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CHAPTER 2
APOLLO LIGHT FLASH INVESTIGATIONS

by

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Introduction

Crewmembers of the Apollo 11 mission were the first astronauts to describe an unusual visual phenomenon associated with space flight. During transearth coast, both the Commander and the Lunar Module Pilot reported seeing faint spots or flashes of light when the cabin was dark and they had become dark-adapted. It is believed that these light flashes result from high energy, heavy cosmic rays penetrating the Command Module structure and the crewmembers' eyes. These particles are thought to be capable of producing visual sensations through interaction with the retina, either by direct deposition of ionization energy in the retina or through creation of visible light via the Cerenkov effect.

Crewmembers of Apollo 12 and 13 were questioned concerning this phenomenon during postmission debriefings. All reported the ability to "see" the flashes with relative ease when the spacecraft was dark with their eyes either open or shut. The Apollo 12 Commander stated that "There were big bright ones all over," and added that he had not seen anything similar during his two Earth-orbital Gemini missions. The Commander of the Apollo 13 mission also observed these flashes but could not remember seeing them during his earlier Apollo 8 mission.

The fact that the light flashes could be seen with eyes either open or closed suggests that the flash effect is produced by cosmic radiation penetrating the optical nervous system at some point. The fact that dark adaptation is necessary reinforces the view that the phenomenon is connected with the retina rather than with a direct stimulation of the optic nerve, since the biochemical changes associated with dark adaptation are localized in the retinal tissue.

Light Flash Observation Periods

The debriefing reports of crewmembers on the Apollo 11, 12, and 13 missions led to the establishment of dedicated observing sessions on all subsequent Apollo flights. Three separate one-hour sessions were programmed for Apollo 15 and two one-hour sessions for Apollo 16 and 17. Simple blindfolds, designed to avoid corneal pressure, were used to obtain and maintain a state of complete dark adaptation during the observing session. Crewmembers' comments and descriptions of each event were radioed to tracking stations and simultaneously recorded on tape in the spacecraft.

The flashes were generally described as white or colorless. The only exception was the report by the Apollo 14 Lunar Module Pilot who described a flash as "blue with a white cast, like a blue diamond." Three basic types of flashes were reported. The most prevalent was the "spot" or "starlike" flash, which also has been referred to as a "super nova." Sixty-six percent of the flashes were of this variety, described by the Apollo 15 Commander as resembling a photographic flashbulb that has been flashed across a dark arena, several hundred feet from the observer. The Apollo 14 LMP described the flash as being less clear than he had anticipated. "There still seemed to be at least two flashes, maybe a bright flash followed an instant later by a more subdued flash, or perhaps a halo-like effect - there does not seem to be a set pattern in each case. Sometimes it is a very clear single flash; at other times it seems to be followed by a halo. Sometimes it seems followed by an adjacent flash." On occasion, stars were reported in pairs, either both in the same eye or one star in each eye.

The type of flash described as a "streak" was the second most abundant, occurring about 25 percent of the time. Some streaks were described as sharp lines, while others appeared to be diffuse. Still others were reported as dashed lines, with the most common version consisting of two principal segments with a gap in the middle. All streaks had a sense of movement, appearing to be "going from left to right" or "coming straight at me." It has been hypothesized that these streaks were caused by particles with trajectories approximately tangent to the retina, and their apparent motion was due to either eye movement or the shape of the streak.

The final type of flash was referred to as a "cloud" and occurred in eight percent of the cases. Clouds were flashes with no discernible shape and always appeared in the peripheral visual field. The Apollo 14 Command Module Pilot described the clouds as resembling a lightning discharge when viewed from behind terrestrial clouds in the distance. Some of the cloud flashes were so large as to appear to fill the entire periphery, while leaving the central visual field dark.

The number of events of each type seen by each observer in individual one-hour sessions is shown in table 1. This table also presents the elapsed time in minutes from the start of dark adaptation to the observation of the first event for sessions where that time is known. This elapsed time, that is until the first flash was seen, averages to 19.3 minutes, compared with an average event rate after dark adaptation of one event every 2.9 minutes.

