Stellar Properties:

MASS SIZE ENERGY TEMPERATURE

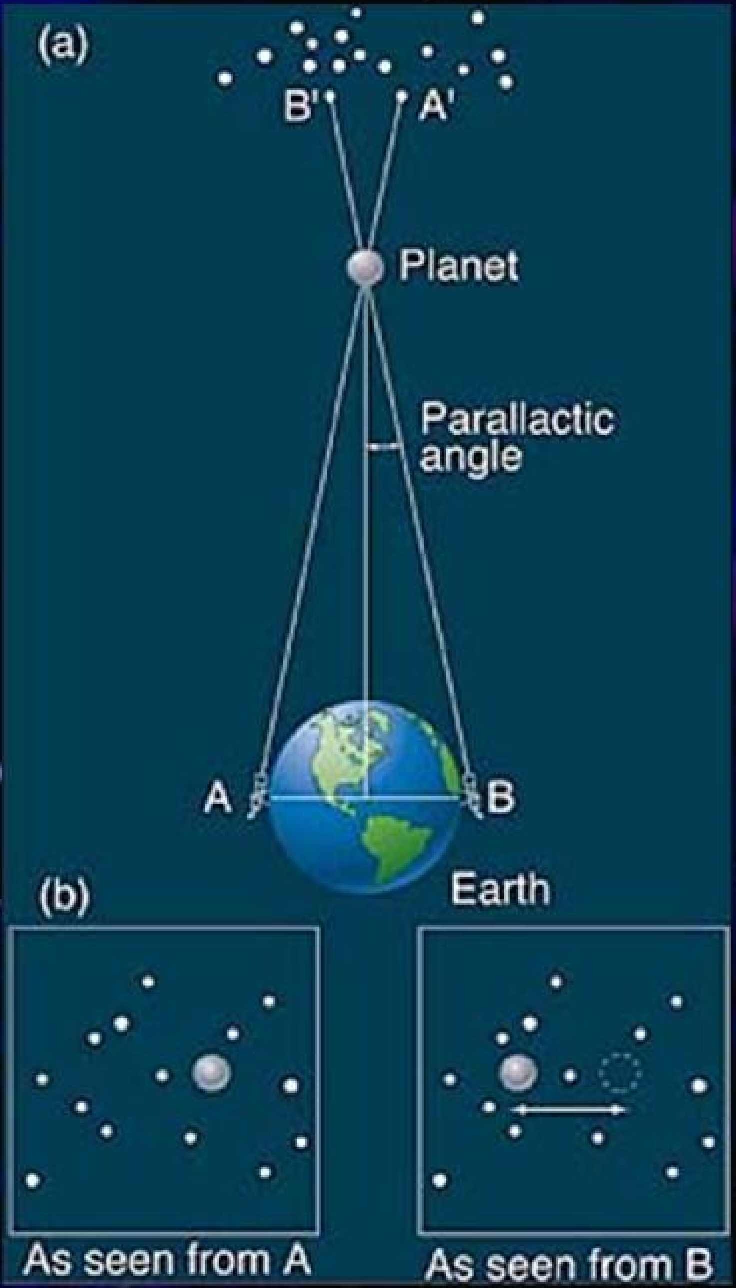
DISTANCE CHEMICAL-COMPOSITION

MOTION EVOLUTION

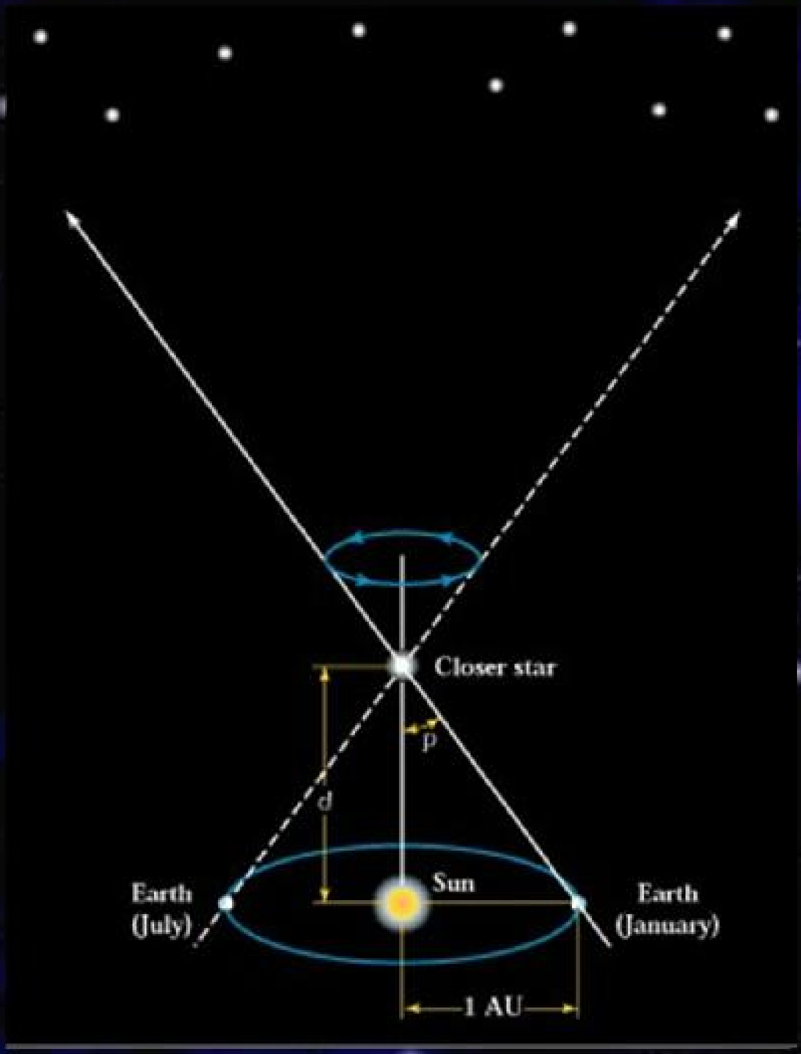
TRIGONOMETRIC PARALLAX

TRIGONOMETRIC PARALLAX

The apparent shift of a “nearby” object with respect to a distant background due to the observer’s own motion.



$$d \propto \frac{1}{p}$$



$$d \propto \frac{1}{p}$$

(apparent brightness)

–

(true energy given off)

∝

(distance)

APPARENT MAGNITUDE (m)

How bright an object *appears* to an observer on Earth

THE MAGNITUDE SCALE

Hipparchus (2nd Century B.C.)

Brightest stars ð 1st magnitude

Faintest stars ð 6th magnitude

Modern astronomers kept old system but adapted it to a modern scale

A difference of 5 magnitudes is a difference of 100 times in brightness

$$\boxed{\sqrt[5]{100} = 2.512}$$

ABSOLUTE MAGNITUDE (M)

The apparent magnitude of a star at a distance of 33 light years.

Related to the amount of energy the star is emitting

(apparent brightness)-(true energy) μ (distance)

$$m - M = 5\log d - 5$$

$$m - M = 5\log d - 5$$

m= -26.5

M=4.83

d=93,000,000 miles

If Absolute Magnitude is related to the amount of energy a star is emitting...

Then

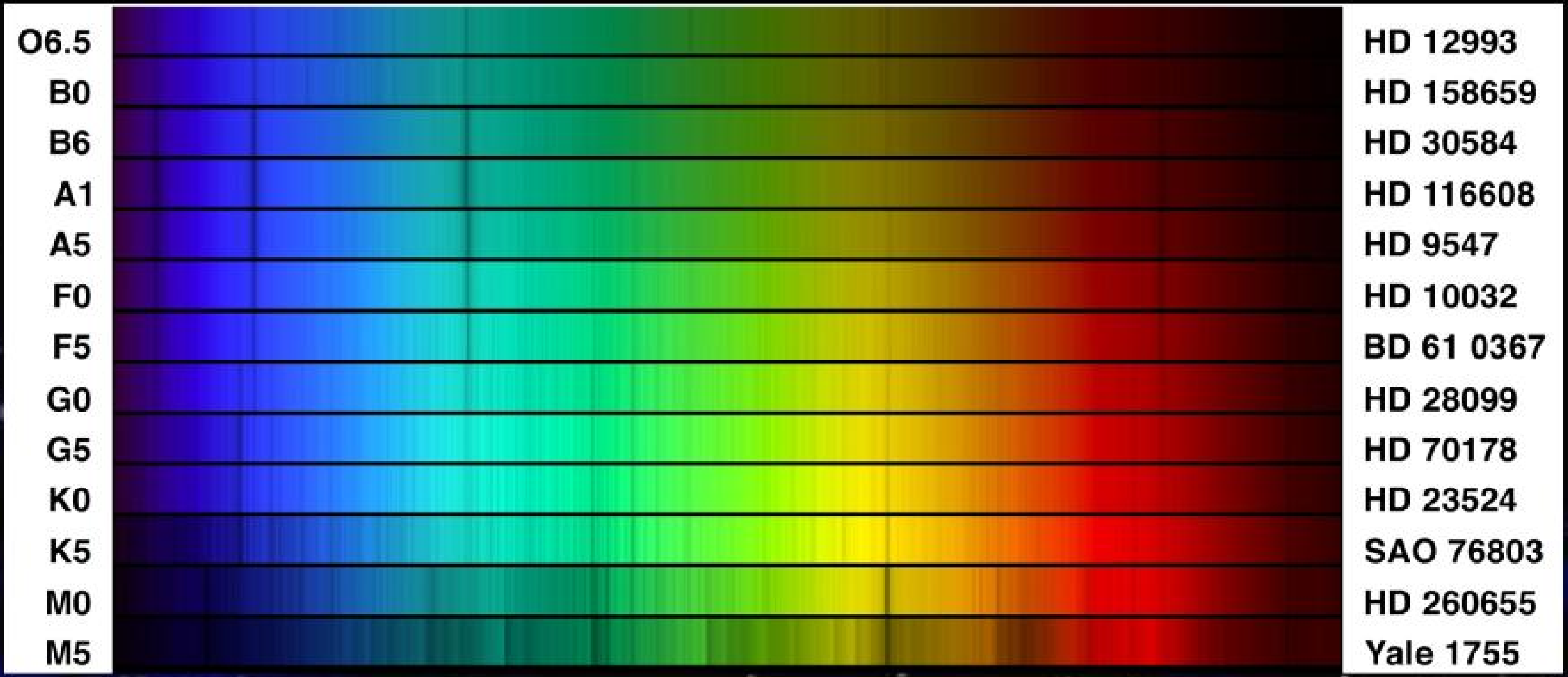
Absolute Magnitude μ Luminosity

But how do we determine a star’s luminosity??

O B A F G K M

Hotest → Coolest

Surface Temperature



O	0-9
B	0-9
A	0-9
F	0-9
G	0-9
K	0-9
M	0-9

Hottest → Coolest

↓

Coolest

Sun - G2

$$L \propto T^4$$

SPECTRAL TYPE ð TEMPERATURE

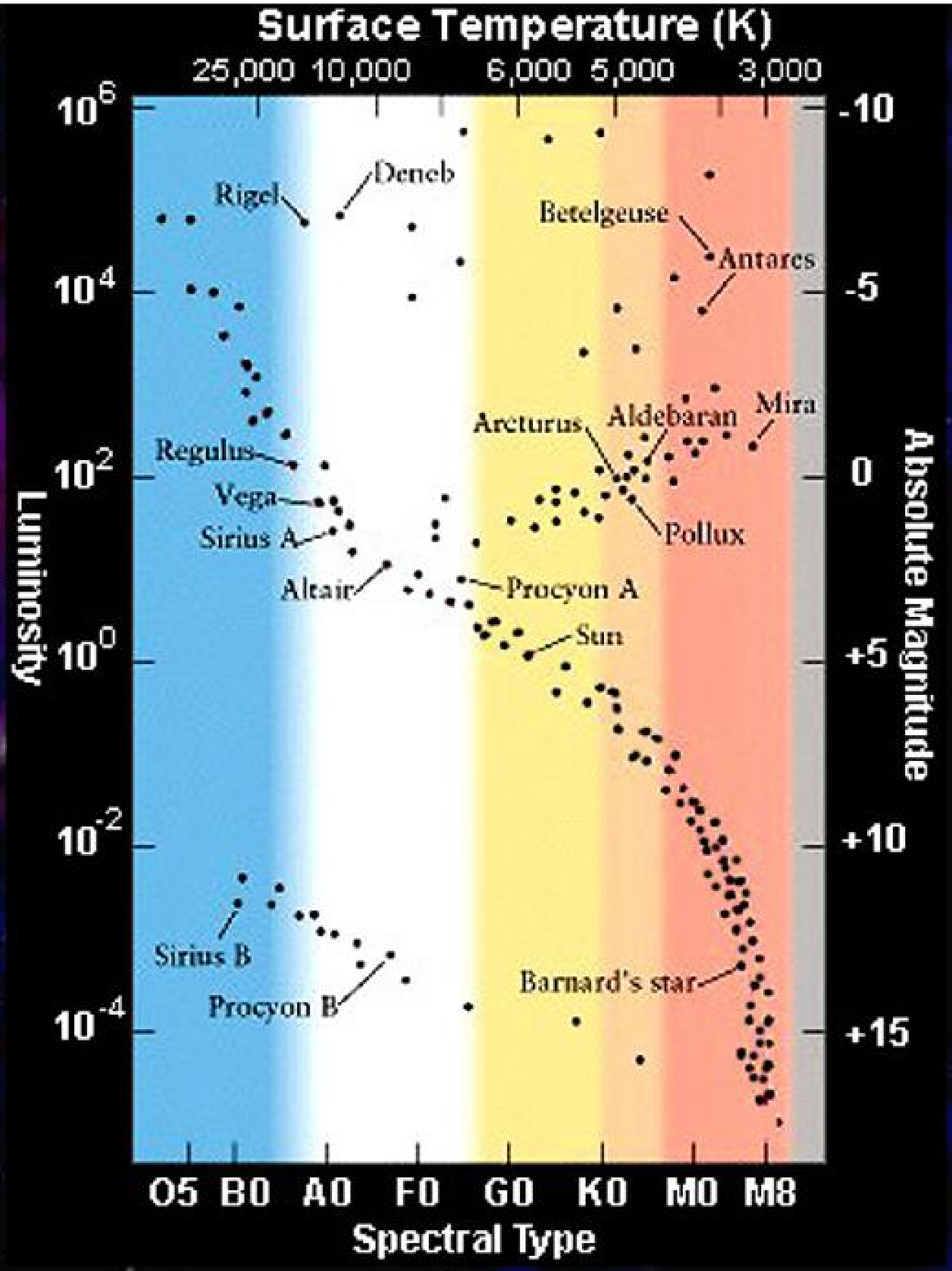
TEMPERATURE ð LUMINOSITY

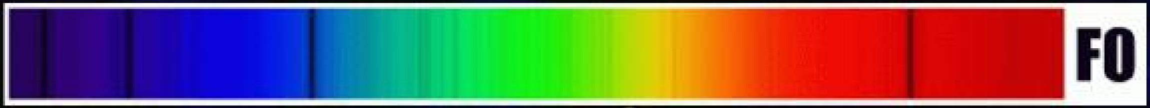
LUMINOSITY ð ABSOLUTE MAGNITUDE

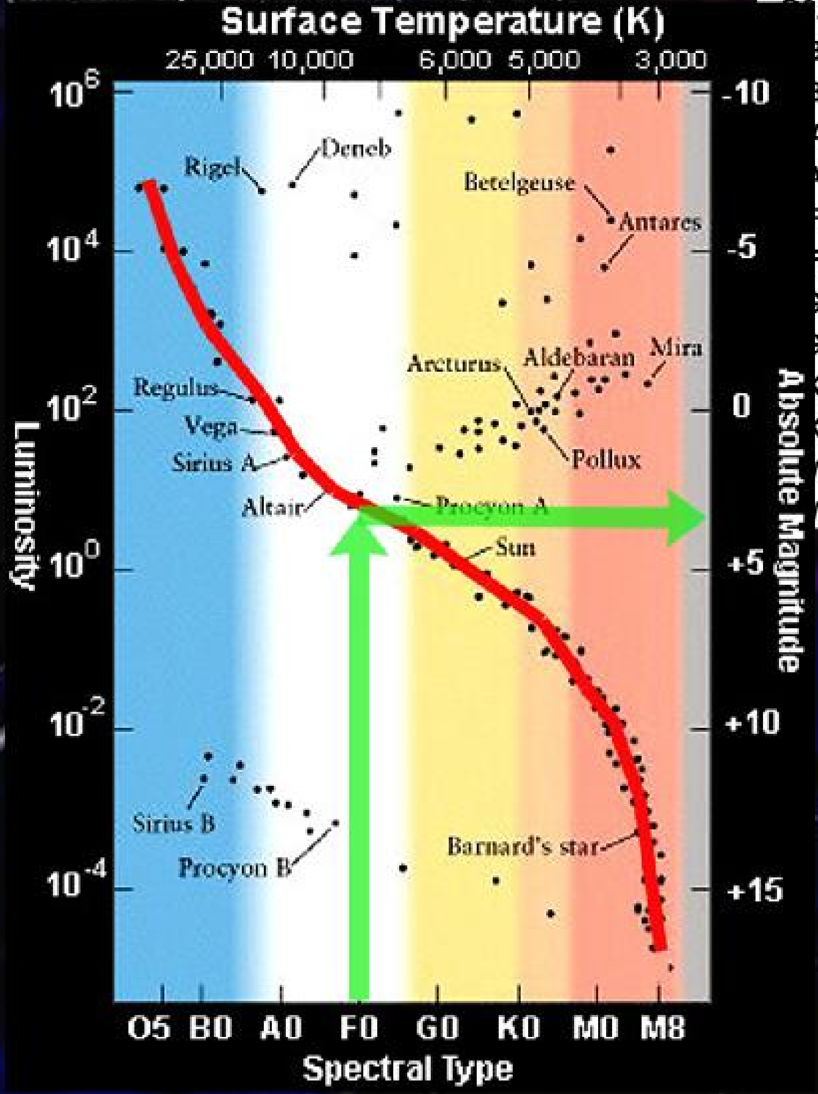
THEREFORE...

