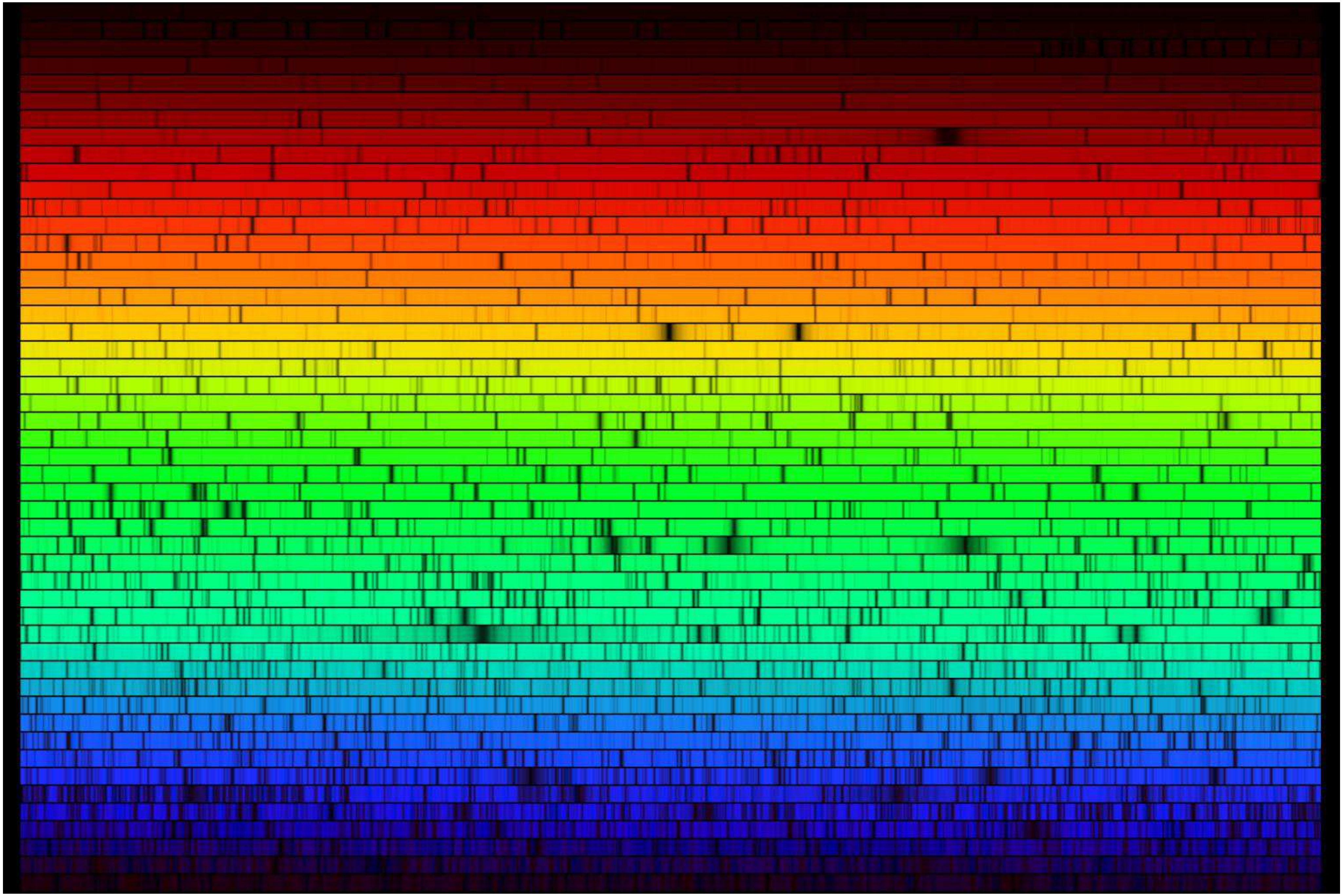
Atomic Spectra in Astrophysics



Potsdam University : Wi 2014-15 : Drs. Lidia Oskinova/Helge Todt

Stars have different colors (Why?):

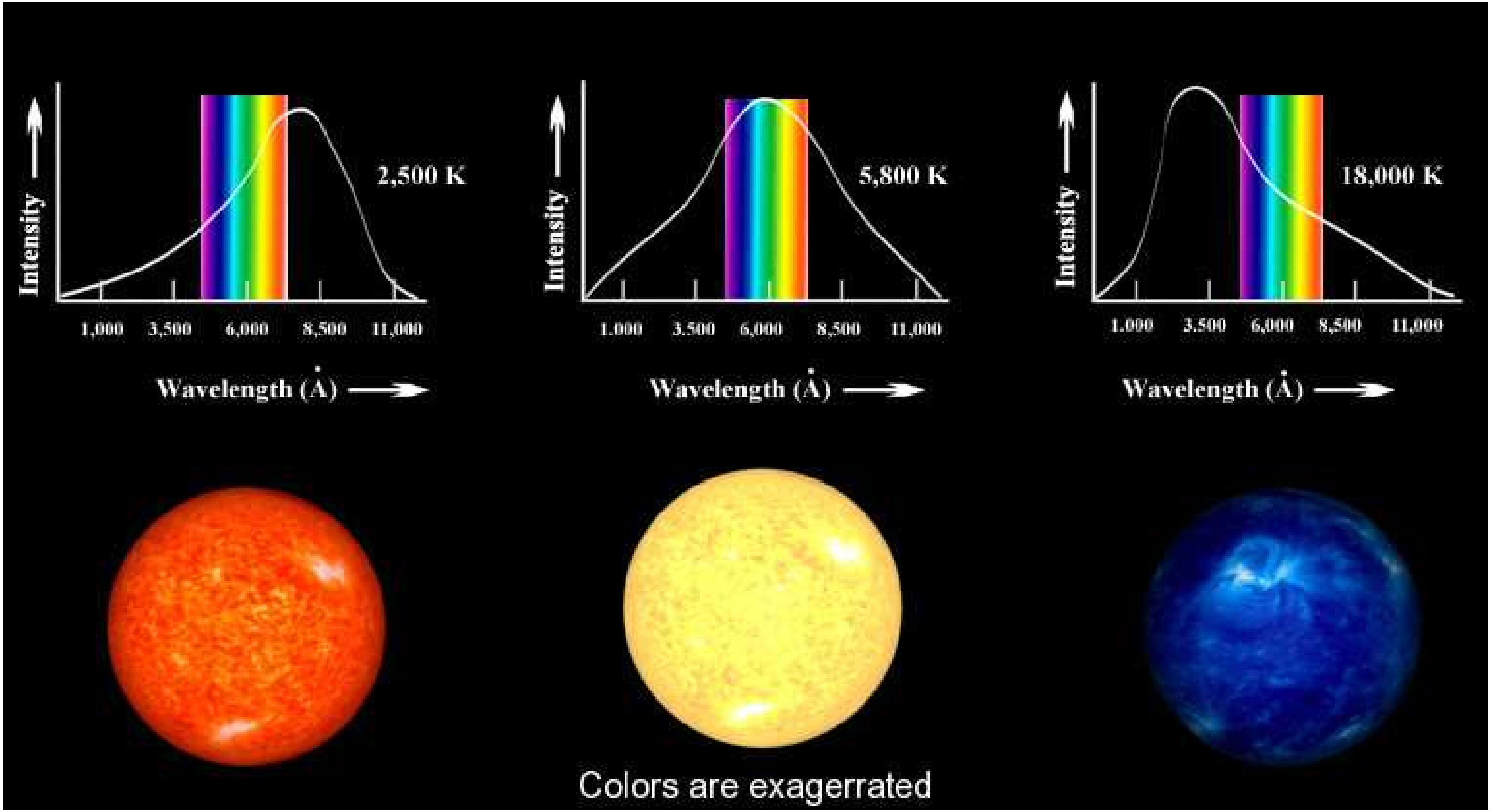
globular cluster M13

- Stars are made of hot, dense gas
- Continuous spectrum from the "photosphere"
- Approximates a BB spectrum.

