Touro Institute מכון טורו

In Conjunction with

massachusetts institute of technology

The Solar System

The javelin event at the Interplanetary Olympics. Under what conditions could a javelin circle the planet and hit you in the back? (Image by MIT OCW.)

Course Highlights

This course features fact sheets in the study materials section and sample problem sets in the assignments section.

Course Description

This is an introduction to the study of the solar system with emphasis on the latest spacecraft results. The subject covers basic principles rather than detailed mathematical and physical models. Topics include: an overview of the solar system, planetary orbits, rings, planetary formation, meteorites, asteroids, comets, planetary surfaces and cratering, planetary interiors, planetary atmospheres, and life in the solar system.

Syllabus

Course Calendar

SES #	TOPICS
1	Organization/Introduction
2	Overview of the Solar System
3	Overview of the Solar System (cont.)
4	The Sun
5	Celestial Mechanics
6	Celestial Mechanics (cont.) Rings
7	Exam 1
8	Planetary Formation
9	Other Planetary Systems
10	Meteorites
11	Asteroids
12	Comets
13	Exam 2
14	Planetary Interiors
15	Planetary Interiors (cont.)
16	Planetary Surfaces
17	Planetary Surfaces (cont.)
18	Planetary Surfaces (cont.)
19	Satellites/Icy Bodies
20	Exam 3

SES #	TOPICS
21	Planetary Atmospheres
22	Planetary Atmospheres (cont.)
23	Planetary Atmospheres (cont.)
24	Life in the Solar System
25	Mars Exploration
26	Review Session

Required Texts

Hartmann, W. K. *Moons and Planets*. Belmont, CA: Thomson Brooks/Cole, 2005. ISBN: 0534493939.

Beatty, J. K., et al. *The New Solar System*. Cambridge, UK: Cambridge University Press, 1999. ISBN: 0521645875.

Reading Assignments

Reading assignments in the readings section are to be completed in the indicated sessions.

Homework

Discussion of homework problems with others is permitted and encouraged, but you must turn in your own work. Copying constitutes academic dishonesty. Homework is due in the sessions mentioned in the assignments section.

Grading Policy

Final Exam

There will be a final exam covering all of the class material. Emphasis will be on a synthesis of the subject material.

Homework

There will be regular homework problem sets.

Academic Dishonesty

Copying of homework problems and discussion of exams when you have obtained an excused absence is considered academic dishonesty. Suspected cases will be immediately submitted to the Committee on Discipline.

Readings

Reading assignments are given in the two required textbooks and are to be completed prior to class in the indicated sessions.

H = Hartmann, W. K. *Moons and Planets*. Belmont, CA: Thomson Brooks/Cole, 2005. ISBN: 0534493939.

B = Beatty, J. K., et al. *The New Solar System*. Cambridge, UK: Cambridge University Press, 1999. ISBN: 0521645875.

SES #	TOPICS	READINGS
1	Organization/Introduction	
2	Overview of the Solar System	H, chapters 1 and 2. B, chapter 1.
3	Overview of the Solar System (cont.)	
4	The Sun	B, chapter 3.
5	Celestial Mechanics	H, chapter 3.
6	Celestial Mechanics (cont.) Rings	B, chapter 16.
7	Planetary Formation	H, chapters 4 and 5. B, chapter 2.
8	Other Planetary Systems	B, chapter 28, pp. 136-140.
9	Meteorites	H, chapter 6.

SES #	TOPICS	READINGS
		B, chapter 26.
10	Asteroids	H, chapter 7. B, chapters 23 and 25.
11	Comets	B, chapters 5 and 24.
12	Planetary Interiors	H, chapter 8. B, chapters 9 and 14.
13	Planetary Interiors (cont.)	B, chapter 4.
14	Planetary Surfaces	H, chapter 9. B, chapter 6.
15	Planetary Surfaces (cont.)	H, chapter 10. B, chapter 12.
16	Planetary Surfaces (cont.)	B, chapters 7, 8, 10, 11, and 17.
17	Satellites/Icy Bodies	B, chapters 18, 19, 21, and 22.
18	Planetary Atmospheres	H, chapter 11.
19	Planetary Atmospheres (cont.)	B, chapters 13, 15, and 20.
20	Planetary Atmospheres	

SES #	TOPICS	READINGS
	(cont.)	
21	Life in the Solar System	H, chapter 12. B, chapter 27.
22	Mars Exploration	H, chapter 13. B, chapter 11.
23	Exam	

Assignments

Sample Problem Sets

The assignments are due in the sessions noted in the table.

SES #	ASSIGNMENTS
4	Problem Set 1 - Featuring a Scale Model of the Solar System in MIT's Infinite Corridor (PDF)
5	Problem Set 2 - Featuring the Death of the Sun and the Destruction of Earth (PDF)
6	Problem Set 3 - Featuring the Javelin Event at the Interplanetary Olympics and a Comet Possibly Aimed Towards Earth (PDF)

The Solar System

Homework Problem Set #1

Please show all work neatly and clearly. Circle final answer for clarity.

