Infrared Images of Tycho on Dark Moon

Abstract. *Infrared images of the thermal anomaly associated with the lunar crater Tycho were obtained during the lunar night after Tycho had ceased to be illuminated by the Sun for as long as 97 hours. In agreement with results of previous studies, these measurements show that the crater is warmer than its surroundings during the lunar night, and that the temperature of the thermal anomaly gradually decreases with time, being no longer detectable after new moon. This work provides strong evidence that the steeper crater walls facing the Sun before local sunset are warmer throughout the cooling phase, and that the Tycho anomaly is thus produced by solar, rather than internal, heat.*

Images of the thermal anomaly Tycho were obtained during the lunar night with a device (*1*) that converts the emitted infrared signal, detected from each resolution element on the lunar surface, into an electric current that modulates the intensity of a glow tube focused on Polaroid film. The visible photographs were constructed by scanning with the device in the image plane of a telescope, thereby achieving a TV-like raster of the scene. Images were produced by use of: (i) conventional radiometric techniques in which the signal from each lunar-surface resolution element is referenced against the output of a blackbody emitter; and (ii) a thermal-enhancement technique (*2*) in which the signal from each resolution element is referenced against the suppressed (or attenuated) signal from the adjacent, partially overlapping element. With the latter technique, each line in the raster corresponds to a derivative of the radiance profile superimposed on the true radiance profile suppressed in intensity.

The observations were made in the 8- to 14-μ range with a liquid helium-cooled, copper-doped germanium detector. The telescope used is an f16, 24-inch (60-cm) instrument located at Concord, Massachusetts, 78 m above sea level. The theoretical spatial resolution on the lunar surface is 12 km, but the achieved resolution was slightly degraded by tracking errors and "seeing" disturbances.

