Estimating the distance to star clusters using Photometry

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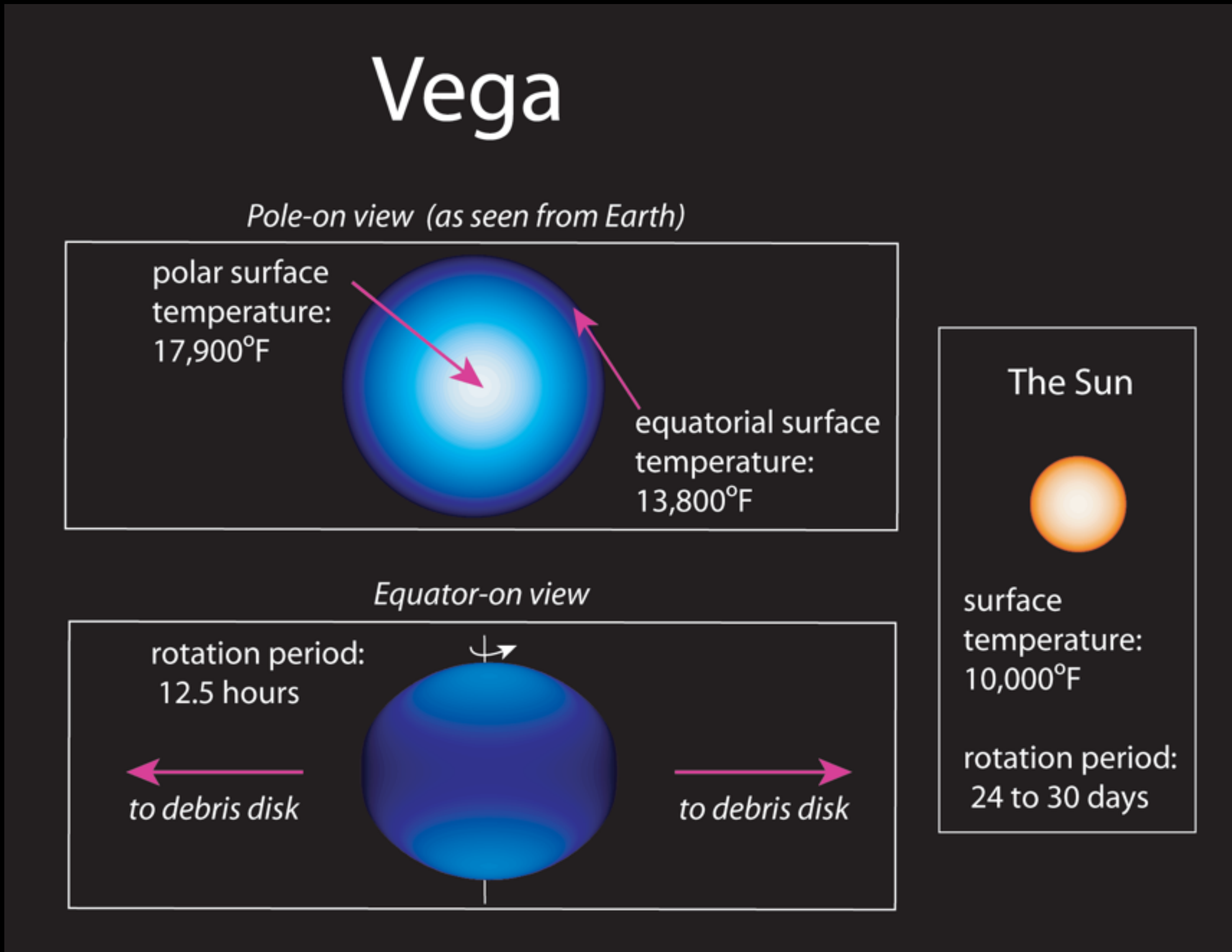
–Stephen Hawking, The Grand Design


Vega
0.0
0.25
0.5
0.75
1.0
Degrees
©2011 F. Espenak, www.AstroPixels.com



Vega
Pole-on view (as seen from Earth)
polar surface temperature: 17,900°F
equatorial surface temperature: 13,800°F
Equator-on view
rotation period: 12.5 hours
to debris disk
to debris disk
The Sun
surface temperature: 10,000°F
rotation period: 24 to 30 days

PHOTO METRY

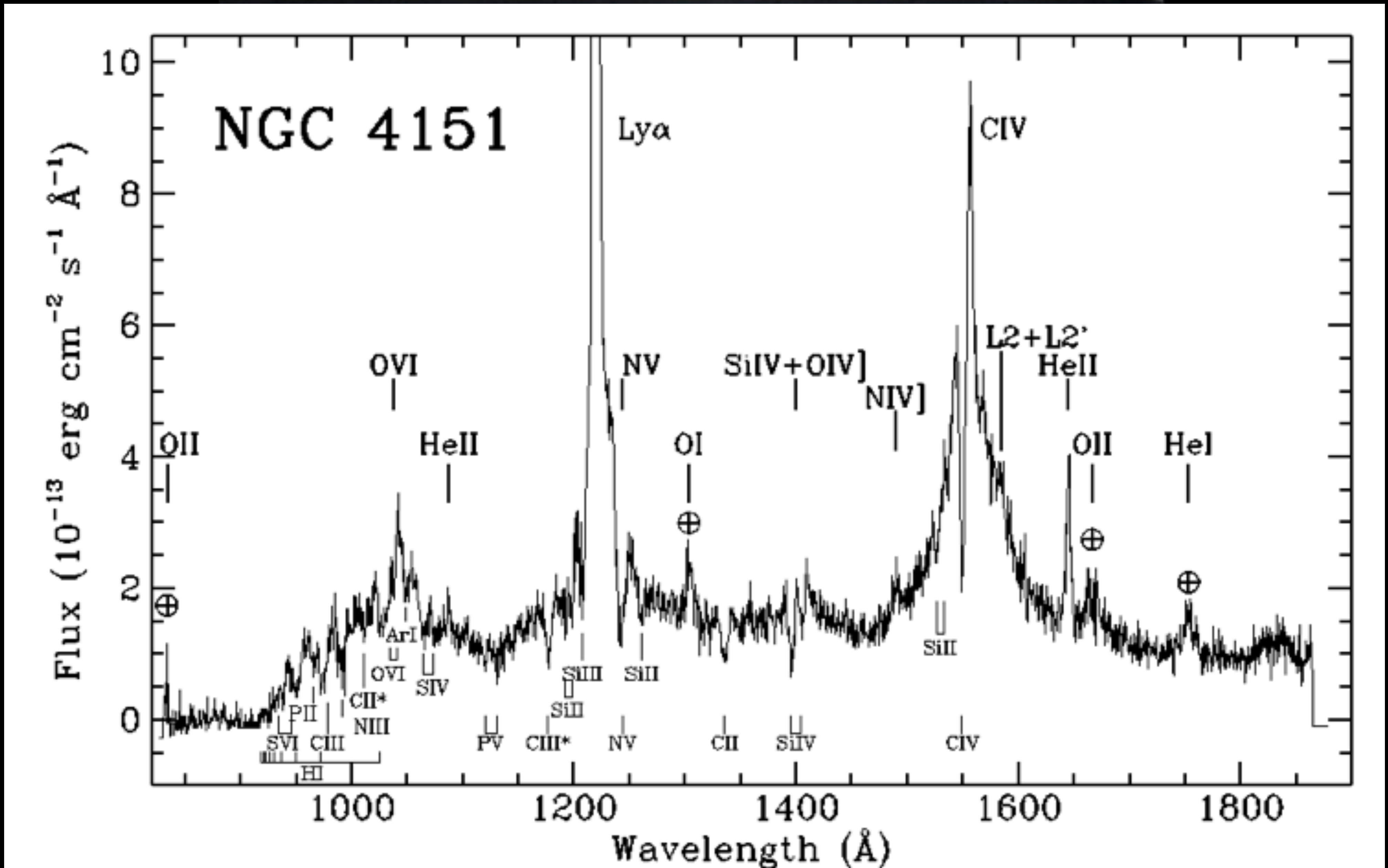
light measurement

Photometry of stars gives the astronomer a direct measurement of the energy output of stars at several wavelengths and thus sets constraints on the models of stellar structure.

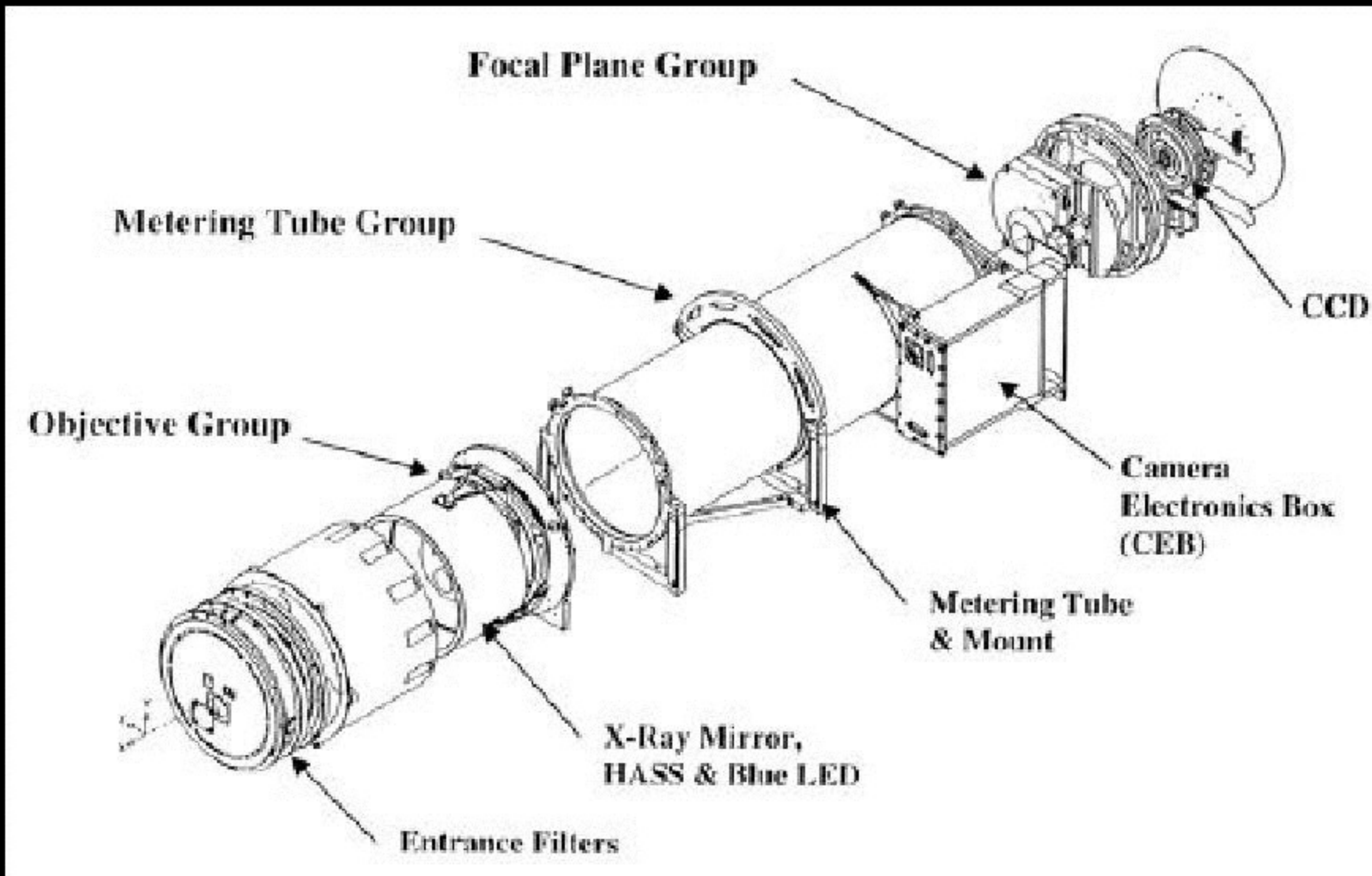
We want the power received by an object outside the earth's atmosphere or energy per second, per unit area, per unit wavelength or frequency interval which is called spectral flux.

Light

Spectrum



So let's measure a star's flux



Assembly photo

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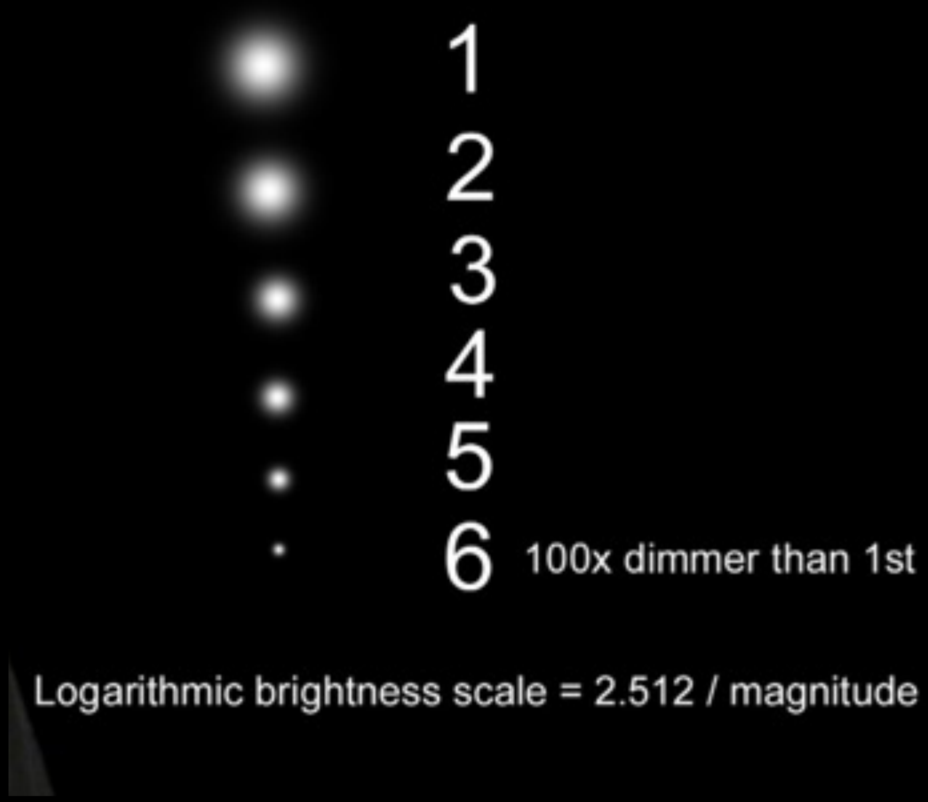
Magnitude System

Brightness ↑ Magnitude ↓

Hipparchus divided the naked eye stars into 6 magnitude classes.



