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*Review*

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# Features of Jupiter's satellites with their cartographic coordinates and clusterring

## Abstract

Some distinct features of Jupiter and its four Galilean satellites are critically considered emphasizing their widely different physical and orbital characteristics. The orbits of irregular satellites and how they cluster into groups have been examined from the consideration of Jupiter's outer moons and their highly inclined orbits as well as the inclinations (°) *vs* eccentricities of the retrograde satellites.

## Key Words

Jupiter's satellites; Jovian moons; Satellites; Moons.

## INTRODUCTION

A huge amount of data on largest planet Jupiter in the solar system has been collected by several flyby spacecrafts since 1973 which are giving a lot of information regarding the large planets and their large systems of moons and rings. If we consider Jupiter's moon system as a scaled-down solar system, then its four Galilean moons correspond to the terrestrial planets. Their orbits are in the same sense as Jupiter's rotation, approximately circular, and lie near to Jupiter's equatorial plane. They have a wide range in size from slightly smaller than Earth's Moon (Europa) to slightly greater than Mercury (Ganymede)[1]. It is the purpose of the paper to examine the reported physical and orbital characteristics of the planet Jupiter and its satellites including the orbits of irregular satellites and their type of cluster formation in groups.

## SALIENT FEATURES OF JUPITER'S SATELLITES

Galileo Galilei made the sketches after discovering four moons orbiting Jupiter in January 1610. The moons are later named as Io, Europa, Callisto and Ganymede.

Their discovery also led to the end of the popular theory that Earth was the center of the universe and an understanding that the planets in our solar system orbit the Sun. Figure 1 shows the translation of the key passages of journal of Galileo Galilei detailing the discovery of four moons orbiting around Jupiter.

Figure 2 shows the draft of a letter to Leonardo Donato, Doge of Venice, August, 1609, and Notes on the Moons of Jupiter, January 1610 by Galileo Galili.

Three sharply noted salient features of Jupiter's satellites are pointed out here:

(i) Jupiter, a giant gas-rich and ice-rich planet of the outer solar system, may be taken as the center of a system of at least 16 ice and rock satellites and a narrow ring of much smaller particles. An important reason Jupiter became so much larger than the rocky inner planets is that it developed in a cool region of the solar nebula where water ice was stable[2]. Jupiter mainly consists of hydrogen and helium wherein a core of silicate ice is embedded deep within the planet[2]. The colored bright atmosphere is banded and has large semi permanent storm systems.

(ii) The largest Galilean satellite, Ganymede, has a variable surface owing to heavily cratered terrain and large swathes of bright younger, intensely grooved terrain, formed by foundering of old crust and flooding with

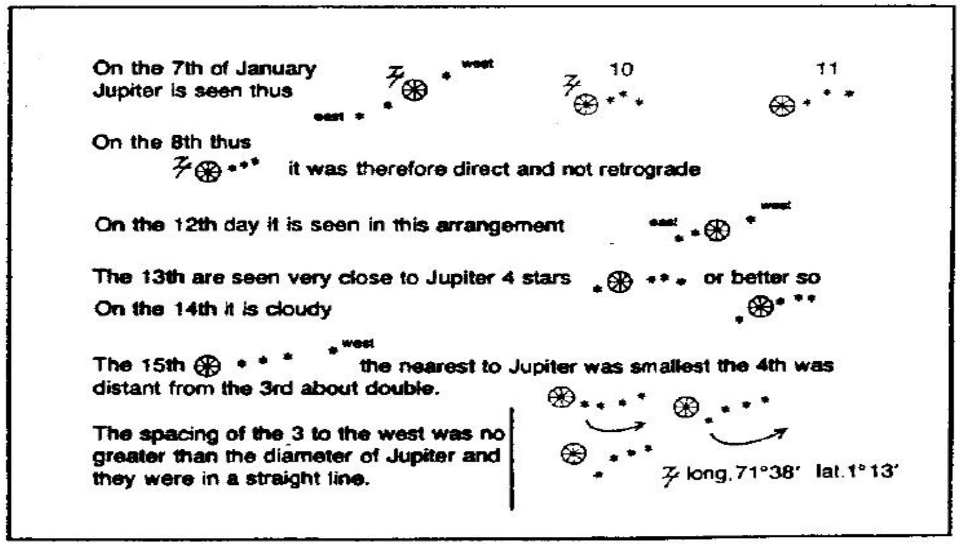


Figure 1 : The translation of the key passages of Galileo Galilei's journal detailing the discovery of four moons orbiting around Jupiter [Credit: NASA]

