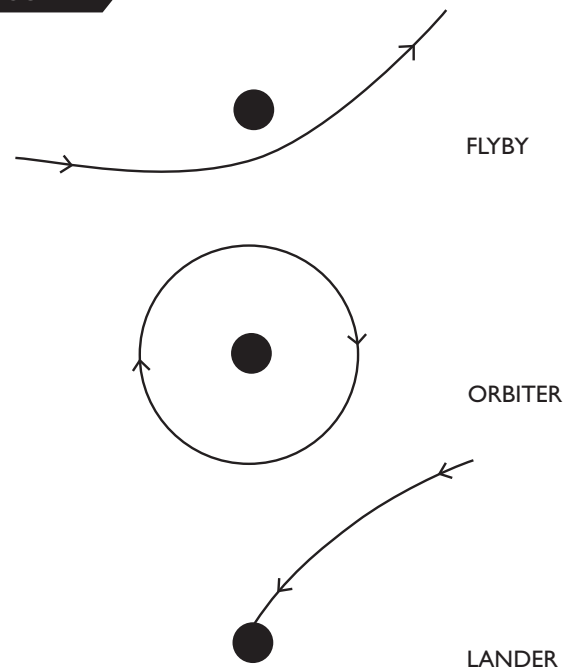


- ★ A **lander** lands on the surface (for example, *Viking Lander*).
- ★ A **rover**, after landing on the surface, moves about under its own power (for example, the Mars Exploration Rovers: *Spirit* and *Opportunity*). Rovers have helped explore the Moon and Mars. In the case of Venus, some of the *Venera* spacecraft, launched by the then Soviet Union, landed on the planet. But no rover has yet moved over Venus's surface.

Planet	Probe	Type	Dates
Mercury	<i>Mariner 10</i>	flyby	1974 and 1975
	<i>MESSENGER</i>	orbiter	2011
Venus	<i>Mariner 2</i>	flyby	1962
	<i>Mariner 5</i>	flyby	1967
	<i>Mariner 10</i>	flyby	1974
	<i>Pioneer Venus</i>	orbiter	1978-92
	<i>Magellan</i>	orbiter and radar-mapper	1990-94
Mars	<i>Mariner 4</i>	flyby	1965
	<i>Mariner 6</i>	flyby	1969
	<i>Mariner 7</i>	flyby	1969
	<i>Mariner 9</i>	orbiter	1971-72
	<i>Viking 1</i>	lander orbiter	1976-83
	<i>Viking 2</i>	lander orbiter	1976-80
	<i>Pathfinder</i>	lander with rover	1997
	<i>Mars Global Surveyor</i>	orbiter	1997-present
	<i>Mars Odyssey</i>	orbiter	2001-present
	Mars Exploration Rovers (<i>Spirit</i> , <i>Opportunity</i>)	rovers	2004-present
<i>Mars Reconnaissance Orbiter</i>	orbiter	2006	
Jupiter	<i>Pioneer 10</i>	flyby	1973
	<i>Pioneer 11</i>	flyby	1974
	<i>Voyager 1</i>	flyby	1979
	<i>Voyager 2</i>	flyby	1979
	<i>Galileo</i>	orbiter	1995-2003
Saturn	<i>Pioneer 11</i>	flyby	1979
	<i>Voyager 1</i>	flyby	1980
	<i>Voyager 2</i>	flyby	1981
	<i>Cassini</i>	orbiter and probe	2004-present
Uranus	<i>Voyager 2</i>	flyby	1986
Neptune	<i>Voyager 2</i>	flyby	1989

FIGURE 2



The inner planets—Mercury, Venus, Earth, and Mars—are all terrestrial. The outer planets—Jupiter, Saturn, Uranus, and Neptune—are gas giants with no solid surface. At the outer edge of the solar system is Pluto, which was once categorized as a planet. Now, however, it is classified as a dwarf planet. Pluto orbits in a belt of smaller bodies that never coalesced to form an actual planet. A list of planets and the spacecraft that the U.S. space program has sent to them appears at left.

