Welcome to "Gravitation and Astrophysics"

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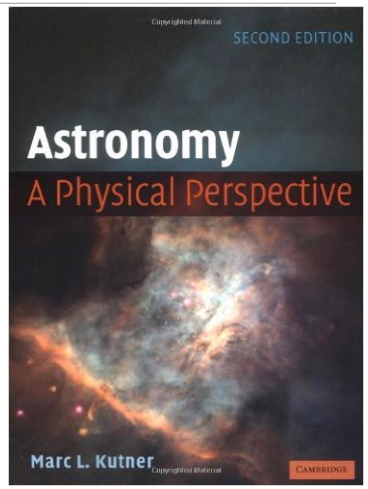
General info - "Gravitation and Astrophysics"

- 10 Lectures
- Assessment
  - End-of-year exam (1 out of 2 Questions)
    - ➡ Mastering Physics tutorial
    - ➡ late assignment won't receive any credits
- Problem sets and concept tests will be available on Blackboard.

My lecture notes will be available in Blackboard after each lecture

Recommended books

- Recommended text: *"Astronomy: a Physical Perspective"* by Marc Kutner, (Cambridge)
  - Check this link (google books)
- "University Physics" by Young & Freedman
- *Astronomy: a beginner's guide to the Universe*, Chaisson & McMillan. Pearson Education. Google books link.
- *The Cosmic Perspective*, Bennett et al., Pearson Education. Google books link.



What I expect from you: learn by doing

- Attend lectures & ask questions. Engage!
- In addition to mastering physics tutorial, you should work through concept tests and problem sets that will be available on Blackboard
- ResponseWare: can be used in any browser, or you can get an app for your phone/tablet.

www.responseware.eu
session ID: **gravity**

Lecture 1: Basic Astrophysical concepts

Reading: Ch. 1 of “The Cosmic Perspective” (Bennett et al.),
Ch. 0 “Astronomy” (Chaisson & McMillan),

Prof Aline Vidotto

What we will cover today…

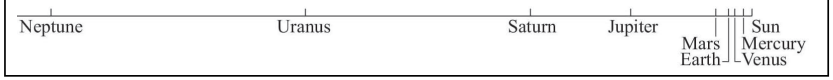
Goal: develop perspective of the universe (introduce the big picture)

1. The scale of the universe
2. Our movement through space
3. Basic Observations

1. The scale of the universe

Our place in the the solar system

Relative distances in the solar system: We are in a big empty space!



Planet	Sun-planet distance a (AU)	m	Titius-Bode law distance (AU)
Mercury	0.39	-∞	0.4
Venus	0.72	0	0.7
Earth	1.00	1	1.0
Mars	1.52	2	1.6
Ceres (asteroid belt)	2.77	3	2.8
Jupiter	5.20	4	5.2
Saturn	9.55	5	10.0
Uranus	19.22	6	19.6
Neptune	30.11	7	38.8

- The Astronomical Unit (AU or au) is the average Sun-Earth distance

Titius-Bode “law”:

$$a = 0.4 + 0.3 \times 2^m$$

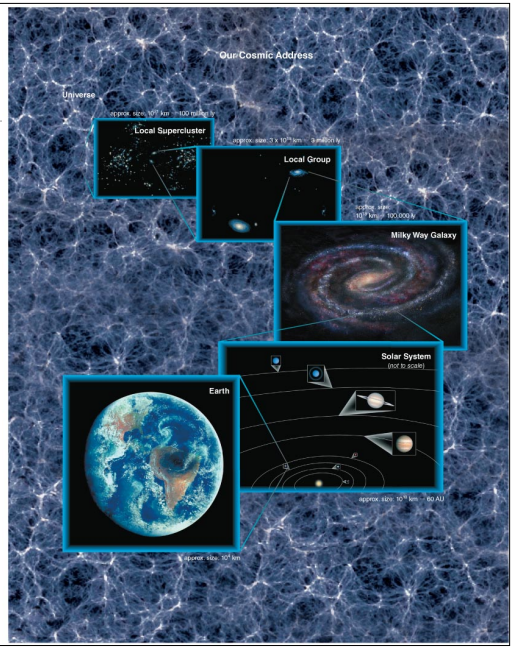
$$m = -\infty, 0, 1, 2 \ldots$$

Predicted before they were found!

*No need to memorise this! There is no theoretical explanation for the T-B law. Today, it is accepted as a simple mathematical coincidence.

