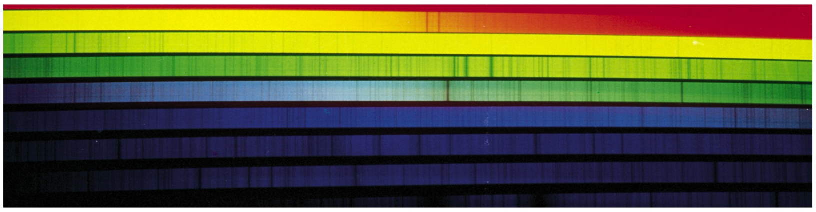
Spectroscopy

Spectroscopy

Spectroscopy is the technique that allows astronomers to decode the messages contained in starlight. Stellar spectra can tell us the intrinsic luminosity of a star, how hot it is, how fast it rotates, and its composition.

Early Classifications

In 1823, Joseph Fraunhofer observed that stars have spectra that are characterized by dark lines crossing a continuous band of color. William Huggins, in 1864, first identified some of the lines in stellar spectra with those of known terrestrial elements.



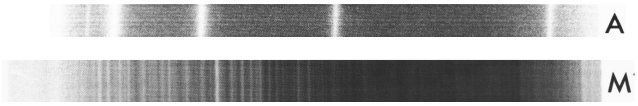
Early Classifications

In 1863, Angelo Secchi classified stars into four groups according to the general appearance of their spectra.

Pickering and Fleming (both at Harvard) in the 1890s labeled spectra with capital letters according to the **strength of their hydrogen absorption lines**, beginning with the letter A for the broadest lines.

Hydrogen Line Strength Order

A B C D E F G H I J K L M N O P Q R S T

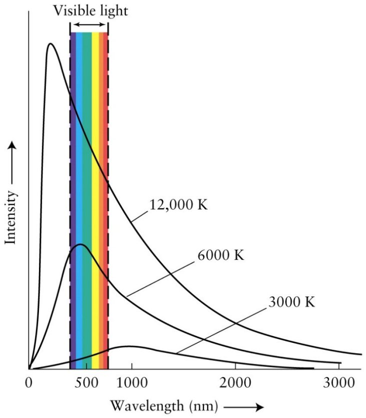


Note: Back when photographic plates were used (prior to digital cameras), the developed plate was a negative. Although the lines are bright, these are absorption-line spectra. Astronomers did not print a “positive” picture because that would have introduced noise.

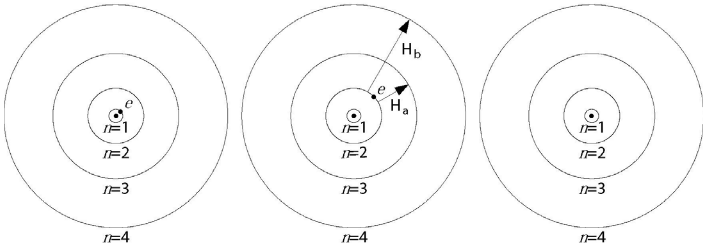
Temperature Effects

The dark absorption lines are due to the presence of a particular element in the atmosphere of the star observed. Detailed analysis has shown that **most stars have very similar compositions**.

The primary cause of differences in stellar spectra is that stars have very different **temperatures** in their outer layers.



Temperature Effects



Cool gas; electrons in ground state; no lines.

Hot gas; electrons have been ionized; no lines.

Warm gas, electrons in various energy levels; many lines.

Temperature Effects

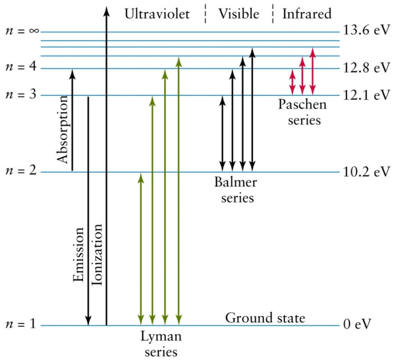
For example: Hydrogen

In hot stars, it is completely ionized, so it cannot make absorption lines.

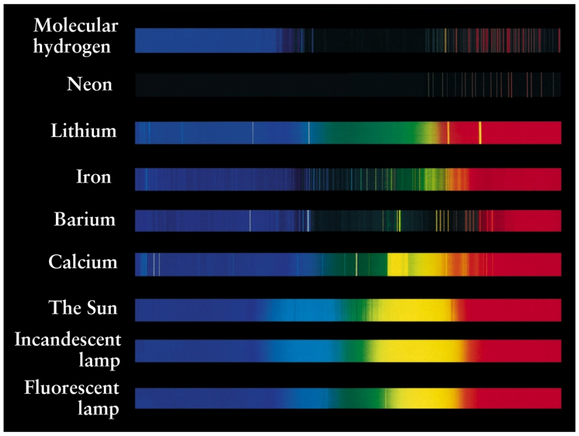
In cool stars, it is neutral and can absorb photons.

