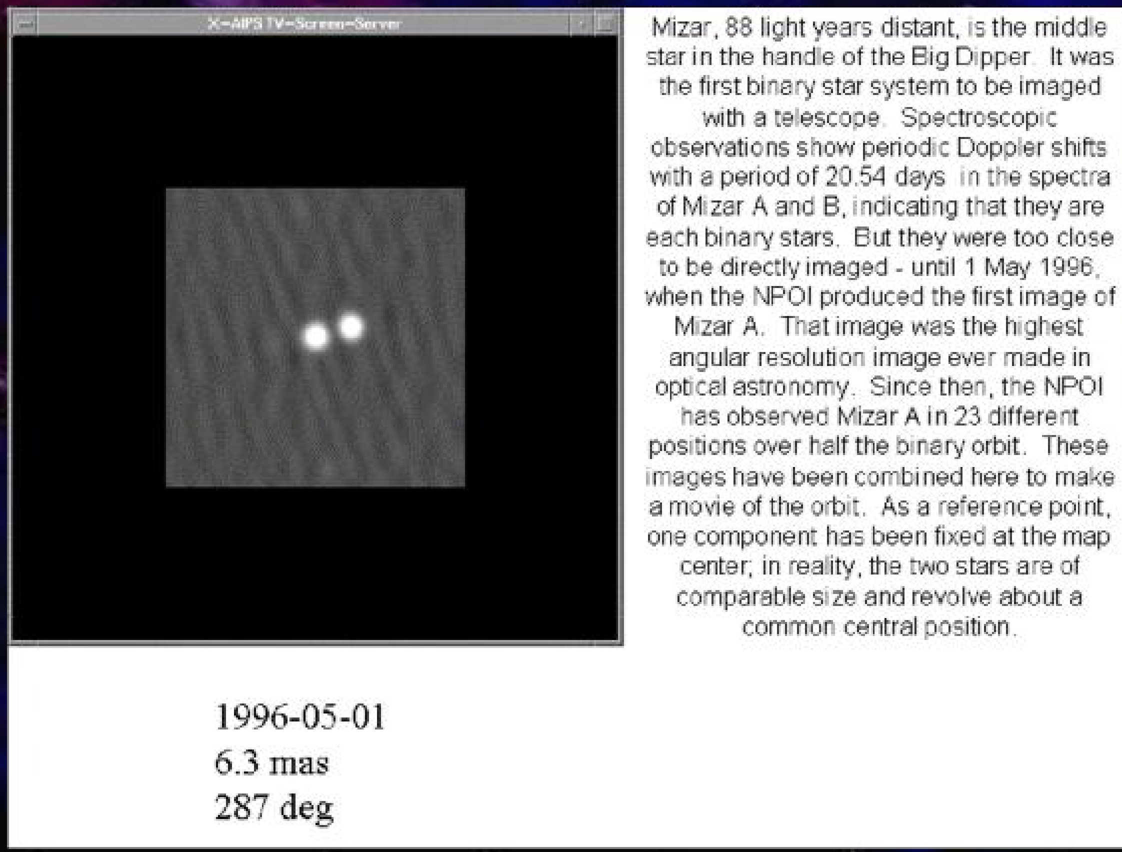
BINARY STARS

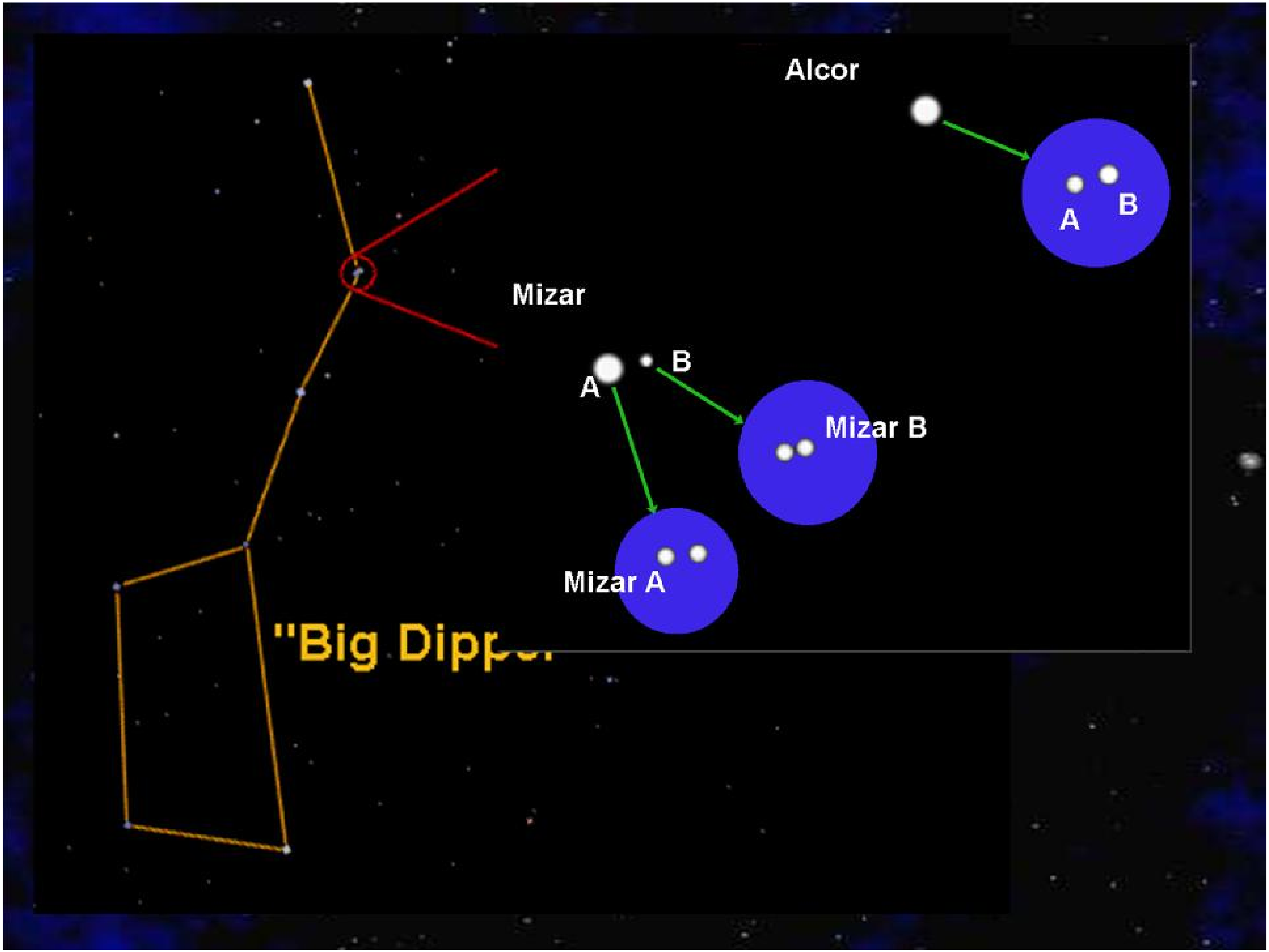
Binary Stars:

Two or more stars in orbit around each other.



Binary Stars:

- Usually formed together
- Can be complicated multiple systems



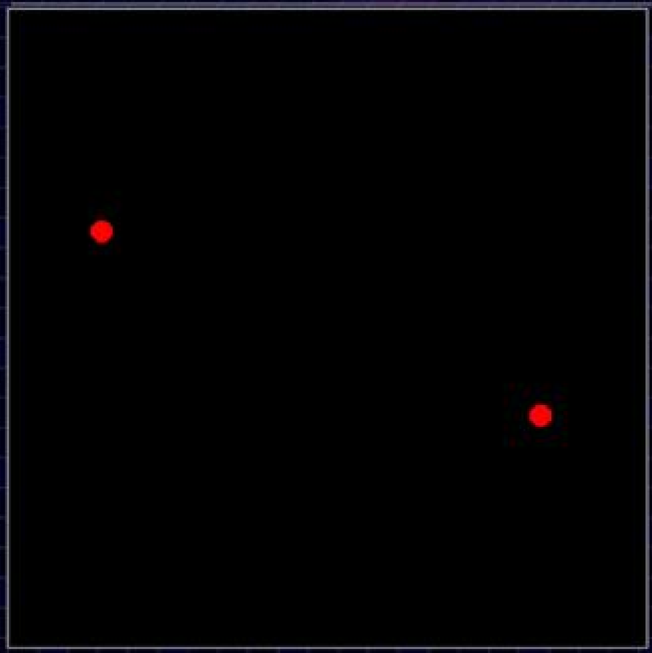
Alcor
A
B
Mizar
A
B
Mizar B
Mizar A
"Big Dipp

Binary Stars:

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

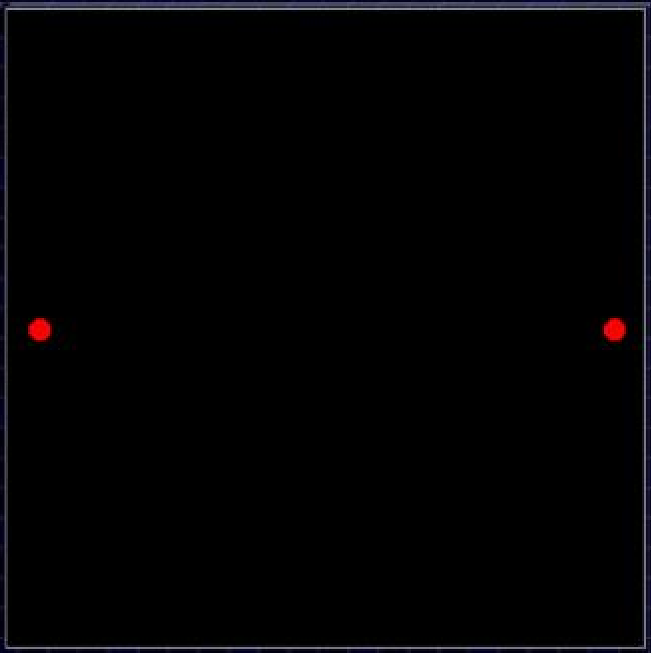
More than 66 % of all stars are members of binary systems.