Our place in the Universe

- Earth is part of the solar system, which is in the Milky Way Galaxy, which is a member of the Local Group of galaxies in the Local Supercluster.
- The Milky Way is one of about 100 billion galaxies.
- 10^{11} stars/galaxy x 10^{11} galaxies ≈ 10^{22} stars in the Universe
- and each star likely to have a planetary system



Far away means back in time

- Light travels at a finite speed (c≈300,000 km/s). Thus, we see objects as they were in the past

distance

Destination	Light travel time
Moon	1 second
Sun	8 minutes
Proxima Centauri (nearest star from Sun)	4 years
Andromeda Galaxy	2.5 million years

The farther away we look in distance, the further back we look in time.

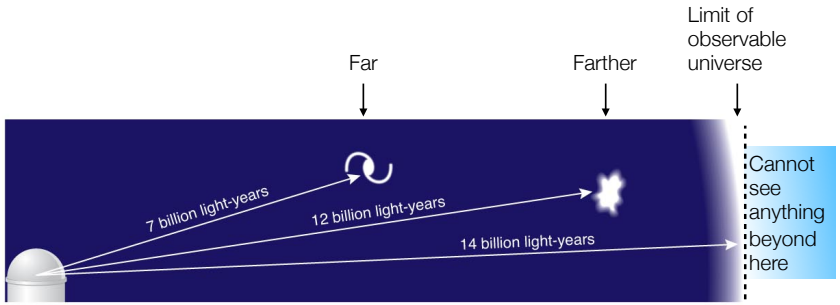
- **Light-year (ly)**: The **distance** light can travel in 1 year

$$1 \text{ light-year} = (\text{speed of light}) \times (1 \text{ year})$$
$$= \left(300{,}000 \frac{\text{km}}{\text{s}}\right) \times \left(\frac{365 \text{ days}}{1 \text{ yr}} \times \frac{24 \text{ hr}}{1 \text{ day}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{60 \text{ s}}{1 \text{ min}}\right)$$
$$= 9.46 \times 10^{12} \text{ km}$$

What is the size of the observable Universe?

- The Universe is ≈14 billion years-old, hence:

$$t = 14 \times 10^9 \text{yr} \longrightarrow \text{size} = 14 \times 10^9 \text{ ly} = 1.32 \times 10^{23} \text{ km}$$



Conceptual question

If the speed of light were half what it is now, then a "light-year" would

(a) take half as long to traverse at light speed
(b) take the same amount of time to traverse at light speed
(c) last twice as many months
(d) last half as many months

Conceptual question

If the speed of light were half what it is now, then a "light-year" would

(a) take half as long to traverse at light speed

(b) take the same amount of time to traverse at light speed

(c) last twice as many months

(d) last half as many months

Explanation: 1 light-year is defined as the distance light can travel in one year. Hence, if we could change the speed of light, we would not affect the time taken for light to travel in one year. However, the distance itself would change.

2. Our movement through space

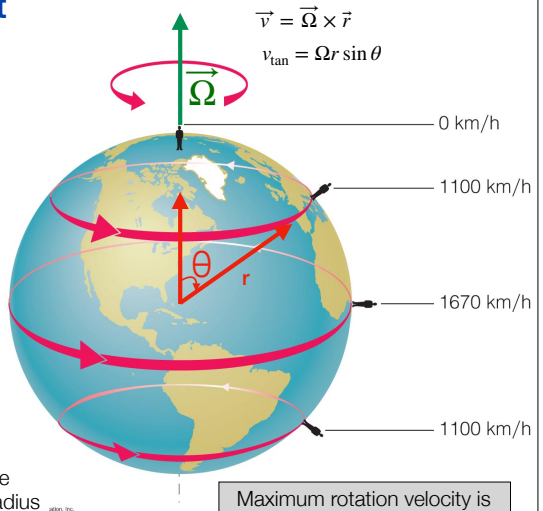
- The Earth rotates around its axis once every day, from West to East (*anticlockwise* as seen from above the north pole):

$$\Omega = \frac{2\pi}{P_{\text{rot}}} = \frac{2\pi}{24} = 0.26 \text{ rad/h}$$

- θ is co-latitude
- Ω is the angular rotation rate
- r = 6400km is the Earth's radius

