# 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<br>Annie J. Cannon | Mass in Comparison to Sun | Contraction to Zero Age Main Sequence<br>Not well known | Surface Temp. (K) | Luminosity compared to sun | M<br>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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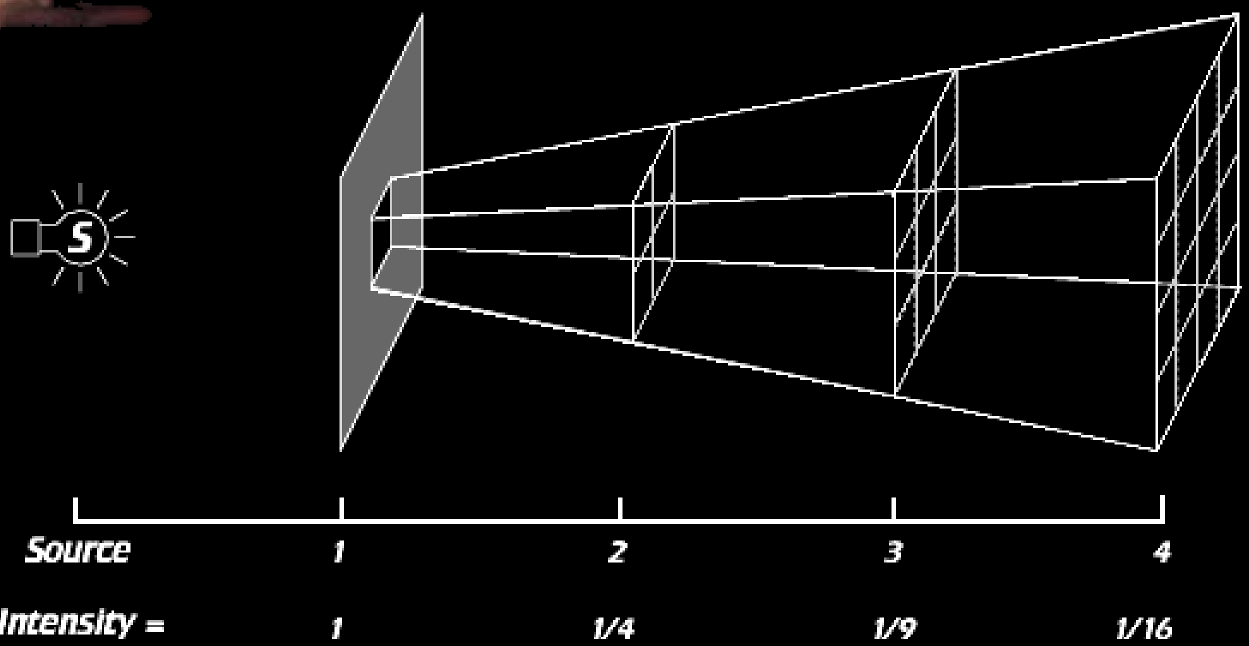
$$\text{Intensity} = \frac{1}{d^2}$$

## Inverse Square Law

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# Intensity Scale Between Magnitudes


Brighter ↑

-3

-2

-1

0

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

2.511886432... Intensity difference between magnitudes

+1

$\blacktriangleright$ 2.512

+2

$\blacktriangleright$ $2.512^2$ = 6.310

+3

$\blacktriangleright$ $2.512^3$ = 15.85

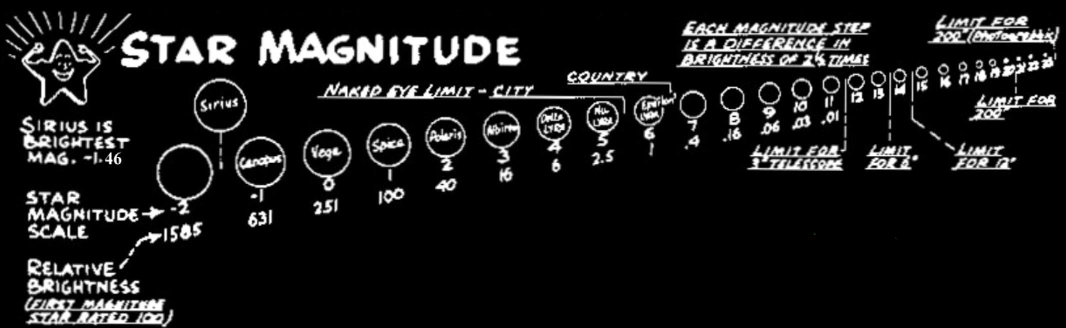
+4

$\blacktriangleright$ $2.512^4$ = 39.82

+5

$\blacktriangleright$ $2.512^5$ = 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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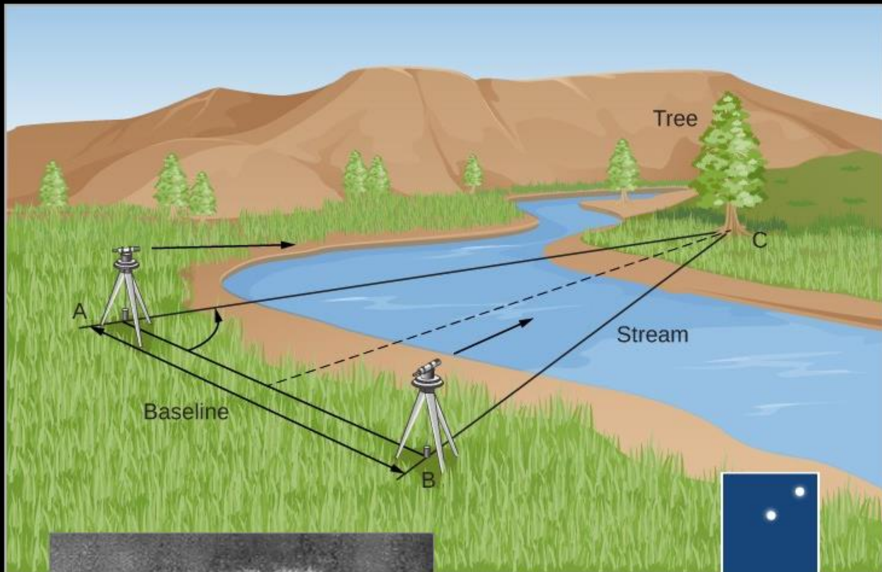
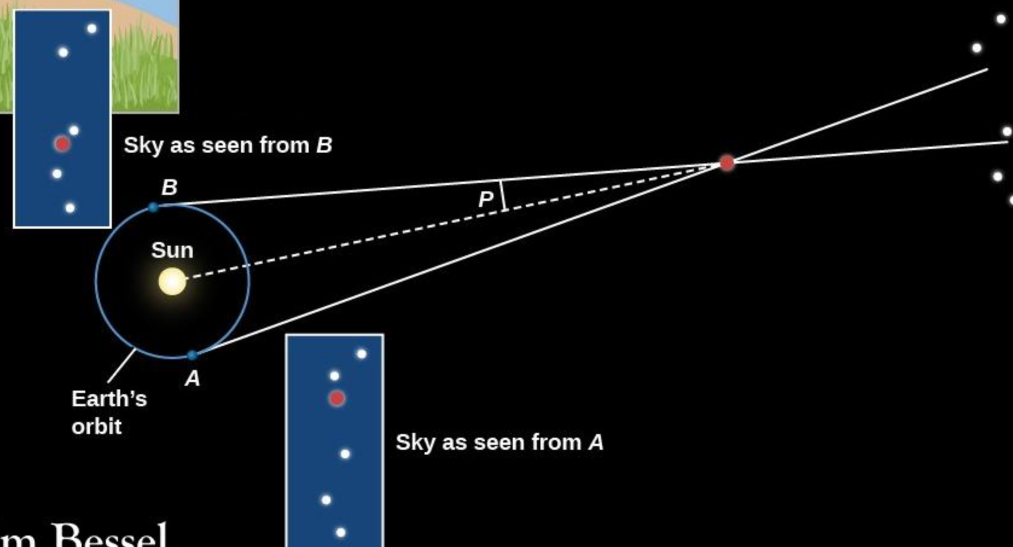
# Surveying the Universe



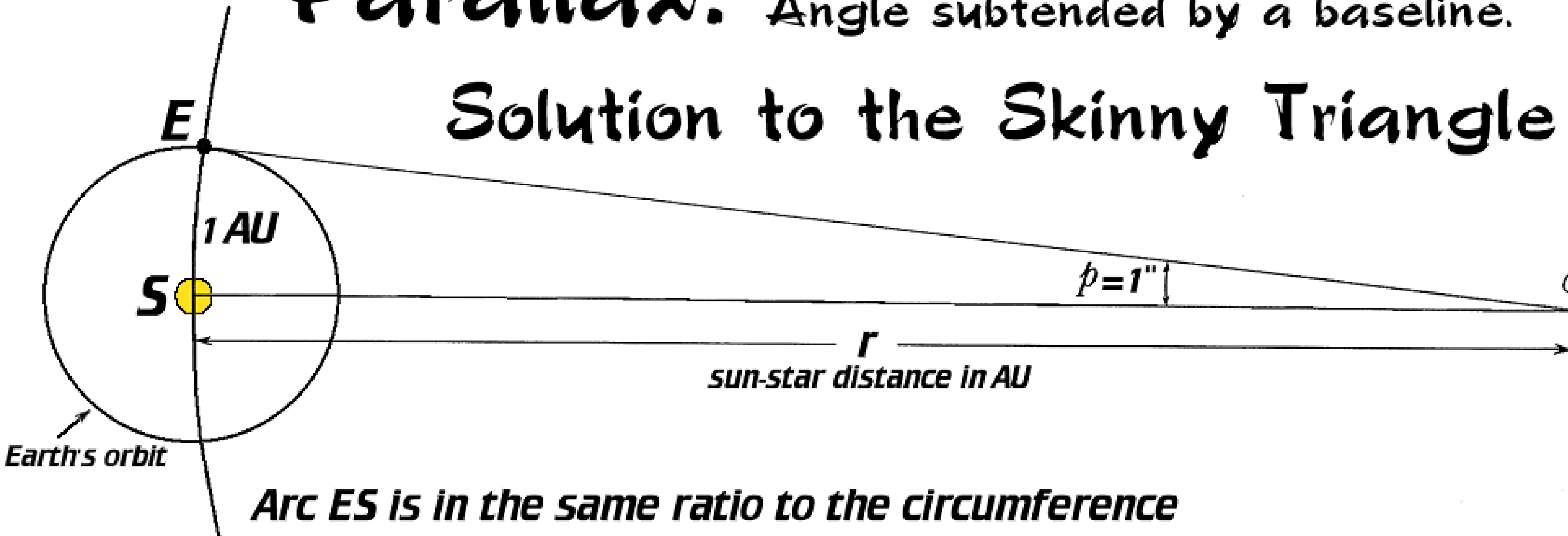

Friedrich Wilhelm Bessel
(1784-1846)
First authenticated parallax-61 Cygni-1838




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*

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## *Distance Modulus*

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

*Where*
*M = absolute magnitude*
*m = apparant magnitude*
*r = distance in parsecs*

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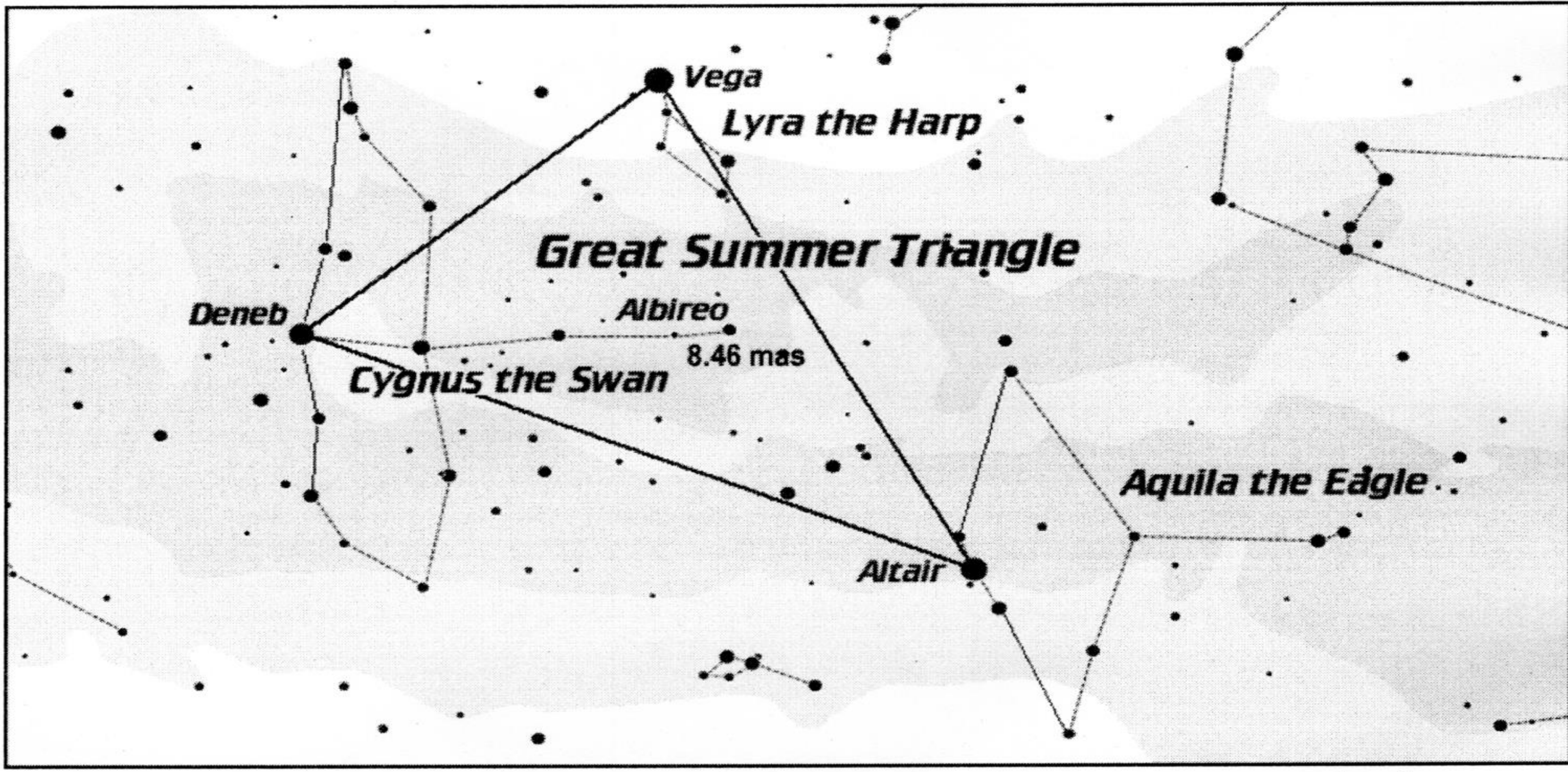
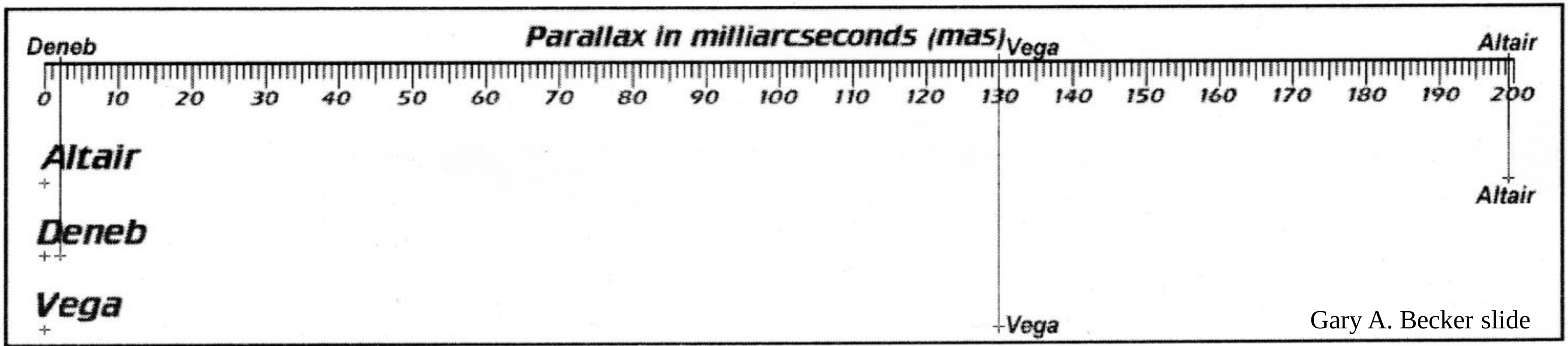



Use this Scale to measure the parallax angles of the three stars of the Great Summer Triangle.

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

**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?
$I = 2.51^{\Delta M}$; $I = 2.51^{7.29}$; **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

**$D_{pc} = 1/p''$**

$2.0\text{ mas} \times \frac{1''}{1000\text{ mas}} = 0.0020''$ $D = \frac{1}{PAR''}$ $\frac{1}{0.0020''}$ = **500 pc** × 3.2616 ly/pc = **1600 ly**

**Absolute magnitude of Deneb:**

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

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

$M = +6.24 - 5(2.699)$

$M = +6.24 - 13.49$

$M =$ **−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 = $2.51^x$**

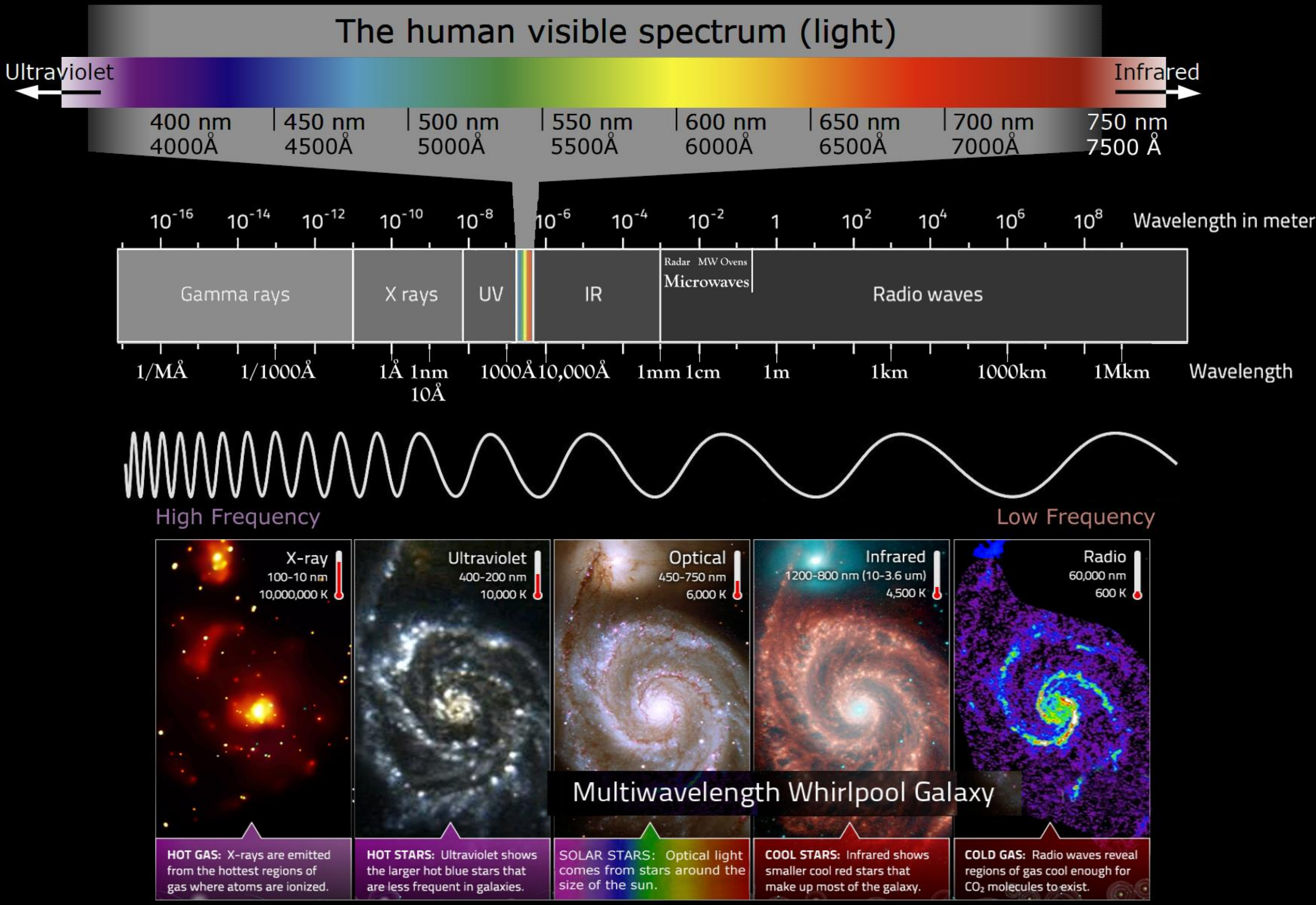
$\Delta M = +4.83 - (-7.25)$

$\Delta M = 12.08$ **12**

$I = 2.51^{12.08}$

$I = 67{,}307$ = **67,000 TIMES BRIGHTER THAN SUN**

# Electromagnetic Spectrum

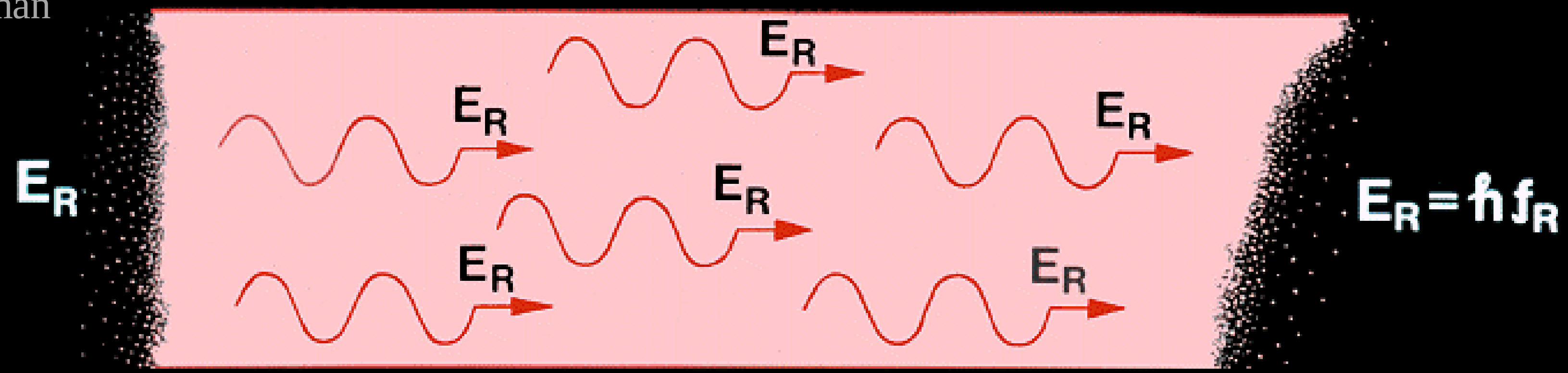



Constructed from many different slides by Gary A. Becker

# Relationship Between Energy and Wavelength

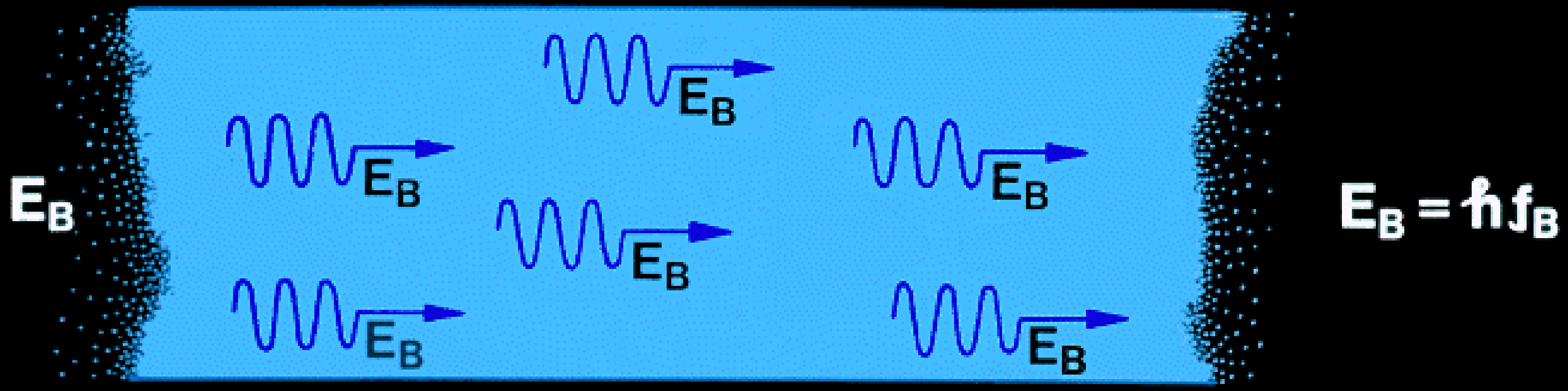
Max Planck-1858-1947
German

*Light acts like a particle*




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

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

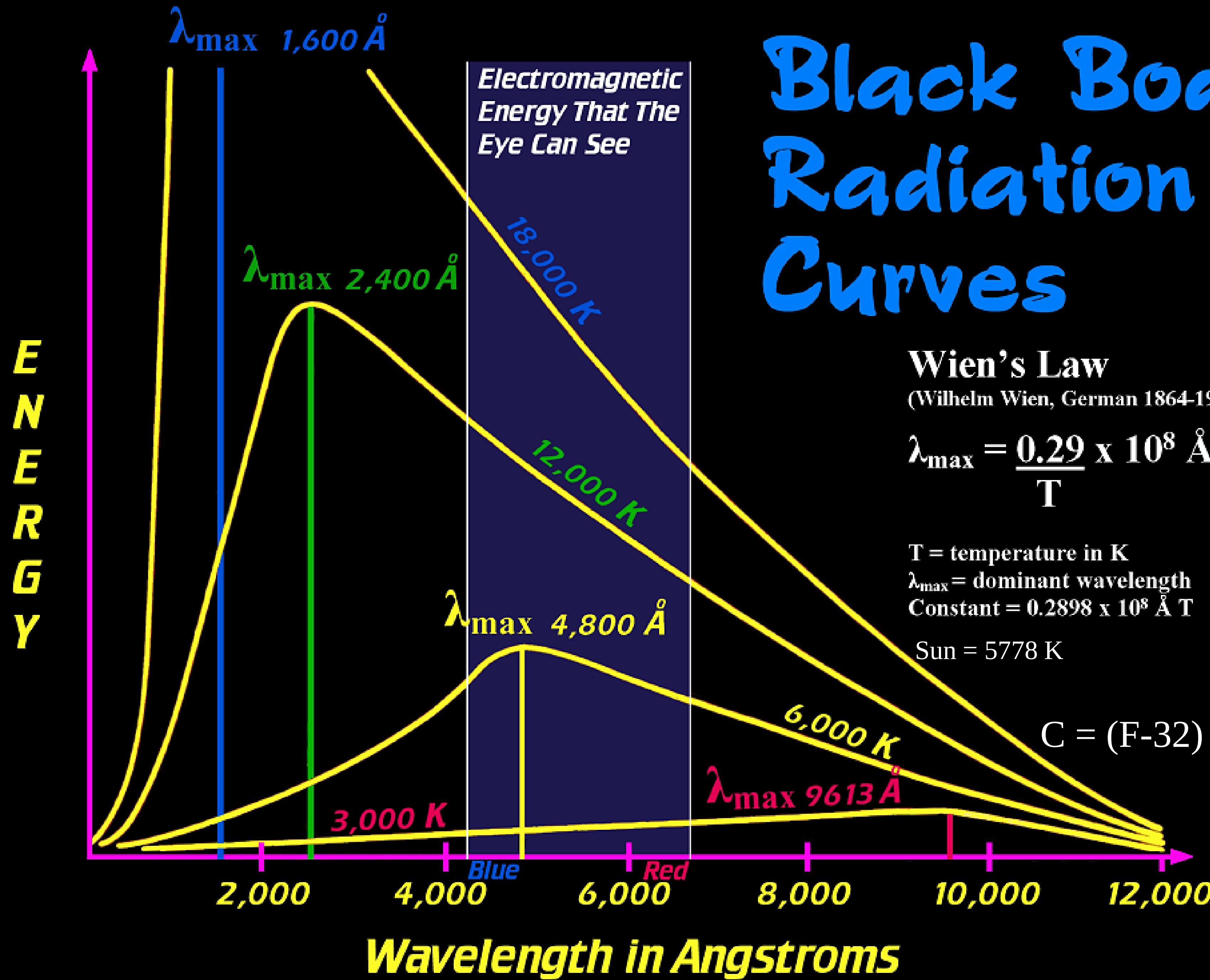


**Planck's constant**: $6.626196(50) \times 10^{-27}$ erg s

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

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




**Wien's Law**
(Wilhelm Wien, German 1864-1928):

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

T = temperature in K
$\lambda_{max}$ = dominant wavelength
Constant = $0.2898 \times 10^8$ Å T

Sun = 5778 K

C = (F-32) x 5/9

# 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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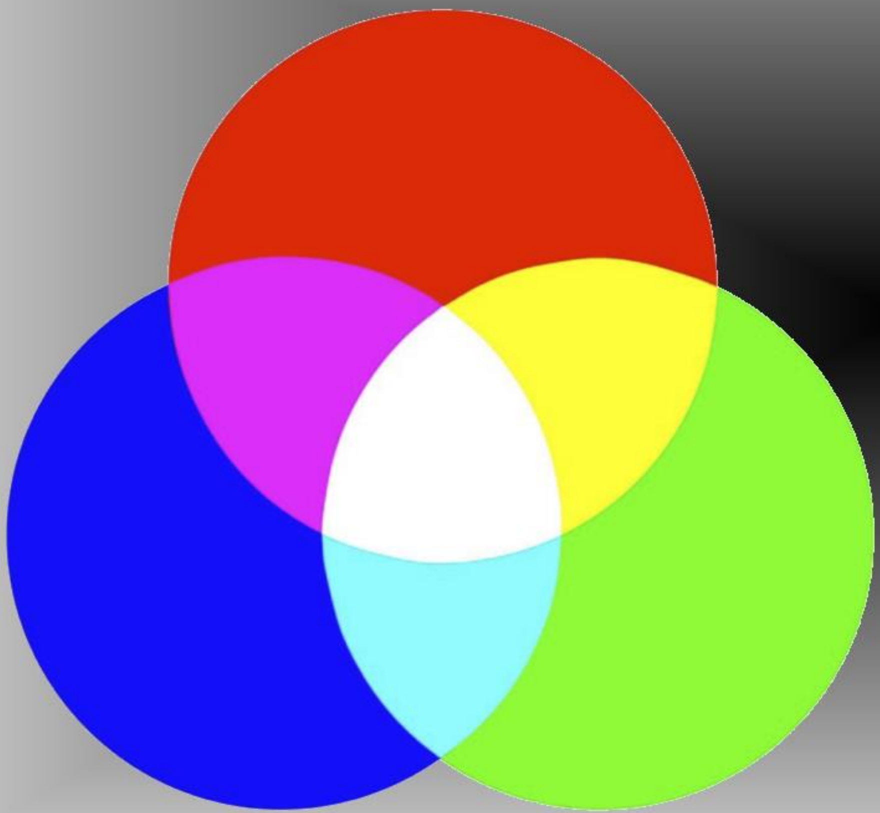
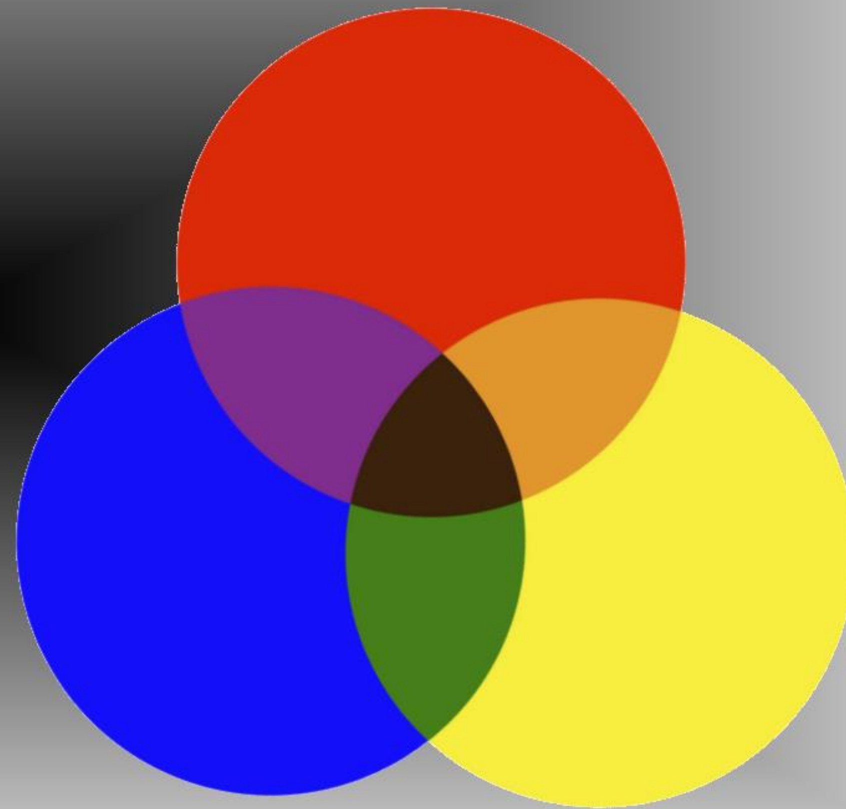
# Additive and Subtractive Colors

