RocketSTEM

Vol. 5 • No. 1 • March 2017 • Issue 14

Rebirth of historic Launch Pad 39A

Falcon Heavy nearing debut

Dawn reveals secrets of Ceres

SpaceX's plan to colonize Mars

Mars is becoming a crowded planet

Follow us online:

facebook.com/RocketSTEM

twitter.com/rocketstem

www.rocketstem.org

All of our issues are available via
a full-screen online reader at:

www.issuu.com/rocketstem

Editorial Staff
Managing Editor: Chase Clark
Astronomy Editor: Mike Barrett
Photo Editor: J.L. Pickering

Contributing Staff
Mike Barrett • Laurie Bonneau
Lloyd Campbell • Chase Clark
Loretta Hall • Rich Holtzin
Cole Jetton • Julian Leek
Dan Leppold • Sebastian Kings
Meha Magesh • Joe Maness
Mavesa Nguyen • Igor Rozenberg
Chris Starr • Aurthur Thomas

Other Contributors
Dick Clark • Joe Kowsky
Kim Shiflett

RocketSTEM • March 2017
Vol. 5 No. 1 Issue 14 (ISSN: 2326-0661)

RocketSTEM Media Foundation, Inc.
38 S. Blue Angel Parkway, PMB 313
Pensacola, Florida 32506

email: ***info@rocketstem.org***

Outside Cover: *A SpaceX Falcon 9 rocket is perched atop the historic LC-39A launch pad – the same spot from where the Apollo 11 was launched in 1969. Credit: SpaceX*

This Page: *Artist's illustration of Kennedy Space Center from the 1960s showing the plan for Launch Complex 39 with three launch pads. The northernmost pad was never built. Credit: NASA via Retro Space Images*

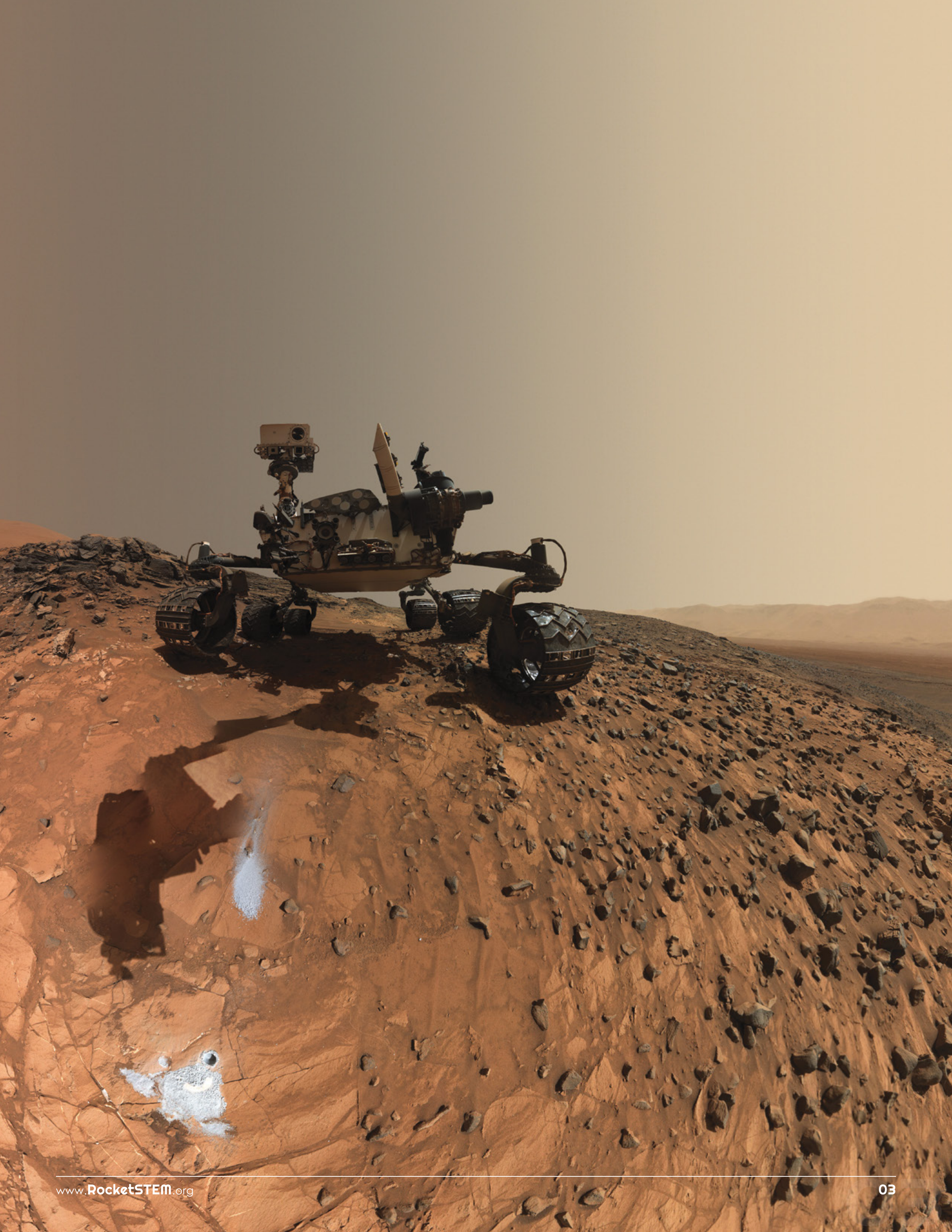
Inside the
MAGAZINE

Also Inside:

Spotlight on Mars:

RECORD NUMBER OF MISSIONS AT THE RED PLANET

This low-angle self-portrait of NASA's Curiosity Mars rover shows the vehicle in the "Marias Pass" area of lower Mount Sharp. Credit: NASA/JPL-Caltech/MSSS



By Chris Starr FRAS FBIS

So, the 'Great Galactic Ghoul' strikes again? This tongue-in-cheek entity is invoked by NASA scientists and engineers when missions experience difficulties, especially at Mars. After a seven month journey for ESA's first ExoMars mission, contact with its Schiaparelli Lander was lost just before its scheduled touch-down on 19th October last year, although its Trace Gas Orbiter (TGO) successfully entered into orbit around the Red Planet and is functioning well. However, rather than the work of a cosmic 'gremlin', the apparent loss of Schiaparelli appears to have been due to incorrect data triggering a premature release of the lander's parachute and cutting off its braking thrusters while still some 3.7km above the surface, resulting in a crash- rather than a soft-landing.

Mars has gained a bad reputation in the past, with fewer than half of the 40-plus missions sent there arriving safely and completing their mission successfully, especially in the early days of planetary exploration. Mars is not an easy target, particularly if you wish to land on its surface. Its thin atmosphere requires more than aero-braking and parachutes to slow a spacecraft down sufficiently for a soft landing. This has necessitated the use of thrusters or inflatable air-bags to ensure that landers arrive intact, making for complex automated procedures which have to function perfectly.

However, despite Schiaparelli's silence, ESA's latest orbital emissary joins a growing armada of spacecraft and landers operational at the Red Planet, more than ever before at any solar system body at any one time. These now comprise six orbiters and two rovers. ExoMars' companions have all enjoyed spectacular success in their missions to help us understand present day conditions on Mars, as well as its past evolution.

A brief overview of these missions is given here, while ExoMars 1 is discussed in detail elsewhere in this issue of *RocketSTEM*.

MISSIONS CURRENTLY OPERATIONAL AT MARS AT TIME OF EXOMARS/SCHIAPARELLI ARRIVAL

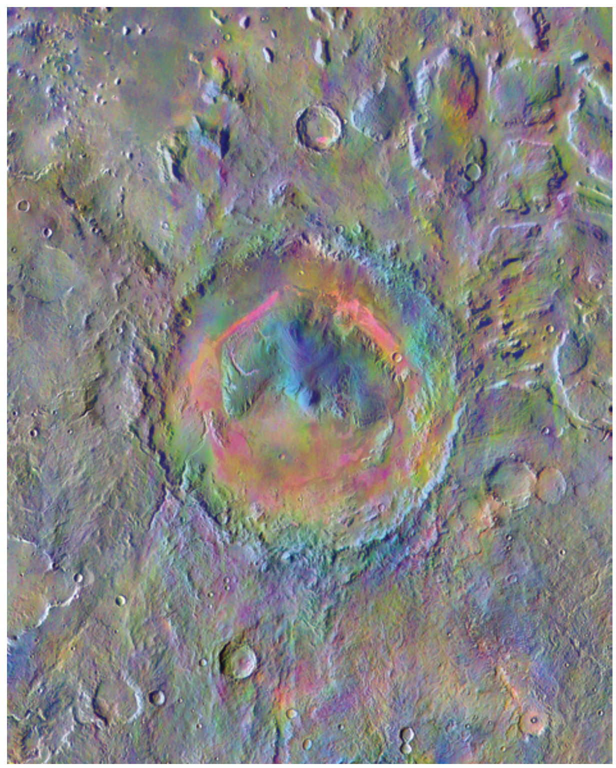
Project	*Launch date*	*Agency*	*Type*	*Remarks*
Mars Odyssey	7 Apr 2001	NASA/USA	Orbiter	Arrival at Mars on 24 October 2001. Expected to remain operational until 2025.
Mars Express	2 June 2003	ESA/Europe	Orbiter	Arrival at Mars on 25 December 2003. Enough fuel to remain operational until 2026.
Opportunity (Mars Exploration Rover-B)	8 July 2003	NASA/USA	Rover	Landed 24 January 2004, using a comination of parachute, thrusters and airbags. Still operating after over 12 years. Its twin, Spirit, also greatly exceeded expectations, but ceased operating in March 2010.
Mars Reconnaisance Orbiter (MRO)	12 Aug 2005	NASA/USA	Orbiter	Arrival in Mars orbit on 10 March 2006.
Curiosity (Mars Science Laboratory)	26 Nov 2011	NASA/USA	Rover	Landed on 6 August 2012, using new sky crane system successfully
Mangalyaan (Mars Orbiter Mission)	5 Nov 2013	ISRO/India	Orbiter	Entered Mars orbit on 24 September 2014 Primary mission completed – extension
MAVEN (Mars Atmosphere and Volatile EvolutioN)	18 Nov 2013	NASA/USA	Orbiter	Orbital insertion 21 September 2014. Mission extended until September 2018.

KEEPING A WATCHFUL EYE – THE ORBITERS

2001 Mars Odyssey

2001 Mars Odyssey has survived longer than any other spacecraft in orbit around a planet other than Earth and is the record holder for longevity among operational planetary missions, after the Voyagers and Cassini. Named 'in tribute to the vision and spirit of space exploration as embodied in the works of renowned science fiction author Arthur C. Clarke', and launched on 7th April 2001, it arrived at Mars on 24th October 2001.

The mission's main goals have been to study and map the global distribution of different chemical elements and minerals that make up the Martian surface. The orbiter has also provided valuable information on the features and structure of the Martian surface and the processes which may have been active in creating these.



MARS ODYSSEY VIEWS MINERALS AT CURIOSITY'S HOME This mosaic image of the 154 km (96 mile) diameter Gale Crater, home to MSL Curiosity on Mars, was made using data from the Thermal Emission Imaging System (THEMIS) on NASA's Mars Odyssey orbiter. The false colours represent different mineral compositions. For example, windblown dust appears pale pink and olivine-rich basalt looks purple. The bright pink on Gale's floor appears due to a mix of basaltic sand and windblown dust. The blue at the summit of Gale's central mound, Mount Sharp, probably comes from local materials exposed there. Typical Martian surface soil appears grayish-green. Mission scientists use such false-colour images to identify places of potential geological interest, one key factor in the choice of Gale Crater/Mount Sharp as a landing site for MSL in 2012 Credit: NASA/JPL-Caltech/Arizona State University

Odyssey has also sought to find evidence of present or past water and ice. One way of doing this is to determine the abundance of hydrogen in the shallow subsurface, and the probe's studies led mission scientists to discover vast water ice deposits buried just below the surface in the Martian Polar regions.

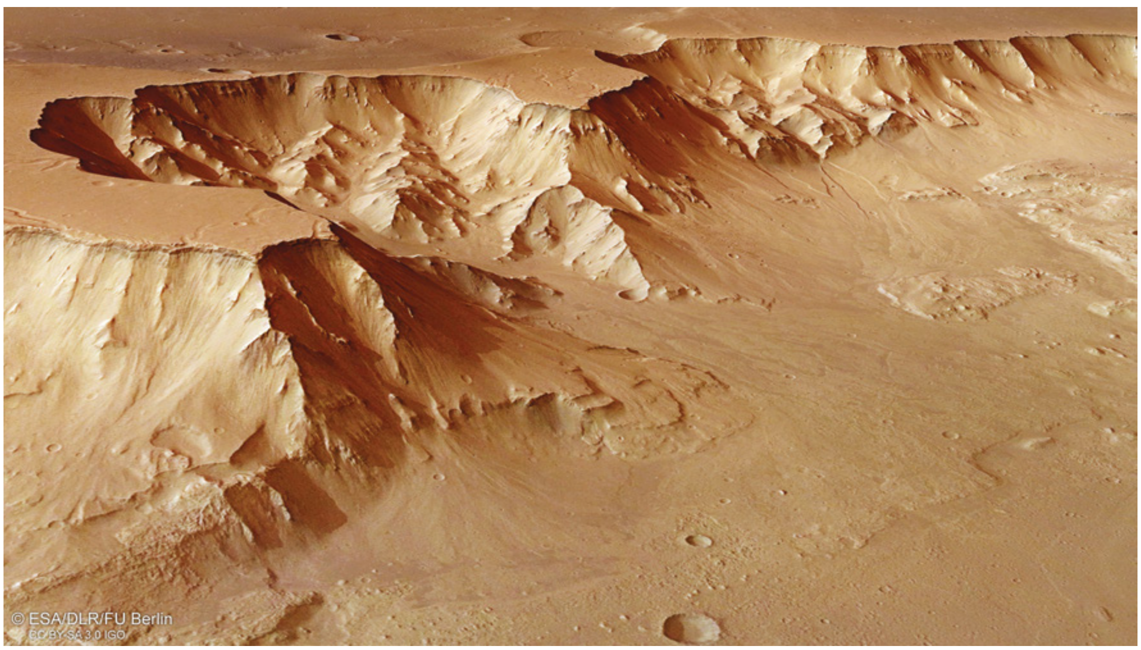
Finally, the orbiter has conducted important measurements of Mars' radiation environment. This is invaluable in helping to determine the likely health risks for human explorers.

Odyssey's primary science mission ended in August 2004, since then the orbiter has fulfilled a series of extended missions. It broke the record for longest serving spacecraft at Mars on 15th December 2010, and continues to study Martian geology and climate, as well as serving as a communications relay for the rovers on the planet's surface. The spacecraft is in good shape and could continue operating until 2025.

Mars Express

Mars Express, named for its rapid and streamlined development, was ESA's first spacecraft to visit another planet in the Solar System. Having deployed the UK's Beagle-2 lander five days previously, it entered orbit around the Red Planet on 25th December 2003. As with the current ExoMars mission, contact with the lander was lost, although it was identified, partially deployed on the surface, in images from NASA's Mars Reconnaissance Orbiter early in 2015.

At the time of its arrival, Mars Express was going to carry out the most detailed and complete exploration of Mars ever done. It was the first to conduct a thorough search for water on the Red Planet, from below ground and up into the atmosphere. The scientific objectives of the mission include detailed global high-resolution photo-geology of the planet, besides geochemical and mineralogical mapping of its surface, and even studies of the near sub-surface in the search for permafrost. Its suite of instruments is also designed to study atmospheric composition, global atmospheric circulation and surface-atmosphere interaction, as well as interaction of the atmosphere with the interplanetary medium.



PERSPECTIVE VIEW IN AURORAE CHAOS/GANGES CHASMA: A close-up of features in Ganges Chasma, close to Aurorae Chaos, imaged by ESA's Mars Express orbiter. The image focuses on the valley walls in this region, which show evidence for slumping and landslides. Material closest to the valley floor shows a stepped morphology, which could reflect different water or ice levels over time. Small channels are observed on the cliff tops. Credit: ESA/DLR/FU Berlin

This very successful mission – coming up for 13 years – has produced a wide range of significant results, some of its main achievements being the detection of hydrated minerals, including phyllosilicates (clays), the identification of recent glacial landforms, and most intriguingly the possible detection of methane in the atmosphere. This latter phenomenon is one of the main targets for study of ExoMars Trace Gas Orbiter.

Beyond its ongoing science mission, Mars Express also forms, with the NASA orbiters, part of a communications infrastructure currently active at Mars for other missions. Because of its great success, ESA has extended the mission for a further two years, until 2018. This will give the High Resolution Stereo Camera (HRSC) on board more opportunities to record the entire surface of Mars in high resolution, colour and, above all, in 3D.

CAUGHT IN THE ACT - AVALANCHES ON MARS' NORTH POLAR SCARPS: MRO's High Resolution Imaging Science Experiment (HiRISE) camera has the ability to image small-scale, short-term changes in the Martian surface, including recent impact craters only a few metres across, dust devils and seasonally-changing flow structures on steep slopes. Here it has captured avalanches of debris in action on the edge of the dome of layered deposits centred on Mars' north pole. It is very rare to catch such a dramatic event in action. Material, probably including fine-grained ice and dust and possibly even large blocks, has detached from the 700 m (2300 ft) tall 60 degree scarp to the left and cascaded to the gentler slopes below. The largest cloud is about 180 meters (590 feet) across. The top part of the scarp is still covered with bright (white) carbon dioxide frost which is disappearing from the polar regions as spring progresses. Credit: NASA/JPL-Caltech/Univ. of Arizona

Mars Reconnaissance Orbiter (MRO)

NASA's Mars Reconnaissance Orbiter was launched in 12th August 2005, on a quest for evidence that water may have been present on the Martian surface for a long period of time. While other Mars missions have shown that water did indeed flow across the surface at various times during the Red Planet's history, it remains a mystery whether water was ever around long enough to provide a habitat in which life could originate and develop.

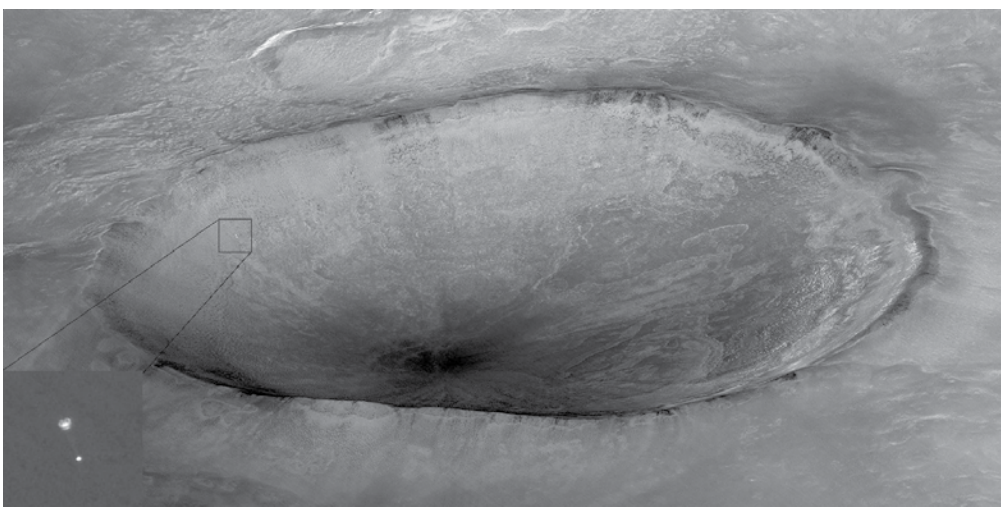
In its survey of Mars, MRO is looking particularly at small-scale features. One of its cameras – the High Resolution Imaging Science Experiment (HiRISE) camera - is the largest ever flown on a planetary mission, and has a resolution of just 0.3 m per pixel from a height of 300 km. 'Though previous cameras on other Mars orbiters could identify objects no smaller than a school bus, this camera can spot something as small as a dinner table…. Its imaging spectrometer could identify key (water-related) minerals in patches as small as a swimming pool at a few thousand carefully chosen sites, while covering the whole planet at a resolution of 200 meters (650 feet)' (NASA Fact Sheet).

The spacecraft is more than its camera though, and carries six science instruments for examining Mars in various parts of the electromagnetic spectrum from ultraviolet to radio waves. (Two other investigations use the spacecraft movements as a means of sounding out both the atmospheric structure and internal structure of the planet.) Their main goals, among others, are to identify deposits of minerals of aqueous origin, which could have formed in water over long periods, and also to look for evidence of ancient shorelines, and erosion and deposition carried out by flowing water.

MRO's studies have found evidence of a variety of past watery environments – including clay minerals, carbonates, hydrated silica and sulphates - and have shown that Mars is more diverse and dynamic than previously thought. Excitingly, some of the minerals detected in Martian surface rocks appear to have formed with the right pH and sufficient water to permit life to develop, if it was ever able to start.

Cameras on Mars orbiters have taken thousands of images that have enabled scientists to build a more comprehensive history of Mars' geology and atmosphere. While most landscapes don't appear to have changed much in millions of years, MRO's cameras are enabling us to see rapid or seasonal changes at the local scale, including recently discovered transient activity involving salty liquid water. Studying such processes can help determine how the landscape has evolved, and may help us understand better the circulation of volatiles, such as water and carbon dioxide ices and gases.

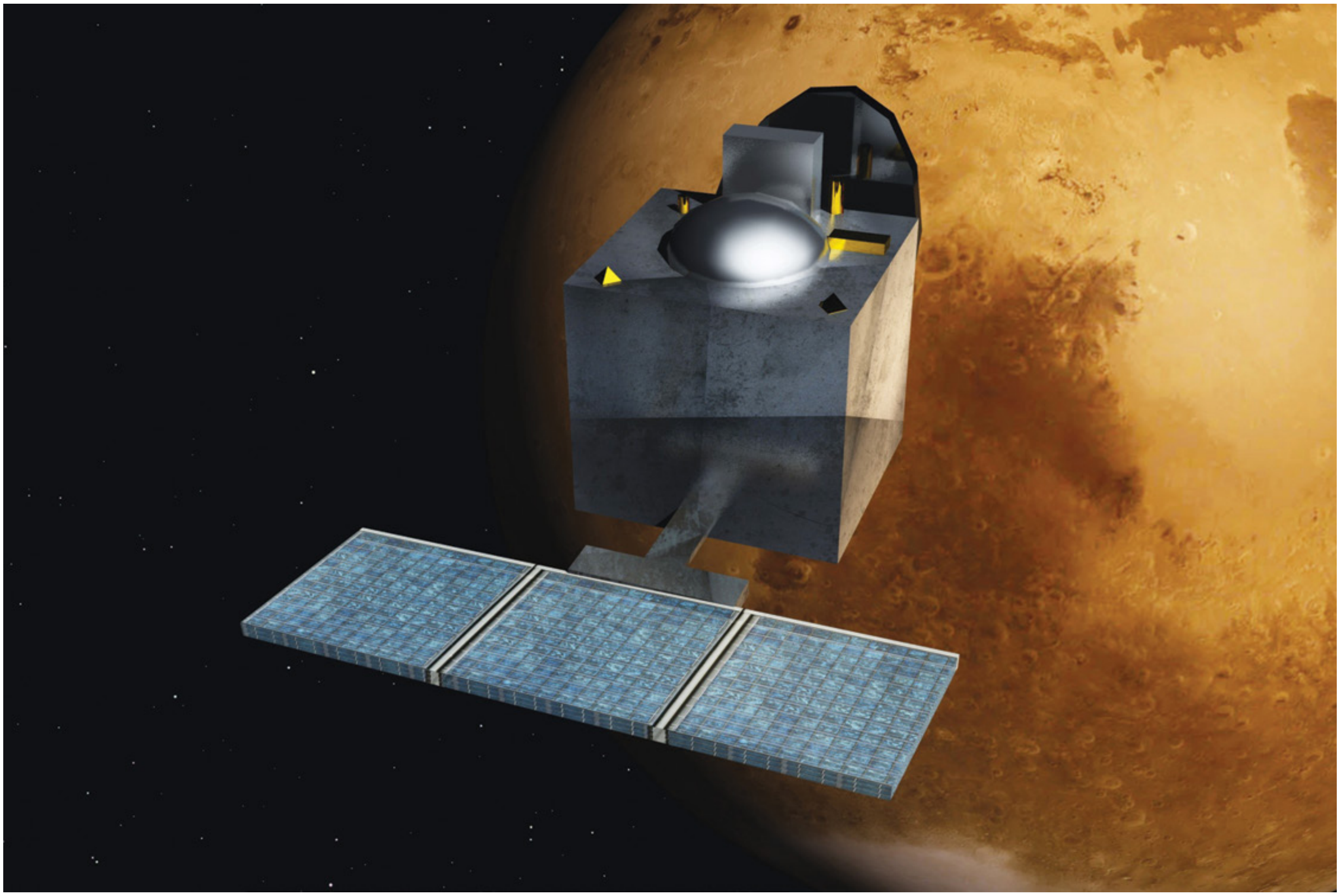
In addition to conducting its own science mission, Mars Reconnaissance Orbiter has also been useful in the selection of landing sites for future missions, its capability allowing it 'to identify obstacles such as large rocks that could jeopardize the safety of landers and rovers, including the Phoenix mission and Mars Science Laboratory mission.' Like Mars Odyssey, it also serves as a communications relay satellite for lander and rover missions such as MSL Curiosity. Having fulfilled its planned science goals during its two-year primary science mission, it is now in its fourth mission extension, and could remain a key element in NASA's Mars Exploration Program fleet for a number of years yet.



