ESCAPADE

Escape and Plasma Acceleration and Dynamics Explorers

Unraveling cause-and-effect in Mars' unique hybrid magnetosphere

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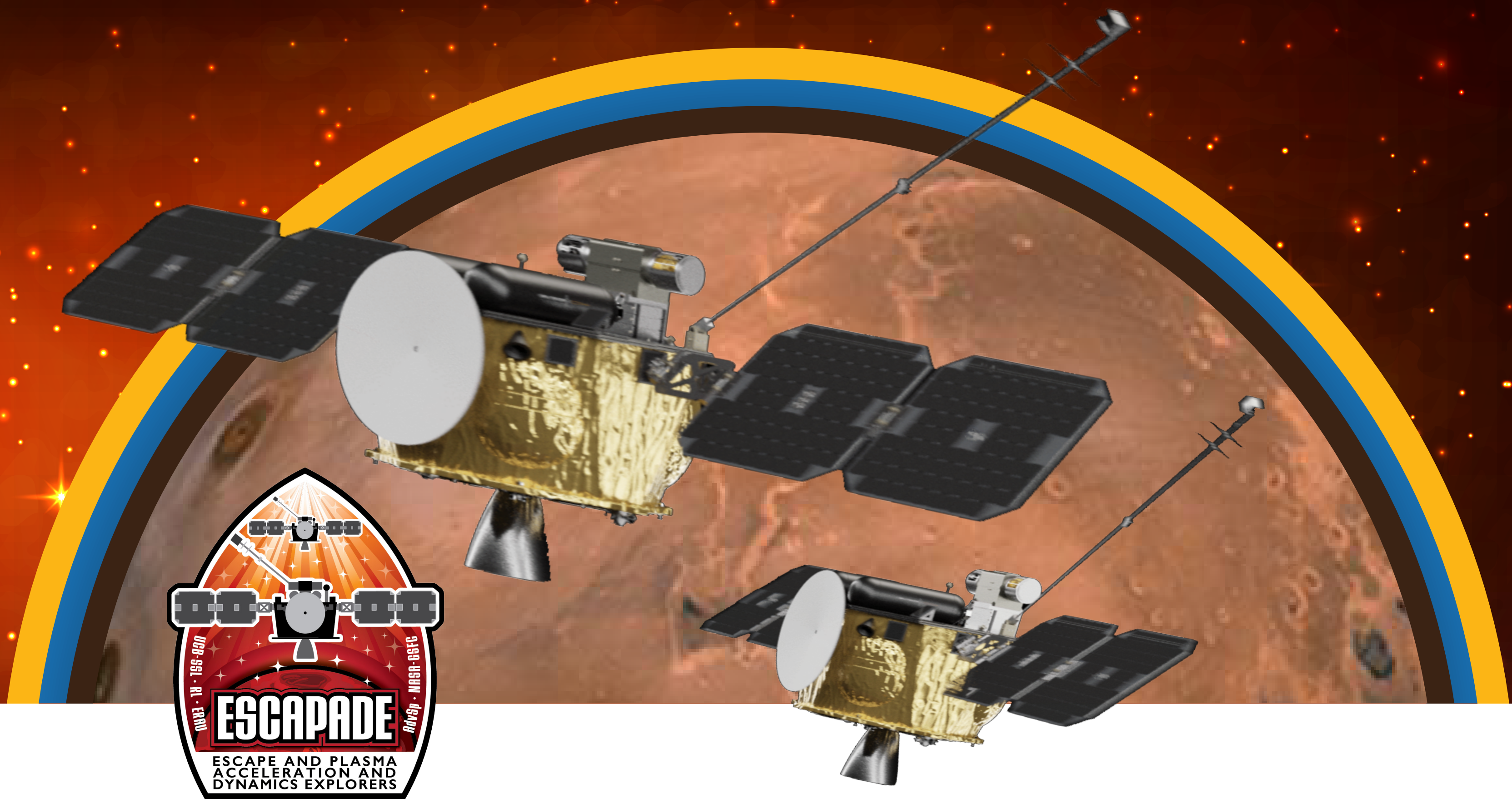

REVEALING MARS' DYNAMIC SPACE WEATHER

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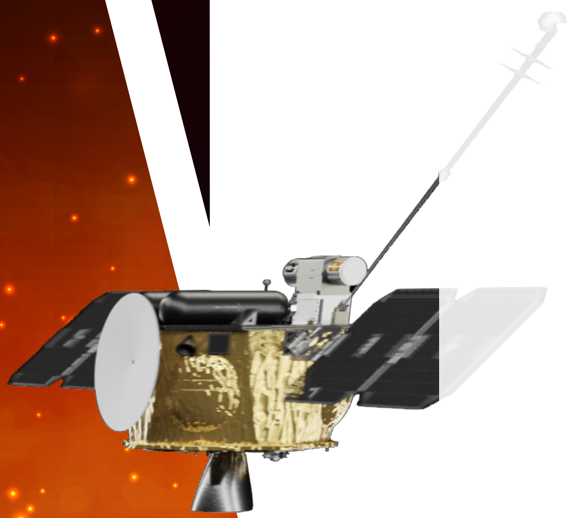

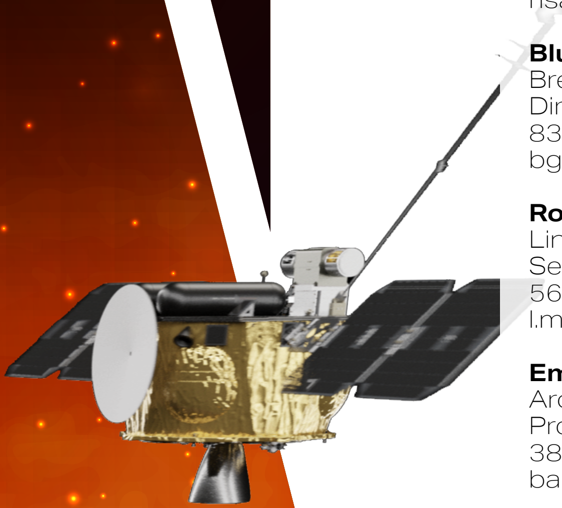

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For more information about ESCAPADE, visit www.nasa.gov/escapade

Mission Overview

Launched on Nov. 13, 2025, the Escape and Plasma Acceleration and Dynamics Explorers (ESCAPADE) mission will put two identical satellites in orbit around Mars. The twin satellites will work in tandem to collect comprehensive data on how space weather affects Mars' unique "hybrid" magnetosphere and how this dynamic interaction drives atmospheric loss. This data is crucial for understanding Mars' climate history and the processes behind the loss of its once-dense atmosphere, which supported the conditions necessary for liquid water, and potentially oceans and even life on Mars' surface.

