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Enigma of the Birth and Evolution of Solar Systems May Be Solved by Invoking Planetary-Satellite Dynamics

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1. Introduction

From ancient times there has been a quest to understand the position of human kind in the cosmic order and to develop predictive system which could warn us of the impending natural calamity. In a continuing quest for an accurate predictive system, in Greek times Ptolemy kept our Planet at the center of the Universe and propagated the Geo-centric World View [Gale (2005-2006), Lawson (2004)]. In 16th century at the height of Renaissance, in a paradigm shift work but which was very much in keeping with common-sense, Nicolaus Copernicus, mathematician, astronomer and catholic monk, presented his book "*De revolutionibus orbium coelestium* (on the Revolution of the Heavenly Spheres)" first printed in 1542 in Nuremberg, Holy Roman Empire of the German Nation [Hawking (2005), Kuhn (1957), Windleband (1958), Crowe (1990)]. It offered a new framework for calculating the positions of the planets and this computational framework was tied to a Helio-centric World View [Hawking (2005)].

This Helio-centric Model was a natural consequence of common sense logic because the Sun was the heaviest object. The mass of Sun had been established during the renaissance by Sir Issac Newton [Hawking (2005)]. This simple model at one stroke removed all the anomalies observed in the motion of the planets till then. But still it stood against a wall. The concept of helio-centrism was very much there in Greek Times [Gomez 2011] but the religious dogma and over-possessiveness of the idea of superiority of human-kind over all living kinds compelled geo-centric world view as the correct and the official tenant of the Greek times.

This dogma persisted. Such were the dogmatism of the Dark Mediaeval Period that in 1553 Michael Servetus [Goldstone & Goldstone(2002), Janz (1953)] was burnt at stake for advancing new ideas contrary to those of the Church. New ideas were considered heretical ideas.

In 1584 a young theologioan and naturalist by the name of Giordano Bruno [Singer (1950), Yates (1964), Brix (1998)] came on the European Scene. He boldly proclaimed the correctness of Helio-centric Model and he went a step forward saying that all stars were like our Sun, that there may be many more *extra terrestrial solar systems*, *many more exo-planets* and *many more extra terrestrial intelligence*. There was nothing sacrosanct about Man and his Earth just as there is nothing special about Chinese Civilization and their Middle Kingdom. This was the final nail in his coffin.

In 1592 Bruno was arrested by the Inquisition, a Church Court. His philosophical and political views were censored and he himself was burnt at stake in 1600. He was the martyr of “Free Thought and Modern Scientific Ideas”. He was the bold harbinger of a New Cosmology during the Italian Renaissance.

De Revolutionibus was banned “until corrected”. In 1620 nine sentences were deleted and then it was brought into circulation.

The debate about **extraterrestrial intelligence** continued and it was argued that if indeed there is **extraterrestrial intelligence** elsewhere there must be Earth-like planets in our Milky Way Galaxy. It was also argued that SETI must concentrate in those regions of our Galaxy where Earth-like planets are most likely to be found by anthropomorphic principles. By anthropomorphic principles the best places to find life in our galaxy could be on planets that orbit the Red Dwarf Star. Gliese 876 falls in this category. It is one-third the mass of our Sun and only 15 light years distant from us. It is three planet system. The planets falling in “Goldilocks Zone” around these Red Dwarfs will have maximum probability of **extraterrestrial intelligence**. These zones are the area around the star which is neither hot nor cold for liquid water to stay. The full lifecycle of a star is dependent on its mass. The lifecycle is inversely proportional to the mass. The massive stars are short lived, their life being of million years. The light stars like Red Dwarf star are very long lived, their life cycle extend up to 100 billion years. Therefore Red Dwarf planetary system has a greatest chance of harboring an evolved form of life. Thus the idea of Extra-Solar Systems and Exo-Planets were born. Extra-Solar Systems are the Solar -Systems around other main-sequence stars and members of the extra solar -systems are exo-planets.

M Dwarf or Red dwarf stars are most abundant outnumbering sun-like G Type stars by 10 to 1. Since these stars are likely to have earth like planets falling in Goldilocks Zone hence they are the primary target for SETI missions.

The following table gives the types of Stars and the likelihood of finding extra-solar systems:

Types	Mass	Likelihood
F- Type	1.3 to 1.5 M _⊙	10%
G- Type (sun like)	1 M _⊙	7%
K-Type	0.3 to 0.7 M _⊙	3 to 4%
M-Type	0.1 to 0.3 M _⊙	Unlikely.

Table 1. The types of stars and the likelihood of extra-solar systems with different types. [Zimmerman 2004]

2. The discovery of first extra-solar system¹

In 1986, two proposals came from the University of Arizona and the University of Perkin-Elmer for space based direct imaging of Extra-Solar Systems using 16m- infrared telescope and optical telescope respectively.[Shiga 2004, Zimmerman 2004]. Atmospheric turbulence smears the star’s light into an arcsecond blob and reduces the resolution therefore ground based imaging of exo-planets was impossible.

¹ [Lissauer 2002]

Adaptive Optics overcomes the atmospheric turbulence. Adaptive optics measures the scrambling due to air turbulence with a special sensor, then sends the information to a flexible mirror that deforms and undulates many times a second to tidy up the image. The rapid changes in the shape of the mirror exactly compensates the distorting effect of the churning atmosphere.

Recently extreme adaptive optics has been developed. It replaces hundreds of tiny pistons that reshape current flexible mirrors with thousands of smaller ones, and correct the incoming light not hundreds but thousands of times a second. This would spot a young glowing Jupiter in a much wider orbits. The road to another earth lies through another Jupiter, hence the presence of wide orbit Jupiter will mark the stars which should be closely examined first for earth like planets and then for life and intelligence.

In 1991 the first extra-solar system around a Pulsar was discovered by Alexander Wolszczan and Dale Frail. This pulsar is PSR1257+12, a rapidly rotating neutron star about $1.4M_{\odot}$ and at a distance of 2000 to 3000 light years of our Earth. In this solar-system three planets were observed. The two planets have orbital period of a few months, small eccentricities and masses a few times as large as the mass of Earth. Third planet, innermost planet, has a period of one month and the mass is that of our Moon.

Name	Jupiter	Gliese 229B	Teide1	Gliese229A	SUN
Type of object	Planet Gas Giant	Failed star Brown Dwarf	Failed star Brown Dwarf	M type Main Sequence Star Red Dwarf	G type Main Sequence Star, Yellow Dwarf
Mass($\times M_J$)	1	30	55	300	1,000
Radius(km)	71,500	65,000	150,000	250,000	696,000
Temperature(k)	100	1,000	2,600	3,400	5,800
Age(years)	4.5Gy	2-4Gy	120My	2-4Gy	4.5Gy
Hydrogen fusion	No	No	No	Yes	Yes
Deuterium fusion	No	Yes	Yes	Yes	Yes
Distinguishing feature of star.	No fusion whatsoever	Not hot enough for Hydrogen Fusion but deuterium fusion starts and after that the fusion fizzles out. Hence we say it is a failed star.	Not hot enough for Hydrogen Fusion but deuterium fusion starts and after that the fusion fizzles out. Hence we say it is a failed star.	Full scale fusion takes place from Hydrogen onward till Iron is nucleosynthesized. It can't go beyond Iron since Iron has the maximum binding energy.	Full scale fusion takes place from Hydrogen onward till Iron is nucleosynthesized. It can't go beyond Iron since Iron has the maximum binding energy.

Table 2. Distinction among Planets, Brown Dwarfs and Main Sequence Stars.

In 1994, 60-inch telescope on Palomar Mountain, coupled with primitive adaptive-optics system, imaged a brown dwarf orbiting the star Gliese 229. The brown dwarf was orbiting the host star at a semi-major axis of 40AU(Astronomical Unit) where 1AU is 1.5×10^8 km. The same system was photographed by Hubble Space Telescope. The ground-based imaging of this binary-star was confirmed by space image. This established the technical feasibility of taking ground-based images of sub-stellar objects using telescopes fitted with adaptive-optics.

In 1995 Mayor and Quiloz discovered the first exo-planet orbiting the star 51Pegasi. They used ELODIE spectrograph. In this the wobbling motion of the host star is used to detect the companion object. The wobbling motion of the host star gives rise to an effective radial velocity along the line-of-sight. Hence light coming from the host star experiences Doppler Effect. When the host star is approaching us, we record a blue shifted light and when host star is receding we record a blue shifted light. The recording of the alternate blue and red shift along the time axis gives the orbital period of the exo-planet and the magnitude of the shift gives us the mass of the host star. Since we may not be having an edge-on view of the orbital plane and the orientation radius vector of the orbital plane may be at an angle i , the angle of inclination of the orientation vector with respect to the line-of-sight, therefore the mass observed is $M \sin i$. We do not get the true mass of the exo-planet unless we have an edge-on view.

In 51Pegasi extra-solar system, we have the exo-planet orbiting the host star at a semi-major axis of 4.8 million miles. The orbital period is 4.2 days. This exo-planet is named 51 Pegasi.b. The mass observed, i.e. $M \sin i$, was more massive than that of Saturn.