DESCENT OF THE PHOENIX: This remarkable image, captured from a distance of some 760km by MRO's High Resolution Imaging Science Experiment (HiRISE) camera, shows the descent of NASA's Phoenix Lander on 25th May 2008, just a few seconds after its parachute opened. It is seen against a 10 km (6 mile) diameter crater informally called "Heimdall", together with an improved full-resolution image of the parachute and lander (inset). Although Phoenix appears to be descending into the crater, it is actually about 20 km (12 miles) in front of it. Phoenix operated successfully in the north polar region of Vastitas Borealis for 157 Martian sols, discovering ice just beneath the surface. Credit: NASA/JPL-Caltech/University of Arizona

India's Mars Orbiter Mission

Named 'Mangalyaan', from the Sanskrit for 'Mars-Craft', the Mars Orbiter Mission is India's first interplanetary mission. On 24th September 2014, the Indian Space Research Organisation (ISRO) became the fourth space agency to reach Mars, making India the first Asian nation



MANGALYAAN AT MARS: Artist's concept of the ISRO Mars Orbiter Mission spacecraft at the Red Planet. Credit: Nesnad – Creative Commons

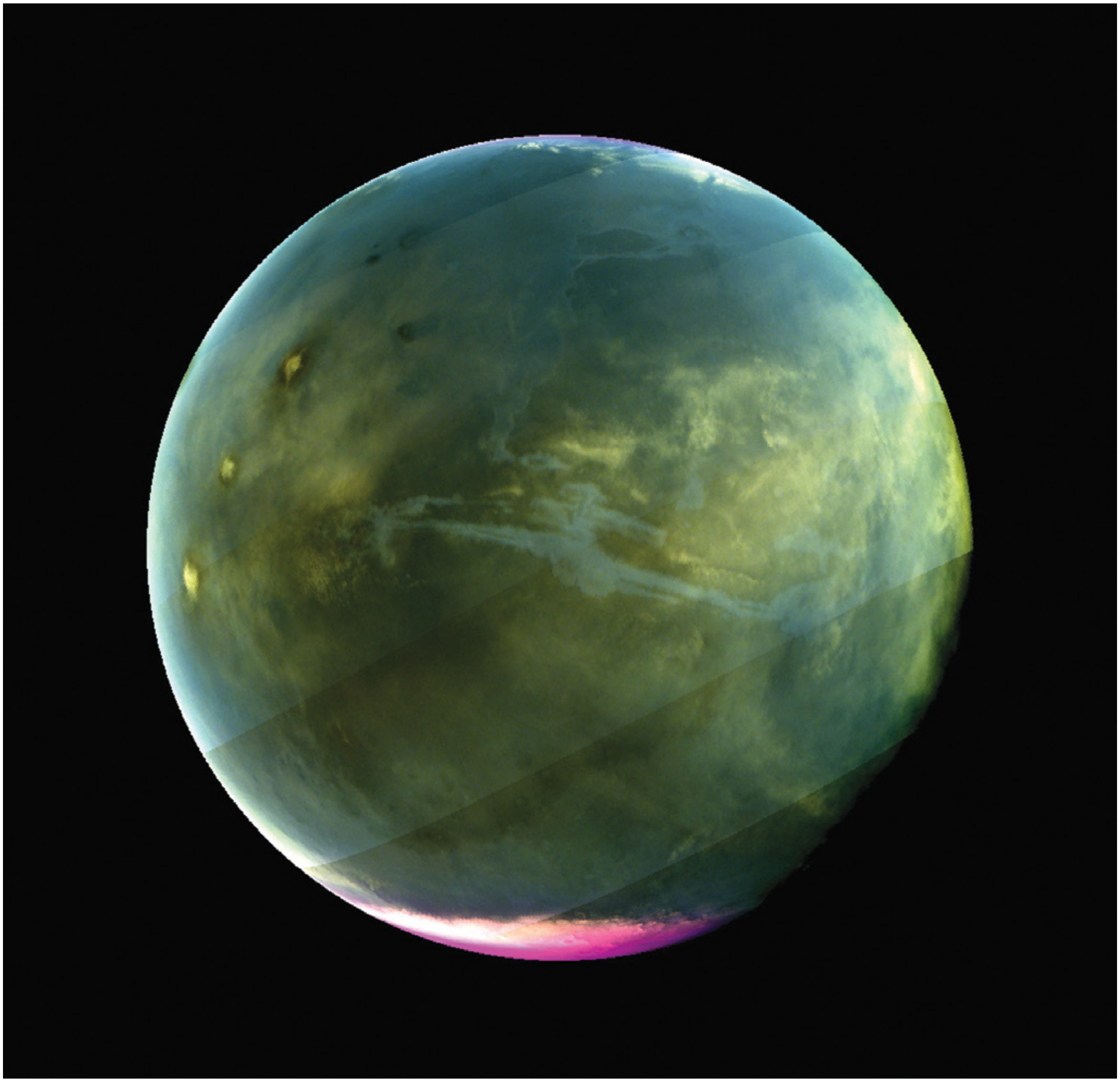
to reach Mars orbit, as well as the first nation in the world to achieve this at its first attempt, and on a modest budget of only $73 million!

Mangalyaan is a technology demonstration project, aimed at developing the technologies needed for designing, planning and carrying out interplanetary missions. The spacecraft also has a science payload, consisting of a colour camera, which has returned many stunning and detailed images, and other scientific instruments for studying the morphology and composition of surface features, as well as the Martian atmosphere.

While MOM has not delivered many new science results as yet, the mission itself is considered a big success, as all of its engineering goals have been achieved, and the spacecraft has outlived its expected lifespan. ISRO will certainly be able to embark on future interplanetary missions with confidence.

MAVEN – The search for Mar's lost atmosphere

Launched in November 2013, the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft is the first one dedicated to exploring the Red Planet's tenuous upper atmosphere. Its main aim is to try and help scientists understand the climate history of the planet. Key goals for investigation are the role of the solar wind in stripping away the atmosphere, its current state and rates of gas loss to space today. By then extrapolating back through time, scientists will be able to determine the evolution of Martian climate, the total atmospheric loss over Mars'



MARS VIEWED IN ULTRAVIOLET: MAVEN's Imaging Ultra-Violet Spectrograph took this image of Mars on July 13, 2016, when the planet appeared nearly full, viewed from the highest altitudes in the MAVEN orbit. The ultraviolet colours of the planet are shown in false colour, to show what we would see with U-V-sensitive eyes. North is up. The deep Valles Marineris canyon (centre of image) appears blue due to the scattering of ultraviolet light by the atmosphere, which masks the canyon floor. The overall greenish tinge of is a combination of reflection from the surface and atmospheric scattering. The three tall Tharsis volcanoes at left have white clouds forming as the winds flow over them. Bright white polar caps appear at both poles, typical for this season of transition from southern-hemisphere winter to summer. The magenta-coloured region visible at the South Pole shows where ozone is absorbing ultraviolet light, as it does on Earth, protecting life from harmful UV radiation.
Credit: NASA/Goddard/University of Colorado/LASP

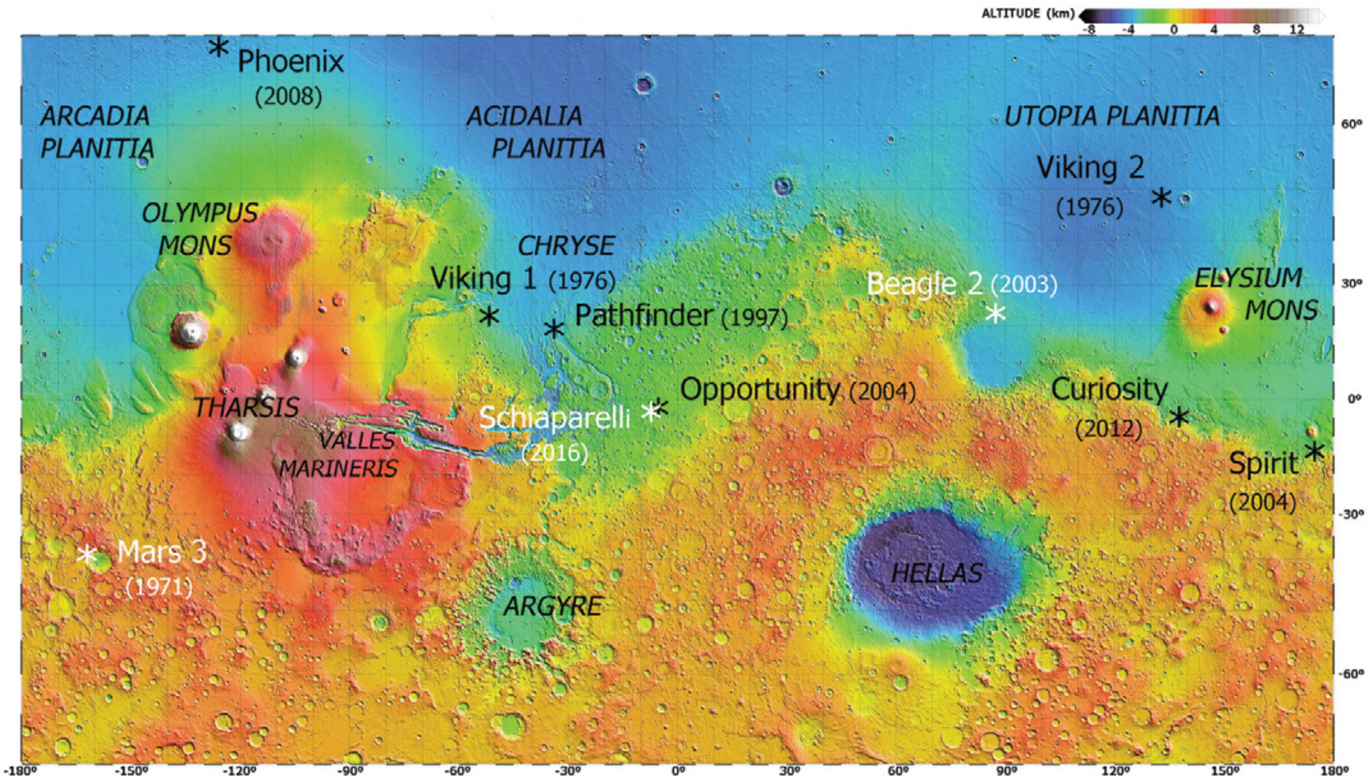
history, and whether the planet has ever been (or is!) able to support life.

As of 3rd October this year, MAVEN had completed one Mars year of science observations (just under two Earth years). Among the many significant discoveries and science results so far achieved is the most detailed characterisation to date of the structure, composition, and variability of the planet's upper atmosphere. The spacecraft has also enabled scientists to make the most accurate estimation yet of the rates of past and current atmospheric loss to space, and how this is related to the action of the solar wind and major Sun-storm events. This gas loss would appear to have been the major factor in the transformation of

Mars' climate from a warm, wet one to the frigid, dry conditions we observe today.

NASA has declared MAVEN's primary mission successful, its proposed science objectives achieved, and approval has been given for a two-year extended mission until the end of September 2018.

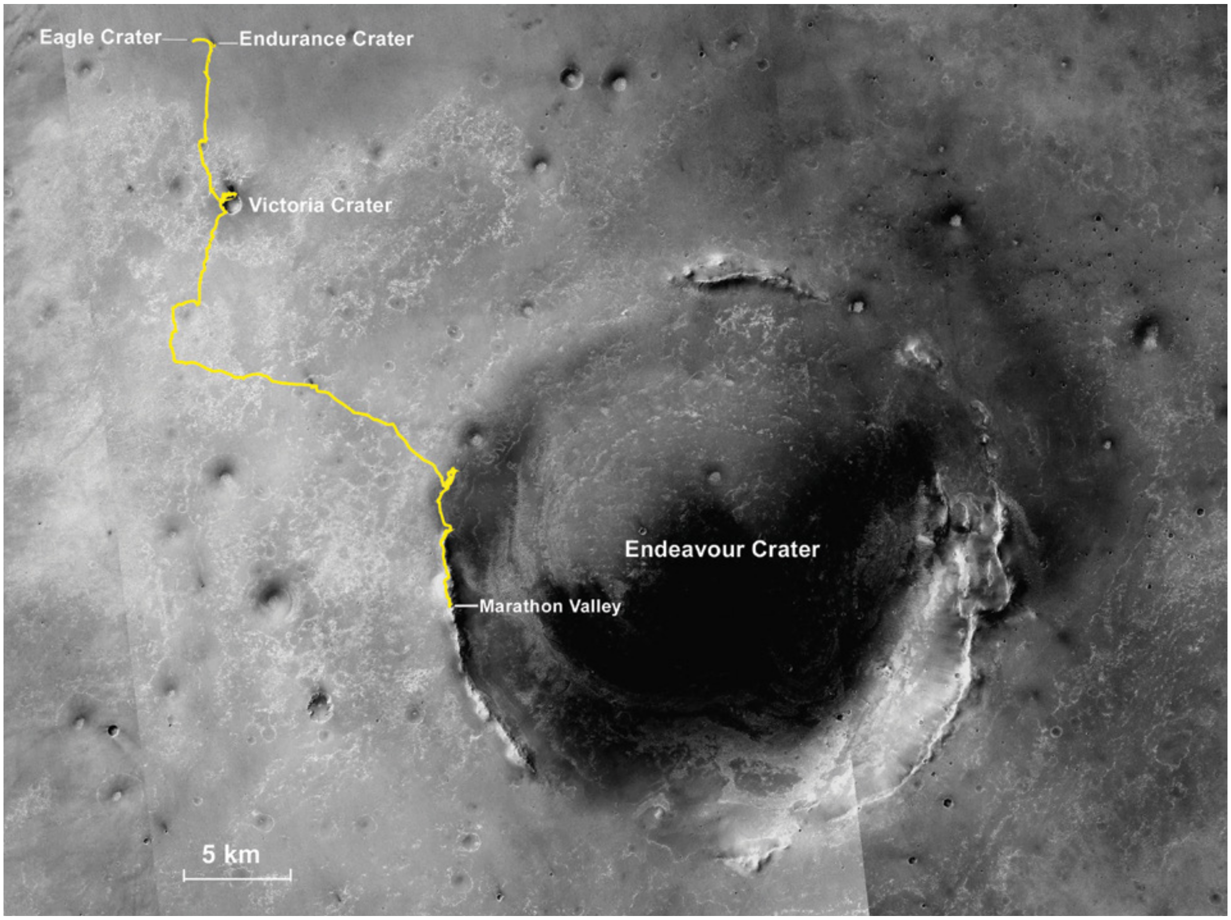
LANDERS AND ROVERS



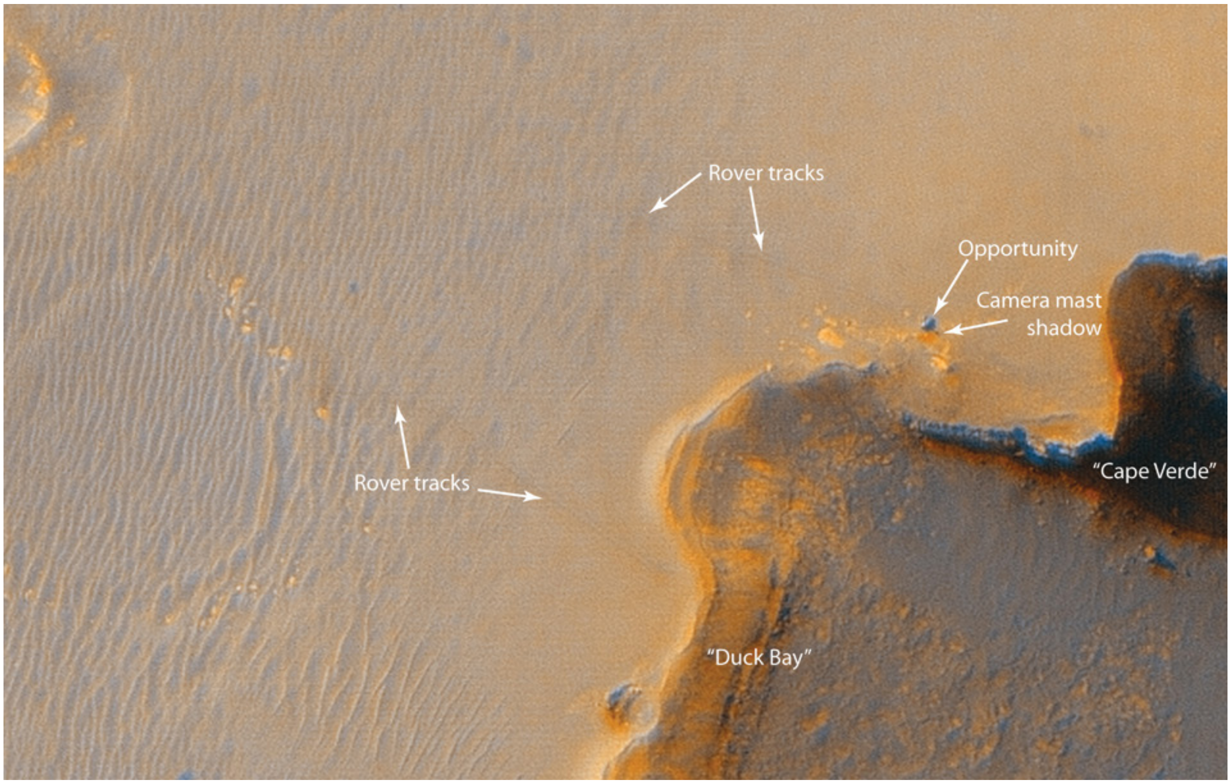
MARS LANDER SITES: Global topographic map of Mars, showing the sites of landers and rovers which have successfully soft-landed, together with the year in which they landed. The planned landing site of ESA's Schiaparelli is also shown, as are those of the Soviet Mars 3 and ESA's Beagle 2. Contact with Mars 3 was lost shortly after landing. Beagle 2 failed to communicate, but has recently been imaged by the MRO HiRISE camera, intact but only partially deployed. The base map shows relative elevations of the Martian surface, using data from the Mars Orbiter Laser Altimeter (MOLA) on NASA's Mars Global Surveyor, a very successful mission which operated at the Red Planet from September 1997 to November 2006. Some key regions and topographic features are named for reference. Credit: Base map: NASA-JPL/MOLA Science Team - Annotations: Chris Starr

Mars Exploration Rover (MER) – Opportunity

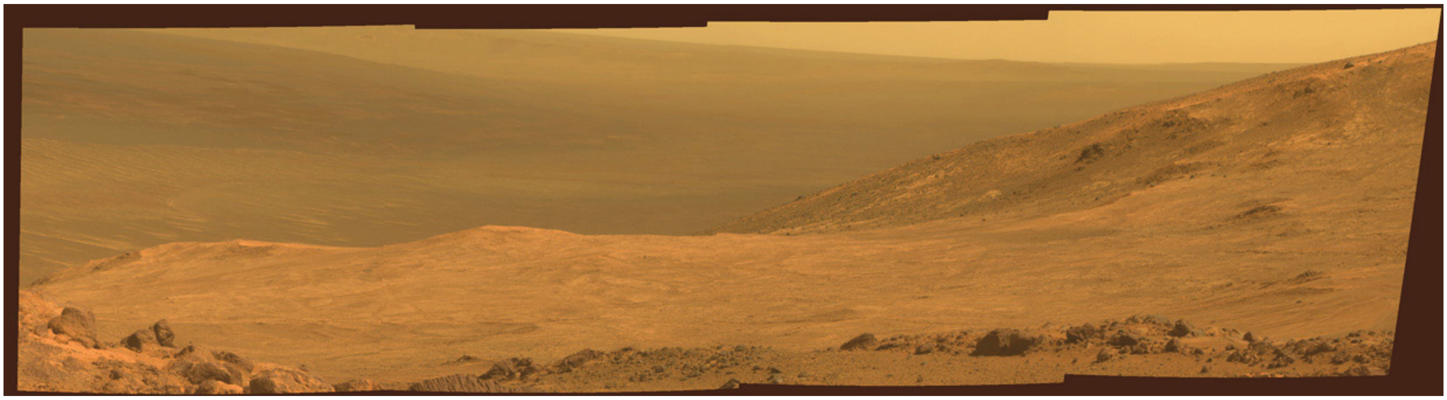
Named by the winners of a student essay contest, Opportunity and its companion rover Spirit arrived on the surface of Mars in January 2004. Armed with a complex array of cameras, scientific instruments and a rock abrasion tool, and powered by solar panels and radioisotope heater units, their main scientific goal was to search for and characterize a wide range of rocks and soils that might provide evidence of past water activity on Mars. While the Mars Exploration Rovers were not equipped to detect life directly, their search for evidence of past water could help establish the potential habitability of the environment in the planet's history. The rovers' target sites – on opposite sides of Mars - were considered likely to have been affected by liquid water in the past. Spirit went to Gusev Crater, a possible former lake in a giant impact crater. Opportunity targeted Meridiani Planum where mineral deposits indicative of a humid past had been identified from orbit, particularly by Mars Global Surveyor and Mars Odyssey.



'MARS MARATHON': MER Opportunity's journey since landing on Mars on 24th January 2004. As of Sol 4527 (Oct. 18, 2016), the total distance travelled was 26.99 miles (43.44 kilometers). Credit: NASA/JPL/University of Arizona



OPPORTUNITY AT VICTORIA CRATER: Iconic enhanced-colour view of, taken by High Resolution Imaging Science Experiment (HiRISE) on NASA's Mars Reconnaissance Orbiter. Victoria is an impact crater about 800 meters (half a mile) in diameter at Meridiani Planum near the equator of Mars. Opportunity arrived at the rim of Victoria in October 2006, after a drive of more than 9 kilometres. Credit: NASA/JPL/University of Arizona



MARATHON VALLEY: This view from NASA's MER Opportunity shows part of "Marathon Valley," on the western rim of Endeavour Crater, as seen from an overlook north of the valley. It combines four images taken by the rover's panoramic camera (Pancam) on 13th March 2015. This location was chosen as a science destination for the rover as evidence of clay minerals was found here by observations from MRO's Compact Reconnaissance Imaging Spectrometer for Mars (CRISM). Such minerals may be indicative of ancient, wet environments on the planet. Credit: NASA/JPL-Caltech/Cornell University/Arizona State University

The MER rovers also had the task of calibrating and validating surface observations made by Mars Reconnaissance Orbiter instruments, so as to help determine the accuracy and effectiveness of instruments surveying Martian geology and surface composition from orbit.

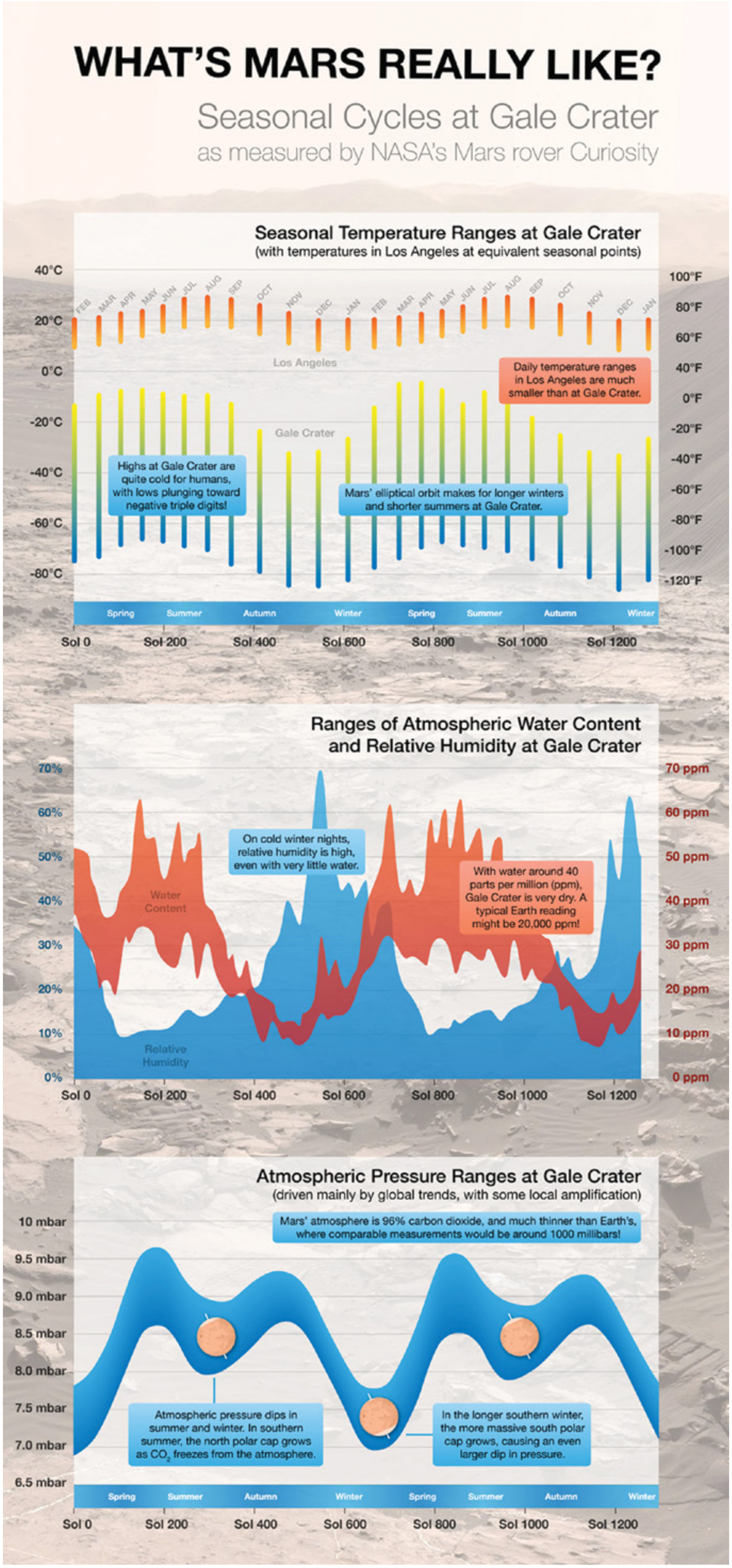
Both rovers greatly exceeded their original primary 90-sol missions (one sol = one Martian day, or the equivalent on Earth of 24 hours 39 minutes 35 seconds), surpassing their science mission objectives, and capturing the public imagination on their slow but epic journeys across the Martian surface. Spirit became stuck in sand in late 2009 and eventually fell silent on Sol 2210 (March 22, 2010), having covered a distance of 7.73 km (4.8 miles), visiting a number of craters, climbing and exploring the Columbia Hills and surviving dust storms.

Having completed its 'marathon', covering over 43 km (27 miles) to date, Opportunity is still operational. Having visited Endurance Crater and the 800m-wide (half-mile) Victoria Crater (where it spent two years), it is now located at 'Spirit Mount' on the rim of the 22 km (14 mile) diameter Endeavour Crater, the first science target of its 10th extended mission phase. Here it continues to analyse the type and composition of rock samples, and seeking to confirm the past importance of water on Mars. Like Spirit, it has also made astronomical observations and obtained atmospheric data.

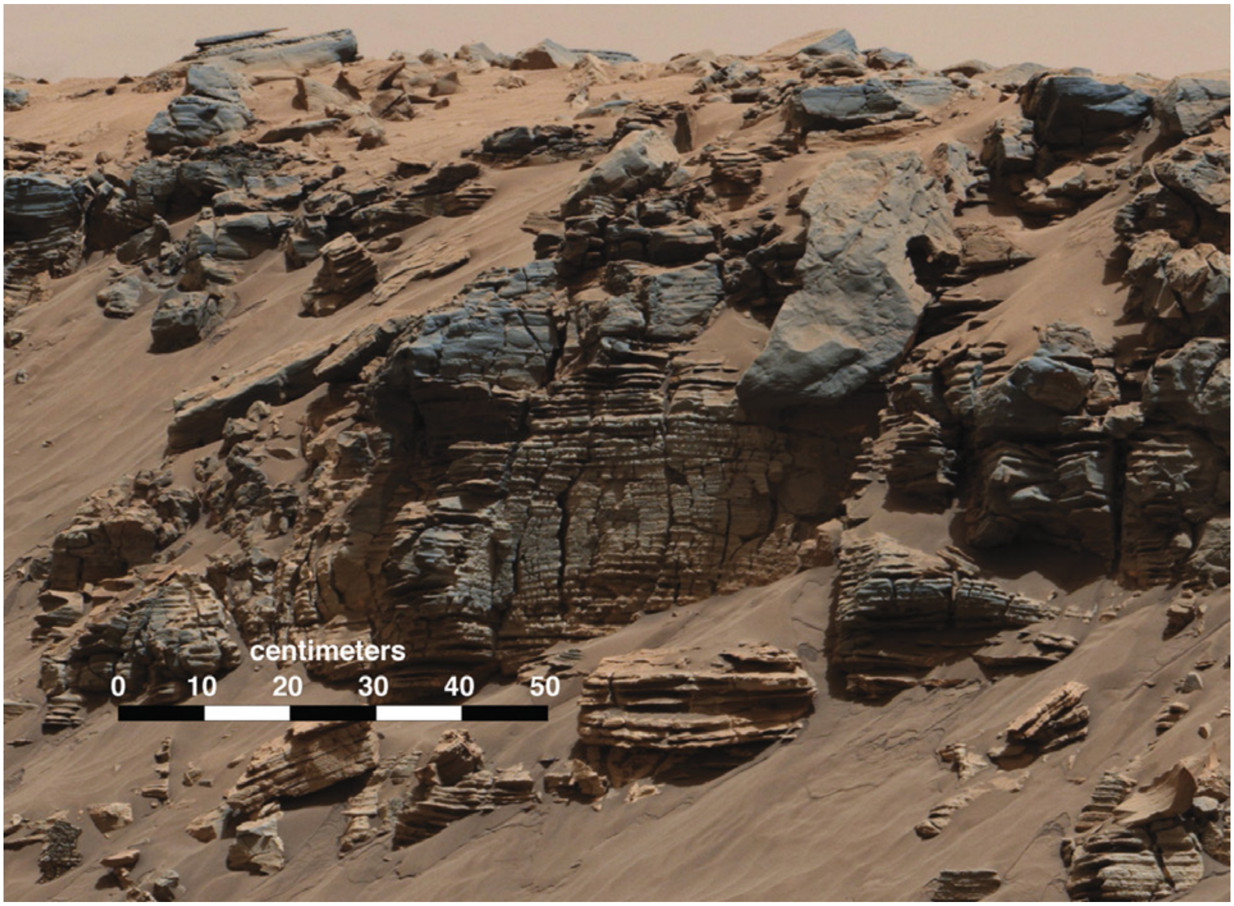
Mars Science Laboratory – Curiosity

Few of us who followed the arrival of NASA's Mars Science Laboratory (MSL) at the surface of Mars on the 6th August 2012 will forget the so-called 'seven minutes of terror', as this 899 kilogram (1,982 pound) car-sized wonder was delivered to the Martian surface by the new 'sky-crane', in one of the most complicated spacecraft landings ever attempted. Its target was Gale Crater, a suspected former lake location with a 5 km-high (3 mile) mountain of layered materials – named Aeolis Mons or 'Mount Sharp' - in its centre. Studies from orbit had revealed different mineral compositions of these layers, depending on their height, and the possibility that these might hold a record of two billion years of Martian history. There are also flow channels in this target study area.

