Night Sky Network
Explorers' Guide to the Solar System

#	**Visual** All copyrighted images are used with permission.	**Narration**	**Presenter's notes** Suggested questions for your audience are in blue. *Anticipated answers are in italics.* Additional information is in regular black type.
1	Title Page (Composite photos and artist's concept) Image credit: NASA/JPL		The larger pictures of the planets (lower portion of the image) shows them in their correct relative sizes. The illustration in the upper portion of the image shows the relative spacing of the orbits correctly, but not the correct relative sizes of the sun and planets.
2	Distant Saturn Image credit: NASA/JPL/SwRI (Cassini mission)	The Solar System isn't easy to explore. The distances are vast, the difficulties are enormous. So why go to all the trouble?	What do you think are some good reasons to explore the solar system? This image of Saturn was taken by the Cassini spacecraft from a distance of 177 million miles (285 km) as it approached the planet. The little dot to Saturn's upper left is Titan, whose brightness has been enhanced relative to Saturn.
3	Jupiter and Callisto (Composite not to scale) Image credits: Jupiter: NASA/JPL/UA (Cassini mission) Callisto: NASA/JPL-Caltech (Galileo mission)	Because traveling to other worlds stretches our minds and excites our imaginations like nothing else. And because it's the only way to answer some of our deepest questions.	
4	People gazing at Moon and planets Image credit and copyright: Michael Wilson	Did life ever exist on other worlds? Does it still?	What does life require? As far as we know, life requires liquid water, energy, and nutrients. That's why NASA has been looking for evidence of liquid water on Mars and elsewhere. What kind of life might we find on other worlds in our solar system? Maybe something like bacteria under the Martian surface. Who knows what might live in Europa's ocean if it exists? In the photo, two bright planets can be seen above the crescent moon. Below the brighter of the planets is a star.

5	Ice worm This and similar images are part of a press release from Pennsylvania State University, available at http://www.science.psu.edu/alert/iceworms.htm	How did Earth become the home of living things?	This image shows a methane ice worm, one of a colony of rosy-pink worms, 1-2 inches long, that were found burrowing in mounds of methane-rich ice erupting from the sea floor in the Gulf of Mexico. It's one of many extremophiles that have pushed back the limits of where life can be found.
6	Mars image taken by Hubble Space Telescope. Image credit: NASA/STScI	Will we someday live on other planets?	Why might we want to migrate to other planets? *We're ruining Earth, so let's start fresh on another planet.* Living on any other planet would be vastly more difficult than living in the worst conditions on Earth. We'd better take care of Earth because there really isn't another place to go. *We shouldn't keep all our eggs in one basket. Collision with a giant comet or asteroid could wipe out human beings unless some of us live on another world.* True, but we could save a lot more people by detecting large potential impactors early enough to deflect them away from Earth. The image is of Mars, the extraterrestrial planet most likely to host colonies of humans in the future.
7	Venus (Computer-generated image) Image credit: Magellan Project, JPL, NASA	Can studying processes on other worlds, like the ones that turned Venus into a planetwide oven, help us understand Earth and keep it a good place to live?	Venus' surface was first seen in the early 1990s, when the Magellan spacecraft's imaging radar penetrated the clouds that hide the surface from visible-light telescopes. Colors in this computer-generated picture are based on data from the Soviet Venera landers. Venus has a crushingly dense atmosphere of mostly carbon dioxide, and experienced a runaway greenhouse effect that made its surface hot enough to melt lead.
8	Meteor hitting Earth http://impact.arc.nasa.gov/gallery_main.cfm (Artist's concept) Artist: Don Davis Image credit: NASA	Can we avoid the fate of the dinosaurs by detecting and deflecting any large meteoroids that come our way?	What are some ways we could deflect a large meteoroid? (An object is a meteoroid while traveling through space. It becomes a meteor as it passes through Earth's atmosphere, and a meteorite if it hits the surface.) The farther away an object is when we detect it, the less we have to deflect it to make it miss us. Many clever techniques have been suggested, including using the subtle pressure of sunlight to influence an object's trajectory.

9	Mars landscape Image credit: NASA/JPL/Cornell (MER mission)	How are other planets similar to Earth?	This is the first color image of Mars taken by the panoramic camera on the Mars Exploration Rover called Spirit. Images of some places on Earth, especially the driest parts of the Atacama desert in Chile, look strikingly similar, except that the sky is blue. Mars has some similarities to Earth in that it is a rocky planet with an atmosphere (and atmospheric phenomena such as dust devils), frozen water at the poles, and roughly similar temperatures in some places compared to the other planets. Differences include an atmosphere that is mostly carbon dioxide and much thinner than Earth's, little or no liquid water at the surface, frozen carbon dioxide at the poles, lower gravity and no global magnetic field.
10	Venus landscape (Computer-generated image) Image credit: JPL (Magellan mission)	How are they different?	Venus differs from Earth primarily in that it has a crushingly dense atmosphere of which carbon dioxide constitutes more than 96% of the mass, and that it experienced a runaway greenhouse effect that makes the surface hot enough to melt lead. At this temperature, there is no water of any kind on the surface. Venus bears some similarity to Earth in that it is a rocky planet of about the same size. A portion of the eastern edge of Alpha Regio is displayed in this three-dimensional perspective view of the surface of Venus. The view is at the center of an area containing seven circular dome-like hills. The average diameter of the hills is 25 kilometers (15 miles) with maximum heights of 750 meters (2,475 feet). Three of the hills are visible in the center of the image. The hills may be the result of viscous or thick eruptions of lava coming from a vent on the relatively level ground, allowing the lava to flow in an even lateral pattern. Resolution of the Magellan data is about 120 meters (400 feet). Magellan's synthetic aperture radar was combined with radar altimetry to develop a three-dimensional map of the surface. A perspective view was then generated from the map. Simulated color and a process called radar-clinometry were used to enhance small-scale structures. The simulated hues are based on color images recorded by the Soviet Venera 13 and 14 spacecraft. The image is a single frame from the movie released at the May 29, 1991 Magellan news conference.
11	Protoplanetary disk (Artist's concept) Image courtesy Pat Rawlings/NASA/JPL	And how did it all begin? How did Earth and the other planets form and develop? The answers to that one can be found in places in our solar system where ancient history has been preserved.	An artist's impression of the forming sun and its protoplanetary disk.

