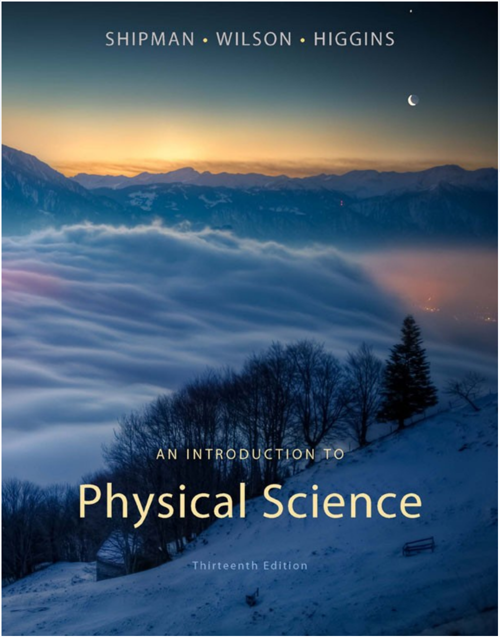

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CENGAGE Learning™

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Chapter 18

The Universe

Read sections 18.1 through 18.5.

The Universe

- When we use the term universe we are discussing the totality of all matter, energy, and space.
- In this chapter we will examine the stars, galaxies, and cosmology.
  - In particular we will discuss our sun and the classification of the stars.
  - Galaxies are giant assemblages of stars.
  - Cosmology deals with the structure and evolution of the universe.

Audio Link

Studying the Universe

- Stars and galaxies emit the full spectrum of electromagnetic radiation.
- For many years we were only able to gather information from one type of emitted electromagnetic radiation – visible light.
- In 1931 radio telescopes became operational, giving scientists the ability to start gathering information from other wavelengths.

Studying the Universe

- Unfortunately for the astronomers, the Earth’s protective atmosphere also absorbed much of the incoming radiation from the non-visible wavelengths.
- Scientists were soon devising ways to minimize or eliminate the Earth’s atmospheric filtering.
- Observatories were located on high mountains where the atmosphere is thin .
- Balloons, aircraft, satellites, and spacecraft were utilized to transport instruments to ever greater heights.

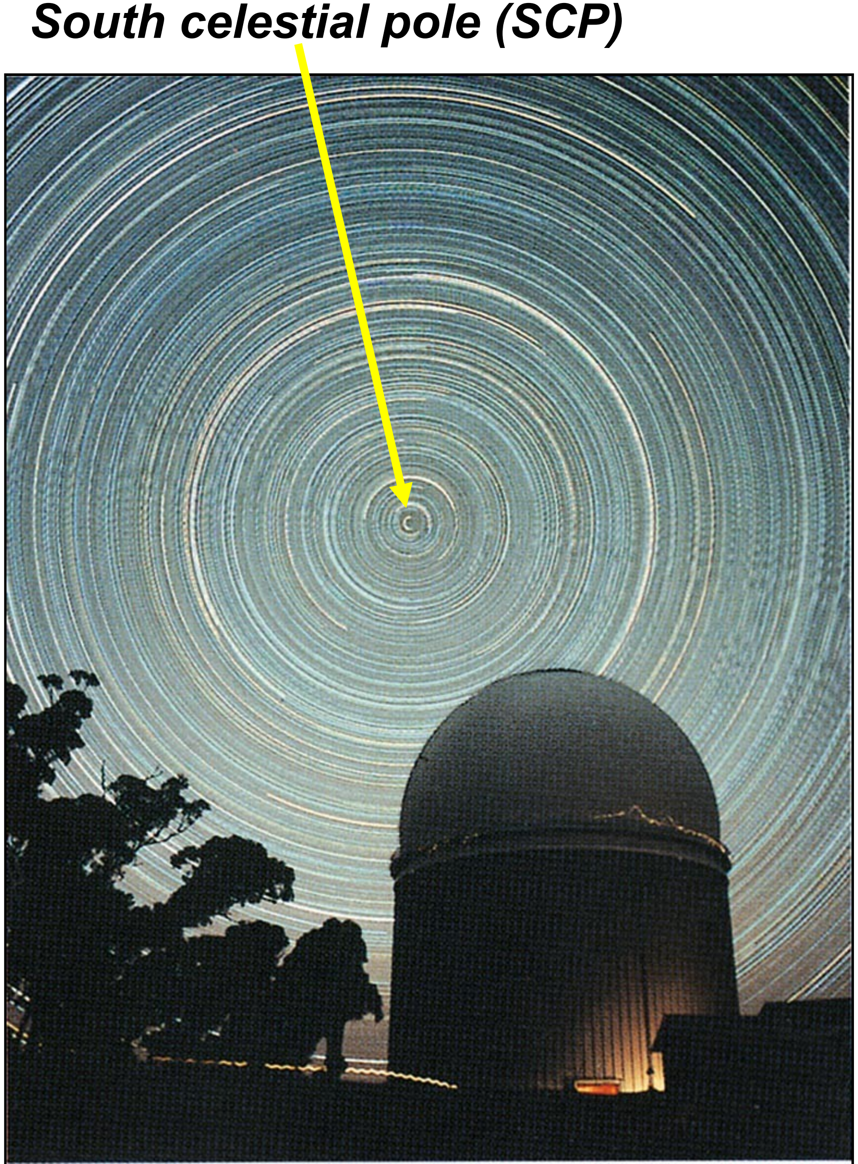
??Astronomy – Astrology??

- Astronomy is the scientific study of the universe beyond the atmosphere of Earth.
  - Astronomers largely study the electromagnetic radiation emitted by celestial bodies that eventually reaches their instruments.
- Astrology is the ‘study’ of how the position of planets/stars at the time of one’s birth may affect an individual’s personality and/or future.
  - Although many people closely follow their astrological chart, there is no known scientific basis for a cause/effect relationship.

The Celestial Sphere

- Celestial sphere – the huge imaginary sphere of the sky on which all the stars seem to appear
- During any given night, the great dome of stars appear to progressively move westward, from an observer’s vantage point on Earth.
- North celestial pole (NCP) – the point in the Northern Hemisphere that the stars seem to rotate around
  - Polaris or the “North Star”
- South celestial pole (SCP) – the point in the Southern Hemisphere that the stars seem to rotate around

Star Trails

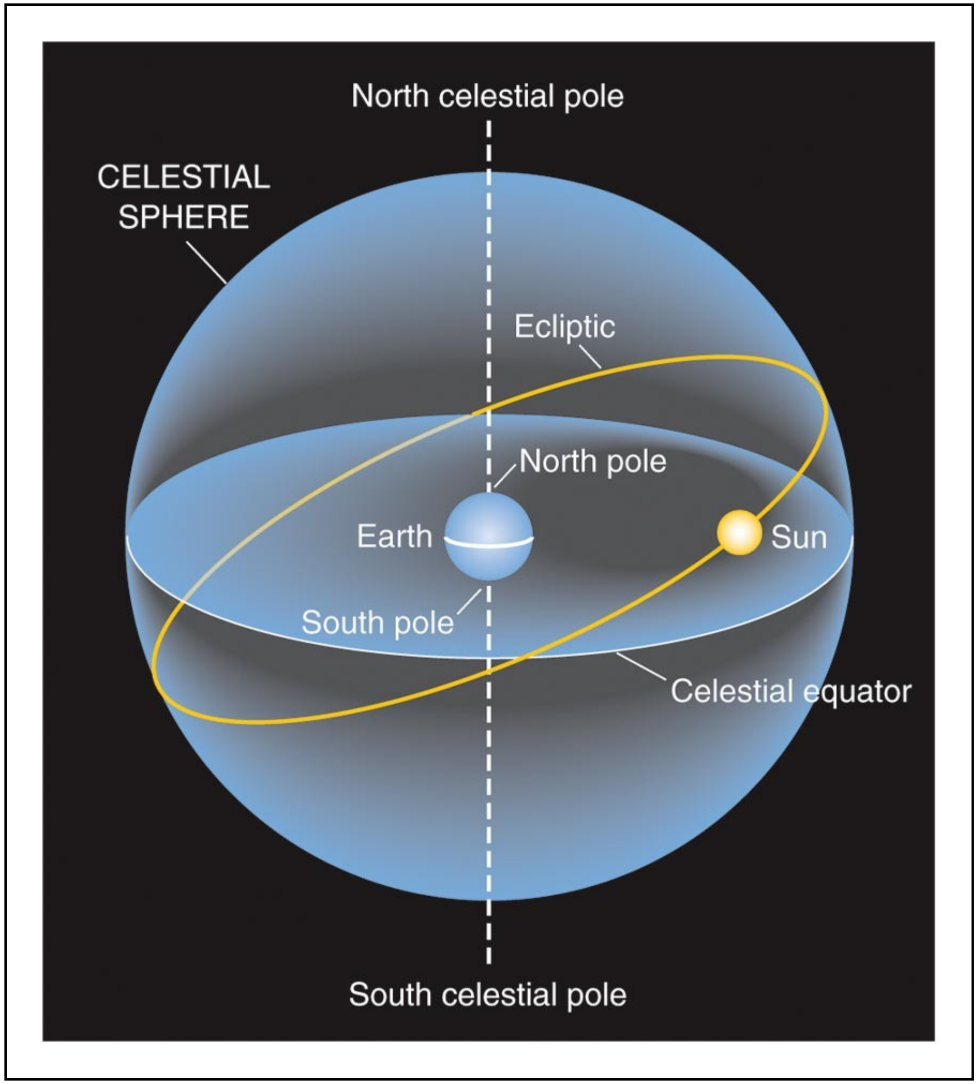


- The stars' apparent movement is due to the Earth's actual west-to-east rotation.
- The NCP & SCP are simply extensions of the Earth's rotational axes.