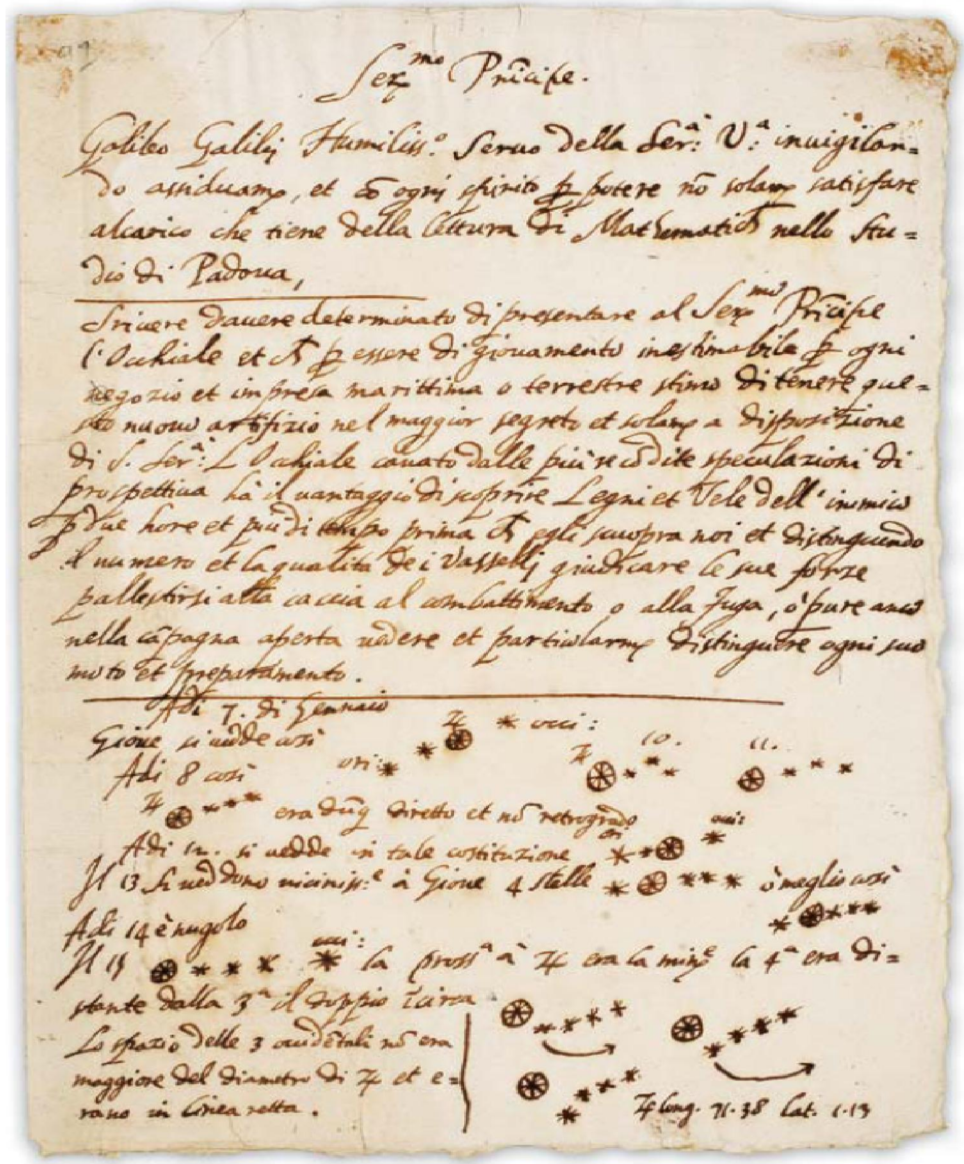

Figure 2 : Draft of a letter to Leonardo Donato, Doge of Venice, August, 1609, and notes on the Moons of Jupiter [Credit: University of Michigan Special Collections Library]

volcanic flows of liquid water. The innermost Galilean satellite Io, has a young surface and is now volcanically active. Tidal flexing of this moon supplies a continued input energy to melt parts of the interior of this rocky planet.

