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## **Planetary Environments, Part 6: Mars in the 21<sup>st</sup> Century** by Garry Toth and Don Hillger ([Un-manned Satellite Philately](#))

This is the sixth article in the *Astrofax* series on planetary environments. It is a continuation of the fifth one, *Planetary Environments Part 5: Mars Through the 20<sup>th</sup> Century*, which appeared in the Summer 2024 *Astrofax*. The first five articles in this series appeared in the previous five 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)

The first Mars article concluded with the only two successful NASA Mars spacecraft missions in the 1990s (the *Mars Global Surveyor* and the *Mars Pathfinder* mission). They were mixed in with a string of failures. As a result of those failures, NASA reformulated

its [Mars Exploration Program](#) in 2000 and introduced a new overarching theme, “Follow the Water.” A detailed discussion of what is now known about water on Mars is found [here](#). Since 2000, NASA missions to the Red Planet have all been successful. Other countries have begun their own Mars programs, with some notable successes, and a few failures.

The [NASA list of spacecraft missions to Mars](#) is a good starting point for Mars missions, including those of the 21<sup>st</sup> century. The [Planetary Society also has a list](#).

NASA’s [Mars Odyssey orbiter](#) (Fig 1) reached Mars in 2001. Its [primary objectives](#) were “to use spectrometers and a thermal imager to detect evidence of past or present water and ice, as well as study the planet’s geology and radiation environment. The data *Odyssey* obtains are intended to help answer the question of whether life once existed on Mars and create a risk assessment of the radiation that future astronauts on Mars might experience.” However, “the payload’s [MARIE \(Mars Radiation Environment Experiment\)](#) stopped taking measurements after an intense solar storm bombarded *Odyssey* on October 28, 2003.” Furthermore, NASA reported that “On May 28, 2002 (sol 210 [Martian day 210]), *Odyssey*’s GRS [Gamma Ray Spectrometer] had detected large amounts of hydrogen, a sign that there must be ice lying within a meter of the planet’s [polar] surfaces, and proceeded to map the distribution of water below the shallow surface [the map is found [here](#)]. The orbiter also discovered vast deposits of bulk water ice near the surface of [some] equatorial regions.”



Figure 1. S. Tomé & Príncipe, Sc 1685a, 2007.

The European Space Agency (ESA) got into the game in 2003 with its [Mars Express](#) (Fig 2) mission. Its orbiter went into orbit as planned, but its Beagle-2 rover failed on the surface when some solar panels failed to deploy. The orbiter studied the atmosphere and its interactions with the [interplanetary medium](#) and used its MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding) instrument to determine the subsurface structure and search for ice. See [here](#) for details. Some science results are presented [here](#). “Early in its mission, *Mars Express* detected abundant water ice extending down [from the polar regions] to the mid-latitudes.” More recently, the orbiter has found that “water ice buried at Mars’ equator is over 2 miles [~3.5 km] thick,” which is



Figure 2. Djibouti, no Sc, 2023.



Figure 3. Great Britain. Sc 3368, 2012.

“enough water ice to ... cover the entire planet in a shallow ocean if melted ... While it’s not the first time that evidence for ice has been found near the Red Planet’s equator, this new discovery is by far the largest amount of water ice detected there so far ... The presence of subsurface water ice at low and equatorial latitudes hints at how Mars’ climate was very different in the distant past.” Fig 3 reproduces an image from *Mars Express* that shows ice in an impact crater. The original image, with a bit of explanation, is found [here](#).

The two *Mars Exploration Rovers* (*MER-A* and *-B*), *Spirit* and *Opportunity* (Fig 4), were robotic geologists that arrived on the surface of the Red Planet in January 2004. *Spirit*'s landing site, Gusev Crater, was chosen because it had the appearance of a crater lakebed (from various observations including those of *MGS* and *Mars Odyssey*). *Opportunity* landed in *Meridiani Planum*, a site which displayed evidence of coarse-grained hematite, an iron-rich mineral which typically forms in water. Its measurements led to the conclusion that water once flowed in the region, which might be the shoreline of an ancient salty sea. In July 2007, a major dust storm blocked sunlight and threatened the *MERs*' ability to gather sunlight, to the point that engineers feared that one or both might be permanently disabled. They both survived, however.

