Stellar Astrophysics

Policies

* No Exams
* Homework 65%
* Project 35%
* Oral Presentation 5%
* More on the project
* http://myhome.coloradomesa.edu/~jworkman/teaching/fall13/396/syllabus396.pdf

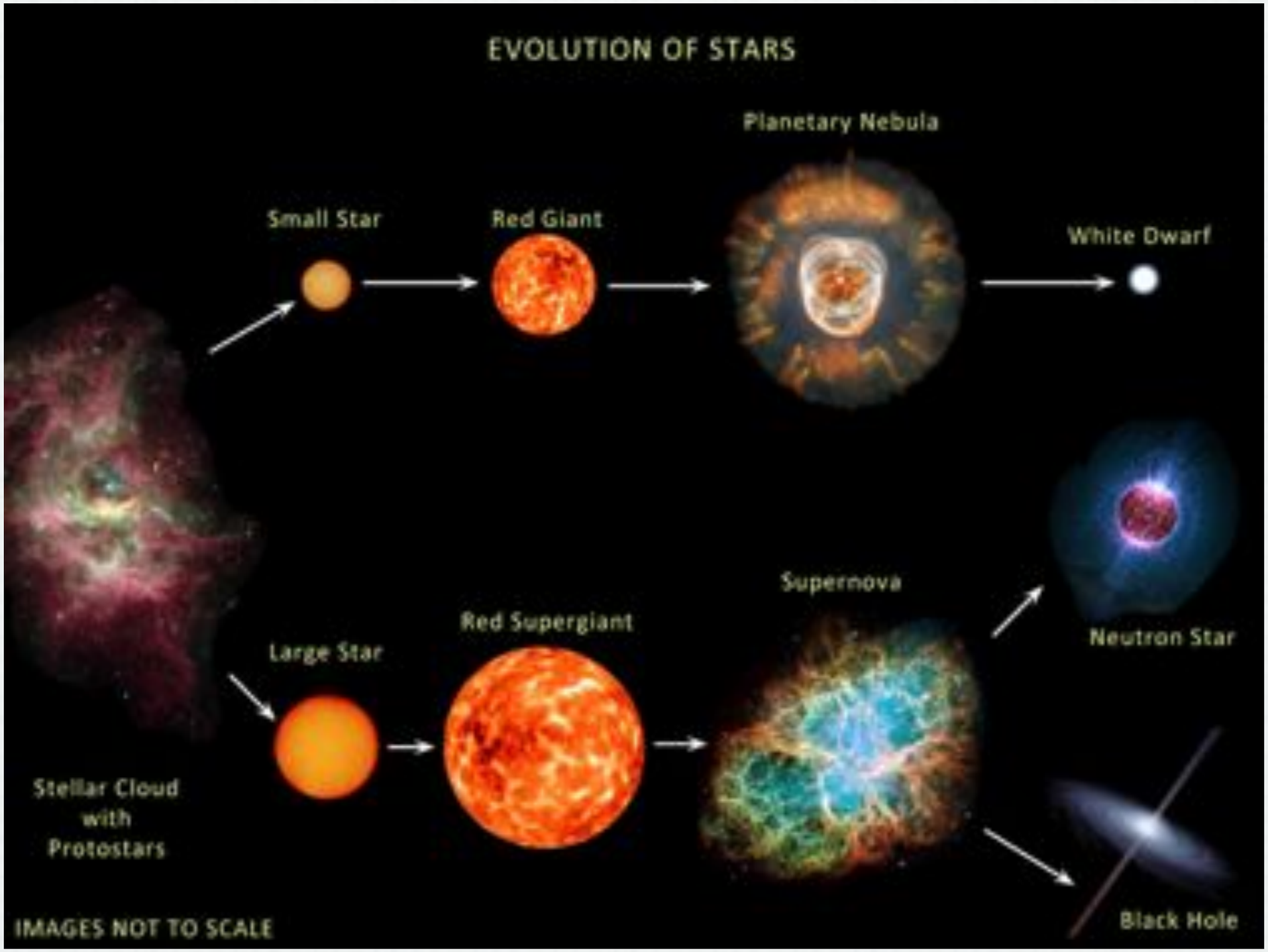
You need to self study using other resources

* My notes
* The Web
* On Reserve Introduction to Modern Astrophysics at Library
* You should be good at Calculus 1 and 2 and differential equations

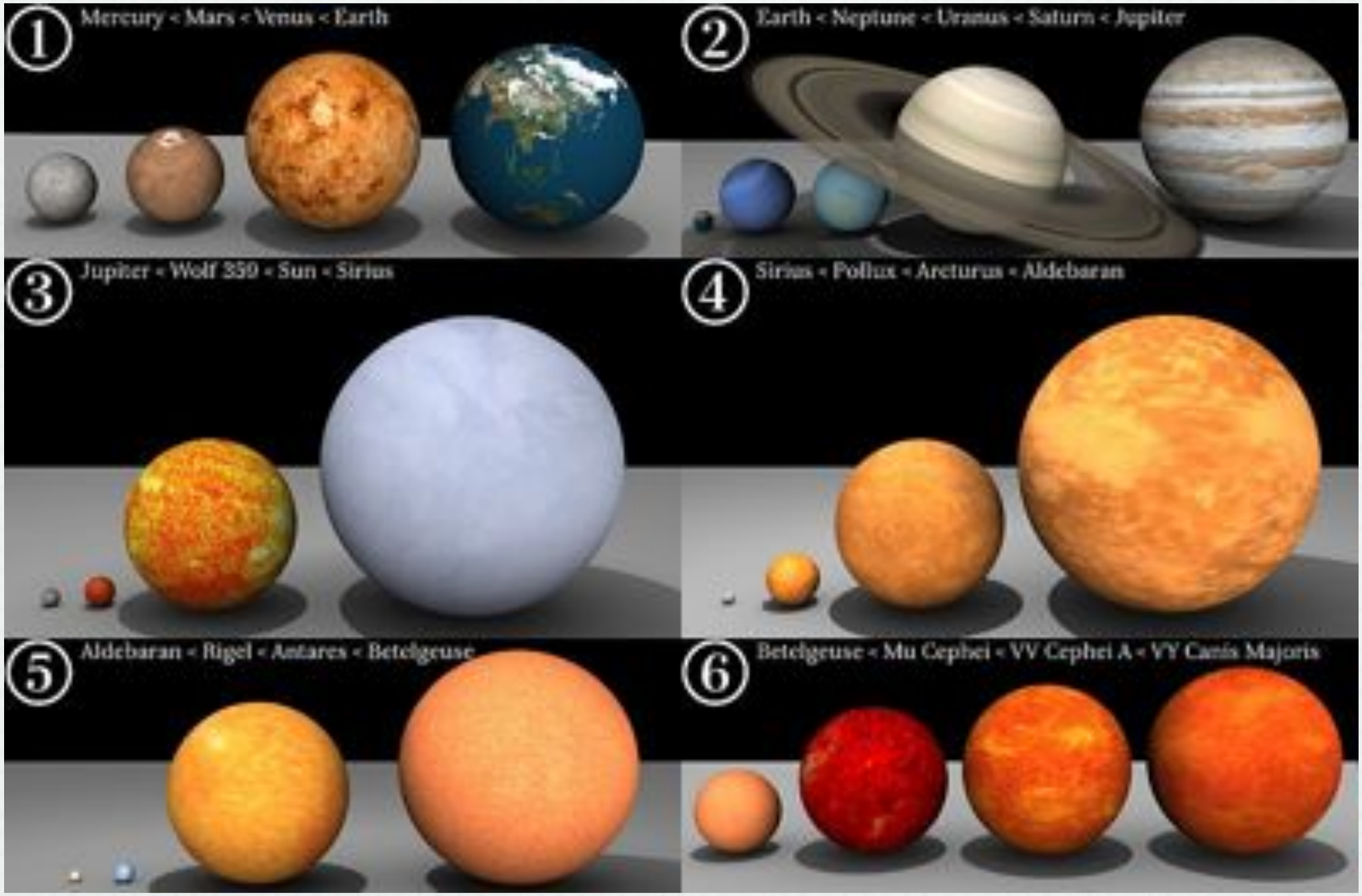
What we'll (try) to cover

* The Fundamentals of Stellar Astrophysics
* -Basic Concepts
* -Stellar Formation
* -Radiative Transfer
* -Stellar Atmospheres
* -Stellar Interiors
* -Stellar Evolution
* -Nucleosynthesis
* -Stellar Remnants

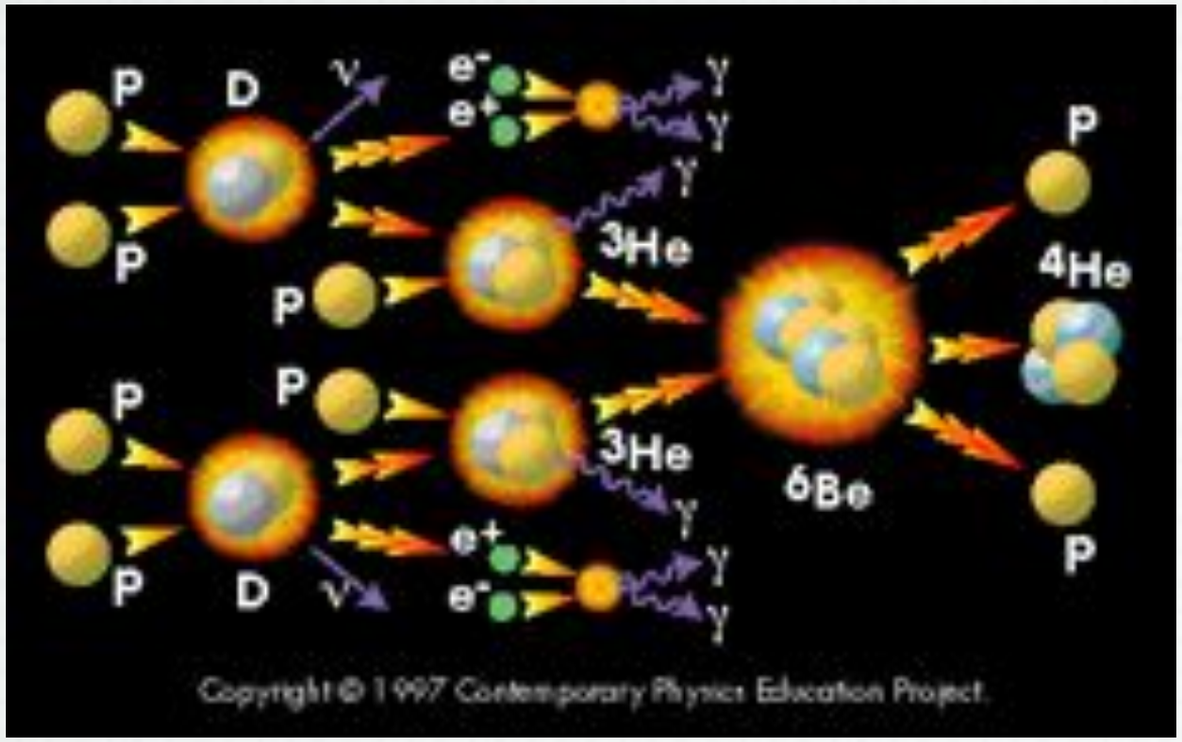
Stars


EVOLUTION OF STARS
Planetary Nebula
Small Star
Red Giant
White Dwarf
Supernova
Red Supergiant
Large Star
Neutron Star
Stellar Cloud
with
Protostars
Black Hole
IMAGES NOT TO SCALE

http://www.youtube.com/watch?v=Bcz4vGvoxQA




the sun
Sunspot
Penumbra
Umbra
Granule
Photosphere
Temperature minimum
Convective zone
Corona
Flare
Chromosphere
Transition region
Prominence