Mars used to have a strong global magnetic field like Earth's, but the iron-core dynamo that generated it shut down 3.5-4 billion years ago. However, Mars retains remnants of this ancient dynamo: regions of strongly magnetized crust producing magnetic fields that rotate with the planet and influence the space around Mars. The constant stream of charged particles and magnetic fields emanating from the Sun within the solar wind also continuously collides with Mars' relatively thin atmosphere. This space weather interacts with electrically charged atoms and molecules, or ions, in Mars' upper atmosphere (a region known as the ionosphere) and induces a magnetic field there. Together, Mars' magnetized crust and induced magnetic field form a relatively weak, yet unique and complex "hybrid" magnetosphere surrounding Mars that controls ion flow and influences the processes driving the planet's ongoing atmospheric loss.

Throughout the ESCAPADE mission, the two satellites will take simultaneous measurements from nearly the planet's entire upper atmosphere and magnetosphere, ranging from altitudes between approximately 100 and 6,200 miles (160 and 10,000 kilometers). Coordinated, multipoint observations are necessary to accurately characterize the temporal variability and real-time response of Mars' near-space environment to space weather, and ultimately, unravel the chain of cause and effect within the system.

The ESCAPADE mission funding was awarded via NASA's Small Innovative Missions for Planetary Exploration (SIMPLEx) program in 2019. NASA's SIMPLEx investigations are complete but relatively inexpensive missions using small spacecraft. The ESCAPADE mission is led by the Space Sciences Laboratory at the University of California, Berkeley (Principal Investigator Robert Lillis), which is responsible for the mission's management, key science instruments, systems engineering, navigation, operations, and eventual science data processing and archiving. Other key partners include NASA's Goddard Space Flight Center (project oversight and magnetometer), NASA's Launch Services Program (launch contract), Rocket Lab (spacecraft development), Embry-Riddle Aeronautical University (plasma measurements), Advanced Space LLC (mission design), and Blue Origin (launch complex and launch vehicle).

Quick Facts

Launch Date: Nov. 13, 2025, 3:55 p.m. EST
Launch Site: Launch Complex 36, Cape Canaveral Space Force Station
Launch Vehicle: Blue Origin New Glenn 2
Earth-Proximity Orbit: 12 months
Cruise to Mars: 10 months
Mars Orbit Insertion: September 2027
Science Mission: June 2028 to May 2029
Science Campaign A: Both spacecraft in same orbit ("string-of-pearls" formation)

- Identical 160 km x 8,400 km elliptical orbit, 65° inclination, period: 5 h 40 m

Science Campaign B: Spacecraft are in different orbits

- Spacecraft 1: 160 km x 7,000 km elliptical orbit, 65° inclination, period: 4 h 54 m
- Spacecraft 2: 160 km x 10,000 km elliptical orbit, 65° inclination, period: 6 h 35 m

Instruments: Electrostatic Analyzer (UC Berkeley), Magnetometer (NASA Goddard), Langmuir Probe (Embry-Riddle Aeronautical University)
Student Instruments: Visible and Infrared Cameras (Northern Arizona University)

Partners and Roles

NASA's Goddard Space Flight Center (Greenbelt, Maryland)
- Overall program management
- Project oversight
- Science communication
- EMAG (magnetometer) instrument design, build, and management

University of California, Berkeley, Space Sciences Laboratory (Berkeley, California)
- Principal investigation (science leadership)
- Project management
- Systems engineering (technical engineering support for instrument and spacecraft development teams)
- Safety and mission assurance
- EESA (electrostatic analyzer) instrument design, build, and management
- 2-meter boom (for specific instrument deployment)
- Payload electronics
- Payload flight software
- Mission and payload operations (includes ground commanding, flight operations, navigation, and data downlink via NASA's Deep Space Network)
- Science operations (instrument commanding)
- Data processing & archiving

Embry-Riddle Aeronautical University (Daytona Beach, Florida)
- ELP (ESCAPADE Langmuir Probe) design, build, and management

Northern Arizona University (Flagstaff, Arizona)
- Visible & Infrared Cameras (student-built instrument)

Rocket Lab (Long Beach, California)
- Spacecraft bus design, management, assembly, integration, and testing
- Mission operations support

Advanced Space, LLC (Westminster, Colorado)
- Mission design and trajectory optimization
- Maneuver design
- Launch targets
- Planetary protection support
- Navigation operations support
- Blue Origin (Kent, Washington)
- New Glenn reusable launch vehicle
- Launch complex and integration facilities

Mars

Distance from Sun: 1.38 to 1.62 AU (128 million to 151 million miles); elliptical orbit

Diameter: 4,238 miles (6,780 km), slightly more than half (53%) of Earth's

Gravity: 38% of Earth's

Axial Tilt: 25° (Earth is 23°); Mars' elliptical orbit means southern summer is shorter and hotter than northern summer

Surface Temperature: -220°F to +65°F (-150°C to +25°C)

Early Climate (~3-4 billion years ago): Many signs of past flowing/standing liquid water, inferring a much thicker atmosphere in Mars' early history

Current Atmosphere: Thin, cold, dry, poisonous, ~0.6% of Earth pressure, 95% carbon dioxide

Ionosphere: A layer of charged particles above 75 miles (120 km) altitude in Mars' atmosphere that consists primarily of ionized carbon dioxide, carbon monoxide, nitric oxide, and atomic and molecular oxygen; ionization occurs in this area when an atom or a molecule acquires a negative or positive charge by gaining or losing electrons after exposure to the Sun's ultraviolet light

Induced Magnetic Field: Relatively weak magnetic field resulting from the solar wind's interaction with the charged particles in Mars' ionosphere

Crustal Magnetic Fields: Localized magnetic fields caused by areas of strongly magnetized crust, primarily in the southern hemisphere

Hybrid Magnetosphere: The combined total system of the induced and crustal magnetic fields surrounding Mars

Launch

The ESCAPADE mission was carried into orbit on the second launch of Blue Origin's New Glenn rocket. New Glenn is a single-configuration, heavy-lift orbital launch vehicle capable of routinely carrying both spacecraft and people to low Earth orbits, geostationary transfer orbits, cislunar orbits (between Earth and the Moon), and beyond via Earth-departure orbits like the one required for ESCAPADE. New Glenn's manufacturing and assembly takes place in Blue Origin's manufacturing complex in Cape Canaveral. It launches just nine miles away, from Cape Canaveral Space Force Station Launch Complex 36 (LC-36), which Blue Origin rebuilt from the ground up. The vehicle is named after John Glenn, the first American astronaut to orbit Earth.

