# SAMPLE

## Solar System Missions: Voyager

The Grand Tour

Aira Astralis

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# Contents

Introduction

Chapter 1: The Discovery of Voyager

Chapter 2: Understanding Voyager

Chapter 3: Key Characteristics of Voyager

Chapter 4: The Science Behind Voyager

Chapter 5: Observation and Measurement of Voyager

Chapter 6: Important Features of Voyager

Chapter 7: Voyager in Context

Chapter 8: Modern Understanding of Voyager

Chapter 9: Research and Exploration of Voyager

Chapter 10: Significant Discoveries About Voyager

Chapter 11: Challenges and Mysteries of Voyager

Chapter 12: Future Directions in Voyager Research

Chapter 13: Fun Facts and Trivia About Voyager

Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

# Introduction

Voyager 1 is a space probe launched by NASA on September 5, 1977, as part of the Voyager program, to study the outer Solar System and the interstellar space beyond the Sun's heliosphere. It was launched 16 days after its twin, Voyager 2. It communicates through the NASA Deep Space Network (DSN) to receive routine commands and to transmit data to Earth. Real-time distance and velocity data are provided by NASA and JPL.

At a distance of 171.19 AU (25.6 billion km; 15.9 billion mi) as of August 2026, it is the most distant human-made object from Earth. Voyager 1 is projected to reach a distance of one light day from Earth in November 2026. The probe made flybys of Jupiter, Saturn, and Saturn's largest moon, Titan. NASA had a choice of either conducting a Pluto or Titan flyby. Exploration of Titan took priority because it was known to have a substantial atmosphere.

Voyager 1 studied the weather, magnetic fields, and rings of the two gas giants and was the first probe to provide detailed images of their moons. As part of the Voyager program and like its sister craft Voyager 2, the spacecraft's extended mission is to locate and study the regions and boundaries of the outer heliosphere and to begin exploring the interstellar medium. Voyager 1 crossed the heliopause and entered interstellar space on August 25, 2012, making it the first spacecraft to do so.

Two years later, Voyager 1 began experiencing a third wave of coronal mass ejections from the Sun that continued to at least December 15, 2014, further confirming that the probe is in interstellar space. In 2017, the Voyager team successfully fired the spacecraft's trajectory correction maneuver (TCM) thrusters for the first time since 1980, enabling the mission to be extended by two to three years. Voyager 1 experienced successful revivals of several thrusters in 2018, 2019, and 2025.

Voyager 1's extended mission is expected to continue to return scientific data for several more years. Its radioisotope thermoelectric generators (RTGs) may supply enough electric power to return engineering data until 2036. As of 2026, only two instruments are operational, the Plasma Wave Subsystem and magnetometer. A 1960s proposal for a Grand Tour to study the outer planets led NASA to begin work on a mission during the early 1970s. Initially, Voyager 1 was planned as Mariner 11 of the Mariner program.

A 2013 reckoning put its Sun-relative speed at roughly 17 km/s, about 61,200 km/h. With the velocity the probe is currently maintaining, Voyager 1 is traveling about 523 million km (325 million mi) per year, or about one light-year per 18,000 years. As of 2026, Voyager 1 is more than 160 astronomical

units from the Sun, the most distant human-made object, moving at about 61,000 km/h relative to the Sun.

The craft is presently less than one-seventh the distance to the aphelion of Sedna, and it has not yet entered the postulated position of the Oort cloud, the hypothetical source region of long-period comets, regarded by astronomers as the outermost zone of the Solar System.

On May 22, NASA announced that Voyager 1 "resumed returning science data from two of its four instruments", with work towards the others ongoing.

The second of the pair, Voyager 2, left Earth on August 20, 1977 aboard a Titan IIIE-Centaur, sixteen days before its twin.

Voyager 2's closer, sharper images of that moon only deepened the puzzle, showing terrain with almost no vertical relief whatever. Europa is internally active due to tidal heating at a level about one-tenth that of Io. Europa is thought to have a thin crust (less than 30 km (19 mi) thick) of water ice, possibly floating on a 50 km (31 mi)-deep ocean.

Roughly five hours after leaving Neptune behind, the spacecraft swung past Triton, the planet's largest moon, at a range of some 40,000 km (25,000 mi)

# Chapter 1: The Discovery of Voyager

The mission began as an idea in a graduate student's calculation. In 1965, working at JPL, Gary Flandro examined the trajectories a spacecraft could take through the outer planets and discovered that a rare alignment of Jupiter, Saturn, Uranus and Neptune, recurring only every 176 years, would allow a probe to visit all four giants within a single mission, using each planet's gravity to pay for the trip to the next. The concept, christened the Grand Tour, promised a scientific bounty that no single-planet mission could match.

The idea shrank on its way through Congress. Budget pressure reduced the proposed fleet to two spacecraft, the outer legs to Uranus and Neptune were made optional extensions, and the program was renamed Voyager, refocused on a guaranteed tour of Jupiter and Saturn. The engineers understood, even if the public did not, that a trajectory past Saturn's moon Titan would fling Voyager 1 out of the plane of the planets entirely, and that Voyager 2, on a slower path, could still be steered onward if the first craft succeeded at Titan. Both probes were built with that hidden agenda, their communications and power margins designed for a lifetime no funding document officially promised.

