Week 9 Thursday

Today's Agenda

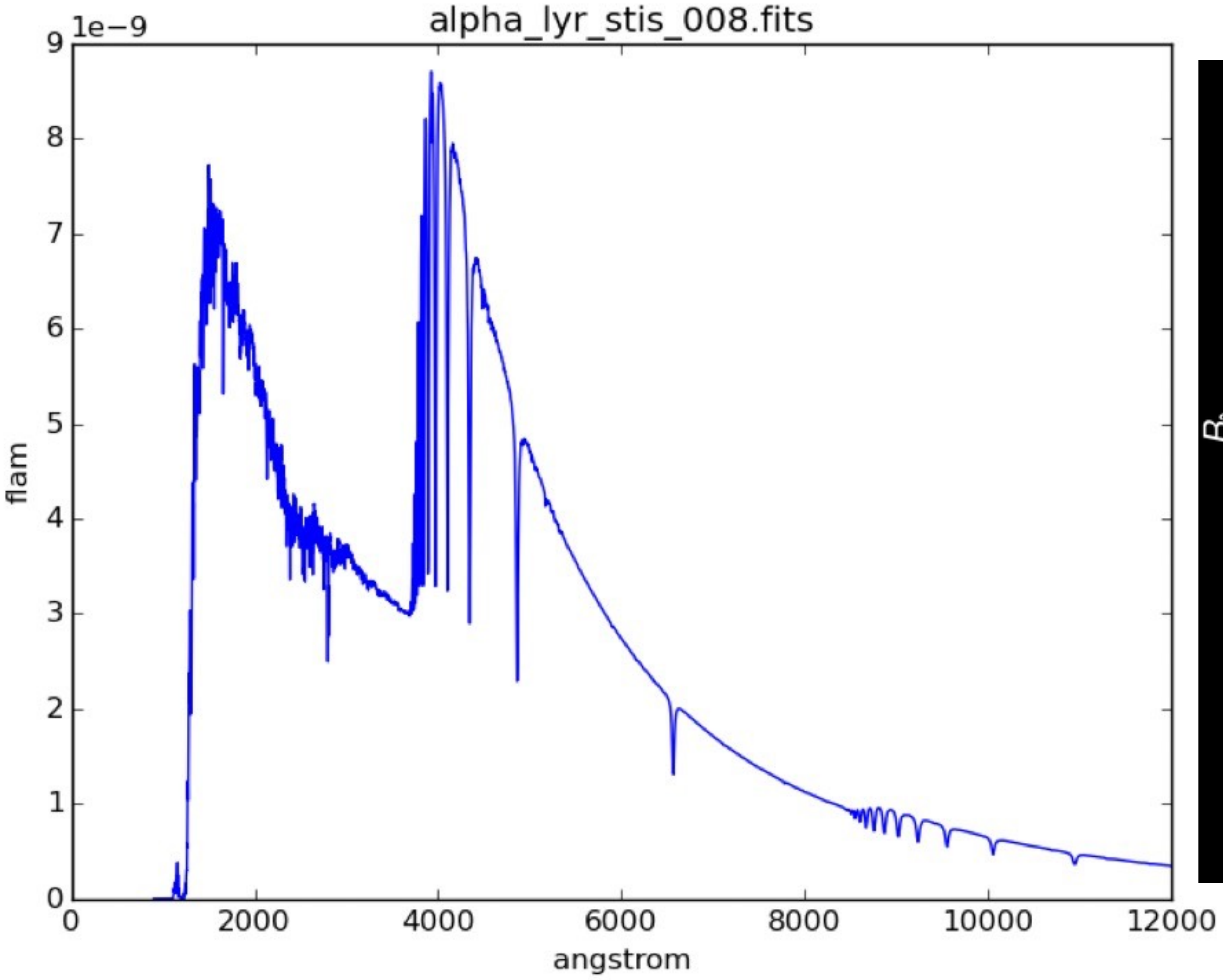
- Magnitude system
- Practice with magnitudes
- Filters, colors, temperatures
- Stellar types

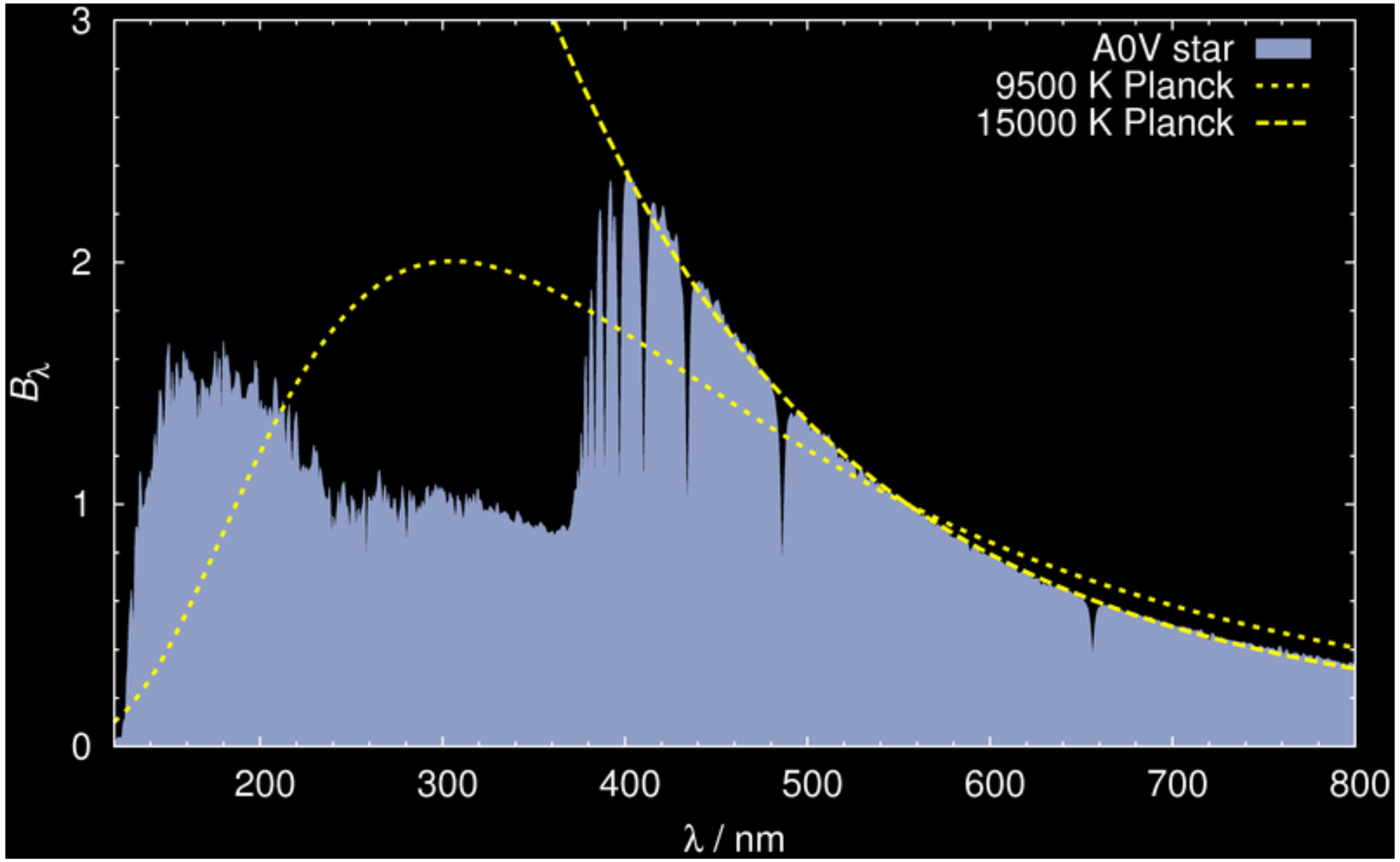
Announcements / Reminders

- HW 6 due Friday 1min before midnight
- Read Chapters 14 & 15.3

- HEAP talk at 4pm on Thursday
  - Spica: its stars and nebula
- Colloquium at 2pm on Friday
  - Breaking the Myth of the "Non-Traditional" Physicist: The Real Story About Employment for Physics Graduates

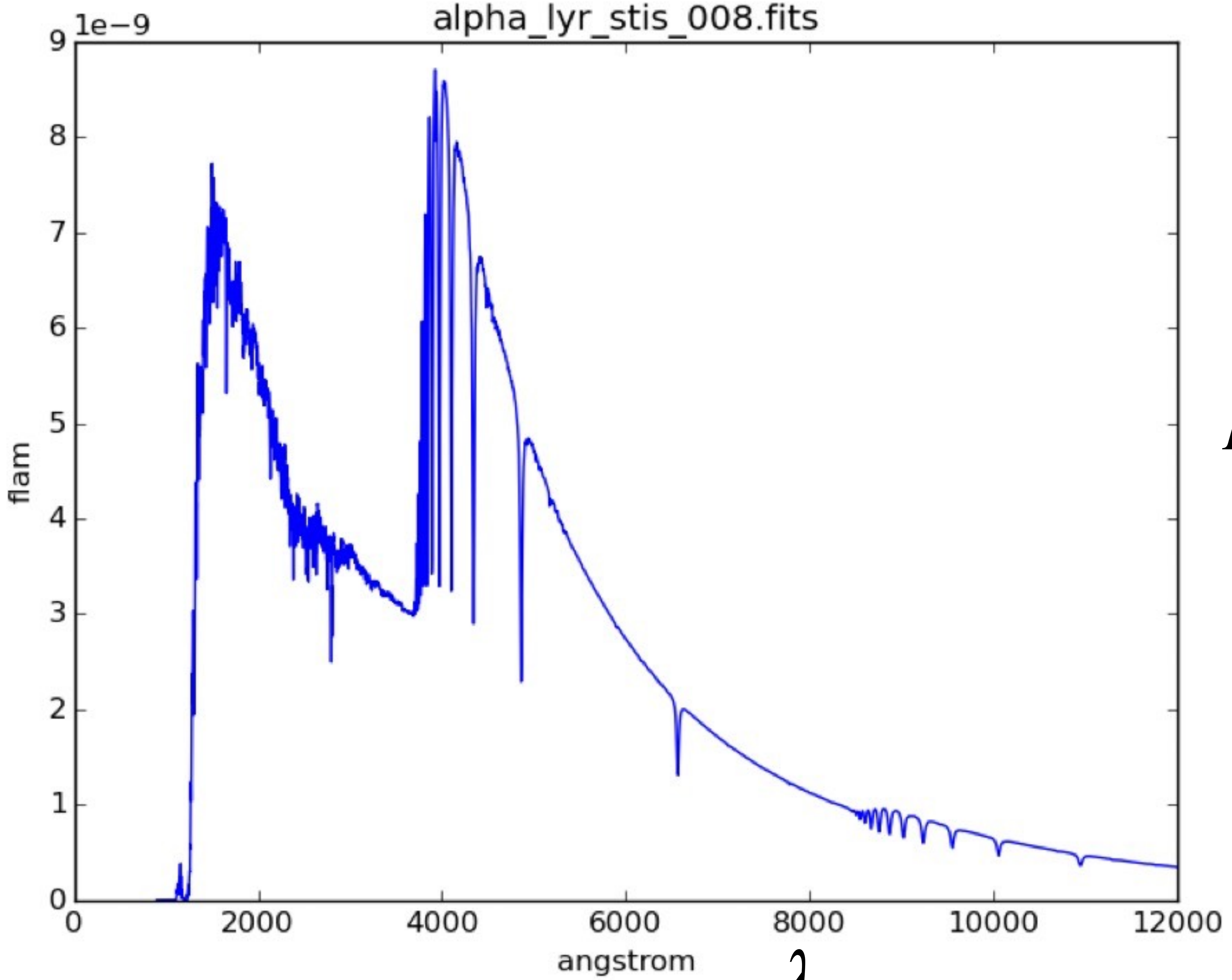
Vega is a blackbody ;)





