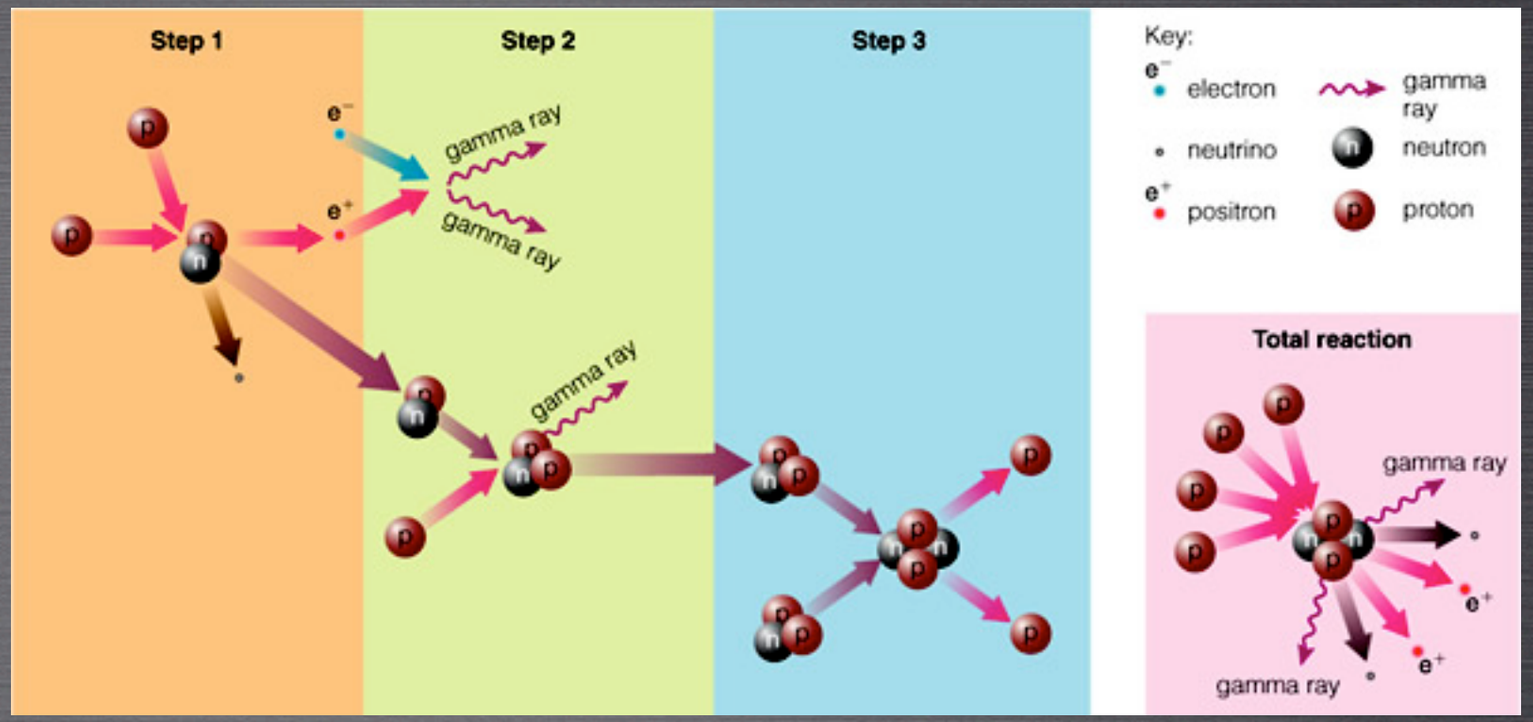
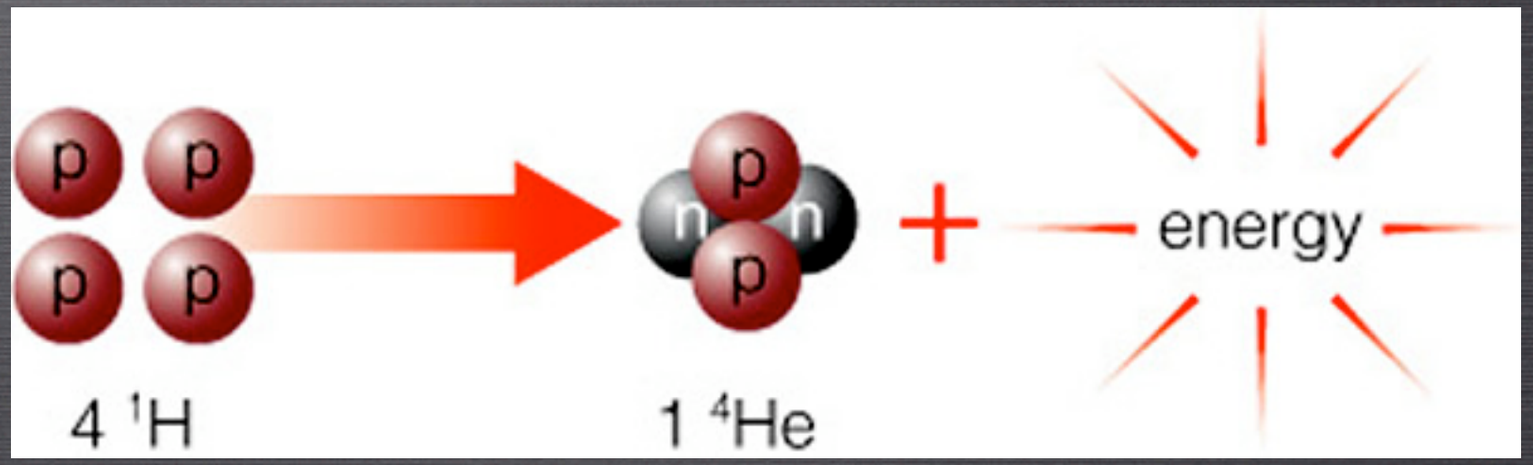
Review

