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Mangalyaan, an Indian messenger to Mars
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In 2012 The Indian Space Agency, ISRO, expressed its intention of launching India’s first Red Planet space mission. At the time of the announcement, not many technical details have been shared to the press, but despite that, the feedback received showed the huge interest of the people for this subject.

We will try to reveal in this article how this project was born, which solutions were chosen and what is the general context of the mission.

Mangalyaan, the name chosen for the Indian satellite, was approved by the Indian government on the 3rd of August 2012, after ISRO finalized a preliminary study regarding the procurement and manufacturing aspects. A few months later, the Indian authorities have announced that the satellite was going to launch on the 27th of November 2013, trying to catch a favorable launch window which opens every 26 months. Next launch opportunity would have been in 2016.

Such delays happened in the past with some other Martian missions, one good example being the Curiosity rover. Curiosity was supposed to fly initially in October 2009, but as the mission was not ready at that time (due to some pending problems regarding the command and control mechanisms), NASA decided not to take the risk and to postpone the launch, even if this involved additional costs.
The delay offered the engineers the necessary time to solve these technical problems. In the end Curiosity was successfully launched in November 2011 and its flight to Mars was perfect.

By contrast, a bad managerial decision has been taken for the Russian project Phobos-Grunt. At the beginning of November 2011 the Phobos-Grunt mission, which was supposed to bring Russia back in the planetary exploration after a 20 years long period of inactivity, remained captive on an orbit close to the Earth.
Even though the first part of the launch was successful (separation from the Zenit rocket), the second phase was disastrous (when the satellite was supposed to overcome the Earth gravity entering an interplanetary transfer trajectory).

The Phobos-Grunt project was initiated in 1996 with some extremely ambitious objectives - reach Phobos, the natural satellite of Mars, in order to collect soil samples and return them to Earth. The last Russian Martian mission was Mars 96, while the last successful interplanetary mission was the second probe of the Phobos program launched in 1988.

Russia has an absolute negative record for the Mars exploration missions (0% success rate) - all 20 probes launched previously have failed.
Ignoring this negative statistics and despite the fact that the system tests were not completed, the Roskosmos management insisted to keep the satellite launch date in order to not lose the favorable launch window. Assuming a major risk, sadly, as stated above, everything backfired proving once again that the space industry isn't a lottery.

Returning to the main topic, at the end of March 2013, ISRO reported that they have begun integrating the instruments. The mission's budget was estimated at $82 million, out of which $41 million were allocated for the first phase. Mangalyaan was scheduled to fly from the Satish Dhawan Space Center on board the Polar Satellite Launch Vehicle.

The C25 PSLV's flight, had to use the XL version of the rocket, substituting the powerful GSLV which was not ready in time for Mangalyaan (the new version of the rocket, using an indigenous cryogenic engine for the last stage, had at that time two consecutive failures: on the 15th of April 2010 and on the 25th of December 2010, both test flights).

PSLV or Polar Satellite Launch Vehicle is a 294 tons rocket, with four stages using solid and liquid fuel. The standard configuration is able to place 3200 kg into a lower orbit (LEO) or 1600 kg into a sun-synchronous orbit (SSO). In April 2008, PSLV established a world record for the number of simultaneous launched satellites (10 satellites launched at the same time). That record lasted until November 2013 when the Minotaur and the Dnepr rockets have set new limits.

The XL version has an increased transport capacity compared with the standard version: 3800 kg for LEO and 1750 kg for SSO.
The rocket is equipped with six PSOM XL/S 12 propulsion boosters. The first stage is powered by a PS1/S138 booster and provides 4817 kN. The second stage uses a PS2/L40 engine which provides 799 kN, the third has a PS3/S7 engine with a force of 238 kN. The last stage is using a PS4 engine with a power of 12.6 kN.

ISRO has an increasing budget (about one billion dollars per year) financed from its own resources and by providing launching services for other international operators. More than 16.000 engineers are working for ISRO in research/design/infrastructure.
Even if the financial conditions do not look outstanding compared with the Western standards (the monthly average salary slightly more than 1500 dollars), they are still very attractive for a country where the cost of living is very low. On top ISRO is offering a series of advantages for its employees i.e. housing services in residential areas built specially for the families of the engineers, private schools for the kids, free transportation etc., which transforms the Indian Agency in one of the most attractive employers in India.

Although the Indian space program is in ascension, there are some negative points and unfortunately a lot of them are critical to India's long term ambitions - manned flights or launches to the Moon and Mars. In 2012, when Mangalyaan started, the weak link was the GSLV launcher, as mentioned previously. GSLV was considered the top of the iceberg for India's aerospace industry which is demanding a bigger transport capacity and new scenarios for its space missions, behind the Earth's orbit.
India hoped to completely develop the GSLV rocket in house and to reduce the technological distance to USA and Russia, the leaders of the global space race.
Having the GSLV rocket ready could offer India a chance for its ambitious space program (sending astronauts into space or a manned exploration mission for the Moon).

ISRO's plan included shifting from the current version GSLV-Mark1 to a new version GSLV-Mark2 (capable of transporting up to 5 tons in a LEO low orbit). The GSLV (Geosynchronous Satellite Launch Vehicle) type Mark1 is a launcher with a mass of 402 tons and is built in three stages which combine solid and liquid fuel. It's been in service since 2001. It has a transport capacity of 5000kg for a low orbit (LEO) or 2200kg for a geostationary transfer orbit (GTO).

The next version GSLV Mark 2 was expected to enter in service for commercial launches before 2011. The entire program was put on hold, after a series of technical problems which resulted in the two failed launches, mentioned earlier.
The problems were solved very lately, on the 5th of January 2014, when GSLV managed to successfully take off from the same Satish Dhawan Space Center.

Mark2, completely re-engineered compared with its predecessor, comes not only with better launch capabilities, but it also halves the price per flight. Mark2 should be the foundation for Mark3 version – the mature product of the GSLV program and the workhorse for India's future space missions (mainly manned space flight programs, scheduled from 2015 onward).
The four start boosters will be replaced with two bigger ones, a new engine with liquid fuel for the first stage will be introduced, also a restart able engine for second and third stage, and an improved version of the cryogenic engine tested on Mark2.

For consistency, it should be reminded that the Indian manned space flight program began in 2007 with the flight of the so-called Space Recovery Capsule, a capsule of 550kg. The future Indian Space Capsule will be derived from the 2007's version and will be able to transport two astronauts on a LEO orbit with a 400km altitude. The entire program will cost India 2.2 billion dollars.
But switching to the Mark2 version of GSLV was a difficult task even for an advanced space program like the Indian one.

India has for some time an extended partnership with Russia, who should provide technical support to Indian specialists, mainly in human spaceflight activities, propulsion systems and interplanetary missions. The agreement was signed with Roskosmos in December 2008 during the visit of Medvedev in India and continues the tradition of bilateral cooperation that began in 1984 with the flight of the first Indian astronaut (on board the Salyut capsule). In addition to the logistic support following this agreement, the preparation for the flight of another Indian astronaut on board of a Soyuz mission will start soon.

However, the collaboration does not stop here and came to fruition with technical support for the Indian rocket engines - more specific for the 3rd stage of GSLV rocket. This, a type KVD-1M engine, supplied until now by Russia (from the Proton rocket), will be replaced by an Indian built cryogenic engine.

The old Russian engine uses liquid oxygen and hydrogen and was sold to India at the beginning of the ‘90s, after the collapse of the Soviet Union, in a number of 7 pieces.

Later, due to technology transfer regulations that were put in place worldwide, India couldn’t buy Russian components anymore and was forced to take the decision of developing its own engine. Its development process however, took more than 18 years.

Cryogenic engines are more efficient than their conventional alternatives, but imply more complex designing techniques because of low temperatures affecting the structure of components.

Besides replacing the 3rd stage’s motor, there will also be small structural modifications for inferior stages of the launcher for performance improvement.

But let’s come back to Mangalyaan.
GSLV not being ready in time, ISRO was forced to use the PSLV rocket (much modest in terms of lift-off performances and theoretically inadequate to the flight of Mangalyaan). Because of this, the engineers had to re-design the entire mission. After launching, the satellite had to do a series of intermediate maneuvers around the Earth for increasing the orbit’s apogee before following a transfer trajectory to Mars. Because of the ‘weak’ start, the entire transfer scenario was spread over 10 months (with the arrival to Mars on September 2014).