With its rover named Curiosity, the MSL mission is part of NASA's Mars Exploration Programme, the goal of which is to determine the planet's habitability and to try and discover whether or not it has ever had an environment able to support microbial life. Curiosity is designed to collect data on all aspects of its surroundings - geological, chemical, atmospheric, water, radiation – and is also looking out for signs of organic



THE WEATHER FROM CURIOSITY: Changing atmospheric conditions as measured by Curiosity since its arrival in Gale Crater. This infographic shows seasonal temperature changes, variations in humidity and atmospheric pressure. A sol is a Martian day, equal to 24 hours 39 minutes 35 seconds. Since a year on Mars is about 687 Earth days, its seasons are correspondingly longer than those on Earth. Credit: NASA/JPL-Caltech



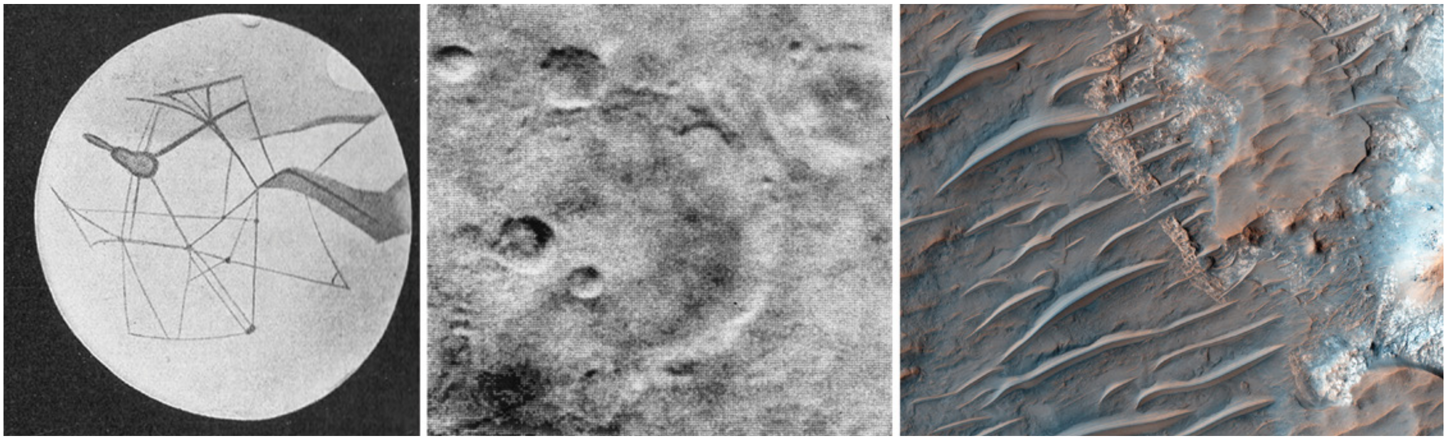
EVIDENCE OF RIVER AND LAKE SEDIMENTS IN GALE CRATER: This evenly layered rock photographed by the Mast Camera (Mastcam) on NASA's Curiosity Mars Rover shows a pattern typical of a lake-floor sedimentary deposit not far from where flowing water entered a lake. The image shows a vertical cross section through geological layers typical of deposition by rivers, deltas and lakes. A delta builds where a river enters a body of still water, such as a lake, and the current decelerates abruptly so sediment delivered by the river settles to the floor. The colour has been approximately white-balanced to resemble how the scene would appear under daytime lighting conditions on Earth.
Credit: NASA/JPL-Caltech/MSSS

compounds, as well as any features that might show evidence of biological processes.

To do this, the rover is equipped with the largest, most advanced suite of scientific instruments ever landed on the Martian surface, and it is more mobile and flexible than previous rover missions. Curiosity analyses in its on-board laboratory samples scooped up from the soil and drilled from rocks. This is helping to assess the past Martian environment through the structure and chemical composition of rocks and soils.

So far, the rover has been spectacularly successful. For instance, it has identified a range of sediments of aeolian (wind), lacustrine (lake) and fluvial (stream or river) origin, the latter confirming the importance of water in the past evolution of the floor of Gale Crater and lower slopes of Mount Sharp explored so far. As part of its two-year mission extension that began on 1st October, it is now continuing to head uphill, towards areas containing more minerals associated with past water action.

The MSL mission also had the goal of demonstrating the ability to land a very large, heavy rover on the surface of Mars, using radical new 'sky-crane' technology. Landing large payloads will be necessary for any future Mars Sample Return mission to collect rocks and soils and send them back to Earth. Such a mission is the proposed next stage in the Mars Exploration Programme. Curiosity is also providing useful data for use in future manned missions, as are all of the spacecraft and landers operating at the Red Planet.



OUR CHANGING VIEWS OF MARS – EVER CLEARER IMAGES OF THE RED PLANET: Left: One of Percival Lowell's drawings of Mars, based on telescopic observations made from the Lowell Observatory in Flagstaff, Arizona about 1914. Centre: Mariner 4 image of the crater named after it, the 151 km diameter Mariner crater at 35° S, 164° W. Mariner 4 was the first successful fly-by of Mars, and the first ever mission to obtain close-up images of another planet. This one was taken from 12,600 km during the spacecraft's July 1965 fly-by. North is up. Right: Up close and personal. Sand ridges imaged by MRO's HiRISE camera. Shaped by the constant Martian wind, these dune-like features stand up to 6 meters (18 feet) tall. Credits: Left: Wikimedia Commons/Public Domain; Centre: Mariner 4-NASA; Right: NASA/JPL-Caltech/Univ. of Arizona

What next?

We have long since dispelled Percival Lowell's dreams of Martian civilisations, inspired by the 19th century works of Giovanni Schiaparelli and Camille Flammarion. Their maps, based on telescopic observations of the time, had shown 'canali' – channels, natural or artificial –which ultimately proved to be spurious optical illusions, as did those seen by Lowell himself. And we have come a long way from the grainy photos of Mars taken by the early missions of the 1960s, although many astronomers still believed up to this time that there might be some form of hardy life on this tantalising world.

The missions currently active at Mars have helped provide us with an increasingly detailed understanding of the planet's atmosphere, surface environment, history of water, and potential for life.

Looking ahead, despite the failure of Schiaparelli, ESA member states agreed, at a council meeting in December, to fund the extra €436 million ($466 million) needed to ensure delivery of the second stage of the two-part Exomars mission, which is due to land a rover on the Red Planet in 2021 to drill into the Martian soil and look for biochemical traces of living or fossil organisms.

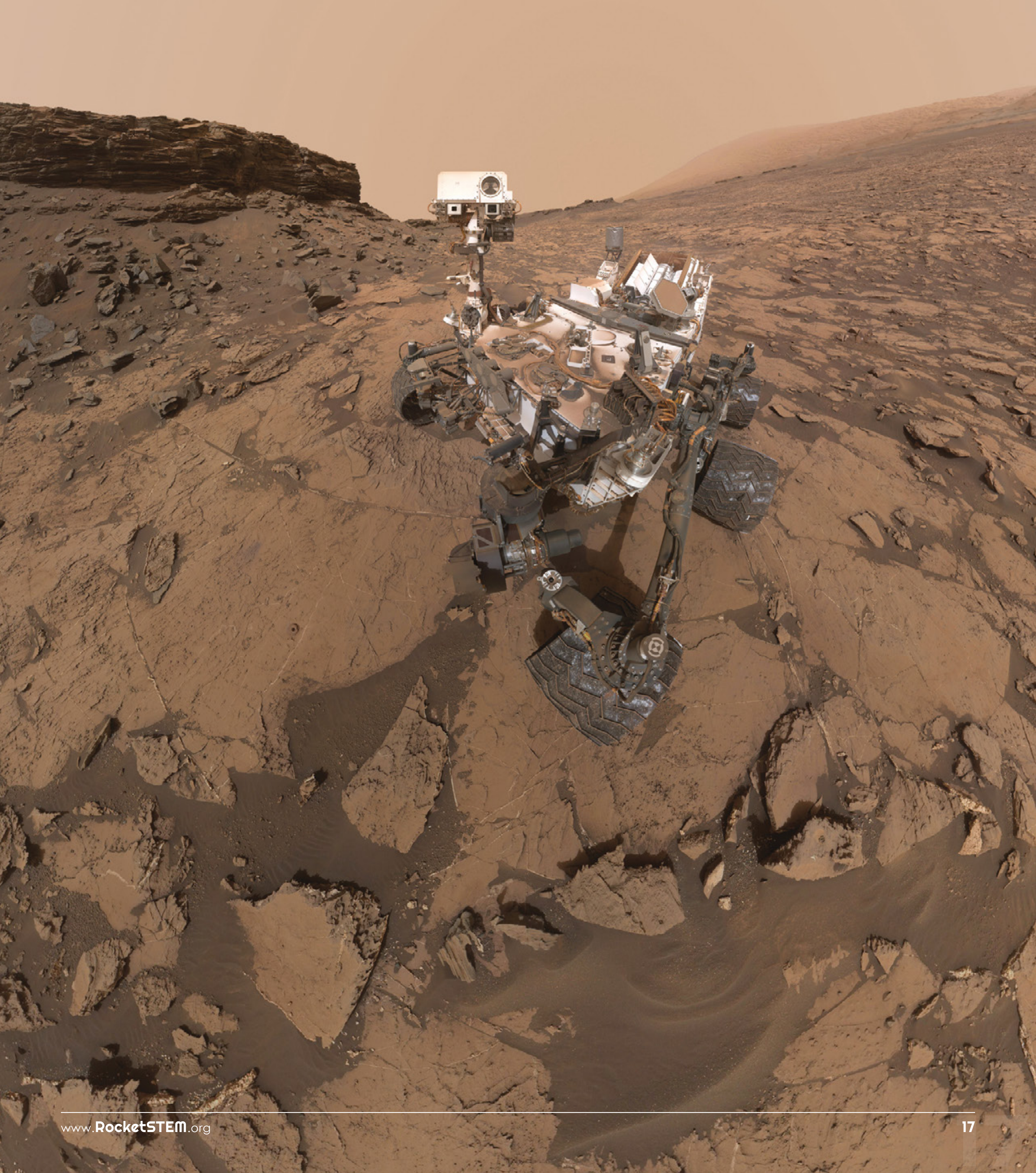
As for NASA, its FY 2017 Budget Request kept on track its Mars 2020 rover plans, although it now remains to be seen where the priorities of the new Administration will lie. Before this, in 2018, we hope to see the launch of InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport), the first mission dedicated to investigating the deep interior of Mars.

However, cuts to planetary science budgets - despite recent spectacular successes, not only at Mars, but across the Solar System from Ceres to Saturn and beyond to Pluto - mean that we might not see such a golden age of robotic exploration again for a while. And the manned exploration of the Red Planet still looks far off for now. In the meantime, these orbiters and rovers, now hardy veterans, will continue to be our pioneering emissaries at the Red Planet.

To find out more on the current Mars missions, their science payloads and discoveries, visit:

- https://www.nasa.gov/mission_pages/mars/main/index.html
- http://www.esa.int/Our_Activities/Space_Science/Mars_Express
- http://www.isro.gov.in/pslv-c25-mars-orbiter-mission

CURIOSITY SELFIE: A self-portrait taken by Curiosity at 'Murray Buttes' on lower Mount Sharp in September 2016. The panorama is made up of 60 images taken by the Mars Hand Lens Imager (MAHLI) camera at the end of the rover's arm. (The view does not include the rover's arm nor the MAHLI camera itself). These Martian buttes and mesas, with their distinctive layering, have been revealed by Curiosity to be eroded remnants of ancient sandstone that originated when winds deposited sand after lower Mount Sharp had formed. This was then buried, chemically altered by groundwater, then exposed again by erosion to form a landscape not dissimilar to that of the deserts of the American south-west. The informal name Murray Buttes was chosen as a tribute to Bruce Murray (1931-2013), a member of the science teams for NASA's earliest missions to Mars who later served as director of NASA's Jet Propulsion Laboratory. Credit: NASA/JPL-Caltech/MSSS



Artist's impression of the ExoMars 2016 Trace Gas Orbiter at Mars. Credit: ESA/ATG medialab

Skimming an alien atmosphere

After the smooth arrival of ESA's latest Mars orbiter, mission controllers are now preparing it for the ultimate challenge: dipping into the Red Planet's atmosphere to reach its final orbit.

The ExoMars Trace Gas Orbiter is on a multiyear mission to understand the tiny amounts of methane and other gases in Mars' atmosphere that could be evidence for possible biological or geological activity.

Following its long journey from Earth, the orbiter fired its main engine on 19 October 2016 to brake sufficiently for capture by the planet's gravity.

It entered a highly elliptical orbit where its altitude varies between about 250 km and 98 000 km, with each circuit taking about four Earth days.

Ultimately, however, the science goals and its role as a data relay for surface rovers mean the craft must lower itself into a near-circular orbit at just 400 km altitude, with each orbit taking about two hours.

Mission controllers will use 'aerobraking' to achieve this, commanding the craft to skim the wispy top of the atmosphere for the faint drag to steadily pull it down.

"The amount of drag is very tiny," says spacecraft operations manager Peter Schmitz, "but after about 13 months this will be enough to reach the planned 400 km altitude while firing the engine only a few times, saving on fuel."

During aerobraking, the team at ESA's mission control in Darmstadt, Germany, must carefully monitor the craft during each orbit to ensure it is not exposed to too much friction heating or pressure.

The drag is expected to vary from orbit to orbit because of the changing atmospheric, dust storms and solar activity. This means ESA's flight dynamics teams will have to measure the orbit repeatedly to ensure it does not drop too low, too quickly.

The aerobraking campaign is set to begin on 15 March, when Mars will be just over 300 million km from Earth, and will run until early 2018.

Mission controllers are now working intensively to prepare the craft, the flight plan and ground systems for the campaign.

Late last month, they adjusted the angle of the orbit with respect to the Mars equator to 74° so that science observations can cover most of the planet.

Next, to get into an orbit from where to start aerobraking, the high point will be reduced on 3 and 9 February, leaving the craft in a 200 x 33 475 km orbit that it completes every 24 hours.

ESA mission controllers have some previous experience with aerobraking using Venus Express, although that was done at the end of the mission as a demonstration. NASA also used aerobraking to take the Mars Reconnaissance Orbiter and other spacecraft into low orbits at Mars.

"This will be our first time to use aerobraking to achieve an operational orbit, so we're taking the extra time available now to ensure our plans are robust and cater for any contingencies," says flight director Michel Denis.

Aerobraking proper will begin on 15 March with a series of seven thruster firings, about one every three days, that will steadily lower the craft's altitude at closest approach – from 200 km to about 114 km.

Flight dynamics experts at our ESOC operations centre work on every ESA mission, from those in very low orbits, like Swarm and CryoSat, to those exploring our Solar System, like Rosetta and ExoMars.

"Then the atmosphere can start its work, pulling us down," says Peter Schmitz. "If all goes as planned, very little fuel will then be needed until the end of aerobraking early in 2018, when final firings will circularise the 400 km orbit."

No date has been set, but science observations can begin once the final orbit is achieved. In addition, the path will provide two to three overflights of each rover every day to relay signals.

Overall, the spacecraft is in excellent health. On 30 November, it received an updated 'operating system'. To date, only one 'safe mode' has been triggered, when a glitch caused the craft to reboot and wait for corrective commands. That happened during preliminary testing of the main engine, when a faulty configuration was quickly identified and fixed.

"We are delighted to be flying such an excellent spacecraft," says Michel. "We have an exciting and challenging mission ahead of us."

Why did Schiaparelli crash during landing?

Contact with the ExoMars Schiaparelli lander was lost during its attempt to make it to the surface last October. It was later discovered that the lander had crashed into the surface of the Red Planet.

A large volume of data recovered from the Mars lander shows that the atmospheric entry and associated braking occurred exactly as expected. The parachute deployed normally at an altitude of 12 km and a speed of 1730 km/h. The vehicle's heatshield, having served its purpose, was released at an altitude of 7.8 km.

Schiaparelli's heat-scorched shield while descending through the atmosphere of Mars. Credit: ESA/ATG medialab

As Schiaparelli descended under its parachute, its radar Doppler altimeter functioned correctly and the measurements were included in the guidance, navigation and control system.

However, saturation – maximum measurement – of the Inertial Measurement Unit (IMU) occurred shortly after the parachute deployment. The IMU measures the rotation rates of the vehicle. Its output was generally as predicted except for this event, which persisted for about one second – longer than would be expected.

When merged into the navigation system, the erroneous information generated an estimated altitude that was negative – that is, below ground level. This in turn successively triggered a premature release of the parachute and the backshell, a brief firing of the braking thrusters and finally activation of the on-ground systems as if Schiaparelli had already landed. In reality, the vehicle was still at an altitude of around 3.7 km.

This behaviour has been clearly reproduced in computer simulations of the control system's response to the erroneous information.

"This is still a very preliminary conclusion of our technical investigations," says David Parker, ESA's Director of Human Spaceflight and Robotic Exploration. "The full picture will be provided in early 2017 by the future report of an external independent inquiry board.

"But we will have learned much from Schiaparelli that will directly contribute to the second ExoMars mission being developed with our international partners for launch in 2020."

Helo, Mars!

Objective

Apply trigonometric ratios to the NASA Mars Helicopter Scout so that flight data such as climb angle and average speed can be calculated given initial flight parameters.

Vocabulary

- **Slope:** The angle the rille wall makes to the horizontal.
- **Above Ground Level (AGL):** The altitude as measured from the local area.
- **Altitude:** The height that an object is in the air.
- **Average Speed:** The Round Trip Distance divided by the Travel Time Climb.
- **Angle:** The angle formed between the rover and the FTP.
- **Distance to FTP:** The distance from the rover to a point above and downrange of the rover.
- **Flight Time Capacity:** The amount of time that is available to fly.
- **Fly–To–Point (FTP):** A point above the Martian surface.
- **Ground Distance:** The downrange distance from a rover.
- **Hover Time:** The amount of time spent in a stationary position above the ground.
- **Round Trip Distance:** The distance from the rover to the FTP and back to the rover.
- **Travel Time:** The time it takes to fly a certain distance.

Narrative

Roving on Mars is a great way to get from point A to point B, with scientists back on Earth always looking for interesting places for the rovers to go visit and analyze. However, sometimes finding the next spot to visit can be a daunting task since scientists have to rely on satellite imagery to find compelling places to visit. But even these satellite images are not that detailed; it follows that a closer inspection of the places is always more desirable.

For a more in-depth treatment of this high school project by Joe Maness & Rich Holtzin visit www.stemfortheclassroom.org.

In the same way that a ship on the ocean has a Crow's Nest where the crew can see further, getting to higher ground allows for greater vision of the rover on Mars. But how on Mars can one get to a higher place to see further?

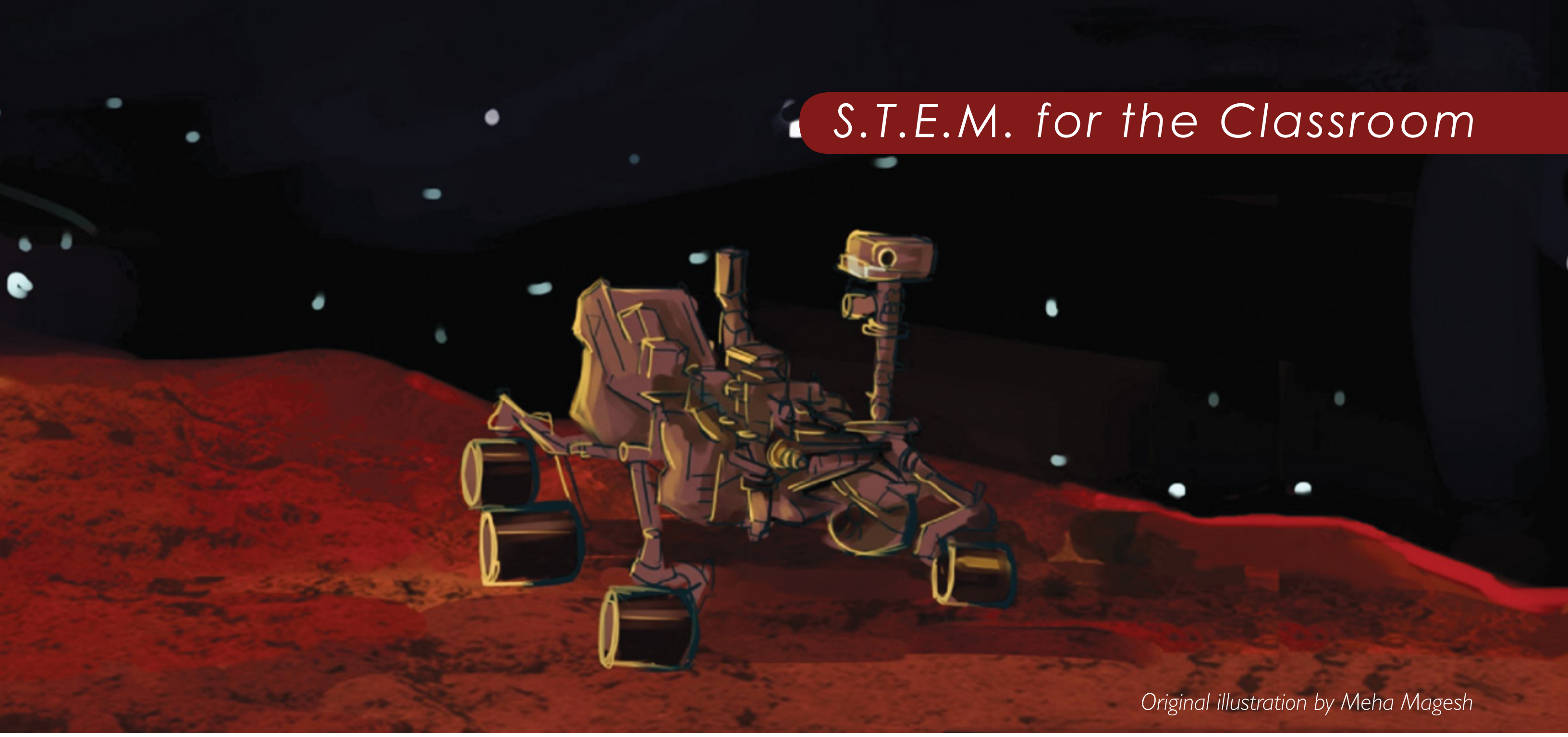
Several solutions present themselves, but each solution is not noteworthy. For example, a tower can be erected from the rover, but the complexity and the mass penalty is probably too much. It would be nice if we could scout the area ahead of the rover, and survey without weighing too much. The reason is because an increase in mass equals to an increase in the amount of propellant needed just to get off the ground.

Analysis

Enter the Mars Helicopter Scout (MHS). This little and ultra light weight flying machine can take off from the rover and fly out to a distance that the rover cannot see. It has solar panels on the top of the machine, and has two counter–rotating rotors that generate lift in the thin Martian air. The best part? The entire helicopter has a mass of only one kilogram!

The MHS is activated, and is sent instructions to go to a certain Fly–To–Point (FTP) away and above the rover. The helicopter lifts off and flies to the FTP, hovers, and takes images of the terrain that the rover cannot see. Afterwards, the MHS flies back to the rover where it shuts itself down and uses the solar panels to recharge its batteries. Nice!

The MHS has around 3 minutes (180 seconds) of flight time capacity, and has a maximum altitude of 120



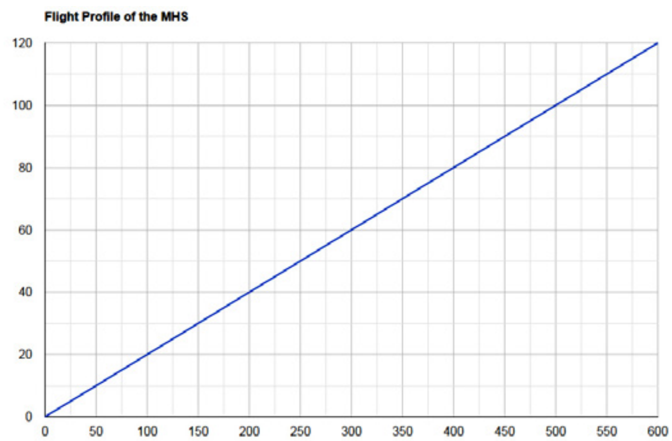
Original illustration by Meha Magesh

meters AGL with a maximum Ground Distance of 600 meters downrange from the rover. These numbers will serve as our constraints for the MHS app.

Scientists on Earth feed the MHS its flight information, and off it goes. The information given to the MHS consists of three parts:

1. Desired Altitude (in meters AGL)
2. Desired Ground Distance away from the rover (in meters)
3. Desired Hover Time (in seconds)

The Rover and FTP form a right triangle, which can be solved easily using trigonometric and triangle identities!



The maximum flight path capability of the MHS, with a maximum downrange distance of 600 meters and a maximum altitude of 120 meters AGL (Graph is NOT drawn to scale). Credit: S.T.E.M. For the Classroom

We can use the Pythagorean Theorem to find the Distance to the FTP, which is the hypotenuse of the right triangle. The tangent ratio is used to determine the climb angle (in degrees). The Travel Time becomes the Flight Time Capacity minus the Hover Time. We can then use that information to calculate the average speed of the MHS.

- $Distance\ to\ FTP = \sqrt{(Ground\ Distance)^2 + (Altitude)^2}$
- $Round\ Trip\ Distance = 2(Distance\ to\ FTP)$
- $Climb\ Angle = tan^{-1}\left(\frac{Altitude\ AGL}{Ground\ Distance}\right)$
- $Travel\ Time = Flight\ Time\ Capacity - Hover\ Time$
- $Average\ Speed = \frac{Round\ Trip\ Distance}{Travel\ Time}$

Example

Scientists on Earth want the MHS to go to a FTP that is 400 meters downrange with an altitude of 100 meters AGL, and a hover time of 60 seconds so that the MHS can take a image of the rover. Find the Round Trip Distance, Climb Angle, and Average Speed of the MHS.

$$Distance\ to\ FTP = \sqrt{(Ground\ Distance)^2 + (Altitude)^2}$$

$$= \sqrt{(400)^2 + (100)^2}$$

$$= \sqrt{160000 + 10000}$$

$$= \sqrt{170000}$$

$$= 412\ meters$$

$$Round\ Trip\ Distance = 2(Distance\ to\ FTP)$$

$$= 2(412)$$

$$= 825\ meters$$

$$Climb\ Angle = tan^{-1}\left(\frac{Altitude\ AGL}{Ground\ Distance}\right)$$

$$= tan^{-1}\left(\frac{100}{400}\right)$$

$$= 14°$$

$$Travel\ Time = Flight\ Time\ Capacity - Hover\ Time$$

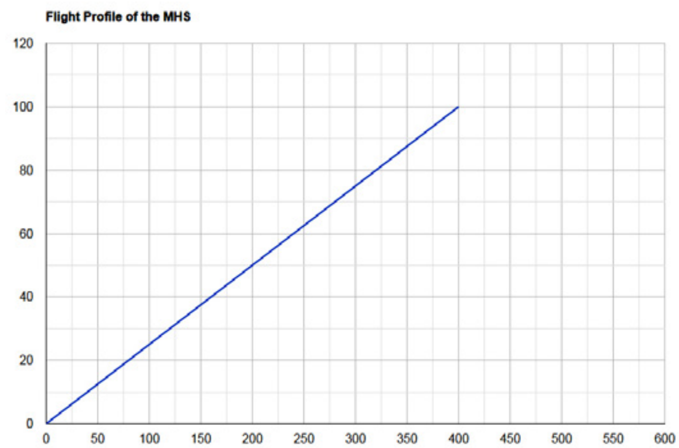
$$= 180 - 60$$

$$= 120\ s$$

$$Average\ Speed = \frac{Round\ Trip\ Distance}{Travel\ Time}$$

$$= \frac{825}{120}$$

$$= 6.87\ m/s$$



Flight path of the MHS. (Graph is NOT drawn to scale). Credit: S.T.E.M. For the Classroom

With initial conditions of 400 meters downrange, an altitude of 100 meters AGL, and a 60 second hover time, the MHS will fly a Round Trip distance of 825 meters with a Climb Angle of 14 degrees from the horizon and an Average Speed of almost seven meters per second.