H Absorption lines are strongest in the spectra of stars whose atmospheres have temperatures near 10,000 K.

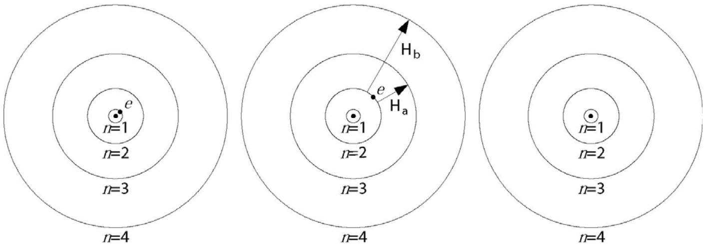
We need only to observe which patterns are present in the spectrum of the star to learn its temperature.



Spectra of Different Elements



Temperature Effects



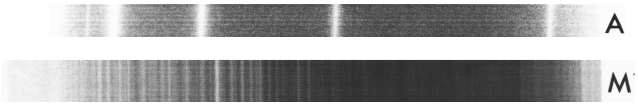
Cool gas; electrons in ground state; no lines.

Hot gas; electrons have been ionized; no lines.

Warm gas, electrons in various energy levels; many lines.

Hydrogen Line Strength Order

A B C D E F G H I J K L M N O P Q R S T



Note: Back when photographic plates were used (prior to digital cameras), the developed plate was a negative. Although the lines are bright, these are absorption-line spectra. Astronomers did not print a “positive” picture because that would have introduced noise.

Henry Draper Classification

In 1909, **Annie Jump Cannon** rearranged and consolidated the sequence of spectra and added decimal subdivisions.

A0, A1, A2, …, A8, A9

With these changes, the Harvard classification scheme became a **temperature** sequence.

Temperature Order

A B C D E F G H I J K L M N O P Q R S T

O B A F G K M

OBAFGKM

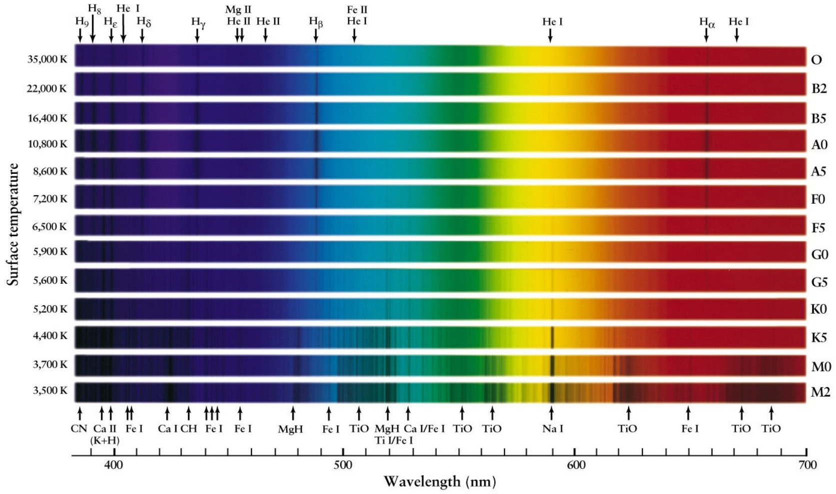
Oh Be A Fine Girl/Guy Kiss Me

Oh Big And Fierce Gorilla Kill Me

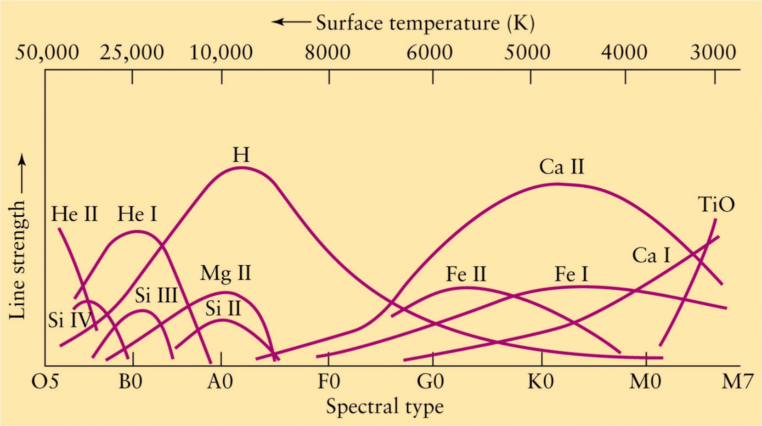
Often Buzz Attacks Ferociously Georgia’s K-9 Mascot

