

LECTURE NOTES

ASTRONOMY (PFI-223)

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**PROGRAM STUDI FISIKA
FAKULTAS MATEMATIKA & ILMU PENGETAHUAN ALAM
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Assessment

- 20% assignment
- 30% mid-semester exam
- 50% final exam

ASTRONOMY

Prelude

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What is astronomy?

The scientific study of celestial objects (stars, planets, galaxies)

Came from the Greek:
astron=star and nomos = law

What are we going to learn?

- Celestial Sphere
- Celestial Mechanics
- Stars
- Solar system

Eratosthenes

- Determined the first fairly accurate measurement of the Earth's diameter

Aristotle

- Discussed about the phase (the changing shape) of the Moon (which is the fact that it is not self-luminous but shines by reflected sunlight)
- Discussed that the Sun is more distant than the Moon (from the fact the the Moon occasionally passes between the Earth and the Sun and temporarily hides the Sun from view: a *solar eclipse*)

Hipparchus

- Compiled a star catalogue of about 850 entries
- Designated for each star its celestial coordinate
- Divided the stars according to their apparent brightness into six classes (or *magnitudes*) and specified the magnitude of each star
- Pointed the Earth's precession
- Refined the technique to obtain the distance of the Moon first applied by Aristarchus

Ptolemy

- Compiled a series of 13 volumes on astronomy known as the *Almagest*
- Proposed a geometrical representation of the solar system that predicted the motion of the planets (including the retrograde motion of Mars) with considerable accuracy and put the Earth as the center of the universe (geocentric idea)

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Development of Astronomy

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Greek Astronomy

- The science of astronomy was developed by the Greeks in the first millennium B.C.
- Some of the Greek astronomers:
 - Pythagoras
 - Aristotle
 - Aristarchus of Samos
 - Eratosthenes
 - Hipparchus
 - Ptolemy of Alexandria

Pythagoras

- Pictured a series of concentric spheres for the seven moving objects (the planets: Mercury, Venus, Mars, Jupiter, Saturnus, the Sun and the Moon) around the Earth, and are separated from the sphere for the stars.
- Thought that the Earth, the Moon and other celestial objects were spherical.

Aristotle

- Discussed that the Earth is a sphere (from the fact that during a lunar eclipse, as the Moon enters or emerges from the Earth's shadow, the shadow seen on the Moon is always round)
- Pointed out that the apparent daily motion of the sky can be explained by the rotation of celestial sphere (not the Earth)
- Supported the geocentric ideas

Aristarchus

- Proposed the heliocentric hypothesis (the Earth revolves about the Sun)
- Attempted to calculate the relative distance of the Sun and Moon from the Earth
- Attempted to calculate the diameter of the Sun (compared to the Earth)

Kepler

- Based on Tycho's data, proposed three laws on planetary motion:
 - The orbits of all planets (including the Earth) are ellipses with the Sun at one focus
 - The area swept out in space by an imaginary line connected the Sun and a planet in equal intervals of time are always equal
 - The ratio of cubic power of sidereal period of a planet and the square of semimajor axis of its orbits is the same for all planet

Modern Astronomy

- The origin of modern astronomy was developed since the Renaissance
- Some astronomers involved in the development:
 - Nicolaus Copernicus
 - Tycho Brahe
 - Johannes Kepler
 - Galileo Galilei
 - Isaac Newton

Galileo

- Discovered the nature of the Milky Way, the large-scale feature of the Moon, the phases of Venus, the four Galilean satellites of Jupiter and the rotation of the Sun from observations of sunspots
- Supported the heliocentric ideas

Copernicus

- Proposed the heliocentric model of the universe (presented in his book *De Revolutionibus*)
- Worked out the scale of the solar system

Newton

- Formulated the law of gravitation
- Formulated the three laws of motion in which the Kepler's laws can be derived mathematically from the basic principle in physics

Tycho

- Conducted the most accurate observation of the stars and planets of his time

ASTRONOMY

Celestial Sphere

What is it?

- Celestial sphere = globe of stars (picture of the sky) turning around the Earth
- Celestial = heaven (from Latin)
- The stars on the celestial sphere appear to move because the Earth is rotating on its axis inside the celestial sphere

What can be seen?

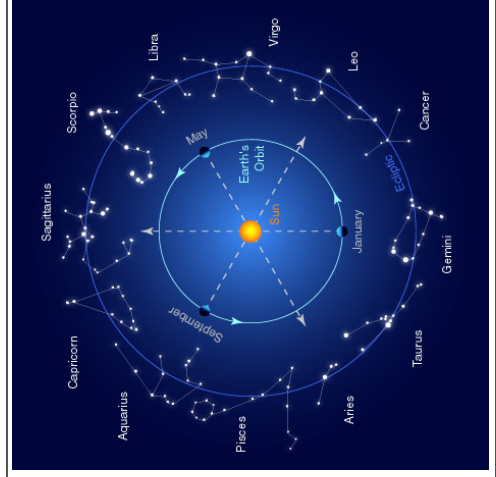
- **Constellations** = groups of stars that form recognizable patterns in the sky
- **Asterisms** = popular unofficial star patterns
- Different stars during the night since the Earth rotates on its axis
- Different constellation during the year since the Earth revolves around the Sun

• Facts:

- There are 88 constellation officially recognized by the International Astronomical Union
- 48 of them recognized since the ancient Greek
- 12 of them located around the **ecliptic** (apparent path of the Sun against the background stars), called **zodiac**
- The Moon and planets follow paths near ecliptic through these 12 constellation
- There are some constellations that appear all the time called **circumpolar constellation**

Constellation of The Zodiac

- Aries
- Taurus
- Gemini
- Cancer
- Leo
- Virgo
- Libra
- Scorpio
- Sagittarius
- Capricornus
- Aquarius
- Pisces



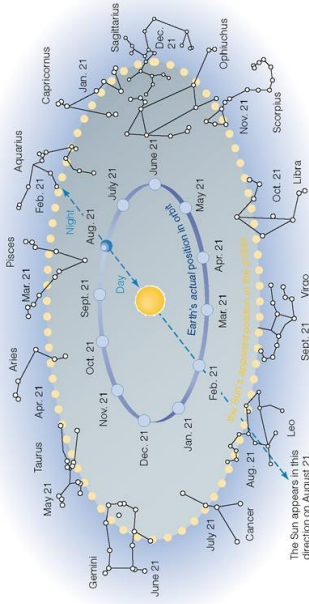
Celestial coordinates

Stars are located on the celestial sphere. To describe their position, we can use:

- Horizontal (local) coordinates
- Equatorial coordinates
- Ecliptical coordinates

Basic Terms

- **Zenith** = the point on the celestial sphere directly over your head
- **Nadir** = the point on the celestial sphere directly below your feet
- **Horizon** = the great circle on the celestial sphere 90 degree from your zenith
- **Celestial Meridian** = the great circle passing through your zenith and the north and south points on your horizon



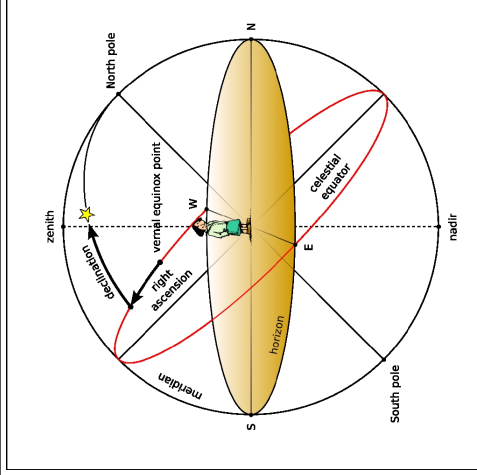
- Draw the diurnal circles for the star with declination of 40 and -40 observed from latitude of +45, -45, 0 and +90

Finding Latitude

- Latitude is equal to the altitude of celestial pole (within 1 degree of Polaris)
- You can also use the altitude of any star as it crosses the meridian
 - Suppose Vega crosses meridian at altitude 78° in S
 - The declination of Vega is $+38^\circ$
 - Thus, celestial equator crosses meridian at $78^\circ - 38^\circ = 40^\circ$ in S
 - Celestial equator altitude is $(90^\circ - \text{latitude})$
 - Hence, the latitude is 50° N

Equatorial Coordinates

- Commonly known as celestial coordinates, represented by declination and RA
- *Celestial Equator* = the projection of the Earth's equator out of the sky
 - **Declination** = angular distance above or below the celestial equator (has analogy to the Earth's latitude)
 - **Right Ascension (RA)** = distance measured eastward along the celestial equator from zero point, the **vernal equinox**, measured in hours (1 hour = 15 degree)

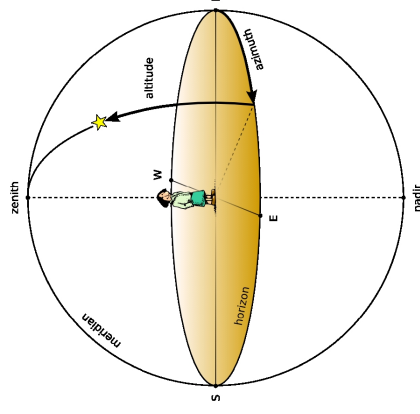


Drawing The Celestial Sphere

- Draw the sphere
- Define the North point
- Draw the horizon
- Define the North Celestial Pole
- Draw the Celestial Equator
- Draw the diurnal circle according to the star's declination
- The celestial equator crosses the horizon on the west and east point

Basic Terms

- The stars move from east to west and **transit**, or cross your celestial meridian
- A star **culminates**, or reaches its highest altitude, when it is on the celestial meridian
- The stars appear to move in **diurnal circles**, or daily path, around the celestial poles



Local Coordinates

- Represented by azimuth and latitude
- **Azimuth** = angle clockwise from the North along the horizon
 - **Altitude** = angle from the horizon to the celestial object along the circle passing zenith

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Solar System

Solar System



What can be found in Solar System?