Guided practice

The MHS science team back on Earth wants to image a rock formation ahead of the Mars rover. They wish to fly several sorties. Find the Round Trip Distance, Climb Angle, and Average Speed of the MHS given the different initial flight parameters.

1. Downrange: 50 m; Altitude: 120 m AGL; Hover Time: 60 s
2. Downrange: 150 m; Altitude: 75 m AGL; Hover Time: 45 s
3. Downrange: 320 m; Altitude: 45 m AGL; Hover Time: 35 s
4. Downrange: 550 m; Altitude: 50 m AGL; Hover Time: 30 s
5. Downrange: 400 m; Altitude: 45 m AGL; Hover Time: 35 s

Artwork

Draw a picture of the MHS in its brief flight over the Martian surface in search of interesting places to record as the Earth shines brightly in the sky overhead.

R.A.F.T. writing

- **Role:** Teacher/Instructor/Master
- **Audience:** 8th Graders
- **Format:** Step–By–Step Instructions
- **Topic:** How to calculate the Distance to the FTP by solving for the hypotenuse of a right triangle given the lengths of the two other sides.

Discussion topics

- What is your visual picture of the surface of Mars?
- Do you agree or disagree with the notion of funding explorations to other planets?
- What kind of noise do you think the MHS makes while flying in the Martian atmosphere?
- How is the MHS similar to drones used on Earth? How is it different?
- Could a version of the MHS be used on other planets?
- If you could somehow hop aboard the MHS, describe what you would see.

Conclusion

The Mars Helicopter Scout can fly from its perch on a rover and travel ahead to find captivating places for it to visit. The MHS will certainly make it easier for scientists to "see" further than the rover which is limited in its vision due to being so close to the ground.

Eventually, humans are going to have helicopters flying on Mars. Pretty amazing. One can only imagine what they will they think of next.

Guided practice answer key

1. Round Trip Distance = 260 m	Climb Angle = 67°	Average Speed = 2.17 m/s
2. Round Trip Distance = 335 m	Climb Angle = 27°	Average Speed = 2.48 m/s
3. Round Trip Distance = 646 m	Climb Angle = 8°	Average Speed = 4.46 m/s
4. Round Trip Distance = 1,105 m	Climb Angle = 5°	Average Speed = 7.36 m/s
5. Round Trip Distance = 805 m	Climb Angle = 6°	Average Speed = 5.55 m/s

RocketSTEM Word Find

Z	E	E	H	C	N	A	L	A	V	A	U	R	E	V	O	H	U	P	L
C	S	X	Q	T	Y	T	R	E	T	P	O	C	I	L	E	H	M	V	A
S	E	F	O	N	S	E	R	E	H	P	S	O	M	T	A	C	Z	E	N
C	R	N	U	M	E	O	A	P	E	C	U	R	I	O	S	I	T	Y	D
F	E	C	U	O	A	M	O	L	H	Z	Z	X	W	D	Z	S	R	M	I
L	C	F	V	Y	K	R	T	B	C	L	I	M	A	T	E	H	F	G	N
A	R	V	E	S	T	A	S	D	B	T	L	O	O	U	Q	K	E	N	G
M	E	K	R	Q	Y	T	I	N	U	T	R	O	P	P	O	E	L	X	V
E	F	W	N	O	Z	Z	L	E	S	G	E	N	E	C	E	R	N	A	N
T	I	U	T	S	H	A	I	L	L	E	R	A	P	A	I	H	C	S	B
R	L	R	E	H	C	N	U	A	L	E	L	I	B	O	M	B	M	P	Q
E	L	Y	X	P	R	O	P	E	L	L	A	N	T	O	M	E	E	B	N
N	A	N	A	A	Y	L	A	G	N	A	M	X	W	U	I	P	R	A	Y
C	O	D	O	P	P	L	E	R	A	F	C	V	S	R	M	K	L	F	E
H	N	W	A	D	V	O	L	C	A	N	I	C	D	O	M	E	I	F	S
Z	C	R	A	T	E	R	V	E	N	A	H	T	E	M	H	M	N	Y	S
D	A	P	H	C	N	U	A	L	N	N	E	L	G	N	H	O	J	I	Y
Z	F	M	J	Z	I	A	L	A	M	R	E	H	T	O	R	D	Y	H	D
C	F	E	X	S	A	H	U	N	A	M	O	N	S	R	E	V	O	R	O
C	Y	V	A	E	H	N	O	C	L	A	F	B	S	K	J	L	O	M	W

Ahuna Mons
Atmosphere
Avalanche
Boost
Ceres
Climate
Crater
Curiosity
Dawn
Doppler
ExoMars

Falcon Heavy
Flame Trench
Gene Cernan
Helicopter
Hover
Hydrothermal
John Glenn
Landing
Launchpad
Mangalyaan
Merlin

Methane
Mobile Launcher
Nozzle
Odyssey
Opportunity
Propellant
Refill
Rover
Schiaparelli
Vesta
Volcanic Dome

Cosmic 'winter' wonderland

Although there are no seasons in space, this cosmic vista invokes thoughts of a frosty winter landscape. It is, in fact, a region called NGC 6357 where radiation from hot, young stars is energizing the cooler gas in the cloud that surrounds them.

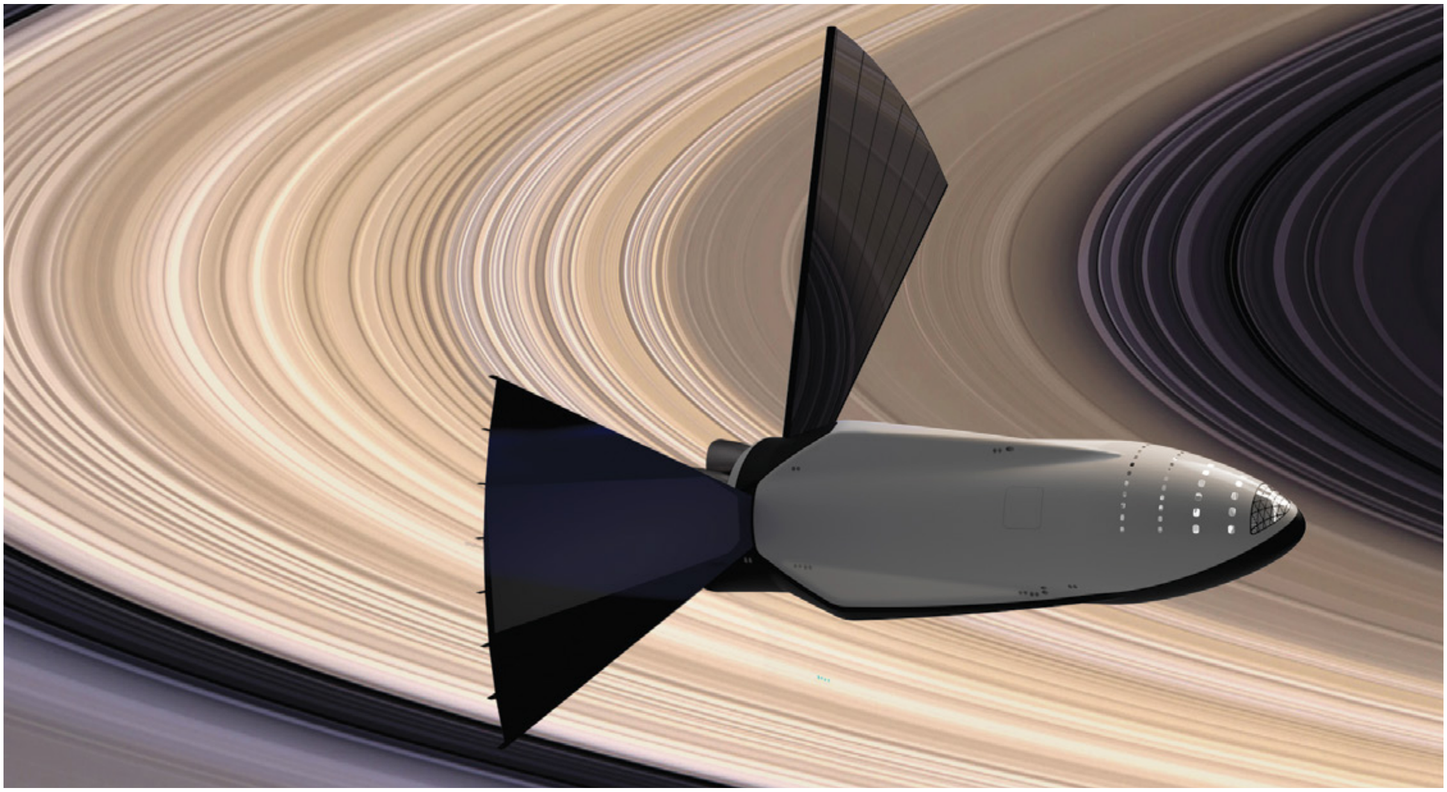
This composite image contains X-ray data from NASA's Chandra X-ray Observatory and the ROSAT telescope (purple), infrared data from NASA's Spitzer Space Telescope (orange), and optical data from the SuperCosmos Sky Survey (blue) made by the United Kingdom Infrared Telescope.

Located in our galaxy about 5,500 light years from Earth, NGC 6357 is actually a "cluster of clusters," containing at least three clusters of young stars, including many hot, massive, luminous stars. The X-rays from Chandra and ROSAT reveal hundreds of point sources, which are the young stars in NGC 6357, as well as diffuse X-ray emission from hot gas. There are bubbles, or cavities, that have been created by radiation and material blowing away from the surfaces of massive stars, plus supernova explosions.

Astronomers call NGC 6357 and other objects like it "HII" (pronounced "H-two") regions. An HII region is created when the radiation from hot, young stars strips away the electrons from neutral hydrogen atoms in the surrounding gas to form clouds of ionized hydrogen, which is denoted scientifically as "HII".

Researchers use Chandra to study NGC 6357 and similar objects because young stars are bright in X-rays. Also, X-rays can penetrate the shrouds of gas and dust surrounding these infant stars, allowing astronomers to see details of star birth that would be otherwise missed.

Credit: X-ray: NASA/CXC/PSU/L.Townsley et al; Optical: UKIRT; Infrared: NASA/JPL-Caltech



44

Elon Musk unveils plans for an Interplanetary Transport System

42

SpaceX is preparing to debut Falcon Heavy from same pad where Apollo 11 launched

28

The evolution
of KSC's historic
Launch Complex 39A

America's GATEWAY TO SPACE: LC-39A

Story by Lloyd Campbell

Credit: NASA via Retro Space Images

The iconic launch pads, Pads 39A and 39B at Kennedy Space Center's Launch Complex 39, have been the starting point for many space flights including the first manned lunar landing. The original design for Launch Complex 39 called for three to five launch pads, designated 39A – 39E, that would have been spaced approximately 1.6 miles apart to protect them from damage if any mishaps occurred at an adjacent pad. Also part of Launch Complex 39 is the Vehicle Assembly Building, or VAB. Towering more than 500 feet, it can be seen easily from miles away. The Launch Control Center, or LCC, where all the launch controllers, support personnel, and equipment required to safely launch a vehicle from either of the launch pads is also a part of the large complex.

Pad 39A from sand to Apollo

Pad 39A was originally designated to be Pad 39C in the complex's original plan, however it became 39A when plans to build the three additional pads were scrapped in 1963. Launch Complex 39's A pad was completed first. Construction began in November of 1963 and was completed in early September 1965. Built on around a quarter square mile of land, the launch site is an eight sided polygon and measures 3,000 feet across. The pad itself is 390 feet by 325 feet and is constructed of reinforced concrete. The hardstand stands 48 feet above sea level. To get from sea level up to the hard stand, a five-percent sloped ramp was constructed. Which raises the question, "Why build up and not down to avoid having to have a ramp up to the pad?". The answer is simple, the pads are located in Florida just a quarter mile away from the Atlantic Ocean, and digging down just a few feet you will encounter water. So to protect all the equipment and facilities that are under the pad, the decision to build above ground was made.

For Apollo, the pad would be a clean pad, no structure, towers, or other support equipment was located on top of the pad. All these items would be brought with the vehicle. The vehicle was assembled on a massive platform known as a Mobile Launcher. On the Mobile Launcher was a Launch Umbilical Tower (LUT) and a mobile service structure which allowed for crew access, all the umbilical connections for the rocket, elevators, service platforms, everything you needed to get the vehicle ready for launch on the pad. The Mobile Launcher was transported by a new vehicle, called the Crawler, from the Vehicle Assembly Building out to the pad. The Mobile launcher would be lowered onto pedestals located atop the hardstand.

Without the Mobile Launcher at the pad, from the outside mostly what you see at Pad 39A is the pad itself, however much more lies beneath the exterior. A two-story pad terminal connection room which houses all of the electronic equipment that would connect the Launch Control Center with the Mobile Launcher when it's on the pad, is located on the western side of the pad. Also on the same side is the environmental control systems room which supports the air conditioning and water systems. Beneath the east side of the pad is the high-pressure-gas storage facility, where nitrogen and helium gases piped from the converter-compressor

Aerial views of Launch Complex 39A during construction throughout 1964 and 1965. Unless otherwise noted, all photos are credit of NASA and Retro Space Images.

facility would be distributed from. Dissecting the east and west sides is the 58 foot wide, 450 foot long, Flame Trench. A Flame Deflector, weighing some 700 tons, would be rolled into place via a rail system in the Flame Trench until it was just under the rocket. The deflector directed the flames down the trench and away from the vehicle and pad.

Also located inside of the pad area is a blast room. If a hazardous condition came up that required the Apollo astronauts to egress from the spacecraft, they would move from the spacecraft back to the Mobile Launcher's tower and ride the high speed elevator down 30 stories, in about 30 seconds. Then they would slide down an escape tube to the blast room. The blast room has thick steel doors which could withstand the explosion if the vehicle erupted on the pad. The crew could survive for at least 24 hours in the blast room until they could be rescued.

The first flight from Pad 39A would be Apollo 4, an unmanned test of the great Saturn V rocket. Following it would be another unmanned test, Apollo 6. The third launch was the historic first trip to the moon, Apollo 8, which took Frank Borman, Jim Lovell, and Bill Anders on a trip to the moon where they did 10 orbits before coming back to Earth. And the fifth launch from Pad 39A would be Apollo 11, the first manned Lunar landing when Neil Armstrong and Buzz Aldrin became the first human beings to step on another space body. Pad 39A would be the starting point for every Saturn V mission except for Apollo 10 which launched from Pad 39B. Twelve flights of the Saturn V started at Pad 39A and half of them were the manned lunar landing missions. The pad's significance as a historical landmark will never be in question due to the fact the first manned landing missions to the Moon all began there. It also served as the launch pad for the Skylab orbiting outpost – our first space station – which was also the last flight of the Saturn V rocket and the last mission to launch from Pad 39A for more than six years.

From Apollo to Space Shuttle

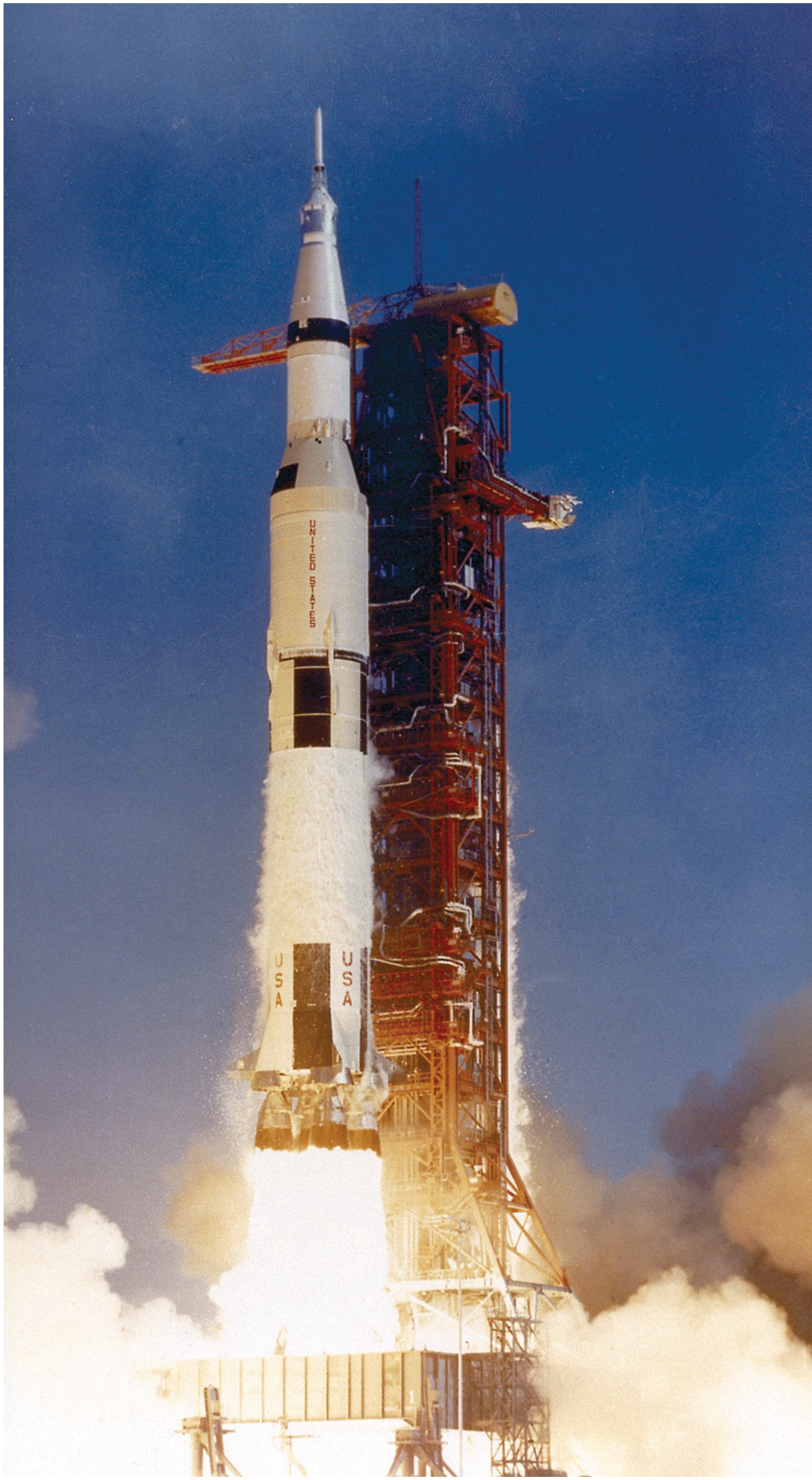
Shortly after Skylab launched, modifications to the pad began for the next step in our continuing exploration of space. The Space Shuttle program had been approved before the Apollo missions were even finished. In fact, Apollo 16 Commander John Young and his Lunar Module Pilot Charlie Duke were walking on the surface when word came up from Mission Control that the budget had passed, including the vote for the Space Shuttle program.

The Shuttle would be a totally different vehicle than the mighty Saturn V and Saturn 1B rockets that had flown from Launch Complex 39 up until now. While the new vehicle would be less than two thirds the height of the Saturn V, its design required a complete reconfiguration of the pad structure and the mobile launcher. A lot of work on the ground had to take place before the Shuttle would ever fly.

The pad would now be the permanent site for the umbilical tower, or as it was now called the Fixed Service Structure (FSS). This was not a completely new structure however, the upper portion of Launch Umbilical Tower (LUT) that Apollo used was removed from the Mobile Platform and installed on the Launch Pad 39A's hardstand to become the FSS.

A Saturn V rocket atop Launch Pad 39A with the fixed and mobile service structures in place.

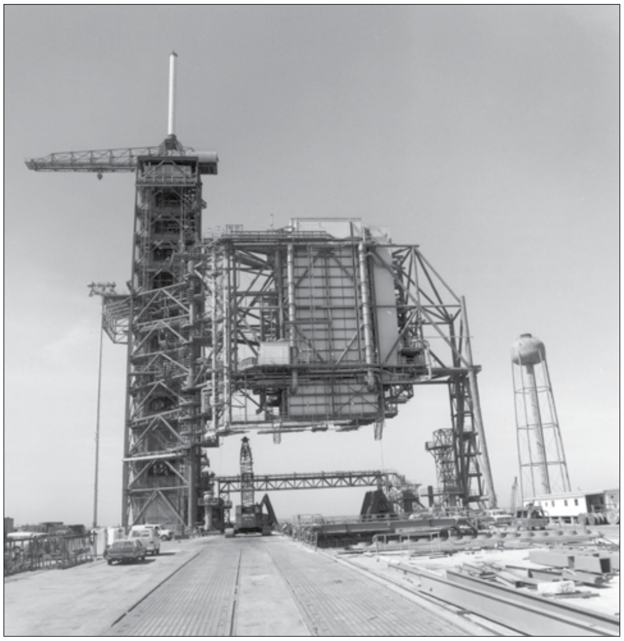
Aerial view of Launch Pad 39A during the Apollo/Saturn era.



The Apollo 11 Saturn V lifts off with Neil Armstrong, Michael Collins and Buzz Aldrin on July 16, 1969.

Standing 347 feet high, the new FSS would have 12 floors, 20 feet apart. Each floor is actually not solid, but metal grates, so looking down at your feet you can actually see down a number of floors. The exception is the 195 foot level where the crew accesses the orbit, it has solid floors because, well you'll find out later in the story. It had three access arms that provided services or access to the Shuttle. On top of the structure was a new 80 foot tall lightning mast, and just below the mast, an Apollo era Hammerhead crane was installed to be used for any heavy lifting operations needed at the pad. The crane was removed in 1994 when cost analysis revealed it to be more cost effective to bring in mobile cranes when needed rather than to maintain the Hammerhead crane.

Located between the 207 foot and 227 foot level of the FSS was the Gaseous Oxygen Vent Arm. On the end of that arm was a 13 foot diameter hood, known as the "Beanie Cap." The cap would heat gaseous oxygen that vented from the Shuttle's External Tank that could freeze and form potentially dangerous ice. The oxygen travels just a few feet away from the hood where it is safely released into the atmosphere. The arm would be in place before fueling and would be swung away approximately 2.5 minutes prior to launch.

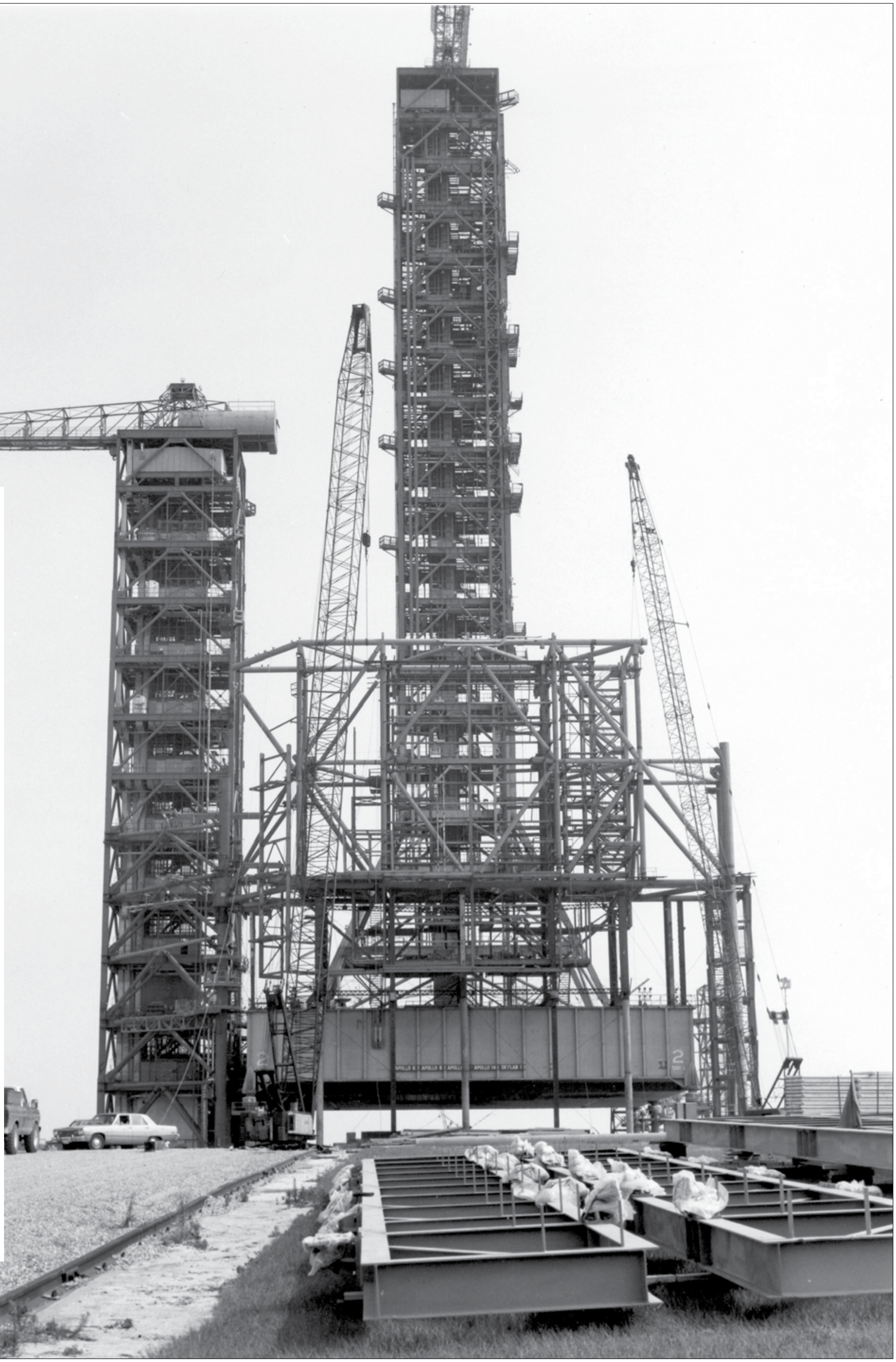


The Beanie Cap served an important purpose – preventing extremely cold oxygen that vented from the External Tank from turning into ice and potentionally damaging the launch vehicle.

Headed down the FSS, we next find the External Tank Hydrogen Vent Umbilical and Intertank Access Arm located at the 167 foot level. The 48 foot long arm gives the pad crew access to the External Tank intertank compartment if needed. It also allows for mating of the External Tank umbilical and vent lines. Around five days prior to launch, the arm is retracted leaving just the umbilical vent line connected to the External Tank to support tanking and launch. The vent line part of the umbilical serves basically the same purpose as the Beanie Cap, except venting hydrogen from the tank. Also rather than releasing the hydrogen close by, it is taken through the line, into a venting system that takes it far away from the pad where it is safely burned off. The line itself detaches at first motion of the vehicle at launch and is pulled away downward away from the vehicle and secured.