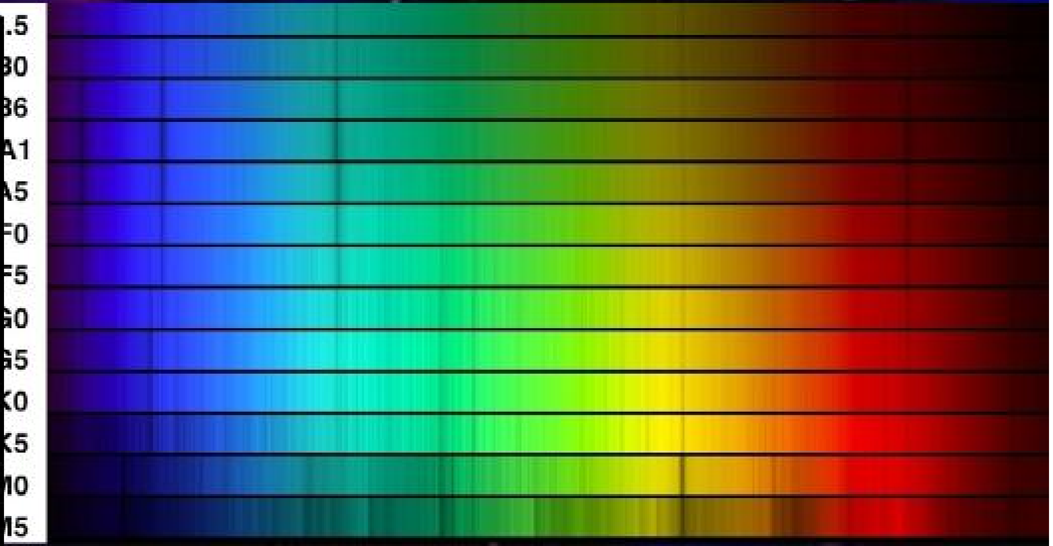
SPECTRAL TYPE ð ABSOLUTE MAGNITUDE

The Hertzsprung – Russell Diagram



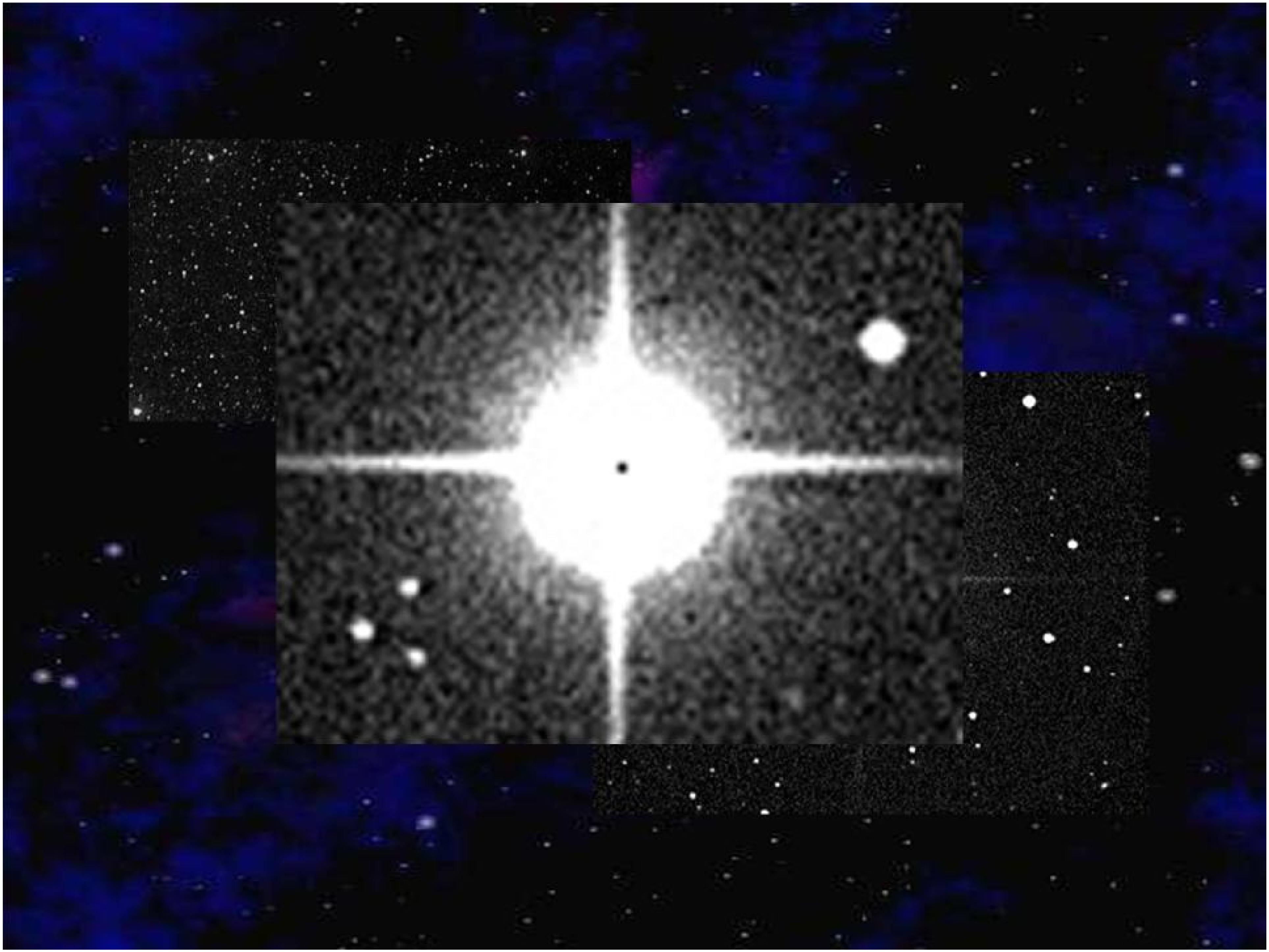


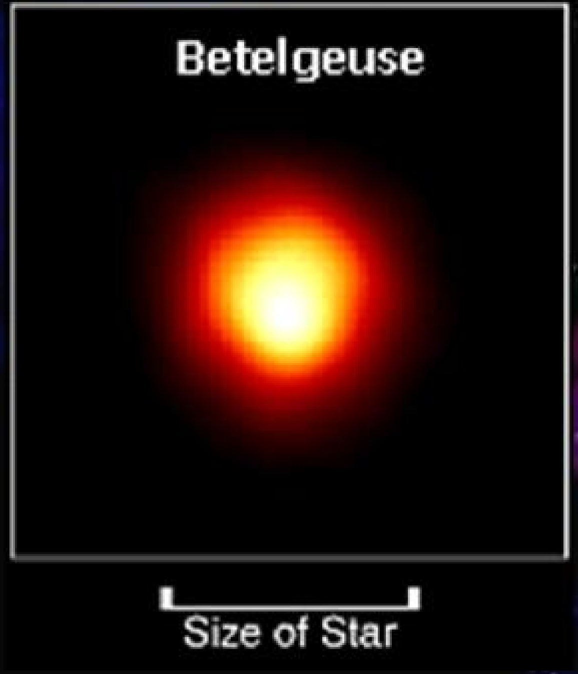




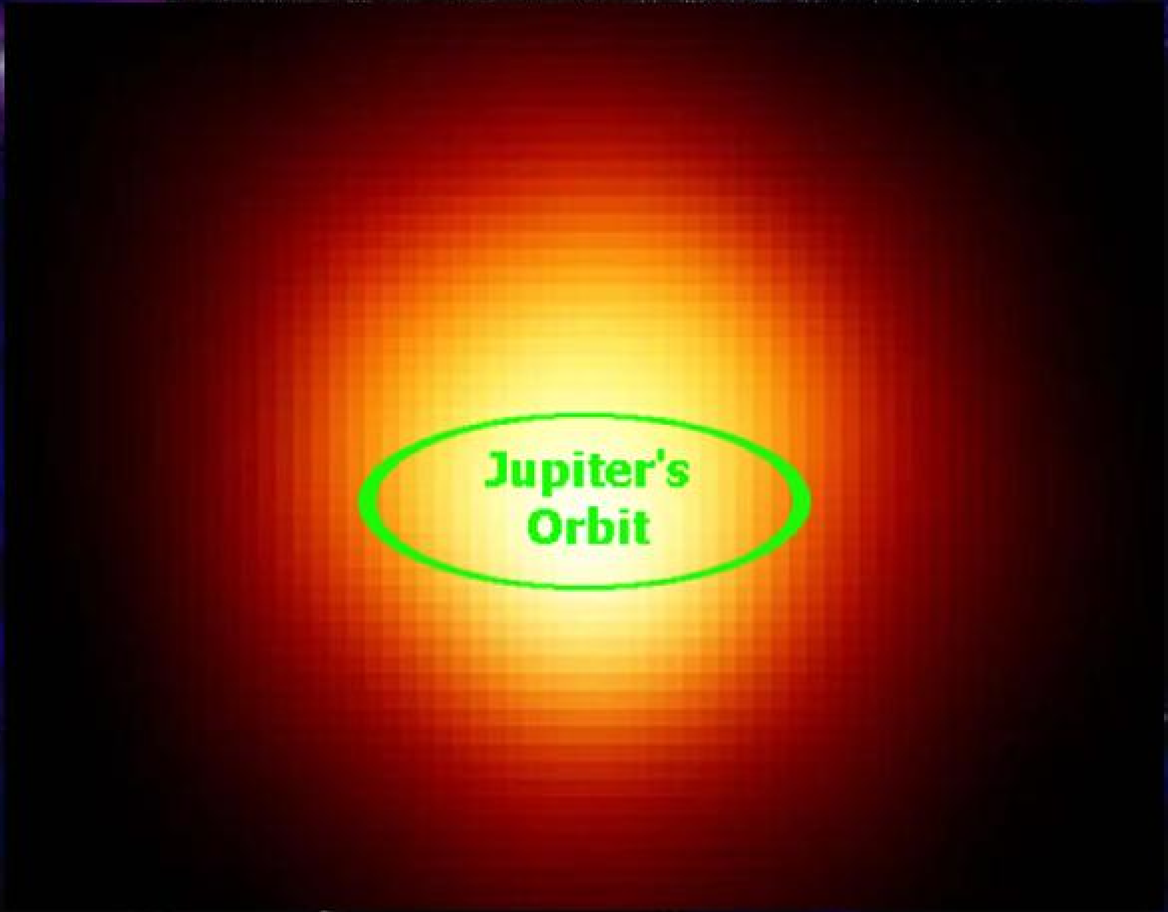
$$m - M = 5\log d - 5$$

Spectroscopic Parallax




Betelgeuse
Size of Star


Betelgeuse


Jupiter's
Orbit

Temperature – Radius – Luminosity Relationship

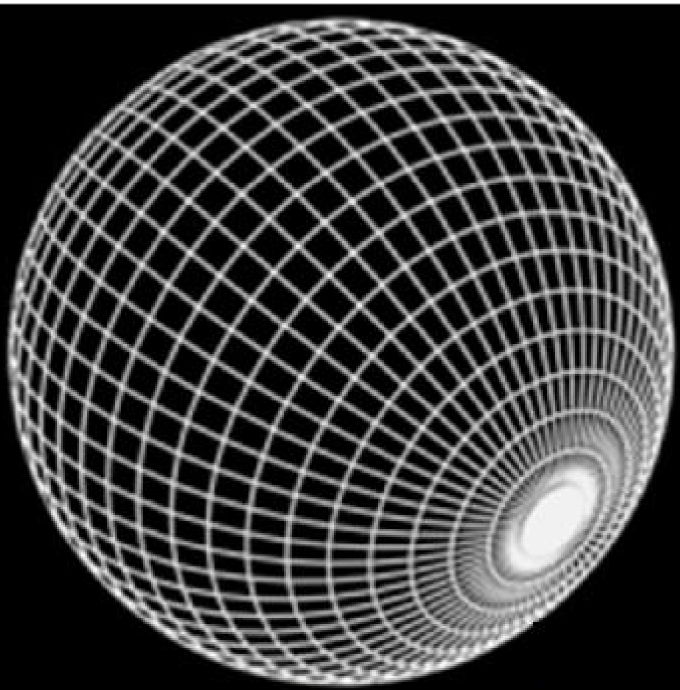
$$L = 4pR^2 sT^4$$

L = luminosity of the star

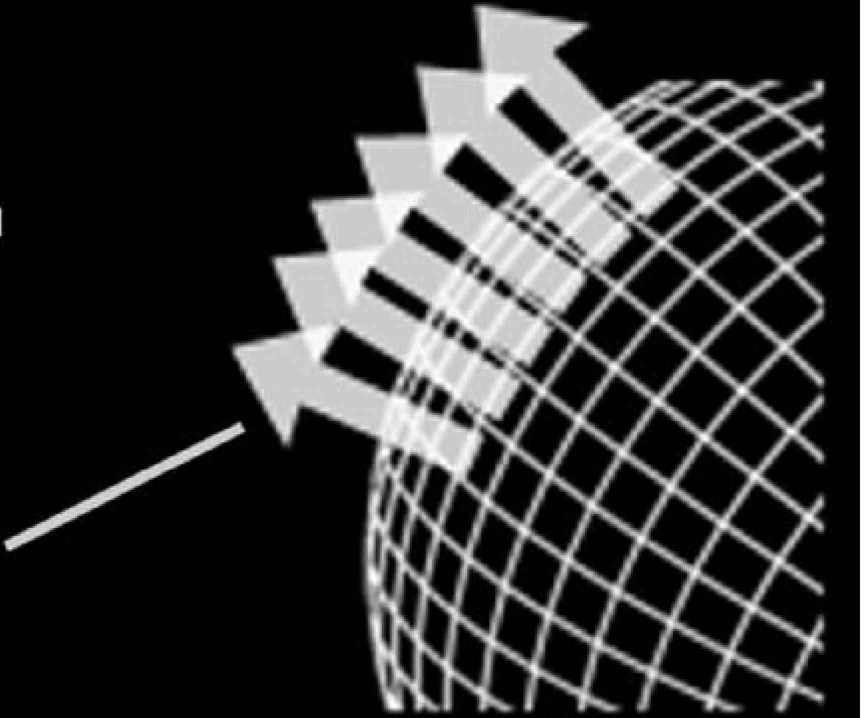
R = radius of the star

T = surface temperature of the star

π,σ = constants



$$L = 4pR^2 sT^4$$



$4\pi R^2$

Surface area of sphere

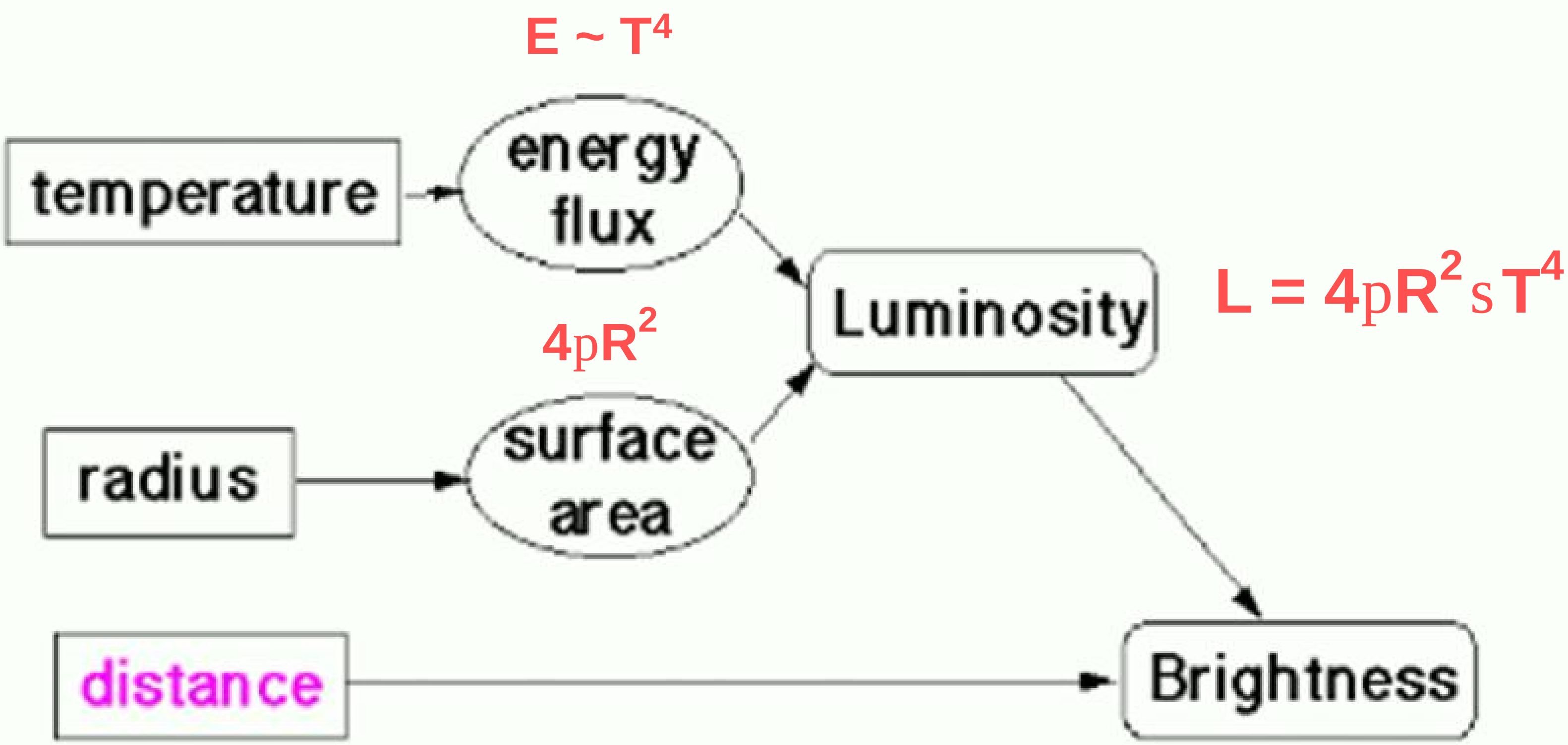
σT^4

energy per unit area

$$R = \sqrt{\frac{L}{4ps T^4}}$$

$$R \propto \frac{L}{T}$$

Luminosity and Brightness



$E \sim T^4$

temperature

energy flux

$4pR^2$

radius

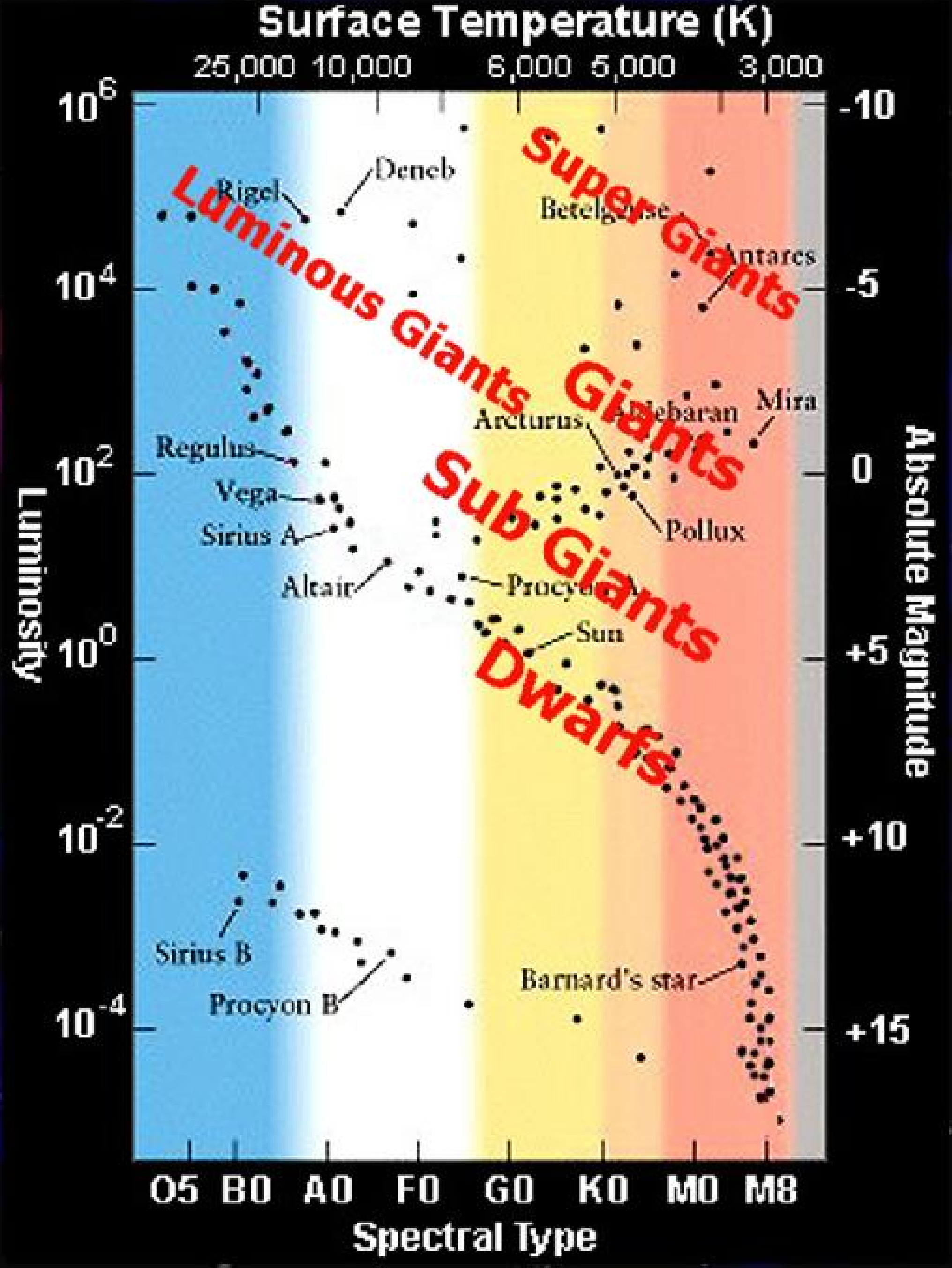
surface area

Luminosity

$L = 4pR^2 sT^4$

distance

Brightness


Surface Temperature (K)
25,000
10,000
6,000
5,000
3,000
Luminosity
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
Absolute Magnitude
-10
-5
0
+5
+10
+15
Spectral Type
O5
B0
A0
F0
G0
K0
M0
M8
Rigel
Deneb
Betelgeuse
Antares
Regulus
Vega
Sirius A
Altair
Procyon A
Sun
Arcturus
Aldebaran
Mira
Pollux
Sirius B
Procyon B
Barnard's star
Super Giants
Luminous Giants
Giants
Sub Giants
Dwarfs

