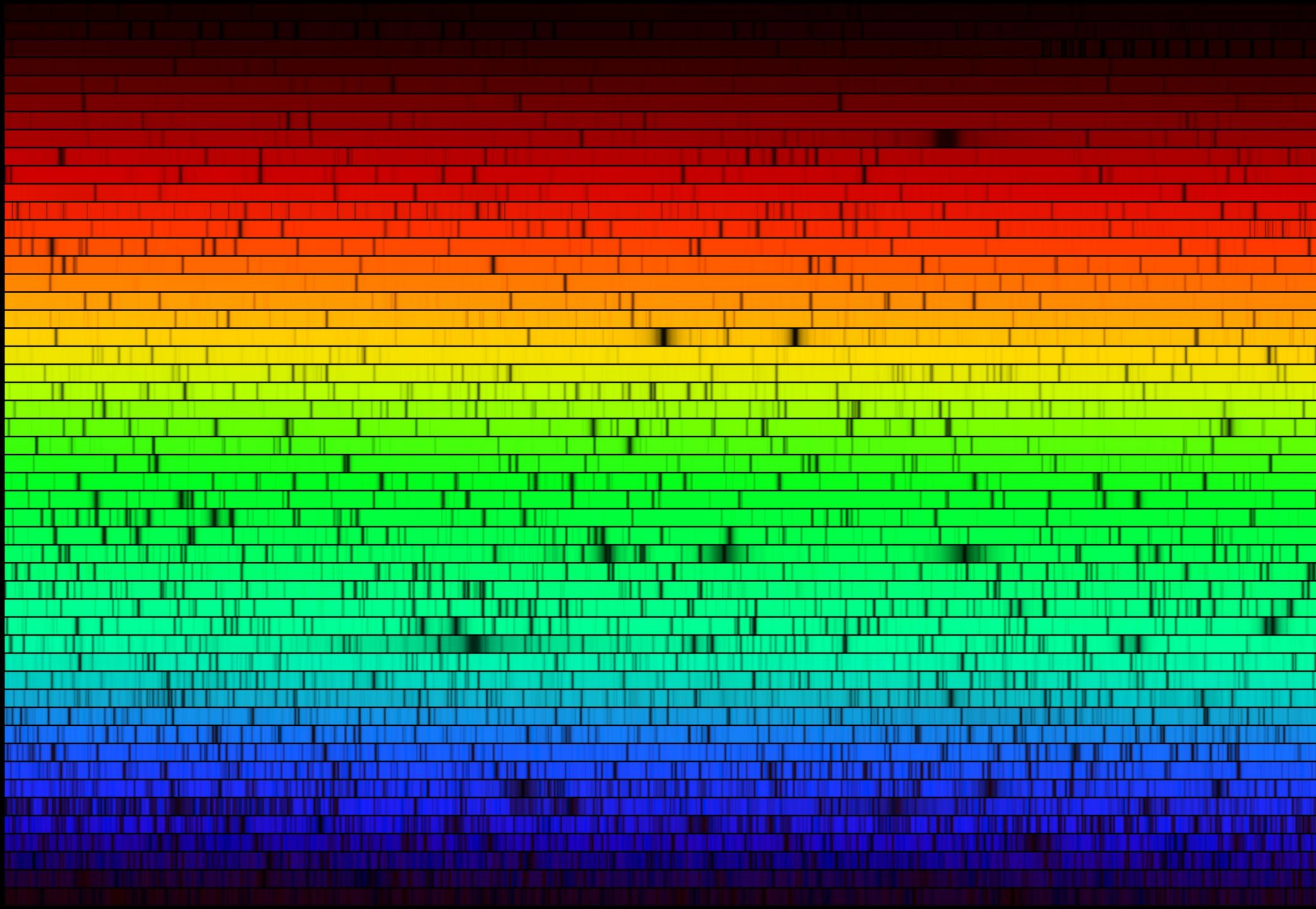
Bölüm 3 – Tayf Sınıfları



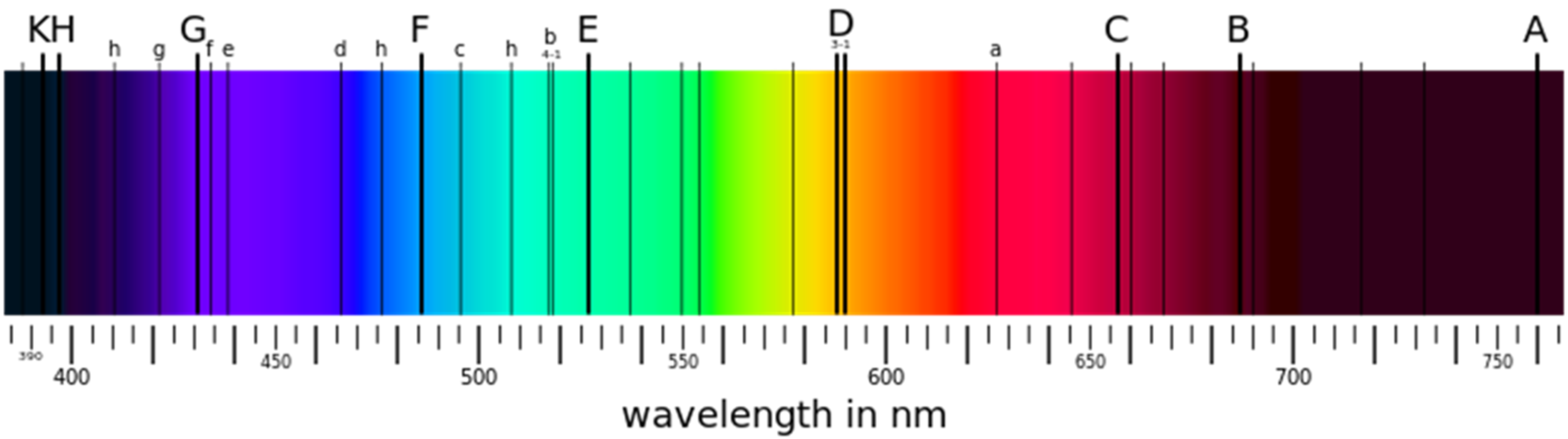
Fraunhofer Tayfı

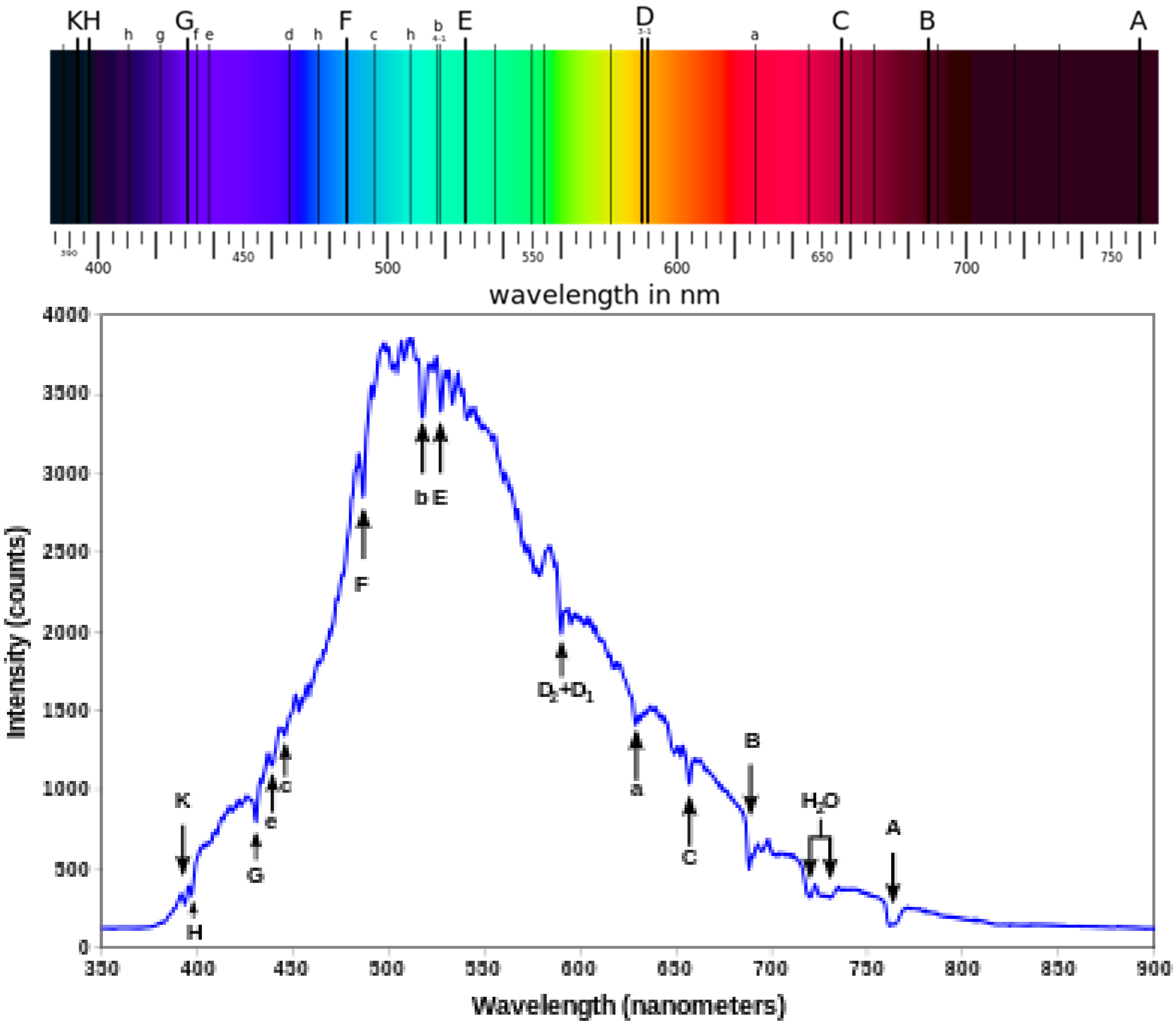
Joseph von Fraunhofer
(1787-1826)

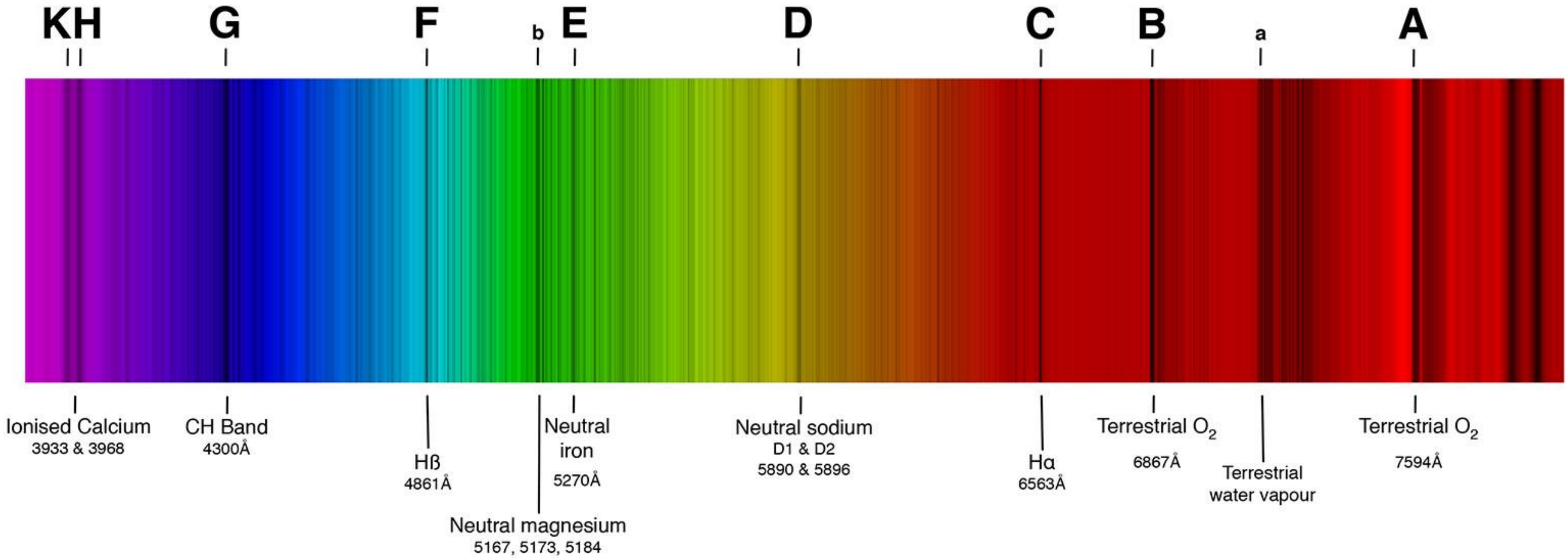
Güneş'in tayfı ilk defa 1800'lü yılların başında Joseph von Fraunhofer tarafından haritalandı.
500'den fazla soğurma çizgisi gözledi. Uzun dalgaboyundan kısaya doğru bunların en baskın olanlarını harfledi.
Bu harflerin kimyasal sembollerle bir alakası yoktu. Bu harflerin çoğu günümüzde bile kullanılmaktadır. Örneğin Ca II H ve K çizgileri gibi.

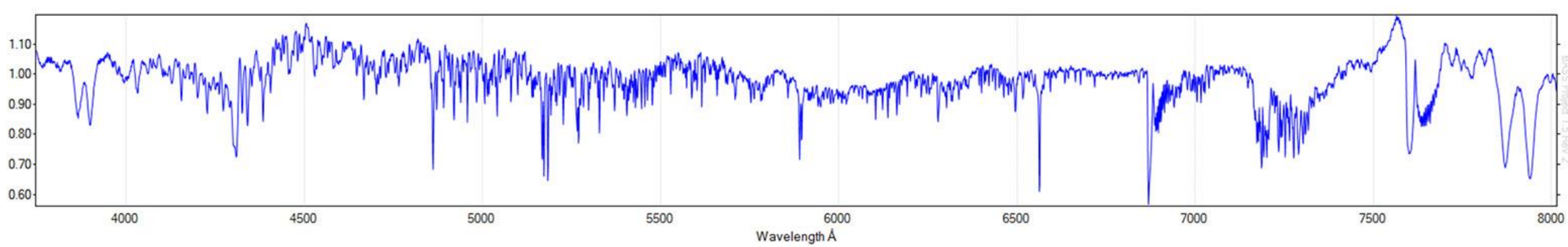
H, K…..Ca II λ3968 ve Ca II λ3934
C, F, h…Hα, Hβ, Hδ hidrojenin Balmer çizgileri

1800'lü yılların ortasında teleskop ve tayfçekerlerin gücü arttı.
1901, Harvard (veya Draper) Sınıflaması.




KH h g G f e d h F c h b E D a C B A
400 450 500 550 600 650 700 750
wavelength in nm
Intensity (counts)
Wavelength (nanometers)
K H G e c F b E D_2+D_1 a C B H_2O A
0 500 1000 1500 2000 2500 3000 3500 4000
350 400 450 500 550 600 650 700 750 800 850 900


K
H
G
F
b
E
D
C
B
a
A
Ionised Calcium
3933 & 3968
CH Band
4300Å
Hß
4861Å
Neutral magnesium
5167, 5173, 5184
Neutral
iron
5270Å
Neutral sodium
D1 & D2
5890 & 5896
Hα
6563Å
Terrestrial O_2
6867Å
Terrestrial
water vapour
Terrestrial O_2
7594Å


1.10
1.00
0.90
0.80
0.70
0.60
4000
4500
5000
5500
6000
6500
7000
7500
8000
Wavelength Å

Name	λ (Å)	Origin
A	7594	terrestrial oxygen (O_2)
a	7165	terrestrial water vapor
B	6867	terrestrial oxygen
C	6563	Hα
D	5890, 5896	neutral sodium (Na I)
E	5270	neutral iron (Fe I)
b	5167, 5173, 5184	neutral magnesium (Mg I)
F	4861	Hβ
d*	4384	neutral iron (Fe I)
G	4300	CH band
g*	4227	neutral calcium (Ca I)
h*	4102	Hδ
H	3968	ionized calcium (Ca II)
K*	3934	ionized calcium (Ca II)

* Not an original Fraunhofer designation: added later.