Finally at the 147 foot level you would find the Orbiter Access Arm. At 65 feet long, 5 foot wide, and 8 feet high, it's the largest arm on the FSS. This metal bridge provides access to the crew compartment of the orbiter. Located at the end of the arm is the "White Room," an environmentally controlled chamber which mates with the orbiter and can hold up to six people. After the crew is loaded and all the pad personnel have left, the arm remains in place until 7 minutes and 24 seconds prior to the launch to serve as an emergency escape if needed. After that time it can be repositioned in about 15 seconds if any emergency arises.

Looking like a giant erector set, Launch Pad 39A underwent major renovation in the 1970s to evolve it from the Apollo era 'clean' pad to include more fixed structures to support Space Shuttle launches.



Fueling of the Shuttle required a lot of propellant as the External Tank held over 500,000 gallons of propellants. Two spheres on opposite sides of the pad perimeter, approximately 3,000 feet apart, held the propellants until they were pumped into the Shuttle's External Tank. One tank could hold up to 900,000 gallons of liquid oxygen at –297 degrees Fahrenheit while the other tank could hold 850,000 gallons of liquid hydrogen at –423 degrees Fahrenheit. The propellants were transferred from the storage tanks in vacuum-jacketed lines that feed into the orbiter and External Tank via the tail service masts on the mobile launcher platform.

The Apollo blast room was mothballed and instead a new Emergency Egress System was installed. The new system was located at the 195 level of the FSS, the same height as the Crew Access Arm, and is a slide wire system with baskets for astronauts and pad workers to speedily escape the pad in the event of an emergency. In 135 launches, the system was never used, however if it had been, fire nozzles would release heavy sprays of water over the pad area. Remember earlier I mentioned how the 195 foot level had a solid floor? The water spray would be so heavy that the crew and pad personnel would only be able to see their feet and the floor, so a bright yellow pathway was painted on the floor, sometimes humorously referred to by the pad and crew as the Yellow Brick road, this would lead them to the escape baskets.

At the slidewire basket landing area, STS-116 crew members sit in one of the baskets used for emergency egress away from the launch pad. From left are Pilot William Oefelein and Mission Specialists Joan Higginbotham and Christer Fuglesang. Credit: NASA/Kim Shiflett

Seven baskets and slide wires were in place, each basket capable of transporting three people to the ground some 1200 feet to the west of the pad in just 90 seconds. The basket would reach a top speed of 55 MPH and would be slowed by a drag chain before coming to a complete stop in the catch net at the end of the system. When reaching the ground, the crew and pad personnel would find a bunker and one or more M-113 Armored Vehicles. In the event of an imminent detonation, the bunker could provide the best protection; otherwise they would board the M-113 Armored Vehicles and make a hasty departure to a safe zone more than a mile away from the pad.

Another addition to the pad would be the Sound Suppression Water System. With the orbiter so close to the Mobile Launcher, the sound waves produced by the three Space Shuttle Main Engines and the massive Solid Rocket Boosters upon ignition could have possibly damaged anything in the orbiter's cargo bay and possibly the orbiter itself. The solution was to reduce the sound waves with a flow of water over the Mobile Launch Platform and the pad itself. A 300,000 gallon water tank located on the northeast side of the pad contains

36

Crew members of space shuttle Discovery's STS-133 mission (left) ride in an M-113 armored personnel carrier, which is kept at the foot of the launch pad in case of an emergency.

The Mobile Launch Platforms (right) have served both the Apollo and Space Shuttle programs, and have undergone renovation to also be used for the SLS program.

Closeup view of Launch Pad 39A (below) showing both Service Structures, the Flame Trench and a MLP with Atlantis atop it. Credit: Chase Clark

Space Shuttle Columbia (inset top) arrives at Launch Pad 39A on Dec. 29, 1980, in preparation for its maiden liftoff on April 12, 1981.

Space Shuttle Atlantis (inset left) is seen as it lifts off from Kennedy Space Center to begin the STS-132 mission on May 14, 2010. Credit: Chase Clark

The exhaust plume (left) from Space Shuttle Atlantis is seen through the window of a Shuttle Training Aircraft (STA) as it launches from NASA's Florida spaceport on July 8, 2011. Credit: NASA/Dick Clark

the water used in the system. Using gravity alone, the water is dumped onto the MLP and the Flame Trench of the pad via a system of quench nozzles, also known as "rainbirds". When a Shuttle would launch, the intense heat from the engines would turn much of the water into steam, resulting in the large white cloud seen around the pad prior to booster ignition.

Attached to the FSS is the Rotating Service Structure or RSS. The main purpose of the RSS is to allow installation and servicing of the Shuttle's payload for that mission, at the pad. It also allows technicians access to certain systems on the orbiter. A typical Shuttle launch begins a month or so prior to liftoff when the Shuttle, aboard the Mobile Launch Platform, is moved to the pad. Having payload installation at the pad allows the payload to be loaded much further along in the launch processing.

Measuring in at a healthy 102 feet long, by 50 feet wide, and 130 feet high, the RSS is quite a sight on its own. It rotates 120 degrees and is moved away from the Shuttle well before fueling and launch. The Payload Changeout Room is the main feature of the RSS. It's an environmentally controlled area that is enclosed and supports the delivery of the payload to the orbiter's payload bay. Also if the payload requires any servicing at the pad it is performed there. Inside there are five platform levels that allow access to the payload.

Two other parts of the RSS, the Orbiter Midbody Umbilical Unit, and the Hypergolic Umbilical unit, provide access and service to two important areas of the orbiter. The first provides fluids to the orbiter's reactant storage and distribution system as well as fuel for the orbiter's three fuel cells. The Hypergolic Umbilical Unit supplies Hypergolic fuel and oxygen service lines along with helium and nitrogen service lines which supply the orbiter's Orbital Maneuvering System (OMS) pods.

Of the 135 Space Shuttle missions, Pad 39A served as the launch pad for 80 of them, including the first mission, STS-1, and the last mission, STS-135.

Other notable Space Shuttle missions to launch from Pad 39A

- STS-7, which carried Sally Ride, the first female American Astronaut into orbit
- STS-41c, the first mission to retrieve, repair, and re-deploy a satellite (SolarMax)
- STS-82 – the second Hubble Space Telescope servicing mission
- STS-103 – the third Hubble Space Telescope servicing mission
- STS-109 – the fourth Hubble Space Telescope servicing mission (The last successful mission by Columbia)
- STS-125 – the fifth and final Hubble Space Telescope servicing mission
- Also many of the International Space Station assembly missions, Spacehab missions, and Shuttle/Mir docking missions were launched from Pad 39A. Pad 39A saw the last launch of every orbiter except for Challenger.

A Falcon 9 rocket lifts off from the historic LC-39A launch pad – the first commercial rocket to ever do so – to begin the CRS-10 mission to the ISS. Credit: SpaceX

Pad 39A moves from NASA to commercial providers

After the Shuttle program ended, NASA turned its attention to its next vehicle, the Space Launch System. A new rocket, derived from the Shuttle legacy which would launch humans beyond Earth orbit for the first time in over 40 years. This new vehicle would, like the Saturn V, bring all its support equipment with it to the pad, so the pad would once again be a clean pad. Work on Pad 39B to return it to a clean pad began even before the Shuttle program had ended. With a low flight rate, and a full Mobile Launcher being used to launch the new rocket, NASA determined in December of 2013 that it would only use Pad 39B, and the decision to lease Pad 39A to one of the commercial providers was made.

SpaceX was awarded the use of the iconic launch pad and signed a 20 year lease in April of 2014. Since that time SpaceX has already began modifications to the pad area including the construction of a new Horizontal Integration Facility where processing of their boosters and some payload integration will occur. SpaceX is looking at also doing payload integration vertically now as that is a requirement of getting contracts with the U.S. Air Force for launches. The new building is located alongside the crawlerway just before the incline to the hard stand.

The Flame Trench has been modified to accommodate Falcon 9 launches as well. The south side of the Flame Trench was completely filled in; all exhaust from the Falcon 9 launches will be directed out the north end of the trench via the Flame Deflector. That side has been resurfaced with refractory concrete to withstand the intense heat of launches.

The Fixed Service Structure from the Space Shuttle Program will be left in place for now. Modifications to accommodate crewed missions and access to the Dragon capsule will be made in the future. The Crew Access Arm from the Shuttle era was removed by NASA, presumably to be preserved for a museum or space facility to display.

New kerosene storage tanks have already been installed on the northeast side of the pad, the Falcon burns rocket grade kerosene (RP-1)and liquid oxygen (LOX), and SpaceX plans to utilize the liquid oxygen tank used by the Shuttle program for their LOX.

Falcon 9 rockets are moved horizontally to the pad on what is called a Transporter/Erector. Rails have been installed from the HIF up to the hard stand to guide the Transporter/ Erector to the pad. SpaceX recently tested the new Transporter/Erector at Pad 39A.

Launching of the Falcon Heavy from Pad 39A has been delayed numerous times over the past year and a half, however Pad 39A was returned to active use recently with the successful launch of the Falcon 9 rocket on Sunday, February 19 on the CRS-10 resupply mission to the International Space Station.

Later this decade, crewed missions once again will blast off from the historic pad. Initially just to the ISS, but SpaceX also has set its sight on establishing a colony on Mars beginning as soon as the following decade.

Artist's rendering of a Falcon Heavy rocket rising above KSC's Launch Complex 39A. Credit: SpaceX

SpaceX set to debut Falcon Heavy this year

By Cole Jetton

After a 'very fast fire', a four-month hiatus, a complicated anomaly, and a general shaking of confidence, SpaceX was finally able to launch – and land – their Falcon 9 rocket once again last month. This is the first of 27 missions for 2017, a slate of launches that will not only introduce the final version of the Falcon 9, but will also include SpaceX's next great launch vehicle, the Falcon Heavy.

Launching from the Kennedy Space Center at Launch Pad 39A, the maiden flight of the Falcon Heavy will lift off with 5,180,000 pounds of thrust. It's two boosters will run through most of their fuel first, then separate from the center core to prepare for landing maneuvers, a trademark of SpaceX's technology. Firing up its center engine during decent, and with the four steering grids, the two boosters simultaneously maneuver themselves to soft landings onto either one of SpaceX's barges or landing pads on mainland. Cruising far above them, the center core separates from the upper stage, delivering the demonstration payload into orbit. As before, the main stage flips its orientation, and begins its own decent. If everything goes as planned, SpaceX will be able to bring home all of its three rockets

Announced in April of 2011, the Falcon Heavy builds off the success of the Falcon 9 program, doubling SpaceX's current payload capacity. With the goal of almost full reusability, and a price tag of only $90 million, the Falcon Heavy rocket acts as the next step of SpaceX's journey to Mars.

At the center of the rocket stands a Falcon 9 Full Thrust, and on either side are two Falcon 9 first stages, which act as boosters for the rocket. Using Falcon 9 parts eliminates the need to develop alternative boosters, cutting down on developmental costs and complexity while increasing reliability. Each core has nine engines, and with each engine having a thrust-to-weight ration of 1:180, this will be both the most efficient and powerful rocket on the market.

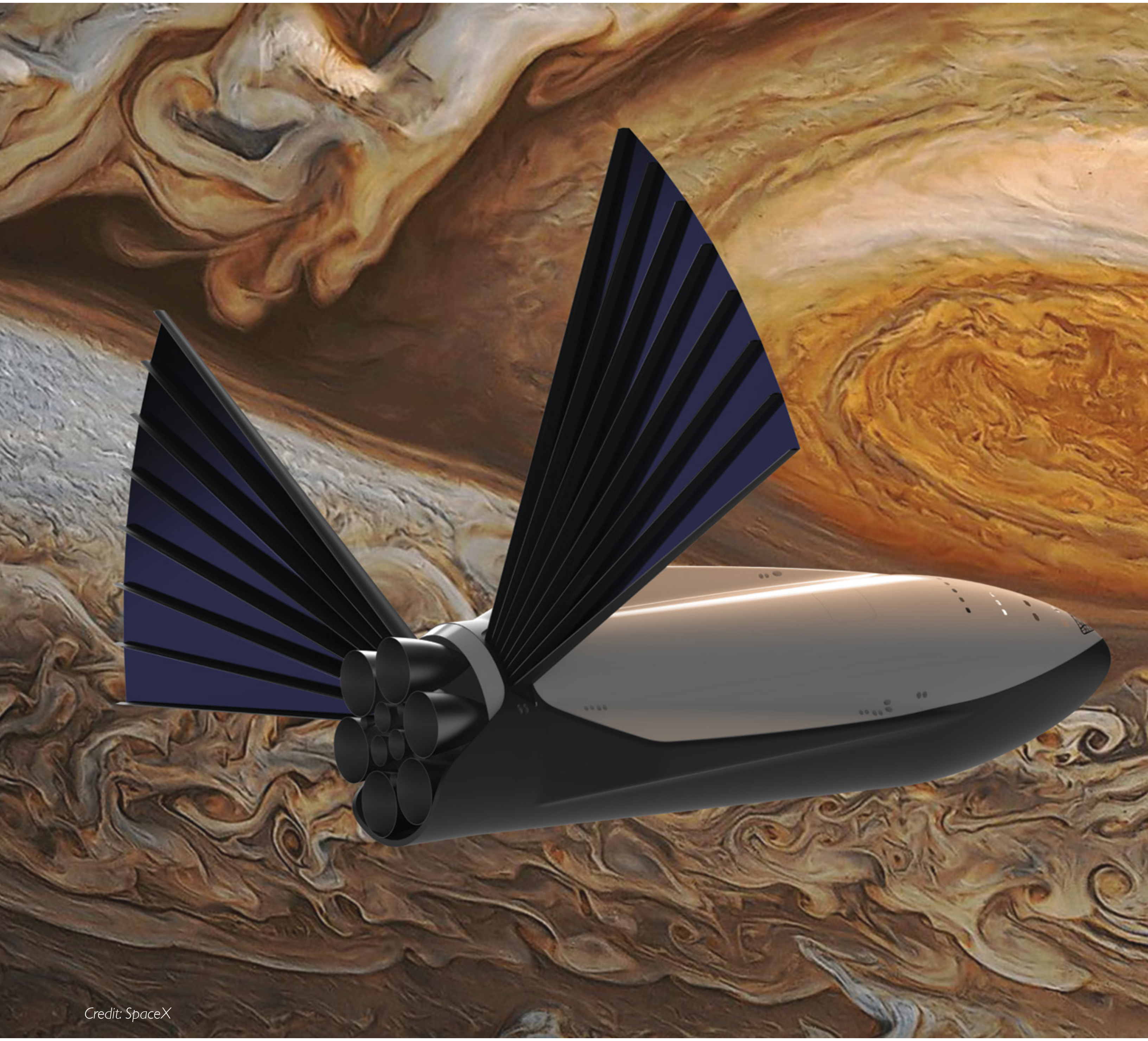
Stacked on top on the center core is the upper stage, which is powered by another Merlin engine. However this one is different, designed both to work in a vacuum and have a long and wider nozzle than those at the base of the rocket. A wider nozzle is necessary for optimal performance in a vacuum. This is because a rocket engine is most efficient when the pressure of the propellant exiting the nozzle is equal to its surrounding. For this type of nozzle, the wider the exit point, the lower the pressure.

While the Falcon Heavy is a technological marvel, the cost alone stands as a testament to the culture of persistence at SpaceX. The staggeringly low $90 million price tag allows for a lower "price-per-pound" for space missions, which brings launch costs down to as low as $750 per pound to low Earth orbit. Compare that to almost $6,000 per pound for the Delta IV Heavy – currently the most powerful rocket – and the decision of which to go with is quite clear. If anything, it shows the economic effectiveness of reusability.

Unsurprisingly, Elon Musk has been adamant about utilizing reusable rockets, a step that he believes is necessary in order to even consider colonizing other worlds. In September 2016, Musk unveiled the first details about the long rumored Interplanetary Transport System, an exploration platform that could open up the entire solar system to us. However, as inspiring as that is, it important to remind ourselves not to get too distracted with the next generation of space systems. The hard working scientists and engineers must remained focused, and take this one day at a time, perfecting the Falcon 9 and preparing for more rapid reuse and frequent flights.

A goal of the Falcon Heavy is the completion of the 2018 Red Dragon mission. This will be SpaceX's first time venturing out of Earth's orbit, working with NASA to land their Dragon v2 spacecraft on the surface of Mars. The team is working closely with NASA engineers, and is currently on track for a 2018 launch date, delivering their craft on a Trans-Mars Injection using a Falcon Heavy. NASA will be providing technical support for the company, sharing all the necessary information that they have learned from their previous Mars missions. If they succeed, then they shall be the first company to land on another planet in our solar system, a feat not many countries can even claim. Looking forward with optimism, it seems as if SpaceX has a bright future ahead of them.

Interplanetary Transport System



spacex's bold new vision for manned exploration of the solar system

By Cole Jetton

orbiting jupiter

refueling on enceladus

Credit: SpaceX

It has long been known that SpaceX's long term goal is the colonization of Mars. Everyone from the engineers to their CEO, Elon Musk, dreams of a world away from home. In September of 2016, we got a glimpse of how SpaceX is going to get there. At last, the long rumored Interplanetary Transport System was finally announced during the 67th International Astronautical Conference in Guadalajara, Mexico.

During his keynote address, "Making Humans a Multiplanetary Species," Musk revealed the first official details of SpaceX's next big leap in technology: the Interplanetary Transport System, or ITS for short. It's difficult to oversimplify it as a system because, as Musk noted, "everything is a system, including your dog." SpaceX plans on travelling to Mars, and hopefully other planets, using four pieces of hardware: the Booster, the Interplanetary Spaceship, the Refueling Craft and the Propellant Production plant. SpaceX has not released any details on the Propellant Production Plant; however the chemical process is well documented and relatively simple.

The pieces of launch hardware (the booster and two spaceships) will be constructed using a specialized carbon fiber designed to be non-interactive with the propellant inside. This will cut down on weight as it will allow the superstructure and the tank to all be one piece.

How will the whole system actually work, and how will it all fit together? Here's how the brilliance and ingenuity of SpaceX come into play.

First the passengers and supplies can be loaded onto the Interplanetary Spacecraft, which will sit atop the Booster. At the base of the Booster are 42 Raptor engines – the next generation of SpaceX's engines – each contributing 3,000 kilo-newtons (7,000 pounds) of liftoff force. As the rocket burns through its cryogenic liquid methane and oxygen fuel, the booster will have a total liftoff thrust of 128 mega-newtons (28,000,000 pounds). That's more than three times the power of the Saturn V, whose five F-1 engines provided a liftoff force of only 35 mega-newtons (7,800,000 pounds).

Simply because of the ITS's sheer size, the Saturn V is the only vehicle that has ever operated that's even remotely comparable, and still, it's a stretch to

draw any connections. The launch height of the ITS is 122 meters, compared to the 111 meters of the Saturn V. Additionally, the Saturn V was designed as a single use vehicle, delivering it's payload into orbit using an expendable three stage setup, meaning that after each use the hardware is simply dropped into the ocean. On the other hand, the Interplanetary Transportation System is a two stage vehicle and is designed to be fully reusable.

Once the Booster has delivered the Interplanetary Spacecraft to low Earth orbit, it will turn around and begin its descent back to Earth. Utilizing the method that SpaceX has become so famous for, the Booster will use its grid fins and engines to land back near the launch platform. At this point, the Booster can be refueled and the Refueling Craft is loaded on top for its next departure.

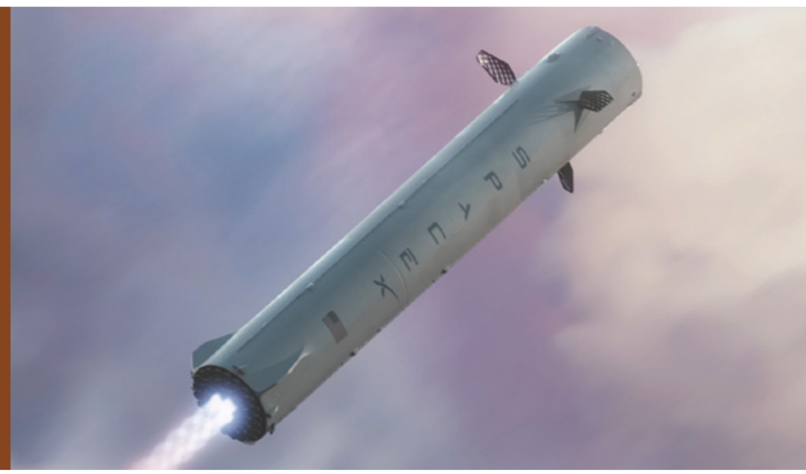
The Refueling Craft is the key to the system, compared to a Saturn V, for example, which used a three-stage rocket that maximized the payload, but increased both the cost and complexity of the mission. Refueling means that you don't have to bring as much mass with you in the first place, as you can simply launch the craft multiple times, which reduces mission complexity and vehicle size. Not refueling in orbit would require building a three-stage rocket at five to 10 times the size and cost.

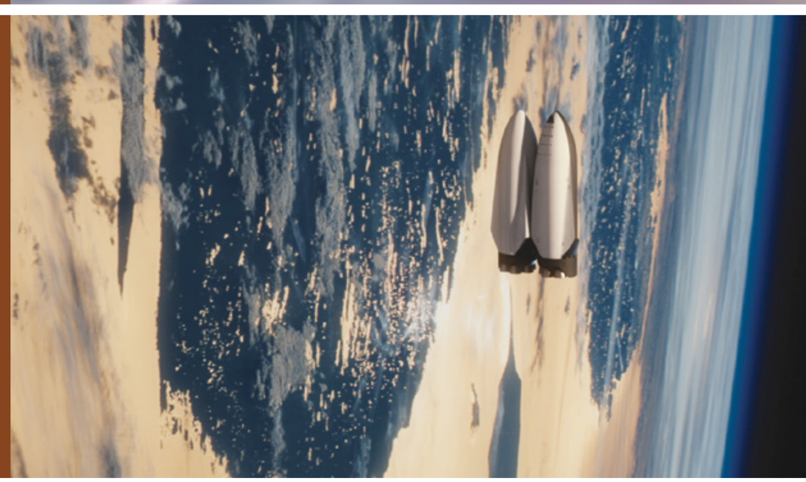
The Refueling Craft itself is almost externally identical to the Interplanetary Spacecraft, sharing the same superstructure which cuts down on development costs. At the base are six vacuum-optimized Raptor engines set around a set of three gimbled engines (each engine sits on controllable hydraulics to control the direction of the thrust). Before departing to Mars, the spacecraft will take on fuel from three to eight times, depending upon the mass of the payload.

Once the craft has begun its journey, two solar panels will be deployed and supply the craft with 200 kilowatts of electricity. It will coast away from Earth at 100,800 kilometers an hour towards Mars, before aerobraking in the Martian air as it prepares for landing. The craft is designed as a "lifting-body", echoing that of the now retired Space Shuttle, providing the lifting force during atmospheric entry to slow down the craft to

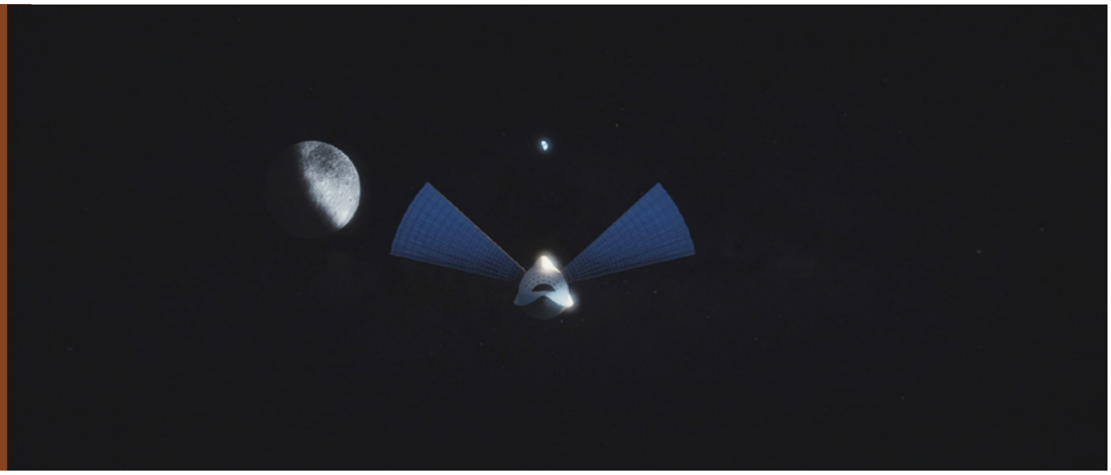

launch pad 39a

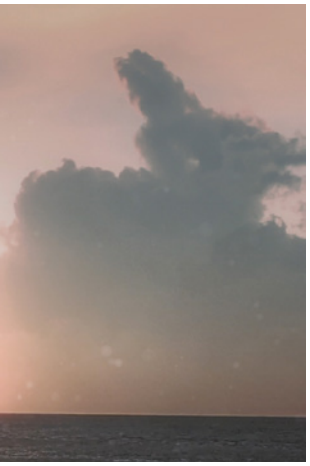

rocket launch


booster return


in earth orbit

venturing out



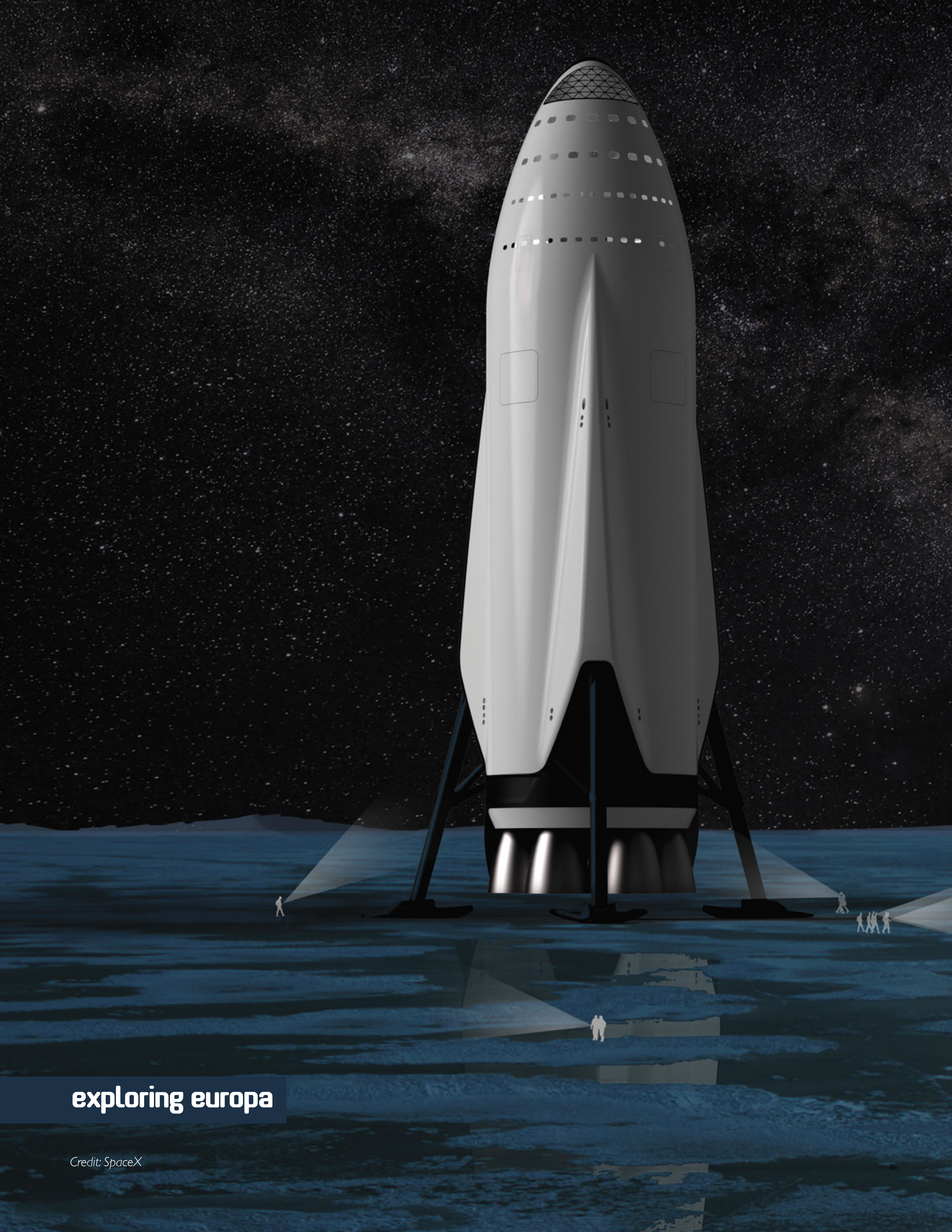


mars descent

touchdown

Credits: SpaceX

exploring mars



exploring europa

Credit: SpaceX

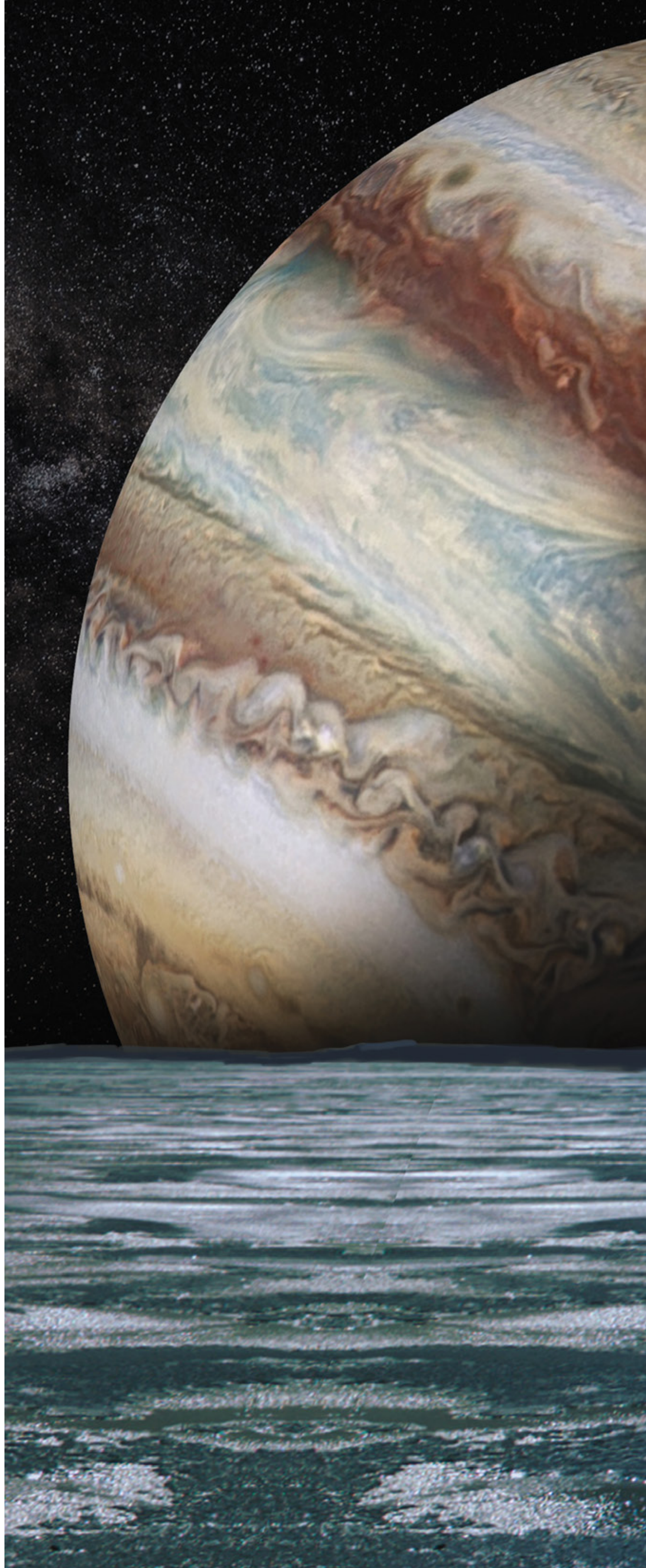
a desirable speed. Once it reaches that point the craft is able to rotate and fire up the three descent engines and land vertically on the Martian surface.