$$\vec{v} = \vec{\Omega} \times \vec{r}$$

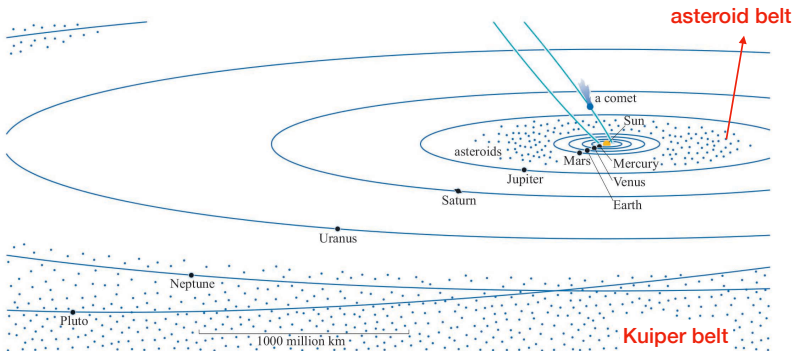
$$v_{\tan} = \Omega r \sin\theta$$



Maximum rotation velocity is 1675 km/h ≈ 0.46 km/s

the Earth is NOT flat

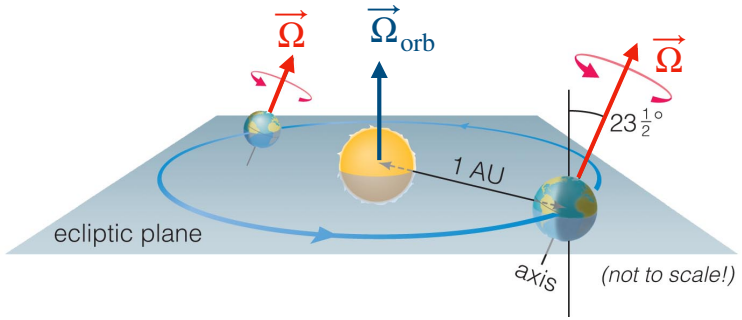
The Sun and all the planets lie in a "plane" called the "Ecliptic plane"



Note: Pluto does not orbit in the ecliptic plane. Part of the Kuiper belt along with many other similar objects (hence why it is classified as a "dwarf planet" and not a planet)

But Earth's rotation axis is not perpendicular to this plane

$\vec{\Omega}$ is tilted 23.5° with respect to $\vec{\Omega}_{orb}$



- The Astronomical Unit (AU or au) is the average Sun-Earth distance:

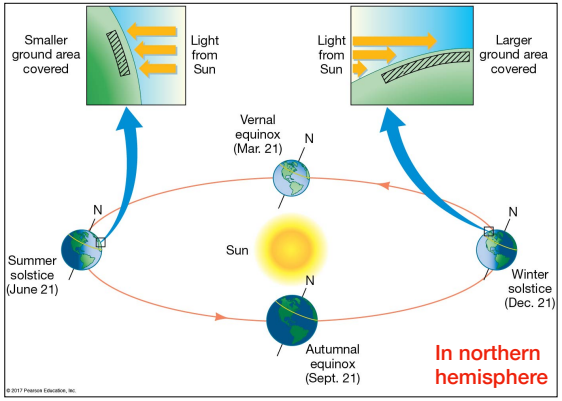
$$1 \text{ au} = 1.5 \times 10^8 \text{ km}$$

- Homework: Demonstrate that the orbital velocity of the Earth around the Sun is 30 km/s = 108,000 km/h.

The seasons

$\vec{\Omega}$ is tilted 23.5° with respect to $\vec{\Omega}_{orb}$

- Seasons are caused by the tilt of the Earth's rotation relative to the ecliptic (orbital plane)
- …**not by its distance from it.** Remember: Earth's orbit is nearly circular!



1) Same incident energy from the Sun throughout year, but different ground area coverages:
- Summer: Smaller area → rays more concentrated → heat delivered to a given area is greatest
- Winter: Larger area → rays less concentrated → less heat

2) In addition: more hours of daylight during summer → more heating

The seasons in other planets

- Seasons: summer is when your hemisphere is tipped toward Sun
- Other planets have different tilts, and thus different types of seasons
- Uranus has the most extreme seasons in Solar System
  - Uranus tilt is 98°: tipped on its side
  - Rotation lies almost in the orbital plane
  - Uranus takes 84 Earth-years to go around the Sun
  - So the North polar regions of Uranus have summer (in this case, continuous sunlight) for 42 Earth-years!

Wanna know why such a different tilt?
https://www.jpl.nasa.gov/edu/learn/video/dancing-uranus/

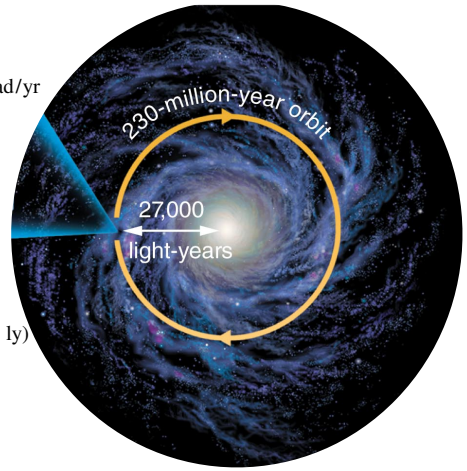
The solar system rotates around the Galactic centre every 230 million years