Bolometric flux or magnitude is sum over all λs

F_λ



λ

$$F_{\text{bol}} = \int_0^\infty F_\lambda d\lambda$$

Measuring Stars

Parallax

$$d = \frac{1\ \text{pc}}{\pi''}$$

Inverse Square Law

$$F = \frac{L}{4\pi d^2}$$

Effective Temperature

$$T_{\text{eff}} = \left(\frac{L}{4\pi R^2 \sigma_{\text{SB}}}\right)^{1/4}$$

$$m_2 - m_1 = 2.5\log(F_1/F_2)$$

Apparent Magnitude

$(m_\odot = -26.75)$

$$m = C - 2.5\log(F)$$

Absolute Magnitude

$M_{\text{bol},\odot}$ ↙

$$M_{\text{bol}} = 4.74 - \log\left(L/L_\odot\right)$$

Distance Modulus

$$m - M = 5\log\left(\frac{d}{10\ \text{pc}}\right)$$

Practice with Magnitudes

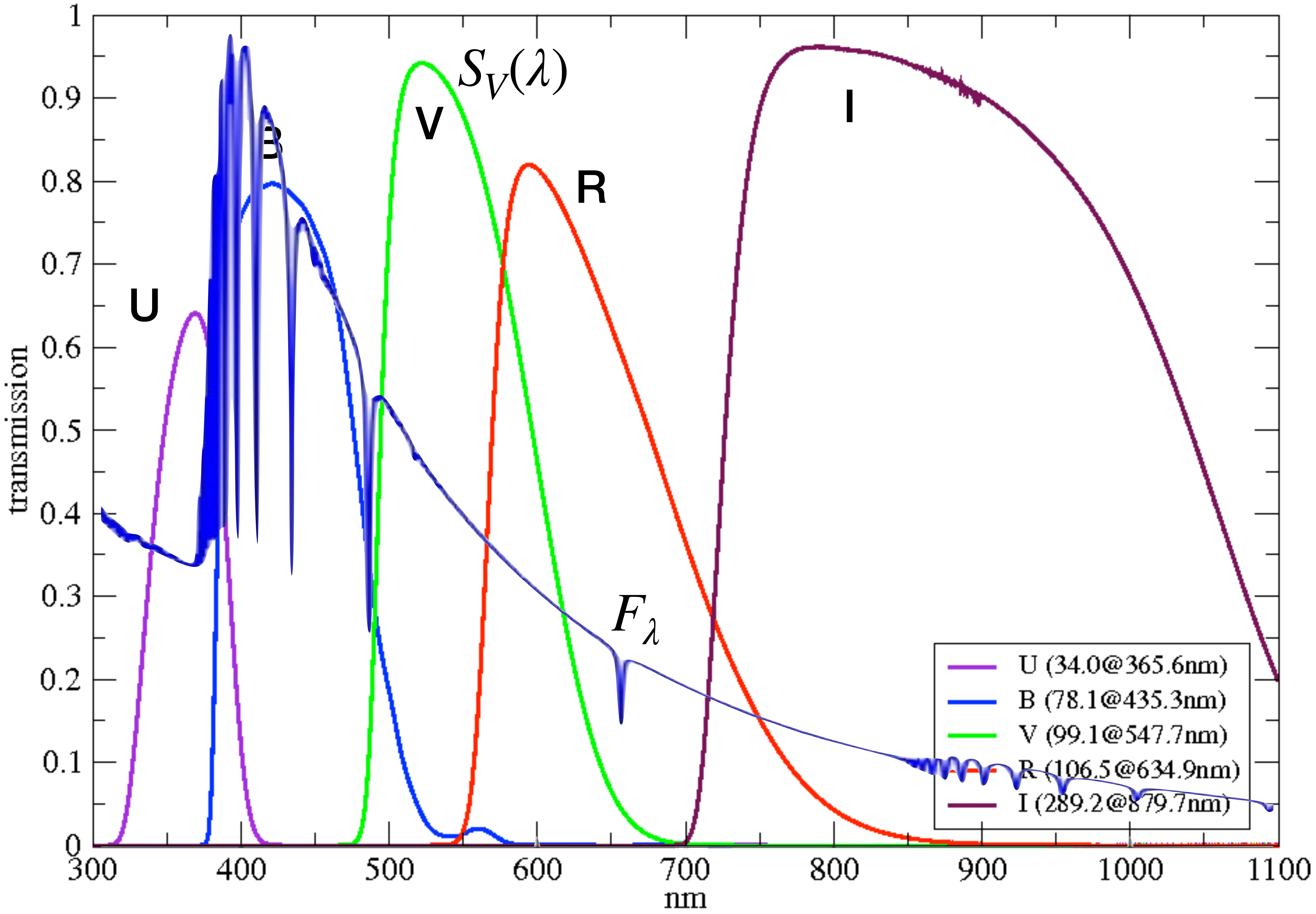
Consider 2 stars in a binary system, A & B.
A is brighter, and the difference in their magnitudes is 2.5.
If $m_B = 10$, what is m_A?

If the parallax angle to the system is 0.025”,
what is the absolute magnitude of star B?
What is the difference in absolute magnitudes
between the 2 stars?

Another star elsewhere in the sky is found to have a very similar spectrum to star B.
Assuming their intrinsic properties are similar and this star has a magnitude of 15,
how far away is it?

Magnitudes tied to filter systems

(which are not universal)



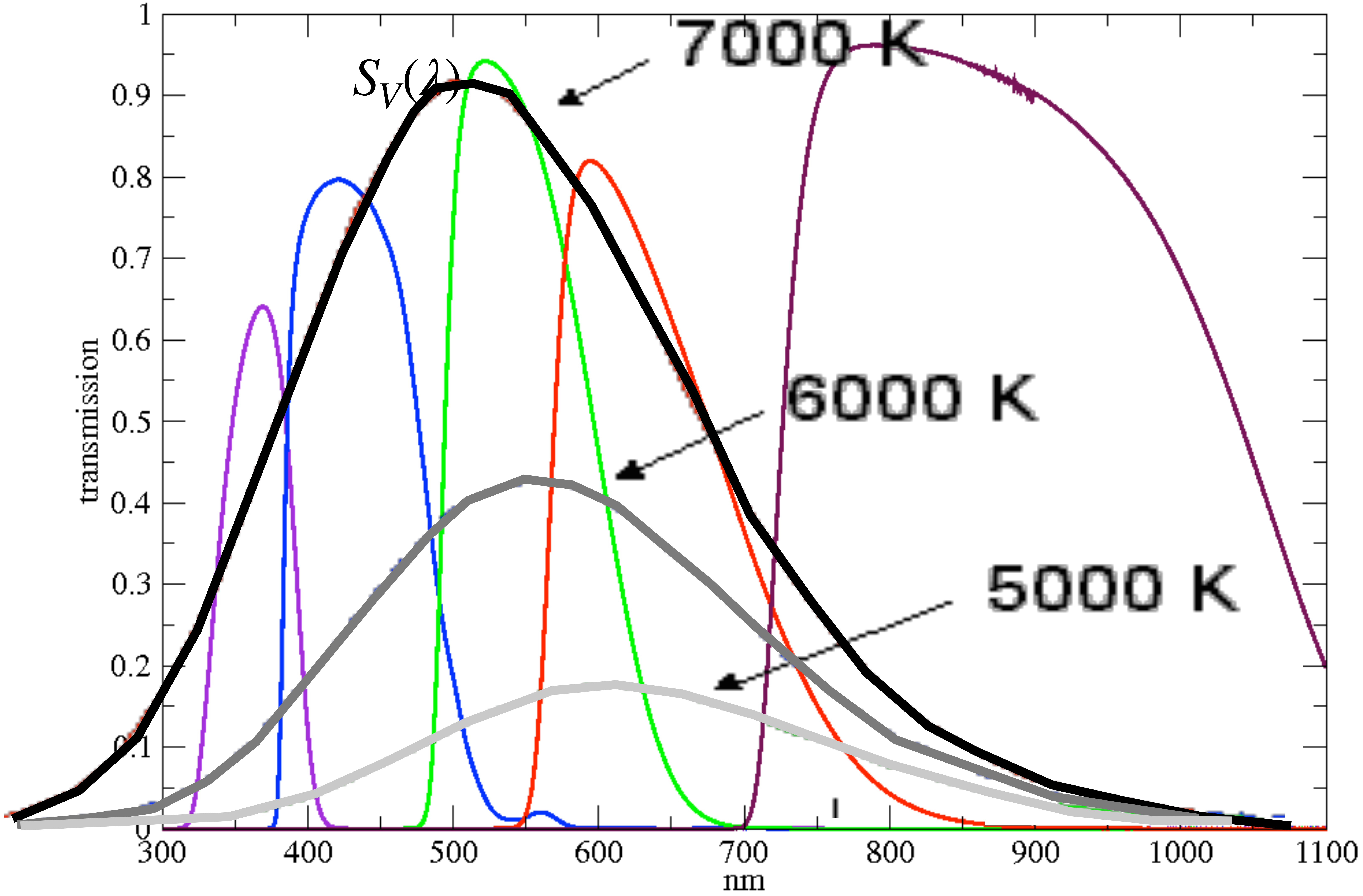
$$F_V = \int_0^\infty F_\lambda S_V(\lambda) d\lambda$$

$$m_V = C_V - 2.5 \log F_V$$

$$M_{V,\odot} = 4.83$$

Magnitudes tied to filter systems

(which are not universal)