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

**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 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

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

**<u>Emission Spectrum</u>**—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.

**<u>Absorption Spectrum</u>**—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**

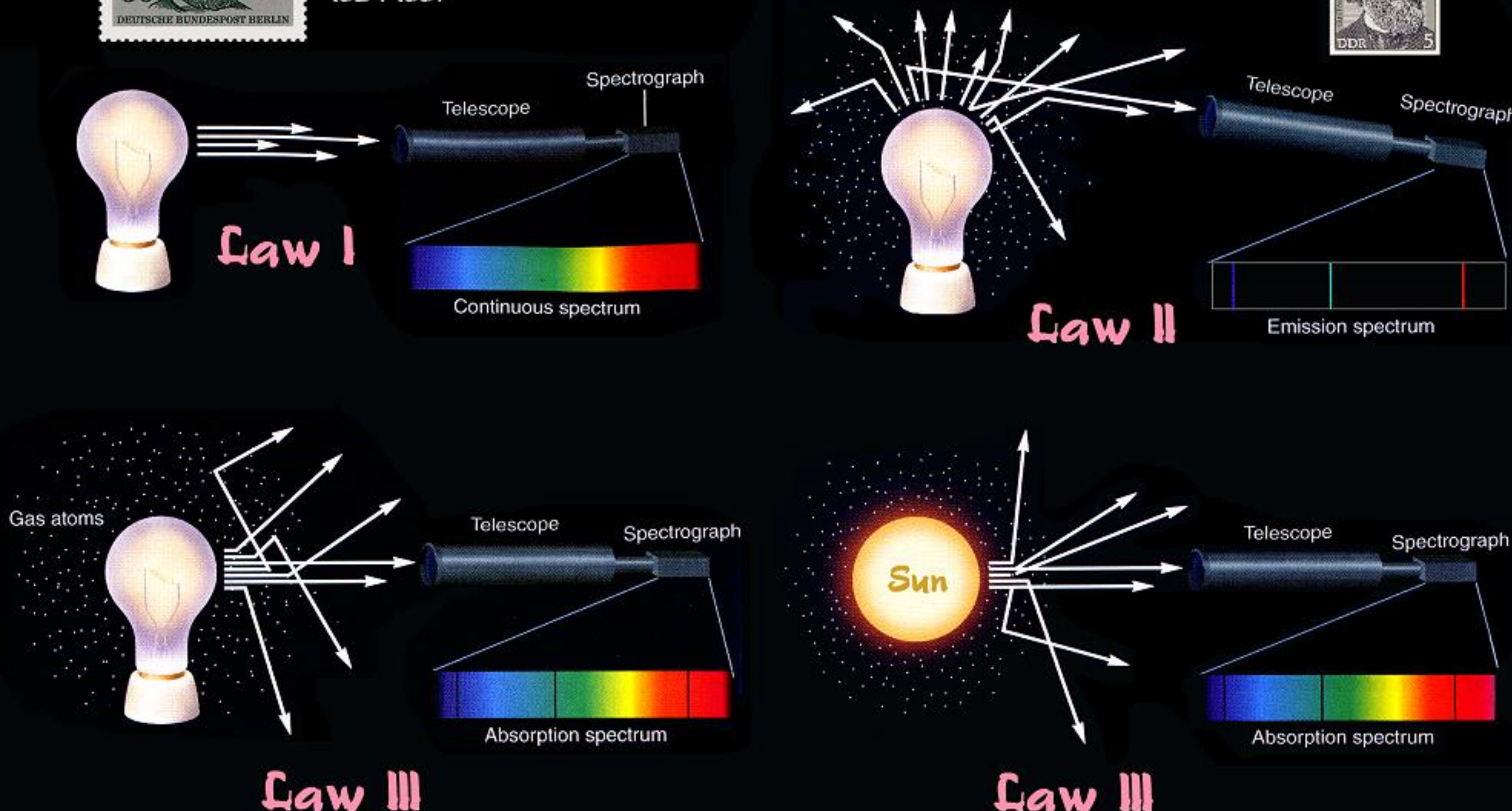
**Absorption Spectrum**

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

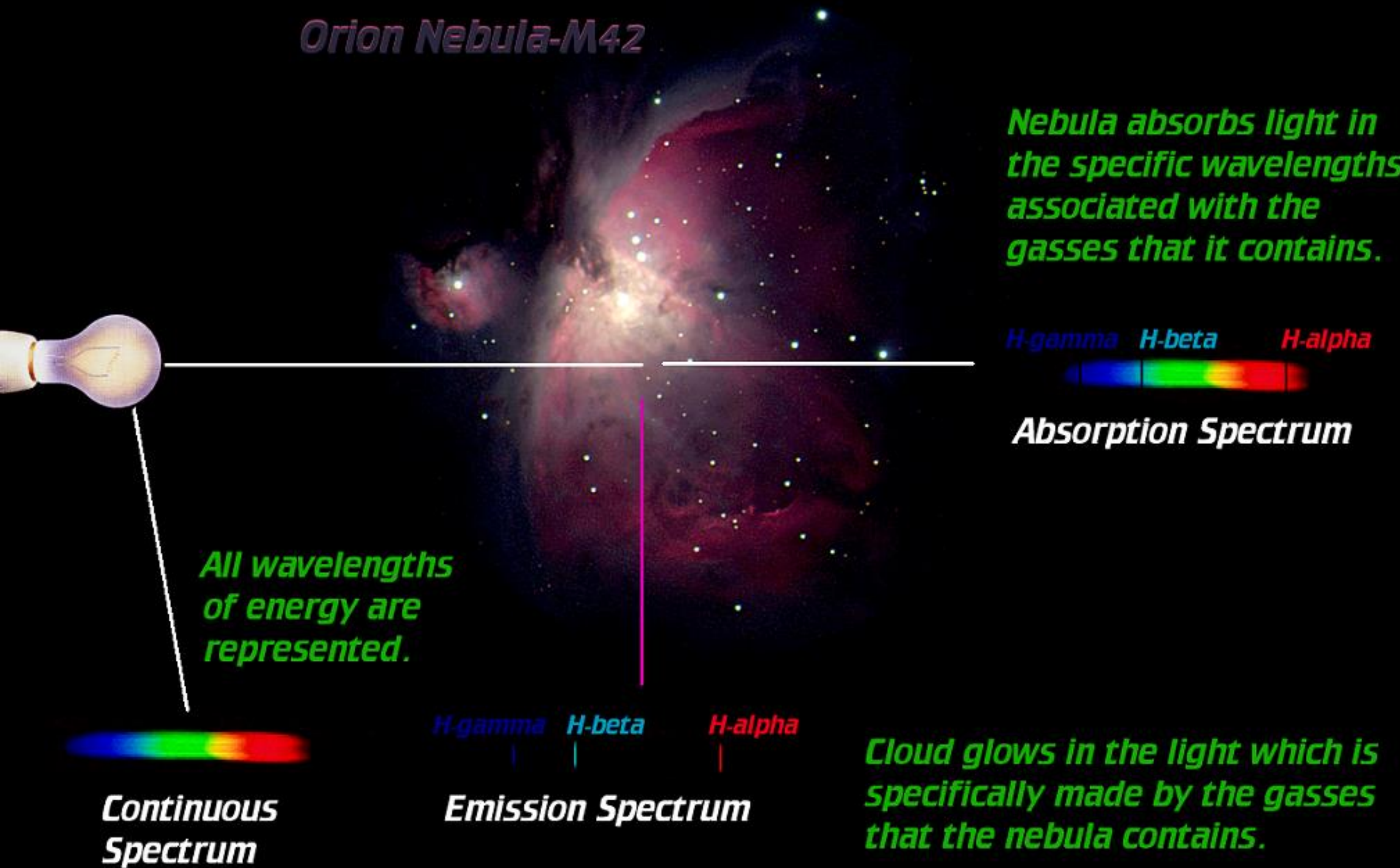
# Gustav Kirchhoff's Three Laws of Spectroscopy Illustrated


Kirchhoff was German

1824-1887

# Kirchhoff's Three Laws Illustrated

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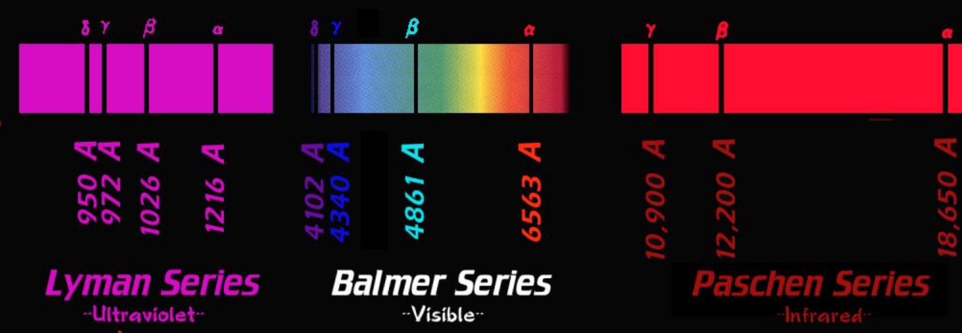
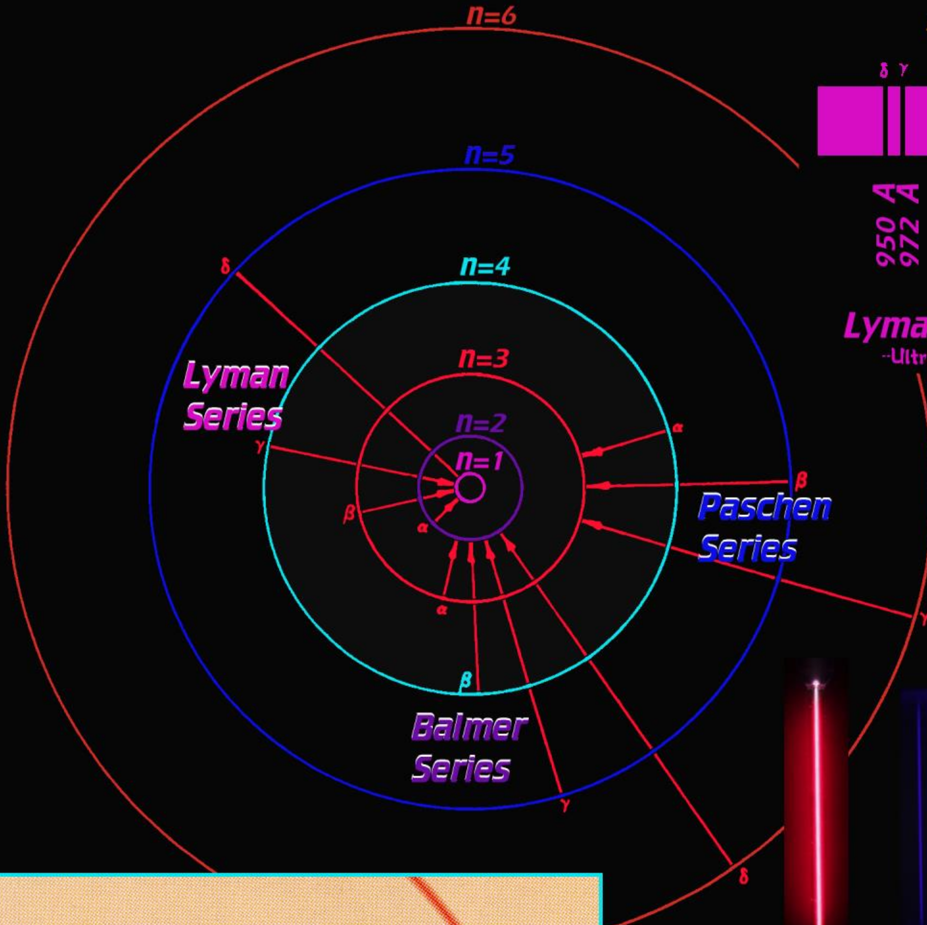
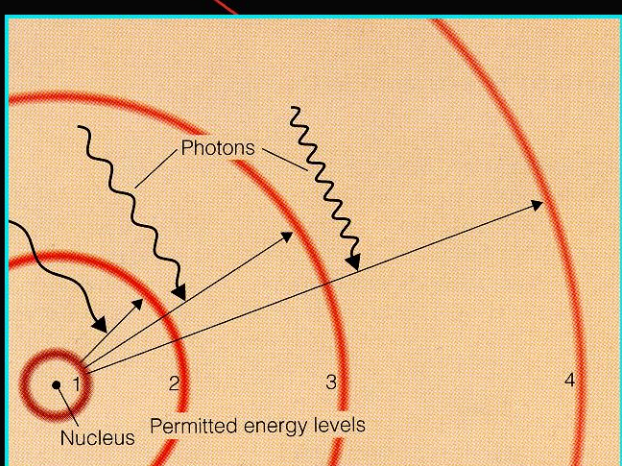
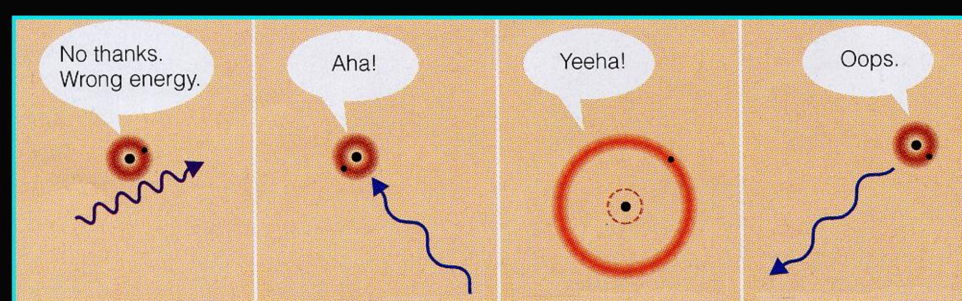
# Absorption Spectra



