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学位申請論文

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（学位論文題目）

Morphological Study of the Solar Granulation Ⅲ,
The Mesogranulation

（太陽粒状斑の形態的研究Ⅲ；メゾグラニュレーション）

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（論文内容の要旨）

観測条件の極めて良好な時，白色光で太陽面を撮影すると粒状斑と称せられる直径1″位の模様が太陽面一面にみえてくる。また強い吸収線の中心部分の光で撮影した単色像にも直径40″位の超粒状斑と称せられる模様も存在する。粒状斑も超粒状斑も共に太陽表面近くに存在する対流層の対流要素であるが，何故太陽対流層の対流要素が1″と40″という2つだけになるのか，あるいは更に異なった直径をもつ対流要素が存在するのか，議論のあるところである。

本論文は，フランスの国立ピック・デュ・ミディ天文台で撮影された分解能0.″2の非常にすぐれた太陽写真像を解析したものである。この写真像は30秒間隔で連続的に撮影されたものであるが，申請者は特に良質の像の揃っている4分間の連続写真を用いて54″×52″の面積に含まれる747個の粒状斑の時間的変化を追跡した。その結果粒状斑の形態的特質として，(1)活動的粒状斑，(2)静的粒状斑，(3)減衰粒状斑に分類した。申請者は活動的粒状斑の太陽表面における分布は無秩序ではなく鎖状であるが，静的粒状斑及び減衰粒状斑の太陽表面における分布は全く無秩序であることを見出した。

申請者は，ついで研究対象とした54″×52″の太陽表面の光度分布を測定した。この面積範囲において，ある一定の明るさよりも明るい部分の面積が全体のq％，またこの一定の明るさよりも暗い部分を（100－q）％とする。全面積中の活動的粒状潑の数eをqの関数として，e(q)を求める。すると殆んどの活動的粒状斑は明るい面積q＝30％に集中していることが確かめられ，申請者は太陽表面の明るさと活動的粒状潑の存在との間によい相関が存在することを発見した。

申請者は光球面上の明るさの揺らぎの自己相関関数を求めた。この明るさの揺らぎは極めて小さいために，光球面上での揺らぎのパターンを求め

ることは困難であったので，より明るい30％面積の光球上の明るさを１，それ以外は０とおいた。申請者の調べた面積上で63ケの自己相関関数の平均を求めた所，間隔10″において自己相関関数の極大値を発見した。これは鎖状に分布した活動的粒状斑の分布の平均直径を示すものである。

活動的粒状斑分布パターンの物理的意味を明らかにするため，申請者はごく最近米国サクラメントピーク天文台で求められたMgI－b吸収線にもとづく太陽面上の速度場について，同様の自己相関関数を求めこ所，申請者の求めた明るさの揺らぎの自己相関関数とほぼ一致した。この速度場とは速度振幅は60 ms^{-1}，直径7″～15″の第三の対流要素メゾグラニュレーションを示すものと解釈されている。申請者の研究は，光球面上の明るさの揺らぎが対流要素メゾグラニュレーションに対応していることを示した。この事実はメゾグラニュレーションの存在を確かなものとすると同時に，メゾグラニュレーションが活動的粒状斑分布と物理的に関係しているという興味ある事実を明らかにしたのである。

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（論文審査の結果の要旨）

太陽面上で観測される粒状斑は対流的不安定によって発生した対流要素であるので，その形態的研究は対流層構造の理解のために重要である。しかしながら粒状斑は直径1″であり．隣合った粒状斑の間に幅0″.3の粒状斑間隙があり，粒状斑の形態的研究を行うには，0″.3以下の分解能を有する白色光写真が必要である。申請者の使用した観測材料は分解能0″.2程度の，現在の観測技術で求めうる最高の質のものである。

申請者は747個の粒状斑の4分間に亘る時間的変化を追跡し，粒状斑を(1)活動的粒状斑，(2)静的粒状斑，(3)減衰粒状斑の3種類に分類した。これらの粒状斑の表面分布について，活動的粒状斑だけが無秩序でなく，鎖状に分布するが，静的粒状斑及び減衰粒状斑は無秩序分布を示すことを発見した。この発見は申請者がメゾグラニュレーションという新しい対流要素の同定に成功した直接の要因でもあった。

ある分布パターンが物理的な意味があるかどうかを決定することは難しい問題であり，天体物理学では自己相関関数がよく用いられる。活動的粒状斑は鎖状に分布するけれども，その分布は不連続であり，直接に自己相関関数を求めることはできない。そこで，まづ，申請者は測光計を用いて光球面の明るさと活動的粒状斑の分布の相関を調べた。活動的粒状斑は殆んど例外なく光球の明るい部分に分布することを確かめた後，申請者は光球面の明るさの揺らぎを求めた。しかしながら光球面の明るさの揺らぎはごく僅かであり，明るさをそのままとるという通常の方法によっては，相関関数の極大値がノイズに埋れてしまう。申請者は活動的粒状斑の明るさがある明るさよりも明るいとき，その明るさを1，それ以外を0と置くことにより，ノイズを最小におさえ10″という距離に相関関数の極大値を求めることに成功した。この方法は申請者の独創性を示したということができる。

研究の最終段階として，直径10″というパターンのもつ物理的な意味を

明確にするため，ごく最近公表された太陽面上の速度場との比較を行った。この速度場は既知の対流要素，即ち直径1″の粒状斑と直径40″の超粒状斑による速度場を消去して作られたものである。その結果この速度図には，直径5″～15″，速度振幅60 ms^{-1} という第三の対流要素メゾグラニュレーションの存在が示されている。申請者はこの速度場についても自己相関関数を求めたところ，光球面の明るさの揺らぎから求めた自己相関関数と見事に一致した。

申請者は活動的粒状斑は鎖状に分布してメゾグラニュレーションを作ると結論している。この発見は太陽対流層の理論的研究に大きな刺激を与えたものと高く評価することができる。また参考論文三篇は太陽物理学及び木星の電波観測によるもので，申請者の幅広い研究対象を示している。

よって本論文は理学博士の学位論文として価値あるものと認める。

なお，主論文及び参考論文に報告されている研究業績を中心とし，これに関連した研究分野について試問した結果，合格と認めた。

主論文

Morphological Study of the Solar Granulation

III. The Mesogranulation

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Abstract

Time-sequential high quality photographs of the photospheric granule on a quiet region of the disc center obtained at the Pic du Midi Observatory by Kawaguchi are analyzed. The size variation of individual granules in the area of 64"x 64" on the photosphere are traced over a period of 4 min. The granules are classified according to their mophological features as follows. (1) Active granules, they repeat the expansion and the fragmentation. (2) Quiet granules, they do not alter the size noticeably during the observed time span. (3) Declining granules, they disappear without further fragmentation or merging.