- Our Sun orbits the Galaxy every 230 million years.

$$\Omega_{sun/gal} = \frac{2\pi}{230 \times 10^6} = 2.73 \times 10^{-8} \text{ rad/yr}$$

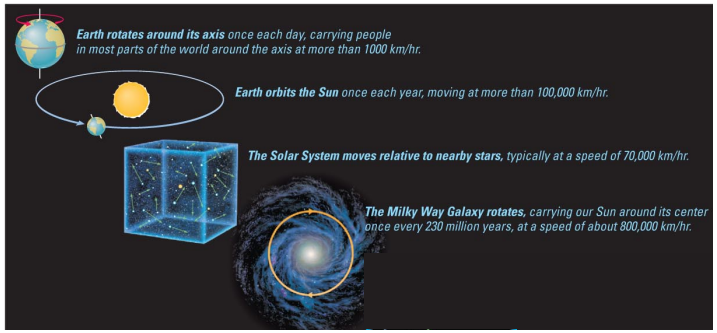
- We are r=27,000 ly away from the Galactic centre, hence our velocity about the Galactic centre is

$$v_{sun/gal} = \Omega_{sun/gal}\, r$$
$$= (2.73 \times 10^{-8} \text{ rad/yr})(27000 \text{ ly})$$
$$= 7.4 \times 10^{-4} c$$
$$= 221 \text{ km/s} = 800{,}000 \text{ km/h}$$



Comparative analysis of rotation

	Velocity (km/s)	Velocity (km/h)
Earth about its axis (equator)	0.46	1,675
Earth about the Sun	30	108,000
Sun about the Galaxy	221	800,000



Conceptual question

Which of the following has astronomical distances listed in order from smallest to largest?

(a) 1 AU, 1 light-year, the size of the solar system
(b) 1 AU, the size of the solar system, 1 light-year
(c) 1 light-year, 1 AU, the size of the solar system
(d) 1 light-year, the size of the solar system, 1 AU
(e) the size of the solar system, 1 AU, 1 light-year

Conceptual question

Which of the following has astronomical distances listed in order from smallest to largest?

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(c) 1 light-year, 1 AU, the size of the solar system
(d) 1 light-year, the size of the solar system, 1 AU
(e) the size of the solar system, 1 AU, 1 light-year

Conceptual question

Which of the following is NOT a way in which we move through the universe?

(a) The Milky Way orbits the centre of the universe.
(b) Our solar system orbits the centre of our galaxy.
(c) The Earth orbits the Sun.
(d) The Earth is spinning on its axis.

Conceptual question

Which of the following is NOT a way in which we move through the universe?

(a) The Milky Way orbits the centre of the universe.

(b) Our solar system orbits the centre of our galaxy.

(c) The Earth orbits the Sun.

(d) The Earth is spinning on its axis.

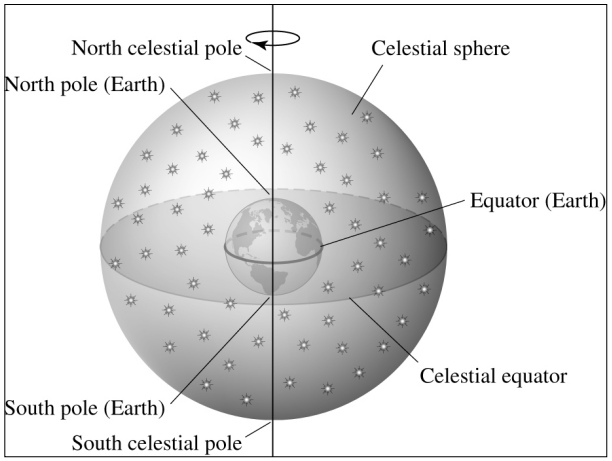
Explanation: Universe has no centre!

The Milky Way is part of the Local Group of galaxies and it moves relative to other galaxies.

