Stellar Properties

Basic Stellar Properties

- Distance (next time)
- Brightness
- Temperature
- Composition
- Speed
- Mass

Stellar Brightness

BRIGHTNESS

- *Stellar brightness is affected by ….*
  - Distance
  - Size
  - Temperature

  (Size and Temperature: Luminosity)

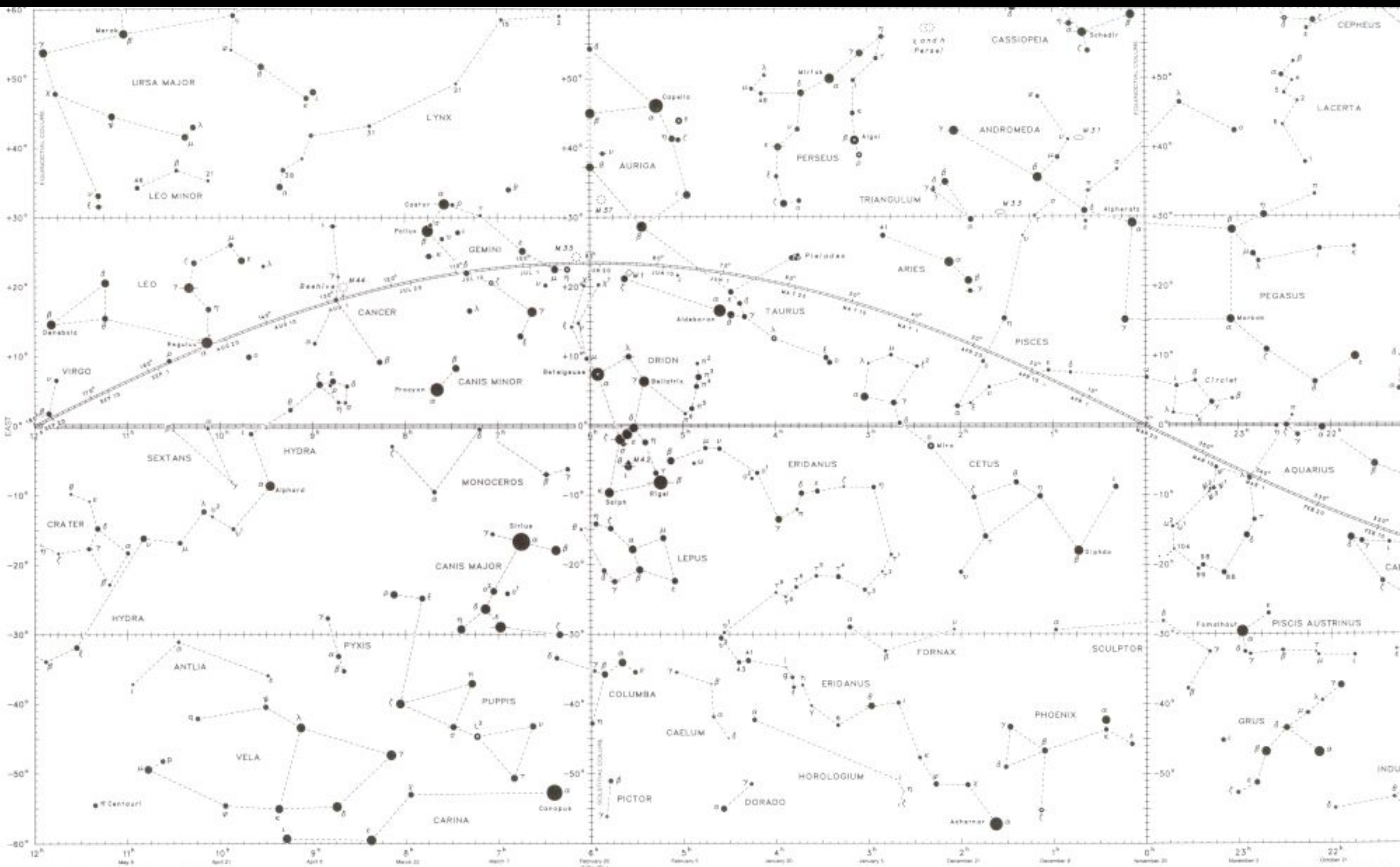
- *There are two brightness scales…*
  - Apparent Magnitude
  - Absolute Magnitude

Apparent Magnitude

(or apparent brightness)

- The APPARENT MAGNITUDE SCALE is the brightness scale for stars as they appear in the sky to the naked eye (e.g. the size of the dots on star charts).

- The Apparent Magnitude scale was first proposed by the Greek astronomer Hipparchus (150 BC)



Each hour circle is labeled with the date on which it coincides with the meridian above the celestial pole at 8 p.m. local time.

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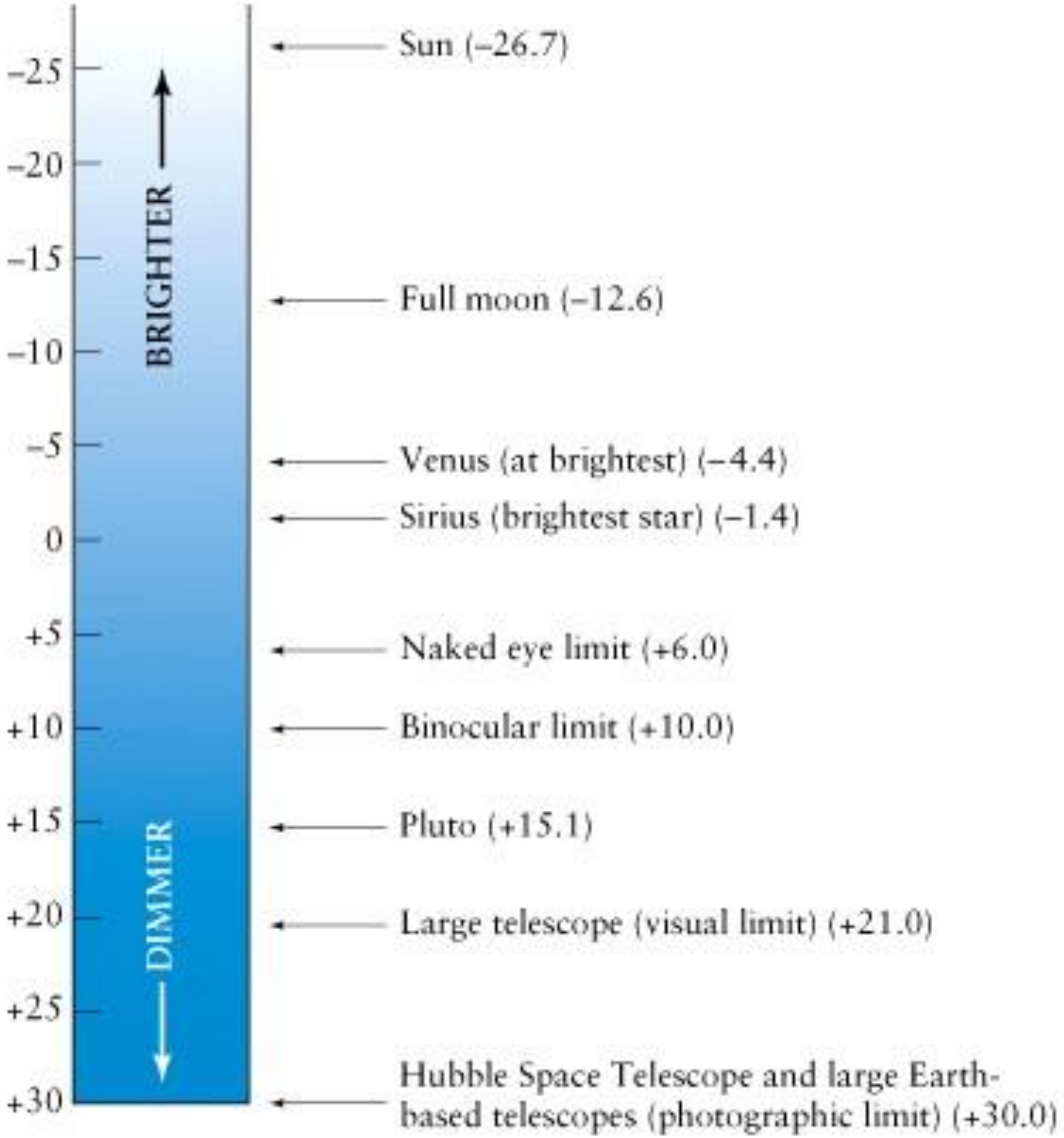
Hipparchus' Apparent Magnitude Scale

