

LOWELL OBSERVATORY

BULLETIN No. 157

VOL. VII

FLAGSTAFF, ARIZONA

No. 20

THE DEVELOPING STAGES OF THE MARTIAN YELLOW STORM OF 1971

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November 30, 1971

On September 22, 1971, a brilliant white elongated feature appeared suddenly overnight across the Hellespontus-Noachis on International Planetary Patrol photographs taken by G. Roberts at the Republic Observatory. This feature was not evident on photographs obtained on September 21. Figures 1 and 2 show two pre-storm photographs of this region of the planet for comparison. The white streak was second in brightness to the South Polar Cap; and it was sharply defined in red light, somewhat diffuse in green light, and identifiable but low contrast in blue light. The brightest area lay on the northeast border of the Noachis next to Mare Serpentis. The bright, initial core of the storm lay in a northeast-southwest direction across the disk with the east end located at coordinates 301° ; -23° and the west at 344° ; -35° . It was about 2400 km long and covered approximately 10,000 square km. The core remained in this location for three days, slowly expanding to cover about 15,000 square km. During this same period, part of the core at 320° longitude shifted south about 250 km.

On September 24 (third day) the storm began to advance from each end of the core. The eastern edge moved across the dark Yaonis into the Hellas, where it expanded to completely cover this area by September 28 (seventh day). The storm advanced more slowly to the east than to the west and consequently covered little territory in this direction. There is some evidence that it got as far as the Ausonia Australis because the Mare Hadriacum was obscured. The western edge advanced 1800 km across the Noachis during the next three days, from September 24 to 27. A bright extension moved

northward across the Pandorae Fretum into the Aram area on September 26 (fifth day). After the 27th the storm expanded rather rapidly towards the west and southwest, affecting the Argyre I to Dia region, with bright concentrations appearing in the Argyre I, Dia, Thaumasia, Sinai, and Chryse areas. The Sabaeus Sinus and part of Margaritifer

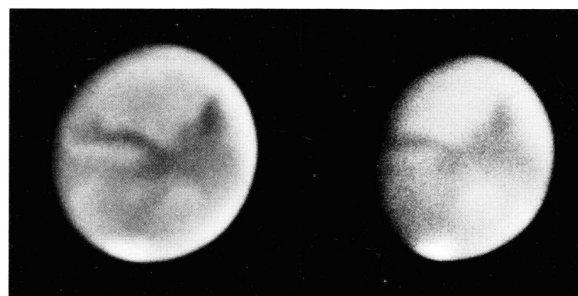


FIGURE 1. Mars as it appeared in red light on September 14, 1971, at 1556 UT, eight days before the yellow storm. The longitude of the central meridian (LCM) is 325° .

FIGURE 2. A normal Mars was photographed in green light on September 21 at 2003 UT, just one day before the beginning of the storm. The LCM is 321° .

All photographs in this Bulletin were obtained by the participating observatories of the International Planetary Patrol Program. Photographic processing, compositing, and automatic dodging were done at the Planetary Research Center of Lowell Observatory.

