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# The terrestrial planets at the dawn of the space age

It is difficult to overstate the profundity of the change in our perception of the planets during a single generation in the latter part of the twentieth century. The revolution is second only to that in the generation from Copernicus to Kepler at the end the sixteenth century. The very character of the scientific questions changed as the planets went from being astronomical objects to geological objects.

A primary goal of this chapter is to document some of the changes in perception and scientific issues involving terrestrial planets that happened as we went from the purely telescopic to the spacecraft era. While I have documented some technical material, I have allowed myself, as one who lived through this change, to include some anecdotal material. For example, I grew up making backyard telescope observations of planets when such observations could exceed the best photographic imagery; I experienced Sputnik 1 while at college; I was at graduate school under Professor Gerard Kuiper as he supervised a lunar mapping program for the Apollo landings, before a graduate program in planetary sciences was available; I was a co-investigator in the first orbital mapping of Mars; and I attended professional meetings where international friends and colleagues announced the first close-up results from Mercury, Venus, Jupiter, Saturn, Uranus, Neptune, Halley's Comet, Gaspra, Ida, Mathilda, and so on.

An additional aspect of this chapter involves the philosophy of science and exploration. The change from an astronomical to a geological approach is interesting because some of the burning questions of the astronomical era were not so much answered with great fanfare by space probes, but rather "fizzled out" as scientific interests shifted to new observations. For example, much effort was spent trying to map the markings of Mercury, but this effort virtually died when the first photographs were returned; curiously, it is still unclear to what extent early observers, such as Eugène Antoniadi, were recording real albedo features, and how these features match the geology of Mercury.

This is also an interesting issue from the point of view of pursuing one's own career. For example, major parts of careers and grants were spent on issues such as mapping and interpreting markings, photographing Venusian clouds, trying to estimate surface pressures from inadequate data, and so on. Were these valuable steps toward a goal, or poor choices of research activity? Should the researchers and funding agencies simply have waited for better data – especially once it became clear that probes would be a reality? Often, research time and expenditures on such issues increased dramatically *before* missions, because of interest in what the probe would find, even though the results would soon be rendered obsolete by a single click of a shutter on a spacecraft. With hindsight, we can see that some efforts, such as the first proof of $CO_2$ on Venus or Mars, became fundamental advances to be cited in many future textbooks, while for others whole subjects were swept away by flyby probes or landers.

A related subject is the subtle abandonment of early "burning questions." Probably the most argued photographic–visual–telescopic question about Mars in the first half of the twentieth century was the fundamental underlying cause of the dark markings. Mariner 9 showed that they involved windblown dust, and the case seemed to be closed. But then the question was, why is the dust not mixed? What is the nature and source of the dark or light material? Do

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bare rock outcrops exist and are they a source of spectrally fresher and less weathered material, perhaps of lower albedo than the weathered dust? Spectral and thermal observations seem to show that the dark material is coarser, fresher basalt and the light material is finer, oxidized, and weathered material. With this finding, the issue is currently on a back-burner. Still unresolved is where the fresh basalt material is coming from (especially since lava flows are more evident in light areas like Tharsis and Amazonis). In that sense, the original, underlying question that drove much of early Mars research is still unanswered. An "answer" was given, based on results obtained with instruments then available, but it did not answer the original question. This example illustrates a slightly unsettling characteristic of science: that the phenomena we measure and debate are not necessarily the "most important" phenomena of nature, identified objectively, but rather are heavily weighted by the particular instruments we happen to have and the subdisciplines that have emerged through socio-scientific processes.

It is unsettling to discover that one's students or younger colleagues don't share certain pivotal experiences that shaped planetary science, and that to them, these experiences are prehistory, or even unknown! Many of the contributors to this book have passed through various moments of shock with various successive waves of students: the ones who don't remember Sputnik, the ones who don't remember Gagarin's flight or President Kennedy's announcement a few weeks later of the Moon landing program, the ones who don't remember the first photographs of Mars, and, finally, the ones who weren't even born when Neil Armstrong stepped onto the Moon. For these reasons, I shall try to capture some of the character of the early developments as experienced at the time.

