

CORRELATION OF INDIVIDUAL COSMIC RAY NUCLEI WITH
THE OBSERVATION OF LIGHT FLASHES
BY APOLLO ASTRONAUTS

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A nuclear emulsion detector known as the Apollo Light Flash Moving Emulsion Detector (ALFMED) was designed: 1) to record tracks of primary cosmic rays; 2) to provide time-of-passage information via a relative plate translation technique; 3) to provide particle trajectory information; and, 4) to fit into a masklike device that could be located about the head and eyes of an astronaut. An ALFMED device was worn by an astronaut observing light flashes for 60 minutes on each of the last two Apollo missions. During the Apollo 17 experiment seventeen separate flashes were reported by the observer. With one-third of the total plate area completely analyzed, two definite correlations have been found between $Z > 8$ cosmic ray nuclei traversing an eye and the reports of visual sensations.

1. Introduction. The observation of flashes of light in space was first reported during the post-mission debriefing of the Apollo 11 crew. These reports led to formal light flash observing sessions on the subsequent Apollo and Skylab missions. Analyses of the subjective data from these sessions⁽¹⁾ has led to the following conclusions about the phenomena: 1) the observer must be reasonably well dark adapted (e.g. ~ 10 minutes in total darkness) before he is able to observe any flashes; 2) the frequency of occurrence of flashes varies from observer to observer and can even vary with a single observer at different times in the same external physical environment; 3) the flashes come in several distinct types, the most prevalent of which have been given the generic names of "spot", "streak", and "cloud"; and, 4) from Skylab observations in earth orbit, there is a strong correlation between the variation in the flash rate and the geomagnetic modulation of the primary cosmic ray flux seen by the spacecraft during the highly inclined orbits.

Prompted by the earlier observations in space and by those made at accelerators⁽²⁾, the present experiment was undertaken to look for direct correlations between reported visual sensations and individual cosmic ray

nuclei ($Z \geq 10$) which passed through at least one of the observer's eyes. With this objective in mind, a nuclear emulsion detector known as the Apollo Light Flash Moving Emulsion Detector (ALFMED) was designed: 1) to record the tracks of cosmic ray nuclei; 2) to provide time of passage information via a relative plate translation technique; 3) to provide particle trajectory information; and, 4) to fit into a masklike device that could be located about the head and eyes of an astronaut.

2. Technique. The relative plate translation technique employed in ALFMED is depicted in Figure 1. The plates are arranged in pairs, one of them

being fixed with respect to the head and eyes of the observer, and the second is normally stored in the reference position but made to translate at a uniform rate relative to the fixed plate during the observing session as indicated in Figure 1. Because of the large flux of incident particles before and after the session, (e.g., on a typical mission only ~1% of the tracks will be from the session), the design included a provision for rapid spring return of the moving plates to their reference position upon conclusion of the translation.

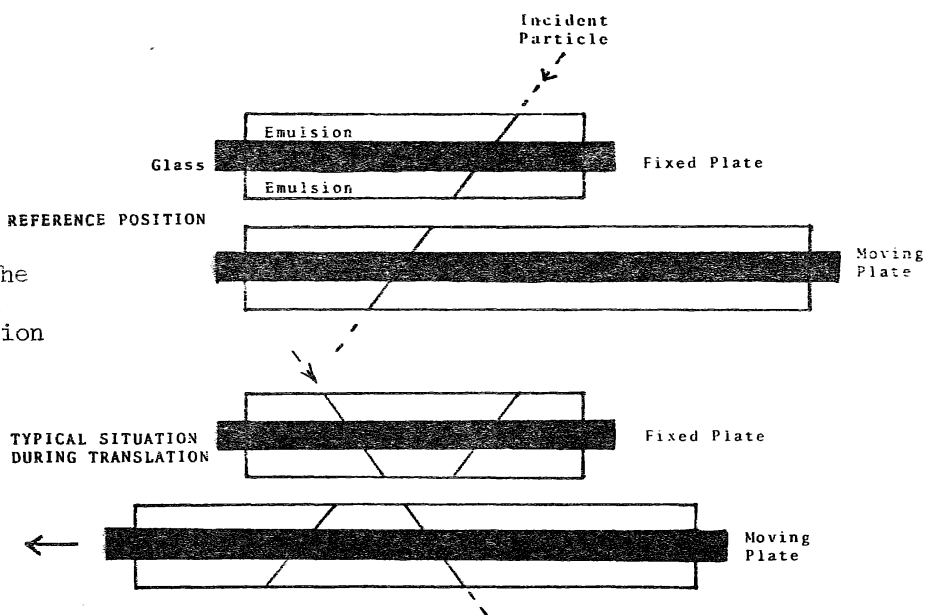


Fig. 1. Schematic of ALFMED operation.

