In This Issue

- **Planetary Environments Part 3: Mercury** – Garry Toth and Don Hillger
- **Astrophilately and the Star of Bethlehem** – Gene R. Major
- **New Issues**

Planetary Environments Part 3: Mercury

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

This is the third article in the *Astrofax* series on planetary environments. The first two appeared in the Summer (Introduction) and Fall 2023 (the Moon) issues. The second article introduced important concepts such as temperature measurement, longwave and shortwave radiation, heat transfer, exospheres, volatile compounds, and elements of **space weather** such as the **magnetosphere** and the **solar wind.** It is assumed in this and further articles in this series that the reader is familiar with those concepts.

Mercury was known through visual observations by ancient peoples such as the Babylonians, Chinese, Greeks and Romans. Because it moves so quickly across the sky, the Romans named it after their god Mercury, whom they believed rapidly carried messages between the gods and mortals.

Mercury is hard to observe because it is close to the Sun (average distance 0.39 **astronomical units (au)**; Earth is at 1 au). It is visible from Earth only low in the sky during dawn or twilight, or in its rare passages ("transits") in front of the Sun. The most detailed non-telescopic observations of Mercury (and many other astronomical objects) were made by the Danish astronomer Tycho Brahe (1546-1601) (**Fig. 1**). Galileo may have attempted telescopic observations of the planet around 1610 or later, but details are scarce. There are **clear records**, however, that the French astronomer Pierre Gassendi (1592-1655) (**Fig. 2**) observed Mercury as it transited the Sun on 7 November 1631, using Kepler's 1627 **Rudolphine tables** (which were based on Brahe's observations) to find its position in the sky. On 3 May 1661, the Dutch astronomer Christiaan Huygens (1629-1695) (**Fig. 3**) also observed Mercury in a solar transit.

Fig. 1. Denmark, Sc 300, 1946

Fig. 3. Netherlands, Sc B36, 1928

Fig. 2. France, Sc 1281, 1970, FDC w/Gassendi

As time passed, observational difficulties hindered the quest for reliable information about details such as Mercury's surface features and period of rotation. With improved telescopes, astronomers such as Giovanni Schiaparelli (1835-1910, best known for his Martian observations), E.E. Barnard (1857-1923), and Percival Lowell (1855-1916) did what they could. Some observations indicated that Mercury was "tidally locked" to the Sun (i.e., its rotation was such that one side always faced the Sun, like the side of the Moon that always faces Earth). This would mean that the solar-facing side would be extremely hot, while the opposite side would be frigid because of cooling by outbound longwave radiation. In 1934, the astronomer Eugenius Antoniadi (1870-1944) published the first attempt at a map of the surface features of Mercury. It depended on the tidal locking hypothesis.

Things began to change in the early 1960s. *"In June 1962, Soviet scientists at the Institute of Radio-engineering and Electronics (no stamp is known to the authors) of the USSR Academy of Sciences, led by Vladimir Kotelnikov, became the first to bounce a radar signal off Mercury and receive it, starting radar observations of the planet. Three years later, radar observations by Americans Gordon H. Pettengill and Rolf B. Dyce, using the 300-meter Arecibo Observatory radio telescope* [**Fig. 4**] *in Puerto Rico, showed conclusively that the planet's rotational period was about 59 days"* [**from COSMOSPNW**]. This proved that there was *no* tidal locking: Mercury in fact rotates 1.5 times per orbit. This means that from one planetary perihelion to the next, opposite sides of Mercury are exposed to the greatest amount of solar heating, so that there must exist two alternating equatorial "hot poles" on opposite sides of the planet. One estimate from this era of the maximum temperature of the surface on the Sun side was 347 °C. The coldest parts of the planet would then necessarily be the permanently shadowed regions in Mercury's polar areas. In 1961, American physicist Kenneth Watson had hypothesized that volatiles such as water ice might exist in such cold pools on Earth's Moon. To the authors' knowledge, at the time there was no corresponding speculation for Mercury.

Fig. 4. USA, Sc 3409f, 2000

A telescopic study conducted in 1969 and 1970 used an infrared spectrometer and found that the average surface temperature of the whole dark side of Mercury was around -162 °C [**Ref. 1**]. Apparently, the instruments used at the time allowed no better resolution. That study also concluded that the Moon and Mercury probably have similar top surface layers.