Luminosity Classes

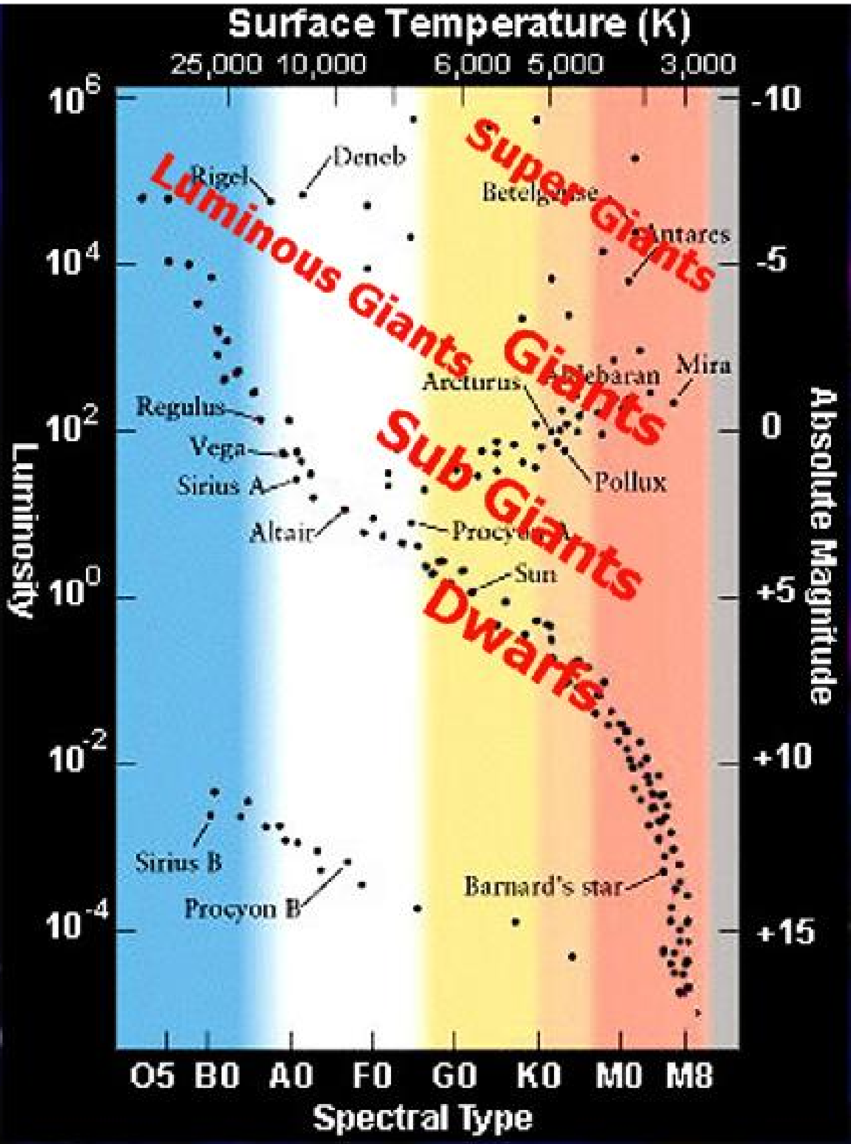
I	Super Giants
II	Luminous Giants
III	Giants
IV	Sub Giants
V	Dwarfs

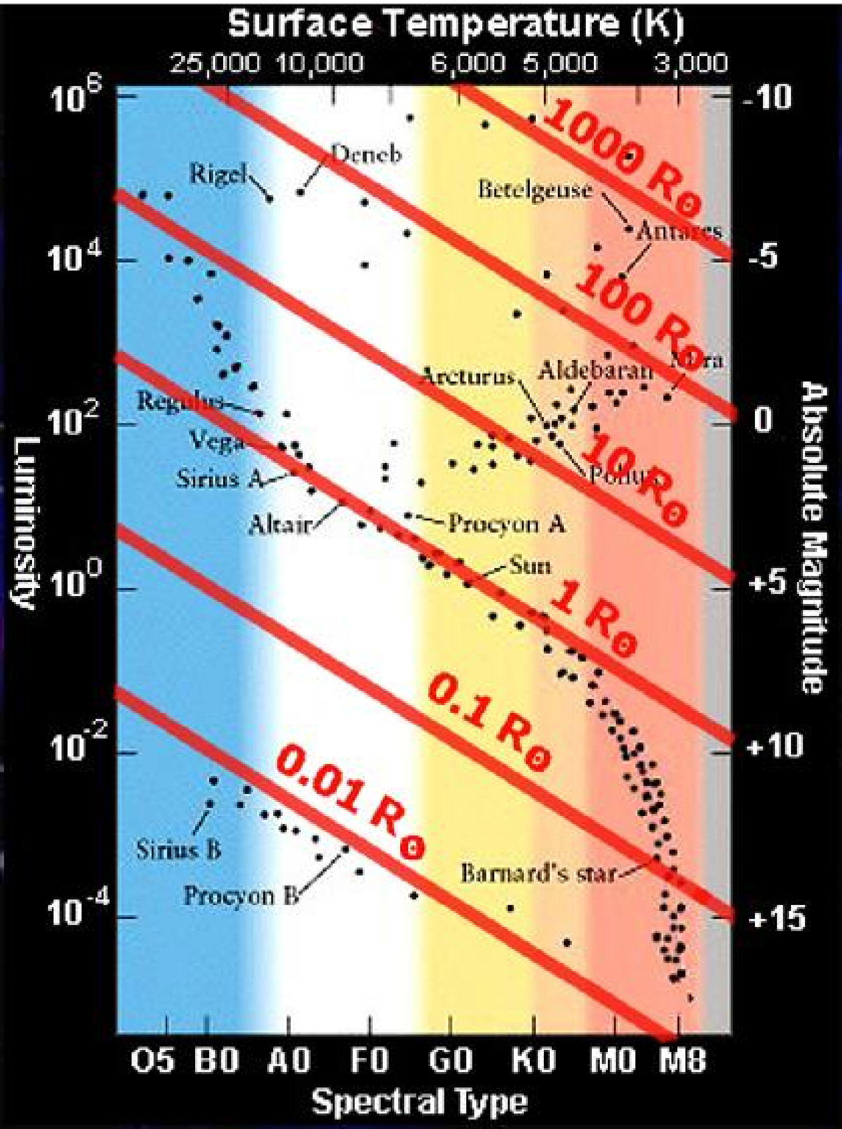
The Sun is a Dwarf…

So finally, stars can be classified...

By spectral type (OBAFGKM)

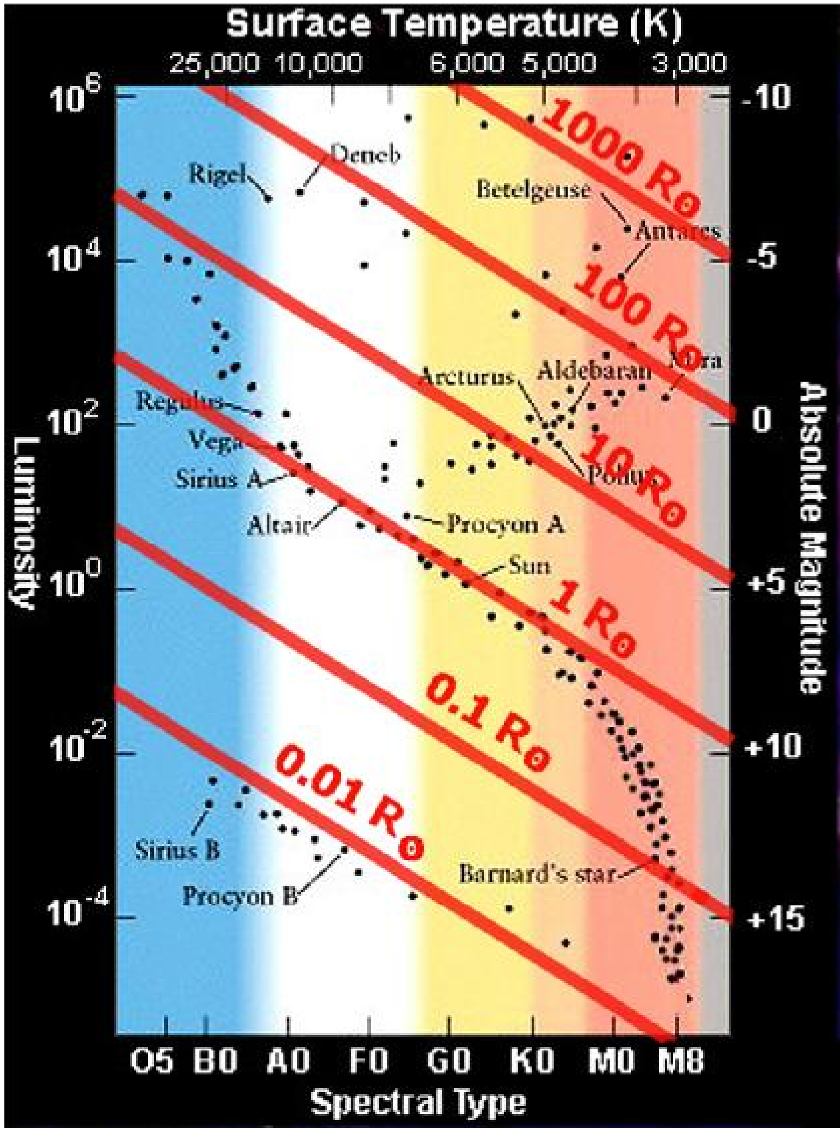
Luminosity class (I,II,III,IV,V)

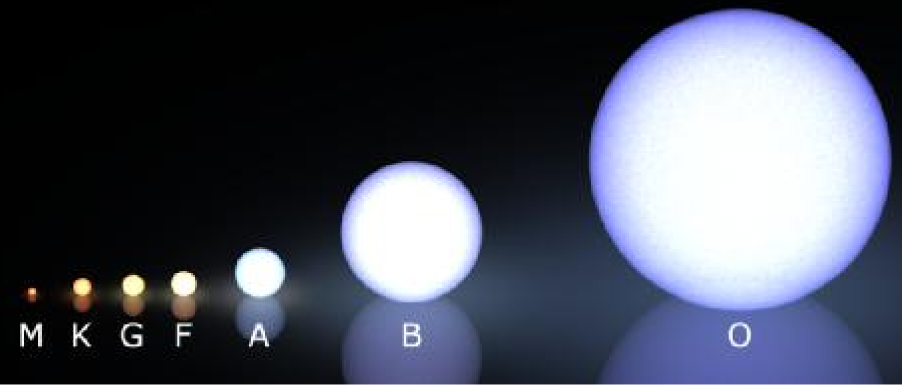


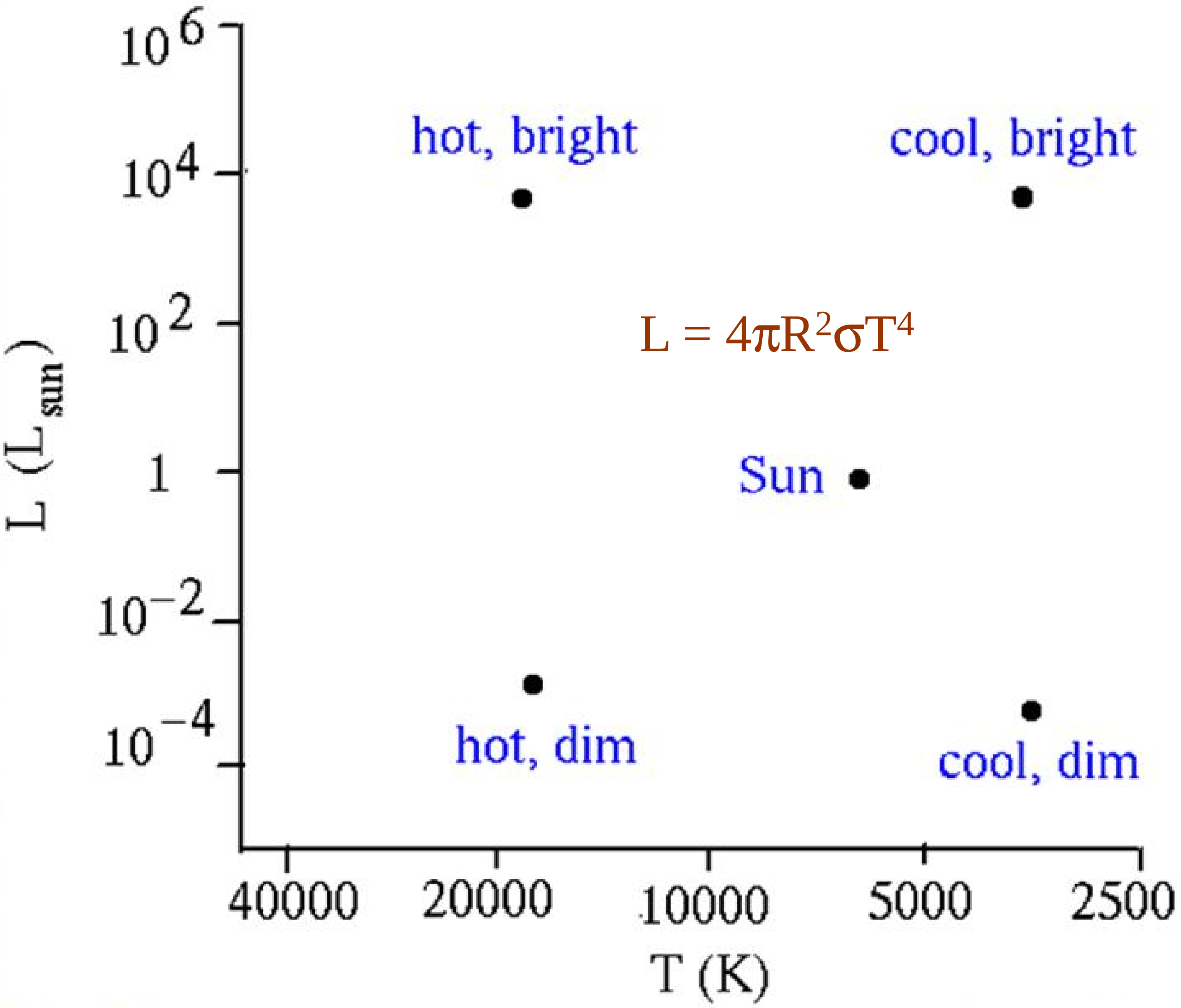


Betelgeuse: M1 I

Sun: G2 V

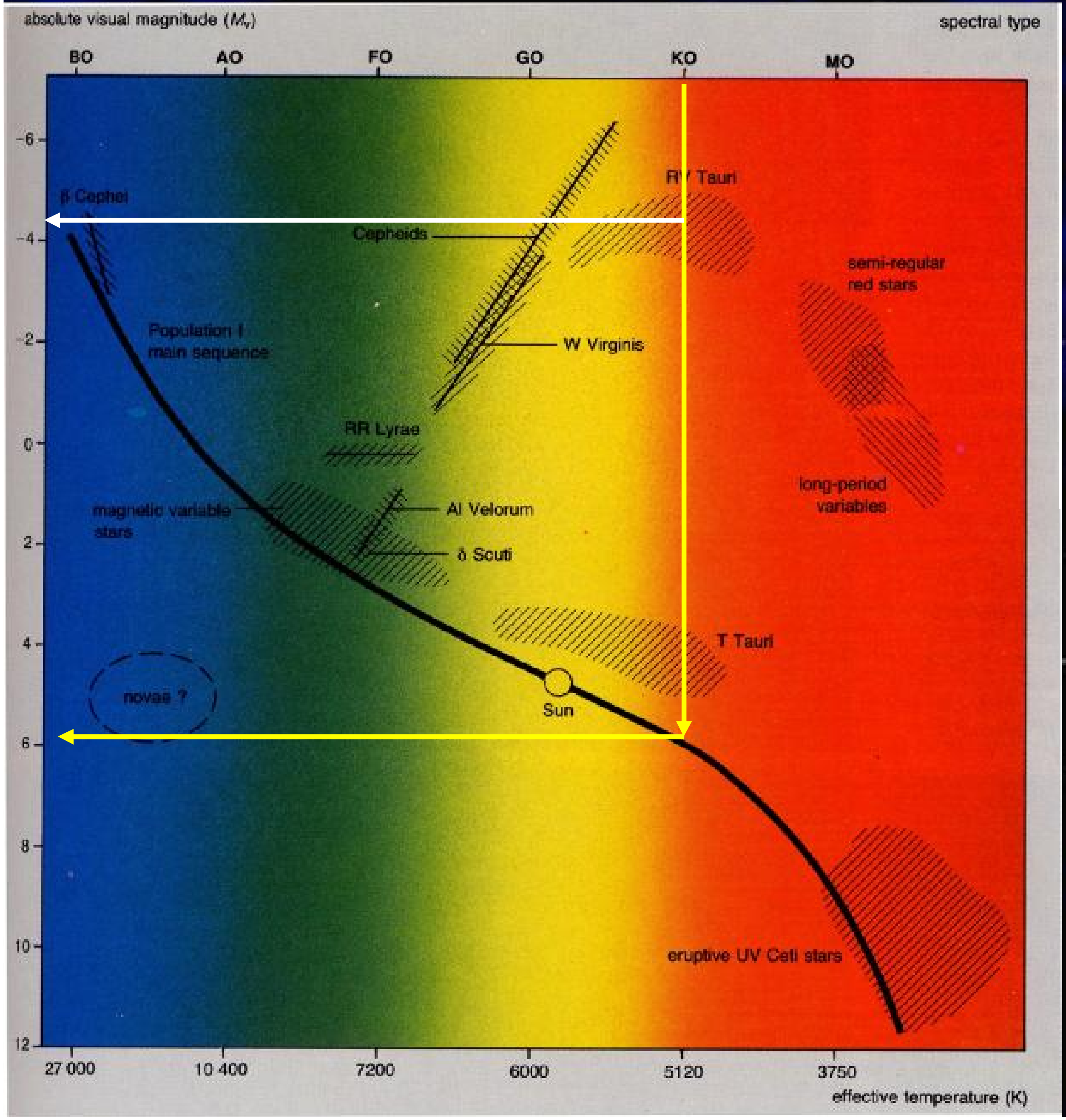

Surface Temperature (K)
25,000
10,000
6,000
5,000
3,000
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
Luminosity
-10
-5
0
+5
+10
+15
Absolute Magnitude
1000 $R_\odot$
100 $R_\odot$
10 $R_\odot$
1 $R_\odot$
0.1 $R_\odot$
0.01 $R_\odot$
Rigel
Deneb
Betelgeuse
Antares
Mira
Arcturus
Aldebaran
Pollux
Regulus
Vega
Sirius A
Altair
Procyon A
Sun
Sirius B
Procyon B
Barnard's star
O5
B0
A0
F0
G0
K0
M0
M8
Spectral Type