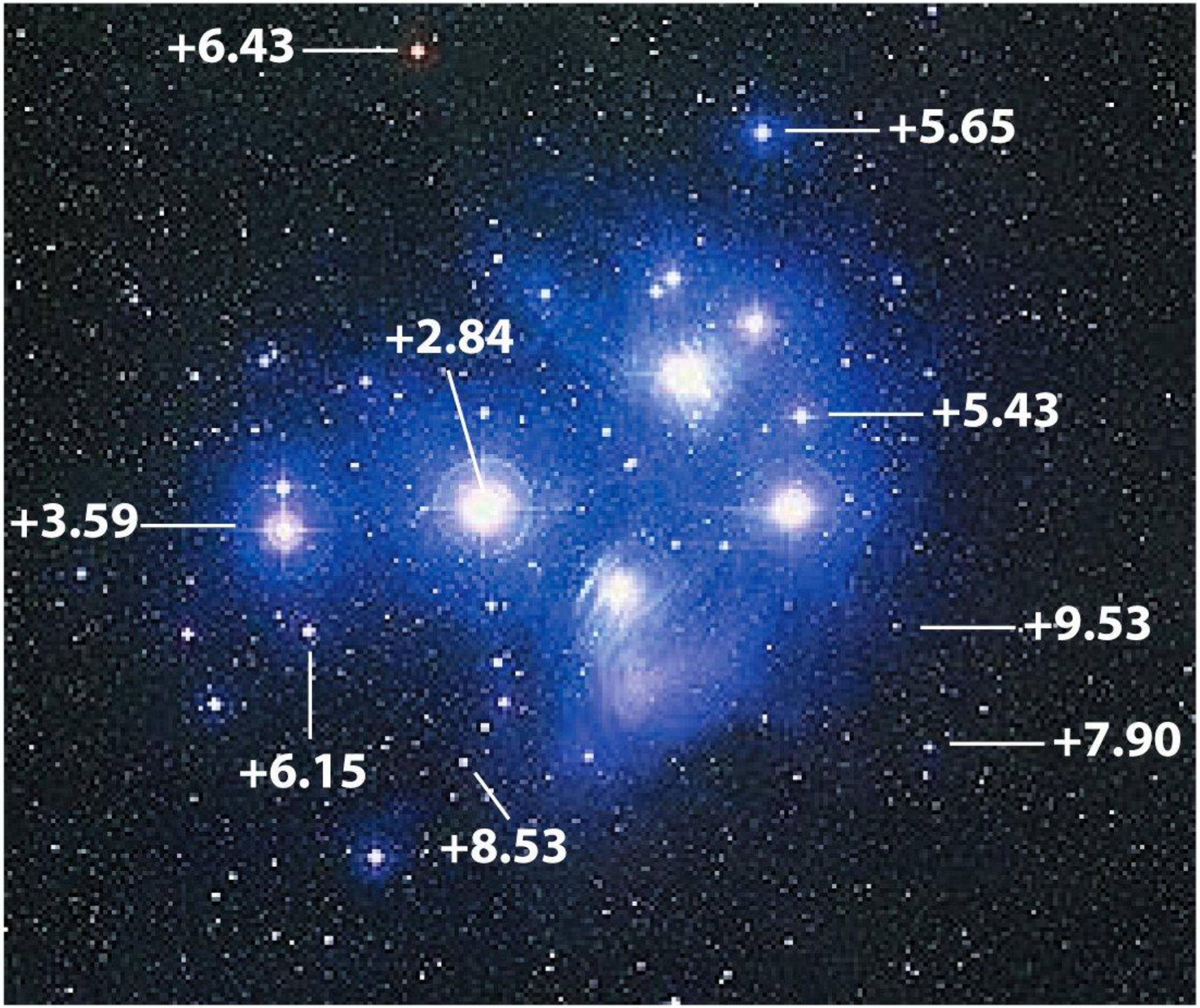
Brightest Stars	1st Magnitude	1st Magnitude
Next Brightest Stars	2nd Magnitude	½ the 1st Magnitude
.	3rd Magnitude	½ the 2nd Magnitude
.	4th Magnitude	½ the 3rd Magnitude
.	5th Magnitude	½ the 4th Magnitude
Dimmest Stars	6th Magnitude	½ the 5th Magnitude

Apparent Magnitude (m_v)

- 19th century photographers learned how the eye responds to light.
- Doubling the brightness is not perceived as a doubling by the eye.
- Eye response is logarithmic.
- Pogson (19th century) established a logarithmic scale for stellar magnitudes.
- Pogson said that 1st magnitude stars are 100 times brighter than 6th magnitude stars.



–25
–20
–15
–10
–5
0
+5
+10
+15
+20
+25
+30
BRIGHTER
DIMMER
Sun (–26.7)
Full moon (–12.6)
Venus (at brightest) (–4.4)
Sirius (brightest star) (–1.4)
Naked eye limit (+6.0)
Binocular limit (+10.0)
Pluto (+15.1)
Large telescope (visual limit) (+21.0)
Hubble Space Telescope and large Earth-based telescopes (photographic limit) (+30.0)



Apparent magnitudes of stars in the Pleiades

Luminosity

- Surface temperature and surface area determine the luminosity of a star.

- Luminosity : the rate at which a star radiates energy.

- Stefan-Boltzmann Law – The luminosity *(energy per second)* of a star of temperature T and surface area $4\pi r^2$ is found by the following equation:

$$L = 4\pi R^2 \sigma T^4$$

Luminosity = Surface Area x Flux (depends on temperature)

Don't Panic! I am not going to ask you to do any math problems with this formula!

Solar Luminosity

- The Sun's luminosity is 3.9×10^{26} Watts (joules per second) or…
- The symbol for the Sun's luminosity is …. $L_{\odot}$
- $b_{sun} = (3.86 \text{x} 10^{26} \text{W})/4\pi(1.5 \text{x} 10^{11} \text{m}) = 1370 \text{ W/m}^2$
- This means that a 1 meter square solar panel can collect 1370 W from the Sun.

Absolute Magnitude (M_v)

- The magnitude that a star would have if it were 10 parsecs away from Earth.

- **Absolute magnitude is another way to represent a star's luminosity.**

- To calculate M_v, you must know the star's apparent magnitude and distance (using the parallax method).

