National Aeronautics and Space Administration

MAVEN

Mars Atmosphere and Volatile Evolution Mission

CU/LASP • NASA GSFC • UCB/SSL • LM • NASA JPL

exploring mars' climate history

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NASA Television Transmission

NASA Television is available in continental North America, Alaska, and Hawaii by C-band signal via Satellite AMC-18C, at 105 degrees west longitude, transponder 3C, 3760 MHz, vertical polarization. A Digital Video Broadcast-compliant Integrated Receiver Decoder is needed for reception. Transmission format is DVB-S, 4:2:0. Data rate is 38.80 Mbps; symbol rate 28.0681, modulation QPSK/DVB-S, FEC 3/4.

NASA-TV Multichannel Broadcast includes: Public Channel (Channel 101) in high definition; Education Channel (Channel 102) in standard definition; and Media Channel (Channel 103) in high definition.

For digital downlink information for each NASA TV channel, access to all three channels online, and a schedule of programming for MAVEN activities, visit *http://www.nasa.gov/ntv*.

Media Credentialing

News media representatives who would like to cover the launch in person must be accredited through the NASA News Center at Kennedy Space Center. To apply for credentials, visit *https://media.ksc.nasa.gov*. Journalists may contact the KSC news media accreditation office at 321-867-6598 or 321-867-2468 for more information.

News Conferences

An overview of the mission was presented in a news conference broadcast on NASA TV originating from NASA Headquarters in Washington, on Oct. 28, 2013 at 2 p.m. Eastern. A pre-launch press briefing is scheduled for Nov. 15 at 1 p.m. Eastern. A Spanish briefing is scheduled for 2 p.m. Eastern. The mission science briefing will be held on Nov. 17 at 10 a.m. Eastern. All of these briefings will be carried on NASA TV. Specific information about upcoming briefings, as they are scheduled, will be kept current on the Internet at *http://www.nasa.gov/maven*.

Internet Information

Information about NASA's MAVEN mission, including an electronic copy of this press kit, press releases, status reports and images, is available at *http://www.nasa.gov/maven*, *http://lasp.colorado.edu/maven* and *http://mars.jpl.nasa.gov/programmissions/missions/future/maven/*

Frequent updates about the mission, together with public feedback, are available by following MAVEN on Twitter at *http://www.twitter.com/MAVEN2Mars* and on Facebook at *http://www.facebook.com/MAVEN2Mars*.

Broadcast-quality animations of MAVEN and its orbital passes are found at *http://1.usa.gov/15UDvz2*.

Videos produced in connection with the MAVEN mission are found at *http://www.youtube.com/MAVEN2Mars*.

Quick Facts

Spacecraft

Spacecraft dimensions:

- Length: 37.5 feet (11.43 m, with solar panels deployed)
- Width: 90 inches (2.29 m)
- Height: 11.4 feet (3.47 m)
- High gain antenna: 6.56 feet (2 m) in diameter
- Dry (unfueled) mass: 1,784 pounds (809 kg)
- Wet (fueled) mass: 5,410 pounds (2,454 kg) at launch. Fuel is hydrazine.
- Power for orbiter: More than 2,000 solar cells on four panels, covering 129 square feet (12 m^2). Solar panels generate between 1,150 and 1,700 watts. Wattage depends on the spacecraft's position in Mars orbit. The panels power two 55-amp-hour Lithium ion batteries.
- Science payload: 143 pounds (65 kg) in eight instruments: Solar Energetic Particles (SEP), Solar Wind Ion Analyzer (SWIA), Solar Wind Electron Analyzer (SWEA), SupraThermal and Thermal Ion Composition (STATIC), Langmuir Probe and Waves (LPW), Magnetometer (MAG), Neutral Gas and Ion Mass Spectrometer (NGIMS), Imaging Ultraviolet Spectrograph (IUVS).
- Communications relay: 14 pounds (6.5 kg) Electra UHF communications package to provide data relay from rovers and landers on Mars back to Earth.

Launch

- Launch time and place: Nov. 18, 2013, 1:28 p.m. EST, from Launch Complex 41, Cape Canaveral Air Force Station, Fla. This is the earliest possible launch time during MAVEN's 20-day launch period. Each day during this period presents a two-hour window for launch.
- Launch Vehicle: Atlas V 401 provided by United Launch Alliance, tail number AV-038. The vehicle consists of an Atlas first-stage engine and a Centaur second-stage engine, with no additional strap-on solid rocket boosters.

Mission

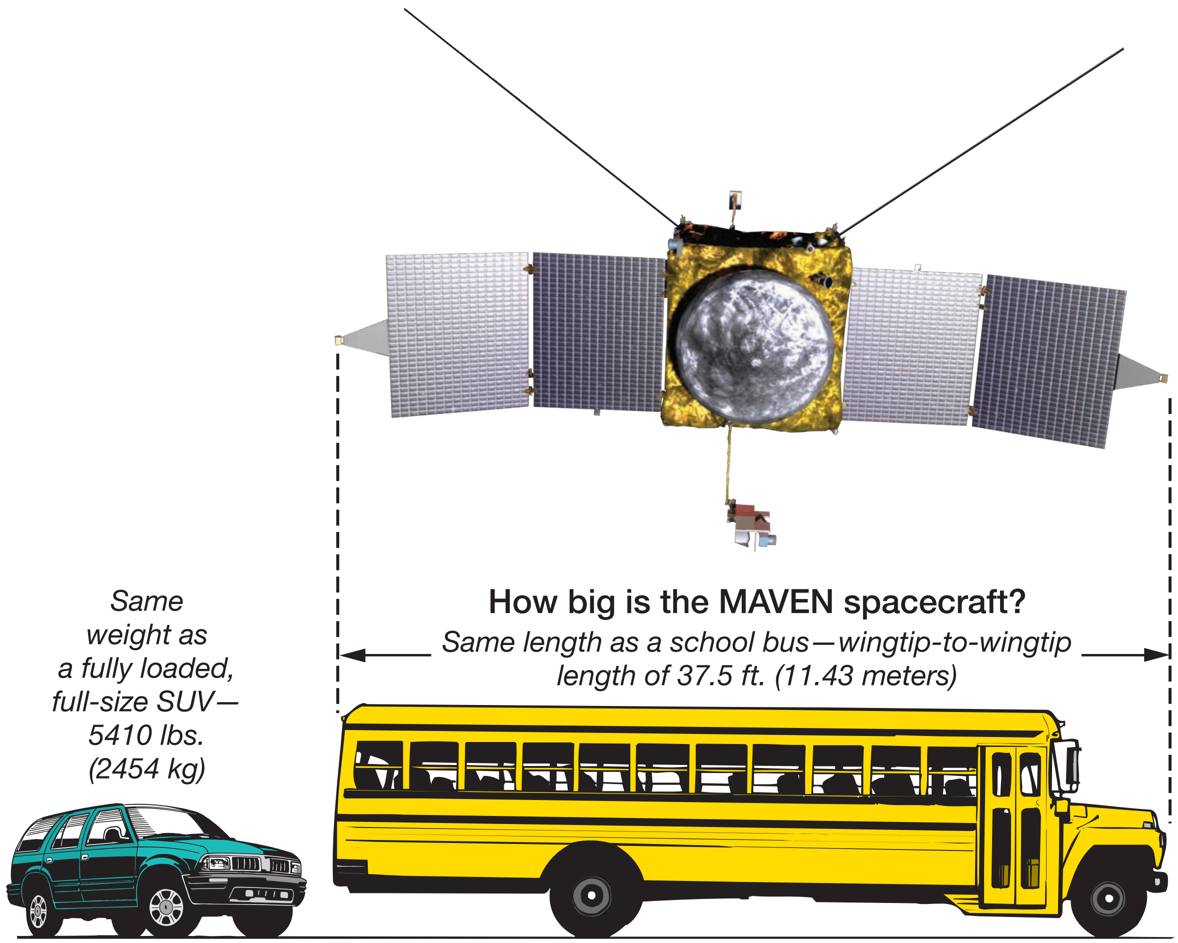
- Date of orbit insertion: Sept. 22, 2014, if MAVEN launches on the first day of its launch period
- Commissioning phase (time between orbit insertion and commencement of primary mission): 5.5 weeks
- Primary mission: One Earth year (52 weeks)
- Lowest orbital altitude: 77.6 miles (125 km) above Mars surface, within the upper atmosphere
- Highest orbital altitude: 3,864 miles (6,220 km) above Mars surface
- One-way radio transit time: Between 4 and 20 minutes, depending on the positions of Earth and Mars in their respective orbits

Program

- Cost: $671 million over its full life cycle.

Historical Context

- MAVEN is NASA's 10th Mars orbiter launched (three of these did not achieve Mars orbit).
- Three other active spacecraft currently orbit Mars: Mars Odyssey (launched 2001), Mars Express (launched by the European Space Agency in 2003), and Mars Reconnaissance Orbiter (launched 2005).
- Two active rovers study Mars' surface: Opportunity (launched 2003) and Curiosity (launched 2011).



Mars at a Glance

General

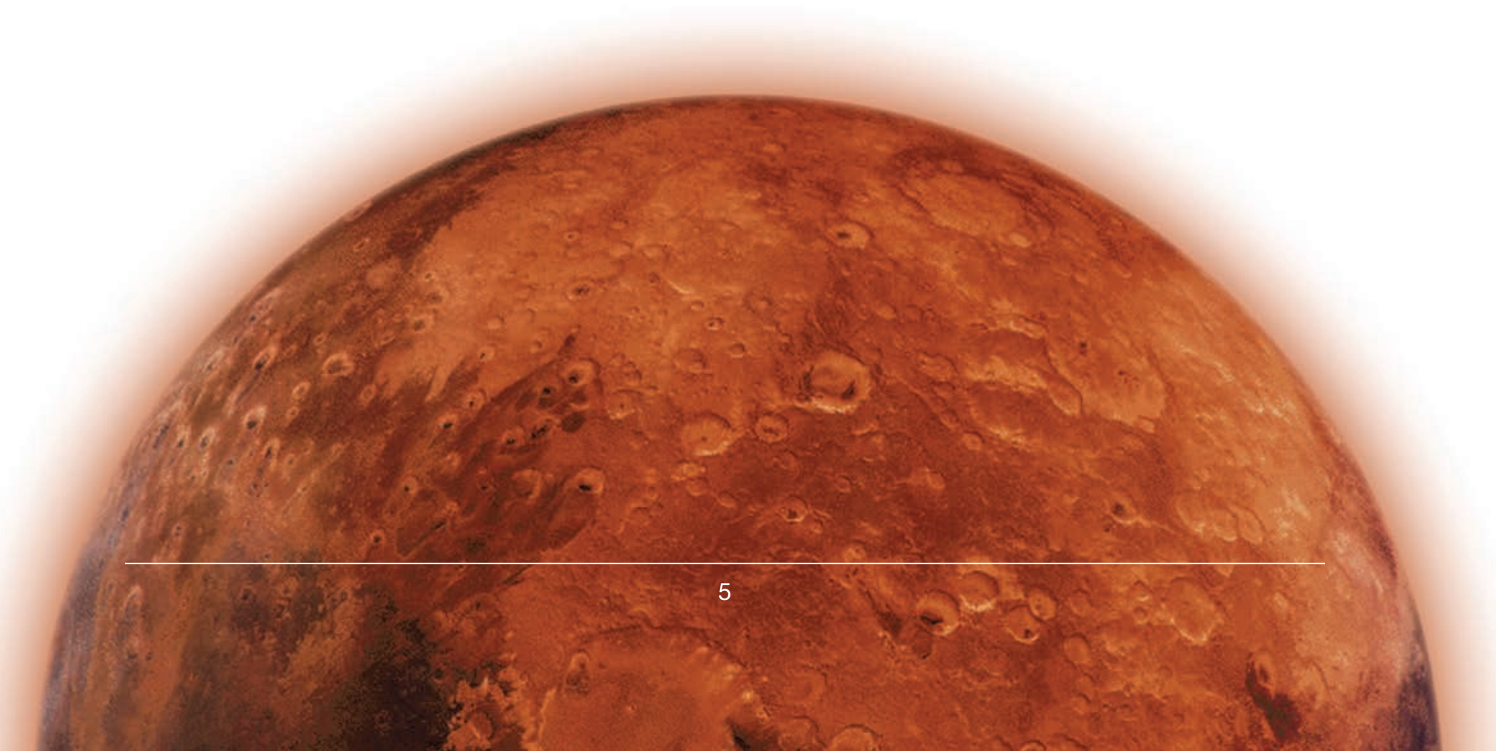
- One of five planets known to ancients; Mars was the Roman god of war and agriculture. Galileo Galilei first viewed the planet through a telescope in 1610.
- Mars appears yellowish brown to red due to oxidized iron in the planet's soil and dust in the atmosphere; occasionally, Mars is the third-brightest object in the night sky after the moon and Venus
- Mars will be near the constellation Leo in the eastern sky on launch day, Nov. 18, 2013, which coincides with the annual Leonid meteor shower. Mars will be in the constellation Scorpius in the southern sky on orbit insertion day, Sept. 22, 2014.