P
D
ν
e-
e+
γ
3He
4He
6Be
P
D
ν
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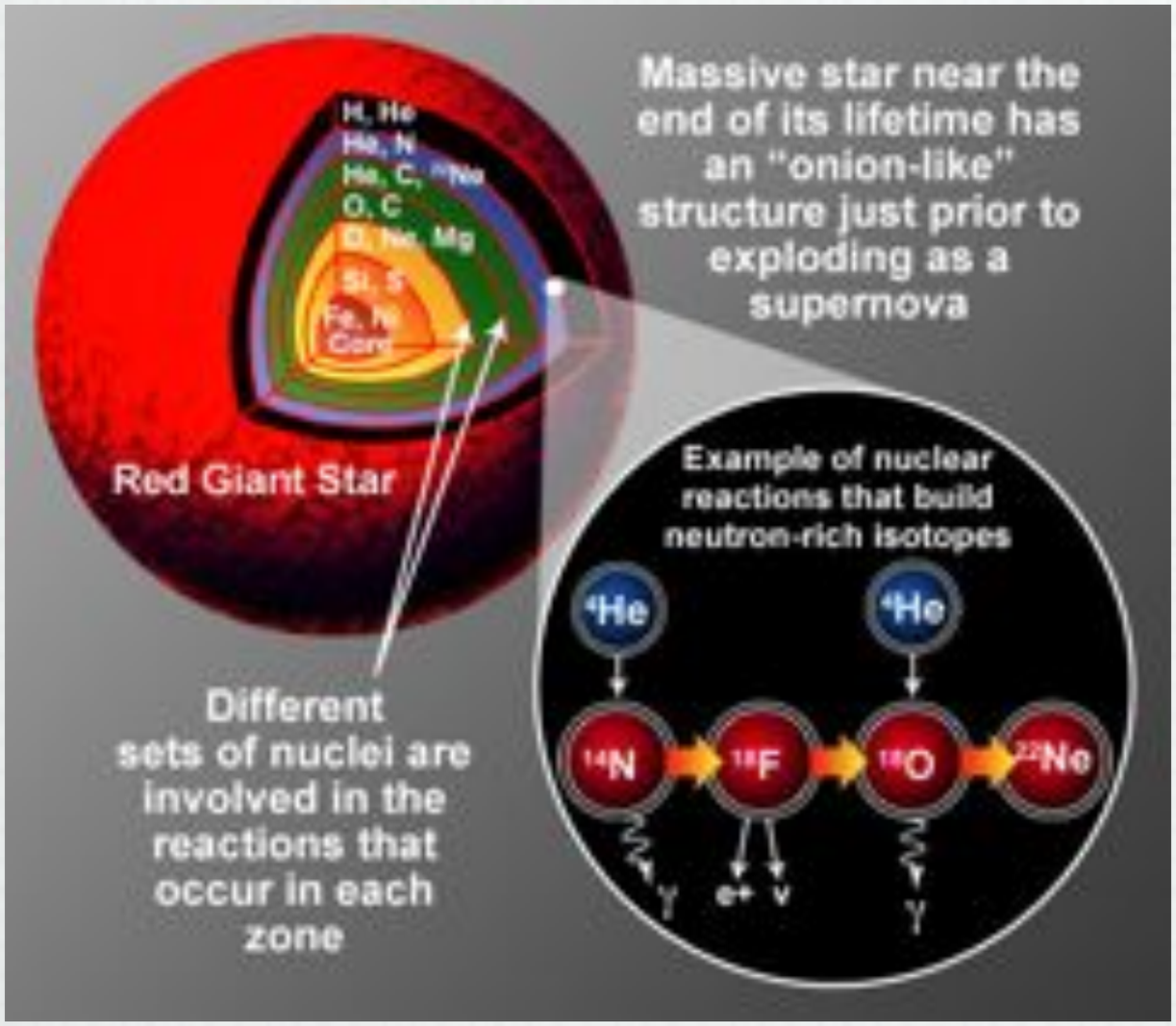
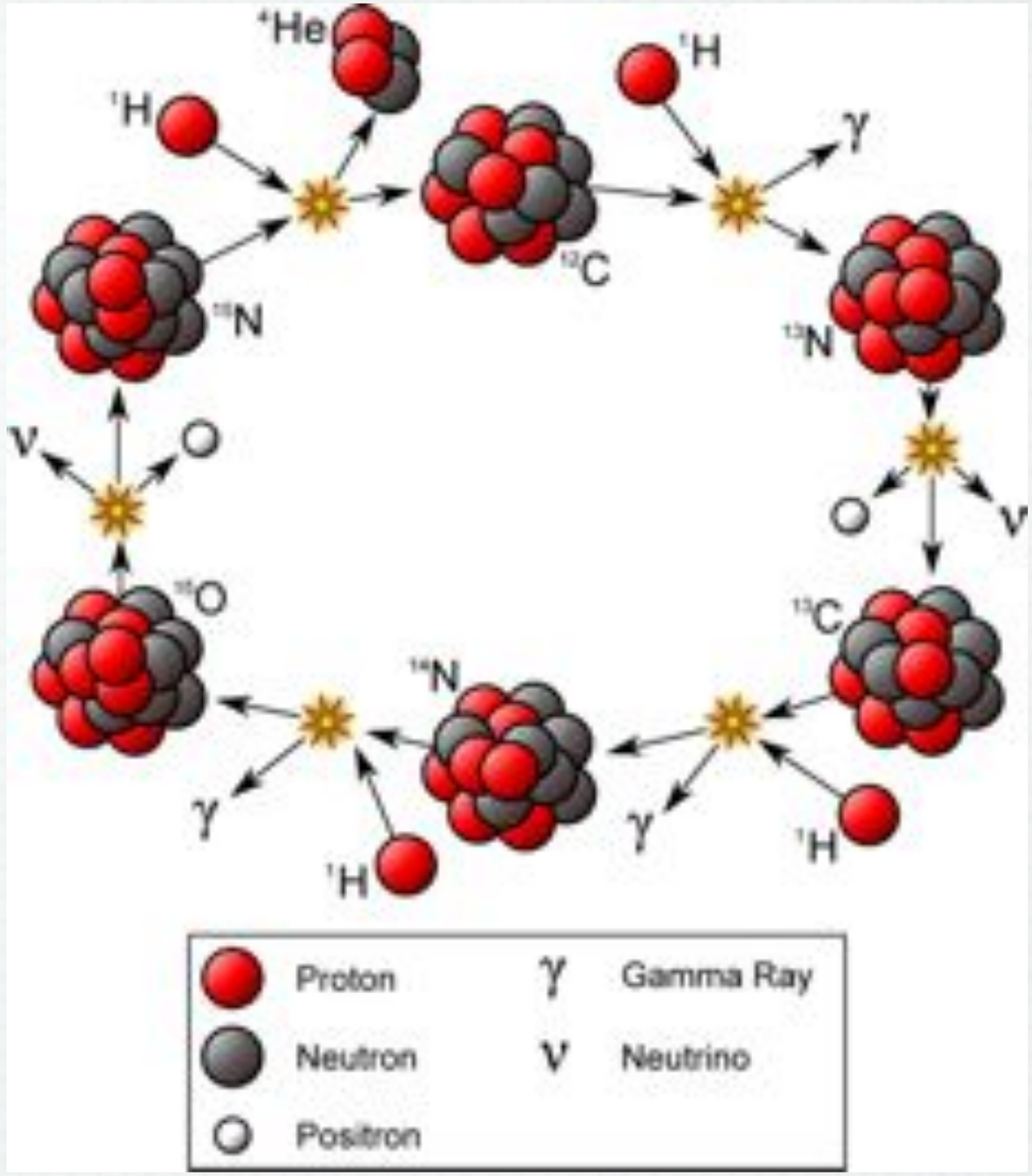
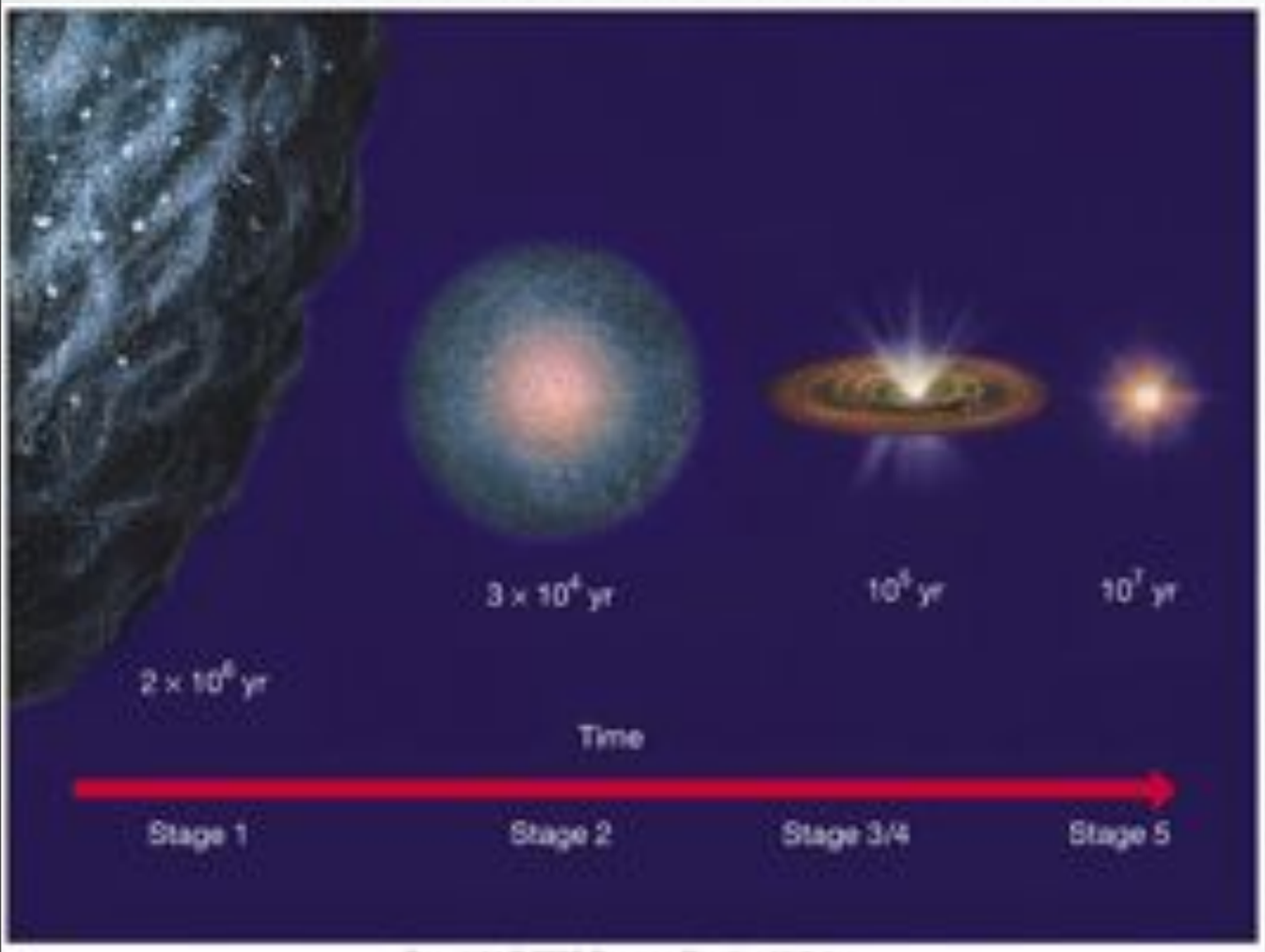
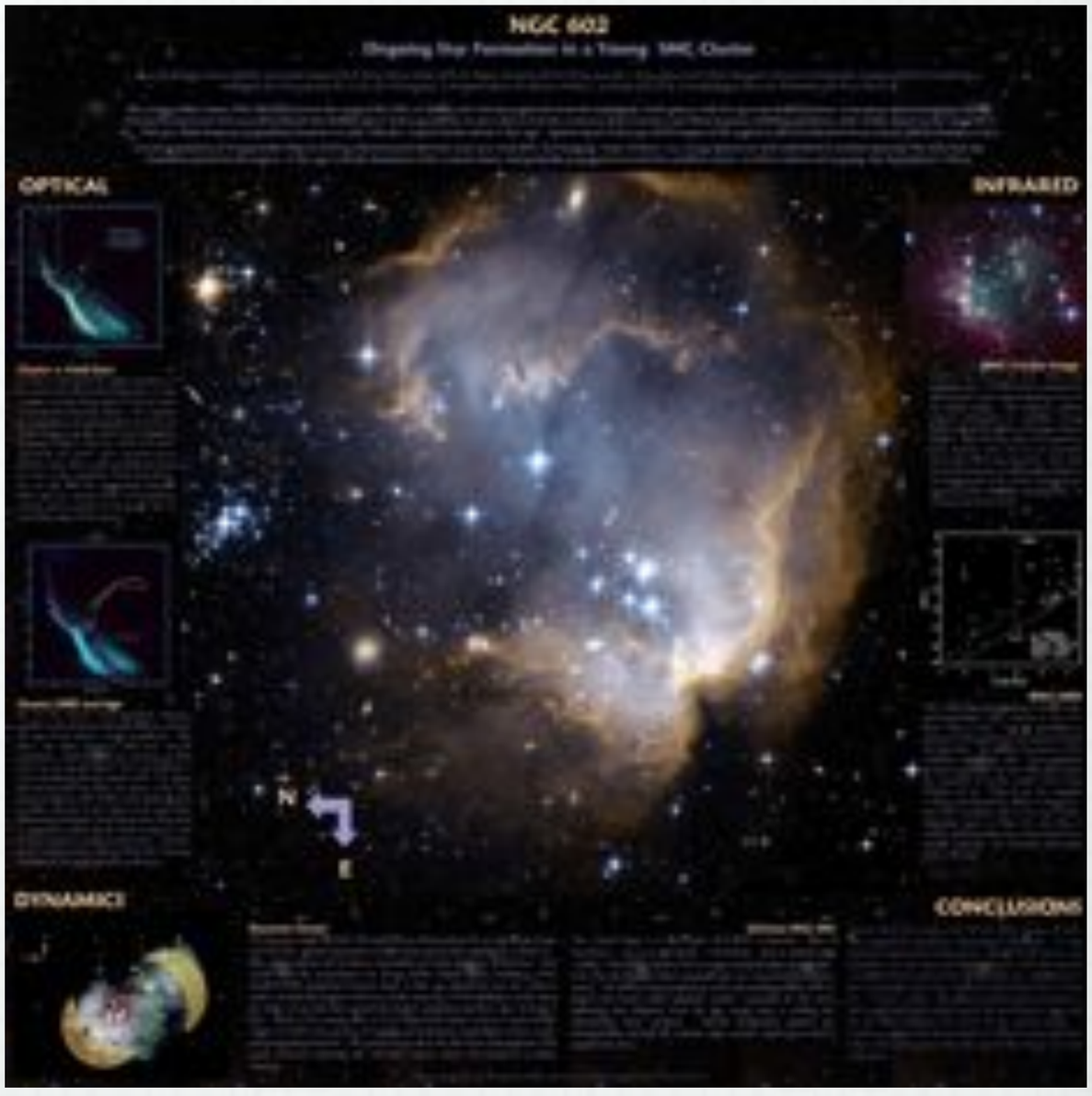