12	Sun Image credit: SOHO (ESA & NASA) (SOHO mission)	Most of the original solar nebula—the giant cloud of gas and dust from which the solar system formed—is preserved in the outer layers of the sun. Samples of it shoot out into space as the solar wind.	The sun still contains most of the material of the original solar nebula. Its internal nuclear reactions have modified the material at the sun's core. However, the surface layers, which have not mixed with the core in its present state, have quite accurately preserved the original nebular composition. We can't send a spacecraft to the sun to pick up samples for analysis. However, the sun shoots out streams of its outer material, which we call solar wind. The Genesis spacecraft collected samples of these chemicals and returned them to Earth for scientists to analyze.
13	Comet NEAT Image credit: NASA, NOAO, NSF, T. Rector (UAA), Z. Levay & L. Frattare (STScI)	Comets are also relics of the earliest times. They're clumps of the original ice and dust particles that swirled around the young sun before the planets formed.	This image of Comet C/2001 Q4 (NEAT) was taken at the WIYN 0.9-meter telescope at Kitt Peak National Observatory near Tucson, AZ, on May 7, 2004. The image was taken with the Mosaic I camera, which has a one-square-degree field of view, about five times the size of the Moon. Even with this large field, only the comet's coma and the inner portion of its tail are visible. This color image was assembled by combining images taken through blue, green and red filters. A small star cluster (C0736-105, or Melotte 72) is visible in the lower right of the image, between the head of the comet and the bright red star in the lower-right corner.
14	Asteroid belt (Artist's concept) Image credit: NASA/JPL-Caltech	The asteroid belt is thought to consist of pieces of a planet that was in the process of forming when it was interrupted by Jupiter's powerful gravity.	In this artist's concept, a narrow asteroid belt filled with rocks and dusty debris orbits a star similar to our own sun when it was approximately 30 million years old. The distances between objects in our solar system's asteroid belt are actually much larger than is suggested by this illustration.
15	Earth's moon Image credit: NASA (Apollo 11 mission)	The surface of the Moon contains material that has been preserved for as much as 4-and-a-half billion years—almost dating back to when Earth and the Moon formed. Most of the large craters on the Moon are from a time about 4 billion years ago when the inner solar system was bombarded by huge numbers of meteoroids. Earth must have been hit at the same rate, but its record of that time was wiped nearly clean by weathering and geological processes. So, with all these reasons to explore the solar system, how do we go about it?	What are some of the ways we can learn about the things in our solar system from right here on Earth? Telescopes will probably be the most popular response. As discussed below, radar and naked-eye observations are two other methods of remote sensing from Earth, and meteorites offer another Earth-based way to study certain solar system objects.

16	Copernicus This is a painting by Jan Matejko called "The Astronomer Copernicus, or Conversation with God" from 1873.	Solar system exploration began with no tools but the eyes and brains of curious people, who noticed that planets move across the sky from night to night differently than the stars do. Cultures around the world incorporated what they observed in the heavens into their religions and mythologies. Some developed the ability to calculate the apparent motion of the sun, planets, and star constellations with remarkable precision. Eventually, using naked-eye observation, people like Copernicus here actually figured out the basic structure of the solar system.	Greek astronomer Aristarchus of Samos is said to have suggested 17 centuries earlier than Copernicus that Earth and the other planets revolve around the sun.

17	Murchison meteorite Image credit: DOE	Sometimes nature is nice enough to deliver small samples of the solar system to Earth, where we can take them into our laboratories. This is a piece of the Murchison meteorite, an important discovery in the effort to determine whether meteorites could have seeded Earth with the basic building blocks of life.	The Murchison meteorite fell in several fragments in Australia in 1969. About 100 kg were recovered. Life on Earth relies on a number of complex organic molecules, such as the amino acids that make up proteins. Murchison is one of a number of asteroids found to contain amino acids, some of which are like those found on Earth and some of which are not. Observations of cold molecular clouds in space indicate that many complex organic molecules form there. When portions of these vast clouds collapse and form stars, the organics are incorporated into the disks of gas and dust that ultimately form planets and other bodies in the new solar systems. Fragile organic molecules are unlikely to survive the hot, violent processes that form planets like Earth. But they may survive in comets and in some of the more delicate and primitive asteroids, the products of a gentler accretion process in colder parts of the protoplanetary disk. It also appears possible for complex organic molecules to form from simpler molecules within the disk, either on individual motes of ice-covered dust or after becoming embedded in comets and asteroids. Thus it is possible that molecules delivered by comets and asteroids served as a starter kit for Earthly life. Also, it is widely thought that Earth's present supply of water and atmosphere (that is, the prebiotic version of the atmosphere) arrived courtesy of the impactors raining down on the inner solar system during the Late Heavy Bombardment, about 4.2 billion years ago. Whatever water and atmosphere Earth had at its beginning were likely blasted and boiled away by the massive collisions—certainly by the one that created the Moon. An asteroid that impacts at high velocity is vaporized, and then its hydrogen, deuterium and oxygen reform into H_2O and HDO (heavy water).
18	Mercury Image credit: NASA (Mariner 10 mission)	Radar gives us another way to explore very distant places without leaving our planet. Scientists have bounced radar waves off of Mercury, which you see here, and found evidence that it has a molten core. Earth-based radar also provided evidence of lakes on Saturn's moon, Titan, before the Cassini-Huygens spacecraft arrived there.	Mariner 10 was the only mission to Mercury prior to MESSENGER, which is en route and scheduled to fly by the planet in 2008 and begin orbiting in 2011. As discussed in slide 47, Titan's lakes are not water. They are thought to be liquid hydrocarbons such as methane.

