Chapter 1

Introduction

In this Chapter, a brief account on conceptual development of cometary science has been given. Starting with the earliest notion about comet apparitions, the confirmation of their celestial nature has been narrated first. This is followed by a discussion on their trajectory, origin and the structural details. After that the importance of studying comets has been discussed. Finally, the objective and layout of the thesis has been presented.

1.1 Introducing comets

A comet is a very small solar system body made mostly of ices, mixed with smaller amounts of dust and rock. The main body of the comet is called the nucleus, and it can contain water, methane, nitrogen, ices and others. When a comet passes close to the Sun, it gets heated by the Sun and its ices begin to sublimate. The mixture of ice crystals and dust get blown away from the comet nucleus by the solar wind, creating a pair (dust and ion) of tails. The dust tail is what we normally see, when we view comets from Earth. This phenomenon has attracted and fascinated the common man to a large extent for the last two thousand years or so. The early information on comets comes from the ancient records of paintings or drawings of comets on caves, clothes, etc. as well as from the observations of early writers. The ancient peoples looked at the occurrence of unexpected transient events, like eclipses, comets, novae and meteors as portents of upcoming disasters, wars, pestilence and death. Comets in particular were received with a mixture of fear, woe and fascination, owing to their sudden and sometimes spectacular apparitions. A treatise on earliest record of comet apparitions to modern cometary science has been presented in chronological order in the following sections.

1.2 Earliest records of comet apparitions

Comets have been observed and recorded since ancient times by many cultures. The Chinese were the most prolific observers whose careful observations of comets and other phenomena like novae, meteors, aurora, eclipses and sunspots, since the period of Shang Dynasty (1600-1046 BC) have been preserved until now. In 635 BC, Chinese astronomers pointed out that the comet tail always pointed away from the Sun. Besides the Chinese, the Koreans and Japanese also contributed with a significant number of observations during the said time span. It is also possible that the Babylonians, Mesoamerican civilizations (Mayans, Aztecs, and other peoples), Hellenic civilization (Greece and surrounding areas around the Mediterranean Sea, including Alexandria) kept a good record of comet apparitions during 1200-1300 BC, though very few documents have survived until present. However, these available ancient accounts of comet apparitions are in general very vague, which were included incidentally within descriptions of historical events as bad omens. The ancient civilizations seem to have paid special attention to the observation of these bodies and other transient phenomena like fireballs and meteor showers, basically owing to their desire to predict future events rather than by mere scientific curiosity. The first reliable document describing a comet apparition in 674 BC was uncovered in a Babylonian stone tablet [Kronk, 1999]. One of the few Hellenic sources of comet observations during the 500-600 BC is by Greek scholar Aristotle's treatise 'Meteorologica' written in 329 BC. There are some references to comet apparitions from Roman scholars, in particular by Pliny the Elder and Lucius Annaeus Seneca of first century AD. ([Fernández, 2005], [Swamy, 2010])

1.3 Discussion on nature of comets: heavenly bodies or atmospheric phenomena

Many of the early astronomers began discussion on whether comets were celestial bodies or atmospheric phenomena. The Pythagoreans (600 BC), Hippocrates of Chios (440 BC), Anaxagoras of Clazomenae (500-428 BC) and the atomist Democritus of Abdera (460-370 BC) believed comets were planets or were produced by the close approach or conjunction of two planets giving the appearance of a single elongated object. Anaxagoras interpreted both the Sun and comets as made up of burning stones. A few dissenters, like Apollonius of Myndus (around 300 BC) supported them and added that the changing brightness of a comet is due to its varying distance from the Earth. Zeno of Citium on the island of Cyprus (336-264 BC) considered that stars united their rays to create the image of an elongated star. The Roman philosopher Lucius Annaeus Seneca (4 BC - 65 AD) noted in his 'Quaestiones naturales' that comets were permanent creations of nature moving perhaps in close orbits. Pliny the Elder (23-79 AD) discussed in his 'Natural History' a classification of comets into 10 types according to their shapes and observed features.

