PART IV.

Considerations on Localized Velocity Fields in Stellar Atmospheres: Prototype — The Solar Atmosphere.

A. - Convection and Granulation: Preview on Granulation — Observational Studies.

Chairman: E. BÖHM-VITENSE

— E. BÖHM-VITENSE:

This afternoon we consider the photosphere of the sun. It is generally assumed that most of the velocity fields which we observe in late-type stars (stars with low effective temperature $\leqslant 1 \cdot 10^4$ °K) can be traced back to the hydrogen convection zone, which occurs, in the case of the sun, in a layer at a depth of about 400 km. I mention the sun because it is the only star where we can really see the effect which the convective layer has on the photosphere. We are going to see some films about these effects, which are observed as the phenomena called granulation. We will observe layers ranging between about 400 km and about 250 km as the observed region moves from center of the disk to the limb. Finally, note that with our instruments on the surface of the earth, we can usually resolve an area about 1 second of arc due to the limit of seeing in the earth's atmosphere; this corresponds to a distance of 700 km on the surface of the sun.

J. RÖSCH: **Observations from the Pic du Midi.**

As an observing astronomer, I have been very much interested in the high degree of completeness of the theories, and in the difficulties arising in reaching an agreement between different theories. I hesitate to bother both the theoreticians and the aerodynamicists with this other major problem, which is to get an agreement between theory and observation. But I will show you some examples of what may be done by trying hard under the best possible conditions, and show you the limitations which we have in the observations. From these observational results you will see, I hope, what limitations you have on the theories; and the limit to what we know from the observational point of view, so then you are completely free for theory.

In order to show you some examples of the limitations in the observation of the solar granulation—I shall first show some slides before the film. The first was obtained at the Pic du Midi Observatory under good atmospheric conditions with an objective of 23 cm aperture; we believed for a long time that this was the best we could obtain. This slide is (1) to allow you to compare these with subsequent results obtained with larger objective. With this type of picture one may evaluate the average distance between the center of granules, then compute the mean diameter of the granules, make autocorrelation functions, and so on. We had the impression that something better could be obtained with good atmospheric conditions, because on occasion we had some details finer than these. The next slide shows a sunspot with umbra, penumbra, and granulation on the average photosphere, taken in the same conditions. The next slide shows the same spot but printed in such a way that one sees inside the umbra small granules, smaller than those on the photosphere; we had the impression that these granules were below the limit of resolution of our instrument but rather separated from one another and bright and small. We had also photographs showing the granules near the limb of the sun, and you see that granules appear elongated parallel to the limb within a few seconds of arc of the limb, and with a width which is definitely smaller than 1″ of arc. Next is just the same type of thing with elongated granules. Then we come to another type of record (Fig. 1), which is obtained always at the Pic du Midi with an objective of 38 cm aperture (theoretical resolving power of about $\frac{1}{3}$ of a second). This photograph has not been taken in white light, but in orange light, in a bandwidth of approximately 100 Å between 5 900 and 6 000 Å. We here have a decidedly different type of thing. From our first results we thought it was possible to define something like an average granule with an average size and so on. Here it appears much more difficult, if not impossible, to define an average granule, because we have big circular granules, other elongated small ones, and so on. As definition is improved, things become more and more difficult to interpret. We have not yet succeeded in taking simultaneous pictures of the same field on the sun at different wavelengths, but I hope we soon will get such pictures. The structures have roughly the same appearance in differing wavelengths, but probably the contrast between granules and intergranular spaces is different. The next slide demonstrates the method used long ago to obtain a determination of the lifetime of the granules, which is, of course, an important element in the granulation. It is what one calls a « moiré » picture, obtained

(1) Almost all the slides presented and not reproduced in the present publication may be found (except the « moiré » effects) in: *L'Astronomie* (1957), p. 129.

