

A PRELIMINARY REPORT ON CHROMOSPHERIC SPICULES OF EXTREMELY SHORT LIFETIME

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ABSTRACT

Small spikes of chromospheric material, observed in *H α* with the coronagraph and quartz-polaroid monochromator, are described. These spicules, seen in polar regions of the sun, have very brief lifetimes, amounting on the average to 4 or 5 minutes. The typical spicule is low in brightness and has a height at maximum of less than 15 seconds of arc. At least in polar regions, they appear to be present in greater or smaller numbers at all times. The spicules are apparently distributed at random in the polar regions studied. The behavior of the spikes, while well typed, exhibits considerable variation. Possible association with polar coronal "plumes" and with "rice grains" of the disk is discussed.

For many years solar observers have been aware of the irregular appearance of the chromosphere of the sun when viewed under the best observing conditions. Frequent reference has been made to Secchi's observations of the "vertical flames" of the chromosphere in polar regions of the sun.¹ In discussing Lick Observatory eclipse photographs Menzel has called attention² to the "spike" prominences of the chromosphere and to the fact that "the difference between the chromosphere and the prominences is merely one of degree." The irregularities of the chromosphere are evident in the eclipse photographs reproduced by Menzel and, still more strikingly, in the photographs taken by Marriott, of Swarthmore College, at the eclipse of October, 1930. In the latter, small vertical polar prominences are clearly visible in some sections of the solar limb.

During the fall of 1943 I noticed that small chromospheric spike prominences were clearly discernible in photographs of the polar regions of the sun which I was taking with the Lyot-type coronagraph of the Harvard College Observatory located at Climax, Colorado. I was amazed at the extremely brief lifetimes and the great frequency of occurrence which visual observations of these spicules indicated. Consequently, I decided, toward the end of the year, to undertake a further investigation of this interesting phenomenon. On December 12, 1943, under the very best conditions of atmospheric steadiness and purity, I obtained a motion-picture film centered near the position angle of the north pole of solar rotation. The 35-mm film was exposed at a rate of one picture per minute through an interference polarization monochromator designed and built by Dr. John W. Evans³ and similar to that used by Pettit for prominence observations.⁴ Exposures were about 2 seconds on a 103 *H α* sensitization film produced especially by Eastman Kodak Company. With a red-glass filter and the special film, the over-all transmission band utilized was about 4 Å wide, centered on 6563 Å of *H α* .

From this first film and from subsequent visual and photographic observations I have ascertained, at least roughly, the behavior of the typical polar chromospheric spicule. The typical spicule shows first as a barely detectable lump on the solar limb. The lump rapidly enlarges and brightens to a maximum intensity that is still relatively faint for prominences in general. Within a minute or two of first appearance the lump elongates to maximum height, after which there is no detectable motion but simply a relatively gradual fading-out. Average proportions for a spicule at maximum extension are approximately 3'' or 4'' \times 10'', though strong observational selection undoubtedly favors the recording of the large spicules and the overlooking of the small ones. Average total lifetimes are

¹ E.g., Abetti, *The Sun*, p. 134, 1938.

³ *Pub. A.S.P.*, 52, 305, 1940.

² *Pub. Lick Obs.*, 17, 287 ff., 1931.

⁴ *Pub. A.S.P.*, 53, 171, 1941.

about 4–5 minutes. Spicules much smaller than the typical one exist, and perhaps the frequency of occurrence for the smaller ones is even greater than for those I have called typical.

At a given moment of time I have observed visually more than 25 of the spicules within a 60° arc centered on the solar pole. Only the larger ones show on even the best photographs. On no occasion of satisfactory seeing and atmospheric purity have I failed to find the spicules present in considerable numbers in both polar regions. The intensity of the spikes is very low, on the average, and a great number of them exists at the very threshold of visibility. It is doubtful that they would be visible in apparatus not possessing relatively high resolution and high image-to-background contrast. Thus it is not surprising that the spicules have not attracted greater attention previously. Also it is unlikely that