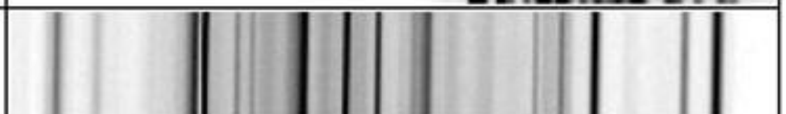




# Bohr Model of the Hydrogen Atom

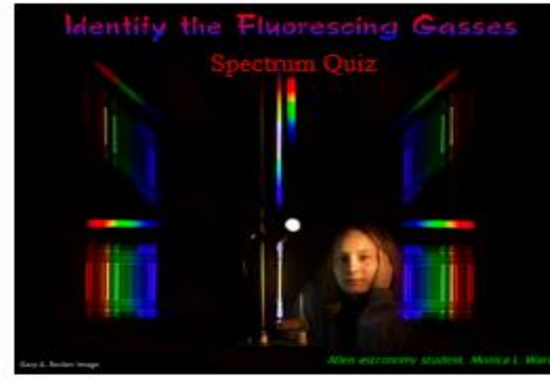



# EMISSION SPECTRUM LAB

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

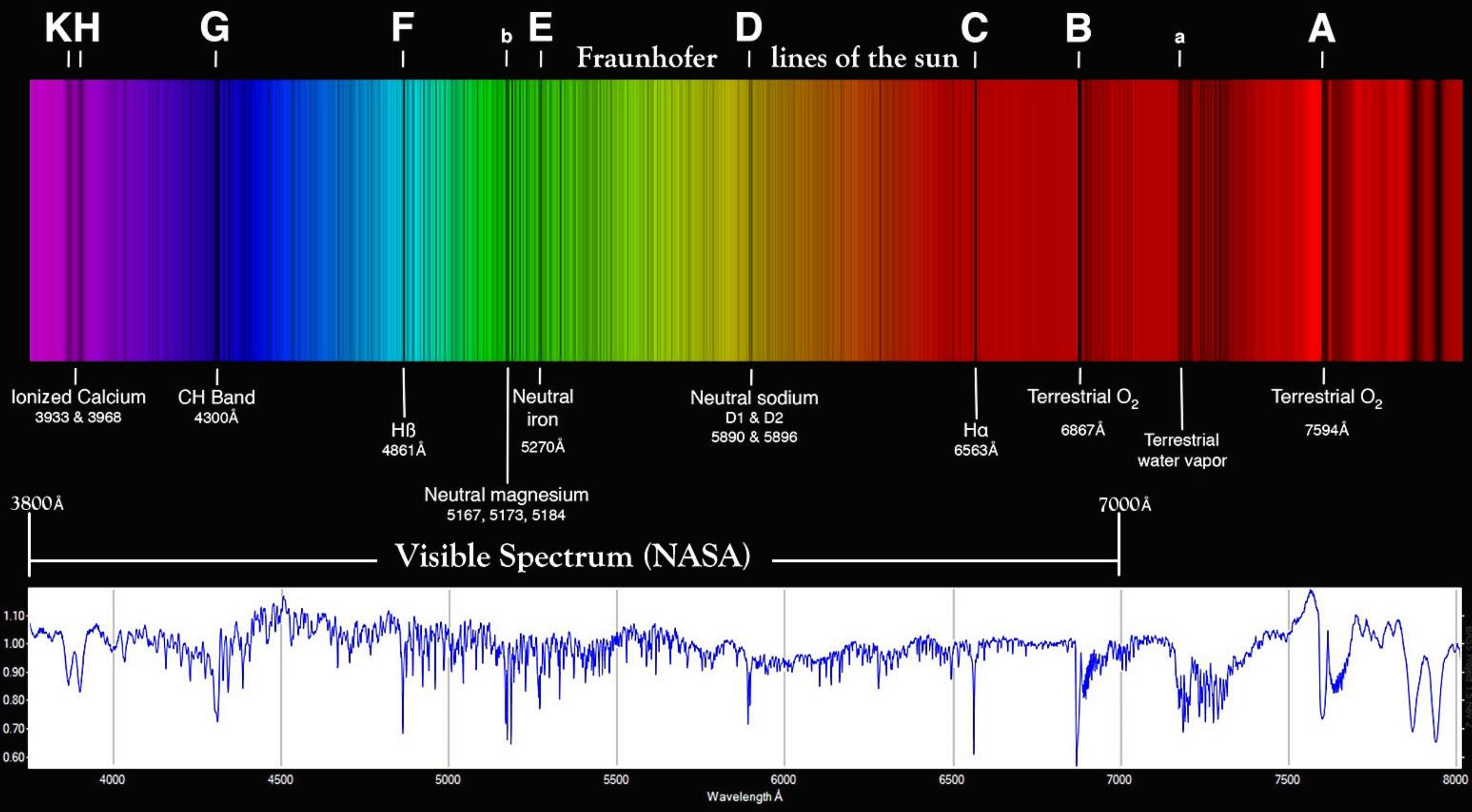
1




2

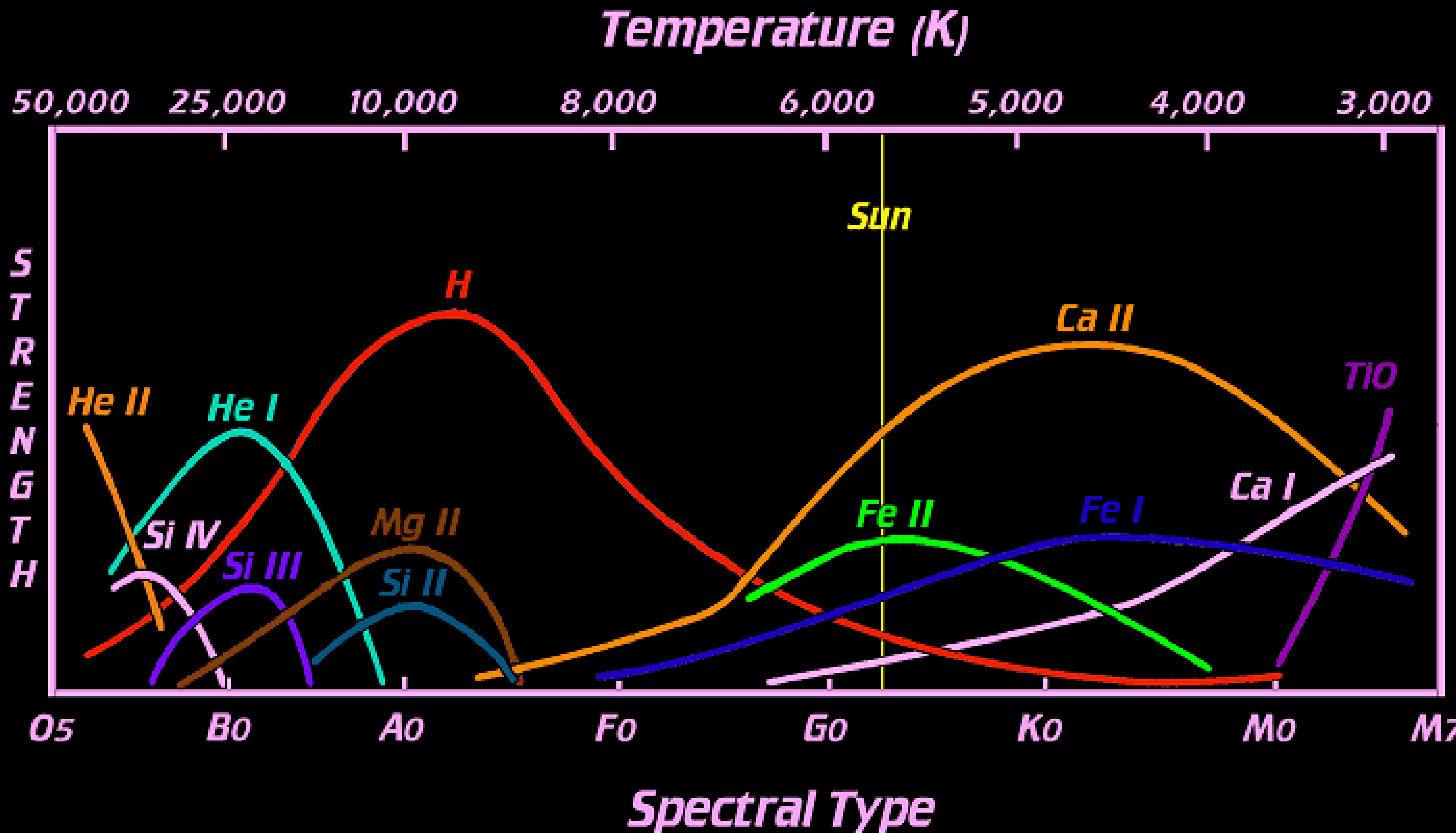

3

# Solar Absorption Spectrum

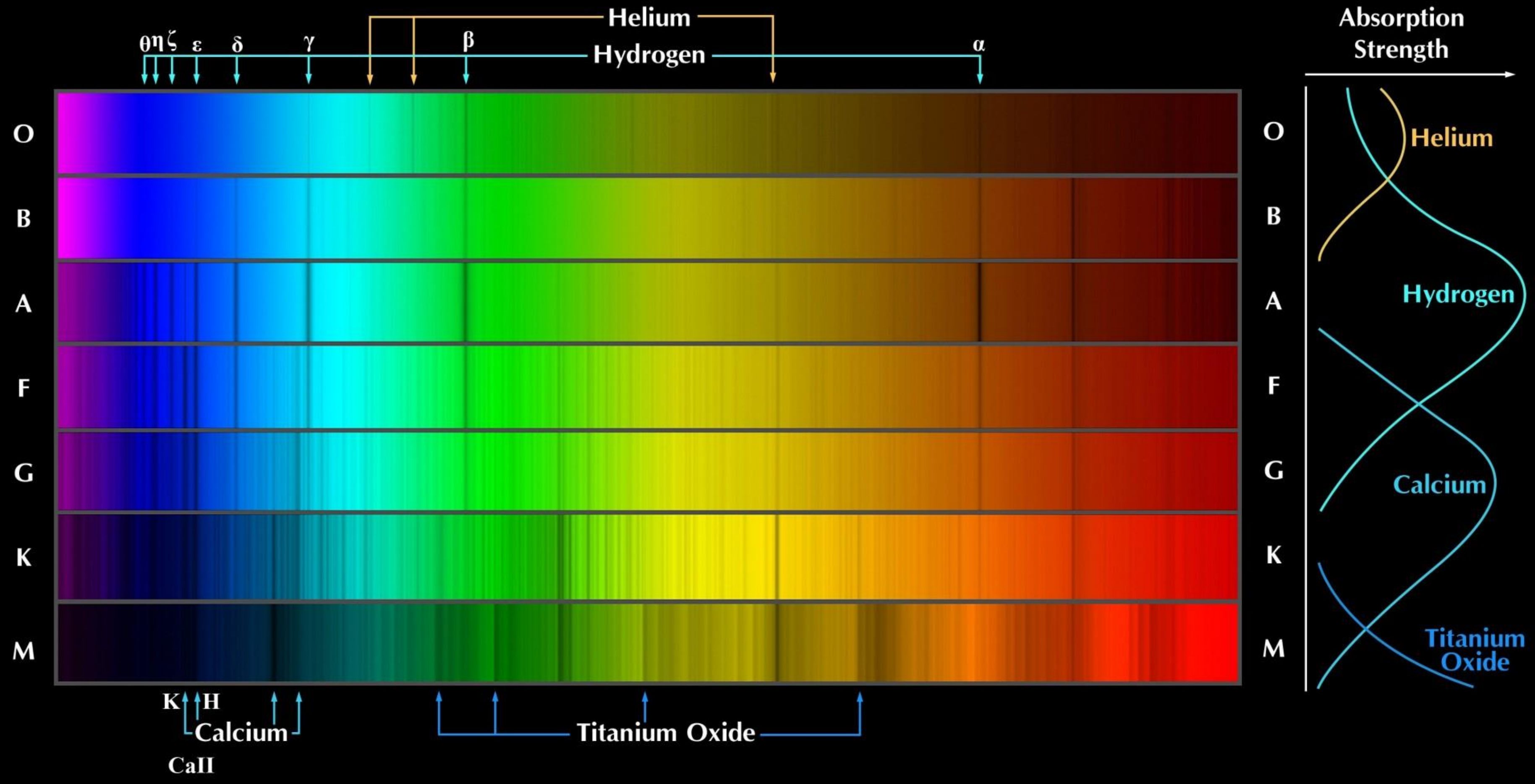



Adapted from NASA materials-Gary A. Becker

# Temperature and Line Strength

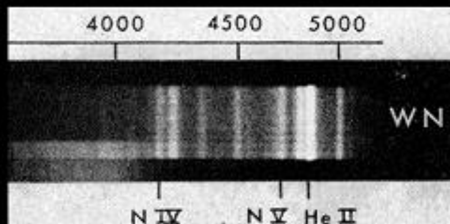


# Temperature and Line Strength

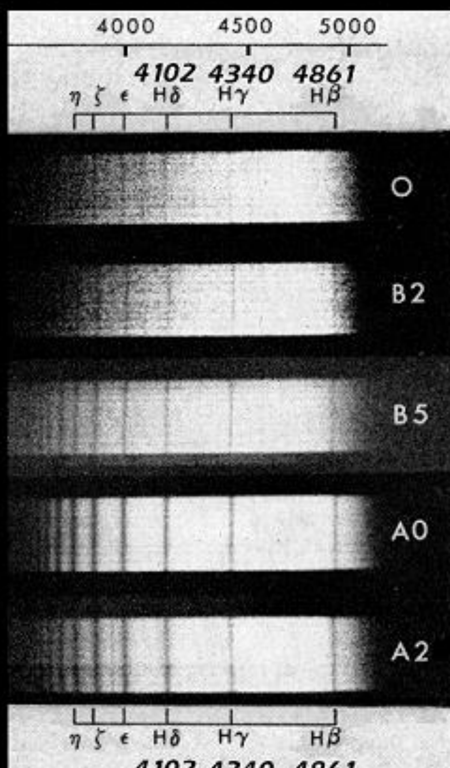


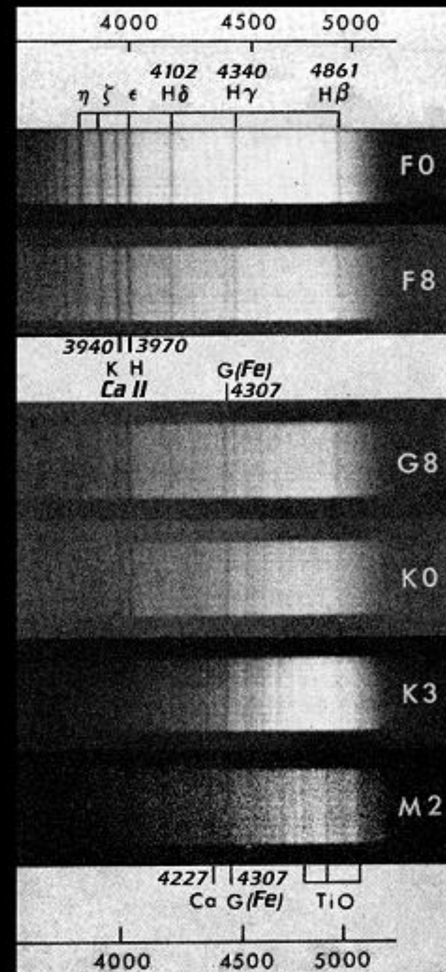

Modified from azastro.pbworks.com

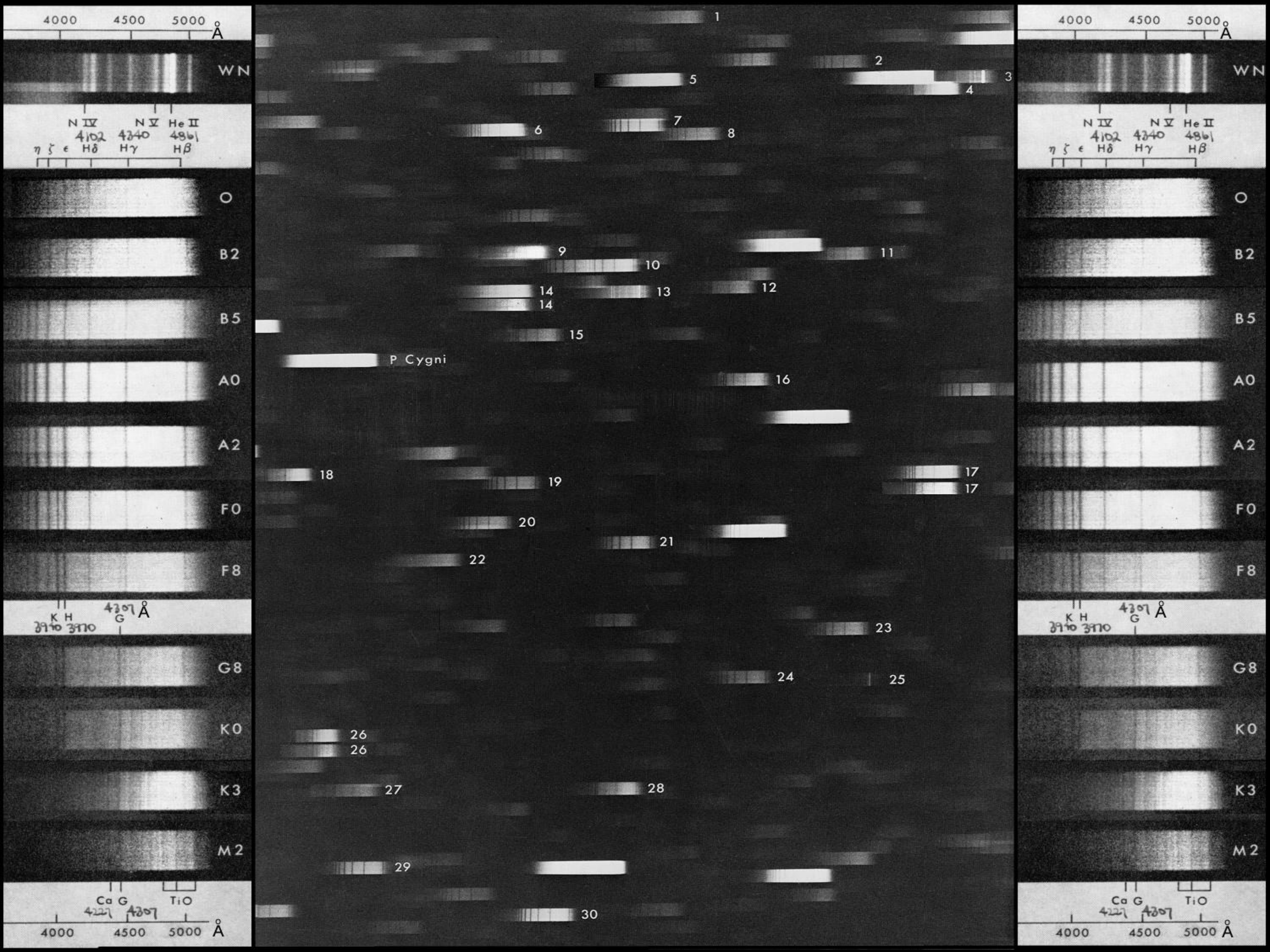
# Spectral Classification




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



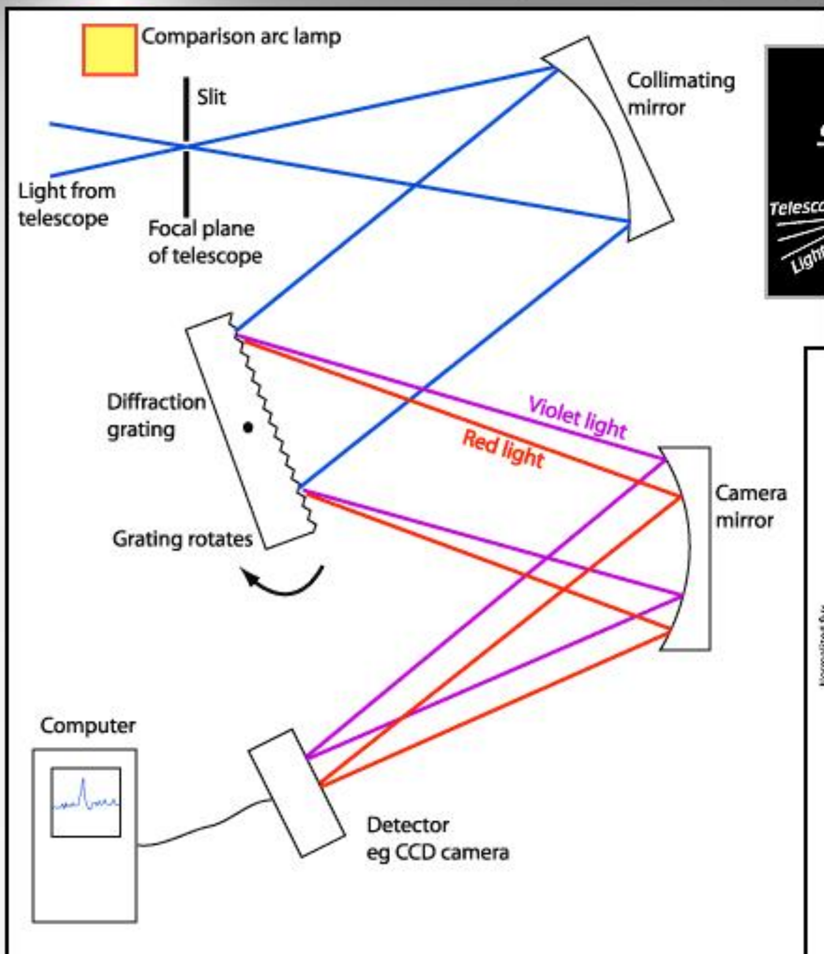





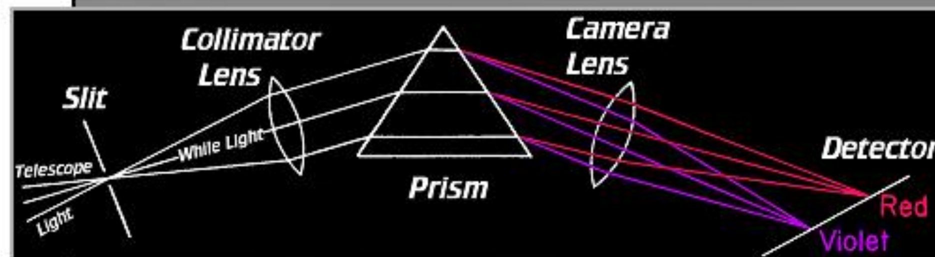
4000 4500 5000 Å
WN
N IV N V He II
4102 4340 4861
η ζ ε Hδ Hγ Hβ
O
B2
B5
A0
A2
F0
F8
K H 4307 Å
3940 3970 G
G8
K0
K3
M2
Ca G TiO
4227 4307
4000 4500 5000 Å
1 2 3 4 5 6 7 8 9 10 11 12 13 14 14 15
P Cygni
16 17 17 18 19 20 21 22 23 24 25 26 26 27 28 29 30

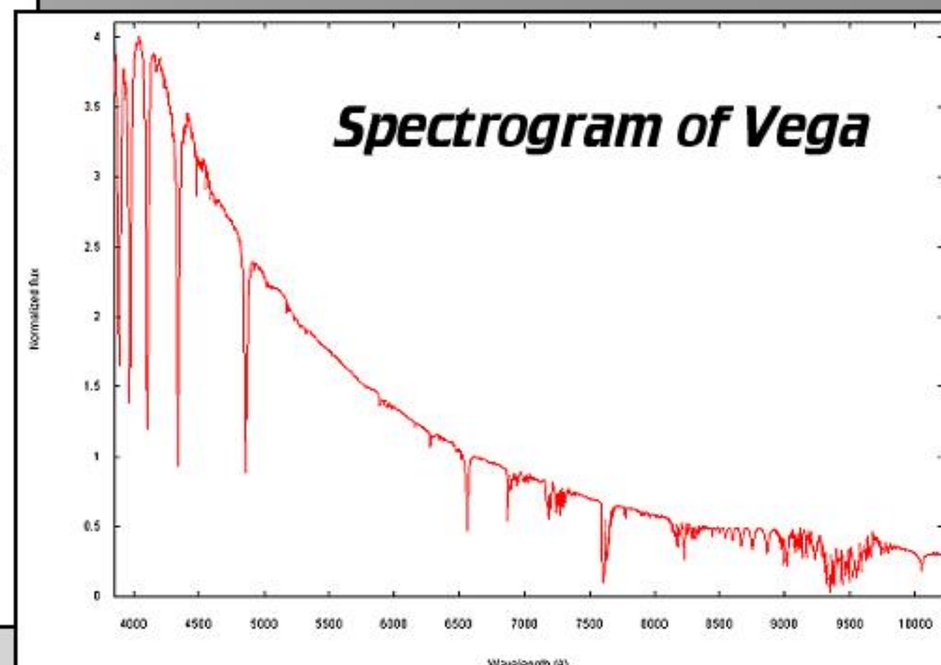
# Spectrograph

## Schematic of a Slit Spectrograph

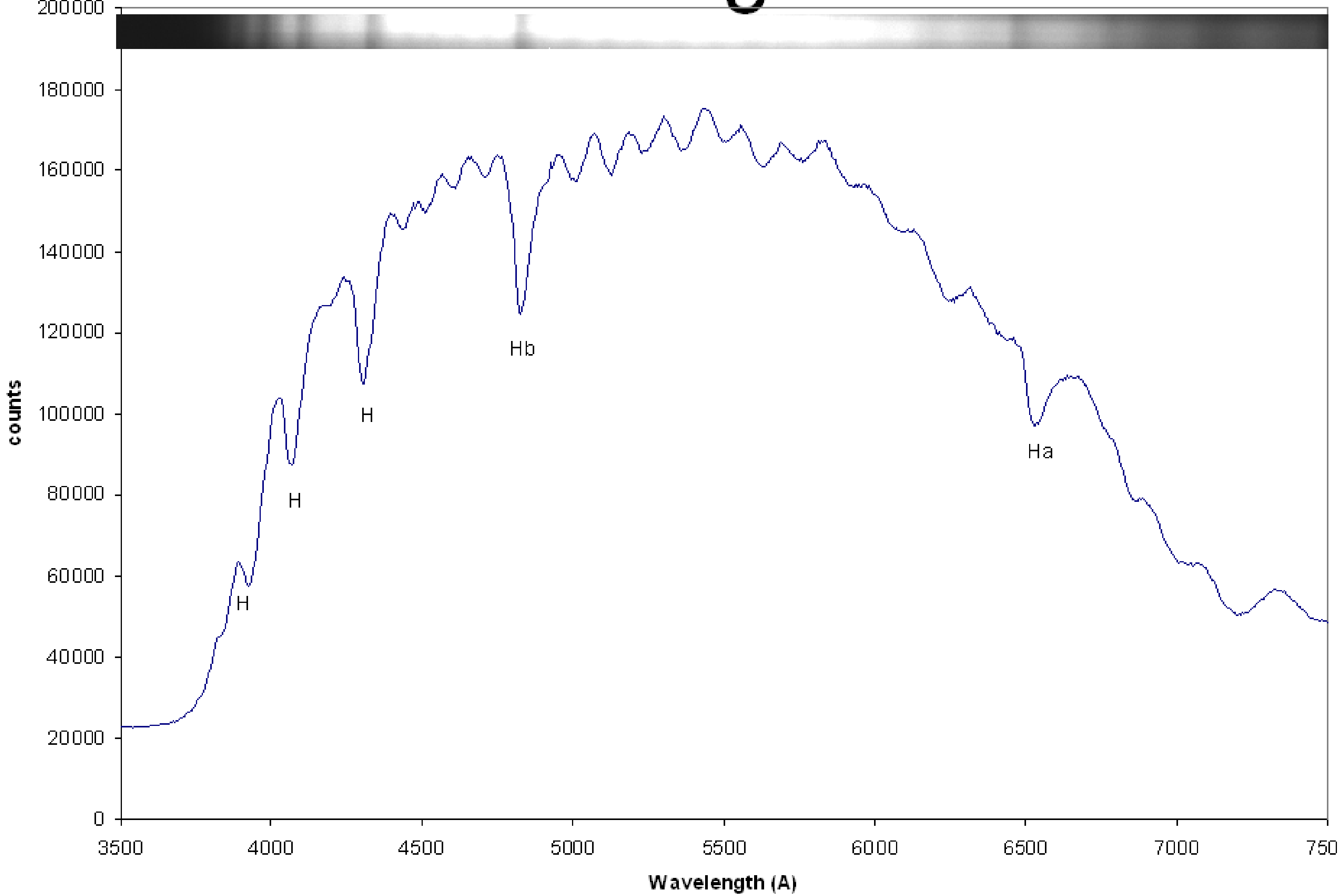



## Spectrograph using a Prism



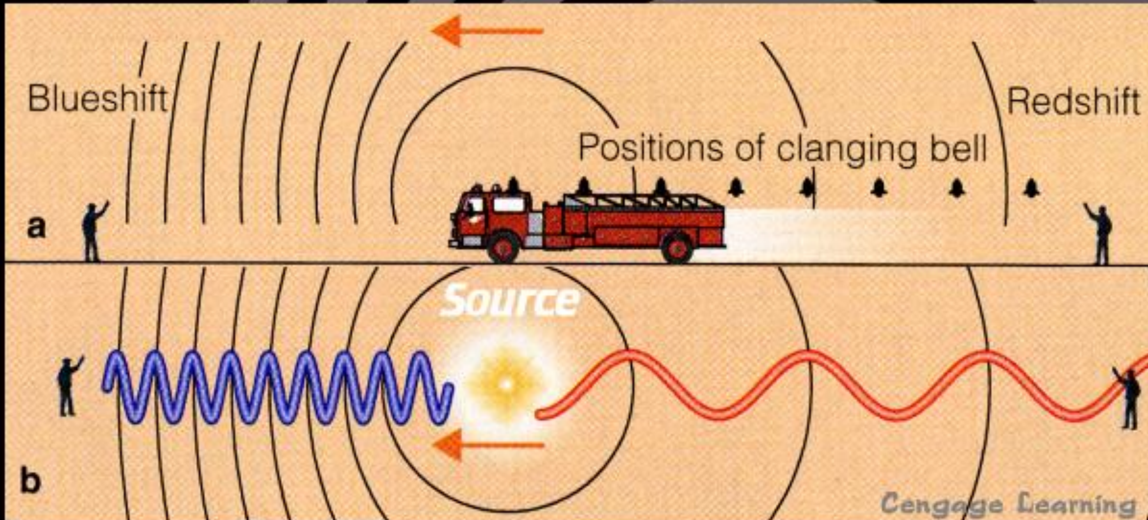



# Sirius A1V Magnitude -1.5



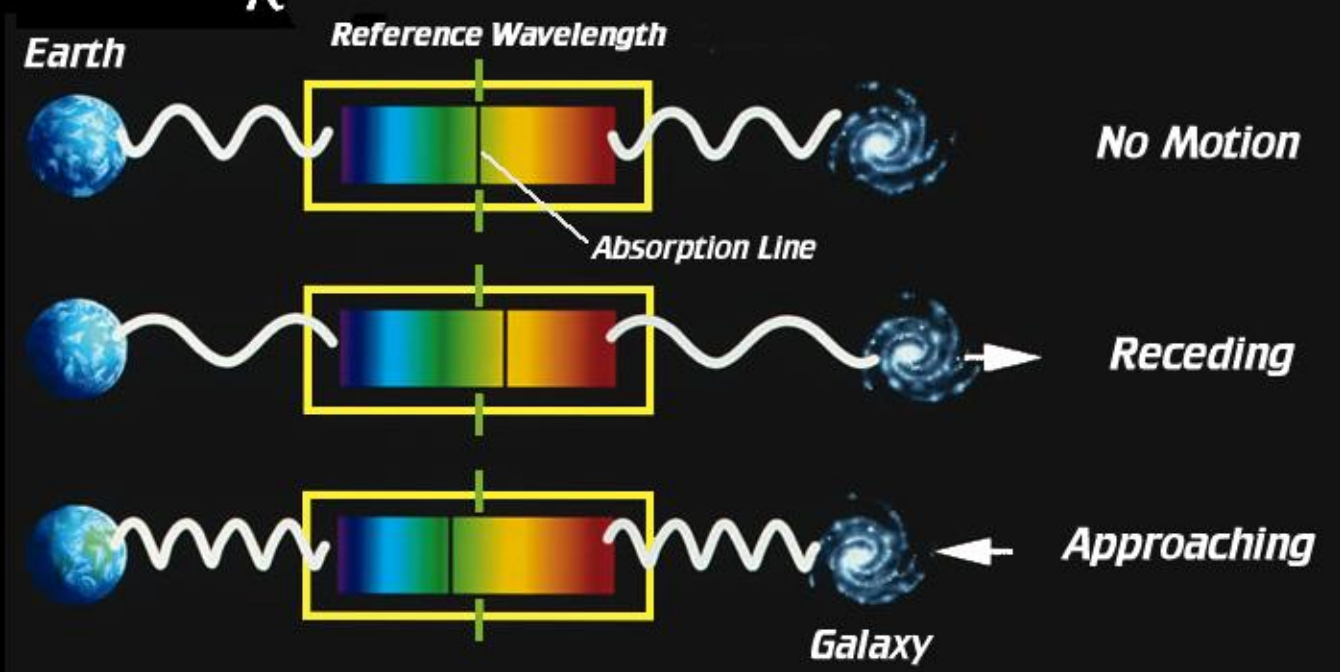
# Doppler Shift

Receding

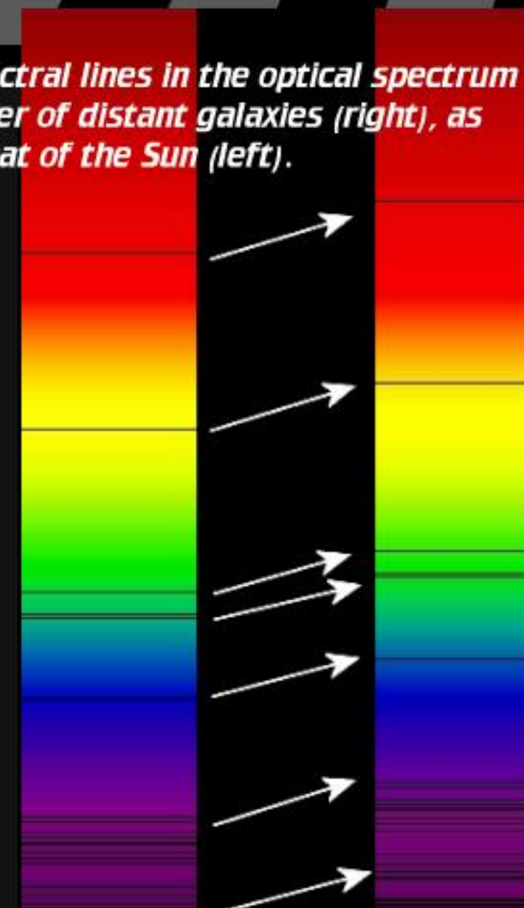


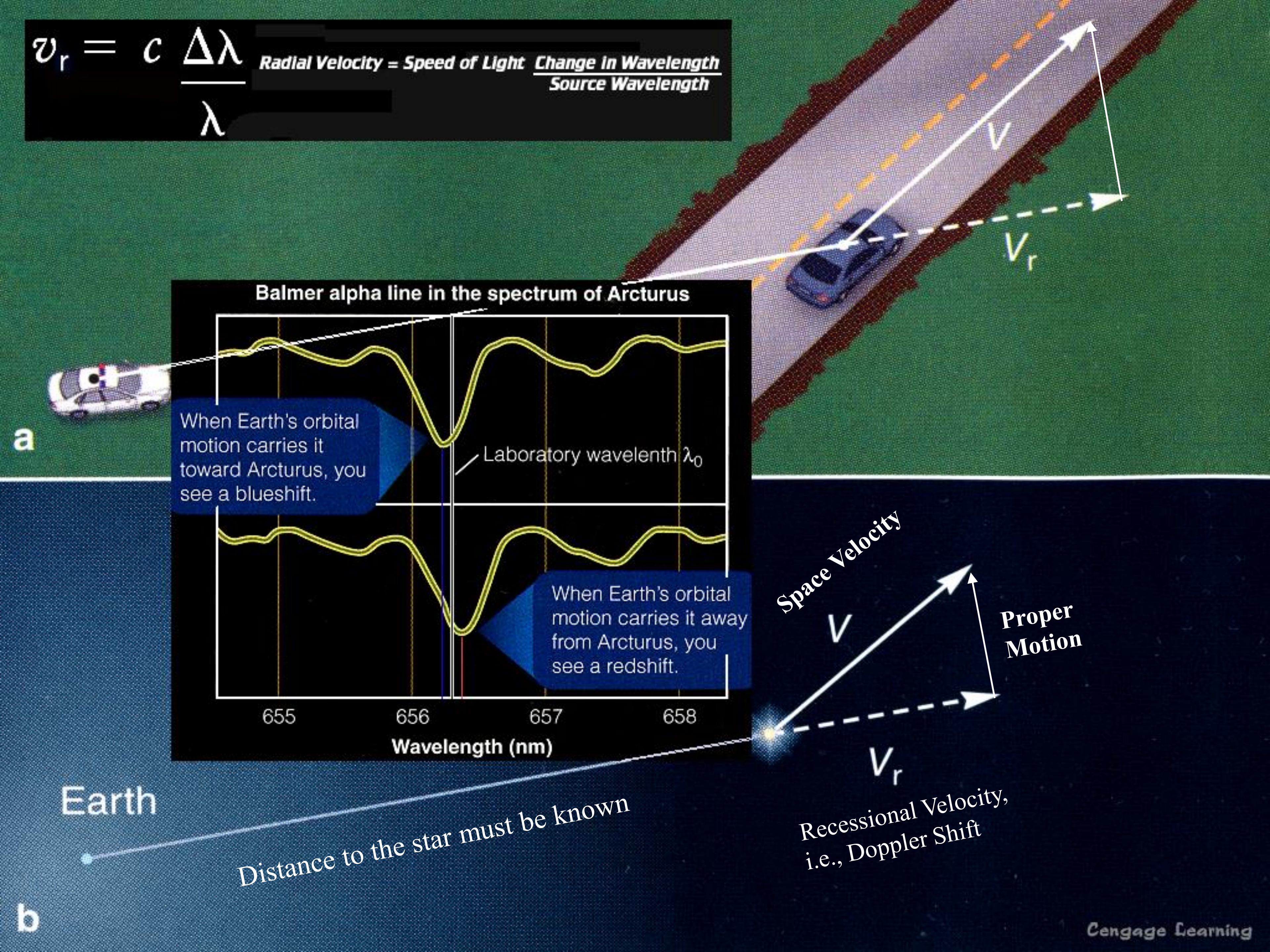

$$v_r = c\,\frac{\Delta\lambda}{\lambda}$$

Radial Velocity = Speed of Light $\frac{\text{Change in Wavelength}}{\text{Source Wavelength}}$

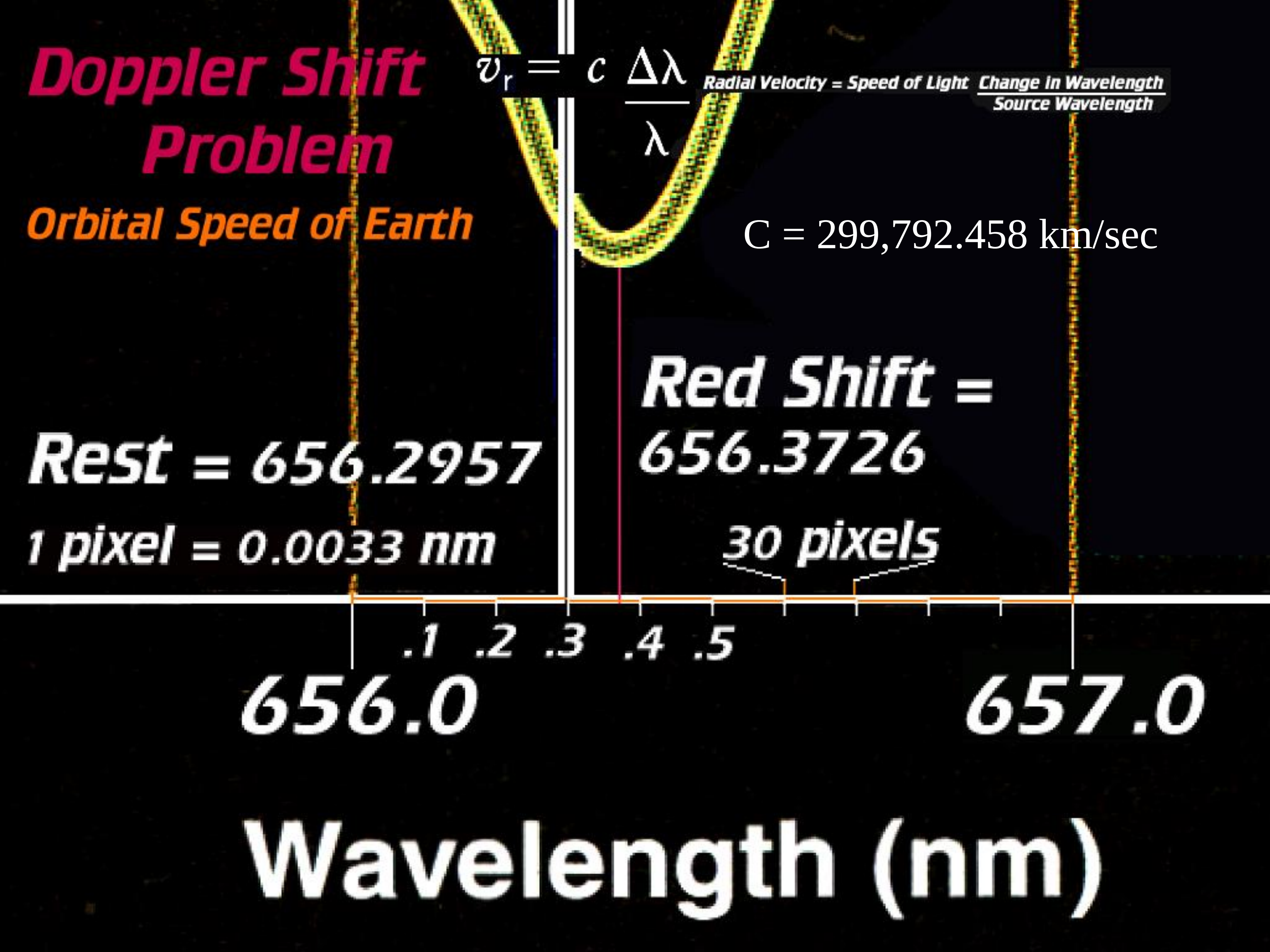



Redshift of spectral lines in the optical spectrum of a supercluster of distant galaxies (right), as compared to that of the Sun (left).





