From the Current Literature

Visual observation of cosmic rays

M. A. Gintzburg
Usp. Fiz. Nauk **109**, 411-413 (February, 1973)

During the flight of the spaceship Apollo 11, the astronaut Aldrin observed flashes, with an approximate frequency of one per minute. He reported them to his companions and asked to verify his observations. Neil Armstrong and Michael Collins confirmed his result, and they have also seen "light spots," "lightnings," and sometimes "double points." The travelers in the later Apollo flights have also seen such flashes, even when their eyes were closed. The main cause of the flashes are cosmic rays penetrating through the hull of the ship and interacting with the pupil of the eye[1].

The possibility of this effect was indicated by Professor Tobias (University of California) 11 years before the Apollo flight. In a study of the radiation damage that can be incurred in space flight, he reached the conclusion that a man adapted to darkness can "see" strongly ionized trajectories in the form of small light flashes.

Comstock et al.[2] have observed in the plastic helms of the Apollo astronauts traces of cosmic rays. According to their estimate, during the two years that it would take to travel to Mars, an astronaut not provided with special shielding will have quite many vital cells damaged beyond recovery in this manner. The percentage of damaged and unrecovered cells is estimated at 0.12% in the cortex of the brain, 0.05% in the retina of the eye, and more than 1% in the central nervous system.

Similar experiments with artificial cosmic rays, i.e., ultrafast particles obtained with accelerators, were recently performed at the University of California by Professor Tobias and co-workers. A proton synchrotron was used to accelerate protons to 36 GeV.

Three scientists, the laboratory director and Nobel laureate MacMillan, the astronaut Philip Chapman, and Tobias, observe light flashes when they placed their heads in a stream of nitrogen ions. Flashes were observed only in positions such that the ion beam passed through the inner part of the retina. If the ion beam penetrated through the rear parts of the brain (where the perception of vision takes place), through the front part of the retina, or finally through a body glasslike object, no flashes were observed. It was therefore concluded that fast ions produce "lightnings" and flashes only when they interact directly with the retina and are furthermore at the end of their travel, when the ionization is maximal.

Even prior to these experiments, analogous flashes due to neutrons were observed by a number of experimenters (USA, England) who placed their heads in a neutron beam and have also seen "lightnings." The neutrons generated charged particles that acted on the retina.

The ion energies in outer space can be even higher than in laboratory accelerators. A fraction of the flashes is accordingly produced also by another mechanism, namely Cerenkov radiation of fast ions in the vitreous body of the eye (Jelley, Fazio, Chapman).

Cerenkov radiation can be observed only with very sensitive receivers, such as photomultipliers. But a darkness-adapted eye has under ideal conditions characteristics on a par with the best electronic devices.

The flash intensity is proportional to the square of the per-unit charge of the particle. This is precisely why no such visual flashes have been observed on earth. Outside the atmosphere, the cosmic rays consist of particles having a wide range of specific charge, viz., protons, alpha particles, and nuclei of carbon, oxygen, iron, and other elements. The heavy nuclei, however, do not reach the earth's surface, owing to absorption and decay in the atmosphere. The cosmic rays (usually secondary) at the earth's surface consist of small-charge particles such as electrons, muons, and a small number of protons. Their charge is small and therefore the Cerenkov radiation is weak, below the limit of the eye's sensitivity. Cerenkov counters are used, but in conjunction with photographic films.

In the early 60's, Porter and d'Arcy (Ireland) investigated the correlation between cosmic rays at the earth's surface and light flashes. The cosmic rays (mainly mesons) were registered with scintillation counters located below and above the observers. The observer went through darkness adaptation lasting not less than 30 minutes. Porter and d'Arcy reached the conclusion that the observed flashes could indeed be due to cosmic rays, but did not identify any concrete mechanism for such light flashes.

Their experiments were repeated by Chapman and Rowland. A statistical analysis has revealed a positive correlation between the cosmic rays and the light flashes: when the cosmic rays (muons) penetrated the observer's eye, flashes were seen.

