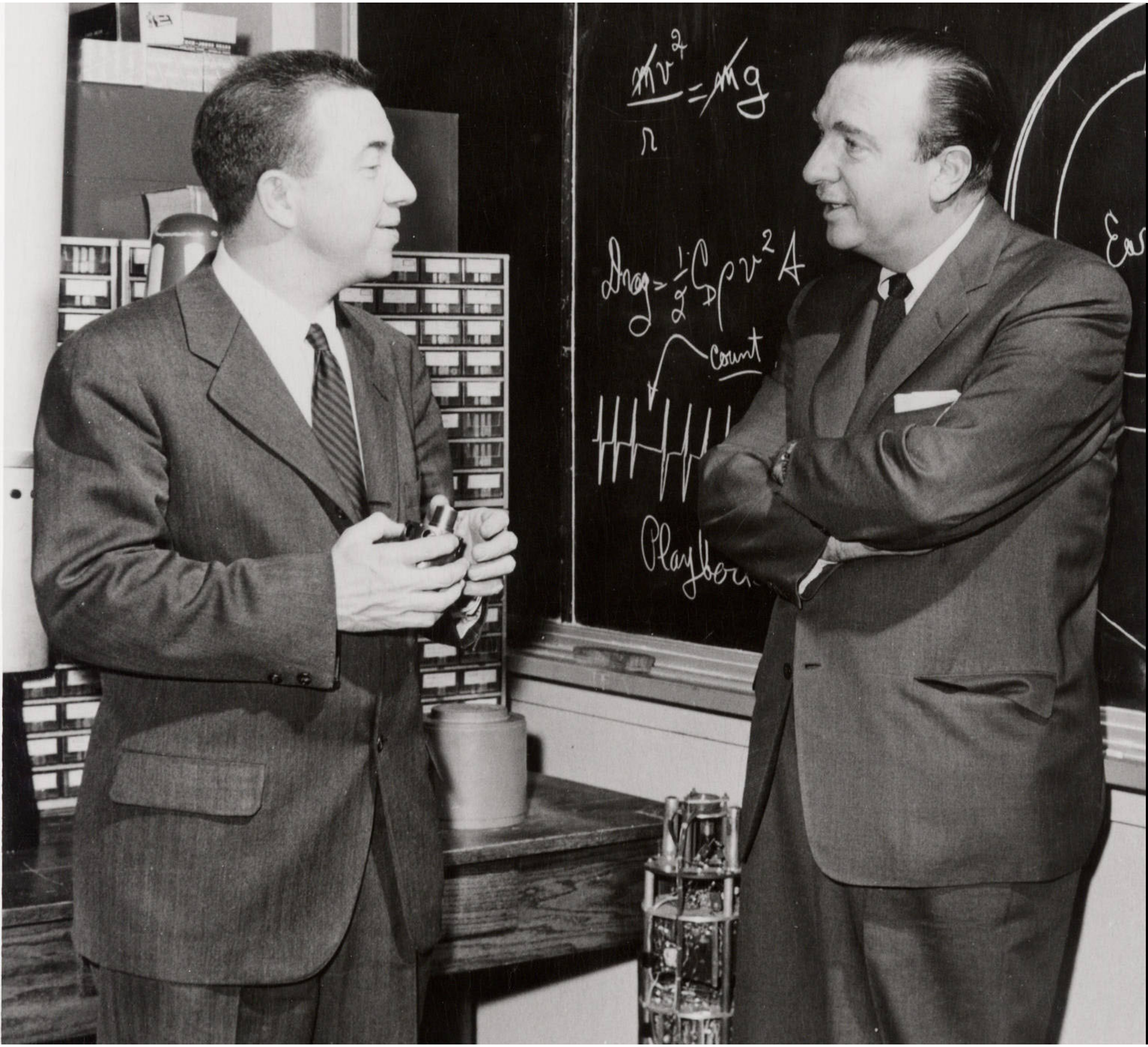
$\frac{\cancel{m}v^2}{r} = \cancel{m}g$