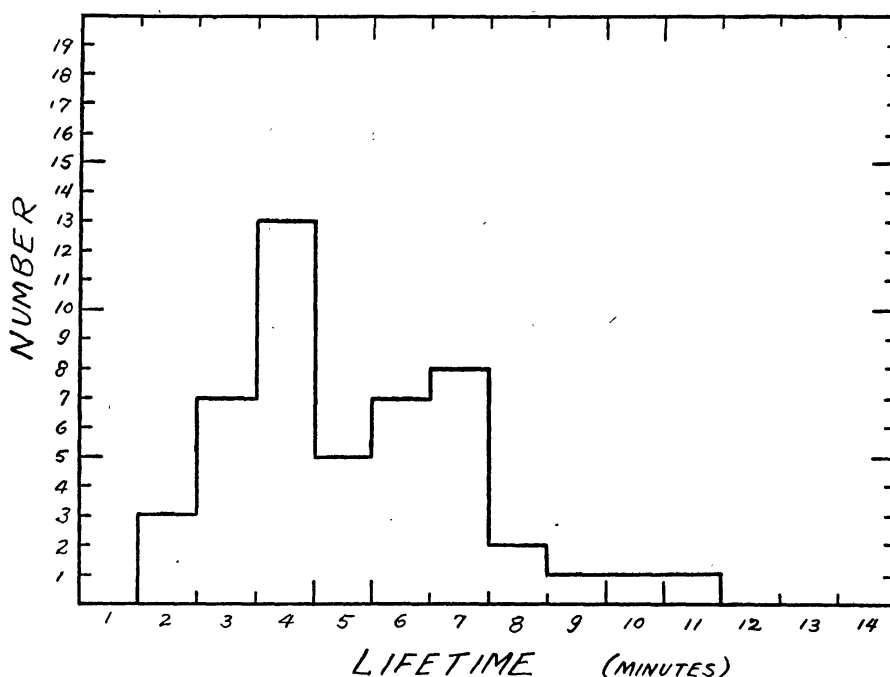


FIG. 1.—Histogram showing the frequency distribution of the lifetimes of spicules. Strong observational selection undoubtedly favors the inclusion in the measurements of spicules of long lifetime. The double maximum is probably not significant.

observers would be attracted to them in preference to the more striking prominences usually in evidence in other portions of the sun's disk. To study the spicules in detail from drawings is almost impossible, in spite of the advantages of visual observation, because of their intricacy and their rapid changes and because they are frequently obliterated momentarily by atmospheric unsteadiness. The drawing in Plate V depicts the general character of the spicules as seen during brief intervals of outstanding seeing steadiness. The drawing displays resemblance to eclipse photographs but does not quite show the fineness of detail drawn by Secchi from spectroscopic observations. In Plate VI, direct photographs of the spicules are shown. These photographs were taken under unusually favorable observational conditions. Comparison of the two parts of Plate VI shows that in the 8-minute interval between the two photographs, *A* and *B*, all the spicules visible in the first have disappeared and those in the second are new.

I have partially analyzed the film obtained on December 12, 1943; but for more complete studies I shall need improved measuring equipment. Preliminary results from the

first 50 frames of this motion picture, taken at the rate of one picture per minute, disclosed the formation of just over 50 distinct spicules. The 48 which could be measured with improvised apparatus displayed the frequency distribution of lifetimes given in Figure 1. These tabulated lifetimes represent simply the difference in number between the frame on which the spicule was first seen and the one on which it was last seen. The results are rough because of the difficulty of ascertaining the frame of first and last appearances with variable picture quality and too long an interval between pictures. The double maximum in the frequency distribution need not be regarded as significant in view of the grossness of the measurements and the small number of spicules involved. The drop in frequency for the shorter lifetimes may possibly be simply the result of observational selection. I have secured other films of the spicules at the more suitable rate of 6 frames per minute, and these should reveal more accurately the lifetime and behavior of the small spikes when adequate measuring apparatus is devised and constructed.

