SOME OBSERVATIONAL RESULTS ON MOUSTACHES*

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Abstract. The results of new observations of moustaches in Hα filtergrams and in Hα spectra are presented and their relations to photospheric and chromospheric phenomena are studied. The main findings and conclusions are: (1) previous results on basic data (size, brightness, lifetime, etc.) are essentially confirmed; (2) limb observations located the moustaches at the base of the structured Hα chromosphere, just above the level of the emission of Hα ± 1 Å. At the disk moustaches are, in general, covered by absorbing and slightly Doppler-shifted chromospheric elements which determine the Hα core in the moustache spectrum. However, absorption-free moustaches with an Hα emission core revealing a pure (true) moustache spectrum have also been found; (3) moustaches have been found to coincide with continuous facular granules; it is suggested that they are an extension of facular granules into the chromosphere rather than a low-level flare-like phenomenon.

1. Introduction

Moustaches or bombs are known as small, short-lived sources of a peculiar line emission. Their most conspicuous spectral features are wide emission wings in the Balmer lines separated by a strong central depression (see Figure 4); maximum excess intensity is recorded at about ±1.0 Å from the line center. In Hα filtergrams, for instance, moustaches are therefore visible (as bright points) with the highest contrast at Hα ±1.0 Å, and frequently are not observable in the line center at all.

Moustaches have been investigated extensively at the Crimean Observatory (Severny, 1957, 1959, 1964, 1968; Severny and Koval, 1961; Koval, 1962, 1964, 1965, 1966, 1967) and by McMath *et al.* (1960). The latter gave a report on the early observations of 'bombs' (as the feature – following Hale (1917) – is called by American authors) and showed that the 'bright points' observed in photographs taken in the wings of Hα are identical with the sources of the moustache or bomb spectrum. Further studies have been carried out by Beckers (1964), Howard and Harvey (1964), Engvold and Maltby (1968), Ramsey *et al.* (1968), and Bruzek (1968). The present investigation is based on observations made at the domeless Coudé refractor at the Anacapri Observatory in several observing periods in the years 1966–71. These observations are: (1) filtergrams in the range Hα ± 1.0 Å taken with a Halle Hα filter (passband 0.5 Å) on Eastman Kodak emulsions 4 E, SO 375 and SO 392 respectively; exposure about $\frac{1}{10}$ s, diameter of the Sun on the negative 150 mm; (2) spectra around Hα covering about 10 Å taken on 4 E film with exposures 5–15 s, Sun's diameter 330 mm; (3) white light photographs with an exposure $\frac{1}{500}$ s, Sun's diameter 330 mm.

The present paper starts with some results concerning the basic properties of moustaches such as size, brightness, lifetime, number, occurrence, etc. A large part of

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the paper deals with moustache observations carried out in the limb zones of the solar disk in order (1) to study the association of moustaches with sources of continuous emission which are visible in the limb zones only, (2) to get additional information on the nature of the dark chromospheric features which are observed frequently associated with moustaches. Shape and association with the moustaches can be observed best in the limb zone, (3) to get some direct information on the level of moustache occurrence from observations at the very limb. Limb moustaches offer, moreover, a unique possibility to recognize the true shape of moustaches which, on the disk, appear invariably as circular bright points or knots. Another part of the paper is dealing with the moustache spectrum in the core of Hα in order to provide evidence for the cause of the peculiar central line profile.

2. Basic Properties

A. APPEARANCE (SIZE, SHAPE, BRIGHTNESS)

Moustaches are visible under good seeing conditions only. Even then they appear in general, as bright points or roundish knots. Only in a few cases were moustaches photographed at the solar limb (Figure 3) found to have the shape of a small mound or cone with fine curvilinear extensions into the chromospheric fine structure. Apparently the spatial resolution was never sufficient to reveal the true shape of moustaches on the solar disk. Apparent size and brightness, therefore, will be largely determined by the overall resolution which depends on the seeing conditions and on the telescopic and photographic resolving power. Measured values can give a rough estimate only.

In order to get the order of magnitude and to check previous results I measured 1340 moustaches photographed on 47 (Hα ±1.0 Å)-filtergrams using three different emulsions (4 E, SO 375, and 392). Two different simple methods were used: (a) the diameters were measured in projected negatives providing a scale $1'' = 2$ mm; (b) photometric intensity profiles were determined for a sample of the moustaches and the full half width of the profile was considered the diameter of the moustaches. The diameters derived by the two methods agreed within 0.1″–0.2″. Systematic differences were found, however, between the filtergrams taken on different emulsions: the average (and smallest) measured diameters were largest on 4 E and smallest on SO 392. There is an apparent correlation with the resolving power of the emulsion.

80% of the moustaches measured on SO 392 films had a diameter $\leqslant 1.0''$. Extreme values ever measured were 0.″4 and 3.″0 respectively. These values should be compared with the results of McMath *et al.* (1960) and Engvold and Maltby (1968) who found from micrometric measurements a range of 0.″4–5.″0 and 1.″0–3.″5 (mean 1.″75) respectively; Severny and Koval (1961) measured 0.″9 in spectra.