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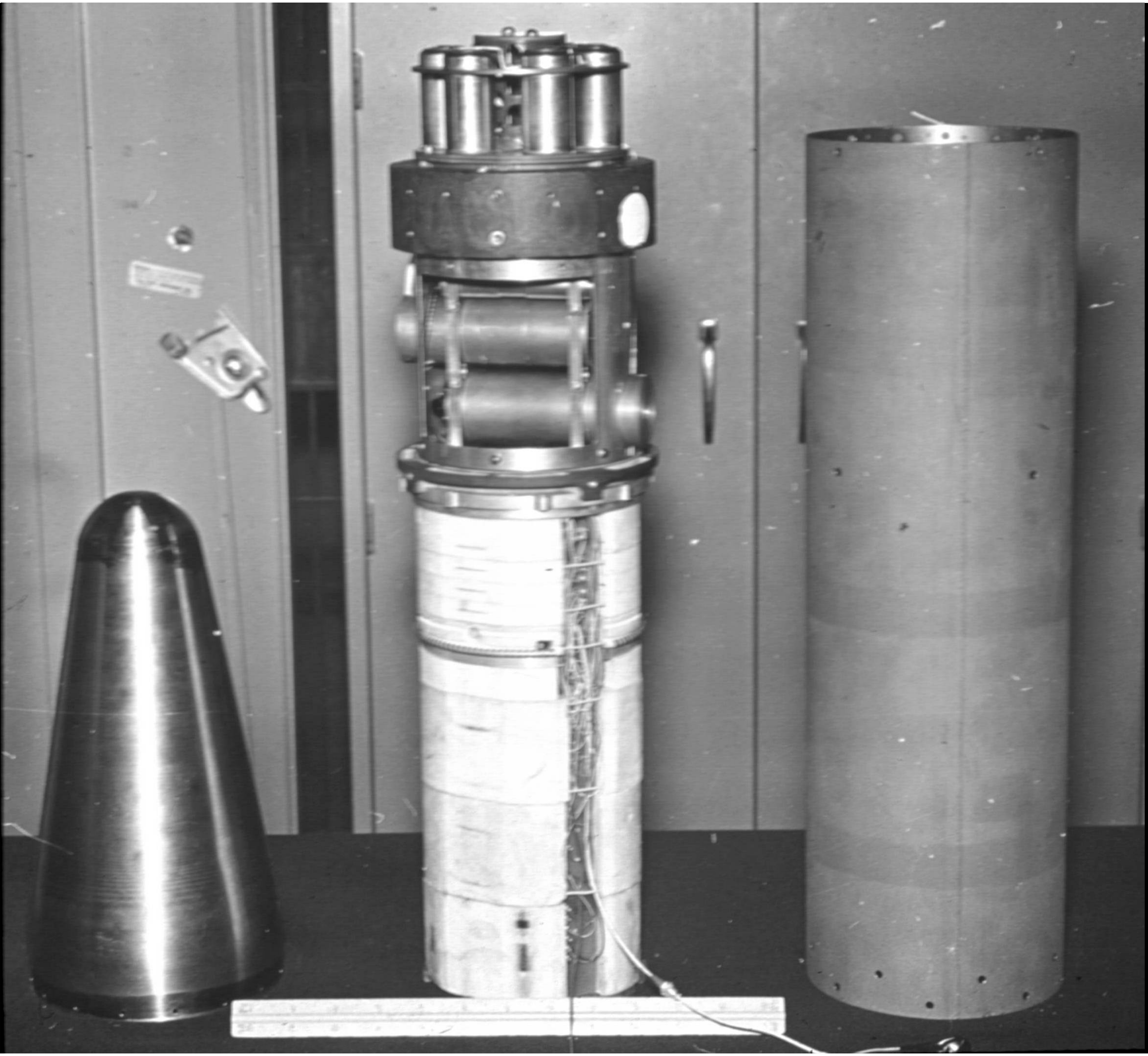