$$F_V = \int_0^\infty F_\lambda S_V(\lambda) d\lambda$$

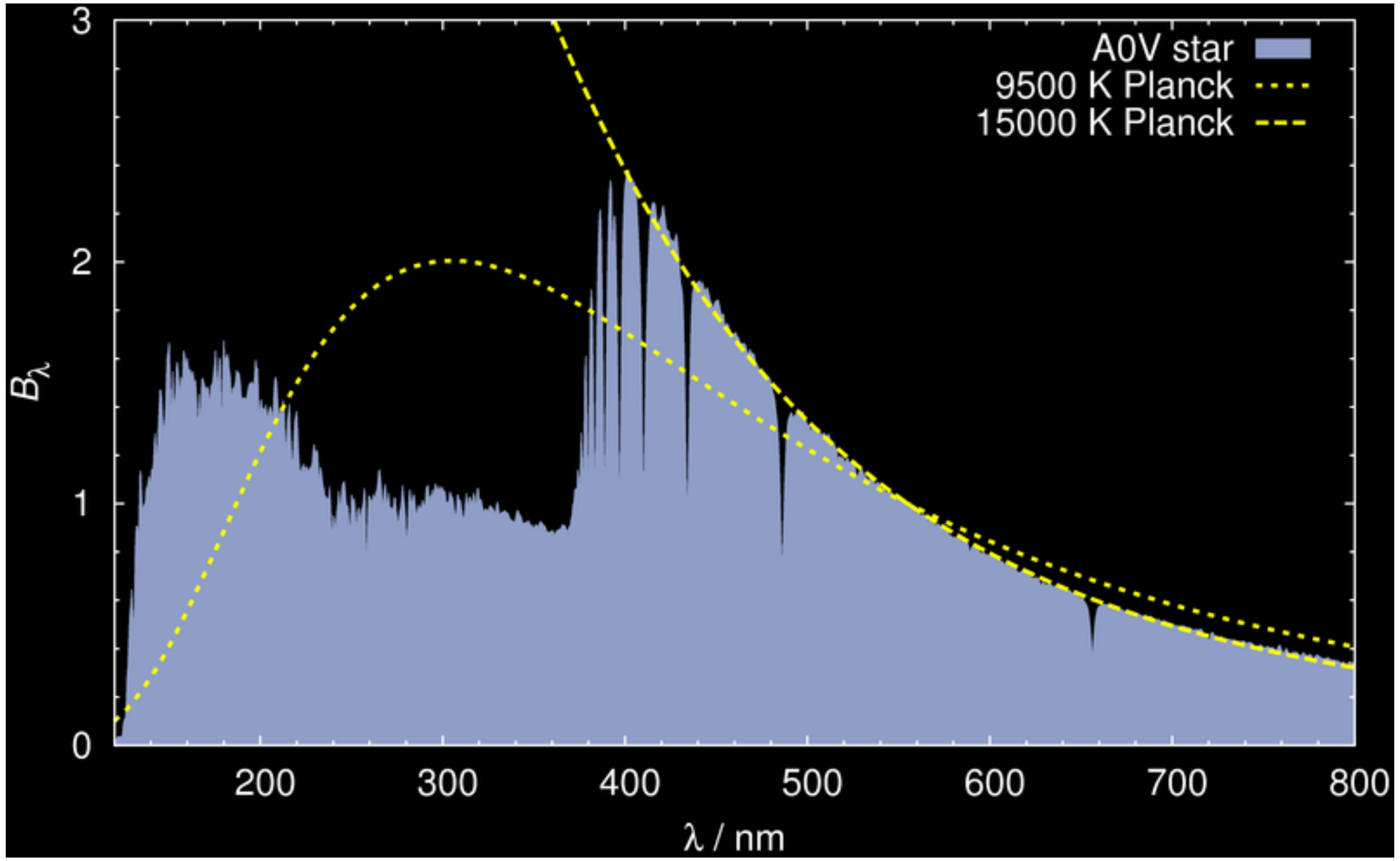
$$m_V = C_V - 2.5 \log F_V$$

Colors:

$$B - V = m_B - m_V$$

(shorthand)

Vega magnitude system: $m_B = m_V = m_R = \ldots = 0$



Vega $T \approx 10{,}000\ \mathrm{K}$

$B - V = 0$

$B - V > 0\,,\ T < 10{,}000\ \mathrm{K}$

(Less blue light, fainter in B band, so m_B is larger than m_V)

$B - V < 0\,,\ T > 10{,}000\ \mathrm{K}$

$$T \approx \frac{9000\ \mathrm{K}}{(B - V) + 0.93}$$

(empirical relation)

Bolometric correction & Effective Temperature

$$BC_V = m_{\rm bol} - m_V = M_{\rm bol} - M_V$$

$$BC_{V,\odot} = M_{\rm bol,\odot} - M_{V,\odot} = 4.74 - 4.83 = -0.09$$

Corrects for flux emitted by source but missed by the bandpass (filter)

Can define an "effective temperature" based on BB (even if spectrum not a BB):

$$L = 4\pi R^2 \sigma_{\rm SB} T^4 \longrightarrow T_{\rm eff} = \left(\frac{L}{4\pi R^2 \sigma_{\rm SB}} \right)^{1/4}$$

How does R, T, and lifetime depend on mass?

$$\frac{R}{R_\odot} = \begin{cases} 1.06(M/M_\odot)^{0.945}, & M < 1.66\ M_\odot \\ 1.33(M/M_\odot)^{0.555}, & M > 1.66\ M_\odot \end{cases}$$

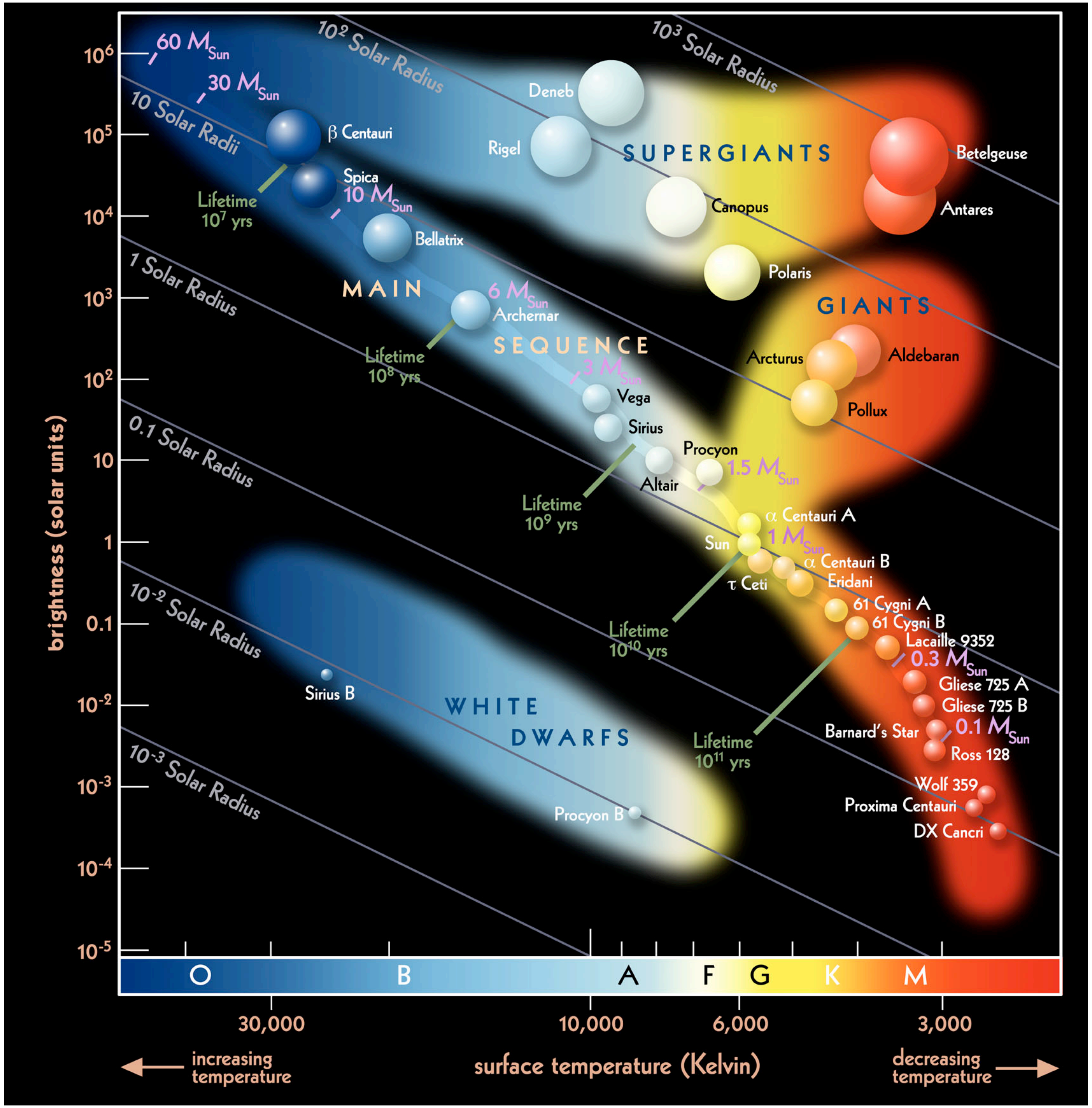
$$\frac{L}{L_\odot} = \begin{cases} 0.35(M/M_\odot)^{2.62}, & M < 0.7\ M_\odot \\ 1.02(M/M_\odot)^{3.92}, & M > 0.7\ M_\odot \end{cases}$$

Main Sequence Lifetime
(fuel / burning rate)

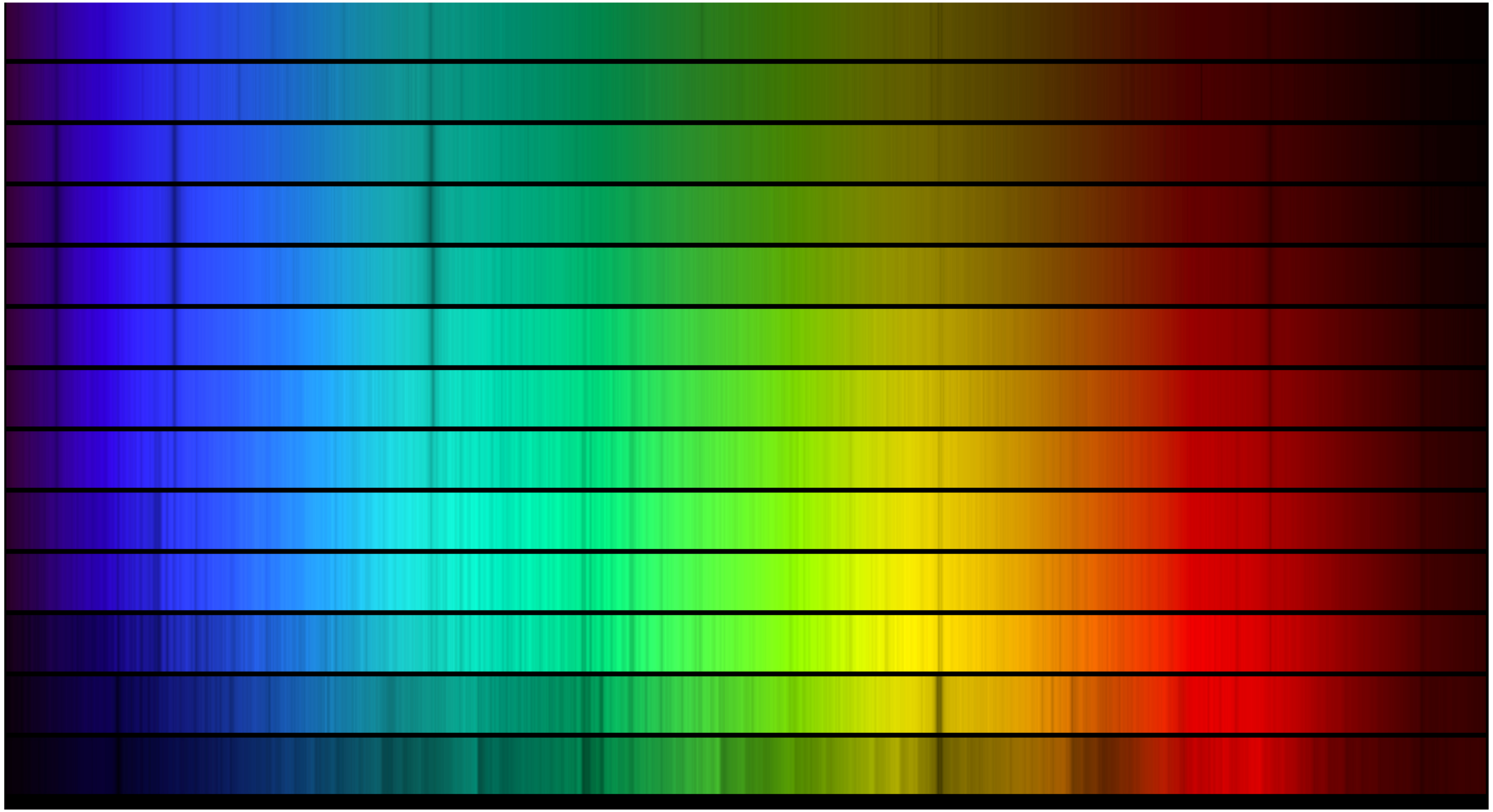
$$\tau \propto \frac{M}{L} \propto \begin{cases} M^{-1.62}, & M < 0.7\ M_\odot \\ M^{-2.92}, & M > 0.7\ M_\odot \end{cases}$$

Luminosity vs Temperature

$$T_{\rm eff} = \left(\frac{L}{4\pi R^2 \sigma_{\rm SB}}\right)^{1/4}$$



But early on, no distances and no temperatures



Just spectral lines! And no quantum mechanics!!!