Since the measured diameters are of the order of the achieved spatial resolution, it would be questionable to apply corrections in order to derive true diameters. We may, however, conclude that the true diameters cannot be much smaller (say, by an order of magnitude) than the measured values, otherwise the true brightness would have to have unacceptable high values. We may therefore assume that typical sizes of mous-

taches are in the range 0″.5–1″.0. There are indications that much larger objects may be an unresolved close pair or a triplet, provided they are not bright single moustaches enlarged by low resolution (bad seeing, long exposure, etc., see Figure 1).

The brightness of moustaches was measured in calibrated (Hα ±1.0 Å)-filtergrams as well as in Hα spectra. In filtergrams maximum intensities up to 1.45 times the intensity of the undisturbed background at the same wavelength were found, that is an excess intensity of 30% in units of the undisturbed continuum. The majority of moustaches measured had peak intensities 1.2–1.3 times the background intensity, the faintest observable were 1.05 times the background. Excess intensities of the same order were also measured in moustache spectra at the intensity peaks of the profile at Hα ±1.0 Å. These measured values agree with those derived by McMath *et al.* (1960) and by Severny and Koval (1961). Due to the limited resolution, they are only a lower limit to the true intensity.

B. LIFETIME, DEVELOPMENT

The lifetime of moustaches was estimated in two different ways:

(1) It was attempted to follow the development of individual moustaches in time series of filtergrams. Unfortunately, the intervals between filtergrams of good resolution are relatively large and vary in a wide range so that the majority of moustaches can not be followed throughout their whole life; only lower limits for the lifetime can be derived: 55% of 127 selected moustaches had a life >20 min, 15%>40 min and 7%>60 min. Extreme values found for individual moustaches were 3 min and >2 h respectively.

(2) Another estimate was made by a kind of half-life method (Bruzek, 1959) which does not require the observation of the full lifetime. Half life is understood as the time t which is needed for the decay of half the number of moustaches observed at time t_0. $2t$ is a measure for the mean lifetime and was found to be about 30 min.

A correlation was found between brightness and lifetime. The moustaches were classified into four brightness classes using a gross four-step brightness scale: very bright, bright, medium and faint. The following mean and extreme lifetimes were found to be respectively:

	Number	Mean lifetime	Extreme values
Very bright	32	38 min	8–120 min
Bright	35	29	3–110
Medium	29	15	– 40

Lifetimes for faint moustaches could not be determined since they can not be followed with certainty.

Moustaches typically appear and brighten rapidly (in the order of minutes), then keep their brightness at approximately the same level for the main part of their life