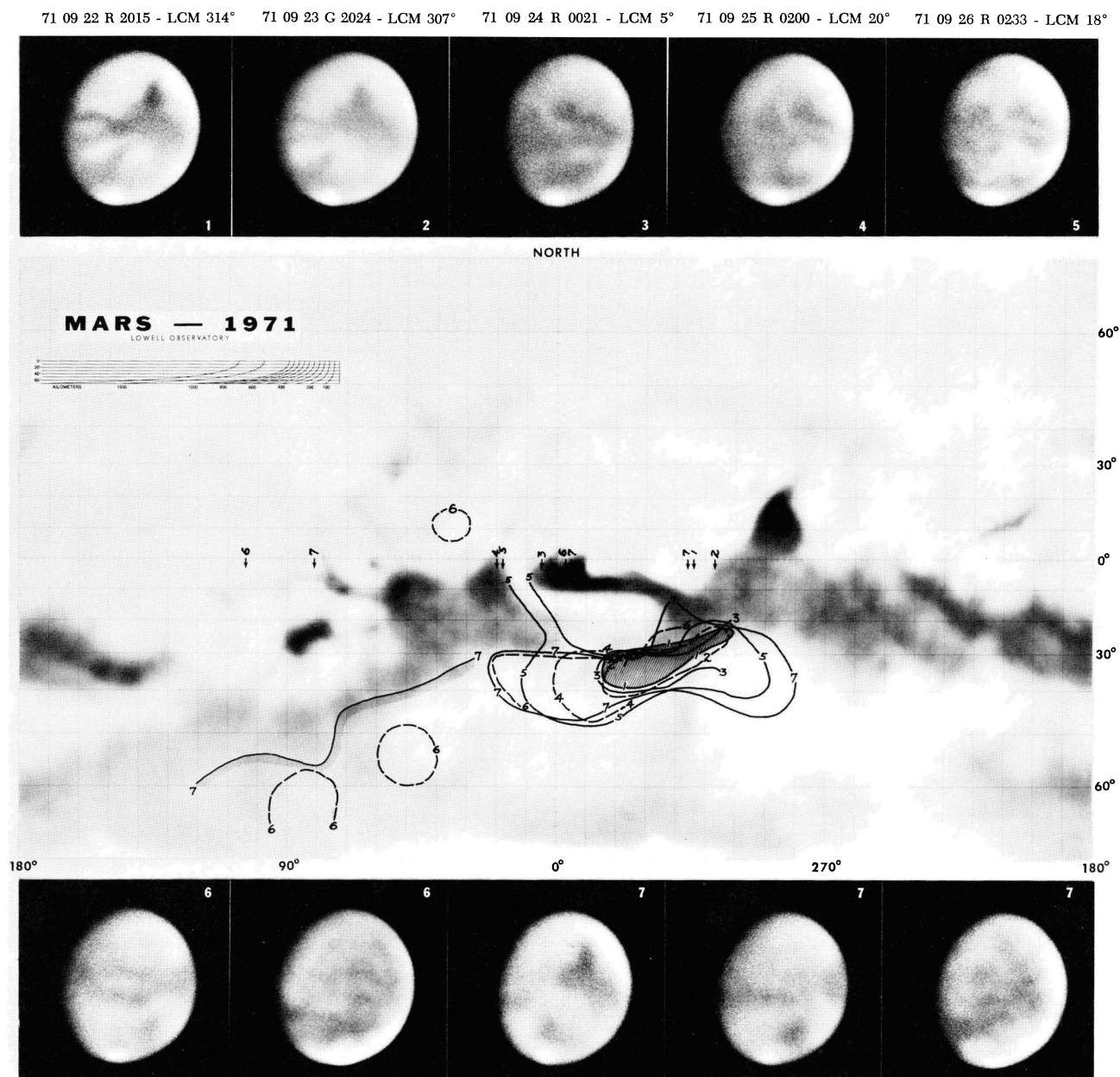


FIGURE 3. A preliminary map of the yellow storm's daily progress during the first seven days is plotted here on the Lowell 1971 Mars map. Approximate boundaries of the anomalously brightened areas are numbered by days beginning with day "1" (September 22), which is shaded. The corresponding day number on the arrows along the equator locate the central meridians of the selected photographs that were measured on the planet image projector. A broader haziness that obscured normal Martian features is not shown on the map. The cloud boundaries for even-numbered days are dashed lines. A non-closed boundary line (day 7) is shaded on the side that was bright. Above and below the map are some of the Mars photographs used to plot the initial developing stages of the yellow cloud. They are numbered chronologically by days to correspond with those on the map.