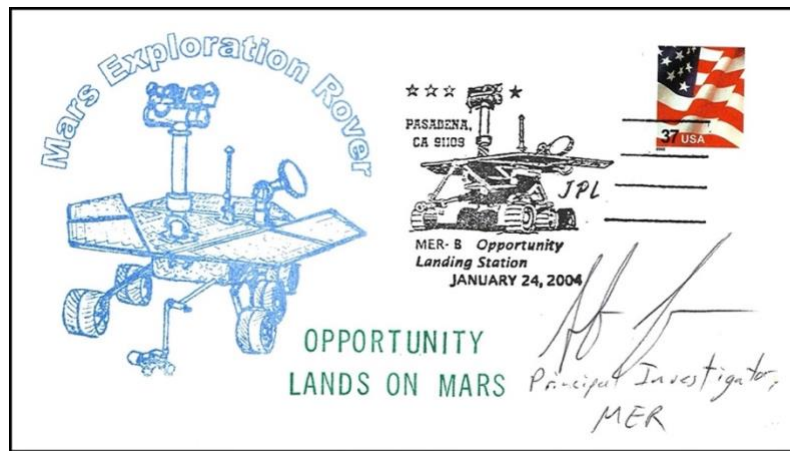


Figure 4. *MER-B Opportunity*, cachet maker unknown, 2004.

NASA's *Mars Reconnaissance Observer* (*MRO*, Fig 5) entered Mars orbit in 2006. Its principal science objectives were “to observe the present climate, particularly its atmospheric circulation and seasonal variations; search for signs of water, both past and

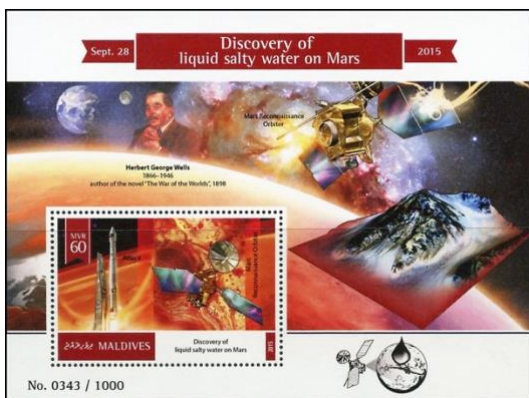


Figure 5. Maldives, Sc 3563, 2016

present, and understand how it altered the planet's surface; and map and characterize the geological forces that shaped the surface.” *MRO* used its Mars Climate Sounder (MCS) instrument to obtain the data needed to create daily global weather maps of the basic variables of Martian weather: temperature, pressure, humidity, and dust density.” It used its Shallow Radar (SHARAD) sounder to investigate the internal structure of the polar ice caps and to gather planet-wide information about underground layers of regolith, rock, and ice. SHARAD complemented the *Mars Express* MARSIS

instrument. The banner at the top of the souvenir sheet of one stamp (SS1) in Fig 5 announces the “discovery of liquid salty water on Mars” (by *MRO*). That hearkens back to the hypothesis put forth by the Swedish chemist and Nobel prize winner Svante

Arrhenius in around 1910 (discussed in the previous Mars article). *MRO* detected what are now called *recurring slope lineae*: dark streaks on slopes, caused by what might be flowing brine in relatively warm conditions at or near the surface. On September 28, 2015, this finding was presented at a NASA news conference. That date is also found in the SS1 in Fig 5. However, the idea remains controversial. Some researchers say that the dark streaks could be caused by *dry* grains of soil that “flow” downhill under certain conditions, perhaps related to the presence or absence of dust storms. These ideas are discussed in [Seasonal flows on warm Martian slopes](#) and [Recurring slope lineae and chlorides on the surface of Mars](#).