19	Galileo and Newton Image credits: Portrait of Galileo Galilei by Justus Sustermans painted in 1636. Portrait of Isaac Newton by Godfrey Kneller painted in 1689.	But most of our Earth-based exploration has been done with telescopes. Galileo, on the left, started the practice of using telescopes for astronomy about 400 years ago. Isaac Newton improved the instrument with a system that uses mirrors instead of lenses—that's the kind most often used today.	Galileo didn't invent the telescope, but he is believed to be first to apply it to astronomy. Galileo used a refracting telescope, which uses lenses to focus light. Isaac Newton invented the reflecting telescope, which uses mirrors, and is the kind most often used today by professional observatories. 2009, the International Year of Astronomy, is the 400th anniversary of the first recorded observations of the heavens through a telescope, conducted by Galileo in 1609. He was first on record to see Saturn's rings, 4 of Jupiter's moons, the phases of Venus, and mountains and craters on Earth's moon. His observations provided revolutionary evidence in support of Copernicus' contention that Earth is not the center of the universe.
20	Keck observatory Image credit: NASA/JPL	The Keck Observatory in Hawaii is one of the best of today's telescopes. Telescopes gather and focus light, enabling us to see distant objects much more clearly than we can with our naked eyes.	At the summit of Mauna Kea, Hawaii, NASA astronomers have linked the two 10-meter (33-foot) telescopes at the W. M. Keck Observatory. Together, they are called the Keck Interferometer, and they make up the world's most powerful optical telescope system.
21	Keck and spectrum	And telescopes can be hooked up to instruments that break light down into its individual colors, or wavelengths, including the visible light that our eyes can sense—you see that little rainbow in the middle of the spectrum—and light that has wavelengths too long or too short for our eyes to detect. Reading the light spectrum—also known as the "electromagnetic spectrum"—is really the key to the universe. By seeing which wavelengths the various heavenly bodies emit or reflect, scientists can tell what they're made of, what their temperatures are, and even how quickly they're moving toward or away from us.	The light-colored vertical lines in the visible part of the spectrum shown in this image are the "bright-line spectrum" produced by hydrogen. The Doppler effect, which "red-shifts" or "blue-shifts" recognizable spectral signatures, is what enables the determination of motion toward or away from Earth.
22	Saturn in infrared Image credit: NASA/JPL	Here's a picture of Saturn that Keck took in the infrared part of the spectrum. Those bands show how suddenly the temperature changes with latitude—that was a surprise to the scientists who saw this image.	This is the sharpest image of Saturn's temperature emissions taken from the ground. It is a mosaic of 35 individual exposures made at the W.M. Keck I Observatory on Feb. 4, 2004. The prominent hot spot at the bottom of the image is right at Saturn's south pole. The warming of the southern hemisphere was expected, as Saturn was just past southern summer solstice, but the abrupt changes in temperature with latitude were not expected. A small section of the ring image is missing because of incomplete mosaic coverage during the observing sequence.

23	Keck and spectrum	The nice thing about telescopes on the ground is that they're less expensive and much easier to service than spacecraft. But they do have one major problem—they have to look through Earth's atmosphere.	What are the advantages of telescopes on the ground, as compared to spacecraft? What are the disadvantages?
24	Keck and spectrum	The atmosphere blocks almost all of the light with wavelengths shorter than violet, which includes ultraviolet light, X-rays, and gamma rays...	
25	Keck and spectrum	...and it blocks a lot of the wavelengths longer than red, including much of the infrared section and microwaves.	
26	Starry sky Image credit: © Stefan Seip - astromeeting.de	Also, if you've ever noticed the stars twinkling, you've seen how the atmosphere distorts the light that does pass through it. One solution to the twinkling problem is a computerized system called "adaptive optics."	Can you think of a way to solve both the twinkling problem and the blocked-wavelength problem?
27	Spitzer (Artist's concept) Image credit: NASA/JPL-Caltech	But a solution to both problems is to put telescopes above the atmosphere, into space—like the Spitzer Space Telescope shown here. The Spitzer specializes in the infrared part of the spectrum. There's also the Chandra Observatory, which sees X-rays, and of course the Hubble, which sees visible, ultraviolet, and some infrared light.	In this illustration, Spitzer is pointing its high-gain antenna toward Earth to exchange information and instructions.
28	Jupiter aurora in UV by Hubble Image credit: NASA and the Hubble Heritage Team (STScI/AURA) Acknowledgment: NASA/ESA, John Clarke (University of Michigan)	Here's a Hubble shot of an aurora at Jupiter's north pole, taken in the ultraviolet. Since our eyes can't actually see infrared or ultraviolet wavelengths, these pictures are artificially colored.	Auroras are curtains of light resulting from high-energy electrons racing along the planet's magnetic field into the upper atmosphere. The electrons excite atmospheric gases, causing them to glow. Magnetic "footprints" can be seen in this image from Io (along the left-hand limb), Ganymede (near the center), and Europa (just below and to the right of Ganymede's footprint). These emissions, produced by electric currents generated by the satellites, flow along Jupiter's magnetic field, bouncing in and out of the upper atmosphere. They are unlike anything seen on Earth.
29	Galaxy Image credit: NASA, ESA, and The Hubble Heritage Team (STScI/AURA)	Now, telescopes are great for viewing the solar system and the universe beyond. But all of these telescopes on Earth or in the vicinity of Earth have one big restriction—they're really far from everything we want to see, so there's a limit to how much they can show us. There's no alternative for observing some things, like this galaxy. But for the solar system, well, let me show you...	This image shows NGC 1300, which is considered to be typical of barred spiral galaxies. Barred spirals differ from normal spiral galaxies in that the arms of the galaxy do not spiral all the way in to the center, but are connected to the two ends of a straight bar of stars containing the nucleus at its center.