The distribution of active granules on the photosphere reveals a presence of a cellular pattern. The relationships between the cellular pattern and the brightness on the quiet photosphere are investigated. The results show that there is a good spatial correlation between them. The autocorrelation analysis shows a kind of periodicity on the photospheric intensity and its mean wavelengths are 11".3. The size of the cellular pattern is comparable, in magnitude, to that of mesogranulation found by November et al.(1981) on the velocitygram obtained at the Sacramento Peak Observatory. Then the cellular pattern revealed by the chain of granules in the present study may be tentatively identified as the mesogranulation. The possible physical connection between the mesogranulation and the clumpy assemblage of active granules is briefly discussed.

1. Introduction

The properties of the photospheric granules are important for constructing the model solar atmospheres and for understanding the hydrodynamical nature of the solar convection zone. Bray and Loughhead (1958b) found that the 57 percent of 125 granules showed no detectable variations in brightness, size or shape over a time period of nearly 7 minutes and other granules showed some kind of variations. Rösch and Hugon (1959) and Rösch (1962) have asserted that there were four phases in the evolution of the granules: the birth phase, growth phase, break up phase and the declining phase. The existence of exploding granules was uncovered by Carlier et al. (1968) and later its physical nature was studied by Musman (1972), Allen and Musman (1973). Namba and van Rijbergen (1977), Mehrtretter (1978), Nelson and Musman (1978) and Kitai and Kawaguchi (1979).

Kawaguchi (1980) studied the evolution of the granule on the basis of the white light images of superb quality obtained at the Pic du Midi Observatory The size variation of individual granules in an area of approximately 17"x 17" on the solar surface was traced for the time span of 46 minutes. Some of the evolutional features pointed out by him are: (1) The granules form the families in which granules have been produced by the process of repeated fragmentation and merging. The duration of the families of granules seems to be as long as 46 minutes or longer; (2) If the lifetime of granules is defined as the time interval from the moment of formation of a granule by fragmentation or merging until the moment of the next fragmentation or disappearance, then the mean lifetime of a single granule is 5.7 min. The value is shorter than that obtained by other observers (Rösch and Hugon, 1959; Bahng and Schwarzschild, 1961; Bray and Loughhead, 1967; Mehltretter, 1978); (3) The

granules larger than 2" in diameter certainly split or merge and then develop while the smaller granules tend to disappear without further developing.

Recently. on the velocitygram obtained by Mg I line at the Sacramento Peak Observatory, November et al.(1981) detected a new convective cellular pattern whose diameter is, in magnitude, in between the granulation and supergranulation. According to them, the rms velocity amplitude of the cell is about 60 m/sec, superposed on the supergranular flow and they call it the mesogranulation. They suggested the origin of the mesogranulation as being due to the convective motion arising from the He ionization. If it is real, it seems to be very important for understanding the physics of solar convection zone to study the new cellular pattern on the solar photosphere whose wavelengths are comparable to that of the mesogranulation.

As pointed out by Kawaguchi (1980) (Figure 1 of his paper), the bright and exploding granules tend to cluster and to form a chain of granules. Motivated by the nature of bright granules, the purpose of the present paper is to study the possibility that such a chain of granules may form a new cellular pattern such as the mesogranulation.

2. The surface distribution of expanding granules on the photosphere

The variation of granular size with time is traced on the time sequential photographs of superb quality The original negatives were obtained at the Pic du Midi Observatory by using a refractor with an objective of 50 cm in diameter The brief summary of the observation has been described by Kitai and Kawaguchi (1979). The time span of the observation is as long as 46 minutes and the high quality images enough to resolve the intergranular lanes are

distributed comparatively uniformly in the series of original negatives. The time interval between any two successive images is 30 sec long. The best image in this series has already been reproduced in this journal by Kitai and Kawaguchi (1979).

For searching the new pattern on the surface distribution of granules, nine successive images have been selected according to their quality The time span of these nine images are only 4 minutes long and this new time sequence of images forms the basis of the present study

At first, the evolution of granules is traced in detail on the enlarged reproductions of each negative. A common area to all the images has been selected whose area is 54"x 52" The total number of granules included in this area amounts to 747 on the first reproduction. It is well known that the size of granules will depend upon the blackening of the photographic paper For making sure that the blackening of the reproductions keeps roughly constant from image to image, the size of a small sunspot seen in all the reproductions was examined to have a constant blackening.

The measurement of the granular size is so troublesome that the following simple method was adopted in the present study We measure the length of each granule along the long axis, i.e. giving the largest dimension of the granule and also measure the length along the short axis, i.e. perpendicular to the long axis. Figure 1 shows a few examples of the long and short axes in the granules with various shapes, where L and l indicate the long and short axes respectively In this study, the arithmetical mean of the lengths along both axes is regarded as the size of the granule.

When a single granule is surrounded by narrow dark intergranular lanes, the measurement of granular size is straightforward. However, it is difficult and rather subjective to define a single granule if the intergranular lanes

are faint and the granules are on the process of fragmentation or mergings. We were, in some cases, obliged to give up to measure the size of granules with diffuse boundaries or with very complicated forms. Thus we performed the measurements of the granules contained in the selected area.

In Figure 2, the examples of evolutional features of typical granules are shown by plotting the size of individual granules versus time. On the upper part of the figure, the full line marked by 'spot' shows the measured size of the sunspot mentioned above. Since the spot seems to be stable during the short observing time span, a constant size of the spot serves as the evidence of the uniform blackening of all the reproductions. The ramification of the full line shows the splitting of the granule and the cross means the disappearance of the granule.

Based on the evolutional features of all the granules, it seems to be reasonable to classify the granules into three distinct types. (1) The active granules, repeating fragmentation and merging and increasing their size monotonically during the time from the splitting to the next splitting. (2) The quiet granules, being stationary in size. (3) The declining granules, decreasing the size monotonically and finally disappearing. In Figure 2, the sign of (+ , o and -), drawn on the left side, indicates the active, quiet and declining granules respectively The number frequency of granules in each type is given in Table 1.