[redacted]

SATELLITE OBSERVATIONS OF ELECTRONS ARTIFICIALLY INJECTED INTO THE GEOMAGNETIC FIELD

By James A. Van Allen, Carl E. McIlwain, and George H. Ludwig

DEPARTMENT OF PHYSICS, STATE UNIVERSITY OF IOWA

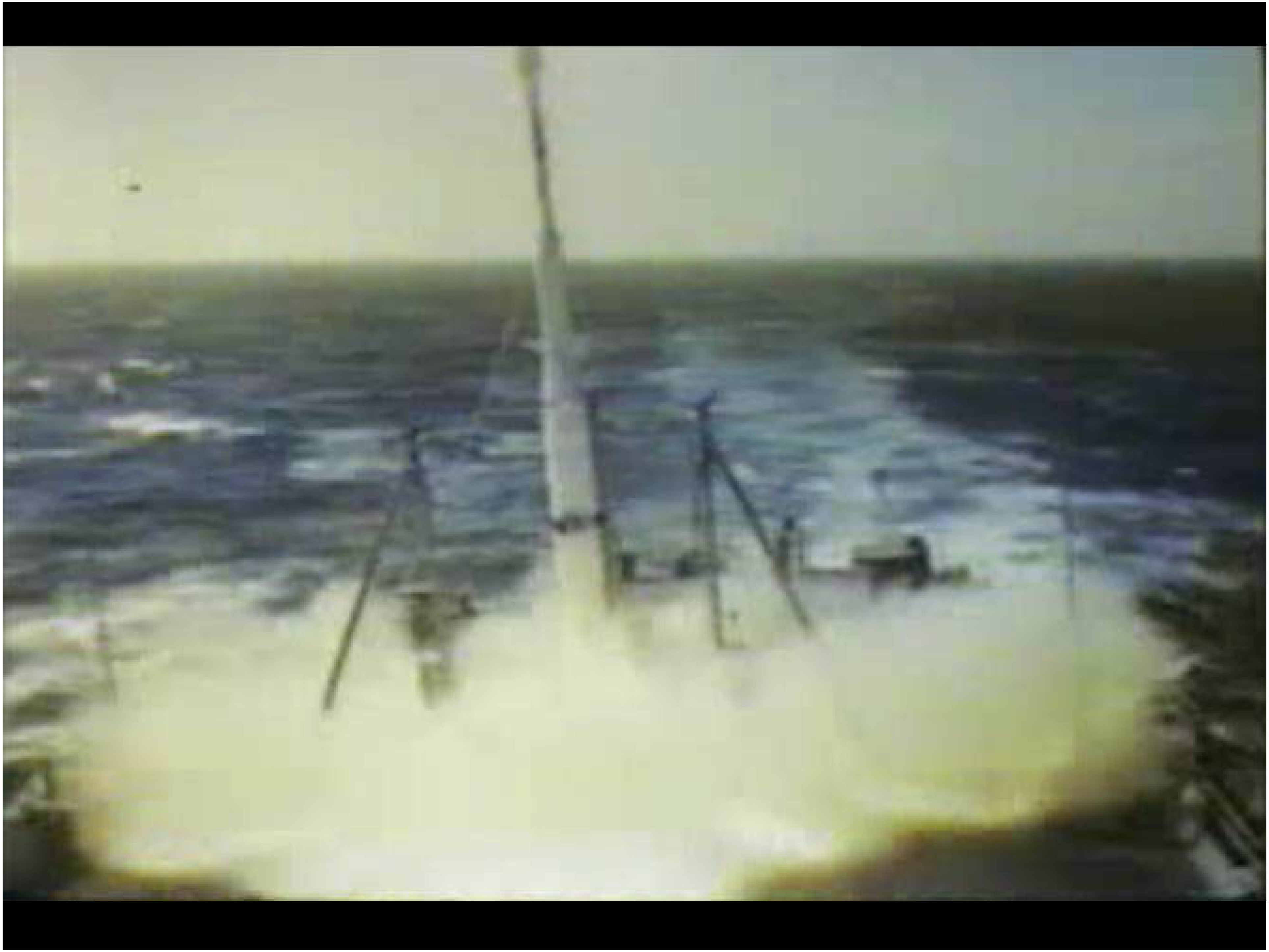
Following our discovery with Explorer I (Satellite 1958 Alpha) and with Explorer III (Satellite 1958 Gamma) that there were very great intensities of charged particles trapped in the geomagnetic field,[1] we undertook to make arrangements for a further satellite flight of equipment of greater discrimination and much greater

[redacted]

dynamic range for the purpose of detailed study of the properties of the radiation and of its spatial distribution. The progress of such arrangements was greatly aided by Richard W. Porter, chairman of the Technical Panel for the Earth Satellite Program of the U.S. National Committee for the International Geophysical Year, and by Herbert York, then chief scientist of the Advanced Research Projects Agency of the Department of Defense.

In October, 1957, Nicholas C. Christofilos of the Lawrence Radiation Laboratories of the University of California at Livermore had proposed in an unpublished memorandum that many observable geophysical effects could be produced by an atomic detonation at high altitude above the earth in the tenuous upper atmosphere. Of the various effects contemplated one of the most interesting promised to be the temporary trapping of high energy electrons at high altitudes in the geomagnetic field. Such electrons result from the radioactive decay of fission fragments and, less importantly, of neutrons.

A subsequently organized study group carried out more detailed estimates of the various effects to be expected and concluded that the proposed experiments (later named "Argus" experiments) were indeed feasible. This study group, led by W. K. H. Panofsky, also concluded that satellite observations would be of great value.