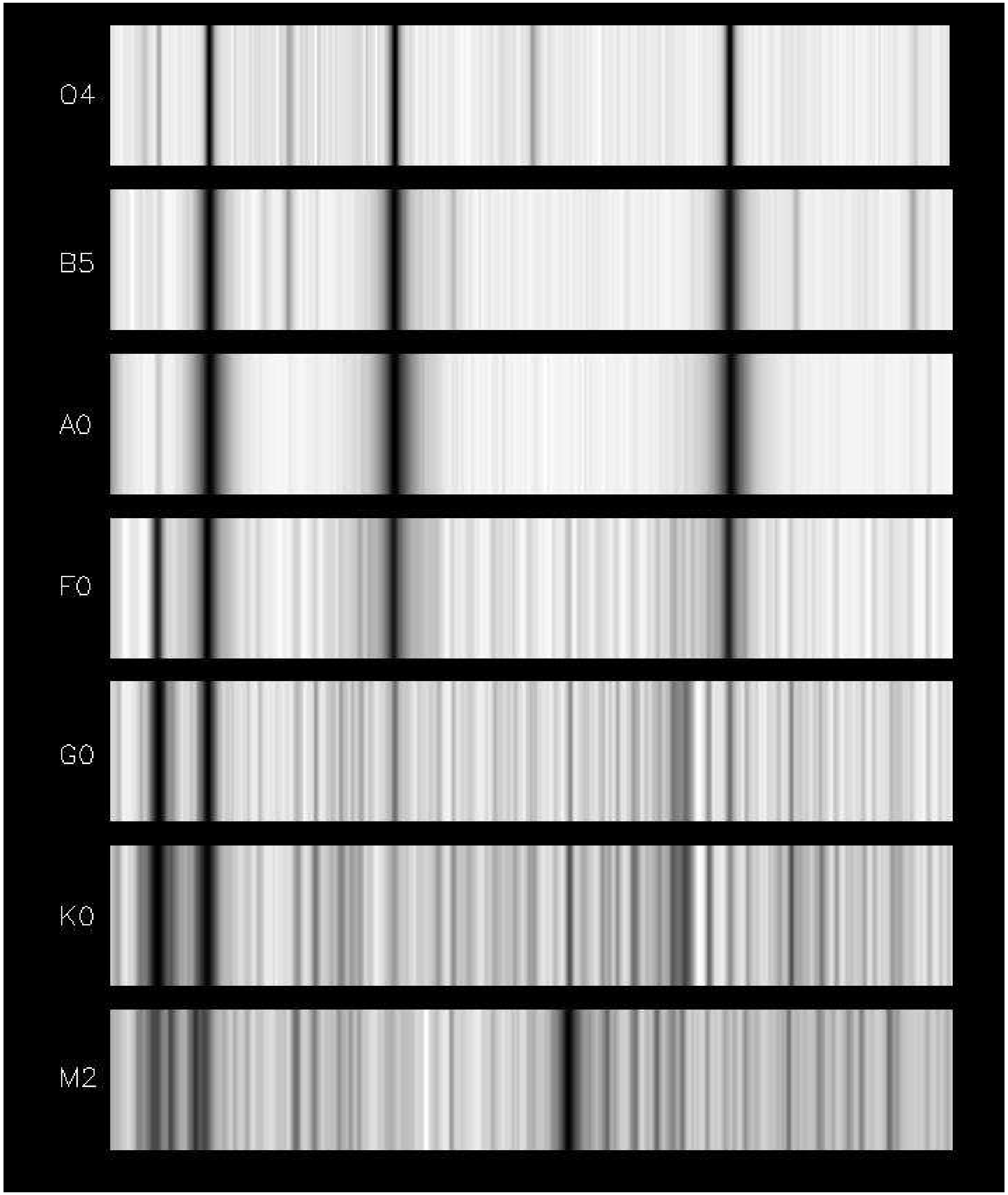
Hot stars T>10000K **Blue**

Solar-type: T ~ 6000K **Yellow**

Cool: T ~ 3000 K **Red**



Intensity
2,500 K
1,000
3,500
6,000
8,500
11,000
Wavelength (Å)
Intensity
5,800 K
1,000
3,500
6,000
8,500
11,000
Wavelength (Å)
Intensity
18,000 K
1,000
3,500
6,000
8,500
11,000
Wavelength (Å)
Colors are exagerrated



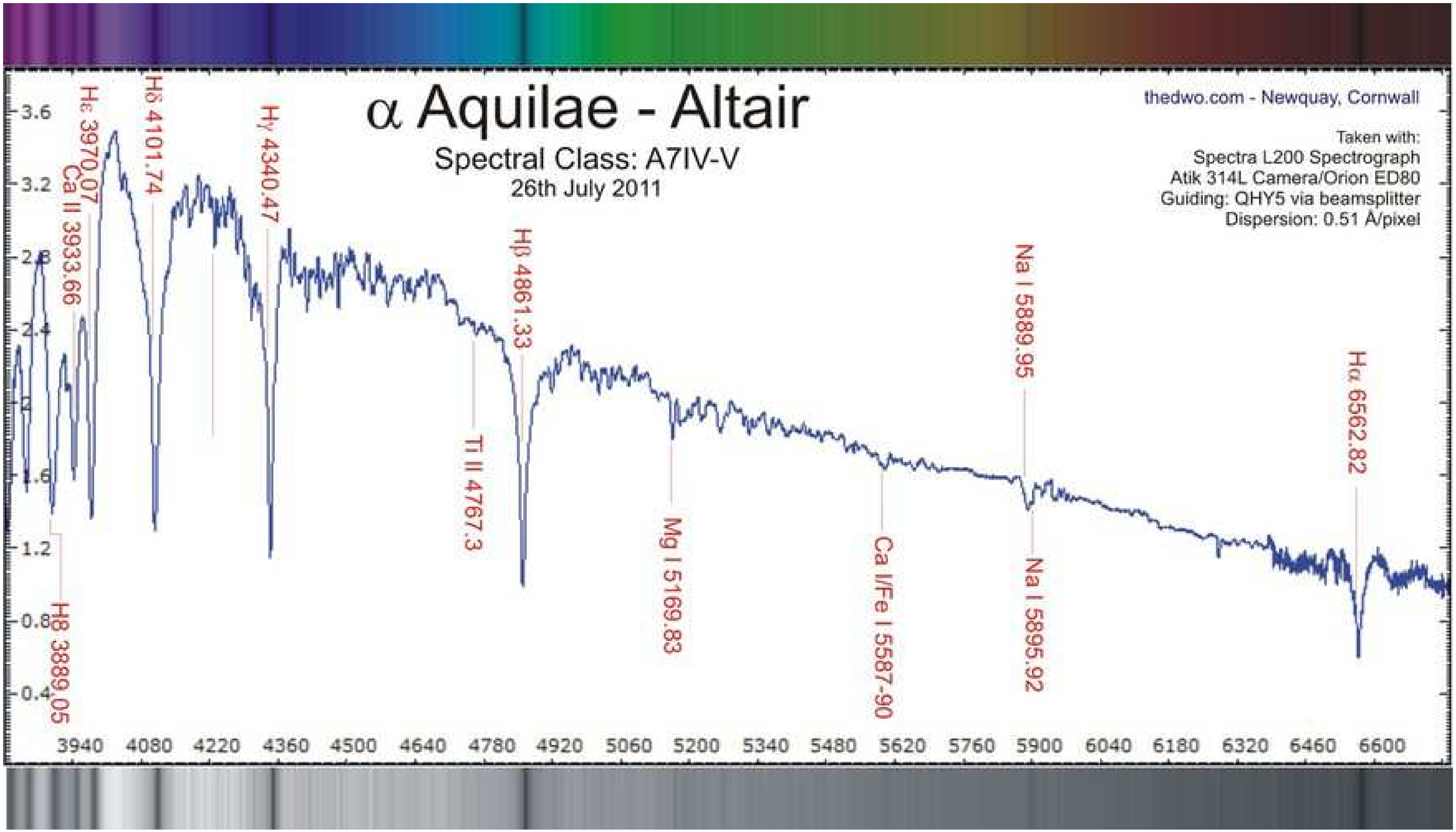
Stellar Spectra

- Above the hot and dence photosphere is a thin layer of cooler gas - atmosphere.
- Absorption lines are formed in the atmopshere
- Spectrum formation: chemical composition, element ionization and exitation, radiation field, fundamnetal stellar parameters

Requerement: qunatum mechanics; radiative transfer

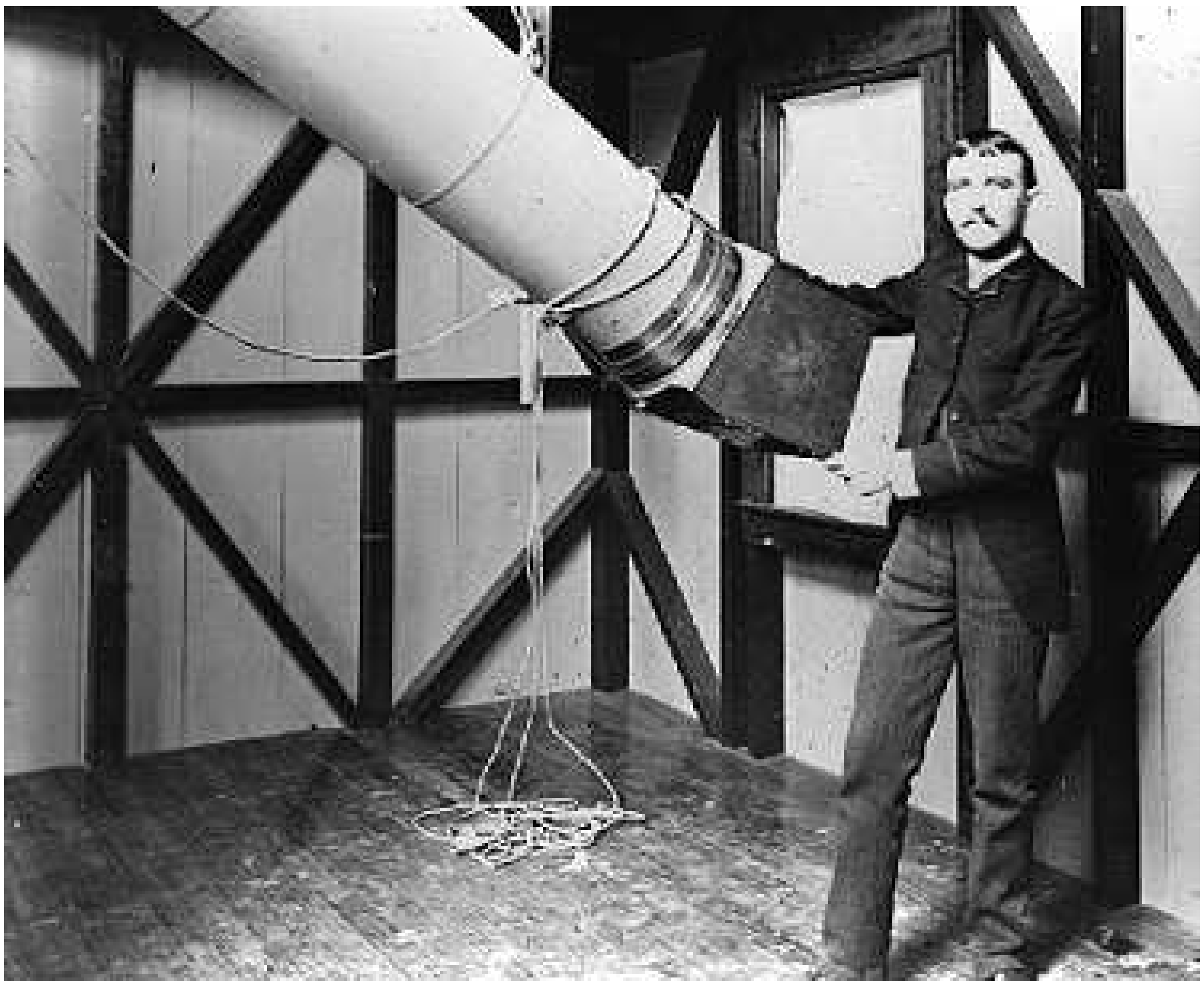
Stars

Stellar photosphere is blackbody with T_{eff}. Absorption lines formed in cooler atmosphere.



