The Modern Solar System

Planetary science has experienced a renaissance in the past 20 years. With more and more spacecraft data and our new technologies reexamining older information, a new, bolder picture of the history of the solar system is being written…

About seven billion years ago, a type II supernova detonated in the Milky Way galaxy. The elements created in that conflagration interacted with other clouds of gas and dust from previous events, triggering the creation of stars, including our Sun. The remnants of that stellar birth became the planets.

A number of major events occurred very early in the history of the Solar System. When the Sun's fusion fires ignited, the resultant flash of heat and light drove the leftover dust and gases out of the inner solar system. Some was gathered by the outer planets, notably Jupiter, but far more condensed beyond the orbit of Pluto, forming the Kuiper Belt and Oort Cloud of comets. Subsequent volcanic activity and the impact of comets reformed the atmospheres of Venus, Earth and Mars. The comets deposited the water seen on the inner planets as oceans. Life is believed to have begun in its simplest form within 200 million years of the creation of the planets. However, a massive greenhouse effect sprung up on Venus, boiling away its water and halting the rise of life there. With no way to chemically or biologically remove its carbon dioxide and reduce the intensity of the trapped heat., it remains a hellish world. It appears to melt its entire surface every 500 million years or so.

Earth developed life forms that converted carbon dioxide to oxygen, and later to calcite (sea shells, bones, etc) which moderated the greenhouse here. However, up to 700 million years ago, the entire planet repeatedly endured giant ice ages, due in part to our oxygen/nitrogen mixture of air. Mars, due to its lighter gravity and inherent cooler temperatures, lost much of its atmosphere and essentially froze. It is possible life arose on Mars, but it may be very difficult to find evidence of it now after some 3.5 billion years.

Massive bombardments of the inner planets abated some 3.5 billion years ago. In the first 50 million years of the Earth, a Mars-sized object impacted our planet, speeding up its rotation and casting off most of the crust of the planet. The core of that impactor merged with ours setting up our magnetic field. The rings of crustal material formed the Moon, perhaps within less than 10,000 years after impact. Venus was hit with a glancing blow around the same time, which melted the surface of that world and reversed its rotation. The core of that object moved close to the Sun, becoming the planet Mercury. Mars suffered two large impacts, forming the Argyre and Hellas basin structures, and much of its atmosphere was lost. Lastly, the planet Uranus was literally kicked on its side, devastating its moons and forming its ring system.

Life on earth changed the planet, but it has endured at least 5 major extinctions, now all believed to have been triggered at least in part by impacts of asteroids or comets. Most notable is the Permian extinction 250 million years ago, where more than 95% of all species were wiped out. It could have been worse. Our moon bears the scars of huge impacts, now filled with dark basalt, forming the maria as seen from Earth between3.9 and 2.8 billion years ago. The lunar highlands and parts of the lava flows still show the craters from meteorites that could have hit Earth, were it not for our natural satellite.

This constant bombardment has sculpted the features that we see on the lunar surface, with the formation of a meters thick layer of crushed rock, or regolith. The surface of Mercury also shows impact features, and also rapid cooling and even planetary shrinkage, demonstrated by its unique lobate scarps.

Vulcanism in its first 2 billion years of history saw the creation of a 4,000 mile-long canyon-like graben, and some of the largest shield volcanoes in the Solar System on the surface of Mars. Two major impacts, forming Argyre and Hellas Planitia, may have triggered this activity, but at the cost of most of the Red Planet's atmosphere. A shallow northern sea may have frozen into the soil of Mars, especially near the poles. Perhaps as little as 200 million years ago a large comet approached too closely to Saturn, and its myriad fragments became the ring system we see today. Jupiter has fielded many comets and asteroids over the aeons, and it's satellites bear the scars of these near-misses. In 1994 astronomers got a front row seat to what happens when a comet impacts a planet, as Comet Shoemaker-Levy 9's fragments bombarded Jupiter over a period of a week.

The study of any one body in the Solar System can occupy the astronomer for a lifetime. Let us examine these worlds around us.

Definitions

PLANET - A non-selfluminous spheoidal celestial body illuminated by a nearby star, around which it orbits, and is gravitationally dominant in is orbit.

MOON - Any natural satellite orbiting a planet whose orbital center of gravity is within its parent planet.

COMET - A celestial body, observed only on its approach to the Sun, having a solid nucleus of ices and dust, surrounded by a coma of gases, which is blown back from it by the solar wind to form a vapor tail.

INFERIOR PLANET - A planet which orbits the Sun within the orbit of Earth.