Physical Characteristics of Mars

- Average diameter 4,212 miles (6,780 km); about half the size of Earth, but twice the size of Earth's Moon
- Same land area as Earth
- Mass approximately 1/10th of Earth's; gravity only 38 percent as strong as Earth's
- Density 3.9 times greater than water (compared with Earth's 5.5 times greater than water)
- No planet-wide magnetic field detected; only localized ancient remanent fields in various regions

Orbit

- Fourth planet from the Sun, the next beyond Earth
- Distance to the Sun is around 1.5 Astronomical Units (AUs). One AU equals the distance from the Sun to Earth.
- Orbit is elliptical; distance from sun varies from a minimum of 128.4 million miles (206.7 million km) to a maximum of 154.8 million miles (249.2 million km); average is 141.5 million miles (227.7 million km)
- Revolves around sun once every 687 Earth days
- Rotation period (length of day): 24 hours, 39 minutes, 35 seconds (1.03 Earth days)
- Poles tilted 25 degrees, creating seasons similar to Earth's



Mars at a Glance (continued)

Atmosphere and Environment

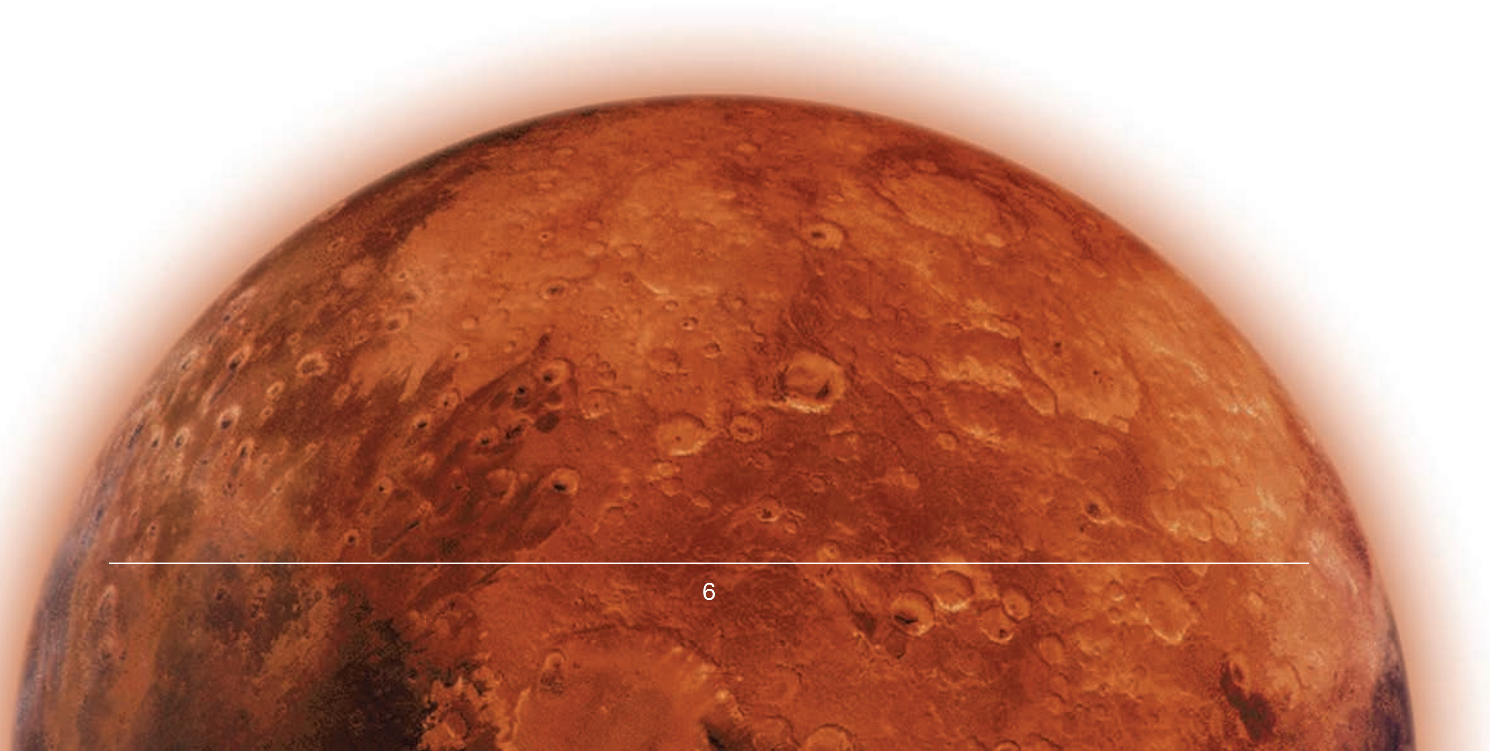
- Atmosphere composed chiefly of carbon dioxide (95.3 percent), nitrogen (2.7 percent) and argon (1.6 percent)
- Atmospheric pressure at the surface is about 0.6% of the Earth's surface pressure
- Surface winds of 0 to about 20 miles per hour (0 to about 9 m/s), with gusts of about 90 miles per hour (about 40 m/s)
- Local and regional dust storms with global dust storms occurring roughly every two years; whirlwinds called dust devils that are similar to dust devils on Earth have also been observed
- Surface temperature averages minus 64 F (minus 53 C); varies from minus 199 F (minus 128 C) during polar night to 80 F (27 C) at equator during midday at its closest point in orbit to sun

Surface Features

- Highest point is Olympus Mons, a huge shield volcano about 16 miles (26 km) high and 370 miles (600 km) across; has about the same area as Arizona
- Deepest canyon is Valles Marineris, the largest and deepest known canyon system in the solar system; extends more than 2,500 miles (4,000 km; distance from Washington, DC to San Francisco, Calif.) with 3 to 6 miles (5 to 10 km) of relief from floors to tops of surrounding plateaus. By comparison, the Grand Canyon of Arizona stretches only 277 miles (446 km) with only one mile of relief.

Moons

- Two irregularly shaped moons, named Phobos ("fear") and Deimos ("terror"), named for attributes personified in Greek mythology as sons of the god of war.
- Larger moon, Phobos, is only 16.7 miles (27 km) long, while smaller Deimos is only 9.3 miles (15 km) long.



NASA's Mars Atmosphere and Volatile EvolutioN (MAVEN) mission advances our understanding of planetary habitability and climate change by investigating how Mars lost its early atmosphere and abundant liquid water. Geological evidence indicates that Mars' ancient climate was much warmer, yet Mars today is a cold, dry desert. The most likely explanation is that the solar wind (an extremely tenuous outflow of energetic particles from the Sun) eroded the Martian atmosphere over hundred of millions of years due to Mars' lack of a protective planetary magnetic field. MAVEN will investigate this hypothesis by measuring rates of modern atmospheric escape, distinguishing between the various processes responsible.

Recent Mars missions have supplied conclusive evidence of flowing water on an ancient Mars. Surface features, imaged from orbit by cameras such as the Mars Reconnaissance Orbiter's HiRISE, show river networks, lake basins and glacier formations. Rovers Opportunity and Curiosity continue to collect geological evidence of ancient water, notably small-scale ripples preserved in rock formations and minerals that could have formed only in the presence of water.

But Mars' atmosphere is too thin, and the temperatures are too dry, is for water to remain liquid. Any surface water on Mars would either evaporate or freeze, since temperatures average minus 64 F (minus 53 C). Liquid water requires higher pressure and a warmer climate, both provided by a thicker atmospheric blanket. Discovering the fate of Mars' water may depend on determining the fate of its atmosphere.

MAVEN will study the boundary between the planet's current atmosphere and outer space, measuring solar energy inputs to the atmosphere, the composition of the upper atmosphere, and the current rates of loss of atmospheric gas to space. Information about these escaping gases' chemical, atomic and energetic character will inform scientists about the processes at work.

MAVEN is the first mission dedicated to studying Mars' upper atmosphere. By the end of MAVEN's one-Earth-year primary mission, planetary scientists will use models of solar activity, coupled with MAVEN's assessment of sun-atmosphere interactions, to reconstruct a model of the ancient Martian atmosphere and a timeline of its escape. In essence, MAVEN hopes to tell the history of climate change on the Red Planet.

Ancient Atmospheres

Our solar system began as a swirling plane of dust and gas surrounding a nascent yellow star approximately 4.5 billion years ago. Planets formed through collisions of rocky, icy chunks called "planetesimals," which coalesced into more massive bodies.

As planets grew, their internal structures organized themselves into layers of different densities, with lighter rock sitting atop denser cores, much like oil and water separating after being mixed. A planet's internal heat drives convection, which brings hot, less dense material to the surface and takes cooler, denser material back into the interior. On Earth, we see that convective movement reflected at the surface in the long-timescale movement of continents via plate tectonics.

Cores of inner planets Mercury, Earth, Mars and (probably) Venus consist of dense metal such as iron and nickel. Temperatures are hot enough that the metal is molten, and convection of this liquid metal core generates a magnetic field.

Earth's magnetic field deflects many of the energetic particles emanating as the solar wind from the sun. Sweeping planet-wide magnetic lines act like a boulder in a stream, diverting the solar wind and protecting Earth from the full onslaught of the sun's energy.

Early Mars likely enjoyed the same protection. The young planet's core generated a magnetic field to protect the warm, wet planet and its thick atmosphere. This environment may have persisted for nearly the first billion years of Mars' history. The hot core likely triggered volcanic activity, which released gases into the atmosphere. Earth experienced the same atmosphere-building processes around the same time.

