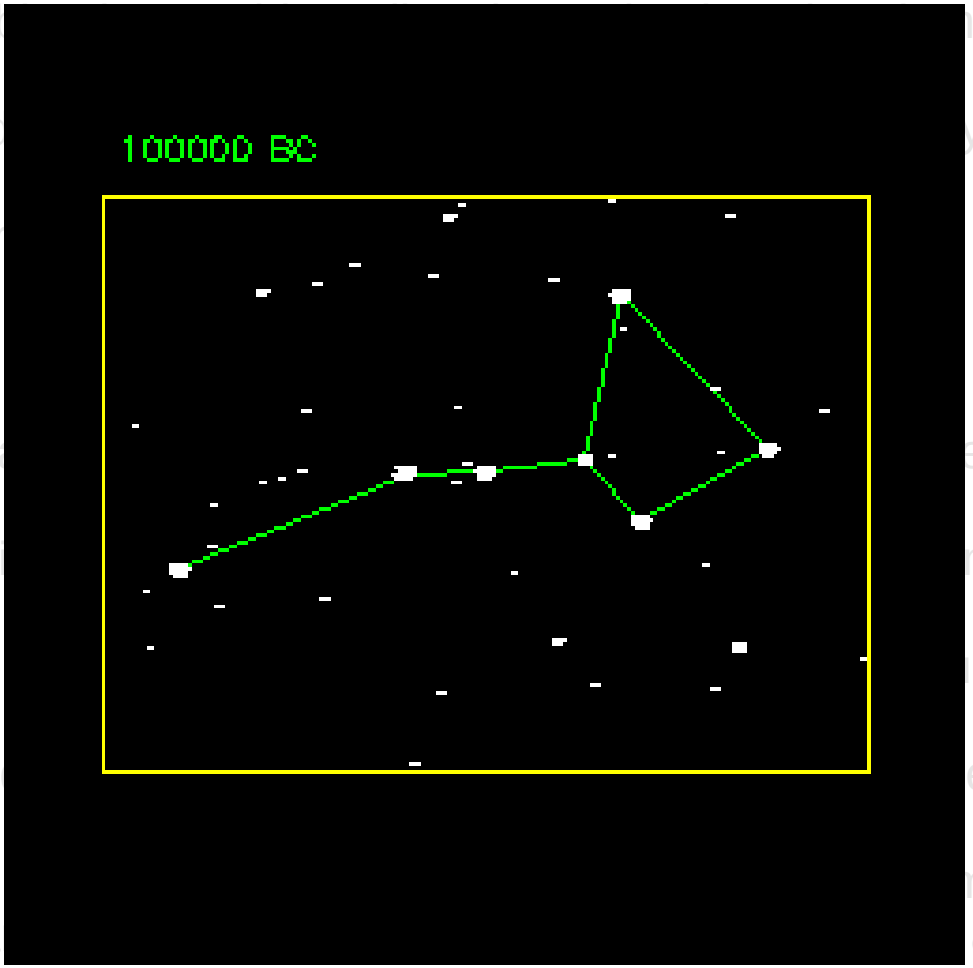
STARS - S04

Wladimir (Wlad) Lyra
Brian Levine

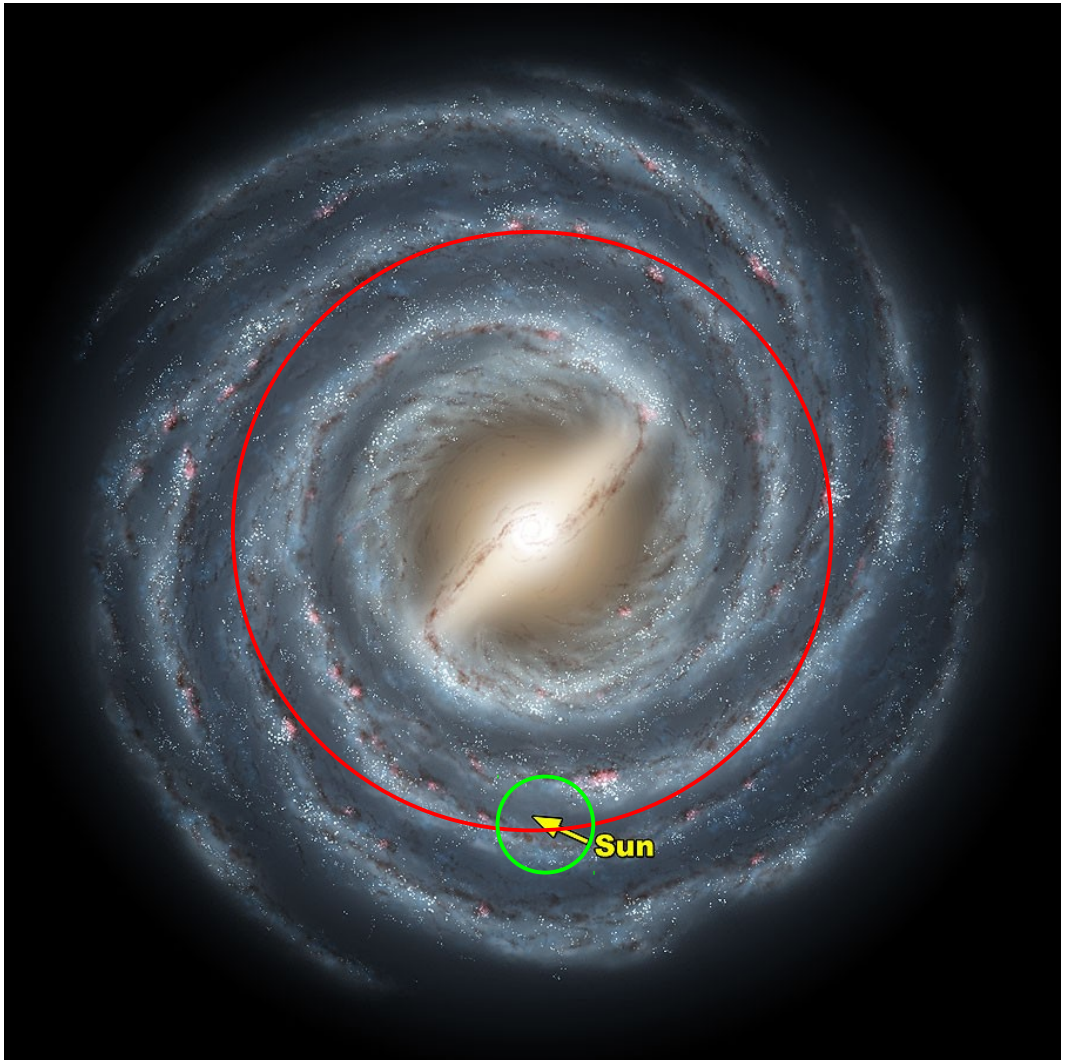
AMNH After-School Program

From last class

Proper motion: movement of stars in the sky. Typical 0.1”/yr. Barnard's star 10”/yr.



The Solar Orbit



Orbital Speed:

220 km/s

Semi-major axis:

8 kpc

1pc ~ 3 x 10^{16} m
1yr ~ 3 x 10^{7} s

The Sun's orbital period
(i.e., the "Galactic Year"?)

~ 250 Myr

From last class

Proper motion: movement of stars in the sky. Typical 0.1”/yr. Barnard's star 10”/yr.

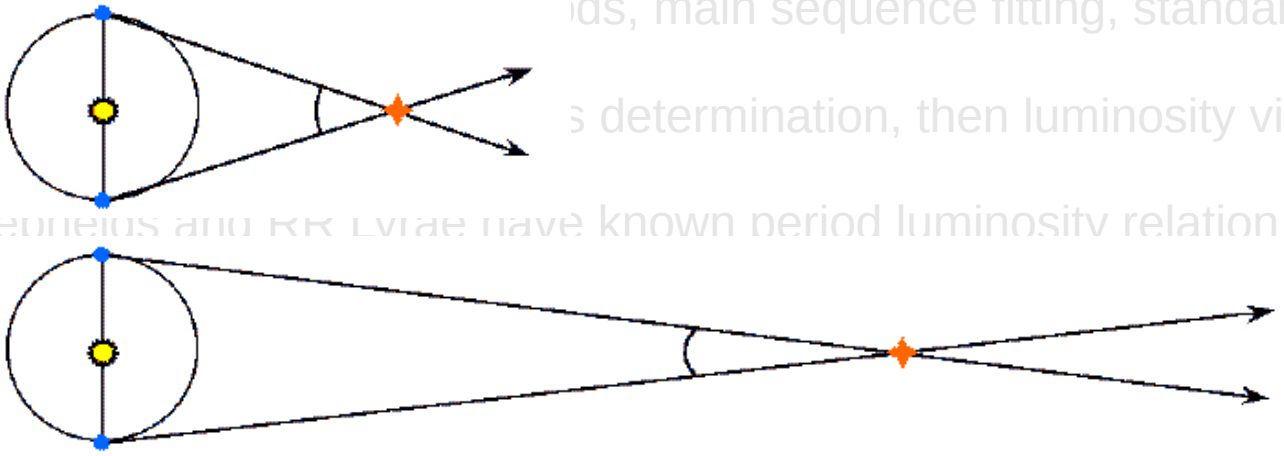
Distance is hard to measure. Parallaxes only work up to 1000 pc.

Beyond that ods, main sequence fitting, standard candles.

Ec s determination, then luminosity via

Cepheids and RR Lyrae have known period luminosity relation

Type Ia Supern gical distances



Stellar spectra are absorption spectra, thus hot source covered by colder gas

Spectral lines are chemical fingerprints, and a mine of information

Five photometric passbands UBVRI. Five magnitudes.

Magnitude difference = color. A measurement of temperature.

Spectroscopy = individual accuracy. Photometry = large number statistics.
Tens of thousands of stars can be automatedly measured in a single frame.

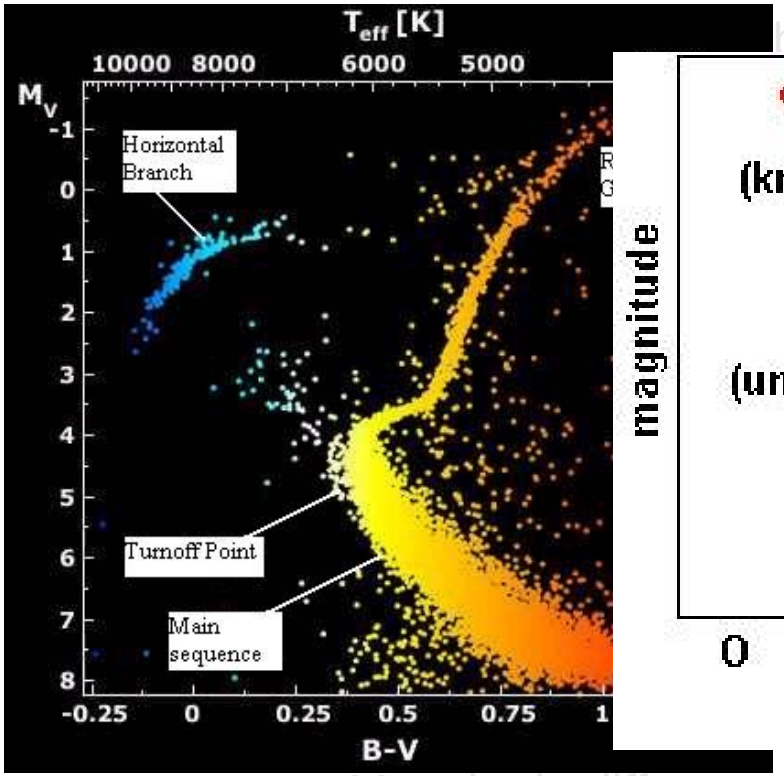
CMD is the photometrically equivalent to the HR diagram.

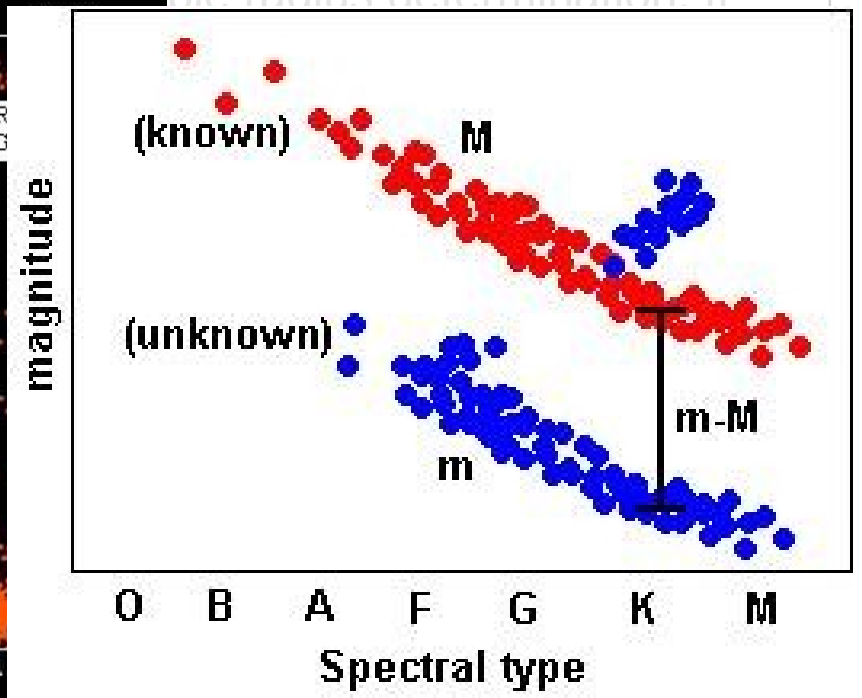
From last class

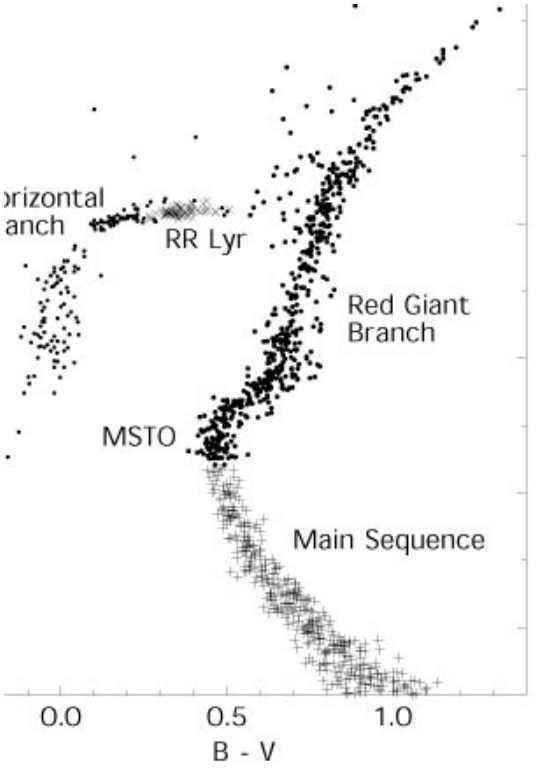
Proper motion: movement of stars in the sky. Typical 0.1”/yr. Barnard's star 10”/yr.

Distance is hard to measure. Parallaxes only work up to 1000 pc.

Beyond that we need to use other methods, main sequence fitting, standard candles.







Calibrated (or from model)

Observed

Magnitude difference = color. A measurement of temperature.

Spectroscopy = individual accuracy. Photometry = large number statistics.
Tens of thousands of stars can be automatedly measured in a single frame.

CMD is the photometrically equivalent to the HR diagram.

From last class

Proper motion: movement of stars in the sky. Typical 0.1”/yr. Barnard's star 10”/yr.

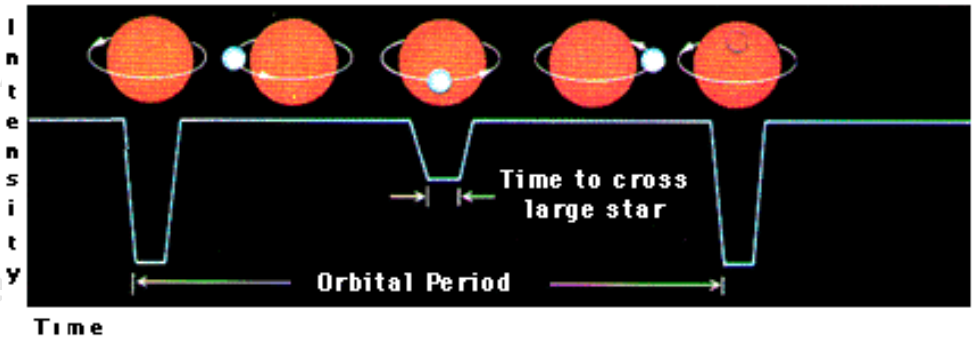
Distance is hard to measure. Parallaxes only work up to 1000 pc.

Beyond that we need to use other methods, main sequence fitting, standard candles.

Eclipsing binaries enable radius determination, thus luminosity via $L=4\pi R^2\sigma T^4$

Cepheids and RR Lyrae have known period luminosity relation

Type Ia Supernovae are v smological distances



Stellar spectra are by colder gas

Spectral lines are chemical fingerprints, and a mine of information

Five photometric passbands UBVRI. Five magnitudes.

Magnitude difference = color. A measurement of temperature.

Spectroscopy = individual accuracy. Photometry = large number statistics.
Tens of thousands of stars can be automatedly measured in a single frame.

CMD is the photometrically equivalent to the HR diagram.

From last class

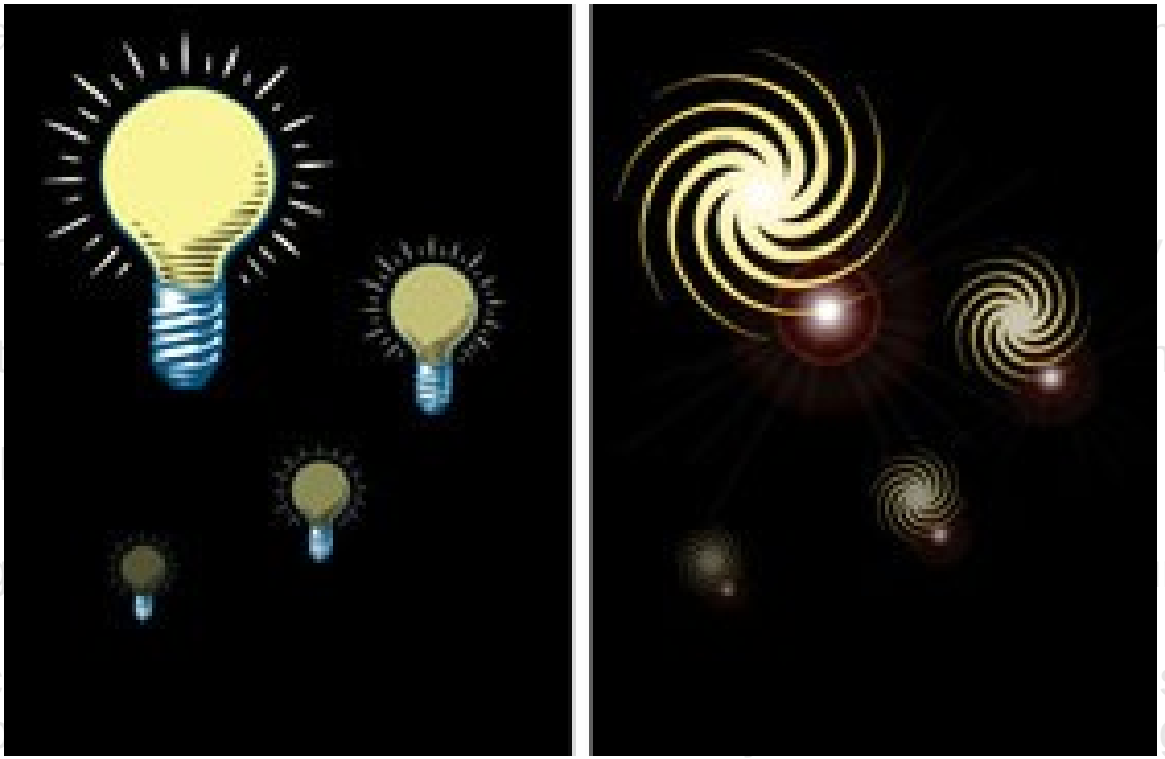
Proper motion: movement of stars in the sky. Typical 0.1”/yr. Barnard's star 10”/yr.

Distance is hard to measure. Parallaxes only work up to 1000 pc.

Beyond that we need to use other methods, main sequence fitting, standard candles.

Eclipsing binaries enable radius determination, then luminosity via

Standard Candles



Type Ia Supernova nological distances

Stellar spec colder gas

Spect nation

Mag re.

Spectrosc statistics.
Tens of tho gle frame.

CMD is the photometrically equivalent to the HR diagram.

From last class

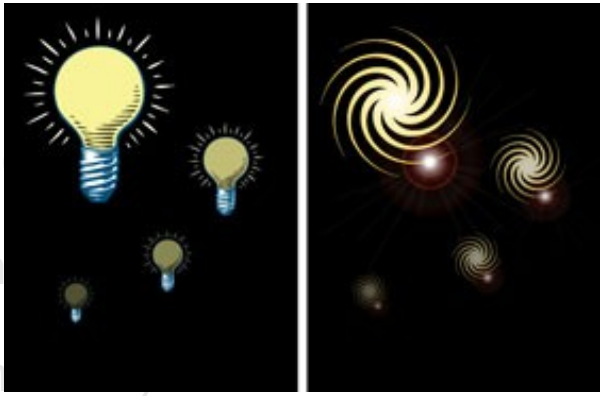
Proper motion: movement of stars in the sky. Typical 0.1”/yr. Barnard's star 10”/yr.

Distance is hard to measure. Parallaxes only wo

Beyond that we need to use other methods, main sequenc

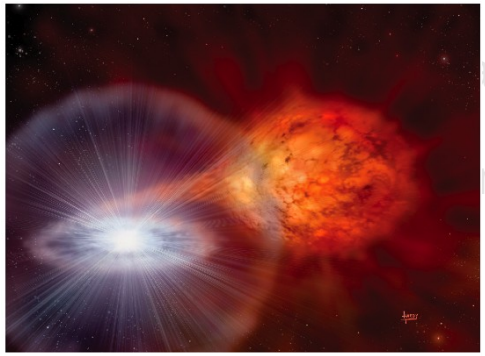
Eclipsing binaries enable radius determination, th

Cepheids and RR Lyrae have known period lu



Type Ia Supernovae are very luminous standard candles, seen over cosmological distances

Kirchhoff's three laws of spect



re absorption spectra, thus hot so

nes are chemical fingerprints, and

photometric passbands UBVRI. F

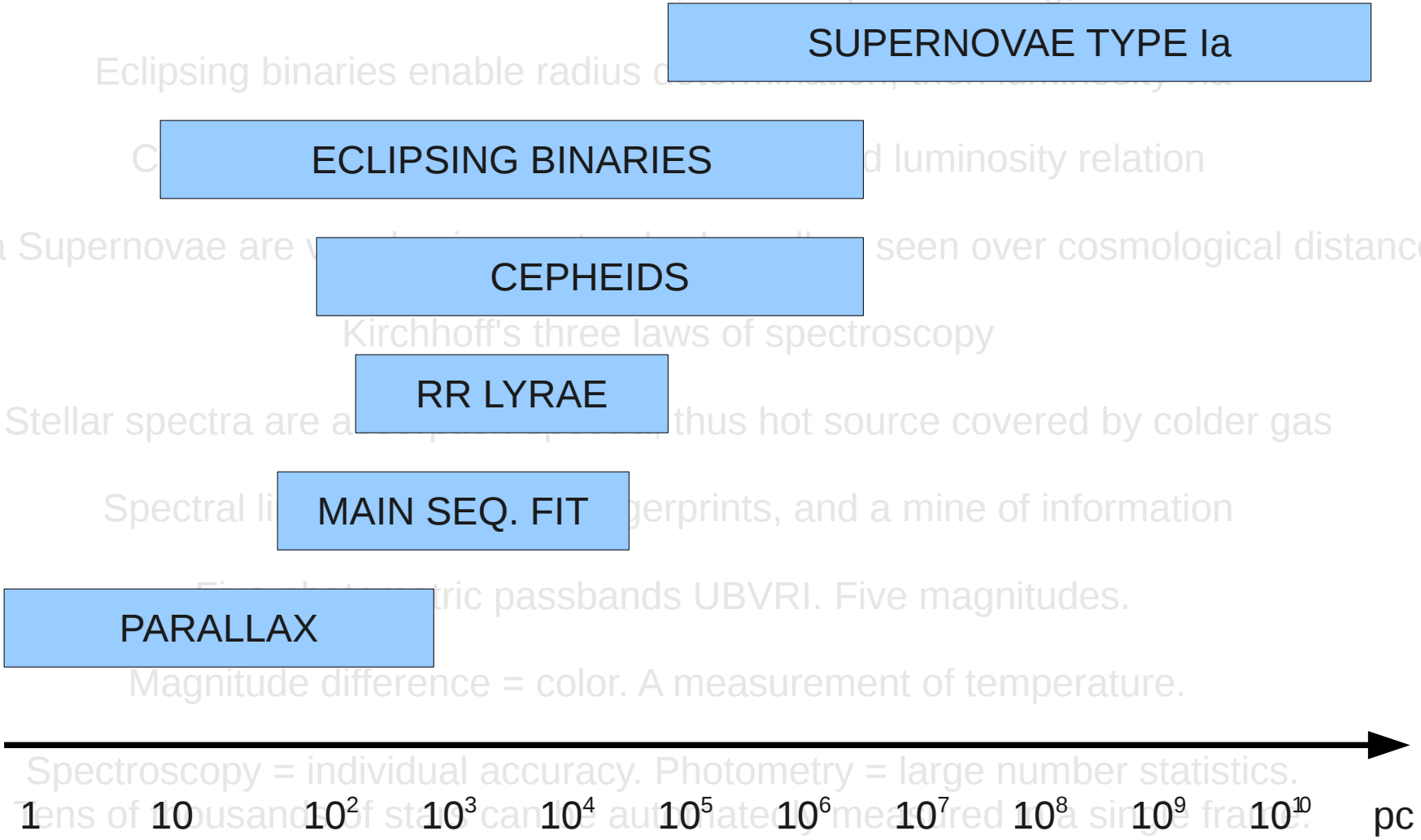
le difference = color. A measureme

Spectroscopy = individual accuracy. Photometry

Tens of thousands of stars can be automatedly m

CMD is the photometrically equivalent to

From last class



Outline

- **Spectroscopy**
  - The three laws of Kirchhoff
  - Hydrogen lines
  - Chemical abundances