Father Secchi Sınıflaması

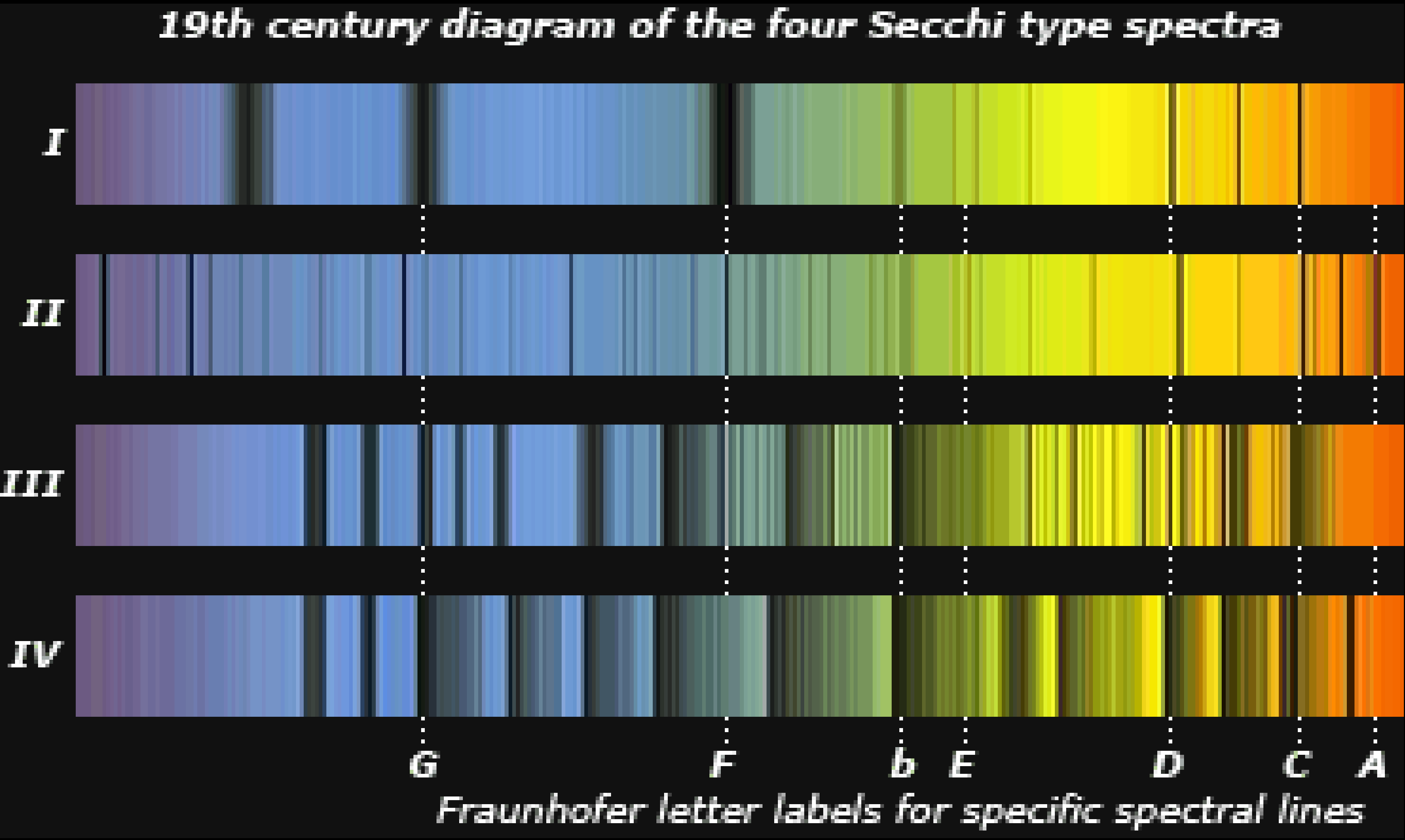
Tür I Kuvvetli hidrojen çizgileri,
mavi-beyaz yıldızlar, Sirius, Vega

Tür II Birçok metal çizgisi (Na, Ca, Fe), zayıf hidrojen,
sarı-turuncu yıldızlar, Güneş, Capella, Arcturus

Tür III Çizgi yerine baskın bantlar ve Tür II'nin metal çizgileri
turucu-kırmızı yıldızlar, Betelgeuse, Antares

Tür IV Uzun dalgaboyuna doğru yoğunlaşan bantlar

Tür V Parlak tayf çizgileri

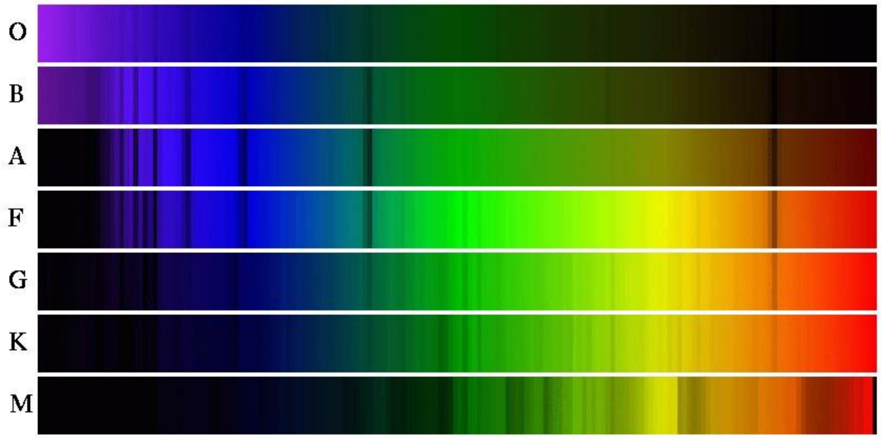


19th century diagram of the four Secchi type spectra
I
II
III
IV
G
F
b
E
D
C
A
Fraunhofer letter labels for specific spectral lines

Harvard Sistemi

Yıldızlara ait soğurma çizgilerini fotoğraflayan ilk kişi Henry Draper.
Harvard'da yapılan tüm tayf katalogları Harvard Annals'da yayımlandı.
Yıldızlara HD numaraları verildi.
İlk kataloglarda A'dan Q'ya kadar harfler verildi. (1890)

"Harvard Computers"

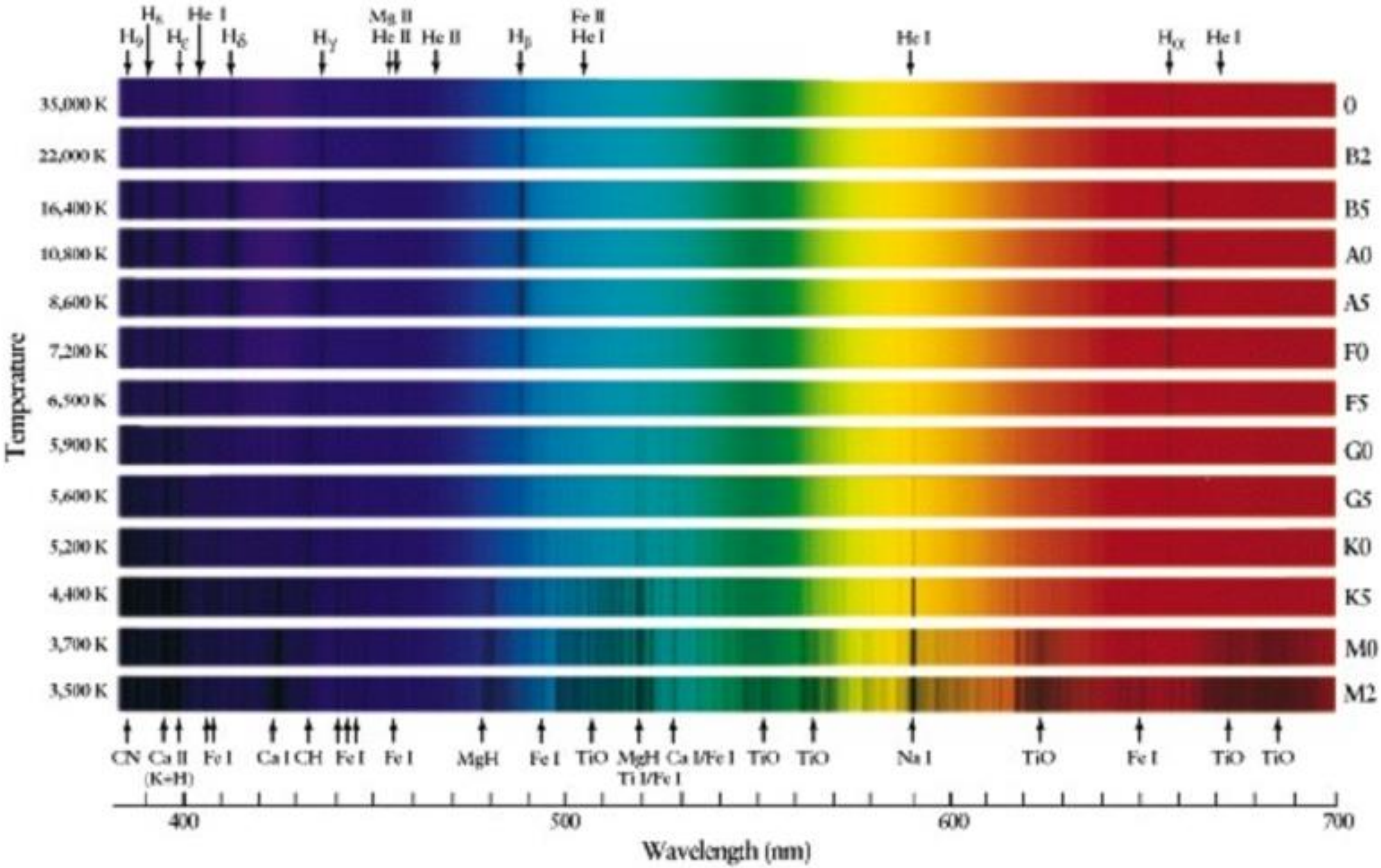


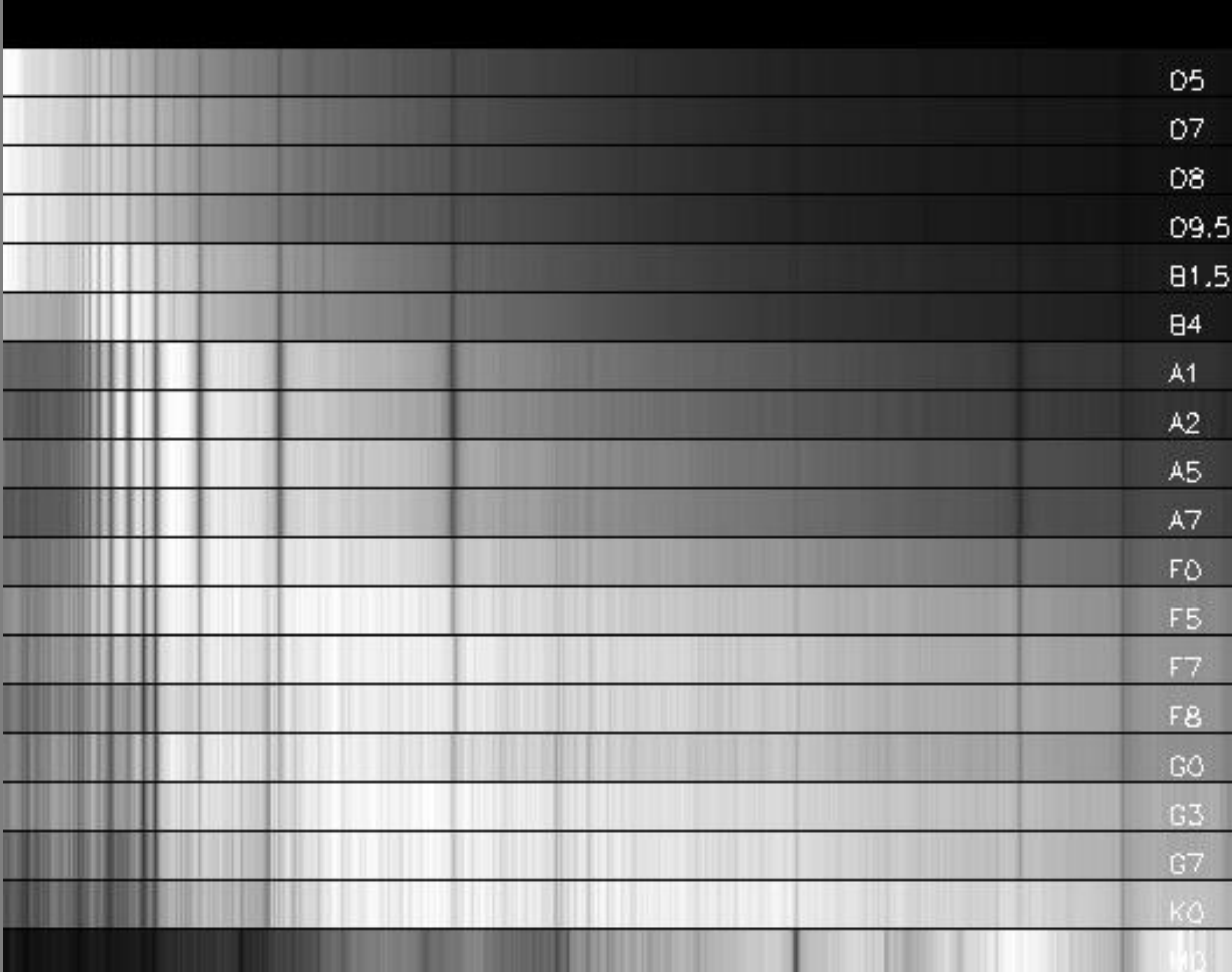
Class	Temperature	Apparent color	Hydrogen lines	Other noted spectral features
O	≥ 30,000 K	blue	Weak	ionized helium lines
B	10,000–30,000 K	blue white	Medium	neutral helium
A	7,500–10,000 K	white to blue white	Strong	ionized calcium (weak)
F	6,000–7,500 K	white	Medium	ionized calcium (weak)
G	5,200–6,000 K	yellowish white	Weak	ionized calcium (medium)
K	3,700–5,200 K	yellow orange	Very weak	ionized calcium (strong)
M	≤ 3,700 K	orange red	Very weak	Titanium oxide lines

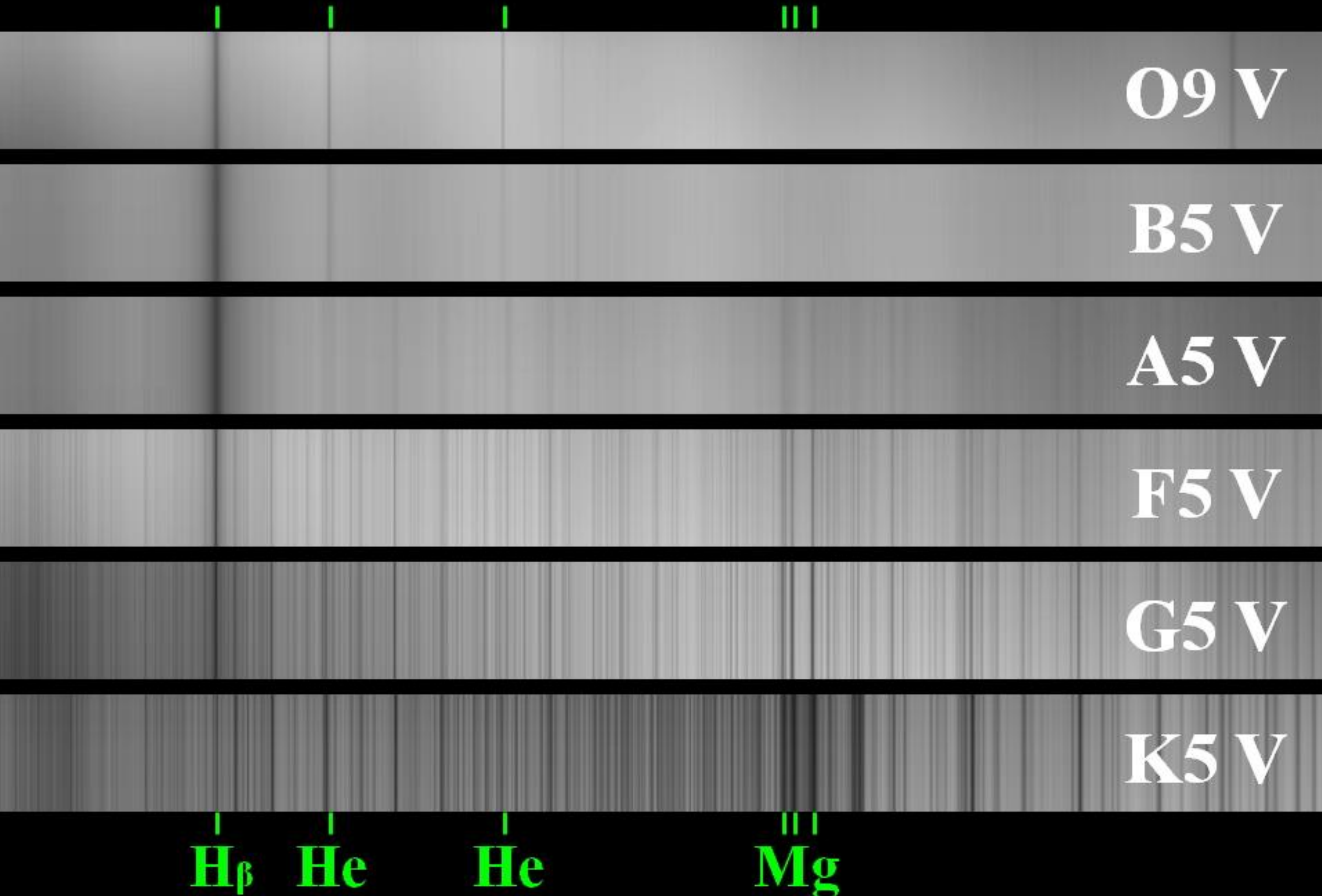
TABLE 17.3 Stellar Luminosity Classes

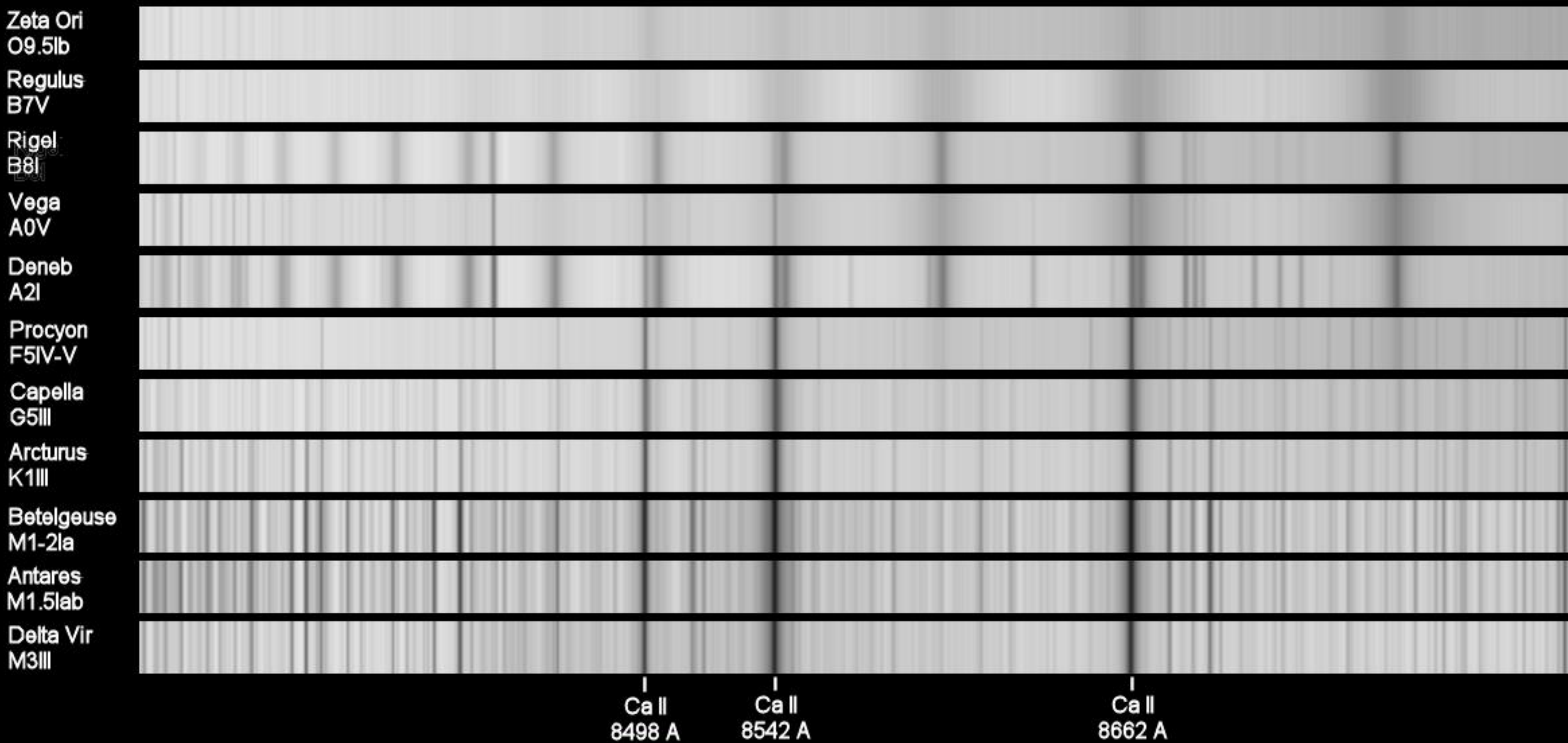
Class	Description
Ia	Bright supergiants
Ib	Supergiants
II	Bright giants
III	Giants
IV	Subgiants
V	Main-sequence stars and dwarfs

