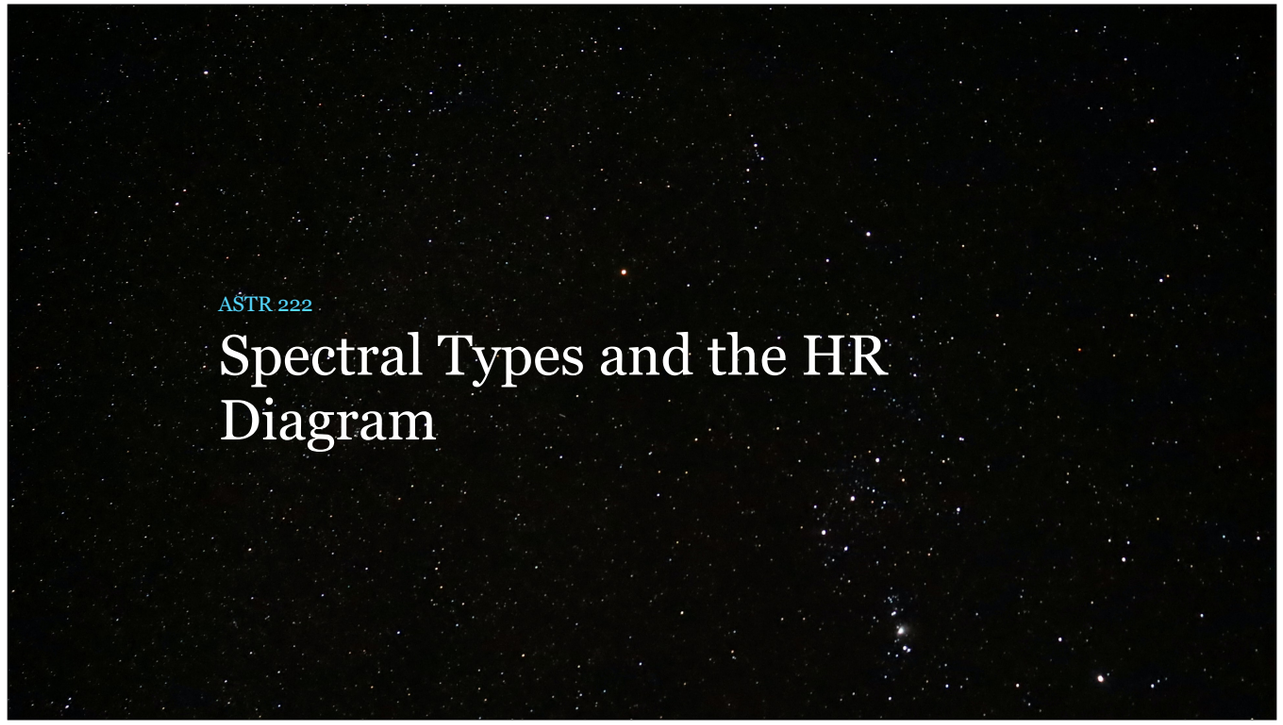
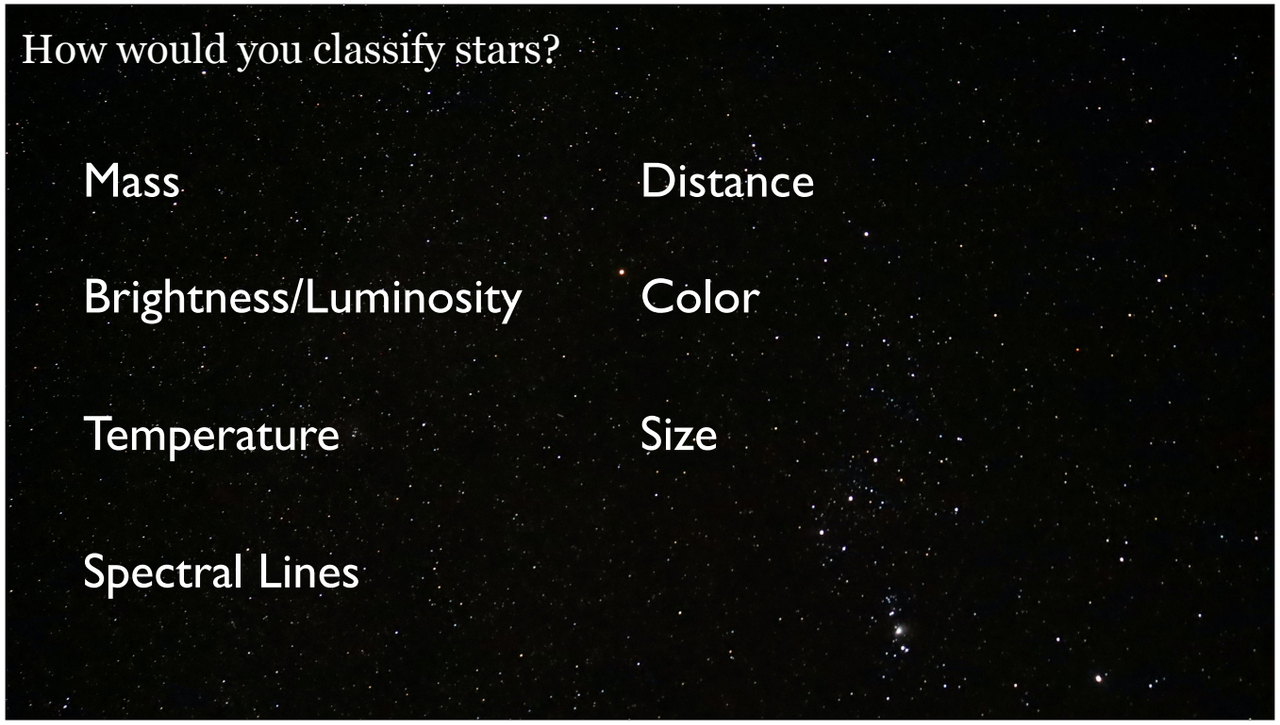


ASTR 222

Spectral Types and the HR Diagram


How would you classify stars?


How would you classify stars?
Mass
Distance
Brightness/Luminosity
Color
Temperature
Size
Spectral Lines

Henry Draper and His Catalog

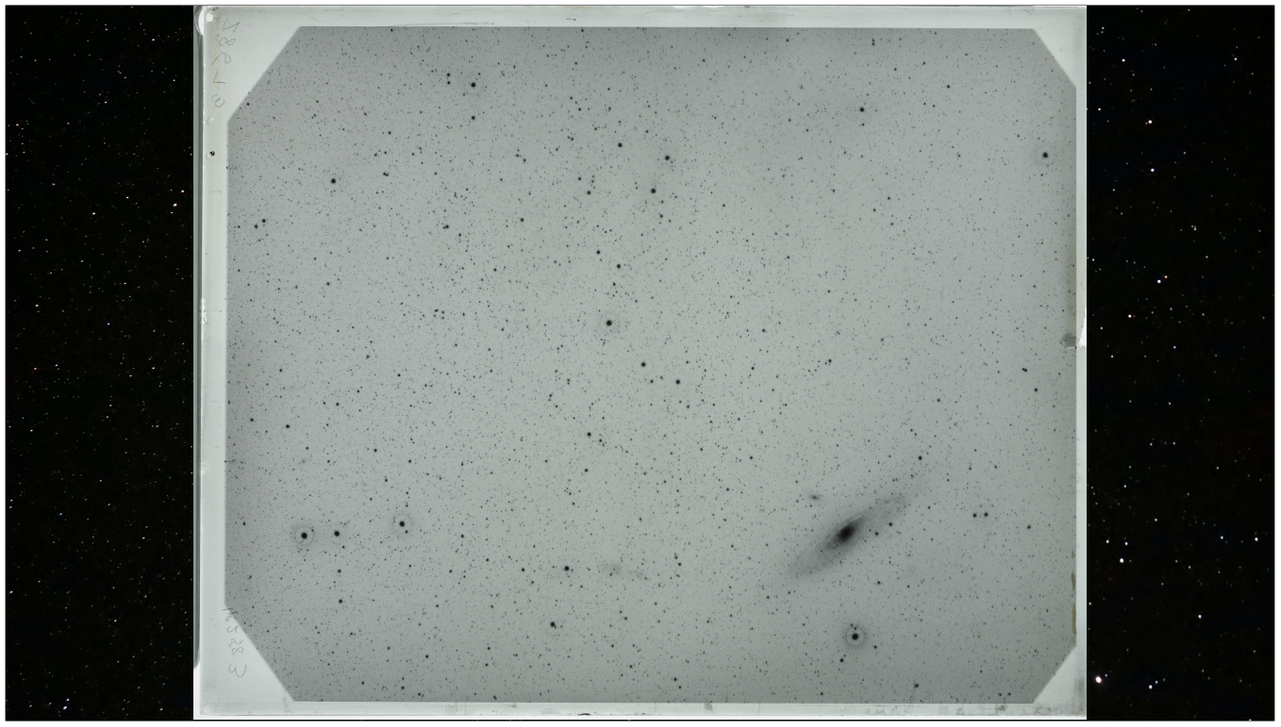
Henry Draper was an American doctor with an interest in astronomy:

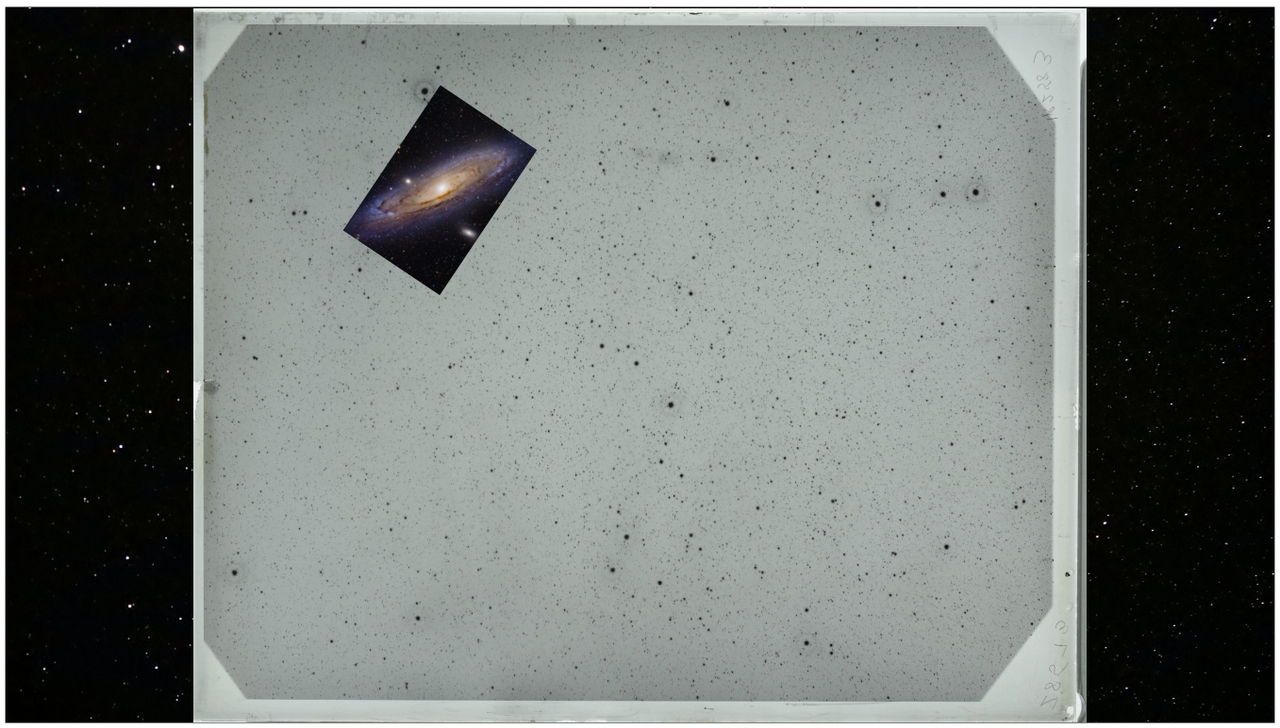
- He was the first person to photograph the Moon through a telescope and the first person to photograph the Orion Nebula, pioneering the field of astrophotography