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by superimposing two pictures, but not exactly identical. If you slightly move these two pictures with respect to one another, then you find some patches or series of things like that. You have either rows, straight lines or arcs de-

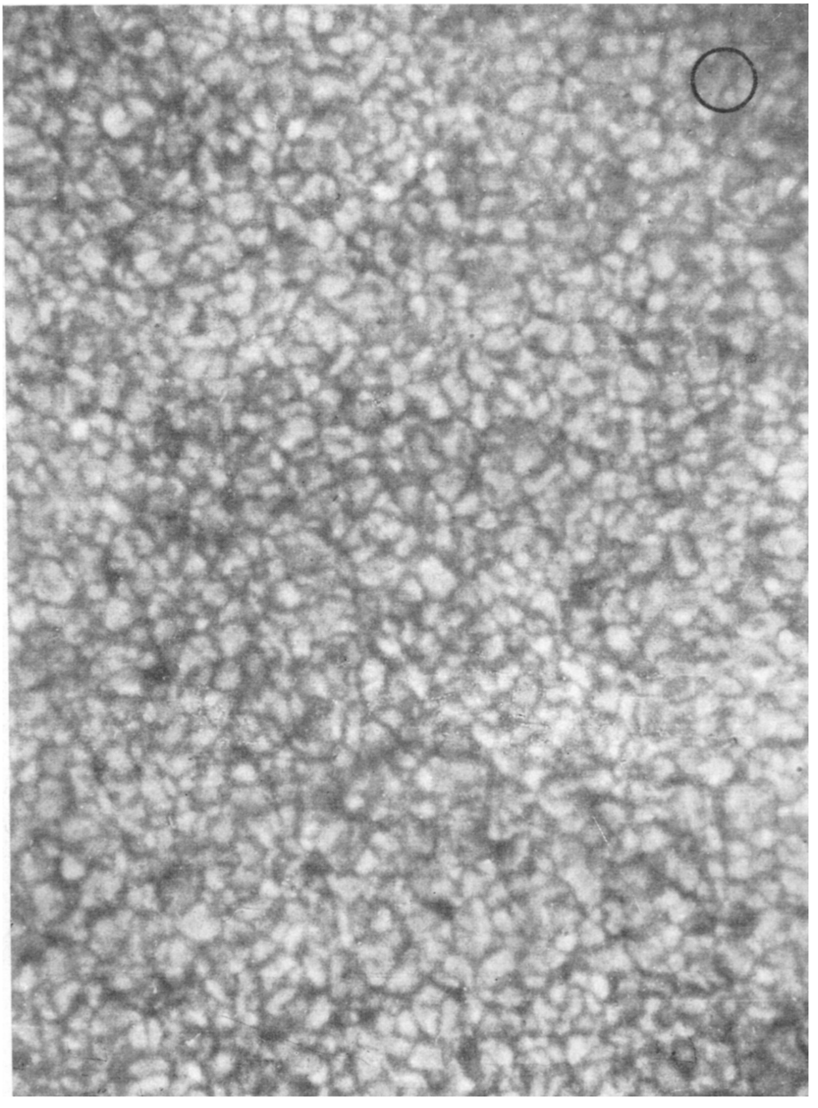

Fig. 1.

pending upon the direction of the displacement of the two pictures. As long as you have « moiré » effects on such pictures, you can say that there is something in common to the pictures; this was used for instance by GROTRIAN,

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https://doi.org/10.1017/S0074180900104516 Published online by Cambridge University Press

TEN BRUGGENCATE and others to have an estimate of the lifetime of granules. The next slide has been obtained by superimposing two images taken at 2½ minute intervals in time; the preceding one was obtained with two plates at 5 minute interval. The effect is much more evident on those at shorter interval, but it is still evident at 5 minutes, and this may give an idea about the lifetime of the granules. Our experience showed that it was difficult to have an accurate estimate by this method. When we increase the definition of the pictures, and the details in each granule become more important, then it is still more difficult to obtain « moiré » effects. We found that really the only