One of the biggest drawback of Doppler Method of detection is that only Gas Giants of the size of Jupiter and Saturn can be detected.

ELODIE spectrograph has been further improved into CORALIE echelle spectrograph mounted on the 1.2m-Euler Swiss telescope at La Silla Observatory, ESO, Chile. This has been refined and exo-planets of Uranus mass have also been detected.

In 1999, a planet around HD209458 was detected by transit method. The actual mass and the size of the planet orbiting HD 209458 has been determined by combining the transit method and Doppler shift method. The density has been inferred and it is established that HD 209458b is a gas giant primarily constituted of Hydrogen just as Jupiter and Saturn are.

In 2001 the exoplanet OGLE-TR-56b detected by transit method. A polish team using 1.3m Warsaw Telescope at the Las Campanas Observatory in Chile made this discovery. In the transit method a dip in star light is caused while the exo-planet is transiting across the host star just as we record a solar eclipse when Moon is transiting across the face of Sun on NO MOON day. In the case of OGLE-TR-56b the dip occurred for 108 minutes and repeated every 1.2 days. Using 10m Keck I telescope on Mount Kea, Hawaii, the finding was confirmed by Doppler Method in January, 2003.

Both these discoveries were too close to the host star for comfort. In the classical model there was no place for gas giants to be orbiting closer than 1 to 2 AU. These exo-planets were called hot-jupiters and they defied the conventional wisdom.

3. The menagerie of exo-planets discovered till date²

708 exo-planets have been discovered till 17th December, 2011. 81 multiple exo-planet systems have been discovered till now. 10 earth and super-earths discovered. 2 of these are in Goldilock zone.[“Coming Soon, Earth’s Twin.” The Economic Times on Sunday. December 11-17, 2011 Pg.15.] Generally the exo-planets have eccentricities equal to zero. That is they are orbiting in perfect circular orbits like our nine planets. But there are other exo-planets which are in highly elliptical orbits like comets. Planets have been found orbiting binary stars, in circum-binary configuration, as well as in three star-systems. [Doyle et. al. (2011), Welsh et.al(2012)]. Planets have been found orbiting pulsars.

The only exoplanet with an orbital period larger than that of Jupiter is the one orbiting 55Cncr. Its MSini = 4M_J and its orbital period is 14 years.

Planet as massive as 14M_E have been discovered around Mu Arae [Appenzellar 2004].Orbital period is 9.5 days. Hence it is very close to the parent star.

1992 Arecibo Radio Telescope	<i>Scientists announce the discovery of planets around a pulsar – a spinning neutron star. They are unlike any known planets and almost certainly hostile to life but are the first exo-planets to be found.</i>
1995 Haute –Provence Observatory	<i>Astronomers discover a planet around a sunlike star, 51 Pegasi, by tracking stellar motions. This is the Doppler Shift method. The same technique has revealed more than 130 planets.</i>
1999 STARE Project.	<i>For the first time the shadow of a Jupiter-size planet is detected as the planet passes across the face of the star , HD 209458. This is the transit method.</i>
2001 Hubble Space Telescope.	<i>By observing light from HD 209458 as its planet passes, astronomers see hints of a planetary atmosphere containing sodium.</i>
2003 Keck Interferometer	<i>The interferometer combines light from two existing Keck telescopes, eliminating atmospheric “ noise” with adaptive optics. It will search for debris disk around stars, which could signal planet formation, and look directly for giant planets.</i>
2006 Large Binocular Telescope	<i>Its twin mirrors will search for debris disk and for newly formed Jupiter-size planets.</i>
2007 Kepler Mission.	<i>This space-based telescope is surveying more than 100,000 stars for dimming that hints at the presence of Earth-size planets.</i>
2009 Space Interferometry Mission (SIM)	<i>SIM will combine light from multiple telescopes to map stars and seek planets almost as small as Earth.</i>
2014-2020 Terrestrial Planet Finder (TPF)	<i>A two part space mission, TPF will detect from Earth-size planets and search for signs of habitability.</i>
2025? Life Finder	<i>The space- based Life Finder will search newfound Earths for signs of biological activity.</i>

Table 3. Chronological Order of the milestones achieved in exo-planetary studies.[Appenzellar 2004]

² [Shiga 2004, Zimmerman 2004]

Planets have been orbiting very close to their parent star so much so that they are slowly evaporating due to the heat and solar wind from their parent star. These are the hot Jupiters referred to above. As mentioned these defy the common wisdom of planet formation. By the year 2000, dozen exoplanets discovered and majority of them were hot Jupiters.

The catalog of exoplanets is growing and hot-jupiters seem to be an exception. The average planet size is falling and orbital distance is growing. That is exo-planets are being discovered farther and farther away from their parent star.

Table 3. gives a chronological order of the milestones achieved in exo-planetary studies

4. Conditions conducive to exo-planet growth

In general it is found that single star system favour planet growth. Heavier stars favor giant planet growth while lighter stars favour terrestrial planet growth [Thommes et.al.(2008)]

The extra- solar systems have a much larger probability in younger and more metal-rich regions of the spiral galaxies. The parent stars of exo-planets have higher metallicity [Santos 2005]. They have a higher abundance of elements heavier than hydrogen and helium.

The time factor is also very important. There is a very narrow time slot of few million years after the birth of the solar nebula in which the planets can be formed. The building blocks of planets are dust and gas. The dust particles of the accretion disc are continuously spiraling into the parent star by Poynting-Robertson drag and gas-dust smaller than 0.1 micron are being pushed out by solar radiation insolation by the process known as photo-evaporation [Ardila 2004].

In our Solar System there exists dusty debris disk in the asteroid belt. This causes the zodiacal light hence it is called zodiacal belt of dusty debris. This extends from 3AU to 10AU. There also exists Kuiper Belt of dusty debris from 30AU to 100AU. Similar dusty debris disk surround the stars with planetary system. These have been imaged by IRAS(infra red astronomical satellites) in 1983.It carried out complete survey of the sky in mid to far infra-red wavelength from 12 to 100 microns. The star itself is too hot, about 1000 Kelvin, to emit at far IR. But an accompanying debris disk will heat up and reradiate at far IR. This will give a bump in the stellar spectrum. The excess energy at infrared wavelength invariably indicate the presence of dusty debris disk. These debris disks are tenuous and faint but they have definite IR hazy glow. A gap in the debris disk is the signature of a protoplanet orbiting the parent star. The planet is in formative stage.

The dust in the debris disk either comes from the collisions of the initial leftover planetismals during planet formation or could be coming from collisions of comets and asteroids much after the formation has been completed. This debris disk generally range from 100AU to 1000AU and their composition is similar to that of our comets. The central part is a gap.

Ground based detectors cannot observe IR because of the absorption effect of the atmosphere. Millimetric radiations reach the surface of the Earth. Therefore Submillimeter Common-User Bolometer Arrays (SCUBA) are used on the ground observatory for detecting the mm radiation coming from the debris disk of the stars. A combination of IR and mm wavelengths observations made by Hubble Space Telescope, SCUBA and IR detectors from

the ground observatories have established that a dozen stars possess the dusty debris disk including Beta Pictoris. These debris disks are the analogue of Kuiper belt debris and hence are cooler than expected.

The debris disk depend on the age. Young stars in formative stage possess a much larger and heavier dusty debris disk as compared to our Solar System which is 4.56Gy. In our Solar System much of the debris has been used up in planet formation and the residual has spiraled in due to Poynting-Robertson (PR) drag or photoevaporated. The dust presently seen in asteroid belt and Kuiper belt is the result of collision and evaporation of comets and asteroids. They are continuously being removed by PR drag and by photoevaporation and they are also being replenished by collisions and evaporation. Hence the young stars have a much larger debris disk.

So far the stars with debris disk have not given the confirmation of the presence of planets and stars with extra- solar systems have not shown up any debris disk.

Name of the star	Age	Extent of the dusty debris disk	implications
HD 100546	<500My	? Revealed a gap at 10AU	A protoplanet might be orbiting the parent star.
Beta Pictoris	15My	1400AU edge-on disk debris disk detected at optical and near IR.	10,000 times as much dust as our solar system does. This means it has 100 times more planetismals as compared to our sun.
HD 141569	< 20My	Long spiral arms of dust. Debris disk detected at optical and near IR.	The companion stars could have created these features. It could be due to accompanying planets.
Fomalhaut		200AU in radius , edge on ring of dust is observed. Debris disk detected at thermal IR. A ring of warm materials detected very near the star.	Observed at 70 microns by SPITZER. The inner warm ring is akin to asteroid belt and its IR glow was observed at 24 micron.
Au Mic (M Type star)	15My	50 AU to 210AU	Excess of far-IR radiation points to the existence circumstellar dust grains;
HR4967A	< 20My	debris disk detected at optical and near IR.	
Vega		debris disk detected at thermal IR.	
ε Eridani		debris disk detected at thermal IR.	

Table 4. Stars with dusty debris disk and the implications.

The debris disks have definite large scale features such as rings, warps, blobs and, in one case, a large spiral. All the extra-debris disks so far detected are much more massive than our Asteroid belt debris and Kuiper belt debris.

