STARS AND LIGHT

KAHS Astronomy
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Part 1:
Light and the Electromagnetic Spectrum

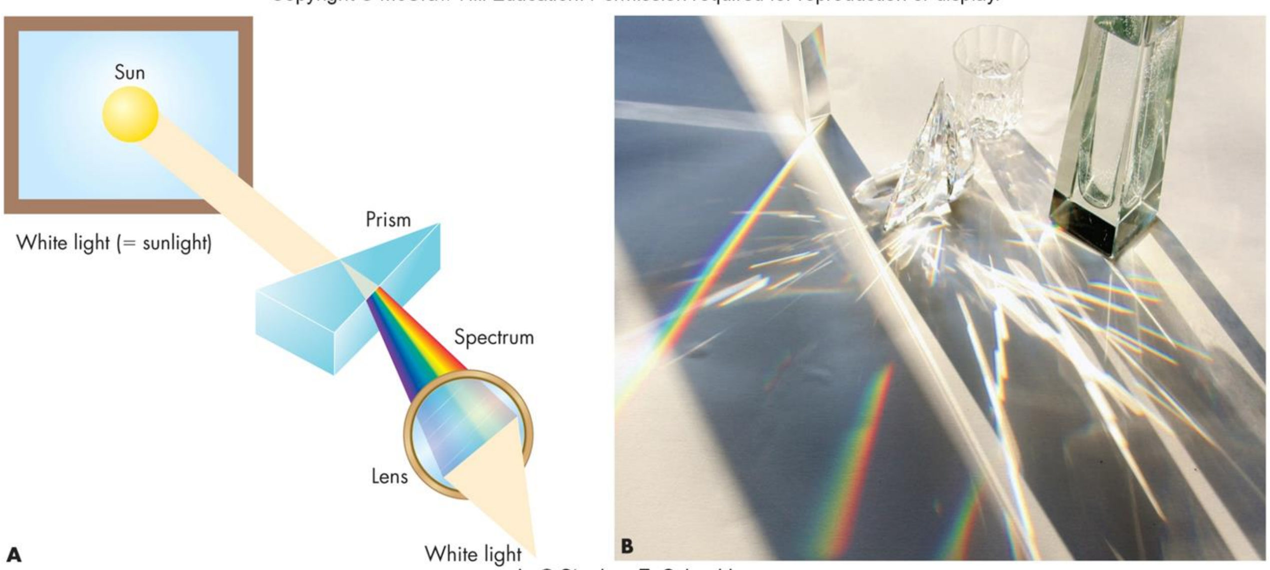
Goals:

1. What is “light”?
2. What is the Electromagnetic Spectrum?
3. What types of radiation have high energy?
4. What types of radiation have low energy?
5. What is the relationship between wavelength and energy?

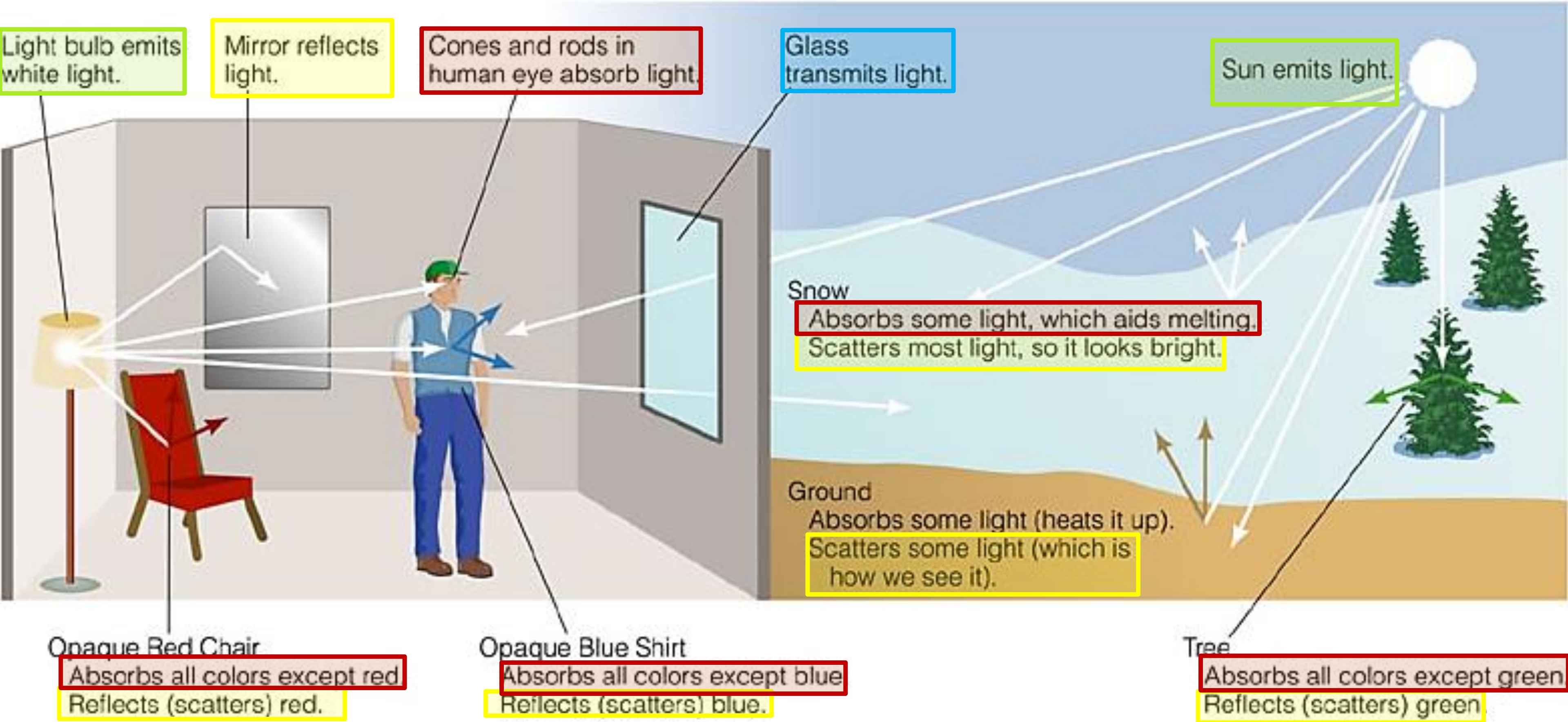
Light

- Light interacts with matter in 4 ways: *emission, absorption, transmission, and reflection*

- The light we see is referred to as "visible light"
  - We see a "rainbow of colors", that when perceived together produce *white light*.



4 Interactions between Light and Matter

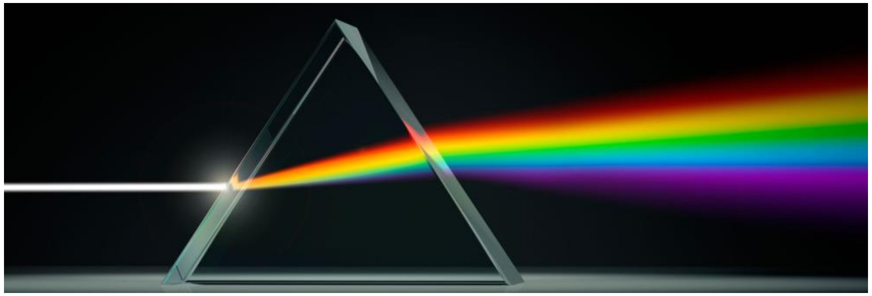


4 Interactions between Light and Matter

1. **Emission**: a light bulb *emits* visible light.
2. **Absorption**: when you place your hand near an incandescent light bulb, your hand *absorbs* some of the light. *"Opaque" objects absorb light*.
3. **Transmission**: Some forms of matter, such as glass or air, *transmit* light, or allow light to pass through.
4. **Reflection/scattering**: light can bounce off matter, leading to reflection (bouncing is in same general direction) or scattering (bouncing of light is more random)

Light

- **Spectrum-** a rainbow showing light in its different forms(colors).
  - *"ROY G BIV"*



- ***White Light*** is what we call light from the sun or from a light bulb.
  - Seen when we view equal proportions of all colors
  - *Black* is what we perceive when there is no light and hence no color.
  - We see the color that is being reflected from objects to our eyes (that object is absorbing all other colors)

What is Light?

Light , AKA "**Electromagnetic Radiation**" is a form of energy

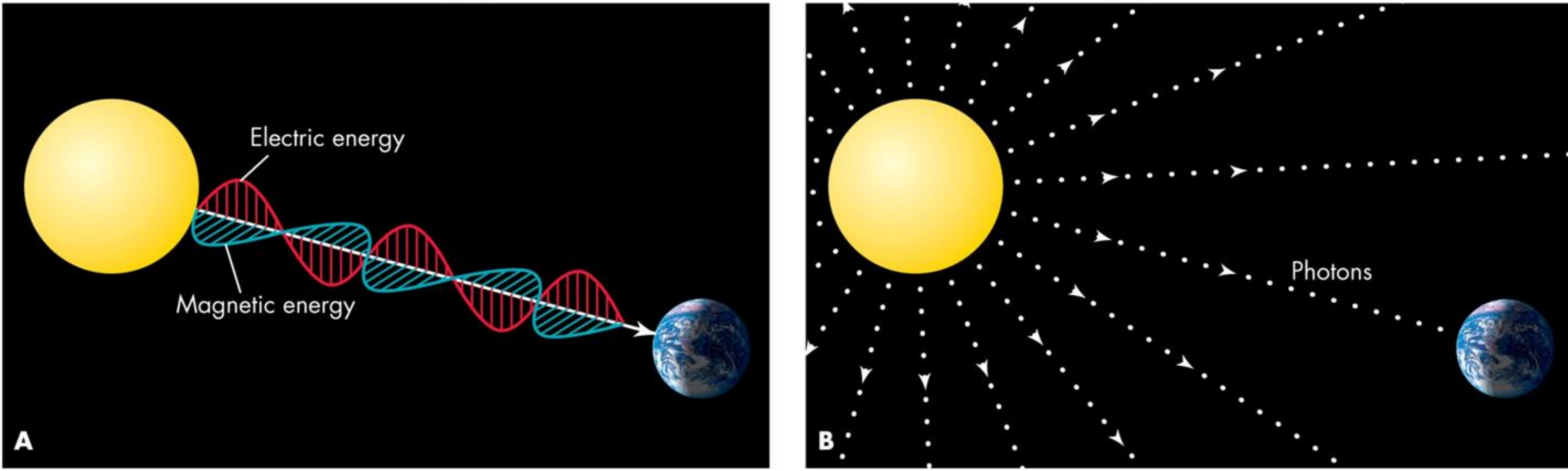
Light is both a wave and a particle.

- **Electromagnetic Wave-** vibrates electric and magnetic fields (not particles).
  - *Can be observed by lining up electrons that wriggle like a snake when they interact with electromagnetic waves.*
- **Photon**- a "piece" or particle of light.
  - Photons can be counted because they strike objects one at a time.
  - Every photon carries a specific amount of energy.

What is Light?

Light , AKA “**Electromagnetic Radiation**” is a form of energy

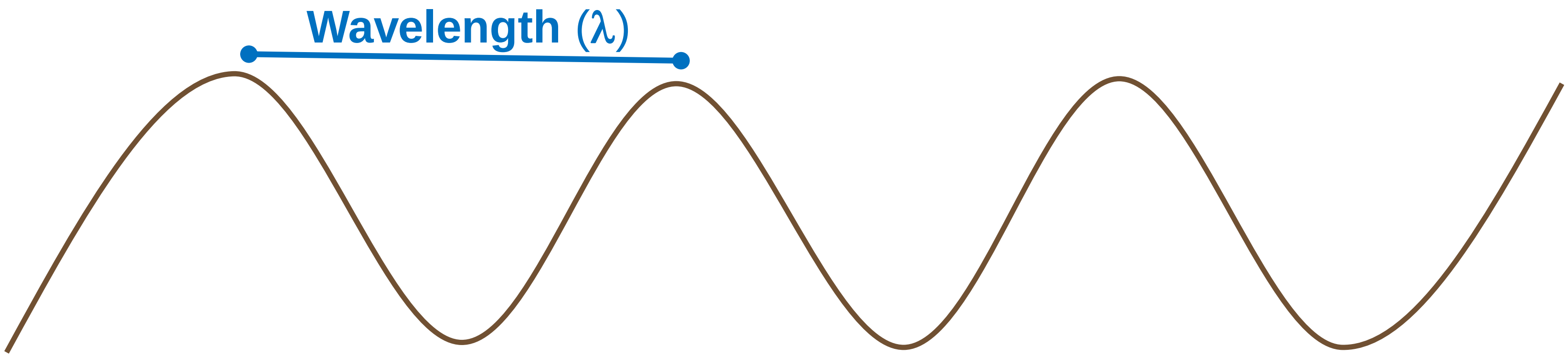
Light is both a wave and a particle.



What is Light? (cont'd)

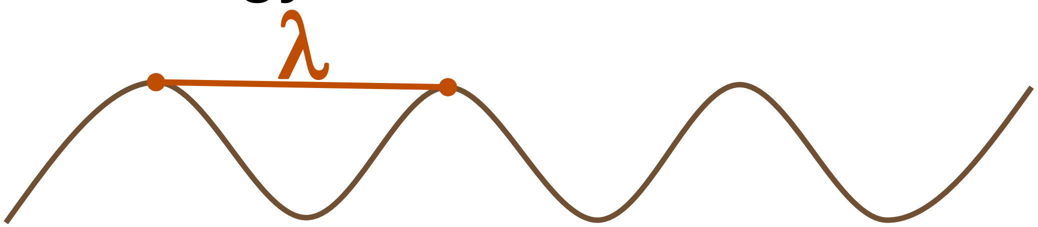
Electromagnetic Waves have 3 basic properties:

1. **Wavelength** (λ) - distance from one peak to the next
2. **Frequency** (f) – number of peaks that pass by any point in one second.
3. **Speed** (c) – how fast the peaks travel.
   - ***Speed of Light (c) = 300,000 km/s***
   - The "speed of light" is always the same for any time of electromagnetic radiation.

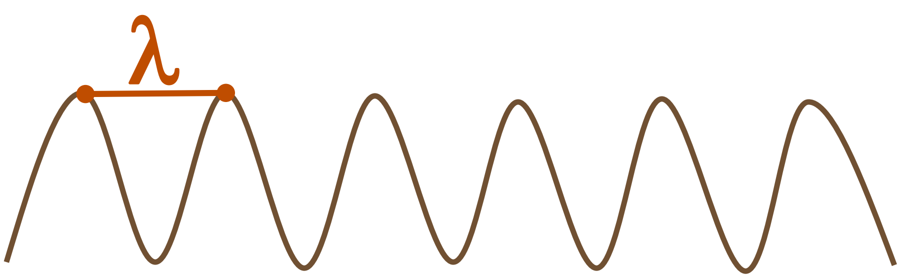


What is Light? (cont'd)

Wavelength and frequency of a light wave are related to energy.



Longer Wavelength
Lower Frequency
Lower Energy



Shorter Wavelength
Higher Frequency
Higher Energy

What is Light? (cont'd)

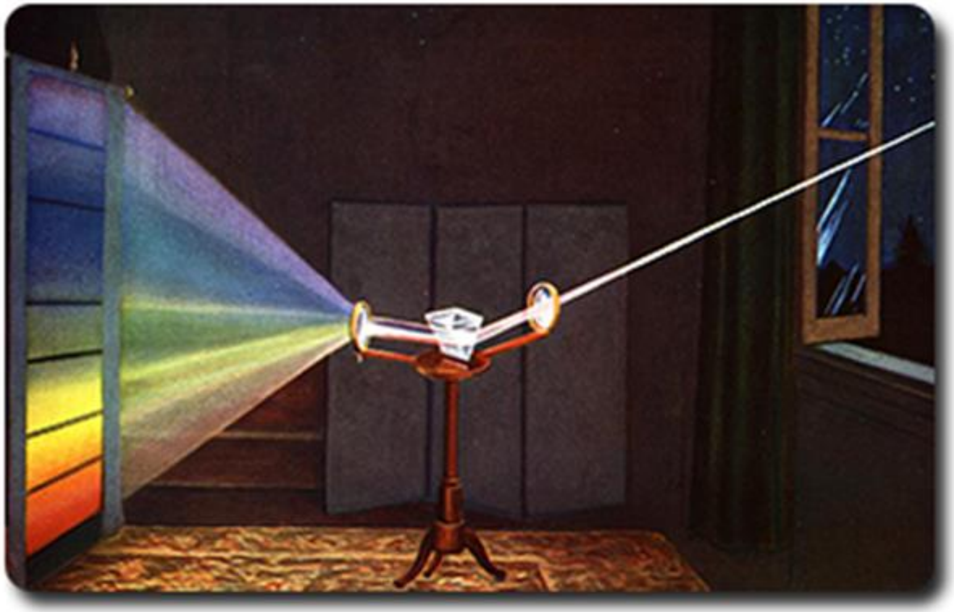
Humans can observe electromagnetic waves within a short range of wavelengths. Each color of the rainbow has a different wavelength and frequency.

Visible Light wavelengths range from

400 nm (blue/violet) → 700 nm (red)

Violet (short wavelength)

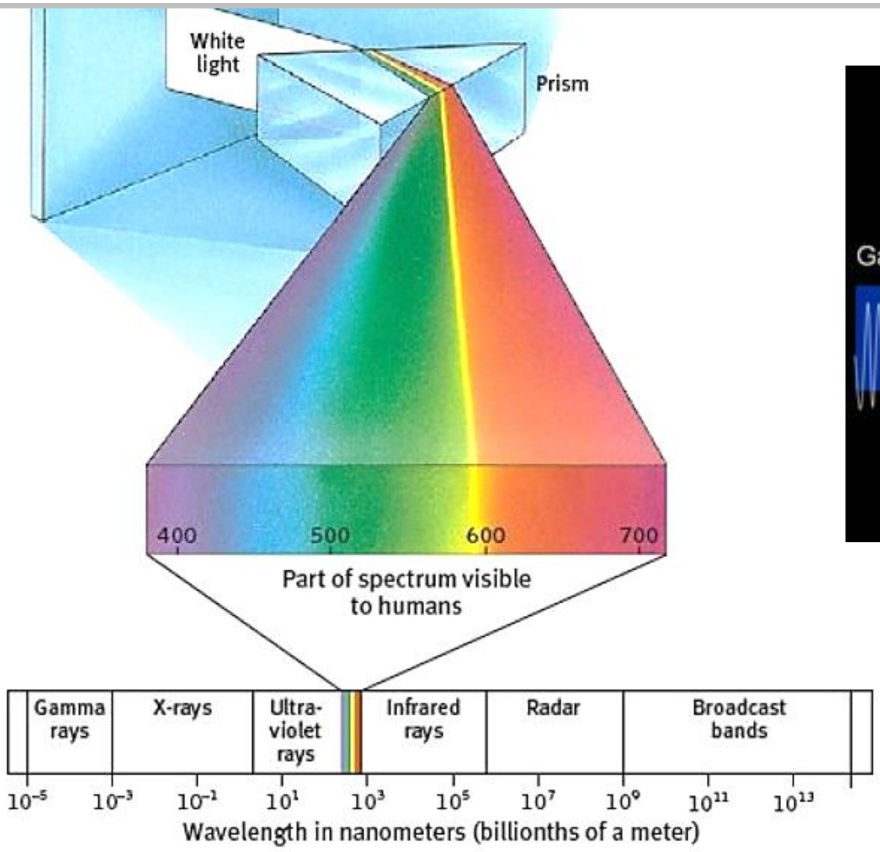
Red (longer wavelength)

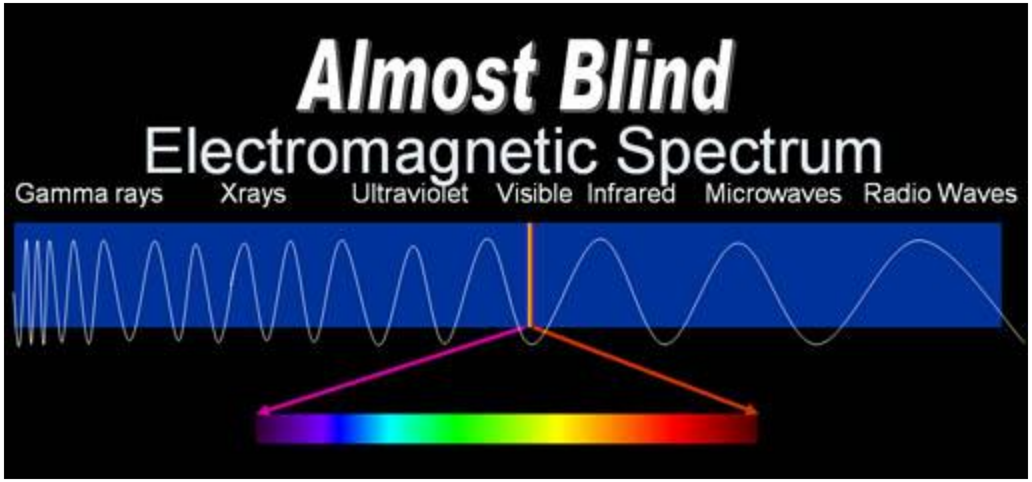


Each color on the electromagnetic spectrum has a different wavelength.

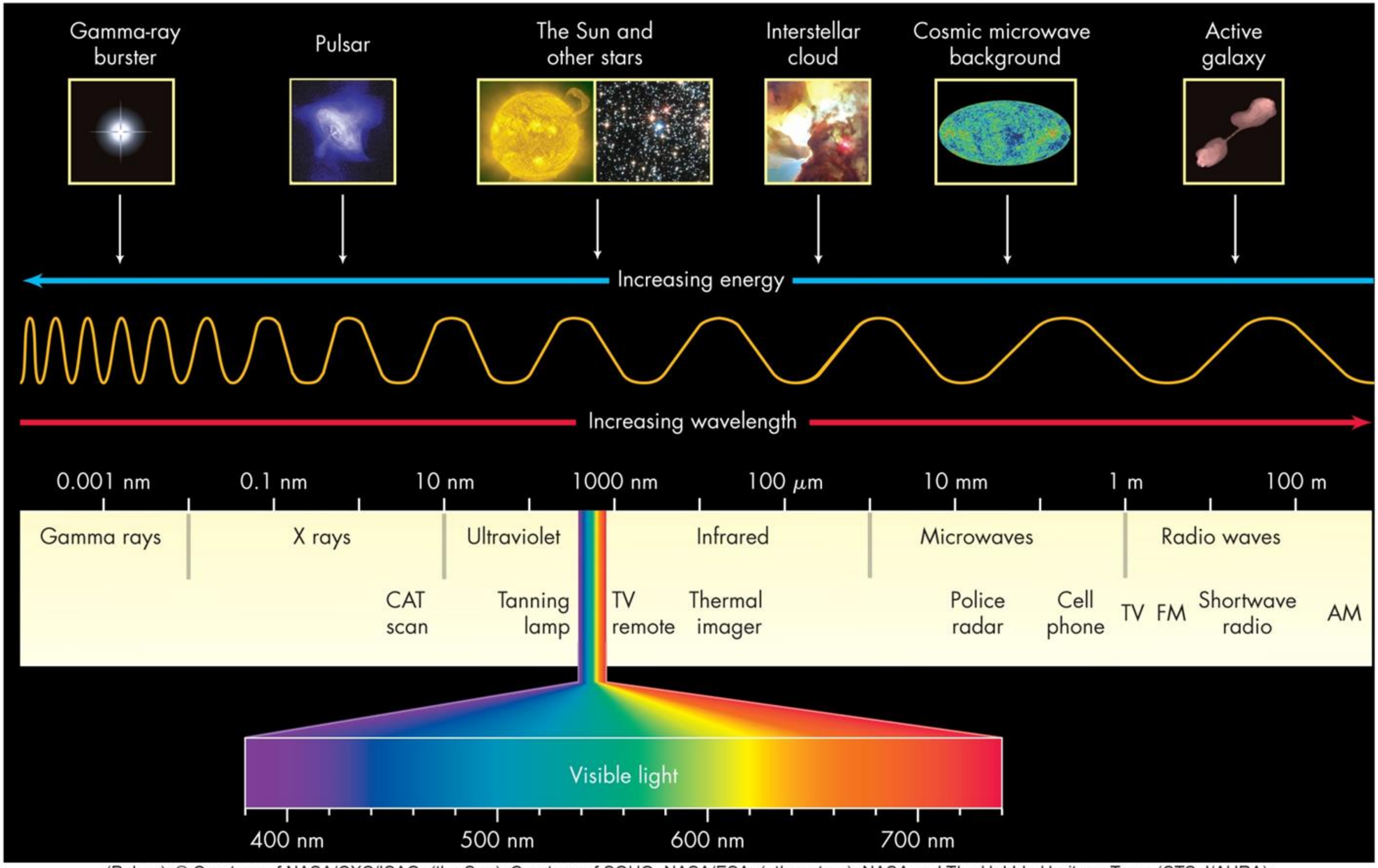
Electromagnetic Spectrum

- There is light "beyond the rainbow".
- Visible Light differs from other forms of light only in the wavelength and frequency of photons.