The Space Era began in 1957, but because of the technical challenges it took a long time for planetary probes to be sent to Mercury. Only three spacecraft have managed the voyage. The Planetary Society provides **a list**; Wikipedia has **another list**. Mercury is the least-explored planet of the inner Solar System of the four rocky planets Mercury, Venus, Earth and Mars.

NASA's *Mariner-10* spacecraft was launched in November 1973. It provided the first close-up pictures of Venus and took advantage of that planet's gravity "slingshot" to enter a solar orbit from which it made three close flybys of Mercury at the planet's perihelion. The last one, in 1975, was the closest (only 327 km from the surface). The FDC in **Fig. 5** depicts *Mariner-10* in the stamp and reproduces one of its photographs in its cachet. The planet is full of craters and looks like the Moon.

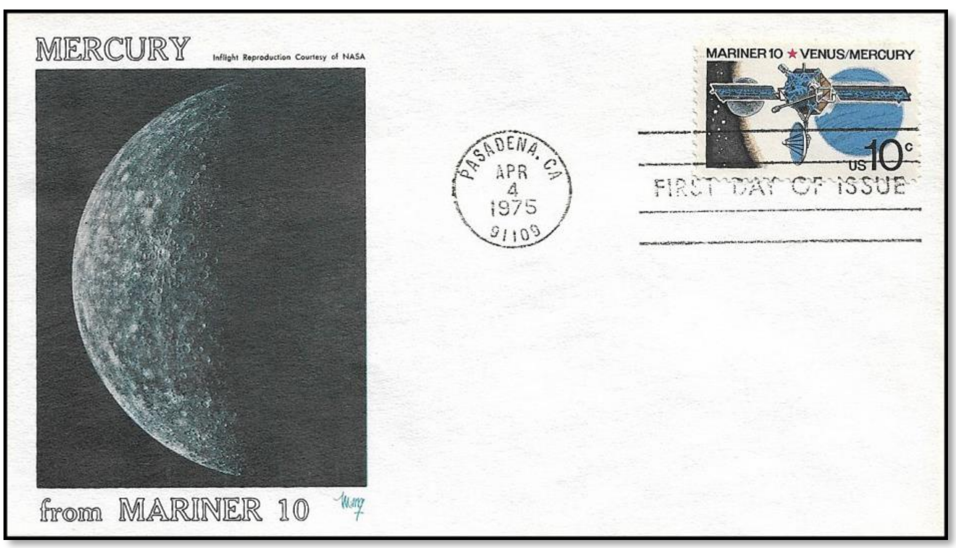

Fig. 5. USA, Sc 1557, 1975, FDC Mariner-10 Mercury flyby.

Mariner-10's ultraviolet radiation photometer observed atomic hydrogen (H), helium (He) and atomic oxygen (O), thus proving that the planet has a near-vacuum type of atmosphere known as a surface-based exosphere. Earth's Moon also has such an atmosphere. Traces of atmospheric sodium and magnesium were later discovered by Earth-based observations. A modern estimate of Mercury's miniscule surface pressure is around 5×10^{-13} kPa (compared to 100 kPa on Earth). The total mass of the atmosphere may be only around 10,000 kg (the corresponding estimate for the Moon is around 25,000 kg).

Mariner-10 also found, surprisingly, that Mercury possesses a magnetosphere that is quite active even though it is only about 1% as strong as that of Earth. This space weather research is summarized in a *Mariner-10* event cover for its third (and final) flyby (**Fig. 6**): a "primary objective" was "to study [Mercury's] magnetic field." That included "investigation of [the] solar wind and cosmic ray particles." As we shall see, space weather effects and their interaction with Mercury's magnetosphere are very important for the planet and its atmosphere.