Elliptical Orbits



A Binary Star System

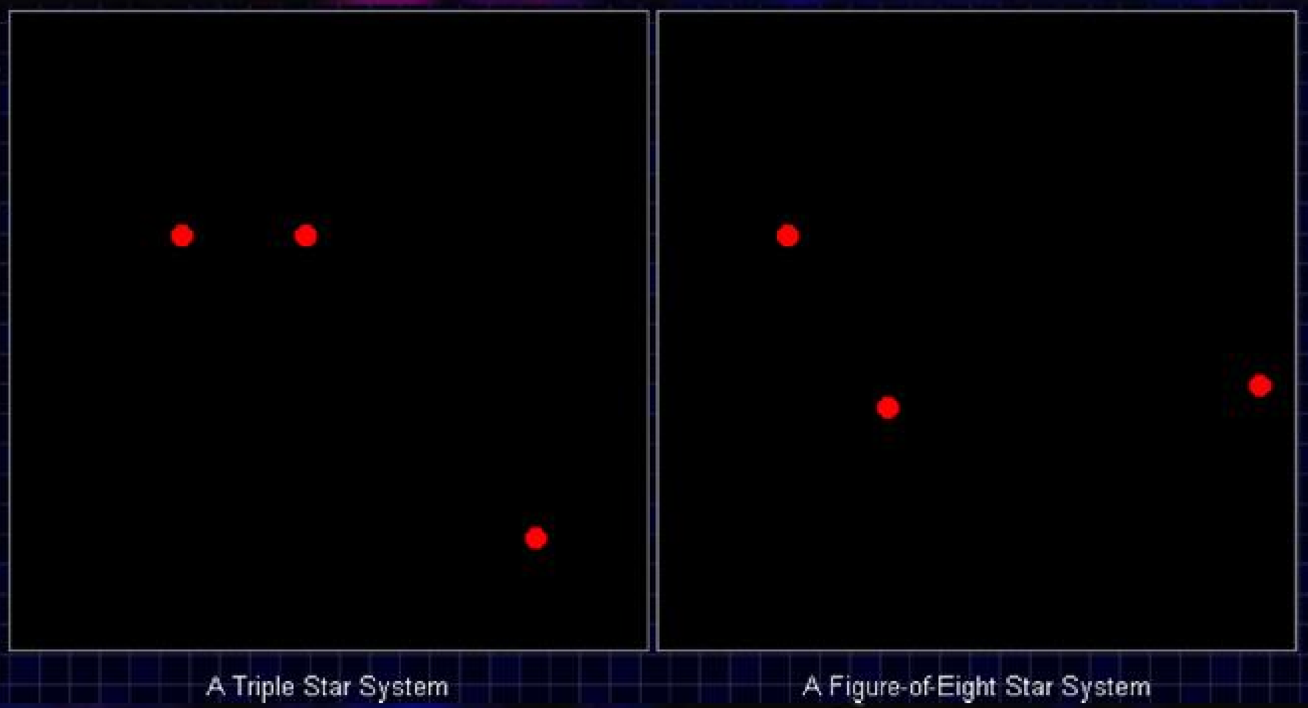
Circular Orbits



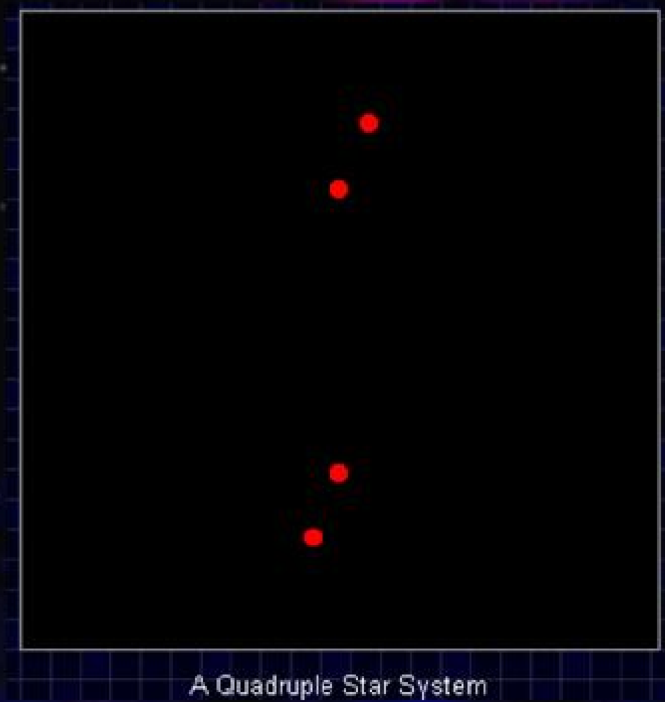
A Circular Binary Star System

Triple Star

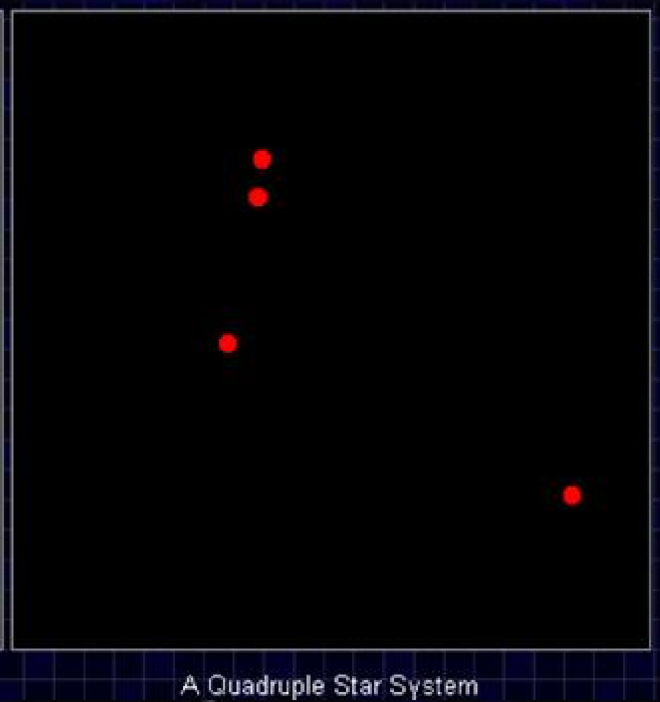
Figure 8 Orbits



Double Binary Orbits

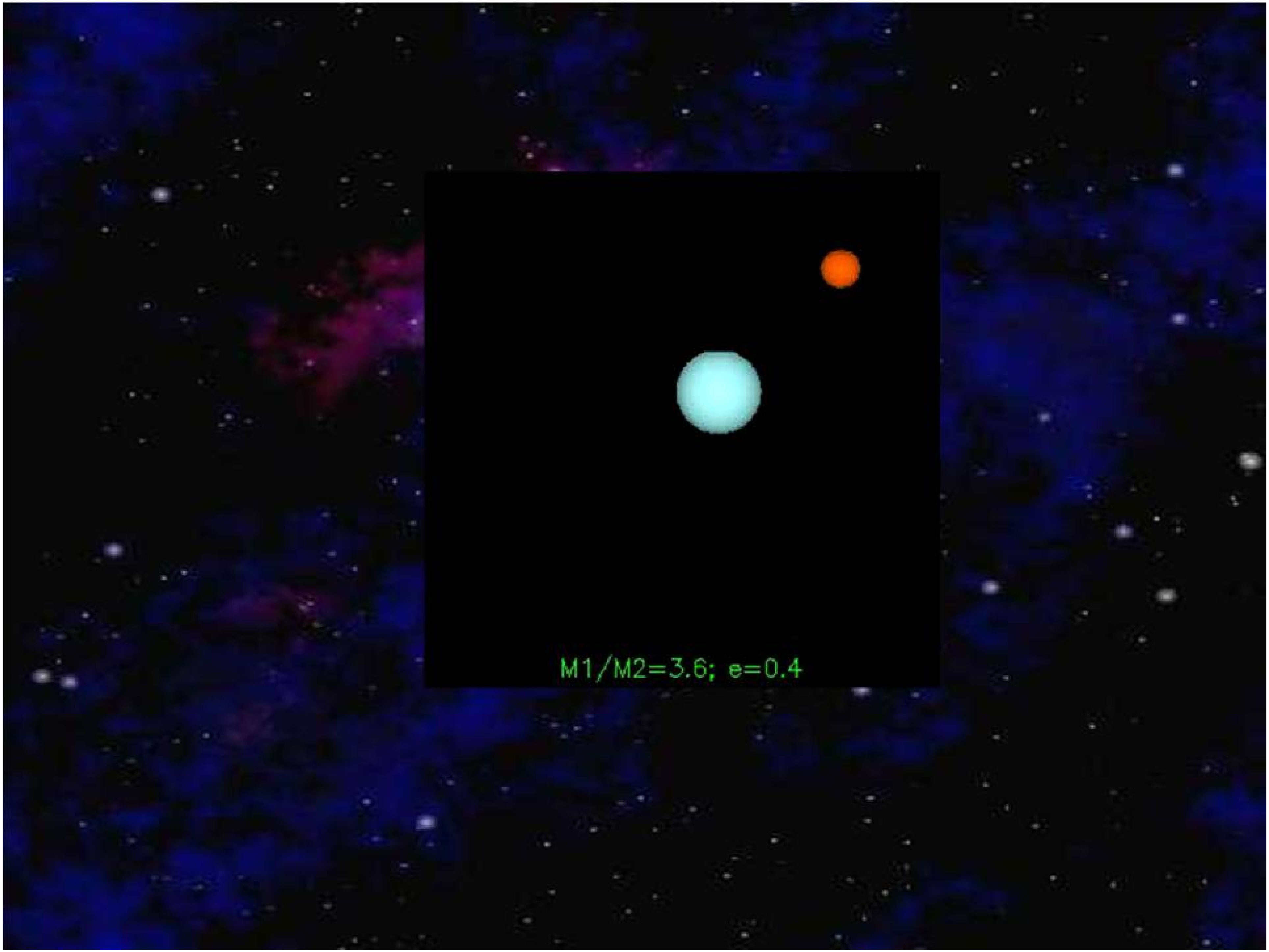


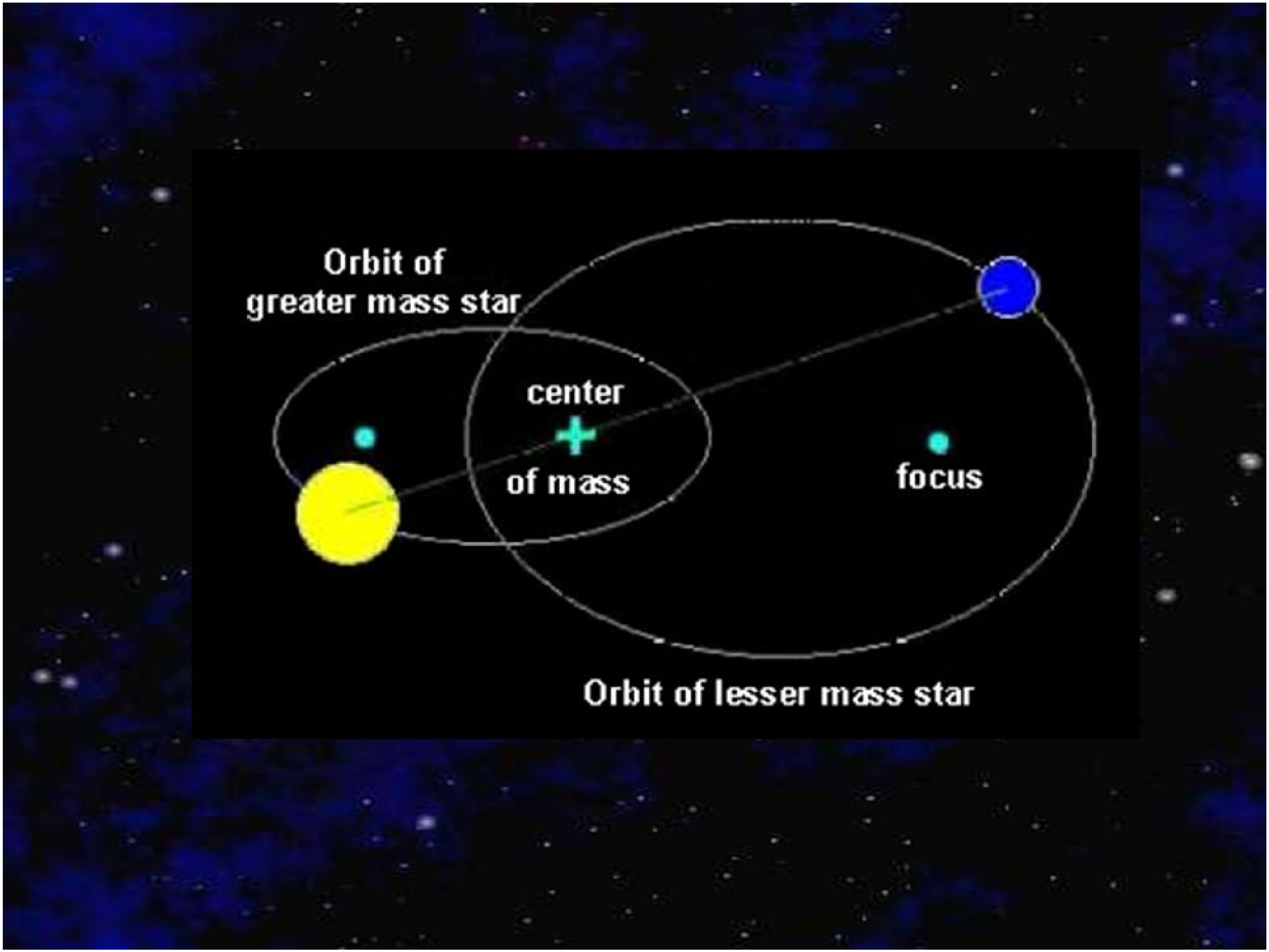
Quadruple System



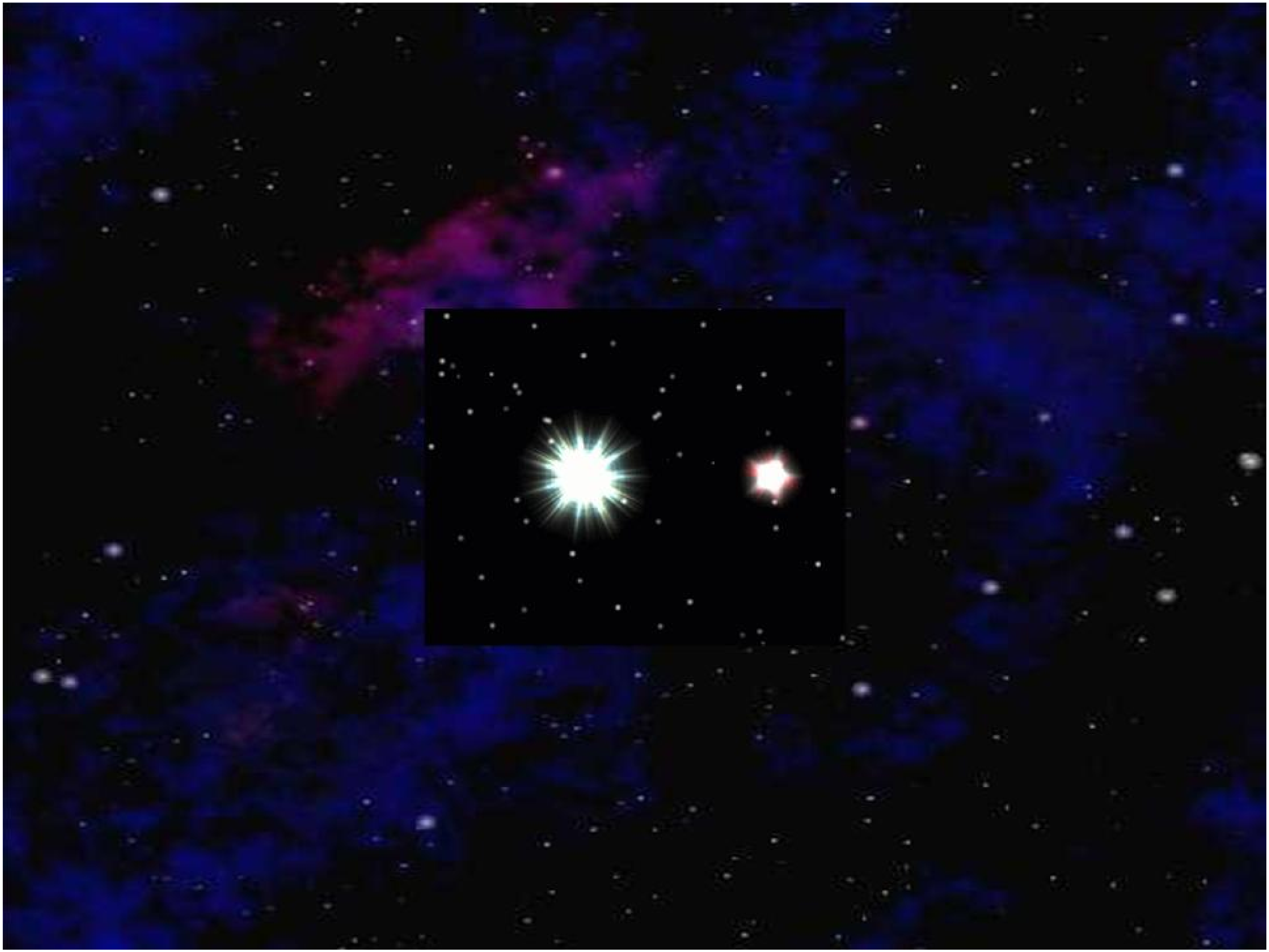
Visual Binary Systems:

- 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

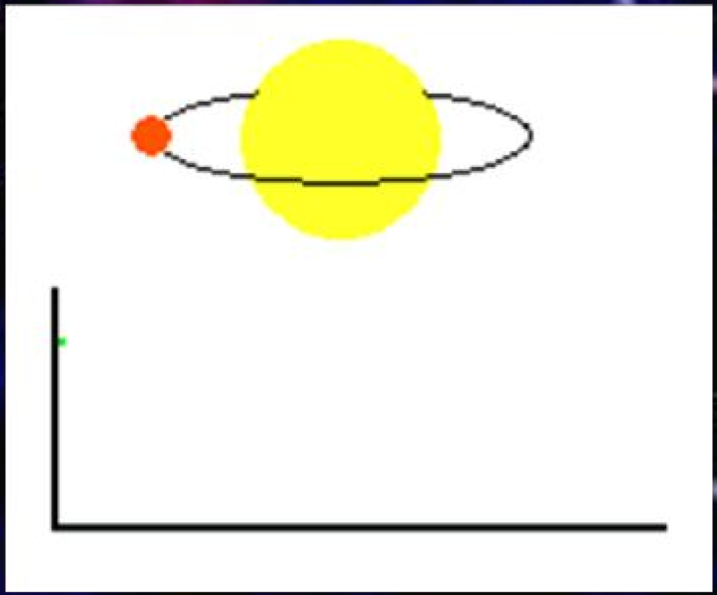

Orbit of
greater mass star
center
of mass
focus
Orbit of lesser mass star

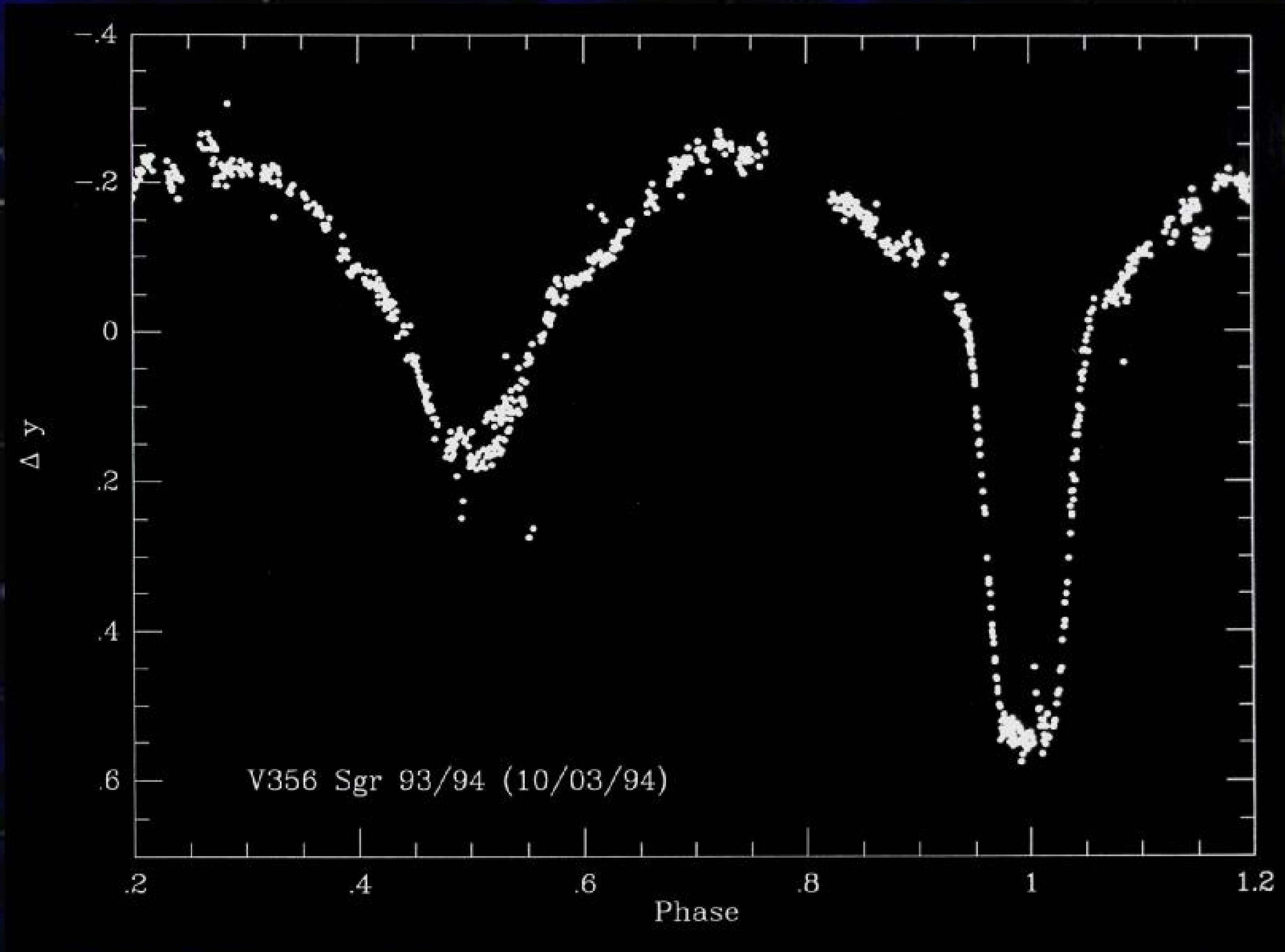
What about stars that are too close together to be seen as individual stars?

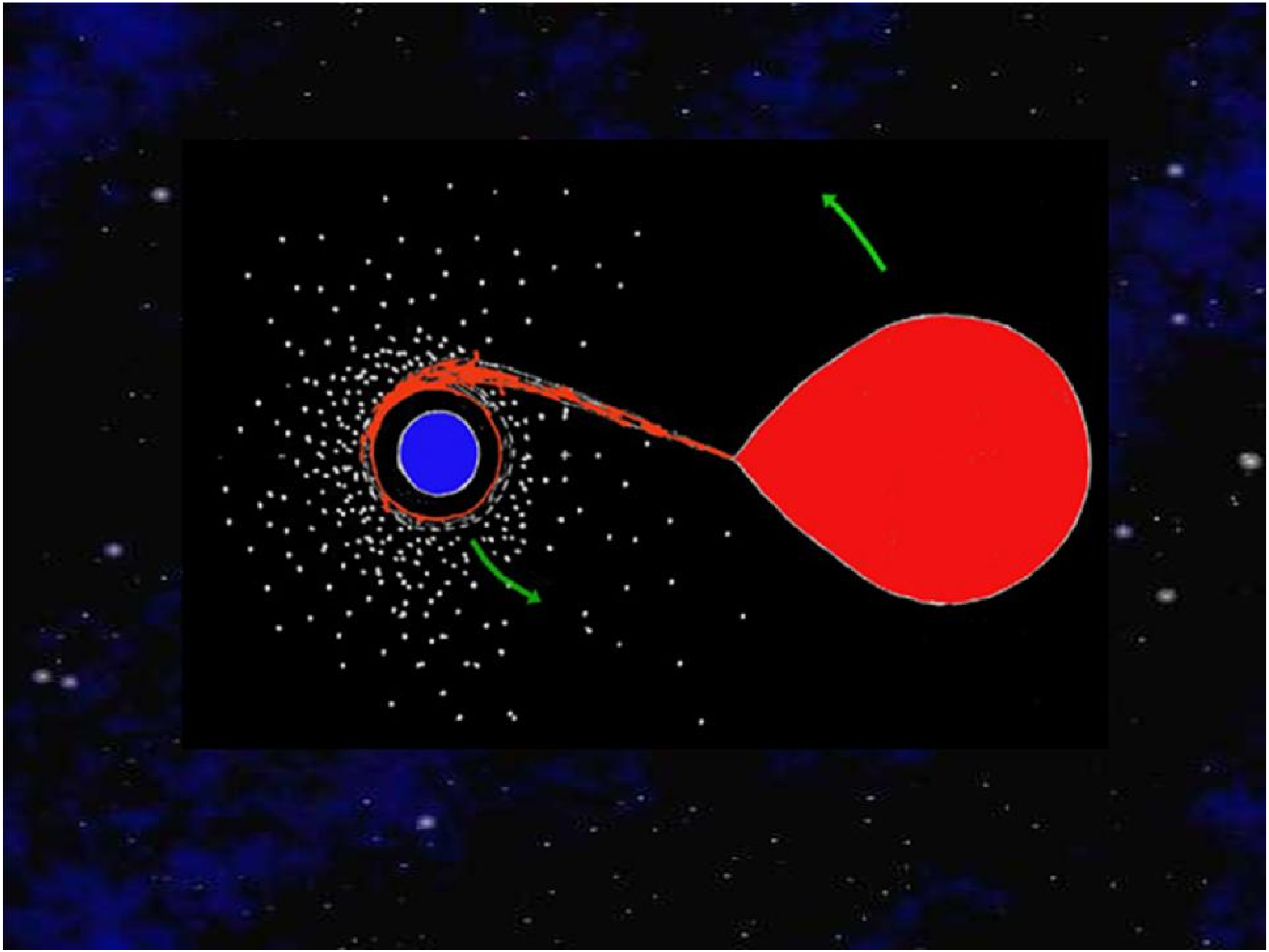


Eclipsing Binary Systems:

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



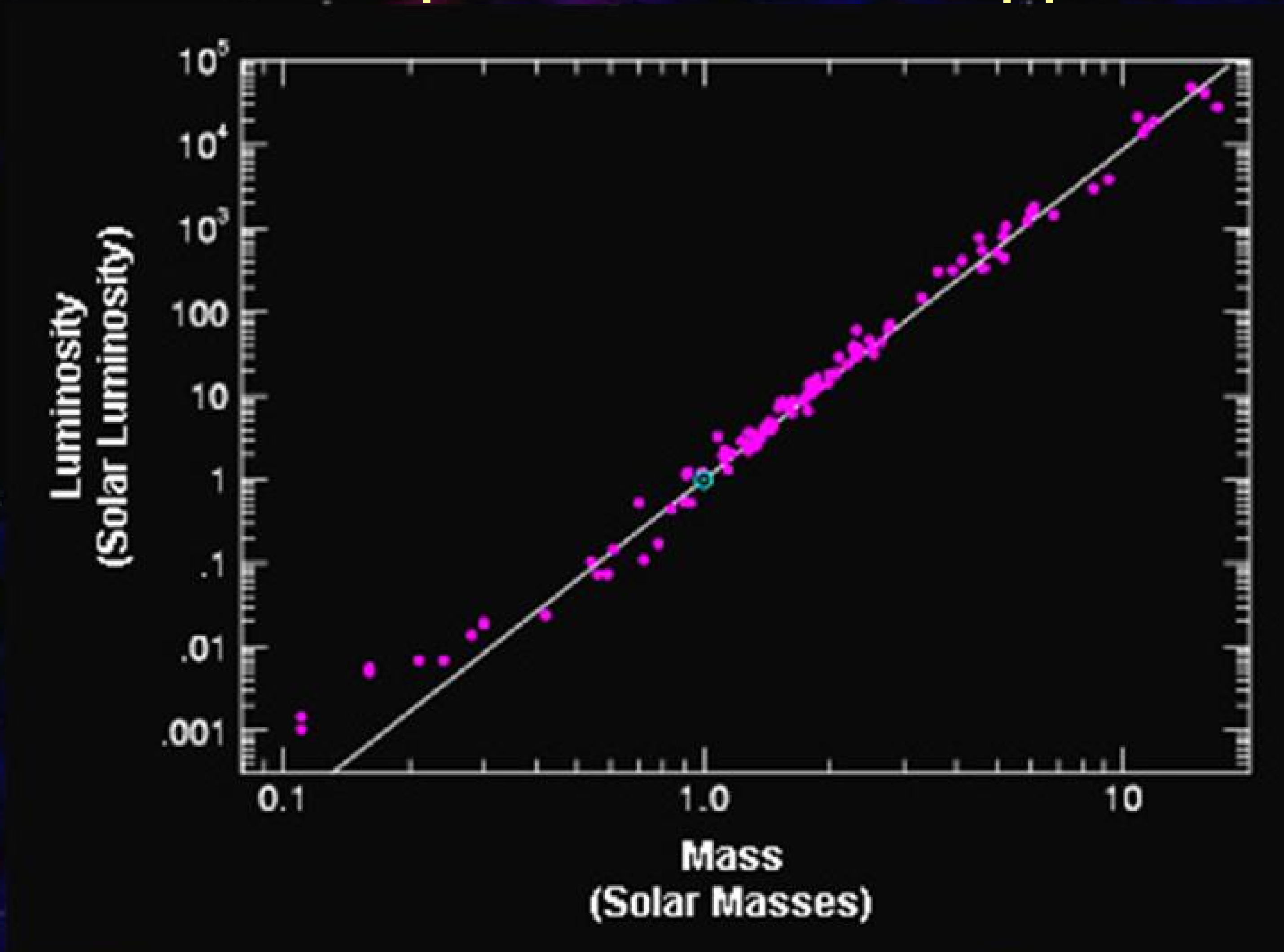

-.4
-.2
0
.2
.4
.6
Δ y
V356 Sgr 93/94 (10/03/94)
.2
.4
.6
.8
1
1.2
Phase

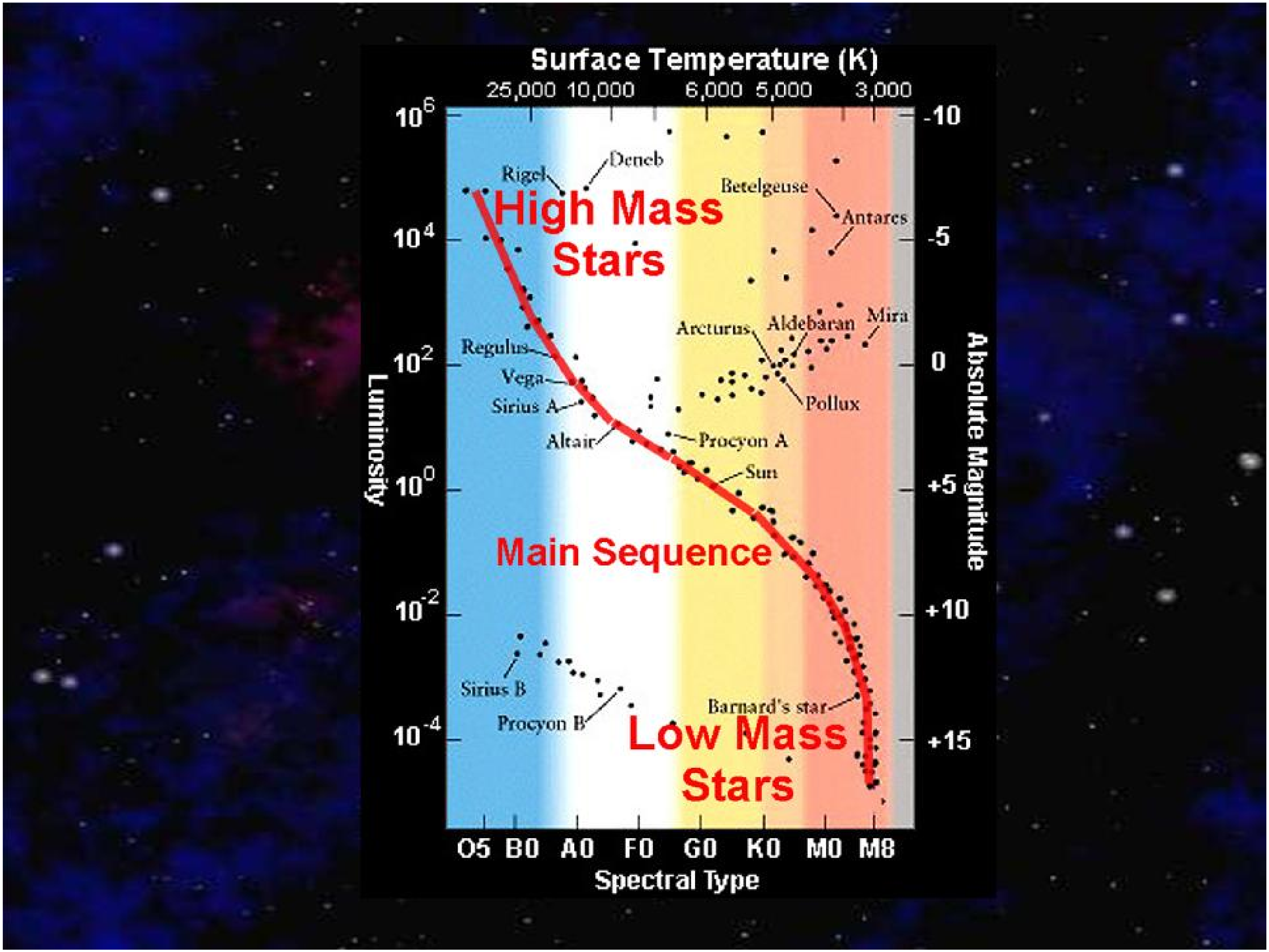


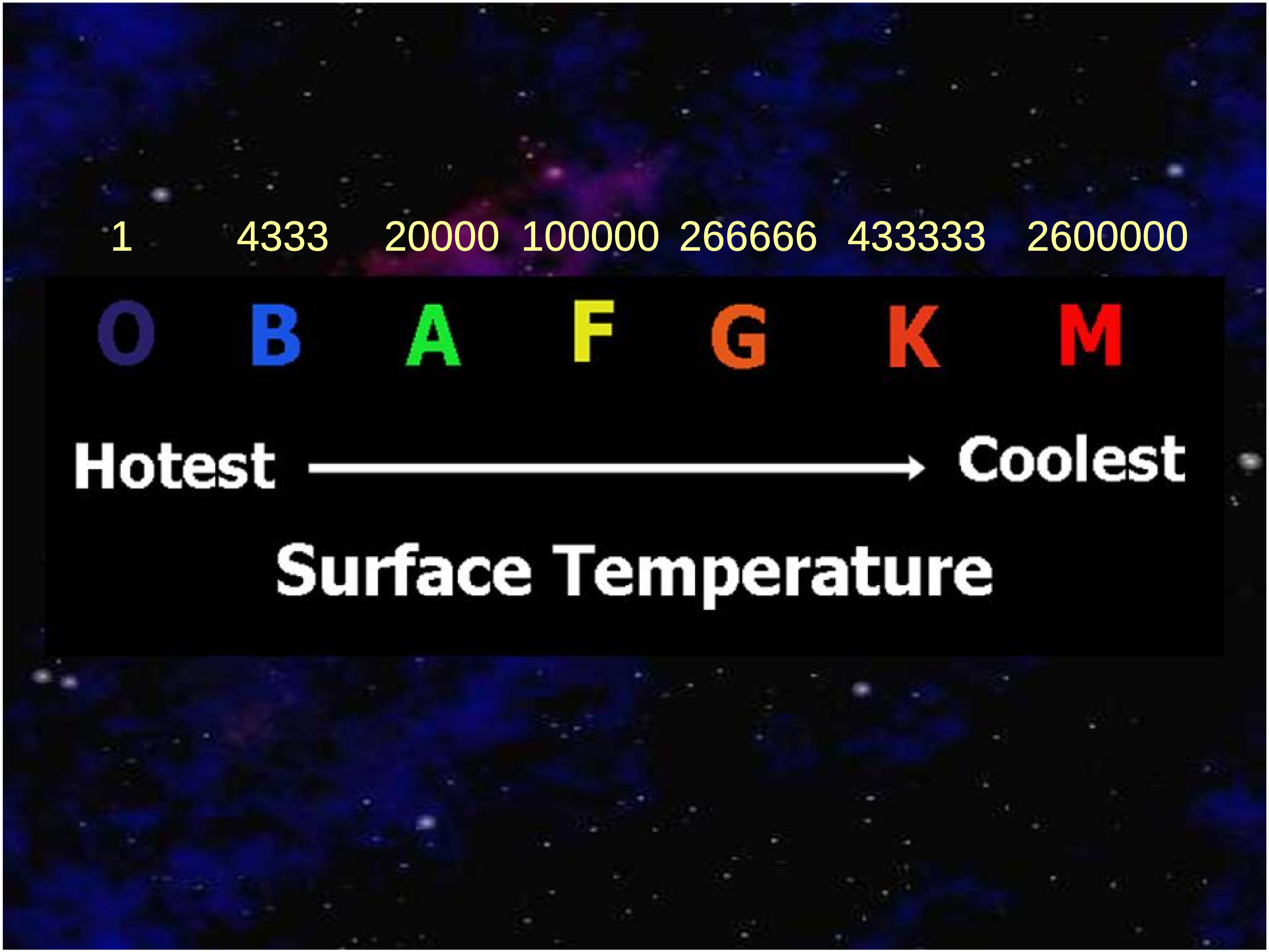
$$(m_1 + m_2) \propto \frac{d^3}{p^2} \qquad \frac{m_1}{m_2}$$

The masses of the individual stars can be calculated.

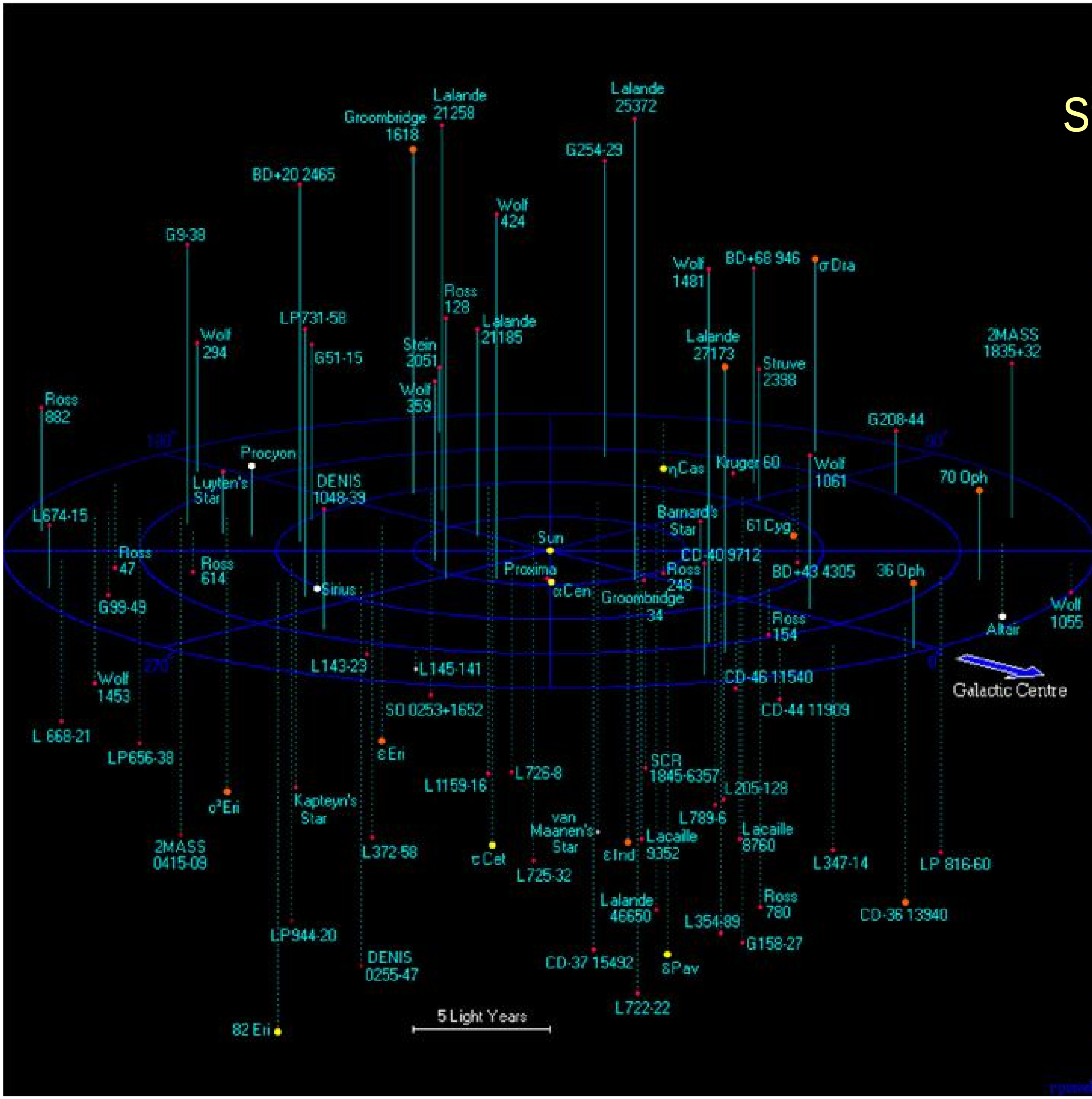
By gathering the masses of a large variety of stars in binary systems a fundamental relationship soon became apparent.