Astrophotogrpahy

- Henry Draper (1837-1882) made the first photograph of a star's (Vega) spectrum showing distinct spectral lines in 1872.

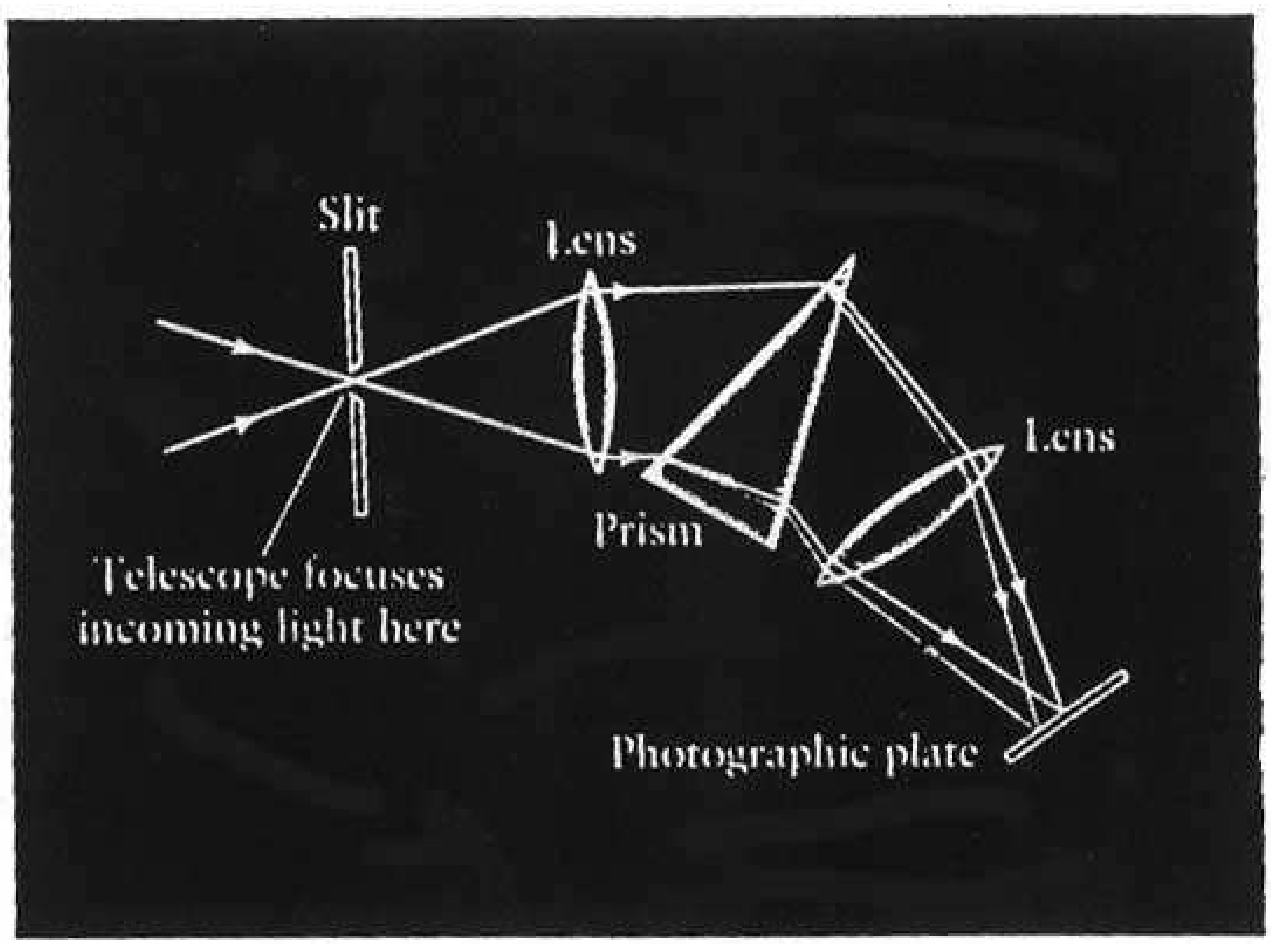


- Other works by HD (degree in medicine): • Are there other inhabited worlds?, 1866; • Delusions of Medicine, Charms, talismans, amulets, astrology, and mesmerism, 1873; • The Discovery of Oxygen in the Sun by Photography, 1877.

Objective Prism Photography

- Henry Draper took hundreds photographs of stellar spectra before his death in 1882 (45yo).

- The objective prism method.

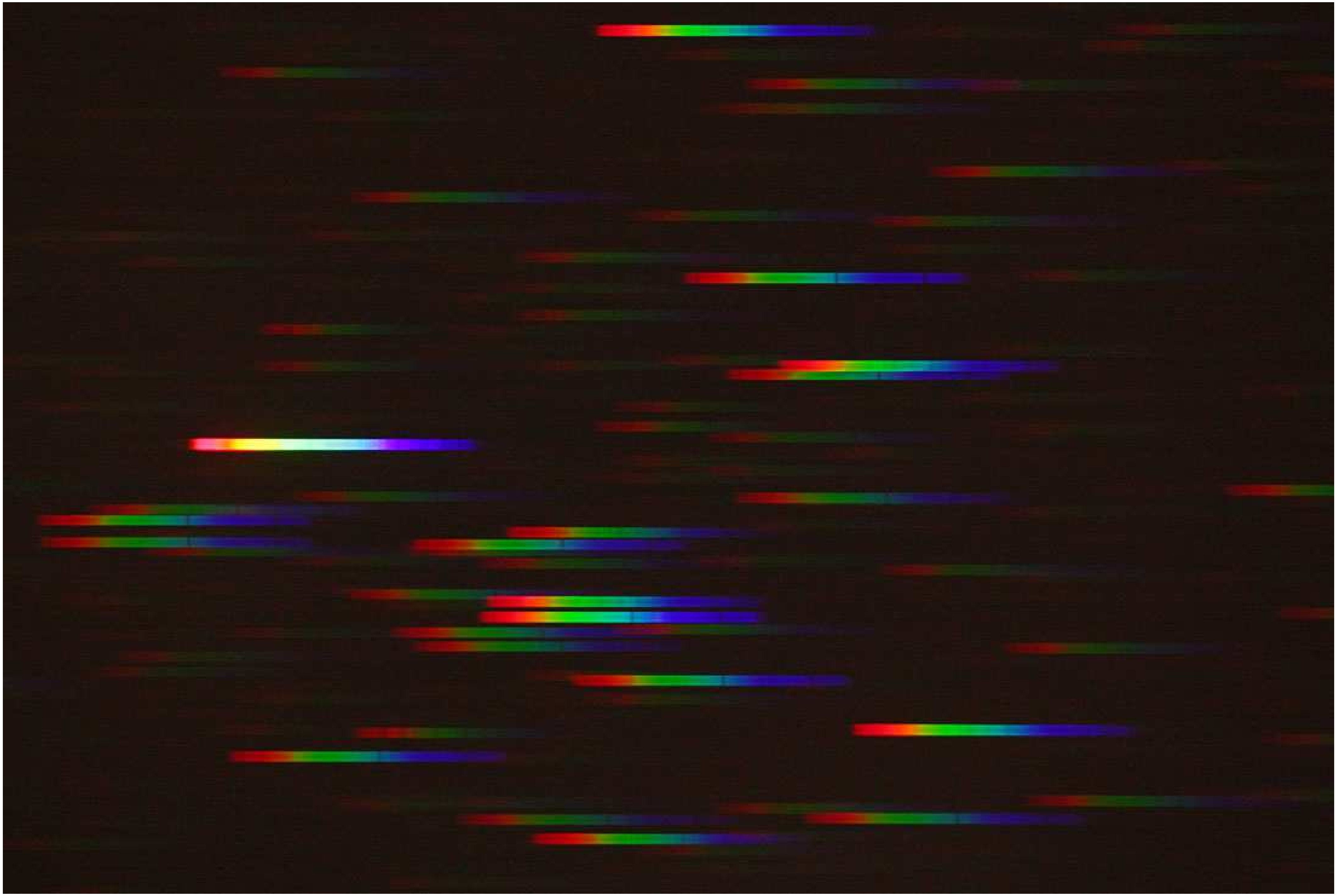


- 1885 Edward Pickering began to supervise photographic spectroscopy at Harvard
- Obtained spectra of >100,000 stars hired women to analyze spectra
- 1886 Draper's widow became interested in Pickering's research and funded it under the name Henry Draper Memorial

- 1890 Draper Catalogue of Stellar Spectra, 10 351 stars.

