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On the Nature and Visibility of Crater-Associated Streaks on Mars

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R. O. Kuzmin has proposed that all crater-associated wind streaks on Mars are depositional and consist of unresolved barchan-like dunes. He claims that any streak can appear either bright or dark relative to its surroundings depending on the azimuth of the Sun relative to the streak axis and on the elevation of the Sun above the horizon. Our studies of the entire Mariner 9 picture collection as well as of available Viking data lend no support to these ideas. We find that the conditions for visibility of bright and dark streaks are identical. In Mariner 9 images both types of streaks are visible for viewing angles $\epsilon \lesssim 60°$, illumination angles of $15° \lesssim i \lesssim 75°$, and over the whole range of phase angles covered (about 15 to 85°). There are numerous examples of dark *and* light streaks visible at the same azimuth angle of the Sun, contrary to Kuzmin's claim. There is much evidence to indicate that bright and dark streaks differ both in morphology and in character. The common ragged dark streaks are probably erosion scars, while most bright streaks probably represent accumulations of bright dust-storm fallout. There is no evidence at present that these accumulations have a barchan-like texture.

INTRODUCTION

Kuzmin (1975) has proposed that all crater-associated streaks on Mars are depositional and consist of unresolved barchan-like dunes. He claims that any streak can appear either bright or dark relative to its surroundings depending on the azimuth of the Sun relative to the streak axis. It is the purpose of this note to point out that this and related assertions made by Kuzmin are inconsistent with the bulk of Mariner 9 and Viking data. Specifically, on the basis of a study of 169 streaks visible in Mariner 9 imagery, Kuzmin asserts that (a) dark streaks are seen only when the Sun's azimuth relative to the streak axis is less than 90°; (b) bright streaks are seen only when the Sun's azimuth exceeds 90°; (c) dark streaks are seen when the Sun's elevation is between 15 and 45° (that is, when the angle of incidence is between 75 and 45°); (d) bright streaks are seen when the Sun's elevation is between 20 and 59° (incidence angle between 70 and 31°); (e) streaks are not visible when the Sun's elevation exceeds 65° (incidence angle less than 25°).

Kuzmin apparently holds that all streaks on Mars are identical in nature in that they are deposits of wind-transportable material and have the topographic texture of barchan-like dunes. He claims that under photometric conditions in which there are substantial shadows visible to the observer a streak will appear dark, whereas under photometric conditions in which shadows are not prominent the same streak will appear bright. We do not argue whether or not this explanation accounts for assertions (a) to (e), since we show that these specific claims are in fact unsup-

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ported by the data. We show that (1) Mariner 9 data do not indicate any difference in the photometric conditions under which dark and bright streaks are visible; (2) there is no known case of a bright streak turning into a dark streak (or vice versa) under a change of viewing or lighting conditions; (3) there is ample evidence that bright and dark streaks are fundamentally different in nature and in origin; and (4) there is no evidence that either bright or dark streaks consist of unresolved barchan-like dunes.

VISIBILITY OF STREAKS

The Mariner 9 collection contains approximately 700 frames in which streaks are visible (if one considers only frames obtained after orbit 110, that is, after the 1971 dust storm had essentially dissipated). The photometric conditions under which bright and dark streaks are seen in the Mariner 9 coverage are summarized in Figs. 1 to 3.

There is essentially no difference in the conditions under which bright and dark streaks can be seen. Both types are de-