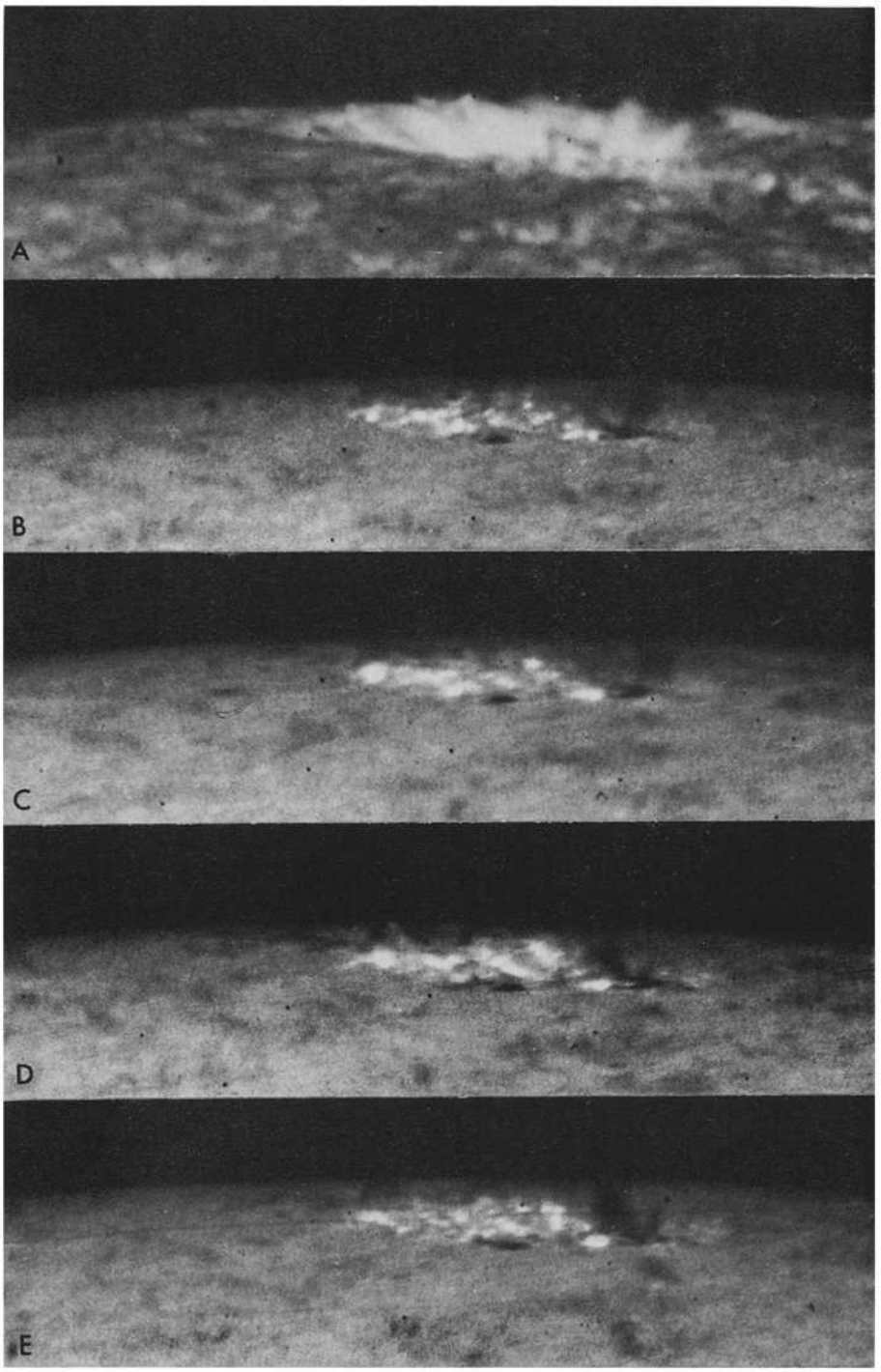

Fig. 1. Filtergrams of an active region containing a large number of bright moustaches near the solar limb (SO 375 emulsion; moustaches are overexposed). The frames were taken July 30, 1969 at 1149, 1200, 1203, 1220 and 1230 UT respectively, A in Hα center, B–E in H$\alpha \pm 1.0$ Å. Note the changes with time.

and finally disappear rather quickly. Even bright and long-lived moustaches have been observed to disappear within a few minutes.

C. OCCURRENCE, NUMBER

It was found that moustaches are most frequent and most conspicuous in the interspot region of young active bipolar spot groups, in particular in the region where the arch filament systems occur (Bruzek, 1968). They are also rather frequent in mature, large spot groups and around large regular spots (McMath *et al.*, 1960; Beckers, 1964; Koval, 1966). I found no evidence in my observations which would confirm Koval's (1966) statement that moustaches prefer the immediate vicinity of the magnetic neutral line in an active region.

The number of moustaches varies considerably from spot group to spot group and with time within a spot group. Five very bright and some thirty bright and medium moustaches may be present at a time in a moustache-rich region.

Sometimes many more moustaches seem to exist: at moments of excellent seeing a very large number of bright, star-like points become visible in the eyepiece of the Hα filter which, at first sight, may be considered as clouds of hundreds of tiny moustaches (see also Beckers, 1964). There is, however, evidence that these bright points are a different phenomenon: examination and comparison of filtergrams and white-light photographs show that these clouds of tiny bright points coincide with regions covered by photospheric faculae. In the spectrum, on the other hand, fine streaks of continuum emission, much fainter than moustache wings, are observed to penetrate the Hα line as far as ± 1 Å from the line center. Severny (1964) called these spectral features 'grains of continuous emission'. These grains will appear under excellent seeing conditions as tiny bright points in observations at Hα ± 1.0 Å and might be mistaken for moustaches. This suggest that the 'grains' in the spectrum and the tiny bright points in filter observations are identical with one another and with facular granules. It cannot be excluded that a continuous transition between grains and moustaches exists (see Section 5).

3. Association of Moustaches and Chromospheric Structures

The relation between moustaches and chromospheric features has been studied in filtergrams and in spectra (see also Section 6).

A. OBSERVATIONS IN Hα FILTERGRAMS

It has been observed previously (see e.g. McMath *et al.*, 1960; Koval, 1965; Ramsey *et al.*, 1968) that moustaches frequently appear associated with dark oblong and Doppler-shifted features which sometimes were simply referred to as 'surges'. Actually, in filtergrams taken outside about ± 0.5 Å from Hα moustaches are frequently observed to occur at the end (or quite close to it) of various types of dark chromospheric structures such as strong dark mottles, fibrils, superpenumbral filaments, but also at the base of surge-like features and at the ends of arch

filaments (they are found, however, also below the middle parts of arch filaments).