Occasionally Barney And Fred Go Kill Mastodons

Spectroscopy



Ionization via Temperature



Spectral Sequence

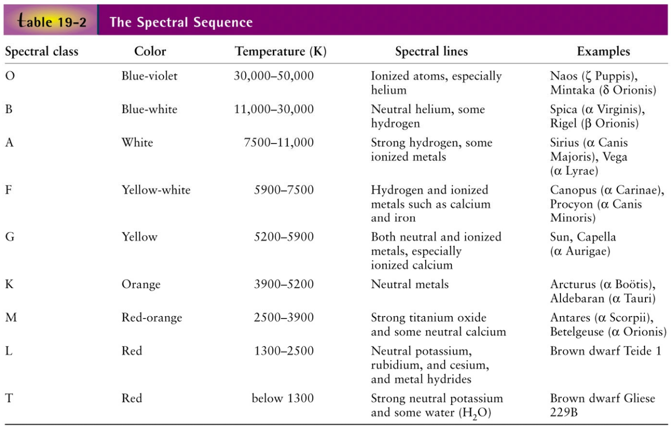
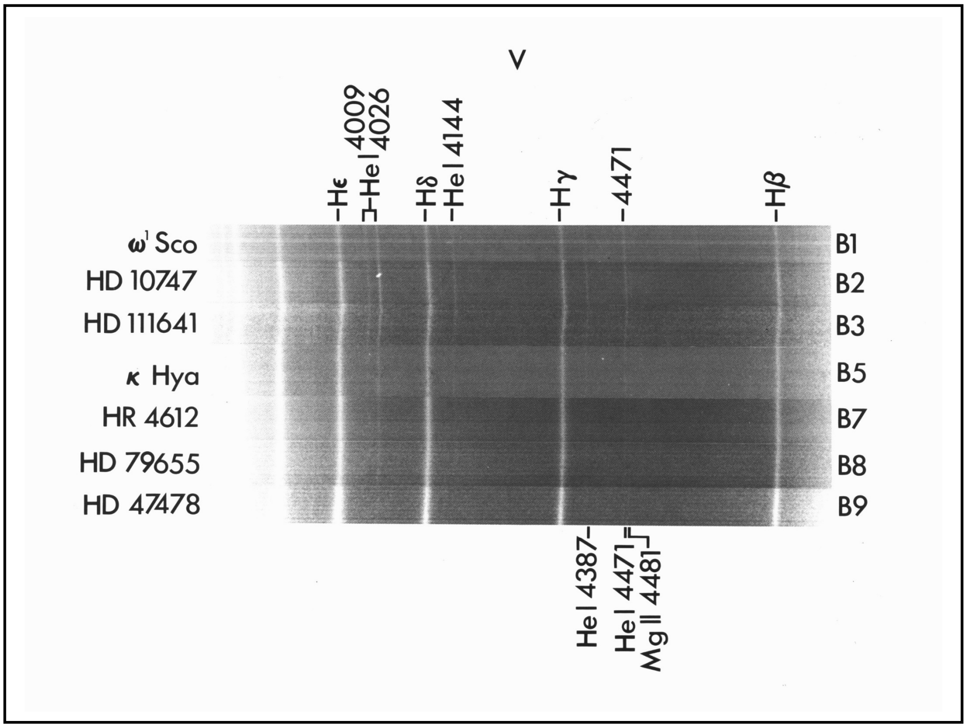
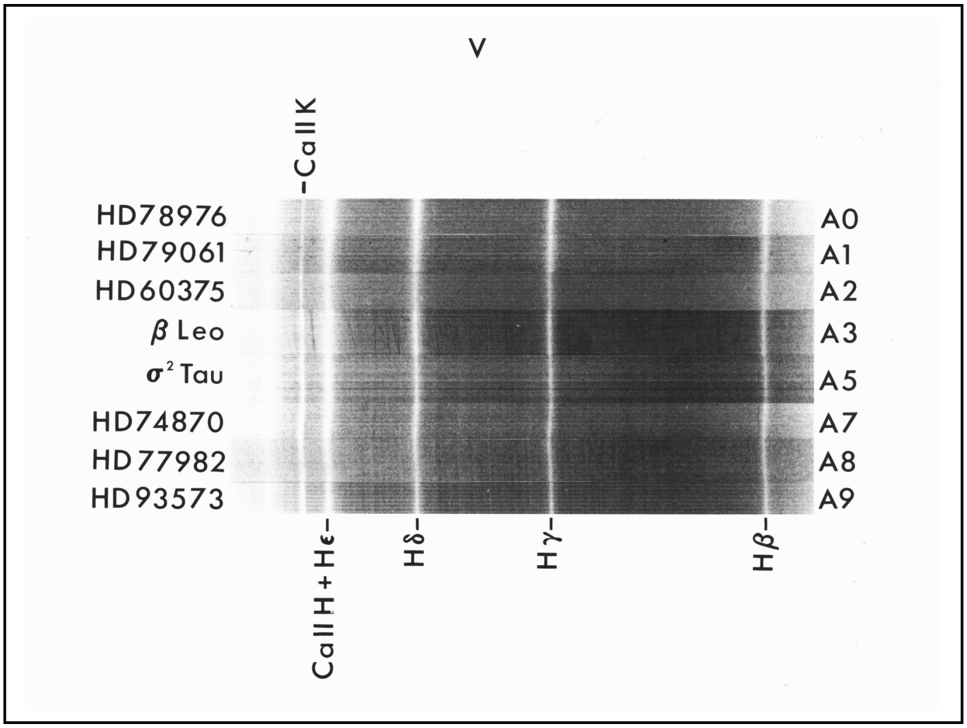
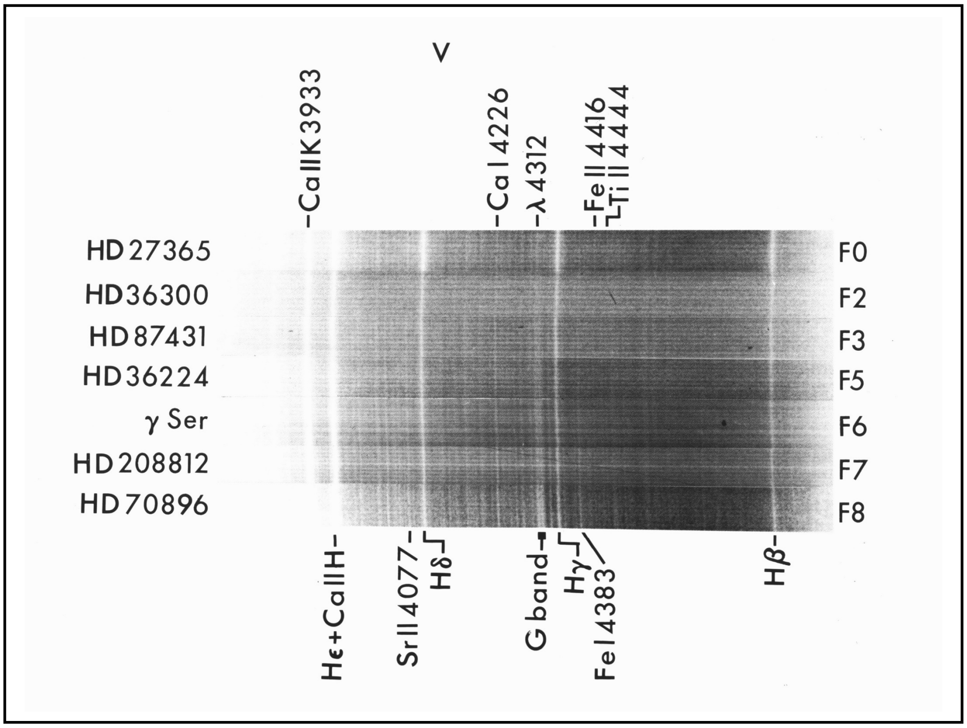


