The Evolution of Stars

Mars Desert Research Station, Hanksville, UT

Gary A. Becker

Characteristics of Main Sequence Stars

Class Annie J. Cannon	Mass in Comparison to Sun	Contraction to Zero Age Main Sequence Not well known	Surface Temp. (K)	Luminosity compared to sun	M Absolute Magnitude	Years on Main Sequence	Radius in suns
O6 mid	29.5 blue supergiant	10 Th	45,000	140,000	-4.0	2 M	6.2
O9 late	22.6	100 Th	37,800	55,000	-3.6	4 M	4.7
B2 early	10.0	400 Th	21,000	3,190	-1.9	30 M	4.3
B5 mid	5.46	1 M	15,200	380	-0.4	140 M	2.8
A0 early	2.48	4 M	9,600	24	+1.5	1 B	1.8
A7 late	1.86	10 M	7,920	8.8	+2.4	2 B	1.6
F2 early	1.46	15 M	7,050	3.8	+3.8	4 B	1.3
G2 sun	1.00	20 M	5,800	1.00	+4.83	10 B	1.0
K7 late	0.53	40 M	4,000	0.11	+8.1	50 B	0.7
M8 late	0.17 minimum	100 M	2,700	0.002	+14.4	840 B	0.2 two Jupiters

$A_{Sphere} = 4\pi r^2$

Luminosity is proportional to mass$^{3.5}$ (sun = 1)

Time on the main sequence = 1/mass $^{2.5}$ x 10BY (sun = 10 billion years)

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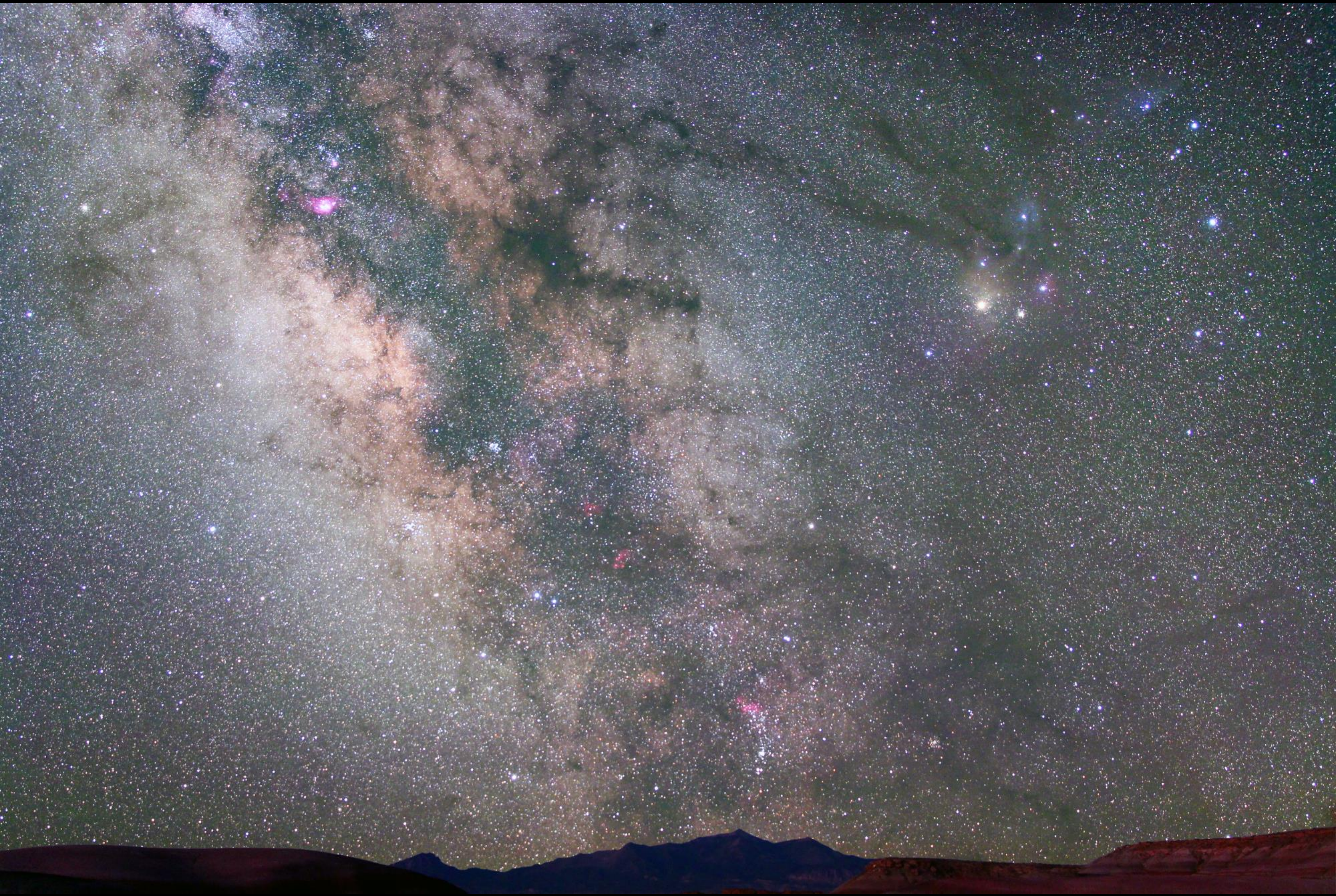
Characteristics of Main Sequence Stars

High to Low Low to High

Class Annie J. Cannon	Mass in Comparison to Sun	Contraction to Zero Age Main Sequence Not well known	Surface Temp. (K)	Luminosity compared to sun	M Absolute Magnitude	Years on Main Sequence	Radius in suns
O6 mid							
O9 late							
B2 early							
B5 mid							
A0 early							
A7 late							
F2 early							
G2 sun							
K7 late							
M8 late							

What's the Trend?
What's the Trend?
What's the Trend?
What's the Trend?
What's the Trend?
What's the Trend?



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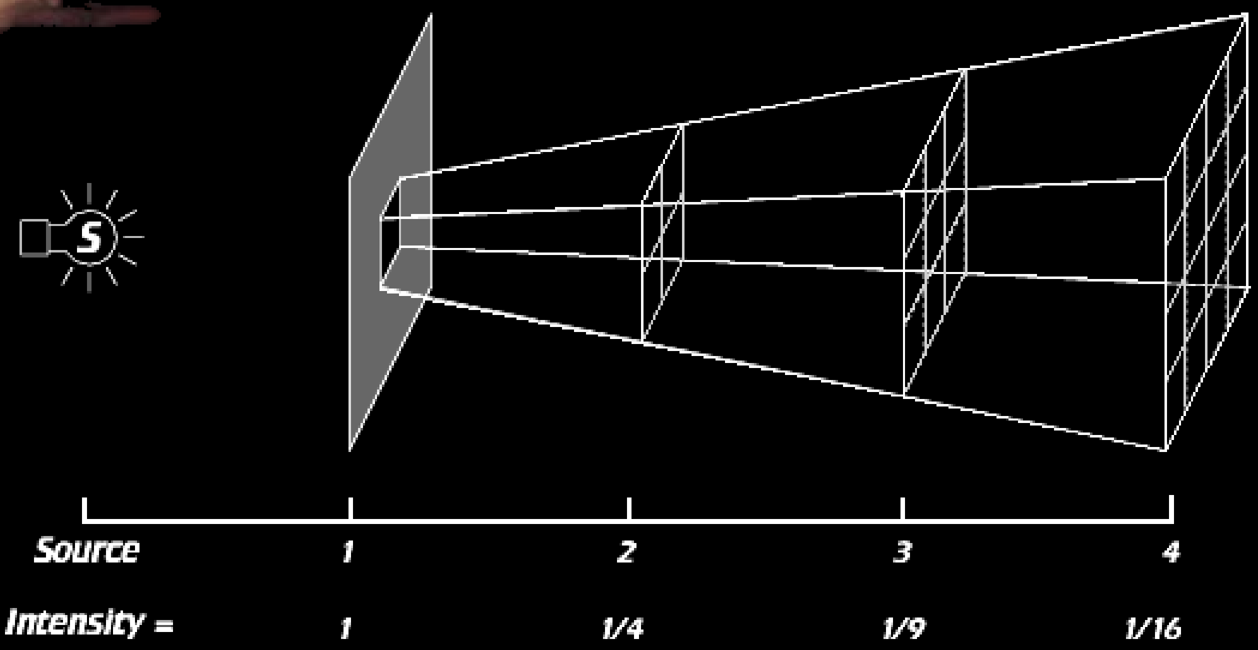
$$\text{Intensity} = \frac{1}{d^2}$$

Inverse Square Law



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Intensity Scale Between Magnitudes

Brighter

-3

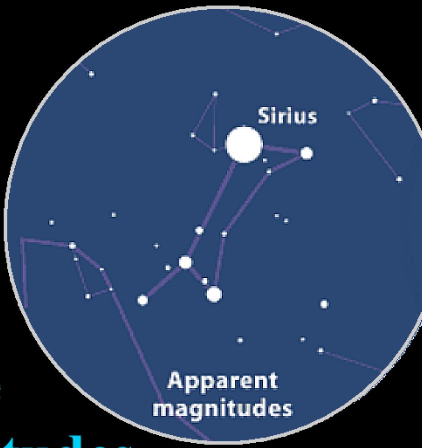
-2

-1

0

Intensity = $2.51^{\Delta M}$ ΔM = change in magnitude

2.511886432... Intensity difference between magnitudes



+1

2.512

+2

$2.512^2 = 6.310$

+3

$2.512^3 = 15.85$

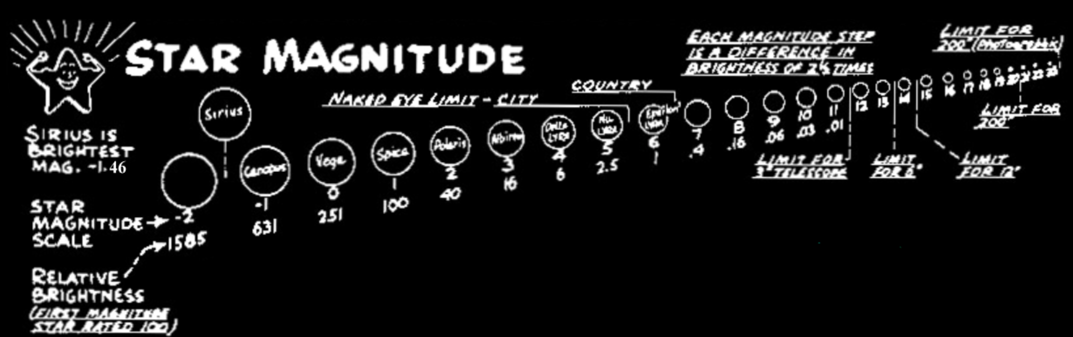
+4

$2.512^4 = 39.82$

+5

$2.512^5 = 100.0$

+6



+7

+8

Fainter

The larger the dot, the brighter the star

Apparent Magnitude:

The brightness of an object as measured from Earth.

Comparing Apparent Magnitudes

Object	Apparent Magnitude
Sun	-26.74
Moon	-12.6
Venus	-4.4
Jupiter	-2.1
Sirius	-1.46
Vega	+0.03
Capella	+0.07
Polaris	+1.99
from Bethlehem	+3.5
from Rural Locales	+6 to +6.5
with Binoculars	+8 to +10
Hubble Space Tel.	+30
James Webb S. T.	+32 to +35

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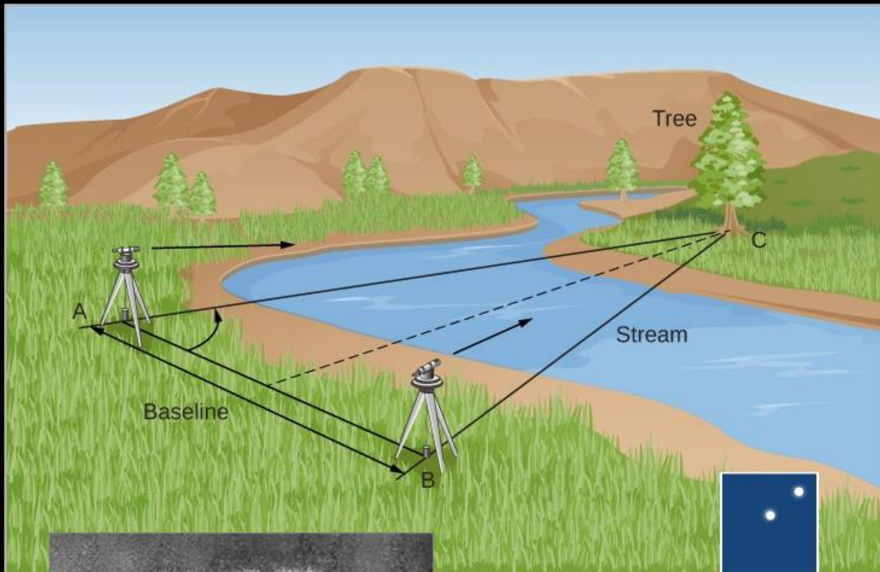
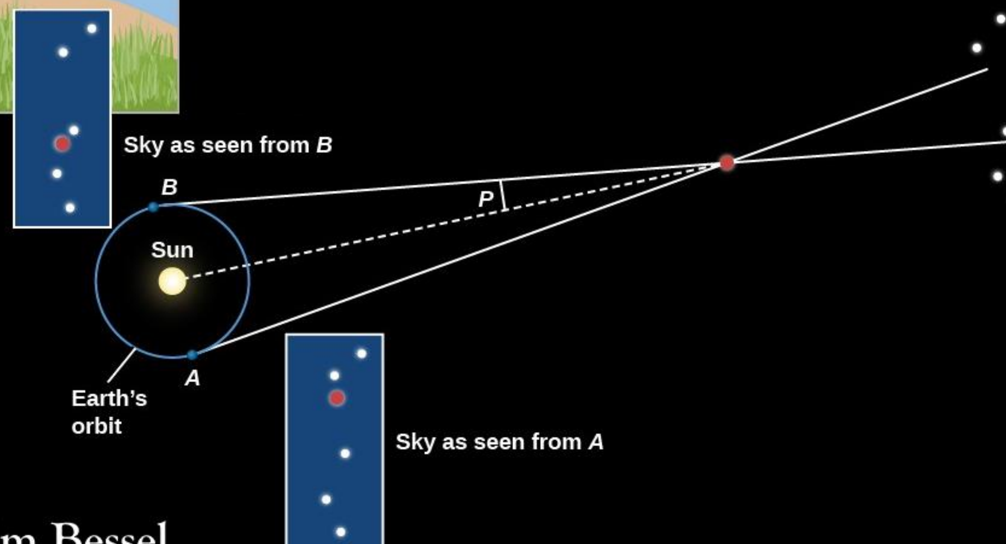
Surveying the Universe



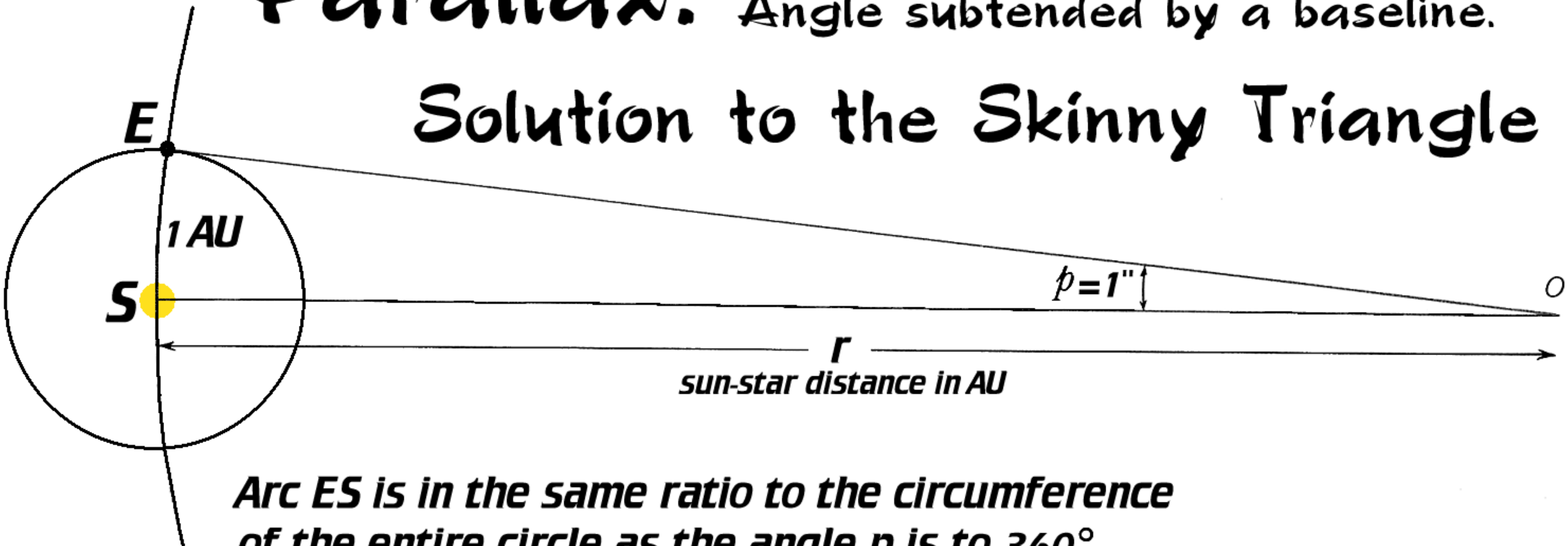
Friedrich Wilhelm Bessel
(1784-1846)
First authenticated parallax-61 Cygni-1838



https://courses.lumenlearning.com/astronomy/chapter/surveying-the-stars/

Parallax: Angle subtended by a baseline.

Solution to the Skinny Triangle



Arc ES is in the same ratio to the circumference of the entire circle as the angle p is to 360°.

$$\frac{ES}{2\pi r} = \frac{p}{360°}.$$

Solve for r.

Parsec:	***Distance (r) created by a parallax angle of 1" of arc subtended over a baseline of 1 AU.***

Speed of light = 186,282.4 miles/second

1 Light Year = 63,239.73 AU

Distance Modulus

$$M = m + 5 - 5 \log r$$

Where
M = absolute magnitude
m = apparent magnitude
r = distance in parsecs

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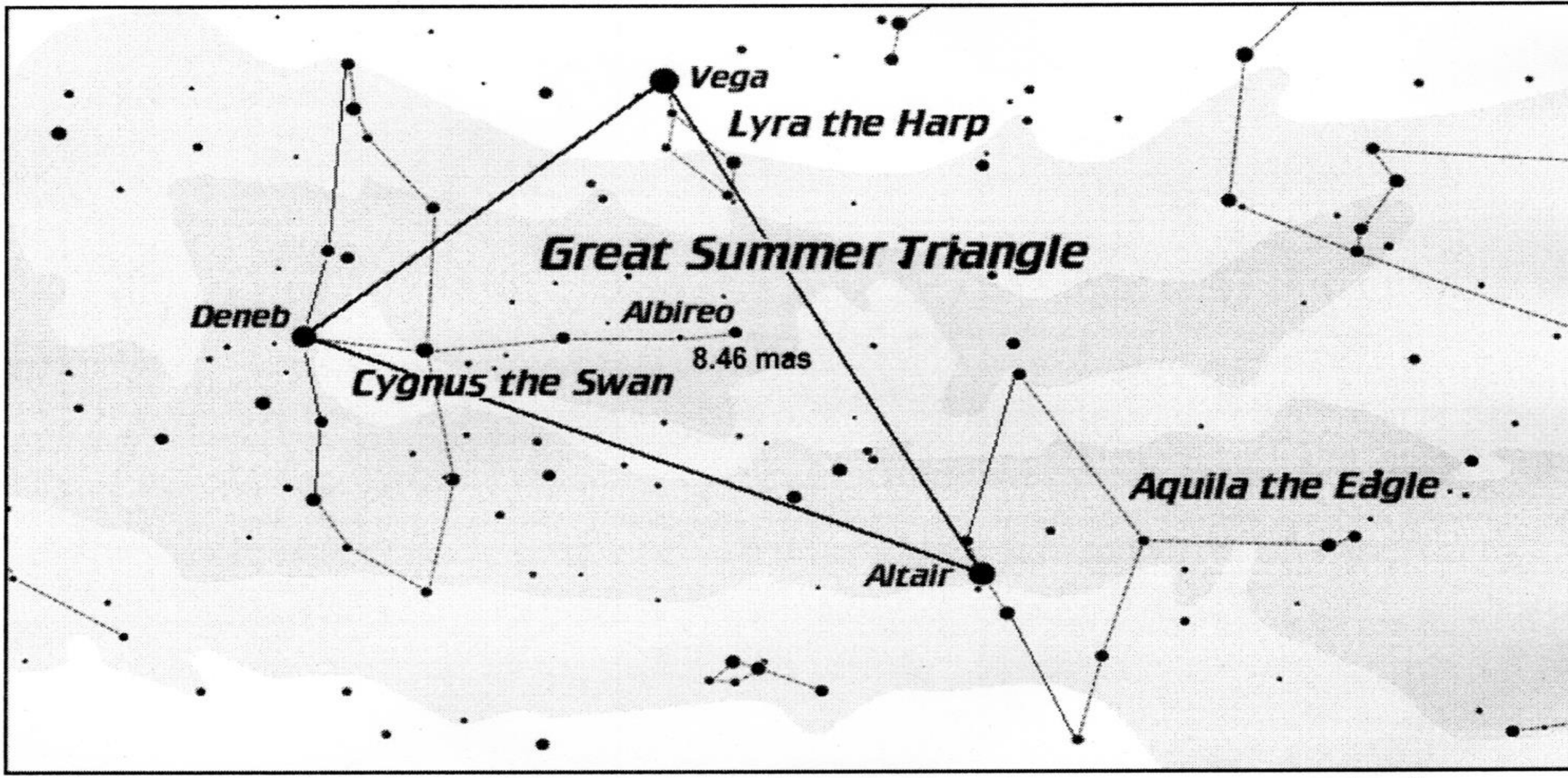
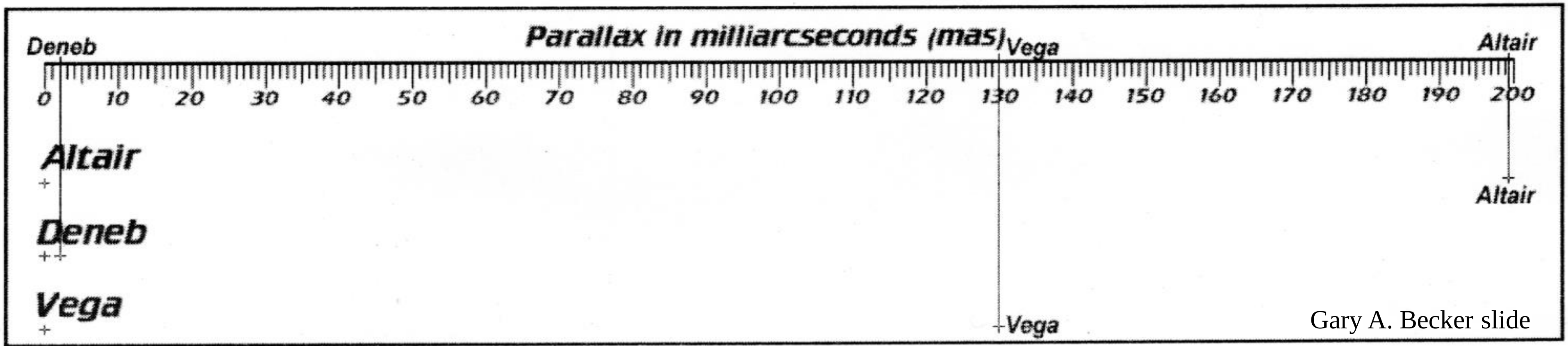


Use this Scale to measure the parallax angles of the three stars of the Great Summer Triangle.



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PRACTICE WITH THE DOUBLE STAR ALBIREO: Significant numbers are a requirement.

First, find the Distance to Albireo. Parallax of Albireo = 8.46 mas (three significant figures)

$$8.46 \text{ mas} \times \frac{1''}{1000 \text{ mas}} = 0.00846''; \quad D = \frac{1}{p''}; \quad \frac{1}{0.00846''} = \mathbf{118\ pc} \times 3.2616 \frac{\text{ly}}{\text{pc}} = \mathbf{386\ ly}$$

Then, find the absolute magnitude of Albireo. Apparent magnitude of Albireo = +2.90 (given)

$M = m + 5 - 5\log r$; $M = +2.90 + 5 - 5\log 118$; $M = +2.90 + 5 - 5(2.072)$; $M = +7.90 - 10.36$

$\mathbf{M = -2.46}$

Finally, find the intensity difference between the sun and Albireo. Which star is brighter, the sun or Albireo?

Difference in magnitude = $\Delta M = M_{sun} - M_{star}$; $\Delta M = +4.83 - (-2.46) =$ **7.29 magnitudes**.
Since Albireo has the brighter (more negative) absolute magnitude, it is the more luminous star.
What is the actual intensity difference?
$I = 2.51^{\Delta M}$; $I = 2.51^{7.29}$; $\mathbf{I = 820}$, taking into account significant figures Albireo is brighter than the sun by an intensity difference of 820 times.

Data Table for the Great Summer Triangle Lab
(Correct Significant Figures Required)

Name of Star	Parallax (mas) (Number of Significant Figures to be used is in parentheses)	Apparent Magnitude (given) (m)	Distance in Parsecs/ Light Years $D_{pc} = 1/p''$ pc / ly	Absolute Magnitude $M = m + 5 - 5\log r$ Distance Modulus (M)	Change in Magnitude $M_{sun} - M_{star}$ (ΔM)	Intensity in Comparison to the Sun $I = 2.51^{\Delta M}$ (I)	Which Star is Brighter, the Sun or the Other Star? (Star's Name)
Albireo	(3) 8.46	+2.90	118 / 386	-2.46	7.29	820	Albireo
Altair	**(3)**	**+0.77**	/				
Deneb	**(1)**	**+1.24**	/				
Vega	**(2)**	**+0.03**	/				

On the next page, show all work, i.e., steps in the problem's solution, including the correct usage of significant figures.

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Solution for Deneb

Two Significant Figures

Distance to Deneb in parsecs/light years: PARALLAX = 2.0 mas

$D_{pc} = 1/p''$ $2.0\,\text{mas} \times \frac{1''}{1000\,\text{mas}} = 0.0020''$ $D = \frac{1}{\text{PAR}''}$ $\frac{1}{0.0020''} = \boxed{500\text{ pc}} \times 3.2616\,\frac{\text{ly}}{\text{pc}} = \boxed{1600\,\text{ly}}$

Absolute magnitude of Deneb:

$M = m + 5 - 5\log r$

$M = +1.24 + 5 - 5\log 500$

$M = +6.24 - 5(2.699)$

$M = +6.24 - 13.49$

$M = \boxed{-7.3}$ -7.25

Difference in intensity compared to the sun:

Difference in $M = x = M_{sun} - M_{Deneb}$; **$M_{sun} = +4.83$** **Intensity $= I = 2.51^x$**

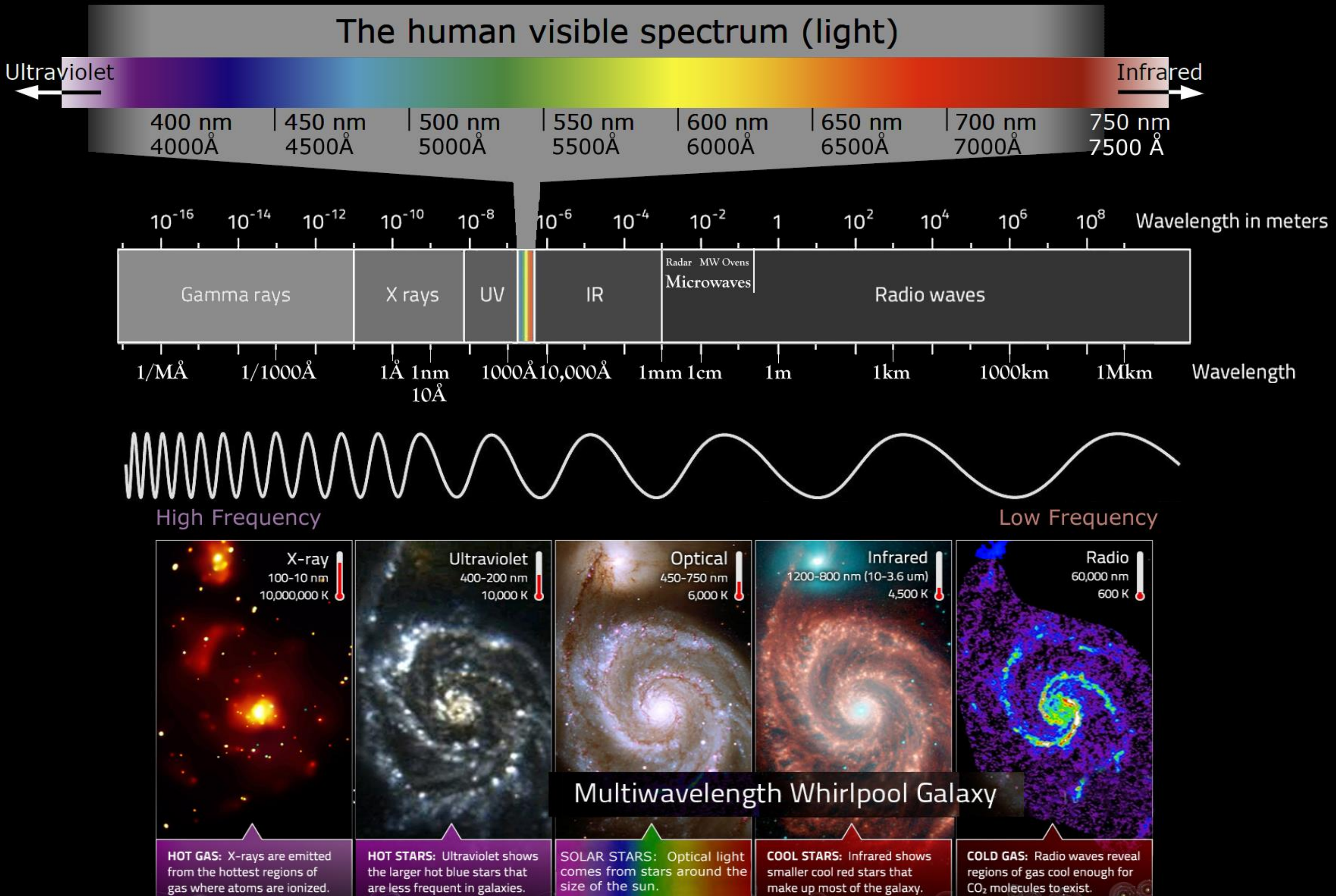
$\Delta M = +4.83 - (-7.25)$

$\Delta M = 12.08$ $\boxed{12}$

$I = 2.51^{12.08}$

$I = 67{,}307 = \boxed{67{,}000 \text{ TIMES BRIGHTER THAN SUN}}$

Electromagnetic Spectrum

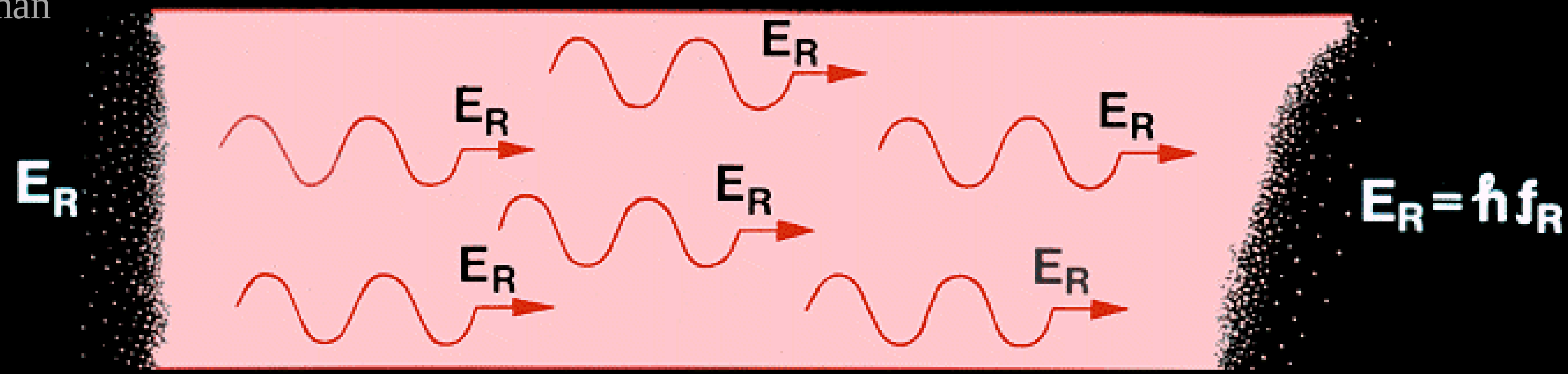


Constructed from many different slides by Gary A. Becker

Relationship Between Energy and Wavelength

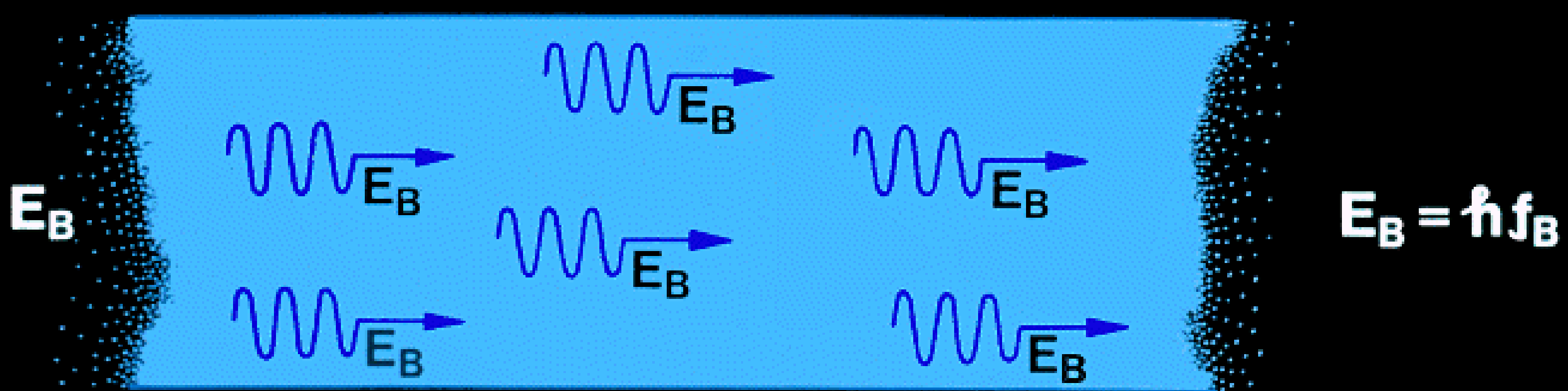
Max Planck-1858-1947
German

Light acts like a particle



E = Energy; h = Planck constant; f = Frequency

Planck constant = 6.626 x 10^{-27} erg sec



Planck's constant: 6.626196(50) x 10^{-27} erg s

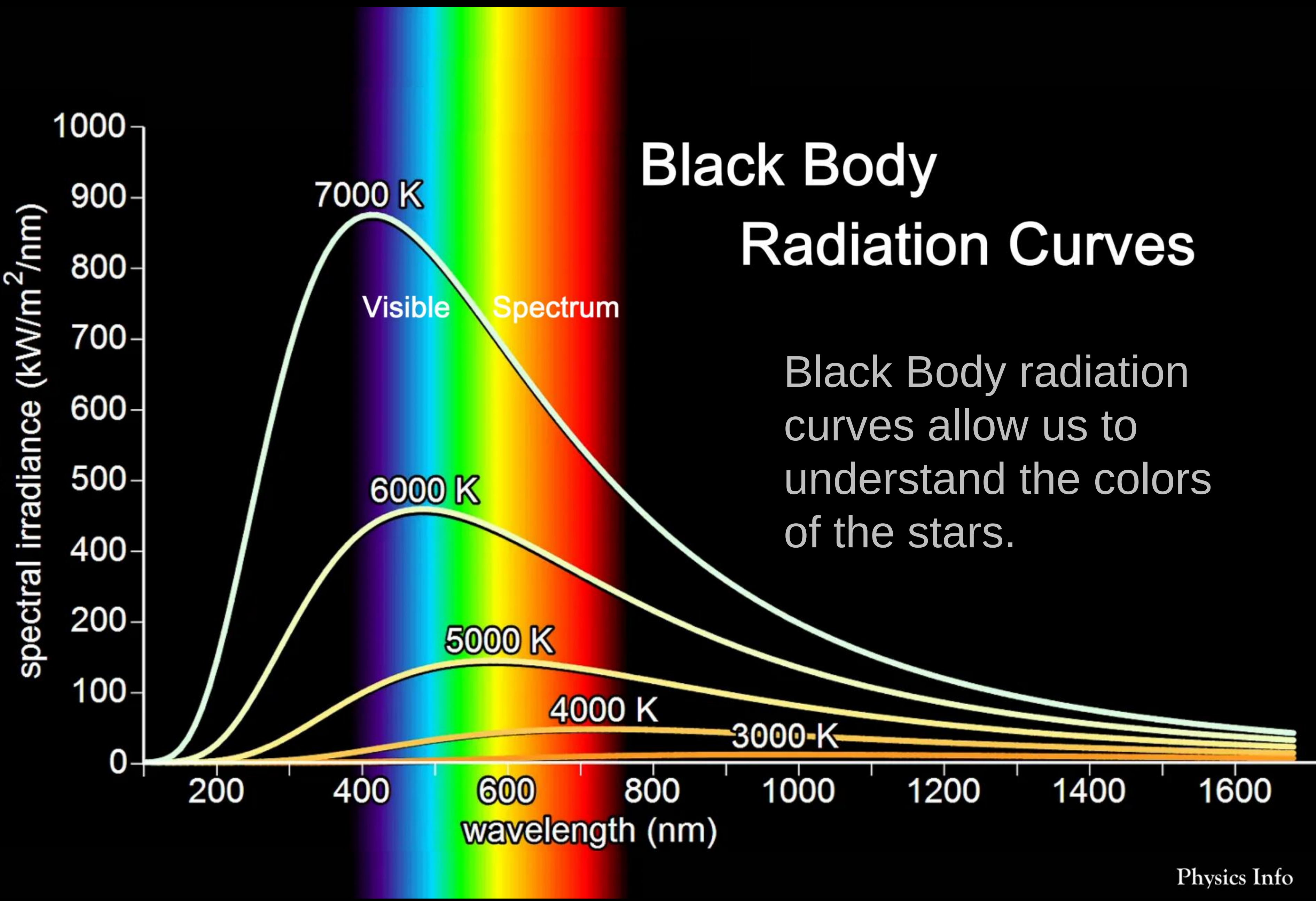
A **dyne** is defined as the **force** required to **accelerate** a mass of **one** gram at a rate of **one centimeter per second squared**

Velocity-Time Table

Time (s)	Velocity (cm/s)
0	0
1	1
2	2
3	3
4	4

An **erg** is the amount of **work done** by a **force** of **one dyne exerted over a distance of one centimeter**. In the CGS base units, it is equal to one gram centimeter-squared per second-squared ($g \cdot cm^2/s^2$).