Surface Temperature (K)
25,000 10,000 6,000 5,000 3,000
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
High Mass Stars
Main Sequence
Low Mass Stars
Rigel
Deneb
Betelgeuse
Antares
Regulus
Vega
Sirius A
Altair
Procyon A
Sun
Arcturus
Aldebaran
Mira
Pollux
Sirius B
Procyon B
Barnard's star

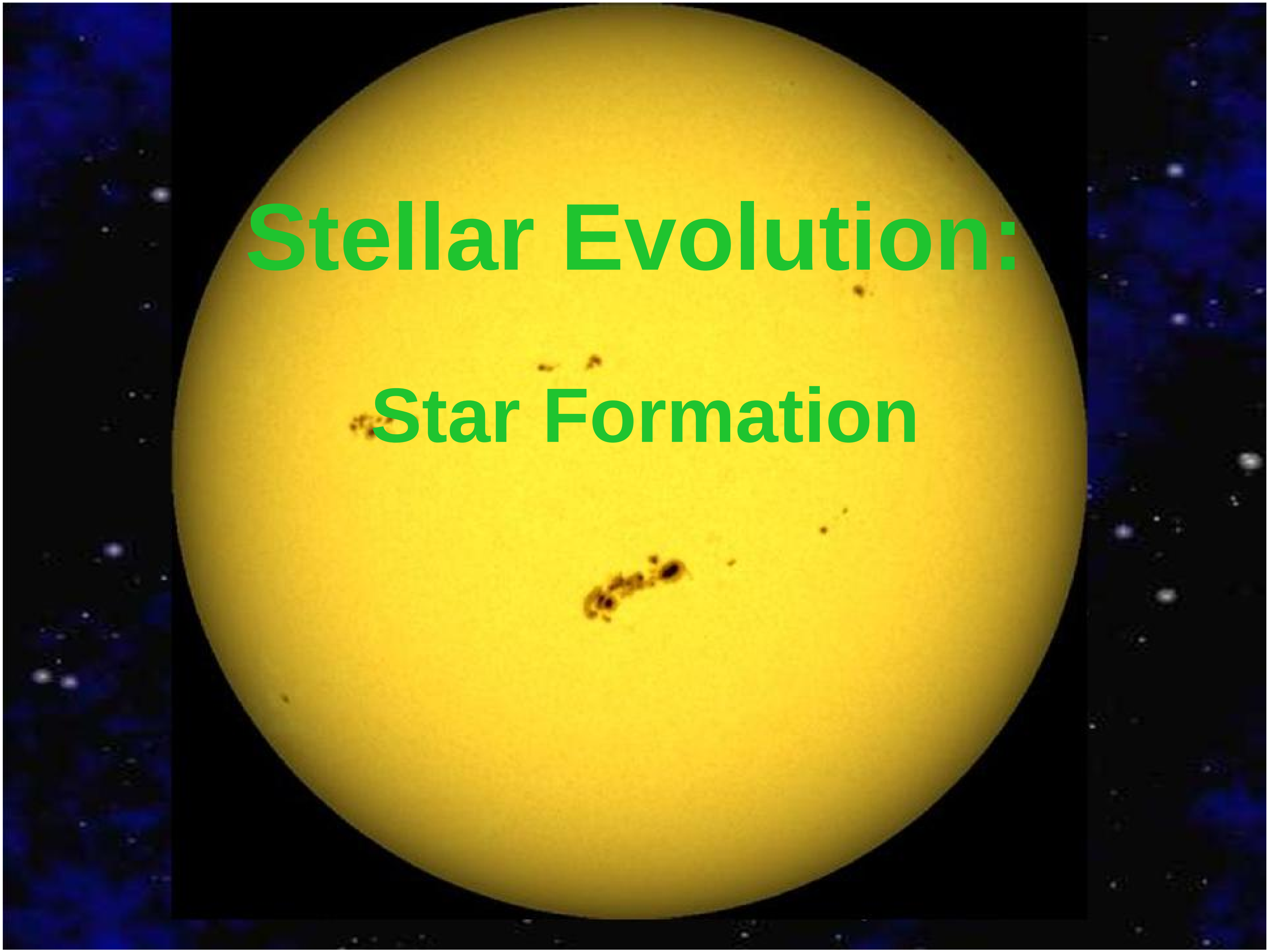

1 4333 20000 100000 266666 433333 2600000
O B A F G K M
Hotest
Coolest
Surface Temperature

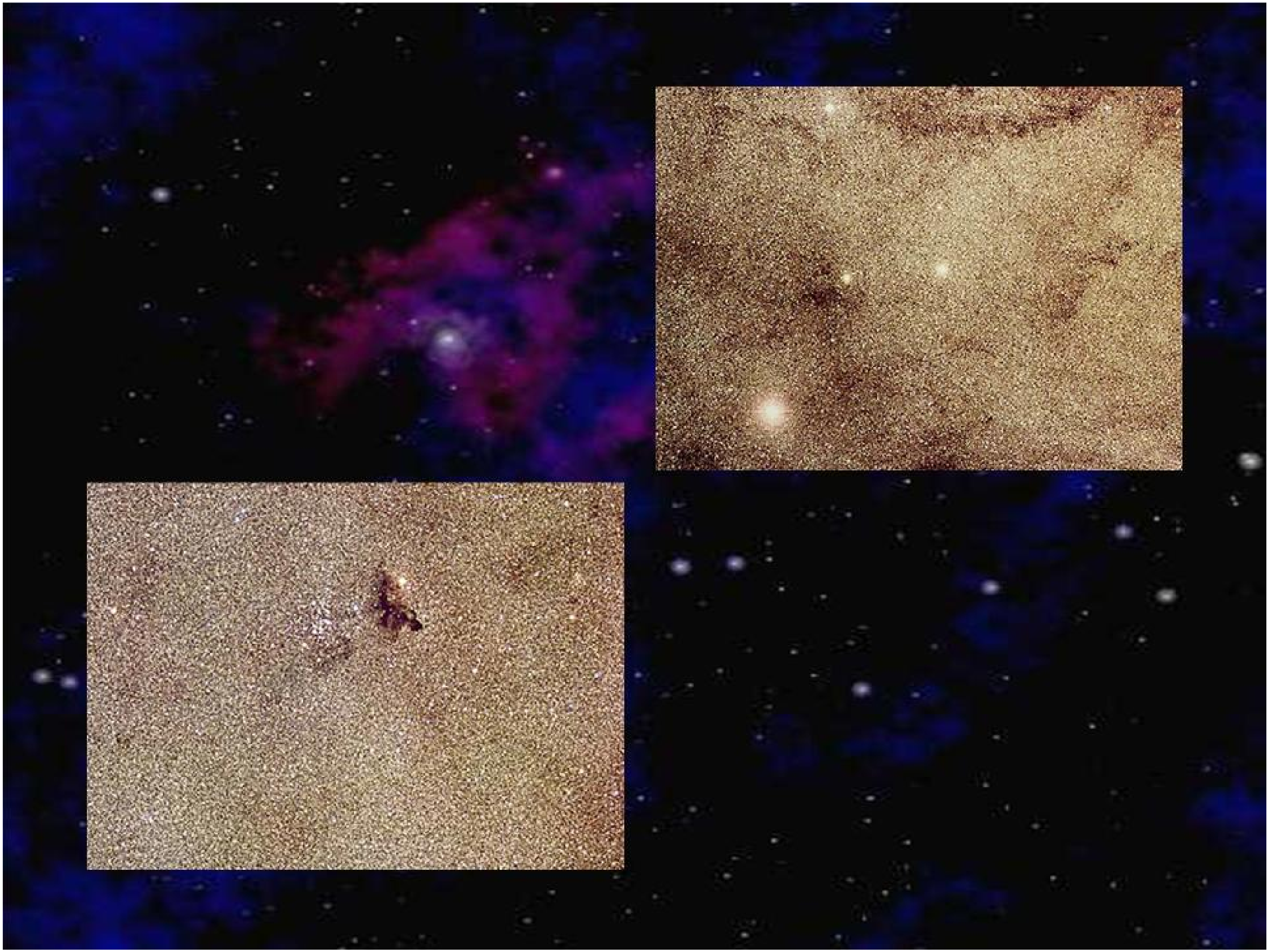
Stars within 20ly



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)

Interstellar Gas

- 99% of the ISM
- 90% Hydrogen ~10% Helium (by number)
- 1 atom/cm^3
- Interstellar Clouds: 1000+ atoms/cm^3
- Molecular Clouds: 10^6 atoms/cm^3

The Interstellar Medium

Dust:

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

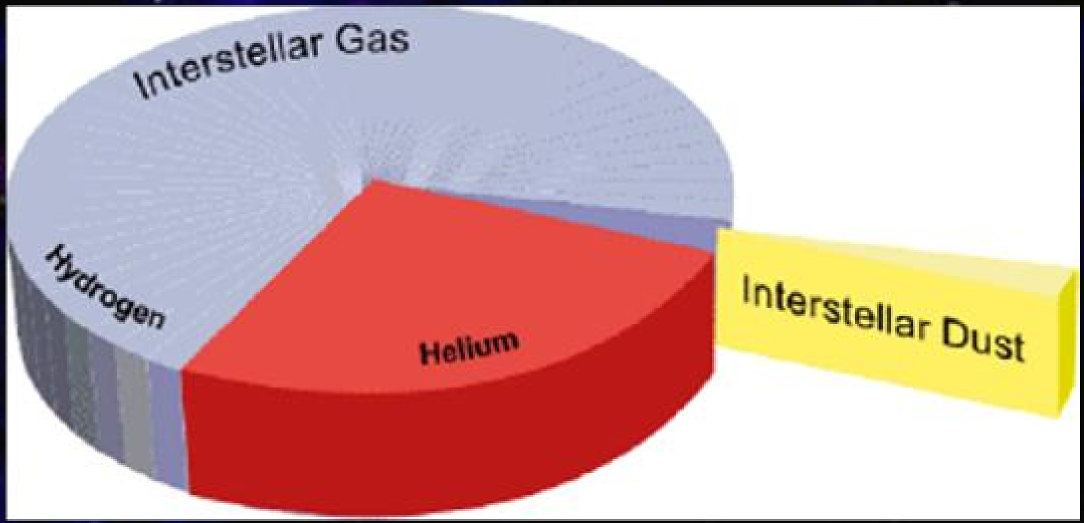
Interstellar Dust

- 1% of the ISM
- 50% of total cosmic carbon & oxygen
- 1 dust grain/cm^3
- 10^{-4} mm in size
- Carbon, silicon, oxygen (silicates)
- Coated with ice

Interstellar Medium (ISM)

GAS DUST CHARGED PARTICLES

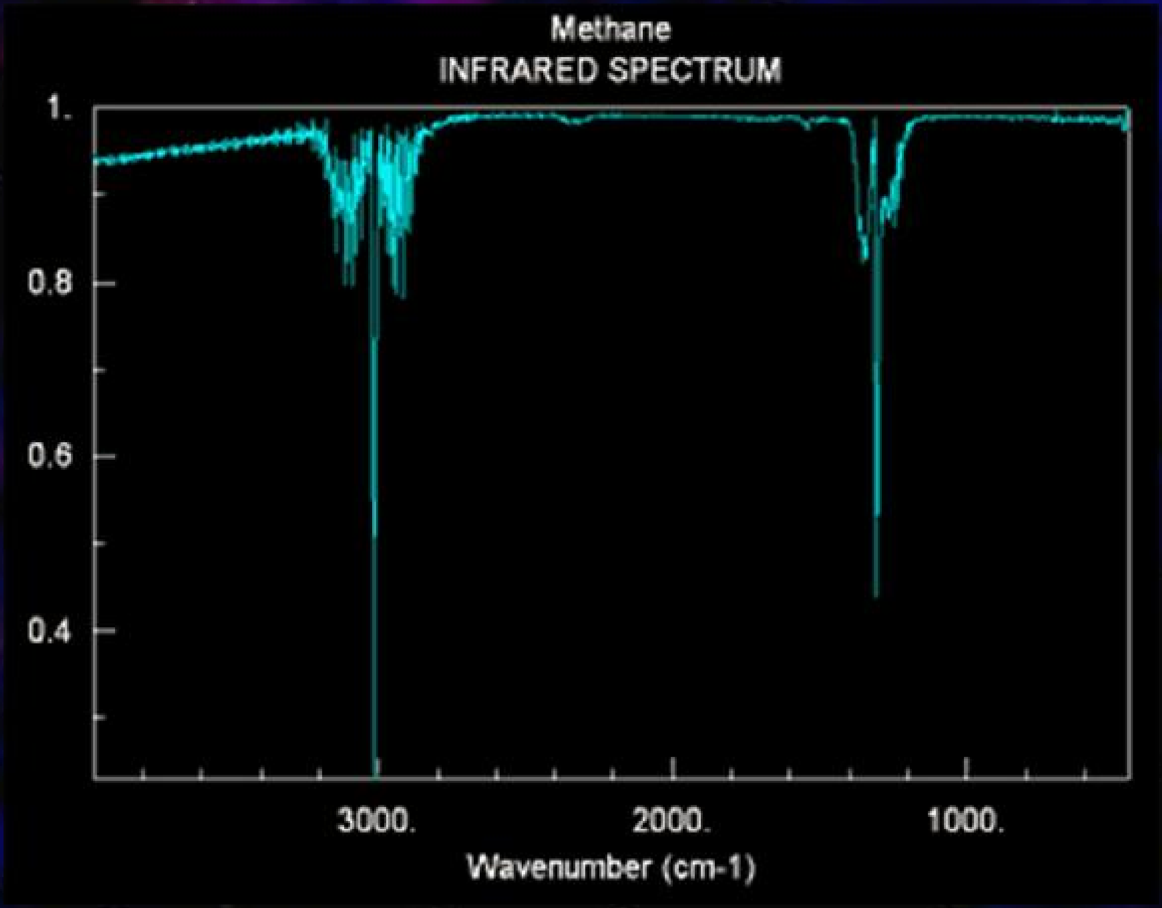
MAGNETIC FIELDS PHOTONS



AQUILA RIFT
Beta Arae
Upper-Scorpius OB Association
Pi Scorpii
Sigma Scorpii
umbbell Nebula
Lupus Dark Cloud
Rho Ophiuchi Dark Cloud
Rho Ophiuchi
Dschubba
Upper Centaurus-Lupus OB Association
Sadalsuud
Zeta Ophiuchi
S27
Graffias
G317 Dark Cloud
Rasalgethi
Beta Sagittae
Kappa Centauri
Chameleon I Dark Cloud
Sadalmelik
Alpha Sagittae
Hadar
Pi Sagittarii
Antares
Coalsack
Eta Centauri
Helix Nebula
Peacock
Shaula
Lower Centaurus-Cru
OB Associatio
Mimosa
Pi Herculis
Phi Sagittarii
Nu Coronae Borealis
Zeta Coronae Borealis
Nunki
Acrux
IC 2602
Enif
Albireo
Alpha Arae
R Hydrae
Theta Carinae
Aspidiske
Gamma Cygni
Zeta Cygni
Gamma Lupi
Beta Crucis
Sulaphat
Spica
Kappa Velorum
Rastaban
R Aquarii
Avior
Nu Carinae
Omicron Velorum
RR Lyrae
The Sun
Achernar
LOOP I
IC 2391
Alpha Reticuli
SS Cygni
Scheat
Lambda Velorum
Chi Carinae
Alkaid
Sirius Supercluster
LOOP III
Hyades
Algenib
Elnath
LOCAL BUBBLE
Furud
Beta Cephei
Mu Leporis
Eta Aurigae
Nihal
Epsilon Leonis
Iota Aurigae
Adhara
Delta Persei
Betelgeuse
NGC 2451
Lambda Tauri
Bellatrix
Polaris
Xi Puppis
Epsilon Cassiopeiae
Pleiades
Praesepe
T Tauri
S184
Gamma Cassiopeiae
Perseus OB3
Taurus Dark Cloud
HL Tauri
CW Leonis
Mirfak
Zeta Tauri
Mirzam
Mira
Owl Nebula
Zeta Aurigae
Beta Monocerotis
Medusa Nebula
Eta Persei
LOOP II
Arneb
Mebsuta
Rigel
LINDBLAD RING
Eta Orionis