Pogson proposed that a difference of five magnitudes be exactly defined as a brightness ratio of 100 to 1

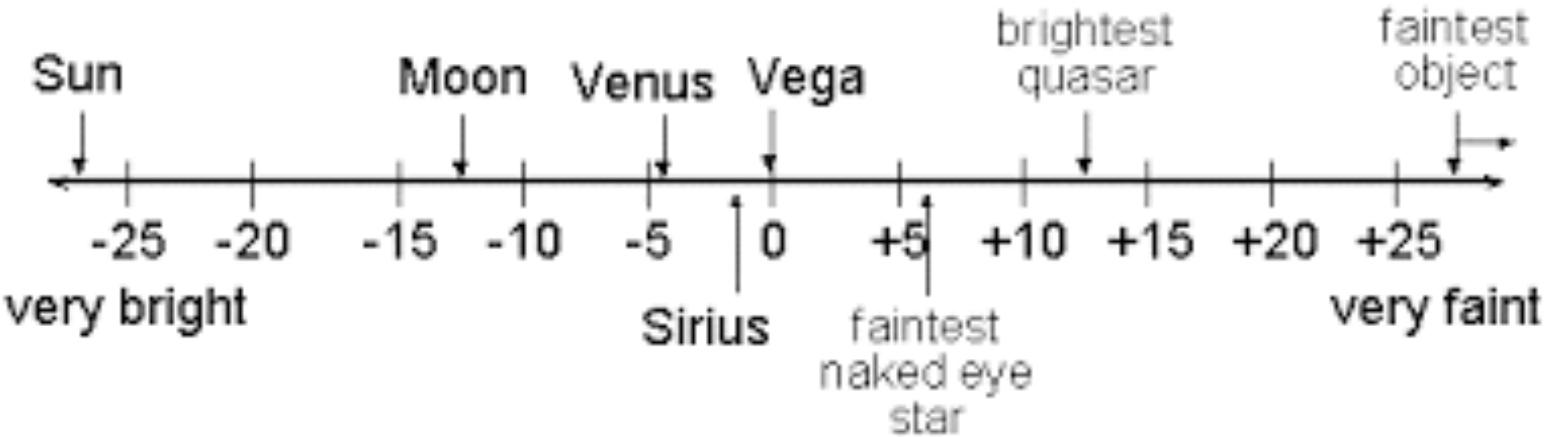
One magnitude thus corresponds to a brightness difference of exactly the fifth root of 100 (10^(2/5)), a value known as the *Pogson ratio*.

$$\frac{f_2}{f_1} = 100^{(m_1 - m_2)/5}$$

or

$$\boxed{m_1 - m_2 = -2.5 \log_{10}\left(\frac{f_1}{f_2}\right)}$$

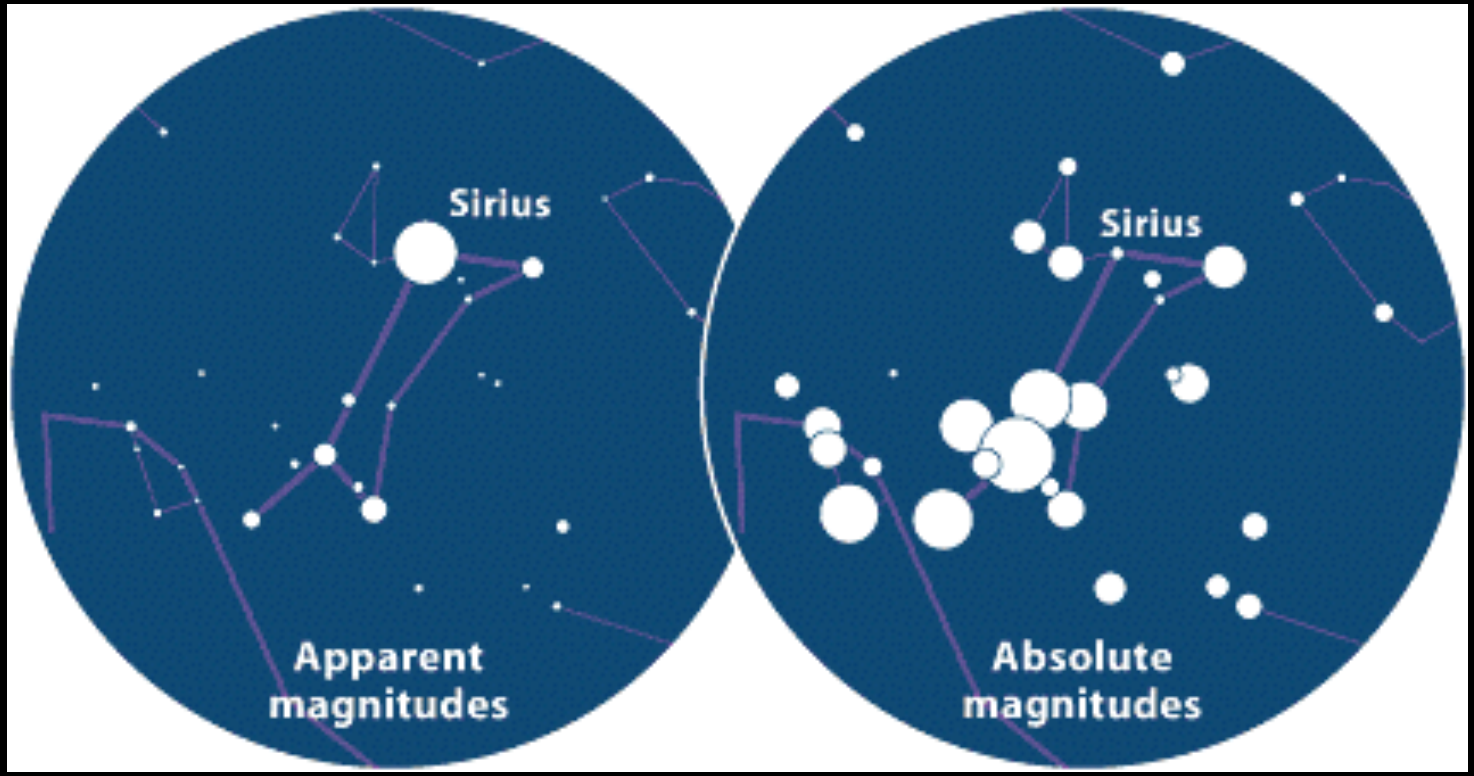
where *F1,F2* and *m1,m2* refer to the fluxes and magnitudes of two stars.



Apparent brightnesses of some objects in the magnitude system.

- *Apparent Magnitude* is a measure of how bright a star would appear from Earth.

- *Absolute Magnitude* is a measure of how bright a star would appear from a distance of 10 pc



On the left-hand map of Canis Major, dot sizes indicate stars' apparent magnitudes; The right-hand version indicates the same stars' absolute magnitudes

Colour

What does the colour of a celestial object tell us?

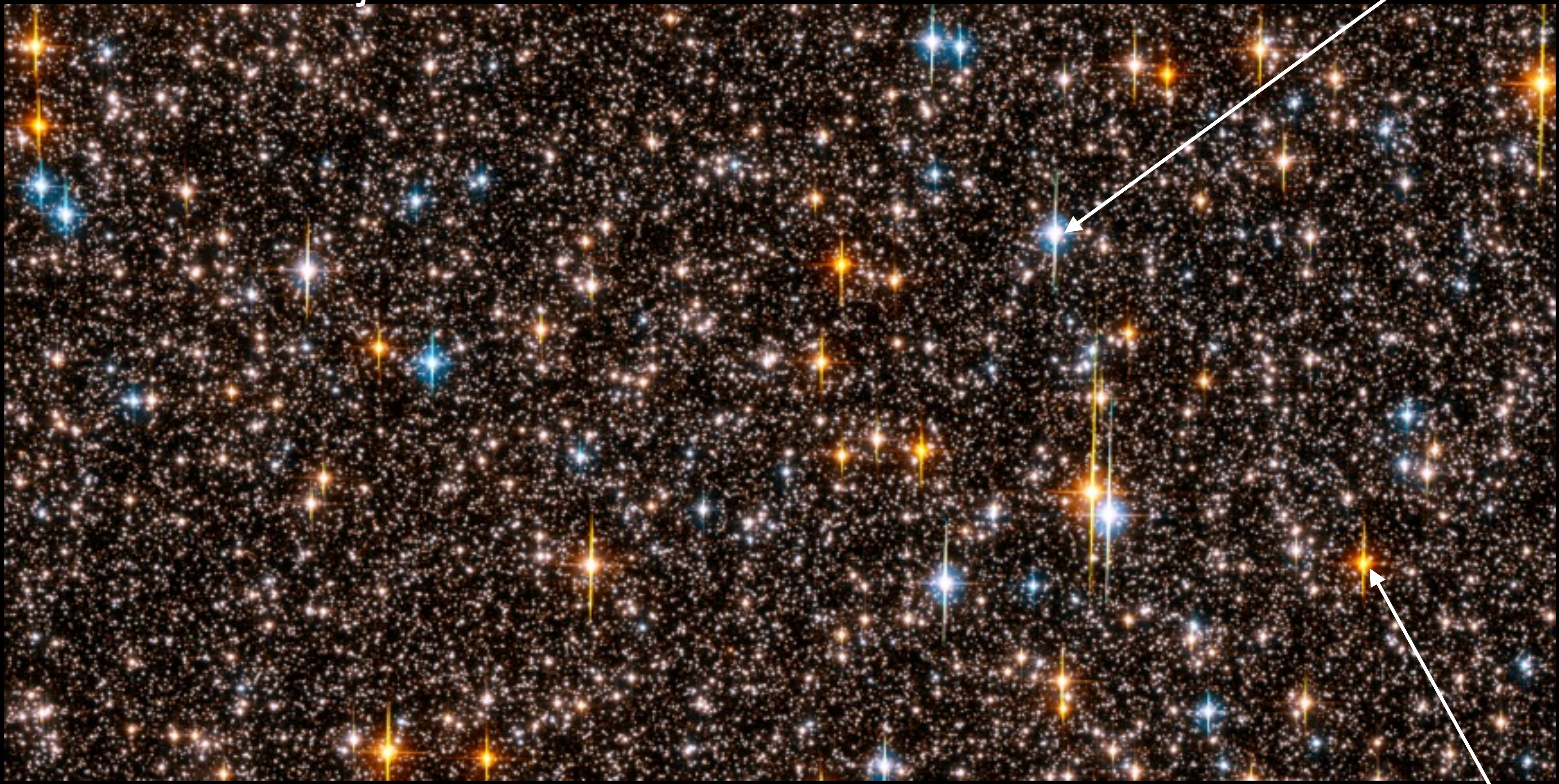
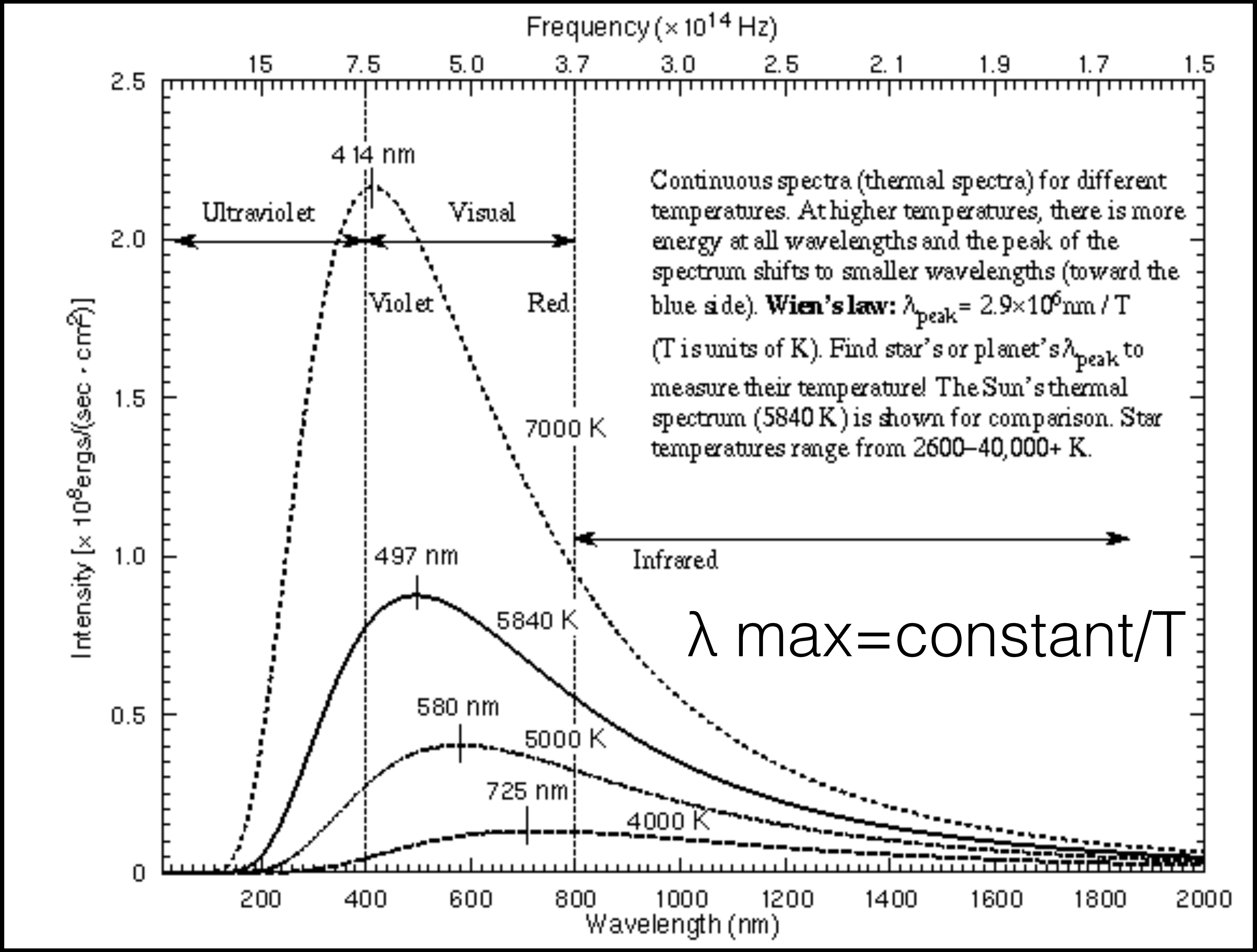


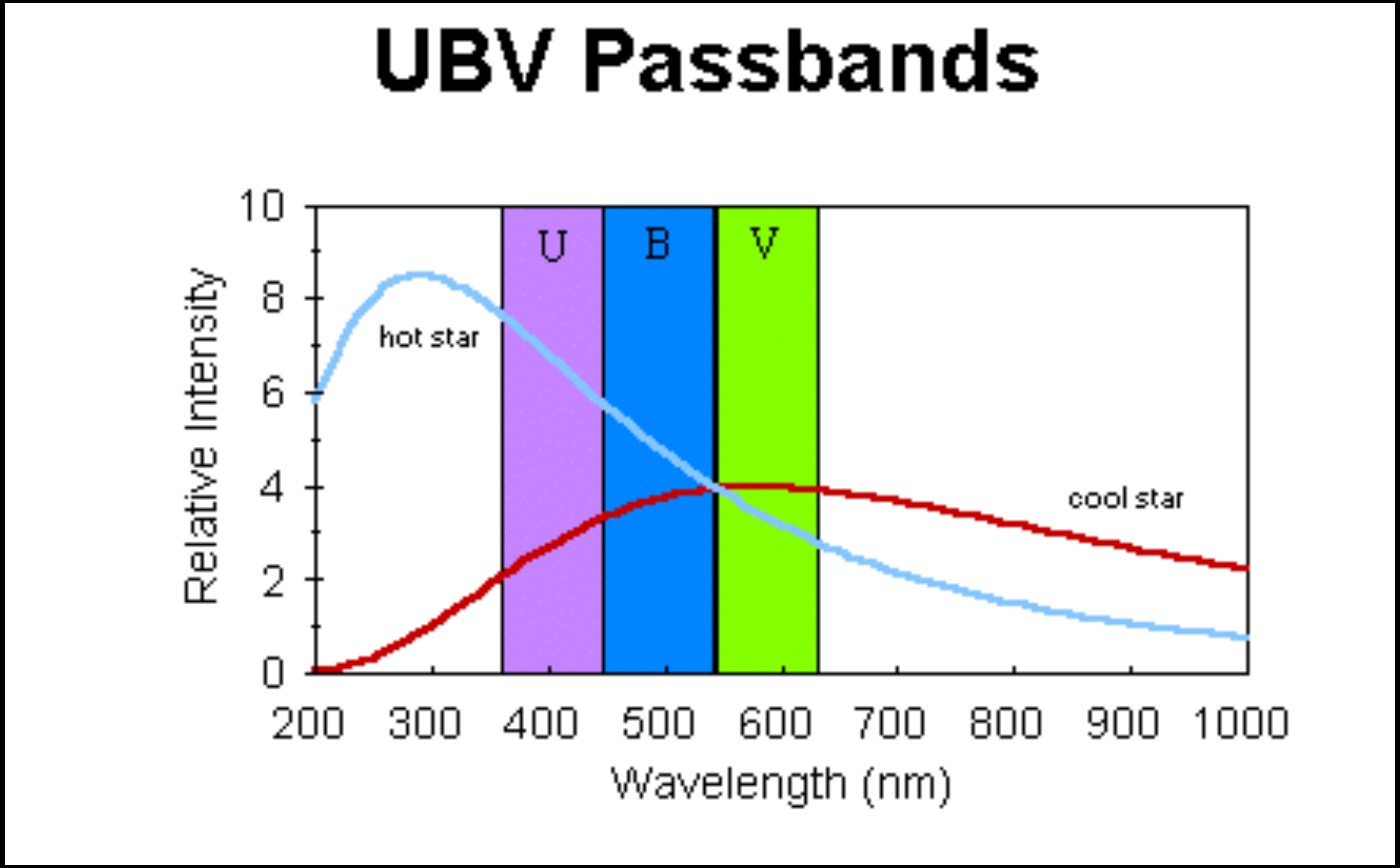
Fig: Exoplanets | ESA/Hubble

Blackbody radiator, a highly idealised radiation source described by theoretical physics, approximately defines the radiation leaving a star.

