Physics 1025: Lecture 15 Comparative Planetology: Terrestrials vs Jovians

Announcements

Terrestrials
Moon: small, 1/4 diameter of earth. Cooled rapidly and now is solid to core. No plate tectonics. No atmosphere, no erosion except by cratering. Moon proceeded through first 3 stages of differentiation followed by cratering (producing the bright highlands) and later flooding producing the dark lowlands maria. Now the moon is frozen between stages 3 and 4.

Mercury: also a dead planet, frozen between stages 3 and 4. 40% larger than our moon, but is basically moon-sized metallic core, surrounded by a thin mantle. No atmosphere, no moving plates. Differentiation combined with the Fe-Ni core and rotation justifies magnetic field seen. Flooding and cratering on the surface with long wrinkle ridges (called scarps formed as the planet cooled and contracted). It’s the planet with the body of earth and the face of earth’s moon. A unique feature is Mercury’s rotation: bolometers in the 1960s proved it’s in semi-synchronous rotation, rotating 1.5 times per revolution, tidally locked to sun at perihelion and presenting alternate sides to the sun at closest approach. Only 1 in 3 greatest elongations is visible enough to resolve features, hence earlier astronomers guessed synchronicity. Some think the origin of Mercury was violent in that a giant impact may have stripped off an earlier larger mantle and crust.

Venus: brightest object in sky after moon and sun; a twin to earth in size and density (hence cooled slowly). It has an active surface hidden by dense clouds. No magnetic field has been detected, due to the slow rotation (243 days, retrograde!), though even this should produce some magnetic field. The rotation of Venus appears to be controlled by earth – it rotates so as to present the same face towards earth at closest approach; the rotation period is longer than the revolution period. Radar maps show impact craters, flooded basins and deep valleys and evidence for moving plates and tectonics. Some surface photos show geologically young rocks. The Magellan radar maps show long trenches due to extension stress (one is named Gumby) and lobate-shaped volcanic flows, also large uplifted oval features called coronae due to heated magma bulges. All craters are less than 800 million years old; and all craters are larger than 8km across. Radar photos are exaggerated: 80% of Venus’ surface is within 1% of the mean radius (difference between the highest and lowest features is only 15km). The dense atmosphere is 97% CO₂ with N₂ most of the rest; atmospheric pressure on the surface is 90 times earth’s, at a temperature of 900˚F. These noxious conditions are thought to be due to a run-away greenhouse effect, wherein sunlight filters in but the re-radiated IR radiation cannot penetrate the CO₂ clouds so things just get hotter and hotter. (On earth liquid water dissolved the CO₂ and prevented this disaster – unless we cannot curb present production of this gas from burning fossil fuels). Surprisingly little erosion is seen on Venus.

2012 was a special year for Venus with the second transit occurring in June at sunset here. Astronomers used this event to practice detecting atmospheres of exosolar planets, whereas in earlier centuries observations focused on refining solar system distances (earlier measurements were hindered by the black-drop effect and poorly positioned observers, weather, etc.) Next such event is in 2117.
Mars: is similar to earth in rotation, seasonal changes, tilt of axis, year but only ½ earth’s diameter (twice moon’s), with 10% of earth’s mass. Small size means it cooled fast and much of the original atmosphere leaked away leaving the present CO₂ atmosphere (about 1% earth’s). For 100 years people speculated about life on Mars, from seasonal changes and observed markings labeled canals by early observers. We now know the changes are due to planet-wide dust storms and winds, triggered by an unknown mechanism. The first Mariner probe (1965) found the southern hemisphere old, heavily cratered, lunar-like. The second Mariner probe photographed the younger, less eroded northern hemisphere with its two volcanic areas (the biggest being Olympus Mons at 16 miles high) and the huge Valles Marineres, 2500 miles long, 4 miles deep, 120 miles wide, which may be the edge of a crustal plate (where on Mars the plates thickened and froze before they could spread apart, unlike on earth where they are still moving). On earth we see strings of volcanoes related in age whereas on Mars there’s just one huge volcano which kept growing in one place. The largest canyon was not cut by water; it is a tectonic crack. But there are many signs of copious water on Mars at an earlier time, river beds and channels that could only have been made by water. So Mars appears to have had a thick atmosphere and running water early on, but some believe it suffered from a run-away refrigerator effect, cooling as it lost its atmosphere: the last rain fell over 3 billion years ago. We see frozen water under the present CO₂ cap in summer. Mars has a tiny magnetic field – since it’s spinning rapidly enough, it probably hasn’t a metallic core as on earth. Mars is in the fourth planetary developmental stage now, in a slow decline as the huge periodic dust storms are sand blasting it to smoothness. Concerning Martian life, no visual evidence has been found and the atmospheric gases are not unusual (as when life is present). The Viking lander experiments in 1976 carried out critical tests for life nicknamed the Father, Son and Holy Ghost wherein gas exchange was monitored, evidence of respiration or ingestion of the radioactive gases was explored: in all cases an effect was found but later explained as just exotic chemistry unlike that found on earth. We do have samples of Martian rocks including atmosphere encapsulated inside of the rocks – these are the SNC meteorites found in the Antarctic.