The [Phoenix Mars Lander](#) (*PML*, Fig 6) was designed to study the atmosphere and the near-surface environment in a high northern area of Mars. It landed in May 2008 on a Martian Arctic plain. The site was farther north than any previous mission. The lander dug trenches in the ground, analyzed the samples, and verified the presence of water ice, thus confirming the remotely sensed data from orbiters as far back as *Mars Odyssey*. *PML* was also equipped with a meteorological station. It measured temperature and pressure and was able to scan the atmosphere at altitudes up to 20 km to obtain data about cloud characteristics as well as possible fog and dust plumes.

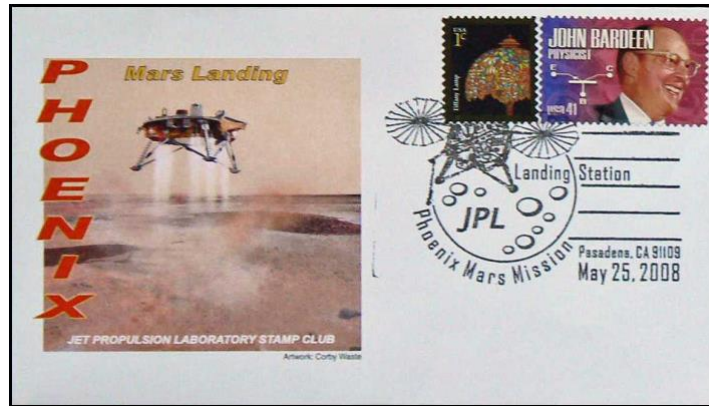


Figure 6. *Phoenix Mars Lander*, JPL Cachet, 2008.

The [Mars Science Laboratory Curiosity](#) (*MSL*, Fig 7) is a NASA rover that landed in Gale Crater in 2012. It is much bigger than the previous rovers. Its atmospheric science goals are to study Martian water and CO<sub>2</sub> for data that could be applied to the question of how the atmosphere has evolved over billions of years. There used to be a lot of [water on Mars](#) and the atmosphere must have been much thicker than it is now. How did the planet become so arid, with such a thin atmosphere?



Figure 7. Burundi, Sc 1155b, 2012

*MSL* carries the [Rover Environmental Monitoring Station](#) (REMS), a weather station that can measure temperature, pressure, wind, humidity and UV

radiation. This [Climate of Mars](#) page contains an interesting table of monthly temperatures (highest max, mean max, mean min and lowest min) observed by *Curiosity* in the Gale Crater. The presence of the REMS UV sensor relates to MSL's other science goal: to study all types of Martian surface radiation with its Radiation Assessment Detector (RAD). In fact, the RAD was active and making measurements during the cruise to Mars as well as on the surface of the planet. Such data are important because they will help determine how much radiation shielding will be needed to protect future Mars mission astronauts. The RAD is a follow-up to the MARIE instrument that was carried by *Mars Odyssey*. [An online article](#) from June 2024 reports that the RAD typically records around 700 [micrograys](#) of radiation each day on the Martian surface, but in the major solar storm of May 2024 the level spiked to 8,100 micrograys! The storm was so strong that *Mars Odyssey* was knocked temporarily offline, and its solar panels experienced about a year's worth of degradation in a single day. Future astronauts on Mars will have to be prepared to protect themselves from potentially significant space weather effects.

In May 2024, [MSL was in Gediz Vallis](#), a channel that might be an ancient Martian riverbed. JPL has decided that *MSL* will continue to follow the channel, given the importance of learning about ancient Martian running water.



Figure 8. Sierra Leone, Sc 3719a, 2016.

India's [Mangalyaan Mars Orbiter Mission](#) (*MOM*, Fig 8) spacecraft went into orbit around the Red Planet in September 2014. Its science goals included measuring atmospheric methane ( $\text{CH}_4$ ) and  $\text{CO}_2$ , studying the exosphere, and examining how the solar wind and radiation influence the loss of atmospheric [volatiles](#) to outer space. *MOM* also mapped the albedo of the Martian surface.

