STELLAR SPECTRA

ASTROPHYSICS

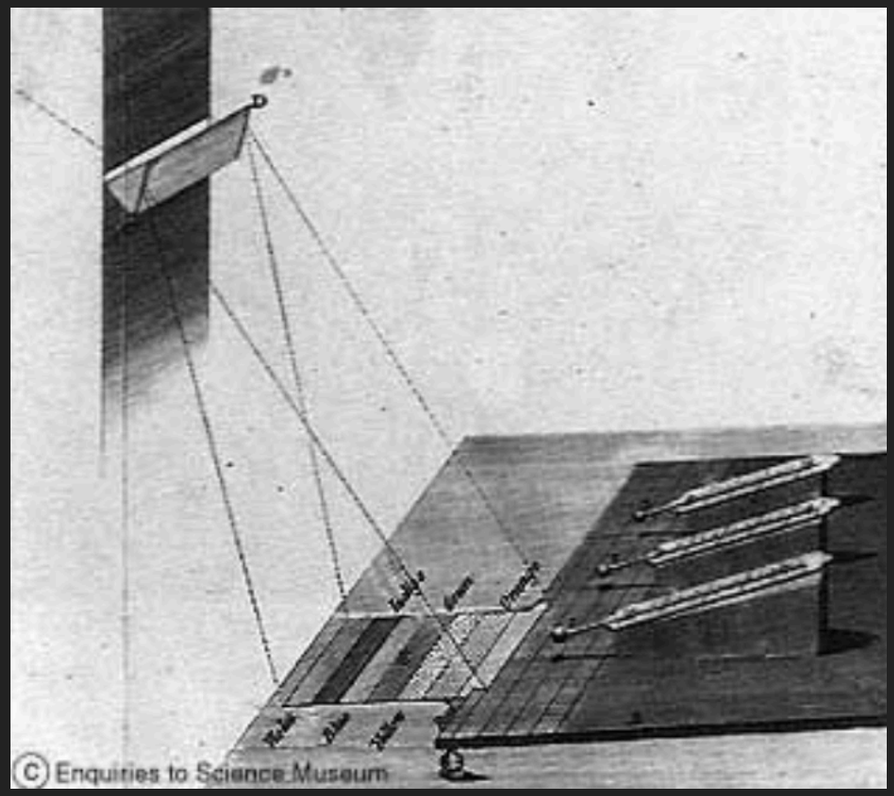
Dr H.T.Sener

NEWTON – 1666

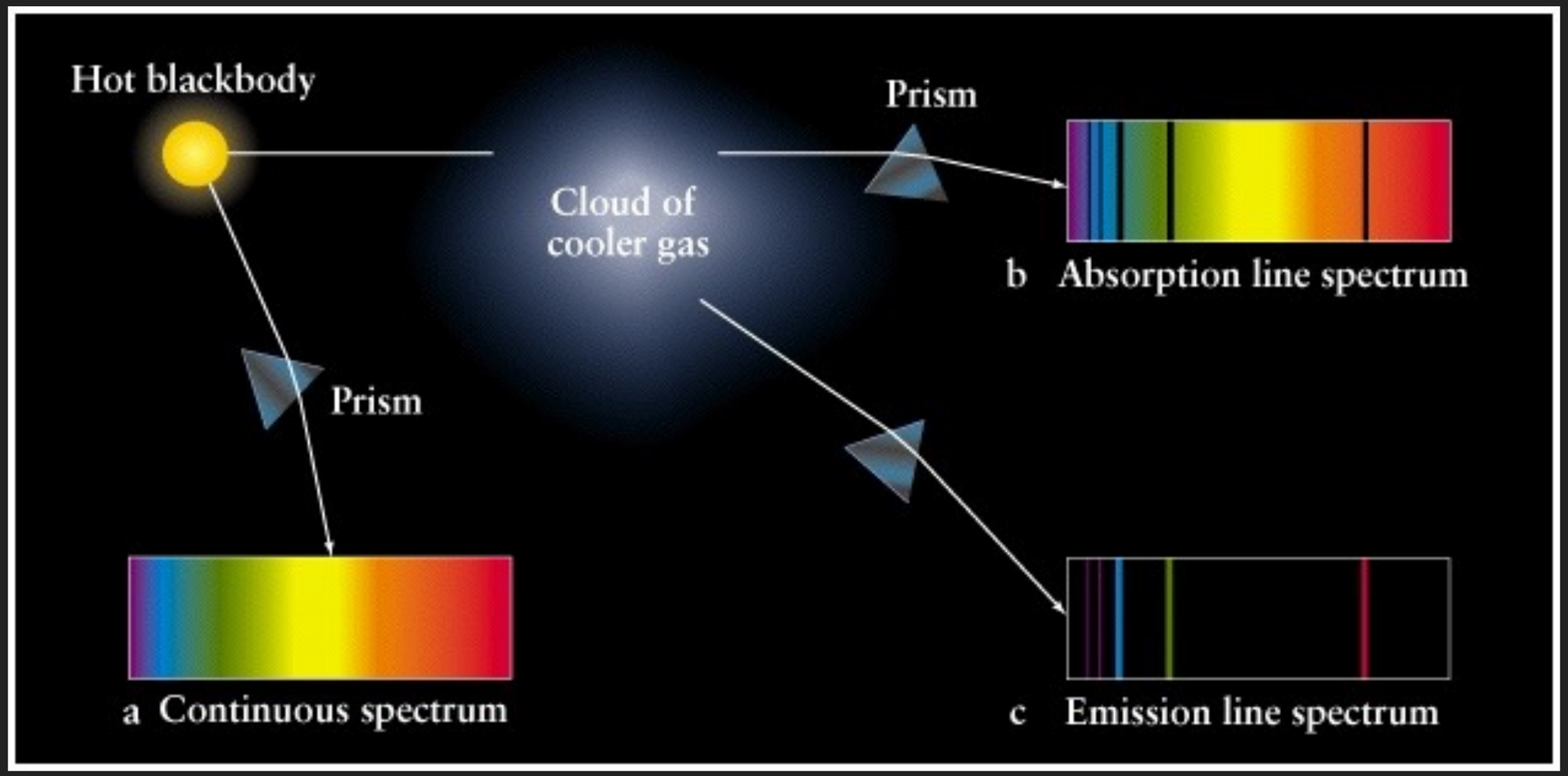
- "I procured me a triangular glass prism,... having darkened my chamber and made a small hole in my window shuts, to let in a convenient quantity of the sun's light, I placed my prism at this entrance, that it might be thereby refracted to the opposite wall. It was at first a pleasing divertissement to view the vivid and intense colours produced thereby."

HERSCHEL – 1830S

- Optical prism: refract the light
- allowing safe visual observation
- solar observation

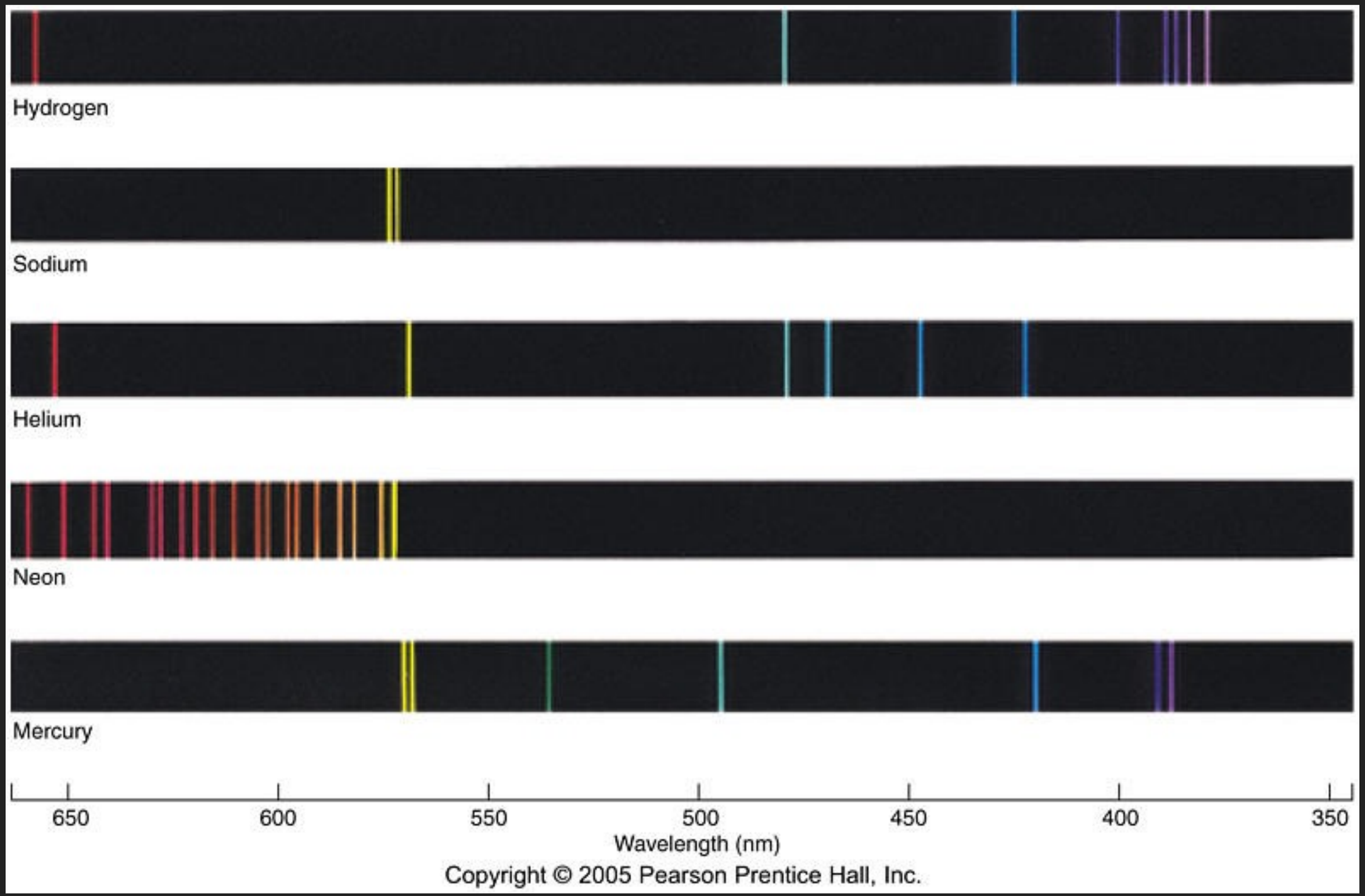


KIRCHHOFF'S LAWS



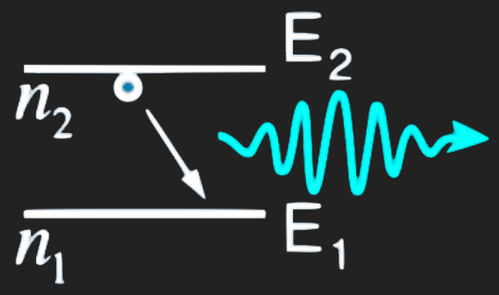
- A hot solid, liquid or gas, under high pressure, gives off a continuous spectrum.
- A hot gas under low pressure produces a bright-line or emission line spectrum.
- A dark line or absorption line spectrum is seen when a source of a continuous spectrum is viewed behind a cool gas under pressure.

SPECTRAL LINES



ELECTRON TRANSITIONS

- The Bohr model for an electron transition in Hydrogen between energy levels with different quantum numbers n yields a photon by emission with quantum energy:



- A downward transition involves emission of a photon of the energy:

$$E_{photon} = h\upsilon = E_2 - E_1$$

$$h\upsilon = \frac{Z^2 m e^4}{8h^2\varepsilon_0^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] = -13.6Z^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] eV$$

Z = atomic number

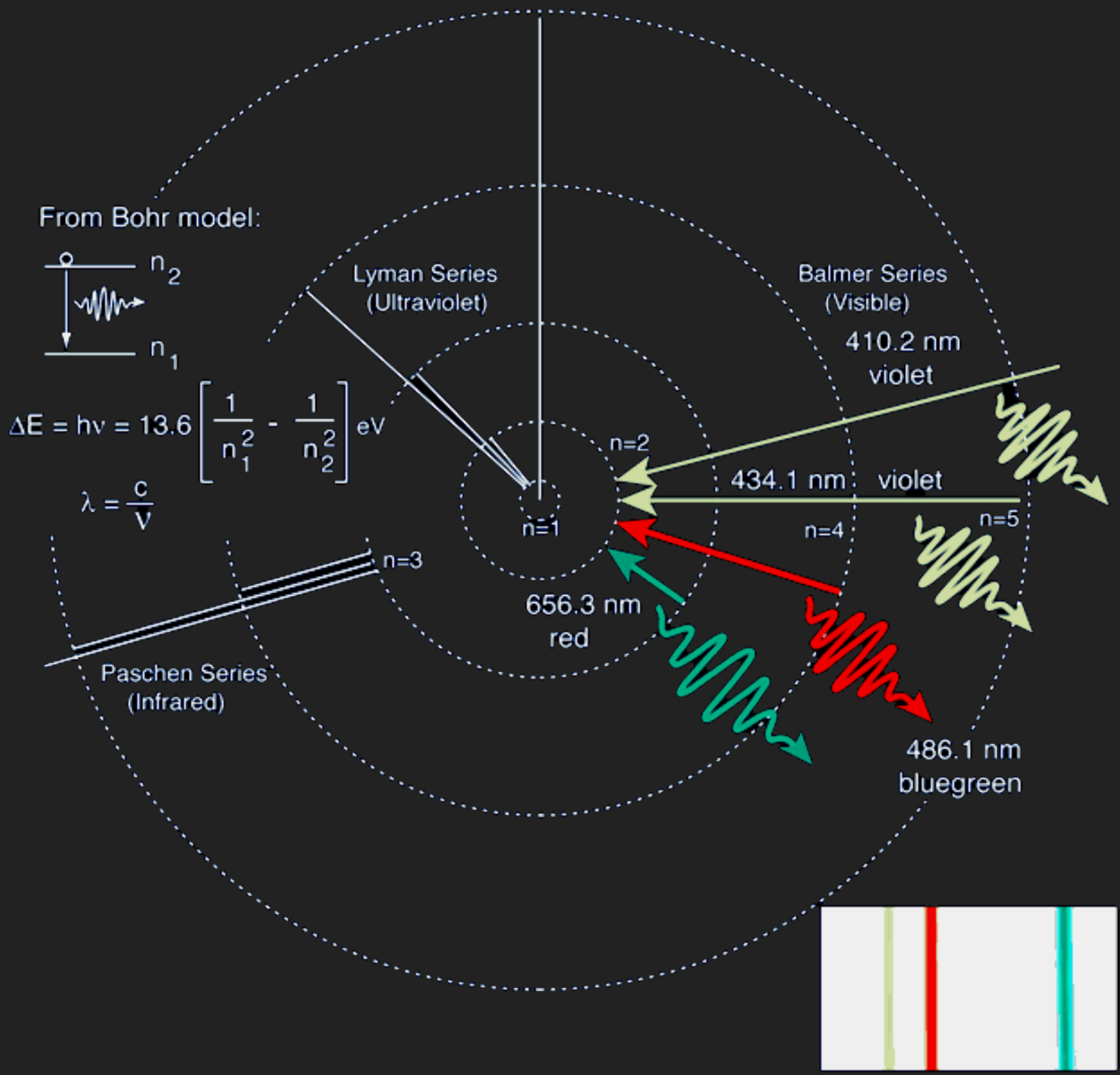
ELECTRON TRANSITIONS

- In terms of the inverse wavelength or "wave number":

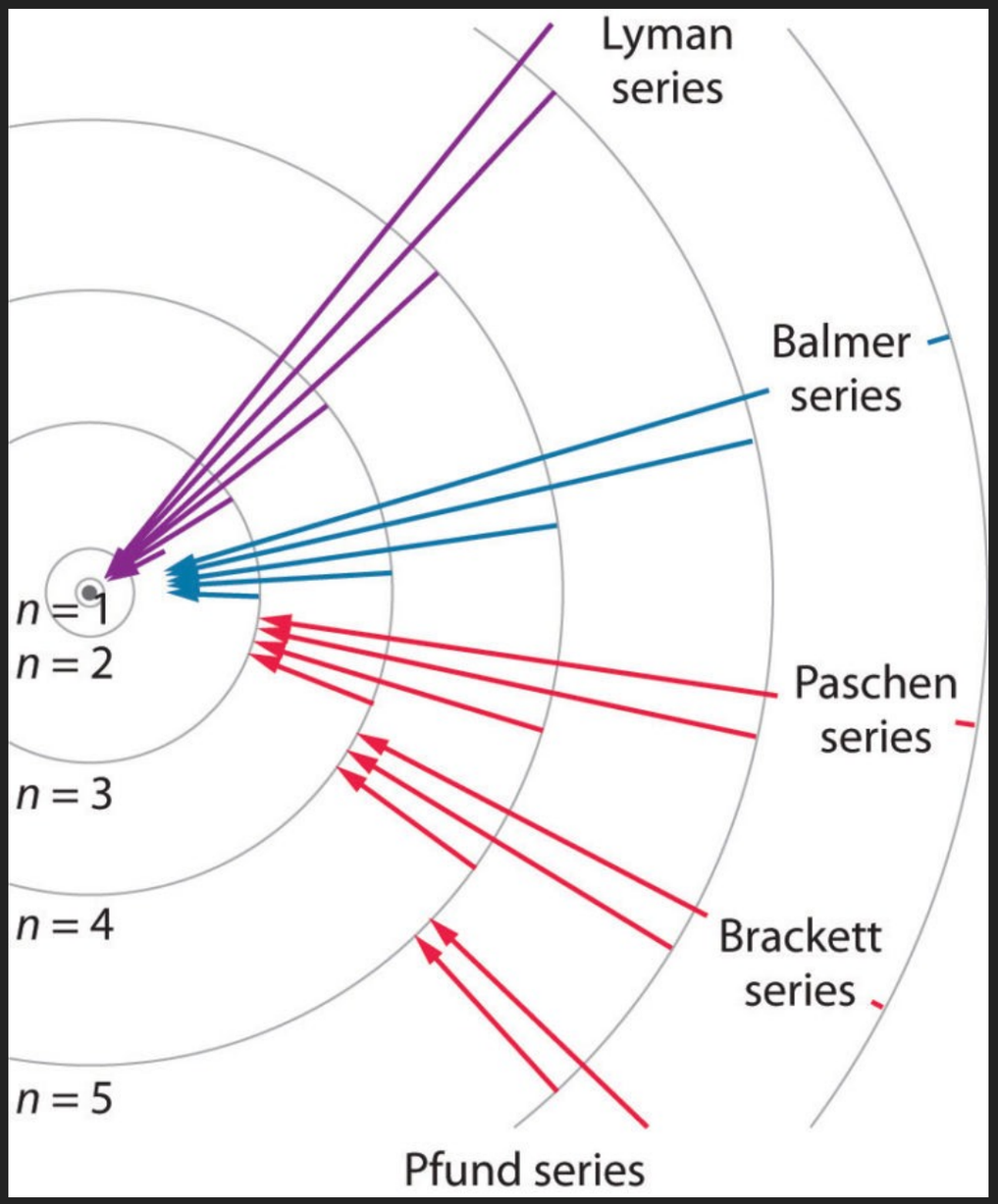
$$\frac{1}{\lambda} = R_H Z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$$ where $$R_H = \frac{me^4}{8h^3 c\varepsilon_0^2}$$ is called the Rydberg constant.