SUPERIOR PLANET - A planet which orbits the Sun beyond the orbit of Earth.

INFERIOR CONJUNCTION - For an inferior planet only, that part of its orbit which brings the planet directly between the Sun and Earth.

SUPERIOR CONJUNCTION - For an inferior planet only, that part of its orbit that places the Sun directly between the planet and Earth.

CONJUNCTION - used especially for superior planets; that part of a planet's orbit which places the Sun between it and Earth.

OPPOSITION - for a superior planet only, that part of a planet's orbit that places the Earth directly between it and the Sun; usually the best time to observe said planet.

ELONGATION - for an inferior planet only, that time in which the planet is furthest from the Sun, as seen from Earth.

QUADRATURE - For a superior planet only, that part of the planet's orbit when it is at right angles to the Sun as seen from Earth.

Planetary Motions

Between 1609 and 1621, Johannes Kepler used the exacting visual observations of Tycho Brahe to define three basic laws of planetary motion. Simply stated, these are:

1) A planet moves along an ***elliptical orbit*****,** with the Sun at one focus of said ellipse.

2) An imaginary line from the Sun to the planet will sweep out ***equal areas of space in equal time periods.***

3) For any planet, the ***square of its orbital period in Earth years is equal to the cube of its distance from the Sun when measured in astronomical units***, the distance between the Earth and the Sun (1 AU = 93 million miles).

When these laws of motion are combined with Newton's laws of gravitation, and further refined by Einsteinian physics, they can be applied to all orbital phenomena.

Planetary Orbital Spacing

Any description of the creation of the planets must take into account the very placing of the planets in their orbits.It is more or less accepted that instabilities in the original dust cloud triggered the creation of large bodies in the solar system.

In 1772 **Johann Elert Bode** rediscovered an interesting mathematical relationship of planetary spacings originally noted by **Titius** and attempted to build upon his work. It integrated the spacing of the planets and their observed distances from the Sun.

Divide the distance between the Sun and Saturn into 100 parts (Saturn was the farthest planet known at that time). It can then be seen that that Mercury is 4 parts distant from the Sun; Venus, 4 plus 3 = 7 parts; Earth, 4 plus 6 parts = 10 parts; Mars 4 plus 12 = 16 parts. A gap was then noted; where 4 plus 24 = 28 parts predicted a planet would be, none was to be had. Today this is known to be the average distance of the main asteroid belt. The discovery of the first asteroid, **Ceres,** in 1801 was said to have been the "missing" world. The "Law" could be extended beyond Saturn to "predict" the existance of other worlds. The full chart is shown below, with modern values added.

planet	**calculated value**	**actual value**
Mercury	4 + 0 =4	3.90
Venus	4 + 3 = 7	7.20
Earth	4 + 6 = 10	1.00
Mars	4 + 12 = 16	1.52
(asteroids)	4 + 24 = 28	2.77
Jupiter	4 + 48 = 52	5.20
Saturn	4 + 96 = 100	9.54
Uranus	4 + 192 = 196	19.18
Neptune	4 + 384 = 388	30.06

Pluto	4 + 768 = 772	39.44

Planetary Parameters

Mercury	Distance from Sun	0.39 AU
	Orbital period	88 days
	Rotational period	58.8 days
	Diameter	3031 miles
	Density	5.4 g/cc
	Atmosphere	Transient; captured from solar wind H, He, Ar, other gases
	No satellites	
	Composition	Silicates, Fe-Ni core

Surface heavily cratered, showing some evidence of tectonic activity. One major feature, the **Caloris Basin**, is believed to be a remnant of a major asteroidal impact some 3 billion years ago.

Venus	Distance from Sun	0.72 AU
	Orbital period	224.7 days
	Rotational period	243 days, retrograde
	Diameter	7526 miles
	Density	5.1 g/cc
	Atmosphere	Extremely dense; 95 bar pressure greenhouse effect CO2,Ar,N
	No natural satellites	
	Composition	Silicates, Fe-Ni core

Radar studies from Earth, the Soviet Venera landers, the U.S. Pioneer Venus and, most recently, the Magellan orbiter spacecraft have revealed an enormous rift valley 4 miles deep by 900 miles long, as well as gigantic mountain features almost seven miles higher than the average for the planet. This is the largest feature that the planet's crust can support. Surface features are apparently being altered by ongoing vulcanism and "planet- quakes". The atmosphere is layered with clouds of sulfuric acid and related compounds. The clouds circle the planet about every 4 days.