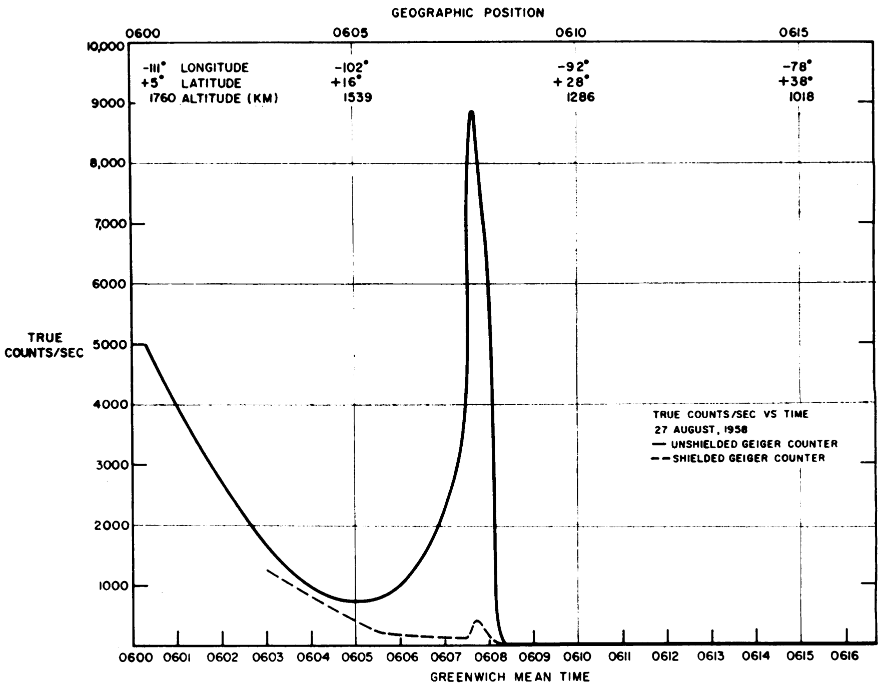


FIG. 7.—Same data as on Figure 6, plotted with a linear scale of ordinates.

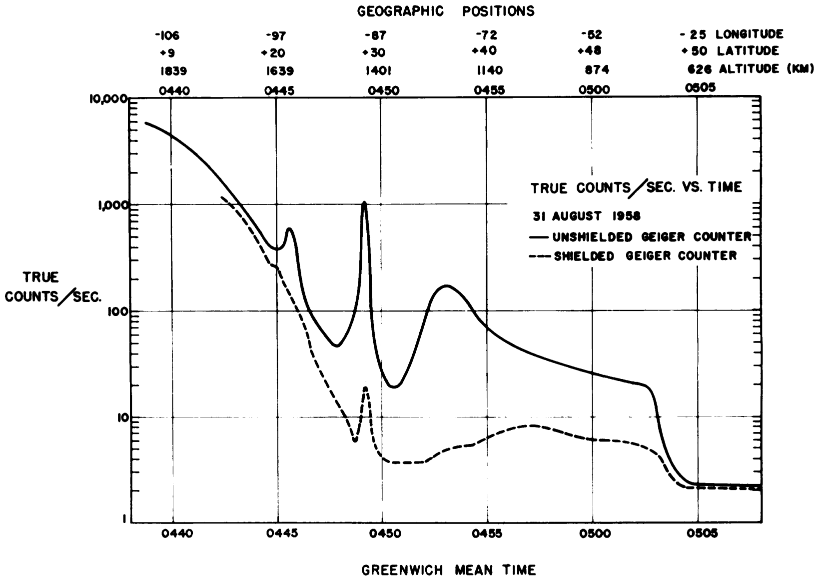


Fig. 8.—A plot of radiation observations on August 31, 1958 showing the decaying Argus I peak (at 0446 U.T.) and the fresh Argus II peak (at 0449 U.T.).