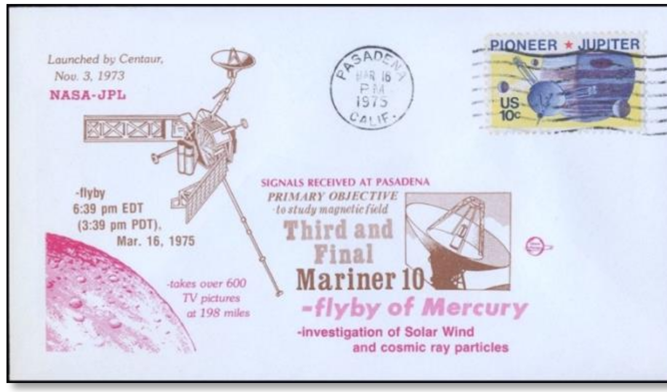

Fig. 6. USA, Sc 1556, 1975, Mariner-10 3rd Mercury Flyby

In 1991, radio astronomers at JPL and CalTech conducted an updated radar mapping of Mercury (**Ref. 2**). Pulses of energy were transmitted from the Goldstone antenna in California (illustrated in the cachet of the *Mariner-10* launch cover in **Fig. 7**, though the depicted spacecraft is the *Mariner-3/4* type), while the return signal was received by the Very Large Array (VLA) (**Fig. 8**) in New Mexico.

Fig. 8. USA, Sc 3409b, 2000

Fig. 7. USA, 1973. Goldstone antenna on Mariner-10 launch cover

The hardware and software had improved to the point that the astronomers were able to attain a resolution of around 15 km. They were astounded to find regions of high reflectivity in Mercury's polar regions that could be interpreted as areas of water ice. Furthermore, those regions corresponded to observed large, deep craters near the two poles. Other explanations were possible, but ice was a tantalizing hypothesis.
The Arecibo radio telescope was significantly upgraded in the mid-1990s to improve its sensitivity. *"One of the early achievements with the upgraded radar was the re-imaging of Mercury's north pole at a much finer (1.5 – 3 km) resolution. These 1998–1999*

observations revealed many additional north polar 'ice' features, including some at relatively low latitudes, and provided a more detailed picture of the ice distribution within individual craters" [**from [Harmon, et al. (2011)]**]**.** Further observations were made in 2005. This was still not absolute proof of the presence of water ice on Mercury, but the evidence was becoming stronger and stronger.

Fig. 9. USA, Sc 4528, 2011

NASA's *MESSENGE*R (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) spacecraft (**Fig. 9**) was launched in 2004 to make multiple scientific studies of the planet. After two close flybys in 2008, it went into orbit around Mercury in 2011. During the flybys, *MESSENGER* confirmed the presence of sodium (Na), calcium (Ca), and potassium (K) ions in the atmosphere, along with magnesium and surprisingly large amounts of water vapor. It also investigated Mercury's long atmospheric "tail", which stretches off into space due to the pressure of the solar wind (much stronger at Mercury than at Earth) and its interactions with the planet's magnetosphere. Sodium and calcium have been found in the tail, whose composition varies seasonally with Mercury's distance from the Sun (the planet is in a highly elliptical orbit). Some of Mercury's atmosphere is lost in that tail. Earth's Moon has no corresponding feature (it has no significant magnetic field and experiences a weaker solar wind). Some of Mercury's atmosphere can also escape to space through local accelerated motions of atmospheric components resulting from energy transfers due to collisions with the solar wind, facilitated by the planet's relatively weak gravity and weak magnetosphere. If the atmospheric mass is stable overall, those sinks must be balanced by sources such as the solar wind itself, meteoric vaporization, and sputtering.

MESSENGER confirmed that Mercury's atmosphere is highly variable in space and time. Why does it vary so much and so quickly? One reason may be the strength of the solar wind that hits the planet. The solar wind drags part of the solar magnetic field with it and can distort and even overpower Mercury's much weaker magnetic field. The two can twist together and intensify, producing what is called in space weather parlance a "magnetic flux transfer event," and can be thought of as a "magnetic cyclone" or a "magnetic tornado." An event like this mixes up the whole Mercurian atmosphere because when it happens, the solar wind descends all the way to the surface, where atoms and molecules can receive enough energy to be hurled skyward, increasing the atmospheric density and changing its composition wherever they go. Some escape to space, but most are eventually pulled back down by gravity to other locations, thus modifying the atmosphere where they land. Such "magnetic cyclones/tornadoes" can be large or small and long-lasting or short-lived. They are probably at least part of the explanation for the extreme variability of Mercury's surface-based exosphere.

