PRELIMINARY RESULTS OF THE APOLLO 17 INFRARED SCANNING RADIOMETER*

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Abstract. The thermal emission of the lunar surface has been mapped by an infrared scanner from lunar orbit. Samples from approximately 2.5×10^5 scans reveal the full range of lunar temperatures from 80 K to 400 K. The temperature resolution was 1 K with about $\pm$ 2 K absolute precision. Spatial resolution was approximately 2 km over most of the horizon-to-horizon scan. The total mapped area amounted to approximately 30 % of the lunar surface.

The data currently available confirms the large population of nighttime thermal anomalies in western Oceanus Procellarum predicted by Earthbased observations. Most of these 'hot spots' are associated with fresh impact features or boulder fields. Also seen in the data are 'cold spots' where the local nighttime temperature is depressed relative to the general soil background. Such regions exhibiting low surface conductivity are inferred to be relatively young, non-impact features.

1. Introduction

The Infrared Scanning Radiometer (ISR) was among the complement of lunar orbital science experiments aboard the Apollo 17 Command-Service Module (CSM). The principal experimental objective of the ISR was the mapping of infrared thermal radiation emitted from the nighttime lunar surface within view of the spacecraft. The nighttime temperatures and cooling rates can be analyzed to provide values of the thermophysical parameters of the lunar surface layer.

Earth-based telescopic measurements have shown that the lunar soil layer is an excellent thermal insulator (Pettit and Nicholson, 1930). During the lunar day the surface temperature is strongly controlled by absorbed solar radiation. Very little heat is conducted into the subsurface layer. During the lunar night this small amount of stored heat is reradiated into space. Nighttime temperature measurement is a sensitive indicator of the surface thermal properties.

A simple, one-dimensional conductive model of the soil layer (Krotikov and Shchuko, 1963) demonstrates very well the general behavior of surface temperature. In such a model, families of temperature curves can be generated in terms of a single thermal parameter, $\gamma = (k\varrho c)^{-1/2}$, where k is the thermal conductivity, ϱ is the bulk density, and c is the specific heat. The model is simplified in that it disregards radiative transfer in the surface layer, but it is still useful to characterize the thermal response in terms

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of γ. The best Earth-based measurements of the lunar midnight temperature (Mendell and Low, 1970) place $\gamma \sim 850\ \mathrm{cal}^{-1}\ \mathrm{cm}^2\ \mathrm{K}\ \mathrm{s}^{1/2}$.

Thermal mapping of the nighttime lunar surface from Earth is a difficult observational task (Mendell, 1971). An orbital experiment, on the other hand, eliminates the problem of the terrestrial atmosphere and simultaneously allows an increase in spatial resolution.

2. Instrument Description

The ISR is a thermal imaging line scanner, built by Barnes Engineering Company (McIntosh and Mendell, 1972). A schematic of the optical system is shown in Figure 1. The spherical-spherical Cassegrain optical system has a 7-in. aperture. The instantaneous field of view is 20 mrad. The latter translates to a circular lunar surface resolution element ranging from 2.0 to 2.6 km in diam during accumulation of prime data. This spatial resolution is an order of magnitude improvement over Earth based observation.

The secondary mirror is mounted concentrically with the 45° plane scan mirror, and the entire assembly rotates continuously at 41.7 rpm during ISR operation. An aperture in the casting allows the beam to sweep from horizon to horizon perpendicular to the spacecraft ground track. The orbital motion of the CSM spaces the scans along the ground track. The angular velocity of mirror rotation was chosen such that consecutive scans would be contiguous on the lunar surface when the spacecraft altitude was 60 nautical miles (111 km).

At the Cassegrain focus of the detector system is mounted the detector assembly, consisting of a thermistor bolometer bonded to a hyperhemispheric silicon immersion lens. The spectral response of the radiometer is determined primarily by the lens as the only transmitting element in the optical path. The effective spectral pass band detectable by the ISR ranges from 1.2 μm to approximately 70 μm. The long wavelength cutoff is apparently caused by transparency of the detector flake. No filter was found which would both filter out reflected solar radiation at short wavelengths and also not compromise the long wavelength (low temperature) sensitivity.