- **Photometry**
  - UBVRI system of magnitudes
  - Photometric colors
  - Color-magnitude diagram

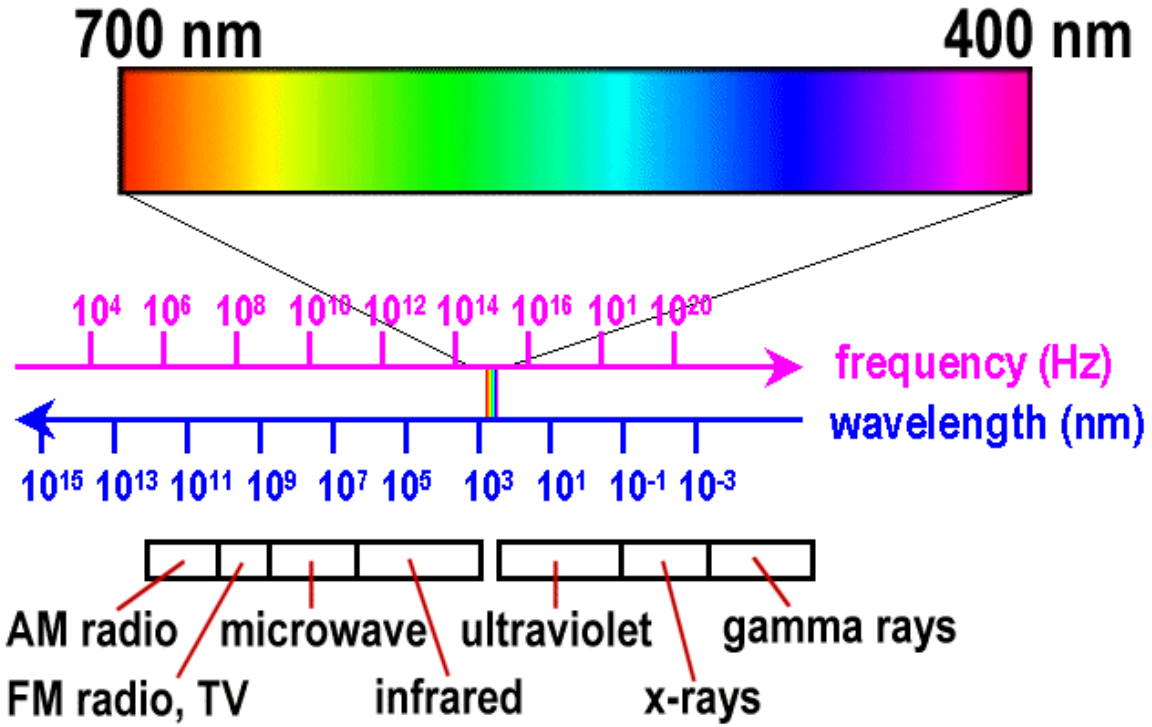
- **Structure of the HR Diagram**

Spectroscopy

Information we get from stars

Direction of the radiation	***Astrometry***
Amount of radiation	***Photometry***
Spectral distribution of the radiation	***Spectroscopy***

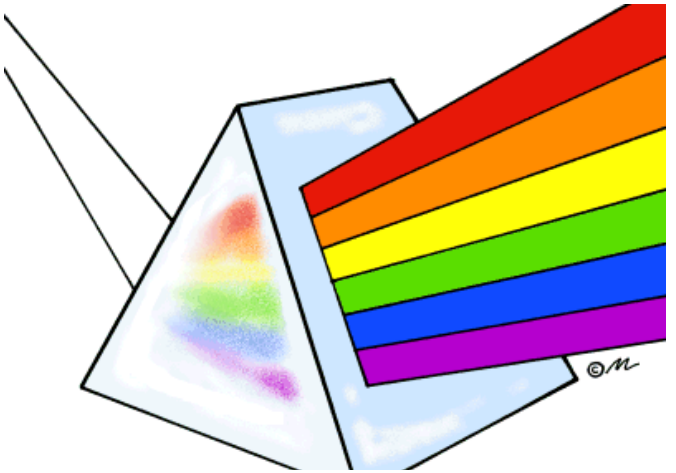
The electromagnetic spectrum

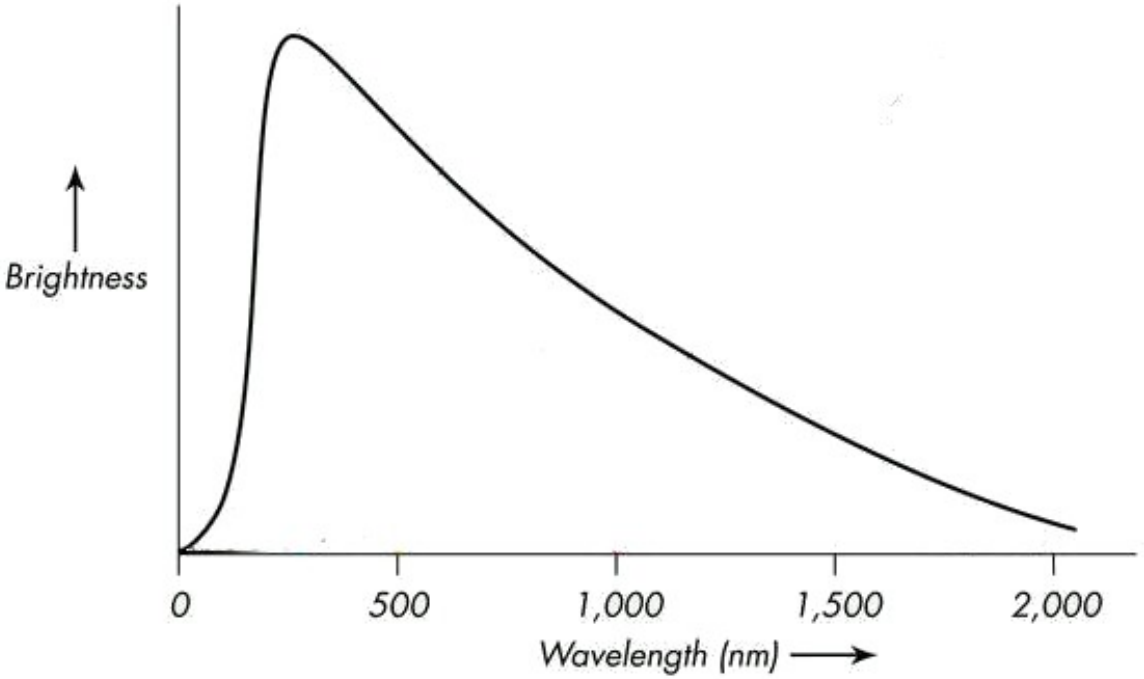


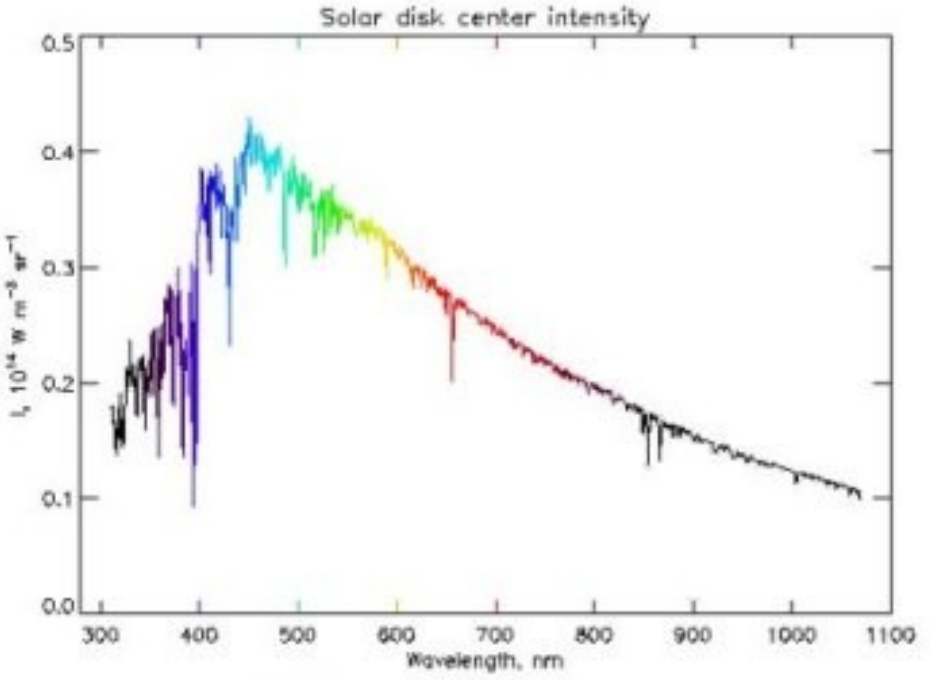
Spectroscopy

Information we get from stars

Direction of the radiation	***Astrometry***
Amount of radiation	***Photometry***
Spectral distribution of the radiation	***Spectroscopy***

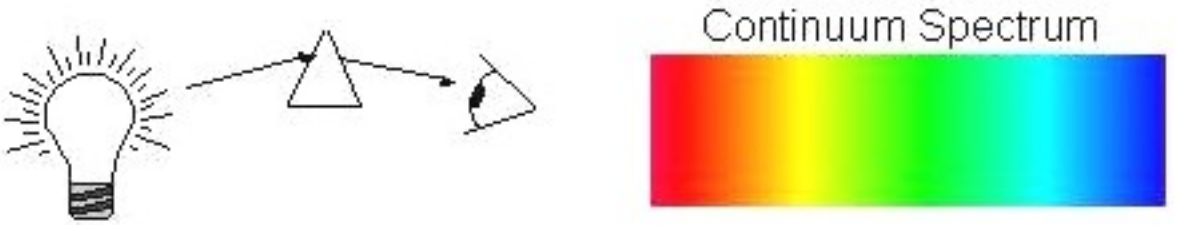






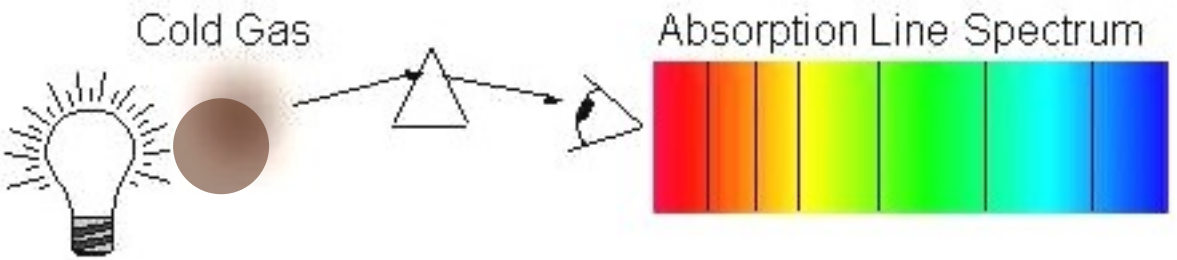
Spectroscopy

Spectral lines – Kirchhoff's three empirical laws of spectroscopy



A hot solid or a hot dense gas produces a continuum spectrum.

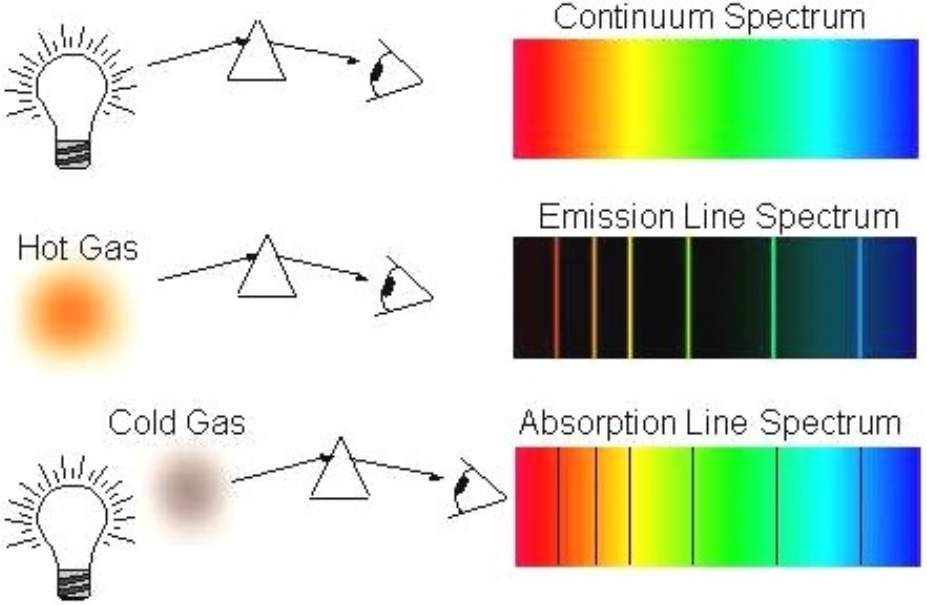
A hot low-density gas produces an emission-line spectrum.

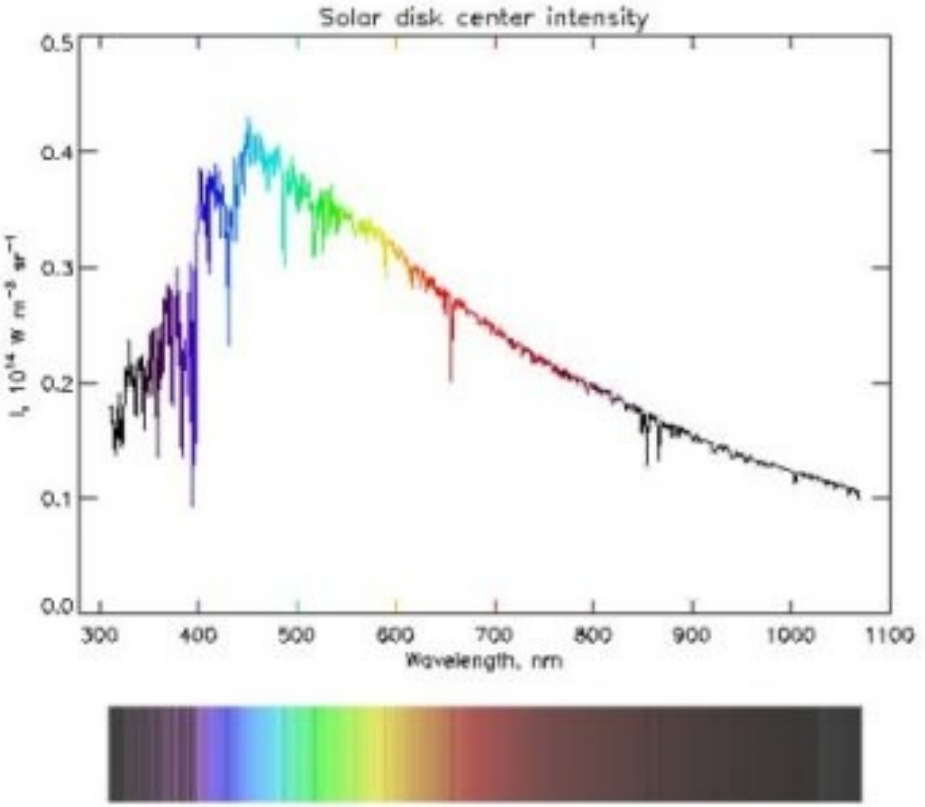


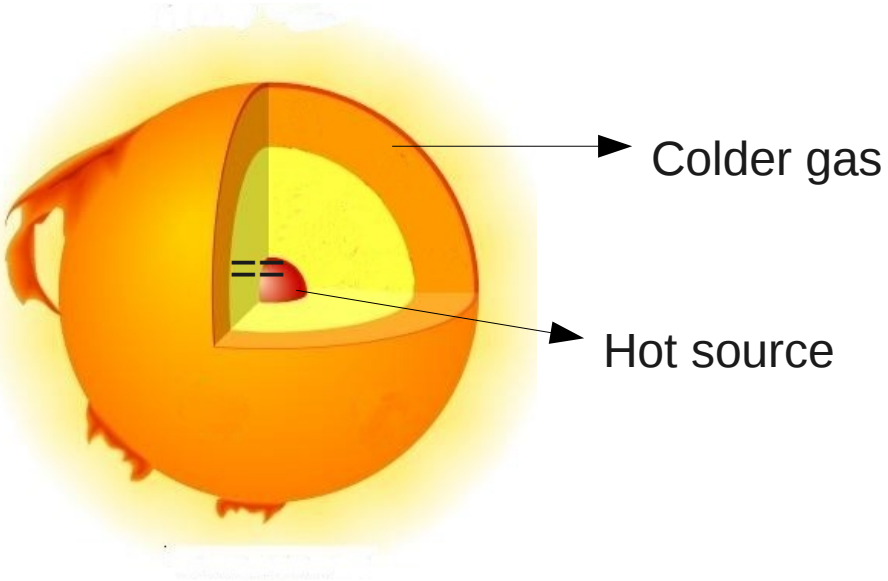
A continuos source viewed through a cold gas produces an absorption-line spectrum.

Spectroscopy

Spectral lines – Kirchhoff's three empirical laws of spectroscopy

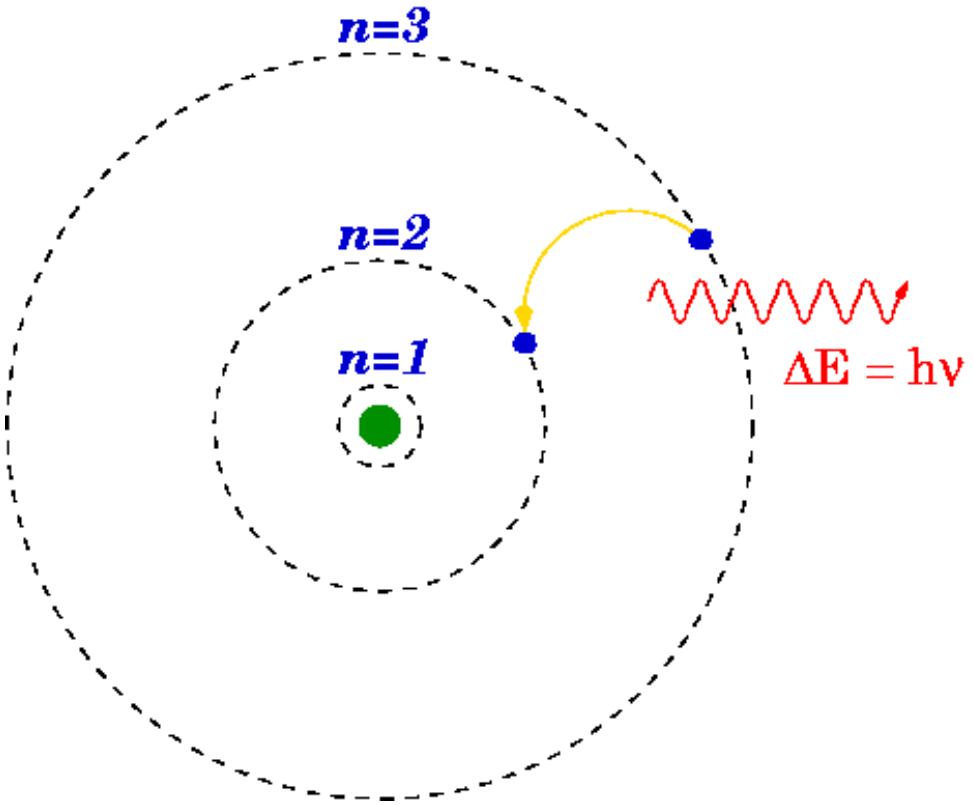


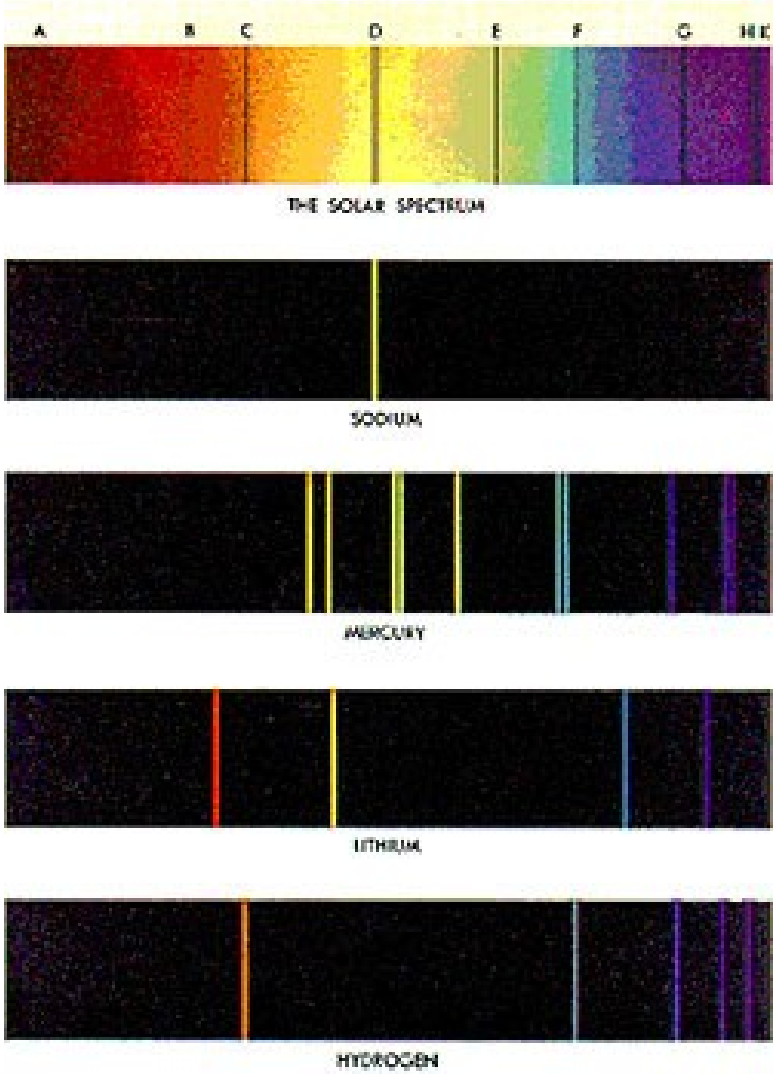




Spectroscopy

Spectral lines are chemical signatures

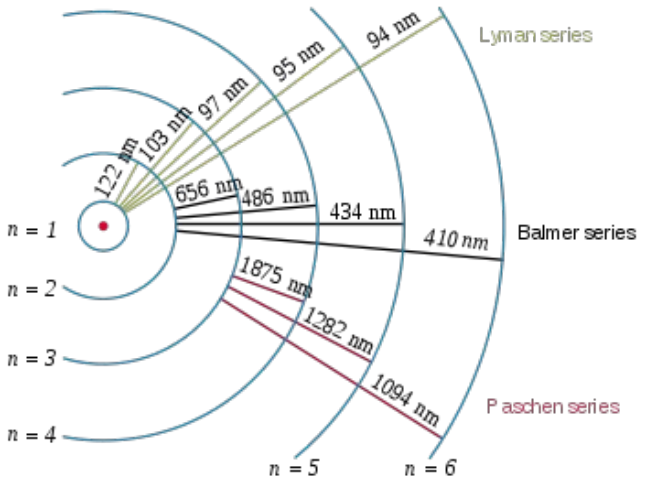


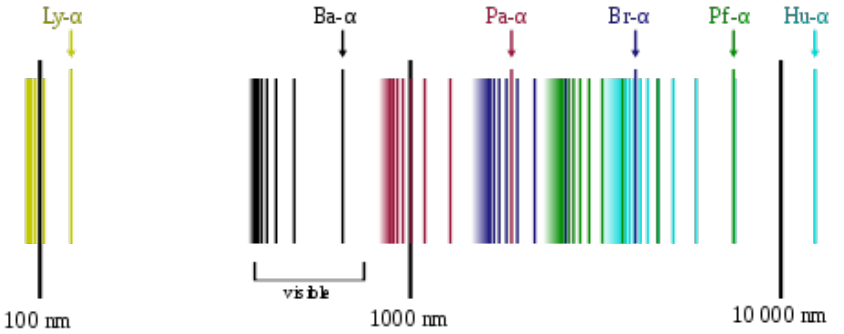


Different elements have different energy levels,
Thus different spectral lines

Spectroscopy

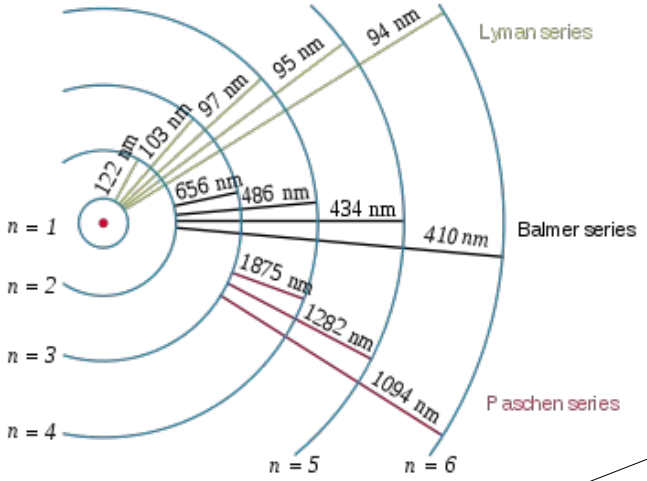
The hydrogen spectrum

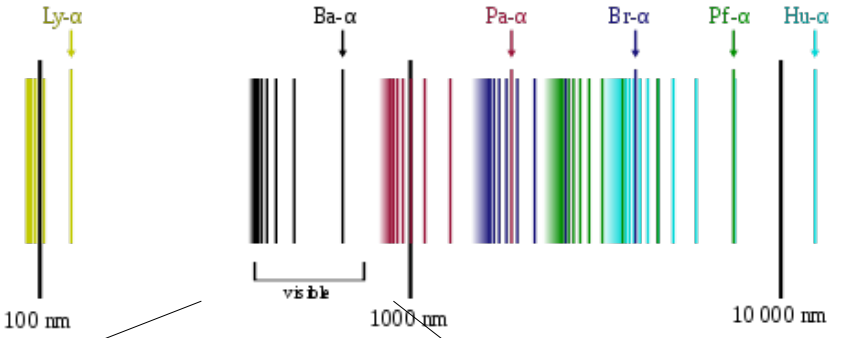




Spectroscopy

The hydrogen spectrum





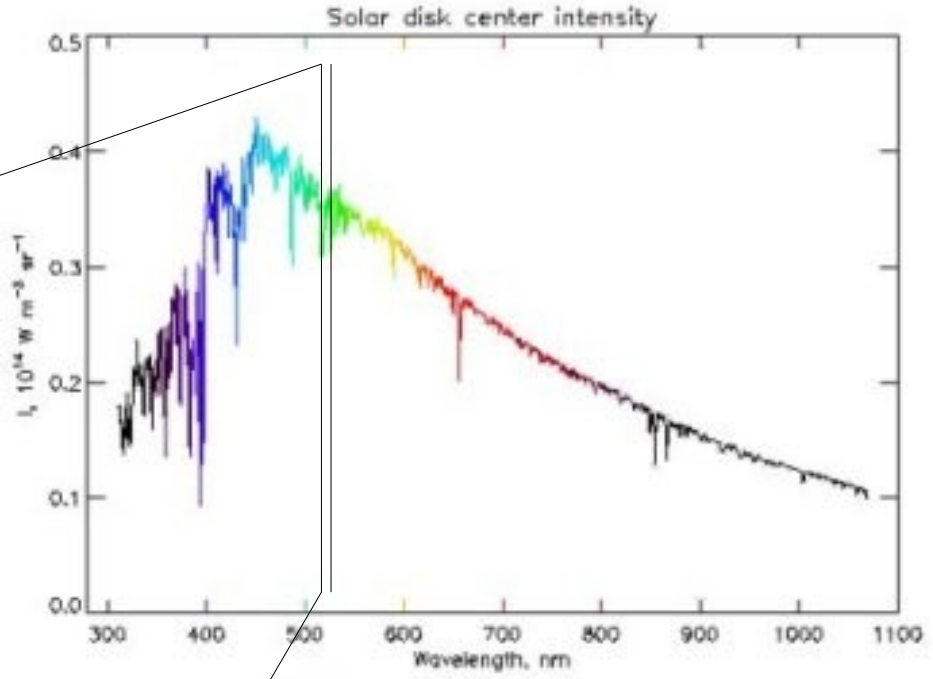
The Balmer series (n=2) is in the visible range