Proton-proton chain of reactions is the main reaction in stars such as our Sun



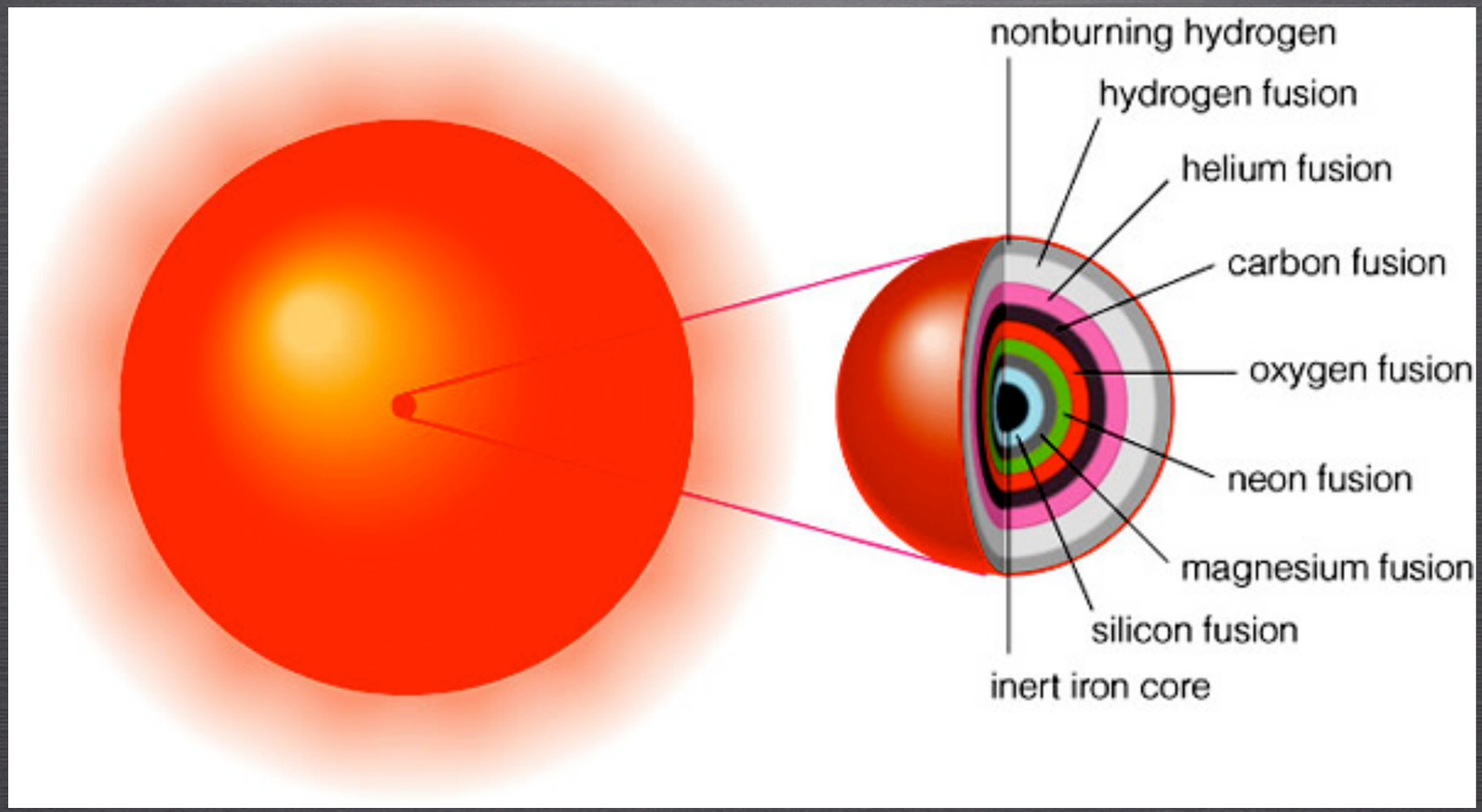


$p + p \rightarrow D$

$D + p \rightarrow {}^{3}He$

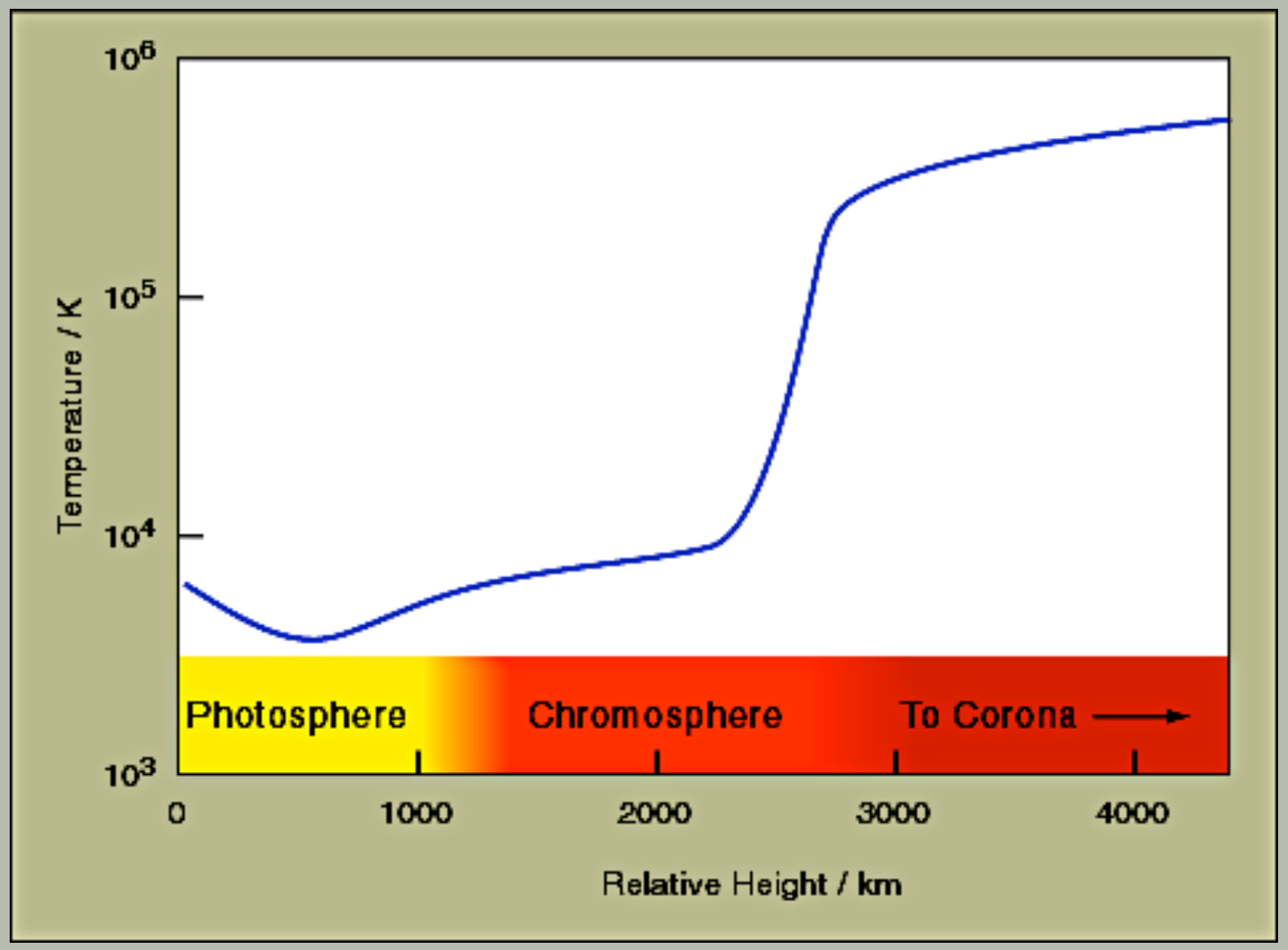
${}^{3}He + {}^{3}He \rightarrow {}^{4}He + p+p$

Different types of reactions in massive stars



The Sun's atmosphere has three layers:

- The ***photosphere*** is the layer that we see. It has a temperature of about 5800 K.
- The ***chromosphere*** lies above the photosphere. Surprisingly, it is hotter - up to a million degrees K.
- The ***corona*** is the outermost layer that extends out to several solar radii. Its temperature is about 2 million degrees K.



THE ELECTROMAGNETIC SPECTRUM

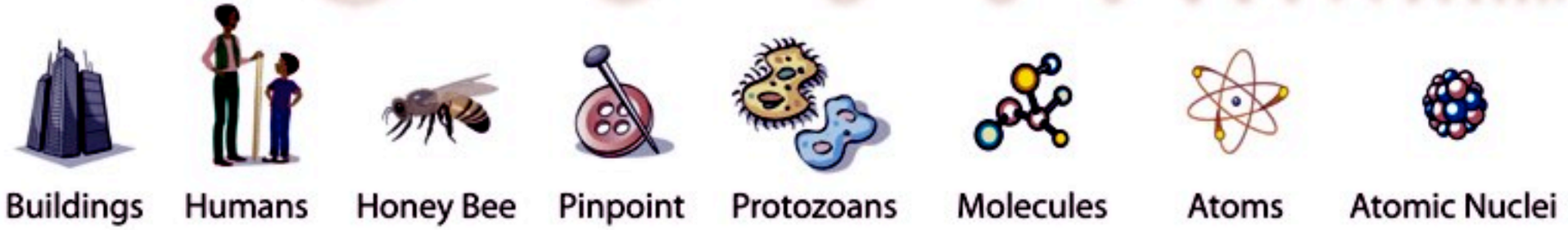
Penetrates Earth Atmosphere?

Y		N		Y	N

Wavelength (meters)

Radio	Microwave	Infrared	Visible	Ultraviolet	X-ray	Gamma Ray
10^{3}	10^{-2}	10^{-5}	$.5 \times 10^{-6}$	10^{-8}	10^{-10}	10^{-12}

About the size of...

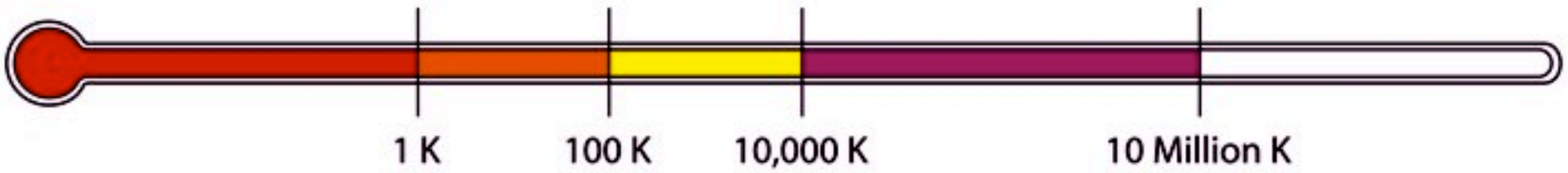


Buildings | Humans | Honey Bee | Pinpoint | Protozoans | Molecules | Atoms | Atomic Nuclei

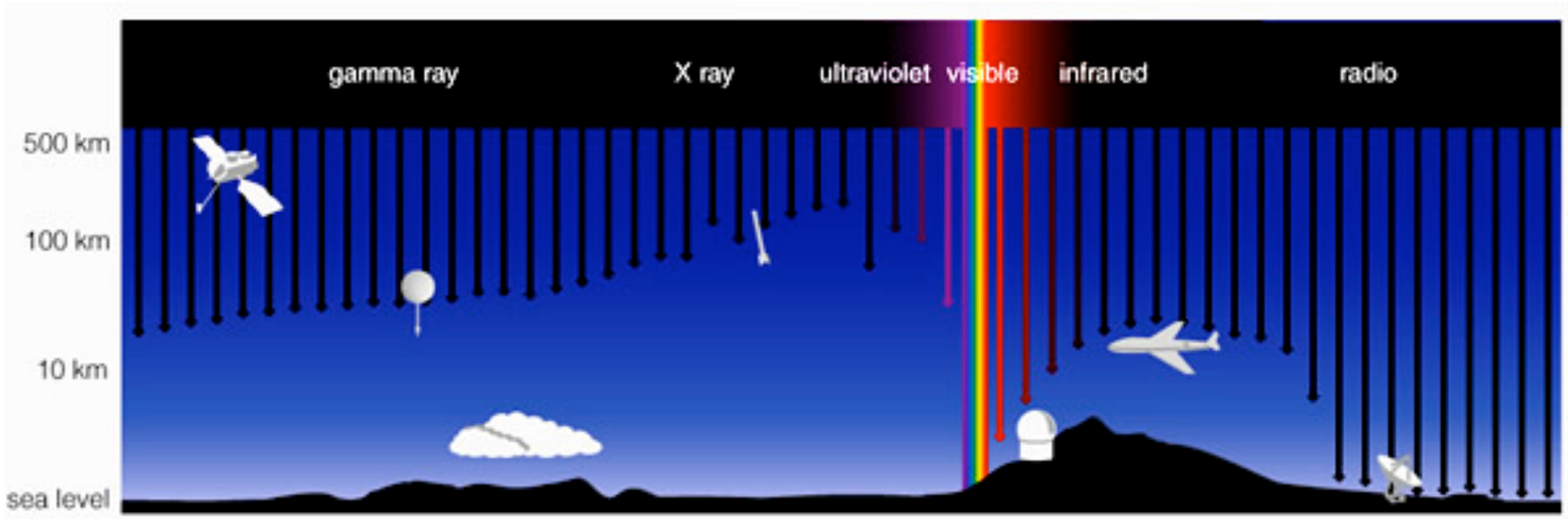
Frequency (Hz)