The true spatial shape of these absorption features and their connection with the moustaches can be recognized best in regions near the solar limb. There moustaches were found actually at the base of surges, spikes and arches (see Figure 2). The majority of these features shows internal Doppler shifts indicating mass flow; downward

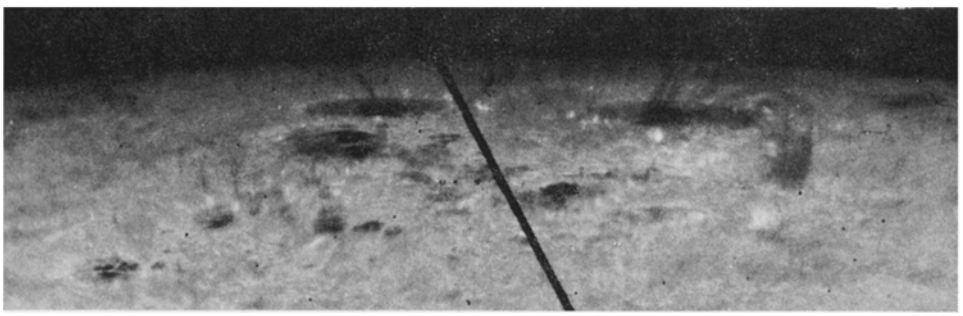

Fig. 2. Moustaches and associated absorption features near the solar limb (SO 392 emulsion). Note that many of the surge-like or arch-like absorptions end at or at least point to moustaches, indicating that the moustaches are their base (August 6, 1969).

motion seems to be prevailing but upward motion occurs also. However, moustaches occur also at the roots of fainter, less conspicuous features which are quite similar to the oblong dark mottles or bushes emanating from normal bright mottles (or plagettes) at the supergranulation border; however, many moustaches are not connected with a visible structure at all. At the very limb, moustaches are sometimes seen at the base of rather faint, thin features which would hardly be visible on the disk, or they are connected with low arched chromospheric structure (Figure 3). Summarizing, it can be stated that only a part of the moustaches are connected with strong, conspicuous

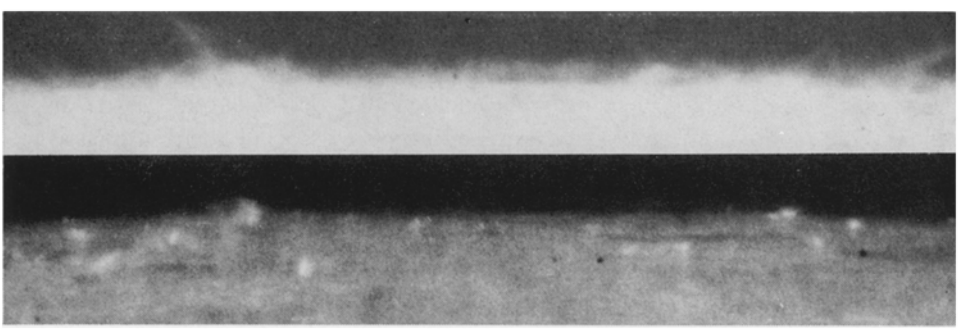

Fig. 3. Moustaches very close to and at the solar limb. Same region as in Figure 2, photographed August 7, 1969, 1126 UT in H$\alpha \pm 1.0$ Å. Both frames are printed from the same negative. The bottom frame shows in a normal print moustaches on the disk and on the (H$\alpha \pm 1.0$ Å)-limb; vertical extension of moustaches is 500–1000 km. The top frame shows in a light print a faint, structured chromospheric layer with some brighter features in the vicinity of the moustaches. This layer is about 2000 km high.

dark features; the association with fainter structures is not unique for the moustaches since it is observed with other bright features, too.

The majority of moustaches are not visible in the Hα line center because they are covered by some absorbing chromospheric structures which may or may not be physically connected with them. Only in rare cases moustaches were observed in the Hα center leaking through in between dark features (as e.g. arch filaments); sometimes a careful comparison of (Hα ±1 Å) filtergrams with Hα filtergrams revealed that an unconspicuous bright point seen in Hα center was a moustache or that a moustache formed the bright kernel of a bright mottle or plage element.

B. THE Hα CORE SPECTRUM OF MOUSTACHES

It is known that the photometric profiles of the moustache spectrum are asymmetric in the majority of cases insofar as the intensity maximum at the blue side of the Hα center is higher than the red one ('blue asymmetry') or the red one is higher than the blue one ('red asymmetry'); the central intensity minimum may also be displaced to the red or blue. Blue asymmetry in the intensity peaks is prevailing (Severny and Koval, 1961; Severny, 1968).

In the Hα core spectrum on the other hand, dark, slightly inclined and more or less Doppler-shifted inhomogeneities are present which apparently correspond to chromospheric structures overlying the moustache (Figure 4). Engvold and Maltby (1968) and Koval (1965) suggested that the observed asymmetry in the line profile of moustaches is due to these chromospheric structures. Severny (1968) rejected this explanation as inadequate and considered the asymmetry as an intrinsic property of the moustache (i.e. its line-forming mechanism). In order to contribute more arguments to that problem I made a simple statistical study.

