Mercury's Rotation and Visual Observations

DALE P. CRUIKSHANK, *Lunar and Planetary Laboratory, University of Arizona*
and CLARK R. CHAPMAN, *Department of Astronomy, Harvard University*

THE ITALIAN discoverer of the Martian canals, G. V. Schiaparelli, announced in 1890 that the planet Mercury rotates once every 88 days, keeping one side always approximately toward the sun. This synchronous rotation appeared to be fully confirmed by the eminent planetary observer E. M. Antoniadi in the 1920's. Therefore, it was quite a surprise, particularly to those who had made maps assuming the 88-day period, when in 1965 Cornell radio astronomers G. H. Pettengill and R. B. Dyce discovered that Mercury rotates in 59 ± 5 days.

The new period found by Doppler radar techniques helped explain the high temperatures measured on the previously supposed eternally dark side. Theoreticians were quick to offer dynamical reasons (based on tidal resonance) for expecting a rotation period exactly two-thirds of the 87.9693-day orbital period, or 58.6462 days.

Prior to this new determination of the rotation period, about 20 maps of Mercury had been compiled, some based on extensive visual work by such experienced observers as Antoniadi, V. and G. Fournier, W. H. Haas, and A. Dollfus, others on high-resolution photography in 1942 and 1944 at Pic du Midi Observatory. That any maps could have been prepared at all had appeared to be an independent confirmation of an 88-day period.

Clearly, optical study of Mercury must be reorganized. But why did the earlier work fail? It is tempting to conclude that the visual observations were worthless, but the answer is not that simple.

Observing Mercury is difficult for many reasons. Always less than 30 degrees from the sun, the elusive planet is visible to the unaided eye only low in the sky during morning or evening twilight. Poor seeing conditions near the horizon rarely allow telescopes to show details on Mercury's tiny disk, which averages only seven seconds of arc in diameter.

Therefore, some observers work in the daytime, when the planet is high in the heavens. But usually the surface brightness of the blue sky is greater than that of Mercury, thereby reducing the contrast of its markings to close to the visual contrast perception threshold. When the sky is hazy or the telescope optics slightly dusty or seeing conditions less than excellent, Mercury always appears featureless. It is impossible to get more than vague hints of markings on even the best photographs.

Nevertheless, around sunset or sunrise, surface features can be seen on Mercury, though with difficulty, even in telescopes as small as a 4-inch. One need not rely on imagination to sketch the planet; experienced observers can make crude but objective drawings when conditions are good. Why, then, were astronomers unable to discover the correct rotation period? A little gullibility combined with an interesting natural coincidence is the answer.

Mercury's synodic period of 116 days (the cycle of phases) is almost exactly 4/3 the time of orbital revolution, twice its 59-day rotation period, and about 1/3 of a terrestrial year. The result of these numerical agreements is that, to a first-order approximation, objective drawings of Mercury will be consistent with *both* the correct 59-day rotation period and the incorrect 88-day period!

As Mercury moves around its orbit, it swings back and forth in the sky from evening visibility on the eastern side of the sun to morning visibility on the western side. Each such appearance is called an apparition, and usually the planet can be studied effectively for only about two weeks around the date of greatest elongation from the sun. Generally there are three eastern and three western apparitions in a year. And the average interval between successive morning (or evening) elongations is the synodic period of 116 days.

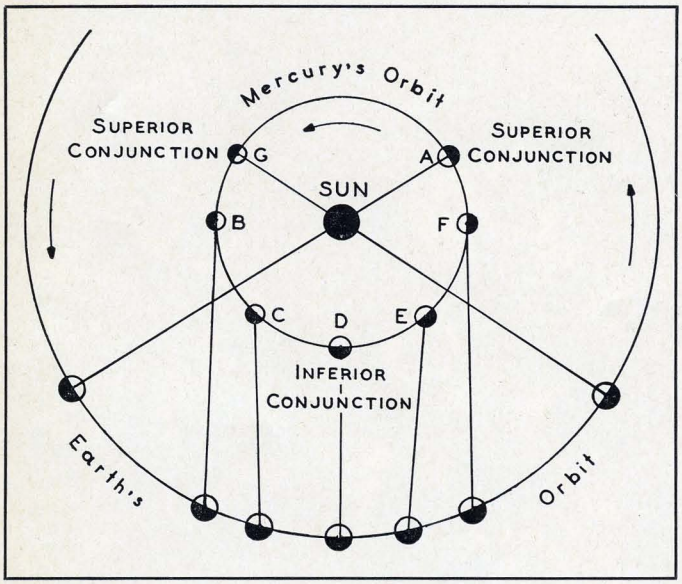
Not all apparitions are equally favorable for observers in north temperate latitudes. Eastern apparitions are advantageous in the spring because the ecliptic rises steeply from the horizon at sunset and Mercury is relatively high in the sky. However, in the autumn the planet has a more southerly declination than the sun and is already low at sunset. The reverse is true for morning apparitions, the autumn ones being more attractive than those in spring.