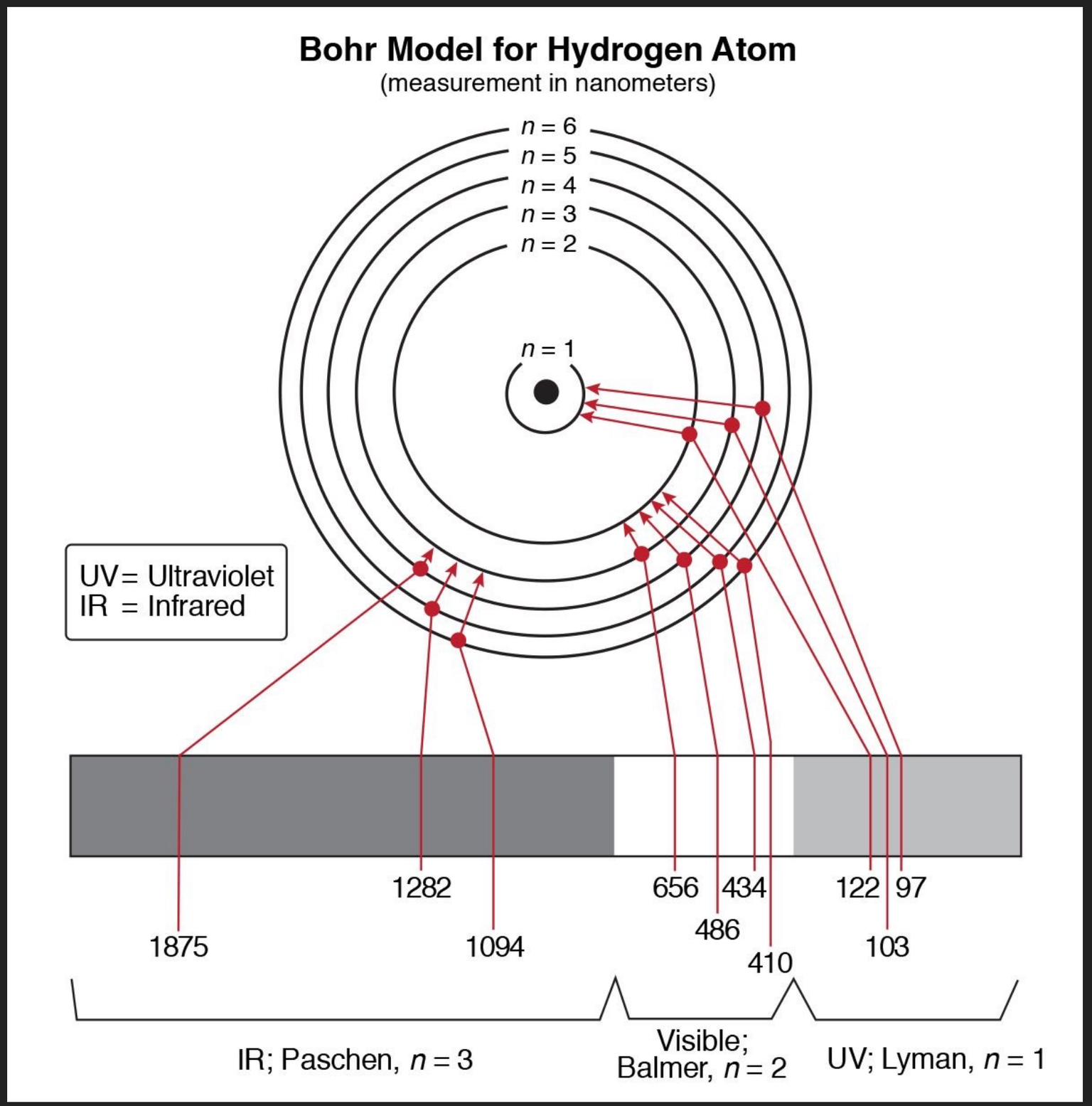
$$R_H = 1.09677576 x 10^7 \, m^{-1}$$ for hydrogen.