The surface distribution of active granules are shown in Figure 3a in which the individual active granule is marked by a small circles. We can see at once that the active granules are not distributed at random on the photosphere and the distribution may form some kinds of network structure. It should be emphasized that the surface distribution of granules of other types does not form such a network structure as seen in Figure 3a. The area bounded

by a dotted line in the figure shows the location of a small sunspot and a short line in the right part of the figure shows the linear scale of 10"

3. The relation between the surface distribution of active granules and the photosphric brightness

As the next step of the present study, we are looking for the relation between the surface distribution of active granules and the photosperic brightness. Unfortunately, the original negatives were not uniformly exposed. A slight, large-scale gradient of blackening exists on the original negatives from one side of the frame to the other, although the center of the solar disc was photographed in the observation. Then we abandon to transform the observed density to the energy scale and instead we will discuss the photospheric brightness in terms of the observed photographic density.

The photographic density of the original negatives was transformed to a digital value by a computor-controlled isophotometer The scanning aperture was 26 square micron corresponding to 0.137 square arc sec on the solar surface. The digital value was chosen so as to give the clear portion of the negative as zero and the photographic density of 3.0 as 255 in an arbitrary unit. Any other digital value was obtained by the linear relation between the photographic density and the digital value. In consequence, on the original film, the digital value is 125 and 184 at the umbra of the small sunspot and the brightest portion of the photosphere respectively.

As mentioned previously, a large-scale gradient of photospheric blackening is seen on each frames of the original film. Since such a large-scale inhomogeneity is troublesome for studying the photospheric brightness, it

should be removed in the isophotal diagram. We have applied the two dimensional Fast Fourier Transform (FFT) method to the intensity distribution of the photosphere (Brault and White, 1971; Edmonds and Webb, 1972a; Aime et al. 1977; Aime et al. 1979; Schmidt et al. 1979; Koutchmy and Legait, 1980). The spatial scale of the inhomogeneity seems to be larger than 20" so that we cut off the components larger than 20" and then the corrected intensity distribution was obtained by the inverse-FFT method. It can be seen in Figure 4 that the large-scale inhomogeneous intensity gradient has disappeared completely

The correlation between the spatial distribution of active granules and the phtospheric brightness was examined by using a function of q. We define N as the total number of granules and E as that of active granules in the whole area traced by the isophotometer Next we count the total number of granules n(q), and that of active granules e(q) which are found in the brightest area occupying q % of the whole area studied. In table 2, we give the n(q) and e(q) with q values.

According to the definition of n(q) and e(q), n(q)-e(q) is the number of the non-active granules as a function of q. If the size and the brightness of the non-active granules are distributed at random over the solar surface, n(q)-e(q) should increase linearly as q increases. Further, the area occupied by the intergranular lanes are included in the area traced by the isophotometer Since the brightness of the intergranular lanes are surely smaller than that of all granules, the area with a small value of q concerns to the area occupied only by granules and the area with a large value of q consists of both areas of granules and those of intergranular lanes. In Figure 5, the behavior of (n(q)-e(q))/(N-E) is shown as a function of q. The dotted line indicates the extrapolation of the linear relation of (n(q)-e(q))/(N-E) with q. From this figure, we can obtain the fractional area of intergranular lanes

over the whole surface, i.e. about 32 % which is in good agreement with the value published by Namba and Diemel (1970), Bray and Loughhead (1976, 1977).

In Figure 5, the brightness distribution of active granules is also indicated by the symbol e/E as a function of q. The comparison of the distribution of e/E with that of (n-e)/(N-E) shows clearly that the active granules are statistically brighter than the non-active granules. In the figure, the number ratio of active granules to non-active granules are shown by the dotted-broken line as a function of q. It is about 1.5 in the brightest 5 % area but it decreases to 0.72 over the whole surface. Then it seems that the active granules distribute mainly in the brightest thirty percent area.

In Figure 3b, we show the brightest 30 % area obtained from the isophotometer and the location of active granules is drawn by small hatched circles. It is intuitively seen from the figure that allmost all active granules occupy the major portion of the bright area on the solar surface as our statistics shows. Further, in order to see clearly the surface distribution of active granules, we show in Figure 3a only the location of active granules on the same area as that indicated in Figure 3b. In this figure, we see that the surface distribution of active granules make some network pattern in the similar way as the rosette structures make the pattern of supergranulation in the Hα monochromatic image, though the linear dimension is much different. Then the next step is to see how significant such a network is on the statistical point of view.

4. Statistical Study on the size of the network structure

Instead of obtaining the autocorrelation function by a standard way, the

following procedure was adopted for revealing clearly the existence of the network pattern. The autocorrelation function is defined by the following equation,

$$A(\ell) = \frac{1}{B}\sum I(x)I(x+\ell) \qquad (1)$$

where B is a normalization factor, I(x) is the intensity at a point x and ℓ is the distance lag. We divide the solar surface into two areas, i.e. the brightest 33.4 % area and the other We take I(x)=1 when the point x is included in the brightest 33.4 % area and I(x)=0 when the brightness of the point is not large enough to be included in the area.

A number of the autocorrelation function were obtained by tracing the area successively. The total number of the scans amounts to 63. In Figure 6(a), a few examples of the autocorrelation function are given where the abscissa is the distance lag ℓ (arc sec) defined by the equation (1) The general feature of the autocorrelation function lies in the existence of the secondary maximum at the distance lag of approximately 10" The mean of all autocorrelation functions thus obtained is given by the full line in Figure 6(b)

On the other hand, as seen from Figure 4, a small sunspot is included in the area selected for the present study The position of the sunspot is indicated by the crosspoint of two arrows drawn in Figure 4. There exists a fairly bright area surrounding the sunspot and we speculate that such a region may disturbe the general feature of the autocorrelation function in the quiet granulation field. Then the mean autocorrelation function was obtained by excluding the area surrounding the small sunspot. In Figure 6(b), the dot-dashed line shows the mean autocorrelation function over the area on the left of A-B indicated in Figure 4.