When he died early at the age of 45, his very rich window, Mary Anna Draper donated his equipment to the Harvard College Observatory and endowed Harvard with money to continue the research

What became of that money was the *Henry Draper Catalogue*, a collection of photographic plates for 225,300 stars

Henry Draper
1837 - 1882

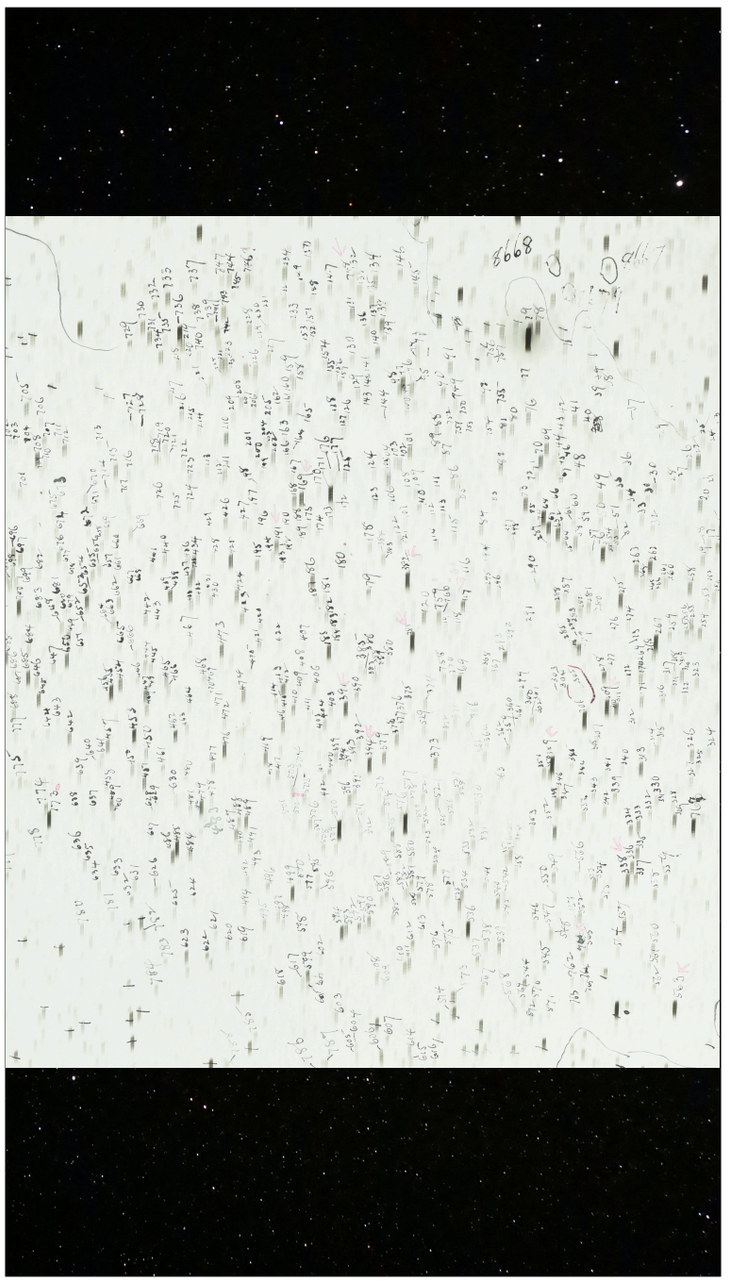




Pickering and His Computers

Edward Pickering was the Director of the Harvard College Observatory and in charge of Draper's catalog and plates

He began to collect the spectra of stars by putting a large prism in front of a photographic plate, capturing the spectra of over 220,000 stars



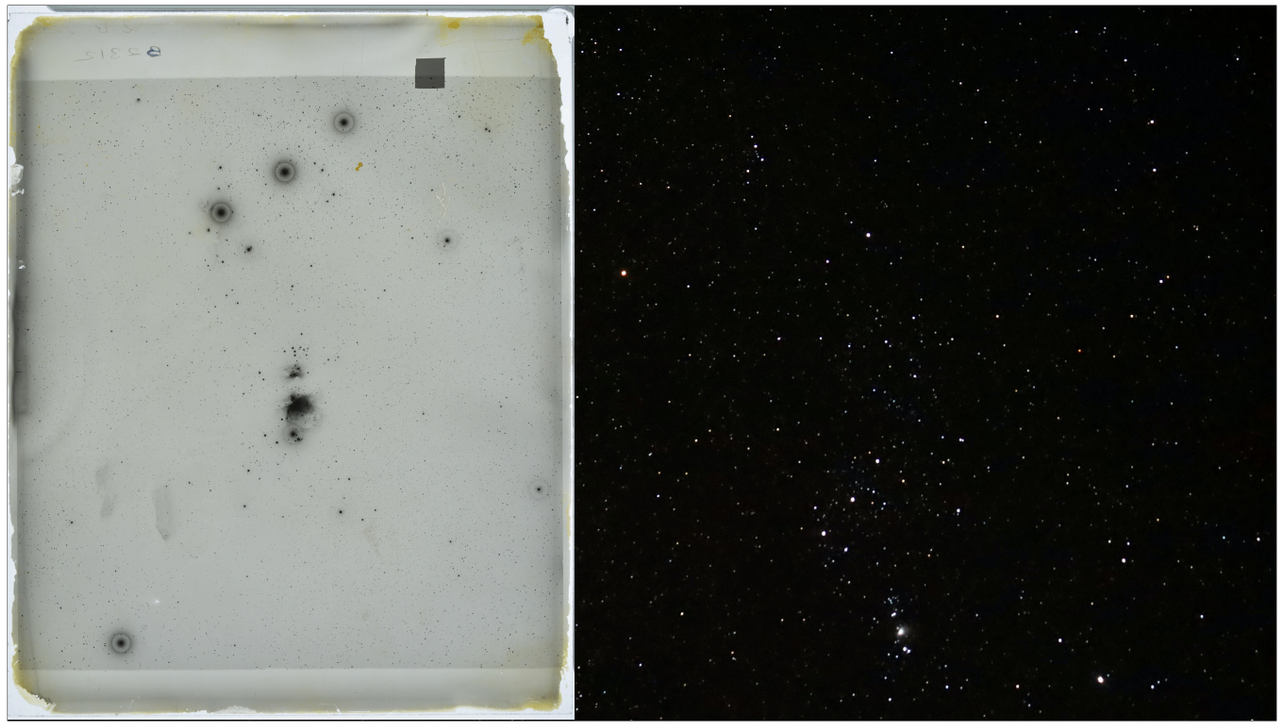
Pickering and His Computers

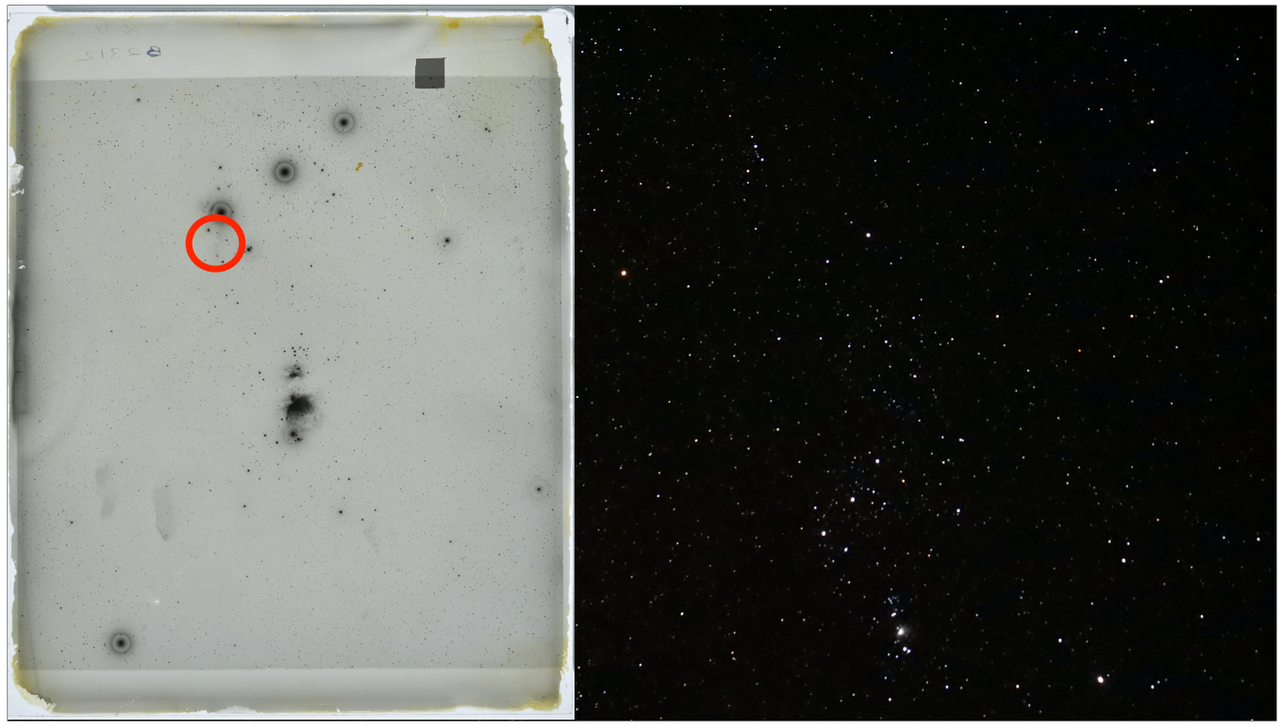
Despite some women being astronomy grads, they usually earned $0.25 - $0.50 per hour ($7-$13/hr in 2020), more than a factory worker