It is quite obvious from well-resolved spectra that the shape of the line profile in the Hα core at any position is completely determined by the dark elements present. The elements existing at the position of moustaches may or may not be physically associated with them. The question is whether they are responsible for the observed asymmetry. I studied therefore the correlation between the Doppler shifts of the absorption elements at the moustache position and the moustache asymmetry. The result was that the majority of the dark elements is red-shifted and that 94% of the red-shifted elements superposed on the moustache spectrum were associated with a blue asymmetry in the intensity peaks of the moustache.

This result is strong evidence that, in most cases, the asymmetry in the core of the moustache spectrum (between about Hα ±1.5 Å) will be due to the Doppler shift of the superposed absorption elements. This confirms the conclusions of Koval (1965) and Engvold and Maltby (1968). It cannot, of course, account for an asymmetry of the emission wings, in particular not for the 'one-sided' moustache spectra (see Severny, 1968).

It is moreover clear from the above considerations that the moustache spectrum within about Hα ±1.5 Å provides no information whatsoever on the moustache proper if it is superposed by absorption elements; only in 19 out of a selection of 223

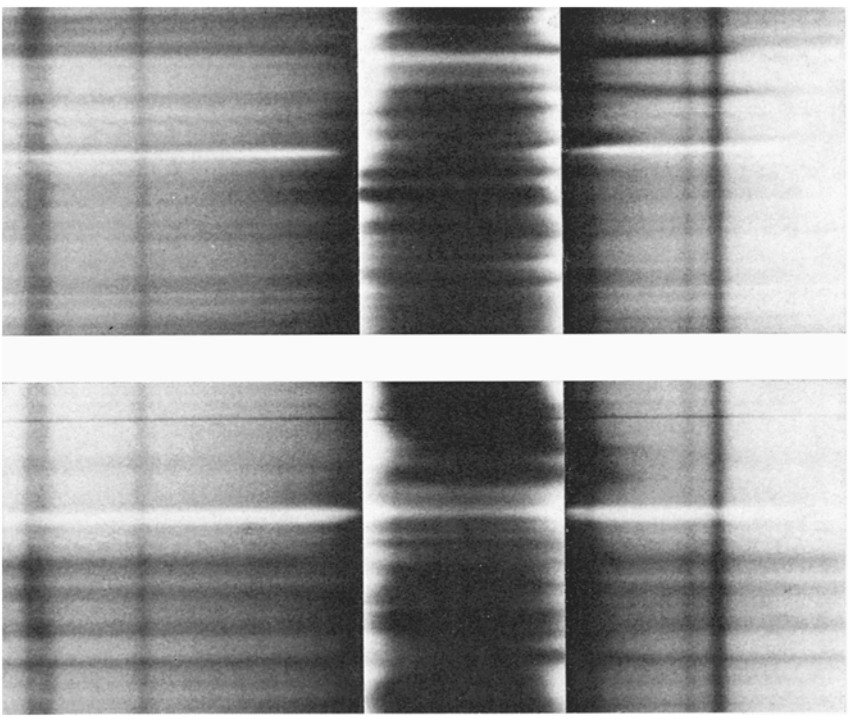

Fig. 4. Two types of moustache Hα spectra are shown in composite spectra: the wings are shown by a short exposure, the core is shown by the superposed long exposure. The top frame is an example of the common 'absorption core' with a slightly inclined absorption element at the position of the moustache producing the deep depression in the line profile. The bottom frame presents an 'emission core': the thick emission band in the wings is produced by a close pair of moustaches; the core spectrum of the lower one is again covered by an absorption element while the upper one is free and shows the 'pure' moustache spectrum with a streak of enhanced emission crossing the core.

properly exposed and well-resolved moustache spectra (i.e. in less than 10%) no such element was present. In these 'absorption free' cases the moustache emission is seen to cross the Hα core as a thin streak (Figure 4) with an excess brightness in the center ranging from a few percent up to about 30% relative to the undisturbed background. The true contrast will be higher since seeing and photographic effects and light scattering certainly reduce the observed excess intensity considerably.

Such a spectrum unaffected by obvious chromospheric absorption elements might be considered as the proper moustache spectrum revealing the 'true' moustache line profile. However, even in this case, the intensity as well as the contrast in the line core is still lower than at the Hα ± 1.0 Å intensity peaks. This is evidence that still absorption is effective, probably by a quasi-homogeneous chromospheric layer above the moustache.

4. Level of Moustache Occurrence

An important problem of the moustache phenomenon is the question of the level of

occurrence in the solar atmosphere. The observations in filtergrams as well as in spectra discussed above have shown that the majority of moustaches are covered by absorbing chromospheric elements and that even in the seemingly absorption-free cases still chromospheric absorption must be present. This is clear evidence that they are rather deep-seated phenomena, probably as deep as the roots of the structures of the active Hα chromosphere. About the same is indicated by the position of the intensity peaks of the moustache line profile at the border of the structured Hα line core.