Vehicle Specifications

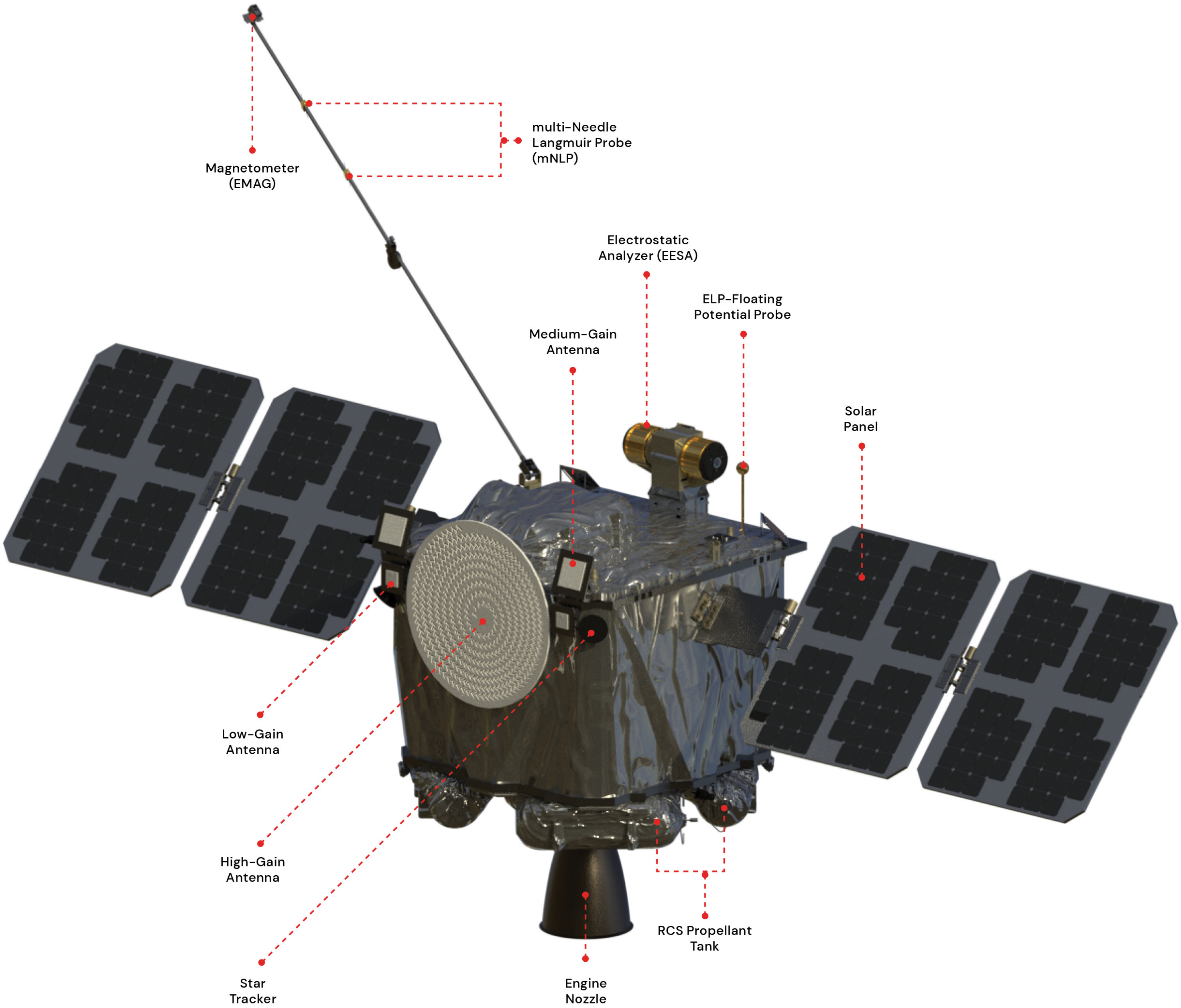
- Reusable first stage designed for a minimum of 25 missions.
- Powered by seven BE-4 engines, the nation's first reusable, oxidizer-rich staged combustion booster engine using liquid oxygen and liquefied natural gas (LNG), a commercial form of methane.
- Engines generate 3.85 million pounds of thrust at launch, or roughly half of the Saturn V's.
- Seven-meter fairing enables twice the payload volume of any five-meter-class commercial launch system.
- Designed to launch payloads of more than 13 metric tons to geostationary transfer orbit and 45 metric tons to low Earth orbit.

Facilities

- Blue Origin has invested more than $3 billion in facilities and infrastructure at all sites, including $1 billion invested in the rebuild of the historic LC-36 in Cape Canaveral.
- LC-36 was completed in 2021. It includes the integration and refurbishment facilities, fuel supply, environmental control center, and launch pad, and represents the first newly rebuilt launch complex since the 1960s.
- The Manufacturing Complex is 650,000 square feet and more than four football fields long.

Spacecraft

Designed, built, integrated, and tested at Rocket Lab's Space Systems Production Complex and Headquarters in Long Beach, California, the spacecraft's design originated from Rocket Lab's Explorer spacecraft, a high-delta-V interplanetary platform. The duo features Rocket Lab-built components and subsystems, including solar panels, star trackers, propellant tanks, reaction wheels, reaction control systems, radios, and more.



SPACECRAFT SPECS

DESIGNED FROM ROCKET LAB'S EXPLORER SPACECRAFT

SIZE

Stowed: 1.20 m x 1.65 m x 1.09 m
Deployed: 4.88 m x 1.65 m x 1.09 m

MASS

Dry Mass: 209 kg **Wet Mass:** 535 kg

PROPULSION

Main engine: Hypergolic bipropellant, mixed oxides of Nitrogen (MON) and Monomethyl Hydrazine (MMH) engine

Reaction Control System (RCS) Thrusters: Cold gas Nitrogen thrusters, capable of translation and rotation

On-board tanks:

- Two fuel tanks, additively manufactured metal
- Two oxidizer tanks, additively manufactured metal
- Two pressurant (He) tanks, Composite Overwrap Pressure Vessel (COPV)
- Four RCS (N2) tanks, COPV

POWER

Science (nominal) mode power draw:
128 W (about as much as a tea kettle)
Power generation at Earth: 800W

Power generation at Mars (aphelion): 288W

Energy storage: Five 7s5p battery assemblies

AVIONICS

Redundant flight computers

GUIDANCE AND NAVIGATION CONTROL

Sensors: Two star trackers, four fine sun sensors

Actuators: Four reaction wheels, reaction Control Thrusters

TRAJECTORY

Interplanetary Cruise: 10 months
Primary Science Mission: 11 months

COMMUNICATIONS

Total planned downlinked science data: 45Gb
Rocket Lab Frontier-X radios
• Redundant radios
Antennas:

- Four low-gain patch antennas
- Two medium-gain patch antennas
- One radial line slot array high-gain antenna

Uplink and Downlink: X-band

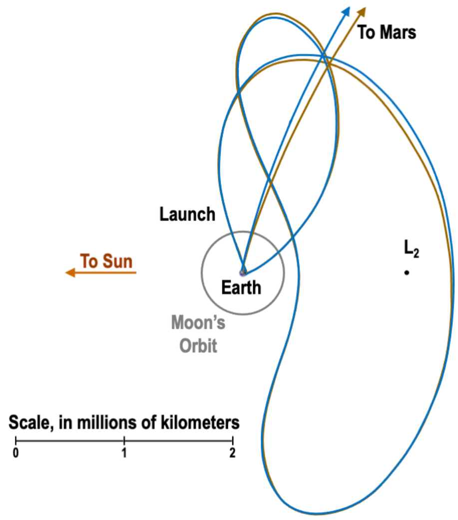
Mission Design

Advanced Space LLC leads the overall mission and trajectory design for ESCAPADE. Faced with all the technical challenges inherent to interplanetary science, Advanced Space created a robust mission design that maximizes the chance for a successful Earth-proximity phase, interplanetary cruise, Mars orbit insertion, and science orbits. Advanced Space also worked with the rest of the mission team to build navigation capabilities to avoid any impact with Mars or its moons, satisfying NASA's policies for planetary protection.

