Planetary Exploration: What next?

This year we commemorate a decade of Planetary Sciences and Exploration Programme, which was initiated in 2001 at Physical Research Laboratory to provide a platform for Planetary Exploration in India, specifically to meet the challenges of Chandrayaan-1 mission. It is also the Golden Jubilee year of the first human flight around the world by Yuri Gagarin in 1961. At this point it is appropriate to review accomplishments of these exciting years of ever expanding horizons of planetary exploration and prepare for missions planned in the near future.

Planetary Exploration began in a big way with the six Apollo and three Luna missions to Moon in quick succession during seven years (1969-1976) following Apollo 11. The two types of missions represented highest degree of technical achievement in both human and robotic exploration. After a relative lull for about two decades, planetary exploration picked up again and the first decade of this century marks many achievements which expanded our knowledge to the farthest reaches of the solar system and beyond. All the planets and most of the satellites and rings of the solar system, and some comets and asteroids have been examined, photographed, and studied from a close distance using sophisticated instruments. Robotics has been developed to a high degree of perfection so that samples of comets, asteroids and even particles from the sun have been brought back to earth for a detailed laboratory study. In all the three aspects, i.e. remote sensing of planetary bodies, exploration on the planet's surfaces (by landing instruments or well equipped rovers, by impacting and digging their surfaces) and laboratory studies of the returned samples, major scientific breakthroughs were accomplished.

To recount some of the major achievements of the past decade, the ***Genesis*** mission brought back the first solar wind sample in 2004, Hayabusa brought back the first asteroid samples of Itokawa in 2010 and ***Stardust*** mission brought back the first comet sample from Wild 2 in 2006. The study of these small but scientifically precious samples led to a deep insight into the way these bodies formed and conditions prevailing in the infant solar nebula. For example the solar particles caught by the silicon wafers on ***Genesis*** showed that the Sun has a higher proportion of oxygen-16 than the Earth. This implies that oxygen-16 from the Sun's protoplanetary disc was depleted prior to the coalescence of dust grains that formed the Earth. Itokawa and Eros both were found to be S type asteroids whose composition match low iron group stony meteorites. Dust collected from the surface

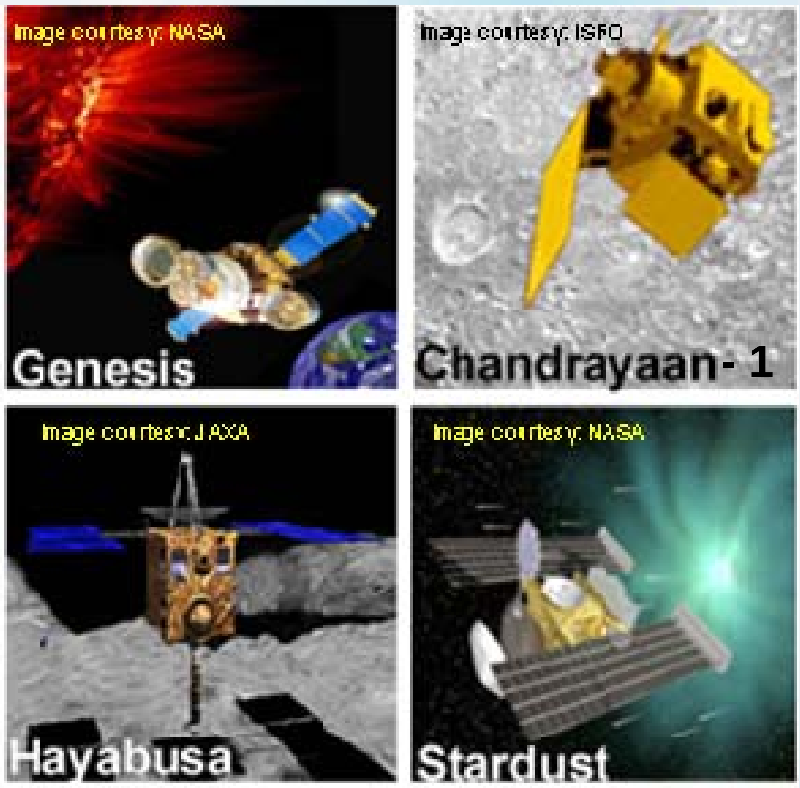

Figure 1: Important accomplished missions in past

of Itokawa was found to be young, exposed only for about eight million years, a period much shorter than the formation age of the asteroid, implying thereby that probably it was originally a part of a larger asteroid and broke off recently. Earlier ***Galileo*** mission had found binary asteroids, a small moonlet Dactyl going around the asteroid Ida. The ***DEEP IMPACT*** **Mission** impacted on comet TEMPEL in 2005 and thousands of kilograms of dust and water was ejected due to this impact. Its analysis showed clays, carbonates, sodium and silicate grains and also traces of ethane. There was more dust and less ice than expected, ruling out "the loose dust" model of cometary surfaces. The crater so created became obscure due to the ejected dust and was photographed later in 2007 by another mission, the extended ***Stardust*** Mission.