Hyades cluster

Objective prism spectra of Hyades cluster



Edward Pickering (director, Harvard Observatory, 1877 to 1919)

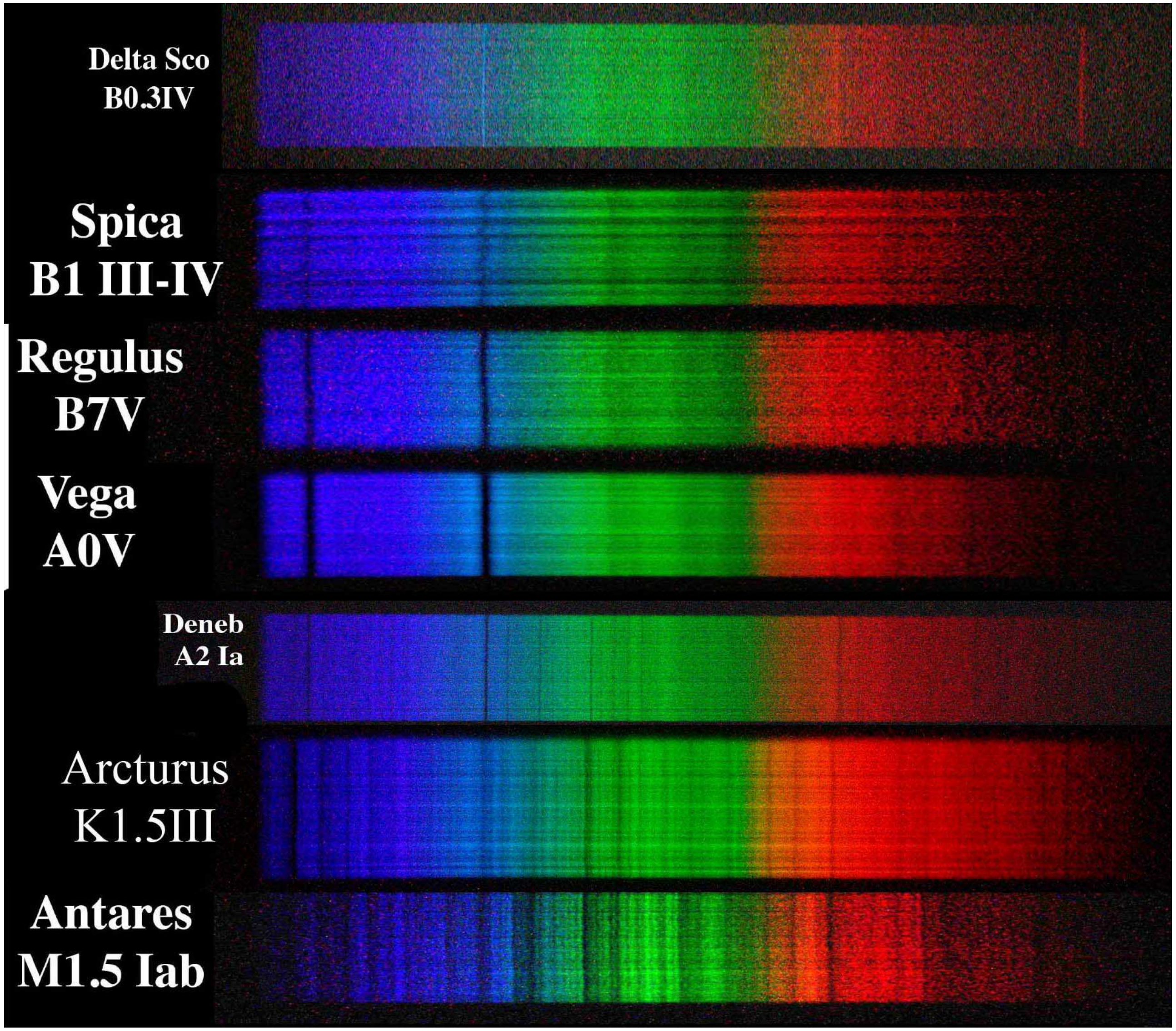
Hired women as “computers” to systematically look at stellar spectra

‘Harvard computers’ incl. Williamina Fleming, Annie Jump Cannon, Henrietta Swan Leavitt and Antonia Maury


β AURIGÆ. DEC 1889

Harvard Classification

Edward Pickerings first attempt at a systematic spectral classification: Sort by Hydrogen absorption-line strength; Spectral Type A = strongest Hydrogen - followed by types B,C,..,N (weaker)



Problem: Other lines followed no discernible patterns.

O B A F G K M

Annie Jump Cannon Leader of Pickerings computers, she noticed subtle patterns among metal lines.

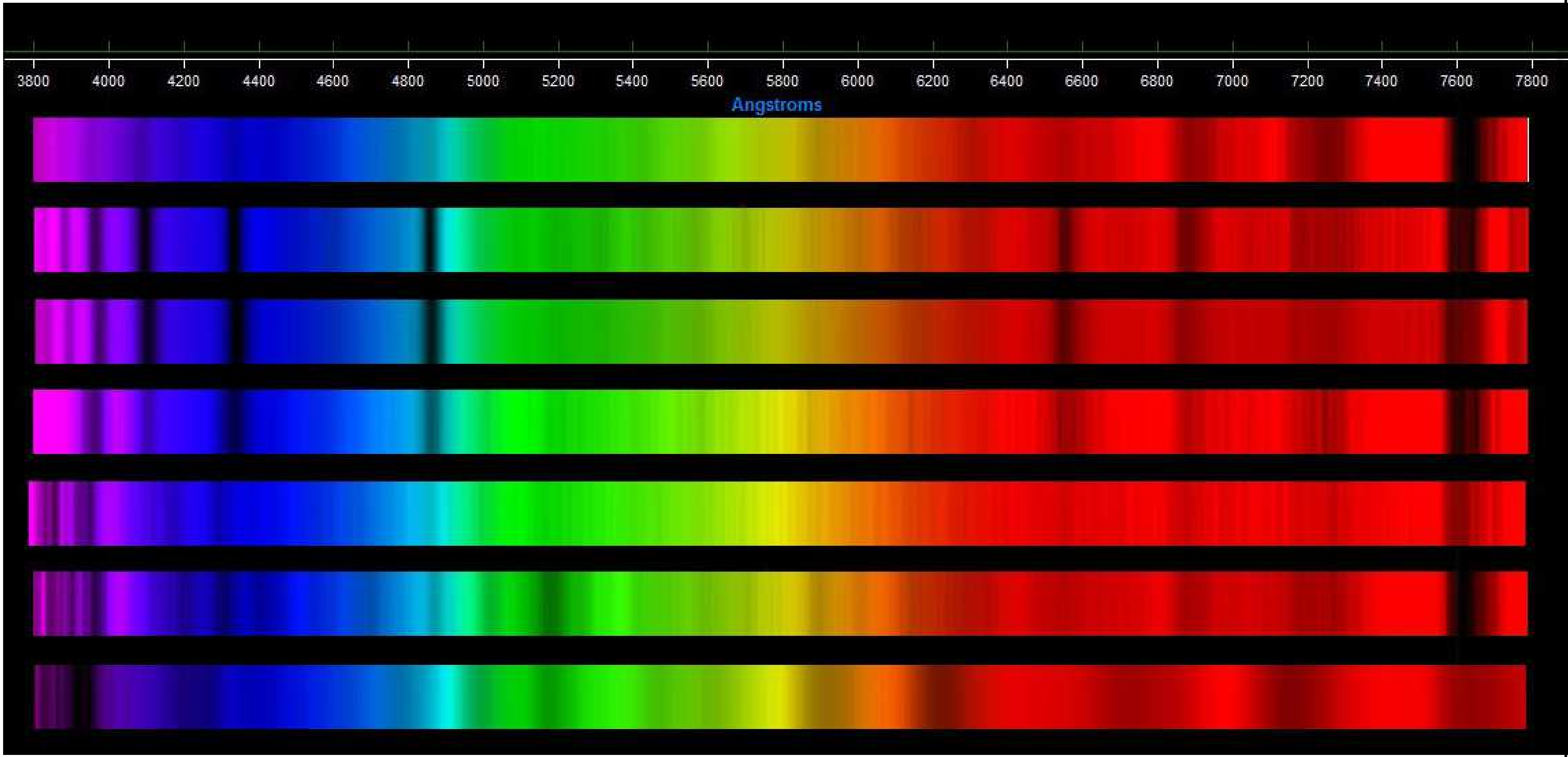
Re-arranged Pickerings ABC spectral types, throwing out most as redundant.

Left 7 primary and 3 secondary classes

Unifying factor:

Temperature

Be Pickering's computer: identify the lines

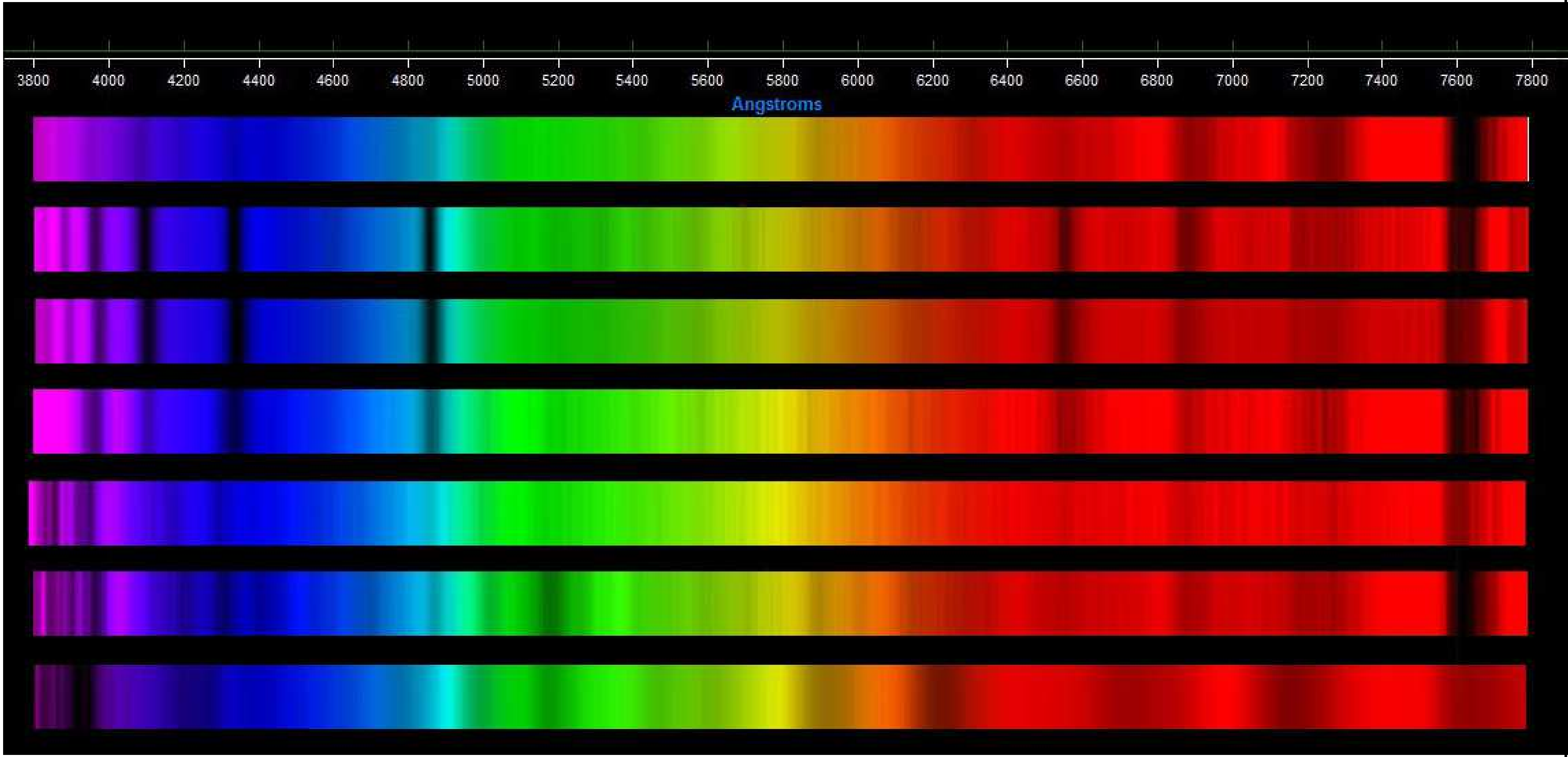


Become a Pickering's computer: identify the lines

Rydberg: $\frac{1}{\lambda} = \frac{R_\infty}{1+\frac{m_e}{m_H}}\left(\frac{1}{i^2} - \frac{1}{j^2}\right)$

Hα λ6564.6Å, Hβ λ4862.7Å, Hβ λ4341Å, ...

