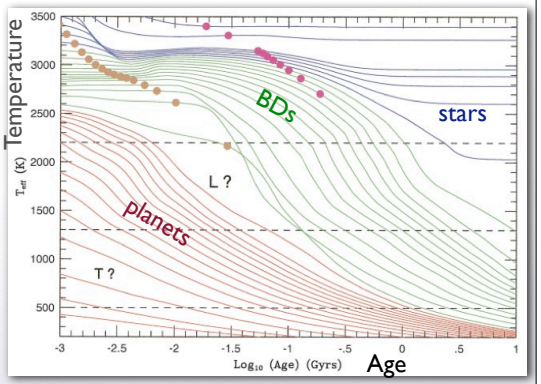
Stellar classification

Spectral Type	Atmospheric Temperature (K)	Hydrogen (Balmer) Features	Other Features	$M/M_\odot$
O	>33,000 K	weak	Ionized Helium (He^+) features sometimes in emission Strong UV continuum	20-60
B	10,500-30,000 K	medium	Neutral He absorption	3-18
A	7,500-10,000 K	strong	H features maximum at A0 Some features of heavy elements, eg Ca^+	2.0-3.0
F	6,000-7,200 K	medium		1.1-1.6
G	5,500-6,000 K	weak	Ca^+ H&K, Na "D" Sun is G2V	0.9-1.05
K	4,000-5,250 K	v. weak	Ca^+, Fe, Strong molecules, eg CH, CN	0.6-0.8
M	2,600-3,850 K	v. weak	Molecules, eg TiO Very red continuum	0.08-0.5



Brown dwarf specifics

- Cool temperatures
  - different chemistry
- Gravities
  - line broadening



New classes

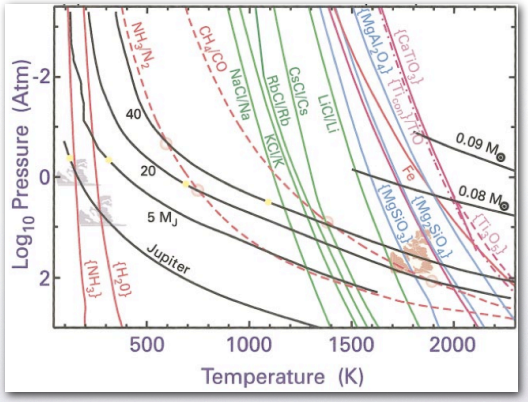
SUMMARY OF LETTERS TO GUIDE CHOICE OF NEW SPECTRAL TYPE

Letter (1)	Status (2)	Notes (3)
A	In use	Standard spectral class
B	In use	Standard spectral class
C	In use	Standard carbon-star class
D	Ambiguous	Confusion with white dwarf classes DA, DB, DC, etc.
E	Ambiguous	Confusion with elliptical galaxy morphological types E0–E7
F	In use	Standard spectral class
G	In use	Standard spectral class
H	OK	
I	Problematic	Transcription problems with I0 (10, Io) and I1 (11, II, Il)
J	In use	Standard carbon-star class
K	In use	Standard spectral class
L	OK	
M	In use	Standard spectral class
N	In use	Standard carbon-star class
O	In use	Standard spectral class
P	Problematic?	Incorrect association with planets?
Q	Problematic?	Incorrect association with QSOs?
R	In use	Standard carbon-star class
S	In use	Standard spectral class for ZrO-rich stars
T	OK	
U	Problematic?	Incorrect association with ultraviolet sources?
V	Problematic	Confusion with vanadium oxide (V0 vs. VO)
W	Ambiguous	Confusion with Wolf-Rayet WN and WR classes
X	Problematic	Incorrect association with X-ray sources
Y	OK	
Z	Problematic?	Incorrect implication that we have reached "the end"?

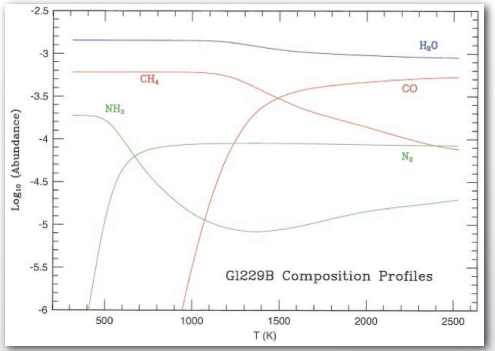
Kirkpatrick et al. (1999)