But over the next several hundred million years, Mars' climate drastically changed. The planet's core seems to have cooled and solidified, dissipating the magnetic field and exposing the planet to atmospheric loss processes. Remnants of the planet's past magnetism persist in rocks from this age (called remanent magnetism). Mars' water began to evaporate into the dwindling air and freeze as buried ground ice. Atmospheric analysis suggests that Mars must have lost most of its atmosphere around 4 billion years ago, and has experienced a continuous slow leak of air ever since.

Today, the planet is a forbidding, frozen desert. While Earth developed into a lush world, teeming with myriad variations of complex life, Mars' surface became a wind-swept, desolate desert. It's possible that Mars may have developed microbial life, however any current life on Mars, or remnants of ancient life, likely lies in the subsurface.

Scientists acknowledge two hypotheses for where the air may have gone – either down into the ground through geological processes, or up and out into space. Rovers have found some carbonate minerals (formed from carbon dioxide) in Martian soil, but not enough to account for all the missing air. The loss-to-space hypothesis is supported by measurements of argon isotopes of atmospheric gases. Isotopes are atoms of the same element having different masses. The lighter isotopes are lost to space more easily, so that the surprisingly low measured ratio of light to heavy isotopes in the atmosphere indicates that substantial loss to space has occurred.

Thus, we know that atmospheric gas both went down into the subsurface and up to be lost to space. What we don't know is how important each of these processes was.

The sun is the primary suspect in this case of atmospheric thievery. It pumps a constant wave of high-energy particles and magnetic fields into space. This solar wind is comprised of electrons and charged ions of hydrogen and helium. Occasional solar storms or flares eject bursts of solar material along with high-energy ions called solar energetic particles. At Earth, our strong planetary magnetic field deflects most of the solar wind, which can interact with our atmosphere at the poles, creating the aurora borealis.

But Mars' global magnetic field had quietly died out by approximately 4 billion years ago, leaving only remanent crustal magnetism too localized and too weak to deflect the solar wind. Over time, the energetic and magnetic aspects of the wind likely eroded away the atmosphere.

Atmospheric Escape Processes

MAVEN investigates the processes whereby atmospheric gases may have escaped from Mars. In order to escape, gas molecules must attain sufficient energy to break free of the planet's gravity. MAVEN will monitor the input of energy to the atmosphere from the sun and observe escaping gas species. The mission will investigate how the amount and composition of escaping gas changes in response to different space weather events. These escape processes can be classified according to the underlying physics and chemistry driving it:

Kinetic Energy

Atmospheric atoms and molecules naturally bounce around, colliding with one another in random directions and with random energies. The higher-energy atoms at the top of the atmosphere may have enough kinetic energy to jump right out of the atmosphere.

This process, dubbed "Jeans escape" after English astronomer James Jeans, may account for the loss of most neutral (non-ionized) hydrogen from Mars. Because this hydrogen ultimately comes from water, tracking the loss of Mars' hydrogen is equivalent to tracking the loss of water.

Photochemistry

Solar ultraviolet (UV) light can eject electrons from atoms and molecules, creating positive ions. When some molecular ions (such as ionized oxygen, carbon and nitrogen) re-combine with electrons, the reaction releases energized atoms at escape speeds. Photochemical processes are extremely active, producing some ions that can also fall prey to other escape processes.

Solar Wind Pickup

Charged molecules, such as ions in Mars' upper atmosphere, follow magnetic field lines, such as those carried by the solar wind. These ions can be accelerated to velocities up to hundreds of miles per second, well above escape speed, and many are carried away into space.

Sputtering

Not all of these pickup ions escape Mars, however. Some are flung back down into the atmosphere with terrific speed, transferring their energy to other molecules. This process, called "sputtering," can account for the loss of heavier neutral atoms.

Science Objectives

MAVEN scientists use present atmospheric conditions as the key to the past. The spacecraft's instruments will assess the amount, energy, and velocity of energetic solar particles in the solar wind and solar storm events. MAVEN's extreme ultraviolet detector will simultaneously monitor the amount of incoming solar UV energy driving photochemical reactions. Taken together, these measurements comprise the net solar input of energy and mass into the Martian atmosphere that can drive escape.

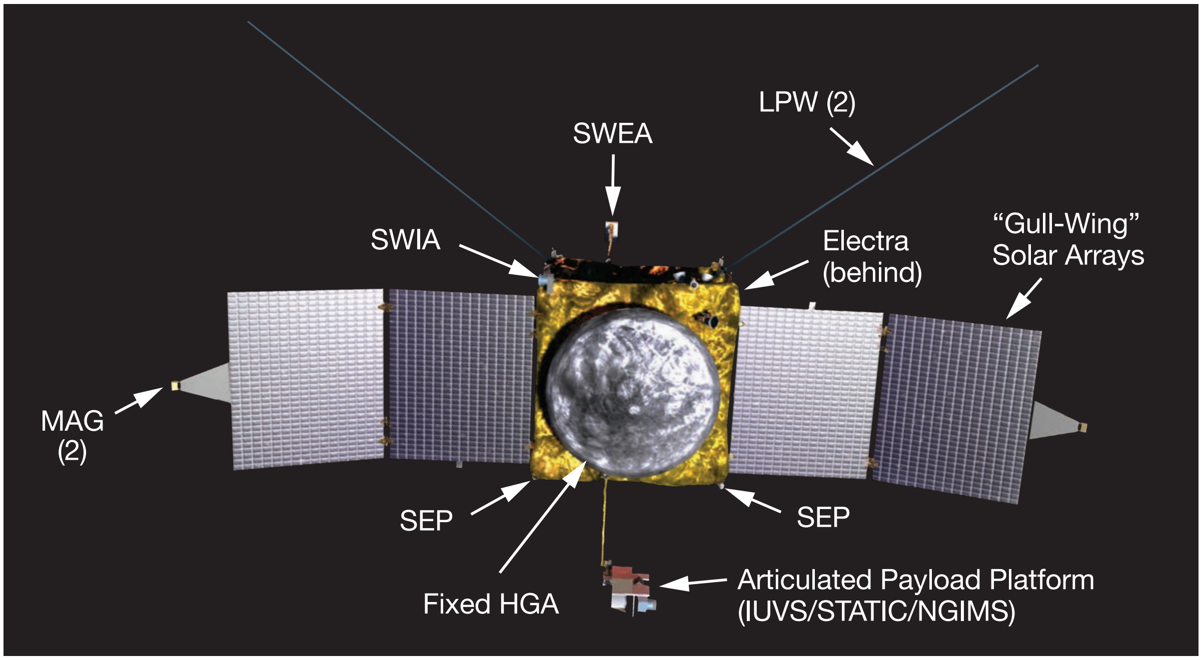
MAVEN's instruments will also measure the amount and types of gas particles escaping Mars' atmosphere today. Over the course of MAVEN's mission, scientists will monitor how escaping gas composition changes in reaction to different energy inputs. This will help determine which solar processes fuel the loss of different molecules from the atmosphere.

MAVEN's goal is to determine the role that loss of volatiles from the Mars atmosphere to space has played through time, exploring the histories of Mars' atmosphere and climate, liquid water, and planetary habitability.

To achieve this, the mission has three stated objectives:

- Determine the structure and composition of the Martian upper atmosphere today and understand the processes controlling them.
- Determine rates of loss of gas to space today and understand the processes that lead to escape.
- Measure properties and processes that will allow us to determine the integrated loss to space through time.

MAVEN's science payload consists of eight instruments in three packages.



Six instruments comprise the Particles and Fields package:

- Solar Energetic Particle (SEP)
- Solar Wind Ion Analyzer (SWIA)
- Solar Wind Electron Analyzer (SWEA)
- SupraThermal and Thermal Ion Composition (STATIC)
- Langmuir Probe and Waves (LPW)
- Magnetometer (MAG)

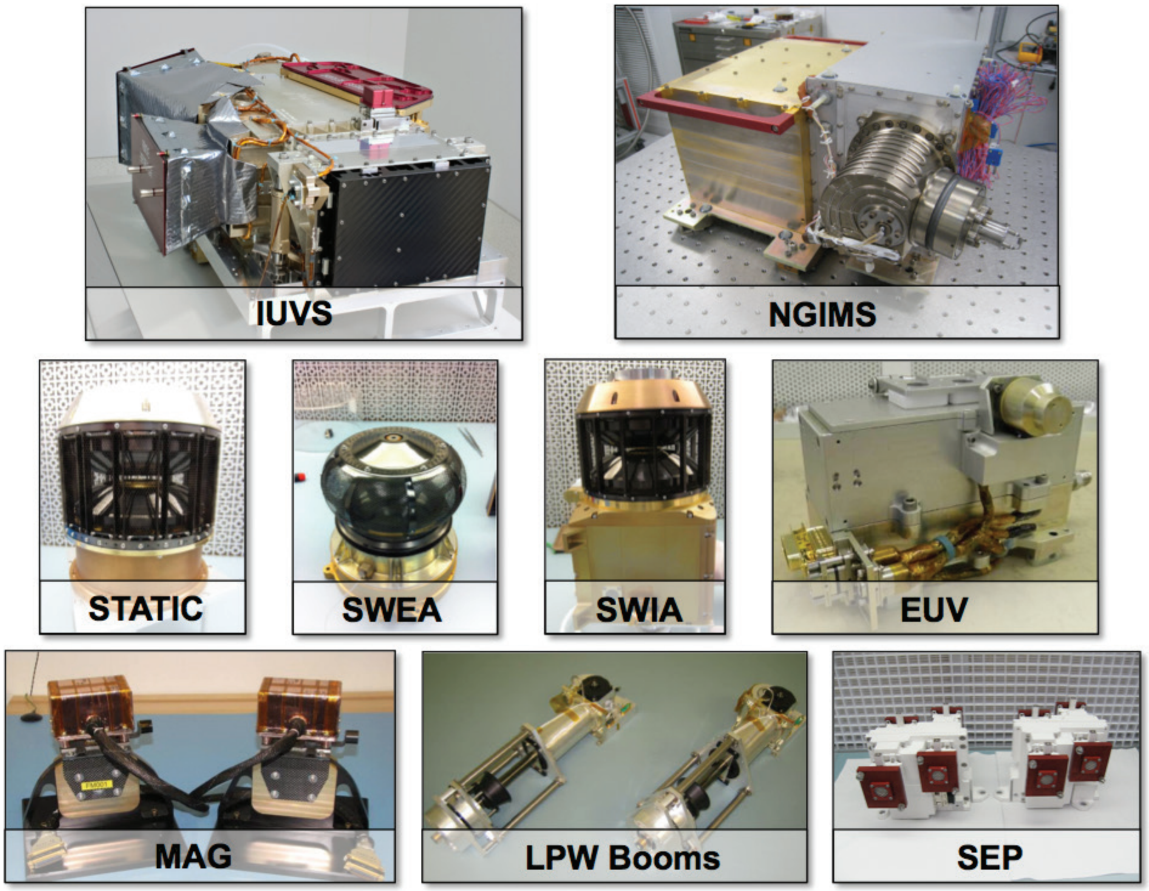
Four Particles and Fields Package instruments (SWIA, SWEA, SEP, and STATIC) were developed at the University of California, Berkeley's, Space Sciences Laboratory. SWEA includes components provided by the Institute of Research for Astrophysics and Planetology in Toulouse, France. LPW was developed jointly between UC Berkeley and the University of Colorado Boulder. MAG was developed at NASA's Goddard Space Flight Center in Greenbelt, Md. UC Berkeley's Space Sciences Laboratory integrated the six instruments into a complete package for delivery to the spacecraft.