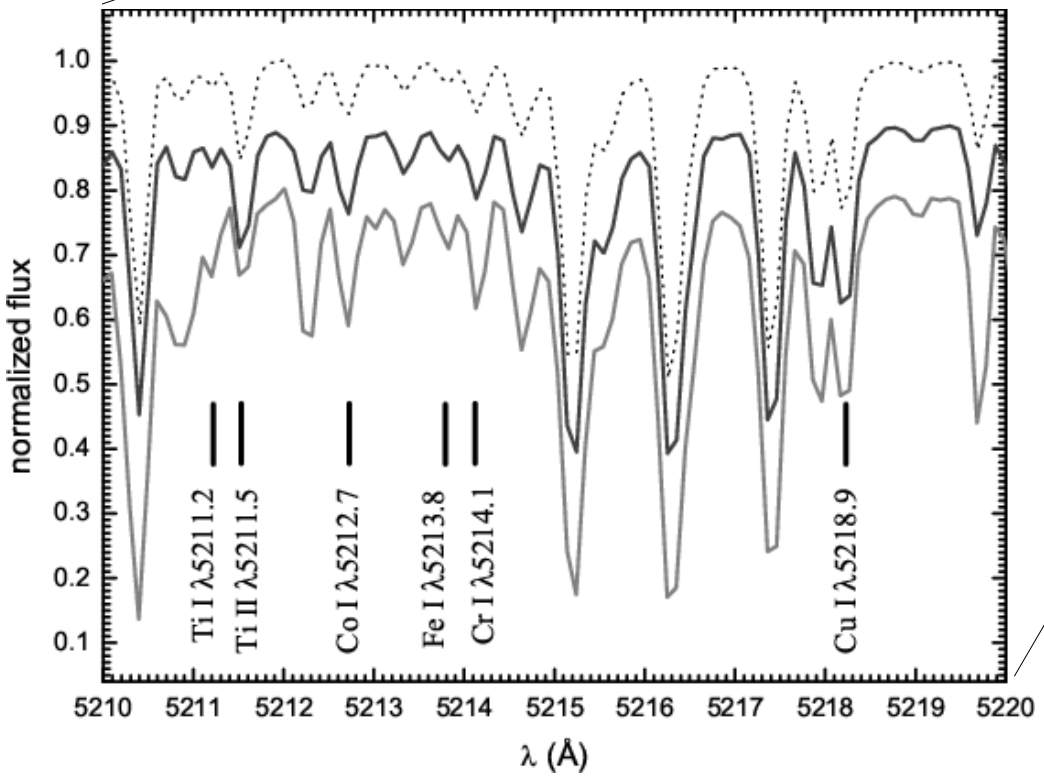
Line	Hε Hδ Hγ	Hβ	Hα
Wavelength	434nm	486nm	656nm

Spectroscopy

Spectroscopy is very accurate

We can measure line positions to an accuracy of *mili-Ångströms (mÅ)*.

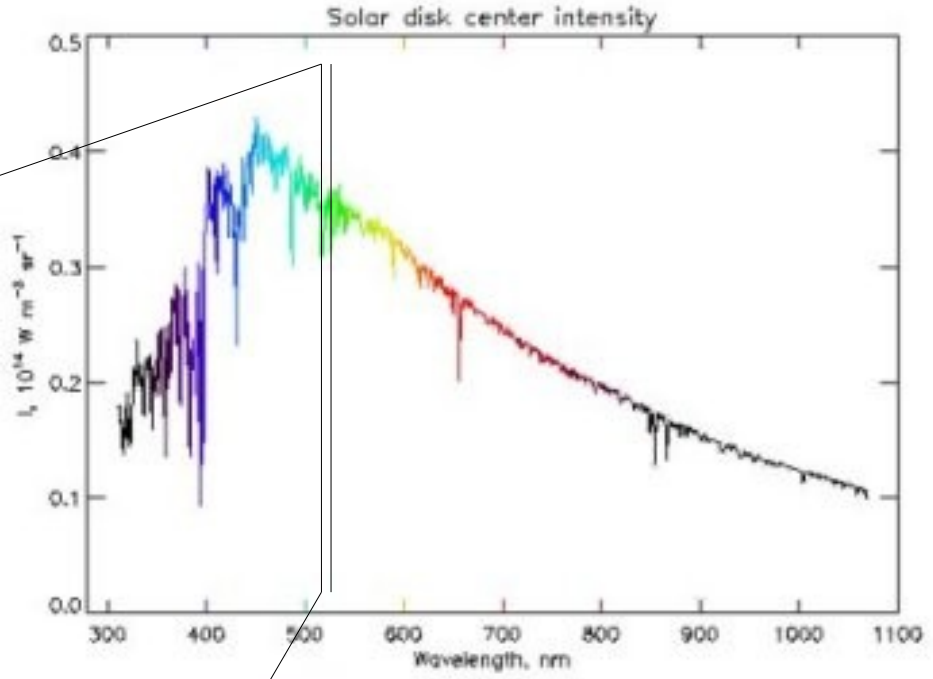


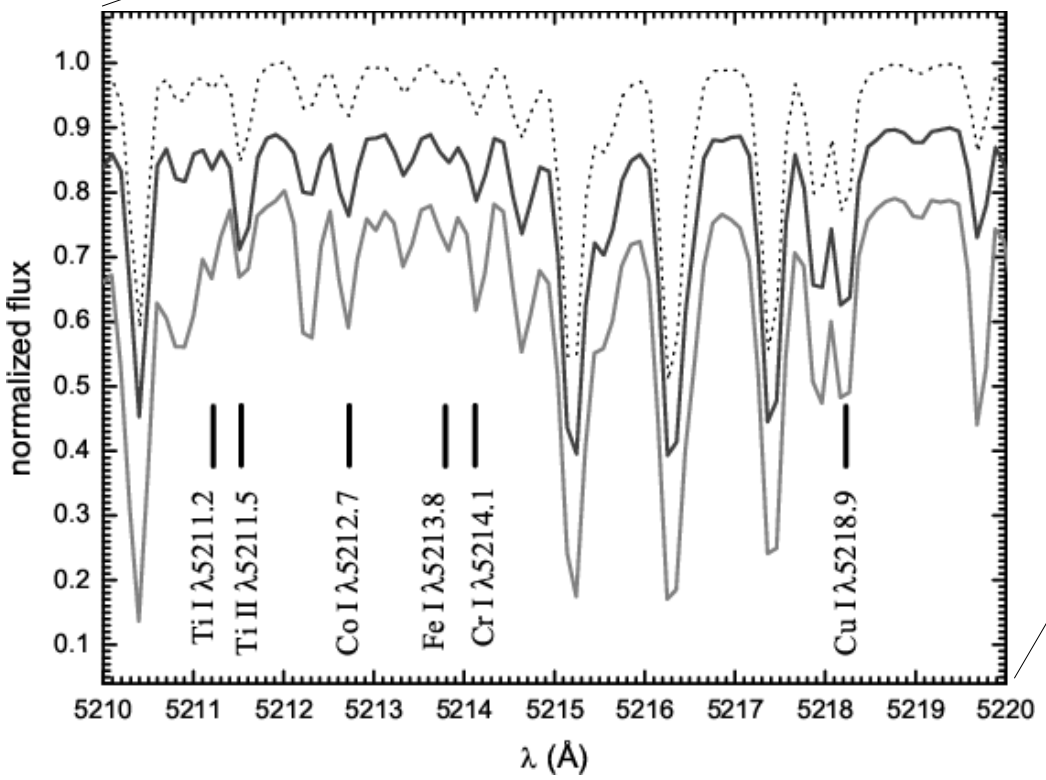


Spectroscopy

Spectroscopy is very accurate

We can measure line positions to an accuracy of *mili-Ångströms (mÅ)*.



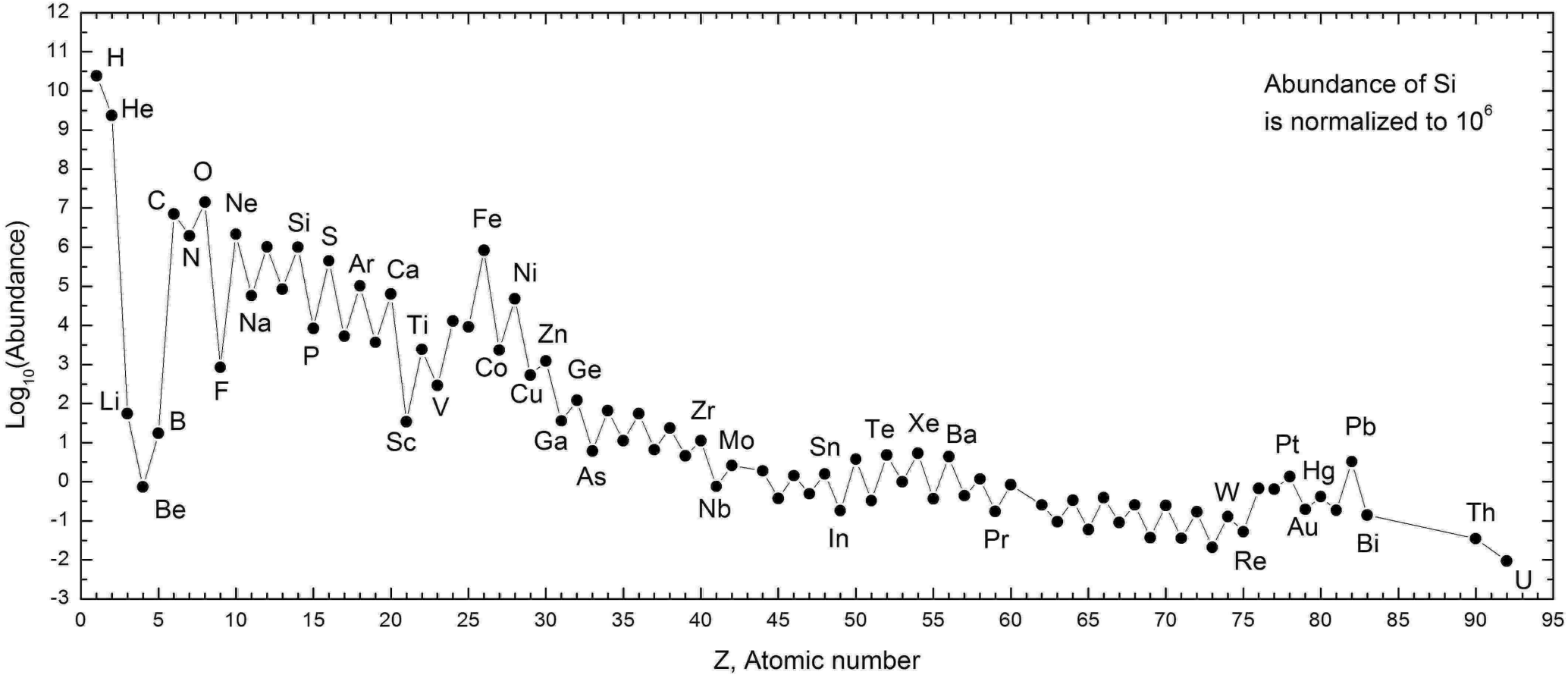


Ångström

1Å = 10^{-10} m
= 10^{-1} nm

Spectroscopy

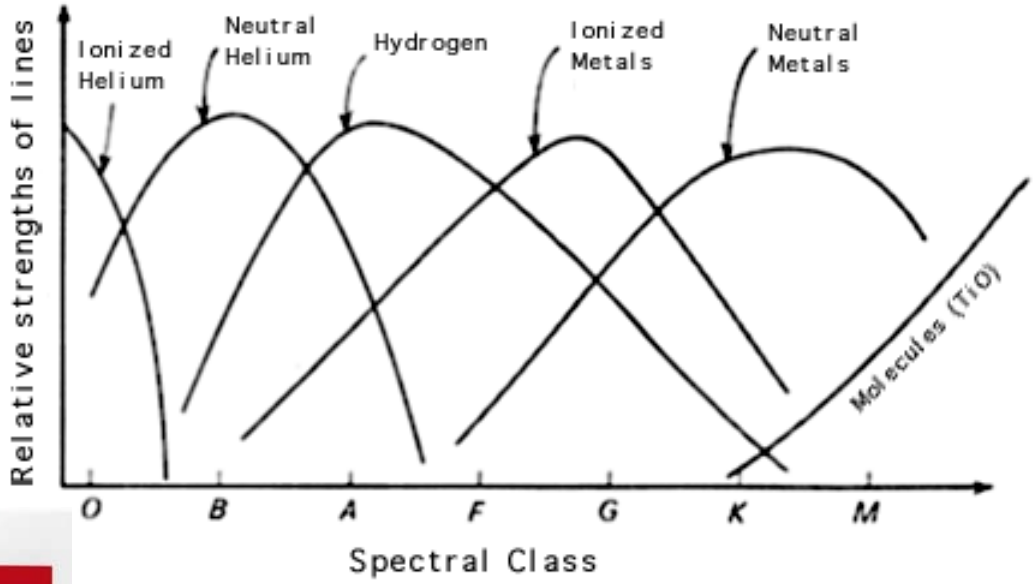
The chemical composition of the Sun

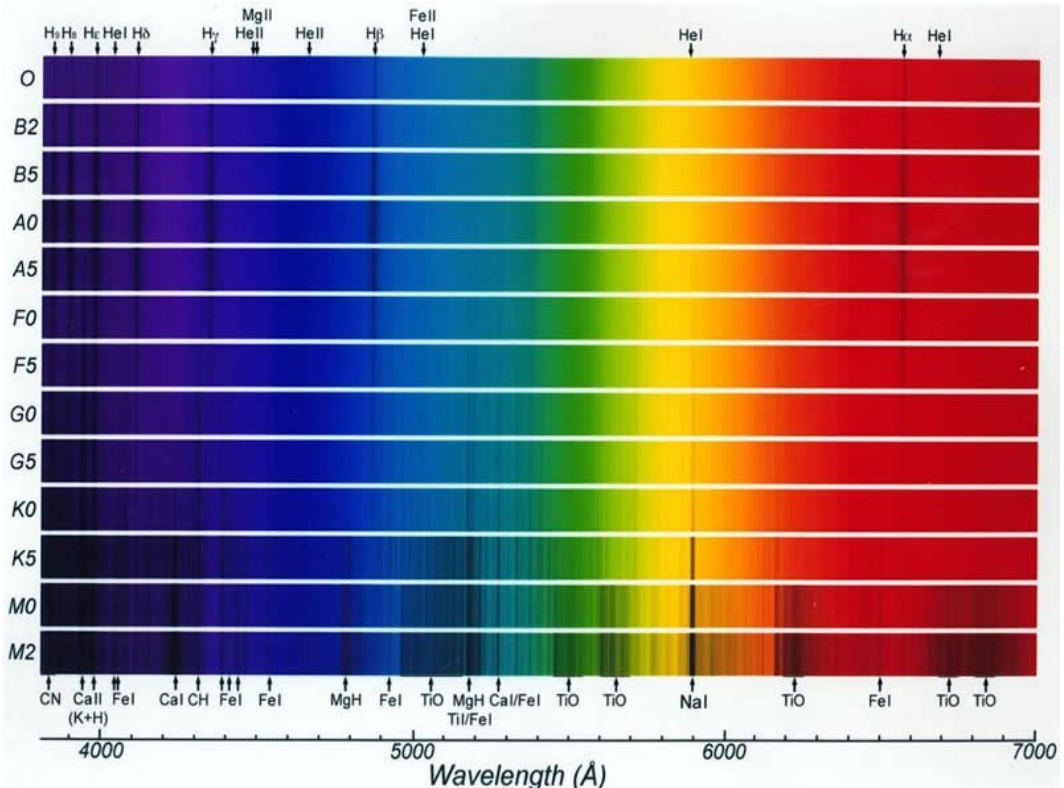


Spectroscopy

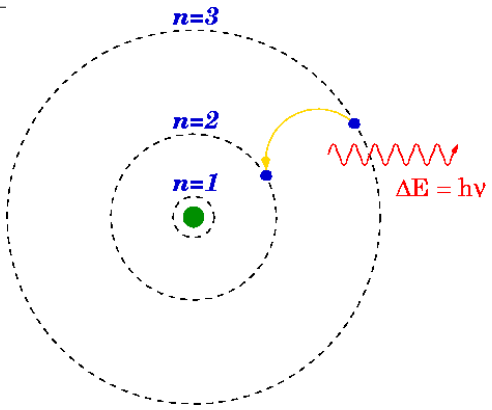
The strength of spectral lines enables a measurement of the stellar temperature