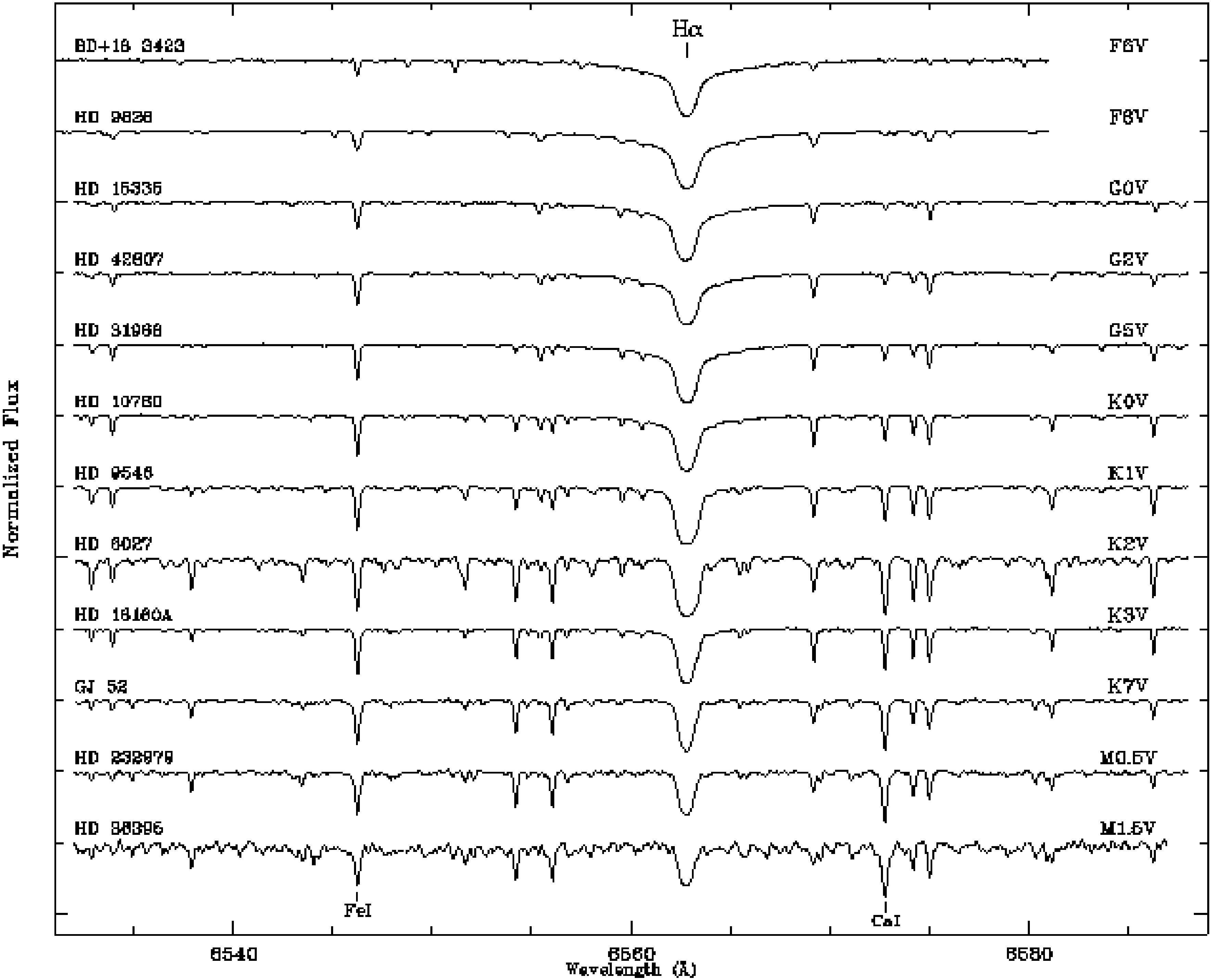
Spectral Classification of Stars



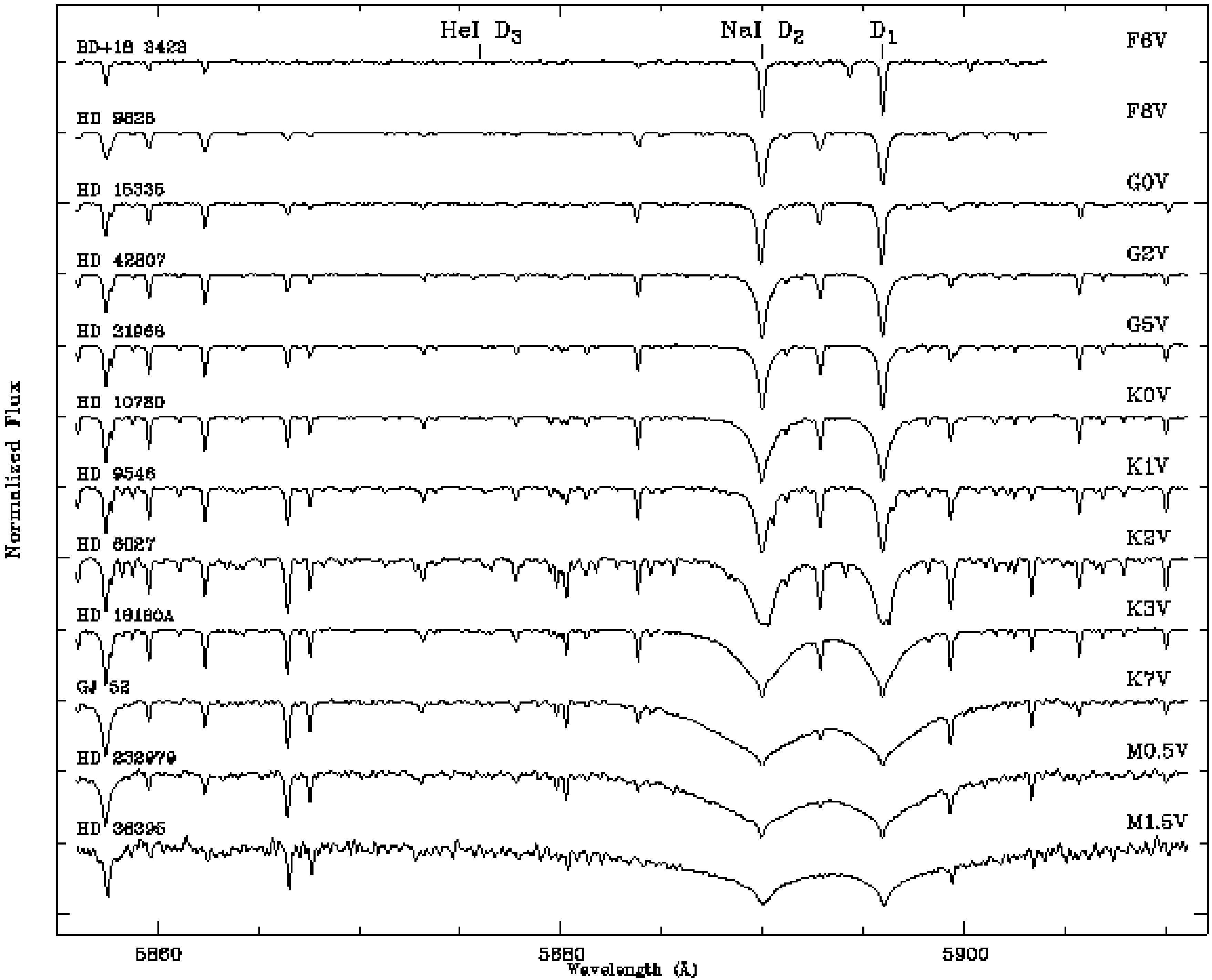

O5
O7
O8
O9.5
B1.5
B4
A1
A2
A5
A7
F0
F5
F7
F8
G0
G3
G7
K0


O9 V
B5 V
A5 V
F5 V
G5 V
K5 V
Hβ
He
He
Mg

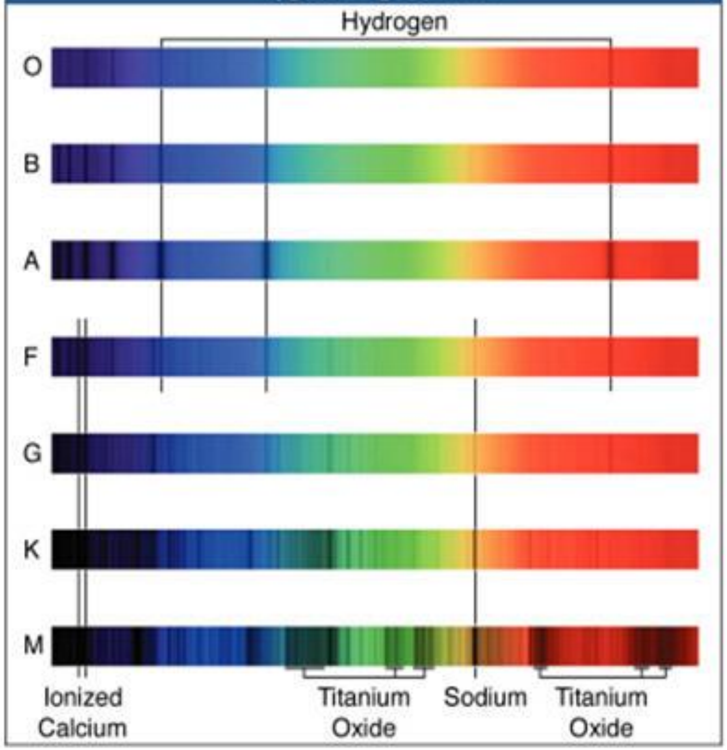

Zeta Ori
O9.5Ib
Regulus
B7V
Rigel
B8I
Vega
A0V
Deneb
A2I
Procyon
F5IV-V
Capella
G5III
Arcturus
K1III
Betelgeuse
M1-2Ia
Antares
M1.5Iab
Delta Vir
M3III
Ca II
8498 A
Ca II
8542 A
Ca II
8662 A



Hα
BD+18 3423
F8V
HD 9826
F8V
HD 15335
G0V
HD 42807
G2V
HD 31966
G5V
HD 10780
K0V
HD 9540
K1V
HD 6027
K2V
HD 16160A
K3V
GJ 52
K7V
HD 232979
M0.5V
HD 36395
M1.5V
FeI
CaI
Normalized Flux
6540
6560
6580
Wavelength (Å)


HeI D3
NaI D2
D1
BD+18 3423
F6V
HD 9826
F8V
HD 15335
G0V
HD 42807
G2V
HD 31966
G5V
HD 10780
K0V
HD 9546
K1V
HD 6027
K2V
HD 19180A
K3V
GJ 52
K7V
HD 232979
M0.5V
HD 36395
M1.5V
Normalized Flux
5860
5880
5900
Wavelength (Å)

Typical Spectrum

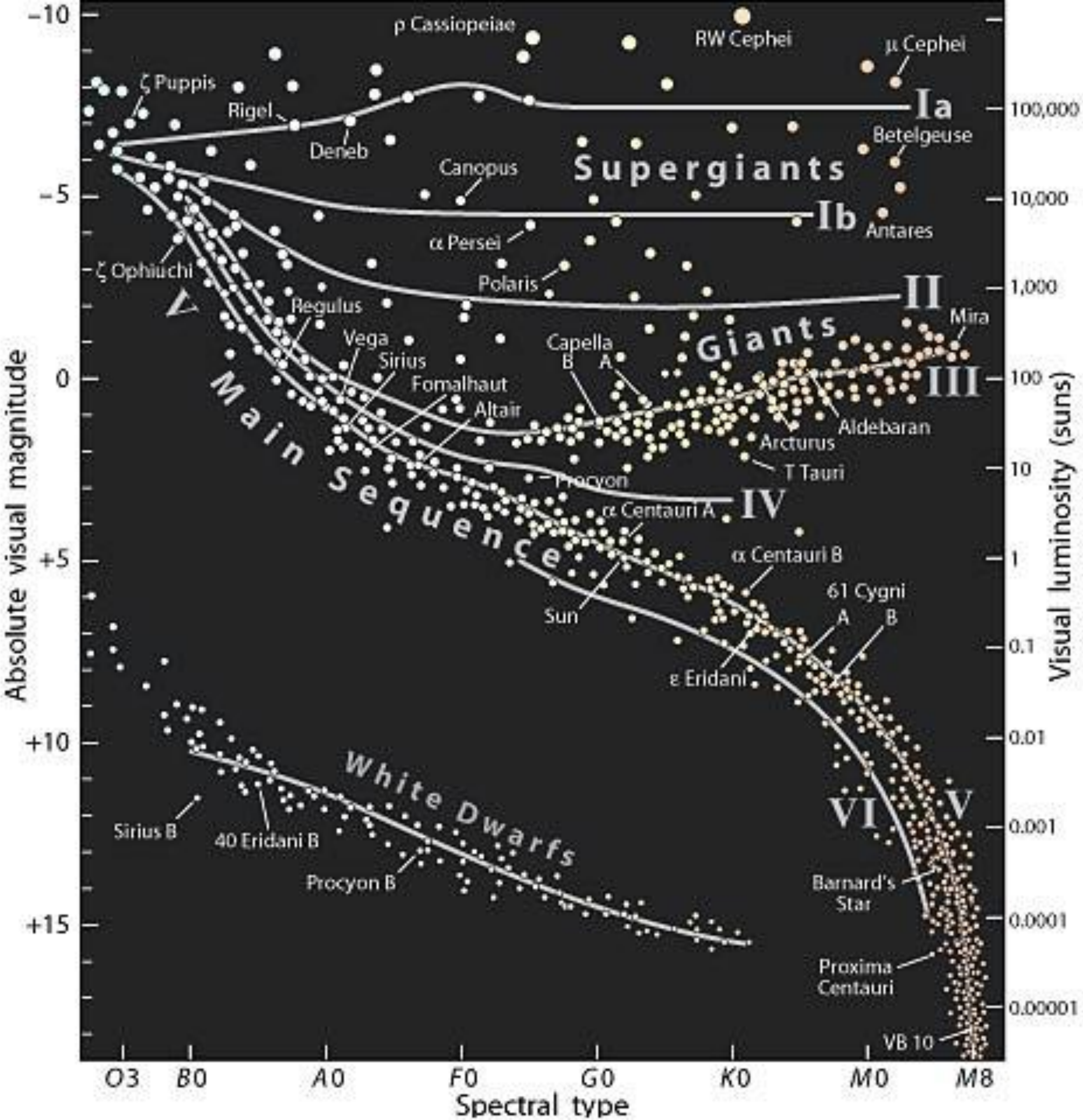


Spectral Type	Example(s)	Temperature Range	Key Absorption Line Features	Brightest Wavelength (color)
O	Stars of Orion's Belt	>30,000	Lines of ionized helium, weak hydrogen lines	<97 nm (ultraviolet)*
B	Rigel	30,000 K–10,000 K	Lines of neutral helium, moderate hydrogen lines	97–290 nm (ultraviolet)*
A	Sirius	10,000 K–7,500 K	Very strong hydrogen lines	290–390 nm (violet)*
F	Polaris	7,500 K–6,000 K	Moderate hydrogen lines, moderate lines of ionized calcium	390–480 nm (blue)*
G	Sun, Alpha Centauri A	6,000 K–5,000 K	Weak hydrogen lines, strong lines of ionized calcium	480–580 nm (yellow)
K	Arcturus	5,000 K–3,500 K	Lines of neutral and singly ionized metals, some molecules	580–830 nm (red)
M	Betelgeuse, Proxima Centauri	<3,500 K	Molecular lines strong	>830 nm (infrared)

*** All stars above 6,000 K look more or less white to the human eye because they emit plenty of radiation at all visible wavelengths.**

TABLE 17.2 Stellar Spectral Classes

Spectral Class	Approximate Surface Temperature (K)	Noteworthy Absorption Lines	Familiar Examples
O	30,000	Ionized helium strong; multiply ionized heavy elements; hydrogen faint	Mintaka (O9)
B	20,000	Neutral helium moderate; singly ionized heavy elements; hydrogen moderate	Rigel (B8)
A	10,000	Neutral helium very faint; singly ionized heavy elements; hydrogen strong	Vega (A0), Sirius (A1)
F	7000	Singly ionized heavy elements; neutral metals; hydrogen moderate	Canopus (F0)
G	6000	Singly ionized heavy elements; neutral metals; hydrogen relatively faint	Sun (G2), Alpha Centauri (G2)
K	4000	Singly ionized heavy elements; neutral metals strong; hydrogen faint	Arcturus (K2), Aldebaran (K5)
M	3000	Neutral atoms strong; molecules moderate; hydrogen very faint	Betelgeuse (M2), Barnard's Star (M5)



ρ Cassiopeiae
RW Cephei
μ Cephei
ζ Puppis
Rigel
Deneb
Canopus
Betelgeuse
Supergiants
Ia
Ib
Antares
α Persei
ζ Ophiuchi
Polaris
II
Regulus
Mira
Giants
Vega
Sirius
Capella
B
A
III
Fomalhaut
Altair
Main Sequence
Aldebaran
Arcturus
T Tauri
Procyon
IV
α Centauri A
α Centauri B
Sun
61 Cygni
A
B
ε Eridani
White Dwarfs
VI
V
Sirius B
40 Eridani B
Procyon B
Barnard's Star
Proxima Centauri
VB 10
Absolute visual magnitude
−10
−5
0
+5
+10
+15
Visual luminosity (suns)
100,000
10,000
1,000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
O3
B0
A0
F0
G0
K0
M0
M8
Spectral type

Table 3.3. *The Harvard classes and their later development*

Type	Characteristic			Main sequence temperatures
O	He II, emission common			28 000–50 000 K
B	He I			9 900–28 000 K
A	H			7 400– 9 900 K
F	metals, H			6 000– 7 400 K
G	Ca II, metals			4 900– 6 000 K
K	Ca II, Ca I, molecules	R (CN, C_2)	} C	3 500– 4 900 K
M	(TiO) S (ZrO)	N (C_2)	} C	2 000– 3 500 K
Increasing carbon →				

Development of class O

Oa, Ob, Oc	→ w →	WC5–WC8	(carbon sequence)
		WN6–WN8	(nitrogen sequence)
Od, Oe	→	Oe	(H emission)
		Of	(He and N III emission)
Oe5	→	O5–O9	