Harvard College Observatory

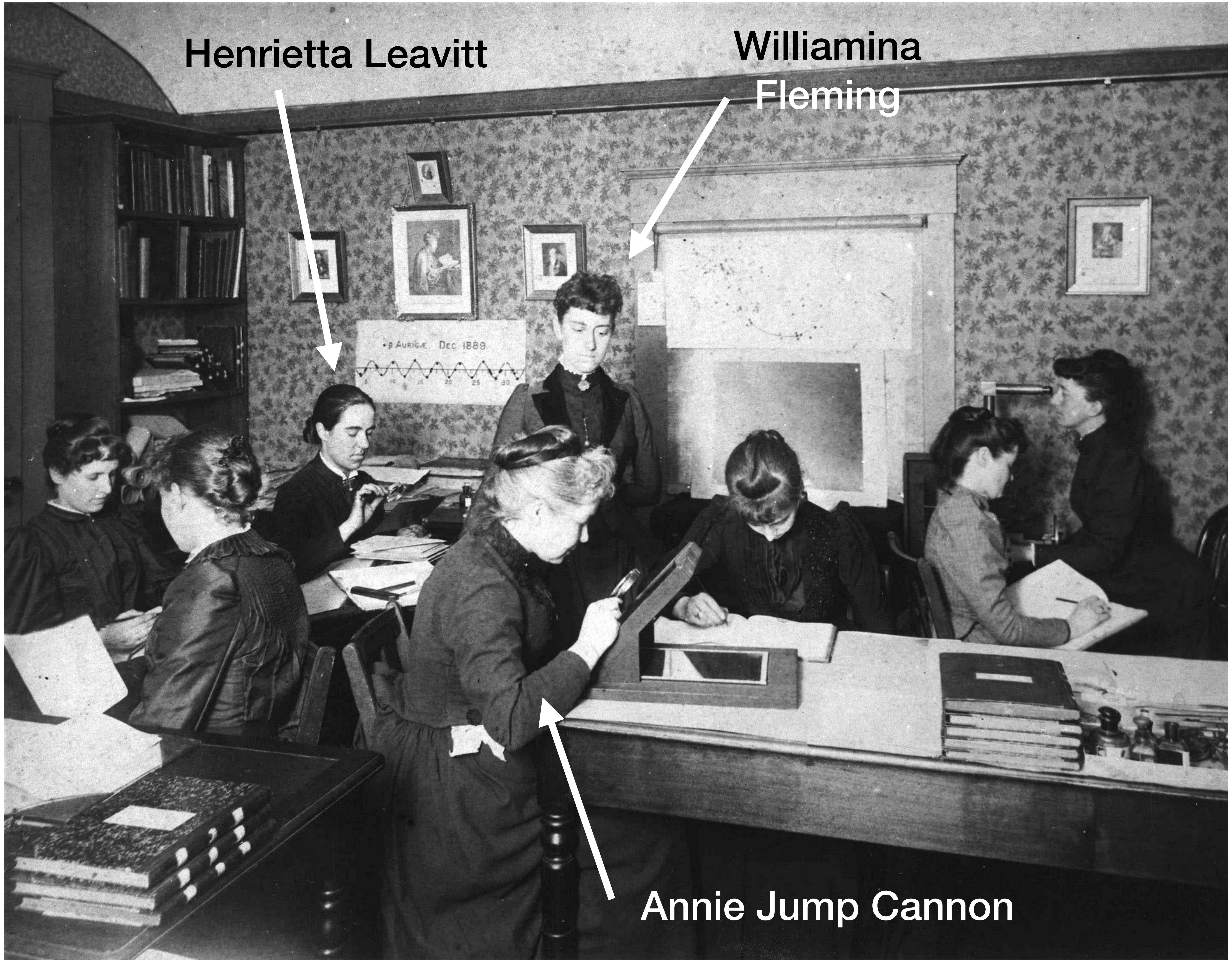
~1890

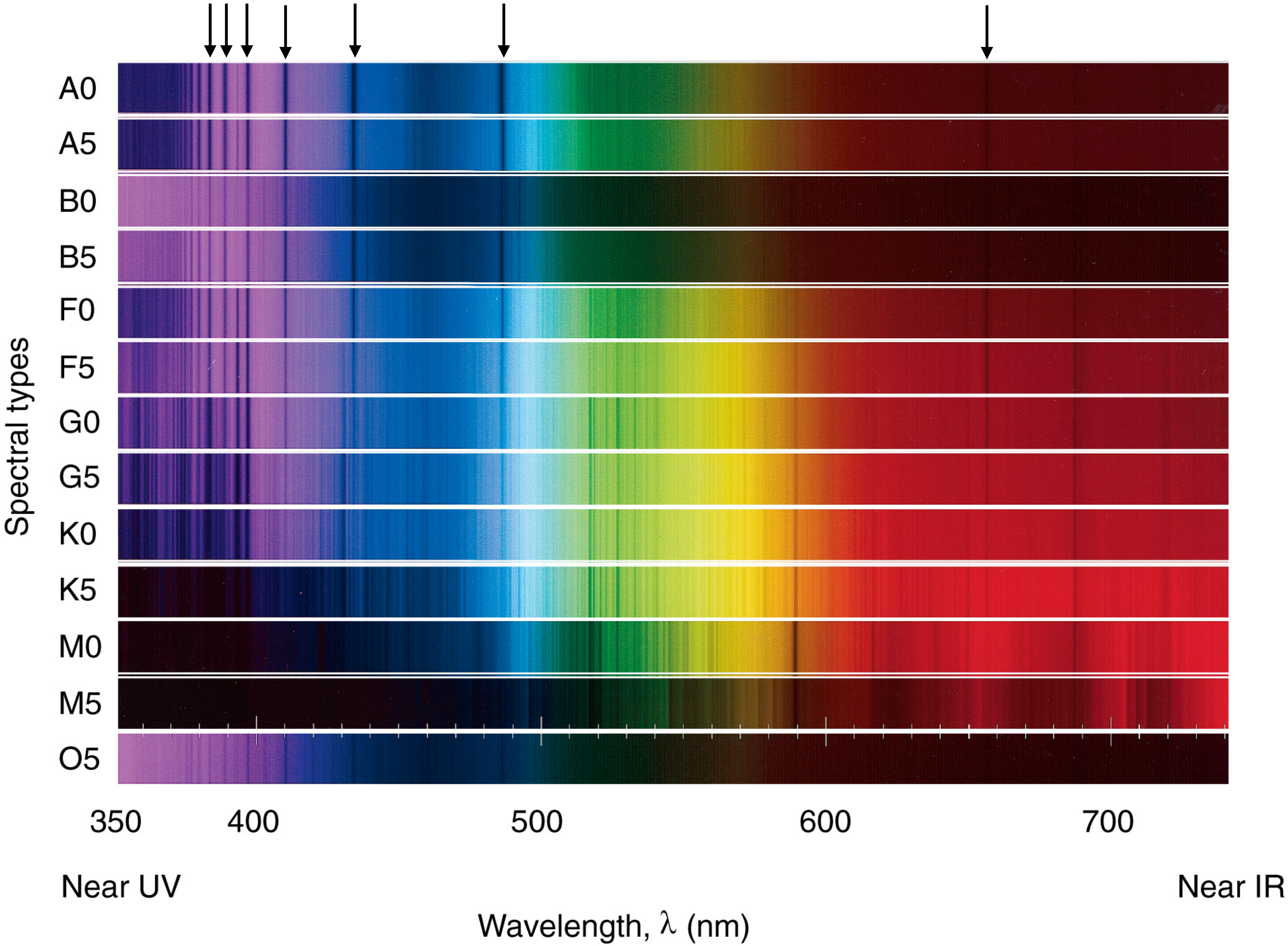
👎 “Pickering’s Harem” 👎

Prof Pickering did not really consider astronomy science, but the widow of Henry Draper (of the HD star catalog) donated a bunch of money.

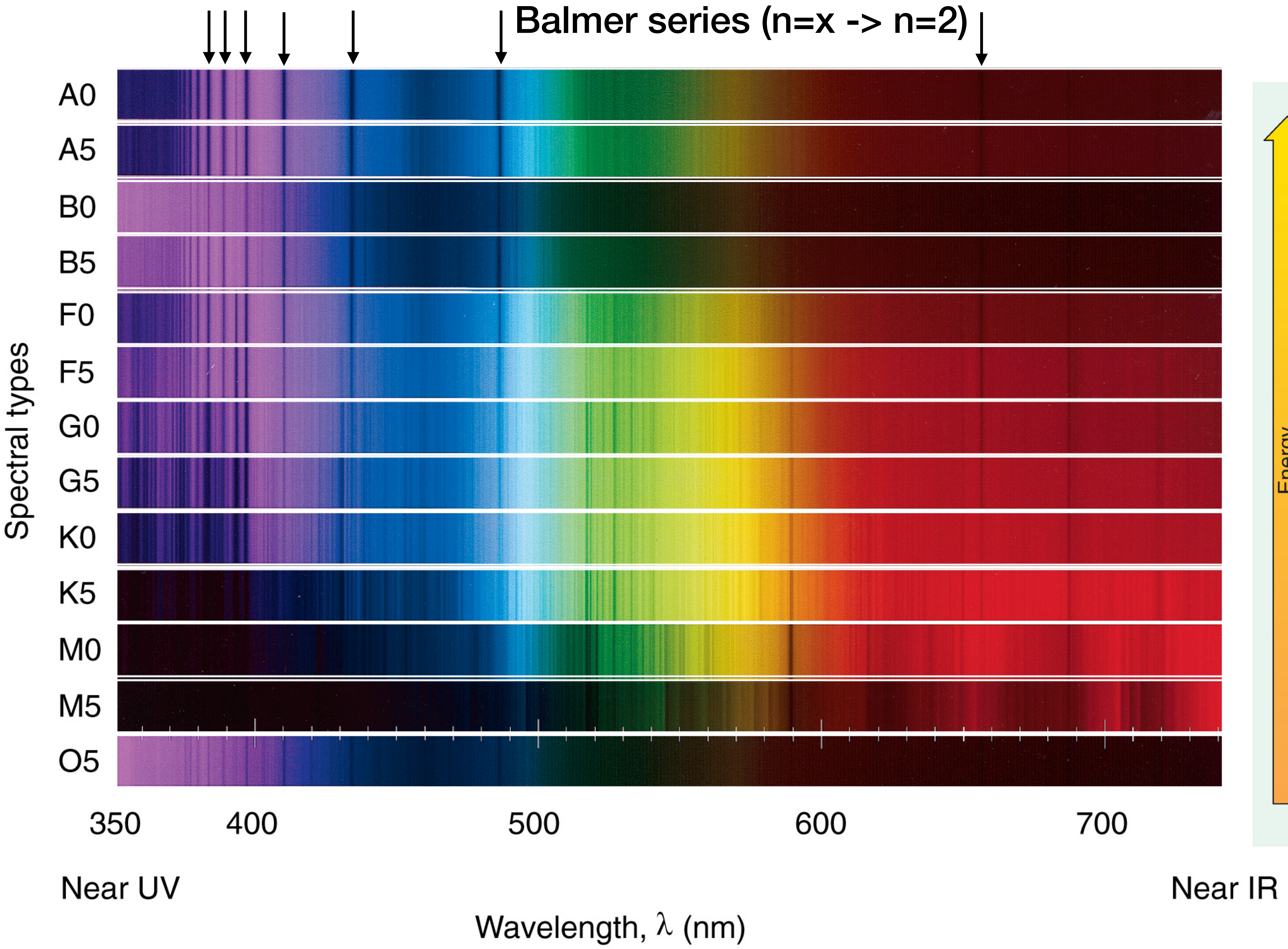
His housekeeper, Williamina Fleming, was more competent (and cheaper) than his male assistant, so she ran the show