As the next step, we have attempted to see whether the network pattern uncovered in the present study is related to the mesogranulation proposed by November et al.(1981) Since the mesogranulation was detected by the velocity field and the network pattern was by the brightness fluctuation, the comparison may be made only by the size of the structure. On the basis of the published velocitygram, for this purpose, we obtained the autocorrelation function by taking the downflow as $I(x)=1$ and upflow as $I(x)=0$ in the similar way as our procedure. The result is shown by the dotted line given in Figure 6(b) It is to be noted that the behavior of the autocorrelation function about the intensity fluctuation is not reliable in the range $\ell > 20''$ because the linear dimension of our scanning is only 64" and the number of products $I(x)\cdot I(x+\ell)$ decreases as ℓ increases. Based on the similarity of the behavior between these three autocorrelation functions in Figure 6(b). we suggest that the network pattern is surely related to the mesogranulation.

We give, in Figure 7, the histogram of the distance lag at the secondary maximum of the autocorrelation functions (Simon and Leighton, 1964; Teske, 1974) The major part of the distribution, about 80 % in magnitude, falls in the range between 9" and 13" and the mean is 11".3. According to November et al. (1981). the spatial scale of mesogranulation is 5 Mm to 10 Mm in magnitude which is comparable with our value.

5. Discussion

We have seen that the chain of active granules forms a network pattern as shown in Figure 3a and the size of the network is comparable with that of mesogranulation. Then the network pattern may have some physical significance.

Firstly, the areas are relatively bright: they have the higher temperature than other areas. Secondly, the areas are more dynamicaly active. In ordinary granular field, Bray and Loughhead(1976) pointed out in their analysis of monochromatic images taken by a photospheric line (Fe I λ6569.2) that there is very high correlation between the brightness and the velocity field. And also, recently, Durrant and Nesis (1982) found out that the bright elements are strongly correlated with upword motions and the correlation coefficient of about 80 % was found in structures with a size between 3" and 5" which corresponds rather to families of granules (Kawaguchi, 1980). The inspection of Figure 3a may give the impression that the chain of families is rather similar to convective cells whose linear dimension is intermediate between the ordinary granulation and the supergranulation. However, a convective cell is the blobs of gas in which the gas is rising in the interior and sinking on the periphery If the active granules can be regarded as the source of rising gas, we can not point out the boundary of the convective cells unambiguously on Figure 3.

With respect to the interpretation of Figure 3a, the clumpy structure may appear as the secondary maximum in the autocorrelation functions shown in Figure 6. If the network pattern can be identified as the mesogranulation, the mesogranulation may be characterized as the aggregate of active granules superposed on the ordinary granulation field. In reality, Kawaguchi has already pointed out that the bright granules tend to expand almost simultaneously

November et al.(1981) suggested that the mesogranulation will be the convective motion resulting from the first ionization of He atoms in the outer envelope of the Sun. Accepting the origin of mesogranulation, the origin of the group of active granules may be deep in the He ionization zone. A blob of

gas will begin to rise up through the He convection zone due to convective instability According to the mixing length theory (Böhm-Vitense, 1958), the turbulent gas blob will expand as the blob rise up and loose the identity giving some impacts on the gas layer a little higher in the zone. The impacts become new sources of rising blobs of gas and so on. If we assume a depth of He convection zone as 7×10^3 km and the mean pressure scale height is of the order of magnutude of several hundred kilometers, it is naturally understood the clumpy structure of the granulation field.

At present, the state of the theory of turbulent convection is very unsatisfactory On the other hand, the recent high resolution observation of granulation reveals the complicated features in the evolution of solar granulation and we have no theory for the explanation. If the physical connection between the He convection zone and the clumpy assemblage of active granules are fully confirmed, it will offer an interesting subject for the theory of solar turbulent convection. However, it will be highly desirable, at present, to make velocitygram with a resolution better than 0".5 together with the high resolution monitor image.

6. Summary

Analyzing the evolution of granulation on the normal photosphere for a short time span (4 min). some new morphological aspects of the granulation field have been revealed. We may summarize the results of the present study as follows.

(1) The behaviors of the size variation of granules may be classified into three types: active, quiet and declining granules. The active granules

repeat fragmentation and merging and their distribution forms some networke structure on the photosphere. The active granules are not distributed at random. The declining granules are the remnants after the fragmentation of active granules. Figure 3a shows the distribution of active granules.

(2) In order to seek for the relationship of distributions between active granules and photosphric intensity fluctuation, we compared the distribution of active granules with the map of intensity fluctuation of the photosphere (Figure 3a and Figure 3b) The major part of active granules in number was found to lie within the brightest thirty percent area (Figure 3). There is a very good spatial correlation between the locations of active granules and the brighter region of the photosphere.

(3) And also, Figure 5 shows that the area of intergranuler region occupies about 32 % in area on the normal photosphere. The magnitude is in good agreement with the results obtained by other investigators.

(4) The spatial periodicity of the network structure was analyzed by the autocorrelation functions of the photospheric intensity fluctuation. The locations of secondary peaks in the autocorrelation functions provide the information about the spacing of network structures. Figure 7 shows the distribution of distances of secondary peaks from the central peak in the autocorrelation functions. The mean value of the distances is 11".3. It agrees well with the size of mesogranulation recently found November et al.

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Captions

Table 1. The number frequency of granules in three types.

Table 2. The number of granules within the brightest q % area. n is total number of granules and e, the number of active granules within the brightest q % area.

Fig.1. Schematic illustration of granular size. L and l are the length along the longest axis and along the axis perpendicular to it respectively The size of a granule is defined as the mean of L and l Typical and confused shapes of granules are displayed.

Fig.2. Evolutions of granules. The size variations of nine granules which exist in the first reproduction are plotted against the time lapse. A ramification shows the splitting of a granule and a cross shows the disappearance of the granule. The label 'spot' shows the size of a small sunspot. The constant size of the sunspot means the constant blackening of the reproduction. The signs (+,0,-) mean the granules of three types; active, quiet and declining granules respectively

Fig.3. (a) The distribution of the active granules. Active granules are distributed along network structures. The dotted line shows small sunspot. A short line in the right part shows the reference scale of 10" (b) The relation between the distribution of active granules and the brightest 30 % area. Active granules are displayed by small hatched circles.

Fig.4. An equi-density contour map of the brightest q % area. Data processing region is 64"x 64" wide. Here painted regions indicate the bright areas and hatched regions the faint areas.

Fig.5. Behavior of the number of active granules and that of other granules against the photospheric brightness level of q %. (see table 2.)