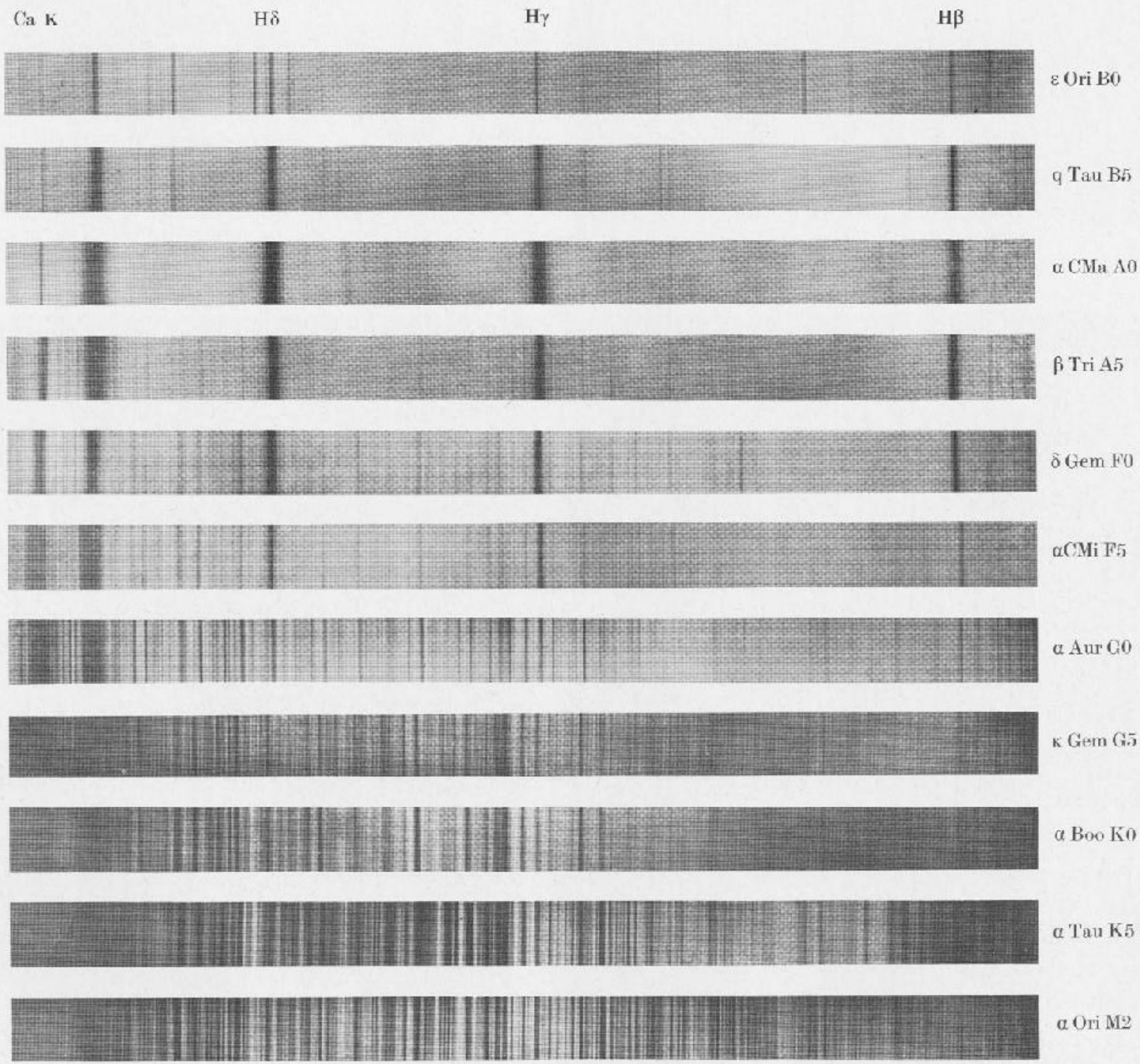
Development of class M

Ma → M0–M2
Mb → M3–M5
Mc → M6–M8
Md → M0e–M8e

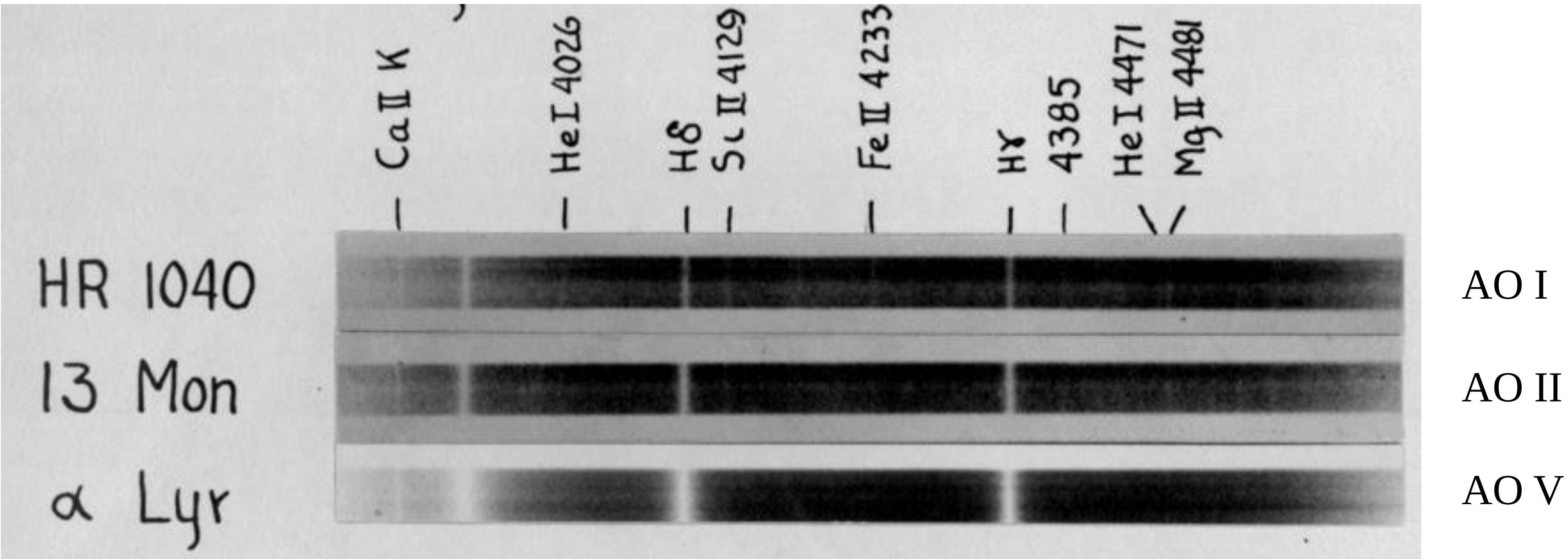
Table 3.4. *Development of carbon star classes*

Harvard	Shane	KM	Equivalent normal star[a]
	R0	C0	G4–G6
R0	R1	C1	G7–G8
	R2	C2	G9–K0
R3	R3	C3	K1–K2
R5	R4		
	R5	C4	K3–K4
	R6		
	R7		
R8	R8	C5	K5–M0
	R9		
	N0	C6	M1–M2
	N1		
Na	N2	C7	M3–M4
Nb	N3		
	N4	C8	
	N5		
Nc	N6		
	N7	C9	

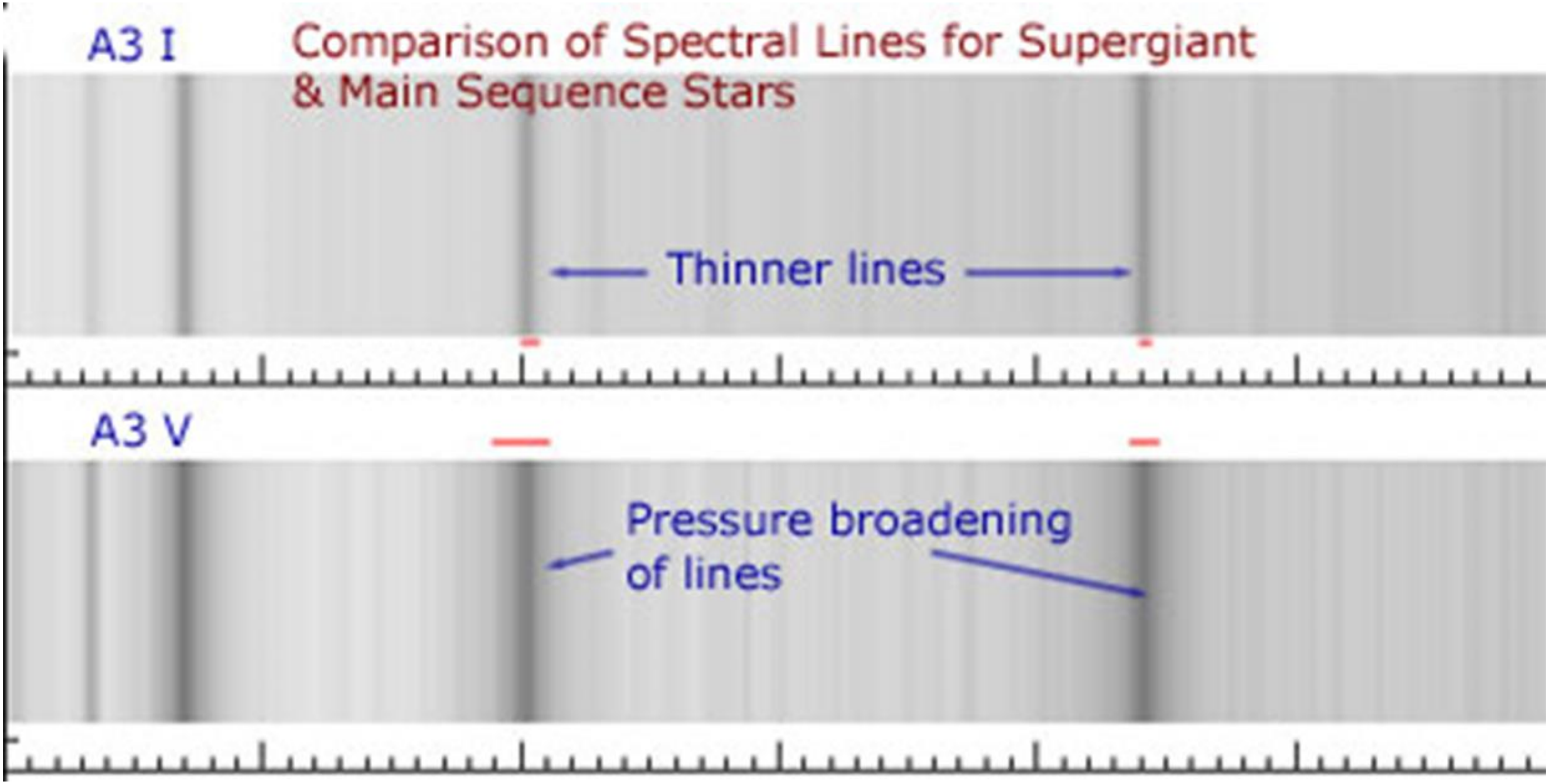
[a] Original equivalents published by Keenan and Morgan. They are only approximate, and for the later classes very much so. There is good evidence that the N stars correspond to M classes later than given here. The C-type responds to both carbon abundance and temperature and consequently there is a large and essentially unknown temperature range for each carbon subclass.


Ca K
Hδ
Hγ
Hβ
ε Ori B0
q Tau B5
α CMa A0
β Tri A5
δ Gem F0
αCMi F5
α Aur G0
κ Gem G5
α Boo K0
α Tau K5
α Ori M2

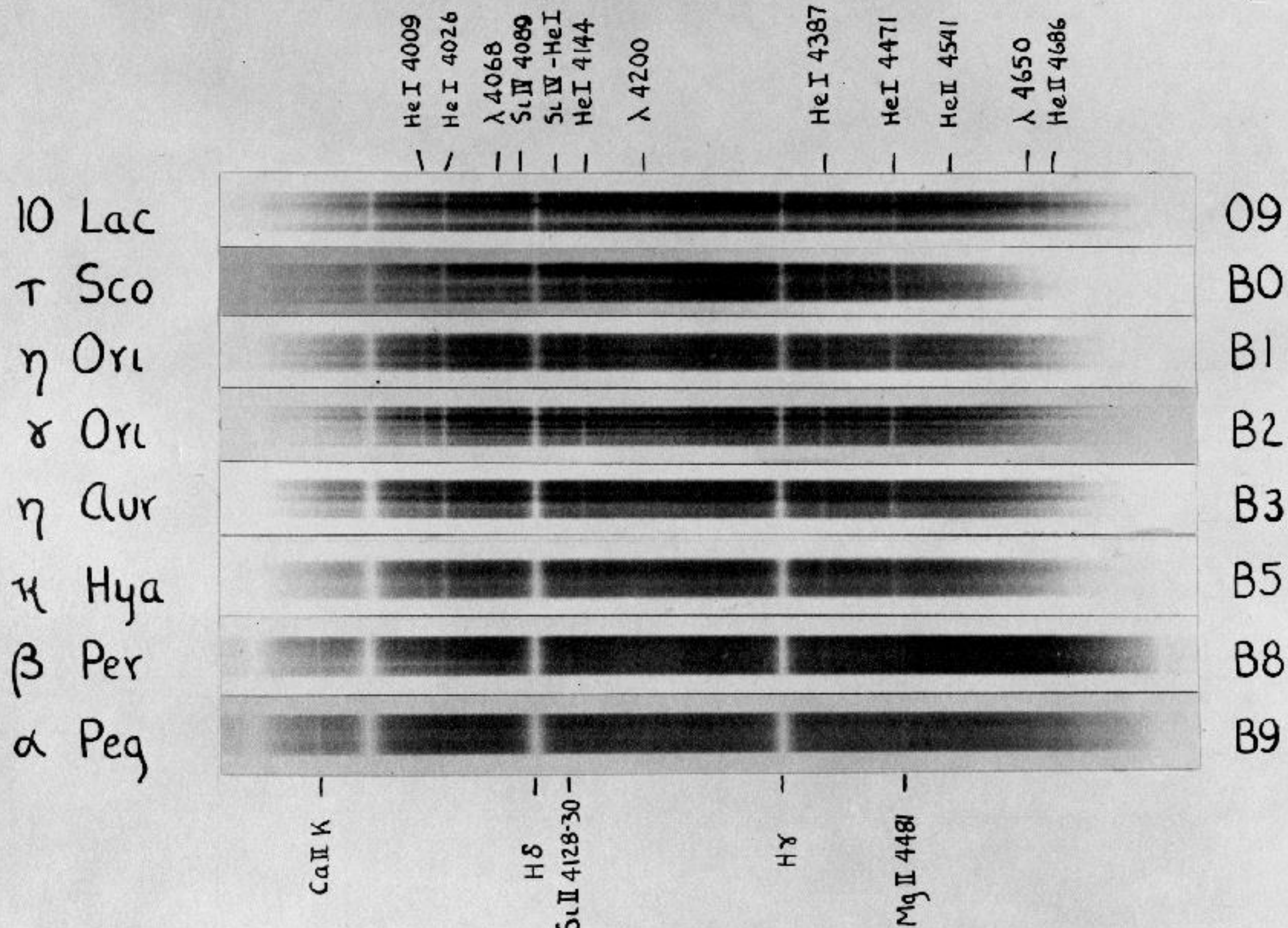
Işıtma sınıflamasına örnek



Yüksek ışıtma sınıflarına doğru gittikçe hidrojen çizgileri düşük atmosfer basıncından dolayı daha dar.

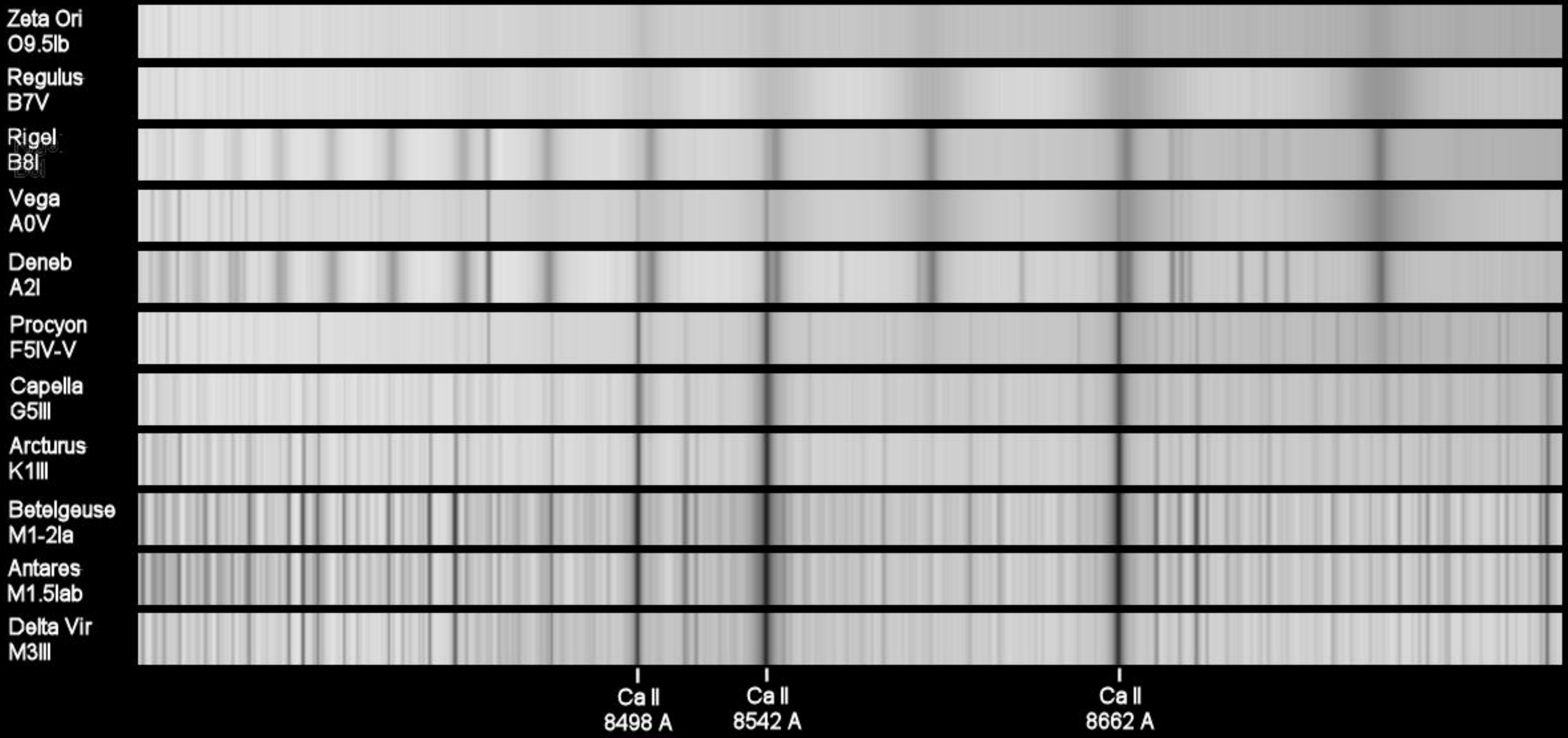

A3 I
Comparison of Spectral Lines for Supergiant & Main Sequence Stars
Thinner lines
A3 V
Pressure broadening of lines