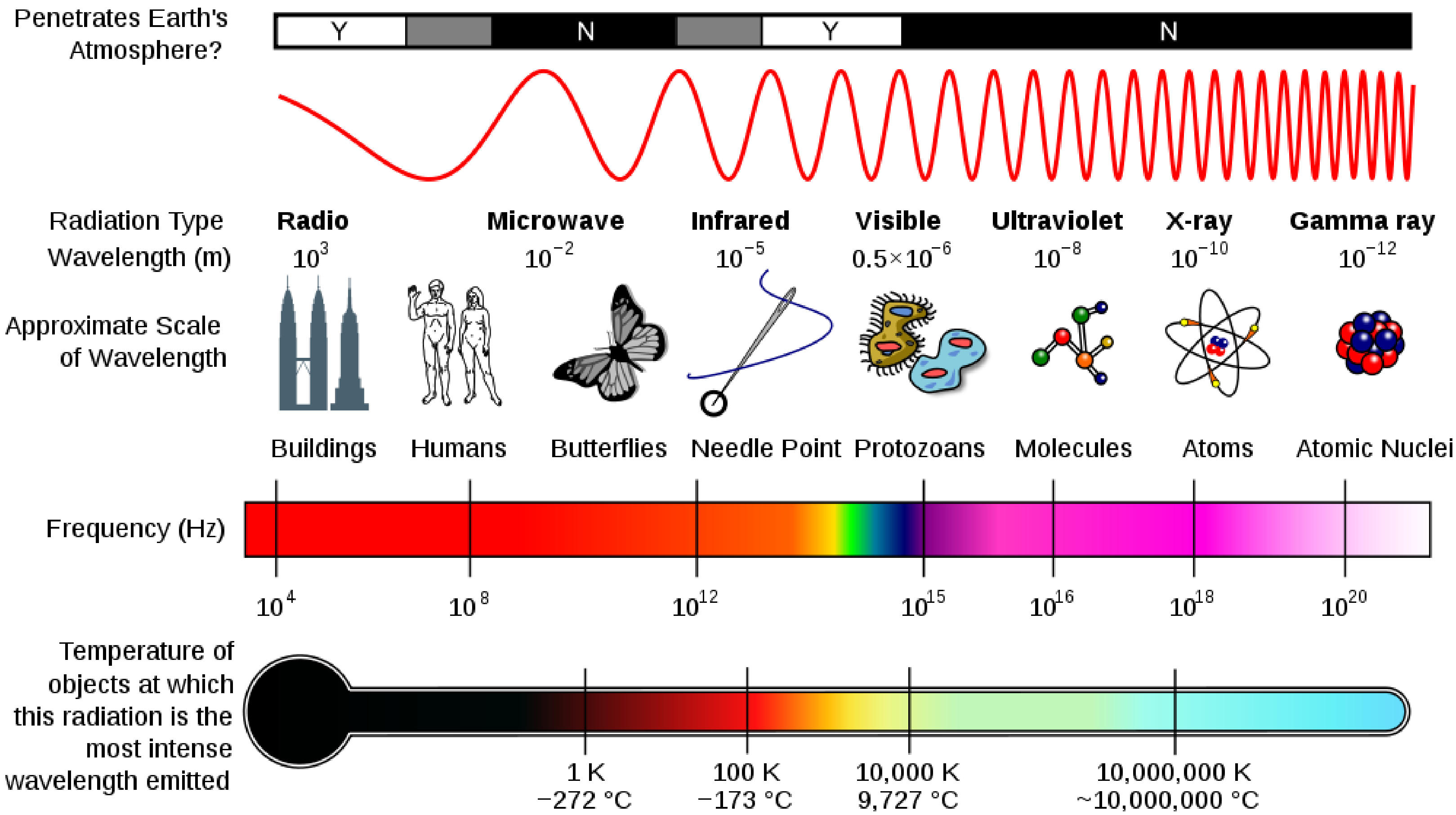
The Electromagnetic Spectrum is the entire range of wavelengths from short gamma rays to long radio waves.



(Pulsar): © Courtesy of NASA/CXC/ISAO; (the Sun): Courtesy of SOHO, NASA/ESA; (other stars): NASA and The Hubble Heritage Team (STScI/AURA); (Interstellar cloud): A. Caulet (ST-ECF, ESA) and NASA; (Cosmic microwave background): Courtesy of NASA/WMAP Science Team; (Active galaxy): © NRAO/AUI/NSF; © Science Source

Electromagnetic Spectrum

- *Note: This graphic shows higher energy radiation on the right and lower on the left (opposite from previous slide)*



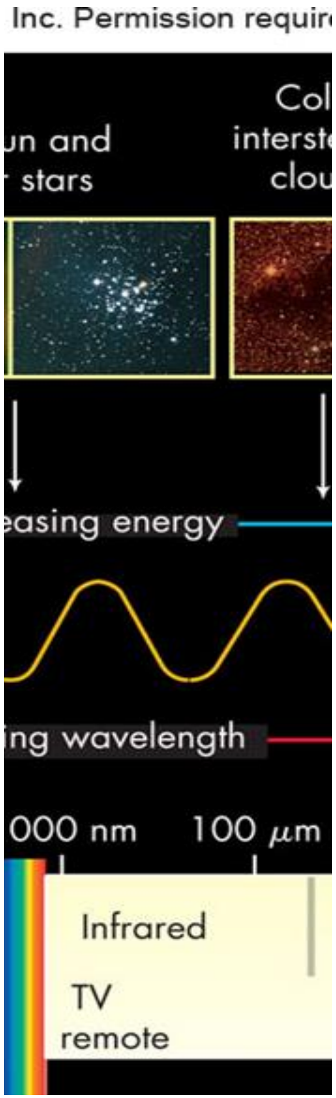
The Electromagnetic Spectrum

- The ***electromagnetic spectrum*** is composed of radio waves, microwaves, infrared, visible light, ultraviolet, x rays, and gamma rays

- Longest wavelengths are more than 10^3 km
- Shortest wavelengths are less than 10^{-18} m
- Various instruments used to explore the various regions of the spectrum

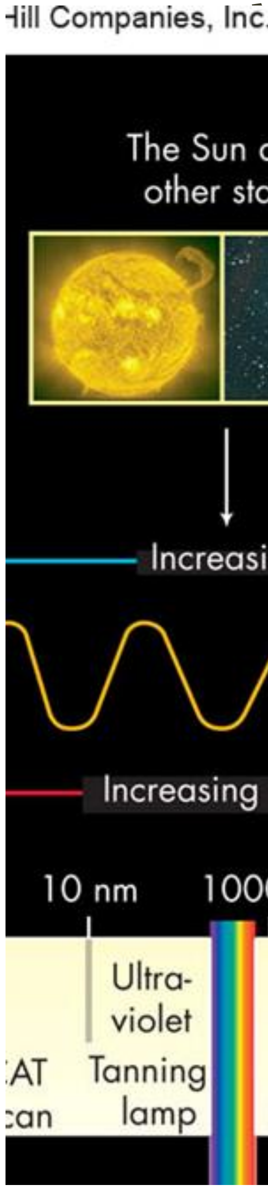
Infrared Radiation

- Sir William Herschel (around 1800) showed heat radiation related to visible light
- He measured an elevated temperature just off the red end of a solar spectrum – ***infrared*** energy



- Our skin feels infrared as heat

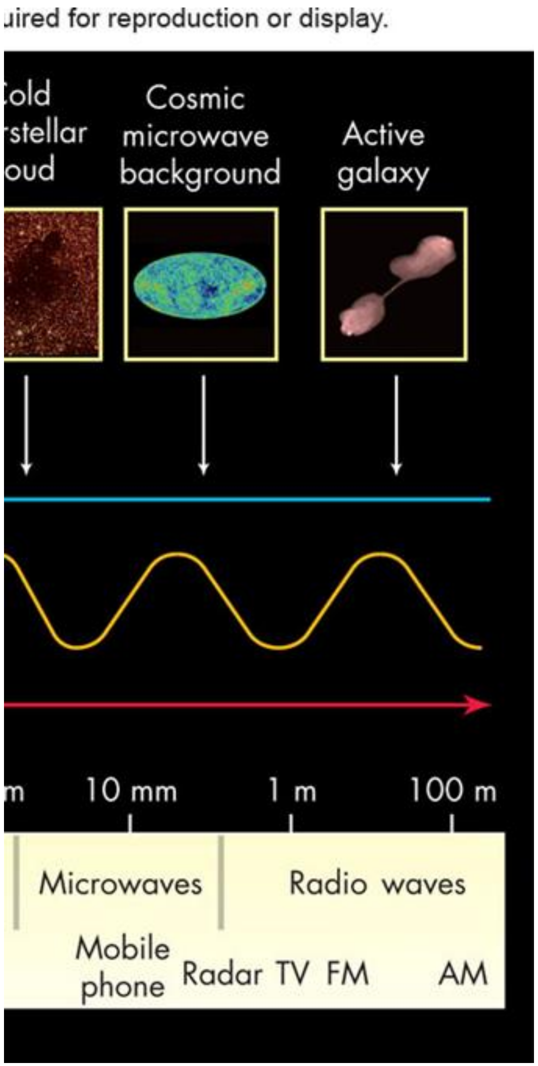
Ultraviolet Light



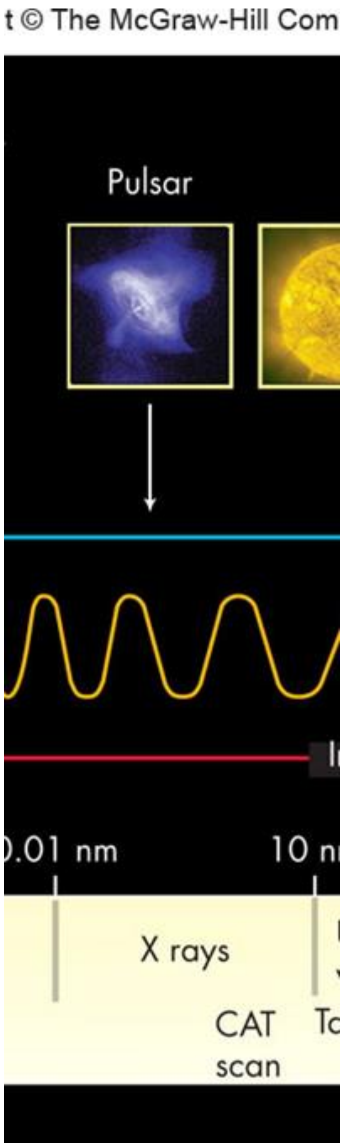
- J. Ritter in 1801 noticed silver chloride blackened when exposed to “light” just beyond the violet end of the visible spectrum
- Mostly absorbed by the atmosphere
- Responsible for suntans (and burns!)

Radio Waves

- Predicted by Maxwell in mid-1800s, Hertz produced ***radio waves*** in 1888
- Jansky discovered radio waves from cosmic sources in the 1930s, the birth of radio astronomy
- Radio waves used to study a wide range of astronomical processes
- Radio waves also used for communication, microwave ovens, and search for extraterrestrials

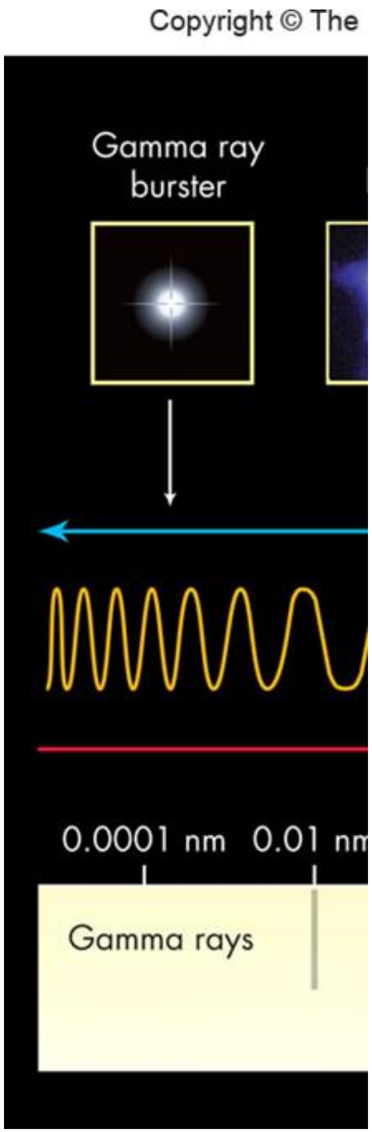


X-Rays



- Roentgen discovered X rays in 1895
- First detected beyond the Earth in the Sun in late 1940s
- Used by doctors to scan bones and organs
- Used by astronomers to detect black holes and tenuous gas in distant galaxies

Gamma Rays



- Gamma Ray region of the spectrum still relatively unexplored
- Atmosphere absorbs this region, so all observations must be done from orbit!
- We sometimes see bursts of gamma ray radiation from deep space

We can see MORE using long and short-wave detecting telescopes

Antennae: Merging Galaxies

Composite image NASA

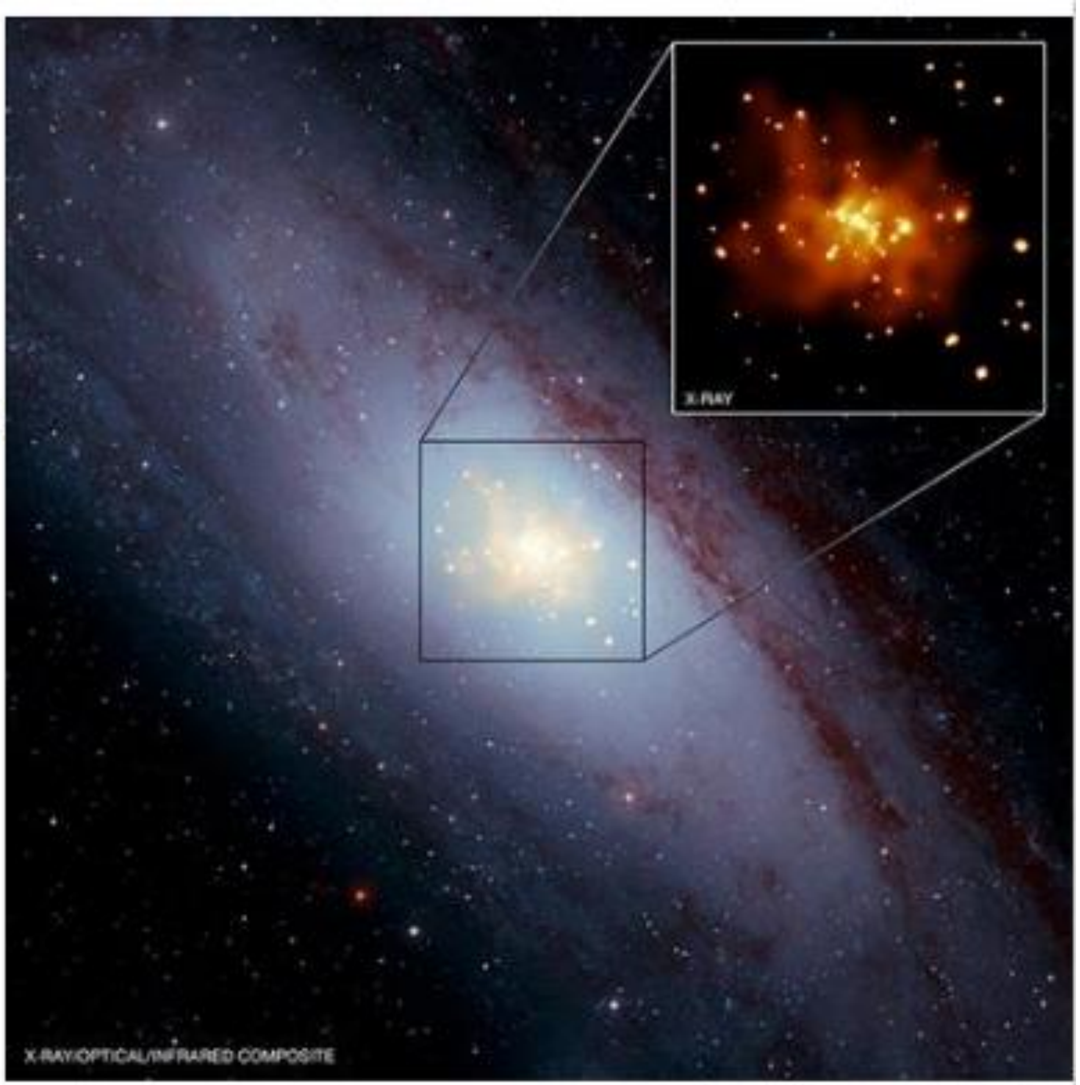
Visible 1, Infrared B, X-ray III

We can see MORE using long and short-wave detecting telescopes

M31 Andromeda Galaxy

Composite Image
NASA

Visible 6, Infrared D, X- Ray II



NASA/JPL Caltech/CXC/SAO/STScI

Energy Carried by Electromagnetic Radiation (as mentioned previously)

- Each photon of wavelength λ carries an energy E given by the formula:

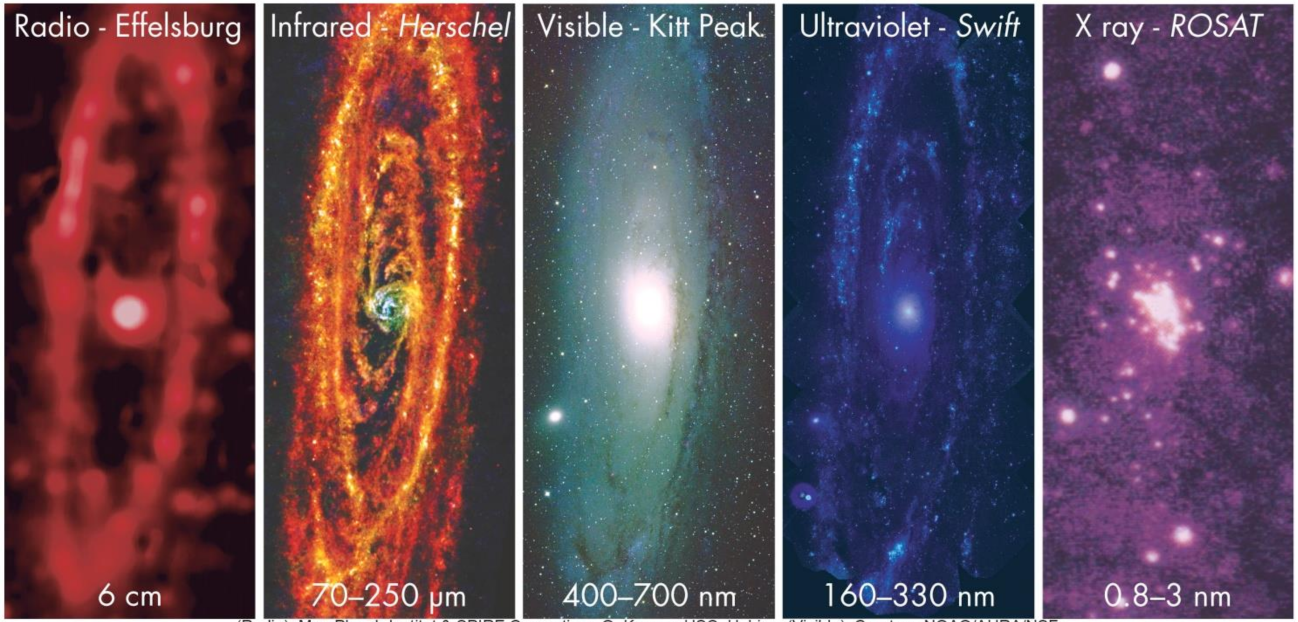
$$E = hc/\lambda$$

where h is Planck's constant, c is speed of light

- **Notice that a photon of short wavelength radiation carries more energy than a long wavelength photon**

- Short wavelength = high frequency = high energy
- Long wavelength = low frequency = low energy

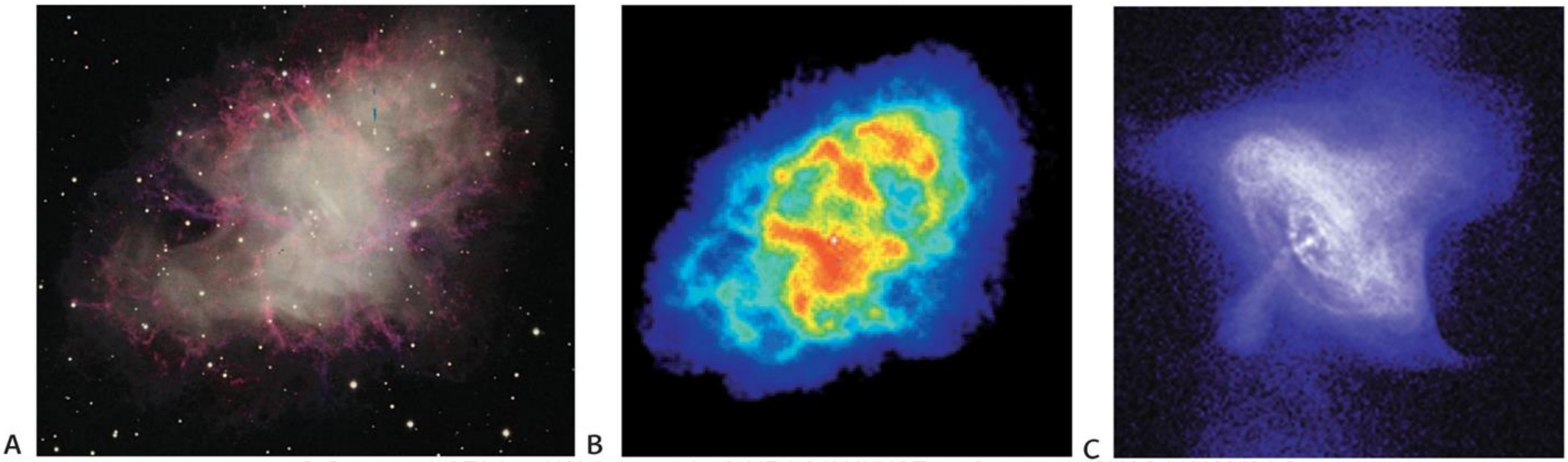
Different Wavelengths, Different Science



(Radio): Max-Planck-Institut & SPIRE Consortium, O. Krause, HSC, H. Linz; (Visible): Courtesy NOAO/AURA/NSF; (Ultraviolet): NASA/Swift/Stefan Immler (GSFC) and Erin Grant (UMCP); (X-ray): ROSAT, MPE, NASA

- We "see" different phenomena in different wavelengths.
- Visible light shows the distribution of stars.
- Infrared reveals dust in the galaxy.
- X-rays reveal supernovae, etc.

Crab Nebula



Visible Light Photograph

Radio Image

X-Ray Image in false color

Check for Understanding!

- What is wavelength? What's the symbol for wavelength? Draw a diagram to show what wavelength is.
- Which has a longer wavelength, blue or red light?
- How is wavelength related to frequency and energy?
- What form of electromagnetic energy has the highest energy? Lowest energy?

Electromagnetic Spectrum, cont'd

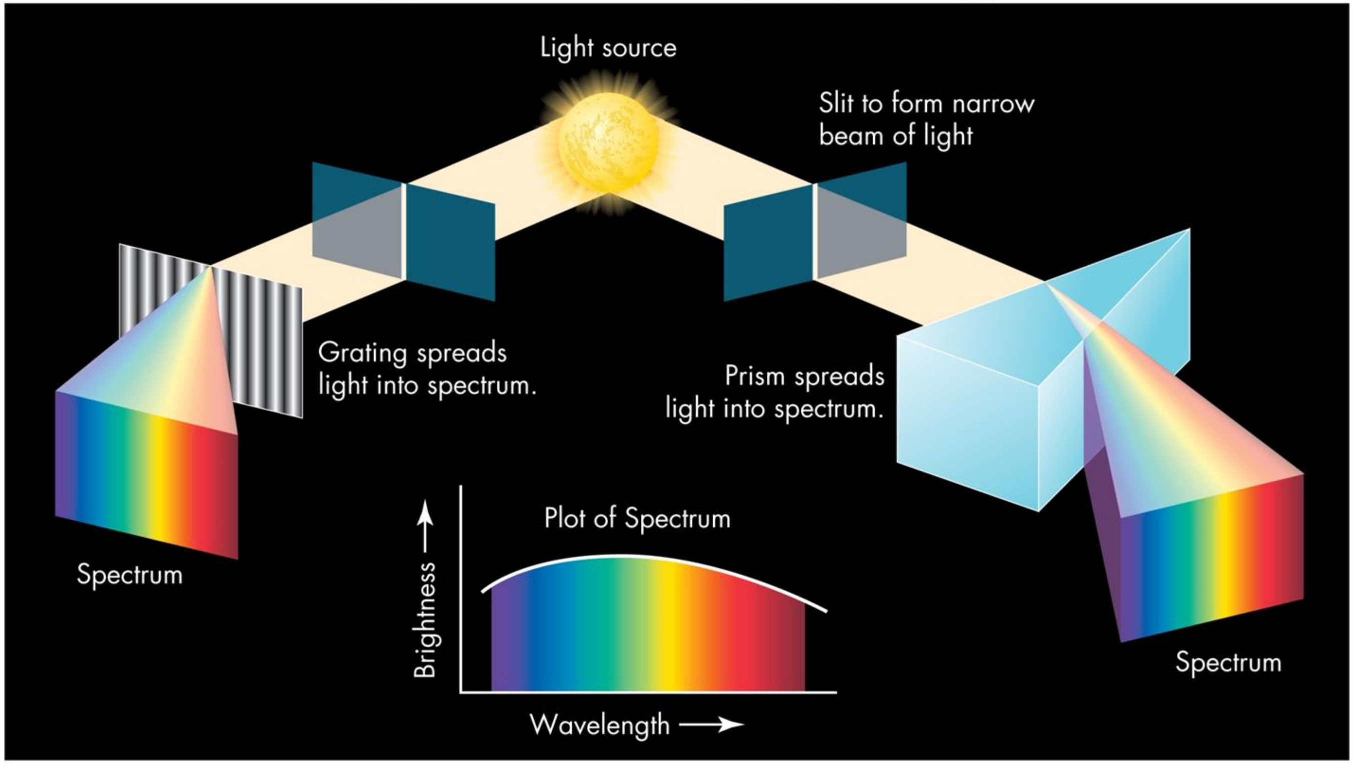
- The various forms of EM Radiation each interact with matter in unique ways.
- Atoms and molecules that make up objects in the universe leave unique "fingerprints" in light that astronomers decode.
- Astronomers seek to observe light of all wavelengths to determine the **temperature** of objects, their **composition**, and **relative motion**.