Till date(1.01.2012) in last 16 months, since the Kepler Program was started, 2,326 planet candidates have been discovered out of which 31 have been confirmed. Kepler 22b is orbiting Sun-like star whereas Gliese-581d and HD 85512b are orbiting smaller and cooler stars but they are all in Goldilock zone.

The discovery of earth-like exo-planet would be the Holy Grail of astrobiology- a place where life started from scratch independently of life on Earth. The strategy is to first detect an earth-like exoplanet in the Goldilock zone of some star nearby say within 100 lightyears and then use terrestrial planet finder (TPF) to detect the biomarkers in the atmosphere of the given exoplanet.

5. Evolution of solar system building material

In NASA's DEEP IMPACT mission a 820 pound impactor collided with Comet Tempel 1. By the study of Comet material it was concluded that it was made of the pristine constituents of early solar system. This pristine material consisted of fragile organic material. This material includes polycyclic aromatic hydrocarbons(carbon based molecules found on charred barbeque grills and automobile exhaust on Earth).

On the other hand, the asteroids are the leftovers of planet formation and they therefore represent a more evolved form of matter. About 4000 Asteroids have been categorized. The Asteroid belt exists from 2.1AU to 3.3AU. Asteroids are coplanar with Ecliptic Plane. They move in the same direction as the Planets.

In terrestrial planets there is a metallic core and surrounding basaltic-granitic mantle.

But a Solar System which is in transition like HD113766 and which has a dusty disk has material in between the primitive kind contained in comets and more evolved kind found in asteroids.

Planet bearing Extra Solar Systems invariably have an environment rich in metal[Santos 2005]. The stars with twice the metallicity have 25% chance of harbouring a planet whereas stars with Sun's metallicity has only 5% chance.

There is a very narrow time slot of tens of millions of year in which Gas Giants birth and growth must take place. The dust part is continuously spiraling inward due to Poynting - Robertson photo assisted drag and gas-dust particle smaller than 0.1 micron are pushed out by the solar radiation insolation also known as photo evaporation.. Thus the gas-dust circumstellar disc is dissipated after tens of millions of years. If the opportunity is not seized for the birth and evolution of Gas Giants then no planetary formation would take place. The formation of Gas Giants is essential for Earth-like terrestrial planets.

6. The difficulties in discovering exo-planets

Doppler shift technique is the most convenient method of detecting Jupiter sized planets in tight orbits around their parent stars. The other methods are enumerated in Table 5.

Method	Description
Terrestrial direct imaging	<p>Largest telescopes such as Keck, Gemini and Subaru are being used for direct imaging. Orbital architecture can be determined hence true mass is known.</p> <p>Easier to detect gas giants in wide orbits like ours.</p> <p>Young stars are ideal target as their companion planet would be glowing brightly in infra red wavelength because of the accretion generated heat.</p>
Space direct imaging	<p>William SPARKS(Space Telescope Science Institute) is using Hubble Space Telescope’s Advanced Camera for Surveys for direct imaging. Orbital architecture can be determined hence true mass is known.</p> <p>Easier to detect gas giants in wide orbits like ours.</p> <p>Young stars are ideal target as their companion planet would be glowing brightly in infra red wavelength because of the accretion generated heat.</p>
Radial Velocity technique or Radiovelocimetry or reflex motion of solar type stars	<p>A color change in the star light betrays the wobble caused by the companion planet. When star is approaching, light experiences a blue shift and when star is receding, light experiences red shift. This is also known as Doppler Shift technique.</p> <p>There is uncertainty about the orbital angle of inclination hence real mass is indeterminent. Only the lower limit of the true mass is determined.</p> <p>Easier to detect gas giants in tight orbit.</p>
Astrometric method	<p>Recording the proper motion of the star on the celestial sphere i.e. the dome of the sky.</p> <p>Most sensitive for gas giants in nearby stars.</p> <p>Since 2-D picture is obtained therefore actual mass is determined.</p> <p>Wide orbit planets produce larger amplitude of the proper motion of stars hence easier to detect but wide orbit means longer orbital period hence a longer timeline of observations.</p>
Transit photometry method	<p>If the planet lies in the orbital plane of the star and we have an edge on view then the planet transit or Venus transit-like will cause a periodic square-well shaped dip in the star’s brightness. It gives the estimate of planet size and the orbital period. The mass will have to be determined by astrometric or Doppler shift technique.</p>
Gravitational microlensing	<p>This method is used for detecting very faint stellar and sub-stellar bodies within our galaxy. A massive body intervening the space between the source and observer causes gravitational bending of light from the source leading to the brightening of the image of the source.</p> <p>If the intervening body is a star with a planet then the lining up of the source planet, intervening star and the observer will lead to considerable brightening up of the image of the source. As planet moves out of the line of sight, the brightening will diminish. The</p>

Method	Description
	period of fluctuation in the image of the source is the orbital period and the amount of fluctuation gives the mass of the planet.
Lyot method	Suppresses 98.5% of the starlight by the use of a coronagraph and images the companion planet at near-IR wavelength or images the starlight reflected by the companion planet or by the circumstellar debris disk.
Nulling interferometry.	Large binocular telescope is used for canceling the starlight by nulling interference and image the exo-planet or the debris disk. Starlight are collected by two mirrors but with a path difference of half wavelength. This results into destructive interference along the central line of sight but it is constructive interference off the line of sight.
Radio emissions similar to those from Jupiter.	Radio emissions similar to those from Jupiter could reveal the presence of planets.

Table 5. Various methods of detecting exo-planets.[Shiga 2004],

Time is the greatest difficulties. The orbital periods of Jupiter and Saturn are 12 and 29.5 years. Hence one will have to wait for that long to measure its periodicity.

Second is the resolution of the Doppler Technique. With the present resolution we could keep looking for century and not detect a Saturn of that mass and of that semi-major axis.

The masses of Jupiter and Saturn are 318 and 95M_E and those of Neptune and Uranus are 17.2 and 14.6 M_E . The amplitude of Doppler oscillation is proportional to (MSin*α*)/a^{1/2}. Hence observational bias is towards heavier masses and shorter semi-major axis.

Table (6) gives the radial velocity which have been detected [Schwarzschild 2004].

Mass of the host star (×M _⊙)	Mass of the planet (×M _E)	Semi-major axis a (AU)	Amplitude of oscillation of Radial velocity of the host star (meter/ second)
Red dwarf -Gliese 436 0.5	21	2.6 days 0.028AU	18
μ- Arae 1	14	9.5 days 0.084AU	4
ρ Cancrī sun-like 1	18	2.8 days 0.04AU	6
Sun-like star 1	1	1AU	0.1
Sun	Jupiter	11.86 yrs 15AU	12.5
Sun	Saturn	30 yrs 20AU	2.7

Table 6. A comparative study of the radial velocity of the host star for different combinations of star-planets.

As seen from the Table(6), with decreasing mass of the planet and increasing mass of the host star, the amplitude of oscillation of the radial velocity decreases. As the amplitude of oscillation decreases it becomes increasingly difficult to decipher the periodic planetary signal in the presence of various noise sources that produce random fluctuations in star's apparent radial velocity.

Recently HARPS spectrometer has been developed by the Swiss team which discovered the first exoplanet Pegasi 51. This spectrometer has the required precision to decipher the tiny Doppler shift due to 0.1 m/s radial velocity of the host star harboring an earthlike planet. The instrument is kept in high vacuum and precisely controlled low temperature so that the sources of noise can be eliminated and optical stability may be imparted for obtaining the required precision. Through HARPS only Mu Arae's planet, 14 times M_E , was detected.

By Astrometric measurements, the inclination of the planetary orbit and orbit-globe parameters can be determined. Astrometry is the precise measurement of two-dimensional stellar positions on the celestial sphere. The astrometric studies complement the radial velocity method. Through this method the ellipse traced by the centroid of the star during one orbital period of the planet can be exactly determined. From this ellipse the angle of inclination α and other globe-orbit parameters can be determined.

Space Interferometry Mission scheduled for 2009 will give sufficient accuracy to astrometric method for discovering a new planet.

7. The classical model of the birth and evolution of a solar system

From the three new Neptune-like planets [Schwarzschild 2004] the scientists conclude the following:

- i. The shock waves of a Supernova explosion sets a giant cloud of gas and dust, passing nearby, into a spinning mode. The rapid spin cannot be accommodated by one hydrostatic star hence it results into the fragmentation of the cloud into binary or multiple star system. Even the new multiple system cannot accommodate the excess angular momentum and the individual clouds are flattened out as pancake shaped disc of accretions. The central part collapses into a proto-star surrounded by a thick disk of gas and dust. From these Keplerian debris disks the planets are born. The solar insolation is causing the photoevaporation of gas out of the system and the dust particles are spiraling inward due to Poynting-Richardson Drag and settling down in the midplane of the disc. Thus gas is blown out and the host star vicinity is filled with heavy suspension of dust particles larger than a micron size. These micron size dust randomly collide and stick together building up km-sized planetismals. But before the build up can take place the random collision may result in repeated breakups preventing the formation of planetismals. But if there is heavy dust suspension, with the gas blown out, runaway gravitational accretion takes place resulting into full scale terrestrial planets.