These female “computers” founded modern astronomy

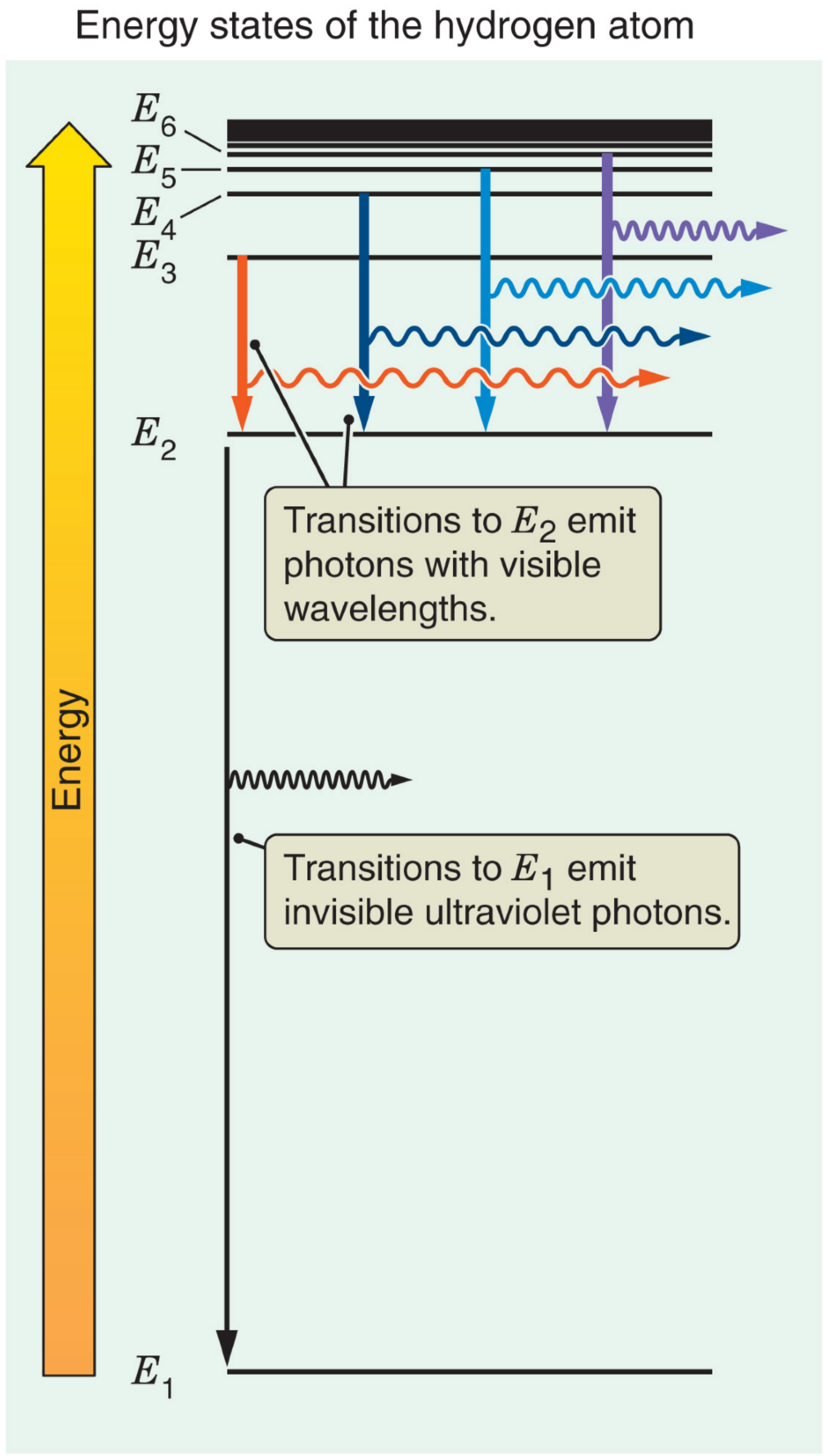




A0
A5
B0
B5
F0
F5
G0
G5
K0
K5
M0
M5
O5
Spectral types
350
400
500
600
700
Near UV
Near IR
Wavelength, λ (nm)



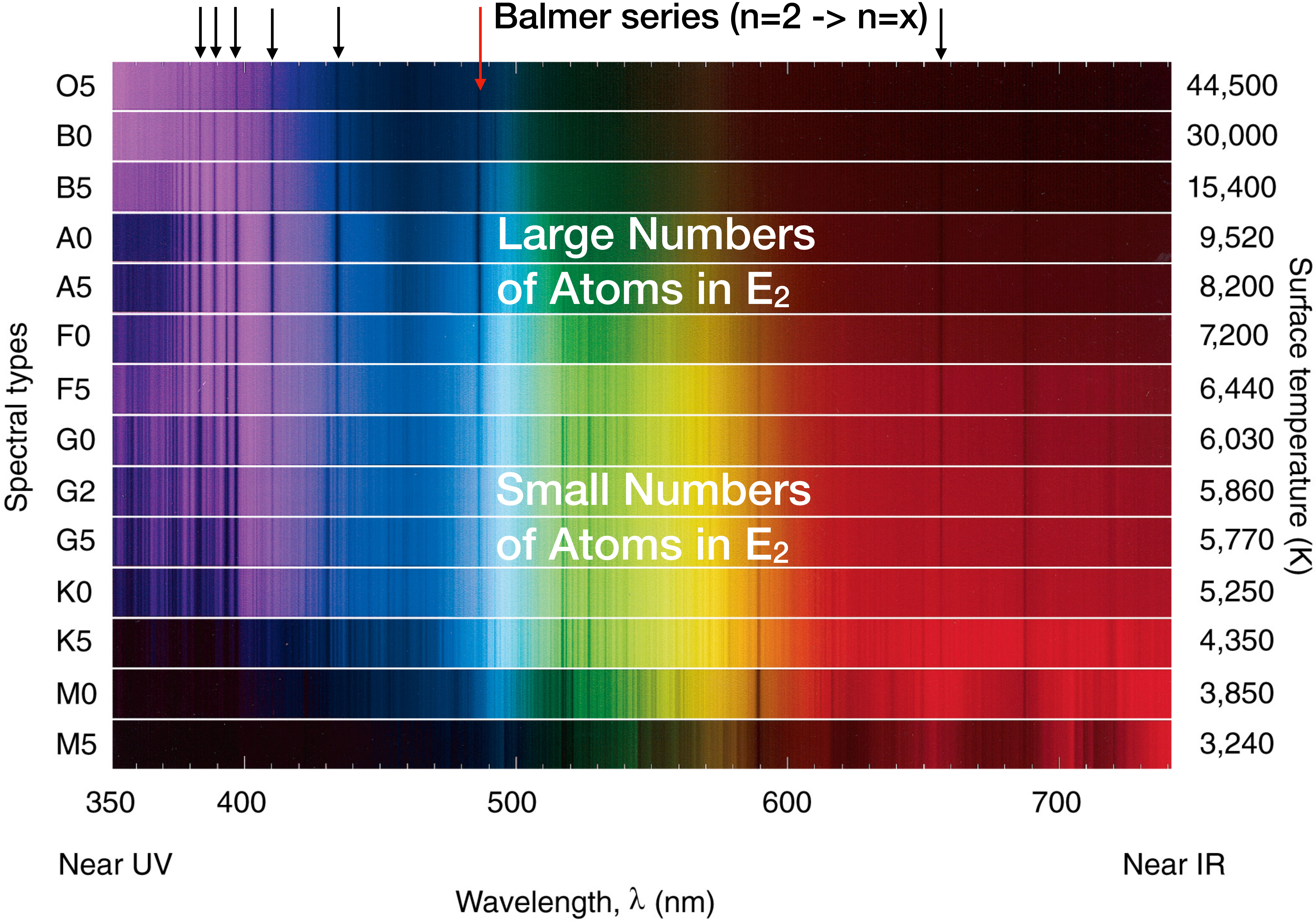
Balmer series (n=x -> n=2)
A0
A5
B0
B5
F0
F5
G0
G5
K0
K5
M0
M5
O5
Spectral types
350
400
500
600
700
Near UV
Near IR
Wavelength, λ (nm)



Energy states of the hydrogen atom
Energy
E_6
E_5
E_4
E_3
E_2
E_1
Transitions to E_2 emit photons with visible wavelengths.
Transitions to E_1 emit invisible ultraviolet photons.

Annie Jump Cannon Classifies the Stars

- part of the effort to catalog every star in the sky down to 9th magnitude
- defined the classification scheme for stellar spectra
- manually classified over 350,000 stars
- realized stellar types correlated with temperature (but not in the original order)