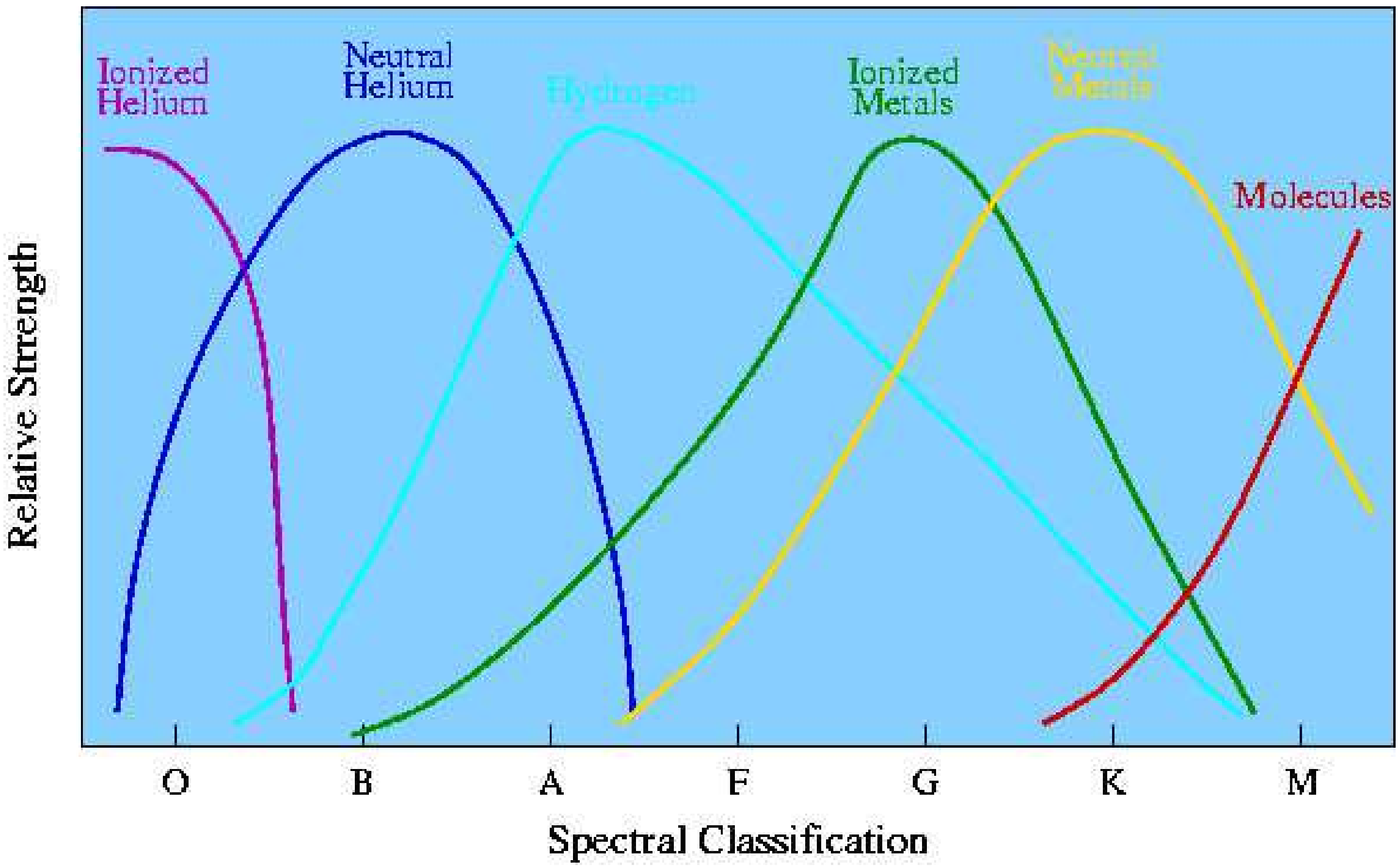
HeII λ4541Å, HeII λ4200Å, HeI λ4471Å, HeI λ4026



The Spectral Sequence is a Temperature Sequence

Gross differences among the spectral types are due to differences in **Temperature.**

Composition differences are minor at best. - Demonstrated by Cecilia Payne-Gaposhkin in 1920s



Why?

What lines you see depends on the state of excitation and ionization of the gas.

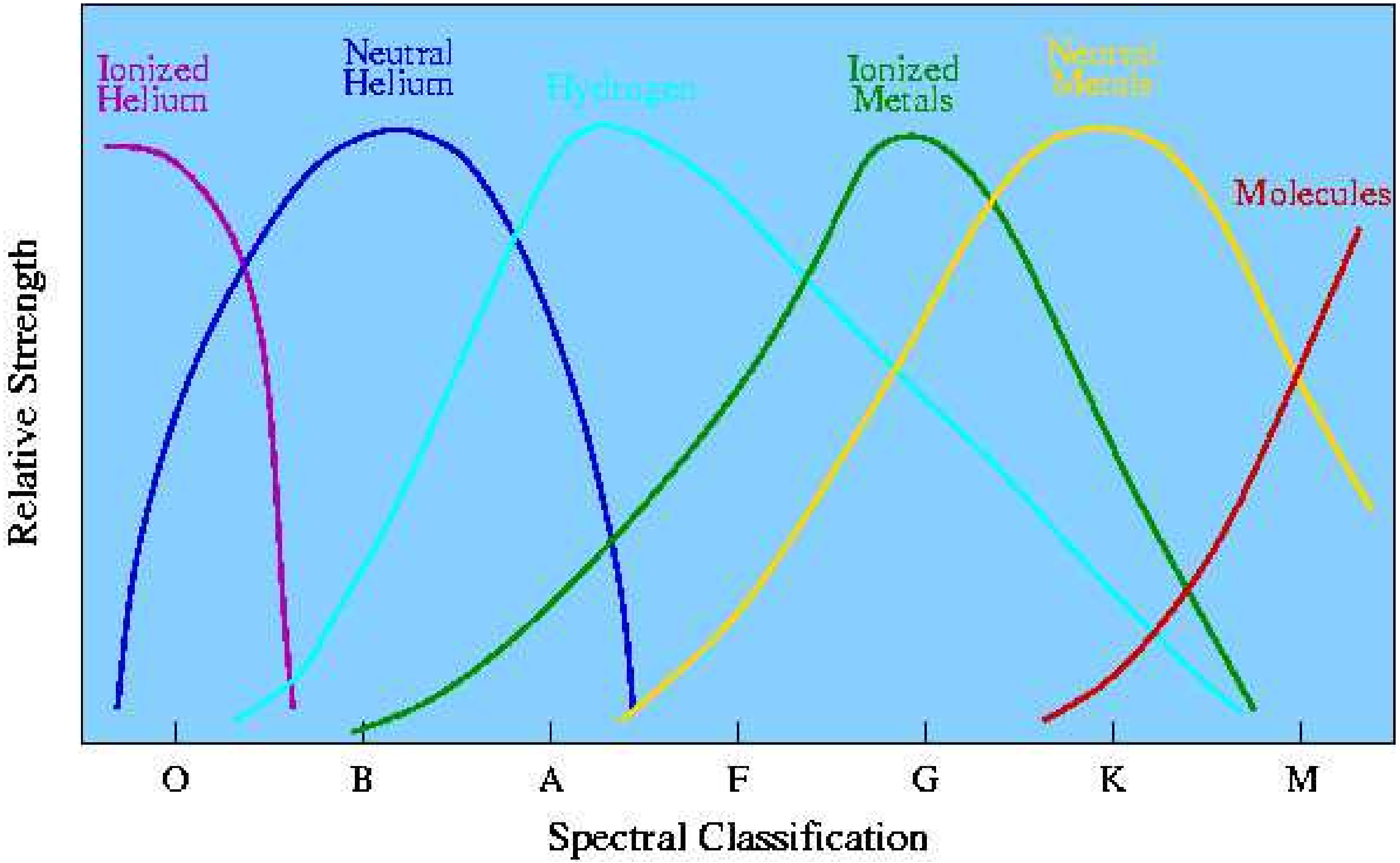
Example: Hydrogen Line Hα λ6564.6Å

B Stars (15-30 000 K): Most of H is ionized, so only very weak Hα

A Stars (10,000 K): Ideal excitation conditions, strongest Hα

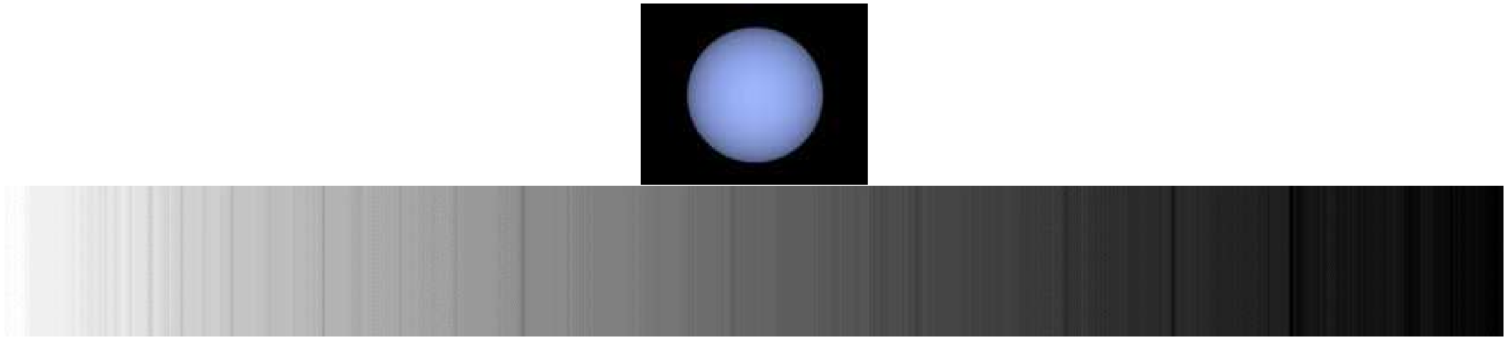
G Stars (6000 K): Too cool, little excited H, so only weak H lines.