In many years there is only one favorable eastern and one favorable western elongation. For example, in the Graphic Time Table of the Heavens in SKY AND TELESCOPE for January, in 1967 the "Mercury rises" and "Mercury sets" lines cross the twilight lines only for the February and November apparitions. Generally, for half a dozen years favorable eastern (or western) apparitions follow each other at intervals of three synodic periods.

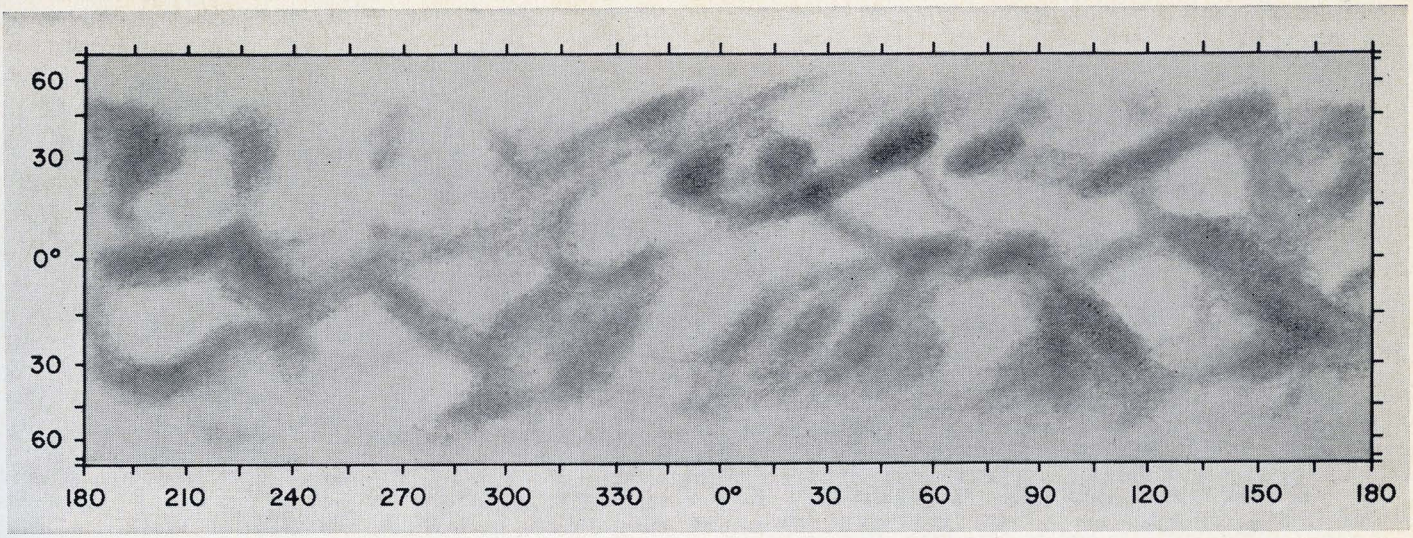
Two kinds of observations led early observers to deduce an 88-day rotation period. First, markings do not appreciably change position on the disk from hour to hour or from day to day. Hence the rotation must be longer than a few weeks. Also, features seemed to be recorded in the same places during successive eastern (or western) apparitions, which is compatible with Mercury keeping the same side toward the sun. Surprisingly, the early observers did not seem to notice that both facts are also consistent with a spurious 50-day period, during which Mercury would make two rotations between presentations of the same face to Earth.

Since the true rotation period of 59 days is 2/3 of the planet's year, there are three Mercurian sidereal days or two Mercurian years between successive sunrises at a fixed point on the planet. But this is about as long as $1\frac{1}{2}$-synodic periods. Thus, if we originally observe Mercury at a morning apparition, the next time its same face becomes illuminated is $1\frac{1}{2}$ synodic periods later, when the planet is at an evening apparition and we are viewing the opposite hemisphere.