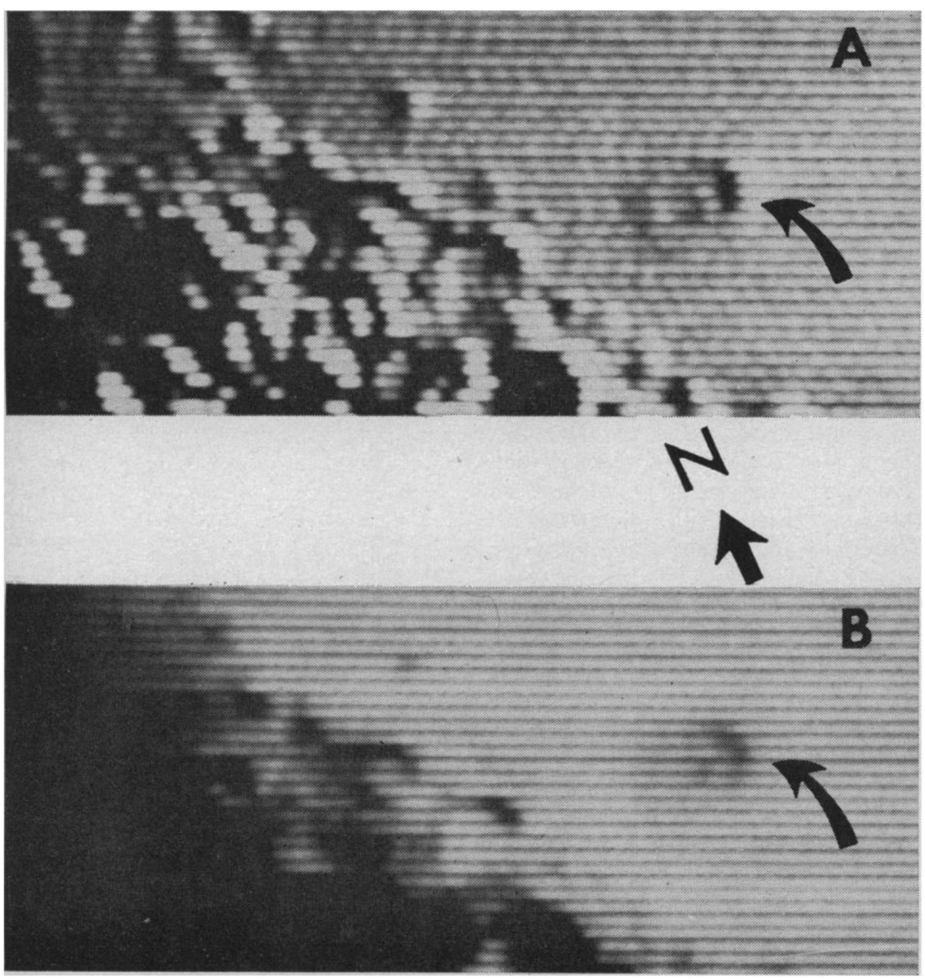

Fig. 1. Infrared images of Tycho (curved arrow) obtained 8 October 1966: (A) by a thermal-enhancement technique at 0946 U.T. Tycho had not been illuminated for about 22 hours; (B) by conventional radiometric techniques at 1003 U.T.

When an infrared image was produced by conventional radiometric methods (Fig. 1B) Tycho had not been illuminated by the Sun for approximately 22 hours. Infrared images were produced by the thermal-enhancement technique (Figs. 1A, 2, and 3) after Tycho had ceased to be illuminated for from 22 (Fig. 1A) to approximately 97 hours (Fig. 3). Darker shades of gray on these images indicate relatively warmer temperatures if one assumes black- or gray-body behavior for the surface materials. The Tycho region was examined again on the evenings of 20 and 21 October 1966, when Tycho had not been illuminated for more than 305 and 337 hours, respectively; it was then no longer detectable as an anomalous thermal feature.

Figures 1–3 make it clear that: (i) the crater is warmer than its surroundings; (ii) the thermal anomaly is confined to the crater itself, although it extends to the outer walls; (iii) the steeper slopes facing the setting sun prior to our measurement persist in being relatively hotter; and (iv) the temperature of the thermal anomaly decreases with time.

Using conventional radiometric techniques for earlier studies of the dark Moon, Murray and Wildey (*3*) detected Tycho as a thermal anomaly as long as 32 hours after the crater ceased to be illuminated, but could not detect the anomaly after new moon; the anomaly appeared to be distributed somewhat irregularly over an area considerably larger than the crater itself. Their results are not completely consistent with ours.

Although we also found the anomaly undetectable after new moon, we found it confined to the crater proper. The only irregularity of the anomaly is apparently related to solar heating of the steeper crater walls before local sunset. It would appear that the differences between our results and theirs can be accounted for by their lower (50-km) spatial resolution and their lack of ability to record infrared images. Instead of imaging the Tycho anomaly, they simply scanned with the telescope across the terminator and into the region on the darkened lunar surface where they knew Tycho to be located. This technique is almost certain to result in errors in location, which may account for the apparent large size and irregular distribution of the anomaly detected.

Using a thermal-enhancement technique similar to ours, Low (*4*) also studied the dark Moon, but in the 17.5- to 24-μ region of the spectrum. Like Murray and Wildey, Low had lower (30-km) spatial resolution and lacked the scanning capability necessary to produce images; he detected small and large hot and cold areas before and after new moon, but presented no specific information on the location or magnitude of any of these anomalies except one. From this limited description of his results it is difficult to determine whether or not he detected Tycho; he should have done so, since it is the most prominent thermal anomaly in the (astronautical) southwestern quadrant of the Moon. The one anomaly for which Low presented information is an exceptionally hot spot near the southwestern limb, which we did not detect. More complete publication of Low's results seems necessary before their significance can be evaluated.

Infrared studies of Tycho have been made also during lunar eclipses. The results of Saari *et al.* (*5*) are consistent with ours in that they show (*5*, pp. 25, 36) that the thermal anomaly is essentially confined to the crater. The eclipse data indicate that Tycho has symmetrical cooling behavior consistent with its near-vertical illumination prior to the eclipse.