What lines you see depends on the state of excitation and ionization of the gas.



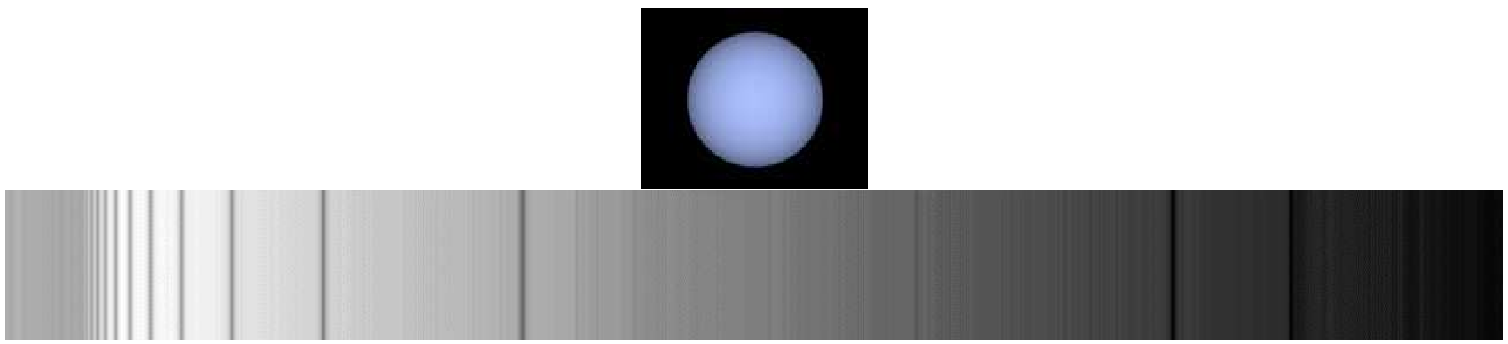
O stars

T>30 000 K; He+, O++, N++, Si++, He, H



B stars

T = 11,000 - 30,000 K, He, H, O+, C+, N+, Si+

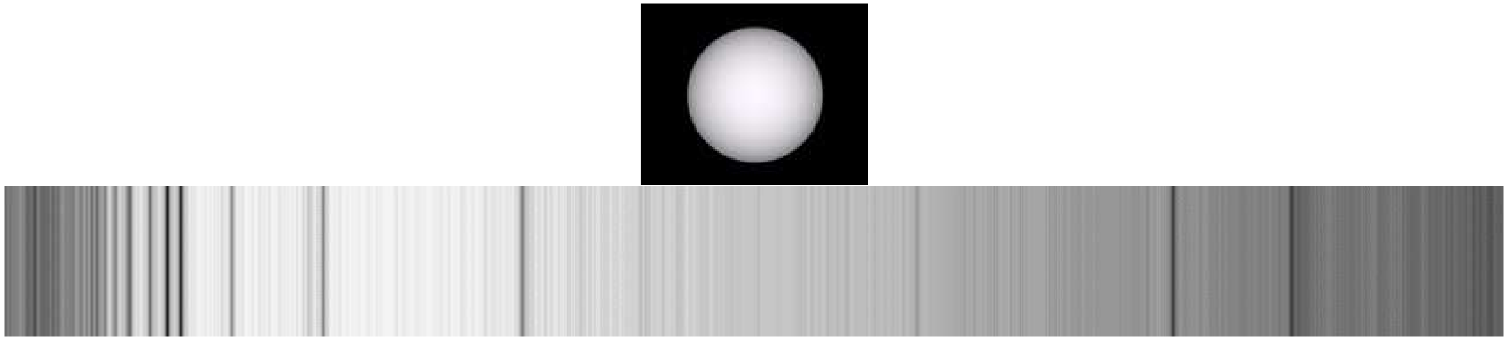


A stars

T = 7500 - 11,000 K, H(strongest), Ca+, Mg+, Fe+

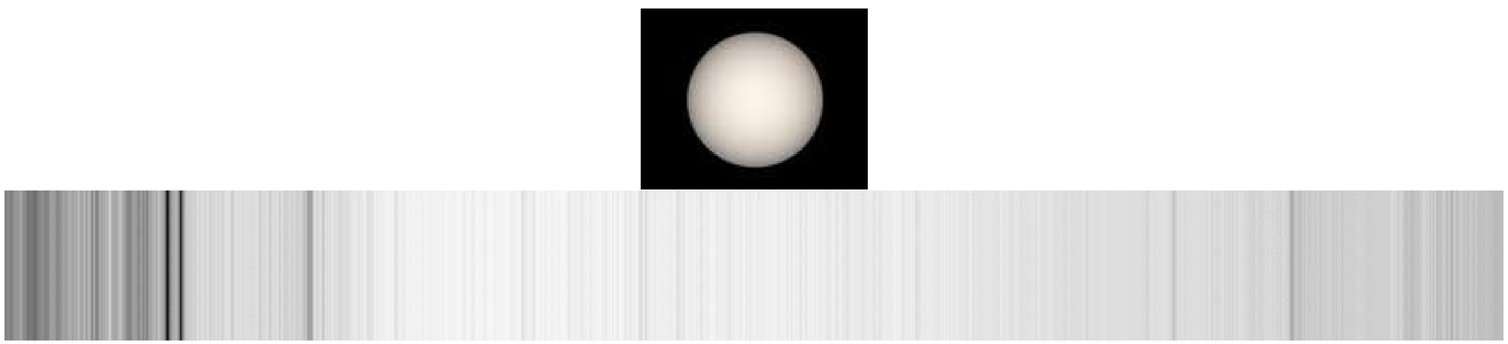
F stars

T = 5900 - 7500 K; H(weaker), Ca+, ionized metals



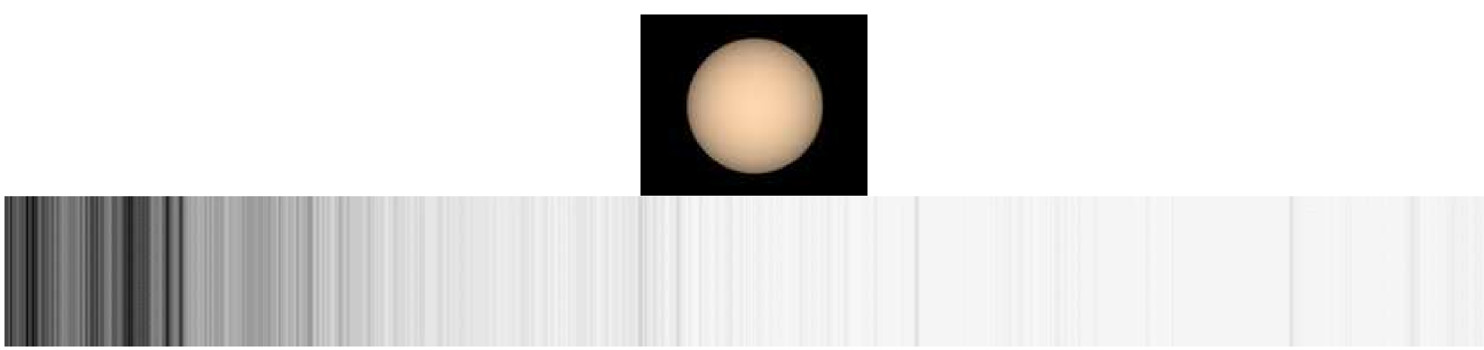
G stars

T = 5200 - 5900 K; Strong Ca+, Fe+ and other metals dominate



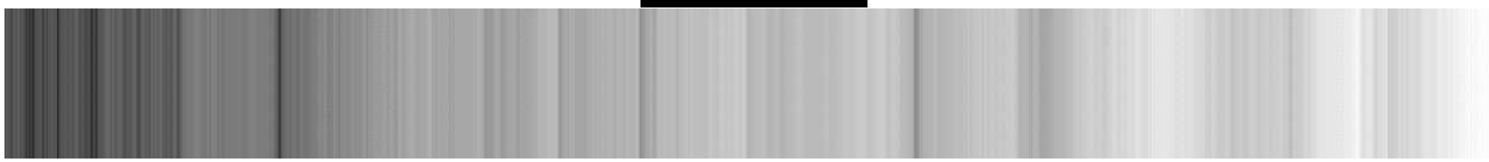
K stars

T = 3900 - 5200 K; Ca+(strongest), neutral metals, H(weak), CH & CN



M stars

T = 2500 - 3900 K Strong neutral metals, TiO, VO, no H

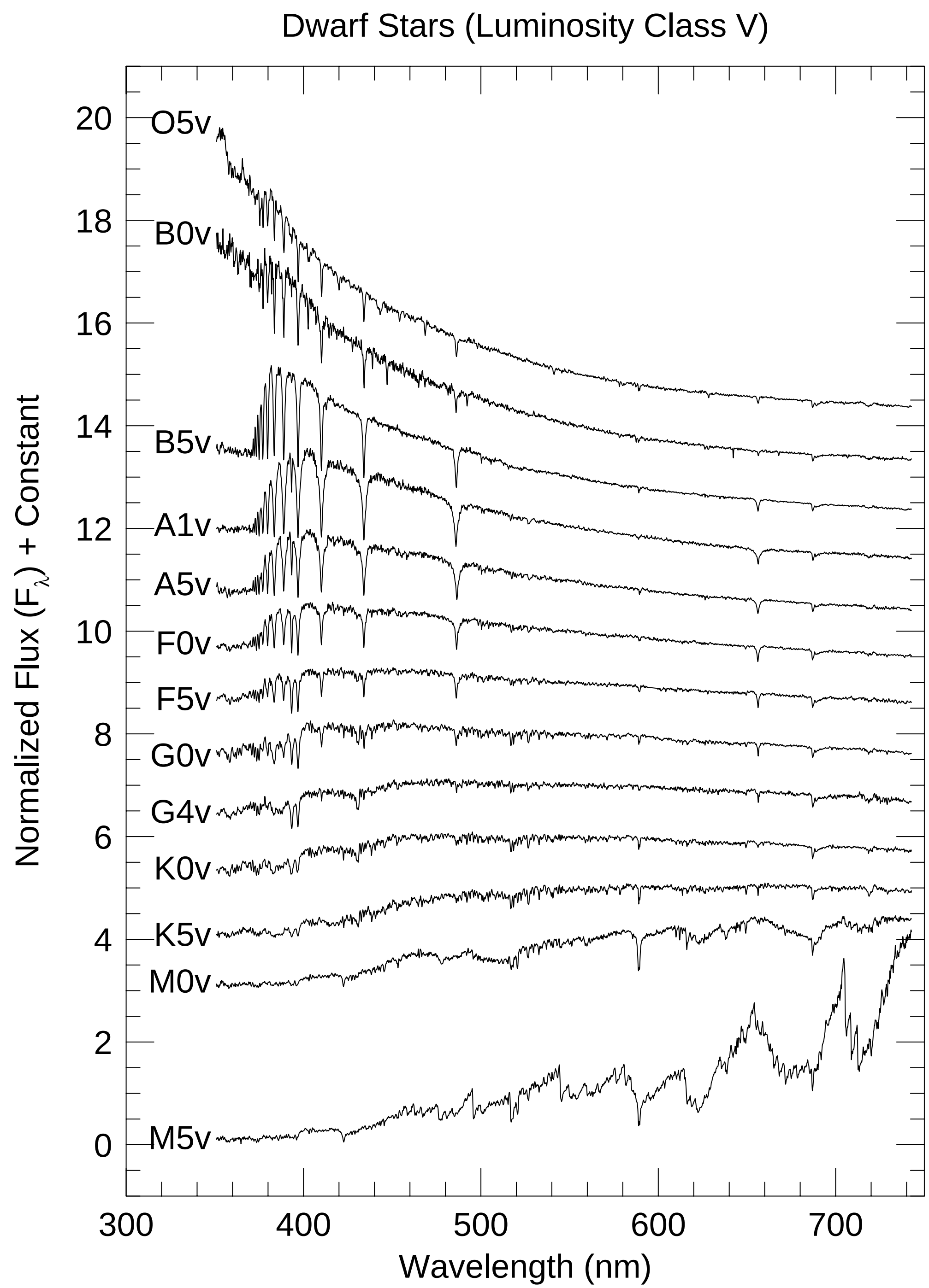


L stars

T = 1300 - 2500 K; strong molecular absorption bands particularly of metal hydrides and neutral metals like sodium, potassium, cesium, and rubidium. No TiO and VO bands. No spectra yet.