MESSENGER also provided multiple observations of the presence of hydrogen (a part of water ice) in regions of permanent shadow in Mercury's polar regions, matching and confirming the earlier radio astronomy observations. The spacecraft measured surface temperatures as cold as -223 °C (50 K) in the most extreme of those "cold traps," and

+277 °C (550 K) or more in open areas exposed to the Sun in the mid-latitudes of Mercury's northern hemisphere **(see JHU/APL's MESSENGER site, in the popup "Read more" for "No. 2: Polar Deposits" under "Top 10 Breakthroughs" tab**). The hottest conditions occur on the Sun side equator at Mercury's perihelion, where the surface temperature can be as high as 430 °C. Such hellish temperatures are not the hottest in the Solar System though. As we shall see in Part 4 of this series, that dubious honor belongs to Venus. Mercury *does* hold the record for the planet with the greatest *range* of surface temperatures: one estimate, from the numbers above, is 653 °C (+430 °C to -223 °C)! This is a result of the planet's proximity to the Sun (for intense heating by shortwave solar radiation) combined with its near lack of an atmosphere (for strong cooling by longwave radiation from constantly shaded dark areas). Mercury's average surface temperature, over its whole surface, has been calculated to be +167 °C. *MESSENGER* collected data until 30 April 2015 when, due to lack of fuel, the spacecraft's orbit had decayed to the point that it crashed into Mercury's surface. Part of *MESSENGER's* legacy is that it discovered that Mercury's core fills 85% of the planet's volume (much more than the 15% value for Earth).

Why is the core so large? How does it generate the planet's magnetic field? The joint ESA (European Space Agency)/JAXA (Japan Aerospace eXploration Agency) spacecraft *BepiColombo*, launched in 2018, will attempt to answer those and other scientific questions. It was named for the Italian scientist Giuseppi "Bepi" Colombo (1920–1984), who first proposed the interplanetary gravity assist ("slingshot") technique now frequently used by planetary spacecraft.

After a complicated series of flybys past Earth, Venus and Mercury, *BepiColombo* is expected to finally enter orbit around Mercury on 5 December 2025. The mission is in fact composed of three distinct vehicles:

1. Mercury Planetary Orbiter (MPO): Built by ESA, MPO will study the composition and dynamics of Mercury's surface-based exosphere, including the mechanisms of generation and escape of its components. Its gamma ray and neutron spectrometers will be used to verify the presence of water ice in permanently shadowed polar craters. Other instruments will study Mercury's surface, composition, interior structure, and magnetism.
2. Mercury Magnetospheric Orbiter (MMO): Built by JAXA, MMO will study Mercury's magnetic field/magnetosphere and its space environment.
3. Mercury Transfer Module (MTM): Built by ESA, this spacecraft carries the other two and will deliver them to Mercury.

Most philatelic items for *BepiColombo* show the ensemble: the MTM carrying the MMO and MPO in what could be termed the mission's "cruise configuration." One example is found in the launch cover in **Fig. 10**. The postage stamp in **Fig. 11** depicts MPO (yellow orbit) and MMO (red orbit) in their eventual separate orbits around Mercury. One hopes that they will be as scientifically successful as the two spacecraft that have already visited the planet.

Fig. 10. France. 2018. *BepiColombo* launch cover, Lollini cachet

Fig. 11. Germany. Pvt Post, 2018. MPO and MMO components of *BepiColombo*.

The interested reader can refer to the authors' extensive lists and images for stamps and covers for **Planetary Spacecraft**, including the spacecraft mentioned above, and/or to their **Space Weather** web page for space weather-related philatelic items.

References

(Ref. 1) Murdock, T. L. and E. P. Ney, 1970: "Mercury: The Dark-Side Temperature." *Science*, New Series, Vol. 170 (3957) (30 Oct 1970), pp. 535-537.

(Ref. 2) Lewis, John L., 1996: *Rain of Iron and Ice*, Helix Books, Addison-Wesley Publishing Co., ISBN 0-201-48950-3, Ch. 10, pp. 133-135.

About the Authors

Garry Toth, M.Sc., now retired, worked many years with the Meteorological Service of Canada. Correspondence to gmt.varia@gmail.com is welcome.
Don Hillger, Ph.D., now retired, was a research meteorologist with the National Oceanic and Atmospheric Administration (NOAA) and held a cooperative position at Colorado State University. Correspondence to don.hillger@colostate.edu is welcome.

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.

Astrophilately and the Star of Bethlehem

by Gene R. Major

"When Jesus was born in Bethlehem of Judea, in the days of King Herod, behold, magi from the east arrived in Jerusalem, saying, 'Where is the newborn king of the Jews? We saw his star at its rising and have come to do him homage.' – Matthew 2:2