Black Body Radiation Curves



Black Body radiation curves allow us to understand the colors of the stars.

True Color Of The Sun or Why There Are No Green Stars

Center of Disk
Red = 203
Green = 204
Blue = 198

Limb of Disk
Red = 154
Green = 141
Blue = 125

Surface Temperature 5772K

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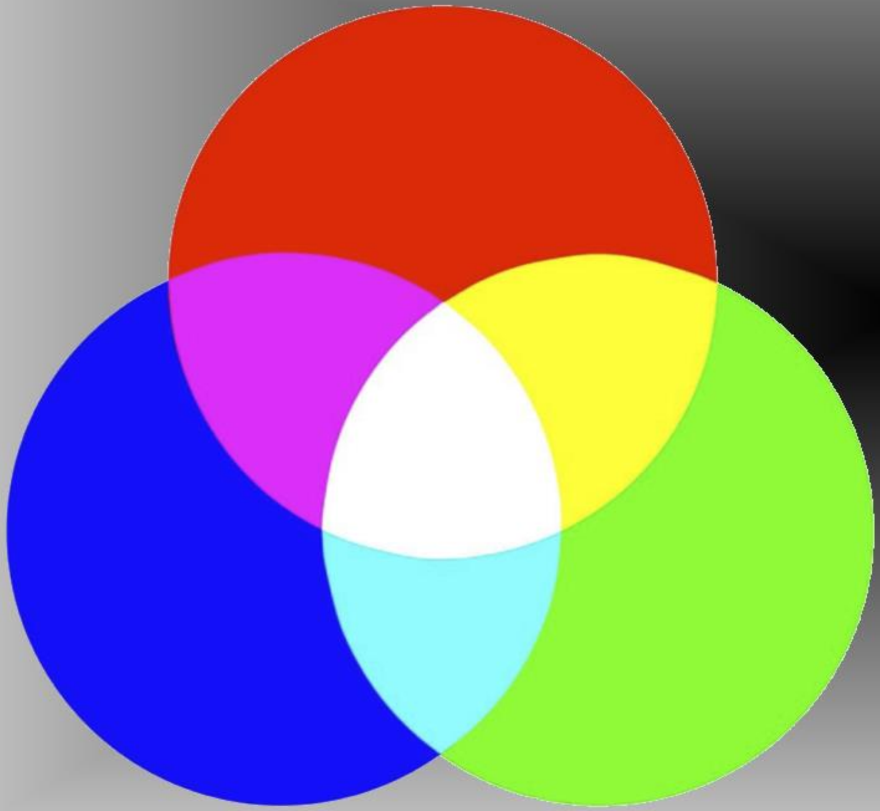
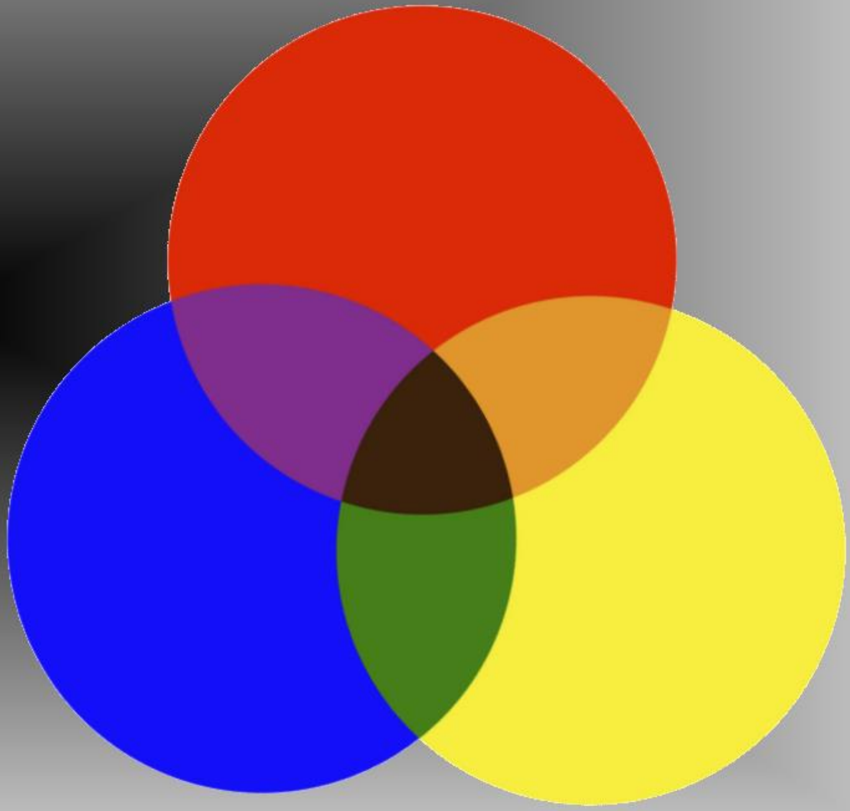
Additive and Subtractive Colors

Similar to the blackbody radiation of the sun where all colors are represented.



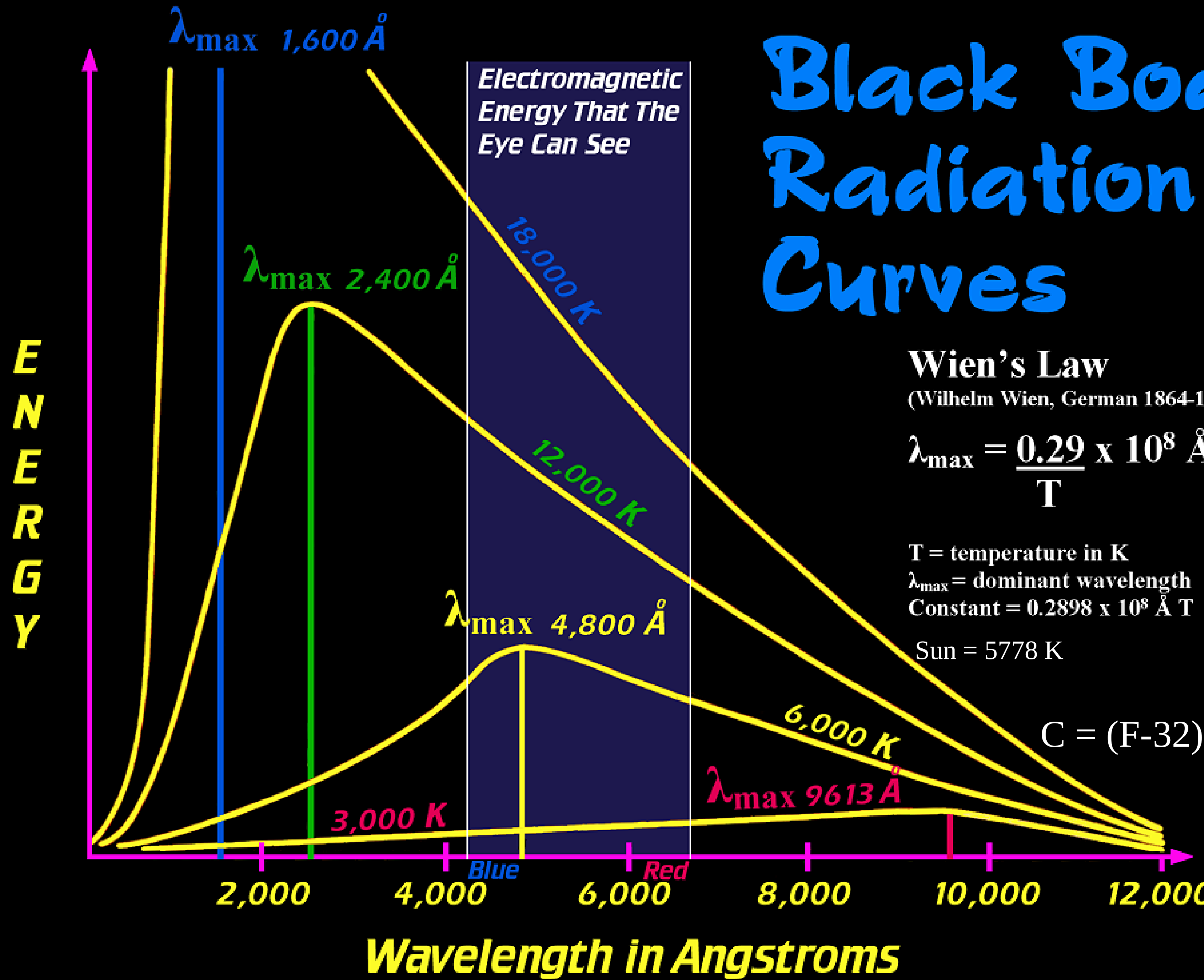
Additive Colors

Similar to an artist mixing different pigments on a palette.



Subtractive Colors

Black Body Radiation Curves



Wien's Law

(Wilhelm Wien, German 1864-1928):

$$\lambda_{max} = \frac{0.29 \times 10^8 \text{ Å T}}{T}$$

T = temperature in K

λ_{max} = dominant wavelength

Constant = 0.2898 x 10^8 Å T

Sun = 5778 K

C = (F-32) x 5/9


Daylight = 5500 K (daylight-balanced photographic film standard)
Gary A. Becker image

Fluorescent = Dominant green line in emission, 5000 K

A **modern fluorescent lamp** consists of a glass tube filled with a mixture of argon and mercury vapor. **Older lamps**, like in this picture, contained just mercury vapor. Metal electrodes at each end give off electrons easily. When current flows through the gas between the electrodes, the gas is ionized and emits specific wavelenghs of visible light and ultraviolet radiation. The inside of the tube is coated with phosphors, substances that absorb ultraviolet radiation and fluoresce, reradiating the energy as visible light.

Gary A. Becker image

Incandescent = 2700 K
Gary A. Becker image

Kirchhoff's Three Laws of Spectroscopy

Continuous Spectrum—Kirchhoff's First Law: A solid, liquid, or gas (under high pressure) emits a continuous spectrum in which all colors (wavelengths) are represented.

Emission Spectrum—Kirchhoff's Second Law: A gas under low pressure when made to fluoresce (glow) will emit energy at certain discrete wavelengths which are specific to its composition/atomic structure.

Absorption Spectrum—Kirchhoff's Third Law: A rarefied gas lying between a continuous source and an observer will produce a continuous spectrum with discrete wavelengths of light missing. These missing wavelengths are specific to the composition/atomic structure of the gas through which the light from the continuous source is passing. These same gases if made to fluoresce would produce emission lines at the same positions of the absorption lines which these gases create.

Types of Spectra

Continuous Spectrum

Emission Spectrum

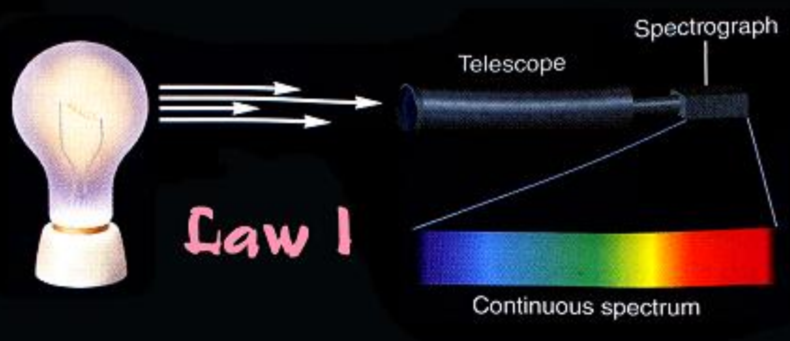
Absorption Spectrum

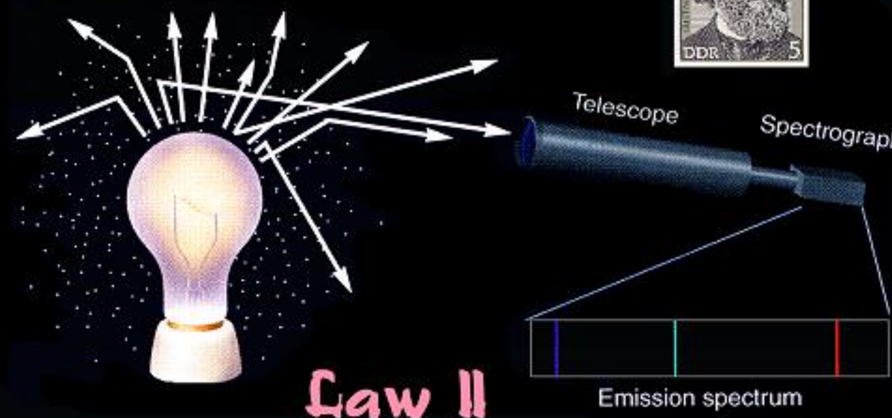
modified http://en.wikipedia.org/wiki/Spectral_line

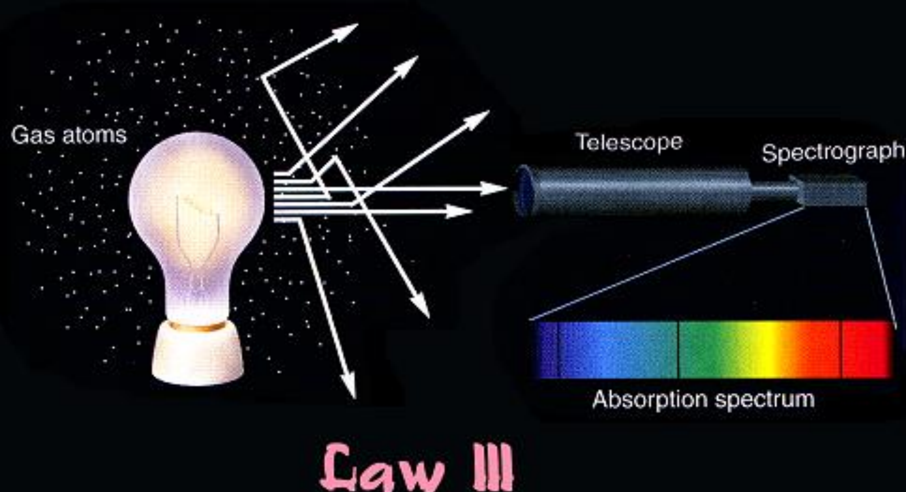
Gustav Kirchhoff's Three Laws of Spectroscopy Illustrated

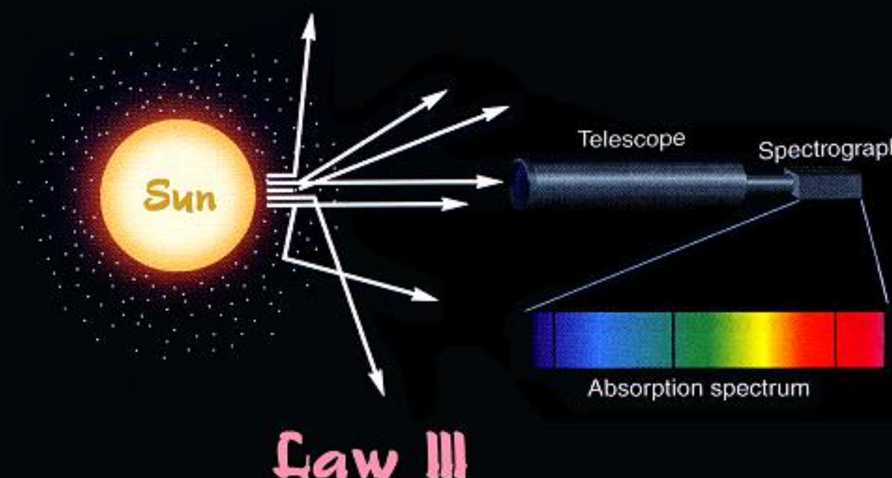
Kirchhoff was German

1824-1887

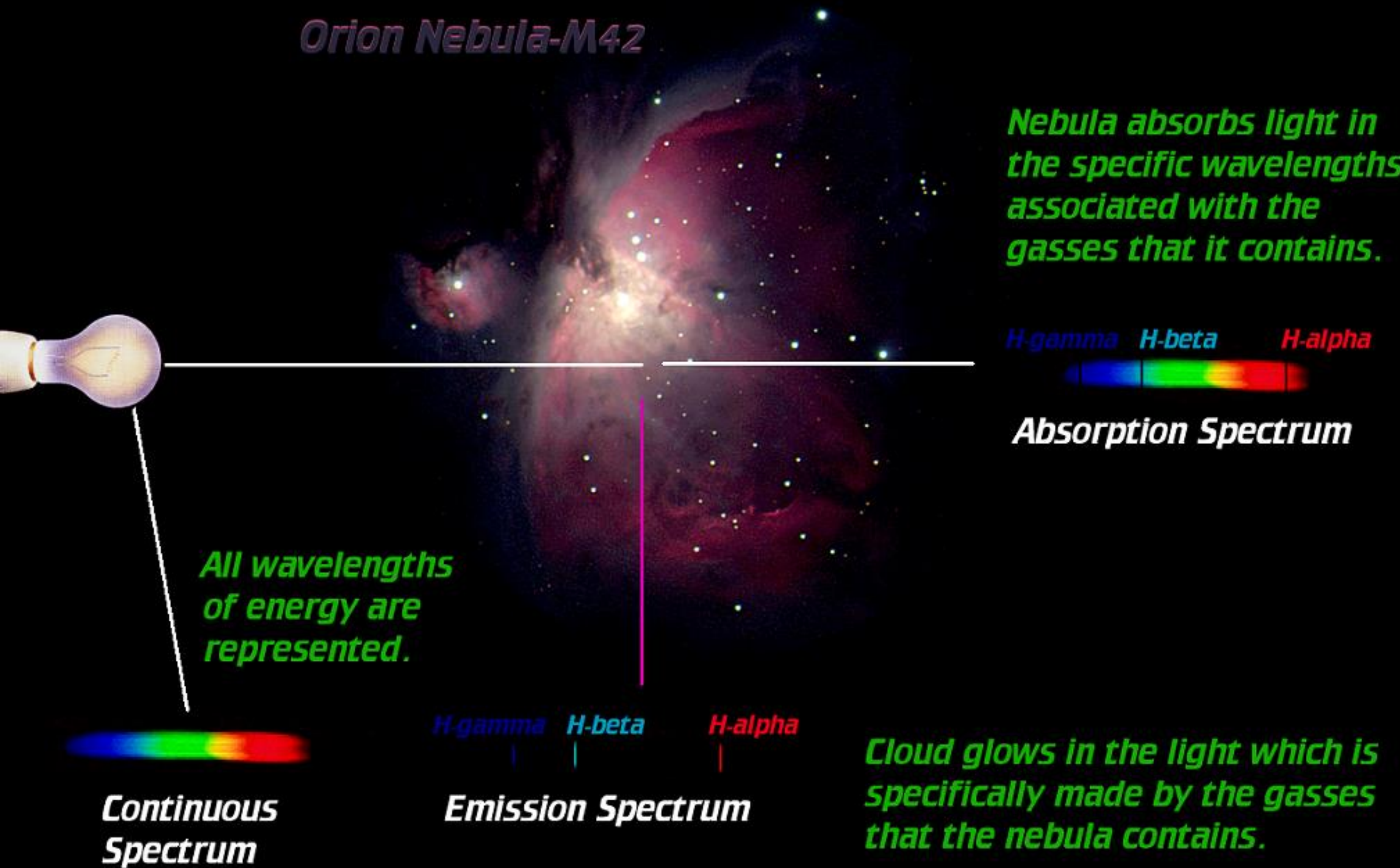








Kirchhoff's Three Laws Illustrated



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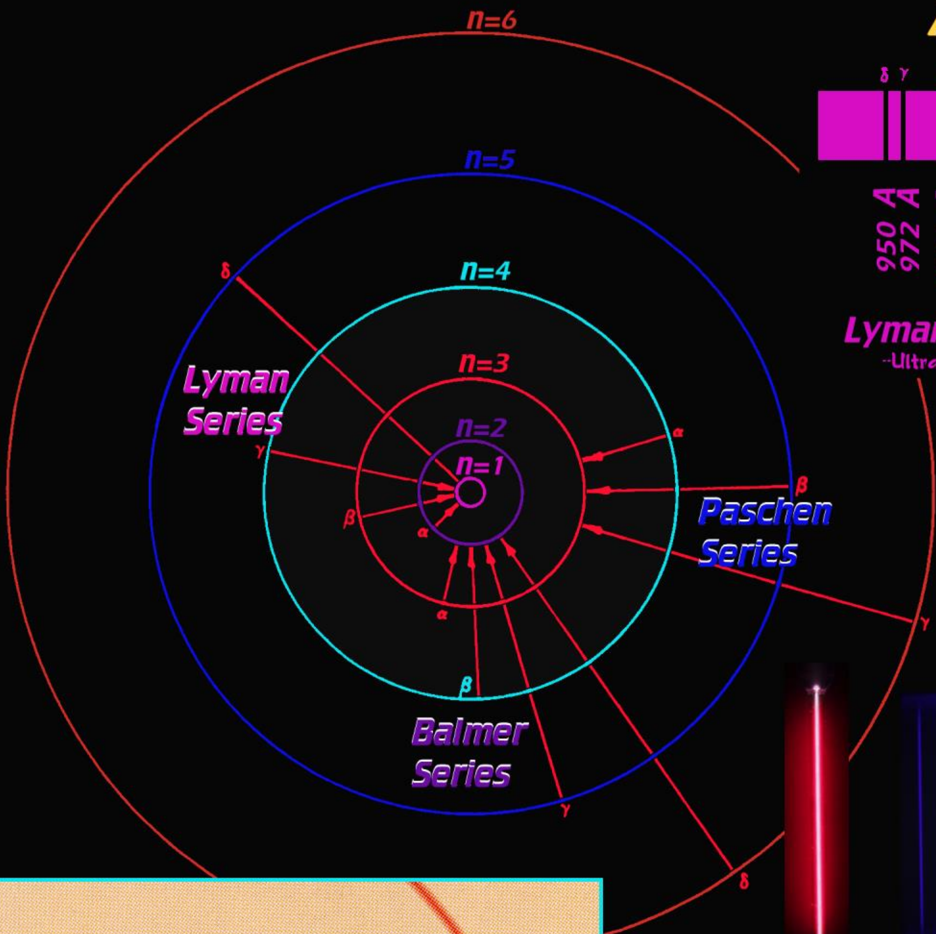
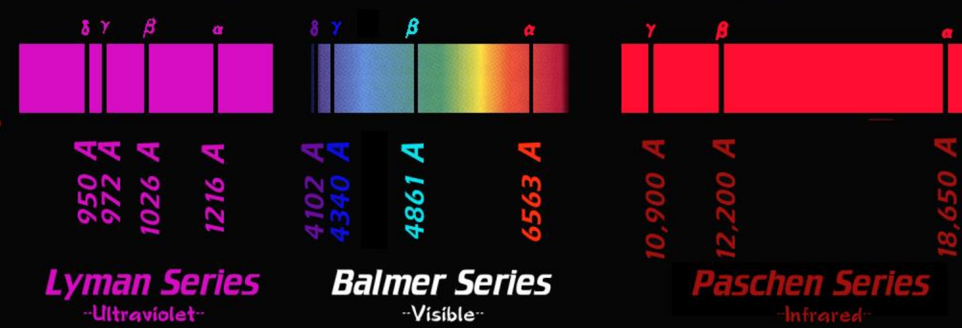
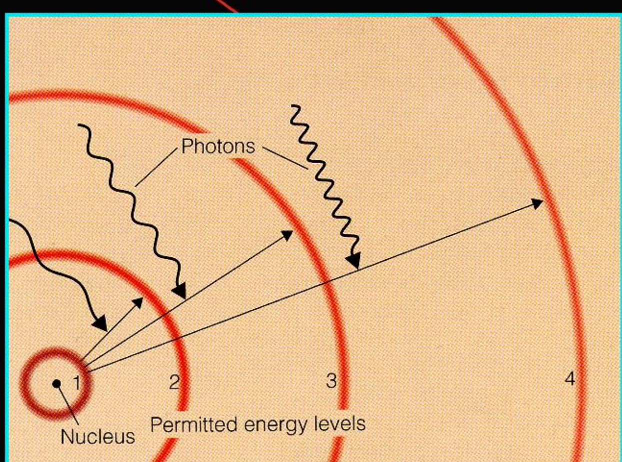
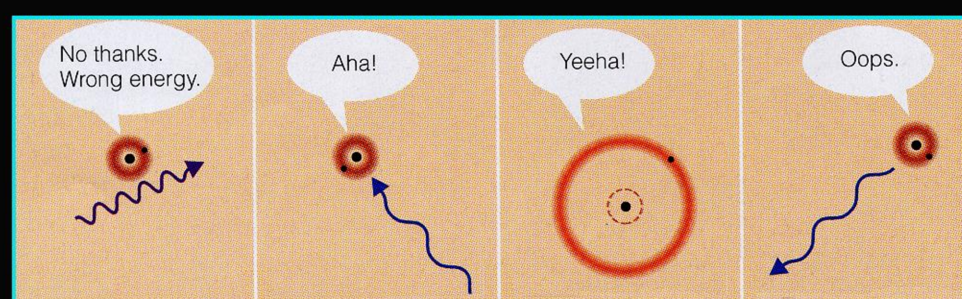
Bohr Model of the Hydrogen Atom



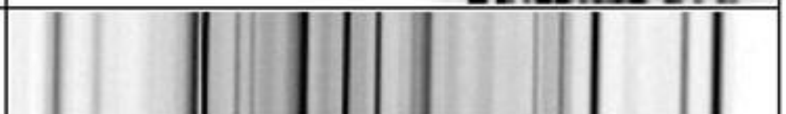
Absorption Spectra



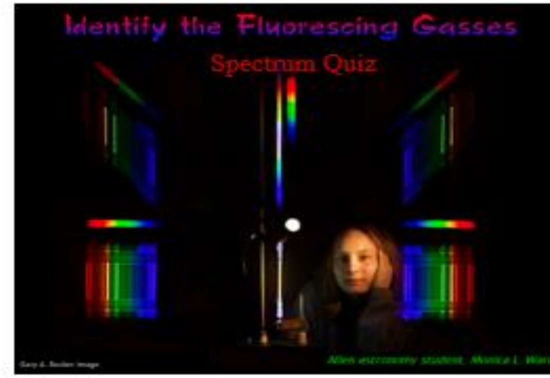




EMISSION SPECTRUM LAB

Name of Plasma Gas	Line Colors and Positions Blue…..G…...Y…...O…..Red
Hydrogen	
Neon	
Oxygen	
Chlorine	
Mercury	
Nitrogen	
Argon	
Xenon	
Carbon Dioxide	
Helium	

