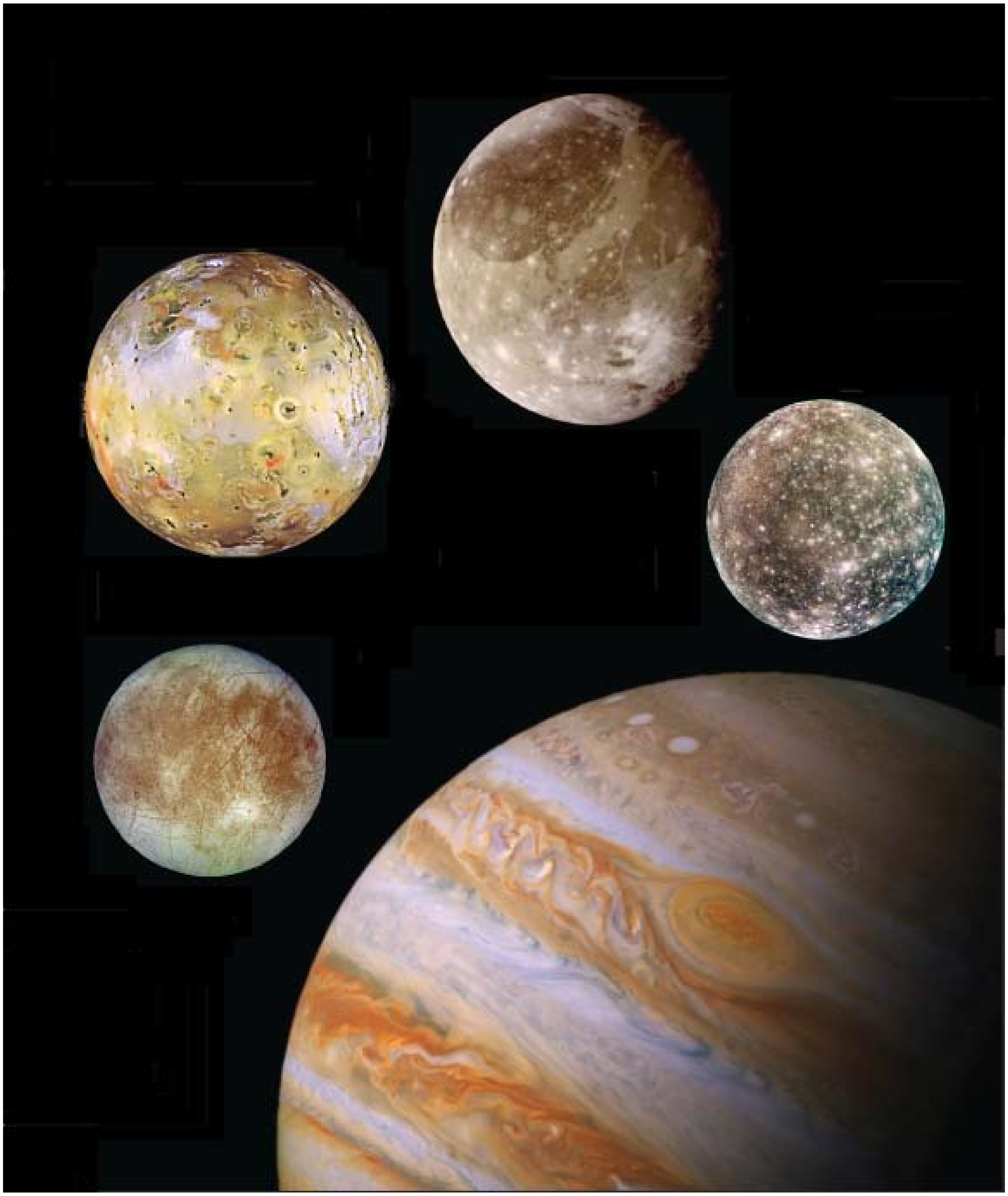
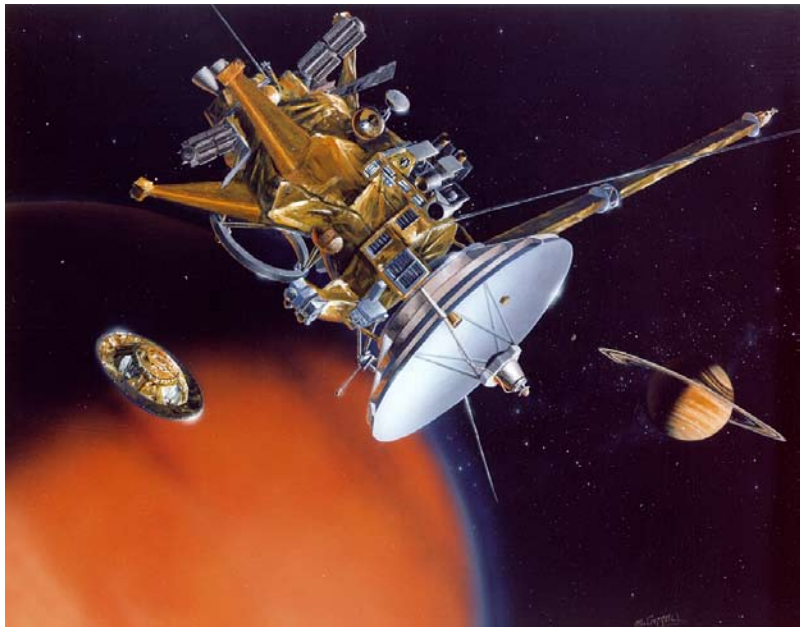
Moons of the Solar System



by Cary I. Sneider and Alan D. Gould
revised by Toshi Komatsu

Cover photograph collage of Jupiter with four moons courtesy of NASA/JPL



Cassini Spacecraft Mission to Saturn (1997 to 2009+) including probe to descend to the surface of Titan (NASA drawing)

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Moons of the Solar System

Contents

Introduction

Moons of the Solar System was designed for public audiences and for school children in grades one and above. Presentations for younger age children (grades 1-3) require simplification as noted in the script.

The program begins by students observing how the Moon changes position and apparent shape during a two week time period. To better understand their observations, each student models the Earth-Moon-Sun system with a light in the center of the planetarium representing the Sun, a hand held ball as the Moon, and the student's own head as the Earth. This is the best way we have found for anyone (including adults) to understand why the Moon goes through phases. The model is also used to explain lunar and solar eclipses.

In the next activity, students observe the moons of Jupiter. Classes of children in grades 4 and up will be able to plot the Galilean moons' positions on a data chart. Younger groups will watch the moons' positions change from night to night and draw conclusions from those observations without attempting to record them.

The last part of the program is a tour of the solar system to see the moons of each planet through the eyes of spacecraft that have visited those planets. Viking and Voyager images are featured.

We would be very grateful to hear from you about how you used this program, what modifications you made, what worked well and what didn't work well.

Objectives

After attending this planetarium program, the students will be able to:

1. Explain the phases of the Moon—why the Moon appears to change shape in a monthly cycle.
2. Explain why we have solar and lunar eclipses.
3. Explain how Galileo was able to measure the periods of Jupiter's four largest moons.
4. Explain the role of meteoroids in crater formation.
5. Name and describe some of the moons found in the solar system.
6. Differentiate between a "planet" and a "moon" or "satellite."

Primary grade students will be able to:

1. Describe the phases of the Moon.
2. Describe the appearance of the Moon close-up.
3. Explain that other planets have more than one moon, and that these moons look different from Earth's moon.

Materials

1. **Planetarium**

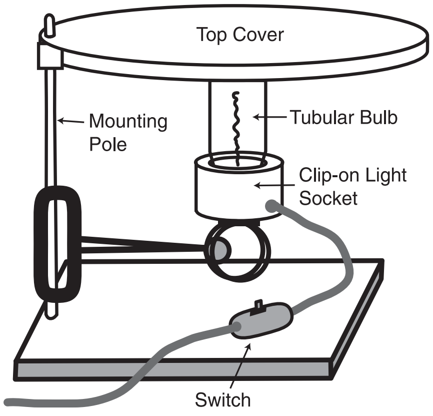
   Your planetarium must have the capabilities of diurnal motion and Moon phases with proper position relative to an image of the Sun.

