C-1. MINOR PLANETS AND PLANETARY RINGS

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ABSTRACT

Circumstances of the discovery of the first Asteroid and the characteristics of various orbits followed by them have been discussed. Their shapes, compositions and evolutionary histories so far known have also been described. The review also covers the present status of knowledge about the rings surrounding 3 giant planets.

The subject of the present review covers two different types of objects in our solar system; the main point of common interest is that both have attracted considerable attention in recent years. They constitute a small fraction of the total mass of the solar system, but contain critical bits of information in their dynamics, compositions and structures which are likely to lead to our understanding of solar system cosmogony. Recent spurt in the investigational activities is due to the application of advanced techniques which have rendered the fine structures of these basically faint objects within our reach.

ASTEROIDS :

Although, chronologically, the rings were discovered earlier, first part of the review covers the asteroids, which were discoved almost two hundred years after the first spotting of Saturn's ring structure. A passing reference to a missing planet between the orbits of Mars and Jupiter was made by Kepler in 1596, but it was only in 1766 when Titius Von Wittenburg formulated what is known as "Titius-Bode Law" astronomers' attention to the subject was attracted. It was Bode who stressed that the relation indicated a missing planet between Mars and Jupiter. The law had a real boost when Uranus was discovered in 1781. The discovery opened up a renewed effort for the search for the missing planet. On the first night of the nineteenth century, i.e: on January 1, 1801, Piazzi from the observatory at Palermo in Sicily spotted a new object; for 41 nights the object was followed which was believed to be a comet. Bode and a few others believed that Piazzi had found the missing planet. The method of computation of orbit was not fully developed yet; it was Gauss who solved the mathematical problem and predicted its reappearance. Accordingly, the object was rediscovered on 7-12-1801; it was named Ceres, after the goddes of harvest, the tutelary deity of Sicily.

The brightness of this planet was much fainter than others; so it was not surprising that one more was discovered shortly afterwards. In fact, over the next seven years theree more bodies were discovered. Then no new bodies were discovered for about forty years till 1845. Later with the developments of better and larger telescopes there were more discoveries; but the real flood of success came with the introduction of astronomical photography in the eighties. Fig. 1 shows the progress over the years. To the present day named asteroids with determined orbits number over 2100; there are innumerable numbers of small objects.

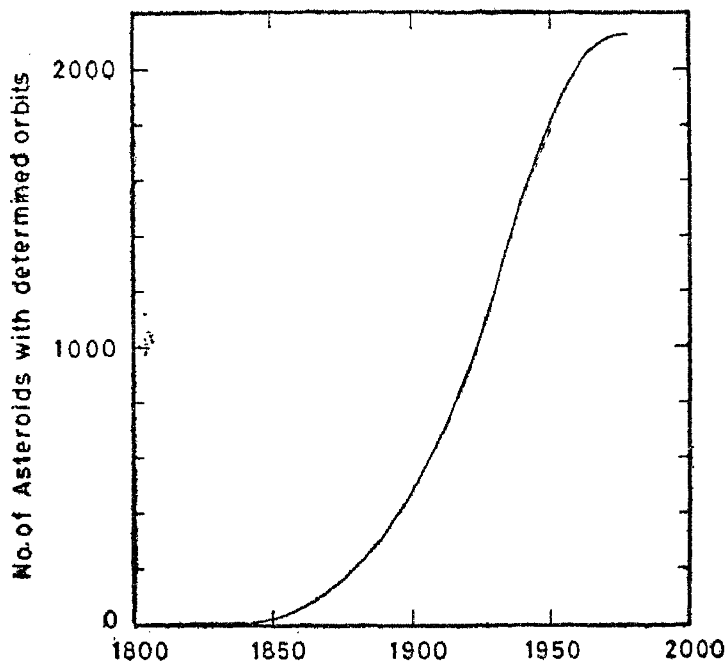

Fig. 1. — Progressive discoveries of asteroids:

All large asteroids were initially named after mythological female figures; later when asteroids in large numbers were discovered the practice was changed. Usually the discoverer had the privilege of naming, and many unusual names, including those of friends and relatives were given. Some asteroids. particularly the later discoveries are designated by numbers only. The names are usually preceded by a catalogue number, given serially in chronological order of their discoveries. The list thus starts with 1 Ceres, 2 Pallas and so on.