$v_r = c \frac{\Delta\lambda}{\lambda}$
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 $\lambda_0$
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):

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

**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**

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

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

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

**What is $\lambda_{max}$ of the sun if the sun's temperature = 5800 K**

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

$$\mathbf{5 \times 10^3\ Å}$$

$$\mathbf{5000\ Å}$$

**<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 $5.67 \times 10^{-5} \frac{\text{erg}}{\text{cm}^2 \text{ sec T}^4}$**

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

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

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

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

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

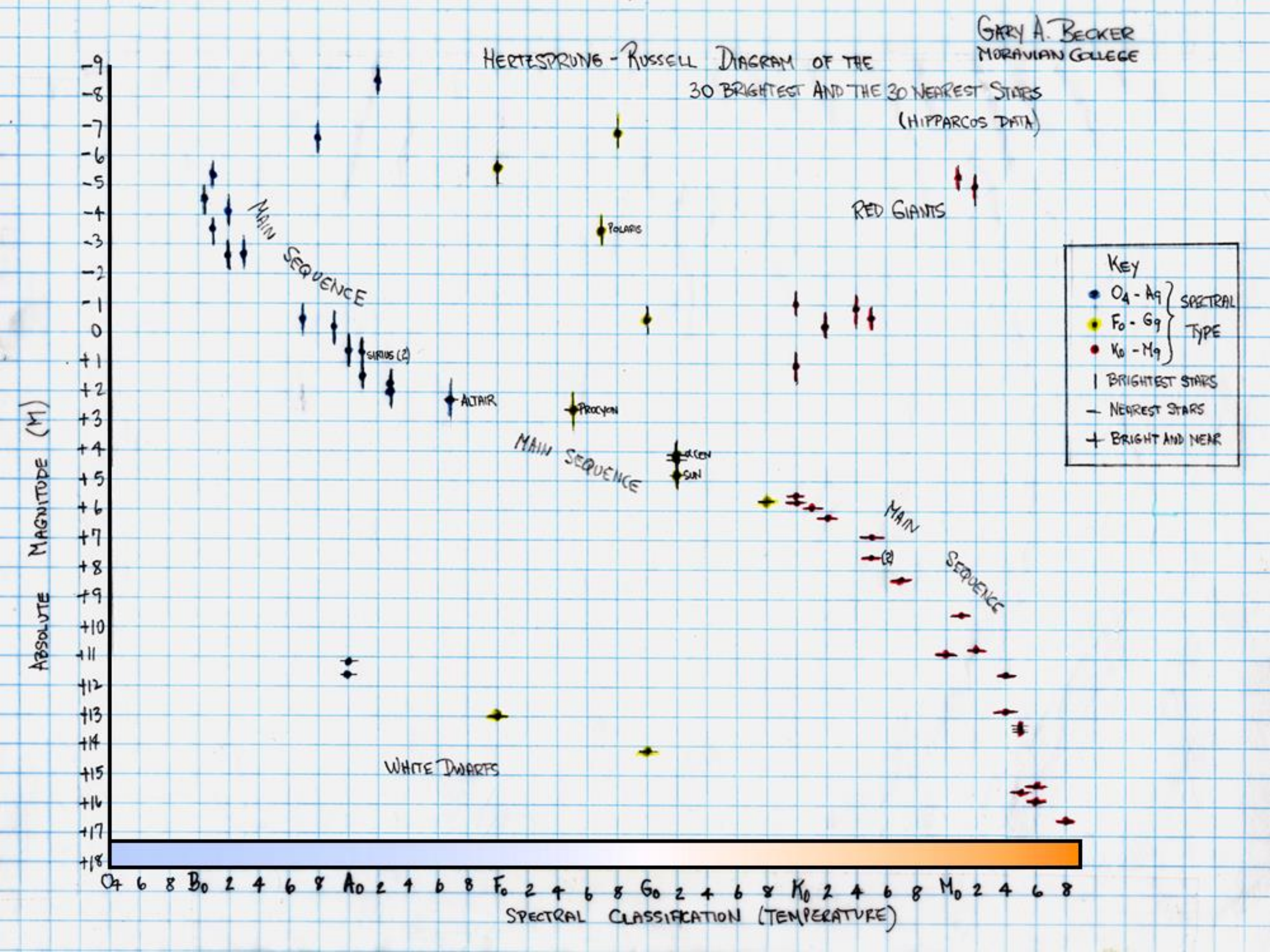
$$E = \rho T^4; \quad E = 5.67 \times 10^{-5} \text{ erg cm}^{-2} \text{ sec}^{-1} \text{ T}^{-4} \times (5800K)^4$$

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

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

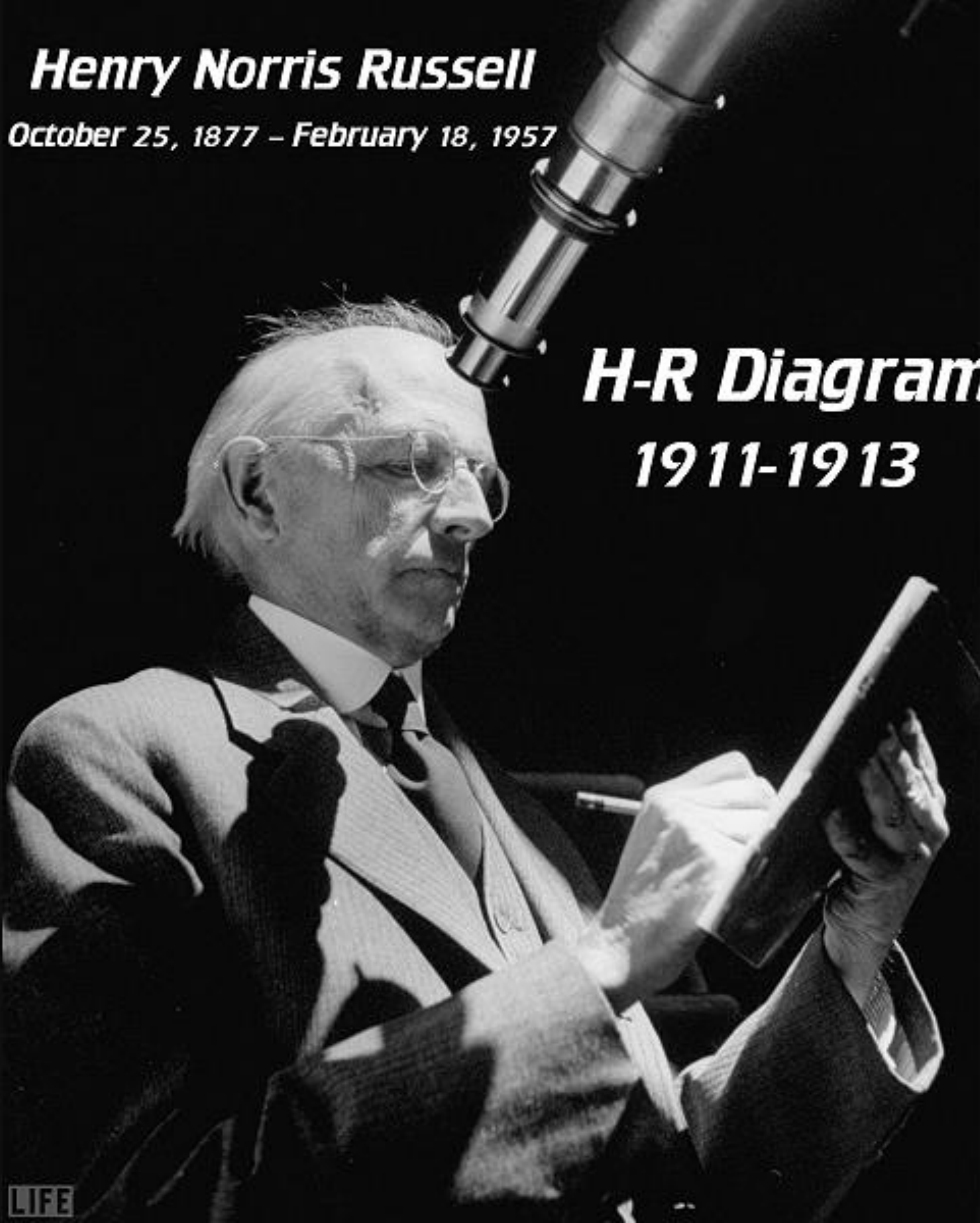
$$E = 6.29 \times 10^{10} \frac{\text{ergs}}{\text{cm}^2 \text{ sec}} \times 6.088 \times 10^{22} \text{ cm}^2 = 38.3 \times 10^{32} \frac{\text{ergs}}{\text{sec}}$$

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


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

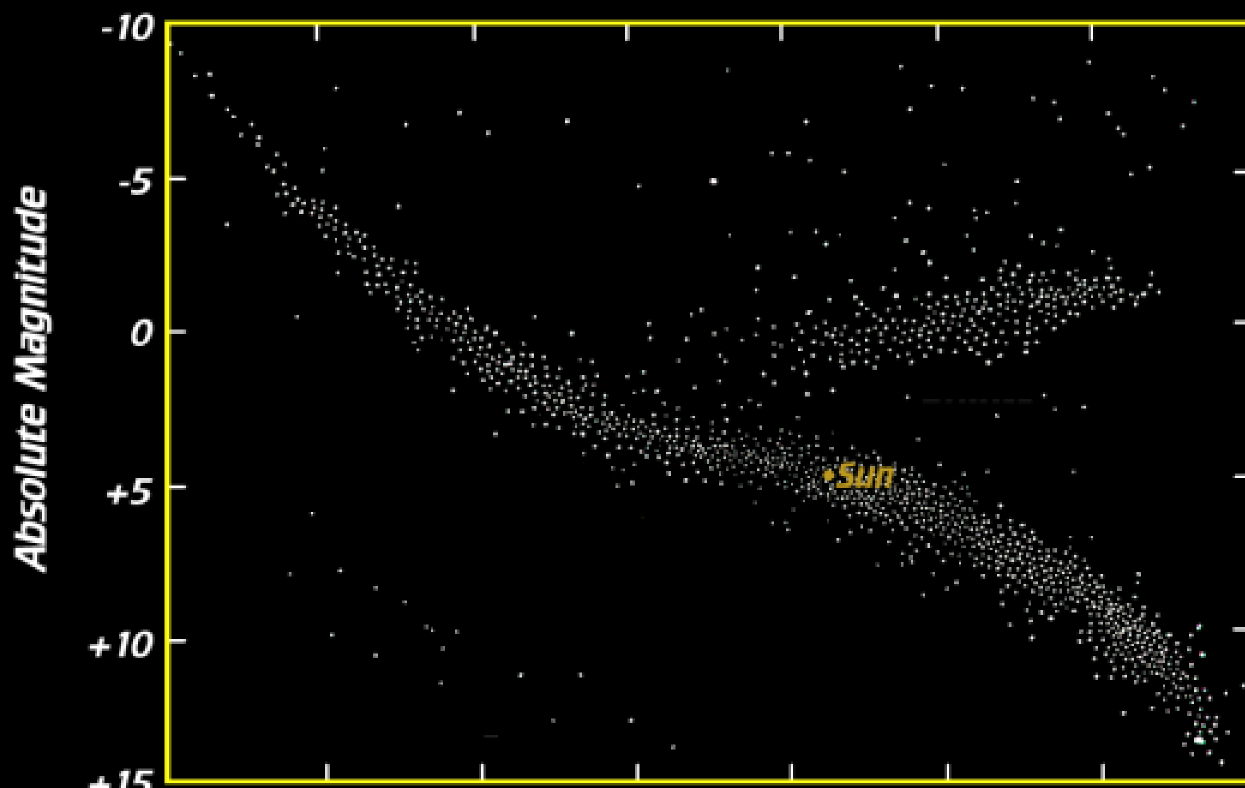


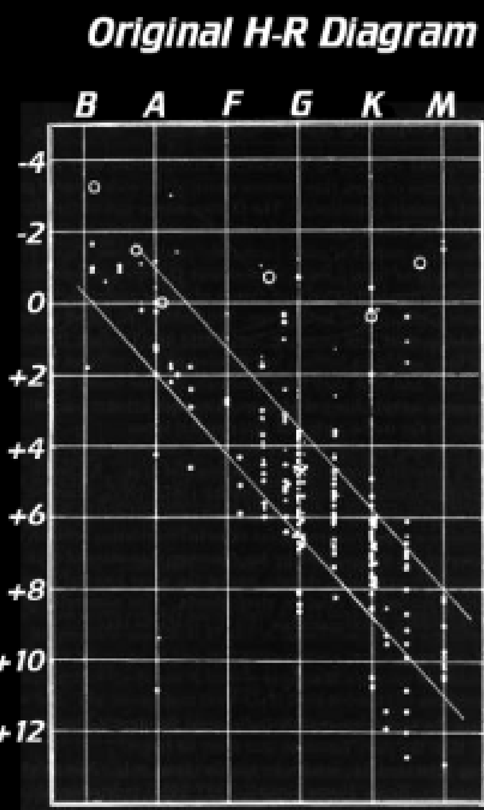

# H-R Diagram
## 1911-1913

# Ejnar Hertzsprung

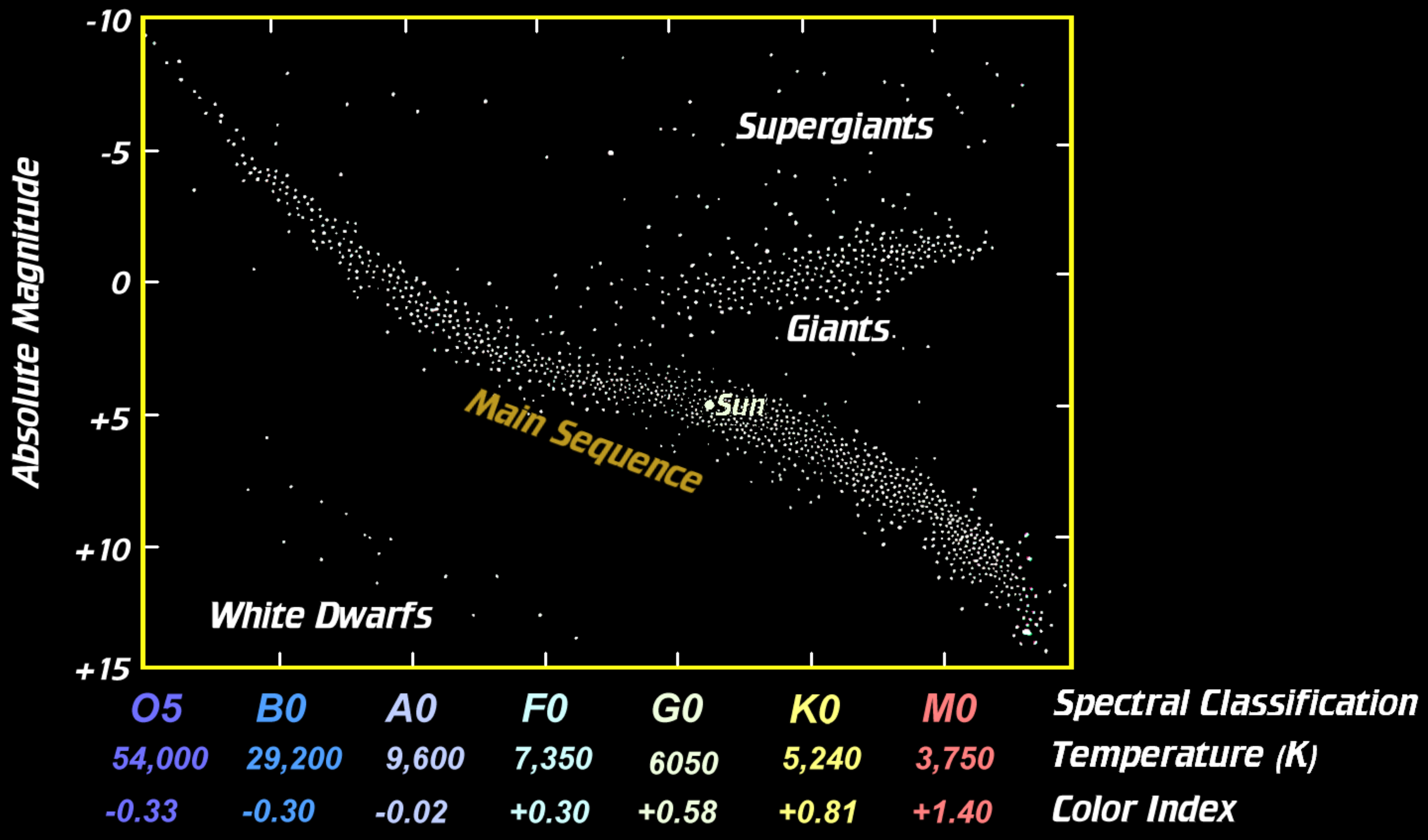
October 8, 1873 - October 21, 1967

# Hertzsprung-Russell Diagram



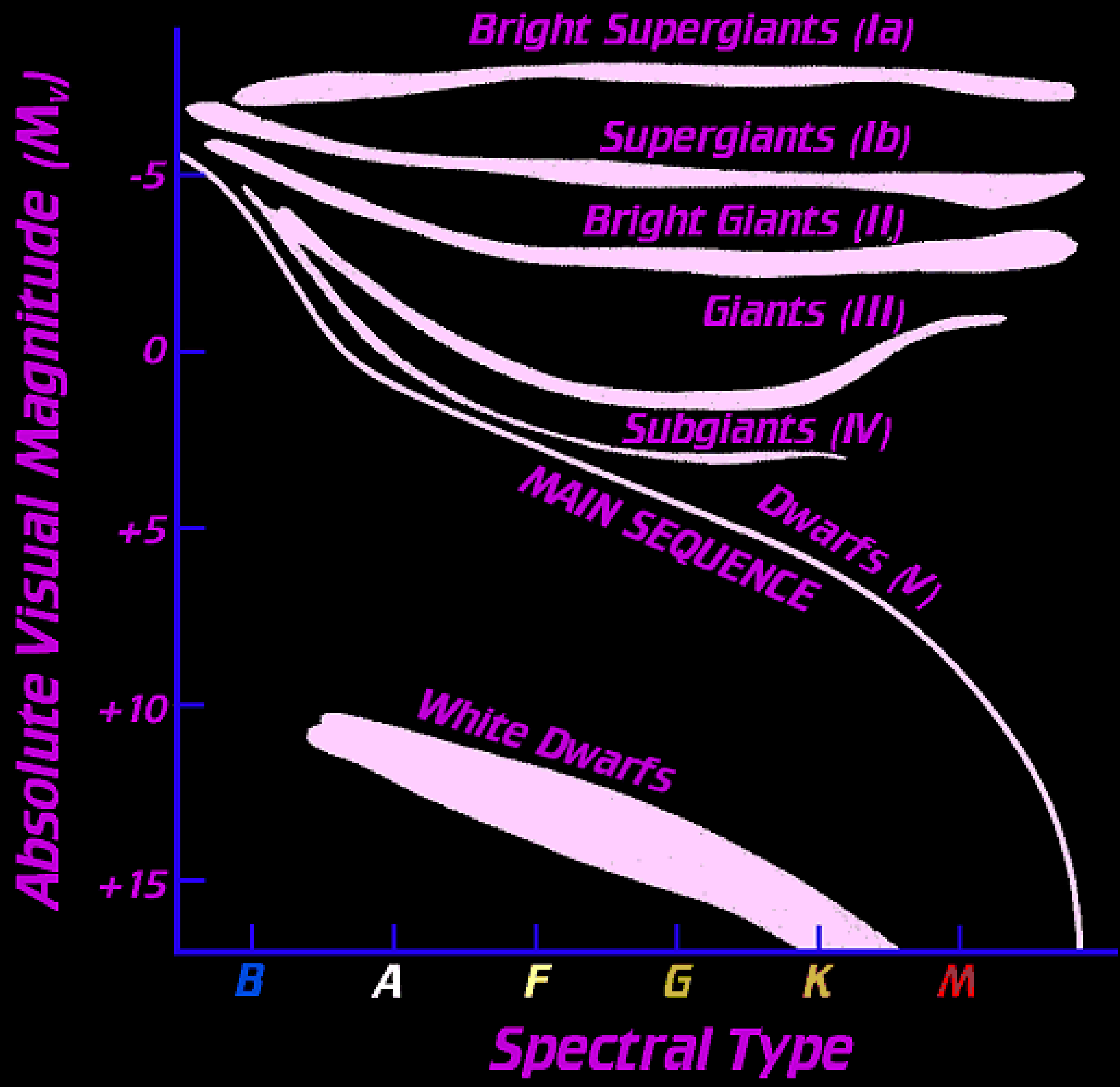



# Hertzsprung-Russell Diagram

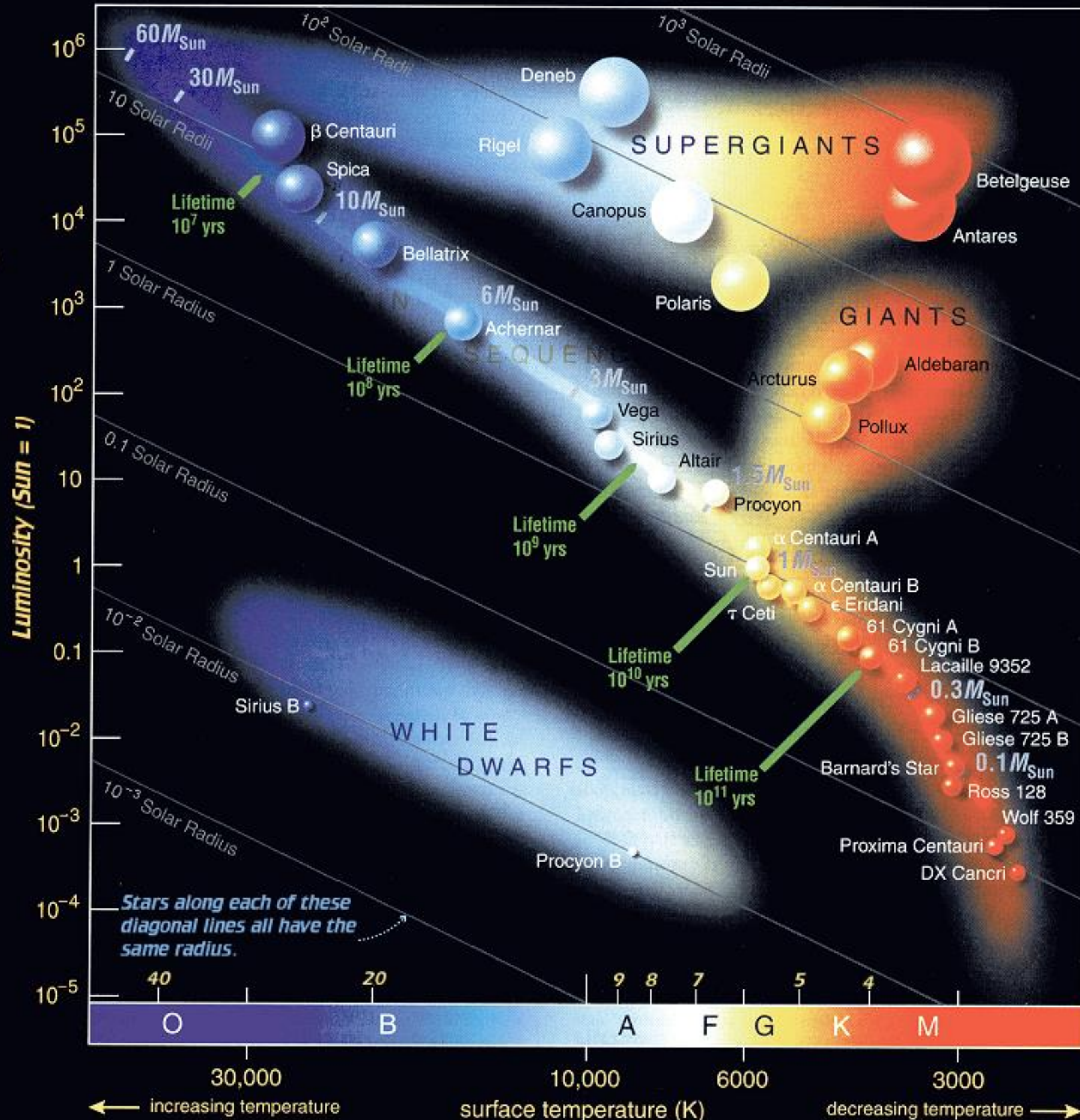



Gary A. Becker slide

# Luminosity Classifications

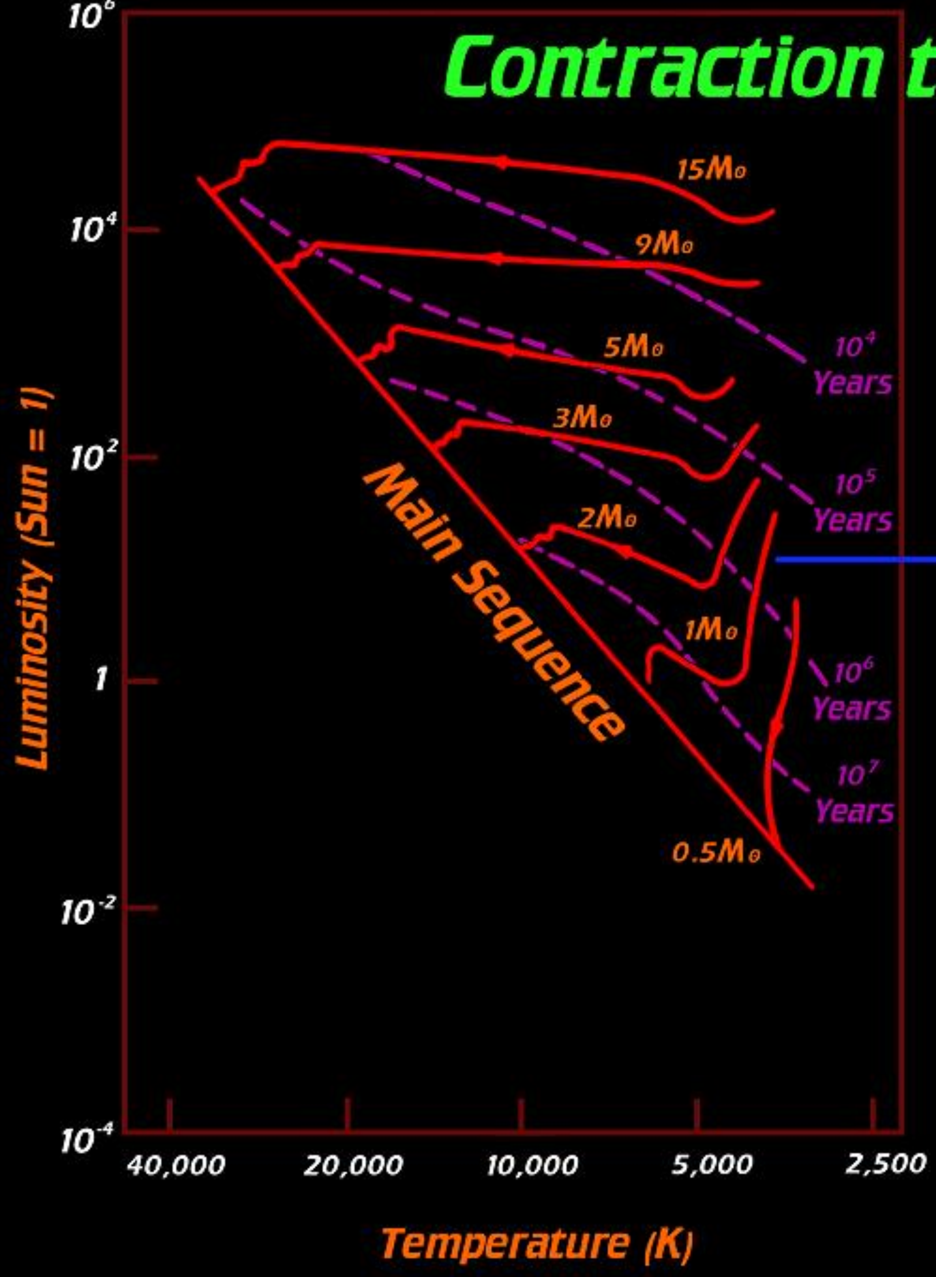


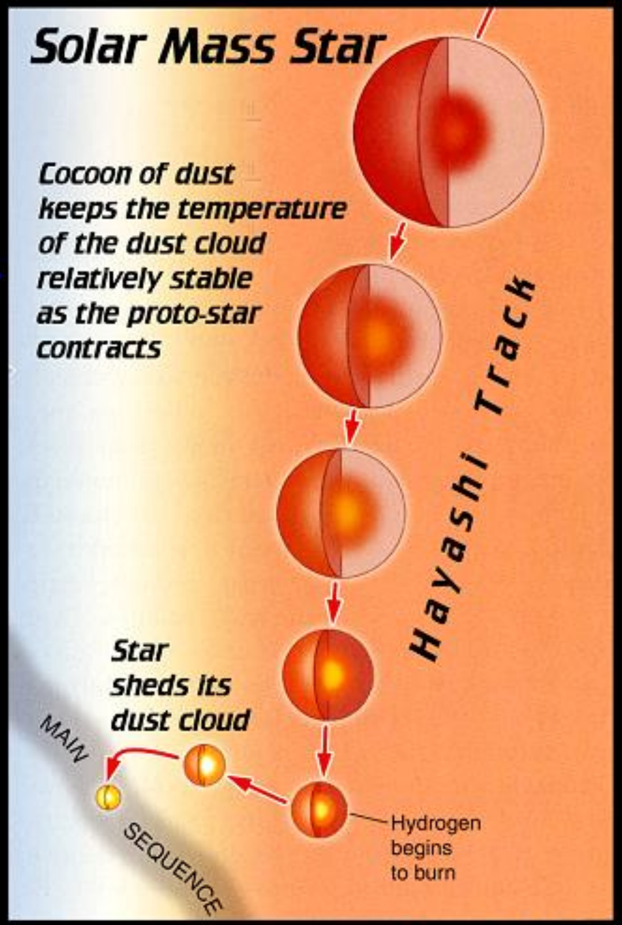
# H-R Diagram



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
Deneb
Rigel
β Centauri
Spica
Bellatrix
Achernar
Vega
Sirius
Altair
Procyon
Canopus
Polaris
Betelgeuse
Antares
SUPERGIANTS
GIANTS
Arcturus
Aldebaran
Pollux
MAIN SEQUENCE
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
Lifetime 10^7 yrs
Lifetime 10^8 yrs
Lifetime 10^9 yrs
Lifetime 10^10 yrs
Lifetime 10^11 yrs
Sirius B
WHITE DWARFS
Procyon B
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 →

# Contraction to Zero Age Main Sequence




Cengage Learning

# Monroe

## Cabarrus County, NC

Ordinary Chondrite H4, 8.6 kg total mass

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

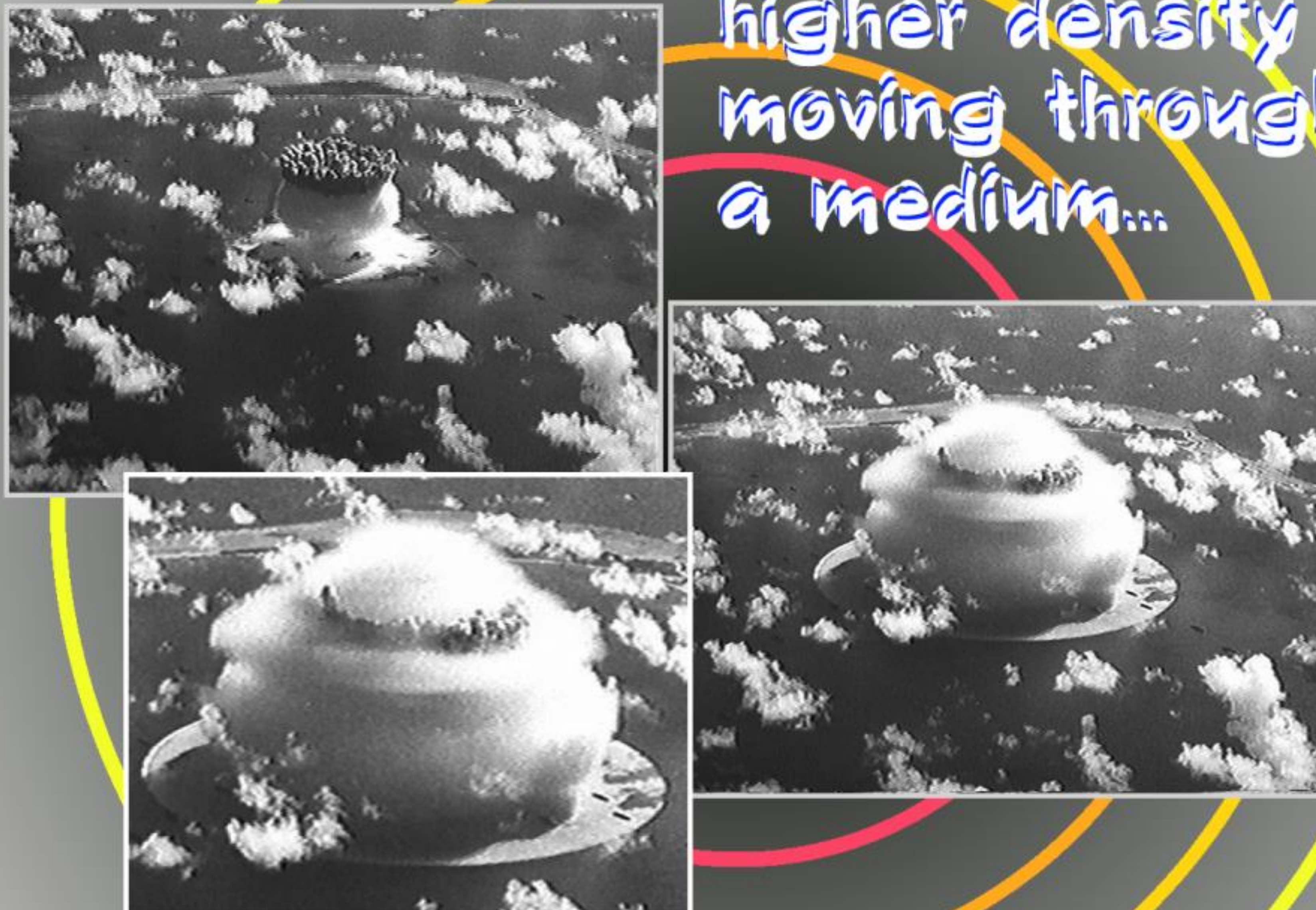
1 gm specimen

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...