Apart from them, there were some believers of atmospheric nature of comets whose theoretical development overlooked other opinions of that time. According to Xenophanes of Colophon (570-470 BC) comets were dry exhalations from the Earth in a similar manner that clouds were condensations of moisture raised from the sea. Aristotle (384-322 BC) regarded comets, shooting stars and even the 'Milky Way' as meteorological phenomena. He classified the world into the sub-lunar world (composed of four concentric spheres ordered according to their density- the Earth, the watery, the airy and the fiery sphere on the top) and the super-lunar world (composed by a fifth element or quintessence and populated by the heavenly bodies move in circles). Following Xenophanes, Aristotle argued that comets were formed from warm and dry exhalations that rise up from the Earth when it was heated by the Sun. These exhalations ascended through the airy sphere to the fiery sphere. There, they were ignited by friction, producing comets, which were carried about the Earth by the circular motion of the heavens. Aristotle was the first to provide a physical explanation of why comets should foreshadow droughts, avoiding any kind of supernatural explanation of these bodies as portents or omens. Posidonius (135-51 BC) followed Aristotle's ideas about comets and added that comets burn as long as find nourishment in the ethereal region. Claudius Ptolemy (100-175 AD) also adopted Aristotle's view of comets as atmospheric phenomena and described them in his book 'Tetrabiblos', devoted to astrology. Henry of Hesse (1325-1397 AD) also thought that comets were meteorological phenomena, and that pestilence often follows comets because they are produced by the exhalation from the Earth of pestilential vapor.

During the Middle Ages, comets continued to be regarded as meteorological phenomena under the influence of the unquestioned authority of Aristotle and Ptolemy. Until the fifteenth century, no new original ideas or observations were added to the knowledge of comets, which were relegated to superstitious beliefs. ([Fernández, 2005], [Swamy, 2010])

1.4 Confirmation of comets' celestial nature

By the end of the middle ages, a new stimulating environment for scientific enquiry and discussion started to emerge. During the sixteenth century most astronomers were interested in determining the parallax of a comet in order to settle the debate on whether they were atmospheric phenomena or celestial bodies. The mathematician Girolamo Cardano noted that a comet seen in 1532 AD had an apparent speed smaller than that of the Moon, thus suggesting a greater distance which would make comet a celestial body. Girolamo Fracastoro (1478-1553 AD) and Peter Apian (1495-1552 AD) showed independently that comet tails always point away from the Sun (a property already known by Chinese astronomers in 600 BC). But it was the bright comet of 1577 AD that gave astronomers all around Europe a great opportunity to measure its parallax. Tycho Brahe, Michael Maestlin and Helisaeus Roeslin were among the observers who could successfully obtain a parallax and the calculated distance had placed the comets in the supralunar world. The heavenly nature of comets reached finally wide acceptance by the end of the seventeenth century.

Despite the advancement in the understanding of the celestial nature of comets during the sixteenth and seventeenth centuries, and the discussion of their motion with scientific arguments, the superstitious fears unleashed by their apparitions did not subside. Such fears were shared by some of the most respected scholars of the time, like Tycho Brahe, Kepler, Michael Maestlin, Martin Luther. ([Fernández, 2005], [Swamy, 2010])

1.5 Trajectories of comets

After comet was accepted as celestial body, a wide range of opinions were competing to determine the kind of trajectory they followed. Johannes Kepler (1571-1630 AD) believed that comets were ephemeral bodies that formed out of impurities in the celestial ether and moved along straight, rectilinear paths. Tycho suggested that comets moved around the Sun on circular orbits, like Venus and Mercury (In Tycho's system, the Sun itself, Mars, Jupiter, Saturn and the fixed stars moved around the Earth). Tycho even suggested that the orbit of the comet could be somewhat oblong, being the first person to suggest that a celestial body might move on an orbit different from a circle. The Italian-French astronomer Jean Dominique Cassini considered that comets moved around the Earth but in highly eccentric orbits. The Polish astronomer Johannes Hevelius concluded that they moved on paths slightly curved towards the Sun, on either a hyperbola or a parabola. This was corroborated by the German astronomer Georg Dorffel, a student of Hevelius, who was able to fit a parabola to the motion of the bright comet observed in 1680. Fortunately, at the very same time, Isaac Newton had almost completed his theory that predicted elliptic orbits for the planets moving around the Sun, which would occupy one of the foci and then developed a method to fit a parabola to the comet's motion. Edmond Halley was the first to fully exploit the new theory of gravitation to the case of comets. Halley computed parabolas and ellipses for a sample of 24 well observed comets. He concluded that comets observed in 1456, 1531, 1607 and 1682 (observed by himself) were same and predicted its return again in 1758. The comet was recovered by the German farmer-cum-amateur astronomer Georg Palitzsch and Halley had as a homage the comet named after him. Since then, it was agreed that comets moved on parabolic, nearly parabolic, or slightly hyperbolic orbits, though a few of them, like Halley, had orbits elliptic enough to record several returns on historic times. Later on, Leonhard Euler, noticed a decrease in the period of comet Halley between 1531-1607 and 1607-1682, which was explained by Alexis-Claude Clairaut, taking into account the perturbations of cometary orbit by Jupiter and Saturn. ([Fernández, 2005], [Swamy, 2010])