Direct information on the level of moustache occurrence has been obtained from limb observations: a number of active regions producing many moustaches could be followed on their course to and on their passage across the solar limb. Quite a number of moustaches were observed touching the (Hα ±1.0 Å)-limb from outside. None, however, were seen detached from (i.e. above) the limb.

Figure 3 shows one of these regions at limb passage in two prints (light print and normal print) from the same negative. In the bottom frame a number of moustaches is seen on the disk and a few just on the limb. Moustaches on the limb indicate an irregular shape (mound, spike, etc.) and are about 1000 km high. Frequently they appear to have some extensions or rather to lie at the lower end of some chromospheric structure of surge-like feature. This is indicated in the light print (top frame) which shows a faint structured chromospheric layer about 2000 km thick above the limb with some brighter features in the vicinity or on top of the moustaches.

For the interpretation of the features seen in Figure 3 it has to be recalled that the Halle filter used transmits two 0.5 bands if it is tuned to '±1.0 Å' that is 0.75–1.25 Å on both sides of the line center. Therefore, the transmitted band contains still some light from the structured line core, i.e. the structured chromosphere which is seen in the light print. The moustaches apparently occur at the bottom of this layer, just above or on the level where the (Hα ±1.0Å)-radiation becomes optically thick. This level virtually coincides with the continuum limb

The level of moustache occurrence strongly suggests that the moustaches have to be considered as a feature intermediate between photospheric and chromospheric phenomena rather than a chromospheric one. This suggestion is supported by the results of the following section.

5. Association between Moustaches and Facular Granules

Severny (1964) and Engvold and Maltby (1968) have observed that the emission spectrum of moustaches frequently is superposed on 'grains of continuous emission' (Section 2). Visual inspections of the spectrum which I carried out in different wavelength regions confirmed that Hα moustaches in the limb zone ($\vartheta \geqslant 60°$) frequently coincide with continuous grain emission all over the spectrum. Moreover I found in a few cases that Hα moustaches near the solar limb coincided with bright points visible in integral light in a projected image of the Sun.

In order to identify the source of this continuous emission associated with mous-

taches I took (Hα ± 1 Å)-filtergrams and integral photographs as close in time as possible; unfortunately, the instrumental array did not permit simultaneous exposures in Hα and in the continuum. The intervals between the two types of photographs depended on the variation in seeing conditions since exposures were to be made, of course, at moments of best seeing. The continuum photographs were made through a broad band green filter, exposure time being $\frac{1}{500}$ s.

In 1971 a number of integral photographs of moustache regions in the limb zone could be secured which have a resolution sufficient to show the photospheric granulation and the facular granules. Comparing them with moustache photographs taken within 6 min or less, it was found that virtually all moustaches existing in distances 50–75° from the center of the disk coincided with individual facular granules; 27 out of 29 moustaches in three spot groups (Zürich type C to E) coincided exactly with facular granules. The correlation was found less pronounced for various spot groups (type C, D and H) quite close to the solar limb ($\vartheta > 80°$).

(Hα ± 1 Å)-filtergram and continuum photograph of a spot group near the solar limb is presented in Figure 5. A number of bright moustaches and their respective associated facular granules are indicated by lines with the same orientation. The coincidences between the two features are quite evident. It is remarkable that the observed shapes and sizes of related objects are quite different. Although this may be partly due to some observational effects (such as seeing, different exposure time) it is quite obvious, in this case, that the differences are real. Their interpretation simply would be that the continuum facular granules are roundish, virtually flat features which appear foreshortened near the solar limb while the moustaches have a certain extension in height (see Section 4, Figure 3) and appear there more or less 'en face' projected against the disk. This difference in geometry accounts also for the observed decreased correlation between moustache and facular granule occurrence close to the solar limb: the visibility of the flat facular granules deteriorates beyond $\vartheta = 71°$ (Waldmeier, 1949) because of foreshortening effects while the 'spatial' moustaches remain well visible until the very limb.

Besides the coincidence in position, there exist some other significant analogies between moustaches and facular granules: (a) statistically, they are about the same size: facular granules are 1″–2″ (Bray and Laughhead 1961), moustaches are $\leqslant 1''$; (b) their lifetimes are of the same order: facular granules live 10–60 min according to Macris (1953) and >1 h according to Bray and Laughhead (1961), moustaches have a mean lifetime of 30 min: (c) the time pattern of the development of both features is the same: also the facular granules brighten comparatively fast, remain essentially unchanged during their whole life and disappear rapidly (Bray and Laughhead, 1961). This is different from the behaviour of flares which brighten fast and decay gradually after a distinct maximum.