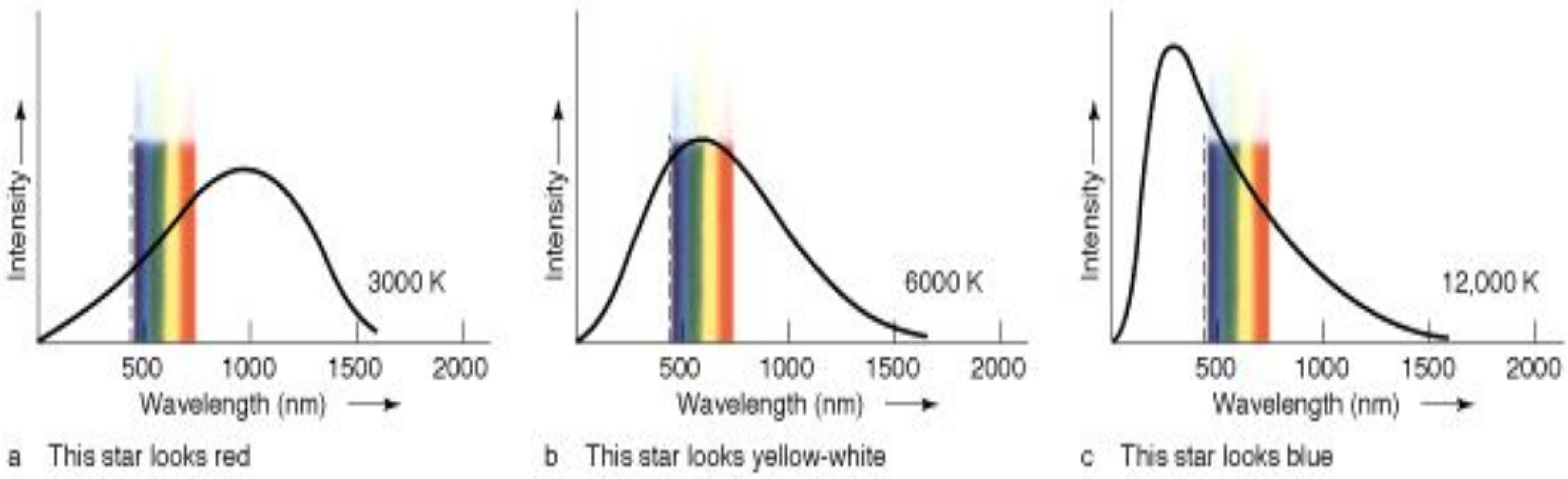
Absolute Magnitude & Luminosity

Absolute Magnitude	Luminosity (x Sun)
-5	10,000
0	100
5	1
10	0.01

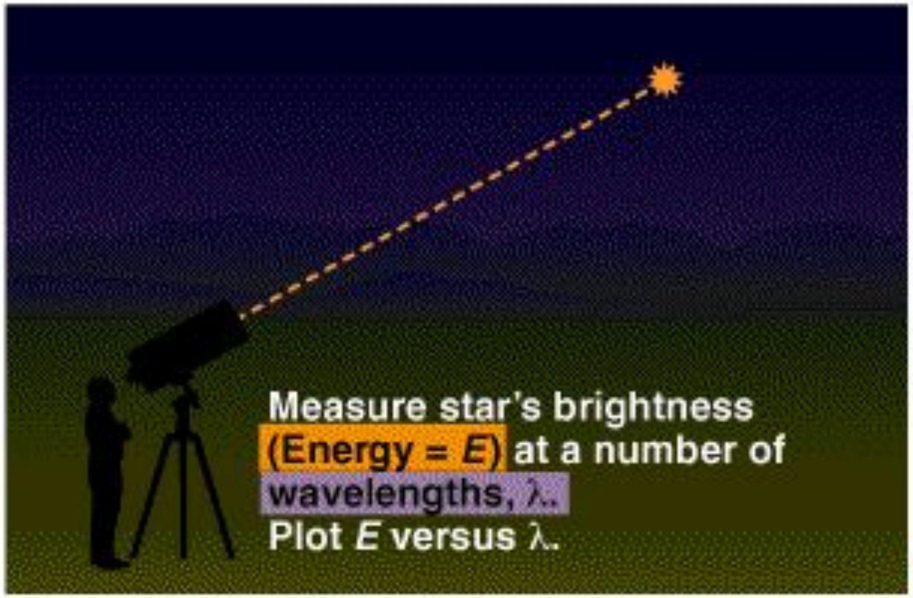
Stellar Temperatures

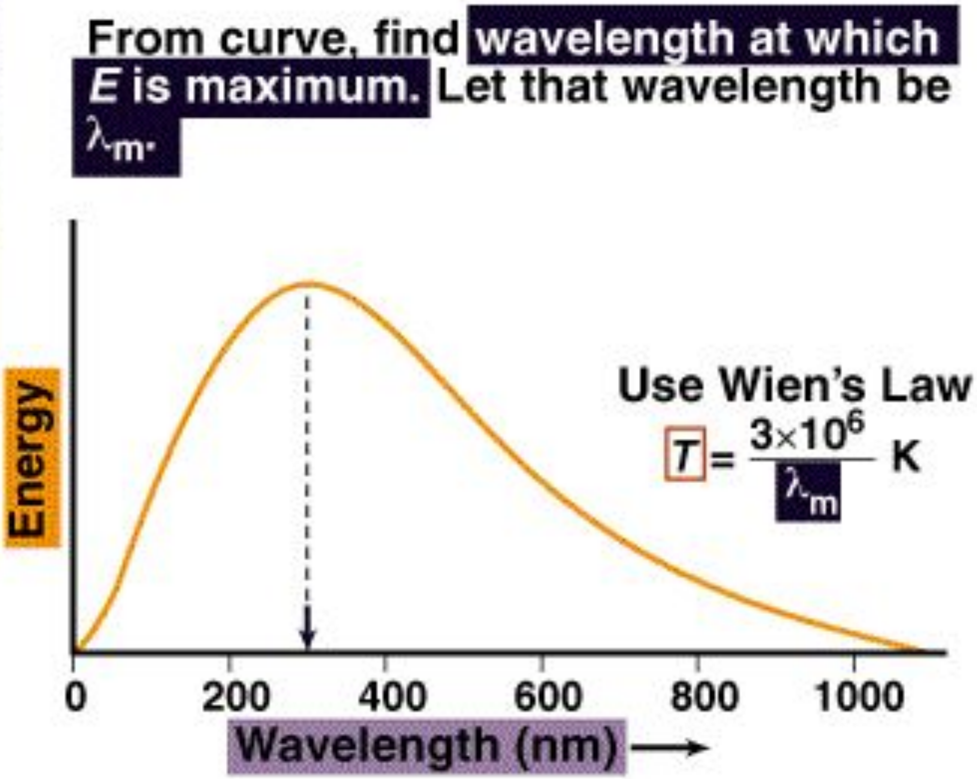
Measuring A Star's Temperature

- A star's surface temperature can be determined from its color using Wien's Law.

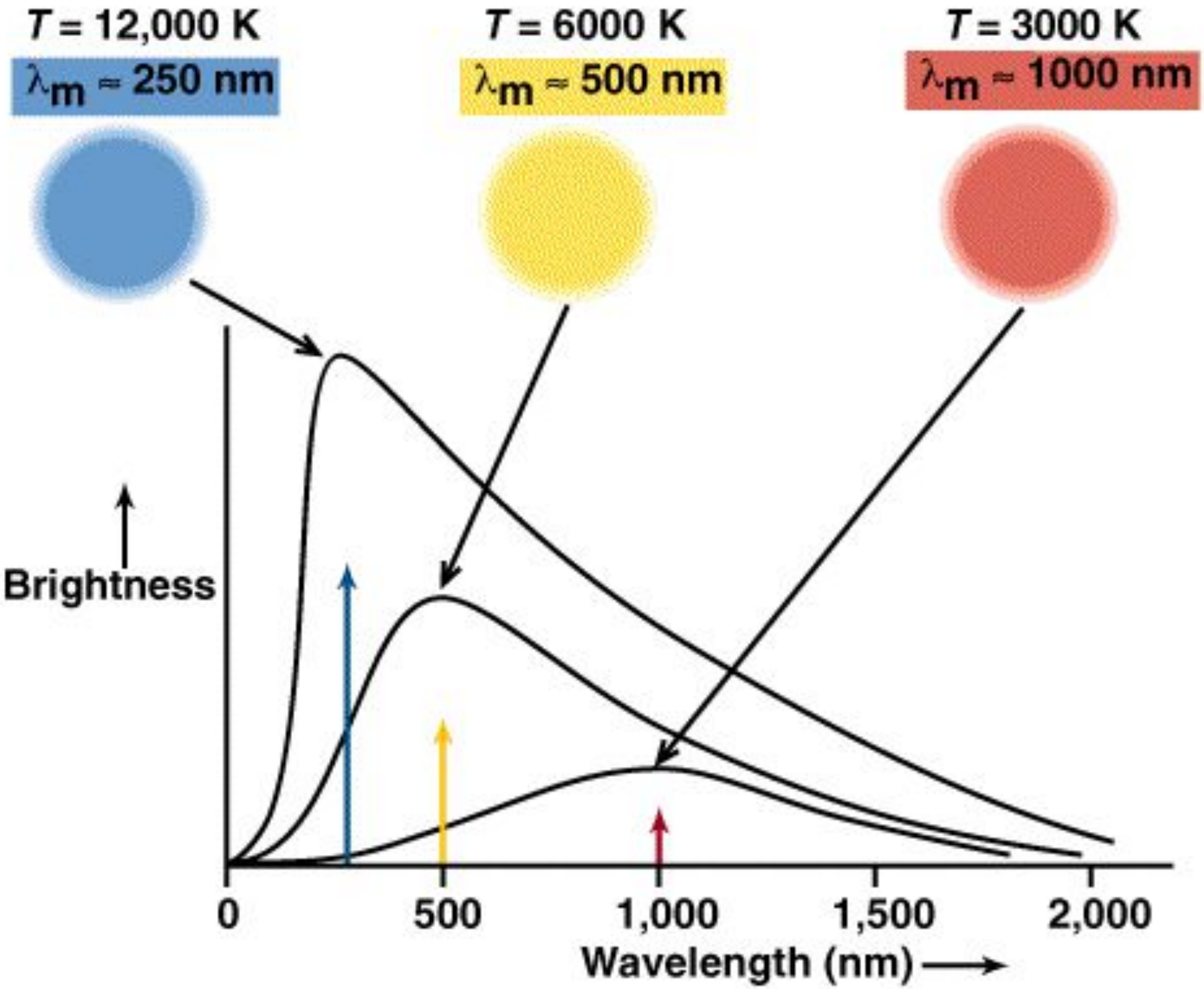


Measuring a Star's Temperature from its Color





Wien's Law



T = 12,000 K
λm ≈ 250 nm
T = 6000 K
λm ≈ 500 nm
T = 3000 K
λm ≈ 1000 nm
Brightness
0
500
1,000
1,500
2,000
Wavelength (nm)

Wien's Law

- The wavelength of the peak of the blackbody curve is inversely proportional to the temperature.

$$\lambda_{\max} \propto \frac{1}{T}$$

$$\lambda_{\max} = \frac{2.9 \times 10^{-3}\,Km}{T} \qquad T = \frac{2.9 \times 10^{-3}\,Km}{\lambda_{\max}}$$

Stellar Composition

Measuring a Star's Composition

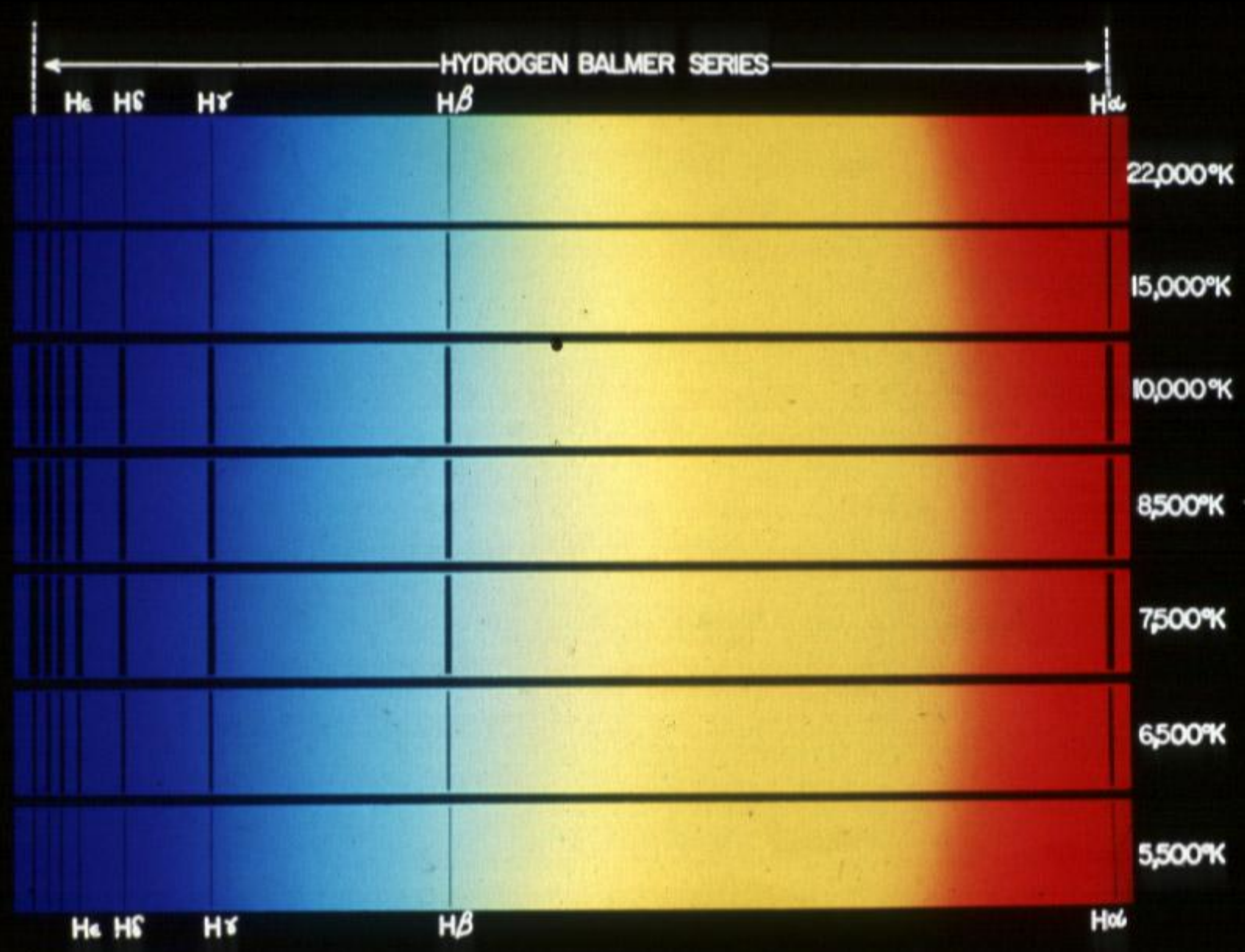
- Each atom absorbs a unique combination of wavelengths of light -- from this we can determine the composition of a star.