Analyses of the elapsed time between events for a particular observer, and between events for any observer, both indicate that the events seen during each one-hour session were randomly distributed in time. Further, there does not appear to be a significant preference for one eye or the other, either for a single event or for all events taken together.

Table 1

Summary of Light Flash Events Observed During Apollo Dedicated Sessions
(The tapes containing detailed descriptions of events observed
on the Apollo 15 translunar coast were lost during playback to the ground.)

Phase of Flight	Crewman	Length of Session (min)	Time to First Event (min)	Number of Events				
				Total	Streak	Star	Cloud	Mixture
				Apollo 14				
TEC	CMP	47	29	12	2	8	1	1
	LMP	47	17	22	5	13	3	1
	CDR	47	18	14	3	8	1	2
				Apollo 15				
TLC	CMP	60	10	22	–	–	–	–
	LMP	60	9	12	–	–	–	–
	CDR	60	10	25	–	–	–	–
LO	LMP	60	10	12	6	5	0	1
TEC	CMP	60	30	8	2	5	0	1
	LMP	60	26	9	3	5	0	1
	CDR	60	17	6	0	6	0	0
				Apollo 16				
TLC	LMP	60	†	47	7	36	2	2
	CDR	60	†	22	6	14	1	1
TEC	CMP	60		0	0	0	0	0
	LMP	60	‡	21§	1‖	4‖	2‖	1‖
	CDR	60	21	8	1‖	0	0	0
				Apollo 17				
TLC	CMP	60	15	17	5	10	1	1
	CDR	60*	39*	11	6	4	1	0
TEC	CMP	60						
	LMP	60						
	CDR	60						

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*A high phosphene level was reported during the first half of the session. †The crew were already dark-adapted and seeing flashes when the time session began. ‡The first seven flashes were not reported in real time; the elapsed time to the first event is not available but is probably about 15 minutes. §The total includes those not reported in real time. ‖Complete event descriptions were not available.

LO = Lunar orbit
CMP = Command Module Pilot
LMP = Lunar Module Pilot
CDR = Commander
TEC = Transearth coast
TLC = Translunar coast

It can be noted in table 1 that no results are presented for the Command Module Pilot of the Apollo 16 mission. He was the only Apollo crewmember briefed to look for the phenomenon who failed to see it. He volunteered the information that he considers his night vision to be poor.

An interesting feature of the light flash phenomenon is shown in table 2. The data presented indicates the mean time between events after dark adaptation for each observer, and the average value for all observers for each session. Session averages were computed by weighting the individual values according to the corresponding dark-adapted observing times. It can be seen from the table that the average time between events was longer during transearth coast (TEC) (returning from the moon) observation periods than during translunar coast (TLC) sessions. TEC dark adaptation times (time to witness the first flash) also were considerably longer than those found during TLC sessions. In addition, most crewmembers commented that the flashes seemed not only less frequent during the TEC sessions but also much less brilliant. The most dramatic example of this difference occurred on Apollo 17, when all crewmen reported that no events were seen during the entire one-hour transearth coast session. During a similar translunar coast session, the two observing crewmen reported a total of 28 events.

Table 2

Mean Time Between Events After Dark Adaptation Times. No observing session was scheduled for the Apollo 14 translunar coast. No events were reported in the Apollo 17 transearth coast session. (See legend to Table 1 for abbreviations.)

Flight	Crewman	Translunar Coast Sessions		Transearth Coast Sessions	
		Mean Time Between Events (min)	Dark Adaptation Time (min)	Mean Time Between Events (min)	Dark Adaptation Time (min)
Apollo 14	CMP			1.64	29
	LMP			1.43	17
	CDR			2.23	18
	Average			1.71	21.3
Apollo 15	CMP	2.38	10	4.29	30
	LMP	4.64	9	4.25	26
	CDR	2.08	10	8.60	17
	Average	3.05	9.7	6.01	24.3
Apollo 16	LMP	1.28	–	2.50	–
	CDR	2.73	–	5.57	21
	Average	2.00	–	3.85	21.0
Apollo 17	CMP	2.81	15.0*	–	–
	CDR	2.10	–	–	–
	Average	2.59	15.0	–	–
All sessions combined		2.58	11.0†	2.91	22.6§

*Dark adaptation time available for the CMP only. †Averaged over four observers. §Averaged over seven observers.