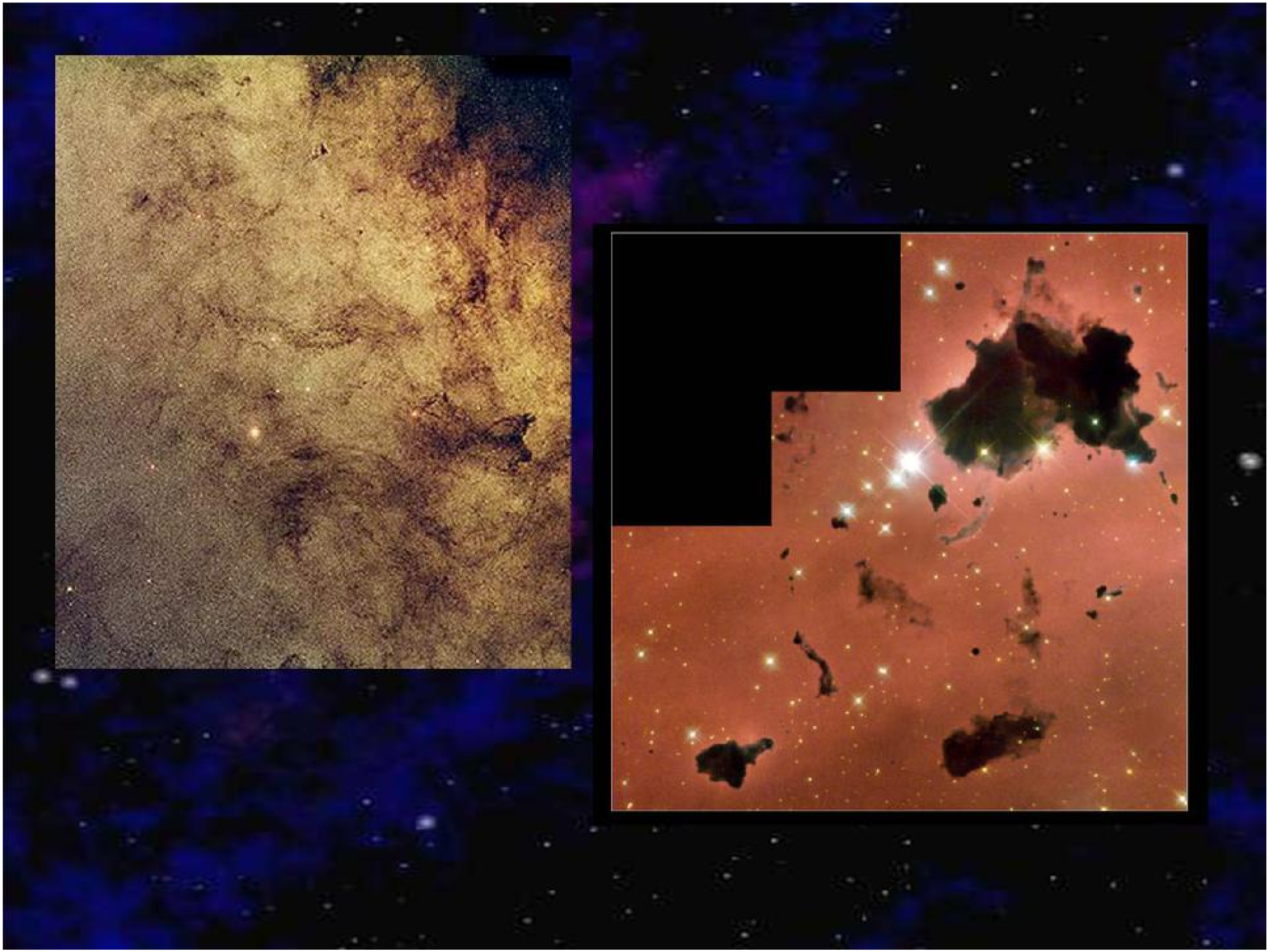
How do we detect the chemical makeup of the ISM?

Absorption & Emission line features



What molecules does the ISM contain?

Symbol	Molecule	Symbol	Molecule
H_2	molecular hydrogen	H_2S	hydrogen sulfide
C_2	diatomic carbon	N_2O	nitrous oxide
CN	cyanogen	H_2CO	formaldehyde
CO	carbon monoxide	C_2H_2	acetylene
NO	nitric oxide	NH_3	ammonia
OH	hydroxyl	HCO_2H	formic acid
NaCl	sodium chloride	CH_4	methane
HCN	hydrogen cyanide	CH_3OH	methyl alcohol
H_2O	water	CH_3CH_2OH	ethyl alcohol



The North American Nebula

Nebula – "cloud"

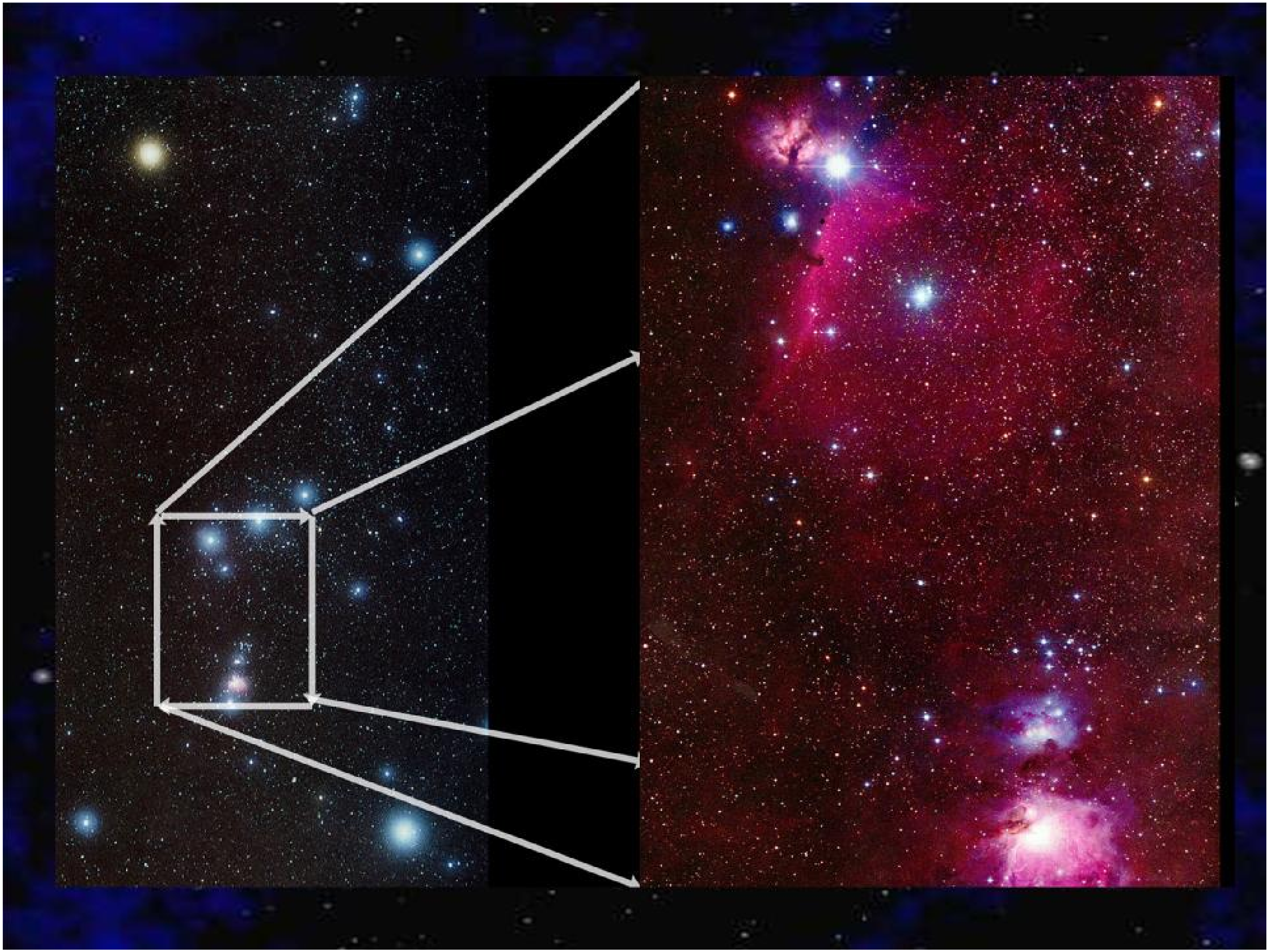
Nebul*<u>ae</u>* – "cloud<u>s</u>"