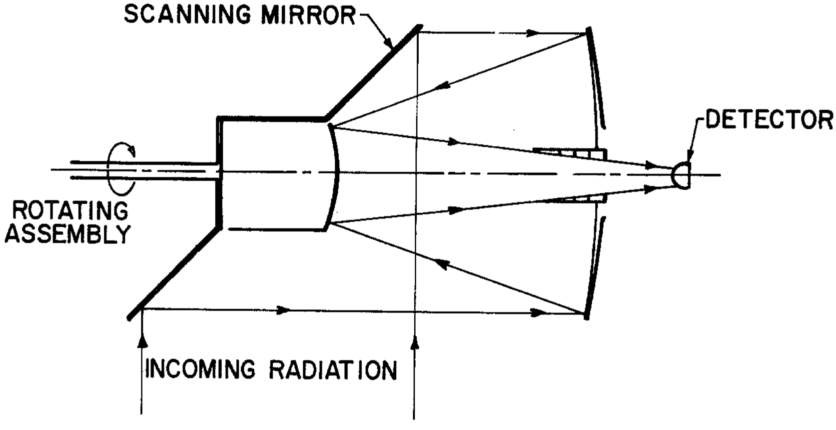

Fig. 1. Optical system schematic for Apollo 17 infrared scanning radiometer.

The ISR measured the full range of lunar temperatures from 80 K to 400 K. The instrument output was simultaneously transmitted on three different channels at three different gains. In this manner the low temperature sensitivity was maintained while the large dynamic range of signal was covered.

A special feature of the ISR radiometric calibration is the space clamp circuit. Once each scan, as the radiometer views deep space prior to crossing the lunar limb, the detector output is sampled and saved. This stored voltage is electronically subtracted from the detector output for the remainder of the scan. Therefore, each lunar scan is referenced to the radiometric 'zero' of deep space. The clamp circuit enhances the absolute accuracy of the measurement while suppressing low frequency detector noise.

3. Lunar Surface Coverage

The sunrise terminator was located at longitude 82° E, in the eastern part of Mare Serenitatis, at the time of the first ISR scans of the Moon. By the time of Trans-Earth Injection, it had moved to 46° W, just east of Aristarchus. On the front side of the Moon, the orbit constrained nighttime coverage to the southern portions of Mare Serenitatis and Mare Imbrium, Oceanus Procellarum, and the equatorial region at the western limb. On the far side, the night-time ground tracks passed south of Hertzsprung and Korolev over to Aitken and Van de Graaff.

A horizon-to-horizon scan from an altitude of 111 km includes an arc of 40° on the lunar sphere. Foreshortening seriously degrades surface resolution at the horizon. Good spatial resolution is achieved over a lunar spherical arc of 20° centered on the ground track. It follows from this fact that approximately 20–25% of the lunar surface was mapped at a spatial resolution better than 10 km.

4. Data Quality

The ISR transmitted approximately 97 hr of lunar data during the mission. Approximately 10^8 independent measurements of the lunar temperature were made. Data was received via telemetry at range stations around the world and recorded on magnetic tape. Samples of the data were available in real time at the Mission Control Center so that instrument performance could be assessed continuously. The available sampling was equivalent to a scan of the lunar surface once every six degrees of longitude. The tentative conclusions presented here are based on a quick look at this real-time sample, which comprises less than 2% of the entire data set.

The scans shown have not been processed, and the amplitudes are proportional to radiance (instrument output voltage) rather than temperature. The figure captions indicate the approximate temperature of various features.

Examination of the scans will show that the radiance of space just past the trailing (right-hand) limb of the Moon is not zero. Although the offset is not entirely understood, there is strong evidence that some object aboard the spacecraft falls into the skirts of the ISR field of view on that side of the aperture where the beam enters the housing. Scans of space during Trans-Earth Coast show that the feature is approximately linear and can be removed with only a modest increase in the noise on the affected portion of the scan.