A number of possible mechanisms were examined in an attempt to explain the decrease in flash events during TEC observing sessions. These included physical factors such as geomagnetic shielding effects from the Earth's magnetosheath tail, a relative difference in spacecraft shielding, and possible flux modulation due to solar activity. None of these mechanisms offered an adequate explanation. Crewmember variables such as fatigue or some visual impairment also were investigated. All crewmembers reported feeling well rested and alert for the TEC sessions and no basis was found to ascribe this phenomenon to a physiological change. It was suggested by the Apollo 16 Command Module Pilot that the extremely bright albedo light from the lunar surface as viewed from lunar orbit may have been sufficient to produce residual effects such as dark adaptation impairment for the TEC duration. This suggestion is currently being investigated independently. The anomaly remains as an apparently real effect for which no unique explanation has as yet been demonstrated.

Monte Carlo Simulations

A Monte Carlo simulation of the exposure of an astronaut to cosmic radiation during a mission was accomplished as a means of gaining additional insight into the light flash observations. The Monte Carlo calculation was done by tracing the fate of each of a large number of cosmic ray particles through the spacecraft-observer system to assess its effectiveness in causing a light flash. Physical variables used in this simulation included the charge, energy, and direction of motion of particles, as chosen from established cosmic ray charge and energy distributions and a random direction distribution. Also taken into account, as appropriate, were (1) solar modulation of the primary cosmic ray energy spectrum; (2) effects of the Earth's magnetic field, including specific dependence of cutoff rigidity upon particle momentum direction; and (3) shadowing of the primary cosmic rays by the Earth. Detailed models of spacecraft shielding presented to the cosmic ray beam also were included.

Physiological parameters used in the simulation were: (1) thickness of the sensitive region of the retina; (2) minimum projection of the sensitive region track segment on a plane tangent to the surface of the retina; and (3) minimum energy loss rate for the ionizing particles in the sensitive region. A water phantom was used as being a reasonable approximation of the geometry of the observer. Accumulated experience indicates that observer sensitivity to light flashes can vary by a factor of two; therefore it was not deemed necessary to incorporate the best available model of the human anatomy. Physiological parameters were adjusted, within boundaries dictated by light flash data obtained in accelerator experiments and by physical measurements of the retina, in order to achieve agreement between observed and predicted flash rates. This was done with and without the inclusion of Cerenkov radiation. Table 3 shows the values used for visual system parameters in the simulation and presents the predicted Monte Carlo flash rates.

The Monte Carlo calculations also resulted in predicted charge and energy spectra at the retina for particles believed to cause light flashes. The predicted charge spectrum is shown in table 4, which also includes the primary cosmic ray charge spectrum to facilitate comparisons. Inspection of the Apollo predictions shown in table 4 reveals that almost all of the Apollo light flashes probably were caused by particles with $Z \geqslant 12$, even though only approximately 25 percent of the $Z \geqslant 6$ primary cosmic rays have $Z \geqslant 12$. This can be understood by an inspection of table 5, which contains a summary of the predicted energy spectra for the effective particles. Only at very low energies (0 to 200 MeV/nucleon), that is near the end of their range, do members of the C and O group have an energy deposition rate large enough for them to cause light flashes.

Table 3

Monte Carlo Simulation Parameters and Flash Rate Comparisons

Visual System Parameters	
Effective retina thickness	50μm
Minimum projected track length inside retina with energy loss rate greater than minimum value	40μm
Minimum energy loss rate 370 MeV cm^2/gm or 37 keV/μ in water	
Apollo Flash Rates	
Maximum observed rate	0.8/min
TLC average rate	0.4/min
Monte Carlo rate without Cerenkov	0.7/min
Monte Carlo rate with Cerenkov	1.0/min

Table 4

Predicted Relative Fluxes at the Retina for Particles Believed to Cause Flash Response