- The Sun as the central star
- 8 planets (and their satellites): Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune
- Dwarf planets: Ceres, Pluto, Eris
- Small bodies inside the solar system: Asteroids, satellites, Trans-Neptunian Objects (TNO), comets, meteoroids

Facts

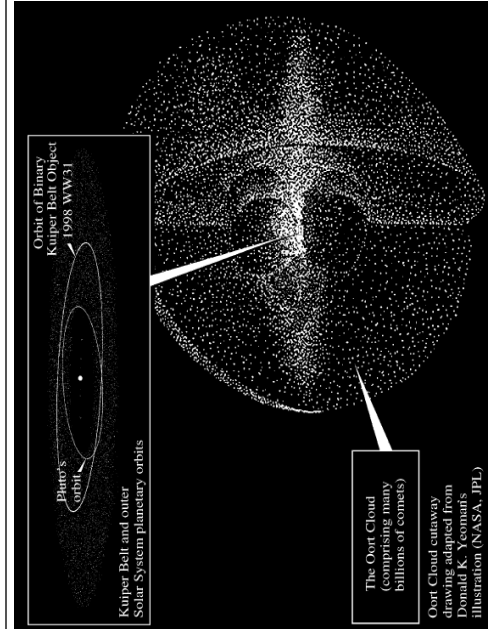
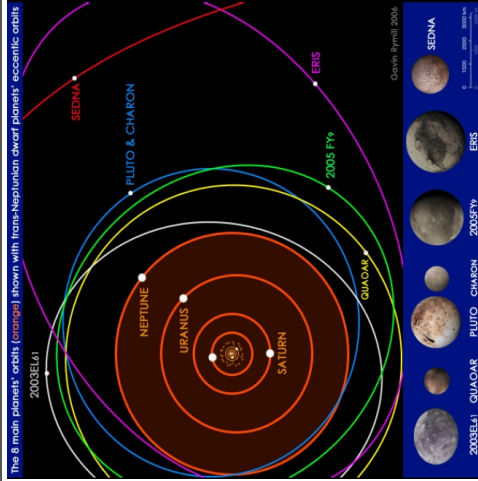
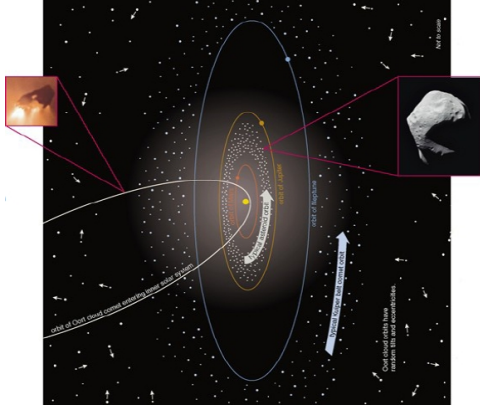
- All of the planets revolve the Sun in the same direction → counterclockwise as seen from above
- The planets also rotate as they revolve. Their rotation is also counterclockwise as seen from above (except for Venus and Uranus)
- The mean plane of Earth's orbit around the Sun is called the **eciptic**. The orbit of all planets are nearly in the same plane
- Only 5 planets (Mercury, Venus, Mars, Jupiter & Saturn) which can be seen from Earth with naked eyes since the ancients

- These 5 planets was thought to rule one day of the week which was given its name (in Latin)
- We take the name (in English) for days of the week from the Anglo-Saxon

Day	Ruling planet	Anglo-Saxon Equivalent	Latin
Sunday	Sun	-	Dies Solis
Monday	Moon	-	Dies Lunae
Tuesday	Mars	Tiw	Dies Martis
Wednesday	Mercury	Woden	Dies Mercurii
Thursday	Jupiter	Thor	Dies Jovis
Friday	Venus	Frigg	Dies Veneris
Saturday	Saturn	Seterne	Dies Saturni

Structure of Solar System

- The Sun
- 4 terrestrial planets (Mercury, Venus, Earth, Mars)
- Asteroid belt
- 4 jovian planets (Jupiter, Saturn, Uranus, Neptune)
- Kuiper Belt
- Oort Cloud



IAU Definition for 'Dwarf Planets'

Dwarf planet = celestial body that is

- In orbit around the Sun
- Has sufficient mass to assume a nearly spherical shape
- Has **not** cleared the neighborhood around its orbit
- Is not a satellite

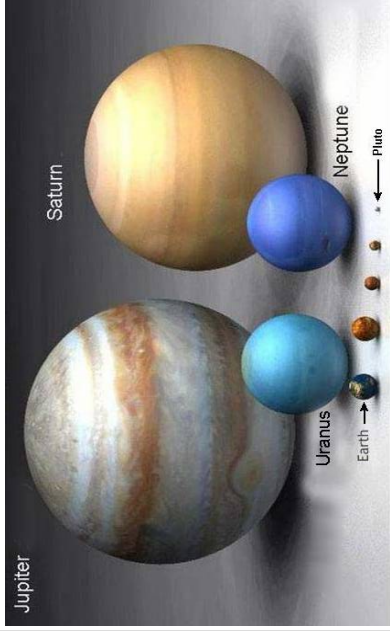
*Pluto fits in this category, thus since 2006, Pluto is considered as **dwarf planet***

- Thus, everything else except satellites, planets and dwarf planets is called '*Small Solar System Body*'
- A satellite is a body which orbits the primary body so that the center of mass (barycenter) is inside the primary
Example: Earth-Moon, the barycenter is inside the Earth, then the moon is Earth's satellite
- If the barycenter is outside the primary, then the system is called a *binary system*
Example: Pluto-Charon, the barycenter is outside Pluto, then they are called a binary system

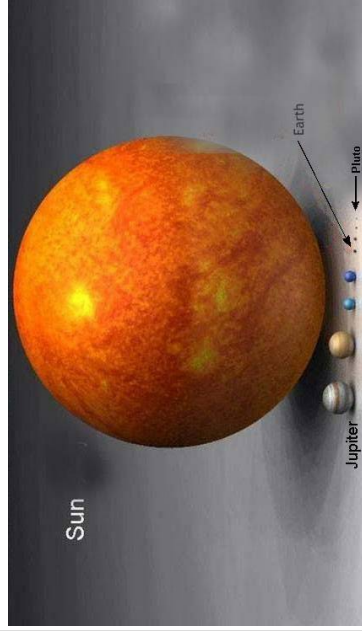
Distance to the Sun

- Earth-Sun mean distance is 149,6 million km defined as 1 Astronomical Unit (AU)
- The distance of the other planets can be stated using this unit. For example: the distance of Neptunes to the Sun is $30 \text{ AU} = 30 \times 149,6 \text{ million km}$
- J.D Titius and J. Bode proposed a way to remember the distance of planets to the Sun using Titius-Bode's Law

Planetary Comparison



Planets vs The Sun



IAU Definition for 'Planets' (2006)

Planet = celestial body that is:

- In orbit around the Sun
- Has sufficient mass to assume a nearly spherical shape
- Has cleared the neighborhood around its orbit

Pluto doesn't match the 3rd definition → not a planet

• Terrestrial Planets:

- Relatively small, dense
- Solid, rocky surfaces
- Metals in interior
- Closer to Sun

• Jovian Planets:

- Larger, smaller density
- Gas giant, made of H compounds (water, methane, ammonia)
- Very dense interior
- Farther from Sun
- Have rings, rocky or icy moons

• Asteroids:

- Small, rocky bodies
- Most orbit in the same plane and same direction as planets

• Comets:

- Small, icy bodies (water, methane, ammonia ice)
- Come from both Kuiper Belt and Oort Cloud
- Occasionally approach Sun in elliptical orbit
- Tails of glowing gas

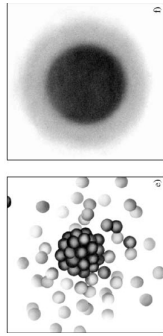
Asteroids



Comets



e) the clumps drifted together, forming planet-size bodies and...



f) began to collect gas and dust from the surrounding



g) the strong solar wind blew away extra gas and dust; the planet formation was finished

Solar System Formation

- The theory should be able to explain some exceptions for the solar system planetary orbit:
 - Uranus' rotation axis tilt is nearly at the ecliptic plane
 - Venus and Uranus' rotation direction are opposite to the other planets'
 - Some satellites have 'backward' orbits
 - Earth's moon is anomalously large

Titius-Bode's Law

The distance of the planets to the Sun follows the series of number 0, 3, 6, 12, 24, etc (doubled) and then added to 4 and divided by 10