So there are two scenarios:

- a. The first scenario is the earliest stage of planet formation when the protostar is not experiencing full scale thermonuclear fusion. At that stage there is a very light density suspension of dust in a thick envelope of gas. The gravitation is too weak and

gravitational accretion is prevented. But snowline criteria is not applicable as thermo-nuclear furnace is not switched on yet. Hence the dust is coated with ice which is amorphous and hence sticky (Ordinary ice is a open-pack hexagonal crystalline structure and is non-sticky whereas ice at -230°C is fluffy amorphous structure. If small ceramic ball is covered with fluffy, amorphous ice falling from a height of 12 cm it bounces to 1 cm whereas ball covered with crystalline ice bounces to 8 cm. The colder, more disordered ice absorbs more of the energy of the impact because the molecules rearrange themselves during the collision. Therefore the dust particles coated with amorphous ice will stick together rather than rebound). Through collision and agglomeration (or sticking), km-sized planetismals are formed which are then set on the path of gravitational accretion. Once $10M_{\text{E}}$ cores have formed the gravitational field is strong enough to cause the wrapping of these icy-rocky cores with thick envelopes of gas resulting first into gas giants and subsequently into ice giants.

- b. The second scenario is when gas has been exhausted both by the process of gas giants and ice giants formation and also by photoevaporation. At this stage lack of gas assists runaway gravitational accretion of the thick dust suspension into terrestrial planets. Radioactive dating of the core by Hf-W has established that Earth and Mars were formed 29 million years and 13 million years respectively after the birth of the solar nebula [Cameron 2002, Yin et al 2002, Kleine et al 2002]. There was an extended core formation period. The interior of the planet is heated partly due to Helmholtz Contraction (or gravitational energy release) and partly due to radioactivity particularly that of ^{26}Al . Accumulative collision between small bodies produce the planet. When a small body collides into a large body the core of the small body gets embedded into the mantle of the large body. The heat of impact melts the interior and molten iron core of the smaller body percolates to the core of the larger body.
- ii. According to core-accretion theory or dust bunny theory, by agglomeration-accretion a rock or ice core is formed of mass $10 M_{\oplus}$. Beyond that critical mass the core rapidly envelopes itself by gravitationally captured gas from the surrounding circumstellar disk. This process terminates with the formation of a gap in the circumstellar disc.

Douglas Lin (University of California, Santa Cruz) says “Many incipient gas giants won’t make it to jovian mass before the disk dissipates after a few million years. So we can expect lots of failed Jupiters to show up as Neptune”.

The farther the planet is the longer it takes to form. Infact it may be 100 billion years whereas the lifetime of the debris disk may be only several million years.

Computer models of Jonathon Lunine give the following picture:

- In the inner part of the solar system debris disk is dense. In this dense part, the gas giants are formed in first million years through a chain of core formation and gas accretion;
- In the next ten million years the leftover rock and dust accreted to form the moon – sized embryos. Dust clumps together into gravel, gravels to rock and rocks to hundred of planetary embryos moving in tidy, sedate circular orbits. The collisions stop.
- Jupiter’s influence that is gas giant’s influence have two effects:
- It churns an orderly set of embryos into an unruly, colliding swarm which through collision and accretion evolves into a set of terrestrial planets like our Earth and Mars in another 10 to 20 million years but these rocky planets are bone dry;

- Gas Giants in outer regions would cause icy embryos to veer inward and collide with newly evolved rocky planets. In the process water is transferred to the inner rocky planet;
 - Gas Giants also act as bodyguards for these small watery worlds. There are large chunks of residual rock an ice which are on the loose and which would smash the inner rocky planets in next 100 million years. Gas Giants with its powerful gravitational fields took direct hit from these marauder chunks, some were flung out of the system and most others were herded into the asteroid belt;
- iii. According to gas instability theory there is an abrupt formation of gas giants. The gravitational instability in the circumstellar disc leads to gas-giant formation. There is no unfinished middleweights planets.
- iv. In classical theory the explanation given for the infernally tight orbits of the hot jupiters is the following:

These must have formed much farther away beyond the snow-line which is about 1AU. Subsequently the tidal interaction with the protoplanetary disc caused the hot Jupiter to spiral in. This protoplanetary disc itself dissipates off due to Poynting-Robertson drag and due to photo- evaporation. So the inward migration must be fast before the dust-gas protoplanetary disc dissipates off [Schwarzschild 2004]. This is too contrived a situation. But in the new planetary-satellite model this naturally occurs.

8. The extra-solar planets which donot fit in any model

Lately many exoplanets have been discovered apart from hot-jupiters which donot fit any Model of planet birth and evolution and hence present a conundrum. Table (7) presents the list of the exoplanets and the reasons why they have become an enigma.

Name of the extra-solar system	Description	Reason for enigma
'Pegasi' exoplanets	Gas Giants in 100 times smaller orbit as compared to the orbit of Jupiter and Saturn	Gas Giants can form only beyond snowline which is at 1AU. Then how come hot-jupiters are in orbits of a less than 1 AU ? Gliese 436- a=0.028AU Mu Arae - a = 0.084AU Rho Cancrī-a=0.04AU
HD 188753 (triple star system)	Hot Jupiter orbiting the primary star; Orbital period=3.35d; Orbital radius = 0.05AU; Mass= 1.14M _J ; Primary star mass=1.06M _⊙ ; Secondary system is a binary system of total mass=1.63M _⊙ ; Orbital radius of secondary with respect to the primary= 12.3AU; Orbital period of the primary and	A close and massive secondary will truncate the circumstllar disk around the primary to a radius of 1.3AU and the disk will be heated to temperatures which will prohibit the formation of a gas giant;*

Name of the extra-solar system	Description	Reason for enigma
	secondary around each other is 25.7y;	
HD 41004 (binary stars)	Stars are orbiting each other at distances of 20AU Primary containing the exoplanet is as massive as 3 times or more as compared to the secondary	
GI 186(binary stars)	Stars are orbiting each other at distances of 20AU; Secondary star is a white dwarf; Primary containing the exoplanet is as massive as 3 times or more as compared to the secondary	How did the planet of G186A survive the violent changing phases of the white dwarf, post main sequence evolution of star? A white dwarf is a spent out main sequence star which expands into Red Giant and then shrinks into a White Dwarf.
γ Cephei(binary stars)	Stars are orbiting each other at distances of 20AU & an orbital period of 56y; Primary containing the exoplanet is as massive as 3 times or more as compared to the secondary; Companion planet is $M_{\text{Sini}}=1.7M_J$ Orbital radius= 2.13AU; Orbital period=906d;	
19 binary or multiple star systems are inhabited by a planet	Massive short period planets are found in multiple star system	Five short period planets in multiple star system cannot be explained in a classical fashion. [Eggenberger et al 2003]

* Initially it was thought that Giant planets must have formed in colder region far from their parent stars. Icy nuggets act as seeds that accumulate enough dust to build up to a critical mass where by runaway accretion it is enveloped by a large mass of gas giving birth to gas giants. These icy nuggets can form only beyond snowline[Sasselov & Lecar 2000]. But in HD 188753 this could not have happened. This is because the secondary system of star pair would truncate the disk to 1.3AU leaving nothing beyond in the colder region that could nucleate and grow into a giant planet.

"Giant planets in circumstellar disks can migrate inward from their initial formation positions. Radial migration is caused by inward torques between the planet and disk, by outward torque between the planet and the spinning star and by outward torques due to Roche lobe overflow and consequent mass loss from the planet." [Trilling, Benz et al 1998]. Through numerical solutions it has been shown that taking all the torques into consideration, Jupiter-mass planets can stably arrive and survive at small heliocentric distance just as hot-jupiters do in scorchingly tight orbits.

Table 7. The exoplanets which are conundrum.[Konacki 2005, Hatzes & Wuchterl 2005, Mugrauer 2005, Hatzes et al 2003]

9. Planetary satellite dynamics

On 21st July 1994, the Silver Jubilee Celebration Year of Man's landing on Moon, NASA gave a press release stating that Moon has receded by 1 meter in 25 years from 1969 to 1994. Using this piece of data, the first Author redid the analysis of Earth-Moon System [Sharma 1995]. In a subsequent paper the Authors [Sharma, B. K. and Ishwar, B " Basic Mechanics of Planet-Satellite Interaction with special reference to Earth-Moon System", 2004, <http://arXiv.org/abs/0805.0100>] found that Satellites-Planet Systems have a characteristic lom(length of month)/lod(length of day) equation:

$$\text{LOM/LOD} = E \times a^{3/2} - F \times a^2 \text{ [The proof is given in SOM Appendix A]}$$

Where l.o.m. = length of month (sidereal period of orbital rotation of the natural satellite around host planet which in case of our satellite Moon is 27.3 days);

l.o.d. = length of day (spin period of the host planet which in our case is 24 hours or 1 solar day);

a = semi- major axis of the elliptical orbit of the satellite (for Moon it is 3,84,400 Km);

E = $J_T / (BC)$;

J_T = total angular momentum of the Satellite- Planet System,

= $(J_{\text{spin}})_{\text{planet}} + (J_{\text{orbital}})_{\text{system}} + (J_{\text{spin}})_{\text{satellite}}$;

B = $\sqrt{[G(M + m)]}$;

G = Gravitational Constant = $6.67 \times 10^{-11} \text{ N-m}^2/\text{Kg}^2$;

M = mass of the host planet;

m = mass of the satellite;

C = Principal Moment of Inertia around the spin axis of the Planet;

F = $m / [C(1+m/M)]$;

When lom/lod = 1 we have geosynchronous orbit.

$$E \times a^{3/2} - F \times a^2 = 1 \quad (1)$$

Equation (1) has two roots and hence planet -satellite systems have two geo-synchronous. Only at these two Geo-synchronous orbits the system is in equilibrium because the orbits are non-dissipative. Elsewhere the system is dissipative hence in non-equilibrium either spiraling out to the outer geo-synchronous orbit or spiraling inward to its certain doom. The inner Geo-synchronous orbit lies at energy maxima whereas the outer Geosynchronous orbit is at energy minima. Therefore the inner geo-orbit is an unstable equilibrium orbit and the outer geo-orbit is a stable equilibrium orbit.