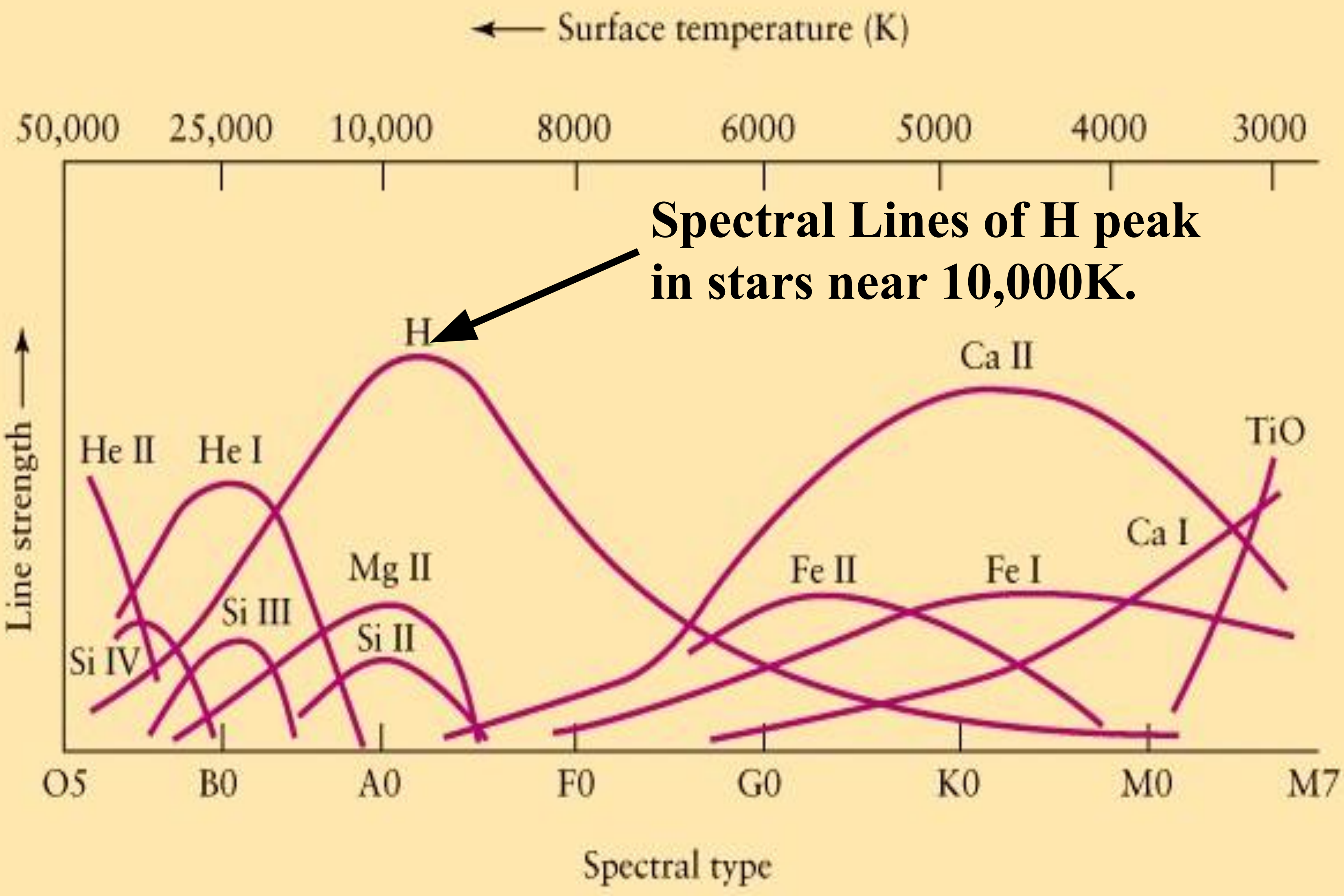
- Spectroscopy reveals what chemical substances are present in the star.

- Star's are composed of mostly hydrogen.

So why don't all stars have strong hydrogen lines?

Temperature!





← Surface temperature (K)
50,000
25,000
10,000
8000
6000
5000
4000
3000
Spectral Lines of H peak in stars near 10,000K.
H
Ca II
TiO
He II
He I
Ca I
Mg II
Fe II
Fe I
Si III
Si II
Si IV
Line strength →
O5
B0
A0
F0
G0
K0
M0
M7
Spectral type

Stellar Spectroscopy

Putting all the pieces together!

Stellar Spectroscopy

- Stellar Spectroscopy (began in 1817) is the study of the properties of stars by measuring absorption line strengths (line spectra).

- At first, stellar spectral classification was done by ordering their spectra according to complexity of spectral lines (strength or weakness of H lines).

- This was an alphabetical system: A to Q.

Astronomical Computers (Harvard College Observatory 1900)

13 May 1913

- A group of women astronomers working under the direction of W. Pickering. Paid 50 cents per hour
- These astronomers spent years examining the spectra of stars obtained from a number of observatories.
- The project finished in the early 1920s with the publication of the Henry Draper Catalog of 225,300 stars.

Astronomical Computers (Harvard College Observatory 1900)

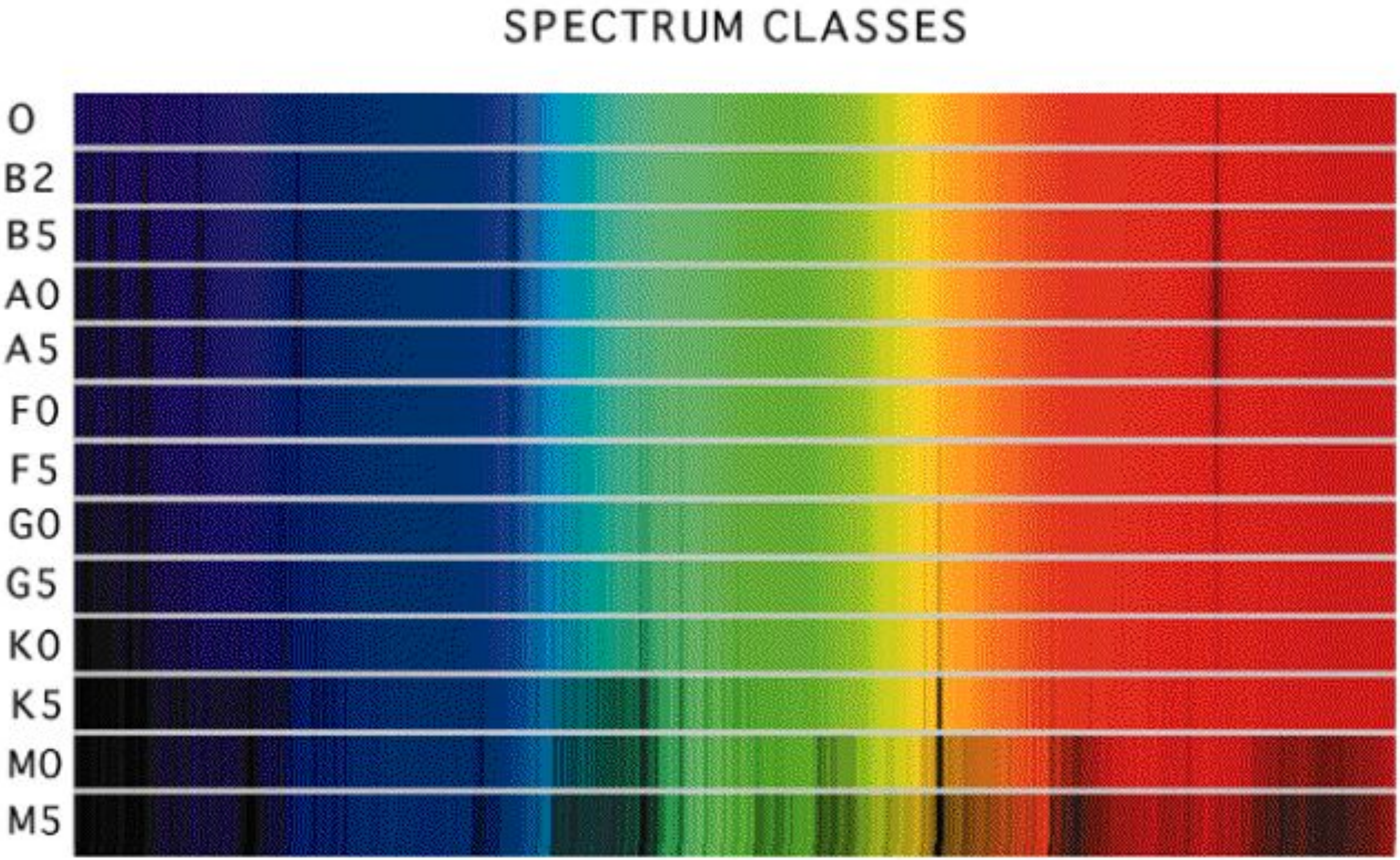
- Thanks to the work of these computers, the stellar classification system was reordered by temperature (they kept the old alphabetical labels).