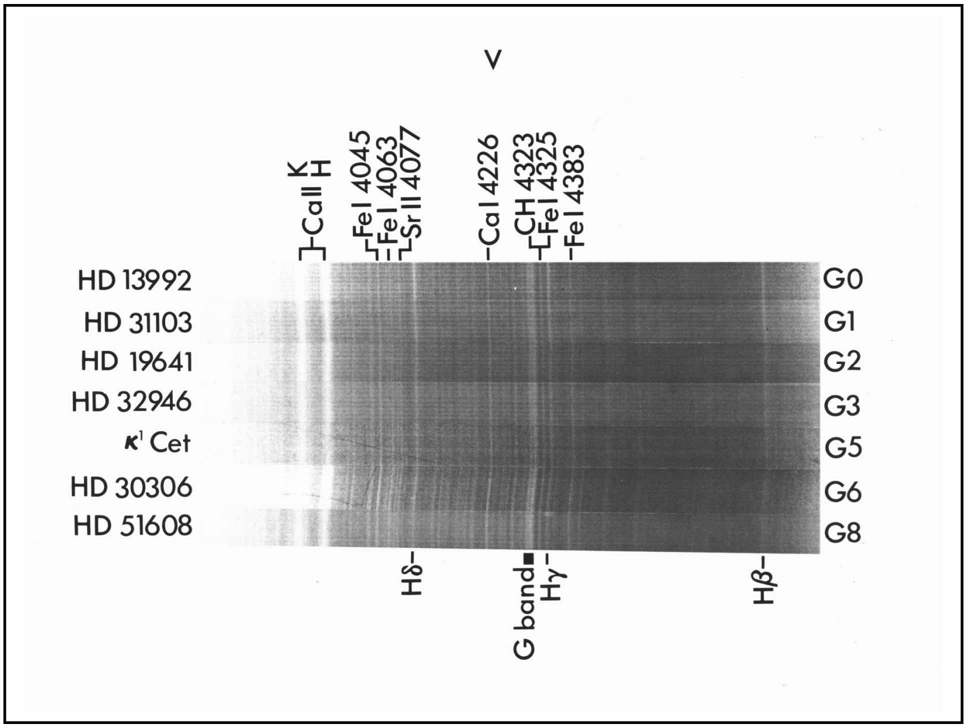
table 19-2 The Spectral Sequence

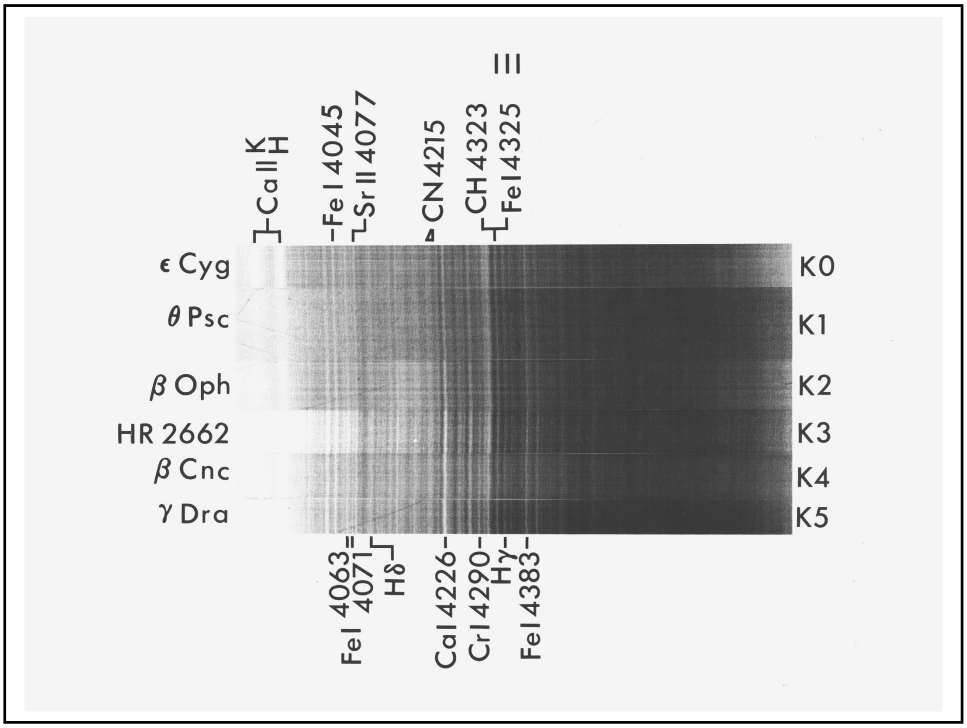
Spectral class	Color	Temperature (K)	Spectral lines	Examples
O	Blue-violet	30,000–50,000	Ionized atoms, especially helium	Naos (ζ Puppis), Mintaka (δ Orionis)
B	Blue-white	11,000–30,000	Neutral helium, some hydrogen	Spica (α Virginis), Rigel (β Orionis)
A	White	7500–11,000	Strong hydrogen, some ionized metals	Sirius (α Canis Majoris), Vega (α Lyrae)
F	Yellow-white	5900–7500	Hydrogen and ionized metals such as calcium and iron	Canopus (α Carinae), Procyon (α Canis Minoris)
G	Yellow	5200–5900	Both neutral and ionized metals, especially ionized calcium	Sun, Capella (α Aurigae)
K	Orange	3900–5200	Neutral metals	Arcturus (α Boötis), Aldebaran (α Tauri)
M	Red-orange	2500–3900	Strong titanium oxide and some neutral calcium	Antares (α Scorpii), Betelgeuse (α Orionis)
L	Red	1300–2500	Neutral potassium, rubidium, and cesium, and metal hydrides	Brown dwarf Teide 1
T	Red	below 1300	Strong neutral potassium and some water (H_2O)	Brown dwarf Gliese 229B