HYDROGEN ENERGY LEVELS

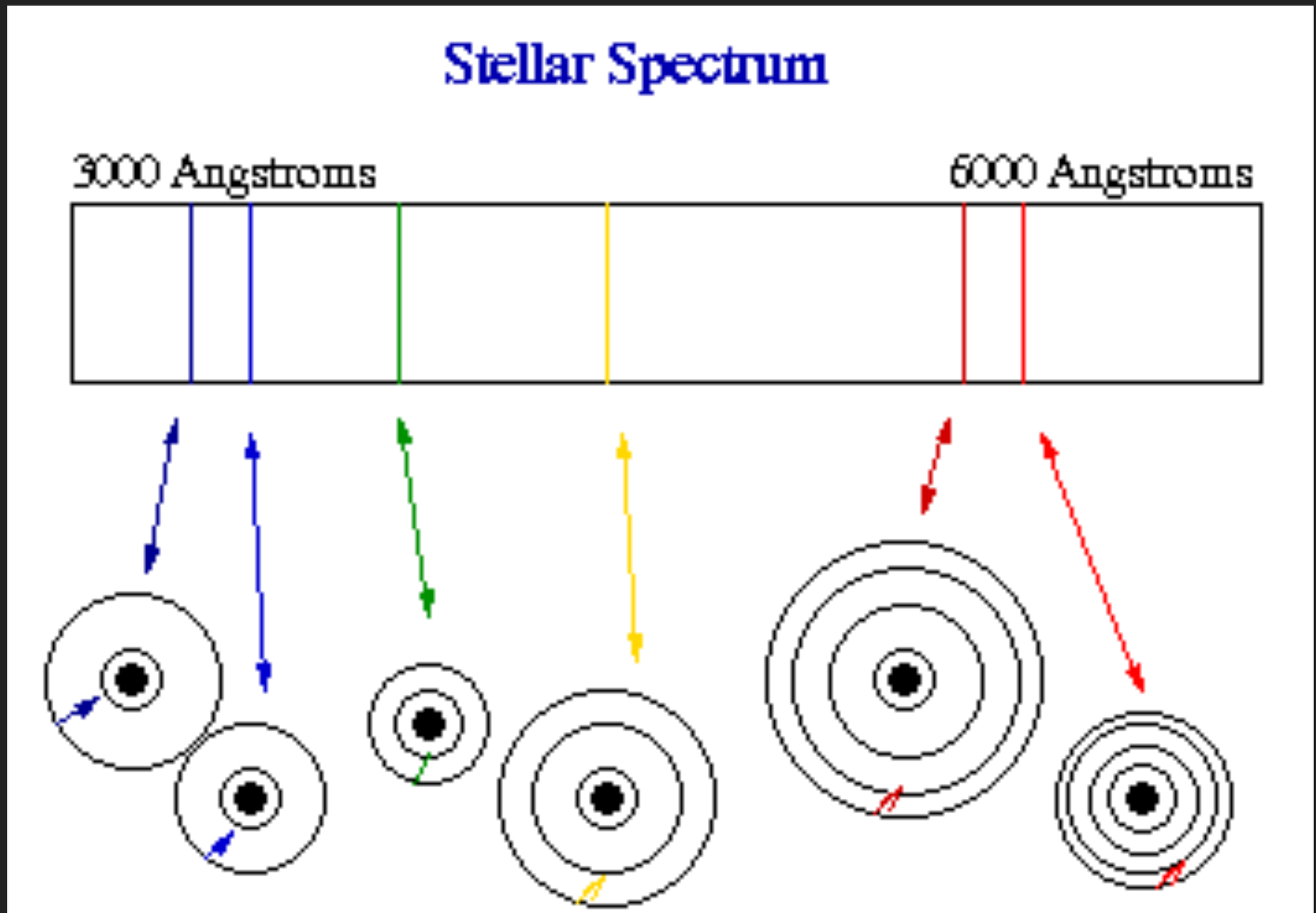


HYDROGEN ENERGY LEVELS

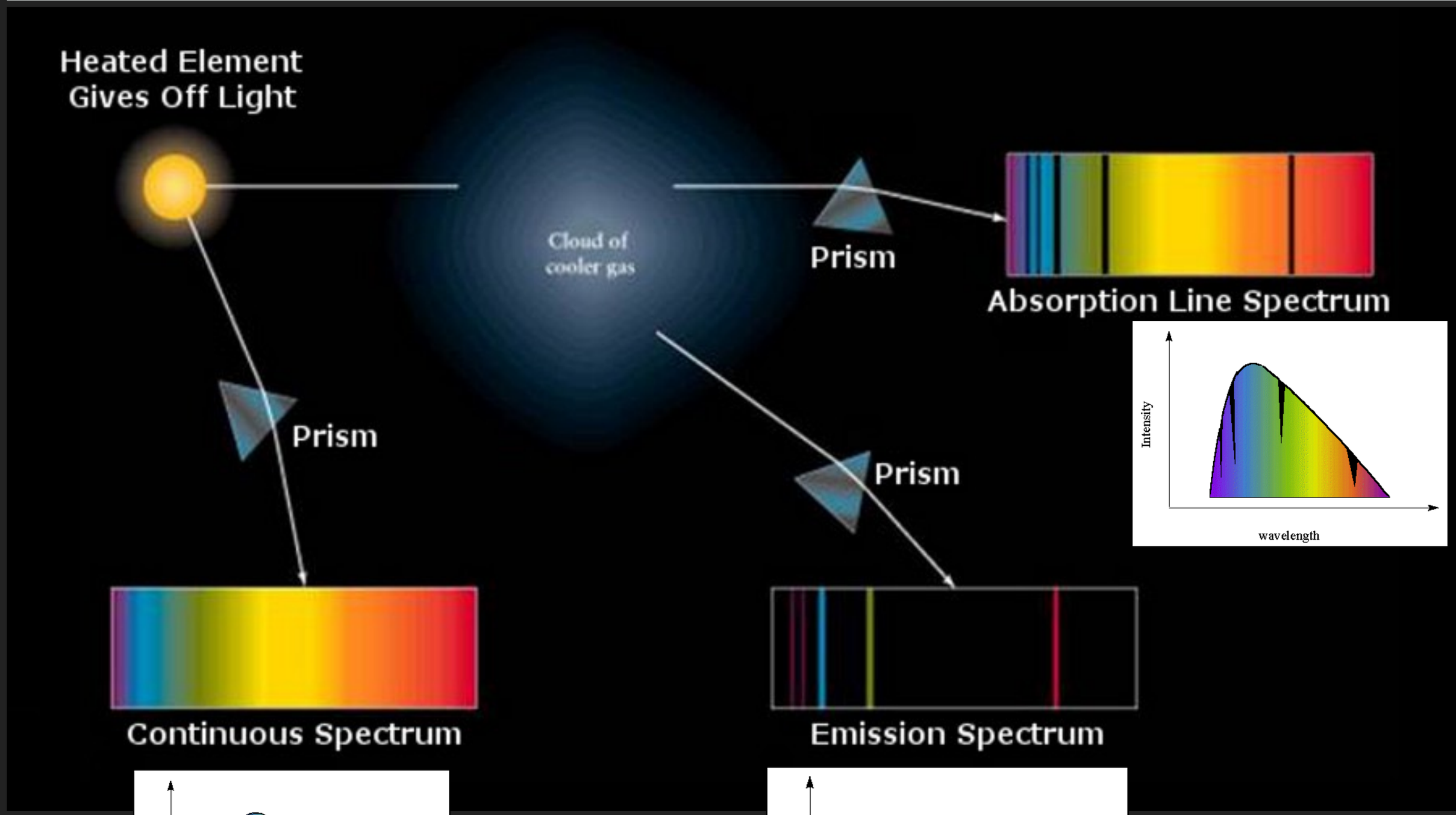


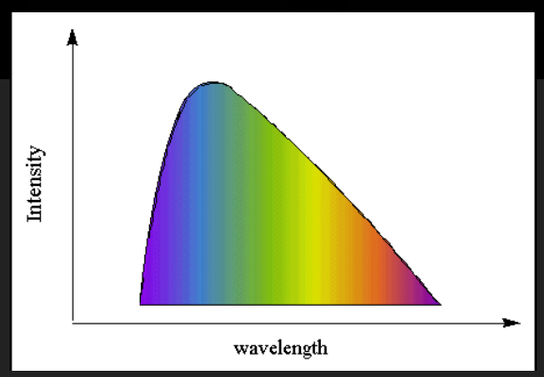


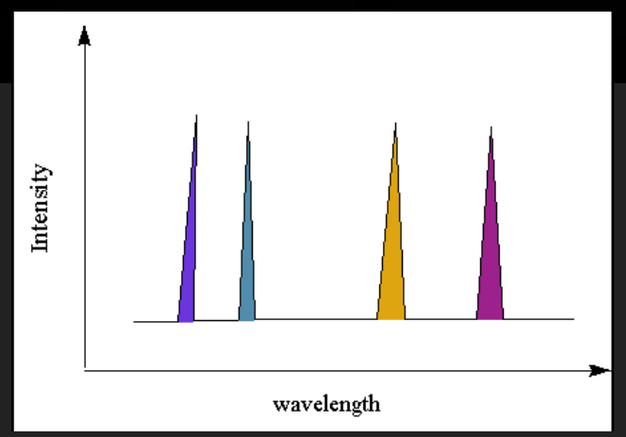
STELLAR SPECTRA



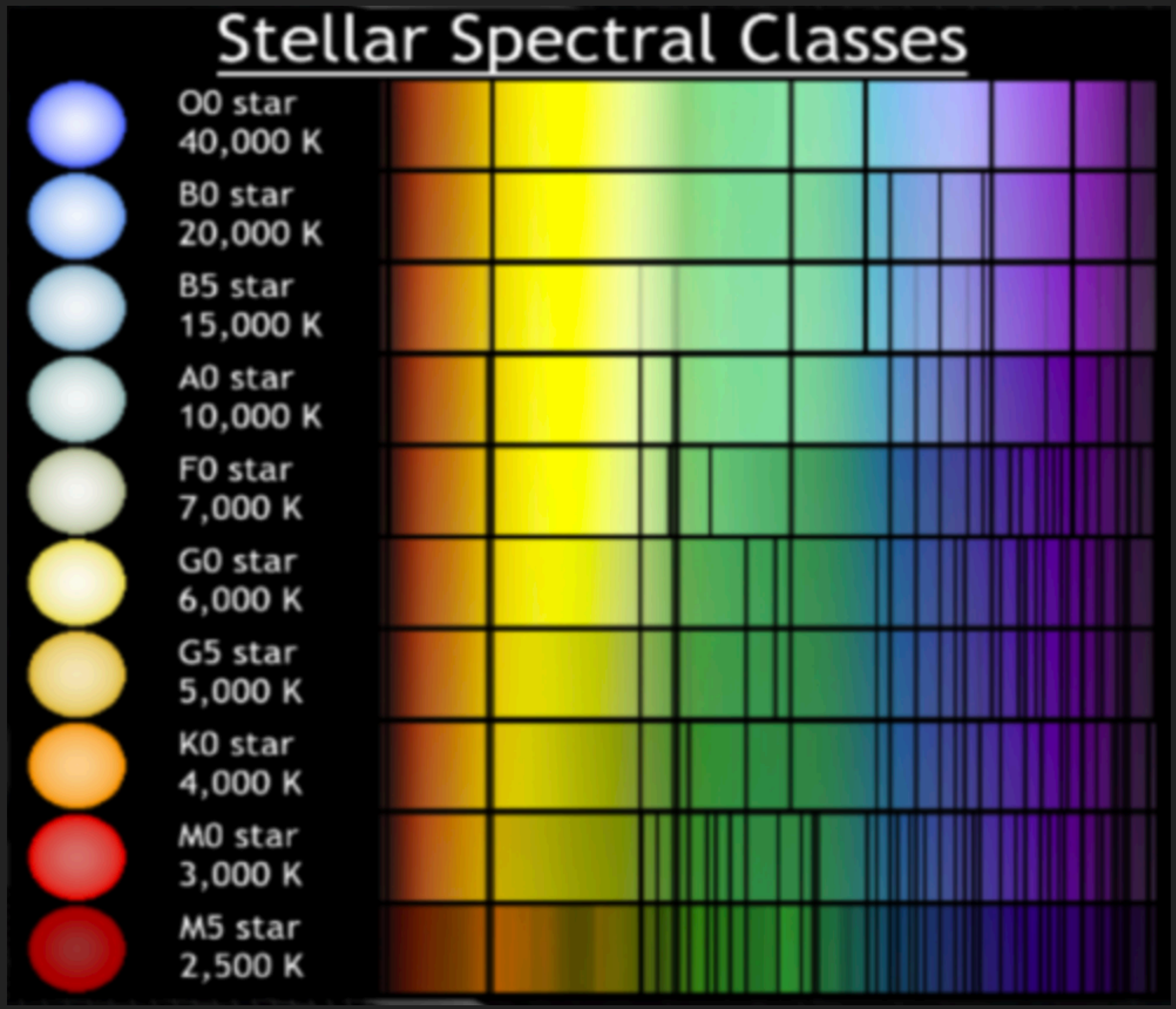
KIRCHHOFF'S LAWS



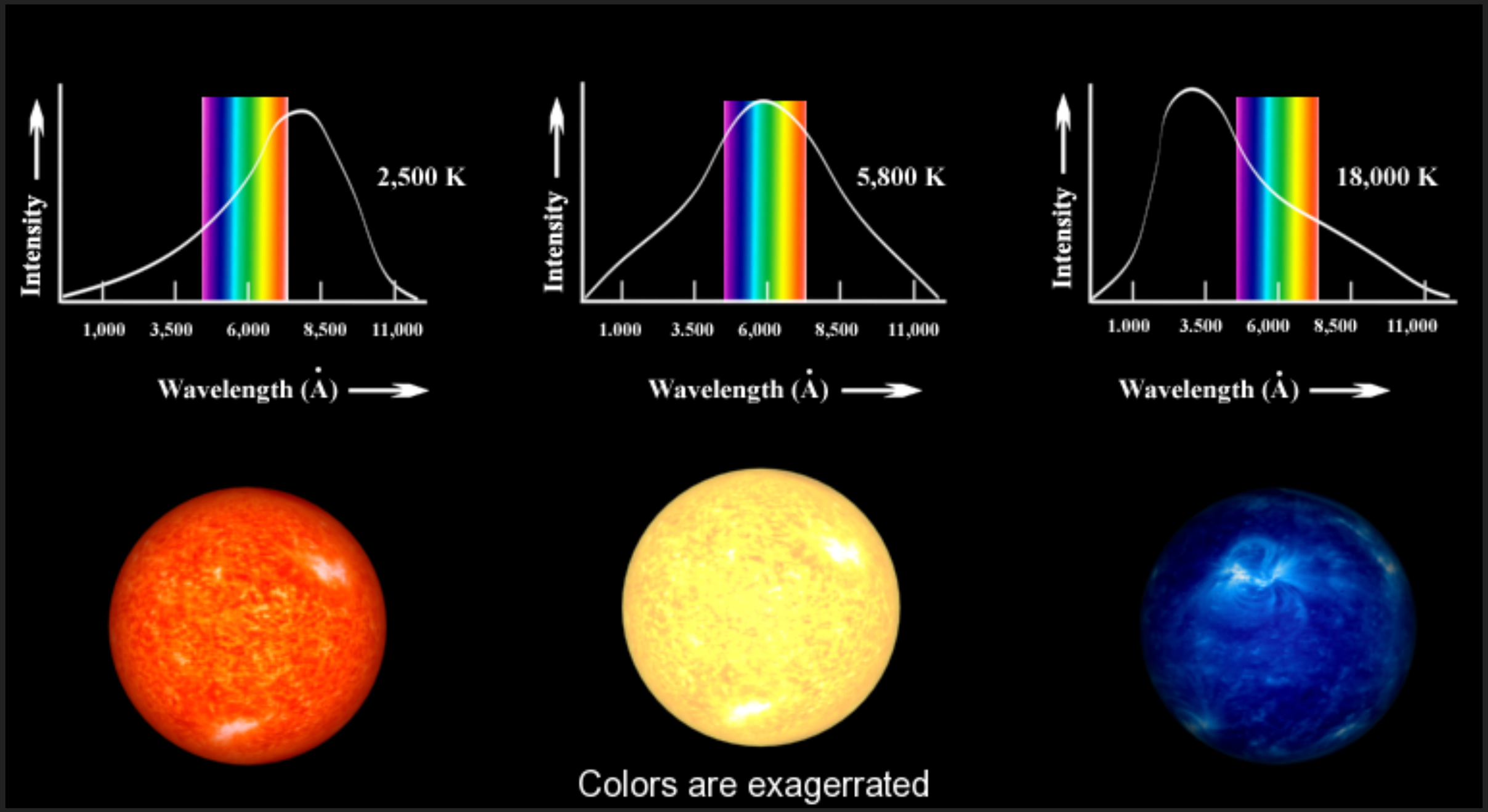




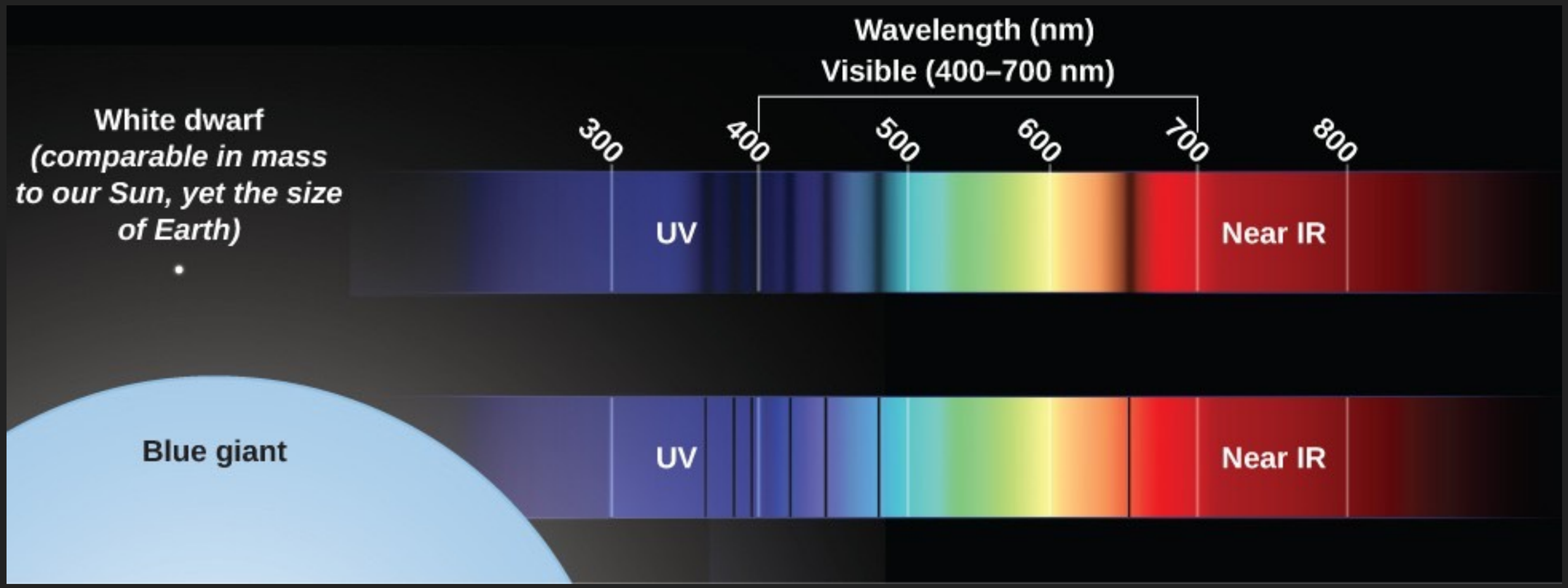
STELLAR SPECTRA



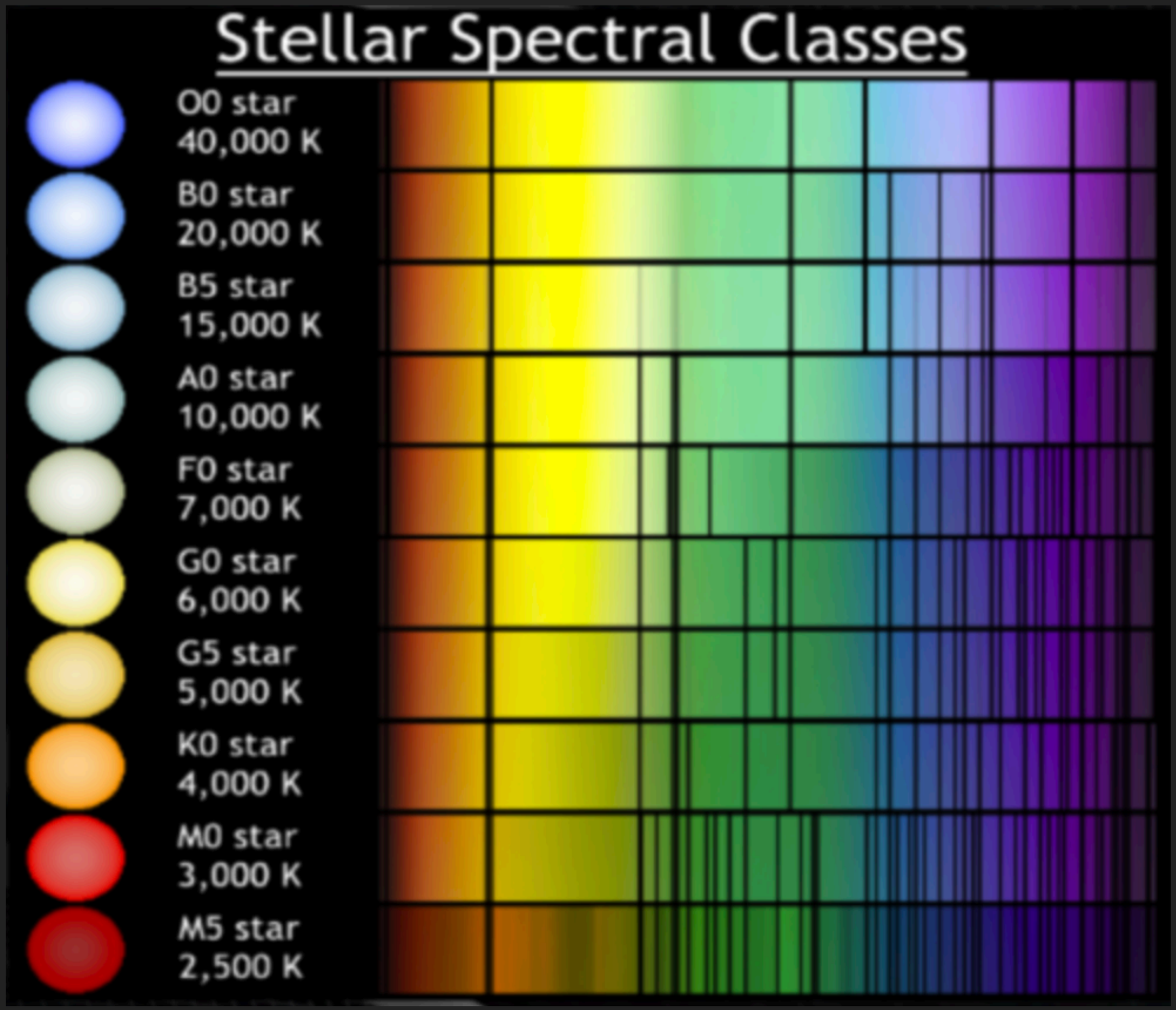
SURFACE TEMPERATURE



THE SIZE OF STARS VIA SPECTRA



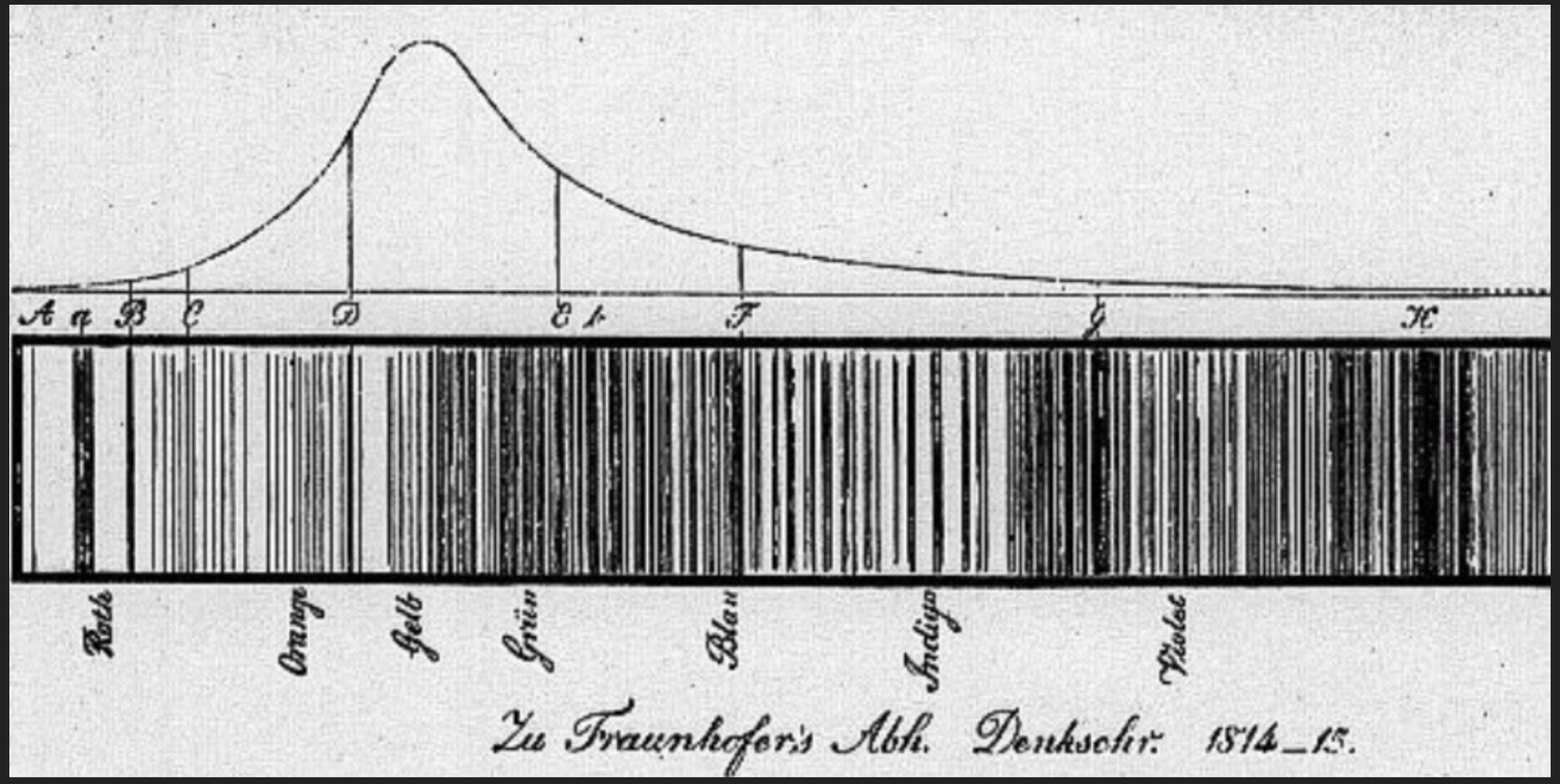
CLASSIFICATION OF STARS



CLASSIFICATION OF STARS

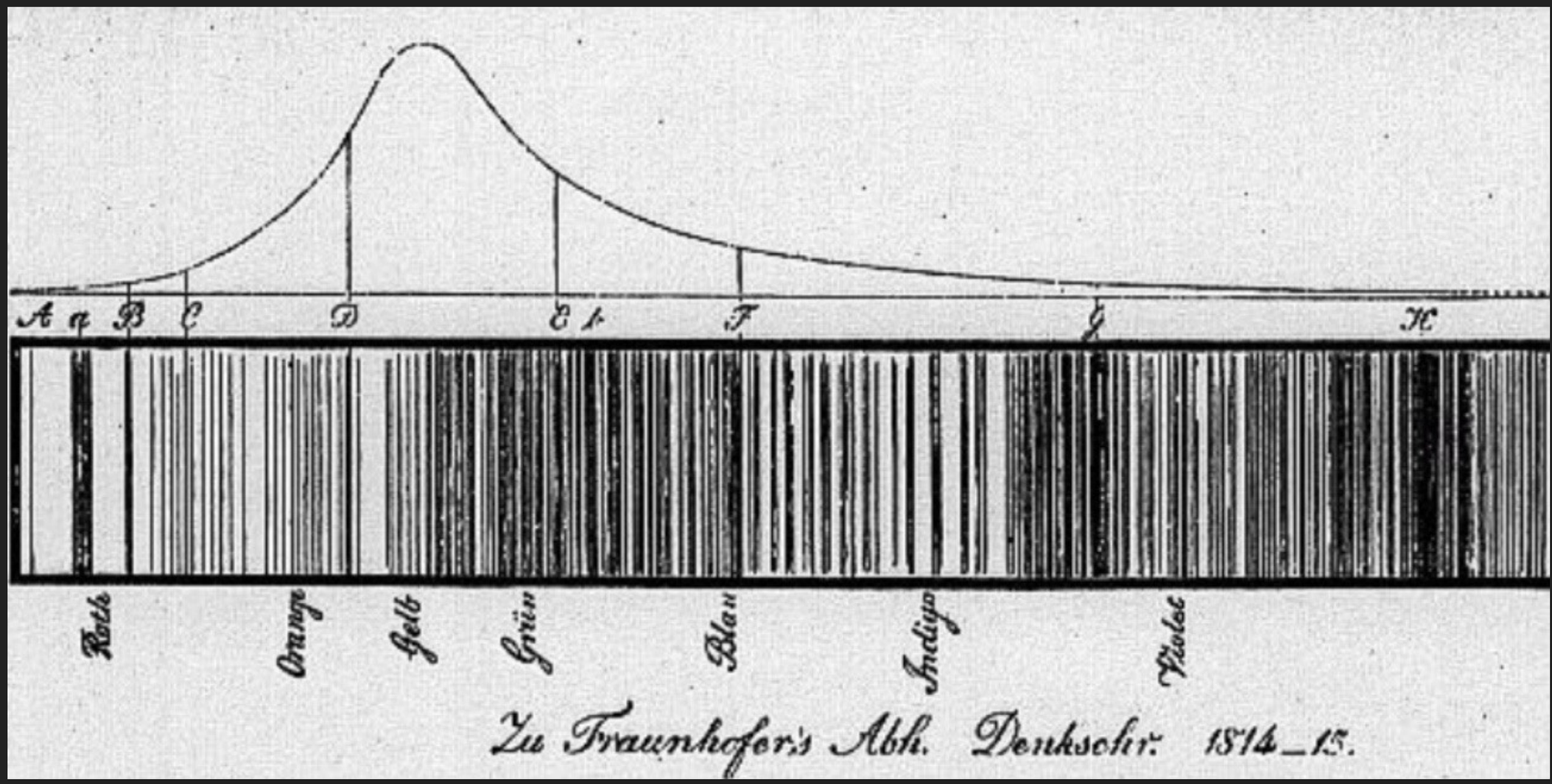
- Joseph von **Fraunhofer** observed **a continuous color change across the spectrum; no color discontinuities at the dark lines.**

- Fraunhofer's observations (1817) of the solar spectrum and the spectra of several bright stars, published in 1823.



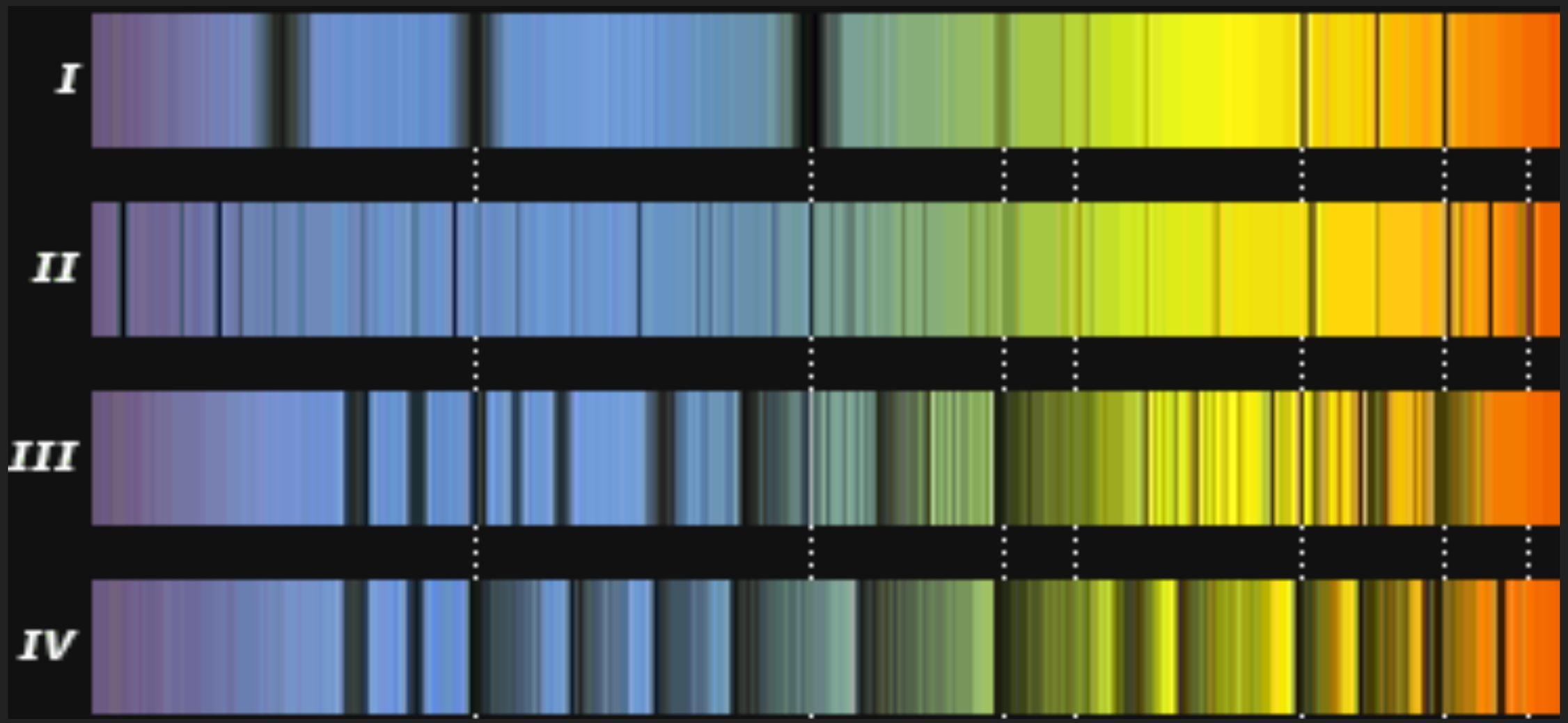
FRAUNHOFER'S LINES

- Dark lines in the spectra of stars!
- Some of the lines in stars were absent in the Sun: not all of the lines were of terrestrial origin.