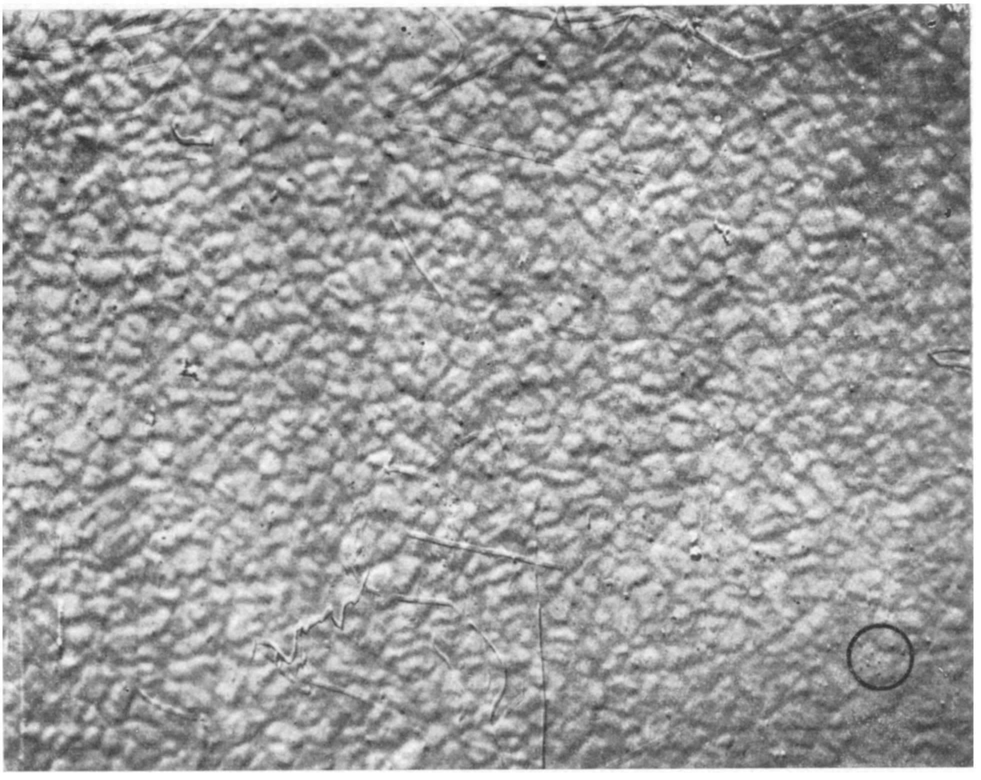

Fig. 2.

way to have some idea about the evolution of granules was to try to have good resolving power and compare the granules one by one, compare several images of the same granule, and the best way to do that, if possible, is to have moving pictures. This is not easy.

Fig. 2 is a way of representing the results of granulation. It is obtained with two images of the type which you have seen in orange light, but it shows not the *brightness* of the granules but the *gradients* in brightness. It is obtained

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by superimposing a positive and a negative of the same image; it may be shown (this has been worked out by Mr. HUGON, one of my assistants) that what appears is the gradients of density on the negative. It is amazing to see how clearly the details appear; this technique may be useful for some studies on the granulation. The next slide is an example of what we have picked out of a series of images obtained during a number of minutes. It shows that quite often a granule changes in form, in shape, and in size with time. One granule splits just as, let us say, a living cell or a coffee grain. For instance, the lower part, which becomes a triangle, splits in three parts and here it has almost disappeared. The next slide is a series obtained at intervals of 1 minute of time. Fig. 3 is another series covering 18 minutes and several features may be remarked on this. For instance, (*a*) splits and almost disappears—here (*a′*). The small one (*b*) is a part of an old granule. It will increase gradually here (*b′*), it is bigger, and here (*b″*) again it increases and gets bigger and bigger, and here (*b‴*) it begins to split in several small parts. Look also at these two there (*c*, *d*). You may follow them all in this interval of 18 minutes but with some sign of splitting here (*c′*); this one increases, you see and takes a shape like fingers of the hand with three fingers here (*d′*)—here you see one, two, and three fingers—then the fingers divide (*d″*) and so on.