Stellar Classification System:

- O B A F G K M
  - Oh, Be A Fine Girl (Guy) Kiss Me

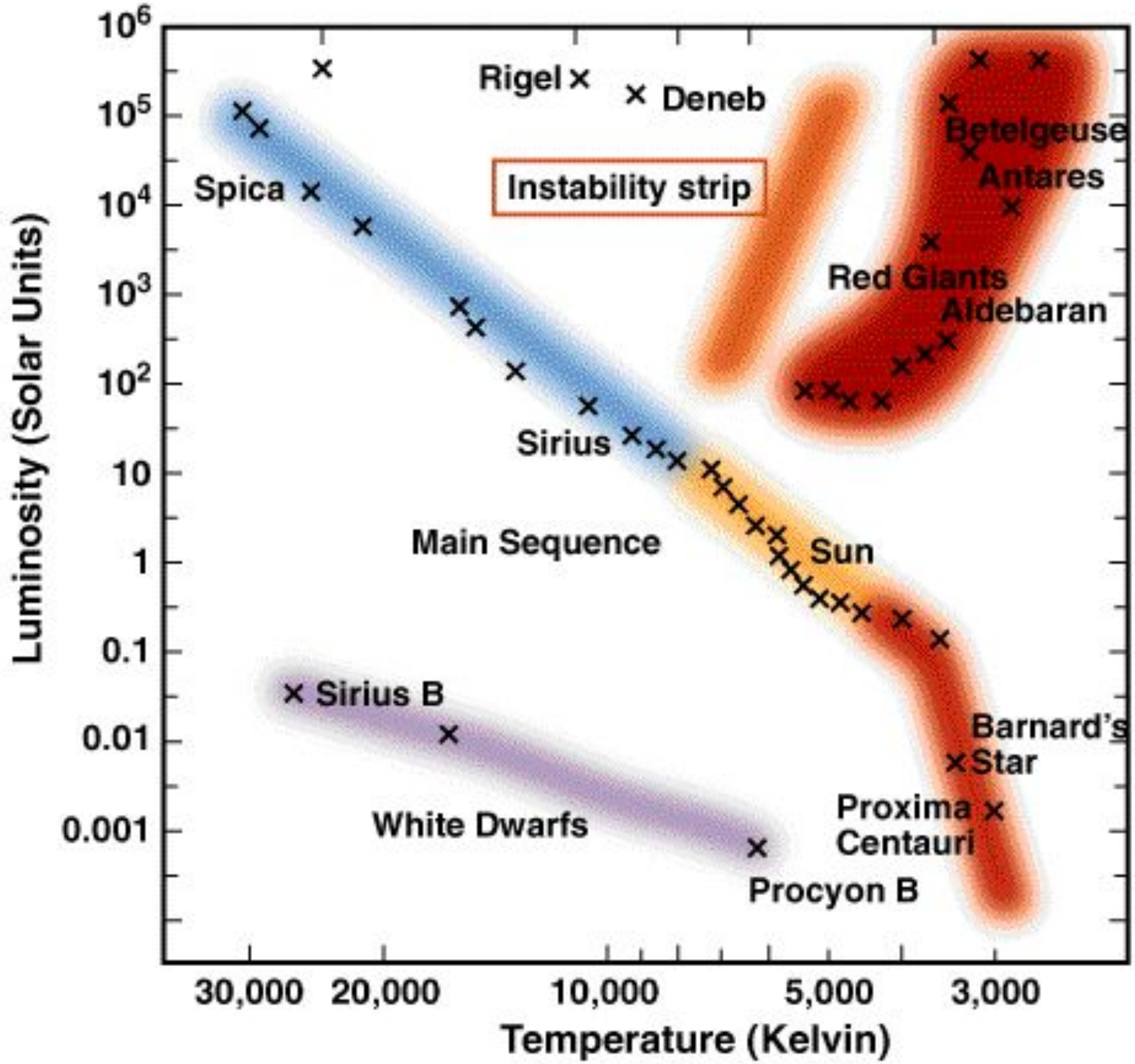
CLASS	COLOR	SURFACE TEMP (K)
O	BLUE-VIOLET	30,000 – 50,000
B	BLUE-WHITE	11,000 – 30,000
A	WHITE	7,500 – 11,000
F	YELLOW-WHITE	5,900 – 7,500
G	YELLOW	5,200 – 5,900
K	ORANGE	3,900 – 5,200
M	RED-ORANGE	2,500 – 3,900

Star Spectrum Classes

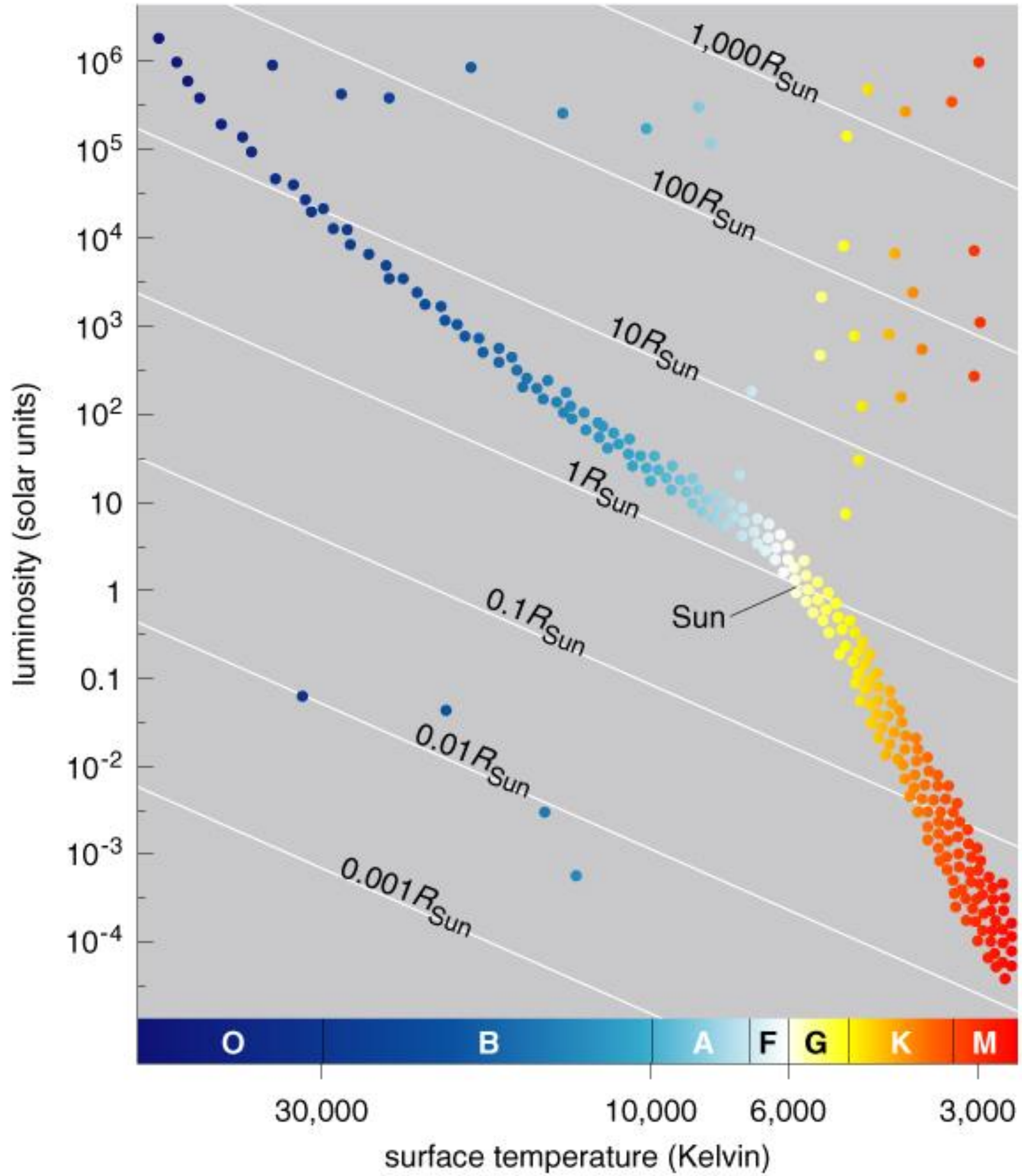


Hertzsprung-Russell Diagram

- Plots of luminosity versus temperature for known stars
- Most stars on the H-R diagram lie along a diagonal curve called the main sequence.
- Main sequences stars are still 'burning' Hydrogen through the process of fusion.



Luminosity (Solar Units)
Temperature (Kelvin)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
0.01
0.001
30,000
20,000
10,000
5,000
3,000
Rigel
Deneb
Spica
Instability strip
Betelgeuse
Antares
Red Giants
Aldebaran
Sirius
Main Sequence
Sun
Sirius B
Barnard's Star
Proxima Centauri
White Dwarfs
Procyon B

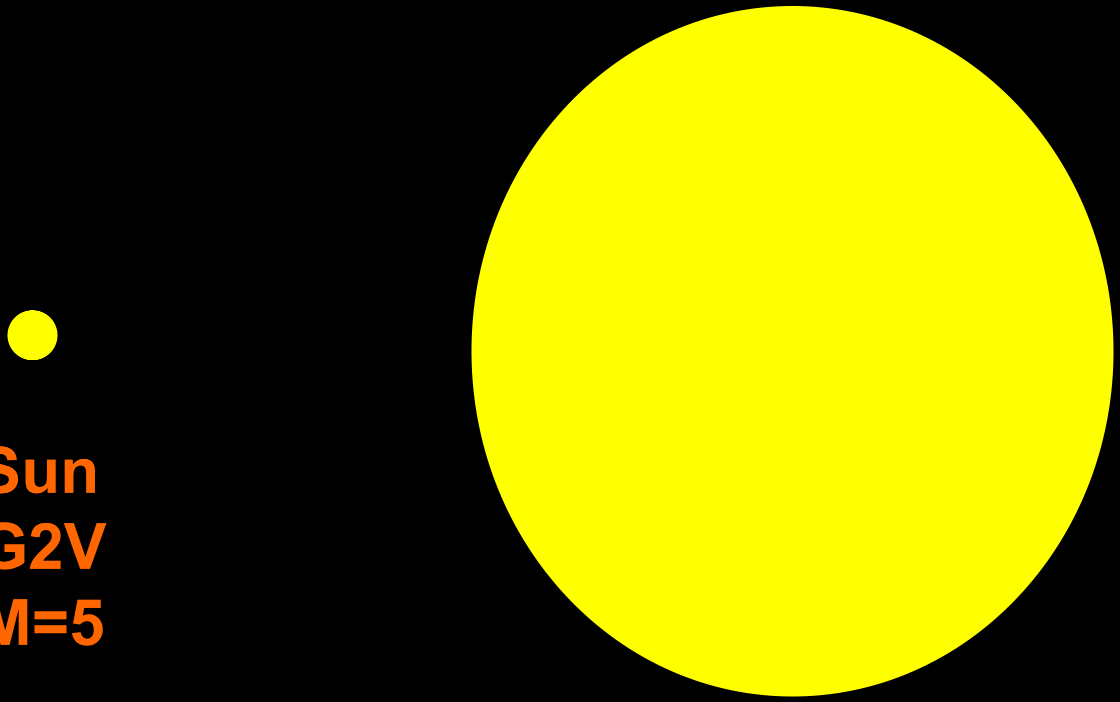

luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^-2
10^-3
10^-4
1,000R_Sun
100R_Sun
10R_Sun
1R_Sun
0.1R_Sun
0.01R_Sun
0.001R_Sun
Sun
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
surface temperature (Kelvin)