However, after two Mercurian solar days, or three synodic periods, we see the same face of the planet at the same phase. And since three synodic periods is also the



Although Mercury completes one sidereal revolution around the sun (from *A* to *A*) in 88 days, it must continue on to *G* before again being at superior conjunction as seen from Earth. This synodic period averages 116 days, and is the time between recurrences of the planet's phenomena in the sky: *B*, greatest evening elongation; *C*, stationary point; *D*, inferior conjunction; *E*, stationary point; *F*, greatest morning elongation.



The new composite map of Mercury, based on 130 visual observations, with south at the top. A rotation period of exactly two-thirds the orbital period was assumed. The map projection is a cylindrical orthographic equal-area. Positions are accurate to no better than 10 degrees, and the rather small effect of libration in latitude was ignored.

time interval between favorable apparitions, an observer working only at such times will see the same surface features in the same places for half a dozen years in succession – just the criterion used to justify an 88-day period!

After that, however, the periodicity gets out of phase, and a region 120 degrees removed in longitude on Mercury will be seen during succeeding years. But since maps of Mercury are usually based on only a few years of telescopic work, it is not surprising that most of an observer's drawings are consistent with one map.

For example, Antoniadi's third and last map is based upon observations in 1924, 1927, 1928, and 1929. Of the nine eastern-apparition drawings in his book (*La Planète Mercure,* Paris, 1934), seven show a single face of Mercury. In the other two, which represent a region about 120 degrees away, the major dark marking Sinus Criophori is entirely missing! Four of the five western-apparition drawings show the same face. If these Antoniadi depictions are representative, it is not surprising that he found the majority of them consistent with his map and with an 88-day period.

Of course, not all observers confined themselves to every third apparition, east or west, so there were bound to be some discrepancies. But most people went to the telescope believing in the results of Schiaparelli and Antoniadi, which implied one should see the same markings every time. It was easy for an observer subconsciously to force elusive features to conform with his preconceptions.

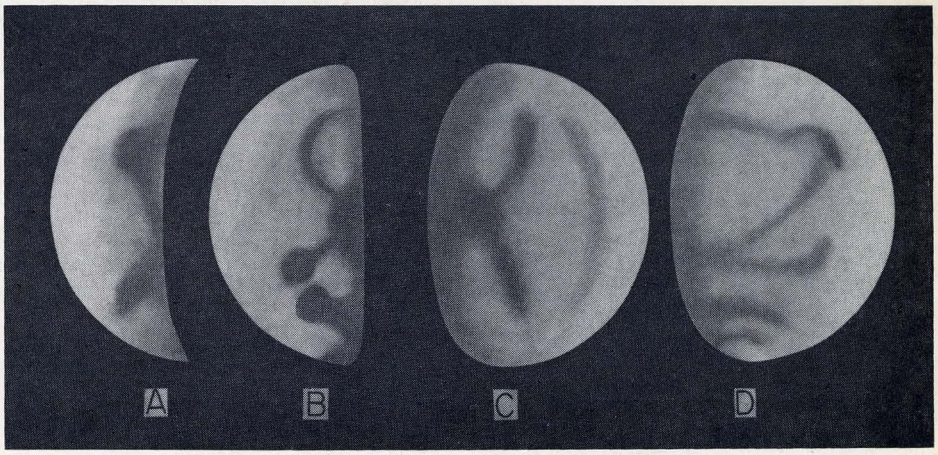
When conditions were so good that the view unmistakably differed from expectation, several rationalizations could be applied. For one, because of the large orbital eccentricity and inclination, Mercury was expected to librate 23 degrees in longitude and seven degrees in latitude. Though a few observers actually computed the librations, others assumed that they accounted for shifts in surface features. The Fournier brothers went so far as to hypothesize seasonal changes in the planet's features, and Antoniadi invoked secular changes.

Also, it is clear that many observers have been biased in favor of earlier maps, and that many drawings, particularly those made under unfavorable conditions, are subconscious reproductions of Antoniadi's chart. Is it possible to salvage meaningful information from the earlier data?