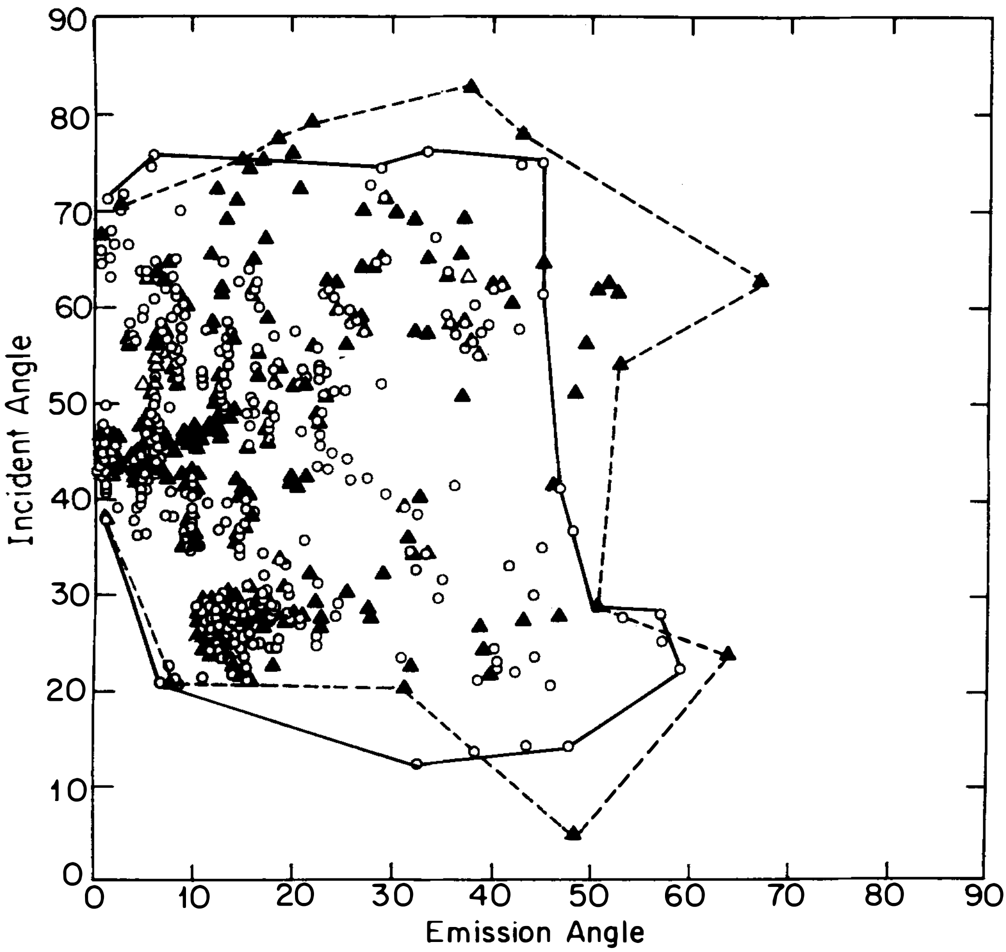

FIG. 1. Regions in the (i, ϵ) plane within which dark and bright streaks are visible in Mariner 9 images. ——, Light streaks (○); – – –, dark streaks (▲).