SECCHI CLASSIFICATION

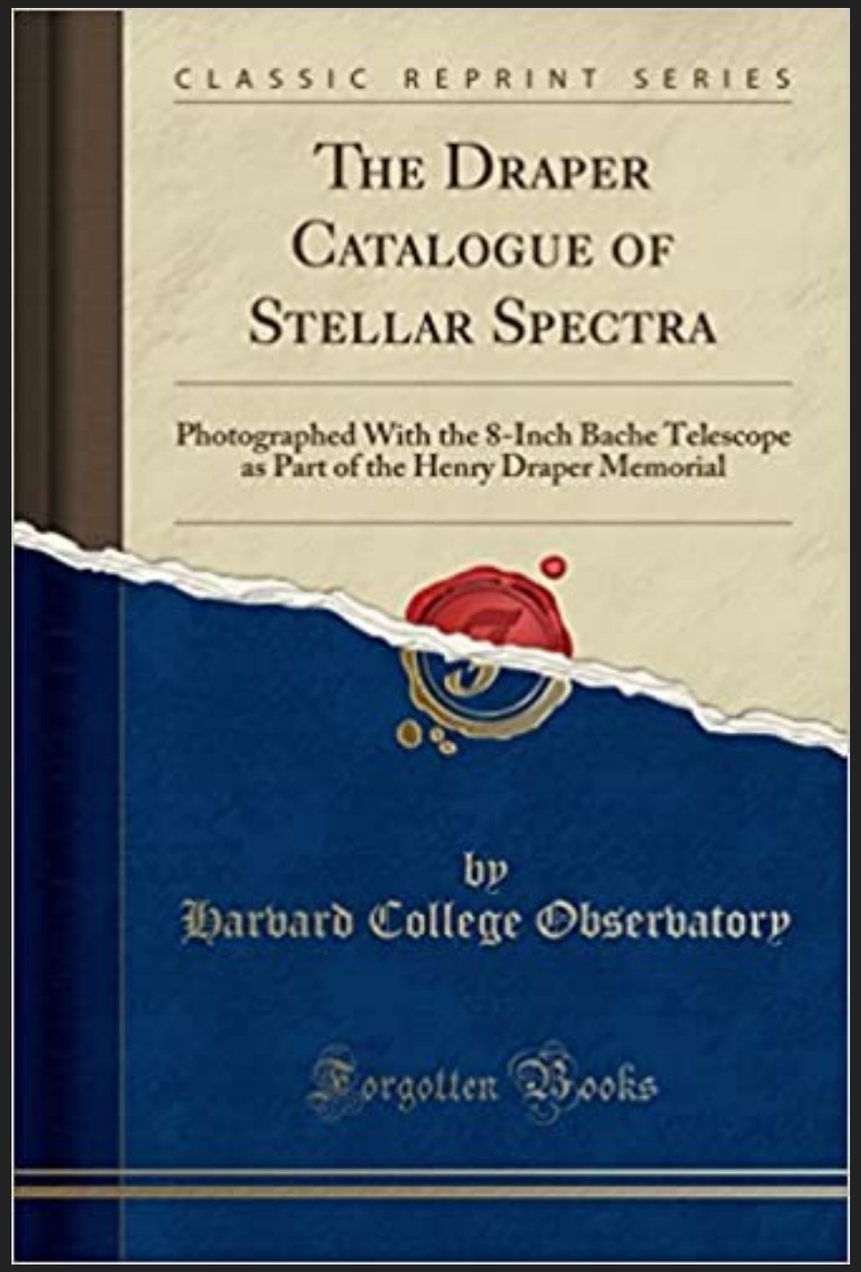
- On the basis of **star colour** and **the relative strength and width of spectral absorption features.**



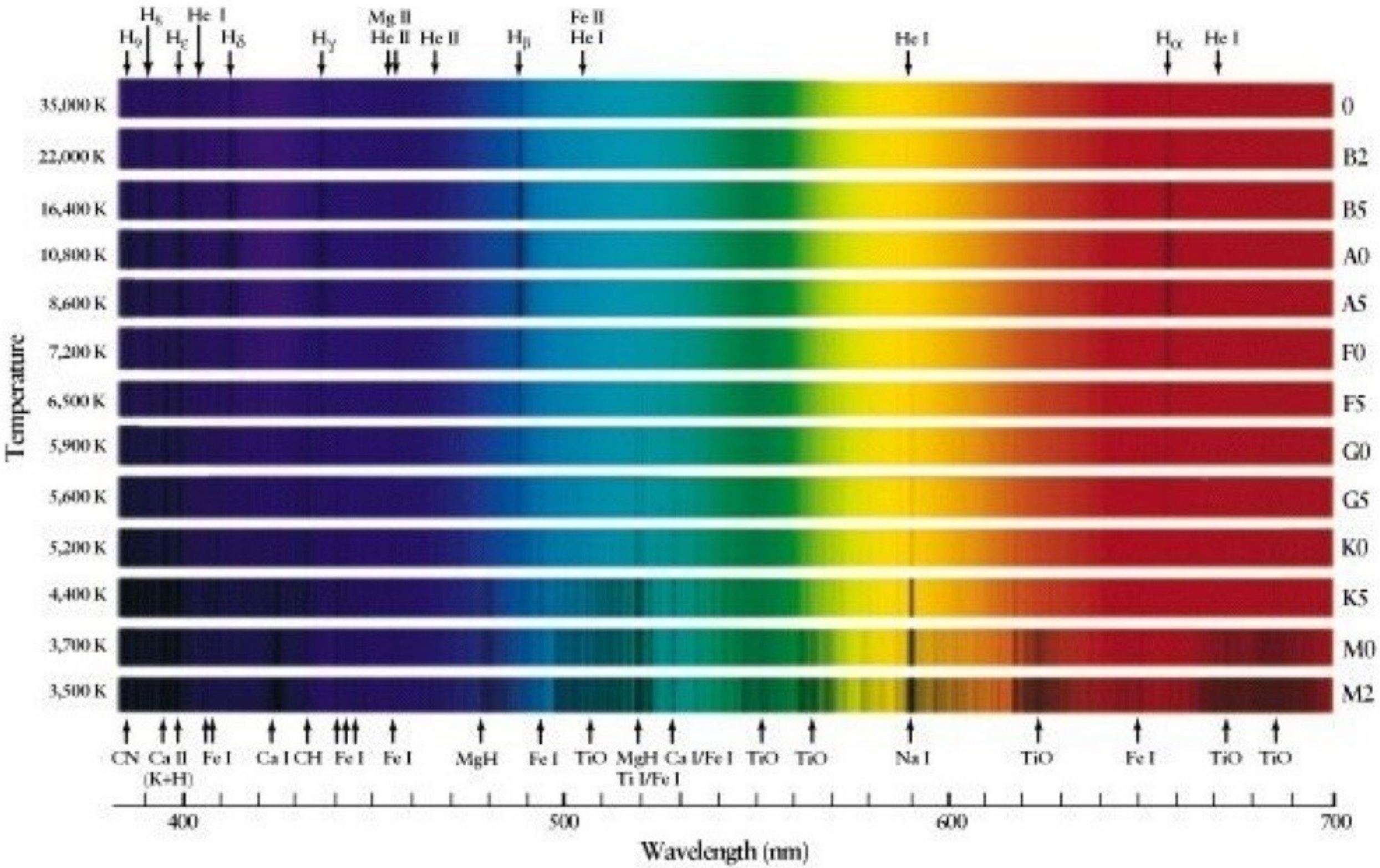
DRAPER SYSTEM

- 1880s Pickering
- 1890 published: Draper Catalogue of Stellar Spectra
- Williamina Fleming
- Used Secchi classes but added extra

Secchi	Draper	Comment
I	**A**, **B**, C, D	Hydrogen lines dominant.
II	E, **F**, **G**, H, I, **K**, L	
III	**M**	
IV	N	Did not appear in the catalogue.
V	**O**	Included Wolf–Rayet spectra with bright lines.
V	P	Planetary nebulae.
	Q	Other spectra.
*Classes carried through into the MK system are in **bold**.*		



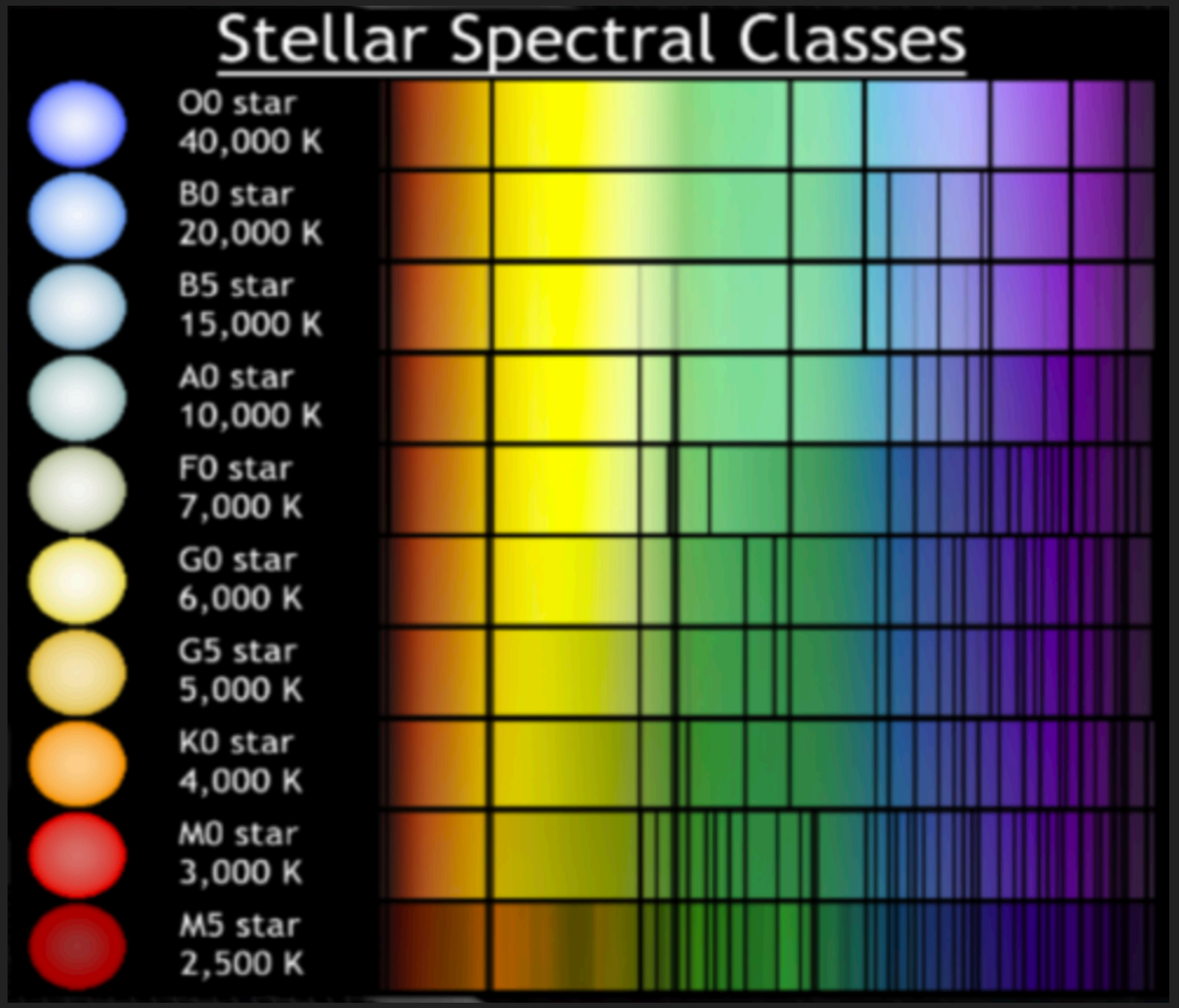
DRAPER SYSTEM



HARVARD SYSTEM

- Additional categorization by **Antonia Maury**, Annie Jump Cannon and Henrietta Swan Leavitt among others.
- In 1901 Annie Jump Cannon revised the system.
- dropped most of the letters, leaving A,B,F,G,K,M and O.
- 10 divisions: A0, A1, A2…. A9.
- re-ordered: based on the stars' surface temperatures, not the strength of the Hydrogen line, with the hottest stars first.
- Final version: 1912