Particles that pass through the detector while it is translating leave tracks in the emulsions such that the track segments can be realigned

only when the emulsion parts are placed in the proper relative orientation. Since the uniform translation rate is known, the displacement distance from the reference position is a measure of the elapsed time of occurrence after the translation started. The ALFMED translation rate was 10 $\mu\text{m}/\text{sec}$. This gives a total observing duration of 1 hour with the 3.6 cm maximum plate travel that is available. As shown in Figure 2, the fixed plates

were arranged with one rectangular plate directly in front of the face and eyes and a parallelogram-shaped plate extending along each side of the head to a point near the back of the ear. The moving plates were mounted outside of, and parallel to, the fixed plates on a set of precision slides that were free to translate vertically. The reference position was chosen with the overhang of the moving plates extending downward, and with the plate translation direction upward

relative to the head. The slide was driven by a 440 cycle AC synchronous motor reduced through an harmonic drive and simple sprocket gears to obtain the proper translation rate. The final mechanical coupling to the slide was through a precision recirculating ball lead screw. The deviation in translation rate from the nominal uniform value is primarily a function of fluctuations in the line frequency from the spacecraft power supplies. The frequency was constantly monitored during the observing sessions and varied by less than 0.02%. (This amounts to a maximum of about 0.7 second error near the end of plate translation).

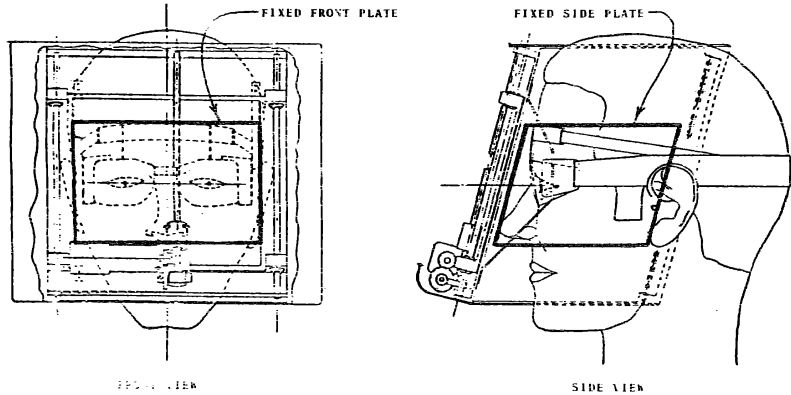


Fig. 2. Diagram of ALFMED to illustrate plate locations.

Accurate trajectory information is obtained by coating both sides of each plate with nuclear emulsion. Even though the emulsion volume is distorted during processing, the bond between the emulsion and the glass surface on either side of a plate is very stable. Thus one can use the track positions at the emulsion-glass surfaces as two stable points from which to reconstruct the original trajectory. The glass plates were polished on both surfaces to optical quality flatness; however, in practice the two flat surfaces were not parallel. This proved to be only a minor inconvenience.

Charge measurements and direction of propagation information can be obtained by examining the track structure and properties of each event. The fixed plates were coated on each surface with 200 μm thick Eastman Kodak NTB-3 nuclear emulsion, and the moving plates had 50 μm on each surface. (The Apollo 16 flight unit employed plates with 200 μm of emulsion on all surfaces).

The entire instrument is contained in a masklike device that serves both as a light tight enclosure and a mounting frame for the head attachment apparatus. The unit has a spectacle type nose bridge and a contoured forehead for attachment points to the head of the observer. The unit is held in place with several sets of velcro faded elastic straps which can be adjusted to maintain firm pressure on the attachment points. Experience in zero-G aircraft indicates that the unit stays well positioned in a weightless environment, even with violent head motions. The outside of the ALFMED case has photographic target decals to allow accurate head positioning information to be obtained from "in-use" photographs. (The units were photographed on the observer from several perspectives both before and after each of the sessions). From pre-mission crew fitting measurements, and post-mission photographic analysis, we have estimated the maximum uncertainty in the position of any point on the retina is $\sim \pm 2$ mm.