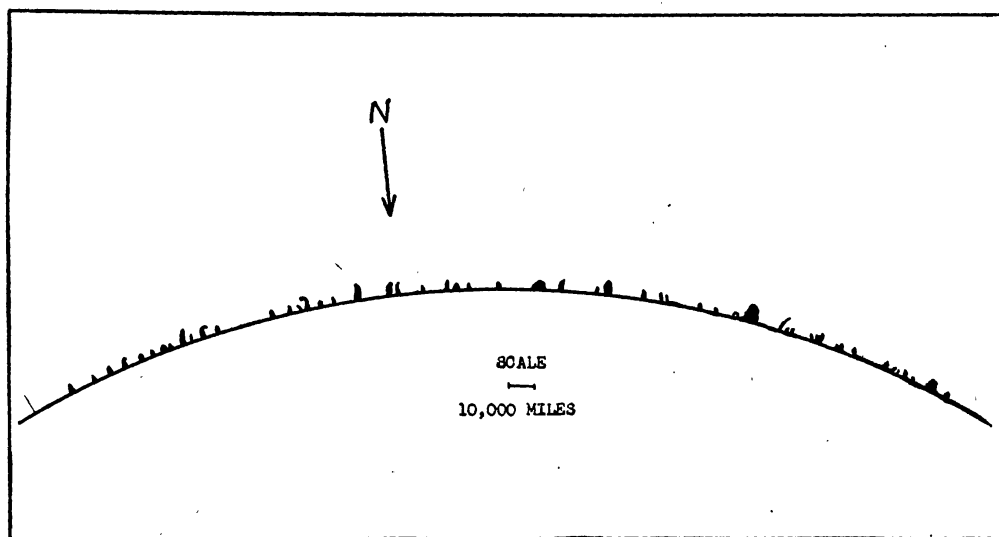


FIG. 2.—Composite drawing showing location, size, and shape of all the spicules measured in the first fifty frames of the motion-picture film of December 12, 1943.

The diagram in Figure 2 exhibits the distribution along the limb of the spicules detected in the first 50 frames of the December 12 film. No significant clustering exists; no large number of spicules came from any particular point of the arc, nor was any significant part of the arc devoid of the small spikes. No significant relationship to the position angle of the pole appears to exist.

Plates V and VI and Figure 2 also display to some extent the variation in behavior of the spikelets, one from another. Considerable range in size and shape exists. The size and length of life seem from rough comparison to be correlated strongly. The largest spicule in Figure 2 possessed the 11-minute lifetime, and some of the smallest as short as 2-minute lifetimes. This correlation serves further to accentuate the observational selection favoring observation of the larger and longer-lived spicules.

I have also made numerous visual observations of the small-scale chromospheric structure in the low latitudes of the sun. In most cases the spicules, if present, appear to have a more complex structure at low latitudes than at high. The inclinations to the vertical seem systematically greater, and the curvatures of the spikes themselves seem to be greater. Typical spicules definitely appear in low latitudes at times and apparently most conspicuously when the activity of larger prominences is at a minimum. I have taken motion-picture films to check this observation, but these will be too difficult to examine

without improved measuring apparatus. At present the data are too meager to say more than that the typical spicule structure is generally most pronounced in polar latitudes.

An interesting feature of the spicules—as, indeed, of all prominences—is the extreme sharpness of the boundaries of the emitting gases. In all cases the edges of prominences, from the faintest spicules to the brightest surges and the largest eruptives, appear perfectly sharp with no evident diffusion or haziness at the borders. This is definitely not an effect of the use of high-contrast photographic records, since not only are many of my films developed to a gamma well under 1 but also the effect is most noticeable by visual observation. To the very limit of resolution of the coronagraph (about $1''$) the boundaries appear clear and distinct, and even the internal structure of the larger prominences seems invariably to be a complex interlacing of perfectly sharp filaments and knots of prominence gas.

There appears to be no mention elsewhere of measurements of the lifetimes or frequencies of spicules. Hale has referred⁵ to “spike” prominences, but the phenomenon to which he was referring is evidently of a somewhat different nature, being very bright and related closely to a sunspot group. Hale’s observation probably relates to a prominence of the “sunspot” classification (Class III) according to Pettit.⁶ The small chromospheric spicules are not mentioned by Pettit in his prominence classification scheme,⁶ nor does reference to them appear in the works of McMath and his collaborators or in the publications available here of Lyot or Waldmeier.