Stardust encountered the comet *Wild 2* in 2004 and brought back its sample to the earth. High temperature minerals like anorthite, calcic pyroxene, spinel and Al-Si rich glass were found in a grain named COKI , indicating that comets like Wild -2 were not formed in isolation but high temperature material from the inner solar system, close to the sun, got transferred to the far away comet forming regions. Absence of a short lived radioisotope Al-26 showed that such a transfer took about ~2 million years, during which this radioisotope had decayed. This calls for a revision of the models of exchange of material in the infant solar nebula and formation of comets. An organic compound glycine was also discovered in this comet. Thus important pieces of information were obtained by these missions. Remote sensing studies of planets were carried out by orbiters around several planets which included Mercury, Venus and the outer planets. ***Messenger*** which was launched in 2004 arrived on Mercury in 2011 and has already started sending good data which suggest that Mercury was formed in a highly reducing environment. ***Venus Express***, launched by European Space Agency in 2005, was captured in a polar orbit around it in 2006 and has been sending data about Venusian atmosphere all along. The ***Cassini-Huygens*** launched in 1997, explored the outer planets and made many discoveries related to Saturn and Titan. It discovered 3 new moons of Saturn, subsurface water on Phoebe as it flew past this satellite, and water on Enceladus. ***Huygens*** probe which landed on *Titan* in 2005 discovered large hydrocarbon (ethane and methane) lakes, hundreds of kilometer in size. **NEW HORIZON** was the first *Pluto-Charon* and KBO (Kuiper Belt Objects) Flyby mission. ***Dawn*** mission, launched in 2007, has already orbited asteroid Vesta and will soon orbit Ceres, making a detailed study by remote sensing techniques. A major breakthrough was attained with discovery of over 1000 exoplanets outside our solar system, some of which may be like our earth.

Mars was the center of exploration by National Aeronautics and Space Administration, USA and the twin rovers ***Spirit*** and ***Opportunity*** roamed over the martian surface for many years, finding Blue berry like spherules, vugs, and sedimentary minerals e.g. sulfate, Jarosite and hematite, as if salty sea shore existed there. The mission also provided atmospheric temperature profile. The latest addition to the large number of missions is the ***Mars Science Laboratory*** with a highly advanced rover Curiosity, which was launched only a few weeks ago.