Luckily it's not a one-way trip. On the surface, the ship will be able to refuel using Mars' atmosphere and ice deposits. It only needs carbon dioxide (CO_2) and water (H_2O) which are then processed to produce methane (CH_4) and oxygen (O_2) for refueling. Since Mars has only 37.6% of the Earth's gravity, less fuel is needed for the return trip, eliminating the need for a booster. SpaceX hopes that the prospect of being able to return to Earth will encourage more colonists.

It has long been known that SpaceX's goal is to colonize Mars. Talk to one of their engineers and you'll understand the enthusiasm that they put into their work, even if they're not working on that particular project. They plan on bringing down the cost of a trip to Mars to the median cost of an American house, thereby hoping to encourage citizens to risk the trip out to the Red Planet. Each craft will deliver anywhere between 100 and 200 Martian colonists, with the final plan being to establish a self-sustaining colony by the end of the century.

As Musk noted near the end of the presentation last year, this is more than just a Mars colonization craft. It is the window into the rest of the solar system. Because of the propulsive landing capabilities and ability to refuel, one could theoretically visit any body in the solar system. If there were refueling stations in the asteroid belt, possibly utilizing the large ice deposits of the dwarf-planet Ceres, then the Interplanetary Spacecraft could 'hop' to the outer solar system.

With the hard work of the engineers and technicians at SpaceX, humanity is one step closer to putting people on Mars. As noted, however, the system can do so much more. It could take us to our Moon. We could travel to Ceres and Vestas in the asteroid belt. We even explore the moons of Jupiter and Saturn, heading into the ice crevasses of Europa or experimenting in the thick atmosphere of Titan. SpaceX's Interplanetary Transportation System opens up a gateway of possibilities, both on Mars and the rest of the solar system. This first step shows that SpaceX is serious about making humans a multiplanetary species.



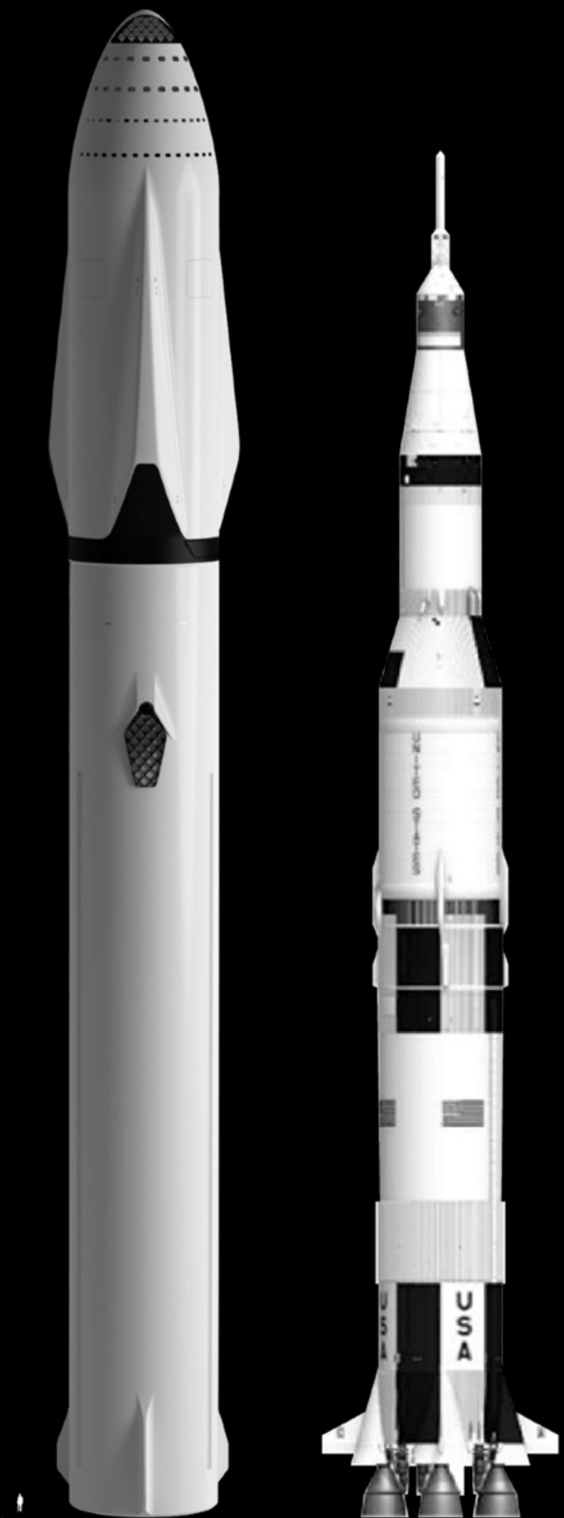
ITS BY THE NUMBERS

Select slides from Musk's presentation at the International Astronautical Conference

	MARS VEHICLE	SATURN V
GROSS LIFT-OFF MASS (t)	10,500	3,039
LIFT-OFF THRUST (MN)	128	35
LIFT-OFF THRUST (t)	13,033	3,579
VEHICLE HEIGHT (m)	122	111
TANK DIAMETER (m)	12	10
EXPENDABLE LEO PAYLOAD (t)	550	135
FULLY REUSABLE LEO PAYLOAD (t)	300	–

Credit: SpaceX

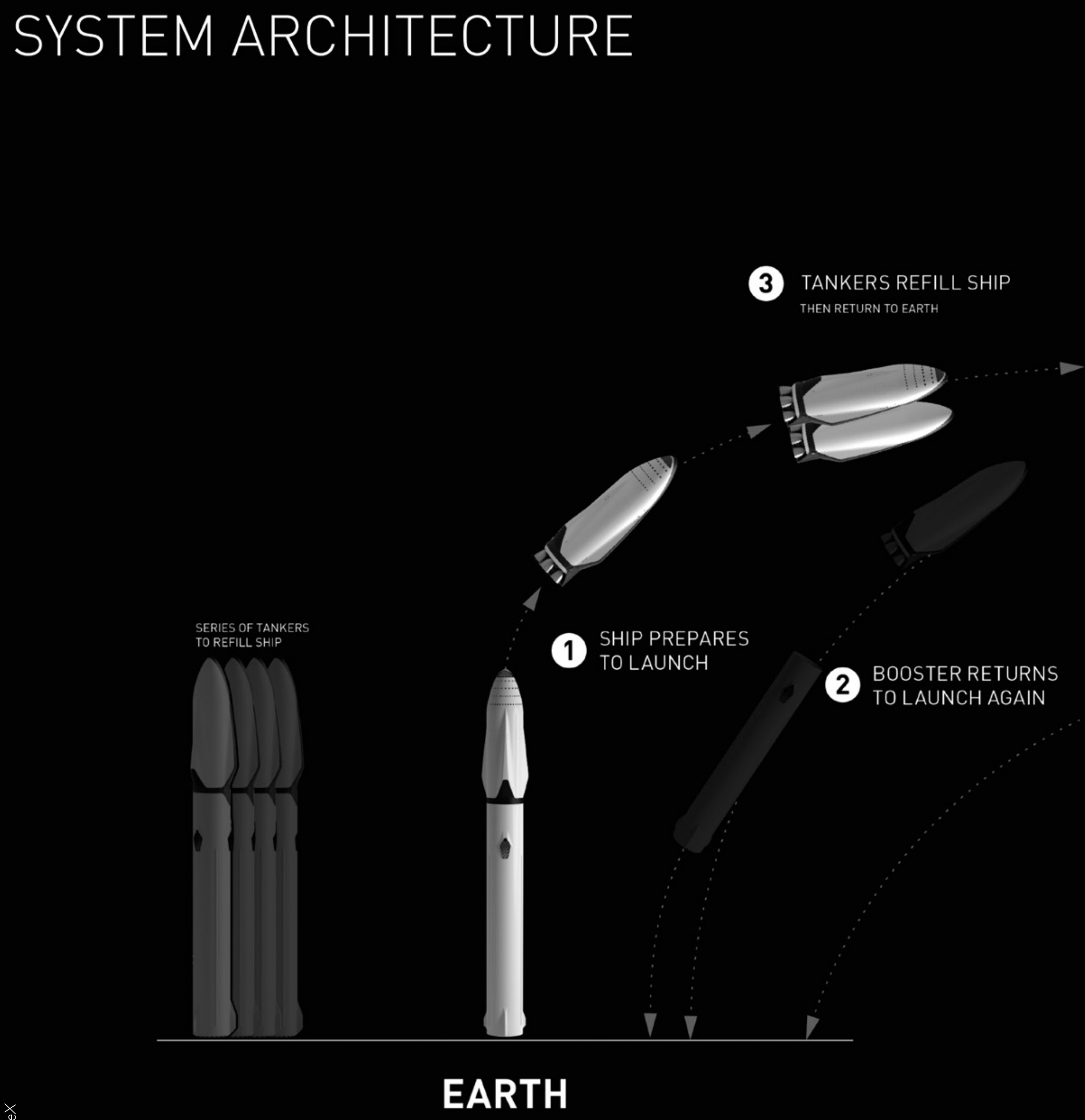
RATIO
3.5
3.6
3.6
1.1
1.2
4.1
–



HUMAN

ITS BY THE NUMBERS

Select slides from Musk's presentation at the International Astronautical Conference



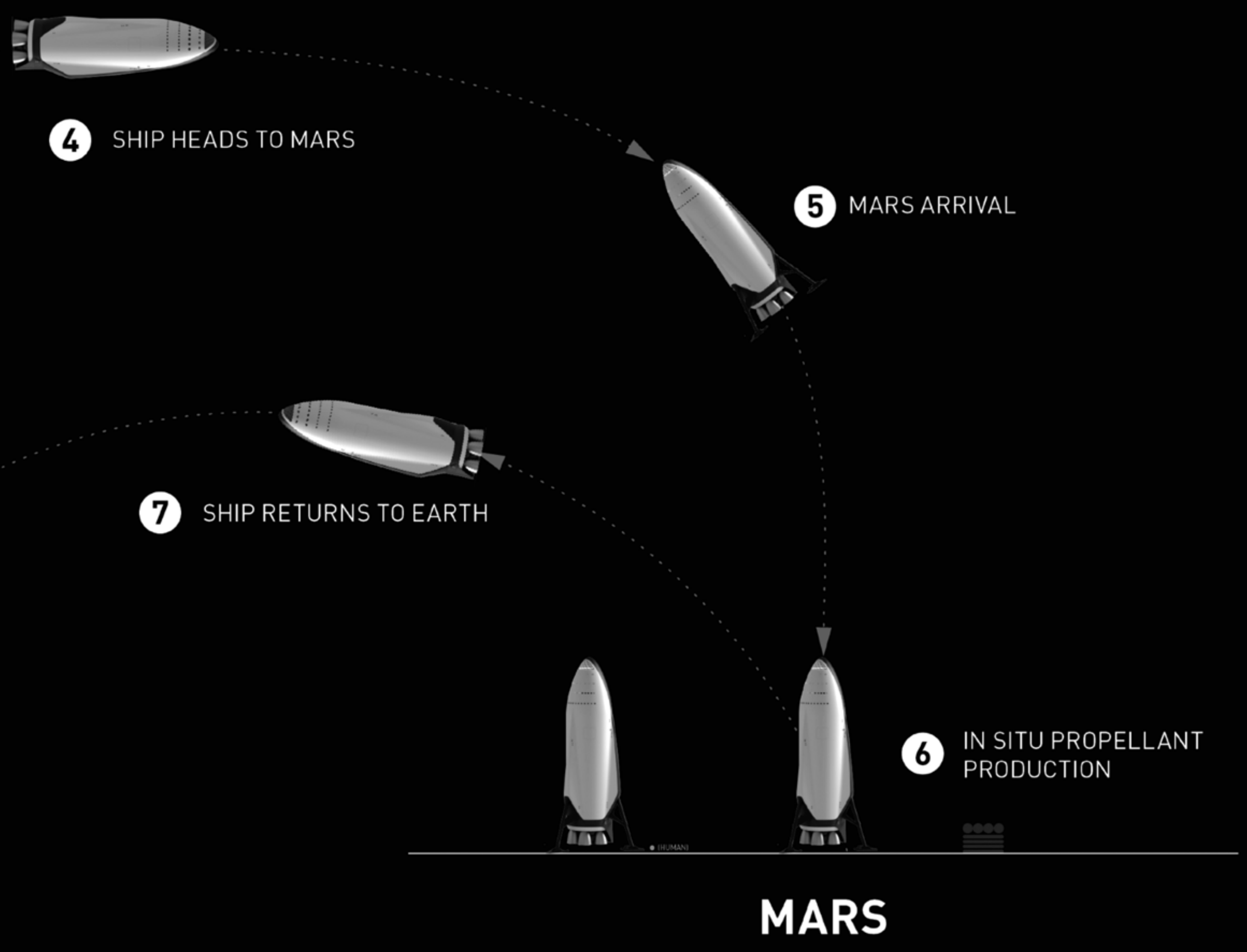
Credit: SpaceX

TARGETED REUSE PER VEHICLE

1,000 uses per booster

100 per tanker

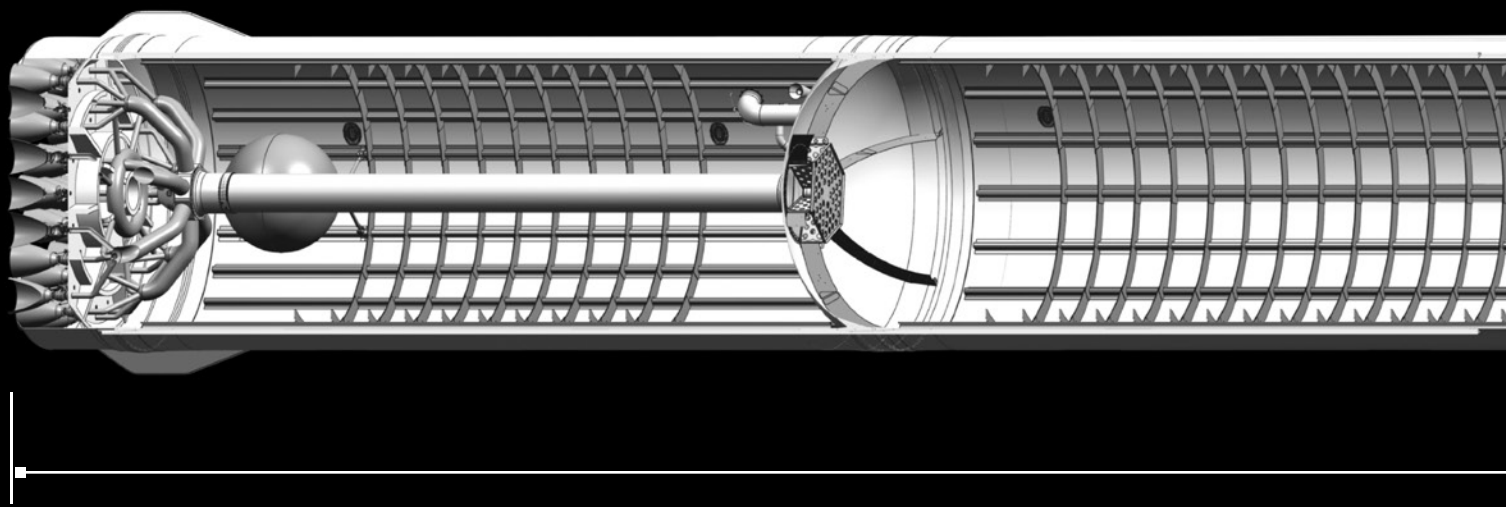
12 uses per ship



ITS BY THE NUMBERS

Select slides from Musk's presentation at the International Astronautical Conference

Carbon-fiber primary structure
Densified CH_4/O_2 propellant
Autogenous pressurization



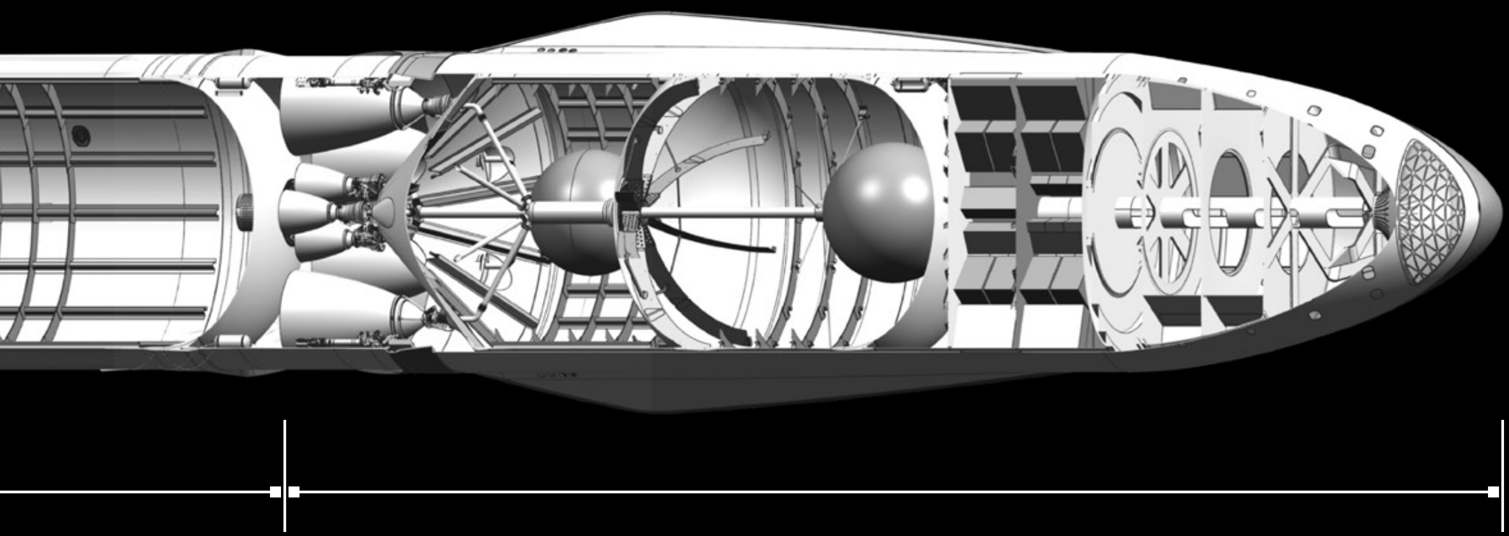
Length	77.5 m
Diameter	12 m
Dry Mass	275 t
Propellant Mass	6,700 t
Raptor Engines	42
Sea Level Thrust	128 MN
Vacuum Thrust	138 MN

Booster accelerates ship to staging velocity, traveling 8,650 km/h (5,375 mph) at separation

Booster returns to landing site, using 7% of total booster prop load for boostback burn and landing

Grid fins guide rocket back through atmosphere to precision landing

Credit: SpaceX



Length	49.5 m
Max Diameter	17 m
Raptor Engines	3 Sea-Level - 361 Isp
	6 Vacuum - 392 Isp
Vacuum Thrust	31 MN
Propellant Mass	Ship: 1,950 t
	Tanker: 2,500 t
Dry Mass	Ship: 150 t
	Tanker: 90 t
Cargo/Prop to LEO	Ship: 300 t
	Tanker 380 t
Cargo to Mars	450 t (with transfer on orbit)

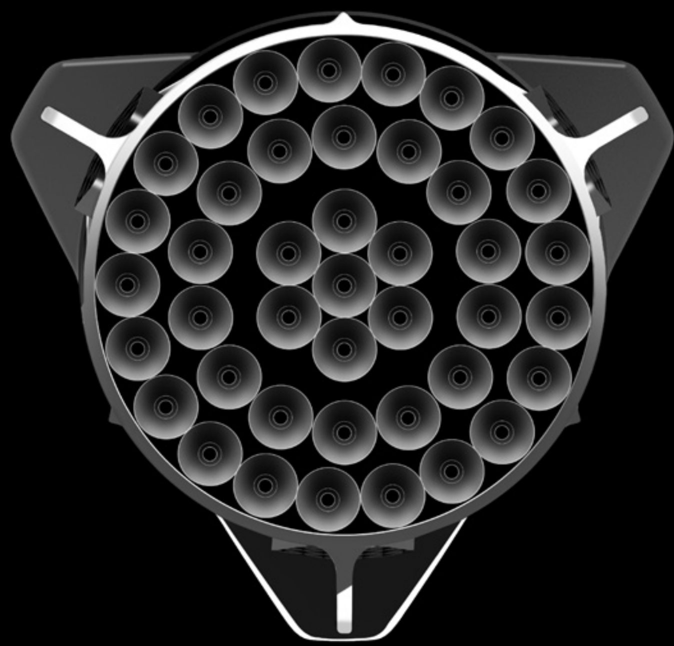
Long term goal of 100+ passengers/ship

ITS BY THE NUMBERS

Select slides from Musk's presentation at the International Astronautical Conference

RAPTOR ROCKET ENGINE

Credit: SpaceX



Cycle	Full-flow staged combustion
Oxider	Subcooled liquid oxygen
Fuel	Subcooled liquid methane
Chamber Pressure	300 bar
Throttle Capability	20% to 100% thrust
Sea-Level Nozzle	Expansion Ratio: 40 Thrust (SL): 3,050 kN Isp (SL): 334 s
Vacuum Nozzle	Expansion Ratio: 200 Thrust: 3,500 kN Isp: 382 s
Engine configuration	Outer ring: 21 Inner ring: 14 Center cluster: 7 Outer engines fixed in place Only center cluster gimbals

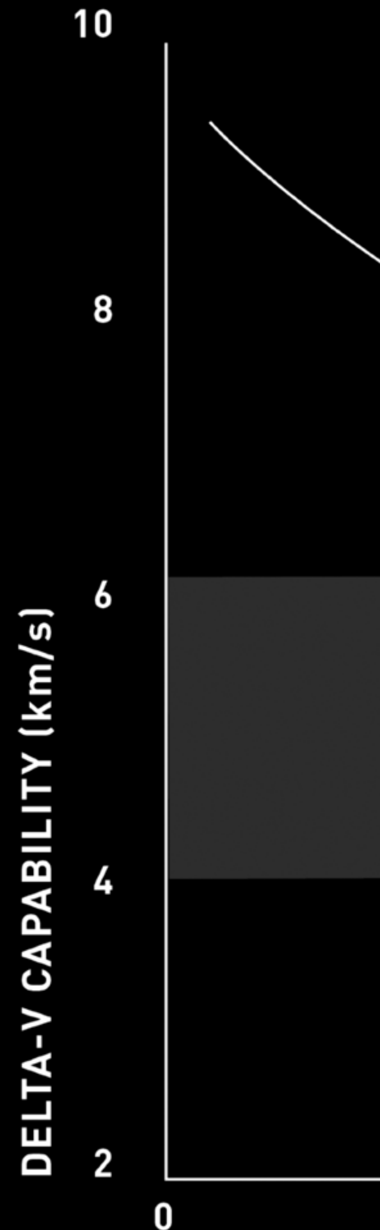
ITS BY THE NUMBERS

Select slides from Musk's presentation at the International Astronautical Conference

SHIP CAPACITY WITH FULL TANKS

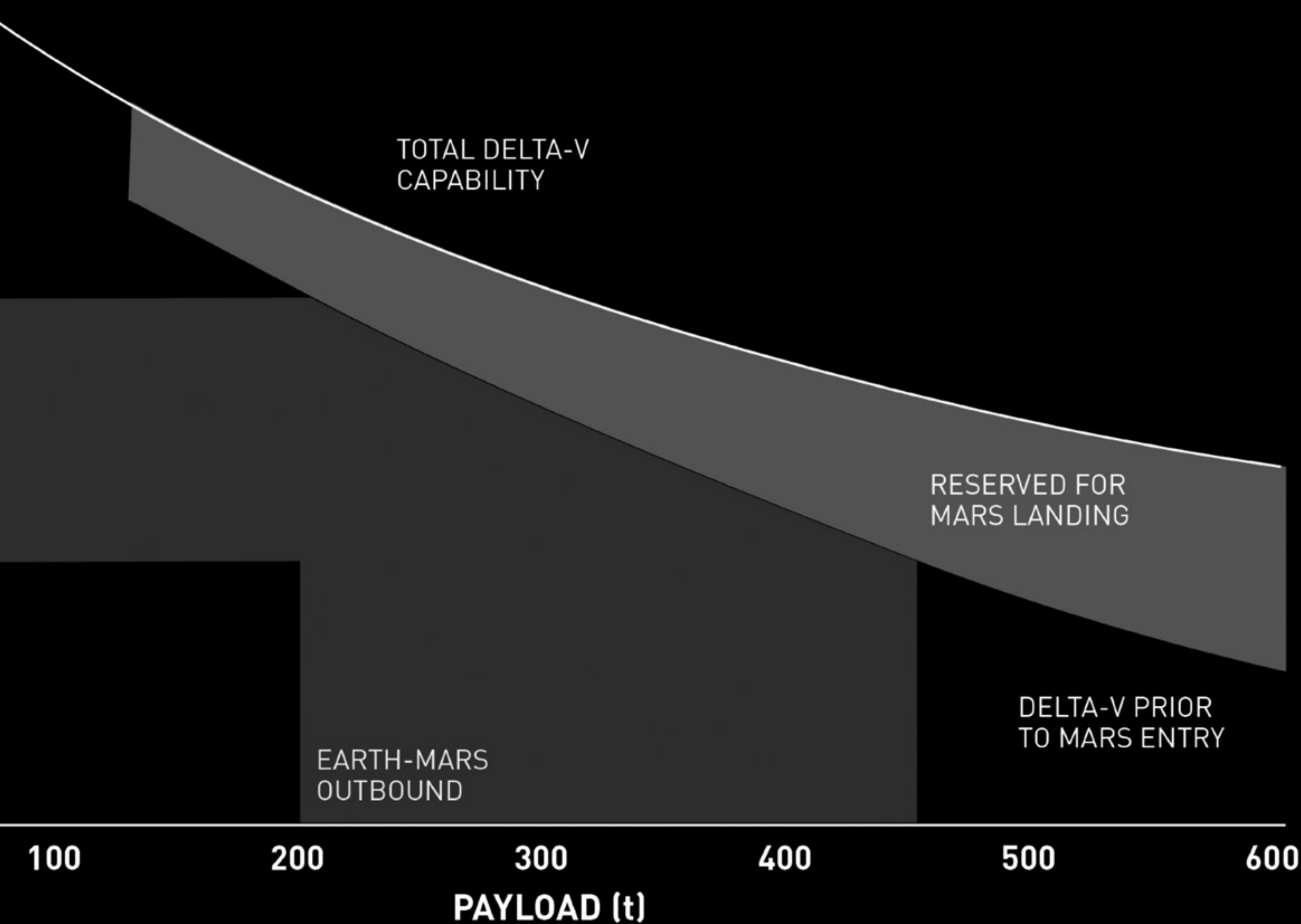
EARTH-MARS TRANSIT TIME (DAYS)
BY MISSION OPPORTUNITY

YEAR	TRIP TIME (d)
2020	90
2022	120
2024	140
2027	150
2029	140
2031	110
2033	90
2035	80
2037	100
AVERAGE	**115**



TMI DELTA V: 6 km/s
Mars Entry Velocity: 8.5 km/s

Credit: SpaceX


TOTAL DELTA-V
CAPABILITY
RESERVED FOR
MARS LANDING
DELTA-V PRIOR
TO MARS ENTRY
EARTH-MARS
OUTBOUND
100
200
300
400
500
600
PAYLOAD (t)

India lofts 104 satellites to set single-launch record

In a record-breaking flight, ISRO's Polar Satellite Launch Vehicle (PSLV) successfully orbited the 714 kg Cartosat-2 Series satellite along with 103 co-passenger satellites on February 15 from the Satish Dhawan Space Centre in Sriharikota, India.