Planck Spectrum

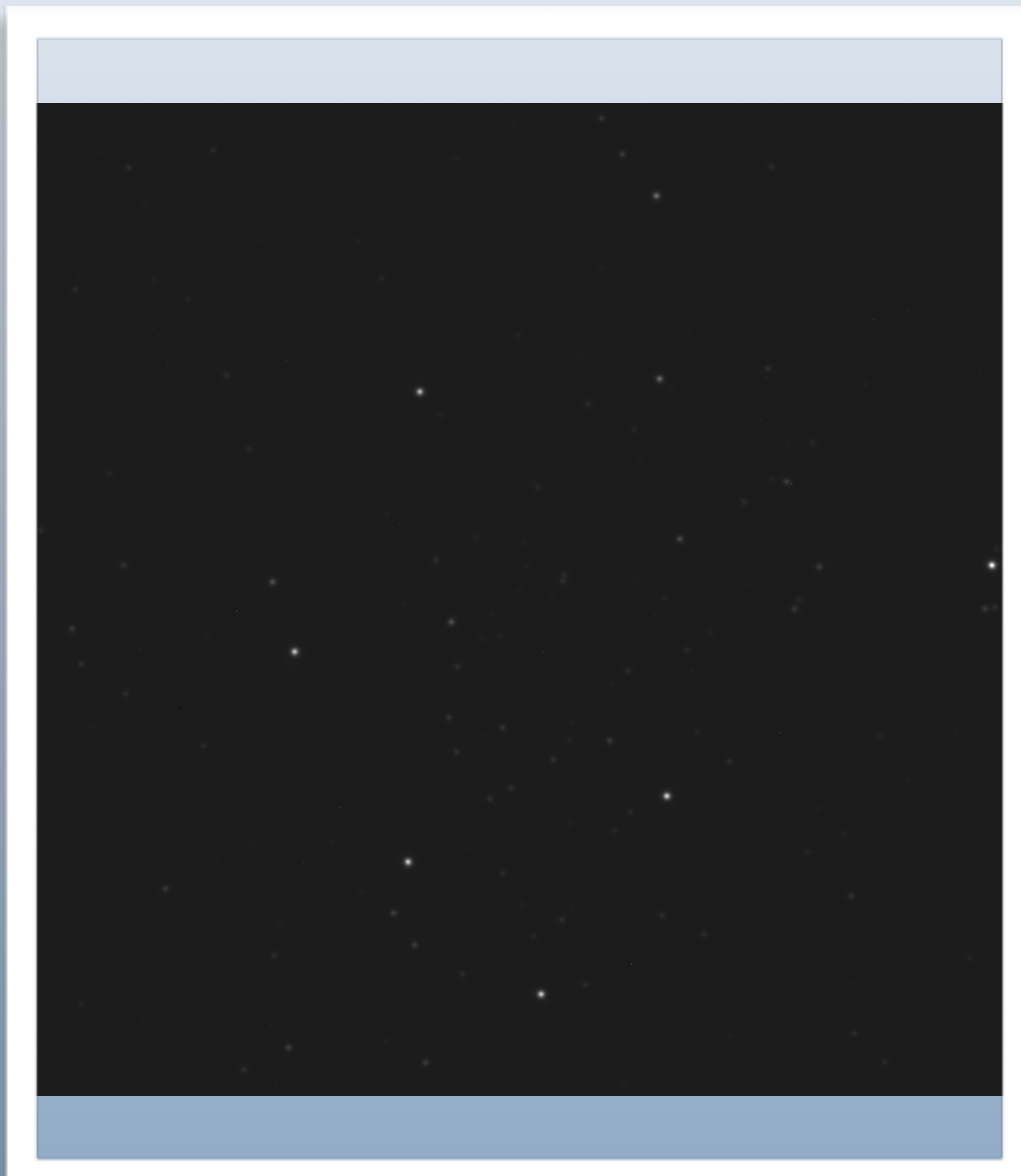


The difference between magnitudes in different spectral bandpasses is called a colour index. Astronomers routinely use colour indices - often in place of either temperature or spectral type when conveying information about a star.

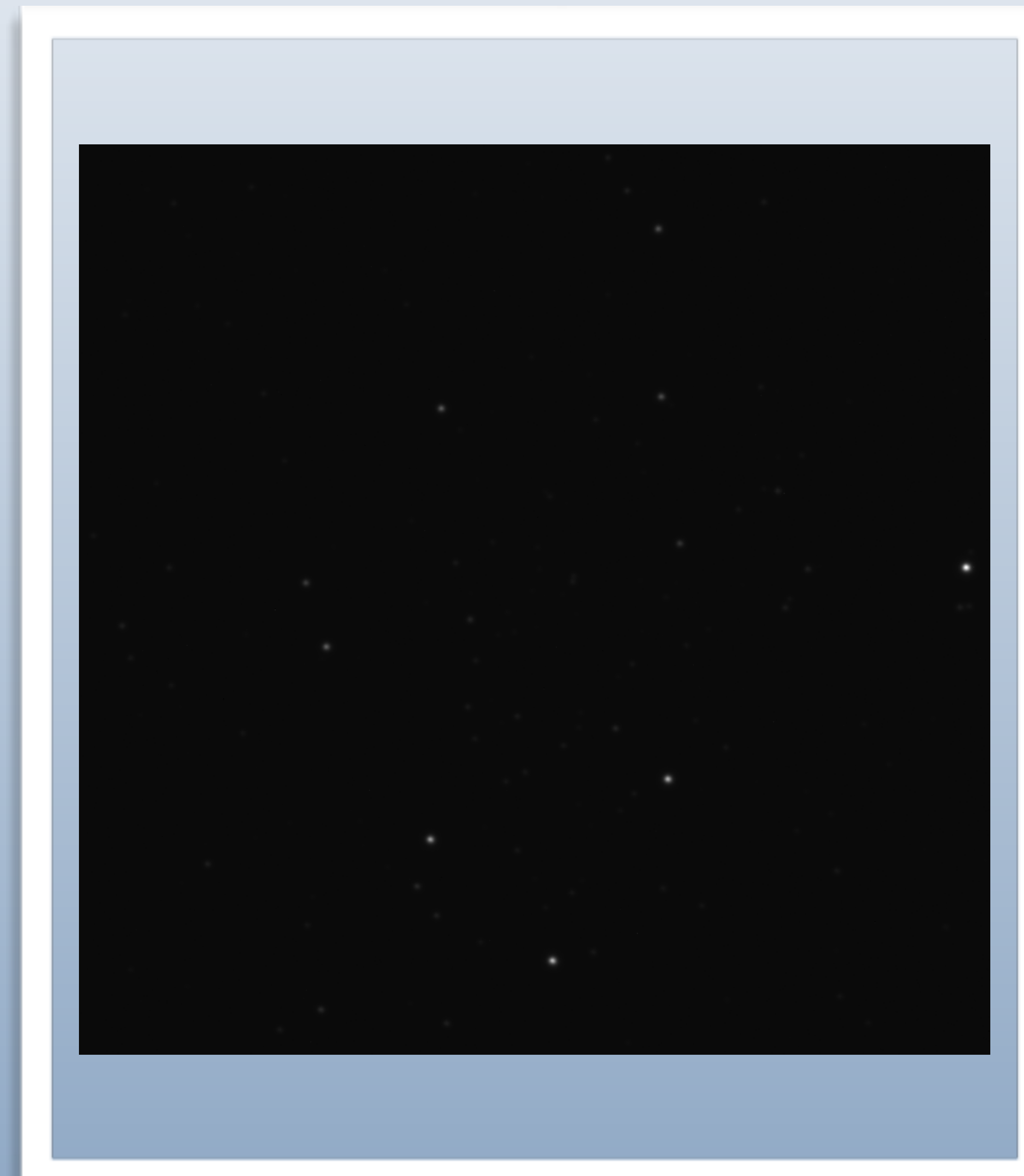


Photometry

INPUT : CCD images in FITS format

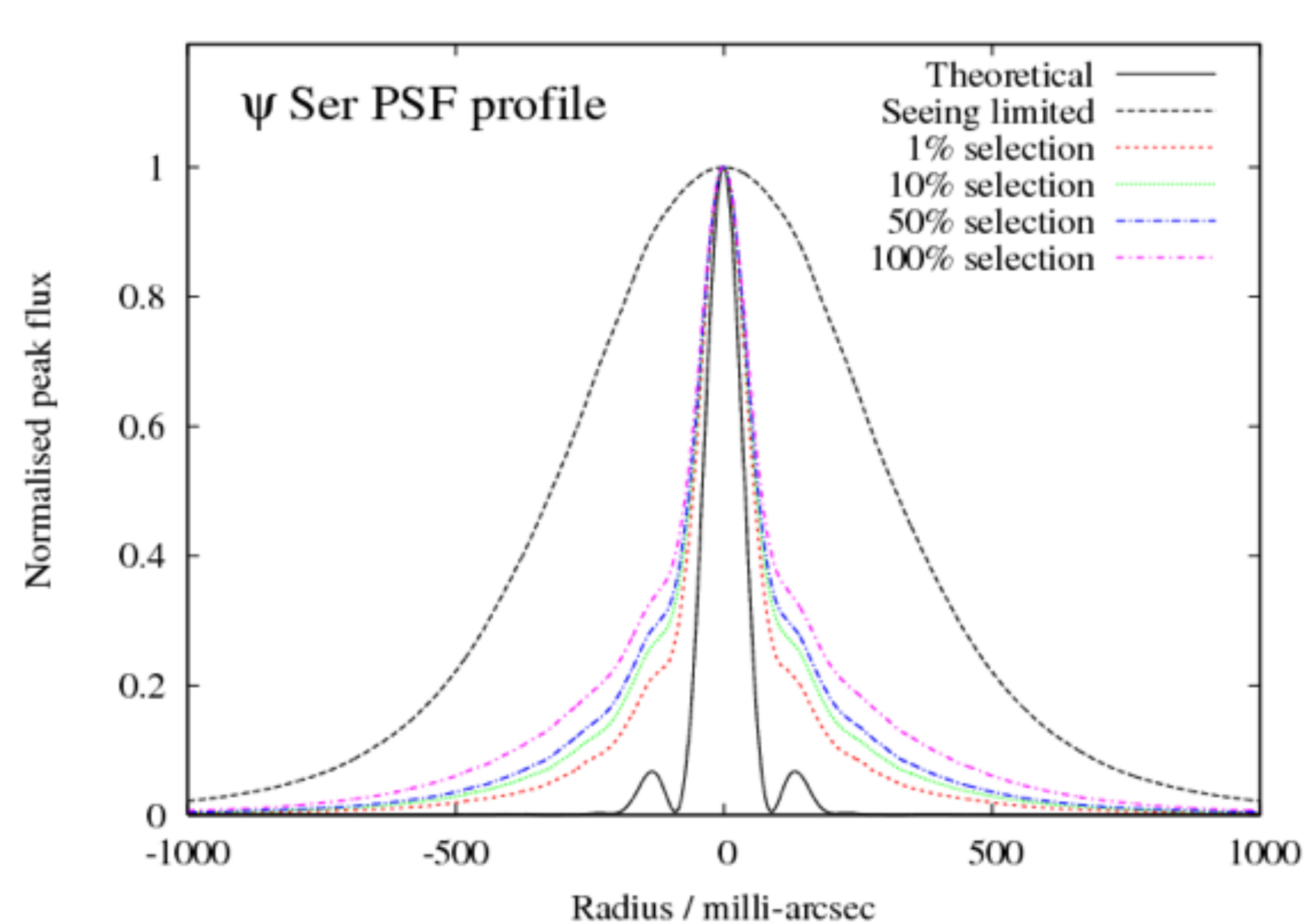


NGC 2420 B filter image



NGC 2420 V filter image

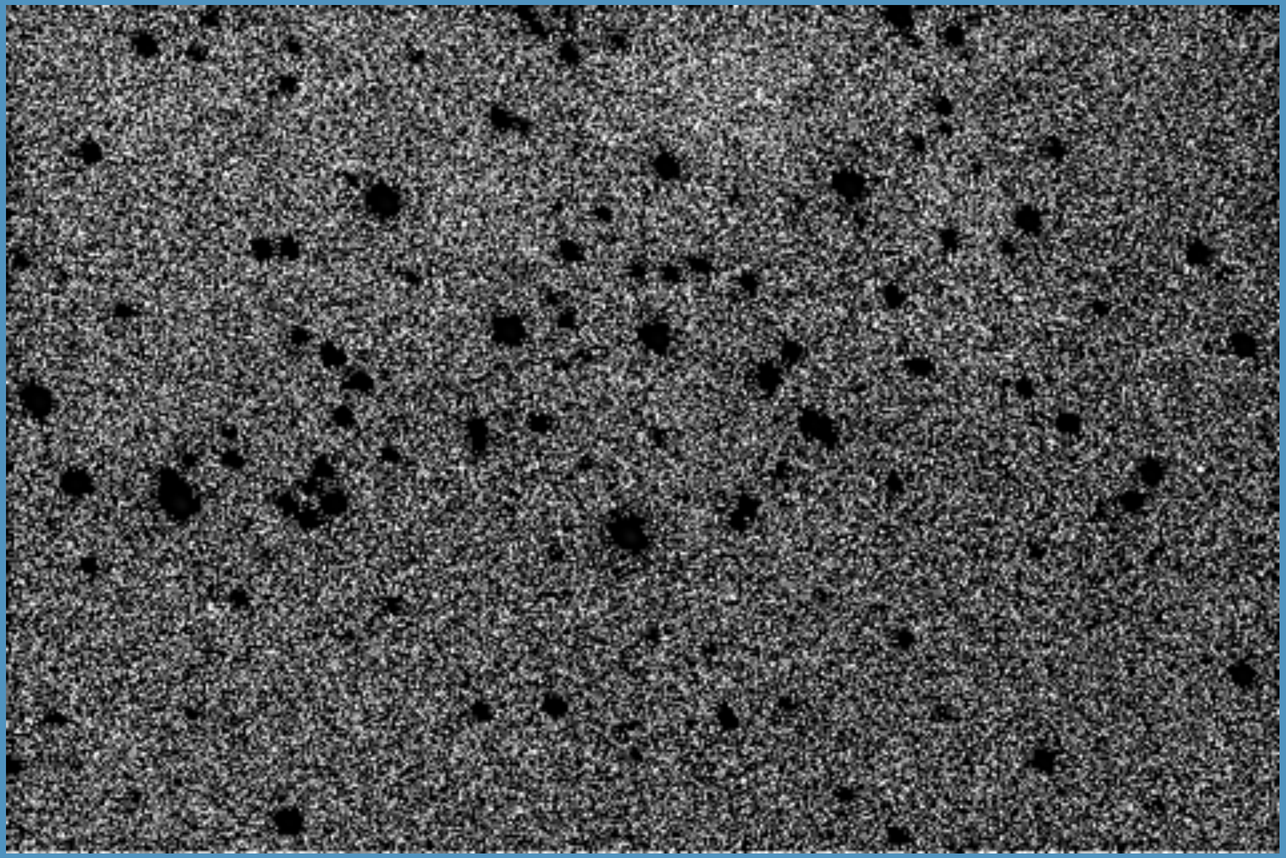
- Why is the image of a star a blob?