Main Sequence O9-B9

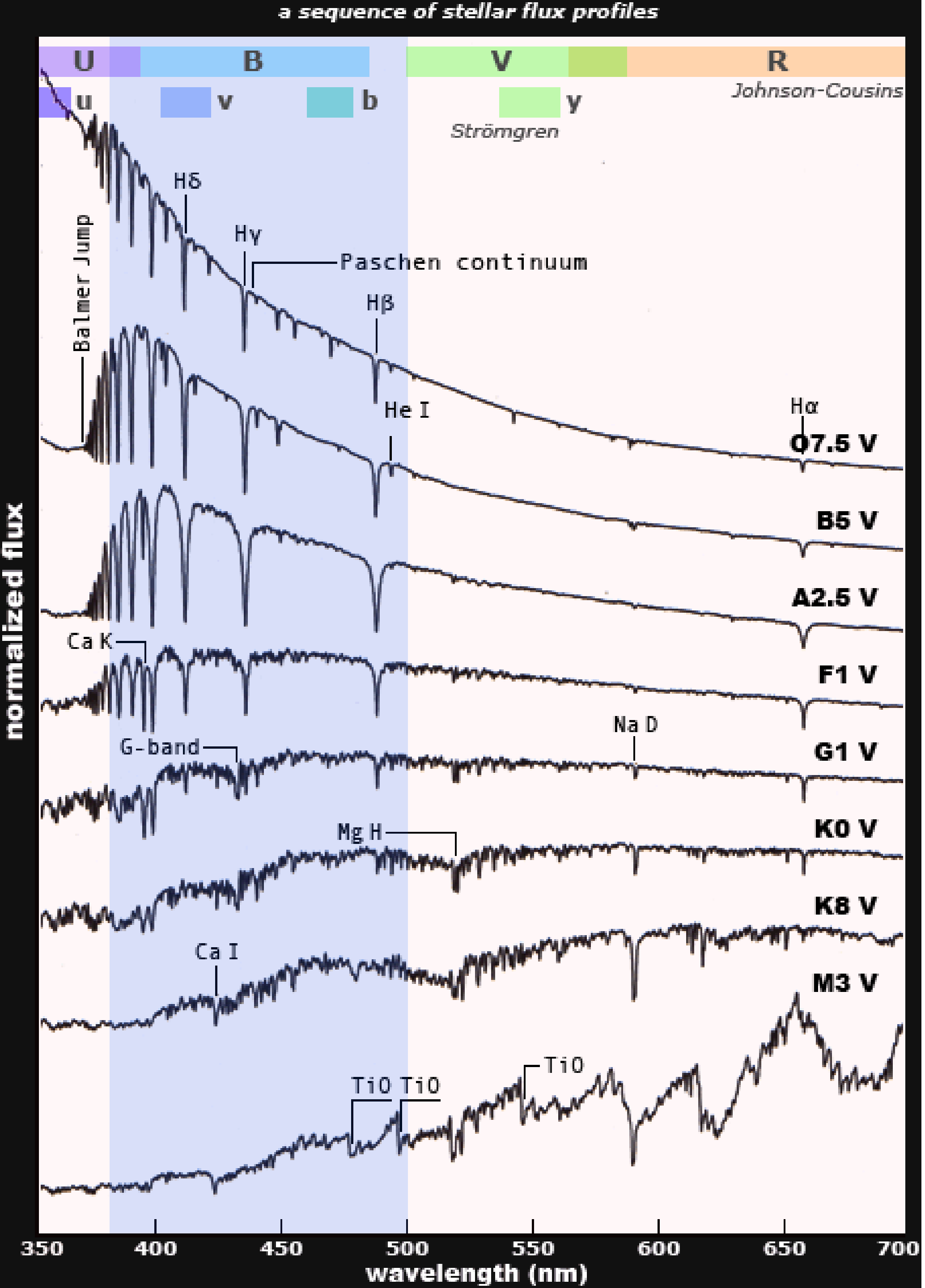


All of the above stars are of luminosity class V

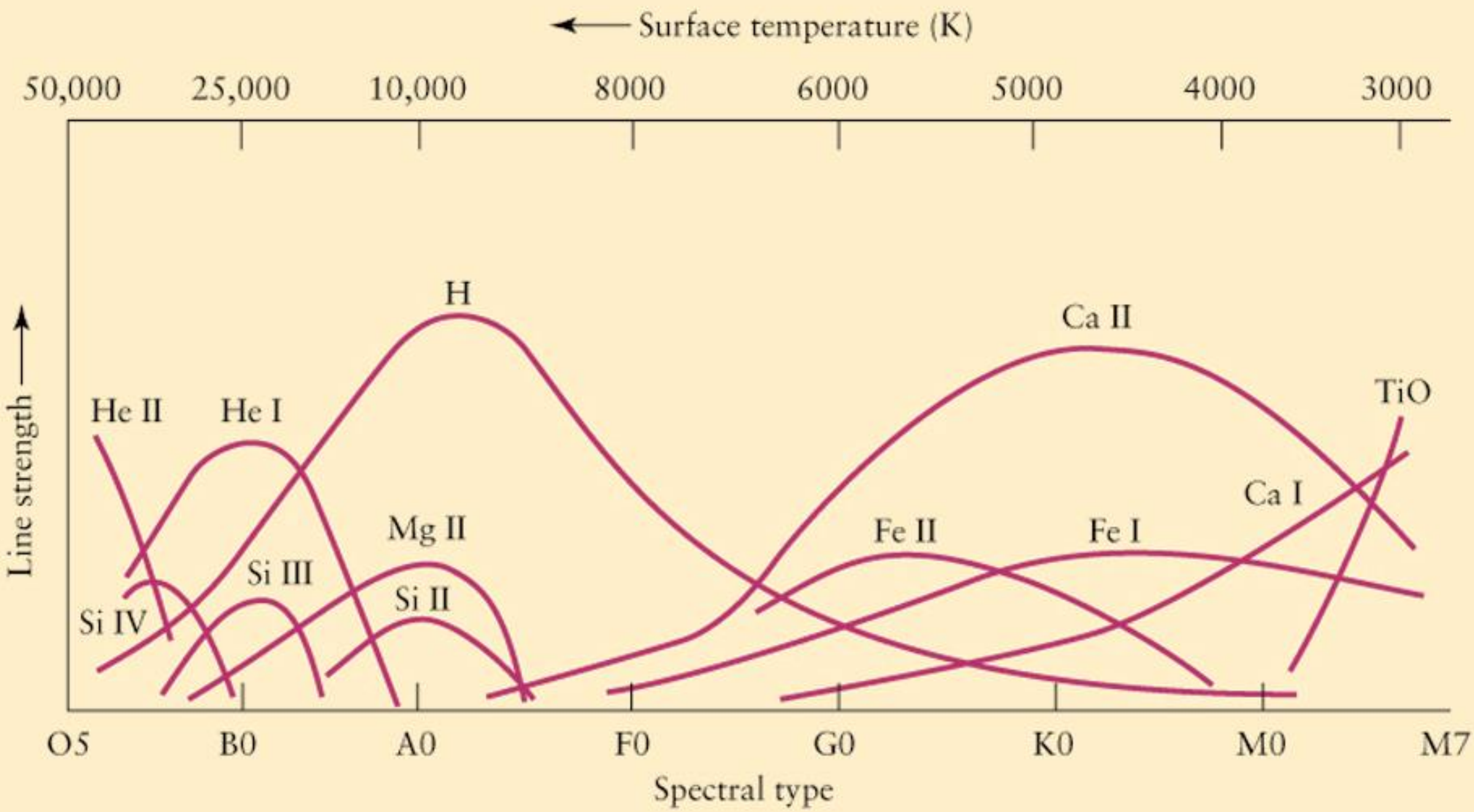
İyonlaşmış Kalsiyum Tripleti



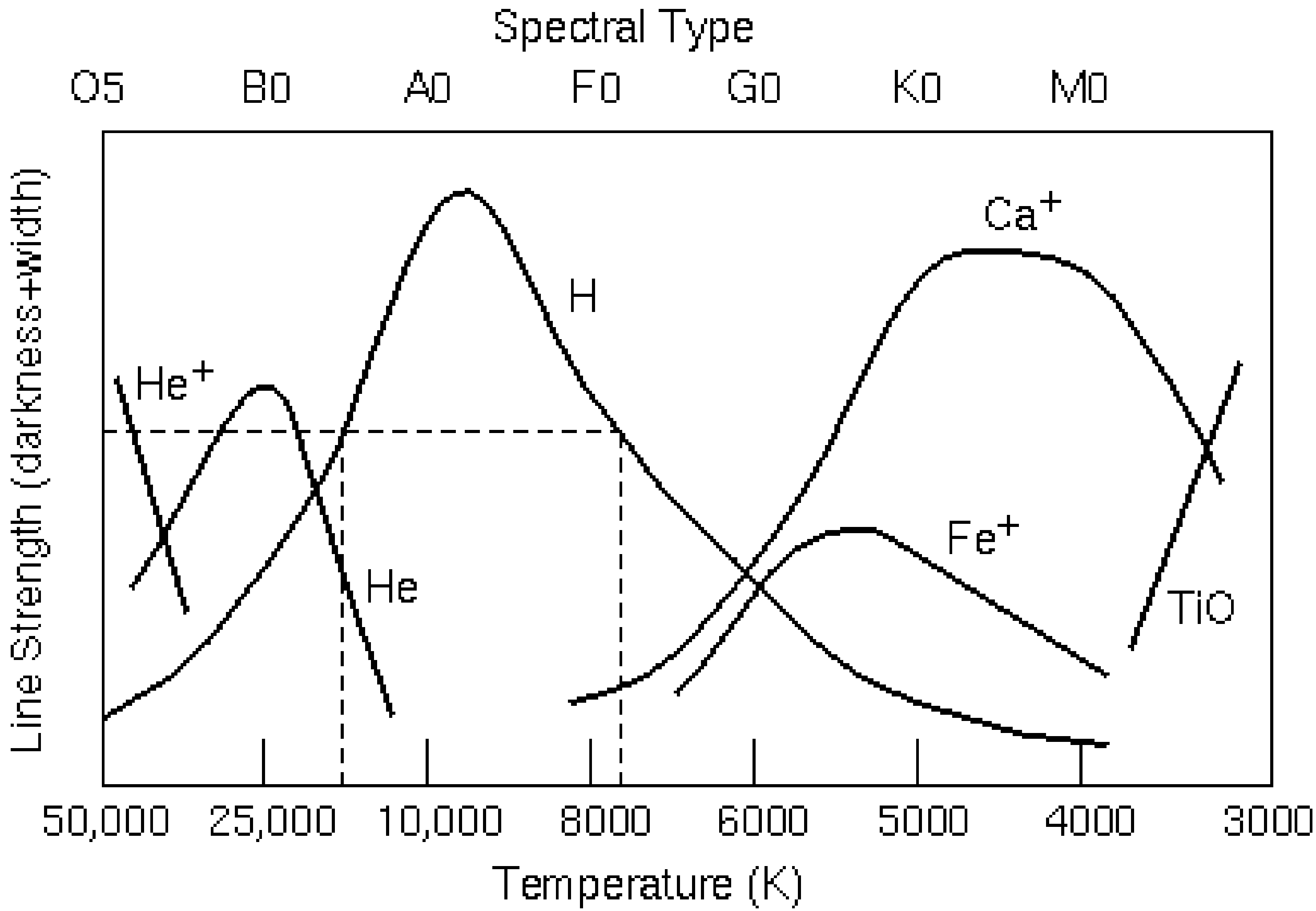
Ca II kızılöte tripleti. Kuvvetli salma gösterir. G, K ve M tayf türünden yıldızlarda görülen baskın soğurma çizgileridir.



a sequence of stellar flux profiles
U
B
V
R
u
v
b
y
Johnson-Cousins
Strömgren
Hδ
Hγ
Paschen continuum
Hβ
Balmer Jump
He I
Hα
O7.5 V
B5 V
A2.5 V
Ca K
F1 V
Na D
G-band
G1 V
Mg H
K0 V
K8 V
Ca I
M3 V
TiO TiO
TiO
normalized flux
350
400
450
500
550
600
650
700
wavelength (nm)

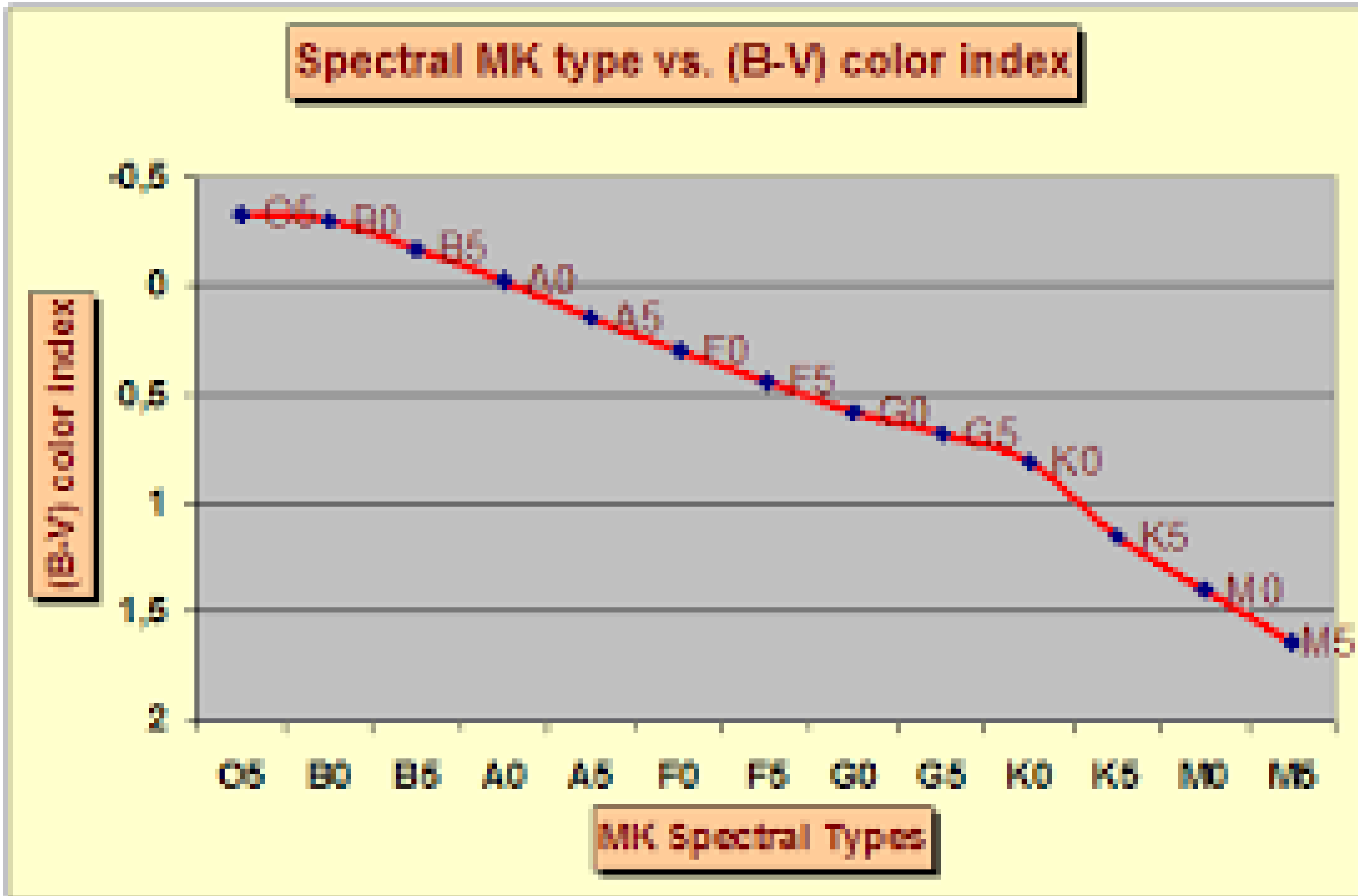


Surface temperature (K)
50,000
25,000
10,000
8000
6000
5000
4000
3000
Line strength
H
Ca II
TiO
He II
He I
Ca I
Mg II
Fe II
Fe I
Si III
Si II
Si IV
O5
B0
A0
F0
G0
K0
M0
M7
Spectral type

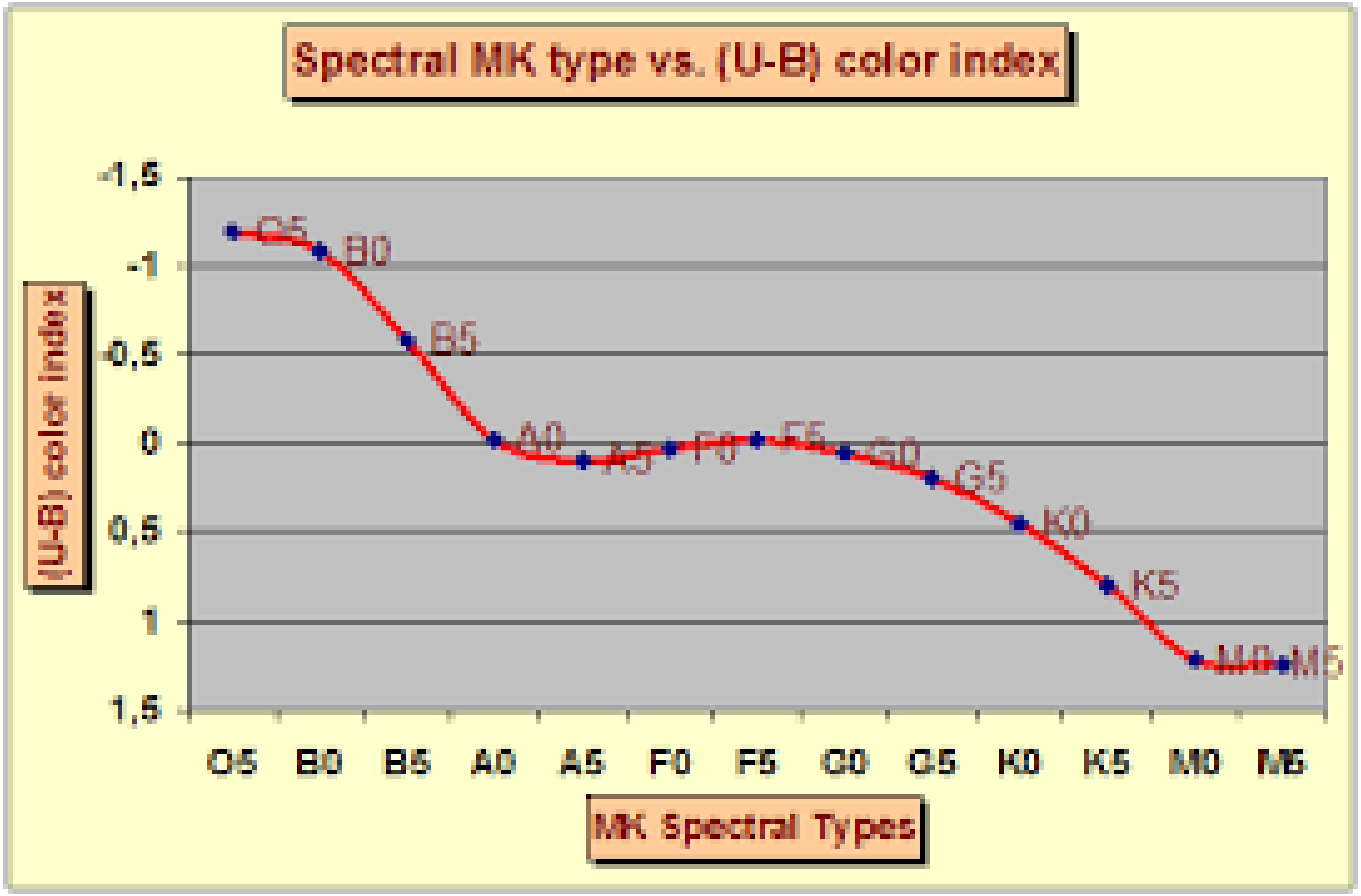


Cross-referencing different line strengths narrows the possible temperature range. A given strength for the Hydrogen line could mean two possible temperatures (hot or warm). If Helium line is present, then the choice is the hot temperature. If the ionized Calcium line is present (and Helium not present), then the choice is the warm temperature.