[redacted]

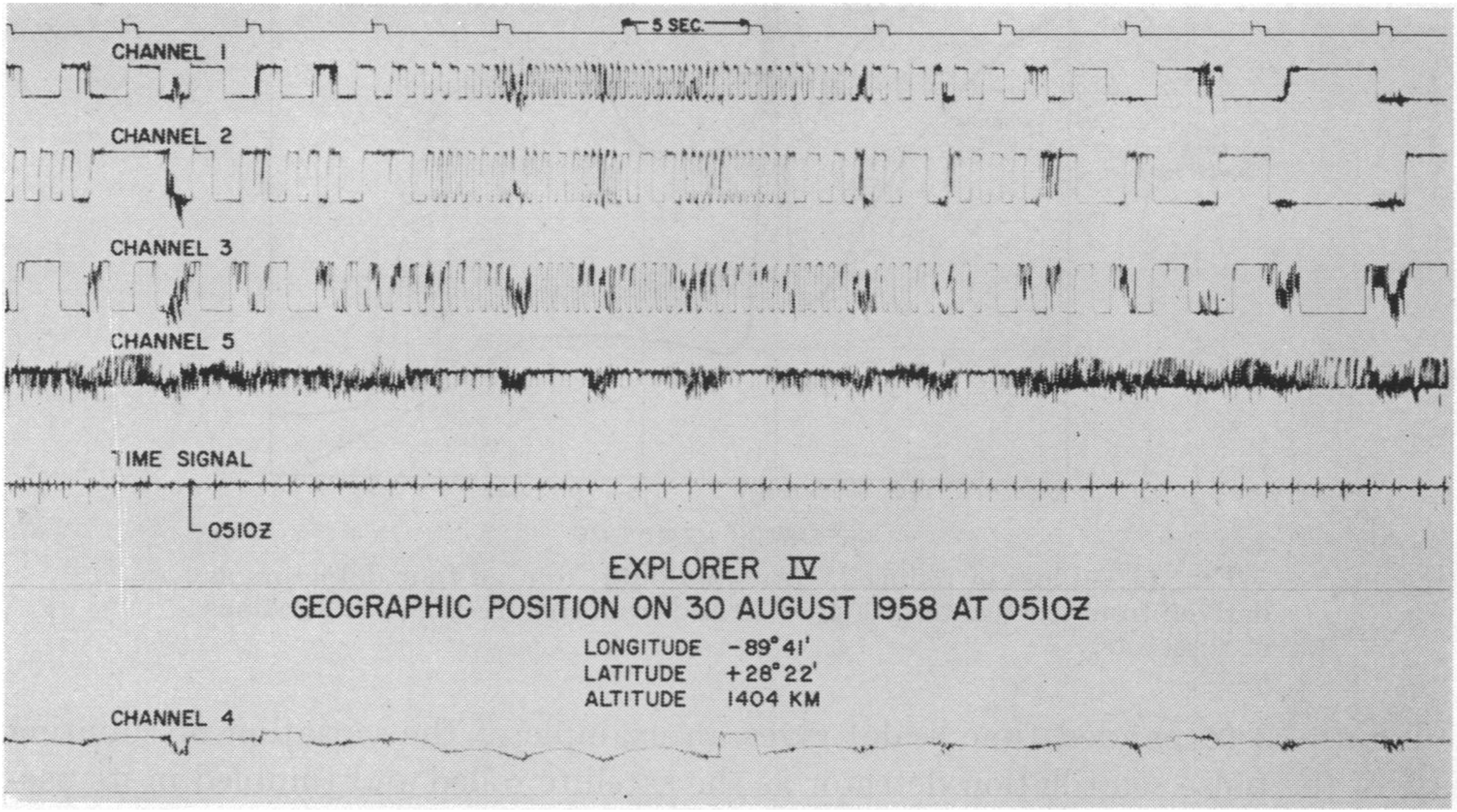


FIG. 10.—Photograph of raw telemetry record (Offner pen-and-ink recorder) of a pass through the Argus II shell on August 30, 1958.

gus III. Figure 10 is a photograph of a raw telemetry record of the passage of Explorer IV through the Argus II shell and Figure 11 gives plots of the reduced, corrected data from all four detectors. These two figures exemplify the data reduction

As mentioned earlier, the various observations occurred at a great variety of positions in space. And, of course, the irregular nature of the geomagnetic field produces essential complications. The foundations for organizing the data are indicated in Figure 13. By the basic Poincare-Stoermer-Alfven theory of the trapping of charged particles in the geomagnetic field the magnetic moment of a spiraling particle is an adiabatic invariant of the motion. That is