Excitation-ionization sequence



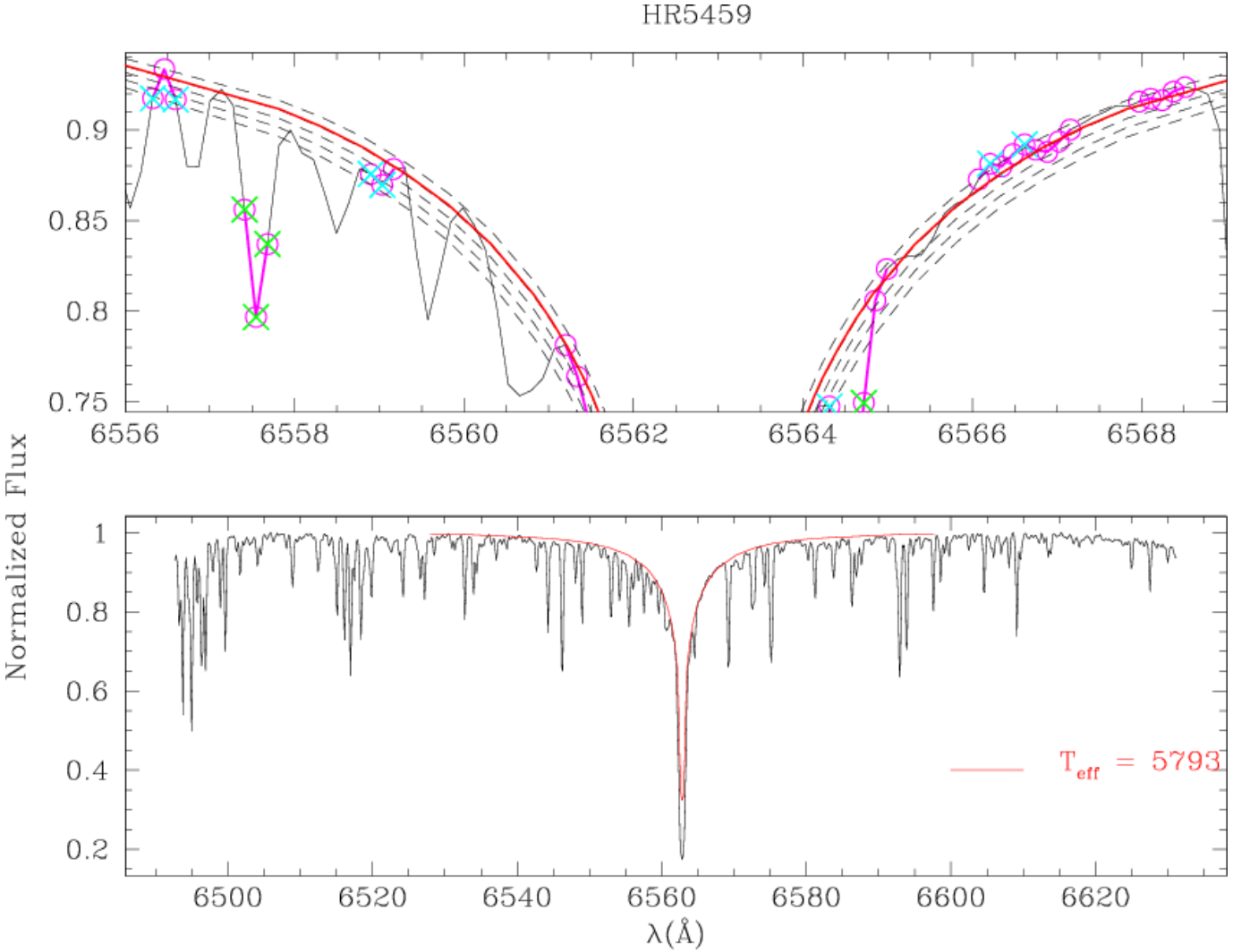


Resulting lines



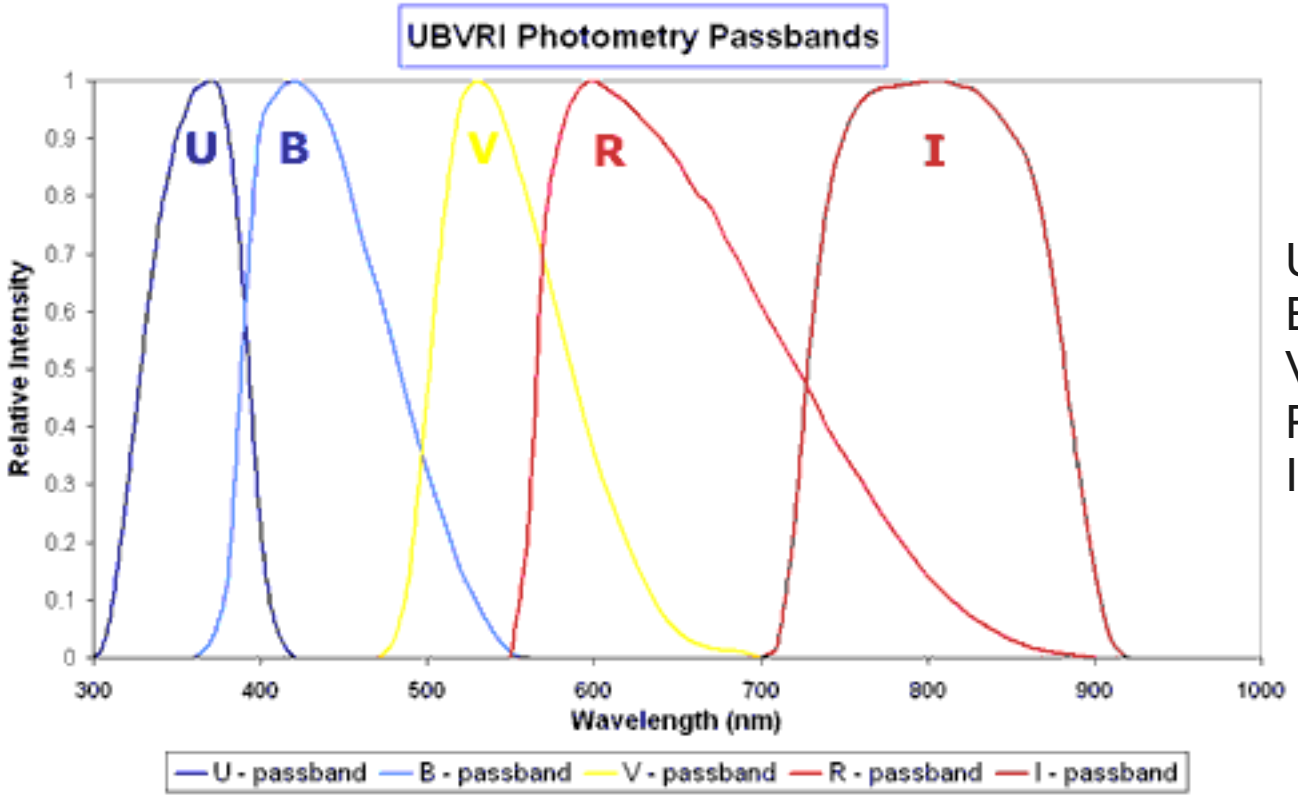
Spectroscopy

Measuring temperatures by the wings of Hα



Photometry

The UBVRI system – 5 little quantities that carry a lot of information



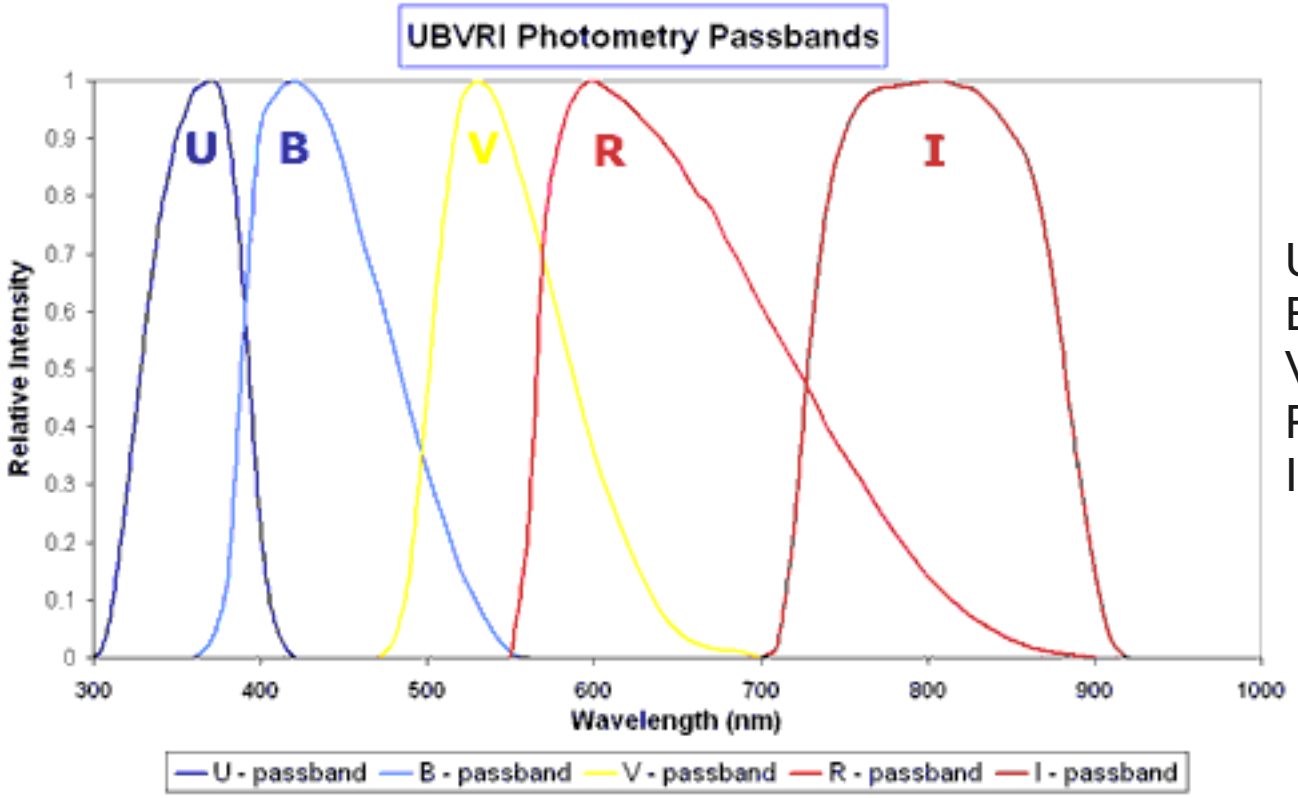
Ultraviolet
Blue
Visible
Red
Infrared

These are magnitudes!

$M_U \; M_B \; M_v \; M_R \; M_I$

Photometry

The UBVRI system – 5 little quantities that carry a lot of information



Ultraviolet
Blue
Visible
Red
Infrared

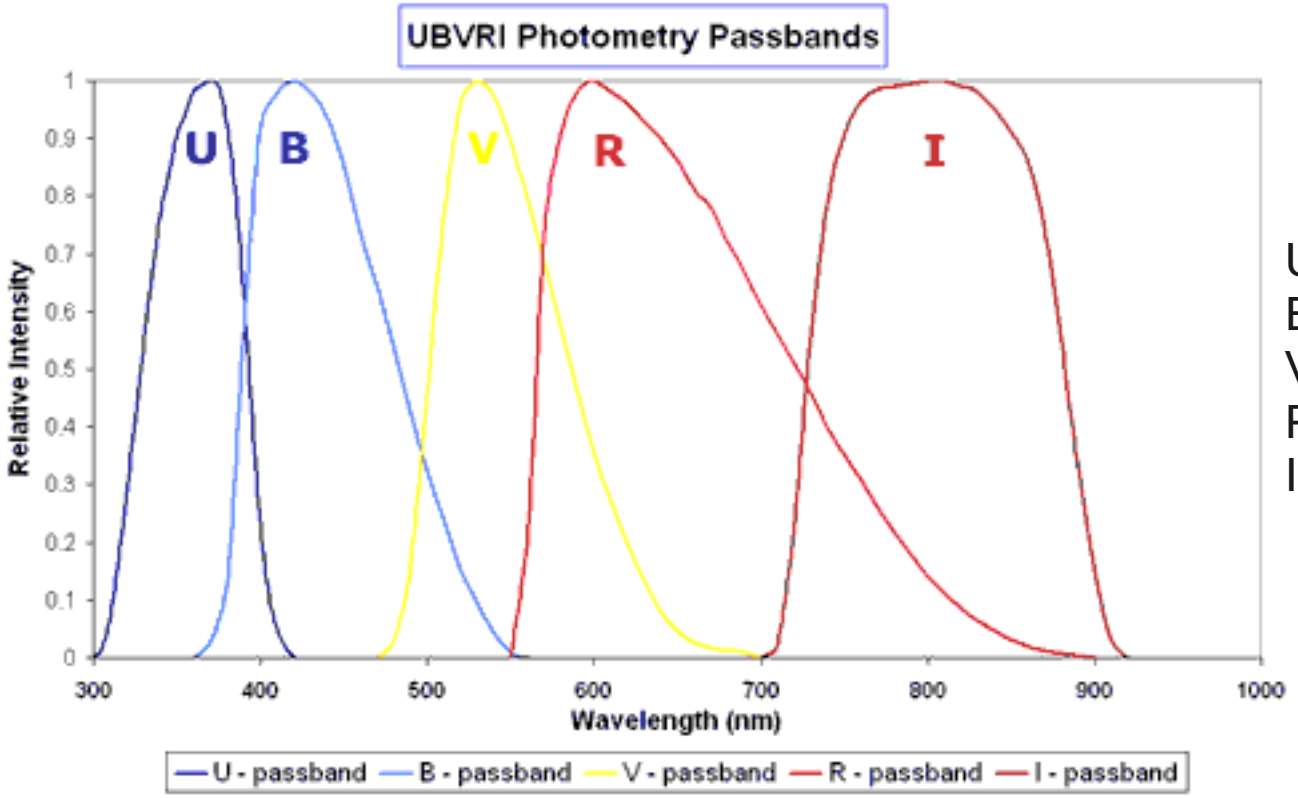
These are magnitudes!

$M_U \; M_B \; M_v \; M_R \; M_I$

When you ask an astronomer for a magnitude, you have to specify the waveband.

Photometry

The UBVRI system – 5 little quantities that carry a lot of information



Ultraviolet
Blue
Visible
Red
Infrared

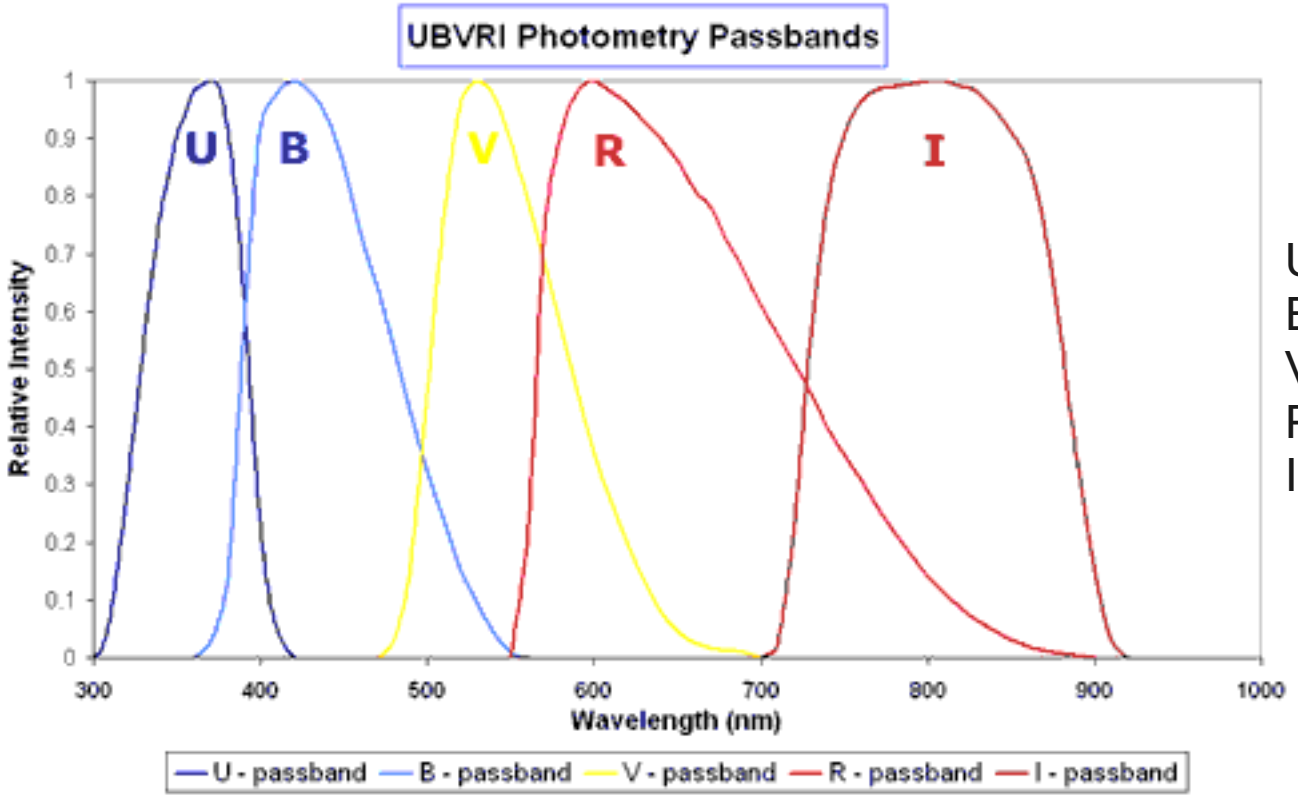
These are magnitudes!

M_U M_B M_v M_R M_I

Bolometric Magnitude (M_{bol})

Photometry

The UBVRI system – 5 little quantities that carry a lot of information



Ultraviolet
Blue
Visible
Red
Infrared

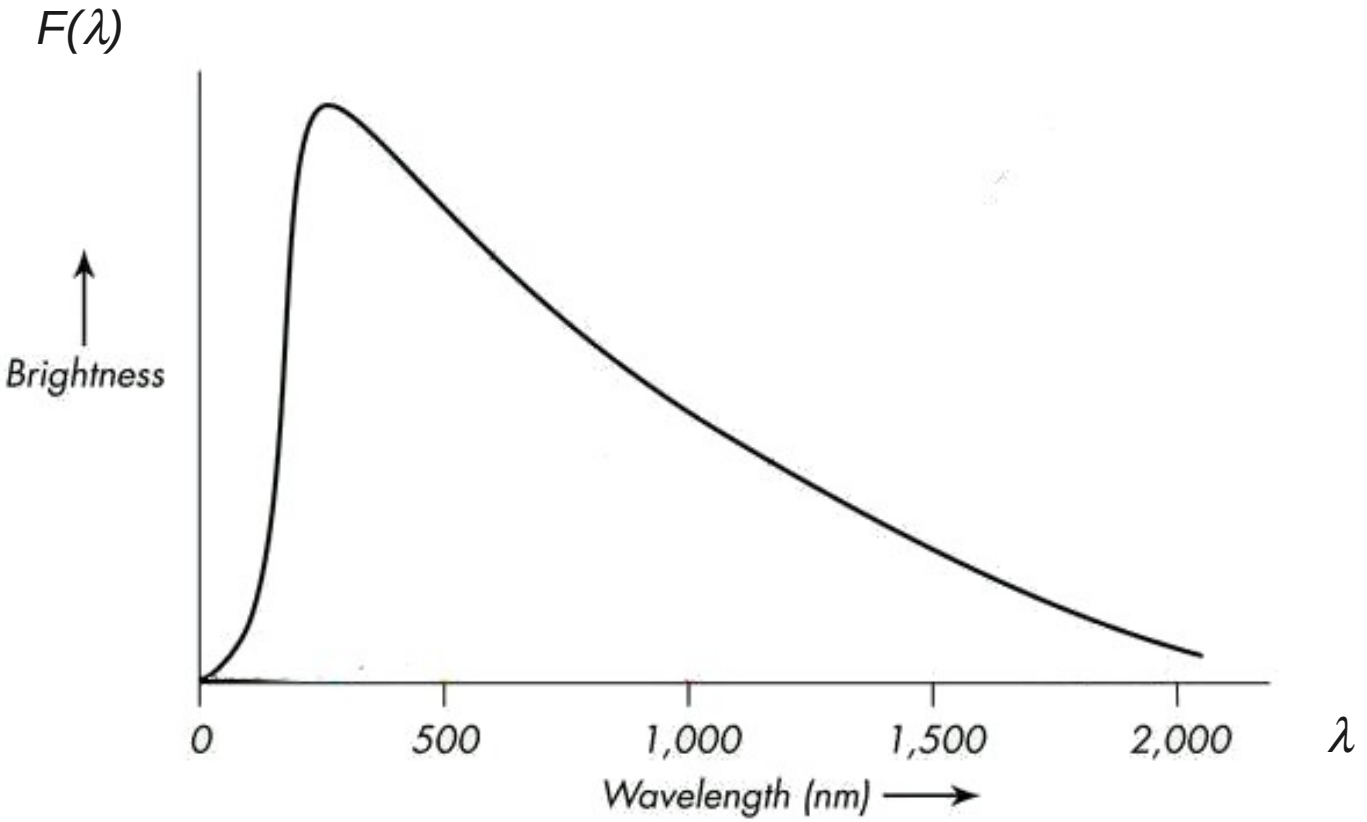
These are magnitudes!

M_U M_B M_v M_R M_I

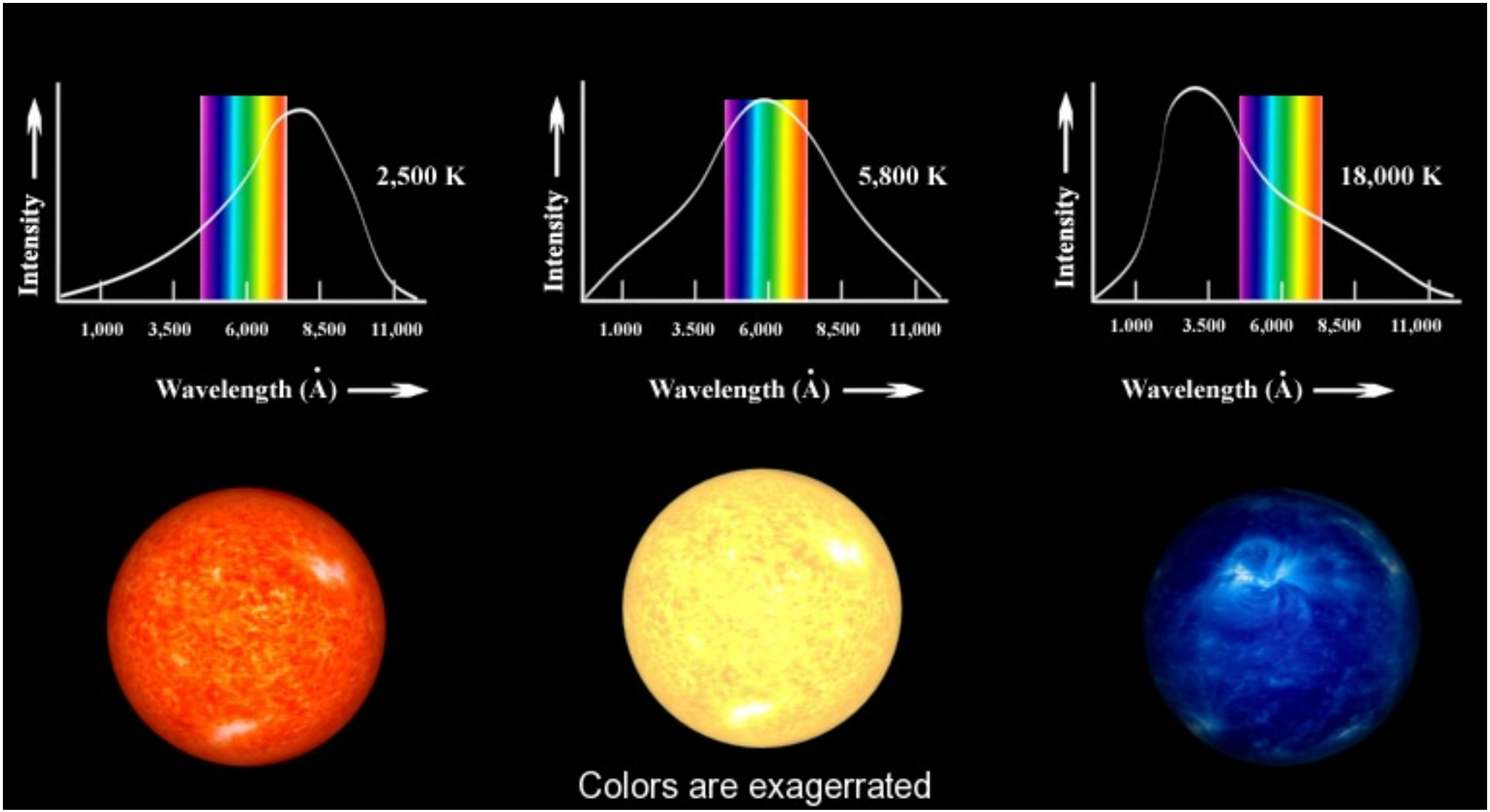
Bolometric Magnitude (M_{bol}) = In all wavelengths

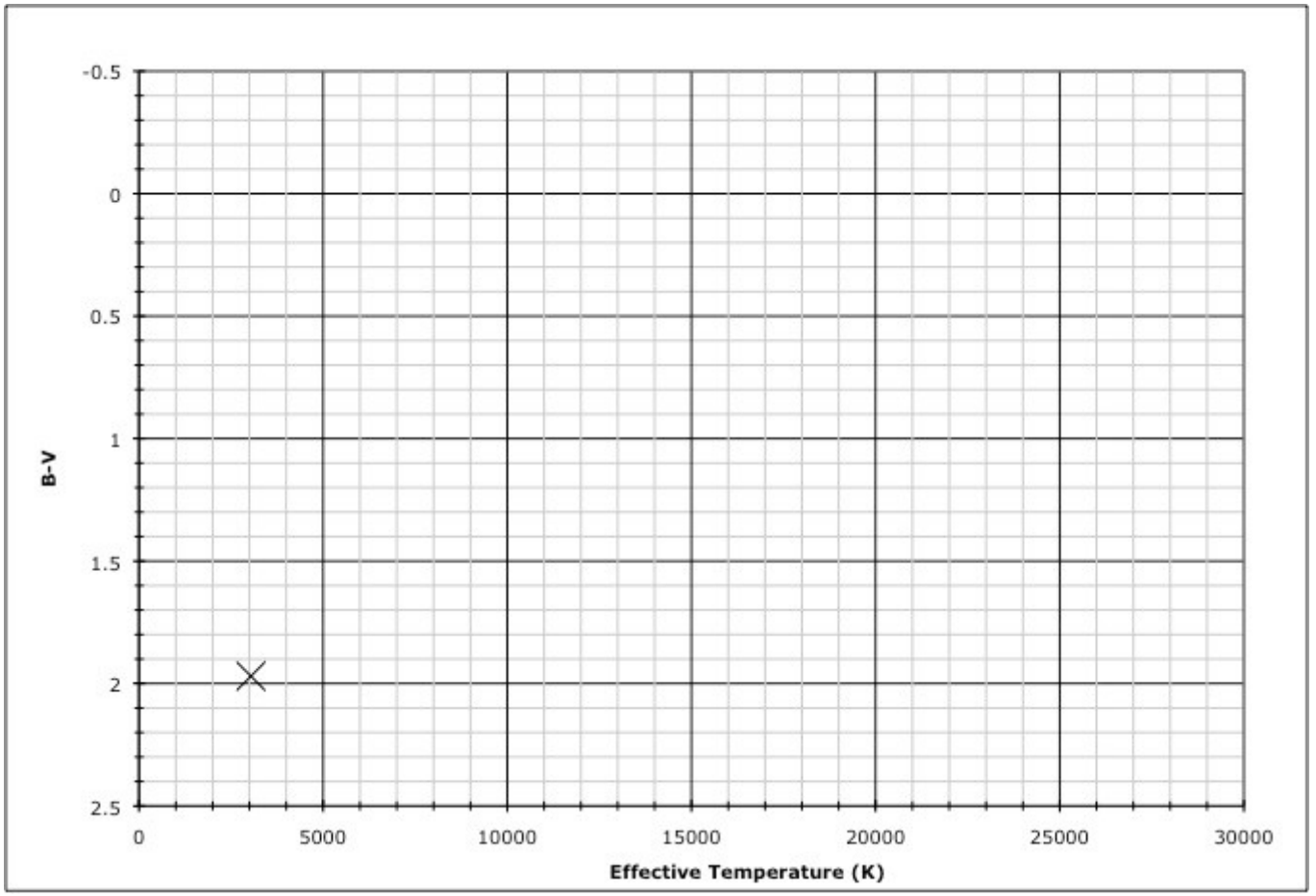
*(*integrated over the whole electromagnetic spectrum, from radio to gamma rays*)*