PSLV-C37 lifted off at 9:28 am IST, as planned, from the First Launch Pad. After a flight of 16 minutes 48 seconds, the satellites achieved a polar Sun synchronous orbit of 506 km inclined at an angle of 97.46 degrees to the equator. In the succeeding 12 minutes, all 104 satellites successfully separated from the PSLV fourth stage in a predetermined sequence beginning with Cartosat-2 series satellite, followed by INS-1 and INS-2.

After separation, the two solar arrays of Cartosat-2 series satellite were deployed automatically and ISRO's Telemetry, Tracking and Command Network at Bangalore took over the control of the satellite. The satellite will be brought to its final operational configuration following which it will begin to provide remote sensing services using its panchromatic (black and white) and multispectral (colour) cameras.

The co-passenger satellites comprised of 101 nano satellites, one each from Kazakhstan, Israel, Netherlands, Switzerland, United Arab Emirates (UAE) and 96 from the United States, as well as two nano satellites from India.

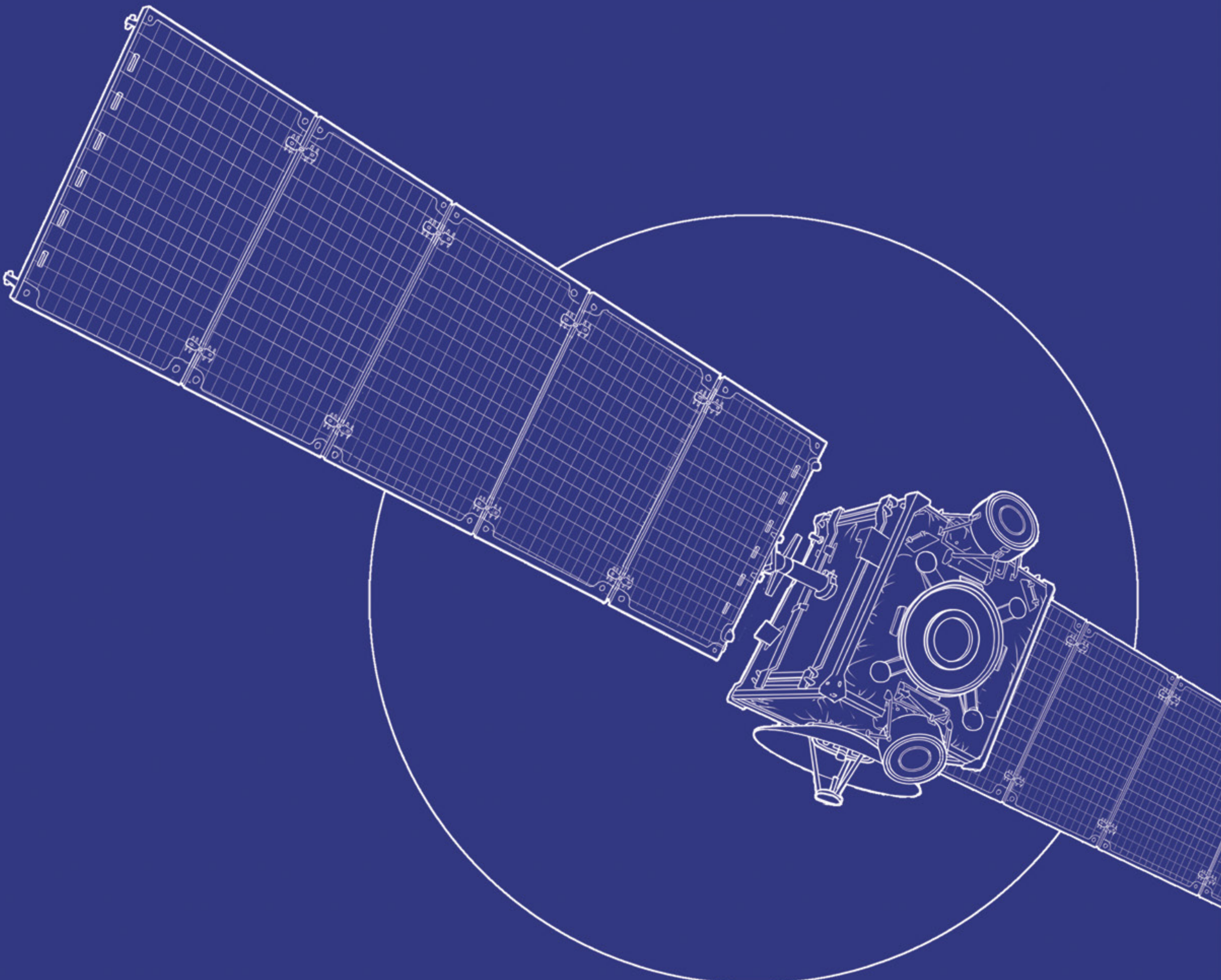
Among the 96 American satellites were 88 Dove satellites from Planet, a San Francisco based imaging company. It was the 15th launch of Dove satellites, which comprise the largest private satellite constellation in history, totalling 149 satellites.

PSLV-C37 also carried two ISRO Nano satellites (INS-1A and INS-1B), as co-passenger satellites. These two satellites carry a total of four different payloads from Space Applications Centre (SAC) and Laboratory for Electro Optics Systems (LEOS) of ISRO for conducting various experiments.

This was the sixteenth flight of PSLV in the 'XL' configuration which includes the use of solid strap-on motors. The total weight of the 104 satellites carried on-board PSLV-C37 was 1378 kg (3038 lb).

India's PSLV-C37 rocket lifts off with the Cartosat-2 Series satellite as well as 103 smaller co-passenger satellites. Credit: ISRO

Credit: ISRO



Original illustration by Sebastian Kings

Dawn's rich harvest
Ceres gives up secrets

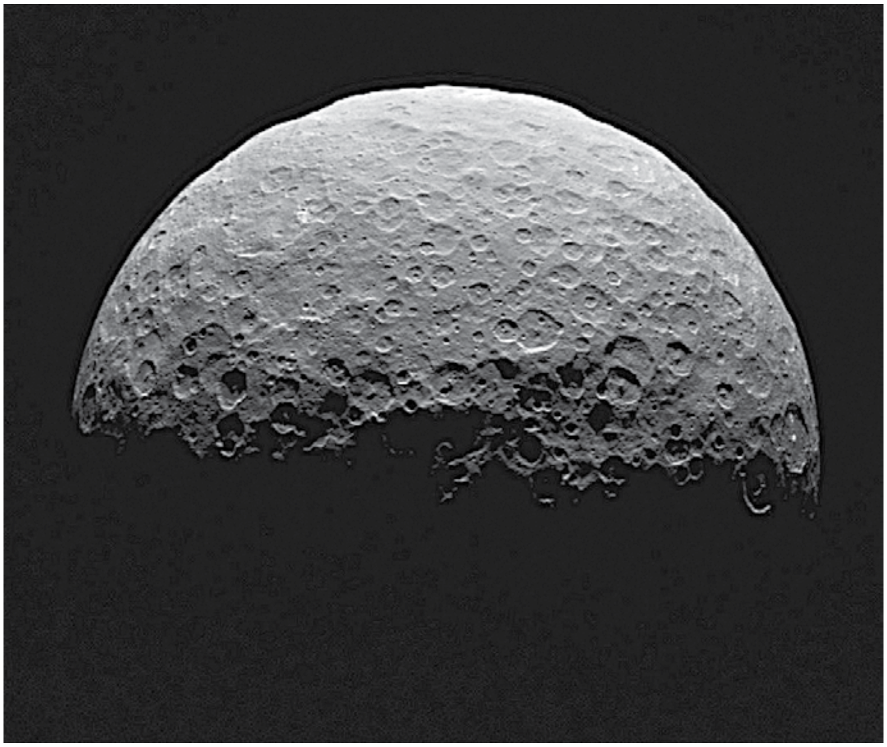
By Chris Starr FRAS FBIS

Last June, the NASA-JPL Dawn mission team received the Robert J. Collier Trophy from the U.S. National Aeronautic Association (NAA), at a presentation in Arlington, Virginia. It was presented to them 'In recognition of the extraordinary achievements of orbiting and exploring proto-planet Vesta and dwarf planet Ceres, and advancing the nation's technological capabilities in pioneering new frontiers in space travel." Previous recipients of this prestigious annual award, given for the greatest achievement in aeronautics or astronautics in the USA, include Orville Wright, Chuck Yeager, the crew of Apollo 11, and NASA/JPL's Voyager (1980) and Mars Science Laboratory/ Curiosity (2012) mission teams.

L-R: NASA Deputy Administrator Dr. Dava Newman, Dr. Charles Elachi, Director of NASA's Jet Propulsion Laboratory, and Dr. Marc Rayman, Dawn Mission Director and Chief Engineer at NASA's Jet Propulsion Laboratory, accepting the 2015 Robert J. Collier Trophy on behalf of the NASA/JPL Dawn Mission Team at the Annual Robert J. Collier Trophy Dinner on Thursday, June 9, 2016 in Arlington, Virginia. Credit: NASA/ Joel Kowsky

Dawn is certainly one of the most remarkable accomplishments yet in space exploration, being the only spacecraft to have visited and entered into orbit around two different bodies, thanks to its revolutionary ion-propulsion system. As Dr. Marc Rayman, Dawn Chief Engineer and Mission Director at JPL, explains in his entertaining and informative 'Dawn Journal', 'Providing the merest whisper of thrust, the ion engine allows Dawn to manoeuvre in ways entirely different from conventional spacecraft.'

The technical background to the Dawn mission, its science payload



ARRIVING AT A NEW WORLD: NASA's Dawn probe captured this view of dwarf planet Ceres' northern regions on 14th and 15th April, 2015, shortly after its arrival, from a distance of about 22,500 kilometres (14,000 miles). Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

and versatile ion propulsion system were discussed in Issue #10 of 'RocketSTEM' ('Journey to the Beginning of the Solar System', February 2015), as were the results of the first phase of its mission at asteroid 4 Vesta. Since then, it has continued its journey on to dwarf planet Ceres, which it has been orbiting since March 2015. Here we provide a summary of what Dawn has revealed so far about this small but significant world, described by Dr. Rayman before the encounter as 'an intriguing and mysterious orb that has beckoned for more than two centuries' since its discovery by Giuseppe Piazzi on 1st January 1801.

Why was Ceres a significant target?

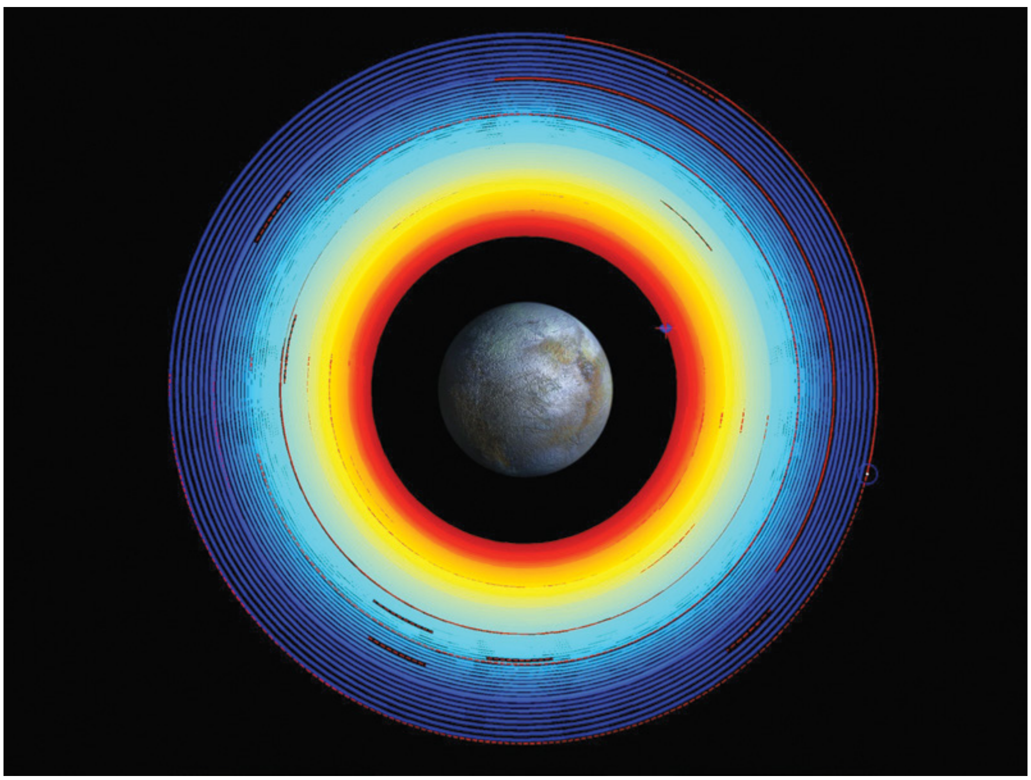
Ceres, like Vesta, was chosen for study by the Dawn mission because it is thought to hold keys to unlocking the secrets of the Solar System's early history. This has, indeed, proved to be the case for Dawn's first target, Vesta, which was confirmed by the spacecraft to be one of the last remaining rocky proto-planets, a remnant building-block of the kind that formed the terrestrial planets, and the only known asteroid with an Earth-like differentiated internal structure of core, mantle, and crust.

As for Ceres, much of its attraction as a target for scientists was the fact that it is an 'oddball' of the asteroid belt. Thought at its discovery in 1801 to be a comet, then considered a planet, it was finally re-designated an asteroid in the 1850s when increasing numbers of small bodies were discovered orbiting the Sun between Mars and Jupiter. However, with an average diameter of 945km (587 miles) it is much larger than any other object in this region of the solar system. It is massive enough for its gravity to have pulled it into a roughly spherical shape, which led to it being reclassified once more in 2006, this time as a 'dwarf planet'. Finally, Earth- or near-Earth-based observations of Ceres hinted at the presence of ice and clay minerals at or near its surface, and even traces of water-vapour in its proximity, indicators perhaps of a different origin to that of many asteroids and of possible geological activity at its surface.

Getting up close

Since entering into orbit around Ceres on 6th March 2015, after its two and a half year cruise from Vesta, Dawn's science instruments have been revealing its nature in detail from a series of ever-closer orbits. Following a brief period in a 'rotation characterisation' orbit, Dawn spiralled inwards and took up its 'Survey orbit' 4,430km (2,750 miles) out on 6th June 2015, from which it made detailed global maps of the dwarf planet with its framing camera and visible and infrared mapping spectrometer (VIR).

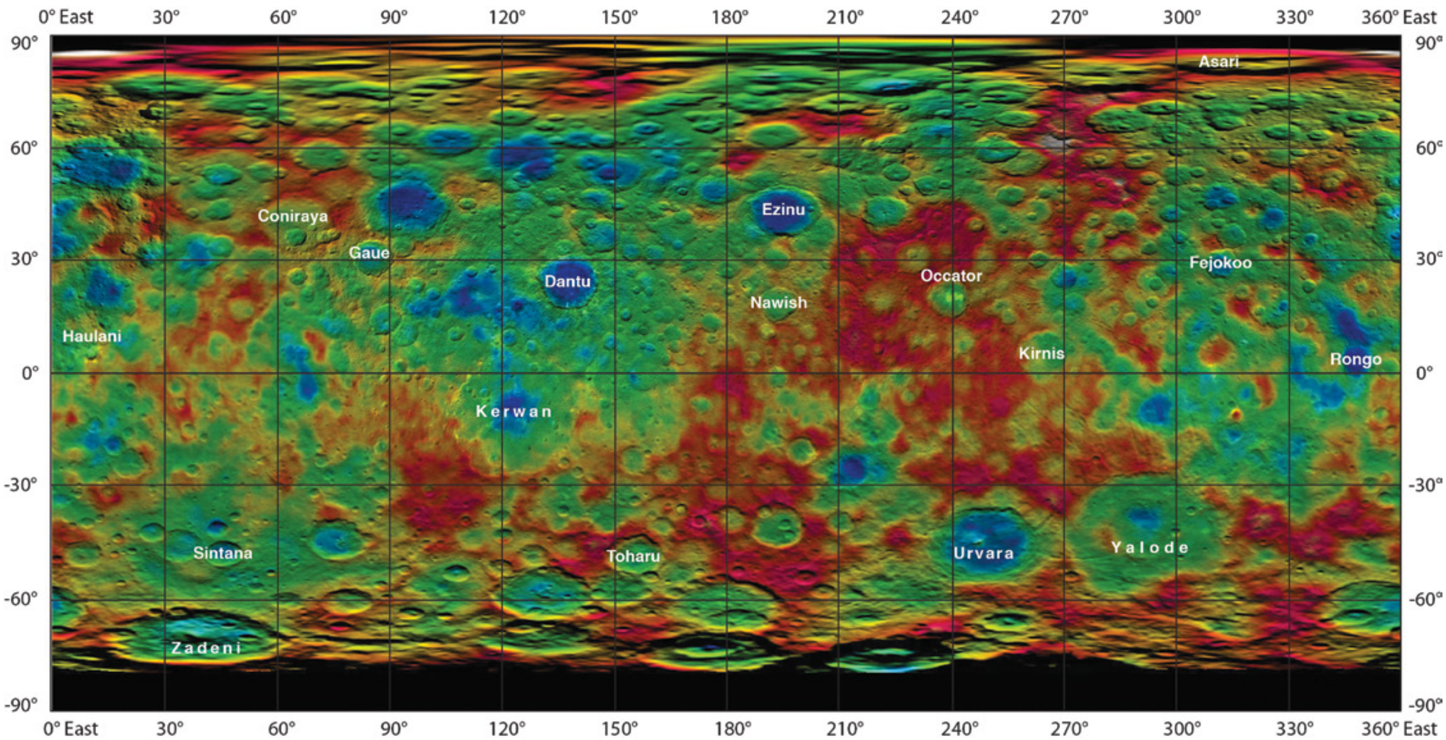
Following a problem with one of its ion engines, which was resolved successfully, Dawn then descended to reach its High-Altitude Mapping Orbit (HAMO) at 1,480 km (920 miles) in August 2015. From this altitude, it spent a period of two months mapping Ceres at higher resolution, again with the framing camera and VIR, before spiralling slowly inwards once more to reach a Low-Altitude Mapping Orbit (LAMO) in December 2015, a mere 375km (233 miles) above the Cerean surface. From this low altitude the spacecraft's instruments, particularly its gamma-ray and neutron detector (GRaND), were focused on trying to determine the chemical composition at and just below the surface of Ceres.



DAWN'S SPIRAL TRANSFER FROM HAMO TO LAMO: This diagram shows Dawn's patient spiral descent of 160 revolutions over a two-month period towards its closest orbit around Ceres, using its ion thrusters. For clarity, the trajectory is shown changing from blue to red as time progresses over this period. Red dashed sections are where ion thrusting was stopped so the spacecraft could point its main antenna towards Earth. Once in LAMO, closer to Ceres than the ISS is to Earth, the spacecraft was orbiting Ceres every 5.5 hours. Credit: NASA/JPL-Caltech

From LAMO, Dawn was also able to probe deeper down to try and discover the dwarf planet's internal structure. By using radiometric data – that is, detecting tiny variations in the spacecraft's orbit from Doppler shifts in the radio waves of signals transmitted back to Earth - the gravity field and, thus, internal distribution of mass in Ceres' interior can be determined. As Marc Rayman explains 'If, for example, there is a large region of unusually dense material, even if deep underground, the craft will speed up slightly as it travels toward it. After Dawn passes overhead, the same massive feature will slightly retard its progress, slowing it down just a little.'

By the beginning of September 2016 Dawn had completed more than eight months of 'virtually flawless activities at this altitude, over 1,100 orbital revolutions, returning far, far more data than ever anticipated.' For instance, of the more than 51,000 photos of Ceres taken since December 2014, over 37,000 of those have been taken in this lowest orbit at very high resolution, as little as 35m per pixel, or some 850 times better than that of the Hubble Space Telescope's view of Ceres from the vicinity of the Earth.



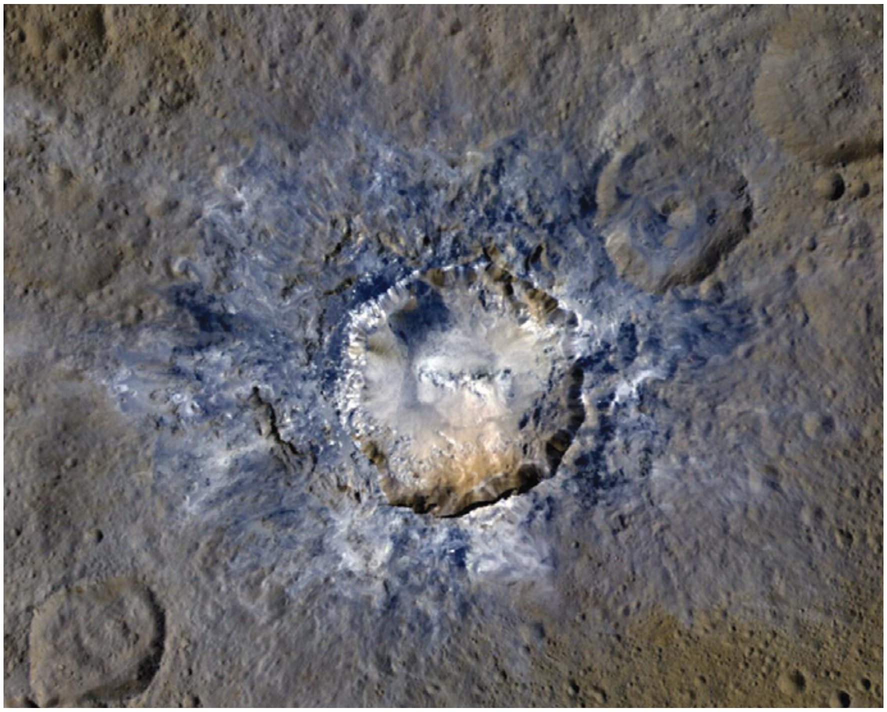
GLOBAL MAP: This map of Ceres shows its topography ranging from 7.5km (4.7 miles) low in indigo to 7.5km (4.7 miles) high in white. The names of features have been approved by the International Astronomical Union. Following the theme of the asteroid's original naming after the Roman goddess of agriculture, names of agricultural deities have been given to craters on Ceres, and agricultural festivals for everything else. This map was constructed from analysing images from Dawn's framing camera taken from varying sun and viewing angles, combined with an image mosaic of Ceres and projected as a simple cylindrical projection. Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

Little world, big surprises!

Dawn's instruments have confirmed Ceres' unique status in the main asteroid belt. While its surface is heavily marked by craters of all types and ages, as well as mountains, fractures and faults, like other larger members of this region of the Solar System, the varied crater distribution across its surface 'indicates crustal heterogeneities and a complex geologic evolution' (H. Hiesinger et al, Science 353, aaf4759, 2016). The probe has revealed not only a world with a rich and varied history, but also one which shows evidence of recent and even continuing geological activity.

Globally, with a bulk density of only 2.161 g/cm3 , Ceres is composed of a mixture of rock and ice, as compared to Vesta, with its silicate mantle and metallic core and a higher mean density of 3.456 g/cm3 (for comparison, the Earth, with its massive iron-nickel core has a density of 5.51 g/cm3). Ceres appears to be differentiated into a rocky (silicate) core, overlain by a 100km thick icy mantle, with a thin, dusty outer crust.

Prior to the Dawn mission, it was believed that Ceres had a deep



A VARIED HISTORY: An enhanced colour view of Ceres' Haulani Crater, taken from Dawn's High-Altitude Mapping Orbit (HAMO). Named after the Hawaiian goddess of plants, this 34km (21 mile) diameter crater holds one of Ceres 'bright spots'. It is characterised by its central mountain ridge and land-slides along its relatively sharp rim. The colour blue represents here younger material on the cerean surface, and this highlights the rays of ejected material which have partially blanketed surrounding older terrain and craters. Part of this ejecta forms clear flow fronts, probably a result of the melting of subsurface ice at the time of impact. Credit:NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

ice-rich layer below its rocky surface. At least a quarter of Ceres's mass is water, a much greater proportion than seen in most asteroids. There is a lack of very large craters, which initially pointed to the idea that most large craters would have 'relaxed' into more shallow configurations over long geological time scales. Such 'relaxation' would be due to the viscosity of ice-rich sub-surface material. Since larger impactors have become scarcer over time, only the scars of later, smaller impactors would remain.