Examples:

$$\text{Mercury} = (0+4)/10 = 0,4 \text{ AU}$$

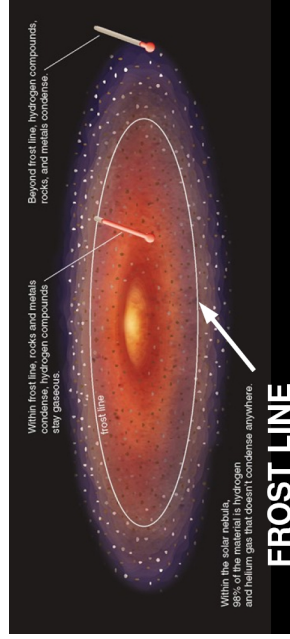
$$\text{Venus} = (3+4)/10 = 0,7 \text{ AU}$$

$$\text{Earth} = (6+4)/10 = 1 \text{ AU}$$

Solar System Formation

Widely accepted theory: *The Nebular Theory* from Immanuel Kant

- Solar system formed out of gravitational collapse of gas (Solar Nebulae)
- The gas heated up and spun up
- Flattened to form **accretion disks**



Terrestrial planets are formed inside the **frost line**

- Beyond the frost line, ice can exist; more and larger planetesimal formed
- Large icy planetesimals capture gas and make miniature solar nebulae; these have accretion disks which form moons and/or rings
- Leftover planetesimals became asteroids and comets
- Kuiper belt = outer part of accretion disk that never formed full-scale planets
- Oort cloud = icy planetesimals flung away by encounters with jovians

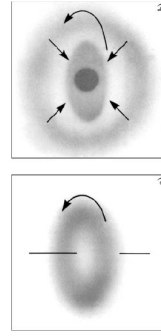
Planetary Comparison

Planet	Diameter (Earth)	Mass (Earth)	Orbital Radius (AU)	Orbital Period (Year)	Rotational Period (Day)	Number of satellite
Mercury	0.38	0.06	0.39	0.24	58.64	-
Venus	0.95	0.82	0.72	0.62	-243.02	-
Earth	1	1	1	1	1	1
Mars	0.53	0.11	1.52	1.88	1.03	2
Jupiter	11.21	317.8	5.2	11.86	0.41	63
Saturn	9.45	95.2	9.54	29.46	0.43	60
Uranus	4.01	14.6	19.22	84.01	-0.72	27
Neptune	3.88	17.2	30.06	164.8	0.67	13

Does it have enough accuracy?

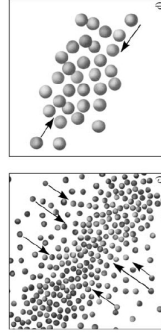
Planet	Astronomical Unit	Titius-Bode
Mercury	0,39	0,4
Venus	0,72	0,7
Earth	1,00	1,0
Mars	1,52	1,6
(Asteroid)		2,8
Jupiter	5,20	5,2
Saturn	9,54	10,0
Uranus	19,22	19,6
Neptune	30,06	38,8

a) a large rotating cloud (3-4 solar mass) start to condense

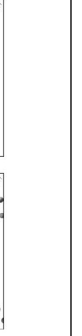


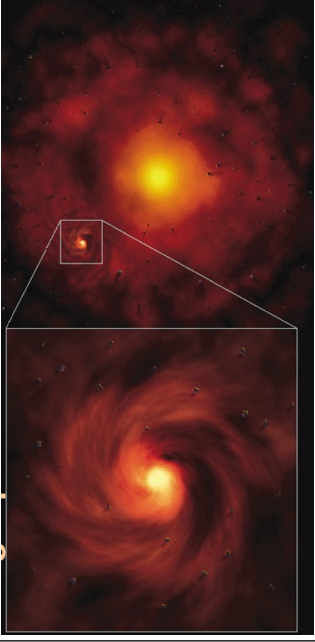
b) a disk of gas and dust formed around the protosun

c) dust particles in the disk collided with each other forming a larger particle



d) particles clumped together into planetesimals





Forming the jovian planets

The Age of The Solar System

- The oldest rock found in Moon and meteorites has the age of 4.4 billion years old → it's about the age of the Solar System

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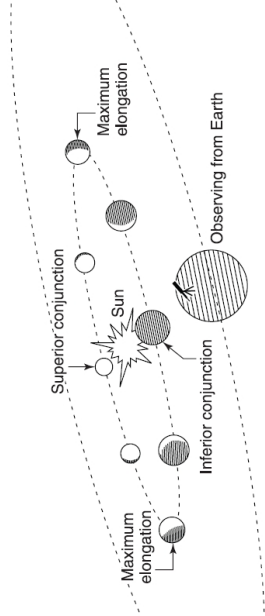
Solar System (2)

Planet Observation

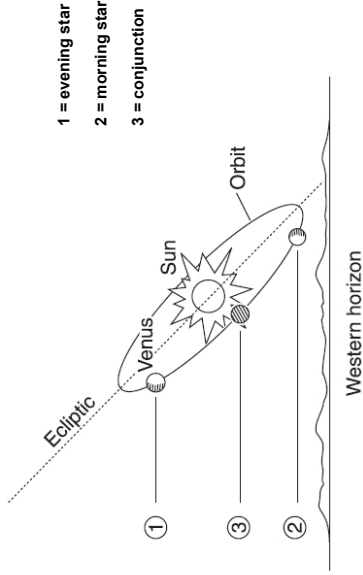
- The planets whose orbits are close to the Sun than Earth's are called **inferior**, while those whose orbits are outside Earth's are called **superior**
- The planets move across the celestial sphere near the ecliptic
- The superior planets generally move eastward through the constellations of the zodiac
- Sometimes the planet seem to move westward, called **retrograde motion**

- Venus and Mercury appear to move forward and backward on either side of the Sun in Earth's sky with **maximum elongation** (distance east or west of the Sun) is 48° for Venus and 28° for Mercury
- Inferior planets show phases as they reflect sunlight to Earth from different places in their orbits around the Sun (like the Moon)
- An inferior planet looks fully lit near **superior conjunction** (the point on the far side of the Sun from Earth)
- It appears as a crescent and biggest near **inferior conjunction** (the point between Earth & Sun)

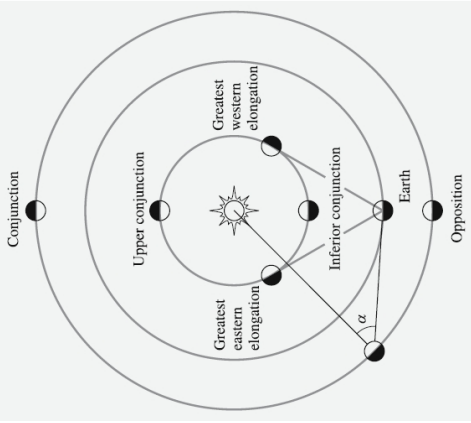
The phases of Venus



The phase of venus



- Superior planets look brightest when they are in the opposite side of Earth from the Sun (The Earth is between the Sun and the planet), such position is called **opposition**
- Superior planets are hardest to observe when they are on the opposite site of the Sun (the planet is behind the Sun), such position is called **conjunction**
- In practice, the planet may not be exactly opposite or behind the Sun because the orbit of the planet and the Earth are not in the same plane

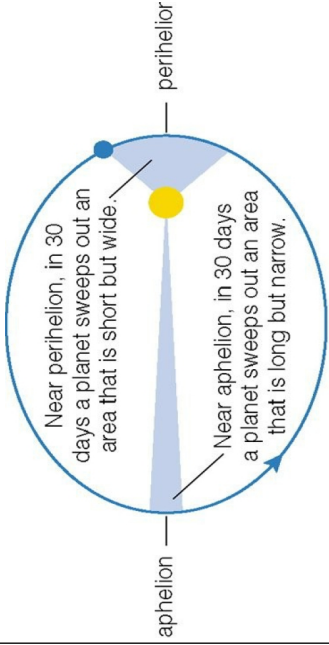


- Inferior planets (Mercury and Venus) are never in opposition
- When the planet is between the Sun and the Earth, it is called **inferior conjunction**
- When the planet is behind the Sun, then it is called **superior conjunction**
- Elongations are called eastern or western depending on which side of the Sun the planet is seen:
The planet is an 'evening star' when it is in **eastern elongation**, and as a 'morning star' when it is in **western elongation**

Period of Revolution

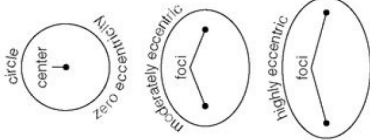
- The period of revolution is the length of time for a celestial body to go around its orbit once
- A planet's **sidereal revolution period** is measured relative to the stars → the length of the planet's year in term of Earth time
- A planet's **synodic revolution period** is the planet's orbital period as seen from Earth

Kepler's Second Law



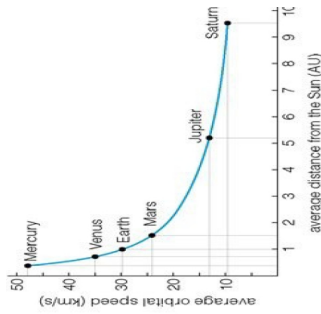
The areas swept out in 30-day periods are all equal.
(A planet moves faster at perihelion and slower at aphelion)

Eccentricity



- A circle is a special case of an ellipse
- Eccentricity (e) define the shape of the ellipse
- For a circle, $e = 0$
- For an ellipse, $0 < e < 1$

Kepler's Third Law



- $p^2 = a^3$
- p = planet's orbital period in years
- a = average distance from the Sun in AU
- Thus, distant planets moves more slowly

Sidereal-Sinodic Period Relation

- Let the sidereal period of two planets are P_1 and P_2 (assume that $P_1 < P_2$), then the sinodic period of the inner planet is

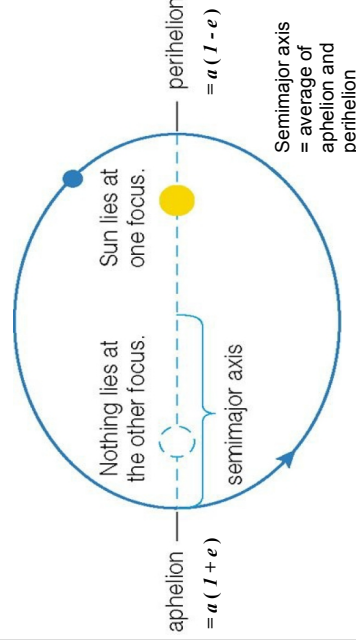
$$\frac{1}{S} = \frac{1}{P_1} - \frac{1}{P_2}$$

- Exercise: the time interval between two successive oppositions of Mars is 780 days. What is the sidereal period of Mars?