Part 2: Electromagnetic Spectra

Goals:

- What are the three basic types of spectra?
- How does light tell us the composition of things in the universe?
- How does light tell us the temperatures of planets and stars?
- How do we interpret an actual spectrum?
- How does light tell us the speed of a distant object?

Spectroscopy

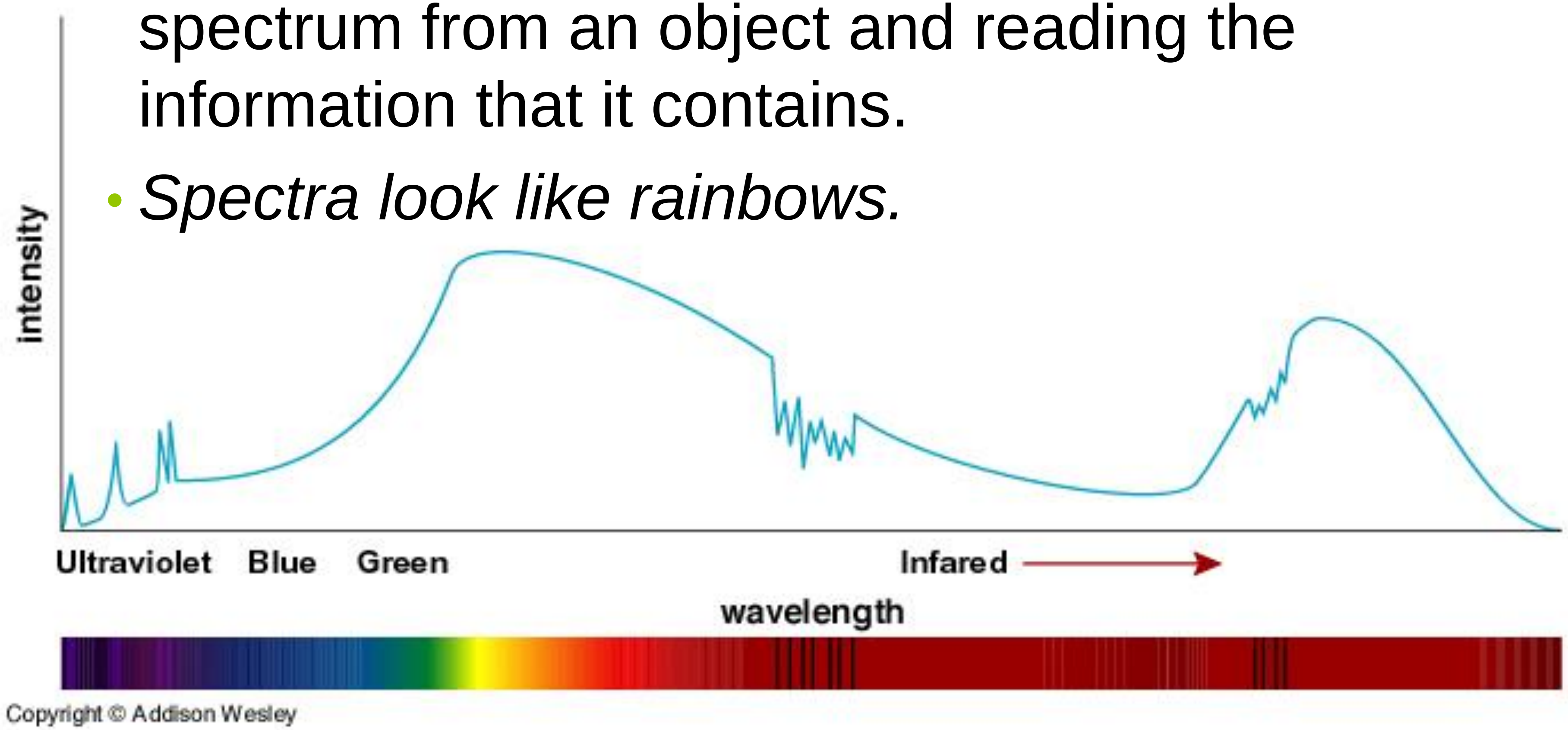


- Allows the determination of the composition and conditions of an astronomical body
- In ***spectroscopy,*** we capture and analyze a spectrum

- Spectroscopy assumes that every atom or molecule will have a unique spectral signature

Spectra

- **Spectroscopy-** the process of obtaining a light spectrum from an object and reading the information that it contains.
- *Spectra look like rainbows.*



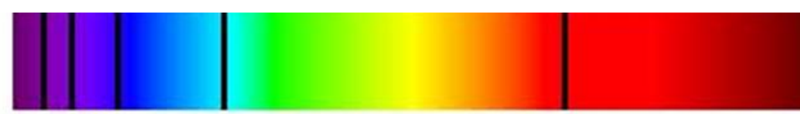
Types of Spectra

Continuous spectrum

- Spectra of a blackbody (source that emits all wavelengths of visible light)
- Produced by an incandescent light bulb, for example.

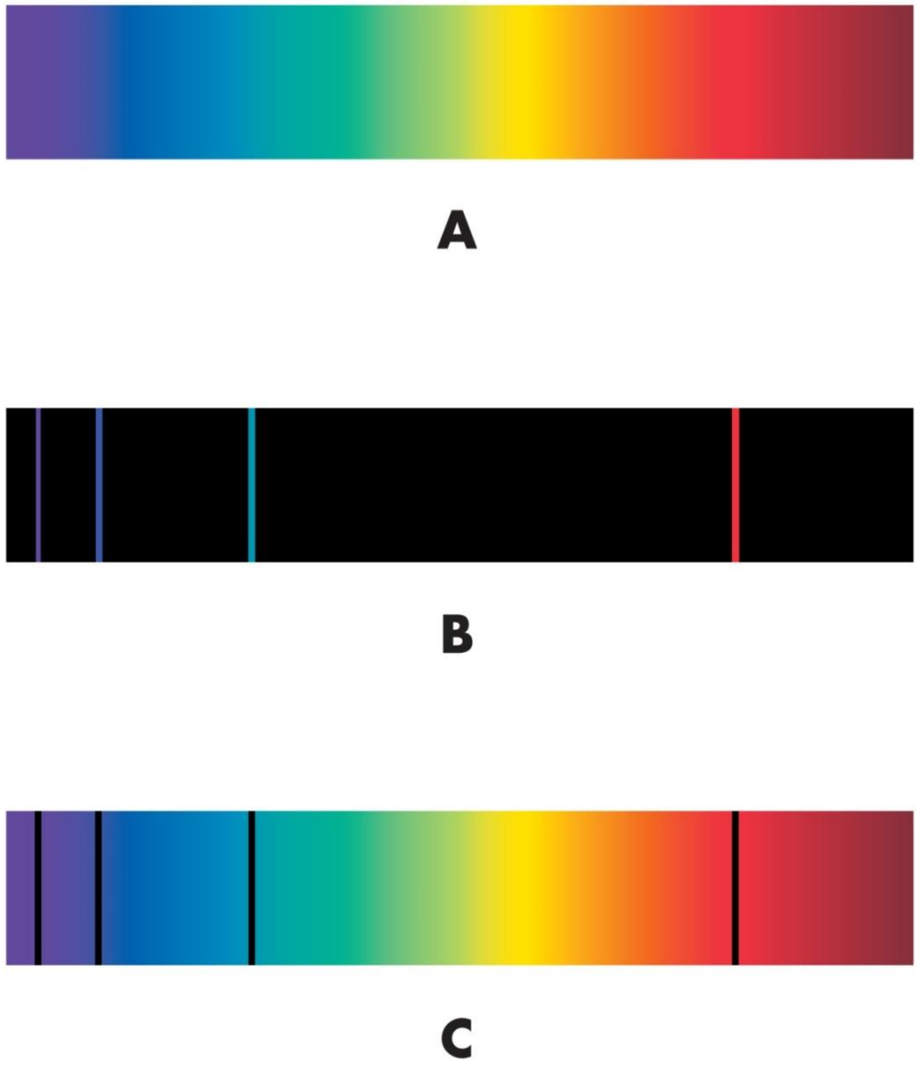
Emission-line spectrum

- Produced by hot, tenuous gases, as photons emit a specific wavelength of electromagnetic radiation.
- Fluorescent tubes, aurora, and many interstellar clouds are typical examples



Absorption-line spectrum

- Light from blackbody passes through cooler gas leaving dark absorption lines (shows which wavelengths are absorbed by the gas)
- Fraunhofer lines of Sun are an example



Can you identify the names of spectra A, B, & C?

Spectra, *continued*

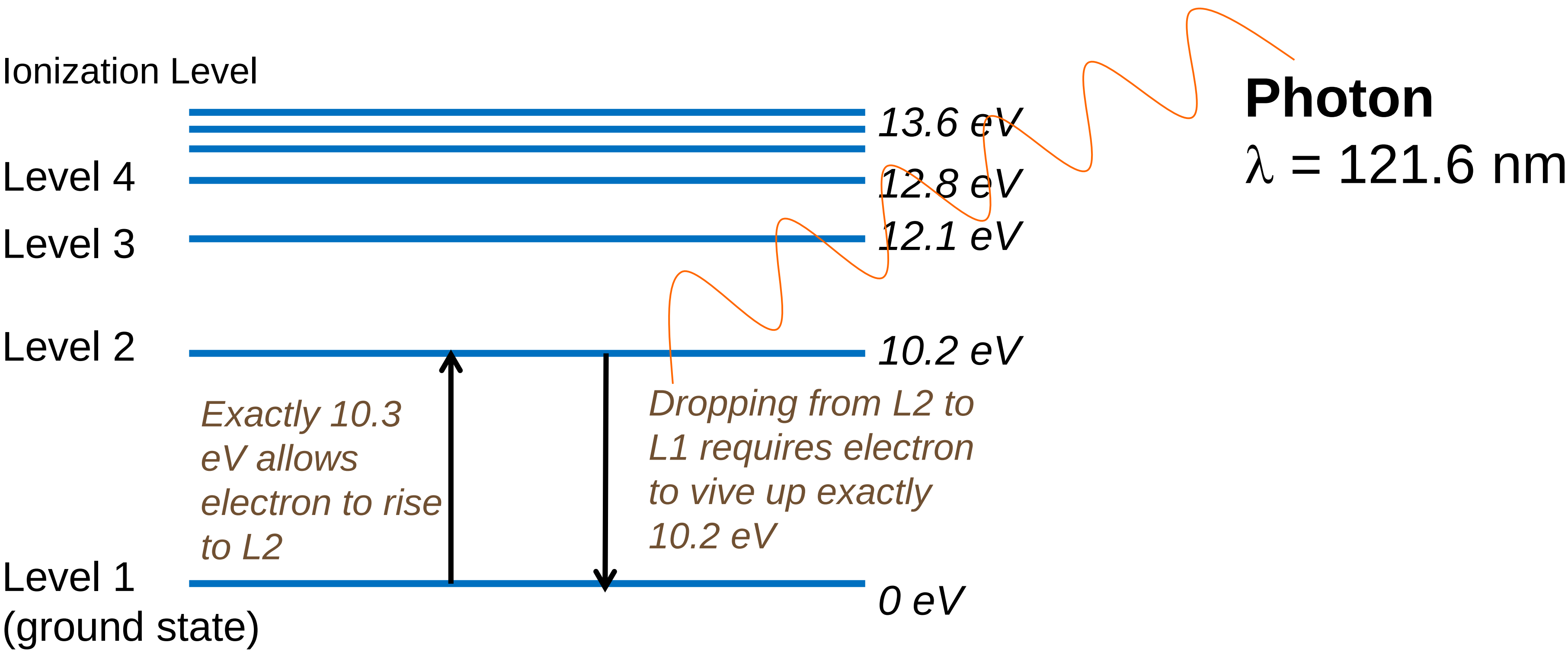
In a cloud of gas, atoms are constantly colliding and exchanging energy, causing:

1. Atoms to bounce in new directions, colliding with other atoms.
2. A transfer of energy to electrons, making them move to higher energy levels.

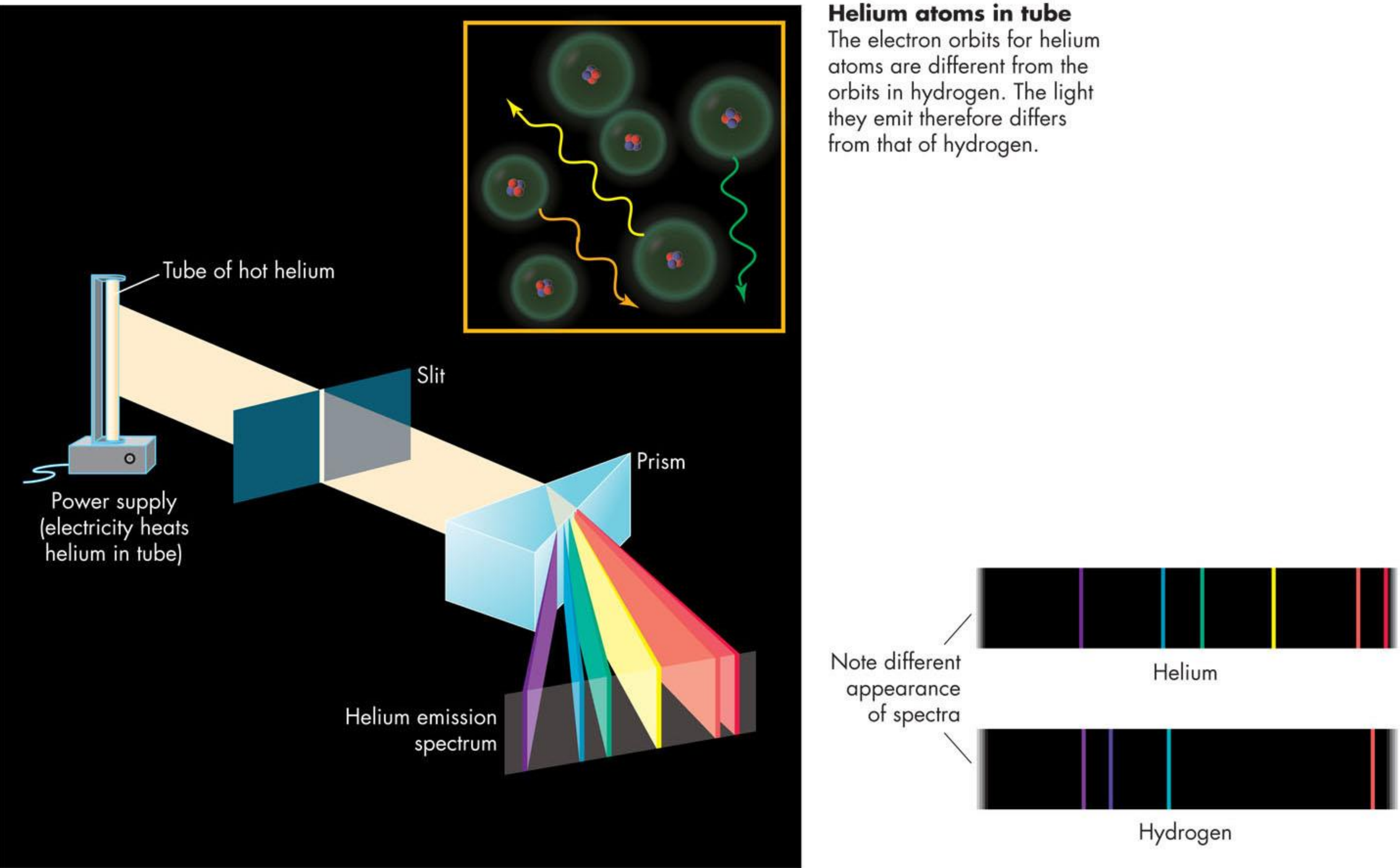
An electron can ONLY get to next higher level if given the exact amount of required energy. It will then drop back down to its original level, releasing the amount of energy it gained in the form of photons.

Spectra, *(Emission Lines)*

*Elements release photons of unique wavelengths

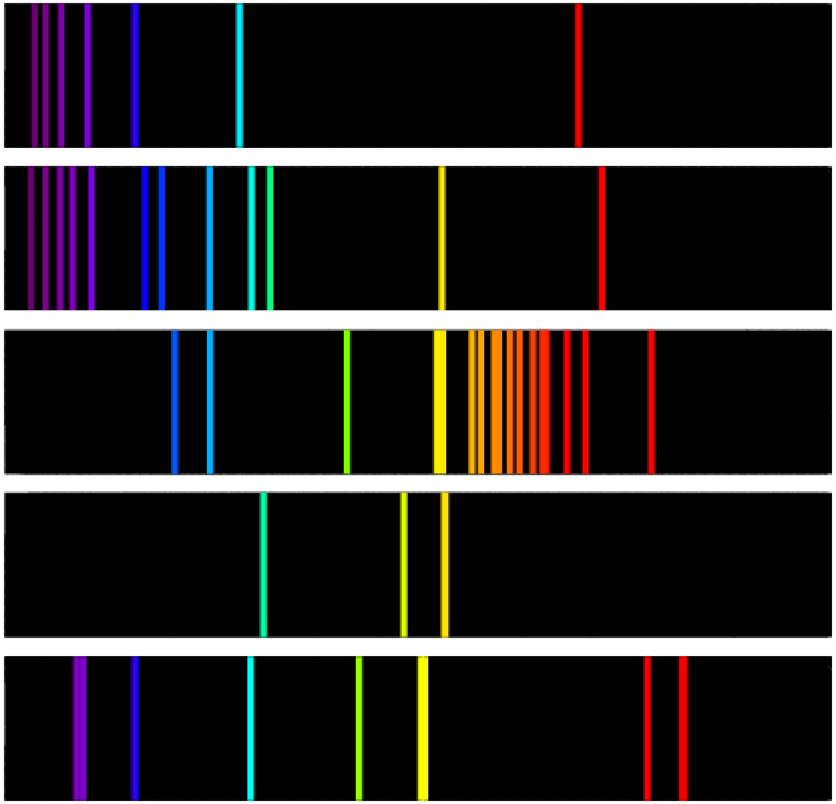


Helium Emission Spectrum



Spectra, *(Emission Lines)*

*Elements release photons of unique wavelengths

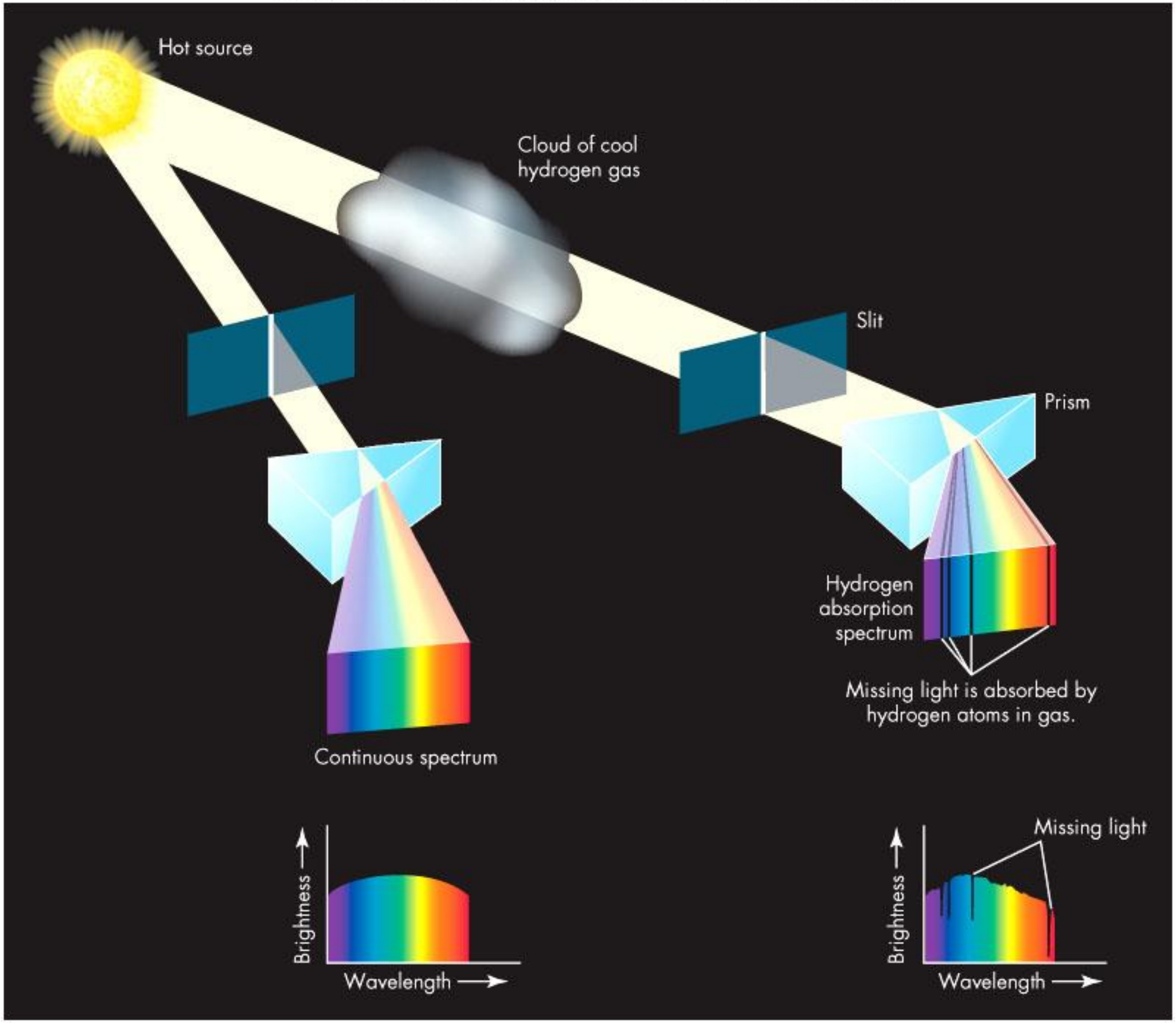


The bright lines show the wavelength of photons that are emitted from a gas cloud.

Remember, each color has a specific wavelength.

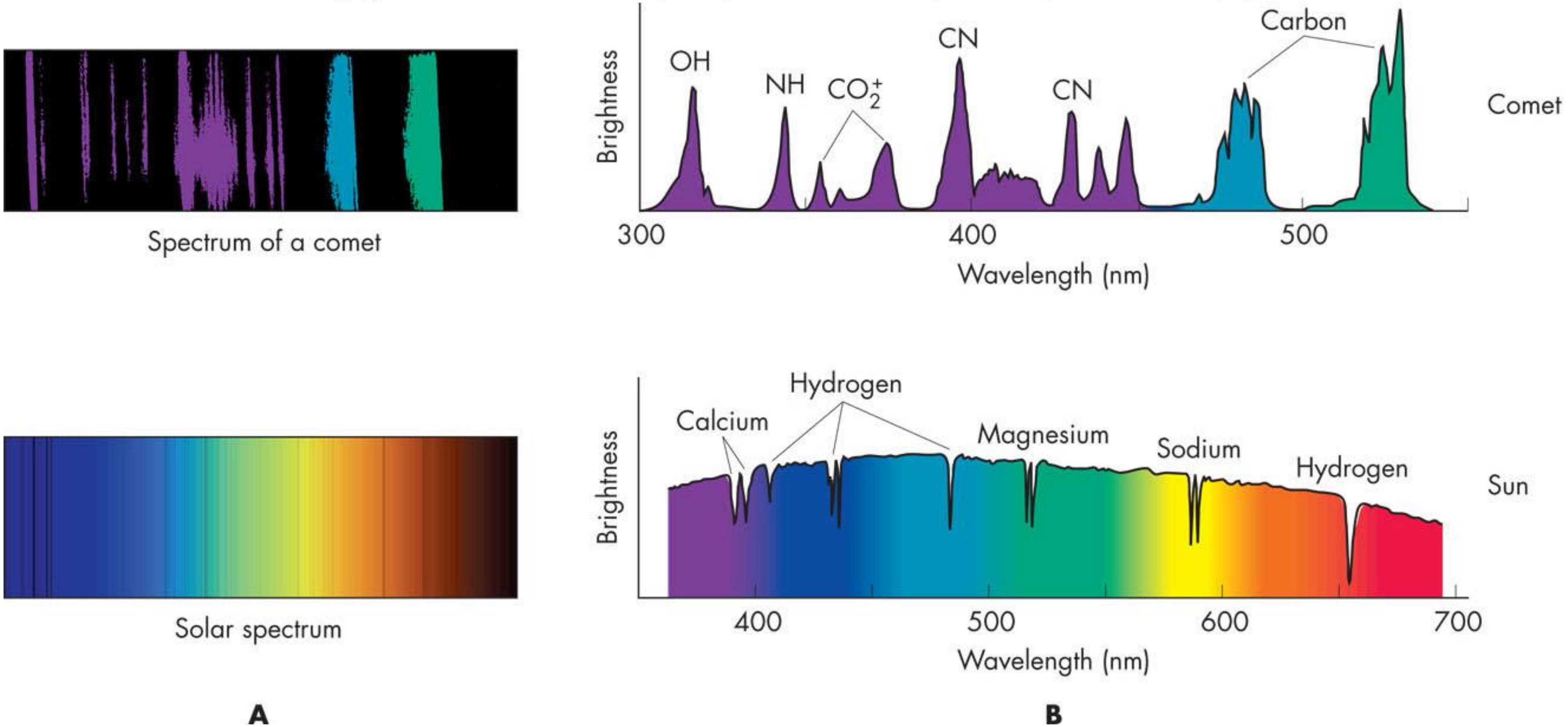
Each of the spectra above comes from a different gaseous element.