HII regions

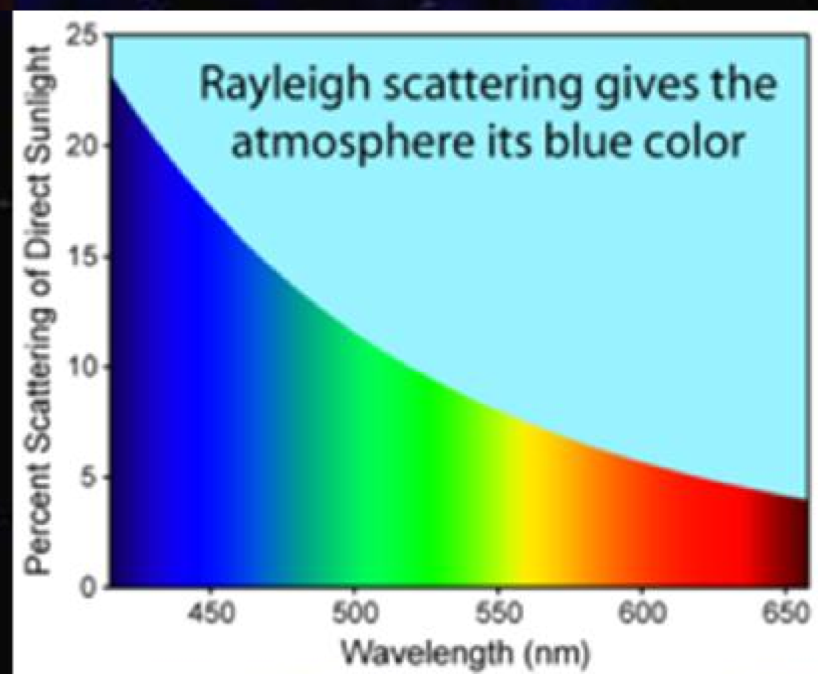
Emission nebulae

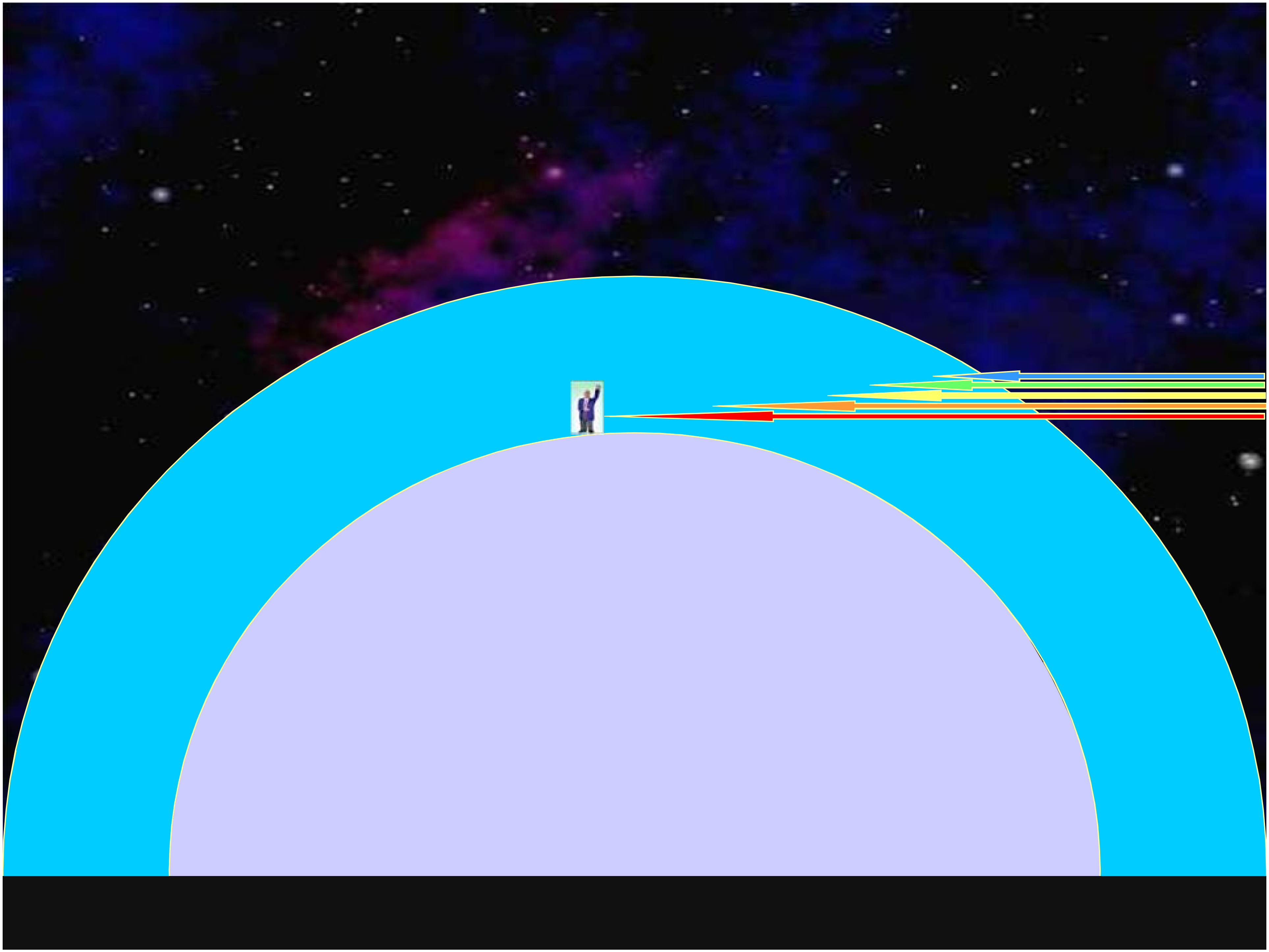
The Rosette Nebula

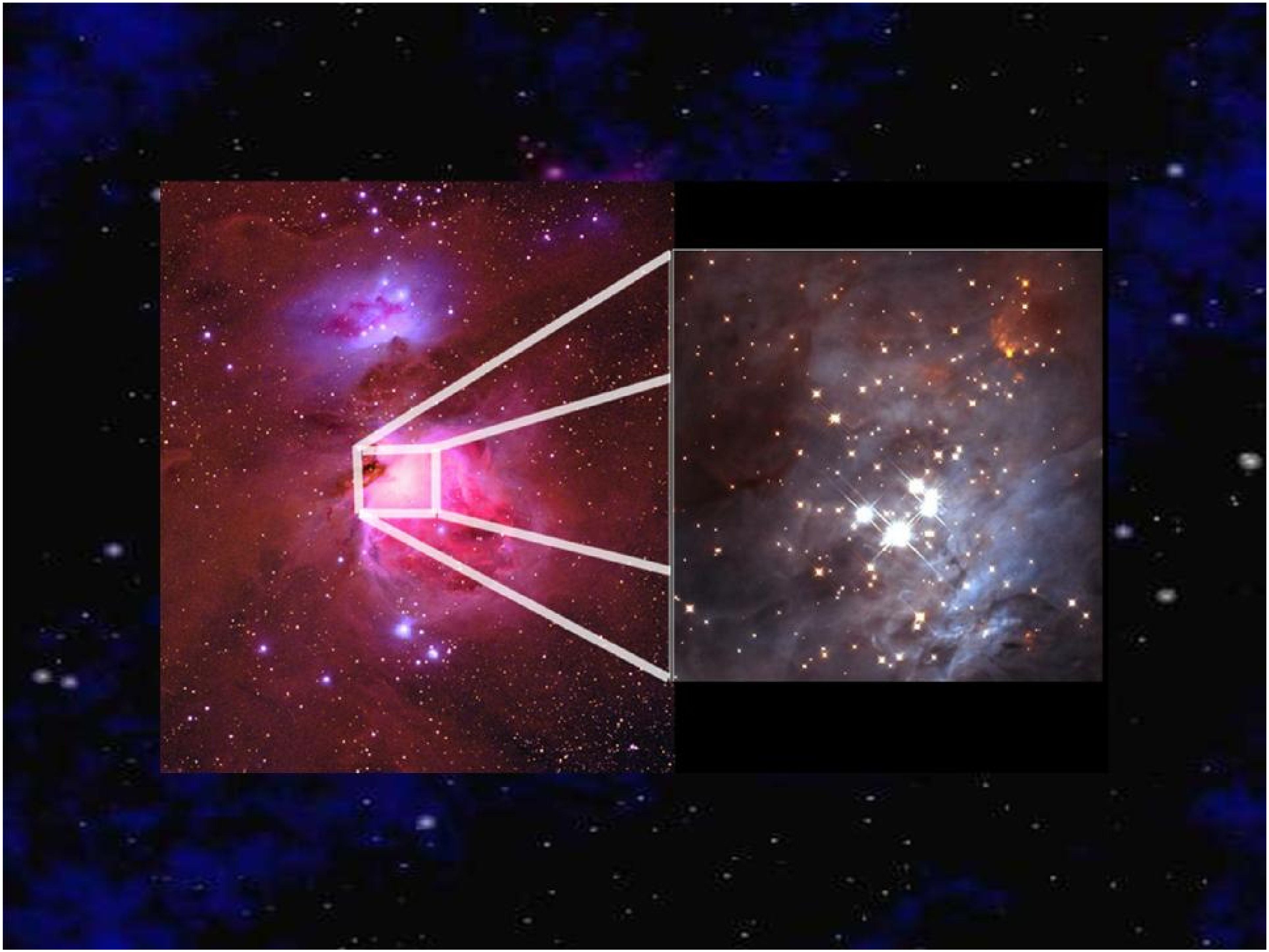
Orion



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







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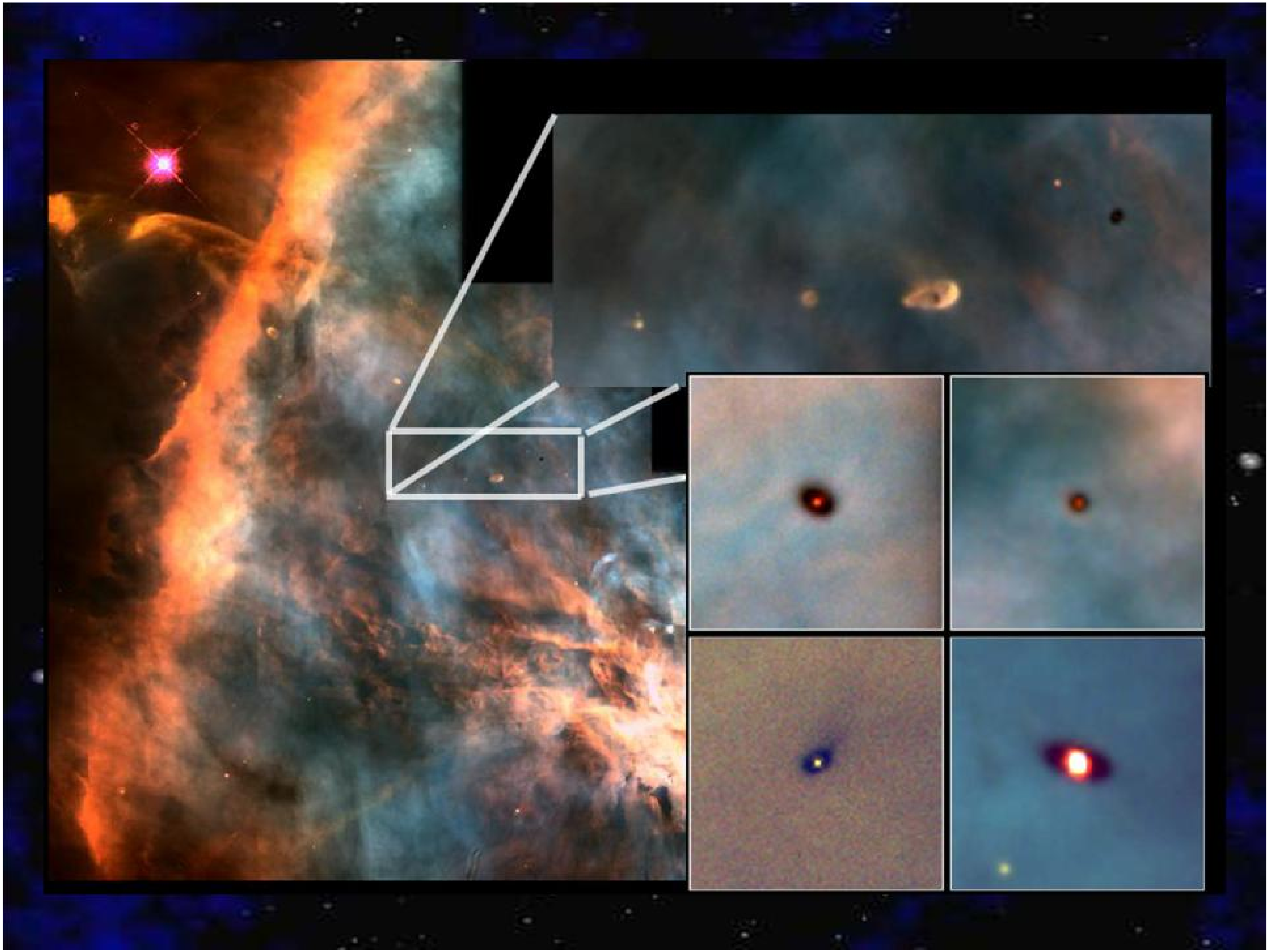
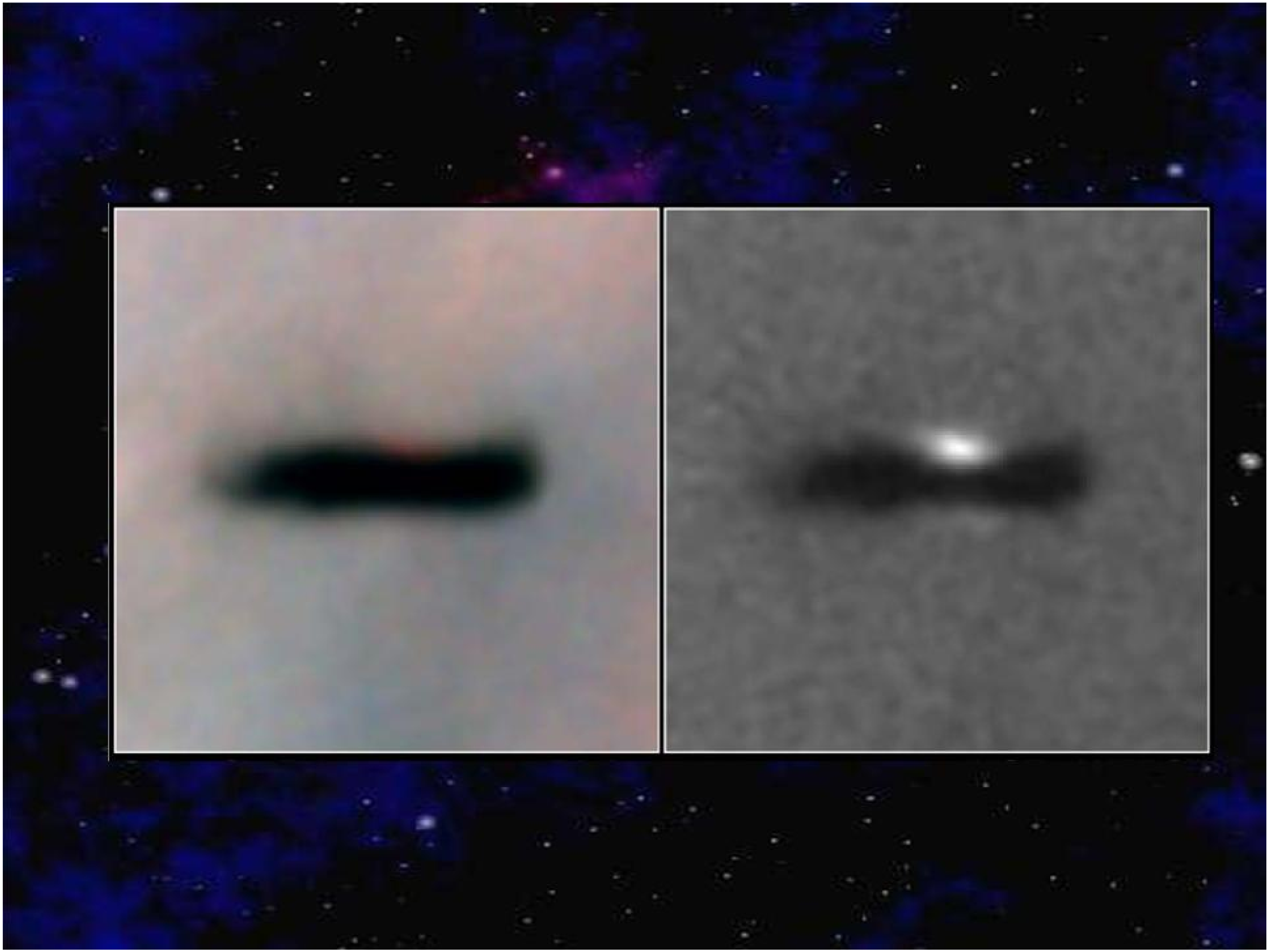




The Horsehead Nebula

M16 (The Eagle Nebula)

M16 (The Eagle Nebula)

M16 (The Eagle Nebula)