These analogies together with the coincidence in position indicate that moustaches are very closely related to continuous facular granules – which in the spectrum appear as grains of continuous emission. It is suggested that the moustaches are extensions of certain facular granules reaching into higher levels of the solar atmosphere. It may be

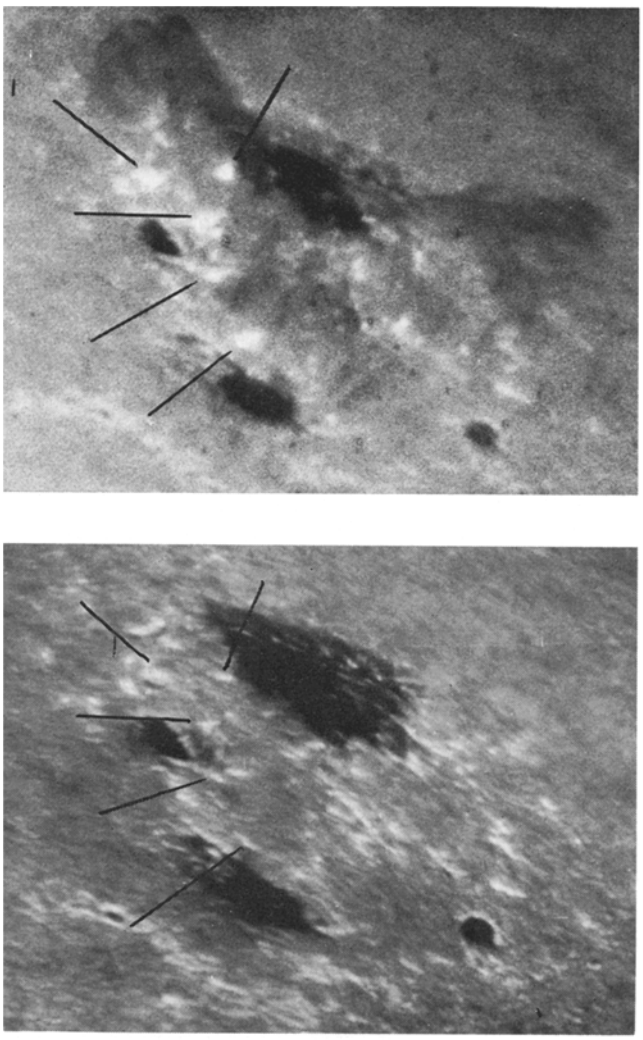

Fig. 5. Coincidence between moustaches and continuous facular granules; photographs of an active region in the limb zone at H$\alpha \pm 1.0$ Å showing moustaches, and in the continuum showing the facular granules (1971, June 22, 1129 and 1131 UT respectively). Moustaches and their respective associated facular granules are indicated by lines with the same orientation.

mentioned here that Bray (1968) did find no detailed correlation between white light faculae and bright Hα (center) elements.

6. Relation Moustaches – Flares

A number of observers considered moustaches and flares as similar phenomena; the Crimean workers in particular presented observations and arguments to establish a close relationship between the two features. McMath *et al.* (1960), on the contrary,

stated that "association of bombs with the position and times of occurrence of flares seems to be one of chance".

An inspection which I carried out on Capri filtergrams taken before, during and after several minor flares (class 1 and S) fully confirmed the McMath statement: some flare knots coincided with the position of moustaches, others ignored existing moustaches. No particular condition for the coincidence or non-coincidence could be found. The majority of moustaches seem to be uncorrelated to flares.

On the other hand, flares with a moustache-type spectrum (wide wings, deep central depression) have been observed (Severny, 1968; Švestka, 1963); this does not necessarily mean that these flares are moustaches or made up of moustaches (with all moustache properties). Švestka (1963) stated for one case that the peculiar spectrum could be explained by the special conditions in the flare region. There are however indications that some moustaches (perhaps a special type) may be actually associated with flares: e.g. the few 'one-sides' moustaches which I found in my observing material appeared quite close to flares. This may have been, of course, a chance coincidence and needs further investigation.

Summarizing, it may be stated that, in general, moustaches are flare independent but that under special conditions flare associated moustaches may be produced.

7. Summary and Conclusions

Hα filtergrams as well as spectra have shown that the majority of moustaches are covered in the core of Hα by dark (absorbing), slightly Doppler-shifted chromospheric elements which may or may not be directly related to the moustaches. These elements are responsible for the observed deep central depression and the asymmetry of the line profile in the core of Hα, as suggested by Koval, Engvold and Maltby. In general the observed central line profile, therefore, provides no information on the moustache at all. Only in less than 10% of the cases were no absorbing elements observed; even in these cases some virtually homogeneous chromospheric absorption is effective since intensity and contrast still are lower in the Hα core than at Hα ± 1 Å. (Maximum observed contrast in the line center was 30% compared to 50% at the ± 1 Å peak.)

These observations are strong evidence that moustaches are rather deep seated phenomena. Limb photographs show them actually situated at the very limb of the (Hα ± 1 Å)-Sun at the bottom of the structured Hα chromosphere. Moustaches appear there as irregularly-shaped features (spikes, mounds) about 1000 km high.