2. **Sun Simulator**

   In the center of the planetarium, mount a short unfrosted tubular light bulb (about 25 to 40 watts) for simulating the Sun. Such a clear, single filament bulb is necessary to create crisp shadows on the model Moons. Ideally, supply electrical power to the bulb through a dimmer switch. Place a top shade over the bulb to prevent reflection of white light from the dome. (See diagrams for ideas for how to make Sun Simulation Light.)

A wire stand can be fashioned to support the shade/cover over the tubular light.

Another version of
Sun Simulator



3. Moon Models
   Make a class set of moon models that can be reused for each program. These can be made with white polystyrene balls, about 2"-3" in diameter, mounted on sticks or pencils. Such balls are made by Plasteel Corp. in Inkster, Michi-gan. Google "polystyrene balls." Polystyrene balls are also available at craft and hobby stores. Styrofoam does not work as well, since it is translucent.
4. Light Pointers
   You will need at least two light pointers (one bright and one dim) or a single light pointer with variable brightness. See Constellations Tonight, News and Articles web page at http://lhs.berkeley.edu/pass/passv05/ PASSv05updates. html for a simple way to make inexpensive LED light pointers,
5. "Tracking Jupiter's Moons" Data Sheet
   For each student, have a pencil and a copy of the (master on p. 8).
6. Reading Lights for the Students
   In our permanent planetarium, we have 7-watt night-light orange bulbs under the cove, with shades so they shine down on the audience. This is very con-venient, because visitors can see their "Tracking Jupiter's Moons" charts and look back at the sky freely. The program can also be done by turning up the daylight for people to mark their charts, and then turning down for the next observation.
7. **Sound effect: Countdown and Rocket Launch Noise**
   This is a very exciting touch for beginning the tour of moons. The bigger and deeper the rocket launch sound, the better the effect. Students can fasten their "safety belts" and imagine they are taking off in a rocket ship. Such an audio segment can be found on sound effects CDs, tapes, record albums, or on free worldwide web sites. Optional: You can have "sunset music" to play when you make the sun set near the beginning of the program.
8. **Images**
   Images for this program are listed on the following page. They have been as-sembled from several different sources. Image 37 in the script is indicated as "Your Planetarium or School" so you must decide what image to put for that image.

Image	Source	Credit*
1. Moon	Lick Observatory	Lick Observatory
2. Mars	Lick Observatory	Lick Observatory
3. Jupiter	http://photojournal.jpl.nasa.gov/catalog/PIA02825	NASA/JPL/U. Arizona/LHS
4. Galileo's Notes	Replica	LHS
5. ColorCode	http://photojournal.jpl.nasa.gov/catalog/PIA02825	NASA/JPL/U. Arizona/LHS
6. Tracking1	http://photojournal.jpl.nasa.gov/catalog/PIA02825	NASA/JPL/U. Arizona/LHS
7. Tracking2	http://photojournal.jpl.nasa.gov/catalog/PIA02825	NASA/JPL/U. Arizona/LHS
8. Tracking3	http://photojournal.jpl.nasa.gov/catalog/PIA02825	NASA/JPL/U. Arizona/LHS
9. Tracking4	http://photojournal.jpl.nasa.gov/catalog/PIA02825	NASA/JPL/U. Arizona/LHS
10. Tracking5	http://photojournal.jpl.nasa.gov/catalog/PIA02825	NASA/JPL/U. Arizona/LHS
11. Tracking6	http://photojournal.jpl.nasa.gov/catalog/PIA02825	NASA/JPL/U. Arizona/LHS
12. Tracking7	http://photojournal.jpl.nasa.gov/catalog/PIA02825	NASA/JPL/U. Arizona/LHS
13. Tracking8	http://photojournal.jpl.nasa.gov/catalog/PIA02825	NASA/JPL/U. Arizona/LHS
14. Tracking9	http://photojournal.jpl.nasa.gov/catalog/PIA02825	NASA/JPL/U. Arizona/LHS
15. MoonCloseup	http://photojournal.jpl.nasa.gov/catalog/PIA00404	NASA/JPL/USGS
16. Tycho	http://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-moon.html#clementine	USGS/NRL/NASA/NSSDC
17. MarsPhobos	NASA Voyager mission	NASA
18. Phobos	http://www.msss.com/mars_images/moc/2003/06/23/	NASA/JPL/MSSSystems
19. Deimos	http://www.solarviews.com/cap/mars/deimos2.htm	NASA/JPL
20. JupiterIoEuropa	http://photojournal.jpl.nasa.gov/catalog/PIA00144	NASA/JPL
21. CallistoGlobal	http://photojournal.jpl.nasa.gov/catalog/PIA03456	NASA/JPL/DLR
22. CallistoSurface	http://photojournal.jpl.nasa.gov/catalog/PIA00561	NASA/JPL/Arizona State
23. GanymedeGlobal	http://photojournal.jpl.nasa.gov/catalog/PIA00716	NASA/JPL
24. GanymedeSurface	http://photojournal.jpl.nasa.gov/catalog/PIA00280	NASA/JPL
25. EuropaGlobal	http://photojournal.jpl.nasa.gov/catalog/PIA00502	NASA/JPL/DLR
26. EuropaSurface	http://photojournal.jpl.nasa.gov/catalog/PIA01127	NASA/JPL/PIRL/U. Arizona
27. IoGlobal	http://photojournal.jpl.nasa.gov/catalog/PIA00583	NASA/JPL/U. Arizona/LPL
28. IoEruption1	http://photojournal.jpl.nasa.gov/catalog/PIA01081	NASA/JPL/U. Arizona/LPL
29. IoEruption2	http://photojournal.jpl.nasa.gov/catalog/PIA00744	NASA/JPL/PIRL/U. Arizona
Movie 29a. Jupiter rotation	(http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=2158)	NASA/JPL
30. SaturnGlobal	http://photojournal.jpl.nasa.gov/catalog/PIA06193	NASA/JPL/SSInstitute
31. SaturnCloseup	http://photojournal.jpl.nasa.gov/catalog/PIA07772	NASA/JPL/SSInstitute
32. Mimas	http://photojournal.jpl.nasa.gov/catalog/PIA06258	NASA/JPL/SSInstitute
33. Iapetus	http://photojournal.jpl.nasa.gov/catalog/PIA08848	NASA/JPL/SSInstitute
34. IapetusRidge	http://photojournal.jpl.nasa.gov/catalog/PIA06166	

http://photojournal.jpl.nasa.gov/catalog/PIA08404...........NASA/JPL/SSInstitute

35. Titan......................http://photojournal.jpl.nasa.gov/catalog/PIA06090............NASA/JPL-Caltech

36. TitanLakes.............http://photojournal.jpl.nasa.gov/catalog/PIA10018............NASA/JPL/USGS

37. SaturnRings...........http://photojournal.jpl.nasa.gov/catalog/PIA09763............NASA/JPL/SSInstitute

Movie 37a. Ring spokes. http://pds-rings.seti.org/saturn/animations/saturn_spoke.mov NASA/JPL

Movie 37b. Saturn's Rings animation http://photojournal.jpl.nasa.gov/animation/PIA07712 NASA/JPL/SSI

38. Uranus..................http://www.windows.ucar.edu/tour/link=/uranus/
images/artist_image.html ....NASA/JPL-Caltech

39. Miranda ....http://photojournal.jpl.nasa.gov/catalog/PIA01354............NASA/JPL-Caltech

40. Titania..................http://photojournal.jpl.nasa.gov/catalog/PIA00039............NASA/JPL-Caltech

41. Neptune ....http://photojournal.jpl.nasa.gov/catalog/PIA01142............NASA/JPL-Caltech

42. Triton ....http://photojournal.jpl.nasa.gov/catalog/PIA00317............NASA/JPL-Caltech

43. Pluto ....http://hubblesite.org/newscenter/archive/releases/
2006/29/image/a/ ....NASA/ESA/JHU/APL/
SwRI/HST PlutoCST

* Image Credits:

Arizona State: Arizona State University, http://www.asu.edu

DLR: Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center), http://www.dlr.de/en/