At the same time, as the twenty-first century begins, one is only too aware that the future progress of planetary exploration and research in general is under threat from anti-intellectual, anti-science, fundamentalist sources. In the USA, the battle over the teaching of biological evolution in schools not only continues, but has expanded into an attack on evolutionary processes, even in physical systems such as stars and galaxies. In 1999, the Kansas state Board of Education, under pressure from fundamentalists who had gained a majority in elections, withdrew not only biological evolution but coverage of the big bang cosmological theory from the subjects covered by the state's educational standards and testing program, effectively excluding them from the curriculum. Generally speaking, the proponents of these views are not well educated about the history of science or the nature of the modern international scientific literature, but take refuge in their own gray literature and national networks of radio programming. Ironically, they wage ghostly echoes of battles already fought and settled nearly two centuries ago by pioneers such as Lamarck and Cuvier – battles subsequently settled by overwhelming and diverse lines of evidence, including radiometric dating. Yet spokespersons for these factions routinely explain in the US media that there is plenty of scientific evidence in their favor. One member of the Kansas Board of Education, a veterinarian who voted to remove evolutionary concepts from the education standards, was described in the *New York Times* and *International Herald Tribune* citing "legitimate scientific doubts about whether the Universe is more than several thousand years old" (Glanz 1999), and this view is widespread in fundamentalist literature. This in spite of the independent and international work by researchers such as Gerling (1942) in Leningrad, Holmes (1946) in Edinburgh, and Houtermans (1947) in Göttingen, who pioneered the modern view of the age of Earth, not to mention the acknowledgment by Pope Pius XII (1951) that the ages of the Earth and Universe must be measured not in thousands, but billions of years. Although the Copernican Revolution started 450 years ago, it has not been won – and this is an indictment of science teachers as well as fundamentalists.

## SETTING THE STAGE: THE 1940s AND 1950s

The terrestrial planets were not major objects of study in the 1940s and 1950s, and only a handful of scientists worked professionally on the Solar System. These included astronomer Gerard Kuiper, who discovered the atmosphere of Titan spectroscopically (Kuiper 1944) and trained newly developed infrared technology on the Venusian and Martian atmospheres after World War II (Kuiper 1952); the Nobel laureate geochemist Harold Urey, who published the epoch-marking book *The Planets* (Urey 1952); astronomer Fred Whipple, who published seminal papers on the nature of comets (Whipple 1950, 1951); and Ernst Öpik, who published amazingly prescient papers on a variety of planetary issues, such as impact cratering by interplanetary bodies (Öpik 1951, 1963, 1964) and the surface of Mars (Öpik 1965). Urey and Kuiper both developed far-ranging ideas on the origin of planets and planetary surface features, but rarely saw eye to eye. It is important to realize that although researchers such as Otto Schmidt and, later, Viktor Safronov (1972) developed a strong school of studies on planetary origins, their work was virtually unknown outside the Soviet Union until the 1970s.

The nature of meteorite craters was wholly unappreciated during this period. Much of the literature about the Moon during the preceding century was consumed with arguments over whether the lunar craters were volcanic or impact features. Scattered suggestions that there were many eroded impact features on Earth had about them the aura of fringe science. Arizona's so-called "Meteor Crater" was still listed as "Crater Mound" by the US Board of Geographical Names, even though it was not a mound (Hoyt 1987). This was allegedly because the first director of the survey, G.K. Gilbert, believed it was a volcanic feature and not an impact crater. This was ironic, because Gilbert himself later championed the impact theory for lunar craters. As late as 1945, US Geological Survey (USGS) scientist N.H. Darton delivered a paper decrying any use of the terms "meteor" or "meteorite" in the crater's title, because "I am convinced that no meteorite is present" due to the lack of discovery of an iron mass during drilling (Hoyt 1987, p. 333). This in spite of the fact that the surface around the crater is strewn with small iron meteorites!

In 1949, Ralph Baldwin, a businessman with a PhD in astronomy from the University of Chicago, published *The Face of the Moon* (Baldwin 1949), a highly original work in which he used his experience with bomb craters in World War II to argue methodically that the geometric properties of lunar craters matched impact explosion features, not volcanic features. This was the turning point in the argument about the origin of craters, and led to wide acceptance of the view that the Moon had been peppered with impacts. (The book, from the University of Chicago Press, was not a big seller; I bought my copy on a remainder table of a favorite bookstore in Pittsburgh for $1.49 when I was a boy, attracted by its cover picture of the Moon.)