STELLAR FORMATION

Giant molecular clouds

Mass ~ 10^6 $M_\odot$

Size ~ 100 LY in diameter

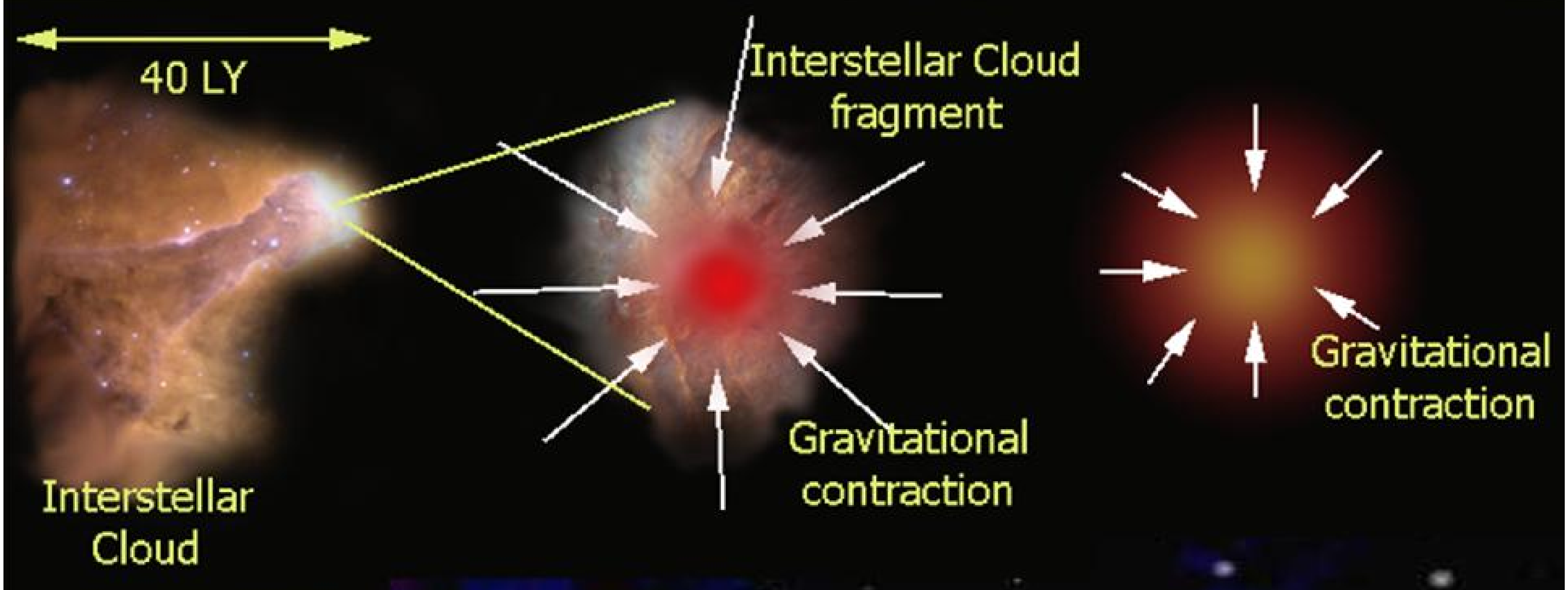
Temp ~ 5 – 15K (- 450°F)

STELLAR FORMATION

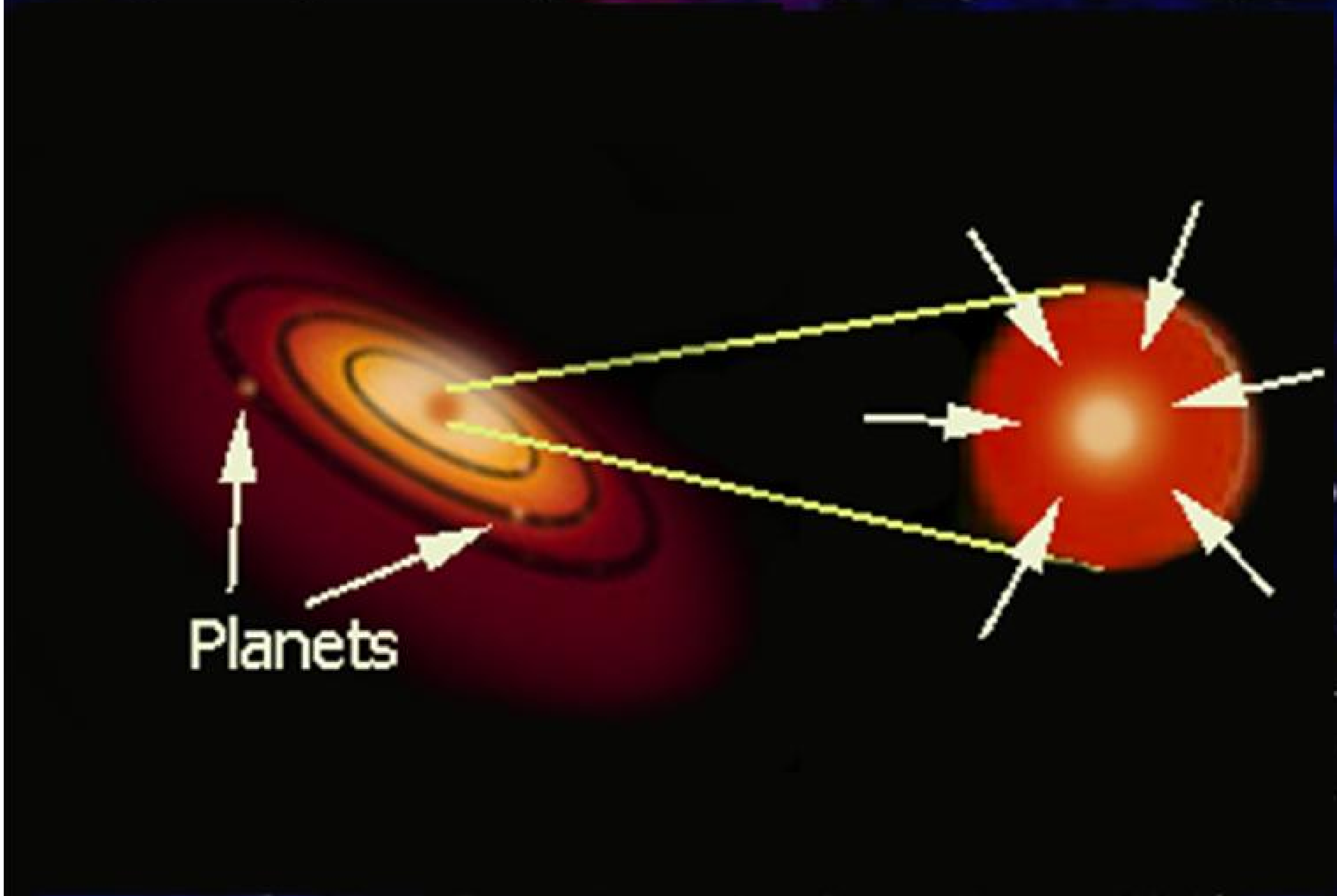
Gas Pressure		Gravity
Outward	<	Inward
(temperature)		(mass of cloud)

GRAVITATIONAL CONTRACTION

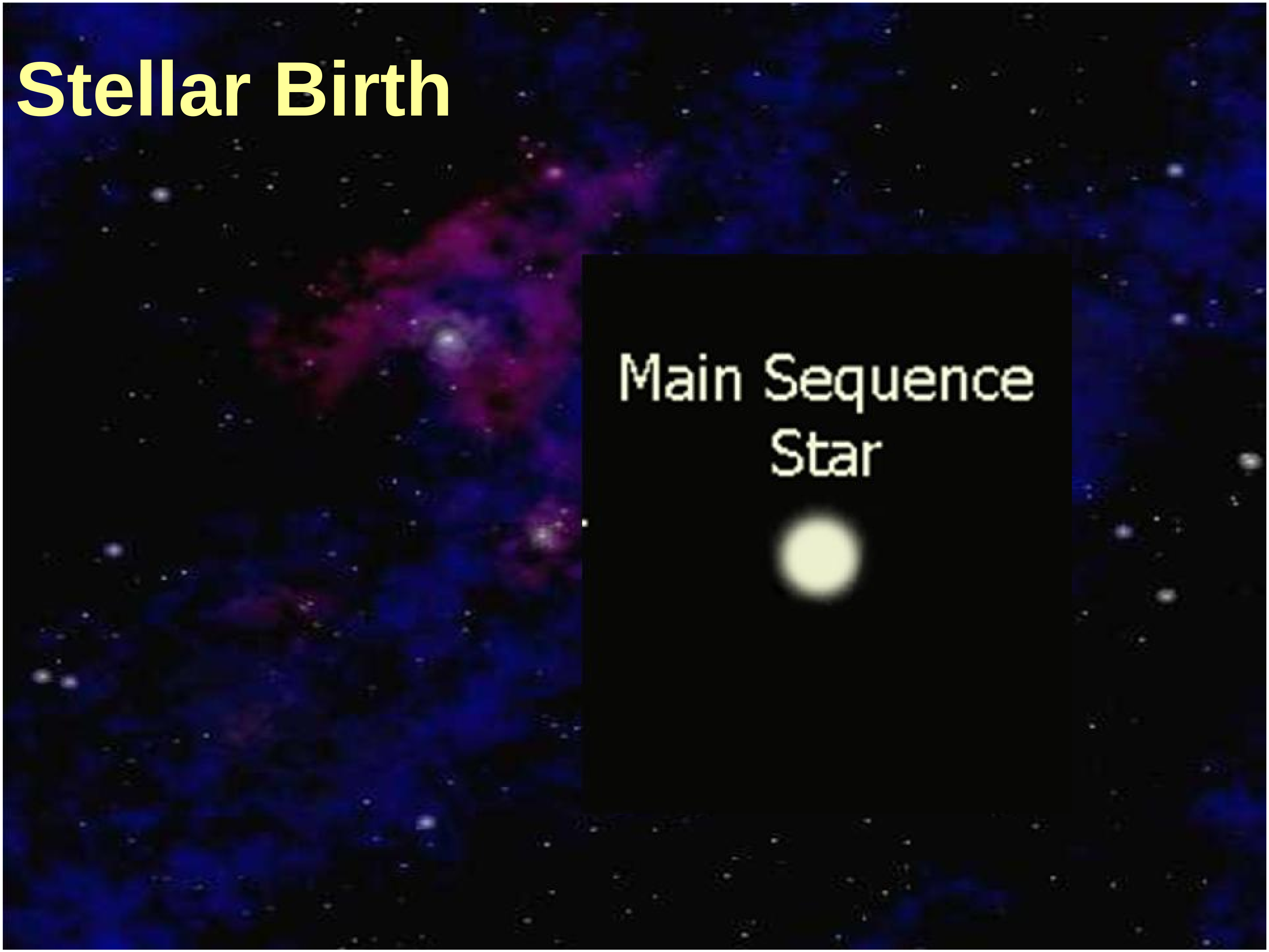
Stellar Birth



Stellar Birth



Stellar Birth


Stellar Birth
Main Sequence Star

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

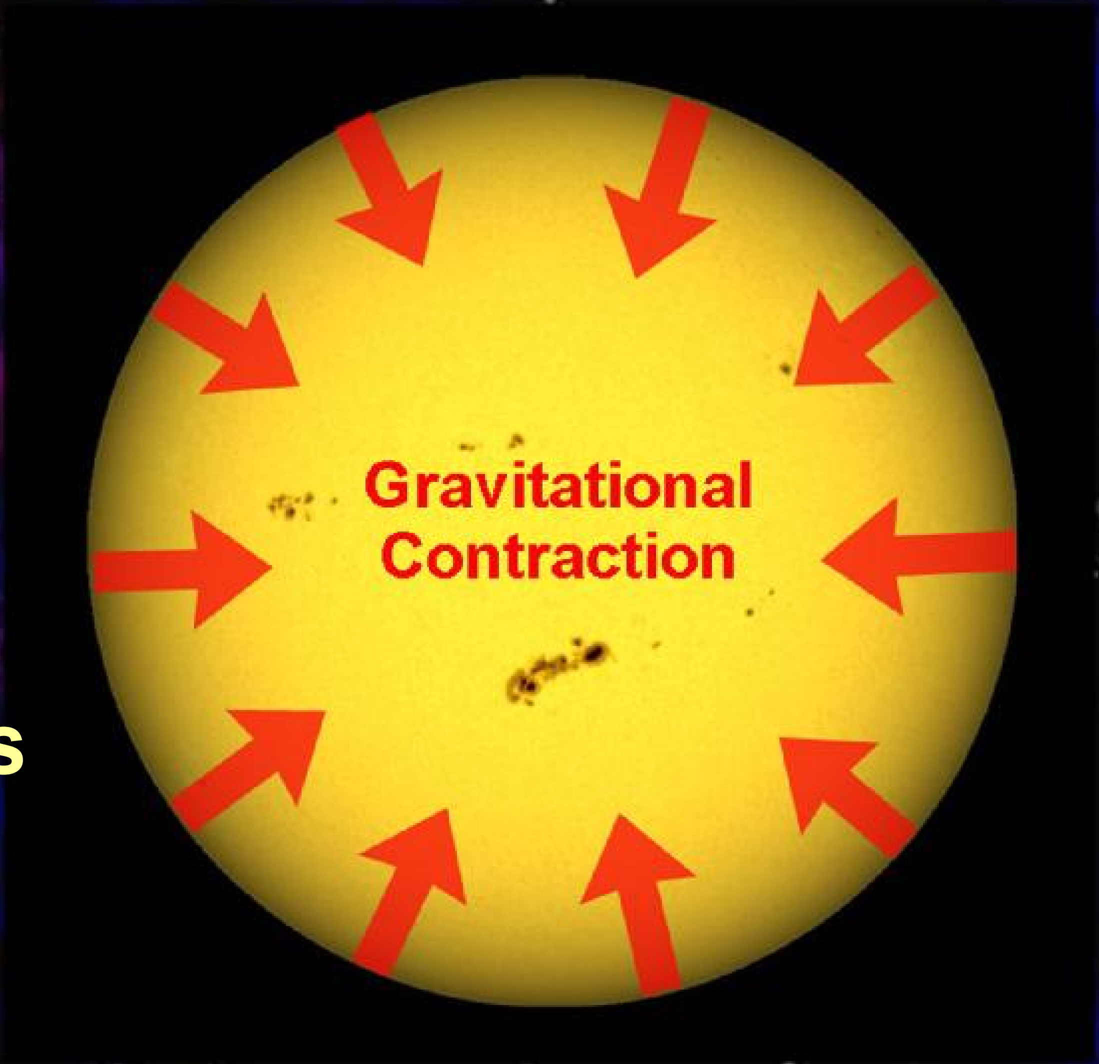
Chemical Burning (coal, wood, gas)

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