HST Pluto CST: Hubble Space Telescope Pluto Companion Search Team, http://hubblesite.org/

JPL-Caltech: Jet Propulsion Laboratory, Caltech, http://www.jpl.nasa.gov

LHS: Lawrence Hall of Science, University of California, Berkeley, CA 94720, http://www.lhs.berkeley.edu/

MSSSystems: Malin Space Science Systems, http://www.msss.com/

NASA: http://photojournal.jpl.nasa.gov/; http://nssdc.gsfc.nasa.gov/photo_gallery/

SSInstitute: Space Science Institute, http://www.spacescience.org/

SwRI: Southwest Research Institute, http://www.swri.org/

U. Arizona: University of Arizona, http://arizona.edu

Views of the Solar System: http://www.solarviews.com/

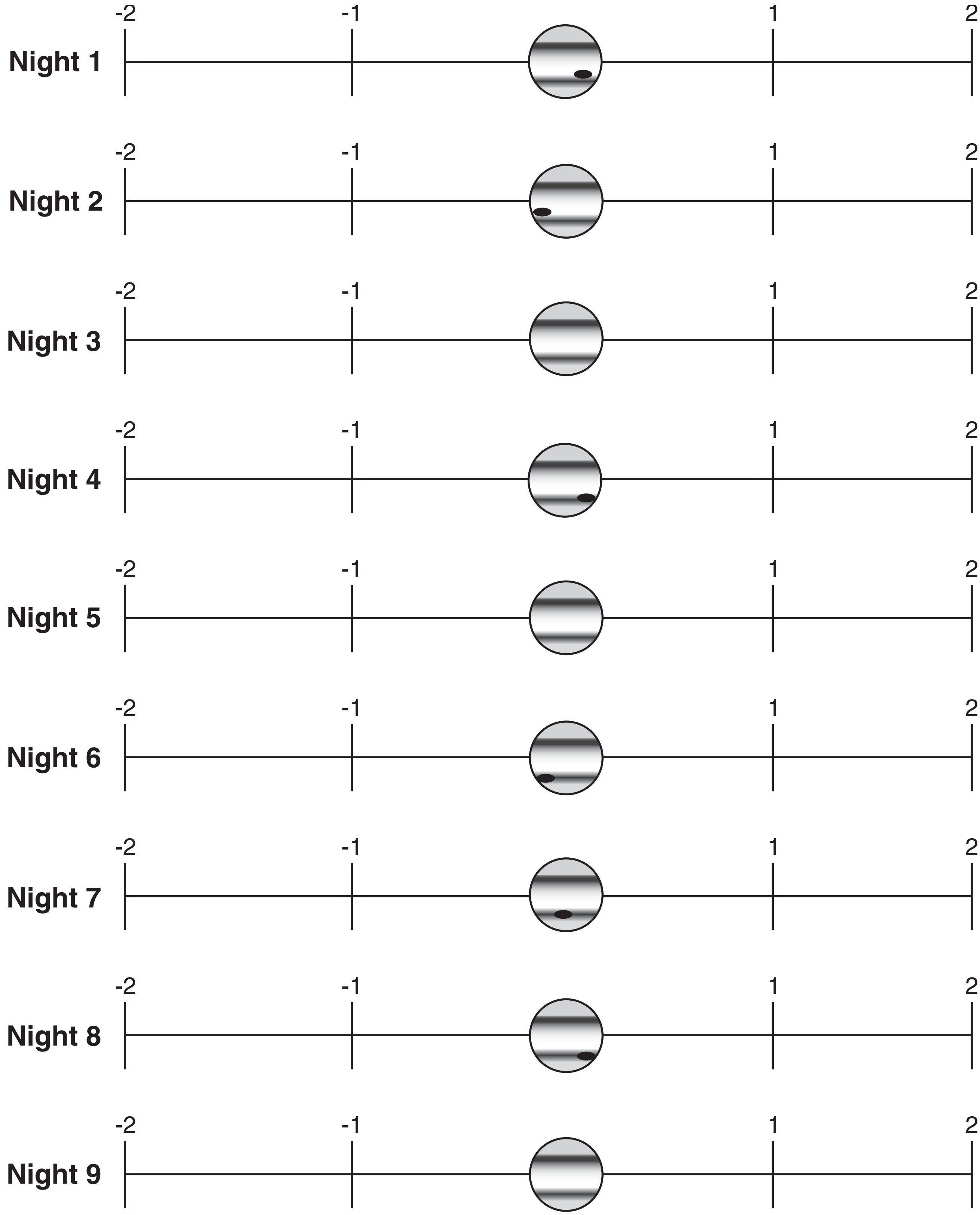
Windows to the Universe: http://www.windows.ucar.edu/

About Image File Names

Image file names are numbered to correspond with the narration script in this document. However, since certain imagery is already available in some fulldome digital systems, we have inserted a "Z" in the file name after the number where there is likely an image already supplied by a fulldome digital system. If that is not the case, then the "Z"-marked image should be used. If there is an alternate image available, "alt" is inserted in the file name.

Color code of your moon:

Tracking Jupiter's Moons



Recommendations for Using the Script

We don't expect the script which follows to be memorized (as an actor might memorize a part) but to be used as a guide in learning, rehearsing, and improving presentations. We recommend that you read the script once or twice, then work with it in the planetarium, practicing the projector controls, slides, special effects, and music. You should be able to imagine yourself presenting information, asking questions, and responding to participants. For your first few presentations, you can have the script on hand, using major headings as reminders of what to do next.

The script is organized in blocks or sections. The purpose of these separations is only to help you learn and remember what comes next. Once you have begun a section, the slides or special effects and your own train of thought will keep you on track. When beginning a new section, make the transition logically and smoothly.

Directions for the instructor are printed in italics in the side column, the instructor's narrative is printed in regular type, and directions and questions to which the audience is expected to respond are printed in bold italics. There is no point in memorizing narration word-for-word since what you need to say will depend upon the participants. The language you use and the number and kinds of questions you ask will depend on how old the participants are, how willing they are to respond, and how easily they seem to understand what is going on.

We believe that the most important elements of the program are the questions and the activities since these involve the audience in active learning. If you must shorten your presentation, we recommend that you borrow time from the narration.

Set-Up

1. Move diurnal motion until the Sun is above the western horizon, about an hour before sunset.
2. Set the Moon phase so that the Moon is about 3 or 4 days old (narrow crescent to the east of the Sun).
3. Test unfrosted tubular light bulb for Sun simulation in the center of the planetarium. Be sure the top cover is over the bulb to prevent dome reflections.
4. Test light pointer(s) (bright and dim).
5. Cue image sets (slides and/or video).
6. Cue audio tape for rocket launch.

Planetarium Show Script

Introduction to Moons of the Solar System

Good afternoon! It is getting close to sunset in our planetarium, but before it gets dark, let's find both the Sun and Moon in the sky right now. It is a common misconception that the Sun and Moon are never up at the same time, but in fact, they often are.

Can you see the Sun and Moon?

Let students use the light pointer to point them out.

Please take careful note of where the Moon and Sun are located while I switch on our planetarium "time machine" to accelerate the sunset.

Turn on music and start diurnal on slow for a leisurely sunset. Slowly turn down daylight and cove lights and turn up stars.

Observing Phases of the Moon

Even though the Sun is now below the horizon, we know about where it is because we saw where it just set.

Point out place on horizon where the Sun set.

We can still see the Moon.

How would you describe the shape of the Moon right now? [Crescent, banana, finger nail clipping.] If we were to watch the sunset from this same spot three days from now, do you think the Moon would look the same? [No.] How might it be different? [Different shape; different location.]

The Moon could change its shape in one of two ways, getting fatter or getting thinner. If you think that in three days the Moon will appear narrower, please indicate so by raising your hand. Raise your hand if you think the Moon will appear fuller three days from now. Let's see if our predictions are correct by moving ahead in time using our time machine.

Turn up daylight. Turn off Sun/Moon. Set Moon ahead about 3 days. For young audiences, have them count the days going by with you. Then turn up the Sun/Moon and turn off the daylight.

Those who thought the Moon would grow fatter are indeed correct.

What shape would you say this Moon is now? [Half Moon.]