After these slides I have just to show you the film. I must explain to you how to look at this film. The meteorological conditions in our situation are generally as follows: a mountain peak 9 200 feet high, rather isolated from the other mountains in the surroundings, and this may be one of the reasons for which the conditions are good. We observe the sun when it rises in the morning, and then the images are not very good because the light goes through a big mass of air. Then the conditions improve and at a certain moment we have good images; not on all days, but fortunately sometimes. Then later on, after 1 or 2 or 3 hours, we have nearby turbulence caused by the warm air going up along the slope of the mountain. We found on this film random motions of the granules which we suspected to be due to the atmospheric turbulence, because, as I said, the film was taken low on the horizon (between 15 and 20 degrees) so that we have remote turbulence which may not affect the sharpness of the images but make a sort of distortion. In order to know what was due to these atmospheric effects, we selected one of the sequences which was good enough to give us about 2 dozen frames of a sharp definition taken within 3 s of time. With this, we have prepared another film, which will be seen first, on which one sees only the atmospheric effects because we can make the assumption (and I think this is probably true) that during 3 s of time we have no change on the sun, at least not within our definition. Then on the second part one sees terrestrial effects plus solar effects. So, on the first part, granules have a sort of random Brownian motion, and there is a sort of pumping of the granules, a granule increasing, decreasing, and so on;

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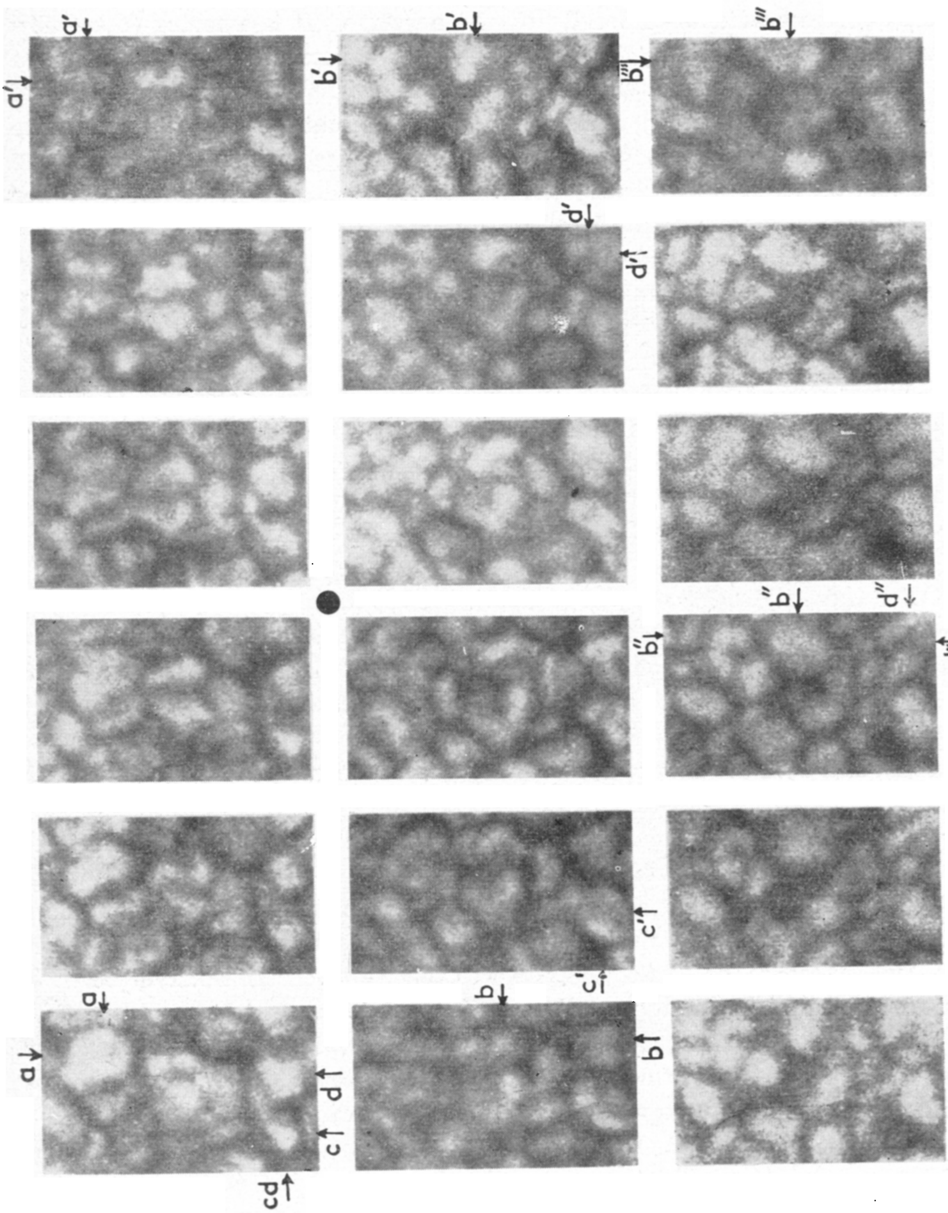