H, He
He, N
He, C, Ne
O, C
Si, S
Fe, Ni
Core
Mg
Red Giant Star
Massive star near the end of its lifetime has an "onion-like" structure just prior to exploding as a supernova
Example of nuclear reactions that build neutron-rich isotopes
4He
4He
14N
18F
18O
22Ne
γ
e+
ν
Different sets of nuclei are involved in the reactions that occur in each zone

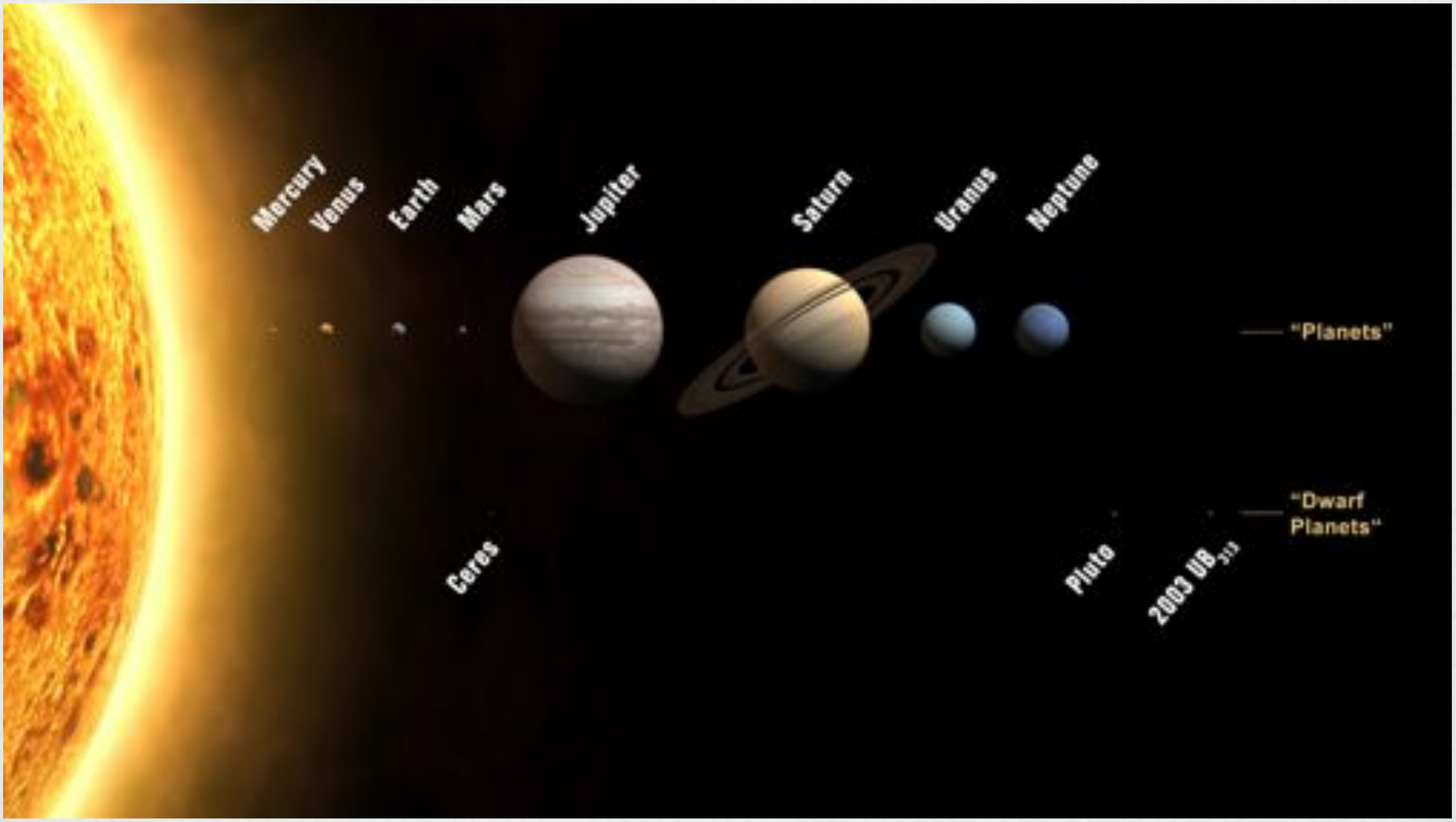

4He
1H
12C
1H
γ
15N
13N
ν
O
O
ν
15O
13C
14N
γ
γ
1H
1H
Proton
Neutron
Positron
γ
Gamma Ray
ν
Neutrino

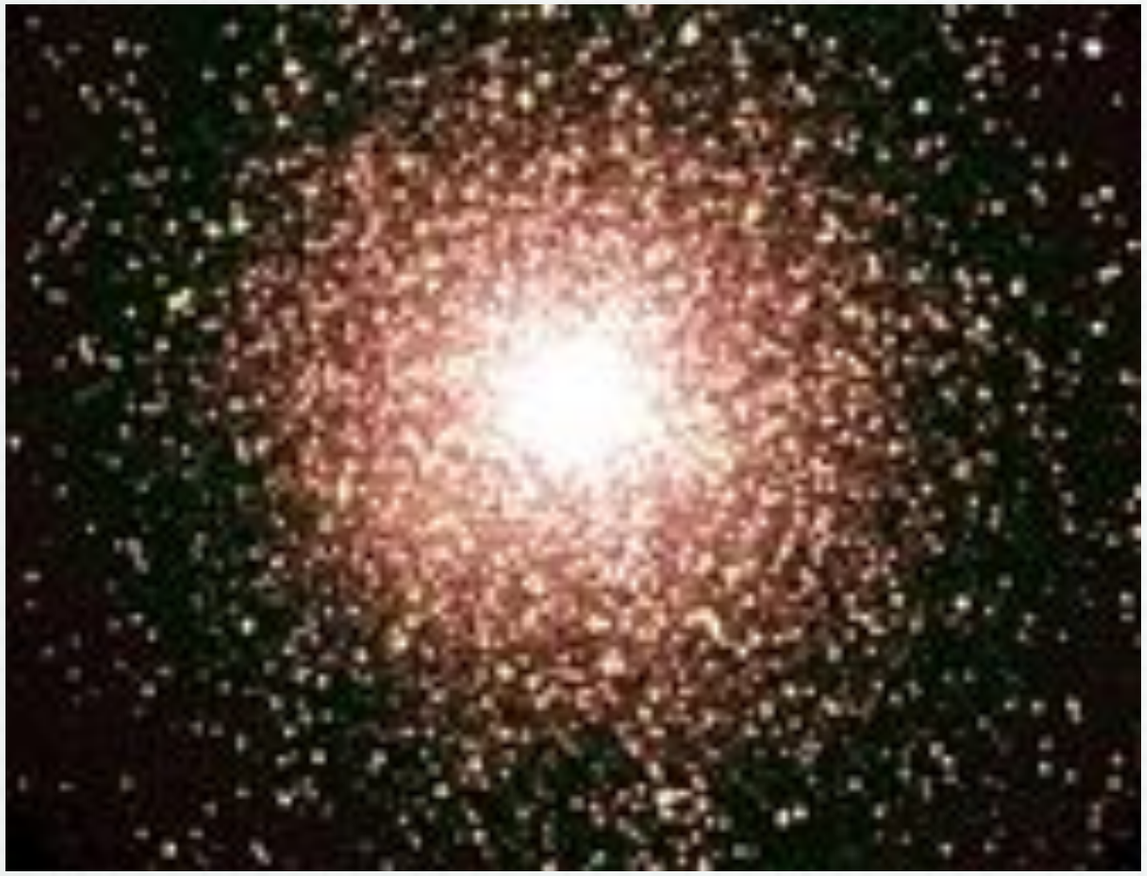
Why do we care?