The Celestial Sphere

- Key planes and points on the celestial sphere include the ecliptic, the celestial equator, the north celestial pole, and the south celestial pole.
- Celestial equator – the extension of the Earth’s equator
- Ecliptic – the apparent annual path of the Sun on the celestial sphere
    - Due to the Earth’s orbit around the Sun, NOT because of the Sun’s movement

Celestial Sphere

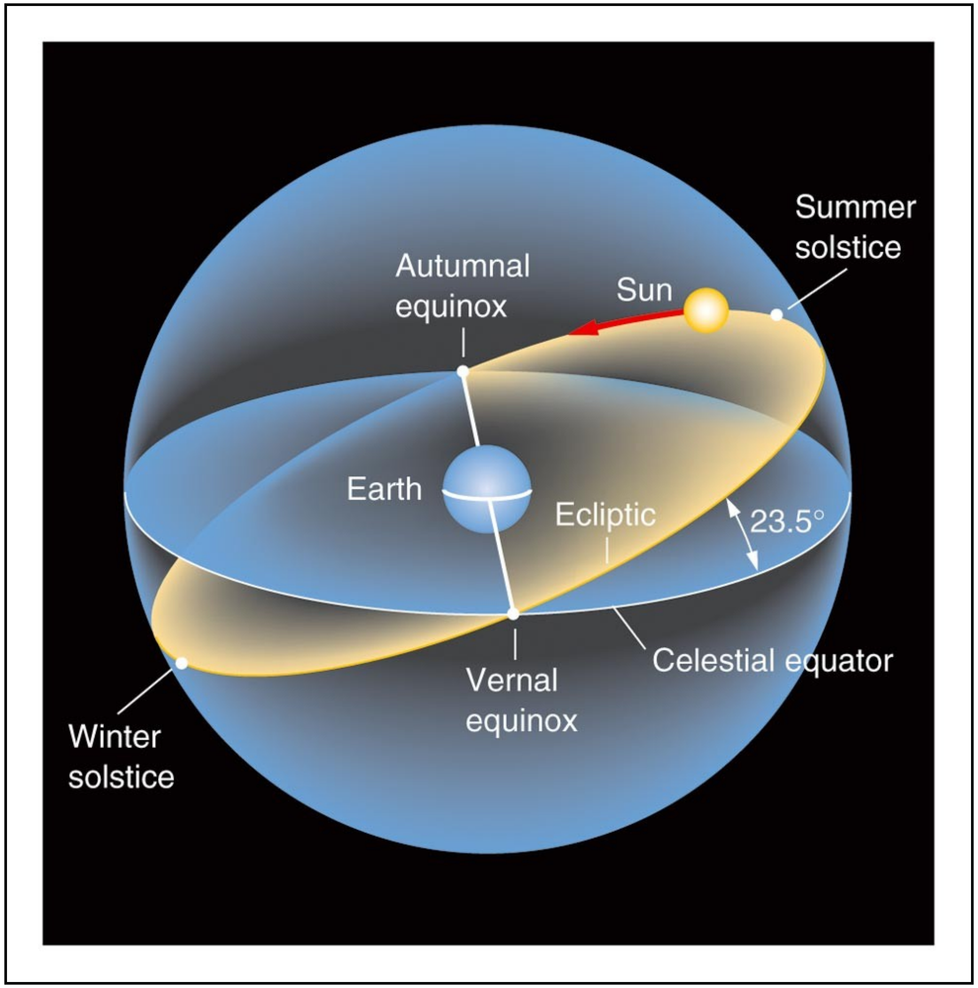


- Because of the 23.5^0 tilt of the Earth's rotational axis, the ecliptic & celestial equator are inclined to one another these two planes intersect at only two points.

Equinoxes

- The two points at which the ecliptic and the celestial equator intersect are called the equinoxes.
- As the Sun appears to be moving southward on the ecliptic, it intersects the celestial equator around September 23, at a point called the autumnal equinox.
- About 6 months later, as the Sun appears to be moving northward on the ecliptic, it intersects the celestial equator around March 21, at a point called the vernal equinox.

Celestial Sphere



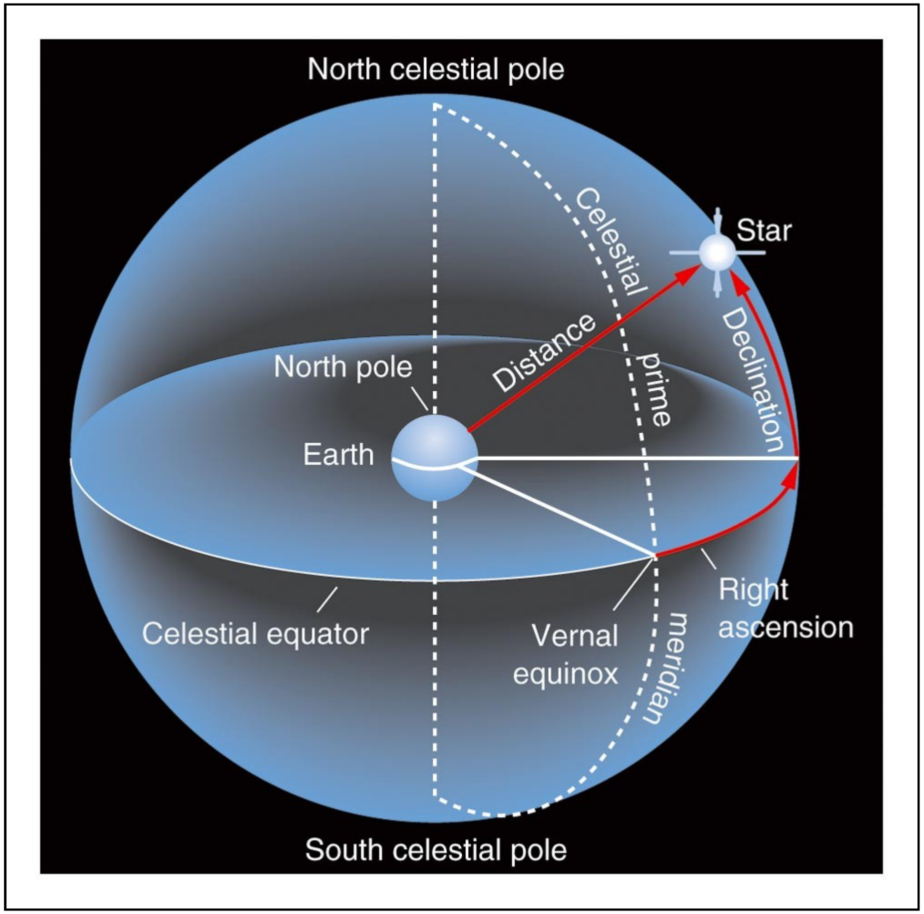
- On these two days the Sun is directly over the equator and every location on earth receives an equal amount of daylight and darkness (12 hours.)

Solstices

- The two solstices also mark significant points on the solar ecliptic.
- Summer solstice - the point along the ecliptic where the Sun’s location is the farthest south
- The winter solstice is the point along the ecliptic where the Sun’s location is the farthest north.

Celestial Prime Meridian

- <u>Celestial prime meridian</u> – the half-circle created by the intersection of the NCP, the vernal equinox, and the SCP
- The celestial prime meridian is therefore a reference line or starting line used to measure celestial longitude.

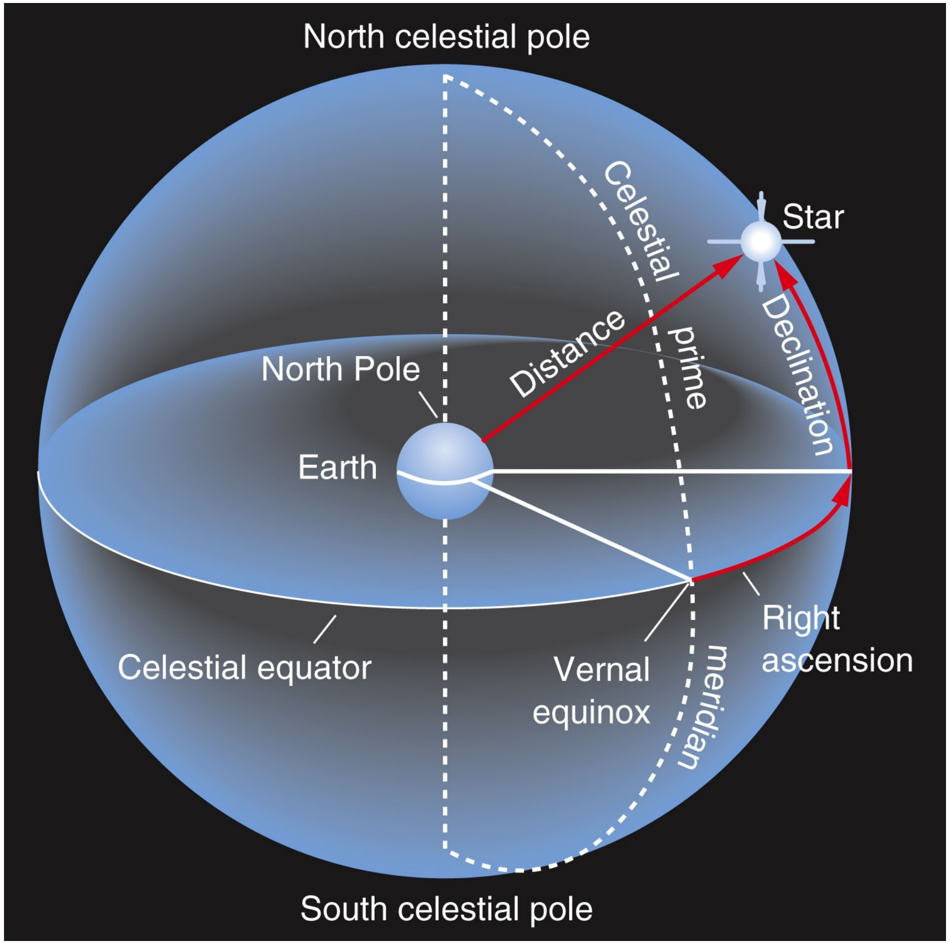


Celestial Longitude & Latitude

- The measure of celestial longitude is called the right ascension (RA) of the star or galaxy.
- The RA is the position of the star/galaxy to the east of the celestial prime meridian.
  - Measured in “hours,” with the full circle having a total of 24 hours
- The declination (DEC) of a star or galaxy is an angular measurement (degrees) north or south of the celestial equator.

Celestial Longitude (RA) and Latitude (DEC)

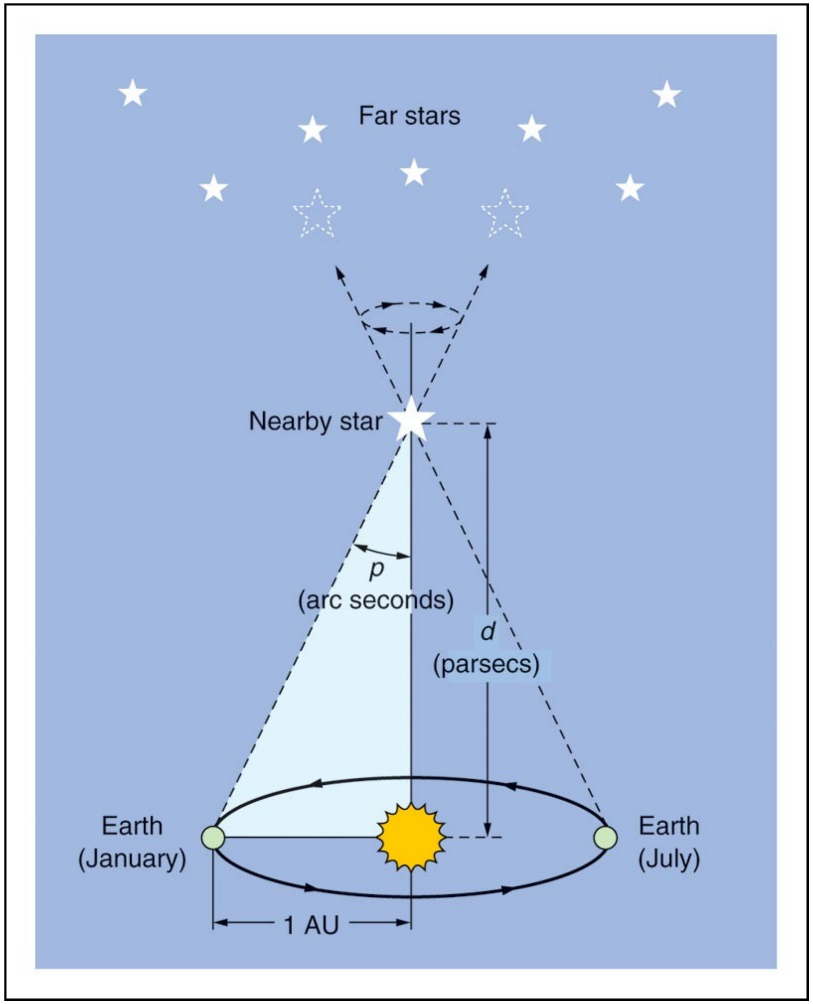
- Maximum RA is 24 hours and maximum DEC would be either $+90^0$ or -90^0



Celestial Distance

- The distance to most celestial bodies is measured in astronomical units (AU), light-years, or parsecs.
- Astronomical unit (AU) – the mean distance between the Earth and the Sun (1.5×10^{8} km)
- Light-year (ly) – the distance light travels through a vacuum in one year (9.5×10^{12} km)
- Parsec (pc) – distance to a star when the star exhibits a parallax of 1 second of arc. 1 pc = 3.26 ly

Annual Parsec of a Nearby Star



- As a viewer's position on Earth changes throughout the year, the position of a nearby star appears to shift, relative to more distant stars.
- This apparent annual motion of the star is called parallax.
- The closer the star, the greater the shift.