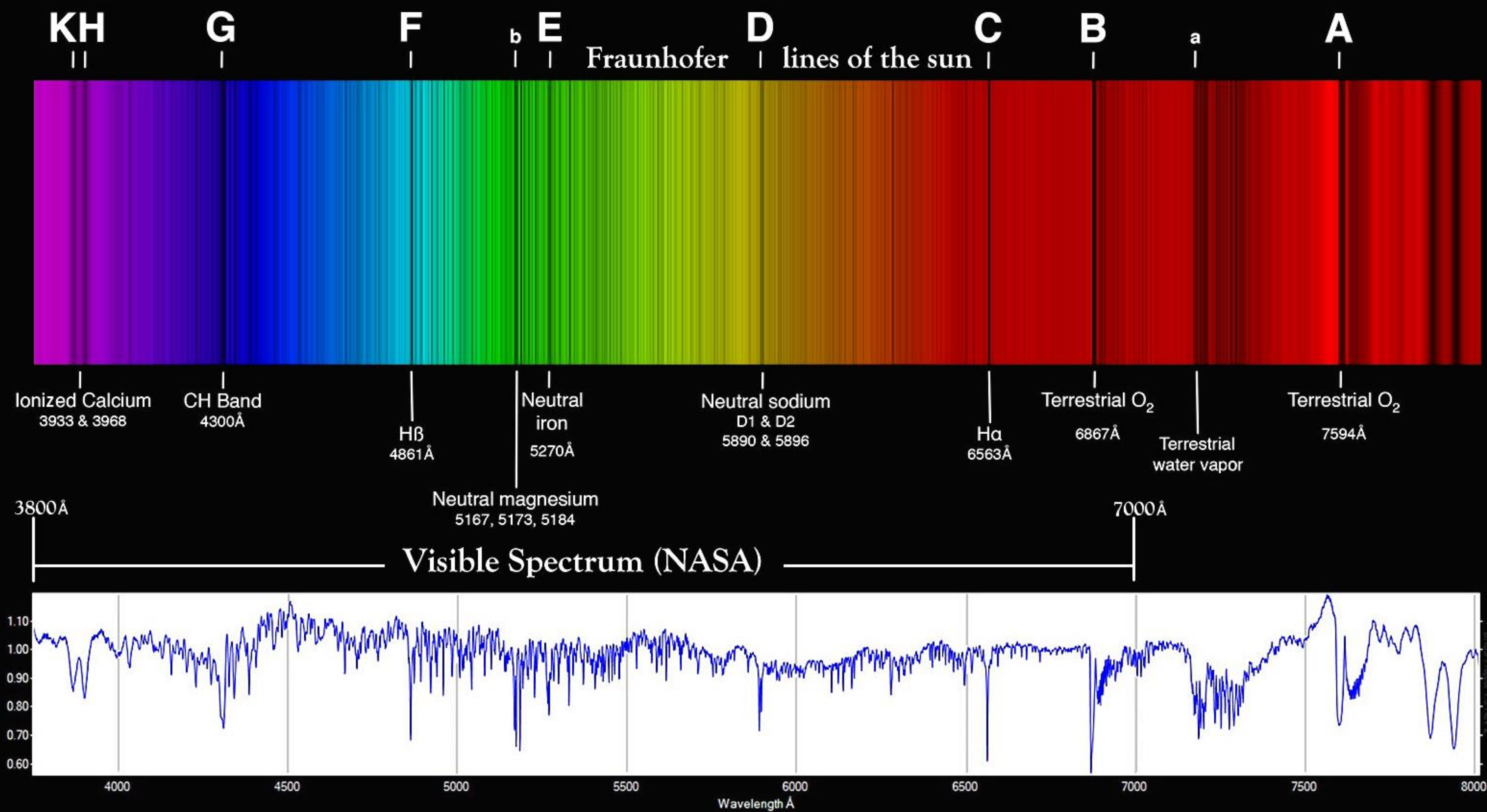
1



2

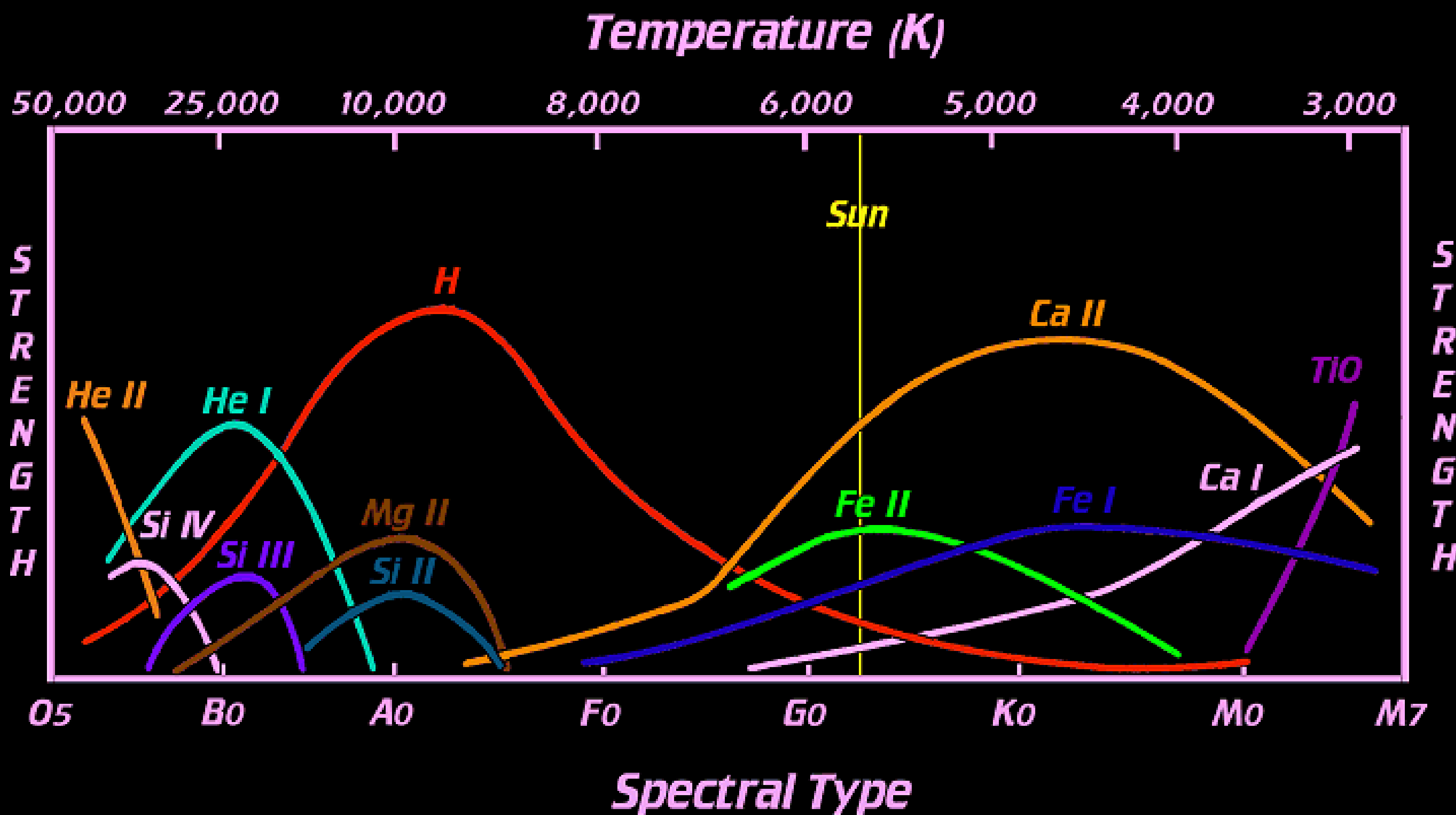
3

Solar Absorption Spectrum

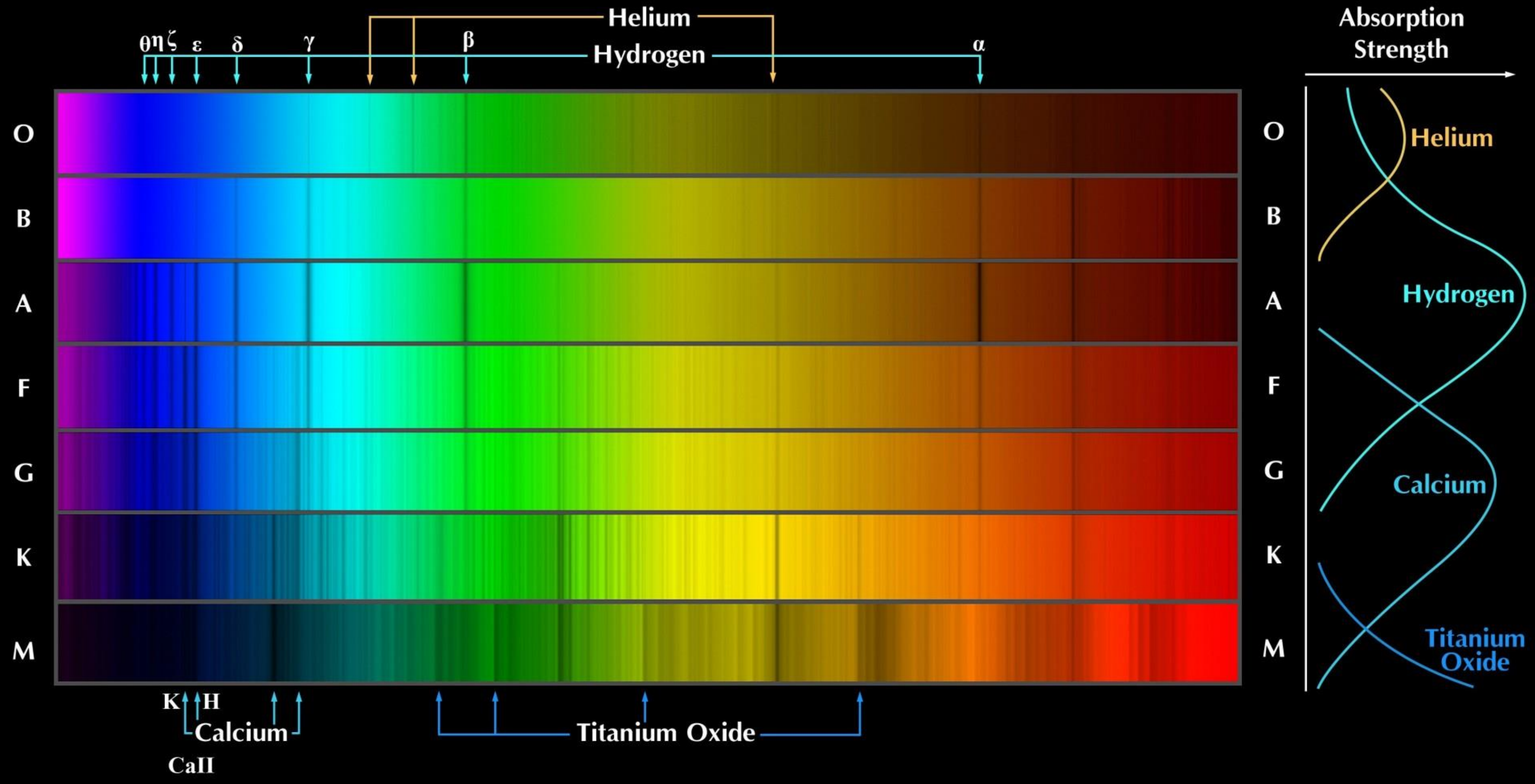


Adapted from NASA materials-Gary A. Becker

Temperature and Line Strength



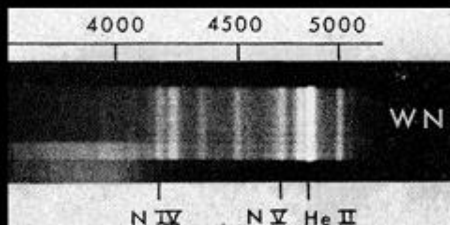
Temperature and Line Strength



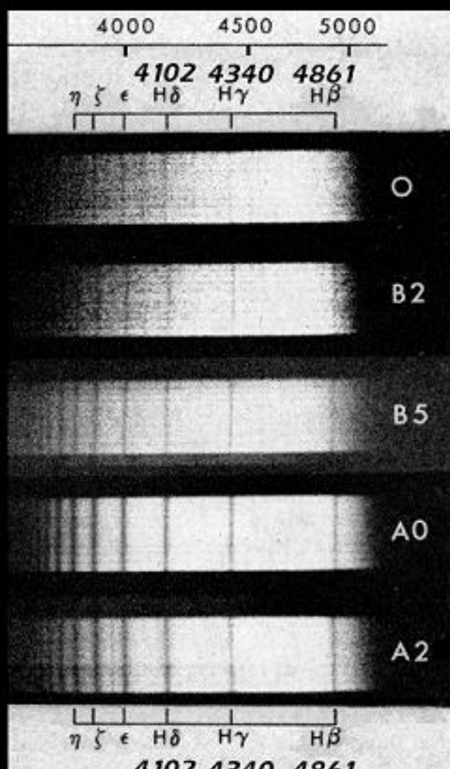
Modified from azastro.pbworks.com

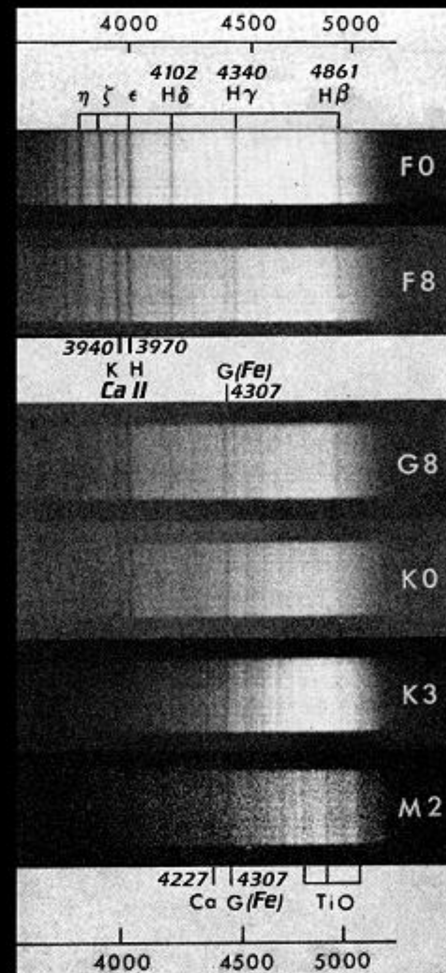
Laboratory Exercises in Astronomy

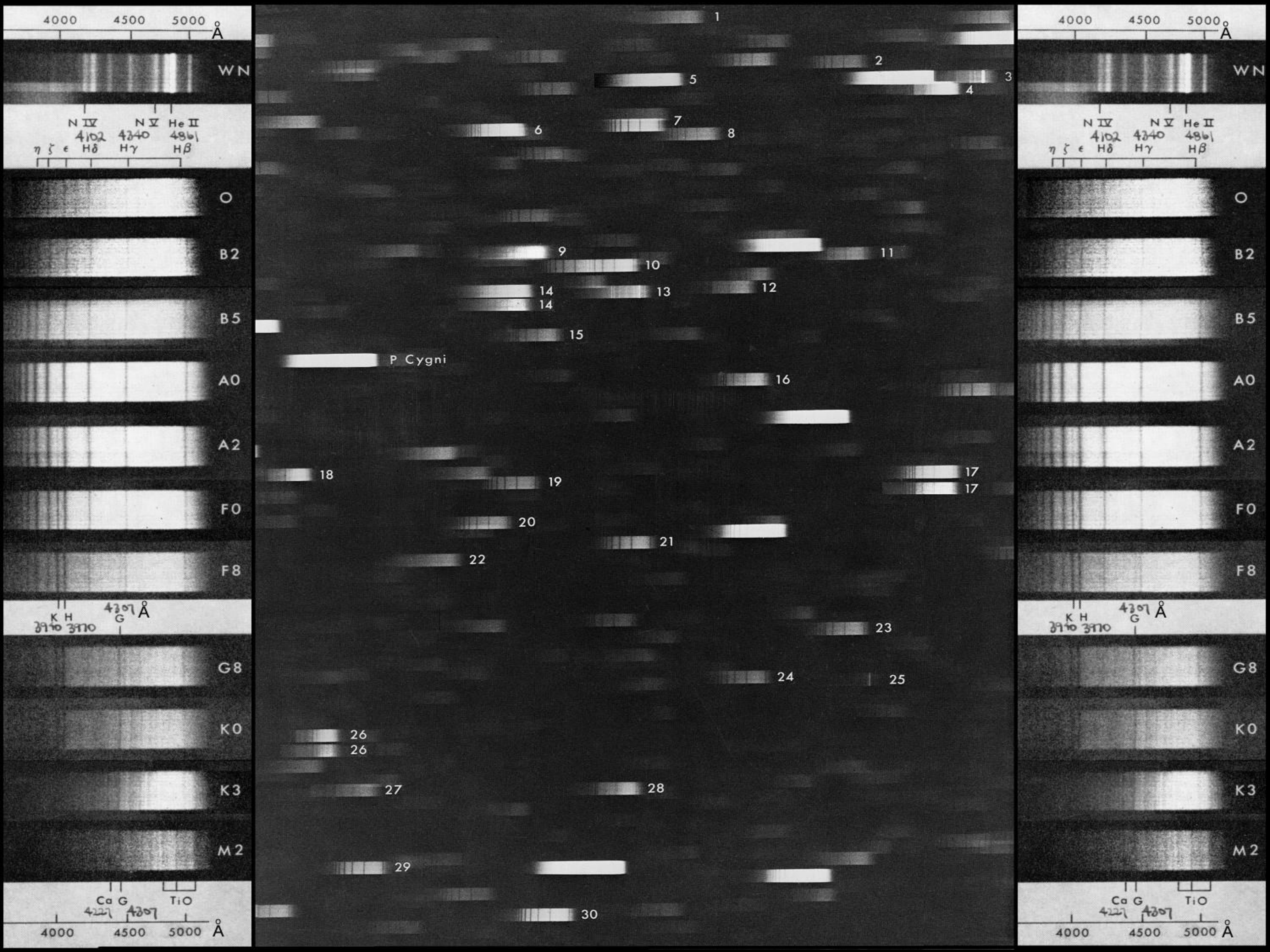
Spectral Classification



eta, zeta, epsilon, delta, gamma, beta,






4000 4500 5000 Å
WN
N IV N V He II
4102 4340 4861
η ζ ε Hδ Hγ Hβ
O
B2
B5
A0
A2
F0
F8
K H 4307 Å
3940 3970 G
G8
K0
K3
M2
Ca G TiO
4227 4307
4000 4500 5000 Å
1
2
3
4
5
6
7
8
9
10
11
12
13
14
14
15
P Cygni
16
17
17
18
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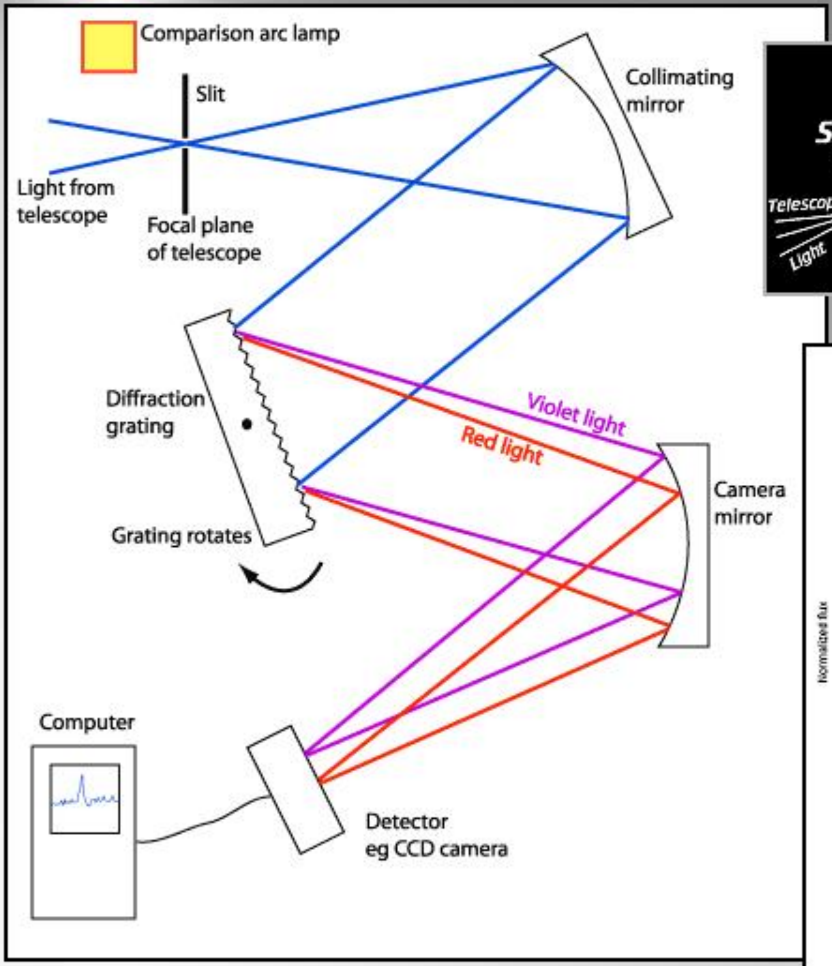
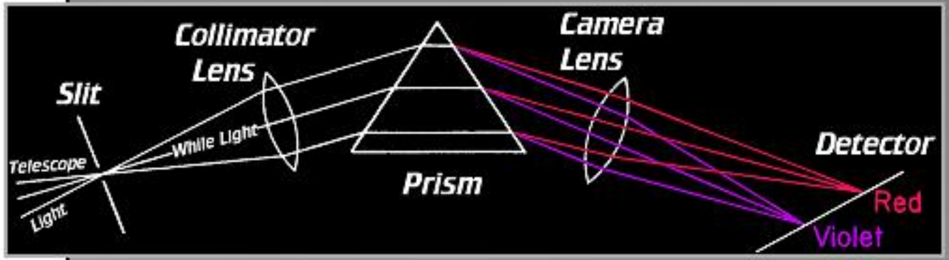
30

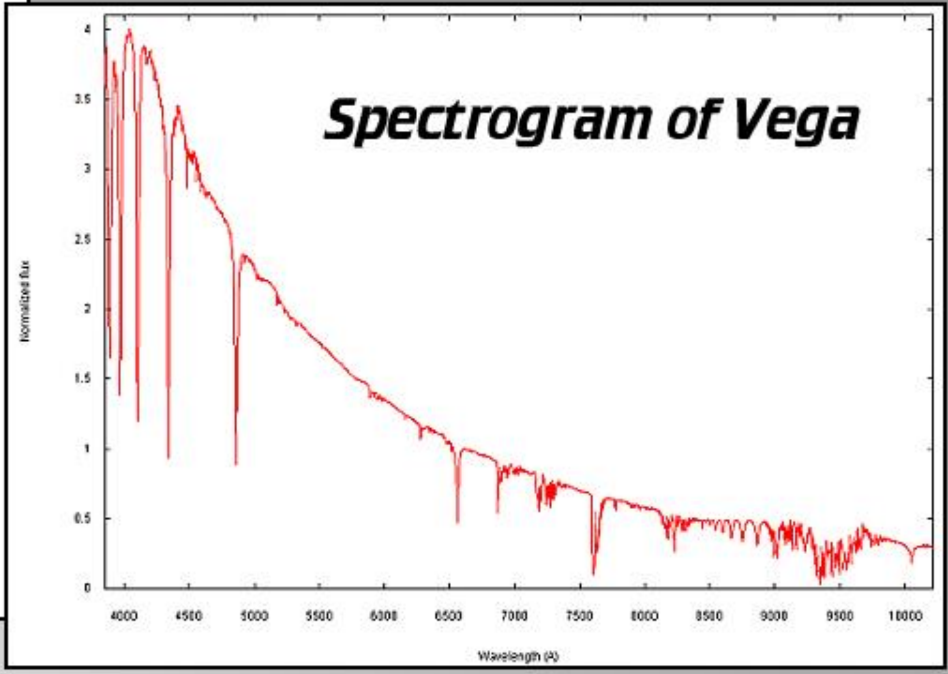
Spectrograph

Schematic of a Slit Spectrograph

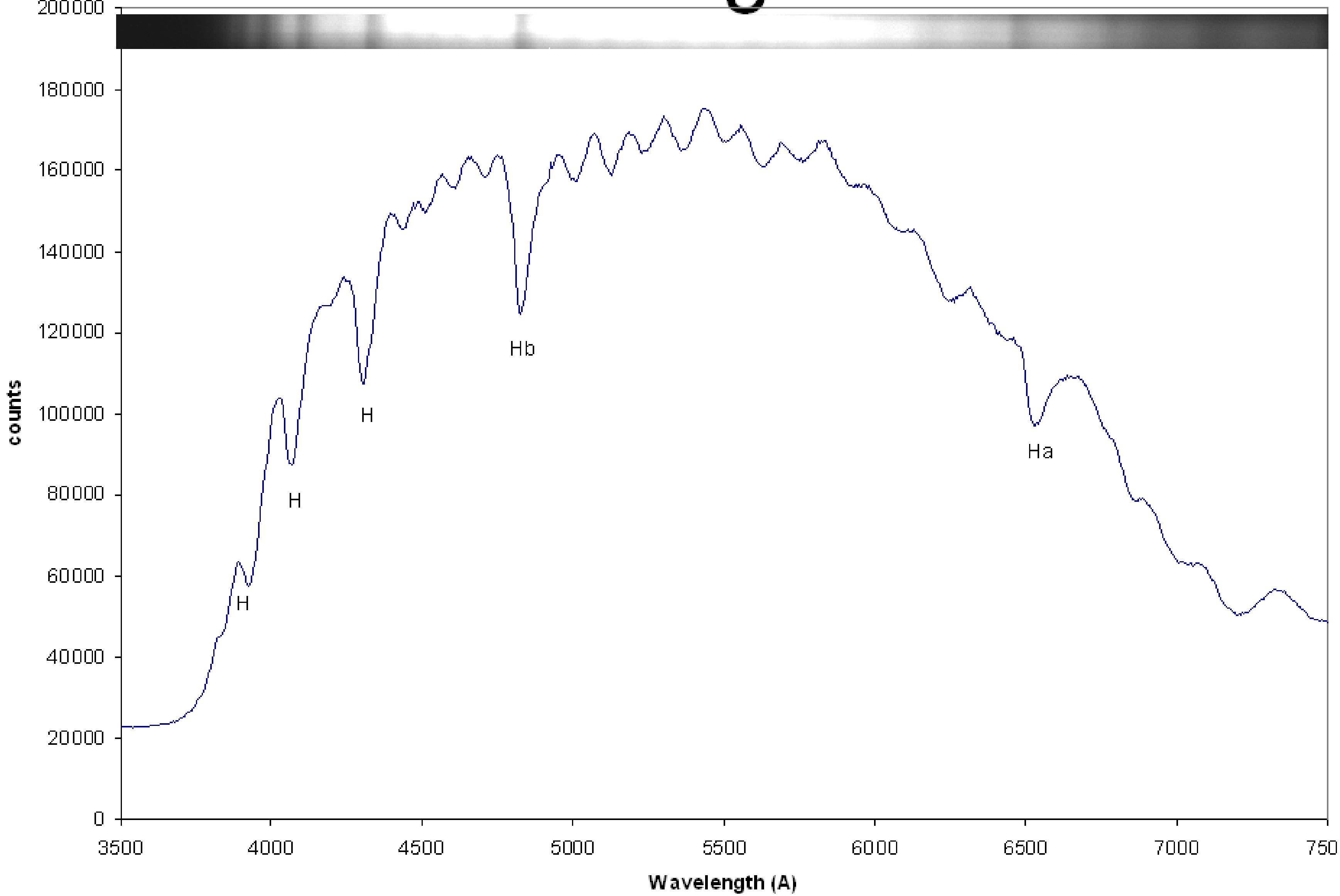


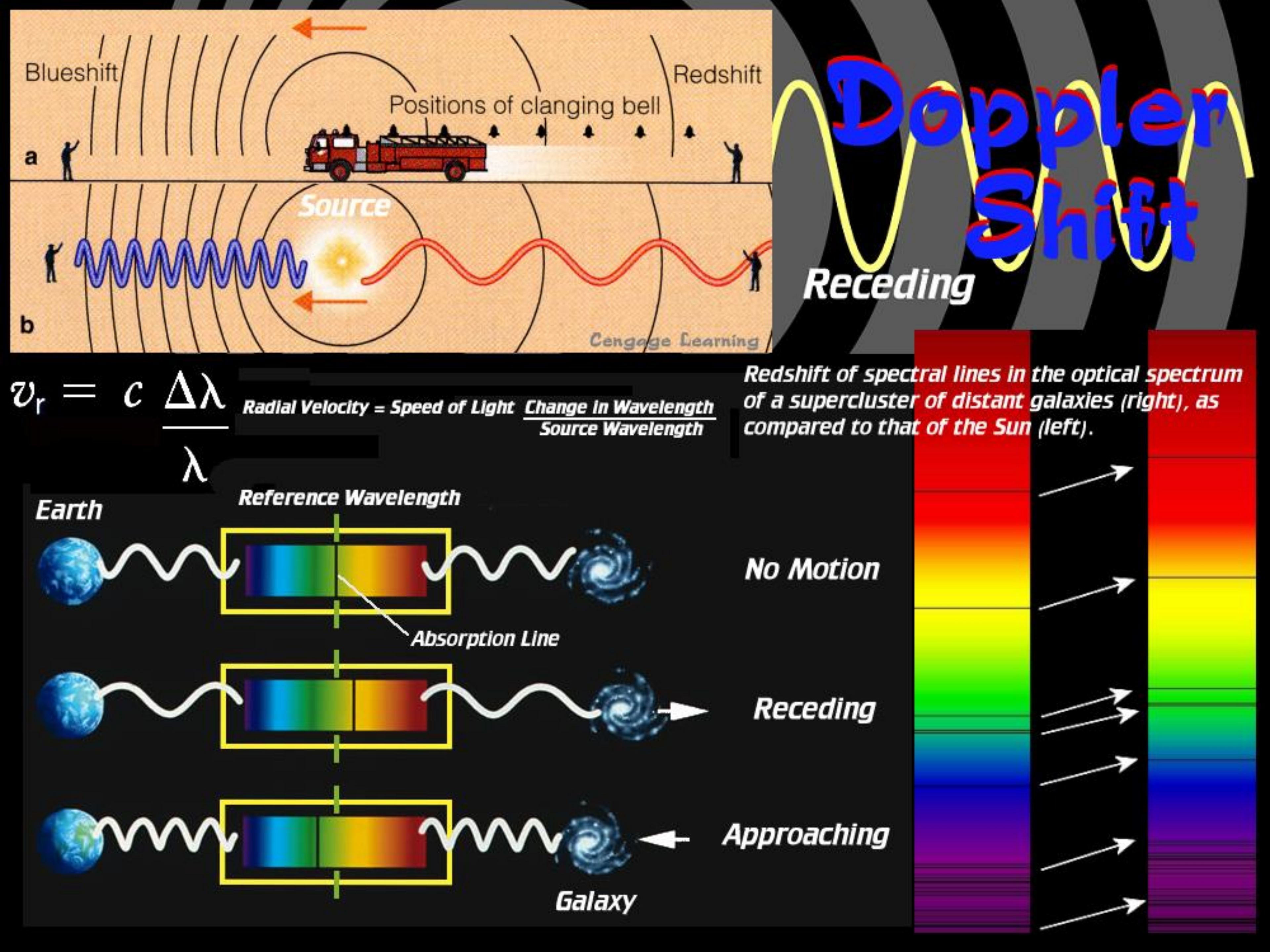
Spectrograph using a Prism



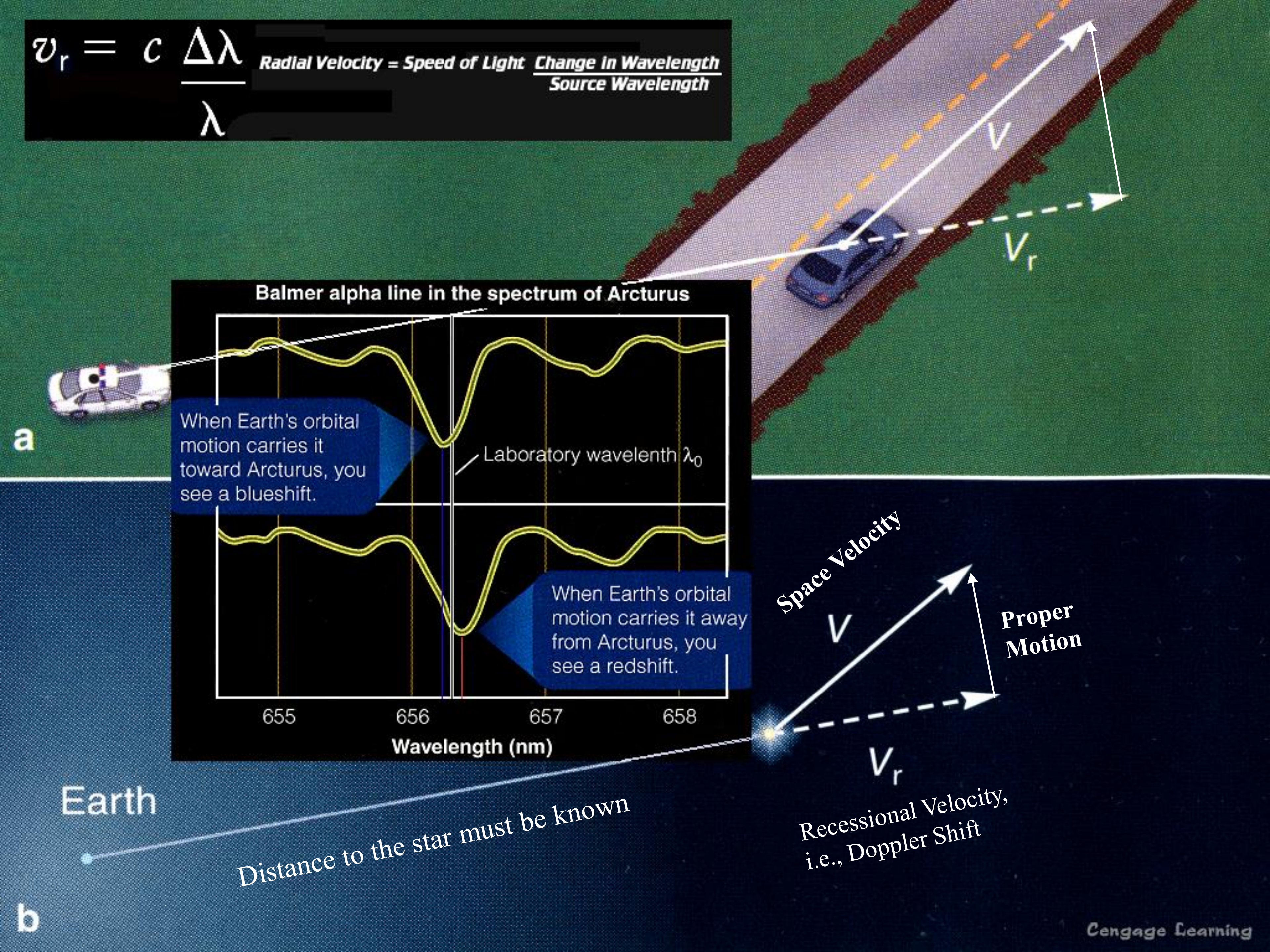


Sirius A1V Magnitude -1.5

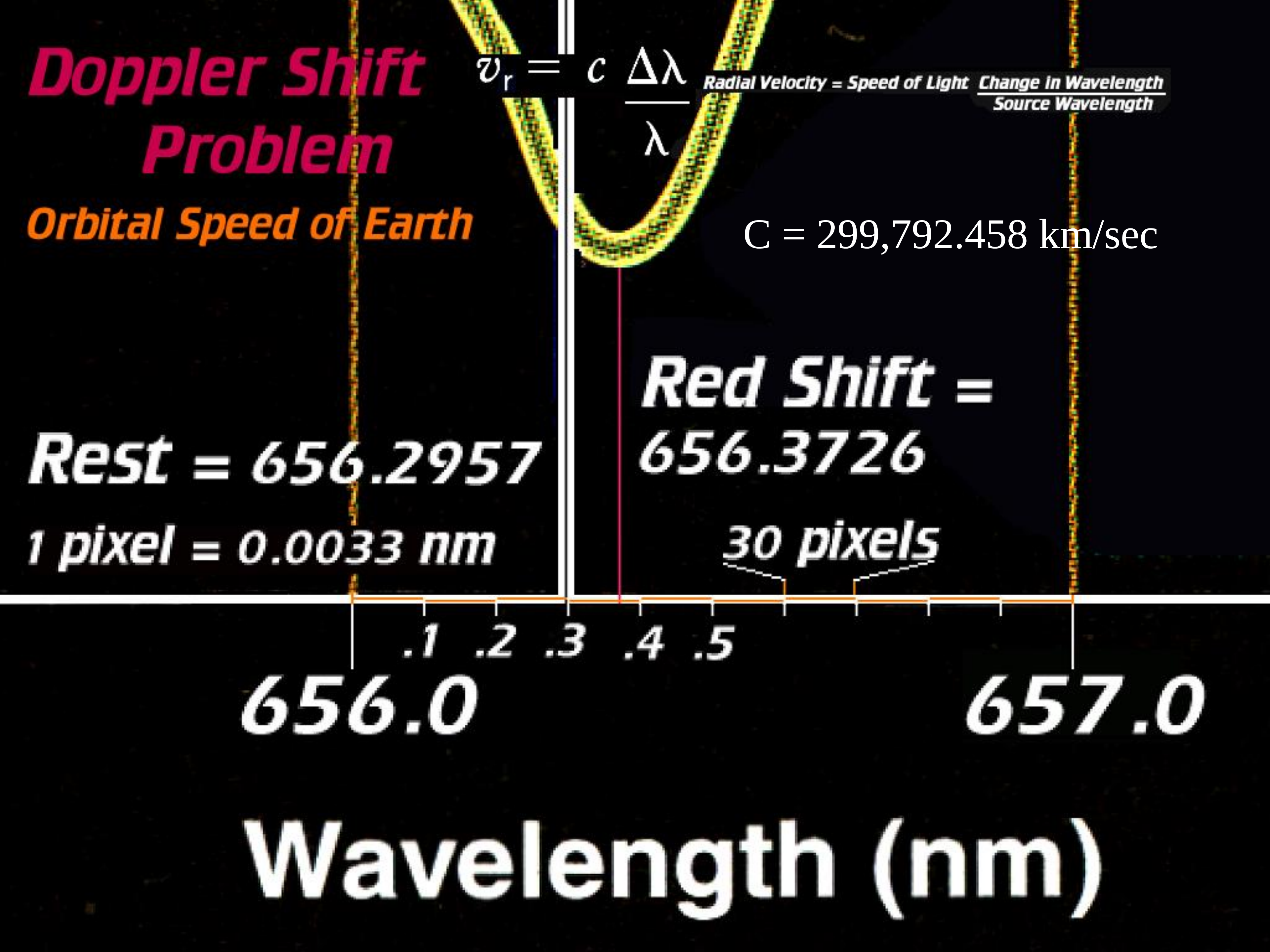




Blueshift
Redshift
Positions of clanging bell
a
Source
b
Cengage Learning
Doppler Shift
Receding
$v_r = c \frac{\Delta\lambda}{\lambda}$
Radial Velocity = Speed of Light Change in Wavelength / Source Wavelength
Redshift of spectral lines in the optical spectrum of a supercluster of distant galaxies (right), as compared to that of the Sun (left).
Earth
Reference Wavelength
No Motion
Absorption Line
Receding
Approaching
Galaxy



$v_r = c \dfrac{\Delta\lambda}{\lambda}$
Radial Velocity = Speed of Light Change in Wavelength / Source Wavelength
V
V_r
Balmer alpha line in the spectrum of Arcturus
When Earth's orbital motion carries it toward Arcturus, you see a blueshift.
Laboratory wavelenth λ_0
When Earth's orbital motion carries it away from Arcturus, you see a redshift.
655
656
657
658
Wavelength (nm)
a
Space Velocity
V
Proper Motion
V_r
Recessional Velocity, i.e., Doppler Shift
Earth
Distance to the star must be known
b
Cengage Learning


Doppler Shift Problem
Orbital Speed of Earth
$v_r = c \frac{\Delta\lambda}{\lambda}$
Radial Velocity = Speed of Light Change in Wavelength / Source Wavelength
C = 299,792.458 km/sec
Red Shift =
656.3726
Rest = 656.2957
1 pixel = 0.0033 nm
30 pixels
.1 .2 .3 .4 .5
656.0
657.0
Wavelength (nm)

Physics Humor

"I love hearing that lonesome wail of the train whistle as the frequency decreases and the pitch lowers because of the Doppler effect."

Wien's Law (Wilhelm Wien (Veen)—German 1864-1928):

$$T = \frac{0.2900}{\lambda_{max}} \qquad \text{or} \qquad \lambda_{max} = \frac{0.2900}{T}$$

Where λ (lambda) equals the wavelength of the greatest amount of energy being emitted in cm

T is the temperature in Kelvin.

Constant of proportionality $2.8977685(51)\times10^{-3}$ m T

$$2.900 \times 10^{-3} \text{ m K} \times \frac{10^2 \text{ cm}}{\text{m}} = 2.900 \times 10^{-1} \text{ cm T}$$

$$= 0.2900 \text{ cm T}$$

There are $10^{-8} \frac{\text{cm}}{\text{Å}}$ **or** $\frac{10^8 \text{ Å}}{\text{cm}}$

What is λ_{max} of the sun if the sun's temperature = 5800 K

$$\lambda_{max} – \frac{0.2900 \text{ cm K}}{5800 \text{ K}} = 5 \times 10^{-5} \text{ cm} \times \frac{10^8 \text{ Å}}{\text{cm}}$$

$$5 \times 10^3 \text{ Å}$$

$$5000 \text{ Å}$$

<u>Stephan's Law</u> (Josef Stefan—Austrian 1835-1893):

$E = \rho T^4$ If T doubles energy increases by 16 fold

The total energy emitted from a black body is relative to the temperature in K to the fourth power of T^4.

$E = \rho\, T^4$

where ρ (rho), a constant, equals $5.67 \times 10^{-5} \dfrac{\text{erg}}{\text{cm}^2\ \text{sec}\ T^4}$

$E = \dfrac{\text{erg}}{\text{cm}^2\ \text{sec}}$ = One erg = the force of a dyne acting over a distance of 1 cm equals 1 dyne cm $= \dfrac{1\ \text{gm}\ \ 1\ \text{cm}}{\text{sec}^2}\ 1\ \text{cm} = \dfrac{\text{gm cm}^2}{\text{sec}^2}$

Let's look at the units only $E = \dfrac{\text{erg}}{\text{cm}^2\ \text{sec}\ T^4}\ T^4$

$$E = \frac{\text{erg}}{\text{cm}^2\ \text{sec}}$$

The sun has a temperature of 5800K. What is its energy production?

The sun has a temperature of 5800K. What is its energy production?