* Almost all energy used by us and presumably other civilizations derives from stars
* All cool systems depends on stars
* We are "Star Stuff" we exist because stellar nucleosynthesis has created more massive elements than hydrogen and helium.
* I'll commonly refer to anything bigger than helium as a metal, nomenclature, don't use it with your chemistry profs.






Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
"Planets"
Ceres
Pluto
2003 UB313
"Dwarf Planets"



The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork

The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here on a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0 μm, and MIPS (the Multiband Imaging Photometer for Spitzer) at 24 μm.

The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.

More information can be found at:
http://sings.stsci.edu/

Ellipticals

Irregulars

Strong Bulge

Strong Bulge

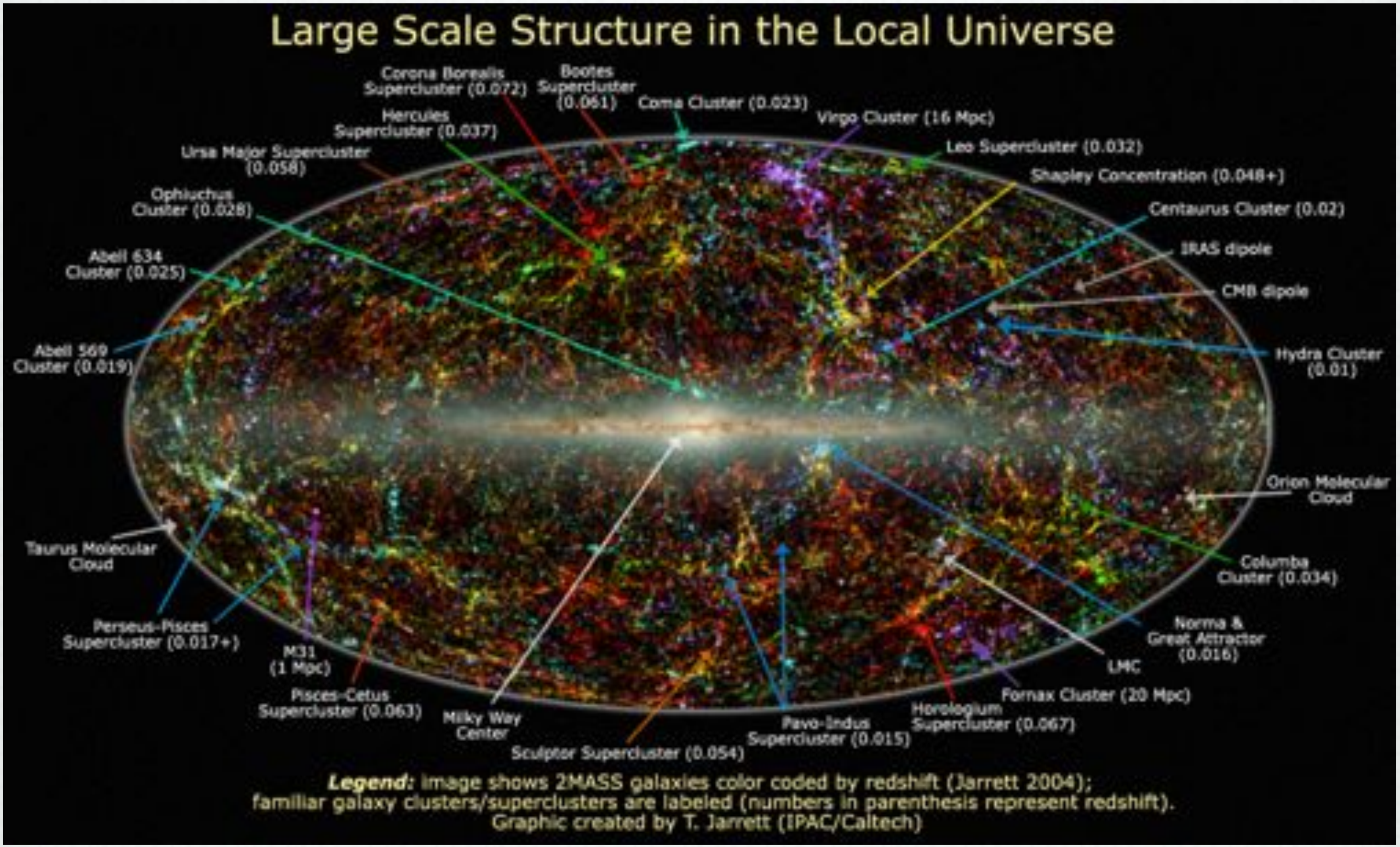
Weak Bulge

Unbarred Spirals

Intermediate Spirals

Weak Bulge

Barred Spirals


Large Scale Structure in the Local Universe
Corona Borealis Supercluster (0.072)
Bootes Supercluster (0.061)
Coma Cluster (0.023)
Virgo Cluster (16 Mpc)
Hercules Supercluster (0.037)
Ursa Major Supercluster (0.058)
Leo Supercluster (0.032)
Shapley Concentration (0.048+)
Ophiuchus Cluster (0.028)
Centaurus Cluster (0.02)
Abell 634 Cluster (0.025)
IRAS dipole
CMB dipole
Abell 569 Cluster (0.019)
Hydra Cluster (0.01)
Orion Molecular Cloud
Taurus Molecular Cloud
Columba Cluster (0.034)
Perseus-Pisces Supercluster (0.017+)
Norma & Great Attractor (0.016)
M31 (1 Mpc)
LMC
Pisces-Cetus Supercluster (0.063)
Fornax Cluster (20 Mpc)
Milky Way Center
Horologium Supercluster (0.067)
Pavo-Indus Supercluster (0.015)
Sculptor Supercluster (0.054)
Legend: image shows 2MASS galaxies color coded by redshift (Jarrett 2004);
familiar galaxy clusters/superclusters are labeled (numbers in parenthesis represent redshift).
Graphic created by T. Jarrett (IPAC/Caltech)

Let's get started

* Used to MKS? Too bad, were going archaic with CGS
* Kg to gram
* Joule to Erg
* Speed of light
* Parsec

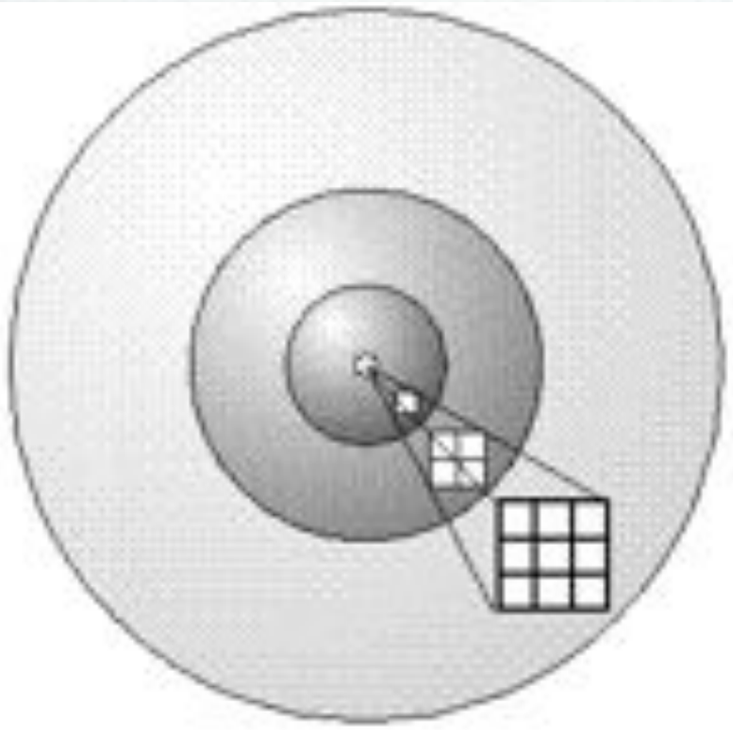
Preliminaries

* Luminosity
* Flux
* Blackbody radiation
* Spectrum
* Stellar Properties

Luminosity

* Intrinsic measure of energy
* Measured in joules or ergs
* Total output of energy
* Solar Luminosity 3.839×10^{33} ergs
* Class O star ~10^{6} times more
* I'll show you how to guestimate this

Flux



Light spreads out with the **square** of the distance. Through a sphere twice as large, the energy covers an area **four** times larger. Through a sphere three times as large, the energy covers an area **nine** times larger.