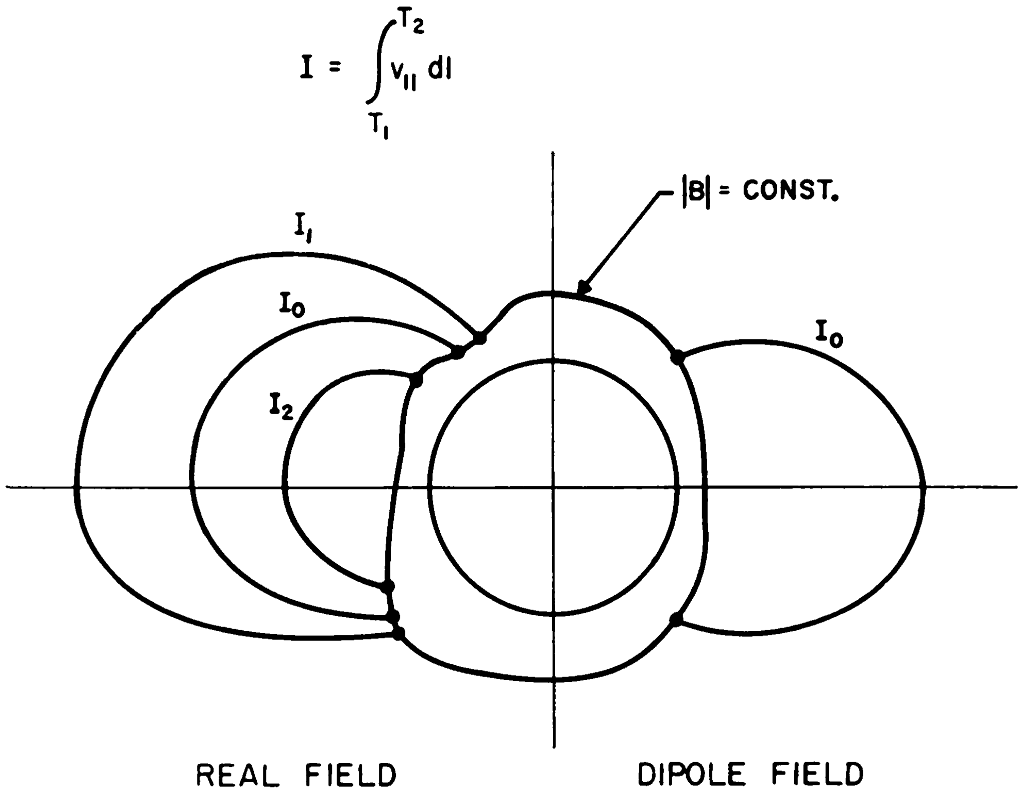


FIG. 13.—A diagram to illustrate the principles of conservation of μ and I in geomagnetic trapping. (See text.)

$$\mu = \frac{{}^1\!/_2\, m\, v_{\perp}{}^2}{B} = \text{constant}$$

[redacted]

Also, as first conjectured by Rosenbluth and Longmire[3] and later discussed in detail by others, the line integral along a line of force between turning points for a given particle:

$$I = \int_{\tau_1}^{\tau_2} v_{||}\, dl = v \int_{\tau_1}^{\tau_2} \sqrt{1 - B/B_\tau}\, dl$$

is an adiabatic invariant (under an important class of physical conditions) of its motion, where B_τ is the scalar value of B at the turning points τ_1 and τ_2.

This latter principle makes possible the identification of a unique sequence of magnetic lines of force which constitute a single valued, three-dimensional surface on which the guiding center of the particle will forever lie—to the extent that the conditions for the conservation of μ and I are met—as it moves about in the irregular geomagnetic field. The argument is illustrated in Figure 13. Let the surface $B =$ const. shown there represent the locus of turning points for a particle having a given

[redacted]

These results, of course, provide a quantitative validation of the principle of conservation of I in the geomagnetic field.