More Violet Light

$$\langle v \rangle = \sqrt{\frac{8kT}{\pi m}}$$

$$\langle E \rangle = \frac{3}{2}kT$$

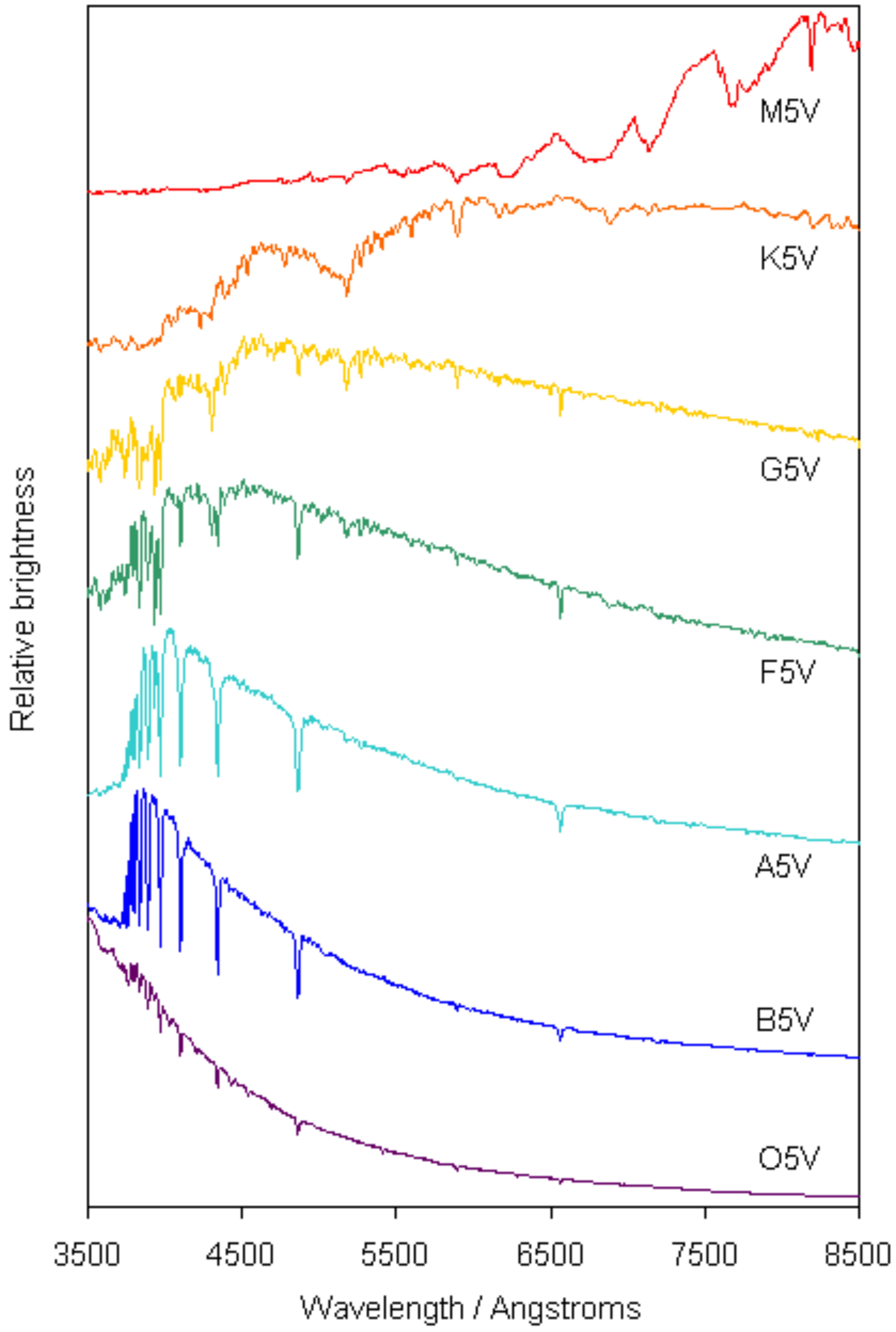
More Red Light

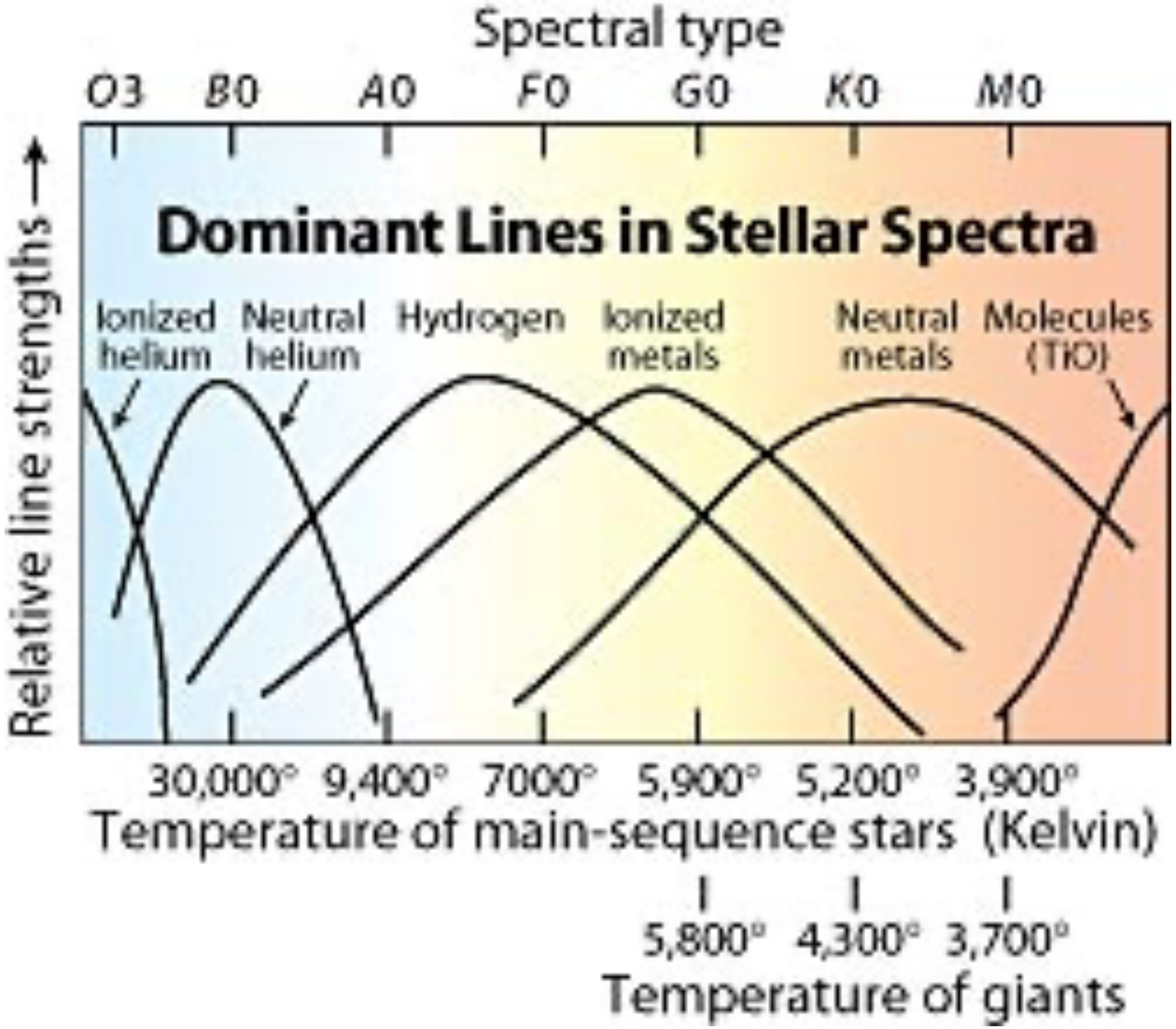
<u>Brown Dwarfs</u>

L (2000 K)

T (<1300 K)

Line Strengths depend on Type





Spectral Classification

Temperature Sequence (color)

OBAFGKM

"Oh, Be A Fine Girl/Guy, Kiss Me!"

"Only Boys Accepting Feminism Get Kissed Meaningfully"

"Only Boring Astronomers Find Gratification Knowing Mnemonics!"

http://www.star.ucl.ac.uk/~pac/obafgkmrns.html

Luminosity Classes

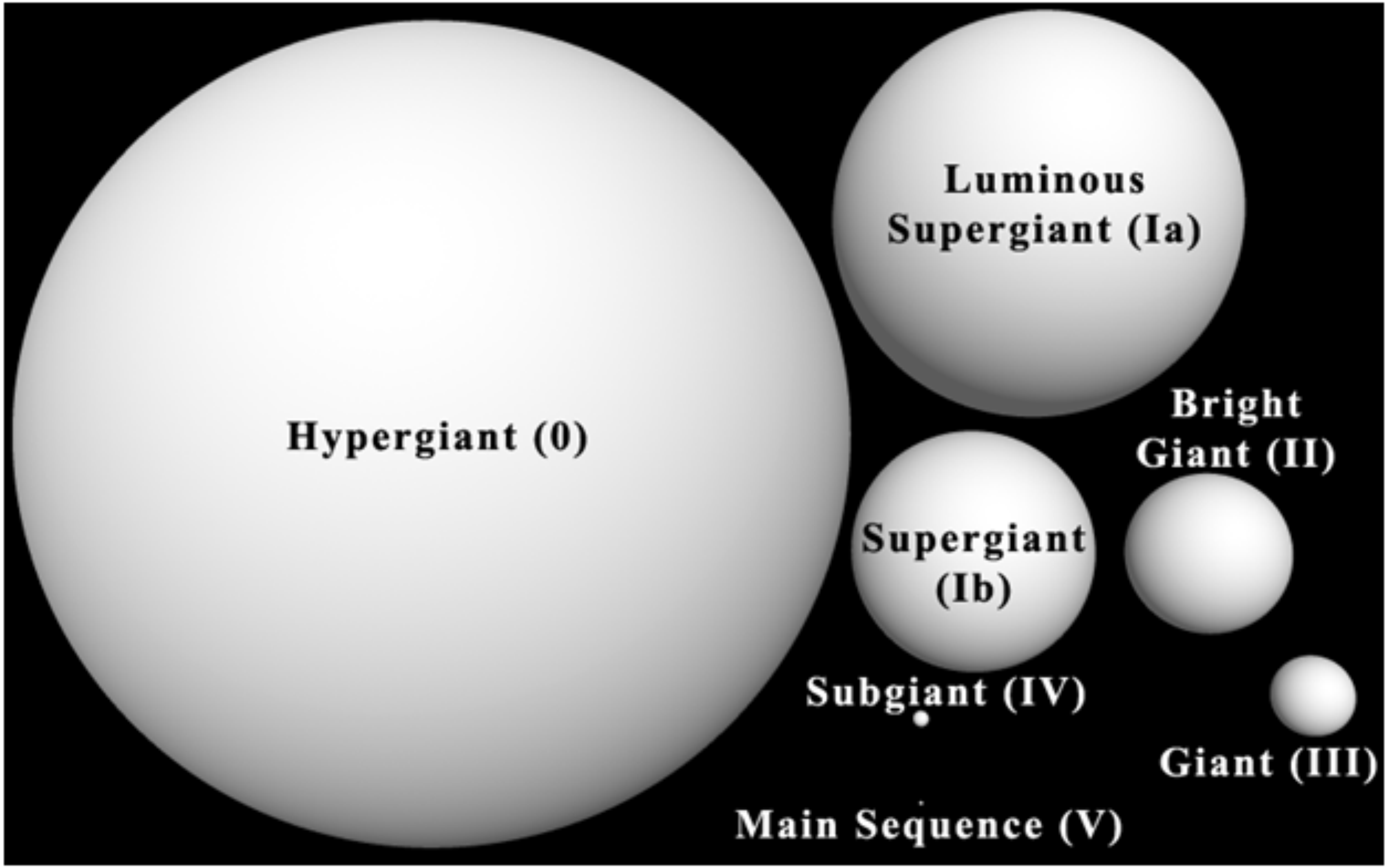
Luminosity Type corresponds to Star's Size

Our Sun is class G2 V

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

???