M
K
G
F
A
B
O



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

The Art of Spectroscopic Parallax



1) **Measure spectral type**
2) **Measure m_v**
3) **Determine luminosity class**
4) **Place on HR diagram**
5) **Read Mv**

Example: Record spectrum of star and find it is K0 V type

Read off Mv

Determine visual mag, m_v

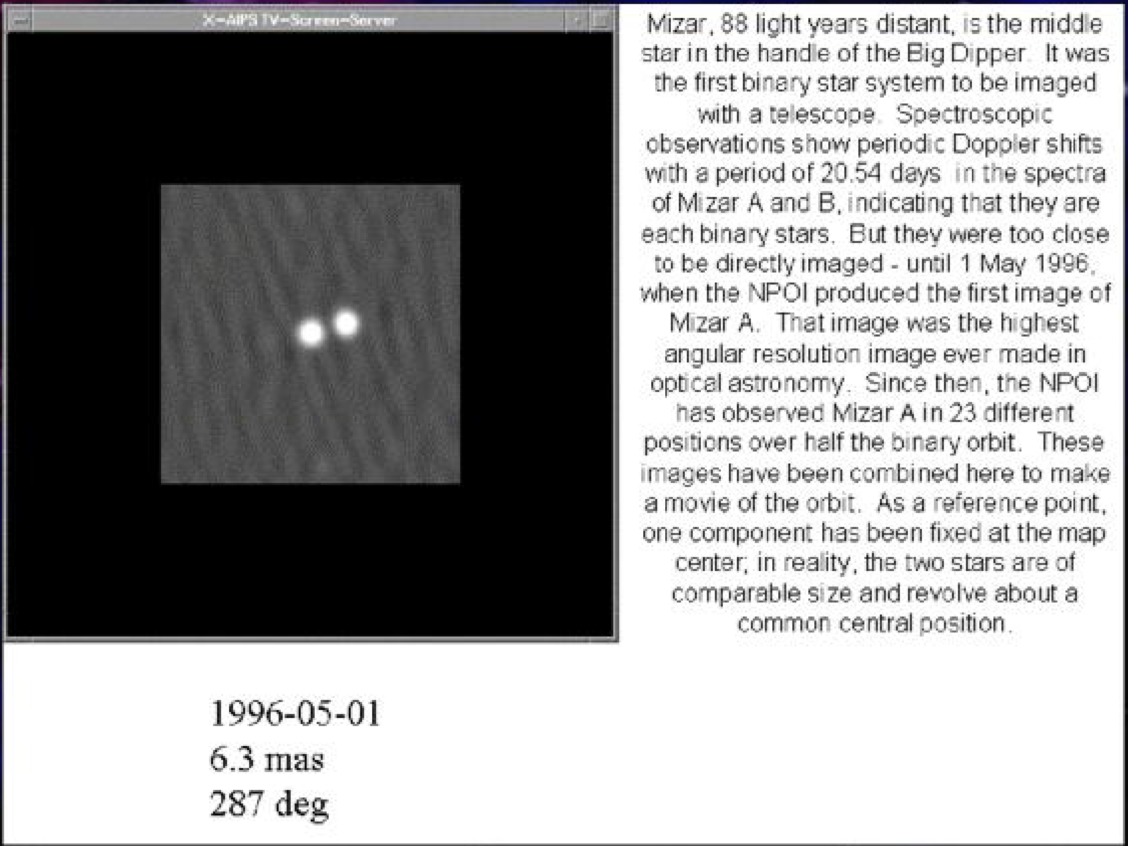
$$m - M = 5\log d - 5$$

100 fold error in d

BINARY STARS

Binary Stars:

Two or more stars in orbit around each other.

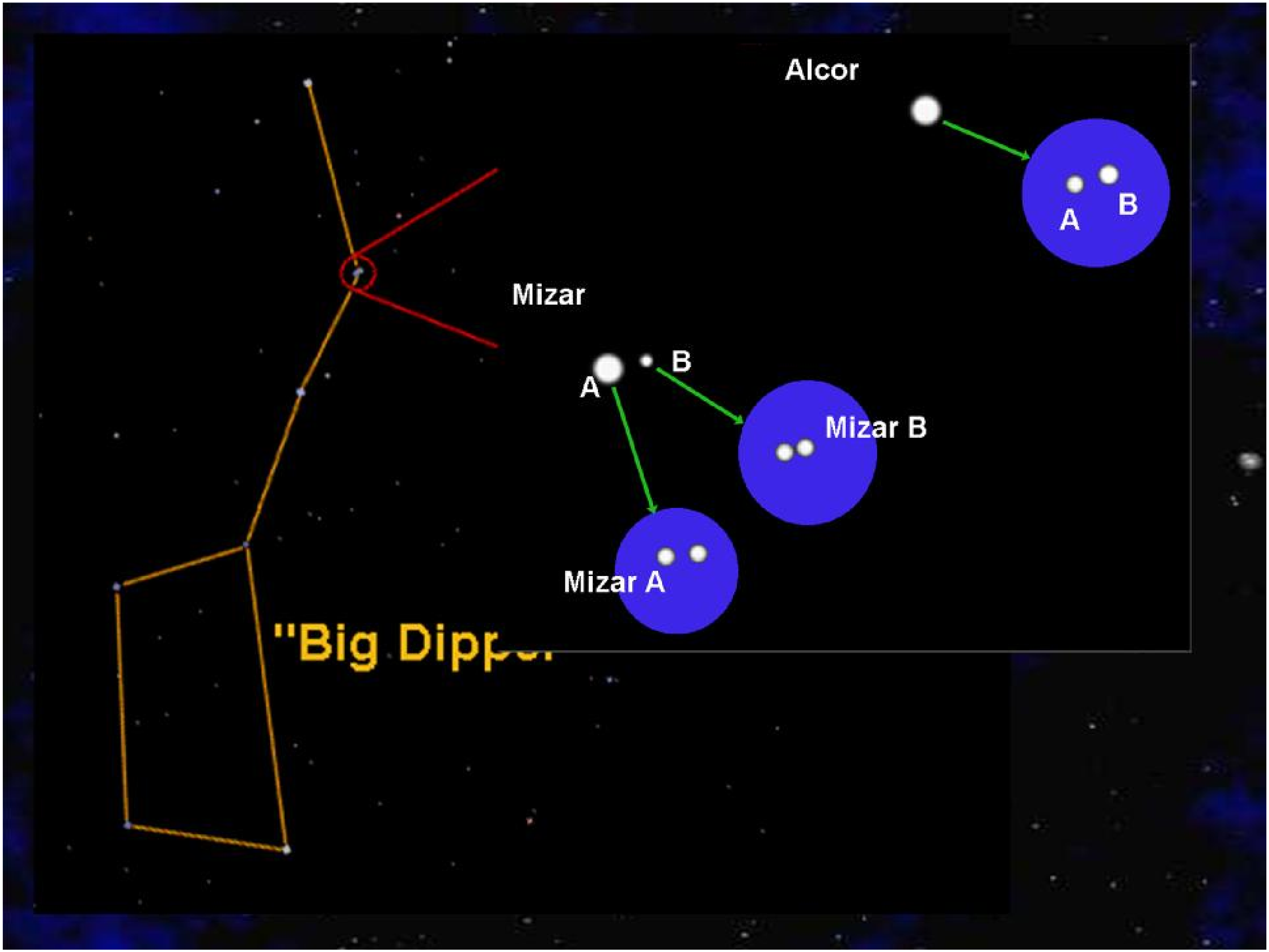


Mizar, 88 light years distant, is the middle star in the handle of the Big Dipper. It was the first binary star system to be imaged with a telescope. Spectroscopic observations show periodic Doppler shifts with a period of 20.54 days in the spectra of Mizar A and B, indicating that they are each binary stars. But they were too close to be directly imaged - until 1 May 1996, when the NPOI produced the first image of Mizar A. That image was the highest angular resolution image ever made in optical astronomy. Since then, the NPOI has observed Mizar A in 23 different positions over half the binary orbit. These images have been combined here to make a movie of the orbit. As a reference point, one component has been fixed at the map center; in reality, the two stars are of comparable size and revolve about a common central position.

1996-05-01
6.3 mas
287 deg

Binary Stars:

- Usually formed together
- Can be complicated multiple systems

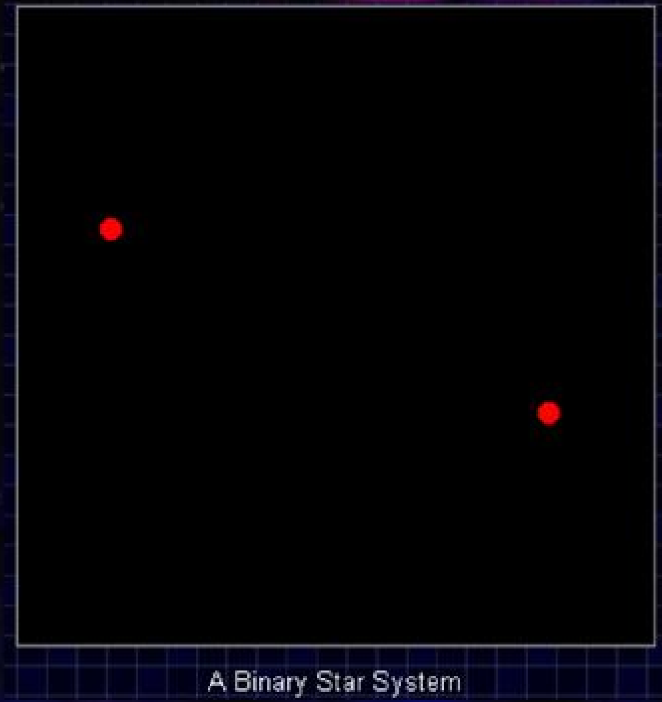

Alcor
A
B
Mizar
A
B
Mizar B
Mizar A
"Big Dipp

Binary Stars:

- Gravitationally bound together
- Stars orbit a common center of mass

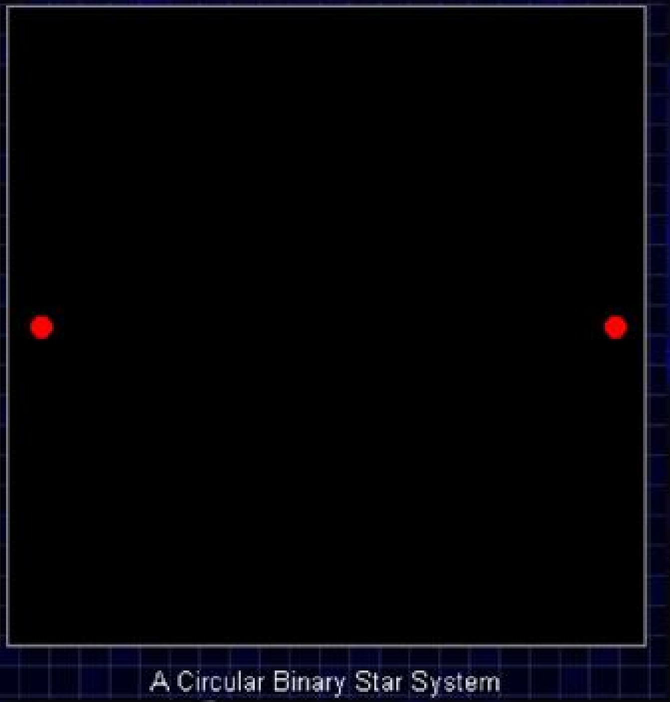
More than 50 % of all stars are members of binary systems.

Elliptical Orbits



A Binary Star System

Circular Orbits



A Circular Binary Star System

Triple Star

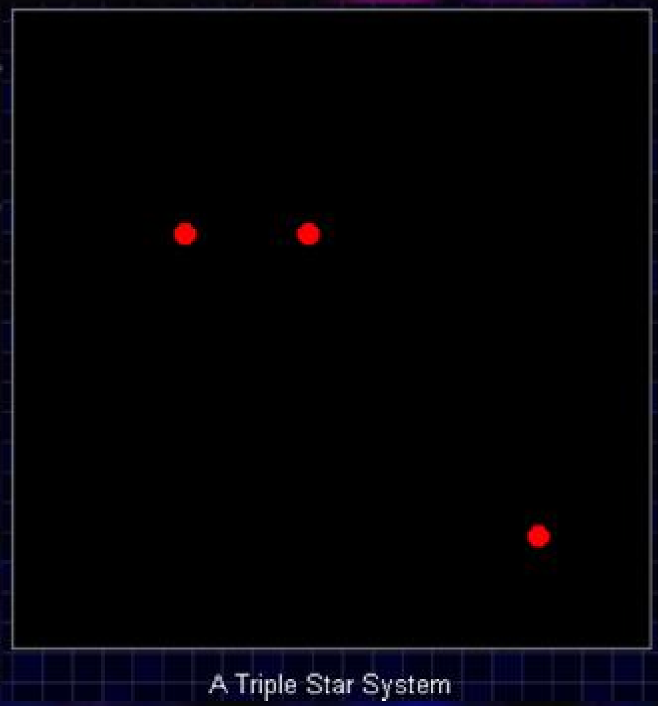
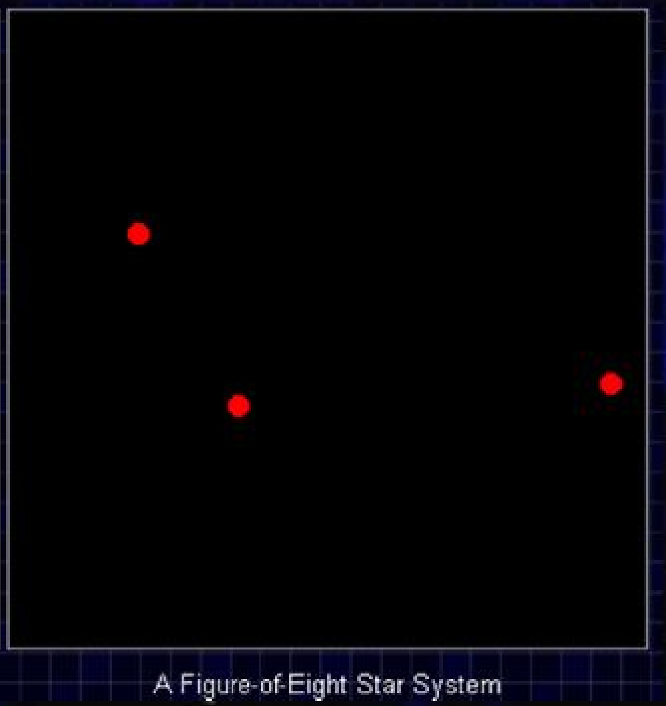
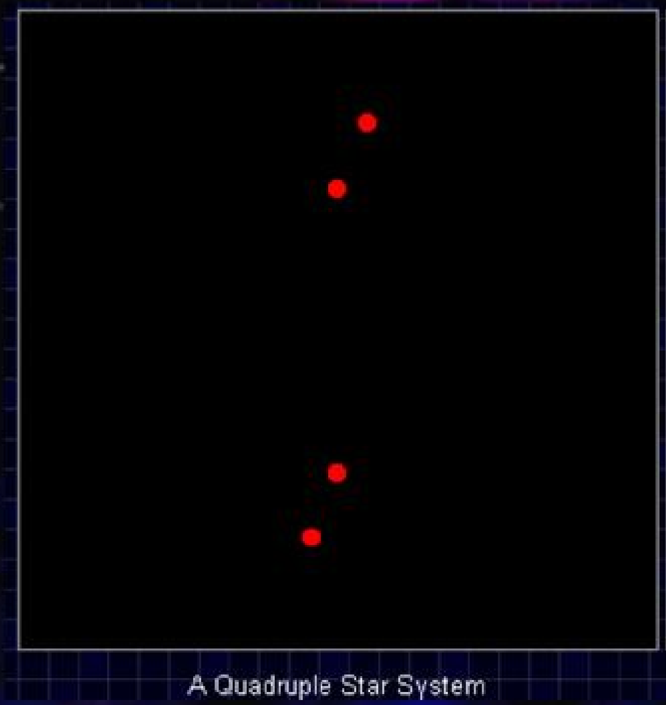