<u>1. Distance Scales </u>The length of the infinite corridor is: 202.4 meters In a scale model of the solar system, let the Sun-Pluto distance (39.5294 AU) be equal to the length of the infinite corridor. On this scale: (Hint: Use pages 387-388 of Beatty)

a. What would be the diameter for the Sun?

b. What would be the diameters for each of the nine planets?

c. What would be the diameter of the Moon and its distance from Earth?

d. How far from the Sun would we place each of the nine planets?

e. How far from the Sun would we place the nearest star?(Alpha Centuri is located 4.3 light-years away.)

2. Spacecraft Communication

a. How many times can a photon travel the Earth's Circumference in one second?

b. A spacecraft is sent to Pluto. At 12:00 noon ground controllers send a command to take an image. Upon receiving the command, assume the spacecraft instantaneously acquires the image and transmits it back to earth. Assuming Pluto is at its mean heliocentric distance, when is the image received?

3. Eclipses

a. What is the apparent angular size of the Moon as seen from Earth?(Use diameter and average distance given in class.)

b. What is the apparent angular size of the Sun as seen from Earth?(Use diameter and average distance given in class.)

c. If a solar eclipse occurs with the Moon and Sun at these distances, does the Moon totally block the disk of the Sun? Explain.

d. The Moon's orbit is not circular and at its closest it is 363,000 km from the Earth. If a solar eclipse occurs with the Moon at this distance, does the Moon totally block the disk of the Sun? Explain.

4. Density of the solar system. Assume that the mass of the nine planets plus Ceres is distributed in a uniform disk,1 cm thick between 0.2 AU and 50 AU

a. Divide the solar system into 10 zones, and compute the density within each zone.

(EXAMPLE: Assume the earth zone extends midway to Venus and to Mars, that is from 0.86 to 1.25 AU. Distributing the Earth's mass in this zone yields 10 g cm^{-3}.)

b. Discuss trends in the density, noting especially zone(s) of substantially lower density.

c. A belt of comets (the Kuiper belt) is believed to extend from 35 to 50 AU from the Sun. The total population of these objects is estimated to be as high as 30,000 objects with diameters between 100 and 400 km. If these objects are taken into consideration in our density calculations, do they noticeably affect the calculated density distribution? (Assume an average diameter of 200 km and an average density of 1 g cm^{-3} for the comets.)

The Solar System

Problem Set #2

Useful Constant:

Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8}$ J sec^{-1} m^{-2} K^{-4}

Please show all work neatly and clearly. Circle final answers for clarity.

THE FATE OF THE EARTH

1 When will the Sun exhaust its supply of hydrogen and no longer maintain the same state of hydrostatic equilibrium that exists today? (Assume that the Sun will run out of hydrogen fuel in its core, due to inefficient mixing, after 5% of the Sun's current total hydrogen content is converted into helium.)

2. After the Sun ceases to be in its current state of hydrostatic equilibrium, it will become a red giant star.

a. What will be the radius of the Sun when it becomes a red giant star, assuming it has a luminosity of 3.83×10^{30} J sec^{-1} and a surface temperature 5000 K?

b. Will the red giant Sun engulf the Earth?

c. What is the change (in percent) in the power (J sec^{-1}) being emitted by the Sun once it enters the red giant stage? (Compare with respect to the present Sun.)

3. You are an astronaut standing on the surface of the Moon, looking back at Earth. Your friend in mission control on Earth, looks out the window at the Moon. If your friend on Earth communicates to you that she sees the phase of the Moon as:

A. New Moon
B. First Quarter Moon
C. Full Moon

D. Last Quarter Moon. For each of these, A through D, explain what phase the EARTH would appear to you, as viewed from the Moon.

The Solar System

Problem Set #3

Useful number: $G = 6.67 \times 10^{-11}$ nt m^2 kg^{-2}Make sure your mass units are in kg, length units in m. Please show all work neatly and clearly. Circle final answer for clarity.

1. Interplanetary Olympics In the interplanetary Olympics, you are a gold medal contender for the longest measured throw of the javelin. Assuming you throw with a constant speed of25 meters / second and at an optimum angle for maximum distance:

a. What is the minimum diameter planet where this event should be held so that the judges can make a determination of how far you threw (i.e. it does not escape)?

b. For a planet having this diameter, what is the minimum time it could take for a javelin you throw to circle the planet and strike you in the back? (The velocity doesn't need to equal your maximum of 25 meters / second.)

(Assume an average density for planetary bodies equal to 3000 kg m^{-3})

1 Tidal Forces Show that the Moon exerts a tidal force on the Earth that is about twice that of the tidal force exerted by the Sun on the Earth.

2 Should We Duck for Cover?

A comet is discovered with the following orbital elements a=110.0 AU e=0.995 i=89 deg Ω=180 deg ω=0 deg T=2008 March 21.

a. How close does the comet come to Earth?
b. If Ω=0 deg, how close does the comet come to Earth?
c. What is the comet’s velocity at 1 AU?

