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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is, four flights made last summer, in which it was possible to maintain good focus over a long time interval and thus to obtain data relevant to time lapse studies. I should say at the outset that I have no connection with any of these activities, my connection with Project Stratoscope, as it is called, is only during the time of this meeting, so that I may show the film which was taken under the direction and leadership of SCHWARZSCHILD. The active participants at the moment are also BAHNG, DANIELSON, and ROGERSON. I would like to report on these two aspects of the studies made from these most recent flights. One is a statistical study of the time-dependence of the brightness field at the surface. If we consider that the brightness field is given by some function $B(x, y, t)$, where x and y are co-ordinates on the solar surface, BAHNG and SCHWARZSCHILD have studied the correlation defined in this way:

$$R(t) = \frac{\int B(x, y, t' + t)\, B(x, y, t')\, \mathrm{d}x\, \mathrm{d}y}{B^2}.$$

I will show you the results of their measurements, and then I will show you the film which has been prepared by DANIELSON on the activity of sunspots.

First slide: It is this kind of material that has been used to evaluate the auto-correlation in time. This shows the same region of granulation at an interval of $2\frac{1}{2}$ minutes.

Second slide: This shows the evolution after 5 minutes of a region. You can still see, of course, granules persisting; and one can follow some individual granules for quite a long time it turns out, perhaps 20 minutes, depending on whether you think the granule is as it was. It distorts considerably, but you can recognize the original entity which is the granule. And, of course, one striking feature is that it seems that the bright regions are greater in area than the dark regions. However, this, of course, depends on how you set the brightness zero, and that is a ticklish point. But the microdensitometer gives the impression that there is more area on the bright region than in the dark intermediate region.

The third slide shows the auto-correlation as a function of time interval. There are two outstanding features: one is, of course, the extremely good fit of an exponential curve to the measures; and the second is the rather good agreement between the behavior near sunspots and away from sunspots. I think you will agree that the lifetimes are somewhat longer than have been suggested previously, certainly by the Potsdam observations. This is something one might have been surprised at, because presumably this is a higher resolution. I should mention that the granules observed are in the range of 300 km to about 1800 km, the 300 km being the lower limit of resolution. It is, however, felt from studies of limb darkening and so on that one is very close to observing the smallest features. This then is the summary of the results on the ordinary granulation. I don't want to discuss here the theoret-

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ical aspects. The fourth slide shows the kind of detail one can get in the sunspots. In the fourth flight last summer, there was made a particular attempt to follow a sunspot. The fifth slide shows a very large sunspot. DANIELSON has given considerable thought to these structures, in particular trying to explain the filamentary character. I do not have time to go into his theoretical discussion, but he seems to have ruled out all possibilities one could think of or one has thought of anyway, except the possibility that this elongated filamentary structure is produced by convective roles. One feels that the prevailing magnetic field which emerges from the sunspot is horizontal in the region of the penumbra, and that this magnetic field inhibits the convection which would have arisen in the absence of the magnetic field. The inhibition gives rise to a new form of convective motion, which has been studied at least in the incompressible case (convective roles being the cause of this pattern) although I am not at liberty to discuss it now because of time.

— R. B. LEIGHTON:

We have been spending about a week here discussing velocity fields, so I would like to take the liberty of showing you some as they appear on the surface of the sun. Let me first outline briefly the results which our observations have indicated to us. First, we have definite evidence for *horizontal motion* (*i.e.*, tangential to the solar surface) whose magnitude lies somewhere in the range 0.2 to 0.5 km/s, on a scale of about 30 000 km. This size is relatively large compared with the solar granulation. These motions represent relatively steady flow away from centers at which upward moving material arrives at the surface. There is some indication of a correlation with the emission in the K line of calcium. In addition, we find *vertical motions* which have a strong correlation between brightness and direction; namely, bright elements seem to be moving upward on the average—here the velocities are in a range 0.3 to 0.4 km/s and the linear scale is about $3\cdot10^3$ km and larger. The lower limit to the size is determined by our resolution—there may well be such motions on a smaller scale. These vertical motions show a strong oscillatory character, with a period of (296 ± 3) s, based upon about 25 observations. The number of oscillations that a given volume element will undergo before the oscillation dies out lies somewhere in the range from 2 to 4.

Now as to the means of observation—this is similar to the scheme devised a few years ago for measuring the magnetic field (R. B. LEIGHTON: *Ap. J.*, 130, 366 (1959))—it is based upon a photographic cancellation procedure in which one simultaneously takes two photographs—(with the spectroheliograph) of the same region of the solar surface and introduces by suitable means a difference between these two photographic images, which difference is a measure of the quantity one wishes to study. We use for the most part a line of Ca I at wavelength 6103 Å, a relatively strong line so that the level in