Calculating the Distance (in Parsecs) to a Star - *An Example*

- Calculate the distance (in parsecs) to Proxima Centauri, the nearest star to the Earth. The annual parallax of the star is 0.762 arc seconds.
- Solution – use equation d = 1/p
- **d** = 1/0.762 = **1.31 pc**

Calculating the Distance (in Parsecs) to a Star - Confidence Exercise

- Calculate the distance (in parsecs) to Sirius, the brightest star in the night sky. The annual parallax of the star is 0.376 arc seconds.
- Solution – use equation d = 1/p
- **d** = 1/0.376 = **2.66 pc**

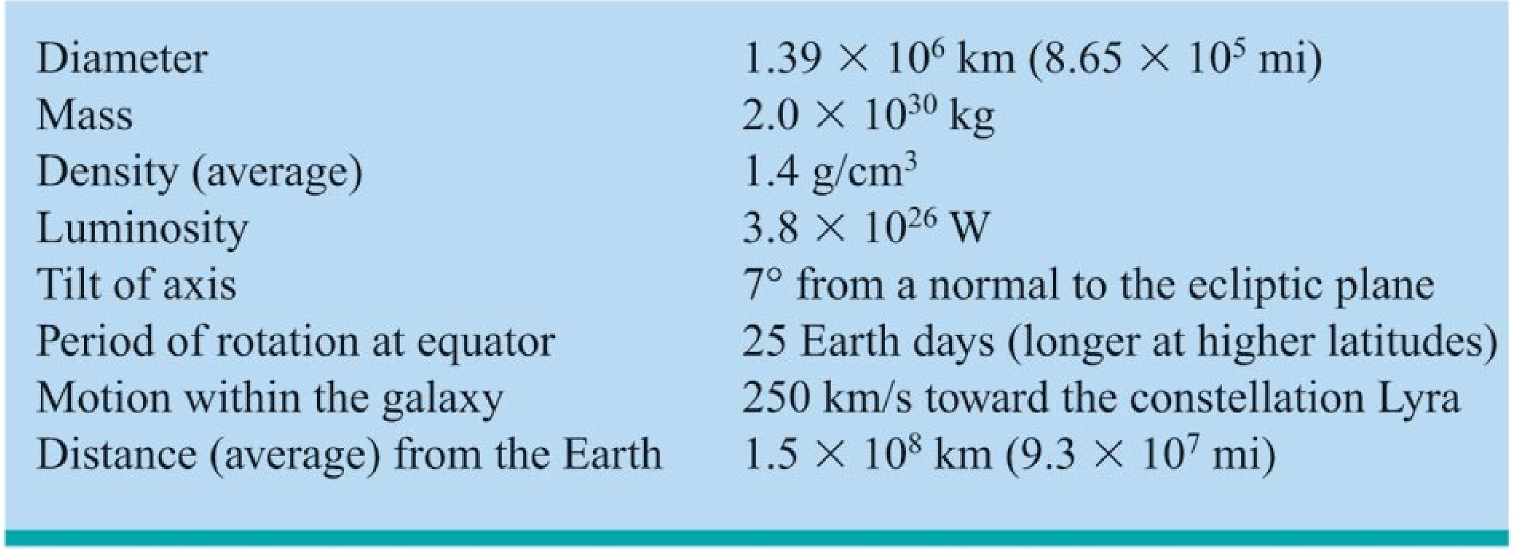
Observing Parallax

- Parallax cannot be detected with the unaided eye.
- Friedrich Bessel, a German astronomer, was the first to observe stellar parallax in 1838.
- Even for the very closest stars, parallax is very small.
  - The parallax angle for the closest stars is the width of a dime at a distance of 6 km!
- Only stars within about 300 ly can have their distance determined by parallax measurements.

The Sun: Our Closest Star

- A star is a self-luminous sphere of hot gases, energized by nuclear reaction and held together by the force of gravity.
- The Sun is the nearest star to Earth.
- The Sun is enormous in size relative to the size of Earth.
  - The Sun’s diameter is approximately 100 times the diameter of the Earth.

Basic Information about the Sun



Diameter	1.39×10^6 km (8.65×10^5 mi)
Mass	2.0×10^{30} kg
Density (average)	1.4 g/cm^3
Luminosity	3.8×10^{26} W
Tilt of axis	7° from a normal to the ecliptic plane
Period of rotation at equator	25 Earth days (longer at higher latitudes)
Motion within the galaxy	250 km/s toward the constellation Lyra
Distance (average) from the Earth	1.5×10^8 km (9.3×10^7 mi)

Structure and Composition of the Sun

- The Sun can divided into four concentric layers:
  - The innermost core
  - The “surface” is called the photosphere.
  - The chromosphere is a layer of very hot gases above the photosphere.
  - The corona is the Sun’s outer solar atmosphere.

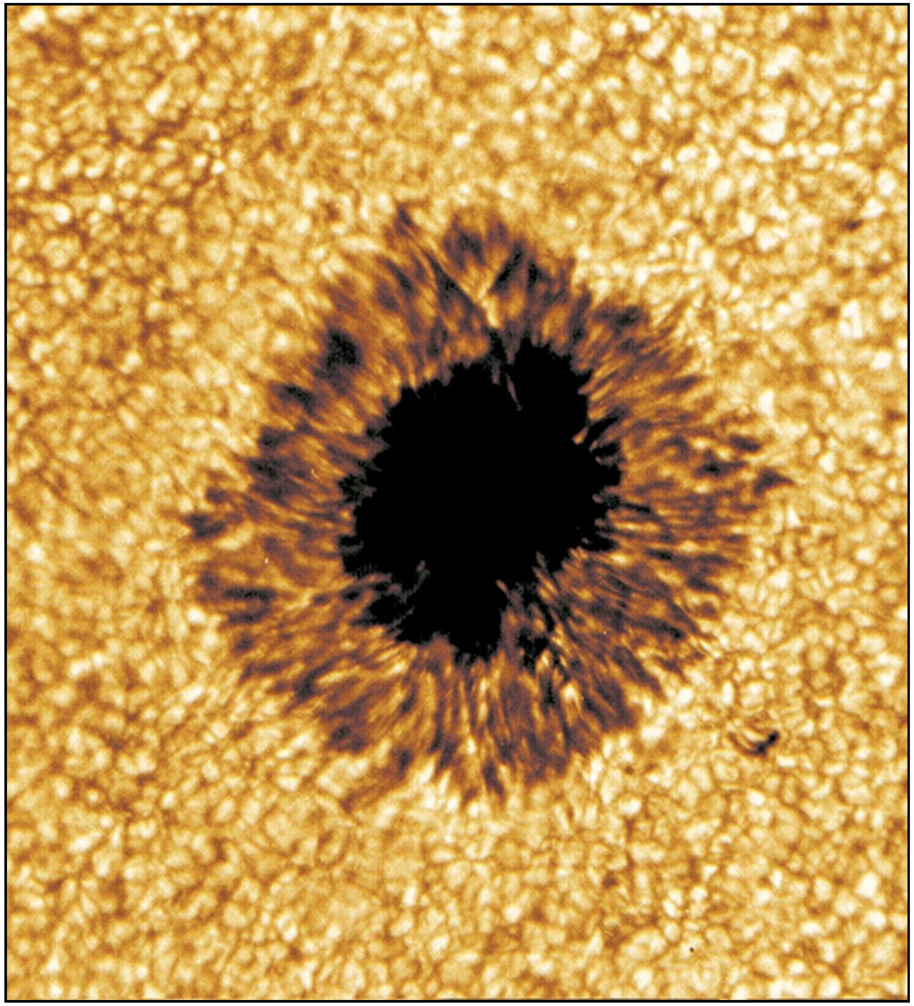
Photosphere

- The photosphere is the bright and visible "surface" of the Sun.
    - Temperature of 6000K
    - Composition of 75% H, 25% He, and 1% C, O, N, Ne, and others
- When viewed close-up, the photosphere surface appears to have a 'granular' texture.
- Each granule is a hot spot caused by an individual convection cell bringing thermal energy to the surface.
    - Each granule is about the width of Texas.

Sunspots

- Sunspots are huge patches of cooler, and therefore darker material on the surface of the Sun.
  - They are a distinctive feature of the photosphere.
- The late 1600’s were an unusually cold period on Earth, marked by an anomalously fewer number of sunspots.
  - In Europe this time was known as the Little Ice Age.
- Apparently, there is a strong connection between solar activity, as displayed by sunspots, and global climates on Earth.

Close-up View of a Sunspot on the Photosphere



Note the granular appearance of the Sun's surface

Sunspot Cycle

- The abundance of sunspots vary through an 11-year sunspot cycle.
- Each sunspot cycle begins with the appearance of a few sunspots near the 30^{0} “N & S” latitudes.
- The number of sunspots slowly increase, with a maximum number in the middle of the cycle at around the 15^{0} region.
- The number of sunspots then slowly taper off during the last half of the 11-year cycle.