* Energy received per square meter or centimeter

$$F = \frac{L}{4\pi r^2}$$

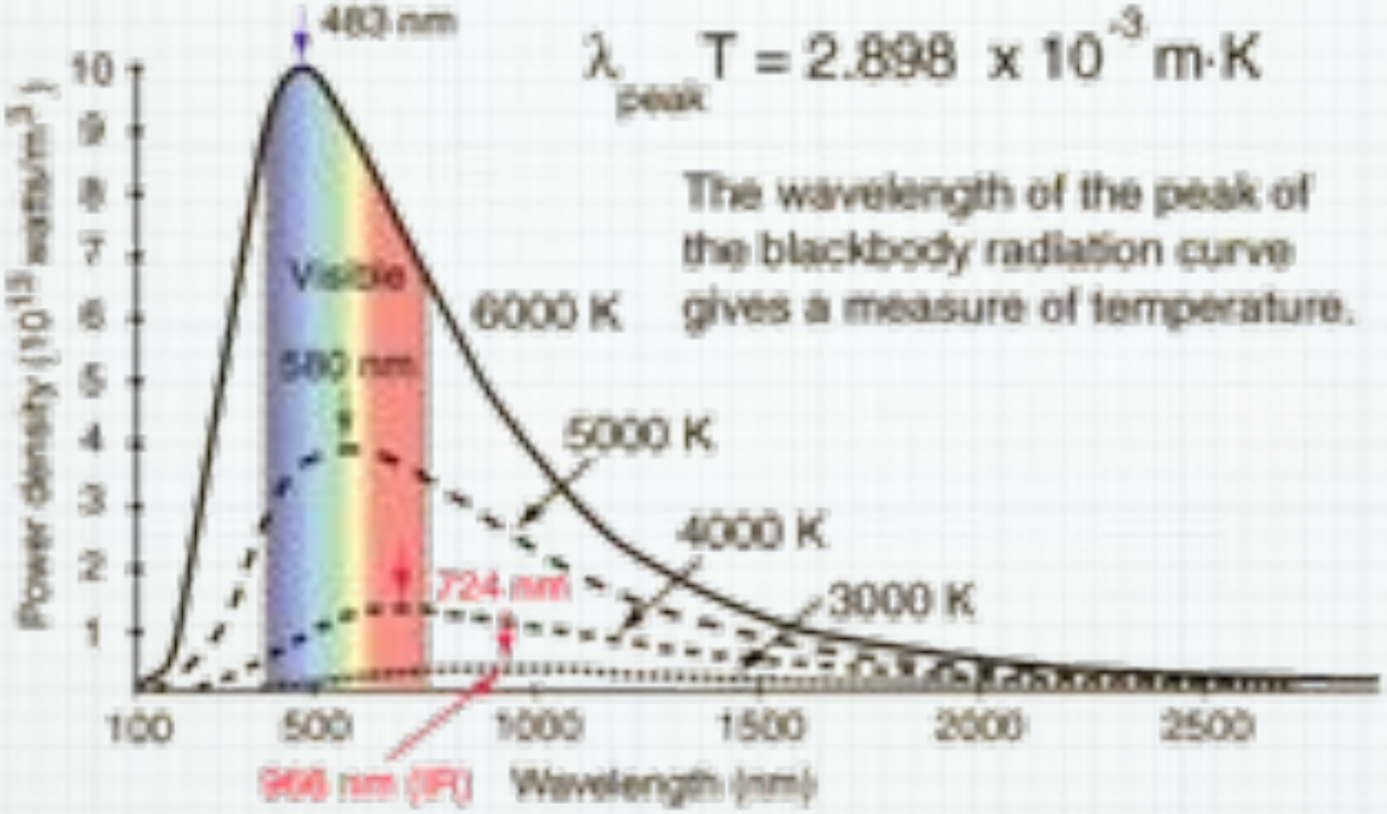
Blackbody radiation

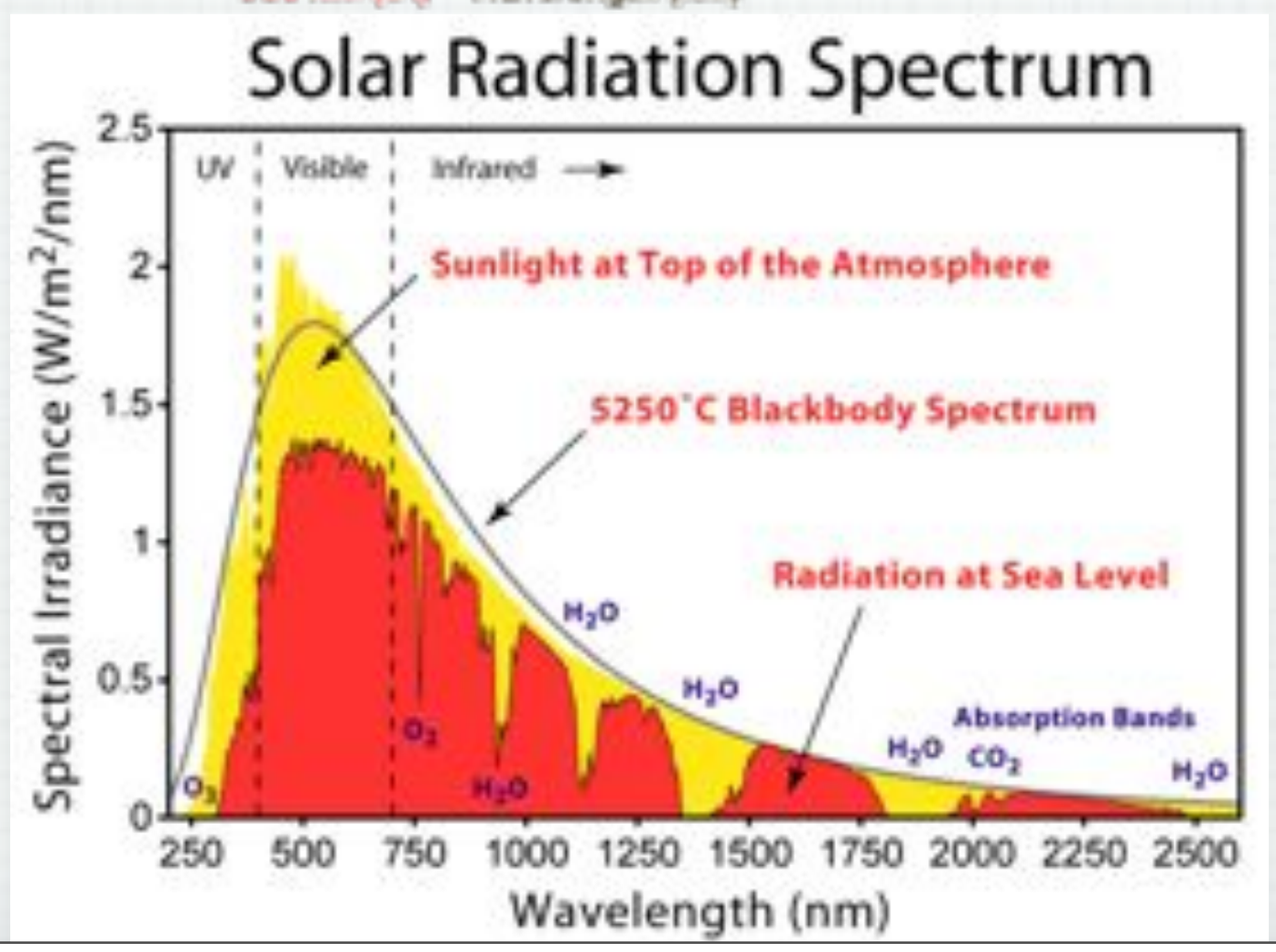
* Radiation emitted by (more or less) solid body with a temperature
* This is called continuous or thermal spectrum

$$I(\nu) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{k_b T}} - 1} \qquad I(\lambda) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_b T}} - 1}$$

Blackbody Radiation

* Energy per unit area per steradian per (herz or wavelength)
* h is Planck constant 6.626×10^{-27} erg s
* kb is the Boltzmann constant 1.38×10^{-16} erg K^{-1}


483 nm
$\lambda_{peak} T = 2.898 \times 10^{-3}$ m·K
The wavelength of the peak of the blackbody radiation curve gives a measure of temperature.
Power density (10^{13} watts/m^2)
Visible
500 nm
6000 K
5000 K
4000 K
3000 K
724 nm
968 nm (IR)
100
500
1000
1500
2000
2500
Wavelength (nm)


Solar Radiation Spectrum
UV
Visible
Infrared
Sunlight at Top of the Atmosphere
5250˚C Blackbody Spectrum
Radiation at Sea Level
H_2O
O_3
CO_2
Absorption Bands
Spectral Irradiance (W/m^2/nm)
Wavelength (nm)

Blackbody and Stars

$$F = \int_0^\infty F_\nu d\nu = \int_0^\infty F_\lambda d\lambda = \sigma T^4$$

$$F_\nu d\nu = F_\lambda d\lambda$$

$$L_{star} = 4\pi R_{star}^2 \sigma T^4$$

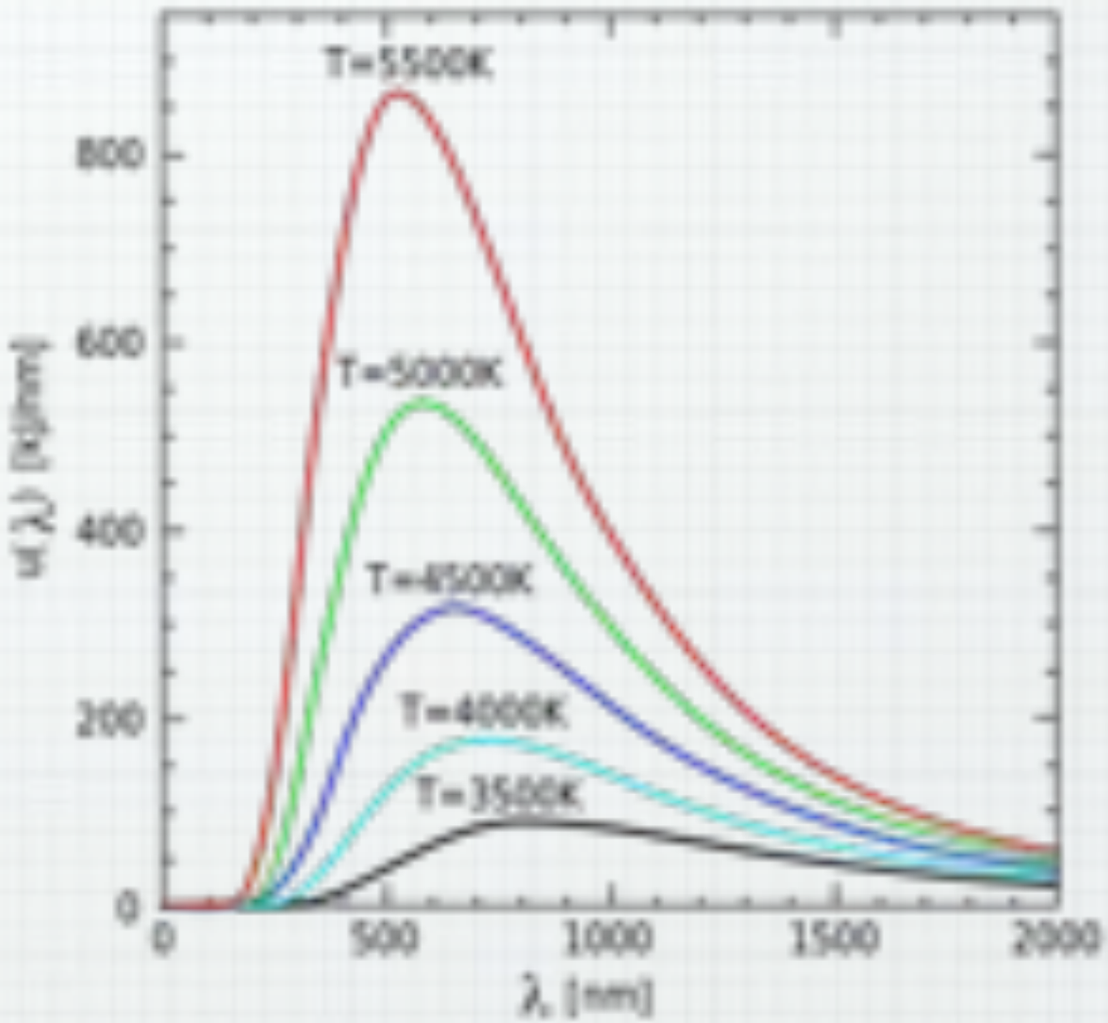
- $\sigma = 5.67 \times 10^{-5}$ erg cm^{-2} K^{-4} s^{-1}
- Proportional to r^2 and T^4
- Double r?
- Double T?
- Triple r?
- Triple T?

Let's play with it

* Our Sun, $r = 6.95 \times 10^{10}$cm, $T = 5778$ K
* Red Dwarf $r = 1.67 \times 10^{10}$ cm, $T=3000$ K
* O star $r = 10 \times r_{sun}$ $T = 40{,}000$ K