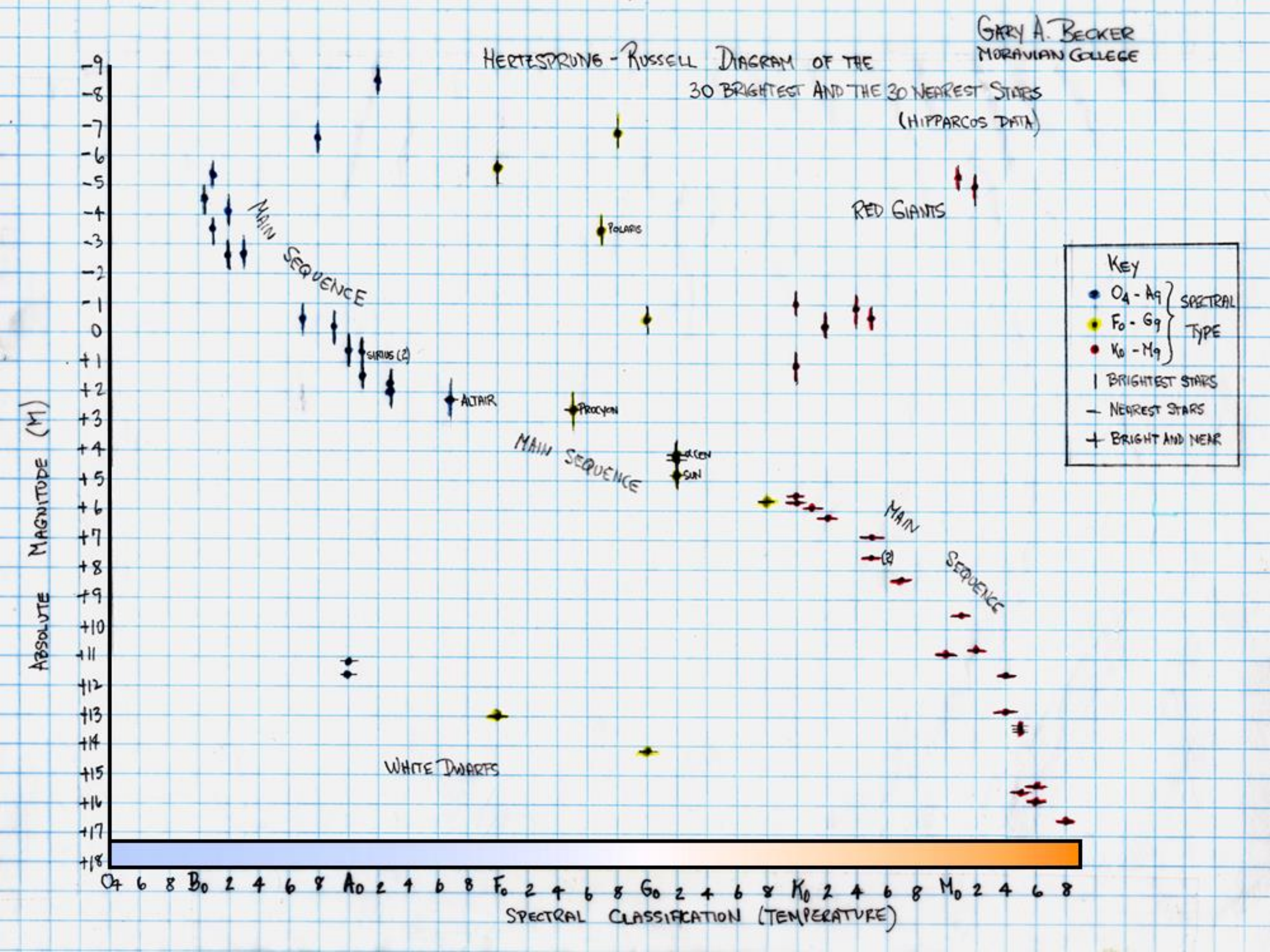
$$E = \rho\, T^4;\quad E = 5.67 \times 10^{-5}\ \mathrm{erg\ cm^{-2}\ sec^{-1}\ T^{-4}} \times (5800\mathrm{K})^4$$

$$E = 5.67 \times 10^{-5}\ \frac{\mathrm{erg}}{\mathrm{cm^2\ sec\ T^4}} \quad \times \quad 1.11 \times 10^{15}\ \mathrm{K^4} \qquad \text{but } \mathrm{K^4} = \mathrm{T^4}$$

$$E = 6.29 \times 10^{10}\ \frac{\mathrm{ergs}}{\mathrm{cm^2\ sec}} \qquad \text{area of the sun} = 6.088 \times 10^{22}\ \mathrm{cm^2}$$

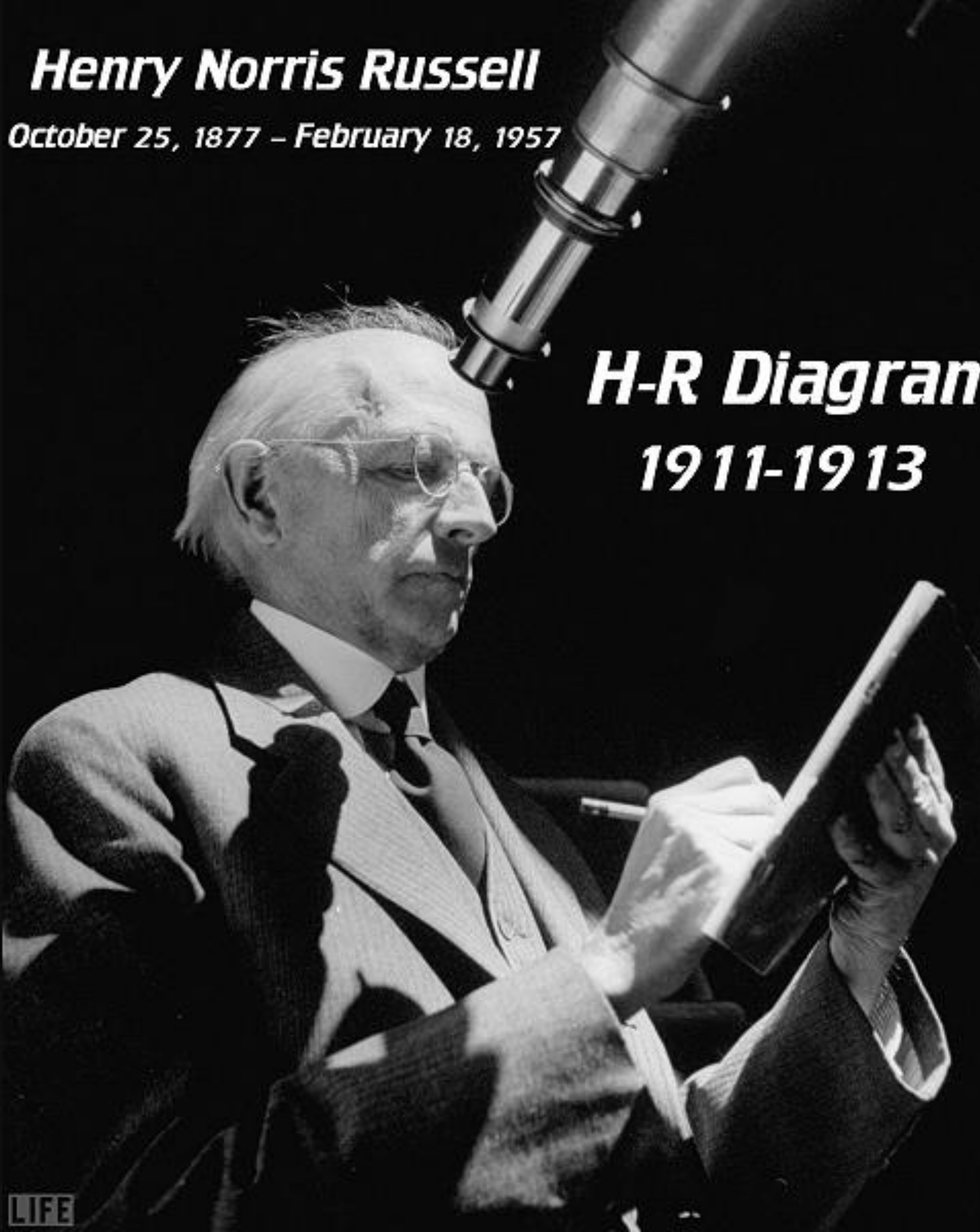
$$E = 6.29 \times 10^{10}\ \frac{\mathrm{ergs}}{\mathrm{cm^2\ sec}} \quad \times \quad 6.088 \times 10^{22}\ \mathrm{cm^2} = 38.3 \times 10^{32}\ \frac{\mathrm{ergs}}{\mathrm{sec}}$$

$$E = 3.83 \times 10^{33}\ \frac{\mathrm{ergs}}{\mathrm{sec}} \qquad \text{accepted value} = 3.839 \times 10^{33}\ \frac{\mathrm{erg}}{\mathrm{sec}}$$


Gary A. Becker
Moravian College
Hertzsprung - Russell Diagram of the
30 Brightest and the 30 Nearest Stars
(Hipparcos Data)
Absolute Magnitude (M)
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
+6
+7
+8
+9
+10
+11
+12
+13
+14
+15
+16
+17
+18
Main Sequence
Sirius (2)
Altair
Procyon
Polaris
Main Sequence
α Cen
Sun
Red Giants
Main Sequence
(2)
White Dwarfs
Key
O_4 - A_9
F_0 - G_9
K_0 - M_9
Spectral Type
Brightest Stars
Nearest Stars
Bright and Near
O_4 6 8 B_0 2 4 6 8 A_0 2 4 6 8 F_0 2 4 6 8 G_0 2 4 6 8 K_0 2 4 6 8 M_0 2 4 6 8
Spectral Classification (Temperature)

Henry Norris Russell

October 25, 1877 – February 18, 1957

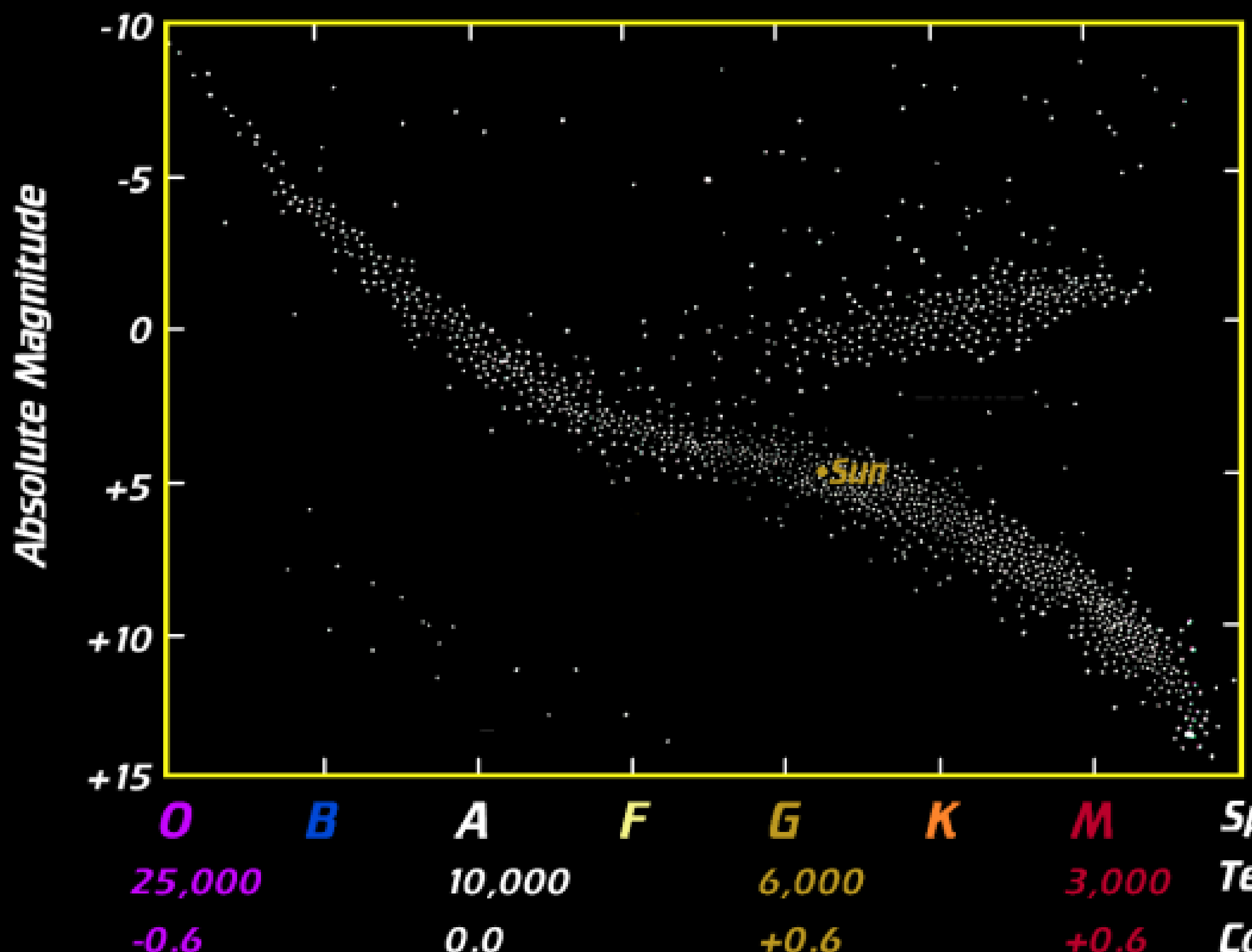


H-R Diagram
1911-1913

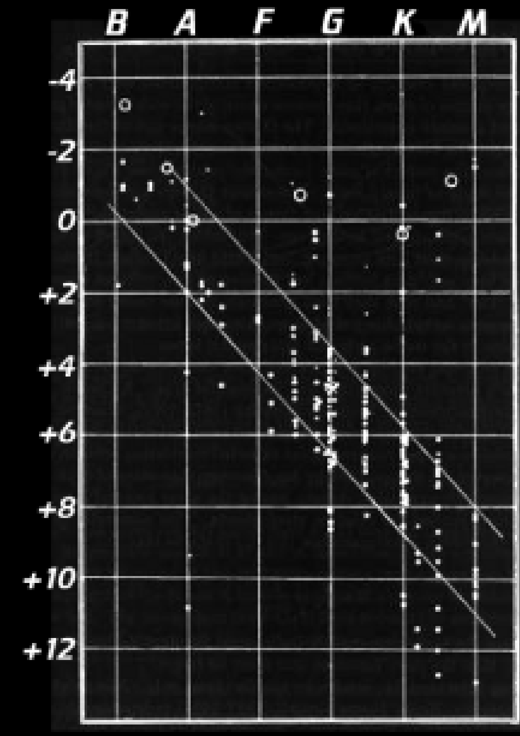
Ejnar Hertzsprung

October 8, 1873 - October 21, 1967

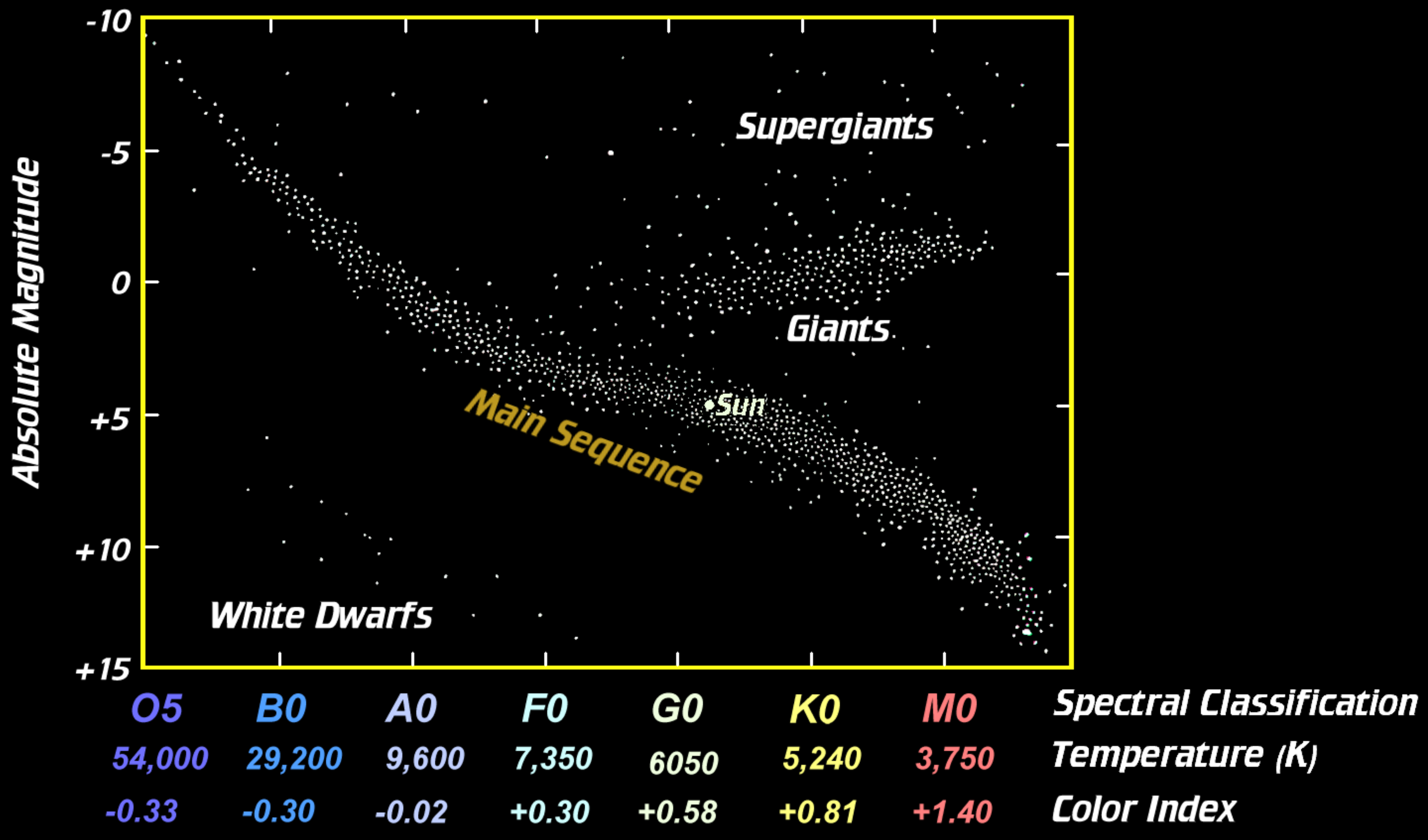
Hertzsprung-Russell Diagram



Original H-R Diagram

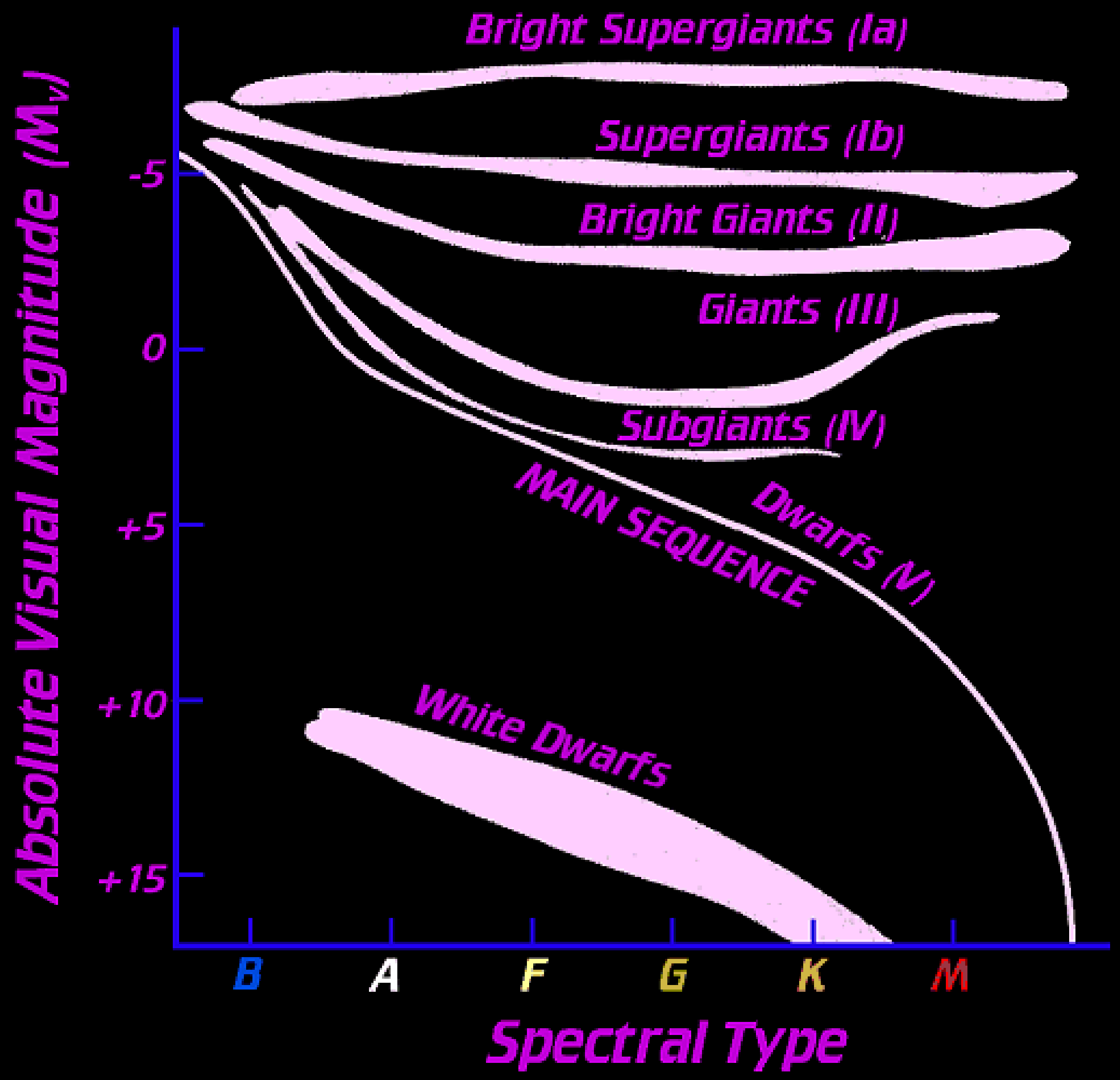


Hertzsprung-Russell Diagram

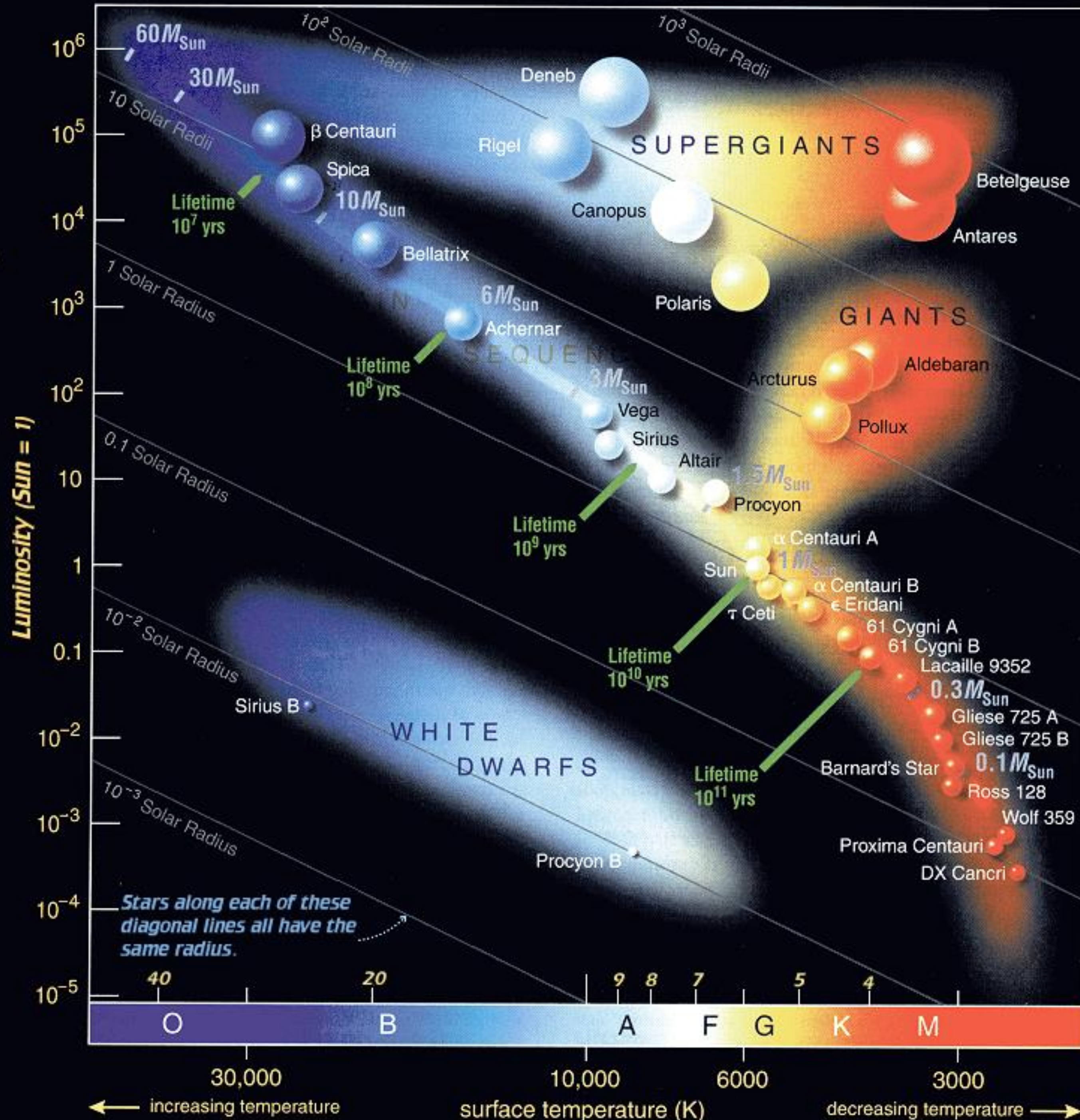


Gary A. Becker slide

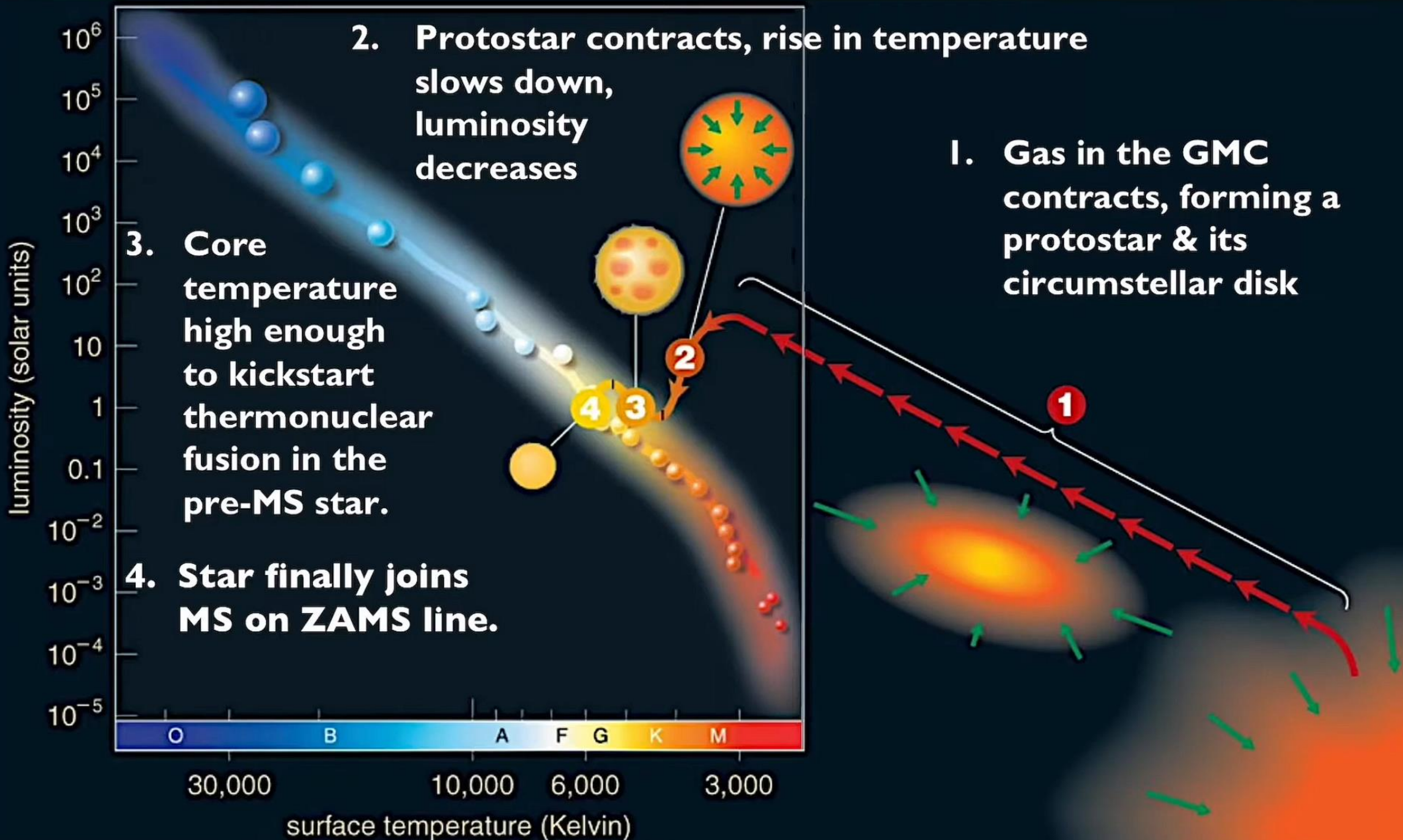
Luminosity Classifications



H-R Diagram

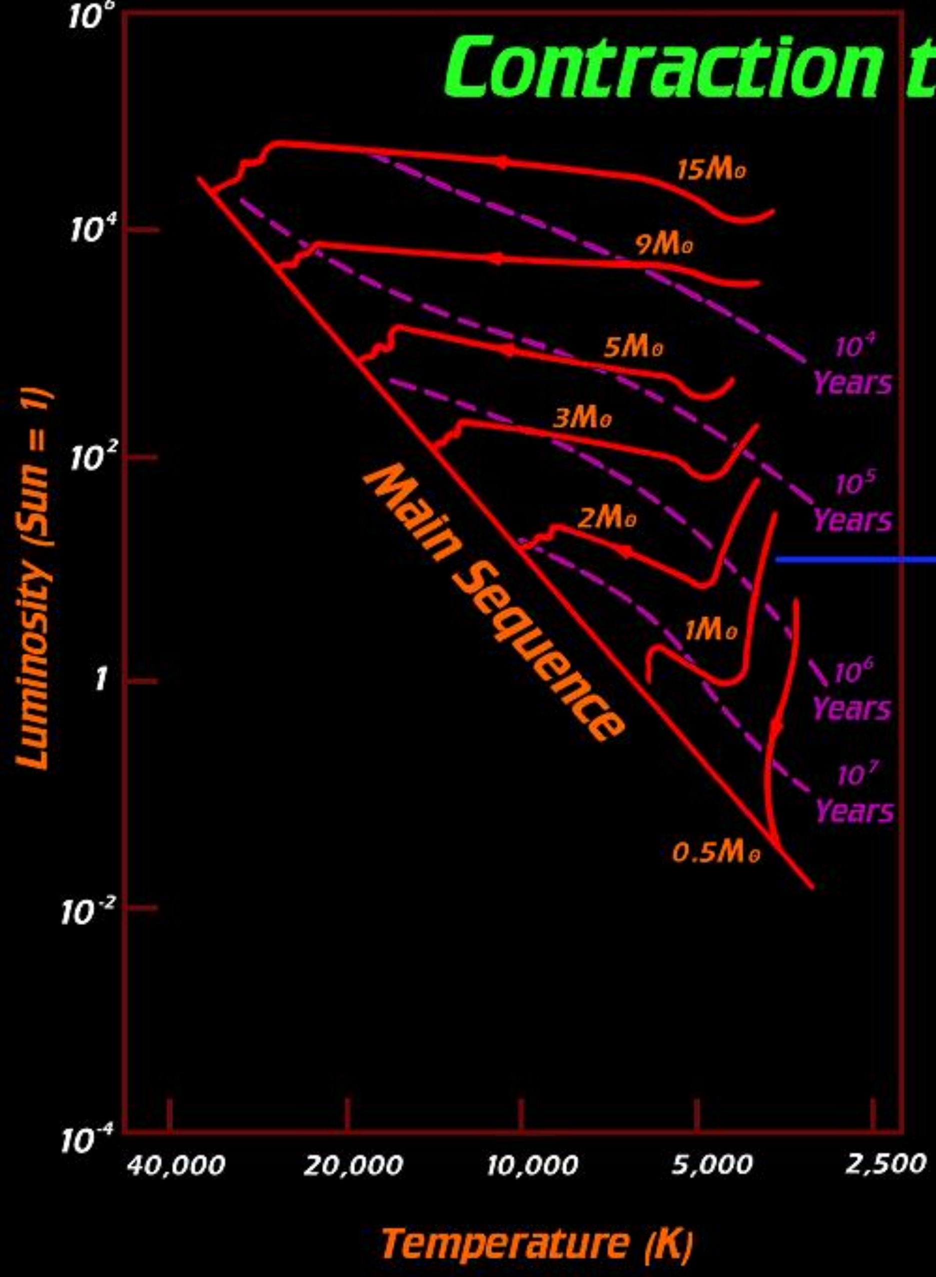


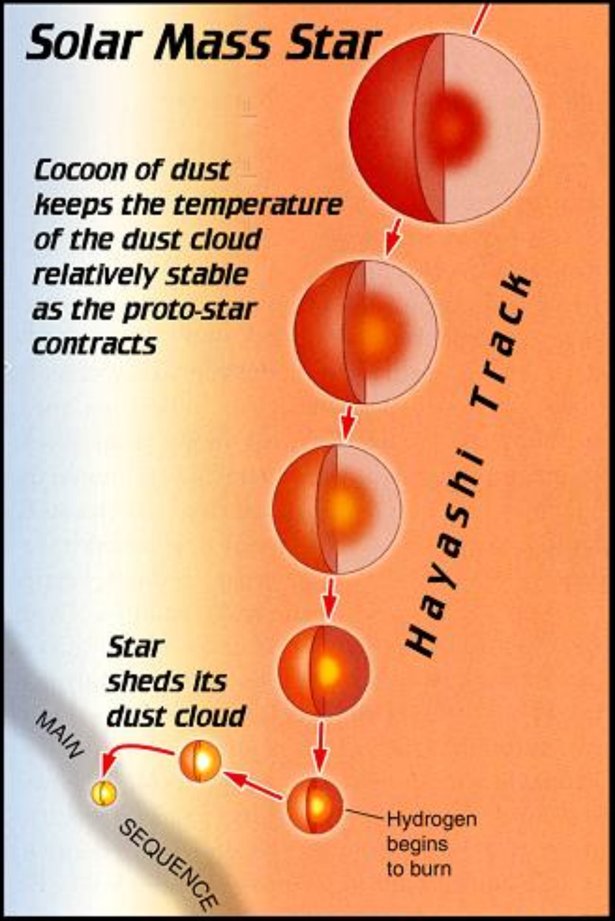
Luminosity (Sun = 1)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^-2
10^-3
10^-4
10^-5
60 M Sun
30 M Sun
10 M Sun
6 M Sun
3 M Sun
1.5 M Sun
1 M Sun
0.3 M Sun
0.1 M Sun
10^2 Solar Radii
10^3 Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^-2 Solar Radius
10^-3 Solar Radius
SUPERGIANTS
GIANTS
MAIN SEQUENCE
WHITE DWARFS
Deneb
Rigel
Canopus
Polaris
Betelgeuse
Antares
Aldebaran
Arcturus
Pollux
β Centauri
Spica
Bellatrix
Achernar
Vega
Sirius
Altair
Procyon
α Centauri A
Sun
α Centauri B
ε Eridani
τ Ceti
61 Cygni A
61 Cygni B
Lacaille 9352
Gliese 725 A
Gliese 725 B
Barnard's Star
Ross 128
Wolf 359
Proxima Centauri
DX Cancri
Sirius B
Procyon B
Lifetime 10^7 yrs
Lifetime 10^8 yrs
Lifetime 10^9 yrs
Lifetime 10^10 yrs
Lifetime 10^11 yrs
Stars along each of these diagonal lines all have the same radius.
40
20
9
8
7
5
4
O
B
A
F
G
K
M
30,000
10,000
6000
3000
← increasing temperature
surface temperature (K)
decreasing temperature →



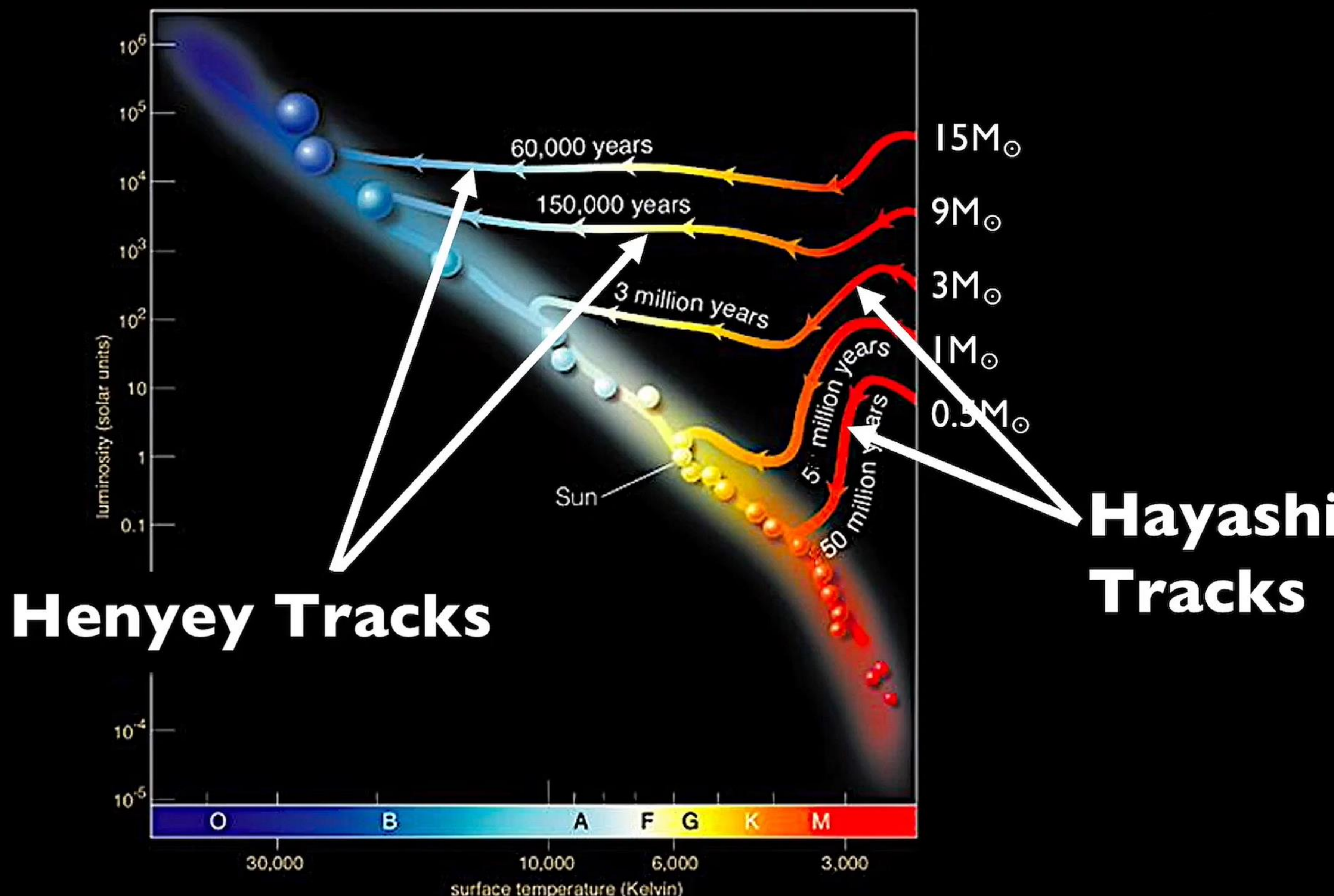
2. Protostar contracts, rise in temperature slows down, luminosity decreases
1. Gas in the GMC contracts, forming a protostar & its circumstellar disk
3. Core temperature high enough to kickstart thermonuclear fusion in the pre-MS star.
4. Star finally joins MS on ZAMS line.
luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^−2
10^−3
10^−4
10^−5
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
surface temperature (Kelvin)
1
2
3
4

Contraction to Zero Age Main Sequence





Cengage Learning



15M☉
9M☉
3M☉
1M☉
0.5M☉
60,000 years
150,000 years
3 million years
million years
50 million years
Sun
luminosity (solar units)
surface temperature (Kelvin)
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
Henyey Tracks
Hayashi Tracks

Monroe

Cabarrus County, NC

Ordinary Chondrite H4, 8.6 kg total mass

Witnessed fall, 3 p.m.
October 31, 1849

1 gm specimen

Gary A. Becker collection

Allende
carbonaceous
chondrite
Mexico
4.567 BY
Front
with
Fusion
Crust
Fell, 01:05, February 8, 1969
Gary A. Becker collection

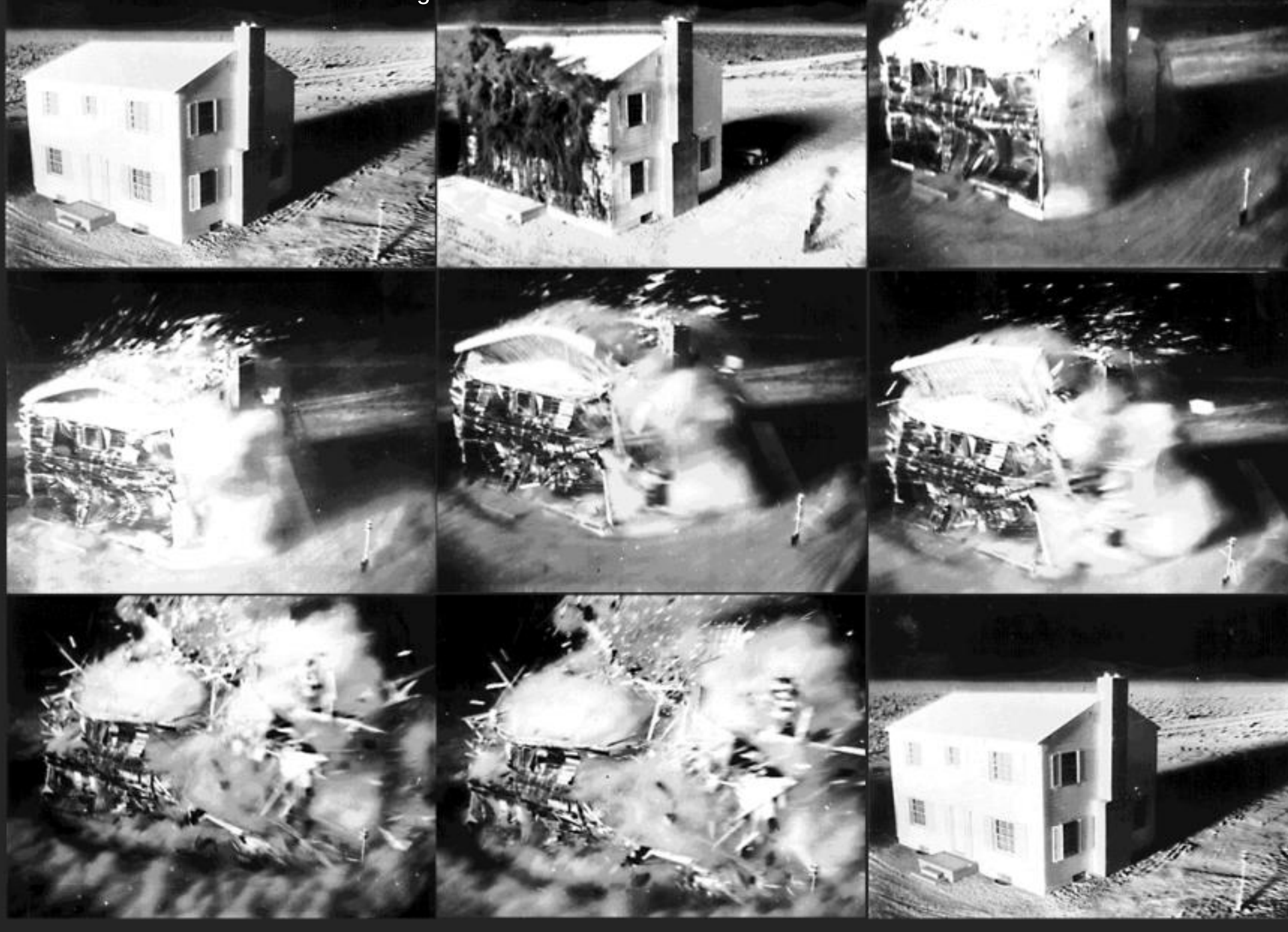
Back Section of Allende

Shock Front: A region of higher density moving through a medium...

