Reports

Mariner 1969: Preliminary Results of the Infrared Radiometer Experiment

Abstract. *The thermal energy emitted by Mars was measured in the 8- to 12- and 18- to 25-micrometer bands. The minimum temperature derived for the southern polar cap is 150°K, an indication that the cap is formed by frozen carbon dioxide. No significant temperature fluctuations were detected with a 100-kilometer scale.*

The complement of scientific instruments of the Mariner 6 and 7 spacecrafts included a radiometer specifically designed to measure the energy emitted in two wide wavelength bands of the thermal spectrum of Mars.

A description of the radiometer has been given earlier (*1*). Essentially it consisted of two 1-inch (2.5-cm) refracting telescopes, each with an uncooled bimetallic thermopile detector. The radiometers were mounted on the pointable instrument platform of the spacecraft and were bore-sighted with the narrow-angle television camera (*2, 3*). The fields of view of both infrared channels were coincident and subtended 0.7 degree at half-peak responsivity. The passbands of channel 1 (8.2 to 12.4 μm) and channel 2 (18 to 25 μm) were defined by interference filters to exclude atmospheric gaseous absorption; consequently, radiation from the surface was measured. The optical train of the radiometer included a rotatable plane mirror which reflected the incident energy into the detector telescopes. Once every 63 seconds the mirror was rotated to view empty space and thus provide a zero energy reference. The planet was viewed by rotating the mirror 90 degrees, observations being taken for 56.7 seconds at intervals of 2.1 seconds. In a third orthogonal mirror position, the instrument measured the thermal energy of a plate, whose temperature was monitored directly by a thermistor every 63 seconds. The radiometer had a dynamic range from approximately 120° to 330°K; channel 1 was selected to emphasize the upper end of this range, while channel 2 was selected to emphasize the lower temperatures. The output over this temperature range was linear in energy and was digitized into 1024 levels. In practice, the detector noise was dominated by the size of the digitization steps.

Data were obtained both in the far-encounter mode, when the spacecraft was at distances exceeding 100,000 km, and during near encounter. The radiometric sensitivity of the units during the flight remained essentially the same as that established in the laboratory calibrations. However, the radiometers were affected by stray light to an extent greater than anticipated.

The energies measured in the near-encounter mode are displayed in Figs. 1 and 2; the corresponding brightness temperatures have been derived on the assumption of unit emissivity of the planetary surface. We now report the data relating to the temperature of the southern polar cap and to the scale of the temperature variations over the surface.

The track of Mariner 7 was chosen to sweep over the south polar cap (*2*). As shown in Fig. 2, the temperature decreased to 225°K when the platform was slewed to latitudes near to, but definitely off, the polar cap. As the track continued southward, the temperature decreased slowly, but around latitude —61 degrees, when the radiometer crossed the boundary of the polar cap, the temperature suddenly dropped below 160°K. As the field of view swept over the cap, the temperature decreased to a minimum of 153°K near the terminator just before the platform was slewed north.

The frost temperature of CO_2 at a vapor pressure of 6.5 mb is 148°K. We interpret the agreement between this value and the observed temperatures, as well as the large change in temperature at the onset of the cap, to provide strong evidence for the polar cap being composed of frozen CO_2. This hypothesis has been discussed by Leighton and Murray (*4*).

The temperatures obtained under the assumption of unit emissivity need not be equal to the actual surface temperature of the polar cap. The TV pictures of Leighton *et al.* (*2*) show bare ground which is not covered by frost within the cap. If only 5 percent of the field of view in the polar cap were filled by sources with a brightness temperature of 200°K, the resultant measured brightness temperatures would be raised by 4°K. A discussion of possible instrumental systematic errors in the measurements is beyond the scope of this report.

It is nevertheless important to point out that the radiometers had a

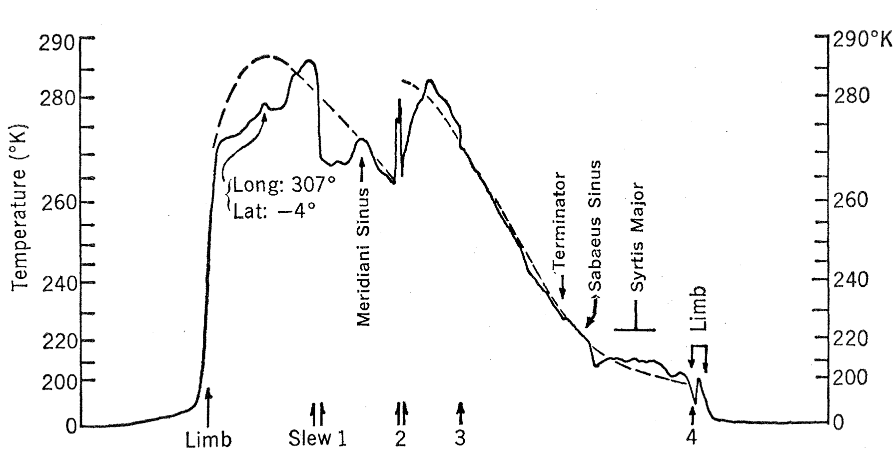

Fig. 1. Temperatures measured in channel 1 (8.5 to 12.4 μm) of the infrared radiometer in Mariner 6 during near encounter (solid curve). The times when the platform was slewed and when prominent planetary features were crossed are indicated. The dashed line represents the cooling curve of a homogeneous solid, with thermal inertia $(K\rho c)^{1/2} = 4 \times 10^{-3}$ cal/cm^2 sec$^{1/2}$ per degree Kelvin, and albedo of 0.85, for local times corresponding to the measured points.