Continuous and Absorption Spectra

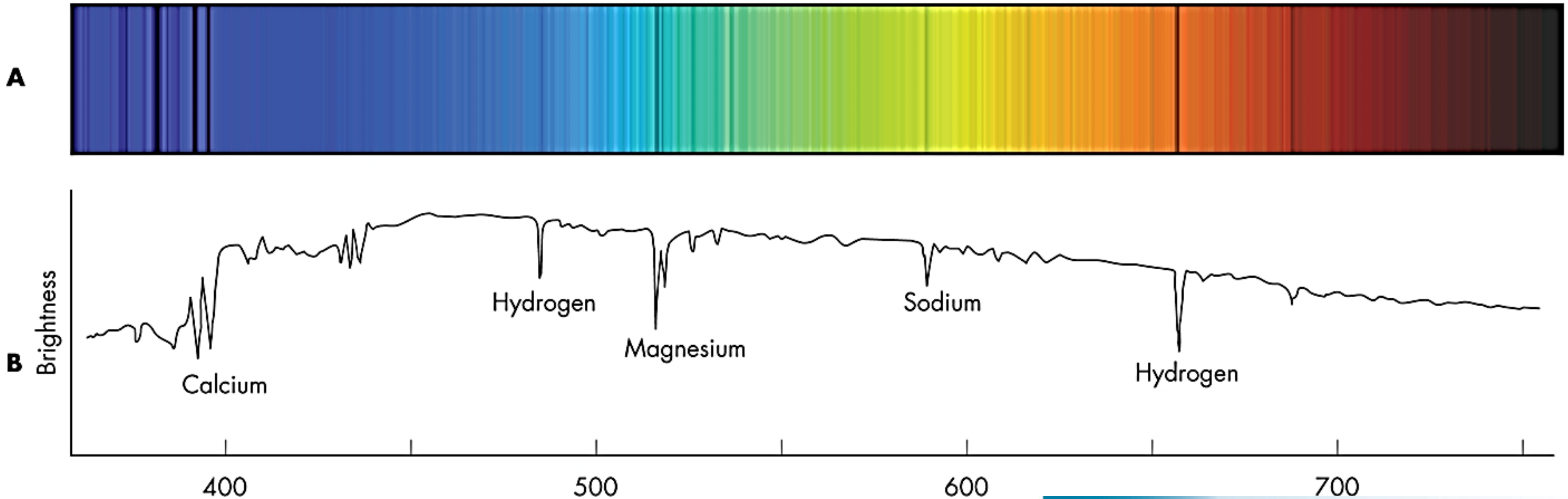


Spectra, *continued*

***Spectroscopy** is used to determine the composition of bodies in space



The Solar Spectra



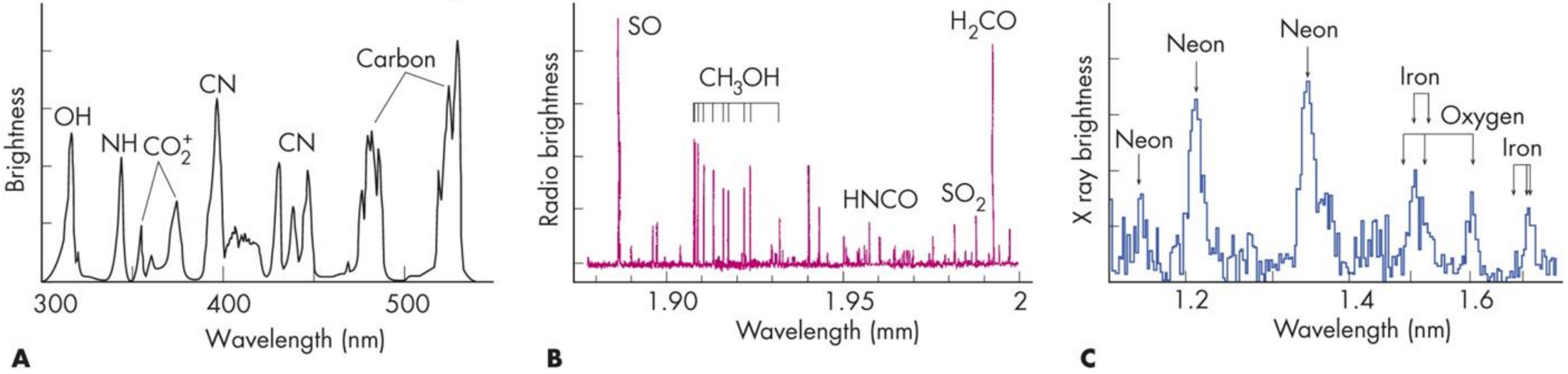
The composition of the Sun has been determined using a careful study of spectral lines.

Table 4.4 Composition of a Typical Star, Our Sun*

Element	Relative Number of Atoms	Percent by Mass
Hydrogen	10^{12}	71.1%
Helium	9.64×10^{10}	27.4%
Oxygen	5.75×10^{8}	0.65%
Carbon	2.88×10^{8}	0.25%
Neon	8.91×10^{7}	0.13%
Nitrogen	7.94×10^{7}	0.08%
Silicon	4.07×10^{7}	0.06%
Iron	3.47×10^{7}	0.14%
Gold	8	0.00000011%
Uranium	0.4	0.000000007%

Spectra *(wavelength intensity graphs)*

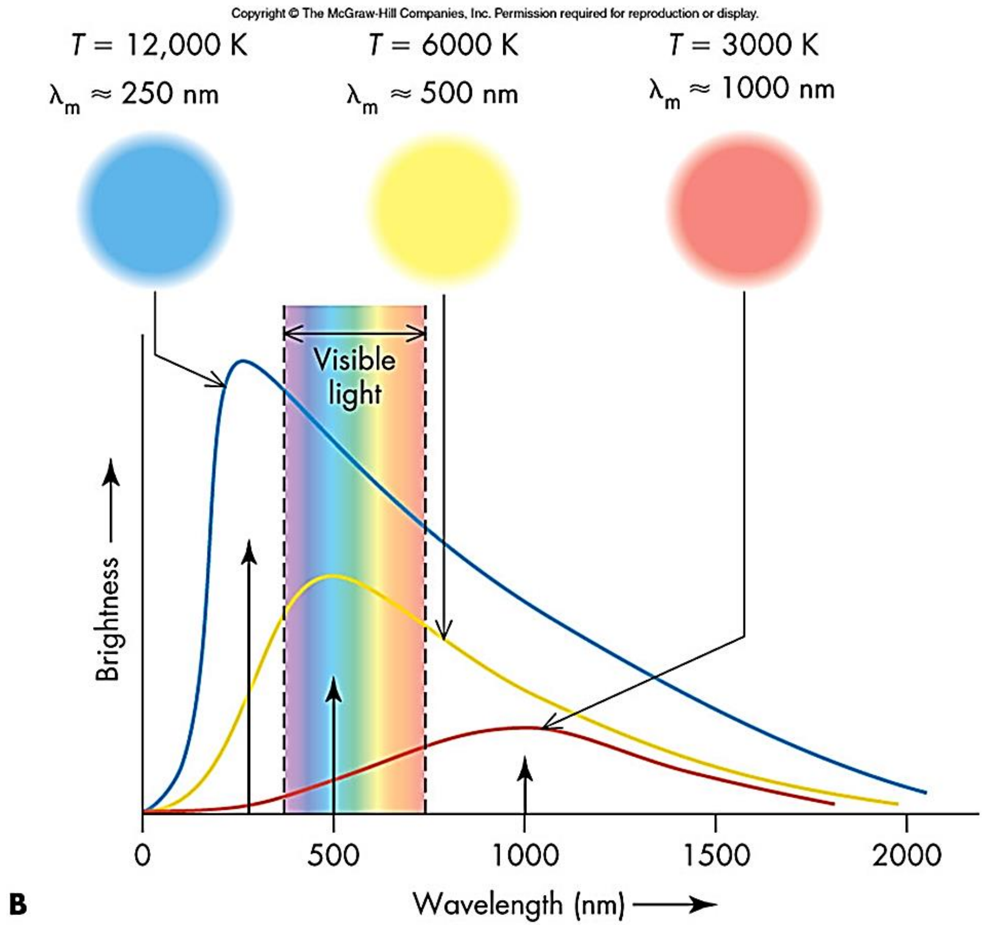
- The pattern observed in wavelength intensity graphs is sometimes more revealing than just the spectral lines.



Spectra (temperature)

Temperature of light emitting objects can be determined using spectroscopy.

Temperature- *average kinetic energy of an object.*



Wein's Law:

Hotter objects emit photons with a higher average energy.

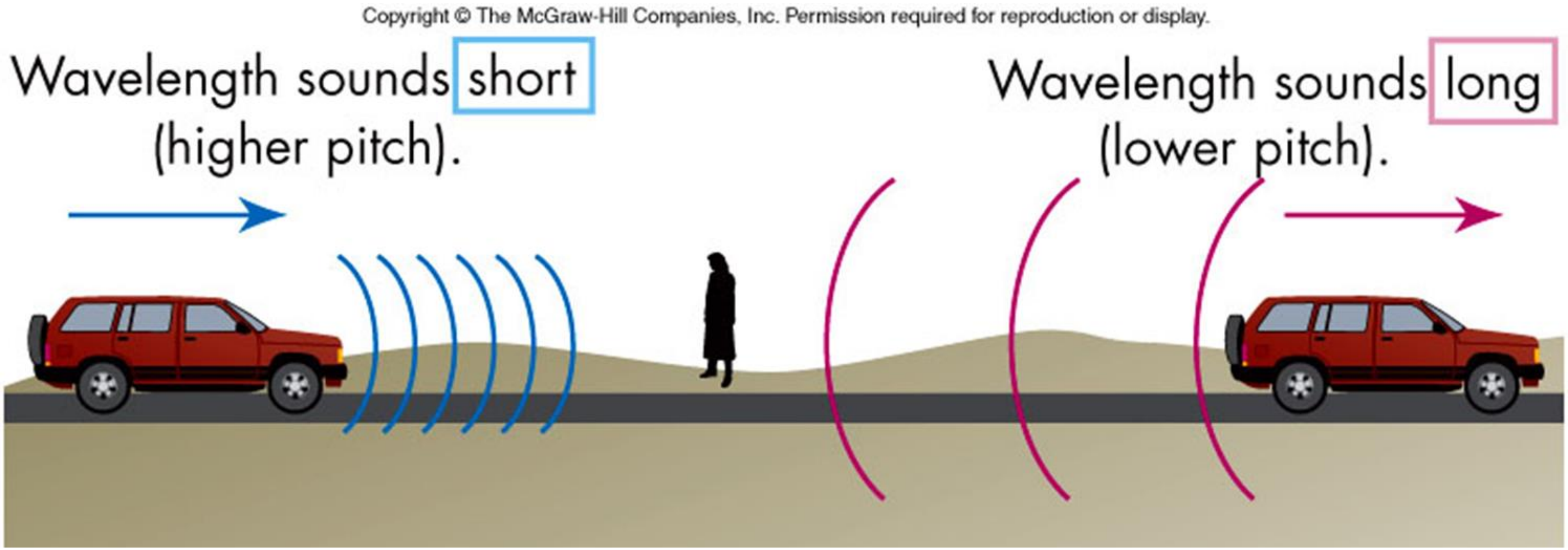
Wein's Law shows this Rule:

BLUE = HOT STAR

RED = COOL STAR

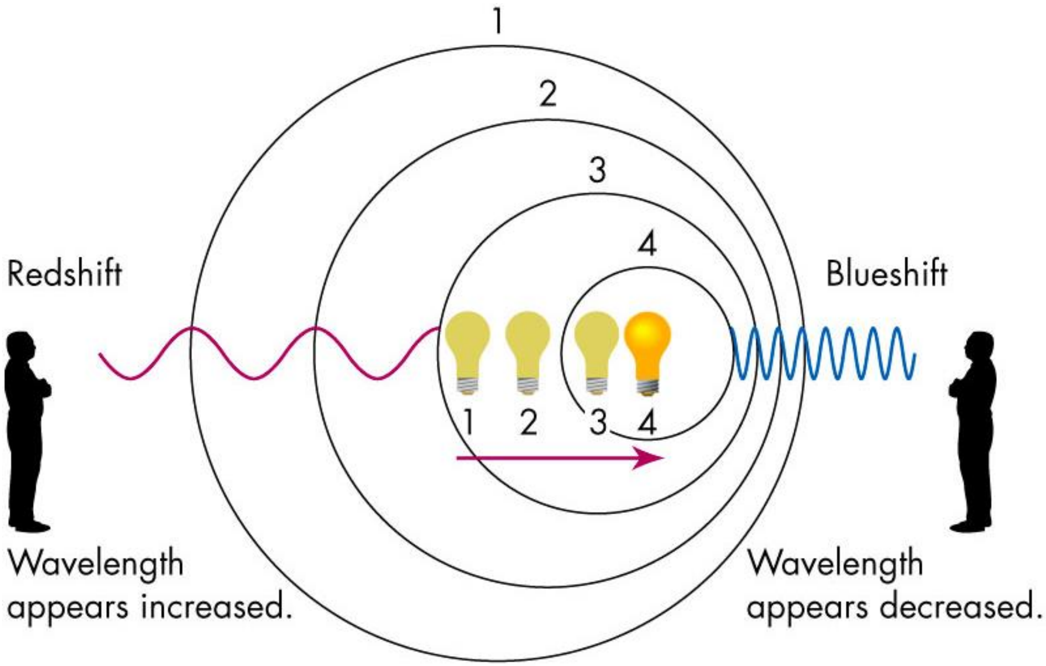
Spectra (motion)

Doppler Shift in Sound- *pitch (frequency) gets higher when an object is coming toward you; pitch (frequency) gets lower when an object is moving away.*



Spectra (motion)

Doppler Shift in light: *If a source of light is set in motion relative to an observer, its spectral lines shift to new wavelengths in a similar way*



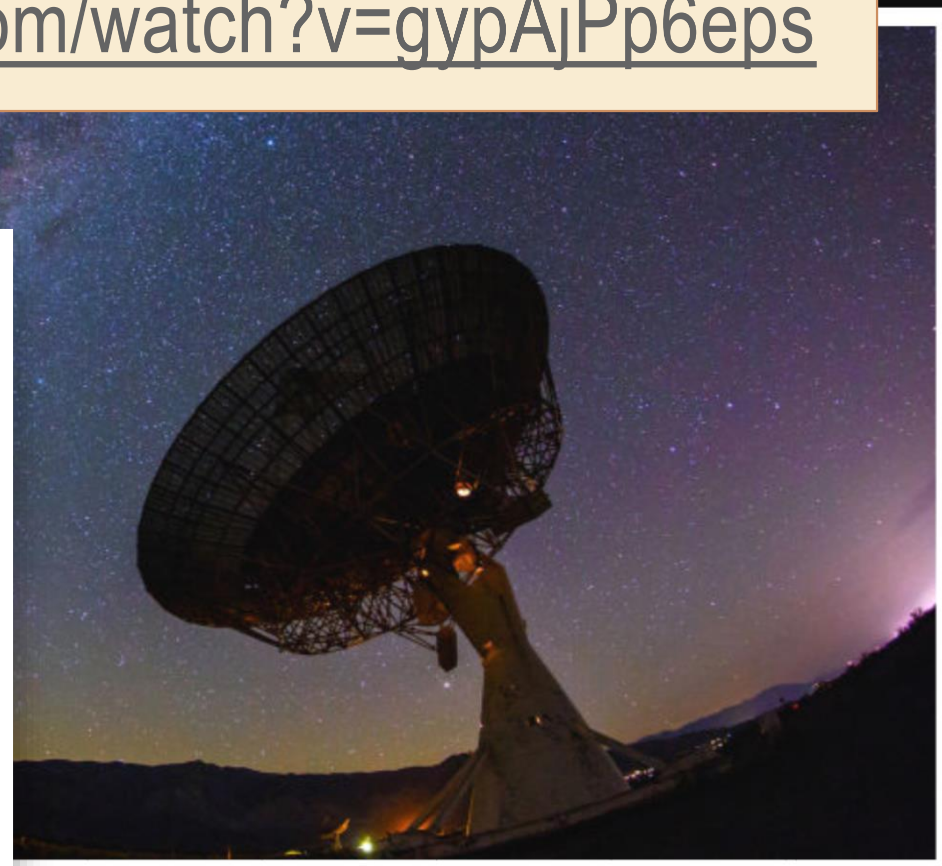
Redshift: the shift to longer wavelengths when an object moves away from us.

Blueshift: the shift to longer wavelengths when an object moves towards us.

TABATHA BOYAJIAN, ASTRONOMER

TED TALK: “THE MOST MYSTERIOUS STAR IN THE UNIVERSE”

https://www.youtube.com/watch?v=gypAjPp6eps



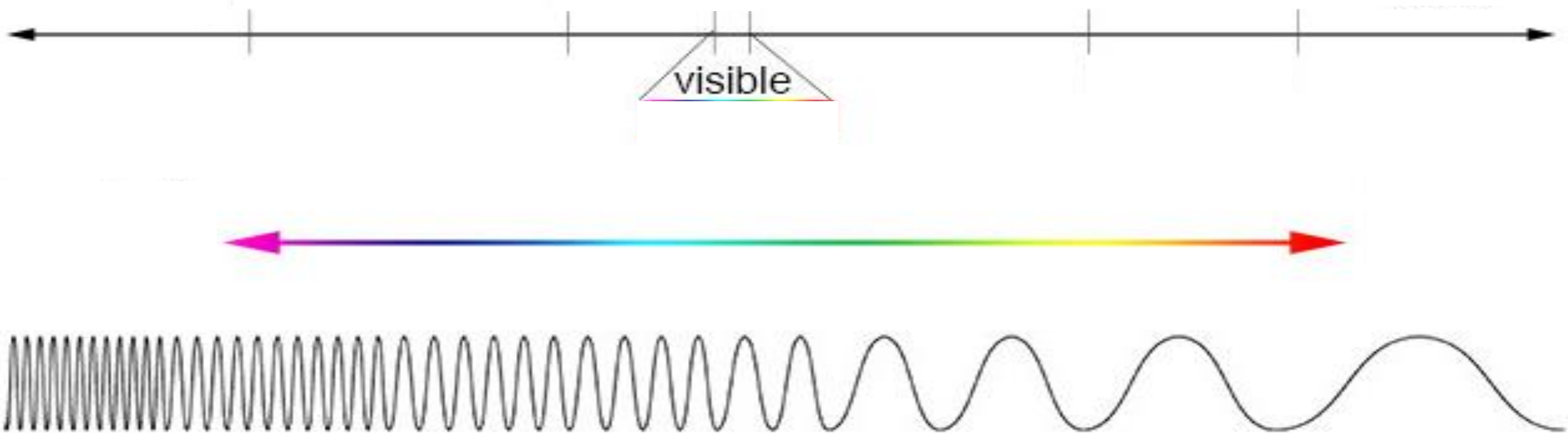
How are you doing?

1. What type of spectrum is this?
2. How are these lines produced?
3. Explain how composition of an object can be determined using spectral lines.
4. You observe a blue star and a red star. Which is hotter?

   high frequency - high energy = ↑T

   Red · 700nm blue 400
5. An astronomer notices the shift of spectral lines towards higher wavelengths. What does this indicate about the motion of that object?

   Red Shift - Away

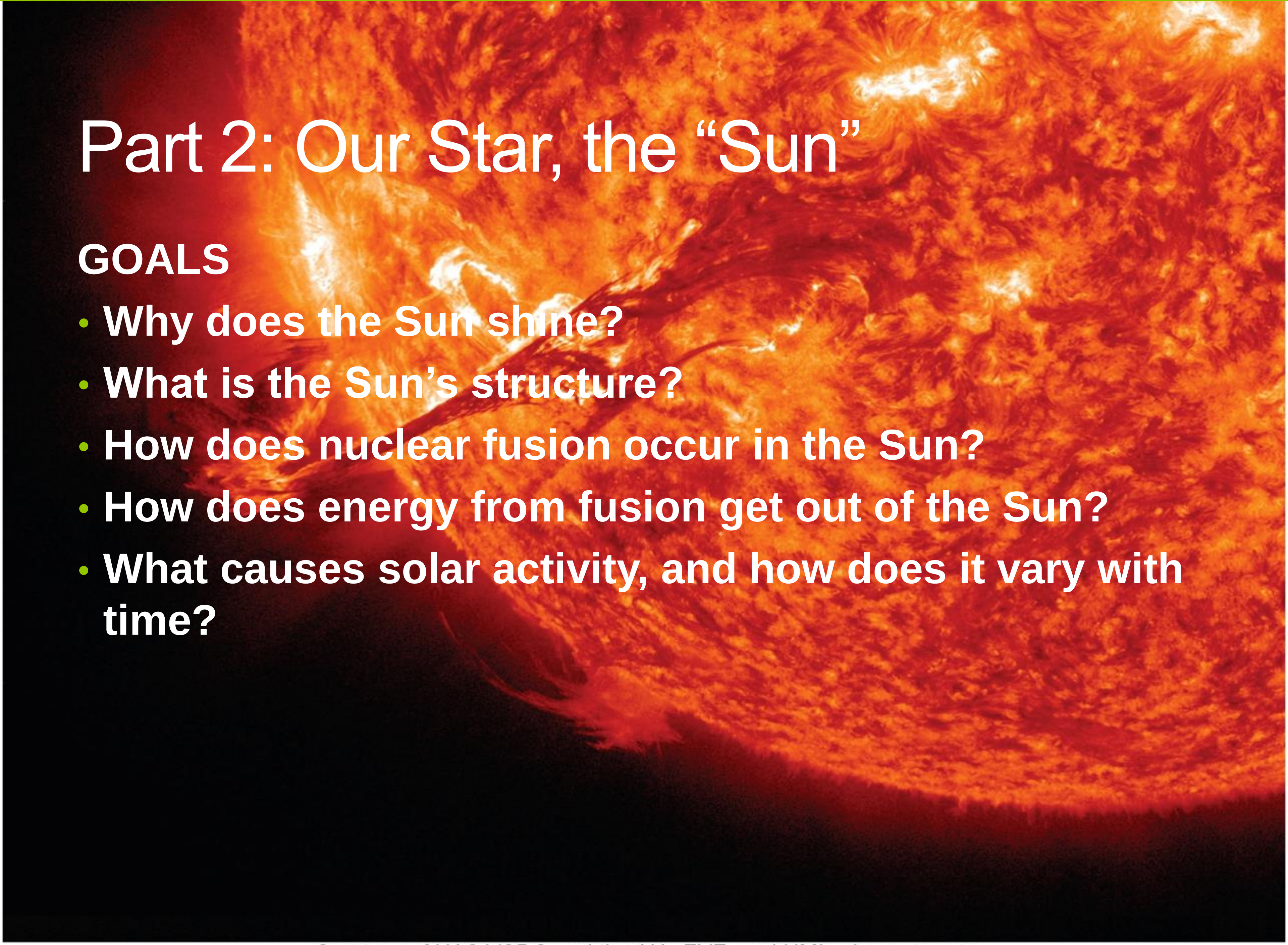


fill in the spectrum*

Part 2: Our Star, the “Sun”

GOALS

- **Why does the Sun shine?**
- **What is the Sun’s structure?**
- **How does nuclear fusion occur in the Sun?**
- **How does energy from fusion get out of the Sun?**
- **What causes solar activity, and how does it vary with time?**



Courtesy of NASA/SDO and the AIA, EVE, and HMI science teams

Why does the Sun shine?

Ancient thinkers… the Sun is a type of fire?

Mid-1800's... Calculations showed that burning wood or coal would not account for the Sun's huge output of energy.

Late 1800's… The Sun generates energy by contracting in size (gravitational contraction).

Later calculations showed that this would have kept the Sun shining steadily for 25 million years.

1905… Einstein's Special Theory of Relativity showed that the energy of the Sun's mass could be converted into thermal energy.

Why does the Sun shine?

By the end of the 1930's, we learned that the Sun converts mass into energy through the process of **nuclear fusion**.