Ön ekler	**c**	sharp lines
	d	dwarf (main sequence star)
	D	white dwarf
Son ekler	**e**	emission (hydrogen emission in O stars)
	em	emission in metal lines
	ep	peculiar emission
	eq	emission with shorter wavelength absorption
	f	emission by helium and neon in O stars
	g	giant
	k	interstellar lines
	m	strong metallic lines
	n	diffuse lines
	nn	very diffuse lines
	p	peculiar spectrum
	s	sharp lines
	sd	subdwarf
	wd	white dwarf
	wk	weak lines

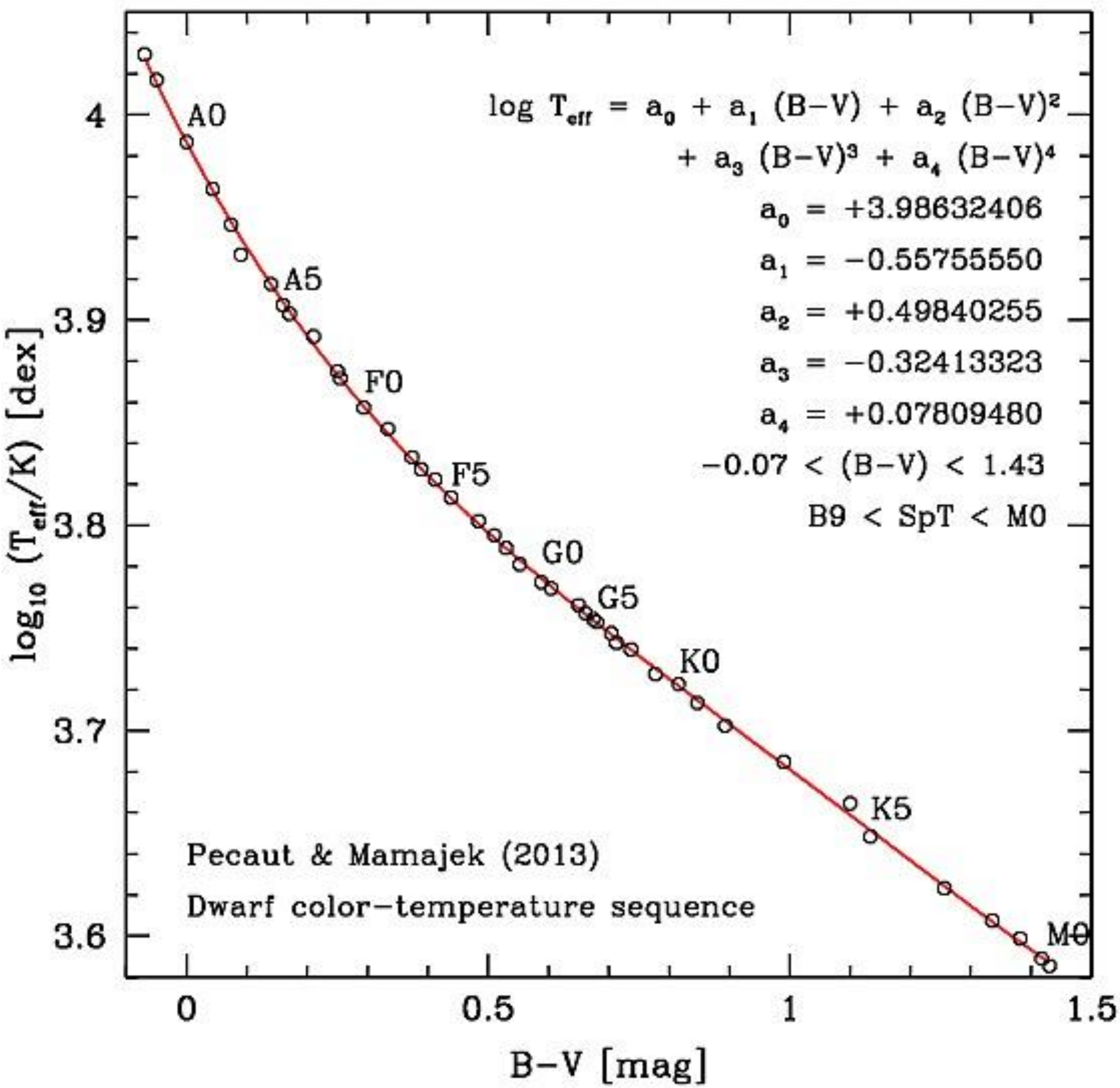


Spectral MK type vs. (B-V) color index
(B-V) color index
-0,5
0
0,5
1
1,5
2
O5
B0
B5
A0
A5
F0
F5
G0
G5
K0
K5
M0
M5
MK Spectral Types

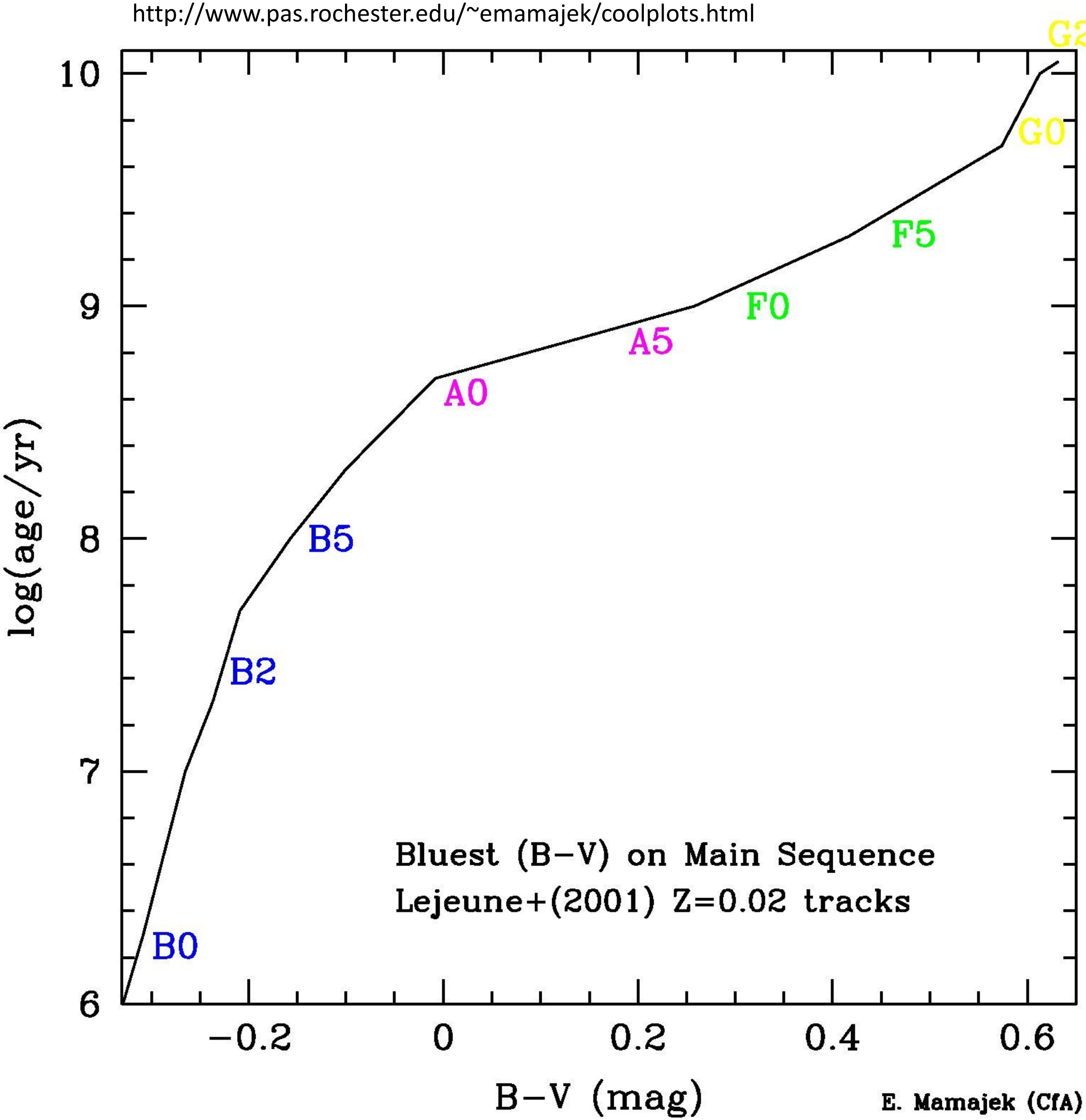


Spectral MK type vs. (U-B) color index
(U-B) color index
-1,5
-1
-0,5
0
0,5
1
1,5
O5
B0
B5
A0
A5
F0
F5
G0
G5
K0
K5
M0
M5
MK Spectral Types

https://figshare.com/articles/B_V_Color_Versus_Effective_Temperature_for_Main_Sequence_Dwarf_Stars_of_Approximately_Solar_Composition/1363846



http://www.pas.rochester.edu/~emamajek/coolplots.html



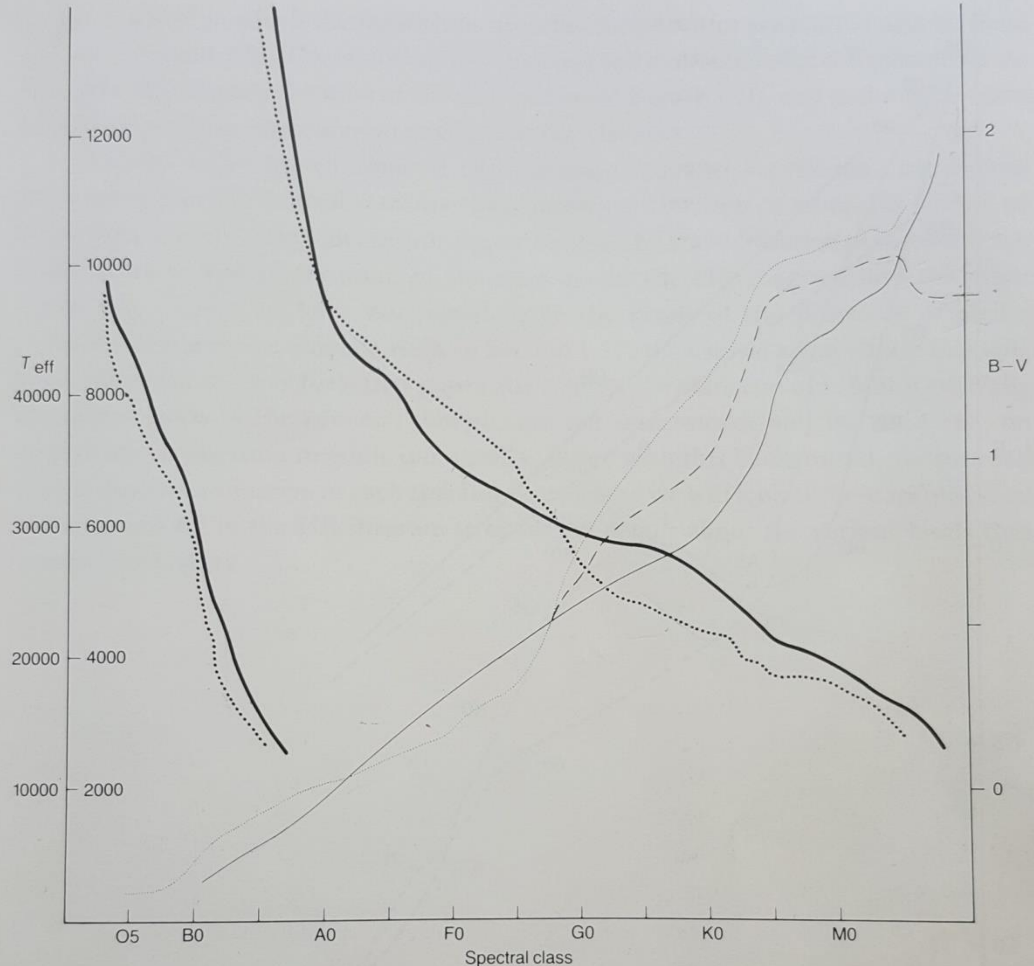
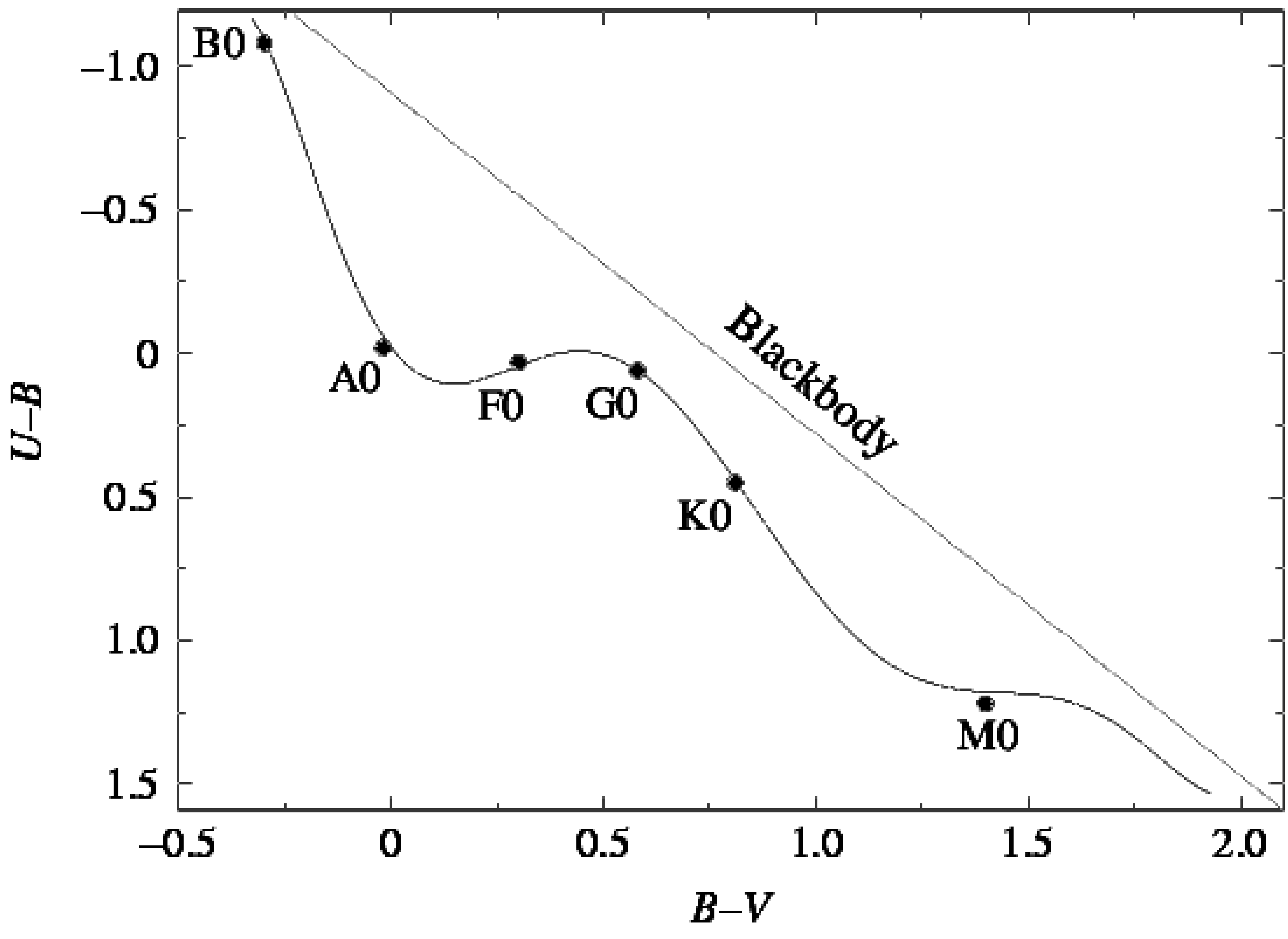


Figure 3.10. The relation between spectral class, effective temperature (T_{eff}) and the B–V color index. The main sequence, giants, and supergiants are respectively indicated by solid, dashed, and dotted lines. The heavier lines refer to temperature; the left-hand curves go with the higher-temperature left-hand scale, and the right-hand curves go with the lower-temperature right-hand scale. The lighter color-plots go with the B–V scale on the far right. Effective temperatures are for supergiants in general (average of Ia and Ib), the colors are specifically for the Ia variety. Earlier than G0 the giant temperatures fall closer to those of the main sequence; later than that they are more like those of the supergiants. Giant colors earlier than F8 are similar to those of the dwarfs. Over most of the spectral sequence the higher luminosity stars have cooler temperatures and redder colors than the dwarfs because of their lowered atmospheric pressures. This relation reverses over a short spectral range between A0 and F8. The reversal of the color-spectral class correlation for late-type giants is caused by the development of powerful molecular bands. Diagram by the author. Temperature data from articles by R. M. Humphries and D. B. McElroy in the *Astrophysical Journal* and by D. M. Popper in *Annual Review of Astronomy and Astrophysics*; color data from T. Schmidt-Kaler in *Landolt–Börnstein Tables*, Group VI, Vol. IIb, Springer, New York 1982.