Features of the emerging spectrum

- Chemistry of the photosphere

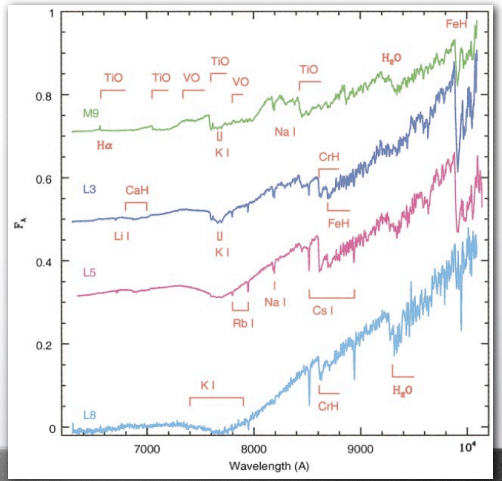


Features of the emerging spectrum



temperature, depth

L dwarfs



L dwarf sequence definition

Kirkpatrick et al. (1999)

- TiO, VO, Na I weakening
- FeH, CrH weakening
- K I broadening

QUALITATIVE DEFINITIONS FOR L SUBCLASSES

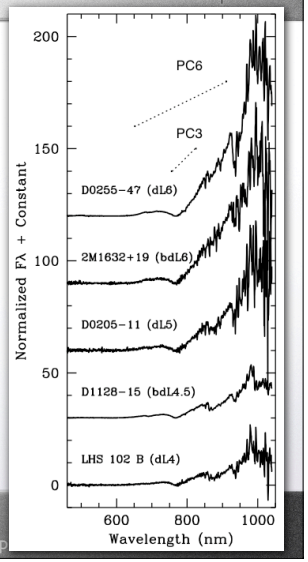
Subclass (1)	Spectral Characteristics* (2)	Example (3)
L0	VO $\lambda\lambda$7400, 7900 at its strongest—7800–8000 Å portion of spectrum is flat TiO λ8432 depth similar to both CrH λ8611 and FeH λ8692 TiO λ7053 present at high signal-to-noise but weak Rb I and Cs I doublets weakly visible but strengthening	2MASP J0345432+254023
L1	TiO λ8432, CrH λ8611, FeH λ8692 nearly equal strength; FeH deeper than CrH, CrH deeper than TiO VO $\lambda\lambda$7400, 7900 weakening; 7800–8000 Å portion of spectrum slightly sloped Na I doublet weakening TiO $\lambda\lambda$7053, 8432 weakening Rb I and Cs I doublets strengthening K I line cores broadening	2MASSW J1439284+192915
L2	TiO λ8432 much weaker than CrH λ8611 or FeH λ8692; FeH deeper than CrH K I line cores still visible and still broadening TiO λ8432 weaker and TiO λ7053 vanished VO $\lambda\lambda$7400, 7900 weakening more; 7800–8000 portion of spectrum distinctly sloped Na I weakening; Rb I and Cs I still strengthening	Kelu-1
L3	K I still broadening with cores still weakly visible VO λ7900 barely present as slight depression in "continuum" between 7800 and 8200 Å TiO λ8432 still weakening Na I still weakening; Rb I and Cs I still strengthening	2MASSW J1146345+223053
L4	K I wings are very broad and line cores no longer visible CrH λ8611 equal in strength to FeH λ8692 VO λ7900 vanished (no depression visible at all between 7800 and 8200 Å) TiO λ8432 still weakening Na I still weakening; Rb I and Cs I still strengthening	2MASSW J1155009+230706
L5	CrH λ8611 now stronger than FeH λ8692 TiO λ8432 very weak K I region shows broad depression Na I still weakening Rb I and Cs I still strengthening; Cs I λ8521 less deep than CrH λ8611	DENIS-P J1228.2−1547
L6	TiO λ8432 barely perceptible K I region shows very broad depression FeH λ8692, 9896 and CrH λ8611 weakening; CrH λ8611 deeper than FeH λ8692 Na I still weakening Rb I and Cs I still strengthening; Cs I λ8521 now deeper than CrH λ8611	2MASSi J0850359+105716
L7	TiO λ8432 virtually gone FeH λ8692, 9896 and CrH λ8611 still weakening; CrH λ8611 still deeper than FeH λ8692 K I region shows very broad depression Rb I and Cs I still strengthening Na I still weakening	DENIS-P J0205.4−1159
L8	FeH λ8692, 9896 very weak CrH λ8611 still weakening though still stronger than FeH λ8692 K I region shows very broad depression Rb I and Cs I still strengthening; Cs I λ8521 ~2 times as deep as CrH λ8611 Na I barely perceptible	2MASSW J1632291+190441

Alternative definition

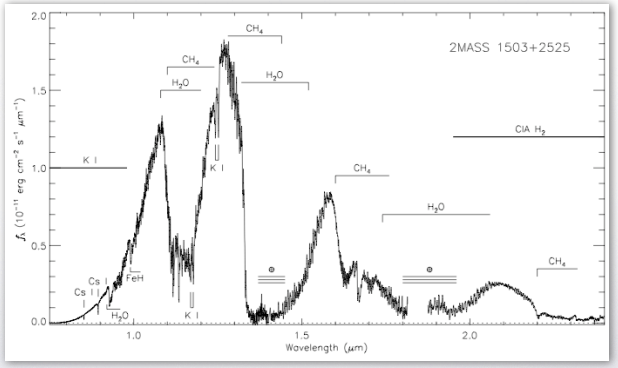
Martín et al. (1999)