3. Basic Observations
(including a tiny bit on Positional Astronomy)

The celestial sphere: what we see projected on sky

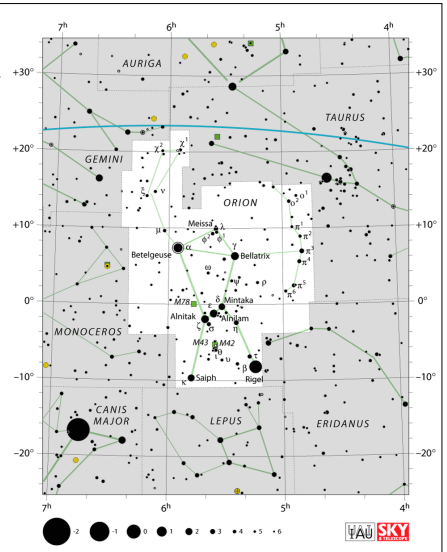
- North celestial pole directly above of the Earth's North Pole
- The celestial equator is a projection of Earth's equator into space



The constellations

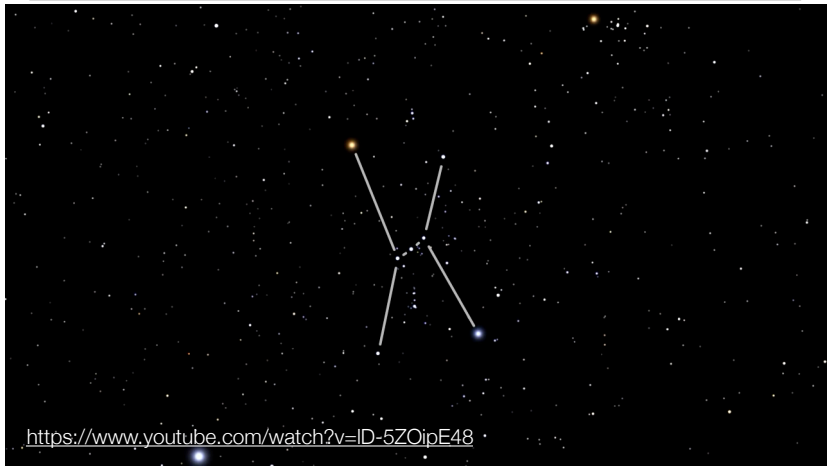
- The celestial sphere is divided into 88 "sectors", or constellations.
  - There is an official set of constellation boundaries, created by the International Astronomical Union
- Stars in a constellation are not necessarily grouped together in 3D space (just a projection effect)

Star	Distance (parsecs)
Betelgeuse	650
Rigel	800
Bellatrix	300
Saiph	1800
Alnilam	1530
Alnitak	1470
Mintaka	1500



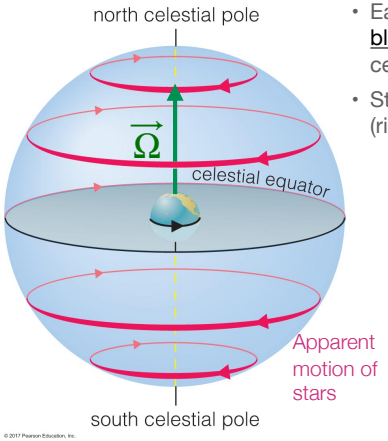
What to their names mean? How to pronounce them?
https://www.iau.org/public/themes/constellations/

The constellation of Orion in 3D

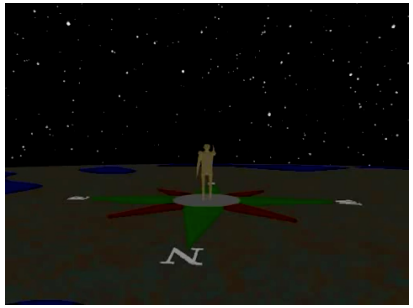


Explore the digital sky survey by the American Astronomical society:
http://www.worldwidetelescope.org/webclient/

Diurnal motion of the celestial sphere



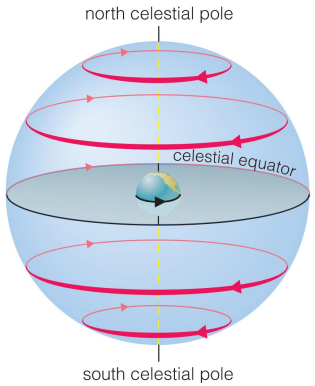
- Earth rotates anticlockwise (from W to E, black arrow) as viewed from above the North celestial pole.
- Stars *appear* to rotate around us clockwise (rise in E, set in W; red arrows)



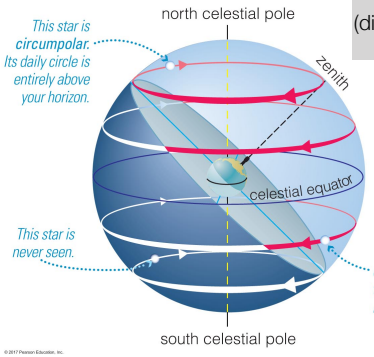
www.youtube.com/watch?v=UtG9XQjhfLc

Variation of the celestial sphere with your latitude

Observer in the North Pole of the Earth: latitude=90º



Observer at latitude +40º.