Fig.6. (a) Examples of autocorrelation functions. (b) Mean autocorrelation functions. The full line associates with the whole area, and the dot-dashed line associates with the area on the left of AB (cf. Fig.5). The dotted line associates with the mesogranulation pattern (the plate L3 of November et al. 1981)

Fig.7 The histogram of the distances of positive secondary maximum from the central peak in the autocorrelation functions is shown. The mean is 11".3.

Table 1.

The number frequency of granules in three types

Type	Number	Frequency (%)
active	313	42
quiet	344	46
declining	90	12

Table 2.

The number of granules

q%	5.7	10.3	14.6	19.9	26.2	29.7	33.4	41.3	49.7	53.8	61.7	100.0
n	140	213	274	352	429	457	498	569	614	650	696	747
e	83	122	158	199	243	254	264	281	298	300	308	313

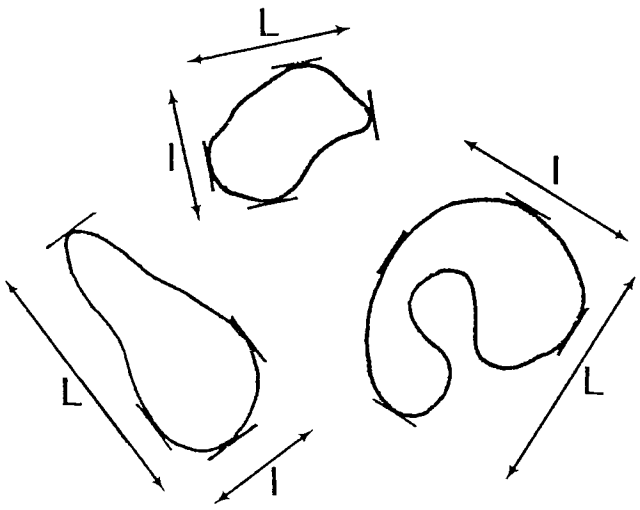


Fig. 1

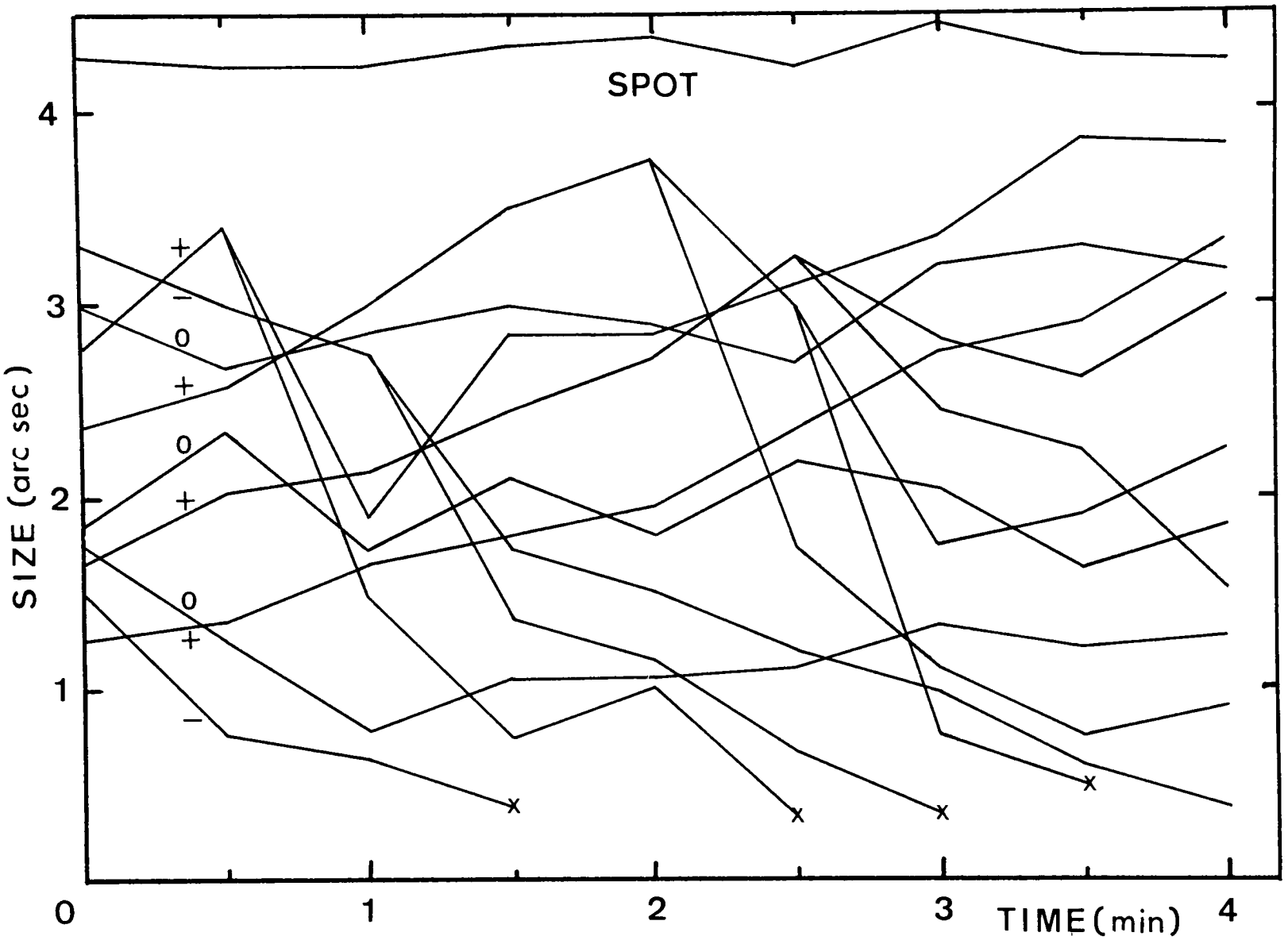
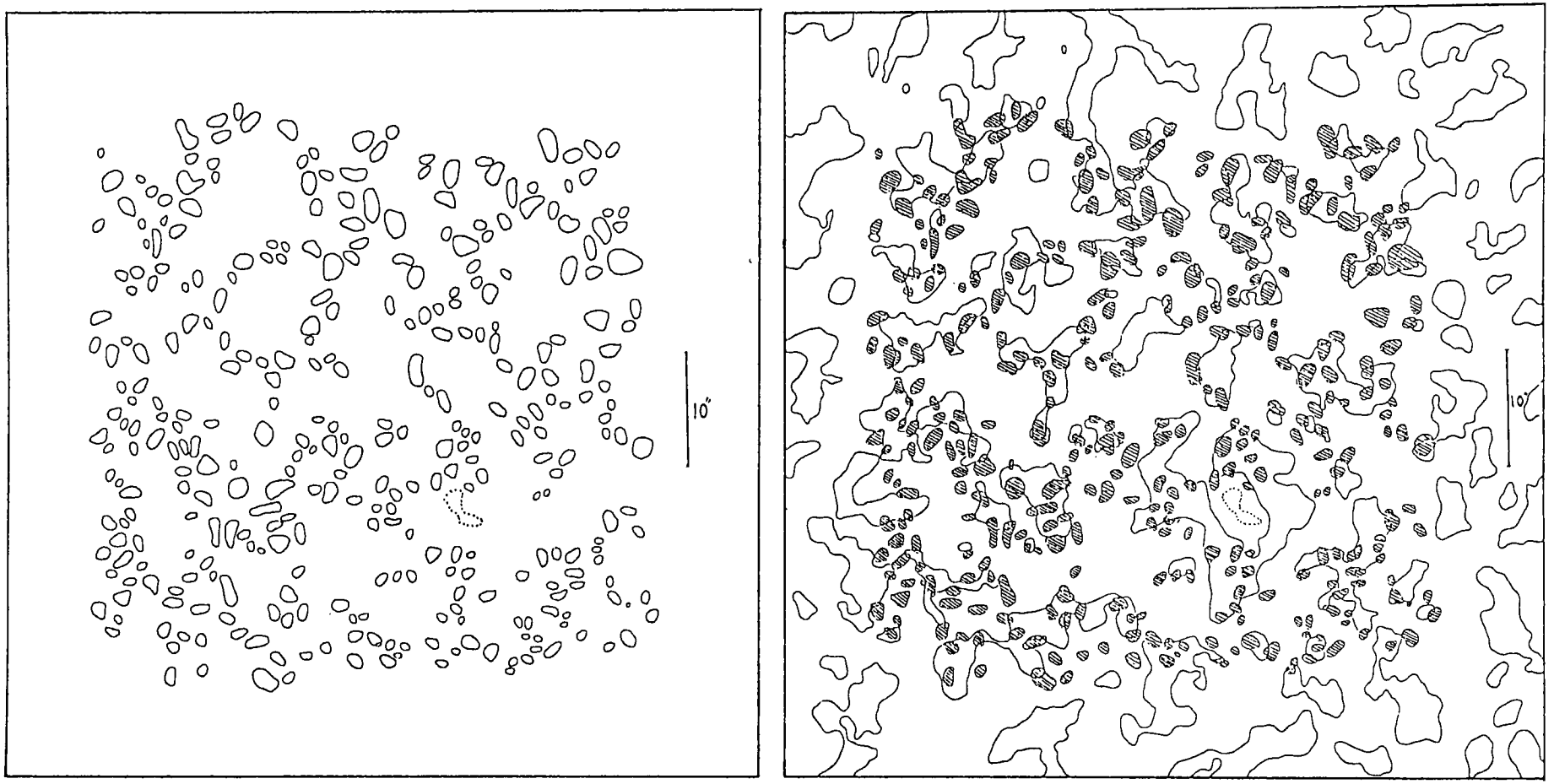