Earth		
	Distance from Sun	93 million miles
	Orbital period	365.25 days
	Rotation period	23 hours 56 min.
	Diameter	7962.5 miles
	Density	5.52 g/cc
	Atmosphere	mild greenhouse effect. N, O2, Co2, Ar
	One natural satellite	
	Composition	Silicates, Fe-Ni core, magnetic field

Surface 70% covered by liquid water; land masses shaped by tectonic activity. Due to the low ratio of size between Earth and Moon, we are often erroneously called a "double-planet system". The presence of life on our world has drastically modified the original composition of our atmosphere.

The Moon

Diameter	2159.9 miles
Mean distance from Earth	238,000 miles
Density	3.0 g/cc.
Atmosphere	Mostly tenuous gases from captured solar wind plus 10 tons of propellant from the Apollo era.
Composition	Silicates, some native iron, virtually no organic compounds

Mars	Distance from Sun	145 million miles
	Orbital period	687 days
	Rotation period	24 hours 57 min.
	Diameter	4220 miles
	Density	4.05 g/cc
	Atmosphere	10 millibar at surface. -120 deg. F at the equator. Poles -195 F, and are of water and CO2 ices. CO2, Ar, N, some water vapor.
	Two natural satellites, four man-made.	
	Composition	Silicates, Fe-Ni core

Liquid water once ran freely on the surface of the planet, creating riverbeds, arroyos, and evidence for a northern ocean.. Permafrost is believed to be mere inches below the surface in some areas. A huge rift valley extends for some 4,000 miles, and areas covered by miles-high volcanoes which indicate major activity some billion years ago. Craters of meteoritic impact origin can be seen even from Earth under exceptional conditions. The results of the Viking search for life on Mars were inconclusive, further work remains to be done in this area of investigation. Subsequent exploration by varius orbital and lander/rover spacecraft have given us a portrait of a dynamic geology for so small a planet.

Jupiter	Distance from Sun	485 million miles
	Orbital period	11.86 years
	Rotation period	9 hours 55 min. ave.
	Diameter	88700 miles at equator
	Density	1.35 g/cc
	Atmosphere	constantly in turmoil from internal heating, with no solid surface. Pressure increases until metallic charateristics develop. Temperatures also increase. H, He, other traces of organic compounds.
	Sixty-three natural satellites.	

The ***Voyager and Galileo*** spacecraft have revealed the largest Jovian moons to be as varied in nature as the inner planets of the solar system. **Io** has been found to possess active volcanoes, with extensive lava flows, giving it a distinctive yellow-brown color. **Ganymede** resembles the moon of Earth, but with ice "maria". **Europa's** surface is covered with a network of cracks in an icy crust (Possibly covering a subsurface ocean?). **Callisto** is the most heavily cratered object ever photographed in the solar system.

The most persistant feature in the Jovian atmosphere in the famous **Great Red Spot.** This is now known to be an immense hurricane-like storm system, with a surface area equal to that of the Earth! It is perhaps millions of years in age. The Jovian magnetosphere is millions of times more powerful than that of Earth, and correspondingly has trapped that much more radiation from the solar wind.

A hot spot of an energy equivalent to hundreds of millions of degrees Farenheit faces the Sun as the planet moves in its orbit. Auroral activity has also been detected.One of the more unusual discoveries from the Voyager spacecraft has been the discovery of a system of rings about the equator of the planet. Much darker than those of Saturn, its origin is still uncertain.

Saturn		
	Distance from Sun	889 million miles
	Orbital period	29.46 years
	Rotation period	10 hours 32 min.
	Diameter	72,000 miles
	Density	0.71 g/cc
	Atmosphere	Much quieter than Jupiter, otherwise similar. H, He, some traces of organic compounds.

Fifty-six satellites confirmed, not to mention a certain ring system of water ices and dust.

The planet has a attenuated magnetosphere, thereby indicating the same heat-driven dynamo in its core. Its satellites show impact craters, and in the case of Enceladus, possible fragmentation from asteroidal impact, with subsequent reforming and reheating! Titan's atmosphere is composed mainly of nitrogen, with a smog of organic materials. Its temperature of -178 C makes the evolution of life as we understand it unlikely. The ***Cassini/Huygens spacecraft*** has revealed Titan to be a frozen analog to the early Earth, with terrain both alien and hauntingly familiar.. Iapetus is half covered with a dark material, possibly from electromagnetic effects on nearby heavily impacted Phoebe. The origin of the ring system is still unknown; effects from the magnetosphere occasionally elevate fine dust particles slightly above the average plane of the rimgs, creating a "spoked" appearance.