Phase I – Launch & Loiter

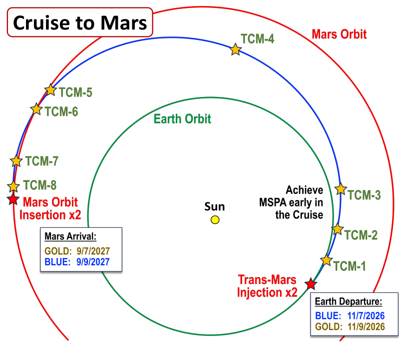
ESCAPADE's spacecraft launched from Cape Canaveral, Florida, on Nov. 13, 2025.

The alignment between Earth and Mars in late 2025 did not allow ESCAPADE to use a traditional direct-to-Mars transfer. Instead, ESCAPADE launched into a "loiter" (or "Earth-proximity") orbit that will loop around Earth's Lagrange point 2 (about a million miles from Earth, opposite the Sun) until the next planetary alignment window. Once the planets have reached the ideal alignment in late 2026, the ESCAPADE spacecraft will use an Earth gravity assist to begin the journey to Mars.



Phase II – Interplanetary Cruise

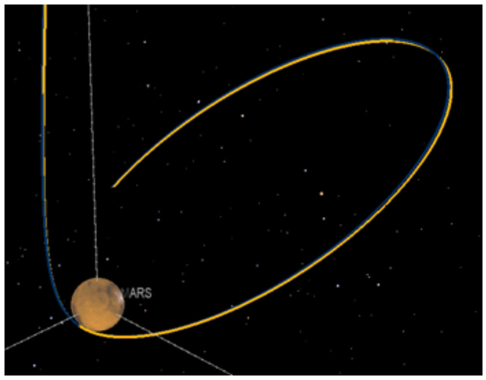
Both spacecraft will use their onboard propulsion systems to conduct deep-space maneuvers, known as trajectory correction maneuvers (TCMs). The TCMs will boost the spacecraft's energy to reach Mars and provide the navigation control to target their unique orbit insertion corridors while maintaining multi-spacecraft per aperture (MSPA), or the ability for one Deep Space Network antenna to communicate with both spacecraft simultaneously. In addition, the mission is designed to be operated by a single team with ample time margin for all activities.



Novel L2 Staging Orbit

Phase III – Mars Orbit Insertion

The spacecraft will arrive at Mars separated by two days, each entering Mars orbit at an altitude of 450 km. Both spacecraft will perform an insertion burn approximately 11 minutes in duration, targeting a capture orbit with a 60-hour period. This capture orbit will allow the spacecraft to eventually maneuver into the desired science orbits within the capabilities and constraints of the onboard propulsion system.



Phase IV – Orbit Reduction and Transition to Science

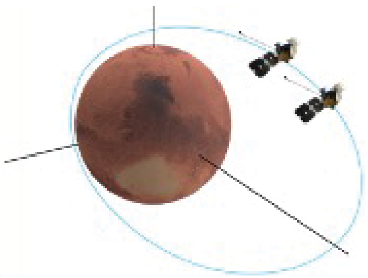
ESCAPADE's spacecraft must transition from their initial orbits around Mars to nearly identical orbits slightly separated from each other, without introducing any risk of collision between them or with anything else at Mars. This transition is done in two stages: the initial orbit reduction phase and the transition to science phase. Initial orbit reduction happens immediately after arrival and must conclude before solar conjunction occurs at the end of 2027, when Mars and Earth will be on opposite sides of the Sun and thus communication between the two planets will be disrupted. At this stage, one satellite will be in an 8.5-hour orbit and the other in a 9.5-hour orbit. Each spacecraft then performs three maneuvers, thereby placing them relative to each other in a way that is optimal for reaching matching science orbits in the next phase.

Following the conclusion of solar conjunction, the spacecraft will begin to transition to their first science formation in April 2028. In this phase, one spacecraft performs two maneuvers while the other performs three. The maneuvers are timed so that at the conclusion of this phase (sometime before June 15, 2028), the spacecraft are in nearly identical orbits and ready to take measurements while only slightly separated from each other.

Phase V – Science

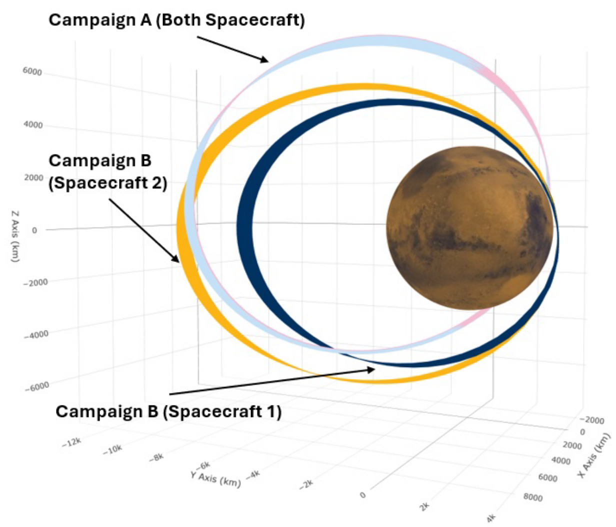
The ESCAPADE science collection phase includes two campaigns, Science Campaign A and B. Science Campaign A is referred to as a "string-of-pearls" campaign, where the two spacecraft are in nearly identical orbits, one chasing the other. The follow distance between the two spacecraft varies within 30 minutes, with the spacecraft shifting their positions on the string of pearls several times. Science Campaign B involves the spacecraft traversing different orbits, collecting observations from distinctly different magnetospheric regions simultaneously.

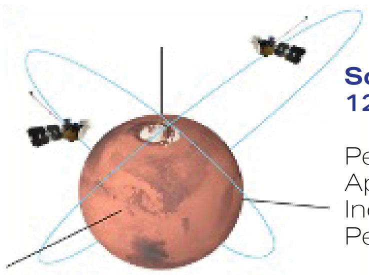
The two campaign orbits (as outlined in more detail below) have been optimized to maximize the science return, including placing the periapse (the part of the orbit closest to the planet) over Mars' southern hemisphere (which contains weak, moderate, and strong crustal magnetic fields), changing the angle of the Sun during periapse over a wide range, and surveying a wide range of geographic and diurnal conditions of the Martian system. The ESCAPADE mission's science is enabled by having more than one platform operating simultaneously: for instance, one spacecraft can be directly sampling the pristine solar wind while the other spacecraft directly measures how that solar wind interacts with the Martian environment.