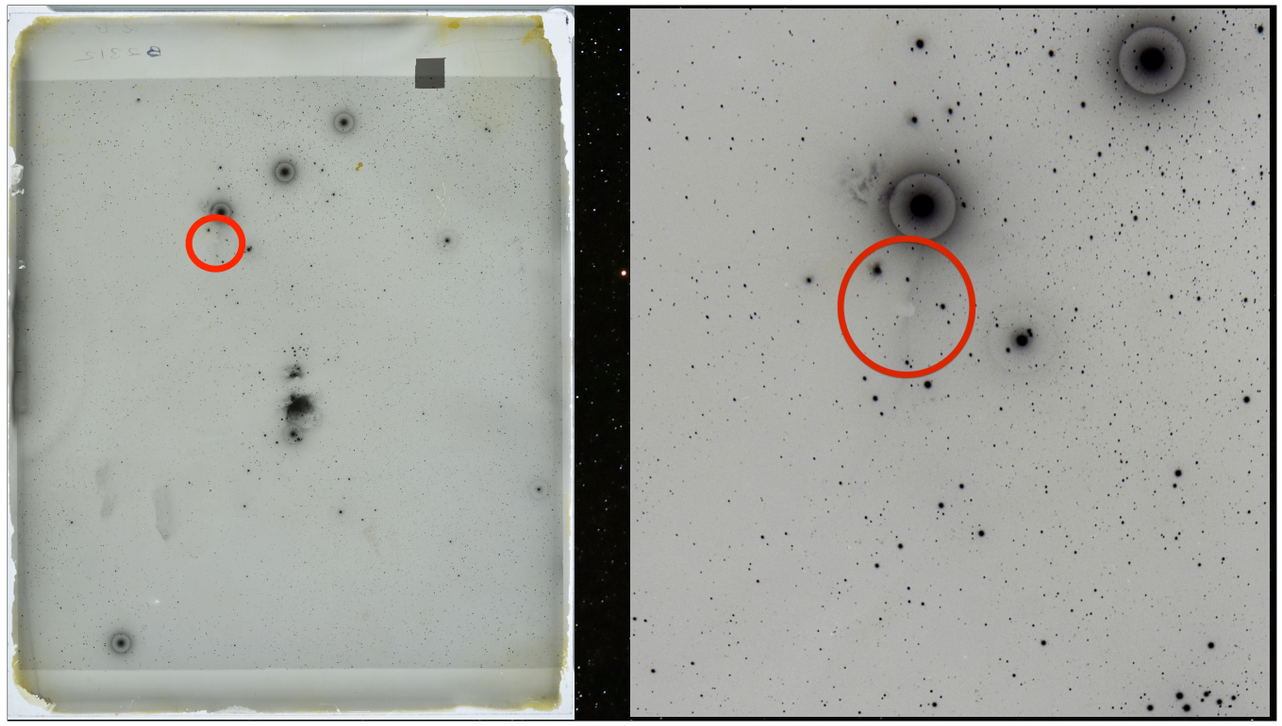
Williamina Fleming
1857 - 1911

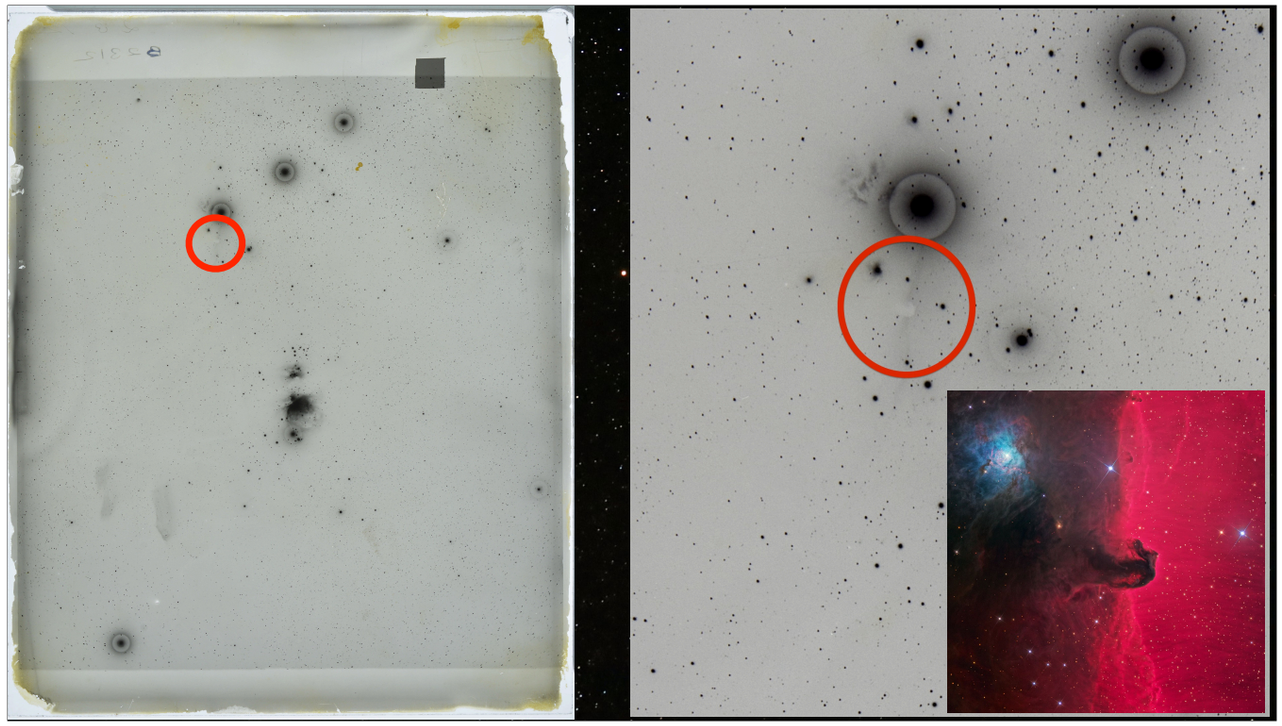
- 59 nebulae
- 310 variable stars
- 10 novae
- The first white dwarf
- Horsehead Nebula

Fleming: originally was a maid for Pickering, his wife suggested that she work at the observatory









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1857 - 1911

- 59 nebulae
- 310 variable stars
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- The first white dwarf
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Henrietta Swan Leavitt
1868 - 1921

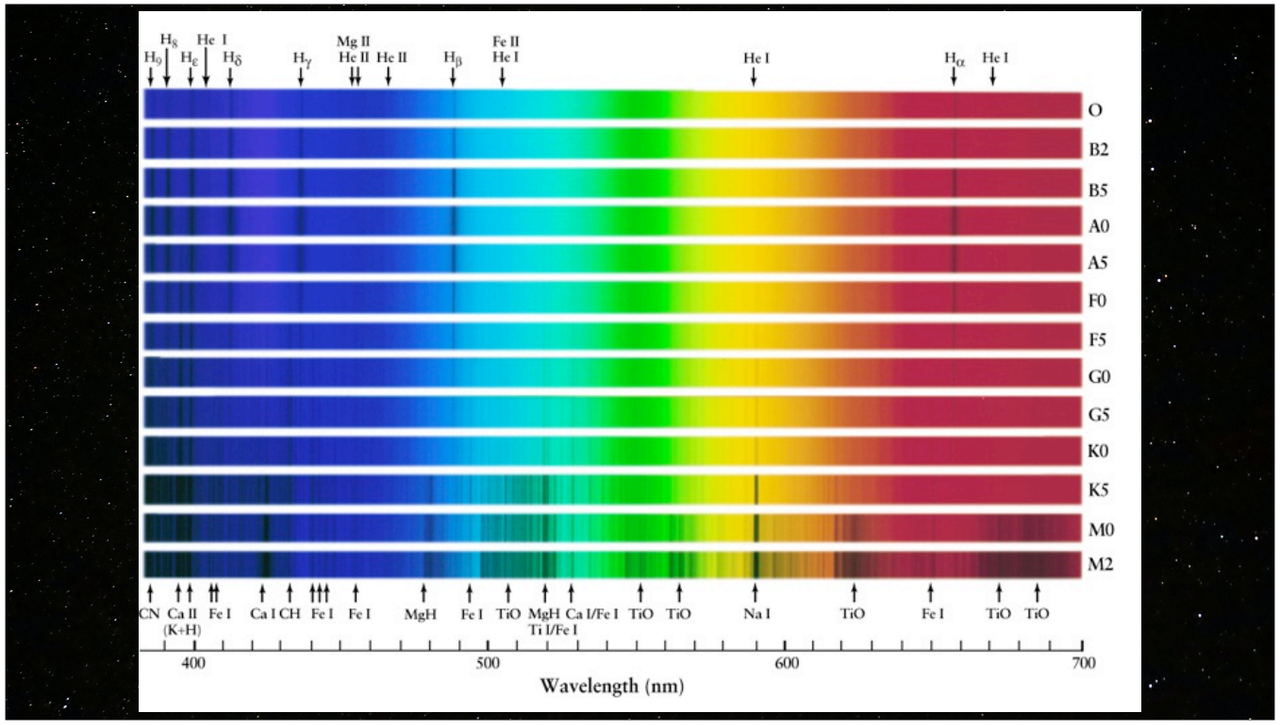
- Cepheid period-luminosity relationship

Annie Jump Cannon
1863 - 1941

- Classified ~350,000 stars
- 300 variable stars
- 5 novae

Leavitt: graduated from Radcliffe College with a bachelor's degree; got an A- in astronomy.

Cannon: graduated valedictorian from Wellesley College with a degree in physics. Got a masters degree from Radcliffe College where Pickering hired her


Hη
Hζ
He I
Hε
Hδ
Hγ
Mg II
He II
He II
Hβ
Fe II
He I
He I
Hα
He I
O
B2
B5
A0
A5
F0
F5
G0
G5
K0
K5
M0
M2
CN
Ca II (K+H)
Fe I
Ca I
CH
Fe I
Fe I
MgH
Fe I
TiO
MgH
Ti I/Fe I
Ca I/Fe I
TiO
TiO
Na I
TiO
Fe I
TiO
TiO
400
500
600
700
Wavelength (nm)

The Composition of Stars

Cecilia Payne
1900 - 1979

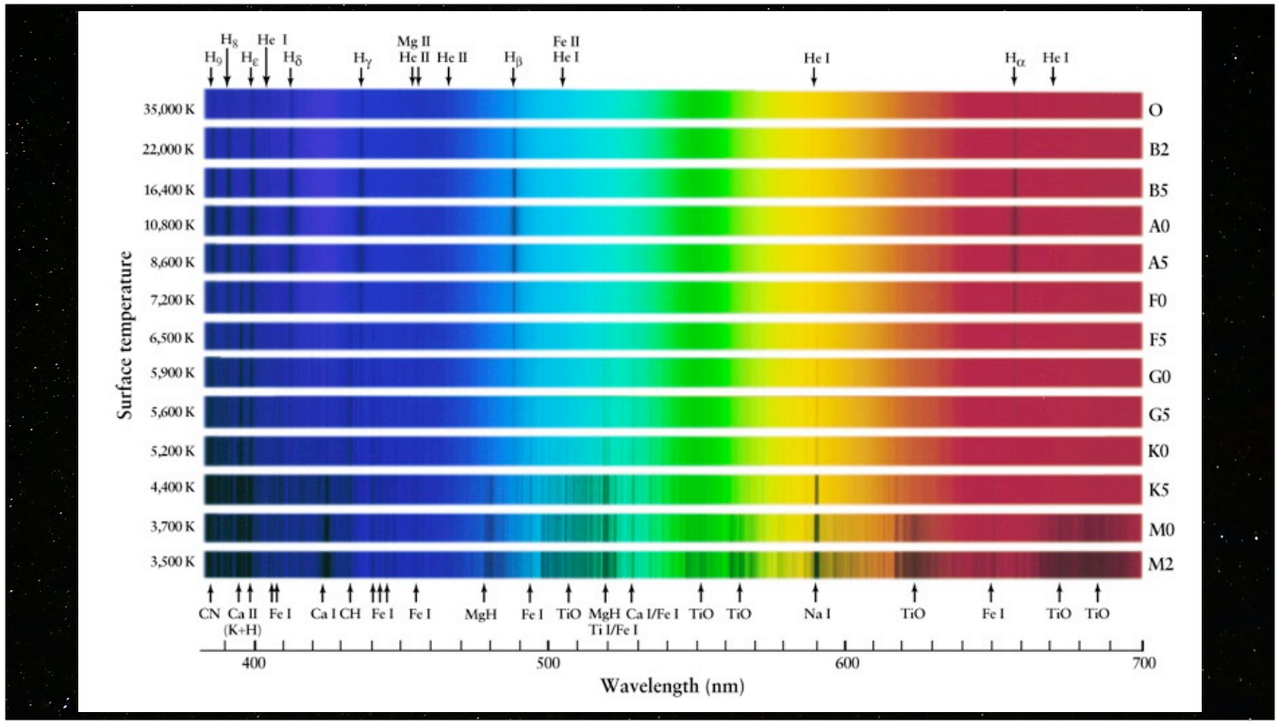
The most prominent features in stellar spectra were from heavy elements, like calcium and iron

Astronomers concluded that the stars were made of the same elements as Earth in roughly the same proportions

After Cecilia Payne emigrated to America, she worked with Cannon and the other computers on understanding the classification system physically

It was Payne who discovered that the spectral type tells what the temperature of a star is and that stars are mostly hydrogen and helium!