Figure 2 shows three lunar night-time scans. Scan 2(A) comes from Oceanus Procellarum. The center of the scan is dominated by the crater Kepler A. The altitude

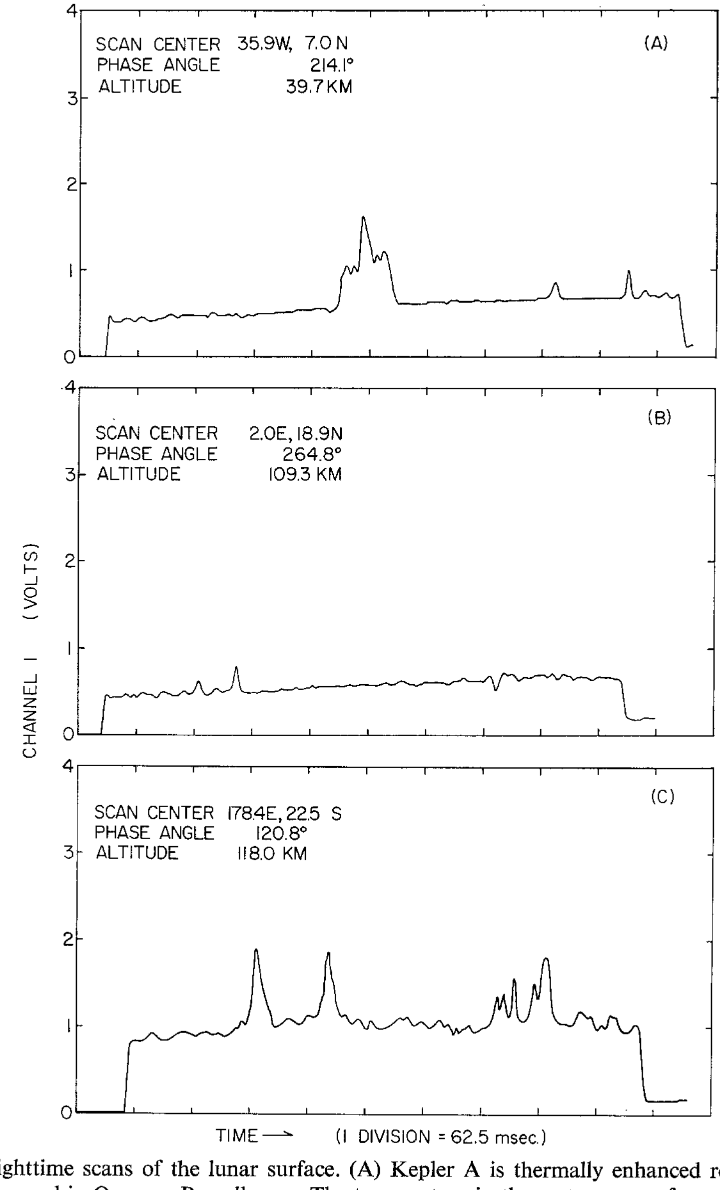

Fig. 2. Nighttime scans of the lunar surface. (A) Kepler A is thermally enhanced relative to the 92 K background in Oceanus Procellarum. The temperature in the crater ranges from 112 K on the walls to a maximum of 126 K in the center. (B) A pre-dawn cold spot shows an 8 K contrast to the 90 K background in the Apennine Mountains. (C) These large farside anomalies are enhanced approximately 22 K relative to an 108 K background two and one-half days after sunset.

of the spacecraft was 39.7 km at the time of the scan, making the ISR resolution element 0.8 km across on the surface. The width of the broad base of the enhancement is 10 km, coinciding with the crater diameter. The thermal pinnacle in the center is approximately 2 km across. The measured radiance in the central region increases linearly from both sides to the center, implying that the actual temperature at the center has not been fully resolved. The dramatic change of material properties within the crater probably reflects exposure of bedrock. The radial gradient may be caused by a corresponding radial distribution of slump material from the crater walls. Unfortunately, no lunar photographs have been found which contain a good view of the crater bottom.