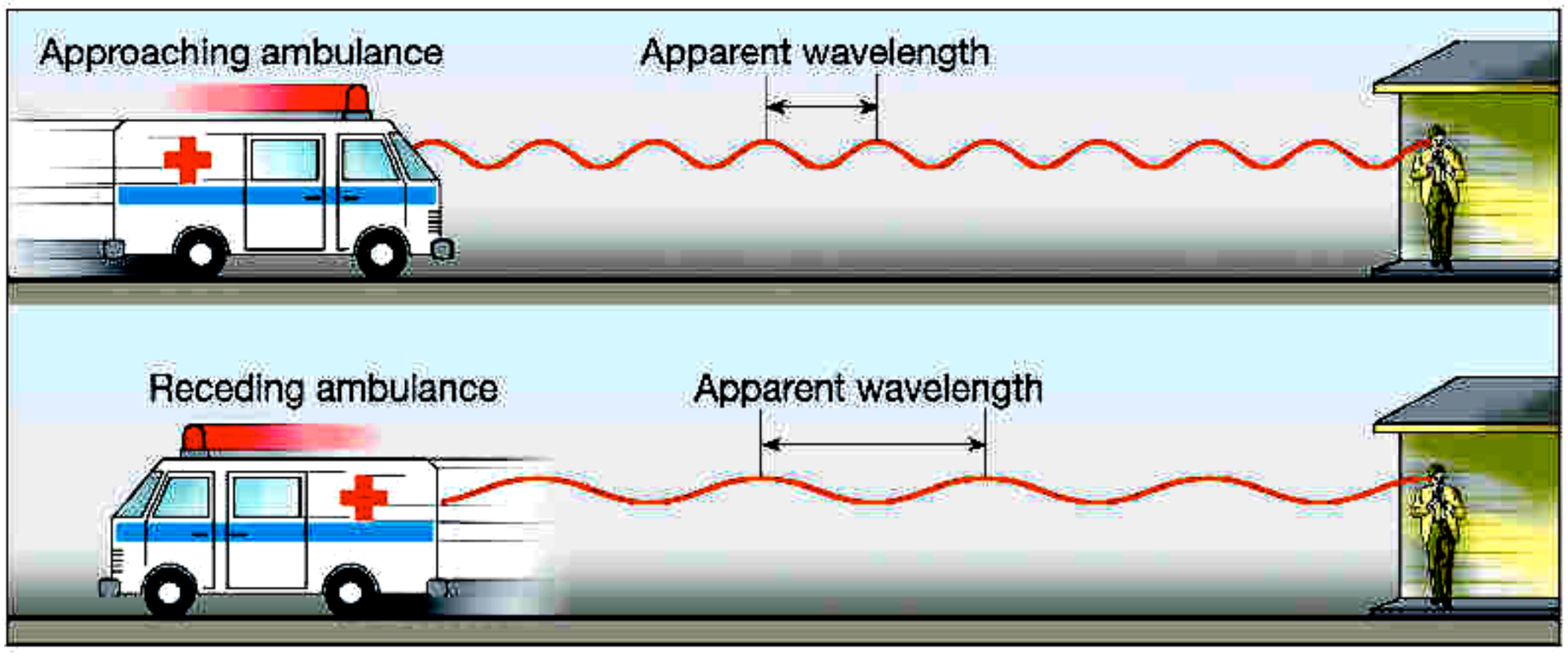
10^{4}	10^{8}	10^{12}	10^{15}	10^{16}	10^{18}	10^{20}

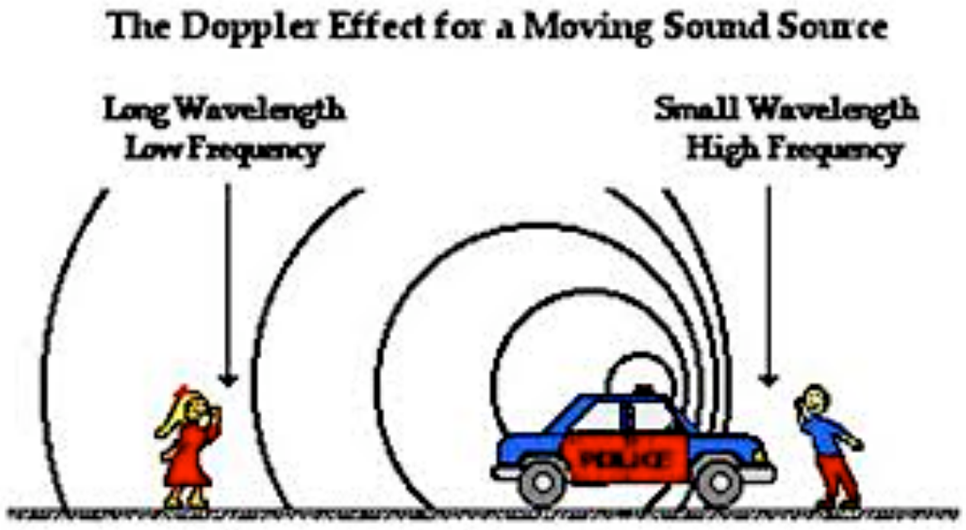
Temperature of bodies emitting the wavelength (K)