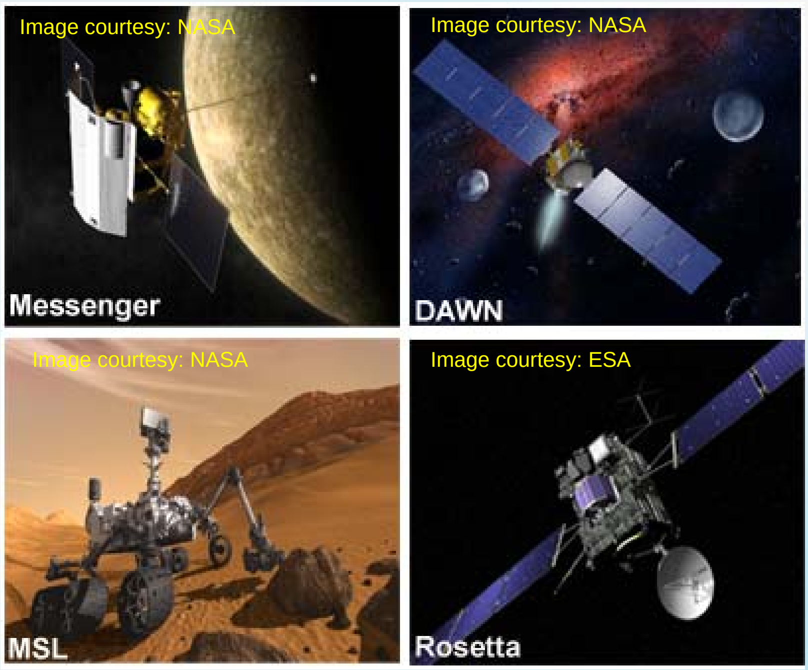

Figure 2: Missions still active with lots of promises

Moon continued to be the prime target for exploration and Japan (JAXA) with ***Selene (Kaguya)*, China (CSA)** with ***Change'-1*** and ***2*** and India (Indian Space Research organization) with ***Chandrayaan-1*** became new members of the space club. Thus during the decade , together with NASA, ESA and Russian Space Agency, there are now six space faring agencies with over 20 nations participating in one way or the other. A welcome development has been a shift from competition to bilateral and multilateral cooperation in space missions. One of the significant findings of the past decade is the discovery of water everywhere in the solar system. Now we know that poles and even some deep craters on Mercury, polar regions of Moon, and as **Chandrayaan-1** and **Lunar Reconnaissance Orbiter** found out, environmental, surficial and subsurface water may exist on Moon. Many missions have found evidence of flowing water channels on Mars and sediment deposits bearing testimony to abundant water on this planet in the past and even now in form of ice. The possibility that volcanic episodes and some large impacts from the nearby asteroidal belt can dig out sub surface water and create a temporary atmosphere for thousands of years, when life can survive, have revived our interest in finding some extinct or extant life there. Several asteroids (e.g. Eros) and many types of meteorites, originating in various asteroids, have shown presence of water or hydrated minerals. Among the satellites, Europa, Ganymede, Callisto have ice on their surfaces and may even have subsurface saline water oceans. As already mentioned active geysers have been found on the saturnian moon Enceladus. Many other satellites or minor planets e.g. Titania, Oberon, Pluto, Triton and Rhea are all good candidates for water and water can as well exist in some atmospheric layers of Jupiter, Neptune and Uranus. Adding to this long list is the hope that many earth- like planets may exist outside the solar system. The ***Kepler*** mission found the planet Kepler 22b which has habitable environment and many more such exoplanets may exist.

Even with this brief and selective summary, it is apparent that the past decade has been an exciting period for planetary exploration. The present decade with Jupiter-Uranus- Neptune orbiter, ***JUNO*** already launched in 2011, Two lunar probes ***GRAIL*** and ***LADEE*** scheduled for 2012, a mission to study Martian Atmosphere and volatile evolution ***MAVEN***, to be followed by ***Exomars*** for Mars landing and subsurface study in 2016, an ambitious Mercury probe ***Bepi Colombo***, two asteroid lander and sample return missions ***Hayabusa-2*** and ***OSIRIS REX*** and ***EPOXI*** for comet Hartley-2 encounter looks even more exciting. To this ambitious program we may add some more moon landers e.g. ***Chang'e-3, MOON NEXT***, Russian robotic moon mission ***LUNNYJ POLIGON***, **Jupiter Icy Moon explorer**, Titan-Saturn System mission and asteroid and Moon manned missions in another one or two decades.

The question naturally arises whether this incremental progress is the best we can do in the near future or we should go for a quantum jump. Can we not perfect the robotic lunar sample return mission, which the USSR carried out about half a century ago by their Luna missions and scale up this technology for a Mars sample return mission. Such missions are not very expensive and may give a big boost to planetary exploration program. A sample return mission has enormous advantages over a remote sensing orbiter or a landing mission since trace element analysis, isotopic analysis and dating can only be carried out in laboratory. It is unlikely that these experimental techniques can be performed by robots in the foreseeable future. We have to bear in mind that a sample return mission is worth much more than all the other missions combined. A force of six space agencies and many more joining in the near future, if they can pool their resources and join hands can truly accomplish much more than is envisaged now.

When Apollo missions went to Moon it was predicted that in two decades or so man will land on Mars. This was an unrealistic expectation, but personally, I had hoped that the Russian robotic sample return missions will bring back samples from a hundred unexplored locations of moon (like polar regions or the far side) by now which will help us resolve some of the outstanding problems of the Earth-Moon system. But even today moon or mars sample return missions remain a distant dream. It seems that what we could do half a century ago cannot be easily repeated any more.

In Indian context, its maiden moon mission Chandrayaan-1 did a good job by any measure but was cut short after nine months of successful operation, because of some communication problems. Three days after this mission was declared over, I had proposed that another similar mission Chandrayaan-1 A should be sent to finish the unfinished task. The idea was that a spare model of each payload will be readily available or can be built in a short time. This would enable us to complete global mapping with all the instruments and rectify some of the problems encountered by Chandrayaan-1 mission. It still remains a good choice in my opinion.

In the light of the above discussion, I would strongly appeal for a robotic sample return mission to Moon and Mars by global cooperation and a supplement mission to Chandrayaan-1 by ISRO.

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