B0
A0
F0
G0
K0
M0
Blackbody
−1.0
−0.5
0
0.5
1.0
1.5
U−B
−0.5
0
0.5
1.0
1.5
2.0
B−V

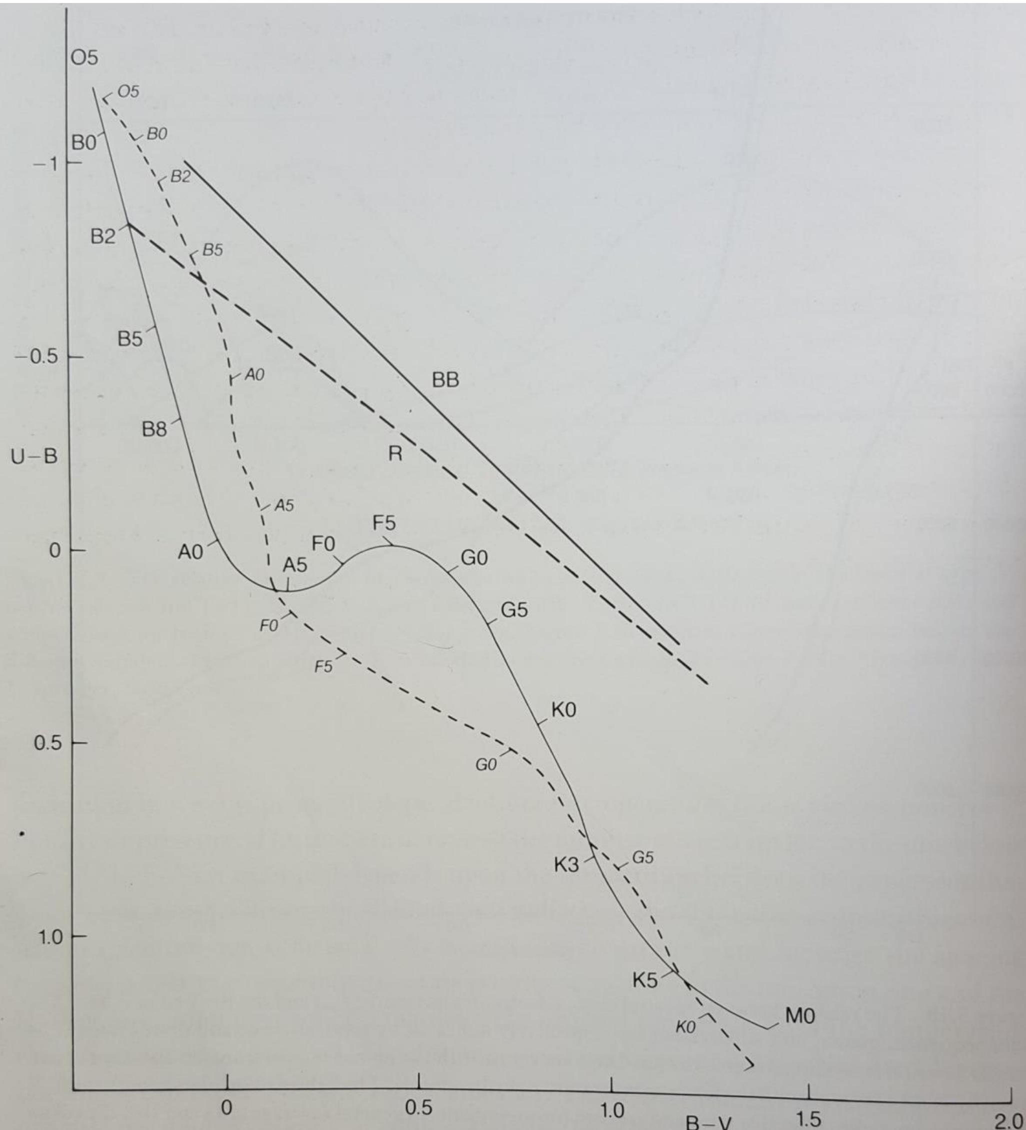


Figure 3.11. The color–color diagram, which shows U−B plotted against B−V for main sequence stars and for supergiants, with various spectral classes indicated; supergiant classes are in italics. The curve for a blackbody is indicated by a solid line labeled 'BB'. Clearly, the stars do not behave like blackbodies, the deviation being caused by atmospheric transparencies that change with wavelength. The hook in the main sequence curve between A5 and G0 is caused by the prominence of the Balmer continuum, which influences U. Its absence in the supergiants is related to the weakness of the hydrogen absorption in these luminous stars (see Figure 3.7). The dashed curve labeled R shows what happens to the colors of a B2 star that is subject to the dimming effects of interstellar dust: see Chapter 9. From data presented by T. Schmidt-Kaler, in *Landolt–Börnstein Tables*, Group VI, Vol. IIb, Springer, New York 1982.

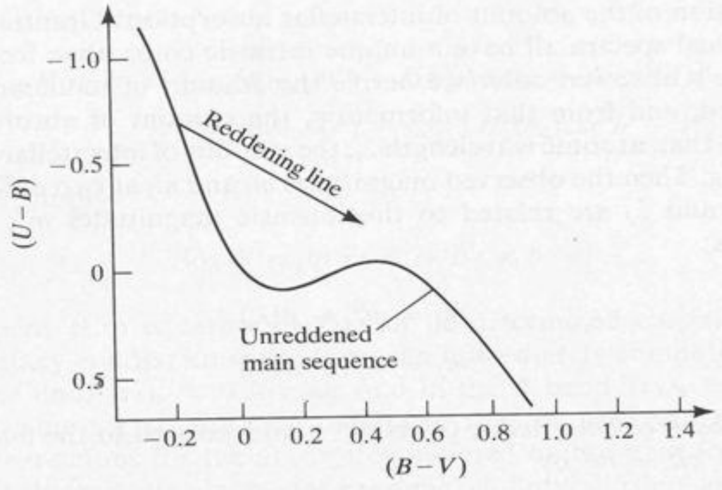
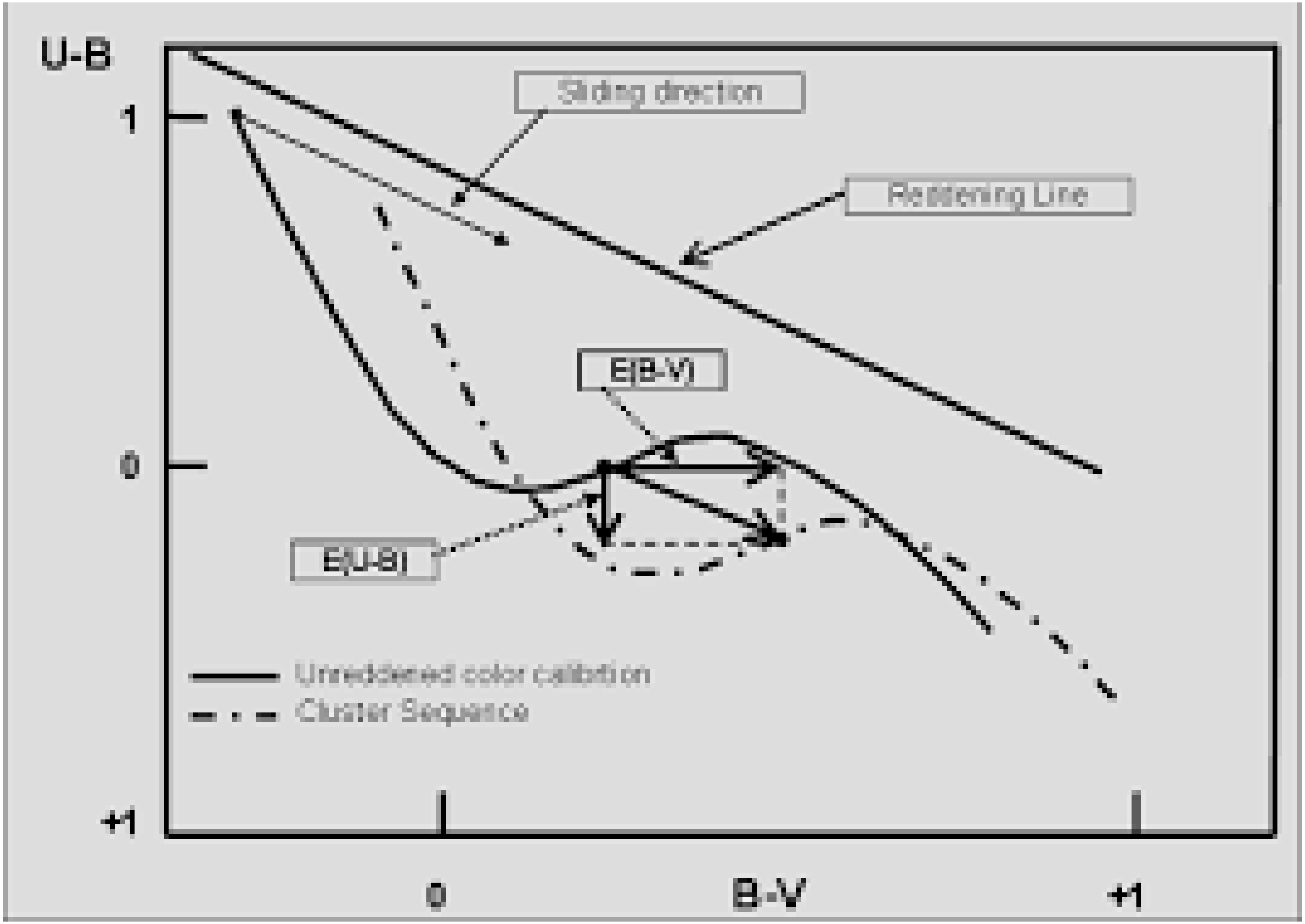


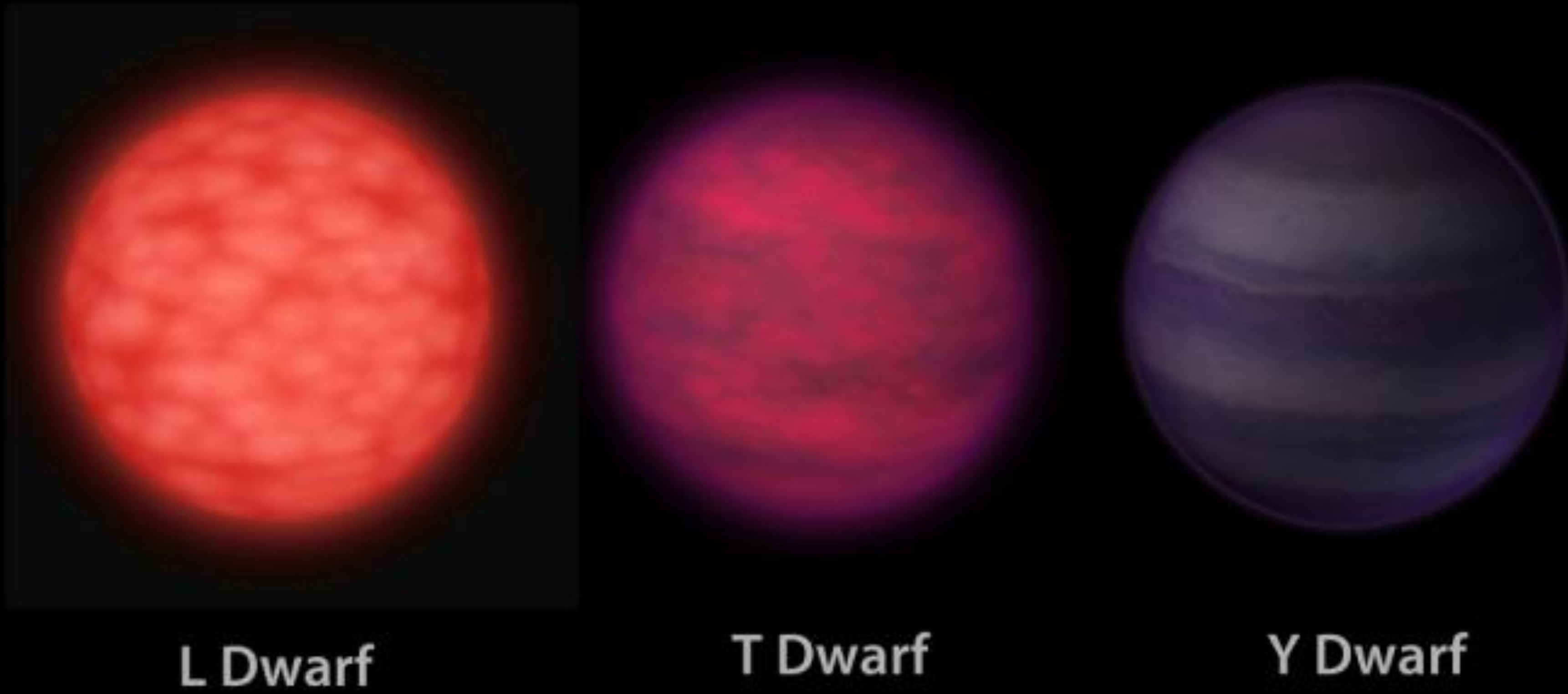
Figure 3-26. Effects of interstellar reddening in the *UBV* system two-color diagram.

Usually can be neglected

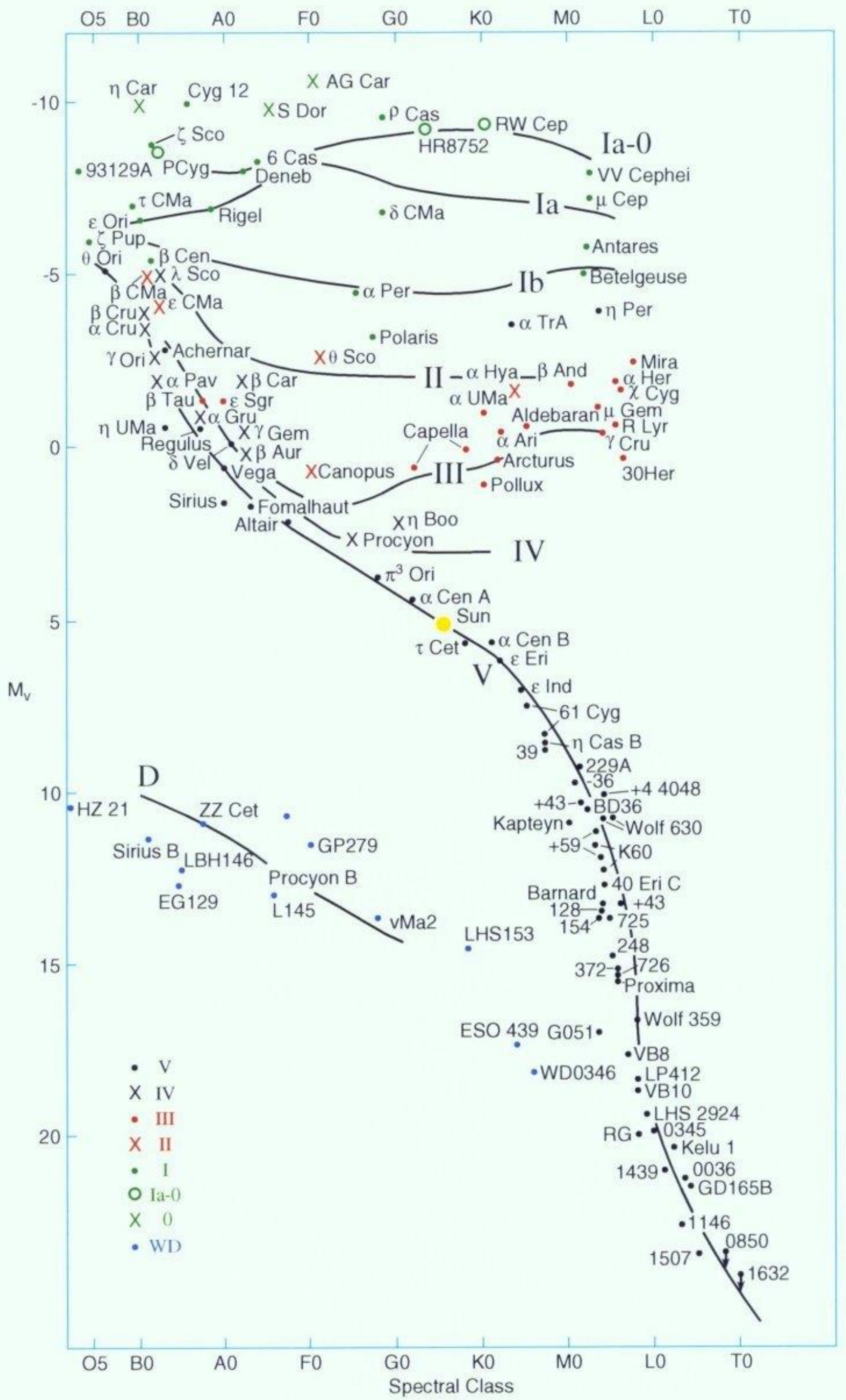
$$\frac{E(U-B)}{E(B-V)} = 0.72 + 0.05\, E(B-V)$$