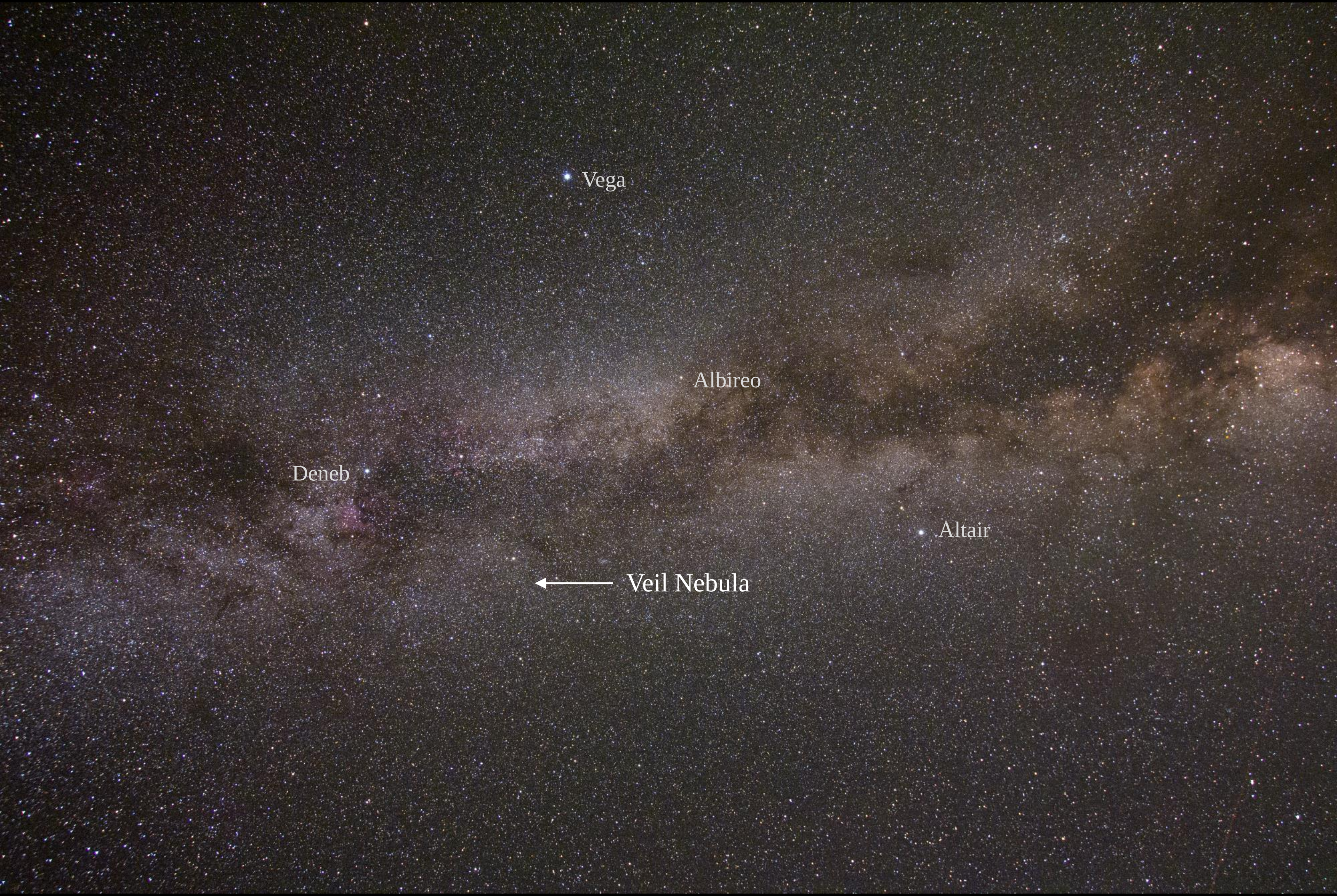


# Atomic Bomb Shock Front

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

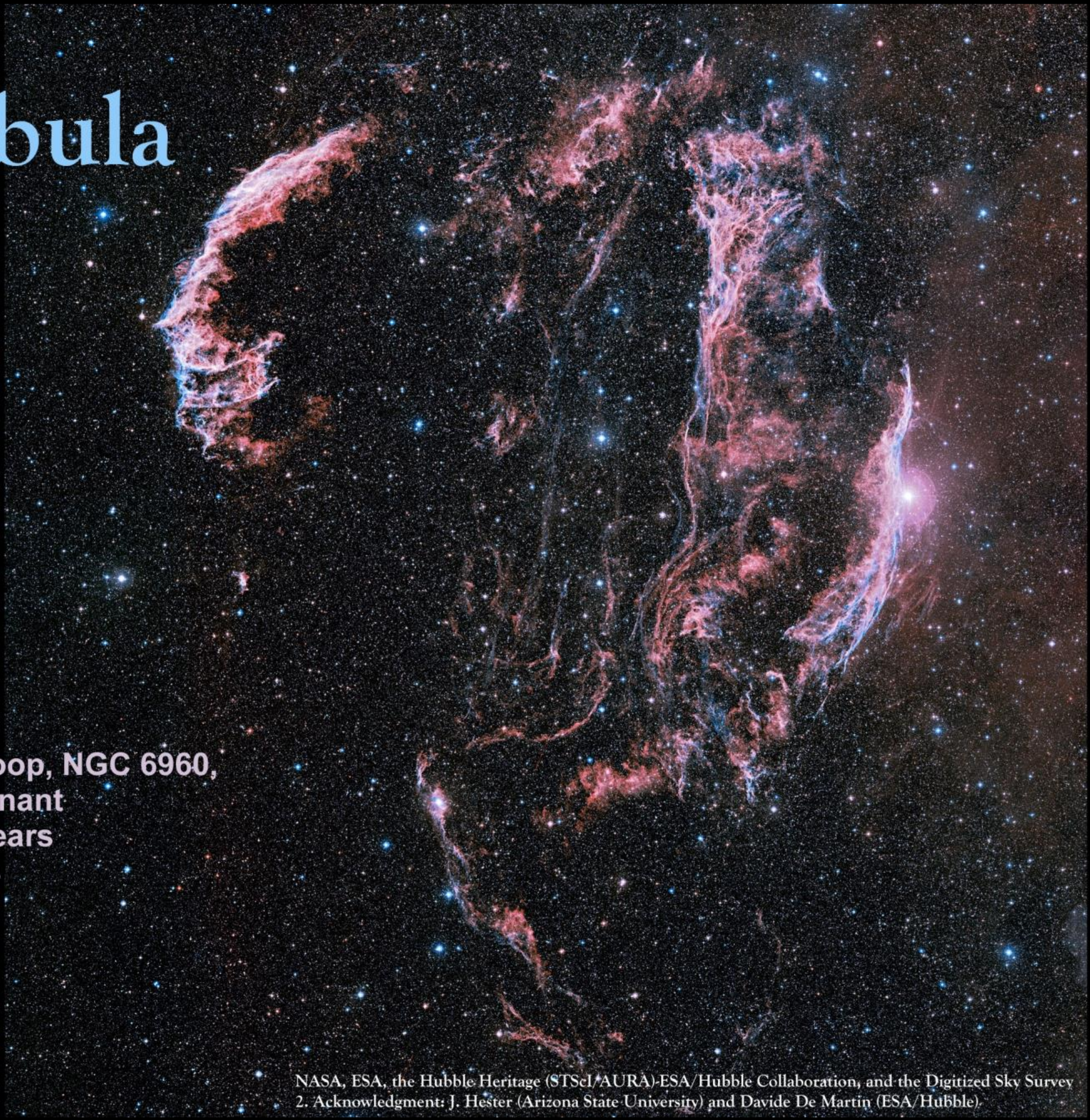

Beirut, Lebanon Explosion
August 4, 2020
3031 tons of ammonium nitrate
Ágoston Németh


Beirut, Lebanon
Ágoston Németh

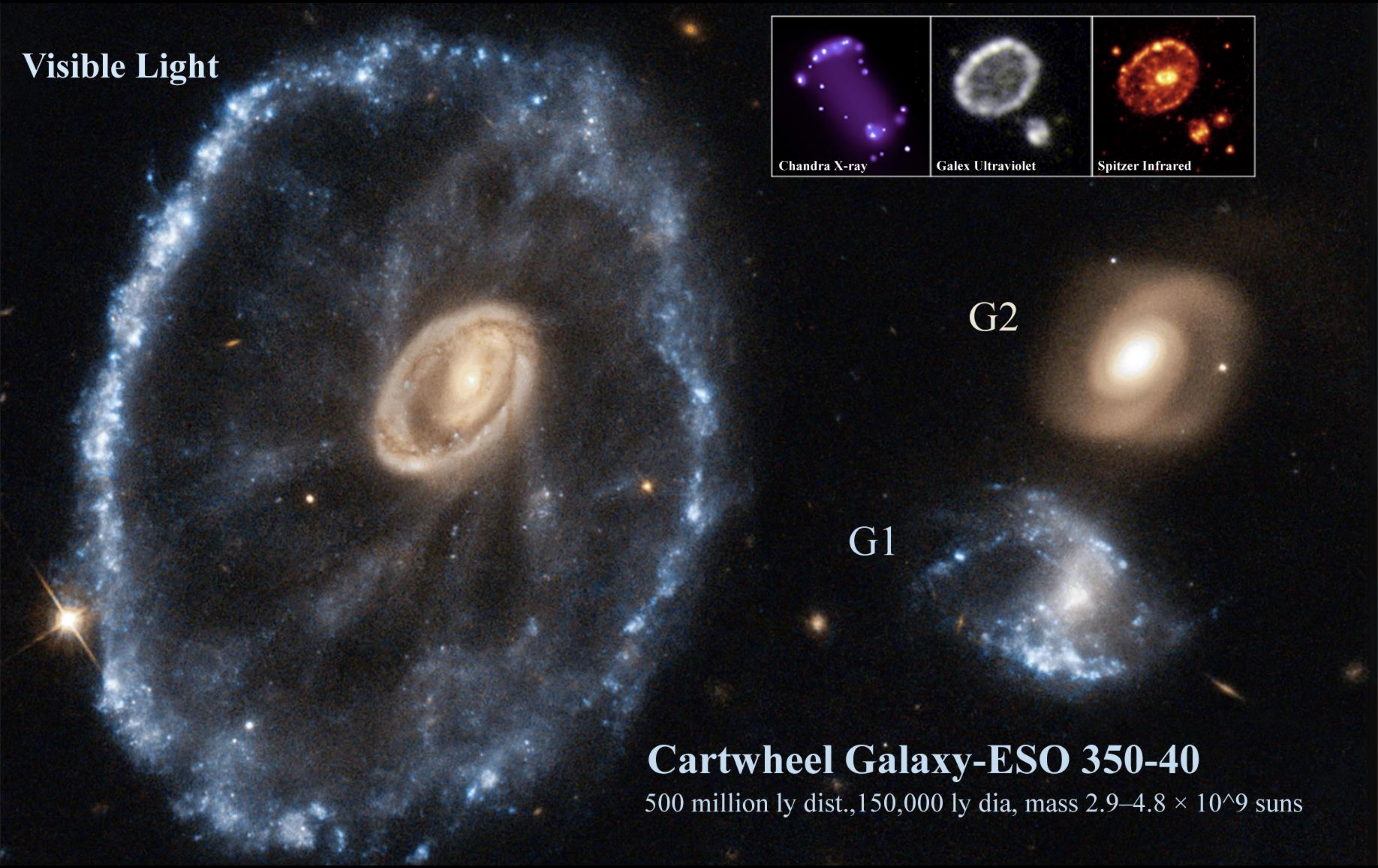



MDRS-Gary A, Becker image

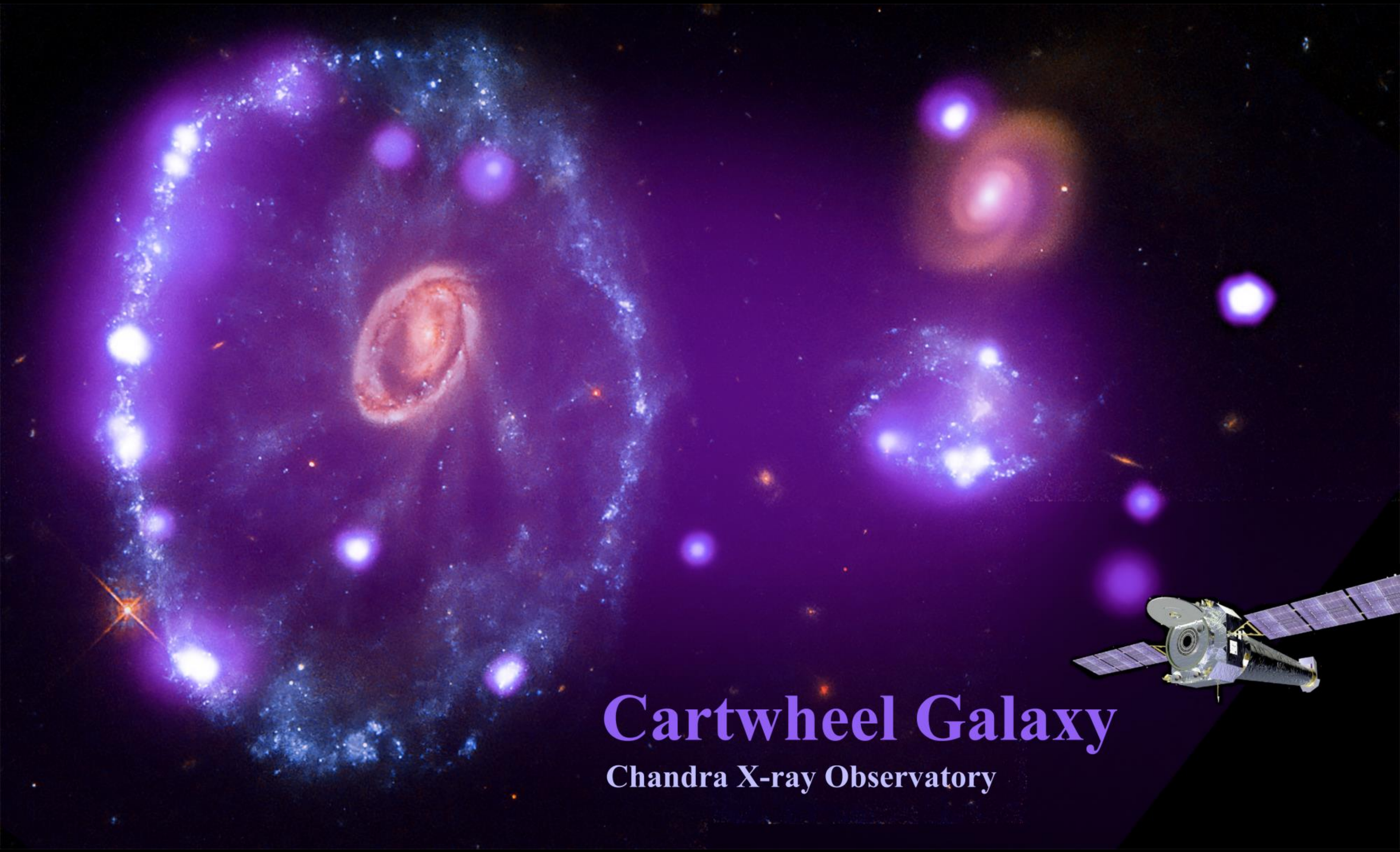
# Veil Nebula




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



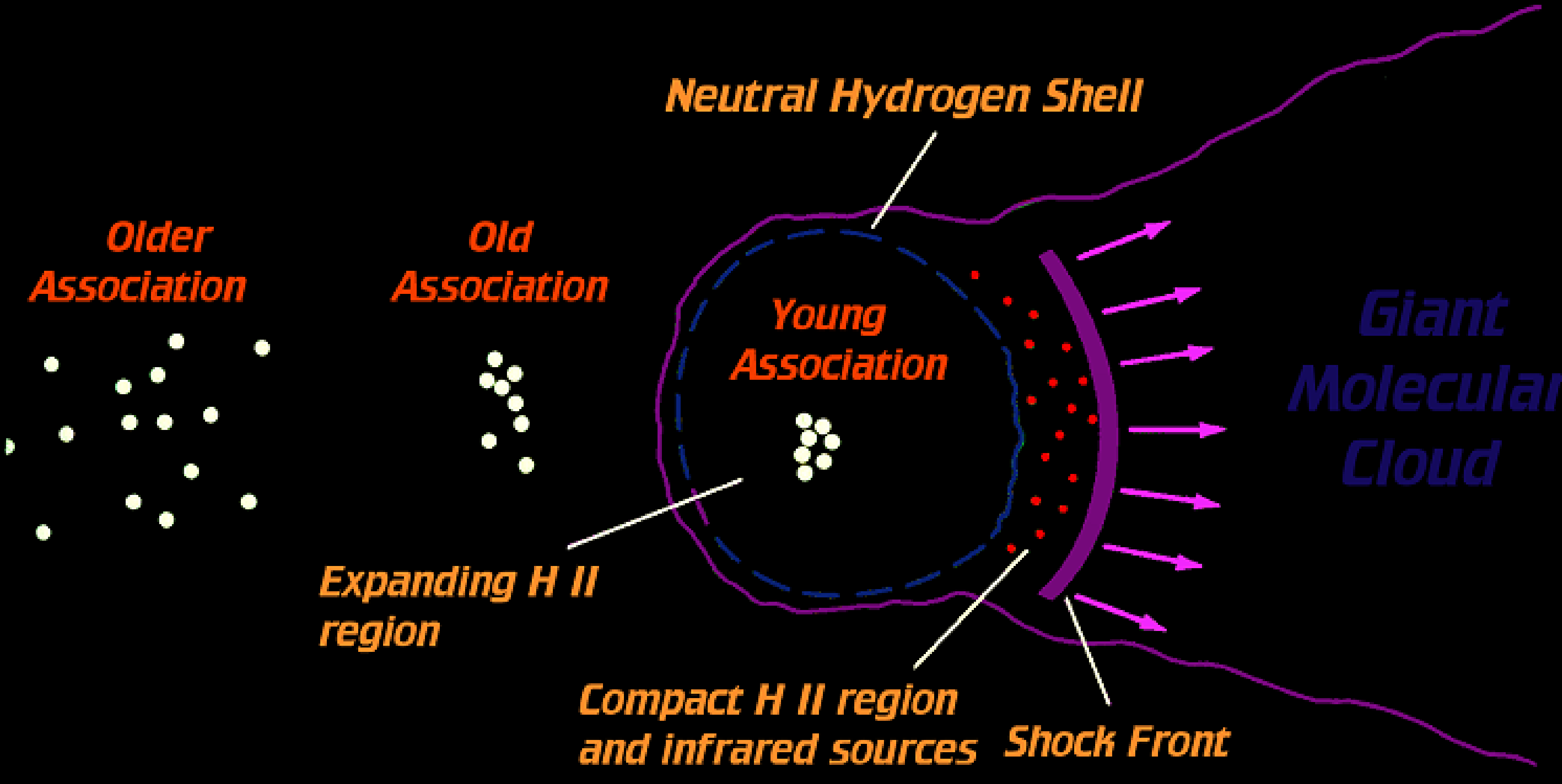

Hubble Space Telescope/insets: Chandra X-Ray Observatory/GALEX: Galaxy Evolution Explorer /Spitzer Space Telescope




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

# Whirlpool Galaxy, M51, NGC 5194/5

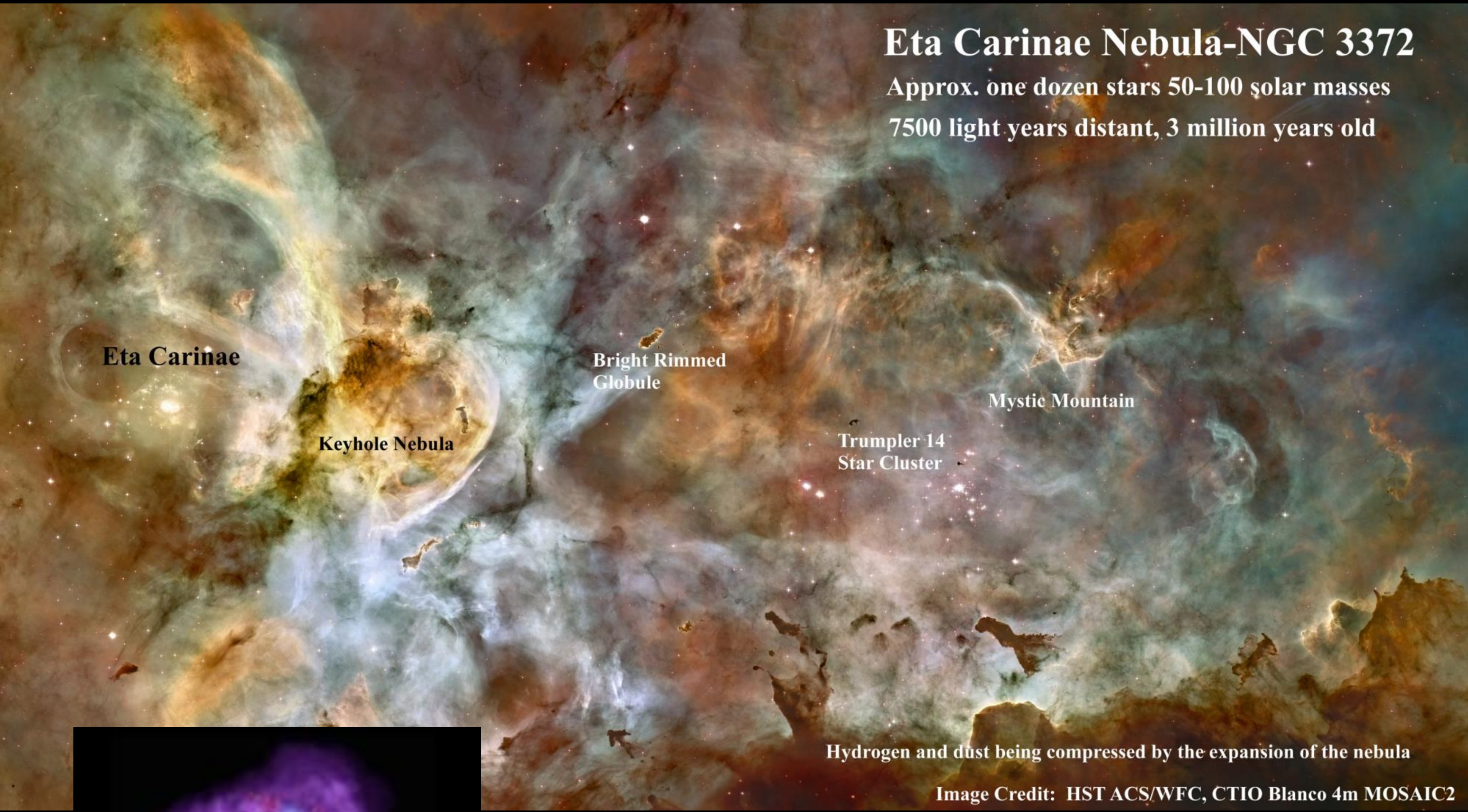
# OB Associations



# Eta Carinae Nebula

Carina the Keel, Southern Hemisphere

Image by Riccardi-Honders Veloce, Kalahari Desert, Namibia

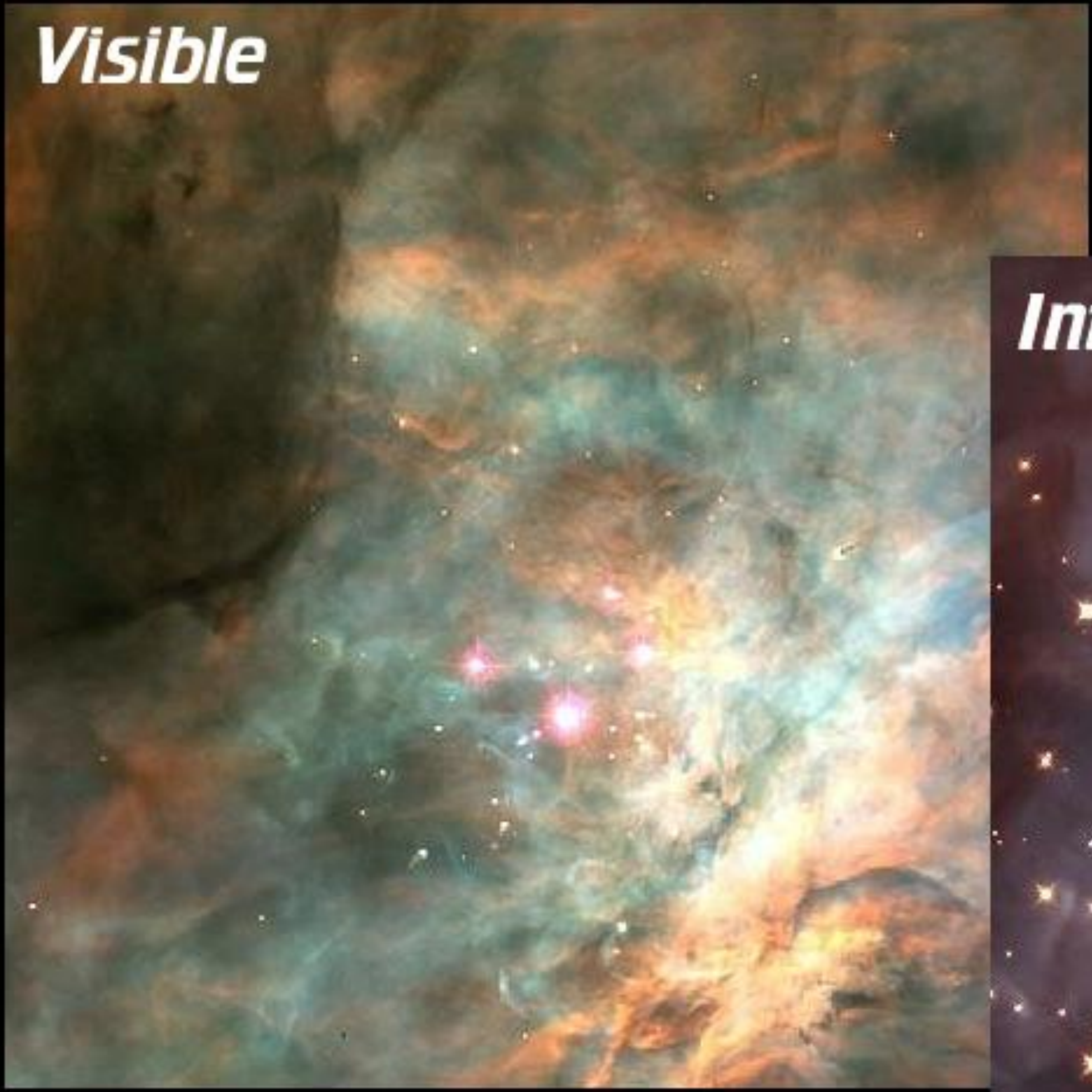

Eta Carinae Nebula-NGC 3372
Approx. one dozen stars 50-100 solar masses
7500 light years distant, 3 million years old
Eta Carinae
Keyhole Nebula
Bright Rimmed
Globule
Mystic Mountain
Trumpler 14
Star Cluster
Hydrogen and dust being compressed by the expansion of the nebula
Image Credit: HST ACS/WFC,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