Fig. 2



(a) (b)

Fig 3

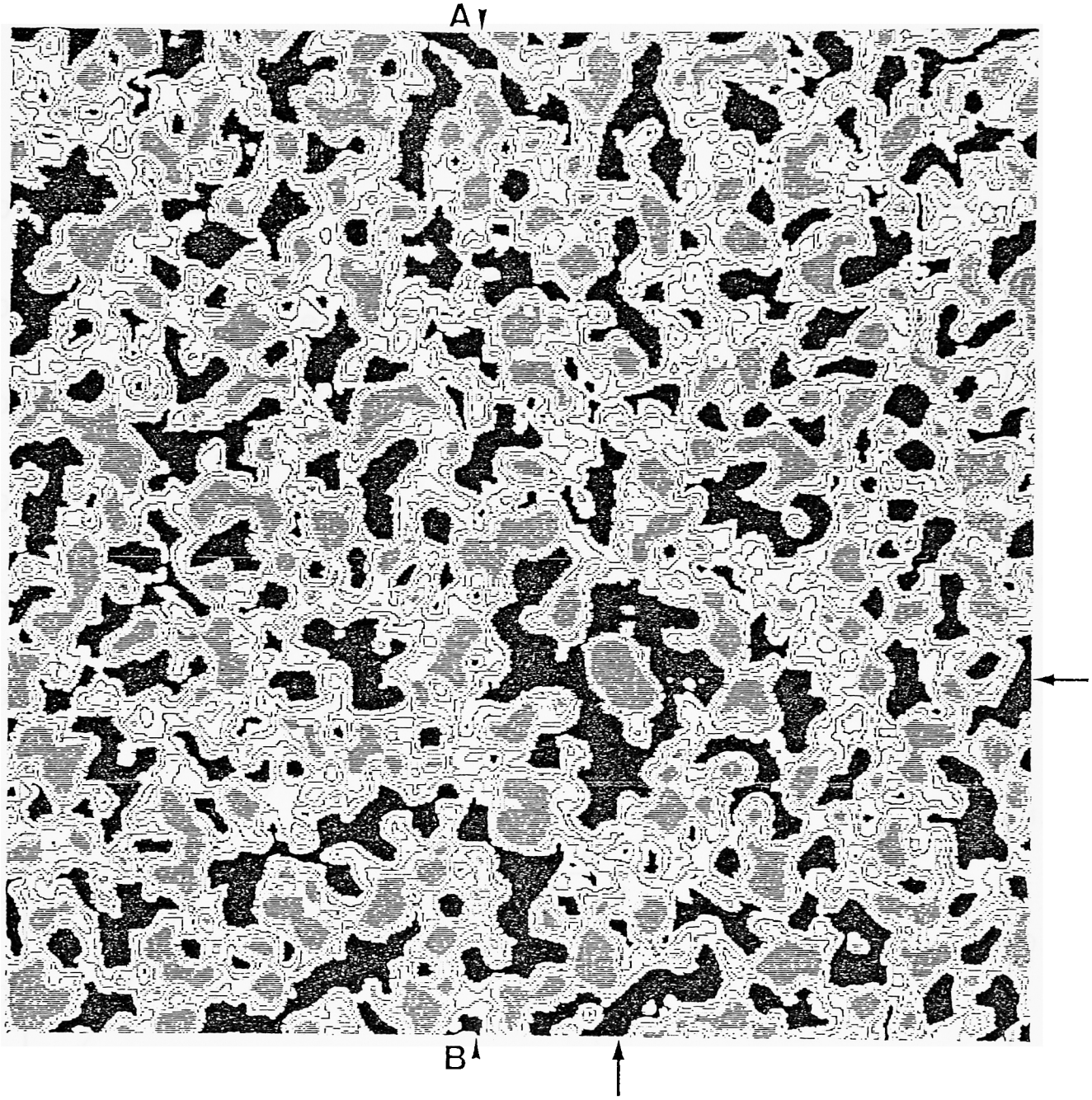
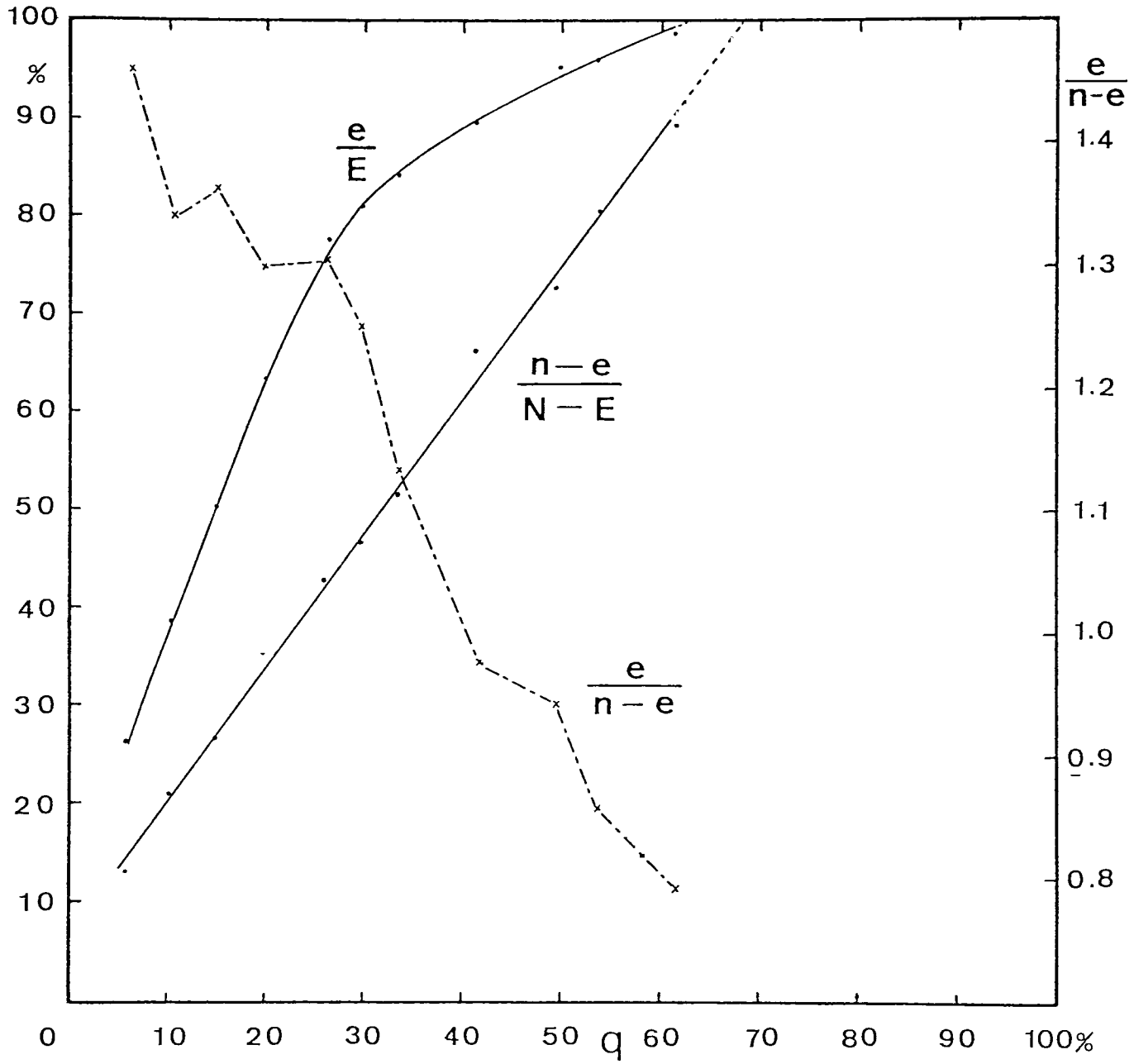


Fig. 4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q
60
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90
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e/E
n−e/N−E
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e/n-e
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0.9
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Fig.5