30	Io by Hubble Image credit: NASA, ESA, and J. Spencer (SwRI)	Here's a Hubble shot of Io, which is one of Jupiter's moons. It's about the size of our moon, and considering that it's about half a billion miles away, that's a pretty impressive picture.	Hubble was monitoring the volcanically active moon Io in support of a flyby by the New Horizons spacecraft in February 2007. The left side of the image is in natural color and the right side is in UV.
31	Io by Galileo spacecraft Image credit: NASA/JPL-Caltech (Galileo mission)	But if you go there, you can see a plume from one of Io's volcanoes.	This image was taken by the Galileo spacecraft. In addition to the plume on Io's edge, there's another one near the terminator (the boundary between day and night). Plumes on Io are blue with reddish shadows. The latter plume, called "Prometheus," can be seen in every Galileo image of this area, as well as every such Voyager image acquired in 1979. It is possible that this plume has been continuously active for more than 18 years.
32	Mars channels Image credit: NASA/JPL/ASU (Mars Odyssey Mission)	If you go there, you can see dry riverbeds on Mars.	One of the many branches of the Mangala Vallis channel system is seen in this image. The water that likely carved the channels emerged from a huge graben or fracture almost 1000 km to the south.
33	Saturn Image credit: NASA/JPL (Cassini mission)	And if you go there, you can see things that you can't see from anywhere near Earth, no matter how powerful your telescope is. Here's a view of Saturn's rings from the side opposite Earth, taken by the Cassini spacecraft. Scientists were able to learn about the particles that make up the rings by sending radio signals through them from Cassini to Earth.	Specially designed Cassini orbits placed Earth and Cassini on opposite sides of Saturn's rings, a geometry known as occultation. Cassini conducted the first radio-occultation observation of Saturn's rings on May 3, 2005. Purple indicates regions where there is a lack of particles less than 5 centimeters (about 2 inches). Green and blue indicate regions where there are particles smaller than 5 centimeters (2 inches) and 1 centimeter (less than one-third of one inch). The saturated broad white band near the middle of ring B is the densest region of ring B, over which two of the three radio signals were blocked at 10-kilometer (6-mile) resolution, preventing accurate color representation over this band. From other evidence in the radio observations, all ring regions appear to be populated by a broad particle-size distribution that extends to boulder sizes (several to many meters across).
34	DSN Goldstone Image credit: NASA/JPL-Caltech	Receiving signals from spacecraft and sending commands to them depends on the Deep Space Network. That's a system of very large dish antennas. Here's one in Goldstone, California.	How many antenna setups do you think we need to be able to communicate continuously with spacecraft? Why? The image is of the 70-m antenna at Goldstone, California at dawn.
35	DSN Madrid Image credit: NASA/JPL-Caltech	There are also sets of antennas near Madrid, Spain, which you see here, and near Canberra, Australia.	Overview of the entire Madrid Complex.

36	Earth Image credit: NASA (Apollo 17 mission)	If you find those three places on a globe, you'll see that they're evenly spread out around the world. The idea is that, as the Earth rotates, at least one of those antenna sites is always in view of a spacecraft no matter where it is in the solar system, as long as the sun isn't blocking its view of Earth. So, if we actually want to go to someplace in the solar system, which usually means sending one of our robots, how do we do it?	This photo was taken en route to the Moon by the crew of Apollo 17 on December 7, 1972. The flight marked the last time that humans left low Earth orbit and the first and only time a geologist, Harrison Schmitt, traveled to the moon.
37	Launch Image credit: NASA/JPL-Caltech (Mars Odyssey mission)	Well, pretty much everybody knows you start out with a launch using powerful rockets. You have to get the spacecraft going very fast to escape Earth's gravity. But what a lot of people don't realize is that most of the time, the rockets shut down and drop off soon after leaving Earth, and the spacecraft just coast the rest of the way. They can't keep rockets burning because the fuel would be too heavy and make the mission too expensive. So they coast, just making little trajectory corrections along the way with small thrusters.	This image depicts the launch of the "2001 Mars Odyssey" orbiter on April 7, 2001. It was named in honor of the movie, "2001: A Space Odyssey."
38	Dawn headed for Vesta and Ceres (Composite not to scale) Image credits: Dawn (artist's concept): NASA Vesta: NASA, ESA, and L. McFadden (UMD) Ceres: NASA, ESA, and J. Parker (SwRI) (Vesta and Ceres images by HST)	One exception is something called ion propulsion, which is being used on the Dawn spacecraft you see here. Dawn is headed for the asteroid belt, between Mars and Jupiter. An ion engine puts out very little thrust—about as much force as you would feel from the weight of a single sheet of paper here on Earth. But it goes continuously, making the spacecraft travel slightly faster and slightly faster moment by moment over the course of months or years, until it reaches really fantastic speeds.	Can you guess how much thrust an ion engine puts out? About as much force as the weight of a single sheet of paper on Earth. It's far too little to lift a spacecraft off of Earth's surface, but once the spacecraft is in space, it's enough to build up to very fast speeds over time. Dawn will be the first spacecraft to orbit two planetary bodies. It's scheduled to orbit Vesta in 2011-12 and Ceres in 2015. Ion propulsion makes the mission possible.

39	New Horizons flying by Jupiter (Artist's concept) Image credit: SwRI (Dan Durda)/Johns Hopkins University Applied Physics Laboratory (Ken Moscati)	The coasting spacecraft have a clever trick, too, that lets them change their speed or direction without using propulsion. It's called "gravity assist." What they do is fly by a planet at just the right distance and angle so that the planet's gravity pulls them but doesn't capture them into orbit or bring them to its surface. Here's an illustration of the New Horizons spacecraft flying by Jupiter to pick up speed. This maneuver will shave about 3 years off the time it will take the spacecraft to get from Earth...	It's sometimes called the "slingshot effect," though a slingshot is not really a very good metaphor for the principle behind gravity assist. In this artist's rendering, New Horizons is just past its closest approach to Jupiter, on Feb. 28, 2007. Near the sun are Earth, Venus and Mercury. The dim crescent shape at the upper right of the Sun is Callisto, the outermost of Jupiter's four largest moons. Just left of Jupiter is the icy moon Europa. New Horizons' gravity assist maneuver at Jupiter increased its speed by nearly 9,000 miles per hour, bringing the speed up to more than 52,000 mph. Note that to *increase* its speed, a spacecraft approaches a planet in the general direction of the planet's orbit around the sun. To *reduce* its own orbital speed around the sun, a spacecraft approaches a planet in a general direction opposite to the planet's orbit around the sun. The MESSENGER spacecraft, which is headed for Mercury, employed such a maneuver several times to enable it to drop down into an orbit closer to the sun.
40	Pluto and its moons: Charon, Nix and Hydra (taken by HST) Image credit: NASA, ESA, H. Weaver (JHU/APL), A. Stern (SwRI), and the HST Pluto Companion Search Team	...to here. That's Pluto and its 3 known moons as seen by the Hubble Space Telescope. New Horizons is scheduled to be their very first visitor from Earth when it arrives in 2015. Gravity assist is such a useful technique that a lot of spacecraft fly complicated routes through the solar system just so they can pass by planets on the way to their ultimate destinations.	Pluto's two smaller moons, Nix and Hydra, were first photographed by the Hubble Space Telescope in 2005. They are about 5000 times fainter than Pluto and are about 2 to 3 times farther from Pluto than is the larger moon, Charon, which was discovered in 1978.