In 1996 4 pieces of evidence from the Martian meteorite ALH10084 convinced some that there was evidence of life inside the meteorite: presence of tiny iron-sulfide magnets, chemical differentiation, presence of PAH molecules, and tiny worm-like structures (remarkably similar and without differentiation into ‘body parts’ or biological evolution). Since then it’s been concluded that each of these indicators could exist in the absence of life, and the worm structures are simply beads of metal evaporated onto the sample to permit electron microscopy scans. A number of Mars rovers have roamed Mars and sent detailed results about Martian geological history, but so far no evidence of life.

Jovians

Jovians comprise most of the solar system mass after the sun and are mostly H and He (which are the only elements which can account for the light densities). Clouds on Jupiter and Saturn are mostly ammonia (NH₃) while methane (CH₄) can still remain as a gas, as opposed to Neptune and Uranus where the clouds are mostly methane. Deeper clouds on Jupiter are ammonium hydrosulfide (NH₄SH) whose sulfur may account for Jupiter’s colorful markings. All the Jovians except for Uranus have about the same temperature even though Neptune is 50% further from the sun. Jupiter generates about the same heat that it receives from the sun, hence due to extreme oblateness, it is hotter at the poles where small
convection cells are seen. Saturn produces twice as much heat per kg of material as Jupiter, possibly due to separation of liquid He sinking gravitationally in the hydrogen atmosphere. The weather and other atmospheric dynamics for the Jovians are very different from earth:

Characteristics of all Jovian planets:
1. Jovians have very deep atmospheres with no solid boundary
2. Jovians spin very fast, accentuating east-west airflow and suppressing north-south circulation (prominent on earth). A consequence is swift eastward equatorial jet streams, 300 km/hr for Jupiter, 1300 km/hr for Saturn and 2100 km/hr for Neptune (almost supersonic)
3. All have internal heat sources contributing about the same heat as received from the sun or greater, generating deep convection
4. All have giant storms: Jupiter’s Great Red Spot has been observed for 400 years, Neptune has a large dark cyclone and every 30 years Saturn has a big storm system generating ovals like those seen on Jupiter; even ‘sidewise’ Uranus has small cyclones recently discovered by Hubble.

Another common characteristic of the Jovians is that they all have large magnetic fields, and large magnetospheres (the region around a planet where the planet’s field is greater than that carried by the solar wind); aurorae are seen on all Jovians. All the Jovians have rings, as detailed below.

The Jovians did not go through the developmental stages characterising terrestrials. They have thick atmospheres of H, He, ammonia and methane – going down into the atmosphere, the clouds gradually blend with liquid H and eventually metallic H. The presence of a rocky central core is still controversial.

Looking at the Jovians in turn:
Jupiter: Contains 70% of all planetary matter in the solar system and just missed becoming a star. Its metallic H core region coupled with rapid rotation generates a large magnetic field (10 times earth’s) creating huge radiation belts. An interesting observation is the relation of the inner Galilean moon Io (which lies inside the inner radiation belt) to the radio emission from Jupiter: we get a radio beam to earth as Io goes into eclipse and its entire sulfur-sodium atmosphere snows out onto the ground as Jupiter shadows it from the sun. Io is one of the two other places in the solar system where there is active volcanism. The other Galilean moons are equally fascinating: Callisto is the world’s largest skating rink with a water-ice interior and a smooth crust of ice which shows the largest impact crater known (concentric rings 1000 miles across but no crater walls due to ice); the surface is divided into dark cratered areas and lighter grooved regions. Europa is the smoothest object in the solar system with a rocky interior and an icy crust and liquid water oceans between (a likely place to search for extraterrestrial anaerobic life); the surface lacks impact craters yet has long wide lines due to crustal fractures from internal motions. Jupiter has thin rings extending 128000 km out, entirely within the Roche limit, the distance from a planet within which a moon is unstable due to tidal shear.