T dwarfs / Brown Dwarfs

T < 1300 K; very low-mass objects, not technically stars anymore because they are below the Hydrogen fusion limit (so-called "Brown Dwarfs"). T dwarfs have cool Jupiter-like atmospheres with strong absorption from methane (CH4), water (H2O), and neutral potassium. No spectra yet.

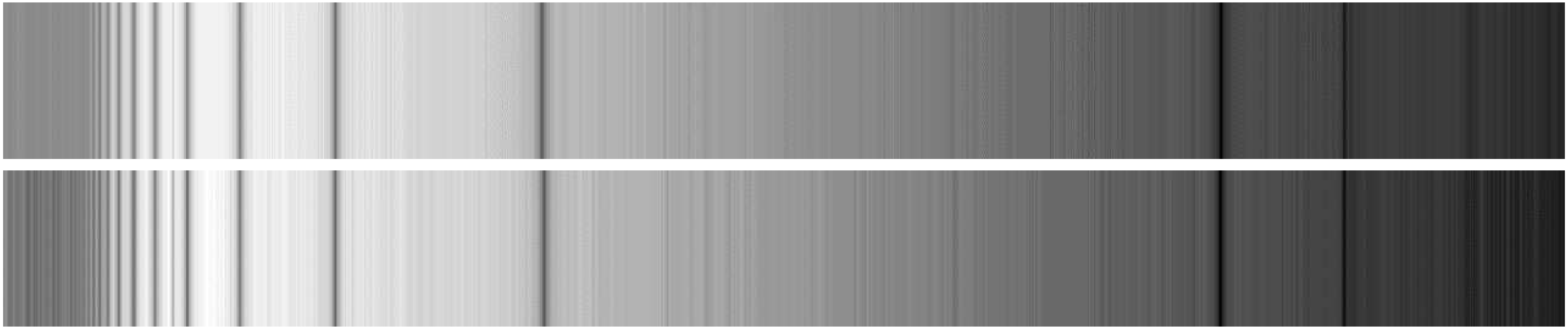

Dwarf Stars (Luminosity Class V)
Normalized Flux (F_λ) + Constant
Wavelength (nm)
O5v
B0v
B5v
A1v
A5v
F0v
F5v
G0v
G4v
K0v
K5v
M0v
M5v
0
2
4
6
8
10
12
14
16
18
20
300
400
500
600
700

Modern MK classification

- An understanding of atomic physics and better techniques permit finer distinctions.
- Morgan-Keenan (MK) Classification System (Morgan, Keenan & Kellman 1943, Johnson & Morgan, 1953, ApJ, 117, 313,)
- Brings in agreemnet colours and spectral classification

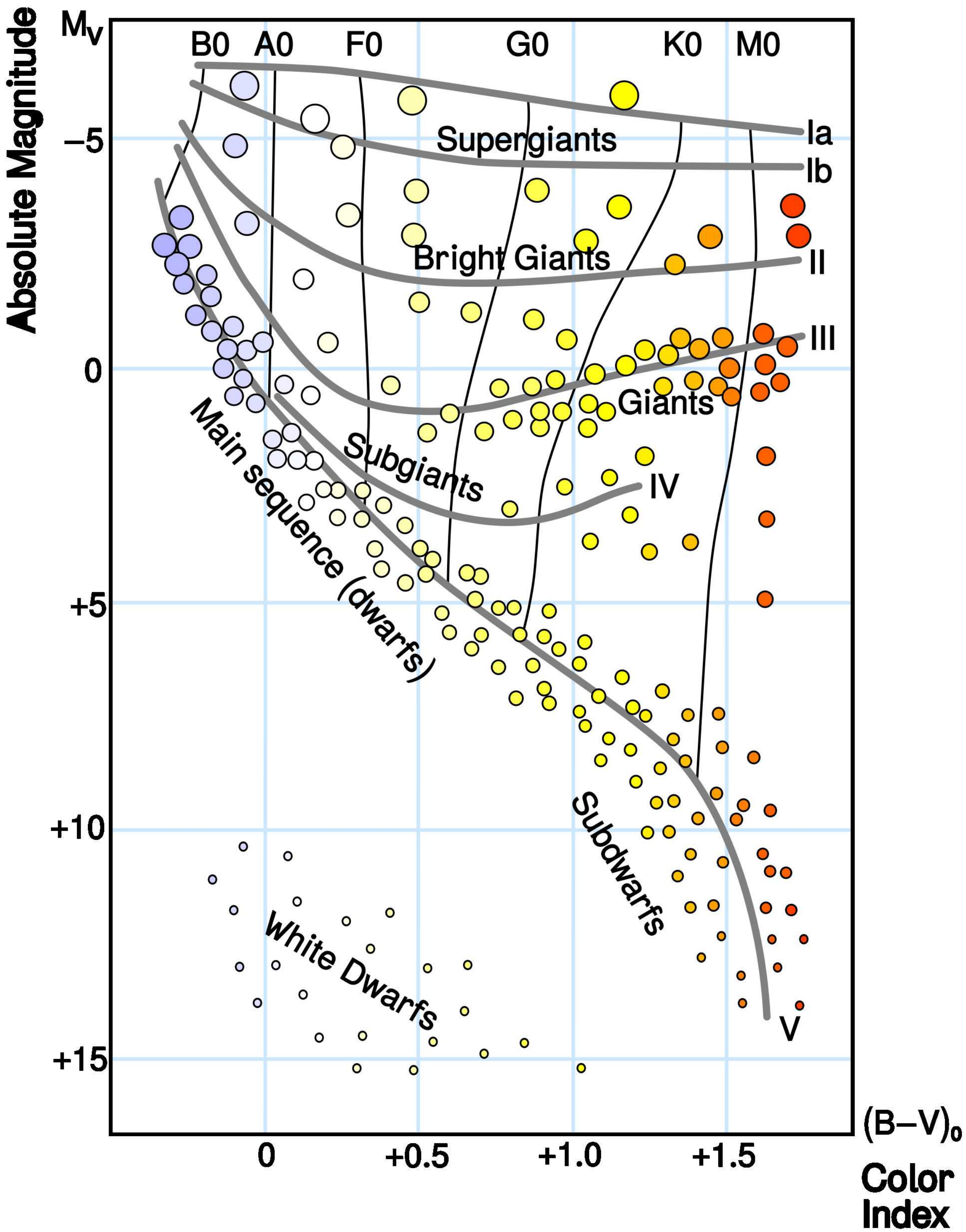
Start with Harvard classes: • **O B A F G K M L T**