Wein's Displacement Law

* Peak of blackbody is derivable by maximizing formula for blackbody



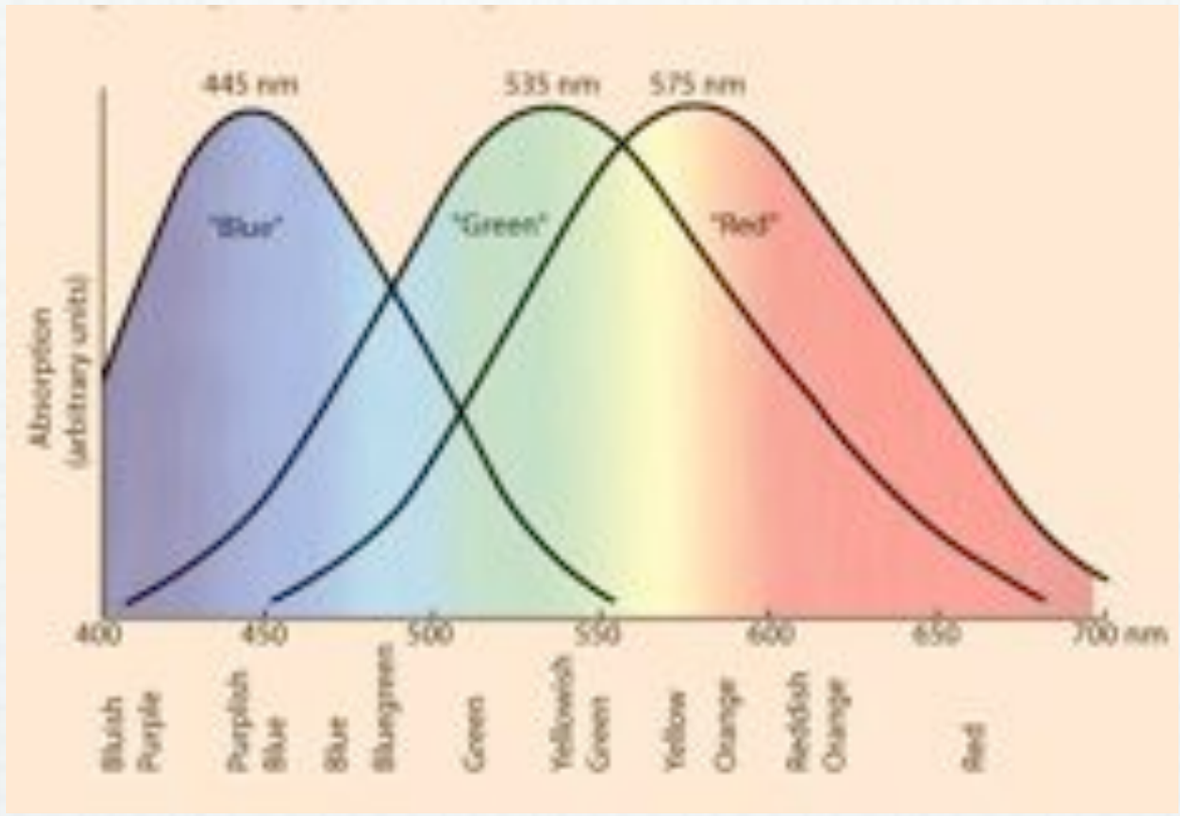
* Remember derivative set equal to zero

* $\lambda_{max} T = 2.897 \times 10^6 nmK$

Temperatures?

* Humans?
* Sun?
* First temperature measure for stars, there will be others.
* Our star actually peaks in the green but has light emitted at other wavelengths

We see a yellow star



Properties of Stars

* $R_{solar} = 6.95 \times 10^{10}$ cm
* $M_{solar} = 2 \times 10^{33}$ g
* $L_{solar} = 3.839 \times 10^{33}$ ergs
* Lifetime solar = 10 billion years
* $T_{solar} = 5778$ K

Stellar Properties Review

Luminosity: from brightness and distance

$(0.08M_{\text{Sun}})$ $10^{-4}L_{\text{Sun}}$–$10^{6}L_{\text{Sun}}$ $(100M_{\text{Sun}})$

Temperature: from color and spectral type

$(0.08M_{\text{Sun}})$ 3000 K–50,000 K $(100M_{\text{Sun}})$

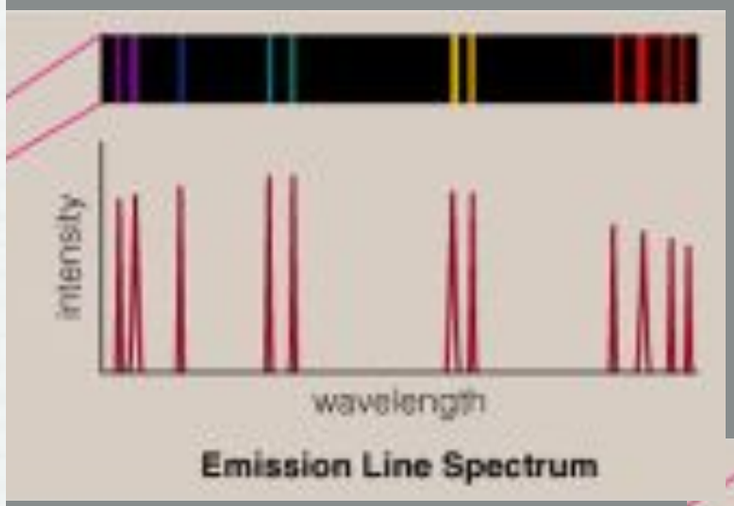
Mass: from period (*p*) and average separation (*a*) of binary star orbit

$0.08M_{\text{Sun}}$–$100M_{\text{Sun}}$

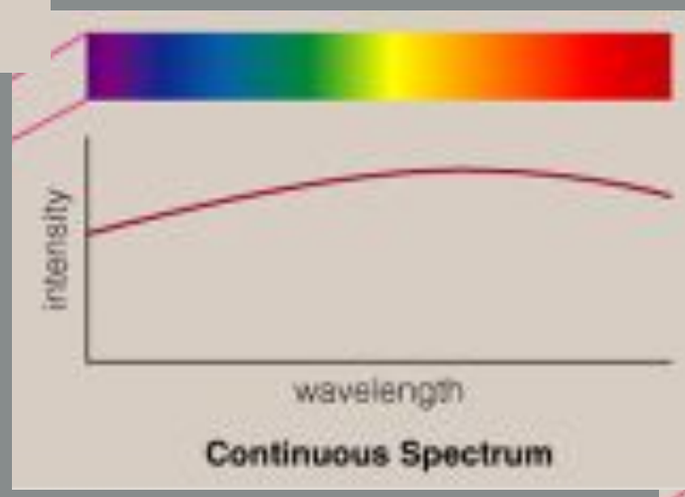
More stellar properties

* Ages range from 10s of millions to hundreds of billions of years
* Radius ranges from 1/10th the sun's to 100 times the sun

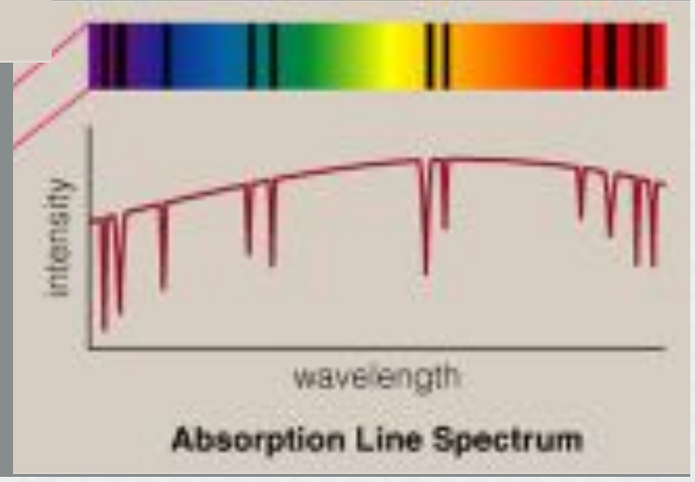
Three types of spectra



Emission Line Spectrum



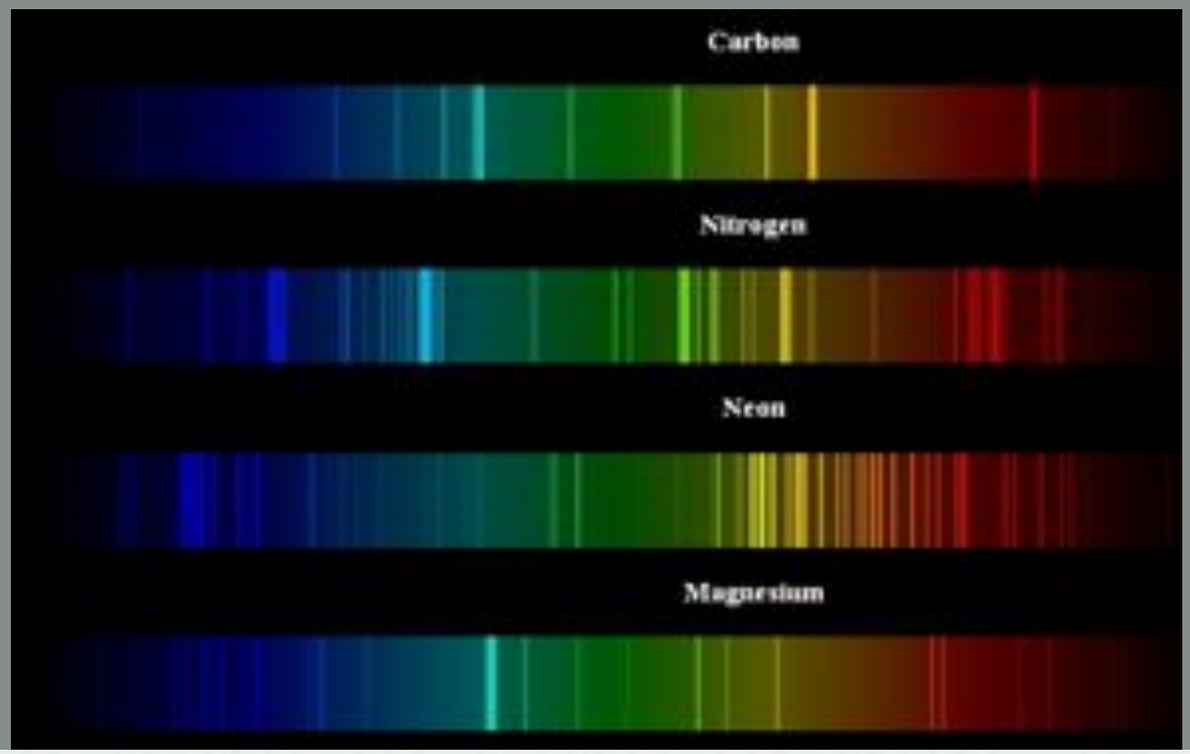
Continuous Spectrum



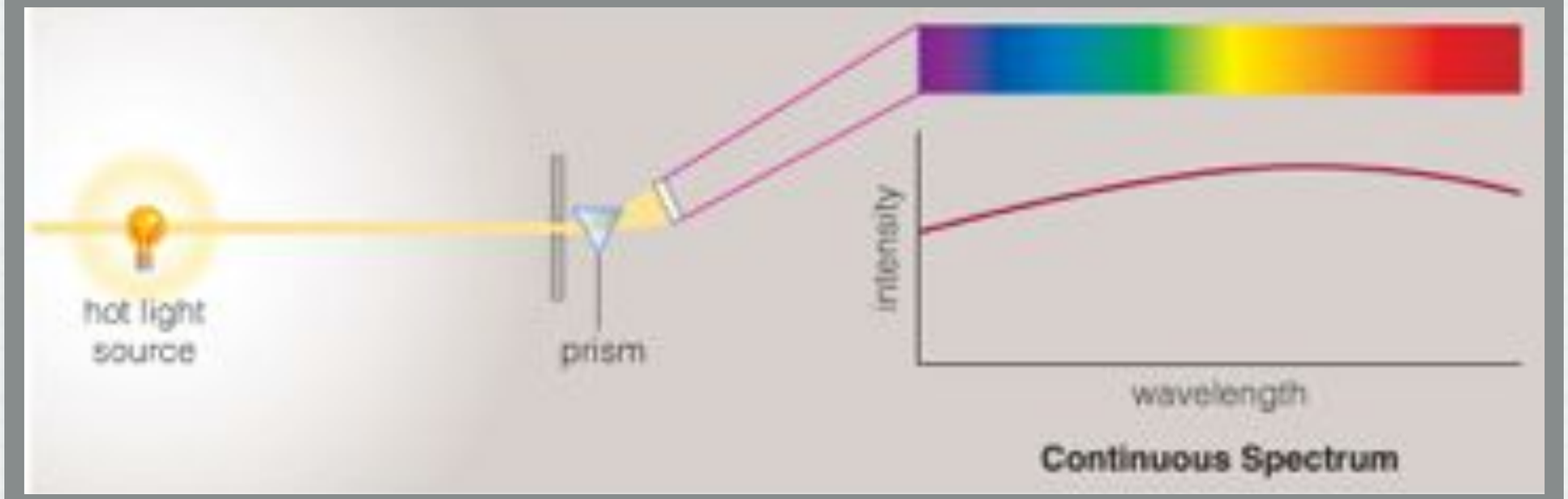
Absorption Line Spectrum

Each atom has a different set of energy levels

- Just like no two people have the same fingerprints, no two elements have the same emission spectrum

