# MEASUREMENTS OF THE RADIATION FROM THE PLANET MARS.

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The radiation from Mars has been measured with vacuum thermocouples attached to the 100-inch telescope, at intervals over a period of about a year. The measurements cover a considerable variety of observing conditions as well as phases, distances and seasons on the planet.

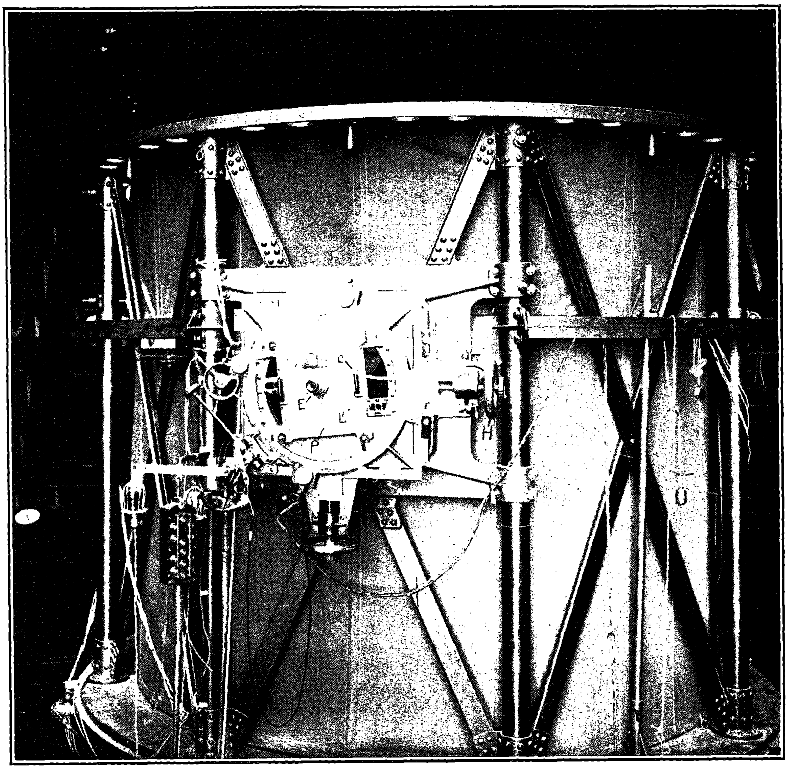
The term "radiation" is used to cover both the radiant energy given off by the warmed surface of the planet and the sunlight reflected from it. There is a common belief that the thermocouple measures "heat radiation," but the fact is that it measures impartally radiation of all wavelengths which falls upon its blackened junctions. It will measure ultra-violet and visual light quite as readily as the infra-red or "heat radiation." In the case of an early-type star most of the radiation which the thermocouple measures is visual light, while in the case of the moon or Mars most of the radiation is invisible and is confined to the far infra-red.

In the measurement of stellar radiation there is probably little difference between the reflector and the refractor, aperture being the principal consideration. In the case of the red stars there would be some troublesome corrections if a refractor were used. For observing the radiation from planets it is necessary to use a reflector, since a piece of glass as thin as a microscope cover-glass is opaque to most of the radiation from their heated surfaces. About all the radiation which a refractor transmits is the reflected sun-light, which in the case of Mars is about 44 percent of the radiation falling on the objective and 14 percent in the case of the moon. The radiation from the dark side of Venus produces a large deflection, but is entirely cut off by a microscope cover-glass.