Z	Primary Cosmic Radiation	Apollo	
		Monte Carlo No Cerenkov	Monte Carlo With Cerenkov
6– 8	.693	.150	.115
9	.025	.029	.022
10	.036	.036	.123
11	.043	.063	.134
12	.074	.100	.131
13–14	.043	.183	.140
15–21	.038	.226	.173
22–28	.047	.213	.163

Table 5

Predicted Relative Energy Spectra of Effective Particles at the Retina for Apollo

Energy Interval MeV/Nucleon	Primary CR	Charge Interval							
		No Cerenkov Radiation				With Cerenkov Radiation			
		6-8	9-14	15-21	22-28	6-8	9-14	15-21	22-28
0- 200	.05	1.0	.27	.05	.07	1.0	.11	.05	.07
200- 400	.11		.53	.08	.08		.21	.08	.08
400- 600	.11		.20	.09	.08		.10	.10	.09
600-1000	.18			.19	.13		.14	.18	.13
>1000	.55			.59	.64		.44	.59	.63

Finally, the Monte Carlo calculations were used to predict the number of $Z \geqslant 6$ and $Z \geqslant 12$ particles which should have passed through an observer's eyes during the Apollo 17 mission. This simulation predicts that, during the 60 minutes of an Apollo 17 observing session, a total of approximately 640 $Z \geqslant 6$ primary cosmic rays (and spallation secondaries) would pass through the eyes, as would approximately 130 $Z \geqslant 12$ particles.

ALFMED Experiment

A system was developed for the Apollo 16 and 17 missions to obtain, for the first time, a direct physical record of incident cosmic ray particles which would allow correlation with crewmembers' reports of light flashes. The measurement system is known as the Apollo Light Flash Moving Emulsion Detector (ALFMED).

The ALFMED was an electromechanical helmet-like device that supported cosmic radiation-sensitive emulsions around the head of the test subject (figures 1 to 3). A direct physical record was provided of cosmic ray particles that passed through the emulsion plates and, in turn, through the head of the subject. The ALFMED contained two sets of glass plates coated on both sides with nuclear emulsion and supported in a protective framework. One set of plates was fixed in position within the headset and surrounded the front and sides of the head. A second similar set of plates was located exterior and parallel to the inner fixed plates and could be translated at a constant rate (10μ/sec) with respect to the fixed plates, thereby providing a time resolution for events to within one second. The total translation time available was 60 minutes, after which the moving plates could be returned to the original or reference orientation.

The postflight analysis of the ALFMED plates proceeded through the following steps:

1. *Location scan* – The fixed plate was placed on a special microscope stage containing the moving plate and positioned in the reference orientation (i.e., the relative orientation of the plates during stowage). The fixed plate was then scanned for tracks directed toward at least one eye, and the counterpart of each such track was sought in the moving plate. The absence of an aligned counterpart indicated that the track was a candidate (i.e., a track that originated while the plates were moving).

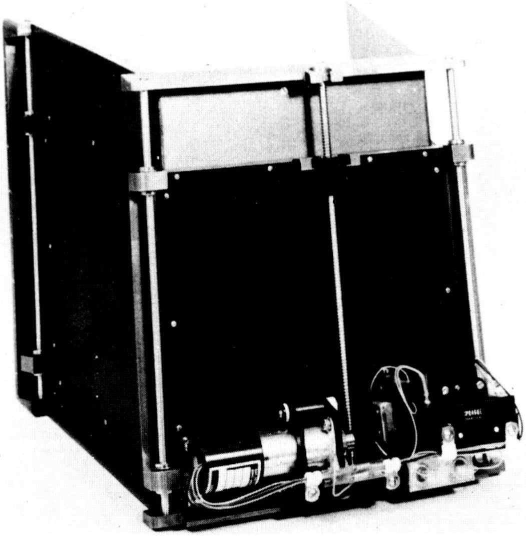

Figure 1. Exterior view of Apollo light flash moving emulsion detector (ALFMED) with outer cover removed.