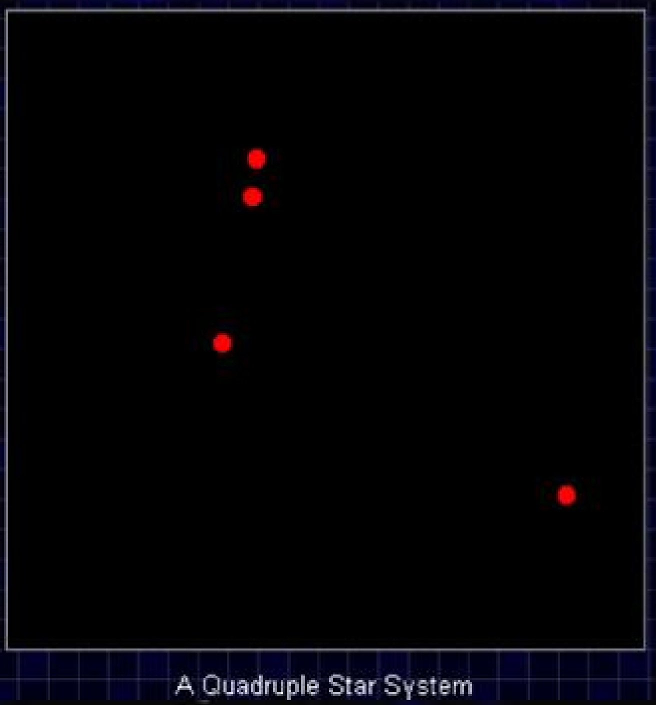
Figure 8 Orbits



Double Binary Orbits

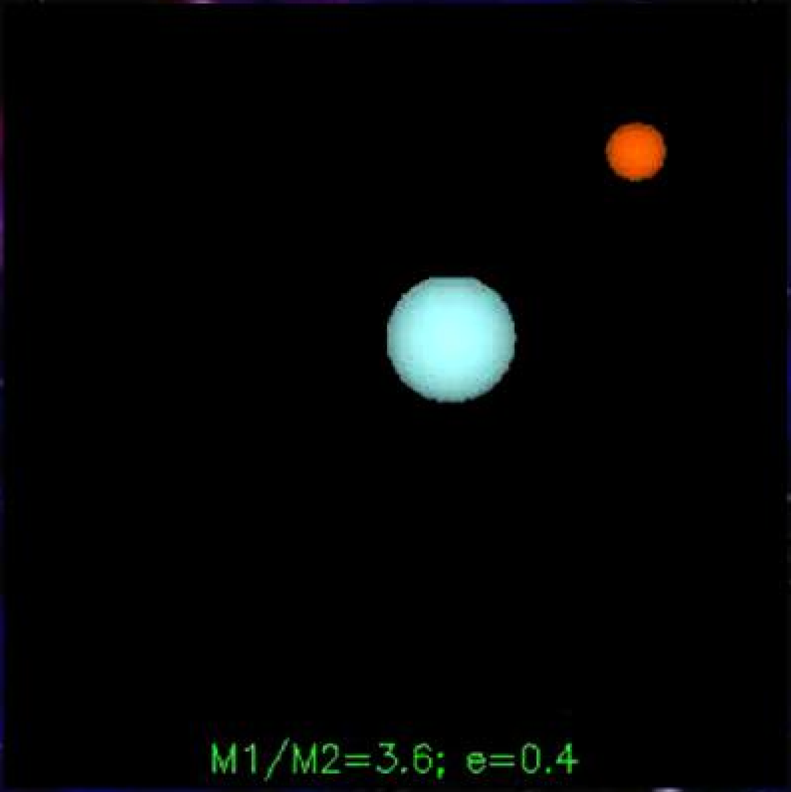


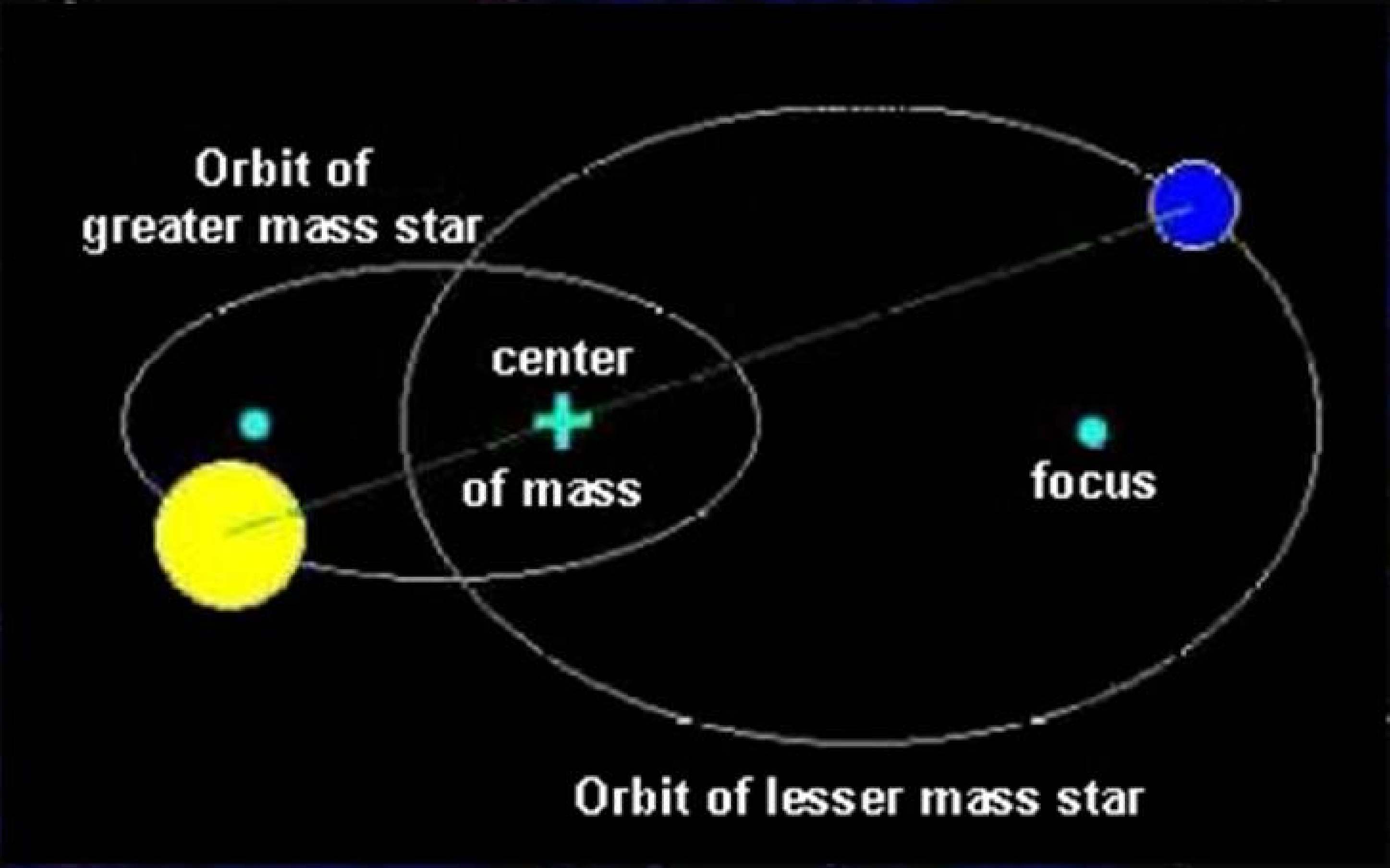
Quadruple System



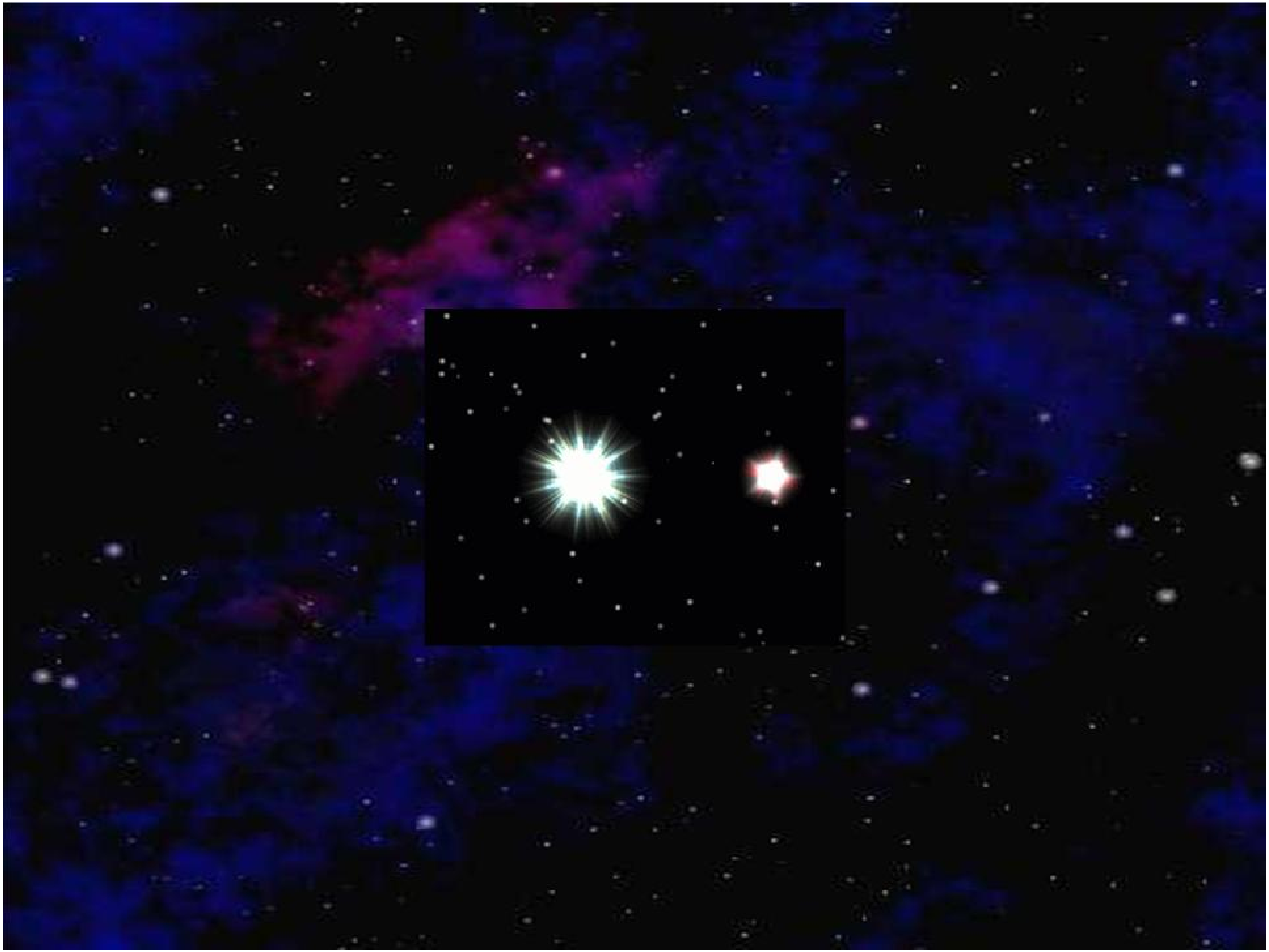
Visual Binary Systems:

- Stars that can be resolved (separated) into two or more stars through a telescope.
- From direct observations we can plot the orbit of each star.


M1/M2=3.6; e=0.4

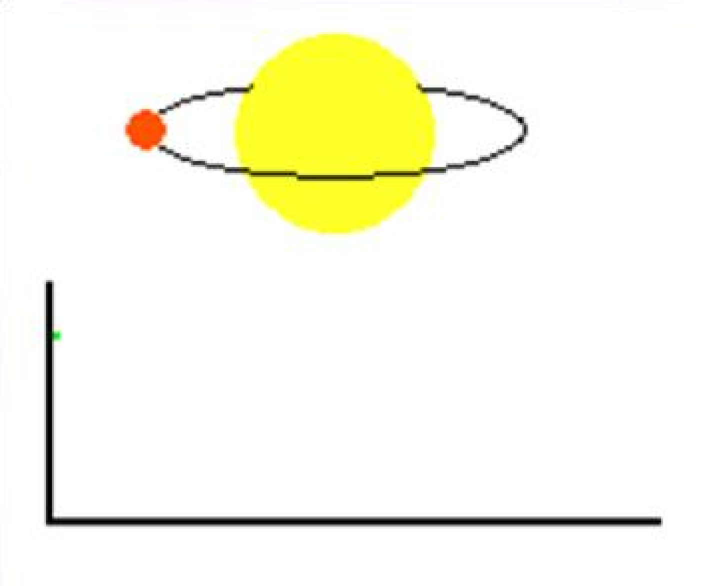

Orbit of
greater mass star
center
of mass
focus
Orbit of lesser mass star

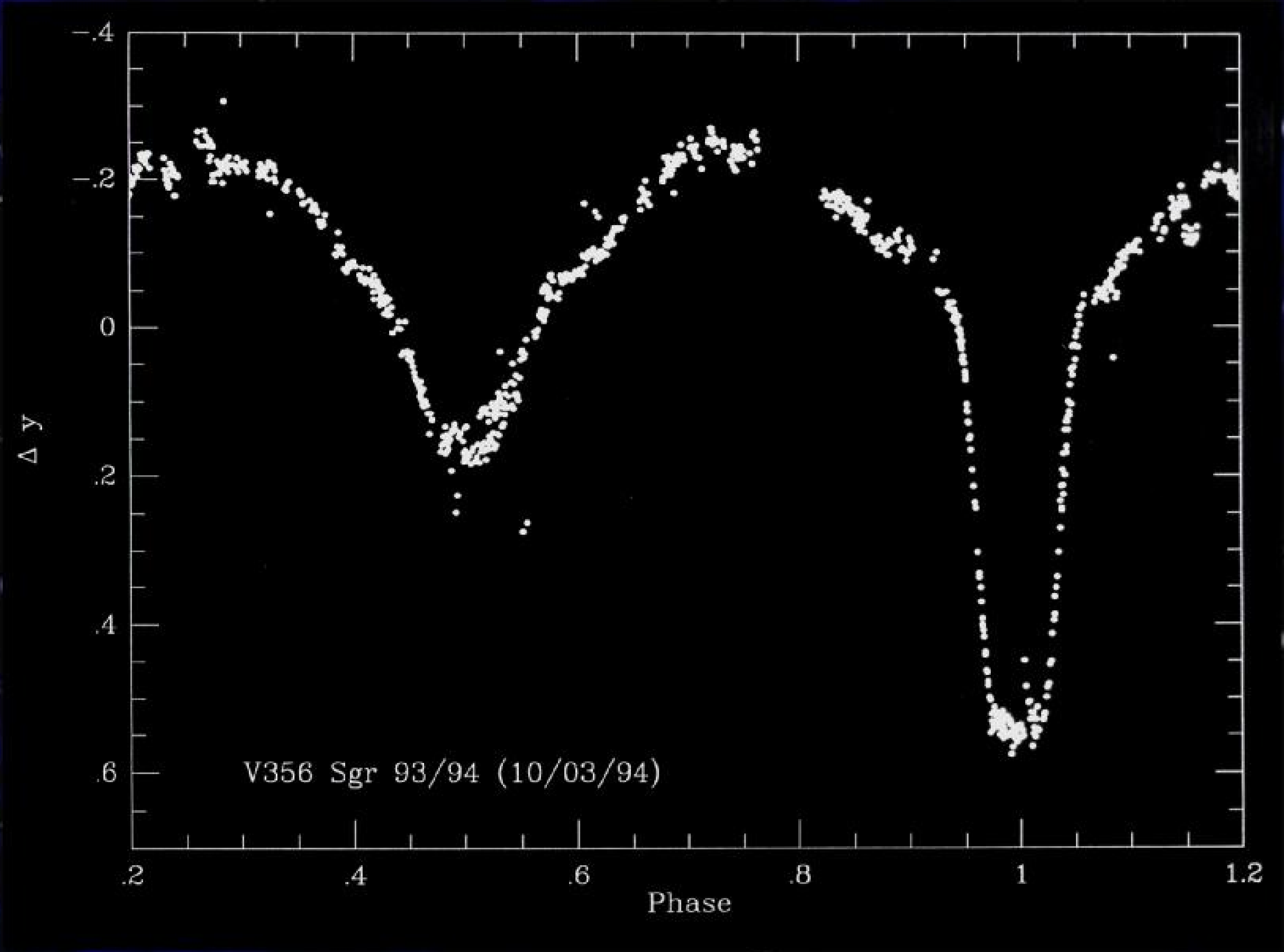
What about stars that are too close together to be seen as individual stars?

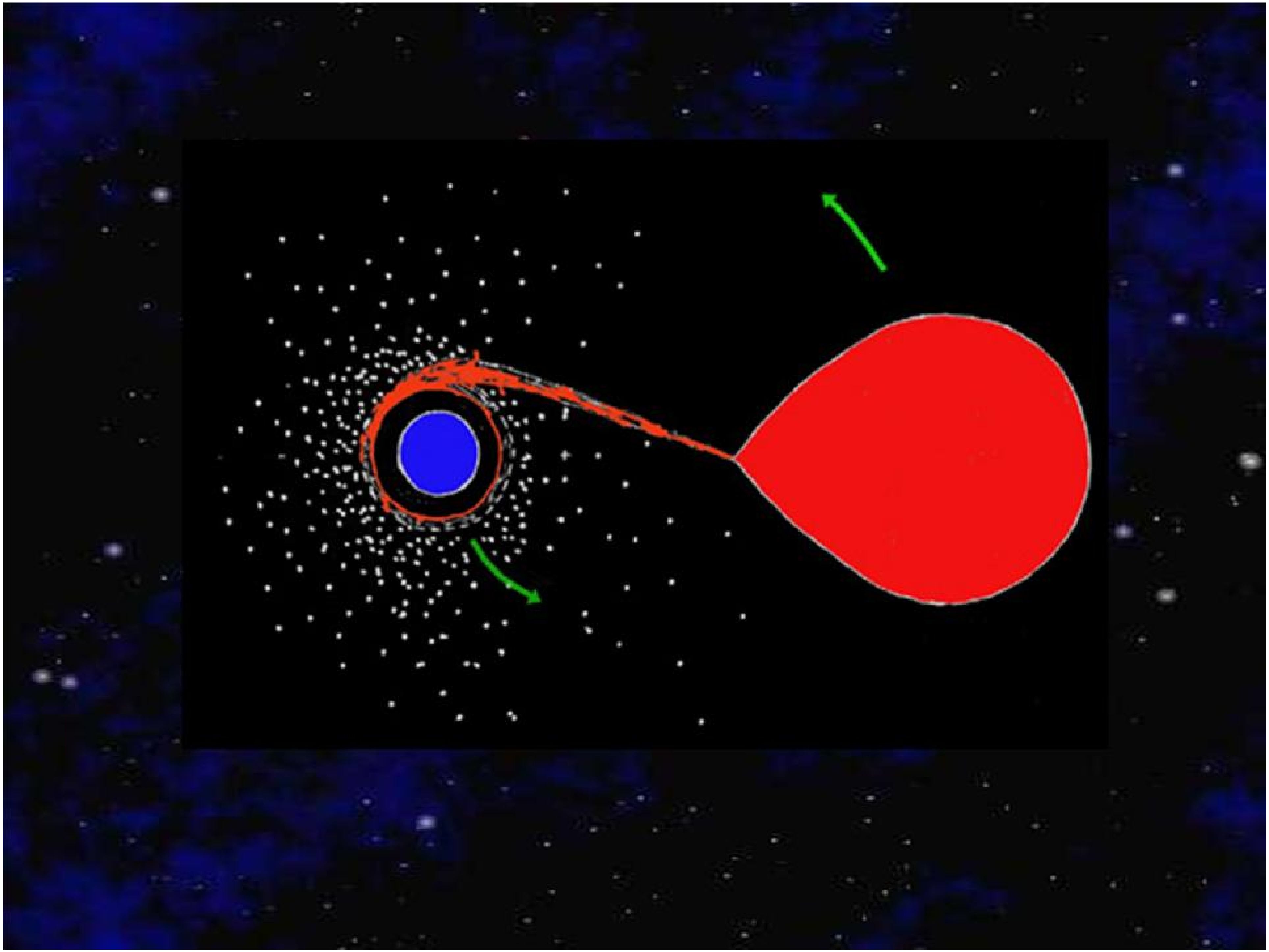


Eclipsing Binary Systems:

When the stars pass in front of each other we see an *eclipse*.