(iii) The outermost of the large satellites, Callisto, is made by heavily cratered terrain. This moon did not expand during its late history and, due to its distance from Jupiter, it received little energy from tidal heating. Europa has a relatively smooth fractured icy surface. No vestiges of the intense bombardment remain on Europa; however, a few small craters have been noticed. Resurfacing due to the outpouring of watery lavas and the flow of solid ice has shaped the surface features. Tidal flexing of Europa has a role to keep the interior warm. The satellites of Jupiter appear to have condensed and thereby accreted in a thermal gradient centered on Jupiter. Thus, the inner moons are silicate-rich, refractory and ice-poor while the outer moons are ice-rich.

Characteristics of the four Galilean Satellites of Jupiter in comparison to Earth's moon are shown in TABLE 1.

Features of four Galilean satellites of Jupiter are given in TABLE 2.

## INTERIOR STRUCTURE OF THE FOUR GALILEAN SATELLITES

It was interesting to find that the moons' densities decrease with increasing distance from Jupiter[4]. On the basis of detailed measurements made by Galileo of the moons' gravitational fields, an elaborate analysis and detailed pictures of the moons' compositions and internal structures were available. It was found that the innermost two Galilean moons Io and Europa have thick rocky mantles similar to the crusts of the terrestrial planets, surrounded by iron/iron sulfide cores[4,5]. It is noted that the Io's core accounts for about half that of the moon's total radius. Europa has got a thin water/ice outer shell which is nearly 150 km thick. The two outer moons Ganymede and Callisto are highly deficient in rocky materials. Lighter materials like water ice may account for as much as half of their total mass. Ganymede shows a relatively small metallic core which is topped by a rocky mantle and a thick icy outer shell[6]. Callisto appears to be a largely undifferentiated mixture of rock and ice. Figure 3 reveals a cutaway diagrams for the interior structure of the four Galilean satellites. Moving outward from Io to Callisto, the densities of the moons steadily decrease as the composition shifts from rocky mantles and metallic cores in Io and Europa to a thick icy crust and smaller core in Ganymede and finally to an almost uniform rock-ice mixing in Callisto.

## PHYSICAL AND ORBITAL CHARACTERISTICS OF THE MOONS

The physical and orbital characteristics of the moons' widely differ[7,8]. The four Galilean moons of Jupiter are all over 3,100 kilometres in diameter. In fact, the largest Galilean moon Ganymede is the ninth largest object in the Solar System after the Sun and seven of the planets as Ganymede is larger than Mercury. All other Jovian moons are less than 250 kilometres in diameter[8]. Orbital shapes of the moons range from approximately circular to highly eccentric and inclined and some revolve in the opposite direction to Jupiter's spin (i.e. retrograde motion). Orbital periods are found to range from seven hours to some three thousand times more which is nearly three Earth years[9]. The relative masses of the Jovian moons have shown in Figure 4. From the figure the relative masses of the four Galilean satellites can be clearly observed. However, those smaller than the moon Europa are not visible at this scale. The combined masses of all other moons would only be visible if the magnification is made 100 times.

## ORBITS OF IRREGULAR SATELLITES

Irregular satellites are thought to have been originated from heliocentric orbit when Jupiter was young. In general, some of the initial energy of the heliocentric objects

**TABLE 1 : Characteristics of the Jupiter's satellites in comparison to Earth's moon[3]**

| Satellite | Diameter (km) | Density ($g/cm^3$) | Surface Composition |
|---|---|---|---|
| Io | 3,630 | 3.57 | Silicates and sulfur |
| Europa | 3,138 | 2.97 | Water Ice |
| Ganymede | 5,262 | 1.94 | Water Ice |
| Callisto | 4,800 | 1.86 | Water Ice |
| Earth's Moon | 3,500 | 3.3 | Silicates |