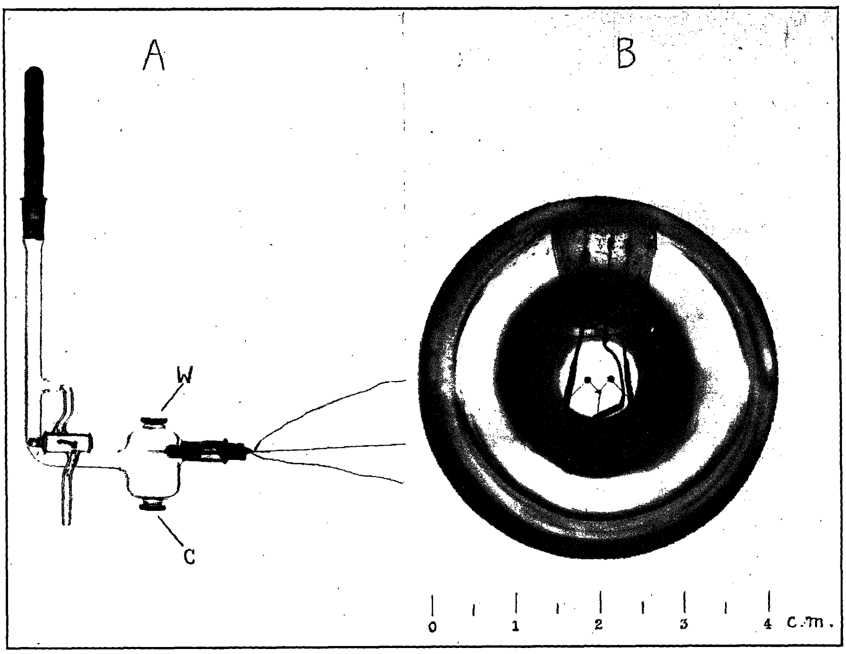
The principal observing equipment consists of the telescope which collects the radiation, a vacuum thermocouple which changes the radiation to electrical energy, a galvanometer to measure the current, a photographic device which registers the galvanometer deflections, and a comparator for measuring the plates upon which the deflections of the galvanometer have been traced photographically.

Plate XXX shows the Newtonian cage of the 100-inch telescope with the thermocouple equipment attached. The thermocouple is clamped to the square plate P in front of the eyepiece E in the double slide plate-holder which is used for direct photography. By means of the lever L a water cell, glass plate or fluorite plate can be thrown in front of the thermocouple in order to study the spectral distribution of the radiation being measured. The cable C carries the current from

# PLATE XXX.



Upper end of the tube of the 100-inch telescope showing the Newtonian plate-holder with thermocouple attached.




(A) The vacuum thermocouple as used in the observations of radiation from Mars.
(B) Junctions of the thermocouple as seen by the observer looking into the eye-piece E.

the thermocouple to the D'Arsonval galvanometer which, together with the registering device is in the basement of the dome, 135 feet away. The telephone T connects the observer at the thermocouple with the observer at the galvanometer.

Plate XXX A shows one of the vacuum thermocouple cells which we have used in measuring the radiation from Mars. The radiation is admitted to the cell by a rock-salt window W. A glass window C enables the observer to see both planet and thermocouple simultaneously, much as one sees cross wires in a finder. The vacuum in the cell, which must be better than that in an X-ray tube in order to keep the thermocouple at its highest efficiency, eliminates losses of heat due to conduction and convection through the air, and increases the deflections about eleven fold.[1]

Looking into the eyepiece E (Plate XXX), one sees the thermocouple junctions as shown in Plate XXX B. By turning the guiding handle H (Plate XXX) either of the small octagonal receivers can be placed on the image of the planet. When these junctions are heated alternately by the image of the planet, they produce currents in reverse

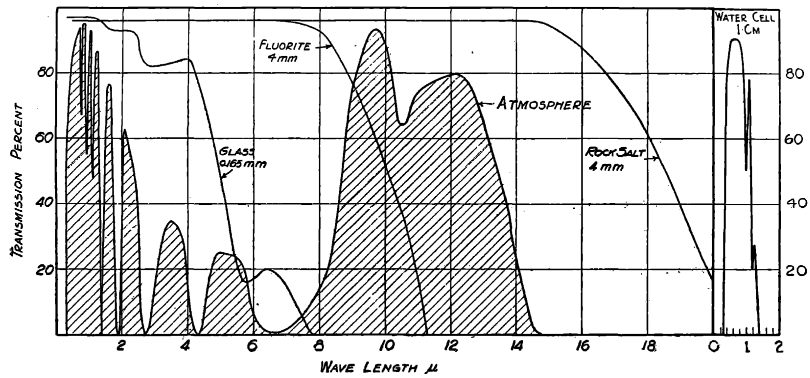



Fig. 1.

Transmission curves of the atmosphere (the shaded curve), glass plate (microscope cover-glass), fluorite plate, rock-salt window and water cell.

directions, and therefore any general radiation, such as that from the sky or the telescope, which falls on both at once, produces a null effect. Hence the instrument can be used to observe stars and planets in the daytime and gives the same deflections as at night. The effect of bad seeing is to decrease the deflections and produce irregular curves.