When the natural satellite is at the inner geo-orbit it is easily perturbed by solar wind or cosmic particles or solar insolation. It tumbles out on an expanding outward spiral path or it falls short of the inner geo-orbit on inward collapsing spiral path. Inward collapsing spiral path is entirely a runaway path. The outward spiral path, because of energy conservation, is initially an impulsive gravitational runaway phase which quickly terminates because of tidal dissipation in the central host body due to tidal stretching and squeezing . This runaway phase is the gravitational sling shot phase. After the gravitational sling shot phase, the natural satellite coasts on its own towards the outer geo orbit. Our Moon is on a midway course in its journey towards the outer geo-orbit. Charon, a satellite of Pluto, has already arrived at the outer geo-orbit. The satellite may remain stay put in the outer geo-orbit as Charon is doing or it may be deflected as our Moon will be.

10. The new hypothesis- gravitational sling shot model of planet-satellite system

The Authors did the Keplerian-approximated analysis of Earth-Moon, Mars-Deimos-Phobos and Pluto-Charon [Sharma & Ishwar 2004A, Sharma, Rangesh & Ishwar 2009]. The Authors were able to generate the outward expanding spiral path of Moon as shown in Figure 1.

In a sequel paper on the New Perspective of the Solar System [Sharma & Ishwar 2004B, Sharma 2011], it was established that Planets experience a similar kind of impulsive sling-shot phase due to Sun as our Moon does due to Earth. This leads to new paradigm on the birth and evolution of our as well as extra Solar Systems.

10.1 The phenomena of gravitational slingshot

Planet fly-by, gravity assist is routinely used to boost the mission spacecrafts to explore the far reaches of our solar system [Dukla, Cacioppo & Gangopadhyaya 2004, Jones 2005, Epstein 2005, Cook 2005]. Voyager I and II used the boost provided by Jupiter to reach Uranus and Neptune. Cassini has utilized 4 such assists to reach Saturn.

A space-craft which passes "behind" the moon gets an increase in its velocity (and orbital energy) relative to the primary body. In effect the primary body launches the space craft on an outward spiral path. If the spacecraft flies "infront" of a moon, the speed and the orbital

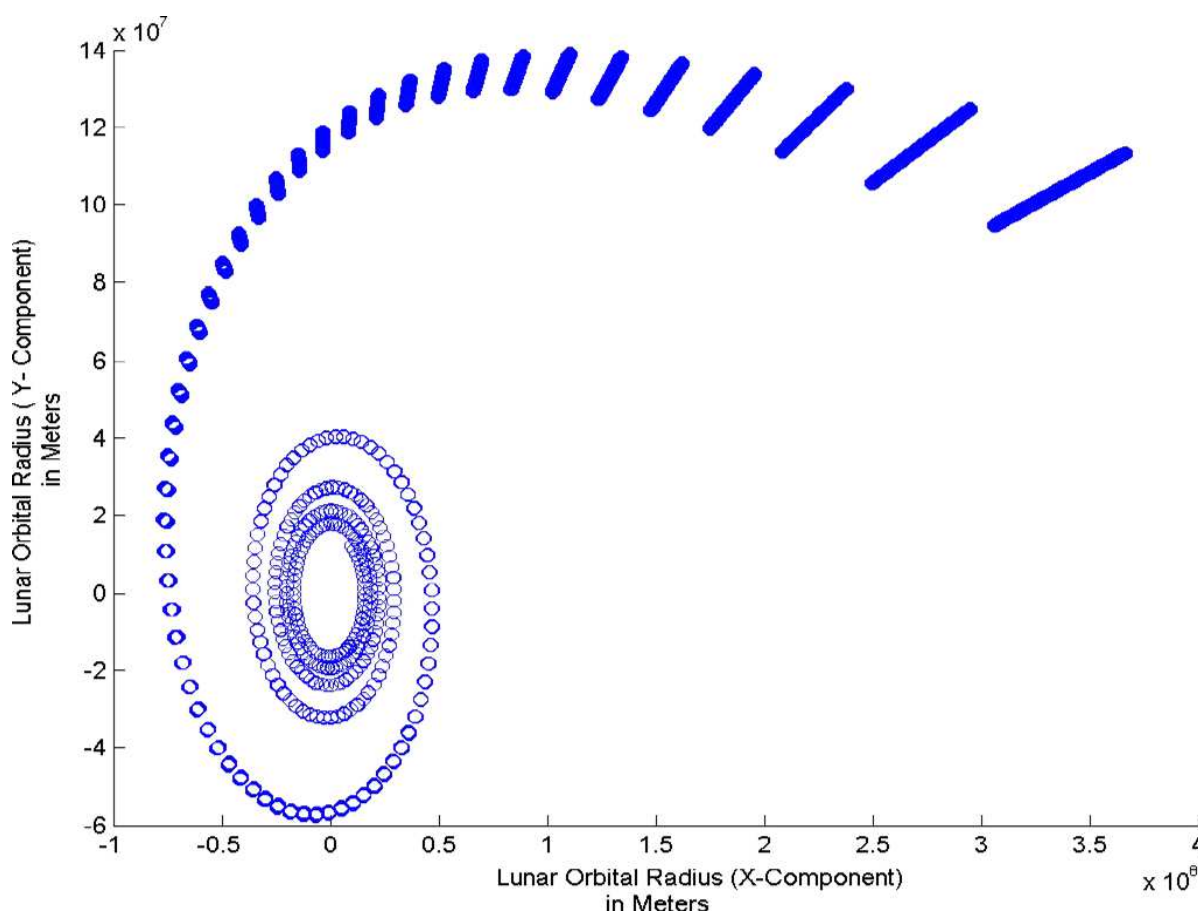


Fig. 1. Lunar Orbital Radius expanding spiral trajectory obtained from the simulation for the age of Moon (i.e. from the time of Giant Impact to the present times covering a time span of 4.5Gyrs).

energy decreases. Traveling "above" and "below" a moon alters the direction modifying only the orientation (and angular momentum magnitude). Intermediate flyby orientation change both energy and angular momentum. Accompanying these actions there are reciprocal reactions in the corresponding moon.

The above slingshot effect is in a three body problem. In a three body problem , the heaviest body is the primary body. With respect to the primary body the secondary system of two bodies are analyzed.

In case of planet flyby, planet is the primary body and the moon- spacecraft constitute the secondary system.

While analyzing the planetary satellites, Sun is the primary body and planet-satellite is the secondary system. But in our Keplerian approximate analysis, Sun has been neglected without any loss of generality and without any loss of accuracy. In fact the general trend of evolution of our Moon has been correctly analyzed [Sharma, B. K. and Ishwar, B “ Basic Mechanics of Planet-Satellite Interaction with special reference to Earth-Moon System”, 2004, <http://arXiv.org/abs/0805.0100>].

While analyzing the Sun-planet system, galactic center is the primary body and Sun-planet is the secondary system. But in our analysis the galactic center has been neglected and we have essentially analyzed Sun-planet as a two body problem.

In a similar fashion in the analysis of Planet Flyby-Gravity Assist Maneuvers, Planet is the primary body. The planet can be neglected and moon-spacecraft can be treated as a two body problem and the same results can be obtained without any loss of accuracy or generality. This will be done in a future paper.

The gravitational sling shot becomes clearer if we look at the radial acceleration and radial velocity profile.

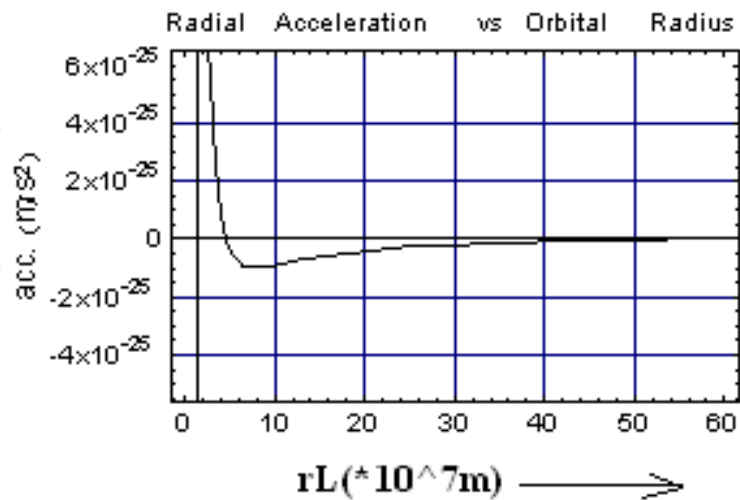


Fig. 2. Radial Acceleration Profile of Moon (Within a_{G1} the Moon is accelerated inward. Beyond a_{G1} the Moon is rapidly accelerated outward under the influence of an impulsive gravitational torque due to rapid transfer of spin rotational energy. The maxima of the outward radial acceleration occurs at a_1 . (This is the peak of the impulsive sling shot torque.)