At present it is difficult to estimate the number of these bodies. Fig. 2 shows a plot which gives an idea of the population. At least 20,000 bodies exist with, masses exceeding 10^{17} gms; assuming normal composition and spherical shapes which, incidentally, are not common, the diameters of these bodies are estimated to exceed 3 kms. The spectrum of sizes is believed to merge smoothly with that of the meteorites. A very rough estimate indicates a density of bodies larger than common meteorites exceeding one per million cubic kilometers.

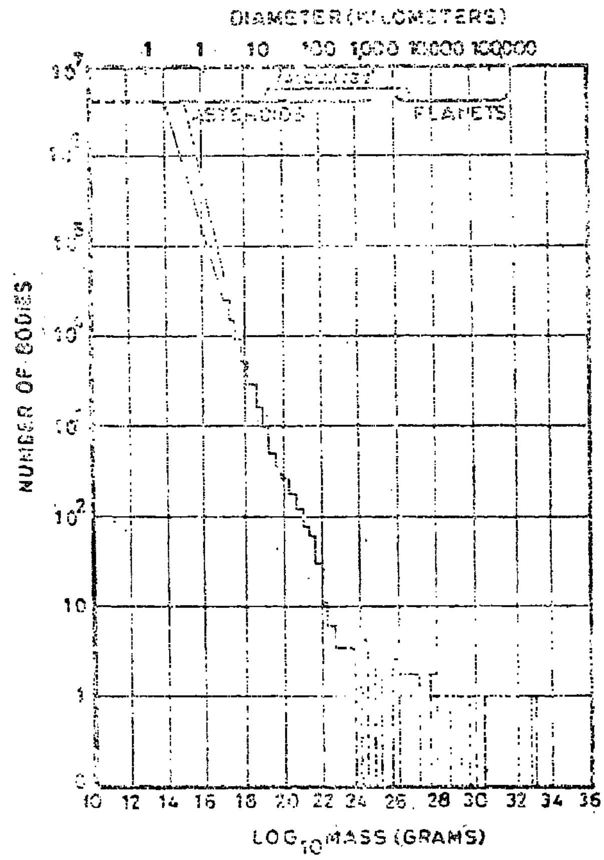

Fig. 2. — Mass distribution of asteroids:

Majority of the larger asteroids move in near circular orbits between those of Mars and Jupiter; but some of them have highly elliptical orbits. This is illustrated in Fig. 3. The main belt of asteroids however is not uniformly populated and there are wide variations in the orbital characteristic of asteroids outside the main belt. Some of the .asteroids come very close to the earth. The asteroid 1566 Icarus is such body. This satellite which was discovered by Baade in 1949 was seen to cross the earth's orbit and move close to the sun. Baade named the asteroid after this mythological pioneer solar explorer. There is a group of asteroids which crosses the earth's orbit to move close to the sun during their perihelion passages; these are called Apollos, the earth crossers. There are two groups of asteroids which come close to earth without crossing its orbit. One group consists of Aten asteroids whose orbits lie entirely within earth's orbit. Till 1980, only three objects were found to belong to this category : 2062 Aten, 2100 Ra-Shalom and unnumbered 1976 UA. There is another group, Amor asteroids, which come close to the earth; they cross the Mars orbit during their perihelion passages. 433 Eros is a prominent member of this group. On the other extreme is a lone asteroid 2060 Chiron discovered by Kowal from the Palomar Schmidt Plates taken in October 1977, which has a perihelion far beyond the jovian orbit.