Point spread function

- The PSF is the shape of the image of a point source (such as a star) at the detector
- It determines the resolution and structure of an image
- The two main influences on the PSF are the optics and the atmosphere.

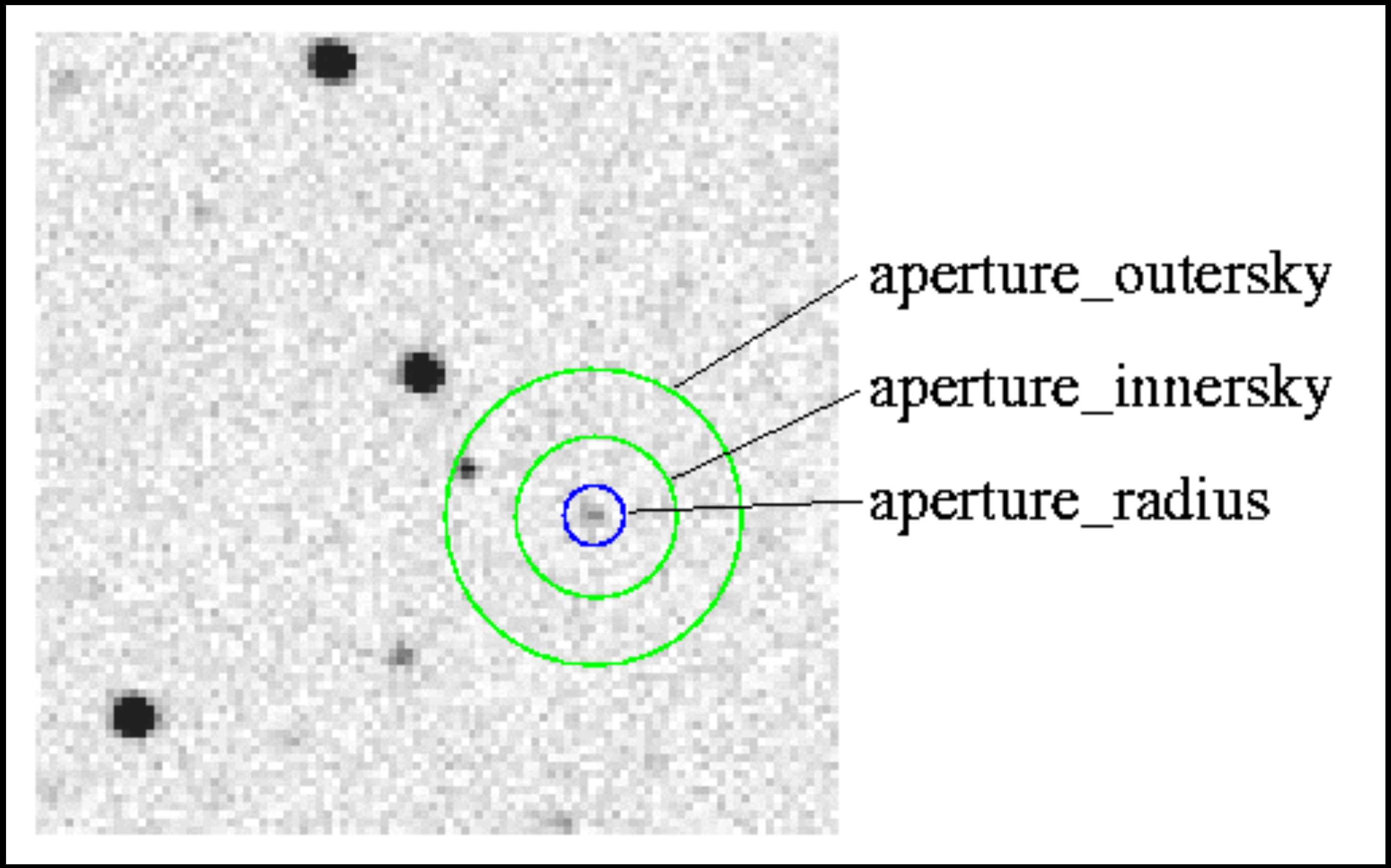
Original Image



Inverted grayscale Image

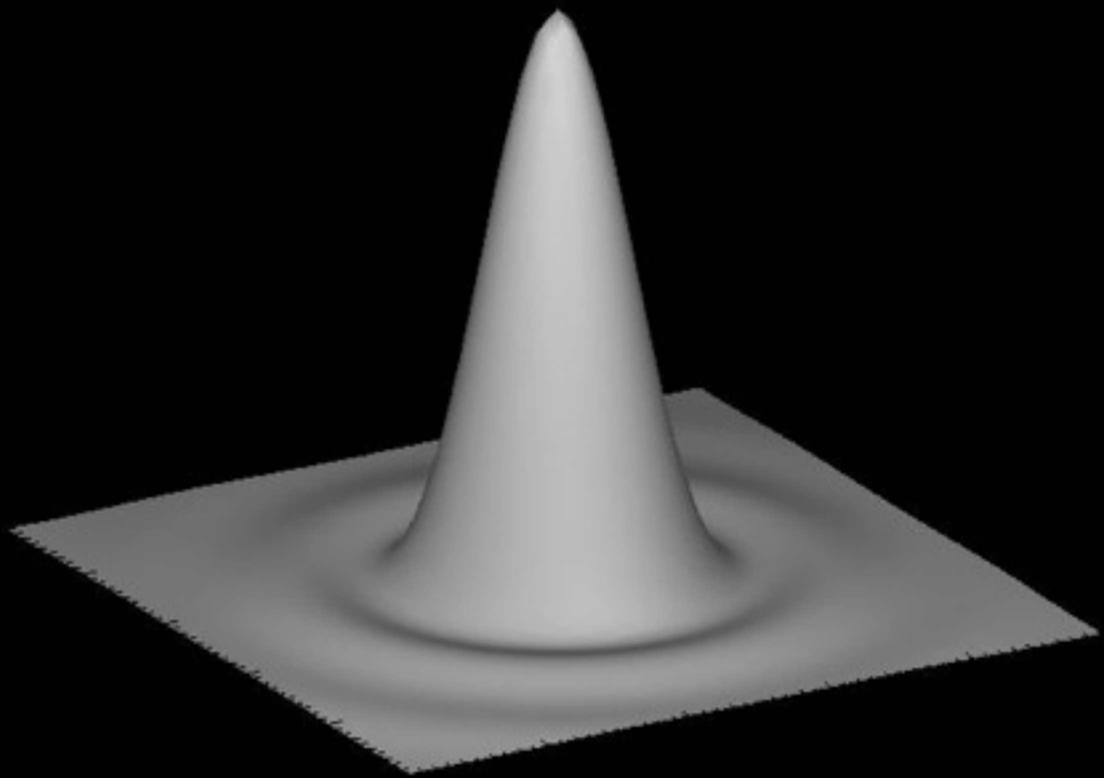
Aperture Photometry

- Simplest method of photometry
- Works for relatively isolated stars



PSF photometry

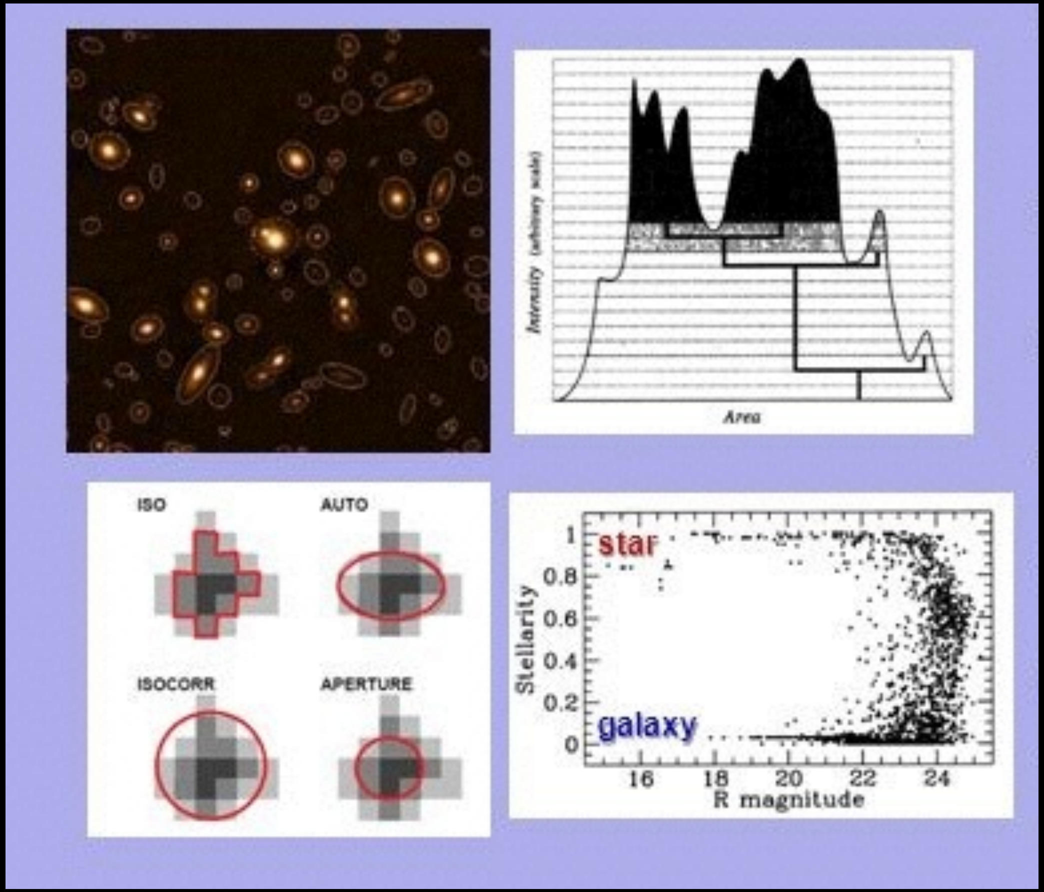
- Mathematically fitting PSF models to images of stars
- Works for crowded star fields



Source detection and photometry

Steps:

1. Estimate Background and its RMS noise
2. Detect objects : consider a “minimum number” of adjacent pixels above a certain threshold
3. Deblend merged objects: multiple pass thresholding to separate neighbour objects detected as a single source
4. Measure shapes and position
5. Perform photometry: Isophotal, isophotal-corrected, automatic, best-estimate and fixed circular aperture
6. Classify objects: Star-like/Galaxy
7. Output catalog



SExtractor is an astronomical software to extract and build catalogs of objects from optical images.

Results of first stage:

- B and V Magnitudes of several stars in a given cluster (*mb,mv)*

- Their colour indices, *mb-mv, were* calculated

- These are necessary to plot the stars on a Colour Magnitude diagram

X axis: Spectral class/ Colour Index/ Temperature

Y axis: Absolute Magnitude/ Luminosity (in some cases apparent magnitude)

What is a star cluster/star clouds?

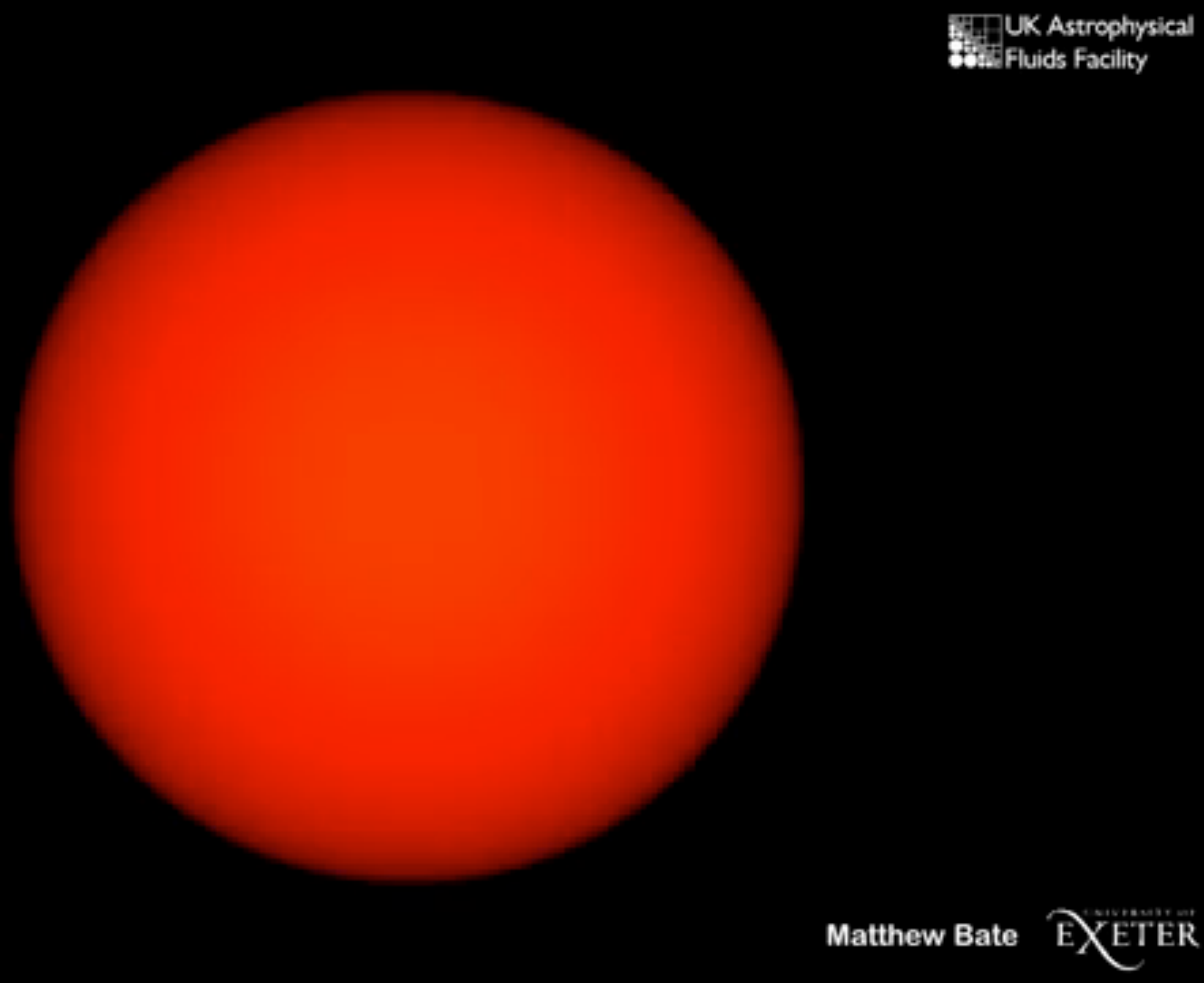
- A group of stars
- Can be distinguished into two types:

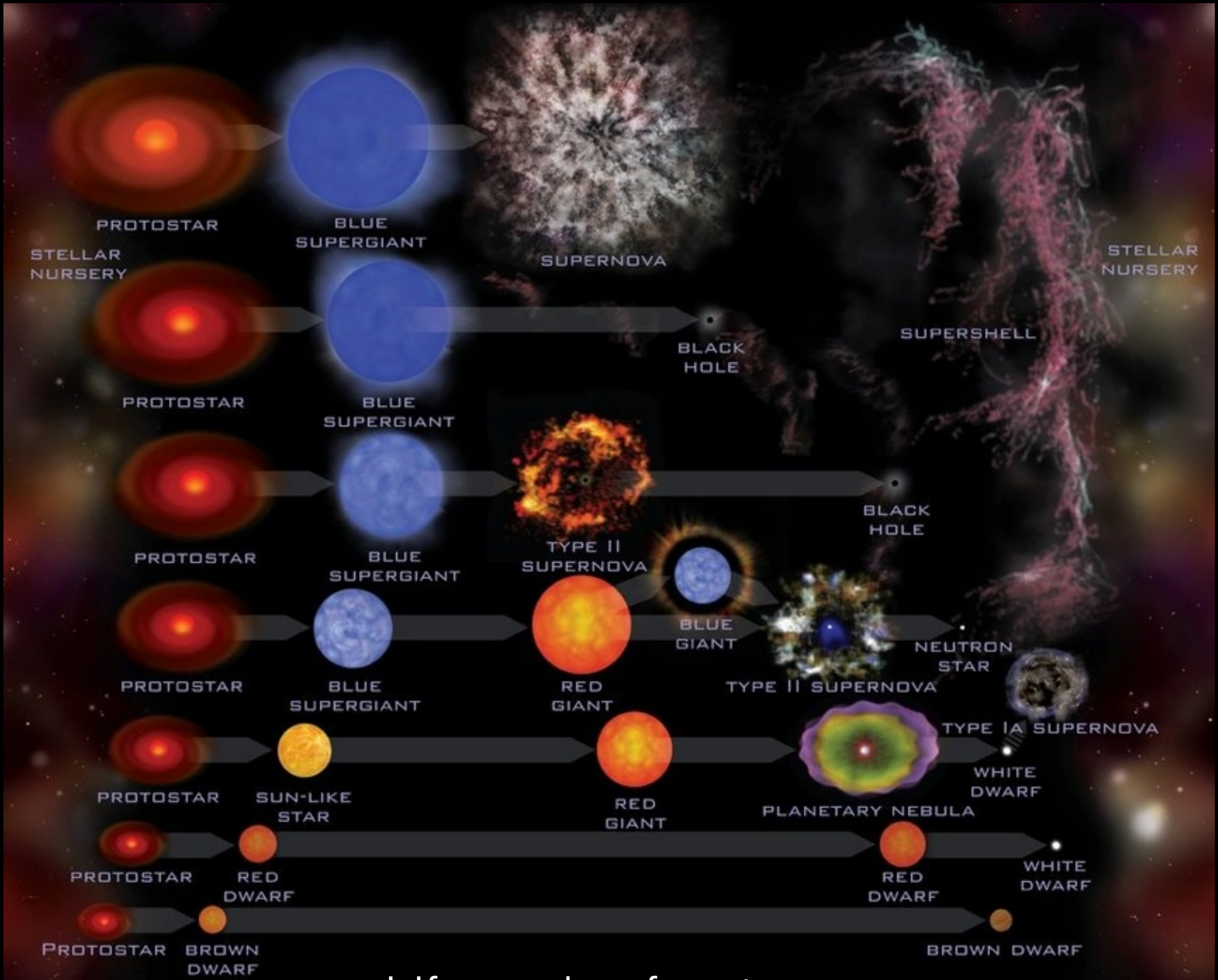
1. Globular Cluster
2. Open Cluster

NGC 2420 open cluster

M80 globular cluster

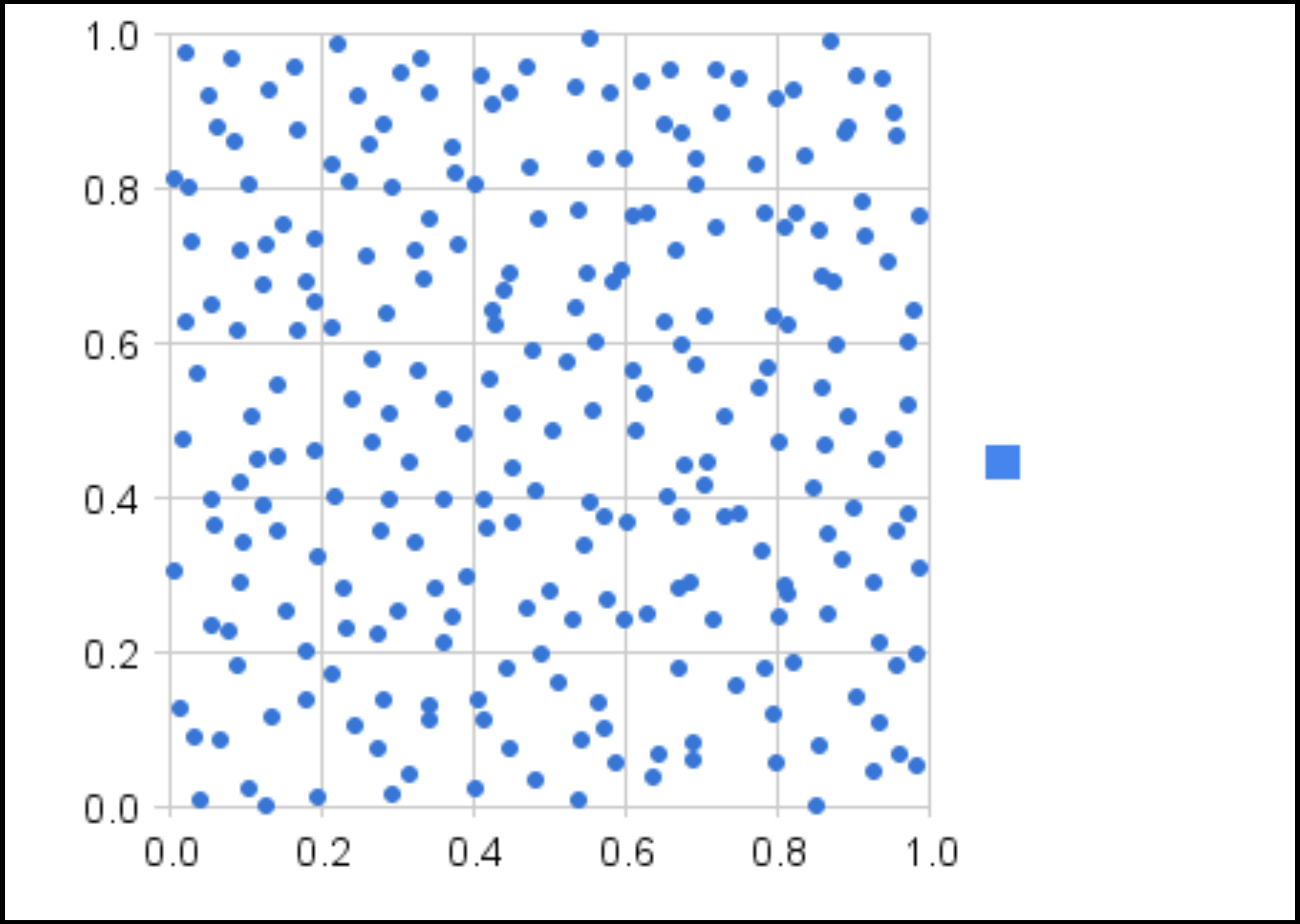
Star Clusters





Life cycle of a star

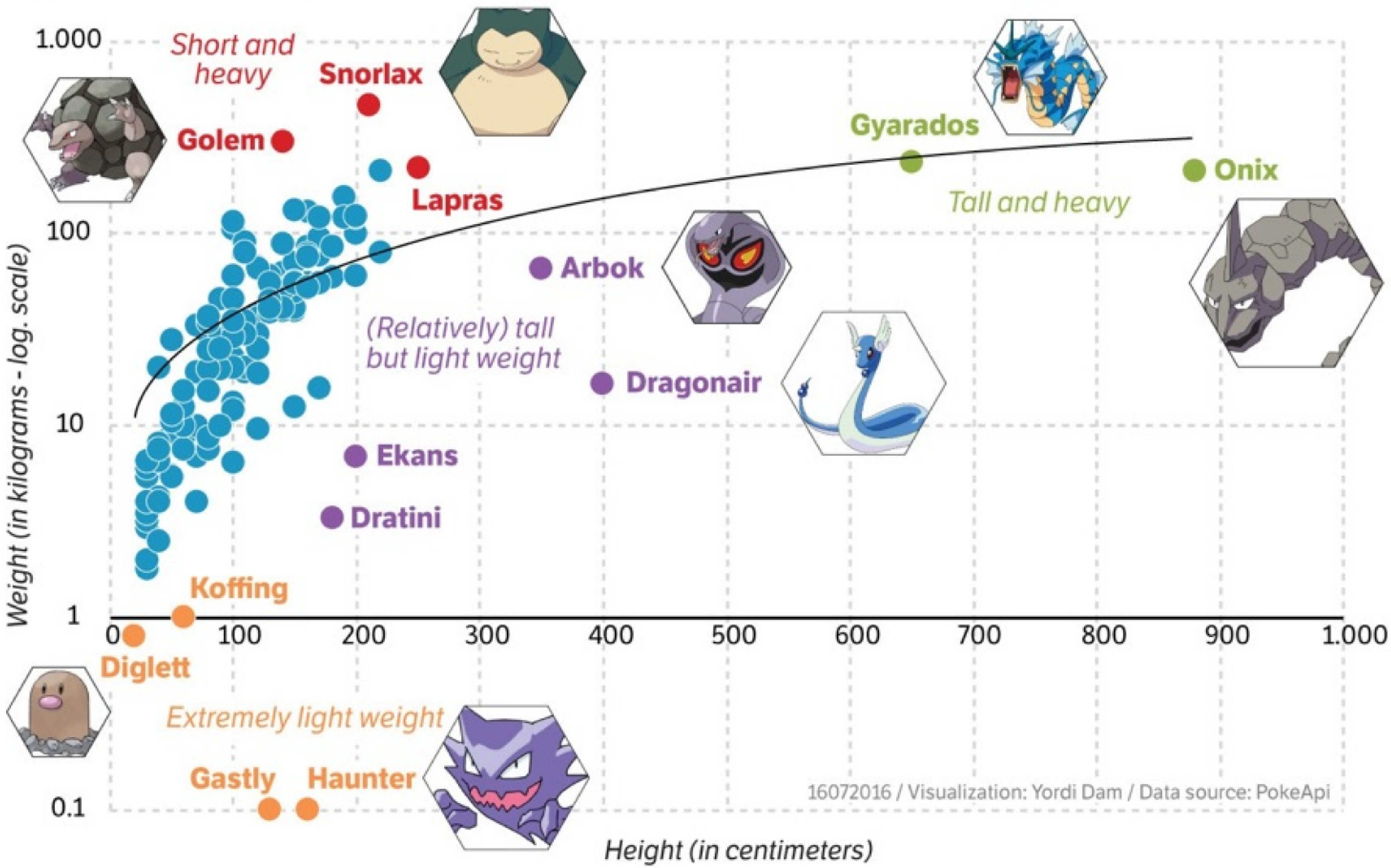
Plotting data



Random distribution of values

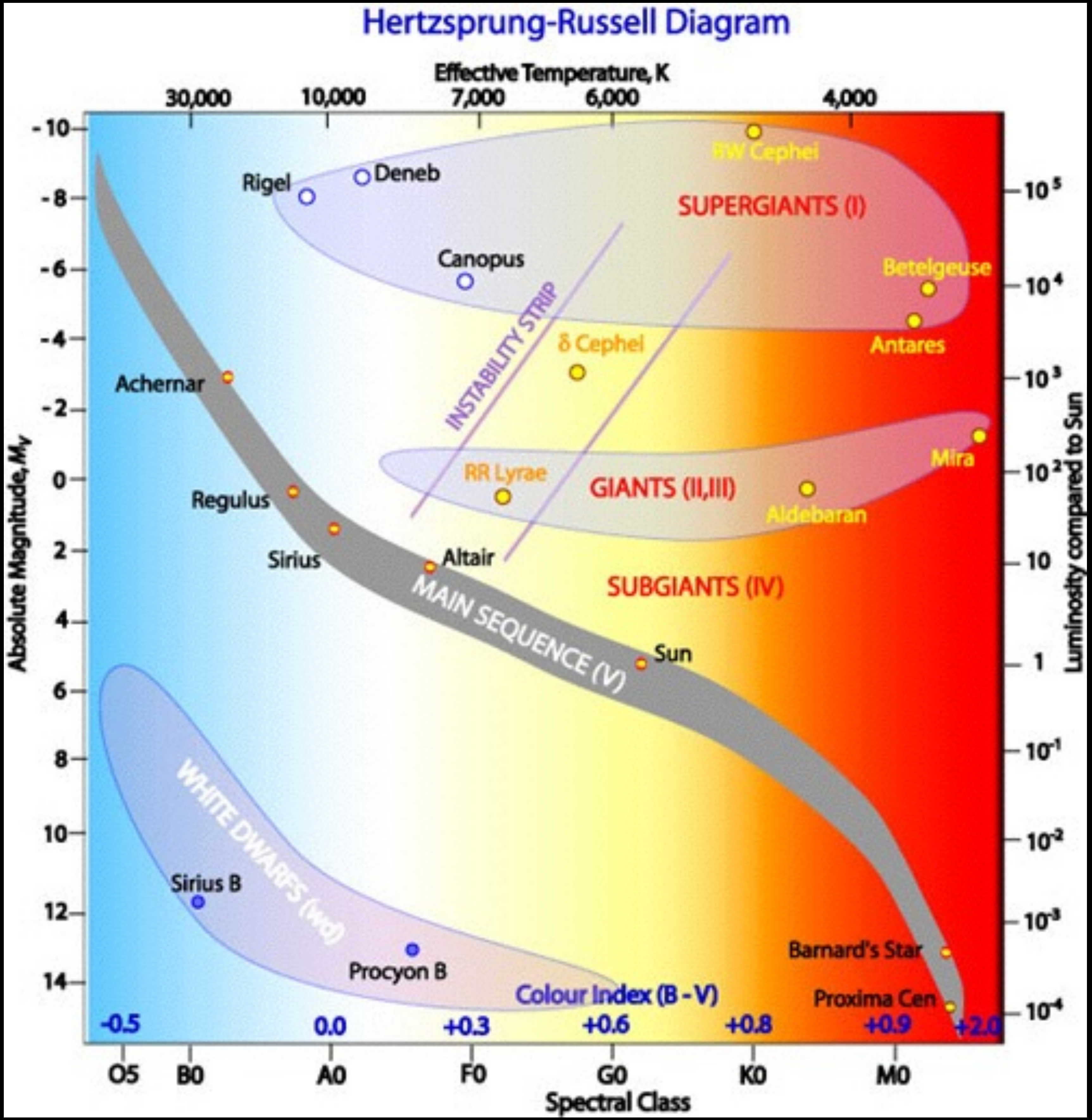
Gotta plot 'em all: height versus weight of Pokémon