Kepler's Laws

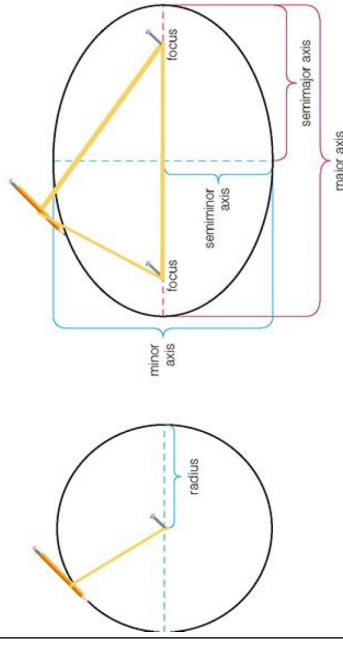
- 1 The orbit of each planet is an ellipse with the Sun at one focus
- 2 For any planet, the radius vector sweeps out equal areas in equal times
- 3 The cubes of the semi-major axes of the planetary orbits are proportional to the squares of the planets' periods of revolution

Kepler's First Law



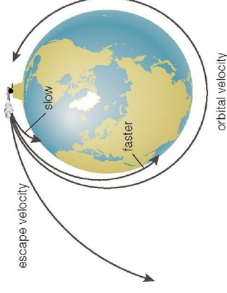
Semimajor axis = average of aphelion and perihelion

Ellipse



- When an object gains enough energy to enter an unbound orbit, then it achieves the **escape velocity**

- Any object requires a velocity of **11 km/s** to escape from the Earth's surface



Newton's Law on gravitation

- Every mass attracts every other mass
- The force of attraction is directly proportional to the product of the masses
- The force of attraction decreases with the square of the distance between the masses

$$F = G \frac{Mm}{r^2}$$

- $G = 6,67 \times 10^{-11} \text{ m}^3/\text{kg s}^2$

How?

- From the law of energy conservation: the mechanical energy on Earth's surface = the mechanical energy above the Earth

$$EP_1 + EK_1 = EP_2 + EK_2$$

$$\frac{-GMm}{R} + \frac{1}{2}mv^2 = \frac{-GMm}{r} + 0$$

since $r \rightarrow \infty$ in order the gravity to vanish, then

$$v_{exc} = \sqrt{\frac{2GM}{R}}$$

Problem

- A 'geostationary' satellite always appears directly overhead (useful for communication) since the orbital period is 1 day. Find the possible orbital radius!

- From the law of gravitation, Newton proved that the orbits of the planets should be an ellipse and that the general version of the third Kepler's law would be:

$$p^2 = \frac{4\pi^2}{G(M+m)}a^3$$

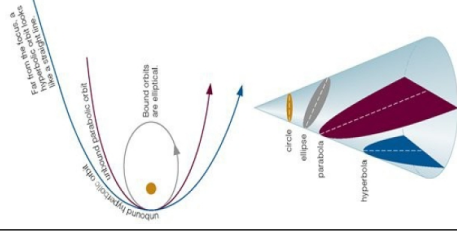
Can use any units,
not just AU and year
 $M = \text{mass of the Sun}$
 $m = \text{mass of the planet}$

- Since $M \gg m$, then

$$p^2 \approx \frac{4\pi^2}{GM}a^3$$

Another generalization from Newton:

- Ellipse is not the only kind of orbit
- **Bound orbit:** object goes around and around
- **Unbound orbit:** object loops around just once
- Described mathematically by conic section

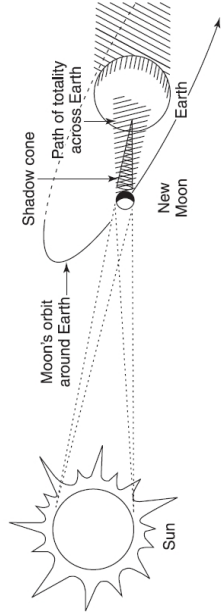


Moon at Apogee and Perigee



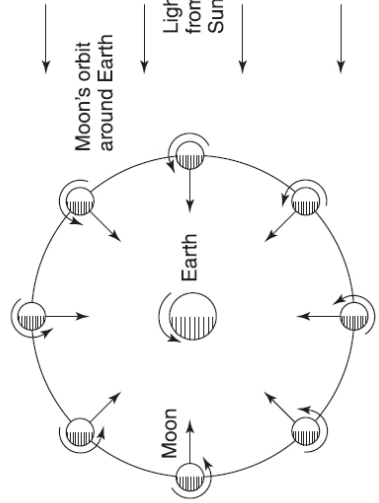
- A solar eclipse occurs when the Earth, new Moon, and Sun are directly in line
- The eclipse is **total** when the Moon is closer to Earth than the length of its shadow cone (max. duration is 7.5 minutes)
- A **partial eclipse** occurs when the Moon is not close enough to the Sun-Earth line so the Sun is not all blocked from view. It also can be seen around the path of the total eclipse

Solar Eclipse



- Full Moon occurs 12.37 times a year, so months having two full Moons occur every 2.72 years
- The second full Moon within a particular month is called **blue Moon**
- The mean time required for the Moon's phases to repeat is called a **synodic month** or **lunation** which is 29.5 days
- Since it revolves (with Earth) the Sun, the Moon changes its location with respect to the stars about 13° (52 minutes) to the east every day

- Since the rotation period of the Moon == The revolution period orbiting the Earth (27.3 days), then the Moon has a **synchronous rotation** = the same side of the Moon face the Earth at all times
- A **lunar halo** happens when ice crystals high up in Earth's atmosphere refract Moonlight as it passes through



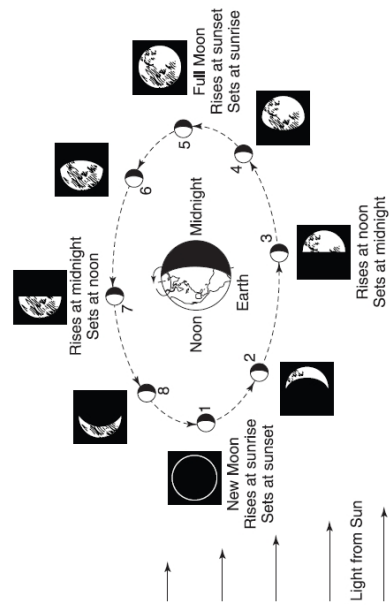
ASTRONOMY

The Moon

Moon Phases

- Phases of the Moon = the recurring cycle of apparent shape of the Moon seen from Earth:
 - New Moon
 - Waxing (growing bigger) Crescent
 - First Quarter
 - Waxing Gibbous
 - Full Moon
 - Waning (growing smaller) Gibbous
 - Third Quarter
 - Waning Crescent
 - New Moon

Moon Phases



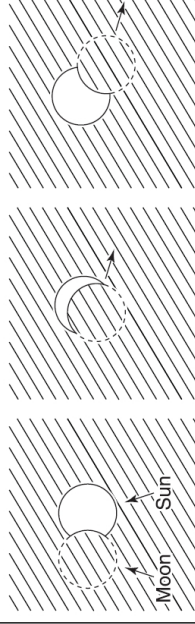
Total Eclipse



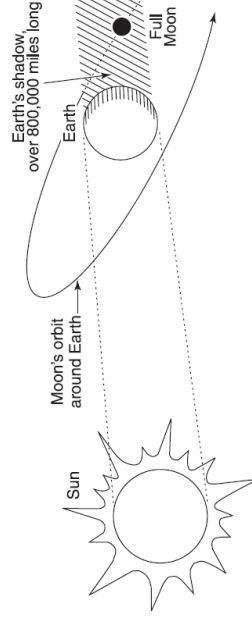
Eclipse of the Moon

- A lunar eclipse occurs when the Sun, Earth and full Moon are directly in line
- The Moon darkens when it enters Earth's shadow, but it still gets some sunlight from Earth's atmosphere (refracted sunlight)
- Max. duration of lunar eclipse in 21st century is 1 hour and 43 minutes occurred on July 27, 2018