Both *Voyagers* are still transmitting data more than 25 years after they were launched. The *Voyagers* have been able to function for so long and from such a great distance from the Sun because they rely on Radioisotope Thermoelectric Generators (RTG) to produce electricity. RTGs convert the heat produced by radioactive decay of plutonium into electricity to power instruments and radio transmitters. Most spacecraft sent to the inner planets produce electricity from solar power, since they are close enough to the Sun to convert sunlight to electricity in solar cells mounted on the exterior of the spacecraft.

Spacecraft have given us a wealth of information about our solar system. Future spacecraft will add to our knowledge, with new trips to the Moon, Mars, Mercury, and Pluto already in the works.

4. Ask students to look at the image of Saturn on the front of the poster and describe what they observe. (The image shows amazing detail in the rings and shadows cast by sunlight hitting the planet and its rings.)

Mars Exploration Rovers (MER)/Viking Lander

1. Look at the Blackline Master of *Viking Lander* and Mars Exploration Rovers (MER) (both on the same sheet). Explain that these are different rovers that landed on Mars 28 years apart—*Viking* in 1976, and the two MERs in 2004. Have students compare and contrast the rovers.
2. Ask how spacecraft get energy to make measurements and transmit them to Earth. If students say “from batteries,” you can ask what happens to batteries over time. (They run down. Their energy is used up.) Ask students if they have seen any devices that use light to produce electricity (light-powered calculators).
3. Ask students what solar panels or solar cells do (make electricity from sunlight). Point out the solar panels on MER. Add that *Viking Lander* produced electricity in a different way (from heat made by radioactivity), so it did not require solar panels.
4. If your students can understand it, explain that the Radioisotopic Thermoelectric Generator (RTG) uses heat produced by the radioactive decay of plutonium to generate electricity for the instruments. You can mention that this process differs from the way nuclear power plants produce electricity.
5. Discuss the four types of spacecraft—rover, lander, orbiter, and flyby. (See “Background Information.”) Have students draw and label the path of an orbiter, a lander, and a flyby. As an example, draw a circular orbit around a planet on the blackboard.
6. Point out that spacecraft lift off from Earth on top of powerful rockets that separate after launch. To protect the spacecraft, they are covered by an aerodynamic shroud or placed inside larger spacecraft not shown in the drawings. Explain that the spacecraft contain small rocket engines, called thrusters, which turn the spacecraft so it points in the proper direction. This is a good time to emphasize that robotic spacecraft usually do not come back. Those displayed in the National Air and Space Museum are models or prototypes used for testing.

7. The Mars Exploration Rovers, *Opportunity* and *Spirit*, are robot geologists. Like human geologists, they study rocks and soil. On Mars, the rovers gather information about the rocks and look for signs of past water activity. Point out the robotic arm. It has a Rock Abrasion Tool (RAT) to scrape the surface of rocks and gather rock particles that other instruments on the arm can analyze to determine the mineral content.
8. Point out the cameras mounted on the top of the rover. These stereo cameras, mounted at about the height of a small adult human (1.5 m or 4.9 ft), show what a geologist standing on Mars might see. Point out the dish antenna. Tell students that the antenna sends and receives radio waves to communicate with the team back on Earth. Ask students if they have seen dishes like this somewhere else (satellite dishes).

MESSENGER/Voyager

9. Look at the Blackline Master of *MESSENGER*. Explain that the magnetometer out on the boom will measure the effect of Mercury’s magnetism in space. (See “Extensions,” paragraph 1.) Mention that the long boom serves to minimize interference from magnets on the antenna and from weak magnetic fields generated by the instruments.
10. Challenge students to fill in the missing labels with the words listed at the left of the Blackline Master. (These are the “sunshade” (which wraps around the body of the spacecraft), “science instruments,” and two “solar panels.”) Suggest that students refer to the first handout if they need help.
11. Ask how *MESSENGER* gets power to run its instruments (from sunlight collected by the solar panels). Remind students that Mercury is the closest planet to the Sun, and then ask why *MESSENGER* needs a sunshade. (Near the Sun, the light is so bright that the instruments would overheat without protection. The sunshade keeps the instruments and systems at room temperature.)
12. Look at the Blackline Master of *Voyager*. Explain that the *Voyager* spacecraft have visited Saturn, Jupiter, Uranus, and Neptune.