The head attachment apparatus also serves as a blindfold. Soft contoured rubber foam seals prevent external light from reaching the eye, and are located so as to avoid any pressure on the eyeballs. While wearing the ALFMED, the observer is completely free to open and shut his eyes.

The lower inside front surface of the external housing mounts the power connector, the drive engage clutch lever, and the on-off switch. After the power is connected, the observer engages the clutch lever and moves the on-off switch to on while simultaneously saying "mark" to signal the start of translation. The observer wears the standard Apollo Lightweight Communication Headset, which is compatible with the ALFMED head attachment apparatus. During the observing period, the observer reports events by first saying "mark" to provide a time check and then proceeds to describe the event. The verbal responses are both recorded onboard and simultaneously transmitted real-time to ground stations via the down-link radio. At the termination of the observing session, the

on-off switch is moved to off, and another verbal "mark" is used to denote this action. The clutch is then disengaged which releases the slide and allows it to return under spring tension to the reference position, where it is locked in place.

The ALFMED adds a total of slightly less than 1 gm/cm^2 of material (Al, glass, emulsion) for a normally incident particle.

3. Data Analysis Procedure. Each set of plates was mounted on a manually encoded microscope stage in the reference position and scanned with a stereomicroscope. The volume between the plates was filled with immersion oil to aid in visibility through to the bottom surface. During this step, tracks were searched for in the fixed plate that did not have counterparts in the moving plate in the reference position, and which had trajectories favoring passage through the eyes. (The requirement for dark adaption localizes the phenomena to the retina!) The second step was to accurately measure the track trajectories of the fixed plate candidate from step one using the Automated Microscope Image Dissector⁽³⁾ (AMID) microscope measuring system. Those candidates whose trajectories were found to definitely pass through an eye were then projected onto the moving plate and a search along the translation line was made for the counterparts. Positive identification can be made by accurately measuring the trajectory space angles of moving plate candidates and comparison with those from the fixed plate tracks. Finally, the charges of the final list of events are estimated.⁽⁴⁾

The total error in the translation distance measurement for the worst case event is currently $\pm 20 \mu\text{m}$. Thus, at present, the maximum error in event times (i.e., those occurring in the largest translations) is slightly greater than ± 2 seconds. Current plans to remeasure the tracks on a microscope with a stage movement capability allowing entire plates to be examined without repositioning promise to reduce these errors by a factor of 2. Even with the current errors, the probability of more than one accidental correlation is small because (for Apollo 17) there were only 17 flashes reported in 50 minutes of dark adapted observing time, during which fewer than 50 potential candidate events occurred. Some fraction of these candidates are certainly below observation threshold in charge, velocity or dE/dx ⁽⁵⁾. These figures are for the Apollo 17 session.

4. Results. This paper is intended primarily to discuss the techniques employed in the experiment and the results obtained to date will be reported elsewhere in detail. Briefly, however, the Apollo 17 plates have been analyzed before the Apollo 16 plates because of extremely high background levels encountered on Apollo 16. The Apollo 17 front plates have been completed and the side plates are nearing completion. From the front plates we have two correlations with the verbal reports (i.e., within the time errors). An estimate based on geometry and Monte Carlo calculations indicates that we should expect four correlations in the

front plates and three in each of the side plates. We believe our total scanning efficiency probably can be improved by a rescan, and see no discrepancy between our predictions and our measurements.

5. Conclusions. The ALFMED was developed to correlate the observation of flashes seen in space with physical records of the passage of cosmic ray nuclei through the eyes of the observer. It has satisfied that requirement. Even though the potential uses for this device in the future are very limited, it may be worthwhile to point out that a modification has recently been proposed⁽⁷⁾ to facilitate any future use. This modification consists of using AgCl detectors⁽⁸⁾ in place of the nuclear emulsions. The switchable properties of the AgCl detectors will eliminate virtually all of the background and circumvent the most time consuming steps in this data analysis.

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7. References.

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