Atomic Bomb Shock Front

16 kt tower blast... House 1100 meters from blast site...

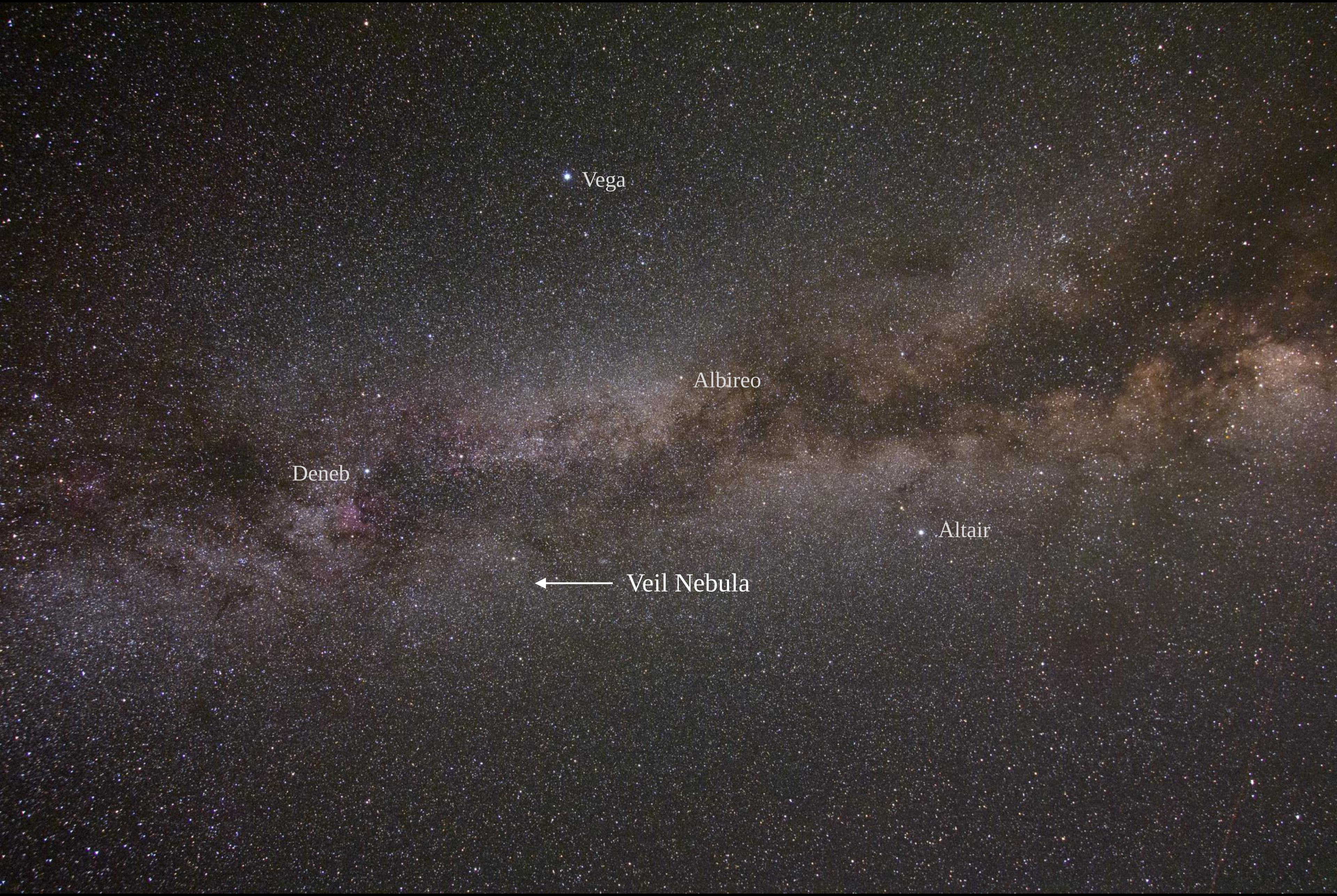
Hiroshima: 12-15 kilotons of TNT/Nagasaki: 22 kiloton blast



Hiroshima - the unknown images

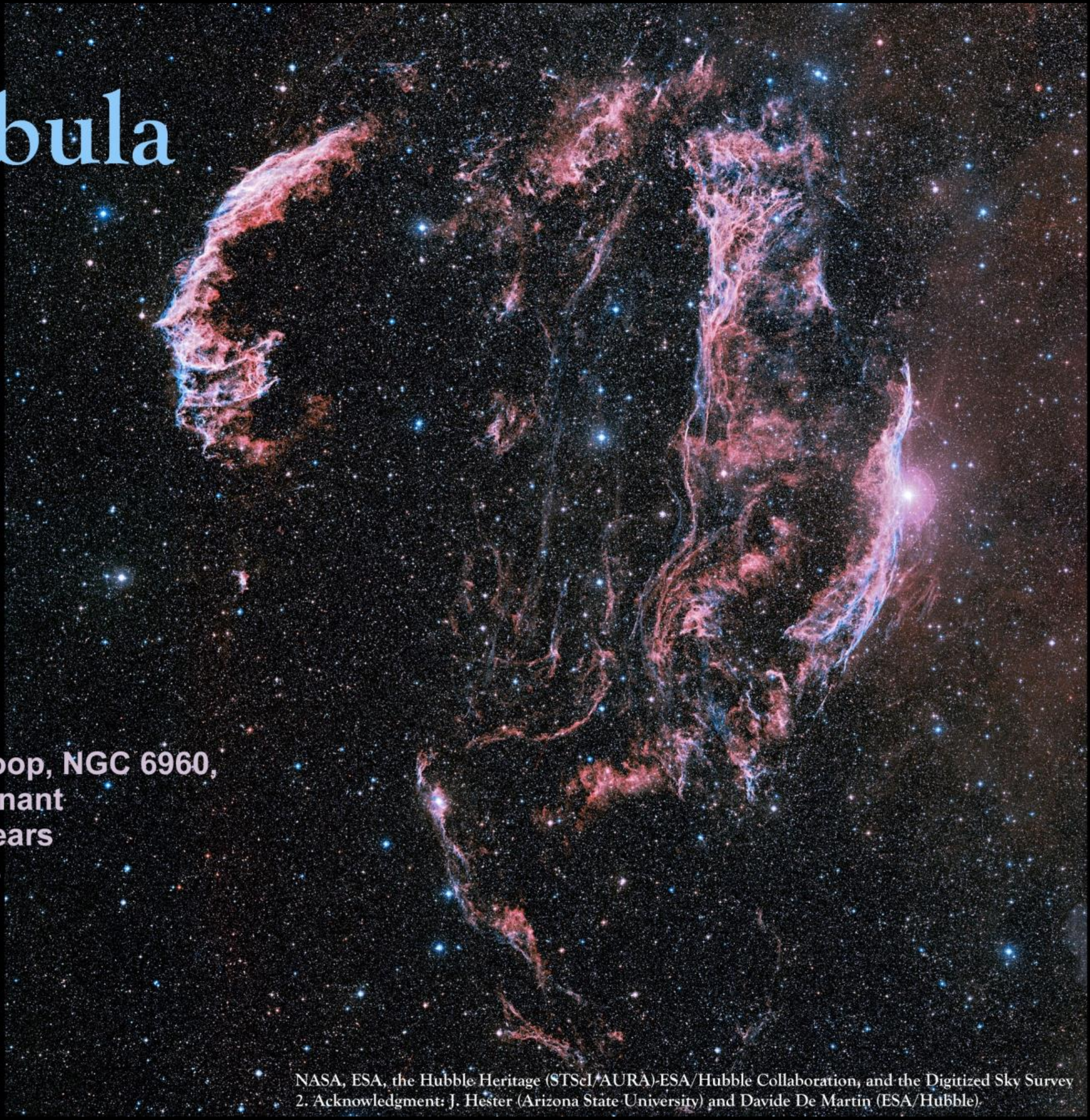

Beirut, Lebanon Explosion
August 4, 2020
3031 tons of ammonium nitrate
Ágoston Németh


Beirut, Lebanon
Ágoston Németh



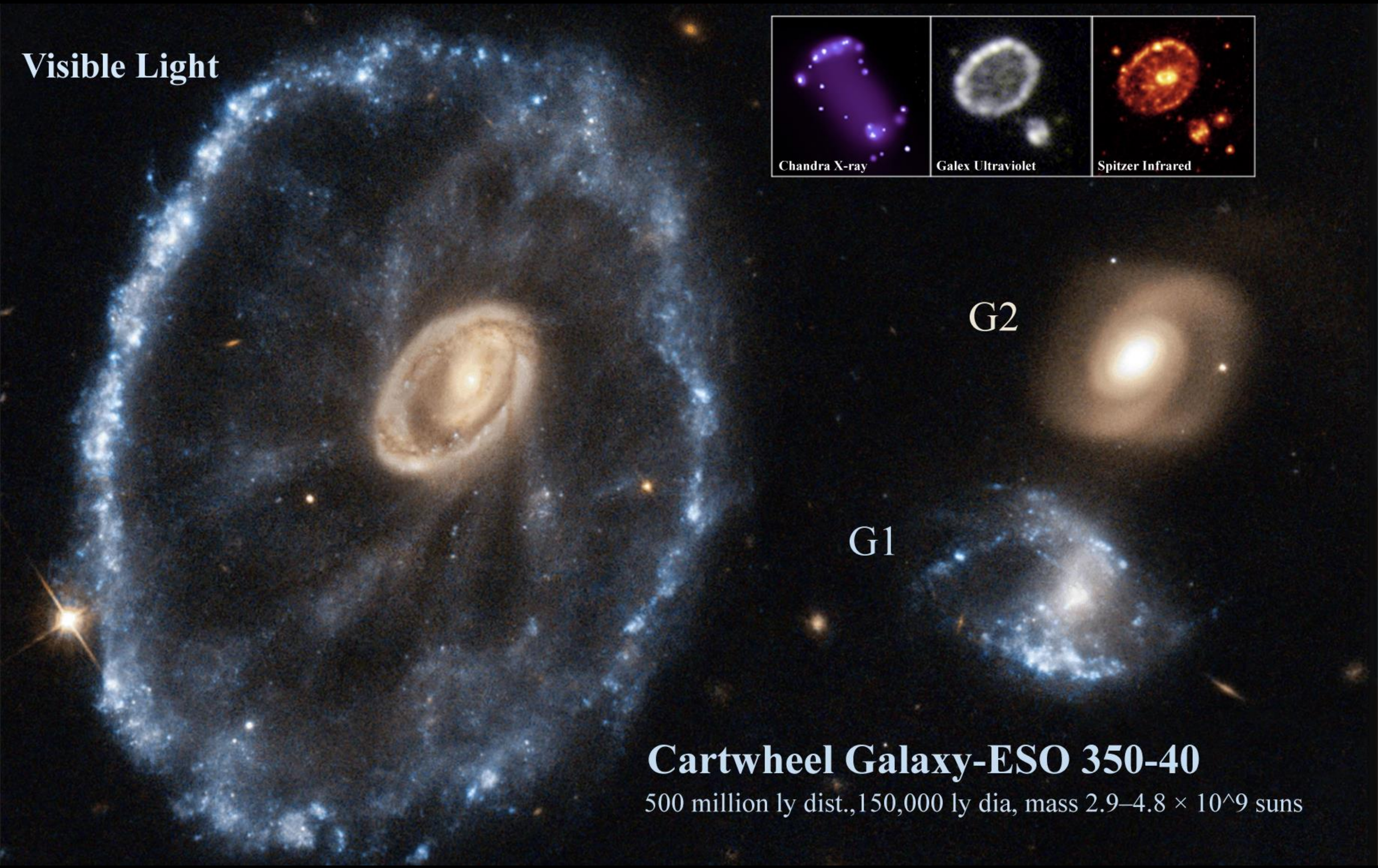
MDRS-Gary A, Becker image

Veil Nebula

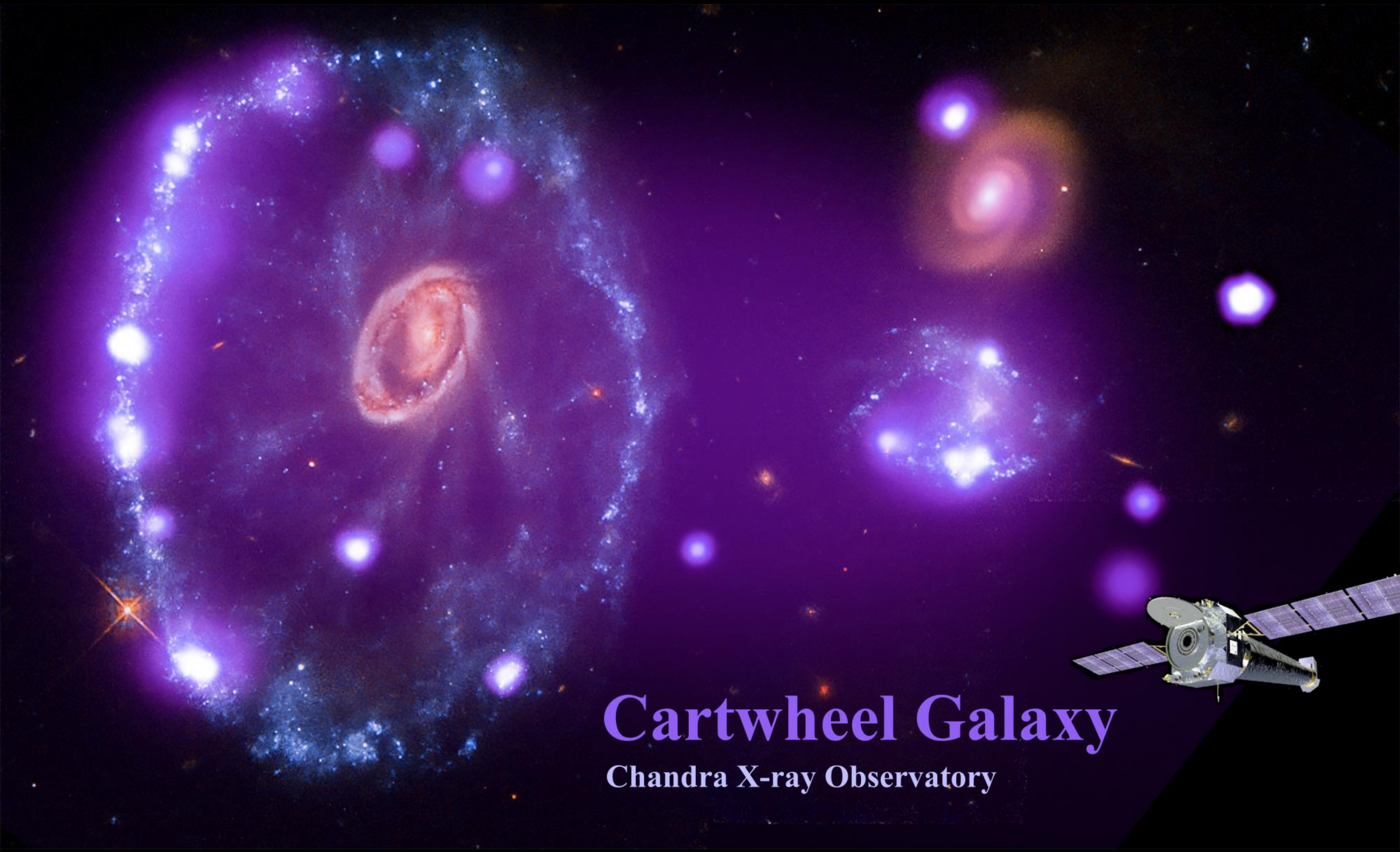


NASA, ESA, the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, and the Digitized Sky Survey 2. Acknowledgment: J. Hester (Arizona State University) and Davide De Martin (ESA/Hubble).

Name: Veil, Cygnus Loop, NGC 6960,
Type: Supernova Remnant
Distance: 1500 light years
Constellation: Cygnus
Category: Nebulae

Hubble Space Telescope/insets: Chandra X-Ray Observatory/GALEX: Galaxy Evolution Explorer /Spitzer Space Telescope



Chandra X-ray Observatory/Chandra X-ray Center (satellite image)

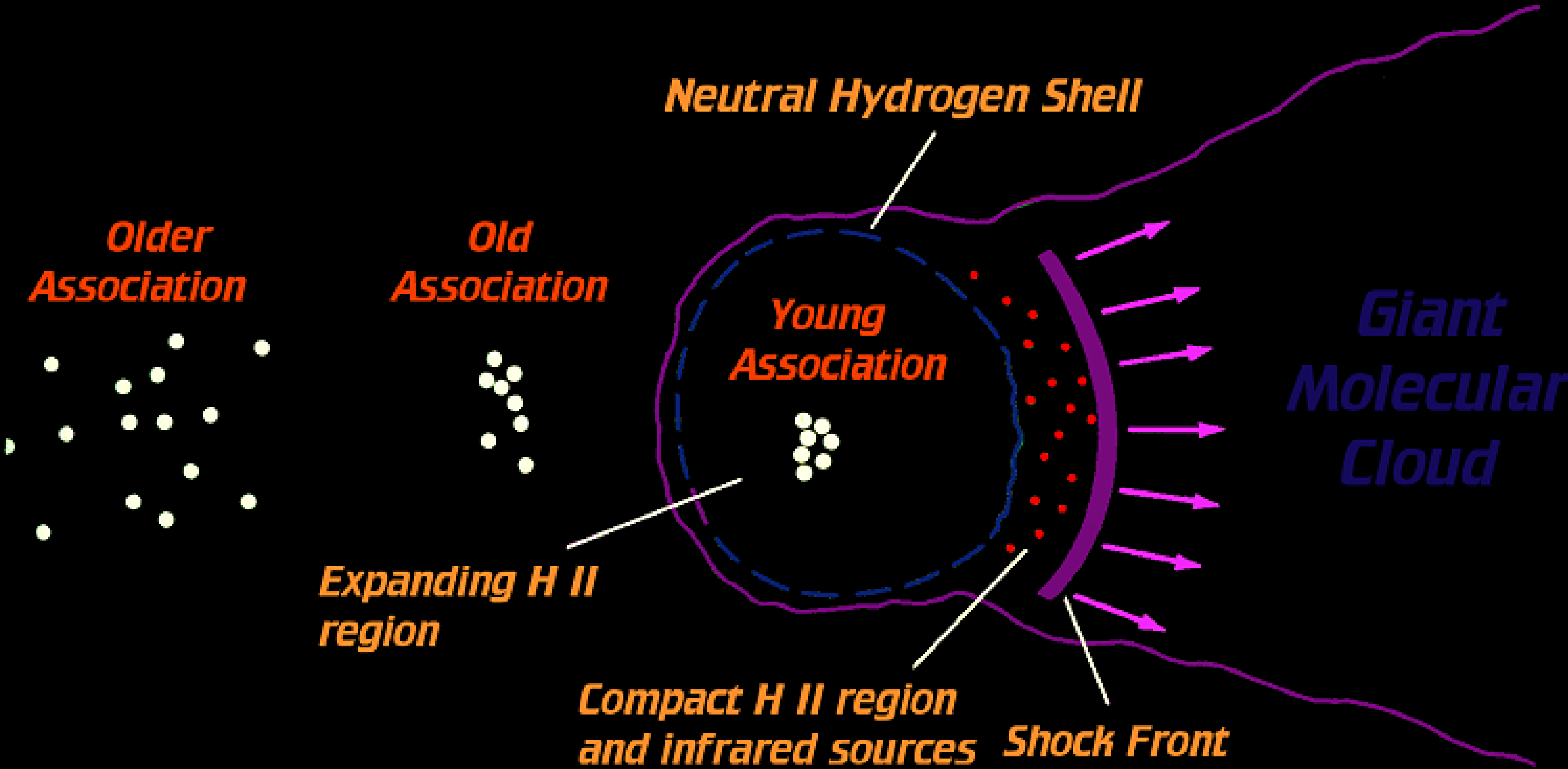
Whirlpool Galaxy, M51, NGC 5194/5

Canes Venatici, near Big Dipper handle

Distance: 31 million ly

Hubble Space

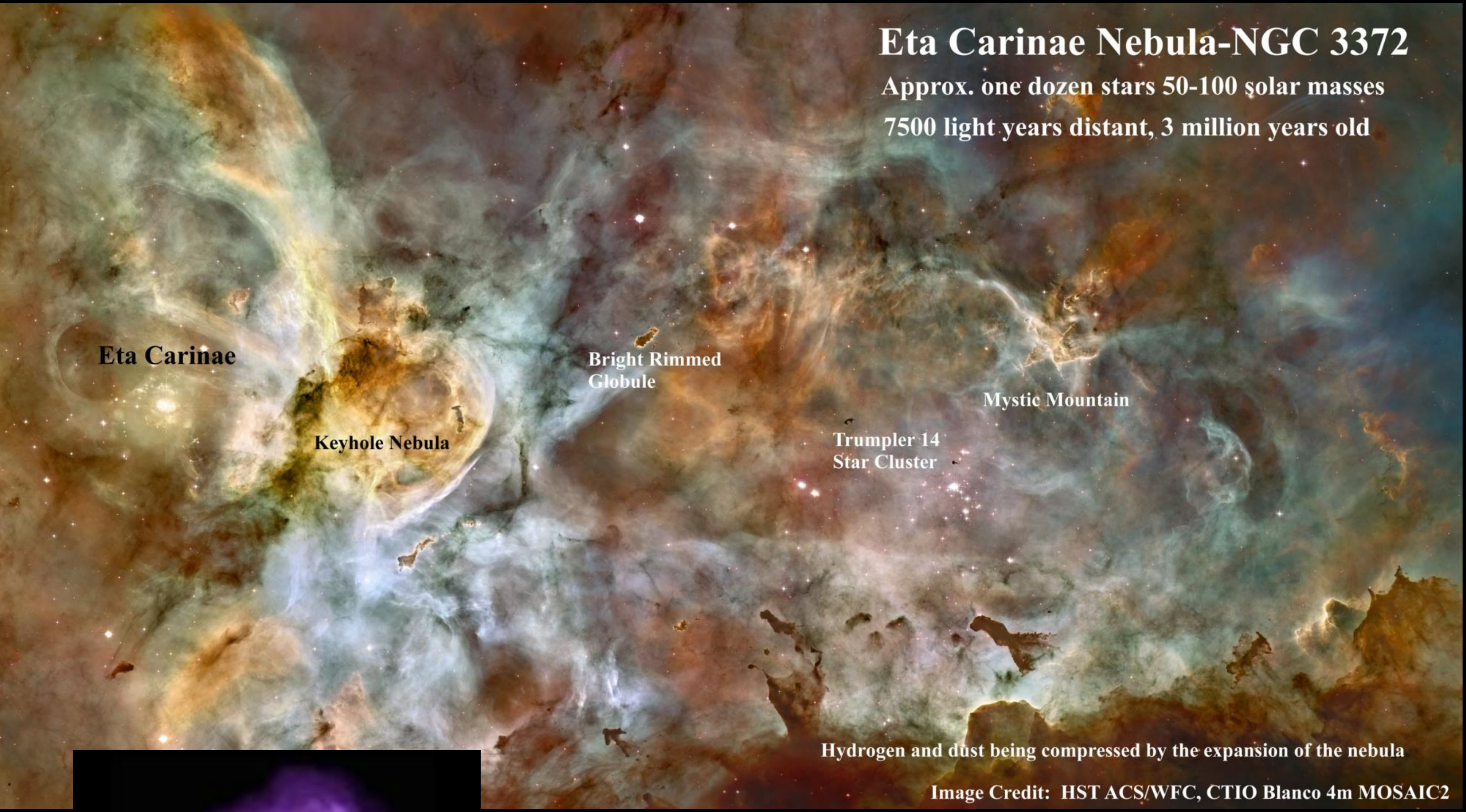
OB Associations



Eta Carinae Nebula

Carina the Keel, Southern Hemisphere

Image by Riccardi-Honders Veloce, Kalahari Desert, Namibia


Eta Carinae Nebula-NGC 3372
Approx. one dozen stars 50-100 solar masses
7500 light years distant, 3 million years old
Eta Carinae
Bright Rimmed Globule
Keyhole Nebula
Mystic Mountain
Trumpler 14 Star Cluster
Hydrogen and dust being compressed by the expansion of the nebula
Image Credit: HST ACS/WFC, CTIO Blanco 4m MOSAIC2