Oddly enough, and for reasons that you will learn in a few minutes, astronomers refer to this shape of Moon as a quarter Moon.

Is the Moon in the same place as it was when it was crescent, three days ago? [No.] Does it seem closer to or farther from the Sun? [Farther.]

Guess where you think the Moon will be and what shape it will be three days from now.

Turn up daylight. Turn off Sun/Moon. Set Moon ahead 3 more days.

Was your guess correct?

When the Moon is this shape, bigger than quarter but not yet full, it is called a gibbous Moon. It seems even farther from the Sun than when it was quarter. Let's step just three more days into the future. Again, try guessing where the Moon will be.

Turn up daylight; turn off Sun/Moon; set Moon ahead 3 more days; advance daily motion forward some to guarantee that the Sun is still below the horizon.

The Moon is very nearly full. Remember where the sunset occurred. Note that the Moon is all the way on the other side of the sky from where the Sun is setting. Whenever a full Moon occurs, you can expect it to rise in the eastern part of the sky right around the time of sunset. The different shapes of the Moon that we observe are known as phases of the Moon.

Why does the Moon seem to change shape as we have just observed? [Accept any answers.]

Explaining the Phases of the Moon

Practically every culture throughout human history has come up with a different explanation in answer to that question. One rather interesting theory was invented by the Egyptians who believed that a new Moon was born each month (literally) and it grew and grew until it was full. At the moment the Moon reached the fullness of maturity, a giant pig attacked it and kept feasting on it for the rest of the month until there was no Moon left, at which time a new Moon was born.

Do you think that's really how the Moon changes its shape?

Even though we don't believe this explanation now, in its time this was a perfectly good explanation and accounted for the phases of the Moon quite well.

The theory most accepted in modern times has to do with relationships between the Earth, Sun and Moon. To see how this works let's make a working model.

Will everyone please stand up?

****Optional***

Show image of Full Moon (file name mss00aoptFullMoon.png) while telling Egyption story of the giant pig eating the Moon.

Turn on the white light (tubular bulb) to about 1/2 brightness.

Let's pretend that this light is the Sun. Pretend that your head is the Earth. All you need to complete the model is the Moon.

Give each student a ball on a stick.

Hold your Moon so that it is directly in front of the Sun.

> ***Does your Moon look dark? [Yes.]***

At this time of month, in reality, the Moon is so dark you could not see it at all. The Moon doesn't stay in one place; it orbits (goes around) the Earth. Slowly move your Moon to your left, just beginning the orbit of the Moon around the Earth (your head). Move the Moon until you see a small part of it lit by the sunlight.

Go around and check to see each student understands and is observing the crescent Moon.

> ***What shape would you call that lit part of the Moon? [Crescent.] Does it look like the shape of the Moon when we first saw it in the planetarium sky today? [Yes.]***

Now continue the Moon in its orbit, moving it slowly to the left, until you see a half disc lit up, which you may recall is the "quarter Moon." Notice that when the Sun is setting, from your viewpoint, the first quarter Moon is directly overhead.

Continue moving your Moon in its orbit until you see the gibbous phase (nearly full). Now try to hold your Moon in a place where it is fully lit and could be called a full Moon.

Let the students discover the shadows of their heads. If necessary, hint that they hold their Moons above those shadows.

We have now modeled the Sun-Moon-Earth system so that we have seen everything that we observed in the planetarium sky. The lit part of the Moon grew from nothing to full and in reality it takes about two weeks for it to do that. However, the Moon does not stop there in its orbit.

> ***What do you think happens as the Moon continues in its orbit? [Appears to get smaller.]***

Try slowly moving your Moon the rest of the way in its orbit around its Earth. Try going slowly through a couple more orbits so you can observe the complete cycle of the phases of the Moon. In reality, it takes about one month for the Moon to complete such a cycle (29.5 days, to be exact; for young students it is fun to refer to this as a "Moonth.")

While we have this model working, let's see if we can explain a couple of other kinds of events that have startled and terrified people through the ages. Hold your Moon right in front of the Sun so that it blocks the Sun.

What is the name for the event in which the Moon blocks the Sun? [Solar eclipse.]

While you hold your Moon so that it blocks the Sun, look around the room at the other "Earths" which are other peoples' heads.

Do you see the shadows of their Moons on them? What phase must the Moon be in for there to be a solar eclipse? [New.]

In the real Sun-Earth-Moon system, that shadow of the Moon on the Earth during a solar eclipse is only about fifty miles (80 km) wide. In comparison, the whole Earth is about 8000 miles (13,000 km) wide.* During a total eclipse of the Sun, only people located in that narrow shadow region can see the eclipse.

Now move your Moon around until it moves into the shadow of the Earth (your head).

What is this type of eclipse called? [Lunar eclipse.] What phase must the Moon be in for there to be a lunar eclipse? [Full.]

People on the whole night time half of the Earth, the half that points away from the Sun, can observe a total lunar eclipse.

Could people who live on the back of your head see the Moon move into the Earth's shadow? [No, it's daytime for them.]

Many more people have seen lunar eclipses than have seen solar eclipses. This is because whenever a lunar eclipse occurs, people on half of the Earth have the opportunity to see it, but to see a solar eclipse, you must be where the comparatively tiny shadow of the Moon sweeps across the Earth.

*Optional

If your head represents the Earth, the shadow of your moon ball should be only about 1/20 inch (1 mm) wide. (In that scale, the light bulb (sun) should be about a mile and a half away and your arm would have to be 20 feet long to hold your moon ball at the proper distance from your head!)

*Optional

Show image of Lunar Eclipse (file name mss00boptLunarEclipse.png).

The Moon Through a Telescope

So far, we have observed the moon just as our ancestors did, thousands of years ago. About 400 years ago, telescopes were invented and exciting new views of the moon were possible. Let's see how our moon looks through a telescope.

Image 1: Moon Through a Telescope. ►

Pretend we are looking through the eyepiece of a telescope. Let's aim it at the moon.

> ***What features can you see? [Dark areas; light areas, little circle.]***

The light areas are mountainous regions.

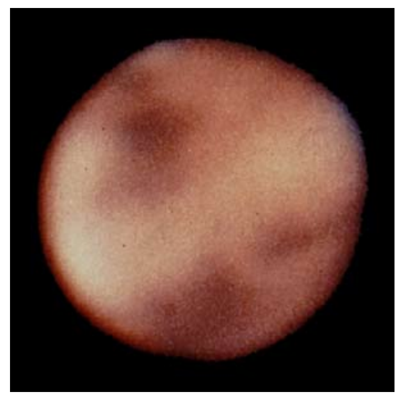
> ***What type of terrain do you think we would find in the darker areas? [Flat.]***

The first person to carefully examine objects in the sky through a telescope was a man named Galileo Galilei, an Italian scientist who lived about 400 years ago. He also thought those dark areas were flat, but he called them "maria," the Italian word for ocean.

> ***Do you think they are really oceans? [There really is no water on the moon.]***

Galileo also looked at the planet Mars and saw how it looked different from stars. Stars are much farther away and look like pinpoints of light, while nearby planets such as Mars can be seen as balls through a telescope.

Image 2: Mars Through a Telescope. ►



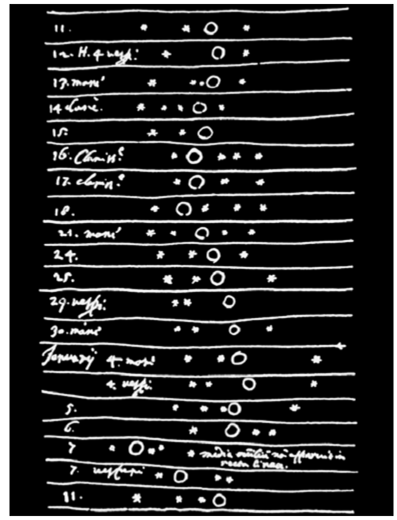
The Galilean Moons of Jupiter

Galileo also looked at Jupiter.

Image 3: Jupiter and 4 Moons. ►

He saw the planet Jupiter with four small objects in a line near it. Galileo thought the objects were stars, but when he observed Jupiter on subsequent nights, those "stars" appeared in different places. This was quite upsetting (and intriguing) since patterns of other stars never change in relation to one another. Galileo kept careful records of the positions of Jupiter's companion "stars."