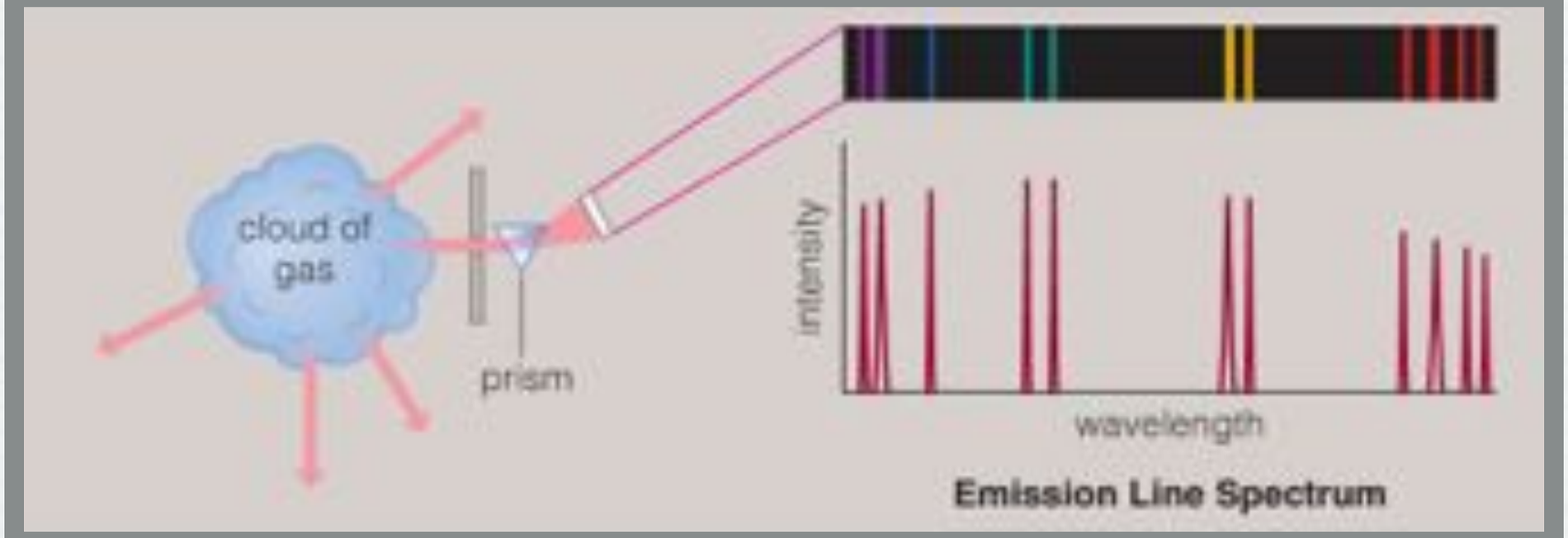


Continuous Spectrum



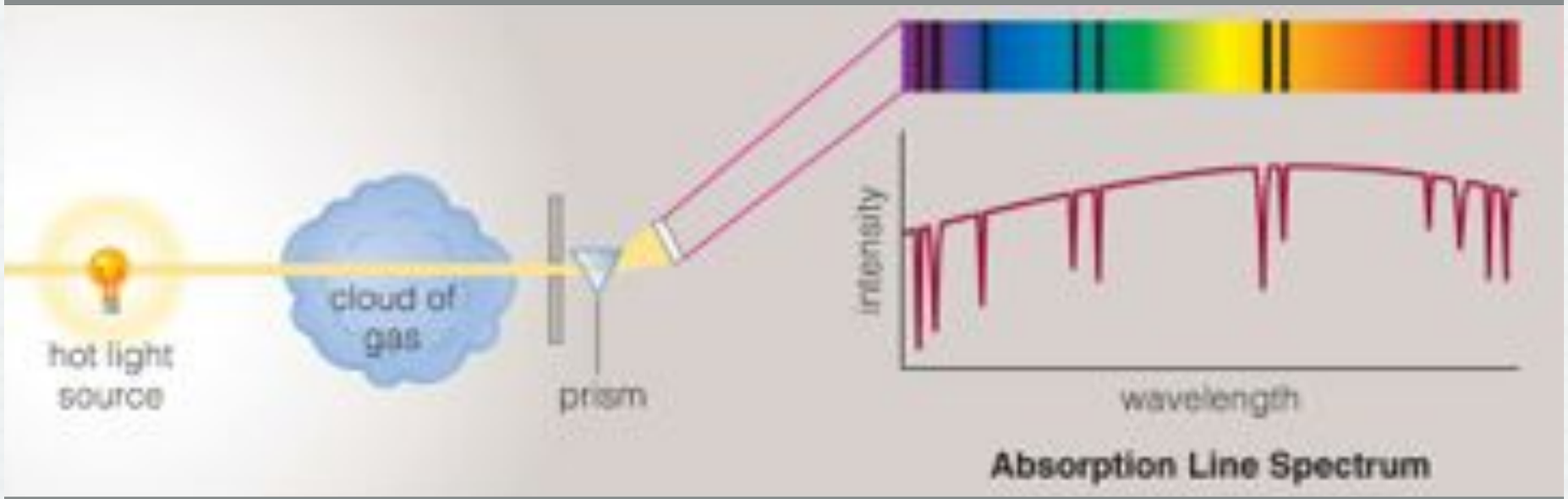
- Hot solids (or dense liquid): Emit a continuous rainbow of light
  - Thermal Radiation *(or Blackbody Radiation)*

Emission Spectra



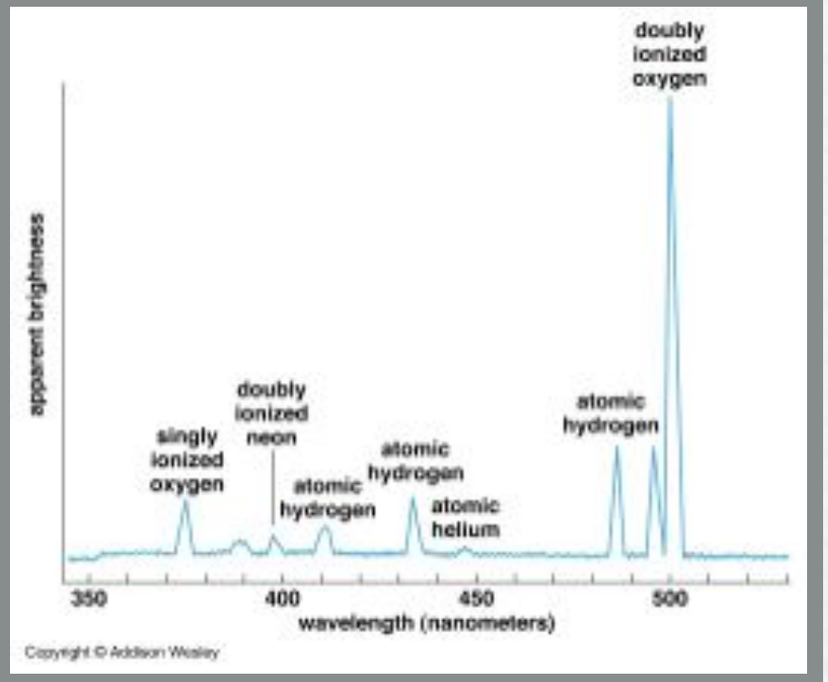
- Emission for thin, hot gas: Gas glows in specific colors.
  - Colors represent electrons "falling down" energy levels
  - This is a FINGERPRINT of the elements in the gas.

Absorption Spectrum



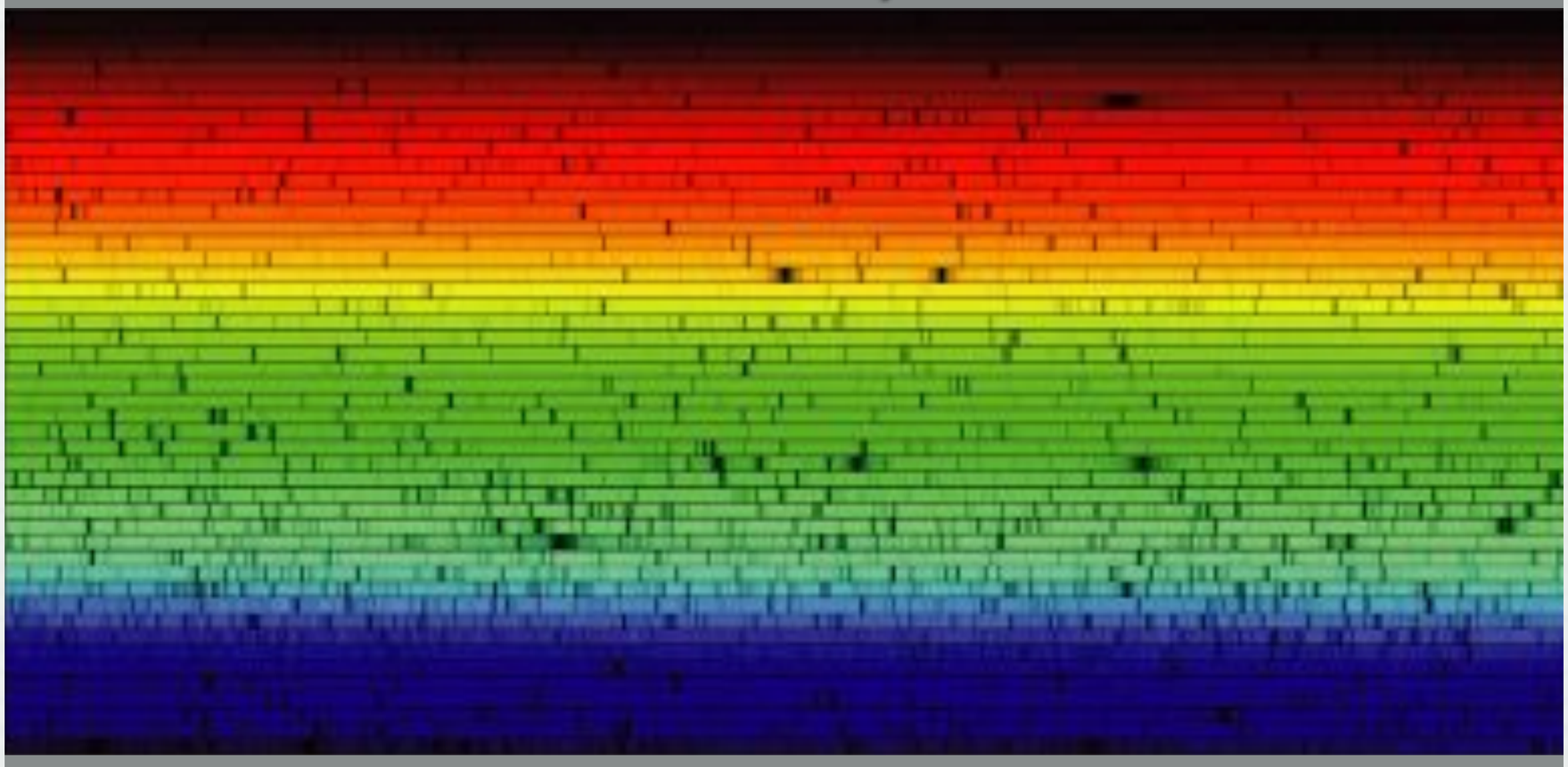
- Hot object viewed through COOL gas: Dark lines on top of a rainbow
  - Gas can only absorb photons OF THE RIGHT ENERGIES to move electrons to excited states