Because our data show the thermal anomaly confined to the crater and its immediate surroundings, it appears that the anomaly is the result of the crater-forming process. It also appears that the heat being released is primarily solar, rather than internal, because the steeper slopes facing the Sun prior to local sunset persist in being warmer than slopes that were facing away from the Sun. These conclusions are consistent with the original suggestion by Sinton (*6*) that the ray-crater Tycho, being of relatively recent origin, may have a thinner layer of dust than its surroundings have; the resultant higher effective density of the Tycho surface materials, and accompanying difference in the thermal parameter $(K\rho c)^{-\frac{1}{2}}$, could cause the difference in thermal behavior. Tycho's enhanced radar return (*7*) also is consistent with a denser surface layer.

The number and complexity of inter-

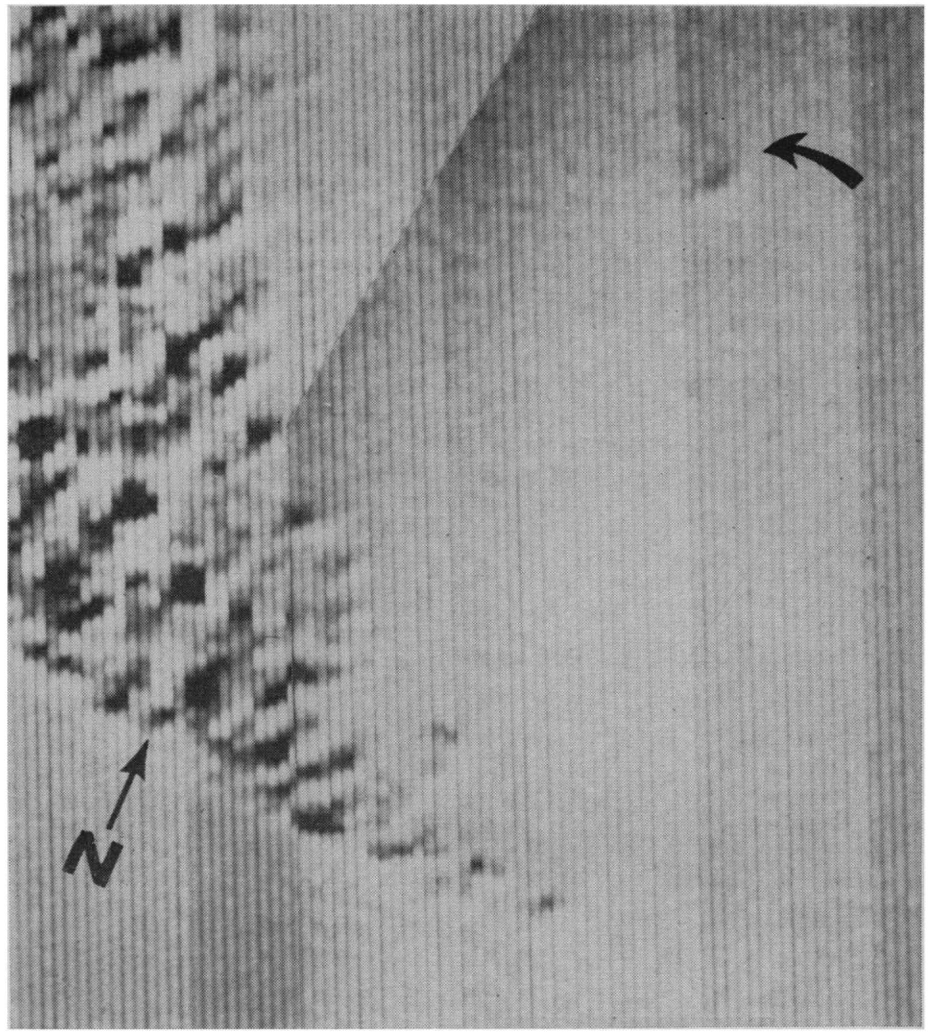

Fig. 2. A mosaic of two infrared images, showing both Tycho (curved arrow) and the terminator, obtained on 9 October 1966 by a thermal-enhancement technique. The image in which Tycho appears was produced at 0958 U.T., when Tycho had not been illuminated for about 46 hours.