NASA's [Mars Atmosphere and Volatile Evolution](#) (*MAVEN*, Fig 9) spacecraft also entered Martian orbit in September 2014. Mars has little or no magnetic field and so is exposed to the solar wind, unlike Earth which is protected by its magnetosphere. The solar wind, therefore, hits the Martian atmosphere directly and slowly [strips it away](#) through energy transfers. Van Allen et al. (Ref 1) discussed this idea in 1965 after *Mariner-4* found little to no magnetic field around Mars. *MAVEN* studied the Martian upper atmosphere and found an average rate of loss to space of 100 g/s (but the rate is significantly greater during solar storms). That "solar wind erosion" may account for the change in the Martian climate over the eons, and the rate of loss may have been greater in the dim past when the atmosphere was denser. That depends on the absence of a magnetic field, though. A young Mars may have had a magnetic field, but recent research

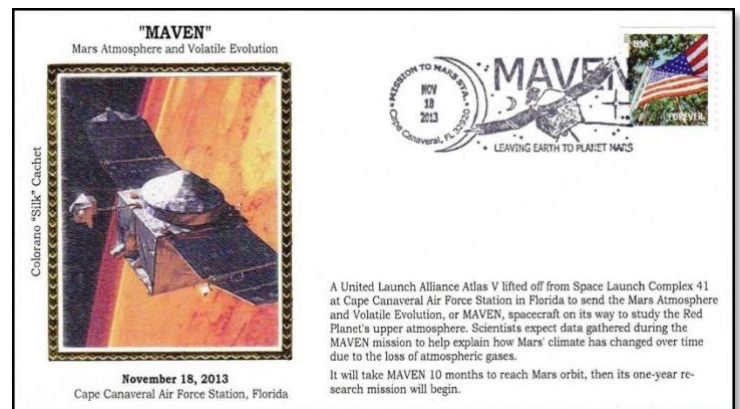


Figure 9. *MAVEN* launch cover; Colorano Silk cachet, 2013.

(summarized [here](#) and [here](#)) concludes that it was temporary. Space weather in a philatelic context is featured in Ref 2. Sections 4.2 and 6.3 of that work focus on Mars.

Another explanation for the loss of the Martian atmosphere has also been proposed. Some [meteorites found on Earth are known to have come from Mars](#) (e.g. Fig 10 features “Mars shergottite meteorite(s)”). How did they get here? They must have been blasted off Mars by a strong meteorite impact there. In what he calls “impact erosion,” John Lewis (Ref 3) claims that “for each kilogram of rock successfully accelerated to escape velocity, millions of kilograms of gas must have been lost into space from the Martian atmosphere” and “so easy is it to erode atmosphere from Mars that there must have been serious loss of gases over geological time scales” and “the tenuous nature of the atmosphere of Mars ... therefore is plausibly explained by the erosive effects of impacts.” Since Mars is closer to the asteroid belt than Earth, it makes intuitive sense that it should be at higher risk than Earth for asteroid impacts. [A recent study](#) supports this idea: it found “about two-and-a-half times more potentially hazardous asteroids at Mars than on Earth.”



Figure 10. Guinea, BL1032, 2006.

It has also been hypothesized that dust storms “may be responsible for a large fraction of Martian water loss and represent an important driver of Mars atmospheric evolution” ([Martian water loss to space enhanced by regional dust storms](#)). All those physical processes are probably valid to some extent. Future research will be needed to determine which, if any, is predominant.



Figure 11. Guyana, Sc 4484, 2016.

The ESA/Roscosmos ExoMars-2016 mission consists of the [Trace Gas Orbiter](#) (*TGO*, Fig 11) and the Schiaparelli lander. *TGO* entered Mars orbit in October 2016, but the lander crashed. The main goal of *TGO* is to observe methane and other trace gases in the Martian atmosphere. That is of interest because in some cases, they could indicate biological activity. Future ExoMars missions that would search for biosignatures have been delayed since ESA has canceled its partnership with Roscosmos. *TGO* has two spectrometer instruments: the Nadir and Occultation for Mars Discovery (NOMAD) and the Atmospheric Chemistry Suite (ACS). The two observe the Sun as it shines through the atmosphere at local sunrise and sunset and can detect trace gases at the parts-per-billion level, the greatest sensitivity ever achieved by a Mars mission. As of April 2019, no methane had been found.