Science Campaign A
6/15/2028 – 12/15/2028

Periapse Altitude:	160 km
Apoapse Altitude:	8,400 km
Inclination:	65 deg
Period:	5.67 hrs





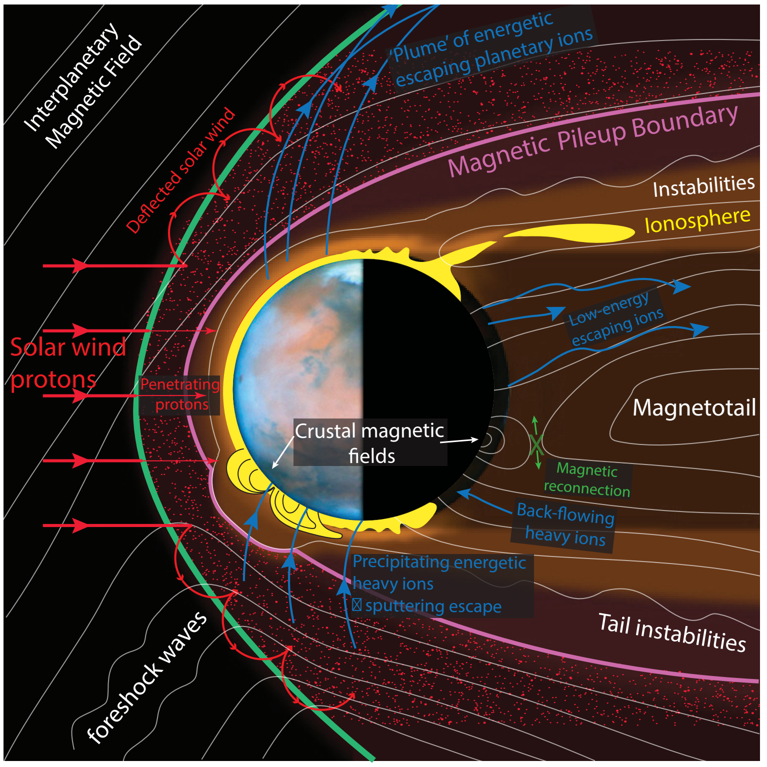
Science Campaign B
12/16/2028 – 5/15/2029

	Spacecraft 1	Spacecraft 2
Periapse Altitude:	160 km	160 km
Apoapse Altitude:	7,000 km	10,000 km
Inclination:	65 deg	65 deg
Period:	4.91 hrs	65.8 hrs

Science

What is Mars' hybrid magnetosphere and why study it?

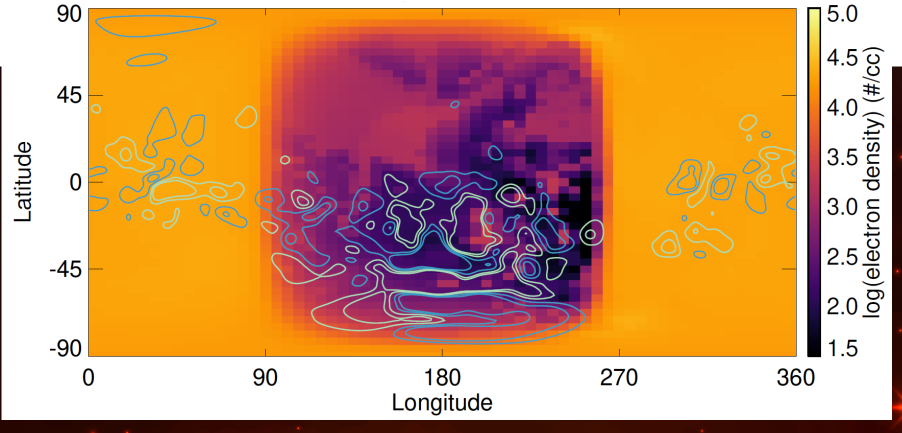
Mars' "hybrid" magnetosphere refers to the relatively weak, yet unique and complex magnetic environment surrounding the planet that originates from two combined sources: 1) patchy remanent magnetic fields emanating from the planet's crust, and 2) what's called an induced magnetic field generated by the interaction between the solar wind and Mars' ionosphere (an ionized layer of the upper atmosphere). This hybrid nature makes Mars' magnetosphere distinct from those of other planets in our solar system, which either have strong global magnetic fields generated by their cores (like Earth) or only solar-wind-induced magnetospheres (like Venus).



Mars' complex "hybrid" magnetosphere and associated phenomena. Illustration courtesy of D. Barrett & R. Lillis

Studying Mars' hybrid magnetosphere is important for several reasons. It helps scientists understand planetary evolution by providing insights into Mars' geological history. This includes understanding why Mars lost its original strong global magnetic field and how it transitioned to its current state. We also know that Mars' hybrid magnetosphere has had and continues to have significant implications for Mars' atmosphere. Unlike Earth, Mars' relatively weak and patchy magnetosphere means it provides less of a protective barrier from the solar wind, which continuously eats away at Mars' atmosphere. Studying this process helps scientists understand how Mars' atmosphere has changed over time and what conditions might have been like in the past. For instance, a stronger ancient magnetosphere probably protected Mars' atmosphere and surface from harsh solar radiation, possibly creating conditions more favorable for life.

Comparing Mars' hybrid magnetosphere with those of other planets also aids in developing broader theories about planetary magnetospheres, including their formation and their influence on planets overall. Such comparative studies of planets in our solar system can, in turn, provide a better understanding of the potential habitability of planets around other stars, called exoplanets. In addition, studying the hybrid magnetosphere of Mars requires advanced technology and scientific techniques. This research drives the development of new instruments and methods that can be applied to other space missions, enhancing our overall capabilities for space exploration. Finally, and perhaps most important of all, understanding Mars' hybrid magnetosphere is essential for planning future missions to the Red Planet, especially those involving human explorers. Knowing how Mars' hybrid magnetosphere interacts with potentially dangerous space weather could help us design better protection for both spacecraft and astronauts.



Ion density by location in Mars' ionosphere
Credit: Melissa Marquette, UC Berkeley

What is the solar wind and how does it interact with Mars' magnetosphere and change Mars' atmosphere?

The solar wind is a stream of charged particles, primarily electrons and protons, continuously emanating from the corona, which is the outermost region of the Sun's atmosphere. The density, temperature, and velocity of these particles (also referred to collectively as plasma) vary with solar activity and the solar cycle. The solar wind travels through space at speeds ranging from 300 to 800 kilometers per second (1 to 2 million miles per hour) while also dragging the Sun's magnetic field with it, thus creating what is known as the interplanetary magnetic field (IMF) throughout our solar system. The solar wind and associated IMF impact planets in several significant ways. For instance, as previously mentioned, the solar wind's plasma and IMF create a weak induced magnetic field around Mars by generating electrical currents in Mars' ionosphere, and thus contribute to Mars' overall hybrid magnetosphere.

Additionally, the solar wind exerts pressure on Mars' hybrid magnetosphere, compressing it on the dayside (the side facing the Sun) and elongating it into a tail on the nightside (the magnetotail), thus giving it a classic windsock shape. This compression affects the structure and dynamics of the magnetosphere and can lead to various space weather phenomena, such as magnetic reconnection, when magnetic field lines in the magnetotail touch. Interactions between the solar wind and Mars' crustal magnetic fields can also lead to the formation of localized auroras. Unlike Earth's polar auroras, Martian auroras can occur in various regions where the crustal magnetic fields are strongest. Moreover, the solar wind and its interactions with Mars' magnetosphere can negatively affect spacecraft orbiting Mars or instruments operating on its surface. Understanding the solar wind's influence on Mars' hybrid magnetosphere and its ionosphere helps in designing instruments and missions that can withstand these varying conditions and accurately collect data.