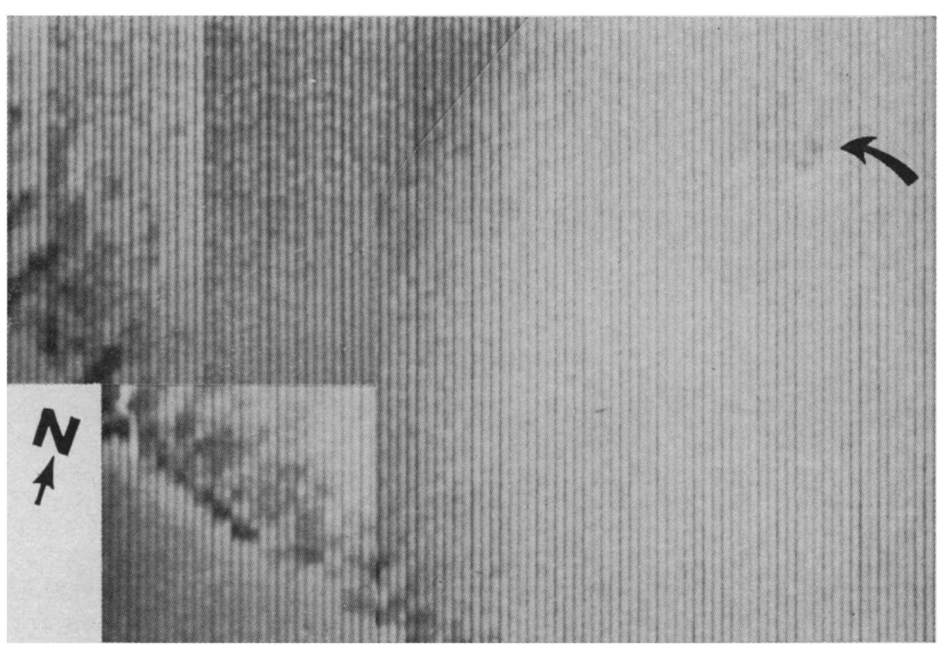

Fig. 3. A mosaic of three infrared images, showing both Tycho and the terminator, obtained on 11 October 1966 by a thermal-enhancement technique. The image showing Tycho was produced at 1220 U.T., when Tycho had not been illuminated for about 97 hours.

relations between the variables involved in both infrared and radar measurements, however, make it difficult to draw firm conclusions regarding the exact cause of Tycho's anomalous thermal behavior. It may be that difference in surface roughness alone could account for all observations (*8*). It is also possible that other thermal anomalies on the lunar surface have entirely different causes. This problem is discussed at greater length elsewhere (*9*).

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7 November 1966

Martian Relief and the Coming Opposition

Abstract. *Ground-based observations of Martian relief may be possible when the Earth-Mars geometry is optimum and the observing conditions are near perfect. There is some evidence that detectable relief is present. Ground-based observations of Martian relief during the coming opposition will be optimum between 1 February and 1 March and between 1 June and 15 August 1967.*

Because of the difficulty of resolving Martian surface features from Earth and because of the small area covered by the Mariner IV photos our present knowledge of Martian relief is very meager. Consequently further study of Martian relief is needed. The possibility of observing relief during the coming opposition is presented in this report.

The first observer reporting Martian relief was Mellish who used the 40-inch (1 meter) refracting telescope of the Yerkes Observatory during the February 1916 Mars opposition to observe what he interpreted as Martian craters. He asserted that between 1 November and 15 December 1915, he saw Martian craters on several occasions, his best views of the craters being on 13 November 1915, shortly after sunrise (*1*). "Using a power of 1100, I saw many small craters and one large one. The latter, estimated to be 200 miles (300 km) in diameter, was in Martian latitude about −50°; north of it were many bright-rimmed small craters" (*2*). Mellish estimated the depth of the large crater at three to four miles (4 to 6 km).