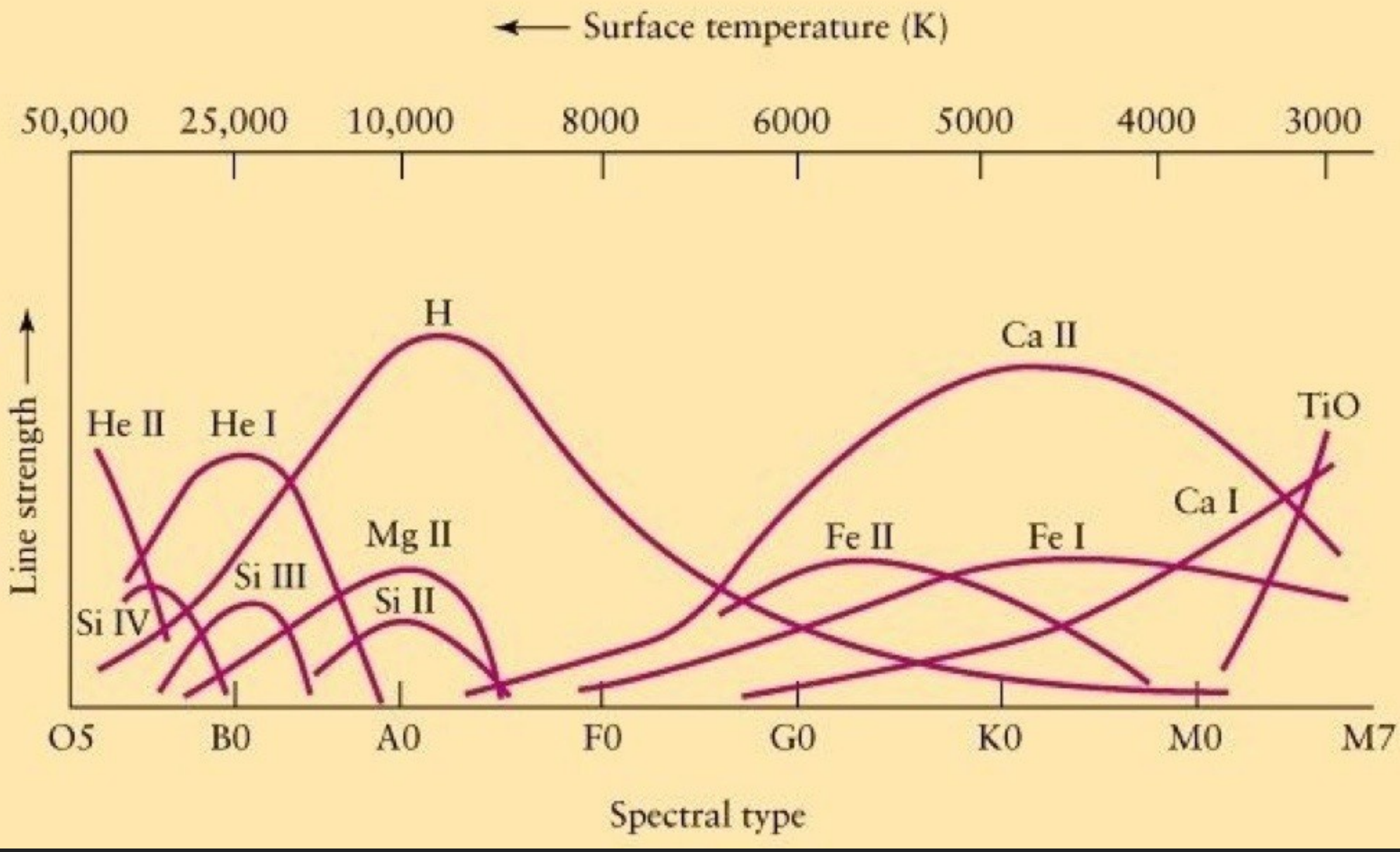
OBAFGKM



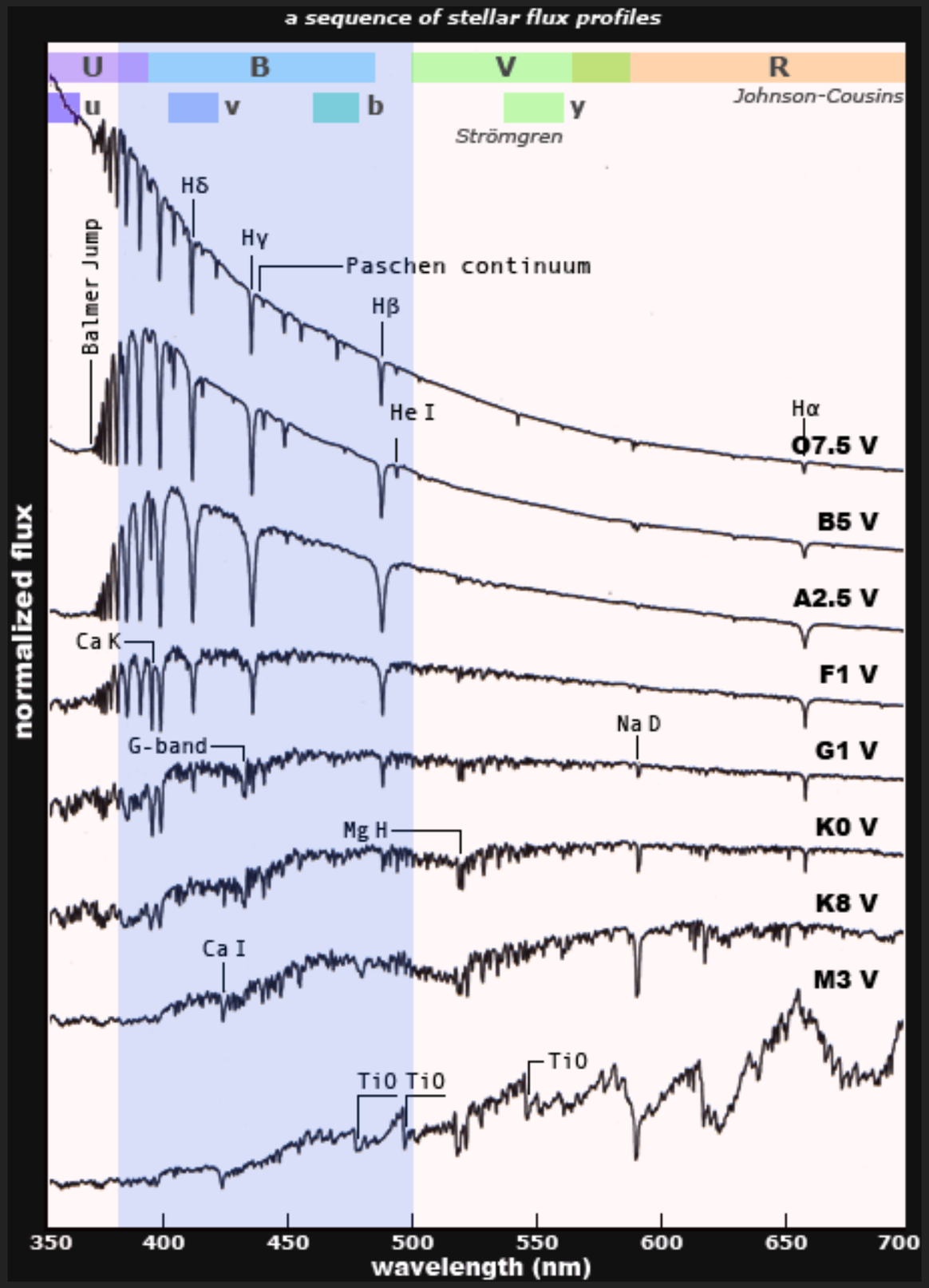
Oh Be A Fine Girl/Guy Kiss Me

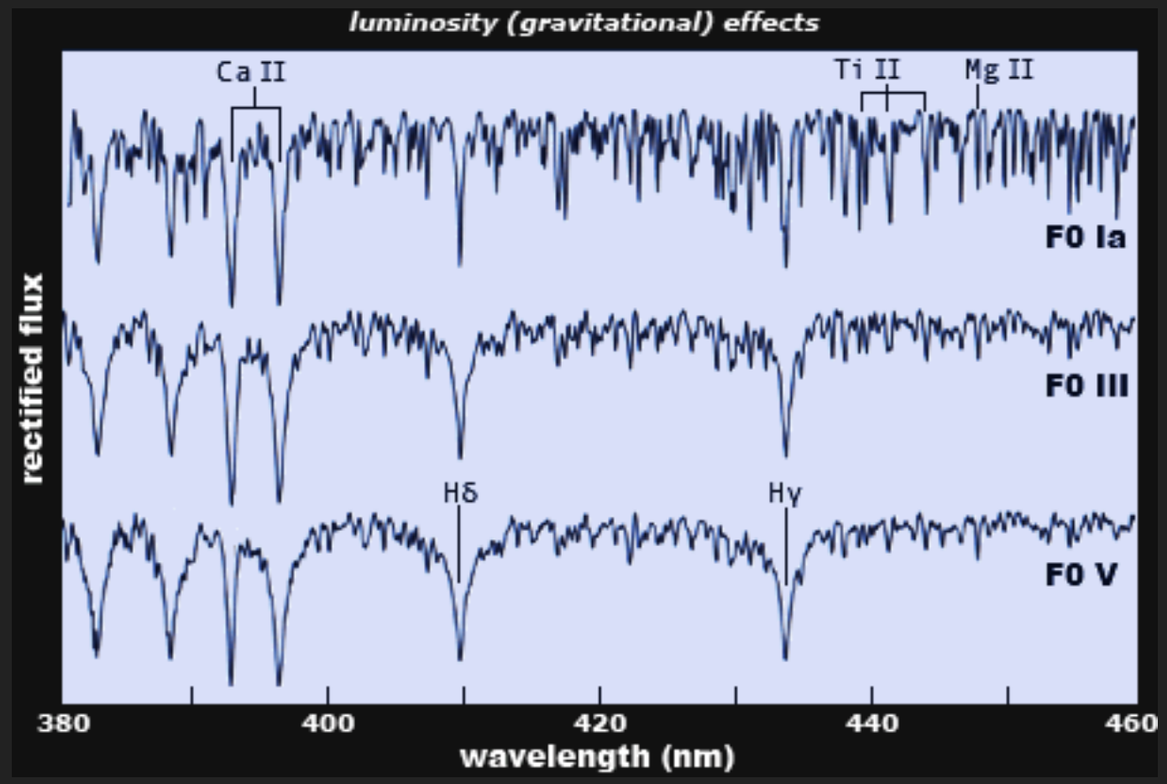
What are the other mnemonics for OBAFGKM?

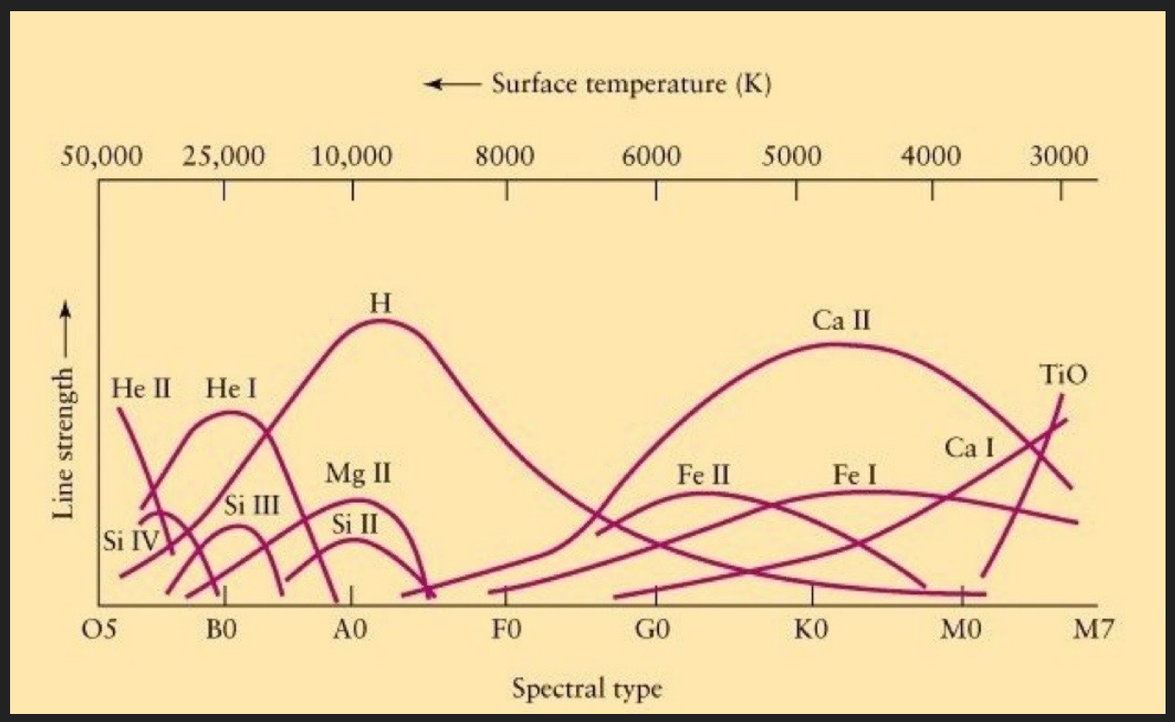
SPECTRAL CLASSIFICATION



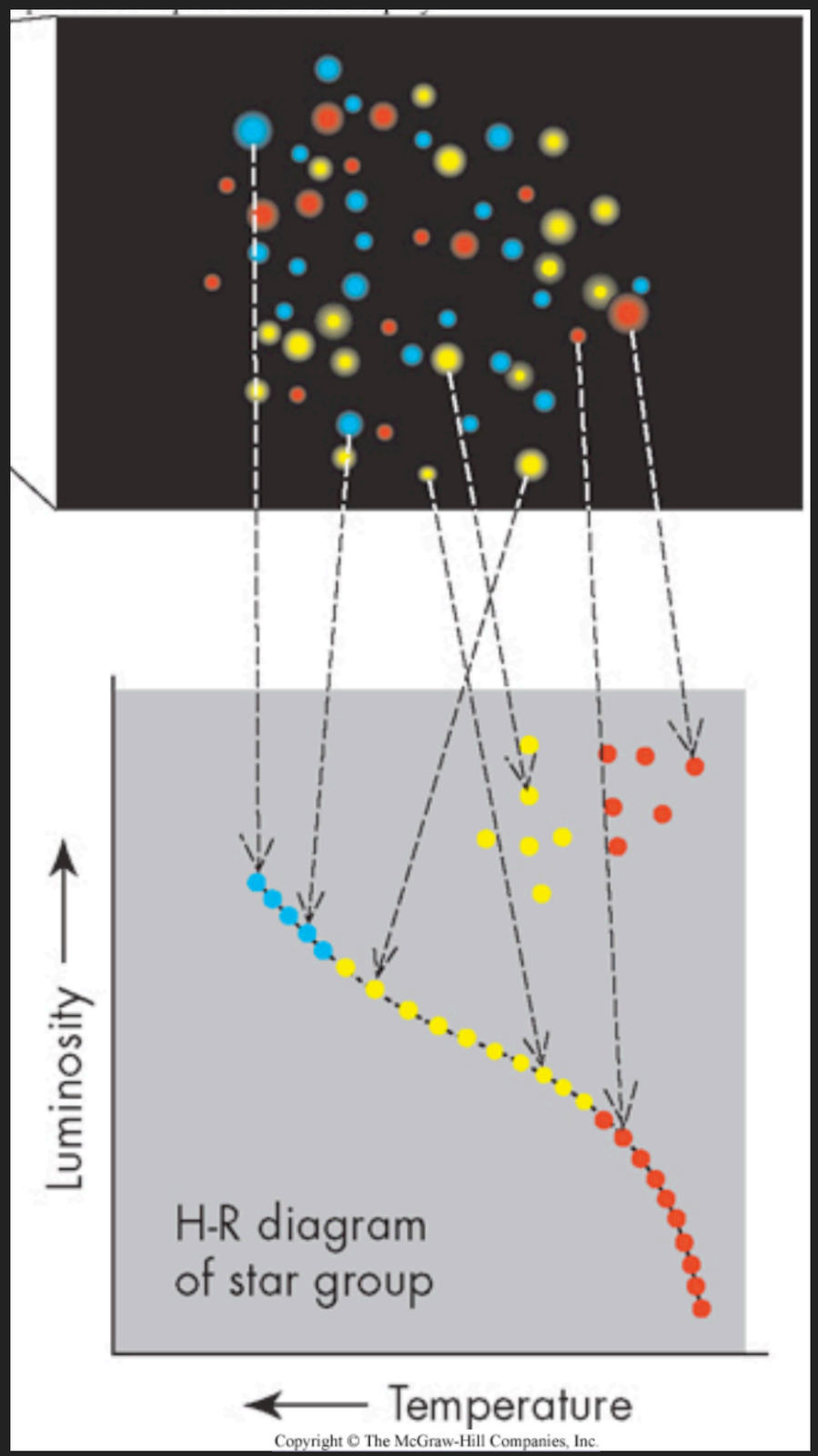
STELLAR SPECTRA







HR DIAGRAM

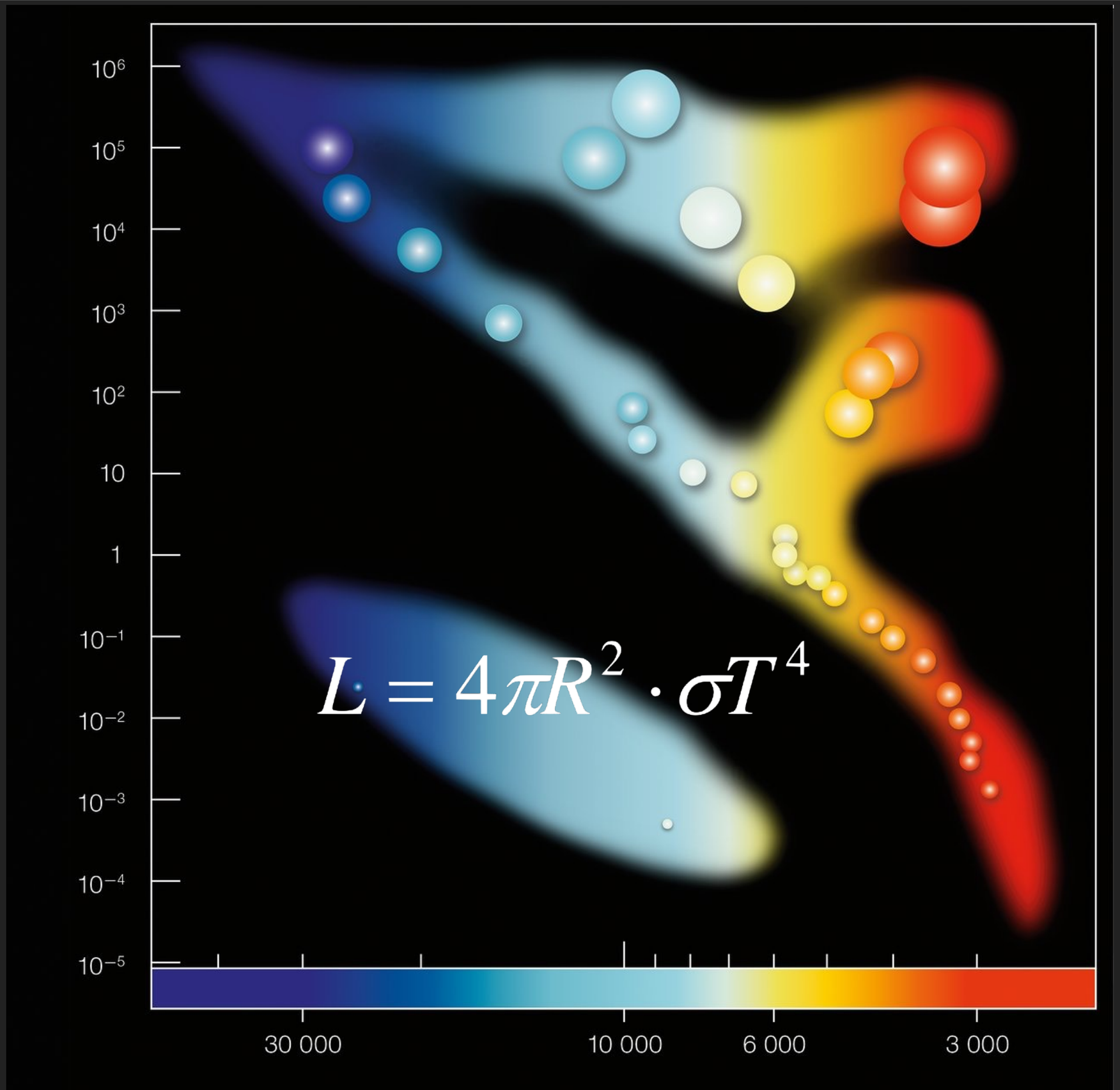


- Maury developed a complex categorization, published in 1897, based partly on temperature and the width of spectral lines;
- This system was cited in Ejnar Hertzsprung's 1905 to 1909 papers
- The way to the **Hertzsprung-Russell diagram, a plot of the distribution of the luminosity and surface temperature of stars.**