Partial Eclipse



Lunar Eclipse

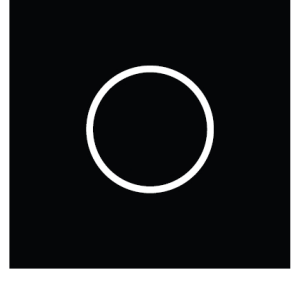


Occultation

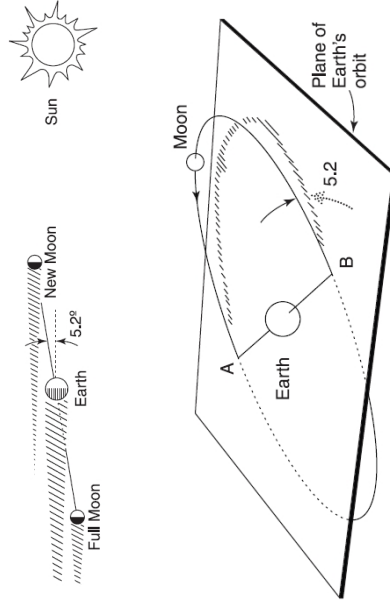
- Occultation = the eclipse of one sky object by another
- **Lunar occultation** occurs when it passes stars or planets



- An **annular eclipse** occurs when the Moon is farther from Earth than the length of its shadow cone
annulus = ring



- Eclipses do not occur every time we have a new or full Moon since the Moon's orbit is tilted 5.2° to the plane of Earth's orbit
- The Moon's orbit crosses the plane of Earth's orbit at two points called **nodes**
- Eclipses only occur when new or full Moon crosses the nodes

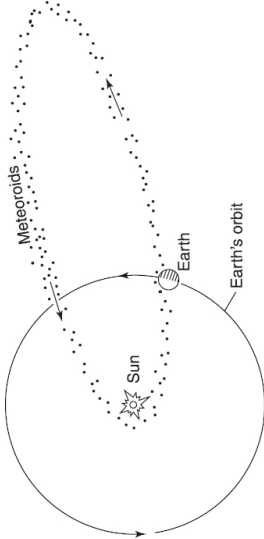


ASTRONOMY

Small Solar System Bodies

Near Earth Objects (NEO)

- NEO = asteroids and comets that regularly come nearby
- If the NEOs struck the Earth, the impact hazard is described using the **Torino Scale**, from 0 (safe) to 10 (dangerous and catastrophic)



List of Meteor Shower

- Quadrantids (max. on January 3)
- Lyrids (max. on April 21)
- Eta Aquarids (max. on May 4)
- Delta Aquarids (max. on July 30)
- Perseids (max. on August 12)
- Orionids (max. on October 21)
- Taurids (max. on November 4)
- Leonids (max. on November 18)
- Geminids (max. on December 13)
- Ursids (max. on December 22)

Comets

Meteoroids

- **Meteors** = streaks of light created by **meteoroids** plunging through Earth's atmosphere and being burned from the air's friction. Commonly called '**shooting stars**'
- When they hit the Earth's surface, then they are called **meteorites**
- A large meteoroid will create an exceptionally brilliant meteor called **fireball**
- Probably fragments of asteroids since they have similar composition

Meteor showers

- Meteor showers = meteors pour down from one part of the sky (**radiant** of the shower) in predictable dates every year, associated with comets
- Usually can be seen after midnight

Asteroids

- Asteroid = starlike (in Greek)
- Asteroids = Small, irregularly shaped rocky bodies that orbit the Sun inside the **asteroid belt** between the orbits of Mars and Jupiter
- The largest asteroid is Ceres (with diameter of 950 km), being the first asteroid discovered (in 1801)
- The brightness of asteroids are vary and repeat after several hours, indicating that they have irregular shapes and are rotating

The types of asteroids

Based on spectrophotometry:

- C-type : carbonaceous, very dark, usually in the outer belt
- S-type : contains silicates mixed with metals, moderately bright, usually in the inner belt
- M-type : metallic, very bright

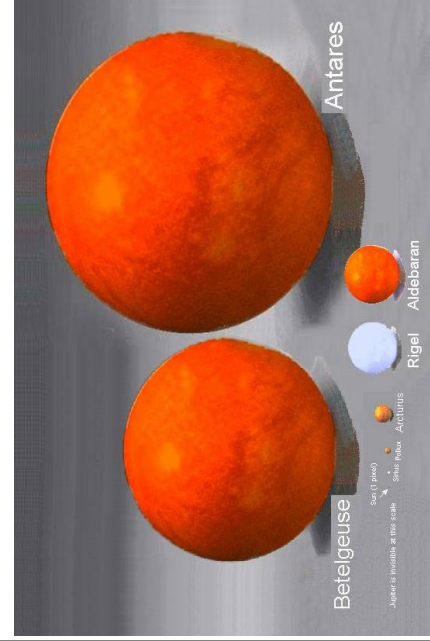
Star's distance (parsec) = $\frac{1}{\text{parallax (second of arc)}}$

- The measured parallax of α -Centauri is 0.74", so

$$\alpha\text{-Cen's distance} = \frac{1}{0.74''} = 1.35 \text{ pc} = 4.4 \text{ ly}$$

- The measured parallax of Sirius is 0.38", what is its distance in light-year?
- Canopus has the parallax of 0.01", what is its distance?
- Proxima Centauri (the closest star to the Sun) has the parallax of 0.77", what is its distance?

- Proxima Centauri is the closest star to the Sun, but it cannot be seen since it is very dim
- Sirius is the brightest star in the Sky, but its distance is farther than Proxima's
- The brightness of a star cannot be used in determining its distance
- The brightness of a star may related to its size



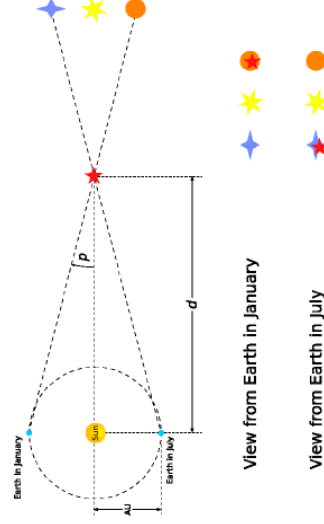
- Light years tells the distance of a celestial object
- However, it also tells the time needed to reach the object

- The speed of light is 3×10^8 m/s**

- Hence, from Earth to the Moon, light needs 1 sec
- From Earth to the Sun: 8 minutes
- to the nearest visible stars (α -Centauri): 4 years
- The distance to α -Centauri is 4 years
- So, now you see the α -Centauri 4 years ago
- What's the state of α -Cen right now... ? Wait until 4 years
- When you see the stars, you see the past...

Parallax

- The method of **parallax** is used in measuring the distance of the nearby stars
- Nearby stars appear to shift back and forth relative to more distant stars as Earth revolves around the Sun (**called stellar parallax**)
- Stellar parallaxes are very small, measured in **second of arc** ($1'' = 1/3600^\circ$)
- 1 parsec (pc) = the distance to a star whose parallax is 1 second of arc ($1''$)
- 1 pc = 3.26 light-years**



$p = \text{parallax}$
 $d = \text{Star's distance to the Sun}$

ASTRONOMY

The Stars

Distance

- How far is the stars? How far is the celestial bodies? How big is our universe?
- In astronomy, distance is not always stated in *meter*
- Commonly used distance units:
 - Astronomical Units (AU)
 - Light Years
 - Parsec

Star Magnitude

Sun	-26,80
Sirius	-1,46
Canopus	-0,72
Alpha Centauri	-0,27
Arcturus	-0,04
Vega	0,03
Capella	0,04
Rigel	0,12
Procyon	0,35
Achernar	0,46
Hadar (β -Cen)	0,66
Betelgeuse	0,70
Altair	0,77
Aldebaran	0,85
Acrux	0,87
Antares	0,92
Spica	1,00

Measuring Star's Brightness

- **Apparent magnitude (m)** is a measure of how bright a star appears
- Hipparchus (Ancient Greek Astronomer) classified the stars in 6 classes based on their brightness (1 for the brightest stars and 6 for the dimmest stars that can be seen)
- Modern magnitude scale defines that a first-magnitude star is exactly 100 times brighter than a sixth-magnitude

- Magnitude differences between stars measure the relative brightness of the stars
- It can be calculated from **Pogson's scale**:

$$m_A - m_B = -2.5 \log \left(\frac{I_A}{I_B} \right)$$

m = magnitude ; I = brightness

- Brightest stars are not always associated with bigger stars, it can be related to their close distance

- Apparent magnitude cannot tell the true brightness of stars

- If we can line up all stars at the same distance from Earth, we can see how they differ in true brightness

- **Absolute magnitude (M)** is the apparent magnitude of stars if it were located at 10 pc from Earth
- It can be calculated from the **distance modulus** (the difference between apparent and absolute magnitude)

$$m - M = 5 \log \left(\frac{\text{distance in parsec}}{10} \right)$$

Intensity

- The intensity of a star is represented by **radiation flux**, defined as the energy emitted each second each area units
- The 'true' intensity of a star (radiated flux) whose radius is R can be calculated as

$$F_{\text{radiated}} = \frac{L}{4\pi R^2} = \sigma T^4$$

- The apparent intensity of a star (received flux) from a distant of r can be calculated as

$$F_{\text{received}} = \frac{L}{4\pi r^2}$$

- So, the Pogson's formula can be rewritten as:

$$m_A - m_B = -2.5 \log \frac{F_A}{F_B}$$

where F_A and F_B are the received flux and m_A and m_B are the apparent magnitudes

- The Pogson's formula can also be rewritten in absolute magnitude term as

$$M_A - M_B = -2.5 \log \frac{L_A}{L_B}$$

where L_A and L_B are the luminosities and M_A and M_B are the absolute magnitudes

Example:

- Sun's received flux at the Earth's outer atmosphere is known as $F = 1368 \text{ W/m}^2$ (called the **Solar constant**). The distance of the Sun is 1 AU and the radius of the Sun is $7 \times 10^8 \text{ m}$. What is the luminosity of the Sun and its surface temperature?