NASA's [InSight \(Interior Exploration using Seismic Investigations, Geodesy and Heat Transport\)](#) lander (Fig 12) reached the Martian surface in November 2018. Its mission was to study the crust, mantle, and core of Mars. Its seismometer made various measurements including the rate of meteorite impacts on the surface (potentially interesting data to compare with the work referred to in Ref 3). It also included an array of penetrating



Figure 12. Djibouti, Sc1588b, 2018



Figure 13. Mozambique, Mi10100, 2019

temperature sensors, such as the one depicted in Fig 13 (“Sonda de temperatura”) that made soil temperature and heat flow measurements. The rover was also equipped with the meteorological package TWINS (Temperature and Wind sensors for *InSight*) along with a barometer and a magnetometer. Those instruments helped to determine the non-seismic environmental contributions to the seismic signals. *InSight* operated until December 2022.

The [United Arab Emirates Al-Amal orbiter \(Hope\)](#) (Fig 14) entered Mars orbit on 9 February 2021. It was the first of three missions that blasted off during the [July 2020 Mars launch window](#). Its mission is to study Martian weather, including dust storms, and to make atmospheric observations that might help explain the planet’s drastic climate changes of the dim past. The mission team said that Hope would be “the first

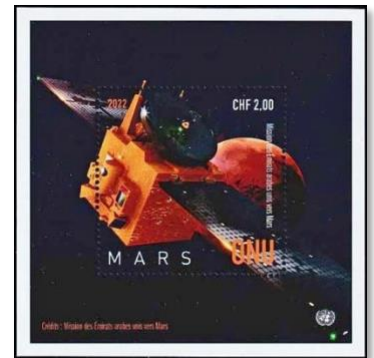


Figure 14. UN-Geneva, Sc 720, 2022



Figure 15. UN-Geneva, Sc 718, 2022

true weather satellite” at the Red Planet. For example, the Emirates Mars Infrared Spectrometer (EMIRS) instrument can measure surface temperatures, create temperature profiles, and observe atmospheric concentrations of ice, water vapor and dust. A photograph of Mars taken by *Hope* (“Mars vue de la sonde *Espoir*”), including the north polar ice cap, is featured in the stamp in Fig 15 (the large orange area at the middle right is the *Arabia Terra*).

Another scientific contribution of *Hope* is that “the Emirates mission has teamed up with NASA’s *Maven* spacecraft to observe the unique auroras forming on the Red Planet” (Ref 4).

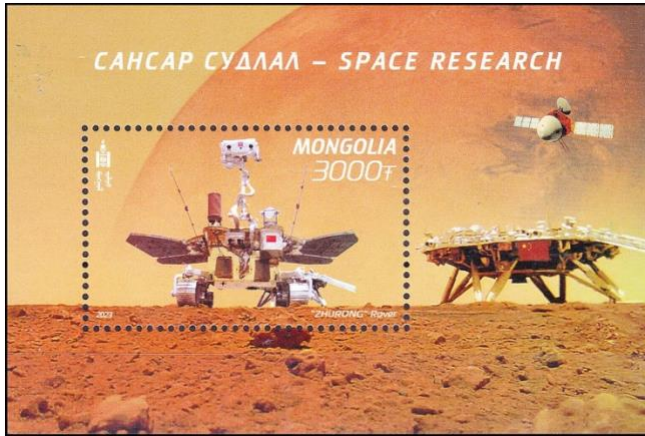


Figure 16. Mongolia, BL397, 2023.

The Chinese [Tianwen-1 mission](#) orbiter entered Mars orbit on 10 February 2021. Its lander, which reached the surface on 14 May of that year, immediately deployed the *Zhurong* rover (Fig 16 depicts all three). The orbiter has instruments to study the Martian space environment and magnetic field, and its radar is investigating surface and subsurface water-ice. The rover is equipped with a subsurface detection radar and other instruments for a variety of studies. Its Mars Climate Station

(MCS) and Mars Meteorological Measurement Instrument (MMMI) measure weather variables. 325 sols of meteorological data from *Zhurong* have been analyzed and [published online](#).