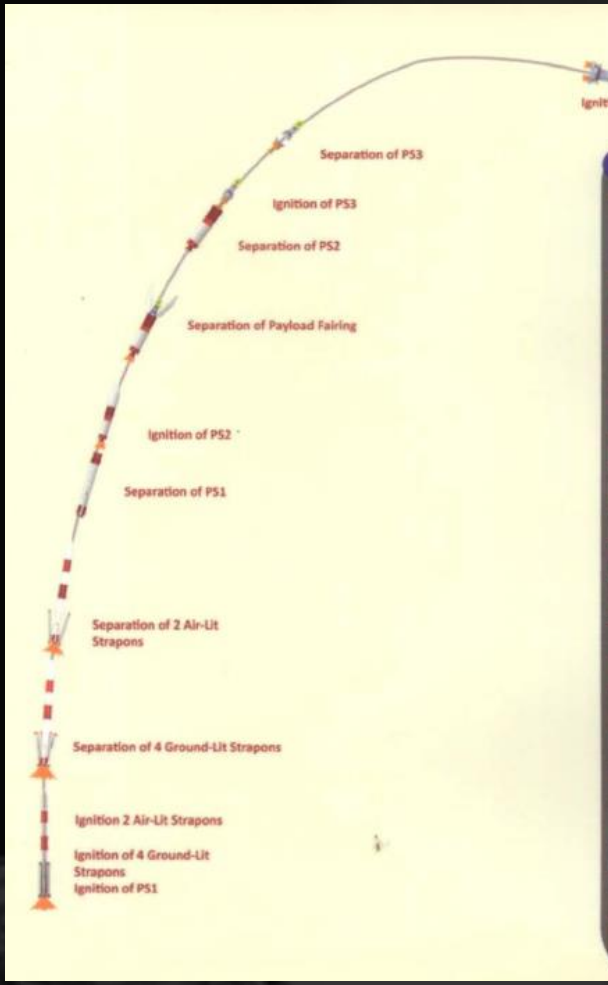
The small budget and the short time for preparation of the mission were major problems. Even though the platform was mainly inspired by the Chandrayaan 1 Moon mission, inheriting a number of components, still the satellite had to be designed and built in approximately one year, at a very low price, without any prior experience in exploring the red planet, with a more-or-less improvised launching.

Some questions were inevitable from the beginning, starting controversies on the project: what are the chances of success for a mission like this? Which are the reasons that forced the space agency to hurry up and is this kind of mission justified in a state in which 350 million people live in extreme poverty?

Finally, on the 5th of November 2013, at 09:08 GMT, India managed to successfully launch their first red planet mission from the Satish Dhawan Space Center, aboard the PSLV (Polar Satellite Launch Vehicle) rocket.
The launch of Mangalyaan, right after a couple of years ago ISRO, the Indian space agency, successfully operated the Chandrayaan satellite around the Moon, indicated India’s long term planetary exploration ambitions.

With that flight, the Indian rocket achieved a rate of 23 successful launches and 63 satellites (28 Indian and 35 foreign satellites) placed on orbit.
The same PSLV carried Chandrayaan in October 2008 and succeeded in placing the satellite on an elliptic trajectory of 255 km x 22860 km around the Earth, from where it could easily be maneuvered to the Moon.

Unlike Chandrayaan, due to the longer transfer distance that the satellite must face in order to reach Mars, Mangalyaan would have been required a more important delta-v at launch, but the PSLV delivered maximum that it could have done.




**PSLV - C25 Flight Events for Launch on 5th Nov. 2013**

| Events | Time (s) | Local Altitude (km) | Inertial Velocity (m/s) |
|---|---|---|---|
| RCT Ignition | -3.00 | 0.024 | 451.89 |
| PS1 Ignition | 0.00 | 0.024 | 451.89 |
| PSOM XL 1,2 (GL) Ignition | 0.46 | 0.024 | 451.89 |
| PSOM XL 3,4 (GL) Ignition | 0.66 | 0.024 | 451.89 |
| PSOM XL 5, 6 (AL) Ignition | 25.04 | 2.670 | 611.52 |
| PSOM XL 1,2 (GL) Separation | 69.94 | 23.489 | 1431.80 |
| PSOM XL 3,4 (GL) Separation | 70.14 | 23.618 | 1436.54 |
| PSOM XL 5,6 (AL) Separation | 92.04 | 39.704 | 2024.36 |
| PS1 Separation | 112.75 | 57.678 | 2387.67 |
| PS2 Ignition | 112.95 | 57.846 | 2387.16 |
| CLG Initiation | 117.95 | 61.955 | 2415.46 |
| Payload Fairing Separation | 201.75 | 113.169 | 3624.69 |
| PS2 Separation | 264.74 | 132.311 | 5379.33 |
| PS3 Ignition | 265.94 | 132.531 | 5378.94 |
| PS3 Separation | 583.60 | 194.869 | 7730.88 |
| PS4 Ignition | 2100.50 | 271.317 | 7642.04 |
| PS4 Cut-off | 2619.72 | 342.515 | 9833.49 |
| Mars Orbiter Separation | 2656.72 | 383.388 | 9804.01 |

The PSLV's C25 flight lasted 44 minutes and 26 seconds (the separation time of the satellite). Most of it was monitored, with a short period of interruptions during the orbital parking after the activation of the 3rd stage and when the rocket leaved the field of view of the Indian ground stations. Two ships anchored in the South of the Pacific have taken over the critical part of the flight - the fourth stage activation signal and then the separation of the satellite.

Despite a small deviation from the plan (the third stage left the rocket on a slightly higher than expected trajectory), in the end (due to the automated corrections of the fourth stage) the separation orbit was close to the desired one (within the accepted limits), respectively 261 km x 23927 km x 19.42 degrees inclination instead of 239 km x 23499 km x 19.2 degrees inclination.

A few critical events followed shortly for the Indian mission: deploying the solar panels to supply power for the platform, activation of the transponder and the establishment of a stable communication with the ground stations. All were correctly executed by the onboard computer, this being confirmed in telemetry by the ground stations.

Soon, the Indian engineers started the execution of the post-launch check procedures for all the spacecraft equipment, in preparation of the six orbital maneuvers that had to follow the launch and which were supposed to progressively modify the orbital apogee and the inclination.

At the end of this period, on the 1st of December 2013, Manglayaan was supposed to leave the elliptic orbit around the Earth and to be placed on a hyperbolic transfer orbit towards Mars.

Unfortunately, as we mentioned already several times, due to the weak orbital injection, the flight to Mars was designed a bit longer than usual (from 1st of December 2013 until 24 September 2014, approximately 10 months).

Mangalyaan, targeting Mars, needed a speed boost much larger than that of PSLV.

India’s large launcher, GSLV, would have been more appropriate for this kind of scenario. However, at the moment of the launch, GSLV was not available in the ISRO’s fleet.

Immediately after its launch, the Indian satellite performed 6 orbital maneuvers which brought it into an elliptical orbit with high eccentricity. The maneuvers were performed on the 6th, 7th, 8th, 10th, 11th and 15th of November.

On the 1st of December, the first Trans Mars Injection was carried out, taking the satellite out from its elliptic trajectory around Earth and placing it on a heliocentric orbit.

Along its transfer from Earth to Mars, Mangalyaan had to make a series of orbital maneuvers (the so called Trajectory Correction Manoeuvers) which would correct any deviation from the optimal trajectory.

A few days later after entering into the heliocentric orbit, on the 11th of December, one of the first four Trajectory Correction Maneuvers was performed with the final purpose of placing the satellite in a stable orbit around Mars. The correction was short, lasting only 40 seconds.

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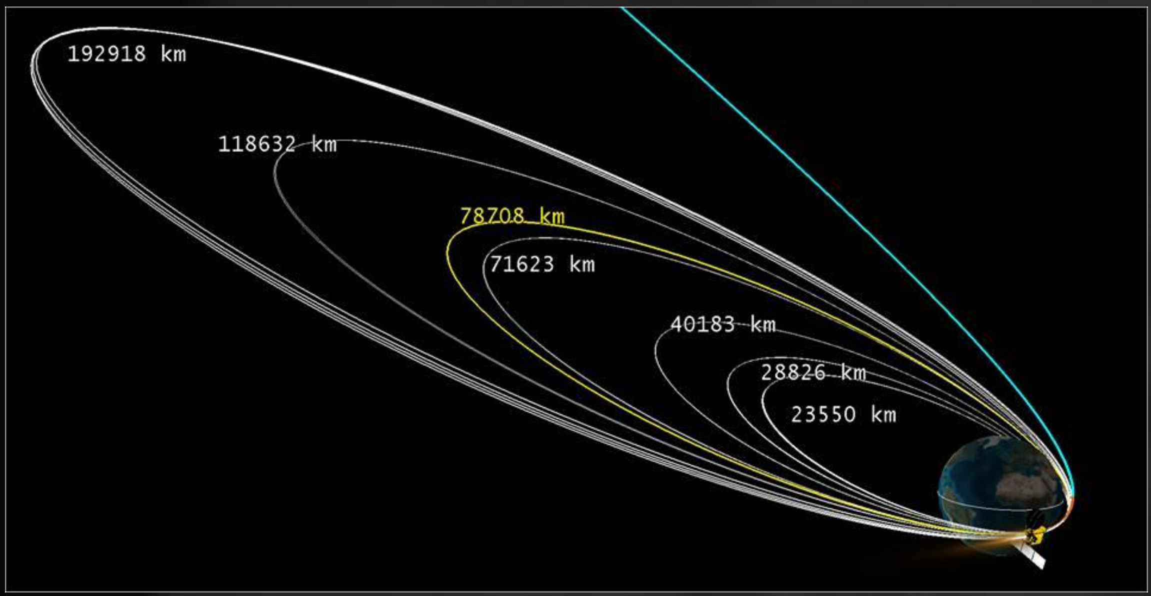
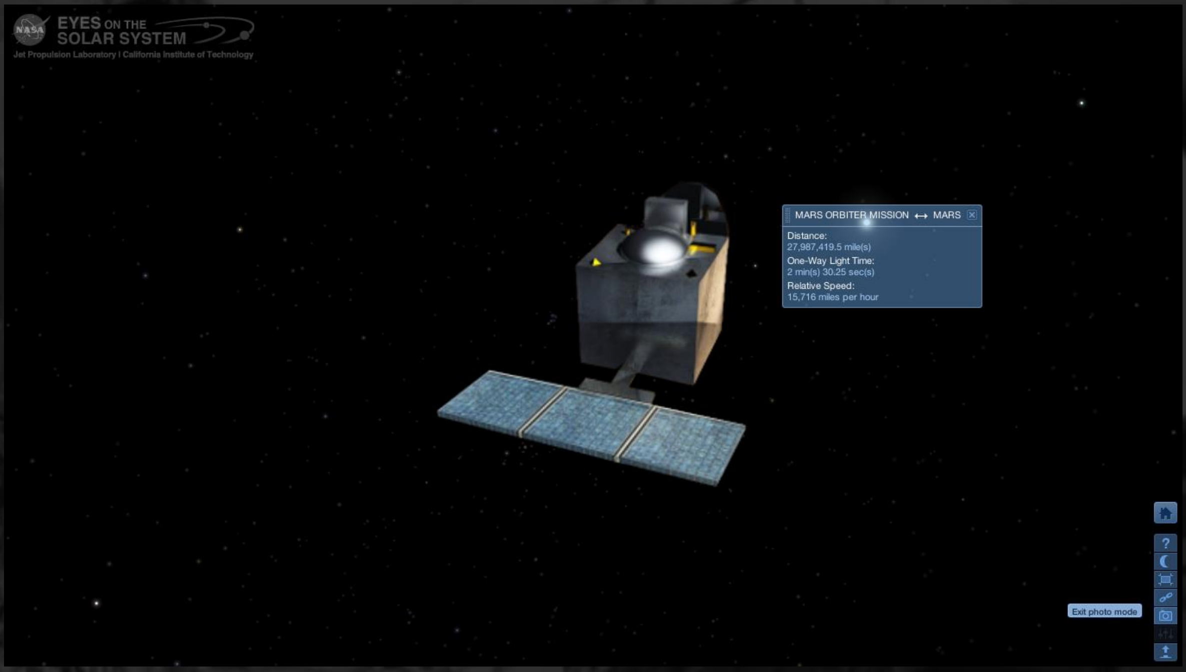