Luminosity Classes

- Luminosity Class implies Size
  - Equal sized pieces (unit areas) of each star are equally bright

Luminosity Class	Star Type
I	Super Giant
II	Bright Giant
III	Giant
IV	Sub-Giant
V	Dwarf

Luminosity Class Example:



Sun
G2V
M=5

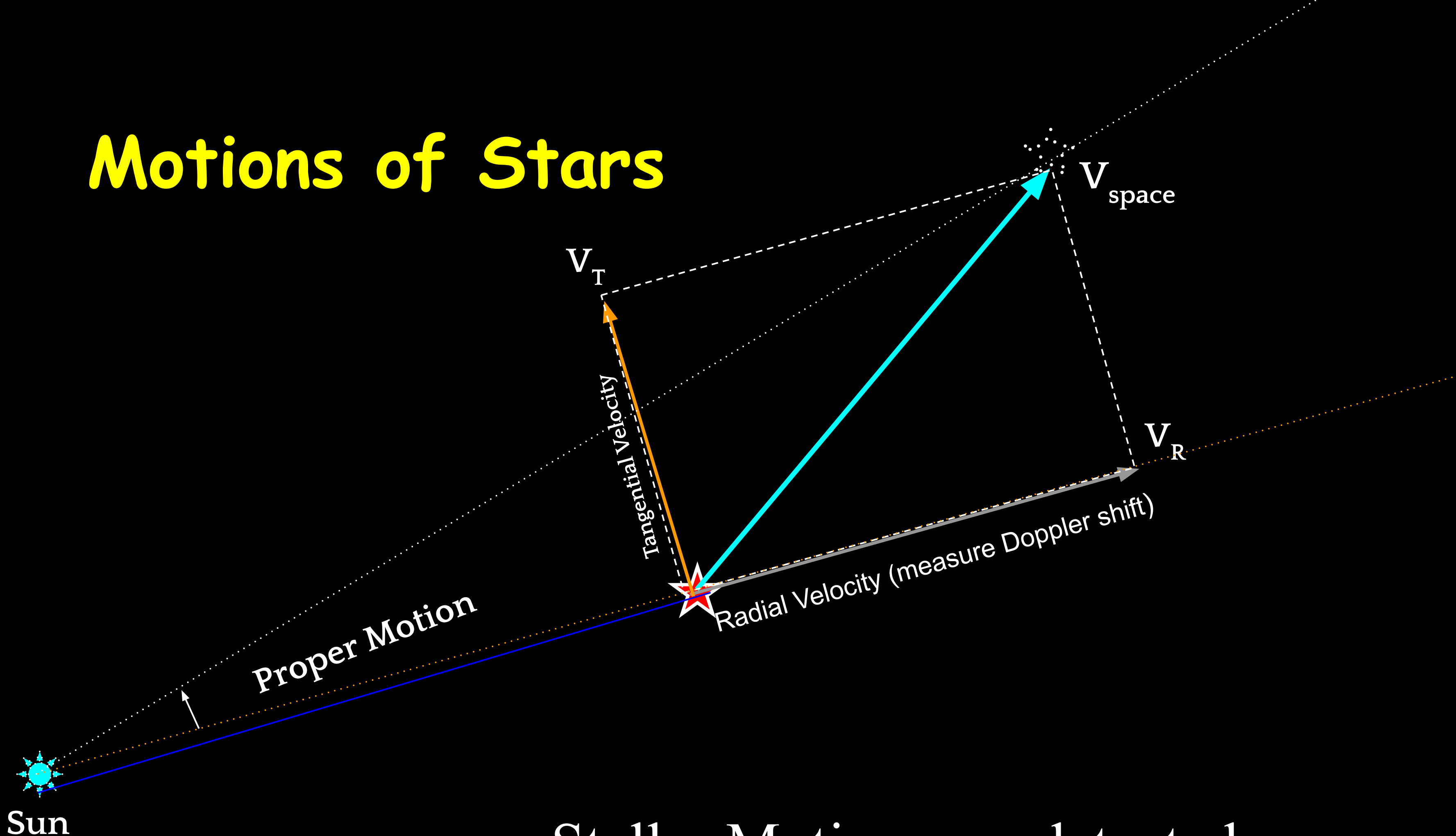
Capella
G2III
M=0

Stellar Motion

Stellar Motion Detection
Two Methods

- Astrometry – the precise measurement and observation of a star's proper motion.
  - This is the only direct method of measuring a star's motion.
- Spectroscopy – Doppler shift in stellar spectra can reveal a star's motion.
  - This is an indirect method of detecting a star's motion.

Motions of Stars



Stellar Motions are detected…

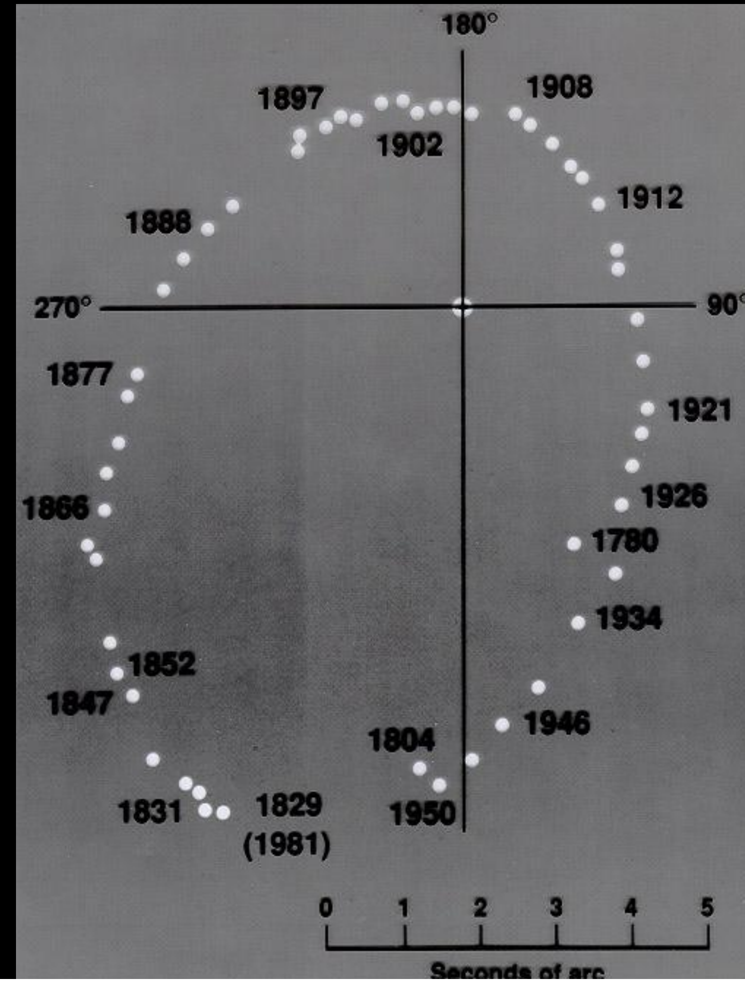
1. Directly
2. Indirectly (doppler shift)

Multiple Star Systems and Stellar Mass

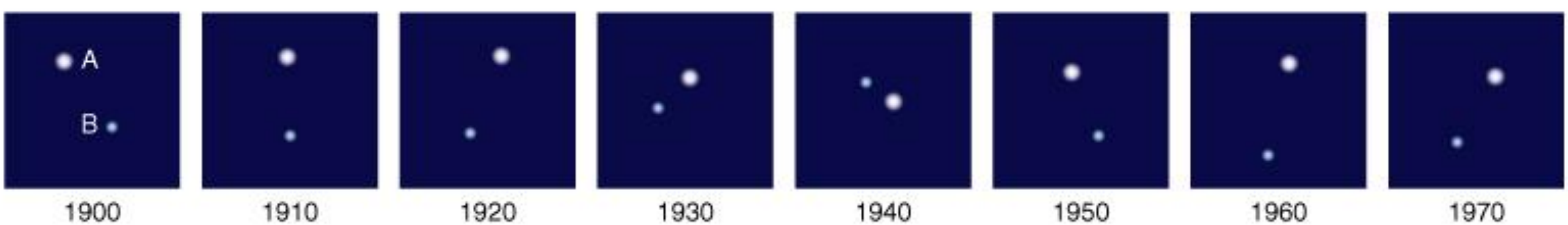
- More than half of what appear as single stars are in fact multiple star systems.
- **Optical doubles** are two stars that have small angular separation as seen from Earth but are not gravitationally linked.
- **Binary star system** is a system of two stars that are gravitationally linked so that they orbit one another.

Binary Stars

Xi Bootes



Sirius



Stellar Mass

Useful information from Stellar Motion

- Speed and Direction of motion.
- If the star is part of a multiple star system…
  - Orbital motion
  - Using Kepler's 3rd Law, we can determine the mass of each star in the system (this is the only way to do this!!!).

