PART II

MARS

A. OPTICAL PROPERTIES

COLORIMETRY OF MARTIAN FEATURES BY MEANS OF AREA SCANNING

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1. Introduction

The contrast between light and dark areas on Mars has been the subject of two photoelectric studies by Younkin (1966) and McCord (1969), both of which were somewhat limited in scope. Younkin's data are based on one night's observations. McCord had a more suitable instrument for making a comparison between two areas on Mars, but still used only six nights. The agreement between these two studies is excellent. However, there is ample evidence from photographs that there are short-term changes in the contrast and brightness of Martian surface features, especially in the case of blue clearing. Visual observations are unsuitable for investigating these changes, due to the limited wavelength range of the eye's sensitivity, as well as the poor accuracy of the eye as a photometric instrument. Even photography is of limited usefulness when high accuracy is desired. Consequently, a program of continuous photoelectric observation of Mars was set up for the 1969 opposition. The technique of area scanning was chosen as the best method of recording the contrast of Martian surface features.

2. Instrumentation

Area scanning is a technique whereby a small aperture is swept rapidly and repeatedly across the disk of the planet. Each successive sweep is added in phase with the previous sweeps, this process continuing until the signal-to-noise ratio of the accumulated scan reaches the desired value. Area scanning was pioneered by Rakos (1965) and has proven to be an extremely powerful method of obtaining accurate data under conditions in which the smearing introduced by the seeing in the Earth's atmosphere is an important factor.

A new dual-beam area scanner was designed and constructed at Lowell Observatory for the purpose of making these contrast measurements. The design embodies a dichroic filter which provides two beams. One beam is used for reference and includes an interference filter 75 Å wide centered at 6000 Å. The other beam passes through a filter wheel with eight filters ranging in wavelength from 3400 Å to 5300 Å. The filter bandwidths range from 150 Å in the ultraviolet to 75 Å in the green.

The scanning is accomplished by physically moving the entrance slit at a rate of two complete sweeps per second. A round aperture 1.2 sec of arc in diameter was used for all the Mars observations. However, in order to calibrate the sensitivity of the photometer, as well as to measure the amount of smearing due to atmospheric seeing, the

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aperture was replaced with a slit, and standard stars were observed each night. In order to provide a measure of the quality of the seeing during the night, a Gaussian curve was fitted to the standard star profile. The standard deviation of the Gaussian provides a quantitative measure of the smearing introduced by the atmospheric seeing.

The dual-beam area scanning method has the advantage that it provides simultaneous observations in two colors, thereby eliminating any possibility that errors in positioning or changes in seeing will affect the measured contrast. For instance, on any particular night the continual repetition of the reference beam scan allows us to state that the variation in contrast ratio to be expected due to changes in the seeing is somewhat less than 2%.

Because the final area scan is composed of from 100 to 300 repeated scans, the area scanner produces accurate data even under conditions of changing transparency. This is most important in the case of an extended program because many more nights are usable than would be the case for conventional photometry.

The observations were made at the *f*/75 focus of the Lowell-Tololo reflector at the Cerro Tololo Inter-American Observatory in Chile. The telescope was shared between this program and the Lowell-NASA International Planetary Patrol Program. Consequently, there was an hourly photographic record in four colors which has proved to be extremely useful in interpreting the photoelectric scans. Observations were made on every possible night from May 28 to July 8, 1969.

3. Blue Clearing

On the night of June 10, 1969, there was a partial blue clearing over Mare Cimmerium. Figure 1 shows the appearance of Mars in red, blue, and green. The southern two-thirds of Mare Cimmerium is visible with extreme clarity, even on the blue photographs. This is not the usual case and represents a strong blue clearing over that portion of the planet. Notice that the Trivium Charontis-Cerberus complex near the center of the disk, although visible in the red, is not visible in the blue photograph, indicating that the blue clearing was present only over the southern part of the planet. Figure 2 shows several typical area scans made at approximately the same time as the photographs in Figure 1. The strong dip to the left is Mare Cimmerium; the shallower dip in the 6000 Å scan is Trivium Charontis-Cerberus. For each of the scans in the left side of the figure a monitor scan at 6000 Å was obtained simultaneously. The differences between the monitor scans are very small; a representative one is shown in the right-hand side, along with a typical instrumental function which includes the smearing due to the finite aperture size combined with that due to the Earth's atmosphere. Defining the contrast as the ratio of the intensity of the dark area to the intensity of the neighboring bright area, we see that it is possible to measure the contrast of the Trivium Charontis region at wavelengths as short as 4600 Å. However, the Mare Cimmerium is visible on the scans, and its contrast can be measured even at 4000 Å.