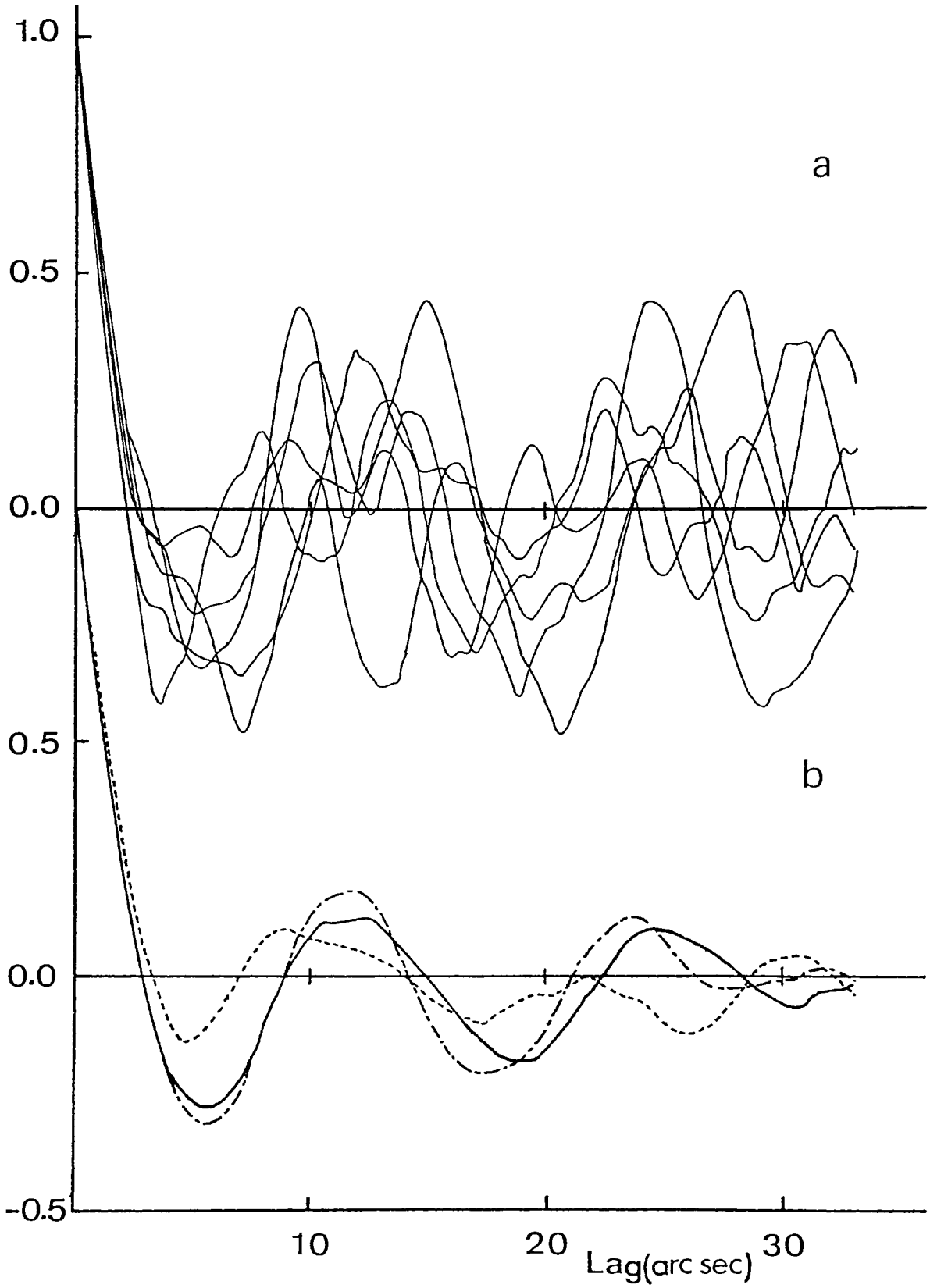

Fig. 6

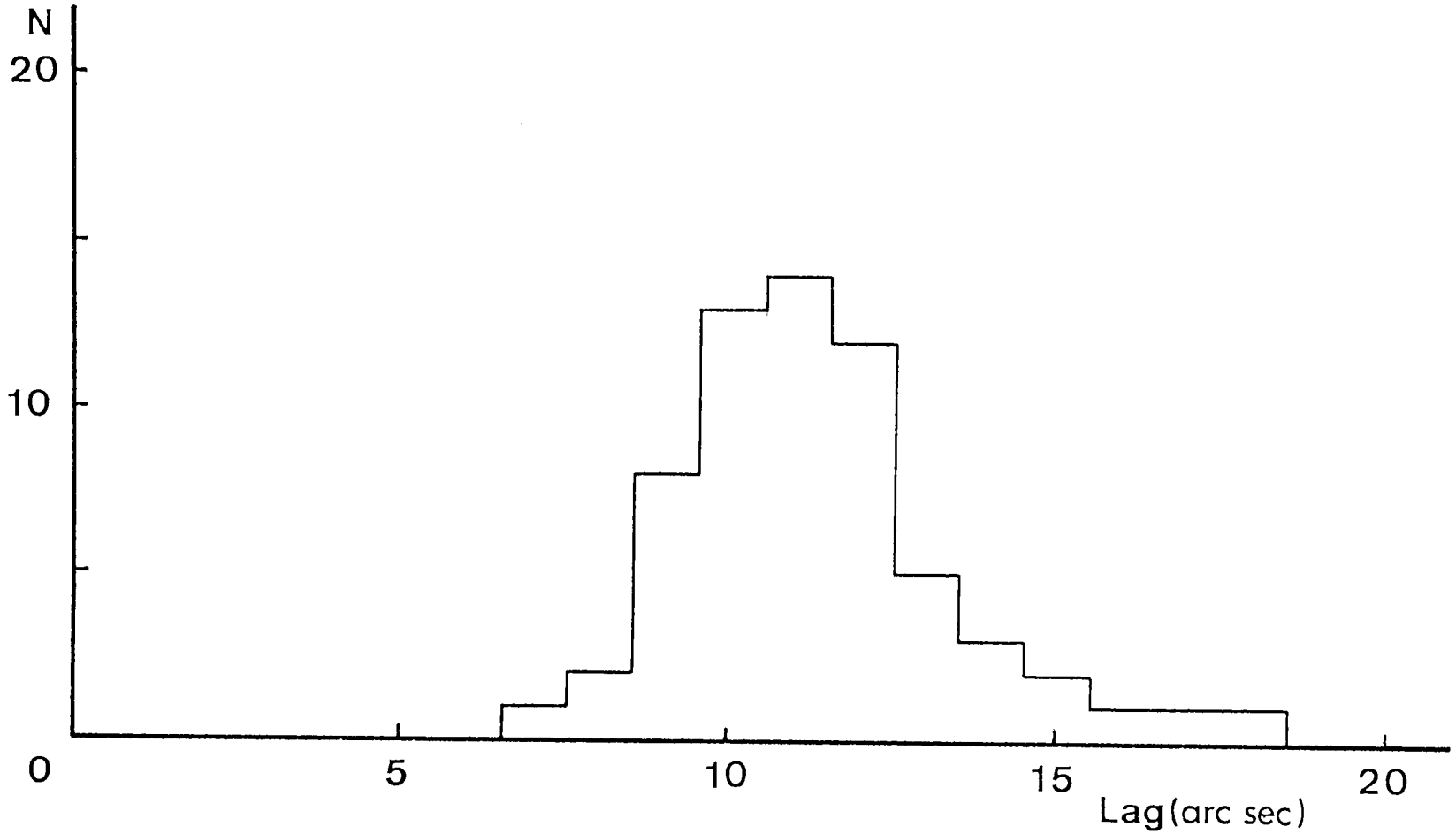

Fig. 7