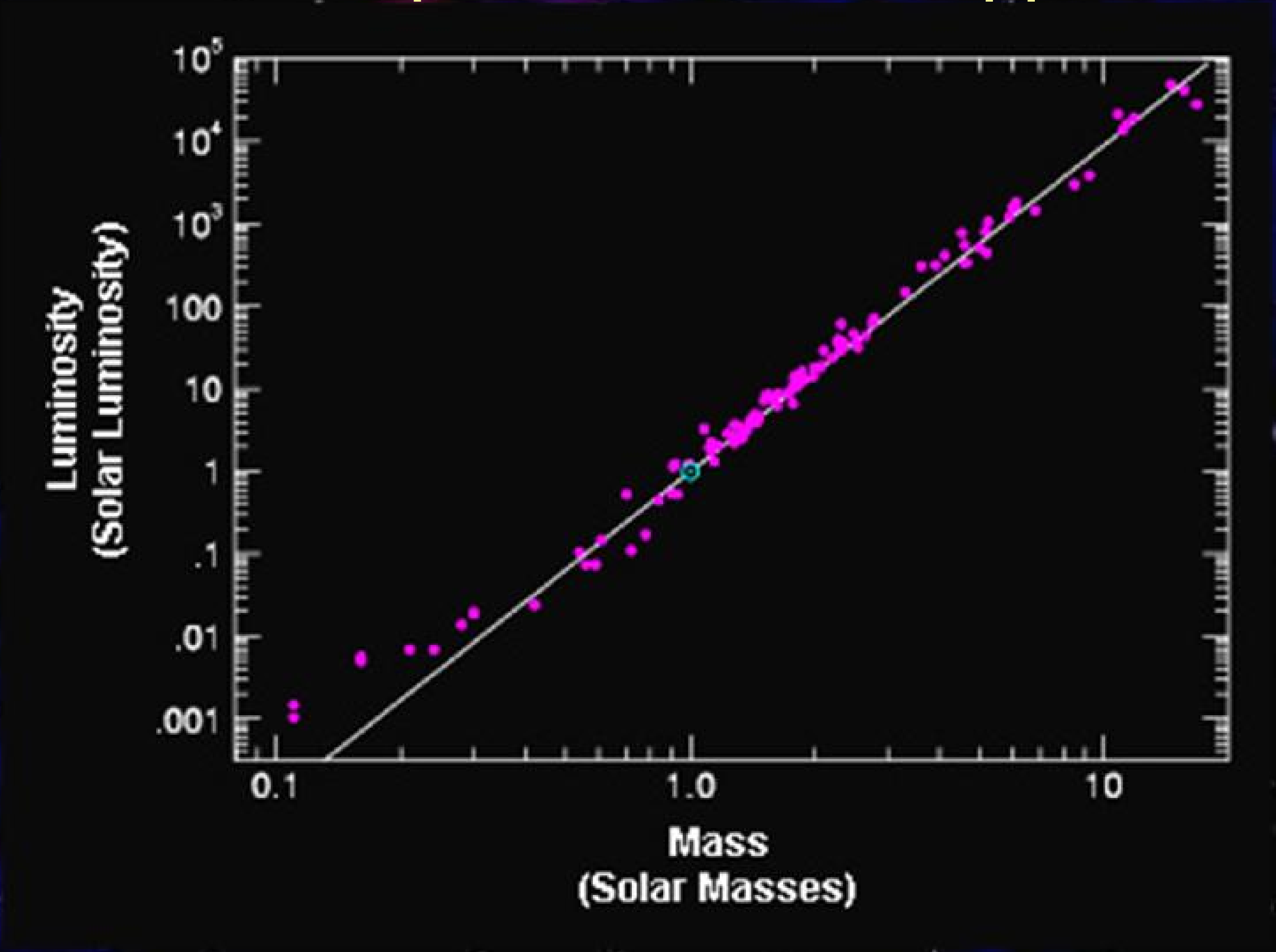

-.4
-.2
0
.2
.4
.6
Δ y
.2
.4
.6
.8
1
1.2
Phase
V356 Sgr 93/94 (10/03/94)

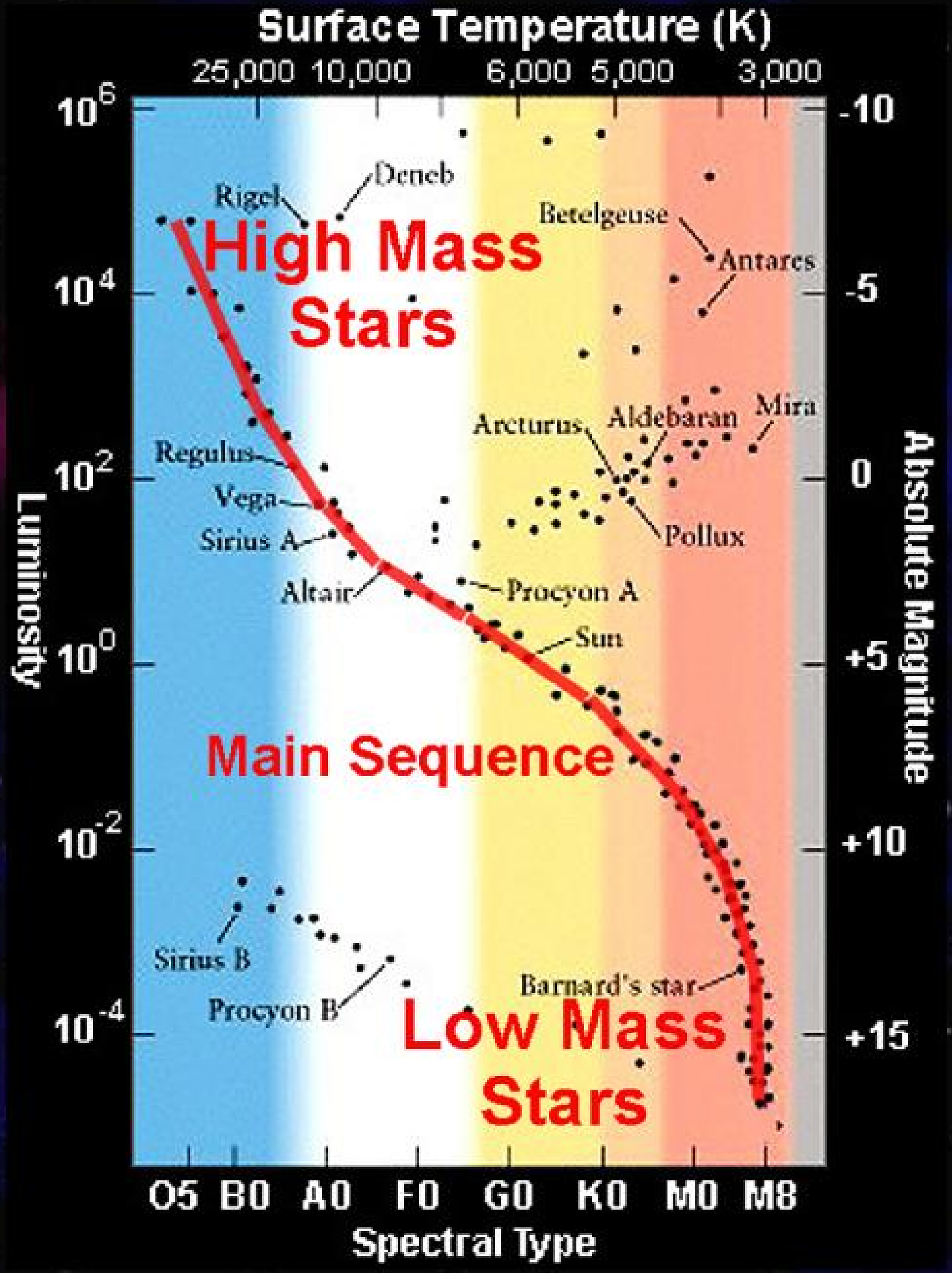


$$(m_1 + m_2) \propto \frac{d^3}{p^2} \qquad \frac{m_1}{m_2}$$

The masses of the individual stars can be calculated.

By gathering the masses of a large variety of stars in binary systems a fundamental relationship soon became apparent.





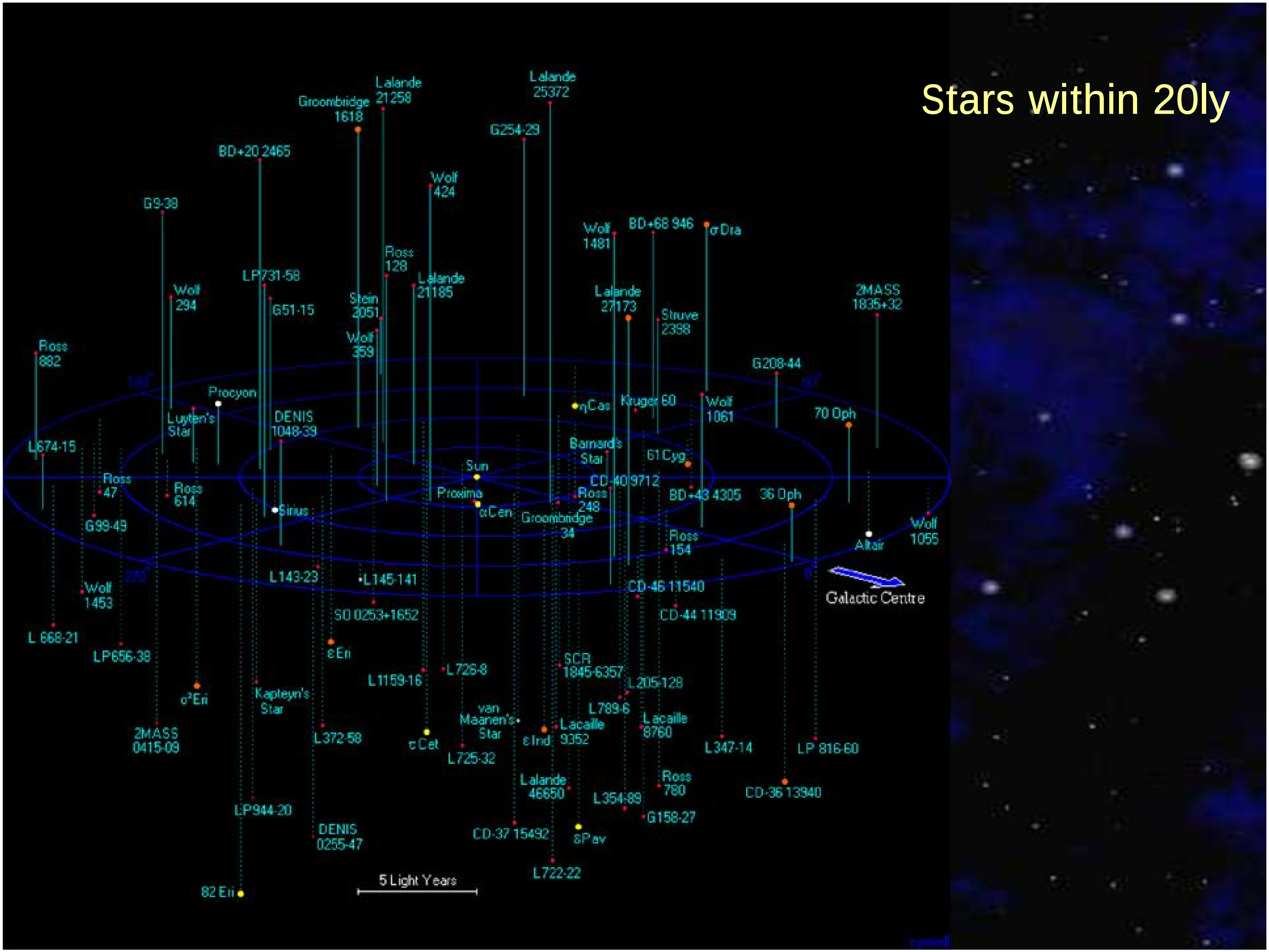
Surface Temperature (K)
25,000
10,000
6,000
5,000
3,000
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
Luminosity
-10
-5
0
+5
+10
+15
Absolute Magnitude
Rigel
Deneb
Betelgeuse
Antares
High Mass Stars
Arcturus
Aldebaran
Mira
Regulus
Vega
Sirius A
Pollux
Altair
Procyon A
Sun
Main Sequence
Sirius B
Procyon B
Barnard's star
Low Mass Stars
O5
B0
A0
F0
G0
K0
M0
M8
Spectral Type

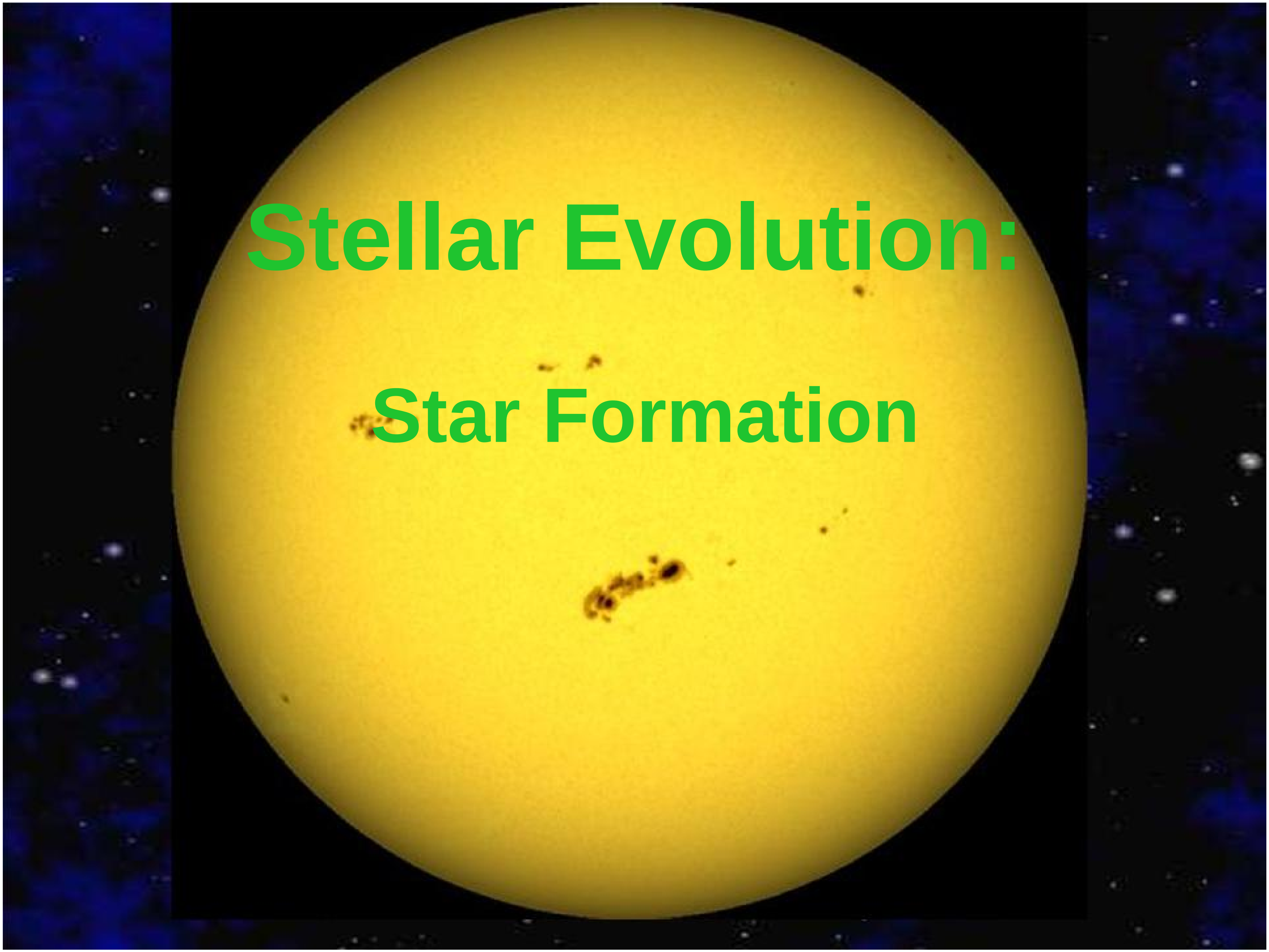
1	4333	20000	100000	266666	433333	2600000
O	B	A	F	G	K	M

Hotest → **Coolest**

Surface Temperature

Stars within 20ly





Stellar Evolution:

Star Formation

What are the stars made out of?

The Sun is composed of:

element	by #	by mass
Hydrogen	92%	73%
Helium	7.8%	25%
all others	0.2%	2%

Carbon, nitrogen, oxygen, neon, magnesium, silicon, sulfur, iron...

Orion

The Interstellar Medium (ISM)

Composed of gas and dust

__ALMOST__ **a perfect vacuum!**

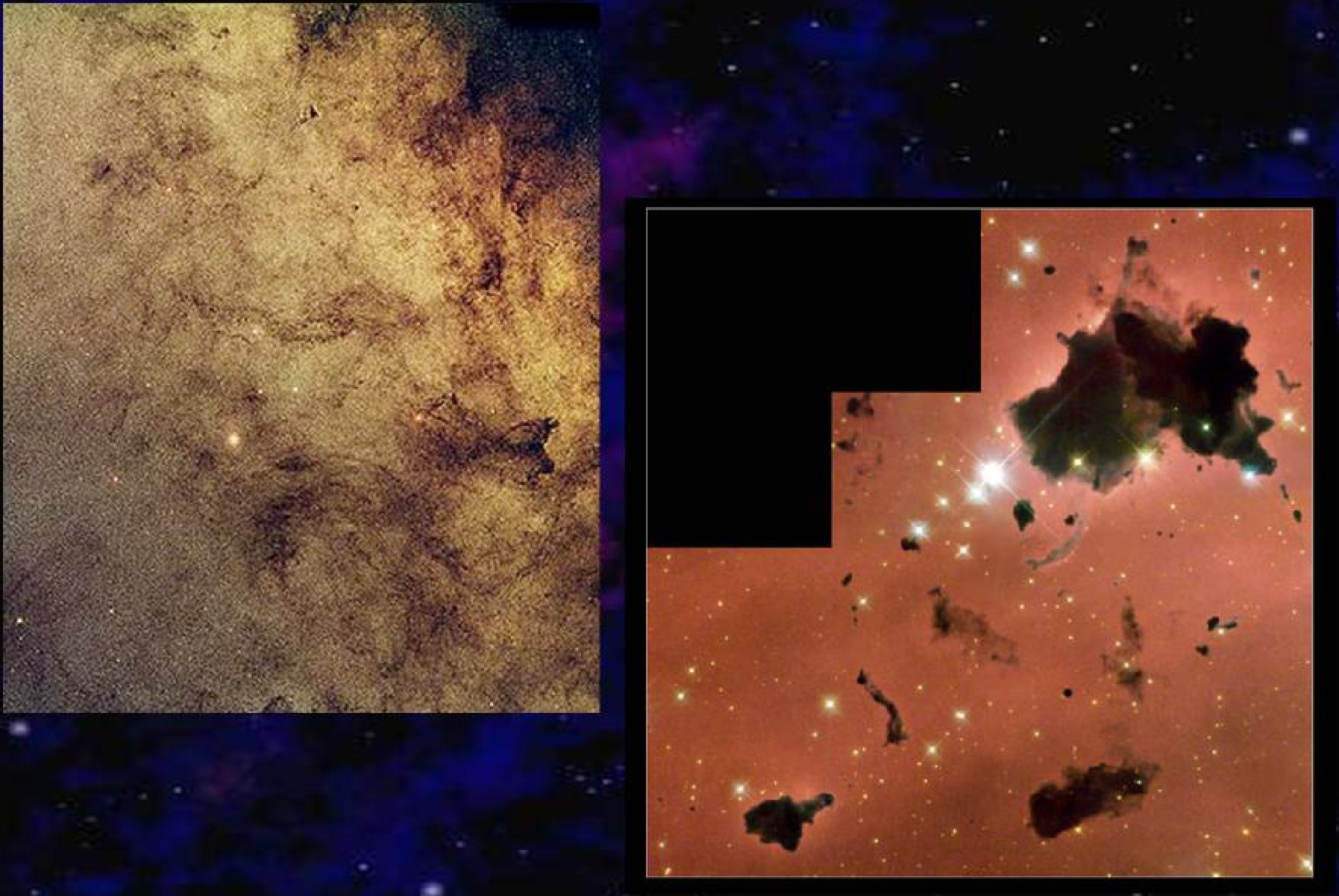
__Gas:__

- 99% of the ISM
- 1 atom/cm^3 (if spread out uniformly)

The Interstellar Medium

Dust:

- 1% of the ISM
- 1 dust grain per 10 cm^3



M51

The North American Nebula

Nebula – “cloud”