41	Uranus and Neptune with Voyager 2 (Composite not to scale) Image credit: NASA/JPL (Uranus and Neptune images are from Voyager 2 mission. Image of Voyager 2 spacecraft is a painting.)	Of course, gravity assist isn't the only reason to fly by a planet. A flyby is the easiest and most inexpensive kind of mission to study a planet or other solar system body, especially if you want to visit more than one on the same trip. Voyager 2 took advantage of a planetary alignment that occurs only once in 176 years to make a grand tour of all four giant planets, including Jupiter and Saturn, and the only flybys so far of Uranus and Neptune, which you see here. The downside of a flyby is you only get a relatively quick look.	Why is a flyby the easiest and most inexpensive way to observe an object, and why is that especially true for observing more than one? To orbit or land on an object, a spacecraft has to burn a rocket to slow down and allow itself to be captured by the object's gravity. That means the rocket and the fuel to burn it have to be lifted off of Earth and transported to the destination. To travel to another destination after doing that requires another rocket burn, which means even more fuel would have to be lifted and transported with the spacecraft. With a flyby, no major rocket burns are required after the initial liftoff from Earth. This picture of Neptune was produced from the last whole-planet images taken through the green and orange filters on the Voyager 2 narrow-angle camera. The images were taken at a range of 4.4 million miles from the planet, 4 days and 20 hours before closest approach. The picture shows the Great Dark Spot and its companion bright smudge; on the west limb the fast-moving bright feature called Scooter and the little dark spot are visible.
42	Orbiter: MRO at Mars (Artist's concept) Image credit: NASA/JPL-Caltech	An orbiter mission lets you take your time. This is Mars Reconnaissance Orbiter, one of several spacecraft currently circling Mars.	Artist's illustration of Mars Reconnaissance Orbiter flying over the Martian surface.
43	Cassini orbiter at Titan (Artist's concept) Image credit: NASA/JPL	The Cassini spacecraft is also considered an orbiter because it orbits Saturn. But at the same time, it conducts repeated flybys of many of Saturn's moons, including Titan. Here's an illustration of a flyby in 2007, when Cassini was in position to observe the sun through Titan's atmosphere. Scientists could learn a lot about that atmosphere by analyzing the spectrum of the sunlight that filtered through it.	

44	MRO illustration (Artist's concept) Image credit: NASA/JPL	Flybys and orbiters carry instruments that can detect a wide range of electromagnetic wavelengths...	In this illustration of Mars Reconnaissance Orbiter, the radar antenna at far left beams down and "sees" into the first few hundred feet (up to 1 kilometer) of Mars' crust to determine how deep the water-ice reservoir detected by the Mars Odyssey orbiter extends. The radar instrument is the only one that emits electromagnetic radiation in order to make its observations. The other instruments sense sunlight reflected by—or infrared radiation emitted by—the objects they observe. The other "beams" in the picture are for illustration purposes only. The next beam to the right of the radar represents data received from the imaging spectrometer, which identifies minerals on the surface. The next beam indicates the high-resolution camera, which can "zoom in" on local targets, providing the highest-resolution orbital images yet of features such as craters, gullies and rocks. The beam that extends almost horizontally symbolizes the Mars Climate Sounder. This instrument is critical to analyzing the current climate of Mars since it observes the temperature, humidity, and dust content of the Martian atmosphere, and their seasonal and year-to-year variations. Meanwhile, the Mars Color Imager observes ice clouds, dust clouds and hazes, and the ozone distribution, producing daily global maps in multiple colors to monitor daily weather and seasonal changes.
45	Graphs of Saturn's temperature and winds Image Credit: NASA/JPL/GSFC (Cassini mission)	...which can reveal composition, temperature, and wind speed among other things.	This data was acquired by the Cassini spacecraft's composite infrared spectrometer when Saturn had just begun summer in its southern hemisphere.

