EVOLUTION PATTERN OF THE EXPLODING GRANULES

O. Namba and R. van Rijsbergen
Astronomical Institute, Utrecht

SUMMARY

The evolution pattern of the so-called exploding granules has been studied on the basis of a time sequence from Princeton Stratoscope pictures of the solar granulation. Some preliminary results are presented (section3). A new interpretation of the phenomenon is suggested (section 4).

1. INTRODUCTION

During the morphological study of the solar granulation (Namba and Diemel,1969) we were puzzled by some large granules which have a round darkening in their centre often with several dark canals radiating from it toward the boundary. In 1967 we began a study of this remarkable class of granules, which are now referred to as "exploding granules" though the term is somewhat misleading. The exploding granule phenomenon was discovered by Rösch and his co-workers (Carlier et al., 1968) in moving pictures obtained at the Pic du Midi Observatory, an example of which was shown during the 1967 I.A.U. Meeting at Prague. Musman (1972) has proposed the first theoretical model of the phenomenon on the basis of his laboratory experiment and observations obtained at the Sacramento Peak Observatory. In this paper we present some observational features of exploding granules, which may be of some importance for the theory of non-stationary convection.

2. OBSERVATIONAL MATERIAL

The observational material is a time sequence of high-definition photographs of the granulation obtained on the Stratoscope flight of August 17, 1959. The duplicate negatives on 35-mm film were kindly lent us by the Princeton University Observatory. The photographs were taken in the green-yellow region with an exposure time of 0.0015 sec at a rate of a frame every 0.929 sec; the highest spatial resolution attained is 0.112" or 271 km on the Sun.

The time sequence lasts about 16min (Frame Nos. 2145 - 3200) and refers to a quiet region near the disk centre; some of the frames are illustrated in Bahng and Schwarzschild (1961), where the observational data are also given. The search for exploding granules and the study of their evolution have been done on positive enlarge-

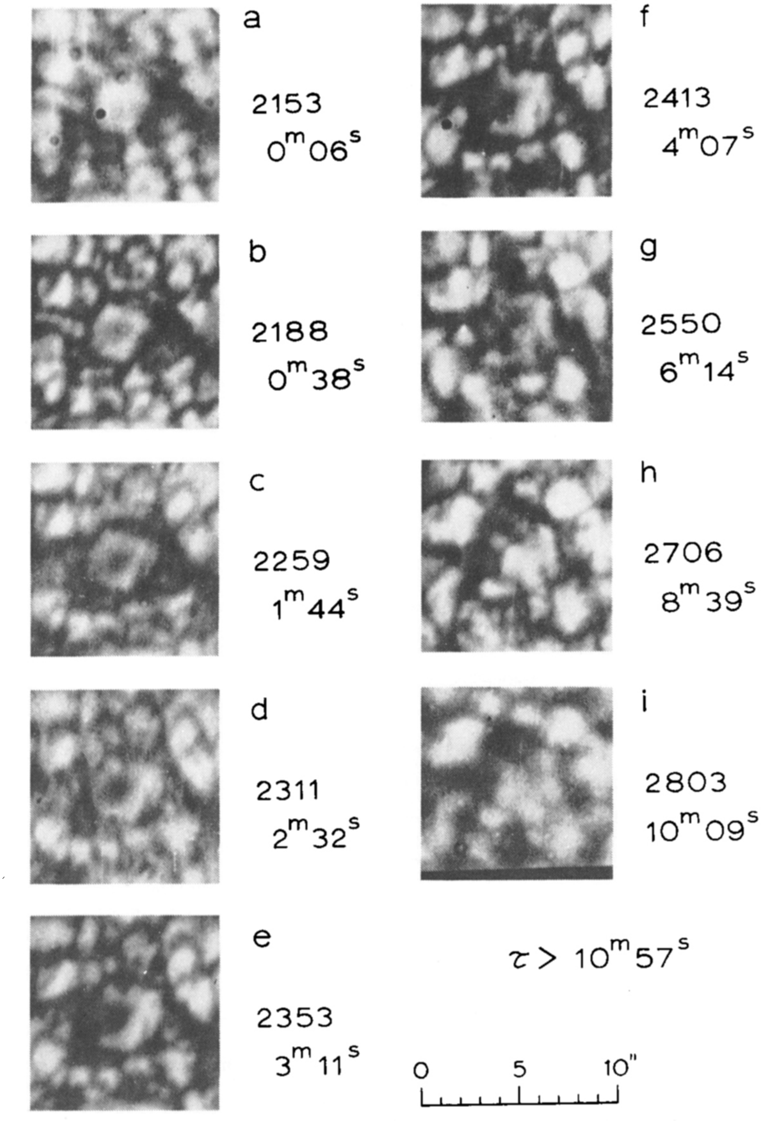

Fig. 1. Evolution of a typical exploding granule (centre) - a time sequence from Stratoscope granulation photographs obtained on August 17, 1959. Indicated are frame numbers, relative times, the lifetime, and the distance scale (1" = 725 km). Note also remarkable stability of surrounding granules. (Small specks and dots in some pictures are blemishes.)