Two thermocouples were employed in observing the radiation from Mars; No. 36 having receivers 0.8 mm in diameter, used to measure the integrated radiation from the planet, and No. 42 having receivers 0.40 by 0.20 mm, used for observations of planetary markings, drift curves, etc.

[1] *Astrophysical Journal,* Vol. 56, pp. 295-317, 1922.

The three screens, a water cell 1 cm thick, a glass plate 0.165 mm thick and a fluorite plate 4 mm thick, made it possible to isolate the regions 0.3$\mu$ to 1.3$\mu$, 1.3$\mu$ to 5.5$\mu$, 8$\mu$ to 11$\mu$ and 11$\mu$ to 14$\mu$, when combined with the transmission of the atmosphere. Transmission curves for the atmosphere (the shaded curve), for the rock-salt window of the thermocouple cell and for the three transmission screens, are shown in Figure 1. The absorption of the atmosphere is due principally to the water-vapor, carbon dioxide, oxygen and ozone. It is through the great transmission band 8$\mu$ - 14$\mu$ that we receive most of the radiation from the heated surfaces of the planets, although a small amount comes through the weak bands between 3$\mu$ and 5.5$\mu$. This we shall call *planetary radiation.* A comparison of these curves will show the need of reflecting telescopes and rock-salt windows in the measurement of planetary radiation.

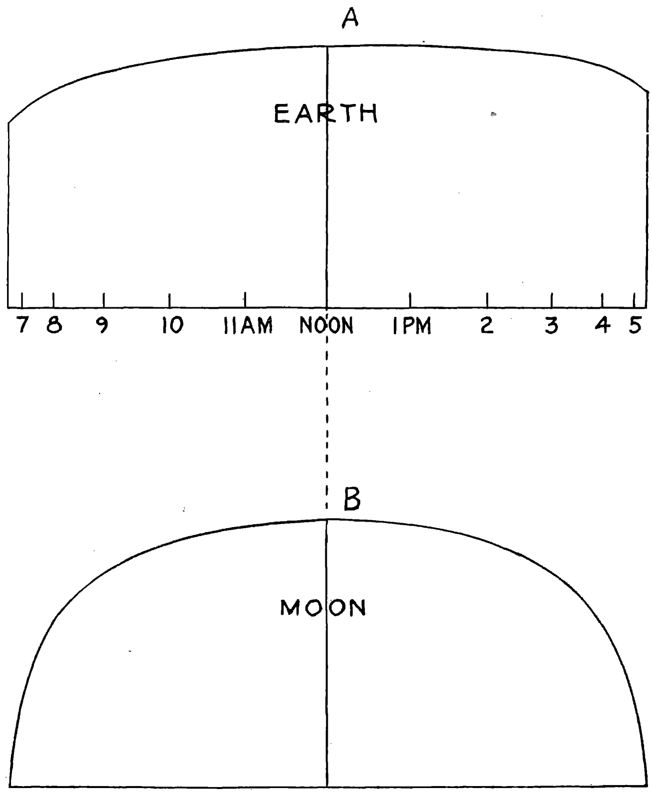



Fig. 2.

Curves of planetary radiation across the earth (computed for the 39th parallel) and across the moon (observed).

The registering device consists of an apparatus by means of which a photographic plate is moved vertically by a motor-driven screw. Light from a straight filament lamp is reflected from the galvanometer mirror and forms an image of the filament upon a long cylindrical lens placed horizontally in front of the plate. The part of the image intercepted by the lens forms a point of light upon the plate, where it traces a line. A synchronized contact gives a signal on a buzzer at the telescope for each centimeter which the plate moves. At each of these signals the observer at the telescopes shifts the thermocouple so that the image of the planet or star falls on the other receiver. The resulting deflection of the galvanometer produces a line which is displaced alternately right and left upon the plate and the amount of this displacement measures the amount of the radiation received by the thermocouple.

