

Juno's View to Jupiter

After almost 5 years in flight, the space probe is about to meet its planet

By Christopher Crockett

Ancient stargazers chose well when they named the solar system's largest planet, Jupiter, after the king of the Roman gods.

With more than twice the mass of all the other planets combined, Jupiter reigns supreme. It's the most influential member of our planetary family — after the sun. Jupiter might have hurled the asteroids that delivered water to Earth, robbed Mars of planet-building material and nudged Uranus and Neptune to the planetary hinterlands. It's also a massive time capsule, a ball of gas that

records what conditions were like when the planets formed over 4 billion years ago.

And yet, despite over four centuries of intense scrutiny, including visits by eight spacecraft, there's still much that scientists don't know about Jupiter. Thick clouds conceal what goes on deep within the planet.

NASA's Juno spacecraft, set to arrive at the giant world on July 4, is about to break through the haze.

"We're going to see beneath the cloud tops for the very first time," says Scott Bolton, a planetary scientist at the Southwest Research Institute in San Antonio and head of the Juno mission. "We don't know what the inside of Jupiter is like at all."

Juno gets its name from Jupiter's wife, a goddess who peered through a veil of clouds and saw the deity's true nature. Launched on August 5, 2011, the probe has traveled about 2.8 billion kilometers to spend 20 months orbiting

Onboard instruments On July 4, NASA's Juno spacecraft arrives at Jupiter to begin a 20-month investigation of what lies beneath the planet's thick clouds.

1. Solar panels Juno's solar panels are the largest flown on an interplanetary spacecraft; at Jupiter's distance from the sun, probes normally use a nuclear power source to generate electricity.

2. Titanium vault Most of Juno's scientific instruments sit inside a 200-kilogram titanium vault, which will protect the electronics during repeated dives through harsh radiation belts that encircle the planet.

3. Radio link Juno's radio link to Earth doubles as a scientific experiment. Doppler shifts in the radio waves will show how the spacecraft accelerates in response to Jupiter's gravity, revealing how mass is spread out within the planet.

4. Magnetometers As Juno cartwheels through space, magnetometers on the end of a 4-meter-long boom will measure Jupiter's magnetic field, which is probably generated by metallic fluid hydrogen swirling deep beneath the clouds.

and scrutinizing the gas giant. If all goes well, Juno will measure how much water lurks beneath the clouds, map Jupiter's interior and deliver humankind's first good look at the planet's polar regions.

Jupiter is no stranger to robotic explorers, but most have come and gone quickly. Many probes use Jupiter's gravity to pick up speed on their way to the outer solar system. Even the Ulysses spacecraft, which was headed toward the sun, went the long way around, using Jupiter in 1992 to get thrown over the poles of the sun. When possible, the probes do some scientific sightseeing while passing by (see Page 32).

Galileo, which reached Jupiter in 1995, was the only spacecraft to orbit the planet. But a few technical difficulties — a malfunctioning antenna and a broken tape recorder — forced Galileo to spend most of its time observing the four largest of

Jupiter's 67 moons rather than the planet itself.

"There's been a crying need to go back to Jupiter and actually study Jupiter," says Jonathan Lunine, a planetary scientist at Cornell University.

Planet of extremes

Jupiter is extreme in every way. "I often think of it as a planet on steroids," Bolton says. If Jupiter were a hollow shell, about 1,000 Earths could squeeze inside. Despite its size, it's the fastest spinning planet in the solar system: One day lasts just under 10 hours. In its turbulent atmosphere, storms come and go, although at least one has raged for centuries. Its famous Great Red Spot, a storm more than twice as wide as Earth, has churned for at least 150 years. Temperatures near the Jovian core may exceed 20,000° Celsius — more than three times as hot as the surface of the sun. And even though it's made predominantly of the lightweight elements hydrogen and helium, Jupiter is 318 times as massive as Earth. The weight of all that gas generates pressures near the center that are millions of times greater than anything people experience.

At Earth's surface, the atmosphere pushes against every square inch with 14.7 pounds of force. "That's like having four people standing on your shoulders," says Fran Bagenal, a planetary scientist at the University of Colorado Boulder. You don't feel it because you're used to it.

At Jupiter, pressure at the cloud tops would feel comfortable. But as you fell — and you would keep falling because there's no surface to stand on — you'd plummet to crushing pressures. To imagine it, replace the four shoulder-balancing people with a thousand elephants, Bagenal says, "and the bottom elephant is standing on one heel."

Much of what scientists know about Jupiter comes from gazing at its clouds with telescopes and spacecraft; the interior is left mostly to speculation. There might be a solid core, a seed from which the planet grew — or there might not. There might be an ocean of metallic fluid hydrogen swirling around that core, a gargantuan electrical conductor that generates Jupiter's far-reaching magnetic field. There might be abundant stores of water vapor beneath the clouds.

Mission timeline

- **August 5, 2011**
Launch
- **August–September 2012**
Deep space maneuvers
- **October 2013**
Earth flyby gravity assist
- **July 2016**
Arrival at Jupiter
- **For 20 months**
Juno will orbit Jupiter 37 times
- **February 2018**
End of mission (plunge into Jupiter)

Jupiter by the numbers

Mass

318 x Earth

Volume

1,321 x Earth

Length of day

9.9 hours

Length of year

11.9 Earth years

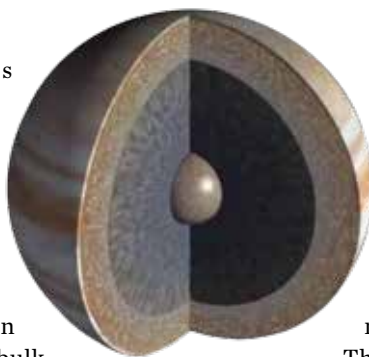
Number of moons

67

Those are the mysteries that Juno will investigate. They address how Jupiter works today and how the planet first came together 4.6 billion years ago.

Researchers think that when Jupiter formed, it hoovered up all the gas within reach. That gas is what the bulk of Jupiter is made of—samples of the material that swirled around the infant sun, now stored in a planet-sized warehouse. Measuring the water abundance of that gas could tell researchers where the planet formed and what the environment was like in the solar system's early days.

"Water plays a key role in the formation of the planet," Bagenal says. Far from the sun's heat, temperatures were cold enough for water to freeze and provide lots of the solid particles from which giant planets could grow. Jupiter might have started as a ball of rock and water ice several times as massive as Earth that then pulled in all the nearby hydrogen and helium to make a giant planet.



A layered planet Jupiter might have a core of rock and ice that sits below a layer of metallic fluid hydrogen (dark gray). Hydrogen and helium gas (brown) might sit atop the liquid hydrogen, just below the clouds. Or the core might not be solid at all.

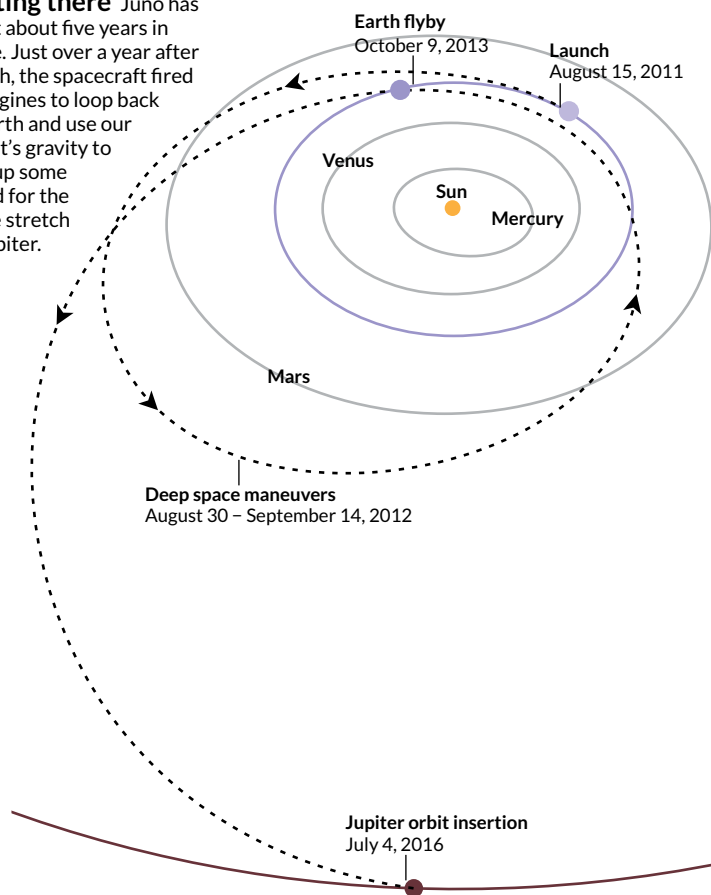
"Until we measure the water, we really don't know," Bagenal says.

The Galileo spacecraft tried to figure out how much water is in Jupiter's atmosphere. As it sidled up to the planet, Galileo sent a probe into the atmosphere that measured temperatures, pressures and chemical abundances. The probe worked flawlessly, descending far deeper than researchers had hoped. But it went in at an unlucky place and its water measurement came up dry.

Galileo's probe dropped into what researchers call a "hot spot," a clearing in the clouds where thermal downdrafts drag dry air deep into the atmosphere. "They went into the Sahara desert of Jupiter," Bolton says. The probe stopped transmitting before traveling deep enough to get a realistic measure of Jupiter's water.

NASA scientists thought that they should try again, perhaps with a mission that could drop multiple probes around Jupiter and to much greater depths, Bolton says. "But that's a very expensive and challenging proposition."

Getting there Juno has spent about five years in space. Just over a year after launch, the spacecraft fired its engines to loop back to Earth and use our planet's gravity to pick up some speed for the home stretch to Jupiter.



Deep dives

So Bolton and colleagues came up with another idea, one that would become the Juno mission. Jupiter glows with microwave radiation as it continues to cool from its long-ago formation. And water excels at absorbing specific microwave frequencies. If a ship could orbit Jupiter and measure to what extent those frequencies were being absorbed, researchers could figure out how much H₂O was hiding beneath the clouds. To measure the microwaves, Juno will loop around the planet many times and record the intensity of multiple frequency bands.

But water alone doesn't tell everything about how the planet was born. For the rest of the story, researchers need to know if Jupiter has a solid core.

One theory for how giant planets form is that they start with a seed of rock and ice that attracts a puffy atmosphere. Another idea is that they form when a blob of hydrogen and helium gas collapses under its own weight, skipping the creation of a solid core entirely.

Juno could resolve this debate. As the spacecraft loops around the planet, it will speed up and slow down in response to subtle changes from one spot to another in Jupiter's gravitational pull. By tracking these accelerations, researchers will be able to figure out how mass is distributed deep inside, including whether the mass is concentrated in a core or not.

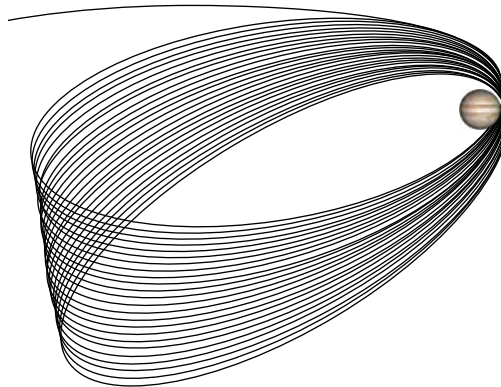
One advantage Juno has over previous spacecraft is its orbit: Juno will circle perpendicular to the equator, flying from pole to pole as it skims the cloud tops. Galileo, by contrast, usually kept its distance from the planet and never strayed far from the equator. Getting in close will allow Juno to make detailed measurements, and the north-to-south flight path lets the spacecraft scan all latitudes and get a global view of the planet's interior. Still, Jupiter doesn't make that easy.

"We're going into a very hazardous region," Bolton says, "probably the most hazardous region in the solar system outside of doing a dive bomb into the sun." Belts of high-energy radiation and charged particles encircle the planet — belts that are not friendly to spacecraft electronics. To survive, Juno's instruments are sealed inside a 200-kilogram titanium vault, speaking to the outside world through heavily shielded cables. "We're like an armored tank going to Jupiter," Bolton says.

That tank carries a camera, spectrometers, magnetometers, plasma and particle detectors, a microwave sensor and a radio antenna. The plan is to repeatedly get in close to the planet and then get far away fast. Once Juno settles into its routine, each orbit will take 14 days. Most of that time will be spent far from the planet, outside the radiation belts. Because of the planet's rotation, each time Juno swoops in, it will scan a different longitude. During those deep dives, the probe will fly just 5,000 kilometers above the cloud tops and gravity will accelerate it to roughly a quarter of a million kilometers per hour, setting a new spacecraft speed record. At that speed, Juno could go from Boston to Los Angeles in one minute.

The poles

In the hours before and after each close brush with the planet, Juno will fly over Jupiter's mysterious north and south poles. "This is terra incognita for planetary scientists," says Leigh Fletcher, a planetary scientist at the University of Leicester in England. Jupiter doesn't have seasons; its axis is almost perpendicular to its orbit. That means



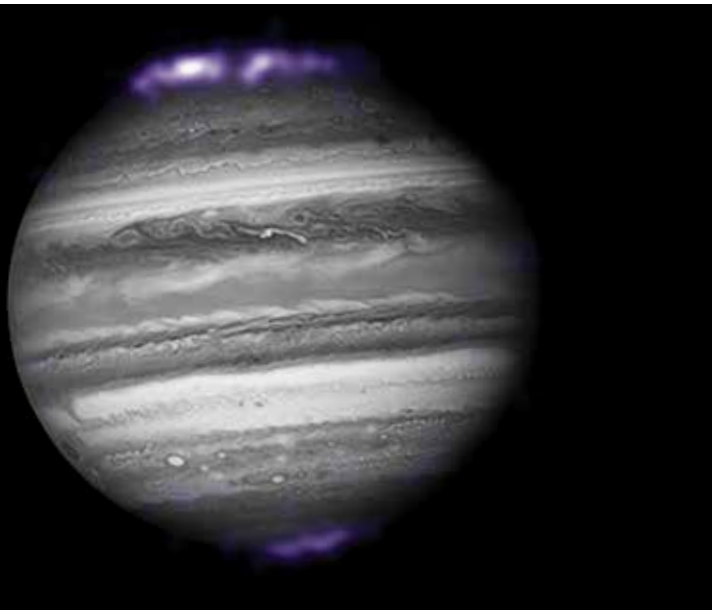
Juno will travel on a series of elongated 14-day orbits. Its trajectory will repeatedly take the craft over Jupiter's poles and keep it away from the radiation belts most of the time.

the poles are practically invisible from Earth. Most other spacecraft have stayed near Jupiter's equator. Pioneer 11 captured a fuzzy parting shot of the north polar region as it departed Jupiter for Saturn. The Ulysses solar probe flew over the poles en route to the sun, but it didn't carry a camera nor did it get as close as Juno will.

At the poles, Juno will give researchers a close look at Jupiter's auroras, the Jovian equivalent of Earth's northern and southern lights. Jupiter's lights are just one of the tools scientists will have for investigating the planet's magnetic field. Most of what researchers already know about the auroras comes from observatories closer to home, such as the Hubble Space Telescope. These dancing ribbons of light are about 1,000 times as powerful as Earth's and are longer than our planet is wide.

If the Cassini spacecraft's visit to Saturn is any indication, there might be surprises waiting at Jupiter's poles. Cassini found hurricane-like vortices swirling around Saturn's poles. "It's like we're looking into a plughole draining down into Saturn," says Fletcher. "We don't know if that's a common

X-rays show Jupiter's auroras (purple) rippling around the planet's poles in this composite image from the Chandra and Hubble space telescopes.





Juno snapped this photo of Earth when it came close for a gravity assist on October 9, 2013.

Point and shoot

Juno is carrying a citizen-science camera. “We’re inviting the public into the room,” says planetary scientist Candice Hansen, who is in charge of the aptly named JunoCam.

Juno’s mission didn’t require pictures. “But we didn’t want to fly to Jupiter without a camera,” says Hansen, of the Planetary Science Institute in Tucson, Ariz. Because JunoCam is an add-on, there is just a skeleton crew working the camera. So Juno’s “team” is the public. Anyone will be able to go online and mark spots on Jupiter they’d like to see photographed (<http://bit.ly/Junocam>).

Jupiter enthusiasts are already uploading images from backyard telescopes to a periodically updated global map that showcases the latest goings-on in Jupiter’s atmosphere. Each time Juno swoops in close, the popular vote will help decide where its camera lens will point. Unfortunately, Juno wasn’t equipped with an extendable arm, so there won’t be any Curiosity-like selfies (SN: 5/2/15, p. 24).

— Christopher Crockett

feature of giant planets or unique to Saturn.”

Excitement as July 4 approaches is tempered by a further wait. Juno’s arrival in July won’t be heralded with new pictures; the instruments will be switched off as the spacecraft whips around the planet and begins its first orbit. Juno’s next close approach — with accompanying snapshots — won’t happen until late August. After two 53-day loops around Jupiter, Juno will settle into its normal routine in November.

As Juno investigates, telescopes around the world and in space will be keeping an eye on Jupiter as well. When the probe buzzes the clouds, it can see only a sliver of the planet at one time. An international observing campaign calls on large observatories in Chile and Hawaii, backyard amateur telescopes and orbiting instruments such as Hubble to see what’s going on in the rest of Jupiter’s atmosphere.

“If you add them all together, you have a much richer and more extensive science return,” Fletcher says. “Everybody is trying to make the most of this moment in time when all eyes are going to be on Jupiter.”

About 1.5 years after its arrival, in February 2018, Juno will plunge to its death in Jupiter’s atmosphere. Galileo’s mission ended the same way in 2003. Scientists don’t want to risk a run-in between Juno and any of the icy moons, such as Europa, which could conceivably harbor life in its buried liquid water ocean. Juno was not sterilized before launch, and if Earth microbes have hitched

a ride, then a crash landing on Europa could contaminate an alien ecosystem.

Europa is the next target for Jupiter-bound missions. A NASA spacecraft is planned for launch in the early 2020s on a mission to repeatedly fly by the ice-encrusted satellite. And the European Space Agency’s Jupiter Icy Moons Explorer, or JUICE, is scheduled to leave Earth in June 2022 (arriving at Jupiter in 2030) to study the potentially habitable Jovian satellites and eventually orbit Ganymede, the largest satellite in the solar system.

Until then, Jupiter is in Juno’s hands. “This is our big generational opportunity to learn something fundamentally new about Jupiter,” Fletcher says.

And the mission’s legacy could extend beyond the giant planet to encompass aspects of the origins of life on Earth. When Galileo’s probe dived into Jupiter, it found that there are more heavy elements such as carbon and nitrogen in its atmosphere than are found in the sun. Those elements are also key ingredients for life.

“The stuff that Jupiter has more of is what we’re made of,” Bolton says. What happened in the early solar system to concentrate life’s building blocks out among the planets? “It’s a profound question,” he says. “I’m not saying we’re going to answer it, but we’re going to get a piece of that puzzle.” ■

“This is our big generational opportunity to learn something fundamentally new about Jupiter.”