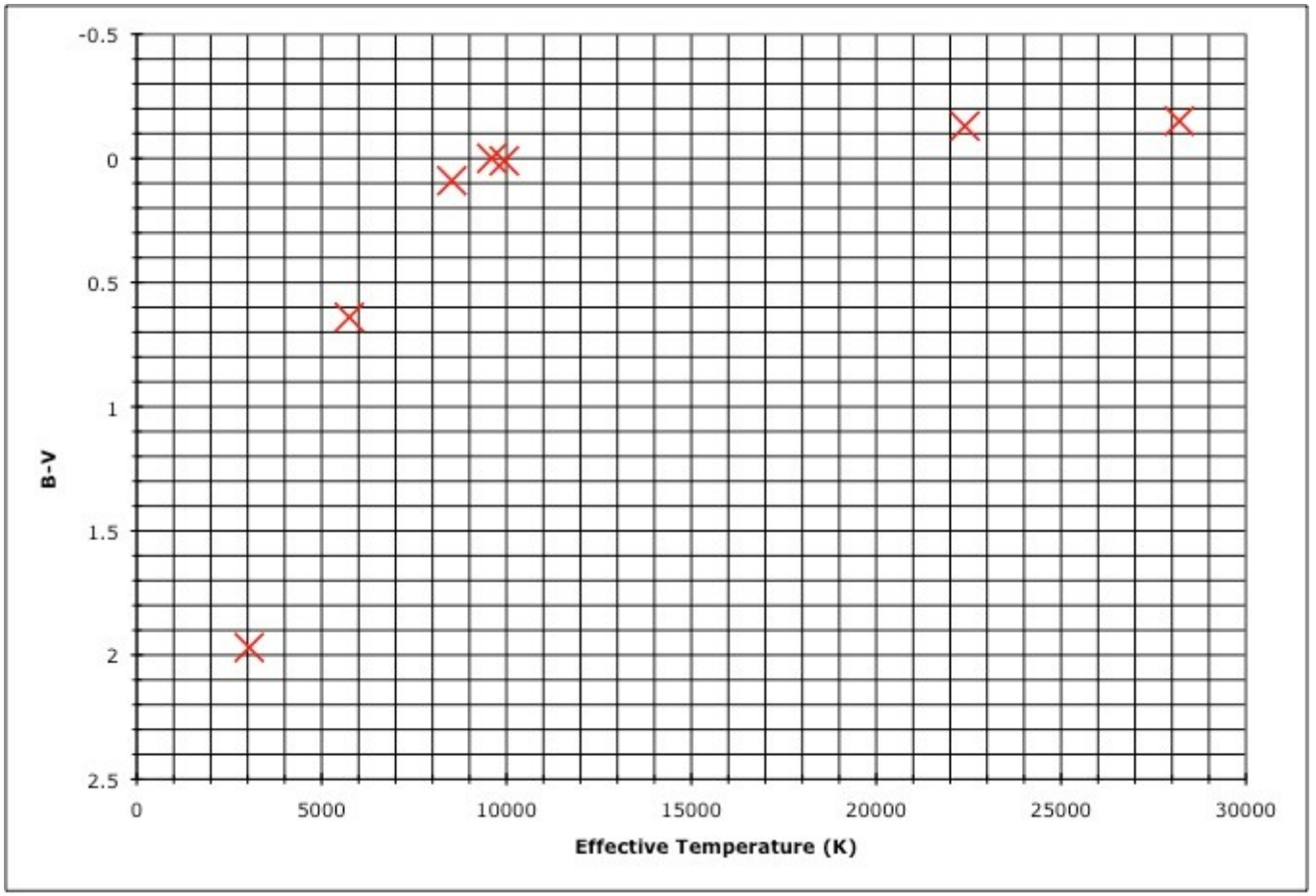
The Black Body radiation curve again



Color as a measurement of temperature

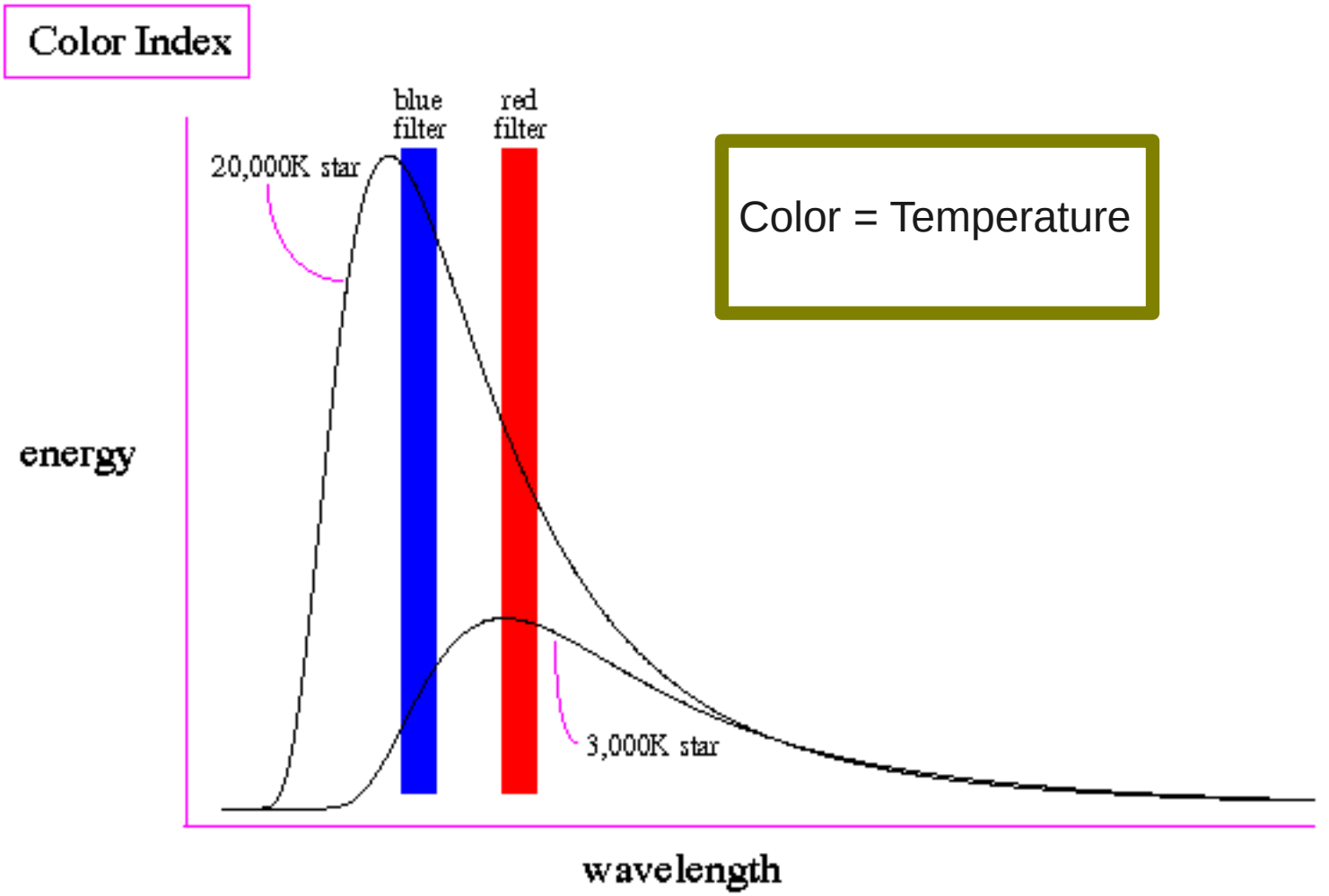



-0.5
0
0.5
1
1.5
2
2.5
B-V
0
5000
10000
15000
20000
25000
30000
Effective Temperature (K)


-0.5
0
0.5
1
1.5
2
2.5
B-V
0
5000
10000
15000
20000
25000
30000
Effective Temperature (K)

Photometry

Color: Magnitude difference between filters. Eg. *B-V, U-B, V-I, B-R*

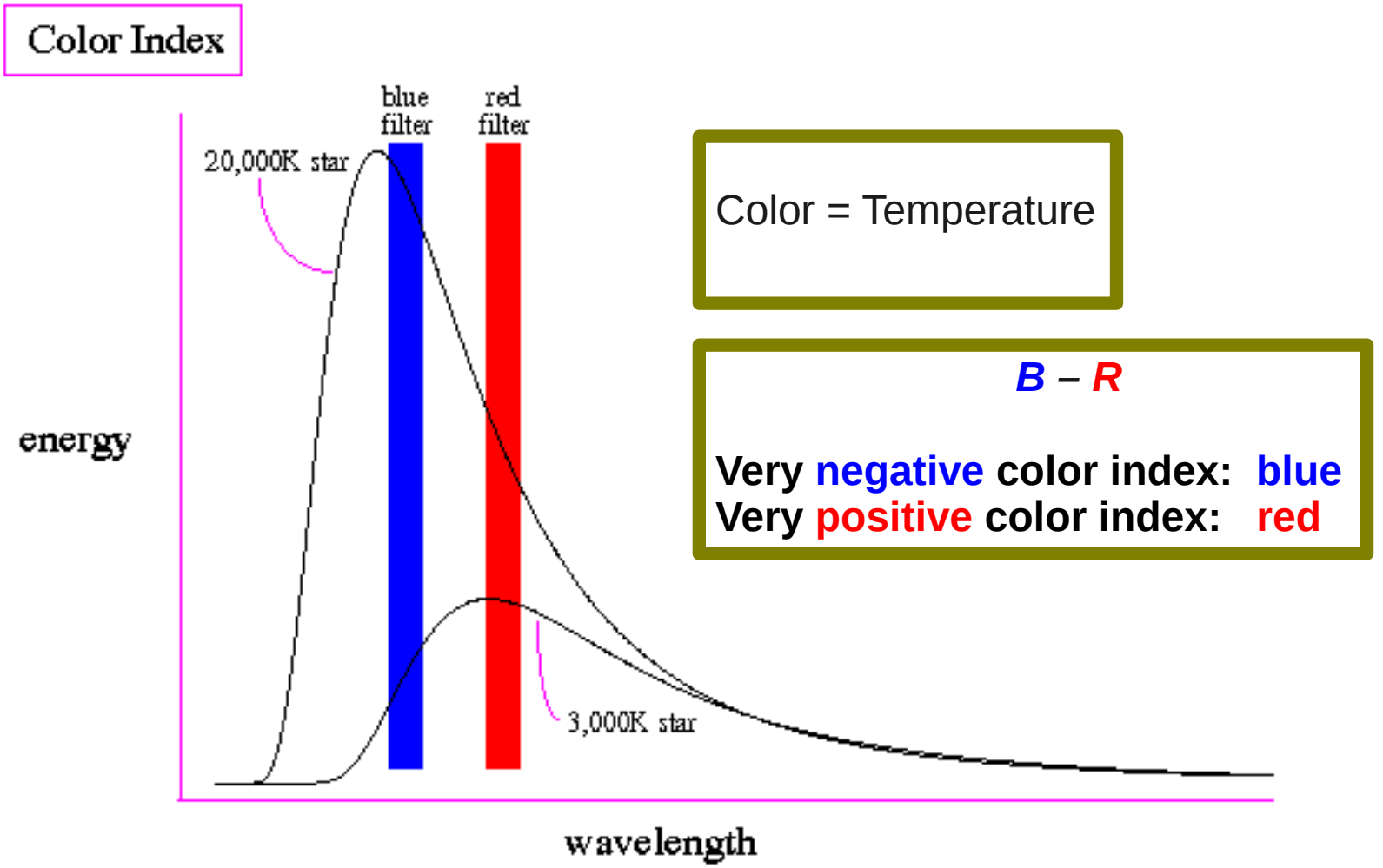


Color = Temperature

Color is a measurement of the **slope** of the Black Body radiation curve
And therefore of temperature!

Photometry

Color: Magnitude difference between filters. Eg. *B-V, U-B, V-I, B-R*



Color = Temperature

B **–** ***R***

Very negative color index: blue
Very positive color index: red

Color is a measurement of the **slope** of the Black Body radiation curve
And therefore of temperature!

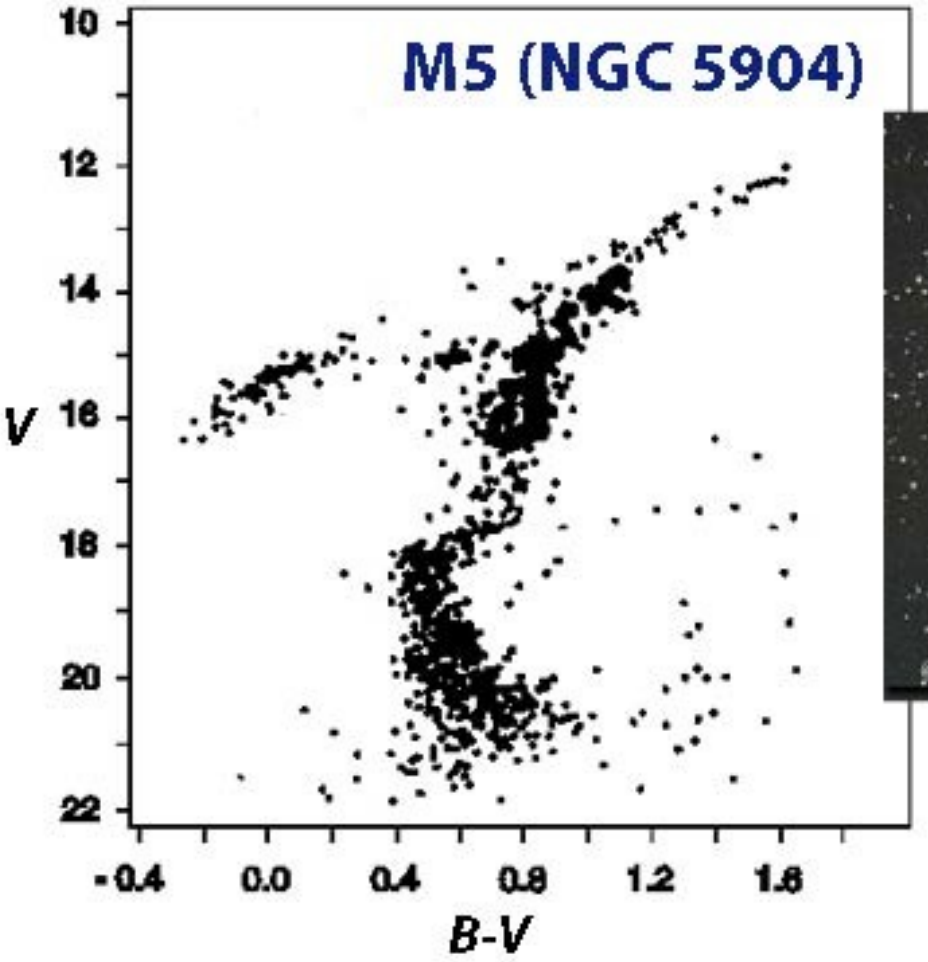
Photometry

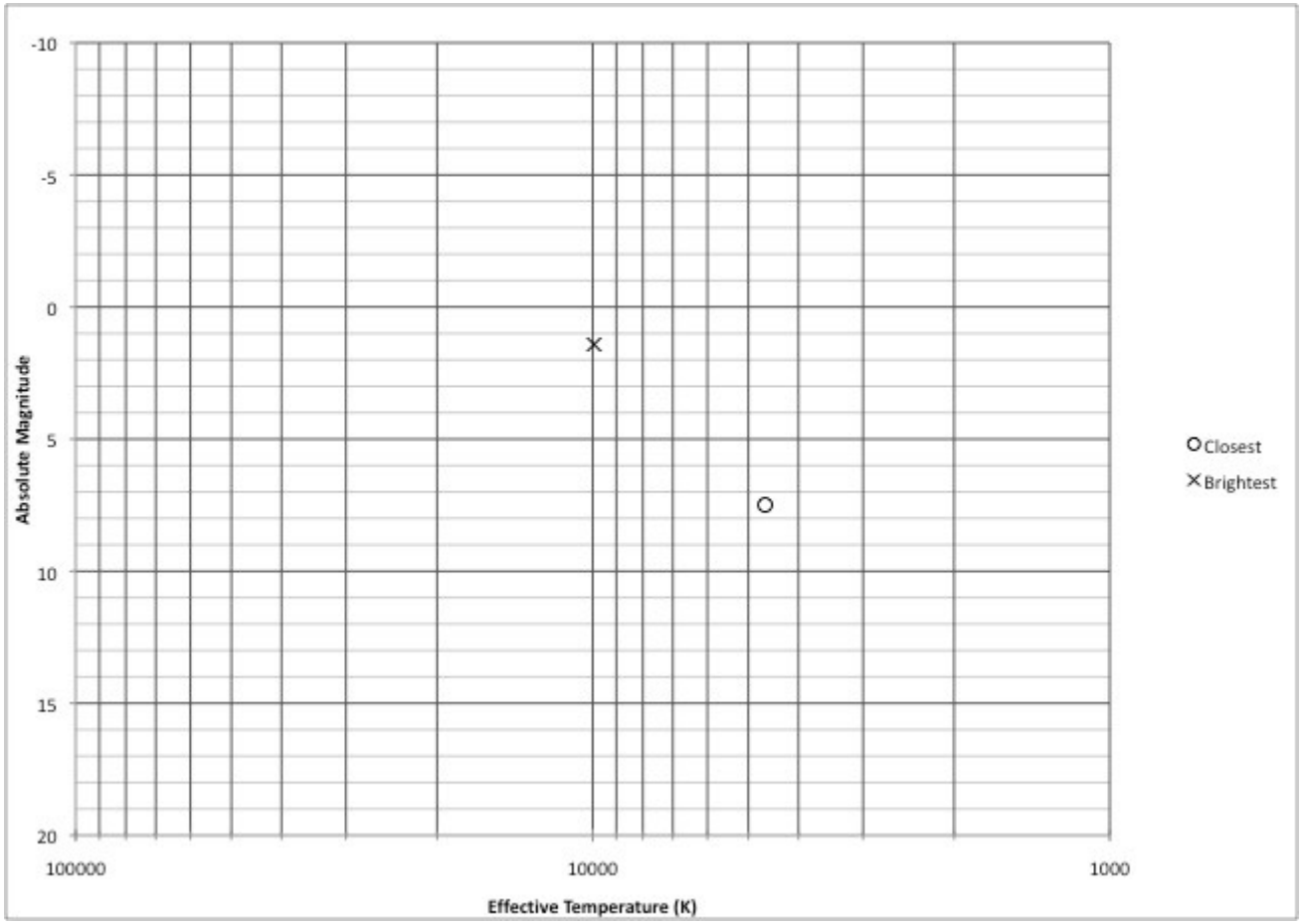
Photometry of a single star is a lot less accurate than spectroscopy of a single star

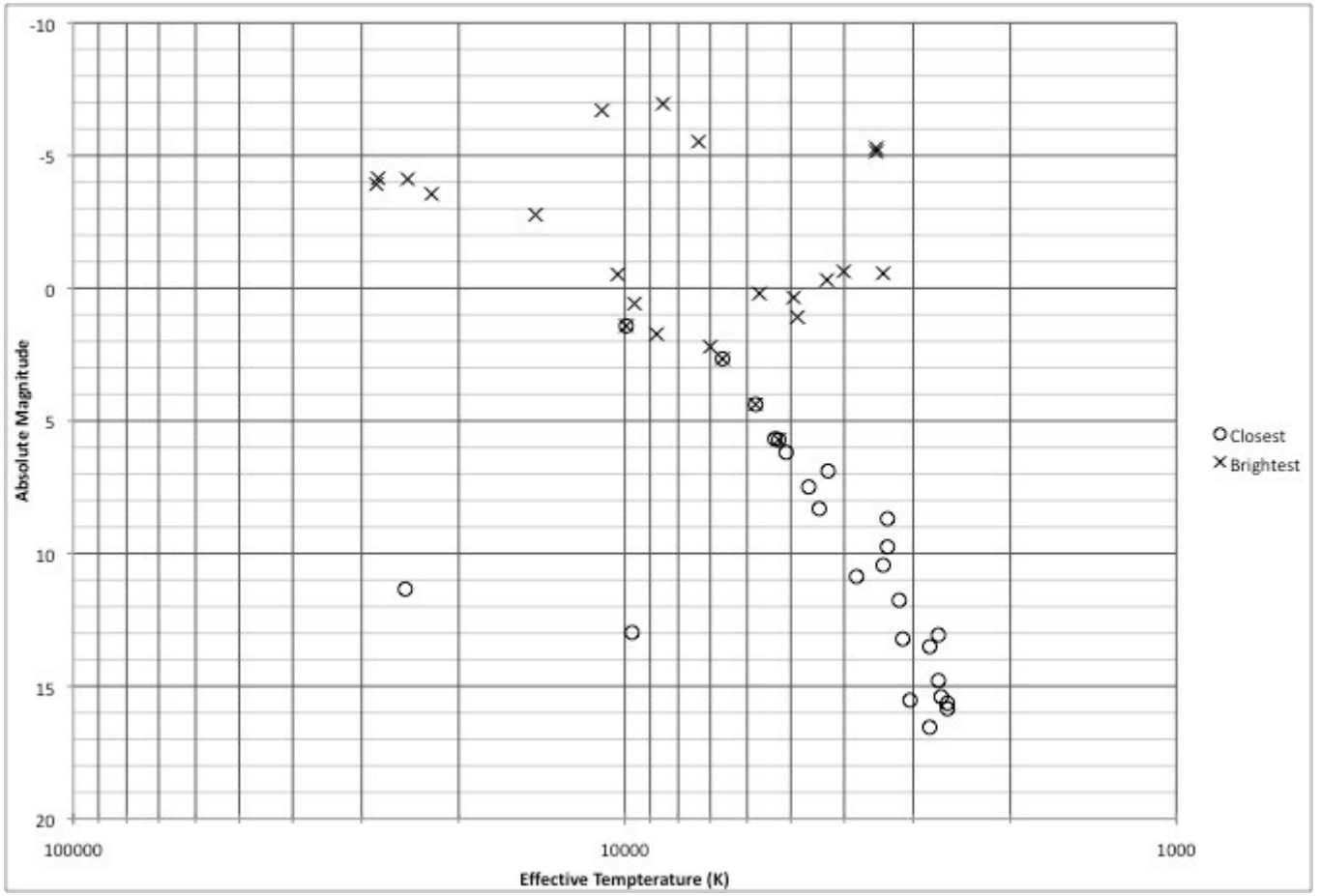
The **main advantage** of photometry over spectroscopy is that
one can easily measure a statistically significant sample of stars.

Application: Clusters
Instead of a HR diagram, we can do a **Color-Magnitude diagram** (CMD)

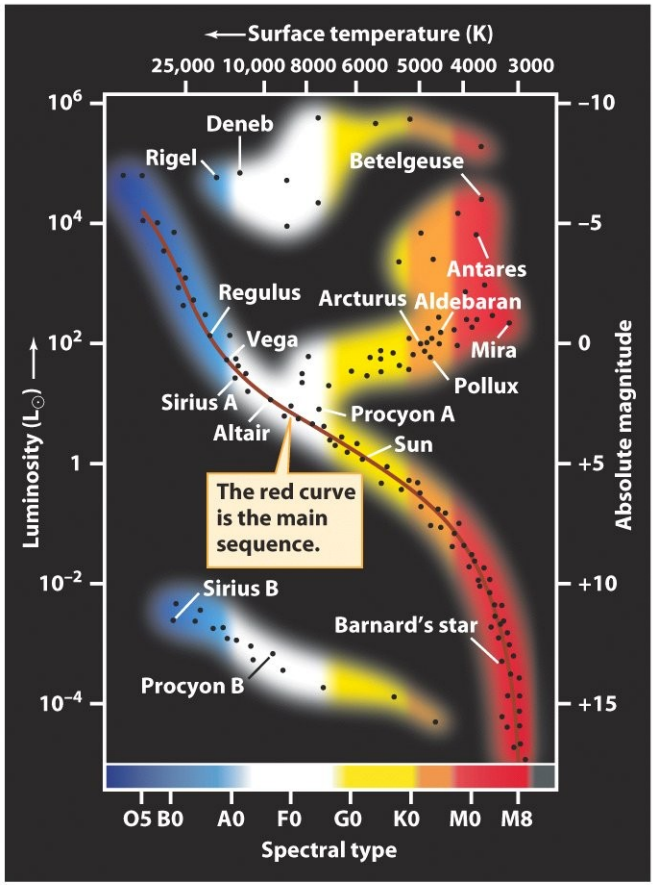
- A cluster has >10^4 stars
- Impractical to do a spectral analysis of every star to get temperatures
- But... we can do photometry of a whole field in one go!



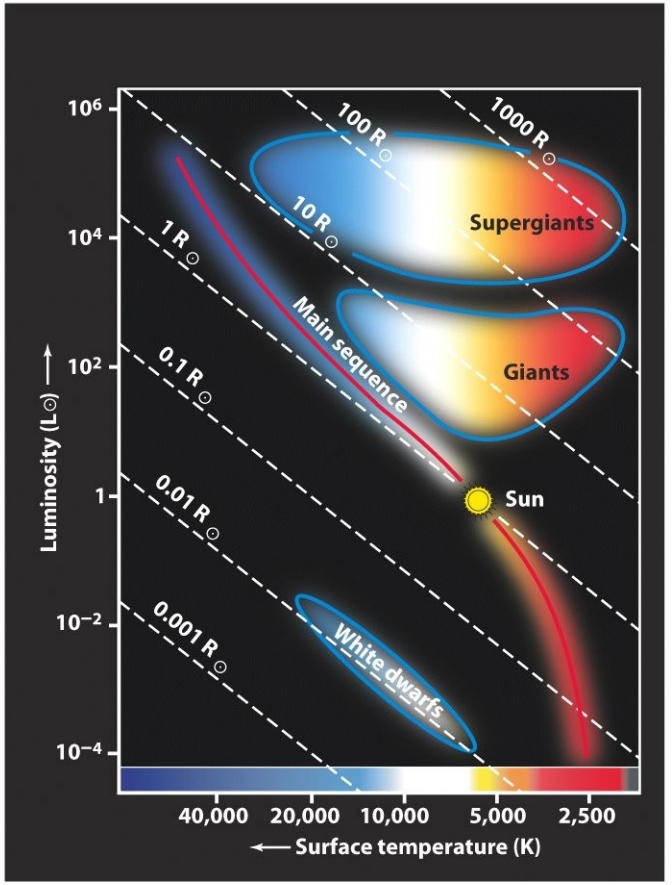

-10
-5
0
5
10
15
20
Absolute Magnitude
100000
10000
1000
Effective Temperature (K)
Closest
Brightest


-10
-5
0
5
10
15
20
Absolute Magnitude
100000
10000
1000
Effective Tempterature (K)
Closest
Brightest