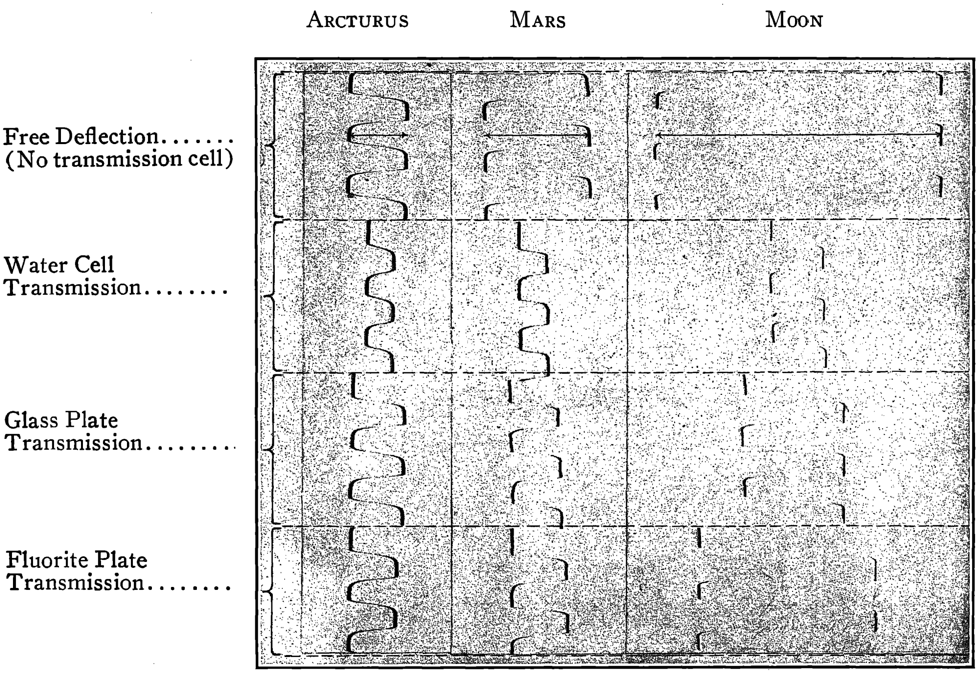



FIG. 3.

Galvanometer deflections from the radiation from Arcturus, Mars and the moon. The size of the deflections is indicated by the arrows.

Figure 3 shows a set of such deflections for Arcturus, Mars and the moon. The values of the free deflections are indicated by the arrows. It will be noted that in the cases of Mars and the moon only a relatively small fraction of the radiation passes through the water cell and cover-glass, while in the case of Arcturus about half of it comes through the water cell and about ninety percent through the cover-glass. This indicates the presence of less infra-red radiation from Arcturus than from Mars and the moon.

The radiometric magnitude of Mars (the magnitude of an A0 star from which we would receive the same amount of radiation) was determined by measuring the radiation from stars in the same region of the sky. The radiometric magnitudes of these stars has been determined by a considerable number of direct comparisons and the atmospheric absorption factors to reduce the observations to the zenith have been determined for both the stars and the planet. Since the image of the planet at opposition is twice the diameter of the receivers of couple No. 36, it is necessary to make a correction for the amount which does not fall upon the receivers. This correction factor was obtained by integrating the drift curves made with couple No. 42 and its value is 0.78 magnitude. If we apply this correction to the radiometric magnitude determined when the junction is placed centrally upon the planet, we find that the radiometric magnitude of Mars at this opposition was —3.92, which is its maximum brightness. The radiometric magnitude of the *dark hemisphere* of Venus at inferior conjunction is nearly one magnitude brighter, namely —4.84. The radiometric magnitude of Sirius is only —1.3, more than two and one-half magnitudes fainter.

In Table I will be found the distribution of the energy in the spectrum of various features on Mars determined with the transmission cells compared with similar data for the moon, Mercury, the sun and Arcturus.

TABLE I.

| | Reflected Light | | ——— Planetary Radiation ——— | | | |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI |
| | $0.3\mu$-$1.3\mu$ | $1.3\mu$-$5.5\mu$ | $1.3\mu$-$5.5\mu$ | $8\mu$-$11\mu$ | $11\mu$-$14\mu$ | $8\mu$-$14\mu$ |
| Mars (Center disk | 28.2 | 13.6 | 6.8 | 17.2 | 34.3 | 51.5 |
| (Pole cap | 33.6 | 16.2 | 13.3 | 6.7 | 30.0 | 37.0 |
| (Integrated | 29.9 | 14.4 | 4.5 | 13.9 | 37.1 | 51.0 |
| Moon (Center, full phase) | 9.5 | 4.6 | 6.2 | 31.2 | 48.5 | 79.7 |
| Mercury | 6.5 | 3.2 | 20.2 | 37.6 | 32.5 | 70.0 |
| Sun | 67.5 | 32.5 | 0 | 0 | 0 | 0 |
| Arcturus | 49.2 | 48.0 | .... | .... | .... | (2.8) |

An inspection of the table will show that Mars is much like Mercury and the moon in that a large percentage of the radiation which it emits is transmitted by our atmosphere through the band between $8\mu$ and $14\mu$ (planetary radiation). Only about 8 percent of the radiation received from Jupiter, Saturn and Venus at full phase is planetary radiation.