46	Venus landscape (Computer-generated image) Image credit: NASA/JPL/USGS (Magellan mission)	Radar can let us see through the hazy atmospheres of Venus and Titan and even underground. This is an image of the surface of Venus, produced from radar data taken by the Magellan spacecraft.	3-D perspective view of Lavinia Planitia. Three impact craters are displayed in this three-dimensional perspective view of the surface of Venus. The viewpoint is located southwest of Howe Crater, which appears centered in the lower portion of the image. Howe is a crater with a diameter of 37.3 kilometers (23.1 miles). Danilova, a crater with a diameter of 47.6 kilometers (29.5 miles), appears above and to the left of Howe in the image. Aglaonice, a crater with a diameter of 62.7 kilometers (38.9 miles), is shown to the right of Danilova. Magellan synthetic aperture radar data is combined with radar altimetry to develop a three-dimensional map of the surface. Rays cast in a computer intersect the surface to create a three-dimensional perspective view. Simulated color and a digital elevation map developed by the U.S. Geological Survey are used to enhance small-scale structure. The simulated hues are based on color images recorded by the Soviet Venera 13 and 14 spacecraft. The image was produced at the JPL Multimission Image Processing Laboratory and is a single frame from a video released at the May 29, 1991, JPL news conference.
47	Titan lakes (Radar image) Image credit: NASA/JPL/USGS (Cassini mission)	And this is a radar image of what are widely interpreted to be lakes on Titan.	Radar-imaging data from Cassini flybys is considered to be convincing evidence for large bodies of liquid. They're not lakes of water, however. At an average distance of 887 million miles from the sun, Titan is far too cold for water to remain liquid on its surface. Its lakes are thought to be liquid hydrocarbons, mostly methane. The existence of such oceans or lakes on Titan was predicted more than 20 years ago. But with a dense haze preventing a closer look, it has not been possible to confirm their presence until the Cassini flyby of July 22, 2006. Intensity in this colorized image is proportional to how much radar brightness is returned, or more specifically, the logarithm of the radar backscatter cross-section. The colors are not a representation of what the human eye would see.
48	Saturn magnetosphere Image credit: NASA/JPL/Johns Hopkins University (Cassini mission)	Other instruments measure gravitational fields, or magnetic fields like this one surrounding Saturn, or the charged particles that fly through space. Scientists look at all these measurements in much the same way that detectives look at blood stains and bits of fiber at a crime scene. They're clues that can lead to dramatic deductions.	Saturn's magnetosphere is seen for the first time in this image taken by the Cassini spacecraft on June 21, 2004. A magnetosphere is a magnetic envelope of charged particles that surrounds some planets, including Earth. It is invisible to the human eye, but Cassini's Magnetospheric Imaging Instrument was able to detect the hydrogen atoms (represented in red) that escape it. The emission from these hydrogen atoms comes primarily from regions far from Saturn, well outside the planet's rings, and perhaps beyond the orbit of the largest moon, Titan.

49	Galileo and Jupiter (Composite of Jupiter photo and artist's rendering of Galileo, not to scale) Image credits: Jupiter: NASA/JPL/UA (Cassini mission) Galileo: NASA	Let me give you an example from the Galileo mission. Galileo orbited Jupiter from 1995 to 2003, and conducted flybys of several of its moons...	This image of Jupiter was actually taken by the Cassini spacecraft en route to Saturn.
50	Europa global Image credit: NASA/JPL (Galileo mission)	...including this one: Europa.	This image by the Galileo spacecraft shows Europa's trailing hemisphere (the hemisphere pointing away from the direction of its orbit around Saturn) in approximate natural color.
51	Europa cutaway (Artist's concept) Image credit: NASA/JPL	Measurements of Europa's gravity and magnetic fields pointed to an ocean of salt water beneath the icy surface. It's just a thin blue band in this illustration, but that's more water than all of the oceans on Earth combined. The measurements also indicated a rocky interior, like Earth has, which could feed nutrients into the water.	The gravity of Europa's neighboring moons induces an elliptical orbit around Jupiter. Variations in Jupiter's gravitational pull at different distances cause stretching and relaxation in Europa, which generates most of the heat that is thought to keep a subsurface ocean in a liquid or slushy state.
52	Europa NIMS image (Image by Galileo NIMS instrument) Image credit: NASA/JPL	The spectrum of light the surface reflected suggested that salt, maybe from seawater, could be rising to the top of the icy crust.	This image by Galileo's Near-Infrared Mapping Spectrometer (NIMS) shows surface compositions ranging from pure water ice to mixtures of water and other minerals which appear bright in the infrared.
53	Europa, global and detail Image credit: NASA/JPL (Galileo mission)	Close-up images revealed that the surface was cracked in a way that supported the idea that liquid water lay beneath. And the scarcity of impact craters showed that the surface was active, frequently recoating itself with fresh ice. That would provide an opportunity for organic material delivered by comets to work its way down to the ocean depths, and for any possible organisms down there to rise to the surface, just as salt seemed to be doing.	The degree and shapes of cracking and the relationships among the cracks indicate that liquid water is between the icy crust and rocky interior. The small number of craters indicates an active surface, both tectonically and from ice circulating.

54	Galileo flying by Europa (Composite of Europa photo and artist's rendering of Galileo, not to scale) Image credits: Europa: NASA/JPL (Galileo mission) Galileo: NASA	All this led scientists to conclude that Europa is a promising place to look for life—without having set a single instrument down on its surface.	JPL scientists say that by measuring the tides (the changing height of the surface ice), a Europa orbiter would be able to determine definitively whether a liquid ocean exists beneath the icy crust. If there is an ocean, the tides should be about 30 meters. If there is no ocean, the tides should be about 1 meter. Determining whether life exists, however, would require a lander.
55	Descent probe: Huygens at Titan (Artist's concept) Image credit: NASA/JPL	While flybys and orbiters observe their subjects from space, probes and landers can actually interact with what they're studying. Huygens, which you see illustrated here, was a descent probe. It rode with Cassini to the Saturn system and then parachuted down to Titan's surface, investigating the atmosphere as it dropped through. Scientists think the chemical processes on Titan may help us understand what led to life on Earth.	Cassini-Huygens arrived at Saturn in 2004. Huygens parachuted to Titan's surface in January, 2005. At the time this illustration was painted, it was unknown whether Huygens would touch down in a hydrocarbon lake. It did not do so.
56	Impact probe: Deep Impact at comet Image credit: NASA/JPL-Caltech/UMD (Deep Impact mission)	A different kind of probe blasts a hole in something to see what's under the surface. This is an actual photo of the Deep Impact mission, in which an impactor was set to collide with a comet while a flyby spacecraft recorded the event.	This spectacular image of comet Tempel 1 was taken 67 seconds after it obliterated Deep Impact's impactor spacecraft. The image was taken by the high-resolution camera on the mission's flyby spacecraft. Scattered light from the collision saturated the camera's detector, creating the bright splash seen here.
57	Stationary lander Image credit: NASA (Viking 2 mission)	The next kind of mission is the stationary lander. Here's a self-portrait of Viking 2, one of a pair of the first really successful landers on Mars. The twin Vikings carried out the first experiments on another world to look for life. The results were inconclusive.	The Soviet Mars 3 achieved the first soft landing on Mars in 1971, but its instruments stopped working after only 20 seconds on the surface. The Twin Vikings landed on Mars in 1976. Viking 2 returned data until 1980, and contact with Viking 1 was lost in late 1982. In this picture, the boulder-strewn field of red rocks reaches to the horizon nearly two miles from Viking 2 on Mars' Utopian Plain. Scientists believe the colors of the Martian surface and sky in this photo represent their approximate true colors. Fine particles of red dust have settled on spacecraft surfaces. The salmon color of the sky is caused by dust particles suspended in the atmosphere. Color calibration charts for the cameras are mounted at three locations on the spacecraft. Note the blue star field and red stripes of the flag. The circular structure at top is the high-gain antenna, pointed toward Earth. Viking 2 landed September 3, 1976 about 4,600 miles from its twin, Viking 1, which touched down on July 20.