Height (in cm) plus weight (in kilograms) of the 151 first generation Pokémon

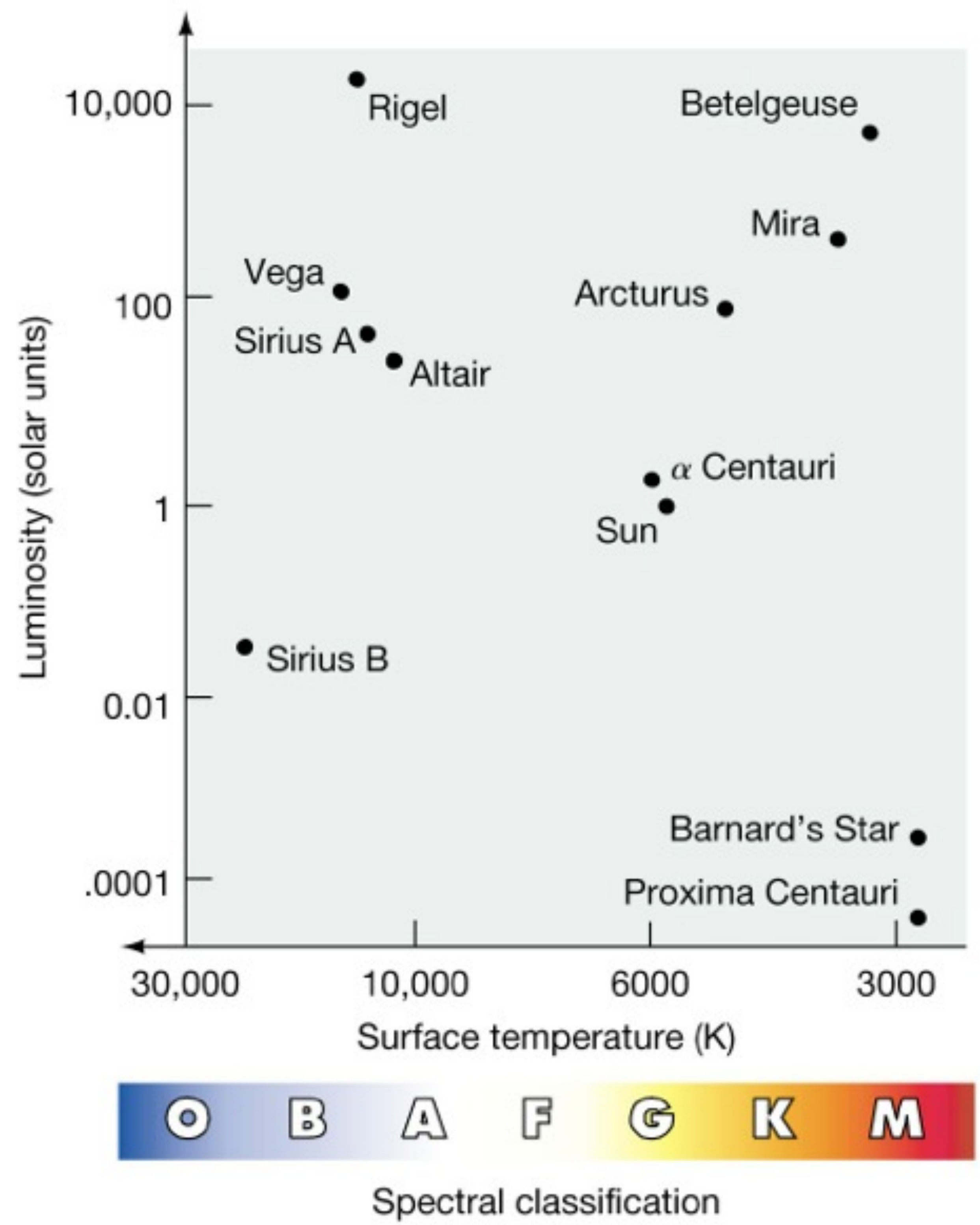


HR diagram

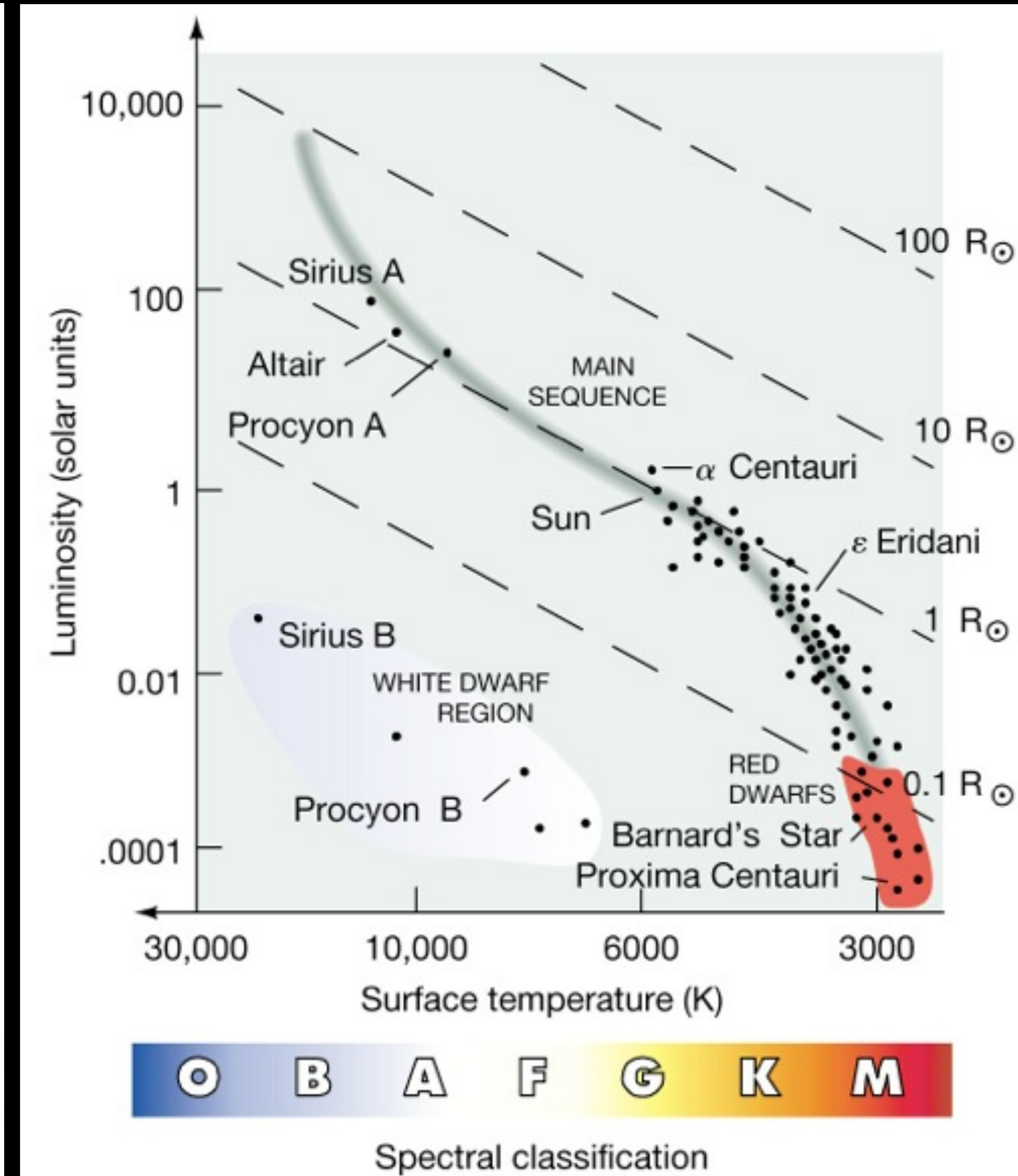
Luminosity of a star is related to its surface temperature



The Hertzsprung-Russell diagram. From the Australia Telescope outreach and education site.



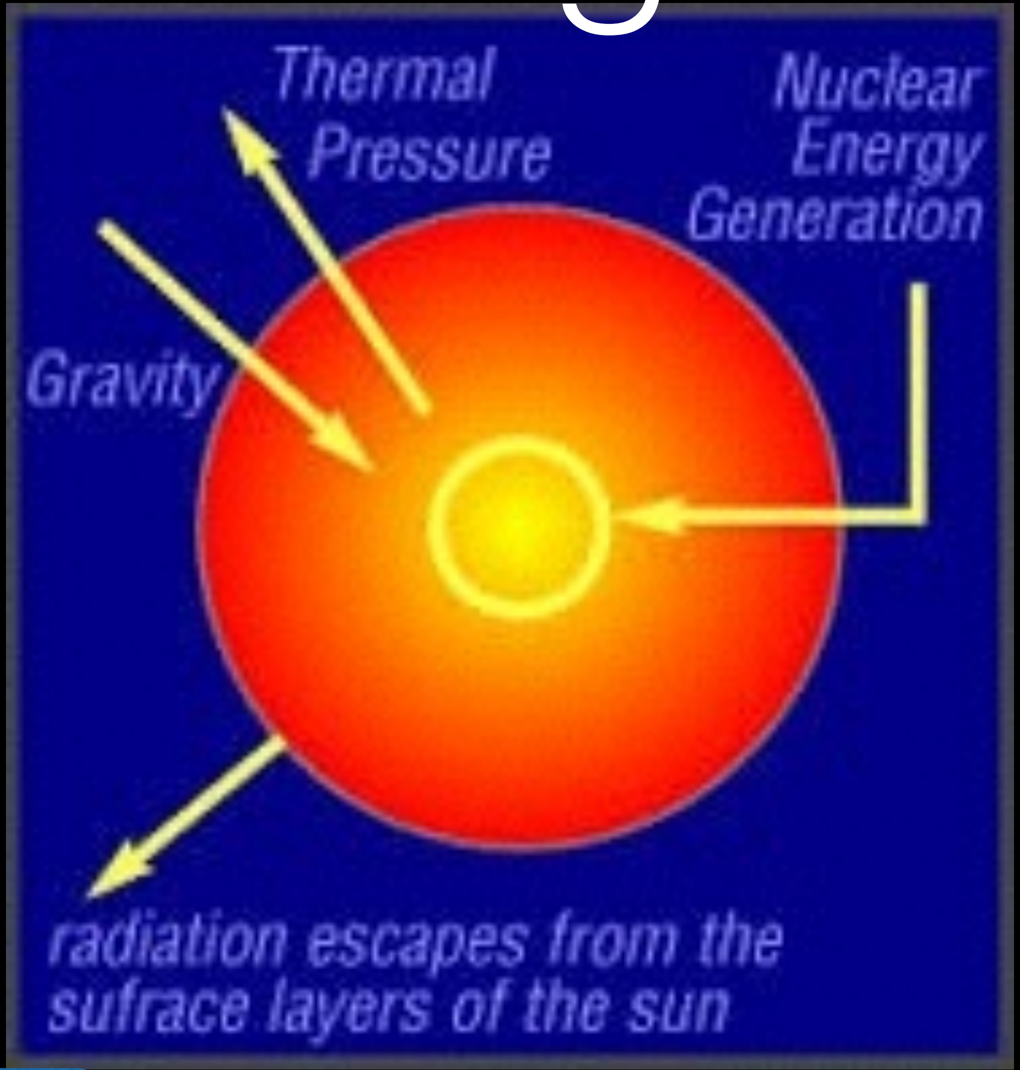
Luminosity (solar units)
10,000
100
1
0.01
.0001
Rigel
Betelgeuse
Mira
Vega
Arcturus
Sirius A
Altair
α Centauri
Sun
Sirius B
Barnard's Star
Proxima Centauri
30,000
10,000
6000
3000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification



Luminosity (solar units)
10,000
100
1
0.01
.0001
100 R⊙
10 R⊙
1 R⊙
0.1 R⊙
Sirius A
Altair
Procyon A
MAIN SEQUENCE
α Centauri
Sun
ε Eridani
Sirius B
WHITE DWARF REGION
RED DWARFS
Procyon B
Barnard's Star
Proxima Centauri
30,000
10,000
6000
3000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification

Mass Sequence Stage

- Main sequence is the longest stage in a star's life where hydrogen fuses into helium which creates enormous amount of energy (nuclear fusion)
- The size of the star does not change much.



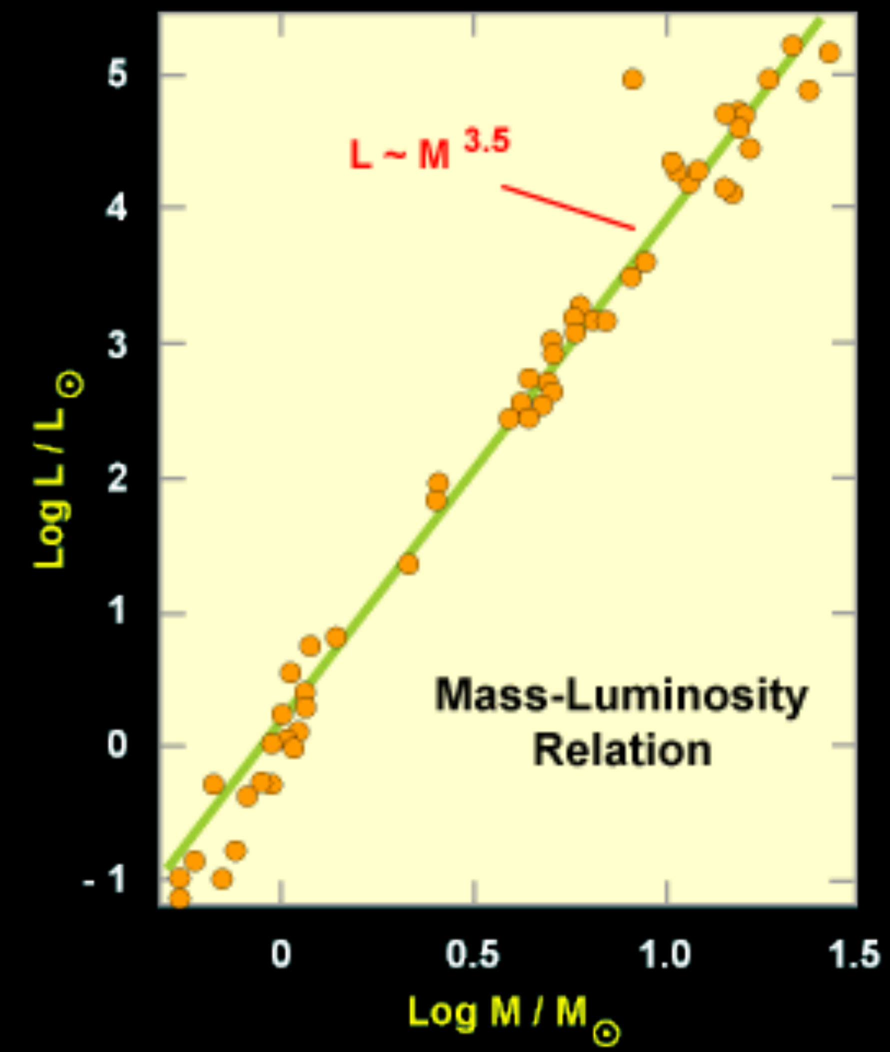
$$L = 4\pi R_*^2 \sigma T_*^4$$

"The Luminosity of a star is proportional to its Effective Temperature to the 4th power and its Radius squared.