The second TCM maneuver was planned for April – however trajectory measurements showed that Mangalyaan was on the desired orbit and thus ISRO chose to delay it until June. This was a bonus for the mission, which could save some fuel. Finally the TCM took place on 11th of June.

By the beginning of May 2014 Mangalyaan had already travelled more than half the distance to Mars. At that time the satellite was 27.9 million miles away from Mars and 37.5 million miles from Earth, approaching Mars with a speed of 15.7 miles per hour.



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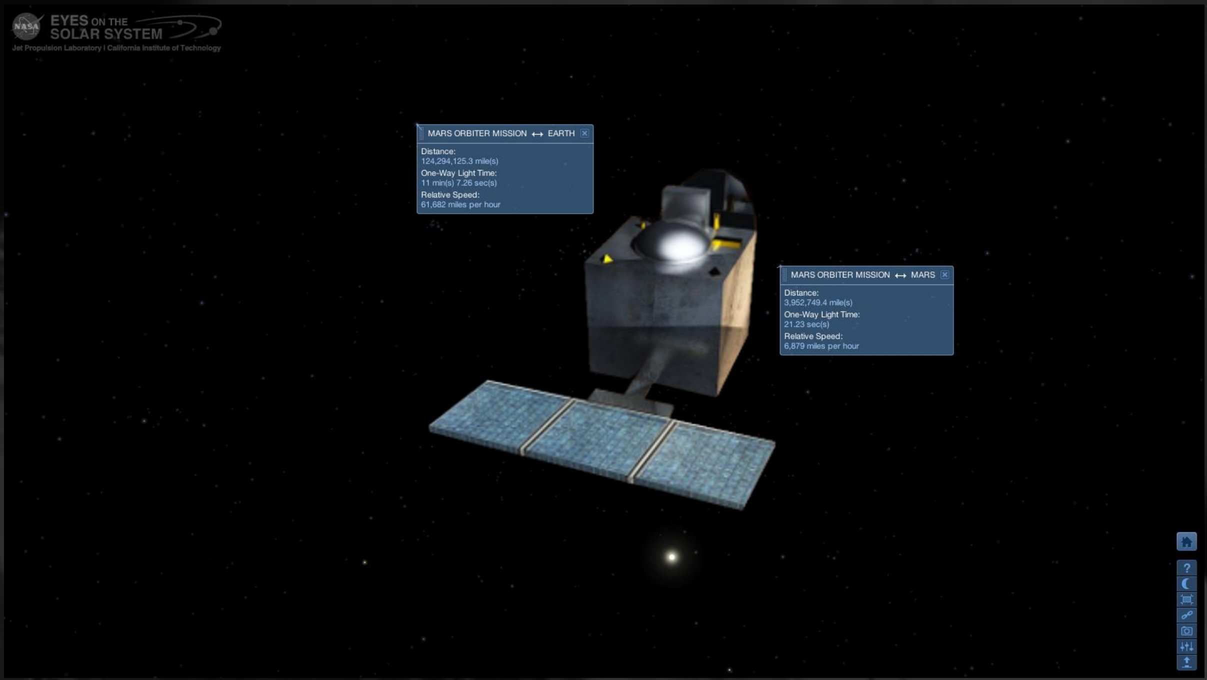
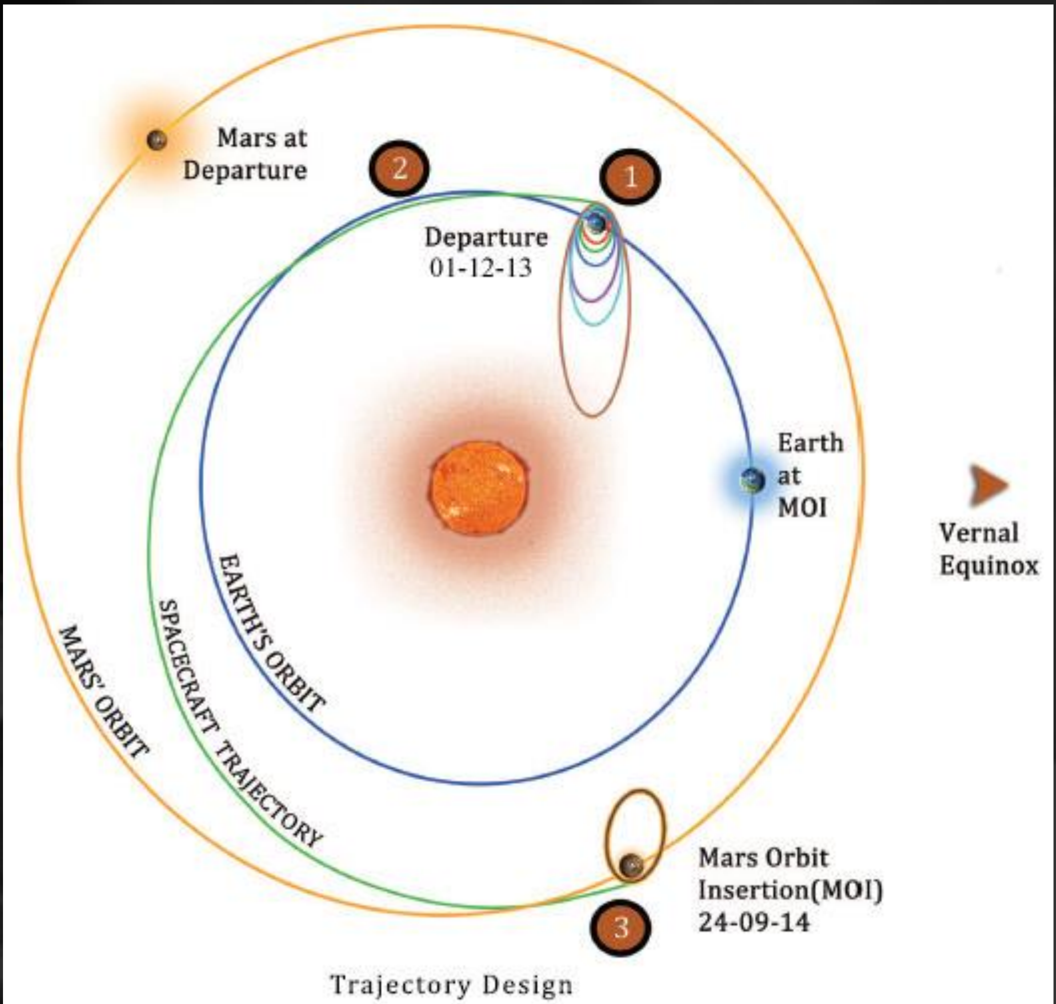
ISRO was maintaining communications with the satellite on a regular basis with the help of its DSN ground stations, but also with technical support from NASA. The on board equipment was continuously monitored in order to prevent any possible anomaly. The position of the probe in space was also measured precisely by using the so-called Delta DOR (Delta Differential One-way Ranging) technique, developed for interplanetary missions.

In August 2014 Mangalyaan came close to its target. Other two TCM actions were expected for August and September, preparing the final insertion in a stable orbit around Mars. The August maneuver was, however, cancelled, since the trajectory was found to be perfectly aligned. At the beginning of September another measurement was carried out, which could possibly lead to another, final maneuver on the 14th of September.