**TABLE 2 : Features of four Galilean satellites [http://home.dtm.ciw.edu/users/sheppard/satellites/jupsatdata.html]**

| Name | a (km) | i (deg) | Eccentricity | Peri (deg) | Node (deg) | M (deg) | Period (days) | Magnitude | H (mag) | Size (km) | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Io | 421800 | 0.036 | 0.004 | 268.7 | 44.3 | 157.2 | 1.77 | 5.0 | x | 3643 | 1610 |
| Europa | 671100 | 0.466 | 0.009 | 225.8 | 219.6 | 33.8 | 3.55 | 5.3 | x | 3122 | 1610 |
| Ganymede | 1070400 | 0.177 | 0.001 | 192.3 | 65.7 | 315.5 | 7.16 | 4.6 | x | 5262 | 1610 |
| Callisto | 1882700 | 0.192 | 0.007 | 46.2 | 305.3 | 181.2 | 16.69 | 5.7 | x | 4821 | 1610 |

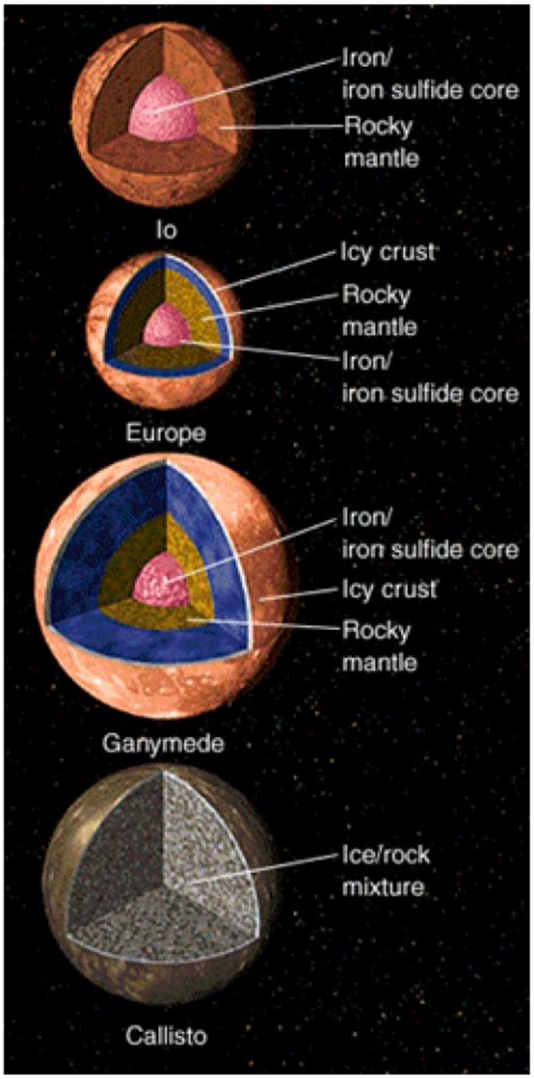


**Figure 3 : Cutaway diagrams representing the interior structure of the four Galilean satellites [http://lifeng.lamost.org/courses/astrotoday/CHAISSON/AT311/HTML/AT31105.HTM]**

must be dissipated so that Jupiter can hold on to them. The origin of the dissipation that leads to the capture of Jupiter's irregular satellites is unknown. At the present time there is no reasonable source of dissipation, so that capturing satellites is presently almost impossible. It is theorized, however, that the Jupiter sustained a full atmosphere that extended far above the cloud tops of the present planet. Friction with this atmosphere could have captured the irregular satellites. Figure 5 shows the Semi-major axis *vs* Inclination of the irregular satellites of the giant planets. Jupiter's dynamical groupings are clearly visible while other planets may have dynamical groupings as well.

