PHOTOGRAPHY OF SOLAR GRANULATION
FROM A MANNED BALLOON

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The best photographs of solar granulation so far obtained\(^1^3\) show a resolution of no more than about 0\(^2\) 7, corresponding to the Rayleigh limit of an 8-inch visual telescope objective. Since attempts to improve this performance have been made for many years with larger telescopes, it seems that this limit is set by the quality of atmospheric seeing, and it is unlikely that more observations by conventional methods on the ground will lead to appreciable improvement. An improvement of this resolution by a factor of only two should lead to a greatly improved understanding of the solar atmosphere.

The chief barrier to good solar seeing is the disturbed air, mostly very near to the ground, but extending perhaps to a height of 10,000 ft, or more in some meteorological conditions. If photographs can be taken with a telescope at a height of some 20,000 ft above the ground in such a way that the air around the instrument is undisturbed, then it seems likely that a marked improvement in the quality of the seeing will result. Earlier experiments made by two of the authors from a piston engined aircraft have shown that the machine creates too much disturbance around itself. This article describes some observations made with an 11-in refractor mounted on a manned balloon: the results of the first flight are discussed.

The design of a telescope for operation at this height presents unusual difficulties. These difficulties increase rapidly with the size of the telescope, and our design has been greatly influenced by the fact that it will eventually be desirable to use a telescope of at least 16-in aperture in this

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![Optical Bench of Telescope](image)
way. This has led to a very simple design, in which the refracting telescope is suspended underneath the balloon basket on an altazimuth mounting and is pointed directly at the Sun. The objective, an 11-in f/10 visual doublet by Schaefer, of fine quality, is mounted in an aluminium cell. The telescope "tube" is a welded framework of thin aluminium alloy tubing, 12 ft long and with a triangular section of 22-in side. It combines extreme lightness with remarkable rigidity; when supported at the ends and loaded in the middle, the deflection in the middle is only $7 \times 10^{-4}$ in/lb, yet its weight is only 12 lb. Such rigidity is necessary to preserve the optical alignment in all positions of the telescope. The optical bench shown diagrammatically in Fig. 1 is mounted at the image end of the welded framework.

The exposure is made by the focal plane shutter of a Contax camera B, with the speed set at 0.8 millisecond: the shutter is very close to the primary focal plane of the objective. The Contax is used here only for the sake of its fast focal plane shutter; it is open back and front and carries neither lens or film. A slow auxiliary shutter $A$ between the objective and the Contax protects the delicate Contax shutter from the heat of the solar image. A field stop very close to the Contax shutter, and 2 mm in diameter, isolates a small portion of the primary image which is enlarged to cover a 35 mm frame by a positive projection eyepiece $C$ of focal length 1-in. The final solar image is 18-in in diameter, giving a plate scale of 1 mm $\equiv 4''$. The eyepiece can be moved, by the gear and pinion $D$, along the optical axis through the position of focus. Photographs are taken on 35 mm panchromatic microfilm (Kodak Microfile Pan), 70 ft of which are contained in a large magazine $E$ which is driven to move the film forward one frame after each exposure. A Wratten No. 58 filter with a peak transmission at 5300 $\AA$ is placed between the eyepiece and the film, whilst the intensity of the solar image is adjusted by a wheel of neutral density filters $F$. The various moving parts of the optical bench are actuated automatically in correct sequence by electric motors and solenoids mounted on the optical bench. All controls, and a remote reading device for the focus setting, are in the balloon basket. The maximum rate of operation is 15 photographs per minute.

The altazimuth mounting of the telescope on the basket is shown in outline in Fig. 2. It is made of aluminium angle, and a battery box weighing 20 lb is used as a counterweight for the telescope.

One of many practical difficulties is that when the telescope is moved about a vertical axis, angular momentum is conserved and the balloon turns in the opposite direction. This particular difficulty is overcome by coupling the vertical axis to a small inertia arm which is moved with a much greater angular velocity in the opposite direction; in this way it is possible to move the telescope without moving the basket. The telescope is directed at the Sun by manipulating the controls until the primary solar image falls on the first shutter; a projection finder has to be used in certain positions of the telescope.

The large balloon was of conventional type made of very light rubberized silk and with a volume of 41,000 ft$^3$. The total weight of apparatus, basket, two observers (D.E.B. and A.D.) and the balloon was about 1650 lb. The first ascent was made from the terrace of the Meudon Observatory on 1956 November 22, when 390 photographs were taken.
during three hours at heights between 18,000 and 20,000 ft. The apparatus is well shown in Plate I, taken at the beginning of the ascent. To facilitate landing, the telescope was dropped by parachute after removing the objective and the camera. At maximum altitude the temperature was about $-30^\circ$C. Poor optical definition can easily arise by heating of cold air in contact with a warmer objective. This effect is unlikely to have caused trouble in this instance because the ground temperature at take-off was already $-3^\circ$C and the apparatus was given adequate time to cool before photography was started. A further difficulty is the uncertain position of focus. The focus is critical to at least 0.1 mm but because of the unknown thermal behaviour of the objective was uncertain to within $\pm$ 2 mm. As there is no provision for visual focusing, the position of the eyepiece was altered in small steps over the range $\pm$ 2 mm during the flight. This unfortunately means that only 7 per cent of all the photographs taken on this first flight could be expected to be in good focus.

The telescope operated as planned, except that the Contax shutter
Solar Photography from a Manned Balloon
A general view of the telescope and balloon basket a few moments after launching at Meudon. Behind is the dome of the 33-inch refractor.
unfortunately gave a speed of about 2 millisecond instead of 0.8 millisecond because of the low temperature. We emphasize at this stage that the only reason why this method is practicable at all is that the exposure time can be made so short that relatively large image motions can be tolerated. If, with an exposure time of 0.8 millisecond, the blurring is to be less than 0.5, the maximum image motion tolerable is 1/3 solar diameter per second. This unforeseen increase in the exposure time was therefore very unfortunate because apart from overexposure it meant that at the position of best focus the telescope was not sufficiently still to give its maximum resolution. The best photographs, however, show the fine structure of granulation with a resolution of about 0.9, and seem little inferior to the photographs by Lyot and others already mentioned; it is encouraging to see that they are free from the defect of réseau photosphérique. It is clear from an examination of all the photographs that the limit to the resolution obtained in the first flight was almost certainly set by image movement. The best photographs obtained with the telescope sufficiently still are apparently not in exact focus. In a second flight we therefore plan to use an exposure time of about 0.2 millisecond, so that image movement will no longer be a serious limitation.

The first flight is the culmination of a long period of development work initiated by Professor R. O. Redman, who has given constant advice and encouragement. We are very grateful to Professor A. Danjon for granting facilities for the two British authors to work at the Meudon Observatory, and for the loan of the Schaefer objective of the Paris Observatory. The balloon has been placed at the disposal of the Meudon Observatory by the French Air Ministry. The aeronaughtical part of the work would have been impossible without the additional help and advice of M. Charles Dollfus of Paris, whilst valuable help was given before the flight by many members of the staff of Meudon Observatory. The telescope "tube" was designed by Professor B. G. Neal and Dr. K. Eikhoff and made in the workshop of the Cambridge University Engineering Laboratory from material given by T. I. Aluminium, Ltd.; the remainder of the telescope itself was made in the Cambridge Observatories' workshops.

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References

(1) See for example G. P. Kuiper (ed.) The Sun, Chicago, 1953.
Solar Flare, 1956 November 7, 17°S 31°E, at (1) 11 h 13 m, (2) 11 h 15 m,
(3) 11 h 35 m, (4) 12 h 16 m

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