Structure of the HR diagram

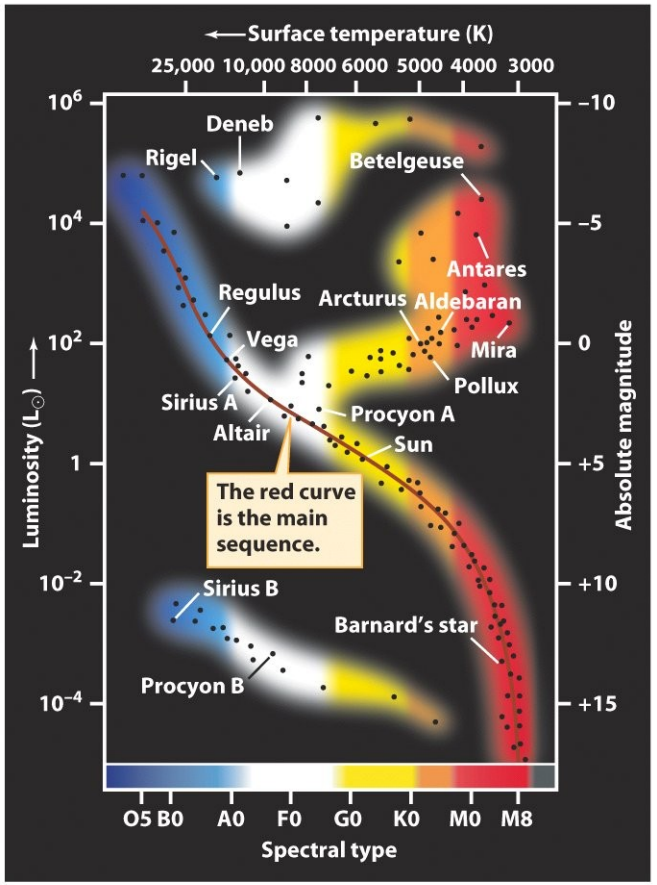


(a) A Hertzsprung-Russell (H-R) diagram

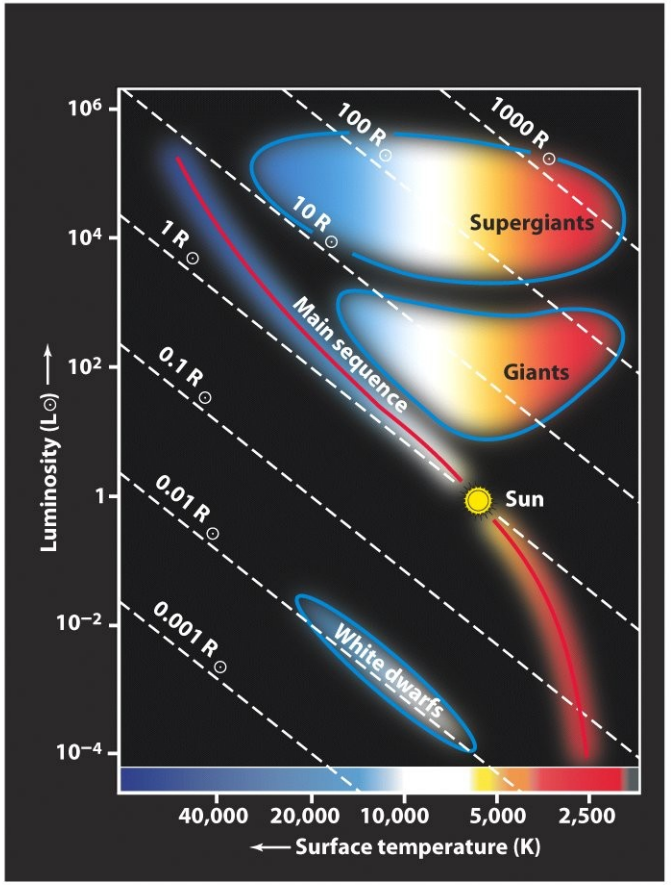


(b) The sizes of stars on an H-R diagram

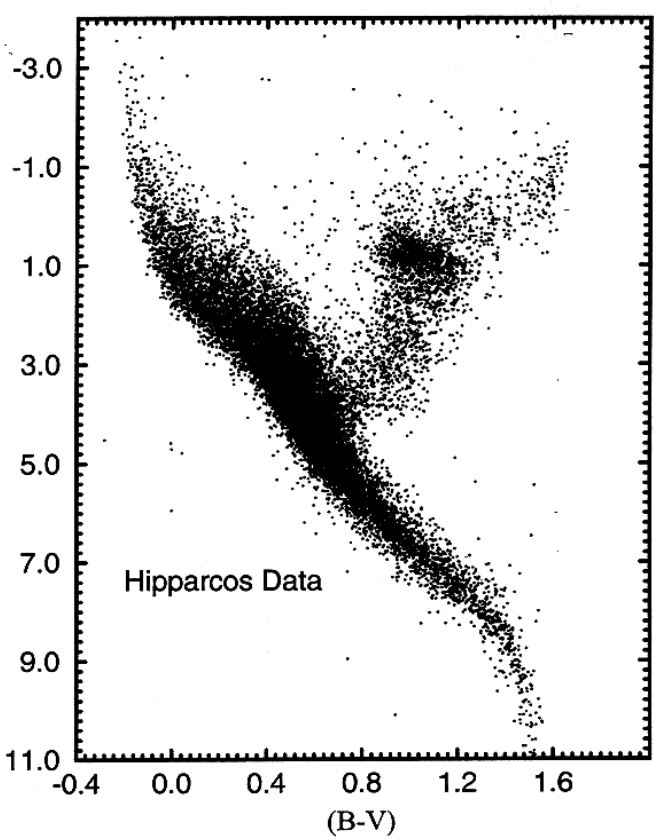
Structure of the HR diagram



(a) A Hertzsprung-Russell (H-R) diagram

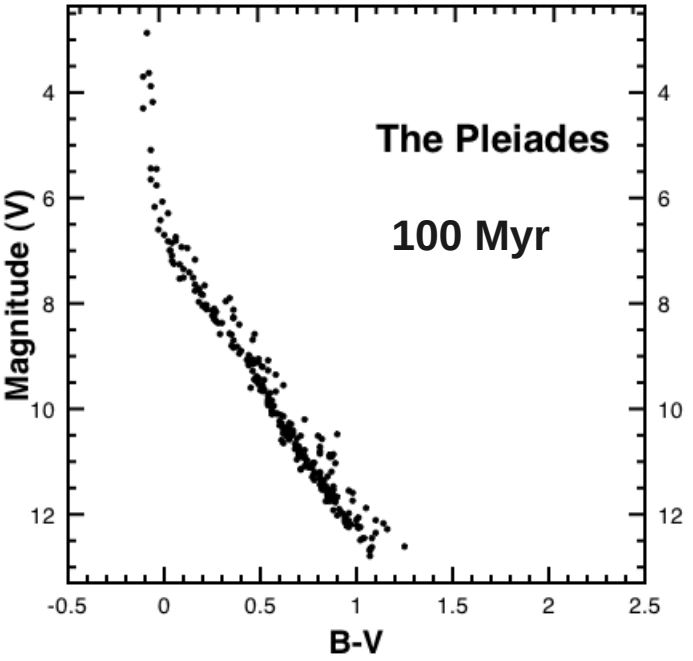


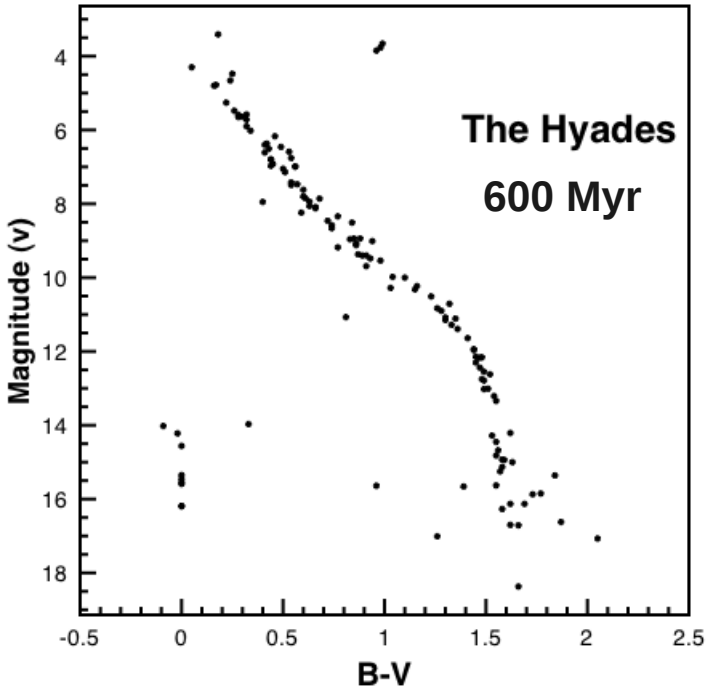
(b) The sizes of stars on an H-R diagram



Spectral type = Temperature = Color

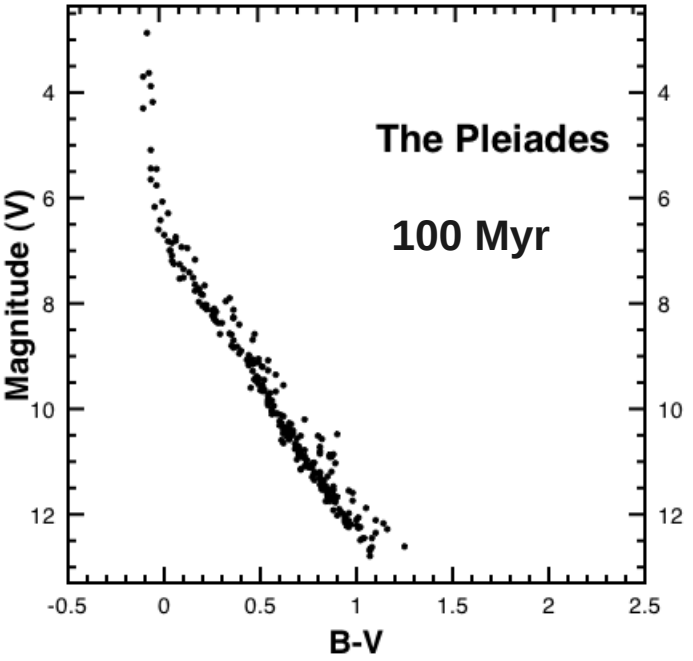
Structure of the HR Diagram: Young Clusters

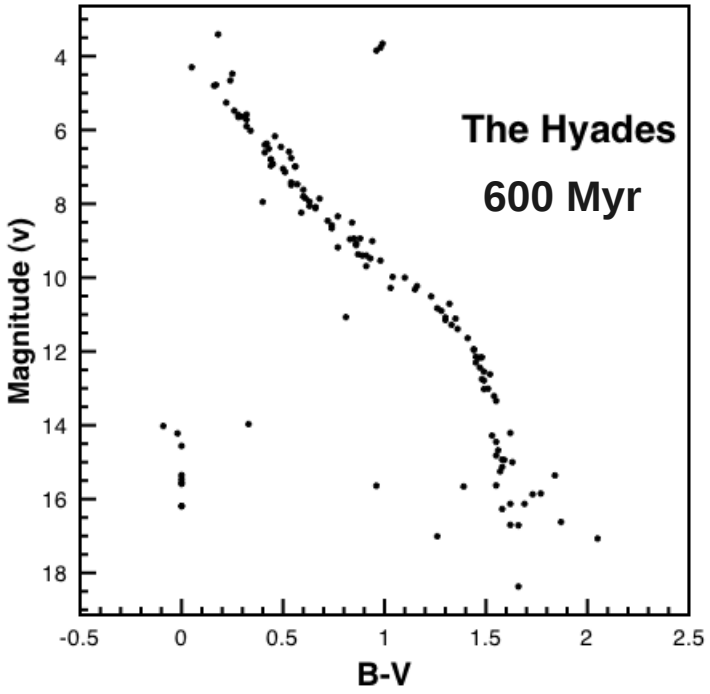




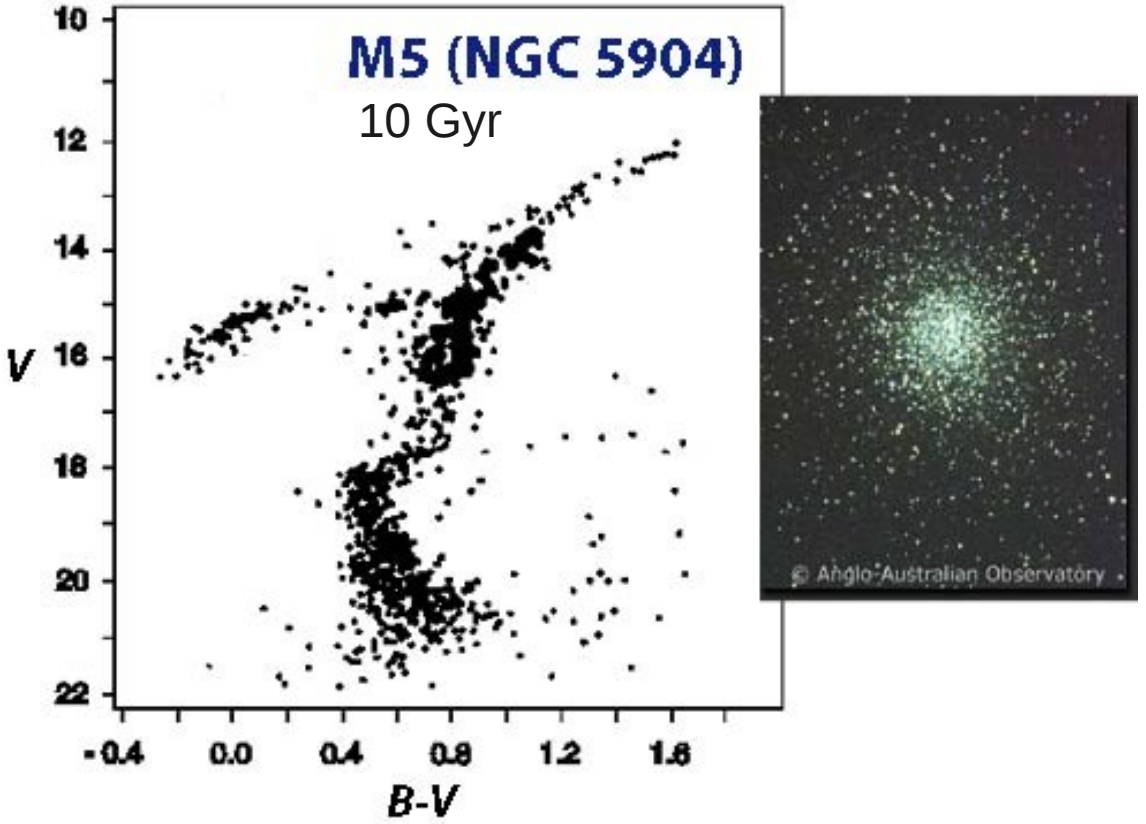
Structure of the HR Diagram: Young Clusters

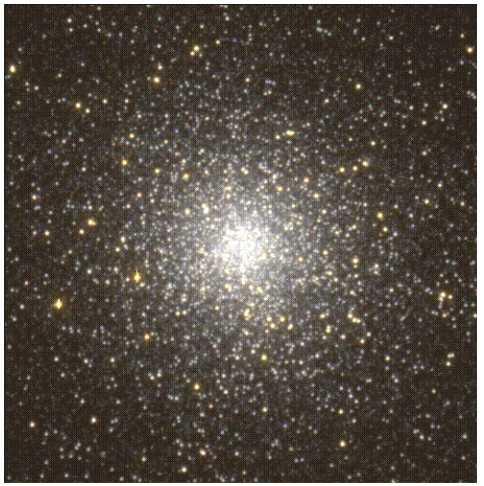
A conspicuous Main Sequence from Blue to Red

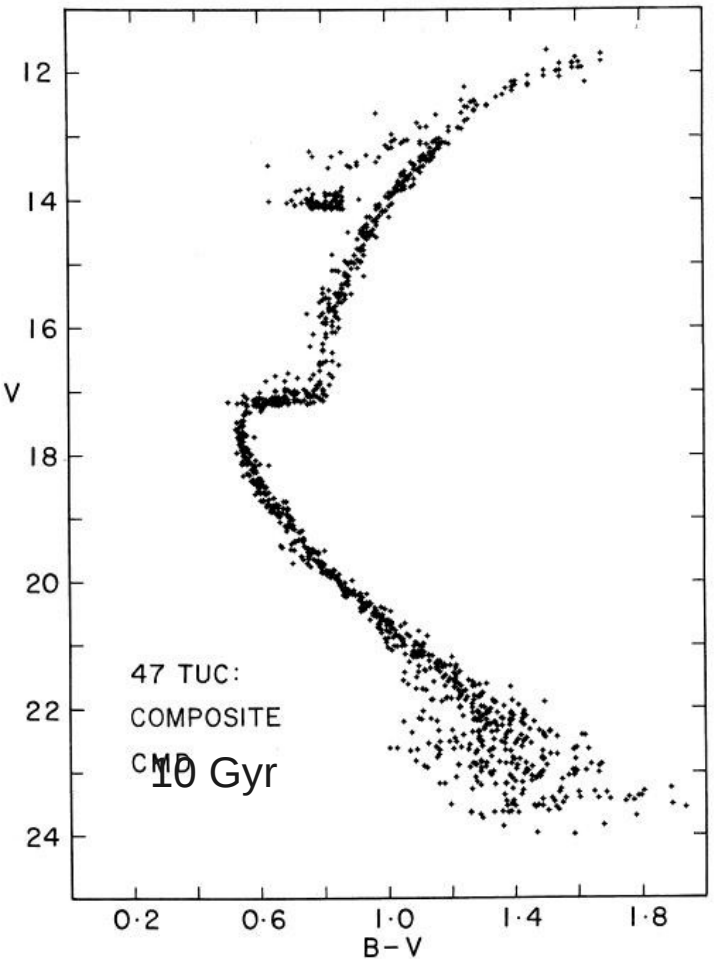




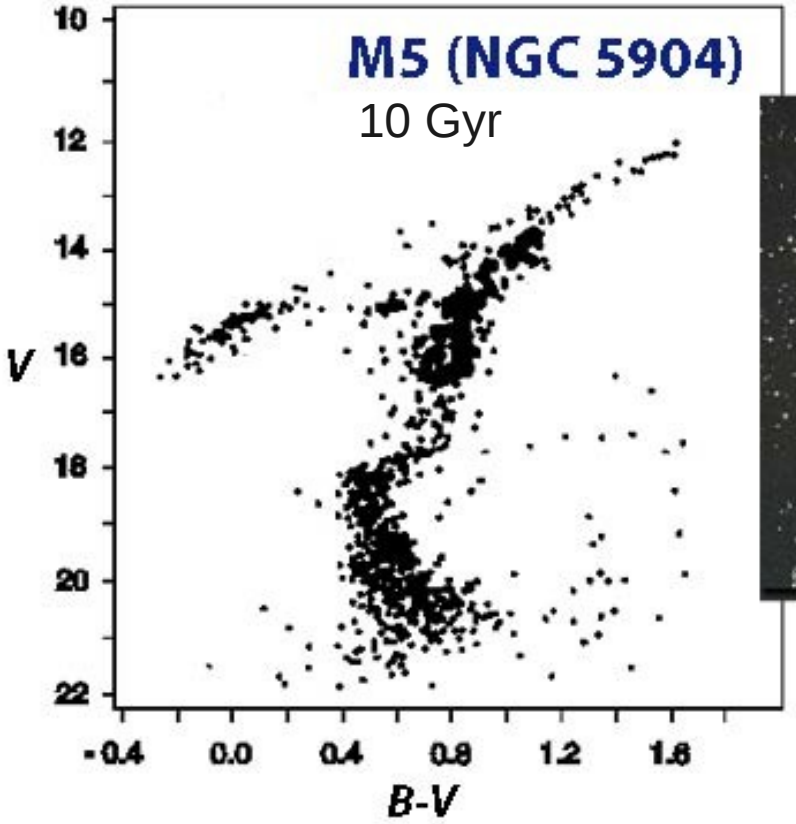
Structure of the HR diagram: Old Clusters

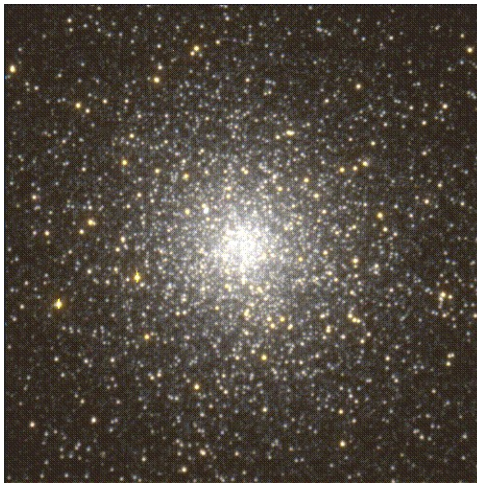






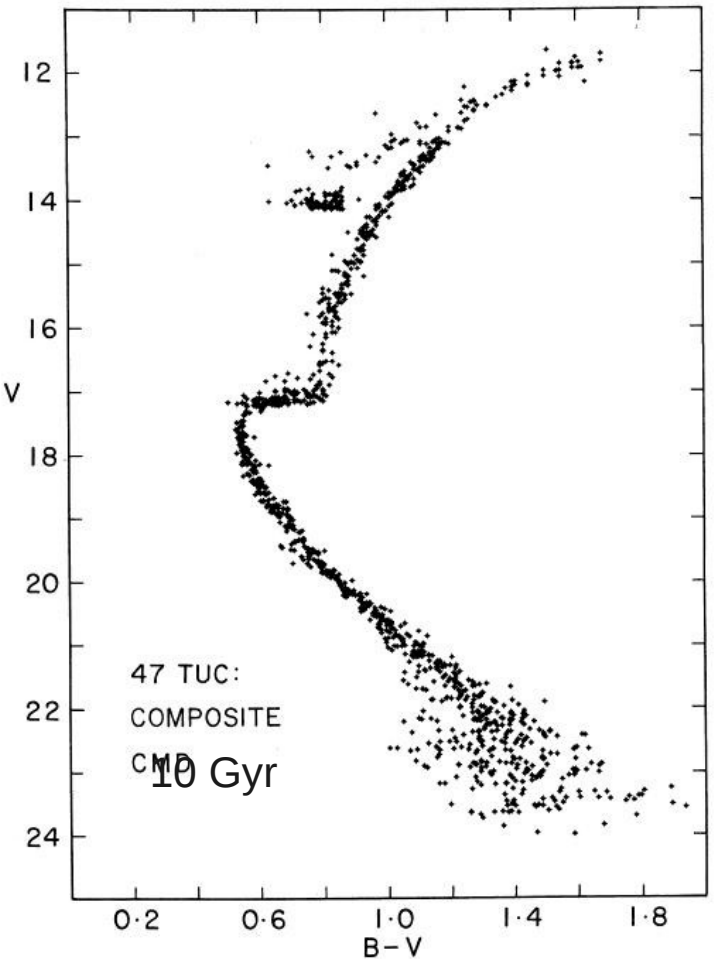
Structure of the HR diagram: Old Clusters



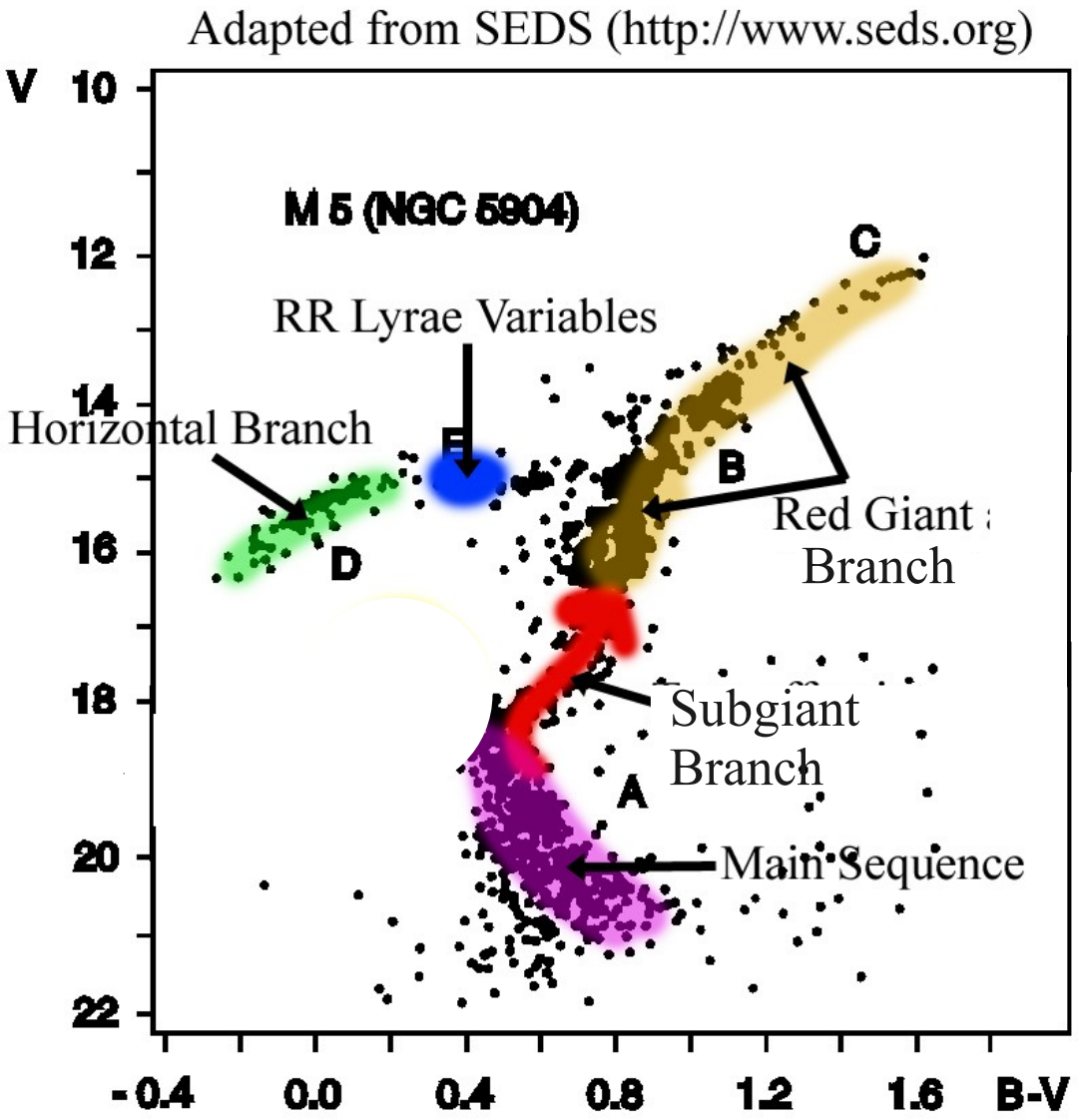


Main Features

- A main sequence devoid of blue stars
- A conspicuous ***red giant branch***
- A (nearly) horizontal branch



