AEROSPACE PALACE ACADEMY, NIGERIA
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LESSON 90: JUNO AT JUPITER

After the Sun, the planet Jupiter is the largest object in the Solar System. Spacecraft have visited Jupiter before: the Pioneer and Voyager missions flew past the planet and the Galileo mission orbited it for fourteen years, and three other missions flew past on their way to another destination. Following these earlier missions and building on their successes—and learning from their data—was the Juno mission. Orbiting above Jupiter's poles, it has gathered information about that planet in unprecedented detail for the last three years.

Next Generation Science Standards (NGSS):

- Discipline: Space Systems
- Crosscutting Concept: Patterns
- Science & Engineering Practice: Analyzing and Interpreting Data

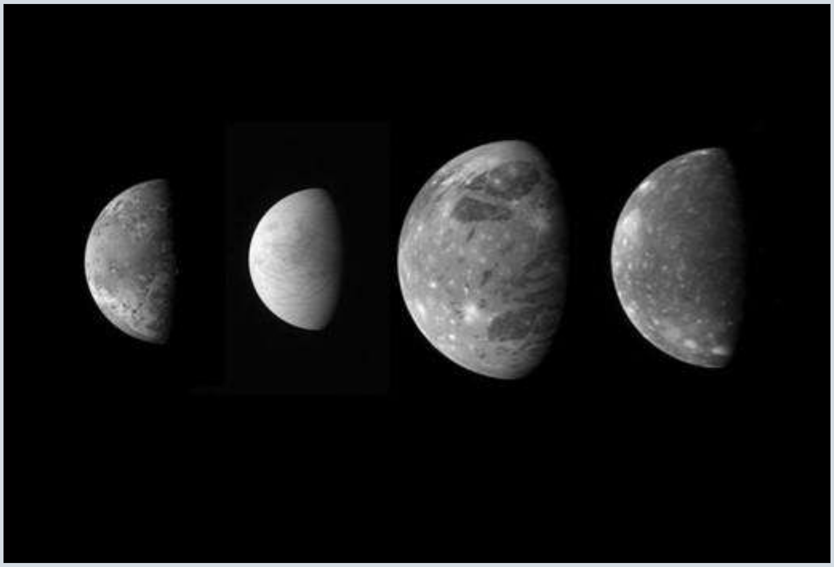
GRADES K-2

1-ESS1-1. Use observations of the sun, moon, and stars to describe patterns that can be predicted.

As the largest planet in the solar system, Jupiter can be seen from Earth without a telescope, so humans have been aware of it since time immemorial. We cannot speak of anybody "discovering" the planet in terms of seeing it for the first time, but the Italian astronomer Galileo Galilei was the first person to see it as anything except a dot of light in the sky. He observed its disk and its four largest moons in 1610 using a telescope he had constructed. He originally thought the moons were faint stars until he observed them further and saw that they followed Jupiter in the sky, appearing sometimes on one side of the planet and at other times on the other side of the planet.

Galileo named the moons "the Medicean planets," after the powerful Medici family, and numbered them I, II, III, and IV. The names they bear today were given by another astronomer, Simon Marius, who had been observing Jupiter around that same time. He credited Johannes Kepler with suggesting the names—Io, Callisto, Europa, and Ganymede—after mythical figures admired by the god Jupiter. Since that time 75 more moons have been discovered, although 23 are still awaiting their official names. NASA has further information about all the moons, including an image gallery.

Grades K-2 (continued)

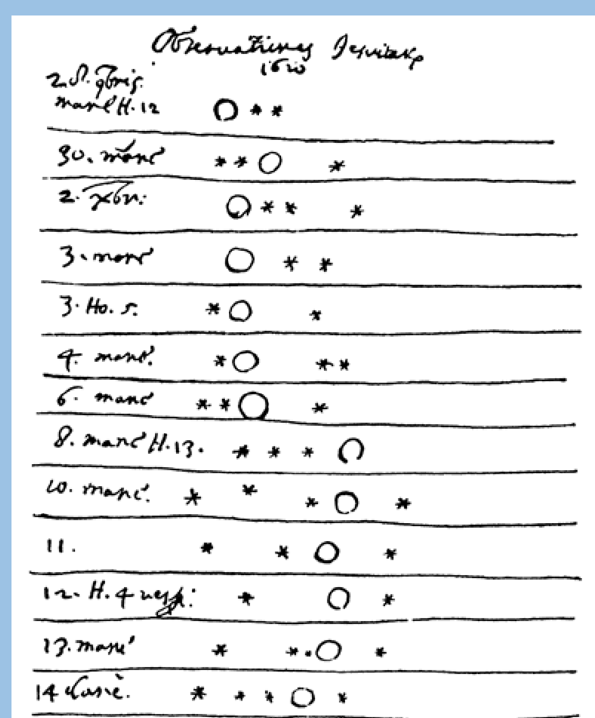


In the intervening centuries, scientists have taken closer and closer looks at the planet Jupiter and its moons. The most recent observer of that planet is the NASA spacecraft Juno, which was launched in August 2011 and arrived at Jupiter on July 4, 2016. It has been there ever since, taking photographs of Jupiter and its moons and making other measurements.

One thing that Juno has been able to do that previous spacecraft—not to mention Earth-bound observers—could do is to fly over Jupiter's poles. This has allowed it to take detailed photographs of the poles that scientists could not see before.

Grades 3-5

5-ESS1-2. Represent data in graphical displays to reveal patterns of daily changes in length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.



Our pictures—first drawings and then photographs—of the planet Jupiter have improved through the centuries as our ability to see the planet has improved. The astronomer Galileo recorded his first drawings of Jupiter and its moons in his notebook. Although he first thought they were faint stars, their movements on the following nights proved to him that they must actually be orbiting the planet and could not be fixed stars like the other stars in the sky.

Grades 3-5 (continued)

Ernie Wright has created a computer animation that shows the movements as recorded in Galileo's notes. You can see as they move through their orbits how sometimes three are visible and at other times all four are visible.

In the centuries since Galileo's first sketches, telescopes have gotten much better and photography was invented. Astronomers now take photographs of Jupiter and its moons through their telescopes. With modern equipment and image processing techniques, people can take quite good photographs of that planet.

The geometry of the Solar System limits the angles from which Earth-based can see Jupiter. Because the Earth stays much closer to the Sun than Jupiter is, Jupiter always appears either completely lit like a full moon or else quite close to full. Space probes that travel to Jupiter, on the other hand, can take pictures of Jupiter from any angle. The flight paths of space probes can be programmed to fly over the polar regions, past the moons, or through other areas of interest. Images from probes are also much clearer since they do not have the interference from the Earth's atmosphere. As successive spacecraft have visited Jupiter, they have sent back better and better pictures of that planet as the imaging technology has improved and as the orbits of the probes have been adjusted.

The first spacecraft to fly past Jupiter were NASA's Pioneer 10 and Pioneer 11 probes. "Launched on March 2, 1972, Pioneer 10 was the first spacecraft to pass through the asteroid belt and the first to make direct observations and obtain close-up images of Jupiter. During the passage by Jupiter, Pioneer 10 also charted Jupiter's intense radiation belts, located the planet's magnetic field, and established that Jupiter is predominantly a liquid planet. … During its flyby of Jupiter on 2 December 1974, Pioneer 11 obtained dramatic images of the Great Red Spot, made the first observation of the immense polar regions, and determined the mass of Jupiter's moon, Callisto.” The two pictures of Jupiter shown below were taken by Pioneer 10 and Pioneer 11 respectively. Notice that the “phase” of Jupiter is not close to

GRADES 3-5 (CONTINUED)

being “full”; the spacecraft were off toward the side of the planet relative to the direction toward the Sun. More pictures by Jupiter from the Pioneer missions can be found here.

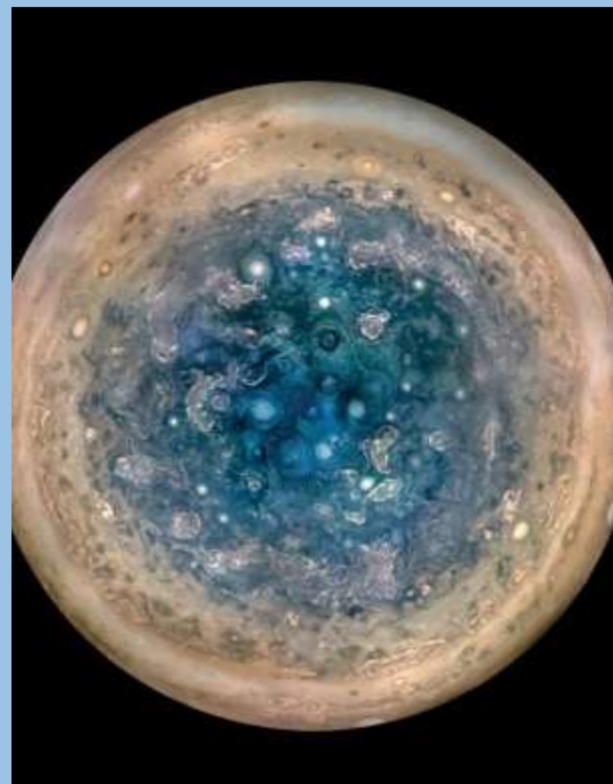
b. *Pioneer 11*, December 1974

The next spacecraft to visit Jupiter were the Voyagers in the 1970s. As they approached Jupiter, they sent back much more detailed pictures. The picture shown at the right was the first one to show the general public a view of Jupiter's moons as worlds in their own right as opposed to simply dots of light in the sky. Your writer remembers the excitement of seeing this picture for the first time, looking at the moons suspended in the void, and also noticing the intricate filigree of the whorls of Jupiter's storms in the background. Suddenly the markings on Jupiter were not just splotches of color, they were clouds that moved around on Jupiter, showing the presence of violent windstorms. You can see the motion of Jupiter's clouds relative to the Great Red Spot between the two pictures below.

GRADES 3-5 (CONTINUED)

The next great improvement in photographing Jupiter was the arrival of the Galileo spacecraft. Because it went into orbit around that planet rather than simply flying by, it could visit the same place more than once and see what had changed between visits. Its controllers could also adjust its orbit to send it past Jupiter's moons, taking close-up pictures of them. Breathtaking though Galileo craft's pictures were, though, they could have been better; the spacecraft's high-gain antenna, which was to transmit most of its data back to Earth, jammed when it was being opened while the spacecraft was following its circuitous path from Earth to Jupiter. Engineers were able to devise several strategies to work around this problem, though, and most of the mission data was transmitted home for scientists to analyze.

On July 4, 2016, the Juno spacecraft went into orbit around Jupiter. Previous missions had been fly-by missions or, in the case of Galileo, a more-or-less equatorial orbit. Juno went into a polar orbit, meaning that its orbit took it over the north and south poles of Jupiter. It was able to look directly down on the planet's poles, photographing them and giving scientists a much clearer picture of what is happening there. They found auroras, much as the Earth has but more powerful, a giant cyclone near Jupiter's north pole, and wall-to-wall storms in the polar region itself. The picture to the right shows a view of Jupiter's south polar region as it would appear if it were all sunlit at the same time; the picture was assembled from pictures taken during three different orbits of Juno.



On its final approach to Jupiter, Juno captured images of the four Galilean moons as they orbited the planet, as can be seen in this time-lapse movie or this longer version.

Grades 6-8

MS-ESS1-2. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.

The Juno mission to Jupiter built on earlier missions to Jupiter. When NASA explores a planet, they usually follow a sequence of mission types starting with flyby missions, continuing with orbiters, and continuing further with special types of landers such as rovers, subsurface probes, and gliders. The missions to Jupiter follow this pattern. First there were the Pioneer and the Voyager flyby missions. (A few other missions have flown past Jupiter on their way elsewhere, but although they gave valuable data they were not really Jupiter exploration missions.) Then came the Galileo orbiter, which explored Jupiter, its moons, and its environment for eight years. Juno has orbited Jupiter for three years now and is planned to gather data for two more years, although if the spacecraft is still working well that mission will most likely be extended. (It has already been extended once from the original plan.) At some point, though, when the Juno spacecraft has almost run out of fuel (it uses little bits of fuel every now and then to adjust its orbit), it will be sent down into Jupiter to end its mission.

A space probe on a scientific mission also needs to have its science experiments selected and designed. There is not a magic "measure everything" device that scientists can put on it. The instruments that the scientists put on the spacecraft dictate what it can and cannot measure. For example, the Juno mission includes a Gravity Science experiment which uses its radio transmissions home to measure precisely what its speed toward or away from the Earth is. These short-term, minuscule variations in its orbit allow scientists to map out the details of Jupiter's gravity field and derive the distribution of its mass deep underneath its cloud layers. Another experiment on board Juno is a three-dimensional magnetometer, which measures the strength and direction Jupiter's magnetic field throughout Juno's orbit, helping scientists to develop a more complete map of this magnetic field. The Galileo mission did not have these experiments.

Juno's mission profile also built on lessons learned from earlier missions. The first spacecraft to fly past Jupiter discovered that the planet has very strong magnetic fields and radiation belts, much like the Earth's Van Allen belt but more so. The radiation in these belts can make electronics stop working. The Galileo spacecraft was designed with hardened electronics to help it resist the effects of the radiation and its orbit was designed to stay far enough away from Jupiter to avoid the worst of the radiation. Unfortunately, this also meant that it stayed too far from Jupiter to be able to take very detailed pictures or

GRADES 6-8 (CONTINUED)

make measurements from close up to the planet. Juno, on the other hand, is swooping down to within about 3,000 miles of Jupiter's cloud tops. To get this close, it was put into a very elliptical polar orbit. It spends most of its time out far away from Jupiter and its radiation belts. Then in each orbit, it comes down over Jupiter's North Pole, underneath the belts, and then out over Jupiter's South Pole. The radiation belts are concentrated near Jupiter's equator so Juno manages to miss the worst of them. It is also moving very quickly when it is closer to Jupiter so it does not spend much time in the high-radiation zones.

NASA has a "Juno-Quest" game that your students may enjoy playing.

GRADES 9-12

HS-ESS1-4. Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.

A space mission does not happen in a vacuum, figuratively speaking (pun acknowledged though not intended). It is the result of years, sometimes decades, of planning. The spacecraft must be designed and built; the rocket to launch it must be built; the facilities to launch the rocket must be built. After launch, radio antennas are needed to keep in communication with the spacecraft, to send up commands and receive data. And for all the data to be useful, somebody needs to analyze it and use it to confirm current scientific thinking or develop new science.

The Juno mission was first selected for development in June 2005. Before this, there had been considerations that "we need to send another spacecraft to Jupiter," but this was the start of the definite Juno mission. It took six years to design the spacecraft and the mission, figure out what rocket would launch it to Jupiter, and get everything built.

Designing the mission was not an easy thing. Simply getting to Jupiter involved sending the spacecraft into a trajectory that brought it back to pass by the Earth, getting a boost in speed so that it could make it all the way out to Jupiter. In addition, the science experiments needed to be selected, designed, and built. Scientists needed to figure out what they wanted to measure, how they were going to measure it, how they were going to get the data back to Earth, and how they were going to interpret the data once they received

GRADES 9-12 (CONTINUED)

it. The experiments needed electricity, so designers needed to figure out how to generate the electricity and wire it through the spacecraft to the experiments. Taking advantage of advances in solar cells, the Juno spacecraft is the first mission to the outer Solar System that uses these instead of radioactivity or nuclear power to generate electricity. Dissipating electricity generates heat; also, space is extremely cold and the Sun is extremely hot. The mission designers needed to figure out how to keep the experiments (not to mention the rest of the spacecraft) from overheating and from freezing. For the Juno mission, they used a combination of radiating louvers, insulating blankets, and (for the parts of the trajectory in the inner Solar System) the main radio antenna as a sun shade.

Once a spacecraft has moved away from the Earth, communicating with it is an issue. To handle this, NASA has developed the Deep Space Network, or DSN, which consists of three stations located around the Earth. One station is located in Spain, near Madrid; a second is at Goldstone near Barstow, California; and the third is near Canberra, Australia. The three sites were chosen in part because they are about 120 degrees in longitude apart; as the Earth turns and one antenna rotates away from a spacecraft (the spacecraft sets below the horizon as seen from the antenna), an antenna from another site sees it high in the sky and can take over communications. Each site has four large radio dish antennas, each of which can communicate with a different spacecraft. Interested people can see which antenna is communicating with what deep space mission at any given time.

The Juno mission uses the large 70-meter-diameter antennas at the three DSN sites. The larger the antenna, the fainter the signal it can detect; or, for a stronger signal, the faster the rate of data it can receive. Apart from the data that each science experiment sends back, the spacecraft sends telemetry data letting the mission engineers know how it is doing and how well all its systems are functioning. There is so much data that NASA requires scientists who propose experiments for a spacecraft to include a “data management plan” that describes how much data will be generated and what will be done with it.

Sixty Years Ago in the Space Race:

September 9, 1959: The heat shield to be used on the American Mercury project was successfully tested on the "Big Joe 1" mission.

September 12, 1959: The Soviet Luna 2 spacecraft was launched toward the Moon and hit its target almost three days later.