Study Materials

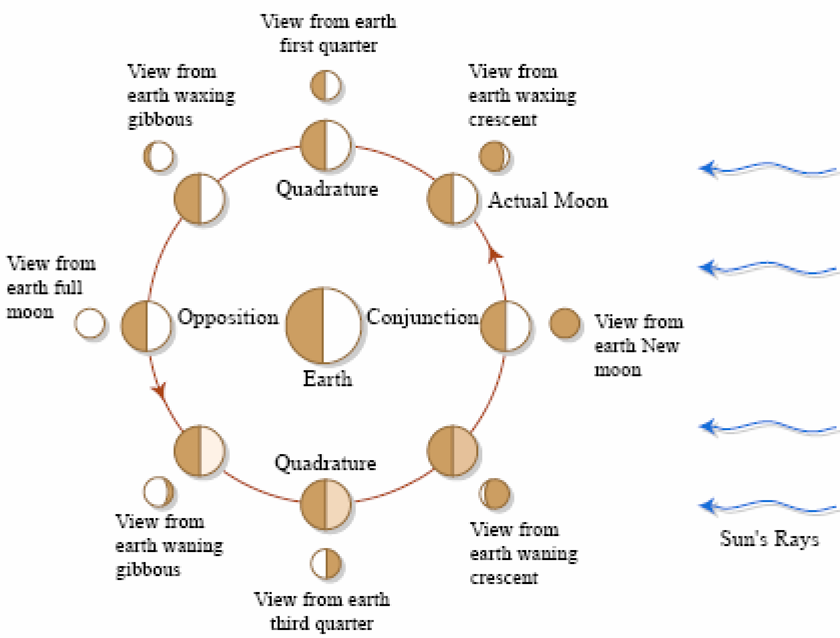
SES #	TOPICS	HANDOUTS
1	Organization/Introduction	Basic Facts (PDF) Moon Phases and Seasons (PDF)
2-3	Overview of the Solar System	Survey of the Planets (PDF)
4	The Sun	Solar Structure (PDF)
5	Celestial Mechanics	Orbital Elements (PDF)
8	Planetary Formation	Solar System Formation (PDF)
10	Meteorites	Meteorite Definitions (PDF)
18	Planetary Surfaces (cont.)	Icy Satellites (PDF)
22	Planetary Atmospheres (cont.)	Atmospheric Basic Properties (PDF) Atmospheric Structure (PDF)
24	Life in the Solar System	Life Notes (PDF)

Basic Facts to Know and Tell

	Distance (AU)	Radius	Mass
Mercury	0.39	0.38	0.05
Venus	0.72	0.95	0.82
Earth	1.00	1.00	1.00
Moon	384,000 km	0.27	0.012
Mars	1.5	0.53	0.11
Asteroids (Ceres)	2.8	0.08	0.00016
Jupiter	5.2	11.2	318
Saturn	9.5	9.5	95
Uranus	19.2	4.1	15
Neptune	30.0	3.9	17
Pluto	39.4	0.18	0.002

Phases of the Moon

Perspective of the illuminated half of the moon, as seen from Earth.

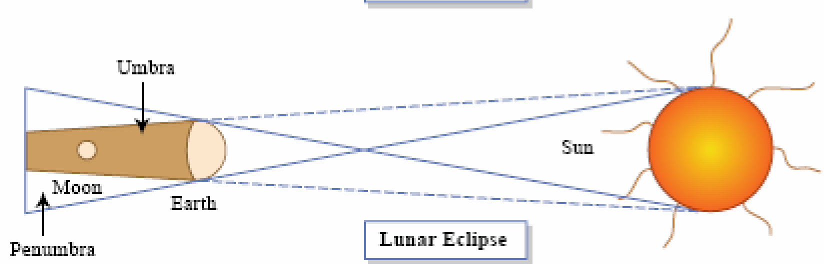


Lunar Phases and Configurations

As the Moon orbits the Earth, we see varying portions of its sunlit side. The phases sketched here (outside the circle representing the Moon's orbit) show the Moon as it appears to an observer in the northern hemisphere.

Phases of the Moon

Perspective of the illuminated half of the moon, as seen from Earth.

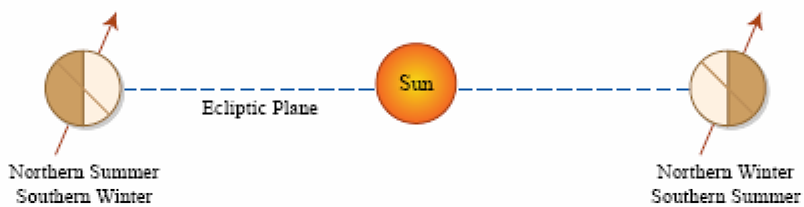


Solar and Lunar Eclipses

The relative positions of the Sun, Earth, and Moon are shown at the times of solar (upper) and lunar (lower) eclipses. Only the dark portion of the shadow (the umbra) is shown in each case. (Not to scale)