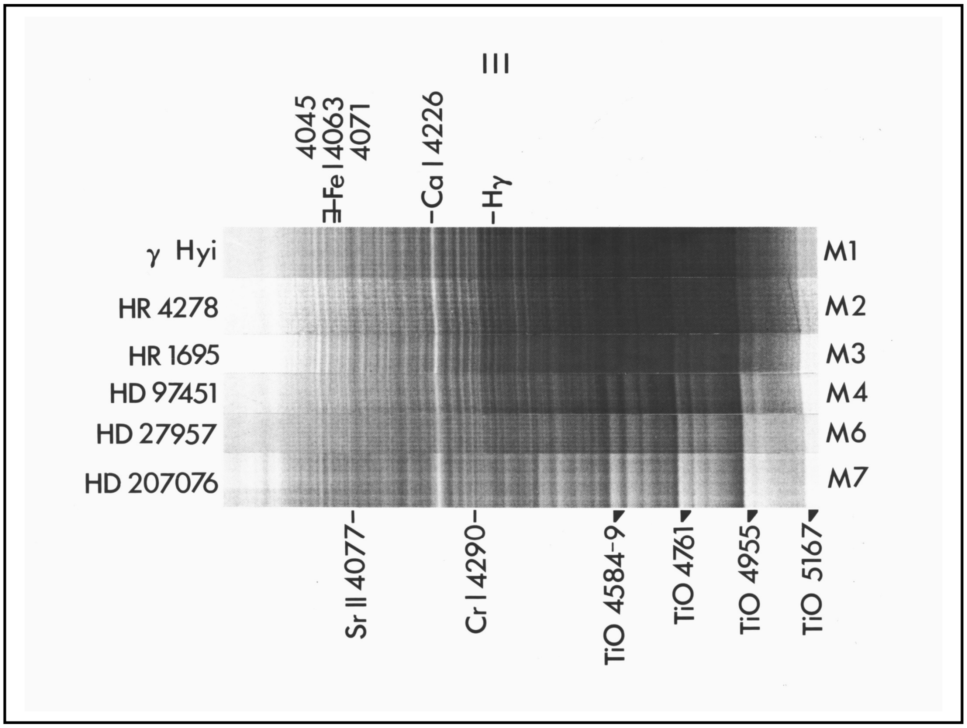

V
Hϵ
He I 4009
He I 4026
Hδ
He I 4144
Hγ
4471
Hβ
ω¹ Sco
HD 10747
HD 111641
κ Hya
HR 4612
HD 79655
HD 47478
B1
B2
B3
B5
B7
B8
B9
He I 4387
He I 4471
Mg II 4481

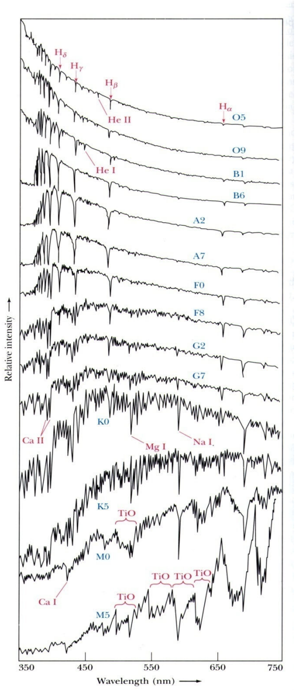

V
Ca II K
HD78976
HD79061
HD60375
β Leo
σ² Tau
HD74870
HD77982
HD93573
A0
A1
A2
A3
A5
A7
A8
A9
Ca II H + Hϵ
Hδ
Hγ
Hβ


V
Ca II K 3933
Ca I 4226
λ 4312
Fe II 4416
Ti II 4444
HD 27365
HD 36300
HD 87431
HD 36224
γ Ser
HD 208812
HD 70896
F0
F2
F3
F5
F6
F7
F8
Hε+Ca II H
Sr II 4077
Hδ
G band
Hγ
Fe I 4383
Hβ


V
Ca II K
H
Fe I 4045
Fe I 4063
Sr II 4077
Ca I 4226
CH 4323
Fe I 4325
Fe I 4383
HD 13992
HD 31103
HD 19641
HD 32946
κ¹ Cet
HD 30306
HD 51608
G0
G1
G2
G3
G5
G6
G8
Hδ
G band
Hγ
Hβ


III
Ca II K
H
Fe I 4045
Sr II 4077
CN 4215
CH 4323
Fe I 4325
ε Cyg
θ Psc
β Oph
HR 2662
β Cnc
γ Dra
K0
K1
K2
K3
K4
K5
Fe I 4063
4071
Hδ
Ca I 4226
Cr I 4290
Hγ
Fe I 4383


III
4045
Fe I 4063
4071
Ca I 4226
Hγ
γ Hyi
HR 4278
HR 1695
HD 97451
HD 27957
HD 207076
M1
M2
M3
M4
M6
M7
Sr II 4077
Cr I 4290
TiO 4584-9
TiO 4761
TiO 4955
TiO 5167