Measures of the dimensions of the spicules and the number visible at a given moment were made, previous to my observations, by Mohler,⁷ of the McMath-Hulbert Observatory, from the excellent eclipse plates of Marriott exposed at the Swarthmore eclipse expedition of October, 1930. Mohler found from the eclipse plates average dimensions of about $2'' \times 11''$ for the spicules, in close agreement with my independent measures. Mohler estimated from the number visible along the limb that the disk of the sun should possess approximately 2×10^6 such spicules.

Of course, it is difficult to decide when a given prominence is to be classified as a spicule. Especially is this true at lower solar latitudes where the extreme simplicity of behavior of the spicules is not preserved uniformly. Undoubtedly all gradations of intermediate behavior between spicules and other prominences are possible. Still, the spicules seem to fall well enough into a pattern of behavior sufficiently typed and sufficiently distinguishable to be regarded as a characteristic phenomenon of the solar poles, at least at this phase of the solar cycle, much as the well-known coronal plumes are considered a phenomenon characteristic of the corona in the polar latitudes of the sun near minimum activity. And it is inviting to consider possible physical associations between the two.

The spicules and their constant rapid changes provide additional evidence of large-scale turbulence in the chromosphere. The velocity of motion of a typical spicule is apparently of the order of 30 km/sec radially outward from the sun’s center. It must be remembered, however, that this “typical” spicule is possibly one of the less frequent and larger spicules because of observational selection. Spicules possess characteristics very close to those now ascribed to solar granulations,⁸ namely, diameters of $1''$ - $2''$ and lifetimes of about 3 minutes. The recent interest in granulations stimulated by the work of Plaskett⁹ and ten Bruggencate¹⁰ impresses one with the importance of the possibility of associating spicules with the granulations. However, the expected velocity of outflow

⁵ *Pub. A.S.P.*, 38, 99, 1926.

⁶ *Mt. W. Contr.*, No. 679; *Ap. J.*, 98, 309, 1943.

⁷ Private communication of unpublished results from Dr. Mohler.

⁸ R. O. Redman, *M.N.*, 104, 99, 1944.

⁹ *M.N.*, 96, 402, 1936.

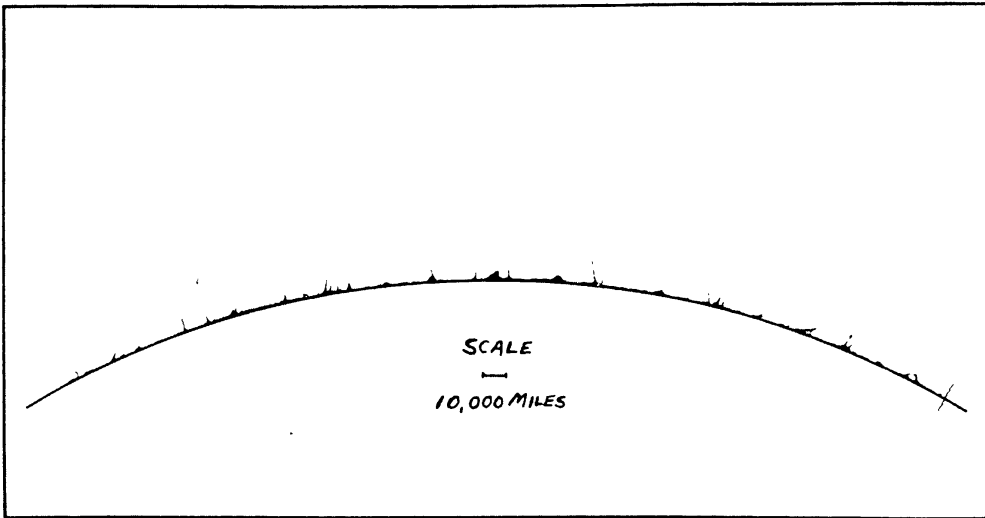
¹⁰ Ten Bruggencate and Grotrian, *Zs. f. Ap.*, 12, 323, 1936; ten Bruggencate, Grotrian, and von der Pahlen, *Zs. f. Ap.*, 16, 51, 1938; ten Bruggencate, *Zs. f. Ap.*, 16, 374.