Image 4:* Galileo's Notes. ►



Don't worry if you can't read the words. It's written in Italian. Each night Galileo recorded the positions of Jupiter (use arrow to indicate), and its 4 companion "stars."

> ***Do you think they are really stars? [No.] What else could they be? [Moons!]***

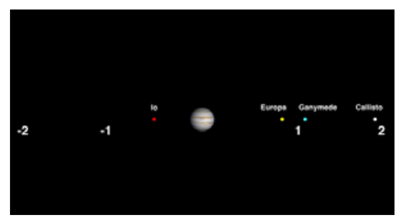
Galileo determined that they were moons. Let's see why. Let's watch Jupiter and its moons for a few nights just as Galileo did. Here is some astronomical note paper for you to note the changing positions.

> ****Optional***
>
> Place image 4 *after* image 14 (Night 9).

Hand out a "Tracking Jupiter's Moons" sheet to each person.

One sticky problem Galileo had was trying to tell which "star" was which. Let's make our job easier by doing something Galileo could not: color each moon a different color.

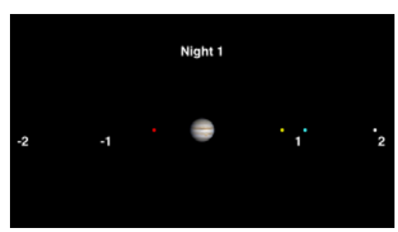
Image 5: Jupiter and Moons Color Coded. ►



Let's further simply our task by specializing: look at only one moon at a time.

Divide the class into four groups and assign each group one "star" to keep track of. Point out color, letter, and name of each moon. Point out numbers that indicate distance from Jupiter in millions of miles. For younger classes (grades 1-2), do not hand out paper. Do not divide the class into groups. Have the entire class observe one moon at a time.

Image 6: Tracking Night 1. ►



Here is our view for our first night's observation. Please put a mark on your "Night 1" line indicating the position of your moon as you see it in relation to Jupiter.

Go around and check to see that each student understands. Help as needed.

Now we will let one day go by to arrive at "Night 2." Then we will let a second day go by to arrive at "Night 3." After eight days have gone by, we will have arrived at "Night 9." Each night, mark where your moon is with respect to Jupiter on the appropriate line.

▼ **Images 7–14: Tracking Nights 2–9.**

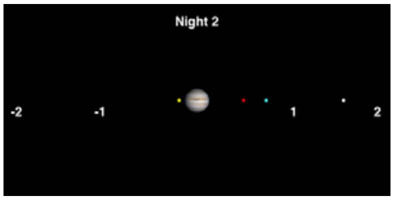


Image 7: Night 2

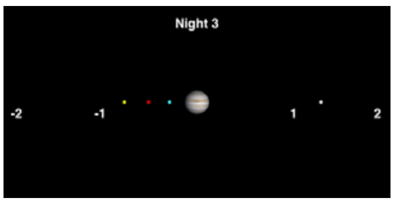


Image 8: Night 3

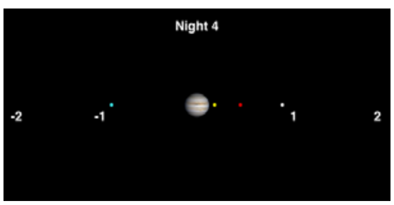


Image 9: Night 4

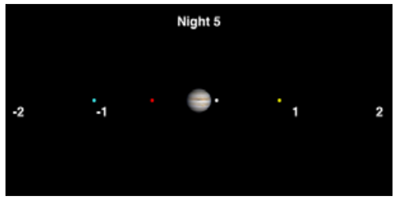


Image 10: Night 5

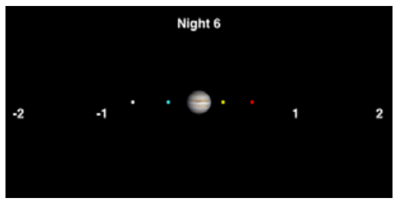


Image 11: Night 6

Image 12: Night 7

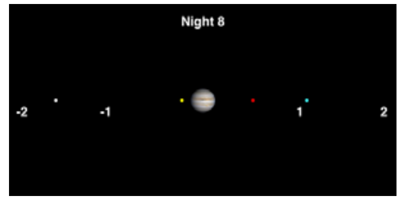


Image 13: Night 8

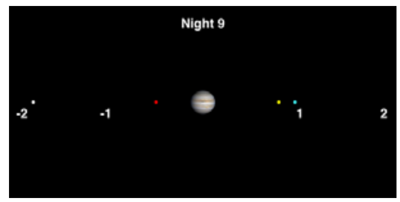


Image 14: Night 9

By now, you can see why Galileo concluded that his odd "stars" must really be moons.

> ***How can you tell they are moons, not stars? [They move back and forth, "around" Jupiter.]***

A moon orbits a planet. These moons seem to move back and forth in a straight line because we see their orbits from the side. If we could see Jupiter from above its North Pole, we would see these moons go around Jupiter.

> ***How could you tell how many days it takes for your moon to orbit Jupiter? [Count how many days it takes to return to its starting position. Be sure to count just the spaces in between the nights to get a correct answer for the number of days gone by.]***

Ask a member of each group to report the orbital period of the moon that s/he tracked.

> ***Can you see any relationship between the farthest distance each moon gets from Jupiter and the time it takes to orbit Jupiter? [The more distant moons go around more slowly.]***

Not all four moons are visible all the time. Sometimes one or more moons are in front of or behind Jupiter and cannot be seen.

Tour of Moons

We are not completely satisfied to look at moons in our solar system through telescopes. Let's take a spaceship ride to some of the planets in our solar system to get close-up views of their moons. While this is an imaginary spaceship ride, we will view real images transmitted to Earth by Viking and Voyager spacecraft. Please fasten your (imaginary) seatbelts while we prepare to lift-off.

Start rocket launch sound effect at countdown. At ignition, start blue daylight and orange covelights alternating in intensity. Turn on stars. Start diurnal motion and gradually accelerate while rocket noise gets louder. As rocket noise subsides, gradually bring diurnal motion to zero and dim daylight and covelights to off.

Before we leave the neighborhood of Earth, let's get a super view of our own Moon.

Image 15: Moon Close-up. (Point out mountains, craters, maria.) ►

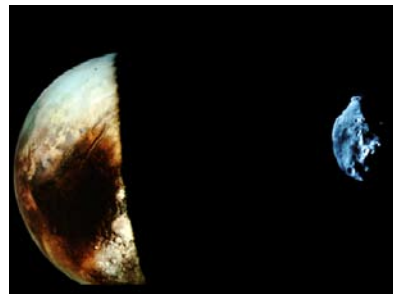
Image 16: Crater (Clementine image of Tycho).▼

Discuss what craters are and how they are formed. See references for latest info on Clementine, Lunar Prospector, and later missions. There is evidence of water ice in polar regions of the Moon!

If it's moons we want to see, there is no point in traveling to the two planets, Mercury and Venus, that are closer to the Sun than Earth. They have no moons at all. Let's journey outward in the solar system towards Mars.

Turn on diurnal and music for journey to Mars. Stop diurnal and lower music on arrival at Mars.

Image 17: Mars and Phobos. ►



Note the shapes of the illuminated parts of Mars and its moon Phobos.

> ***Can you explain those shapes? [Quarter phase.] From which direction is the sun shining?***

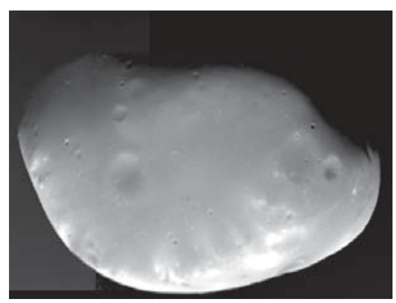
Have an audience member indicate with battery light pointer.