Spectral Sequence

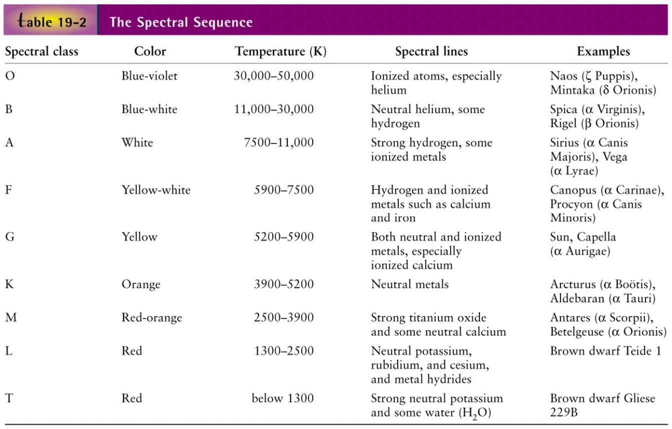


Table 19-2 The Spectral Sequence

Spectral class	Color	Temperature (K)	Spectral lines	Examples
O	Blue-violet	30,000–50,000	Ionized atoms, especially helium	Naos (ζ Puppis), Mintaka (δ Orionis)
B	Blue-white	11,000–30,000	Neutral helium, some hydrogen	Spica (α Virginis), Rigel (β Orionis)
A	White	7500–11,000	Strong hydrogen, some ionized metals	Sirius (α Canis Majoris), Vega (α Lyrae)
F	Yellow-white	5900–7500	Hydrogen and ionized metals such as calcium and iron	Canopus (α Carinae), Procyon (α Canis Minoris)
G	Yellow	5200–5900	Both neutral and ionized metals, especially ionized calcium	Sun, Capella (α Aurigae)
K	Orange	3900–5200	Neutral metals	Arcturus (α Boötis), Aldebaran (α Tauri)
M	Red-orange	2500–3900	Strong titanium oxide and some neutral calcium	Antares (α Scorpii), Betelgeuse (α Orionis)
L	Red	1300–2500	Neutral potassium, rubidium, and cesium, and metal hydrides	Brown dwarf Teide 1
T	Red	below 1300	Strong neutral potassium and some water (H_2O)	Brown dwarf Gliese 229B

Diameters of Stars

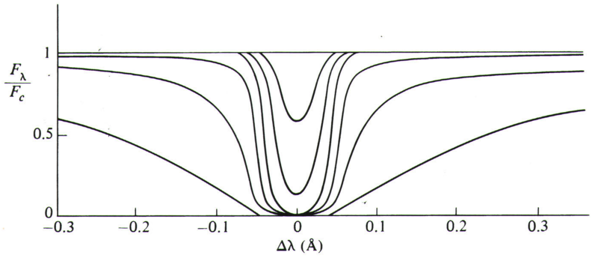
$$L = 4 \pi R^2 \sigma T^4$$

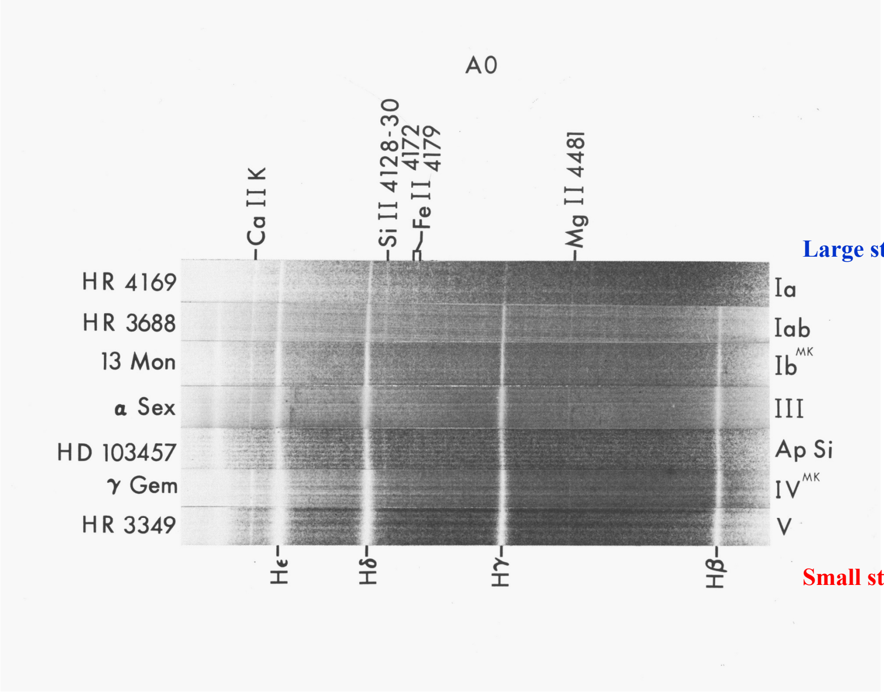
$$L \propto R^2 T^4$$

How do the spectra look different if you have two stars of the same Temperature but with different Radii?