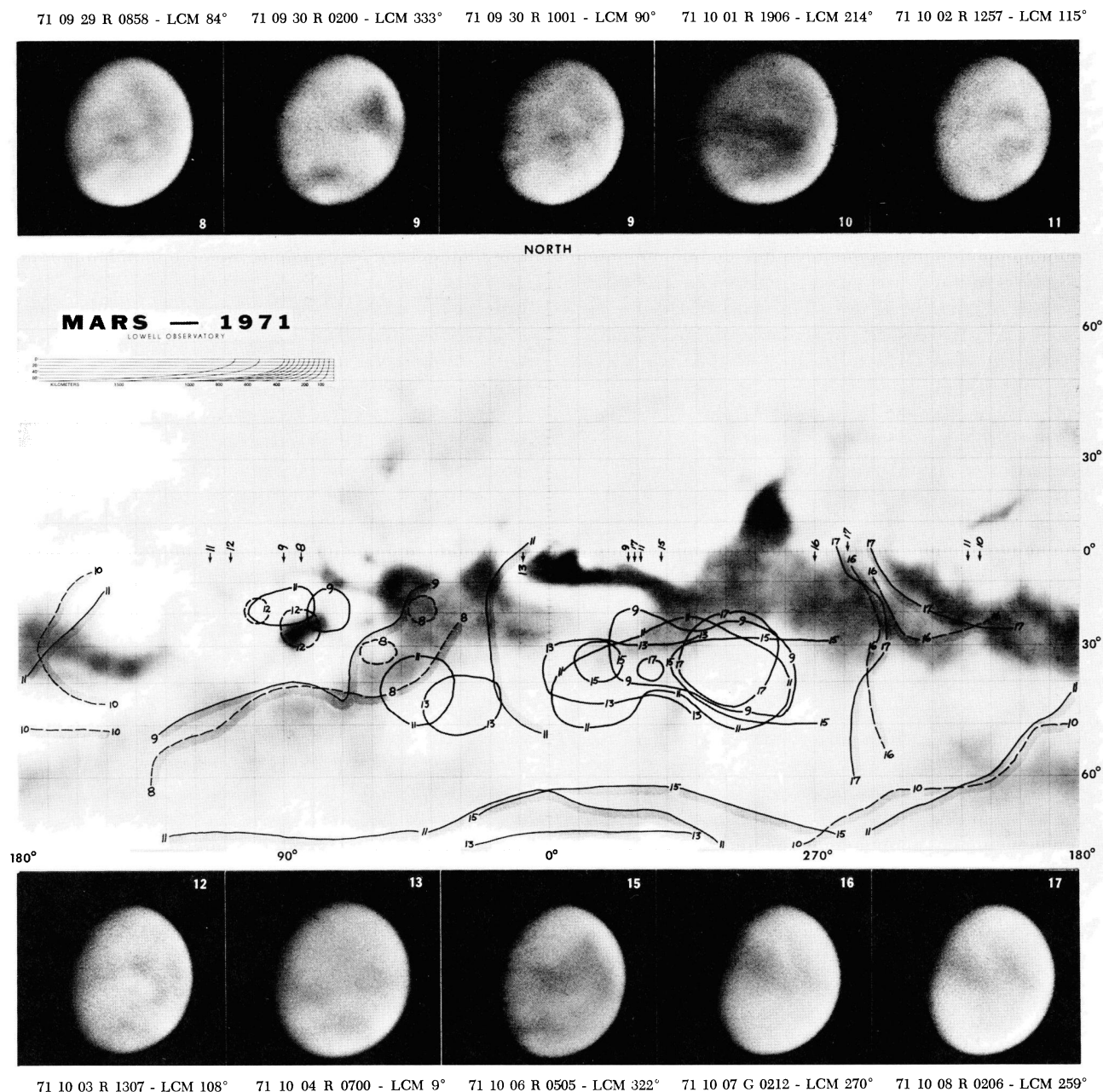


FIGURE 4. A second preliminary map illustrates the progress of the yellow cloud from the 8th to the 17th days. For clarity of mapping, the boundary lines of the initial bright core were omitted for the even-numbered days. Only selected photography was used for any given day, although the storm affected some regions on all sides of the planet during the latter part of this period. Open boundary lines are shaded on the side that was bright. Above and below the map are some of the Mars photographs used to plot the storm's progress during this period. They demonstrate the continuing loss of contrast in areas other than the anomalously brightened ones within the mapped boundaries.