ments of about 50 selected frames (the image factor: 1"= 4 mm for all and 1"= 6 mm for portions including the granules treated here). The work was troublesome, because the focussing of the image was widely variable and high-resolution pictures are not uniformly distributed in the sequence. Furthermore, besides small shifts of the granulation field in the frame, there is a drift of the solar image that divided the time sequence into two parts, one lasting about 10 min and the other 6 min, with some spatial overlapping (cf. Fig.2 below).

In this study seven exploding granules were examined. Fig.1 shows a series of pictures for a typical example. Although the picture quality is somewhat variable, the series illustrates nicely its evolution (cf. Carlier et al.,1968 and Musman, 1972). On the positive prints we measured the area of granules as a whole and expressed them in terms of the average diameter (D). For the pictures shown in Fig.1 microphotometry has been carried out with a Joyce Isodensitracer.

3. RESULTS

Although individual exploding granules behave rather differently, their evolution pattern may be summarized schematically as follows. A granule appears as a bright spot, which grows quickly. As the size increases, a vague shade forms over the central part of the bright granule; it soon becomes a round dark hole - see Fig.1. As the central darkening develops a few dark canals radiate from it toward the boundary. This may be regarded as the primary splitting of the granule, usually into two or three smaller granules. Around the time where the granule reaches its maximum extension the split granules break further into several parts (the secondary splitting?), provided the granule is large. So, one can count from several to more than ten granules, split from a single granule. The evolution after the fragmentation depends upon the granule. One of the split granules may become a new exploding granule while others fade away. Carlier et al. (1968) showed an example that developed three "generations" of exploding granule from a single entity. We should mention that the splitting is a very common phenomenon of granules: even for small granules ($D < 1''$) it is rather difficult to find such granules that do not split.

From the study of seven exploding granules the following characteristic features have been derived.

(a) Measured diameters are plotted in Fig.2 as a function of time. The maximum size reached during the evolution was from 3.3" (2200 km) to 5.4" (4000 km) in diameter. The expansion rate $\Delta D/\Delta t$ is more or less linear with a speed of 1.3 to 3.3km/s. Hence, the radial expansion rate $\Delta R/\Delta t$ ranges from 0.7 to 1.7 km/s, in agreement with the earlier estimates of 1.5 to 2 km/s (Carlier et al.,1968) and of 1.8 km/s (Musman, 1972). These values are only a fraction of the sound speed in the photosphere ($\approx$8 km/s), but they exceed the horizontal flow velocity of 0.34 km/s (maximum) at the top of granules, measured by Beckers and Morrison (1970).

Furthermore,there is a tendency that the expansion speed is proportional to the ma-

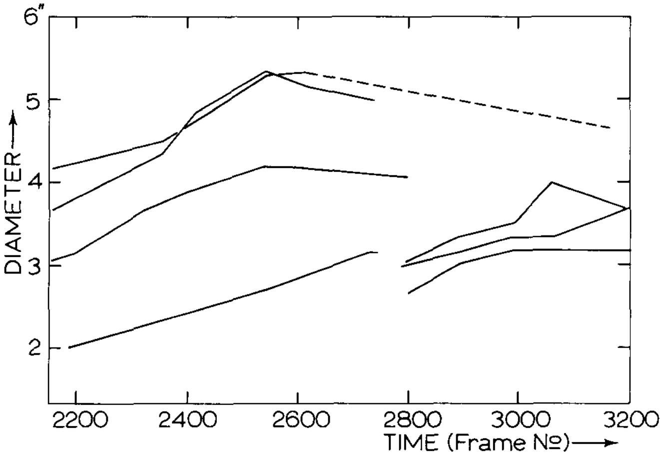

Fig. 2. Growth of exploding granules: average diameter (1" = 725 km) vs. time (a frame every 0.929 sec). The granule, illustrated in Fig. 1, is the third from the top.