NASA's [Mars-2020 mission](#) consists of a large rover (*Perseverance*) and a revolutionary small drone-like helicopter (*Ingenuity*). The lander reached the surface on 18 February 2021. *Ingenuity* was originally expected to simply demonstrate that flight was possible in the thin Martian atmosphere but was so successful that it was retired only on 25 January 2024 after its 72<sup>nd</sup> flight. *Perseverance* and *Ingenuity* are depicted in the left margin of the SS1 in Fig 17, whose stamp shows the lander descending to the surface. The mission's main science goals are to seek signs of habitable conditions on Mars in the ancient past and to search for evidence of water and of past microbial life. To that end, NASA chose to land the rover in the Jezero Crater because it was once flooded with water and was home to an ancient river delta, and so could be a favorable place to search for biosignatures. An artist's drawing of an ancient Martian watercourse, labeled as an "outflow channel", is found in Fig 18. A



Figure 17. S. Tomé & Príncipe, BL1769, 2021.

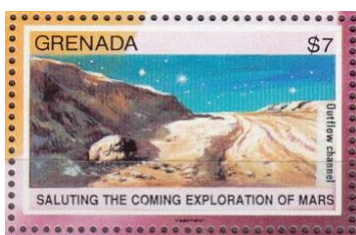


Figure 18. Grenada, Sc 2002i, 1991.

different artist's depiction of a dry Martian watercourse is in Fig 19. *Perseverance* takes [rock samples](#) and places them in sample tubes that a future Mars Sample Return (MSR) mission will pick up and return to Earth (if its major financial and engineering challenges can be overcome).



Figure 19. Republic of Central Africa, Mi 5608, 2023

Future Mars missions are in various states of preparation. Mars launch windows come every 26 months, and the next one will be in the fall of 2024. There are several entries in the “Future Missions” section of the [Planetary Society’s Mars missions web page](#). The list is not complete, though. For example, India’s ambitious [MOM-2 mission](#) is not included. There is even a postage stamp (Fig 20) that anticipates one of those future spacecraft: [MMX, Japan’s planned Martian Moons Mission](#). The [Climate of Mars](#) discusses the weather and climate of the Red Planet and some of its surface and subsurface features such as water ice. It includes many of the elements of the Martian planetary environment presented in this article (and the previous one) about the planet. One major element of the Martian environment, its dust storms, deserves a little more consideration. Relevant online discussions are [here](#) and [here](#) and [here](#) and [here](#).



Figure 20. Sierra Leone, Sc 5063d, 2018

Martian dust can rise into the atmosphere simply through wind stress (roughly, the force exerted by the wind on the surface) if the winds are strong enough. Dust devils provide another lifting process. On Earth they can form in arid regions when the Sun heats the surface, which in turn heats the air above it, which rises, and in some circumstances starts

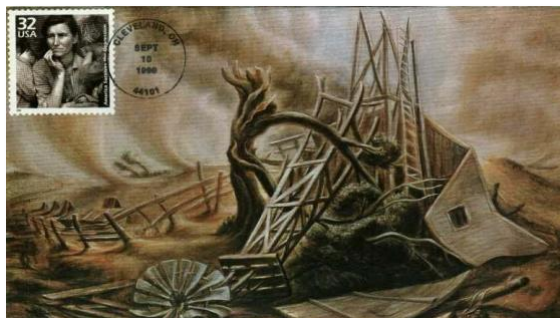


Figure 21. USA, Sc 3185m, FDC, 1991.

rotating to form a dust devil. A similar process probably forms Martian dust devils. The cachet of the FDC in Fig 21 shows a surreal apocalyptic artistic scene from the American Dust Bowl of the 1930s, with at least three large dust devils in the background. The stamp in Fig 22 shows an artist’s depiction of similar Martian dust devils on what the stamp calls the “dusty face of Mars.” Such dust devils can

continue to grow, and merge, through Martian atmospheric dynamics that are not understood. In that growth phase, dust aloft can itself absorb solar energy, which probably accentuates the growth process. Martian dust storms at regional scales sometimes show interesting parallels with Earth’s weather systems. For example, Fig.23, labeled “Martian North Pole Dust Storms,” depicts one type of storm - a counterclockwise swirl of dust with a long line of dust trailing to its southwest. Other Martian dust storms can have different forms, but this one looks like some northern hemisphere low pressure centers on Earth, which have a counterclockwise swirl of clouds and a cold front trailing back toward the southwest. Fig 23 can be compared with Fig 24, in which a similar weather system on Earth is circled in red in a photograph taken by *Apollo-8* on 22 December 1968. The SS1 in Fig 25 includes one of the better reproductions of that photograph on a postage stamp.