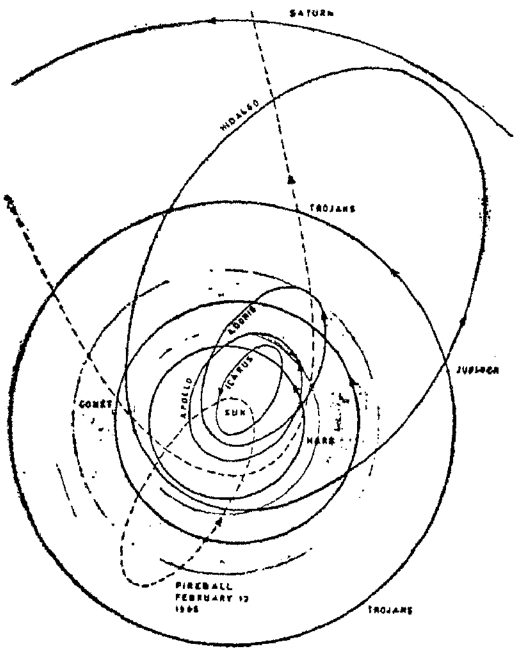

Fig. 3. — Typical orbits of asteroids:

Outside the asteroid belt there are a large number of asteroids called Trojans; first few members being named after the heroes of the battle of Troy, 588 Achilles, 624 Hektor, 911 Agamemnon and so on. They move in the jovian orbit synchronously with the planet Jupiter. They are, in fact, clustered around two points 60° away from Jupiter which coincide with the calculated 4th ond 5th Lagrangian points of the Sun-Jupiter system. Almost a thousand of them have been identified so far. Searches for similar clusters along the saturnian orbit has so far proved inconclusive.

There are a few asteroids with uncommon large orbits, such as 944 Hidalgo, the first asteroid discovered to cross Saturn's orbit during aphelion, and whose orbit resembles those of periodic comets. According to Marsden, Pluto should also be included in this list as the first Neptune crossing asteroid discovered (Marsden 1979). The latest in this class is 2060 Chiron discovered in 1977 which moves in an orbit between Saturn and Uranus. There are asteroids which move in chaotic orbits; most of the chactic movements are explainable in terms of perturbations due to the planets at the time of their close approach.

In the main asteroidal belt the values of semi-major axes of the orbits spread over a range between 2.2 and 3.3 A.U. but certain discrete values are avoided. This is illustrated in Fig. 4. The orbits pertaining to periods which are simple fractions of the period of Jupiter are avoided. This is due to resonance perturbation of Jupiter's gravitational pull as a result of which these orbits become unstable. These gaps were systematically studied by Kirkwood and are known as Kirkwood gaps. The same phenomena is believed to create gaps between different sections of planetary rings.

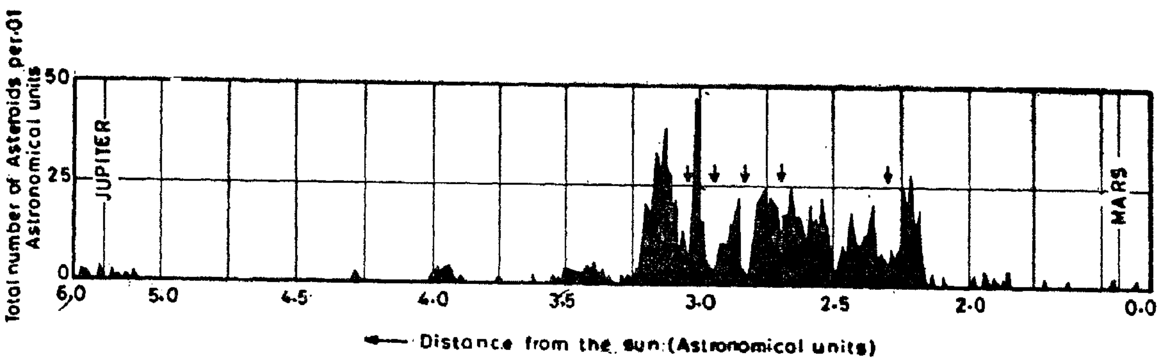

Fig. 4. — Gaps in asteroid belt.