Since his 1915 observations, Mellish has shown his records to many Mars observers including E. E. Barnard whose records of the 1892–93 opposition showed some of Mellish's craters as dark spots (*1*). Similar observations of dark spots by Antoniadi, Lyot, Dollfus, and notably Focas at Pic du Midi show that with good seeing the maria, canali, and oases appear composed of dark spots many of which are nearly circular and thus may possibly be craters (*3*).

Crater counts for Moon and Mars by Hartmann (1966) suggest that very large craters, comparable to lunar mare basins, may exist (*4*). Hartmann's work also suggests appreciable erosion. Relief is therefore probably not greater than that on the moon. However, relief may be widespread. This is implicit in the work of Katterfeld (*5*) and Binder (*6*) which shows that Mars may have a tectonic grid. Admittedly these observations have only recently come to light because of the Mariner IV results, but there is now new interest in the possibility of telescopic detection of Martian relief.

Mellish's observations were made at quadrature of an unfavorable opposition with a 40-inch (102 cm) aperture. Such an aperture (40 inches or larger) should permit detection of large Martian craters when the Earth-Mars geometry is optimum and seeing is nearly perfect. Why then is relief on Mars not generally reported? There are two reasons: (i) perfect atmospheric conditions for large apertures are extremely rare, and (ii) most Mars observations are made near opposition when the visibility of relief is minimum.

The use of telescope time may be optimized by calculating the relative angular size of the shadow of an arbitrary Martian prominence as a function of time. The visibility of the prominence is judged by the angle subtended at the earth by its shadow.

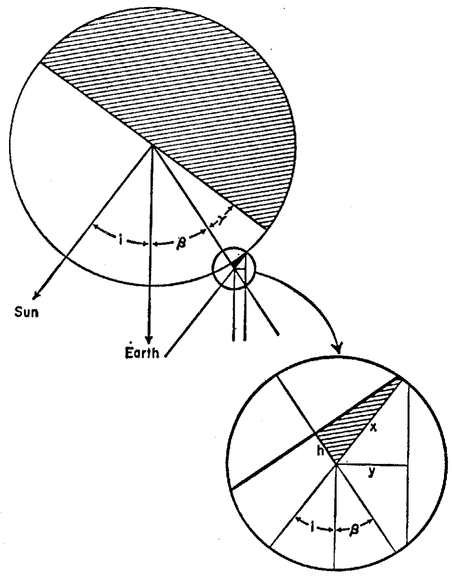

Fig. 1. Geometry for determining the angle subtended by the shadow of an arbitrary Martian prominence seen from Earth.

Consider a prominence of height h above the Martian surface (Fig. 1). The prominence will cast a shadow only if its slope away from the sun is greater than $90°-(i+\beta)$, which is γ. Therefore, the smaller the slope, the closer it must be to the terminator to be visible. In the limiting case a very small slope will be observable only as an indentation of the terminator.

If the prominence is close enough to the terminator to cast a shadow then it will cast a shadow of length x

$$x = h \sec (i + \beta)$$

The same shadow as seen from earth will have an apparent linear length y

$$y = x \sin i$$

If the Earth-Mars distance is R, then the angle subtended at the earth by the shadow will be

$$\alpha = \frac{y}{R} = \frac{h}{R} \sec(i + \beta) \sin i$$
$$= h \csc \gamma \left(\frac{\sin i}{R}\right)$$

The relative visibility of the prominence's shadow may be defined in terms of the positions of Mars and Earth as

$$r = \alpha/(h \csc \gamma) = (\sin i)/R$$

Thus by calculating r for various dates and plotting r against time, we may find the best times to observe Martian craters (Fig. 2) (*7*). The epoch of maximum subtended angle is found by differentiating α with respect to time and