When counters were placed over the visual center of the brain, no correlation was observed between the flashes and the cosmic rays. It was therefore concluded that the point of excitation is not the vision nerve center but the retina.

Cerenkov radiation is emitted in a cone along the particle motion direction. Were it to be generated in a vitreous body, then by looking at the cosmic rays straight on, an observer would see brighter flashes then if the eye were illuminated from the side. The experiment, however, revealed no such intensity difference, thus indicating direct action on the retina.

Another group (Tobias, Badinger, Lyman at Berkeley) to the contrary observed no flashes due to cosmic-ray muons, either on the earth's surface or at an altitude of 10 km (in airplanes). This group notes also that observers exposed to a positive muon beam of low intensity (1.5 GeV/c) saw no light flashes whatever.

To the contrary, observers exposed to neutron beams in the laboratory (Berkeley in the USA, Harwell, Univ.

of Birmingham in England) did see light flashes. After suitable adaptation in the dark, Tobias and Badinger (Berkeley) placed their heads in a neutron beam from the 467-cm cyclotron. When the beam was turned on, they saw starlike flashes. Jelley's group (Harwell Atomic Center) observed both dots and "lightnings." The direction of the "lightning" was parallel to that of the beam.

When the beam entered the rear part of the head, the number of flashes decreased. This indicates, in accord with other experimental data, that the interaction of the beam with the vision centers is not the cause of the flashes. The smaller number of flashes can be attributed to neutron absorption in the skull bones and in the brain when the latter is exposed from the back of the head.

The most probable flash mechanism is direct excitation of the retina by charged particles generated in nuclear reactions with neutrons, and also directly by atomic nuclei. The frequency of the flashes and the length of the "lightning" channel, as estimated by the observers, agrees with the characteristics of protons after they collide with neutrons.

In these laboratory experiments with neutron beams, the Cerenkov radiation could not act as the mechanism. The energy threshold for the excitation of Cerenkov radiation in a vitreous body is approximately 500 MeV. This energy was not always reached, so that at least at low energies, the flashes are produced by ionization in the retina or in adjacent regions. In flights near the moon, the Cerenkov effect could be one of the flash mechanisms. Experiments with nitrogen-ion beams, however, show that although the Cerenkov radiation is not essential here for the explanation of the flashes, it can occur when fast particles pass through matter. This is evidenced by the simple experiments performed on Apollo-14 and Apollo-15.

It is interesting that prior to the Apollo-11 flights no such flashes were observed by the astronauts. Yet the orbits of the Gemini space ships were also outside the atmospheres, yet the cosmic rays were not absorbed. The difference can be attributed to two causes. First, the earth's magnetic field is strong enough to deflect the cosmic rays. Second, in these early flights the astronauts kept the cabin lights on and were in constant communication with the earth. Under these conditions there were neither the rest periods nor the darkness-adaptation periods necessary to observe the flashes.

The damage that particles of very high energy can inflict on non-recoverable eye cells and nerve cells in the brain demonstrate the difficulty of the problem of radiation shielding[2]. Protection against solar cosmic rays and not too strong flashes is relatively easy. But high-energy particles (galactic cosmic rays) cannot be stopped. Hence the paradoxical conclusion that it is precisely in years of high solar activity (when the magnetic field and the irregularities of the solar wind are appreciable and block the galactic solar rays) that there is less danger of damaging nerve and eye cells in long flights.

That γ rays and fast electrons excite flashes in the eye material has been known for a long time. Even in Cerenkov's classical work[3], special measures (lead shield) were taken to eliminate this effect. Experimenters working with cosmic rays have also observed "flashes."

What is new is the systematic investigation of the effect (localization, mechanism) not only with natural but also with laboratory sources and its important application in the planning of space flights.

---

[1] G. Wick, Science **175**, 615 (1972).
[2] G. M. Comstock, R. L. Fleisher, et al., Science **172**, 154 (1971).
[3] P. A. Cerenkov, Trudy FIAN SSSR **2**, No. 4 (1944).

Translated by J. G. Adashko