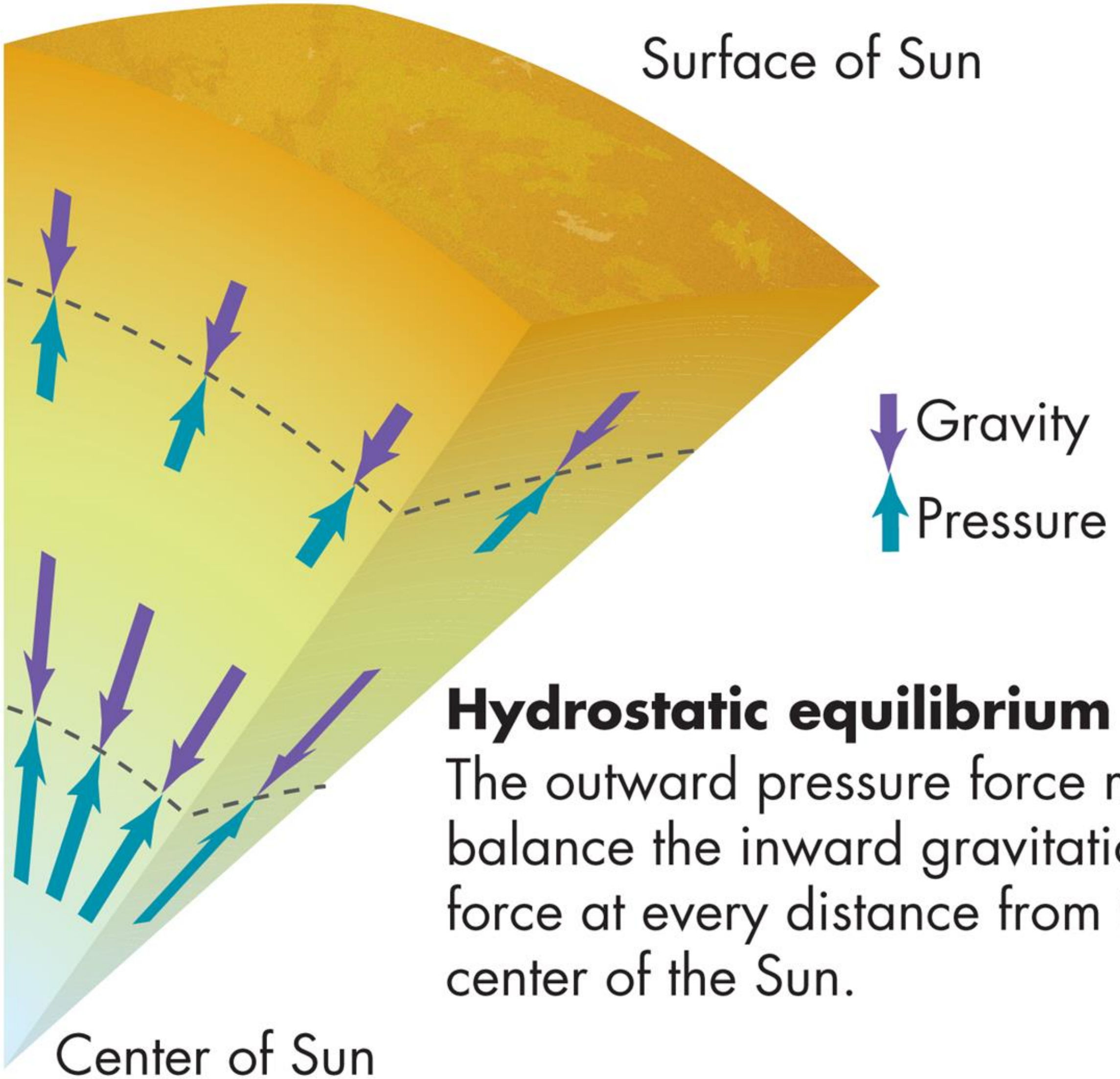
- For nuclear fusion to occur, high pressure and density is required.

  Conditions are present in the core!

- How does the core stay hot and dense?

  Hydrostatic Equilibrium- A natural balance between the inward force of gravity and the outward pressure of hot gases.

Hydrostatic Equilibrium



Hydrostatic equilibrium

The outward pressure force must balance the inward gravitational force at every distance from the center of the Sun.

Solar Basics

- The Sun is a ball of **plasma**– a gas in which many of the atoms are ionized because of high temperature.
- Energy is created in the core

Basic Properties of the Sun

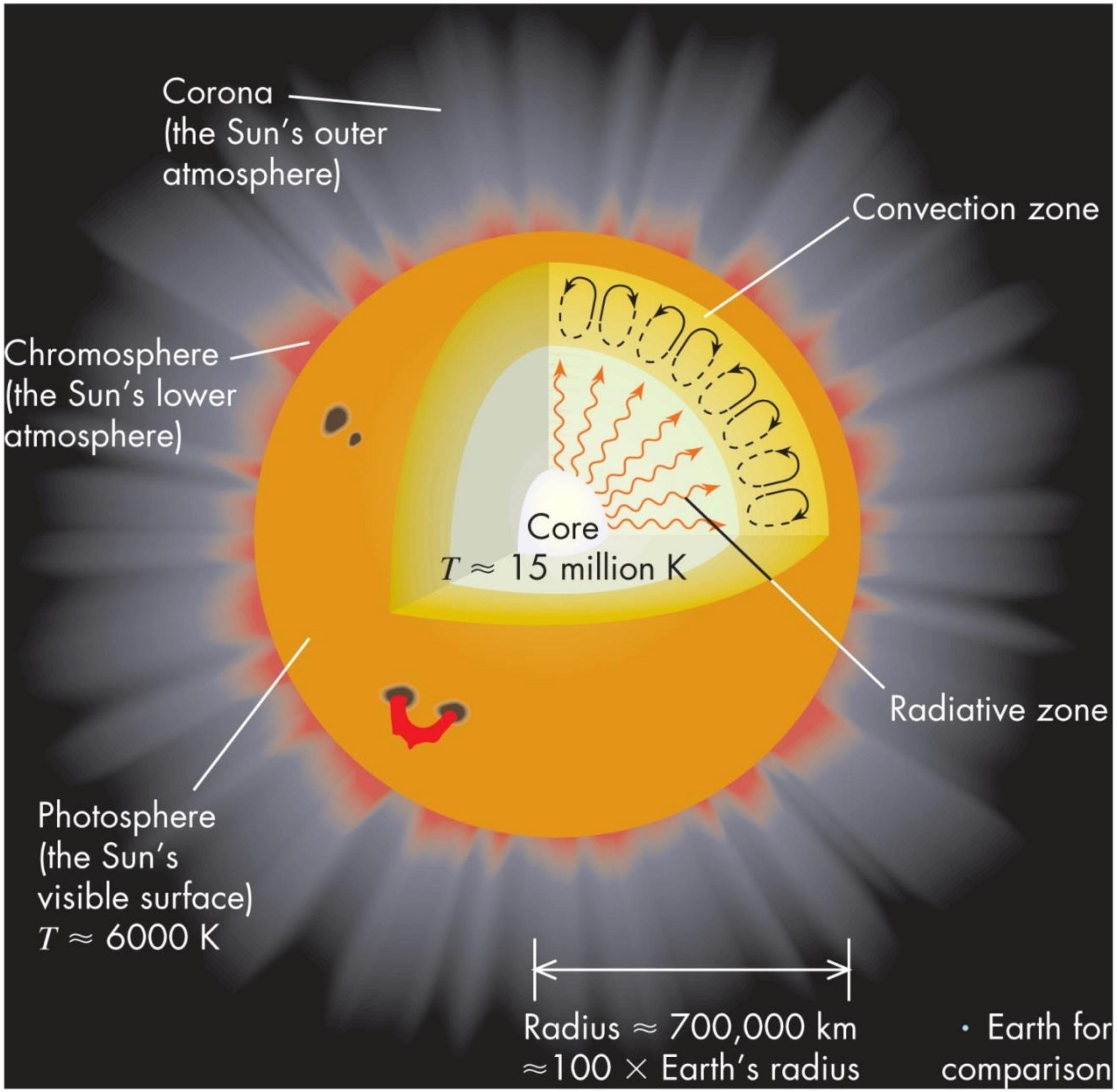
- **Composition** is almost entirely hydrogen and helium.
  - Revealed using spectroscopy
- **Radius** is about 700,000 km (100 X Earth radius)
  - Determined from angular distance measurements
- **Mass** is 2×10^{30} kg (300,000 x Earth's mass)
  - Using Newton's and Kepler's Laws
- It has **Sunspots**, or dark spots that are regions of intense magnetic fields.

Basic Properties of the Sun

- **Rotation rate** = 25 days (equator); 30 days (poles)
  - Observed by looking at the sunspots or by measuring Doppler Shifts on opposite sides of the Sun.
- The Sun radiates energy!
  - **Luminosity** = 3.8×10^{26} Watts
- **Surface Temperature** is 5,800 K (average)
  - Determined through intensity analysis of solar spectra

Solar Structure

1. Corona
2. Chromosphere
3. Photosphere
4. Convection Zone
5. Radiative Zone
6. Core



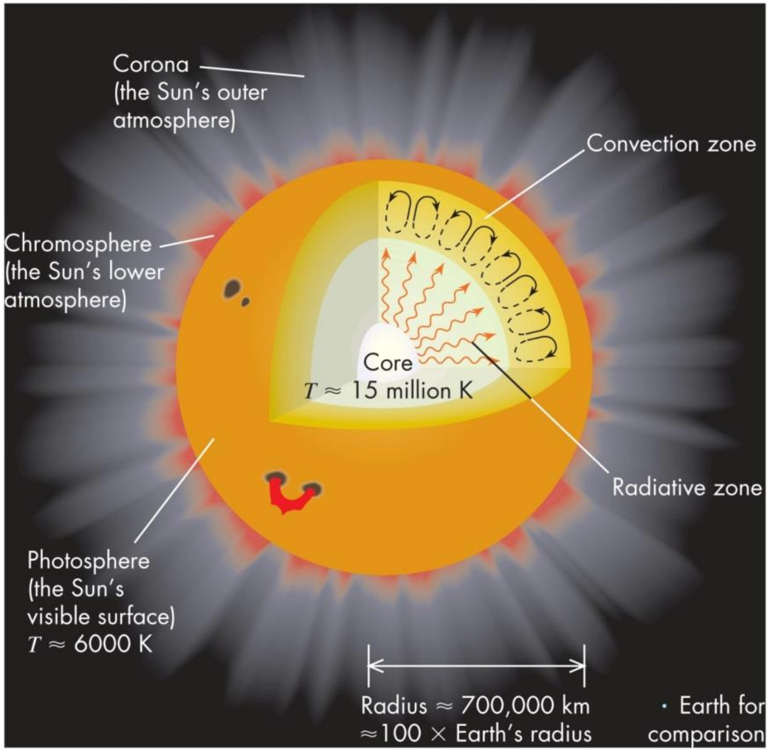
Solar Structure

ATMOSPHERE

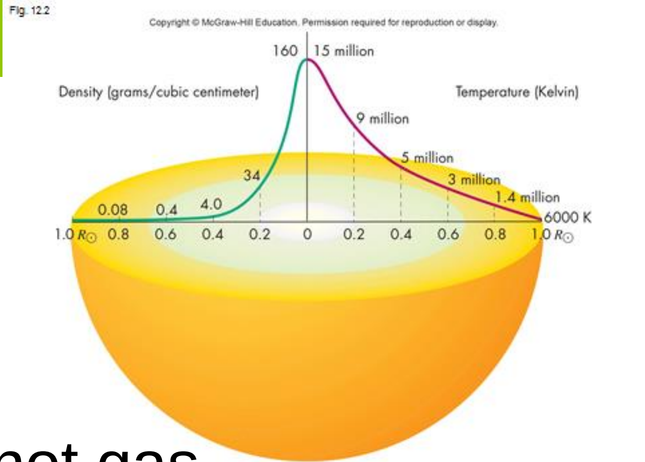
Corona- the outermost layer of the atmosphere, extends several million km above visible surface. (X-Ray)

Chromosphere- middle layer of solar atmosphere. (UV Radiation)

Photosphere- The visible surface of the Sun; where sunspots can be seen.

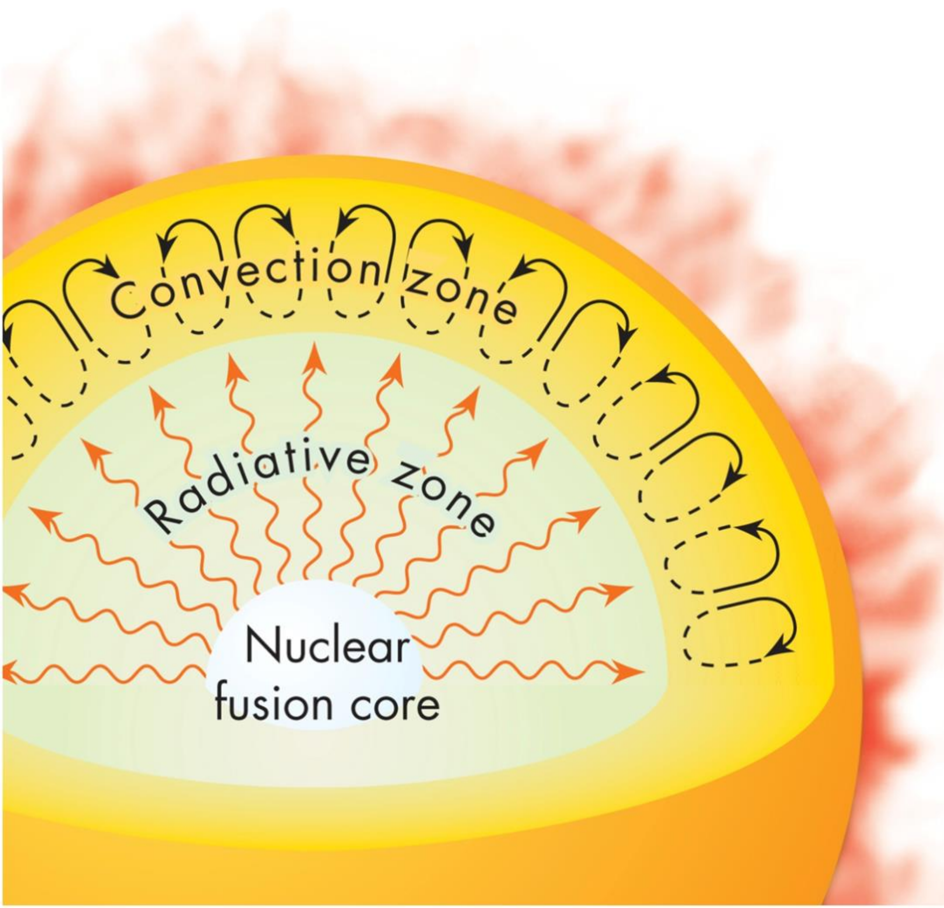


Solar Structure



INTERIOR

Convection Zone- rising and falling of hot gas



Radiation Zone- where energy moves outward in the form of photons.

Core- The Sun's center; source of energy- transforming hydrogen to helium in the process of nuclear fusion. (T = 15 million K)

Nuclear Fusion

15 million K plasma in the solar core is like a "soup" of hot gas with atomic nuclei and electrons whizzing around.

- Nuclei collide and sometimes they "stick" together to form a heavier nucleus (and heavier element).
  - **Fusion-** the process by which two atomic nuclei fuse together to make a single more massive nucleus.

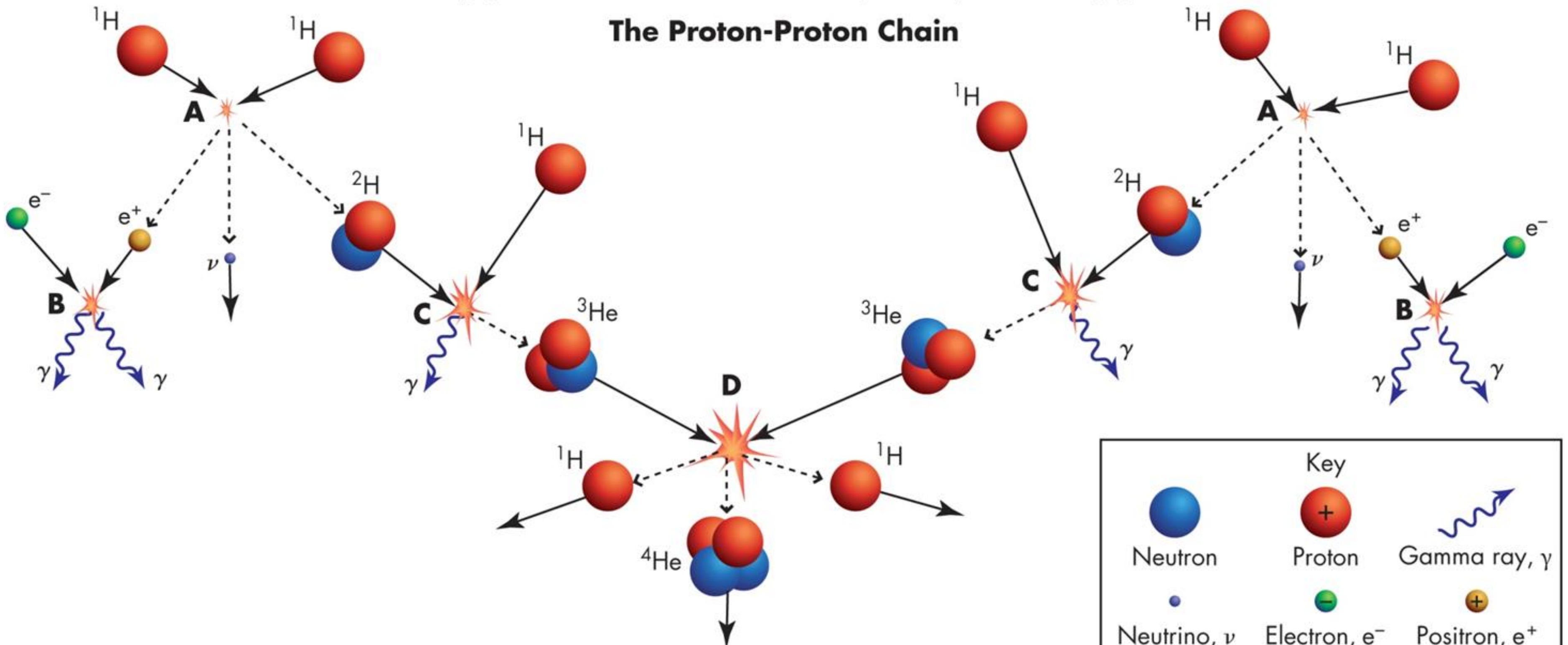
- Energy is released in the process

Fusion converts about <u>600 million tons of hydrogen</u> into <u>596 millions tons of helium</u> every second

Nuclear Fusion in the Sun

4 Steps (Proton-Proton Chain)

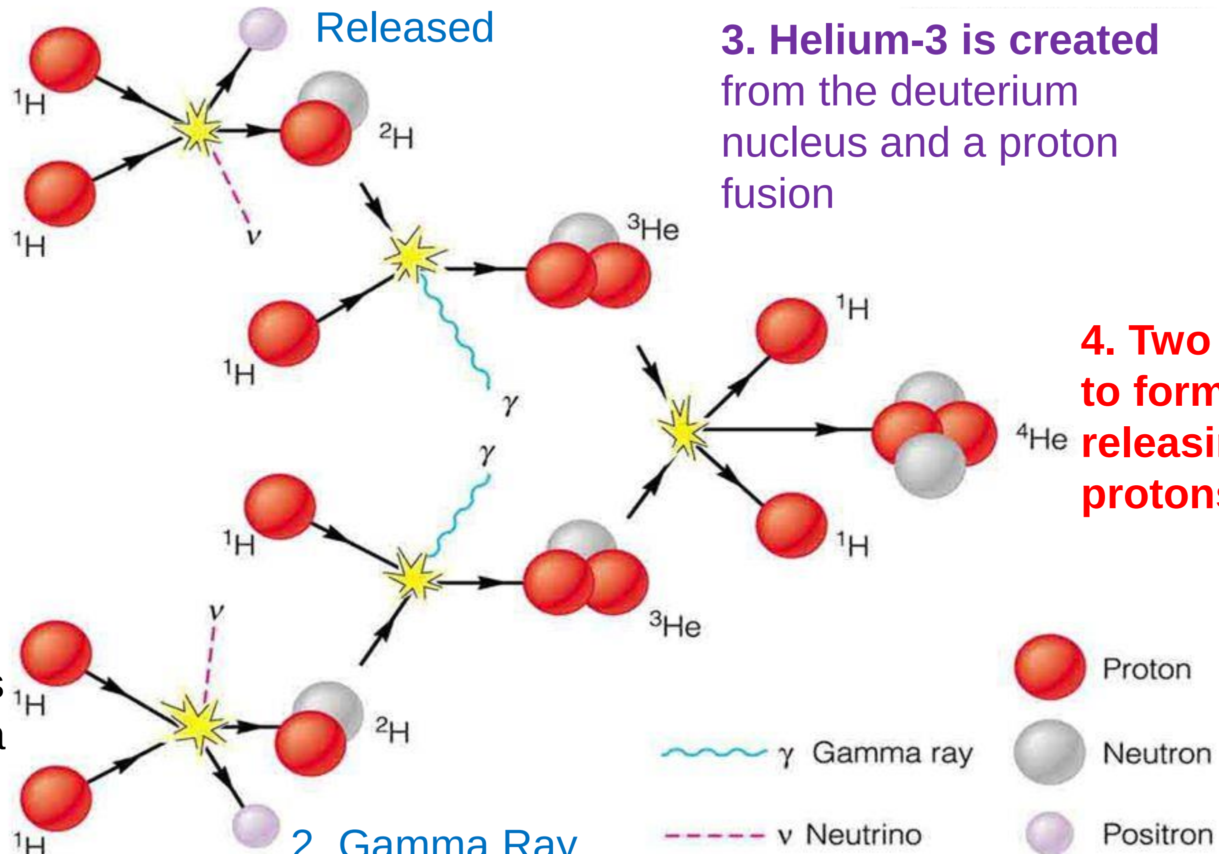
- **RESULT: 4 Hydrogen Atoms fuse to create 1 Helium Atom during the process of fusion.**



1. Two protons fuse to make a deuterium nucleus

2. Gamma Ray Photon & Neutrino Released

3. Helium-3 is created from the deuterium nucleus and a proton fusion



4. Two He-3 nuclei fuse to form Helium-4, releasing two excess protons in the process

1. Two protons fuse to make a deuterium nucleus

2. Gamma Ray Photon & Neutrino Released

Proton-Proton Chain (4 steps)

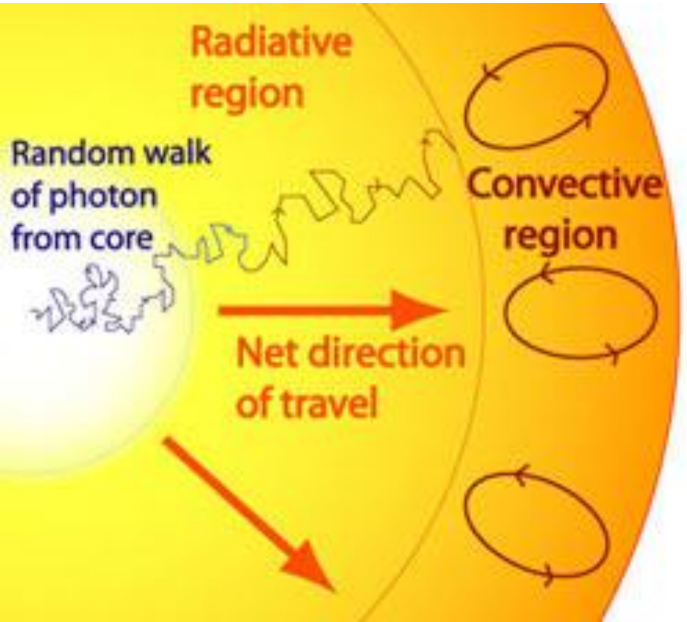
A. **Two protons fuse to make a deuterium** nucleus (1 proton and 1 neutron). This occurs twice.
B. **2 Gamma-Ray photons** are released + 1 **neutrino** (tiny subatomic particle)
C. **Helium-3 is created** from the deuterium nucleus and a proton fusion(occurs twice). Also releases **two gamma ray photons**.
D. Two He-3 nuclei fuse to form helium-4 (2 protons, 2 neutrons), releasing two excess protons in the process.

The Solar Energy Journey

It takes hundreds of thousands of years for solar energy from the core to get to the photosphere.

Radiative Diffusion- the slow, outward migration of photons.

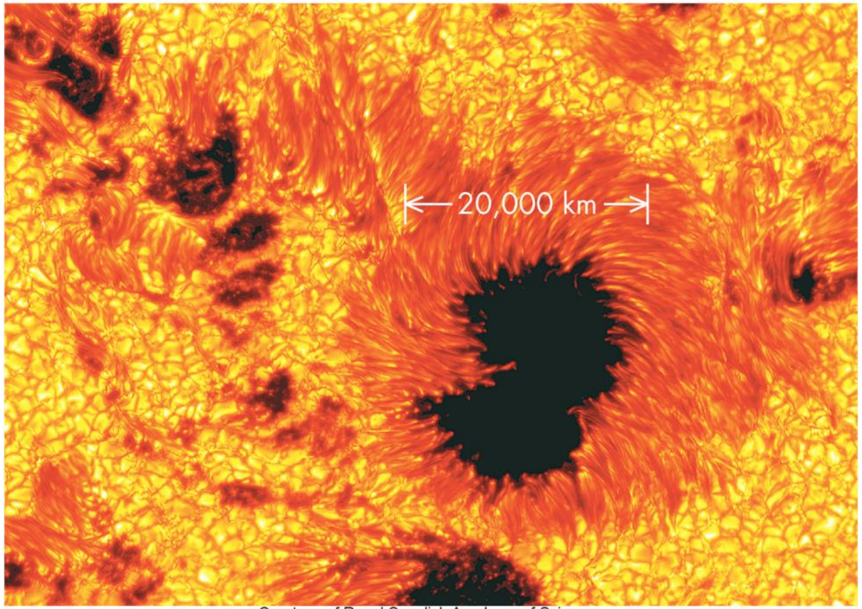
- Photons bounce around haphazardly, called a "*random walk*", and gradually work outward from the core.