Saturn: In addition to the above features, Saturn is the planet with outstanding rings consisting of billions of tiny particles in Kepler orbits around Saturn – you can see starlight through them. The conspicuous gap is Cassini’s Division visible in small telescopes, but now of course the Voyager pictures show hundreds of concentric rings. Earlier the gaps were related to Kirkwood’s gaps in the asteroid belt.
(Kirkwood gaps are places in the asteroid belt where asteroids have periods commensurate with Jupiter); at distances from Saturn commensurate with Saturn's major moons a moonlet would be in resonance and be slowly driven out. For the multitude of new rings known now around Saturn there is no theory – one would have expected them to smooth out. They can either be from moons that broke up, or from pieces left over after Saturn formed that could not come together stably into a moon. Also new features seen by Voyager and Cassini cameras are spiky radial features overlaying the rings and rotating synchronously with Saturn. Secondly, the two outermost rings were twisted or braided as seen by the first Voyager flyby, but were untwisted by the time the second probe passed by. Also the phenomenon of two shepherd moons in the same orbit and keeping one narrow outer ring in shape was seen for the first time. Saturn's biggest moon, Titan, is one of the few moons to have an atmosphere, composed of $N_2$, methane and various hydrocarbons – another place to look for extra-terrestrial life.

Uranus: was plotted occasionally on star charts for 300 years so an accurate orbit is known. Its axis of rotation lies in the ecliptic plane so we see it alternately pole-on or lying edgewise with the moons orbiting in the plane of Uranus' equator. Its rings were first discovered accidentally in 1977 when Uranus occulted a star. The 19 rings all lie within the Roche limit and are chunk-style with little dust (swept out by the magnetic field) and are tiny; 3 rings are only 500 feet across! Again shepherd moons were found for one ring. Uranus itself has a very stable featureless atmosphere, lacking any giant cyclone characteristics of other Jovian planets. It has a magnetic field 50 time earth's (although weaker at the surface), tipped 60° to the rotation axis and offset – an example of an oblique rotator, possibly explained by whatever violent event tipped the axis over into the ecliptic plane. The 5 classic moons have bizarre surface features:

- Oberon has dark patches on crater floors and icy frozen volcanoes
- Titania has rift valleys 100 miles long (diameter only 90 mi)
- Umbriel is black, the darkest object in solar system (sun breaks up methane to form a tarry hydrocarbon coat)
- Ariel is completely coursed by rifts, branching valleys
- Miranda is the most bizarre moon in the solar system – it has 10 types of terrain, tectonically shuffled. There is a chevron-shaped region and two bulls eyes originally called Circus Maximus (after the old Roman chariot racetracks), more recently named “ovoids”. A possible explanation is that the moon broke up and reassembled randomly – it has the strangest landforms in the entire solar system, including a 5km high cliff on this moon 1/8 the size of our own moon

Neptune: was discovered in 1846 as a result of calculations using perturbations of Uranus' orbit. Berlin Observatory found this planet after the French predicted its location and size. It's a twin to Uranus and has weather typical of the Jovian planets including a giant dark spot or cyclone. The atmosphere is cold enough to freeze out water and ammonia so methane is what is seen. Cirrus clouds are seen about 50 km over the rest of the cloud tops and cast shadows -- the first time such 3-dimensional views seen on other planets. As noted, Neptune has the fastest retrograde equatorial winds ever recorded. Its magnetic field is also tipped 50° to the rotation axis and is displaced even more than that of Uranus: a new theory of generation of planetary magnetic fields must be derived for these oblique rotators.
Neptune’s dust rings are only 10-20 km across and have bright sausage-shaped arcs possibly caused by resonances with a moon; their density is comparable to that of Saturn’s rings and there are four major rings. Of the two classical satellites, Triton is unique in that it orbits in a retrograde fashion, the only large retrograde moon in the solar system. The voyager photos of Triton (at 37˚ K the coldest object in the solar system) show signs of past volcanism, dark patches with bright rims, dark plumes and a N₂ crust on the polar cap. The other major moon Neired orbits 30˚ out of the equatorial plane. There are also numerous smaller moons, 50 to 200 km across, orbiting in the equatorial plane.

Pluto: was discovered in 1930 by incorrectly looking at the residual errors in Uranus’ orbit (too uncertain to ever accurately predict this tiny planet, and Neptune, although nearer, hadn’t moved enough since its discovery to determine an accurate orbit). Pluto’s orbit is inclined 17˚ to the ecliptic and it lay within the orbit of Neptune for the last 20 years of the past century. In 1978 Pluto’s moon Charon was discovered, half Pluto’s size and orbiting synchronously with a 6.5 day period in a retrograde orbit at a distance of 12,000 miles. At least 4 other moons have recently been identified. Pluto itself is only 60% larger than our moon and has a density of 2.1 g/cc. It is thought to be a frozen ball of water, ammonia and methane.

In 2006, the IAU re-classified Pluto as a ‘dwarf planet’ along with other larger trans-Neptune icy bodies like Eris and Sedna, and also the asteroid Ceres, containing 70% of the mass of the asteroid belt. The new rules for planethood are that the object must have enough gravity to form into a sphere, must orbit the sun, and must have cleared its orbit of other significant objects. A ‘dwarf planet’ is a non-satellite body that satisfies only the first two criteria.