Seasons

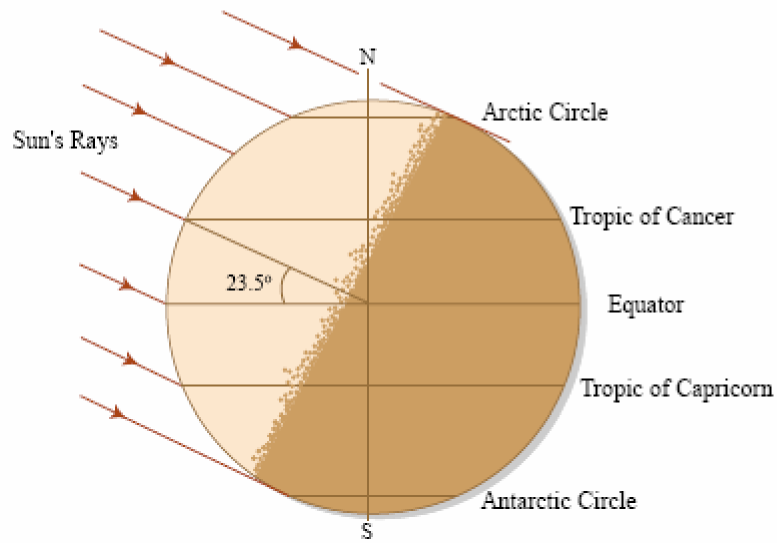
Caused by the 23.5 degree tilt of the Earth's axis with respect to the normal vector of its orbit plane.



Seasons
The Earth's tilted axis retains its orientation as the Earth orbits the Sun. Thus, at opposite points in the orbit, each hemisphere has winter and summer, depending on whether that hemisphere is tipped towards the Sun or away from it.

Seasons

Caused by the 23.5 degree tilt of the Earth's axis with respect to the normal vector of its orbit plane.



The Earth on June 22, the summer solstice in the Northern Hemisphere.

A Survey of the Planets

Mercury

Difficult to observe - never more than
28 degree angle from the Sun.
Mariner 10 flyby (1974)
Found cratered terrain.
Messenger Orbiter (Launch 2004; Orbit 2009)
Rotation is 59 days (discovered by MIT)
Thin sodium (Na) atmosphere - recent discovery
No Moons.

Venus

A near twin to Earth in size and mass
Dense CO_2 atmosphere
Surface pressure ~90 bars (earth atm = 1 bar)
Surface temperature ~750 K (0 K = -273 C)
Retrograde rotation, 243 days
(Prograde rotation is West -> East)
(Retrograde rotation is East ->West)
Surface volcanic features, vast resurfacing
of entire planet about 1 billion years ago.
No Moons.
Mariner, Pioneer, Venera:
Flybys, orbiters, landers (1960s, 1970s)
Magellan Mission 1989 - Radar mapping to
100m resolution (headed by MIT).

Earth

N_2,O_2,H_20 atmosphere
Surface area 71% H_20
Prograde rotation 23hr 56min 04.1sec
=>Why do we use a 24 hour clock?
Weathered, tectonic, volcanic,
and cratered surface.
One satellite (large relative to its primary).

Moon

Cratered surface - formed by impacts
Mare - ("seas") formed by lava flows
Regolith - soil
Age: 4.5 Gy - same as rest of solar system
(Gy = 10^9 years)
0 - 0.5 Gy -heavy bombardment
1.0 - 2.5 Gy - lava flows forming Mare
2.5-4.5 Gy - less frequent bombardment
Origin of the Moon?

Mars

Thin CO_2 atmosphere
 Surface Pressure ~6 mbar (0.6% of Earth)
 Surface Temperature: 190 to 240 K

Rotation is 24.5 hours, prograde

Cratered surface, volcanoes, chasms
 Evidence for water flow! (Where is it now?)

Polar caps - CO_2 and H_20

Missions:
- Mariner 9 (1971) - first orbiter
- Viking 1+2 orbiters and landers (1976)
  - No evidence for life
- Mars Meteorites (1996): Evidence for life? Not.
- Mars Observer (lost in 1993).
- Mars Pathfinder (1997).
- Mars Global Surveyor (1997).
- Mars Climate Orbiter (lost in 1999).
- Mars Polar Lander (lost in 1999).
- Mars Odyssey (2001)
- Mars Express (Europe, 2003)
- Mars Exploration Rovers – landing 2004.
  (Spirit & Opportunity)
- Mars Reconnaissance Orbiter (arrive 2006)

Two small satellites, Phobos and Deimos

Asteroids

First one (Ceres) discovered in 1801
 Location (2.8 AU) fit Bode's Rule
There are >10,000 known asteroids
 Most orbit between Mars and Jupiter,
 region called the "asteroid belt"
Sizes range from boulders - 1000 km
A Disrupted planet? <----No
Probably left-over planetesimals from
 formation of the solar system.

Missions:
- Flybys "Targets of opportunity"
  - 951 Gaspra [12-km] (Galileo 1991)
  - 243 Ida [32-km] (Galileo 1993)
  - 253 Mathilde [52-km] (NEAR 1997)
  - 9969 Braille [2-km] (DS-1 1999)
- Orbiters:
  - NEAR - launch 1996; arrival 2000.
    433 Eros [30-km] near-Earth asteroid.
  - Dawn – to Vesta and Ceres (2007)
- Sample Return:
  - Hyabusa (MUSES-C) Japan.
    Destination: 25143 Itokawa
    Launch 2003, Sample 2005, Return 2007

Jupiter
Largest of the Jovian gas giant planets.
A "star" that failed.
Dynamic atmosphere: H_2, He, CH_4, NH_3
Red Spot - long lived high pressure system
(not a hurricane as often described).
Rotation 9.8 hours
Has a faint ring - discovered by Voyager.
Lots of satellites (current count is 16 or more)
Galilean satellites (discovered 1610)

Ganymede (D=5280 km)
Largest moon in the solar system
(Larger than Mercury and Pluto!)
Icy surface (H_2O), some craters.