The Remote Sensing Package, developed at the University of Colorado Boulder's Laboratory for Atmospheric and Space Physics (LASP), consists of the Imaging UltraViolet Spectrograph (IUVS) and the Remote Sensing Data Processing Unit.

Goddard developed the Neutral Gas and Ion Mass Spectrometer (NGIMS), which comprises the third instrument package.

Two of these instruments, SWIA and SEP, are mounted on the body of the spacecraft. The extreme ultraviolet monitor component of LPW is also body-mounted and faces the sun.

Science Payload (continued)



Two instruments, SWEA and LPW, are mounted on booms extending from the spacecraft. The two magnetometer sensors are mounted at the ends of the craft's solar panels, in order to get them as far away from the core structure of the spacecraft as possible.

Three instruments, NGIMS, STATIC, and IUVS, are mounted on the articulated payload platform, which extends on a boom and continually rotates as the spacecraft orbits so that the instruments can continually view the planet.

Science operations and analysis will be led by Bruce Jakosky, MAVEN principal investigator, of CU-Boulder's LASP; Janet Luhmann, deputy principal investigator, of UC Berkeley's Space Sciences Laboratory; and Joseph Grebowsky, project scientist, of Goddard.
The science instruments are described below:

Solar Energetic Particle (SEP)
SEP measures the energetic ions of hydrogen and helium emitted by the sun during storms, flares, and coronal mass ejections. The instrument characterizes the particles' energy and direction. SEP aims to profile how much energy comes into the upper atmosphere, and where that energy is absorbed. SEP also provides data on the role energetic particles play in heating and ionizing the upper atmosphere, and also their role in the "sputtering" process. SEP detects the highest energy ions.

SEP is a near-exact duplicate of instruments on the THEMIS (launched 2007) and Wind (launched 1994) missions, which both studied how the solar wind interacts with Earth's atmosphere. SEP consists of two identical instrument boxes, mounted at 90-degree angles to each other on opposite sides of the spacecraft. The offset angle allows the twin SEP sensors to record differences in energetic particle impacts from different directions. The instrument is 3.8 inches (9.7 cm) tall, 4.4 inches (11.2 cm) wide, and 5 inches (12.7 cm) deep and weighs 1.6 pounds (0.74 kg).

Each SEP sensor consists of two double-ended, rectangular funnels. A foil within the instrument separates incoming ions from electrons in one funnel direction while a magnet sweeps away low-energy electrons from the other direction. Foil detectors between the two funnels record ions and electrons separately. These sensors are thermally isolated from the spacecraft and operate at around 32 F (zero C). SEP will operate continuously and collect ten measurements per second.

The SEP instrument lead is Davin Larson, a research physicist at UC Berkeley's Space Sciences Laboratory. Larson also led development of SEP's forerunner instrument on THEMIS and analyzed data returned from Wind.

Solar Wind Ion Analyzer (SWIA)

SWIA measures the density, temperature, and velocity of solar wind ions, both in the undisturbed interplanetary medium and as they encounter the Martian environment. Using these data, MAVEN scientists can derive the rate at which neutral atmospheric atoms are ionized by the solar wind, and the acceleration of these new ions in the magnetic and electric fields around Mars.

SWIA's design heritage comes from instruments on the FAST, Wind and THEMIS missions, (the latter two still operating after 19 and six years, respectively). SWIA is mounted on the spacecraft body and is oriented toward the sun, ensuring good coverage of the solar wind. The instrument operates continuously except during the "deep dips" into the Martian upper atmosphere.

Jasper Halekas, research physicist at UC Berkeley's Space Sciences Laboratory, led the development of SWIA. Halekas also studies the moon and participates in the ARTEMIS mission (an extension of the THEMIS mission, launched in 2007), which studies the moon's interaction with the sun. He also participates in the LADEE mission (launched September 2013) to study the lunar atmosphere, and the Solar Probe Plus mission (slated for launch in 2018) to sample the atmosphere of the sun and determine the origin of the solar wind.

SupraThermal and Thermal Ion Composition (STATIC)

STATIC measures the composition and velocity of high-energy ions in Mars' upper atmosphere. These high-speed ions may leap out of the atmosphere into space to be lost, or they may plunge back down into the upper atmosphere, causing sputtering loss.
The instrument measures the densities and velocities of hydrogen, helium, oxygen, and carbon dioxide ions.

STATIC's design was previously used on the Cluster mission (launched in 2000), which observes how Earth's magnetic field interacts with the solar wind. MAVEN's instrument includes a thick foil to ensure instrument accuracy

STATIC is 11.6 inches (29.5 cm) x 6.8 inches (17.3 cm) x 5.8 inches (14.7 cm) and weighs 7 pounds (3.2 kg).

Mounted on the articulated payload platform, STATIC provides a profile of high-velocity ions at different altitudes and quantifies how many of these ions are carried away by solar winds. STATIC's data shows how variations in solar activity drive variations in atmospheric loss. Physicist Jim McFadden serves as instrument lead for STATIC at UC Berkeley's Space Sciences Laboratory. McFadden also participated in development of instruments for Wind, FAST, and Mars Global Surveyor missions.

Langmuir Probe and Waves (LPW)

The LPW instrument has two sensors, one that is the Langmuir probe and Waves sensor and a second that measures Extreme Ultraviolet (EUV) light coming from the Sun.

LPW's measurements allow MAVEN scientists to delineate the boundaries and the density of the ionosphere. The instrument will also measure the temperature of ionospheric electrons. These data will allow scientists to derive photochemical reaction rates, which control atmospheric escape. LPW works in concert with MAG to provides an estimate of electromagnetic energy flow into the ionosphere. This energy can heat up ions, which can also drive escape.

The LPW sensors are mounted on two 23-foot (7-m) booms, so that they can measure electrons without their being influenced by the spacecraft itself. It is designed to measure characteristics of the ionosphere, the ionized region of Mars' atmosphere.

The instrument design draws on forerunner instruments used on STEREO and THEMIS missions. During launch and interplanetary cruise, the booms remain coiled within a canister. Upon arrival at Mars, the booms will uncoil and expand from approximately 1.5 feet in length to their full length. MAVEN's two LPW sensors are oriented such that the spacecraft's wake obscures no more than one sensor at a time.

The LPW also incorporates an EUV detector mounted directly onto the body of the spacecraft. This detector measures the Extreme Ultraviolet light coming from the Sun that is capable of driving photochemical reactions in the Martian upper atmosphere. The EUV detector is derived in part from similar instruments that have flown on the TIMED and Solar Dynamics Observatory missions.

Physicist Robert Ergun, of CU-Boulder's LASP, led development of this instrument. Ergun served as a principal investigator or co-investigator for instruments on the STEREO, FAST and Wind missions. CU-Boulder built the signal processing board and extreme ultraviolet monitor, while UC Berkeley's Space Sciences Laboratory built the booms, sensors, and preamplifiers.

Frank Eparvier, also of CU-Boulder, led development of the EUV component of the instrument, which was built entirely at CU Boulder's LASP.

Solar Wind Electron Analyzer (SWEA)
SWEA measures the energy and angular distributions of electrons with mid-range energies, which helps to fulfill several of MAVEN's scientific objectives.

Neutral atmospheric gases can become ionized by solar ultraviolet light and by collisions with energetic ions and electrons. As these neutral gases are ionized, their trajectories can be altered by electric and magnetic fields, enabling solar wind pickup and sputtering processes. SWEA measures the influx of those solar wind and ionospheric electrons with sufficient energy to cause ionization on impact. This measurement helps determine one source of ionization in the Martian environment.

SWEA can distinguish solar wind electrons from ionospheric electrons due to their different energy distributions. Solar wind electrons display a distribution of different energy levels, while ionospheric electrons appear with more discrete energy levels. Over the course of the mission, as the MAVEN orbit samples different altitudes and latitudes, SWEA measurements can be used to map the solar wind regions both "upstream" and "downstream" of the planet, and characterize the ionosphere on both the day-side and night-side of Mars.

The instrument's 360 x 120 degree field of view enables SWEA to measure how electron motion is controlled by magnetic fields. Electrons flow along magnetic field lines in helical, or "corkscrew", trajectories. Remanent magnetic fields arising from Mars' crust may affect electron flow in one of two ways: either by forming closed loops that trap atmospheric ions, or by connecting with the magnetic field of the solar wind to form "cusps", along which atmospheric ions can escape. These same cusps allow solar wind plasma to precipitate into the atmosphere, which can result in Martian aurorae similar to the Earth's northern lights. SWEA and MAG will work together to discover how each process affects Mars' atmosphere.

SWEA sits at the end of a 5.4-foot (1.7-meter) boom to allow a clear field of view and to avoid interference between diffuse electrons and the MAVEN spacecraft. The sensor head is placed in the shadow of its electronics box to prevent solar UV light from entering the aperture, which could produce photoelectric effects and interfere with low energy measurements. SWEA completes a measurement cycle in 2 seconds.

SWEA was produced in a collaboration between U.C. Berkeley's Space Sciences Laboratory and the Insitut de Recherche en Astrophysique et Planétologie (IRAP) in France. The instrument is closely based on a sensor currently operating on the twin STEREO spacecraft (launched in 2006), which monitor solar activity.

David L. Mitchell, of UC Berkeley's Space Science Laboratory, led SWEA development.

Magnetometer (MAG)

Positioned at the far ends of MAVEN's solar panels, dual magnetometer sensors provide information about the magnetic environment as the spacecraft travels through the solar wind, the Martian ionosphere, or the magnetic field near one of the regions of magnetized crust on the surface. This information provides MAVEN's other instruments with appropriate context, since magnetic fields affect many upper atmosphere processes. MAG assists LPW and SWEA in determining the structure of Mars' ionosphere and magnetic cusp regions formed by Mars' crustal magnetic fields.

MAG utilizes a design with flight heritage dating back to Voyager (launched in 1977). The twin sensors weigh less than a pound (0.39 kg each) with dimensions of 5 inches x 3 inches x 3.6 inches (12.7 cm x 7.6 cm x 9.1 cm).

Since these sensors are extremely sensitive (capable of detecting a magnetic field that is a million times weaker than the Earth's magnetic field), MAVEN engineers needed to eliminate stray magnetic fields during spacecraft construction. The solar panels abutting MAG sensors contain wiring that is laid out in a way that cancels stray fields. A similar approach to magnetic cleanliness was employed on Mars Global Surveyor, where magnetometers were also positioned at the tips of the solar panels. And special precautions were taken throughout the spacecraft to minimize the magnetic field emanating from the various components. Many other spacecraft deploy magnetometers on lengthy, specialized booms in order to isolate the sensors from the spacecraft.

Astrophysicist Jack Connerney led development of the magnetometer at Goddard Space Flight Center. Connerney participated in magnetic field investigations on Mars Global Surveyor, Mars Observer, and Voyager missions. He is also the deputy principal investigator for the Juno mission that is currently en route to Jupiter.

Neutral Gas and Ion Mass Spectrometer (NGIMS)

NGIMS will measure the composition of neutral gases and thermal (or cold) ions in the Martian upper atmosphere, sorting them by electrical charge and isotopic mass. These measurements will provide basic information on the composition and structure of the Martian upper atmosphere and how it varies around the planet and throughout the MAVEN mission. These measurements will show how atmospheric events such as dust storms, and space weather, affect the amount of atmospheric gas escaping to space.