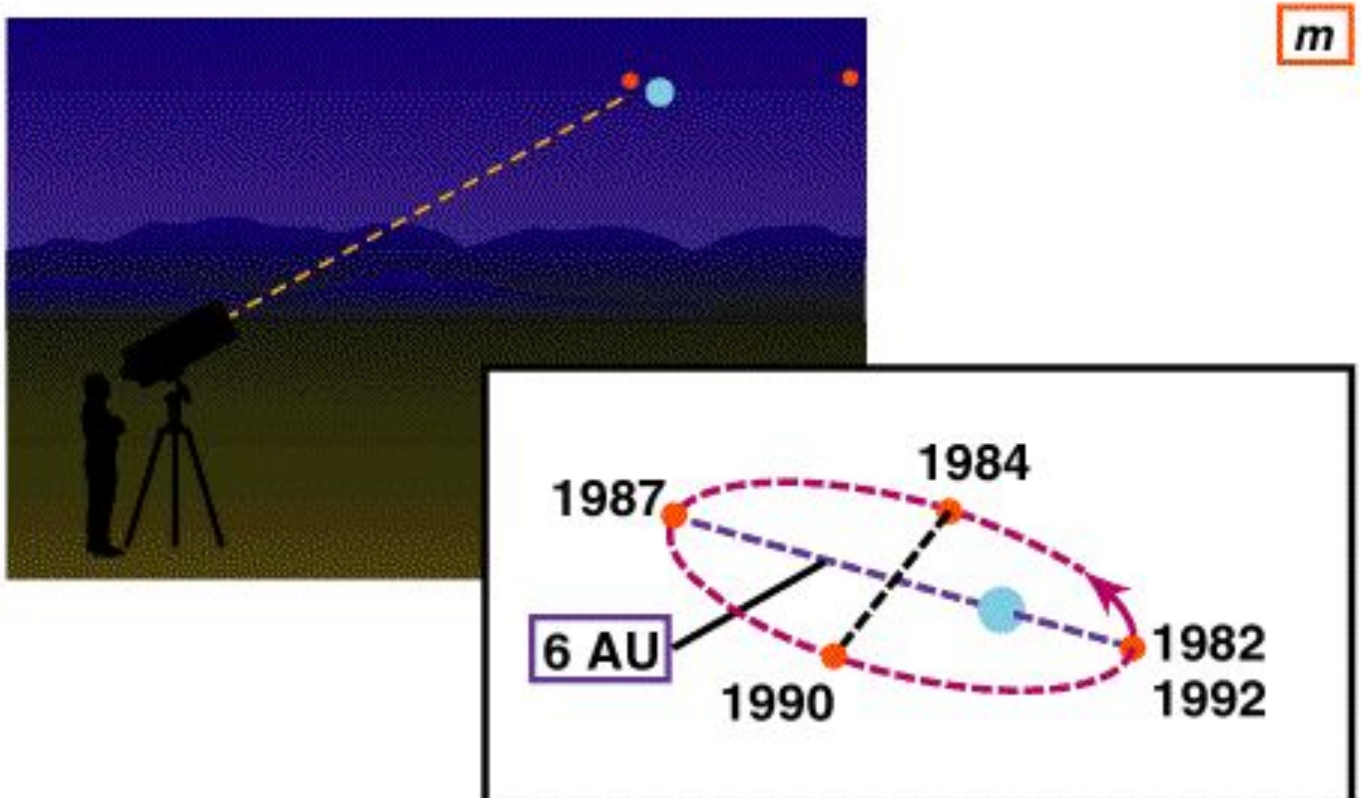
Measuring the Mass of Binary Stars

Plot of star positions ⟶ Period of 10 years

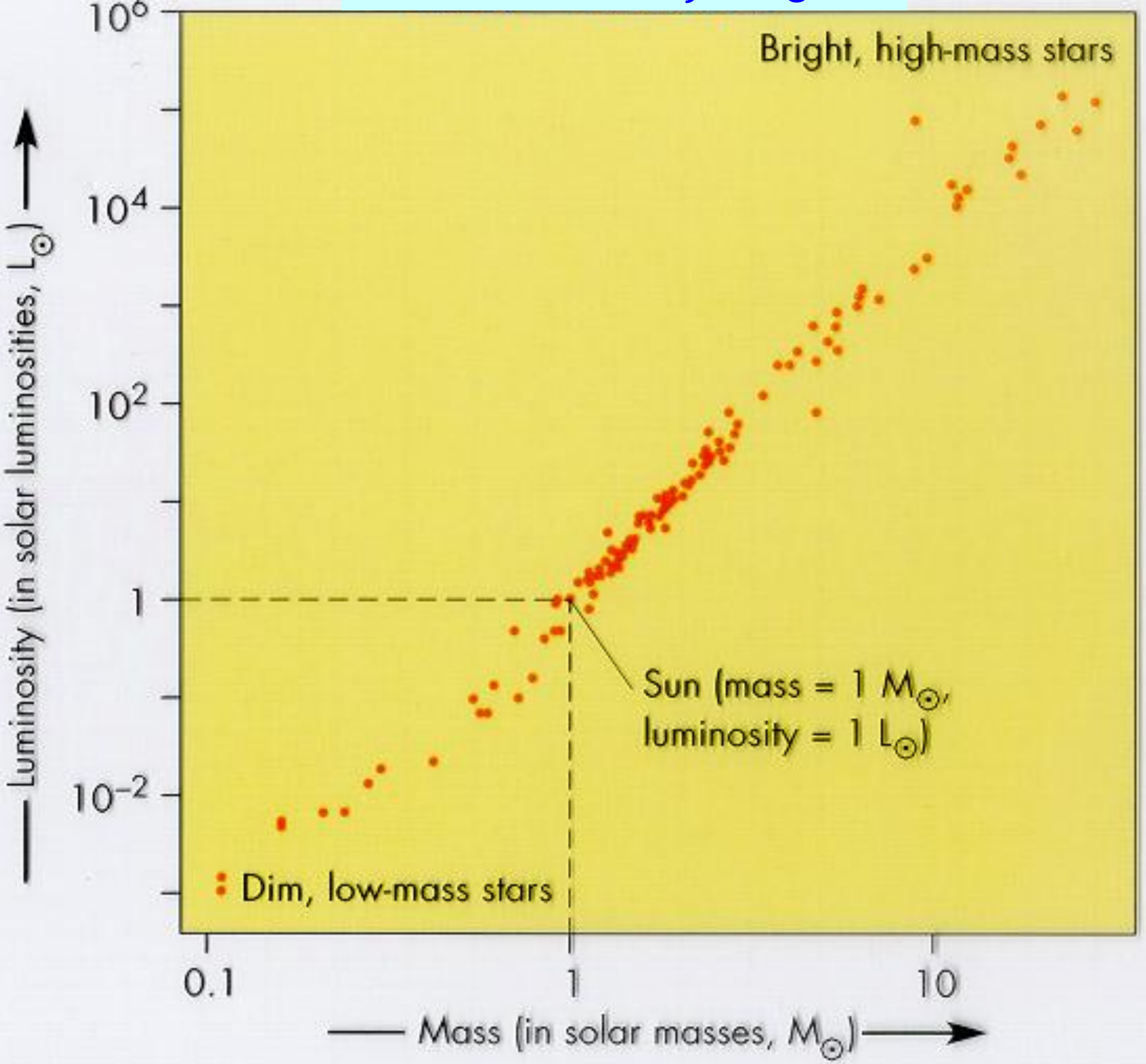
Measure separation = a = 6 AU

Use modified form of Kepler's third law

$$m + M = \frac{a^3}{p^2} = \frac{6^3}{10^2} = 2.16\ M_\odot$$



Mass-Luminosity Diagram



Mass-Luminosity Relationship

- Why is this important?

- It gives astronomers another method to determine the mass of star.

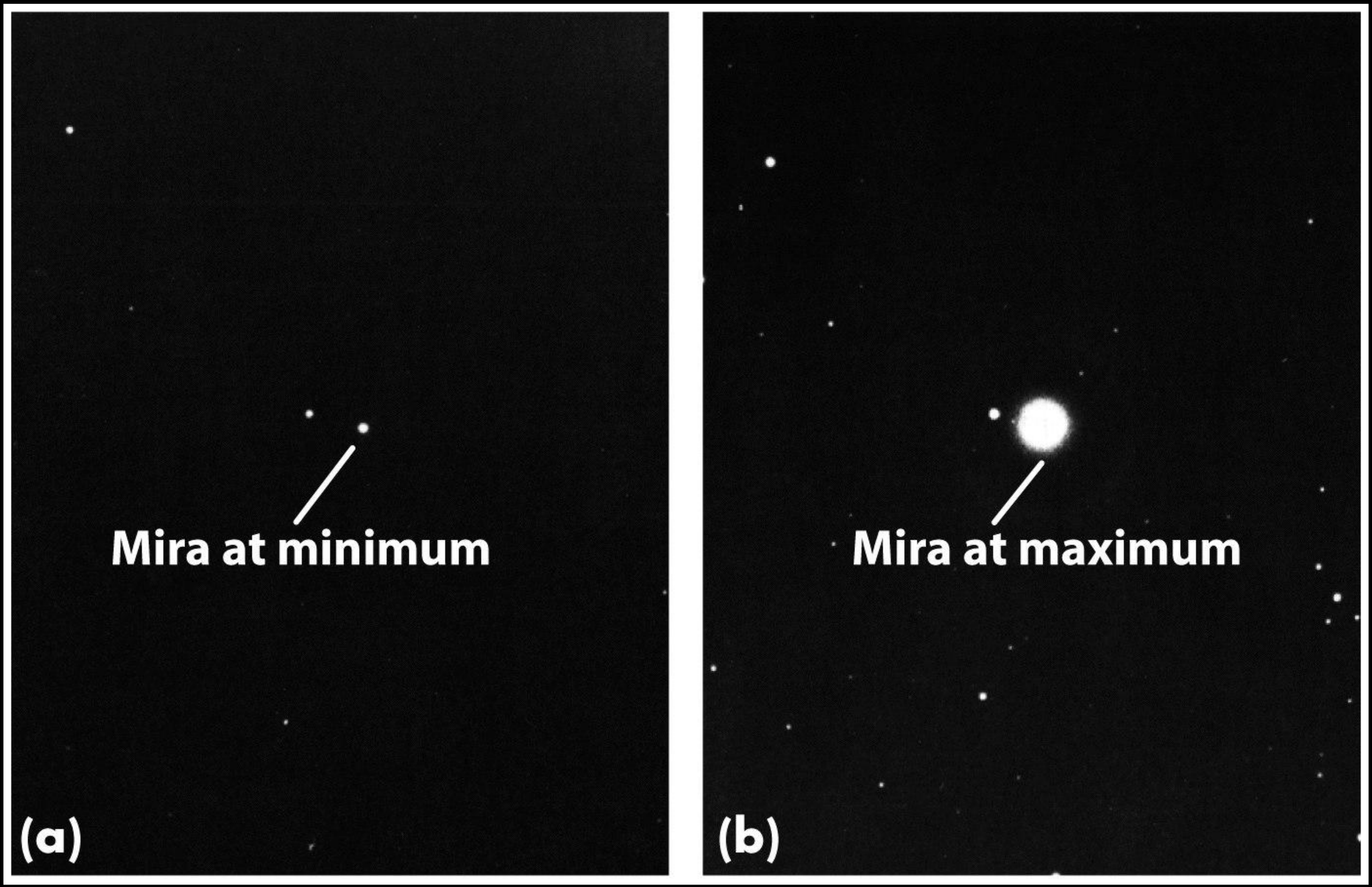
- Especially if that star isn't part of a multiple star system!