Communication with the satellite is facilitated both by IDSN (Indian Deep Space Network) and by NASA stations.
One month away from its final destination Mangalyaan used approximately 65% of its 850 kg of hydrazine. 290 kg of fuel remained for the final and most important part of the mission – when the satellite was supposed to enter in a stable orbit around Mars. The designed Mars operating lifetime is no less than 160 days (like it was announced from the beginning), but this could easily be extended far behind this if the SC health would be ok later on.

On the 24th of September it was the culminating point of Mangalyaan's interplanetary mission, when the MOI (Mars Orbit Insertion) maneuver had to take place. Early estimates showed that 240 kilograms of fuel were needed for this maneuver and thus only 50 would have remained for maintaining and correcting the orbit (an elliptic 365 km x 80000 km x 150 degrees of inclination).
The error margin was, therefore, minimal and the propulsion and stabilization systems had to function perfectly in order to have a successful maneuver.



Trajectory Design

Mangalyaan is built on a platform similar to that of Chandrayaan-1 and inherits lots of technical systems which have proven their reliability throughout time. For example, the LAM orbital engine (Liquid Apogee Motor) which develops 440N, is the same that equips ISRO's geostationary satellites.

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Operating on a mix of UDMH and MON3, it is very flexible, operating in a variety of conditions – larger temperature, fuel pressure and fuel/oxidant concentration ratio range. Although it is only qualified for inactivity periods of up to 30 days (which is a typical demand for GEO satellites moved to their orbital slot shortly after launch), it proved that it can go far beyond these limits when it executed on the Chandrayaan-1 mission, a maneuver 209 days after the previous activation.

For MOM, however, the requirements were even more stringent, since the LAM orbital engine had to be activated after 297 days of pause. In order to avoid any technical problems, the whole fuelling system (including the pipes) was doubled by Indian engineers. It must be said that LAM is assisted by eight smaller motors, of 22 N each, which is part of the stabilization system (Attitude Control System). Although their purpose is to maintain the correct position of the satellite, they can also be used for orbital maneuvers in emergency cases. Hence, they were the ones to carry out the TCM correction maneuvers.

Mangalyaan was not alone at Mars at the time of the MOI. Just 3 days earlier, on the 21th of September 2014, Maven, NASA's latest Mars exploration mission reached the red planet. Although it was launched 2 weeks later than Mangalyaan (18th rather than the 5th of November), its interplanetary transfer was quicker because its initial orbital injection was better (Maven was launched by an Atlas 5 rocket while Mangalyaan only had a PSLV rocket at its disposal).

MOI (Mars Orbit Insertion) took place on Wednesday, September 24th at 01:47 GMT. For approximately 24 minutes the main orbital engine had to brake, slowing the spacecraft to a level of speed at which it is captured in a Martian orbit. The red planet's gravitational attraction affects objects at up to 573473 km from its surface.

This was a critical maneuver, in which the speed had to drop to 1098 m/s, with no safety margin: a too low deceleration would have caused the probe to miss the capture point and to go into deep space escaping Mars, while too much braking could cause even the crash of the probe on the planet's surface.

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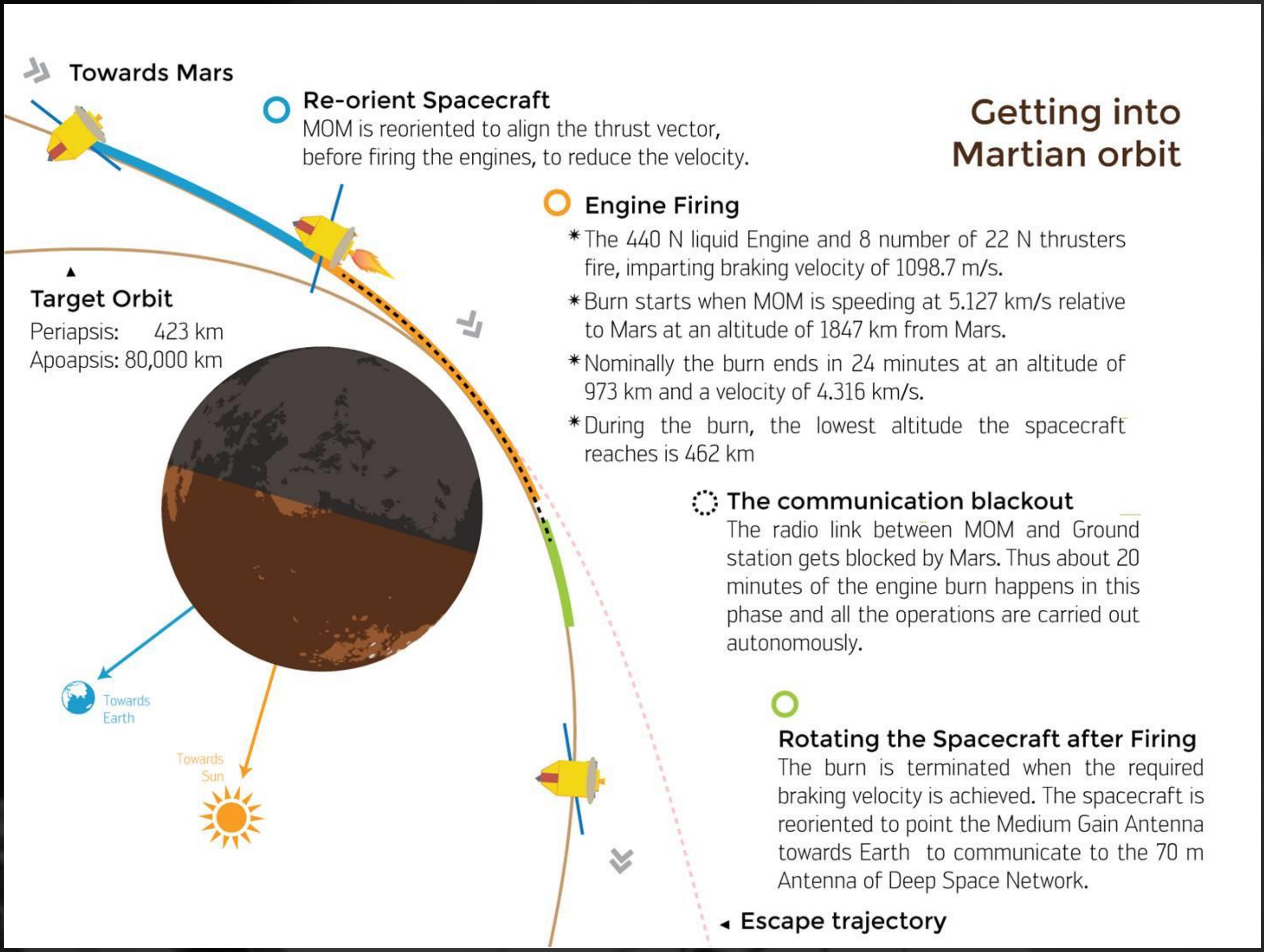



Every other intermediate scenario could lead to a different trajectory than the one Indian engineers designed. This means untested limits for the satellite and such, a risky situation.

As such, Mangalyaan's AOCS System (altitude and orbit control) had very little tolerance for this maneuver.

In fact, Mars by itself is a hard to reach destination, for any space mission; from 1960 until now, out of 51 mission sent there, 58% failed. Neither USA nor URSS succeeded on their Mars attempts from the first try.

This was a big bet for India: a success would transform India in the first Asian nation and the first country in history to have a Martian mission successful from first try.
Even more outstanding if we take into account the fact that ISRO has managed to build the Mangalyaan mission with a budget of 4.5 billion rupees (almost 45 million dollars). This is more than ten times lower than the budget allocated for Maven, NASA's newest satellite orbiting Mars since September 22th, which had a budget of 671 million dollars.

Although that means a budgetary effort of less than 7 cents per citizen, the project has been highly contested, especially as the Indian poverty rate is at an alarming state (a third of the population doesn't have electricity and about a half doesn't have a WC).
The ISRO management has been accused of playing politicians' games, trying to focus public opinion on a false national proud sentiment. However, after the 2014's spring elections, when the BJP Party has won the majority of seats in the Parliament, and Narendra Modi was chosen as prime-minister, the nationalist direction has increased. Thus, the New Delhi Government has promised to focus in the next years on industrialization and consolidation of the country status as a regional power.

India, as well as other nations from Asia (especially its direct competitor, China), treats the investments in space technology as a priority axis which can accelerate the country's development. We must also take into account the first Chinese mission to Mars, which took place no more than four years ago. In 2011, the Russian satellite Phobos-Grunt was launched using a Zenit rocket with the Red Planet as destination. On board there was also Yinghuo-1, the first interplanetary Chinese mission. Unfortunately, we can remember what happened and all the following events which finally lead to the mission's failure.

Back to Mangalyaan (a.k.a. MOM - Mars Orbiter Mission), it reached its destination after a journey of 670 million kilometers, spread over 10 months.

Mangalyaan orbited the Earth six times, increasing the altitude of the orbit progressively using Hohmann transfer, before being accelerated by the orbital engine LAM, after a TMI (Trans Mars Injection) maneuver, taking 1328 s and with a total delta-v of 647.9 m/s, a sufficient speed to escape the gravity of the Earth and to enter a heliocentric trajectory towards Mars.