“The outstanding discrepancies between the astrophysical and terrestrial abundances are displayed for hydrogen and helium. The enormous abundance derived for these elements in the stellar atmosphere is almost certainly not real.”


Hδ
He I
Hε
Hδ
Hγ
Mg II
He II
He II
Hβ
Fe II
He I
He I
Hα
He I
35,000 K
22,000 K
16,400 K
10,800 K
8,600 K
7,200 K
6,500 K
5,900 K
5,600 K
5,200 K
4,400 K
3,700 K
3,500 K
O
B2
B5
A0
A5
F0
F5
G0
G5
K0
K5
M0
M2
Surface temperature
CN
Ca II (K+H)
Fe I
Ca I
CH
Fe I
Fe I
MgH
Fe I
TiO
MgH Ti I/Fe I
Ca I/Fe I
TiO
TiO
Na I
TiO
Fe I
TiO
TiO
400
500
600
700
Wavelength (nm)

Spectral Types

Originally, spectral types were alphabetical, "A" through "Q" excluding "J"

Once Cannon knew that spectral type told the temperature of a star, she threw out redundant types and arranged in order of temperature

Spectral Type	Temperature	Color	"Color"
O	40,000 K	blue	blue
B	20,000 K	deep blue white	blue
A	9000 K	blue white	blue-white
F	7000 K	white	white
G	5500 K	yellowish white	yellow
K	4500 K	pale yellow orange	orange
M	3000 K	light orange red	red

Numbers are added (0-9) to further subdivide the classes

For instance:

- The Sun is a G2
- Betelgeuse is an M1
- Rigel is a B8
- Sirius is an A1

Spectral Type Mnemonics

The original mnemonic is:

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Oh, **B**e **A** **F**ine **G**uy/**G**al, **K**iss **M**e!

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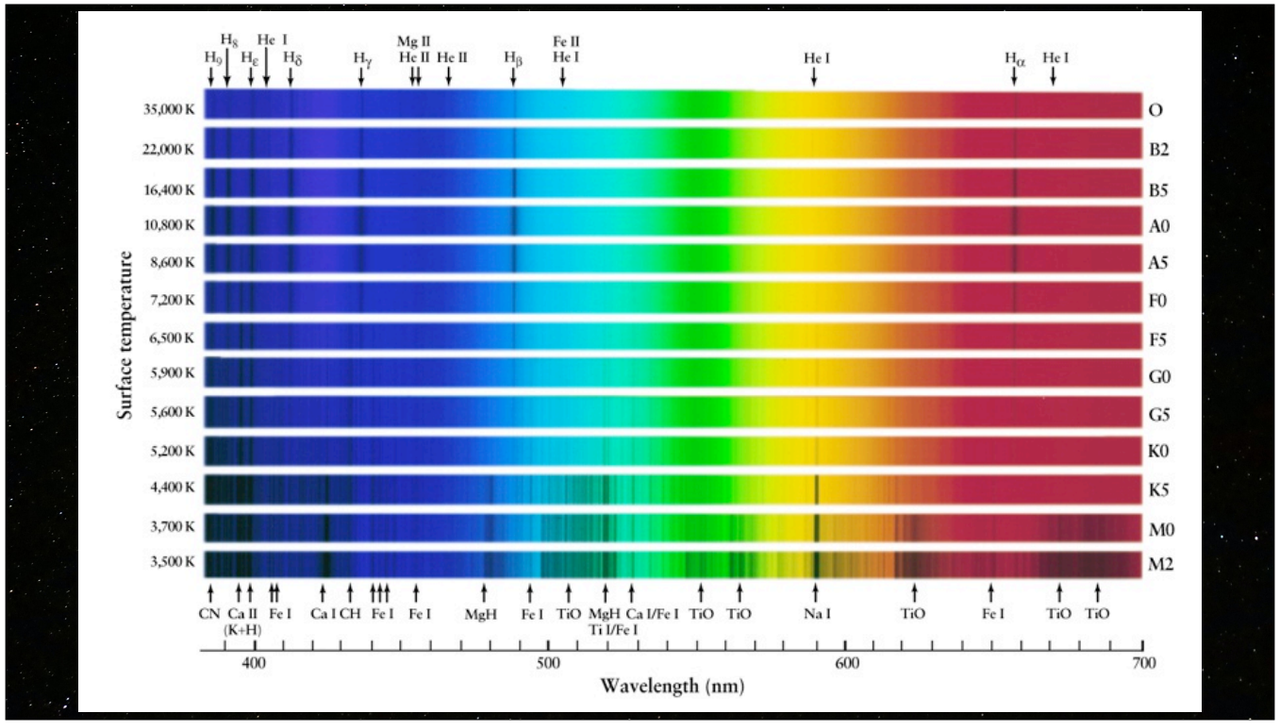
Your turn! Can you come up with a good mnemonic?



What are some patterns you see here?

Explaining the Absorption Lines

The strength of absorption lines depends on the surface temperature of the star

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Let's take the Balmer lines of hydrogen (Hα, Hβ, Hγ, etc):

Two competing effects as temperature rises: (1) the fraction of neutral atoms that have their electron in the $n = 2$ state *increases*, and (2) the fraction of atoms that are neutral *decreases*

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- Hotter and all of the hydrogen has been fully ionized, cooler and there are no excited electrons in hydrogen!

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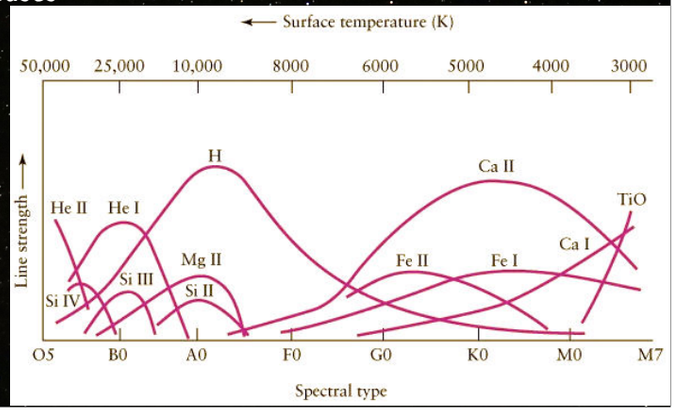


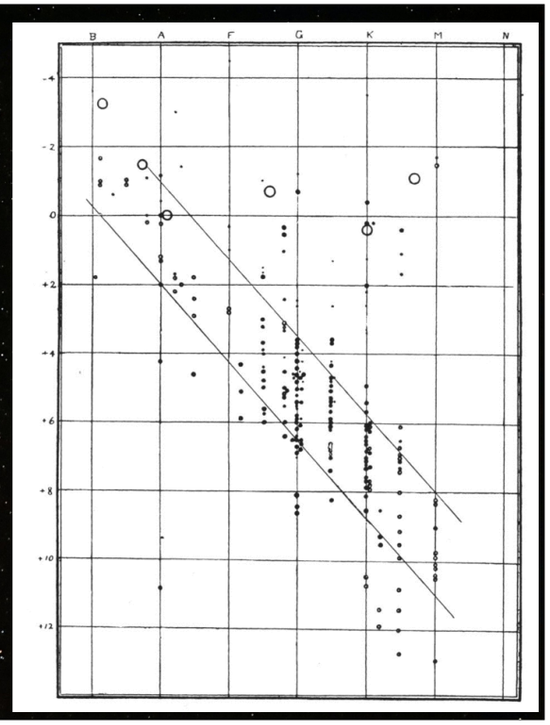
Hertzsprung published in tabular form, so it wasn’t easy to grasp any patterns. He also published in obscure journals, so when he published in 1905, no one noticed.

Russell was an eminent astronomer at Princeton and he singled out one relationship.

Correlations Amongst the Stars

One astronomer who gathered together measurements of many stars was Danish astronomer Ejnar Hertzsprung, but he was not well-known

Several years after Hertzsprung, Henry Norris Russell did the same work, but plotted his results



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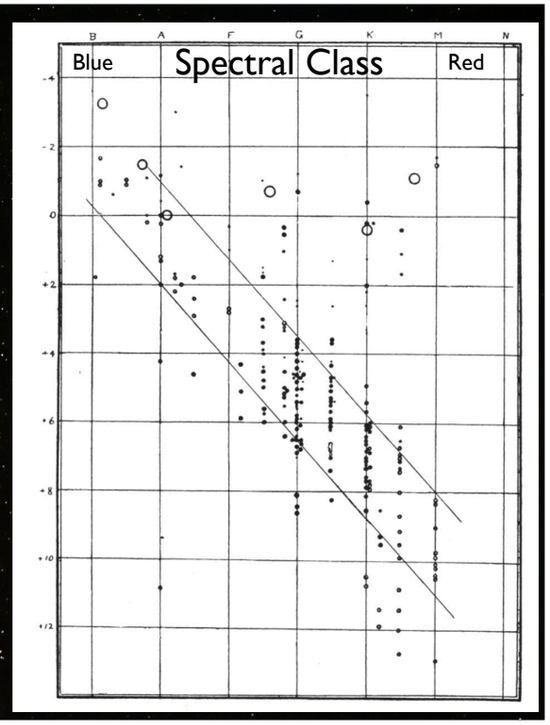

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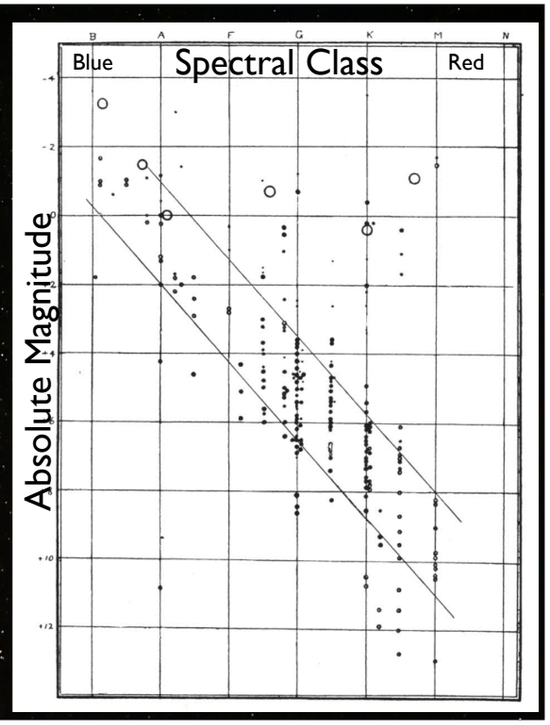