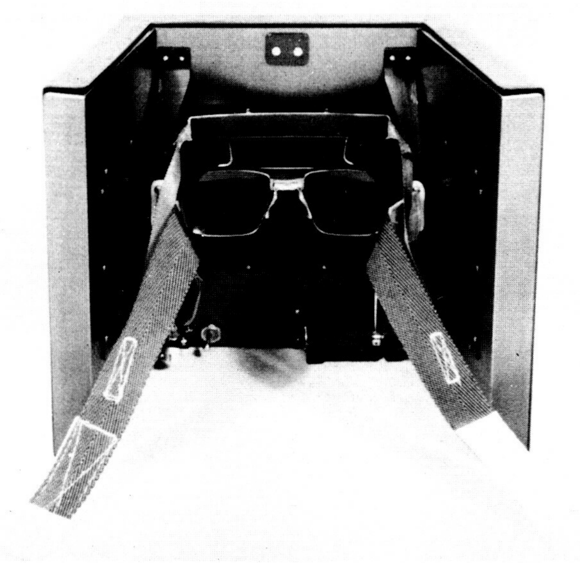

Figure 2. Interior view of ALFMED device.

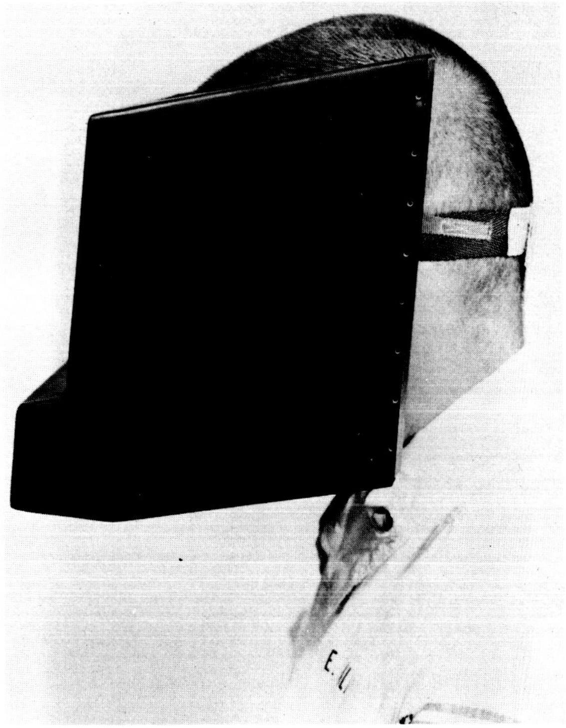

Figure 3. Subject wearing ALFMED device.

2. *Trajectory measurement* – The direction of the track was measured, and the subsequent trajectory through the head was predicted.

3. *Translation scan* – For all the candidate events located in the first step, a scan of the moving plate along the line of translation was made to locate the counterpart track. A measurement of the translation distance for each event was also made, yielding the time of occurrence of the event.

4. *Correlation with observations* – The list of events was compared with the observations reported by the crewmen in an attempt to determine if cosmic rays did in fact cause the phenomenon; if there was an apparent charge, energy, or linear energy transfer (LET) threshold; or if some particular event types correlated with certain particle types (e.g., streaks caused by tracks tangent to the retina, etc.).

5. *Charge and energy measurement* – Particles passing through the emulsion (Eastman Kodak NTB-3) left latent images which were developed in the same fashion as the latent images on normal photographic film due to exposure to light. Some of the secondary electrons (δ-rays) produced by the passage of the particle through the emulsion have sufficient range to leave small tracks of their own. A detailed analysis of the density

of these secondary tracks over the entire available track length in the emulsion could yield charge measurements with an uncertainty of $Z = \pm 1$. For kinetic energies/nucleon in the interval $50 \text{ MeV/nuc} \leqslant E \leqslant 300 \text{ MeV/nuc}$, the analysis could also yield a measurement of the kinetic energy.

Apollo 16 and Apollo 17 ALFMED Results

The ALFMED film plates for the Apollo 16 mission were processed immediately following the flight and examined extensively at that time. The ALFMED fixed plates used for the flight had 200 μm-thick emulsion on both surfaces while the moving plates had 50 μm-thick emulsions. Thus the total emulsion thickness was approximately 500 μm. This, coupled with the extremely high particle flux experienced during the Apollo 16 mission (the highest for any of the Apollo missions), made it quite difficult to scan the plates as originally planned. It was therefore decided that, due to the delays involved, it would be advantageous to proceed with the Apollo 17 analysis first. Experience gained during Apollo 17 analysis procedures then might be used to improve Apollo 16 analysis techniques.