Figure 3 is a plot of the contrast of Mare Cimmerium and Trivium Charontis-Cerberus for June 10 as a function of wavelength. Also included in the figure is the

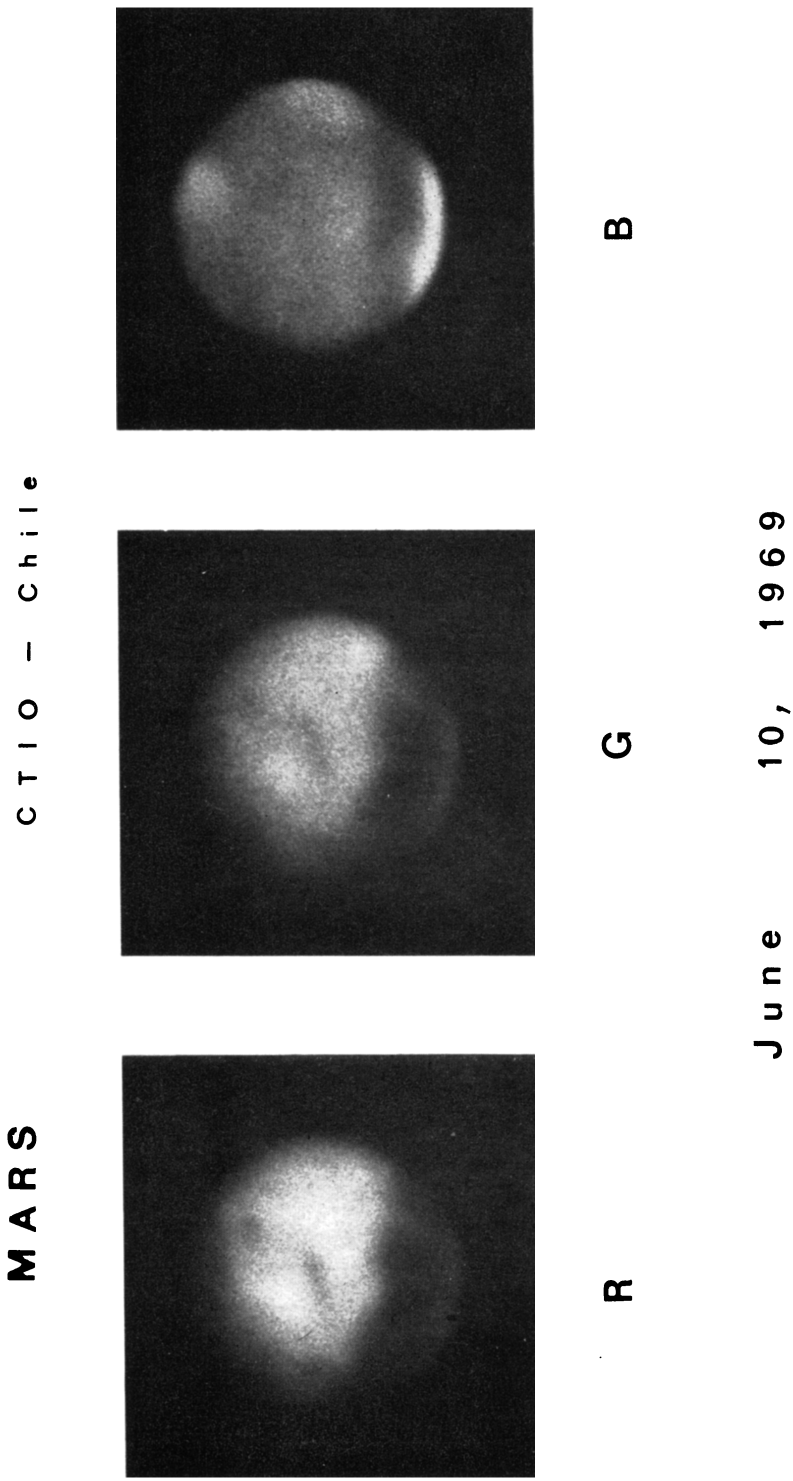

Fig. 1. Photographs of Mars in three colors, showing strong blue clearing over part of the disk.