I	Supergiant
II	Bright giant
III	Giant
IV	Sub giant
V	Dwarf (main sequence)
VI	Subdwarf

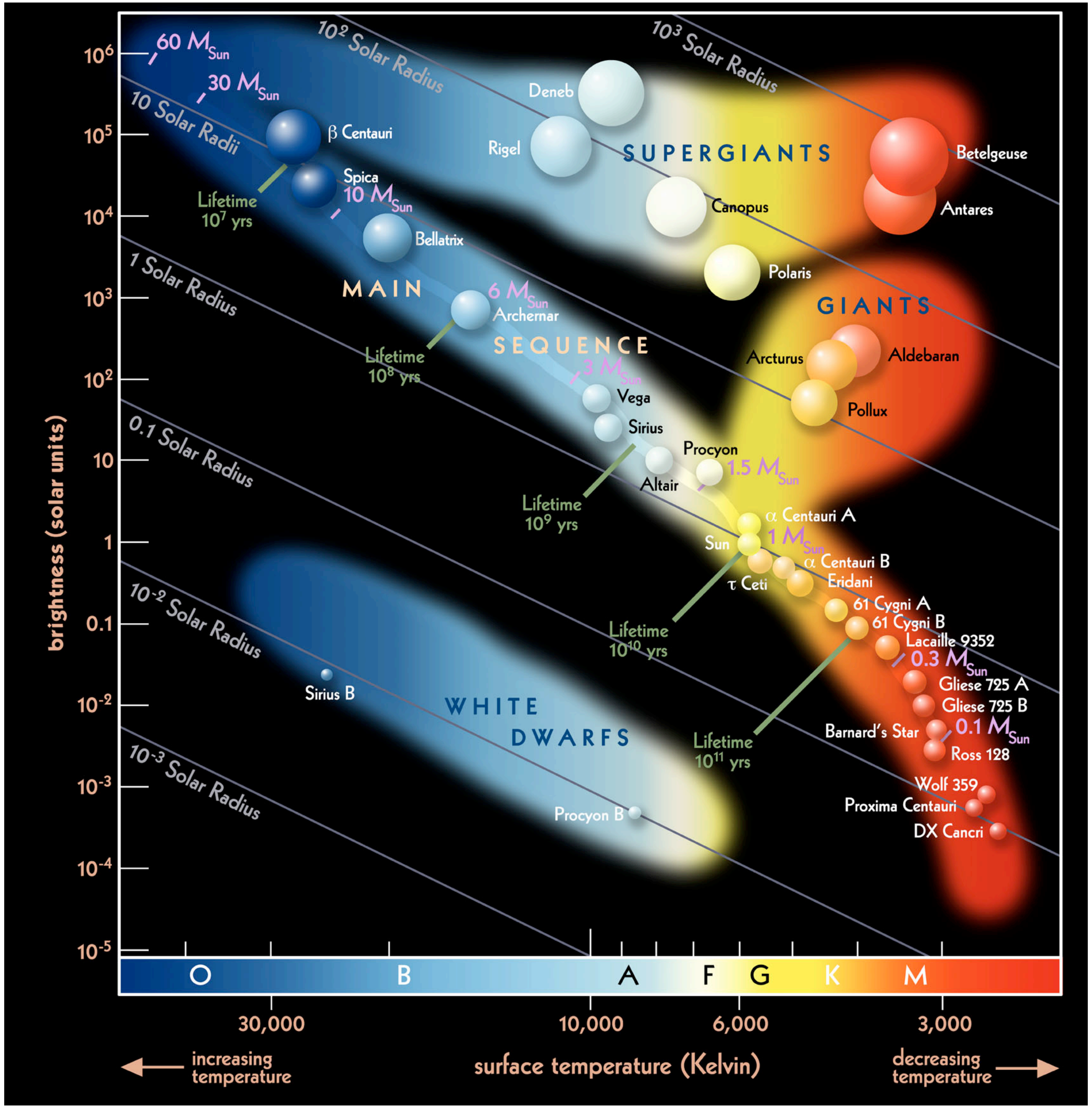

Luminous
Supergiant (Ia)
Hypergiant (0)
Bright
Giant (II)
Supergiant
(Ib)
Subgiant (IV)
Giant (III)
Main Sequence (V)

Hertzsprung-Russell Diagram (or color-magnitude diagram: CMD)

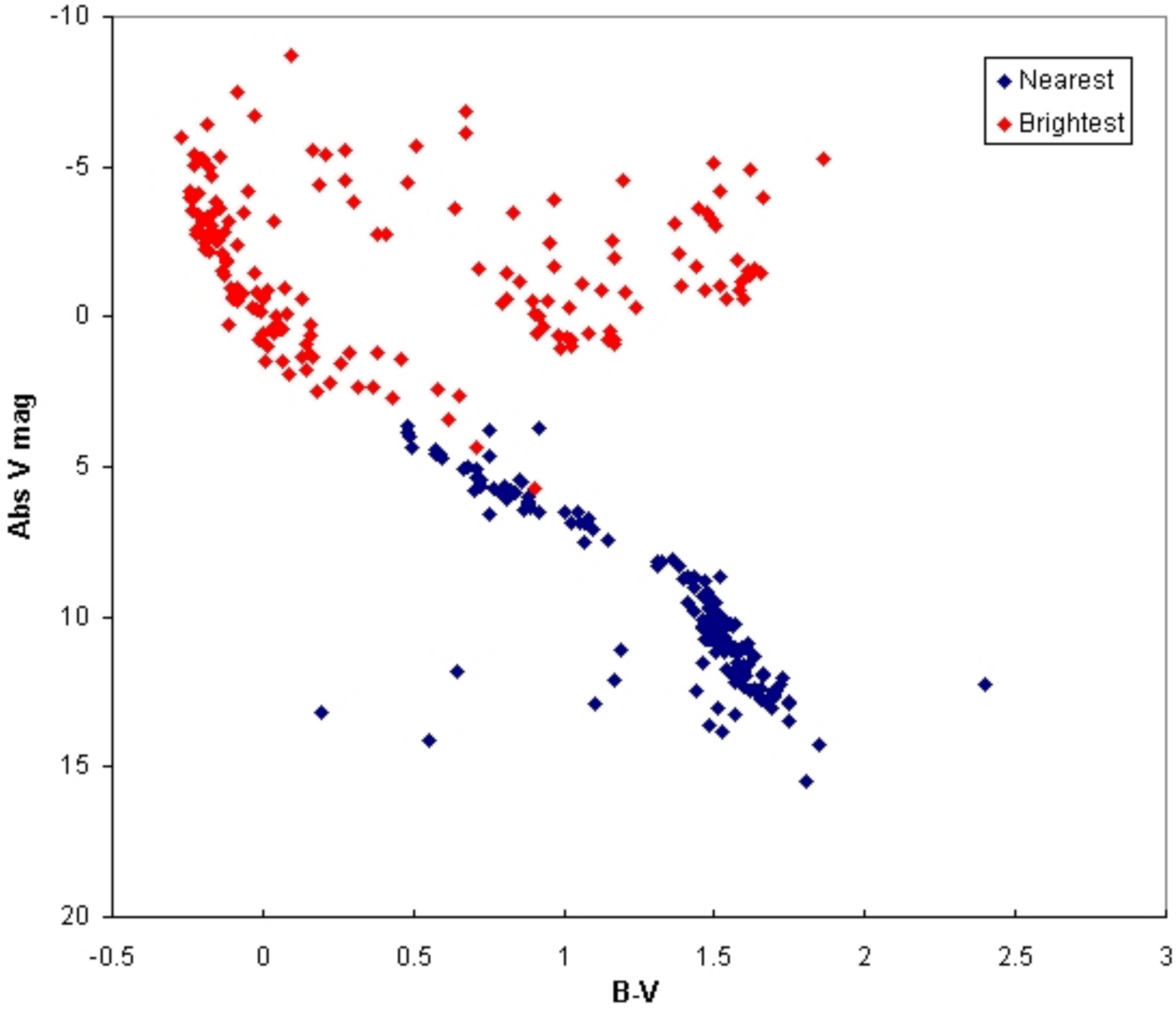
$$T_{\rm eff} = \left(\frac{L}{4\pi R^2 \sigma_{\rm SB}}\right)^{1/4}$$

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

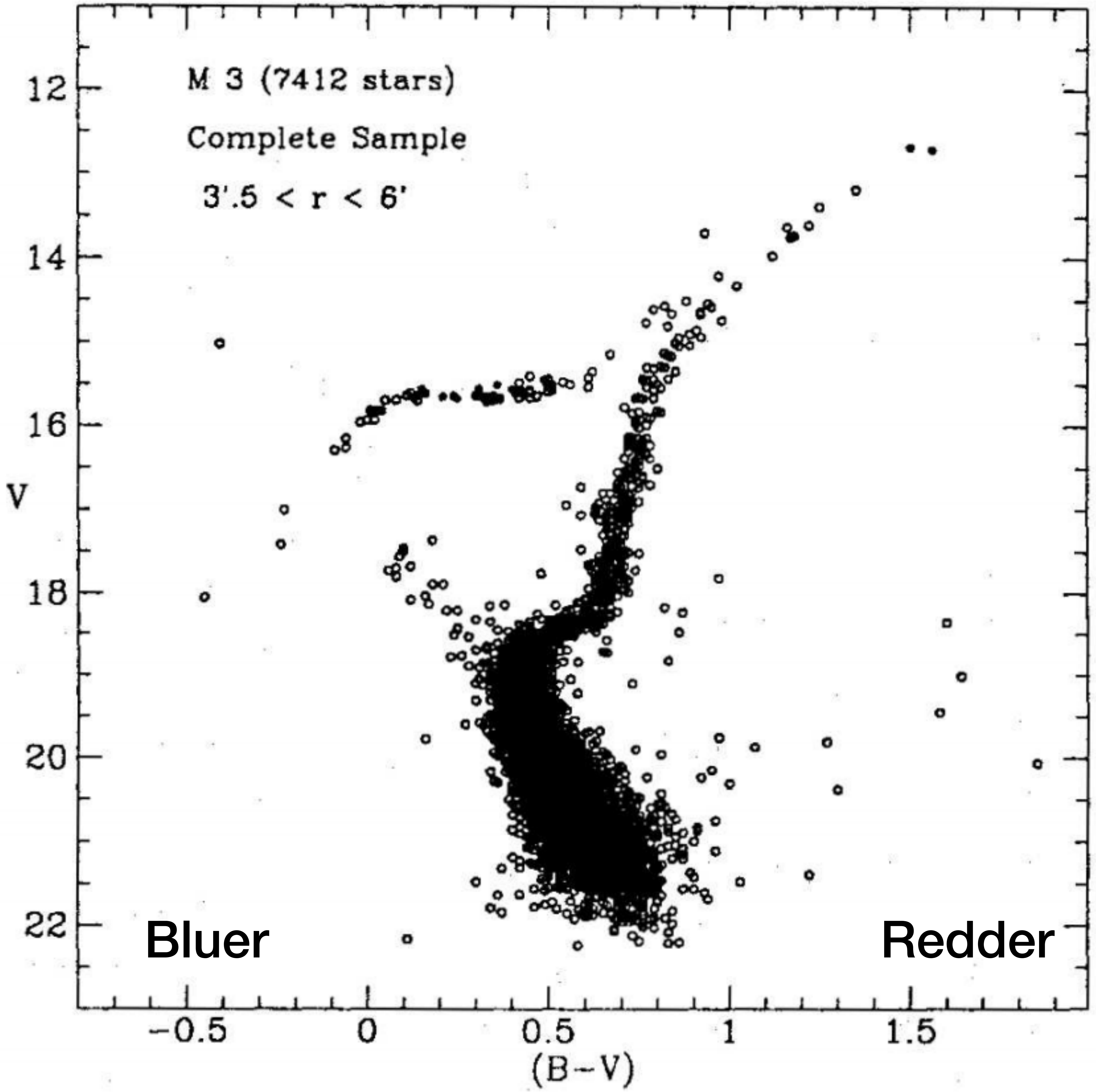
$$\log L \propto 2\log R - 4\log T^{-1}$$