10.2 Setting up of the time integral equation.

In setting up the time integral equation the first step is to set up the radial velocity expression which has been derived in SOM_Appendix A.

The radial velocity expression is as follows:

$$\frac{da_{lap}}{dt} = \frac{K}{a_{lap}^M} \left(\frac{\omega}{\Omega} - 1 \right) \cdot \frac{2a^{1/2}}{m \cdot B} = \frac{K}{a_{lap}^M} (E \cdot a_{lap}^{3/2} - F \cdot a_{lap}^2 - 1) \cdot \frac{2a^{1/2}}{m \cdot B}$$

Or

$$v(a_{lap}) = \frac{da_{lap}}{dt} = \frac{2K}{a_{lap}^M} \cdot \frac{1}{m \cdot B} \cdot (E \cdot a_{lap}^2 - F \cdot a_{lap}^{2.5} - \sqrt{a_{lap}}) \quad (2)$$

Where K is the structure constant and M is the structure exponent. All the other symbols are defined as before. Equation 2 gives the radial velocity of natural Satellite Iapetus with respect to Saturn.

Between a_{G1} and a_{G2} , ω/Ω is greater than Unity hence radial velocity is positive and recessive.

At less than a_{G1} , ω/Ω is less than Unity hence radial velocity is negative and secondary approaches primary.

At greater than a_{G2} , ω/Ω is negative which is physically not possible in a prograde system hence system is untenable and it is a forbidden state.

Spin to Orbital velocity equation yields a root when it is in second mean motion resonance (MMR) position. That is:

$$\frac{\omega}{\Omega} = E \cdot a_{lap}^{3/2} - F \cdot a_{lap}^2 = 2 \quad (3)$$

This gives a root at a_2 which is gravitation resonance point and I assume that after the secondary undergoes gravitational sling shot impetus, it attains maximum recession velocity at this point. After this maxima, recession velocity continuously decreases until it reaches zero magnitude at outer Clarke's Orbit as shown in Figure 3.

Thus as is evident from Eq.2, recession velocity is zero at a_{G1} and a_{G2} . From a_{G1} to a_2 , the system is in conservative phase and secondary experiences a powerful sling-shot impulsive torque which imparts sufficient rotational energy to the secondary by virtue of which the secondary coasts on its own from a_2 to a_{G2} during which time the system is in dissipative phase, Secondary is exerting a tidal drag on the central body and all the rotational energy released by the central body as a result of *de-spinning* is lost as tidal heat, but not completely. This tidal heat is produced during tidal deformation of both the components of the binary if the secondary is not in synchronous orbit. Our Moon is presently in synchronous orbit hence it is not undergoing tidal heating but Earth is undergoing tidal heating.

When the secondary tumbles into sub-synchronous orbit it experiences a negative radial velocity which launches it on a collapsing spiral and the system is *spun-up*. In this collapsing phase, secondary exerts an accelerating tidal torque on the central body and

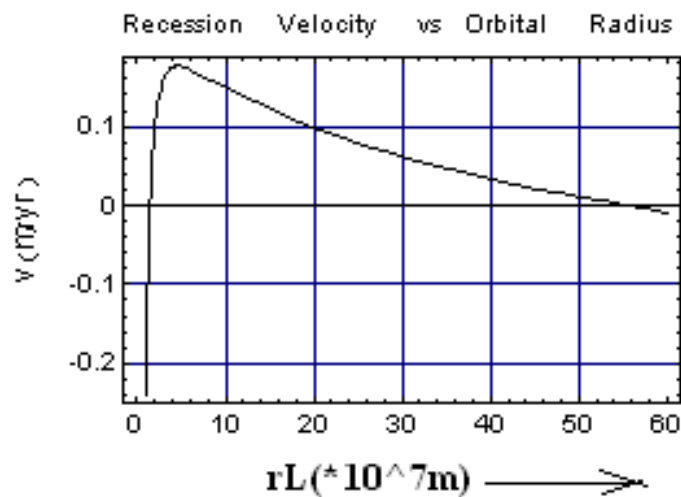


Fig. 3. Radial Velocity Profile of Moon. (Beyond a_{G1} , Moon is rapidly accelerated to a maximum radial velocity, V_{\max} , at a_2 where Sling-Shot Effect terminates and radial acceleration is zero. Then onward Moon coasts on it own towards the outer Geo-Synchronous Orbit a_{G2})

rotational energy is transferred to the primary. This rotational energy causes spin-up of the central body as well as it tidally heats up the central body by tidal deformations.

Since Eq.2 has a maxima at a_2 therefore the first derivative of Eq. 2 has a zero at a_2 . Equating the first derivative of Eq.2 to zero we get:

$$E(2 - M)a_{lap}^{1.5} - F(2.5 - M)a_{lap}^2 - (0.5 - M) = 0 \text{ at } a_2 \tag{4}$$

From Eq.4, structure exponent ‘M’ is calculated.

We donot yet know the structure constant K. We make an intelligent guess of V_{\max} and calculate the value of ‘K’ from Eq. 2 equated to V_{\max} at semi-major axis ‘ a_2 ’.

Using these values of ‘K’ and ‘M’ the time integral equation is set up and tested for the age of the system.

$$\int \left[\frac{1}{v(a_{lap})} da, a_{G1}, a_{lapresent} \right] = \text{transit time from } a_{G1} \text{ to the present value of } a_{lap} \tag{5}$$

This transit time should be of the order of 4.5Gy in the case of Iapetus because that is the age of Iapetus.[Castillo- Rogez et al (2007)]. Through several iterations we arrive at the correct value of K.

10.3 Theoretical verification of the experimentally observed ‘lengthening of day’ curve of our planet Earth by primary-centric analysis³

Since the birth of Earth-Moon System, Earth’s spin has been slowing down and Moon has been receding. Earth’s spin has slowed down from 5 hours to 24 hours today and Moon has receded from 15,000Km to the present Lunar Orbit of 384,400Km.

³ [Sharma, B. K. and Ishwar, B “ Basic Mechanics of Planet-Satellite Interaction with special reference to Earth-Moon System”, 2008, <http://arXiv.org/abs/0805.0100>].

John West Wells through the study of daily and annual bands of Coral fossils and other marine creaturs in bygone era has obtained ten length of day of bygone eras [Wells 1963, Wells 1966]. These benchmarks are tabulated in Table (8).

Leschiuta & Tavella [Leschitua & Tavella 2001] have given the estimate of the synodic month. From the synodic month we can estimate the length of the Solar Day as given in SOM_Appendix [C]. The results are tabulated in Table (9). [Leschitua & Tavella 2001 based on the study of marine creature fossils]

Kaula & Harris [1975] have determined the synodic month through the studies of marine creatures. The results are tabulated in Table (10).

One benchmark has been provided by Charles P. Sonnett et al through the study of tidalies in ancient canals and estuaries [Sonett & Chan 1998]. He gives an estimate of $T_{E4} = 18.9$ hours mean solar day length at about 900 million years B.P. in Proterozoic Eon, pre-Cambrian Age.

T (yrs B.P.)	T* (yrs after the Giant Impact)	Length of obs. Solar Day T_E^* (hrs)
65 Ma	4.46456G	23.627
135 Ma	4.39456G	23.25
180 Ma	4.34956G	23.0074
230 Ma	4.29956G	22.7684
280 Ma	4.24956G	22.4765
345 Ma	4.18456G	22.136
380 Ma	4.14956G	21.9
405 Ma	4.12456G	21.8
500 Ma	4.02956G	21.27
600 Ma	3.92956 G	20.674

Table 8. The Observed lod based on the study of Coral Fossils.

T (yrs. B.P.)	T* (yrs. After the Giant Impact)	Observed Synodic Month (modern days)	Estimated Solar Day (hrs).
900 Ma (Proterozoic)	3.62956G	25.0	19.2
600Ma (Proterozoic)	3.92956G	26.2	20.7
300Ma (Carboniferous)	4.22956G	28.7	22.3
0 (Neozoic)	4.52956G	29.5	24

Table 9. Observed Synodic Month

T (yrs. B.P.)	T* (yrs. After the Giant Impact)	Observed Synodic Month (modern days)	Estimated Solar Day (hrs).
45 Ma	4.48456G	29.1	23.566
2.8 Ga	1.72956G	17	13.67 (with modern C) 16.86 (with $C = 9.99 \times 10^{37} \text{ kg} - m^2$)

Table 10. Observed Synodic Month (Kaula & Harris 1975) based on the studies of Marine creatures.