Generally the asteroid orbits are much more eccentric and inclined to the ecliptic. 30% of all asteroid orbits have eccentricities large than 0.3; there are some with much higher values. Hidalgo, for example, has an eccentricity of 0.65. The average inclination of the orbit of asteroids to the ecliptic is more than 9° — larger than any planet excepting Pluto. Hidalgo has an inclination of 43°, and Pallas of 35°.

No direct close photograph of any of these objects have been obtained yet, which can definitely determine the shapes of these objects. But there are indirect evidences pointing that these are not of spherically symmetrical shapes. These are evident in periodic intensity and polarisation changes with phase angle noticed in their light curves. Most probably, the bodies resemble closely the satellites of Mars, Phobos and Deimos with irregular shapes and surfaces. Some of the larger members whose shapes have been estimated from occultation observations (Millis & Elliot, 1979) perhaps do have general spherically symmetrical forms.

Astronomers are not sure whether some of the bodies are conglomeration of multiple pieces. Some of them show periodic light variations closely resembling binary light curves. Close similarity between the light curves of some of them and those of some well known binary stars are frequently noticed. Actually some of the light curves are so complex that it needs a model of multiple bodies with different modes of motion to explain observed light curves.

Surfaces of these bodies are understandably pitted as a result of collisions with streams of meteorities like most other bodies in the solar system. Larger meteorite pieces of lunar rock samples show such surface irregularities. The effect is displayed in changes in the magnitude of some asteroids near zero phase angle. The departure of observed light variations from the theoretically computed ones can be explained in terms of multiple scattering at the pitted surface of the asteroids.

Spectral characteristics of the reflected light give broad hints to their compositions. Asteroids have been classified according to several of their orbital, and reflectence properties. According to the characteristics of ,their reflectances majority of the asteroids fall in two groups: (1) A very low albedo (less than 0.065) with neutral colour, termed C type and 2) moderate albedo values between 0.065 to 0.23 with reddish sloping spectra, called the S-type. A few cannot be classified in either of these two groups and are placed in a third group called the M-type; these have moderate albedo with slightly reddish spectra. A few do not fall even within these groups and are unclassified and denoted as U type. Recently some of these have been grouped under two new categories E and R on the basis of their colour and albedo sensitive data.

It is plausible, although not proven, that many C-type asteroids are carbonaceous chondrites. S-types are either metal rich silicate assemblages akin to stony-iron meteorities or they are less metal-rich silicate assemblages like ordonary chondrites. Many M-type asteroids bear the spectral signatures of metals in their reflectance, but it is highly possible that they are made of colourless silicates such as olivines (MgO, $Feo/SiO_2 \sim 2$), pyroxines (almost equal proportion mixture of Mgo, Feo or Cao with SiO_2). These two types of silicates predominate the compositions of stony meteorites (Chapman 1979).

Certain observational data suggest that the internal structure of many asteroids consists of chondrite-like chunks bound by finer material. Interior of stony meteorites exhibit such a structure. Technically such a body is called a breccia; the asteroid structure is perhaps a grand version of this picture. In course of evolution they may break apart and form a swarm of asteroids. The asteroid 221 Eos might have been a part of such a compact asteroid as reconstructured from the orbital characteristics of several asteroids (Grade et. al. 1979). Several families of asteroids possess near identical orbital properties supporting such specula tions.

The observations on asteroids can be conducted by a wide range of telescopes and apparatus. Large space telescopes or fly-by missions can, of course, obtain information on the surfaces and shapes of asteroids; it is even possible to think of instrumental landing and collection of rock samples from them. Using ground based large telescopes, a scheme of speckle interferometry can yield interesting and important results. High resolution spectroscopy using refined techniques e.g. FTS or Heteorodyne spectroscopy can bring revolutionary new information. Smaller telescope in the existing and future observatories can commence a program of photometric and polarimetric observations which will immensely enrich the literature on this branch of science. Amateur astronomers venturing on such a program will find the endeavour extremely reyarding. Even with small telescopes they stand equal chances like any big observatory, discovering binary or multiple asteroids when occultation tracks cross their telescope locations.