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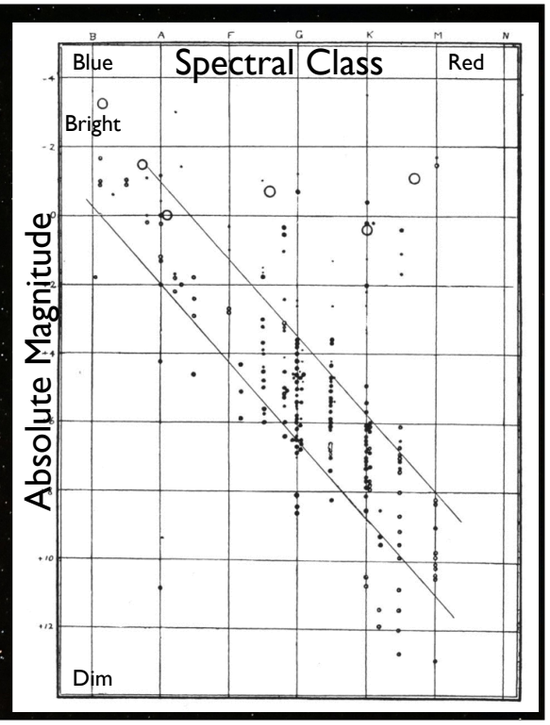
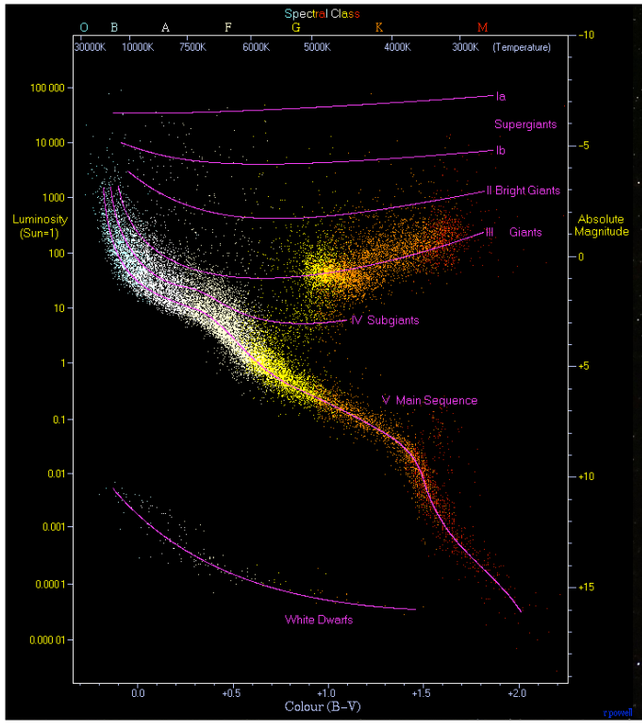
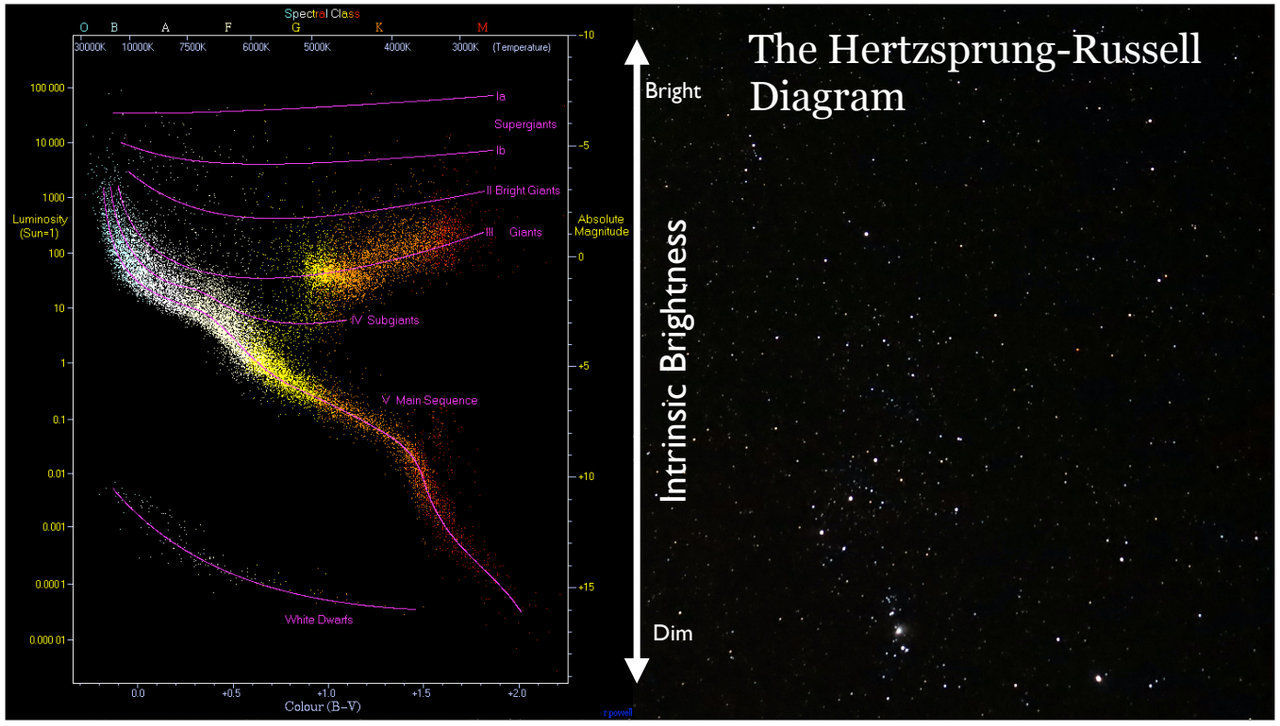
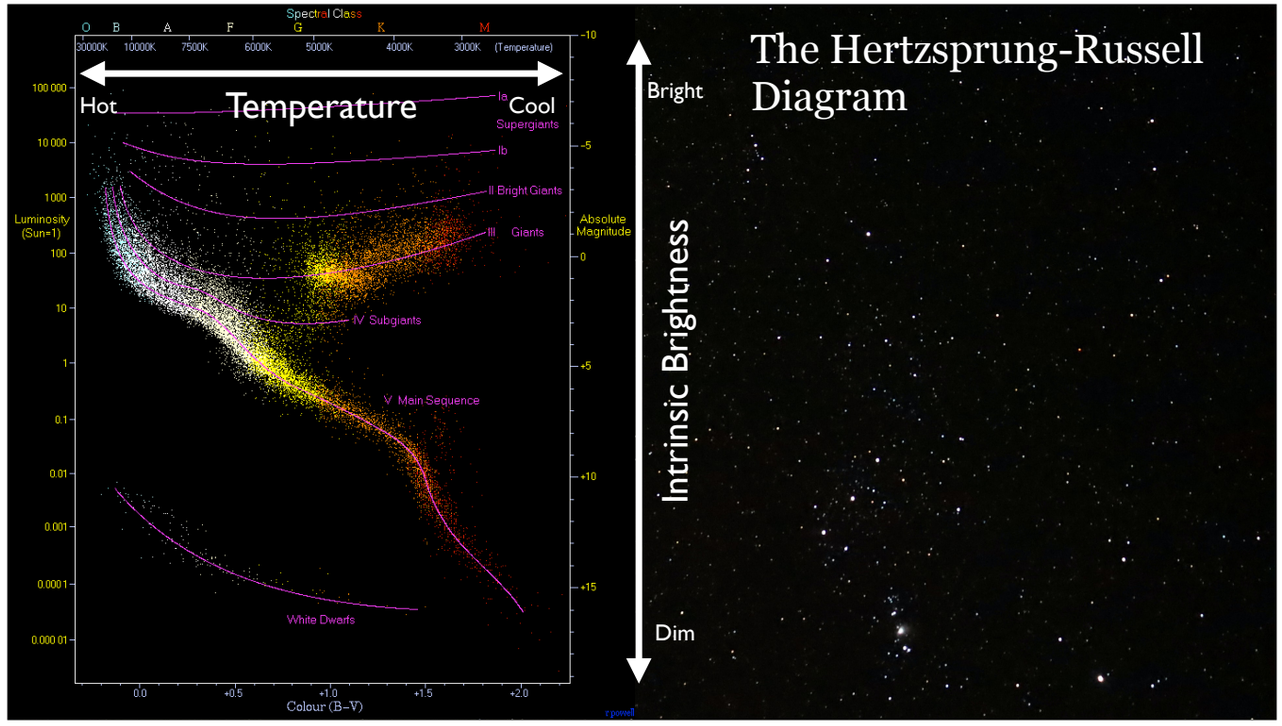


The Hertzsprung-Russell Diagram




Spectral Class
O B A F G K M
30000K 10000K 7500K 6000K 5000K 4000K 3000K (Temperature)
100 000
10 000
1000
100
10
1
0.1
0.01
0.001
0.0001
0.000 01
Luminosity (Sun=1)
-10
-5
0
+5
+10
+15
Absolute Magnitude
Ia
Supergiants
Ib
II Bright Giants
III Giants
IV Subgiants
V Main Sequence
White Dwarfs
0.0
+0.5
+1.0
+1.5
+2.0
Colour (B–V)
r.powell
Bright
Intrinsic Brightness
Dim
The Hertzsprung-Russell Diagram