But perhaps more importantly, without a strong, more uniform global magnetosphere to protect it, Mars' atmosphere is more vulnerable to erosion by the solar wind, resulting in a reduced ability of the atmosphere to retain heat and water. Atmospheric erosion occurs when energy and momentum from the solar wind are transferred through the Martian magnetosphere. This drives ion flow and loss within the ionosphere, ultimately contributing to the thinning of Mars' atmosphere in a process known as atmospheric escape. Atmospheric escape has been the primary driver of climate change on Mars, taking it from a once warm and wet environment to the cold, arid planet we see today. We know that the charged particles in Mars' magnetosphere that originate from the solar wind are mostly hydrogen, while those from Mars' ionosphere are mostly oxygen, but this is only part of the puzzle. Solving the rest of this puzzle requires a deeper understanding of the composition, origin, and movement of charged particles within the magnetosphere. This knowledge will allow us to model more accurately how atmospheric escape occurs now and how it happened in the past.

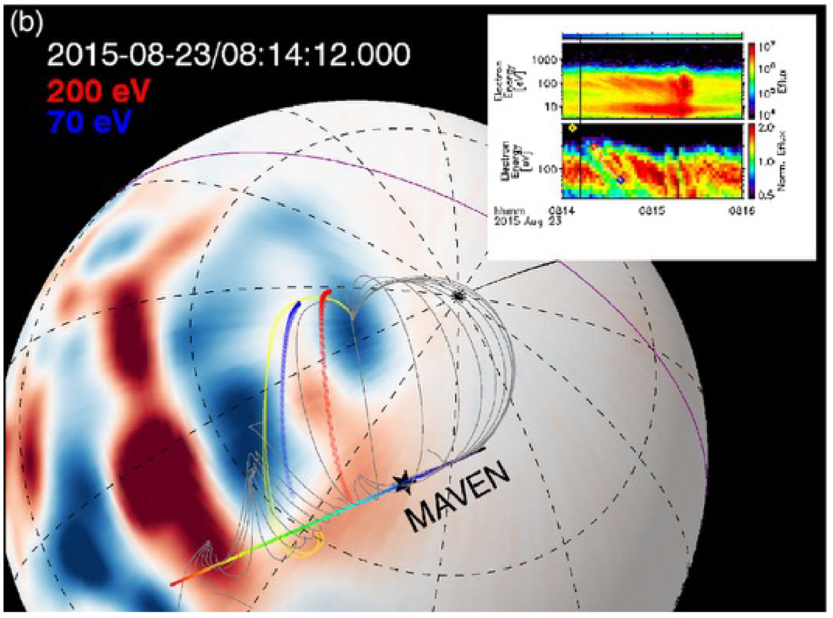
What are some of the important features and phenomena of Mars' hybrid magnetosphere that ESCAPADE's predecessors MAVEN and Mars Express helped shed light on?

What we know so far about Mars has come from decades of research, some of which was made possible by past space missions to the Red Planet. ESCAPADE intends to build on the scientific legacy of these past missions, notably NASA's Mars Atmosphere and Volatile Evolution (MAVEN) mission and the European Space Agency's Mars Express mission. The latter mission has been exploring the atmosphere and surface of Mars from a polar orbit since arriving at the planet in 2003. MAVEN arrived at Mars on Sept. 21, 2014, and was inserted into a highly elliptical orbit to provide scientific data on atmospheric escape.

We now know that Mars' hybrid magnetosphere hosts a complex global system of electric currents that connect its various regions, resulting in features and time-varying phenomena such as the dayside and nightside ionosphere, mini radiation belts, bow shock, magnetosheath, and twisted magnetotail.

Dayside and Nightside Ionosphere: Mars' ionosphere is formed when solar ultraviolet (UV) light creates an ionized layer in the upper atmosphere, with the highest density of ions around 130 km altitude and always on the dayside of Mars. On the nightside (see image at bottom of previous page), where there is no UV light, ion densities are lower and much more chaotic.

Mini Radiation Belts: Mars' remnant crustal magnetic fields (left over from when Mars had a strong global magnetic field) can trap charged particles from the solar wind in much the same way that Earth's Van Allen radiation belts do. These so-called "mini radiation belts" generally have lower energies, but particles can remain trapped for hours. These regions can not only affect Mars' atmosphere (and to some degree its surface), but also pose a potential hazard to missions and equipment operating in these areas.

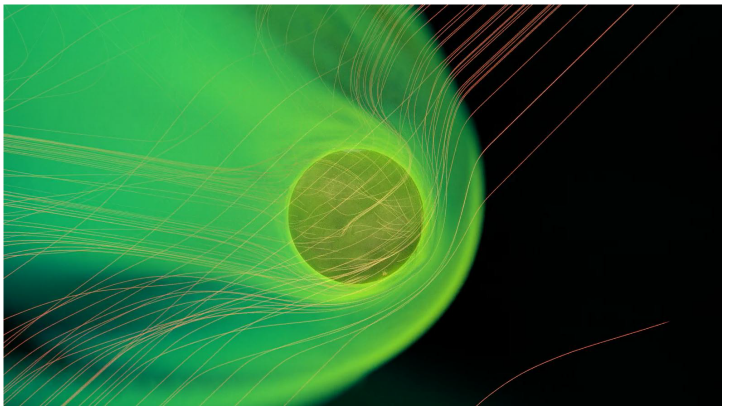


The image above illustrates how electrons travel in Mars' crustal magnetic fields, forming "mini radiation belts." The red and blue arcs represent the paths of high-energy electrons (200 eV) and lower-energy electrons (70 eV), respectively, traveling along magnetic field lines (gray arcs). The red and blue shaded areas on the planet represent positive and negative crustal magnetic fields, respectively, at about 250 miles (400 km) altitude. The inset graph tracks when these electrons were detected, helping scientists understand their movement and origin. The data, collected by the MAVEN spacecraft (represented by the black star), reveals the intricate dance of particles in Mars' unique magnetic environment.

Credit: Y. Harada et al., 2016, https://doi.org/10.1002/2015GL067040

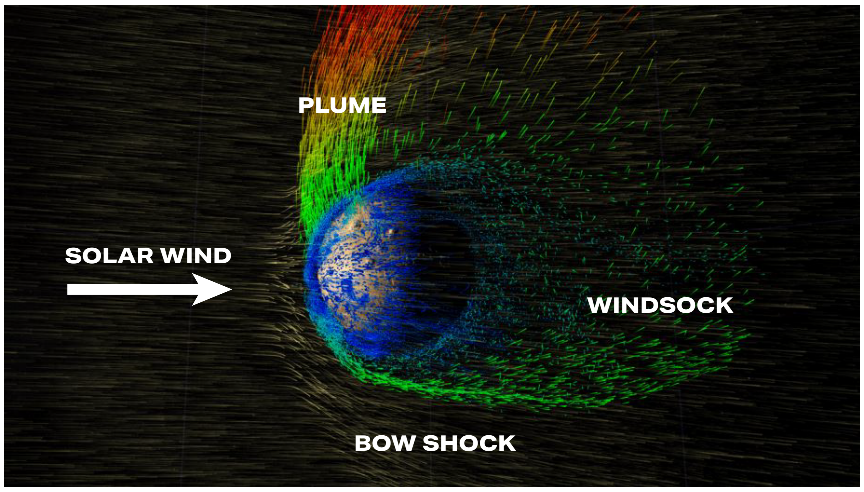
Bow Shock: The bow shock forms when the supersonic solar wind encounters the obstacle of Mars' dayside ionosphere. Here the solar wind is slowed down and heated, resulting in the IMF draping around and piling up in front of the planet.