# Stellar Birth in Orion


Running Man-M43
Orion Nebula-M42
NGC 1980


Hubble Space Telescope

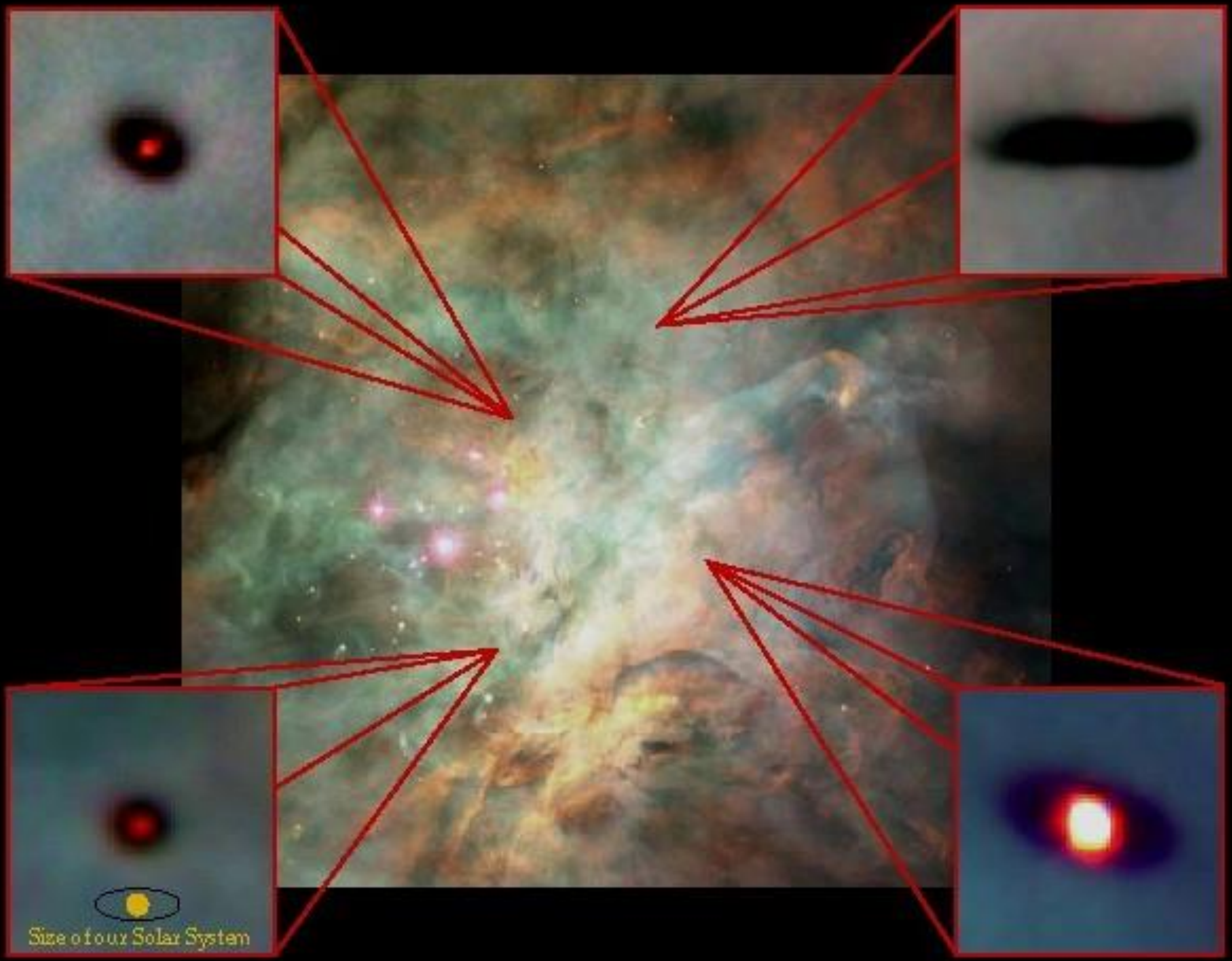
# Trapezium





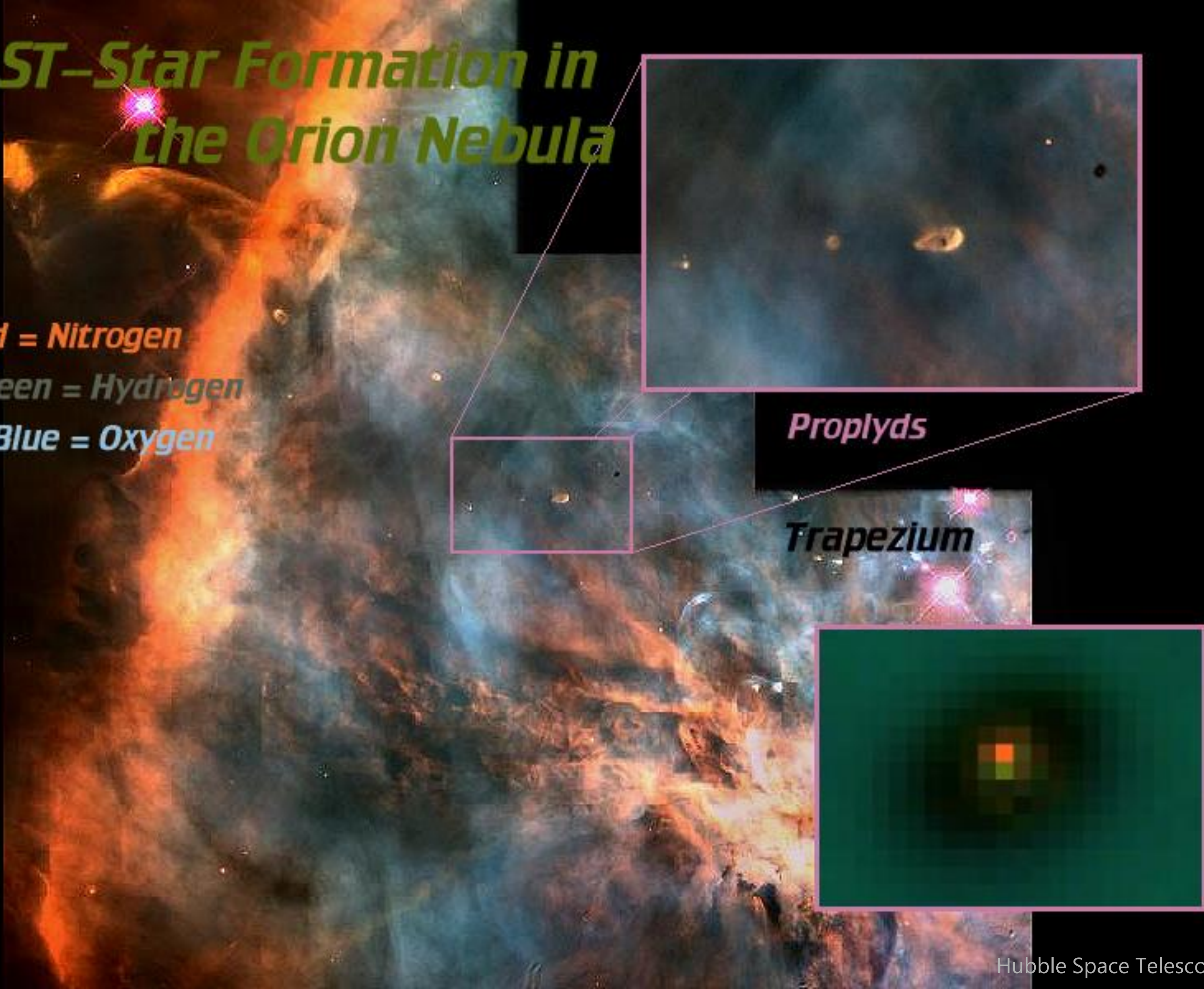
Hubble Space Telescope

# Stellar Birth Near Trapezium




Hubble Space Telescope

# HST–Star Formation in the Orion Nebula




Hubble Space Telescope

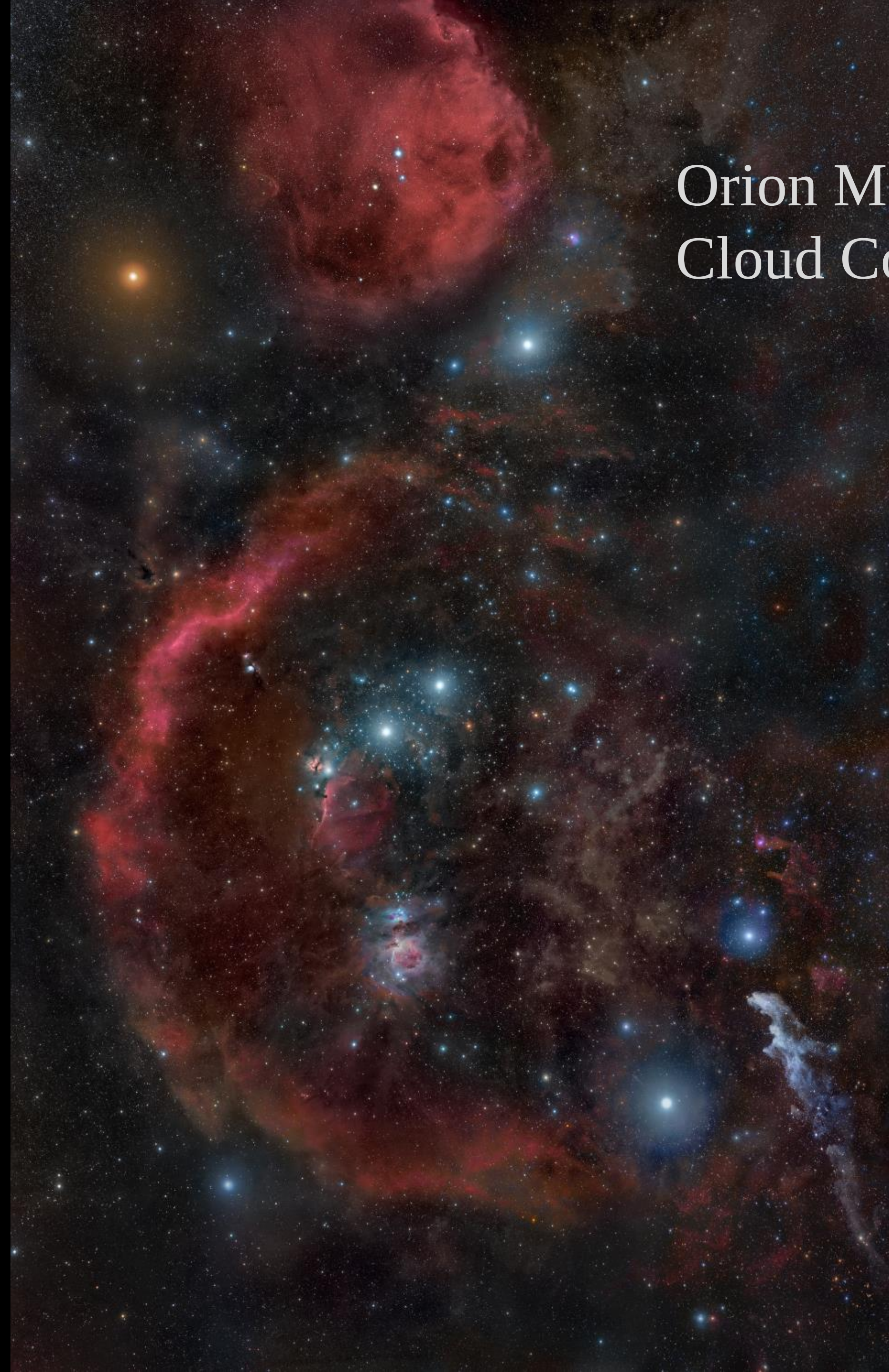
# Which one of these proplyds will become a star?

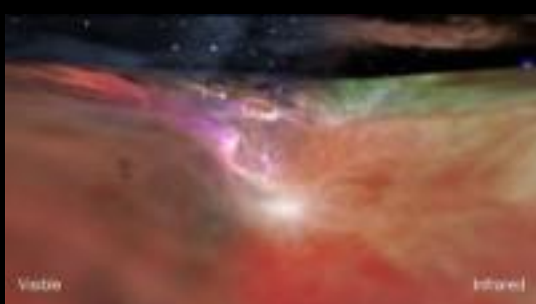
# Sagittarius C

## Center of the Milky Way Galaxy


James Webb Space Telescope

# Orion Molecular Cloud Complex






Rogelio Bernal Andreo

# Horsehead Region of Orion


John Sefic image

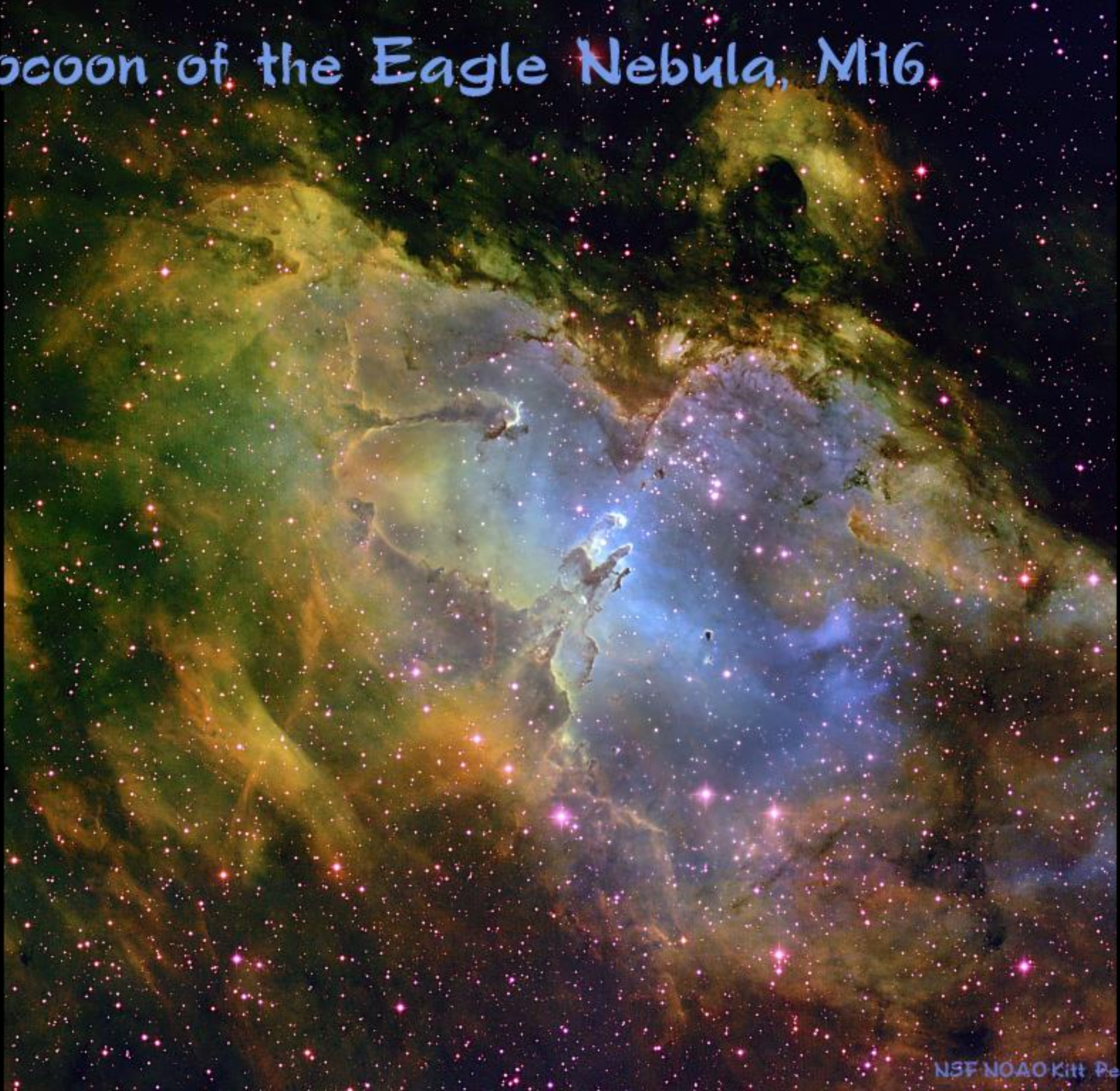
Horsehead Nebula

Barnard 33


# Horsehead

Orion, the Hunter

# The Cocoon of the Eagle Nebula, M16

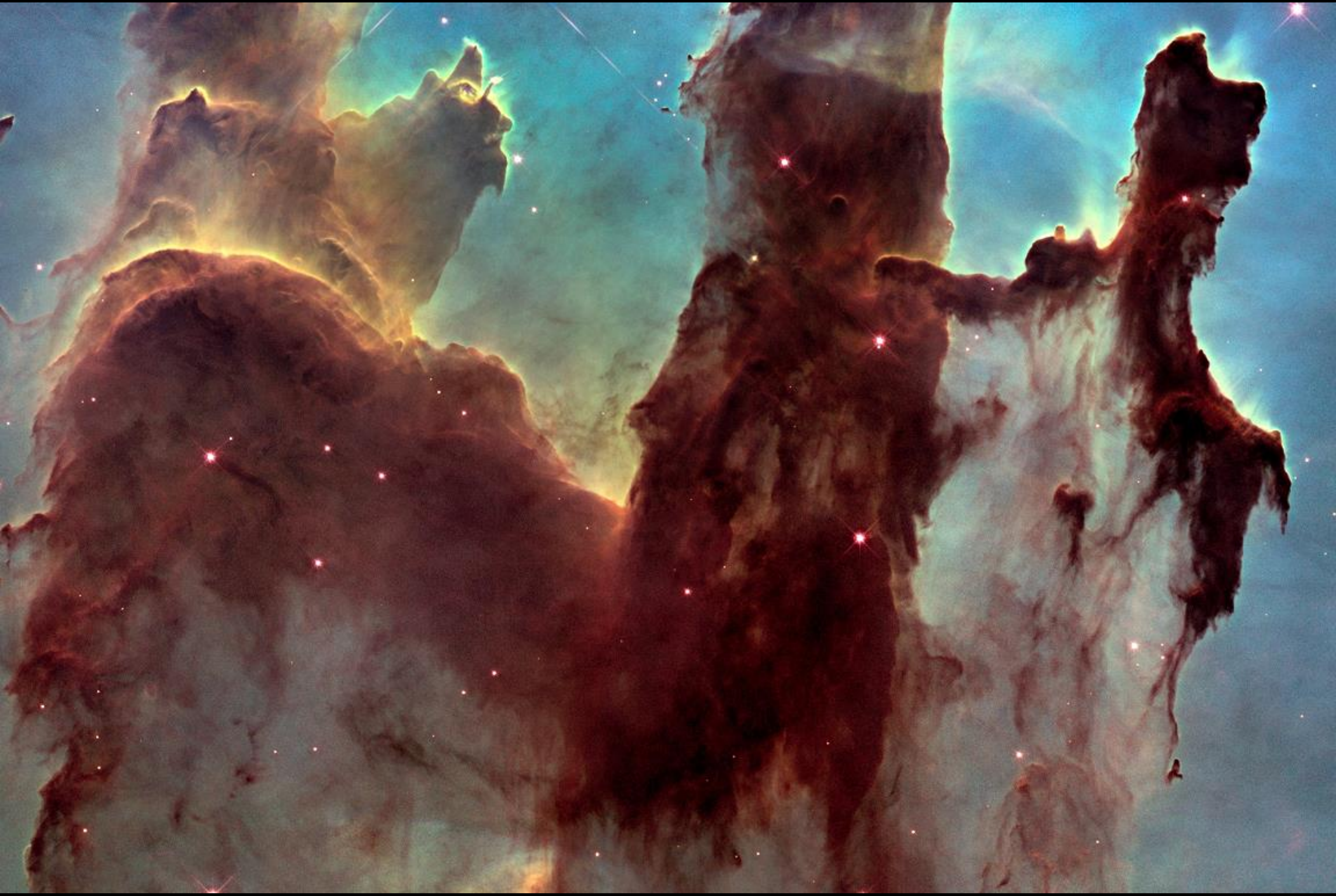


# Eagle Interior

NSF-NOAO-Kitt Peak image

# Pillars of Creation/Visible

# Pillars of Creation/Infrared

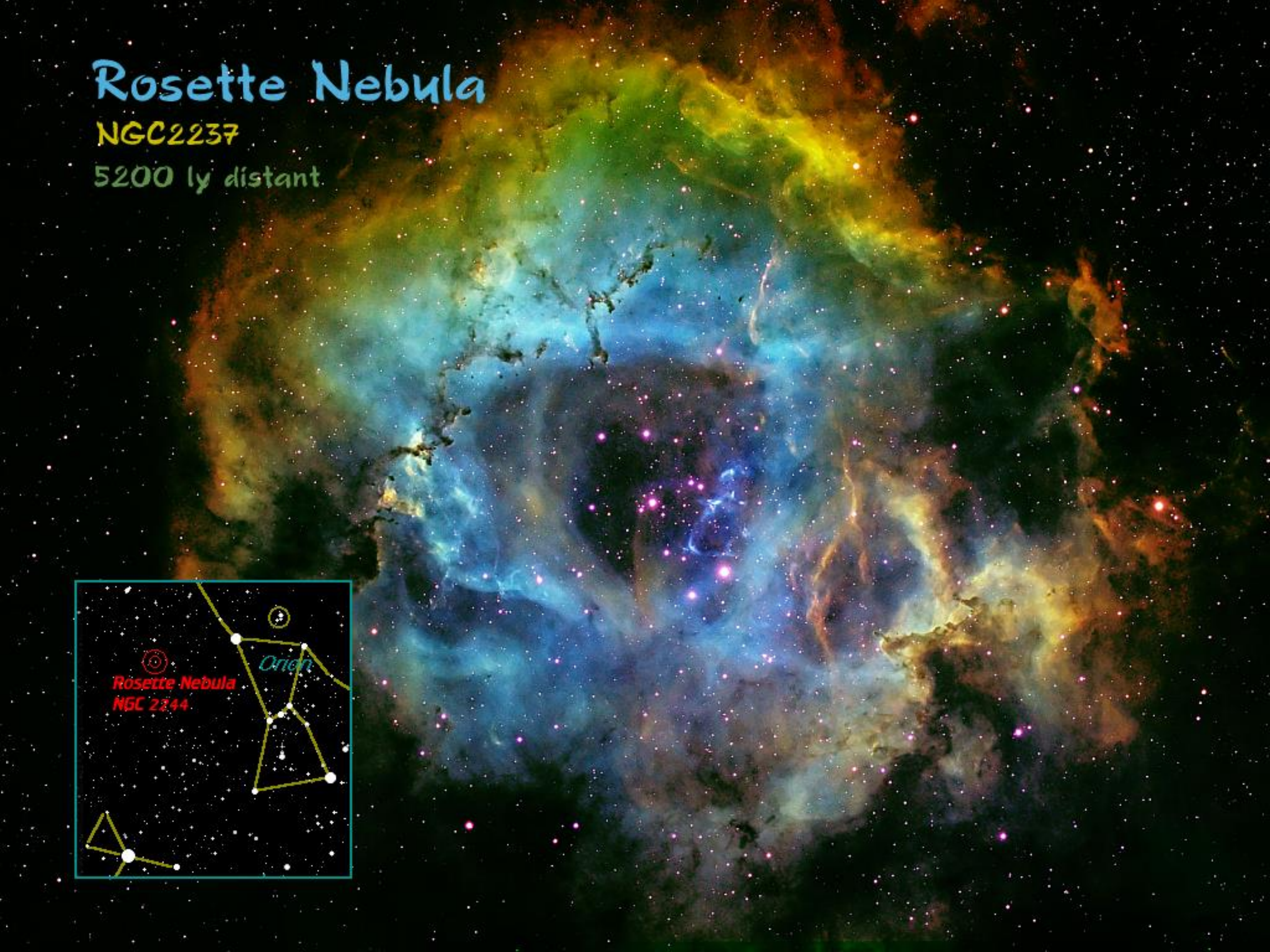


Hubble Space Telescope image

Hubble Space Telescope image

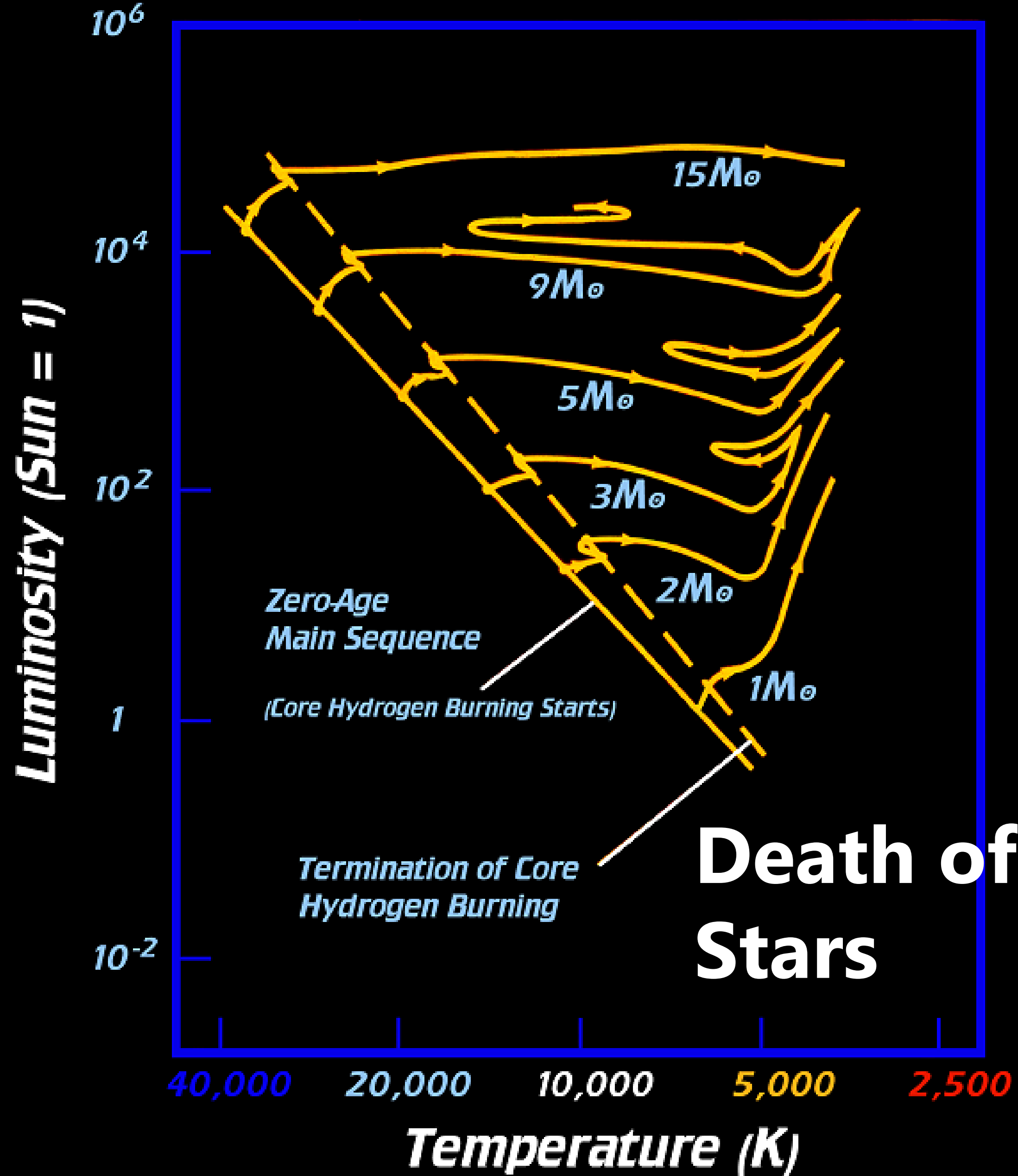
Hubble Space Telescope image


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



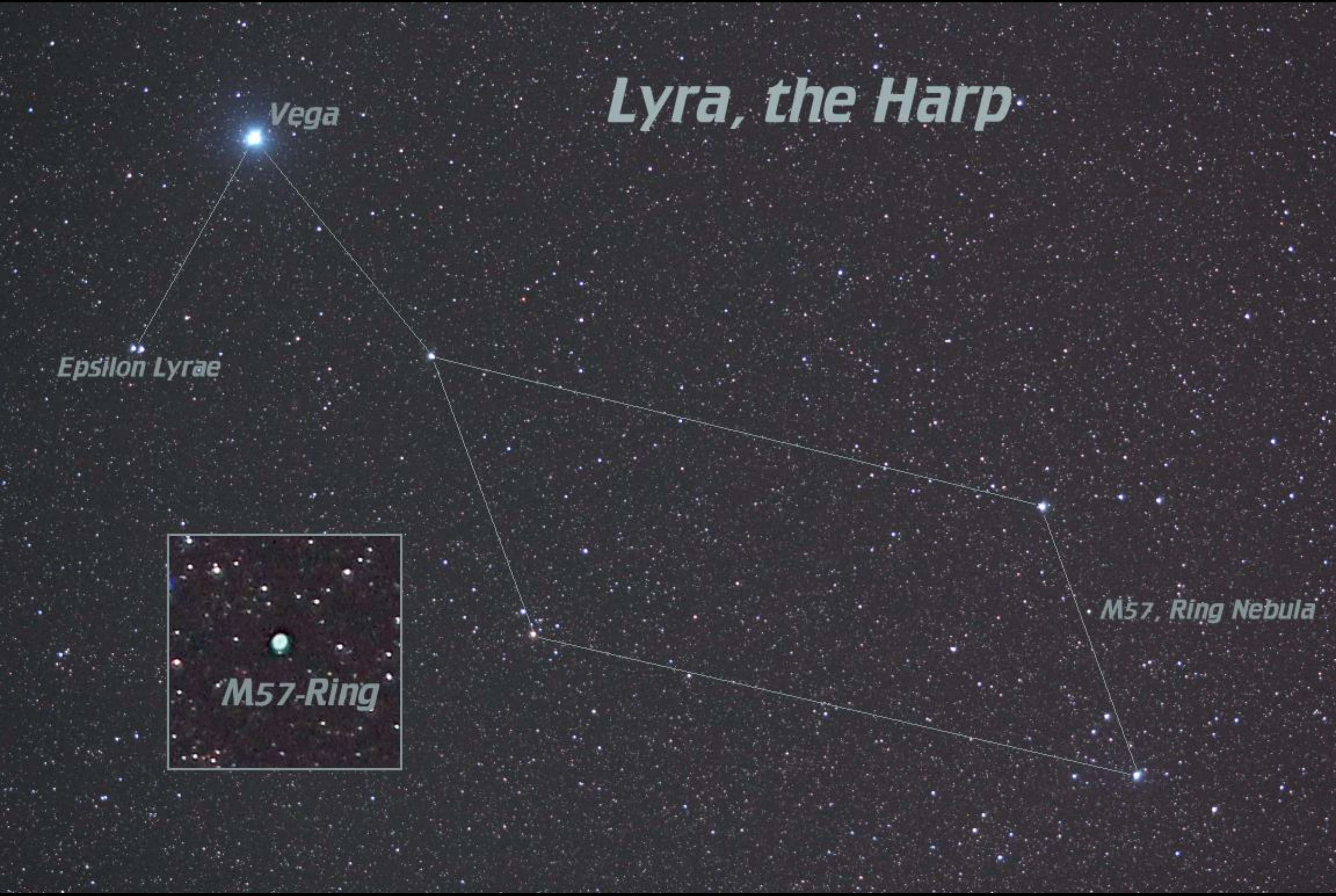
Rosette Nebula
NGC2237
5200 ly distant
Orion
Rosette Nebula
NGC 2244