As a result of the difficulties in scanning the Apollo 16 plates, the Apollo 17 plates were flown with 50 μm-thick layers on both sides, giving a total emulsion thickness of 200 μm. This greatly improved track detectability.

Analysis of the Apollo 17 plates yielded a total of 2360 individual tracks with directions that appeared approximately correct for passage through the eye of the astronaut. Of these tracks, 483 did not initially appear to have positional counterparts in the moving plates. These particles were all considered candidates for events which occurred during the period of observation and while the moving plates were displaced from their reference orientation.

Of the 483 tracks, 229 were in the front plate. Detailed trajectory measurements on the 229 front plate candidates revealed that 65 of that number passed through one eye or the other (or both). (Since the front plate was scanned first in each analysis step, the efficiencies for the various steps were probably somewhat less than those for the side plates.) Upon careful inspection, 50 of the 65 eye-directed tracks were found to have alined counterparts in the moving plate for the reference orientation, thereby reducing the front-plate sample to 15 genuine candidates.

The Monte Carlo calculations predict that one should expect approximately 30 $Z \geqslant 12$ candidate tracks in the front plate which originated during the translation period. The current number of 15 candidates indicates that most probably the first-scan efficiency for such tracks is roughly 50 percent. We consider it unlikely that any $Z \leqslant 8$ events are included in this first-scan sample, but experience leads us to believe that a rescan will result in a considerably improved efficiency, especially for the smaller charges.

Two of the 15 genuine candidates were found to coincide, to within five sconds, with reported flash observations. It is anticipated that after final measurements are made, the coincidences can be determined to accuracies of one or two seconds.

The first coincidence is with the fifth light flash reported, and occurred some 1465 seconds after the plate translation began. It was described as "just a spot" in the left eye. The candidate particle traversed the left side of the left eye, moving upward and slightly to the right, and passed almost tangent to the retina. Detailed charge and energy measurements have not yet been completed; however, the particle was almost certainly heavier than oxygen.

The second coincidence is with the eleventh event reported, and it occurred after 2368 seconds of plate translation. The light flash was described as a glow, "about one eighth of an inch in diameter", and appeared to be three-fourths of the way out from the center to the edge of the visual field at about 10:00 o'clock in the right eye.

The second candidate trajectory passed through the right side of the right eye, heading from the front left to the right rear, and slightly upward. A rough estimate of its location as it would appear to the observer places it in the periphery at approximately the proper distance, but at 8:30 or 9:00 o'clock, rather than at 10:00 o'clock as reported. Eye movement at the time of observation might account for this minor discrepancy. This particle is also most probably heavier than oxygen.

Summary and Conclusions

In summary, available results are consistent with expectations based upon geometrical considerations and upon the Monte Carlo calculations. First, evidence shows that, at least in part, the flashes seen by astronauts are correlated with charged particles traversing the retina. Further, since the flux of these particles is sufficient to explain the entire phenomenon, it is likely that all of the flashes originate in this manner. From our sample of two coincidences, we find no contradiction with the ability of the observer to discern in which eye the event occurred. Finally, the ALFMED technique has been demonstrated to be effective as a procedure for study of the light flash phenomenon.

References

Benson, R.E.; and Pinsky, L.S.: Biomedical Experiments: Part C. Visual Light Flash Phenomenon. In Apollo 16 Preliminary Science Report. NASA SP-315, 1972.

Pinsky, L.S.; Osborne, W. Z.; and Bailey, J.V.: Visual Light Flash Phenomenon. In Apollo 17 Preliminary Science Report. NASA SP-330, 1973.

Pinsky, L.S.; Osborne, W.Z.; Bailey, J.V.; Benson, R.E.; and Thompson, L.F.: Light Flashes Observed by Astronauts on Apollo 11 through Apollo 17. Science, vol. 183, 1974, pp. 957-959.