It may be mentioned here that out of those two thousand and odd asteroids only five were discovered from the Indian soil; and that, too, by one individual in the last century. The discoverer was the famous astronomer, Norman Pogson, whose name is indelibly marked on the pages of history of Astronomy as the formulator of the magnitude scale of stellar intensities. Table I shows the list of these discoveries.

TABLE 1

Asteroid discoveries made in India

No.	Name	Date of discovery	Discoverer	Observatory
67	Asia	April 17, 1861	N. R: Pogson	Madras
80	Sappho	May 2, 1864	,,	,,
87	Sylvia	May 16, 1866	,,	,,
107	Camilla	Nov. 17, 1868	,,	,,
245	Vera	Feb 6, 1885	,,	,,

Planetary Rings :

A detailed account of planetary ring structures was presented in a review talk (Bhattacharyya 1981), sometime back; the present review is. therefore, only in the form of an addendum. Until today, ring structures around three giant outer planets have been established. Rings of Saturn were discovered almost four hundred years ago. Galileo who first spotted the feature could not recognise it as a ring; it was Huyghens who explained the observed feature as a satellite ring structure fifty years later. At first the structure was known to consist of three sections, A, B, & C with a dark division, the Cassini's division, in between. Now-a-days three more section and a number of divisions have been discovered. The sections are schematically shown in Fig. 5. Of special current interest is the structure of the thin F-ring which has been seen to consist of twisted strands. The twisted structure could be explained due to the presence of shepherding satellites. two of which were photogrophed by the Voyager spacecrafts.

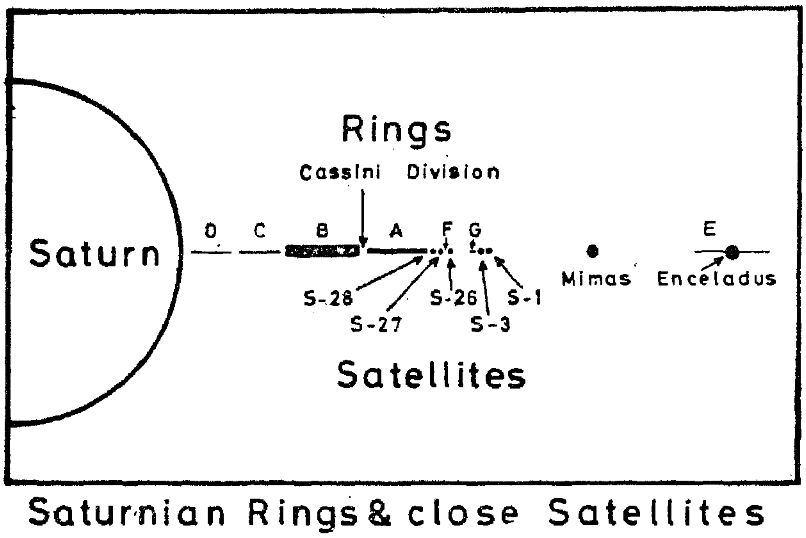

Fig. 5. — Rings of Saturn.

Rings of Uranus were discovered in 1977 during an occultation event. The complete structure speculated from the observations is shown in Fig. 6. A system of thin discs with much more prominent narrow condensation lanes appears to explain the observational results. Several other occultations since then have confirmed some of the structures, particularly the narrow, thin condensation lanes.