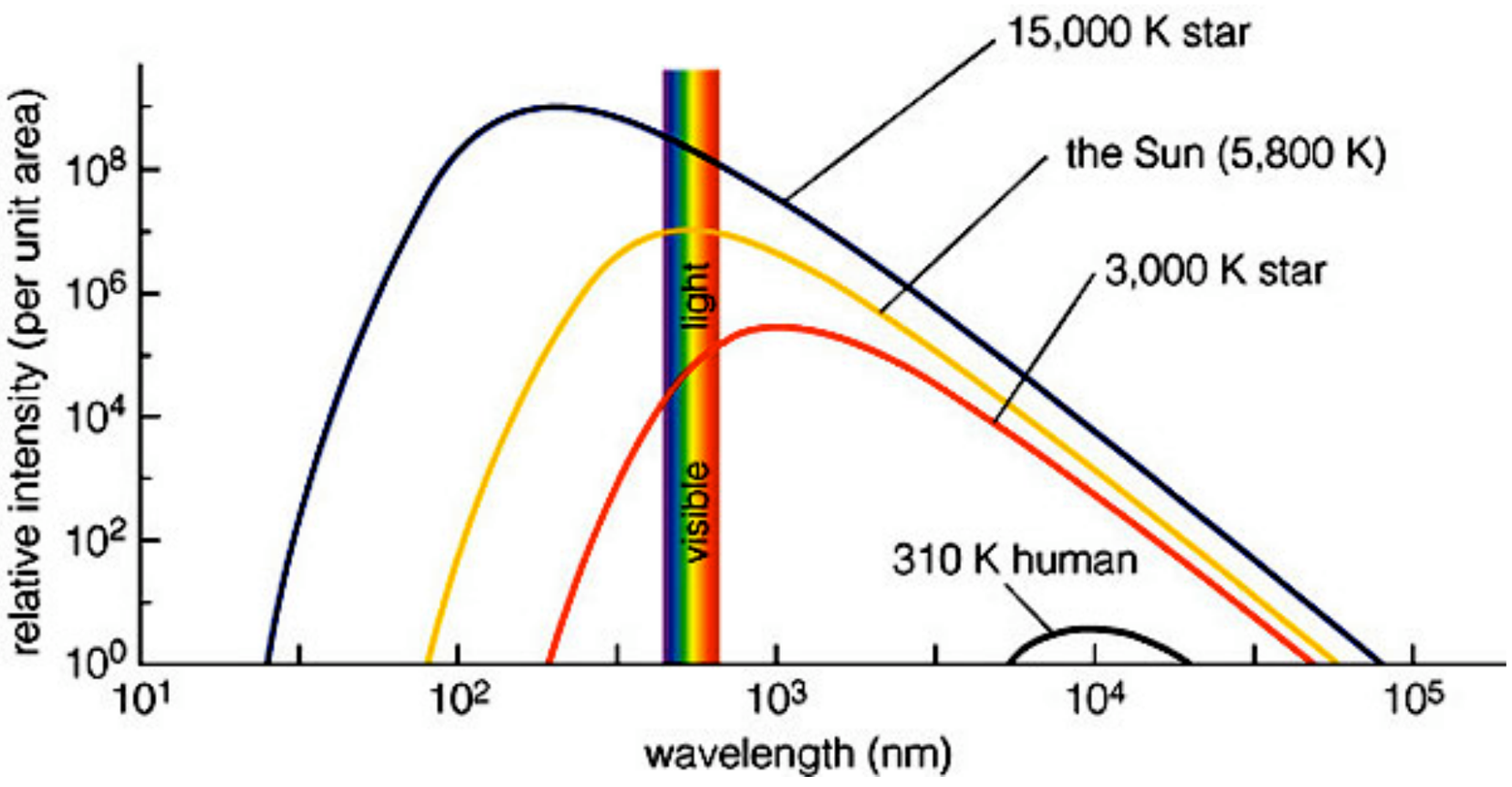
1 K	100 K	10,000 K	10 Million K


gamma ray
X ray
ultraviolet
visible
infrared
radio
500 km
100 km
10 km
sea level

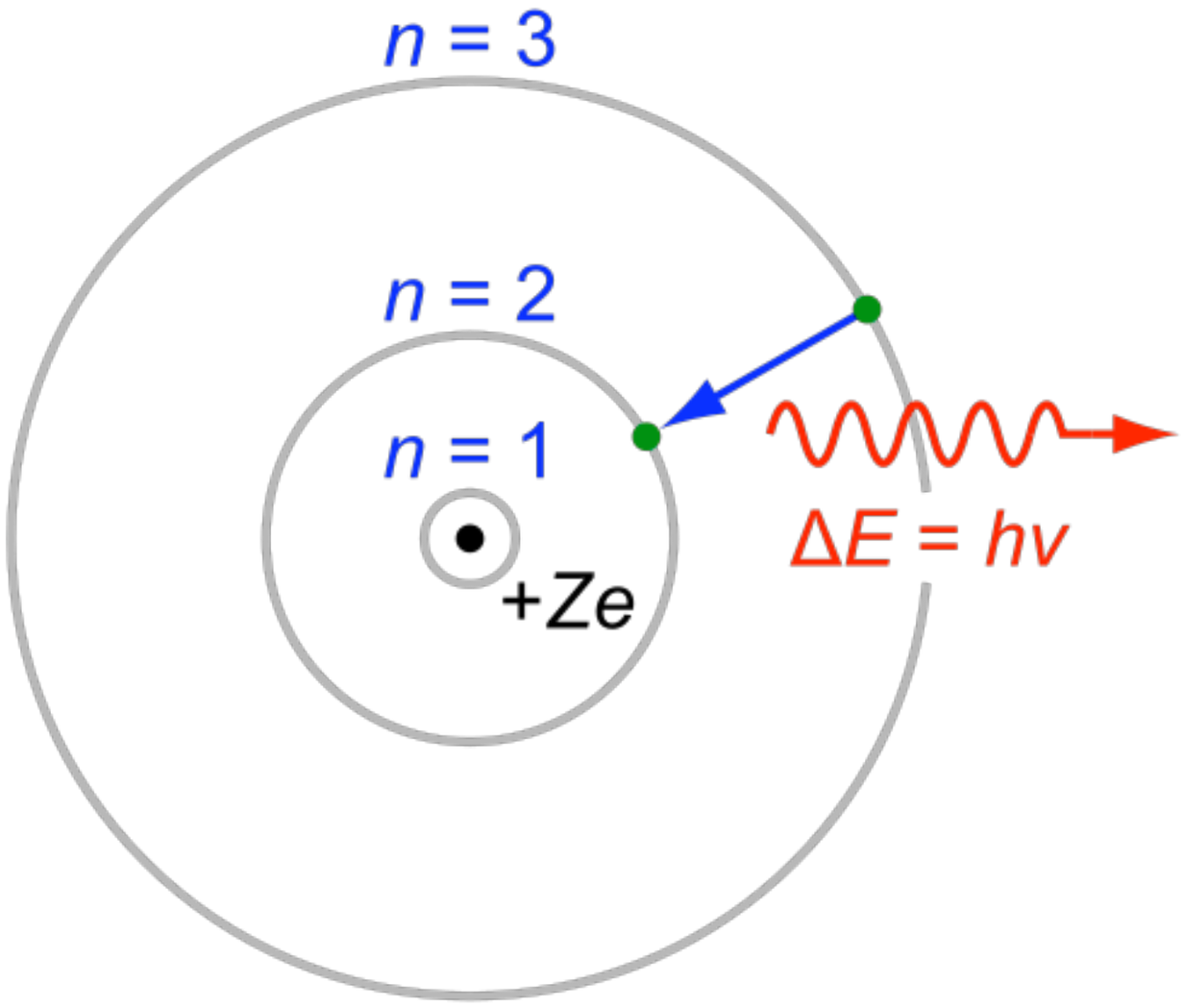

Approaching ambulance
Apparent wavelength
Receding ambulance
Apparent wavelength


The Doppler Effect for a Moving Sound Source
Long Wavelength
Low Frequency
Small Wavelength
High Frequency
POLICE