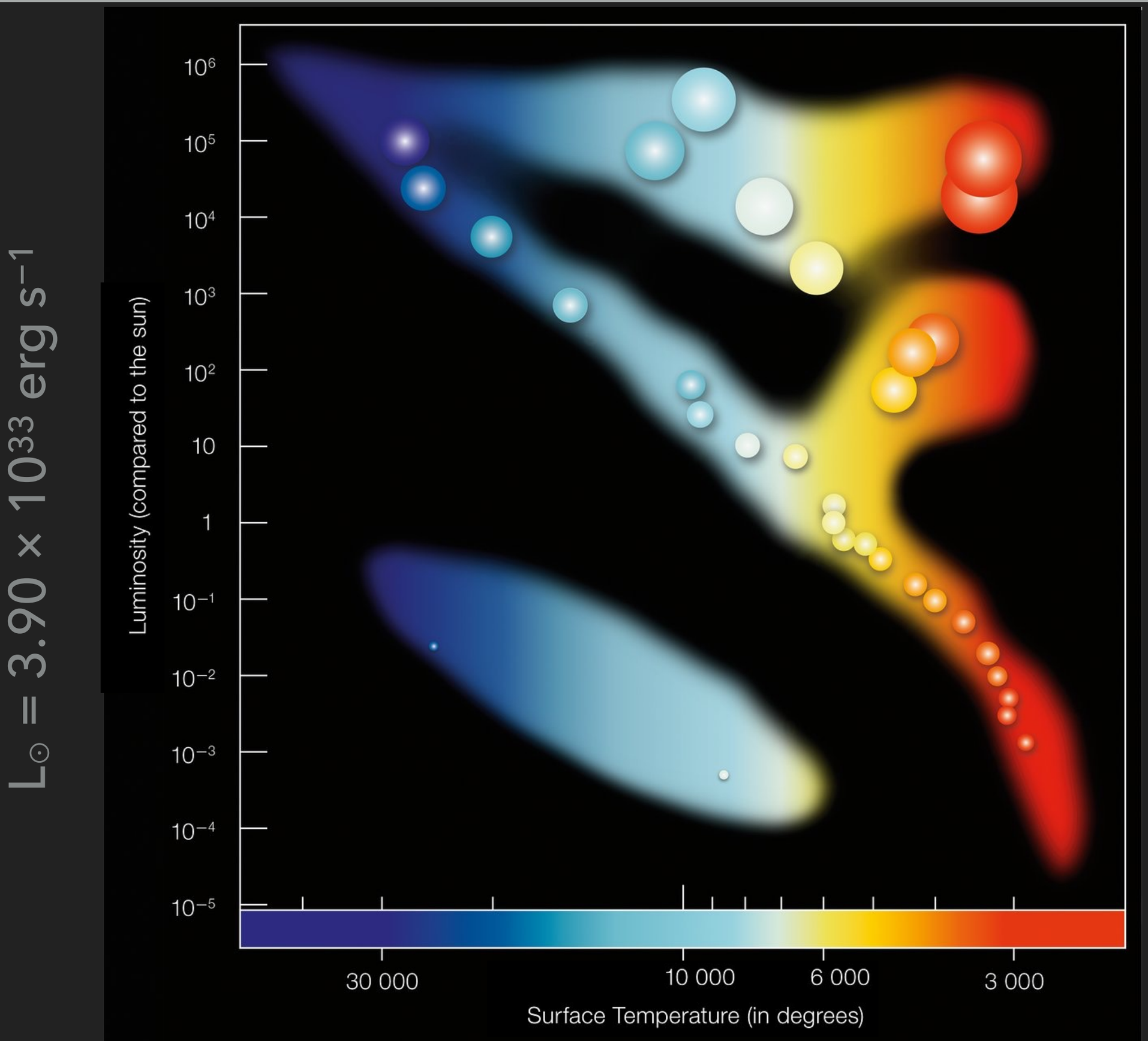
HR DIAGRAM

www.spacetelescope.org

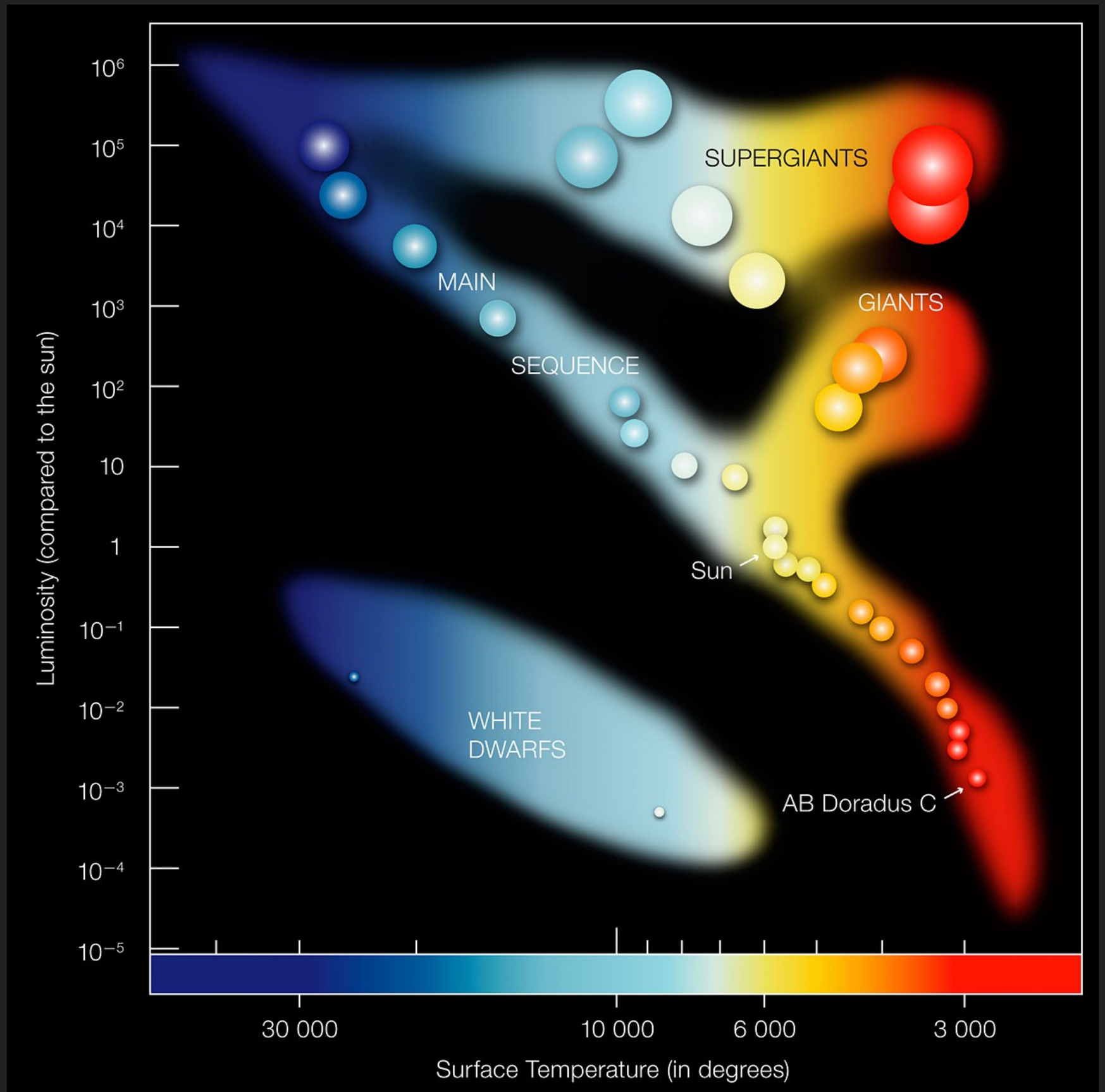
HR DIAGRAM


10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$L = 4\pi R^2 \cdot \sigma T^4$
30 000
10 000
6 000
3 000

HR DIAGRAM

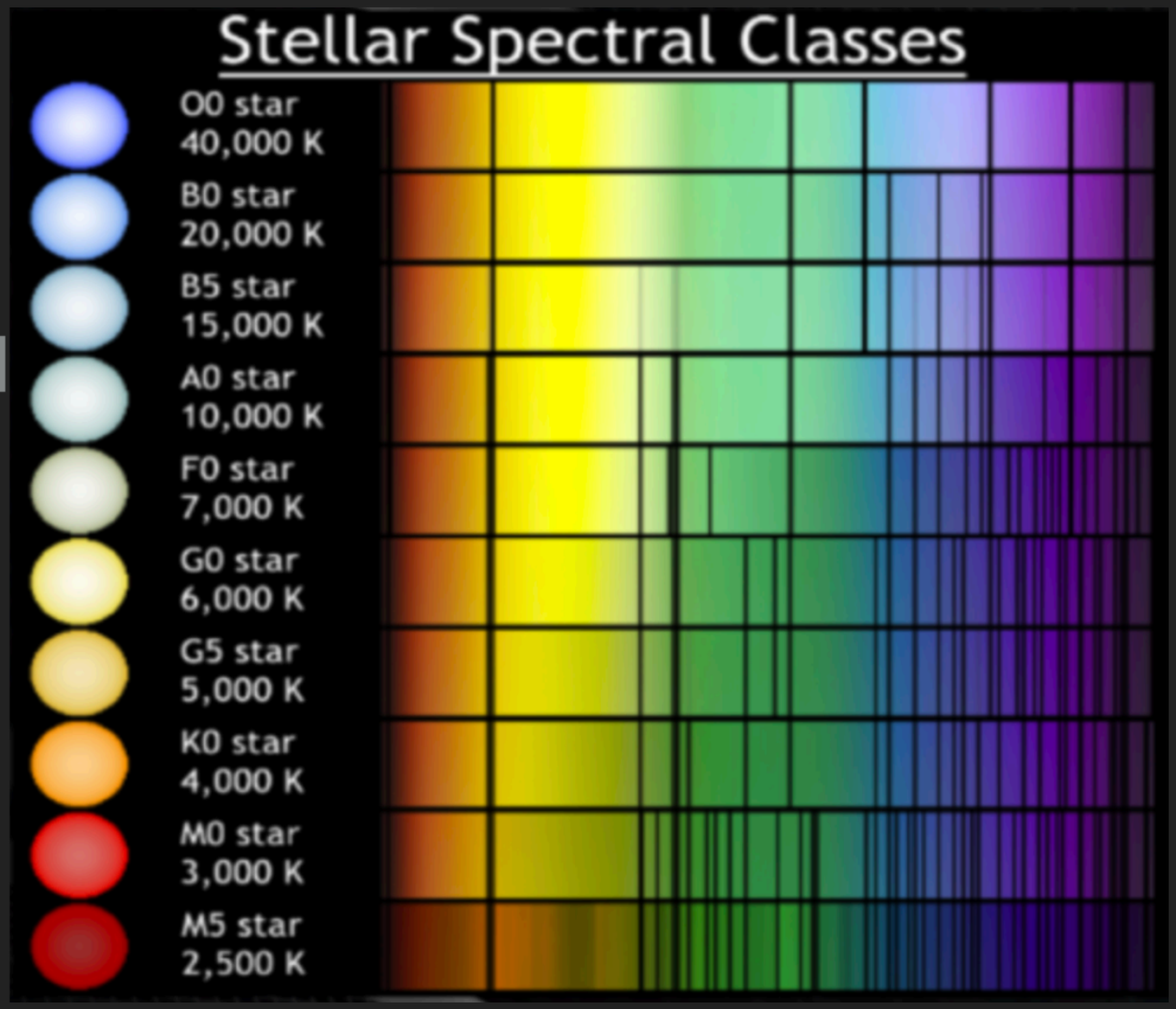

$L_\odot = 3.90 \times 10^{33}$ erg s^{-1}
Luminosity (compared to the sun)
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
30 000
10 000
6 000
3 000
Surface Temperature (in degrees)

HR DIAGRAM

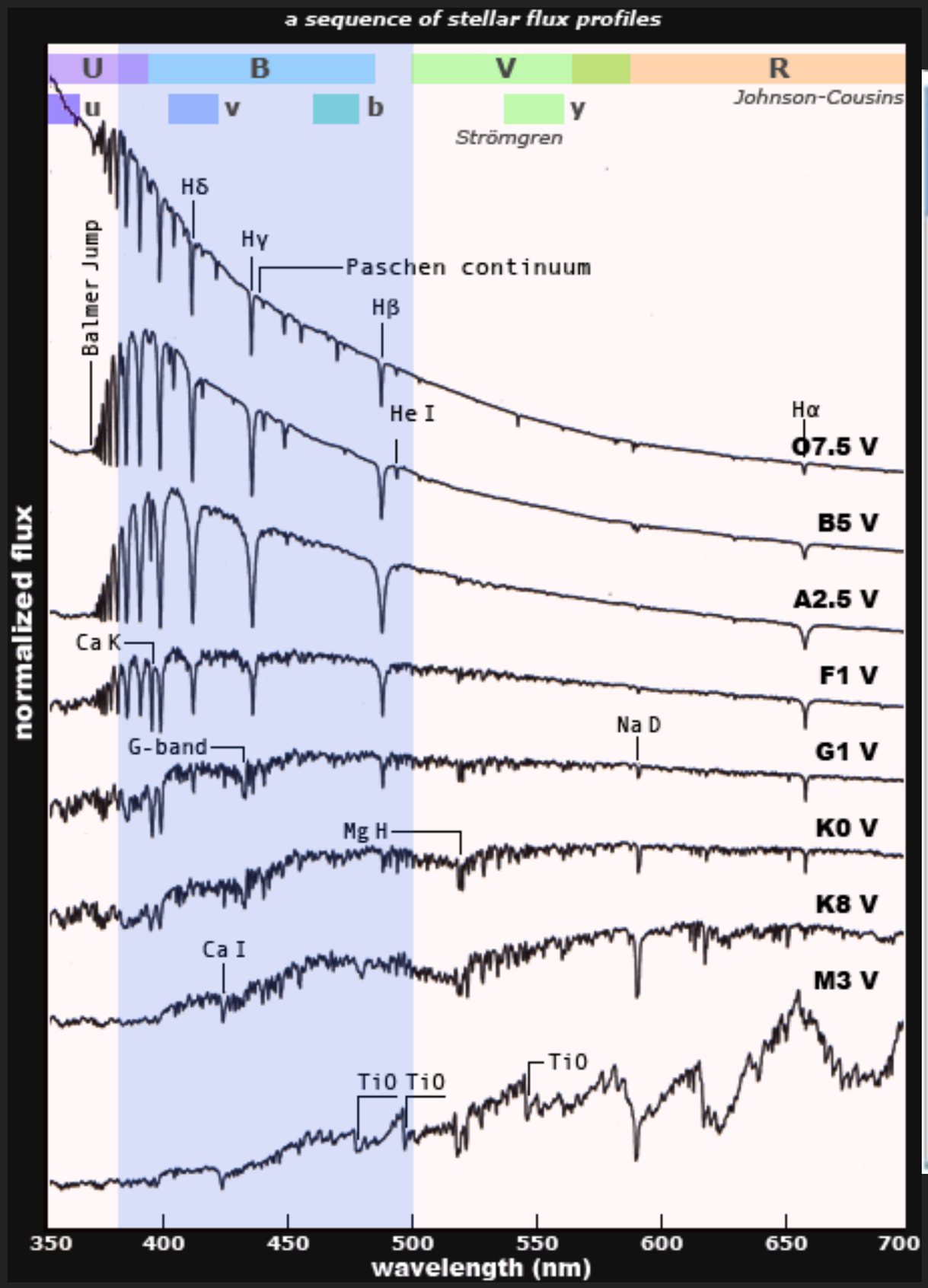

10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Luminosity (compared to the sun)
SUPERGIANTS
MAIN
SEQUENCE
GIANTS
Sun
WHITE
DWARFS
AB Doradus C
30 000
10 000
6 000
3 000
Surface Temperature (in degrees)

HARVARD SYSTEM

- 1D classification (surface temperature) by Annie Jump Cannon
- re-ordered and simplified by Draper
- Each class indicates the effective temperature of the star
- From the hottest to the coldest



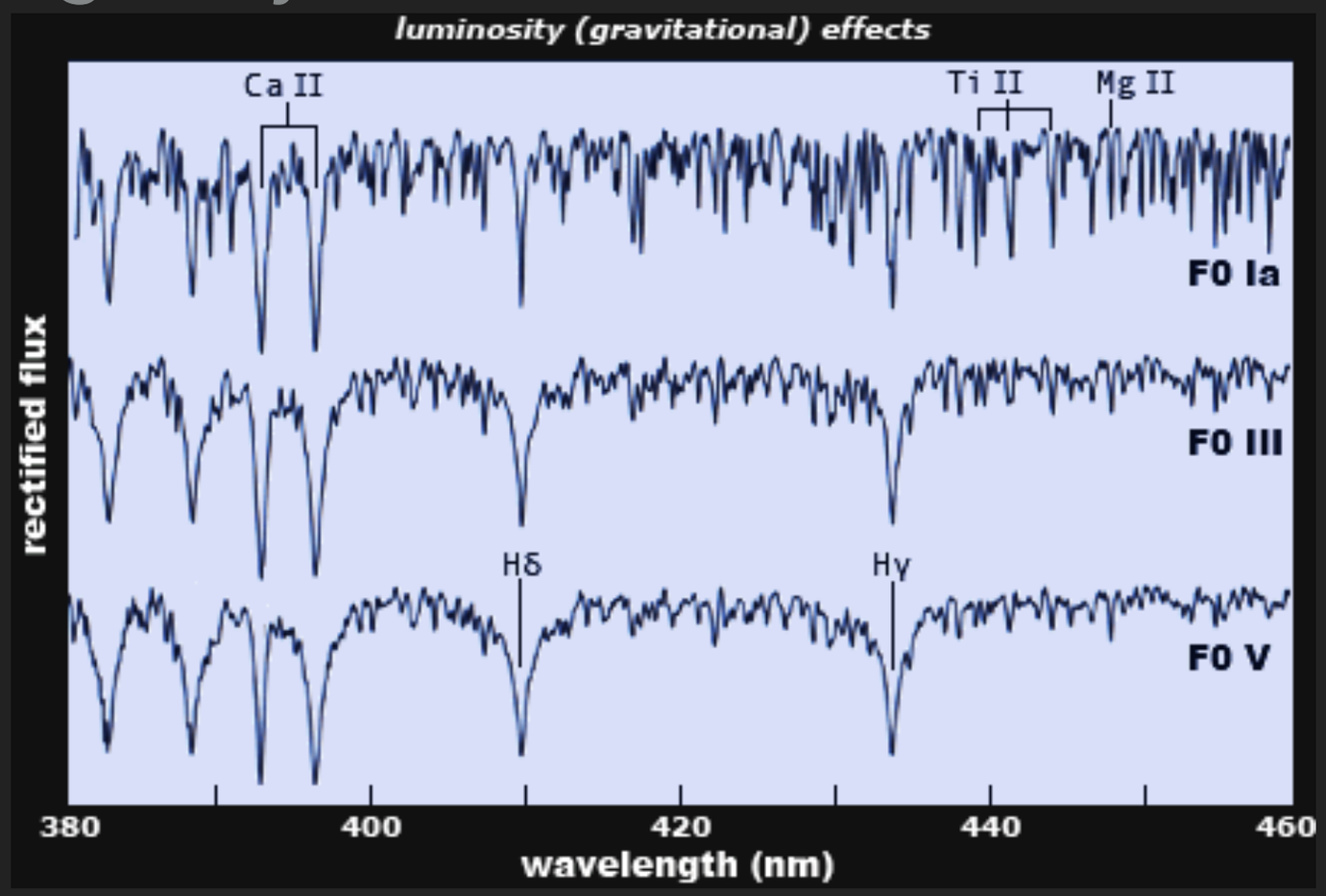
OBAFGKM



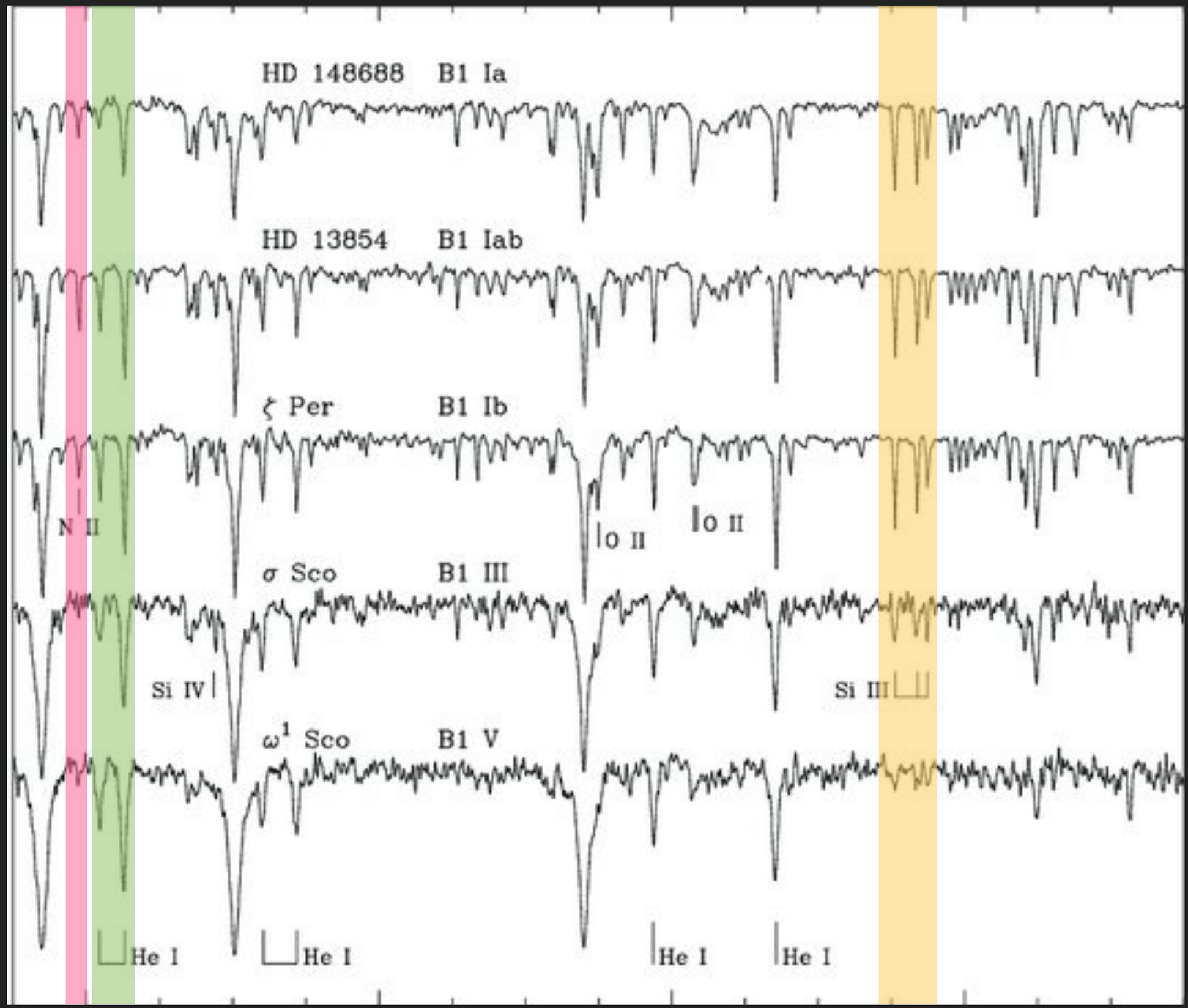
Spectral Type	Example(s)	Temperature Range	Key Absorption Line Features
O	Stars of Orion's Belt	>30,000 K	Lines of ionized helium, weak hydrogen lines
B	Rigel	30,000 K–10,000 K	Lines of neutral helium, moderate hydrogen lines
A	Sirius	10,000 K–7,500 K	Very strong hydrogen lines
F	Polaris	7,500 K–6,000 K	Moderate hydrogen lines, moderate lines of ionized calcium
G	Sun, Alpha Centauri A	6,000 K–5,000 K	Weak hydrogen lines, strong lines of ionized calcium
K	Arcturus	5,000 K–3,500 K	Lines of neutral and singly ionized metals, some molecules
M	Betelgeuse, Proxima Centauri	<3,500 K	Molecular lines strong