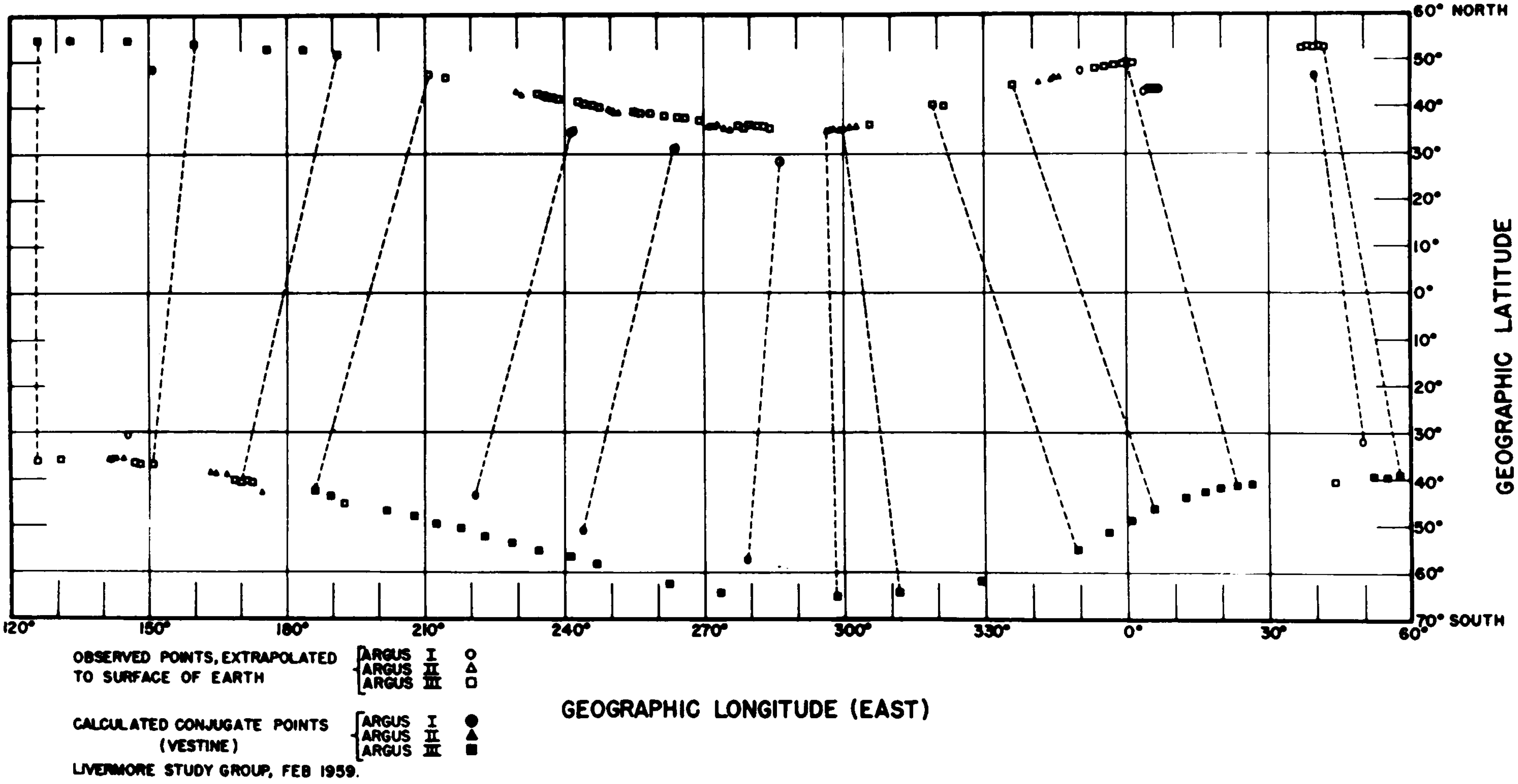
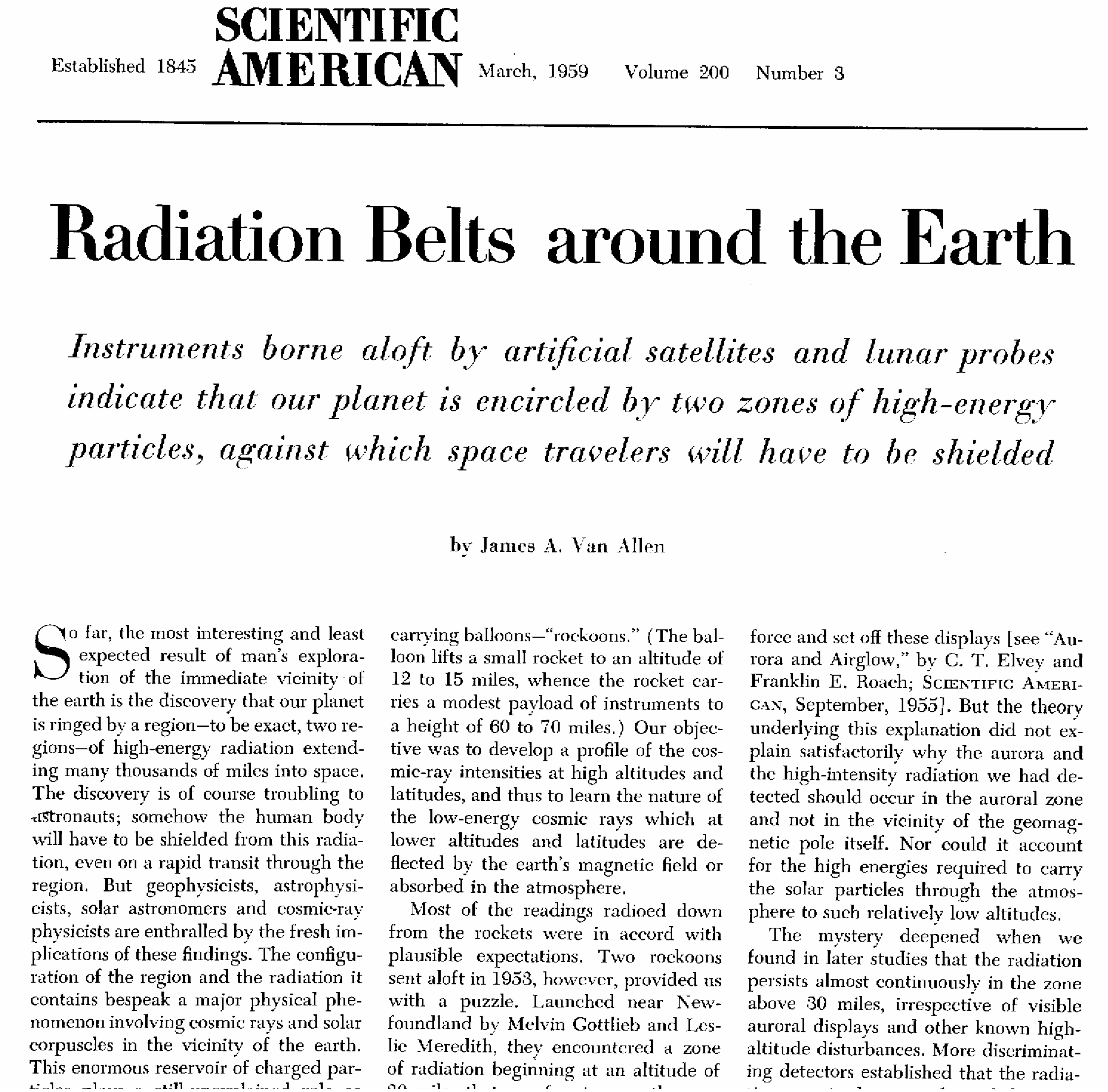