Scan 2(B) contains pre-dawn temperatures, the coldest for any given surface region. The scan center is located just north of Mare Vaporum and south of the Apollo 15 landing site. On the right-hand portion of the scan can be seen a negative anomaly, i.e., a region whose temperature is depressed relative to its environs. In this case, the temperature difference is $\gtrsim 8$ K. A lower limit is given because the deflection is only one resolution element across, implying that the anomaly may not be fully resolved. The anomalous region lies south of the crater Conon in the Apennine Mountains. The magnitude of the temperature contrast implies that the thermal conductivity of the soil there is approximately one-half that of the surrounding material. These underdense regions cannot be impact features. The preservation of the density contrast also implies that they are relatively young on a geologic scale. Low (1965) has previously detected cold anomalies from Earth, but their thermal behavior has not been studied.

Scan 2(C) depicts far-side anomalies. Our abbreviated data survey shows that such features are not common in the nighttime data on the back side. A low frequency of occurrence was anticipated because front side anomalies occur preferentially in the maria, regions which are generally absent in the other hemisphere. The two prominent anomalies on the left side of the scan are located between the large craters Aitken and Van de Graaff. The large peak at the right limb corresponds to the crater Birkeland; the smaller structure to its left is in Van de Graaff.

Figure 3 contrasts two daytime scans. The scan centers are separated by only 6° of longitude, but the contrasting effects of topography in the maria and the highlands are quite clear. The thermal spike to the right of the mare and the dip to the left correspond to the northern and southern rims. The difference in the thermal signatures from the two scarps demonstrates the dominance of local slope (i.e., local sun angle) in the daytime thermal regime.

In Figure 4 lunar temperatures as measured by the ISR are plotted as a function of brightness longitude. The values were taken from scans on the twentieth lunar orbit by the Apollo spacecraft. An attempt was made to choose a point from each scan on the lunar equator. The spacecraft orbital motion causes the actual sequence of the points to go from right to left on the figure. The first point at $t/P = 0.43$ was measured at 08:26 GMT on December 12, 1972. The final point (at approximately the same lunation coordinate) was measured at 10:25 GMT. A data gap exists near the subsolar point for this orbit.