Callisto (D=4840 km, ~Mercury)
Heavily cratered rock + ice surface.

Europa (D=3130 km, smaller than Moon)
Grooved ice terrain, few craters.
What does this imply about surface?
Evidence for subsurface ocean??

Io (D=3460 km, same as Moon)
Most active volcanoes in the solar system. Induced by tidal stresses.

Pioneer 10, 11, Voyager 1, 2 flybys (1970s)
Galileo Orbiter / Probe (1995-2003).
Extensive Galilean satellite tour.

Saturn
Gas planet, H_2, He, CH_4, NH_3 atmosphere
Density < 1 gm / cm^3
Complex Ring System
Lots of satellites (current count is 18 or more)

Titan (D=5120 km, second largest)
Has a substantial atmosphere!
Composition N_2, CH_4
Pressure ~1.6 bar

Iapetus (D=1440 km)
Half-light, half-dark hemispheres
How did this occur?

Hyperion (D=150 km)
Chaotic rotation - it "tumbles" along in its orbit. (Discovered by MIT)

Pioneer 11, Voyager 1,2 flybys (1970s, 1980s)

Cassini Orbiter Mission -
Launch 1997
Saturn orbit 2004. (Four year mission.)
Huygens Titan Probe
Extensive satellite tour.

Solar Structure

Core - Inner region from 0 to 0.25RSite for Hydrogen
fusion reactions Temperature = 15 million K

Radioactive Zone - from 0.25 to 0.7R Core energy transported by radiation Temperature decreases to 1.5 million K

Convective Zone - from 0.7R to surface Efficient convective energy transport

Photosphere - the “surface” of the sun Temperature = 5,700 K

Sunspots - well known photosphere feature. Regions of localized magnetic field variations. Appear dark only because of their lower relative temperature, 3800 K. Sunspot number peaks in 11 year cycles, caused by global polarity changes. Next max in 2011.

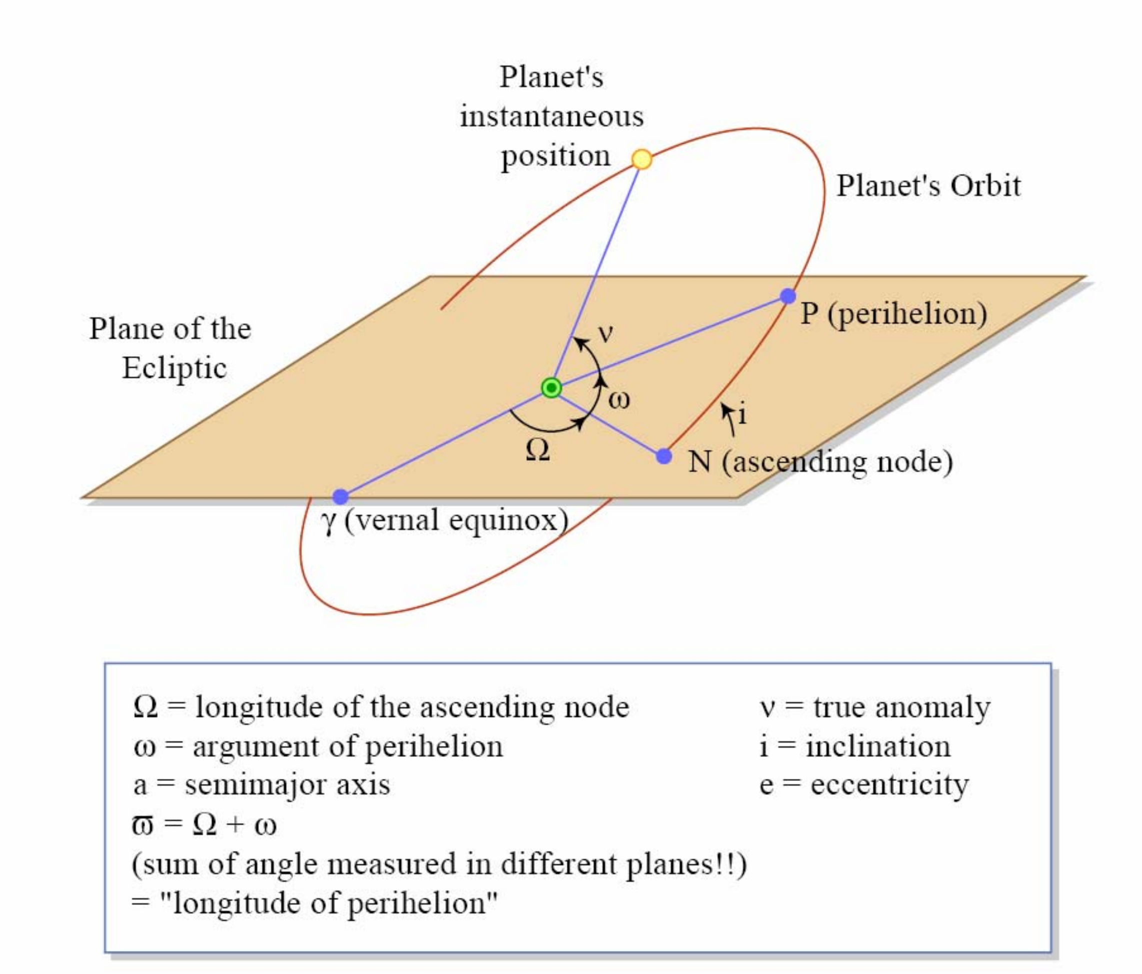
Chromosphere - thin gas layer above photosphere. Thickness ~0.02R T~8000K, heated magnetically?