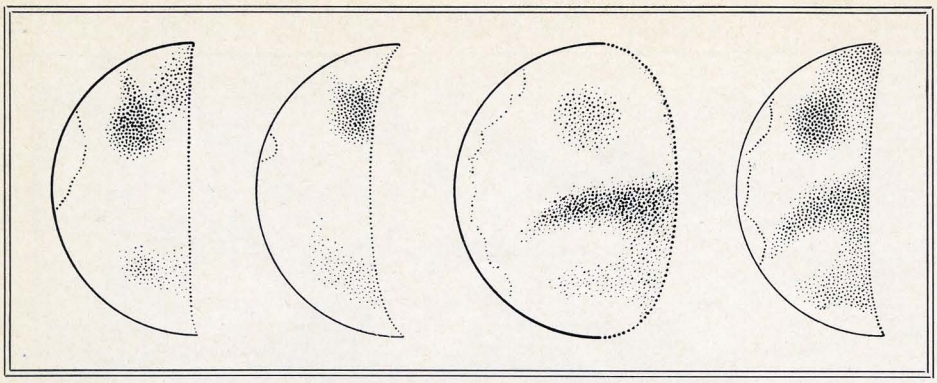
We find that the answer is only marginally yes. One of us (Clark Chapman) has used a computer in an attempt to determine the rotation period more precisely than is possible with radar techniques. About 130 representative drawings were selected from several hundred made by many observers between 1882 and 1963. These were divided into groups showing similar features, and all possible choices of period that could represent the observations were computed. Since the correlation of true features is largely masked by the effects of observers' bias, the results are only marginally significant. Nevertheless, a rotational period of exactly $\frac{2}{3}$ the orbital period was one of the best choices, being determined from the drawings to about 0.03 day.

On the assumption that the rotation period is 58.6462 days, the central meridians of the 130 drawings were computed. It was surprisingly easy to assemble these drawings into the map shown here, which is further evidence that the adopted rotation period is very nearly correct. Although not totally unaffected by earlier biases, this chart probably represents accurately the gross surface features of Mercury. Longitude 0° is defined as the central meridian of the total disk as seen from celestial longitude 0° on Julian Day 2,424,417.5 (September 24, 1925). The map grid is based on the further assumption that the planet's equator lies approximately in the plane of its orbit.

The completed map suggests a ten-



Mercury drawings by V. and G. Fournier with refractors of 9- to 12-inch aperture. *A* and *B* show different faces of the planet at eastern apparition, while *C* and *D* are of different faces at western apparition. There is fair agreement of gross features on these drawings with Clark Chapman's map above; the details show less accord. The dates and approximate apparent central meridians are: *A,* April 9, 1918, 345°; *B,* December 16, 1917, 115°; *C,* February 6, 1918, 65°; *D,* May 10, 1920, 345°. Adapted from *Observatoires Jarry-Desloges: Observations des Surfaces Planétaires.*



Four sketches by E. M. Antoniadi with the 33-inch Meudon refractor when Mercury was at eastern elongation. The so-called Sinus Criophori, the large dark equatorial feature in the two right-hand sketches, is absent from those at left. The reason is that the latter show a different face of the planet, not the same as Antoniadi assumed. Dates and approximate apparent central meridians are (left to right): August 11, 1924, 25°; June 21, 1927, 5°; October 11, 1927, 230°; September 11, 1929, 240°.

dency for Mercury's major dark features to be aligned northwest-southeast and northeast-southwest. The same gross structural trends have long been known for the terrestrial continents and more recently for the ocean floors. The lunar grid system of structural lineaments has its strongest components in these same directions, according to an extensive study in 1964 by Robert Strom of the University of Arizona.

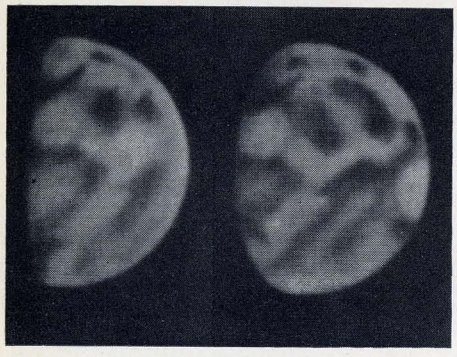
Alan Binder, also at Arizona, found a similar alignment on the Mariner 4 photographs of Mars. This lends credence to a 1959 proposal by G. N. Katterfel'd of Leningrad that Martian canals and other features reveal structural elements in the Martian surface corresponding to the orthogonal diagonal lineaments in the earth's crust. If the new map of Mercury is largely correct, another solar system body can be added to the list of those with diagonally oriented lineaments.

Although such features are not fully understood even for the earth, they are probably related to the thermal and dynamic histories of these bodies (see W. K. Hartmann's article in SKY AND TELESCOPE, September, 1966, page 128). As a solid body contracts thermally and as tidal interactions slow its rotation, energy is dissipated in the crust, which may result in stresses having a well-defined orientation relative to the rotational axis. Such events as fractures along the stress direction may then cause structural lineaments.