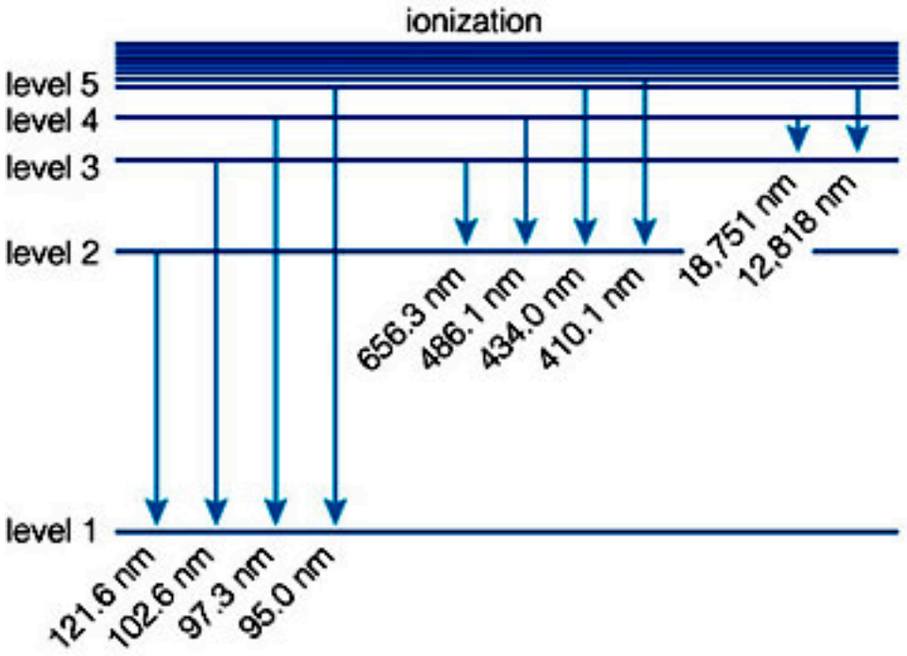
Blackbody radiation

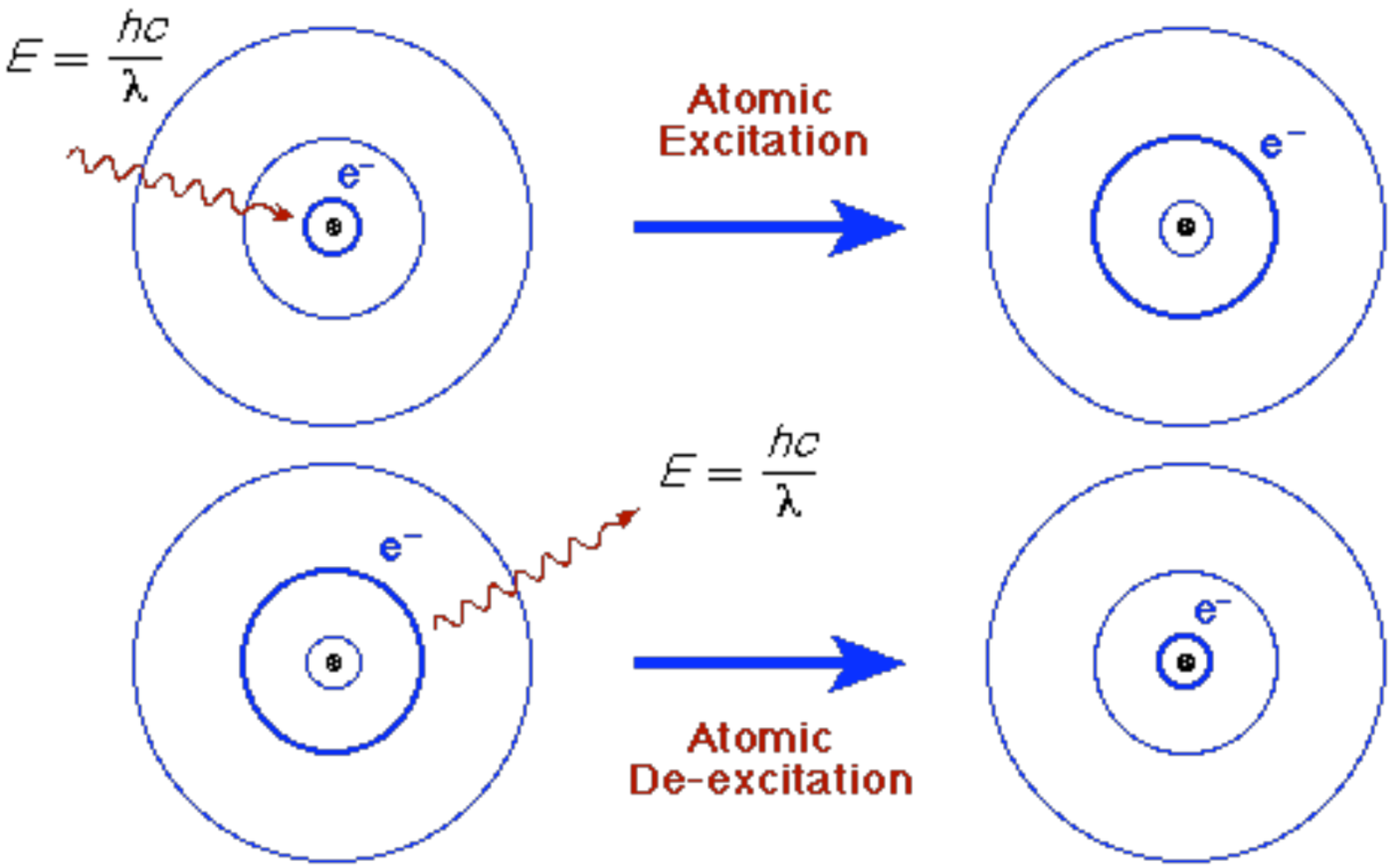


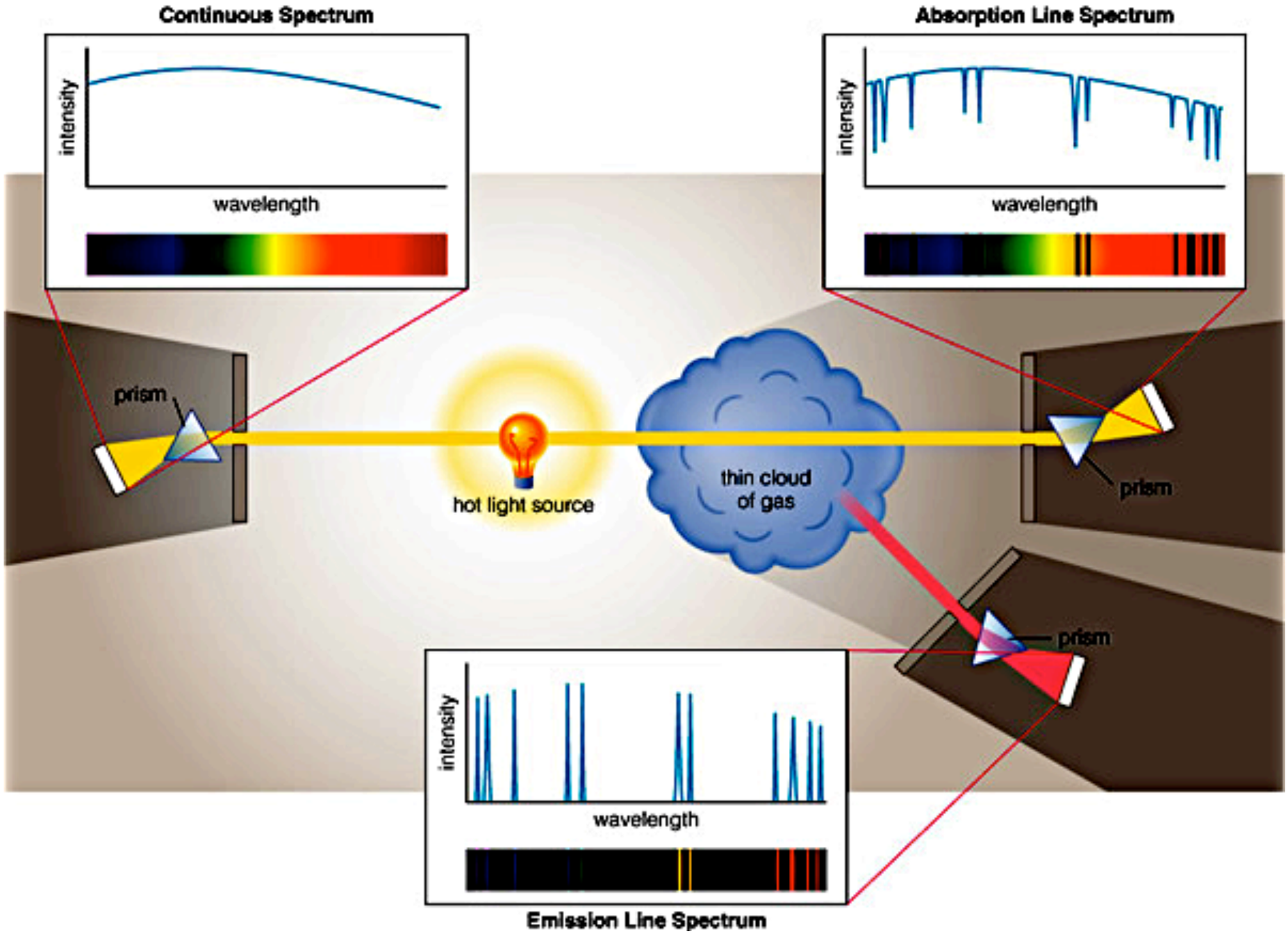
Bohr's model of atom



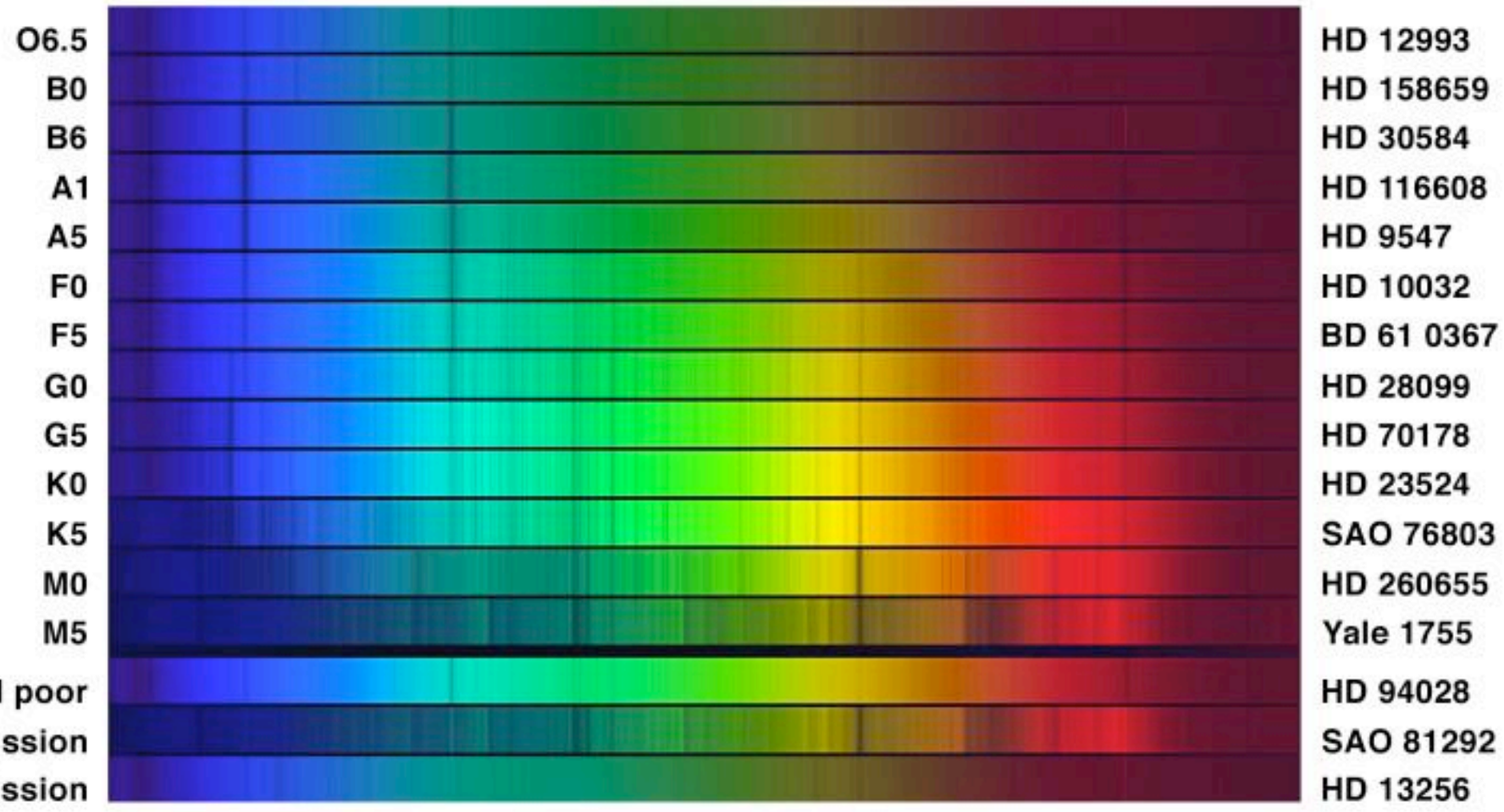
An atom emits or absorbs light only at specific wavelengths that correspond to changes in the atom's energy as an electron jumps between its allowed energy levels.

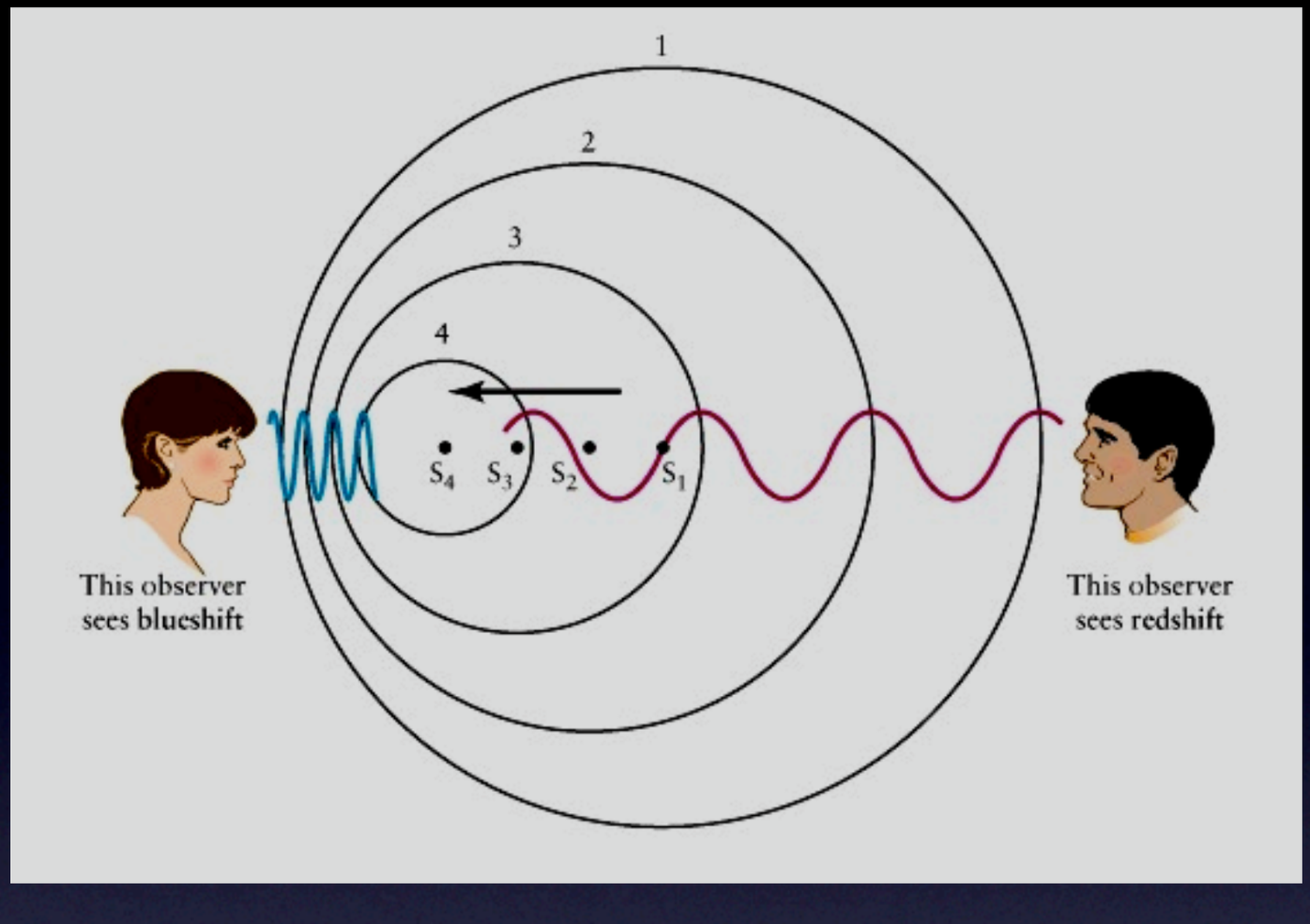



$E = \frac{hc}{\lambda}$
e⁻
Atomic
Excitation
e⁻
$E = \frac{hc}{\lambda}$
e⁻
Atomic
De-excitation
e⁻