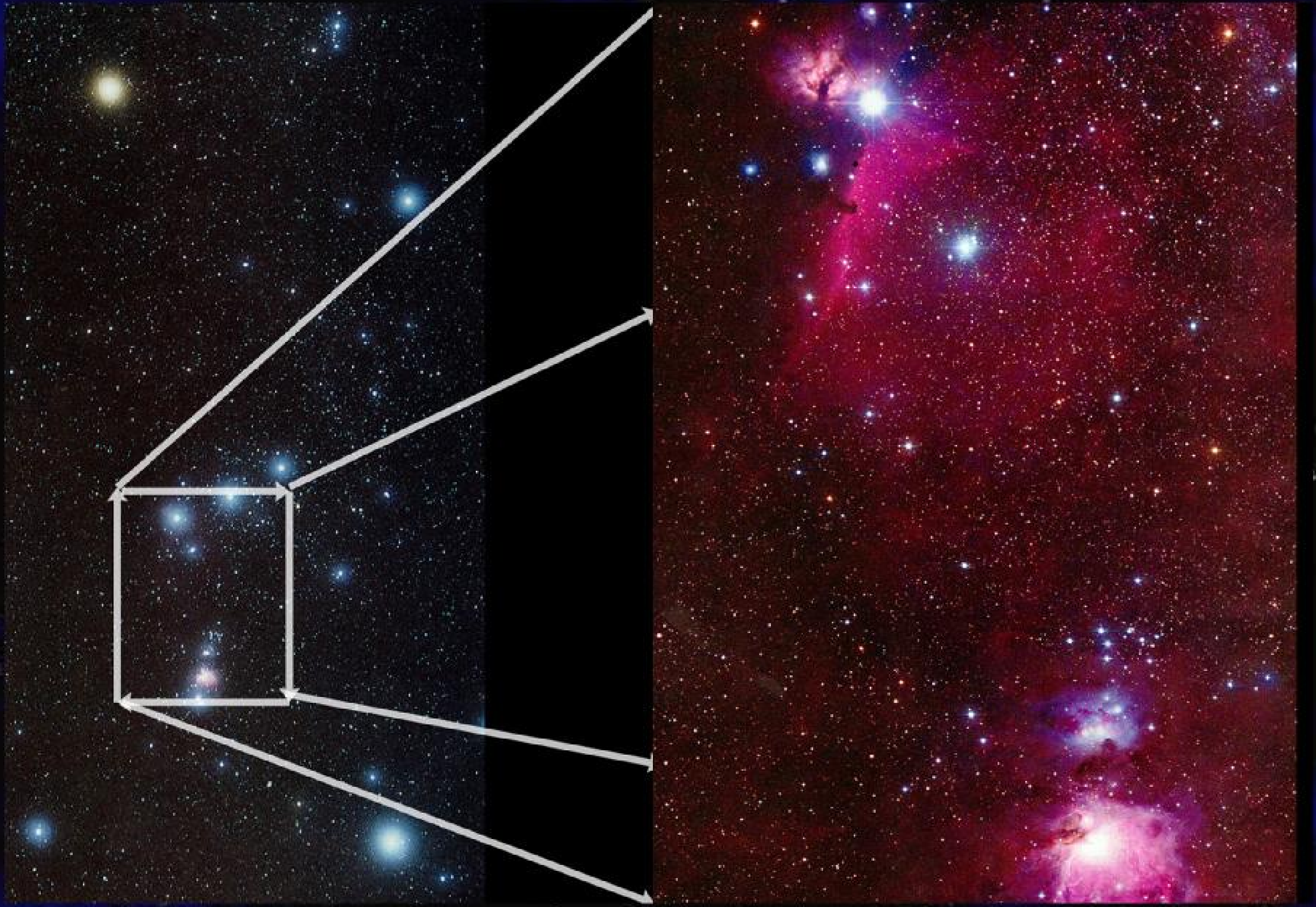
Nebul<u>*ae*</u> – “cloud<u>s</u>”

HII regions

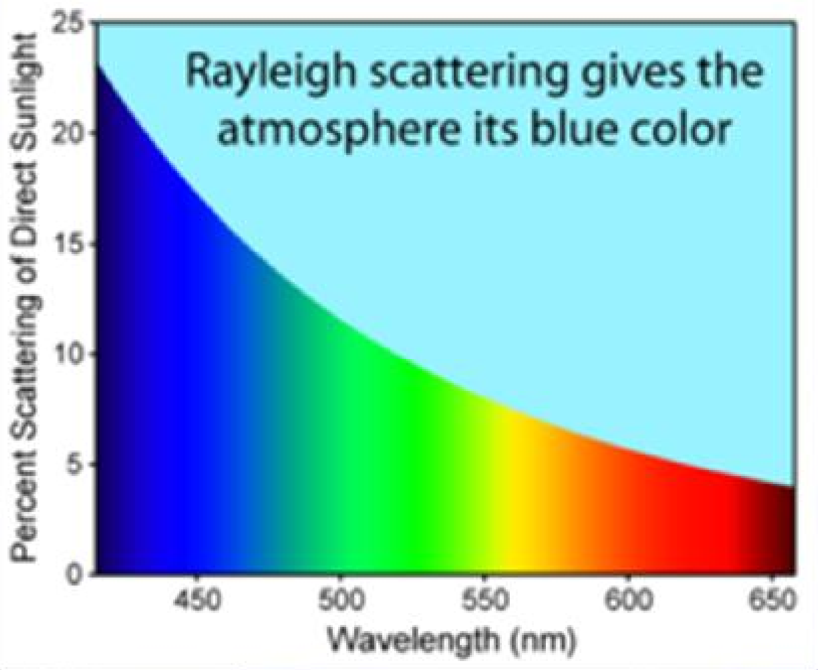
Emission nebulae

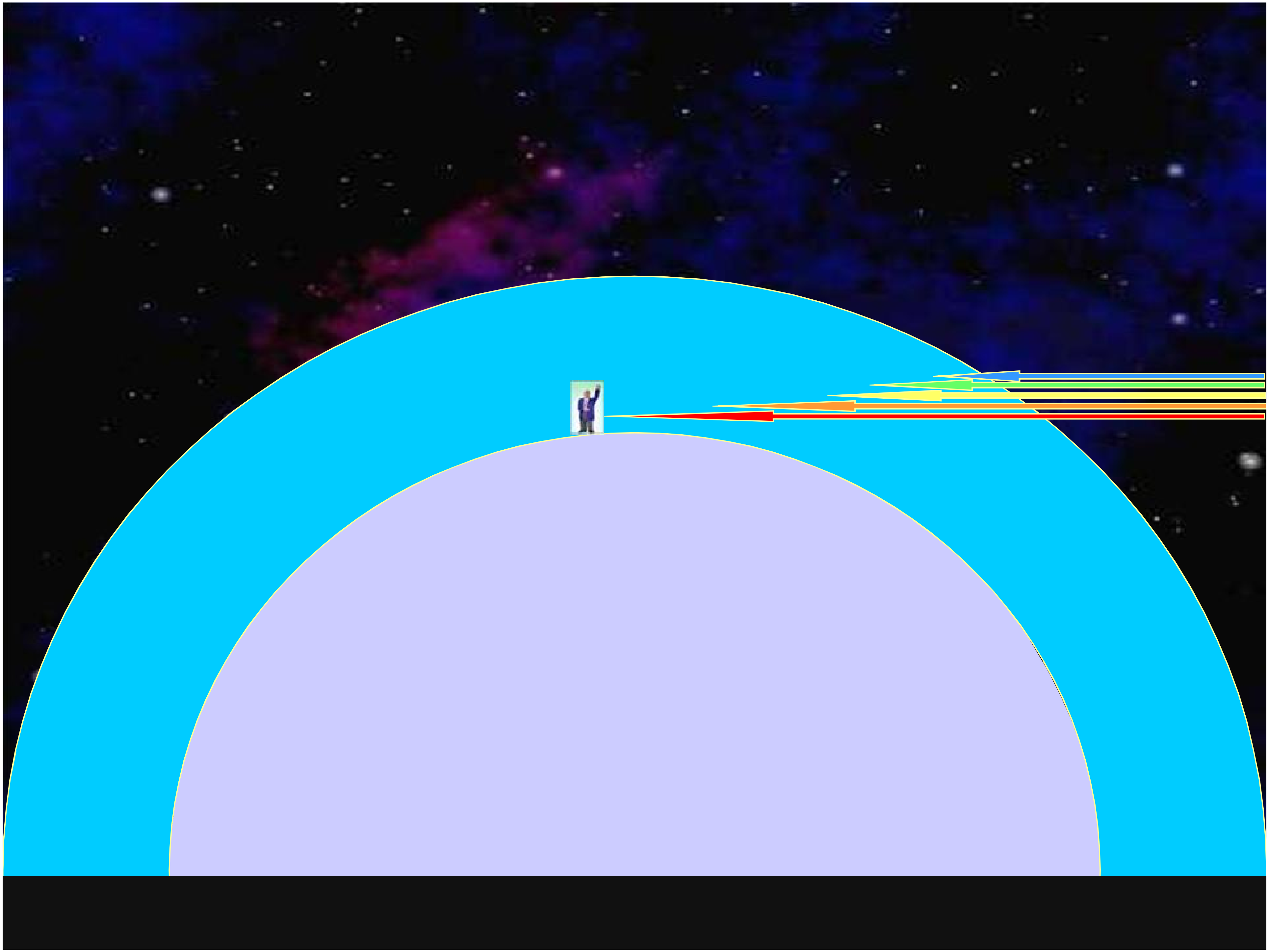
The Rosette Nebula

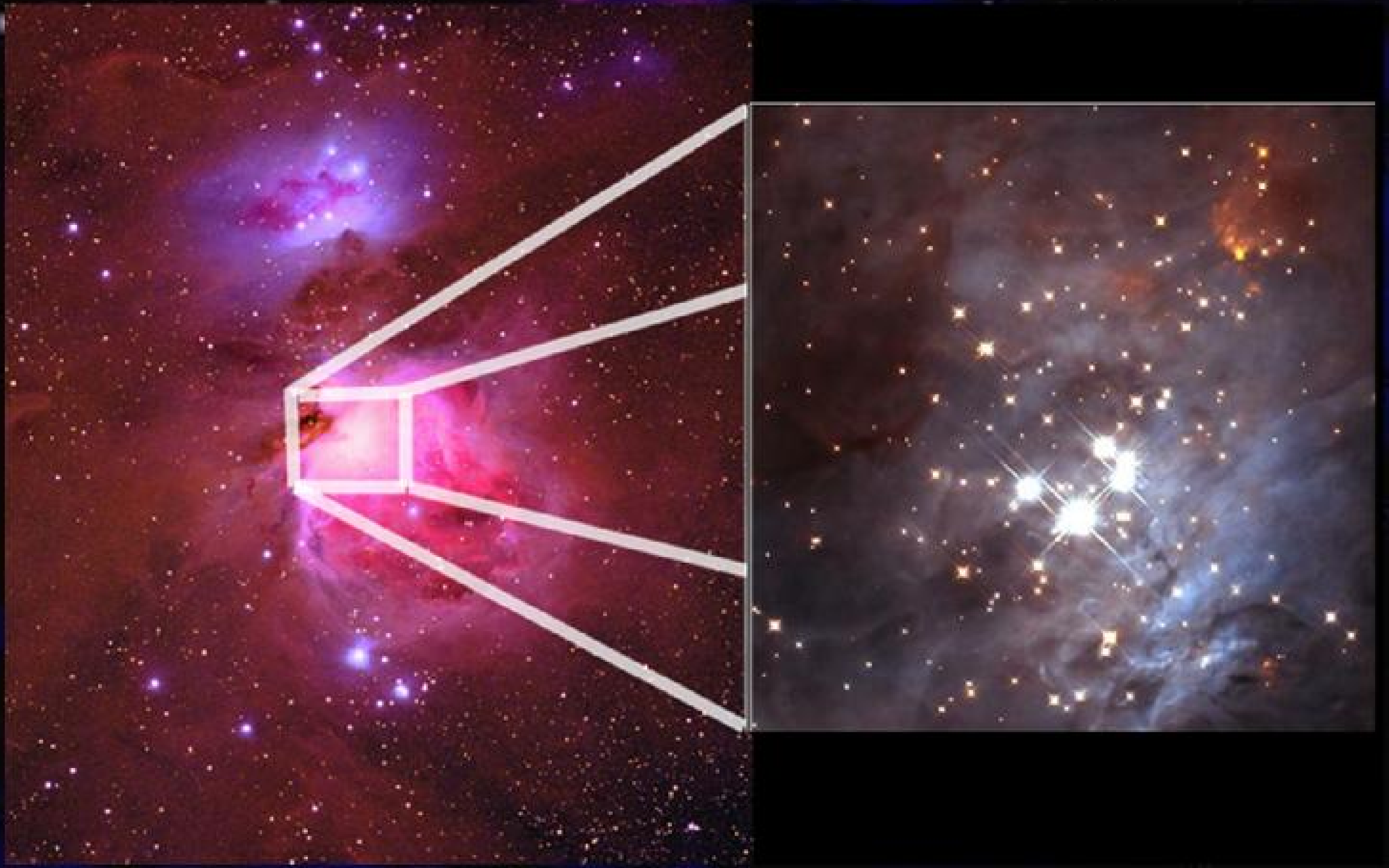
Orion

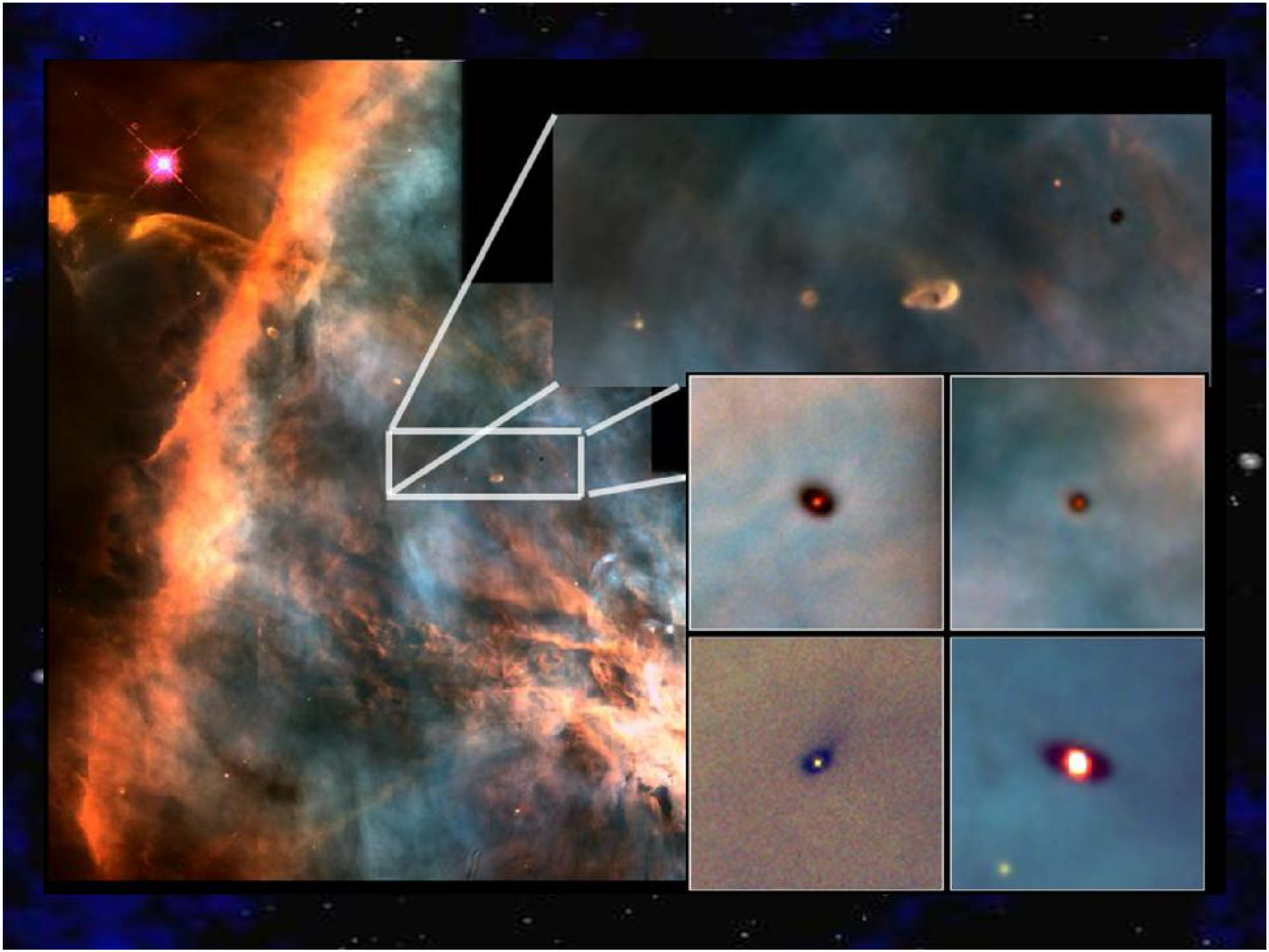


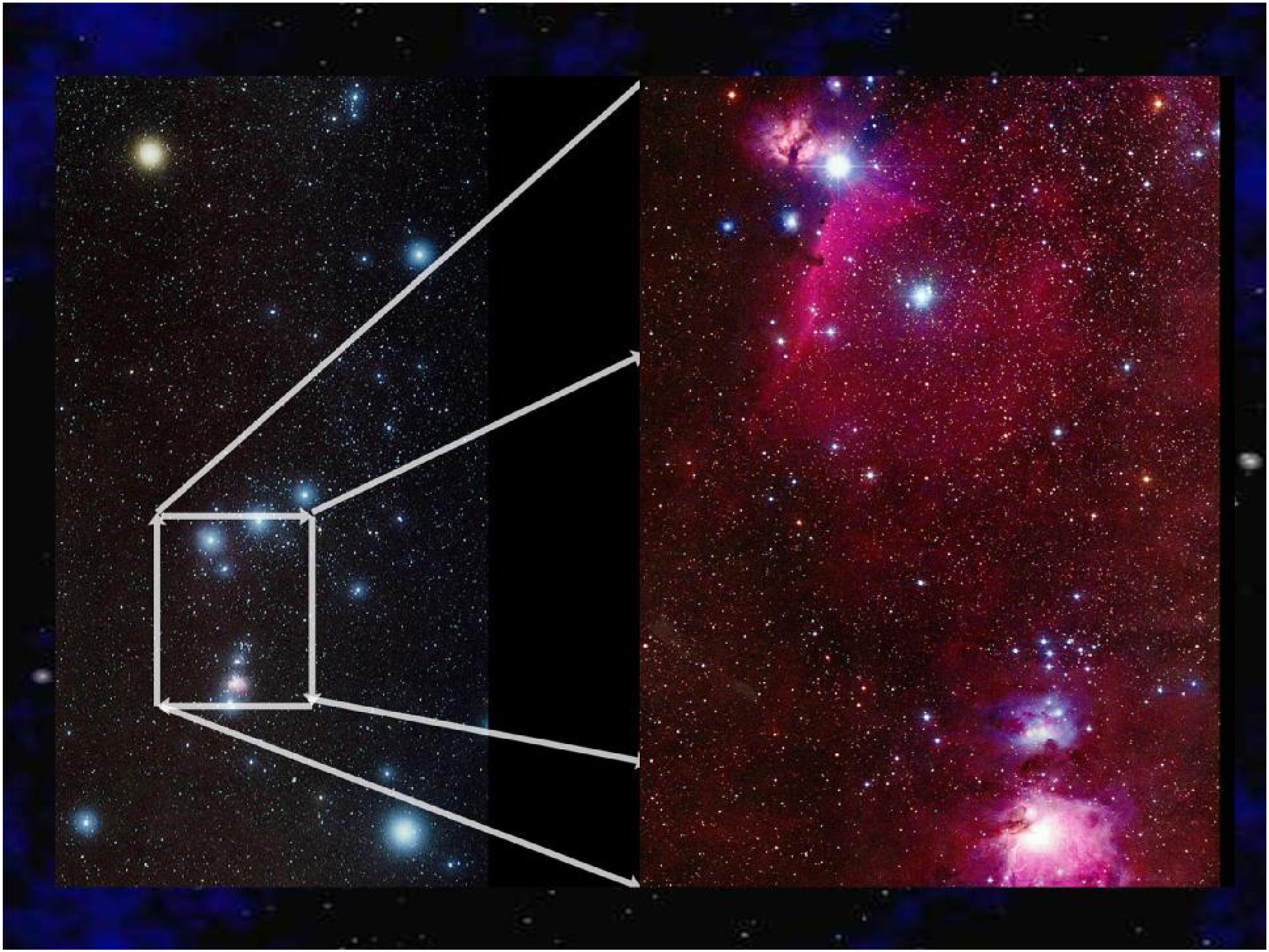
$$\sigma_s = \frac{2\pi^5}{3}\frac{d^6}{\lambda^4}\left(\frac{n^2-1}{n^2+2}\right)^2$$