1.6 Origin of comets: Interstellar visitors or members of the solar system

The motion of comets, their size, shape that depart so remarkably from that of planets, led astronomers to think that they might not be members of our solar system. Some of the main thinkers of sixteenth century discussed the place in heaven where comets were originated. Johannes Kepler (1571-1630) believed that comets came from interstellar space. Rene Descartes (1596 - 1649) believed that comets formed together with planets around the Sun and other stars on vortices. But it was Pierre-Simon Laplace (1749-1827) who developed a complete theory of interstellar origin for first time. Laplace argued that comets were condensations in an interstellar cloud, which attained their observed orbits as the result of the gravitational attraction of the Sun. In 1929, Nicholas Bobrovnikoff concluded from the analysis of the lifetimes of 94 comets that these could not be older than one Myr, and that within this time the Sun must have therefore passed through an interstellar cloud from which it captured the comets. Nolke (1936) argued that condensations within the cloud could only become incorporated within the solar system if their motion was taking place in a resisting medium. He associated this to interstellar material composed of dust and gas (Richter 1963). Raymond Lyttleton considered Bondi and Hoyle's (1944) theory of accretion, according to which interstellar dust particles are gravitationally focused towards the antapex direction where they collide to each other. The dust particles lose kinetic energy via the inelastic collisions, so they will be transferred from the original hyperbolic orbits to elliptic orbits (Lyttleton 1951). Lyttleton's theory not only proposed an origin for comets, but also provided a physical model for its nucleus as an assemblage of interstellar dust particles.

Apart from these some scholars argued that the comets were formed from the members of solar system. Joseph Louis Lagrange (1736-1813) proposed a theory saying comets might originate from gigantic eruptions from one of the larger planets like Jupiter or Saturn. Even though Lagrange's theory could readily explain the origin of the short-period comet family, it did not enjoy the favor of many astronomers. A variant of Lagrange's theory was presented in 1930 by the Soviet astronomer Sergei Vsekhsvyatskii who argued that comets were formed from volcanic eruptions from the giant planets (Jupiter, Saturn, Uranus, and Neptune) or their moons. Then came the Exploded Planet Theory, according to which a tenth planet once existed between the orbits of Mars and Jupiter, which exploded about 3,200,000 years ago, spewing out comets and asteroids. The fragments visible today are those that avoided the disturbing influence of planets: those launched on nearly circular orbits (asteroids) and those launched on elongated ellipses (comets). The interest in the planetary explosion theory for the origin of comets waned with time, given the formidable difficulties to explain the physics and the dynamics of the generated comets.

Modern Cometary Science: At around 1950, the debate on whether comets were interstellar objects or members of the solar system was still unsettled. At that time there were a series of fundamental theoretical developments that were going to turn the tide of thought towards an origin in the solar system, and set the foundations of the "modern" cometary science.

Oort Cloud Theory: The theories postulating an interstellar origin for comets described before regarded the condensations within the interstellar cloud already formed when the Sun encountered them. The new theory says, as the solar system formed 4.6 billion years ago, a cloud of about 10^{14} comets also formed approximately 50,000 au from the Sun. Stars passing near the solar system had perturbed various parts of this Oort cloud and send randomly oriented comets on trajectories that pass near the Sun. As a comet enters the planetary region (0-30 au from the Sun), the gravity of planets (especially Jovian planets) either adds energy to or removes energy from the comet. If energy is added, the comet is usually thrown from the solar system on a hyperbolic orbit. If energy is removed, the comet's orbital period is shortened. With so many comets in the initial cloud (10^{14}), some survived many passes through the inner solar system and are now short-period comets.