Corona - outermost layer extending out to interplanetary space. T ~1 million K.Magnetohydrodynamic heating?

Solar Wind - extension of the Corona. Ions and electrons flowing out from Sun. Velocity ~400 km/sec

Solar Flare - an especially dense burst of solar wind particles. What are the terrestrial effects? Aurorae Disruption of radio communication (ionosphere)

Orbital Elements



Characteristics To Be Explained by Theory

1 Planets lie roughly in the same plane
2 Orbit plane coincides with Sun's equator
3 All planets' and sun's rotation are prograde
4 Planetary orbits mostly low eccentricities
5 Most angular momentum in planets
6 Meteorites show high T inclusions
7 Planets show a compositional gradient

Stages in Forming a Solar System

a. Interstellar Gas Cloud.
b. Instability (pressure wave from nearby supernova explosion?) leads to local density increase which exceeds Virial critical value.
c. Protostar forms at center of cloud.
d. Protoplanets form in nebular disk.
e. ProtoSun begins hydrogen fusion.

f. Disk cools, planetary accretion continues.
g. Sun goes through “T-Tauri phase.” Strong solar wind which occurs a few million years after the onset of fusion in the stellar core. Blows away all remaining gas, clearing the nebula.
h. With the removal of the nebula, planetary accretion ends.

A Recipe for Making Planets

Step 1: From dust 1 mm (10^{-6} m) to cm sizes. Particles stick together electrostatically.

Step 2: From cm to km sizes. Inelastic collisions, particles stick together.

Step 3a (Terrestrial Planets): From 1 km to >1000 km. In each zone, a single large planetesimal dominates. Efficiency increased by “gravitational focusing.” Impacts of the last few remaining large planetesimals could account for the differing obliquities, rotation rates, et

Step 3b (Jovian Planets): Gravitational Accretion. Largest planetesimals dominate their zones *gravitationally* as a “feeding zone.” As mass increases, feeding zone widens. Very rapid, very efficient process. Formation of large satellites may follow as secondary condensation regions around the massive primary.

V. METEORITICS

The study of meteorites.

What happened to left over planetesimals after the end of planetary accretion? Ejection - a close encounter with a planet’s gravitational potential, can eject the body from the solar system through a “sling-shot” effect. Can be a multistage process: earth-crossing -->Jupiter crossing-->ejection. Collision - results in heavily cratered planetary surfaces. A few very large planetesimal collisions may b eresponsible for: Origin of moon? Retrograde rotation of Venus? Non-zero obliquities? Fragmentation - destroyed by mutual collisions between planetesimals. Capture - small planetary satellites. Trojan asteroids at L_4, L_5 of Jupiter. Survival - asteroids and comets.

The Wonderful World of Meteorites

Some Definitions

Asteroid - a rocky body in space larger than a few hundred meters in size. Largest size is about 1000 km in diameter.

Comet - an asteroid-sized body composed of a significant proportion of icy material such that outgassing is observed when the body is near the sun.

Meteoroid - small body in space with a size between ~1mm and a few hundred meters.

Interplanetary dust particle (IDP) - anything smaller than ~1mm. Typically a few mm.

Meteorite - A meteoroid that has reached the Earth’s surface. Typically named after the place they are found. A distinction :Fall - a meteorite whose arrival was witnessed. Find - a meteorite that is “accidentally” found. No information on its arrival.

Icy Satellites

Icy Satellites of Saturn:

All have similar densities (~1.3 g cm^{-3}), indicating >50% ice interiors (plus rock).
Mimas, Rhea – uniformly heavily cratered old surfaces. Unaltered.
Dione, Tethys – heavily cratered plus less cratered areas. Also large fractures.
Suggests some tectonic surface processing. Tectonic energy source?
Enceladus – brightest surface in the solar system (albedo ~1!).
A variety of surface terrains having a wide range of ages. Many regions have no visible craters.
Suggests a very active tectonic process or "water volcanism" to recycle surface. Energy source? Unknown.
Iapetus – bright hemisphere albedo ~0.4.
Dark hemisphere albedo ~0.04.
Dark material centered at motion apex.

Satellites of Uranus:

Average densities ~1.6 g cm^{-3}. Why greater density than Saturnian satellites?
Umbriel, Oberon – uniformly heavily cratered old surfaces. Frozen bodies.
Ariel, Titania – less heavily cratered with ice fracture features. Some resurfacing in the past, now frozen bodies.
Miranda – a bizarre surface showing a variety of geologic units. Disrupted body that reassembled?