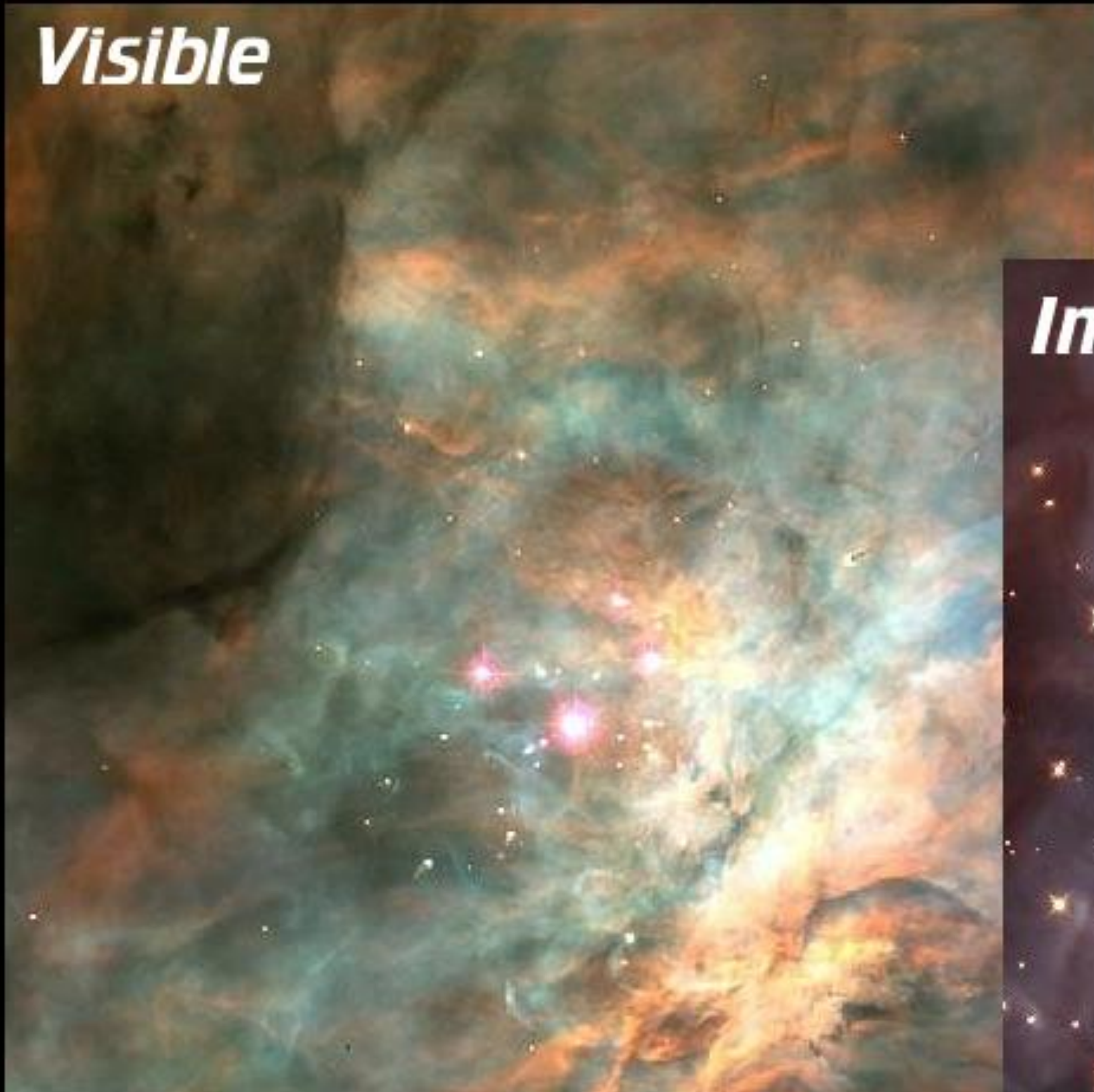

Stellar Birth in Orion

Running Man-M43

Orion Nebula-M42

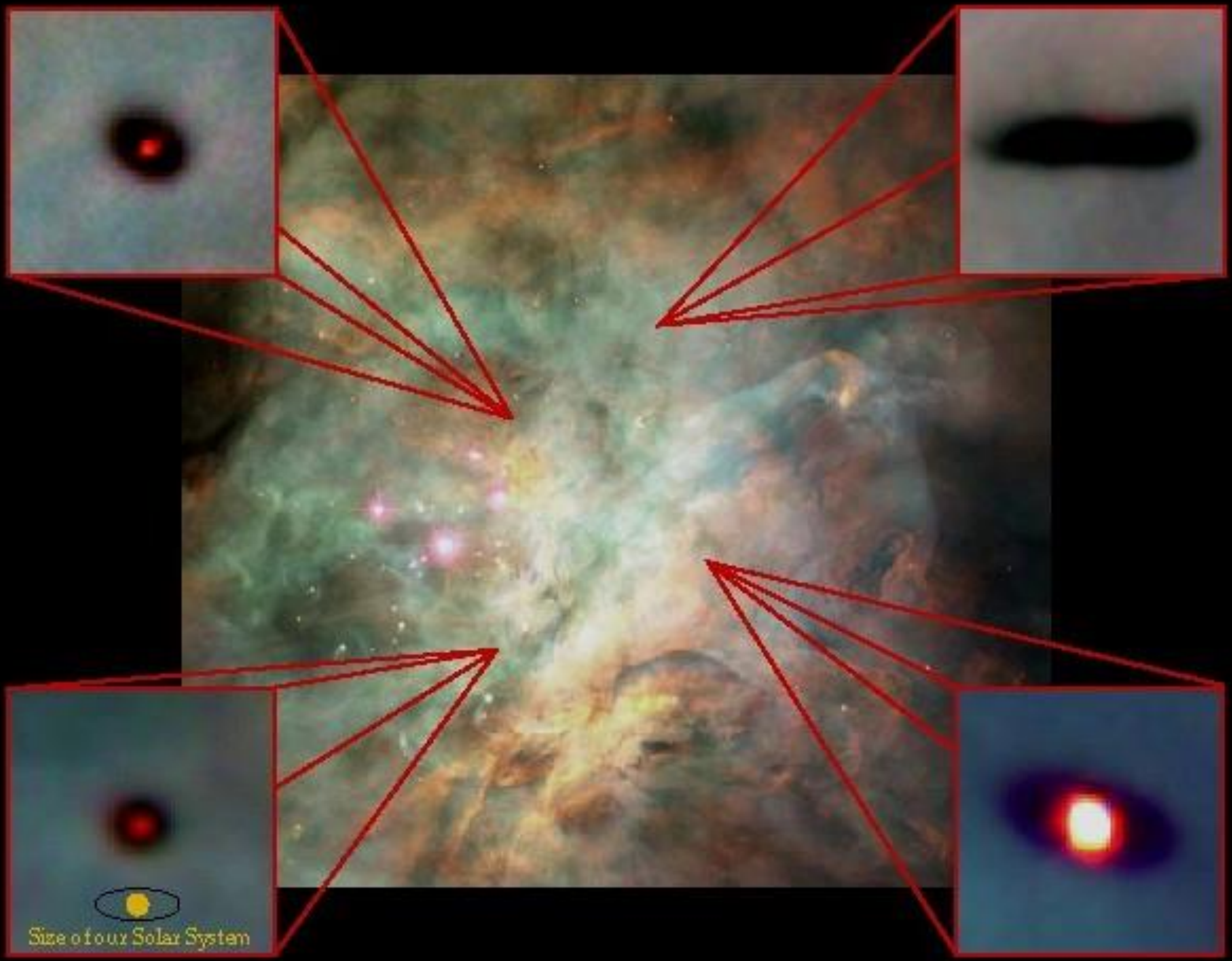

Trapezium
Hubble Photographs the Orion Nebula
Hubble Space

Trapezium

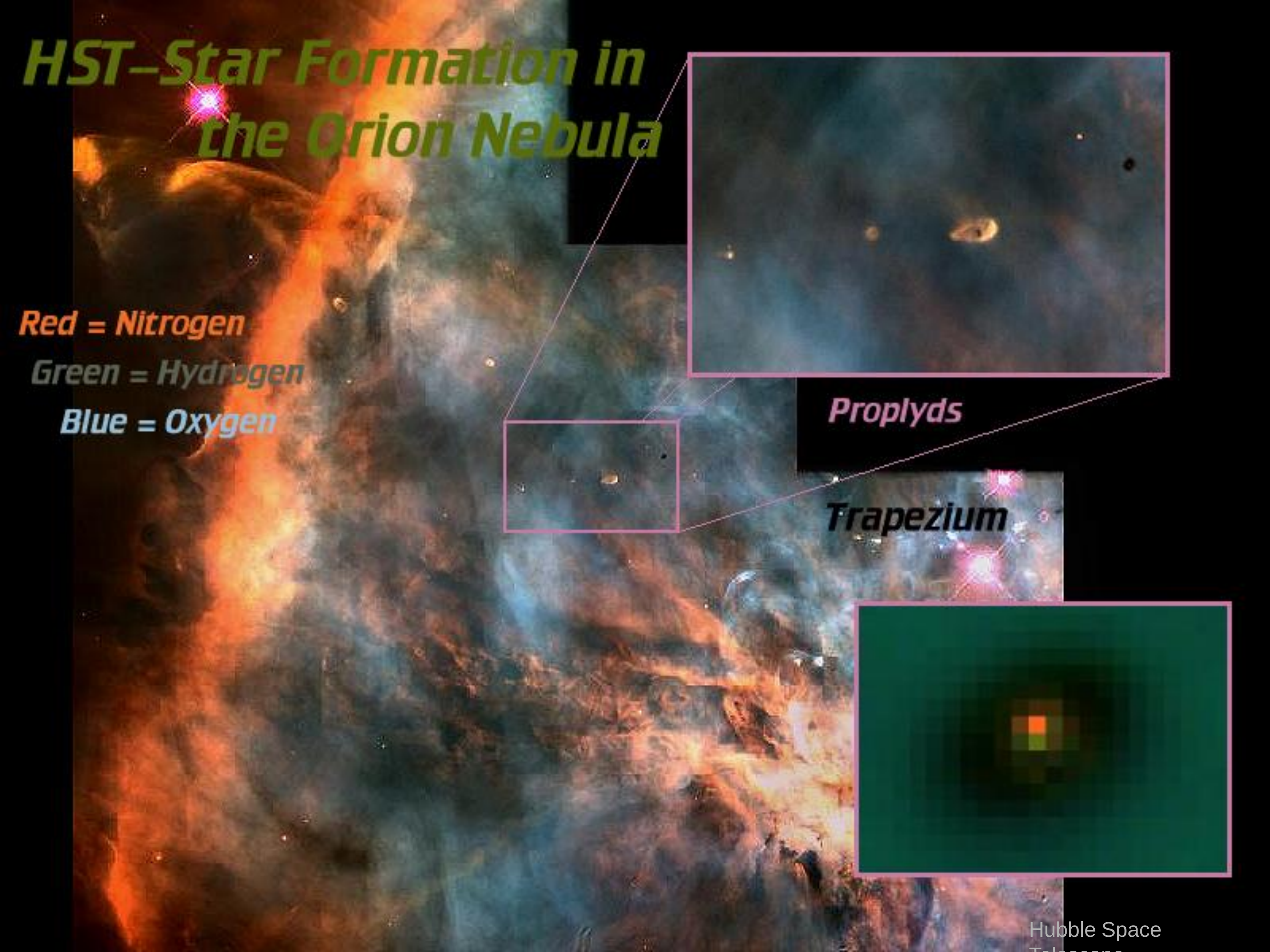


Hubble Space Telescope

Stellar Birth Near Trapezium



Hubble Space Telescope

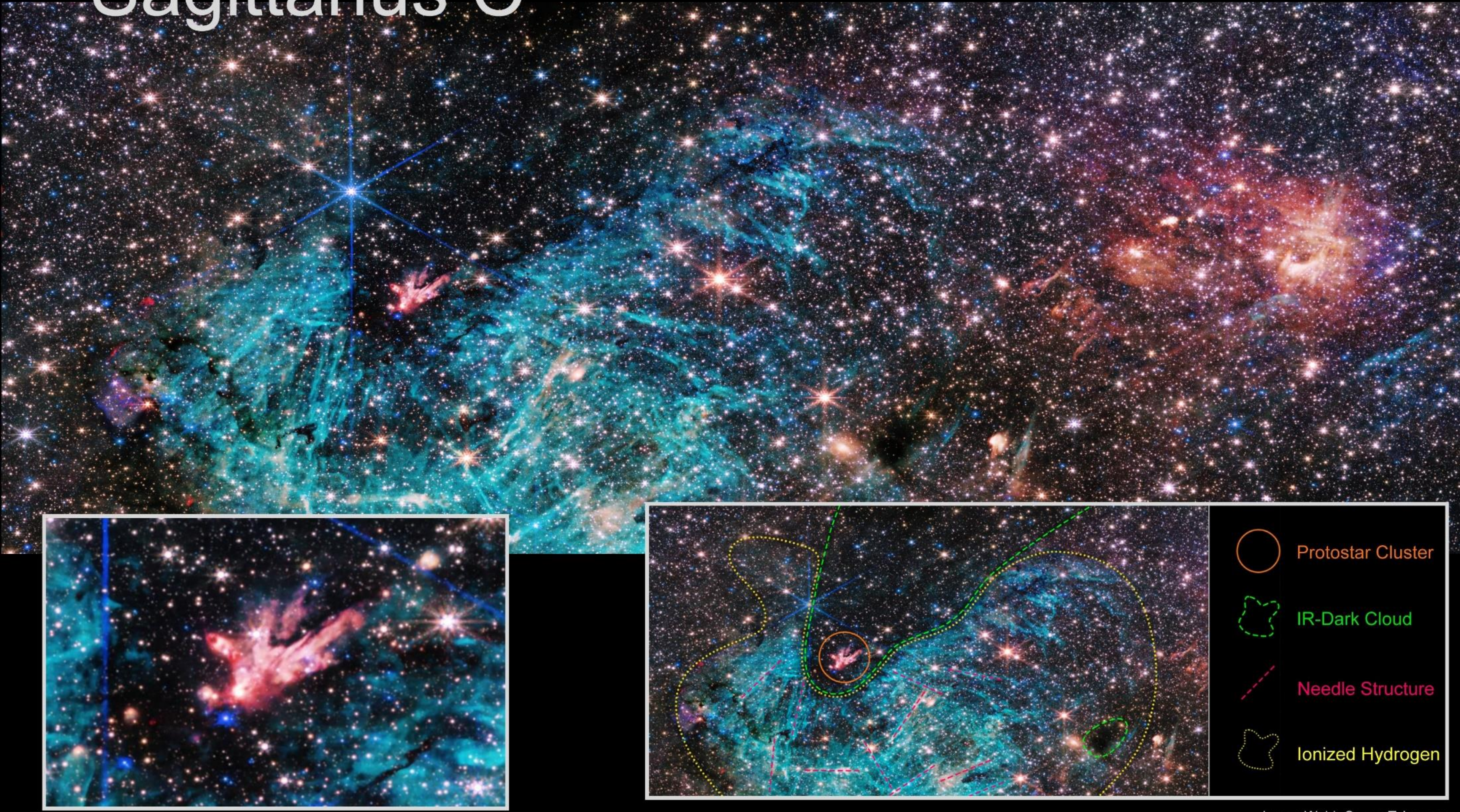


Hubble Space Telescope

Which one of these proplyds will become a star?

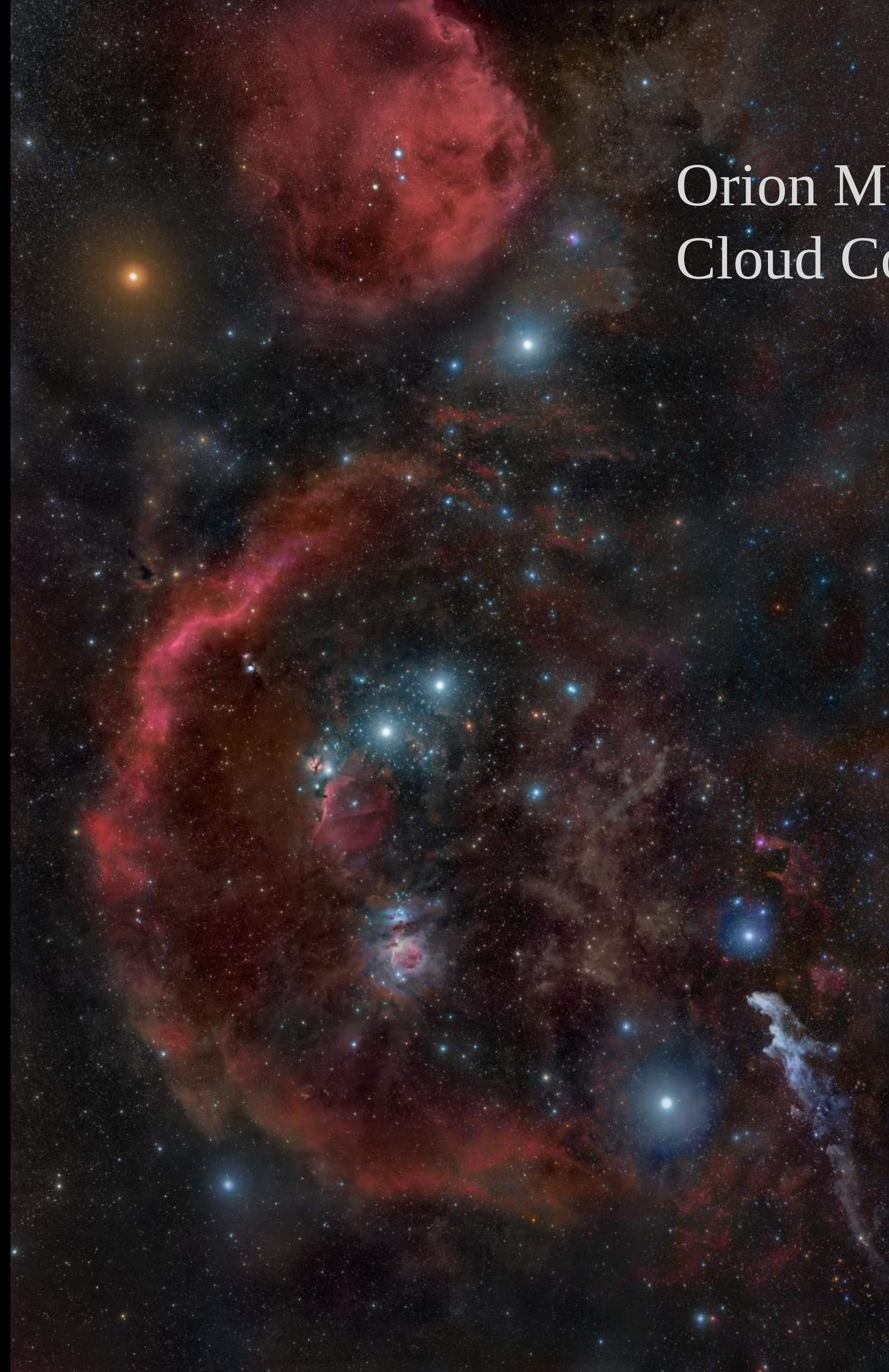
Sagittarius C

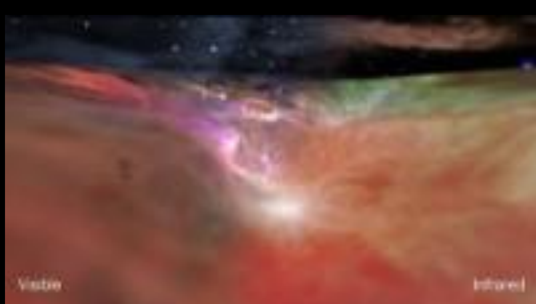
Center of the Milky Way Galaxy



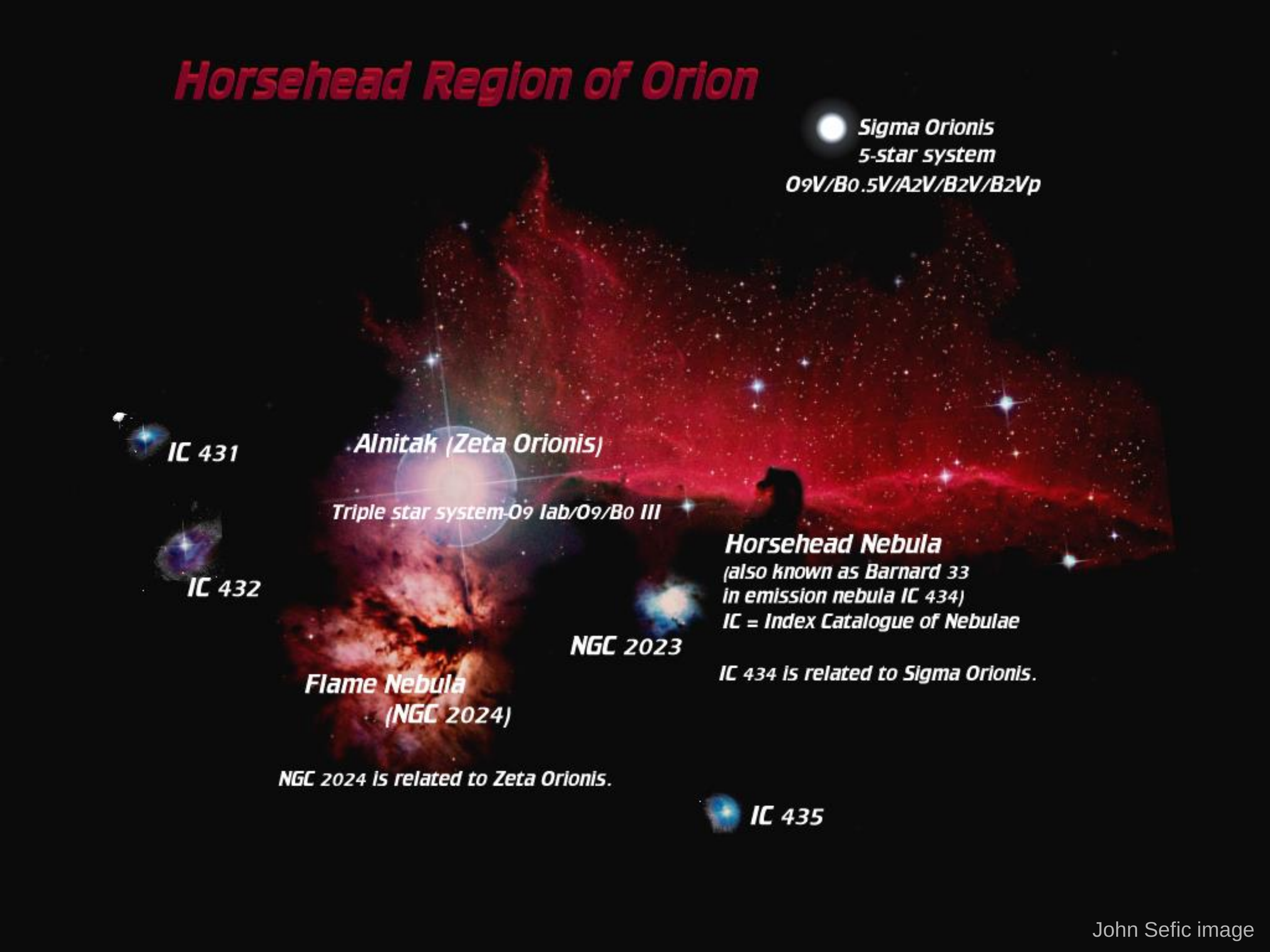
James Webb Space Telescope

Orion Molecular Cloud Complex

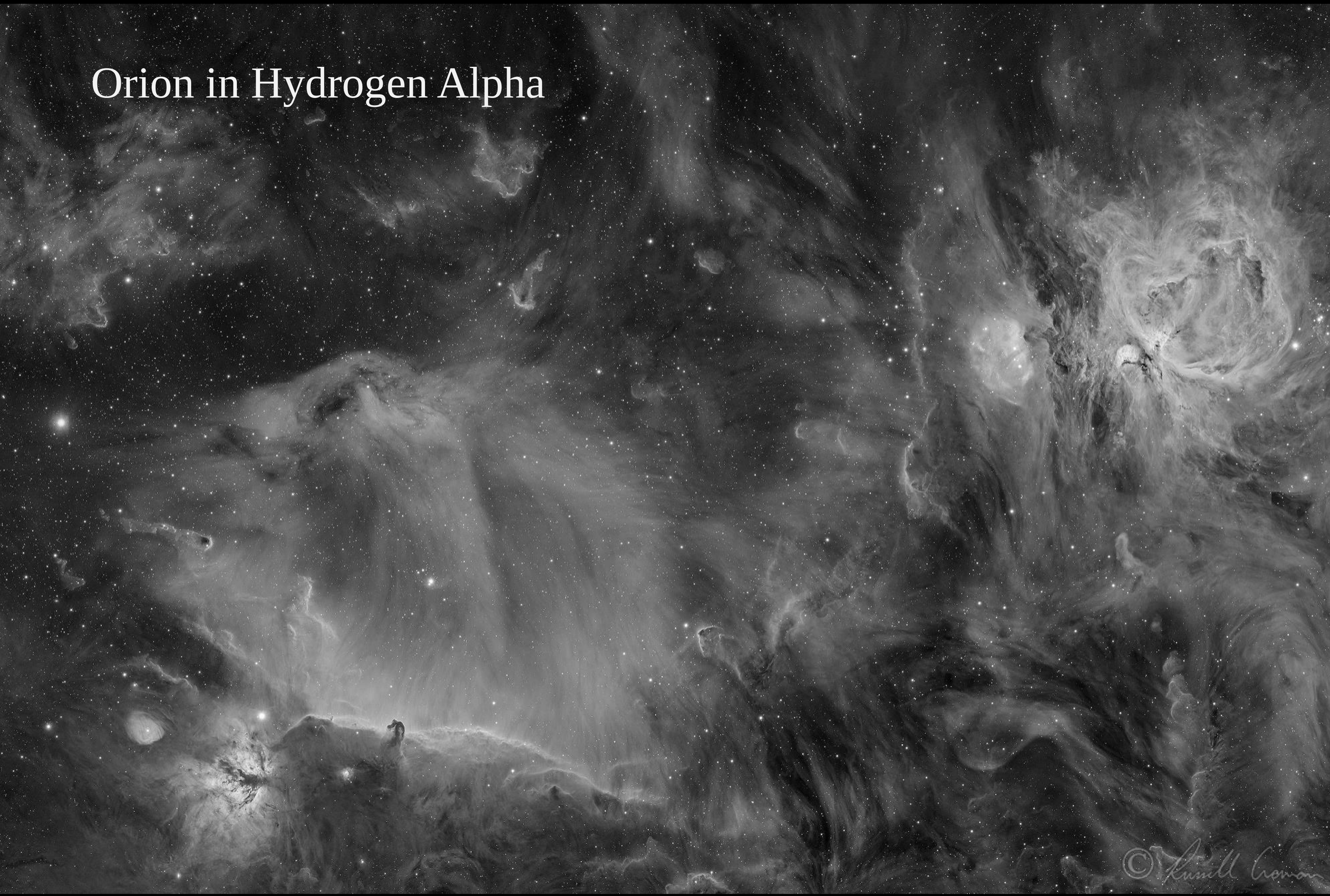




Rogelio Bernal Andreo


Horsehead Region of Orion
Sigma Orionis
5-star system
O9V/B0.5V/A2V/B2V/B2Vp
IC 431
Alnitak (Zeta Orionis)
Triple star system-O9 Iab/O9/B0 III
IC 432
Horsehead Nebula
(also known as Barnard 33
in emission nebula IC 434)
IC = Index Catalogue of Nebulae
NGC 2023
IC 434 is related to Sigma Orionis.
Flame Nebula
(NGC 2024)
NGC 2024 is related to Zeta Orionis.
IC 435
John Sefic image

Orion in Hydrogen Alpha



Russell Croman photography

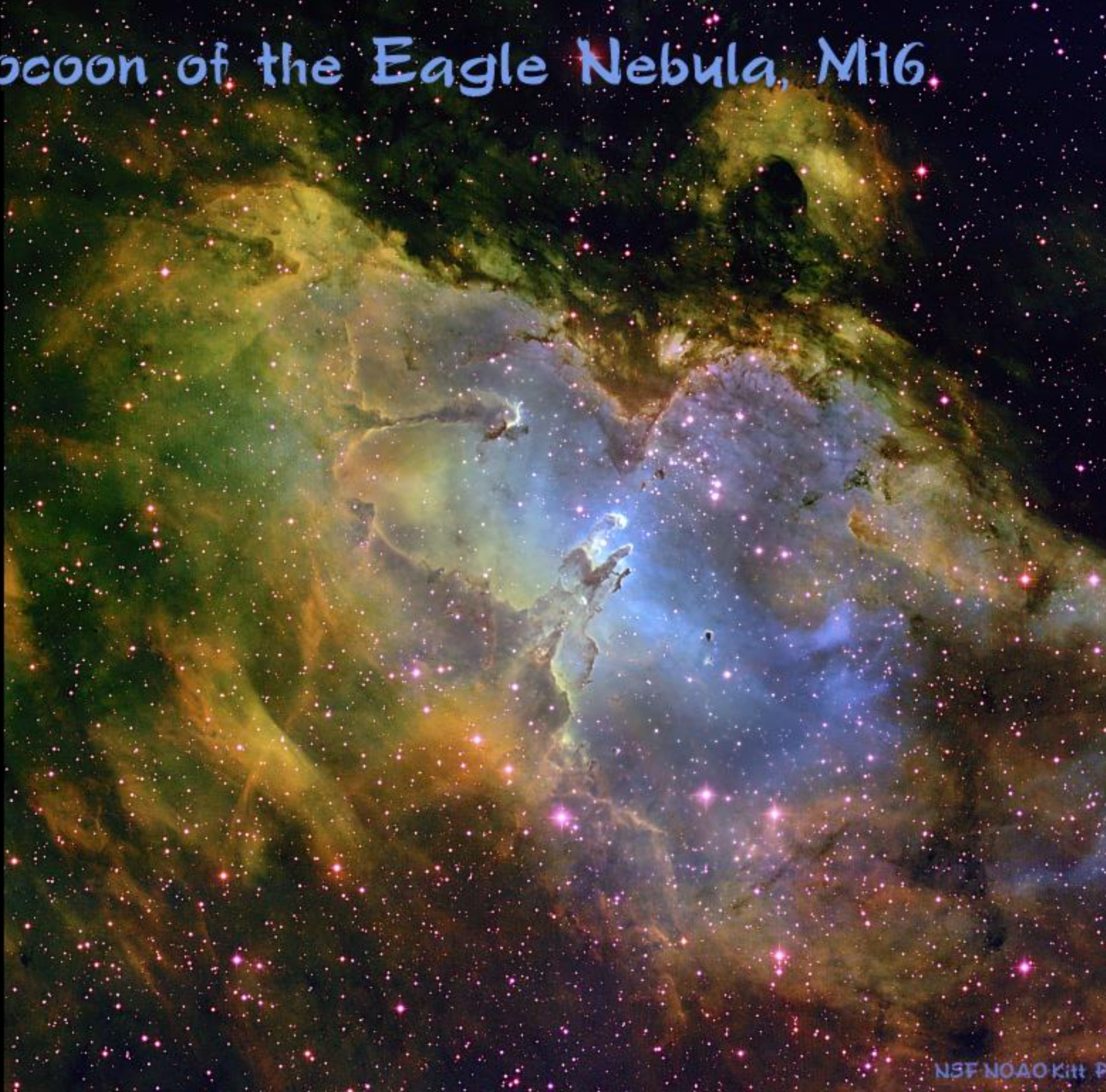
Horsehead
Nebula

Barnard 33

Horsehead

Orion, the Hunter

The Cocoon of the Eagle Nebula, M16



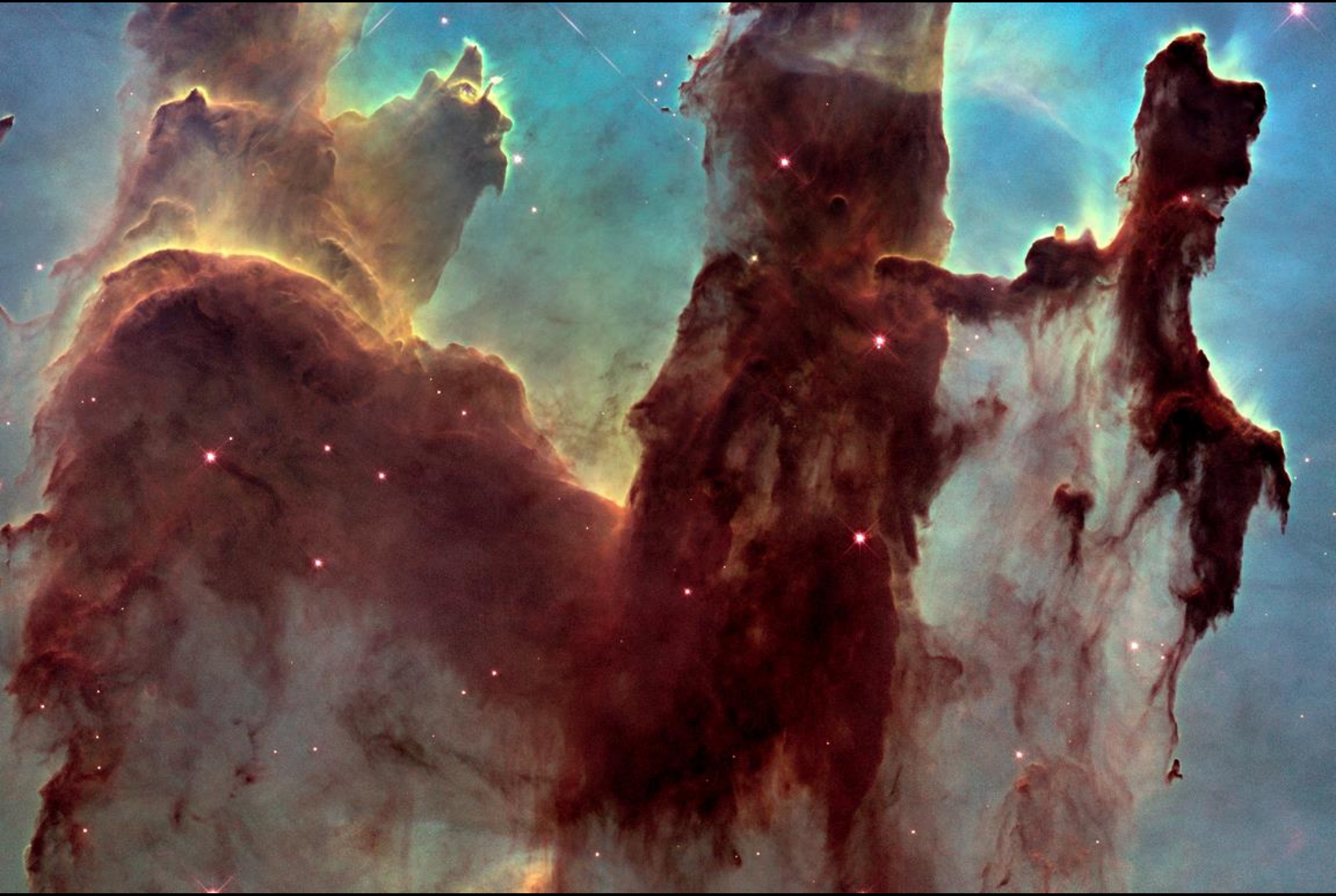
NSF NOAO Kitt Peak image

Eagle Interior

NSF-NOAO-Kitt Peak image

Pillars of Creation/Visible

Pillars of Creation/Infrared

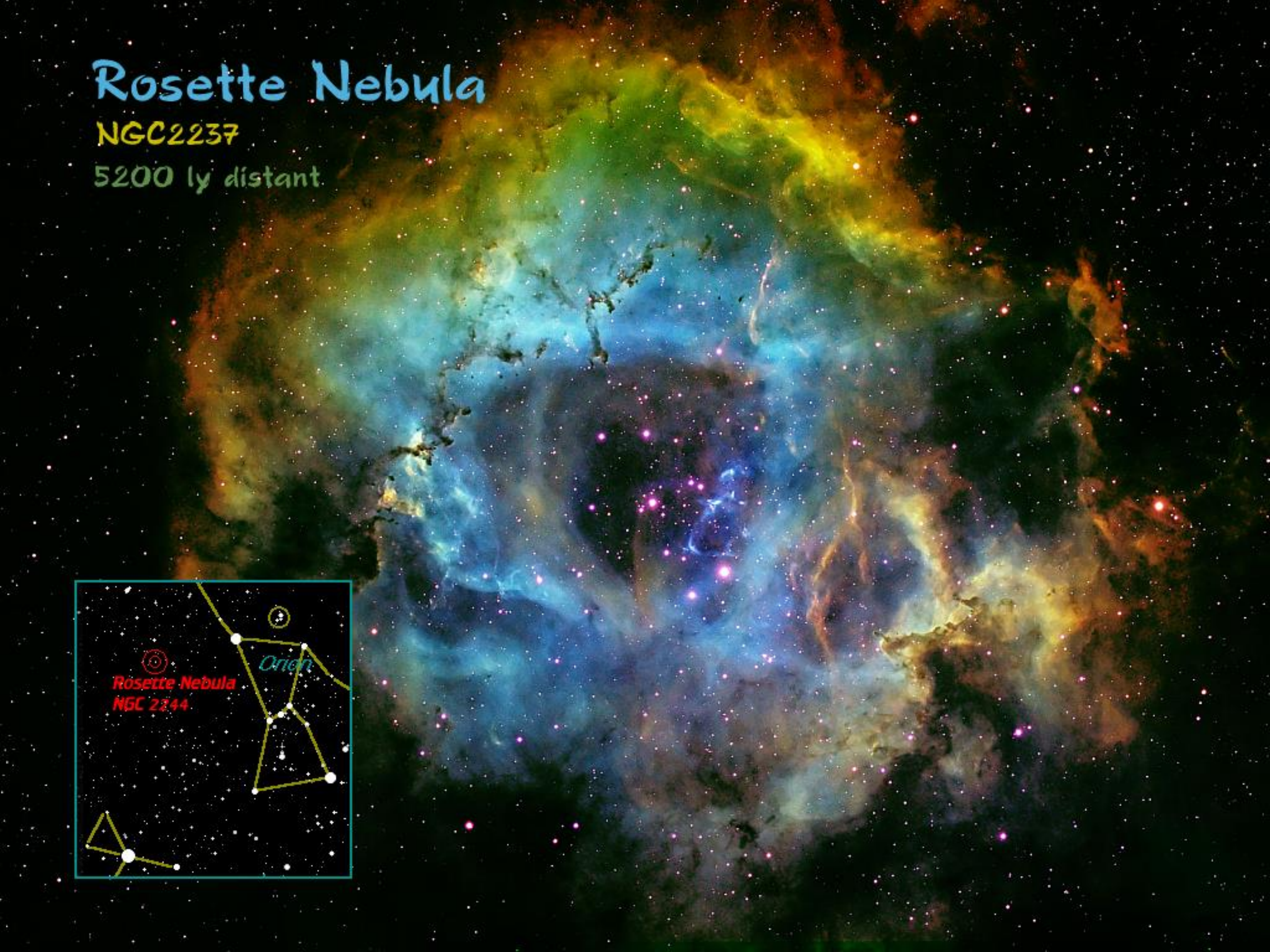


Hubble Space Telescope image

Hubble Space Telescope image

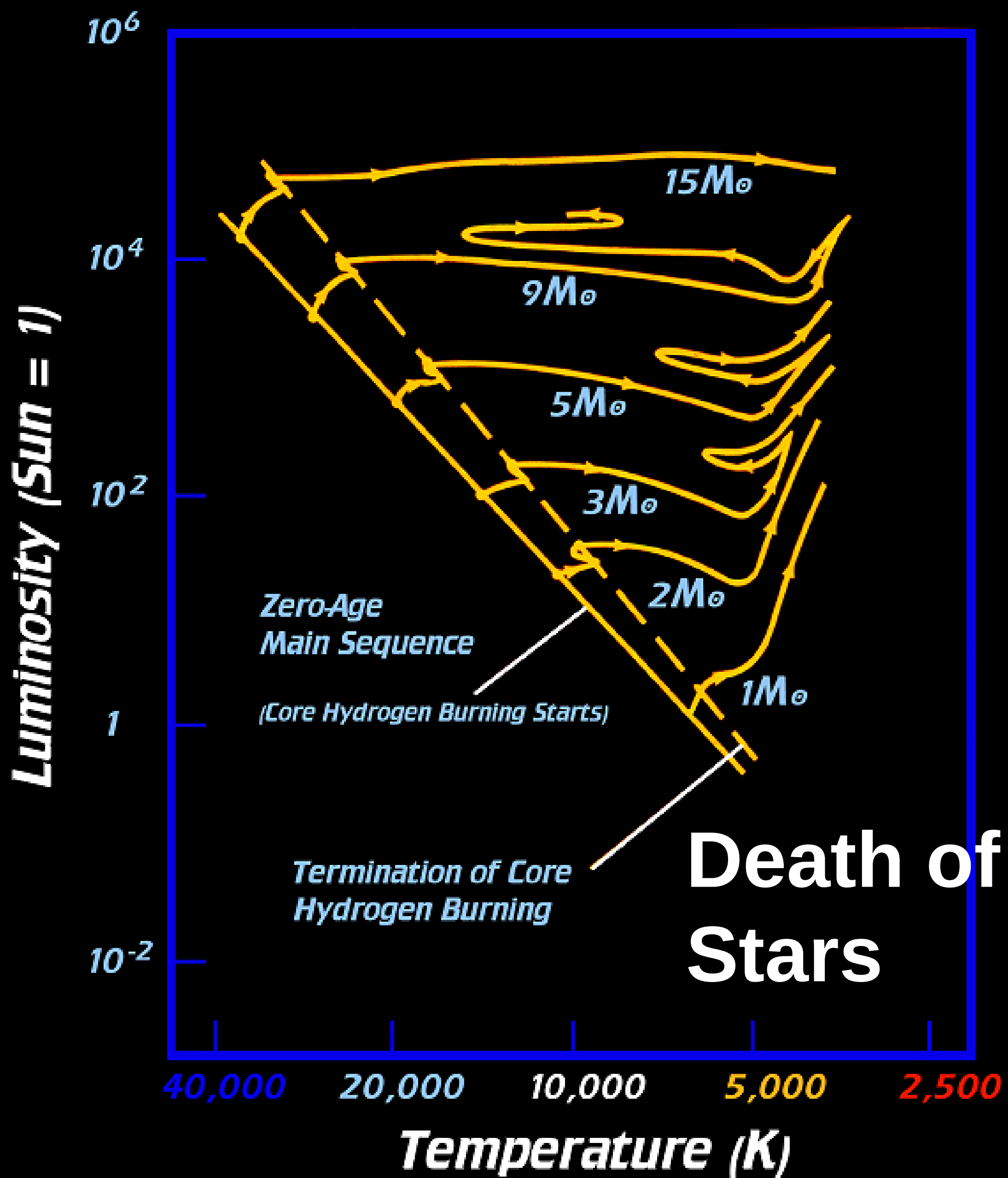
Hubble Space Telescope image


Eagle Nebula in the Infrared
NASA's Spitzer Space Telescope
The Pillars of Creation probably no longer exist because they have been disrupted by the advancing supernova debris.
Red-Coolest: From supernova blast 8-9000 ly distant, headed towards Eagle and Pillars
Pillars of Creation, 7000 ly distant, Eagle Nebula, M16
Temperature/Wavelength
644K/700°F 4.5 microns 4,500 nm HOTTEST
362K/192°F 8 microns 8,000 nm MIDDLE
121K/-242°F 24 microns 24,000 nm COOLEST
Gary A. Becker slide