The planet Jupiter has so far 67 confirmed moons which provide it the largest retinue of moons with more or less secure orbits of any planet in the Solar System[10]. The most massive of these moons are the four Galilean moons discovered in 1610 by Galileo Galilei and were the first objects observed to orbit a body that was neither Earth nor the Sun. By the end of 19th century, dozens of smaller Jovian moons have been discovered which have got the names of lovers, conquests or daughters of the Roman god Jupiter or his Greek predecessor, Zeus. The four Galilean moons are by far the largest objects in orbit around Jupiter while the remaining 63 moons and the rings together become only just 0.003 percent of the total orbiting mass[11,12]. Eight of the moons are marked as regular satellites, with prograde and almost circular orbits that are not largely inclined with respect to the equatorial plane of Jupiter. The shapes of the Galilean satellites are ellipsoidal owing to having planetary mass and hence they would be considered as dwarf planets if they were in direct orbit about the Sun. The other four regular satellites nearer to Jupiter are smaller and serve as sources of the dust to make up Jupiter's rings[13].

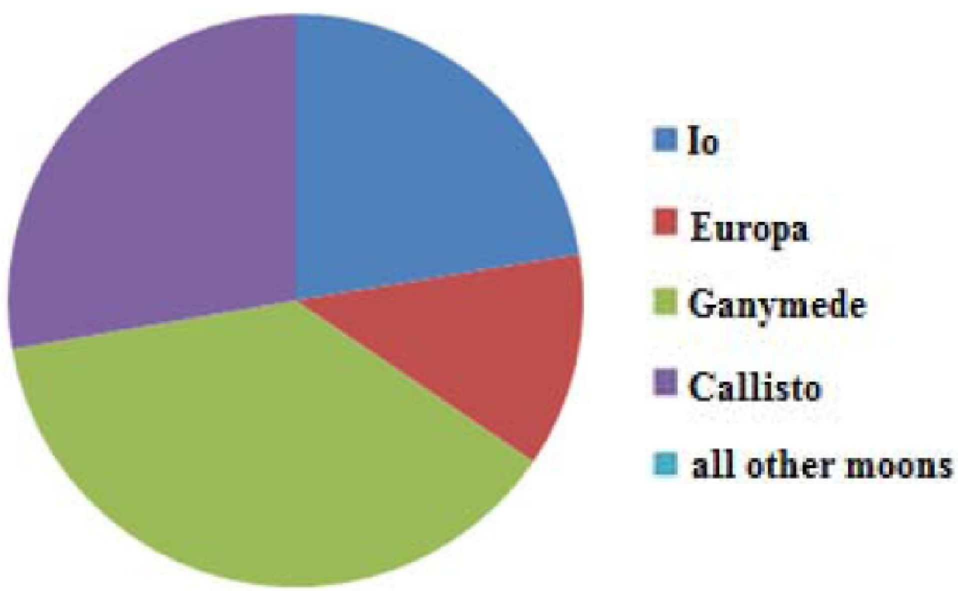


**Figure 4 : The relative masses of the Jovian moons [http://en.wikipedia.org/w/index.php?title=File%3AMasses_of_Jovian_moons.png]**