Phobos is only about 15 miles (10 km) long. It is very small compared to earth's moon which is 2000 miles (3200 km) across. If you want to play baseball, but can't find anyone to play, you could still have a good game on Phobos. The gravity on Phobos is so weak that if you stood on its surface, you could throw a baseball into orbit or beyond (just like superman on Earth). So, you could pitch the ball in one direction, then pick up your bat and wait for the ball to come at you from the other direction.

Image 18: Phobos (Zoom close-up view). ►

Mars may have a small moon compared to earth's moon, but it has an extra moon just for good measure. This moon Deimos is only a bit smaller than Phobos.

Image 19: Deimos. ►



Let's head on to the next planet out in the solar system.

> ***Anyone know which planet that is? [Jupiter.]***

Diurnal and music up for cruise to Jupiter.

Let's see those four moons we tracked before. They each have unique markings and geology.

Image 20: Jupiter and Moons. ►

The Galileo spacecraft arrived at Jupiter on December 7, 1995. Galileo's atmospheric probe plunged into Jupiter's atmosphere and relayed information on the structure and composition of the solar system's largest planet, while the Galileo orbiter studied Jupiter and its moons, encountering one moon during each orbit.

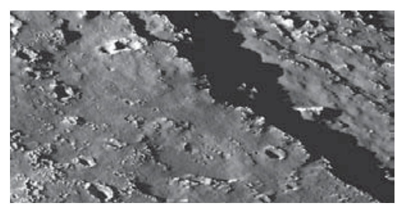
***Optional**

Show image of Jupiter's Ring (file name mss20optJupiterMainRing.png).

Image 21: Global Callisto in Color (NASA Galileo mission). ►

Callisto (the "white moon" we tracked) is pockmarked with ancient craters, easily visible as bright scars on the darker surfaces. In fact, Callisto is the most heavily cratered object in the solar system. The crust of this moon shows remnant rings of enormous impact craters. The largest craters have apparently been erased by the flow of the icy crust over geologic time. The brighter craters seen here are thought to be mainly ice.

Image 22: Callisto Scarp Mosaic (NASA Galileo mission). ►



In this close-up, we can see lots of craters, and a very steep slope—or scarp—crossing the image. This scarp is just a small part of a much larger multi-ringed crater structure 4,000 kilometers (2,485 miles) in diameter.

Image 23: Global Ganymede in Color (NASA Galileo mission). ►

Ganymede (the "blue moon" we tracked) has frosty polar caps as well as two other types of terrains: bright, grooved terrain and older, dark furrowed areas. The two types of terrain suggest to us that Ganymede's entire icy crust has been under tension from global tectonic processes. Ganymede is the largest moon in the solar system—5,276 kilometers (3,280 miles) in diameter.

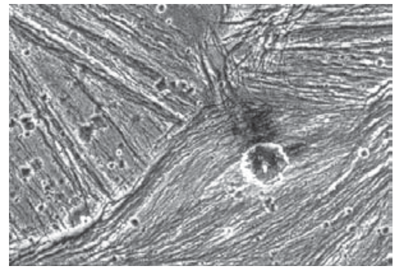


Image 24: Ganymede—Mixture of Terrains (NASA Galileo mission). ►

The image shows fine details of one of the brighter areas of Ganymede, and reveals a mixture of terrain. One part is older and heavily cratered; one part is younger with line-like structures and an impact crater. Seeing terrain like this side-by-side allow scientists to work out the complex geology of Ganymede.

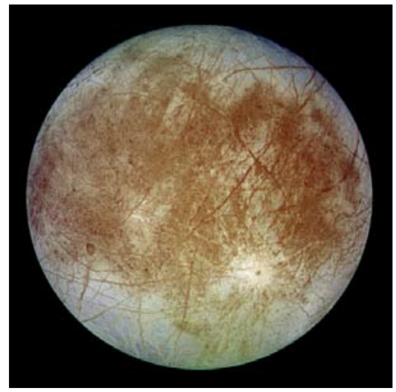


Image 25: Global Europa in Color (NASA Galileo mission). ►

Europa (the "yellow moon" we tracked) is one of the smoothest moons in the solar system, and only slightly smaller than Earth's Moon. With Europa's surface temperature of -260° F, it is completely covered in ice. The lines we see here are cracks in that ice. We expected to find quartz-hard ice like on Ganymede, but we find evidence that slush or even liquid water is beneath the moon's surface. The warmth from a tidal tug of war with Jupiter and neighboring moons could be keeping large parts of Europa a liquid ocean.

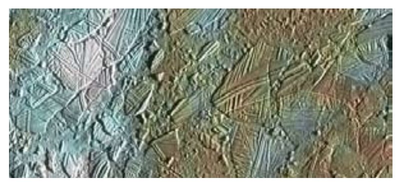


Image 26: Europa—Ice Rafting View (NASA Galileo mission). ►

Large plates of ice seem to be sliding over a warm interior on Europa, much like Earth's continental plates move around on our planet's partly molten interior. Some recent images show features that have many similarities to new crust formed at mid-ocean ridges on the Earth's sea floor.

Europa may be slushy just beneath the icy crust. There are chunky textured surfaces like icebergs, an area littered with fractured and rotated blocks of crust, and gaps where new icy crust seems to have formed between continent-sized plates of ice. Rough and swirly material between the fractured chunks may have been suspended in slush that froze at the very low surface temperatures. Studies of craters on Europa show that they are relatively young and that subsurface ice is warm enough to collapse and fill them in time periods that are short, geologically speaking.

The combination of interior heat, liquid water, and organic material falling onto

Europa from comets and meteorites means that Europa has the key ingredients for life, making this moon a laboratory for the study of conditions that might have led to the formation of life in the solar system.

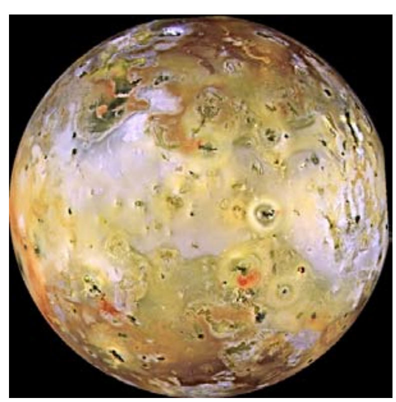


Image 27: Global Io in Color (NASA Galileo mission). ►

Io (the "red moon" that we tracked) is the closest Galilean moon to Jupiter and is slightly larger than Earth's Moon. It is quite a startling contrast to other moons we have seen. Most of the craters seen here were not created by impacts, but by volcanoes!

Image 28: Active Volcanic Plumes on Io (NASA Galileo mission). ►

It is the most volcanically active body in the solar system, sizzling with dozens of molten sulfur and silicate volcanoes. Most bodies in the solar system do not have radical surface changes that are noticeable over short periods of time. But several such changes have been observed on Io between the times of the Voyager spacecraft visits to Jupiter in 1979, when no fewer than nine simultaneously erupting volcanoes were seen, and the Galileo mission of 1989-2003. The extreme volcanic activity is caused by Jupiter's gravity generating 100 meter (330 ft) high tides in its otherwise solid surface. In this color enhanced image, deposits of sulfur dioxide frost appear in white and grey hues, while yellowish and brownish hues are probably due to other sulfurous materials.

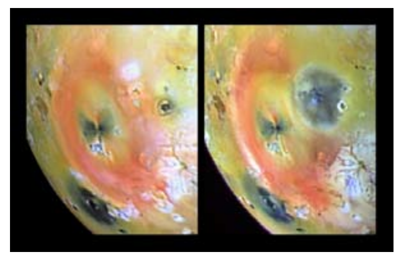


Image 29: Arizona-sized Io Eruption (NASA Galileo mission). ►

The image on the left shows a before picture of a region of Io. The image on the right was taken when the Galileo probe returned some time later, and a new dark spot is visible. This appears to be from a plume that rose 120 kilometers (75 miles) high and then deposited the material in an area about 400 kilometers (250 miles) in diameter—roughly the size of Arizona!

Bright red materials, such as the prominent ring surrounding the volcano named Pele, and black or dark gray spots with low brightness mark areas of recent volcanic activity and are associated with high temperatures and surface changes.

Io acts as an electrical generator as it moves through Jupiter's magnetic field, developing 400,000 volts across its diameter and generating an electric current of 3 million amperes that flows along the magnetic field to the planet's ionosphere.

The Galileo mission was supposed to end December, 1997, but the spacecraft was in excellent shape so its duties were extended to include eight more encounters with Europa (Dec, 1997–Feb 1, 1999) and two more encounters with Io on Oct 11, 1999 and Nov 26, 1999. The extra Europa encounters were aimed at possibly confirming that an ocean presently exists on Europa, and locating some areas where the ice is thinnest. This would lead the way to possible future Europa orbiting or ice drilling missions looking into a key question for the 21st century—is there life on Europa?

Let's move on to the next planet out in the solar system, the most beautiful one for many people: Saturn.

Optional

Movie 29a. Time lapse movie showing Jupiter rotating. It is constructed from dozens of images that the Voyager spacecraft transmitted to Earth during the Voyager's encounter with Jupiter. Jupiter actually rotates about once every 10 hours. If you watch carefully, you can see three moons whiz by.

Image 30: Saturn. ►

Saturn has at least 60 known moons orbiting at distances ranging from 134,000 kilometers to 13 million kilometers (84,000 miles to 8 million miles) from Saturn. The planet itself is not as colorful as Jupiter. It does have a similar banded appearance, but the zones are not as obvious, perhaps because they are partly obscured by higher layers of atmosphere.

Image 31: Saturn Close-up (NASA Cassini mission). ►

Here we see the delicate rings casting shadows on the gas giant. Saturn's colors gradually change from gold to bluish as you move towards its north pole, but scientists don't fully understand why. It may be a seasonal effect, resulting from the cold winter temperatures.

Image 32: Mimas (NASA Cassini mission). ►

Image 33: Iapetus (NASA Cassini mission). ►

This is Iapetus, one of the outermost moons of Saturn. From your knowledge of phases, which direction is the sunlight coming from in this image?

Use pointer to indicate various directions as you poll the audience.

This is actually a trick question because the position of the Sun when this image was made would have been behind us. We would thus expect to see Iapetus in a full phase. This and other images made of Iapetus indicate that one side of it has really dark material on it. The dark side happens to be the leading side of Iapetus with respect to its orbital motion. That's another puzzle for the planetary geologists, as yet unexplained.

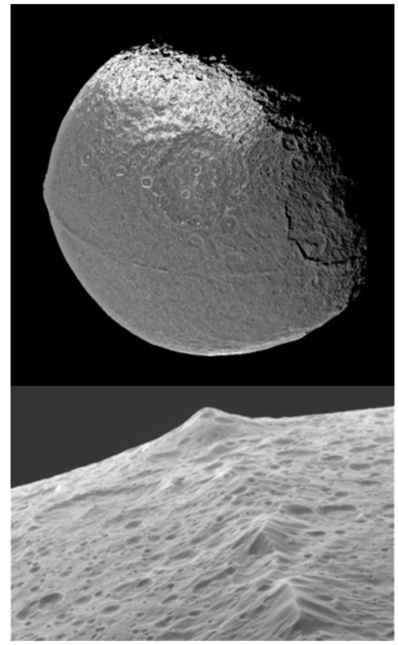


Image 34: Ridge on Iapetus (NASA Cassini mission). ►

Iapetus also has a remarkable ridge that runs around almost the entire moon, closely following its equator. The peak of the ridge reaches over 10 kilometers (6 miles) in height. Where the ridge came from is still unknown. It could have formed from internal material oozing thorough a crack on the surface, or perhaps an ancient ring that once encircled Iapetus crashed onto its surface.

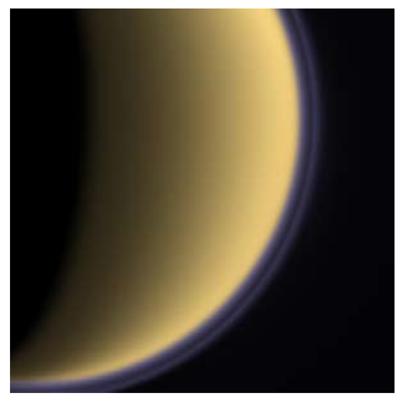


Image 35: Titan (NASA Cassini mission). ►

Titan is almost as large as Jupiter's moons Ganymede and Callisto. But unlike those moons, Titan is able to retain an atmosphere. It can hold an atmosphere because it is in a colder part of the solar system. Any gases near Ganymede or Callisto would be warm enough and energetic enough to escape the gravity of those moons. Titan's cold atmosphere is mostly nitrogen, but is thickly laden with various hydrocarbons that some of the Voyager scientists have jokingly compared with Los Angeles smog. The atmosphere is so thick and opaque that until recently we were denied images of the surface of Titan. Measured temperatures are just about cold enough that pools of liquid ammonia, liquid methane, or liquid nitrogen could exist on the surface.

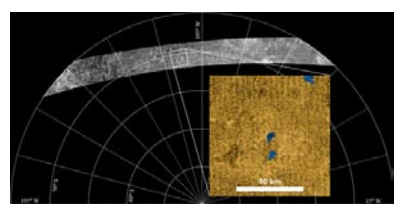
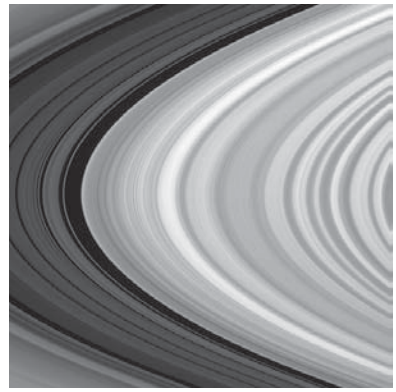


Image 36: Lakes on Titan (NASA Cassini mission). ►

The Cassini spacecraft arrived at Saturn in June 2004 and still is operating [as of January 2008]

As part of the Cassini mission, we got our first detailed data from Titan and its surface. In January 2005, the European Space Agency's Huygens probe drifted through the atmosphere for three hours before touching down on the surface. However, Cassini visited Titan multiple times, taking radar images of the surface. The north pole of Titan has been confirmed to have giant lakes and seas, with at least one larger than Lake Superior. These lakes seem to form from liquid methane and ethane that rains down on this extraordinary moon where the temperature is 94°K (-179°C, -290°F). Images also showed rocks or ice blocks and possible methane or ethane ground fog on surface, clouds, and drainage channels.



There are still many mysteries about Saturn—how did the system of Saturn's satellites form? How are they continuing to evolve? What is the relationship between the icy satellites and the rings of Saturn?

Image 37: Saturn's Rings (NASA Cassini mission). ►

Through the best Earth telescopes, Saturn appears to have only four rings. But as our spacecraft approaches, we see they are made of dozens, indeed hundreds of narrow "ringlets." The rings of Saturn are made of particles of ice, dust and rock. The particles range in size from a grain of sand to something larger than this planetarium. They are all orbiting Saturn as if they were each a tiny "moonlet."

Images (Movies).
37a: Animation of Rings.
37b: Shepherd Moons.

Optional

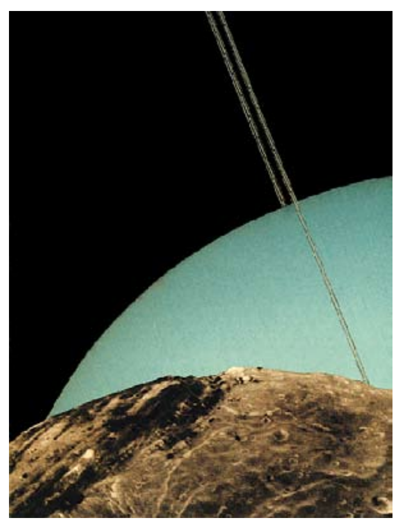
Movie 37a: a time-lapse movie from Voyager made the same way as the one we saw from the Voyager-Jupiter encounter. The dark regions that you see moving around are referred to as "spokes" in the rings and present a great mystery because they seem to contradict laws of orbital mechanics. In the theory of orbital mechanics, particles closer to Saturn should take less time to go around in their orbits than the particles that are closer to the edge of the rings, just as we observed Io to take only 2 days to go around Jupiter while Callisto took 18 days to orbit. Since the spokes go around with the same orbital period for the inner rings as the outer ones, we have a serious dilemma. As yet, there is no theory to explain how the spokes can exist. Yet the spokes exist!