LEIGH FLETCHER

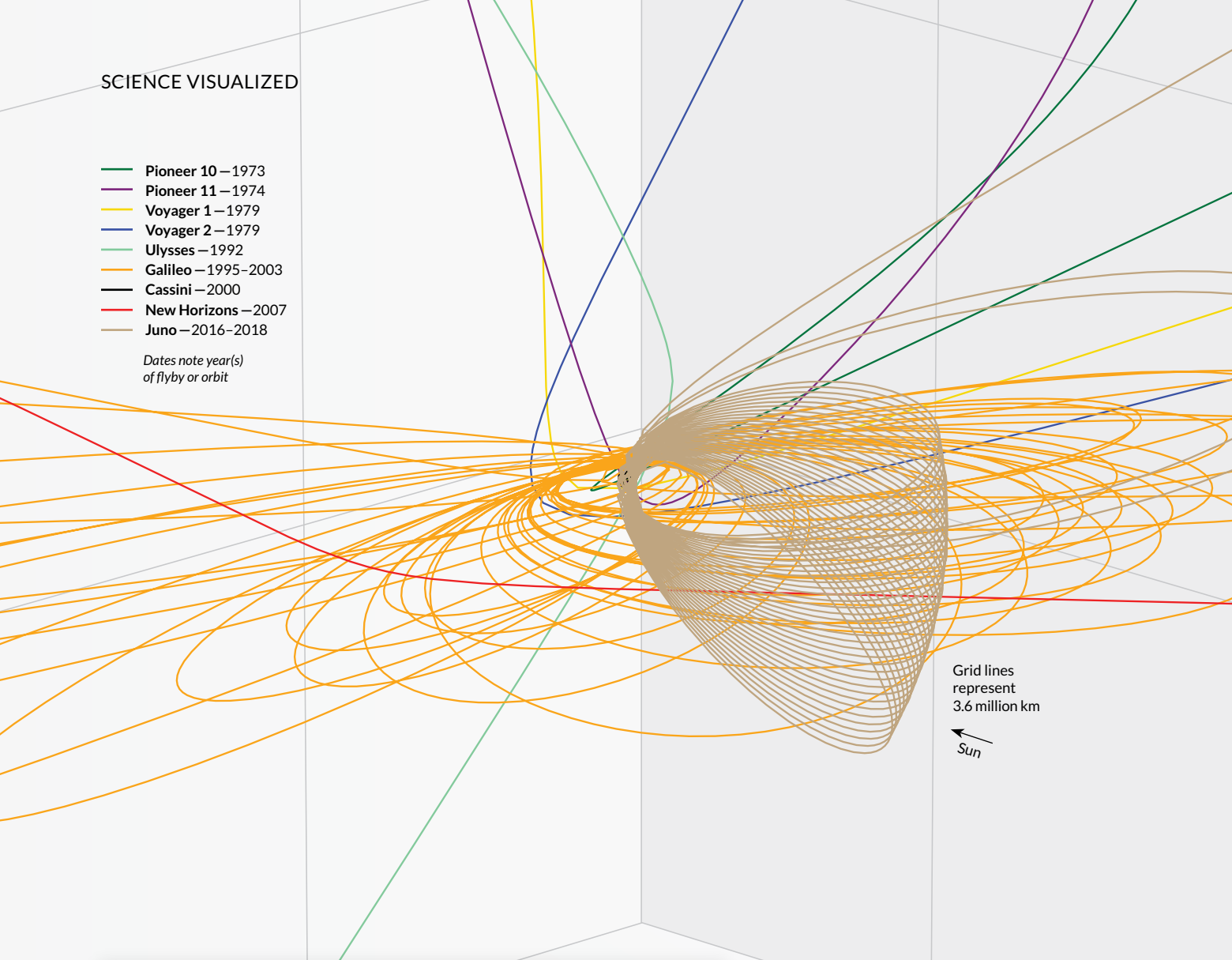
Explore more

■ The Juno mission: www.missionjuno.swri.edu

SCIENCE VISUALIZED

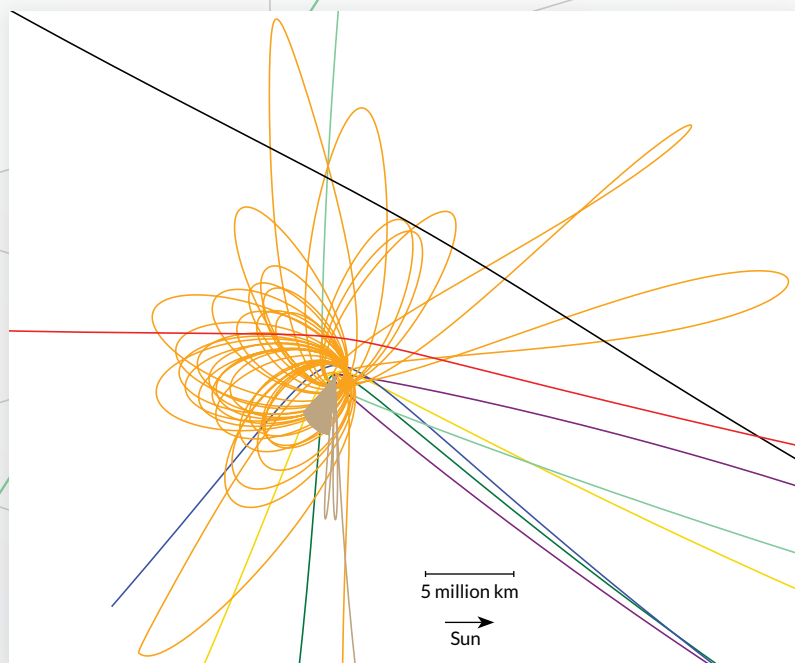
- Pioneer 10—1973
- Pioneer 11—1974
- Voyager 1—1979
- Voyager 2—1979
- Ulysses—1992
- Galileo—1995–2003
- Cassini—2000
- New Horizons—2007
- Juno—2016–2018

Dates note year(s)
of flyby or orbit



Grid lines
represent
3.6 million km

←
Sun



5 million km

→
Sun

Plotting a course around Jupiter

Since 1973, eight spacecraft have flown past or orbited Jupiter. On July 4, NASA's Juno probe will become the planet's ninth visitor (see Page 16). Juno's trajectory is different than all others, as seen in the 3-D plot above. For 20 months, Juno will repeatedly skim the cloud tops, looping over the poles on orbits that are almost perpendicular to Jupiter's equator, as seen at left in a two-dimensional view looking down on the north pole. Most other spacecraft zipped by, using the planet's gravity to speed them along to other destinations. Only Galileo, which arrived in 1995, stuck around; it spent nearly eight years circling Jupiter's equator, repeatedly buzzing the four largest moons. — *Christopher Crockett*

C. CROCKETT, E. OTWELL