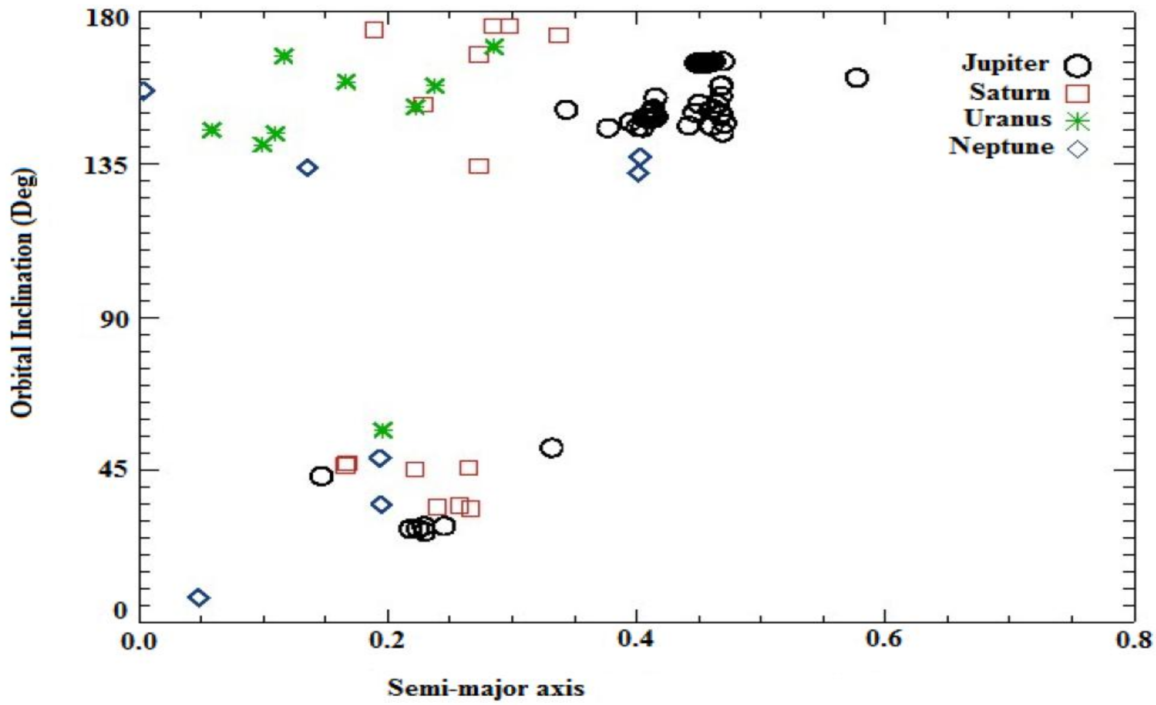


**Figure 5 : The semi-major axis *vs* inclination of the irregular satellites of the giant planets**

The rest of the moons are called irregular satellites, whose prograde and retrograde orbits are much farther from Jupiter and also have high inclinations and eccentricities. These moons are assumed to be captured by Jupiter from solar orbits. There are 16 irregular satellites that have not yet been named. The names of the Galilean moons became popular only in the 20th century, while the rest of the moons are generally expressed in Roman numerals. By a popular convention, Jupiter V, discovered in 1892, was given the name *Amalthea*. The other moons were usually labelled by their Roman numeral until the 1970s[14]. In 1975, the International Astronomical Union's (IAU) Task Group suggested naming process for future satellites to be discovered[15]. Since then the practice was to name newly discovered moons of Jupiter after lovers and favourites of the god Jupiter (Zeus) and from 2004 after their descendants also. Some of the asteroids share the same names as moons of Jupiter: 9 Metis, 38 Leda, 52 Europa, 85 Io, 113 Amalthea and 239 Adrastea.

Observations suggested that the irregular satellite Amalthea, did not form on its present orbit but either farther from the planet or that it is a captured Solar System body[16] Many moons along with a number of as-yet-unseen inner moonlets replenish and maintain Jupiter's faint ring system. It has been noted that Metis and Adrastea assist to maintain Jupiter's main ring, while Amalthea and Thebe help to maintain their own faint outer rings[17,18].

The irregular satellites of Jupiter are substantially smaller objects with distant and eccentric orbits and form families with shared similarities in orbit (semi-major axis, inclination, eccentricity) and composition. It is assumed that these are partially collisional families that were produced when larger parent bodies were shattered due to impacts from asteroids captured by the gravitational field of Jupiter. Figure 6 shows a plan view of the orbits of all 31 known outer irregular satellites of Jupiter known before 2002. Irregular satellites have large orbits, inclinations and eccentricities. Because of their orbit characteristics and small size they are believed to be objects captured during the early formation of Jupiter.

In Figure 6: Black Dot indicates Jupiter's location; Purple dotted line for the orbit of the outer most Galilean satellite Callisto; Green dotted and dashed line for the inner most irregular prograde satellite Themisto; Blue dashed lines are the 5 irregular satellites in the prograde group know before 2002; Red solid lines for the 11 discovered irregular satellites of 2001 in the retrograde group; Red dashed lines for the 14 previously known irregular satellites in the retrograde group.

