Stars and Heavy Primaries Recorded during a V-2 Rocket Flight

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Plates flown to an altitude of 150.7 km in a V-2 rocket exhibit a differential star population of 5000 ± 800 per cc per day and a flux of heavy primaries of about 0.03 per cm^2 per min. above the stratosphere. The star intensity is about 3.6 times greater than that recorded by plates exposed in the stratosphere, the increment being attributable to secondary star forming radiations created by interaction of cosmic-ray primaries with the massive projectile. The flux of heavy primaries is essentially of the same order of magnitude as reported for elevations of 28 km.

I. INTRODUCTION

A SMALL unit of Kodak NT4 plates were flown to a peak altitude of 150.7 km by a V-2 rocket at White Sands, New Mexico, during a test flight on September 29, 1949. The plate holder was recovered in good condition several hours after the landing. The rocket plates together with a set of monitor plates, which had the same history since manufacture, except for the brief high altitude exposure, were returned to this laboratory and developed three days after the flight. All plates developed satisfactorily and a preliminary microscopic examination at low power revealed several large stars in the rocket plates suggesting that a complete study of all plates might yield significant information on the intensity of the star-producing radiation despite the very brief duration of the high altitude exposure.

The results reported must be considered preliminary, as only a comparatively small number of events were recorded in the 2-cc volume of exposed emulsion and hence the statistical uncertainty in the populations is large. Also, by better timing in the manufacture, shipment and development of the plates it should be possible to reduce the magnitude of the accumulated star population in the control plates.

II. CAMERA AND EXPOSURE

The four plates, coated approximately 200μ thick, were bound together as a rigid unit with black cellulose tape and enclosed in a gas-tight aluminum box packed with sponge rubber and fitted with a thick rubber gasket as described in Fig. 1. The plates were predried over calcium chloride and were infected at selected points with a trace of polonium so as to provide precise registration marks for intercomparison of long tracks recorded through the stack. The camera was assembled and bolted to the tail fin of the rocket shortly before the launching. The gas-tight construction was deemed advisable in order to prevent traces of oxidants originating from the rocket fuel from reaching the emulsion, as these vapors, particularly hydrogen peroxide, cause rapid destruction of the latent image of nuclear particle tracks.[1] The simple inclusion of the sponge rubber seems to be adequate protection against damage from the several mechanical shocks involved in the firing of the rocket, the blow-off of the war-head and the final grounding of the fins.

The rocket reached an altitude of 28 km at 60 sec. after the firing and attained the peak of its trajectory 150.7 km after 223 sec. At 336.5 sec. the war-head was blown off by radio command at an elevation of 90.7 km. From this point, the precise period taken in the grounding of the plates is not known, but neglecting air resistance encountered during free fall in the lower atmosphere a period of 75 sec. is estimated for the last stage of descent. The total period between firing and landing is 6.85 min. and the plates spent approximately 4.78 min. above the stratosphere. For purposes of computing time rates the total period above White Sands (elevation 1.22 km above sea level, $\lambda=41°N$) has been employed in computing star intensities and the time spent above 28 km for the rate of incidence of heavy primaries.

III. STAR INTENSITY

The entire areas of the monitor and the rocket plates were scanned microscopically using an 8-mm

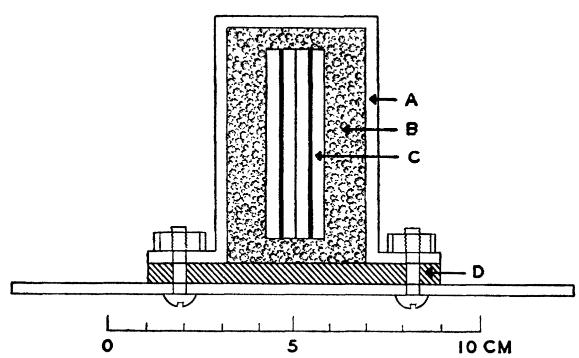

FIG. 1. Cross section of plate holder. A. Aluminum jacket 3 mm thick. B. Sponge rubber packing. C. Plates assembled with emulsion layers adjacent to each other. D. Rubber gasket.

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[1] H. Yagoda and N. Kaplan, Phys. Rev. **73**, 634 (1948); H. Yagoda *Radioactive Measurements with Nuclear Emulsions* (John Wiley and Sons, Inc., New York, 1949), p. 110.

TABLE I. Star populations in rocket and control plates.