- Answers:

$$L = F_{\text{received}} 4\pi r^2 = 1368 \times 4 (1.5 \times 10^{11})^2 \text{ W} = 3.86 \times 10^{26} \text{ W}$$

since $L = 4\pi R^2 \sigma T^4$ then $T \approx 6000 \text{ K}$

BlackBody Radiation

- A body which is able to absorb or emit energy totally (a perfect absorber or emitter) \rightarrow It is not always looked black!
- The radiation emitted from a blackbody is called **blackbody radiation**
- All bodies which have heat radiate blackbody radiation
- Hotter blackbody generates higher intensity of radiation

Wien's Law of Radiation

- Wien stated that the wavelength, λ_{max} , at which a blackbody emits the greatest amount of radiation is inversely proportional to its temperature

$$\lambda_{\text{max}} = \frac{0.29}{T} \text{ (cm)}$$

- Example: human beings have a normal body temperature at 36°C . What is the wavelength of the maximum radiation of human body?

Luminosity

- The amount of energy emitted each second from a star is called **luminosity**
- It can be calculated from the temperature of a star and its radius using **Stefan-Boltzmann's Radiation Law**:

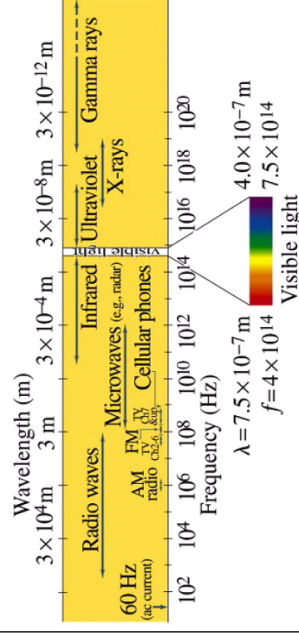
$$L = 4\pi R^2 \sigma T^4$$

- $\sigma = 5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$ is the **Stefan-Boltzmann's constant**

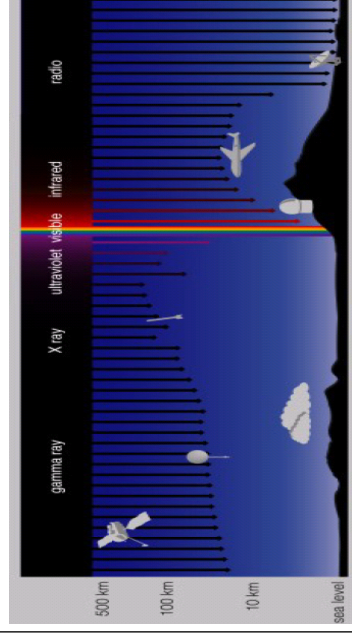
ASTRONOMY

The Stars (2)

- We cannot touch the stars. The only way to study them is from the radiated electromagnetic waves
 - Stars emits thermal radiation in all range of electromagnetic wavelengths
- Spectrum of the electromagnetic waves:



Unfortunately, not all the wavelength can reach Earth's surface, most of them are absorbed by Earth's atmosphere. Only visible and radio wavelength successfully touch the ground

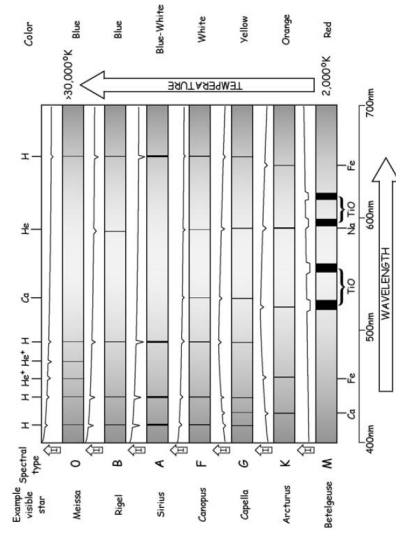


Spectral Classes

Absorption spectra are used to classify stars into 7 principal types called spectral classes:

Spectral Class	Approximate Temperature (K)	Main Class Characteristics
O	>30,000	Relatively few lines; lines of ionized helium
B	10,000–30,000	Lines of neutral helium
A	7,500–10,000	Very strong hydrogen lines
F	6,000–7,500	Strong hydrogen lines; ionized calcium lines; many metal lines
G	5,000–6,000	Strong ionized calcium lines; many strong lines of ionized and neutral iron and other metals
K	3,500–5,000	Strong lines of neutral metals
M	2,000–3,500	Bands of titanium oxide molecules
L	1,300–2,000	Bands of iron hydride molecules
T	~700–1,300	Methane and water vapor

The differences in the dark line patterns of stars are due to their enormously different surface temperature



Star's Motion

- Stars move through the space with respect to the Sun, hence they have a **space velocity**
- Space velocity has two components: **radial velocity** (speed toward or away from us along the line of sight) and **proper motion** (amount of angular change in a star's position per year)
- A star's radial velocity is determined from **Doppler shift** analysis of its spectrum
- The star's wavelengths are shorter (**blueshift**) when it is moving toward us and longer (**redshift**) when it is moving away from us

Stellar Spectra

- Starlight is composed of many different wavelengths
- When starlight is separated into its component wavelengths, the resulting **spectrum** holds many clues about the stars
- There are three basic types of spectra, each produced under different physical condition

Continuous spectrum:



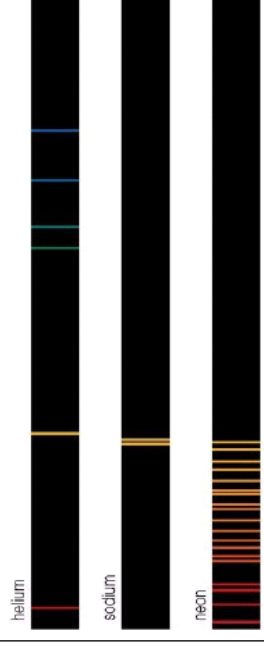
Emission (bright-line) spectrum:



Absorption (dark-line) spectrum:

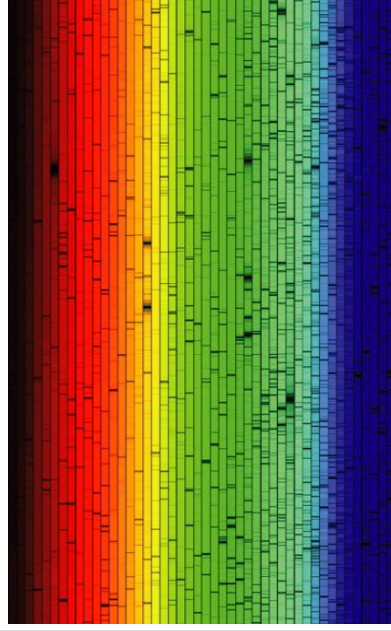


Each chemical element has a unique spectrum (similar to the finger-print)

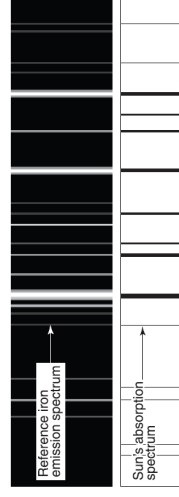


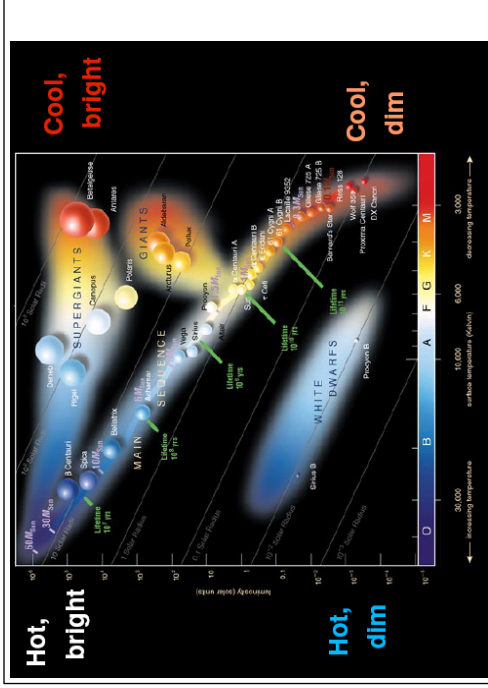
- Spectrum of stars (stellar spectra) are patterns of dark lines crossing a continuous band of colors
- Light from star's surface is radiated into a continuous spectrum
- As the light travels through the star's outer atmosphere, some of the colors are absorbed, producing dark absorption lines
- These absorption lines identify the chemical elements that make up the star's atmosphere