Examples based on the best studied objects:

Callisto (D=4840 km, ~Mercury)
Heavily cratered ice surface. Age?
Fresh craters are bright. Why?
Surface shows very low relief. Why?
=> Low strength of ice.

Ganymede (D=5280 km)
Largest moon in the solar system.
Surface has heavily cratered regions plus less cratered "grooved" regions.
What are the relative ages?
"Grooves" indicate a period of tectonic activity on Ganymede.

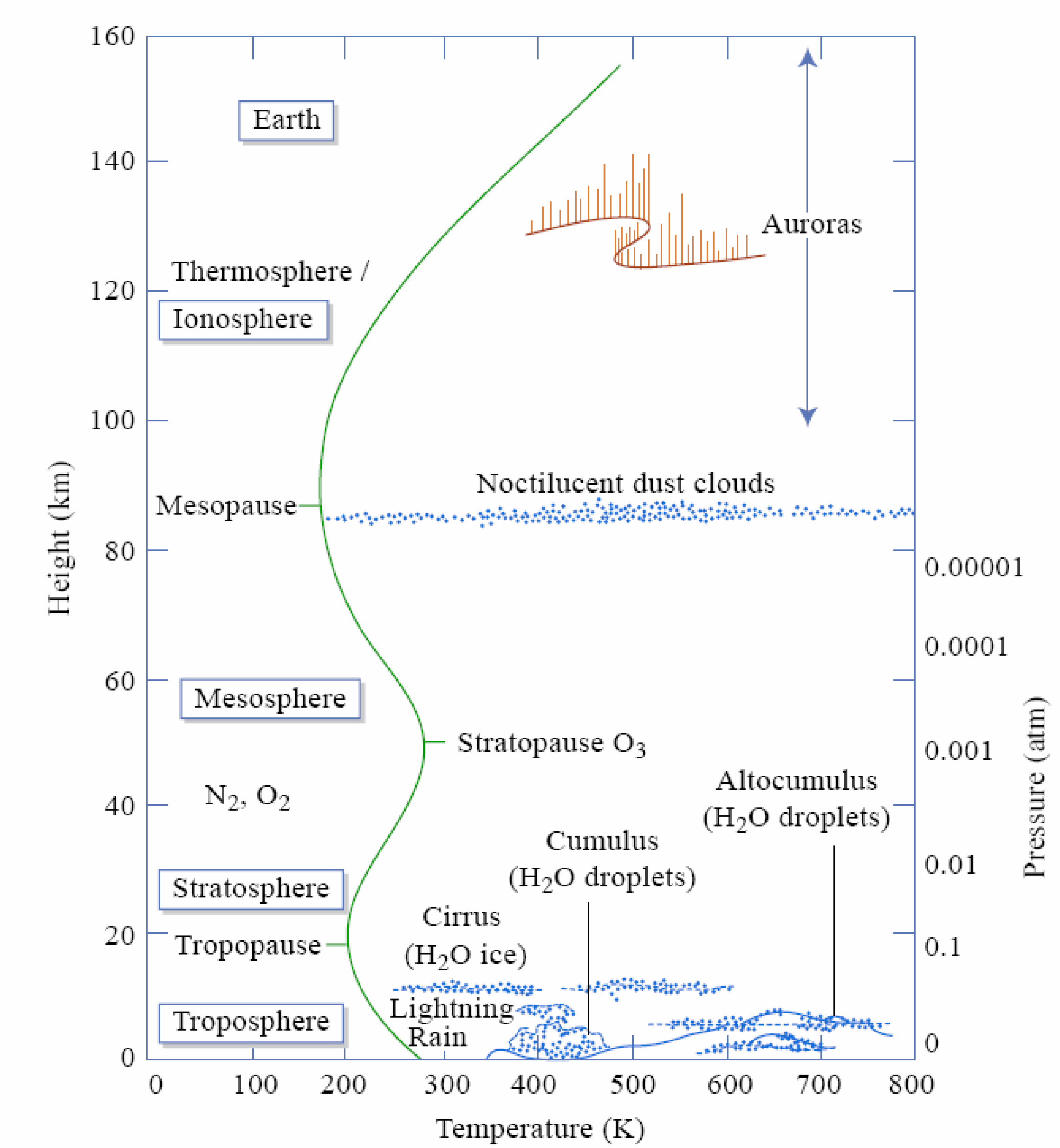
Europa (D=3130 km)
Fractured ice terrain, few craters.
Higher density, larger rock component to its interior. Also closer to Jupiter.
Internal radiogenic, tidal heating?
=> Speculation: 100 km thick ice crust on top of thin liquid water ocean? Tectonic processes recycle surface?

Presence of magnetic field suggests an iron core.
An iron core requires *differentiation*. For a differentiated icy satellite,

subject to tidal stresses, many models suggest a layer of liquid water.
Iron core, radius 600 km.
Silicate mantle, 800 km thick.
Water ice crust, 150 km thick.
Liquid water present at the base of this crust? Life???