In addition to measuring the abundance and composition of both neutral gases and ions, NGIMS' data also measures the isotope ratios for atmospheric gases. The isotopes of different atoms have the same composition but different masses. As the heavier atoms escape to space less readily than the lighter ones, the ratio of the lighter to heavier isotopes left behind tells us how much gas has been lost to space.

Isotopic ratios of oxygen prove especially useful, not only in understanding Mars' upper atmosphere, but also in constraining the search for ancient life on the surface of Mars. Many planetary processes, including Earth's life processes, can alter atmospheric isotope ratios.

MAVEN measures atmospheric processes' impact on isotopes so that surface explorers, such as Curiosity, can better interpret their own isotopic measurements. NGIMS will measure isotope ratios of carbon, nitrogen, oxygen, and argon.

NGIMS will collect these measurements at altitudes ranging from 77.6 miles (125 km) to 248.5 miles (400 km), covering the upper atmosphere of the planet. The instrument only operates in the 12 minutes before and after the periapsis (closest point to the planet) of each orbit. The instrument will measure a variety of gases including helium, nitrogen, oxygen, carbon monoxide, argon, and carbon dioxide.
NGIMS, housed in a box 16.3 in x 15.6 in x 8.6 in (41.4 cm x 39.6 cm x 21.8 cm), is identical to an instrument developed for the CONTOUR mission (launched 2002) and similar in design to the Mars Science Laboratory's SAM module (launched 2011), also developed at Goddard Space Flight Center. The 31-pound (14-kg) instrument sits on MAVEN's Articulated Payload Platform, and will be pointed in the forward direction.

Gas enters the instrument and is ionized in an electron beam. The ionized gas is then filtered by four electrostatic rods, which sort atoms by weight and charge. Detectors at the far end of the rods measure the amounts of the filtered fractions of ions.

NGIMS also carries a reservoir of the gases argon, nitrogen, carbon dioxide, krypton, and xenon for instrument calibration

The principal investigator for NGIMS is Paul Mahaffy, a chemist at Goddard. He is a veteran investigator of planetary atmospheres using spacecraft instruments, and also leads the team supporting the Curiosity rover's Sample Analysis at Mars (SAM) instrument.

Imaging UltraViolet Spectrograph (IUVS)
The ultraviolet portion of the electromagnetic spectrum contains valuable information about the chemical makeup of planetary atmospheres. IUVS will use UV light to chemically map the composition of Mars' upper atmosphere and measure the rate that hydrogen atoms escape from the planet.

Similar instruments, including the UVIS on the Cassini probe (launched 1997, and also built at LASP) have flown to every major planet in the solar system. UV spectroscopy provides "remote sensing" measurements that allow it to map the composition of the upper atmosphere from a distance based on the emitted ultraviolet light. MAVEN will use this technique to collect wide-area, global measurements of atmospheric gases, complementing NGIMS' more-detailed measurements that are made at the single-point location of the spacecraft on each orbit.

Light enters IUVS via one of two openings, one oriented toward the Martian horizon, or limb, and the other pointed directly down toward the planet, at nadir. The light is split into its component wavelengths, and image intensifiers convert the UV light to visible light that can be more easily measured.

Mounted on the articulated payload platform, IUVS observes UV spectra from different viewpoints of Mars depending on spacecraft position and platform attitude. The two openings collect scans from the planet's limb at periapsis and images of the planetary disk and corona at apoapsis (farthest orbital point from the planet).

IUVS can also study carbon dioxide abundance in Mars' lower atmosphere by imaging the UV spectrum of a star as the star passes behind the atmosphere The way that the atmosphere absorbs light tells us the composition of the atmosphere.

Nick Schneider and Bill McClintock, of CU-Boulder's LASP, co-led the IUVS team.

Electra Communications Relay

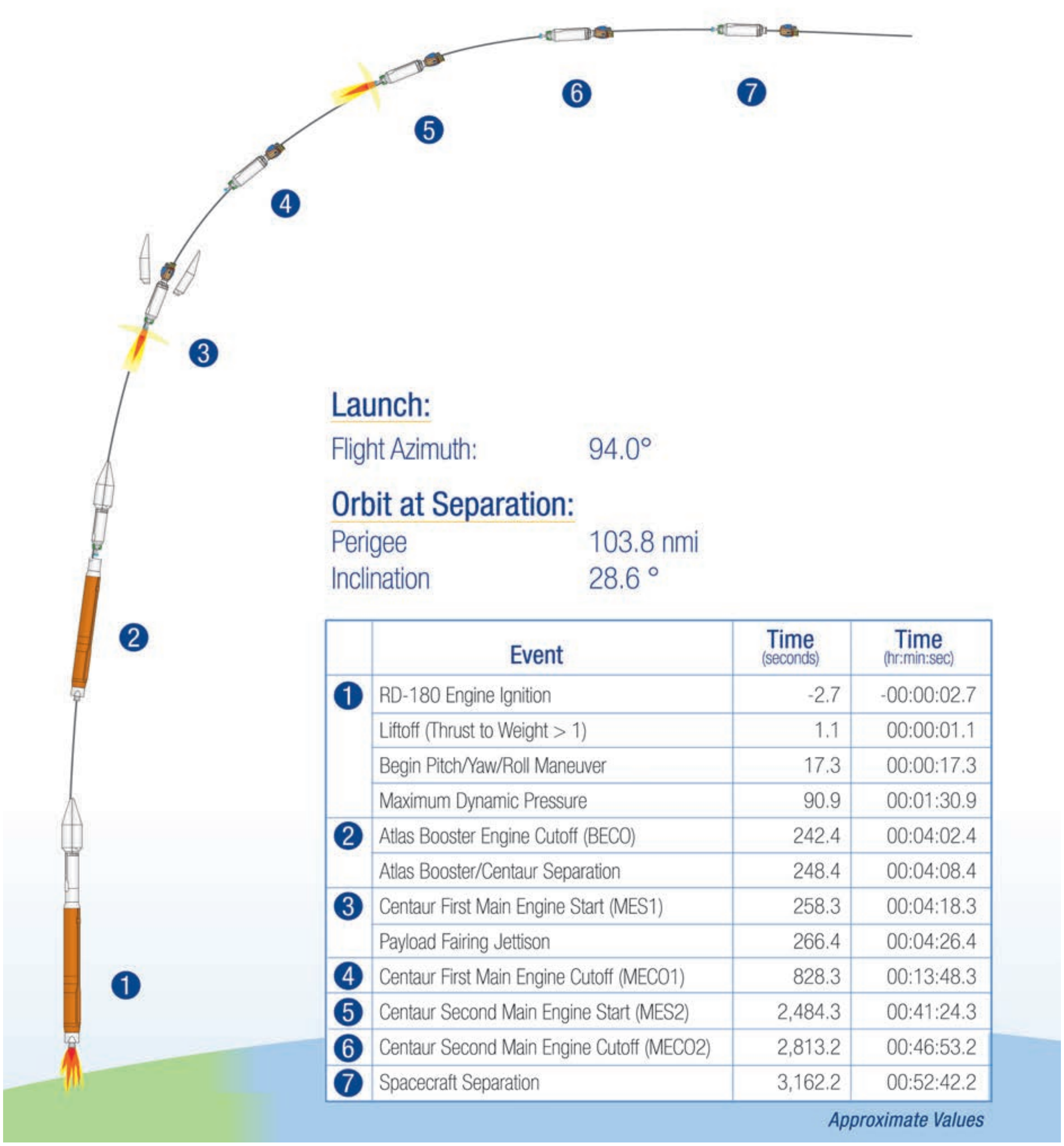
In addition to its science payload, MAVEN also carries Electra, an ultra-high-frequency transceiver. Electra will serve as an additional backup communications relay for the Curiosity and Opportunity rovers. The rovers are able to return much more data to Earth through a relay than they could with direct-to-Earth communications. Mars Odyssey and Mars Reconnaissance Orbiter currently are providing relay services.

NASA's Jet Propulsion Laboratory in Pasadena, Calif., provided MAVEN's Electra transceiver and its helical antenna. The antenna, which measures 10.3 inches (26.2 cm) tall and 8.7 inches (22.1 cm) in diameter, originally served as the Curiosity rover's spare.

MAVEN's mission commences in November 2013 with launch and a ten-month interplanetary cruise toward Mars. Following orbit insertion in September 2014 and a five-week commissioning phase, MAVEN commences its one-Earth-year scientific mission.

Spacecraft Configuration During Mission Phases

Launch: MAVEN launches on an Atlas V-401 rocket. The three digits in the suffix '-401' indicate the rocket's configuration: a 4-meter payload fairing, with zero solid rocket boosters and one engine on the Centaur upper stage. The spacecraft will be clamped to the rocket with a clamp band interface and separation ring. Solar panels will be initially folded to MAVEN's sides with the active solar cells facing inward.



	Event	Time (seconds)	Time (hr:min:sec)
1	RD-180 Engine Ignition	-2.7	-00:00:02.7
	Liftoff (Thrust to Weight > 1)	1.1	00:00:01.1
	Begin Pitch/Yaw/Roll Maneuver	17.3	00:00:17.3
	Maximum Dynamic Pressure	90.9	00:01:30.9
2	Atlas Booster Engine Cutoff (BECO)	242.4	00:04:02.4
	Atlas Booster/Centaur Separation	248.4	00:04:08.4
3	Centaur First Main Engine Start (MES1)	258.3	00:04:18.3
	Payload Fairing Jettison	266.4	00:04:26.4
4	Centaur First Main Engine Cutoff (MECO1)	828.3	00:13:48.3
5	Centaur Second Main Engine Start (MES2)	2,484.3	00:41:24.3
6	Centaur Second Main Engine Cutoff (MECO2)	2,813.2	00:46:53.2
7	Spacecraft Separation	3,162.2	00:52:42.2