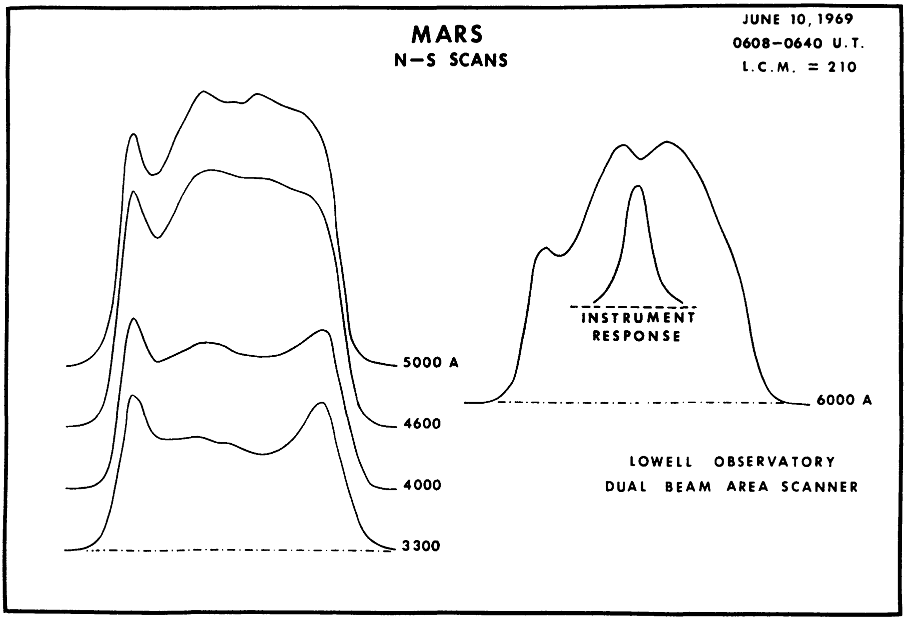

Fig. 2. N–S intensity profiles of Mars through Trivium Charontis-Cerberus. North is at the right.

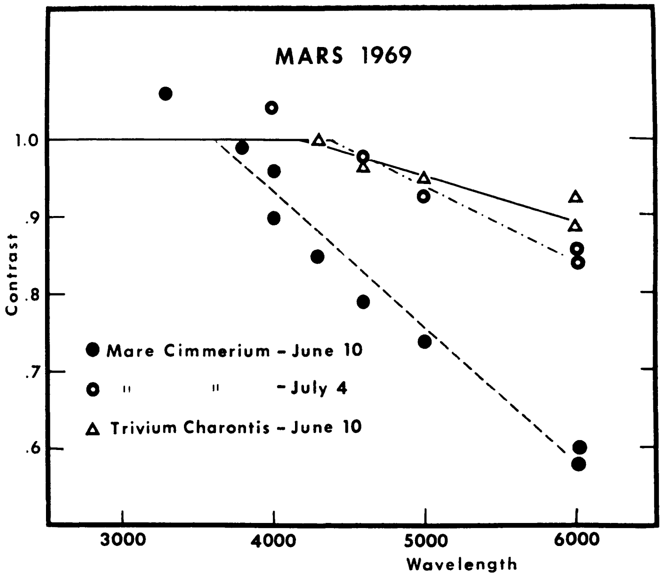

Fig. 3. Contrast ratios between Martian dark areas and adjacent light areas as a function of wavelength. The Mare Cimmerium exhibited strong blue clearing on June 10 (see Figure 1) which is apparent as shift of the contrast curve toward the blue. These ratios are uncorrected for smearing by the terrestrial atmosphere and finite scanning aperture width.

contrast measured for Mare Cimmerium on July 4, when there was no visible blue clearing. Two things are immediately obvious: (1) The contrast seems to increase approximately linearly with wavelength. Reduction of more scans has shown that the normal curve for Mare Cimmerium is typical of the contrast curve for most other dark areas on the disk of Mars. (2) Although these contrast measurements are uncorrected for the effects of seeing, there is a large change in the contrast between the blue-cleared and non-blue-cleared condition. Since the width of the atmospheric smearing profile was approximately the same on both days, this change cannot be due to variations in the conditions of the Earth's atmosphere, but must be intrinsic to Mars.