σ is the Boltzmann's constant

The luminosity of stars on the main sequence increases with the mass with the approximate power law.

$$\frac{L}{L_S} = \left[\frac{M}{M_S}\right]^{3.5}$$



A star's lifetime on the main sequence is how long it takes to use up the hydrogen in its core. It depends on it's MASS.

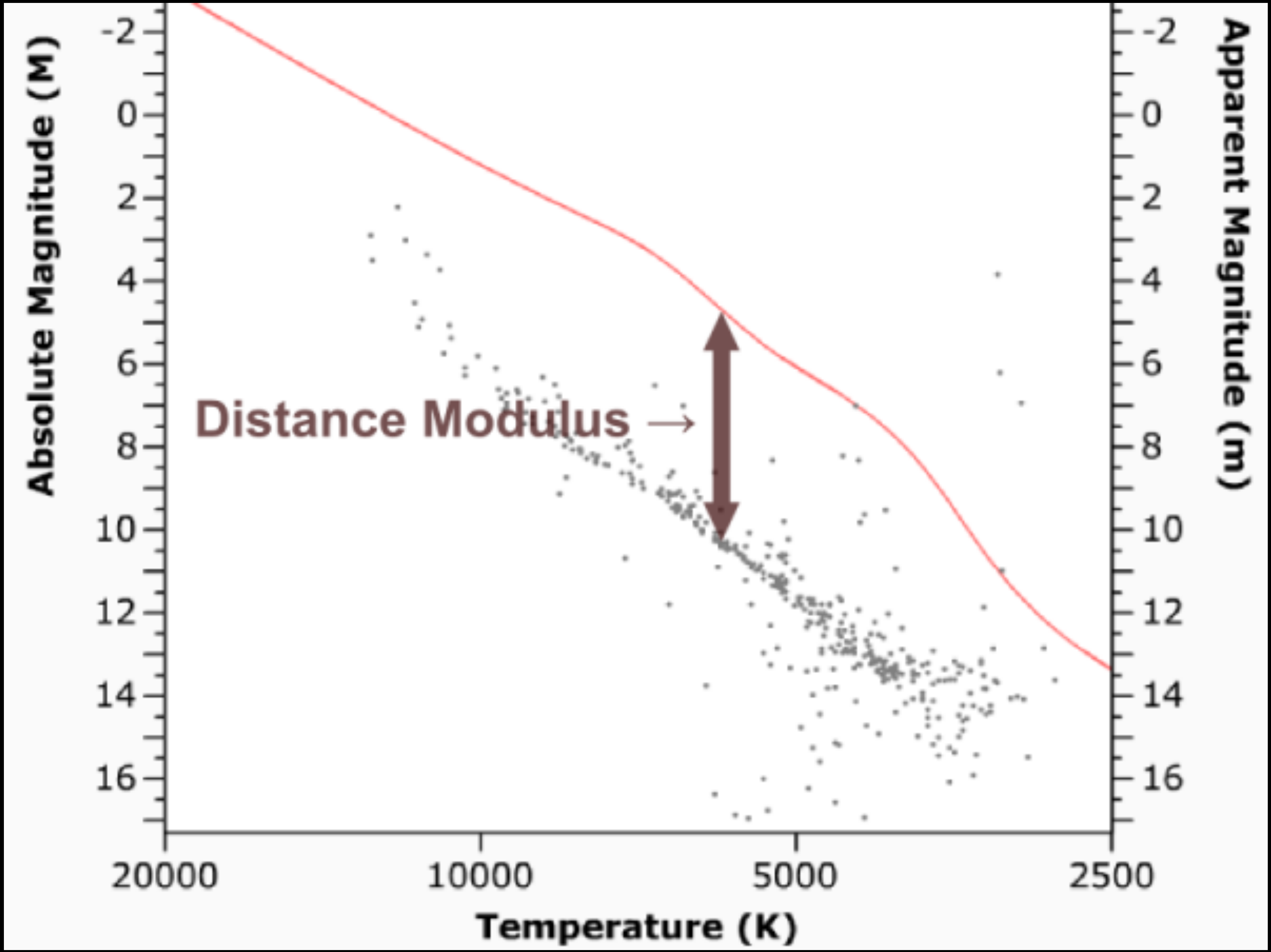
$$t \approx \frac{1}{M^{2.5}}$$

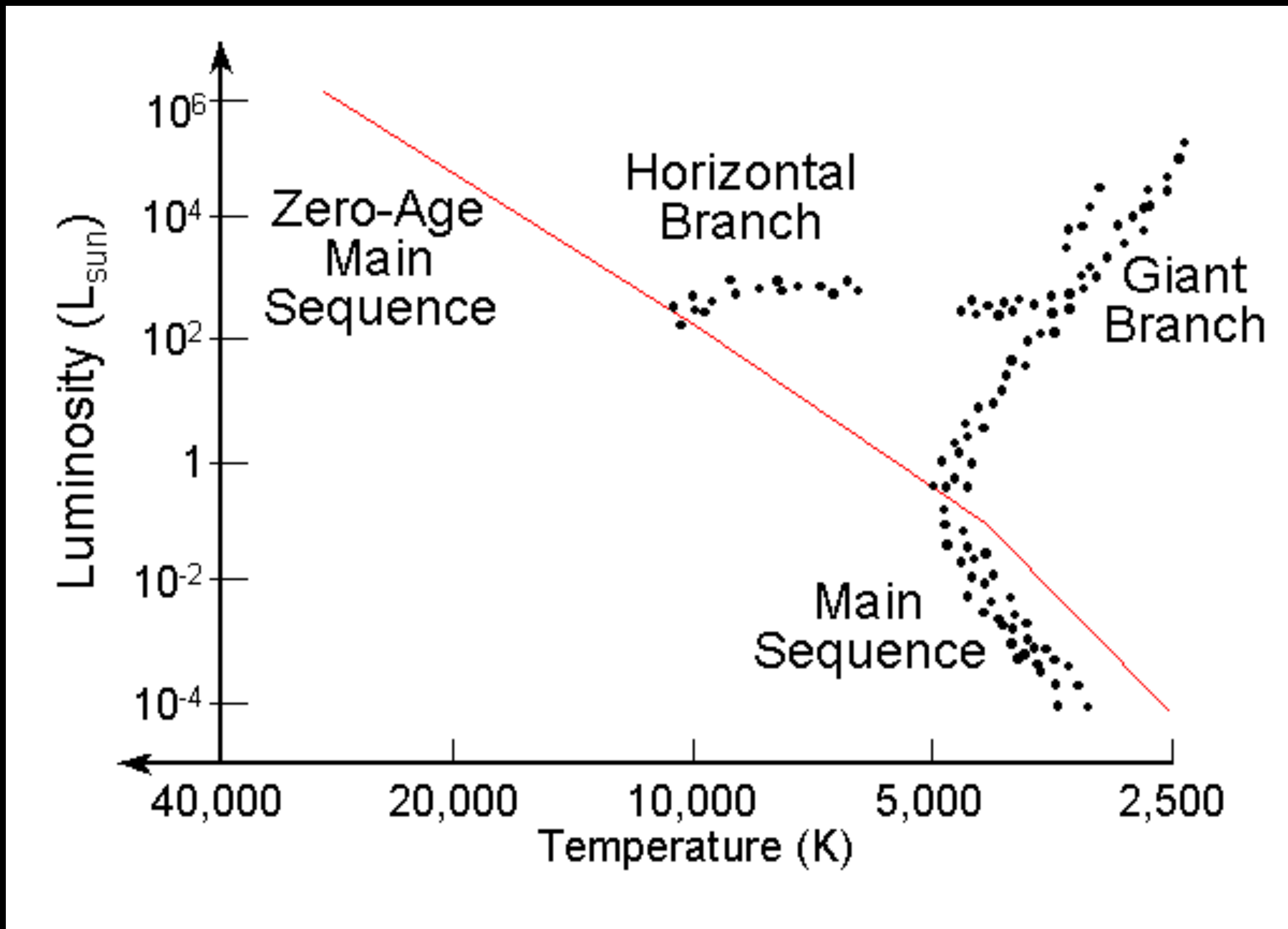
Stars in a cluster

These stars are gravitationally bound, all located at the same distance, and formed at the same time from the same cloud of gas and dust.

The two quantities that get plotted in an HR diagram are LUMINOSITY (y-axis) and TEMPERATURE (x-axis).
But what we measure are the apparent brightness of a star (which depends on luminosity AND distance) and the colour (which depends on temperature). Because we don't directly measure luminosity or temperature, most HR diagrams plot the observable quantities, which are MAGNITUDE (y-axis) and COLOuR (x-axis).