Hubble Space Telescope




# Influence of Mass on the Evolution of Stars

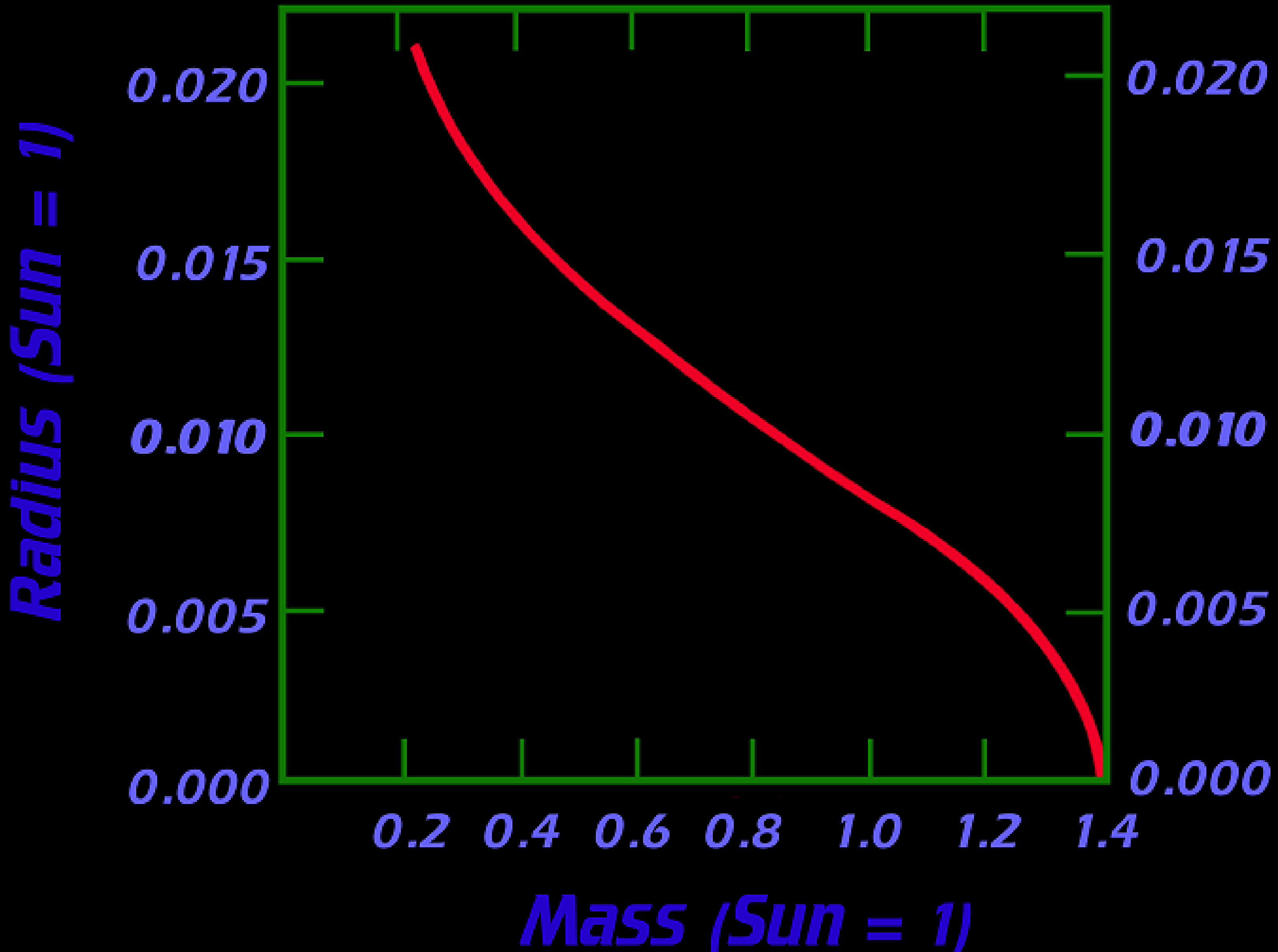
## Death of Low Mass Stars



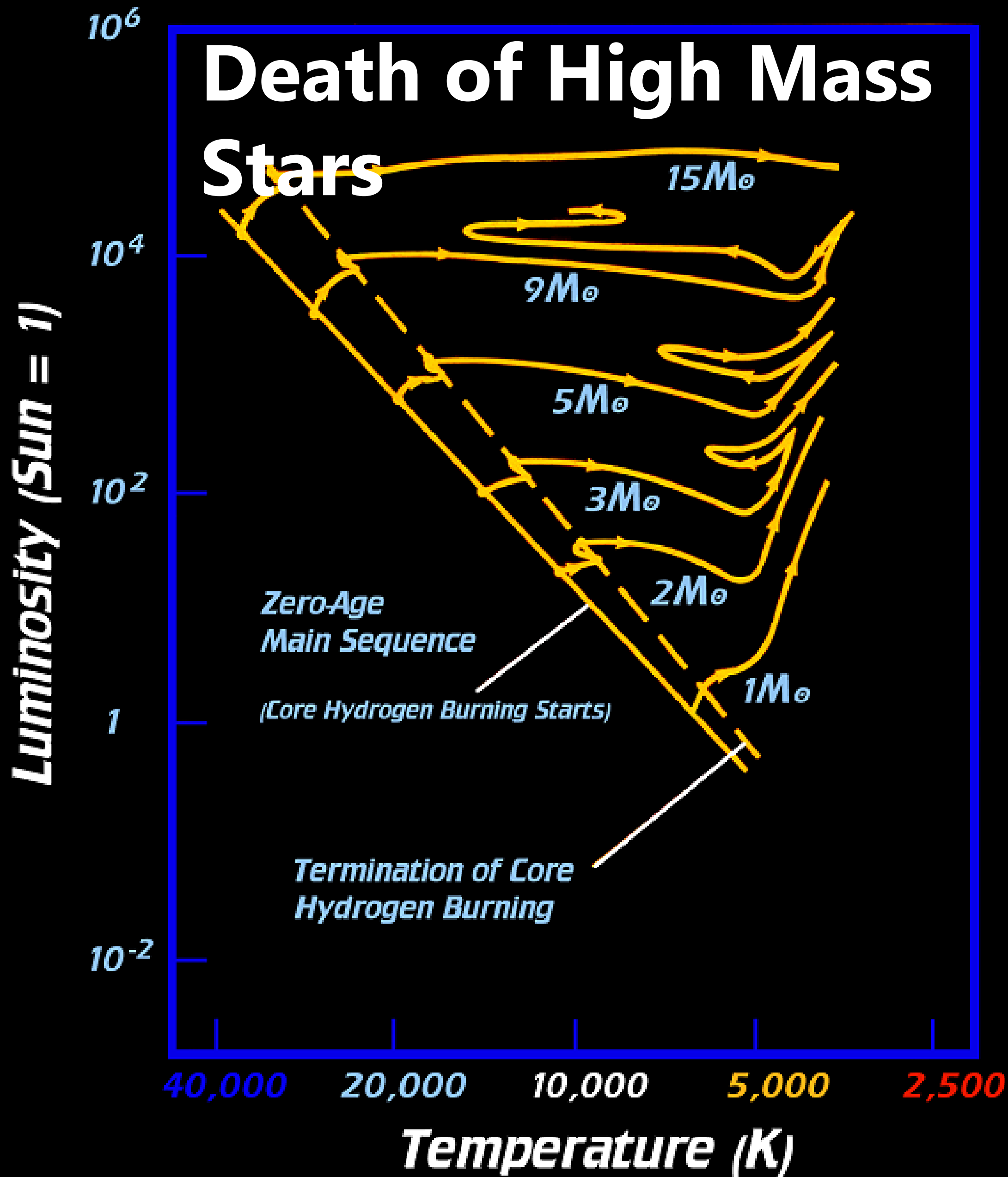

Gary A. Becker image


Ring Nebula
M57
Lyra,
the Harp
Hubble Space Telescope

# Mass/Radius of White Dwarfs

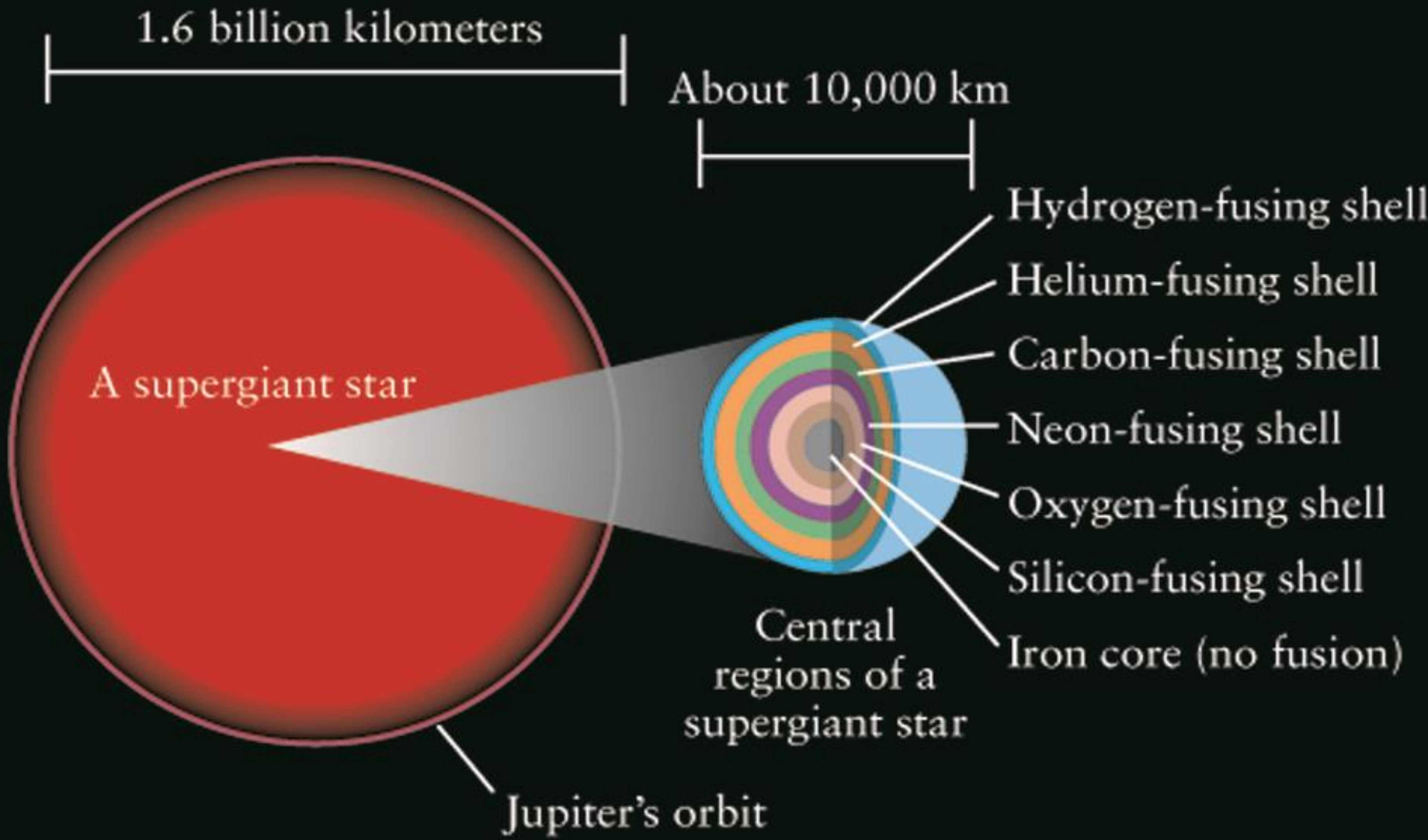


# Death of High Mass Stars

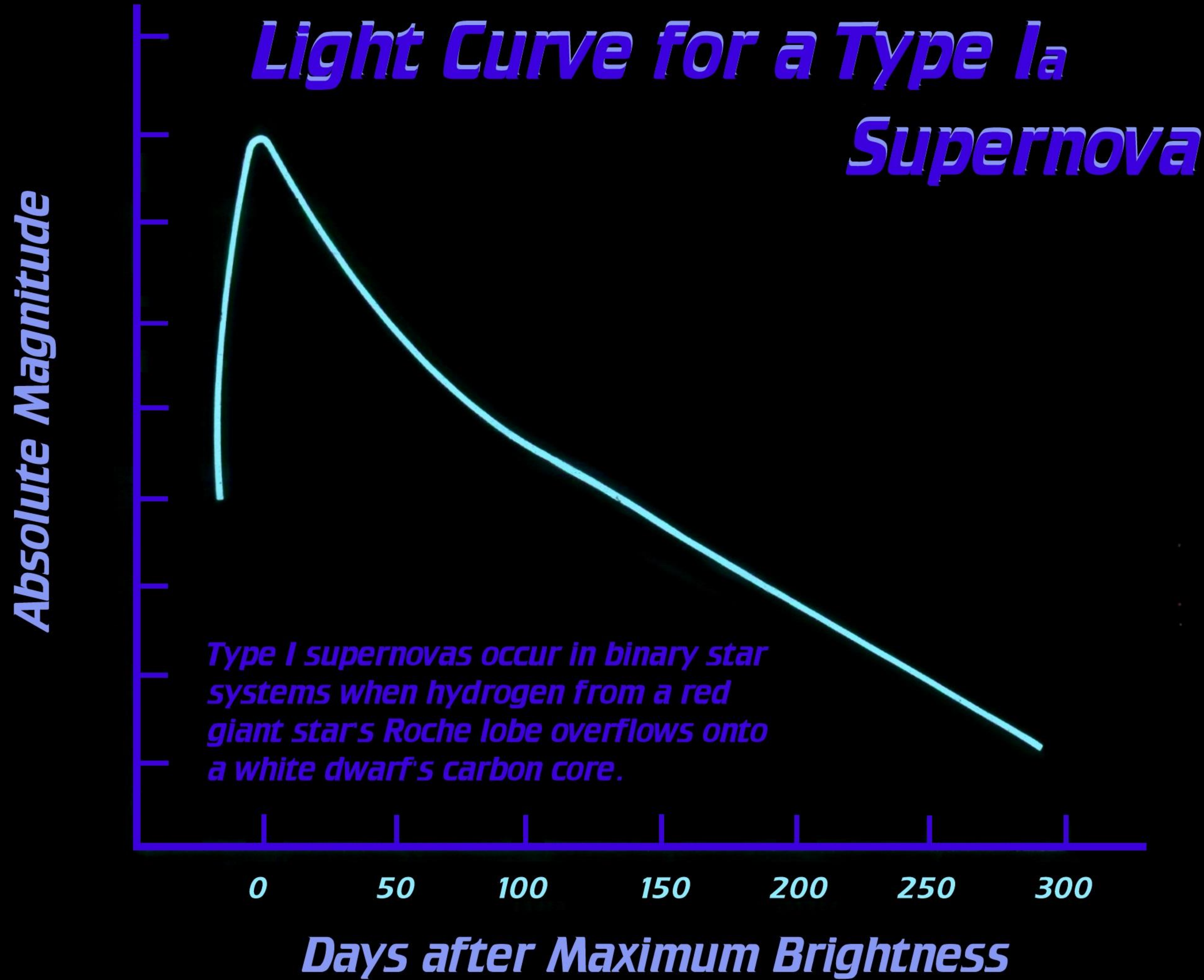


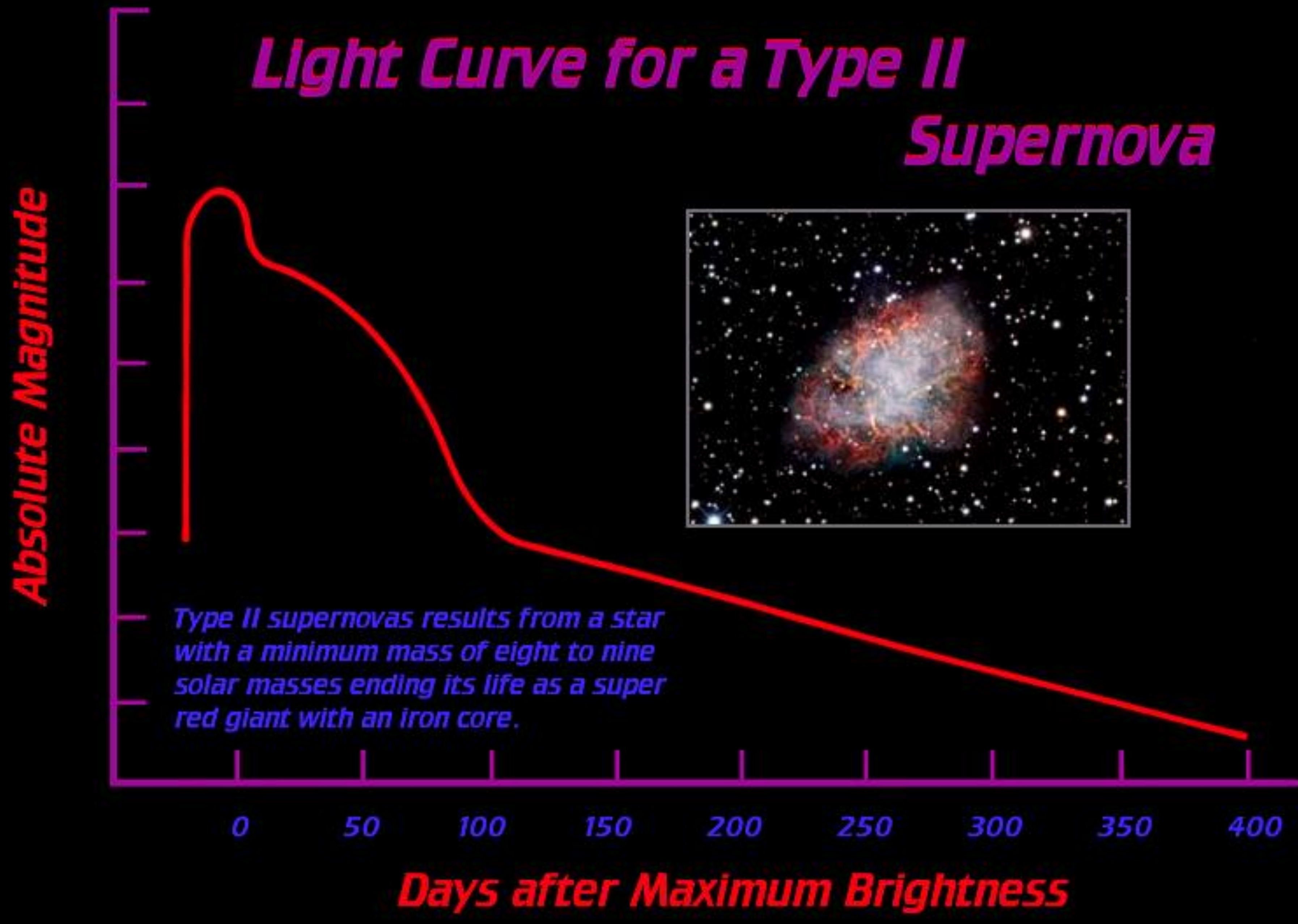

## Influence of Mass on the Evolution of Stars

# Core of a Red Supergiant ready to

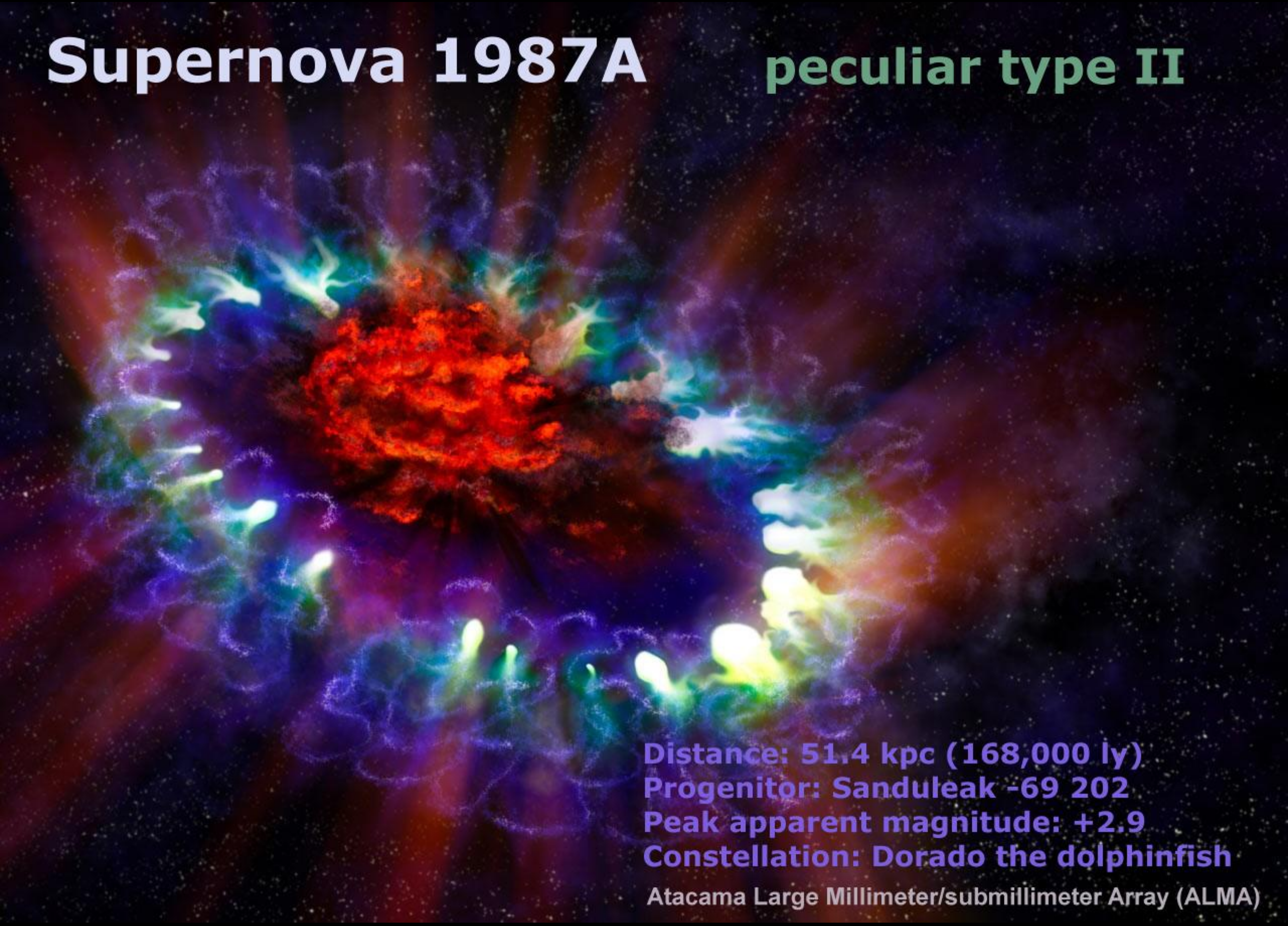



University of Alberta,


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

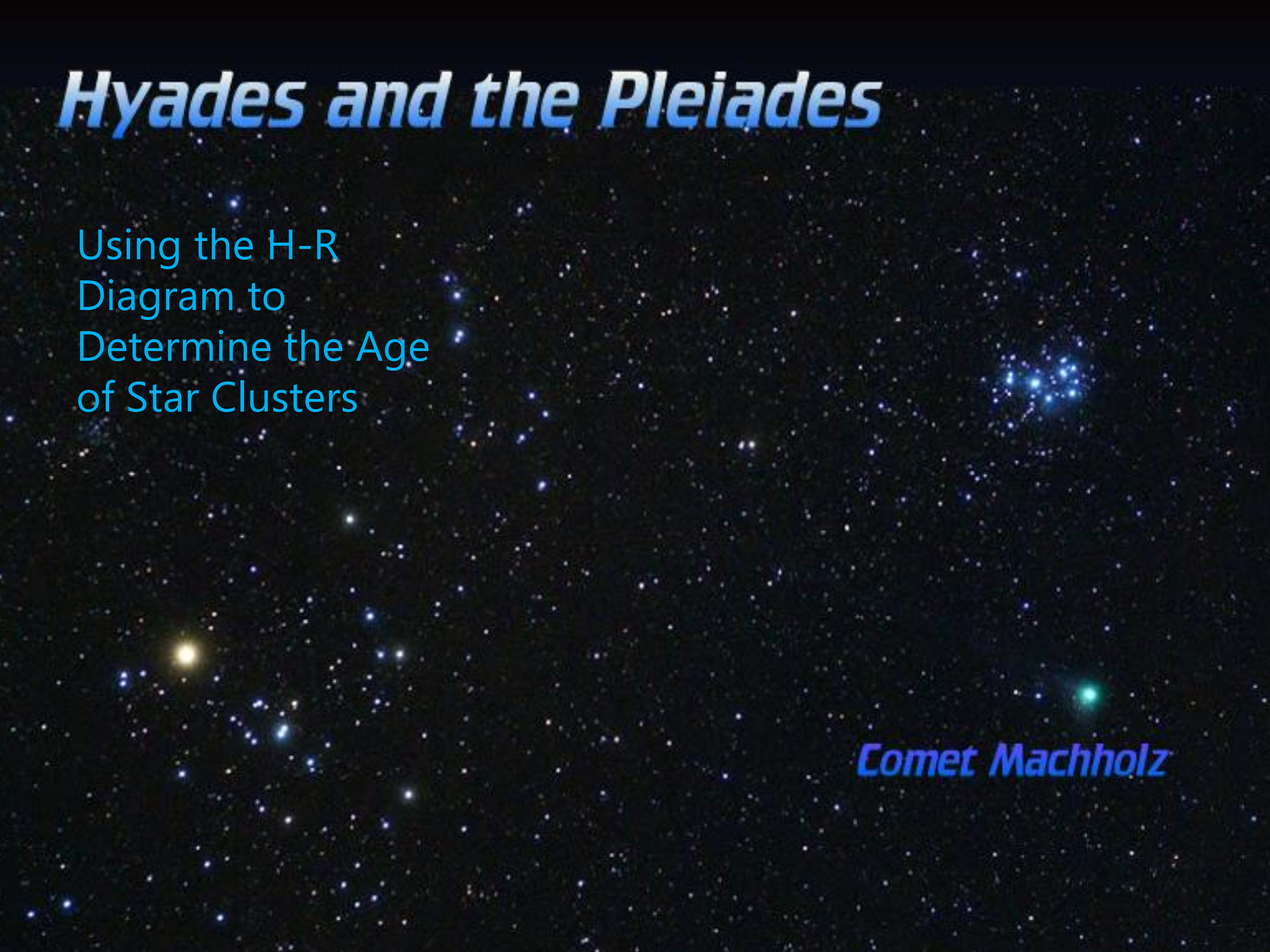


**Distance: 51.4 kpc (168,000 ly)**
**Progenitor: Sanduleak -69 202**
**Peak apparent magnitude: +2.9**
**Constellation: Dorado the dolphinfish**

Atacama Large Millimeter/submillimeter Array (ALMA)

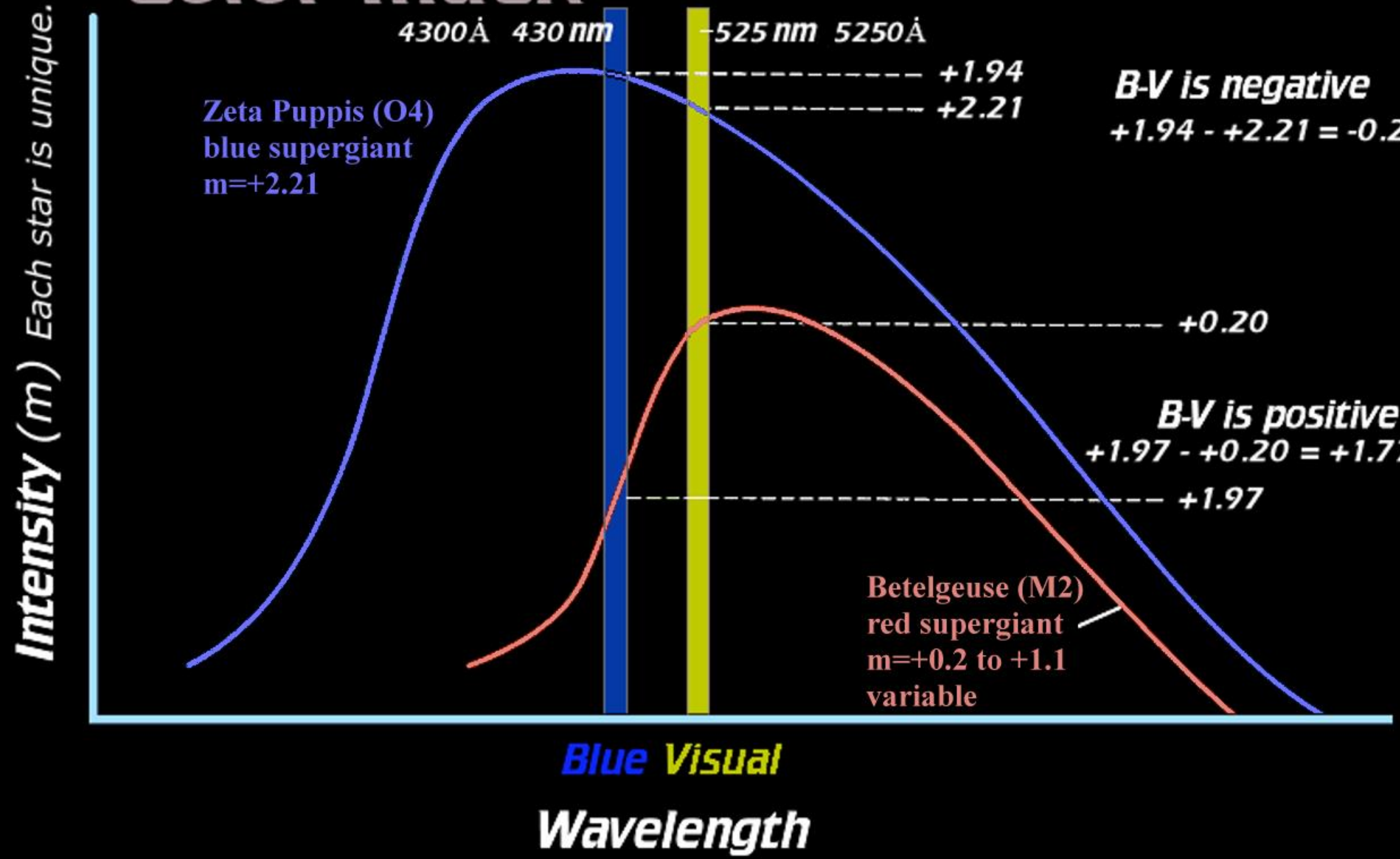
# Hyades and the Pleiades

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



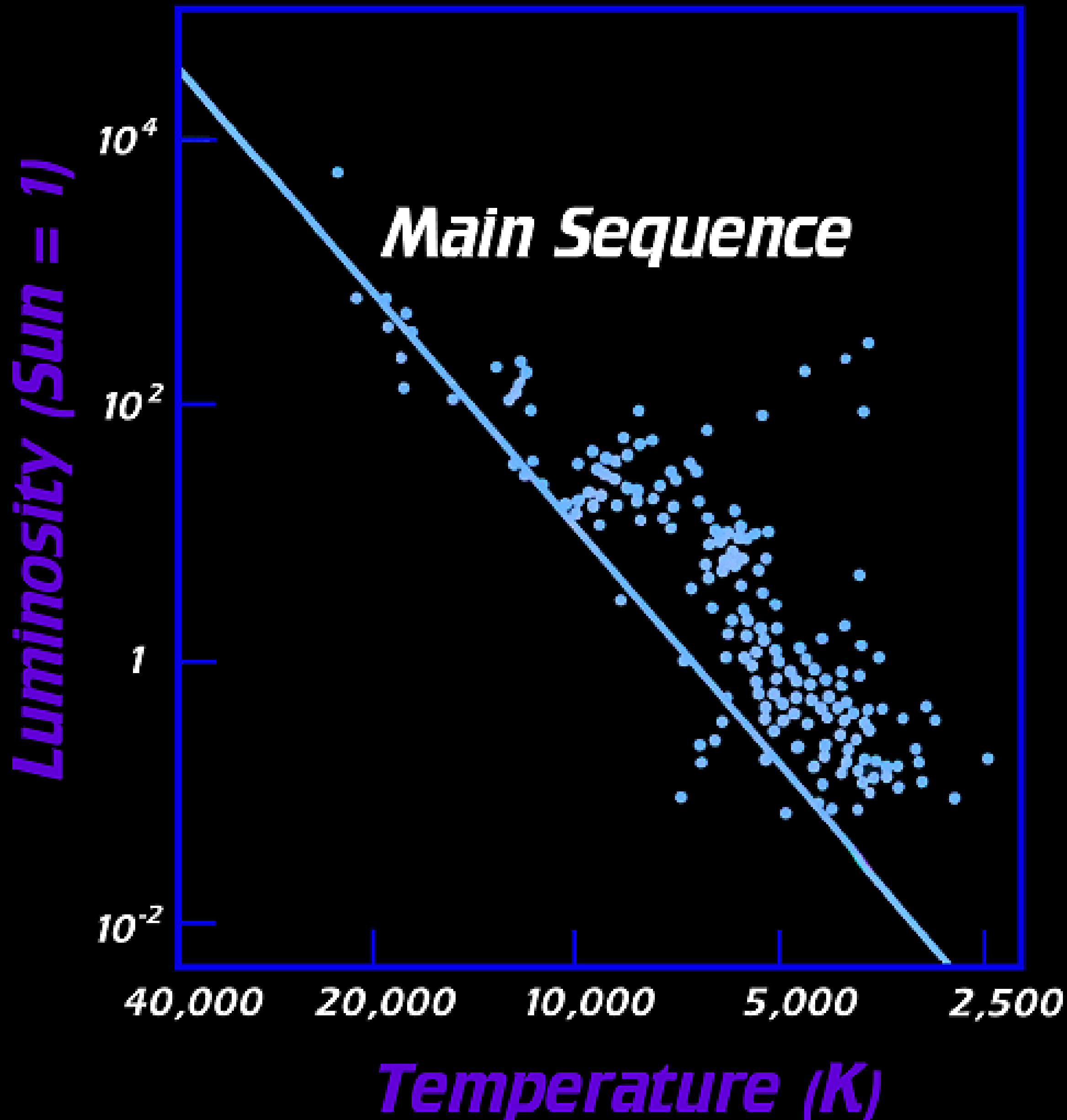
| Temperature | 50,000 K | 25,000 K | 10,000 K | 7,500 K | 6,000 K | 4,800 K | 3,700 K |
|---|---|---|---|---|---|---|---|
| Sp Class | O5V | B0V | A0V | F0V | G0V | K0V | M0V |
| Co Index (UBV) | -0.33 | -0.30 | -0.02 | +0.30 | +0.58 | +0.81 | +1.40 |