Magnetosheath: Mars' magnetosheath is the region of space between the planet's bow shock and its magnetosphere. The magnetosheath is characterized by turbulent, compressed solar wind and magnetic fields that have been deflected by the bow shock. This region also plays a crucial role in the interaction between the solar wind and Mars, affecting atmospheric escape and other space weather phenomena.



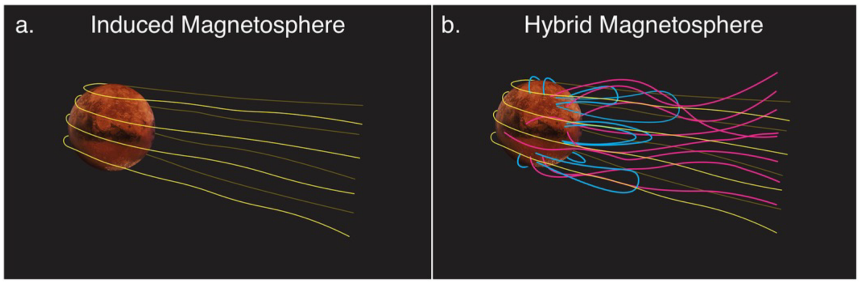
A bow shock forms as the solar wind and interplanetary magnetic field (IMF) collide with Mars' dayside ionosphere.
Credit: AJ Christensen, NASA's Goddard Space Flight Center

Ion Escape Plume: Where the solar wind impacts Mars' magnetosphere, a strong "convection" electric field is formed. Atoms in Mars' tenuous exosphere, the outermost atmospheric layer, are ionized by the Sun's UV light, then get carried away from the planet in the direction of this electric field, hence forming the so-called "ion escape plume," which has been deemed a significant mechanism for atmospheric loss. Observations by missions like MAVEN have helped scientists understand the dynamics of this plume and its impact on Mars' atmospheric evolution.



Formation of the ion escape plume in Mars' hybrid magnetosphere
Credit: NASA/Greg Shirah

Twisted Magnetotail: Due mainly to the relative weakness of Mars' hybrid magnetosphere, Mars' localized crustal magnetic fields end up interacting with the solar wind and IMF in a way that causes the hybrid magnetosphere's field lines to twist and become draped around the planet in a complex manner. This interaction results in a twisted and convoluted magnetotail that is continuously variable in shape. In general, the magnetotail is angled by approximately 45 degrees from the ecliptic (the plane of the solar system). The twisting of Mars' magnetotail reflects the dynamic and fluctuating nature of its magnetic environment, influenced by both the solar wind and the planet's changing position relative to the Sun.



The interaction of Mars' crustal magnetic fields with the solar wind leads to the formation of a twisted magnetotail.
Credit: G. DiBraccio et al., 2018, https://doi.org/10.1029/2018GL077251

Why do we need ESCAPADE? What can ESCAPADE do that prior missions could not?

Coordinated, multipoint observations are necessary to accurately characterize the temporal variability and real-time response of Mars' near-space environment to space weather, thereby unraveling the chain of cause and effect within the system. When a single spacecraft measures a change in local plasma conditions, it's impossible to tell whether conditions have changed globally or if the spacecraft simply entered a new region of space where conditions are different. There's also no way to know for sure if a single event, such as a more intense solar wind, directly results in change elsewhere in Mars' magnetosphere, such as increased ion escape. With two spacecraft, ESCAPADE can distinguish between different scenarios via simultaneous observations, thus addressing the challenge of spatial versus temporal variability.

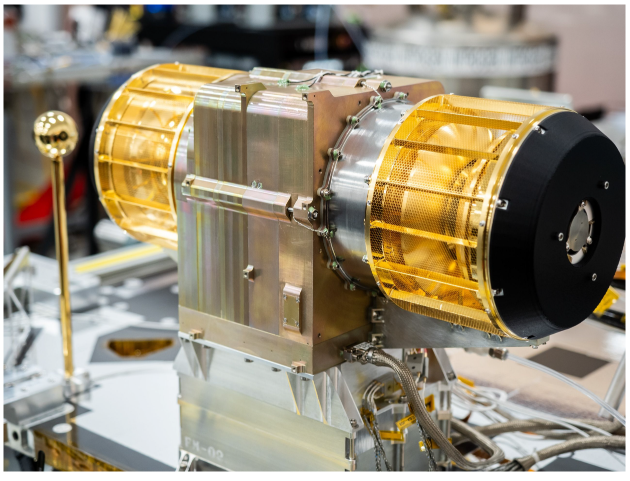
For instance, ESCAPADE enhances the study of plasma dynamics in a particular region of Mars at shorter timescales. The MAVEN spacecraft's orbital period is approximately 3.6 hours. This means the time variability in one particular area of the system can only be probed at timescales longer than this. In contrast, during Campaign A when ESCAPADE's two spacecraft are following each other in the same orbit, they will be able to characterize how areas within the system change on much shorter timescales, between 2 and 30 minutes. During Campaign B, when the two spacecraft are in different orbits, the mission will for the first time be able to study the real-time response to space weather events. For example, a single spacecraft like MAVEN can either be: a) at high altitude in the "upstream" solar wind (which hasn't reached Mars yet), measuring prevailing space weather conditions; or b) "downstream" within Mars' magnetosphere, measuring the impact of that space weather, such as rates of atmospheric escape. It takes MAVEN more than an hour to go from upstream to downstream, whereas space weather impacts happen in minutes or less. The ESCAPADE mission solves this predicament during Campaign B by simultaneously measuring upstream and downstream conditions. This will allow us to untangle, with far more confidence, the cause (i.e., space weather) and effect (i.e., the resulting changes) in this dynamic environment.

Science Instruments

Working together, ESCAPADE's instruments will help us better understand Mars' unique hybrid magnetosphere and how solar energy flows through it, driving ion and plasma movement. Additionally, this research will more accurately uncover the process of atmospheric escape, providing valuable insights for Mars, as well as any planet with an atmosphere.

Each spacecraft has identical copies of the following instruments.