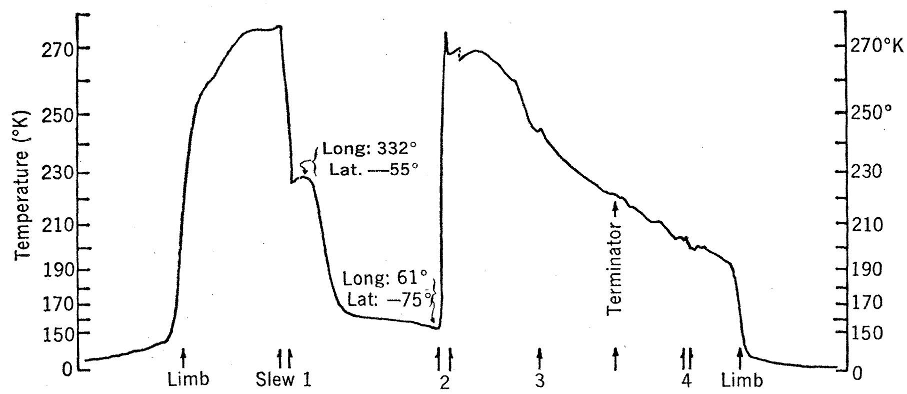

Fig. 2. Temperatures measured in channel 2 (18 to 25 μm) of the infrared radiometer in Mariner 7 during near encounter, in a scale proportional to energy. The times when the platform was slewed and the crossing of prominent planetary features are indicated. The extreme planetocentric coordinates of the swath through the polar cap are also shown.

significant response to off-axis sources. For example, the response of channel 2 of the radiometer aboard Mariner 7 to a point source at a distance of 12 degrees from axis was only 0.3 percent of that for the same source on axis. Because of the large solid angles subtended, however, the extended wings beyond a central area 1 degree in diameter contributed 27 percent of the total response of a measurement of the energy radiated by an isothermal source filling the entire object space. The correction to the minimum temperature measured in Mariner 7, due to the extended response of channel 2 and based on a model temperature distribution over the planetary surface, amounts to about —3°K. At low temperatures, the correction for off-axis radiation was greater for channel 1 than for channel 2. A more refined analysis of the systematic effects, based on data obtained before near encounter and during passage across the limb, is in process. All systematic errors that have been thought of, however, have the effect that the observed temperatures are higher than the true value.

The Mariner flights provided the opportunity to measure temperatures with an areal resolution approximately ten times that obtainable from the earth. Although transitions between dark (maria) and light (desert) areas appear well defined in the data, there were no sharp changes in temperature exceeding 1°K in contiguous fields of view (50 km at closest approach). The only sharp temperature fluctuation which does not seem to be associated with any feature in the "classical" maps of Mars was recorded in both channels of Mariner 6 at longitude 307.0° and latitude —3.5°, identified in Fig. 1. The TV pictures of this area show a complex terrain structure that may be related to this temperature anomaly (*5*).

Because the track of Mariner 6 was nearly equatorial (*3*) and extended well beyond the terminator, it is particularly suited for a determination of the parameters characterizing the gross thermophysical properties of the martian ground. The cooling curve of a homogeneous solid with $(K\rho c)^{1/2} = 4 \times 10^{-3}$ cal/cm^2 sec$^{1/2}$ per degree Kelvin, where K is heat conductivity, ρ is density, c is specific heat, and albedo of 0.85, fits the measurements quite well, although obvious departures are noticeable in Fig. 1. This result agrees with the general conclusions of Sinton and Strong (*6*). Our results should be considered tentative, although we believe that a more detailed analysis of the data will not change the conclusions significantly. A thorough analysis of the systematic effects present in the data is underway; a correlation with the results of the television and infrared spectrometer experiments is planned.

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References and Notes

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3. ———, *ibid.*, p. 684.

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5. We thank R. B. Leighton and the entire Mariner 69 TV team for allowing us to see their pictures before publication and for their valuable comments.

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7. Many persons within the Mariner 1969 Project contributed to the success of this experiment, but our special thanks are due to H. Schurmeier, J. Stallkamp, and C. Kohlhase for their efforts on our behalf. We also thank J. Bennett and D. Griffith for help in the acquisition and reduction of the data.

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Laser Beam Directed at the Lunar Retro-Reflector Array: Observations of the First Returns

Abstract. *On 1 August between 10:15 and 12:50 Universal Time, with the Lick Observatory 120-inch (304-cm) telescope and a laser operating at 6943 angstroms, return signals from an optical retro-reflector array placed on the moon by the Apollo 11 astronauts were successfully detected. After the return signal was first detected it continued to appear with the expected time delay for the remainder of the night. The observed range is in excellent agreement with the predicted ephemeris. Transmitting between 7 and 8 joules per pulse, we found that each return signal averaged more than one photoelectron. This is in good agreement with calculations of the expected signal strength.*

One of the scientific instrument packages placed on the moon by the Apollo 11 astronauts is an array of optical retro-reflectors whose purpose is to permit short-pulse laser ranging from stations on the earth (*1*). The retro-reflector array, for which one of us (J.E.F.) provided the basic design, consists of 100 fused silica corner cubes each 3.8 cm in diameter mounted in an aluminum panel 46 by 46 cm. The reflectors, which have a life expectancy in excess of 10 years, are designed to perform under essentially isothermal conditions throughout lunar night and most of the lunar day. The retro-reflector package on the lunar surface eliminates the stretching in time of the return signal which would otherwise be produced by the curvature and irregularity of the