The values given in columns II and III are computed from the values in columns I and VI assuming that the sunlight is unaltered in quality upon reflection. This indeed is not true, as the color of Mars testifies, and therefore these transmissions have not been used in computing the temperatures for this planet. The values in columns IV, V and VI can be used with more confidence, but here we are confronted with only a general knowledge of the atmospheric transmission in this region of the spectrum.

The amount of the correction to be applied to observed radiation to reduce it to the value it would have outside our atmosphere depends largely on the temperature of the body, the altitude of the observing station and the water vapor content of the atmosphere. The atmosphere transmits three-fourths of the radiation from the sun at the zenith on Mount Wilson, but only one-fourth of the planetary radiation from Mars. Obviously, in the region of low temperatures, the atmospheric corrections will reach a minimum value for the temperature for which the black body curve has a maximum near the middle of the $8\mu$ - $14\mu$ transmission band. A simple computation shows this to be about 265° absolute (—8° C). On either side of this minimum the curve of atmospheric correction against temperature rises steeply, more so on the violet than on the red side. As a result of this asymmetry the minimum actually falls at 290° absolute, where the value of the ratio of the total radiation emitted to that transmitted by the atmosphere on Mount Wilson under average conditions is about 1.4, but reaches 9.3 at 200° C absolute.

We may estimate the temperature of a point on Mars by two methods. First, we may attempt to make the data in Table I fit a black body radiation curve after applying the atmospheric transmission to it, or we may employ the principle of the total radiation formula (fourth power law). In either case the uncertainty of the atmospheric corrections affects the results. The temperatures of Mars computed by the two methods are indicated in Table II.

TABLE II.

| | Temperature Absolute | | |
|---|---|---|---|
| | From Spectrum | From 4th Power Law | Average |
| Center, full phase | 285° C | 275° C | 280° C |
| Limb | | 260 | 260 |
| Pole-Cap | 170 | 240 | 205 |
| Integrated Disk | 240 | 260 | 250 |

The radiation from the disk as a whole comes from regions of considerably different temperatures. In computing the temperature from the integrated radiation of the disk we have used the atmospheric corrections for the temperature for which a black body curve best fits the observations, and the temperature so computed can be regarded only as a general check upon the results. The uncertainty in our knowledge of the water vapor content of the atmosphere affects the values derived from the spectrum and from the fourth power law in opposite directions, and the effect is more pronounced for the low temperatures. Probably the best we can do at present it to take the average.

From these results we may conclude that the radiation temperature of a point in the tropics at noon-day on Mars is a little above freezing and that the mean temperature of the pole cap is about —70° C. The measures on the limb give the mean value over a region extending inward to about one-fourth of the radius toward the center in the tropics, and is about —13° C. The actual temperature at the limb is much lower than this.

That a deflection toward the side of heat is obtained from a body colder than the thermocouple receiver may at first seem somewhat surprising, but a little consideration will show that such is the case. Both receivers are radiating continually through the bands in the atmosphere to space where the temperature is absolute zero. When one junction is covered and the thermocouple then exposed to the sky