Photons can finally escape when they reach the photosphere, where they travel in a straight path at the speed of light.

Solar Activity

- **Sunspots-** most striking feature on surface.
  - Dark spots with strong magnetic fields
  - Less bright because those places are cooler (about 1200 K less than surrounding plasma)

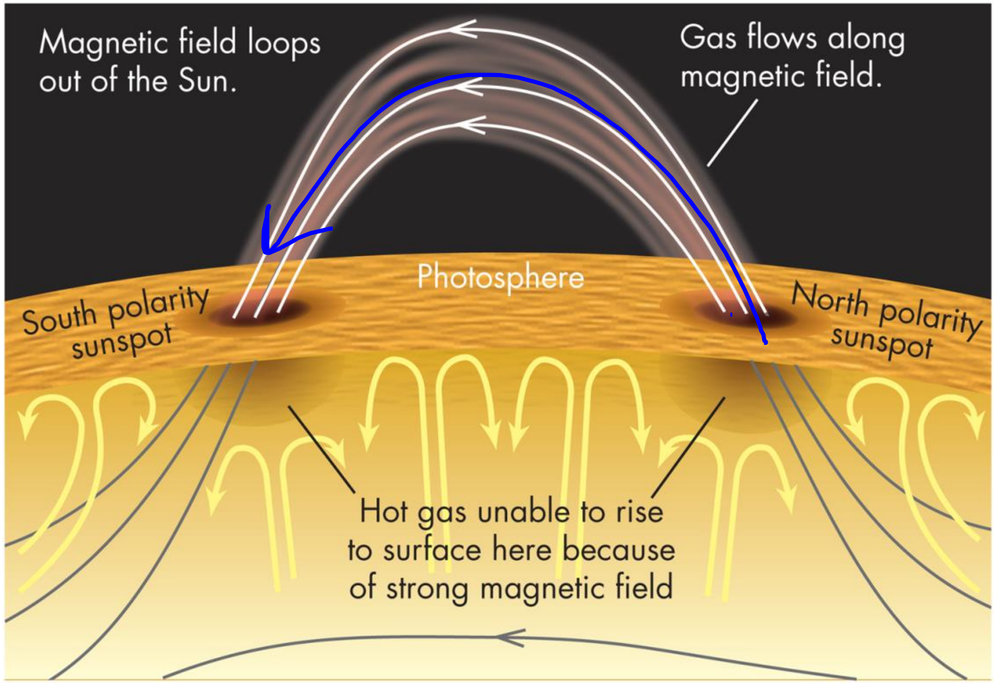


Courtesy of Royal Swedish Academy of Sciences

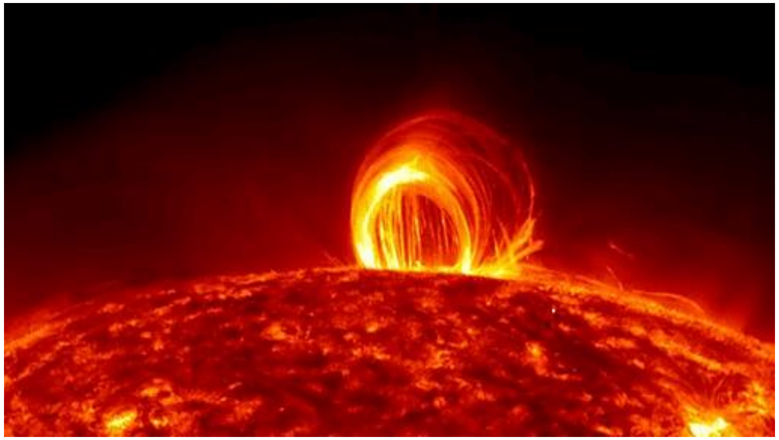
Solar Activity, cont'd.

SUNSPOTS

- Occur in pairs, connected by a loop of magnetic field lines that arc above the Sun's surface.



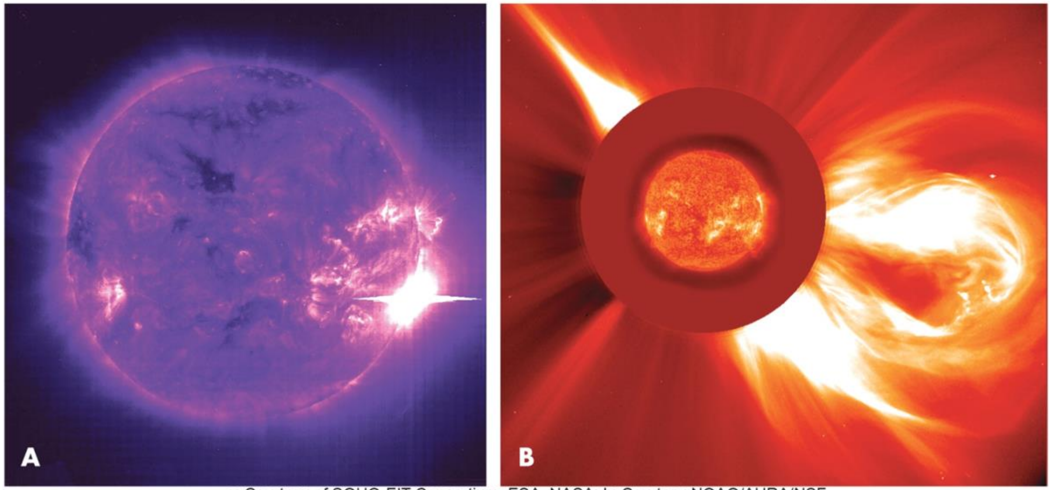
Gases in the Sun's chromosphere and corona becomes trapped in the loops, making giant **solar prominences.**



Solar Activity, cont'd.

SOLAR STORMS

- **Solar Flares-** dramatic storm event
  - Brief, bright eruptions of hot gas in the chromosphere.
- Sometimes followed by **coronal mass ejections** (enormous bubbles of hot gas trapped in magnetic fields that burst from the corona into space.

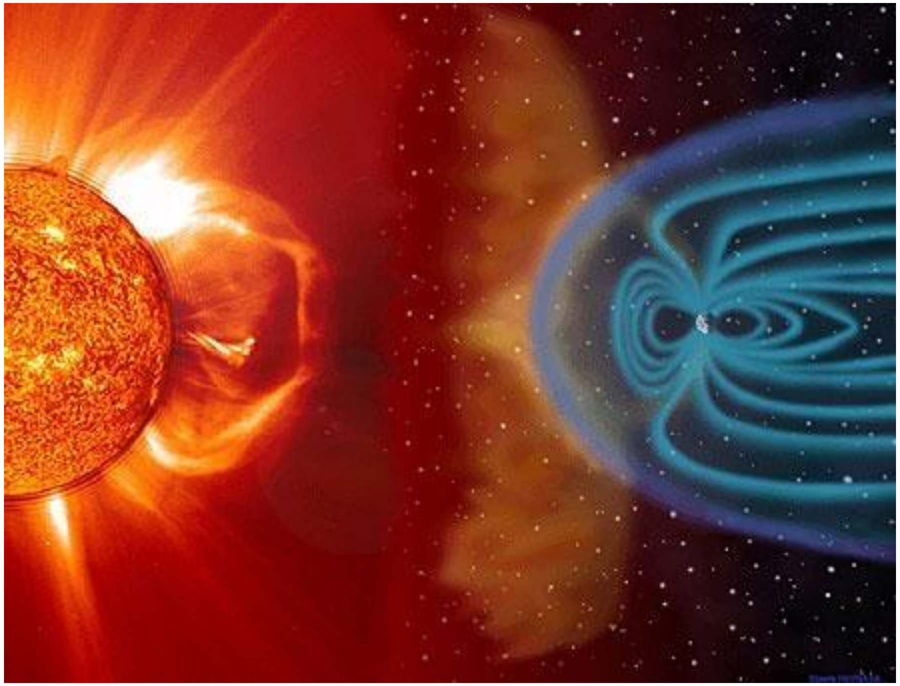


a: Courtesy of SOHO-EIT Consortium, ESA, NASA; b: Courtesy NOAO/AURA/NSF

Solar Activity, cont'd.

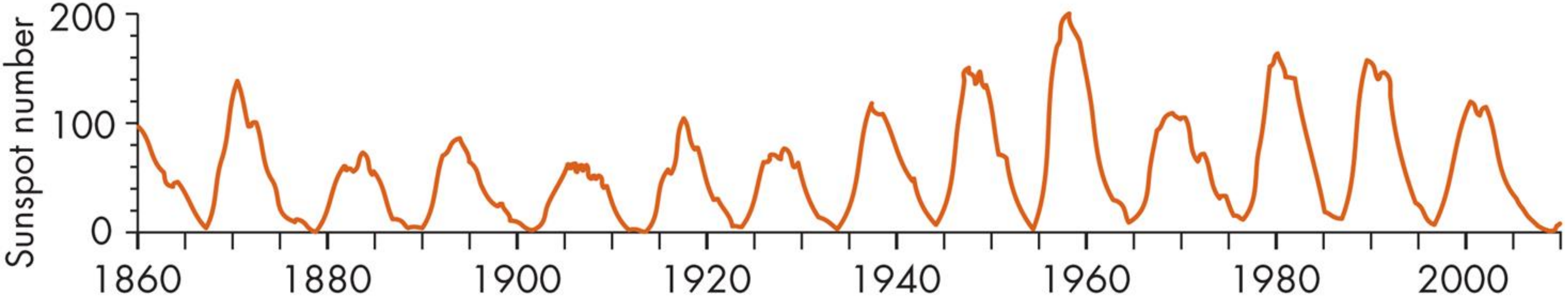
THE SOLAR WIND

- **Solar Wind-** a constant flow of hydrogen and helium that sweeps across the Solar System.
- *Wind Speed is about 500 km/s, but speeds up and slows down in response to magnetic fields*



The Solar Cycle

- The number of sunspots changes from year to year is called the **solar cycle.**
- # of sunspots rise and fall every 11 years *(avg)*
- *The Sun's magnetic field flip-flops every 11 years, resulting in a 22 year magnetic cycle*



Peaks in 1958, 1969, 1980, etc

Does it Make Sense?

Decide whether the statement makes sense (or is clearly true) or does not make sense (or is clearly false). Explain clearly.

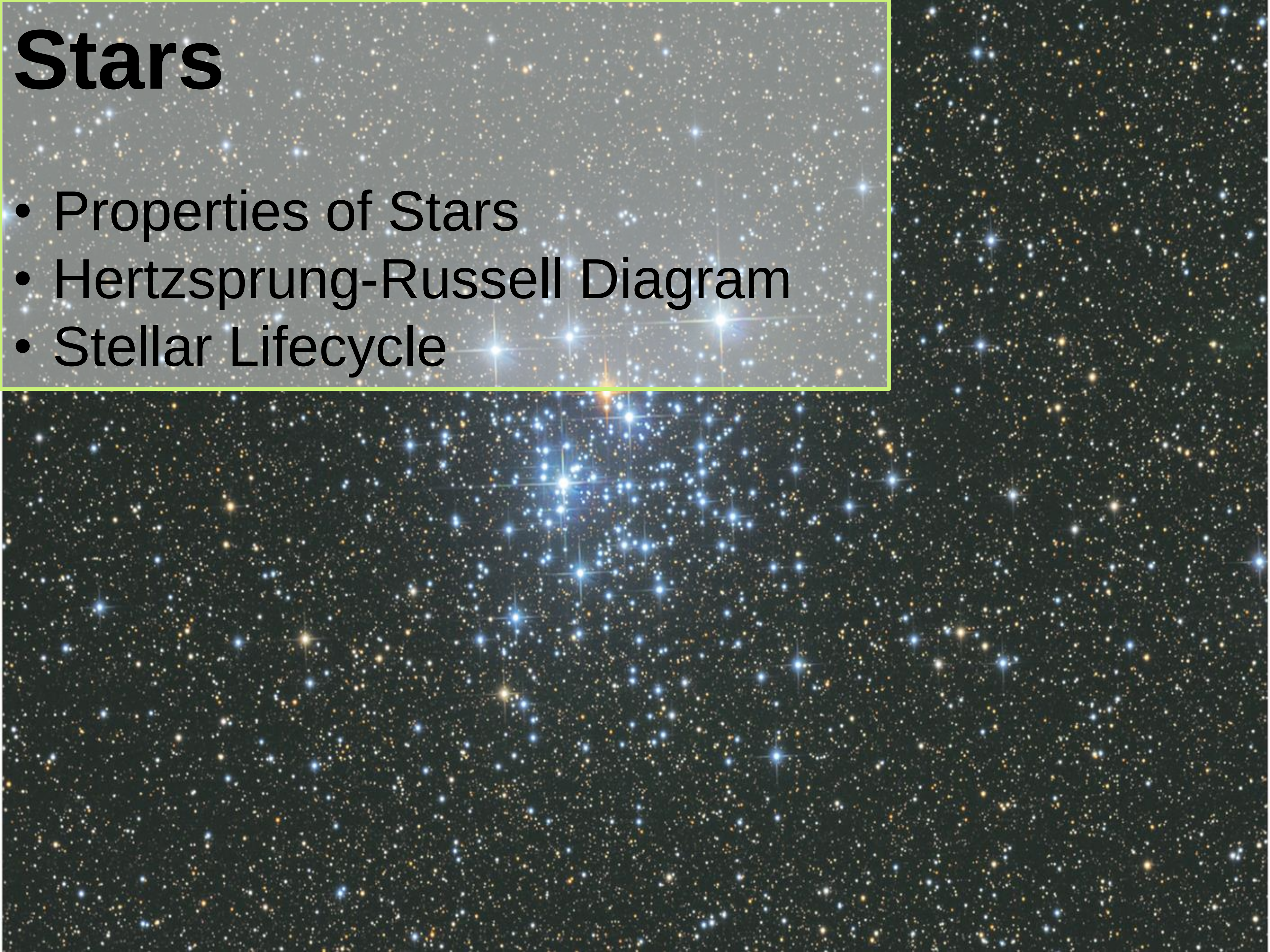
- *If fusion in the solar core ceased today, worldwide panic would break out tomorrow as the Sun began to grow dimmer.*

Review:

- Which layer is the coolest- *the core, the radiation zone, or the photosphere?*
- Why do sunspots appear darker than their surroundings? *(they are cooler than their surroundings, they block some of the sunlight from the photosphere, they do not emit any light)*
- At the center of the sun, fusion converts hydrogen into (a) plasma, (b)radiation and elements like carbon and nitrogen, (c) helium, energy, and neutrinos
- Which poses the greatest threat to communications satellites?(a) photons from the sun, (b) solar magnetic fields, (c) protons from the sun

Stars

- Properties of Stars
- Hertzsprung-Russell Diagram
- Stellar Lifecycle



Properties of Stars

BRIGHTNESS

Brightness of a star depends on distance and how much light it emits.

- **Apparent Brightness or *Flux*-** The brightness of a star as it appears to our eyes; does not take distance into account.
- **Luminosity-** the total amount of power that a star emits into space.
  - Stellar Luminosities span a wide range!
  - Stellar luminosities are stated in comparison to the Sun's luminosity, which we write as L_{Sun} for short.

Stars

Examples of Stellar Luminosities

- Proxima Centauri (the nearest neighbor) is about 0.0006 times as luminous as the Sun, or 0.0006 L_{Sun}
- Betelgeuse (bright left shoulder of Orion): 38,000 L_{Sun}

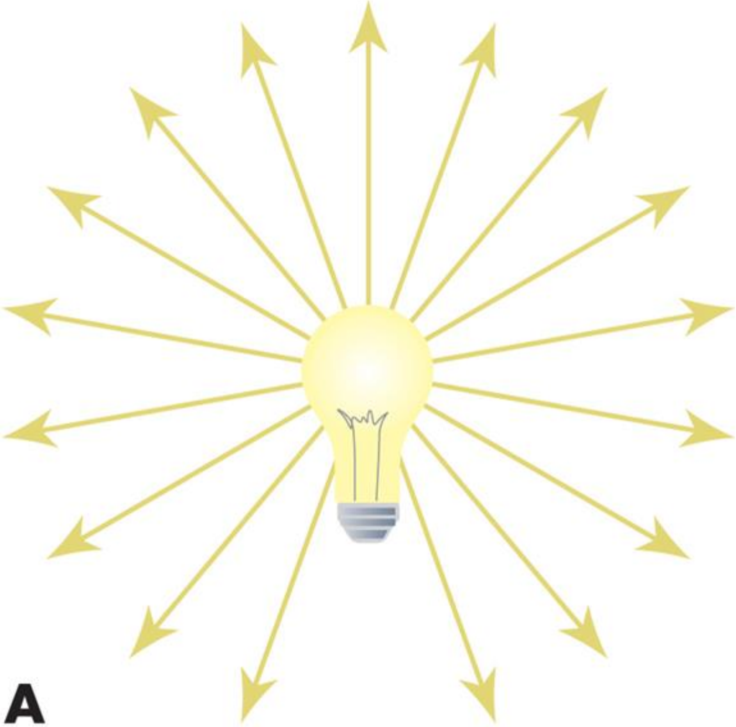
Two important Lessons:

1. Stars have a wide range of luminosities and our Sun is somewhere in the middle.

   Range = $(10^{-4} L_{Sun} - 10^{6} L_{Sun})$

2. Dim stars are more common than bright stars.

Brightness



A

B

b: © Goodshoot/ PunchStock RF

Brightness decreases with distance.

Properties of Stars

STELLAR TEMPERATURES

Unless otherwise stated, when you hear "temperature" in terms of a star, it is referring to surface temperature.

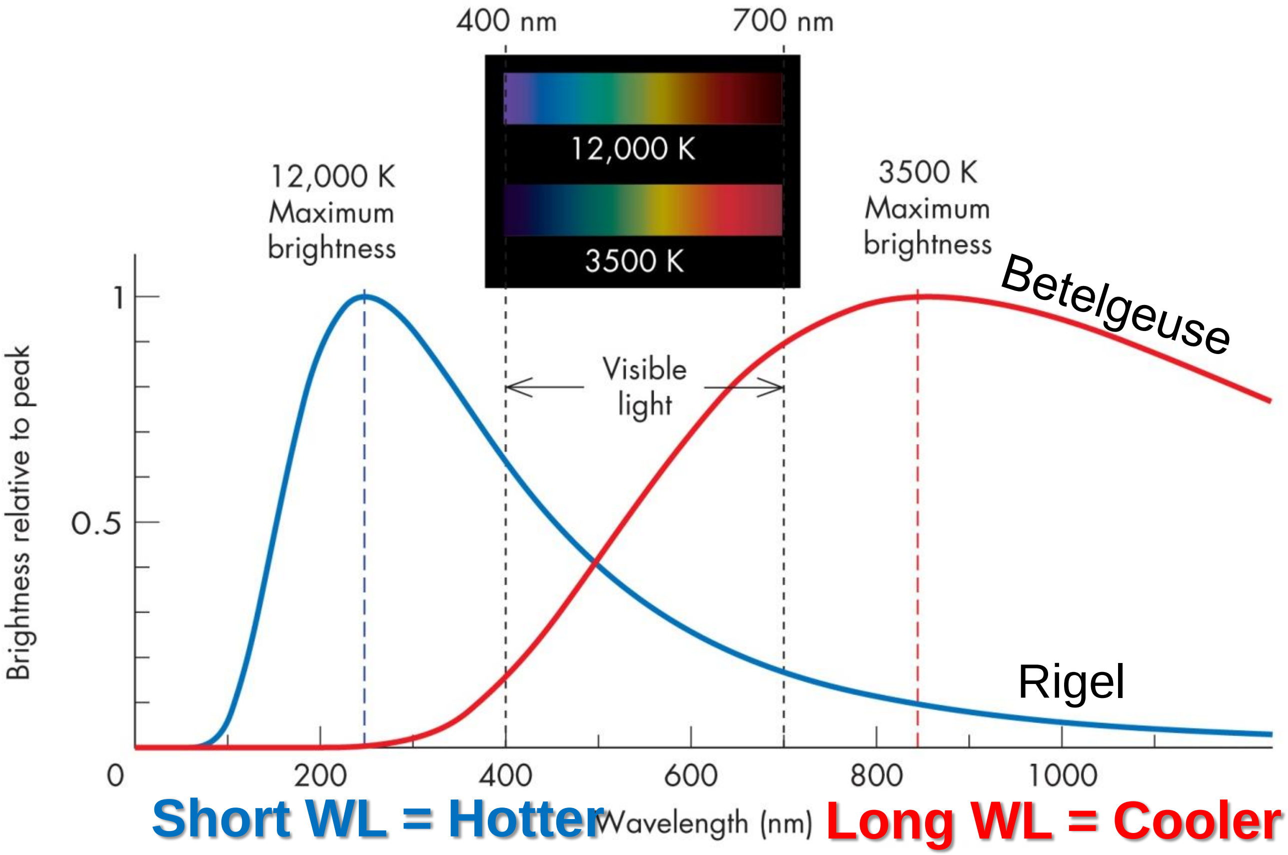
- ***Why?*** *Surface temperature is directly measurable; interior temperatures are inferred from mathematical models.*

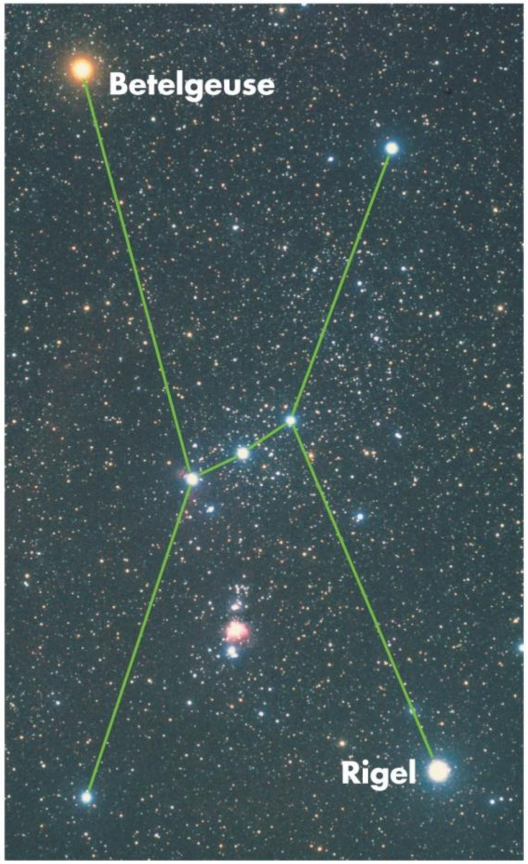
Color and Temperature

Thermal Radiation (heat) at the surface depends on the average energy emitted from the surface.

- *Temperature can be deduced from the color of its emitted light.*
- ***In general, hot stars emit blue light; cooler stars emit red light.***

Color and Temperature





Short WL = Hotter **Long WL = Cooler**

Betelgeuse is red compared to Rigel. This plot of wavelengths vs brightness shows that the stars peak at different wavelengths.