CMD of Old Clusters



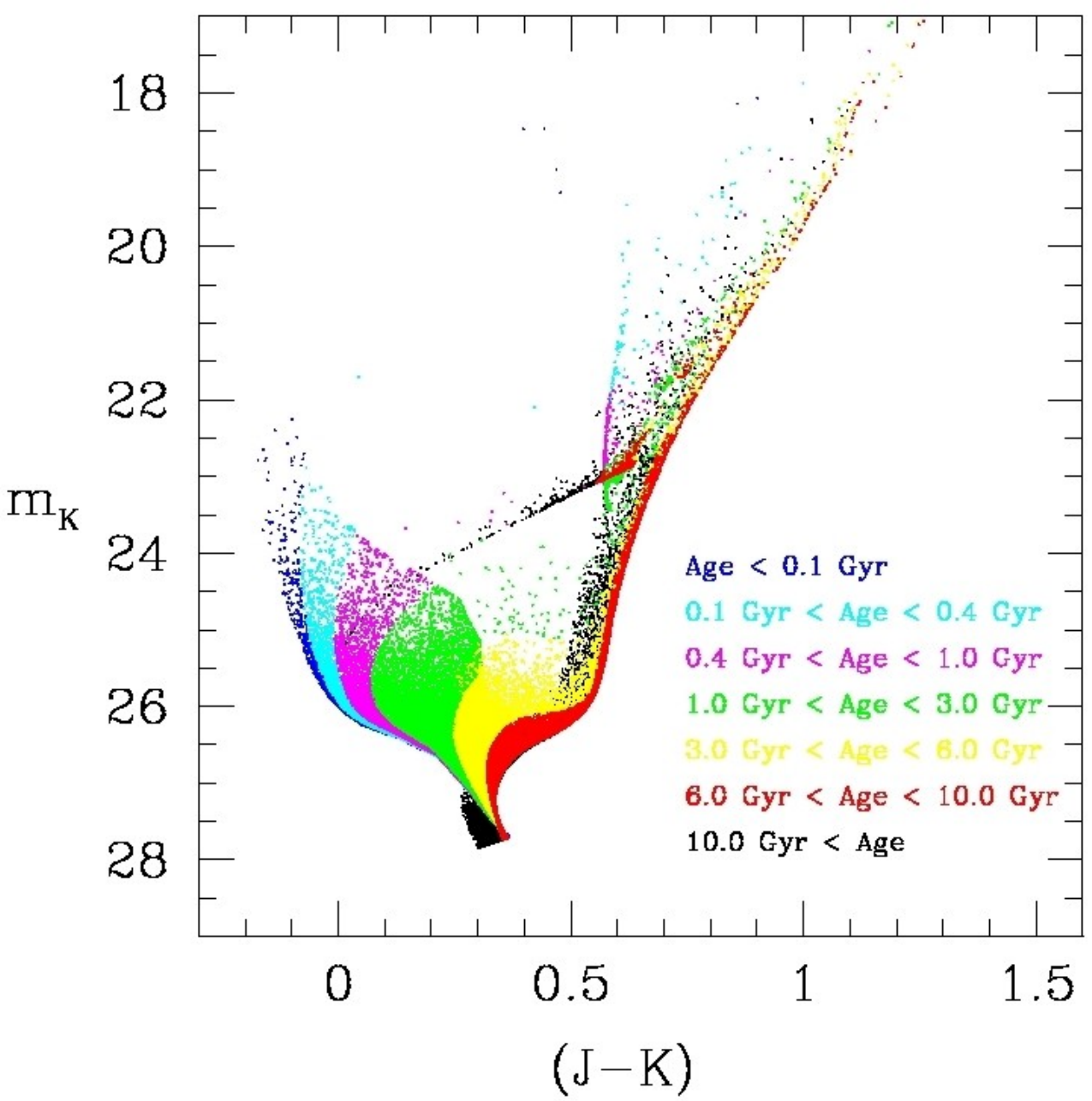
Main Features

- A main sequence devoid of blue stars
- A conspicuous red giant branch
- A (nearly) horizontal branch

Subgiant Branch
Red Giant Branch (RGB)
Horizontal Branch (HB)
Asymptotic Giant Branch (AGB)

Loci of evolved, dying stars, undergoing
Post-Main Sequence evolution

Post-Main Sequence Evolution



Main Sequence (dwarf)

Subgiant

Red Giant

Horizontal Branch

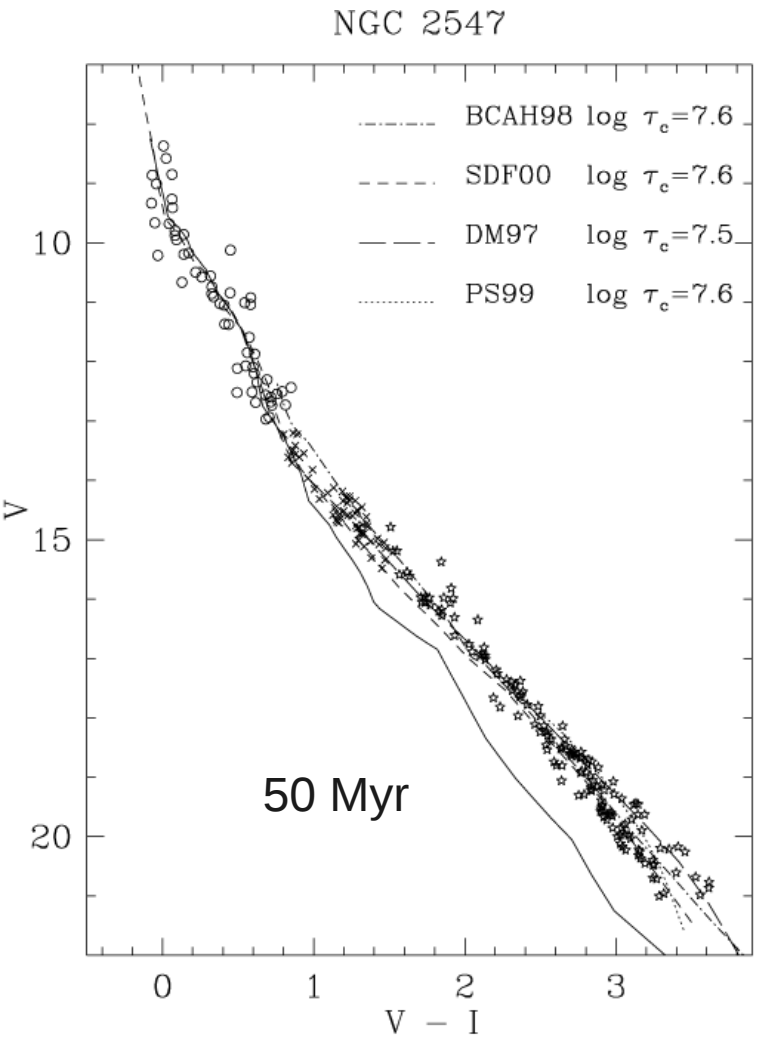
Asymptotic Giant Branch

TIME

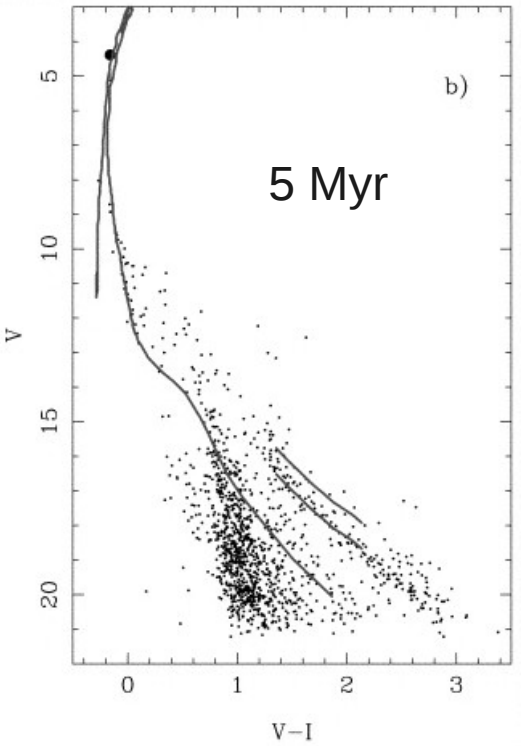
Is there also a pre-main sequence evolution?

Yes, of course!

CMD of very young clusters



NGC 2362



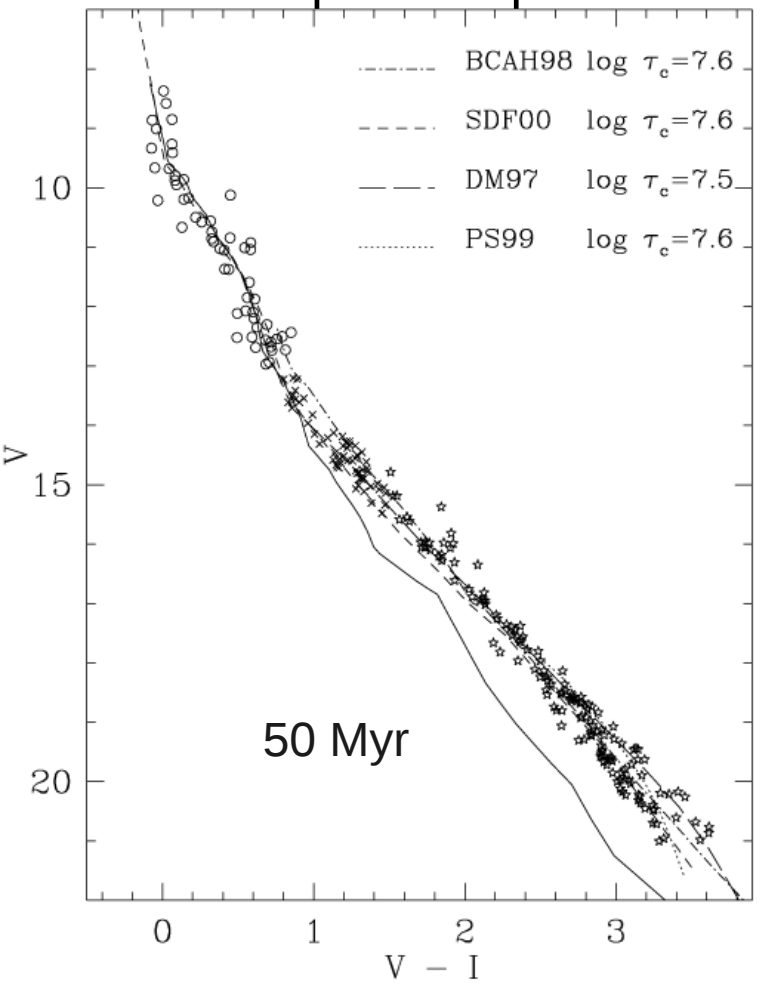
NGC 2547

CMD of very young clusters

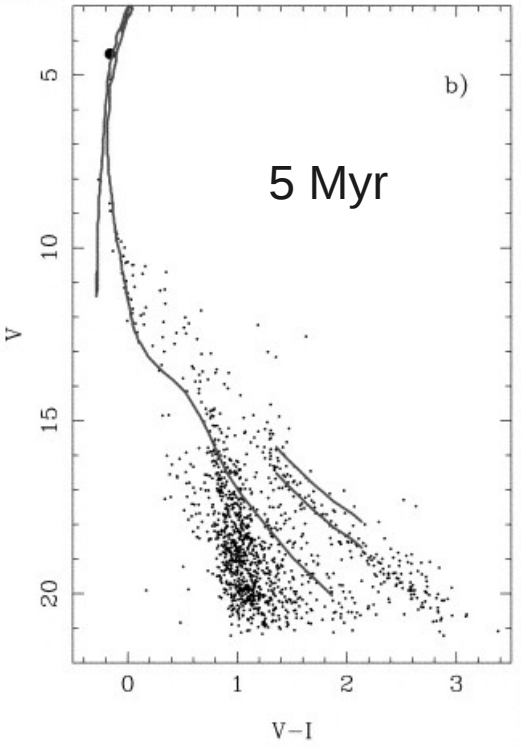
Main features

A main sequence devoid of red stars

A conspicuous pre-main sequence



NGC 2362

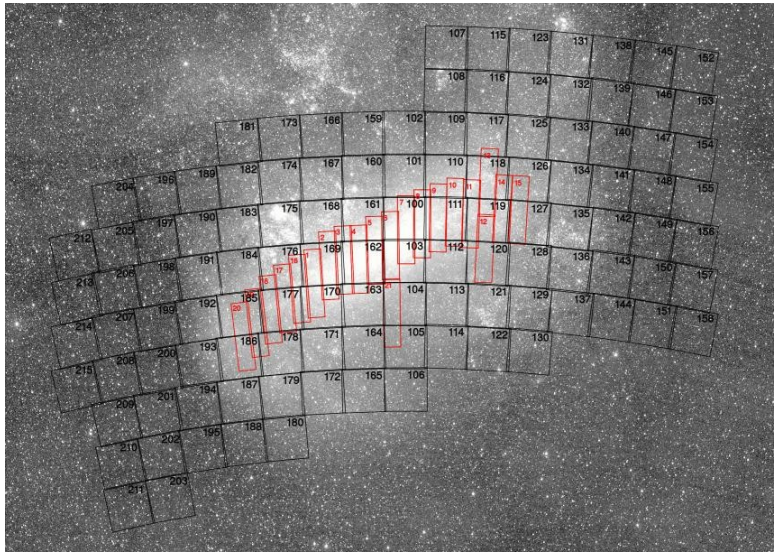


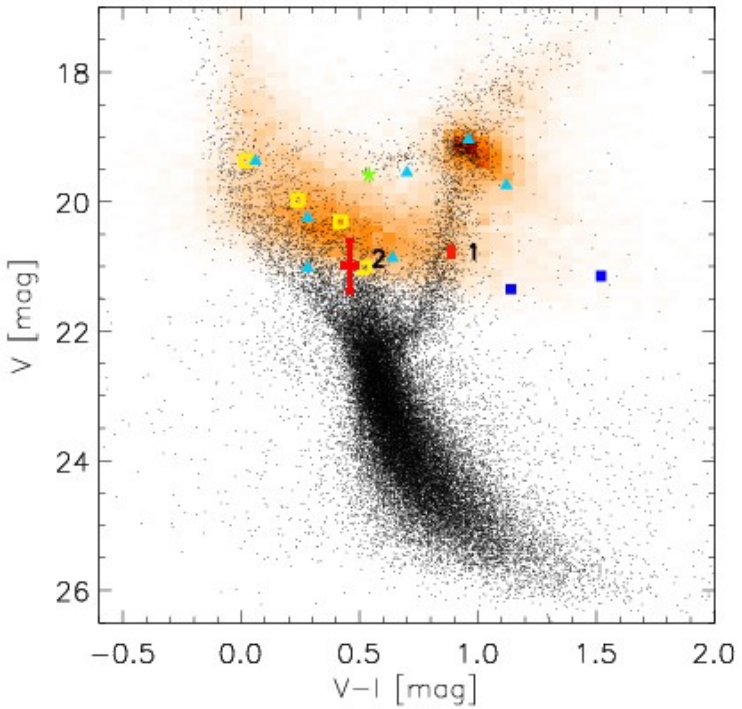
NGC 2547

The Pre Main Sequence is the locus of nascent, baby stars

Photometry of a whole galaxy

CMD of the Large Magellan Cloud





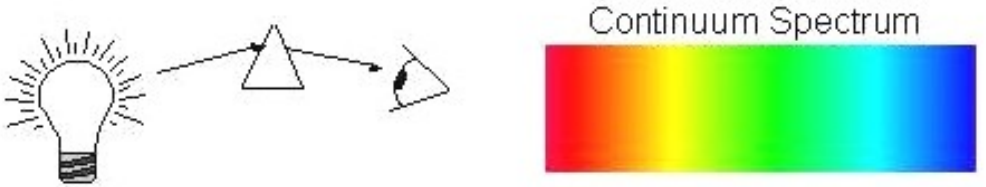
Everything combined!

Why? Star formation goes on CONTINUOSLY!

Both old and young stars.

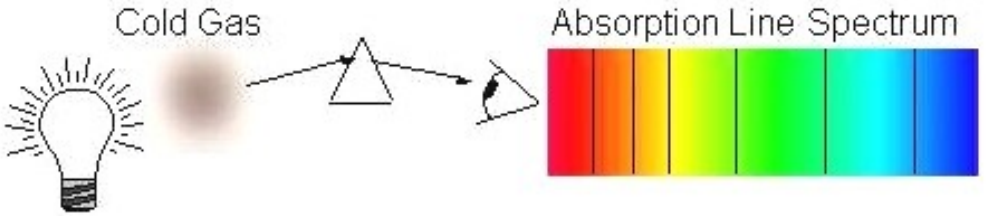
Let's summarize

Kirchhoff's three empirical laws of spectroscopy



A hot solid or a hot dense gas produces a continuum spectrum.

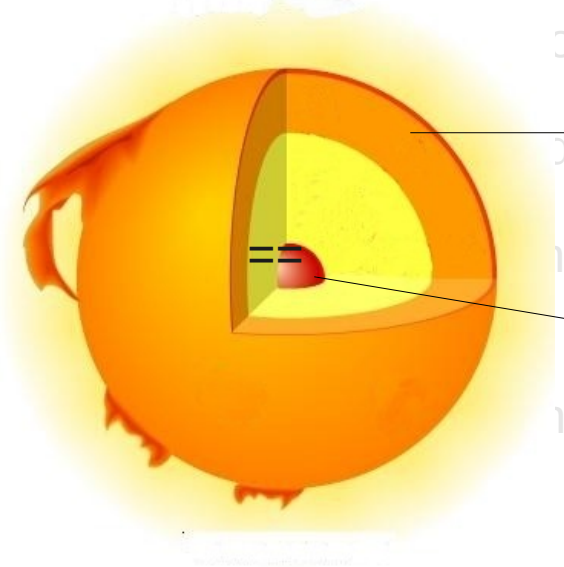
A hot low-density gas produces an emission-line spectrum.

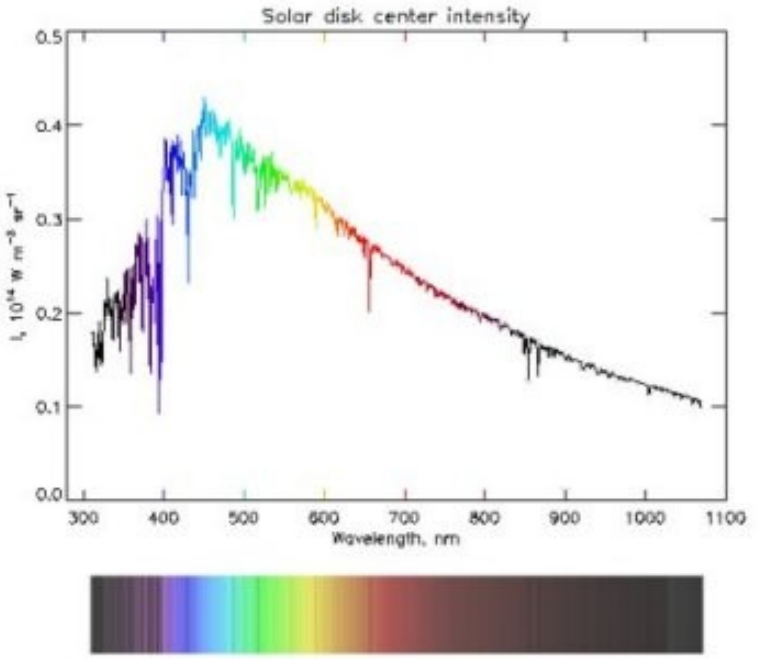


A continuos source viewed through a cold gas produces an absorption-line spectrum.

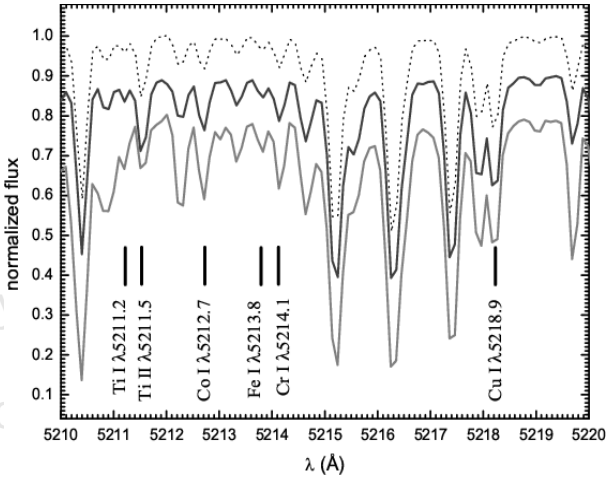
Let's summarize

Stellar spectra are absorption spectra, thus hot source covered by colder gas





Let's summarize

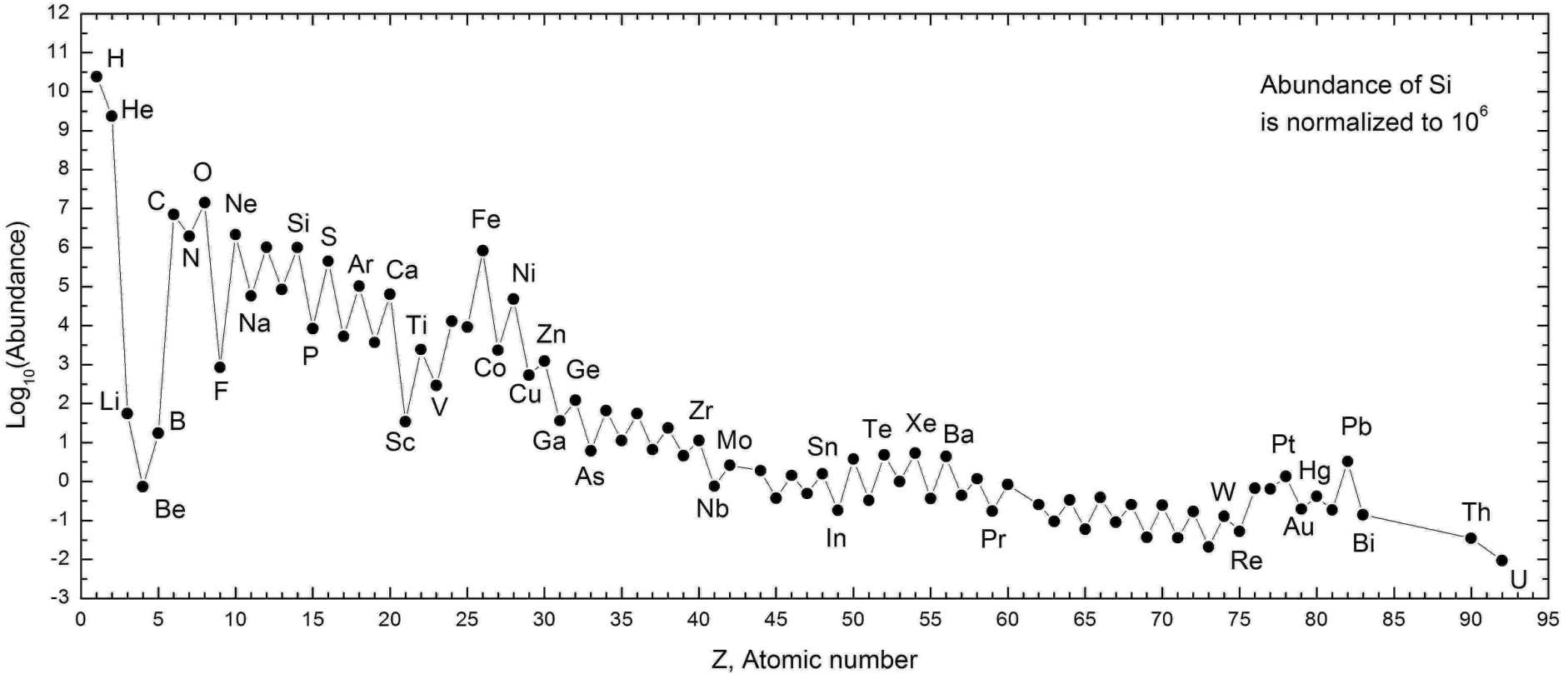


Kirchhoff's three laws of spectroscopy

Stellar spectra are absorption spectra, thus hot source co

Spectral lines are chemical signatures, and a mine of information

Five photometric passbands UBVRI. Five magnitudes.



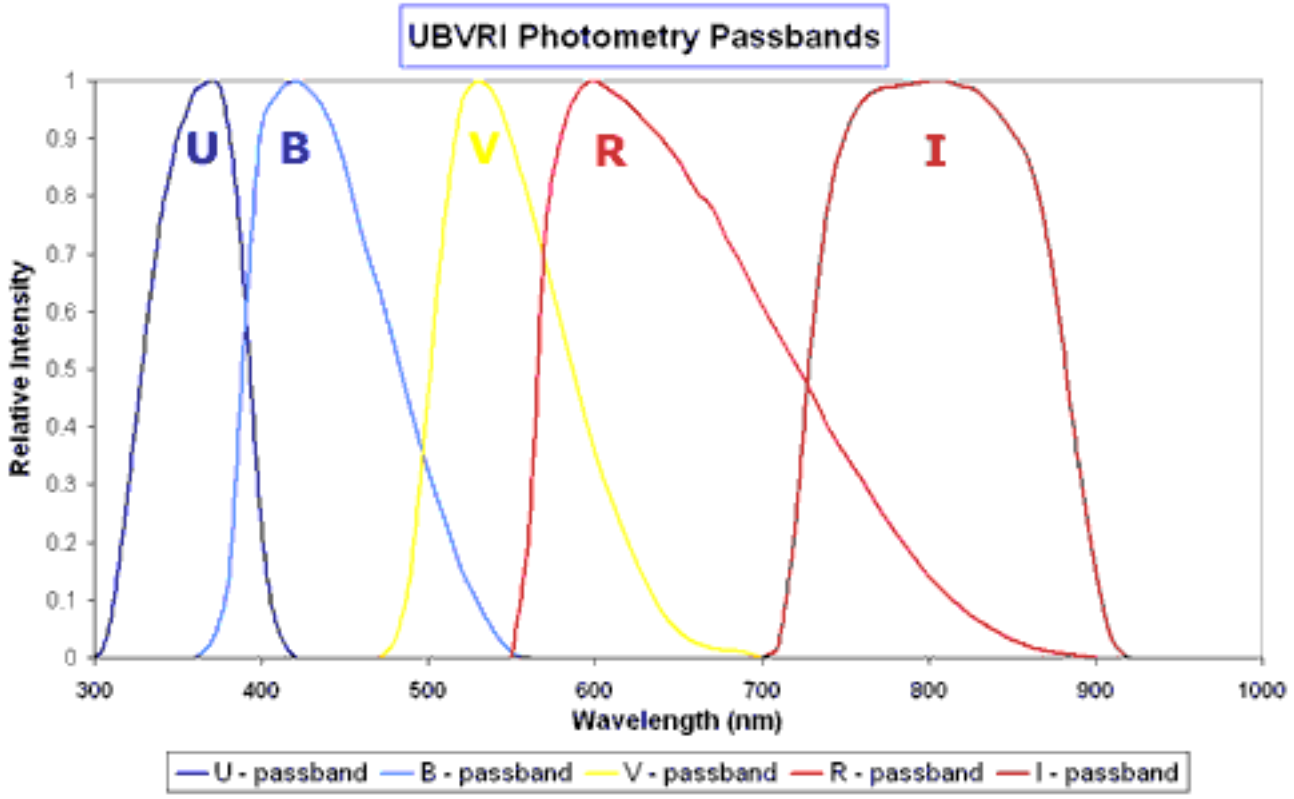
Let's summarize

Kirchhoff's three laws of spectroscopy

Stellar spectra are absorption spectra, thus hot source covered by colder gas

Spectral lines are chemical fingerprints, and a mine of information

Five photometric passbands UBVRI. Five magnitudes.