# Color Index



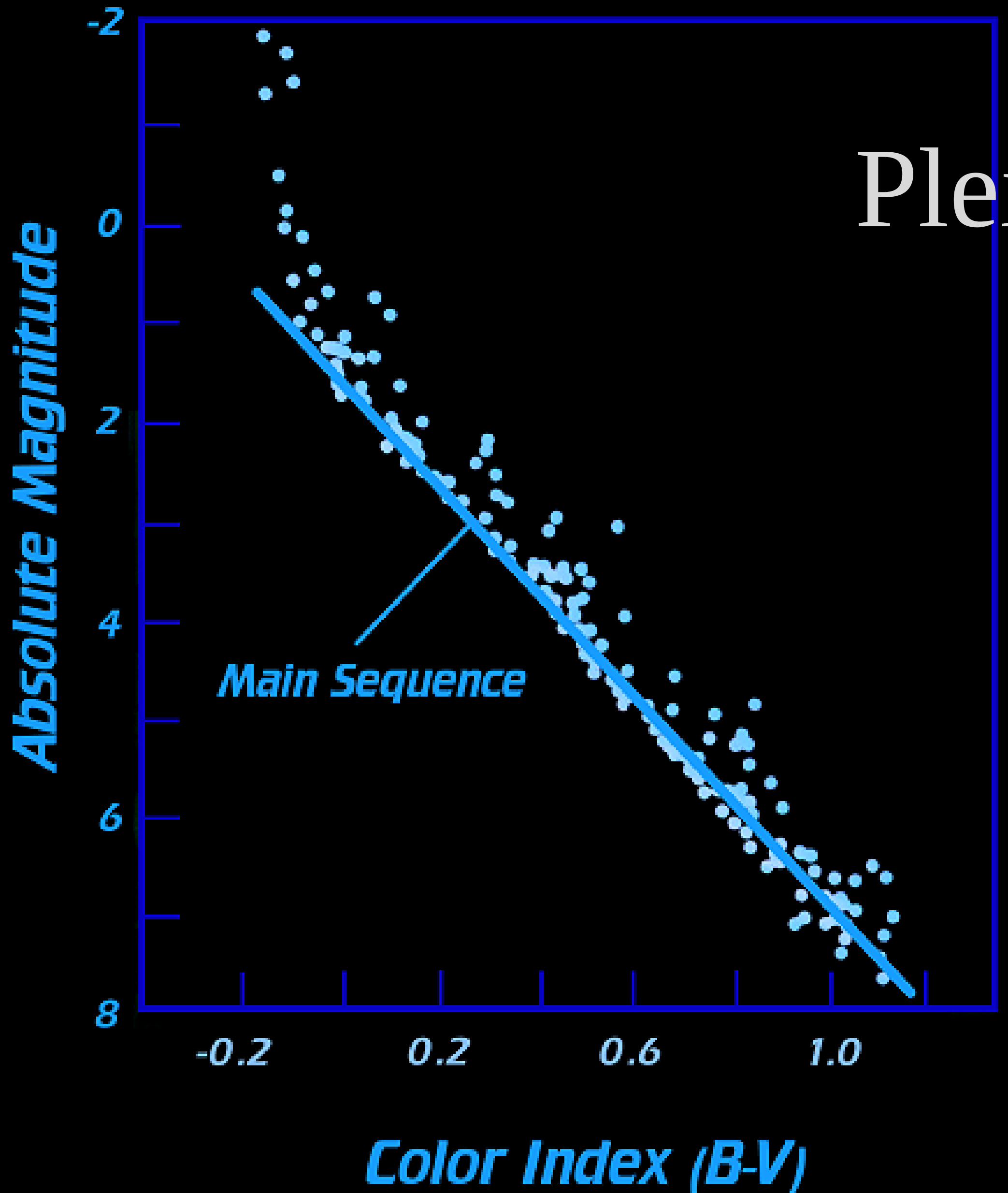

Adapted by Gary A. Becker

# NGC 2264 Young or Old Star Cluster?



Michael-Caligiuri

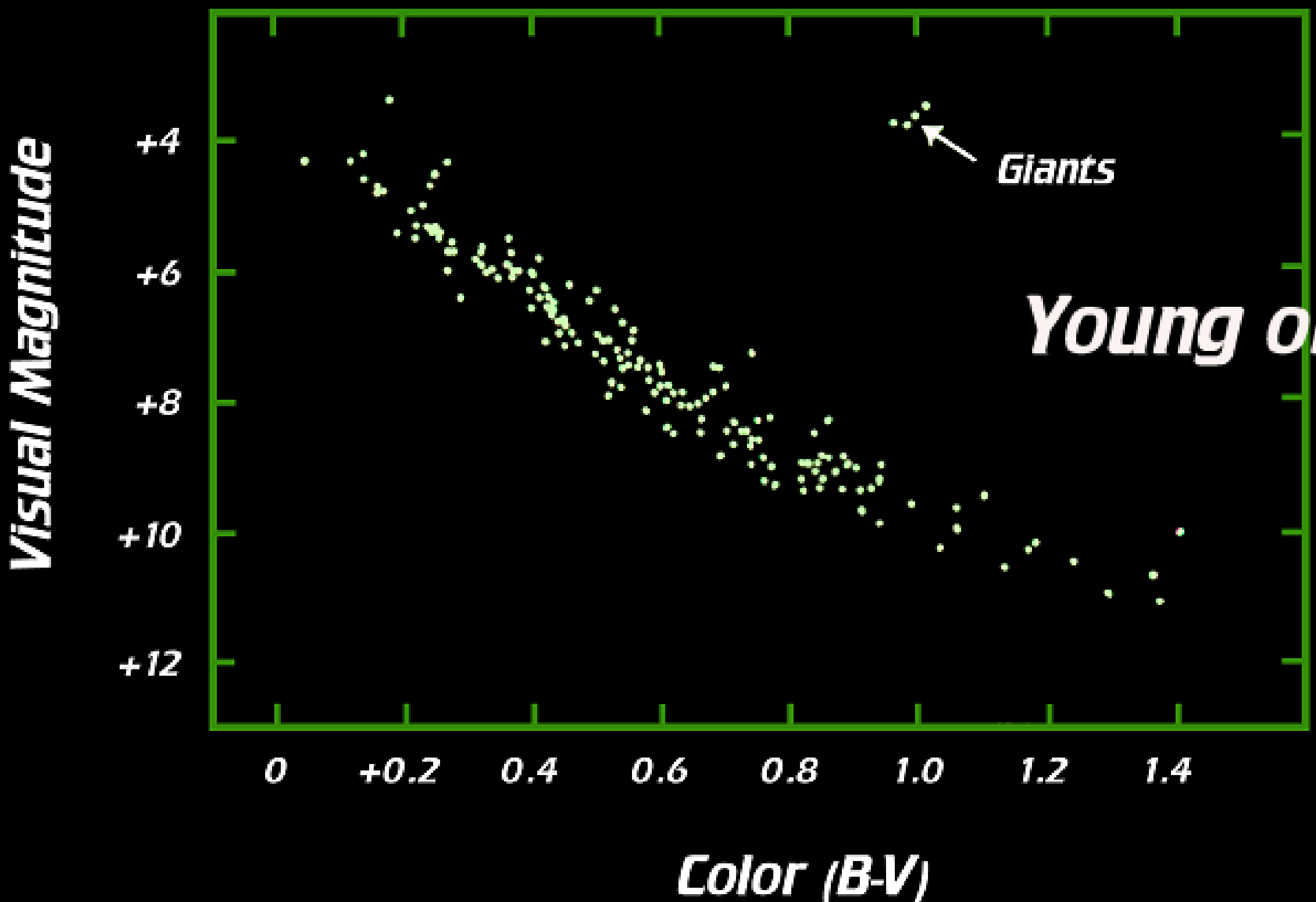
# Young or Old Cluster?




Pleiades

# Pleiades- M45/Taurus, the Bull

# Color-Magnitude Diagram for the Hyades

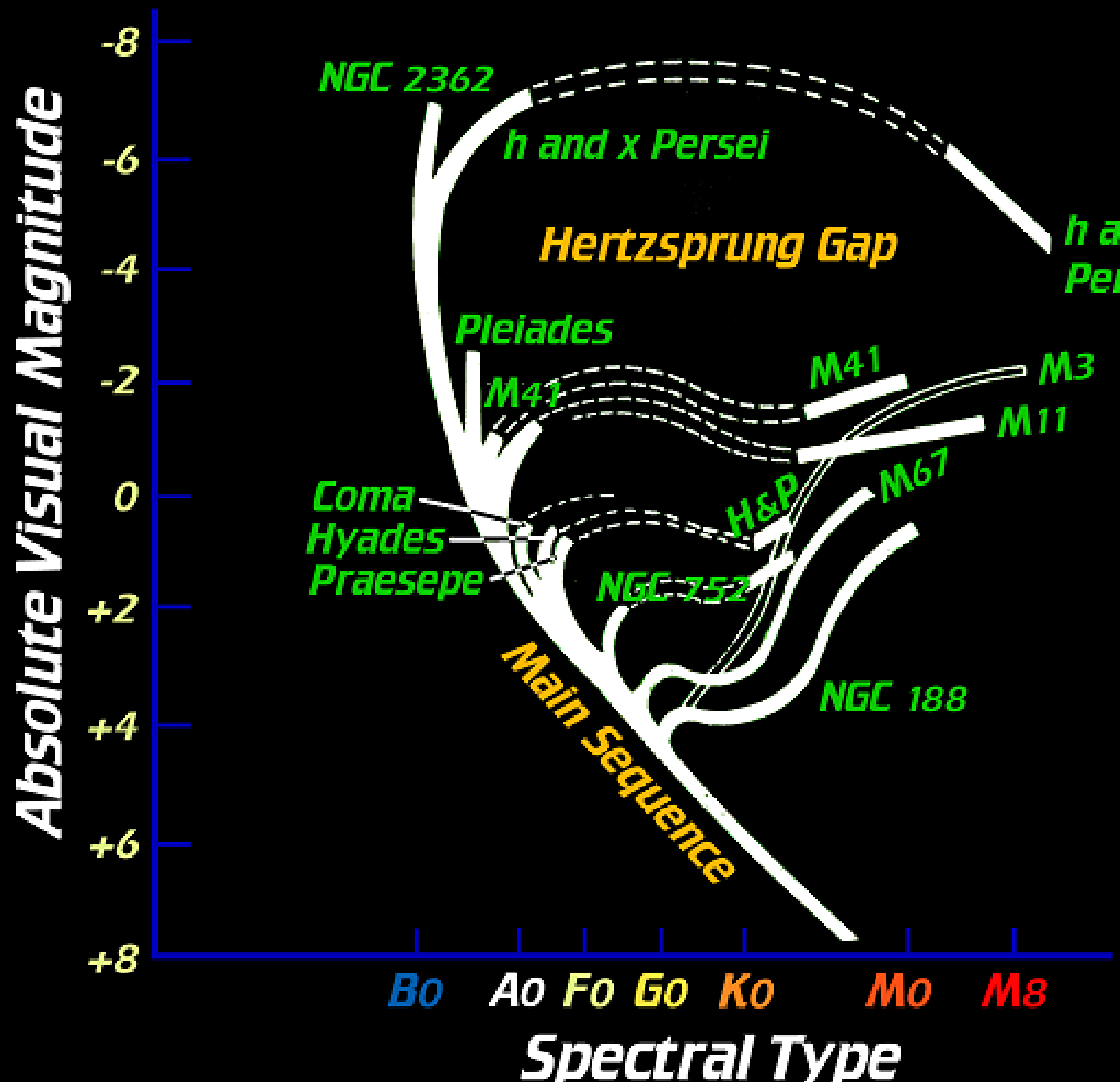



Young or Old?

# Pleiades-Hyades Star Clusters


Rogelio Bernal Andreo image

# H-R Age Sequence Diagram for Clusters



# The End

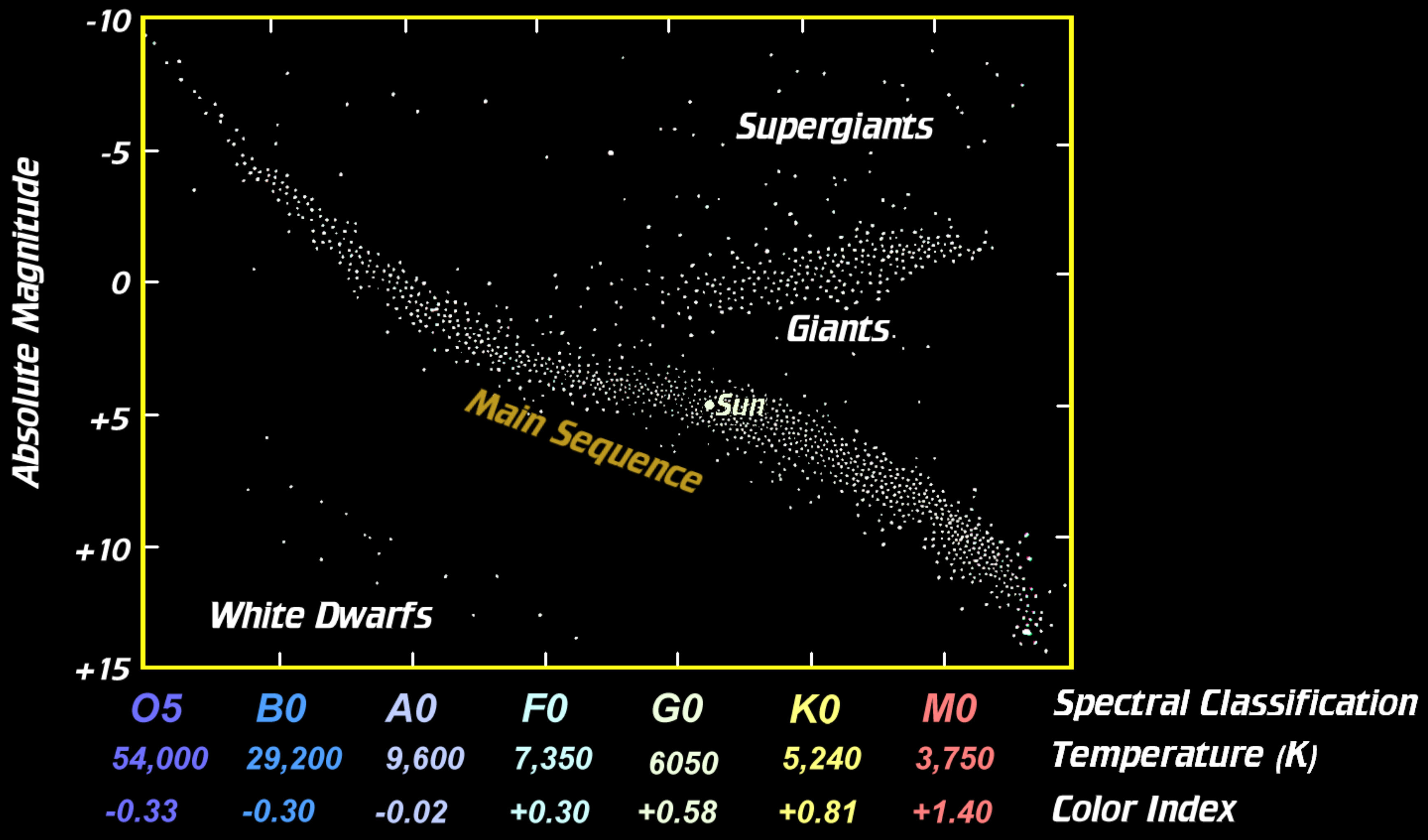
# Finding the Age of Star Clusters Using the Hertzsprung-Russell Diagram

# 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 |

Gary A. Becker slide

# Hertzsprung-Russell Diagram

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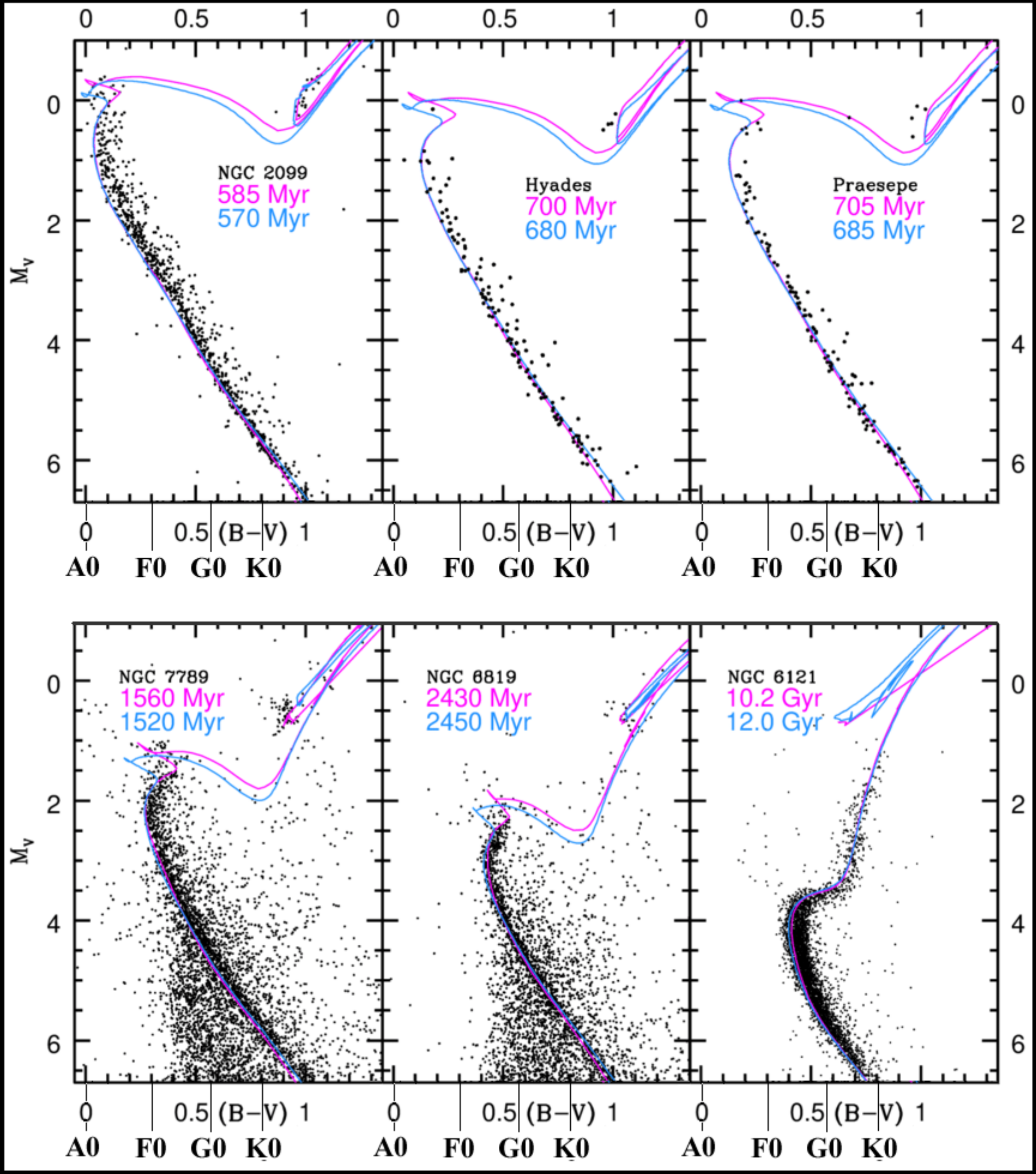
# Comparison of Old Star Clusters of Increasing Age



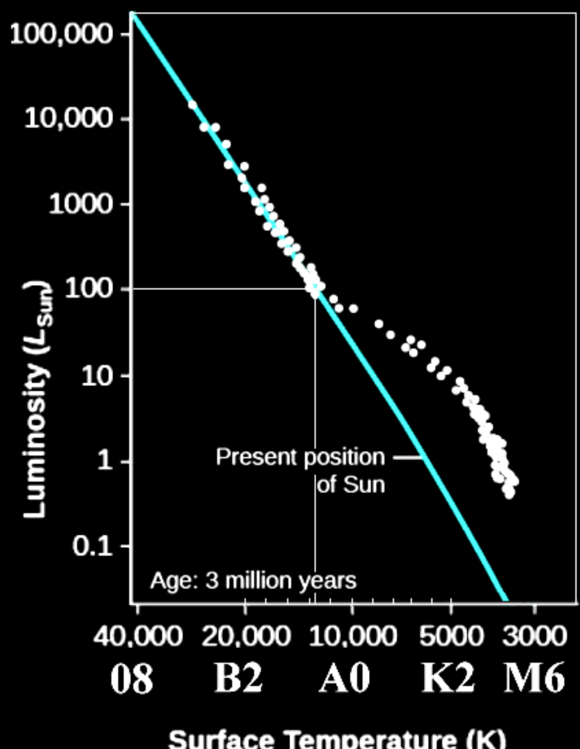

**Left to Right:**
**The clusters become older. Note how the absolute magnitude of the turn-off position becomes fainter and moves towards cooler stars.**

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

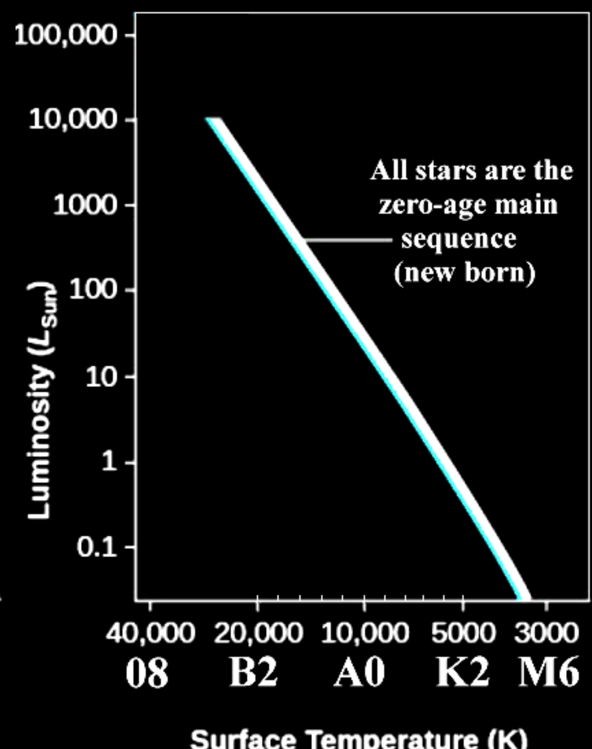
H-R diagrams from J. Cummings-John Hopkins Uni./Color Index-Wikipedia

# 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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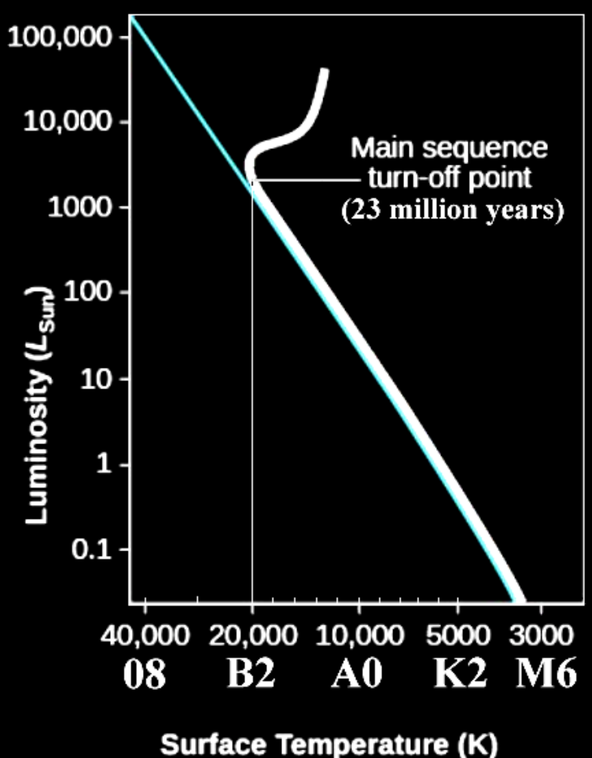
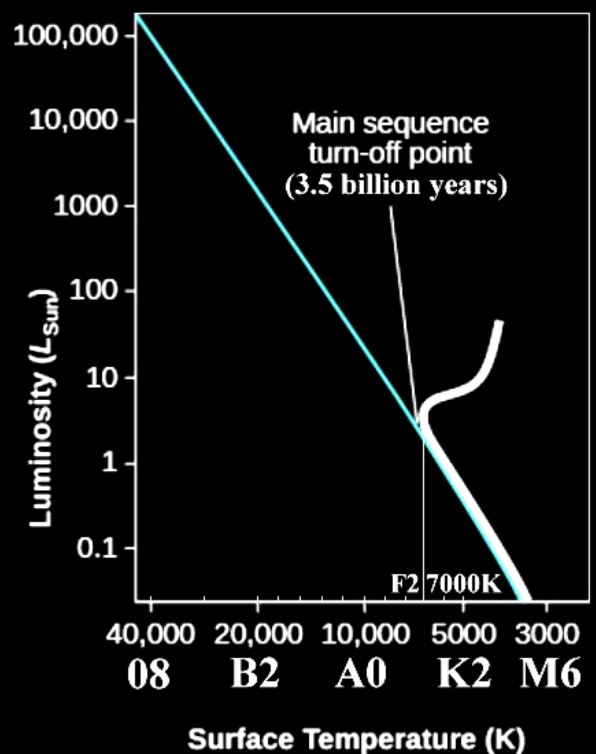
# Evaluating the Age of Star Clusters

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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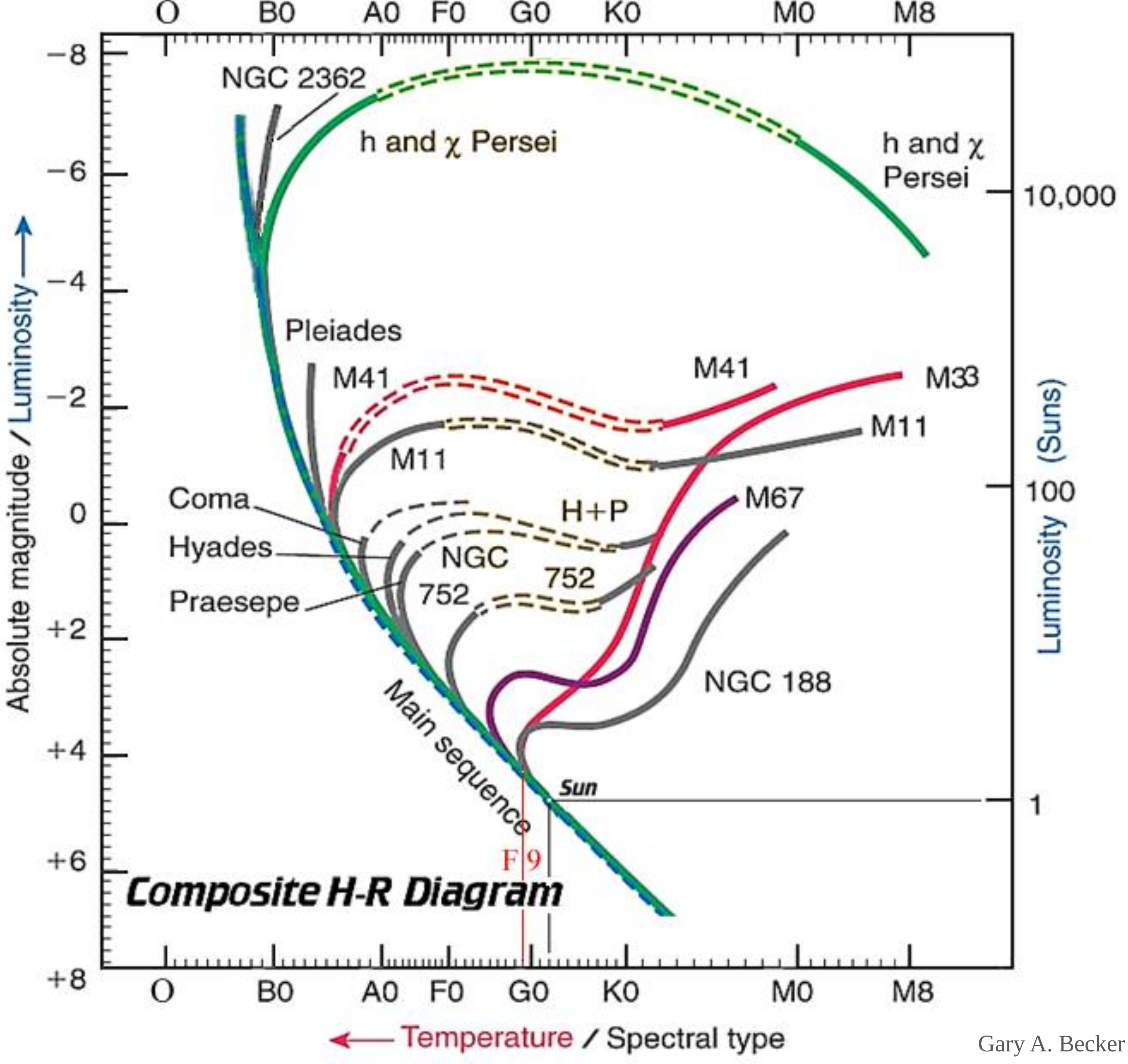


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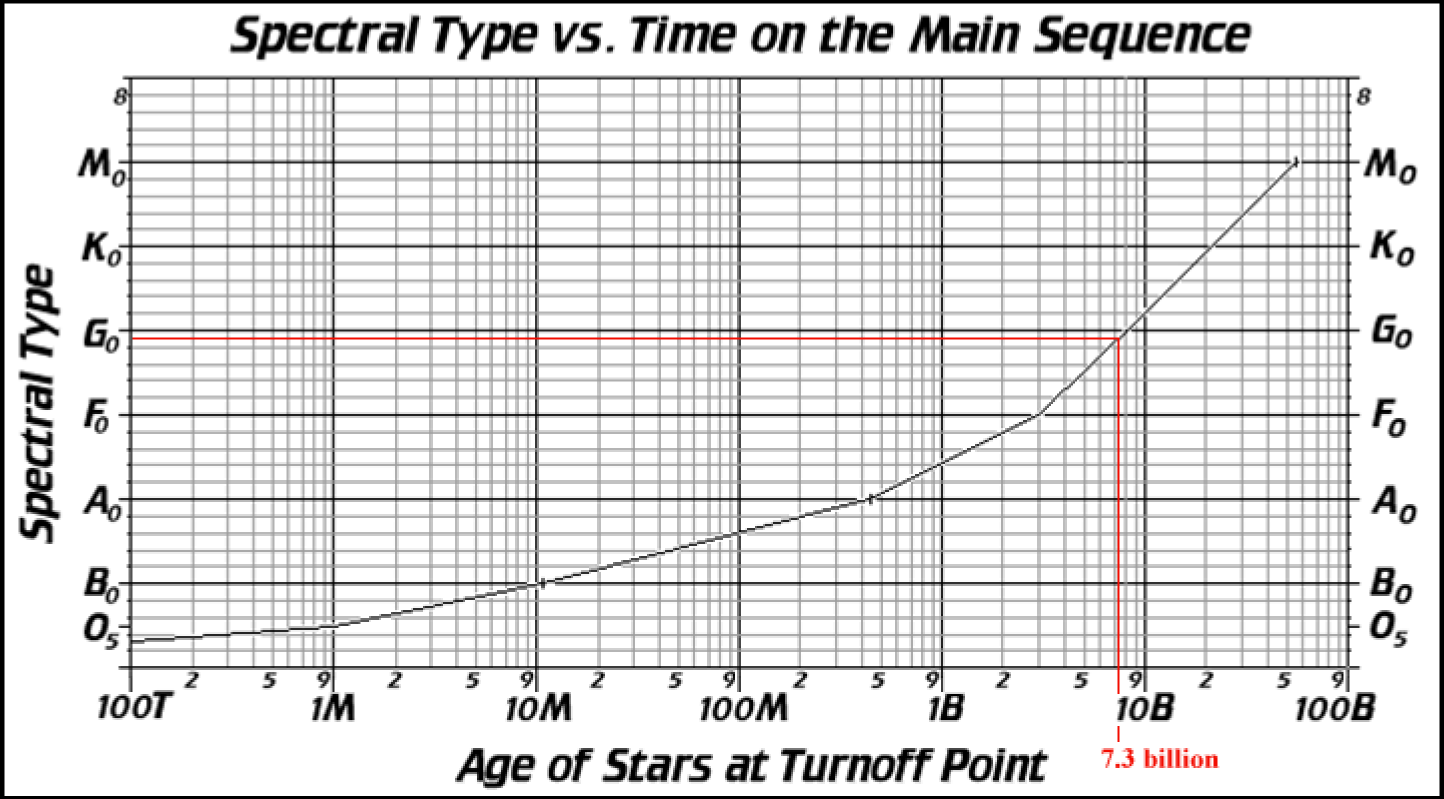


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# The End