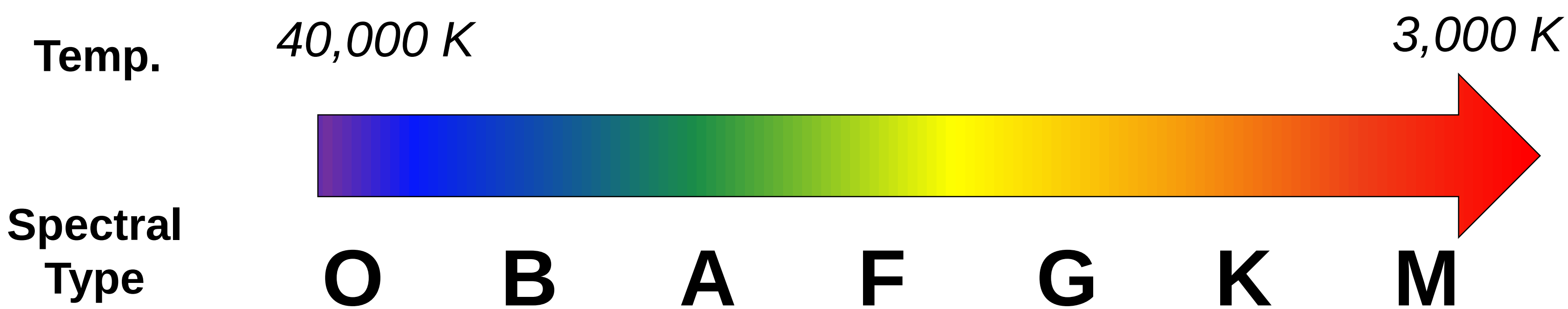
Properties of Stars

STELLAR TEMPERATURES, *continued*

Astronomers classify stars according to surface temperature by assigning a **spectral type** (determined from spectral lines)

Spectral Types: (O, B, A, F, G, K, M)

Each is then further subdivided into #'s 0-9. The larger the number, the cooler the star. Sun is a G2

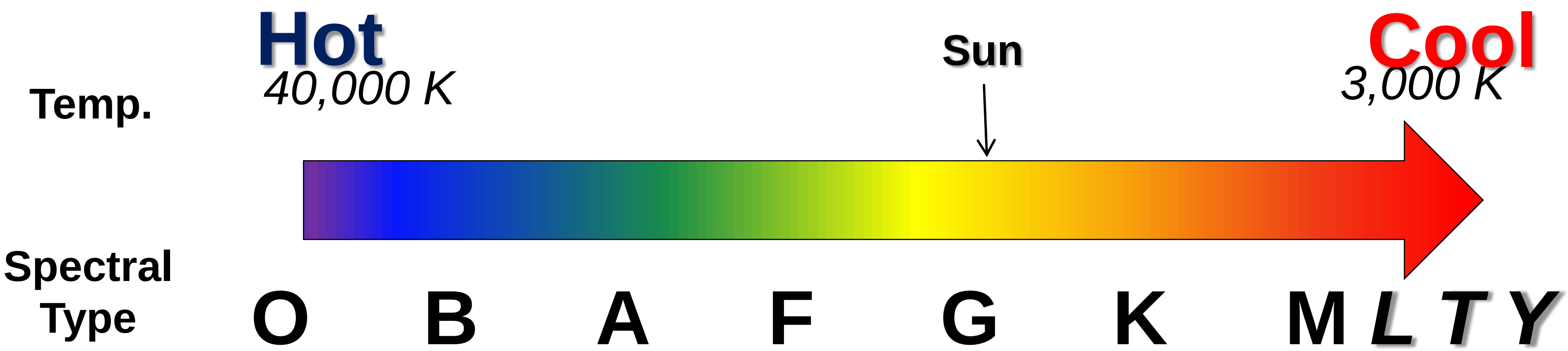


Properties of Stars

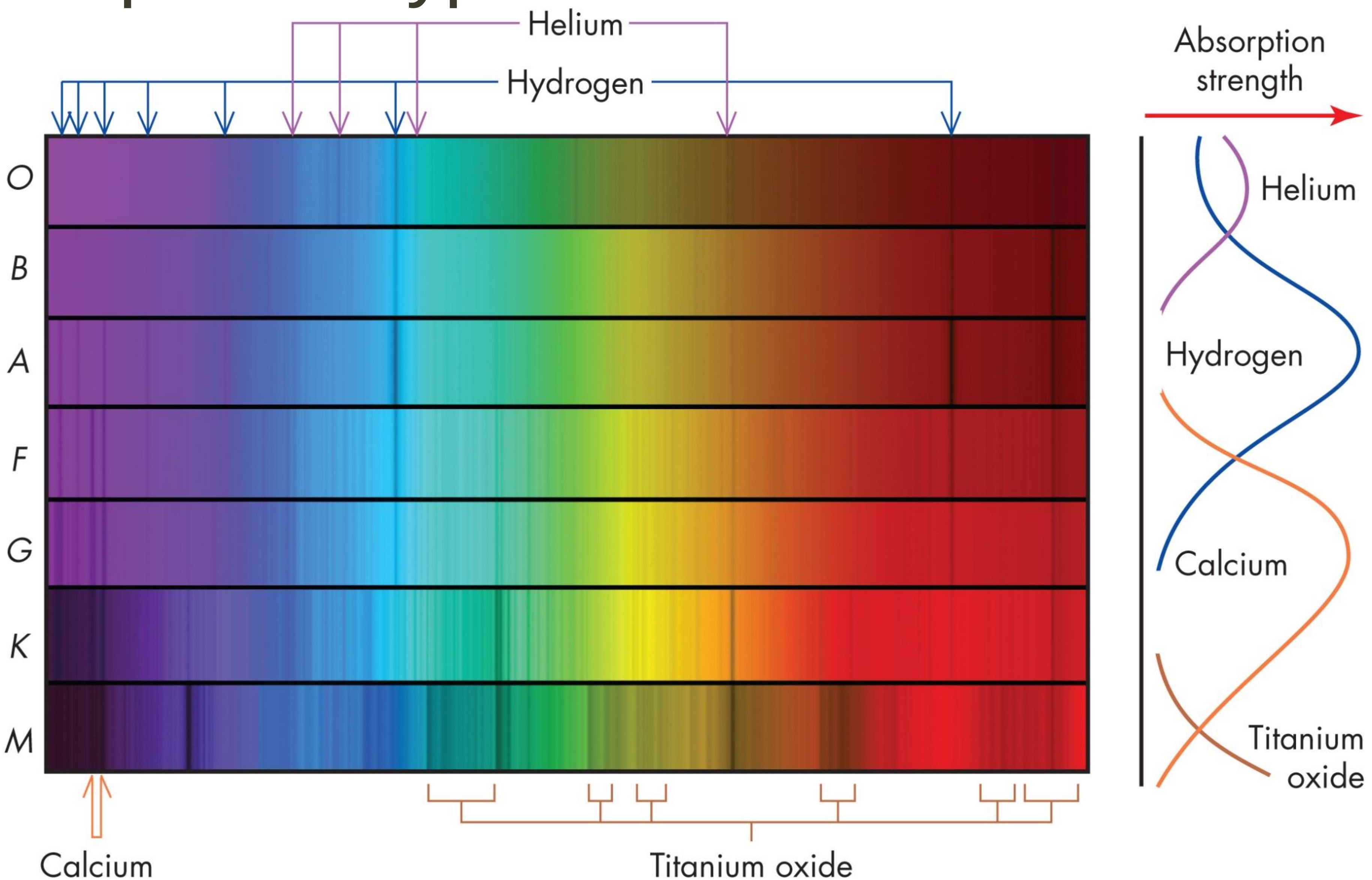
Courtesy of Harvard College Observatory

STELLAR TEMPERATURES, *continued*

Types L, T, and Y were later added to the Spectral Classifications after even cooler stars were discovered



Spectral Types

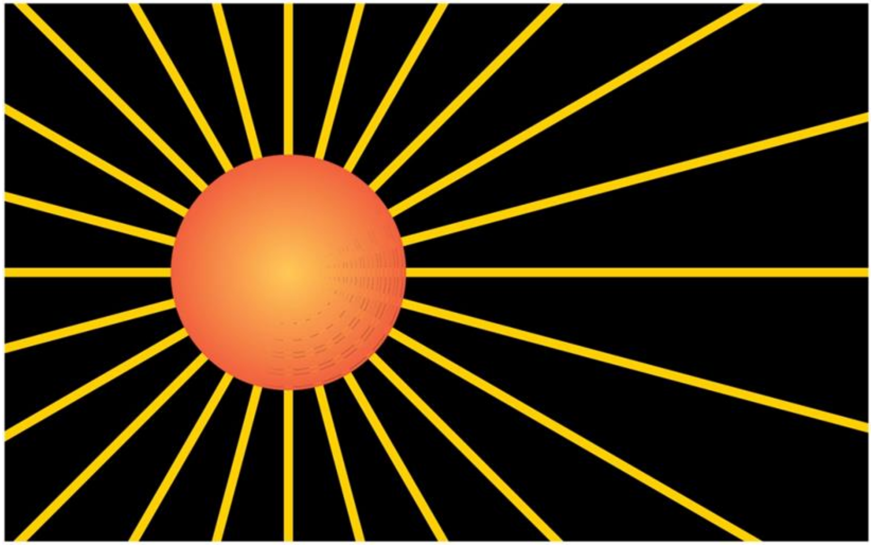


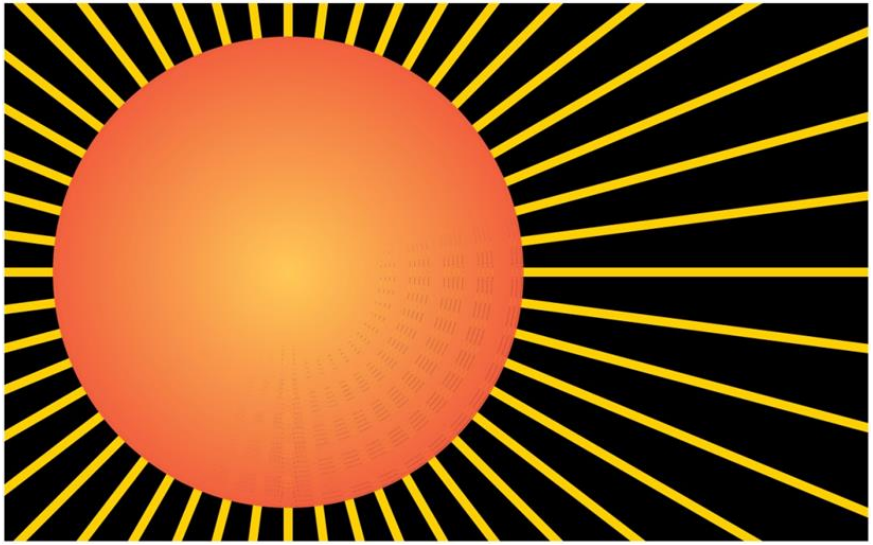
Spectral Types

Table 13.3 Summary of Spectral Types

Spectral Type	Temperature Range (K)	Features	Representative Star
O	Hotter than 30,000	Ionized helium, weak hydrogen	
B	10,000–30,000	Neutral helium, hydrogen stronger	Rigel
A	7500–10,000	Hydrogen very strong	Sirius
F	6000–7500	Hydrogen weaker, metals (especially ionized Ca) moderate	Canopus
G	5000–6000	Ionized Ca strong, hydrogen even weaker	The Sun
K	3500–5000	Metals strong, CH and CN molecules appearing	Aldebaran
M	2000–3500	Molecules strong, especially TiO and water	Betelgeuse
L	1300–2000	Metal hydrides, water, and reactive metals strong, but no TiO	
T	700–1300	Strong lines of water and methane	
Y	<700	Absorption line at 1.55 μm, possibly of ammonia	

Properties of Stars





RADIUS

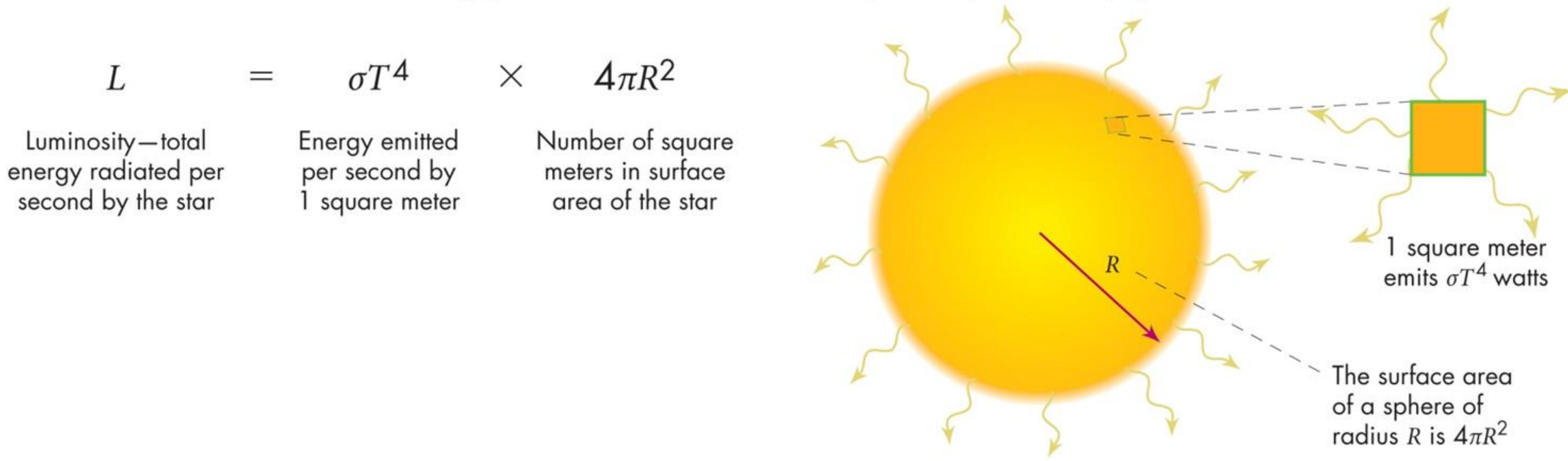
If two stars have the same temperature, but one is more luminous than the other, the more luminous star must have a larger surface area, and therefore a larger radius than the dimmer star.

Properties of Stars

RADIUS

Stefan-Boltzmann law:

A star's luminosity depends on its radius and temperature.



Properties of Stars

RADIUS , continued

Telescopes can be used to measure the size of stars, but if a star were the size of the Sun and 50 ly away, it would require a telescope 300 meters in diameter!

Solution*: Use two or more telescopes separated by large distances (an interferometer) to measure angular distances of stars.. and radii.*

Properties of Stars

RADIUS, continued

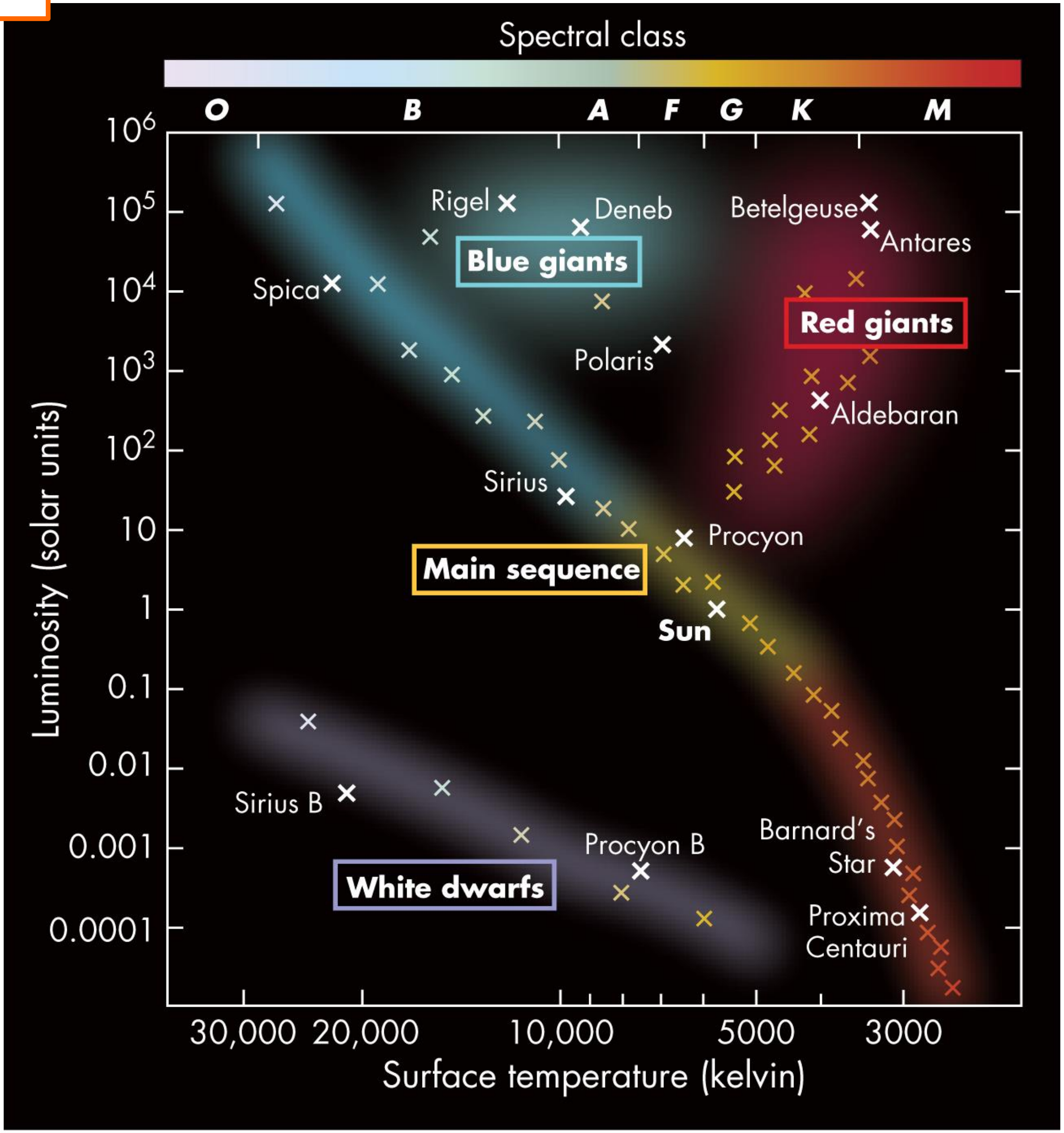
The Stefan Boltzmann law and interferometer observations show that stars differ enormously in radius.

- Some, like Betelgeuse, are hundreds of times larger than the sun and are called **giants**.
- Smaller stars (including our Sun) are called **dwarfs**.

The H-R Diagram

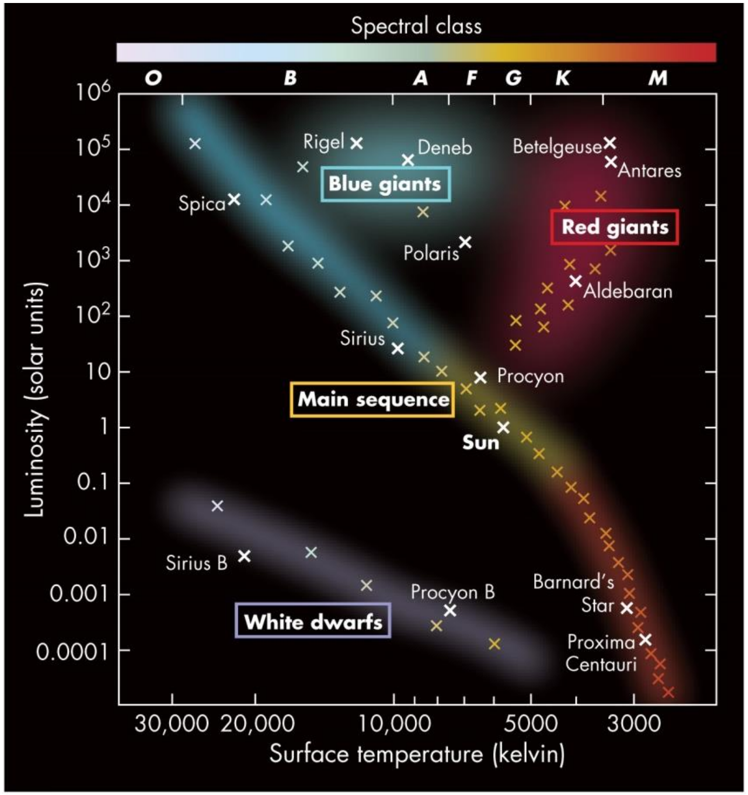
- There are many varieties of stars, but what creates the variety and what does it mean?
- The Hertzsprung Russell diagram shows the relationship between stellar properties.
  - *In 1912, astronomers Ejnar Hertzsprung and Henry Norris Russel independently found that if stars are plotted according to their luminosity and their temperature(or spectral type), most fall in a few specific areas of the diagram.*

H-R Diagram



Spectral class
O
B
A
F
G
K
M
Luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
0.01
0.001
0.0001
Rigel
Deneb
Betelgeuse
Antares
Blue giants
Spica
Red giants
Polaris
Aldebaran
Sirius
Procyon
Main sequence
Sun
Sirius B
Procyon B
Barnard's Star
White dwarfs
Proxima Centauri
30,000
20,000
10,000
5000
3000
Surface temperature (kelvin)

H-R Diagram

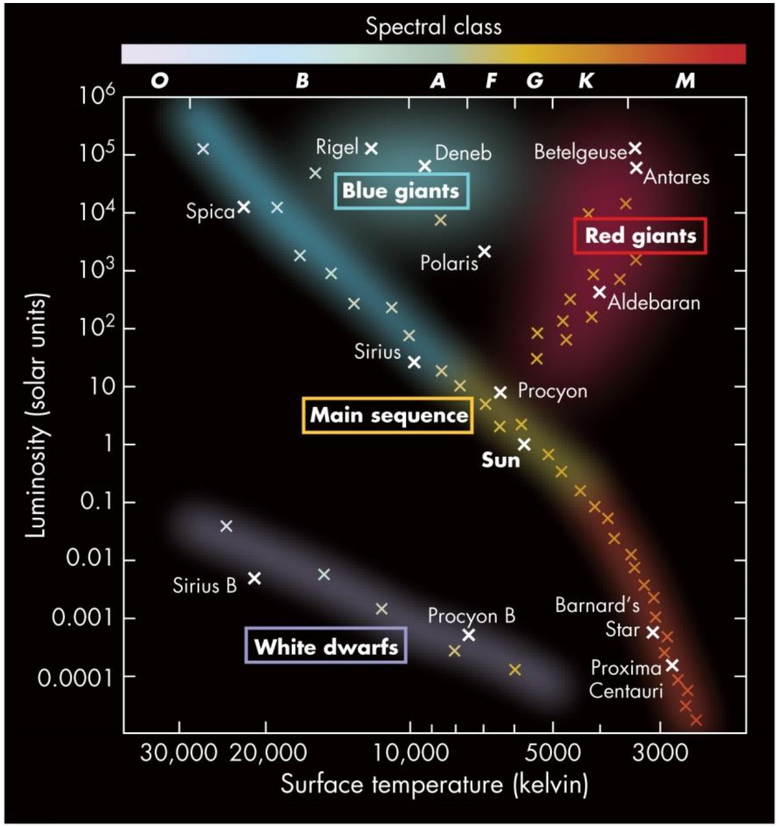


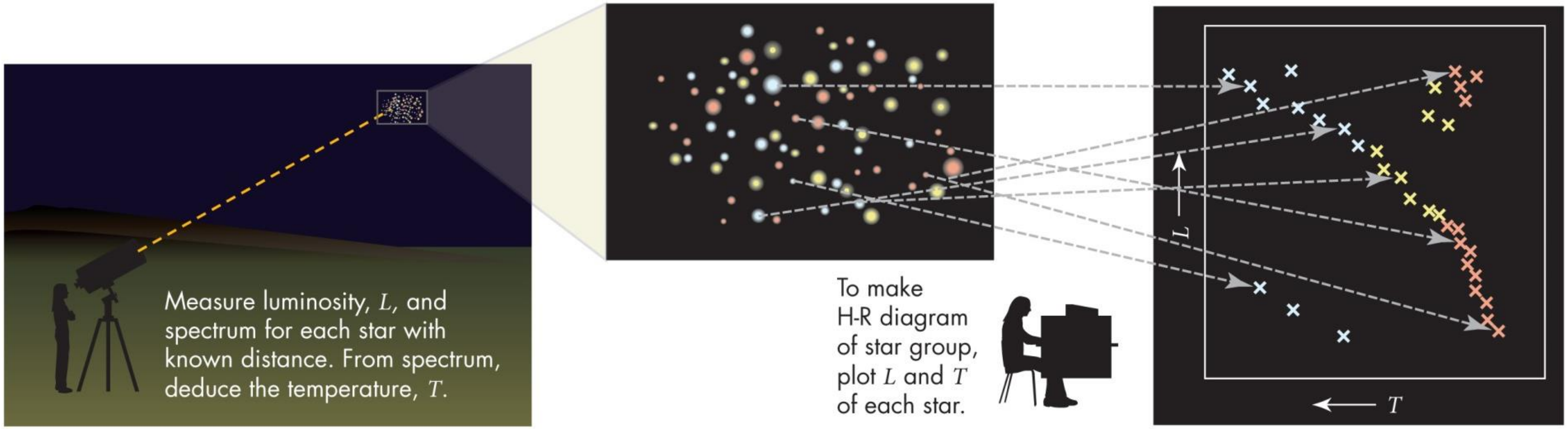
Video: HR Diagram Animation

H-R Diagram

Main Sequence- the approximately straight line on the HR diagram along which the majority of stars lie.