Cryovolcanism (water/ice volcanism) at surface suggests liquid water may be present.

Basic Atmospheric Structure



Basic Properties of Terrestrial Atmosphere

Earth: Major Atmospheric Constituents:N2(77%), O2(21%), H2O (1%)Surface Pressure = 1 bar Average Surface Temperature = 288 K. Mercury: Major Atmospheric Constituents: He (42%) , Na (42%), O (15%)Surface Pressure = 10-13barAverage Surface Temperature = 440 K. Venus: Major Atmospheric Constituents:CO2(96%), N2(3.5%)Surface Pressure = 90 bar Average Surface Temperature = 730 K. Mars: Major Atmospheric Constituents:CO2(95%), N2(2.7%), Ar (1.6%)Surface Pressure = 0.007 bar Average Surface Temperature = 218 K.

Properties of Outer Planet Atmospheres

Jupiter H (81%), He(18%) atmosphere Other components NH3, CH4, H2OSaturnH (88%), He(11%) atmosphere Other components NH3, CH4, H2OUranusH (84%), He(14%), CH4(1%) atmosphere Other components: hydrocarbons Neptune H (84%), He(13%), CH4(2%) atmosphere Other components: hydrocarbons[B 11-8; Smith (1989) Fig 9]PlutoCH4(?%) or CO (?)Surface temperature 58K.[Elliot et al. Fig 4]TitanN2(82-99%), CH4(1-6%), Ar (0-12%), +hydrocarbons Surface P, T: 1.5 bar, 95KLiquid N2, C2H6, CH4on surface??

LIFE IN THE SOLAR SYSTEM

Either we are alone or not in the Universe. Either way, the thought is incredible.

- A simple definition: a single or multiple cell organism that feeds on nutrients and is capable of reproduction.

Basic components of life (as we know it): H, O, C, N

Amino Acids

- Basic molecular component of proteins.
- Amino acids have been found in the interiors of carobonaceous meteorites.
- Earth biology based on left-handed amino acid structure. (handedness decides)
- Amino acids=> life (how?)
  Fossil records show first life forms occurred on Earth > 3.5 Ga ago.
- DNA is made up of amino acids and is key to understanding life.
- **ALL** living things on Earth (except viruses) use the same system.

Sites for Life Elsewhere in the Solar System

The key factor? Liquid H2O

- Venus? Europa? Titan? Mars?

Ideas for life on Mars from early observations and interpretation => reality

Viking Landers on Mars (1976): Searching for remnants of Life

Tests:

- Gas Chromatograph/Mass Spectrometer
- Pyrolytic release
- Labeled Release
- Gas Exchange

Meteorites from Mars: Evidence for Life?

- How do we know some meteorites come from Mars?
- What is the evidence for life in probing them?
- Are there alternative explanations?

History of ALH84001

Evidence

- Fractures in the rock contain globules of carbonate (younger than the rock) indicating that liquid water percolated through the rock in the past.
- Magnetite and FeS found on surfaces of globules.
- PAH's (polycyclic aromatic hydrocarbons) found inside the rock on fracture surfaces, concentrated near carbonate globules.
- Peculiar microbe-like structures photographed (typical size 20-100 nm)

Evidence	Biogenic Explaination	Chemical Explanation	Terrestrial Contamination
Carbonate Globules	Life process known to alter chemical environments .	Non-biogenic chemical process can cause condensation	Unlikely, globules show shock fractured by impact ejection from Mars.
Magnetite and FeS	Bacteria known to cause such precipitates. Magnetite particles resemble magnetosomes.	Magnetite and FeS precipitate in high pH. BUT, observed implies low pH. *	Concentric rinds rule out contamination.
PAH's	Natural decay product of biogenic matter.	Common in other meteorites (but not SNC's). Can be formed by non-biogenic reactions.	Other Antarctic meteorites don't show contaminate. Concentration increases w depth.
"Microfossil" Structures	Fossils of single cell bacteria. 1000x smaller than terrestrial microfossil.	Caused by chemical dissolution of carbonate. Can result from other chemical precipitates.	Unlikely. Freshly cut samples. Lunar samples subjected to same procedures show no such structures.

Where do we go from here? Is There Life Out There? Key constraints.

The Drake Equation
=> How to estimate the number of civilizations within the galaxy capable of making contact.

$$N = n^* \times f_p \times f_h \times f_t \times f_L \times f_i \times f_s \times f_c$$

Symbol	Definition	Pessimistic	Optimistic
n*	# Stars in out Galaxy	10^{11}	10^{11}
F(p)	Fraction of stars with planets	0.01	0.3
F(h)	Fraction of planets habitable	0.1	0.7
F(t)	Fraction of long-term habitable planets	0.1	1.0
F(L)	Fraction of planets where life evolves	0.1	1.0
F(i)	Fraction of life developing intelligence	10^{-4}	1.0
F(s)	Fraction where intelligent life survives	10^{-7}	0.1
F(c)	Fraction of lifetime contact attempted	10^{-3}	1.0
N		10^{-8}	2×10^{9}

Can we communicate?

- SETI: Search for Extraterrestrial Intelligence
- Interstellar Spacecraft

A Perspective: Timescale for Earth origin and life…