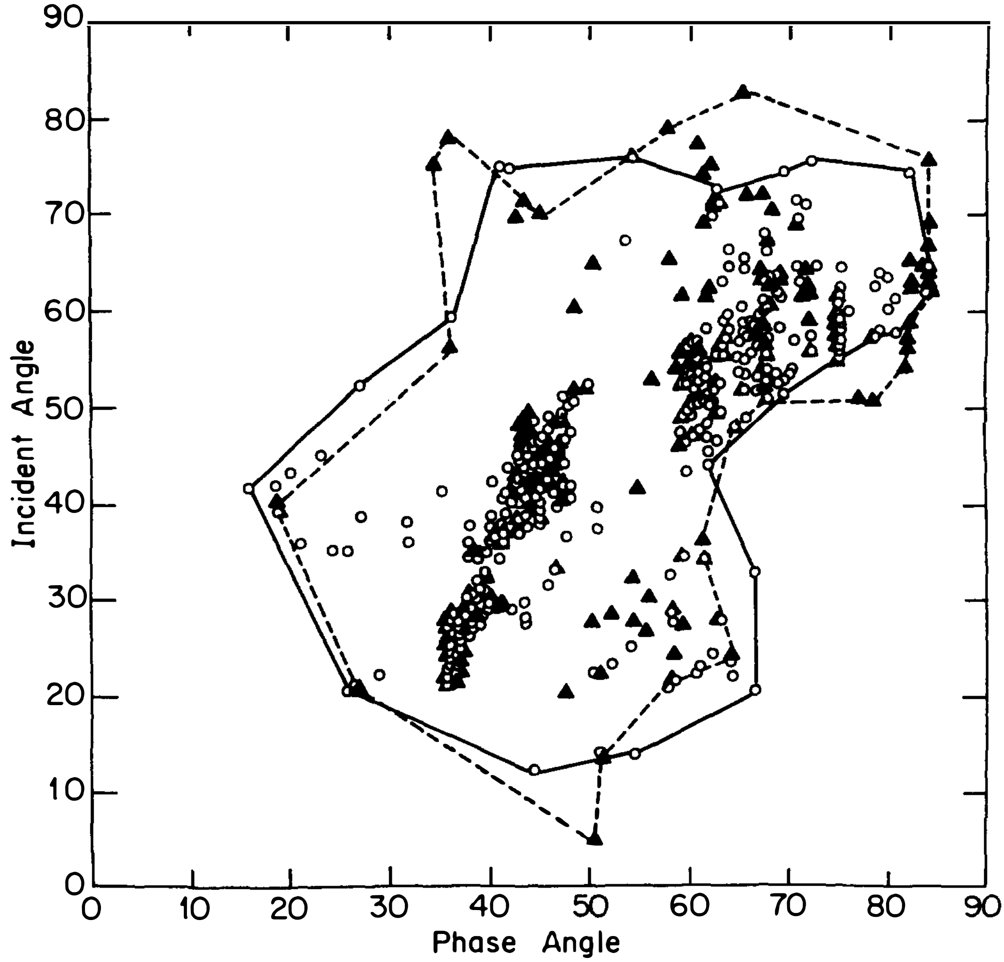

FIG. 2. Regions in the (i, α) plane within which dark and bright streaks are visible in Mariner 9 images. ——, Light streaks (○); – – –, dark streaks (▲).

finitively visible for viewing angles of about 60° or less and for incidence angles between 15 and 75°. Also, both types are visible over the whole range of phase angles (about 15 to 85°) covered by Mariner 9. Thus Kuzmin's assertions (c) to (e) are not supported by the full set of Mariner 9 data. There is *no* difference in the visibility conditions of bright and dark streaks; dark streaks *are* visible at incidence angles of less than 45° (in fact, at least down to $i \simeq 15°$); and streaks *are* visible for $i \lesssim 25°$.

Having disposed of Kuzmin's statements concerning solar elevation effects on the visibility of streaks, we now consider his statements about the effects of the Sun's azimuth.

AZIMUTH EFFECTS

Kuzmin attaches great significance to his assertion that dark streaks are seen only when the azimuth of the Sun relative to the streak axis is less than 90°, while bright streaks are visible when the azimuth is more than 90°. If we denote this angle by A and measure it positive from 0 to 180° counterclockwise, and negative from 0 to 180° clockwise from the streak axis, then Kuzmin's conditions are: $|A| < 90°$ for dark streaks, and $90° < |A| < 180°$ for bright streaks. It is easy to find specific cases which contradict this scheme (Table I). In fact we can find no evidence that the angle $|A|$ has any bearing on the visibility of streaks on Mars.

Even though Kuzmin's specific assertions about the visibility of streaks are invalid, is it possible that his two "deductions," namely, (a) that bright and dark streaks are fundamentally identical in nature, and (b) that they are made up of unresolved barchan-like dunes, have some merit? We now attempt to answer these two questions by briefly summarizing what is known about bright and dark streaks on Mars.

THE NATURE OF BRIGHT AND DARK STREAKS ON MARS

There is no known instance in the vast Mariner 9 and Viking record of a bright streak turning into a dark streak (or vice versa) simply by a change in viewing or lighting conditions. Generally, the mor-