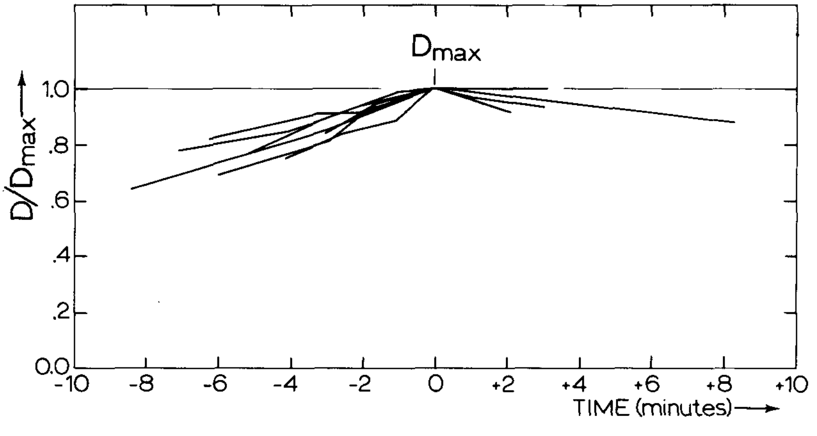

Fig. 3. Relative growth of the exploding granules, derived from Fig. 2. The average rate of growth $\Delta ln\ D/\Delta t \approx 0.045/min$.

https://doi.org/10.1017/S0252921100112357 Published online by Cambridge University Press

ximum diameter reached. In Fig.3, where the mean diameter relative to the maximum diameter is plotted versus time, all the growing branches cluster around a line (not drawn) with a slope

$$\frac{\Delta \ln D}{\Delta t} \approx 0.045/\text{min.} \tag{1}$$

(b) The above relation suggests that in the sub-photospheric layer the upper part of the granules may look like huge cones, as sketched in Fig.4.

(c) The central darkening occurs only when the granule is roundish, uniformly bright and exceeds a certain critical diameter $D_c \approx 2.3''$ (1600 km). It does not show up in large but elongated granules with a width smaller than this value.

The isophotometry of the pictures shown in Fig.1 yielded interesting data about the development of the central darkening for this particular granule. In the interval from picture b to picture e, the central darkness increases linearly with time from 13 to 25% of the surrounding brightness and the diameter at half the central depression grows from 700 to 1100 km at a linear rate of 3.0 km/s while the granule expands at a rate of 3.2 km/s in the same period.

(d) The lifetime for the individual granules has been found to be much longer than the "correlation" lifetime of 8.6 min measured by Bahng and Schwarzschild (1961). The time sequence allowed us to determine only a lower limit of 10 - 11 min. But Fig.3 suggests a lifetime of, say, half an hour. In Fig. 1 also the remarkable stability of normal granules surrounding the exploding granule is apparent: many persist through the 10-min time. This is the case also for small granules in the range of $0.8'' \lesssim D \lesssim 1.7''$ (Namba and P. Provoost, 1973, unpublished).

(e) In the time sequence we counted about 20 certain and 10 suspected exploding granules with the characteristic features (central darkening with or without radial canals) over an area of roughly 70" x 90" at any given moment; they cover 2 to 3% of the total area. In addition, thanks to the time sequence, we found about 10 granules, which became exploding ones, and nearly twice as many already "exploded" granules.

The spatial distribution of exploding granules does not seem to be random, but we lack further observational material to investigate whether there is any correlation between the locations of exploding granules and the supergranulation pattern. Allen and Musman (1973) found no such correlation in their observations.

4. A POSSIBLE INTERPRETATION OF THE EXPLODING GRANULE PHENOMENON

Musman (1972) interpreted the phenomenon as follows. When a rising granule penetrates into the overlying stable region, the internal granular motions and the conservation of angular momentum act to change the form of the granule into a vortex ring, which is stretched out horizontally and breaks. This "smoke ring" model, however, meets difficulties in explaining some observed facts, for example, why some granules are of the exploding type while many others are not, and why a part of the broken ring may

https://doi.org/10.1017/S0252921100112357 Published online by Cambridge University Press