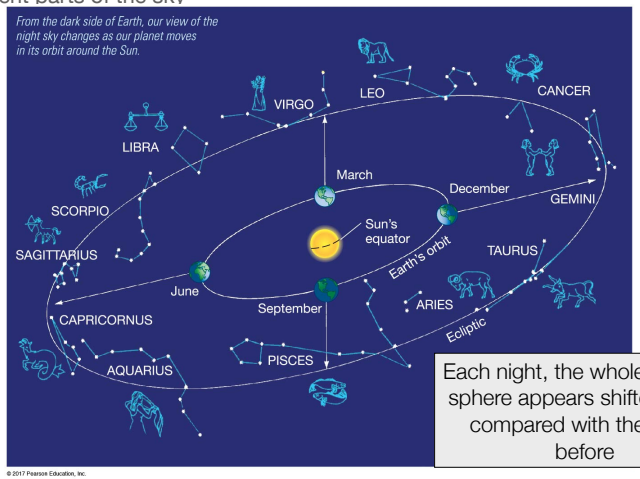


zenith='up' (directly above your head)

Homework: Verify from the figure that the altitude (angle wrt to your horizon) of the celestial pole in your sky is equal to your latitude

Variation of the celestial sphere with time of the year

- As the Earth orbits the Sun, the night-time side of the Earth turns towards different parts of the sky



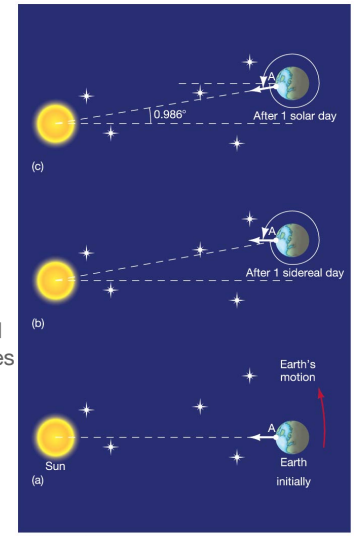
Each night, the whole celestial sphere appears shifted a little compared with the night before

Solar and sidereal days

- Because of this shift, a day measured by the stars (**sidereal day**) differs in length from a **solar day**
- Earth rotates through slightly more than 360º for the Sun to return to the same apparent location in the sky. This additional angle is

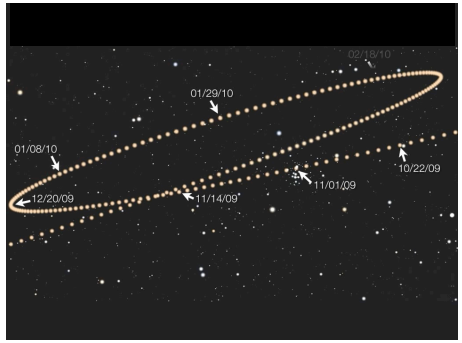
$$\frac{360^o}{365\ \text{days}} = 0.986^o/\text{day}$$

- Between noon at point A on one day and noon at point A the next day, Earth rotates 360.986º. Solar day is longer by about 4 minutes than a sidereal day.
- One rotation takes 23h 56min relative to the stars



The Apparent Motions of Planets on the Celestial Sphere

- Stars move in an 'organised' way through the celestial sphere. Planets don't..
- Motion of outer planets mostly prograde (eastward against the background stars)… but occasionally retrograde (doubling back)



Link to animation

- Why? A: *Retrograde motion is an **artefact** caused by the motion of the Earth*

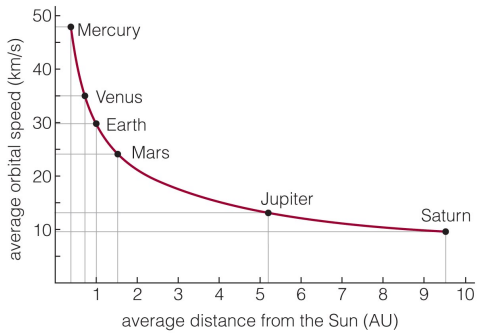
Planet orbital velocity

$$v_{\text{orb}} \propto \frac{1}{\sqrt{r}}$$

We will derive this in future Lectures

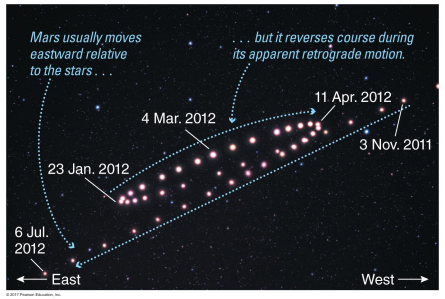
- Inner planets are faster than outer planets. Hence:

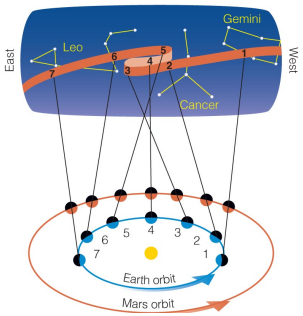
Mars is slower than the Earth



Apparent Planetary Motion

- Consider Mars: usually moves eastward relative to the stars, but it reverses course during its apparent retrograde motion





→ Follow the lines of sight from Earth to Mars in numerical order. Notice that Mars appears to move westward relative to the distance stars (from points 3 to 5) as Earth passes it by in its orbit.