Sunspot Cycle

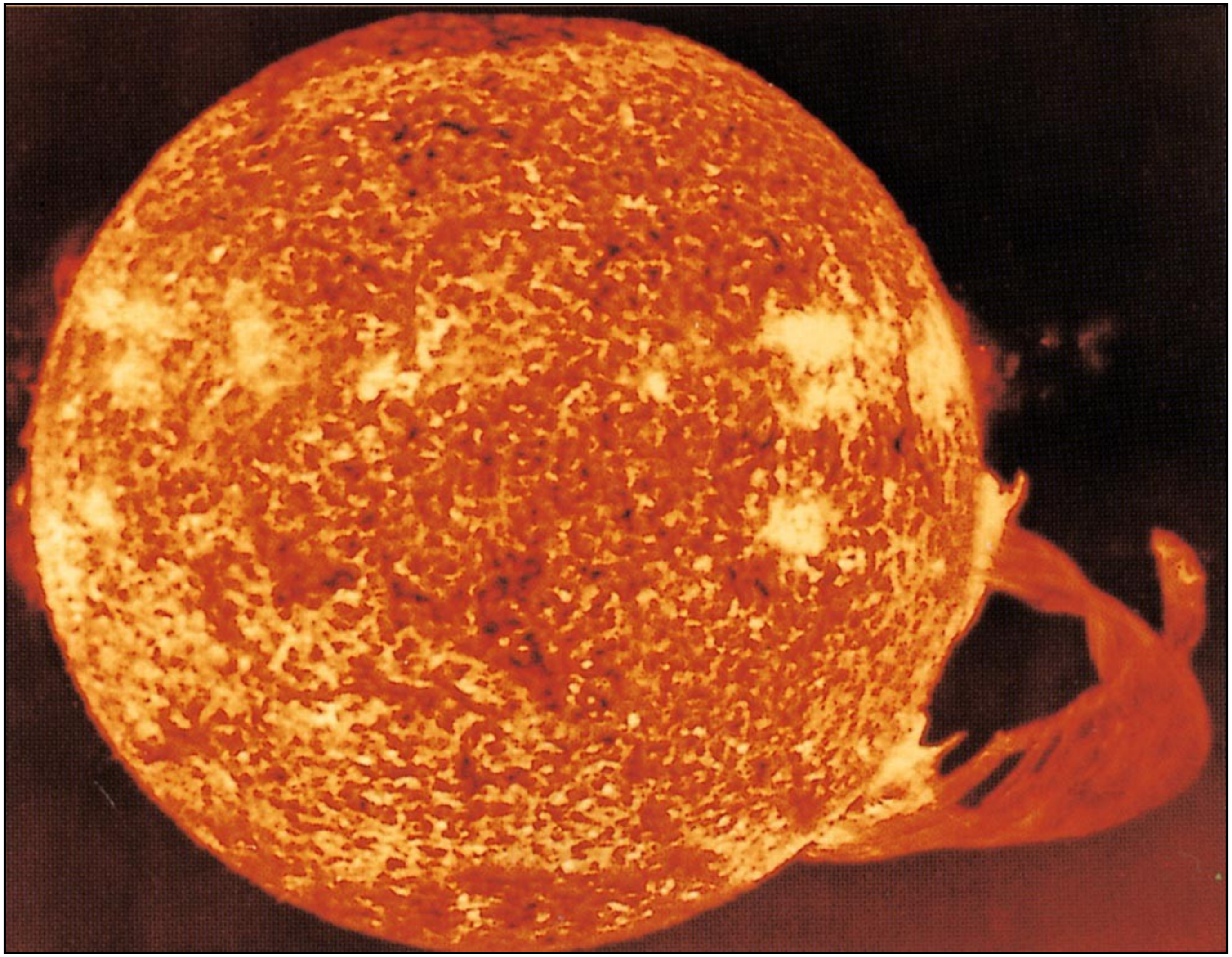
- Interestingly, sunspots also have magnetic polarity.
- Each 11-year cycle is similar except that the polarities are reversed.
- Therefore the 11-year sunspot cycle is actually a manifestation of a more fundamental 22-year magnetic cycle.

Flares and Prominences

- Flares are bright explosive events that occur on the Sun’s surface.
- Prominences are enormous filaments of solar gases that arch out and over the Sun’s surface.
    - Prominences may extend hundreds of thousands of km outward.
    - Since they occur along the outer edge of the Sun, they are particularly evident during solar eclipses.

A Major Solar Prominence

Flares can also be seen as the bright yellow areas



Corona

- The corona is the pearly white halo or crown extending far beyond the solar disk
  - Visible during total eclipses of the Sun.
- The corona can be interpreted to be the Sun's "outer atmosphere."
  - Corona's temperature is approximately 1 million K.
- Prominences occur within the corona region of the Sun.

Solar Wind

- In the extreme high-temperatures of the corona protons, electrons, and ions are furnished with enough energy to escape the Sun's atmosphere.
  - These particles are accelerated enough to escape the Sun's tremendous gravitational pull.
- The solar wind extends out from the Sun at least 50 AU.
- Heliosphere is the volume or "bubble" of space formed by the solar wind.
  - Virtually all the material in the heliosphere emanates from the Sun.

Interior of the Sun

- The Sun's interior is so hot that individual atoms cannot exist.
  - Continuous high-speed collisions result in the separation of nuclei and electrons.
- A fourth phase of matter, called a plasma, is created where nuclei and electrons exist as a high-temperature gas.
- The temperature at the central core of the Sun is 15 million K and the density is 150 g/cm^3.
  - The innermost 25% of the Sun, the core, is where H is consumed to form He.

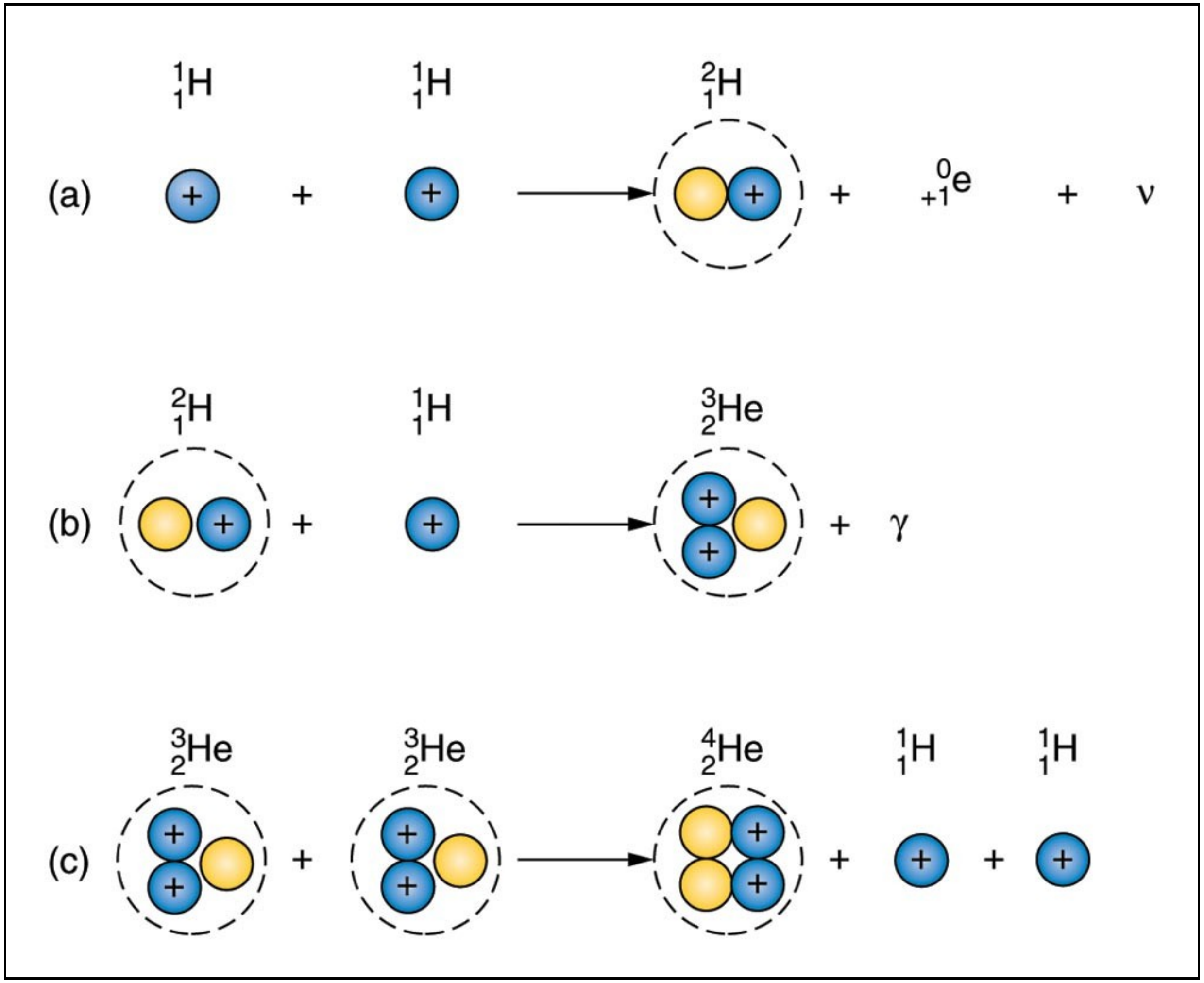
Audio Link

Interior of the Sun

- Moving outward from the core of the Sun, both the temperature and the density decrease.
- It is the nuclear fusion of H into He within the core that is the source of the Sun’s energy.
- In the Sun and other similar stars the nuclear fusion takes place as a three step process called the proton-proton chain.

Proton-Proton Chain or PP Chain

Each reaction liberates energy by the conversion of mass.



Proton-Proton Chain

- In the net reaction of the PP Chain, four protons form a He nucleus, two positrons, two neutrinos, and two gamma rays.

$$4\,{}^{1}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + 2\left({}^{0}_{+1}\mathrm{e} + \nu + \gamma\right) + \text{energy}$$

- The amount of energy released by the conversion of mass conforms with Einstein’s equation, $E = mc^2$.

Solar Longevity

- Approximately 6.00 X 10^{11} kg of H is converted into 5.96 X 10^{11} kg of He every second
- With a total mass of 10^{30} kg of H, scientists expect the Sun to continue to radiate energy from H fusion for another 5 billion years

Solar Constant

- The Earth only receives a very small percent of the Sun’s radiated energy.
- Every second the Earth receives approximately 1.4×10^3 W/m^2, a value known as the solar constant.
- Even a very small variation (+/- 0.5%) in the solar constant would have disastrous effects on our planet’s biota.