The Crab nebula: remains of an exploded star (supernova)

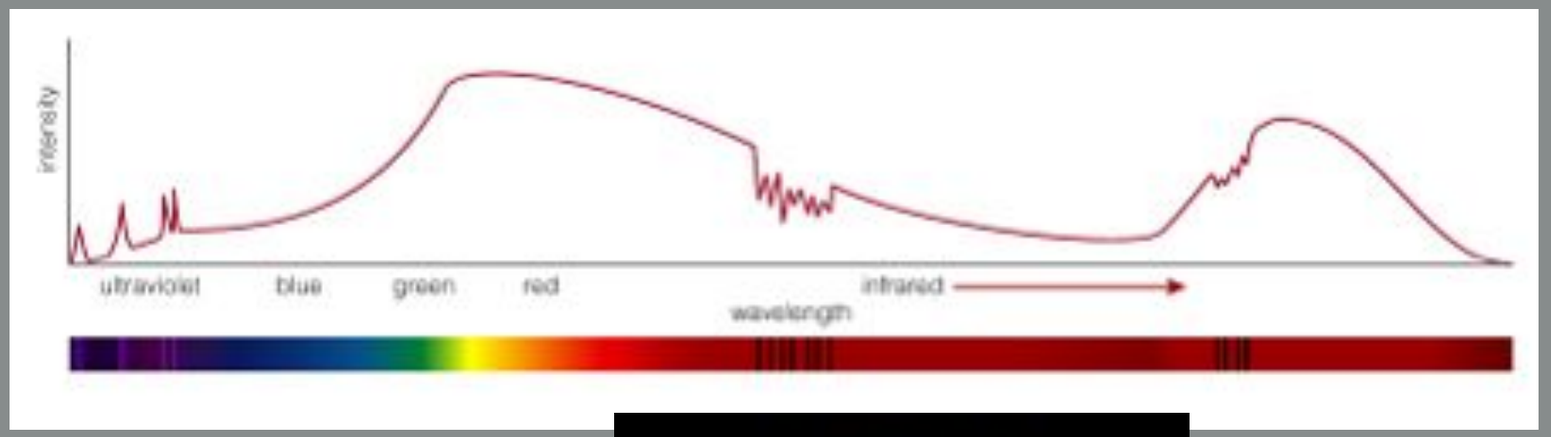


Spectrum shows bright emission lines from various elements

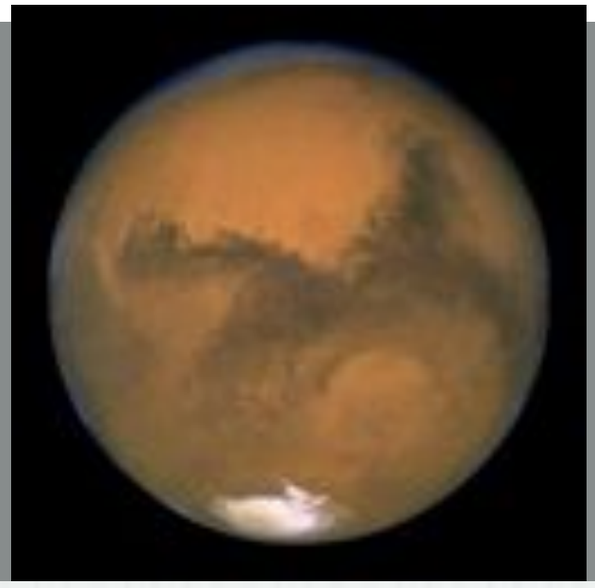
Solar Spectrum (as seen from Earth)



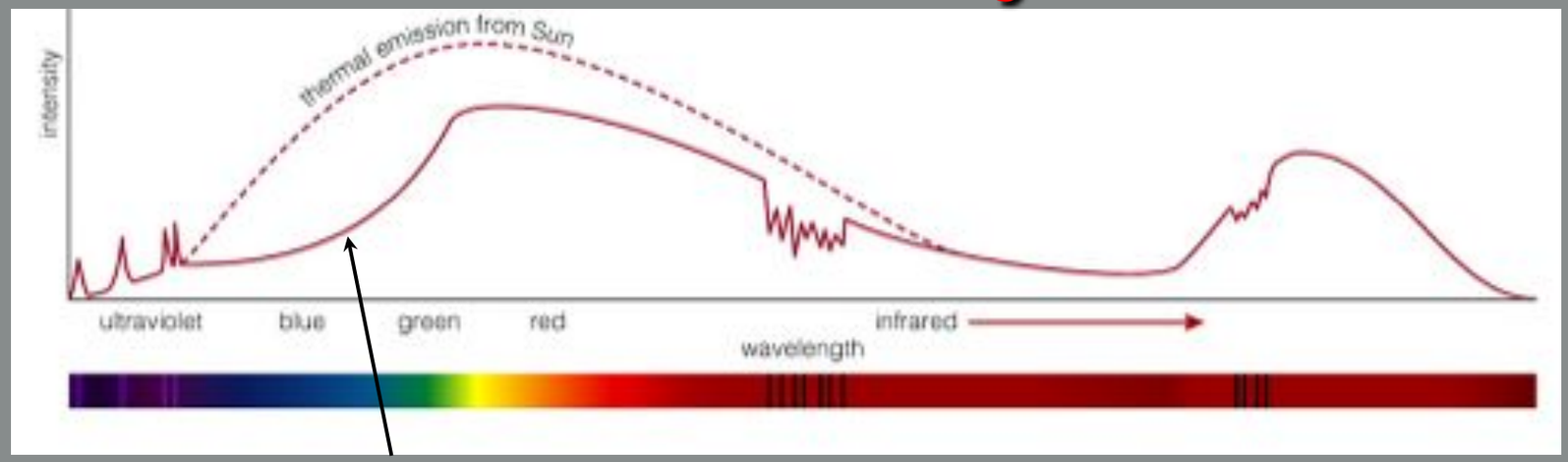
What is this object?



Mars!

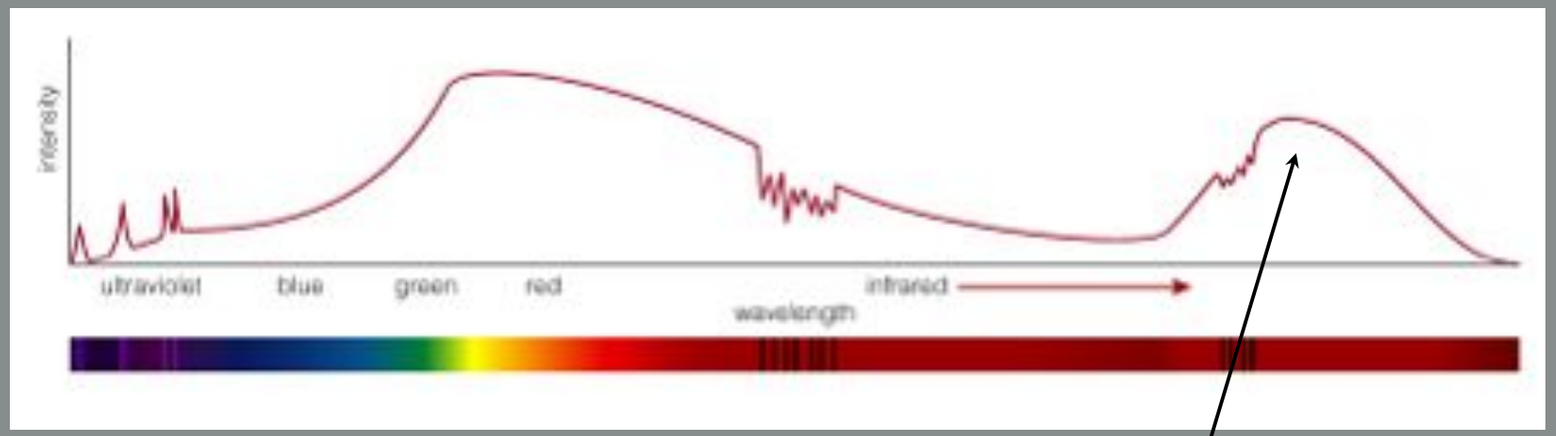


What is this object?



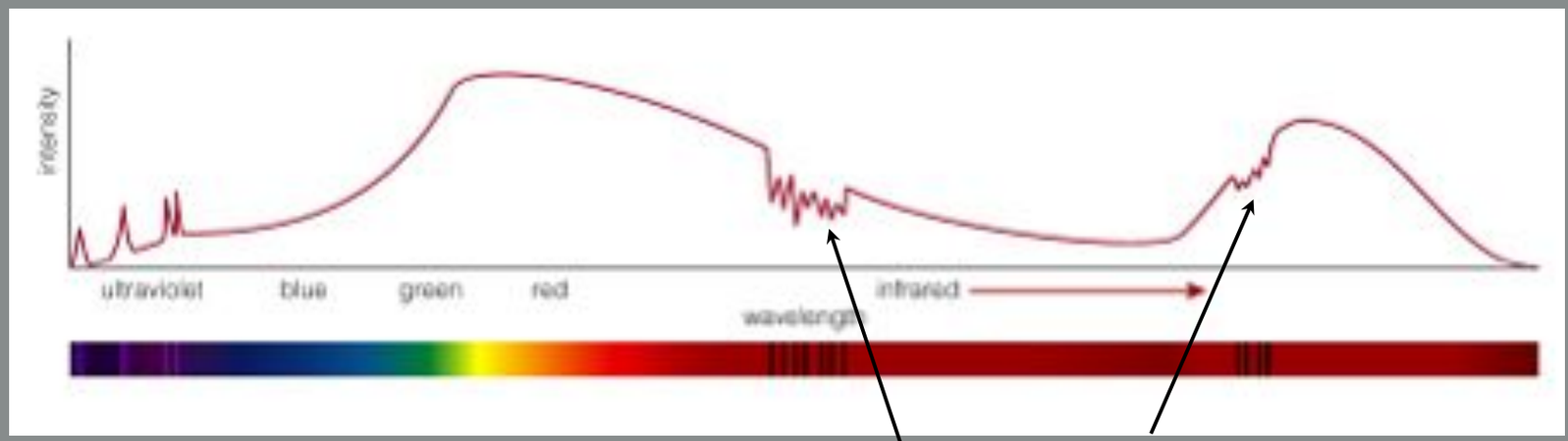
Continuous Spectrum: Spectrum of visible light is like the Sun's except that some of the blue light has been absorbed

What is this object?



Continuous Spectrum: Must be a solid object with peak emission at a wavelength corresponding to a temperature of 225 K

What is this object?



Infrared Absorption Lines: Absorption lines are the fingerprint of CO_2 gas

Spectra

* Gives us
  * Temperature
  * Composition
  * Rotation
  * Velocity
  * Everything
    * No laboratory on earth for astrophysics

Next time

* Magnitudes
* Saha Equation
* HR diagram
* Expect the math to ramp up substantially

Read

* Chapters 1 & 2
* read wikipedia's pages on
  * http://en.wikipedia.org/wiki/Stellar_classification
  * http://en.wikipedia.org/wiki/Stellar_evolution
  * http://en.wikipedia.org/wiki/Hertzsprung%E2%80%93Russell_diagram
  * http://en.wikipedia.org/wiki/Stellar_structure