As for the terrestrial planets, amateurs and professionals alike argued about the cause and significance of the various faint, dusky markings that could be glimpsed on Mars, Mercury, and probably Venus. Frank E. Ross (1928) had shown that the faint, dusky markings of Venus could be photographed with much more clarity and contrast by using ultraviolet filters; they were evidently cloud features, but little more was known about them. Walter Adams and Theodore Dunham (1932) had shown that carbon dioxide was a major atmospheric constituent.

There was a curious flavor to interest in spaceflight or planetary exploration at this time, difficult to recapture today. Popular literature, such as comic books, were full of articles about "post-war marvels." Boys (and a few girls) who read science fiction "knew" that spaceflight was coming, but adults rolled their eyes at such fantasies. In 1952–54, *Collier's* magazine ran a now-famous series of articles by Wernher von Braun, with paintings by the dean of astronomical art, Chesley Bonestell, detailing how we could launch artificial satellites, build a wheel-shaped space station (the design later immortalized in Stanley Kubrick's 1968 film *2001*), and explore the Moon and Mars. In 1956, President Eisenhower surprised many Americans and galvanized science students' imaginations by announcing that the USA, as part of the International Geophysical Year, would attempt to launch an artificial satellite around the Earth. Eisenhower emphasized that the USA would not use existing military rockets, but would develop a new civilian rocket for a fledgling, non-military space program. As is now known publicly, the Soviet Union had also begun development of an artificial satellite project under Sergei P. Korolev, with initial authorization given in January 1956 (Harford 1997, p. 125 ff.).

On 4 October 1957, before the Americans were ready to launch, the Soviet engineers launched Sputnik 1 into Earth orbit. It was followed a month later by the much bigger Sputnik 2 and its booster, which were very prominent in skies around the world. Sputnik 1 was very faint, but the booster of Sputnik 2 was bright and tumbled in its orbit, leading to dramatic variations in brightness with a period of the order of tens of seconds, flashing to about first or second magnitude. This produced profound shock in the USA, leading to massive reorganization of school science programs, and for the first time moved the popular concept of spaceflight from the realm of science fiction to reality. At the same time, the Sputniks galvanized the imagination of young science students in the USA. The spirit of this period is well captured in the film *October Sky*, based on the memoir *Rocket Boys* by Apollo engineer Homer Hickam (1998).

In retrospect, the competing political philosophies of secrecy *v.* scientific openness provide us with important lessons about scientific progress in planetary exploration. The discovery of Earth's radiation belts was credited to James Van Allen from data received by the US Explorer 1 satellite in 1958, but Dessler (1984) reviews how the detectors installed in the earlier Soviet satellite, Sputnik 2, actually measured the radiation belts in 1957. However, according to Dessler, the Soviets chose for reasons of secrecy not to arrange for other countries to detect or decode their satellite signals or pass them on to the Sputnik team. Thus, they did not get enough tracking data from Sputnik 2 to recognize the belts. Dessler remarks that, "Because of their perceived need for secrecy, the Russians missed making one of the most dramatic discoveries in space science."

## THE LOW ATMOSPHERIC PRESSURE AND RED COLOR OF MARS: 1947–64

In the twentieth century, the estimated atmospheric pressure and habitability of Mars fell progressively. Percival Lowell's theories at the beginning of the century suggested a thin but Earth-like atmosphere. Although Lowell has been vilified, and even ridiculed, for his theories about civilizations and artificial canals on Mars, he started by propounding underlying ideas that still have validity. He pointed out that smaller planets lose their internal heat faster than larger planets, and are also more subject to the escape of their atmospheres. Thus, Mars was geologically dying and drying, and the atmosphere was being lost to space. But Lowell thought there was evidence for a thicker atmosphere than really exists. He argued that the warm equatorial regions were the most habitable in terms of temperature but that most of the planet's water was locked in the polar ice. Thus, Martian civilizations had built canals to deliver melt water from the polar ice caps to their equatorial settlements. This view of Mars electrified not only scientists, but writers and intellectuals from Alfred Tennyson to H.G. Wells, who combined it with the ideas of Charles Darwin to speculate upon the implications for humanity if we were not alone in the Solar System. This was the Mars that colored much of twentieth-century Martian research, and served as the framework against which to react. In the first decades of the century, researchers began to realize that the planet must be less habitable than Lowell had thought and the surface conditions were likened to a winter day at the top of a mountain on the island of Spitzbergen in the Arctic Ocean.