Conceptual question

The sidereal day (a full rotation of the Earth measured relative to distant stars) is 4 minutes shorter than a Solar Day. If the Earth's spin were in the opposite direction then a sidereal day would

(a) not change.
(b) change, but remain shorter than a solar day.
(c) be longer than a solar day.
(d) be the same as a solar day.

Conceptual question

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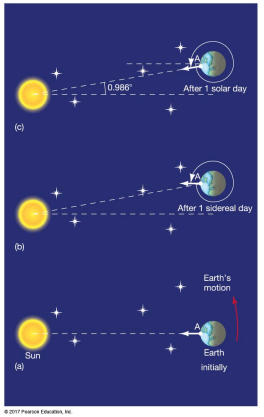
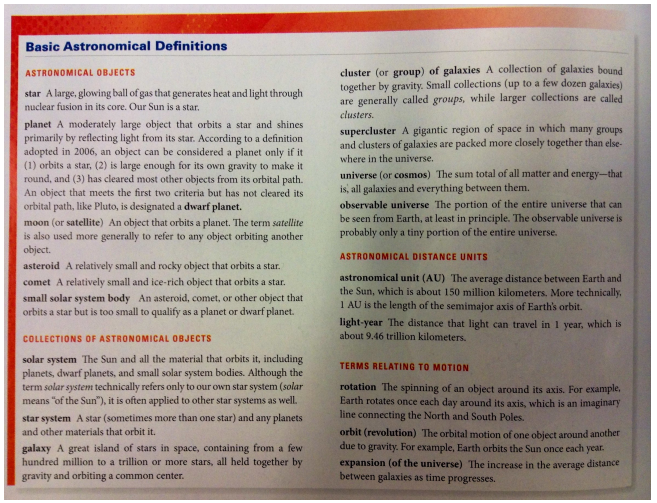


Extra slides - read at home

Basic Astronomical definitions

Page 4,"The Cosmic Perspective", Bennett, Donahue, Schneider, Voit



Basic Astronomical Definitions

ASTRONOMICAL OBJECTS

star A large, glowing ball of gas that generates heat and light through nuclear fusion in its core. Our Sun is a star.

planet A moderately large object that orbits a star and shines primarily by reflecting light from its star. According to a definition adopted in 2006, an object can be considered a planet only if it (1) orbits a star, (2) is large enough for its own gravity to make it round, and (3) has cleared most other objects from its orbital path. An object that meets the first two criteria but has not cleared its orbital path, like Pluto, is designated a **dwarf planet.**

moon (or **satellite**) An object that orbits a planet. The term *satellite* is also used more generally to refer to any object orbiting another object.

asteroid A relatively small and rocky object that orbits a star.

comet A relatively small and ice-rich object that orbits a star.

small solar system body An asteroid, comet, or other object that orbits a star but is too small to qualify as a planet or dwarf planet.

COLLECTIONS OF ASTRONOMICAL OBJECTS

solar system The Sun and all the material that orbits it, including planets, dwarf planets, and small solar system bodies. Although the term *solar system* technically refers only to our own star system (*solar* means "of the Sun"), it is often applied to other star systems as well.

star system A star (sometimes more than one star) and any planets and other materials that orbit it.

galaxy A great island of stars in space, containing from a few hundred million to a trillion or more stars, all held together by gravity and orbiting a common center.

cluster (or **group**) **of galaxies** A collection of galaxies bound together by gravity. Small collections (up to a few dozen galaxies) are generally called *groups*, while larger collections are called *clusters*.

supercluster A gigantic region of space in which many groups and clusters of galaxies are packed more closely together than elsewhere in the universe.

universe (or **cosmos**) The sum total of all matter and energy—that is, all galaxies and everything between them.

observable universe The portion of the entire universe that can be seen from Earth, at least in principle. The observable universe is probably only a tiny portion of the entire universe.

ASTRONOMICAL DISTANCE UNITS

astronomical unit (AU) The average distance between Earth and the Sun, which is about 150 million kilometers. More technically, 1 AU is the length of the semimajor axis of Earth's orbit.

light-year The distance that light can travel in 1 year, which is about 9.46 trillion kilometers.