Names of some Prograde satellites and Retrograde satellites with their particulars are mentioned below[19]: (a) Prograde satellites: (i) Themisto is the innermost irregular moon and not a part of known family, (ii) The Himalia group is spread over barely 1.4 Gm in semi-major axis, 1.6° in inclination (27.5 ± 0.8°) and eccentricities between 0.11 and 0.25. The group could be a remnant of the break-up of an asteroid from the asteroid belt (iii) Carpo is the outermost prograde moon and not part of a known family; (b) Retrograde satellites: (i) S/2003 J 12 is the innermost of the retrograde moons and is not part of a known family, (ii) The Carme group is spread over only 1.2 Gm in semi-major axis, 1.6° in inclination (165.7 ± 0.8°) and eccentricities between 0.23 and 0.27. It is highly homogeneous in color (light red) and is assumed to have originated from a D-type asteroid progenitor, possibly a Jupiter Trojan, (iii) The Ananke group has a relatively wider spread than the previous groups, over 2.4 Gm in semi-major axis, 8.1° in inclination (between 145.7° and 154.8°), and eccentricities between 0.02 and 0.28. Most of the members appear gray, and are believed to have formed from the breakup of a captured asteroid, (iv) The Pasiphae group is quite dispersed, with a spread over 1.3 Gm, inclinations between 144.5° and 158.3° and eccentricities between 0.25 and 0.43. The colors also vary significantly, from red to grey, which might be the result of multiple collisions. Sinope, sometimes included in the Pasiphae group appears red and given the difference in inclination, it could have been captured independently; Pasiphae and Sinope are also trapped in secular resonances with Jupiter, (v) S/2003 J 2 is the outermost moon of Jupiter and is not part of a known family. A plot of inclinations (°) *vs* eccentricities for the retrograde satellites is shown in Figure 7 wherein the Carme's (orange) and Ananke's (yellow) groups can be clearly identified.

## SIZE OF GALILEAN MOONS COMPARED WITH OTHER SOLAR SYSTEM BODIES

Fluctuations in the orbits of the moons reveal that their mean density diminishes with distance from Jupiter. The outermost moon Callisto with least dense of the four has a density intermediate between ice and rock while the innermost and densest moon Io has a density intermediate between rock and iron. Callisto has heavily-cratered and unaltered ice surface and the way of its rotation suggesting its equally distributed density with no rocky or metallic core but consisting of a homogenous mix of rock and ice. In contrast, the rotation of the three inner moons shows differentiation of their interiors with denser matter at the core and lighter matter above. They further indicate significant alteration of the surface. Ganymede shows past tectonic movement of the ice surface essential for partial melting of subsurface layers. Europa shows more dynamic and movement of this nature with a thinner ice crust. Finally, the innermost moon Io has a sulphur surface active volcanism and no sign of ice. From all the available evidences one can conclude that the closer a moon is to Jupiter the hotter is its interior. The existing models suggest that the moons experience tidal heating owing to