During the interplanetary transfer, four other TCM maneuvers (Trajectory Correction Maneuver) had to be done to correct the satellite's course, the last of them taking place on September 22th. The TCM 1, 2 and 3 maneuvers (accomplished with the small attitude correcting thrusters) have been already mentioned.

TCM 4 was due to take place in the middle of August, but it was delayed because the satellite was already in the right trajectory. ISRO had preferred to do the last correction as closer as possible to the destination, because it had a double goal, besides the physical correction of the trajectory: testing the automatic sequence of the maneuver (the on-board computer controlled the maneuver 100%) and testing the performance of the main LAM engine (orbital correcting engine - unused since 2013).

The test was successful, the LAM engine managing to modify the satellite's speed, after an activation of 3.9 seconds, at 2.18 m/s. Had the maneuver been unsuccessful, ISRO had also the option to try to use the secondary engines, with a maneuver of smaller amplitude, but started early and taking more time.

| Date | Name | Duration (s) | Thruster |
|---|---|---|---|
| 6.11.2013 | ORM 1 | 46 | Orbital thruster (LAM) |
| 7.11.2013 | ORM 2 | 570.7 | Orbital thruster (LAM) |
| 8.11.2013 | ORM 3 | 707 | Orbital thruster (LAM) |
| 10.11.2013 & 11.11.2013 | ORM 4 | ? | Orbital thruster (LAM) |
| 15.11.2013 | ORM 5 | 243.5 | Orbital thruster (LAM) |
| 01.12.2013 | TMI | 1328 | Orbital thruster (LAM) |
| 11.12.2013 | TCM 1 | 40.5 | Attitude thrusters |
| Suspendata | TCM 2 | - | - |
| 12.06.2014 | TCM 3 | 16 | Attitude thrusters |
| 22.09.2014 | TCM 4 | 3.9 | Principal thruster (LAM) |
| 24.09.2014 | MOI | 1453.8 | Orbital thruster (LAM) for the maneuver + attitude thrusters for orientation; in case of an anomaly the attitude thrusters can cover a part of the maneuver's delta-v |

ORM = Orbit raising maneuver
TMI = Trans Mars Injection
TCM = Trajectory Correction maneuver
MOI = Mars Orbit Insertion

But let's take a look at what happened Wednesday, on September 24th. In the following table you can see the timeline of the events:

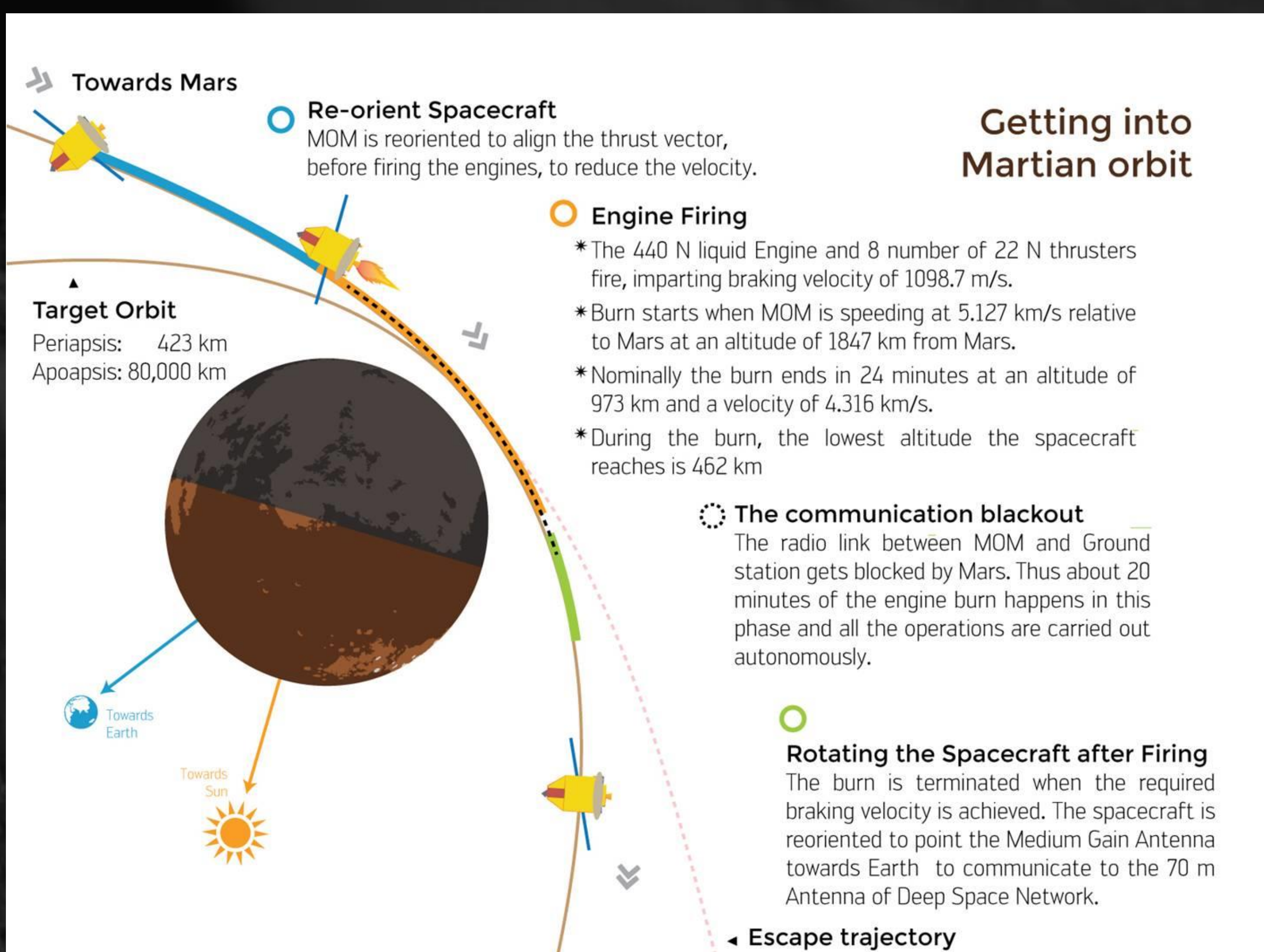
| Time | Event |
|---|---|
| MOI -03:00 | HGA-MGA (high/medium gain antenna) transition |
| MOI -00:21 | Rotation of the satellite against the flight direction and preparation of the maneuver (RWL) |
| MOI -00:05 | Begining of the eclipse |
| MOI-00:03 | Attitude control using the attitude thrusters |
| MOI | Activation of the orbital thruster |
| MOI+00:04 | Start of the Mars occultation |
| MOI+00:05 | Stop of the telemetry data |
| MOI+00:12.5 | Ground confirmation for the start of the maneuver (because of the Earth-Mars direction, the delay of the signal is aproximately 12 minutes) |
| MOI+00:19.4 | Stop of the eclipse |
| MOI+00:24.23 | De-activation of the orbital thruster (end of the maneuver) |
| MOI+00:25.73 | Start of the satellite rotation, back to the nominal flight direction |
| MOI+00:27.78 | End of the Mars occultation |
| MOI+00:30.43 | Start of the telemetry data<br>Ground stations Doppler measurements for the evaluation of the maneuver (satellite's post-maneuver position) |
| MOI+00:35.23 | End of the satellite rotation, back to the nominal flight direction |

If we compare again the mission with Maven, we will see that the ISRO strategy was completely different of NASA's one, taking higher risks. First of all, Maven's propulsion system used parallel thrusting (more thrusters used simultaneously, so it was hard for the satellite to miss the trajectory towards Mars gravity sphere), while Mangalyaan had a single "point of failure" - the main LAM engine. However, in case of an anomaly, the secondary engines can step in and cover a part of the needed delta-v (but because of the weak performance and little time, their effect is marginal).

Secondly, Maven was visible permanently to the ground station and in the sunlight, so the engineers had the possibility to manually step in at any moment (although this is difficult in an interplanetary mission, which implies by definition delays in commanding and telemetry).

Mangalyaan did not have this possibility and the ISRO engineers were simple spectators of the actions taken by the onboard computer.
On the other hand, the Indian spacecraft's orbit is more tolerant, because we are talking about a final trajectory with the characteristics of 423 km x 80000 km x 150 degrees inclination, an almost equatorial trajectory, as opposed to a polar one.
During the maneuver, Mangalyaan was watched by the ground stations Canberra and Goldstone part of the American network DSN, but also by the Indian station Bangalore part of the ISDN network.