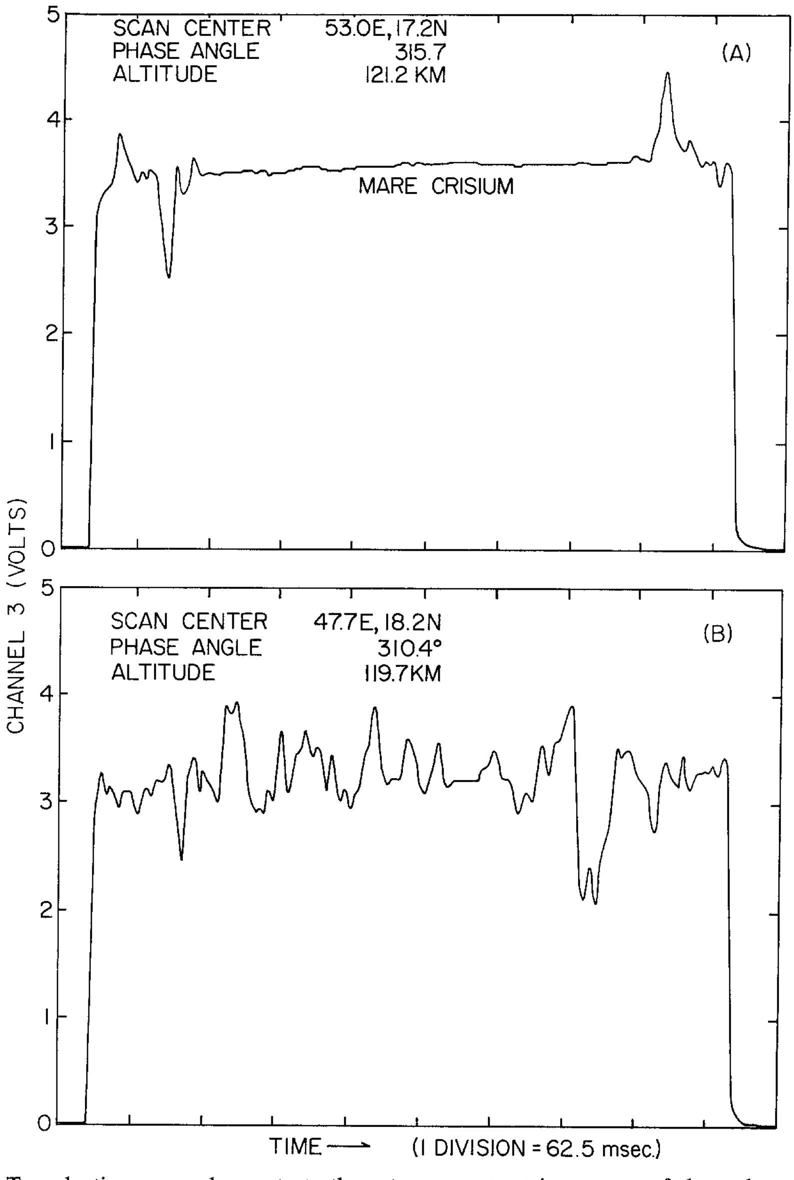

Fig. 3. Two daytime scans demonstrate the extreme contrast in amount of thermal structure in nearby mare and highland terrain. The temperature in Mare Crisium is approximately 368 K.

The plotted temperatures will change as the ISR values are refined. The error estimate is 3 K for the nighttime measurements; the values probably are systematically low. No correction for albedo or topography have been made.

On the same figure are plotted theoretical curves for various values of γ. The theoretical calculations represent the cooling behavior at a single point whereas the data is taken over many different types of material. The cooling curve apparently falls

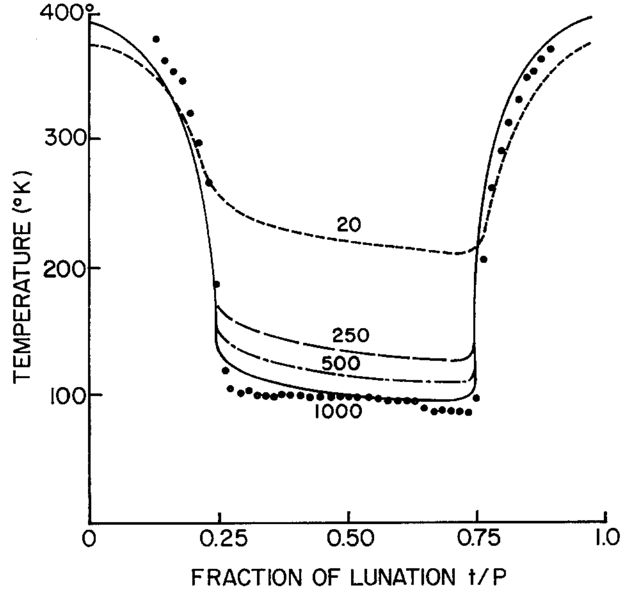

Fig. 4. Equatorial temperatures are plotted as a function of the lunation coordinate. Theoretical curves come from Krotikov and Shchuko (1963).

below $\gamma \sim 850$, even if the error estimate is taken into account. The elevated temperatures near lunar midnight fall in Oceanus Procellarum where general thermal enhancement has been noted in eclipse measurements (Saari and Shorthill, 1965).

The data for lunar afternoon temperatures comes from the highlands on the far side, and the morning points fall in Mare Fecunditatis and Mare Tranquillitatis. The combined effects of albedo and directionality of emissivity account for the apparent systematic deviations to either side of the theoretical curve.

This brief survey of the ISR data has confirmed that a variety of thermal behavior exists on the lunar surface. Further work on the measurements will establish the cooling behavior of the major types of lunar regions and the most interesting exceptions within each category.

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