Revised Oort Cloud Theory: If an unreasonably large number of comets were formed 50,000 au from the Sun, 4.6 billion years ago; they would have been stripped by the passing stars, galactic clouds over a few billion years. Also, short-period comets cannot come from the Oort cloud. So, the original theory has been revised by stating that as the solar system began 4.6 billion years ago, all comets formed in a comet nursery near or just beyond the outer giant planets. Because these comets were relatively near the Sun, passing stars and the massive galactic clouds (molecular clouds) could not drive out them from the solar system. As with planets, these early comets all had prograde orbits near the plane of the ecliptic. Perturbations by the giant planets gave some comets short periods with prograde orbits near the ecliptic plane. The region where these were accumulated is called 'Kuiper belt'. Some perturbations ejected some comets out to form and resupply an Oort cloud, 50,000 au from the Sun. Some passing stars perturbed some Oort cloud comets back into the planetary region, as described by the original Oort cloud theory. ([Fernández, 2005], [Swamy, 2010])

1.7 Cometary orbits

Most comets are observed to move on highly eccentric orbits with orbital periods going from hundreds to several million years. A large fraction of these orbits are close to a parabola ($e \doteq 1$), and some comets even get hyperbolic orbits ($e > 1$). On their way around the Sun, they gain energy from the planets, and thus are lost to interstellar space. The rest of the comets move in elliptical orbits ($e < 1$) with orbital periods around a few years.

Classification: Comets with the shorter periods are called periodic or short-period, whereas the rest are called non-periodic or long-period (LP). The limiting period is set rather arbitrarily at 200 years. It is based on the fact that comets with $P > 200$ years have so far been observed only once (with the recent exception of comet 153P/Ikeya-Zhang with a period $P \doteq 364$ years, observed in 1661 and recovered in 2002). Some examples of LP comets are Hale-Bopp, Hyakutake, Austin, Garradd.

Periodic comets are usually divided into Halley-type (HT) and Jupiter Family (JF) or ecliptic comets with the boundary of period set at $P \doteq 20$ years. The distinction between HT and JF comets is not simply a matter of convention, but it obeys to the reason that both populations may come from different source regions. The distributions of orbital inclinations of the different dynamical classes also show striking differences. All JF comets so far discovered move in direct orbits with most of their orbital planes lying very close to the ecliptic plane. Periodic comets are indicated by ‘P/’ before their names. E.g. 78P/ Gehrels, 290P/Jager, 2P/Encke, 22P/Kopff are JF comets and P/2006 HR30 Siding Spring, C/1991 L3 Levy are HT comets.

Oort worked on only a small sample of comets to build his theory of orbits. Marsden, with his colleagues enhanced the data to 200 well-determined long-period orbits [Marsden et al., 1978]. There are 810 comets listed in Marsden’s catalogues ([Marsden, 1986], [Marsden, 1989]) of cometary orbits, of which 655 are LP comets, 20 are IP comets and 135 are SP comets [Fernández, 1997]. Marsden and Williams’s catalogues ([Marsden and Williams, 1997], [Marsden and Williams, 1999]) brought 1642 comets, of which 1368 are LP comets and the rest are periodic. A significant fraction of the cataloged LP comets are sungrazers that probably come from the tidal disruption by the Sun of parent comets that get sungrazing orbits. The great majority of sungrazers (more than 560 by now) have been discovered from space-borne observatories, and in particular from the ESA/NASA Solar and Heliospheric Observatory (SOHO) spacecraft. ([Fernández, 2005], [Swamy, 2010])

1.8 Structure of comet

The word ‘comet’ has been derived from the Old English ‘cometa’ from the Latin ‘comēta’ or ‘comētēs’. This means ‘long-haired star’, ‘the hair of the head’ and was used to indicate ‘the tail of a comet’ in Greek. Its constituent three major parts viz. nucleus, coma and tail have been discussed below-

Nucleus:

The compact solid core of a comet is the nucleus. It is the most essential part of a comet, because it is the only permanent feature that survives during entire life of a comet. But, the scientific community is still at a very primitive stage in understanding the cometary nuclei. As the nucleus cannot be observed directly from the Earth by ‘Earth Based Telescope’ because of its small size, the information with regard to their possible nature, structure and composition has to come from indirect means. Nevertheless, the preliminary picture has began to emerge through close spacecraft encounters. The International Cometary Explorer (NASA) is the first spacecraft to visit a comet, passing through the plasma tail of Comet Giacobini-Zinner at a distance 7,800 km from the nucleus on September 11, 1985. The flybys to Comets Halley, Tempel 1, Wild 2 and Borrelly have given new insights into this area. The camera systems onboard these missions have revealed single, solid, dark, lumpy, and elongated nuclei which are much more similar than they are different.