YERKES SYSTEM – MKK/MK

- 1943 by William Wilson **Morgan**, Philip C. **Keenan**, and Edith **Kellman** from Yerkes Observatory.
- 2D (temperature and luminosity)
- based on spectral lines sensitive to stellar temperature and surface gravity, which is related to luminosity

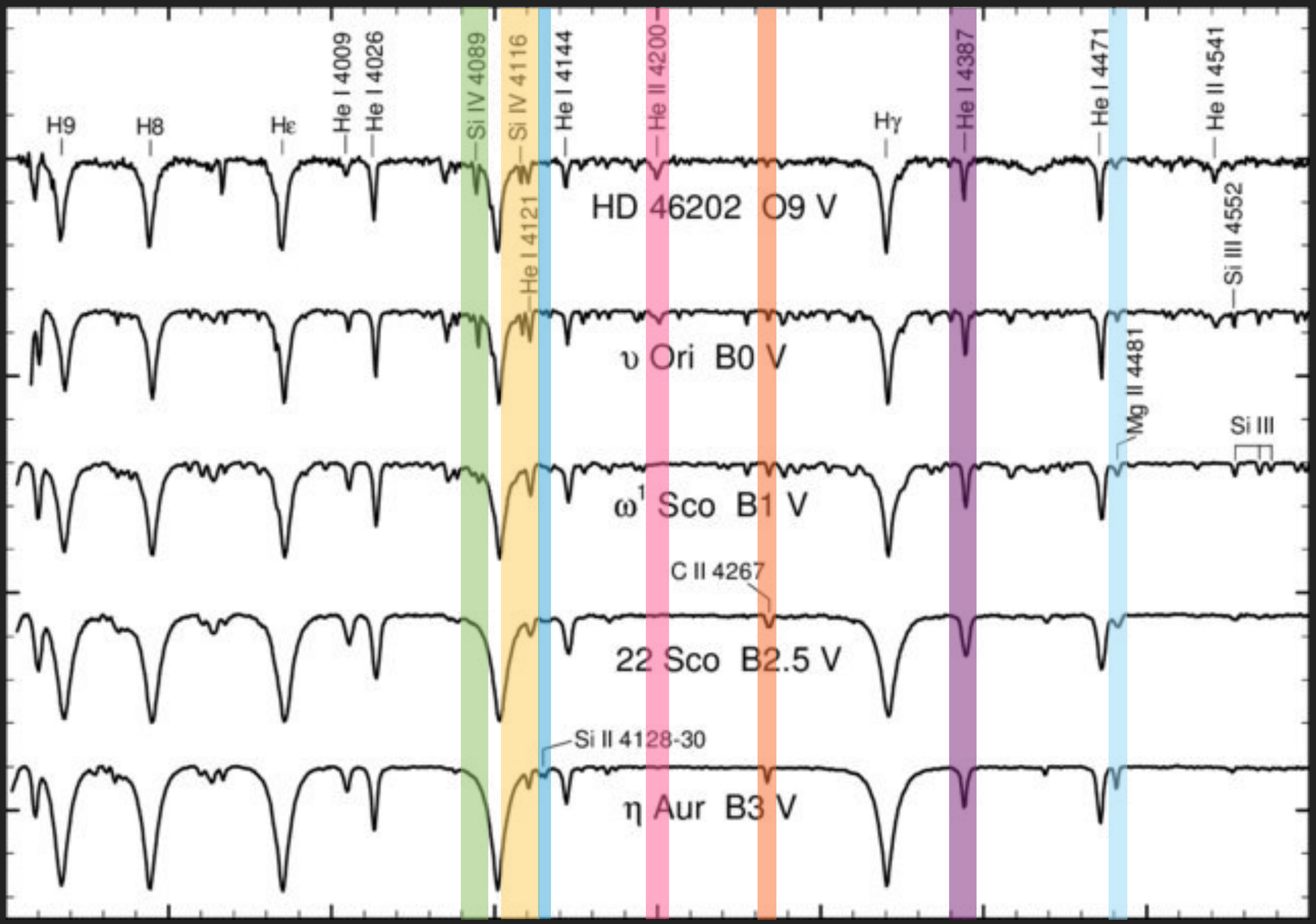


LUMINOSITY CLASS



https://www.researchgate.net/publication/266864685_A_Digital_Spectral_Classification_Atlas/figures

SPECTRAL SUB-CLASS



https://www.researchgate.net/publication/266864685_A_Digital_Spectral_Classification_Atlas/figures

LUMINOSITY CLASSES

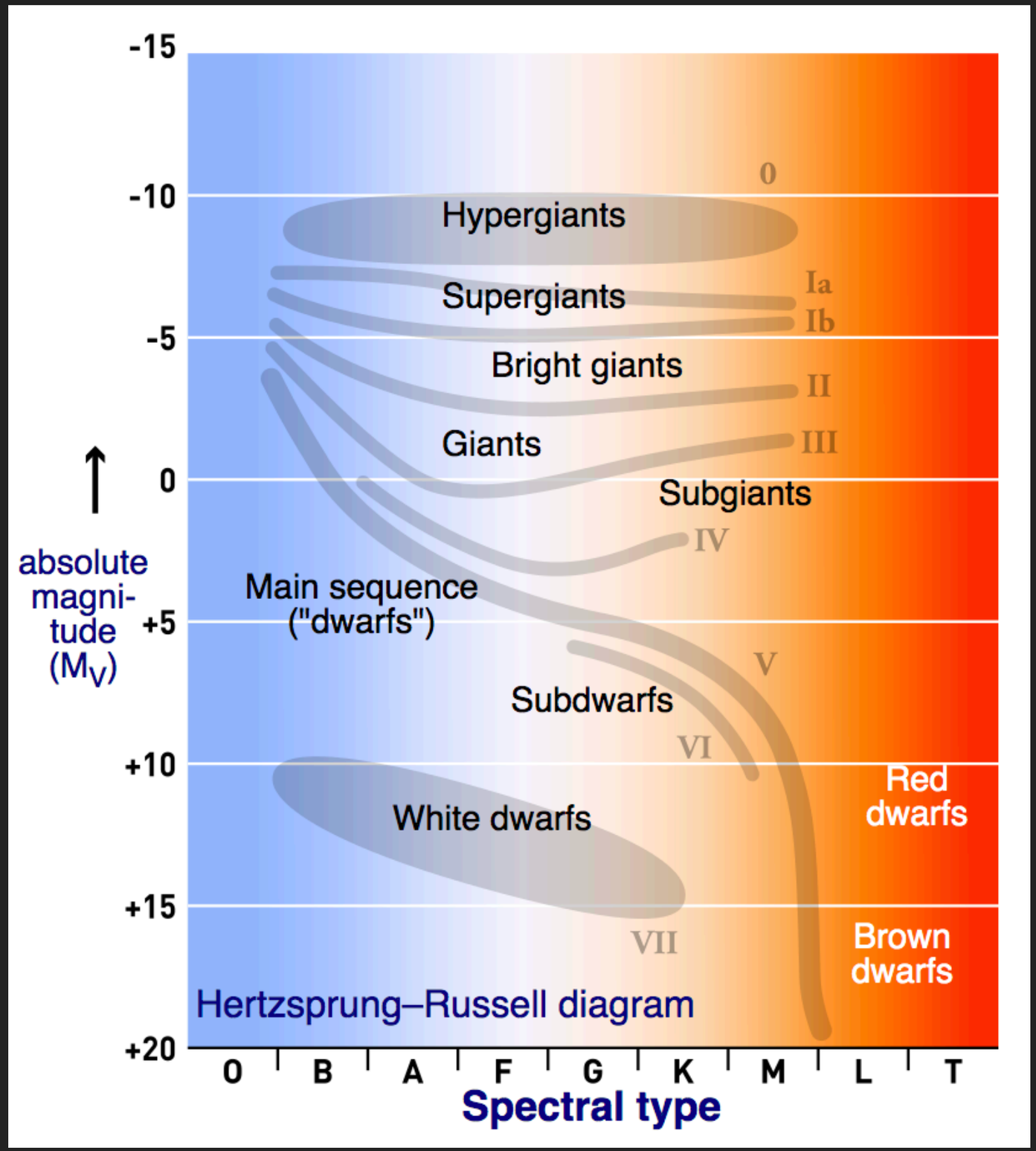
Roman numerals.

- Class 0 or Ia+: Hypergiants
- Class Ia,b : Supergiant
- Class II: Bright giant
- Class III: Giant
- Class IV: Sub-giant
- Class V: Dwarf (Main Sequence)

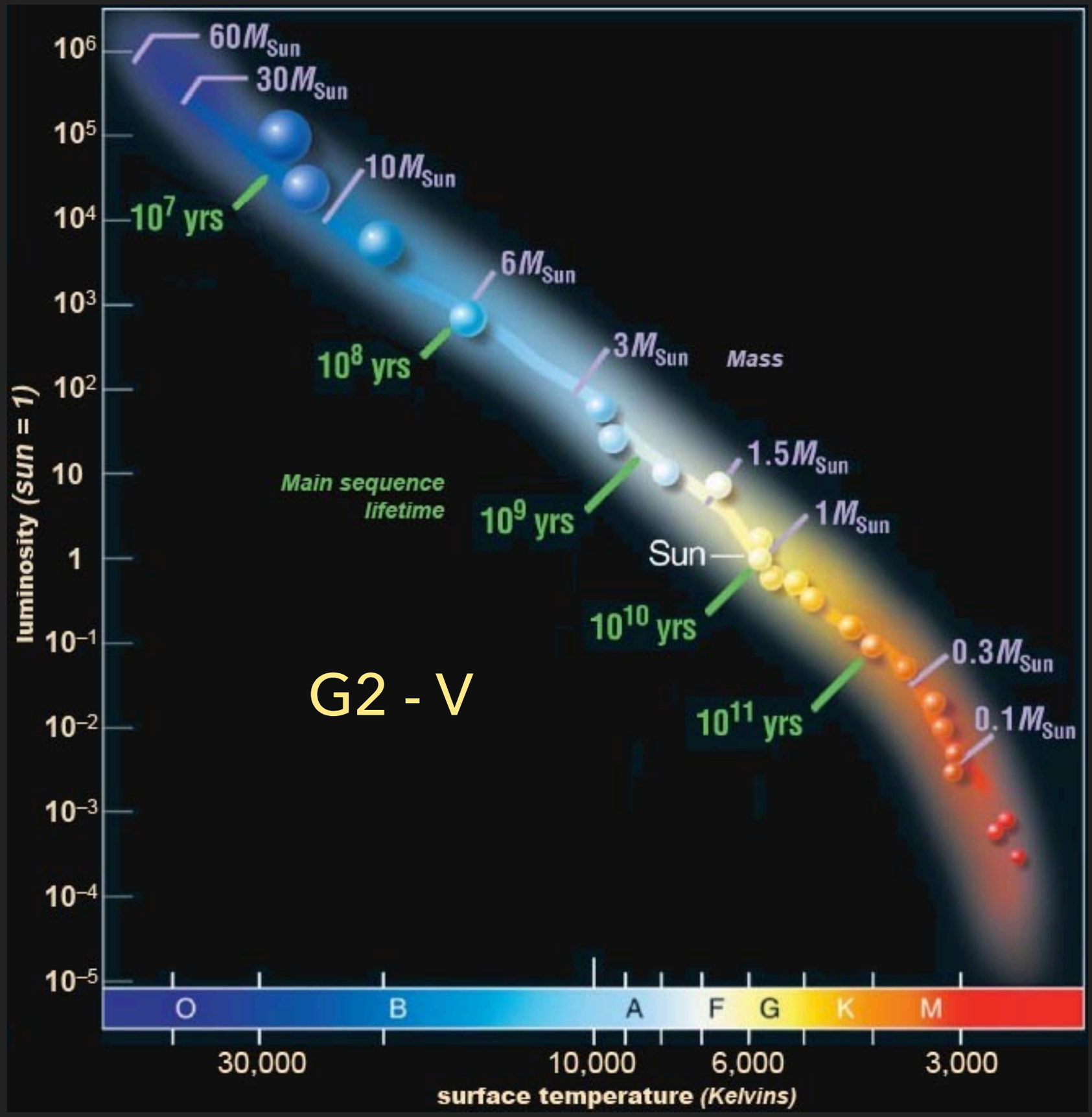
Class sd (or VI): sub-dwarfs

Class D (or VII): white dwarfs

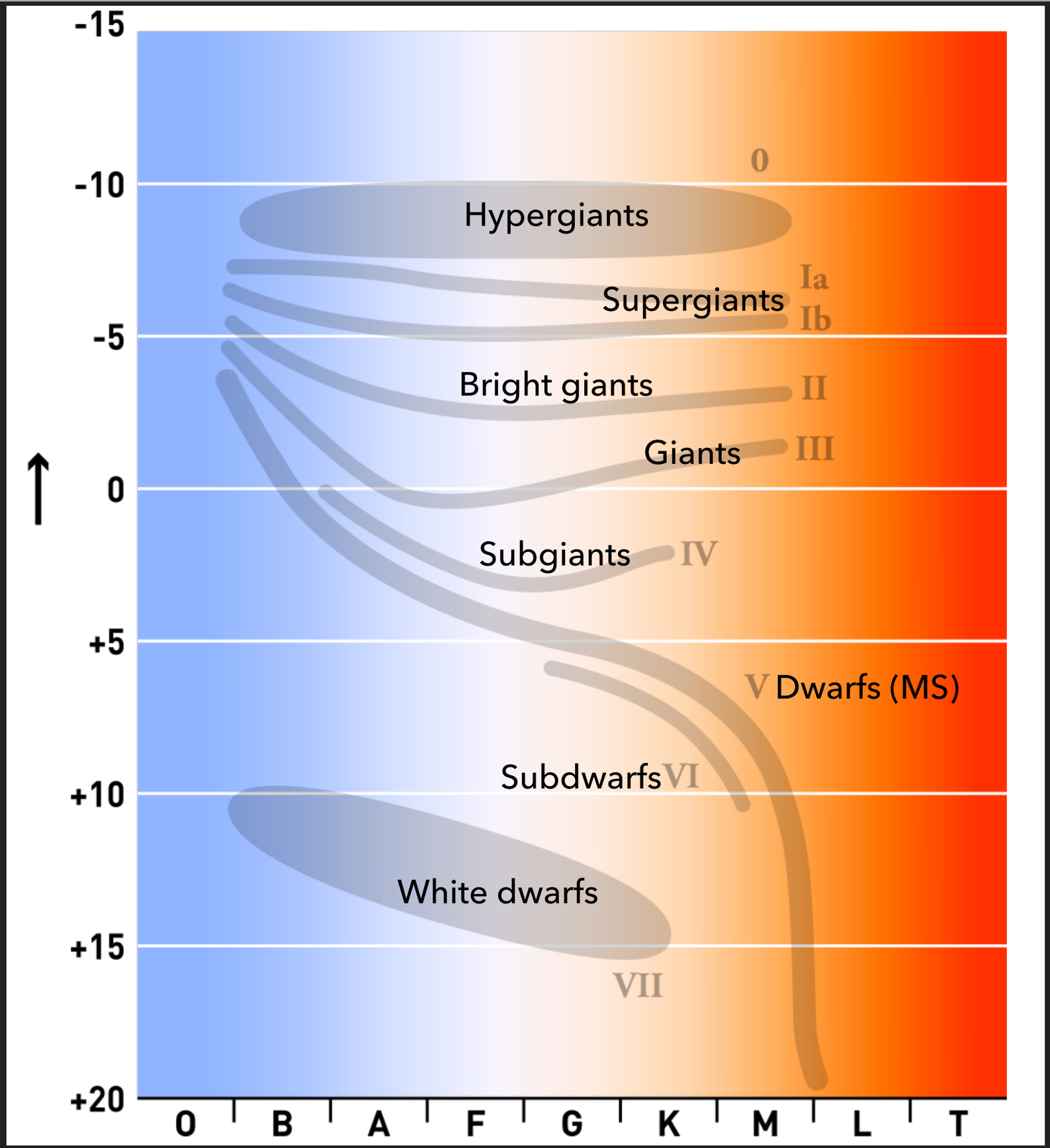
- The Sun is a G2 V star main-sequence star with a surface temperature around 5,800 K.