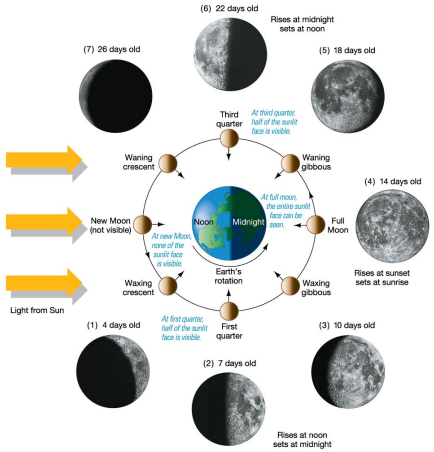
TERMS RELATING TO MOTION

rotation The spinning of an object around its axis. For example, Earth rotates once each day around its axis, which is an imaginary line connecting the North and South Poles.

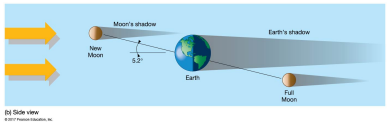
orbit (revolution) The orbital motion of one object around another due to gravity. For example, Earth orbits the Sun once each year.

expansion (of the universe) The increase in the average distance between galaxies as time progresses.

Phases of the moon



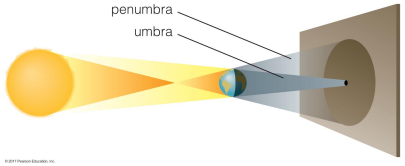
- At any given time, half of the moon is illuminated by sunlight
- Phase depends on the Sun-Earth-Moon angle:
  - Inner images: actual position and illumination of the moon
  - Outer images: appearance of the moon as seen from Earth
- Synchronous rotation: moon rotates with the same period of the orbit, we always see the same face



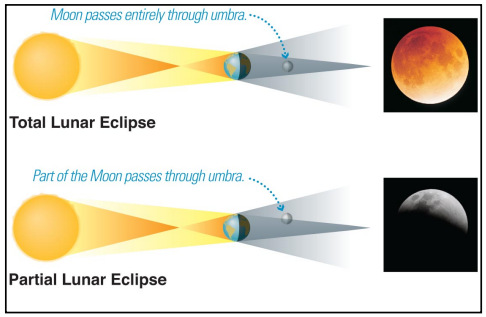
No part of the Moon is in perpetual darkness

What causes a lunar eclipse?

- Umbra/penumbra definition

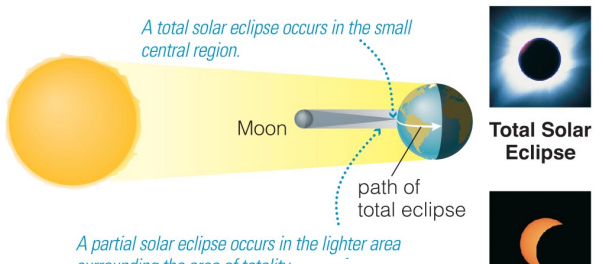


A **lunar eclipse** occurs when the Earth lies directly between the Sun and Moon, so Earth's shadow falls on the moon



What causes a solar eclipse?

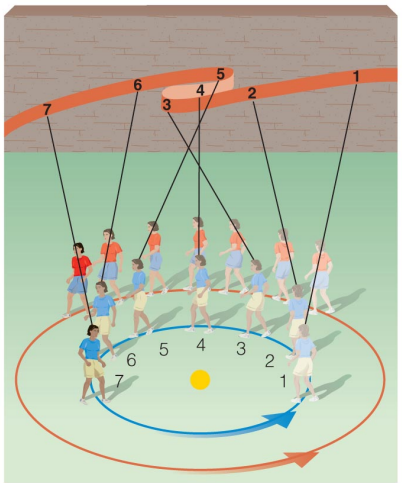
A **solar eclipse** occurs when the Moon lies directly between the Sun and Earth, so Moon's shadow falls on the Earth.



Total Solar Eclipse

Partial Solar Eclipse

The retrograde motion of planets - demonstration



a The retrograde motion demonstration: Watch how your friend (in red) usually appears to move forward against the background of the building in the distance but appears to move backward as you (in blue) catch up to and pass her in your "orbit."

- **How is astrology different from astronomy?**
  - Astronomy is the scientific study of the universe and the celestial objects within it.
  - Astrology assumes that the positions of celestial objects influence human events.
- **Does astrology have any scientific validity?**
  - Scientific tests show that the predictions of astrology are no more accurate than pure chance.