13. Have students compare and contrast *Voyager's* antennas with those on the other spacecraft. (*Voyager* has a dish antenna like the *Viking Lander* and MER. However, *Voyager's* dish is extremely large (13 feet wide) because the planets it visited are so far away that a big antenna was needed to send and receive signals. The dishes, called high-gain antennas, send a narrow “beam” of information directly to antennas on Earth. MER, *Viking*, and *MESSENGER* also carry low-gain antennas that send a much broader radio beam that Earth stations can pick up even when the beam is not pointed at Earth. *MESSENGER* also has new fan-beam, or medium-gain, antennas that transmit information on the status of the flight and receive operating commands from Earth.)
14. Point out the power source, which looks like several cans fastened together. Explain that *Voyager* needed an RTG (Radioisotopic Thermoelectric Generator) instead of solar panels because it traveled so far from the Sun.
15. Have students label the parts listed at the left of the handout.

REFLECTION AND DISCUSSION

Compare and contrast the spacecraft that go to planets close to the Sun (Mercury) with those that go to planets far from the Sun (Saturn and Neptune). (Solar power versus RTG; a smaller dish antenna versus a large dish antenna or no dish).

ASSESSMENT

Tell students that they will now use what they have learned to design a spacecraft to visit a planet of their choice. Give each student a sheet of unlined paper, and explain that he or she will make a labeled drawing. Ask students to write a paragraph for other students to read that tells about their spacecraft, how it was designed, and what it might discover.

EXTENSIONS

Give each group of two to four students a compass. Ask what they observe. (The compasses point in the same direction—north.) Then give each group a magnet, and ask how the magnet changes what the compass shows. (The compass points toward the magnet.) Explain that the magnetometer in a spacecraft (like *Voyager*) enables scientists to investigate the magnetism of a planet. You can explain that the magnetometer is placed on a long boom because the radio antenna contains magnets, which would interfere with the magnetometer's measurements if the magnetometer and antenna were too close.

Hand out a 2-m strip of adding machine tape and a meter stick to each group of two to four students, so the students can make a large scale model of the distances in the solar system. Here are the distances they will need, all measured from the Sun, which is near the left end of the tape.

Sun:	Near the left end of the tape	You might double or triple each measurement and have a group of students make one very large scale model that they can hang horizontally along a wall. Then other students can add drawings of each planet under the corresponding mark on the tape. In addition, you can mention that
Mercury:	1 ½ cm	
Venus:	3 cm	
Earth:	4 ½ cm	
Mars:	7 cm	
Jupiter:	23 cm	
Saturn:	43 cm	
Uranus:	86 cm	
Neptune:	135 cm	

the solar system is so large that light, which could go eight times around Earth in 1 sec, takes 5 ½ hr to go from the Sun to the outer edge of the solar system (and about 8 min to go from the Sun to Earth).

Have students bring in pictures of airplanes. Ask them how the shape of airplanes differs from that of spacecraft. (The outside surfaces of airplanes are smooth and rounded, so they can cut through the air easily. This kind of shape is streamlined. Spacecraft move through outer space, where there is no air, so there is no need to make them streamlined.)