Spectrum of The Sun



The chemical composition of stars can be determined by analyzing the dark lines in the star's spectrum and comparing them with those of each of chemical elements on Earth





redshift:

Reference lines from laboratory source

Absorption lines from star

blueshift:

Reference lines from laboratory source

Absorption lines from star

- If the velocity is non-relativistic, the change in wavelength ($\Delta\lambda$) is proportional to the relative velocity $v = \frac{\Delta\lambda}{\lambda} c$; $\lambda =$ the wavelength of a stationary source
- The average proper motion for all visible stars is less than 0.1 second of arc (0.1") per year
- At that rate, we will not notice any change in the appearance of the constellations during our lifetime

Hertzsprung-Russell (H-R) Diagram

- The relation between luminosities and temperatures of stars was discovered by *Henry Russell* of U.S. and *Ejnar Hertzsprung* of Denmark in the early of 20th century
- H-R diagram is a plot of luminosity versus temperature
- The horizontal axis represents the temperature and the vertical axis represents the luminosity
- In the diagram, 90% of stars lie along a diagonal band called the main sequence

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- At the Sun's core, hydrogen is fused into helium, generating Sun's energy
- In order to have the nuclear fusion, the temperature must be 15 million K
- The energy released in the core is slowly transmitted outward through the radiation zone, where photons are repeatedly absorbed and re-emitted at lower energies
- Then, circulating currents of gas in the convection zone transfer the energy as heat to the outer layer
- It takes 20 million years for energy produced in the core to surface and become sunshine

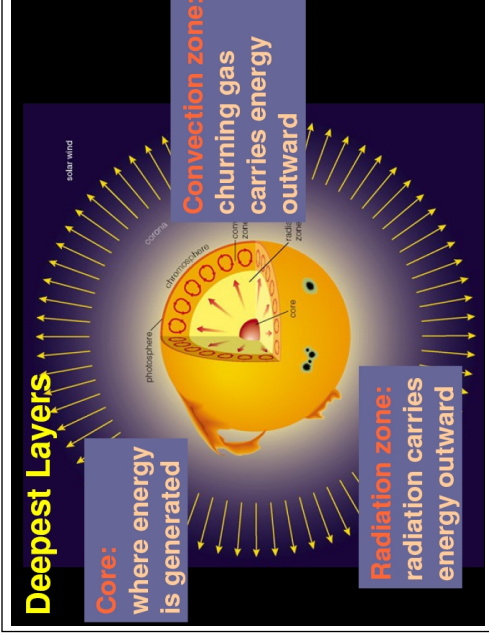
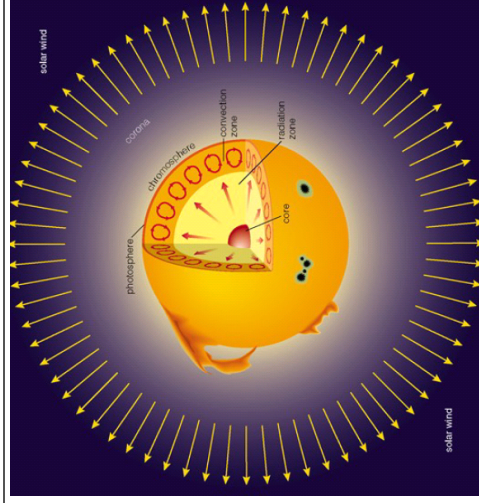
Sun's Structure

- Inner structure
 - Core
 - Radiation Zone
 - Convection Zone
- Atmosphere
 - Photosphere
 - Chromosphere
 - Corona

Sun's Atmosphere

- The **Photosphere** (Greek for 'light ball')
 - The visible surface of the Sun
 - Hot, thin and opaque gas layer with temperature of 5800 K
- The **Chromosphere** (Greek for 'color ball')
 - Thin, transparent layer extending 10000 km above the photosphere
 - Average temperature is 15000 K, increases outward
 - Normally visible from Earth only during total eclipse of the Sun as a red/pink thin layer due to hydrogen gas

Chromosphere

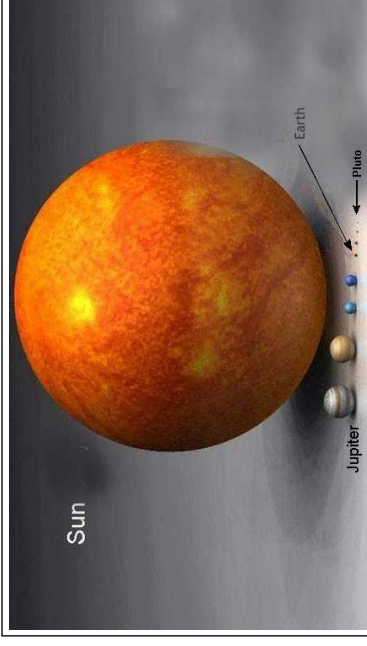


ASTRONOMY

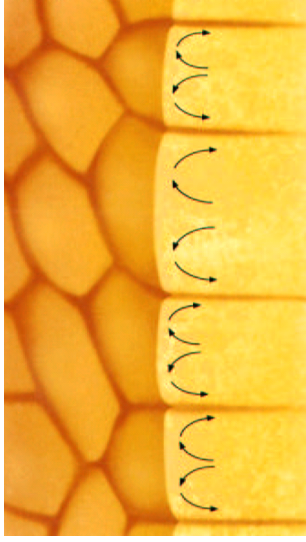
The Sun

Sun's Properties

Quantity	Value	Method of Measurement
Distance from Earth	150 million km	Radar ranging
Angular diameter	30'	Solar telescope
Radius	700 000 km	angular diameter and distance
Mass	2×10^{30} kg	planets' orbital motion
Density	1400 kg/m ³	mass and volume
Solar constant (received flux)	1400 watt/m ²	High-altitude aircraft
Luminosity	3.85×10^{26} watt	solar constant and distance
Surface Temperature	5800 K	luminosity and radius
Apparent Magnitude	-26.74	Photometer
Absolute Magnitude	4.8	apparent magnitude and distance
Rotation period	Equator: 25 days ; Poles: 35 days	Sunspot's motion
Surface gravity	28 times Earth's or 294 m/s ²	



Size comparison between the Sun and its planets

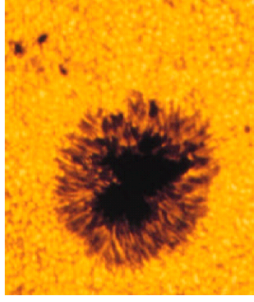


Granules are the tops of rising currents of hot gases from the convection zone

- The **Corona** (Latin for 'crown')
- The outermost Sun's atmosphere
- Rarefied, hot gas extending millions kilometers into space
- Shines bright at X-ray wavelength since its high temperature (up to 2 million K)
- During total eclipse of the Sun, it is visible as a white halo around the hidden photosphere

Sunspots

- Temporary, dark, relatively cool spot on the Sun's bright photosphere
- A typical sunspot is roughly as big as Earth

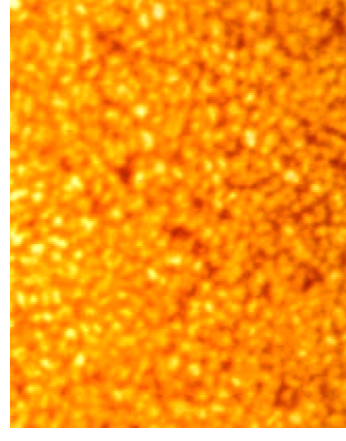


- More than 300 sunspots, or none at all, may appear on the Sun's disk
- The maximum and minimum number of the sunspots is in a cycle of 11 years called sunspot cycle which displays the solar activity cycle
- The sun is most active during the sunspot maximum
- The sun is least active during sunspot minimum
- The last recorded solar activity is in 2001 when sunspot number soared

Corona



The photosphere has a grainy appearance called **granulation**, composed of **granules**