In the March, 1986; five spacecrafts viz. Giotto (NASA), Vega1, Vega2 (an international team headed by USSR), Suisei, Sakigake (JAXA) flew by the comet Halley. Among them, the spacecrafts Giotto, Vega 1 and Vega 2 were the first to take the images of the nucleus of the Comet Halley. It clearly showed the nucleus is not spherical in shape, but highly irregular. It resembles more like a 'peanut' or a 'potato'. The surface has many features such as valleys, hills and craters. The nucleus was also found to be large as well as quite dark in nature (albedo 4%). The salient feature was that the gas emission was not uniform over the entire surface of the nucleus but comes out as discrete jets. Due to rotation of the nucleus the jets will become active, only when they are exposed to the solar radiation. Along with the space missions, some ground based polarimetric observations have revealed the existence of dust jets from nucleus ([Eaton et al., 1988], [Sen et al., 1990]).

The close-by images of Comet Borrelly by Deep Space 1 (NASA; October, 1998- September, 2001) mission showed the nucleus to be shaped like a 'foot print'. The images also showed jets as were seen in Comet Halley. The terrain appeared to be highly complex with some craters. They also showed bumps, troughs and other features. The nucleus of Comet Wild 2 observed by STARDUST (NASA; February, 1999- January, 2006) mission was found to be oblate. It contains depressions ranging in size up to about 2 km across. Some of the depressions are not circular and have complex structures. They could have been formed by impact, sublimation, ablation or a combination of all of these processes. Dust samples collected by the STARDUST Mission from coma of comet Wild2 contain olivine, pyroxene and osbornite. The cold volatiles are expected from an object from the outer solar system. But these minerals are supposed to form at high temperature. It is really a challenge to the understanding of their formation. STARDUST mission had also suggested that the cometary grains are mixtures of aggregates (porous particles) and compacts ([Hörz et al., 2006], [Burchell et al., 2008]). Deep Impact (NASA) released an impactor into Tempel 1 on July 4, 2005. The images of Comet Tempel 1 taken by Deep Impact showed the presence of circular depressions and terrains. One dramatic feature seen was the presence of layers over the entire surface of the nucleus of the comet. Such layers are also found in Comets Borrelly and Wild 2 based on the images taken by the earlier spacecrafts. Deep Impact made an extended mission, designated EPOXI (NASA), which made a close approach to comet 103P/Hartley (or Hartley 2) in November, 2010. It is the first comet in which water that is similar as isotopic composition to that in Earths ocean has been discovered by a team of astronomers using ESAs Herschel Space Observatory.

The European Space Agency spacecraft ROSETTA put itself into orbit around 67P/Churyumov-Gerasimenko on 6 Aug. 2014, and three months later dispatched a lander, named Philae, to the surface of the comet. After bouncing to a stop, Philae completed 80% of a pre-programmed, three-day series of science experiments and radioed the results back to Earth before its batteries died. Gravity measurements taken by the orbiting Rosetta spacecraft show the body of comet 67P/Churyumov-Gerasimenko is about 75 percent dust and 25 percent ice all the way through. Comets being a mixture of dust and ice, when fully compact, would be heavier than water. However, measurements have shown that some of them have extremely low densities, much lower than that of water ice. The low density implies that comets must be highly porous. Martin Pätzold and team have shown that Comet 67P/Churyumov-Gerasimenko is also a low-density object, but they have also been able to rule out a cavernous interior [Pätzold et al., 2016]. In December, 2014; ESA's Rosetta spacecraft has found the water vapour from its target comet to be significantly different to that found on Earth. D/H ratio measured by the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis, or ROSINA, is more than three times greater than that found on Earth's oceans and Jupiter Family comet Hartley 2. The discovery fuels the debate on the origin of our planet's oceans.

Coma: The nebulous envelope around the nucleus of a comet is the coma. It is formed when the comet passes close to the Sun; as the comet warms, parts of it sublimate. This gives a comet a “fuzzy” appearance when viewed in telescopes and distinguishes it from stars.

The coma is generally made up of ice and dust. Water dominates up to 90% of the volatiles that outflow from the nucleus when the comet is within 3-4 au of the Sun. The H_2O parent molecule is destroyed primarily through photodissociation and to a much smaller extent photoionization. The solar wind plays a minor role in the destruction of water compared to photochemistry. Larger dust particles are left along the comet’s orbital path while smaller particles are pushed away from the Sun into the comet’s tail by light pressure [Combi et al., 2004].