The Horsehead Nebula

NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC01-12

M16 (The Eagle Nebula)

M16 (The Eagle Nebula)

esa

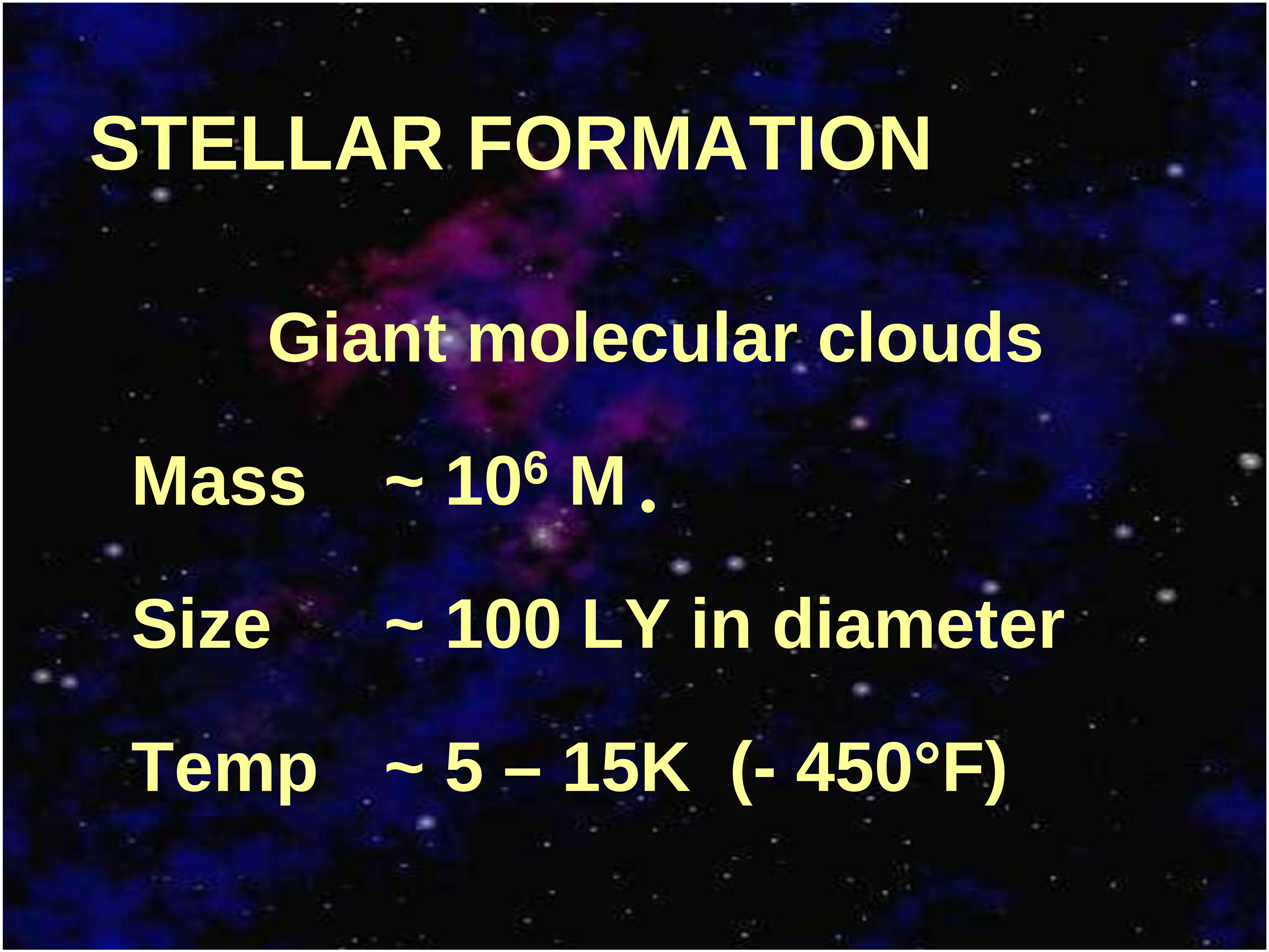
www.spacetelescope.org

M16 (The Eagle Nebula)

esa

www.spacetelescope.org

STELLAR FORMATION



Giant molecular clouds

Mass ~ 10^6 $M_\odot$

Size ~ 100 LY in diameter

Temp ~ 5 – 15K (- 450°F)

STELLAR FORMATION

Gas Pressure

Outward

(temperature)

<

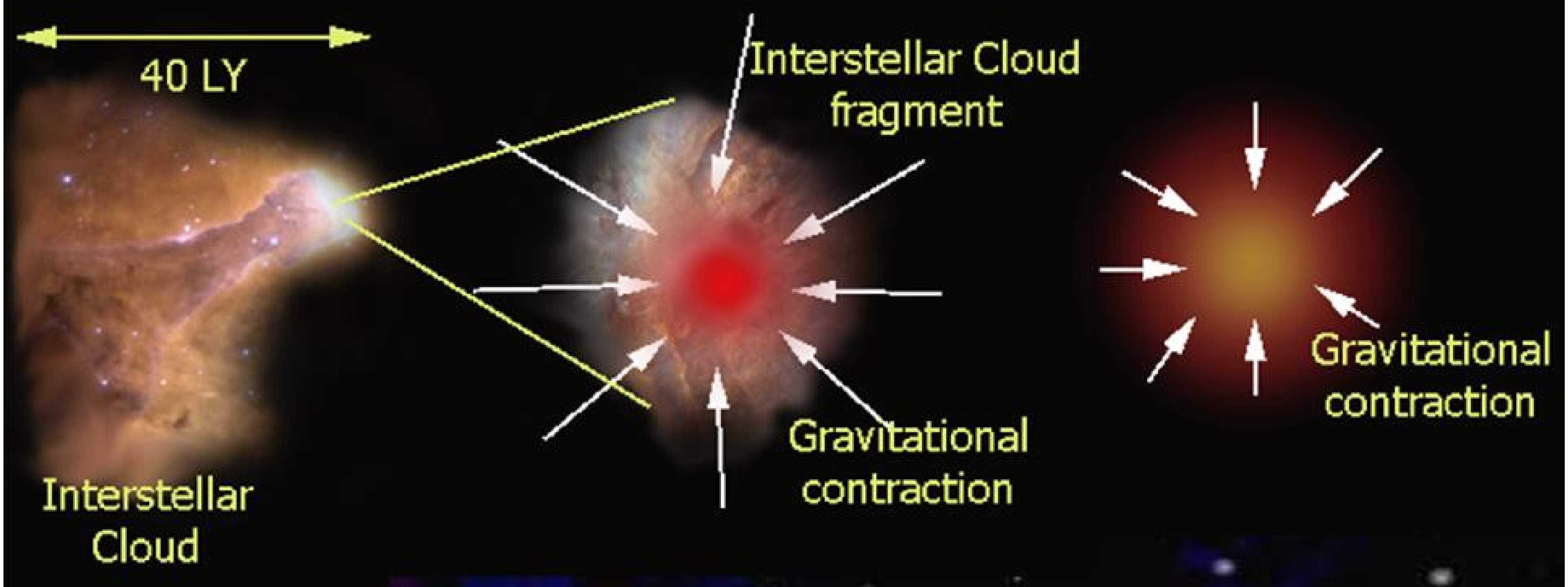
Gravity

Inward

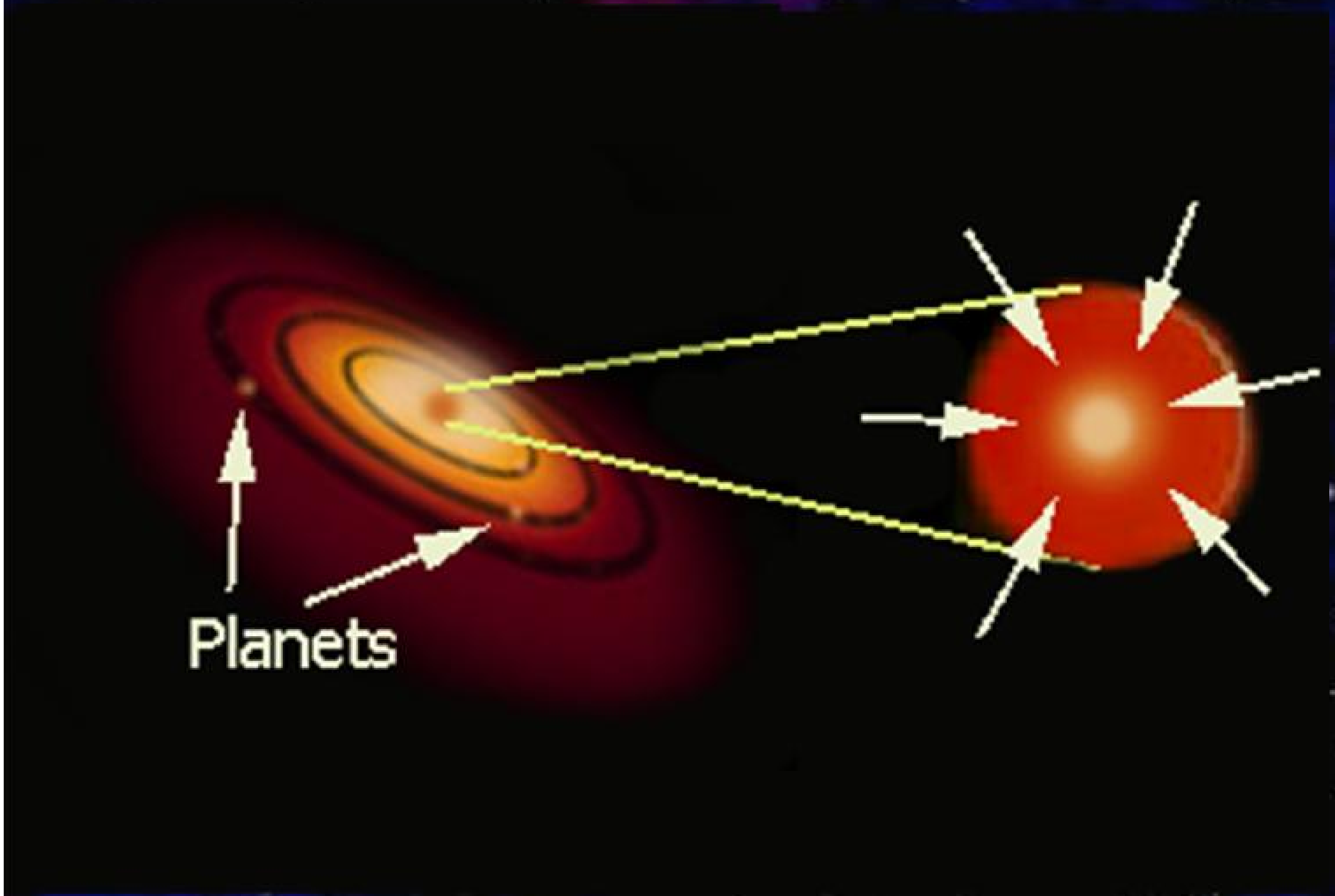
(mass of cloud)

GRAVITATIONAL CONTRACTION

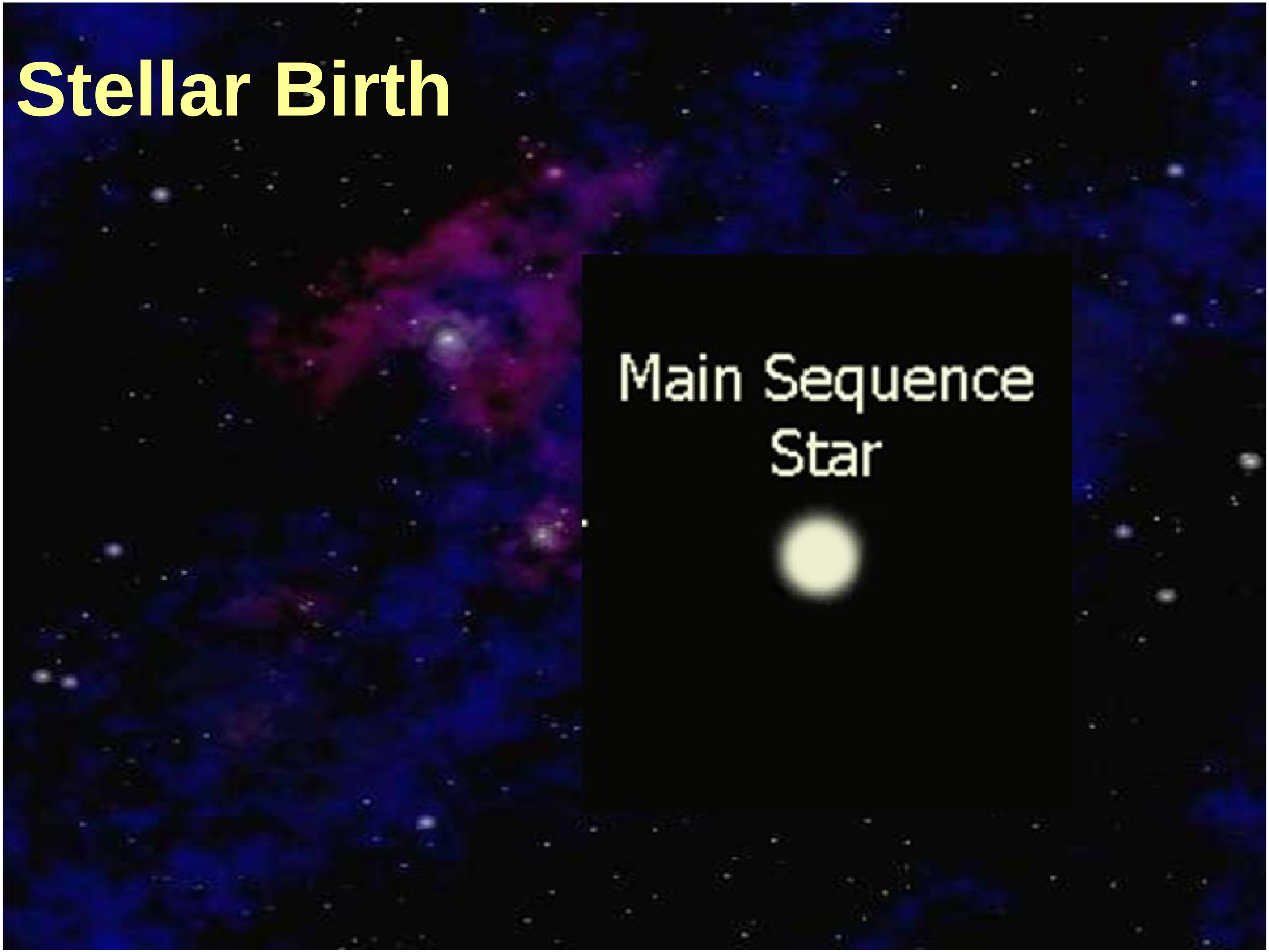
Stellar Birth



Stellar Birth



Stellar Birth



The Pleiades Cluster

What is the source of the Sun’s energy?

Recall the Sun’s Luminosity:

390,000,000,000,000,000,000,000,000 watts

$$Duration = \frac{Amount \quad of \quad fuel}{Rate \quad of \quad consumption}$$

Historical attempts to explain energy production

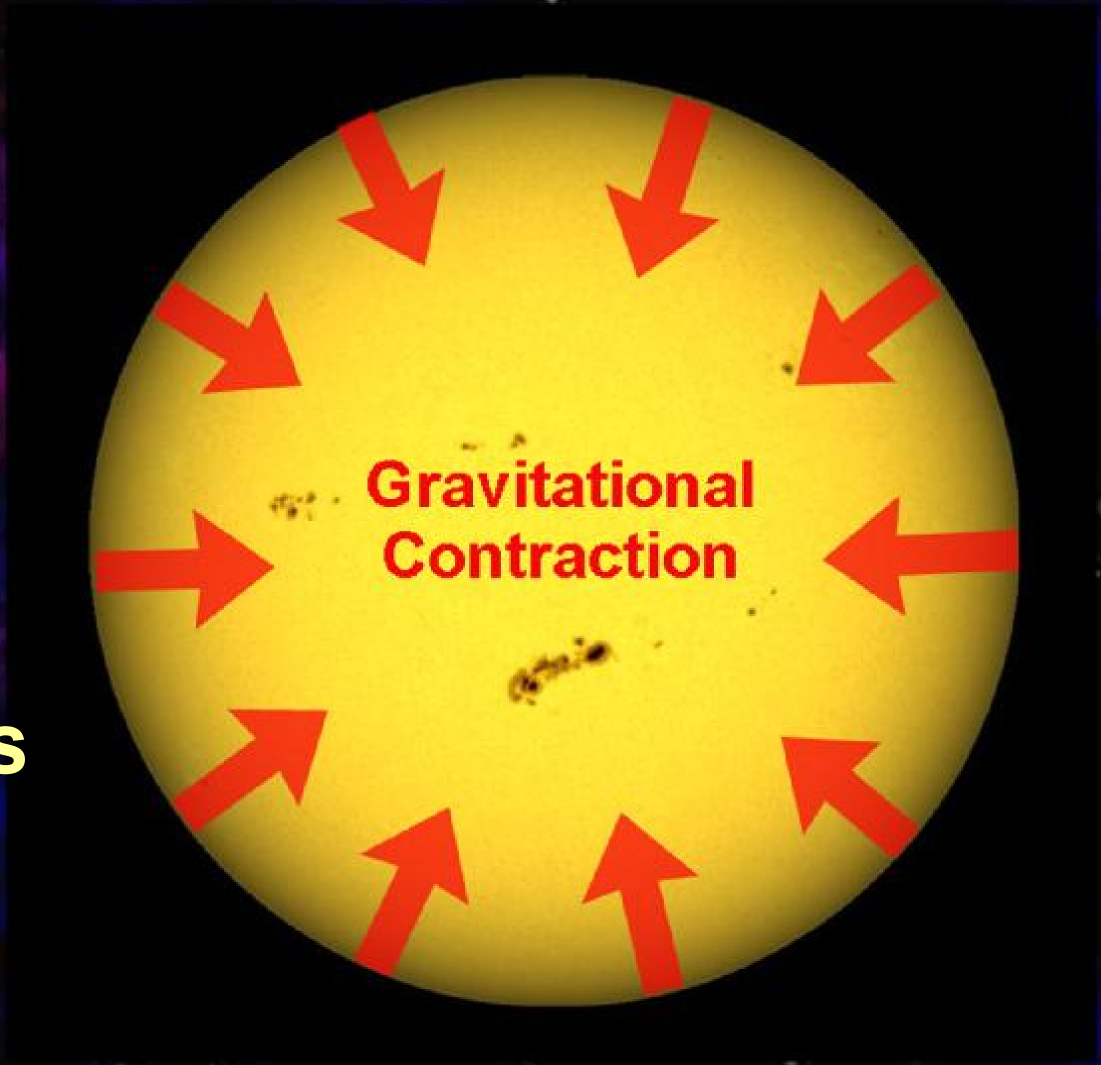
Chemical Burning (coal, wood, gas)

3,000 years

Gravitational Contraction

40 meters/year

50 million years



Albert Einstein (1879-1955)

$$E = mc^2$$

- Mass and Energy are equivalent
- A small amount of mass yields a large amount of energy