Spectral Class
O B A F G K M
30000K 10000K 7500K 6000K 5000K 4000K 3000K (Temperature)
Hot
Temperature
Cool
Ia
Supergiants
Ib
II Bright Giants
III Giants
IV Subgiants
V Main Sequence
White Dwarfs
Luminosity (Sun=1)
100 000
10 000
1000
100
10
1
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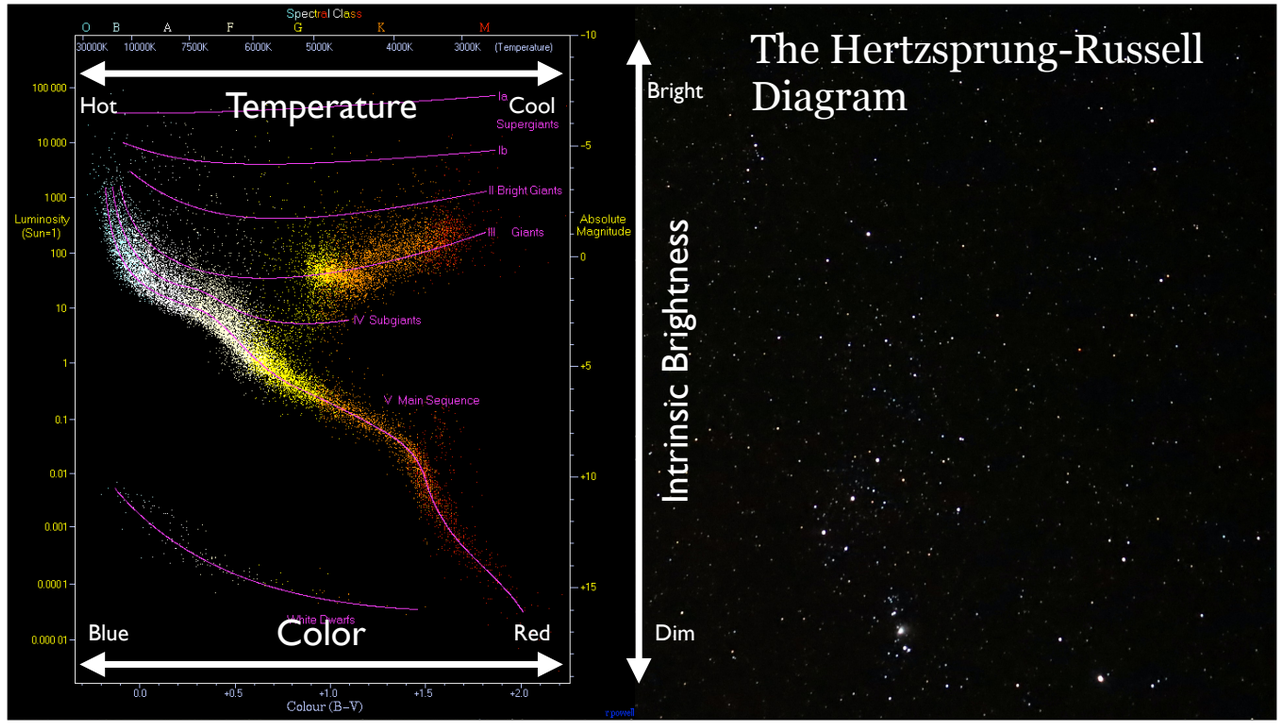
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Blue
Color
Red
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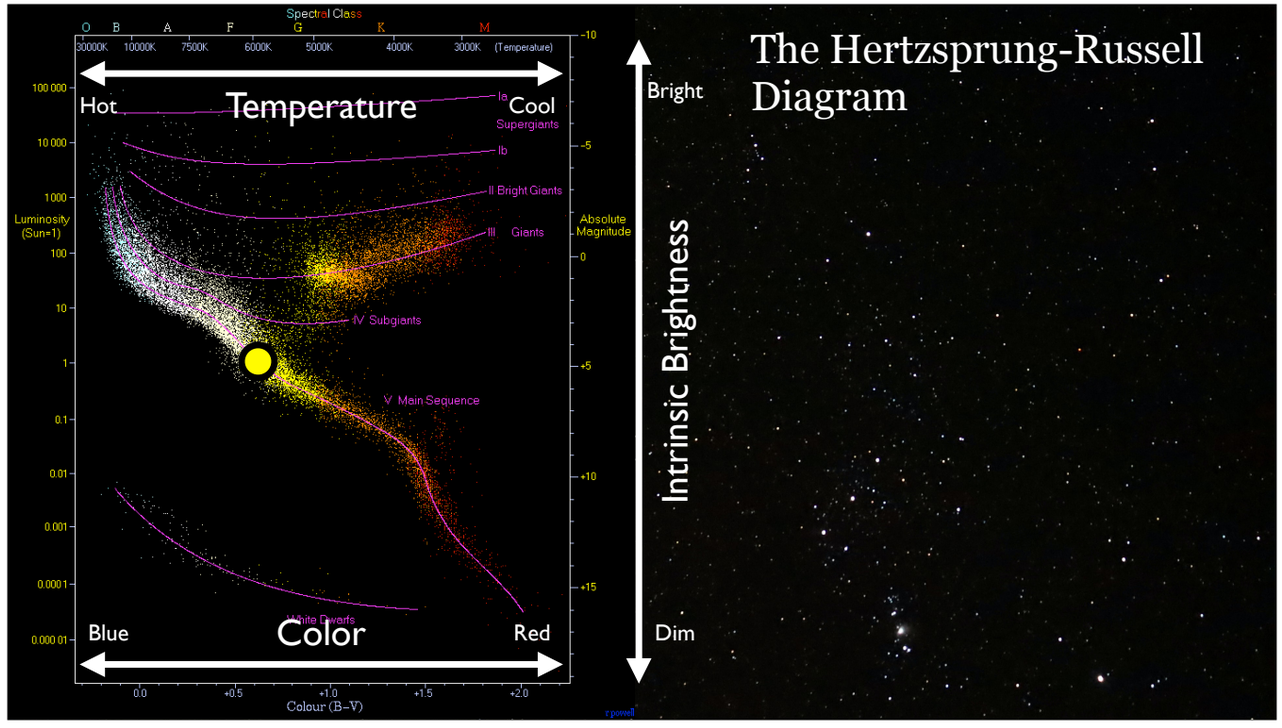
The Hertzsprung-Russell Diagram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O B A F G K M
30000K 10000K 7500K 6000K 5000K 4000K 3000K (Temperature)
Hot
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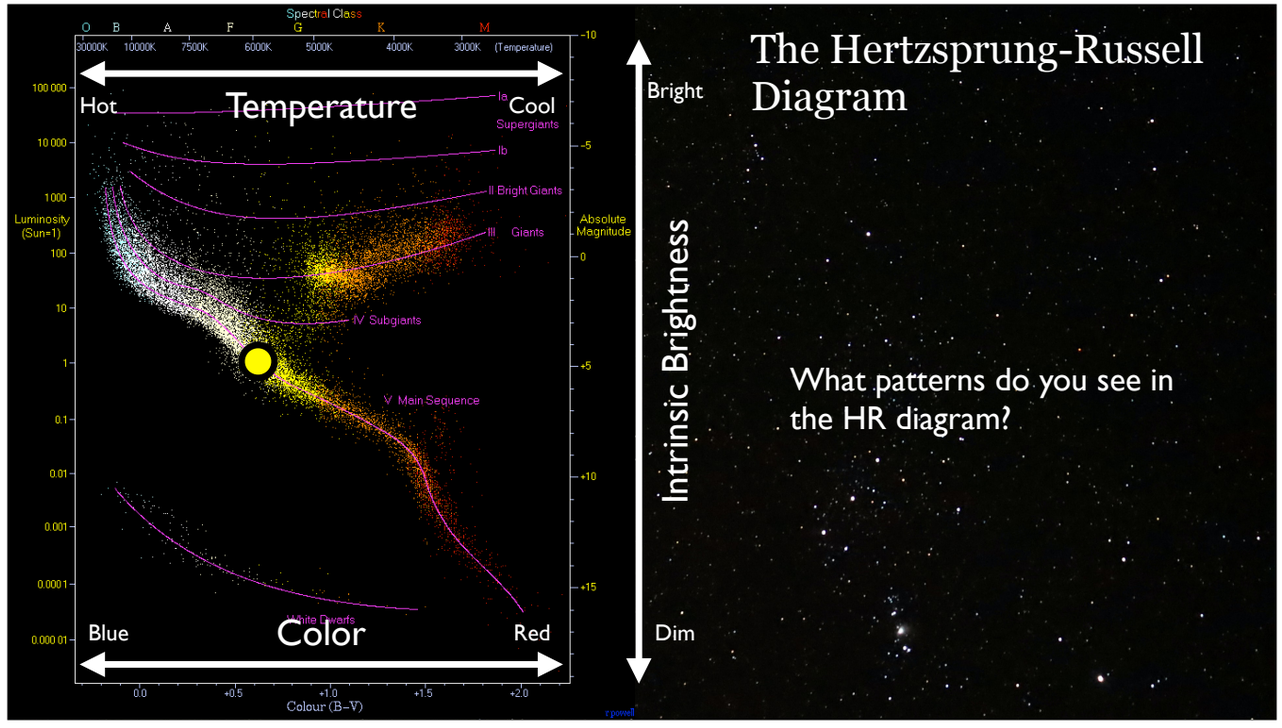
Spectral Class
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0.0 +0.5 +1.0 +1.5 +2.0
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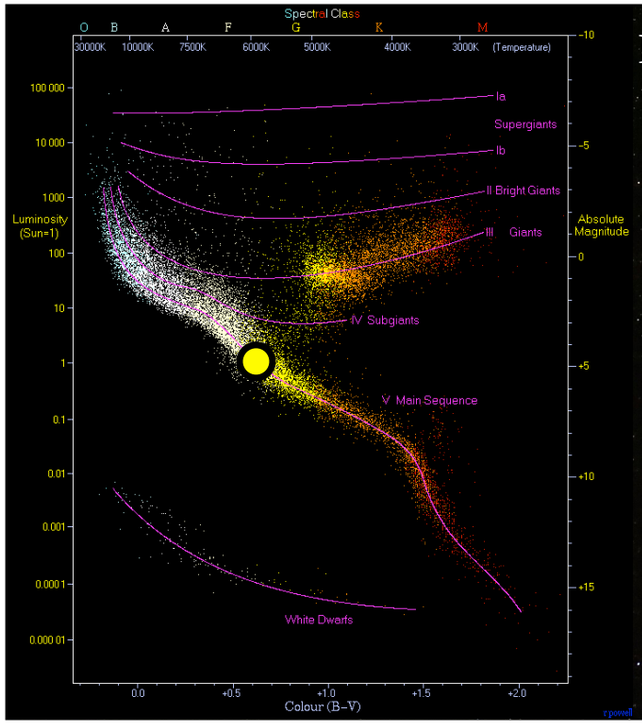
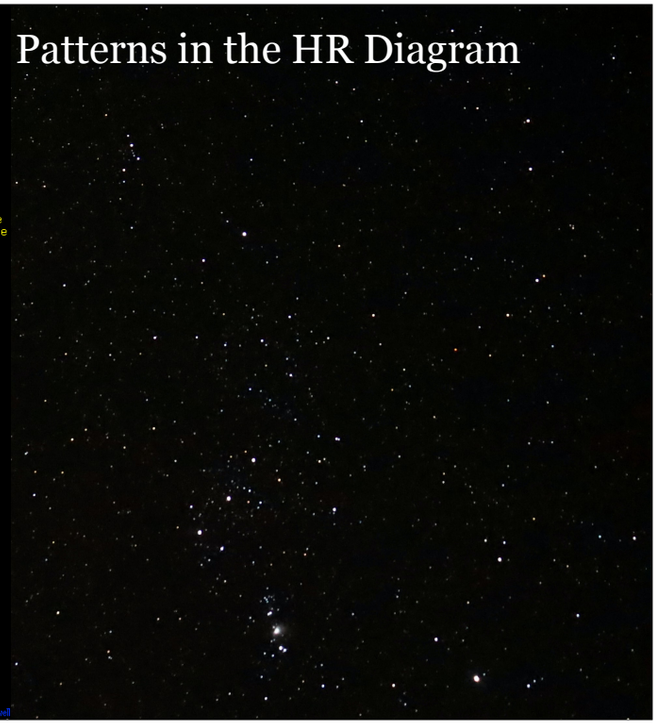
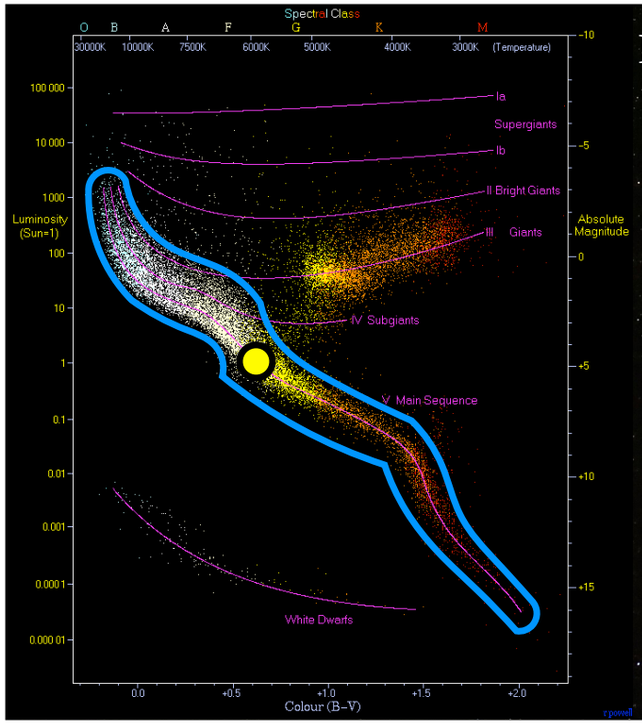
The Hertzsprung-Russell Diagram
What patterns do you see in the HR diagram?