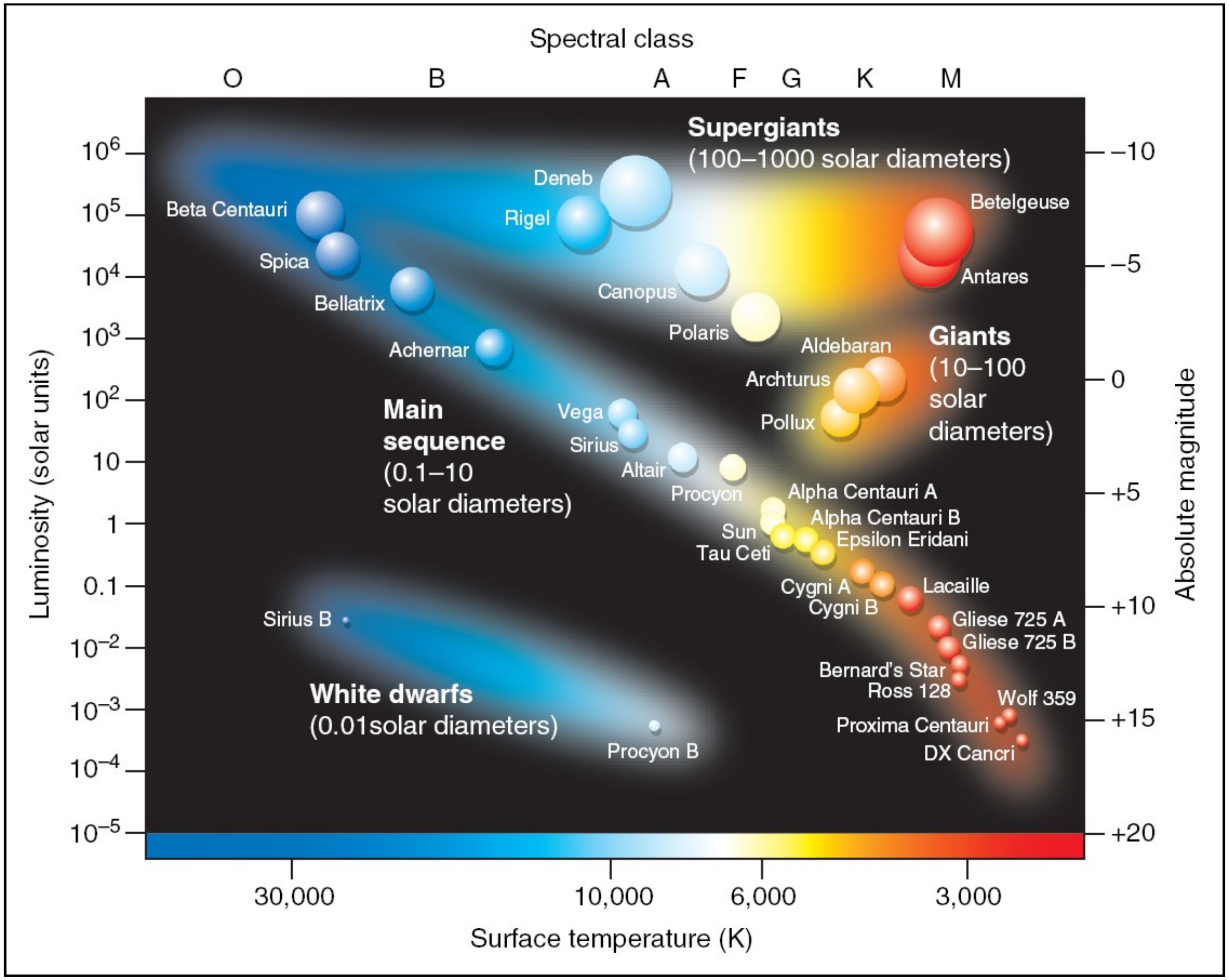
The H-R (Hertzsprung-Russell) Diagram

- The H-R Diagram results from plotting the stars' absolute magnitudes versus the temperatures of their photospheres.
- Most stars become brighter as they get hotter.
- These stars plot as a narrow diagonal band in the diagram – the *main sequence*
- The hottest (and generally brightest) stars are blue. The coolest (and generally least bright) stars are red.

Audio Link

Hertzsprung-Russell Diagram

Note that temperatures increase from right to left.



Note that some stars do not fall along the main sequence.

Stars off the H-R Main Sequence

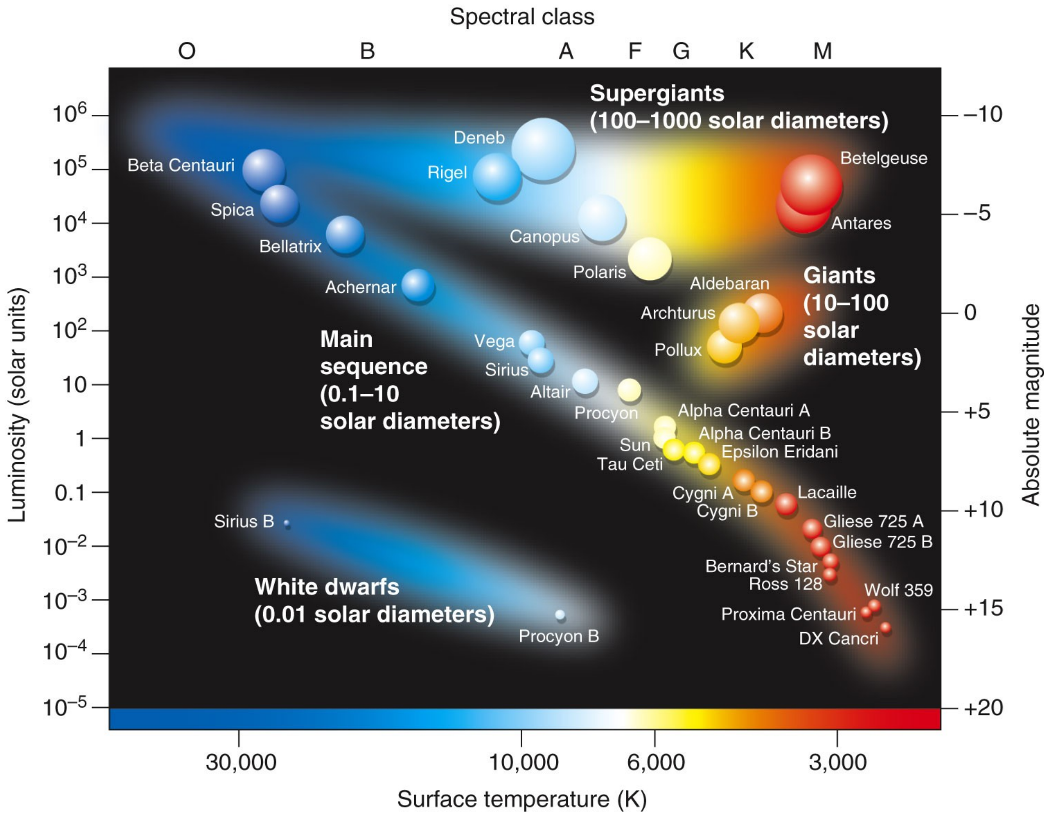
- Several types of star do not fall on the main sequence.
- Red giants – very large stars that are cool, yet still very bright
  - The very brightest are called red supergiants.
- White dwarfs – stars that are very hot, yet are dim due to their small size

Spectral Analysis of the Stars

- Spectral analyses of stars shows that even the most distant stars contain the same elements we find in our solar system.
- However, there are variations in the spectra depending on the temperature of the individual star’s photosphere.
- Therefore, the patterns of the absorption lines in the spectra can be used to determine both the composition and the surface temperature.

Spectral Classes

- In the H-R diagram, stars have been placed in seven spectral classes -- O,B,A,F,G,K,M.
  - Note the horizontal top axis of the diagram.



Spectral Classification

- Our Sun falls close to the middle of the main sequence and is a class G star.
- Sirius is quite a bit hotter than our Sun and is a class A star.
- Astronomers have found that the majority of stars are small, cool, class M stars, also called red dwarfs.
  - Proxima Centauri is the closest star to Earth (besides our Sun) and is a red dwarf or class M star.

Interstellar Medium

- Interstellar medium – gases and dust that is distributed amongst the stars
- The gases consists of about 75% H, 25% He, and a trace of heavier elements by mass.
- The dust (only about 1% of the interstellar medium) consists primarily of C, Fe, O, & Si.
  - About the size of particles in smoke

Audio Link

Nebulae

- The gases and dust do not appear to be distributed uniformly throughout space.
- Nebulae – concentrations of cool, dense clouds of gases and dust
- Two major types of nebulae exist: bright and dark nebulae

Bright Nebulae – *Two Types*

- Bright nebulae can, in turn, be divided into:
  - Emission nebulae – energy from nearby stars ionize the hydrogen gas resulting in fluorescence
  - Reflection nebulae – dust within the nebulae reflect and scatter starlight, giving off a characteristic blue color

The Great Nebula in Orion (M42)
An Emission Nebula

Dark Nebulae

- Dark nebulae – produced by the obstruction of a relatively dense cloud of interstellar dust
- Dark nebulae are visible as relatively dark areas as they are framed against some type of light-emitting region behind them.
- The most famous of the dark nebulae is located in the constellation Orion.
- It appears like the head of a horse, back-lit by a bright emission nebula.

The Horsehead Nebula
A Dark Nebula

General Evolution of a Low-Mass Star

- Stars begin to form as interstellar material (mostly H) gathers together. (accretion)
- The accretion of the interstellar material may be due to several factors:
  - Gravitational attraction of the material
  - Radiation pressure from nearby stars
  - Shockwaves from exploding stars
- A protostar forms as the interstellar material condenses and the temperature rises.

General Evolution of a Low-Mass Star

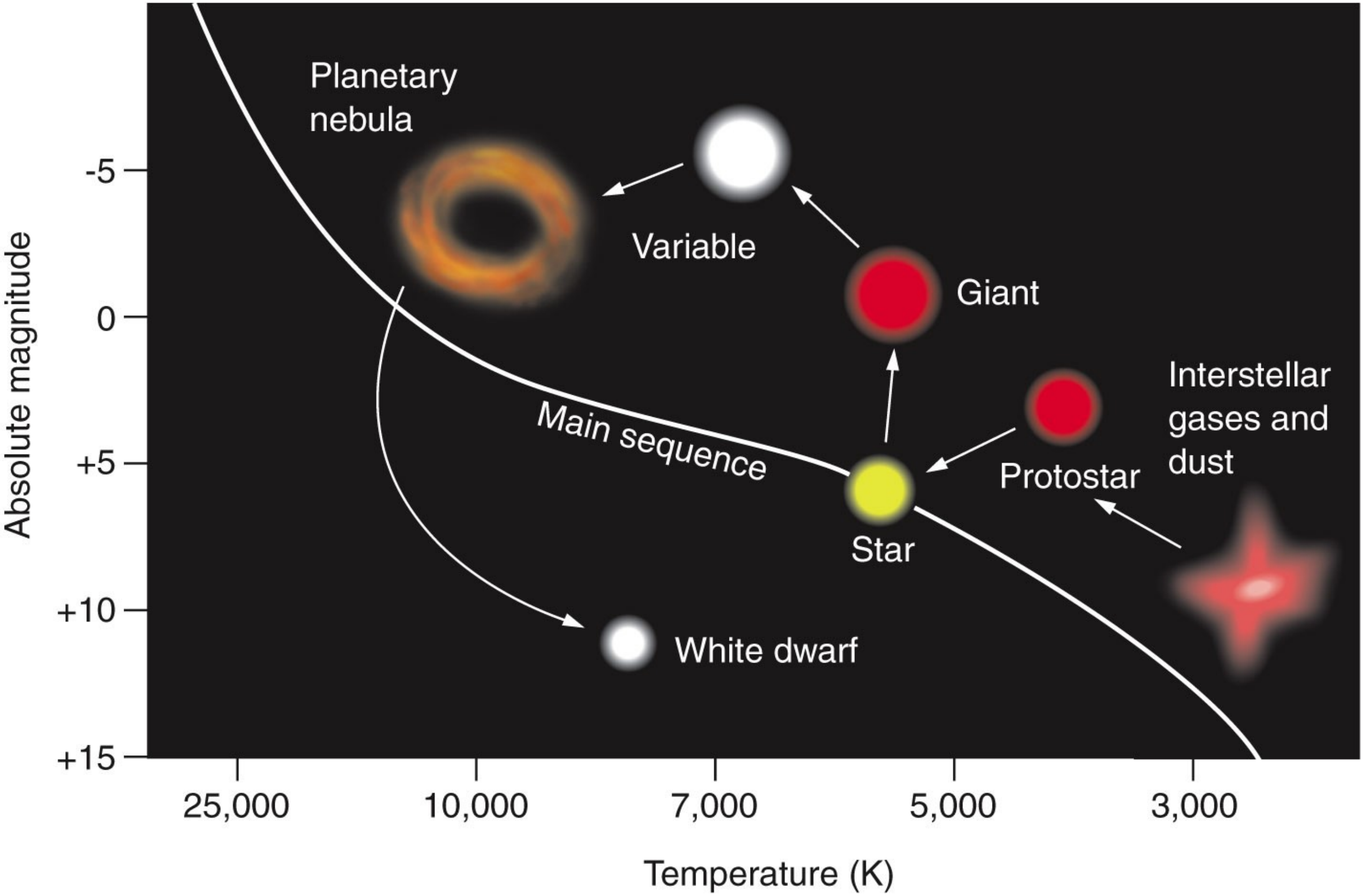
- As the protostar continues to condense, the temperature continue to rise.
- As the temperature continue to rise, the thermonuclear reaction begins in which H is converted to He. (fusion)
  - Recall the reaction below:

$$4\,{}^{1}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + 2\left({}^{0}_{+1}\mathrm{e} + \nu + \gamma\right) + \text{energy}$$

A Star is Born

- When thermonuclear fusion begins, this is the time a star is actually born.
- It moves onto the H-R main sequence, in a position determined by its temperature and brightness.
  - Ultimately both temperature and brightness are dependent upon the star’s mass.