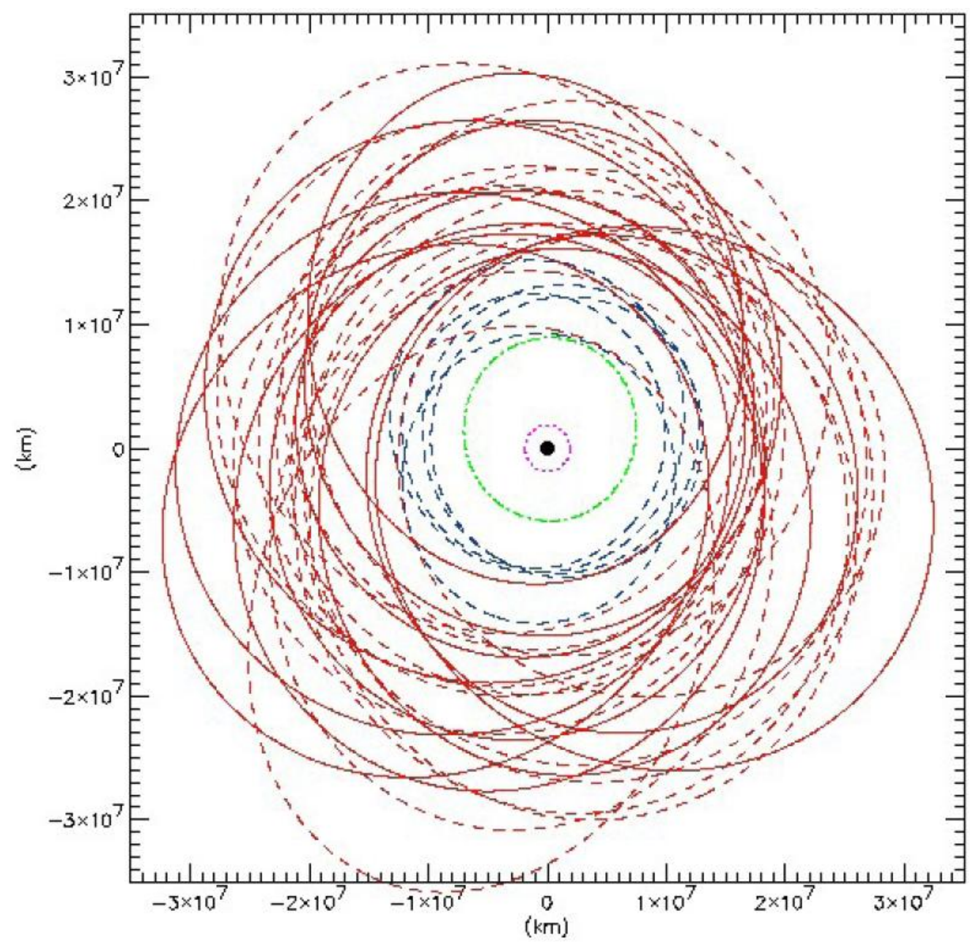


**Figure 6 : A plan view of the orbits of all 31 known outer irregular satellites of Jupiter known before 2002 [http://home.dtm.ciw.edu/users/sheppard/satellites/orbitsall.html]**

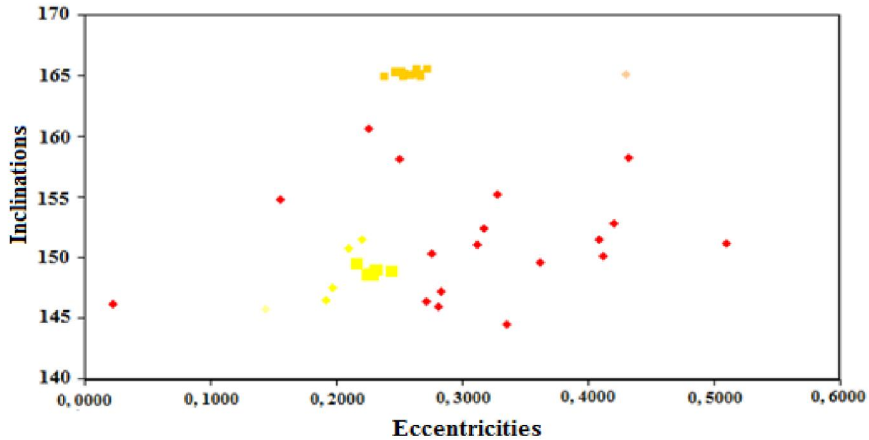


**Figure 7 : Inclinations (°) *vs* eccentricities of the retrograde satellites [http://en.wikipedia.org/wiki/File:Jupiter_sats_i_vs_e.png]**

gravitational field of Jupiter in inverse proportion to the square of their distance from the giant planet.

## CONCLUSIONS

Jupiter is dramatically different from other planets whose gaseous constitution bears little resemblance to the rocky inner planets and it orbits the Sun at a distance five times that of Earth. The difference in the bulk composition of Jupiter from the inner planets is expressed in the nature of its churning interior. Many astronomers think that the formation of Jupiter and the Galilean satellites may have mimicked on a small scale the formation of the Sun and the inner planets. From that consideration study of the Galilean moon system may provide valuable insight into the processes that created our own world. If we assume Jupiter's moon system as a scaled-down solar system, then the Galilean moons correspond to the terrestrial planets. Their orbits are in the same sense as Jupiter's rotation, roughly circular and lie near to Jupiter's equatorial plane. However, not all the properties of the Galilean moons reveal analogs in the inner solar system. For example, due to Jupiter's tidal effect all the four Galilean satellites are in states of synchronous rotation and hence all maintaining one face permanently pointing toward their parent planet[20].

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