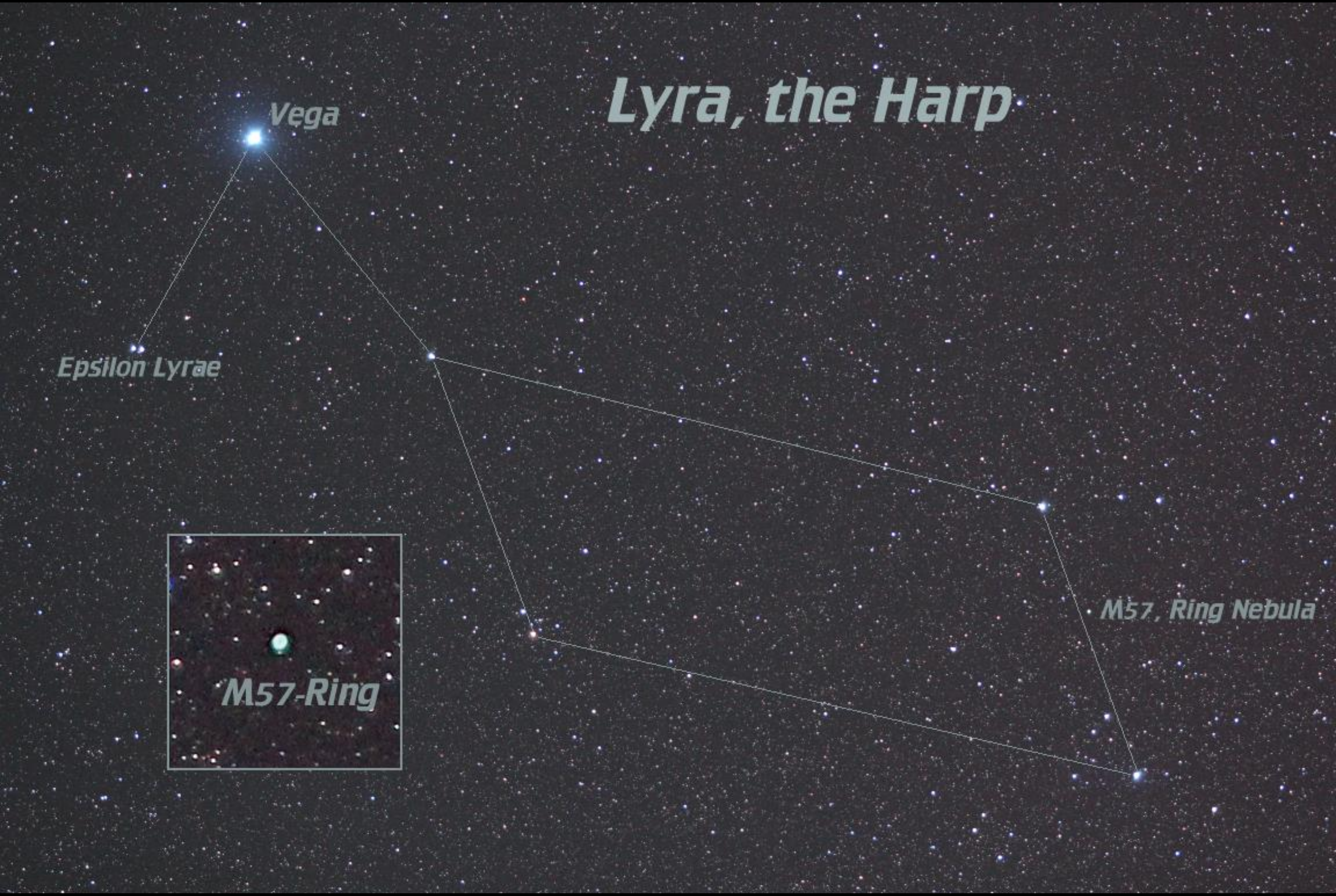

Rosette Nebula
NGC2237
5200 ly distant
Orion
Rosette Nebula
NGC 2244

Hubble Space Telescope

Influence of Mass on the Evolution of Stars



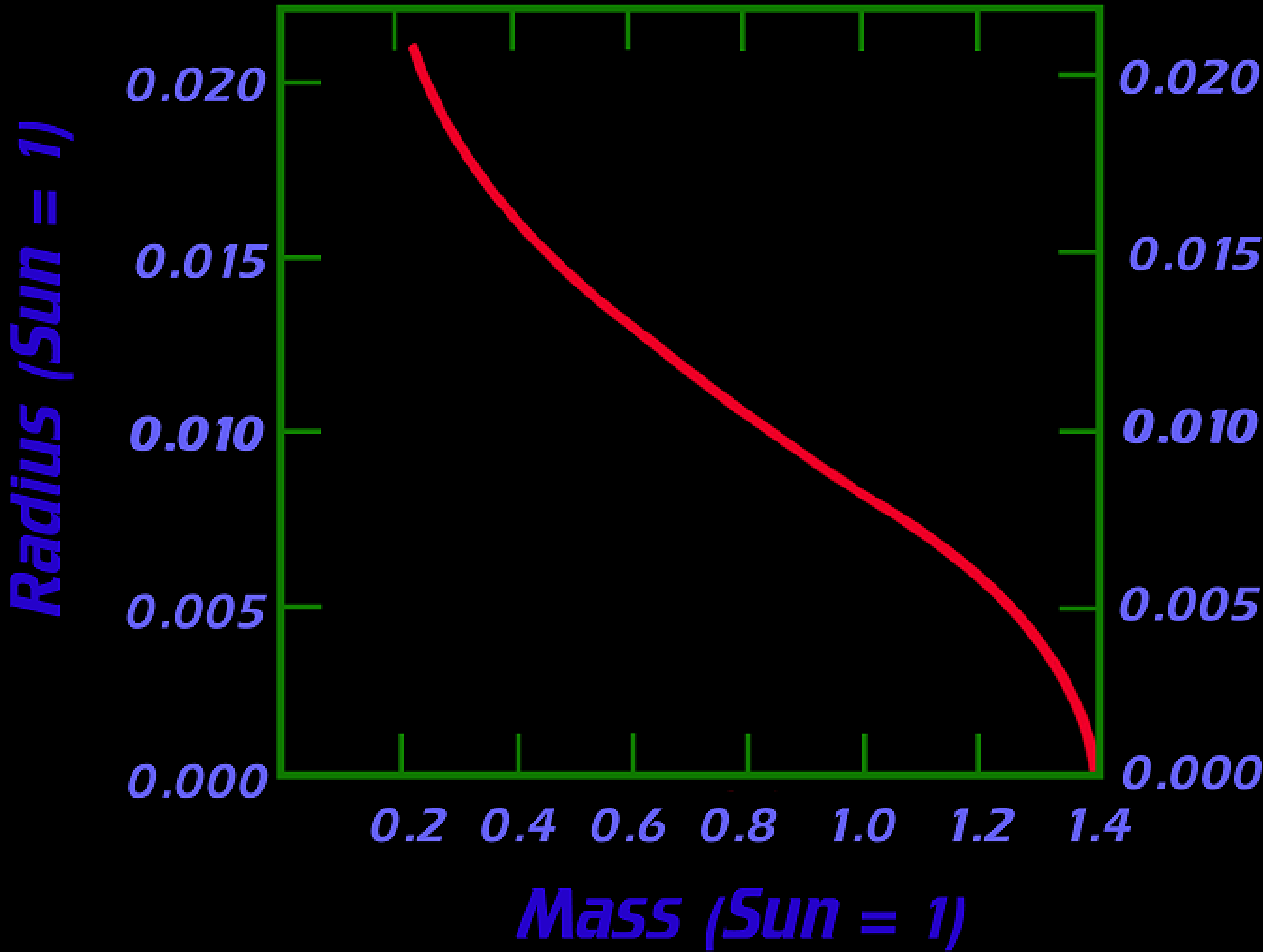
Death of Low Mass Stars



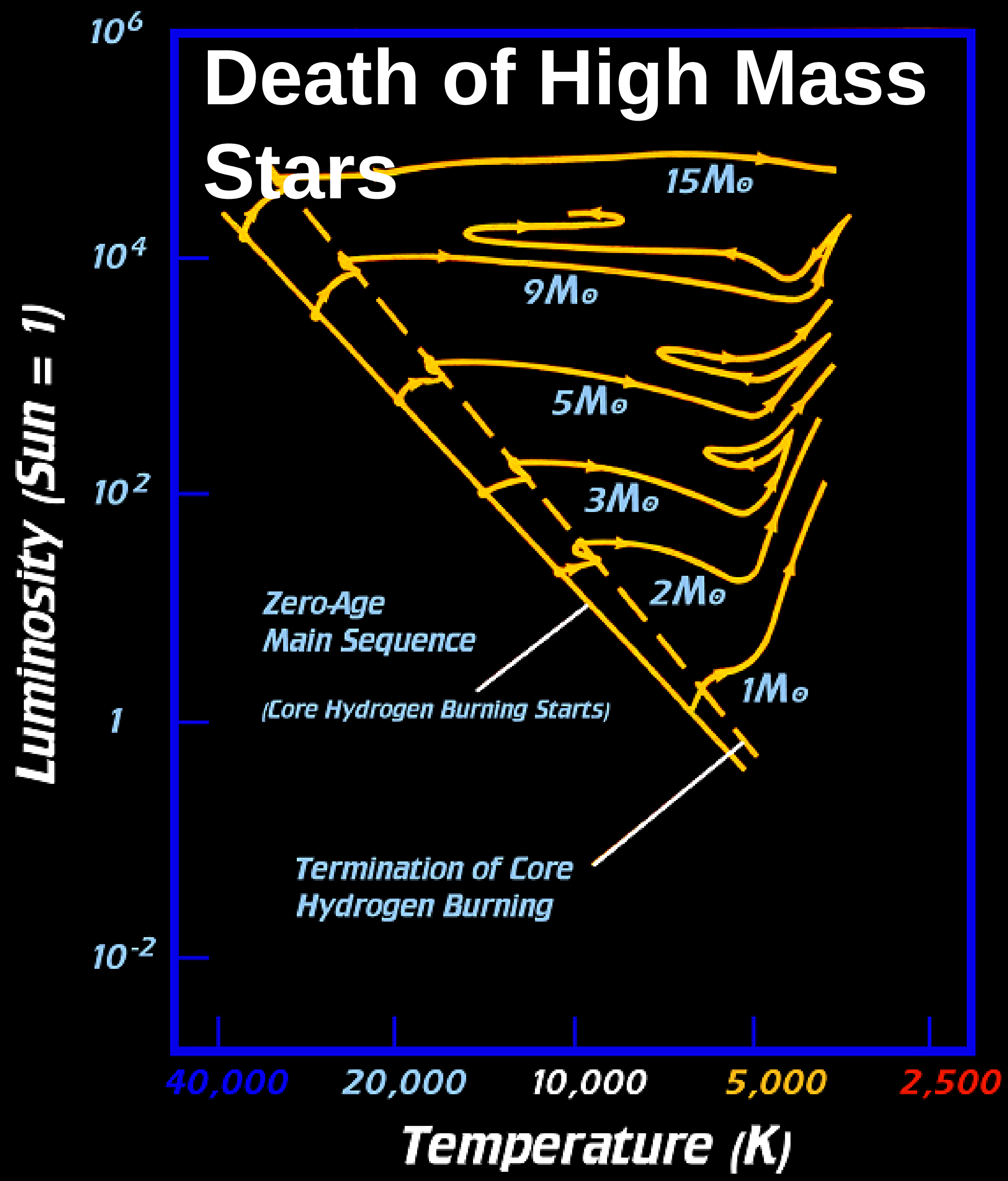
Gary A. Becker image


Ring Nebula
M57
Lyra,
the Harp
Hubble Space

Mass/Radius of White Dwarfs

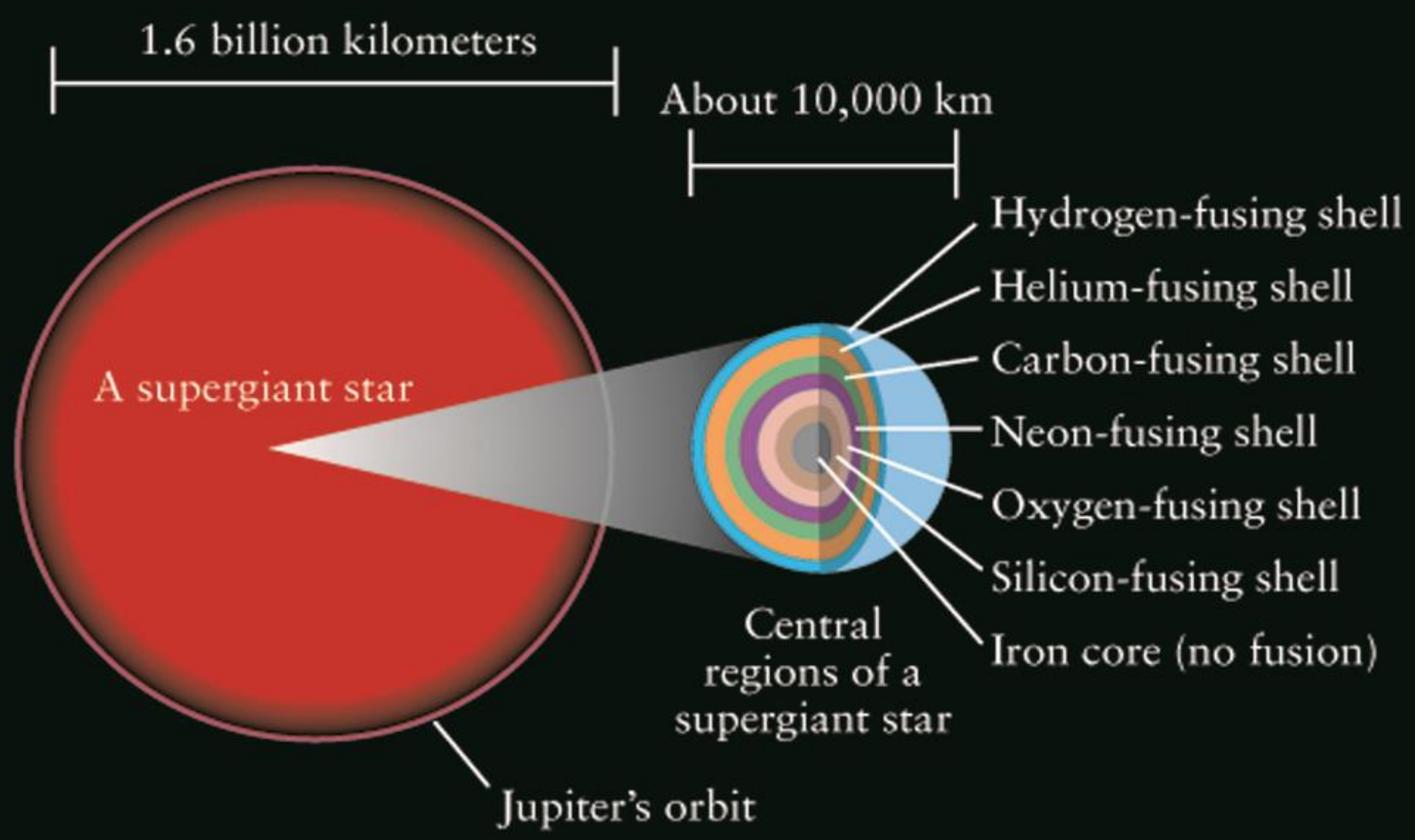


Death of High Mass Stars

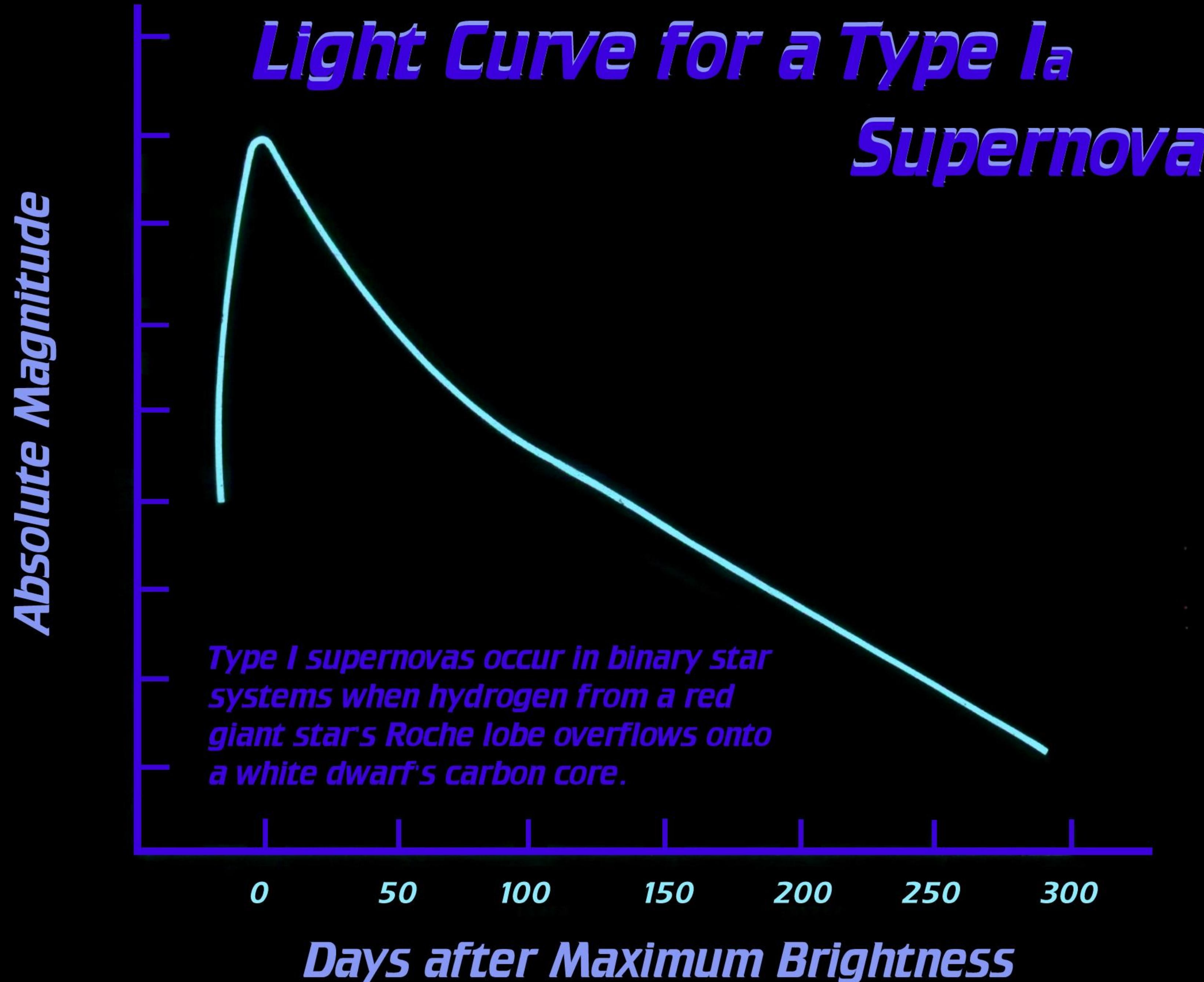


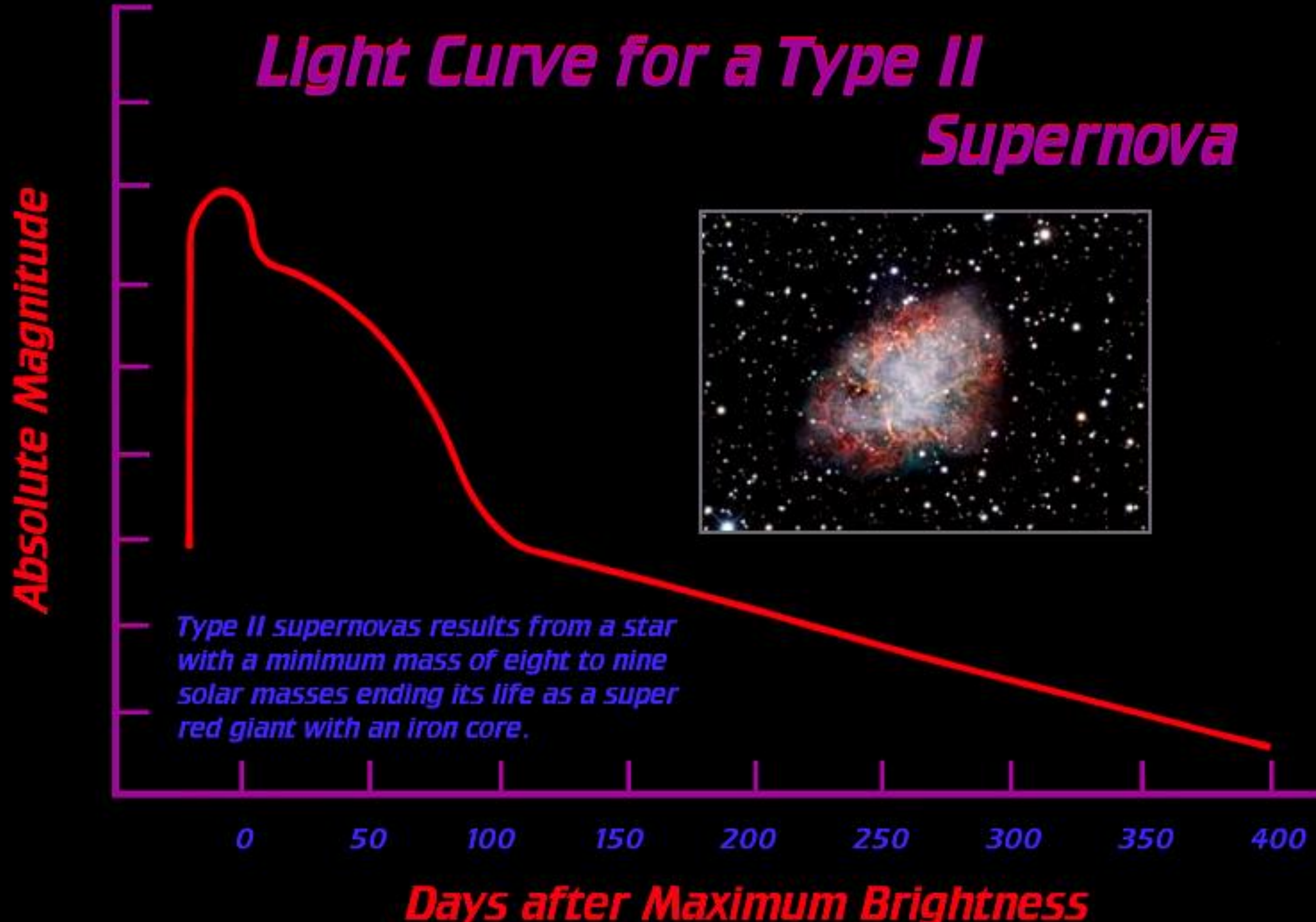
Influence of Mass on the Evolution of Stars

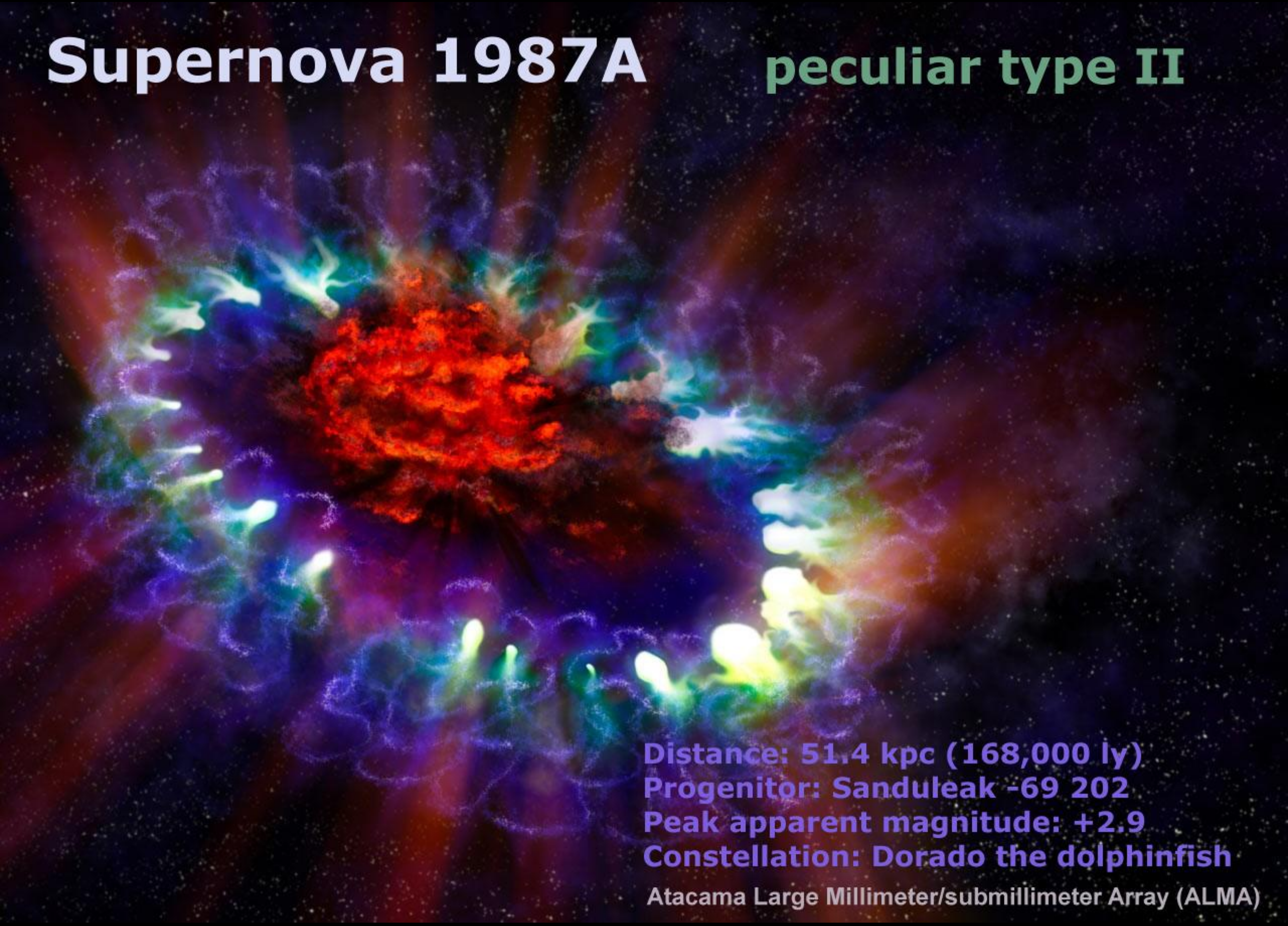
Core of a Red Supergiant ready to



University of Alberta,

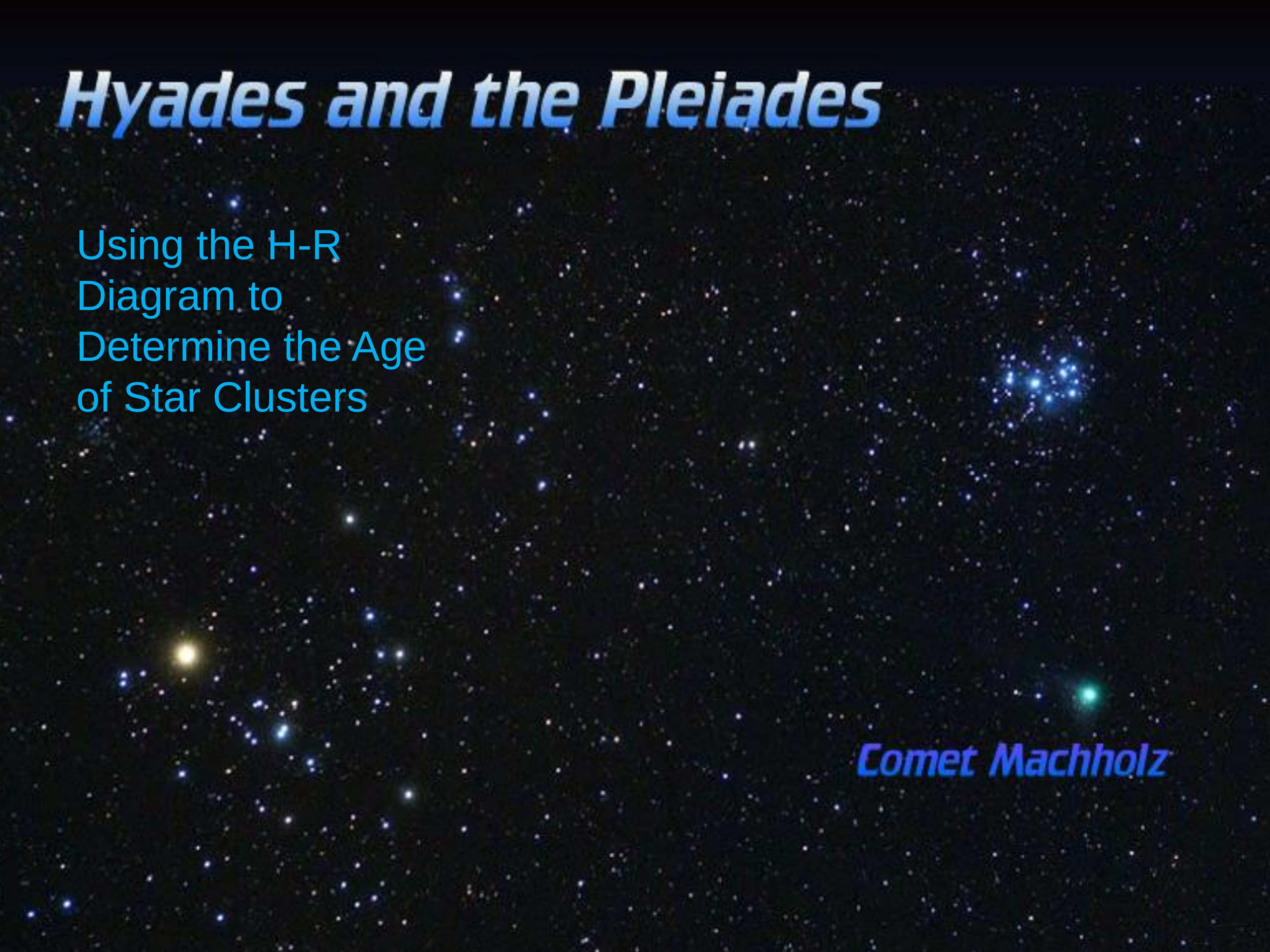

Light Curve for a Type Ia Supernova
Absolute Magnitude
Type I supernovas occur in binary star systems when hydrogen from a red giant star's Roche lobe overflows onto a white dwarf's carbon core.
0
50
100
150
200
250
300
Days after Maximum Brightness


Light Curve for a Type II Supernova
Absolute Magnitude
Type II supernovas results from a star with a minimum mass of eight to nine solar masses ending its life as a super red giant with an iron core.
0
50
100
150
200
250
300
350
400
Days after Maximum Brightness

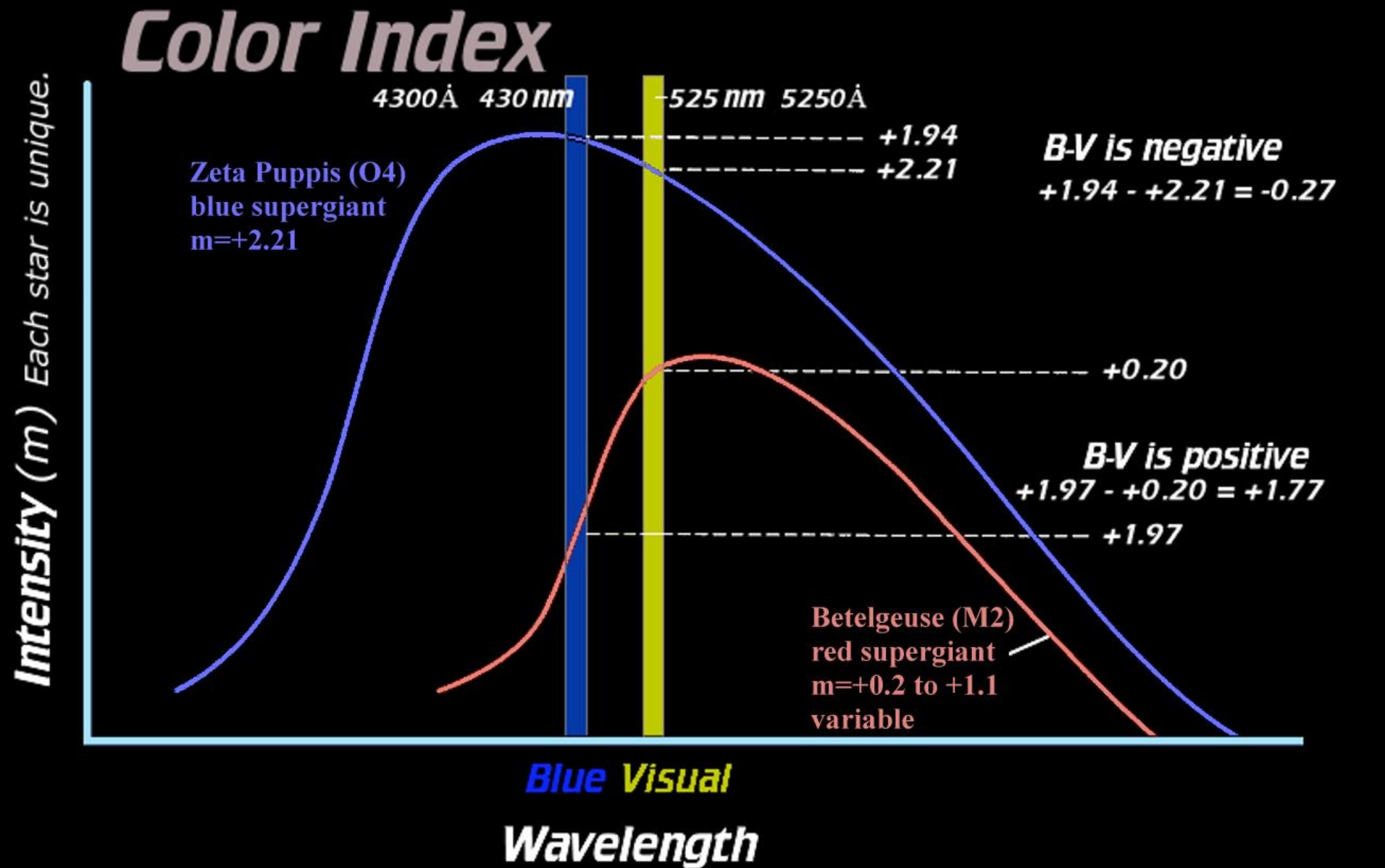

Supernova 1987A
peculiar type II
Distance: 51.4 kpc (168,000 ly)
Progenitor: Sanduleak -69 202
Peak apparent magnitude: +2.9
Constellation: Dorado the dolphinfish
Atacama Large Millimeter/submillimeter Array (ALMA)

Hyades and the Pleiades

Using the H-R Diagram to Determine the Age of Star Clusters

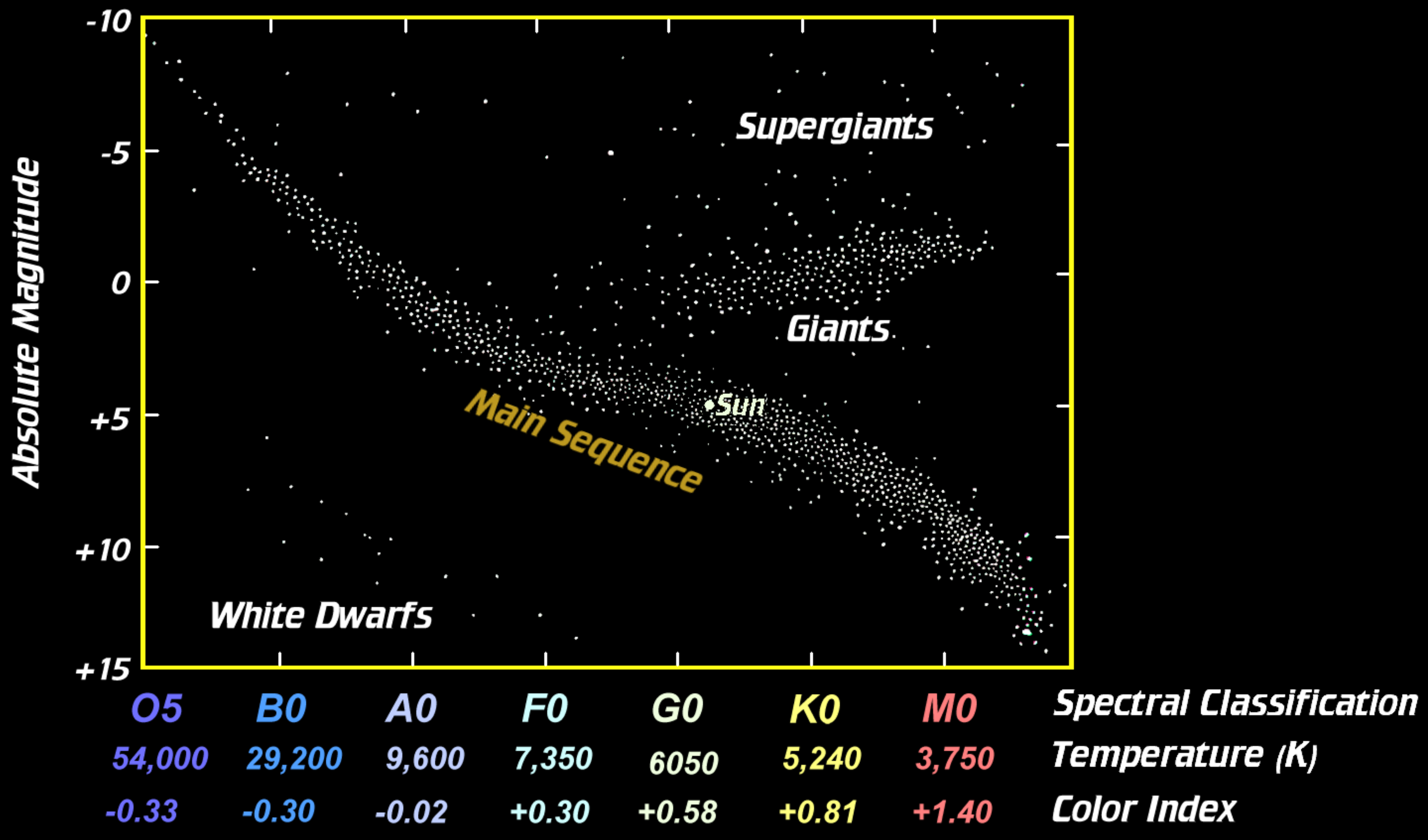


Temperature	50,000 K	25,000 K	10,000 K	7,500 K	6,000 K	4,800 K	3,700 K
Sp Class	O5V	B0V	A0V	F0V	G0V	K0V	M0V
Co Index (UBV)	-0.33	-0.30	-0.02	+0.30	+0.58	+0.81	+1.40