Optional

Movie 37b: Small moonlets have been observed orbiting just along the edges of certain rings. A theory has emerged that these moonlets, by means of their gravity, sweep ring particles inwards or outwards (depending on whether the moonlet is at the inner or outer edge of a ring) and keep the edge of the ring well defined. The moonlets have been dubbed "shepherd moons" and if it weren't for them (if the theory is correct), there would be no well defined boundaries between ringlets as we see in our Voyager images.

Now it is time to move on to Uranus. Voyager encountered Uranus on January 26, 1986. Here is an accelerated version of what you might have seen if you had been on board. This is a computer generated simulation of the encounter.

Image 38a: Uranus Encounter (animation—NASA Voyager 2 mission).
Image 38: Uranus Collage (NASA Voyager 2 mission). ►



This is a collage of Uranus and its ring system as if you were standing on Uranus' moon Miranda. Uranus has a paltry ring system compared with that of Saturn; only ten thin rings were seen. Notice the deep canyon and impact craters in the icy surface of Miranda. (Miranda and Uranus in this slide are Voyager 2 images, while the rings are artist's conception. The apparent blue color of Uranus is its true color and is a result of the absorption of red light by methane in Uranus' atmosphere, leaving primarily blue light to reflect back.)

Here is a great image of Miranda which is about 300 miles diameter (484 km.).

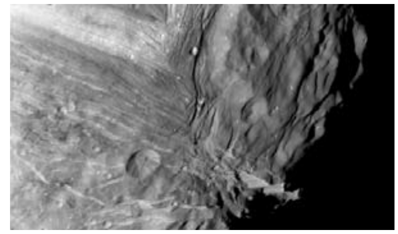


Image 39: Miranda, Cliffs 10-15 kilometers (6-9 miles) high (NASA Voyager 2 mission). ►

Note how strikingly clear and detailed these images are. Voyager also detected 10 new moons, bringing the total number of Uranian moons to 15 at that time (as of 2003, we count 27 moons). Remember that these images were transmitted across more than a billion miles of space by a spacecraft that had already endured encounters with Jupiter and Saturn in its 9-year odyssey through the solar system. (Voyager was launched in 1977.)

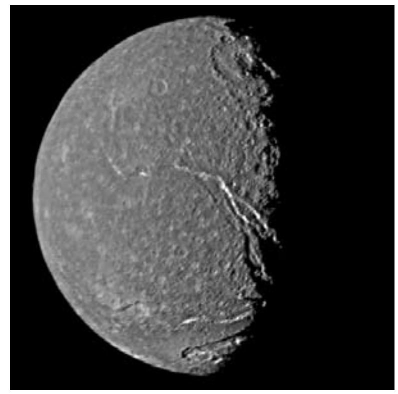


Image 40: Titania (NASA Voyager 2 mission). ►

Five large moons of Uranus were known before the Voyager 2 encounter. In order of increasing size they are Miranda across, Ariel, Umbriel, Titania and Oberon. Titania is one of the largest, about 1,600 kilometers (1,000 miles) in diameter, roughly half the size of Earth's Moon. Titania, for example, is marked by huge fault systems and canyons that indicate some degree of geologic activity in its history. These features may be the result of tectonic movement in its crust.

Voyager has survived its Uranus encounter in which it performed beyond our wildest dreams. It went past Neptune in an encounter in August of 1989.

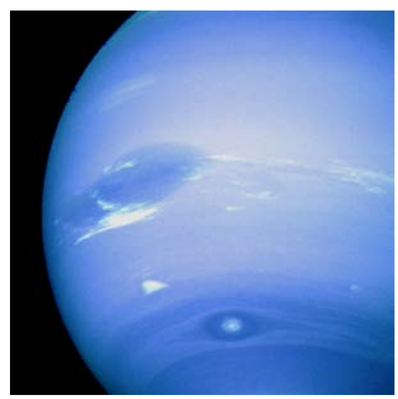


Image 41a: Neptune Encounter (animation)
Image 41: Neptune (NASA Voyager 2 mission). ►

Voyager 2, a senior citizen spacecraft having spent 12 years of rigorous journey through space with three spectacularly successful encounters under its belt, performed superbly in its encounter with Neptune. It allowed us to discover 6 new Neptunian moons, bringing the total number for Neptune to 8 at that time. As of 20083, we know of 13 moons.

Image 42: Triton (NASA Voyager 2 mission). ►

Voyager 2 sent us spectacular images of the huge moon Triton, revealing ice volcanoes. Voyager 2, its primary mission complete, is now on its way to exit the solar system, never to return.

As exciting as the Voyager images are, we must not forget about important discoveries made by astronomers with earth-based telescopes.

Observations obtained by NASA's Hubble Space Telescope and ground-based instruments reveal that Triton seems to have heated up significantly since the Voyager spacecraft visited it in—it has been undergoing a period of global warming. The warming trend is causing part of Triton's frozen nitrogen surface to turn into gas, thus making its thin atmosphere denser. Even with the warming, no one is likely to plan a summer vacation on Triton, even though its temperature has risen about three degrees to a whopping -389 degrees Fahrenheit. If Earth experienced a similar change in global temperature over a comparable period, it could lead to significant climatic changes.

By studying the changes on Triton, the scientists hope to gain new insight into Earth's more complicated environment.

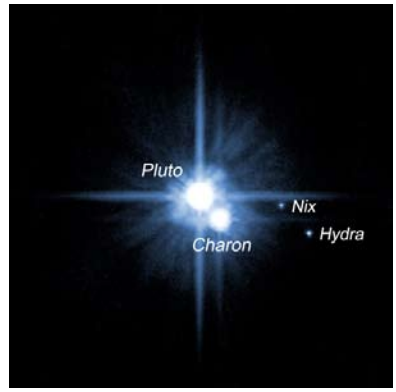


Image 43: Pluto. ►

Pluto, dwarf planet beyond Neptune, was found to have a large satellite companion in 1978 with the aid of an Earth-based telescope. This satellite was given the name Charon (in Greek & Roman mythology, the boatman that carried souls across the river Styx to the underworld, in which the god Pluto reigned). In 2005, astronomers discovered two more companions to Pluto, and named them Nix (goddess of the night and mother of Charon) and Hydra (a nine-headed serpent, whose kept its den at the entrance of Hades, where Pluto lived). These tiny companions were discovered with the Hubble Space Telescope.

We land you now back at __________________ Planetarium [insert your home planetarium here]. We hope you enjoyed your tour of the moons of the solar system. You are invited to come back to the our planetarium sometime to see our other planetarium shows.

Image 44: Your Planetarium or School.

Optional

Show image of Ida and Dactyl (file name mss44optIda.png), asteroid with moon and explain that August 28, 1993 Galileo spacecraft, on its way to Jupiter, came within 2,400 km (1,500 mi) of 243 Ida, the second asteroid ever encountered by a spacecraft. Ida is about 56 x 24 x 21 km (35 x 15 x 13 mi) in size, Dactyl is the first natural satellite of an asteroid ever discovered and photographed. It is about 1.2 by 1.4 by 1.6 km (0.75 by 0.87 by 1 mi) across.

Discover More About Moons of the Solar System

Worldwide Web Connections

Updated information may be found at http://www.lawrencehallofscience.org/pass

Books

J. Kelly Beatty (Editor), Carolyn Collins Petersen (Editor), and Andrew L. Chaikin (Editor), The New Solar System. Cambridge University Press, Sky Publishing, 1999. A superb series of review articles by noted scientists. Thorough, though somewhat technical. Excellent photos.

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Notes

The issues of *Astronomy* and *Sky & Telescope* published during the late fall and early winter of 1989-90 cover the Voyager 2 Neptune encounter in detail.

See also Planetarium Activities for Student Success, Volume 3, *Resources for Teaching Astronomy and Space Science*, section on the solar system.

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PASS Moons of the Solar System Illustrations

p.4, Alan Gould, Sun Simulator diagram

p.8, Alan Gould, Tracking Jupiter's Moons Chart

p.16, LHS, Tracking Jupiter's Moons

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