10.4 Comparative study of lengthening of day curve of our Earth by theory and observation

As seen from the superposition of the two lengthening of day curves, there is remarkable match between Observation and Theory in the recent past after the Pre-Cambrian Explosion

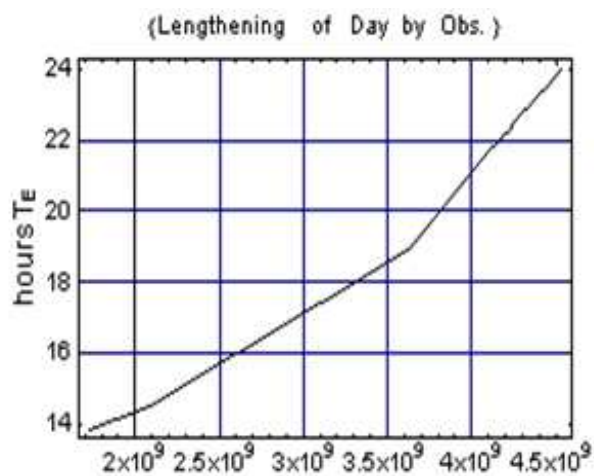


Fig. 4. Lengthening of Day Curve w.r.t. time by Observation

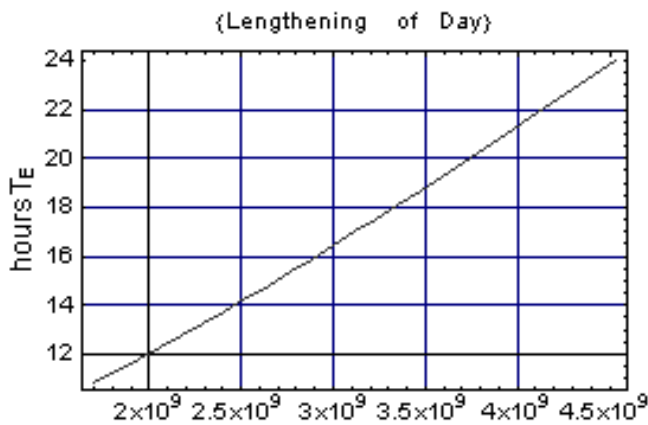


Fig. 5. Lengthening of day curve w.r.t. time by Theory assuming constant C.

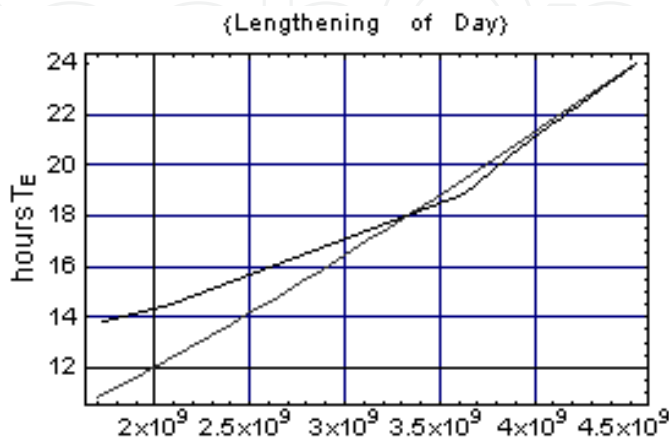


Fig. 6. Superposition of the two curves, one by observation and the other by calculation, with constant C.

of plant and animal life but in the remote past, particularly in early Archean Eon, Earth seems to be spinning much slower than predicted by theory. This implies that rotational inertia was much higher than what has been assumed in this analysis. In fact there are evidence to show that early Earth was much less stratified as compared to modern Earth. It was more like Venus [Allegre, Calde 1994, Taylor, Rose & McLennan 1996].

Through out the analysis C , the Principal Moment of Inertia, has been assumed to be constant whereas infact it was evolving since the Giant Impact [Runcorn 1966].

In the first phase of planet formation, Earth was an undifferentiated mass of gas, rocks and metals much like Venus. At the point of Giant Impact, the impactor caused a massive heating which led to melting and magmatic formation of total Earth. The heavier metals, Iron and Nickel, settled down to the metallic core and lighter rocky materials formed the mantle. The mantle consisted of Basalt and Sodium rich Granite.

Due to Giant Impact, Earth gained extra angular momentum. This led to a very short spin period of 5 hours. It has been calculated that the oblateness at the inception must have been 1% [SOM_Appendix D, Kamble 1966] whereas the modern oblateness is 0.3%. Taking these two factors into account C of Earth must have been much higher than the modern value of $8.02 \cdot 10^{37} \text{ kg} - \text{m}^2$. In this paper the early C has been taken as $9.9 \cdot 10^{37} \text{ kg} - \text{m}^2$.

After Achaeon Eon the general cooling of Earth over a period of 2 billion years led to slower plate-tectonic movement. The 100 continental-oceanic plates coalesced into 12 plates initially and into 13 plates subsequently. The slower plate tectonic engine led to deep recycling of the continental crust and hence to complete magmatic distillation and differentiation of the internal structure into multi-layered onion like structure. Thus at the boundary of Archean Eon and Proterozoic Eon a definite transition occurred in the internal structure.

Before this boundary, the mantle and the outer crust was less differentiated. It was composed of a mixture of Basalt and Sodium-rich granite. After this boundary a slower plate-tectonic dynamo helped create the onion-like internal structure with sharply differentiated basaltic mantle and potassium-rich granitic crust. This highly heterogenous internal structure and less oblate geometry leads to the modern value of C equal to $8.02 \cdot 10^{37} \text{ kg} - \text{m}^2$.

The form the evolving C is as follows:

$$f[(t-2E9)_{-}] := \text{If}[(t-2E9) > 0, 1, 0] \\ \{9.9E37 - (9.9E37 - 8.02E37) \{1 - \text{Exp}[-t/(16E9)]\} - f[(t-2E9)_{-}](1.4E37) \{1 - \text{Exp}[-t/(0.5E9)]\}\} \quad (6)$$

Here $f[(t-2E9)_{-}]$ is defined as a step function which is 0 before 2 billion years and is Unity at 2 billion years and at greater times.

The profile of evolution of C with time is obtained in Fig. (7) :

As can be seen in Fig. (9), there is a much closer fit except for a large deviation at 2.5Gyrs after the Giant impact. This is due to step change in Moment of Inertia, C , at 2Gyrs after the Giant Impact. It would have been more realistic to assume a gradual change in C at the boundary of Archean and Proterozoic Eon. This correction will be made in a sequel paper.

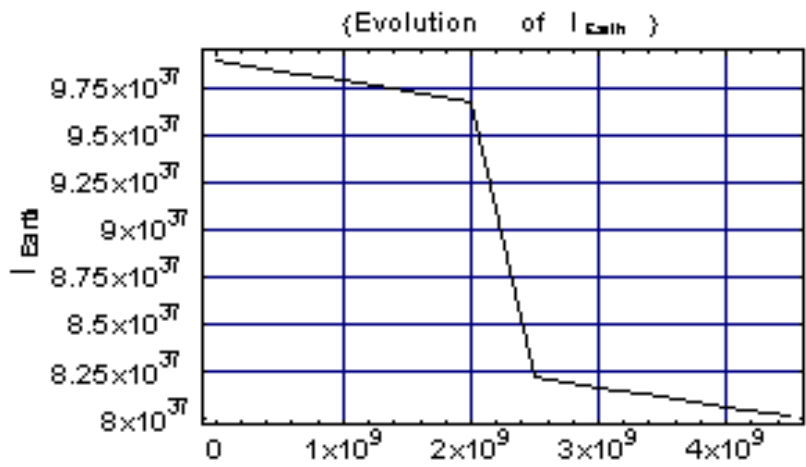


Fig. 7. The profile of the assumed evolving C.

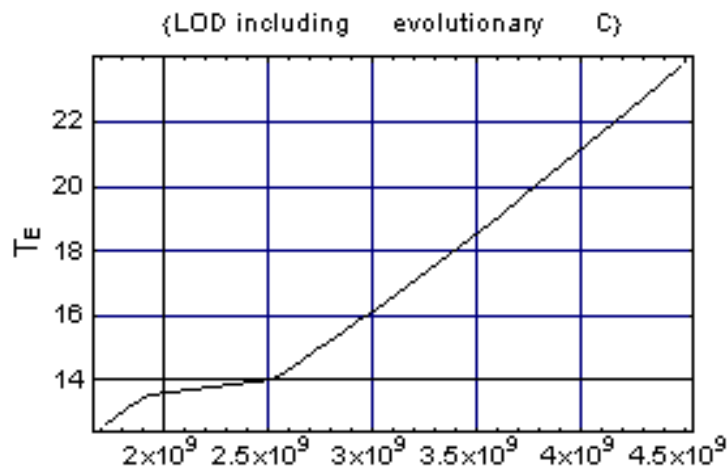


Fig. 8. Theoretical lengthening of day curve with evolving C.