Tail: The gaseous material released by the nucleus also carries with it a large amount of dust. While the gaseous parent molecules are rapidly dissociated and ionized outside the nucleus, the dust grains remain stable under the solar radiation. Even when they are warmed to temperatures of a few hundred Kelvin, they are still chemically and morphologically stable, thus preserving information on the conditions in which they formed, either in the interstellar medium or in the solar nebula. There is an agreement at present that silicate minerals formed in the interstellar medium are amorphous, while crystalline minerals may have formed in the solar nebula, either as gas phase condensates or amorphous silicates annealed into crystals when heated to temperatures above $\sim$ 1000 K (Wooden 2002). Dust grains may be a vehicle for the transportation of significant quantities of condensable elements from the circumstellar winds of evolved stars, novae and supernovae into the parent clouds of young stellar and planetary systems. Therefore, if some fractions of these grains survive intact, the study of their mineralogy and physical properties may shed light into stellar nucleosynthesis and evolution [Williams et al., 1997].

Bessel developed a mechanical theory for the dust particle motion able to explain the cometary tail forms in 1836. He assumed that the diffuse appearance of a comet is due to an agglomeration of very fine dust particles which are expelled from the nucleus by repulsive forces originating at the Sun. This concept was refined by Bredichin around 1900. In 1903 the Russian astronomer Fedor Bredikhin developed a theory considering Sun’s gravitational force and repulsive force due to solar radiation. The idea that the force of repulsion of the Sun, which was originally introduced purely as a hypothesis, may actually originate from radiation pressure of sunlight was first proposed by the Swedish chemist and physicist Svante Arrhenius (1859-1927). More detailed investigations by Schwarzschild in 1901, showed that it is indeed possible to explain repulsive forces on dielectric spheres of sub-micron to micron-size as large as 20-30 times the solar attraction but not more than that. This was a very important result since showed that another physical mechanism - besides radiation pressure - must be at work to explain much greater repulsive forces. These ideas were put on a firm basis by Finson and Probstein in the 1950's. These authors have worked out in great detail the dynamics of grains based on fluid and kinetic concepts and the resulting intensity distributions.

One tail shows a curved shape and its spectrum corresponds to that of the Sun, showing that it is composed of dust particles that scatter sunlight. This is called dust tail or type II tail. The other tail stretches to larger distances in the antisolar direction and is of bluish color. The spectrum of this tail shows the emission bands of several ions, in particular CO^+, N^{2+} ,CH^+,CO^{2+} , and H_2O^+. This is ion tail or type I tail. The ion tail shines by fluorescent radiation; in particular the CO^+ ion - the most abundant ion species in the tail has a strong band in the blue part of the spectrum, giving the tail its characteristic color.

1.9 Importance of studying comets

It is generally believed that the origin of comets is intimately related to the origin of the solar system, a problem of great current interest. They are thought to be leftover building blocks of the outer solar system formation process and the comets offering clues to the chemical mixture from which the giant planets formed some 4.6 billion years ago. The time which the comet spends near the Sun is a very small fraction of its total period. So only a thin layer of the material of the nucleus is ablated at every perihelion passage and nothing much would have happened in the inner regions of the nucleus of a comet. The inner core of the comet may thus represent the composition of the original material at the time of its formation. Therefore, it is hoped that a systematic study of the material of the nucleus of comets can give information with regard to the nature of the material present at the early phase of the solar nebula, 4 to 5 billion years ago, even before the formation of the Earth and the solar system. Therefore, the study of comets can provide clues which may help in understanding the origin and evolution of the solar system.

From the STARDUST mission, it is evident that the comets are highly abundant in crystalline silicate grains. Many of these are high-temperature minerals appear to have formed in the inner regions of the solar nebula. Their presence in a comet proves that the formation of the solar system included mixing of these minerals in large scales in the solar nebula prior to comet formation. This mixing must be taken into account in any theory of our solar system. The most abundant minerals which are common in planetary materials are the crystalline silicate minerals. Finding them in comet is somewhat surprising because cometary material would be similar to interstellar material, in which most silicates are believed to be amorphous. There are generic relationships between comets with the interplanetary dust particles, meteorites, asteroids and interstellar matter. In addition to these possible interrelationships, the comets themselves are interesting objects to study, as their nature and origin are still not well understood. The highly complex molecules and organic compounds seen in comets can finally find their way on to the Earth. These might have played a key role in the complex scenario of chemical evolution finally leading to life on the Earth.