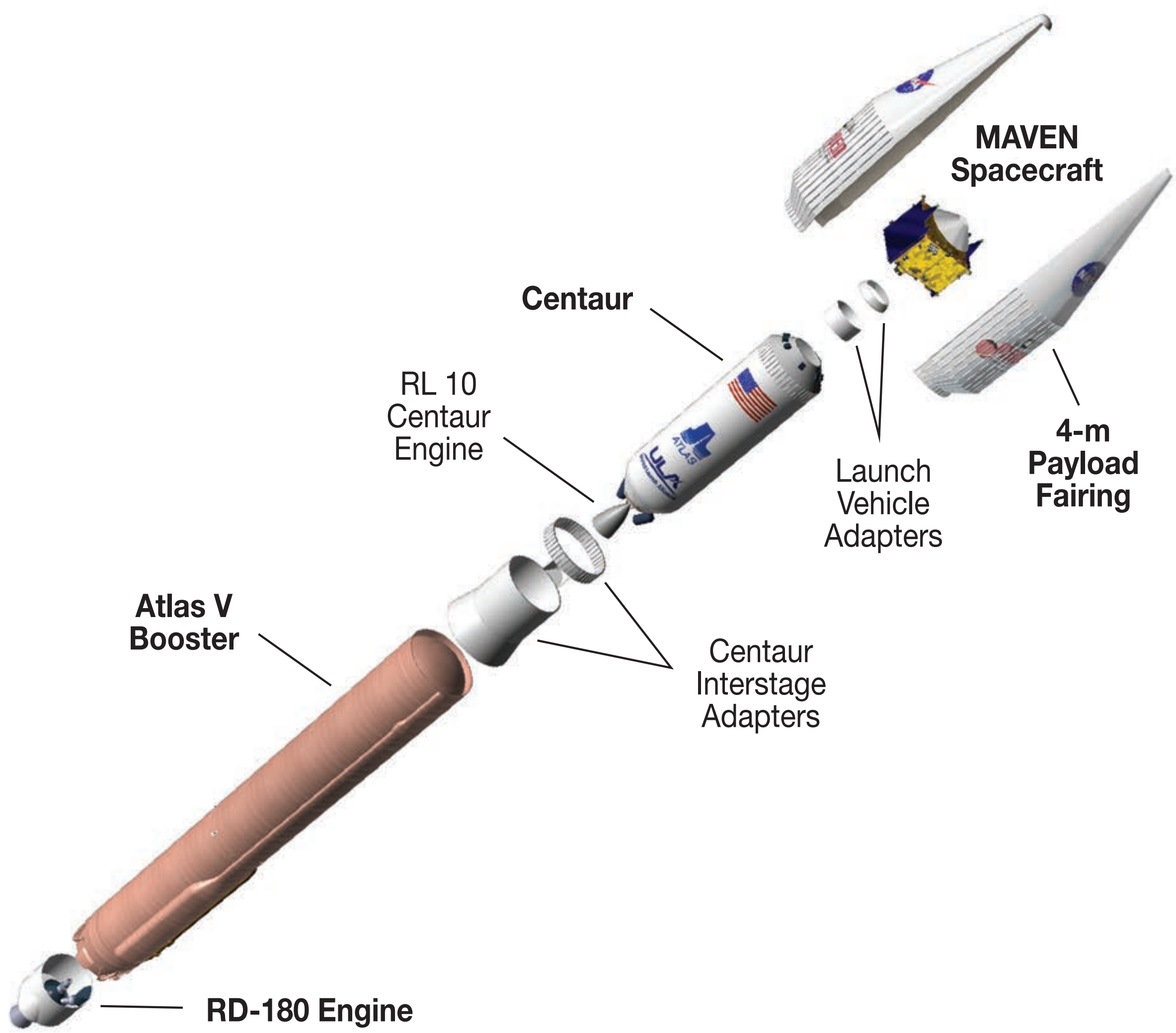
Approximate Values

Separation: After separating from the Atlas launch vehicle and Centaur second stage at around T+53 minutes, MAVEN will extend its gull-wing solar panels and orient itself so that the panels face toward the sun.

Cruise and Orbital Insertion: MAVEN will be oriented with Earth at a 25-degree angle from the high-gain antenna's center and the sun at a 60-degree angle. During the interplanetary cruise, MAVEN's will shift to a position in which Earth sits directly in the high-gain antenna's sight and the sun sits at a 45-degree angle.

Transition: Following a successful Mars orbital insertion, MAVEN will extend four scientific instrument booms—two for the LPW instrument, one for the SWEA instrument, and one for the articulated payload platform.

Science: MAVEN's solar panels will face the sun most of the time. The articulated payload platform will continually move to orient its three science instruments properly.



Launch and Interplanetary Cruise

The 20-day launch period for MAVEN begins on Nov. 18, 2013. Most days during this period offers a two-hour window for launch. Contingency launch days could be implemented out to Dec 23 if necessary. If MAVEN does not launch before the period closes, the spacecraft must wait 26 months, until January 2016, for the next Earth-Mars orbital alignment.

MAVEN launches from Cape Canaveral Air Force Station atop an Atlas V-401 rocket. The 191-foot (58.3-m) tall rocket (including payload fairing) was built by United Launch Alliance, based in Centennial, Colo. The MAVEN spacecraft will sit inside a 13-foot-diameter (4-m) payload fairing atop the Centaur second-stage booster. An Atlas rocket provides 933,406 pounds of thrust to lift MAVEN out of Earth's atmosphere. The Centaur second stage provides 22,300 pounds of thrust to propel the spacecraft out of Earth orbit toward Mars.

Following launch at T-0, the Atlas rocket will fire for around 250 seconds, after which the Centaur second stage will fire twice to boost the craft into its interplanetary trajectory. The Centaur engine's two burns, 9.5 minutes and 5.5 minutes in duration, respectively, are separated by an approximately 30-minute coast phase. MAVEN's payload fairing will jettison at around 4.5 minutes after launch, and at around 53 minutes the spacecraft will detach completely from the launch vehicle. Around 58 minutes, MAVEN will establish communication using its Low-Gain Antenna and extend its gull-wing solar panels. After correctly orienting itself, MAVEN will be in the proper configuration for its 10-month cruise to Mars.

Two to three weeks after launch, most of MAVEN's instruments will power up for the first time and perform a post-launch checkout. The spacecraft will not extend any of its booms at this time. NGIMS and the IUVS will power down following this early checkout procedure, but the Particles & Fields package will remain on and will collect data during the cruise phase.

During the cruise phase, flight operations will execute at least four trajectory correction maneuvers (TCM). The first will use the spacecraft's six orbit insertion thrusters. Following TCMs will utilize the spacecraft's six smaller vector control thrusters. After the first TCM, the team will turn on and checkout all the instruments over a one week period. By approximately day 89, MAVEN will be oriented toward Earth and will activate its high-gain antenna. All activities not related to orbital insertion will conclude 60 days before insertion.

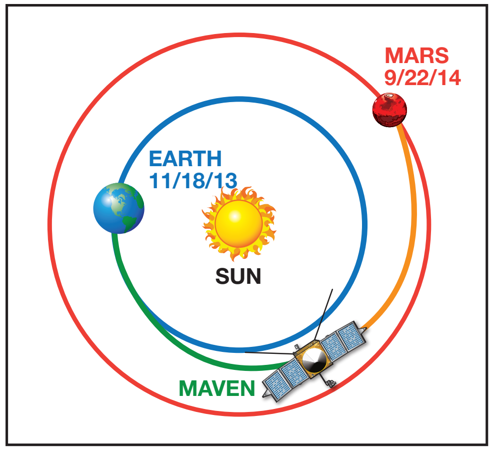
Entry Into Martian Orbit

MAVEN will enter Martian orbit on or around Sept. 22, 2014. Six orbital insertion thrusters, each with 45 pounds of thrust, will fire for 38 minutes to slow the craft and establish a 35-hour orbit at a 75-degree inclination. During this phase, the closest point in the orbit to the planet (periapsis) is 236 miles (380 km).

During a five-week "commissioning phase," MAVEN will carry out five maneuvers to settle into its final, 4.5-hour scientific mapping orbit. The spacecraft will also power up and test all instruments before commencing its scientific mission. Spacecraft booms will be deployed during the commissioning phase.

Orbital Operations
MAVEN's orbit is designed so that the craft will visit a wide range of Martian latitudes at periapsis and encounter all of the different solar-wind-interaction regions at apoapsis. During routine scientific orbits, periapsis will be around 93 miles (150 km) and apoapsis at around 3,860 miles (6,220 km).

While in its nominal science mapping orbits, MAVEN's solar panels will face the sun much of the time. The articulated payload platform will continually move to orient its three instruments correctly. This orientation will vary depending on MAVEN's position in its orbit. Close to periapsis, though, the platform will orient NGIMS in the ram direction, IUVS facing the planet, and STATIC perpendicular to the orbital plane.



MAVEN will follow a ballistic trajectory from Earth to Mars. Launch is timed so that MAVEN gets to Mars at the same time that Mars is there waiting for us.

MAVEN will execute five Deep Dip campaigns, each lasting 20 orbits (approximately five days). During a Deep Dip, MAVEN will descend to a lower periapsis altitude of around 77.6 miles (125 km) to sample a denser region of the upper atmosphere. At this elevation, the atmosphere is around 30 times denser than at nominal science mapping periapsis. Through these campaigns along with its normal orbital operations, MAVEN is able to make measurements throughout the entire upper atmosphere, from its base to its upper boundary where it interacts with the solar wind.

Many of the design features, algorithms, processes, and lessons-learned from previous Mars missions support Deep Dip operations. MAVEN's gull-wing solar panel design is one of those features. The spacecraft's solar panels are bent at a 20-degree angle. As MAVEN travels through the upper atmosphere, the air pressure will increase to a point that could disrupt flight dynamics if the solar panels were flat. MAVEN's bent solar panels shift the center of air pressure away from the spacecraft's center of gravity, providing a self-stabilizing configuration for atmospheric flight. The effect is similar to the self-stabilization provided by feathers on a badminton shuttlecock.

Extended Mission
MAVEN's primary mission lasts for one Earth year (52 weeks). MAVEN is expected to be able to fully satisfy its science objectives during this time period.

If the mission continues for a second Earth year, MAVEN will be able to enhance its science investigations by observing all of Mars' seasons through a full Martian year (98 weeks). Further mission extensions could cover a greater period of the Sun's 11-year solar cycle and provide data on year-to-year variability in both Martian weather and space weather.

During a long-duration extended science mission, ground crews will raise MAVEN's periapsis altitude to 137 miles (220 km). At this altitude, MAVEN can continue science observations for another six years with minimal fuel use and continue to serve as a communications relay for ground-based Mars spacecraft via its Electra antenna.

After MAVEN's fuel is depleted, the orbit will decay due to the drag of even the tenuous upper atmosphere and the spacecraft will eventually fall to the surface of Mars. Planetary protection precautions have been taken to ensure that, when it impacts, the spacecraft will not contaminate the surface of Mars with terrestrial organisms. Such contamination could hamper future investigations into the possible existence of life on Mars.

Communication Plan

MAVEN primarily communicates with Earth using its high-gain antenna. Every 3.5 days, MAVEN will interrupt science collection for five hours and orient its high-gain antenna toward Earth to downlink science and engineering data, receive ground commands, and update on-board systems. Between high-gain antenna communications, ground crews will track MAVEN using radio transmissions from its low-gain antenna.

Planetary Protection

The 1967 Outer Space Treaty stipulates that planetary explorers take measures to avoid contaminating their target environment. NASA's Office of Planetary Protection develops rules and practices to avoid biological contamination in the process of exploration. Each spacecraft mission is responsible for complying with Planetary Protection regulations.

MAVEN is classified as a Category III mission. Its target, Mars, is a site for investigating origins of life, so any contamination by the spacecraft could compromise future investigations. However, MAVEN is an orbiting spacecraft not specifically searching for life or life-related chemical processes. MAVEN's only risks of contamination could come from impact on the surface, either through an accident or at the end of the spacecraft's lifetime. In both scenarios the spacecraft impacts the planet's surface after entering the atmosphere. MAVEN was assembled in a clean environment and the individual components were themselves cleaned to minimize the spacecraft's "bio-burden." Modeling showed that MAVEN would introduce fewer than 500,000 biological spores to Mars in an atmospheric entry and impact event, as required by Planetary Protection guidelines. Additionally, flight engineers designed the spacecraft's initial trajectory to Mars such that the spent Centaur booster rocket would not impact the Martian surface.