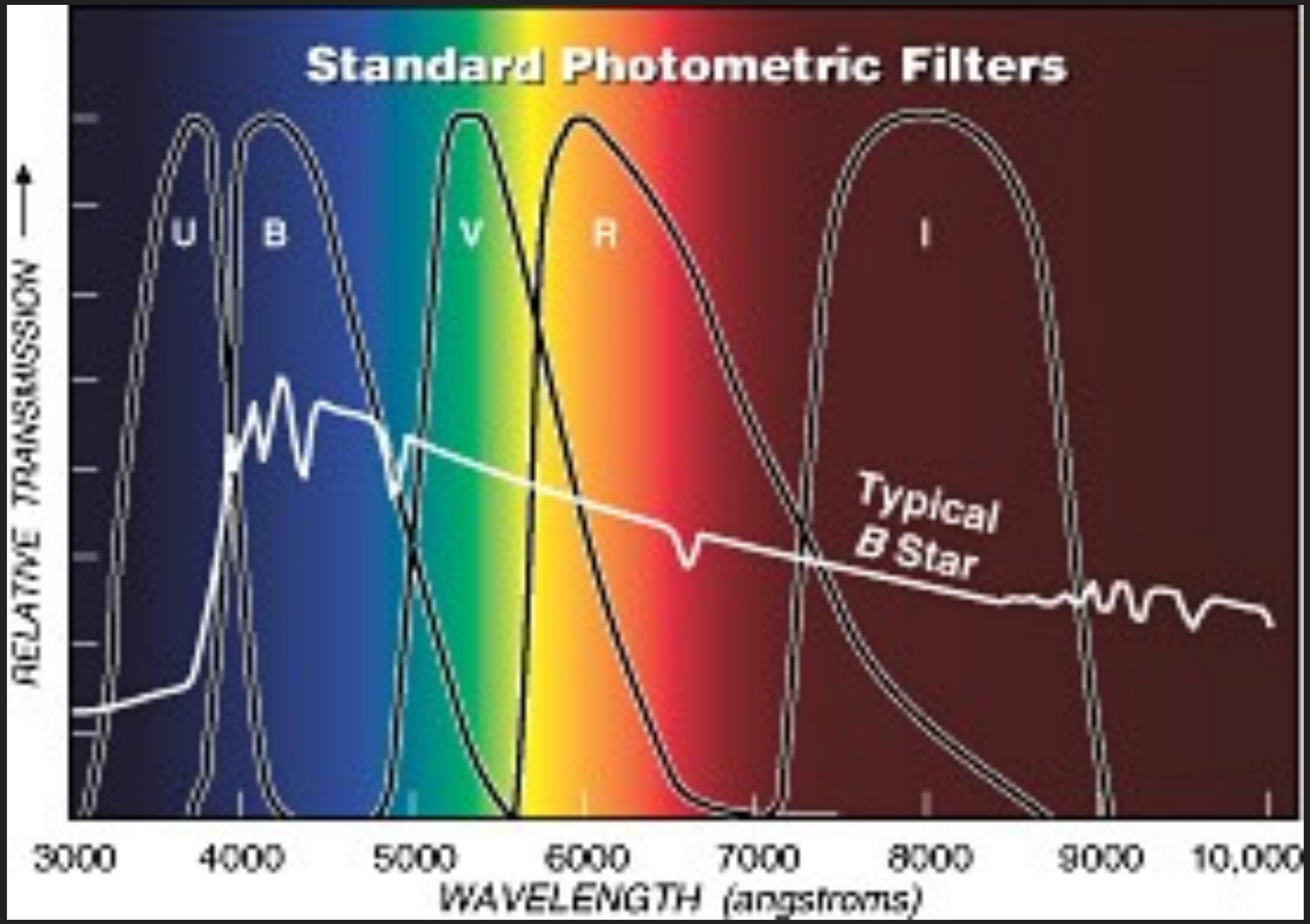
HR DIAGRAM – SUN



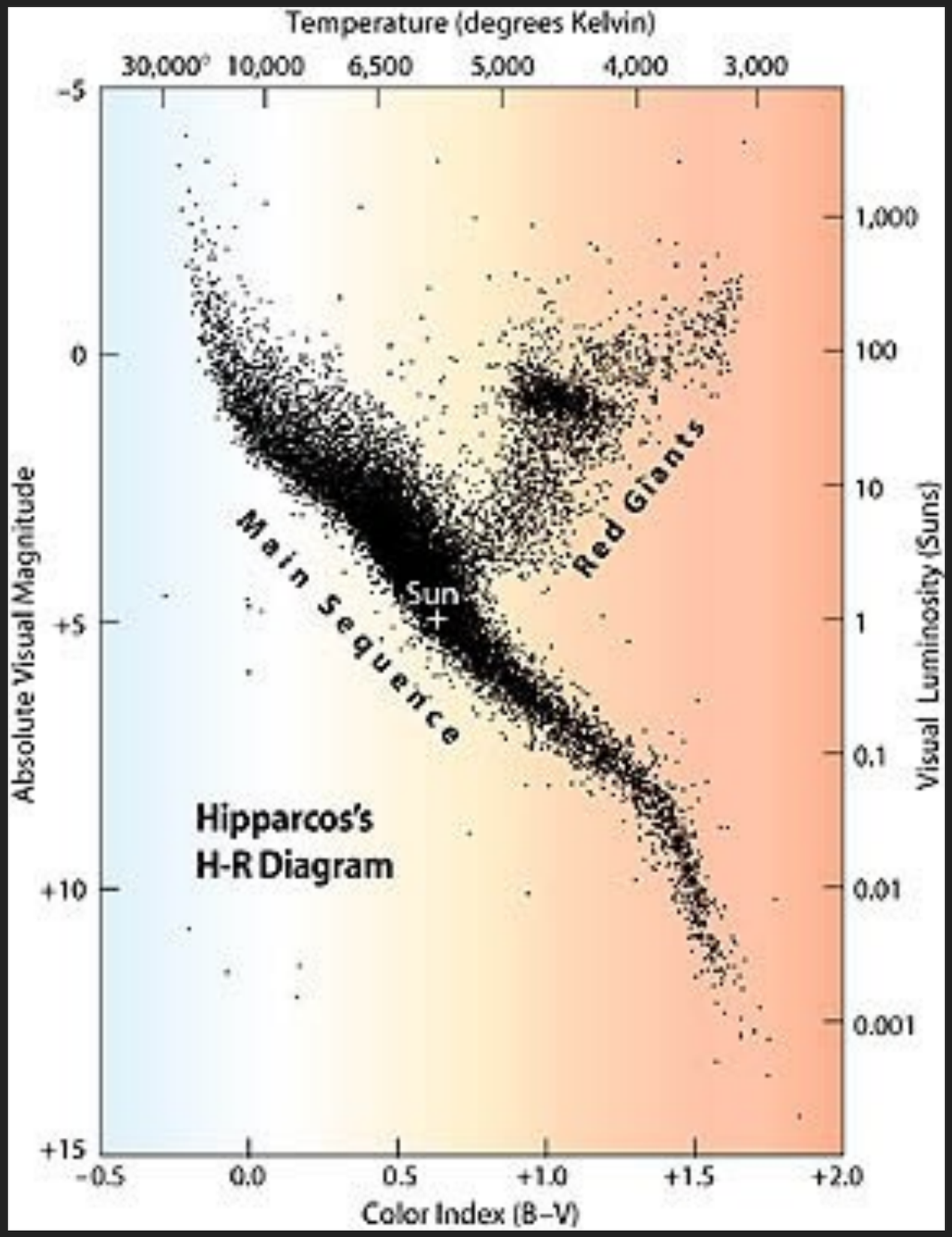
PRACTICE


-15
-10
-5
0
+5
+10
+15
+20
0
Hypergiants
Supergiants
Ia
Ib
Bright giants
II
Giants
III
Subgiants
IV
V Dwarfs (MS)
Subdwarfs
VI
White dwarfs
VII
O
B
A
F
G
K
M
L
T

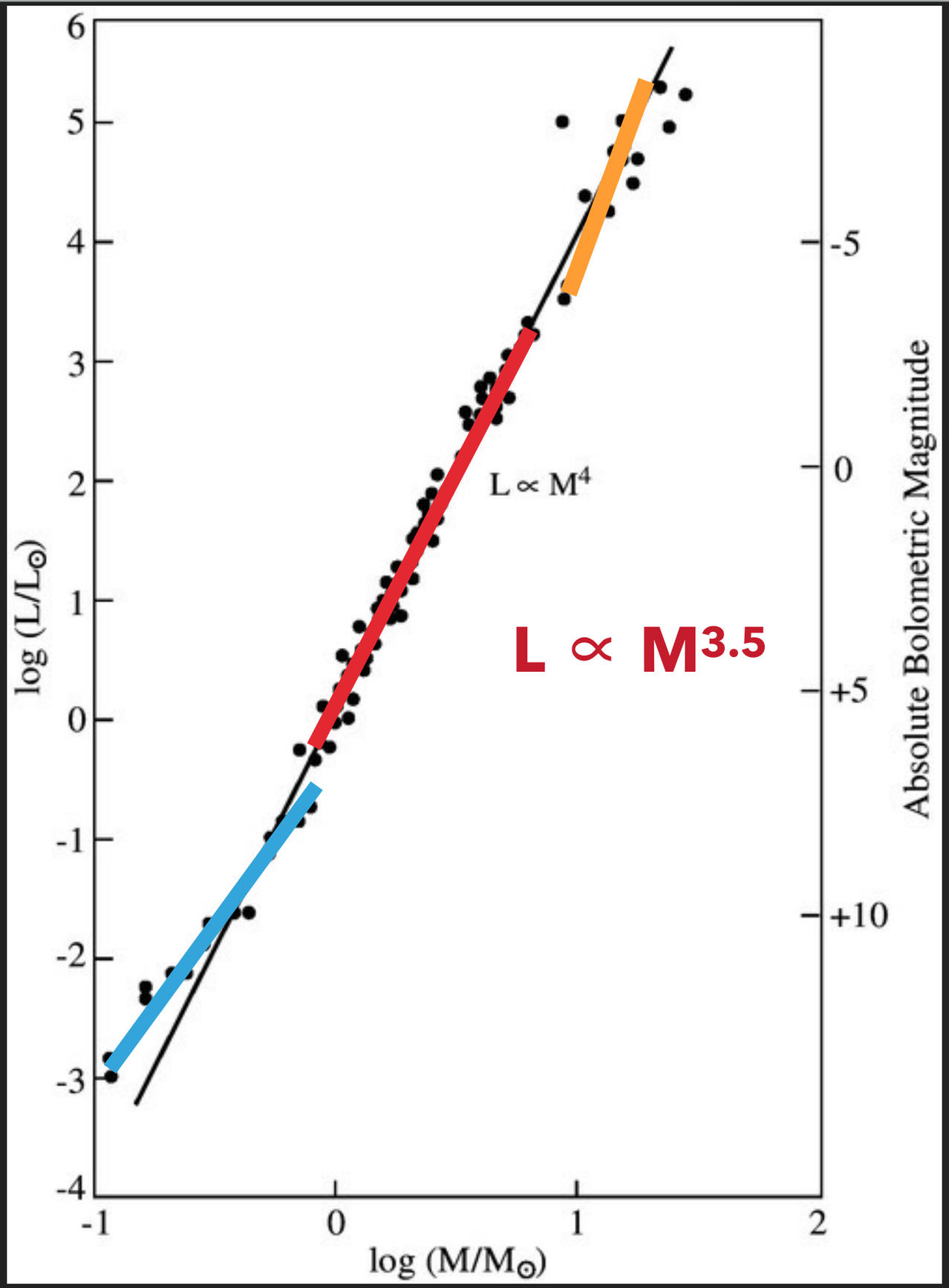
COLOUR – MAGNITUDE DIAGRAM



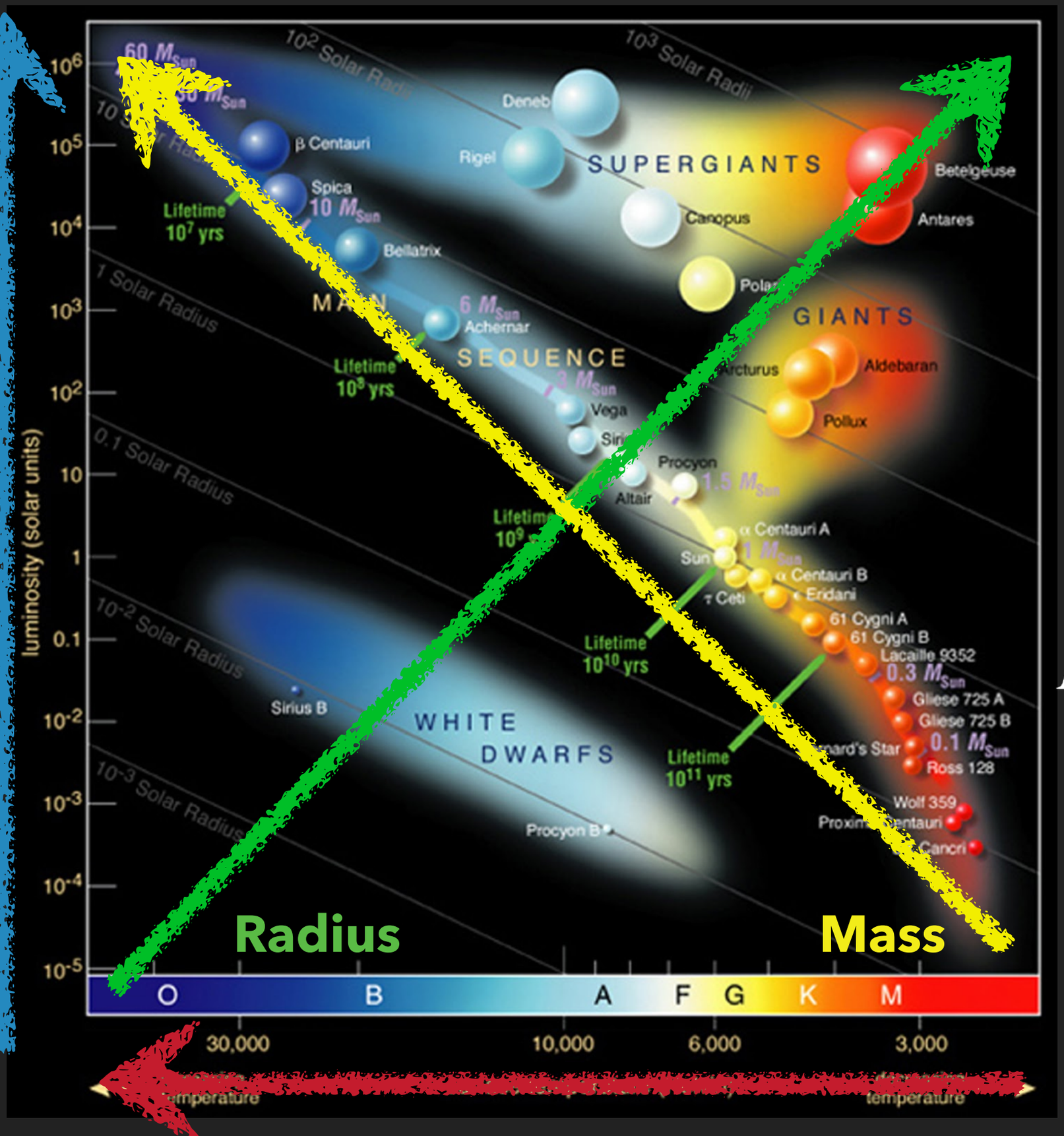
COLOUR – MAGNITUDE DIAGRAM



MASS – LUMINOSITY RELATION



HR DIAGRAM

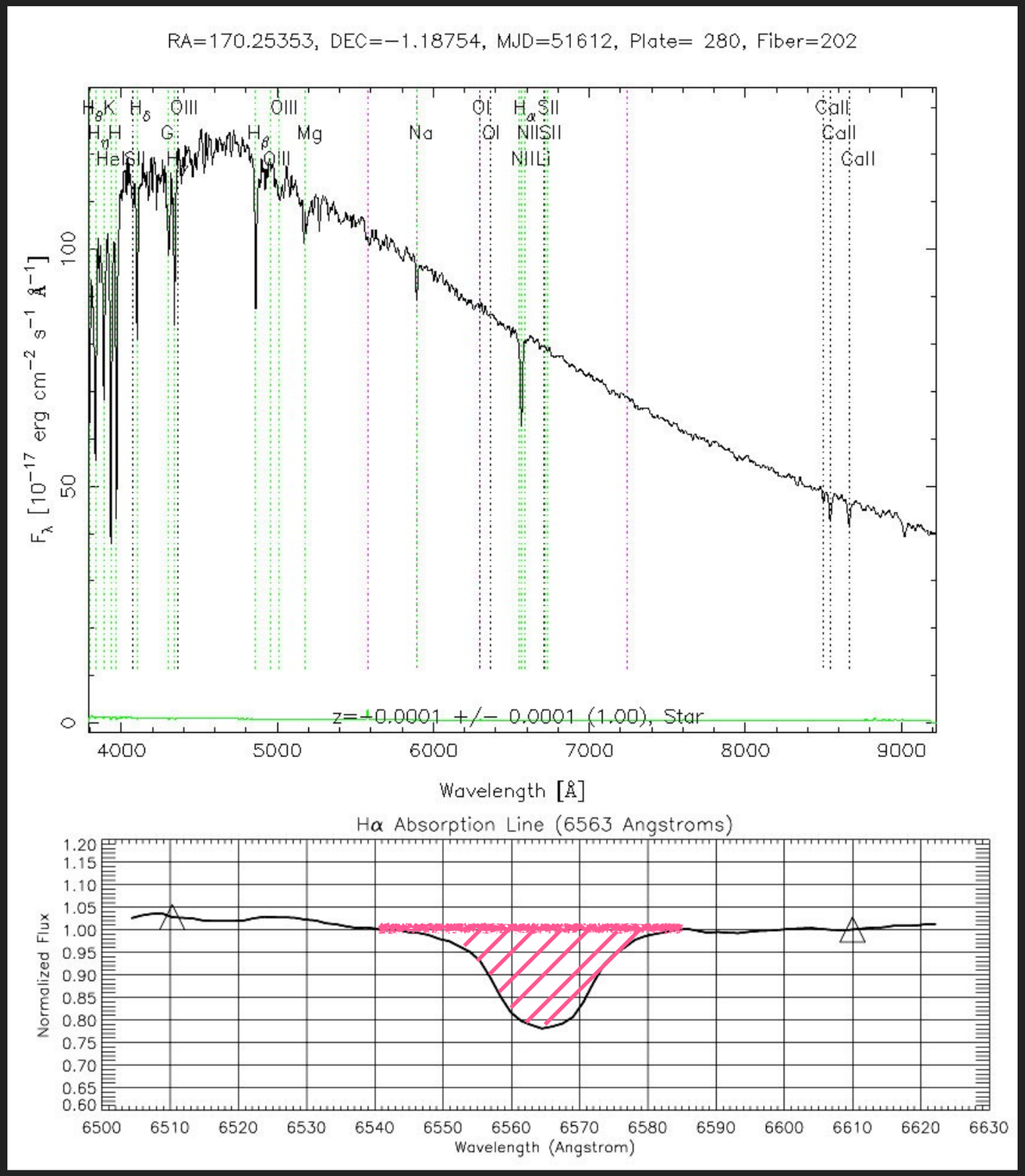


$$L = 4\pi R^2 \cdot \sigma T^4$$

$L \propto M^{3.5}$

Temperature

HOMEWORK



- Put the stars in an order according to the strength of their Hα absorption lines.

RESOURCES

- https://spaceplace.nasa.gov/blue-sky/en/
- http://hyperphysics.phy-astr.gsu.edu/hbase/bbcon.html
- https://www.tec-science.com/thermodynamics/temperature/black-body-radiation/
- https://www.tec-science.com/thermodynamics/temperature/plancks-law-of-blackbody-radiation/
- http://hosting.astro.cornell.edu/academics/courses/astro201/kirchhoff.htm
- http://hyperphysics.phy-astr.gsu.edu/hbase/hyde.html
- https://www.webassign.net/ncchem/bohr.html
- https://collection.sciencemuseumgroup.org.uk/objects/co3632/william-herschels-infrared-prism-prism-optical-demonstration
- https://cas.sdss.org/dr6/en/proj/basic/spectraltypes/lines.asp
- https://www.scienceinschool.org/2007/issue4/spectrometer
- http://www.cs.cmu.edu/~zhuxj/astro/html/spectrometer.html
- https://astro.unl.edu/naap/hydrogen/naap_hydrogen_sg.pdf
- https://astro.unl.edu/naap/hydrogen/hydrogen.html
- https://calgary.rasc.ca/stellarmagnitudes.htm
- https://www.youtube.com/watch?v=iwlMmJs1f5o
- https://earthsky.org/space/what-is-a-parsec
- https://www.astronomynotes.com/index.html

RESOURCES

- https://courses.lumenlearning.com/towson-astronomy-2/chapter/using-spectra-to-measure-stellar-radius-composition-and-motion/
- https://sites.ualberta.ca/~pogosyan/teaching/ASTRO_122/lect6/lecture6.html
- https://www.spacetelescope.org/videos/heic1017b/
- https://pages.uoregon.edu/jimbrau/astr122/Notes/Chapter4.html
- https://thecuriousastronomer.wordpress.com/tag/spectra/
- https://docs.kde.org/trunk5/en/extragear-edu/kstars/ai-colorandtemp.html
- https://www.handprint.com/ASTRO/specclass.html
- https://joelasqo.com/blog/2011/09/10/piano-space-msp-star-spectra-and-dopplerd-time-lasqo-el-valenciano-sf-thu-12-apr-8pm-next-now-4/
- https://www.researchgate.net/publication/266864685_A_Digital_Spectral_Classification_Atlas
- https://skyandtelescope.org/astronomy-resources/the-stellar-magnitude-system/
- http://physics.weber.edu/palen/Phsx1040/Lectures/LStevol1.html