tion rate of CCN from natural sources, based on a production rate of 5×10^6 m^{-2} sec^{-1} for the land (*3*) and 2×10^6 m^{-2} sec^{-1} for the oceans (*11*), yields a value of about 10^{21} sec^{-1}. On a global scale, the rate of production of CCN from anthropogenic sources may be comparable with that from natural sources. This is not to imply that regions far removed from large anthropogenic sources of CCN are appreciably affected by the CCN from anthropogenic sources, since the average residence time of CCN in the atmosphere is only a few days. On the other hand, the CCN in many industrial or heavily populated areas are no doubt dominated by anthropogenic sources. In view of the profound effects that CCN can have on cloud structure and precipitation processes, greater attention should be paid to the anthropogenic sources of these particles.

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Light Flashes Observed on Skylab 4: The Role of Nuclear Stars

Abstract. *The astronauts on Skylab 4 observed bursts of intense visual light flash activity when their spacecraft passed through the South Atlantic Anomaly. Flash rates as high as 20 per minute have in the past been considered unexpectedly high. When the effect of nuclear interactions in and near the retina is included, the apparent anomaly is removed.*

The astronauts on Skylab 4, Dr. Edward Gibson and Lt. Col. William Pogue, reported observing occasional 5- to 10-minute bursts of intense visual light flash activity when their spacecraft passed through that portion of the earth's inner trapped radiation belt known as the South Atlantic Anomaly (SAA). Two experimental sessions were carried out on board Skylab 4 under the direction of Pinsky *et al.* (*1*), who compared the flash rates with the measured flux of particles of Z (atomic number) ≥ 1 that would pass through the astronaut's eyes. The flash rates were found to be anomalously high, which led Pinsky *et al.* to postulate the existence of a previously unobserved inner belt flux of multiply charged nuclei.

Because of the important magnetospheric implications, we explored alternative explanations for the anomalous flash rates that would be consistent with the accepted SAA flux values (*2*) and the limited laboratory data on particle-induced visual sensations in human subjects (*3, 4*). We show here that, when one includes the effects of nuclear interactions in and near the retina which result in star formation (the emission of slow protons and alpha particles from the nucleus in an evaporation-like process), the apparent anomaly is removed.

On the basis of calculations fitting the flash rates observed on Skylab 4 outside the SAA and on Apollo flights in deep space, Pinsky *et al.* (*1*) expressed their threshold requirements for flashes as lower limits on two parameters: the linear energy transfer (LET) must be at least 37 kev/μm, and the path length of the particle's trajectory through the sensitive layer of the retina must exceed 40 μm. Such a particle would deposit a total of 1.5 Mev in the sensitive layer. Because the dark-adapted retina can integrate signals over distances as great as 300 μm, it is possible that particles with LET values below 37 kev/μm might by having path lengths greater than 40 μm still deposit more than 1.5 Mev in the sensitive layer and not be included in calculations of flash rates. This distinction, although possibly not significant outside the SAA, is important inside it. As a result, we express the threshold here in terms of a minimum deposition of energy within a region of the sensitive layer 300 μm in diameter. It is also possible that two particles might traverse the retina near enough to one another for their combined contributions to sum to more than 1.5 Mev although the individual particles do not exceed threshold. The visual effect might still appear as a flash or short streak.

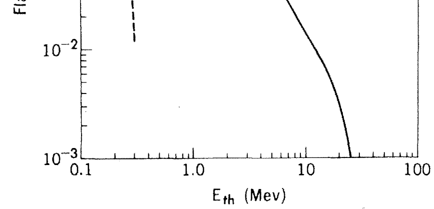

Fig. 1. