In This Issue

Planetary Environments, Part 7: Jupiter

by Garry Toth and Don Hillger (Un-manned Satellite Philately)

This is the seventh article in the *Astrofax* series on planetary environments. The first six in the series appeared in the previous six issues of *Astrofax*:

1. *Planetary Environments, Part 1: Introduction* (Volume 31, Issue 2, Summer 2023)
2. *Planetary Environments, Part 2: The Moon* (Volume 31, Issue 3, Fall 2023)
3. *Planetary Environments, Part 3: Mercury* (Volume 31, Issue 4, Winter 2023)
4. *Planetary Environments, Part 4: Venus* (Volume 32, Issue 1, Spring 2024)
5. *Planetary Environments, Part 5: Mars, Part 1* (Volume 32, Issue 2, Summer 2024)
6. *Planetary Environments, Part 6: Mars, Part 2* (Volume 32, Issue 3, Fall 2024)

We now move across the asteroid belt toward the realm of the outer planets (illustrated in the central margin in Fig 1). This article discusses the gas giant Jupiter. Its huge mass is around 2.5 times that of all the other planets combined, but with a rotation period of just 10 hours, it has the shortest day of them all. It is the oldest planet, composed of dust and gases left over from the Sun's formation around 4.5 billion years ago. It orbits at 5.2 au from the Sun, whose light takes around 42 minutes to arrive. It is named for the supreme Roman god Jupiter (Fig 2, with his wife Juno). Jupiter is equivalent to the Greek Zeus.

Figure 1. Niger, Mi1061, 2022

Figure 2. Guinea, BL1472, 2007

Ignoring Earth's Moon, Jupiter is often the second brightest object in the night sky, after Venus. As one of the five "wandering" planets visible to the naked eye, Jupiter was known to ancient peoples such as the Chinese, Babylonians, Egyptians and Greeks. The ancient Chinese astronomers Gan De and Shi Shen predicted an orbital period of 12 years from their visual observations of Jupiter in around 365 BC (the modern value is 11.86 years). That may have been the basis for the creation of the Chinese zodiac with its 12 animals in a 12-year cycle. In it, Jupiter is considered to be a favorable planet and rules the Rat, a fortunate sign, one of luck and money. The first major Islamic work on astronomy, the *Zij al-Sindhind*, was written by Muhammad ibn Musa al Khwarizmi (Fig 3) in 830 AD. It contained tables for the movements of the Sun, the Moon, and the five "wanderers," including Jupiter. In the late 1500s, Tycho Brahe's painstaking visual measurements of heavenly objects led to the most accurate catalogue of the positions of stars and planets up to that time. Galileo's telescope (Fig 4) was a revolutionary tool. With it he observed Jupiter and its four largest moons (the "Galilean" moons). He published his results in March 1610, in his book *Siderius Nuncius* (*The Starry Messenger*). Other natural philosophers quickly took up the new tool.

Figure 3. USSR, Sc5176, 1983

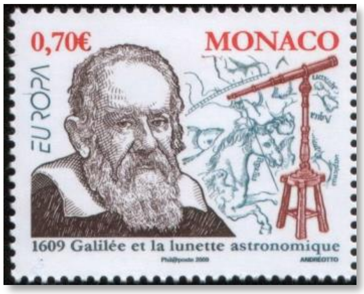


Figure 4. Monaco, Sc2547, 2009

"In the autumn of 1639, the Neapolitan optician Francesco Fontana tested a 22-palm telescope of his own making and discovered the characteristic bands of the planet's atmosphere" (reference). Robert Hooke (Fig 5) in 1664 and Jean-Dominique Cassini (Fig 6) in 1665 observed a so-called "Permanent Spot" on Jupiter, but was it the iconic GRS (Great Red Spot)? Some recent work concludes that it probably was not.

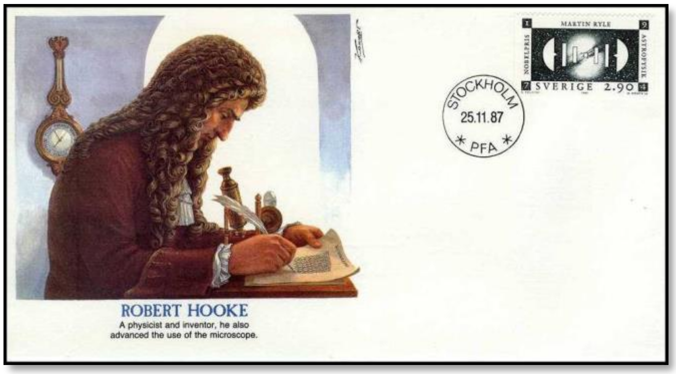


Figure 5. Sweden, Sc1665, FDC, 1987

Figure 6. St. Pierre & Miquelon, Sc378, 1968

In 1711 the Italian artist Donato Creti painted Jupiter with a reddish Spot, but it was only in 1831 that something like it reappeared in the historical record when it was drawn by the German amateur astronomer Heinrich Schwabe (Fig 7). What can be stated with confidence is that the modern GRS has been continuously observed since the American astronomer C. W. Pritchett described it in 1878. He coined the name "Great Red Spot" because of its striking color.

Earth-based telescopic observations of Jupiter continued in the 20th and 21st Centuries. In 1932, the astronomer Rupert Wildt deduced the presence of methane and ammonia in the Jovian atmosphere when he identified their absorption

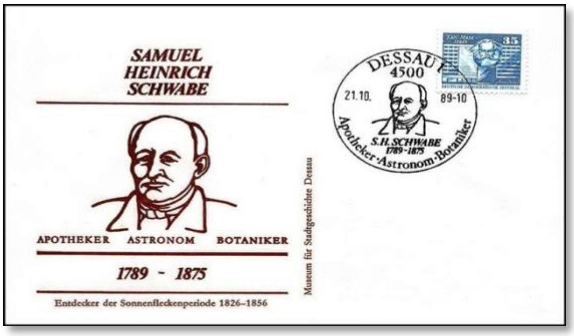


Figure 7. Germany (DDR), Cover, 1989

bands in the planet's spectra. Hydrogen was detected in the same way, but only in 1960 (it is hard to observe spectroscopically). Better instruments have led to better Earth-based observations in recent decades. For example, radio observations with Chile's ALMA (Atacama Large Millimetre/Submillimetre Array) telescopes in 2019 studied ammonia plumes in Jupiter's atmosphere.

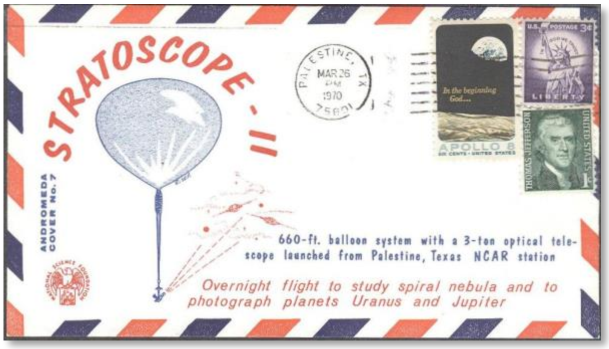


Figure 8. U.S. Stratospheric balloon cover, 1970

Some experiments with balloon-borne telescopes also took place. For example, the Stratospcope-2 mission in 1970 studied spiral nebulae and photographed Uranus and Jupiter (Fig 8).

Space telescopes have become an essential tool for all kinds of astronomical studies, including planetary observations. In the late 1990s the European ISO *(Infrared Space Observatory)* (Fig 9) studied Jovian ammonia. The HST (*Hubble Space Telescope*) has made many observations of Jupiter (Fig 10). One recent series of observations is discussed here. Another image from the HST, from 21 April 2014, is found here. The HST is the key element of OPAL (the Outer Planet Atmospheres Legacy) project, in which the telescope images each of the giant planets – Jupiter, Saturn, Uranus and Neptune – once per year. The HST has "documented striking changes in the planets' atmospheres year over year, including dynamic weather patterns and seasonal variations". Each year, the program turns "Hubble's images into yearly maps of each planet that allow researchers to study the dynamic forces driving the planets' unusual weather patterns" (reference).

Figure 9. Comoro Islands, Sc792, 1992

Figure 10. Antigua & Barbuda, Sc1313, 1999

The JWST (*James Webb Space Telescope*) has recently demonstrated its IR (infrared) prowess in a wide variety of astronomical work, including observations of Jupiter (e.g. Fig 11; information about that image is found here). Observations at many wavelengths provide various types of information. A fine intercomparison of three images is found here: an IR image from the NIRI (Near-Infrared Imager) at Hawaii's Gemini telescope, and visible and UV (ultraviolet) images from the HST. A similar intercomparison is found here. Yet another, with 6 images, is presented in pages 42-43 of Ref. 1.

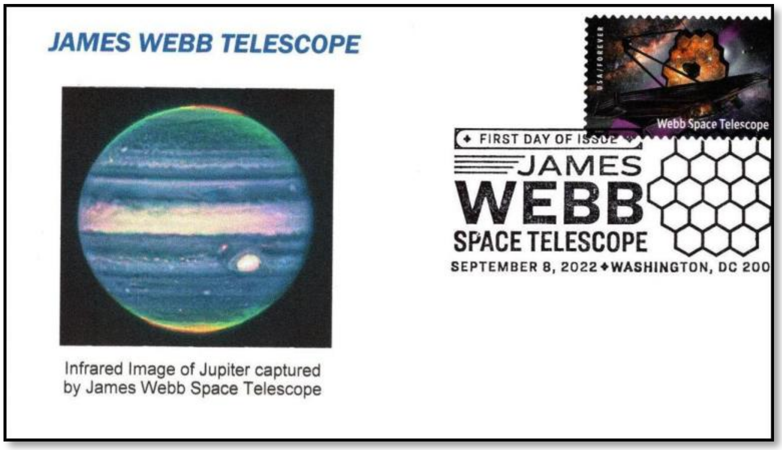


Figure 11. U.S., Sc5720, 2022, FDC with Jupiter images

NASA's SOFIA (*Stratospheric Observatory for Infrared Astronomy*), a Boeing 747SP modified to carry a large telescope, has studied Jupiter's atmospheric circulations. Jupiter is so far away, though, that in-situ observations are necessary for detailed information. Seven spacecraft have done flybys, two have gone into orbit, and three more are en route, for a total of 12. Wikipedia has a summary of those missions. Some details about each are found here. Jupiter itself is emphasized in what follows; its Galilean moons will be discussed in the next article in this series.

Figure 12. U.S., Sc3189i, 1999

Pioneer-10 (Fig 12) blazed the trail: it was launched (Fig 13) on 2 March 1972 and became the first spacecraft to move through the asteroid belt, to brave the wildly intense Jovian radiation, and to attempt (and succeed!) a gravity-assisted "slingshot" around the planet. On 3 December 1973, it flew by at 132,000 km above the cloud tops. It returned the first closeup images of the planet along with observations of its magnetic and radiation fields, and measured the average cloud top temperature at around -123 °C. Before the mission, helium was believed to be present in the atmosphere, and that was proved by *Pioneer-10's* measurements (Ref. 2, p. 94). Perhaps its most important result, though, relates to Jupiter's heat balance. Earth-based observations had shown that Jupiter probably emits more energy than it receives from the Sun (on Earth, the two are in a close balance). The IR measurements made by *Pioneer-10* showed that Jupiter emits around 2.3 times as much energy as it receives from the Sun (Ref. 2, p100). Where does the excess come from? The planet must have its own internal heat, which moves outward from the core in some fashion. However, "the rapid rotation and the flow of internal energy outwards makes the weather patterns very different from Earth's" (Ref. 2, p. 94).

Figure 13. Togo, ScC227, 1994

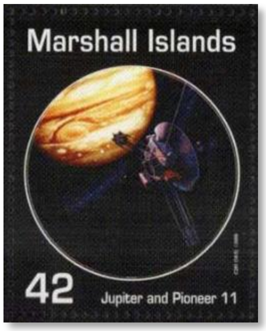


Figure 14. Marshall Islands, Sc930e, 2008

Pioneer-11 (Fig 14) followed a year after its twin. On 2 Dec 1974 it flew by at only 42,500 km above the cloud tops. It sent back detailed images of the GRS as well as the first images of Jupiter's polar regions, and then used a gravity assist to slingshot toward Saturn. Furthermore, "*Pioneer-11* repeatedly crossed Jupiter's bow shock, indicating that the Jovian magnetosphere changes its boundaries as it is buffeted by the solar wind" (reference).
It was deduced from the *Pioneer* observations of Jupiter's density distribution that "the planet is largely liquid; it has no concentrations of mass and [therefore] no detectable crust or solid surface … Somewhere around 970 km below the cloud tops, where the pressure is high enough for the hydrogen to become a liquid, it is unlikely that there is a transition surface similar to the surface of an ocean. Rather, there is most probably a gradual change though a mixture of gas and liquid" (Ref. 2, p 94). Something roughly like the upper, less-dense layer has more recently been called a "meteorological layer" (e.g. see here).

"The Voyager mission was designed to take advantage of a rare geometric arrangement of the outer planets in the late 1970s and the 1980s. This layout of Jupiter, Saturn, Uranus and Neptune, which occurs about every 175 years, allows a spacecraft on a particular flight path to swing from one planet to the next without the need for large onboard propulsion systems. The flyby of each planet bends the spacecraft's flight path and increases its velocity enough to deliver it to the next destination. Using this 'gravity assist' technique, the flight time to Neptune can be reduced from 30 years to 12 years" (Ref. 3).

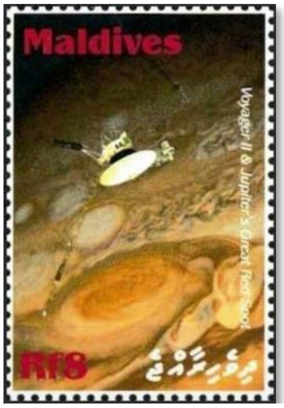


Figure 15. Maldive Islands, Sc2956d, 2008

The twins *Voyager-1* and *-2* were launched in September and August 1977, respectively. Fig 1, for the "45th anniversary of the launch of *Voyager-1*," depicts the launch in its stamps and the two spacecraft with the outer planets in its central margin. Fig 15 shows *Voyager-2* above the GRS. Their closest approaches to Jupiter took place in 1979 (5 March for *Voyager-1*, at 207,000 km above the cloud tops, and 9 July for *Voyager-2*, at 570,000 km). They beamed back thousands of images of both the planet and its moons. A marvelous black and white animation of *Voyager-1* images taken during a period of one month when it was approaching Jupiter clearly shows active latitudinal circulation bands, multiple vortices and apparent storms of various sizes. We now know that the bands are bounded by strong jet streams moving in opposite directions. The huge GRS, at about 22 °S, rotates in a counterclockwise (anticyclonic) direction. One full rotation takes about 7 days, so the wind roars around its periphery at 400 km/h. Winds appear light within the storm, though. The westbound jet to its north and the eastbound one to its south cause a "channeling"

Figure 16. U.N.-Vienna, Sc623, 2018

that may explain why its latitude changes little over time. *Voyager-1* provided another image of the GRS and the nearby turbulent flow on 1 March 1979. In it, the colors have been saturated for dramatic effect. Part of it has been reproduced on a postage stamp (Fig 16).

Figure 17. Bahamas, Sc733, 1991

The observed anticyclonic rotation of the GRS's cloud tops prompted comparisons with Earthly hurricanes, which do have an anticyclonic outflow at their tops, as shown in the flow diagram in Fig 17. Furthermore, energy transfers from the ocean surface drive hurricanes through convection, and something like that may drive the GRS, as discussed later in this article. The two environments are so different, though, that the analogy can be no more than conceptual.

Ulysses was a solar orbiter that did a gravity-assist flyby of Jupiter on 8 February 1992. Fig 18 depicts the spacecraft and shows how it was flung out of the ecliptic by the flyby to end up in a polar orbit around the Sun. *Ulysses* made measurements of Jupiter's magnetic field and radiation environment.

Figure 18. Hungary, Sc3286, 1991

Galileo was deployed from the Space Shuttle *Atlantis* on 18 October 1989. When near Jupiter, it released a probe which descended into the planet's atmosphere on 7 December 1995. Fig 19 depicts the orbiter, the probe and the eponymous *Galileo*. The probe was "slowed by aerodynamic braking for about two minutes before deploying its parachute and dropping the heat shield. The wok-shaped probe floated down about 200 km through the clouds, transmitting data to the orbiter on sunlight and heat flux, pressure, temperature, winds, lightning and atmospheric composition. Fifty-eight minutes into its descent, high temperatures silenced the probe's transmitters. The probe sent data from a depth with a pressure 23 times that of the average on Earth's surface, more than twice the mission requirement. An hour after receiving the last transmission from the probe, at a point about 200,000 km above the planet, the *Galileo* orbiter fired its main engine to brake into orbit around Jupiter" (reference). *Galileo* thus became the first spacecraft to orbit an outer planet.

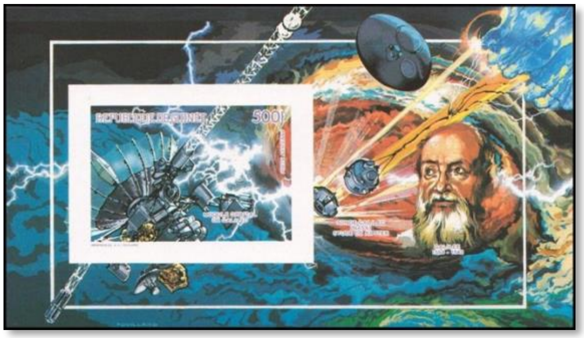


Figure 19. Guinea, ScC172a, 1990

Galileo was the first spacecraft to distinguish different cloud layers in the Jovian atmosphere. It also made the first observation of ammonia clouds in another planet's atmosphere. It operated in Jupiter's magnetosphere long enough to investigate its dynamics and identify its global structure. The orbiter also made the first observations of a comet (Shoemaker-Levy-9) smashing into a planet's atmosphere. Mission extensions were designed so that it could study some of Jupiter's moons. The mission ended when *Galileo* plunged into the planet's atmosphere on 21 September 2003.

Cassini-Huygens (named for astronomers J.-D. Cassini and C. Huygens) was launched in October 1997 on a mission to Saturn. It flew by Jupiter in December 2000 (Fig 20). "The probe's high-resolution cameras caught 26,000 dazzling images of the Jovian atmosphere during its months-long flyby. These photos helped scientists revise their understanding of the red and white bands of gas around the planet" (reference). The spacecraft also confirmed a large dark oval around the north pole in UV wavelengths, following *HST* UV observations of those ovals at the poles in the late 1990s.

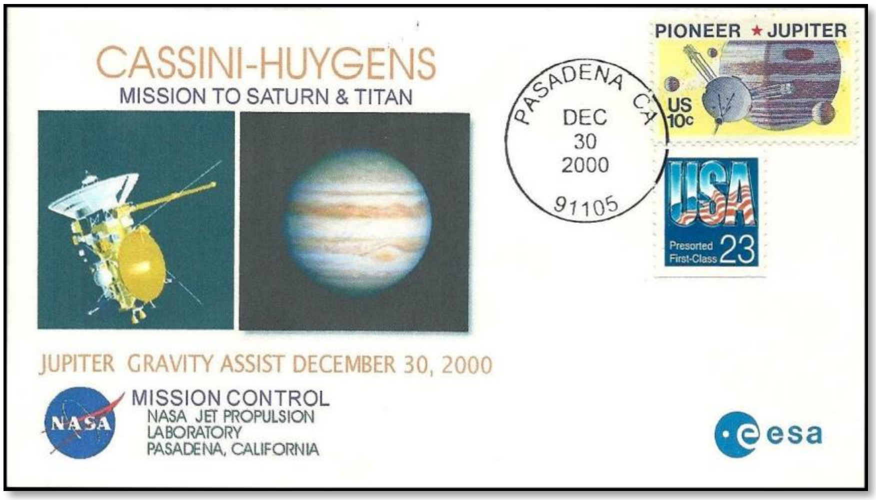


Figure 20. U.S., Cover, Cassini-Huygens Jupiter Gravity Assist, 2000.

New Horizons was launched on 19 January 2006 on a mission to Pluto. It flew by Jupiter between January and May of 2007 (Fig 21), observed some of the inner moons, and took the first spacecraft photos of Jupiter's (LRS) Little Red Spot. "Using data from NASA's *New Horizons* spacecraft and two telescopes at Earth, an international team of scientists confirmed that wind speeds in the LRS have increased substantially over the wind speeds in the precursor storms, which had been observed by NASA's *Voyager* and *Galileo* missions in past decades" (reference). As *New Horizons* left Jupiter, "its trajectory took it down the long tail of the planet's active magnetosphere. The spacecraft made unique observations as it traveled for 160 million km down Jupiter's magnetotail" (reference).

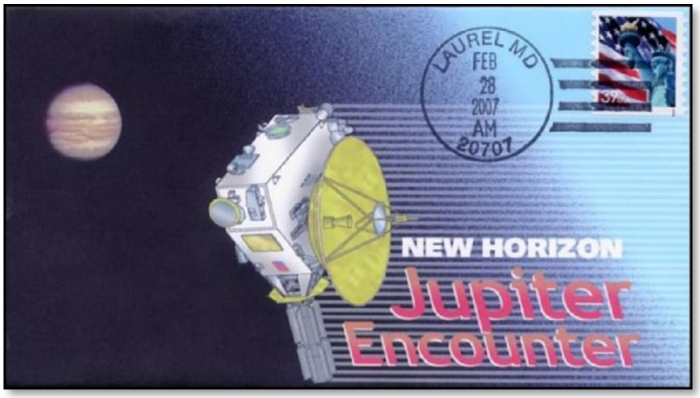


Figure 21. US, Cover, New Horizons Jupiter Encounter, 2007

“In Roman mythology, it’s said that the mighty god Jupiter would cloak himself in clouds to hide his mischievous deeds. Only his wife, the goddess Juno, could peer through the shroud and see his true self” (reference). The souvenir sheet of one stamp in Fig. 22 depicts both the goddess and the *Juno* spacecraft and states much the same thing: “Juno was able to peer through the clouds and see Jupiter’s true nature.” The spacecraft’s name was originally *JUNO*, an acronym for “JUpiter Near-polar Orbiter.”

Figure 22. Sierra Leone, Sc3740, 2016

“By gazing beneath Jupiter’s swirling bands, *Juno* has been able to view the planet’s inner workings in a way no other probe has” (reference). The spacecraft was launched in August 2011 and went into orbit around Jupiter on 4 July 2016. Its prime mission, which ended in 2021, was to study the planet’s interior structure, atmosphere (including polar cyclones, deep atmosphere, and auroras), and magnetosphere. *Juno’s* microwave radiometer allowed it to peer beneath the cloud tops and probe the structure of Jupiter’s storms. “Hot regions correspond to thin clouds, where it is possible to see deeper into Jupiter’s atmosphere. Cold regions represent thick cloud cover, blanketing Jupiter’s atmosphere” (reference). In an extended mission, *Juno* has been exploring the full Jovian system, including close passes above the north pole and observing three of the four Galilean moons. The mission is expected to end in September 2025, when *Juno’s* degrading orbit will take it into Jupiter’s atmosphere.

Figure 23. Sierra Leone, no # yet, 2023

Three Jupiter-related spacecraft, launched recently, are cruising toward the gas giant. *Lucy* (Fig 23) was launched in October 2021 to visit “two main belt asteroids and six Jupiter trojans—asteroids that share Jupiter's orbit around the Sun, orbiting either ahead of or behind the planet” (reference). It is not designed to study Jupiter itself.

Figure 24. France, letter vertre, 2023

JUICE (Fig 24) (*JUpiter Icy Moons Explorer*) was launched in April 2023 to study the moons Ganymede, Callisto and Europa from an orbit around Ganymede.

Europa Clipper (Fig 25) was launched in October 2024 to study the moon Europa in a series of flybys after going into orbit around Jupiter.

Europa Clipper Spacecraft Launch

Goldstone Deep Space Comm Complex - Ft. Irwin CA
October 14 2024

Europa Clipper (previously known as Europa Multiple Flyby Mission) is a space probe developed by NASA to study Europa, a Galilean moon of Jupiter. It launched at 12:06 p.m. EDT Monday October 14 2024 aboard a SpaceX Falcon Heavy rocket from Launch Pad 39A at NASA's Kennedy Space Center. The spacecraft will use gravity assists from Mars on March 1, 2025, and Earth on December 3, 2026, before arriving at Europa in April 2030. The spacecraft will then perform a series of flybys of Europa while in orbit around Jupiter.

Figure 25. US, Europa Clipper launch cover, 2024

In the future, China may get into the game, with its *Tianwen-4* spacecraft that is proposed to go into orbit around Jupiter in 2035.

The remainder of this article presents various aspects of the Jovian environment not already discussed but based on all the research outlined above. Many of the details come from the *Juno* spacecraft.

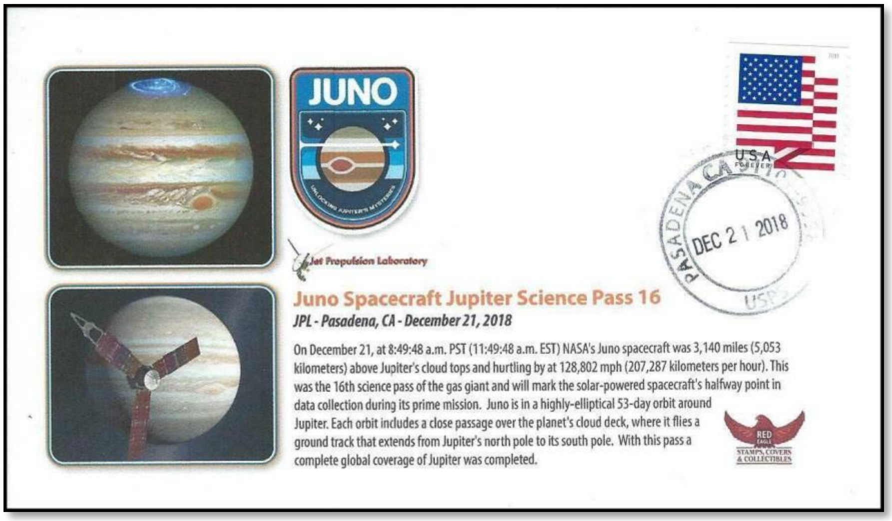
Jupiter is a gas giant composed primarily of hydrogen (86.4%) and helium (13.56%). The principal trace gas components are methane (0.21%), ammonia (0.07%) and water (variable, but > 0.026%) (reference). There are many others in much smaller percentages. Jupiter was the first planet found to be a source of radiation at radio wavelengths (in 1955). It sometimes emitted strong bursts of radio noise that were the earliest evidence of a Jovian magnetic field. We now know that the planet "is surrounded by a powerful magnetic field that is 15 times more powerful than Earth's magnetic field, and in some places, more than 50 times more intense. It rotates with Jupiter and sweeps up charged particles, accelerating them to very high energies and creating intense radiation that bombards anything passing near the planet, including spacecraft. To avoid the highest levels of radiation in the belts surrounding Jupiter, *Juno* flies in long, looping [i.e. highly elliptical] orbits that approach the gas giant from the north. Over the north pole it dives between the radiation belts and the planet, at times descending to 3500 km above the cloud tops" (reference). That closest approach is termed a "perijove." Despite avoiding the worst of the radiation, Juno protects its electronic components with a titanium enclosure. The energy to power the planet's magnetosphere comes ultimately from the planet's rotation combined with the properties of its interior. Interestingly, the volcanically active moon Io has been observed to provide a substantial portion of the charged particles in Jupiter's magnetosphere.

Juno's orbit allows it to study the Jovian poles in detail. It found surprising "polygonal arrangements of giant cyclonic storms at both of Jupiter's poles—eight polygons arranged in an octagonal pattern in the north and five arranged in a pentagonal pattern in the south. Over time, mission scientists determined [that] these atmospheric phenomena are extremely resilient, remaining in the same location" (reference). Recent research using data from *Juno* is attempting to understand how they are created.

The two Voyagers and the "Galileo and Cassini spacecraft also discovered radio evidence of lightning on Jupiter. But the instruments used in these missions weren't sensitive enough to provide a full picture of Jovian lightning. After *Juno* arrived in the Jupiter system in July 2016, however, data started trickling in: the spacecraft's Microwave Radiometer Instrument (MWR) detected 377 lightning discharges in its first eight flybys" (reference) and more recently, *Juno* found evidence of "shallow lightning" that seems to originate somewhere high in Jupiter's atmosphere.

Figure 26. Great Britain, Sc3942, 2020

"High-voltage electrical charges contribute to the formation of auroras at Jupiter's poles, just as they do on Earth. But Jupiter is the solar system's Texas: everything's bigger. The most powerful energies there come to 400,000 eV, while our most powerful auroras on Earth hit only a few thousand eV" (reference). The IR image from JWST in Fig 11 includes the polar auroras. Fig 26 proclaims that "Jupiter's auroras are the strongest in the solar system" and presents a bold artist's depiction of them. In Fig 27 (and also here), the cachet shows bright blue auroras in the planet's north polar region. That image is a composite of several HST observations from 2014 and 2016. The blue auroras are in UV (not visible) light. The image is part of a program "to determine how Jupiter's auroras respond to changing conditions in the solar wind."



Juno Spacecraft Jupiter Science Pass 16

JPL - Pasadena, CA - December 21, 2018

On December 21, at 8:49:48 a.m. PST (11:49:48 a.m. EST) NASA's Juno spacecraft was 3,140 miles (5,053 kilometers) above Jupiter's cloud tops and hurtling by at 128,802 mph (207,287 kilometers per hour). This was the 16th science pass of the gas giant and will mark the solar-powered spacecraft's halfway point in data collection during its prime mission. Juno is in a highly-elliptical 53-day orbit around Jupiter. Each orbit includes a close passage over the planet's cloud deck, where it flies a ground track that extends from Jupiter's north pole to its south pole. With this pass a complete global coverage of Jupiter was completed.

Figure 27, U.S., Juno Event Cover and Jupiter aurora, 2018

Jupiter’s upper atmosphere is a tapestry of latitudinal stripes: lighter ones termed “zones,” and darker ones known as “belts.” Strong zonal (westbound or eastbound) jet streams that commonly reach 100 m/s (360 km/h) or more are found at the boundaries of the stripes. Those jets are probably related to the chaotic motions observed in the Jovian atmosphere. *Juno* found that the jets are surprisingly deep and strong, extending down as much as 3200 km below the cloud tops (reference). How do they form? The answer is unknown, but the planet’s fast rotation probably has something to do with it. As stated here, “the origin of Jupiter's colored banded structure is not completely clear, though it may resemble the cloud structure of Earth's Hadley cells.” Earth’s general circulation is illustrated in Fig 28. It shows the three cells (Hadley, Ferrel and polar) in each hemisphere -- three bands of opposing mean wind direction – a conceptual analogue to what is observed on Jupiter.

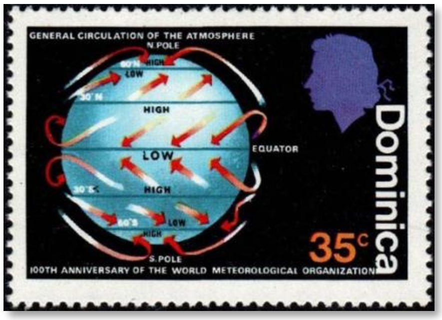


Figure 28. Dominica, Sc358, 1973

“Except for the top of the GRS, Jupiter’s whitish clouds are the highest ones, with cloud-top temperatures of about −150 °C. Those clouds consist of frozen ammonia crystals and are analogous to the water-ice cirrus clouds in Earth’s atmosphere. The darker tawny clouds that are widely distributed over the planet occur at lower levels. They appear to form at a temperature of about −70 °C, which suggests that they probably consist of condensed ammonium hydrosulfide” (reference). A rough analogy could be Earth’s middle level clouds. “At still lower depths in the atmosphere, astronomers expect to find water-ice clouds and water-droplet clouds” (reference) that correspond, roughly, to Earth’s low level clouds. Those three Jovian cloud layers together may be 50-70 km deep. The *Galileo* probe measured increasing temperatures as it descended. When it finally failed, the ambient temperature was around +150 °C, but the probe did not detect any water clouds. It hadn’t detected any significant cold upper clouds either. Subsequent studies concluded that it entered by chance into an atypical cloud-free area known as a “hot spot” (a discussion of Jovian hot spots is found here).

IR observations of the GRS made by *Juno* and other spacecraft show that its cloud tops are colder (and therefore higher) than surrounding clouds, possibly around 8 km higher. The winds howl around the periphery of the GRS but “the interior of the Spot is remarkably tranquil, with no clear evidence for the expected upwelling (and divergence) of material from lower depths” (reference). The internal structure of the GRS is uncertain. Juno’s observations do “indicate that these storms are far taller [i.e. deeper] than expected, with some extending 100 km below the cloud tops and others, including the GRS, extending over 350 km! This surprising discovery demonstrates that the vortices cover regions [vertically] beyond those where water condenses and clouds form [and] below the depth where sunlight warms the atmosphere” (reference). This is an important result.

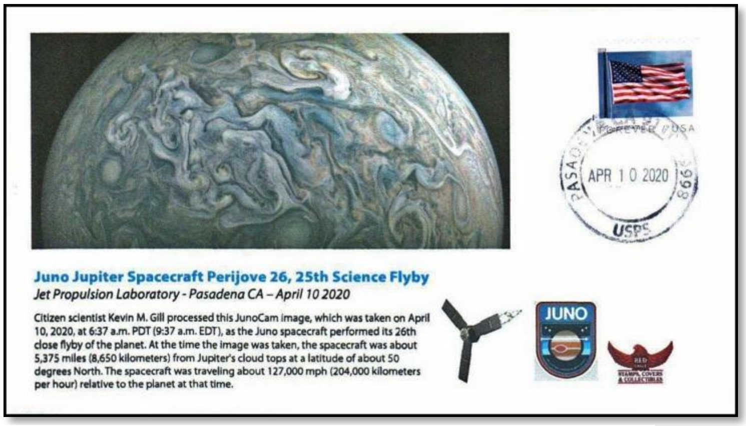
This study examines the question and concludes that “the deep roots of the GRS and other anticyclones may indicate coupling between Jupiter’s interior and deep atmosphere." Other research has built on this idea. This study presents a numerical model in which "the primary driving mechanism [for Jovian vortices] is the deep planetary convection." In it, the authors built a computer model of Jupiter's deep atmosphere/fluid structure driven mainly by heat from below rather than from the Sun, in rapid rotation, and without any solid surface at a lower boundary. They concluded that a "deep planetary dynamo acts to promote additional anticyclones, some as large as Jupiter's GRS, in an overlying atmospheric layer." This means that the energy transfer from the depths of Jupiter to the atmosphere above, via deep moist convection, is the basis for large-scale motions in the planet's atmosphere (Ref. 4). The authors of that work state "We therefore conclude that moist convection—similar to large clusters of thunderstorm cells on Earth—is a dominant factor in converting heat flow into kinetic energy in the Jovian atmosphere." This reference expresses the conclusion in another way: Jupiter's "weather seems to be driven by powerful forces deep within the planet, which may give rise to the gas giant's spectacular tempests." Earthly deep moist convection is the conceptual analogue for such ideas: cumulonimbus clouds (Fig 29) transport heat and moisture upward and can be as tall as 15-20 km in the tropics.

Figure 29, Ciskei, Sc187, 1992

Figure 30. Sierra Leone, Sc2930c, 2009

Fig 30 depicts "Jupiter's atmosphere" as colorful and dynamic in an image that could be from the time of the Voyagers. *Juno* took us into the realm of much higher resolution, with some of its cloud closeups reminiscent of modern art (Fig 31). Even here, though, we can fall back on a conceptual Earthly analogue. Fig 32 depicts the flow patterns and eddies and temperatures of part of the surface of the Atlantic Ocean (ECCO2 project, image credit NASA/Goddard Space Flight Center Scientific Visualization Studio). The two images are similar in their swirling, turbulent and chaotic patterns of motion. Oceanographer Lia Siegelman, at the Scripps Institute of Oceanography, said "When I saw the richness of the turbulence around the Jovian cyclones with all the filaments and smaller eddies, it reminded me of the turbulence you see in the ocean around eddies."

There are, however, many more differences than similarities between the two planets, which make Jupiter's planetary environment foreign indeed. The gas giant will continue to reveal its secrets, gradually, through ongoing scientific investigations.



Juno Jupiter Spacecraft Perijove 26, 25th Science Flyby

Jet Propulsion Laboratory - Pasadena CA – April 10 2020

Citizen scientist Kevin M. Gill processed this JunoCam image, which was taken on April 10, 2020, at 6:37 a.m. PDT (9:37 a.m. EDT), as the Juno spacecraft performed its 26th close flyby of the planet. At the time the image was taken, the spacecraft was about 5,375 miles (8,650 kilometers) from Jupiter's cloud tops at a latitude of about 50 degrees North. The spacecraft was traveling about 127,000 mph (204,000 kilometers per hour) relative to the planet at that time.

Figure 31. U.S., Juno Event Cover, Jupiter image, 2020

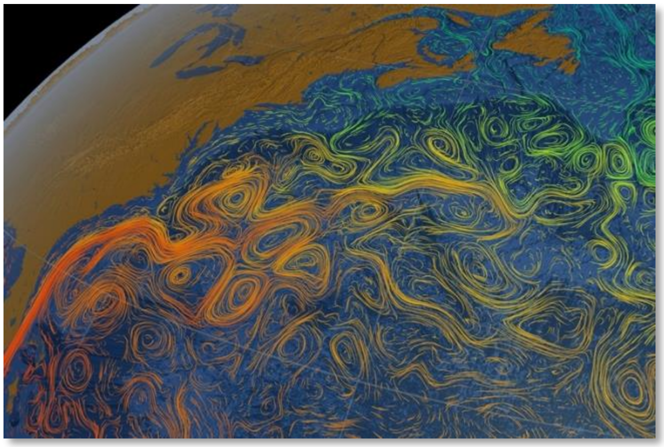


Figure 32. ECOO2 Atlantic Ocean Surface Currents & SSTs, with eddies using 2007-2008 data

References

Ref. 1 Feature article, 2023: "A New Era of Discovery." *National Geographic* (Space Issue), October 2023, pp. 36-49.

Ref. 2 Fimmel, Richard O. et al, 1974: Pioneer Odyssey: Encounter with a Giant. *NASA Scientific and Technical Information Division Report SP-349*, 171 pages.

Ref. 3 JPL Public Information Office, 1993: Voyager Outer-Planet Grand Tour. *NASA Fact Sheet 6-93*, 12 pages.

Ref. 4 Gierasch, P.J. et al., 2000. "Observation of moist convection in Jupiter's atmosphere." *Nature* 403, pp. 628–630.

About the Authors

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We have researched and written extensively about weather, climate, and unmanned spacecraft on stamps and covers, as well as some other topics. See our complete list of our publications, with electronic reproductions.

The authors, Garry Toth and Don Hillger, published a fascinating article: "Nighttime Visible Imagery of Earth from Space" in the December 2024 issue of *Topical Time* (Vol.76, No. 6, Whole No. 448) pp 62-69.