The area of blue clearing on June 10 seems to have no relationship to the light or dark areas since the line between the clear and non-clear areas of the disk runs down the middle of the dark Mare Cimmerium. In the blue photograph, an east-west bright band is present between the equator and latitude $-25°$. It is also quite evident on the photoelectric scans at 4000 Å. This brightening has the appearance of a meteorological phenomenon because of its long east-west extent and transient character. Such cloud-like phenomena have been noted before by Slipher (1962). The rapidity with which the blue clearing can appear and disappear also argues for this being a meteorological phenomenon.

4. Changes in the Polar Caps

The polar caps were visible on all north-south scans taken at wavelengths below 5000 Å. By taking the ratio of the brightness of the polar caps to an average area on the disk and normalizing to the albedo of the whole Martian disk as determined by Tull (1966), it was possible to determine an approximate albedo for the polar caps as a function of wavelength. Figure 4 shows albedos observed on several days. Again, these measurements are uncorrected for the smearing effects due to seeing in the Earth's atmosphere, which is extremely severe for an area on the limb of the planet, such as the polar caps. However, it is immediately evident that the caps have a relatively flat albedo below 4500 Å and that they change in brightness from day to day. The north cap, which at this time of Martian season should more properly be called a 'hood', shows variation in extent and brightness from day to day. This is very typical behavior for the fall hood. At the time of these observations, Mars was just past the fall equinox in the northern hemisphere. Notice that at its brightest the north cap is very similar to the stable southern cap; however, the north cap did show a change in intensity by a large factor during the course of one day from July 4 to July 5. Again, this is a strong indication of some type of meteorological phenomenon, perhaps deposition and sublimation of solid carbon dioxide on the surface.

5. Hellas

This large bright area to the south of Syrtis Major has been known to undergo changes in brightness at the time of the northern autumnal equinox. At this time Hellas will sometimes, but not always, become darker than the desert areas. From a survey of plates available at the Planetary Research Center of the Lowell Observatory,

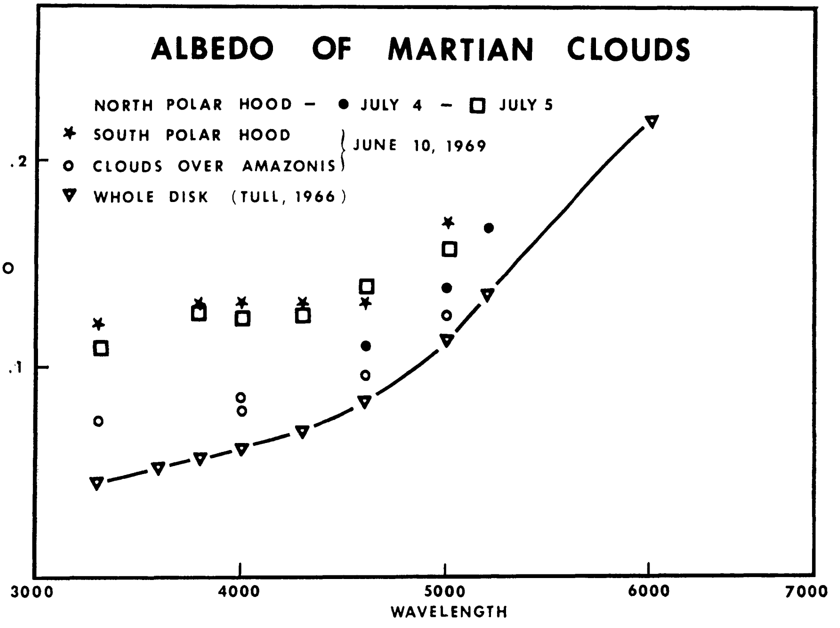

Fig. 4. Albedos of polar caps and 'W clouds' on Mars. Uncorrected for smearing.

it is apparent that Hellas showed this darkening during the oppositions of 1907, 1937, and 1969, but remained quite bright during the opposition of 1922. The darkening, when it does occur, apparently has no relationship to phase angle.