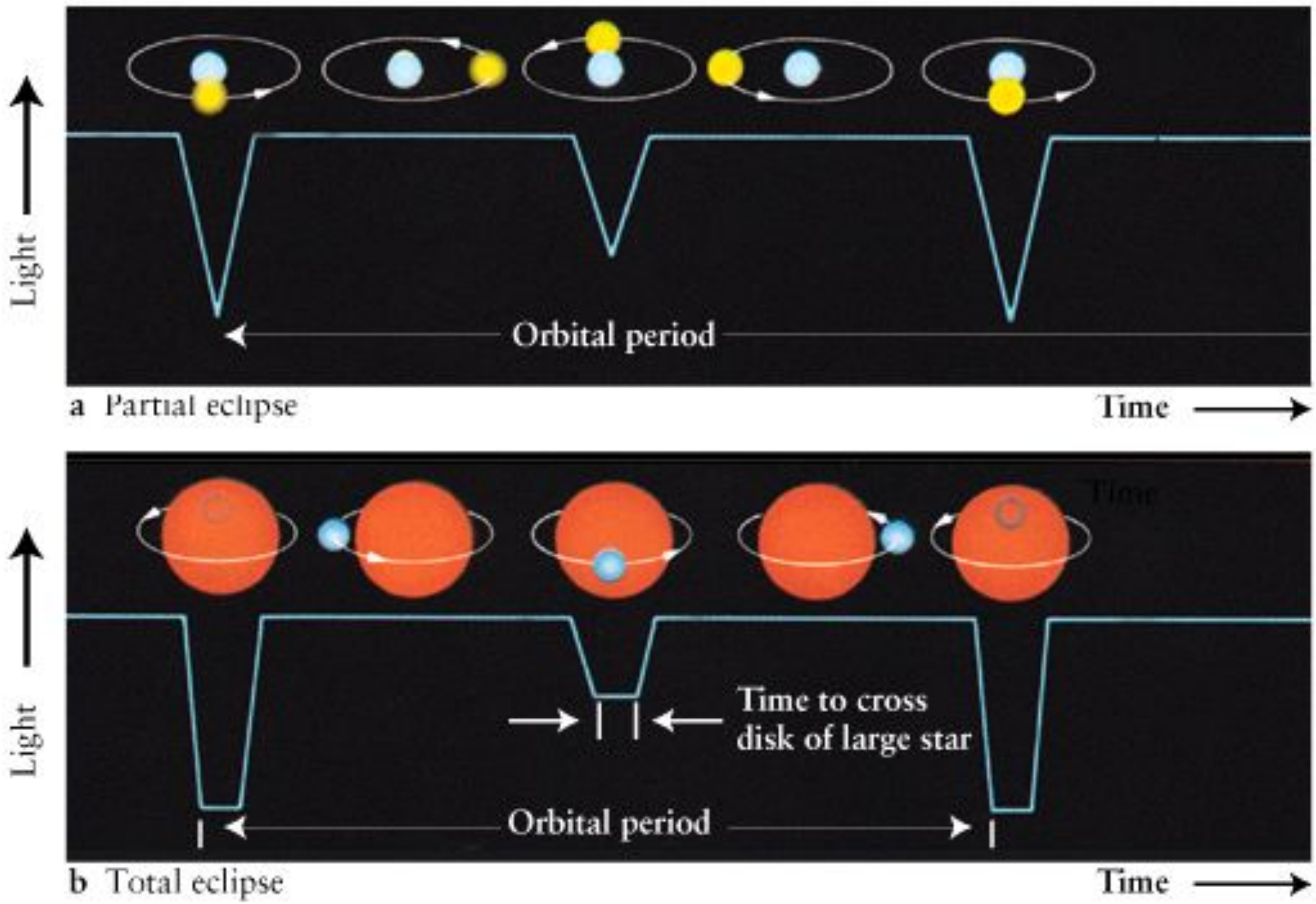
Variable Stars

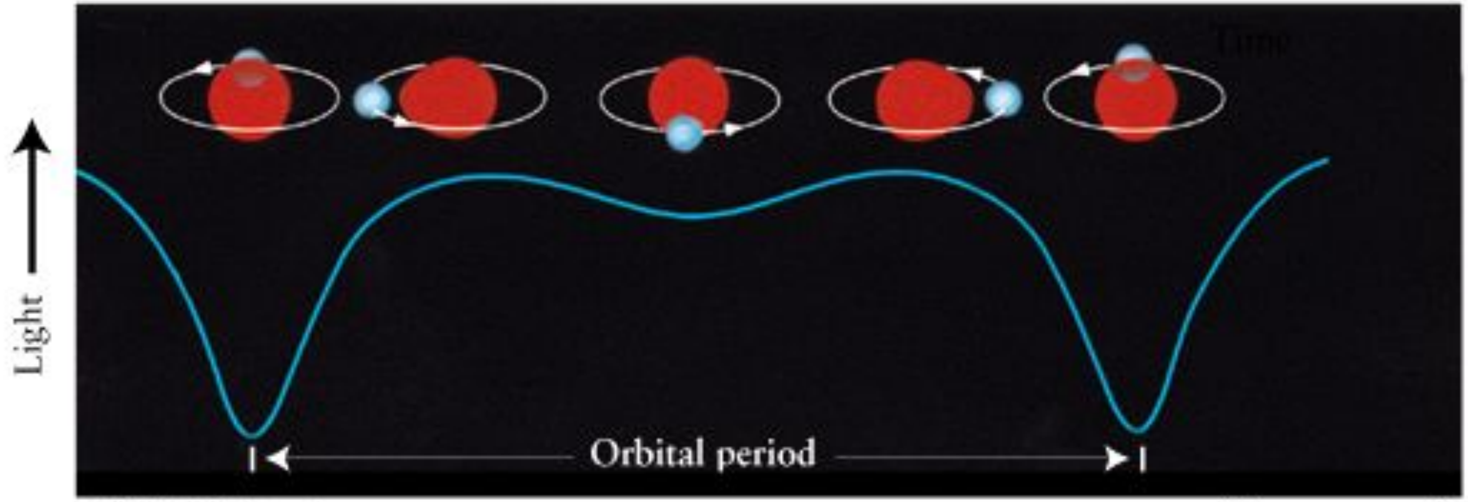
- Stars that have a change in brightness over time are called variable stars.

- Examples:
  - eclipsing binary stars
  - Cepheid variables
  - Mira variables

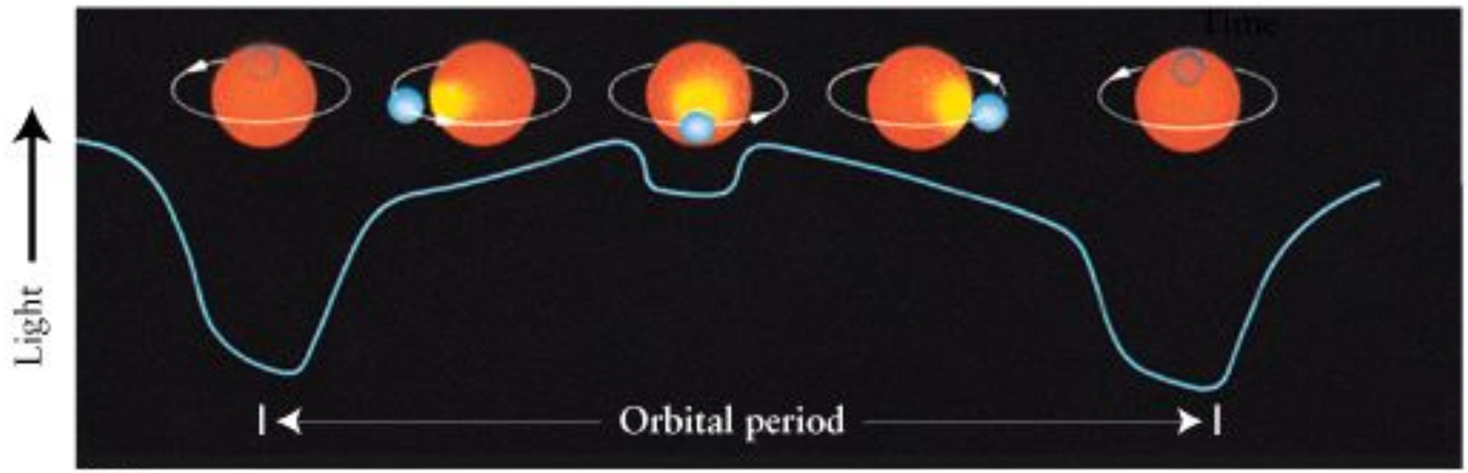
- Light Curve - a plot of a variable star's apparent magnitude versus time


Mira at minimum
(a)
Mira at maximum
(b)


Light
Orbital period
a Partial eclipse
Time
Light
Time to cross
disk of large star
Orbital period
b Total eclipse
Time



c Tidal distortion



d Hot-spot