Due to budget cuts, the mission was reduced to a flyby of Jupiter and Saturn and renamed the Mariner Jupiter-Saturn probes. The name was changed to Voyager when the probe designs began to differ substantially from Mariner missions. Voyager 1 was built by the Jet Propulsion Laboratory (JPL). It has a bus shaped like a decagonal (ten-sided) prism. Attitude control relies on sixteen hydrazine thrusters and gyroscopes, with star references keeping the antenna aligned on Earth.

Collectively, these instruments are part of the Attitude and Articulation Control Subsystem (AACS), along with redundant units of most instruments and eight backup thrusters. The spacecraft also included 11 scientific instruments to study celestial objects such as planets as it travels through space. The radio communication system of Voyager 1 was designed to be used up to and beyond the limits of the Solar System.

It has a 3.7-meter (12 ft) diameter high-gain Cassegrain antenna to send and receive radio waves via the three Deep Space Network stations on the Earth. The spacecraft normally transmits data to Earth over Deep Space Network Channel 18, using a frequency of either 2.3 GHz or 8.4 GHz, while signals from Earth to Voyager are transmitted at 2.1 GHz. When Voyager 1 is unable to communicate with the Earth, its digital tape recorder (DTR) can record about 64 megabytes of data for later transmission.

As of 2025, signals from Voyager 1 took more than 23 hours to reach Earth. Voyager 1 has three radioisotope thermoelectric generators (RTGs) mounted on a boom. Each MHW-RTG contains 24 pressed plutonium-238 $PuO_2$ oxide spheres. The RTGs generated about 470 W of electric power at the time of launch, with the remainder being dissipated as waste heat. The power output of the RTGs declines over time due to the 87.7-year half-life of the fuel and degradation of the thermocouples.

According to current plans, they may continue operating with at least one science instrument into the 2030s. Unlike Voyager's other instruments, the operation of the cameras for visible light is not autonomous, but is controlled by an imaging parameter table contained in one of the digital computers, the Flight Data Subsystem (FDS). Since the 1990s, most space probes have been equipped with completely autonomous cameras. The computer command subsystem (CCS) controls the cameras.

The CCS contains fixed computer programs, such as command decoding, fault-detection and fault-correction routines, antenna pointing routines, and spacecraft sequencing routines. This computer is an improved version of the one that was used in the 1970s Viking orbiters. The Attitude and Articulation Control Subsystem (AACS) controls the spacecraft orientation. It keeps the high-gain antenna pointing towards Earth, controls attitude changes, and points the scan platform. The custom-built AACS systems on both Voyagers are the same.

The Voyager 1 probe was launched on September 5, 1977, from Launch Complex 41 at the Cape Canaveral Air Force Station, aboard a Titan IIIE launch vehicle. The Voyager 2 probe had been launched two weeks earlier, on August 20, 1977.Despite leaving Earth second, Voyager 1 overtook its sibling on the faster trajectory and arrived at Jupiter and Saturn first. Voyager 1's launch almost failed because Titan's LR-91 second stage shut down prematurely, leaving 1,200 pounds (540 kg) of propellant unburned.

Recognizing the deficiency, the Centaur stage's on-board computers ordered a burn that was far longer than planned in order to compensate. Centaur extended its own burn and was able to give Voyager 1 the additional velocity it needed. At cutoff, the Centaur was only 3.4 seconds from propellant exhaustion. If the same failure had occurred during Voyager 2's launch a few weeks earlier, the Centaur would have run out of propellant before the probe reached the correct trajectory.

Jupiter was in a more favorable position vis-à-vis Earth during the launch of Voyager 1 than during the launch of Voyager 2. Left unassisted, the probe's post-launch orbit would have topped out just shy of Saturn's path, so the

gravity-assist design was what made an outer-planet mission possible at all.5 AU (880 million mi). Voyager 2's post-launch path, by contrast, would not have reached even Jupiter's neighborhood unaided.2 AU (580 million mi), well short of Saturn's orbit. Voyager 1 began photographing Jupiter in January 1979.

Its closest approach to Jupiter was on March 5, 1979, at a distance of about 349,000 kilometers (217,000 miles) from the planet's center. Because of the greater photographic resolution allowed by a closer approach, most observations of the moons, rings, magnetic fields, and the radiation belt environment of the Jovian system were made during the 48-hour period that bracketed the closest approach. Voyager 1 finished photographing the Jovian system in April 1979.

Information gathered by the Pioneer 10 spacecraft helped engineers design Voyager to better cope with the intense radiation around Jupiter. Still, shortly before launch, strips of kitchen-grade aluminium foil were applied to certain cables to improve radiation shielding. The discovery of ongoing volcanic activity on the moon Io was probably the greatest surprise. It was the first time active volcanoes had been seen on another body in the Solar System. It appears that activity on Io affects the entire Jovian system.

Io appears to be the primary source of matter that pervades the Jovian magnetosphere - the region of space that surrounds the planet influenced by the planet's strong magnetic field. Sulfur, oxygen, and sodium, apparently erupted by Io's volcanoes and sputtered off the surface by the impact of high-energy particles, were detected at the outer edge of the magnetosphere of Jupiter. Once Voyager 1 passed within 5 RJ from the planet's center, it encountered the Io plasma torus.

No spare thruster hardware remains for the aging probe, leaving the attitude-control system without a fallback should any further component fail.

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# ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.