During the present opposition, Hellas did become quite dark for a period of at least forty days. Figure 5 shows two sets of north-south scans across the Hellas and Syrtis Major areas. The top set of scans was made when Hellas was faint. It is apparent that Hellas is not present on these scans at any wavelength. The brightening on the limb at 4000 Å is not at the position of Hellas and is due to the south polar cap. The bottom set of scans was taken one month later after Hellas had once again reached its normal brightness. It is extremely bright at 6000 Å, becoming less visible at shorter wavelengths. Although these scans have not yet been calibrated in absolute intensity, it is apparent that there is approximately a 30% change in the brightness of Hellas.

Examination of the Planetary Patrol photographs shows that Hellas was not always uniformly dark, undergoing changes in appearance from day to day during the month of June. The most violent fluctuations in the appearance of Hellas occurred during the period of June 14 to 22, when Hellas was recovering its normal bright appearance. At this time, daily changes in brightness and appearance occurred. By June 17, Hellas had become quite bright, but on the 18th it had once again reverted to its dark appearance. On the 20th of June, the eastern half of Hellas was bright, but the western half was still dark. However, by June 22 the whole area of Hellas had become bright. The rapidity and reversibility of these changes seems to indicate a phenomenon that is connected in some way with Martian meteorology.

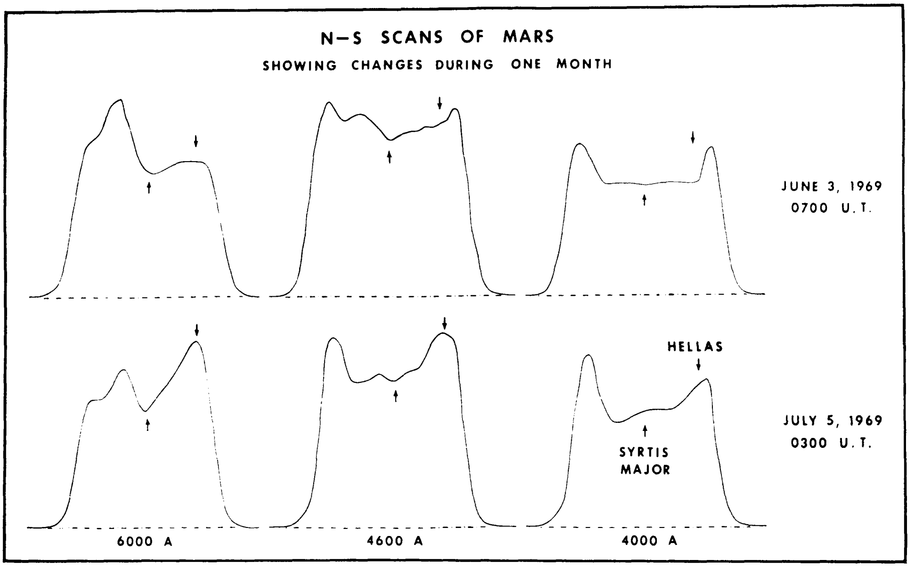

Fig. 5. N–S intensity profiles of Mars through Hellas and Syrtis Major. North is at the left.

This conclusion is reinforced by the diurnal brightening of Hellas which was very apparent as Hellas began to regain its normal appearance. Hellas usually showed a strong brightening in the Martian afternoon, a type of behavior very similar to that of the Martian 'clouds', which are known to be transient phenomena. A detailed photometric investigation of Hellas is sufficient to show the rapidity with which large areas on the surface of Mars can change.

6. Conclusion

It is apparent from photoelectric observations that the Martian blue clearing is indeed due to a change in the contrast of the Martian surface markings. Such changes can be extremely rapid and often cover large areas of the Martian surface. The autumnal polar hood of Mars has likewise been shown to change drastically in intensity over a very short time span. Finally, the area Hellas has also been shown to vary in brightness with a rather short time scale. In this respect, Hellas is one of the most peculiar areas on Mars. It is tempting to think that the lack of craters in the Mariner VII photographs of Hellas is connected in some way with the remarkable brightness changes that Hellas underwent in the month preceding the Mariner encounter.

In any event, it is evident that the surface of Mars undergoes many large-scale, rapid variations of intensity of a type that is very difficult to explain without invoking some sort of meteorological phenomena. It is too early at this time to do more than speculate upon mechanisms which could be responsible for such changes, but it is necessary to be aware that such changes exist and will have to be taken into account by any theory of the Martian surface and lower atmosphere.

Acknowledgments

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