The changing ideas of Mars were also reflected in popular culture. Edgar Rice Burroughs, in his science fantasy novels, peopled Mars with evil queens and great beasts. Ray Bradbury, in his 1940s classic *The Martian Chronicles*, portrayed the last remnants of Martian civilization, eleing out an existence by the languid canals.

By the middle of the century, the estimated surface pressure had dropped to 100–200 mbar. Kuiper (1947) first detected the carbon dioxide of Mars and erroneously reduced the data to give a surface $CO_2$ partial pressure of only 0.35 mbar. Because this was so small, most researchers assumed that $CO_2$ was only a minor constituent in the atmosphere and that nitrogen or some other gas was dominant, with a moderate surface pressure. Gerard de Vaucouleurs (1954), summarizing the available evidence, gave the surface pressure as $85 \pm 4$ mbar. The erroneously low estimate of $CO_2$ abundance was a factor in Kuiper's further conclusion, now disproved, that water ice was the main constituent of the polar ice caps.

These views persisted for some years. Horowitz (1986), with some amusement, cites an advisory report to NASA from a prestigious space science board in 1961, stating that "infrared reflection spectra of the polar caps show conclusively that they are not composed of frozen carbon dioxide," but were water ice and frost. They also advised that the total surface pressure was within a factor two of 85 mbar – exactly the value, as Horowitz points out, that Percival Lowell (1910) had published in his book *Mars as the Abode of Life*.

During the first years of infrared studies, another interesting episode occurred. William Sinton (1957) announced confirmation of three faint bands around 3.4 μm wavelength, which he identified with the C–H bond, specifically chlorophyll. In the title of his paper he called this "Spectroscopic evidence for vegetation on Mars" – the long-sought confirmation that the dark markings were caused by simple plant forms. However, a few years later Sinton himself and other observers showed that these bands were due to other causes. This was as close as ground-based telescopic observers ever came to claiming definitive evidence for life on Mars.

Eventually, a clearer view emerged from the ground-based infrared work. Kaplan *et al*. (1964) studied weak, unsaturated $CO_2$ bands and concluded that the mean surface pressure was 2.515 mbar (Horowitz (1986) refers to this paper as the true beginning of the post-Lowellian understanding of Mars.) In the same year, Owen and Kuiper (1964) used their own spectra and improved laboratory calibration (long-pathlength spectra through low-pressure $CO_2$) to derive a surface pressure of 1.73 mbar, though they still thought that the atmosphere was likely to be dominated by nitrogen (see also Kuiper 1964).

The same period saw the emergence of the basic understanding of the red color of Mars. By the 1960s, broadband infrared spectroscopy had advanced to the point where it could begin to be used to identify major absorption bands due to minerals on the Martian surface. Two graduate students in Kuiper's infrared spectroscopy laboratory, Binder and Cruikshank (1966), showed that there was a good fit between Mars spectra and red, oxidized basalts found in the desert west of Tucson, Arizona. They proposed, essentially correctly, that the color of Mars comes from oxidized iron minerals that exist as stains on the surface of rocks and dust particles; they emphasized limonite and other iron oxide minerals. This work was generally supported by Adams (1968) and McCord and Adams (1969), who examined additional iron oxide minerals.

Philosophically, work of this sort was an extension of the Copernican Revolution and early ideas about the plurality of worlds. The Copernican Revolution revealed that Earth was not a unique center, but merely one of many planetary worlds. The idea of the plurality of worlds introduced an assumption that the other worlds might be other Earths, with environments similar to our own. William Herschel had believed that Mars, on which he saw clouds and polar caps, was Earth-like. Only in the 1950s and 1960s did solid observations begin to accumulate that allowed these ideas to be assessed. The emerging answer, with profound and still under-appreciated consequences, was that many other planets are indeed worlds with Earth-like minerals and geology, and yet each has a personality of its own.

## EARTH: IMPACT CRATERS LEGITIMIZED, *c.* 1960

Research on planetary geology began to be legitimized around this same time. In the late 1950s geologist Eugene

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