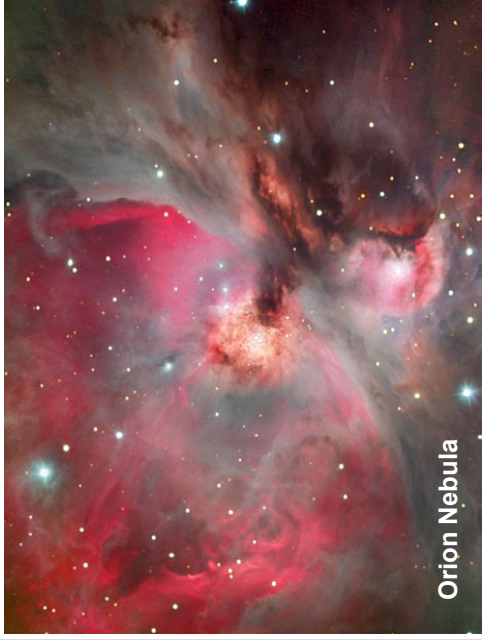
ASTRONOMY

Stars Evolution

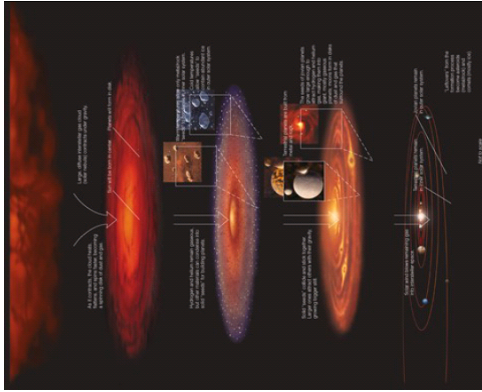
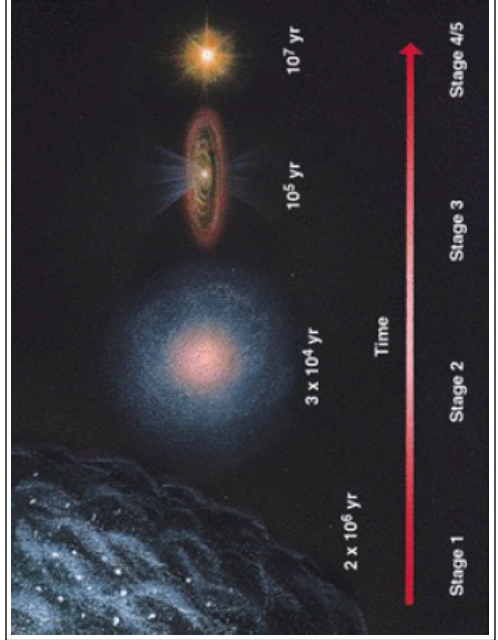
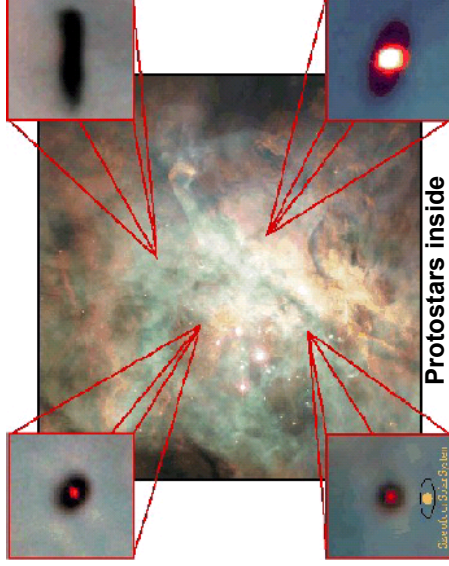
Stars Birth

- Stars form out of matter that exists in space called **interstellar medium** in the form of **nebulae** (cloud of gas and dust)
- When a **shock wave** triggers the nebula to form a high-density clumps, **protostars** is born
- The force of gravity pulls in matter toward the center of the dense clump, causing it to contract and become denser
- Gravitational contraction of the cloud and protostar causes the temperature and pressure inside to rise greatly

- Heat flows from the protostar's hot center to its cooler surface, making it shines at infrared wavelength
- When the temperature in the protostar's center reaches 10 million K, nuclear fusion starts and releases tremendous amounts of energy
- The outward pressure from the internal heat balances the inward pull of gravity (called **hydrostatic equilibrium**)
- The protostar stops contracting. It shines its own light steadily into space. The protostar becomes a newborn star

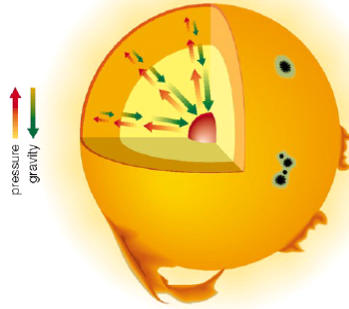


Orion Nebula

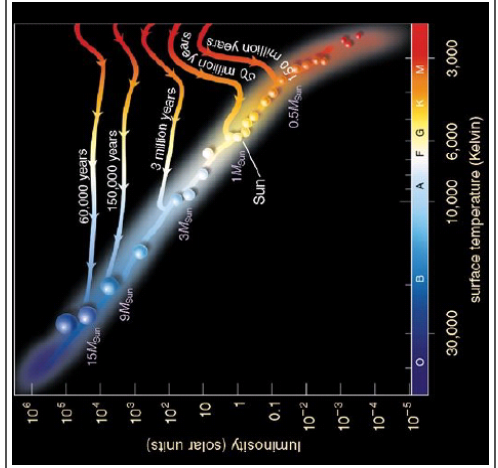


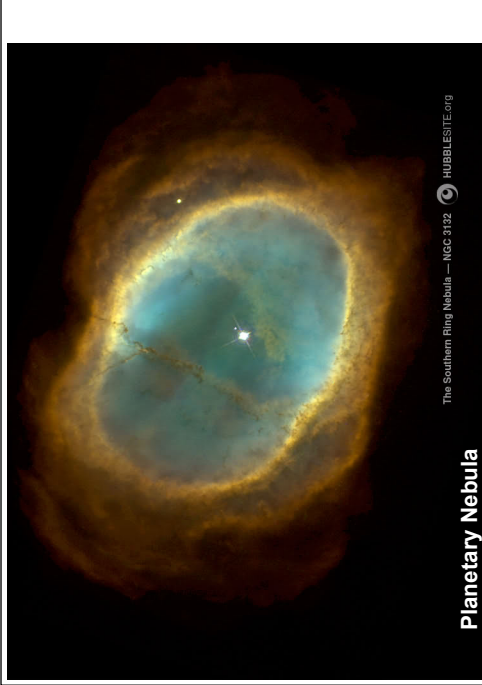
In a rotating cloud, a disk of dust and gas may surround a protostar. Possibly particles in the disk accrete to form planets

Hydrostatic Equilibrium



The clouds in which protostars form do not have identical masses. The bigger the mass, the shorter time it takes to be born





Planetary Nebula

The Southern Ring Nebula — NGC 3132 © HUBBLESITE.ORG

White Dwarf

- After throwing off its gas layer, the star remains as a core of carbon and no longer withstand the pull of gravity
- Gravitational contraction makes the temperature and pressure go up very high and electrons are stripped off atoms
- The star becomes a small, hot **white dwarf** which consists of electron and nuclei

Supernova

- Most stars of > 8 times the Sun's mass die in a big explosion called **supernova**
- Their carbon cores contract gravitationally causing the temperature to reach 600 million K. Then it begins to fuse into magnesium
- When the carbon in the core is used up, a new cycle begins. Elements heavier than carbon are produced inside the star, until the core is mainly iron
- The star's core collapses for the last time until it cannot be compressed any further. Then it explodes violently as a supernova

- As the star expands, its surface temperature drops and its surface color turns to red → **red giant or supergiant**
- The temperature of the giant's core rises to 100 million K, triggering the nuclear fusion reactions where helium is converted into carbon

Life times

- Stars of similar chemistry with higher mass evolve faster, while those of lower mass take the longer time to evolve
- Higher mass stars appear brighter since they fuse more hydrogen
- But if the nuclear fusion is more rapid, the hydrogen in the core runs out faster

Stars Death

- All stars evolve in about the same way, until their cores become mostly accumulated carbon
- The last stage in a star's evolution depends mostly on its mass
- Small stars, ≤ 1.4 times the Sun's mass, finally die quietly, fading away into the blackness of space
- Very massive stars end up with a violent explosion, flaring up brilliantly before giving up life

Planetary Nebula

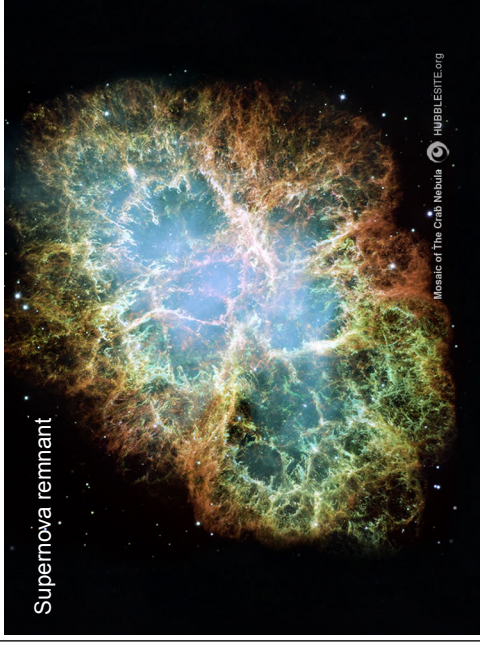
- When a star of mass like our Sun has depleted all of its available helium fuel, it becomes a red giant star for the last time
- The star then throws off some of its mass, the outermost hydrogen layer flies off into space
- Deeper layers are thrown off in an expanding shell of gas called **planetary nebula**
- The star's core is left behind

Old Age

- A star will shine steadily until all the available hydrogen in its core has been converted into helium, then the star will begin to die
- Very massive stars die fastest because they use up their hydrogen most rapidly
- The least massive stars live the longest because they consume their hydrogen least rapidly

- After the hydrogen fuel in the star's core is used up, the star no longer has an energy source there. The core then consists primarily of helium
- The core then begins to contract gravitationally, causing the temperature of the core to rise which in turn heats up the surrounding layers
- The star expands to gigantic proportions where the density is very low everywhere except in the core

Supernova remnant



Superdense Objects

- When a very massive star explodes, it leaves behind its extremely dense core made mostly of neutrons
- It was named a **neutron star** when it was first hypothesized
- In 1967, Jocelyn Bell of Cambridge University found **pulsar** (pulsating radio star) which is a rapidly rotating, highly magnetic neutron star
- If the star is really massive, it may continue to collapse after the pulsar stage to become a **black hole**