Patterns in the HR Diagram

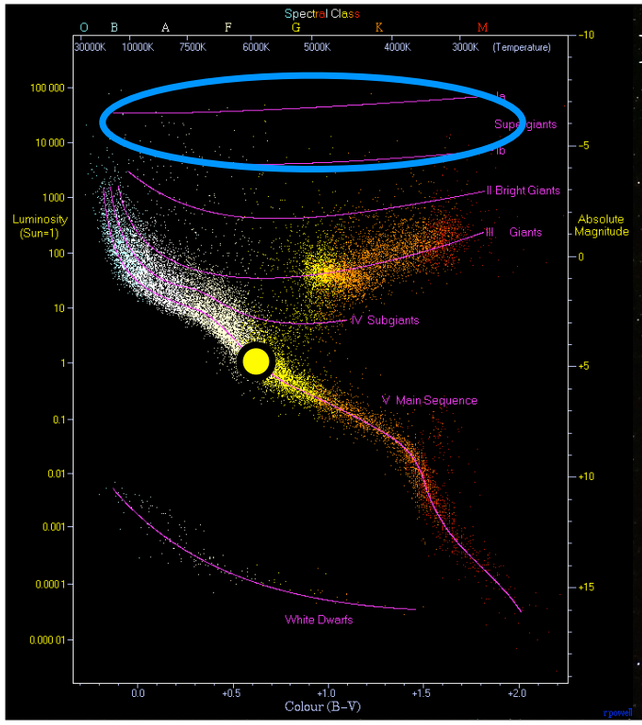






Patterns in the HR Diagram

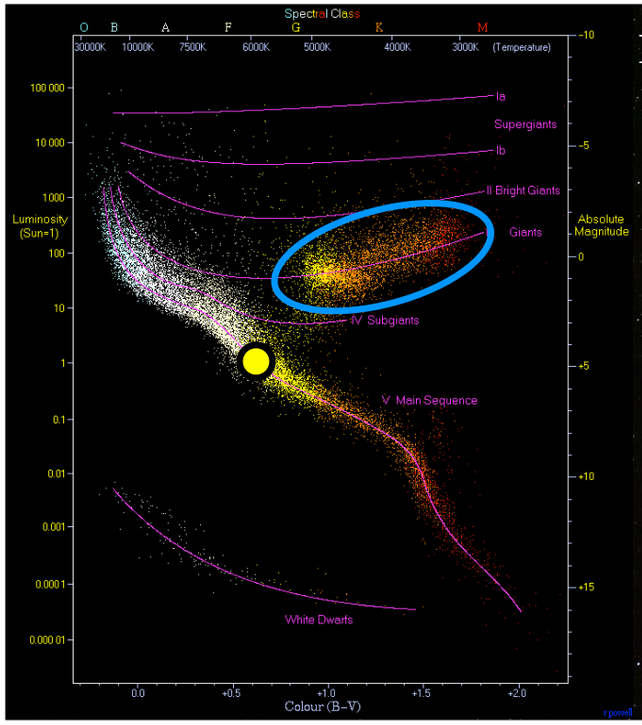
Most stars fall along the main sequence, including our Sun



Patterns in the HR Diagram

Most stars fall along the main sequence, including our Sun

The stars at the very top are supergiants since they are bright and very large

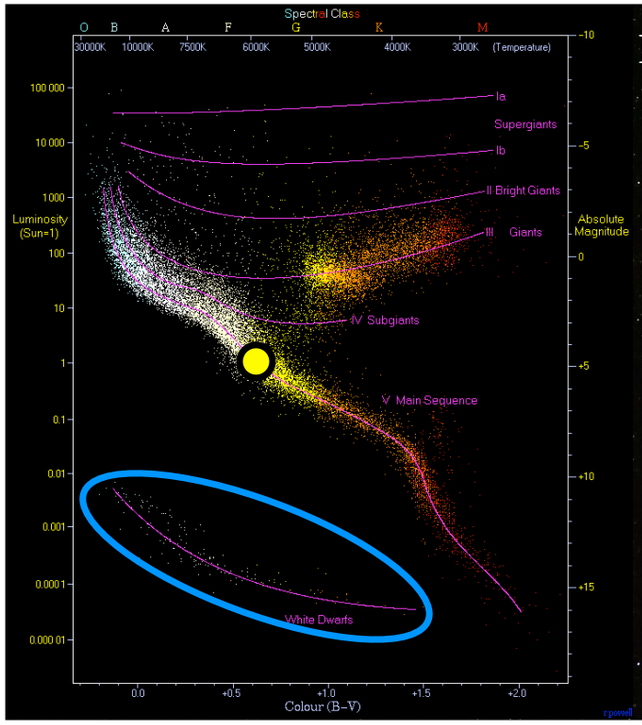


Patterns in the HR Diagram

Most stars fall along the main sequence, including our Sun

The stars at the very top are supergiants since they are bright and very large

Below the supergiants are the giants which are somewhat smaller and dimmer



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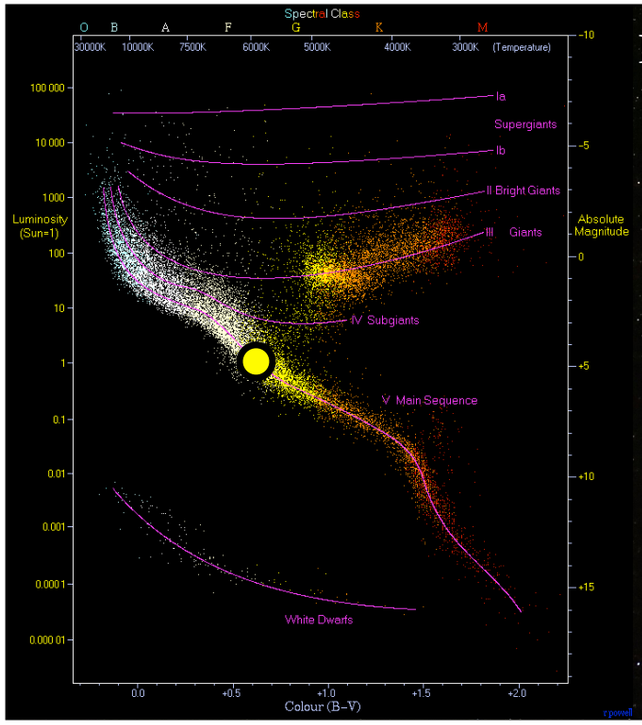
Small in radius, but with high temperature are the white dwarfs



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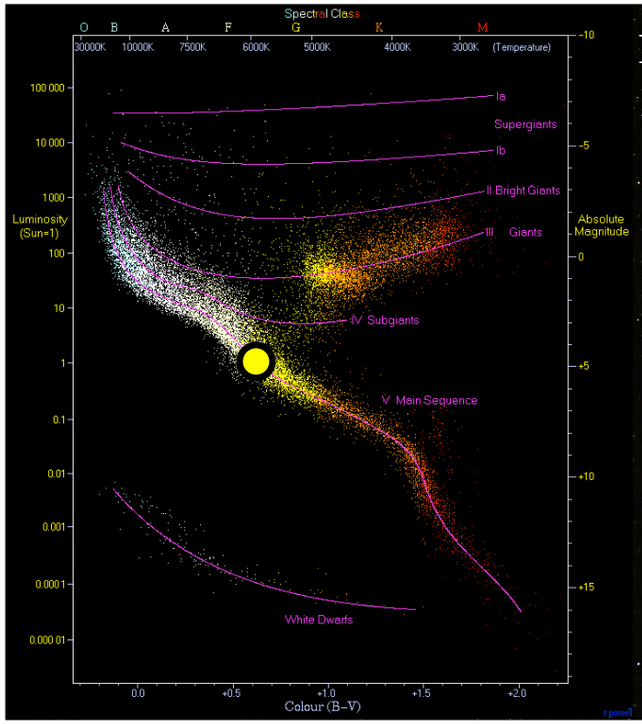
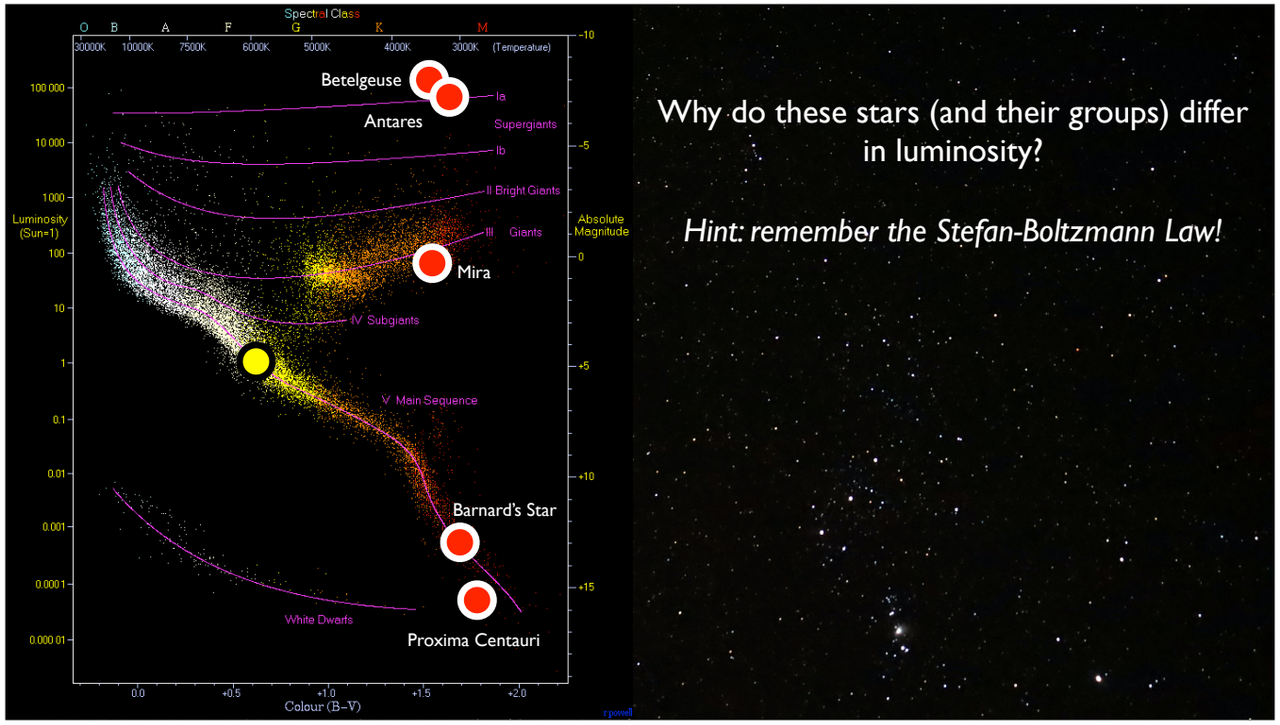


Patterns in the HR Diagram

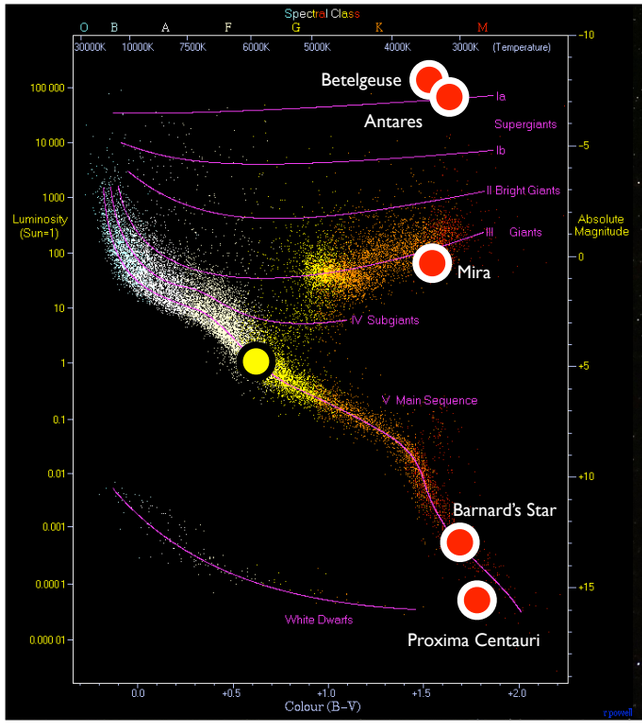
Astronomers also make the distinction between luminosity classes:

Class	Name
I	Supergiants
II	Bright giants
III	Giants
IV	Subgiants
V	Main-sequence
VI	Subdwarf
wd	White dwarf

The Sun's full classification is a G2V star



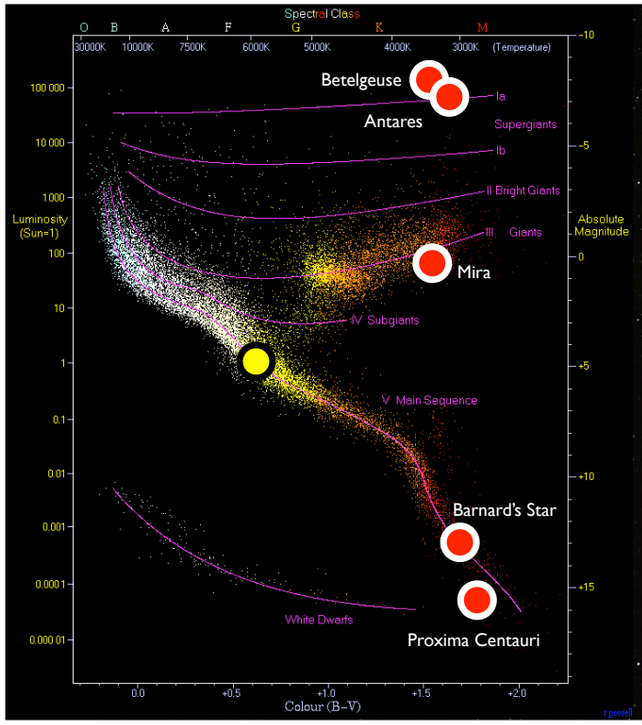
Proxima Centauri - Centaurus
Barnard’s Star - Ophiuchus
Mira - Cetus
Antares - Scorpius
Betelgeuse - Orion



Why do these stars (and their groups) differ in luminosity?