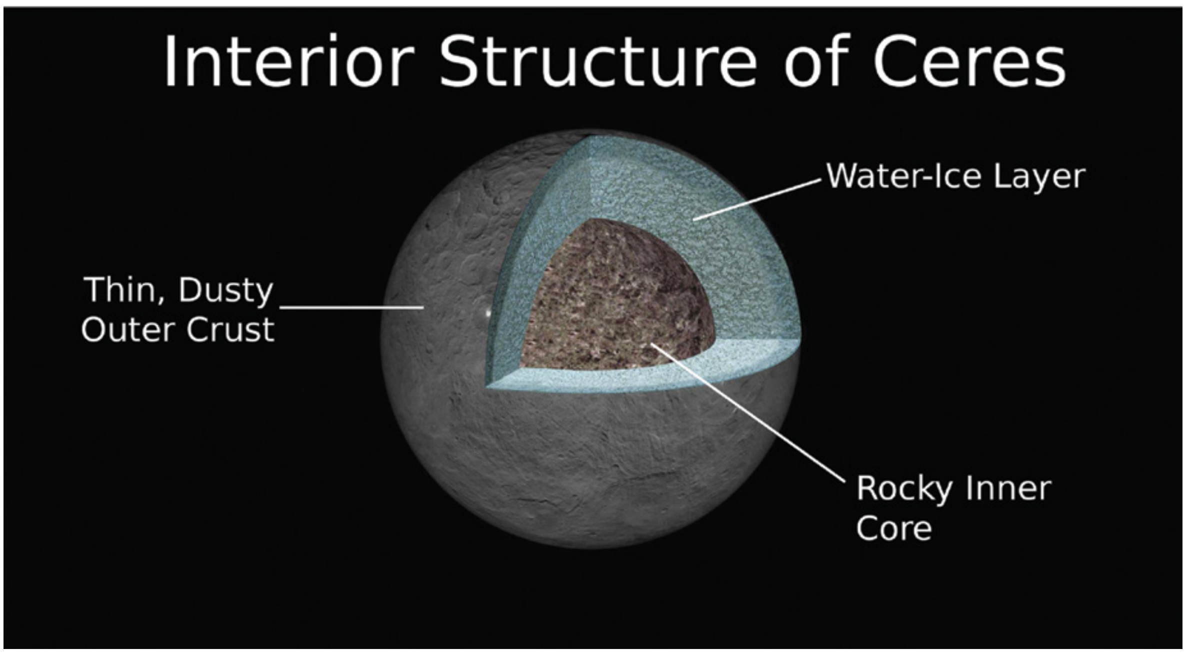
However, analysis of crater depths from Dawn images suggest that they are too deep to be consistent with the existence of an ice-rich subsurface. Viscous relaxation is only found locally in a few areas. According to mission scientists, this finding would indicate that the dwarf planet's subsurface can only be about 30-40% ice, mixed in with rock and a lower-density material, perhaps hydrated salts and clathrates. This would be supported by the latest analyses of GRaND data, presented by the Dawn team on 15th December, indicating widespread ice just below Ceres' surface. These studies show that Ceres' uppermost layer – within about a metre of the surface - is rich in hydrogen, consistent with the presence of water-ice, particularly at mid-to-high latitudes, and that this is likely to be ice contained within a porous mix of rocky materials, rather than pure ice.

The surface of Ceres

The surface composition of Ceres is broadly similar to that of C-type, or carbonaceous, asteroids, which are common in the outer part of the main asteroid belt. Like these it has a typically dark surface, with a low albedo of just 0.09, reflecting just 9% of the light which falls upon it as compared to 12% for our Moon and 30% for the Earth. This is attributed to the presence of organic materials, some of which have been identified by Dawn. For instance, spectral observations have revealed evidence of a form of graphite called graphitized carbon on its surface.

However, Ceres' surface shows important differences from asteroids. It is covered in hydrated materials, including phyllosilicates (clays) and localised deposits of salts such as carbonates, which indicate the presence of significant amounts of water in its interior. Some of these clays appear to be ammoniated – that is, they contain ammonia. This is a significant finding, because ammonia, a volatile substance, is scarce in the inner Solar System, but abundant further out, which has implications when trying to determine the origin of Ceres (see below 'What is the Origin of Ceres?').

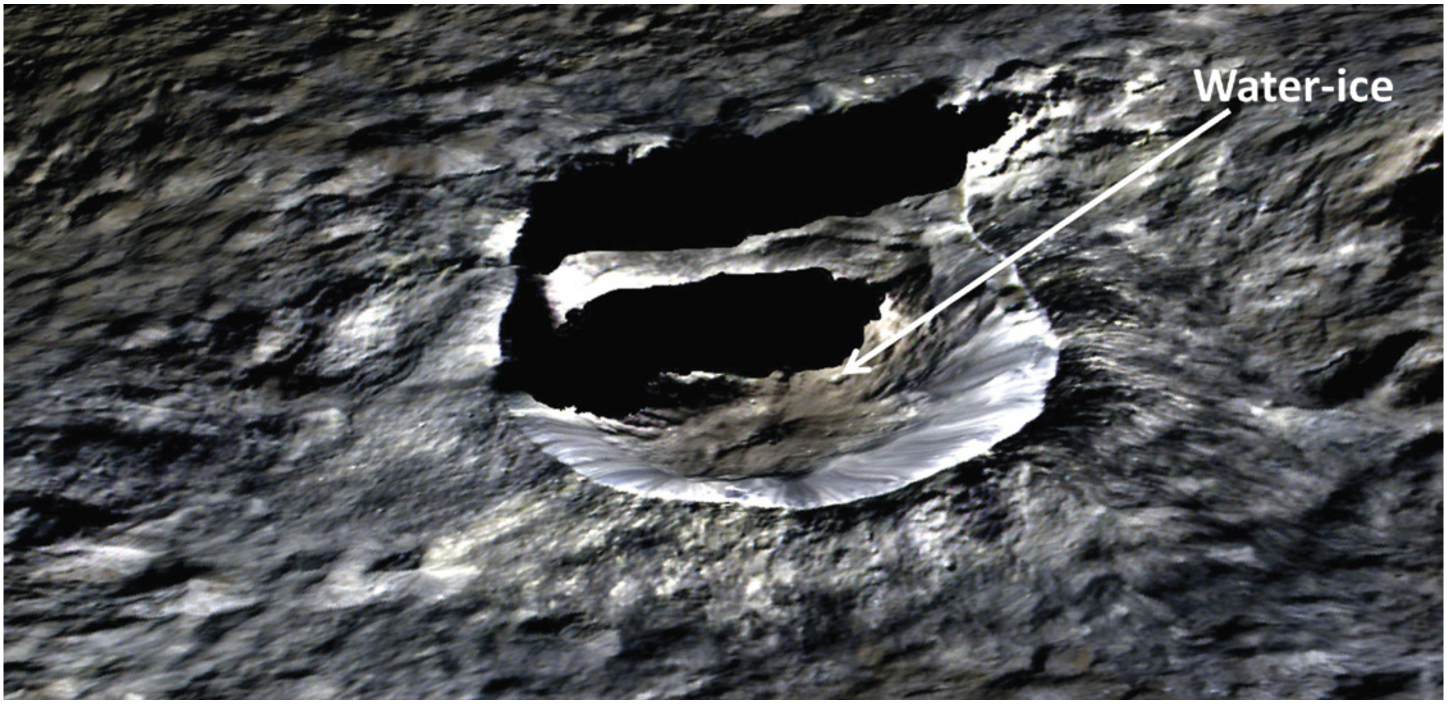
Dark material is left behind on Ceres' surface when ice at the surface sublimates. Ceres' surface is relatively warm. The maximum temperature with the Sun overhead may even reach about 235 K (–38 °C). As surface water ice is unstable at such temperatures and distances of less than 5 AU from the Sun, it sublimes upon direct exposure to solar radiation. So, while there is abundant ice below the surface, any exposed surface ice should have sublimed long ago.



Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA/

One of Dawn's objectives is to try to detect and map water on the dwarf planet. Has any water or ice been found on the surface? Ice may have been exposed relatively recently by impacts or even by geological processes such as cryovolcanism or slumping. However, as yet, water has only been unambiguously identified at one surface site. This is within the small crater Oxo - named after the Candomblé (Brazilian) and Yoruba (African) god of agriculture – located almost 45 degrees north.

Nevertheless, water from sublimed ice may have fallen back to the cerean surface at higher latitudes, where it could be protected from sunlight within deep craters in shadowed areas which don't receive much exposure to the Sun. 'These "cold traps"' says Marc Rayman 'may harbour ice that has accumulated over thousands of years (or even longer).' The most recent analyses of data do indicate deposits of bright material in 10 such craters on Ceres, and data from Dawn's infrared mapping spectrometer has confirmed the presence of ice in one of these.



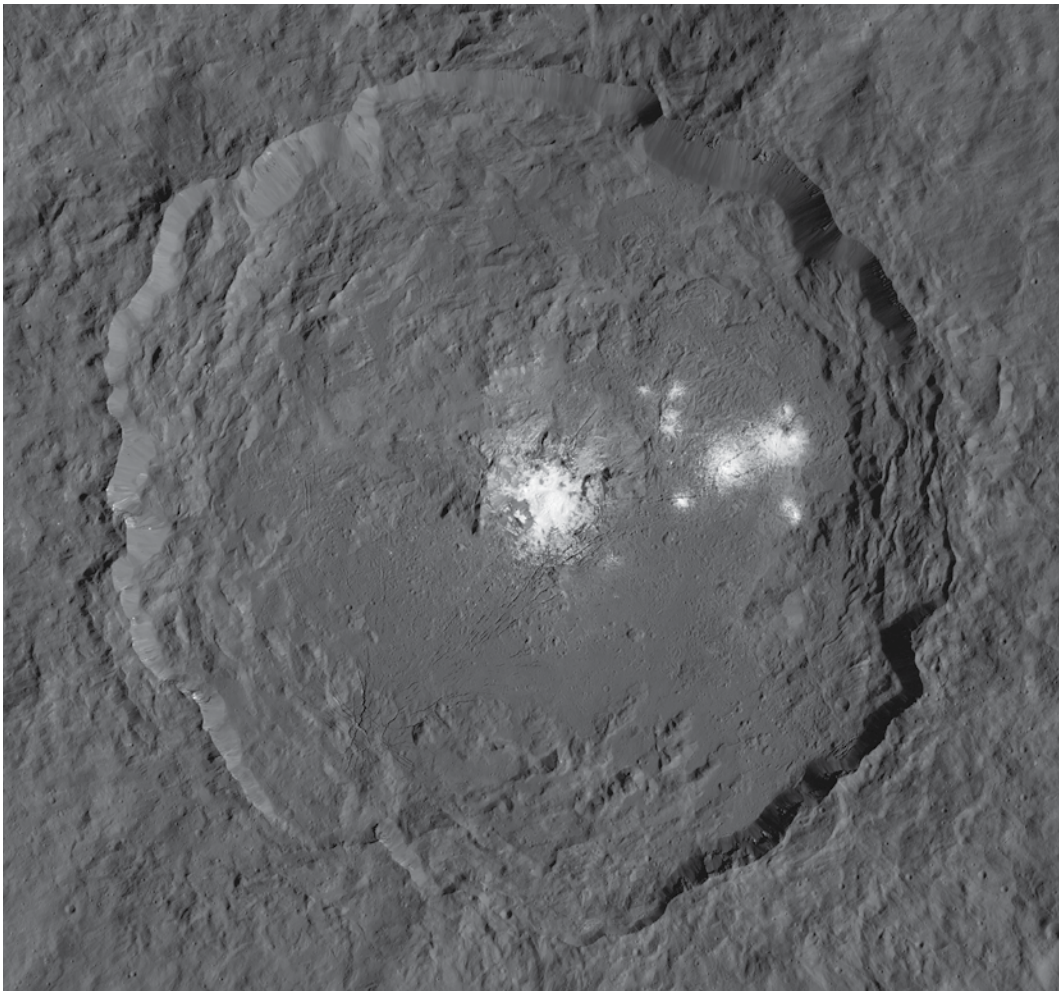
WATER ICE IN OXO CRATER: Oxo, only 10km (6 miles) wide, is the second-brightest feature on Ceres. Only Occator's central area is brighter. Oxo is unique because of the water ice signatures detected within it, and also the large "slump" in its crater rim (seen here at the top of the image), where a mass of material on its rim has collapsed into it. It is shown here in perspective view, and the elevation has been exaggerated by a factor of two. Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

Bright spots and salts

Sublimation of water ice may be responsible for some of Ceres most spectacular and unexpected features – bright spots or faculae, up to 4 times brighter than the average brightness of the surface. Already observed from a distance by Dawn before its arrival, there are over 130 of these features, most of them located near impact craters. The brightest and most striking are those found in Occator, an 80-million year old (fairly recent in geological terms) crater.

OCCATOR'S CENTRAL DOME: Dawn's close-up view of Occator's central bright area reveals a dome in a smooth-walled pit in the centre of the crater. Numerous linear features and fractures criss-cross the top and flanks of this dome. There are also prominent fractures around the dome, and they are also associated with the smaller bright regions found within the crater. It is suggested that briny ice might reach the surface through these fractures – a form of cryovolcanism - where it sublimates, leaving a residue of bright salty deposits. Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA.

Occator's bright spots are the most closely-studied so far. Initially thought to show signatures of the salt hydrated magnesium sulphate, more detailed analysis has now shown that the bright deposits are dominated by sodium carbonate, 'the most concentrated known extra-terrestrial occurrence of carbonate on kilometre-wide scales in the Solar System'. This is of great significance because such salts are like those found in Earth's hydrothermal environments. While they may have been exposed by impacts at Ceres' surface, they are likely to have formed in its interior in a process involving liquid water, which would suggest that it has, or had, a warmer internal temperature than previously supposed.



LITTLE WORLD, BIG SURPRISES!: Striking locally-bright areas are shown in this high resolution image of Ceres' Occator Crater taken from Dawn's Low-Altitude Mapping Orbit (LAMO). Occator has a diameter of 92km (58 miles) and is 4km (2.5 miles) deep. It has been of great interest since Dawn first imaged it on its approach to the dwarf planet in early 2015. Analysis of Dawn's VIR data indicates that these bright areas consist largely of sodium carbonate, a kind of salt found on Earth in hydrothermal environments. Occator seems to represent the highest concentration of carbonate minerals ever seen outside Earth. Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

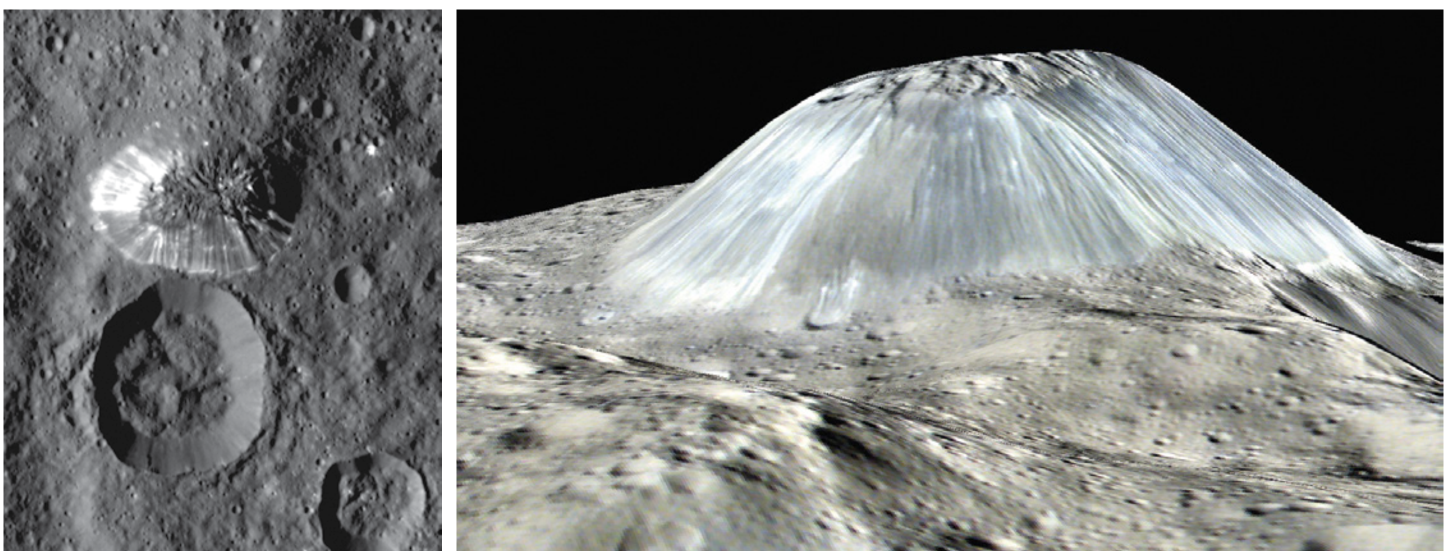
This raises a number of intriguing questions. Could there still possibly be a remnant internal liquid water ocean beneath the layer of ice in Ceres' interior? Or was the water present 80 million years ago when the impact occurred which created Occator? Was it the impact which created the water through melting of Ceres' mantle, generating the heat to drive hydrothermal processes for a while. The apparent degree of internal activity detected at Pluto was a big surprise, and such activity at Ceres is equally unexpected. It is hoped that more detailed analysis of the composition of salts on the dwarf planet's surface will be able to tell us more about conditions deep within it.

Cryovolcanism on Ceres

The presence of what appear to be recent, bright salt deposits at Ceres' surface raises the question of question of whether hydrothermal activity may still be still active. Could it have been responsible for forcing these salts up to the surface? The fractured dome at the heart of Occator's bright central region looks like it could well be of volcanic origin, forced upwards by material rising from the interior.

One piece of evidence which might support the idea of active replenishment of ice or water at Ceres' surface is a haze that appears occasionally in Occator, above some of the bright spots found inside the crater. This haze reoccurs at local 'noon-time', when the Sun would be high in the sky, enhancing any process of sublimation. The bright spots could be creating a transient local atmosphere in this particular region of Ceres. This is the first body in asteroid belt upon which such a process has been observed directly, and would support observations from Earth, made by ESA's Herschel Space Observatory in January 2014, of water vapour being emitted from several mid-latitude sources on Ceres. As yet, this is the only location so far where such a phenomenon has been observed, despite there being many other such spots on the dwarf planet's surface.

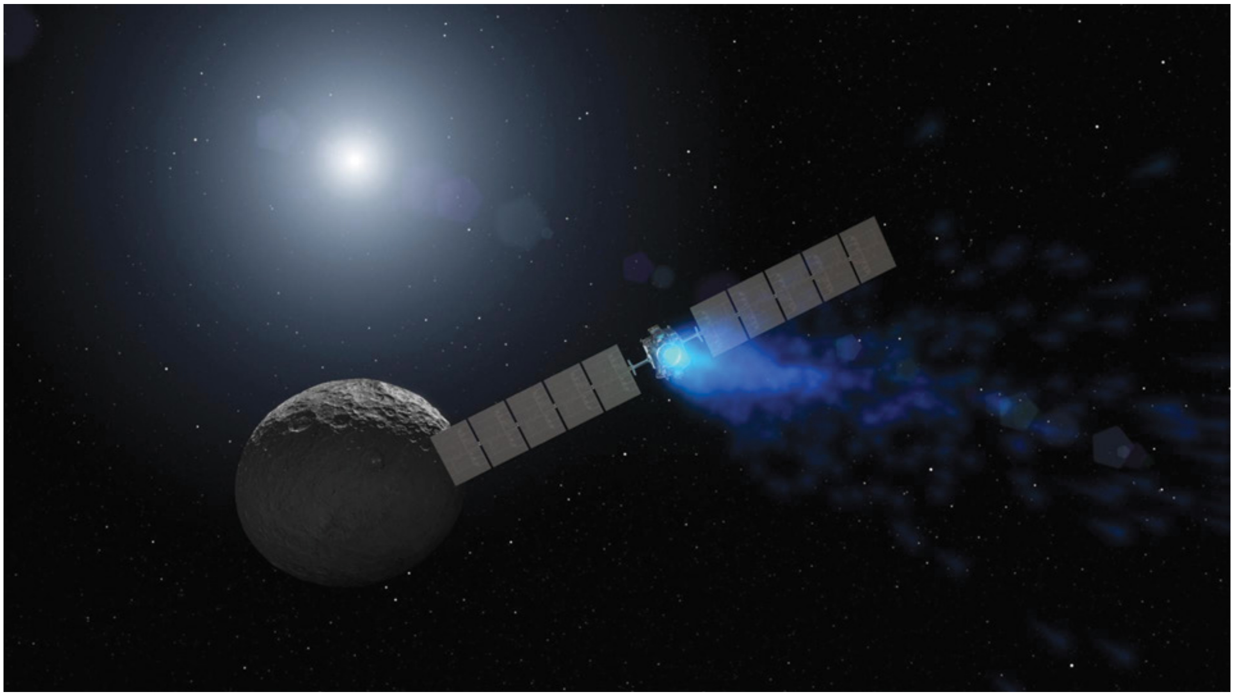
Hydrothermal activity is a form of volcanism, and there is other evidence to suggest that cryovolcanism - cold volcanism involving volatiles such as water ice – has occurred on Ceres at least in recent geological time. For instance, besides the salt deposits and their associated surface fractures, a large number of craters have central pits on their floors which may be due to cryovolcanism, marking places where water may reach the surface from deep below.



AHUNA MONS: a volcanic dome on Ceres?: Left: Imaged by Dawn from its High-Altitude Mapping Orbit. Right: Ceres' lonely mountain, Ahuna Mons, is seen in this simulated perspective view. The elevation has been exaggerated by a factor of two. The view was made using enhanced-colour images from Dawn's Low-Altitude Mapping Orbit. It shows the mountain's sharp, bright, unaltered features which would imply that it is a relatively young feature. Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

The most spectacular evidence for volcanic activity on Ceres is the discovery of a lone mountain, Ahuna Mons, which stands 5km (3 miles) above the surrounding area on its steepest side near the dwarf planet's equator. It resembles a volcanic dome and probably formed as a 'salty mud' volcano. It would appear to be unique so far in the Solar system, being the first cryovolcano observed which has been produced by a mixture of brine and clays, as opposed to rock or ices. Although the volcano is not active now, Ahuna Mons' appearance indicates that it is a surprisingly young feature geologically-speaking. It is bright, sharp, steep-sloped and unmarked by craters, and also has fine features like rock-falls still in evidence, which have not been obliterated by long-term processes like erosion by micrometeorites.

Ahuna Mons' recent volcanism on an isolated dwarf planet is a surprise, as usually only planets, or satellites orbiting around them, have volcanism. Ceres has certainly provided us with many surprises so far and there are no doubt more to come. One of them, the discovery of ammonia-rich materials, may lead to planetary scientists having to re-think our ideas on the dwarf planet's very origins and formation.



Artist concept showing NASA's Dawn spacecraft firing its ion thrusters above dwarf planet Ceres,. Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

What is the origin of Ceres?

Ceres is possibly a remnant proto-planet, like Vesta a survivor from the violent planet-building processes of the early Solar System 4.57 billion years ago, if different in its composition. However, the presence of ammonia-rich clays on Ceres' surface raises the question as to where and how exactly it originated. Ceres appears to be a transition world, neither totally rocky, nor an ice world. But, while it is close to the so-called 'frost-line' in the Solar System, it's not in a cold enough region for such ammonia-bearing materials to form. So, did it form where it is, and accumulate ammonia-rich material which migrated inwards from the early outer Solar System? Or, did Ceres form in the vicinity of Neptune and then move inward when the migration of the giant planets was disrupting these outer regions some 4 billion years ago, flinging most such objects out to form the Kuiper Belt or even out of the Solar System altogether? Hopefully, further detailed studies of the dwarf planet's composition will give us information to help understand this better.

What now for Dawn?

After greatly surpassing its objectives at both Vesta and Ceres, Dawn's prime mission officially ended on 30th June 2016. Project officials had proposed a possible new goal for the spacecraft, another main-belt asteroid, 145 Adeona. The possibility of an extended mission to another body had been considered feasible because of sufficient remaining xenon fuel for the ion engines, and also thanks to steps taken since 2012 to conserve the spacecraft's supply of hydrazine fuel, used for attitude control and orbital insertion. However, on 1st July NASA announced the outcome of its review of current extended planetary and lunar science missions, concluding that the Dawn should remain in orbit around the dwarf planet. One reason for this was felt to be the value of continued long-term monitoring of Ceres, especially at its approach to perihelion, the closest point in its orbit to the Sun.

While some may be disappointed by this decision, Marc Rayman's feeling is that it was the right one. 'It was the result of making a careful choice between two attractive options: remain in orbit around the only dwarf planet in the inner solar system, or fly by a large asteroid that has never been visited. Either would be very rewarding. I am very happy that we were able to give NASA HQ options. Most missions that are in orbit have to stay in orbit for their extended missions, and spacecraft that are not already in orbit at the end of the prime mission cannot enter orbit around something. Dawn has the best of both worlds, so to speak. NASA, supported by an independent panel of esteemed scientists, concluded that the best use of this interplanetary spaceship was to carry out further investigations of the first dwarf planet ever discovered. That is a wonderful outcome!'

And so, Dawn will continue 'extracting secrets from dwarf planet Ceres'. Given the presence of organic materials and the possibility of pre-biotic chemistry, there is no question of allowing the probe to crash onto and contaminate this world's surface at the end of its mission. On the 5th December Dawn completed a month of ion thrusting to reach a new orbit around Ceres. This sixth Ceres science orbit is elliptical, ranging in altitude between 7,520 km (4,670 miles) and 9,350 km (5,810 miles), to begin observing from different angles and gaining new perspectives. The probe is in good health, and its systems are functioning well. It will continue to operate during 2017, then will remain a perpetual satellite of Ceres when the mission is over, due to its highly stable orbit. We eagerly await its future observations of this intriguing world!

Acknowledgements:

Thank you again to Dr. Marc Rayman for information and comments. Visit his 'Dawn Journal' at: http://dawn.jpl.nasa.gov/mission/journal.asp

You can see an animation, narrated by Dr. Marc Rayman, showing some of the highlights of Dawn's exploration of Ceres so far, including Occator and Oxo craters, at http://photojournal.jpl.nasa.gov/catalog/PIA20537

Further reading:

- For mission overview and news: http://dawn.jpl.nasa.gov/
- For information on ion propulsion: http://www.grc.nasa.gov/www/ion/

Glossary

CLATHRATE - a compound in which molecules of one component are physically trapped within the crystal structure of another. One example is methane clathrate, or 'fire ice', in which a large amount of methane is trapped within a crystal structure of water, forming a solid similar to ice. Originally thought to occur only in the outer Solar System, where temperatures are low and water ice is common, significant methane clathrate deposits have been found under sediments on the bed of the Earth's oceans. There is currently concern that ocean warming due to climate change may release methane, a greenhouse gas, from these deposits.

ORGANIC COMPOUND - Any member of a large class of gaseous, liquid, or solid chemical compounds whose molecules contain carbon.

Remembering Gene Cernan

"I always tell young people to aim for the Moon. I tell them 'I walked on the Moon before you were born. What can you do?'"

Naval Aviator • Pilot of Gemini IX • Second American to Walk in Space

"The future is in our kids and we've got to give them something. We've got to give them some self reliance and some self confidence, and something to reach out for. Something that they can feel good about.

" We need dreamers. Because that is how we got to the Moon. We've got to get these kids dreaming again."

LMP of Apollo X • Commander of Apollo XVII • Last Man on the Moon

Remembering John Glenn

"When you are up there and you look back you are looking at huge swaths of the Earth at one time. And you don't see the borders. There are no blue nations, no pink nations, no green nations, like there are on a map."

"Keep your curiosity. The people I've found to be the most productive are the ones with the most curiosity."

Credit: NASA

Marine Pilot • Friendship 7 • First American to Orbit Earth • U.S. Senator