Calculating Line Profiles

The simplest model used for calculating a line profile assumes that the star's photosphere acts as a source of blackbody radiation, and that the atoms above the photosphere remove photons from this continuous spectrum to form absorption lines. Values for the temperature, density, and composition must be adopted for the region above the photosphere where the line is formed. The **density** determines the broadening.

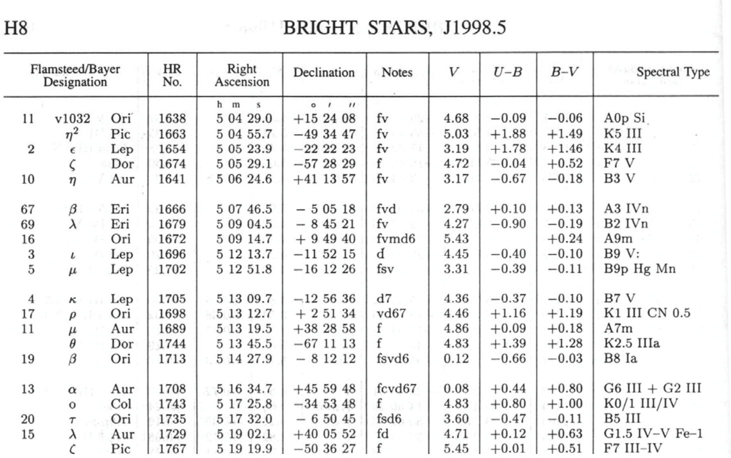




Large stars

Small stars

Table of Colors



H8 BRIGHT STARS, J1998.5

Flamsteed/Bayer Designation			HR No.	Right Ascension	Declination	Notes	V	U–B	B–V	Spectral Type
				h m s	° ′ ″					
11	v1032	Ori	1638	5 04 29.0	+15 24 08	fv	4.68	−0.09	−0.06	A0p Si
	η^2	Pic	1663	5 04 55.7	−49 34 47	fv	5.03	+1.88	+1.49	K5 III
2	ϵ	Lep	1654	5 05 23.9	−22 22 23	fv	3.19	+1.78	+1.46	K4 III
	ζ	Dor	1674	5 05 29.1	−57 28 29	f	4.72	−0.04	+0.52	F7 V
10	η	Aur	1641	5 06 24.6	+41 13 57	fv	3.17	−0.67	−0.18	B3 V
67	β	Eri	1666	5 07 46.5	− 5 05 18	fvd	2.79	+0.10	+0.13	A3 IVn
69	λ	Eri	1679	5 09 04.5	− 8 45 21	fv	4.27	−0.90	−0.19	B2 IVn
16		Ori	1672	5 09 14.7	+ 9 49 40	fvmd6	5.43		+0.24	A9m
3	ι	Lep	1696	5 12 13.7	−11 52 15	d	4.45	−0.40	−0.10	B9 V:
5	μ	Lep	1702	5 12 51.8	−16 12 26	fsv	3.31	−0.39	−0.11	B9p Hg Mn
4	κ	Lep	1705	5 13 09.7	−12 56 36	d7	4.36	−0.37	−0.10	B7 V
17	ρ	Ori	1698	5 13 12.7	+ 2 51 34	vd67	4.46	+1.16	+1.19	K1 III CN 0.5
11	μ	Aur	1689	5 13 19.5	+38 28 58	f	4.86	+0.09	+0.18	A7m
	θ	Dor	1744	5 13 45.5	−67 11 13	f	4.83	+1.39	+1.28	K2.5 IIIa
19	β	Ori	1713	5 14 27.9	− 8 12 12	fsvd6	0.12	−0.66	−0.03	B8 Ia
13	α	Aur	1708	5 16 34.7	+45 59 48	fcvd67	0.08	+0.44	+0.80	G6 III + G2 III
	o	Col	1743	5 17 25.8	−34 53 48	f	4.83	+0.80	+1.00	K0/1 III/IV
20	τ	Ori	1735	5 17 32.0	− 6 50 45	fsd6	3.60	−0.47	−0.11	B5 III
15	λ	Aur	1729	5 19 02.1	+40 05 52	fd	4.71	+0.12	+0.63	G1.5 IV–V Fe–1
	ζ	Pic	1767	5 19 19.9	−50 36 27	f	5.45	+0.01	+0.51	F7 III–IV

What We Learn Via Spectroscopy

A. Temperature

B. Pressure

C. Radius

D. Luminosity

E. Chemical Composition

F. Radial Velocity

G. Turbulence

H. Magnetic Fields

I. Shells and Ejected Gases