Fig. 14.—Plot of (extrapolated) observed intersections of Argus shells" I, II and III with surface of the earth, and computed conjugate points (after Vestine and Pennington). (Livermore study group.)



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Radiation Belts around the Earth

Instruments borne aloft by artificial satellites and lunar probes indicate that our planet is encircled by two zones of high-energy particles, against which space travelers will have to be shielded

by James A. Van Allen

So far, the most interesting and least expected result of man's exploration of the immediate vicinity of the earth is the discovery that our planet is ringed by a region—to be exact, two regions—of high-energy radiation extending many thousands of miles into space. The discovery is of course troubling to astronauts; somehow the human body will have to be shielded from this radiation, even on a rapid transit through the region. But geophysicists, astrophysicists, solar astronomers and cosmic-ray physicists are enthralled by the fresh implications of these findings. The configuration of the region and the radiation it contains bespeak a major physical phenomenon involving cosmic rays and solar corpuscles in the vicinity of the earth. This enormous reservoir of charged par-

carrying balloons—"rockoons." (The balloon lifts a small rocket to an altitude of 12 to 15 miles, whence the rocket carries a modest payload of instruments to a height of 60 to 70 miles.) Our objective was to develop a profile of the cosmic-ray intensities at high altitudes and latitudes, and thus to learn the nature of the low-energy cosmic rays which at lower altitudes and latitudes are deflected by the earth's magnetic field or absorbed in the atmosphere.

Most of the readings radioed down from the rockets were in accord with plausible expectations. Two rockoons sent aloft in 1953, however, provided us with a puzzle. Launched near Newfoundland by Melvin Gottlieb and Leslie Meredith, they encountered a zone of radiation beginning at an altitude of

force and set off these displays [see "Aurora and Airglow," by C. T. Elvey and Franklin E. Roach; SCIENTIFIC AMERICAN, September, 1955]. But the theory underlying this explanation did not explain satisfactorily why the aurora and the high-intensity radiation we had detected should occur in the auroral zone and not in the vicinity of the geomagnetic pole itself. Nor could it account for the high energies required to carry the solar particles through the atmosphere to such relatively low altitudes.

The mystery deepened when we found in later studies that the radiation persists almost continuously in the zone above 30 miles, irrespective of visible auroral displays and other known high-altitude disturbances. More discriminating detectors established that the radia-


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