INTEGRATION LIMITS OF SPECTRAL RATIOS

Name	Numerator (nm)	Denominator (nm)	Feature
PC3	823.0–827.0	754.0–758.0	Pseudocontinuum
PC6	909.0–913.0	650.0–654.0	Pseudocontinuum
CrH1	856.0–860.0	861.0–865.0	CrH λ861.1
CrH2	984.0–988.0	997.0–1001.0	CrH λ996.9
FeH1	856.0–860.0	868.5–872.5	FeH λ869.2
FeH2	984.0–988.0	990.0–994.0	FeH λ989.6
H_2O1.....	919.0–923.0	928.0–932.0	H_2O λ930.0
TiO1	700.0–704.0	706.0–710.0	TiO λ705.3
TiO2	838.0–842.0	844.0–848.0	TiO λ843.2
VO1	754.0–758.0	742.0–746.0	VO λ743.4
VO2	799.0–803.0	790.0–794.0	VO λ791.2



T dwarfs



Burgasser et al. (2006)

T dwarf sequence definition

Burgasser et al. (2002)

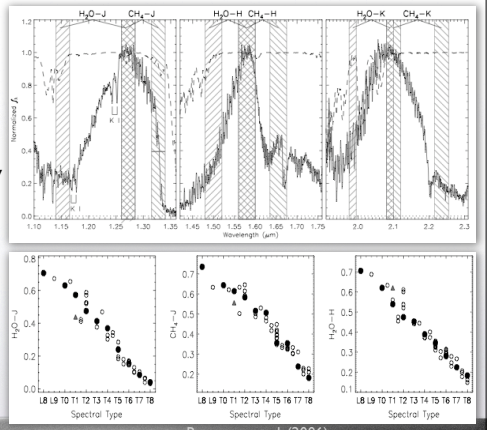
- CH_4 strengthens, CO disappears
- H_2O strengthens

NEAR-INFRARED SPECTRAL PROPERTIES OF T DWARF SUBTYPES

Type (1)	Description (2)	Standard (3)
T1 V.....	Weak CH_4 bands seen at 1.3, 1.6, and 2.2 μm Distinct 1.07 and 1.27 μm peaks separated by 1.15 μm H_2O/CH_4 feature *K*-band peak noticeably depressed relative to *J* and *H* CH_4 and CO bands at *K* equal in strength K I lines at 1.25 μm strong	SDSS 0837−0000
T2 V.....	CH_4 bands strengthening Flux at 1.15 μm feature roughly 50% *J*-band peak *K*-band CH_4 stronger than CO *K*-band peak rounded	SDSS 1254−0122
T3 V.....	Flux at 1.15 μm feature roughly 40% *J*-band peak Flux at 1.6 μm feature roughly 60% *H*-band peak CO barely visible at *K* band	SDSS 1021−0304
T5 V.....	Flux at 1.6 μm trough roughly 50% *H*-band peak No CO present *H* band suppressed relative to *J* and *K* K I lines at 1.25 μm peak in strength	2MASS 0559−1404
T6 V.....	Flux at 1.15 μm feature roughly 20% *J*-band peak Flux at 1.6 μm feature roughly 30% *H*-band peak 1.25 μm K I lines beginning to weaken 1.3 μm CH_4 band blended with 1.4 μm H_2O 2.2 μm CH_4 absorption nearly saturated *K* band beginning to flatten, asymmetric peak centered at 2.11 μm	2MASS 0243−2453
T7 V.....	Flux at 1.15 μm feature roughly 10% *J*-band peak Flux at 1.6 μm feature roughly 10% *H*-band peak 1.25 μm K I lines barely discernible *H*- and *K*-band peaks maximally suppressed relative to *J* *J*-band peak increasingly narrow	2MASS 0727+1710
T8 V.....	Flux at 1.15 μm feature nearly saturated Flux at 1.6 μm feature nearly saturated No 1.25 μm K I lines present Slight increase in *H*- and *K*-band peaks relative to *J* *K*-band peak more sharply peaked and symmetric about 2.07 μm	2MASS 0415−0935

T dwarf sequence definition

- Based on IR spectroscopy
- Geballe et al. (2002) superseded by Burgasser et al. (2006)



Burgasser et al. (2006)

Next lecture

- ARI, Monday 30th, 15:15
- Observational properties of brown dwarfs:
  - classification *(continues)*
  - more about the atmosphere, models
  - variability, activity
- Readings:

  New light on dark stars: end of §2 & §5