L from granulations is about 1 km/sec, only one-thirtieth that estimated for the spicules. Further measures of the spicules and attempts to measure Doppler displacements in the granules should be made in order to determine whether this discrepancy is real. Still further, if direct photography of the polar coronal plumes and spicules can establish a link between the two, it may be reasonable to consider that the spicules associate granulations with the polar corona.

It is also reasonable to hope that a more detailed investigation of spicules may contribute to an understanding of the process of supply of material to the corona and regular prominences. The spicules are the only solar feature thus far discerned which seems observationally to indicate a continuous outflow of material through the chromosphere to the coronal regions. Indeed, it may prove that the spicules and the somewhat similar small-scale, low-latitude prominence structure are all that there is to the chromosphere and that actually the only difference between the chromosphere and the prominences is, as Menzel suggests, one of degree. In this case, the meaning of the "height of the chromosphere" becomes vague and the comparison of different measures extremely uncertain. In any event, the spicules are certainly further evidence of large-scale turbulence at the sun's surface; and, as such, they may provide, after careful study, valuable observational information regarding problems of disk-prominence-coronal interactions in general.

I wish to express my gratitude to Mrs. Roberts and to Miss Dorothy Emery for assistance in observing, recording, and measuring these spicules, and to Lt. Comdr. Donald H. Menzel for assistance and guidance in development of the coronagraph. To the Climax Molybdenum Company, on whose property our observatory is located, I wish to extend thanks for services performed in connection with the establishment of the coronagraphic station.

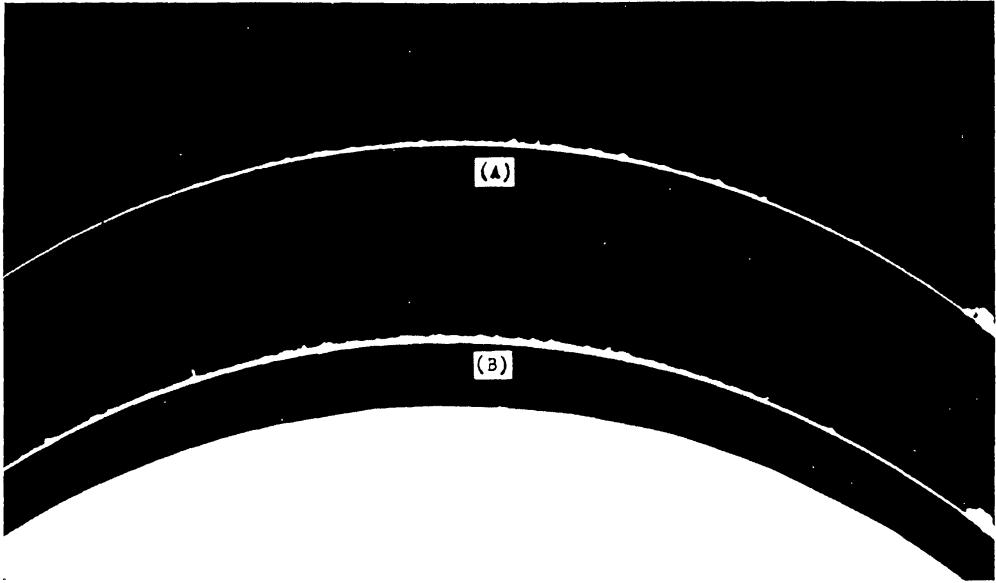
PLATE V



DRAWING SHOWING GENERAL CHARACTER OF THE POLAR REGIONS OF THE SUN

This sketch of the chromosphere was made from visual observations in $H\alpha$ with best seeing conditions and sky purity. The finer details shown have not yet been successfully photographed.

PLATE VI



PHOTOGRAPHS OF CHROMOSPHERIC SPICULES NEAR NORTH POLE OF SUN ON FEBRUARY 3, 1944
The time interval between *A* and *B* is approximately 8 minutes. All spicules of *A* have disappeared by the time of *B*, and a new set shows on *B*.