Plate	Star count	Volume, cc	Stars per cc
Rocket a	11	0.391	28.2
A	15	0.480	31.3
b	11	0.359	30.7
B	16	0.470	34.0
Totals	53	1.700	Av. 31.2±4.3
Control c	4	0.341	11.7
C	3	0:344	8.7
Totals	7	0.685	Av. 10.2±3.9

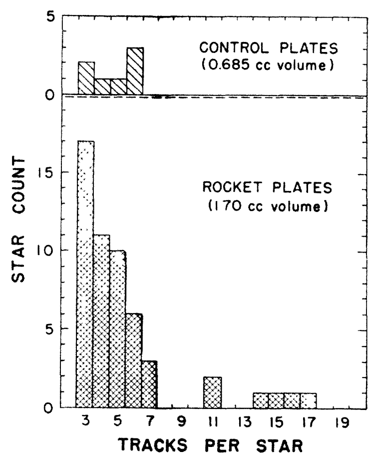

FIG. 2. Histograms of star size distribution in rocket and control plates.

achromatic objective and a pair of 10× wide field oculars, using overlapping fields so that all stars had opportunity for detection. The star counts summarized in Table I show that the plates exposed in the rocket contain a significantly larger population of nuclear evaporations of three or more tracks than the control plates. The size distribution of the events in the rocket plates, shown in Fig. 2, also exhibits the presence of a group of complex stars, characteristic of plates exposed at very high altitudes. In 1.70 cc of emulsion flown in the rocket we observed 53 nuclear evaporations and three stars produced by σ-mesons at the end of their ranges. Scanning of the monitor plates with equal care revealed seven nuclear evaporations, one π-μ-interaction and one σ-meson-induced star in a volume of 0.685 cc. The differential star population, excluding events initiated by mesons, is 21 per cc of emulsion which, if attributed to the 6.85-min. flight of the rocket, corresponds to an average rate of star production equivalent to 5000±800 per cc per day.

The particular batch of plates employed in this experiment did not prove to be sensitive to singly charged particles moving at relativistic velocities. Hence the recorded star spectrum does not include shower particles of fast mesons, or protons with kinetic energies in excess of 60 Mev. Figure 3 depicts one of the more complex evaporations recorded in the rocket plates, which is of interest in exhibiting the tracks of two massive fragments initially ejected with a high charge as indicated by the thin-down of the tracks near the end of their range.

In plates of similar composition, flown in free balloons in Minnesota at altitudes between 27 to 30 km, star populations between 1400 to 2000 per cc per day have been reported in several independent investigations.[2–4] The lower value reported from this laboratory has been corrected for ascent and descent of the balloon and for stars accumulated while the plates remained near sea level, and is therefore selected as a basis for the comparison with the star population recorded in the rocket plates. This basis indicates a rate of star production 3.6 times as large as that observed in the stratosphere. The increment cannot be attributed to the absence of practically all risidual air during the greater part of the rocket flight, but probably has its origin in the formation of energetic secondary particles in the body of the rocket. An intensification factor of 1.5 has been observed by Lord and Schein[5] in the abundance of small stars when plates are exposed in the stratosphere under 15 g/cm^{-2} of lead. Since a large proportion of the stars recorded in the rocket plates are of low multiplicity, the three-and four-branch events constituting 53 percent of the total, the abnormally large value of 5000 per cc per day probably originates in multiplication processes between primary cosmic radiation and the massive rocket body.

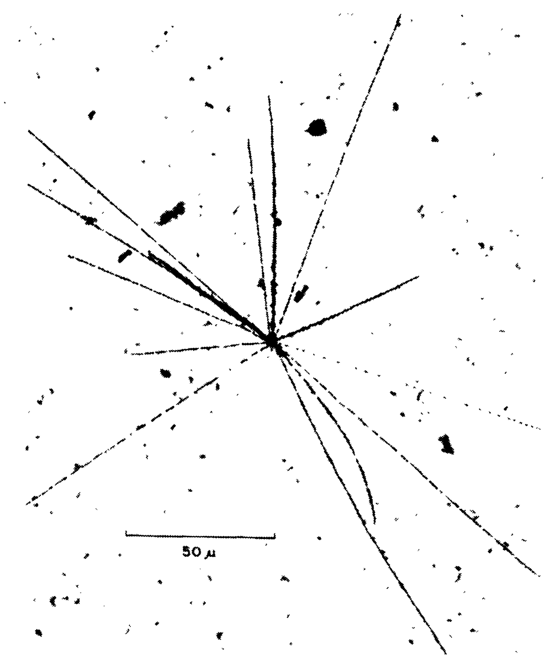

FIG. 3. Nuclear evaporation recorded in one of the rocket plates.

[2] Yagoda, Kaplan, and Conner, Phys. Rev. 76, 171 (1949).
[3] Salant, Hornbostel, and Dollman, Phys. Rev. 74, 694 (1948).
[4] M. Addario and S. Tamburino, Phys. Rev. 76, 983 (1949).
[5] J. J. Lord and M. Schein, Phys. Rev. 75, 1956 (1949).