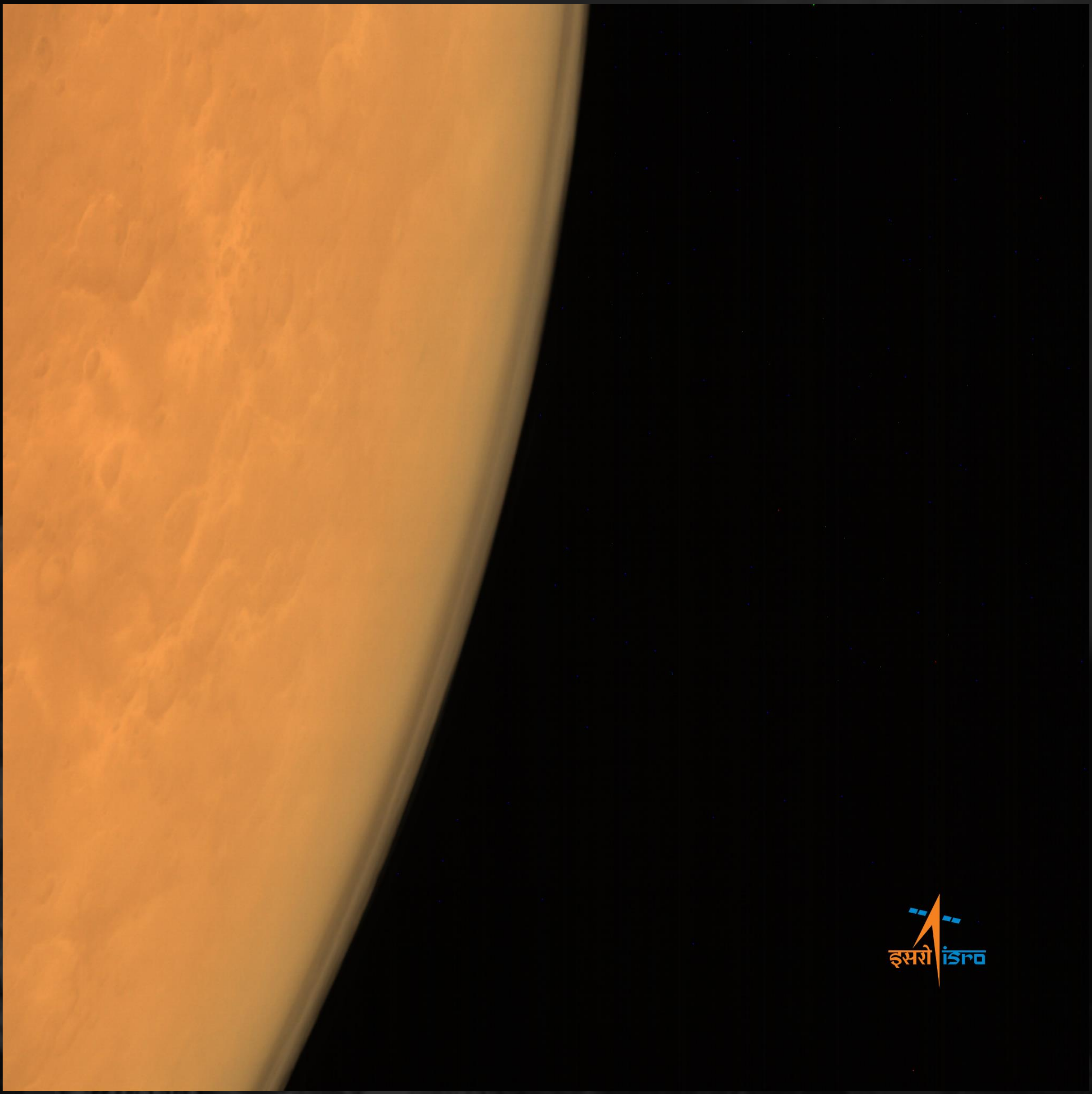
But this time, the history was on the side of the courageous ones. After this complex, 24 minutes long, MOI maneuver on 24th of September, Mangalyaan braked at a rate of 1098m/s and was successfully placed in a stable orbit around the red planet, thus making India the first nation to put a satellite on Mars' orbit from the first attempt.



At the beginning of October 2014 ISRO space agency has made public the first images of Mars, as taken by MCC (Mars Color Camera) on board the satellite Mangalyaan.

The first images delivered by Mangalyaan, were made by the MCC camera. The resolution was not outstanding, because MCC is not a scientific precision instrument, but just an auxiliary one that should give ISRO the possibility of observing Mars in the visible spectrum and to complete the results obtained by the other scientific instrumentation.

The satellite's own orbit (372 km x 80000 km x 150 degrees) is as well not an optimal one for these kind of observations, because of the altitude variation, the resolution varying between 19.5m and 4km.

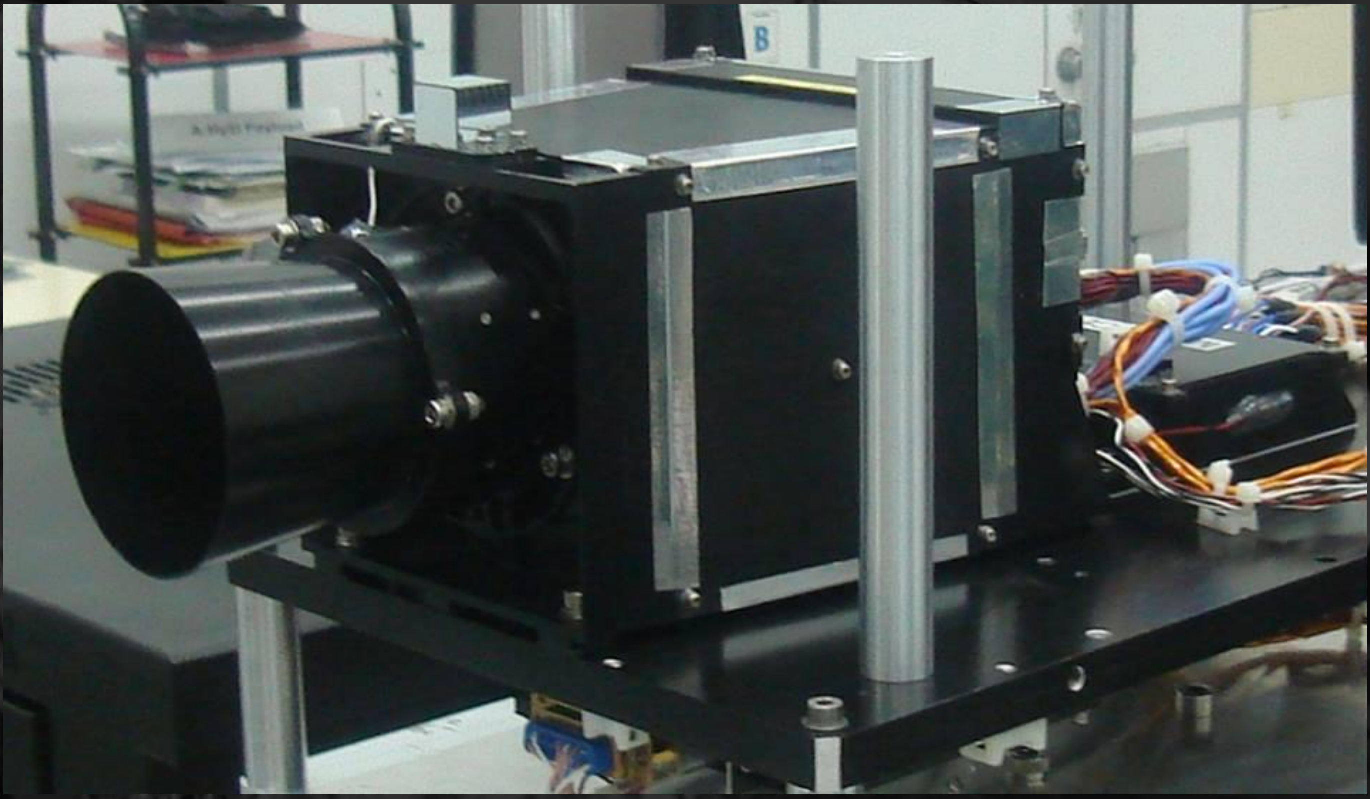


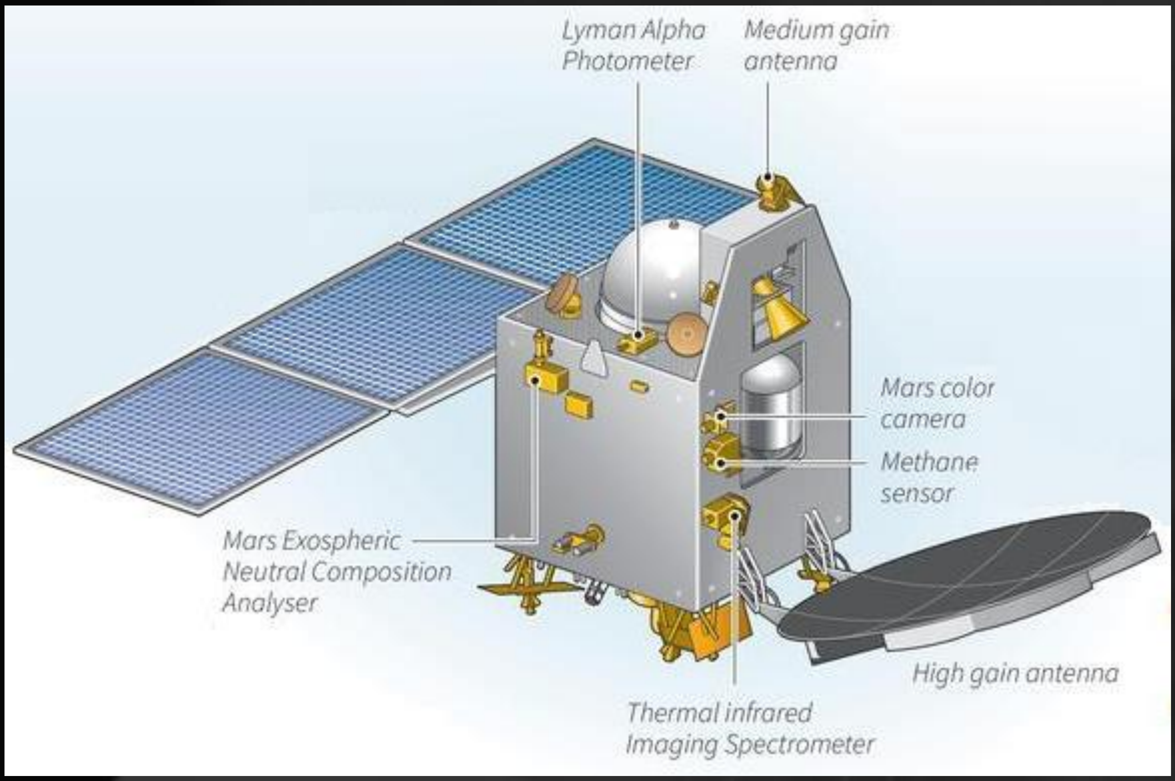
In addition, the camera is equipped with a medium resolution sensor (2024 x 2024 pixels, each pixel having a size of 5 x 5 µm), covered by a Bayer/RGB filter capable of detecting light radiation with wave lengths between 0.4 and 0.7 µm. Thus, by post-processing, the Indian engineers can get color images of the Martian surface.