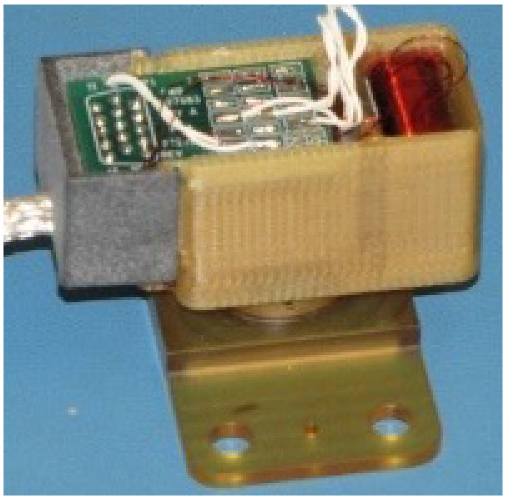
EESA: Electrostatic Analyzer
The ESCAPADE Electrostatic Analyzer (EESA) is designed to measure suprathermal ions and electrons in the spacecraft's elliptical orbits around Mars. The instrument, mounted on the top deck of each spacecraft, consists of two electrostatic analyzers with a common electronics box. The EESA-i sensor measures suprathermal ions in the energy range from 0.5 eV to 30 keV with a field of view of 23 x 23 degrees, while the EESA-e sensor measures suprathermal electrons from 0.5 eV to 6 keV. These measurements help study a) the suprathermal ions produced by extreme ultraviolet radiation from the Sun and b) electron flows and magnetic topology around Mars, respectively. The instrument has a mass of 5.34 kg, uses 6.1 W of power, and makes full measurements every 8 seconds, returning data at 180-250 bits per second (bps).



The ESCAPADE Electrostatic Analyzer includes two sensors: the EESA-i Suprathermal Ions (gold section on the right) and EESA-e Suprathermal Electrons (gold section on the left).

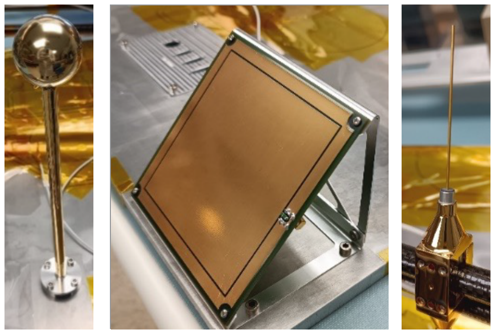
Credit: R. Livi and P. Whittlesey (UC Berkeley Space Sciences Laboratory)

EMAG: Magnetometer
The ESCAPADE Magnetometer (EMAG) is designed to measure DC (direct current) magnetic fields around Mars. Provided by NASA's Goddard Space Flight Center, the EMAG measures Mars' magnetic field with a range up to 2,000 nanoTesla and an accuracy of 0.5 nanoTesla. It is mounted at the end of a two-meter-long boom, alongside a segment of the ESCAPADE Langmuir Probe (see below), to minimize spacecraft interference. The magnetometer has a mass of 0.45 kg, uses 1.3 W of power, and returns data at a rate of 21.5 bps, capturing the ambient magnetic field in various plasma regions encountered during orbit around Mars.



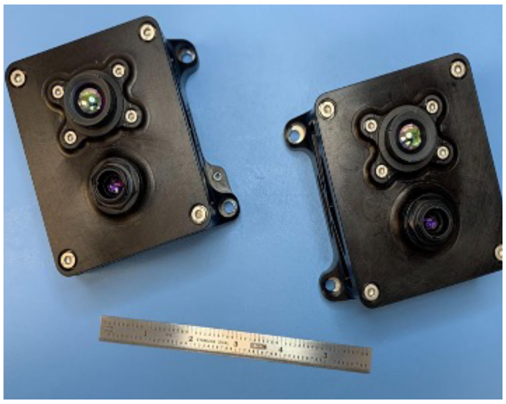
The ESCAPADE Magnetometer will measure magnetic fields around Mars.
Credit: J. Espley (NASA GSFC)

ESCAPADE Langmuir Probe
The ESCAPADE Langmuir Probe (ELP) suite, provided by Embry-Riddle Aeronautical University, consists of three types of Langmuir probes: 1) Planar Ion Probes (PIPs); 2) a multi-Needle Langmuir Probe (mNLP); and 3) a Floating Potential Probe (FPP). These probes are designed to measure the integrated extreme ultraviolet (EUV) flux and thermal plasma density in the solar wind plasma from the elliptical ESCAPADE orbit. The PIPs, mounted on two corners of each spacecraft's top deck, measure the solar EUV flux. The mNLP, mounted at two points along the magnetometer boom, measures thermal plasma density ranging from 50 to 200,000 particles per cubic centimeter. The FPP, mounted on a short boom extending from the spacecraft's top deck, tracks the relative spacecraft potential. The instrument has a mass of 0.538 kg, uses 0.95 W of power, and returns data at a rate of 10.8 bps, providing crucial insights into plasma characteristics including electric potential, electron temperature, and density.



The ESCAPADE Langmuir Probe suite includes a Floating Potential Probe (left), Planar Ion Probe (middle), and multi-Needle Langmuir Probe (right).
Credit: A. Barjatya (Embry-Riddle Aeronautical University)

VISIONS (Visible & Infrared Camera)
Few people in the world, especially college students, can boast that something they built is orbiting Mars. Soon, a cross-disciplinary team of Northern Arizona University students and faculty members will achieve this feat. The team's Visible and Infrared Observation System (VISIONS) camera is an important component of the ESCAPADE mission's suite of science instruments. The VISIONS camera captures images in both visible and infrared wavelengths simultaneously, thereby providing comprehensive information about the composition, physical makeup, and climate of Mars. Unlike most cameras on similar missions that capture images only tens of kilometers wide, VISIONS is designed to capture the entire planetary disk in one frame, enabling the study of phenomena such as seasonal changes in the polar caps. Additionally, the team hopes VISIONS will capture images of Mars' auroras. What truly sets VISIONS apart is its design and fabrication approach. Built largely from carefully selected, commercially available components (such as sensors and optics) rather than expensive custom-made versions, VISIONS represents a low-budget technical demonstration. It aims to prove that a cost-effective, scientific-grade camera with industrial-grade parts can be viable for spaceflight, paving the way for future similar developments and applications.



The Visible and Infrared Observation System was built by Northern Arizona University students.
Credit: C. Edwards (Northern Arizona University)

NASA's Launch Services Program

NASA awarded Blue Origin, LLC, of Kent, Washington, a task order to provide launch services for ESCAPADE as part of the agency's VADR (Venture-Class Acquisition of Dedicated and Rideshare) launch services contract. Building on the agency's venture-class approach, NASA is targeting lower launch costs for more risk-tolerant science payloads by using less agency oversight and greater flexibility in how the commercial company manages the launch services for the mission.

NASA's Launch Services Program (LSP) unites scientific and robotic spacecraft customers' needs with the appropriate rocket, managing the process to ensure the spacecraft is placed in orbit around Earth or the Sun, or powered to destinations deeper into the solar system. Established in 1998 at Kennedy Space Center, LSP manages the launch vehicle services for NASA, assisting customers who need specialized, highly technical support worldwide, and enabling some of NASA's greatest scientific missions and technical achievements.

ESCAPADE History

A timeline of the ESCAPADE mission can be found at
https://escapade.ssl.berkeley.edu/timeline-news/

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