Let's summarize

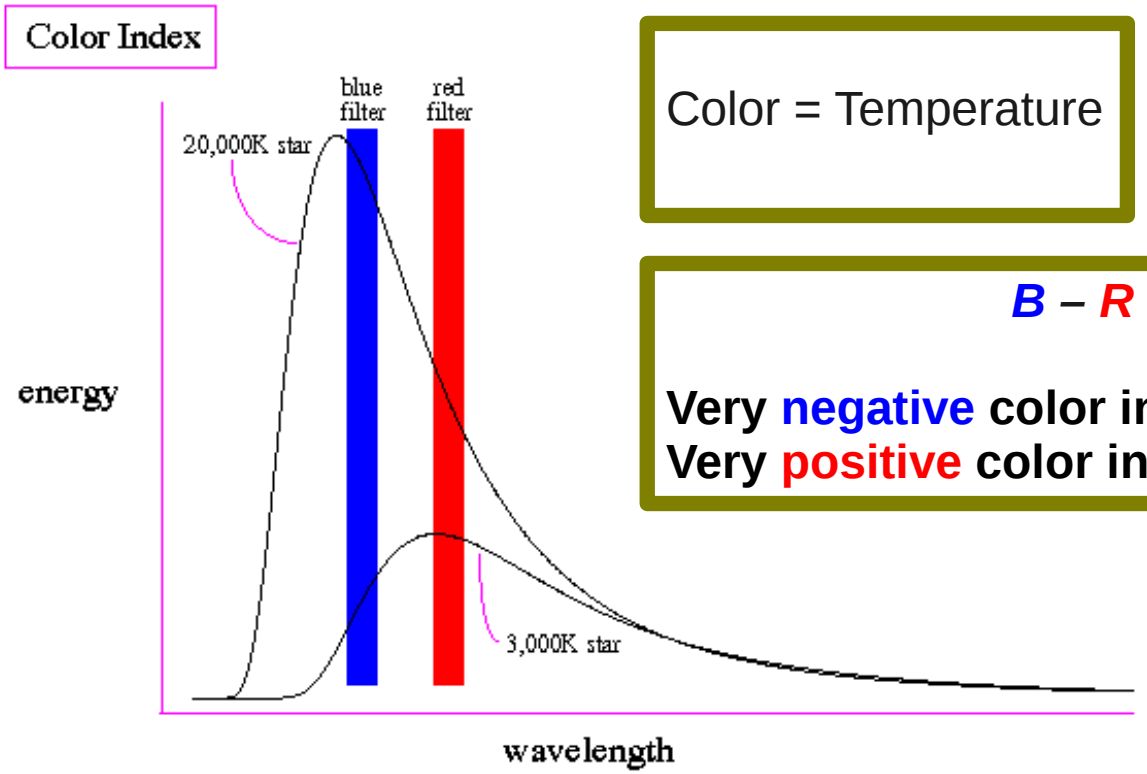
Kirchhoff's three laws of spectroscopy

Stellar spectra are absorption spectra, thus hot source covered by colder gas

Spectral lines are chemical fingerprints, and a mine of information

Five photometric passbands UBVRI. Five magnitudes.

Magnitude difference = color. A measurement of temperature.



Color = Temperature

B* – *R

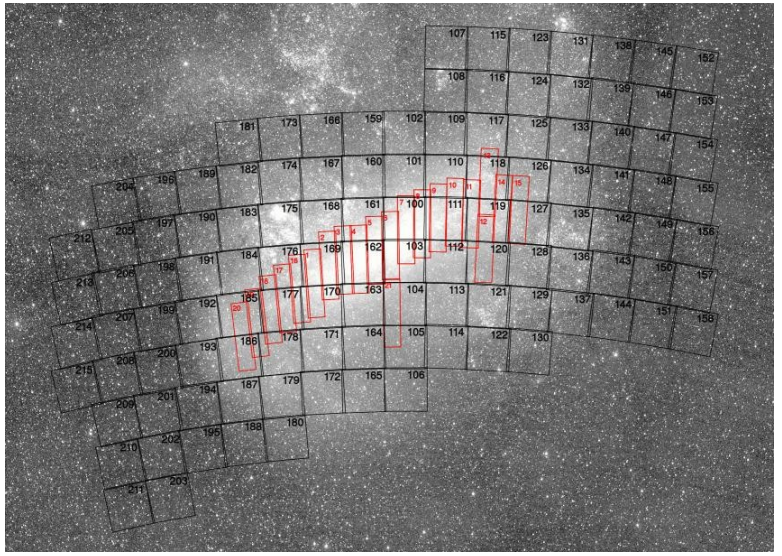
Very negative color index: blue
Very positive color index: red

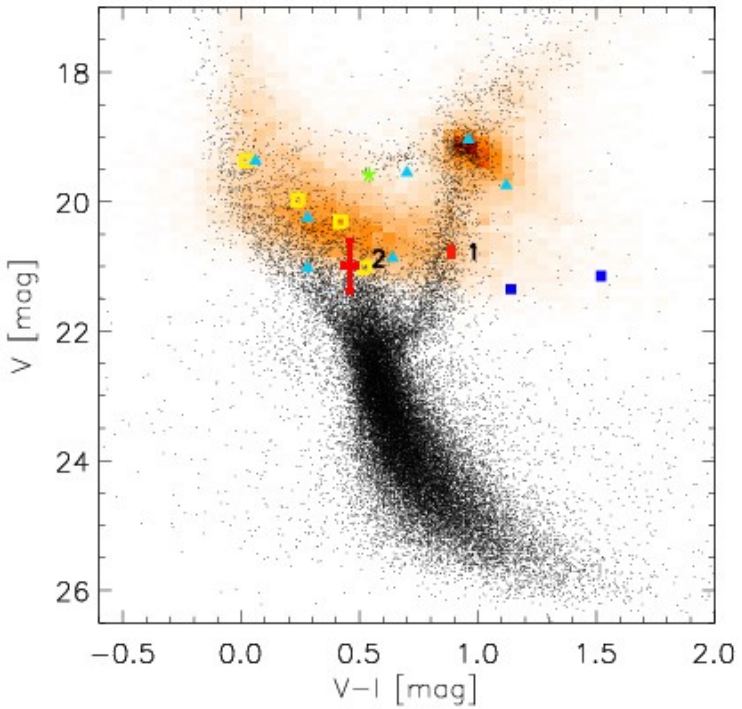
large number statistics.
asured in a single frame.

diagram.

Let's summarize

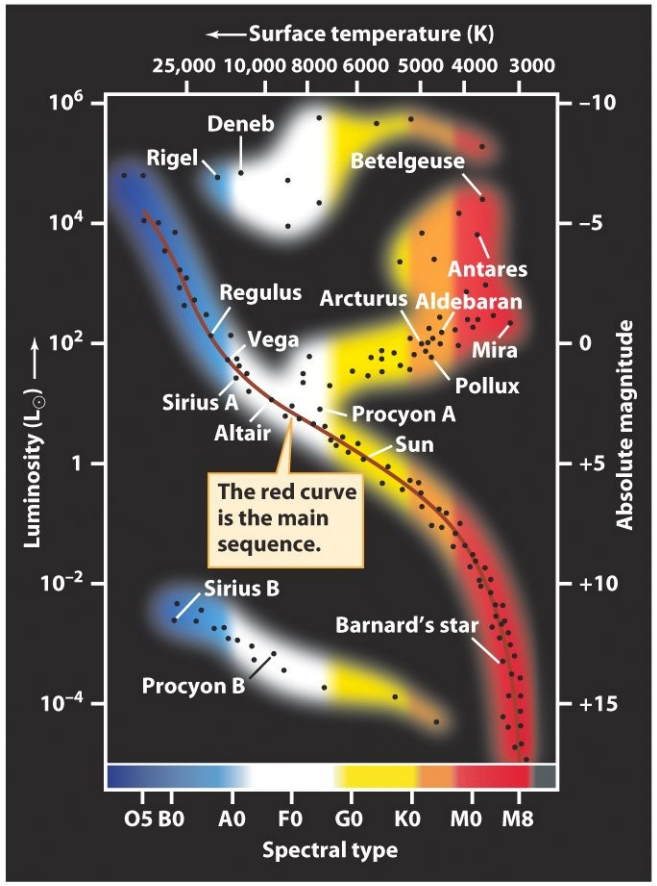
Spectroscopy = individual accuracy. Photometry = large number statistics.
Tens of thousands of stars can be automatedly measured in a single frame.



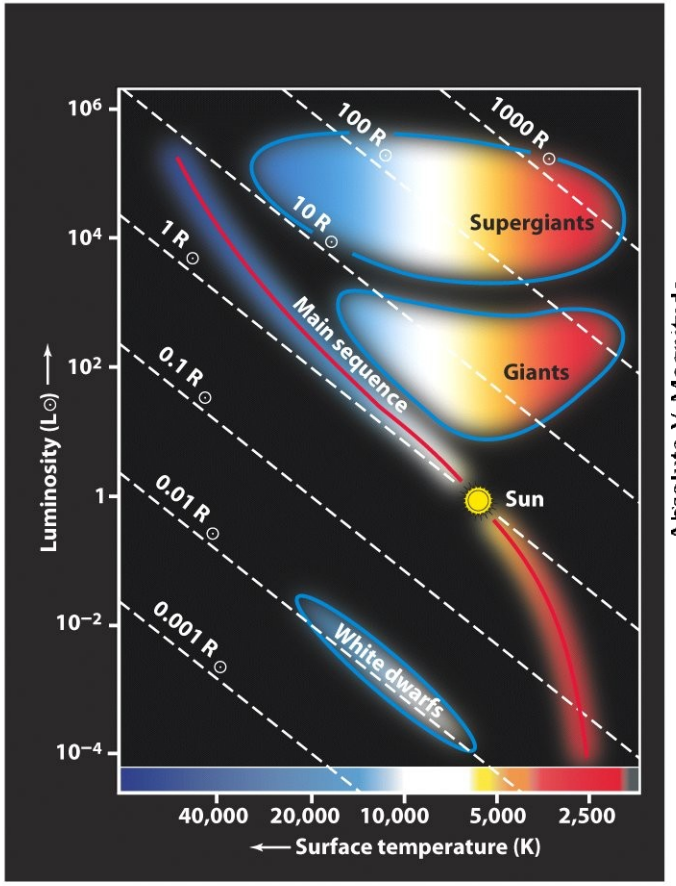


Let's summarize

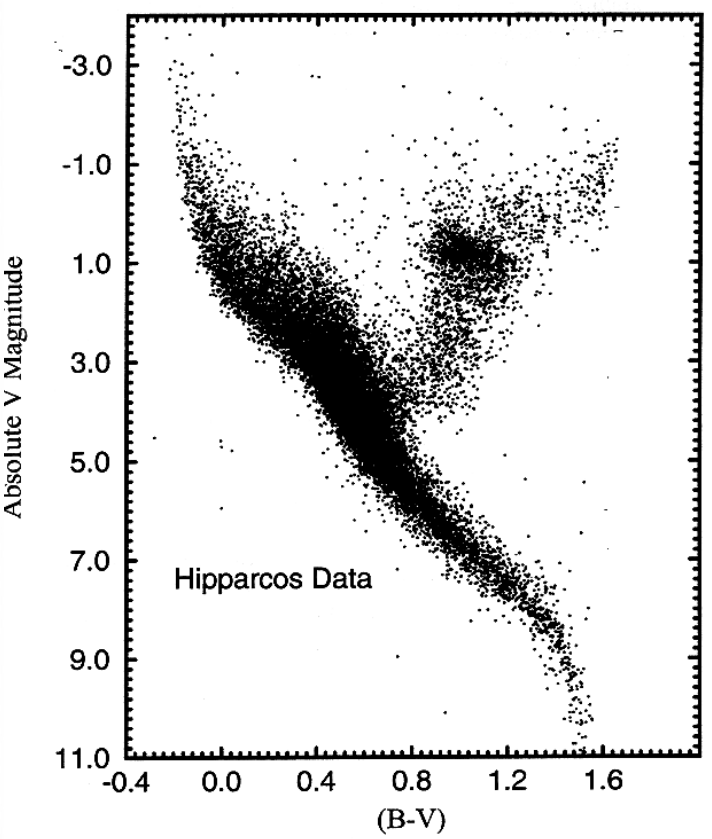
Color-Magnitude Diagram (CMD) is the photometric equivalent of the HR diagram.



(a) A Hertzsprung-Russell (H-R) diagram



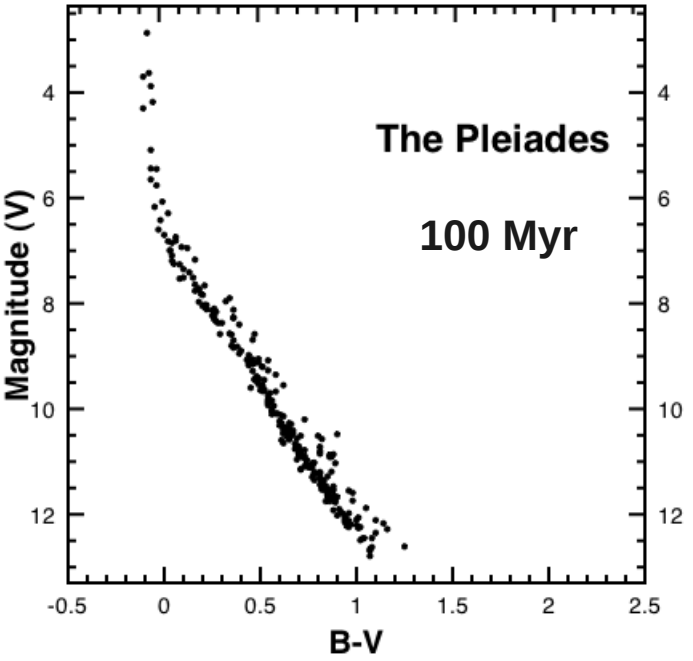
(b) The sizes of stars on an H-R diagram



Spectral type = Temperature = Color

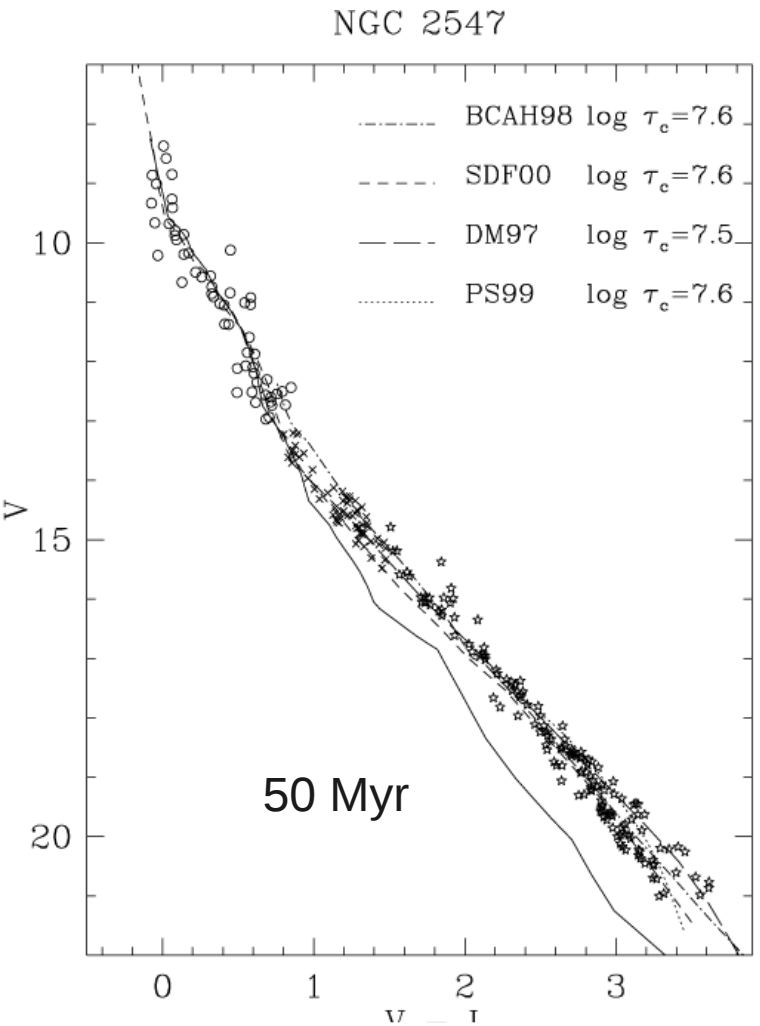
Let's summarize

Young stars are found in the main sequence



Let's summarize

Very young stars are found in the pre main sequence

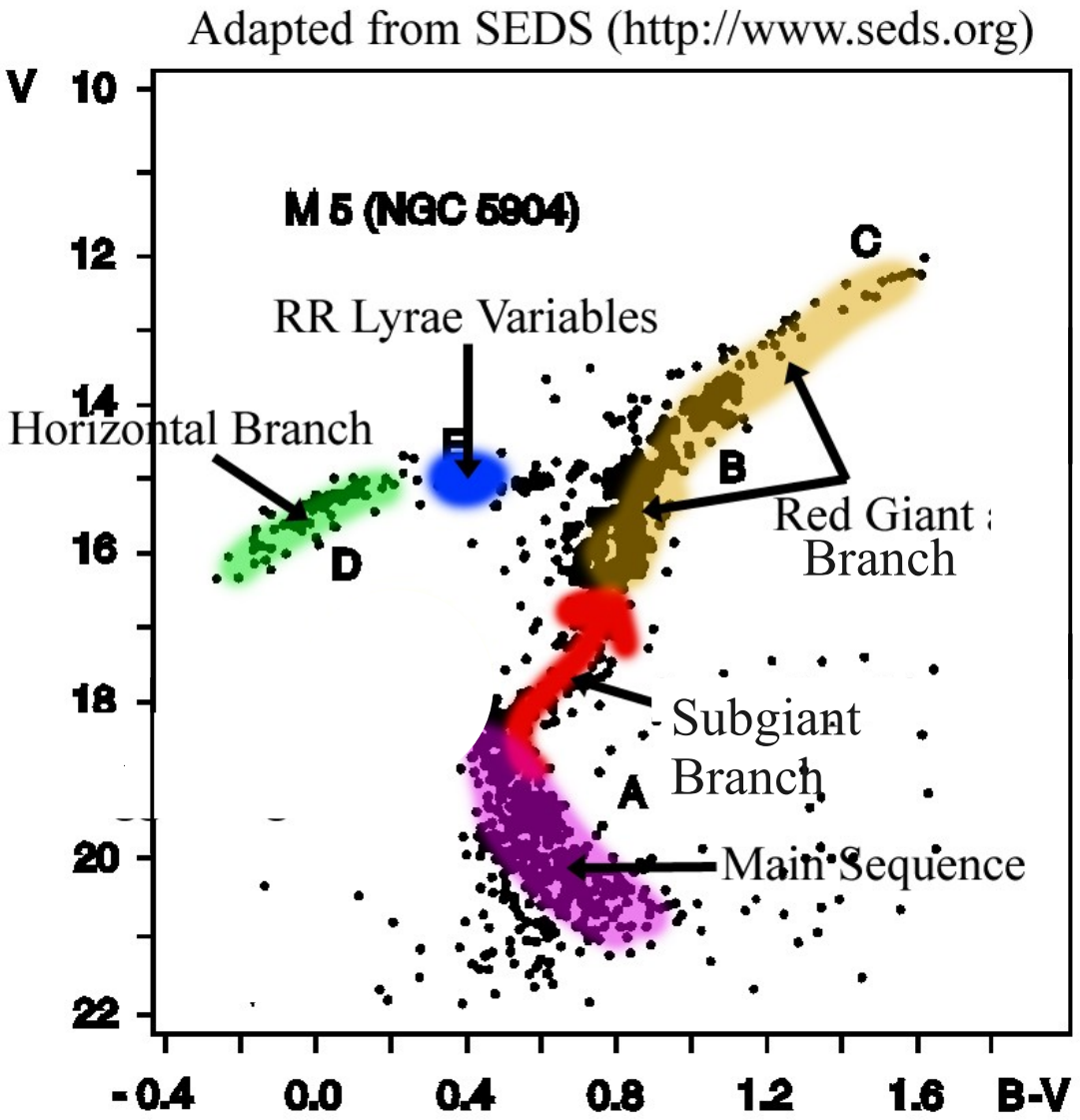


NGC 2547

The Pre Main Sequence is the locus of nascent, baby stars

Let's summarize

Evolved stars are found in special branches in the HR diagram

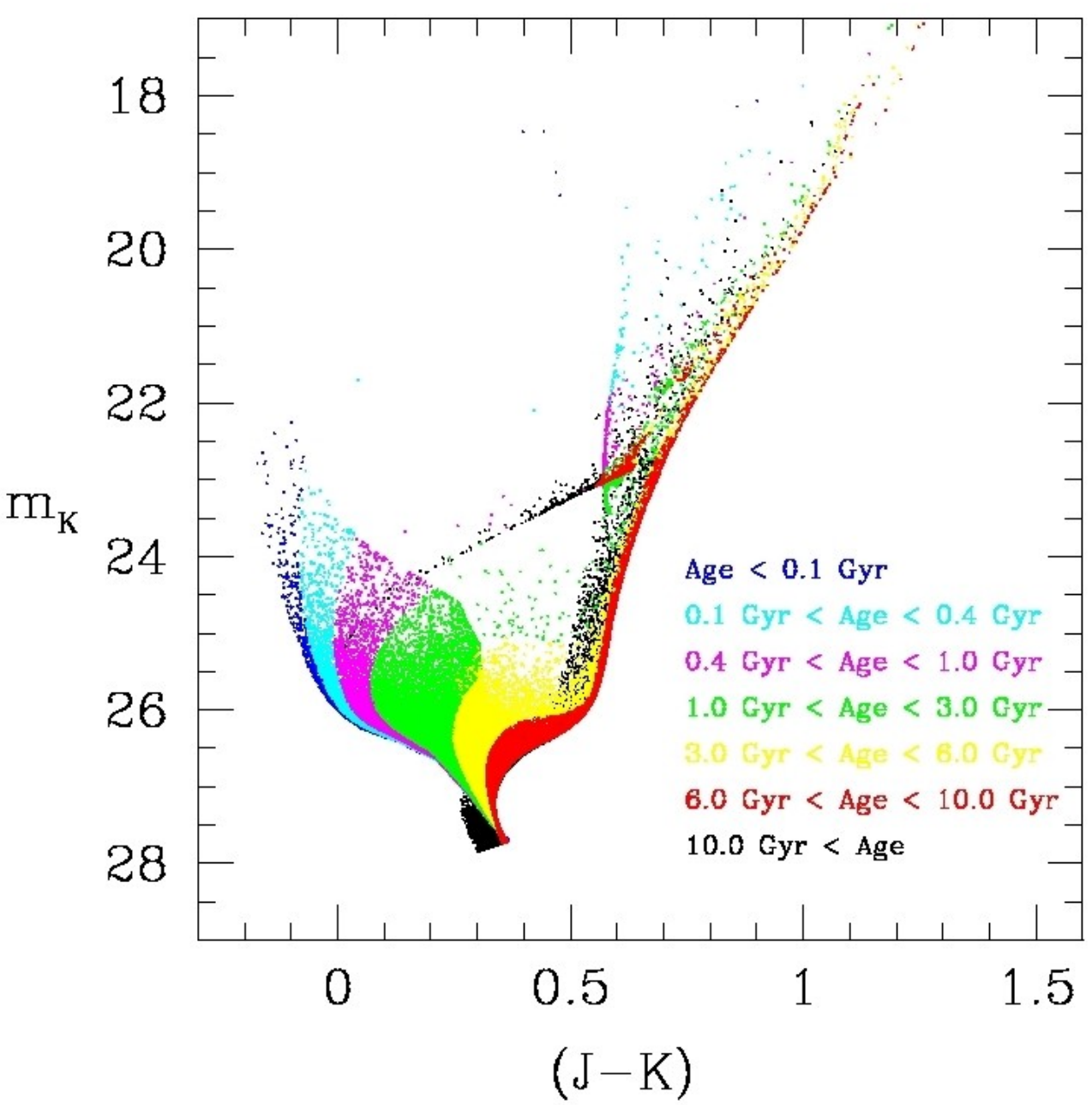


Subgiant Branch
Red Giant Branch (RGB)
Horizontal Branch (HB)
Asymptotic Giant Branch (AGB)

Loci of evolved, dying stars, undergoing
Post-Main Sequence evolution

Let's summarize

Which is understood as an evolutionary sequence



Main Sequence (dwarf)

Subgiant

Red Giant

Horizontal Branch

Asymptotic Giant Branch

TIME