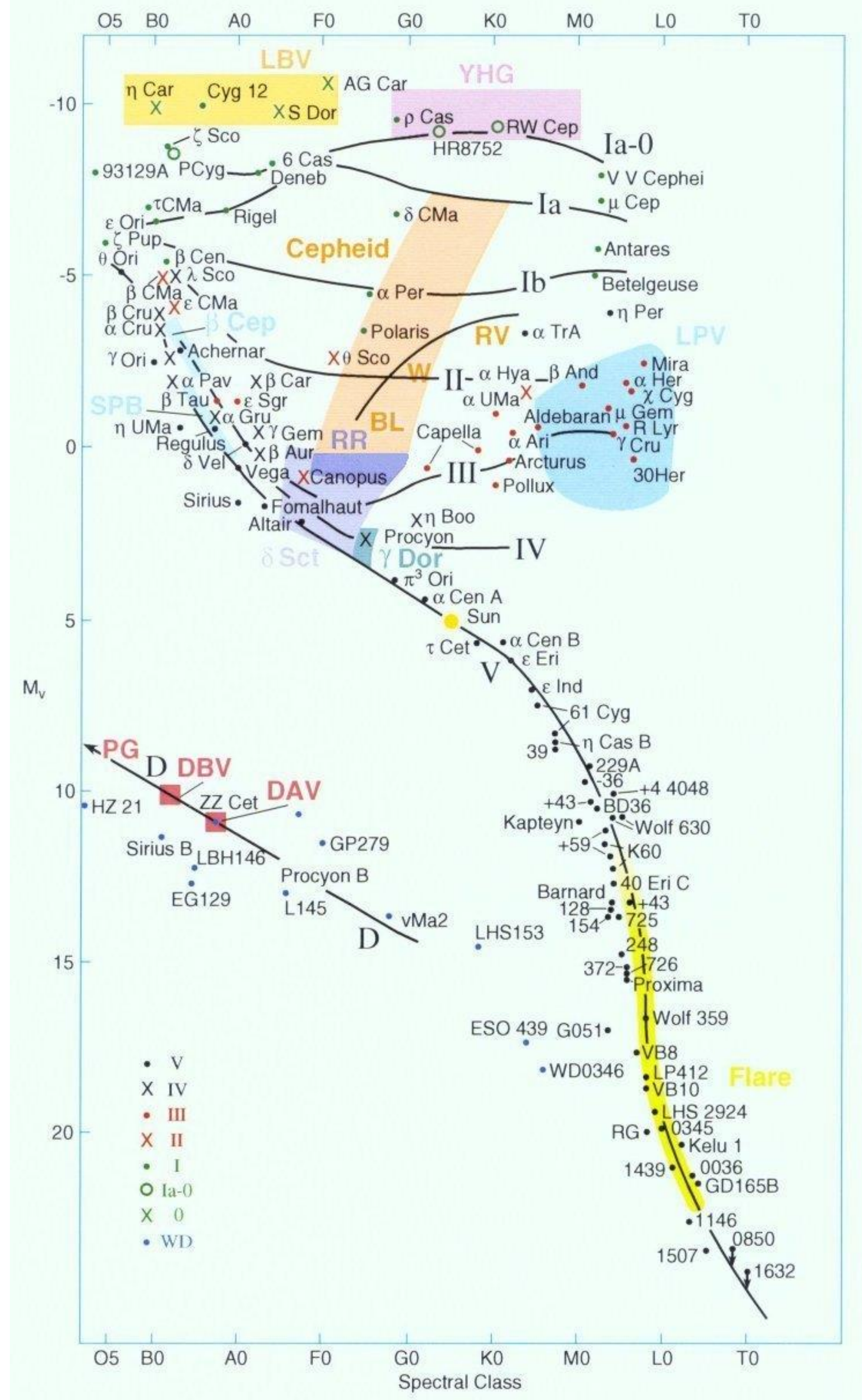


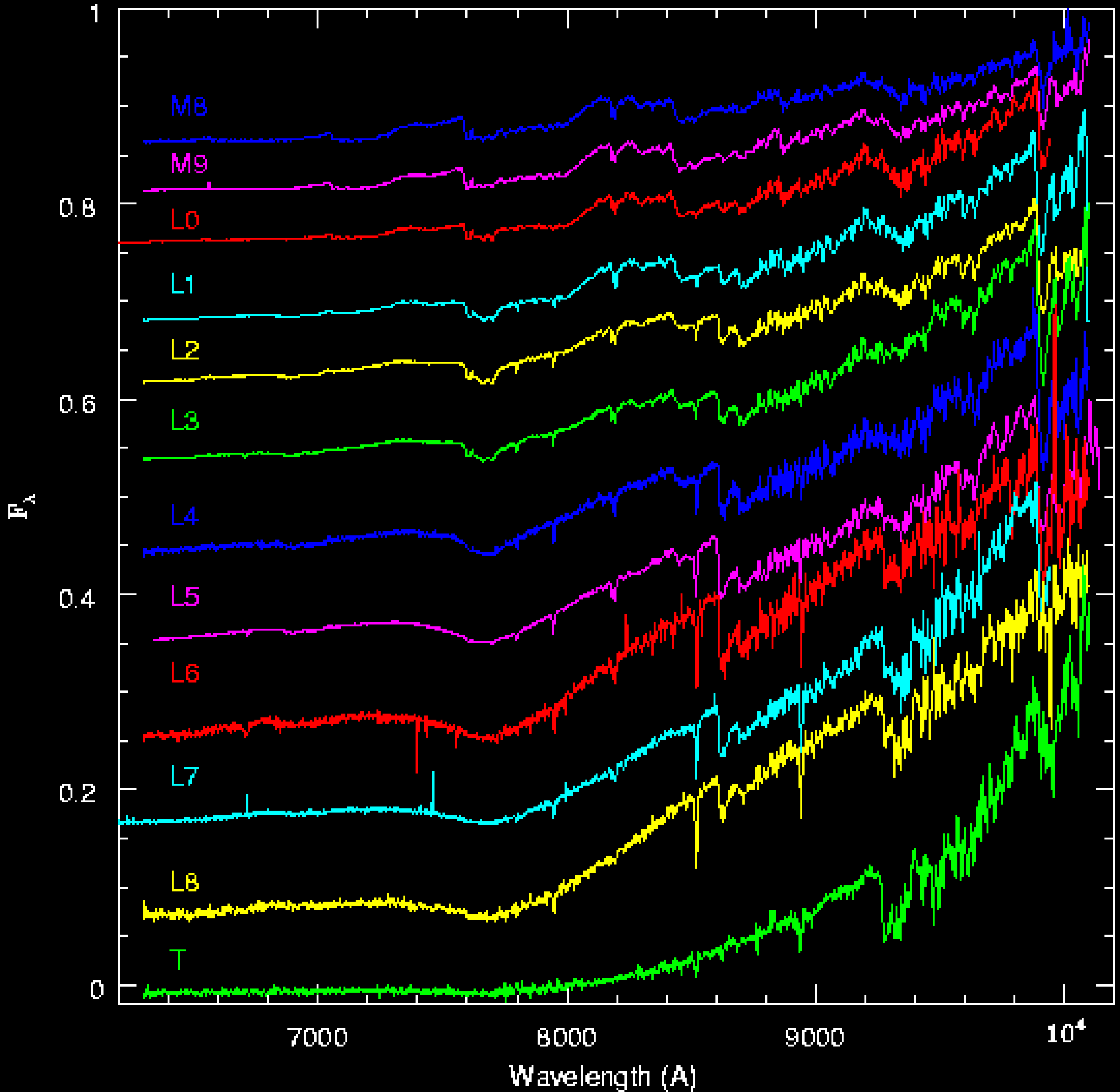
U-B
1
0
+1
Sliding direction
Reddening Line
E(B-V)
E(U-B)
Unreddened color calibration
Cluster Sequence
0
B-V
+1



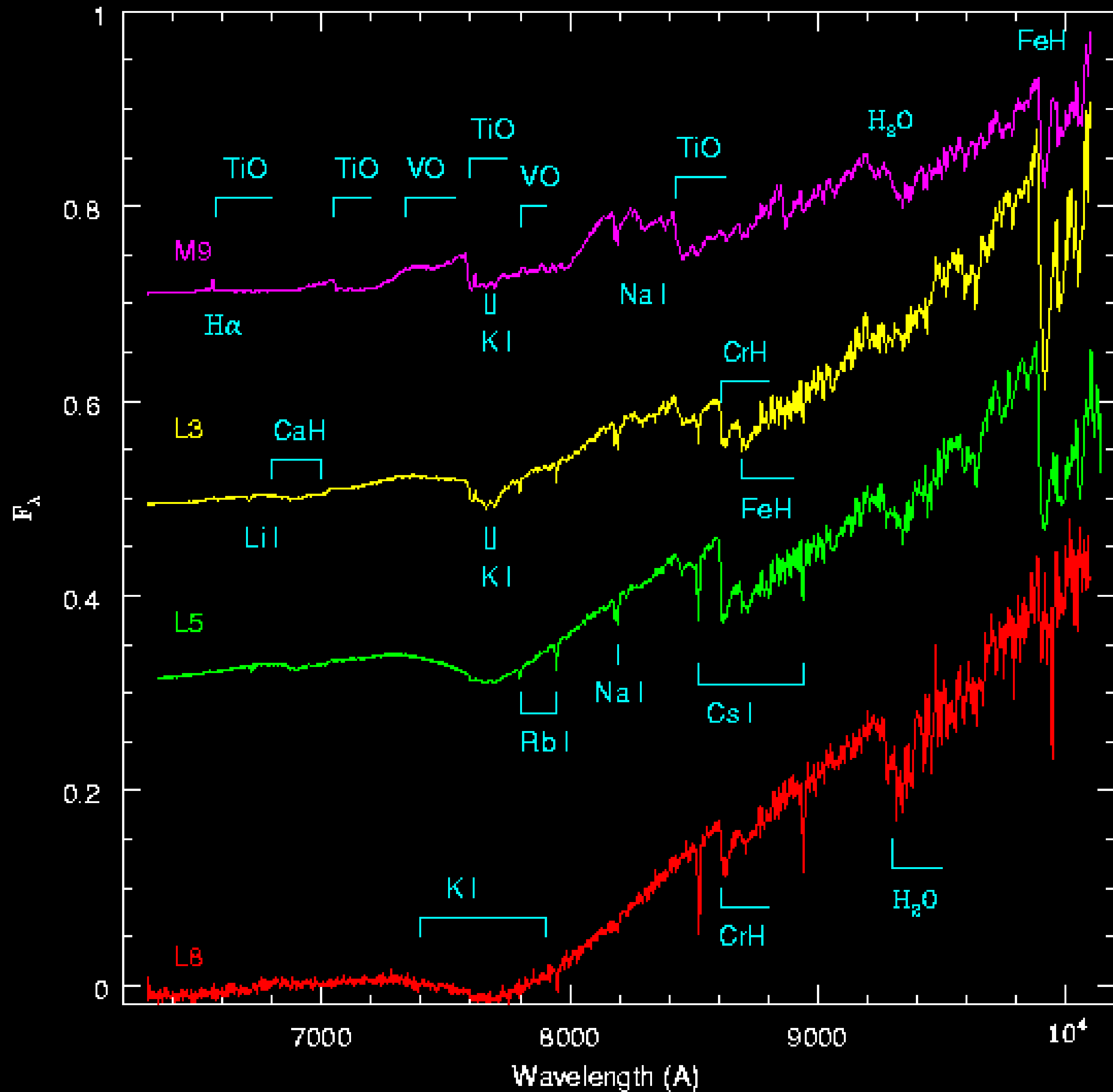
http://www.stsci.edu/~inr/ldwarf1.html


O5 B0 A0 F0 G0 K0 M0 L0 T0
Spectral Class
M_v
-10
-5
0
5
10
15
20
η Car
Cyg 12
AG Car
S Dor
ζ Sco
ρ Cas
RW Cep
HR8752
Ia-0
93129A
PCyg
6 Cas
Deneb
VV Cephei
μ Cep
τ CMa
Rigel
δ CMa
Ia
ε Ori
ζ Pup
θ Ori
β Cen
λ Sco
Antares
Betelgeuse
β CMa
ε CMa
α Per
Ib
β Cru
α Cru
η Per
α TrA
Polaris
γ Ori
Achernar
θ Sco
II
α Hya
β And
Mira
α Pav
β Car
α UMa
α Her
β Tau
ε Sgr
χ Cyg
α Gru
μ Gem
η UMa
γ Gem
Aldebaran
R Lyr
Regulus
β Aur
Capella
α Ari
γ Cru
δ Vel
Vega
Canopus
Arcturus
III
Pollux
30Her
Sirius
Fomalhaut
Altair
η Boo
Procyon
IV
π3 Ori
α Cen A
Sun
α Cen B
τ Cet
ε Eri
V
ε Ind
61 Cyg
39
η Cas B
229A
-36
+4 4048
D
+43
BD36
HZ 21
ZZ Cet
Kapteyn
Wolf 630
GP279
+59
K60
Sirius B
LBH146
Procyon B
40 Eri C
Barnard
EG129
L145
128
+43
vMa2
154
725
LHS153
248
372
726
Proxima
Wolf 359
ESO 439
G051
VB8
WD0346
LP412
VB10
LHS 2924
RG
0345
Kelu 1
1439
0036
GD165B
1146
1507
0850
1632
V
IV
III
II
I
Ia-0
0
WD

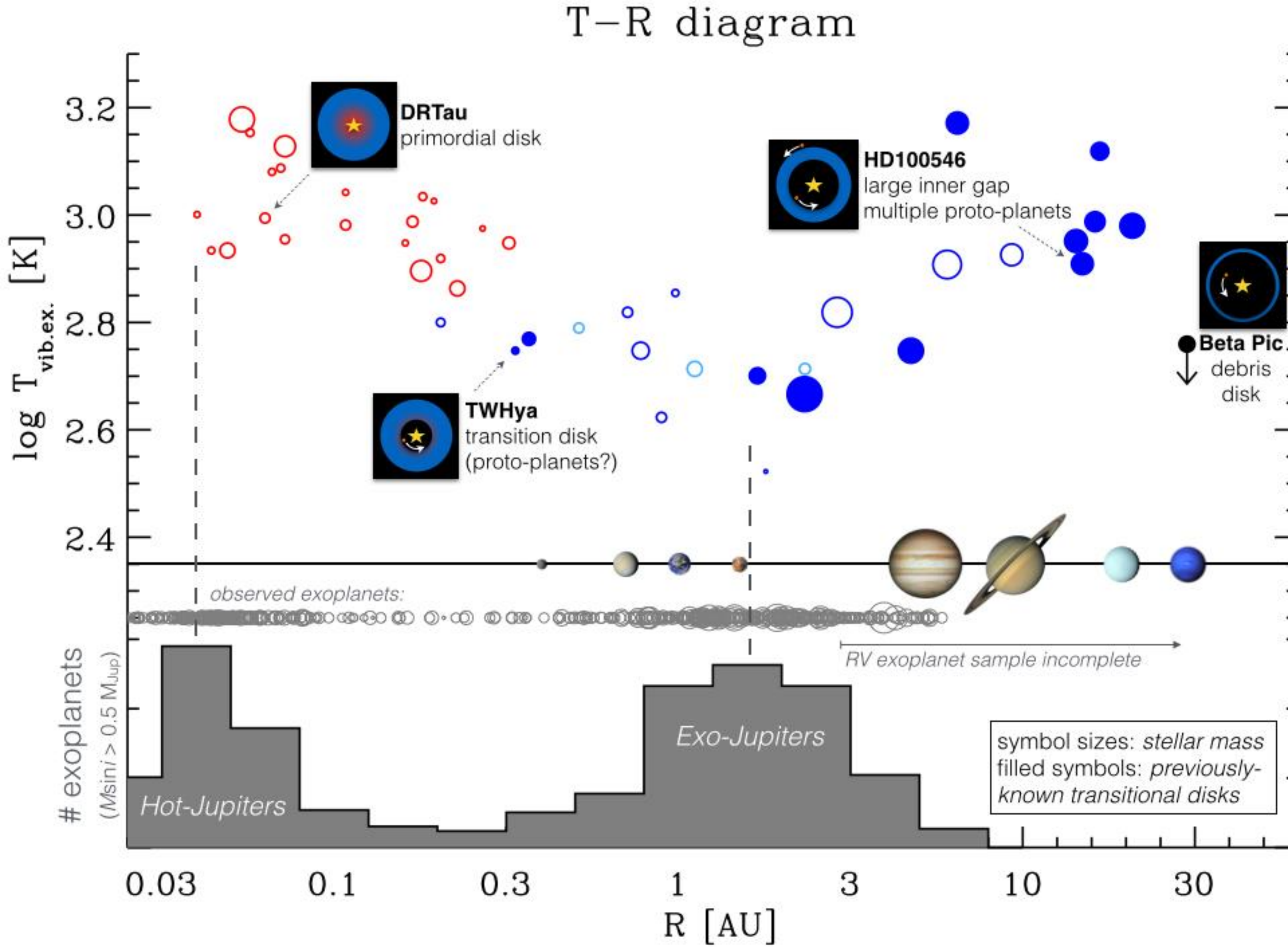

O5 B0 A0 F0 G0 K0 M0 L0 T0
Spectral Class
M_v
-10
-5
0
5
10
15
20
LBV
YHG
η Car
Cyg 12
AG Car
S Dor
ρ Cas
RW Cep
HR8752
Ia-0
ζ Sco
93129A
PCyg
6 Cas
Deneb
V V Cephei
τCMa
Rigel
δ CMa
Ia
μ Cep
ε Ori
ζ Pup
Antares
θ Ori
β Cen
Cepheid
λ Sco
α Per
Ib
Betelgeuse
β CMa
ε CMa
β Cru
α Cru
β Cep
η Per
Polaris
RV
α TrA
LPV
γ Ori
Achernar
θ Sco
W
II
α Hya
β And
Mira
α Pav
β Car
α UMa
α Her
SPB
β Tau
ε Sgr
χ Cyg
α Gru
BL
Aldebaran
μ Gem
η UMa
γ Gem
R Lyr
Regulus
β Aur
RR
Capella
α Ari
γ Cru
δ Vel
Vega
Canopus
III
Arcturus
30Her
Pollux
Sirius
Fomalhaut
η Boo
Altair
Procyon
IV
δ Sct
γ Dor
π3 Ori
α Cen A
Sun
α Cen B
τ Cet
ε Eri
V
ε Ind
61 Cyg
PG
39
η Cas B
DBV
229A
D
-36
DAV
+4 4048
ZZ Cet
+43
BD36
HZ 21
Kapteyn
Wolf 630
GP279
Sirius B
+59
K60
LBH146
40 Eri C
Procyon B
Barnard
EG129
128
+43
L145
154
725
vMa2
D
LHS153
248
372
726
Proxima
Wolf 359
ESO 439
G051
VB8
WD0346
LP412
Flare
VB10
LHS 2924
RG
0345
Kelu 1
1439
0036
GD165B
1146
0850
1507
1632
V
IV
III
II
I
Ia-0
0
WD



M8
M9
L0
L1
L2
L3
L4
L5
L6
L7
L8
T
1
0.8
0.6
0.4
0.2
0
F_λ
7000
8000
9000
10^4
Wavelength (A)



M9
L3
L5
L8
TiO
VO
FeH
H_2O
Hα
K I
Na I
CrH
CaH
Li I
Rb I
Cs I
F_λ
Wavelength (A)
0
0.2
0.4
0.6
0.8
1
7000
8000
9000
10^4


T−R diagram
DRTau
primordial disk
HD100546
large inner gap
multiple proto-planets
TWHya
transition disk
(proto-planets?)
Beta Pic
debris
disk
observed exoplanets:
RV exoplanet sample incomplete
Exo-Jupiters
Hot-Jupiters
symbol sizes: stellar mass
filled symbols: previously-known transitional disks
log T vib.ex. [K]
exoplanets (Msini > 0.5 MJup)
R [AU]
3.2
3.0
2.8
2.6
2.4
0.03
0.1
0.3
1
3
10
30