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From visions to voyages

Juno to Jupiter: Piercing the veil

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Like its namesake, a goddess who peered through the clouds to discover the truth about the god Jupiter, NASA's Juno spacecraft will seek to answer burning questions about our solar system's largest planet. The probe will gather data that may rewrite the history not just of Jupiter and its formation but of the solar system itself, including our own planet.

Juno to Jupiter

by Leonard David
Contributing writer

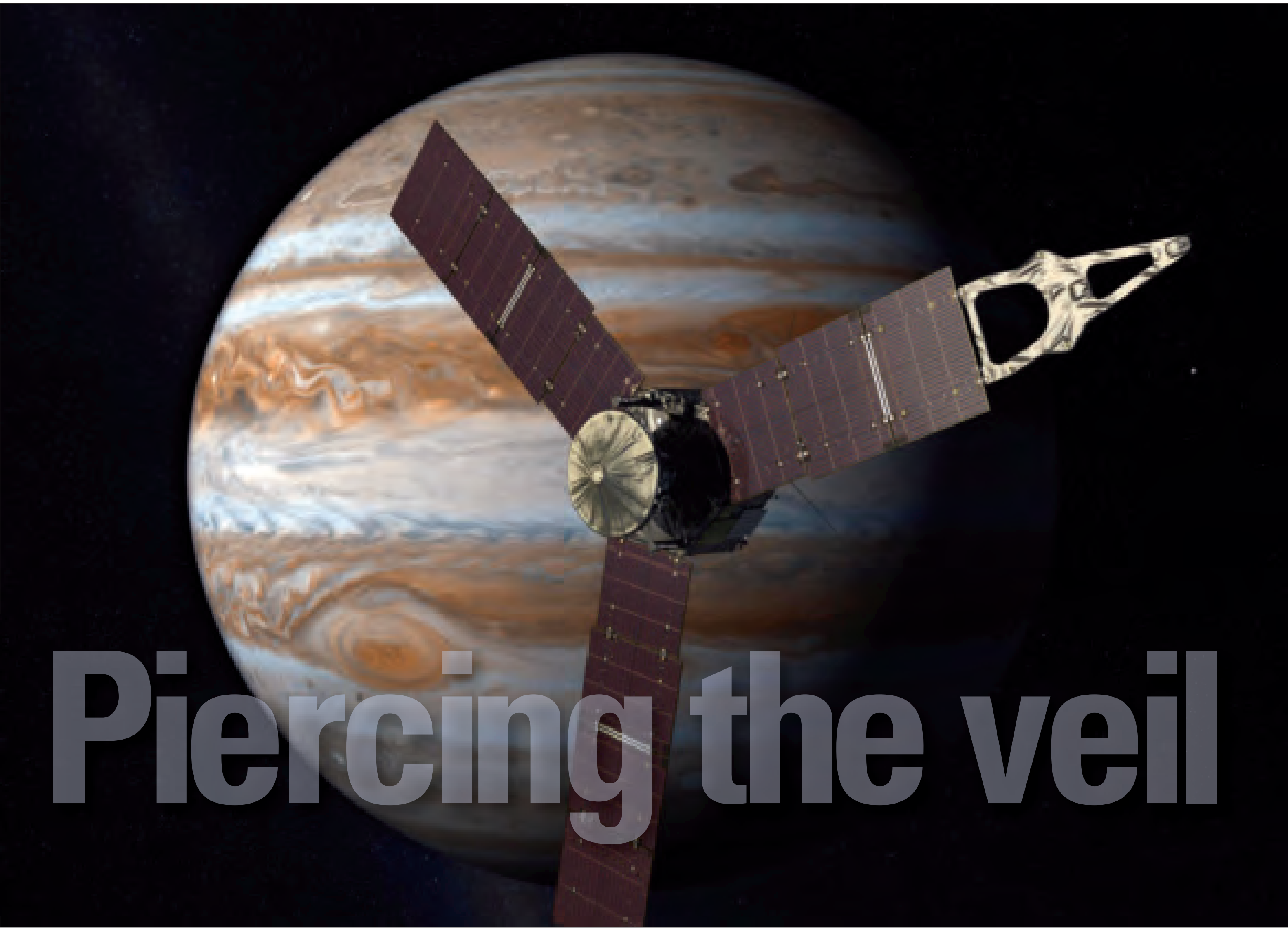
A spacecraft mission to massive Jupiter promises unique insight into the planet's origins, structure, atmosphere, and magnetosphere. But it could also yield findings on the development of our solar system, including the Earth itself.

NASA's solar-powered Juno spacecraft, now ready for an early August sendoff to the giant planet, is built to endure hardware-crippling radiation and brutal thermal conditions. With an orbit five times farther from the Sun than Earth's, Jupiter receives 25 times less sunlight than does our planet.

Juno has a trio of solar wings that give it an overall span of more than 20 m. Its modern solar cells are 50% more efficient and radiation tolerant than the silicon versions that were available for space missions 20 years ago. Spin stabilization will keep the probe pointed toward the Sun, with no need for active control.

Early in the design process, radiation was flagged as one of the top risks to the spacecraft. Juno will avoid Jupiter's highest radiation regions by approaching over the north, dropping to an altitude below the radiation belts, and then exiting over the south. The probe's 11-day elliptical orbit drops under the belts to within 3,000 mi. of Jupiter—closer than any previous spacecraft. Vital to Juno's operation is the placement of sensitive electronics within the first radiation-shielded 'electronics vault'—a titanium chamber whose thickness is optimized for maximum protection.

Juno is the second spacecraft designed under NASA's New Frontiers program, fol-



Juno will explore Jupiter starting in 2016 from an elliptical, polar orbit. Image credit: NASA/JPL.

lowing Pluto New Horizons, a probe now en route to a 2015 flyby of Pluto and its moon Charon. JPL in Pasadena, California, manages Juno's mission; the spacecraft was built by Lockheed Martin Space Systems.

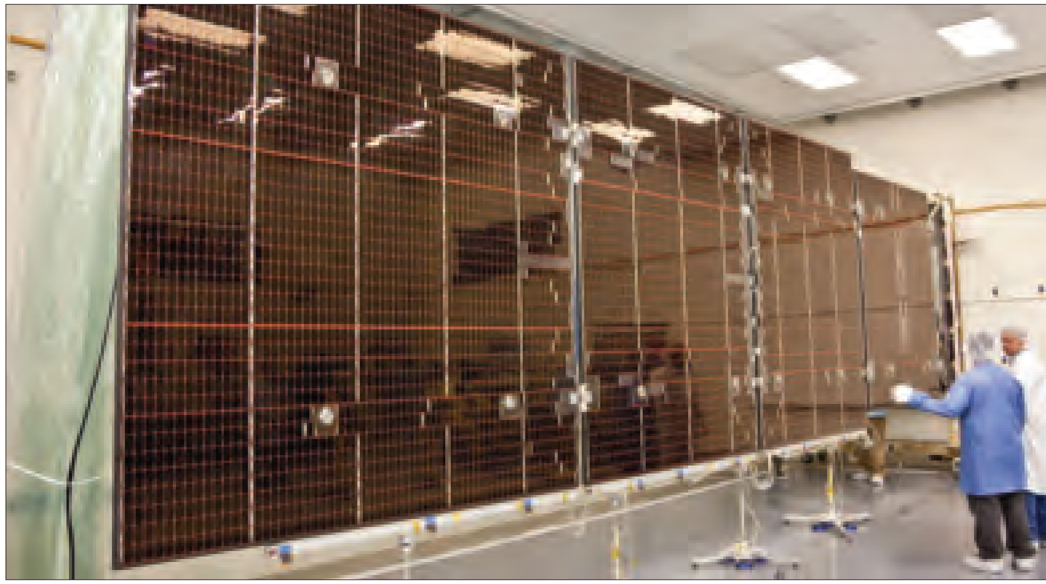
A United Launch Alliance Atlas V will hurl Juno into space from Launch Complex-41 at Cape Canaveral AFS in Florida. The launch window opens August 5 and extends through August 26.

Farthest solar-powered journey

Anyone who visited Lockheed Martin Space Systems while Juno was under construction could see that its elaborate design presented many challenges, particularly given the harsh conditions at Jupiter. The planet has a deadly radiation environment, along with an abundance of charged particles that also charge up the spacecraft. These conditions are much more relentless than those faced by Mars probes, says Tim Gasparrini, Lockheed Martin program manager for Juno. Thanks to the shuttle-launched Galileo spacecraft, which orbited Jupiter from December 1995 to September 2003, "the team has been able to leverage a lot of the experience gained about Jupiter as a place," Gasparrini tells *Aerospace America.*

The electronics of the nuclear-powered Galileo were shielded by special components designed to be radiation resistant. Its mission to Jupiter did not need to survive the harshest radiation regions where Juno will operate.

Without plutonium-fueled radioisotope thermoelectric generators, Juno features some 50 m^2 of solar arrays, meaning it will



Technicians test the deployment of one of the three massive solar arrays that will power NASA's Juno spacecraft. Image credit: NASA/JPL-Caltech/Lockheed Martin.

travel farther than any solar-powered spacecraft ever built, Gasparrini notes. Solar array fabrication was not easy, but the problems encountered early on were eventually solved. "We cherry-picked the solar cells…using thicker cover glasses than you might normally have. On the back of the arrays, there's a patchwork of conductive Kapton to dissipate charged particles."

Juno is equipped with 25 sensors and nine experiments. "So that's a lot of fields of view, and lots of things that you have to keep happy. Everybody wants to look a certain way and do a certain thing and operate at a certain time. And you want to make sure that the interplay of the instruments with the spacecraft isn't taken as science by one of the instruments," he adds.

Vaulting to an outer planet

The radiation belts are shaped like a huge doughnut around the planet's equatorial region and extend out past one of the many Jovian moons, Europa, about 650,000 km beyond the top of Jupiter's clouds.

Gasparrini says Juno's special radiation vault was an early idea. "You had two choices: Either shield the hardware from the radiation, or try and design the hardware to survive the radiation. Trying to go through a design process to screen all those parts to Jupiter's environment was judged

Inside a clean room, technicians installed a special radiation vault onto Juno's propulsion module. The vault has titanium walls to protect the spacecraft's electronic brain and heart from Jupiter's harsh radiation environment. The vault will dramatically slow the aging effect radiation has on the electronics for the duration of the mission. Image credit: NASA/JPL-Caltech/LMSS.

to be much more expensive and invasive into the hardware design," he says.

After lead turned out to be a poor structural metal for the vault, tantalum face sheets with honeycomb were assessed. Tantalum is a rare, hard, blue-gray, lustrous transition metal that is highly resistant to corrosion. It is one of the refractory group of metals widely used as minor components in alloys. While a tantalum sandwich structure offered a lightweight solution for radiation shielding, construction of the vault using the material proved more complicated than machining a piece of titanium.

The vault is not designed to foil every Jovian electron, ion, or proton from striking the system. Rather, it will significantly slow the radiation's aging effects on the electronics for the duration of Juno's explorations.

"For the 15 months Juno orbits Jupiter, the spacecraft will have to withstand the equivalent of more than 100 million dental X-rays," says Bill McAlpine, Juno's radiation control manager at JPL. "In the same way human beings need to protect their organs during an X-ray exam, we have to protect Juno's brain and heart."

The titanium vault is a centralized electronics hub. Parts of Juno's electronics were made from tantalum or tungsten, another radiation-resistant metal. Some assemblies also have their own minivaults for protection. "Virtually all of the spacecraft and instrument avionics are inside the vault," says Gasparrini. Each titanium wall of the vault measures nearly 1 m^2 in area, about 1 cm in thickness, and 18 kg in mass. The vault itself is roughly the size of an SUV's trunk and contains the command and data-handling box, the power and data distribution unit, and some 20 other electronic assemblies. The entire vault weighs about 200 kg.

"Juno is basically an armored tank going to Jupiter," says Scott Bolton, the project's principal investigator, based at Southwest Research Institute (SwRI) in San Antonio, Texas. "Without its protective shield, or radiation vault, Juno's brain would get fried on the very first pass near Jupiter."

Gasparrini says Juno receives roughly half its radiation dose in the first 24-26 orbits of Jupiter. The other half comes during the last eight orbits.

Boa constrictor-like cabling

A close-up look at Juno during its cleanroom assembly reveals a myriad of boa constrictor-like cabling and wiring harnesses that snake in, around, and throughout Juno. Those harnesses are specially treated with copper overwrap, which provides enough radiation shielding that the wires will survive the environment. But all that adds weight, explains Jack Farmerie, Lockheed Martin's lead spacecraft technician on the Juno project.

Farmerie says Juno is a complicated vehicle, not just because of the radiation safeguards but also because it carries so many science instruments. "You have to jam as much as possible, things that typically we would spread out over a whole spacecraft, into the small area of the vault," he tells *Aerospace America*. "Anything we could fit inside the vault, we did. It was definitely the toughest wiring job I've had so far. A huge degree of difficulty."

While there are 'out of the box' items that dot Juno's structure, they have their own built-in shielding. Germanium-coated blankets and conductive Kapton film wraps help offset whatever Jupiter spits at the spacecraft.

Science focus

In October 2013 Juno is to carry out an Earth flyby gravity assist, followed by arrival at Jupiter in July 2016. The 7,992-lb spacecraft carries more than 4,400 lb of propellant for the five-year voyage.

Juno's three large solar panels will be folded into four-hinged segments for launch. Once extended, they will soak up sunlight continuously throughout the mission, except for a few minutes during the

The Juno payload

Juno carries nine instrument suites comprising 26 separate sensors. The Italian Space Agency is contributing an infrared spectrometer instrument and a portion of the radio science experiment.

Gravity science: *X- and Ka-band Doppler gravity measurements will map Jupiter's interior structure (JPL).*

Magnetometer: *Fluxgate magnetometers guided by advanced stellar cameras map Jupiter's interior structure and magnetic dynamo (NASA Goddard and Danish Technical University).*

Microwave radiometer: *Multiple antennas map Jupiter's microwave brightness for deep atmosphere sounding and composition (JPL).*

Jupiter energetic-particle detector instrument: *Particle detectors map electron energy and ion energy/composition over both polar regions (APL/Johns Hopkins University).*

Jovian auroral distributions experiment: *Electron and ion detectors map electron energy and ion energy/composition over both polar regions (Southwest Research Institute).*

Electric and magnetic antennas: *These measure radio and plasma waves in Jupiter's polar magnetosphere (University of Iowa).*

Ultraviolet spectrometer: *This device characterizes spatial, spectral, and temporal auroral structure (Southwest Research Institute).*

Jupiter infrared auroral mapper: *An infrared camera will observe the auroral structure, troposphere structure, and atmospheric sounding (SolexGalileo).*

Junocam: *An education and public outreach visible-light camera provides the first pictures of Jupiter's poles (Malin Space Science Systems).*

Earth flyby. Each solar panel measures 2.6 x 9 m. End to end, the spacecraft and panels cover a circle about 20 m in diameter. Once in orbit at the giant planet, the three arrays will provide about 450 W of electricity. The high-gain antenna is attached to the center of Juno's main hexagonal body.

As a spinning spacecraft, at Jupiter Juno sweeps its instruments' fields of view through space once for each rotation. At three rotations a minute, the fields of view move across Jupiter about 400 times in the 2 hr it takes to fly from pole to pole.

Juno will orbit the immense planet 33 times. To meet planetary protection requirements, specifically to avoid running into any biologically promising Jovian moon, the spacecraft will purposely be aimed to crash into Jupiter in October 2017.

Juno's scientific agenda focuses on four themes:

• Origins: Determine the ratio of oxygen to hydrogen, a clue to the abundance of water on Jupiter. Obtain a better estimate of Jupiter's core mass.

• Interior: Precisely map Jupiter's gravitational and magnetic fields to assess the distribution of mass in its interior, including properties of the planet's structure and dynamics.

• Atmosphere: Map the variation in atmospheric composition, temperature structure, cloud opacity, and dynamics, to depths far greater than 100 bars at all latitudes.

• Magnetosphere: Characterize and explore the 3D structure of Jupiter's polar magnetosphere and its auroras.

Technicians at the Astrotech payload processing facility in Titusville, Florida, complete installation of Juno's high-gain antenna. Photo credit: NASA/Jack Pfaller.

In search of clues

"Juno was conceived by scientists who were very familiar with the hazards of the Jovian environment," says SwRI's Bolton, the lead scientist. "Working with engineers, they were able to put together a concept that simultaneously considered measurement, orbit, and spacecraft requirements that could accomplish our objectives without compromising our goals. The key was having the right people with the right expertise working together right from the start," he tells *Aerospace America*.

He underscores the likelihood not only that Juno will provide answers to the science questions on its agenda but also that these answers will lead to new questions.

"Juno is fully capable of addressing all of our science objectives. The trick is to get the special instruments onboard Juno observing from a very special place—our polar orbit," notes Bolton. "As with all scientific exploration, I expect Juno will allow us to make progress answering our questions and providing the knowledge we need to develop the next set of questions for the next mission. This is the key to learning about the Earth and our solar system origin, to make steady progress with each step—and sometimes we get lucky, with programs like Juno, and get a chance to make a giant leap."

The Juno mission will probe Jupiter's atmosphere for clues to how the largest (and probably oldest) planet in the solar system, and the solar system itself, were formed from a primordial cloud of gas.

"Jupiter contains more matter than all the other planets combined," says Bolton. "By determining how much water is in it, we complete our inventory of the key ingredients that make up Jupiter…to figure out the billion-year-old recipe [for] the first planets in our solar system."

Bolton sees Juno's mission of discovery as conceivably rewriting the books on how Jupiter was born, and possibly even on how our solar system came into being.

Beyond the 'frost line'

Holding a similar view is Juno coinvestigator Fran Bagenal, professor of astrophysical and planetary sciences at the University of Colorado, Boulder. She says that to understand how the solar system formed, scientists need to understand how much oxygen—most commonly found as water—is inside Jupiter.

Did Jupiter collapse from the original

cloud of gas? Or was the planet formed by the gravitational attraction of hydrogen gas onto a core of ice and rock? Or was more ice added later when large leftover ice balls collided with Jupiter? "These different ideas all predict different amounts of water in the outer layers of Jupiter. Unfortunately, scientists have been unable to measure the amount of water at the planet," she says.

Current ideas about the formation of the solar system, Bagenal says, suggest that the Earth was formed at about its present distance from the Sun, where it was too warm for ice to condense. "This means, we think, that Earth formed from balls of rock and metal that condensed out of the original cloud of gas close to the Sun. It means that the water was delivered to the Earth later, after the planet was formed," she says.

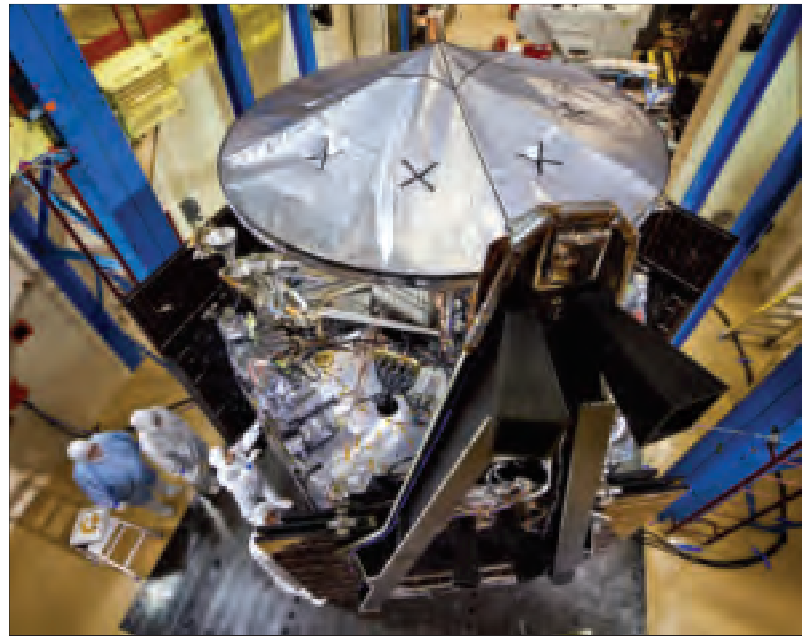
Bagenal says one possible source of Earth's water was a population of large ice balls that condensed out beyond the 'frost line'—likely beyond the asteroid belt. These ice balls were left over from the formation of the cores of Jupiter and the other giant planets. As the largest, most massive planet in the solar system, she adds, Jupiter is thought to have stirred up the leftover ice balls and sent them hurtling to the Earth. Some of them "may have been responsible for the large craters on the Moon. The early phases of the solar system were a dangerous time."

First glimpses

Juno's magnetometers will measure Jupiter's magnetic field with extraordinary precision and supply a detailed picture of what the field looks like, both around the planet and deep within, says NASA Goddard's Jack Connerney. He is the mission's deputy principal investigator and head of the magnetometer team. "This will be the first time we've mapped the magnetic field all around Jupiter…it will be the most complete map of its kind ever obtained about any planet with an active dynamo, except, of course, our Earth," he says.

The spacecraft also totes a color camera that will provide the closest ever images of Jupiter, including the first detailed glimpse of the planet's poles. This hardware, dubbed Junocam, will acquire three-color (red, green, blue) photos of Jupiter during Juno's first seven orbits around the giant planet. The data will be processed and studied by students as part of the Juno Education and Public Outreach program.

Built by Malin Space Science Systems, Junocam is derived from the Mars Science Laboratory's Mars descent imager instrument. The camera images, of approximately 9.3 mi./pixel resolution, will be used by students to create the first color images of the Jovian poles and high-resolution views of the planet's lower latitude cloud belts. After the required seven-orbit design life, Junocam will continue to operate as long as possible in the cruel Jovian environment.



The fully assembled spacecraft went through extensive testing at Lockheed Martin Space Systems near Denver. All three solar array wings can be seen installed and stowed, and the spacecraft's large high-gain antenna is in place on top. Image credit: NASA/JPL-Caltech/LMSS.

Looming line in the sand

Expectations are high that the Juno probe's principal goal of understanding the origin and evolution of Jupiter is attainable. In meeting this objective, Juno is likely to expose other secrets as well, not just about our solar system but also about planetary systems around distant stars.

After an extensive test program, Juno was shipped on April 8 from Lockheed Martin Space Systems, tucked within an environmentally controlled container on an Air Force C-17 Globemaster III. The spacecraft was then transported to Astrotech Space Operations in Titusville, Florida, where it went through final processing.

With the departure date looming, Lockheed Martin's Gasparrini notes, "You have constant tension between mission success and a 21-day launch window. So you're doing everything you can to make sure that the spacecraft operates 100% flawlessly when it gets into orbit....But you have this realization and this reality that you've got 21 days to get it off the planet." A