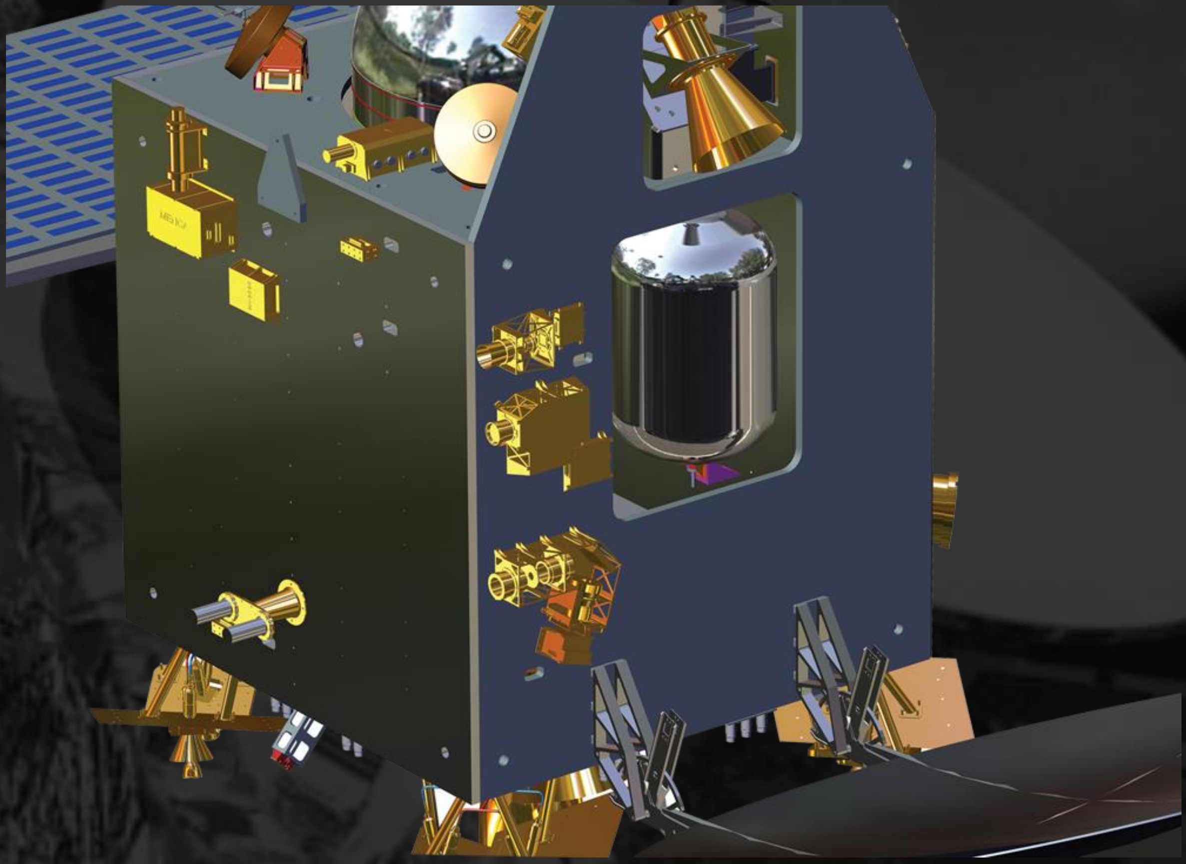
The optical component is fairly simple, but the SW adds a little bit more capabilities, through 16 different exposure modes, depending on the observational scenario.

MCC was designed to:

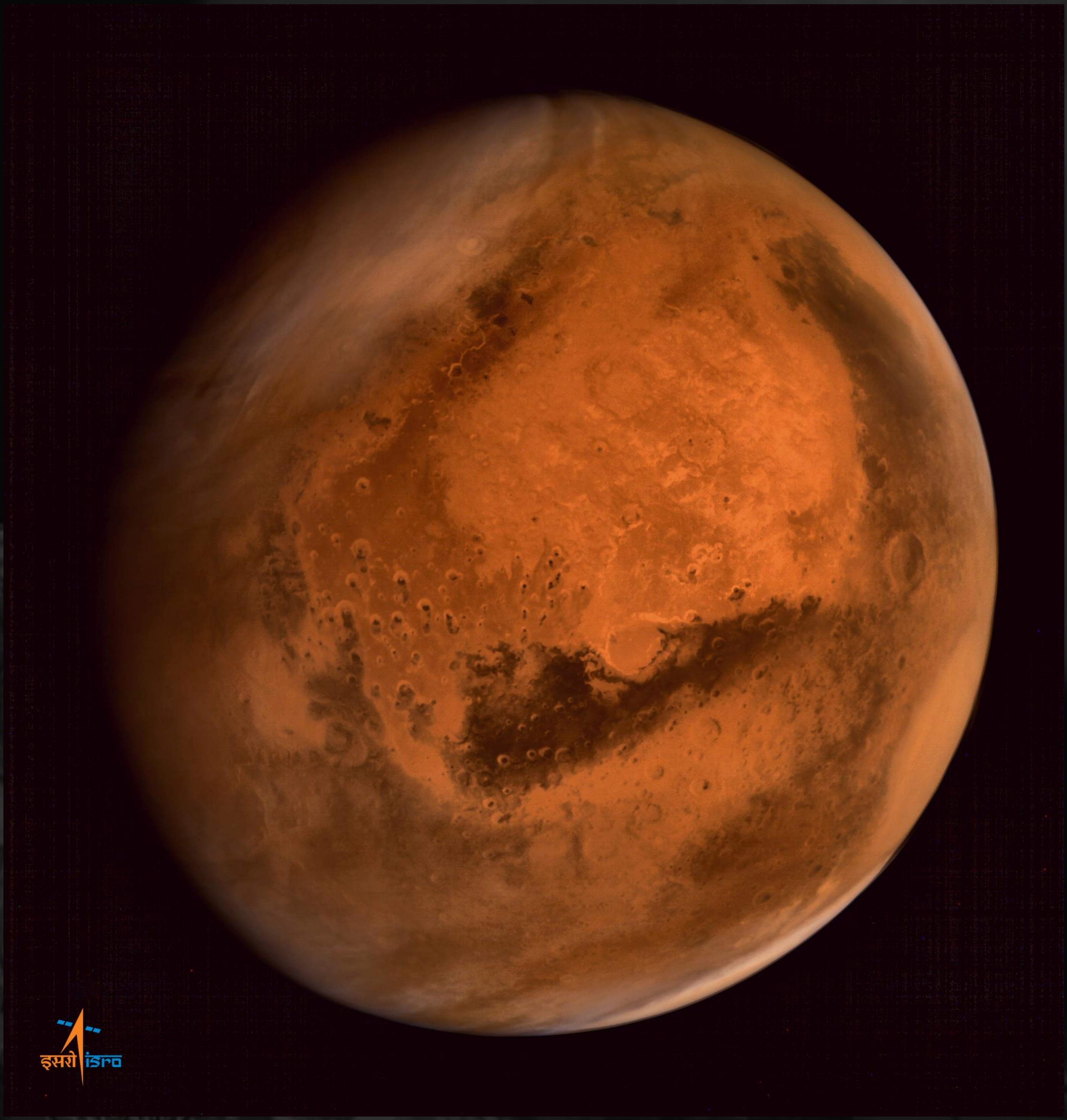
- Observe mountainous regions, craters, vales, volcanoes and sediments on the planet surface
- To investigate, geologically speaking, metal-rich regions which are discovered by other tools
- To study seasonal variation of ice caps
- To monitor the dynamics of Martian sand storms
- To realize visual observations of other targets not related with the planet (ex: comets that have a close trajectory to Mars or Phobos)
- To provide additional information which complete the results of other onboard instruments