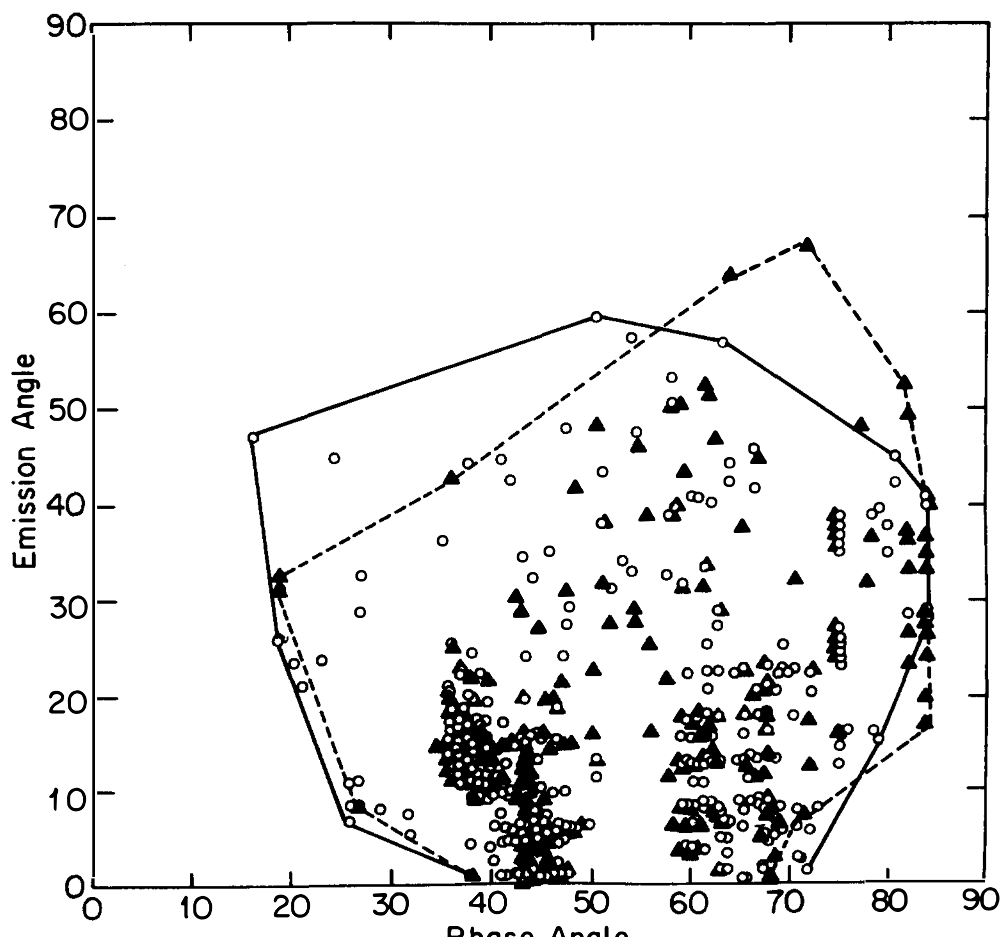

FIG. 3. Regions in the (ϵ, α) plane within which dark and bright streaks are visible in Mariner 9 images. ——, Light streaks (○); - - -, dark streaks (▲).

TABLE I

VALUES OF $|A|$ FOR SEVERAL GROUPS OF STREAKS ON MARS

Picture number	Lat.	Long.	Number of streaks	Average $\|A\|$[a]
Dark streaks				
M9:DAS8981114	25°S	248°W	41	14°
VIK:109A77	30°S	250°W	14	93°
VIK:493A09, 10	34°S	120°W	23	119°
VIK:464A30, 31	25°S	65°W	13	141°
VIK:109A79	27°S	253°W	9	159°
VIK:056A20	26°S	123°W	22	171°
Bright streaks				
VIK:206A05	30°N	13°W	11	6°
VIK:545A52	19°N	184°W	27	25°
VIK:109A77	30°S	250°W	11	79°
VIK:83A43, 46, 47	9°N	25°W	38	116°
VIK:056A07	21°S	130°W	23	134°
M9:DAS8981114	25°S	248°W	52	174°

[a] Absolute value of the azimuth of the Sun relative to the streak axis measured 0 to 180°.

phology of well-developed bright and dark streaks is quite different. For example, common dark streaks tend to be ragged and fan-shaped while bright streaks tend to be longer and more tapered (Veverka *et al.*, 1978). Furthermore, bright and dark streaks differ considerably in their mean lifetimes as well as in the wind patterns that they record. Dark streaks may vary on time scales of tens of days while most bright streaks are stable over at least several Martian years (Sagan *et al.*, 1973; Veverka *et al.*, 1977). The directions of bright streaks outline a coherent windflow pattern characteristic of the near-surface wind regime during the southern summer (Sagan *et al.*, 1973; Gierasch, 1974), while the wind pattern defined by the dark streaks is much more erratic.

These differences are difficult to explain under the assumption that bright and dark streaks are the same phonomenon seen under different lighting and/or viewing conditions. Rather, these differences prove that bright and dark streaks differ fundamentally in nature. Bright streaks can be explained convincingly as accumulations of bright dust-storm fallout in the lees of craters, and common ragged dark streaks essentially as erosion scars (Veverka, 1975). There is no available evidence that the bright streak accumulations have a dune-like texture or that they have any significant topographic expression. Crater-associated streaks on Mars appear to be essentially albedo patterns and as such are best seen under high Sun and near-vertical viewing (at small incidence and emission angles)—in other words, when shadowing due to topography is not important.

Viking Lander photography has revealed bright streaks in the lee of positive relief surface obstacles; while these streaks are smaller by a factor of about 10^5 than crater-associated streaks seen from orbit, they are similar in morphology and closely parallel to the crater-associated streaks and also seem connected with major wind systems (Sagan *et al.*, 1977). There is no evidence that these obstacle-associated streaks significantly change their albedo relative to their surroundings with changes in the solar elevation angle.

We conclude that the full set of Mariner 9 and Viking data does not support any of Kuzmin's claims. The problem with his study is that its data base is too limited and that it makes the implicit assumption that in any small subset of Mariner 9 pictures the crucial photometric parameters (i, ϵ, α, A) will be randomly distributed among all possible values. This is clearly not the case. For example, if the sample consisted mostly of southern hemisphere mapping pictures then the illumination conditions would not vary greatly and most bright streaks would be found pointing to the S or SE while most dark streaks would tend to point E to W. This difference reflects the different origins of the bright and dark streaks and has nothing to do with different visibility conditions.

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