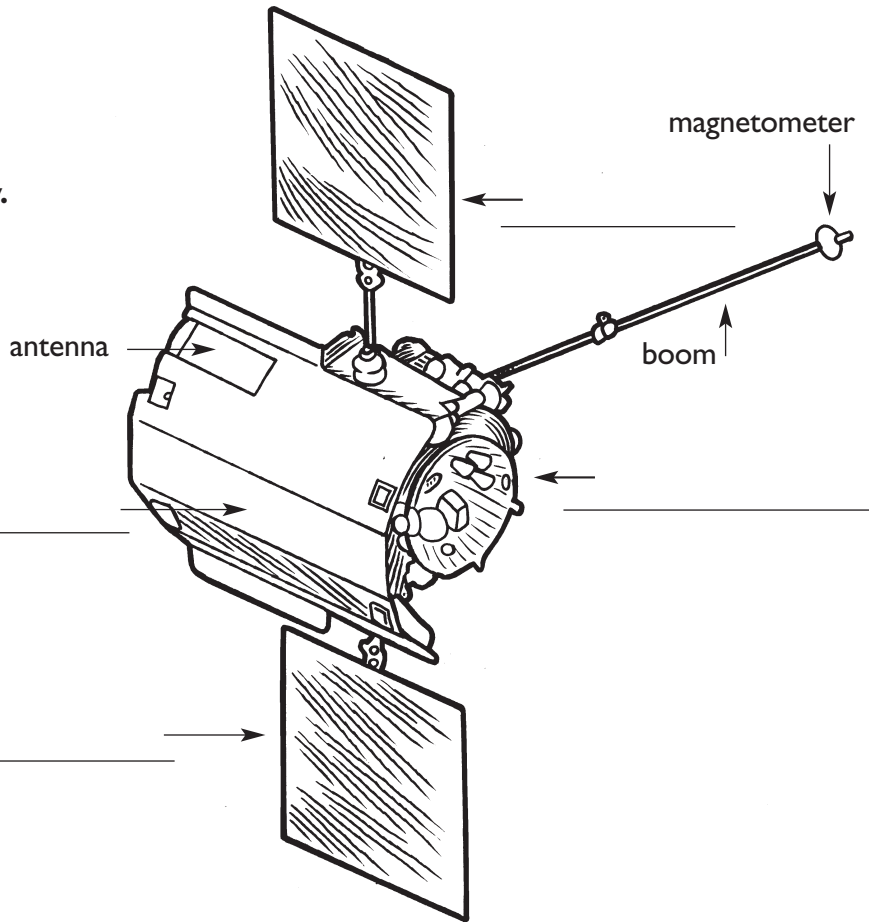
BLACKLINE MASTERS

MESSENGER is going to Mercury.

The distance between the outer edges of *MESSENGER*'s solar panels is about 4 m (13 ft.).

Label these parts:

- ★ sunshade
- ★ solar panels (2)
- ★ science instruments

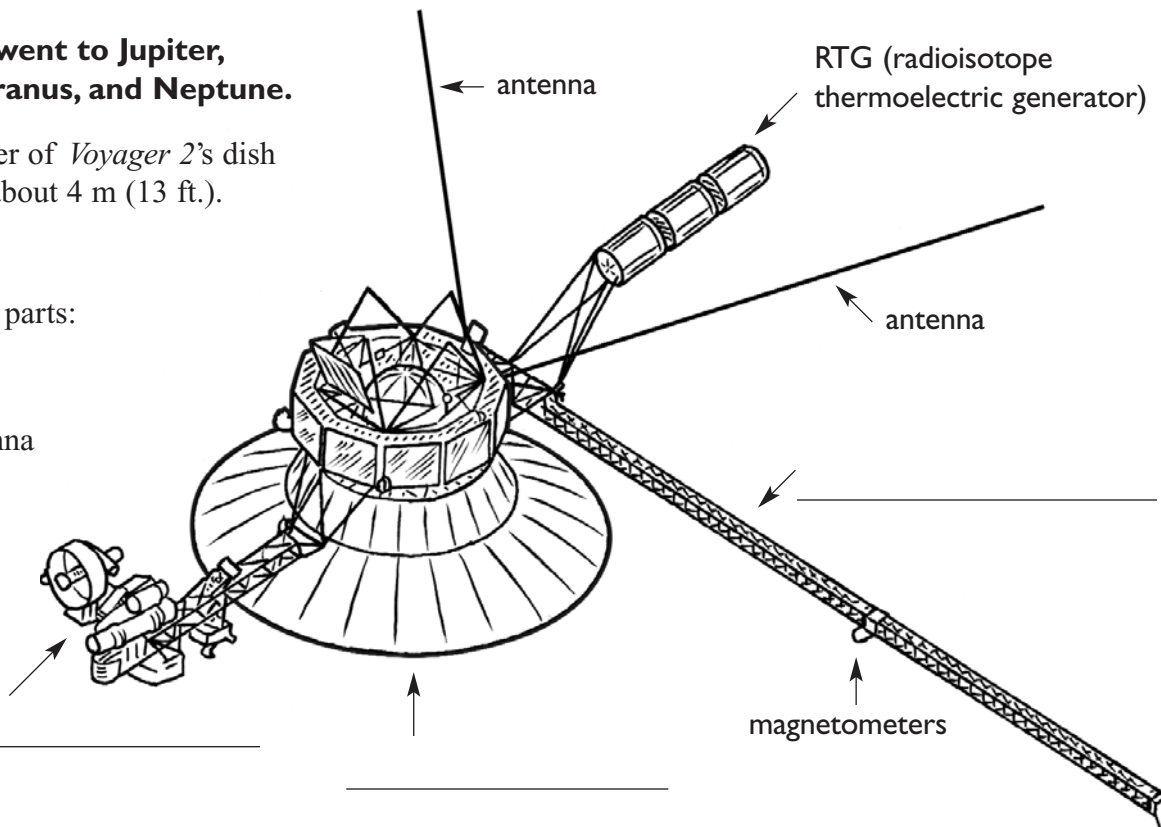


Voyager 2 went to Jupiter, Saturn, Uranus, and Neptune.

The diameter of *Voyager 2*'s dish antenna is about 4 m (13 ft.).

Label these parts:

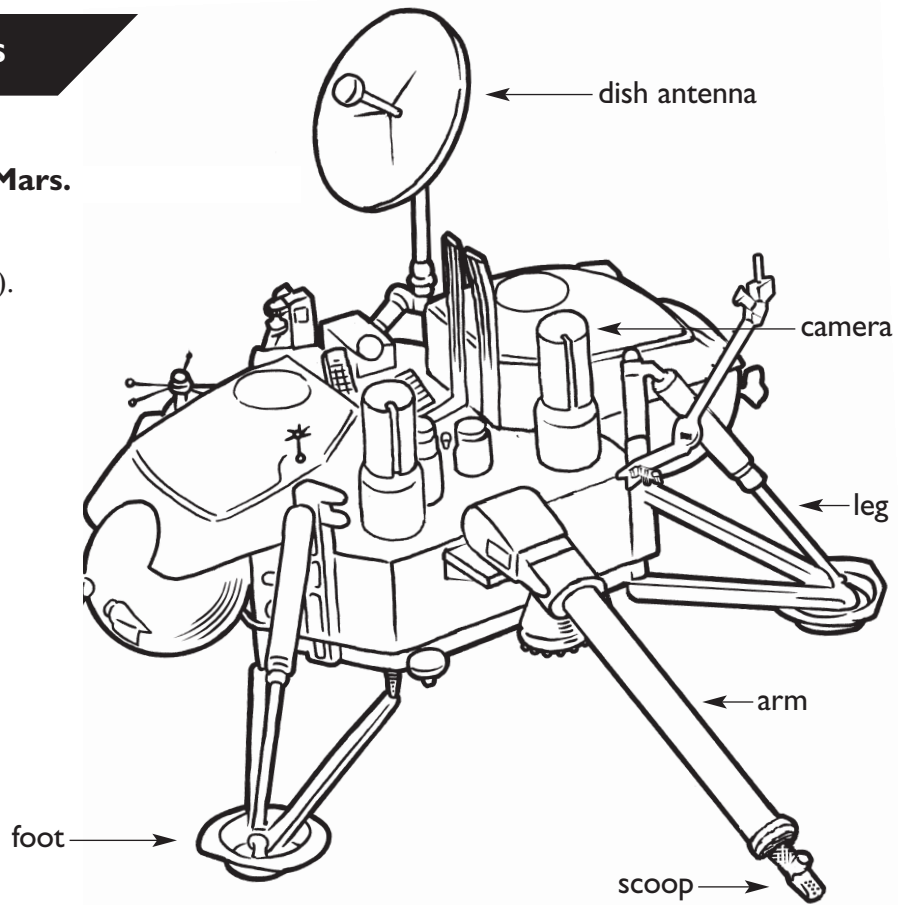
- ★ boom
- ★ cameras
- ★ dish antenna



BLACKLINE MASTERS

Viking Lander went to Mars.

The height of the *Viking Lander* is about 2 m (7 ft.).



Mars Exploration Rovers *Spirit* and *Opportunity* went to Mars.

The height of the Mars Exploration Rovers is about 1.5 m (5 ft.).