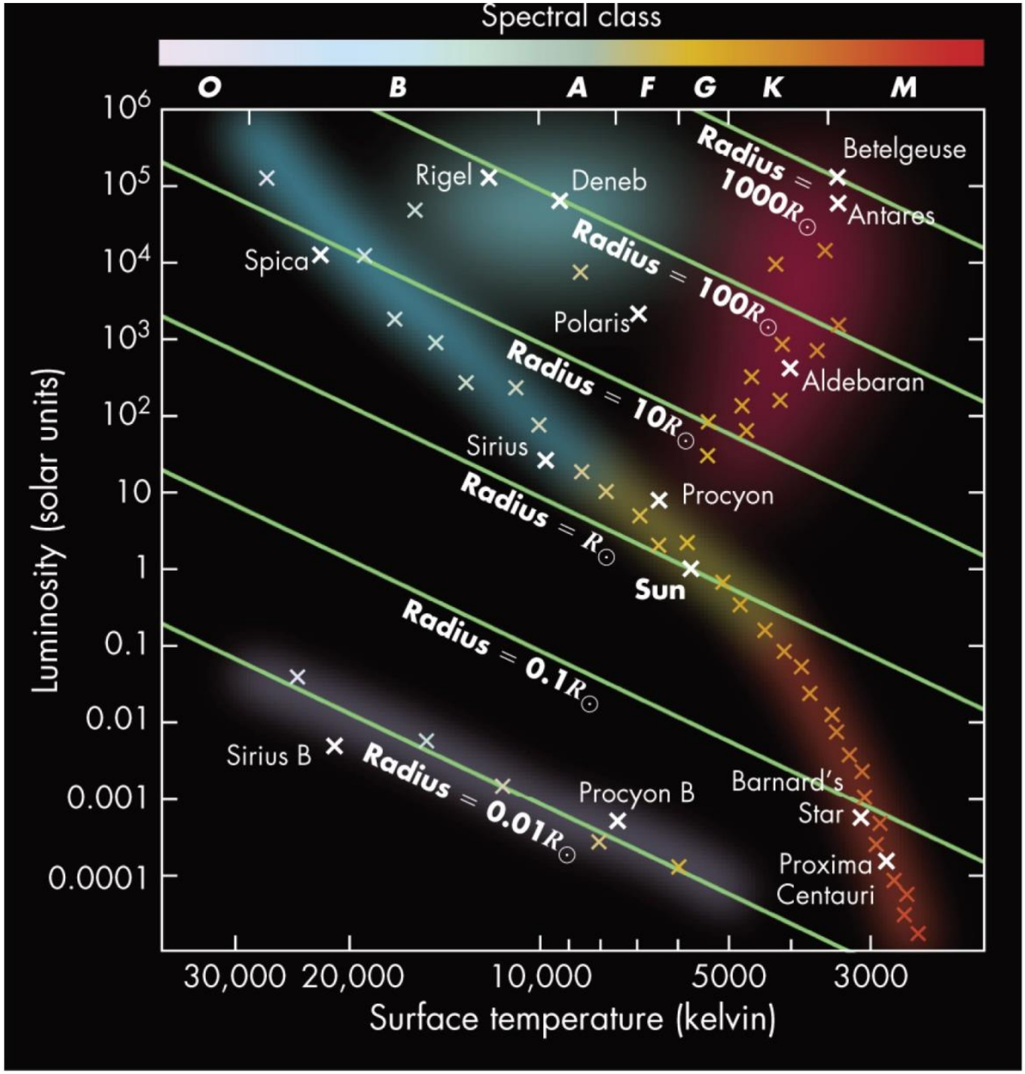
Note: Our Sun is a main sequence star





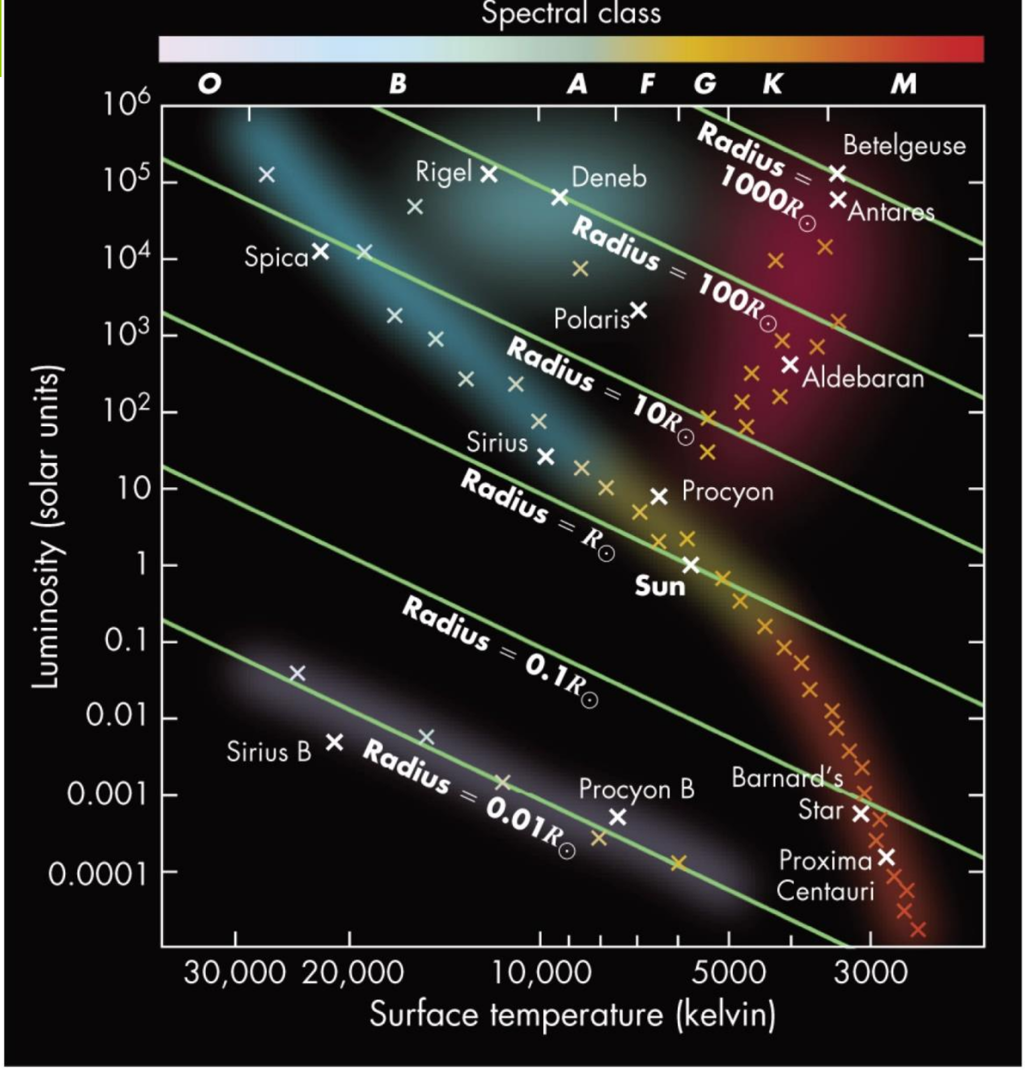
H-R Diagram

Stellar Radii depends on luminosity and surface temperature, so it can be determined with the HR Diagram.



Patterns in the H-R Diagram

- **Main sequence-** 90% of stars fall within this prominent streak
- **Supergiants-** upper right (large and bright)
- **Giants**- larger and brighter than main sequence, but smaller and dimmer than supergiants.
- **White Dwar**fs- near lower left; appear white in color because of high temperature

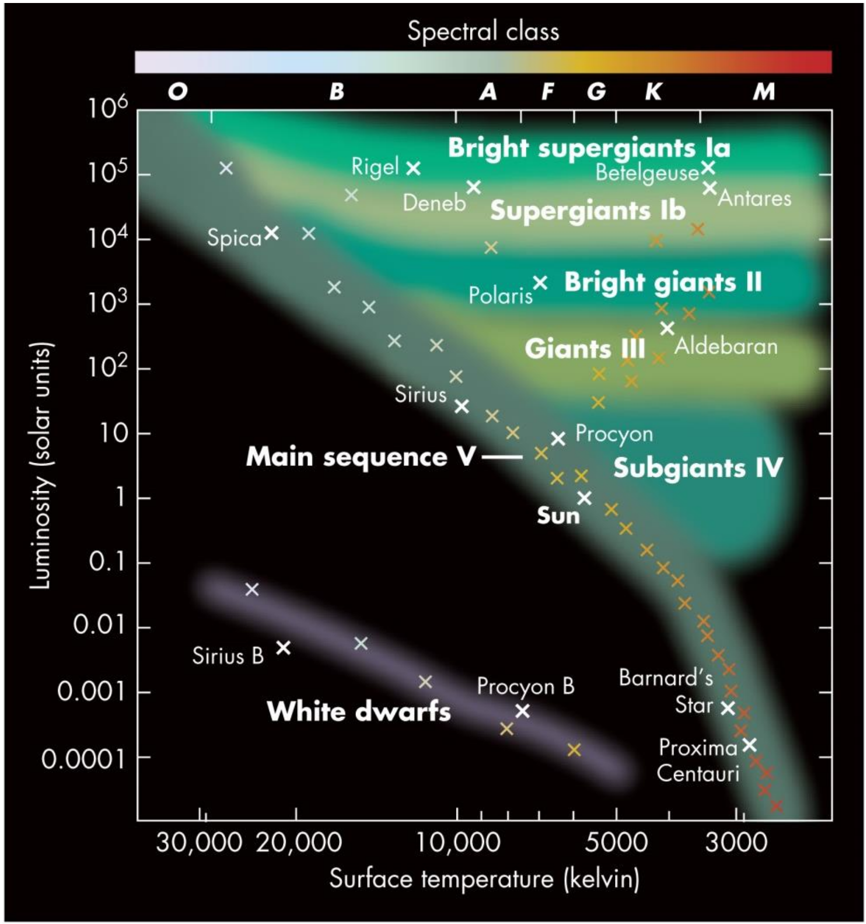


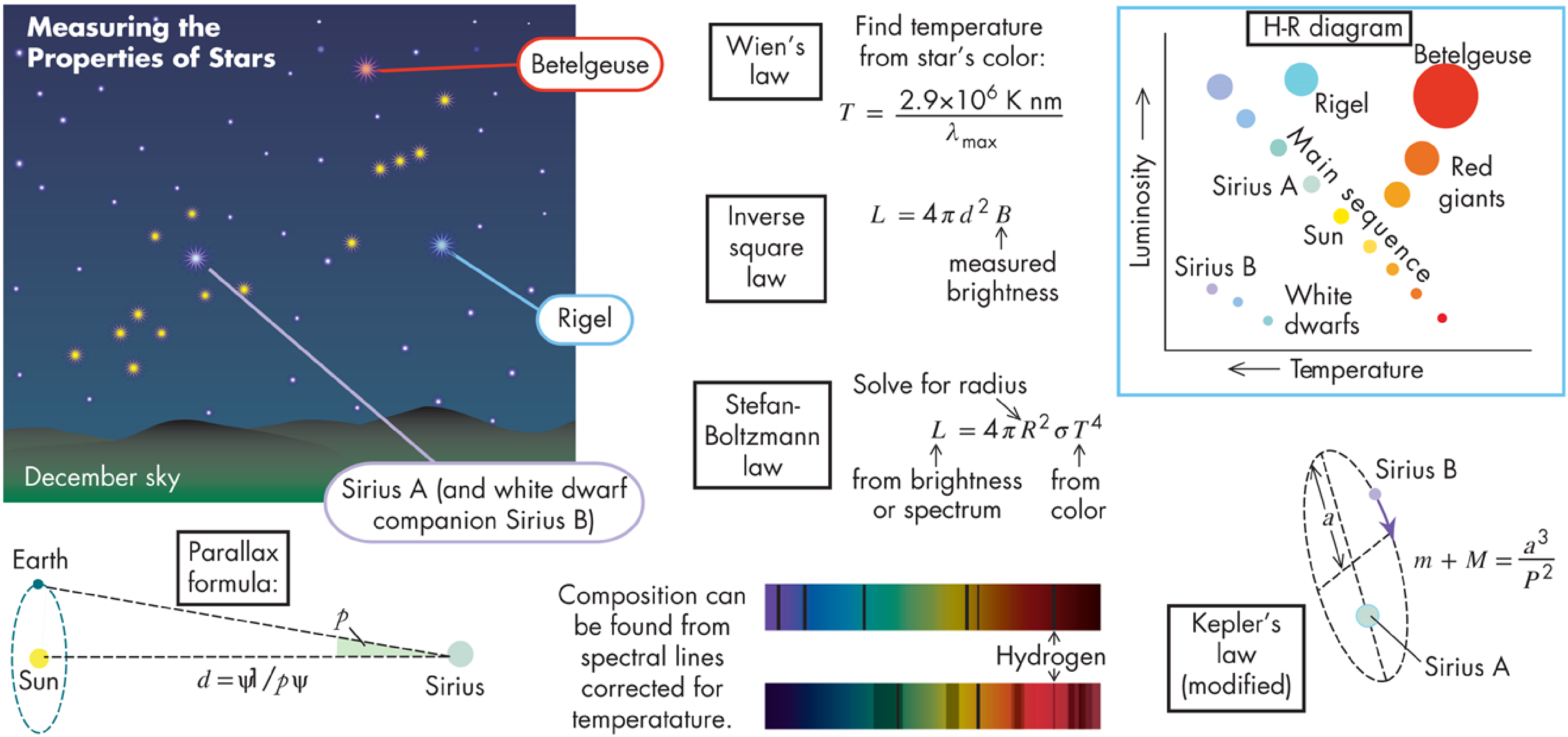
Patterns in the H-R Diagram

Luminosity Classes: I – IV; added to spectral type to give a more complete description of a star's light.

Example: our Sun is a G2V while Rigel is a B8Ia

Class	Description
Ia	Bright Supergiants
Ib	Supergiants
II	Bright Giants
III	Ordinary Giants
IV	Subgiants
V	Main Sequence




Measuring the Properties of Stars
Betelgeuse
Rigel
December sky
Sirius A (and white dwarf companion Sirius B)
Wien's law
Find temperature from star's color:
$T = \frac{2.9\times10^6 \text{ K nm}}{\lambda_{max}}$
Inverse square law
$L = 4\pi d^2 B$
measured brightness
Stefan-Boltzmann law
Solve for radius
$L = 4\pi R^2 \sigma T^4$
from brightness or spectrum
from color
H-R diagram
Luminosity
Temperature
Betelgeuse
Rigel
Main sequence
Red giants
Sirius A
Sun
Sirius B
White dwarfs
Earth
Sun
Parallax formula:
p
d =ψ1 /pψ
Sirius
Composition can be found from spectral lines corrected for temperatature.
Hydrogen
Kepler's law (modified)
Sirius B
a
$m + M = \frac{a^3}{P^2}$
Sirius A

Stellar Lifecycle

- The existence of main sequence stars, red giants, and white dwarfs suggests to astronomers a picture of how stars age.
- **Stellar Evolution-** a star's lifecycle from "birth" to "death".
  - **Driven by gravity-** what begins as a gentle tug grows into a crushing force that heats up a stars interior.
  - Energy from fusion constantly replaces the energy the heat that flows out of a star, establishing a balance with gravity as long as nuclear fuel lasts.
  - *A star dies when its fuel is exhausted*

Stellar Lifecycle

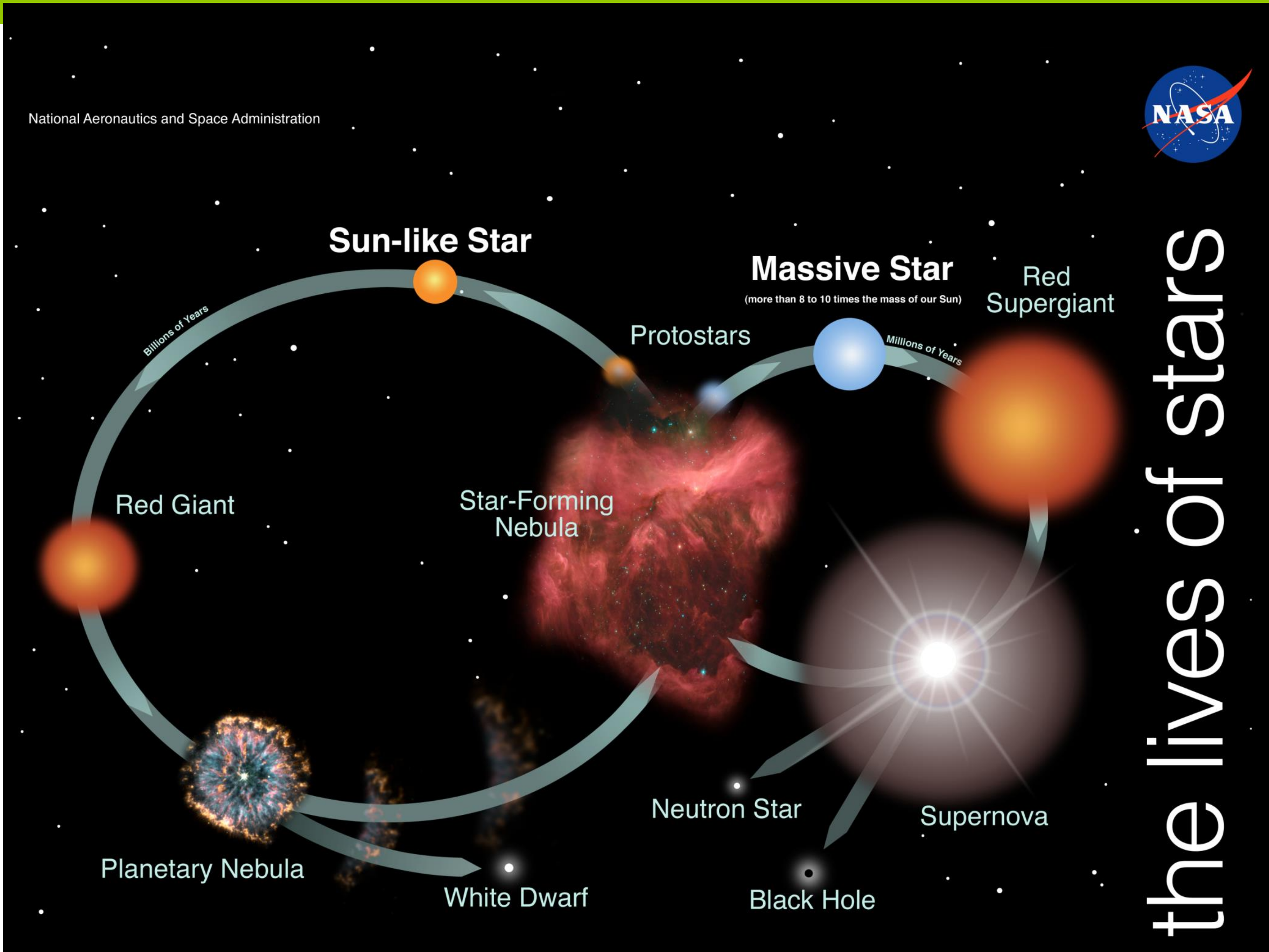
- All stars form when gravity causes a molecular cloud to contract until the center becomes hot enough for nuclear fusion to occur.
  - ***Gravitational Equilibrium-*** *outward pressure of gas is balanced by the inward force of gravity.*
- *When the hydrogen is used up, their structure changes because gravity is no longer counterbalanced.*
- ***A star's life story depends on its mass*** *(how much material it contains).*
  - *Mass determines how strong gravity is and also how much fuel it has.*

Stellar Lifecycle

2 Groups:

1. ***Low Mass Stars****- follow same lifecycle as the Sun*

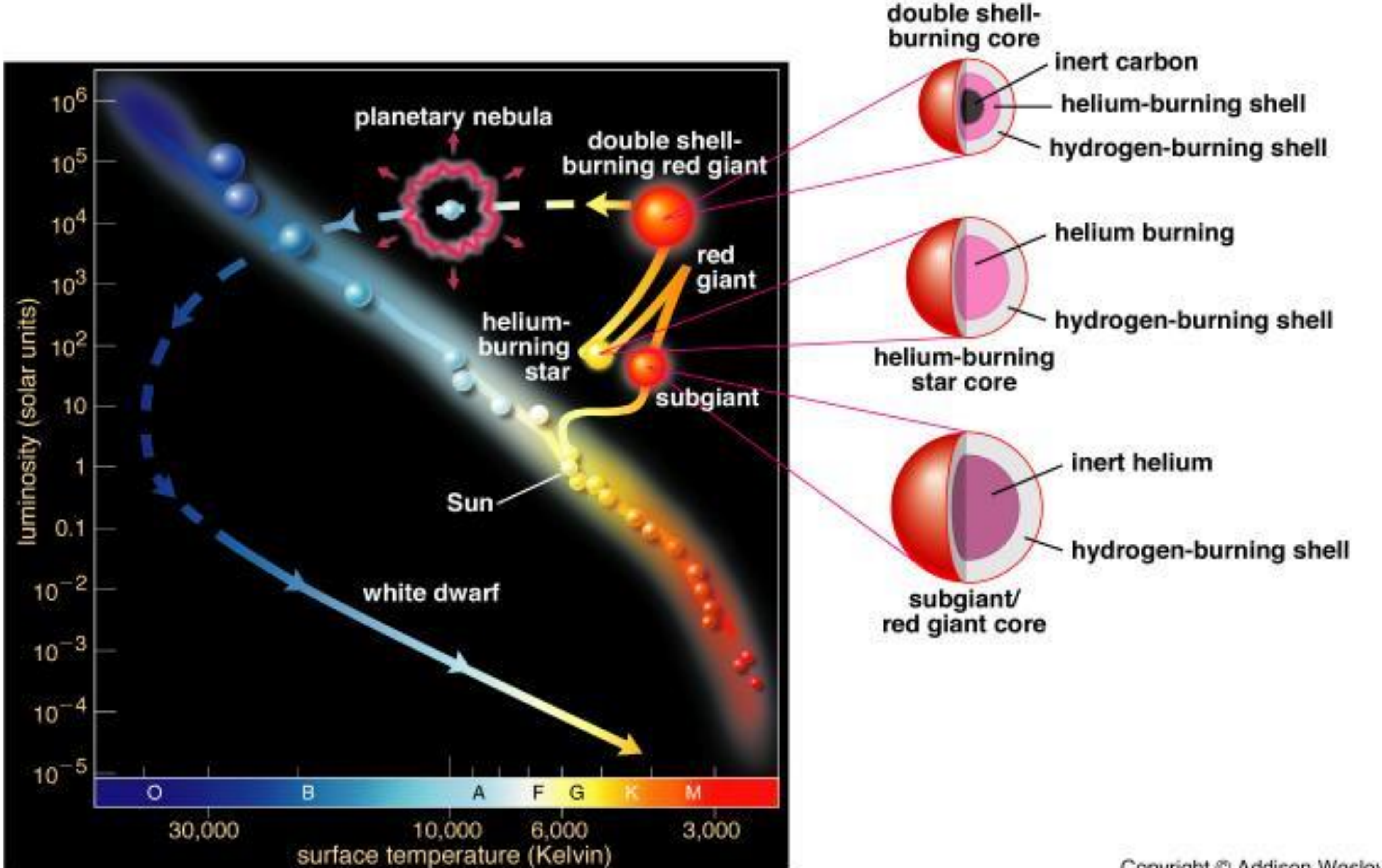
2. ***High Mass Stars****- powerful gravitational pull causes cataclysmic collapse after exhausting all their fuel.*


National Aeronautics and Space Administration
NASA
the lives of stars
Sun-like Star
Billions of Years
Red Giant
Planetary Nebula
White Dwarf
Star-Forming Nebula
Protostars
Massive Star
(more than 8 to 10 times the mass of our Sun)
Millions of Years
Red Supergiant
Supernova
Neutron Star
Black Hole

Lifecycle of Low Mass Stars

1. Interstellar Cloud- cold, dark mass of gas
2. Hydrogen → Helium fusion begins in core
   - If plotted, stars in this phase are Main Sequence stars.
3. After consuming about 90% of hydrogen in the core, the core will shrink, become hotter, and generate energy faster
4. Outward flowing energy will cause expansion and cooler outer layers. **(Red Giant)**
5. Even hotter core fuses helium **(Yellow Giant).**
6. When helium is used up, it will grow into a larger red giant **(planetary nebula**) and outer layers will be driven into space.
7. **White Dwarf-** tiny core but HOT!

Lifecycle of Low Mass Stars



Lifecycle of High Mass Stars

High mass stars have a mass that is 8 times greater than the Sun.

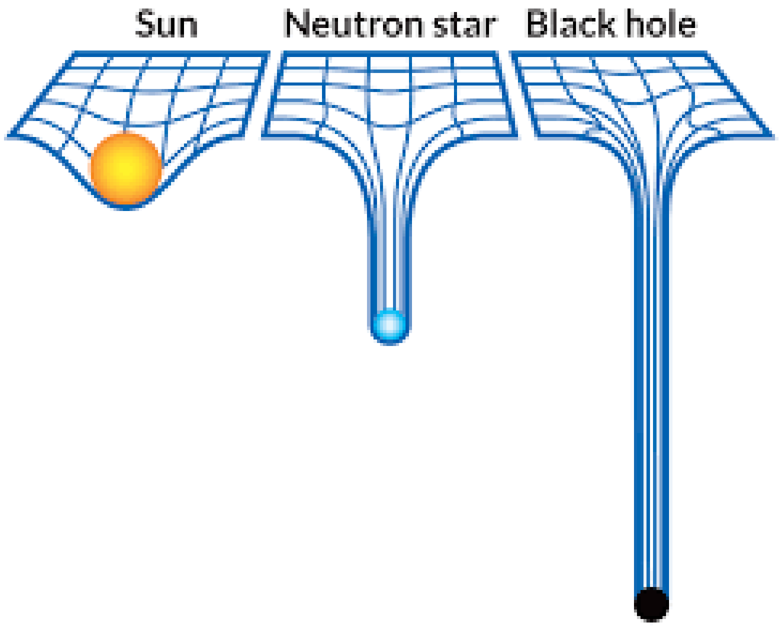
- **Early life is similar to a low mass star** (originates from the collapse of an interstellar cloud, but its greater mass causes it to have higher temperatures)
- **High mass stars burn fuel faster and therefore have shorter life-spans.**

Lifecycle of High Mass Stars

1. Early life like low mass star
2. As a main sequence star, high mass stars are much hotter, bluer, and more luminous than low mass stars.
3. When hydrogen is exhausted, the star swells and grows cooler, becoming a **Pulsating Yellow Giant.**
4. Intense gravitational compression of core causes temperature to rise and fuel to be burned more furiously.
5. Higher temperature permits star to fuse progressively heavier elements (H→ He→ C→ O→ Si→ Fe**)**
   - *Iron does not release energy when it is fused*
6. **Supernova** *(Cataclysmic explosion)*- heavy elements flow into space when core collapses under the intense gravity
7. **Neutron Star** (ball of neutrons) or **Black Hole**

Black Holes

When a star that was initially more massive than about 20 Solar Masses reaches the end of its life and collapses, it creates a core so compact that no radiation (light) can escape.



Additional Resources

- Crash Course: Low Mass Stars
  - https://www.youtube.com/watch?v=jfvMtCHv1q4
- Crash Course: High Mass Stars
  - https://www.youtube.com/watch?v=PWx9DurgPn8
- Crash Course: Black Holes
  - https://www.youtube.com/watch?v=qZWPBKULkdQ