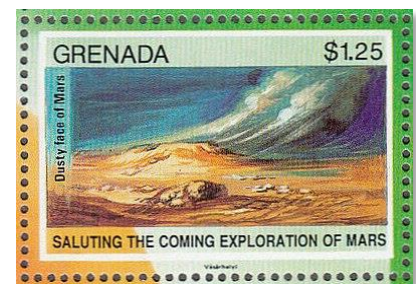


Figure 22. Grenada, Sc 2000c, 1991.



Figure 23. Sierra Leone, Sc 2930a, 2009.



Figure 24. Earth image from *Apollo-8*, 22 Dec. 1968.

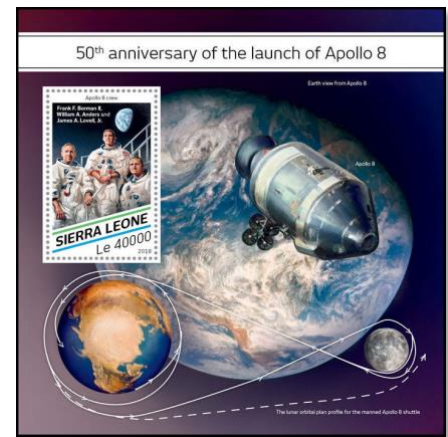


Figure 25. Sierra Leone, Sc 4853, 2018.

Such comparisons suggest that Martian dust can be thought of as a rough analogue of atmospheric moisture on Earth, which can rise, condense, and form clouds on various scales, from individual clouds (~ 1 km or less) to large cloudy low pressure areas (~1000 km). Martian dust can also form dust clouds and storms on various scales and with various shapes, though the largest such storms, which can cover the planet, have no Earthly equivalent.

The details of the physical processes that govern the evolution of Martian dust storms are poorly understood. Like any storms, Martian dust storms must have a source of energy to drive them. Mars' orbit is highly eccentric, so it receives much more solar energy at its perihelion (1.38 au from the Sun) than at aphelion (1.67 au distance). The warmest and windiest time is in the southern hemisphere spring and summer, when dust storms can grow to continental scale or larger, through processes that remain mysterious. Rarely (perhaps once every 6 to 8 Earth years), they grow into [global dust events](#) (GDEs) which can last for months, but contain the seeds of their own destruction: the high concentrations of suspended dust block most of the solar energy normally absorbed by the surface and by the dust already aloft. The storms eventually die out, apparently for lack of energy to continue to drive them.

With that, our examination of Mars is complete. Further articles in the *Astrofax* series on planetary environments will continue to move outward in the solar system. Jupiter will be the subject of the next one.

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Ref. 3: Lewis, John L., 1996: *Rain of Iron and Ice*, Helix Books, Addison-Wesley Publishing Co., ISBN 0-201-48950-3, Ch. 12, pp. 160-161.

Ref. 4: *Hope* studies Martian auroras. *Orbit*, (145), July 2024, p 23.

Extensive lists of stamps and covers for the spacecraft discussed above (and many more) are found in the [Planetary Spacecraft](#) page of the authors' [Un-manned Spacecraft](#) website. Our list of philatelic items for [Planetary Environments](#) is also available online.

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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.

## HEAO–High Energy Astronomy Observatory by John Macco, ASU Member

NASA's first High Energy Astronomy Observatory (HEAO-A) was launched on August 12, 1977 aboard an Atlas-Centaur (#45) SLV-3D rocket from Cape Canaveral, Florida. HEAO-A surveyed and mapped X-ray sources throughout the celestial sphere and also measured low energy gamma ray flux.