Hint: remember the Stefan-Boltzmann Law!

They are different sizes!



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Star	Size
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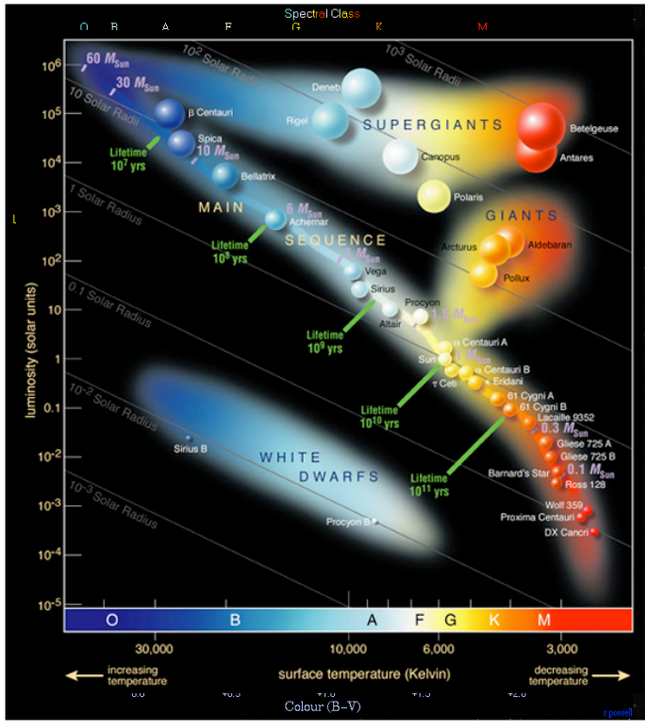
Barnard's Star	0.2 $R_\odot$
Mira	350 $R_\odot$
Antares	700 $R_\odot$
Betelgeuse	900 $R_\odot$



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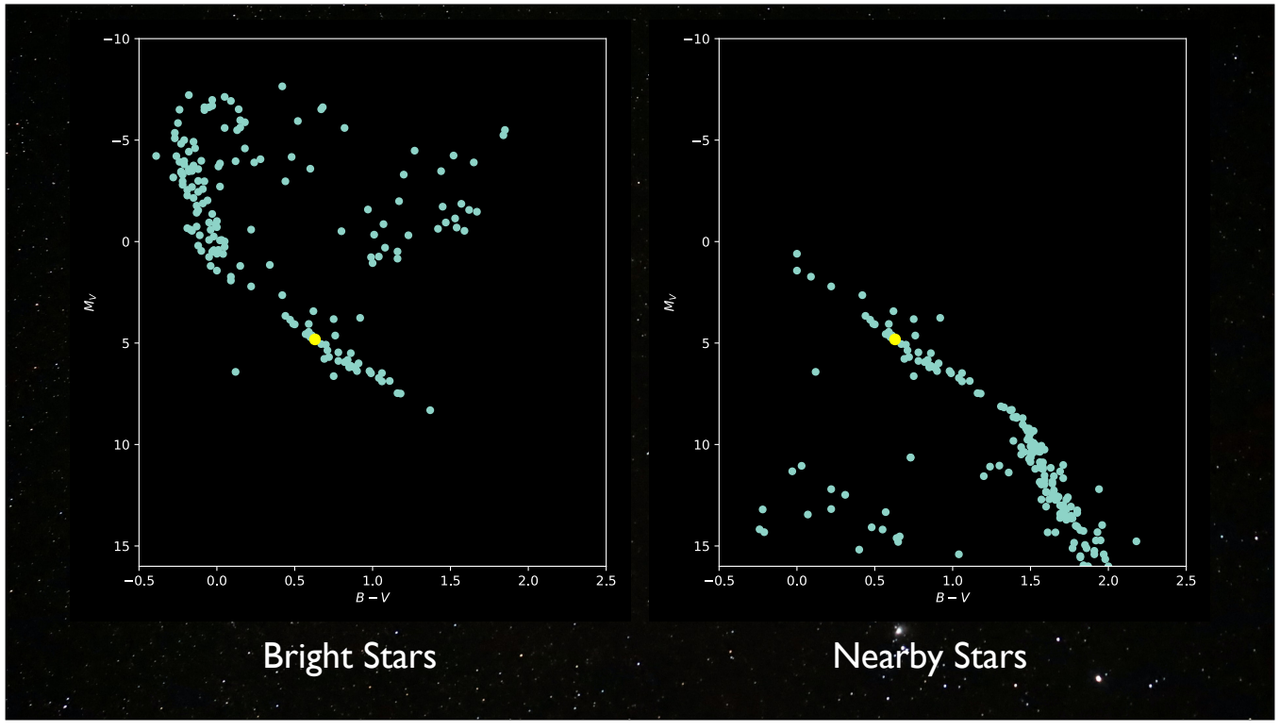
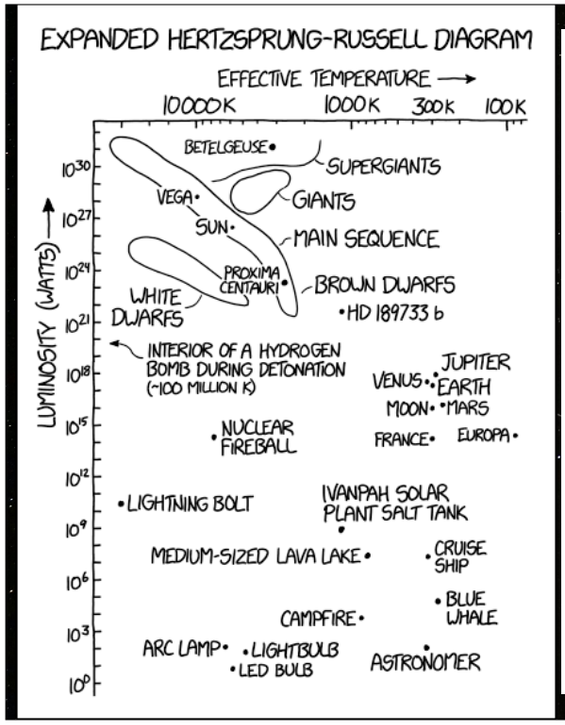
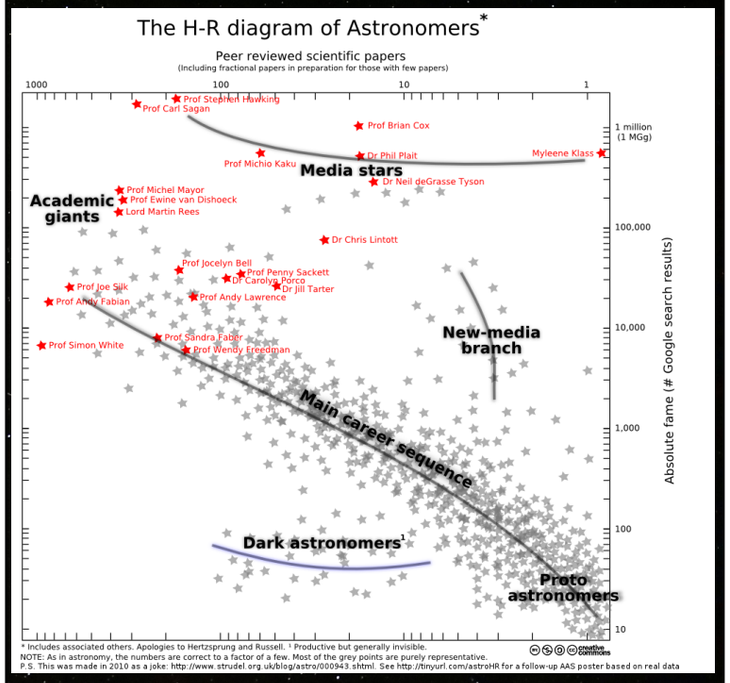


Nearby stars should be a “fair sample” of stars in the galaxy, since there’s nothing special about our location. No supergiants in the Sun’s neighborhood! A few white dwarfs, mostly M dwarfs.

Bright stars are an unrepresentative sample of stars. Most of them are hot, luminous main sequence stars, giants, and supergiants. High luminosity makes them visible over large distances.


EXPANDED HERTZSPRUNG-RUSSELL DIAGRAM
EFFECTIVE TEMPERATURE →
10000K
1000K
300K
100K
LUMINOSITY (WATTS) →
10^{30}
10^{27}
10^{24}
10^{21}
10^{18}
10^{15}
10^{12}
10^{9}
10^{6}
10^{3}
10^{0}
BETELGEUSE
SUPERGIANTS
VEGA
GIANTS
SUN
MAIN SEQUENCE
PROXIMA CENTAURI
BROWN DWARFS
WHITE DWARFS
HD 189733 b
INTERIOR OF A HYDROGEN BOMB DURING DETONATION (~100 MILLION K)
JUPITER
VENUS
EARTH
MOON
MARS
NUCLEAR FIREBALL
FRANCE
EUROPA
LIGHTNING BOLT
IVANPAH SOLAR PLANT SALT TANK
MEDIUM-SIZED LAVA LAKE
CRUISE SHIP
BLUE WHALE
CAMPFIRE
ARC LAMP
LIGHTBULB
LED BULB
ASTRONOMER


The H-R diagram of Astronomers*
Peer reviewed scientific papers
(Including fractional papers in preparation for those with few papers)
1000
100
10
1
Prof Stephen Hawking
Prof Carl Sagan
Prof Brian Cox
Prof Michio Kaku
Dr Phil Plait
Myleene Klass
Media stars
Prof Michel Mayor
Prof Ewine van Dishoeck
Dr Neil deGrasse Tyson
Academic giants
Lord Martin Rees
Dr Chris Lintott
Prof Jocelyn Bell
Prof Penny Sackett
Dr Carolyn Porco
Prof Joe Silk
Dr Jill Tarter
Prof Andy Fabian
Prof Andy Lawrence
Prof Sandra Faber
Prof Simon White
Prof Wendy Freedman
New-media branch
Main career sequence
Dark astronomers[1]
Proto astronomers
1 million (1 MGg)
100,000
10,000
1,000
100
10
Absolute fame (# Google search results)
* Includes associated others. Apologies to Hertzsprung and Russell. [1] Productive but generally invisible.
NOTE: As in astronomy, the numbers are correct to a factor of a few. Most of the grey points are purely representative.
P.S. This was made in 2010 as a joke: http://www.strudel.org.uk/blog/astro/000943.shtml. See http://tinyurl.com/astroHR for a follow-up AAS poster based on real data
creative commons