One of the leading hypotheses on Earth's formation is that it was so hot when it formed 4.6 billion years ago that any original water content should have boiled off. But today, two thirds of the surface is covered by water. In this scenario, it should have been delivered after our planet had cooled down, most likely from collisions with comets and asteroids. The relative contribution of each class of object to our planet's water supply is, however, still debated. The key to determining where the water originated is in the proportion of deuterium. Previous measurements of the deuterium/hydrogen (D/H) ratio in other comets have shown a wide range of values. Of the 11 comets for which measurements have been made, it is only the Jupiter Family comet 103P/Hartley 2 that was found to match the composition of Earth's water, in observations made by ESA's Herschel mission in 2011. The type of water found in Comet 67P/Churyumov-Gerasimenko is so different from terrestrial water that some researchers are starting to second guess that claim, opting instead to look at asteroids as the objects that delivered water to Earth at first. By contrast, meteorites originally hailing from asteroids in the Asteroid Belt also match the composition of Earth's water. Thus, despite the fact that asteroids have a much lower overall water content, impacts by a large number of them could still have resulted in Earth's oceans.

The influx of interplanetary debris that formed the Earth was so strong that the proto-Earth was far too hot for life to have formed. The earliest known fossils on Earth date from 3.5 billion years ago and there is evidence that biological activity took place even earlier - just at the end of the period of late heavy bombardment, some 3.8 billion years ago. But under the heavy bombardment of asteroids and comets, the early Earth's oceans vaporized and the fragile carbon-based molecules, upon which life is based, could not have survived. So the window when life began was very short. But if life formed so quickly on Earth and there was little in the way of water and carbon-based molecules on the Earth's surface, then how were these building blocks of life delivered to the Earth's surface so quickly? The answer may involve the collision of comets with the Earth, since comets contain abundant supplies of both water and carbon-based molecules.

Its believed that comets brought the building blocks of life to Earth some 3.8 billion years ago and subsequent cometary collisions may have wiped out many of the developing life forms, allowing only the most adaptable species to evolve further. A catastrophic cometary collision with the Earth is only likely to happen at several million year intervals on average. However, it is prudent to mount efforts to discover and study these objects, to characterize their sizes, compositions and structures and to keep an eye upon their future trajectories. ([Swamy, 2010])

1.10 Motivation behind the present work

Observation of comets from Earth is possible using ground and near Earth based telescopes and from space using spacecrafts. Many of the space and ground based observations confirmed each other's findings. Space based studies have helped to answer many issues related to cometary grains. But it also gave rise to questions about the formation process of solar system. Current technology does not permit space expeditions to Oort family comets, where ground based observations can help. So, I have opted ground based observation of comets in polarimetric mode to study comets. Such studies can help us to investigate the optical and physical properties of dust grains (ejected by comets when they approach the Sun) and some morphological features of comets. The study can assist to find out a suitable discriminator between Oort and Jupiter Family comets. Most importantly, the study can contribute to the knowledge of understanding the comets and solar system better and give a hand to develop an appropriate theory of origin and formation of solar system.

1.11 Objective and layout of present work

The objectives of my work are-

i) Observations: - For the study of concerned comets, the necessary polarimetric images have been taken at different periods of time from the 2 meter telescope of IUCAA Girawali Observatory, Pune, India and the 0.8m telescope at Haute-Province observatory, France.

ii) Image Analysis: - The raw images have been reduced and analyzed using the NOAO (National Observatory of Astronomical Observation) scientific software package IRAF (Image Reduction and Analysis Facility). Whenever necessary, other scientific software like IRIS was also be used.

Writing scripts - For more effective analysis of polarimetric images, new tasks (scripts) have been developed and written under IRAF.

iii). Interpretation: - To infer the physical properties of cometary dust, the polarimetric features of different regions of cometary coma; the comparisons were made by developing various diagnostic tools (software based).

The layout of this thesis includes following chapters-

1. Introduction
2. Light scattering theory: Polarization
3. Observational technique: Polarimetric
4. Literature survey: Polarimetric study of comets
5. Polarimetric observations of some comets
6. Results and interpretations