IV. HEAVY PRIMARIES

A number of single, densely ionizing tracks were observed, indicative of particles with a charge of two or greater. The positions and orientations of these tracks were noted in an effort to trace the particles through the stack. Only three of the tracks could be followed through the four plates, and on the basis of δ-ray counts (Table II) were identified as particles of charge 14, 8, and 6, respectively. Since the identification of the track as that of a heavy primary was based chiefly on a high δ-ray count along its recorded path, fast He, Li, Be, and B nuclei would escape recognition in a stack of small dimensions. The three tracks thus furnish a rough estimate of the flux of only those heavy primaries of charge $Z \geq 6$. The flux of these particles corresponds to 0.031 ± 0.018 per cm^2 per min. of flight above the stratosphere. During the flight of a V-2 rocket fired on January 22, 1949, Golian and co-workers[6] observed the trajectory of one heavy primary using a 6-in. cloud chamber in which photographs were taken at 25-sec. intervals.

While the flux of heavy primaries evaluated from the three tracks recorded in the rocket plates is subject to a large statistical uncertainty, it is of interest to compare the magnitude with that derived from the more abundant data obtained in plates exposed at stratosphere levels. The measurements of Bradt and Peters[7] showed the presence of 61 primary tracks in a complete survey of 20.2 cm^2 of emulsion exposed for 3 hr. at geomagnetic latitude $\lambda = 51°N$. This is equivalent to an incident flux, independent of angle of entry with respect to the zenith, of 0.017 ± 0.002 per cm^2 per min. of flight, which indicates that our rough estimate for the flux of primaries during the rocket flight is of the correct order of magnitude.

TABLE II. Characteristics of the heavy primary tracks.

Track	R-1	R-2	R-3
Angle with emulsion plane[a]	34.8°	54°	48.5°
Length in top plates[b]	708μ	503μ	533μ
Length in bottom plates	701	493	523
δ-rays in top plates	87	25	16
δ-rays in bottom plates	90	20	14
Average δ-ray count per 100	12.6	4.5	2.7
Probable charge[c]	14±2	8±2	6±2
Range in glass between emulsions	10.5 mm	7.22 mm	7.68 mm
Total range in emulsions and glass	3.2 g/cm^2	2.2 g/cm	2.3 g/cm

[a] The orientation of the plates was defined precisely when initially mounted on the rocket. However, since the particles may have been incident either during ascent or descent, the direction of the primaries with respect to the zenith cannot be established.
[b] The plates were assembled with emulsion layers adjacent. After recording in the top plates the particles traversed two glass backings (each 1.5 mm thick) before reaching the lower set of sensitive layers.
[c] Computed from the relationship described by Bradt and Peters (reference 7): $(n\delta)_z = (0.060Z^2 + 0.2)$ where $(n\delta)_z$ represents the average δ-ray count per 100μ for particles traveling with relativistic velocities.

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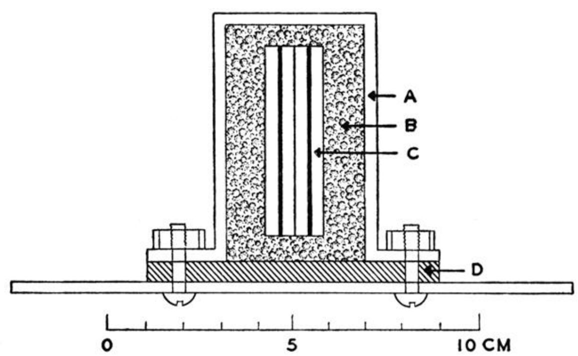
[6] Golian, Johnson, Krause, Kuder, Perlow, and Schroeder, Phys. Rev. **75**, 524 (1949).
[7] H. L. Bradt and B. Peters, Phys. Rev. **77**, 54 (1950).



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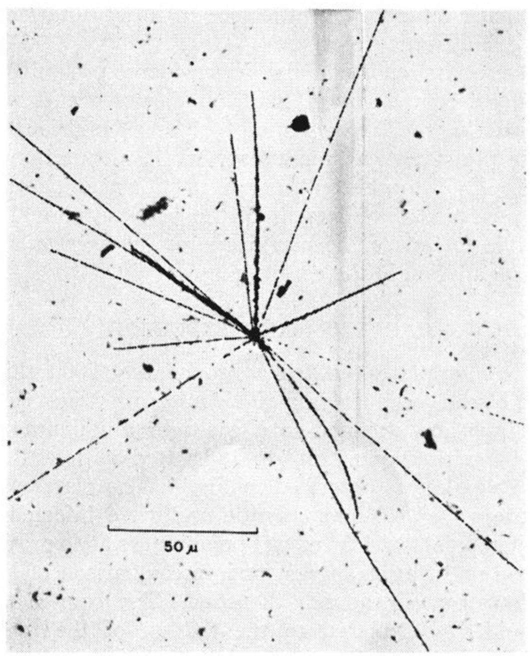

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