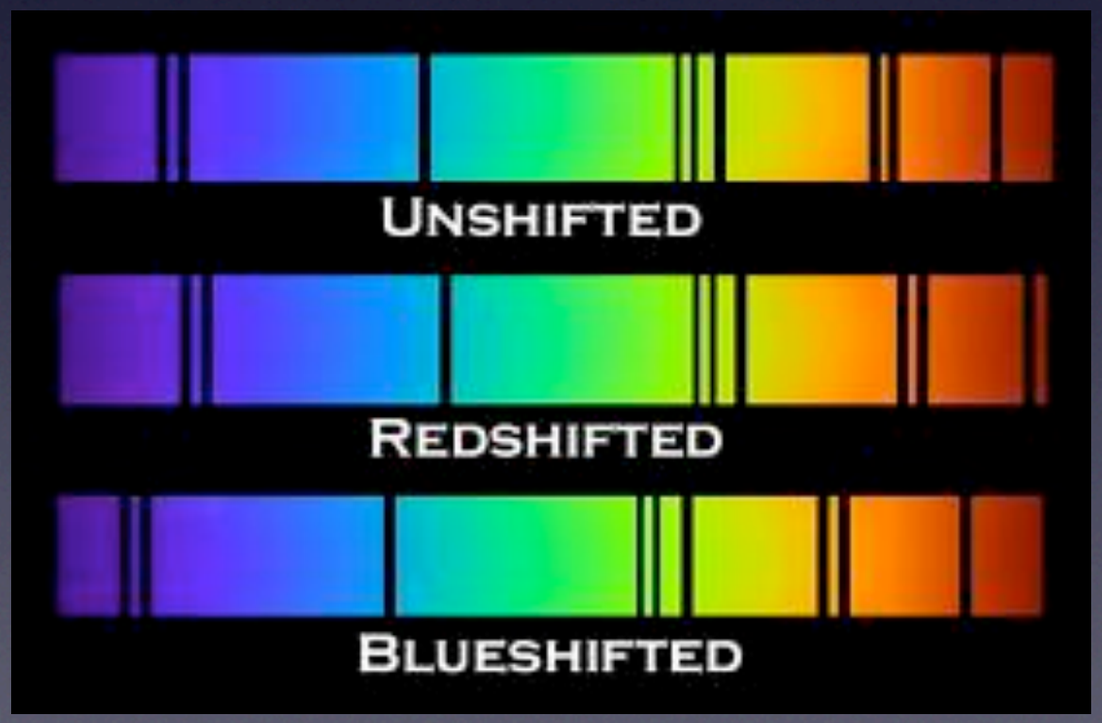

Continuous Spectrum
intensity
wavelength
Absorption Line Spectrum
intensity
wavelength
prism
hot light source
thin cloud
of gas
prism
prism
intensity
wavelength
Emission Line Spectrum