Phase	Entry	Exit	Duration	Objectives
Pre-Launch	Start of countdown sequence	Liftoff	~1 day	• Configure orbiter into Launch mode
Launch	Liftoff	Payload separation	~1 hour	• Achieve interplanetary trajectory
Early Cruise	Payload separation	Activation of high-gain antenna	89 days	• Deploy solar panels • Initial instrument checks • Conduct one Trajectory Correction Maneuver
Late Cruise	Activation of high-gain antenna	Start of MOI sequence	~5 months	• Conduct three Trajectory Correction Maneuvers
Mars Orbit Insertion	Start of MOI sequence	Commissioning orbit	3 days	• Perform Mars orbit insertion maneuver • Achieve 35-hour commissioning orbit
Commissioning	Commissioning orbit	Mission orbit	5 weeks	• Spacecraft checkout and calibrations • Instrument checkout and calibrations • Boom deployments • Mission orbit adjustment
Science Operations	Mission orbit	One year of nominal operations	1 year	• Mission operations • Data product generation • Conduct five Deep Dip campaigns
Extended Mission with Relay	One year of nominal operations	End of mission orbit	Up to six additional years	• Enhance science objectives • Serve as communications relay for surface rovers • End mission orbit activities
End of Mission	End of mission orbit	Impact	N/A	• Conclude mission operations

Lockheed Martin Space Systems designed and built the MAVEN spacecraft at its Littleton, Colo., facility. Lockheed Martin brought substantial experience to MAVEN, having previously developed four NASA orbiters and four NASA landers that have gone to Mars in addition to providing all of NASA's aeroshells used on Mars missions.

Primary Structure
Based on the design of the Mars Reconnaissance Orbiter, MAVEN's central structure is comprised of aluminum honeycomb panels sandwiched between composite face sheets and fastened together with aluminum clips. Two square panels, 1.5 inches (3.8 cm) thick and 7.5 feet (2.3 m) on a side, form the fore and aft decks of the spacecraft, with five gusset panels providing structural support. The gussets surround a 60-inch (152-cm) tall central core cylinder, which contains the fuel tank. A cylindrical aluminum boat tail provides engine structural support on the aft deck.

Additional Structures
Two booms extend the SWEA instrument (5.4 feet, 1.65 m) and articulated payload platform (7.5 feet, 2.3 m) into optimal data-gathering positions away from the spacecraft. These booms deploy after MAVEN's orbital insertion at Mars.

Two motor-driven gimbals on the articulated payload platform orient the NGIMS, IUVS, and STATIC instruments to various commanded viewing directions, depending on MAVEN's position in its orbit. The two-axis gimbal system allows a 175-degree range of motion.

Propulsion Subsystem

MAVEN's hydrazine propellant is stored in a 3,615-lb (1,640-kg) capacity tank, housed in the spacecraft's central core. As mission operations burn hydrazine fuel, pressure in the fuel tank will be maintained with helium, stored in a titanium-lined, 4,800-psi tank. MAVEN's propulsion system largely duplicates Mars Reconnaissance Orbiter system.

The spacecraft features three sets of thrusters. Catalyst bed heaters ("catbed" heaters) maintain MAVEN's thrusters at operational temperatures.

Six orbit insertion thrusters, each with 45 pounds of thrust, decelerate the spacecraft during the critical Mars orbit insertion. Thrust vector control during the interplanetary cruise relies on six 4.95-pound thrusters.

Built-in redundancy and contingency features ensure that the loss of any one thruster does not mean loss of the entire mission.

Thermal Control

MAVEN instruments are designed to operate at temperatures between 5° F (minus 15° C) and 104° F (40° C). Both passive and active thermal control measures keep the craft at the proper temperature.

Passive thermal features include materials that either conduct or isolate heat, along with radiators. The bulk of the spacecraft is covered in multi-layer insulation with the external layer consisting of germanium-coated black Kapton film.

Heaters are controlled by either thermostats or on-board computers. In most heater circuits, temperature sensors provide feedback to the computer, which powers heaters on or off as needed. Secondary heating circuits back up each heater, and additional temperature sensors back up circuits controlled by temperature sensor feedback.

Power

Spacecraft power is supplied by four solar panels in two "gull-wings." Combined, the panels have 84.5 square feet of solar cells that provide at least 1,150 watts of power. The panels can generate power even at a 60-degree angle from the sun.

The panels charge two 55-amp-hour lithium-ion batteries. Power is regulated and distributed to the various users via the Pyrotechnic and Propulsion Unit and the Power Distribution and Drive Unit.

Communication Hardware

MAVEN communicates with Earth through the 6.5-foot (2-m) high gain antenna, operating on the X-band.

Two low-gain antennas, one on the fore deck and one on the aft deck, establish initial contact with Earth following launch, and provide a greater communications coverage area during trajectory correction maneuvers and any safe mode operations. The low-gain antennas also provide spacecraft tracking information to Earth during science operations. The spacecraft position is determined through Doppler and delta-differential ranging information.

Twice per week during the science mission, MAVEN will orient toward Earth to transmit collected data and receive ground commands. The spacecraft can store up to 32 gigabits of data on-board between these communication sessions.

Ground crews will utilize the Deep Space Network antennas throughout the mission for data uplinks and downlinks. Each of these transmissions comprises approximately 3 gigabits per orbit during the science phase.

Attitude Control

MAVEN two star tracker cameras to collect digital images of the stars. These images, fed through a stellar detection algorithm, provide spacecraft attitude information to other navigation systems. Two sun sensors help MAVEN point its solar panels toward the sun in case of an error sending the spacecraft into “safe mode.”

Ring laser gyros detect spacecraft inertial motion, and four reaction wheels provide fine attitude control for proper spacecraft orientation. The four reaction wheels are arranged in the shape of a four-sided pyramid.

Software

MAVEN’s software design pulls from software currently operating on the Juno mission. Prior to Juno, the software is derived from Mars Reconnaissance Orbiter, Phoenix and Mars Odyssey, all of which have a combined runtime of more than 100,000 hours, demonstrating the software’s robustness and stability.

MAVEN uses both flight software (loaded into the spacecraft’s memory) and ground software (used for spacecraft testing).

NASA's Launch Services Program

NASA turns to the engineers and analysts in its Launch Services Program to send robotic spacecraft on their way for some of the most exciting and notable missions in the agency's history.

The Launch Services Program, known as LSP, is based at NASA's Kennedy Space Center in Florida and boasts a roster of engineers and technicians who specialize in all aspects of rocketry and spacecraft integration. LSP selects the appropriate launcher for a mission's spacecraft, in this case the United Launch Alliance Atlas V, or Mars Atmosphere and Volatile EvolutioN, or MAVEN. Sometimes, this selection process takes place years before the first launch opportunity. The program then provides oversight as the designs of the rocket and mission are integrated with each other.

As liftoff nears, teams oversee the launch vehicle's engineering and manufacture and its integration with the spacecraft. LSP conducts the countdowns for NASA's scientific missions and provides additional quality assurance along with other controls to ensure a successful mission.

Working with commercial rocket builders, planners have a number of rocket models to choose from, ranging from the small, air-launched Orbital Sciences Pegasus to the workhorse Delta II rocket from the United Launch Alliance, or ULA, to the powerhouse Altas V, also from ULA. The catalog is growing, too, with the addition of the SpaceX Falcon 9 and Orbital Sciences Antares rockets.

LSP moved its operations to Kennedy in 1998, becoming the first program based at the nation's premiere launch site. The 14 years since then have seen orbiters, landers and rovers to Mars, huge observation spacecraft to Jupiter and the New Horizons mission launched to Pluto and the Kuiper Belt, two astronomical locations that have never been seen up-close before.

Because some spacecraft need to fly in a different kind of orbit, LSP operates several launch centers around the world. Cape Canaveral Air Force Station in Florida is adjacent to Kennedy Space Center and hosts launches to place spacecraft in orbits that remain close to the equator. The LSP launch team goes to Vandenberg AFB in California to run launches that require spacecraft to fly around the world in a north-to-south orbit, known as a polar orbit. LSP also conducts launches from Kwajalein in the Marshall Islands, Kodiak Island, Alaska, and NASA's Wallops Flight Facility on Virginia's eastern Shore.

To learn more about LSP, rockets and NASA missions go to:
http://www.nasa.gov/centers/kennedy/launchingrockets/index.html

Recent, Current, and Upcoming Missions

NASA's Mars Exploration Program builds on scientific discoveries and lessons from past and ongoing missions to establish a sustained observational presence at Mars. This includes orbiters that view the planet from above and also act as telecommunications relays, surface-based mobile laboratories, robots that probe below the planet's surface, and, ultimately, missions that return soil and rock samples to Earth and prepare for human landing.

Compelling questions about Mars drive the long-term program, which develops technologies in coordination with international partners. These technologies make missions possible using the available resources. The program seeks to discover substantial evidence of Mars' past and present environments, including the influence and abundance of water, and the possibility of habitats, past or present, suited for the existence of life.

Recently completed, ongoing and near-term future Mars missions of exploration by NASA and its international partners:

Mars Pathfinder (December 1996 – March 1998):
The first completed mission in NASA's Discovery Program of low-cost planetary missions with highly focused scientific goals, Mars Pathfinder set ambitious objectives and surpassed them. This lander released its Sojourner rover on the Martian surface and returned 2.3 billion bits of information from instruments on the lander and the rover. The information included more than 17,000 images, more than 15 chemical analyses of rocks and soil, and extensive data on winds and other aspects of weather. The observations suggest that early Mars may have been more Earth-like with liquid water on its surface and a thicker atmosphere than it has today. The mission functioned on the Martian surface for about three months, well beyond the planned lifetimes of 30 days for the lander and seven days for the rover.

Mars Global Surveyor (November 1996 – November 2006):
During its primary mapping mission from March 1999 through January 2001, NASA's Mars Global Surveyor collected more information than any previous Mars project. The orbiter continued to examine Mars' surface and monitor its global weather patterns through three mission extensions, successfully operating longer than any previous spacecraft sent to Mars. It had begun a fourth extension and was five days shy of the 10th anniversary of its launch when it last communicated with Earth. Mars Global Surveyor returned more than 240,000 camera images, 206 million spectrometer measurements and 671 million laser-altimeter shots.

Some of the mission's most significant findings include: discovering extensive layering of the planet's crust; discovering ancient deltas; discovering channels, a few of which exhibit modern activity suggesting modern liquid water; identifying concentrations of a mineral that often forms under wet conditions, leading to selection of one large deposit as the landing area for NASA's Mars Exploration Rover Opportunity; laser-altimeter observations producing a nearly global map of the planet's topography, quantifying altitudes and slopes, and characterizing myriad craters, including many eroded or buried craters too subtle for previous observation; and compiling extensive evidence for the role of dust in reshaping the recent Martian environment.

Mars Odyssey (April 2001 – present):
This NASA orbiter's prime mapping mission began in March 2002. Its gamma-ray spectrometer instrument soon provided strong evidence for large quantities of frozen water mixed into the top layer of soil in the 20 percent of the planet near its north and south poles. Subsequently, NASA chose a site in this permafrost terrain as the Phoenix Mars Lander's destination. Odyssey's camera system examined the planet in both visible-light and infrared wavelengths, identified minerals in rocks and soils and has compiled the highest-resolution global map of Mars. Nighttime infrared imaging provides information about how quickly or slowly surface features cool off after sunset, which indicates whether the surface is rocky or dusty. Odyssey's instruments have monitored the Mars atmosphere for more than a decade. Measurements include the tracking of non-condensable gases such as argon as tracers of atmospheric transport. Odyssey has also monitored high-energy radiation at orbital altitudes to help characterize the environment that future missions, including possible human ones, will encounter.