Stellar Evolution on the H-R Diagram



Steller Evolution

- As the star continues to fuse H into He, it remains on the H-R main sequence.
- The period of time that a star remains on the main sequence can vary widely.
- A low-mass star, such as our Sun, will remain on the main sequence for 10 billion years.
- A very low-mass star may stay on the main sequence for trillions of years.
- High-mass stars fuse fuel fast, and only remain on the main sequence a few million years.

Stellar Evolution

- As H in the core continues to convert to He, the core begins to contract and heat up even more.
- This extra heat eventually causes the H in the surrounding shell to proceed more rapidly, which in turn destabilizes the star’s hydrostatic equilibrium, resulting in expansion.
- At this point, when the star expands, it enters the red-giant phase, and moves off the main sequence.

Red-Giant Phase

- When our Sun moves into its red-giant phase (several billion years from now) it will swell and engulf Mercury, Venus, and possibly Earth.
- The core of a red-giant eventually becomes so hot that He will fuse into C and perhaps will create elements up through Ne.
- Nucleosynthesis is the creation of elemental nuclei inside stars.
- In high-mass red supergiants nucleosynthesis may continue all the way up to Fe.

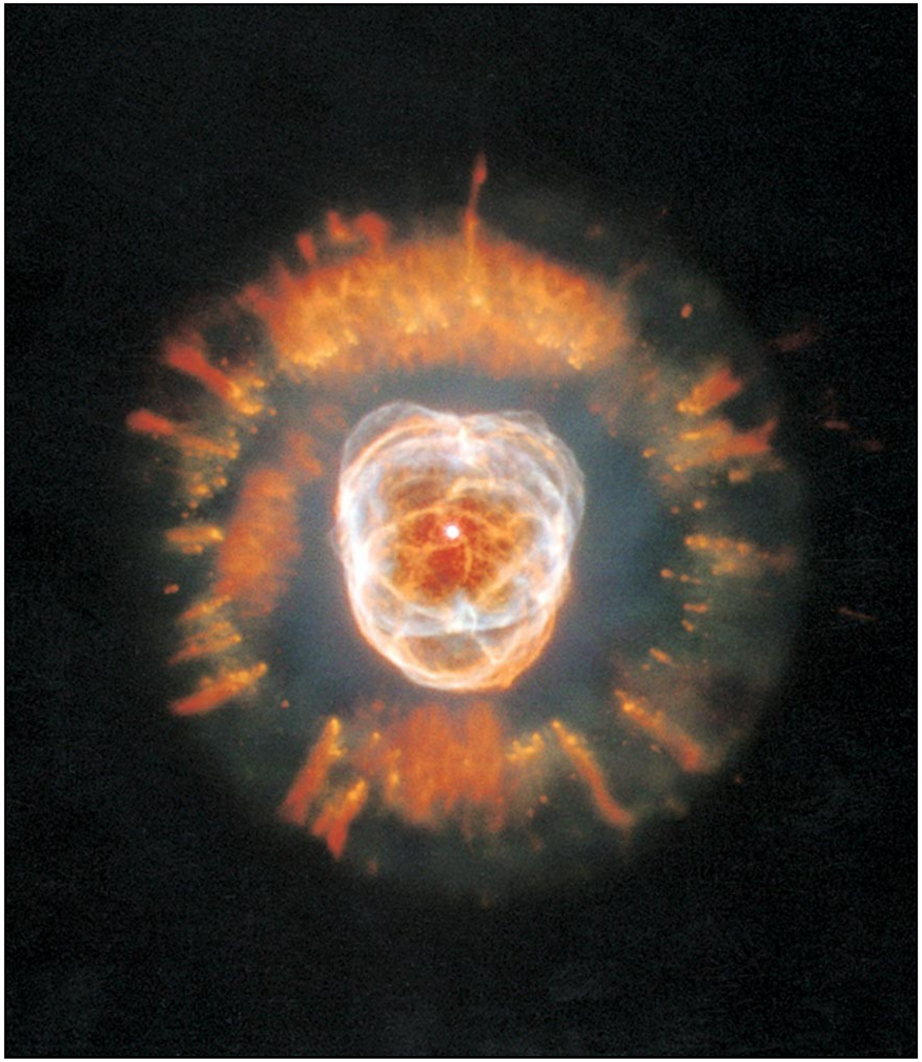
Variable Star

- Variations occur in the star’s temperature and brightness during the red-giant phase.
- For a short time it becomes a variable star, as its position on the H-R diagram moves left.

Planetary Nebula

- During and after the variable star stage the star becomes very unstable, resulting in the outer layers being blown off forming a planetary nebula.
- Planetary nebula have nothing to do with planets.
  - Early and fuzzy photographs of planetary nebula reminded astronomers of an evolving solar system.
- The expelled material diffuses into space, providing material for future generations of stars.

The Eskimo Nebula: *A Planetary Nebula*

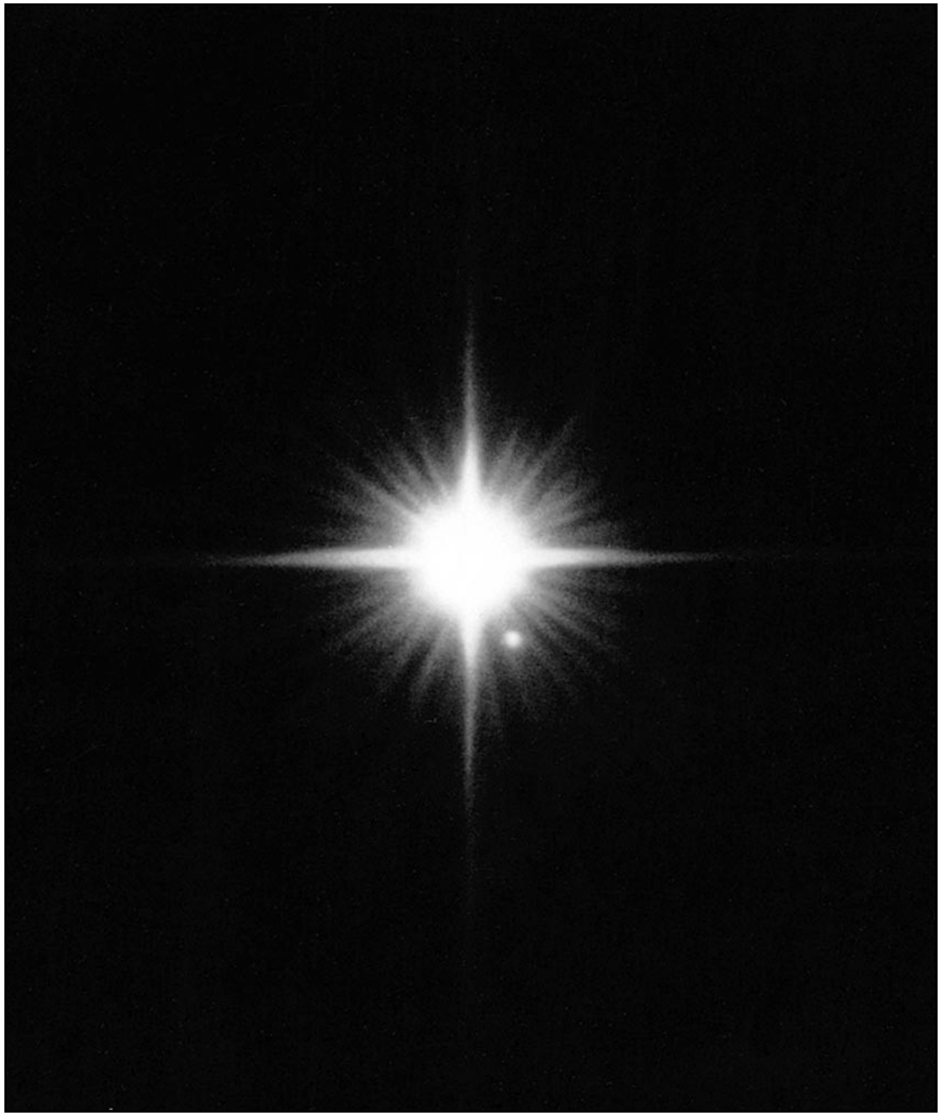


Note the visible white dwarf in the center

White Dwarf

- Following the formation of a planetary nebula the remaining core is called a white dwarf.
- Thermonuclear fusion no longer occurs in a white dwarf and it slowly cools by radiating its residual energy into space.
- White dwarfs are not very bright and fall low on the H-R diagram.
    - A single teaspoon a matter in a white dwarf may weigh 5 tons!