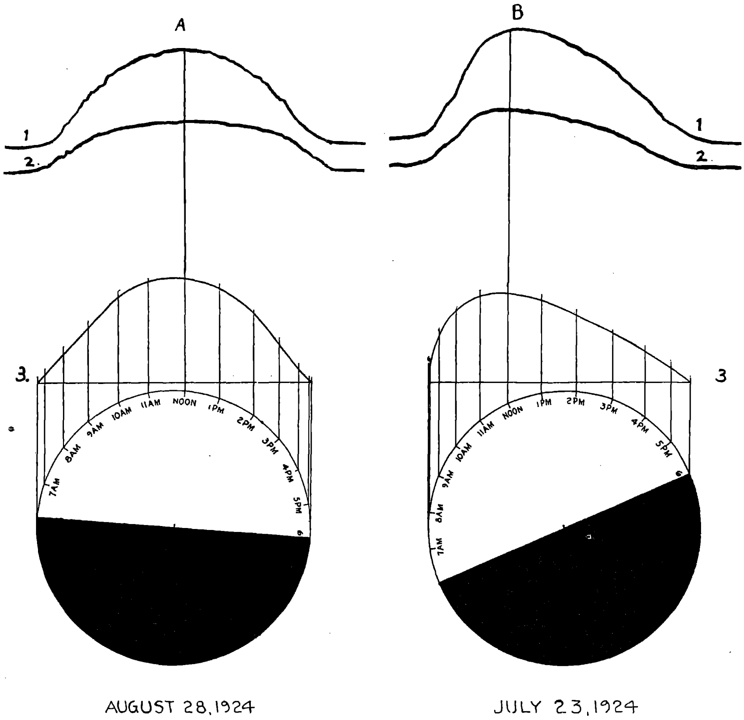



FIG. 4.

(1) Radiation curve across Mars near the equator (free deflection). (2) The same with glass plate inserted in the beam. (3) Curve of planetary radiation across Mars along the equator computed from Nos. (1) and (2) above, and its relation to the planet at the time of observation, A, five days after opposition and B, one month before opposition.

an enormous deflection is registered to the side of cold, since one junction is radiating to space while the other exchanges radiation with the shield. Any object in space which has any heat at all will therefore give a positive deflection regardless of the temperature of the thermocouple.

We may gain some knowledge about the planet's atmosphere and the distribution of heat over its surface by means of drift curves. These curves are obtained by driving the thermocouple junction slowly across the image of the planet and driving the registering device at the same time, both with uniform motion. They are taken in both an east and west direction and in a north and south direction, without and with transmission cells.

Figure 4 illustrates drift curves taken in this manner, A when the planet was five days past opposition, and B one month before the time of opposition. The two upper curves (Nos. 1 and 2) are the original curves taken "free," i. e., without any cell interposed in the beam, and with the glass plate interposed in the beam. Since the glass plate transmits all radiation up to 5.5$\mu$ the differences in the ordinates of these two curves measure the planetary radiation emitted. Curves No. 3 (below) are these differences (corrected for small differential factors due to the orientation of the planet's axis relative to the line of drift across its disk during the observation and the integrating effect of the receiver) plotted to the same scale. They represent the march of the planetary heat as the thermocouple junction moves along a parallel of latitude where the sun is in the zenith at noon. Below each of these sets of curves A and B are diagrams representing equatorial cross-sections of Mars with hours of the day marked upon them in the same relation to the curve that they had during the observation. Lines drawn from these hour marks upward indicate the corresponding points on the radiation curves. No appreciable displacement of the maximum of radiation from the noon point on Mars will be noted either in the original curves or the plotted curves of planetary heat, either at opposition or one month before that time. This result does not agree with that reported by Coblentz and Lampland, who found the temperature higher in the Martian afternoon than in the forenoon.[1]

We may inquire what form of curve we might get from a planet like the earth having a considerable atmosphere, or again from a planet like Mercury or the moon which has a negligible atmosphere. Figure 2 A shows a plot of the theoretical distribution of planetary heat across the earth along the 39th parallel of latitude as seen by an observer on a similar planet. This curve is computed from temperature curves taken at Mount Weather, Va.,[2] and the Eclipse Station at Matheson, Colorado,[3] near mid-summer. It is very suggestive of the distribution of planetary heat across Venus.

Figure 2 B shows the curve of planetary radiation across the full moon. It strongly resembles in form the curve of planetary radiation across Mars (Figure 4, A3). These results, which are confirmed by the large percentage of radiation between 8$\mu$ and 14$\mu$ and its spectral distribution, indicate the practical absence of water vapor and the improbability of an atmosphere of density at all comparable to that of the earth. A detailed discussion of these observations and conclusions will appear in the *Astrophysical Journal.*

Mount Wilson Observatory, October 18, 1924.

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[1] *Science* **60**, 295, 1924. *Pub. Astronomical Society of the Pacific* **36**, 272, 1924. *Popular Astronomy* **32**, 571, 1924.

[2] Bull. Mount Weather Observatory **4**, 389, 1912.

[3] Popular Astronomy **26**, 466, 1918.