Sinus were hidden beneath the haze by September 28. A bright branch of the storm was recorded moving northwest along the Hesperia, between the Mare Cimmerium and Mare Tyrrhenum, on October 7 and 8 (sixteenth and seventeenth days).

Preliminary evaluations and measurements of 1971 photographic data indicate that the yellow storm travelled completely around the planet in a westward direction in about 16 days, to join with the eastern front somewhere in the vicinity of 240° longitude in the Ausonia-Hesperia region. The average rate of advance of the storm over this 16-day interval along the -45° parallel was about 40 km/h. This is not necessarily a measure of the velocity of the local surface winds.

The daily changing aspects of bright phenomena of the storm have been measured on a planetary image projector and illustrated on two Lowell Observatory 1971 Mars maps shown in Figures 3 and 4. These are preliminary measurements intended to give only rough impressions of the storm's progress. They are considered incomplete in that only a small percentage of patrol photography from this period was utilized. The first map shows the initial phase of the storm from September 22 to 28. The second map depicts the period from September 29 to October 8. Further measurement of bright areas was impractical after October 12 because so much of the planet was obscured and contrasts were low. After this date photographic images of Mars in red and green light were devoid of markings; whereas the blue and ultraviolet images exhibited some evening limb and polar brightenings.

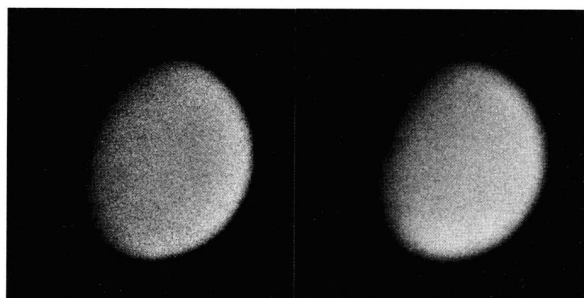


FIGURE 5. The complete obscuration of Martian albedo markings by the yellow storm is evident in this red-light photograph with an LCM of 162° , taken on October 21, 1971 (29th day).

FIGURE 6. The appearance of Mars in ultraviolet light is shown for comparison in this photograph with a similar LCM of 160° , taken on October 23 (31st day).

YELLOW HAZE

A general yellow-haze obscuration is the second observable physical aspect of a yellow storm. It is difficult to determine the haze boundaries and measure its motion accurately because of low contrasts and ill-defined borders. Its presence and extent can be detected only by noting the absence of surface features. Haze was noted on September 26 (fifth day), affecting the eastern end of Sabaeus Sinus and Deucalionis Regio in the north and Mare Australe in the south. Only the Amphitrites-Hellespontica Depressio and Oceanidum remained visible in high southern latitudes as dark islands in a sea of yellow. As the storm progressed west, bright hazes were observed in the light areas from the Pyrrhae Regio to Sinai. An obscuration appeared over the Bosphorus-Thaumasia region on September 28. By the 30th it had extended northward over parts of Solis Lacus and Tithonius Lacus.

The white South Polar Cap was losing contrast relative to adjacent areas on the 26th, and it was completely obliterated by September 30. On October 5 the south polar region developed a bright white-yellowish hood. The cap appeared briefly at times through the haze from October 7 to 31.

The haze continued to expand in all directions during October, covering both light and dark areas. The Mare Tyrrhenum was the least obscured of the southern maria at that time. Northern hemisphere features also exhibited loss of contrast. International Planetary Patrol photographs indicated that the entire Martian globe eventually became obscured, a condition which has happened infrequently in past observational records. Vague details with low contrasts began to appear on the disk of Mars during November. Blue and ultraviolet photographs showed that polar hoods were present over each of the poles.