Odyssey is now the longest-working spacecraft ever sent to Mars, continually mapping the planet while providing relay support for ongoing rover missions.

Mars Exploration Rover Spirit (June 2003 – March 2010):
The first of NASA's twin Mars Exploration Rovers to land on Mars, Spirit was a mobile robotic field geologist sent to examine clues about the planet's environmental history — particularly the history of water—at a carefully selected site. Each rover's mission was planned to run for three months on Mars, but both rovers worked for years. Spirit explored Gusev Crater, a highly eroded crater 95 miles (150 kilometers) in diameter.

Orbital images suggested Gusev may have once held a lake fed by inflow from a large valley network funneling into the crater from highlands to the south. Spirit landed Jan. 4, 2004, on a flat volcanic flood-plain pocked with small craters and strewn with loose rocks. There, the rover found basaltic rocks only slightly altered by exposure to moisture. By June 2004, well into its first extended mission, Spirit had driven to a range named the Columbia Hills, about 1.6 miles (2.6 kilometers) from the landing site, in a quest to find exposed bedrock. Exploring in the hills, Spirit discovered a profusion of rocks and soils bearing evidence of extensive exposure to water, including the iron-oxide-hydroxide mineral goethite and hydrated sulfate salts. It found an outcrop rich in carbonate, evidence for wet conditions that were not acidic. Textures and compositions of materials at a low plateau between hills indicated an early era on Mars when water and hot rocks interacted in explosive volcanism. By driving with one immobile wheel whose motor had worn out after three years on Mars, Spirit serendipitously plowed up a hidden deposit of nearly pure silica. This discovery indicates that the site once had hot springs or steam vents. Similar environments on Earth teem with microbial life. In June 2009, Spirit became embedded in a patch of fine-grained material and was unable to extract itself after a second wheel stopped working. Unable to position its solar array to generate energy, Spirit apparently lost power during the long southern winter, as no further communications were received after March 22, 2010.

Mars Exploration Rover Opportunity (July 2003 – present):
This rover was sent to a flat region named Meridiani Planum, where the spectrometer on Mars Global Surveyor had discovered a large exposure of the mineral hematite — which often forms in the presence of water. On Jan. 25, 2004, Opportunity landed inside a crater only 72 feet (22 m) in diameter and immediately located exposed bedrock in the crater's inner slope. During the next few weeks, the rover discovered sedimentary geological features in the outcrop, settling the long-running debate about whether Mars ever had sustained liquid water on its surface.

These formations showed that the rocks not only had been saturated with water, but had actually been deposited under gently flowing surface water.
For six months beginning in June 2004, Opportunity examined deeper layers of rock inside a stadium-size crater, Endurance, about half a mile (700 m) from the landing site. The wall-rock layers had all soaked in water, but textures in some showed that periods of dry, wind-blown deposition alternated with periods when water covered the surface. After examining its own jettisoned heat shield and a nickel-iron meteorite near this crater, Opportunity drove more than 4 miles (6 km) southward to reach an even larger and deeper crater, Victoria. Here, it examined geological evidence of similar environmental conditions from a greater span of time. The presence of sulfur-rich material throughout Opportunity's study area indicates acidic watery environments.

In mid-2008, Opportunity set off toward a crater 14 miles (22 km) in diameter, Endeavour, where orbital observations have detected water-related clay minerals, different from any Opportunity has seen so far and indicative of less-acidic watery environments. In August 2011, with a total driving odometry of more than 21 miles (34 km), the rover reached the rim of Endeavour Crater to start a new phase of its exploration of Mars. There it found water-deposited veins of gypsum. In May 2013, Opportunity broke the record for distance driven by a NASA vehicle on a planet other than Earth, surpassing the 22 miles (35.7 km) driven by the Apollo 17 Lunar Roving Vehicle.

Mars Express (June 2003 – present):
This is a European Space Agency orbiter with NASA participation in two of its seven science investigations: a ground-penetrating radar, and a tool for studying how the solar wind removes water vapor from Mars' outer atmosphere.

The spacecraft has been returning color stereo images and other data since January 2004 after entering orbit in late December 2003. Its spectrometer for visible and near-infrared wavelengths found deposits of clay minerals indicating a long-ago wet environment that was less acidic than the one that produced the minerals studied by Opportunity. Scientists working with this and similar data from the Mars Reconnaissance Orbiter have proposed a sequence of globally distributed water environments very early in Mars' history, moving from less to more acidic environments. These discoveries have important implications for the habitability of Mars, past and present. Since deployment of the radar antenna in June 2005, the spacecraft has examined ice-rich layered deposits covering the polar regions.

Mars Reconnaissance Orbiter (August 2005 – present):
This multipurpose spacecraft examines the surface, subsurface and atmosphere of Mars in unprecedented detail. It began its primary science investigations in November 2006, following 426 carefully planned dips into the top of Mars' atmosphere to adjust the size and shape of its orbit after arriving at Mars in March 2006.

Specifically engineered to return the vast volumes of data generated by the high spatial resolution of its imaging cameras and spectrometer, the orbiter has returned more than three times as much data as the combined total from all other space missions that have traveled farther than the moon.

NASA's Deep Space Network antennas received more than 190 terabytes of data—including more than 70,000 images—from the six science instruments on Mars Reconnaissance Orbiter during the mission's first eight years at Mars. The mission has illuminated three very different periods of Mars' history. Its observations show that different types of watery environments formed extensive deposits of water-related minerals—including clays, sulfates and carbonates—across the planet early in Mars' history. In more recent times, water appears to have cycled as a gas between polar ice deposits and lower-latitude deposits of ice and snow.

Radar observations reveal internal, episodic patterns of layering probably connected to cyclical variations in the tilt of the planet's rotation axis and the elliptical nature of its orbit. These cycles modulate the solar heating of the poles to a much larger degree than occurs for Earth, with its ice ages, over periods of thousands to a few million years. Radar has also revealed a thick deposit of carbon-dioxide ice buried in the south polar cap, which, if released into the atmosphere, would nearly double the amount of gas in the atmosphere today. With observations of new craters, avalanches and dust storms occurring even now, the orbiter has shown that modern Mars is still a dynamic world. The orbiter's observations have identified sites with high potential for future scientific discovery. In addition, the orbiter's high-resolution cameras can reveal hazards to landing and roving spacecraft, such as rocks and steep slopes, while its atmospheric monitors characterize the environment that can be encountered during landing and operations on the surface. Observations by the Mars Reconnaissance Orbiter enabled the Phoenix mission to choose a landing site less rocky than one previously considered. The orbiter also examined potential landing sites for Mars Science Laboratory and serves as a relay asset for Curiosity's surface operations.

Phoenix Mars Lander (August 2007 – November 2008):
In 2001, NASA announced the Mars Scout missions, a new program of competitively proposed and selected missions to Mars. The Phoenix Mars Lander proposal, submitted by a team led by Peter Smith of the University of Arizona, Tucson, was selected out of 25 proposals in 2003 to be developed for launch in 2007. The mission sent a stationary lander with a robotic digging arm and suite of science instruments to study the summer environment in a far-northern zone. Phoenix confirmed and examined deposits of underground water ice detected from orbit by Mars Odyssey. It identified calcium carbonate deposits suggesting occasional presence of liquid water and also found soil chemistry with significant implications for life. The lander also witnessed a rare sight on Mars: falling snow. The

mission's biggest surprise was the discovery of perchlorate, an oxidizing chemical on Earth that is food for some microbes and potentially toxic for others, and which can lower the freezing point of liquid water by tens of degrees. It completed its planned three months of operation on Mars and worked two extra months before the anticipated seasonal decline in solar energy at its high latitude ended the mission.

Mars Science Laboratory (November 2011 – present):
The Mars Science Laboratory launched on November 26, 2011. The Mars Science Laboratory mission and its rover, Curiosity, evaluate whether the Gale Crater area of Mars could have once supported life.

Curiosity dramatically landed in Gale Crater in August 2012. Early measurements of samples of the atmosphere with the Sample Analysis at Mars (SAM) instrument analyzed the major gas carbon dioxide and as well as water, argon, and nitrogen. The instrument measured isotopes of carbon, hydrogen, and oxygen in the atmosphere, determining the amount of heavy or light isotopes of each element. Results suggested that much of Mars' atmosphere was lost fairly early in the planet's history, with additional slow loss in the past four billion years. In February of 2013 samples were collected from the first set of drill holes on Mars. The interior of the rock was found to be gray, rather than classic rusty Mars red. The samples contained clay minerals that were formed in the presence of water. Analysis of these drill cuttings showed the presence of sulfur, nitrogen, hydrogen, oxygen, phosphorus and carbon, all essential chemical foundations for life. In July 2013, Curiosity began a months-long journey to investigate exposed rock layers on the flanks of nearby Mount Sharp.

Future Missions:

InSight (planned 2016):
The Interior exploration using Seismic Investigations, Geodesy, and Heat Transport lander, or InSight, is designed to probe Mars' interior with geological instruments such as a seismometer and heat flow probe. The mission aims to understand the processes of planet formation and evolution in the inner solar system. The heat flow probe will penetrate the Martian surface to a depth of 16 feet (5 m) to monitor the planet's temperature. InSight is scheduled to launch in March 2016 and land on Mars six months later. The lander's one-Martian-year mission will run through September 2018.

ExoMars Trace Gas Orbiter (planned 2016):
This mission, a partnership between the European Space Agency and Russia's Roscosmos, travels to Mars to survey trace gases in the planet's atmosphere that may indicate active geological or biological processes. The orbiter will carry an Entry, Descent, and Landing demonstrator module (EDM), which will execute a controlled landing on the planet's surface. The EDM will collect data throughout descent and will serve as a test of the ExoMars rover's landing technology. Once on the surface, the EDM will measure wind speed, humidity, pressure, temperature, atmospheric clarity, and electricity in the atmosphere. Meanwhile, the Trace Gas Orbiter will circle Mars, assessing the global distribution of trace gases, imaging potential sources of such gases, and mapping hydrogen in Mars' subsurface.

ExoMars Rover (planned 2018):
The European Space Agency's ExoMars rover will launch in 2018. The six-wheeled ExoMars rover will use a panoramic camera, close-up camera, and drill for Mars samples for in situ analysis. The mission will use ground-penetrating radar to characterize the subsurface and search for water, and evaluate potential organic molecules with an on-board chemical laboratory. NASA is providing the Mars Organic Molecule Analyzer mass spectrometer, a key component of the main instrument suite on the rover.

2020 Mars Rover (planned 2020):
In December 2012, NASA announced plans to launch a rover mission, as a follow-up to Curiosity, in 2020. This spacecraft will search for evidence of life and collect samples for possible return to Earth. The rover will also collect data essential for planning future human expeditions to Mars. The as-yet-unnamed rover will take many of its engineering and design cues from Curiosity.

Beyond 2020:
NASA's Mars Exploration Program continues to adapt to budgetary constraints while focusing on key Mars science goals. These goals are inspired by the National Research Council's decadal survey for planetary science, which includes returning Mars samples to Earth and working toward the long-term goal of landing human explorers on the Red Planet.

Program/Project Management

The MAVEN project is led by principal investigator Bruce Jakosky, of CU-Boulder's Laboratory for Atmospheric and Space Physics. The University of Colorado is the lead institution for the MAVEN project. MAVEN is managed for the Principal Investigator by NASA's Goddard Space Flight Center in Greenbelt, Md

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