Sirius – a Binary Star



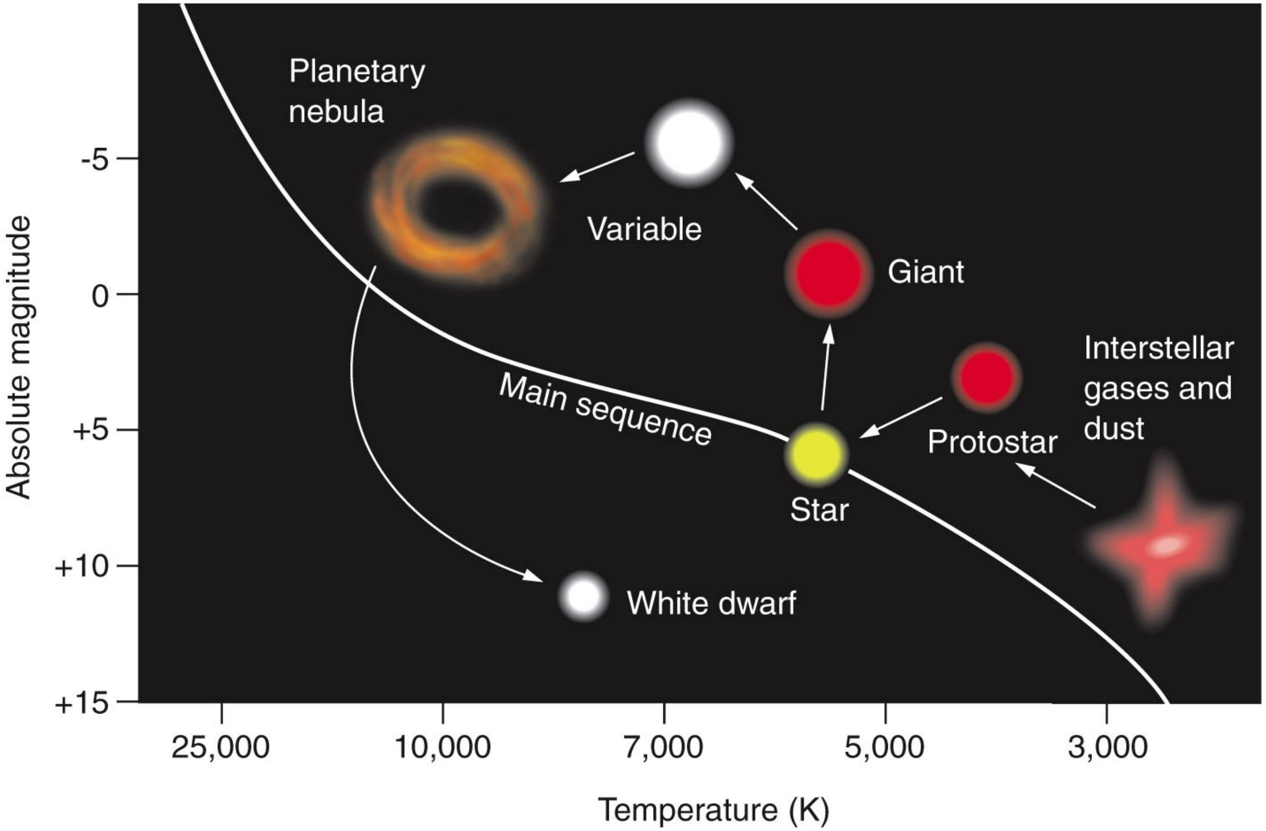
- Sirius A is a class-A main sequence star.
- Sirius B is a white dwarf at about 5 o'clock.

Brown Dwarfs

- During stellar evolution, what if a protostar cannot sustain thermonuclear fusion due to its small mass?
- In this situation the protostar would not progress to the star phase and would result in a “failed star” or a brown dwarf.
- Obviously brown dwarf are very dim.
- The first brown dwarf was not discovered until 1996. – Gleise 229B
  - About 600 brown dwarfs have now been found.

Evolution of a low-mass star

Protostar, main-sequence star, red giant, planetary nebula, and white dwarf



Nova

- Nova – a white dwarf that temporarily and suddenly increases in brightness
  - Although the word nova mean “new star,” it is not.
- Novas result from a nuclear explosion on the surface of a white dwarf.
  - This explosion is caused by small amounts of material falling onto the white dwarf’s surface from its much larger binary companion.

Supernova

- Supernova – the gigantic and catastrophic explosion of a star
  - Large amounts of material and radiation are thrown off as a result of this explosion.
- There are two types of supernovas:
  - Type I supernovas result from the destruction of a white dwarf containing a carbon-oxygen core.
  - Type II supernovas result from the collapse of an iron core of a red supergiant.

Supernova

- The Type I and Type II supernovae can be distinguished by their different spectral signatures:
  - Type I supernova do not have hydrogen spectra nor do they emit radio waves.
  - Type II supernova display hydrogen spectral lines and emit radio waves.

The Crab Nebula
Type II Supernova

Crab Nebula

- The Crab Nebula is the best known and one of fewer than ten supernovae that have been recorded in the Milky Way Galaxy.
- The supernova that resulted in the Crab Nebula was reported in Chinese and Japanese records around 1054.
- During the first two weeks of this supernova’s appearance, the night sky was bright enough to read by.

Nucleosynthesis

- The energy and neutrons emitted during a supernova explosion result in the nucleosynthesis of the elements heavier than iron.
- Other than H and He, all of the elements up to Fe are thought to be made during normal fusion processes in stars of various masses.
- Elements past Fe are thought to be generated exclusively during supernova explosions.

Neutron Stars

- When the nuclear fuel interior of a red supergiant is depleted, the interior undergoes a catastrophic collapse to form a small neutron star.
  - Approximately 20 km in diameter
- As a result of this inner collapse, the outer layers also collapse, bounce off the rigid inner core, and expand into space, resulting in an ever expanding supernova, leaving behind the small core (neutron star.)

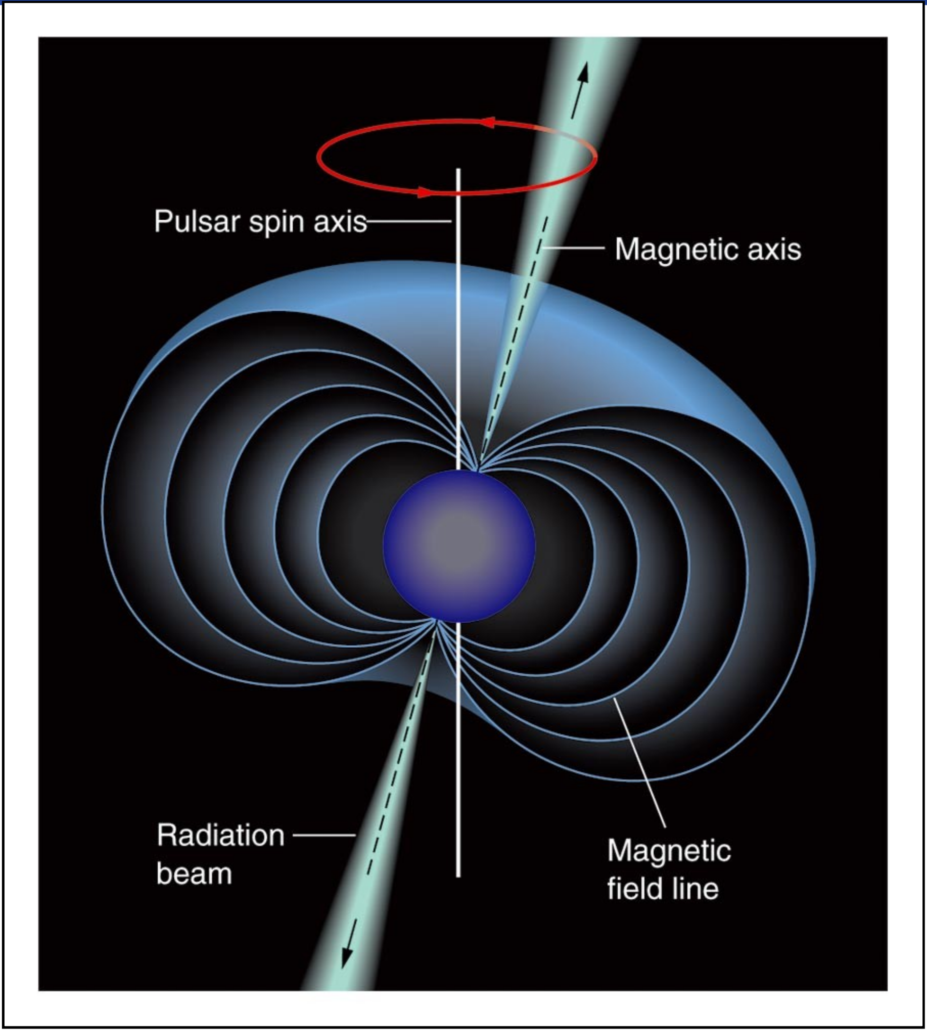
Neutron Stars

- The name “neutron star” comes from electrons and protons combining to form neutrons.
- Neutron stars are extremely dense – in the order of 1 billion tons per teaspoon.

Pulsar – Rapidly Rotating Neutron Stars

- Any angular momentum that the original star had must be maintained.
- Therefore, the small size of the neutron star dictates that it may spin rapidly.
- A <u>pulsar</u> emits radio waves that are detected on Earth in regular pulses apparently due to its rapid rotation.
  - Each pulsar has a constant period between 0.03 - 4s.
- Pulsars are interpreted to have a magnetic axis which is tilted relative to its magnetic axis.

Rotating Neutron Star Model - Pulsar



- As the neutron star rotates the radiation beam (caused by the magnetic field) hits the Earth periodically.
- On Earth the radiation beam is detected in “pulses,” but actually is due to rotation.

Very Large Array (VLA), New Mexico

Designed to detect radio-wave images of distant celestial objects

The Crab Nebula

The pulsar at its center spins 30 time/second. This nebula also emits pulses of visible light.

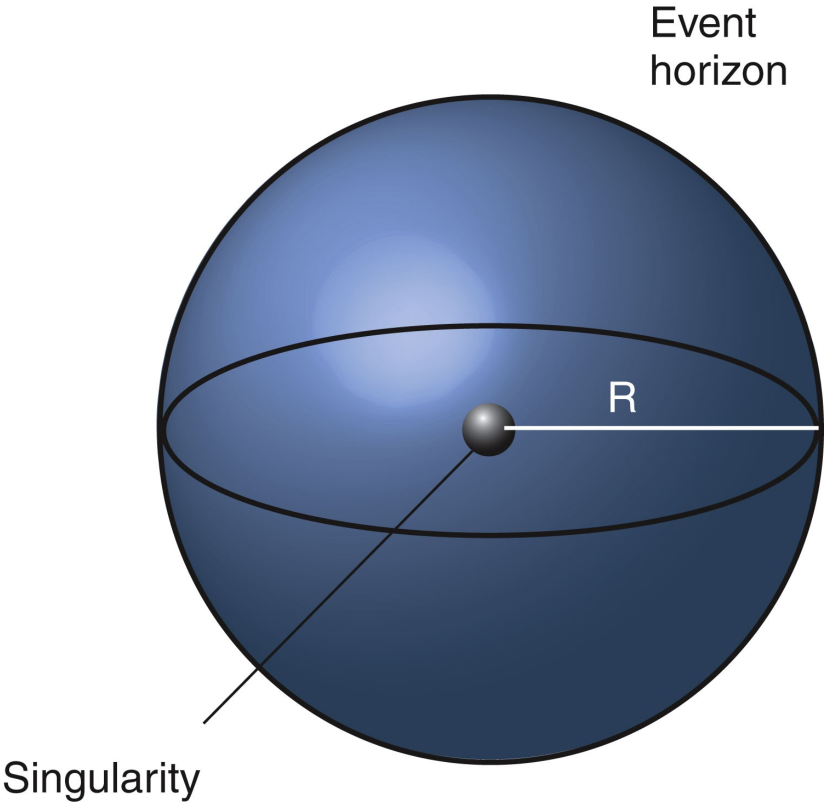
Black Holes

- Black hole – a celestial object so dense that the escape velocity is equal to or greater than the speed of light
  - Gravity's 'final' victory over all other forces
  - Not even light cannot escape from its surface
- Black holes are thought to result from a supernova explosion when the core remaining is greater than 3 times the mass of the Sun.
- The star's matter continues to condense down to an extremely small point, a singularity.