Color (B-V) - Magnitude (V) Diagram (CMD) version



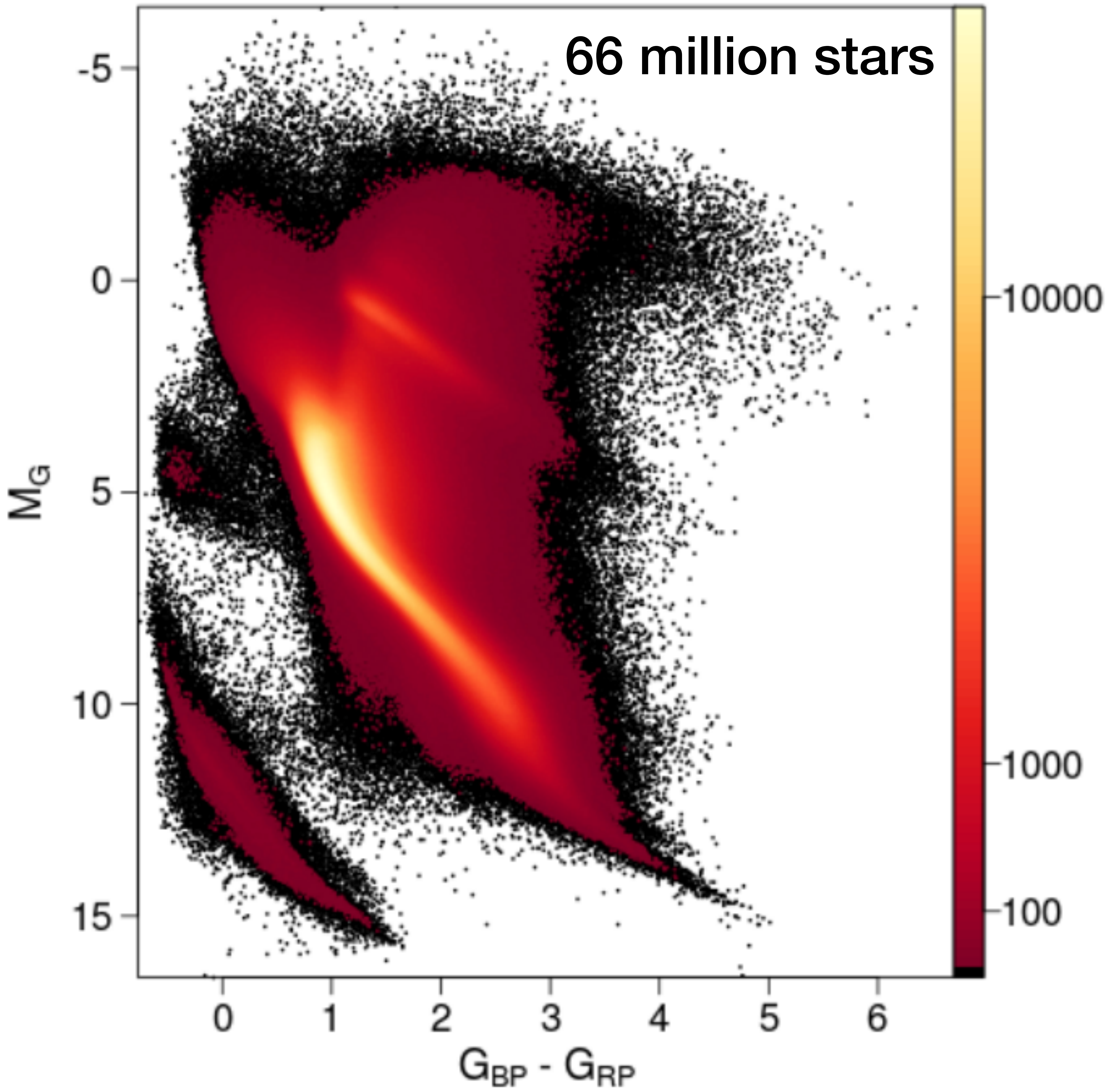
Globular Cluster Color-Magnitude Diagram

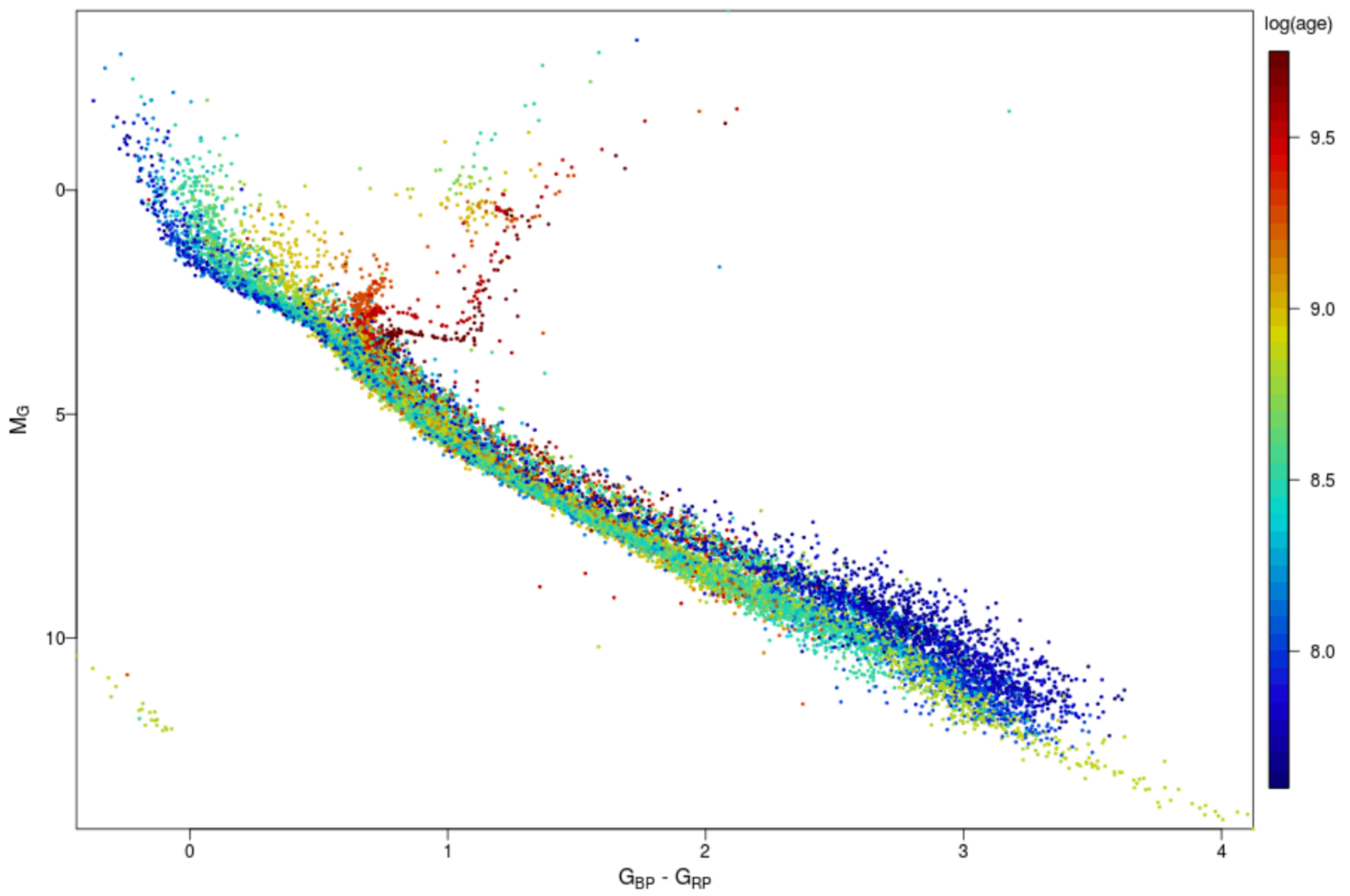


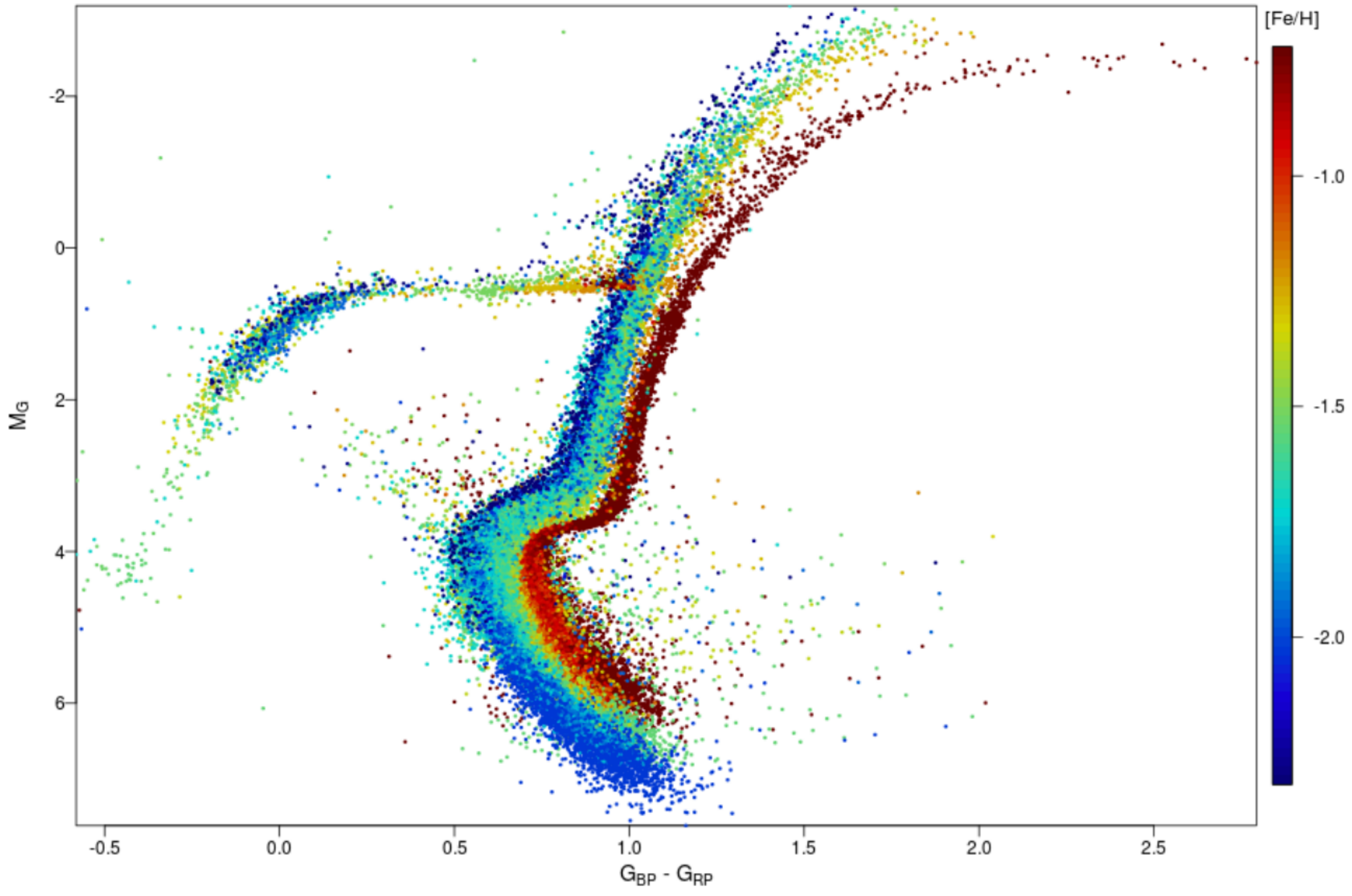
Brighter

Fainter

Gaia CMDs


66 million stars
-5
0
5
10
15
M_G
0
1
2
3
4
5
6
$G_{BP} - G_{RP}$
10000
1000
100


log(age)
9.5
9.0
8.5
8.0
0
5
10
M_G
0
1
2
3
4
$G_{BP} - G_{RP}$


[Fe/H]
-1.0
-1.5
-2.0
-2
0
2
4
6
M_G
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
$G_{BP} - G_{RP}$