CHARACTERISTICS OF 1971 STORM

A phenomenon that shows the magnitude and intensity of the planet-wide envelopment during the later stages was noted on photographs in different colors. Red- and green-light photographs recorded Mars as being much brighter, in blue it was slightly brighter, and ultraviolet photographs showed no significant change in brightness compared to pre-storm conditions. This was evidently due to the very bright yellow haze that completely covered the Martian globe. Several planetary astronomers described the haze as having a highly reflective golden-yellow hue. According to blue-, green-, and red-light photographs, the storm was more yellow and red than blue in color. P. Boyce of Lowell Observatory, observing from Cerro Tololo Inter-

American Observatory with K. Czuia, reported that the brightness and spectral reflectivity of the clouds from photoelectric area scanning did not differ greatly from that of normal Martian light (desert) areas. Color photographs and visual filter-aided observations showed the cloud to be yellowish in nature, and several dark features that were covered by the haze appeared dark orange and brown. J. Robinson, New Mexico State University Observatory, reported that polarization of the Martian disk was down about 50 percent during the period of yellow obscuration.

E. Slipper and S. Miyamoto observed apparent darkening of areas adjacent to the 1956 yellow storm. Possibly these were only contrast phenomena due to the abnormal brightening within the storm-covered areas. Similarly, while the initial 1971 yellow cloud was still confined to the Noachis-Ogygis region, an increase in contrast was recorded in adjoining light and dark areas. The Pandora Fretum exhibited high contrast, while patches in Mare Amphitrites, Mare Oceanidum, Bosporus, Pontica Depressio, Mare Australe, and Thaumasia appeared dark in comparison with their surroundings. This interesting phenomenon needs to be carefully studied photometrically to determine whether it is only a contrast effect or whether some areas actually do become darker.

HISTORY OF YELLOW CLOUDS

"Ocher-colored veils" were suggested as responsible for certain obscurations of Mars by H. Flaugergues as a result of his observations between 1796 and 1809. This is our earliest record of observations of what is now commonly called "yellow" clouds or storms on Mars. Fifty years later Father Secchi noted that a fading of the general reddish color of Mars coincided with a weakening of its dark features. In 1879 C. Burton reported that "orange" colored clouds were present and responsible for a "yellow tinge" upon the South Polar Cap. A. E. Douglass stated that in 1899 he had observed a general haze which lowered the contrast of surface features and appeared to be "yellow dust" rather than "white mist." During the 1909 and 1911 apparitions, E. M. Antoniadi and Maggini confirmed the existence of yellow clouds and haze.

Yellow clouds have been reported in all Martian

seasons; however, the only known planet-wide disturbances have occurred during Martian spring and summer in the southern hemisphere. These great yellow clouds have similar characteristics: 1) They appear when Mars is closest to the Sun (near perihelion) and when the thermal equator (defined as the diurnal track of the subsolar point) has about reached its maximum southern latitude of -24° . 2) They seem to germinate in specific areas in the southern hemisphere. The yellow clouds of 1909, 1911, 1924, 1939, 1956, and 1971 favored the Hellas-Noachis region. 3) The initial formation appears relatively bright and white and later takes on a yellowish-white hue. The physical aspects of the phenomenon are composed of at least three visible parts: the bright white-yellow core of the storm, the large encompassing ocher obscuration of surface features, and the small peripheral blue-white clouds which appear to be associated with a mature yellow storm. 4) They progress mostly in an east-west direction, although some storms have been known to cover the south polar region and migrate into the northern hemisphere. The southern longitudes from 250° westward to 90° have been affected the most during past yellow disturbances.

COMPARISON WITH 1956 YELLOW CLOUD

The similarities between the 1971 yellow cloud and the Great 1956 Yellow Cloud are most remarkable. The behavior of the Martian atmosphere prior to the formation of both yellow clouds was somewhat alike. Little or no white cloud activity was observed, and the contrast of familiar features was high. Just before the appearance of the yellow clouds, the limb showed a light-yellow brightening. Both storms began suddenly within a 24-hour period as a brilliant white streak over the Hellespontus-Noachis region. Their initial dimensions and positions were very similar. In both cases the development toward the east was not so rapid and intense as toward the west. Abnormal darkened areas were associated with both storms. The south cap was obscured from view during periods of each disturbance.

The 1956 storm began 2° before Martian perihelion; whereas in 1971 it began 9° after perihelion. The planet was more thoroughly and extensively covered and for a longer period of time in 1971.