Fig. 3,

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but may I say that a big granule remains a big granule, a bright one remains a bright one and so on. On the second part you will see these effects plus others; and these others are mainly sorts of splittings of the granules just as you have seen on the slides. They give the impression that it is an irreversible phenomenon. This is my impression. Maybe you have another one. Quite often there is a dark point in the middle of a bright granule, and I have been very pleased to see the same dark points on the Princeton photographs.

As a conclusion, may I point out that the program, which we are carrying on since 1954, and which has produced some new results of importance (granules near the limb, 1955; intra-facular granules, 1956; evolution of the granules, 1956; evolution of the granules, 1959) takes its efficiency from the fact of being a long-range program, taking profit of its ground-basis which permits changes in type of observations, operating conditions, and so on. It is very fortunate that other groups have been able to tackle the problem by quite different ways—and with converging results. But I am sure that due to the flexibility of our program, we are in a good position to collect some of the data still so eagerly needed for interpretation of the photospheric phenomena.

E. SPIEGEL: **The Princeton balloon observations.**

As you have seen, the pictures of the solar surface until now revealed a two-dimensional random brightness field. In spite of the required visual appearances, at the one-second resolution limit, microdensitometer traces in the two-dimensional plane have given every appearance of a random brightness field. Now it has been felt, of course, that the statistical properties of this field would be the most direct and relevant clue to the nature of the fluid dynamical activity in the underlying hydrogen convection zone, and so it has been considered of pressing interest to determine as well as possible the statistics of this fluctuating brightness field. At Princeton some years ago it was therefore undertaken to send instruments to a distance above the tropopause where most of the atmospheric motions seem to be taking place that cause the seeing difficulties. And so some years ago a 12 in. telescope, 30 cm aperture, was sent aloft to 80 000 feet (24 km) to take photographs of the solar surface. Four flights were made at that time, and the results of these observations have been published by SCHWARZSCHILD (*Ap. J.* in 1959) as well as the relevant instrumental details. But only single pictures at certain moments turned out to be good enough for the kind of analysis one was interested in. What one found there is that the r.m.s. brightness fluctuation is of the order of 5 percent, this corresponds to about 80° fluctuations in the solar photosphere if one assumes black-body emission. The arguments for this are published in the paper I referred to. However, I would like here to discuss results from the most recent flight which was made last summer; that

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