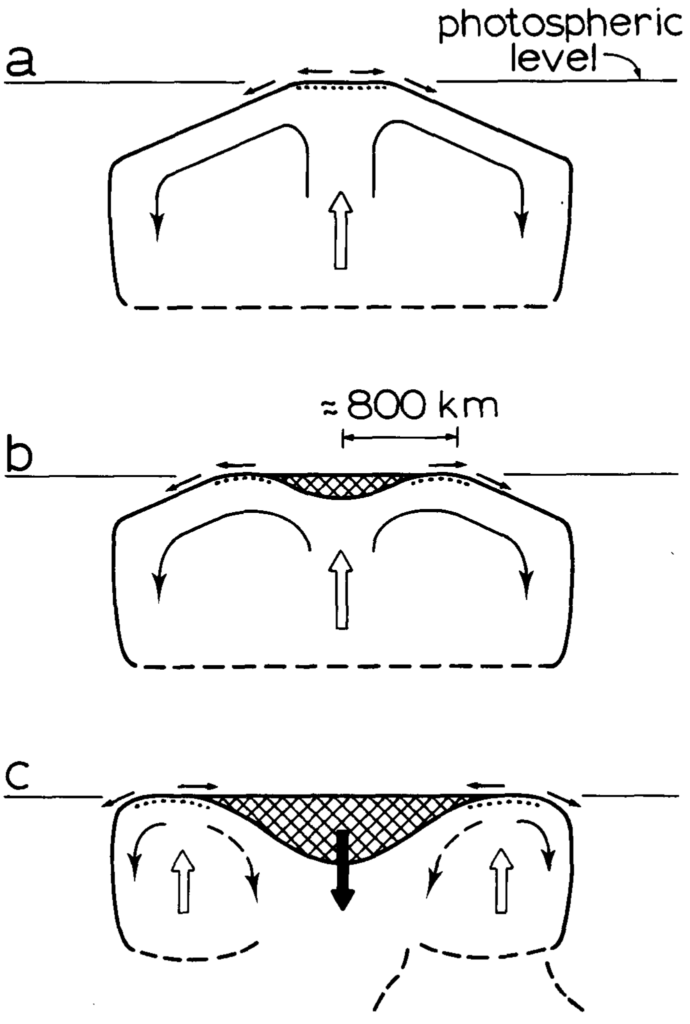

Fig. 4. A possible interpretation of the exploding granule phenomenon - development of the central darkening (vertical cross section). Cf. Fig. 1. a: as the granule rises the top layer is cooled instantly; the cold matter flows out; b: since the granule grows fast and large ($D \gtrsim 1600$ km) the cold matter is left behind the expanding granule boundary, and the central darkening begins to form. It develops parallel to the growth of the granule; c: when the mass of the cold matter in the centre becomes too heavy, it sinks, breaking through the granule. The development is accompanied with splitting of the granule. Some of the split granules may grow further while others fade away.

become a new exploding granule.

The evolution pattern reported here suggests an alternative qualitative interpretation which is illustrated in Fig. 4. As soon as a hot granule reaches the photospheric level its top is cooled. At first the cooled matter flows horizontally (with a velocity of $\stackrel{\sim}{>}$ 0.5 km/s) and then downward to join the surrounding intergranular region (Fig.4a). The upper layer of the steadily growing granule is removed continuously in this way. This process goes smoothly as long as the granule size does not reach the critical diameter mentioned above.

However, when the granule expands with a speed faster than the horizontal flow velocity, the cold matter can never reach the granule boundary and is left behind, and consequently the central darkening begins to form (Fig.4b). By this time the granule diameter may have reached the critical value D_c. The central darkening develops parallel to the growth of the granule (paragraph 3c above).

The mass of the cold matter accumulated in the centre of the granule is supported by the buoyancy and the upward motion in the granule, until its total weight becomes too large. Then the balance is lost and the cold mass sinks, breaking through the granule (Fig.4c).

The development of the central darkening may be accompanied with the fragmentation of the granule. The onset of the downward streaming at the centre might induce the secondary splitting.

Our interpretation predicts a downward motion in the central darkening after some moment. It is of particular interest to determine the Doppler velocity in the central darkening and its change during the evolution of exploding granules.

ACKNOWLEDGEMENTS

Our thanks are due to the late Dr R.E. Danielson of the Princeton University Observatory, who kindly supplied us with the valuable Stratoscope material. The Project Stratoscope I was sponsored by NSF, ONR, and NASA, U.S.A. We thank Mr J.L.A. van Hensbergen for his assistance in photographic work. We acknowledge Drs A.G. Hearn, G.D. Nelson and C. Zwaan for stimulating discussions.

REFERENCES

Allen, M.S. and Musman, S., 1973, Solar Phys., 32, 311
Bahng, J. and Schwarzschild, M., 1961, Astrophys. J., 134, 312
Beckers, J.M. and Morrison, R.A., 1970, Solar Phys., 14, 280
Carlier, A., Chauveau, F., Hugon, M. and Rösch, J., 1968, C.R.Acad.Sc.Paris,226,199
Musman, S., 1972, Solar Phys., 26, 290
Namba, O. and Diemel, W.E., 1969, Solar Phys., 7, 167