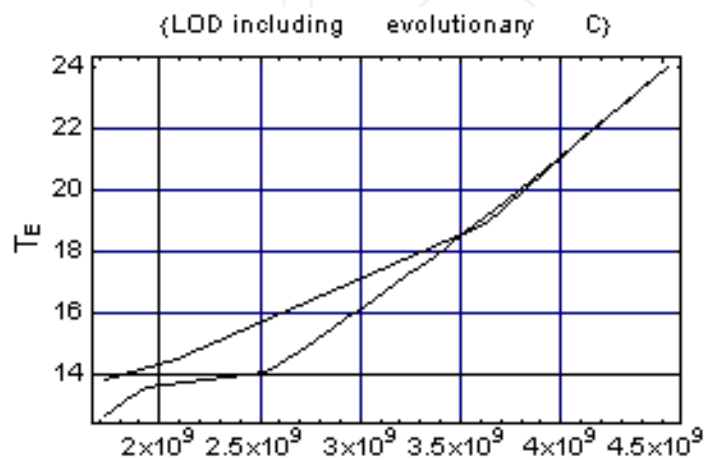


Fig. 9. Superposition of the observed curve and theoretical lengthening of day curve with evolving C.

10.5 A new perspective of birth and evolution of our solar system & extra solar systems

The new perspective holds that:

- i. before the thermonuclear furnace turns on that is before full scale fusion reaction begins, in the inner region of the solar system by a process of agglomeration-accretion the icy-rocky core is formed. As soon as it reaches a critical mass of $10M_E$, it rapidly wraps itself with Hydrogen and Helium gas which is available in abundance in the gas-dust debris. As it grows to $300M_E$, a gaping hole is formed in the disk. This paucity of gas terminates the runaway gas accretion. As we see, the necessity of a snow line does not arise as the inner region is sufficiently cold (100 kelvin) to keep the dust coated with amorphous ice which eliminates impact rebound and permits agglomeration to take place unhindered to km size planetesimal.
- ii. by the above process sequentially the four jovian planets are born i.e. one after another. As the first Gas Giant is formed, because of initial slingshot effect, caused by our Sun, Jupiter spirals out and makes space for the formation of the next gas giant namely Saturn. As Saturn spirals out, the Ice Giants namely Neptune and Uranus are formed.
- iii. Just as Jupiter spirals out to wide orbits, it is equally probable that the gas giant may be perturbed within the inner geo-orbit in other solar systems. Those tumbling short of inner geo-orbit get launched on inward collapsing spiral path doomed to their certain destruction. They become hot jupiters in scorchingly tight orbit. In course of planet discovery, many examples of hot jupiters have turned up.
- iv. the planet formation sequence follows the descending order of mass. The heaviest (i.e. Jupiter) being born the first and the lightest (i.e. Neptune) the last;
- v. the time factor of evolution is inversely proportional to the mass i.e. the massive giants evolve out of their initial orbit very rapidly whereas the lightest one remaining almost stay put. This implies that Jupiter spirals out of the maternity ward very rapidly whereas the terrestrial planets remain orbiting where they were born;
- vi. in the first phase, Gas Giants and Ice Giants are formed when there is abundance of gas and dust. In course of birth and evolution of these massive planets the disk is dissipated of gas partly due to the accretion by the jovian cores and partly due to photoevaporation. The remnant disk is largely populated by planetismals. In the second phase the rocky planetismals gravitationally collapse to form the terrestrial planets in a sequence according to the descending order of mass. Earth was formed the first and Mercury the last. Pluto is a recently captured body. It has not been formed insitu.

11. Observational proofs in support of gravitational sling shot model

In recent days four observations strongly suggest that in remote past Jupiter and the gas giants may have experienced gravitational sling shot and they may have been launched on an outward spiral path just the way Moon has been launched or for that matter all planetary natural satellites have been launched.

- a. 700 Hilda asteroids in elliptical orbit [Franklin et al 2004]. The asteroid belt is populated with hundred thousands of rocky remnants leftover from planet formation. These are

called asteroids and they lie between Mars and Jupiter orbit between a radii of 3AU to 10AU. Most of the asteroids are in near circular orbits. There are 700 odd asteroids known as Hilda which are in highly elliptical orbit and these eccentricities could have been imparted only by a migrating Jupiter set on an expanding spiral path. The migrating Jupiter first ejected some proto-Hilda asteroids out of the system and next elongated the orbits of the residual asteroids. The migrating Jupiter could have also set the planetary embryos on unruly chaotic paths which led to frequent collisions and accretion resulting into terrestrial rocky planets.

- b. Through computer simulation studies [Tsiganis, Gomes, Morbidelli & Lavisson 2005] it has been shown that our planetary system, with initial quasi-circular, coplanar orbits, would have evolved to the current orbital configurations provided Jupiter and Saturn crossed the 1:2 mean motion resonance (MMR). When the ratio of the orbital periods of Jupiter and Saturn is 1:2 it is the strongest resonance point. At all integer ratios resonance is obtained but the maximum is obtained at 1:2. The resonance crossings excite the orbital eccentricities and mutual orbital inclinations to the present values. Jupiter, Saturn and Uranus have the present eccentricities of 6%, 9% and 8% respectively. The present mutual inclination of the orbital planes of Saturn, Uranus and Neptune take the maximum values of approximately 2° with respect to that of Jupiter. The simulation was started with the initial positions of Jupiter and Saturn at 5.45AU and 8AU respectively. 1:2MMR crossing occurs at 8.65AU. The present orbital semi major axes of Jupiter, Saturn, Uranus and Neptune are 10AU, 15AU, 19.3AU and 30AU respectively. This simulation reproduces all aspects of the orbits of the giant planets: existence of natural satellites, distribution of Jupiter's Trojans and the presence of main belt asteroids.
- c. The presence of Jupiter's Trojans can be explained only by 1:2MMR crossing by Jupiter and Saturn [Morbidelli, Lavisson, Tsiganis and Gomes 2005]. These are asteroids which are in the same orbit as that of Jupiter but they are leading or lagging by 60° in their co-orbital motion.
- d. The petrology record on our Moon suggests that a cataclysmic spike in the cratering rate occurred approximately 700 million years after the planets formed [Gomes, Lavisson, Tsiganis and Morbidelli 2005]. With the present evidence we assume the birth of our Solar Nebula at 4.56Gya. The formation of Gas Giants and Ice Giants was completed in first 5 million years and Earth was completed in first 30 million years. This puts the date of completion of Giant Planets at 4.555Gya and the date of completion of the Terrestrial Planets particularly Earth at 30 million years after the solar nebula was born that is at 4.53Gya. At 4.53Gya, the Giant Impact occurred and from the impact generated circumterrestrial debris, Moon was born beyond Roche's Limit at 16,000Km orbital radius. By gravitational sling shot effect it was launched on an outward spiral path. Presently Moon is at the semi-major axis of 3,84,400Km with a recession velocity of 3.7cm/year. Towards the end of planet formation phase, the residual debris of the solar nebula was being rapidly sucked in or swept out of the system. This resulted in heavy meteoritic bombardment of all the big sub-stellar objects including our Moon. Through Apollo Mission studies it has been determined that there is a sharp increase in the bombardment rate and hence in the cratering rate around the period of 4.5 to 3.855Gya. From this it is concluded that

there was a cataclysmic Late Heavy Bombardment of all big sub-stellar bodies, including our Moon, at about 700 My after the completion of formation of Jupiter and Saturn.

As the planet formation was completed, the gaseous circumsolar nebula was dissipated by gravity accretion and finally by photoevaporation. According to Tsiganis et al [2005], Jupiter and Saturn were born at 5.45AU and 8AU respectively where the orbital period ratio that P_S/P_J was less than 2. According to them the resulting interaction with massive disk of residual planetismals Jupiter and Saturn spiraled out on diverging path crossing 1:2MMR($P_S/P_J = 2$) point at 8.65AU and today the ratio is little less than 2.5. At the 1:2MMR crossing due to gravitational resonance their orbits became eccentric. This abrupt transition temporarily destabilized the giant planets, leading to a short phase of close encounters among Saturn, Uranus and Neptune. As a result of these encounters, and of the interactions of the ice giants with the disk, Uranus and Neptune reached their current heliocentric distances of 19.3AU and 30AU. And Jupiter and Saturn evolved to the current orbital eccentricities of 6% and 9%. The same planetary evolution can explain LHB provided Jupiter and Saturn crossed 1:2MMR 700My after their formation. That is LHB occurred at 3.855Gya.

12. Future direction of investigation

This new perspective on Solar System birth and evolution based on planetary satellite dynamics is called Primary-centric World View. This Primary-centric View has led to the fractal Architecture of the Universe [Sharma 2012A]. The Primary-centric View has been applied to Kepler-16b, Kepler 34b and Kepler 35b to explain its circum-binary architecture [Sharma 2012B]. The Primary-centric View has also been used to test the validity Iapetus's hypothetical sub-satellite [Sharma 2012C]. The Author has utilized the primary-centric view to work out the probable evolutionary history of PSR J1719 -1438 and its compacted companion at a distance of 4000ly[Sharma 2012D)]. Presently I am applying this World View to see if star binaries, pulsar binaries, pulsar-black hole, Galaxy of Stars, Clusters and Super-Clusters fall in this frame work or not[Sharma 2011]. A positive test for all these binaries and galaxy of stars will give us a new approach to the dynamics of the Universe.

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