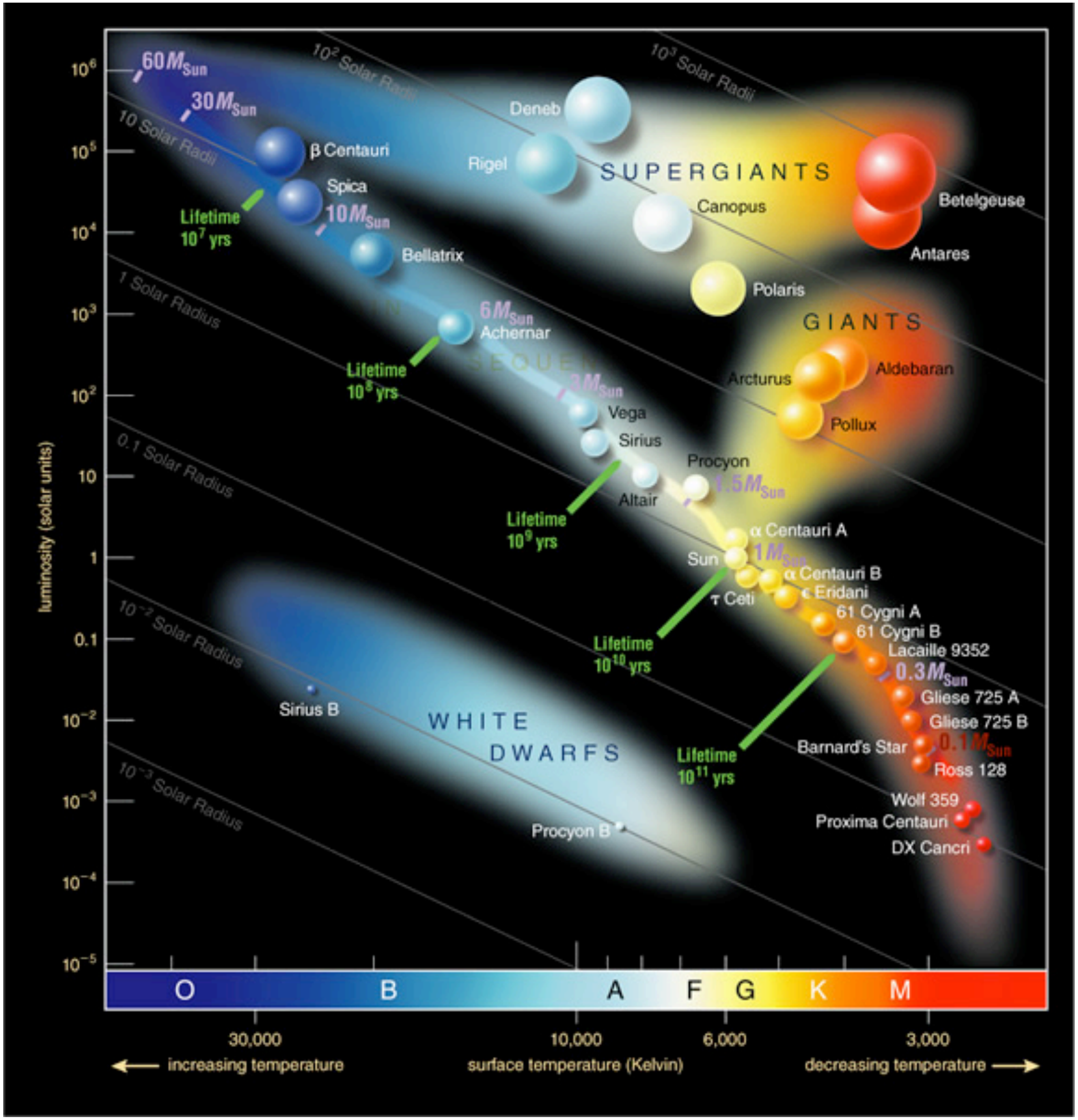
Spectra of different stars

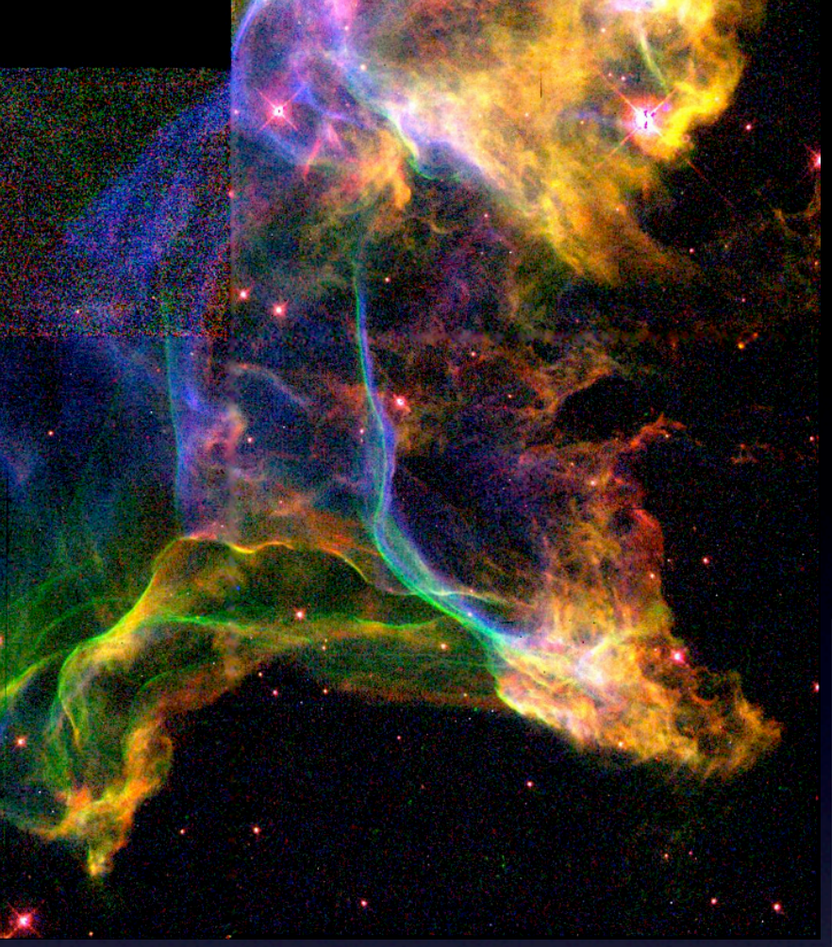


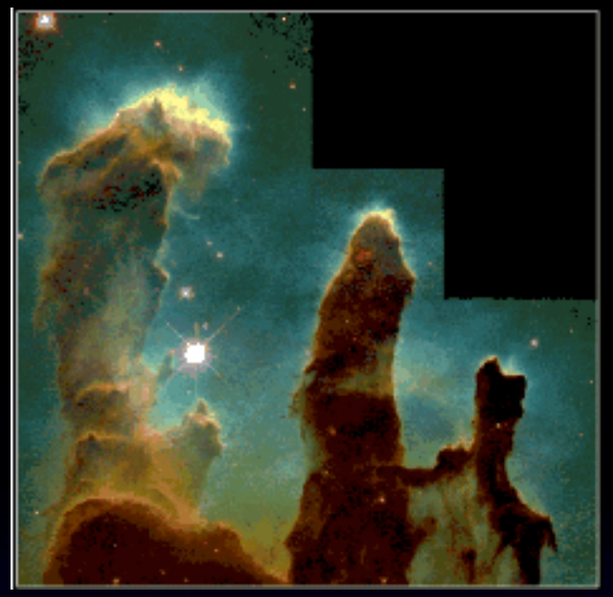


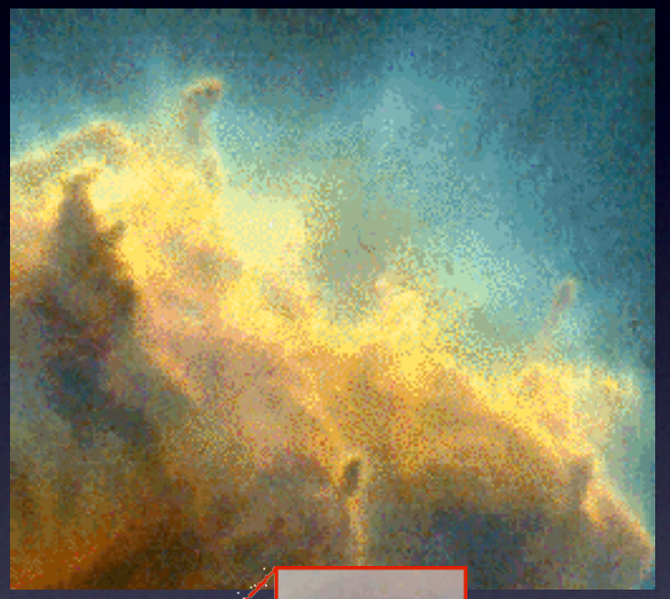
$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

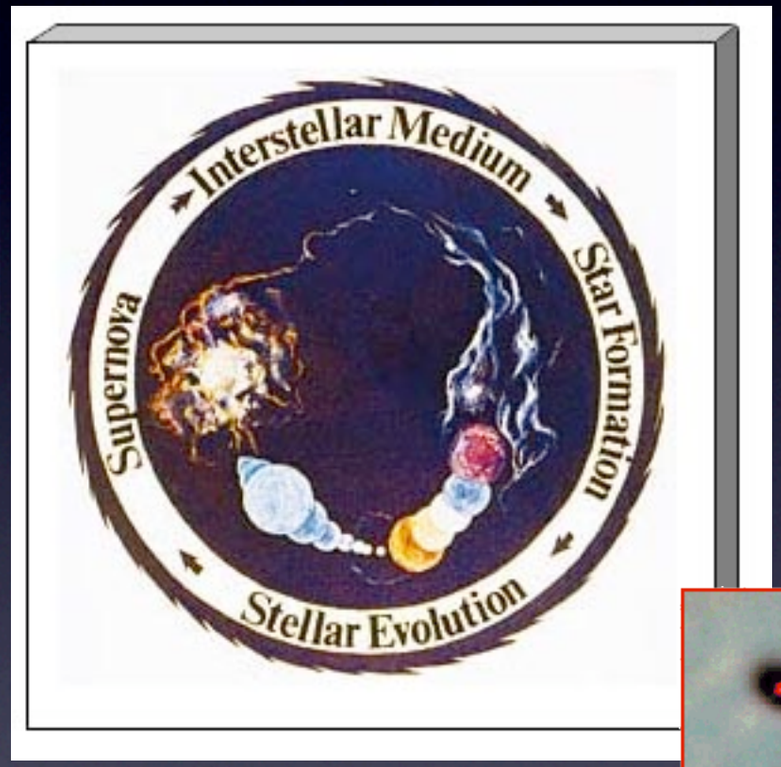


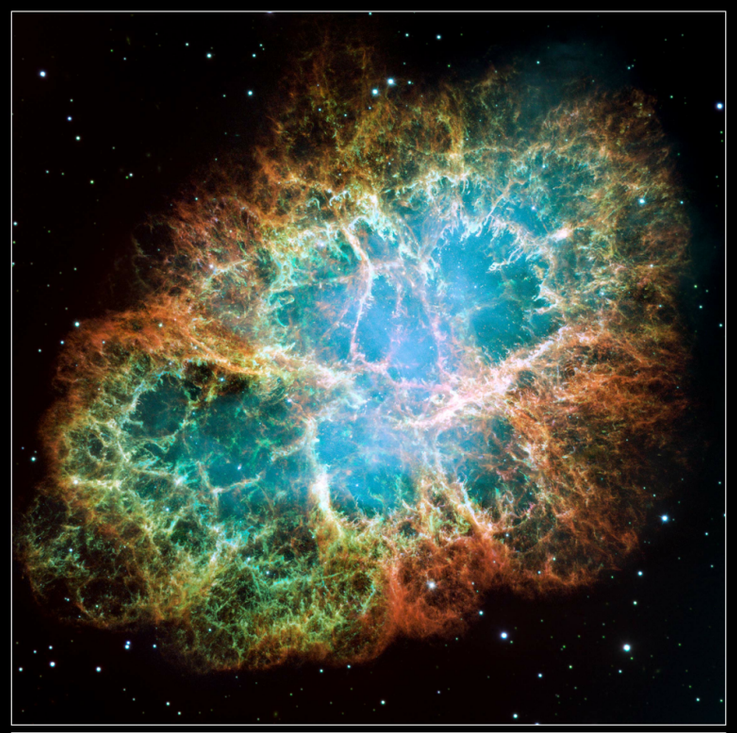

Luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^2 Solar Radii
10^3 Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^{-2} Solar Radius
10^{-3} Solar Radius
$60M_{Sun}$
$30M_{Sun}$
$10M_{Sun}$
$6M_{Sun}$
$3M_{Sun}$
$1.5M_{Sun}$
$1M_{Sun}$
$0.3M_{Sun}$
$0.1M_{Sun}$
Lifetime 10^7 yrs
Lifetime 10^8 yrs
Lifetime 10^9 yrs
Lifetime 10^{10} yrs
Lifetime 10^{11} yrs
Deneb
Rigel
SUPERGIANTS
Canopus
Betelgeuse
Antares
β Centauri
Spica
Bellatrix
Polaris
GIANTS
Achernar
Arcturus
Aldebaran
Pollux
Vega
Sirius
Procyon
Altair
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
WHITE DWARFS
Procyon B
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
increasing temperature
surface temperature (Kelvin)
decreasing temperature