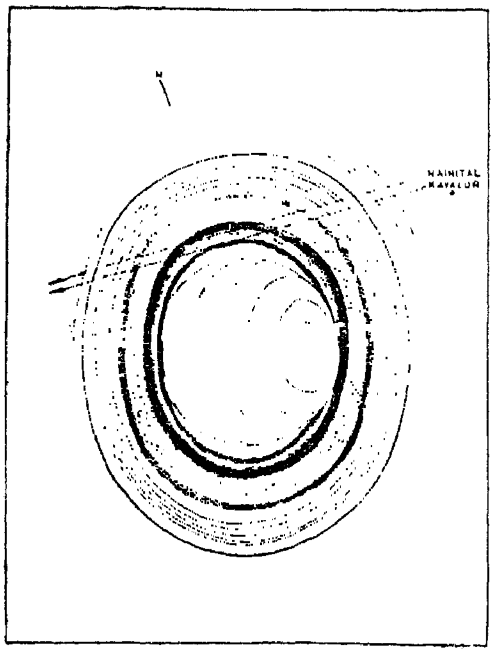

Fig. 6. — Rings of Uranus.

A development since last year is the detection of a twisted structure in one of these condensation lanes. This is exhibited in the occultation light curve through the broadest of the lanes, known as the ε ring. A comparison of light curves from occultations observed from several stations has been carried out by a team of the Indian Institute of Astrophysics in Bangalore, and it is seen that the entire assembledge consists of several lanes. Like the F ring of Saturn, the strands here also show a helical structure (R. Vasundhara et al 1982). A deeper analysis is under way which appears to reveal the existence of shepherding satellites close to the E ring conditions.

Jupiter's rings were discovered by the Voyager spacecrafts. Schematically, the sections ore shown in Fig. 7. The extended halo away from the equatorial plane of the planet appears to be a distinct feature of this system. There had been efforts to detect the ring from ground based telescopes in the infrared with some success. (Becklin 1979):

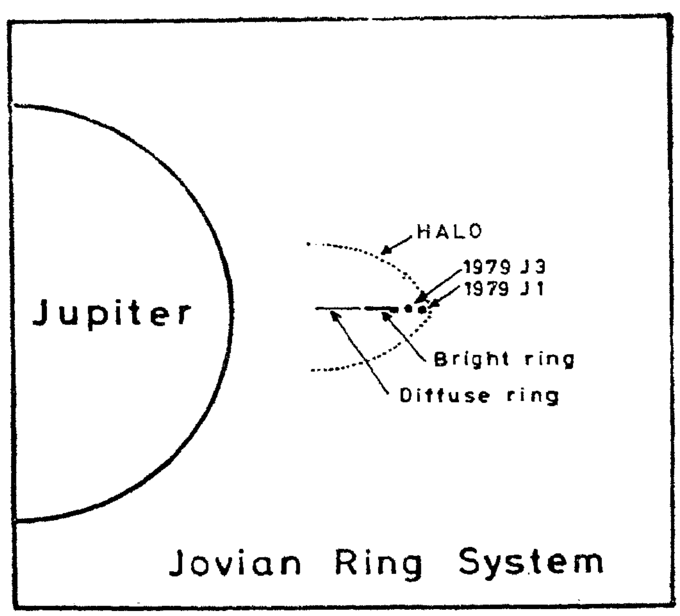

Fig. 7. — Rings of Jupiter.

A common feature of all these ring systems is that they consist of innumerable particles from submicron to metersized chunks in orbit around the planet. The number densities and surface and bulk properties of all these bodies are under investigation by photometric, polarimetric and spectroscopic methods; all observable occultation events are being carefully covered for results which may throw some new light on these structures.

The significance of all those observations about the minor bodies is that a knowledge of the material properties, composition, and dynamics of all these bodies is essential in our understanding of the solar system.

Theories have been put forth suggesting the birth and evolution of the planetary system surrounding the sun; several aspects of those hypothese can be verified from a thorough knowledge of these minor bodies in our close neighbourhood. And we should not forget another aspect: Close encounters with some of these objects have occurred within historical times; future encounters are almost a certainty. It is very essential that we be more familiar with these objects, so that a real preassessment of such future encounters will be possible.

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