58	Rover at rim of Martian crater (Composite of artist's rendering of Opportunity and photo by Opportunity of Victoria crater, to scale) Image credit: NASA/JPL-Solar System Visualization Team	A rover is a lander that can move around. Here is one of the twin rovers, Spirit and Opportunity, at the rim of a Martian crater. They're part of NASA's "follow the water" strategy in the search for past or existing life.	This image superimposes an artist's concept of the Mars Exploration Rover Opportunity on the rim of Victoria Crater to give a sense of scale.
59	Rover examining rock (Artist's concept) Image credit: NASA/JPL/Cornell University	Like a probe, a lander or rover can interact with what it's studying. When Spirit or Opportunity come upon an interesting rock, they can grind through the weathered surface layer and use a microscope to examine what was beneath it, or conduct tests with other instruments they carry. And sure enough, they've found compelling geological evidence that sizable bodies of water once existed on Mars. Coupled with orbiter images that appear to be the tracks of flowing water, this evidence strongly suggests that Mars once had the conditions necessary to support life as we know it.	Artist's concept of a NASA Mars Exploration Rover on the surface of Mars.
60	Blimp at Titan (Artist's concept) Image credit: NASA/JPL	So far, we've only had rovers on the ground—and for that matter, only on Mars. But there's talk of developing another kind of rover for worlds with atmospheres. That could include not only Mars, but Venus and Titan, and could take the form of a balloon or a blimp like this one. Scientists and engineers are constantly striving to make their instruments more and more capable, and at the same time smaller and lighter to make it easier to launch them into space. But there are still some advantages to examining materials here on Earth.	What are some other kinds of rovers we might want to use on planets with atmospheres or with lakes or oceans? Flying vehicles for atmospheres, and submarine-types for lakes (like Titan) and subsurface oceans (like Europa). This illustration portrays one possible design for an aerover for Titan: a small helium-filled blimp that can be steered and moved up and down within the atmosphere to explore different altitudes. Three propellers are likely to be used to allow this maneuvering. The ability of this blimp to move and be repositioned allows for its use as a mobile aerial platform to carry instruments that take readings from different locations, and even follow up on interesting features. Landing is accomplished with an inflatable wheel on the bottom of the blimp, which can cushion a landing on ice, rocks or other surfaces. The blimp will also provide flotation on potential liquid methane lakes, thus making the aerover the ultimate all-terrain vehicle. The aerover will likely have the ability to fly along at 10 kilometers altitude (about 6 miles), circumnavigating Titan every one or two weeks and providing imaging and science well below the upper opaque clouds that prevent viewing from Earth or from orbit.

61	Sample return: Stardust (Artist's concept) Image credit: NASA/JPL	So that leads us to the final category of robotic mission, the sample return. Here's an illustration of Stardust, which flew to a comet, captured particles blown off of its nucleus, and delivered them to Earth...	Artist's rendering of the Stardust spacecraft approaching comet Wild 2 (pronounced "Vilt 2" after its Swiss discoverer). Stardust was launched on February 7, 1999. It collected particles flying off the comet and delivered them to Earth in 2006.
62	Scientists examining Stardust capsule Image credit: NASA/JSC	...where scientists could examine them with laboratory instruments too big and heavy to send into space.	Investigators from University of Washington, Johnson Space Center, and Lockheed Martin Missiles and Space in Denver, Colorado, inspect a canister and sample collector soon after opening a container with Stardust material in a laboratory at the Johnson Space Center.
63	Comet particle tracks in aerogel. Image credits: NASA/JPL and NASA/JPL-Caltech/UW (Stardust mission)	This is what they saw—tiny particles embedded in a special substance called aerogel.	Stardust used aerogel to trap the comet particles. Aerogel is named in the Guinness Book of Records as the world's least-dense substance. It is a silicon-based solid with a porous, sponge-like structure in which 99.8 percent of the volume is empty space. Aerogel is 1,000 times less dense than glass, which is another silicon-based solid. When a particle hits the aerogel, it buries itself in the material, creating a carrot-shaped track up to 200 times its own length. This slows it down and brings the sample to a relatively gradual stop. Since aerogel is mostly transparent—with a distinctive smoky blue cast—scientists use these tracks to find the tiny particles.
64	Apollo astronaut on Moon Image credit: NASA (Apollo 15 mission)	The final kind of mission is one in which astronauts explore a world in person. So far, that's been done only on the Moon in the 1960s and 70s.	In this photo, astronaut Jim Irwin sets up the first Lunar Roving Vehicle during Apollo 15.
65	Future astronaut on Moon. (Artist's concept) Image credit: NASA	Someday astronauts may return to the Moon for extended stays.	This is according to NASA's Vision for Space Exploration. More information is available at http://www.nasa.gov/mission_pages/ exploration/main/index.html