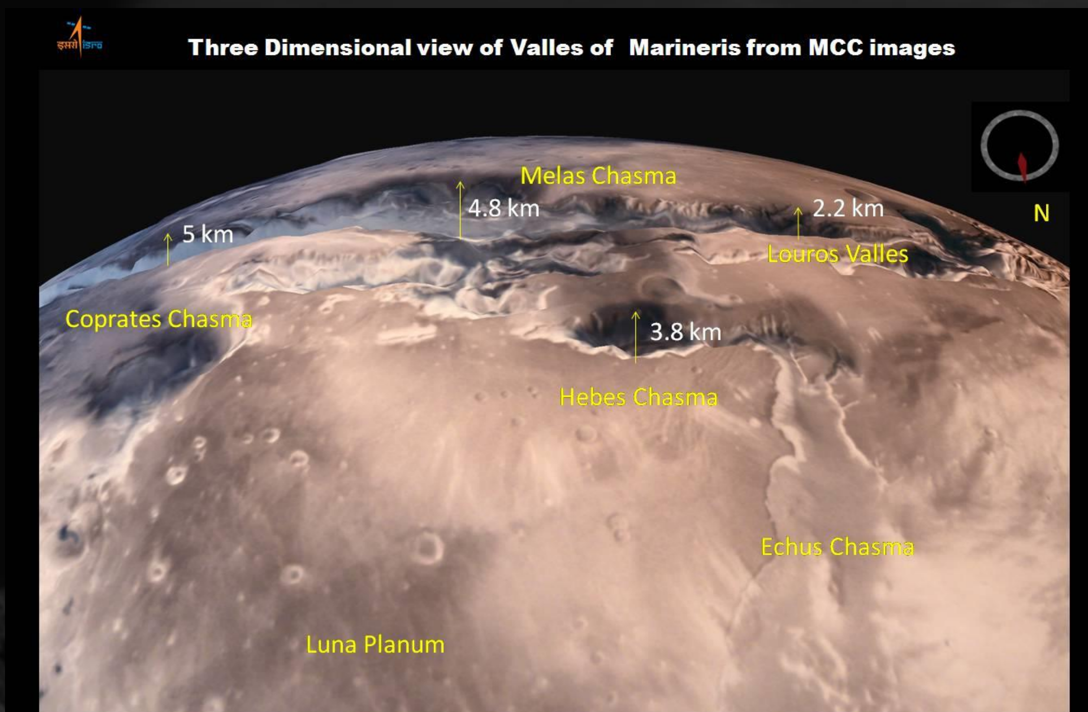

Lyman Alpha
Photometer
Medium gain
antenna
Mars color
camera
Methane
sensor
Mars Exospheric
Neutral Composition
Analyser
High gain antenna
Thermal infrared
Imaging Spectrometer



On the 19th of October, both Mangalyaan and Maven witnessed the Siding Spring comet passing 132.000 km away from the surface of the planet, having the possibility to capture photos from close by.



On 24th of March 2015, MOM completed the first six month of operation at Mars. All the instruments are performing well and there is still additional 37 kg of hydrazine left for attitude maneuvers (in normal conditions, enough for some extra years). As a result ISRO decided to extend the official mission lifetime with additional six months.




Three Dimensional view of central portion of Valles Marineris on Mars taken by Mars Colour Camera. Highs and lows of the canyon are depicted in this image

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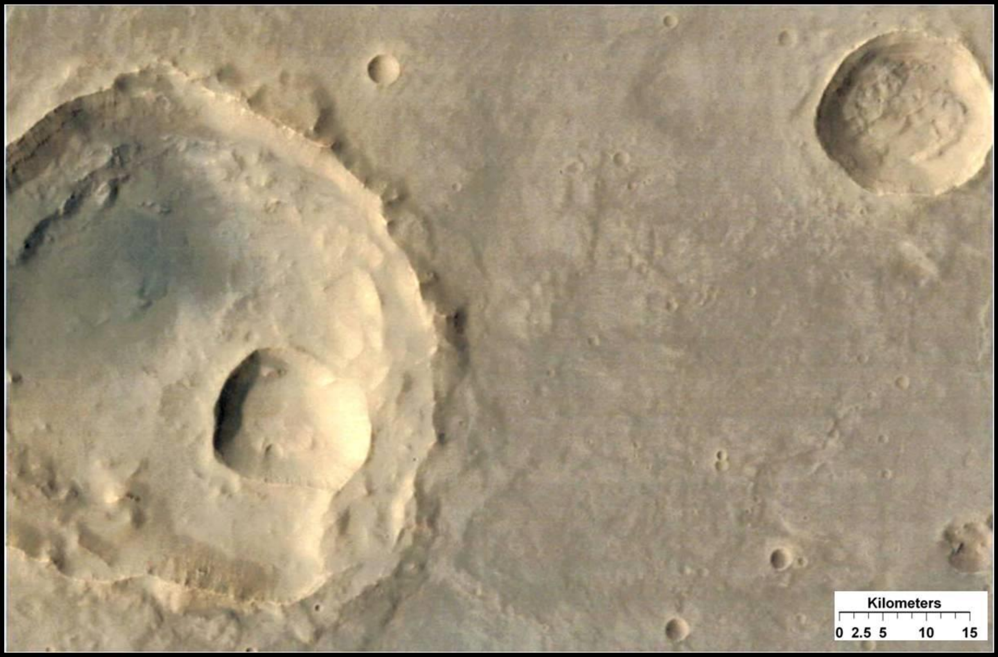
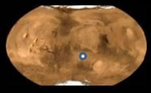
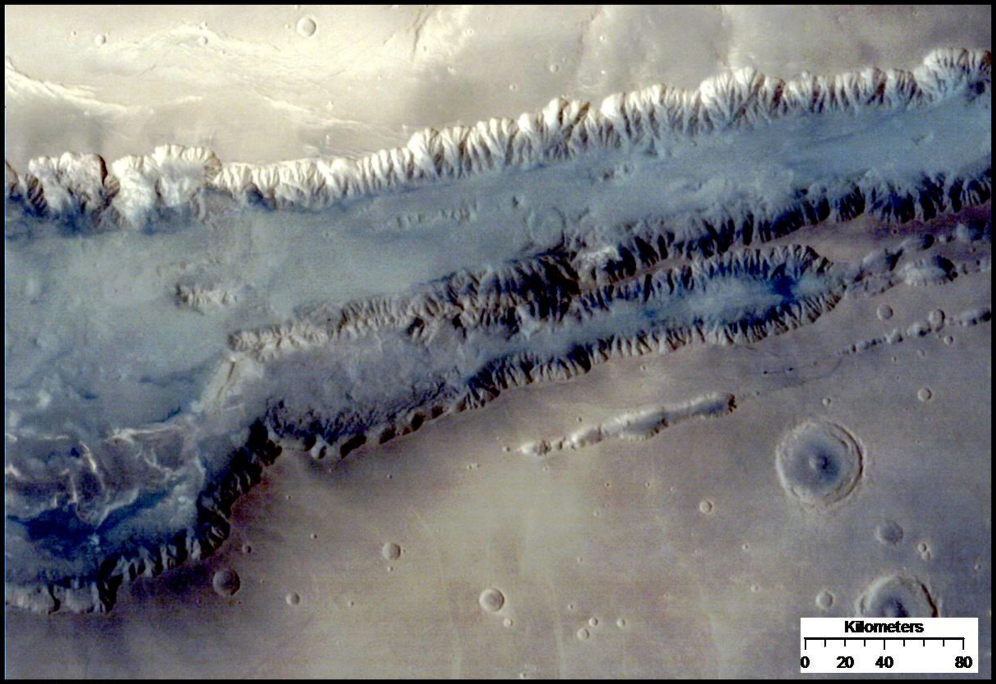
## High Resolution image of Super Imposed Impact Craters on Mars

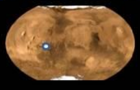


High resolution image of an impact crater taken by Mars Colour Camera on board Mars Orbiter Mission on 19-02-2015 at a spatial resolution of ~19 m from a altitude of 366 km. This image brings out details of floor and rim of a larger impact crater located at right side of image. This image shows smaller craters superimposed on larger crater implying smaller craters are younger than larger crater.

## Higher resolution view for part of Valles of Marineris



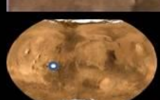



Images of the central portion of Valles Marineris of Mars taken by Mars Colour Camera on 28-01-2015 at a spatial resolution of 300 m from an altitude of 5797 km. Wall of the canyon are clearly seen in this image. At this time of martian year valley is mostly filled by dust haze as seen in this image.

From 6 to 22 of June, the Mars orbit will bring the spacecraft behind the Sun thus a communication blackout will occur. The Indian engineers are preparing for this event, safely commanding the satellite for autonomous operations during this period.

Meanwhile ISRO has announced the plans for a mission follow up called Mangalyaan 2, which should also include a lander and a rover.

**Mars Orbiter Mission (MOM) views the Valles of Marineris : A Large Martian Canyon**

Images of Valles Marineris and adjoining regions of Mars taken by Mars Colour Camera on board Mars Orbiter Mission on 05-12-2014 at a spatial resolution of 1.2 km from an altitude of 24000 km. Valles Marineris is largest canyon system about 4000 km and 200 km wide and 7 km deep.

**Credit ISRO**

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