Adapted by Gary A. Becker

Hertzsprung-Russell Diagram



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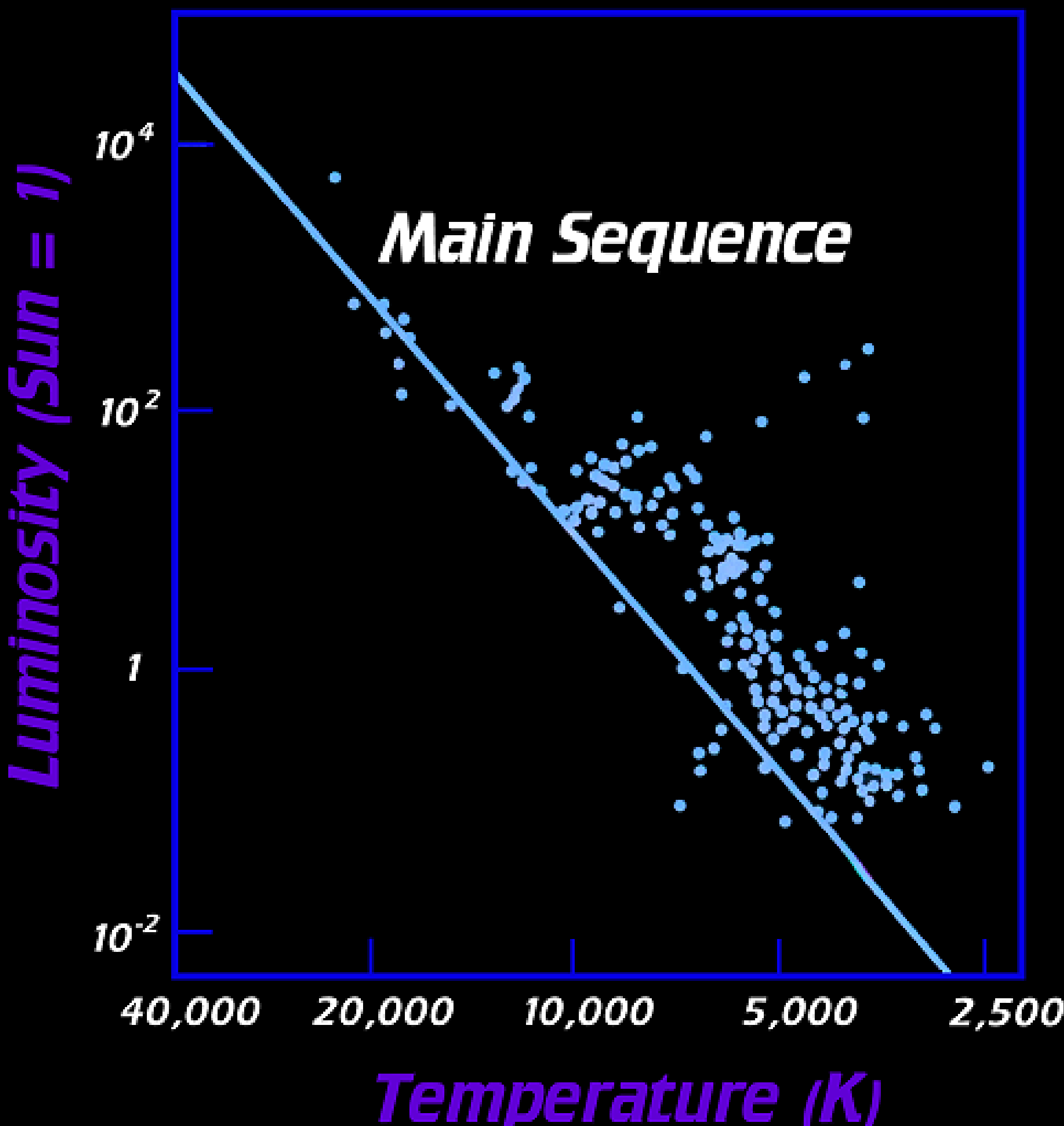
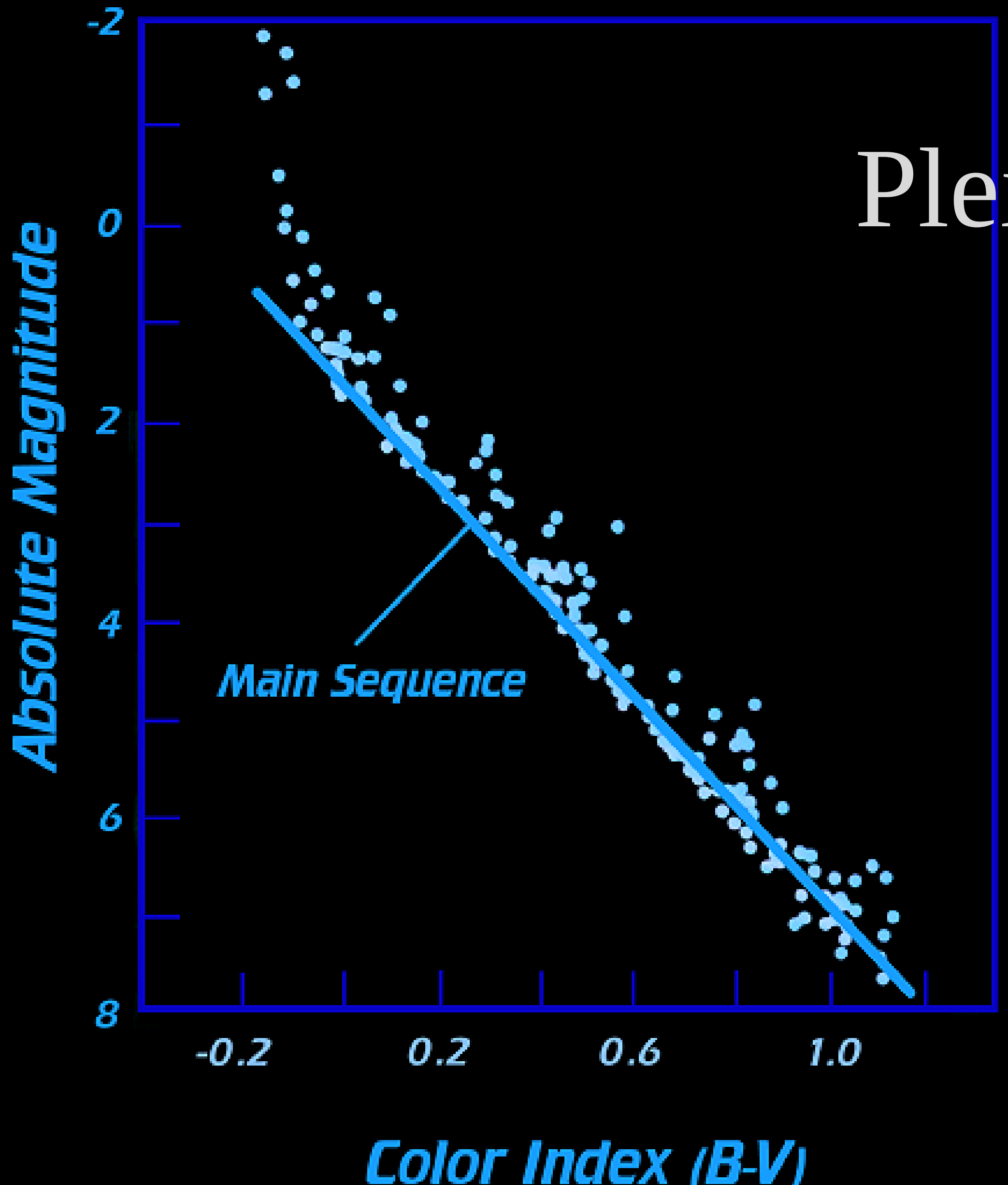
NGC 2264 Young or Old Star Cluster?



Michael-Caligiuri

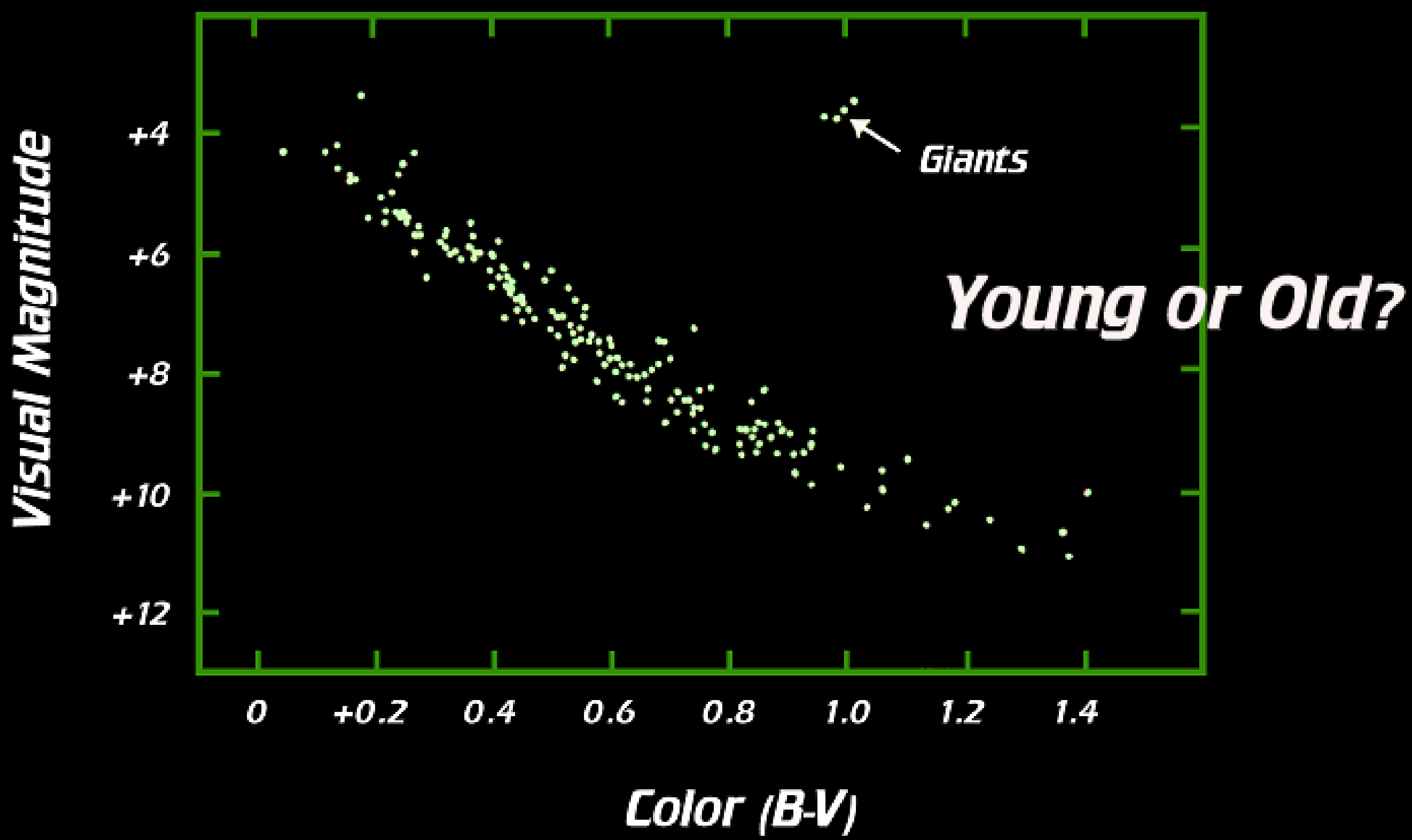
Young or Old Cluster?



Pleiades

Pleiades- M45/Taurus, the Bull

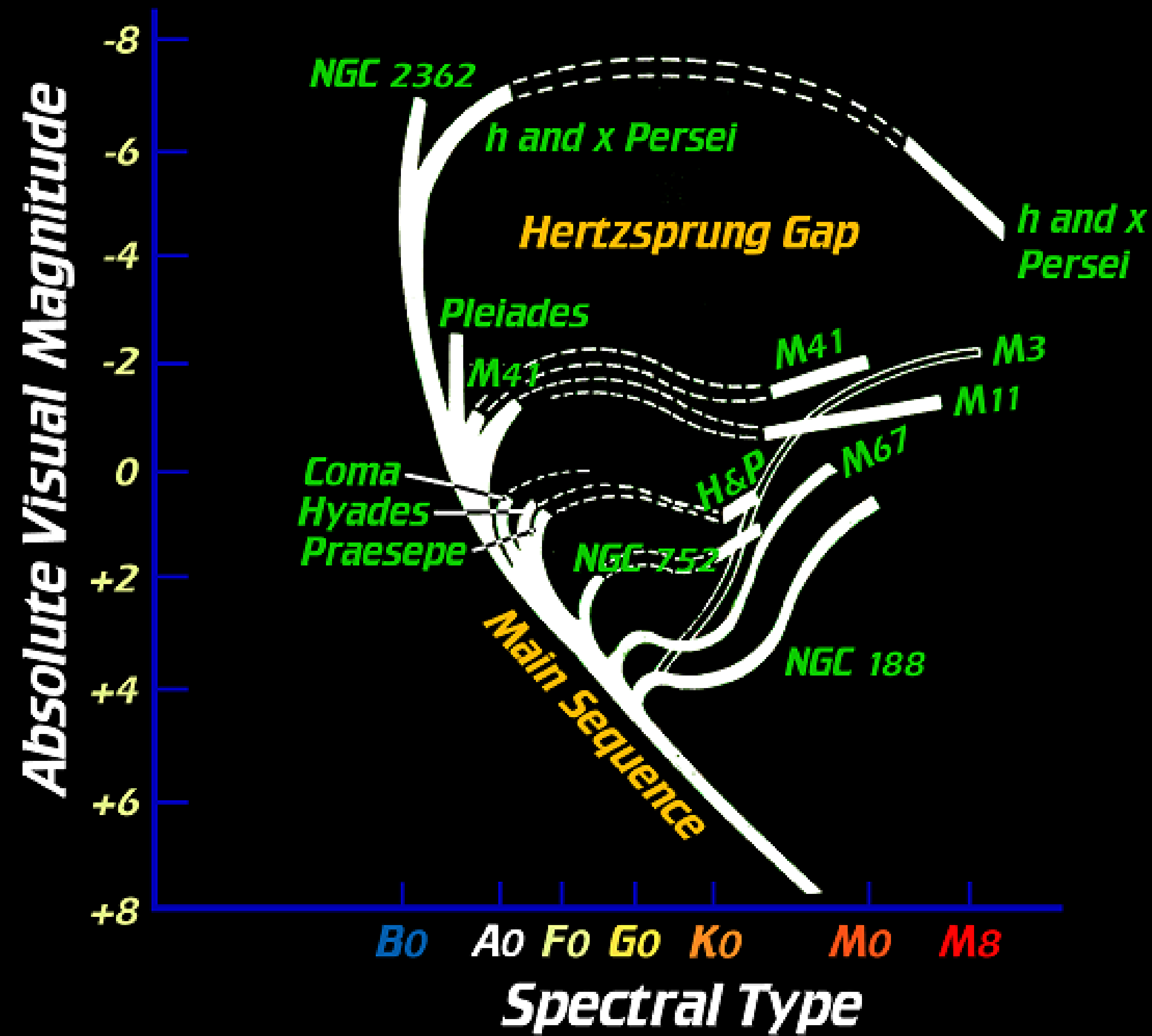
Color-Magnitude Diagram for the Hyades



Pleiades-Hyades Star Clusters

Rogelio Bernal Andreo image

H-R Age Sequence Diagram for Clusters



The End

Finding the Age of Star Clusters Using the Hertzsprung-Russell Diagram

Characteristics of Main Sequence Stars

Class	Mass in Comparison to Sun	Contraction to Zero Age Main Sequence Not well known	Surface Temp. (K)	Luminosity compared to sun	M Absolute Magnitude	Years on Main Sequence	Radius in suns
O6 mid	29.5 blue supergiant	10 Th	45,000	140,000	-4.0	2 M	6.2
O9 late	22.6	100 Th	37,800	55,000	-3.6	4 M	4.7
B2 early	10.0	400 Th	21,000	3,190	-1.9	30 M	4.3
B5 mid	5.46	1 M	15,200	380	-0.4	140 M	2.8
A0 early	2.48	4 M	9,600	24	+1.5	1 B	1.8
A7 late	1.86	10 M	7,920	8.8	+2.4	2 B	1.6
F2 early	1.46	15 M	7,050	3.8	+3.8	4 B	1.3
G2 sun	1.00	20 M	5,800	1.00	+4.83	10 B	1.0
K7 late	0.53	40 M	4,000	0.11	+8.1	50 B	0.7
M8 late	0.17 minimum	100 M	2,700	0.002	+14.4	840 B	0.2 two Jupiters

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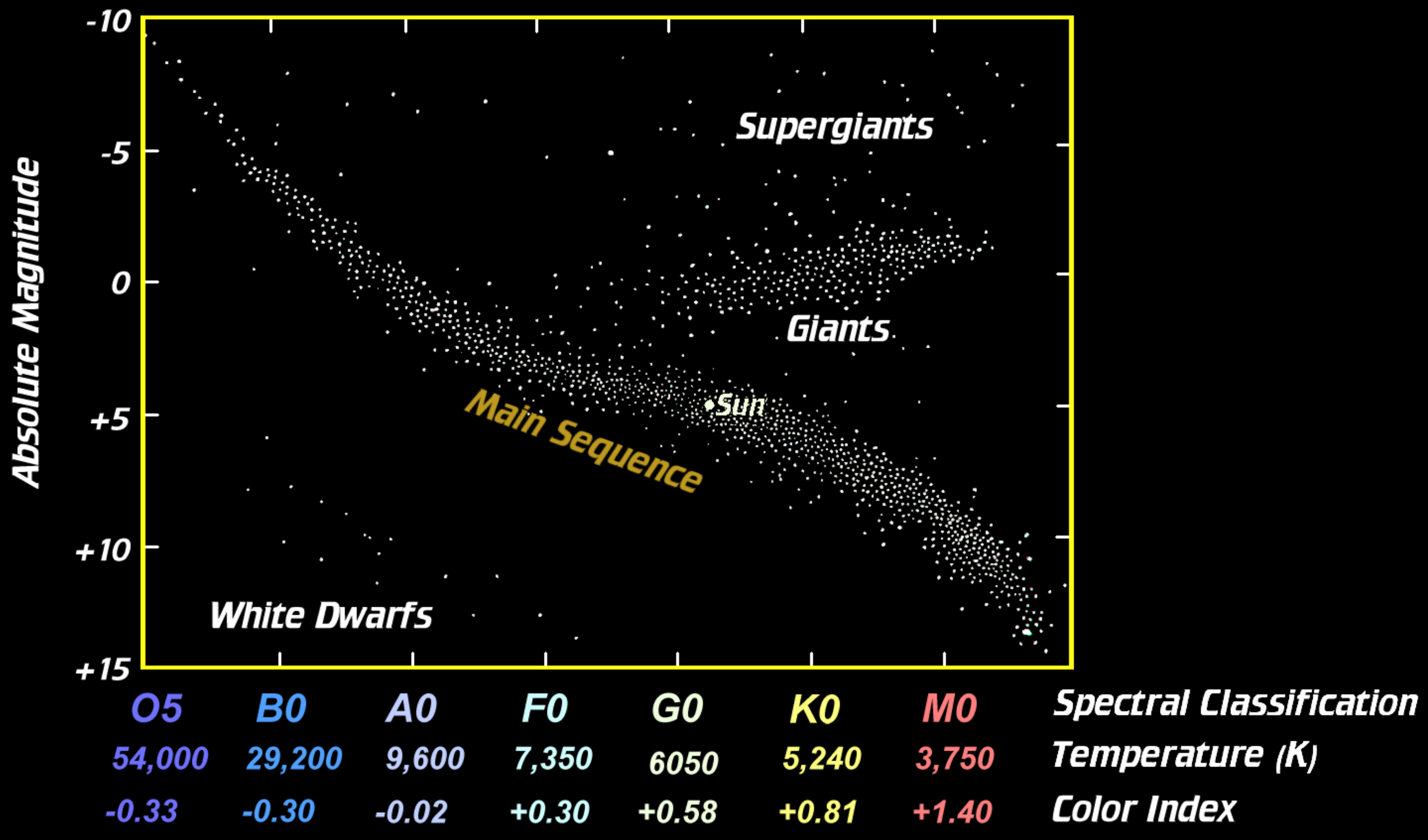
Hertzsprung-Russell Diagram



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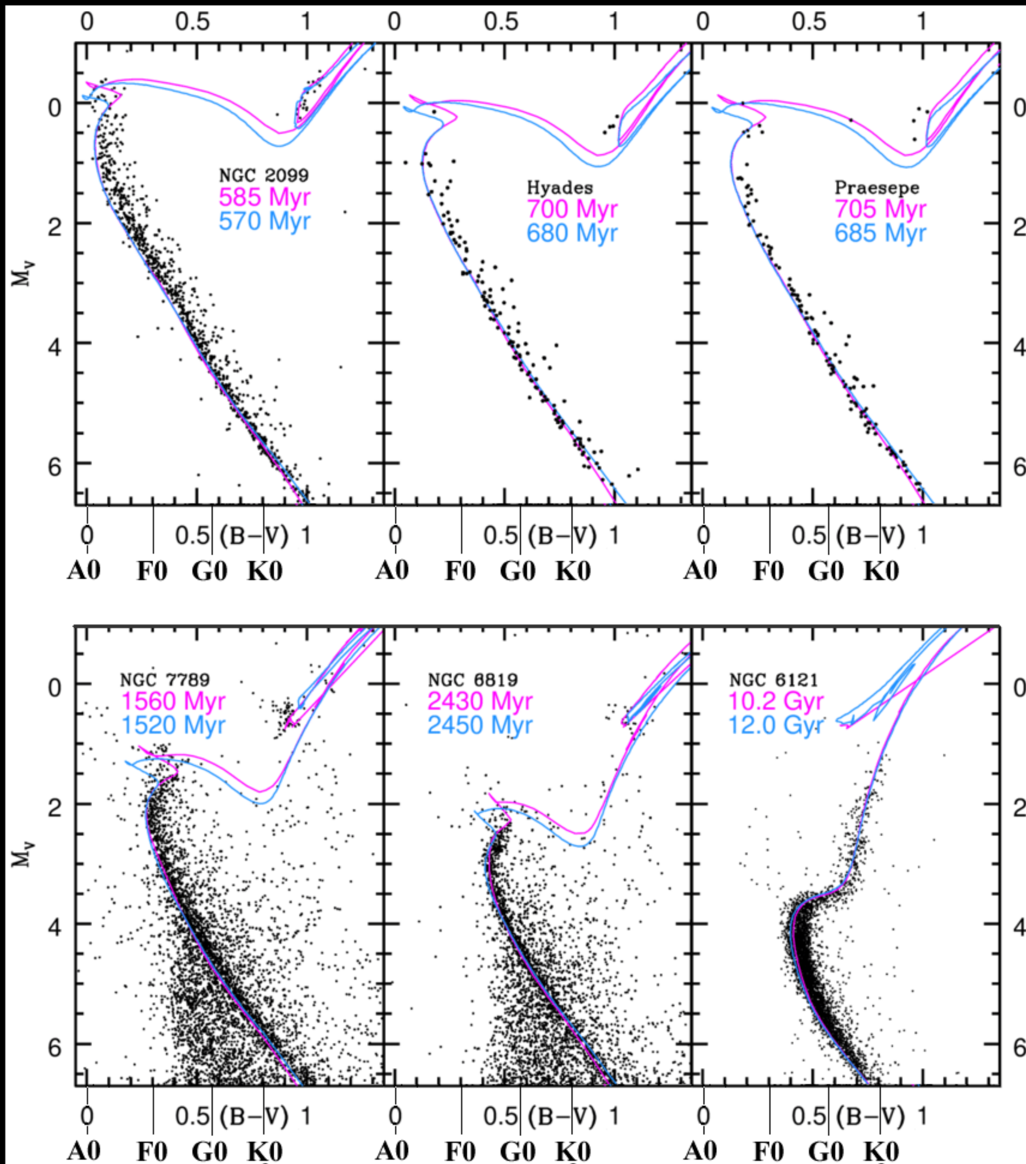
Comparison of Old Star Clusters of Increasing Age



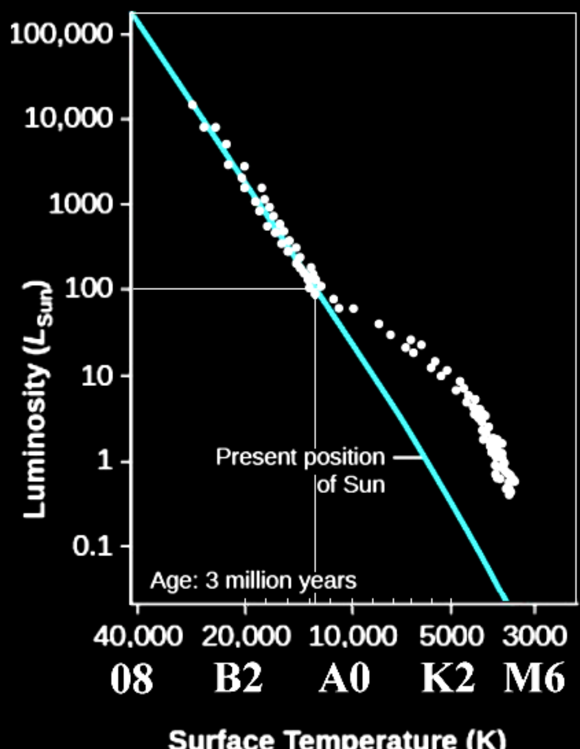
Left to Right:
The clusters become older. Note how the absolute magnitude of the turn-off position becomes fainter and moves towards cooler stars.

Class	B−V
O5V	−0.33
B0V	−0.30
A0V	−0.02
F0V	0.30
G0V	0.58
K0V	0.81
M0V	1.40

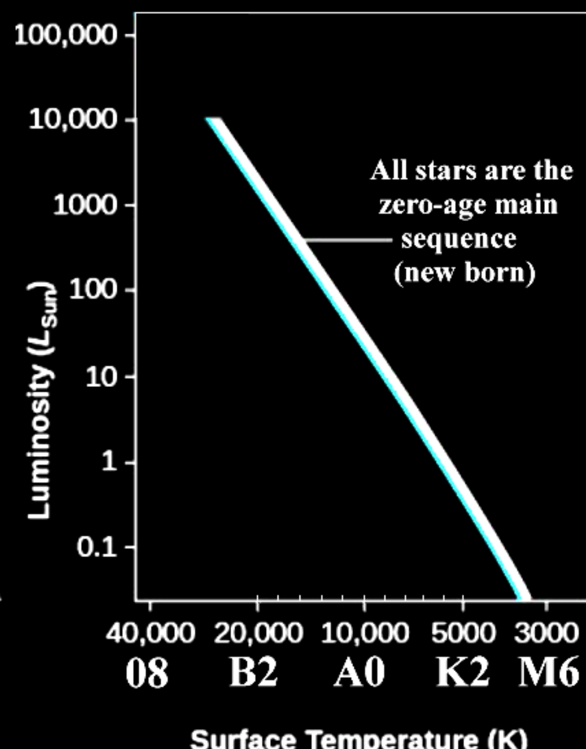
H-R diagrams from J. Cummings-John Hopkins Uni./Color Index-Wikipedia

Evaluating the Age of Star Clusters

Are the stars on the lower main sequence coming or going?



All Stars are on the main sequence.



Characteristics of
MAIN SEQUENCE STARS

Class	Contraction to Zero Age Main Sequence Not well known	Surface Temp. (K)	Luminosity compared to sun	Years on Main Sequence
O6 mid	10 Th	45,000	140,000	2 M
O9 late	100 Th	37,800	55,000	4 M
B2 early	400 Th	21,000	3,190	30 M
B5 mid	1 M	15,200	380	140 M
A0 early	4 M	9,600	24	1 B
A7 late	10 M	7,920	8.8	2 B
F2 early	15 M	7,050	3.8	4 B
G2 sun	20 M	5,800	1.00	10 B
K7 late	40 M	4,000	0.11	50 B
M8 late	100 M	2,700	0.002	840 B

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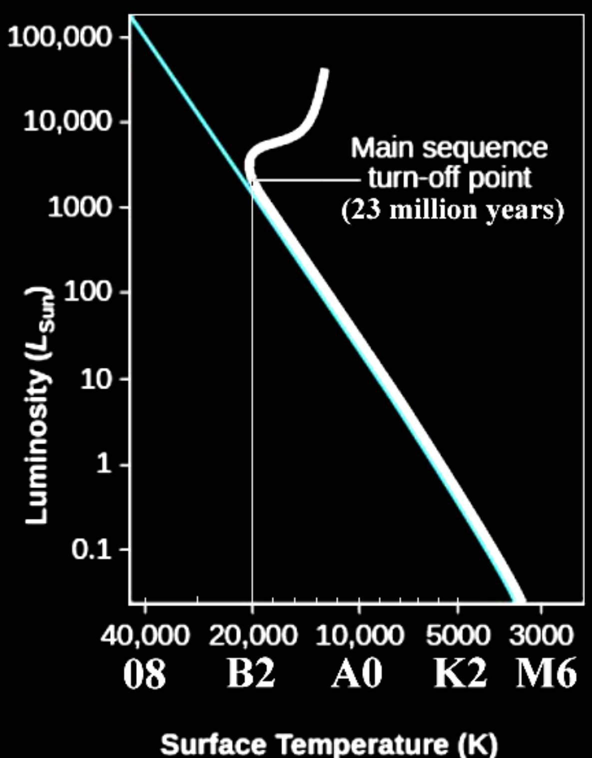
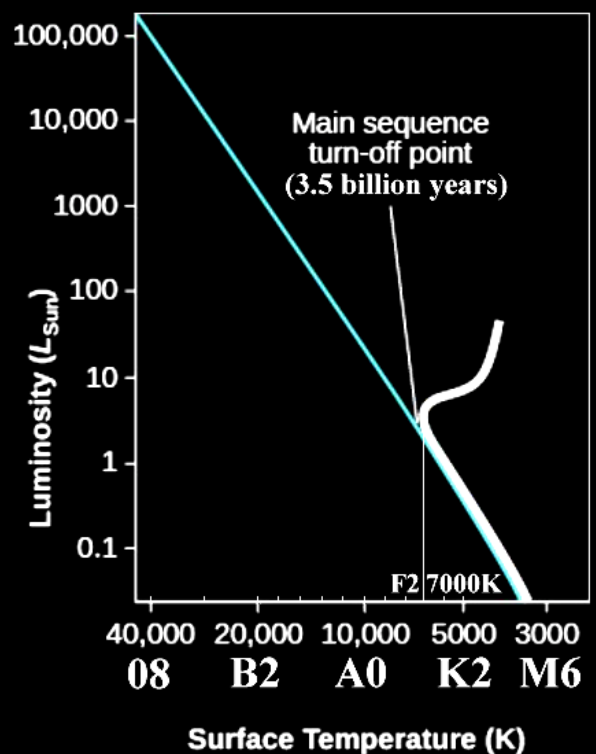
Evaluating the Age of Star Clusters

Turn-off at 20,000K = B2

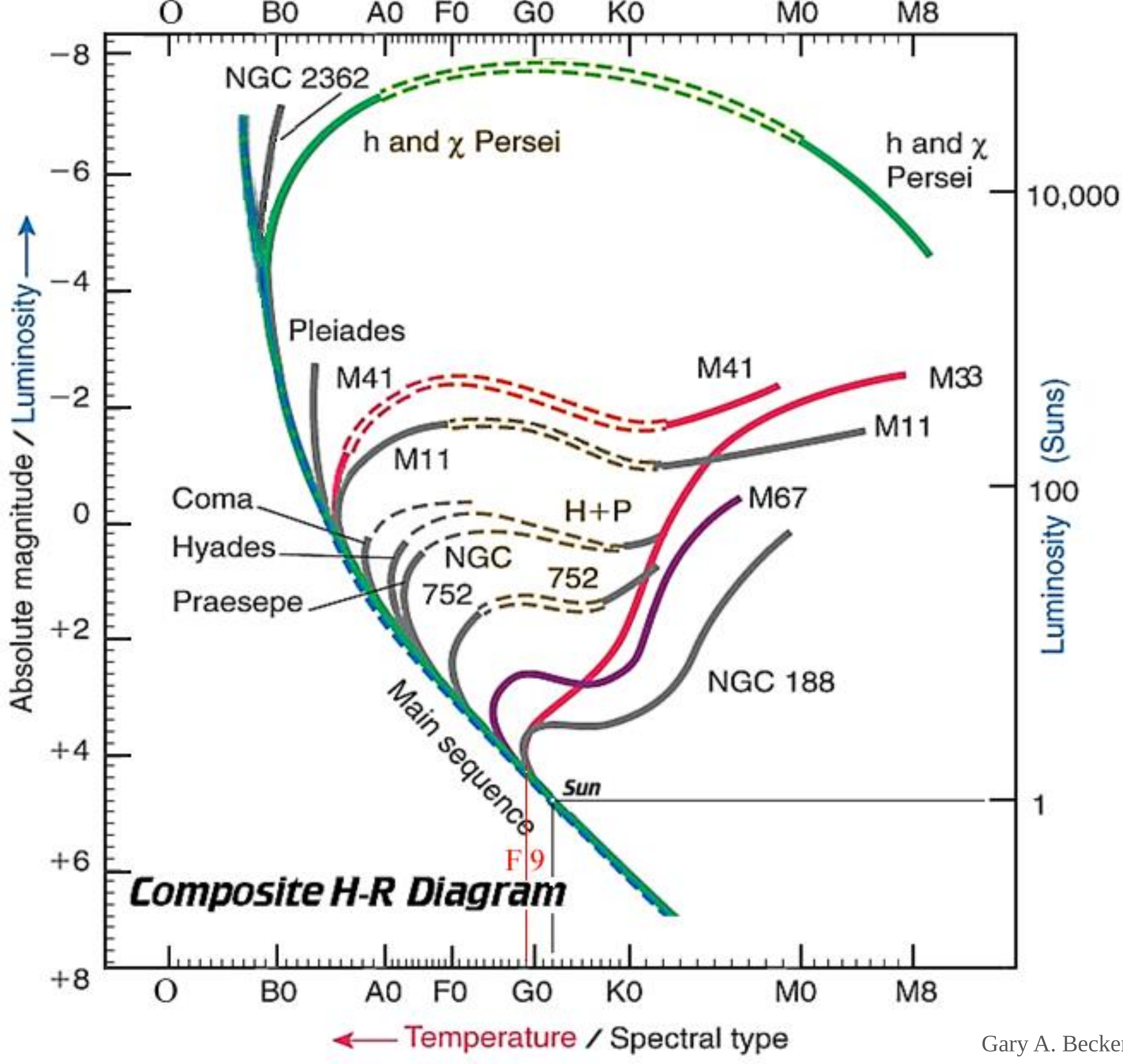


Turn-off at 7,000K = F2



Characteristics of MAIN SEQUENCE STARS

Class	Contraction to Zero Age Main Sequence (Not well known)	Surface Temp. (K)	Luminosity compared to sun	Years on Main Sequence
O6 mid	10 Th	45,000	140,000	2 M
O9 late	100 Th	37,800	55,000	4 M
B2 early	400 Th	21,000	3,190	30 M
B5 mid	1 M	15,200	380	140 M
A0 early	4 M	9,600	24	1 B
A7 late	10 M	7,920	8.8	2 B
F2 early	15 M	7,050	3.8	4 B
G2 sun	20 M	5,800	1.00	10 B
K7 late	40 M	4,000	0.11	50 B
M8 late	100 M	2,700	0.002	840 B



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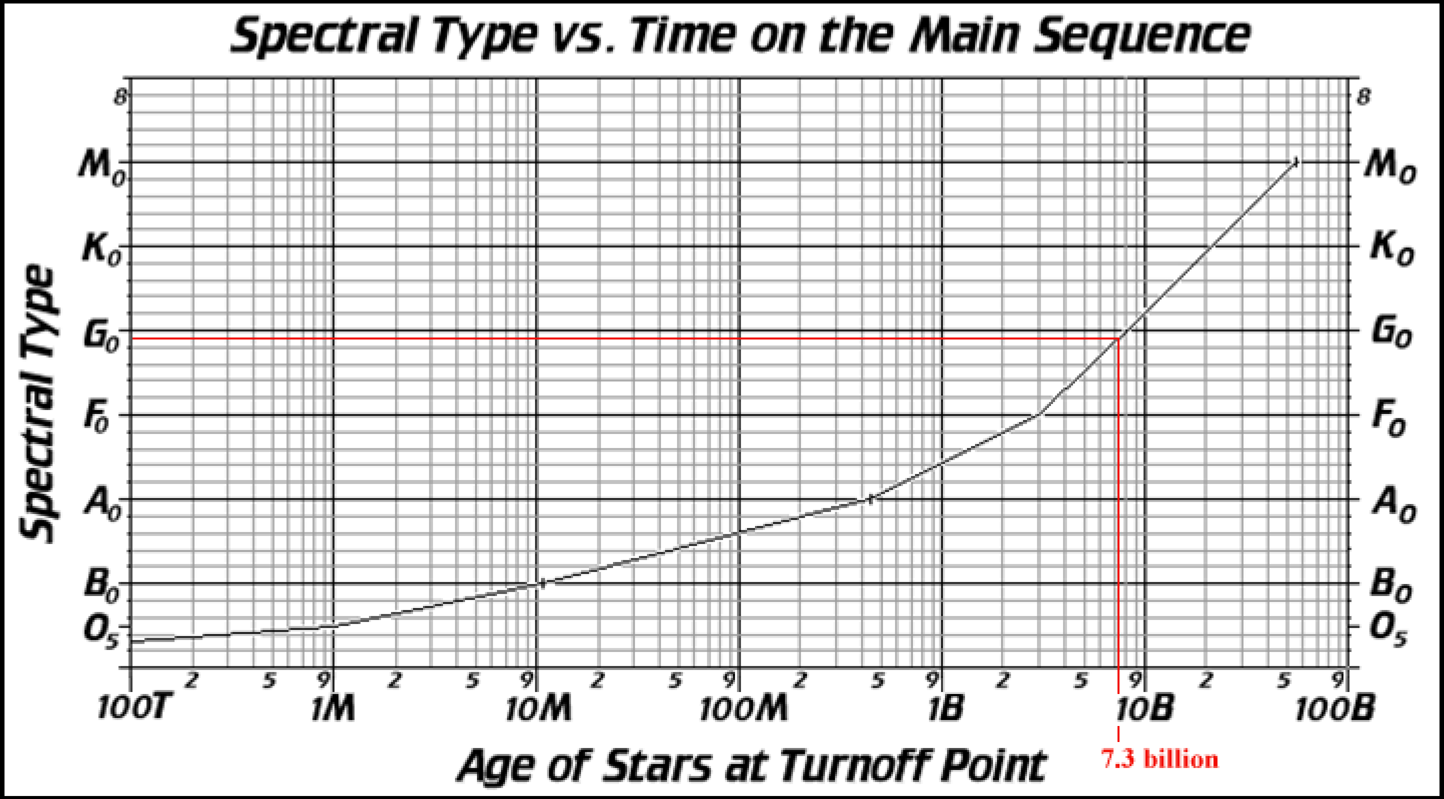

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The End