Moustaches have been frequently located at the end of dark surges, arches and mottles with some internal mass flow. This association, however, is not unique for moustaches: bright mottles and plagettes are also connected with dark mottles, bushes, etc. (at the supergranule borders). Therefore, the 'surges' can hardly be considered as the cause of the moustaches; they rather are an 'associated phenomenon' which probably indicates an enhanced vertical magnetic field just as the dark mottles and bushes are indicative of localized enhanced magnetic fields (Frazier, 1972). This suggestion

has to be proved, of course, by direct magnetic field measurements at the position of moustaches.

Most significant appears the close connection between moustaches and continuum facular granules which has been established in the present paper. It suggests that moustaches may be understood as an extension of (perhaps a special type of) facular granules into the chromosphere. This connection suggest that the appearance of moustaches cannot be explained unless the facular granules are understood; this is not yet the case.

As for the energy requirements, it turns out that the energy of the moustache emissions is only a fraction of the radiative energy losses of facular granules. A very rough estimate including only the Balmer lines and assuming that throughout the 'true' moustache spectrum continuum intensity is attained gives 5×10^7 erg cm^{-2} s compared to about 3×10^9 erg cm^{-2} s for the facular granule. This energy is radiated from 10^{15}–10^{16} cm^2 for about 2000 s, i.e. a total of about 10^{26} erg is required for a typical moustache. It has to be supplied at a rather constant rate since moustaches – unlike flares – are not an eruptive or explosive phenomenon. If we look for the possible origin of the moustache energy we note that the right amount would be available in the mechanical energy flux arising from the photosphere (or rather the hydrogen convection zone) which is estimated to 5×10^7 erg cm^{-2} s (Osterbrock, 1961) and is assumed to heat the solar corona. In the presence of a vertical magnetic field (which is likely to exist in moustaches and facular granules) additional energy would be supplied as magnetoacoustic waves propagating along the field according to Osterbrock (1961), Parker (1964), and Kuperus (1965). Parker suggested that the acoustic energy may produce plages and spicules. It is tempting to assume that it is as well responsible for the appearance of moustaches.

References

Beckers, J. M.: 1964, Thesis, University of Utrecht, p. 33.
Bray, R. J.: 1968, *Solar Phys.* **4**, 318.
Bray, R. J. and Loughhead, R. E.: 1961, *Australian J. Phys.* **14**, 14.
Bruzek, A.: 1959, *Z. Astrophys.* **47**, 191.
Bruzek, A.: 1968, in K. O. Kiepenheuer (ed.), 'Structure and Development of Solar Active Regions', *IAU Symp.* **35**, 293.
Ellerman, F.: 1917, *Astrophys. J.* **46**, 165.
Engvold, O. and Maltby, P.: 1968, in Y. Öhman (ed.), 'Mass Motions in Solar Flares and Related Phenomena', *Nobel Symp.* **9**, 109.
Frazier, E.: 1972, *Solar Phys.* **24**, 98.
Howard, R. and Harvey, J. W.: 1964, *Astrophys. J.* **139**, 1328.
Koval, A. N.: 1962, *Izv. Krymsk. Astrofiz. Obs.* **28**, 241.
Koval, A. N.: 1964, *Izv. Krymsk. Astrofiz. Obs.* **32**, 32.
Koval, A. N.: 1965, *Izv. Krymsk. Astrofiz. Obs.* **33**, 138.
Koval, A. N.: 1966, *Izv. Krymsk. Astrofiz. Obs.* **34**, 278
Koval, A. N.: 1967, *Izv. Krymsk. Astrofiz. Obs.* **37**, 62.
Kuperus, M.: 1965, Thesis, University of Utrecht.
Macris, C.: 1953, *Ann. Astrophys.* **16**, 19.
McMath, R. R., Mohler, O. C., and Dodson, H. W.: 1960, *Proc. Natl. Acad. Sci.* **46**, 165.
Osterbrock, J. E.: 1961, *Astrophys. J.* **134**, 347.
Parker, N. E.: 1964, *Astrophys. J.* **140**, 1170.

Ramsey, H. E., Smith, S. F., and Angle, K.: 1968, Lockheed Report LMSC 681495.
Severny, A. B.: 1957, *Izv. Krymsk. Astrofiz. Obs.* **17**, 129.
Severny, A. B.: 1959, *Izv. Krymsk. Astrofiz. Obs.* **21**, 131.
Severny, A. B.: 1964, *Ann. Rev. Astron. Astrophys.* **2**, 363.
Severny, A. B.: 1968, in Y. Öhman (ed.), 'Mass Motions in Solar Flares and Related Phenomena', *Nobel Symp.* **9**, 71.
Severny, A. B. and Koval, A. N.: 1961, *Izv. Krymsk. Astrofiz. Obs.* **26**, 3.
Švestka, Z.: 1963, *Bull. Astron. Inst. Czech.* **14**, 234.
Waldmeier, M.: 1949, *Z. Astrophys.* **26**, 147.