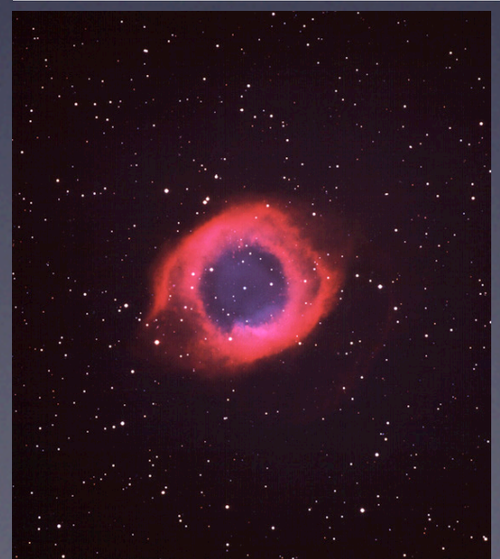


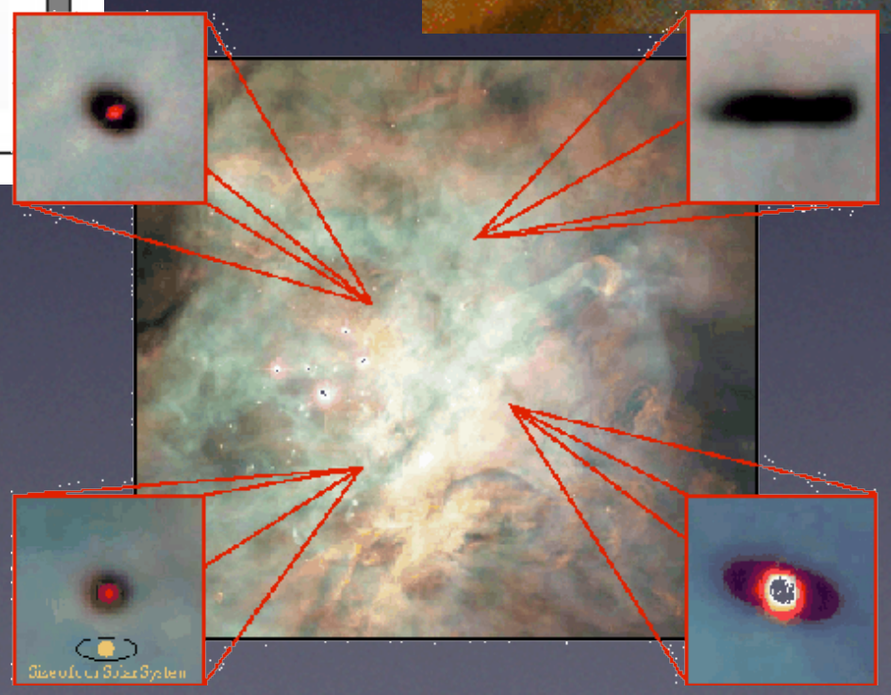




Crab Nebula • M1
Hubble Space Telescope • WFPC2

NASA, ESA, and J. Hester (Arizona State University) STScI-PRC05-37



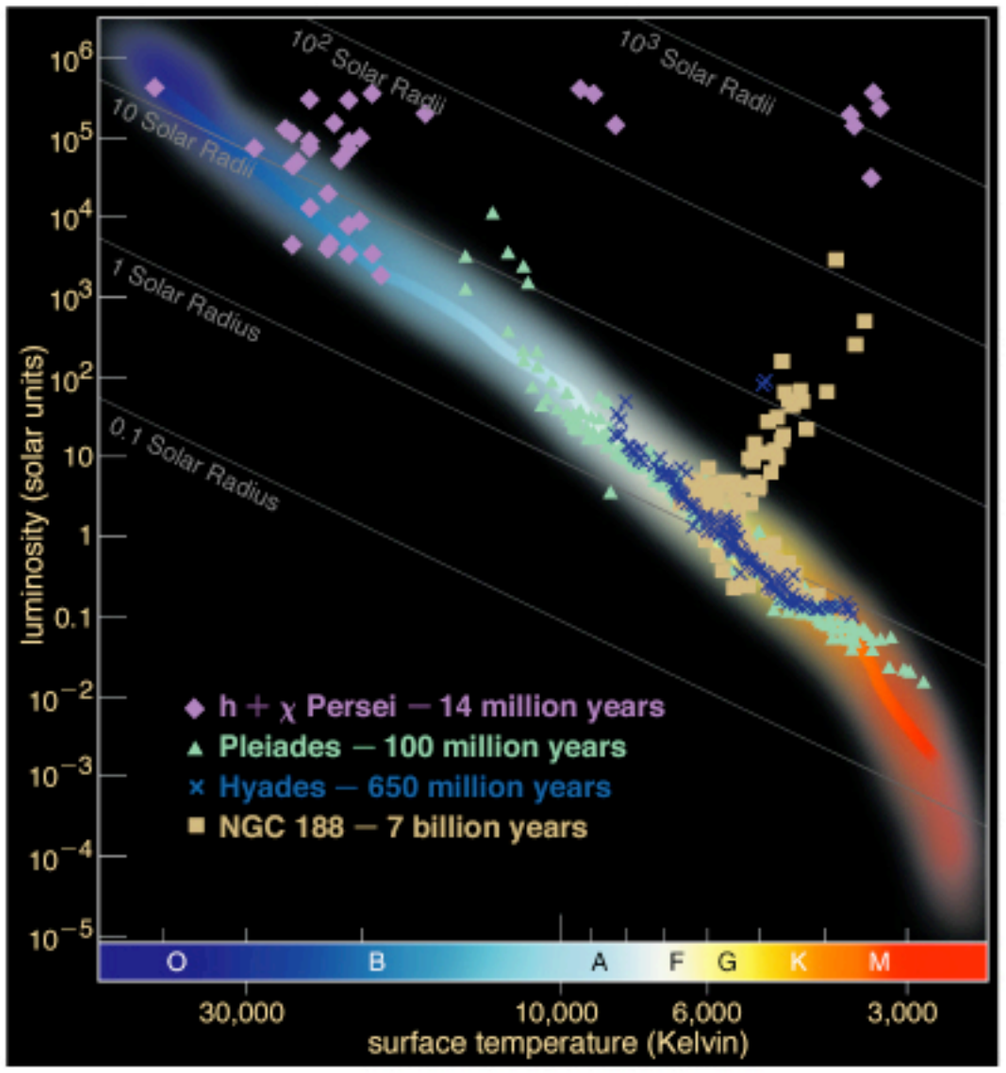


Other nebulae

Carina Nebula

Hubble Heritage

Rosette Nebula

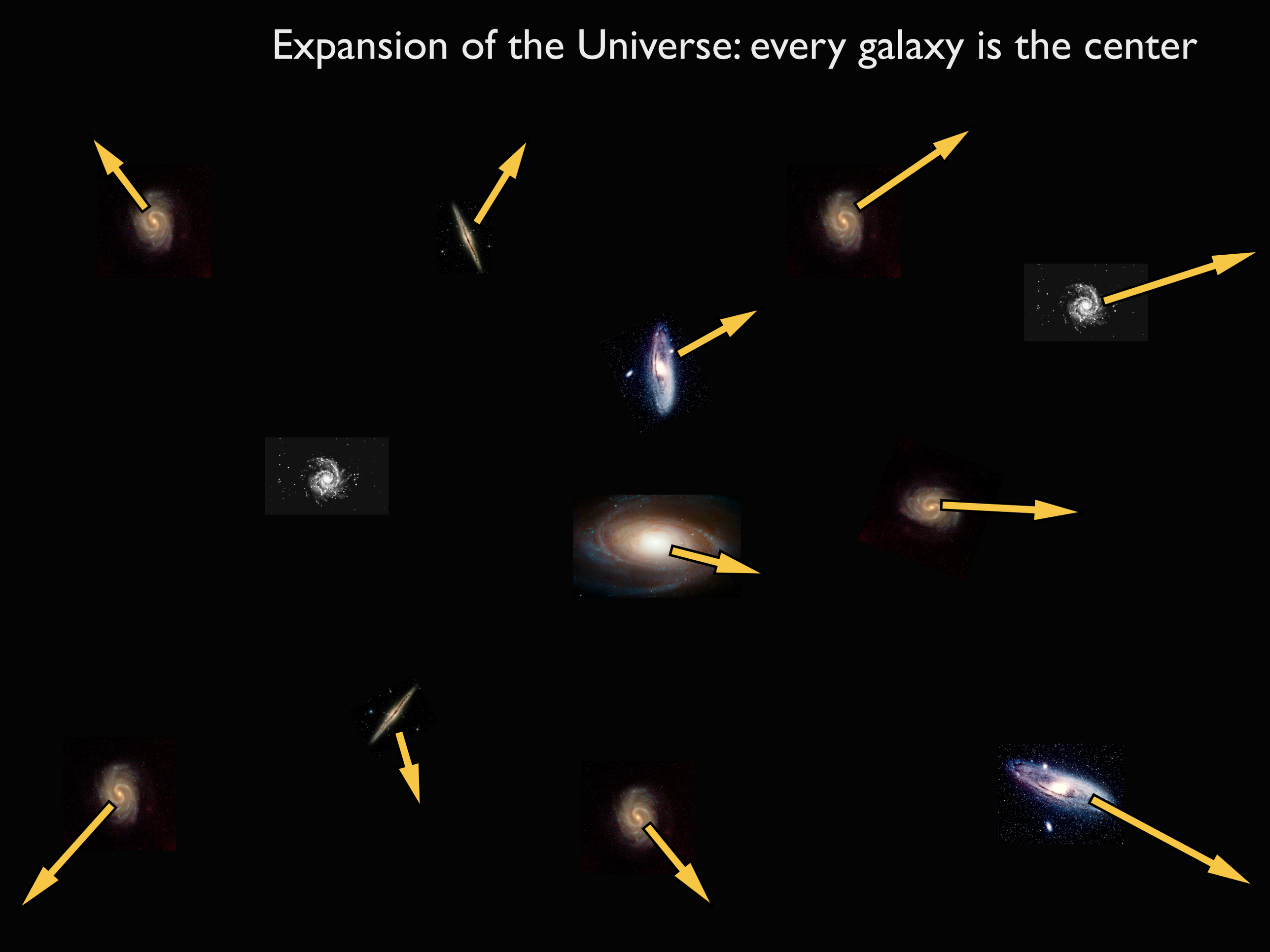


Oldest globular clusters have age of 12Gyrs:
almost as old as the Universe itself.
Age of our Sun is 4.6Gyrs


Spiral Galaxy M101
HUBBLESITE.org

Expansion of the Universe

Expansion of the Universe: every galaxy is the center



Timeline of Big Bang

About 13.7 billions of years ago the observed part of the Universe started to expand very fast.

This expansion did not have a center of the expansion. The expansion is the same around every point in space.

The expansion was not an explosion. It was remarkably quiet with only very small ripples of patches of slightly dense and slightly under-dense in the space.

The Universe was initially very hot. It was filled with all possible particles: some exotic and some normal particles. As the Universe expanded it cooled and exotic particles died out.

When the Universe was about 100 seconds old, it was as hot and as dense as the center of our Sun. During that time some fraction of hydrogen nuclei merged and produced helium. The Universe was too cold for other reactions to produce heavier elements (such as carbon or oxygen). Those element were produced much later in stars.

Timeline of Big Bang

When the Universe was 400,000 yrs old and had temperature 3000 K, hydrogen recombined. At that moment the Universe became transparent. Now we receive photons, which were emitted at the moment of recombination.

First stars formed when the age of the Universe was 400 Myrs

First galaxies formed when the age was 1 billion years.

Our Sun formed when the age was 9 billion years.

When an electron in an atom goes from high energy state to a lower energy state, the atom

1. emits a photon of a specific frequency
2. absorbs a photon of specific frequency
3. can emit a photon of any frequency
4. absorbs several photons

Describe two ways an atom can become excited.

How are wavelength, frequency, and energy are related for photons?

1. Longer wavelength means lower frequency and lower energy
2. Longer wavelength means higher frequency and lower energy
3. Longer wavelength means lower frequency and higher energy

A star is 20 pc away. How many years has its light taken to reach us?

---

a. 20 years
b. 65 years
c. 20 days
d. 20 million years

What is the chemical composition of most of the stars?

a. Hydrogen
b. Hydrogen, Helium and other elements in equal mixture
c. 75% hydrogen, 23% helium and 2% of other elements
d. We do not know because we cannot reach stars

A red star and a blue star have the same radius.

- Which star is hotter?
- Which star if more luminous?

Why will the Sun change drastically in several billion years?