66	Summary of mission types at various locations (Photo montage) Image credit: NASA/JPL	Here’s a summary of the kinds of missions that have been conducted throughout the solar system. Every planet has had at least one flyby, and so have many of the moons and a number of comets and asteroids. There's a flyby on its way to Pluto and other objects in the region beyond Neptune known as the Kuiper belt. There’s a certain progression to the missions. With planets and moons, we’ve almost always started with flybys, and then in many cases moved on to orbiters, and then to probes or landers or both. Each kind of mission lays the groundwork for the next kind. An orbiter helps you determine the best place to send a lander, and what kind of instruments to include. Different types of missions can also support each other. Telescopes on or near Earth often support spacecraft missions. And even after operating very successful rovers on Mars, we still sent another orbiter. Orbiters cover very wide areas, which complements the more detailed but geographically limited capabilities of rovers and landers.	We conducted a sample return with a comet without first conducting a flyby, orbiter, or lander with that same comet. Why? Each comet we encounter is in our part of the solar system for only a brief period, so we typically get only one shot at it before it’s gone for a long time. We did conduct flybys with some comets before performing a sample return with another comet. Rosetta, an ESA mission that includes NASA instruments, is on its way to conduct a combination orbiter-lander mission on a comet in 2014. **Titan:** The Titan probe and lander was the same mission (Huygens). Huygens landed on Titan without being preceded by an orbiter, and so was an exception to the pattern of orbiting a planet or moon before conducting a probe or lander mission. **Asteroids:** In 2001, NASA’s NEAR-Shoemaker spacecraft orbited and then landed on asteroid Eros. Hayabusa is a Japanese mission, in progress as of this writing, to bring an asteroid sample to Earth. The spacecraft landed on asteroid Itokawa in 2005 and, although the sample-capture procedure did not go as planned, it is believed that some dust from the asteroid may have gone into the collection canister. The mission is scheduled to return the canister to Earth in 2010. **Earth’s Moon:** Flybys and probes: Earth’s moon was an exception to the pattern of starting exploration of planets and moons with flybys. In those first efforts to visit a heavenly body, U.S. and Soviet spacecraft were mostly designed to crash into the Moon’s surface rather than fly by it. The purpose of these missions was to take and transmit pictures until impact, not to excavate a hole and see what’s under the surface, so they weren’t really probes in the sense we’ve been using in this presentation. They were more like flybys that didn’t fly by. The Soviet Union conducted some actual flybys (Luna 3 in 1959 and one or more Zond flights in 1965-70), but not before conducting a deliberate crash into the lunar surface (Luna 2 a few weeks before Luna 3). NASA’s Lunar Prospector, after completing its orbital mission in 1999, was deliberately crashed into the Moon near the south pole in hopes of producing water vapor in the debris plume, making it a probe in the sense we’ve been using here. It was observed by Earth-based observatories and spacecraft such as the Hubble Space Telescope. No water vapor was found.

67	Extrasolar planets (Artist's concept) Image credit: NASA/JPL	Far beyond our solar system, there are many others. Our telescopes have already found evidence of hundreds of planets orbiting other stars. Will we be able to send spacecraft to them? Well, consider this...	This is an artist's concept of an extrasolar gas-giant planet.
68	Voyagers at termination shock (Artist's concept) Image credit: NASA/JPL/Walt Feimer	Right now Voyager 1 is the most distant manmade object. It's been traveling for over 30 years and is currently more than 100 times the distance of Earth from the sun, with its twin, Voyager 2, nearly as far but in a different direction.	An artist's concept illustrates the positions of the Voyager spacecraft in relation to structures formed around our sun by the solar wind. Also illustrated is the termination shock, a violent region the spacecraft must pass through before reaching the outer limits (not counting the Oort cloud) of the solar system. At the termination shock, the supersonic solar wind abruptly slows from an average speed of 400 kilometers per second to less than 100 kilometer per second (900,000 to less than 225,000 miles per hour). Beyond the termination shock is the heliosheath, a vast region where the turbulent and hot solar wind is compressed as it presses outward against the interstellar wind that is beyond the heliopause. A bow shock likely forms as the interstellar wind approaches and is deflected around the heliosphere, forcing it into a teardrop-shaped structure with a long, comet-like tail. The exact location of the termination shock is unknown, and it originally was thought to be closer to the sun than Voyager 1 currently is. As Voyager 1 cruised ever farther from the sun, it confirmed that all the planets are inside an immense bubble blown by the solar wind and the termination shock is much more distant.

69	Oort cloud (Artist's concept) Image credit: NASA/ESA and A. Feild (Space Telescope Science Institute). The Oort cloud cutaway drawing is adapted from Donald K. Yeoman's illustration (NASA/JPL).	It's beginning to pass through the Oort cloud, a spherical region of billions of very sparsely scattered comets believed to enshroud the rest of the solar system. On this illustration, the entire solar system we've been talking about so far, from the sun all the way out to Pluto and the Kuiper belt, is that little blue square in the middle, and Voyager 1 is just at the outer part of that little blue square. Now, Voyager 1 is traveling about one million miles per day. At this incredible speed, the spacecraft will take well over 10,000 years to get through the Oort cloud and finally leave the solar system. And at that point, it will not be even half as far from us as the nearest star—and it'll be much farther still from the nearest star where we've found planets. So there are no plans to send spacecraft to other solar systems anytime soon. But with ever-improving telescopes, there's still a lot we can learn about other solar systems.	The ratio of the size of the known solar system (from the sun out to Pluto and the other objects in the Kuiper belt) to the Oort cloud is approximate and may be overly generous. On the scale of the white dots representing the Oort cloud, it's possible that the little blue box should be even smaller than shown here.
70	Montage of planets and moons Image credit: NASA/JPL	And we've just begun to explore our own.	What kinds of missions would you like to see in the future?
71	NASA logo	**Abbreviations used in image credits:** ASU: Arizona State University AURA: Association of Universities for Research in Astronomy DOE: U.S. Department of Energy ESA: European Space Agency GSFC: Goddard Space Flight Center HST: Hubble Space Telescope JPL: Jet Propulsion Laboratory JSC: Johnson Space Center NASA: National Aeronautics and Space Administration	NOAO: National Optical Astronomy Observatory NSF: National Science Foundation SOHO: Solar and Heliospheric Observatory STScI: Space Telescope Science Institute SwRI: Southwest Research Institute UA: University of Arizona UAA: University of Alaska Anchorage UMD: University of Maryland USGS: United States Geological Survey UW: University of Washington