Uranus		
	Distance from Sun	1,783 million miles
	Orbital period	84.02 years
	Rotation period	17.2 hours
	Diameter	29,125 miles
	Density	1.30 g/cc
	Atmosphere	Much quieter than Saturn, otherwise typical for a gas giant; evidence for an ocean of liquid water and ammonia. H, He, CH4

Twenty seven satellites confirmed, with a system of very dark rings.

The Voyager flyby of January 1986 opened a wealth of data that is still being processed. The five largest satellites all show both cratering and subsurface activity. Miranda may even have fragmented and reformed in the very recent (<1 billion years) past!The surface of Ariel is perhaps the youngest of all in the Uranian system, and is covered with a global system of rift valleys. Umbriel lacks fresh craters, and resembles Callisto of Jupiter to a great extent.Titania is about midway between Ariel and Umbriel in resurfacing, giving a clue to whatever processes affected this system. Oberon has sustained at least one major impact in the recent past, as a huge mountain peak extends off the limb of the satellite in Voyager photos (usually, such a feature is found in the center of recent impacts).

This is the first of the historically discovered planets. William Herschel used a 6-inch newtonian reflector of his own crafting to find this planet in 1781. In ensuing years, the five largest satellites, were discovered, and it was found that the planet rotates at an inclination of 92 degrees to the plane of its orbit, effectively circling the Sun on its side! Each pole is in darkness at least 21 years straight, twice per orbit of the Sun. Modern discoveries began in 1977, when researchers watched the planet occult a star. Aside from the planet occulting the star, as was expected, the star also flickered in and out as the planets ring system also obscured the stars light. The ring system's size and density was then estimated from the occultation data and later confirmed by the Voyager spacecraft.

The planet possesses a magnetic field, itself tilted 60 degrees to the axis of rotation! Although the Voyager data has told us of the aftermath of some major catastrophe in the ancient past, it remains for further research to explain exactly what happened.

Neptune

Distance from Sun	2,794 million miles
Orbital period	164.8 years
Rotation period	16 hours
Diameter	27,625 miles
Density	2.47 g/cc
Atmosphere	Similar to Jupiter. H, He, other organics.

Thirteen satellites and a sparce ring system were confirmed by the Voyager 2 flyby.

The discovery of Neptune was a triumph for mathematical astronomy. In 1846, J*ean-Urbain Leverrier* calculated its position to within a half-degree of the actual location from perturbations noted in the orbit of Uranus.

Neptune's atmosphere posesses winds of up to 1400 m.p.h. A Great Dark Spot has been seen, but unlike the Great Red Spot of Jupiter, it is a region of relative cold. Smaller features (one affectionately called the "Scooter") runs counter to the planet's rotation, riding a jet stream around the south polar region.

Triton, the largest of the eight known satellites, possesses a thin atmosphere of nitrogen, with water volcanoes and nitrogen ice glaciers. It is spiralling back toward the planet, and may collide with Neptune in the distant future. Another, the second of the two satellites discovered from Earth-based observation, ***Nereid***, orbits Neptune in about one Earth year, and may actually be a captured asteroid. The Voyager 2 spacecraft flew over the north pole of Neptune in August, 1989. From all accounts, it was just in time! Since summer is now taking place there, by this writing all surface features are probably obscured by a smog of ethane and nitrogen, as happened at Saturn's ***Titan.***

Pluto	Distance from Sun	3,700 million miles
	Orbital period	248.4 years
	Rotation period	6.4 days
	Diameter	1,500 miles
	Density	1.5 g/cc ?
	Atmosphere	Extremely thin N, CH4
		Three natural satellites

This most recently discovered planet was found with the aid of mathematics performed by *James Pickering and Percival Lowell,* and photographed and recognised by the diligent observational powers of an amateur astronomer hired by the Lowell observatory, (then) 23 year old ***Clyde Tombaugh*** in 1930. Because of its exceptionally small size, it is likely that another much more massive planet orbits further away from the Sun, awaiting discovery.

Pluto's moon **Charon**, was discovered in 1978. It orbits its primary at an inclination of nearly 90 degrees. The planet itself is inclined relative to its orbit 118 degrees. At certain parts of its orbit, Charon eclipses Pluto as seen from Earth! Two more tiny satellites, **Nix** and **Hydra** were found in 2006.

More Worlds…

As this is written (9/2006), a controversial decision by an interim vote of the International Astronomical Union has demoted Pluto to a 'dwarf planet' status, as well as including in this classification Kuiper Belt Object **Eris** and the asteroid **1Ceres**. A final decision of status of 'what is a planet' will be made in 2009 by vote of the full IAU membership. Stay tuned!