Main Sequence Fitting

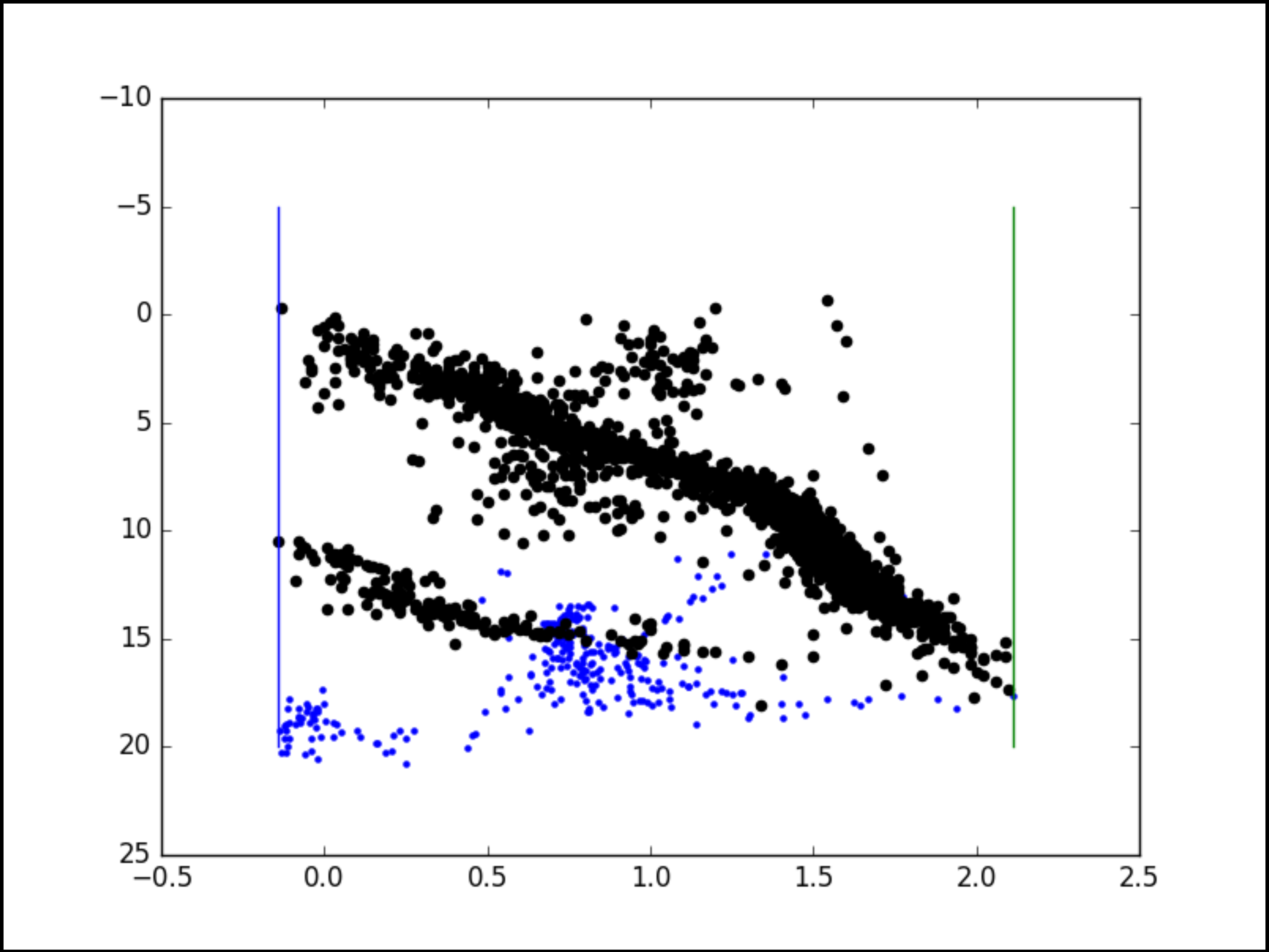




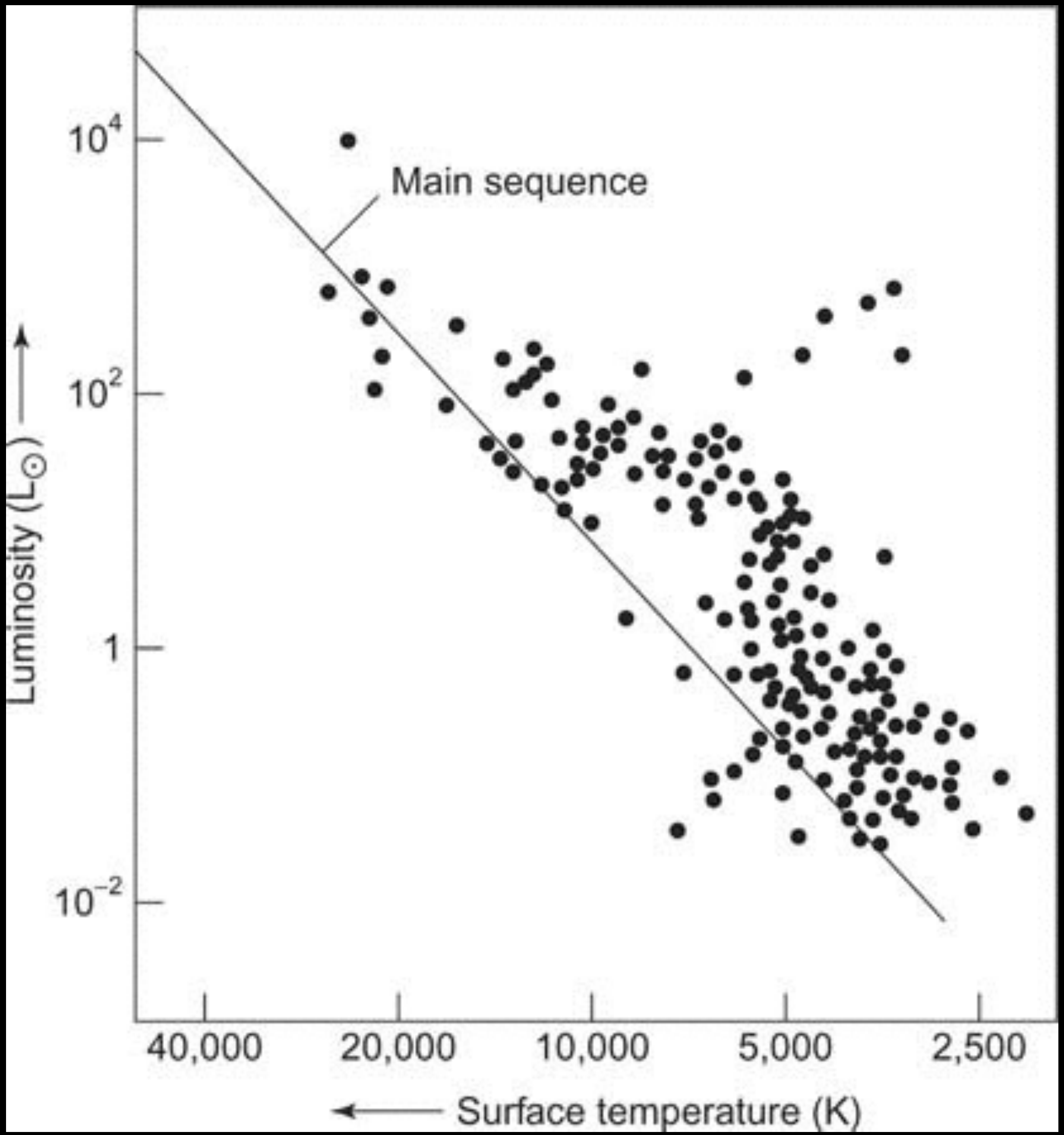
HR diagram of a globular cluster

www.spacetelescope.org

The intersection of the two plots

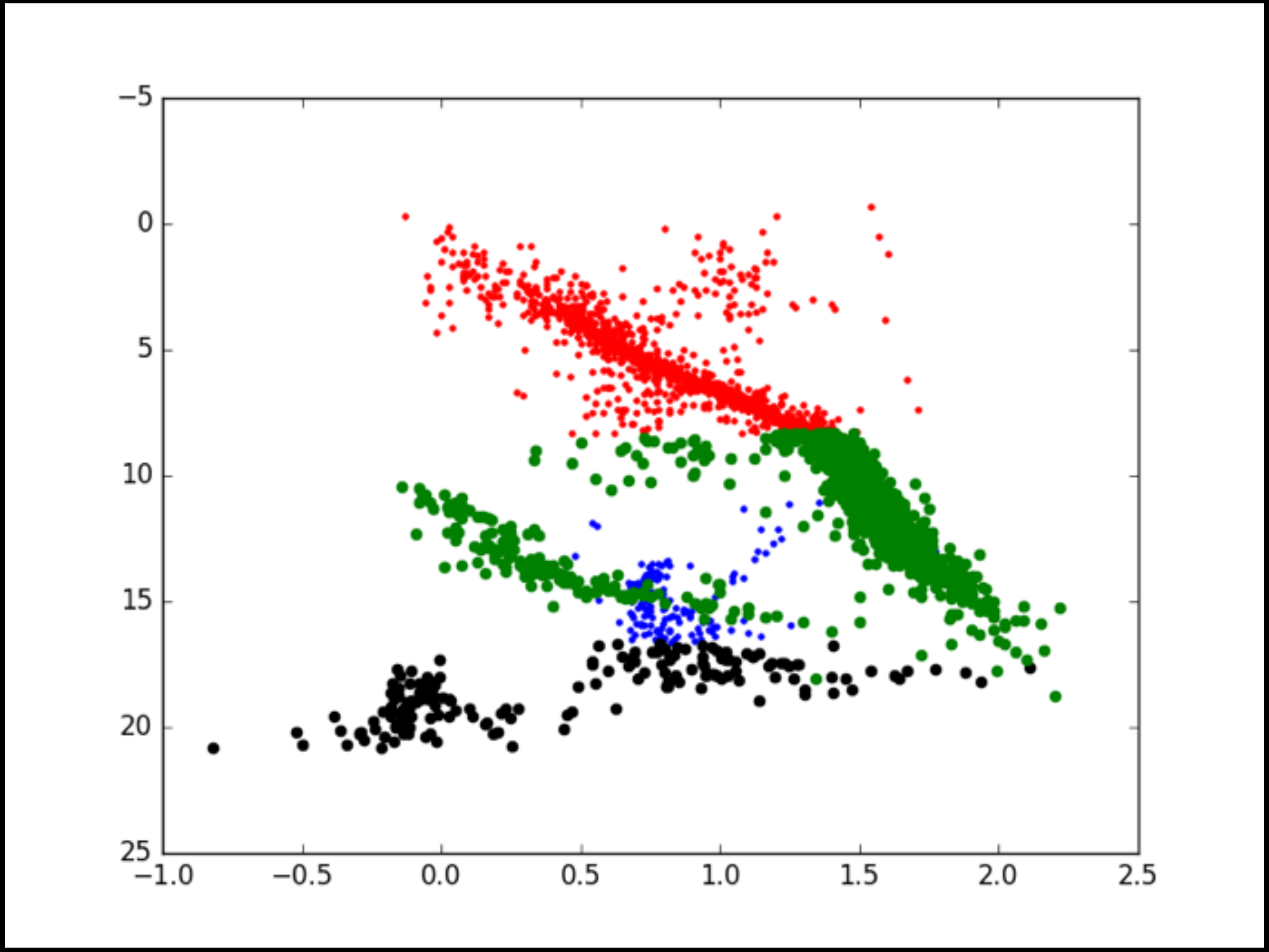


Least squares Model Fitting

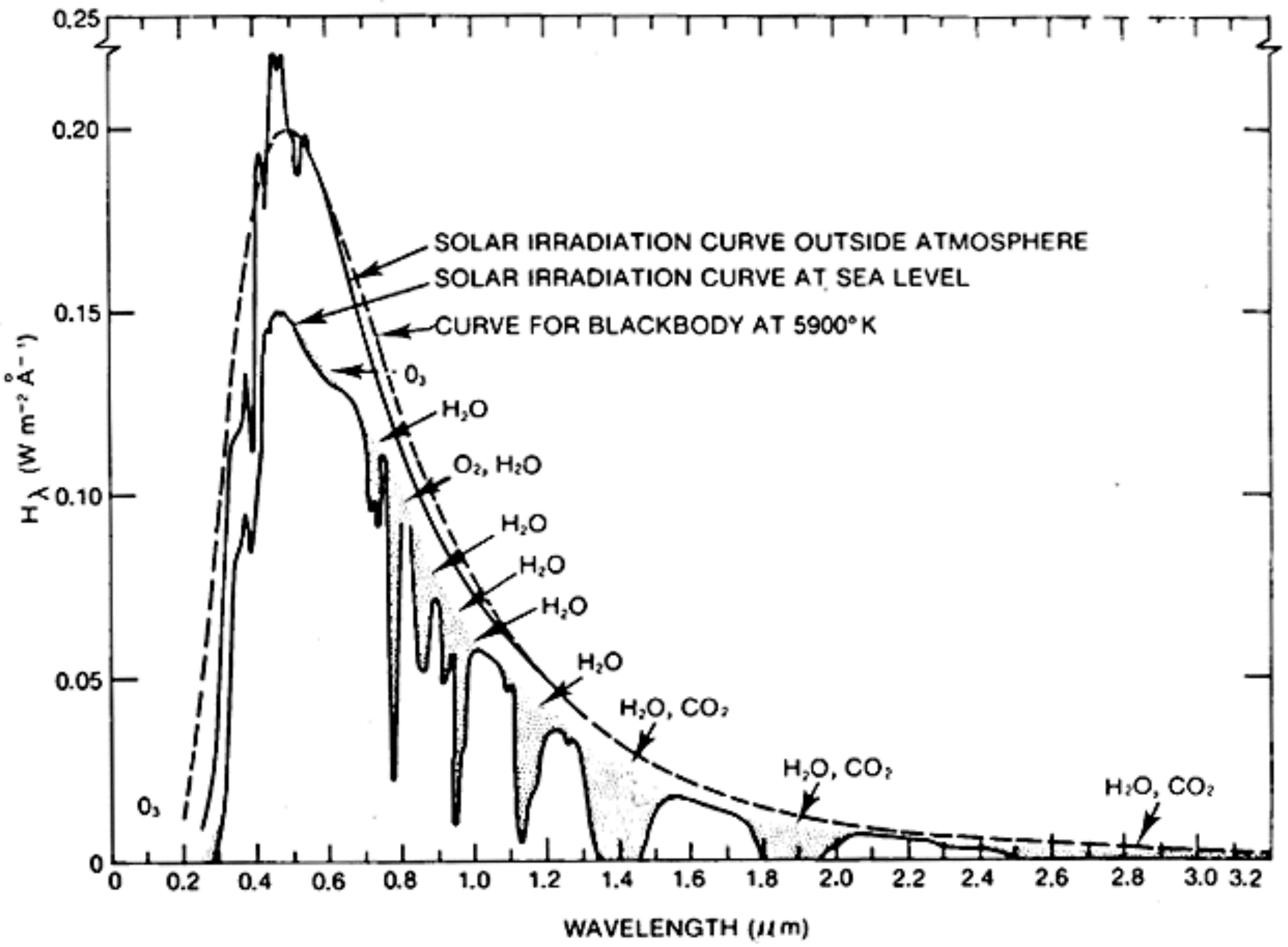


If we could fit a linear model to the main sequences, our task would be completed.

Classification problem
Unsupervised learning



Thanking You,
Aarya Patil



0.25
0.20
0.15
0.10
0.05
0
H_λ (W m^{-2} Å^{-1})
SOLAR IRRADIATION CURVE OUTSIDE ATMOSPHERE
SOLAR IRRADIATION CURVE AT SEA LEVEL
CURVE FOR BLACKBODY AT 5900° K
O_3
H_2O
O_2, H_2O
H_2O
H_2O
H_2O
H_2O
H_2O, CO_2
H_2O, CO_2
H_2O, CO_2
O_3
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2
WAVELENGTH (μm)

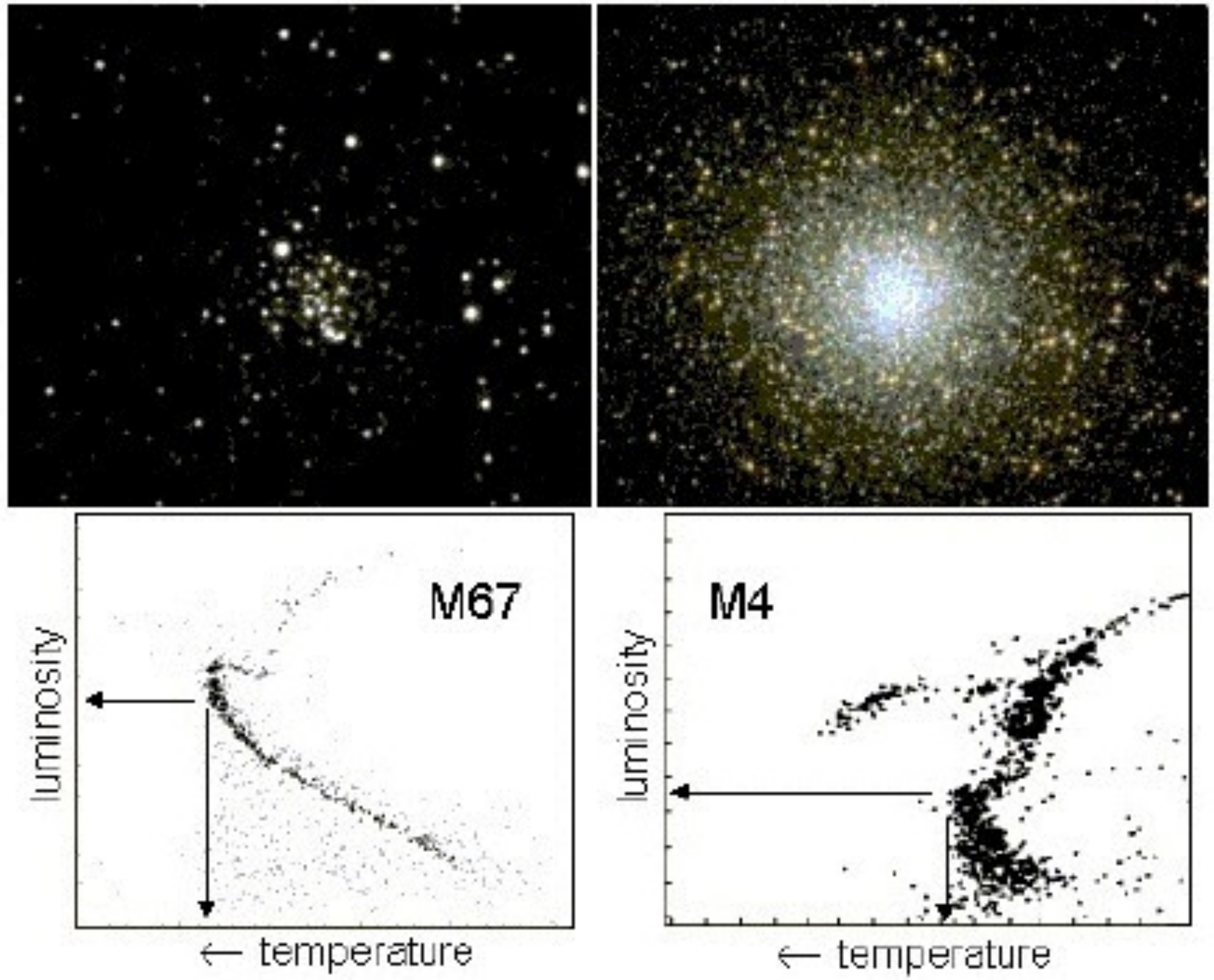
Morphology

Galaxy

Planet

Star

Main Sequence Turn-Off Point



H-R diagrams of two clusters, the **open cluster** M67 (a young cluster), and the **globular cluster** M4 (an old cluster). The **main sequence** is significantly shorter for the older cluster; the **luminosity** and **temperature** of stars at the '**turnoff point**' can be used to date these clusters.

http://astro.berkeley.edu/~dperley/univage/univage.html

Spectral classes

Class	Temperature	Star colour
O	30,000 - 60,000 K	Bluish ("blue")
B	10,000 - 30,000 K	Bluish-white ("blue-white")
A	7,500 - 10,000 K	White with bluish tinge ("white")
F	6,000 - 7,500 K	White ("yellow-white")
G	5,000 - 6,000 K	Light yellow ("yellow")
K	3,500 - 5,000 K	Light orange ("orange")
M	2,000 - 3,500 K	Reddish orange ("red")