Subdivide into numbered subclasses: • **A0 A1 A2 A3 ... A9**



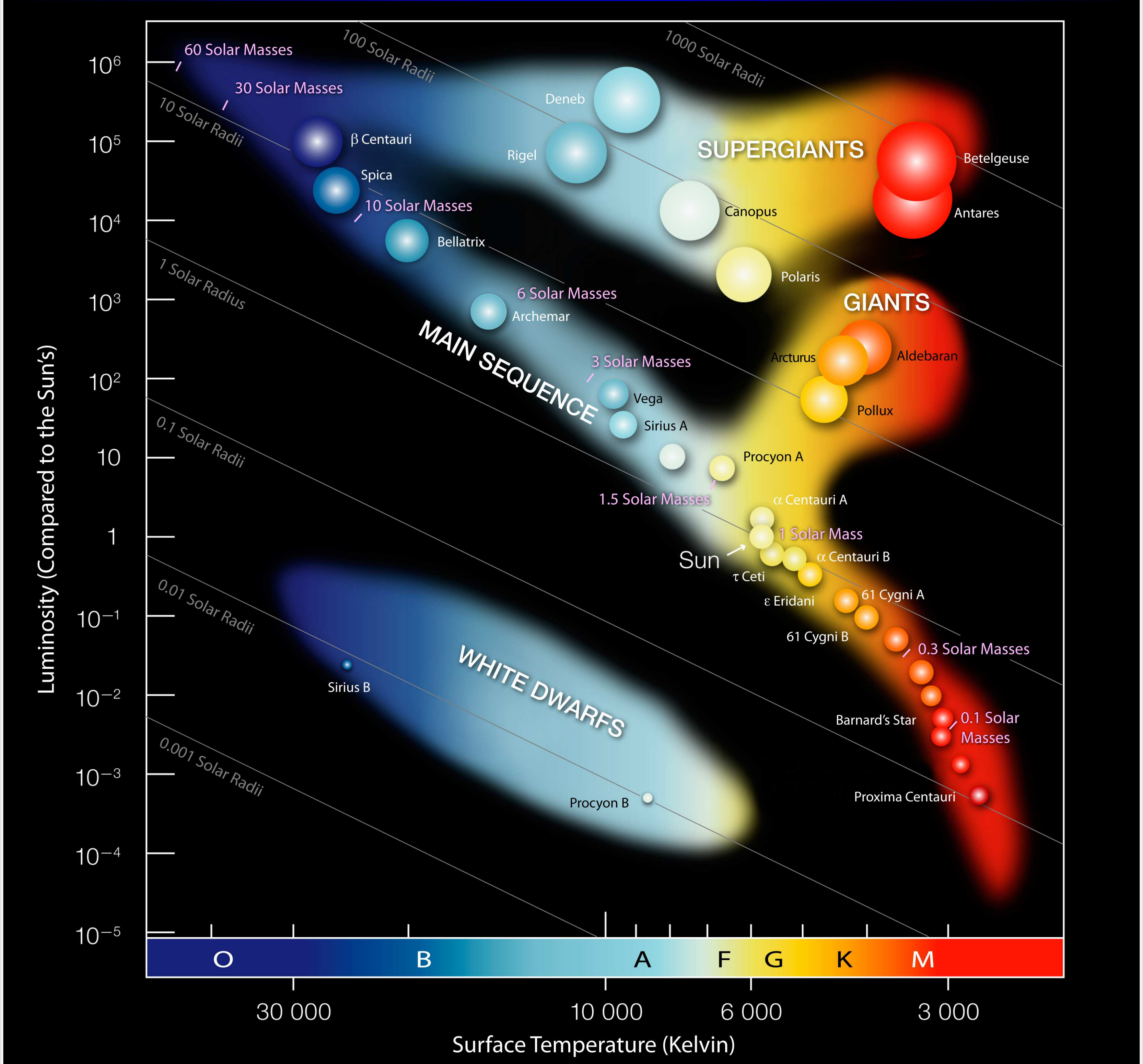
Comparing A1V (T=9000K) spectrum and A5V (T=7880K) spectrum

Modern MK classification: 2-dimentional



- "Phenomenology of spectral lines, blends, and bands, based on general progression of color index (abscissa) and luminosity (ordinate)."

H-R DIAGRAM



Luminosity (Compared to the Sun's)
10^6
10^5
10^4
10^3
10^2
10
1
10^−1
10^−2
10^−3
10^−4
10^−5
60 Solar Masses
30 Solar Masses
10 Solar Masses
6 Solar Masses
3 Solar Masses
1.5 Solar Masses
1 Solar Mass
0.3 Solar Masses
0.1 Solar Masses
100 Solar Radii
1000 Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radii
0.01 Solar Radii
0.001 Solar Radii
Deneb
Rigel
β Centauri
Spica
Bellatrix
Archemar
Canopus
Polaris
Betelgeuse
Antares
SUPERGIANTS
GIANTS
Arcturus
Aldebaran
Pollux
MAIN SEQUENCE
Vega
Sirius A
Procyon A
α Centauri A
Sun
α Centauri B
τ Ceti
ε Eridani
61 Cygni A
61 Cygni B
Barnard's Star
Proxima Centauri
WHITE DWARFS
Sirius B
Procyon B
O
B
A
F
G
K
M
30 000
10 000
6 000
3 000
Surface Temperature (Kelvin)

Hertzsprung, Publ. Astrophys. Observ. Potsdam 22, 1, 1911

• The Harvard classification: 10 sub-classes depending on the absorption features - temperature. The Sun T=5700 K is a G2 star.

• Harvard scheme cannot distinguish between stars with the same temperature but different luminosities

• The Morgan-Keenan luminosity class (MK or MKK): roman numerals between I (supergiant star) and V (main sequence), and subclasses. The Sun G2V.

Ia luminous supergiants

Ib supergiants

II bright giants

III giants

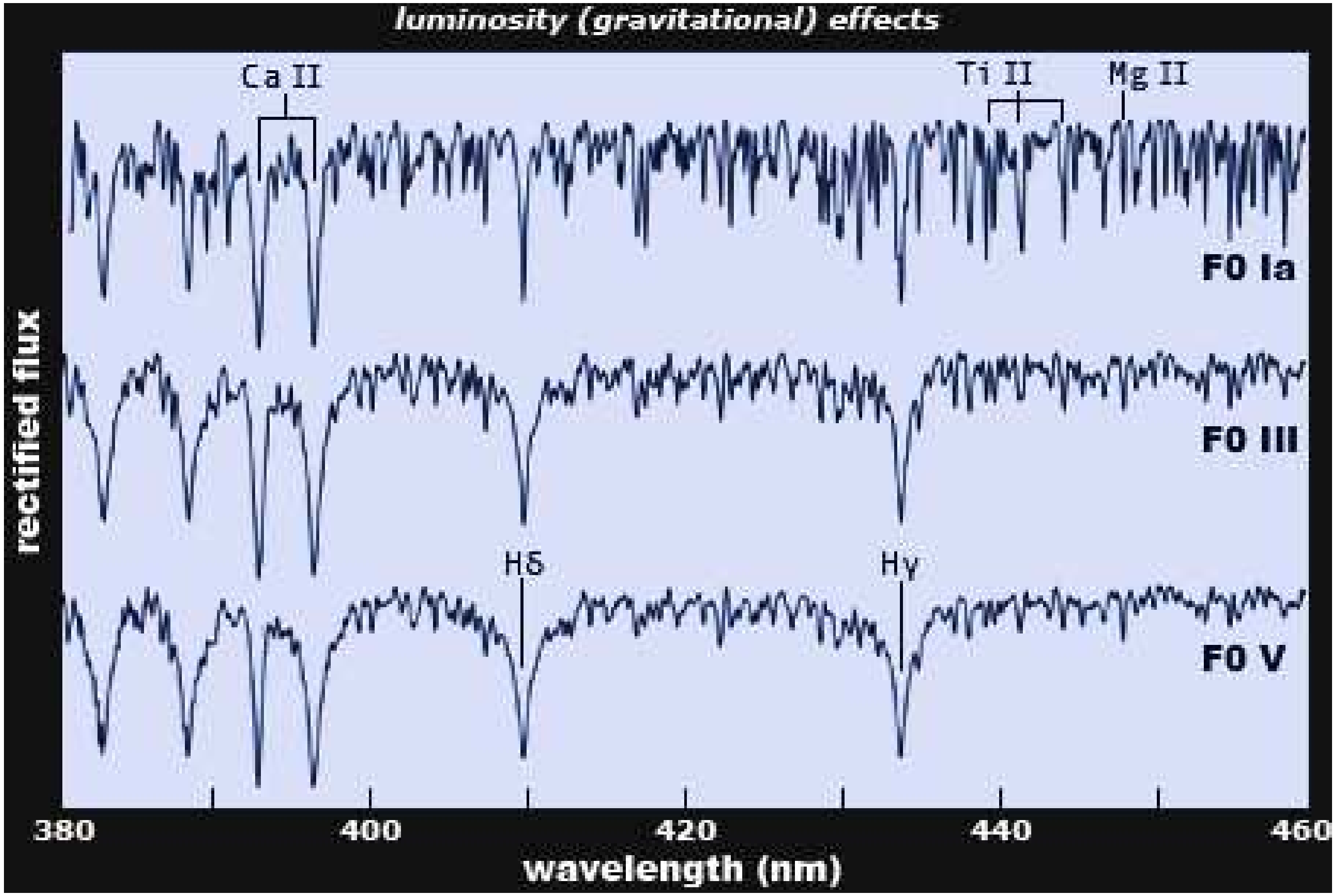
IV subgiants

V dwarfs

sd subdwarfs

D white dwarfs

Luminosity effects



Absorption lines are Pressure-sensitive:

Lines get broader as the pressure increases.

Larger stars are puffier, which means lower pressure, so that

- Larger Stars have Narrower Lines.
- This gives us a way to assign a Luminosity Class to stars based solely on their spectra