Transient and long-term changes in Mercury's markings have been reported frequently. Many cases must now be dismissed as permanent features misidentified because of the old rotation period. However, Antoniadi observed changes within only a day or so and similar short-term variations have been recorded by Henry McEwen in the Mercury Section reports of the British Astronomical Association. Antoniadi thought these changes were produced by clouds in the Mercurian atmosphere. But recent evidence suggests that if any atmosphere exists it is not cool or dense enough to permit cloud formation. In particular, new spectroscopic observations by Binder and Cruikshank and by Michael Belton of Kitt Peak National Observatory indicate so little carbon dioxide on the planet that it exerts a surface pressure of less than 0.01 percent terrestrial atmospheric pressure. The new work contradicts the enhancement of the 1.6-micron bands of carbon dioxide in Mercury's spectrum reported by Vasili Moroz of Moscow in 1963 and 1965. While the reason for the discrepancy is not fully understood, all parties agree that the measurements are very difficult to obtain.

Another possible explanation of short-term changes on Mercury merits consideration. A planet or satellite unprotected by an atmosphere or a strong magnetic field is unceasingly bombarded by ultraviolet light and particles from the sun. There is evidence that areas on the moon respond to this bombardment by a luminescence that can be detected photometrically and spectroscopically. Mercury shares many photometric properties of the lunar surface, including very low albedo, that in the moon's case are believed to be due to solar bombardment. Since Mercury receives nearly 10 times more solar radiation per unit area than the moon does, luminescence effects may change the apparent brightness of some surface areas enough to alter relative contrasts appreciably.

Many clues to the physical nature of Mercury await only systematic visual and photographic observing programs by well-equipped and favorably located observers on Earth. But final answers to these intriguing questions may not come until a space vehicle flies by that planet.



Mercury's dusky markings are seen here in two drawings made by Audouin Dollfus in October, 1950, with the 24-inch refractor at Pic du Midi, powers 750 to 900. The central meridians were about 330° (left) and 0°. Under the best conditions, he says, Mercury's markings are like the moon's seen with the naked eye.

SO THAT observers can compare their own drawings of Mercury with the new map, the table lists the Julian dates (J.D.) between 1960 and 1975 at which the longitude of the central meridian is 0° *as seen from celestial longitude* 0°. This "celestial C.M." for any J.D. can be found by subtracting from the date of observation the preceding J.D. in the table and multiplying the result by 6°.1385, the change in longitude per day. To find the C.M. *as seen from the earth,* subtract the "hermocentric longitude of the earth," which is given approximately by 180° + elongation of Mercury from the sun + geocentric longitude of the sun. (The latter two quantities are tabulated in the *American Ephemeris and Nautical Almanac,* in the 1967 volume on pages 8 and 18, respectively. Mercury's elongation is positive when east of the sun, negative when west.) Accuracy is about ±8°.

JULIAN DAY 2,400,000 plus:

36968	37554	38141	38727	39314	39900	40487	41073	41659	42246
37026	37613	38199	38786	39372	39959	40545	41132	41718	42305
37085	37672	38258	38844	39431	40017	40604	41190	41777	42363
37144	37730	38317	38903	39490	40076	40662	41249	41835	42422
37202	37789	38375	38962	39548	40135	40721	41308	41894	42481
37261	37847	38434	39020	39607	40193	40780	41366	41953	42539
37320	37906	38493	39079	39666	40252	40838	41425	42011	42598
37378	37965	38551	39138	39724	40311	40897	41484	42070	42656
37437	38023	38610	39196	39783	40369	40956	41542	42129	42715
37496	38082	38669	39255	39841	40428	41014	41601	42187	

NUMERICAL EXAMPLE

What is the central-meridian longitude on Mercury for a drawing made November 18, 1967, at 0^h UT? This is J.D. 2,439,812.5, or 29.5 days after the date 2,439,783 in the table.

"Celestial C.M." = 29.5 × 6.1385 = 181°.

From the *American Ephemeris,* on November 18th the elongation of Mercury from the sun is 19° west (−19°), and the geocentric longitude of the sun is 235°.

"Hermocentric longitude of Earth"
= 180° − 19° + 235° = 396° or 36°.

Finally, central-meridian longitude as seen from Earth is about 181° − 36° = 145°.