Audio Link

Configuration of a Nonrotating Black Hole

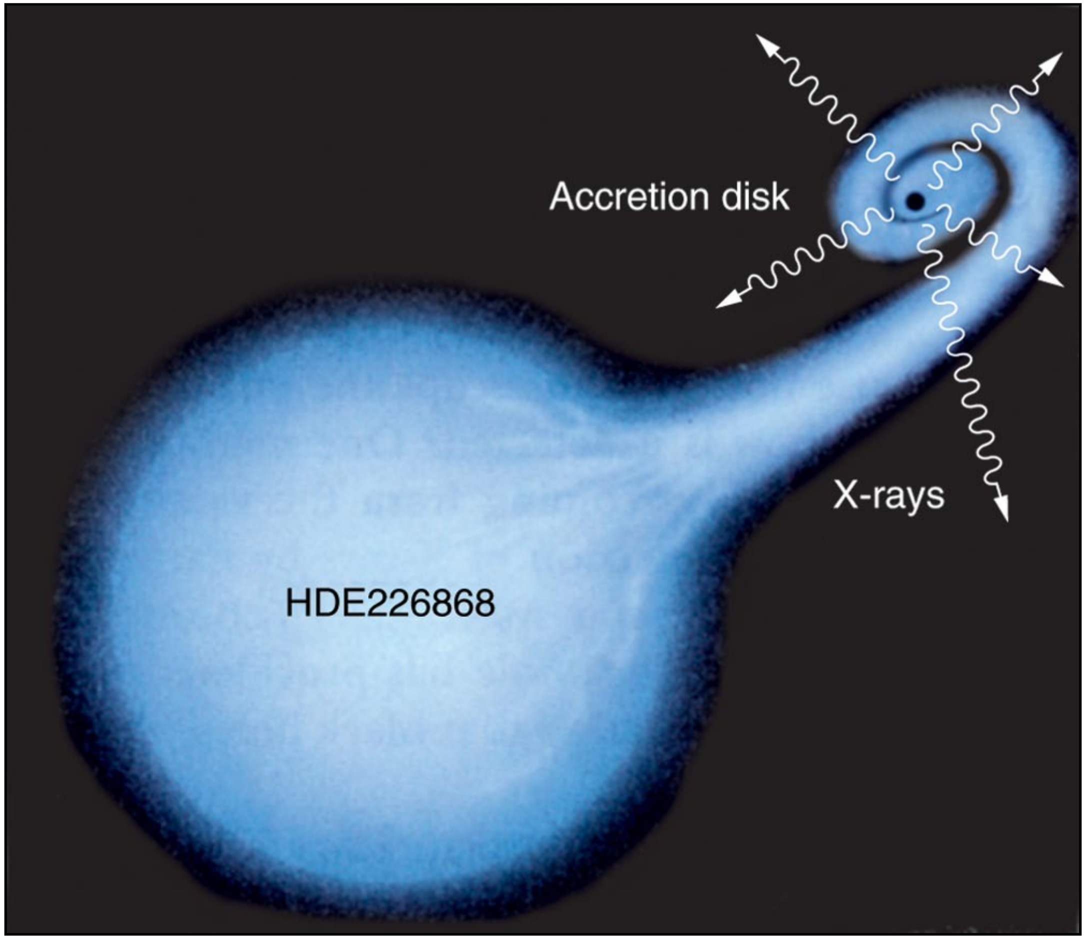
Within the event horizon boundary (the Schwarzschild radius R), the escape velocity is equal to or greater than the speed of light. Therefore no matter or radiation can escape.



Detection of a Black Hole

- The event horizon of a black hole represents a one-way boundary: anything can enter but nothing can escape.
- If nothing, not even electromagnetic radiation, can escape a black hole then how can one be detected?
- One way is the detection of x-ray emission in the vicinity of a black hole.
- Captured gases, just outside the event horizon emit x-rays and form an accretion disk.

Class O Star and Black Hole - Cygnus X-1



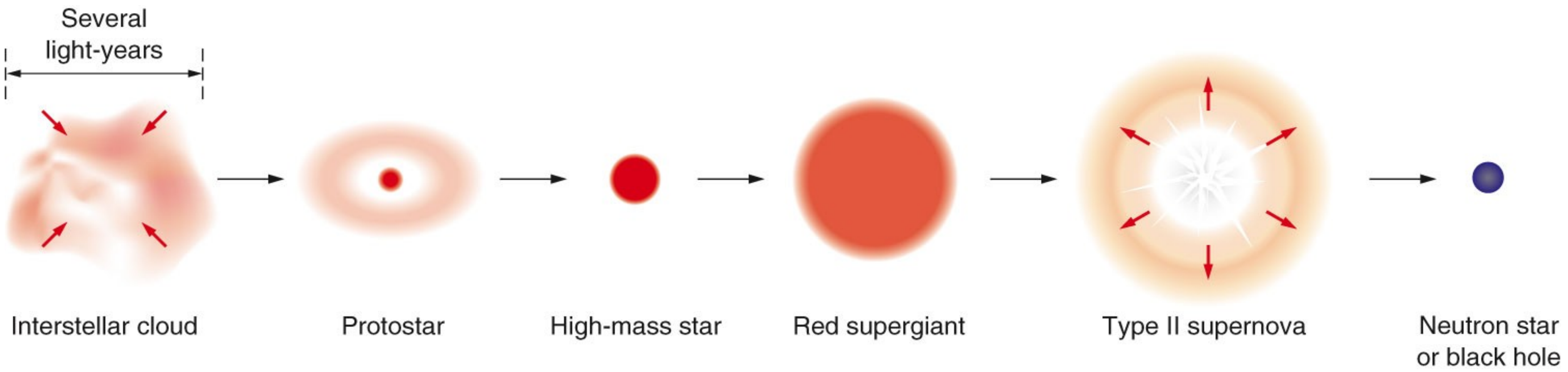
The x-rays that are being generated are apparently due to an accretion disk of gases being captured by the black hole.

High-Mass vs. Low-Mass Stars

- High-mass stars and low-mass stars form initially in similar manners.
- High-mass stars are hotter and brighter than low-mass stars.
  - High-mass star move onto the main sequence at higher points.
- High-mass stars do not stay on the main sequence as long as low-mass stars, due to their higher rate of thermonuclear fusion.

Evolution of a High-Mass Star

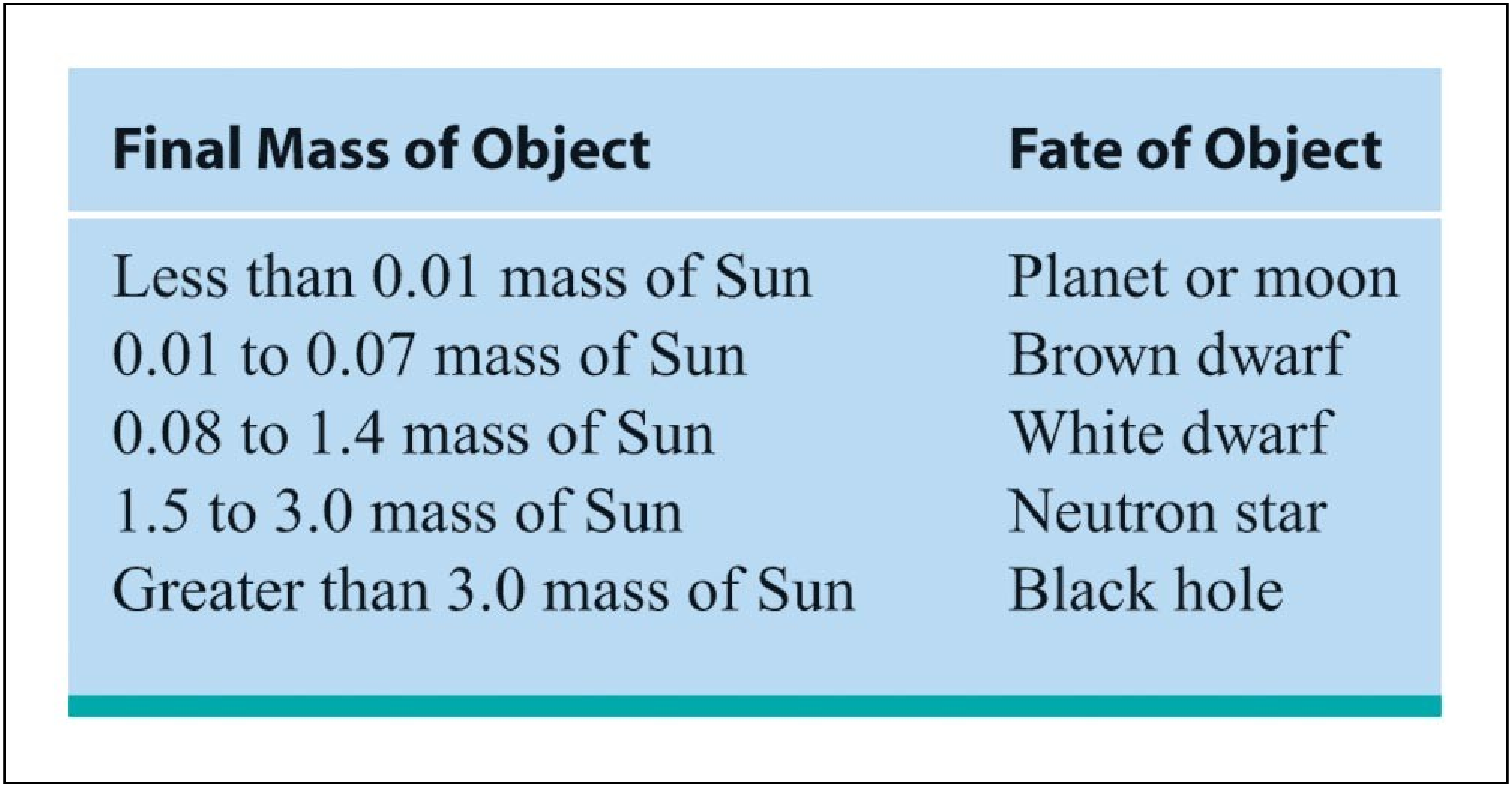
When high-mass stars moves off the main sequence they become red supergiants and eventually explode as Type II supernovae. Much of the material is scattered into space leaving behind a neutron star or black hole.



Mass and Stellar Evolution

- As we have learned in sections 18.4 & 18.5, the initial mass that a celestial object acquires during its formation is very important in determining its eventual fate.
- But the final mass left over after any stellar material is ejected turns out to be the conclusive determinant.

The Fate of Celestial Objects



Final Mass of Object	Fate of Object
Less than 0.01 mass of Sun	Planet or moon
0.01 to 0.07 mass of Sun	Brown dwarf
0.08 to 1.4 mass of Sun	White dwarf
1.5 to 3.0 mass of Sun	Neutron star
Greater than 3.0 mass of Sun	Black hole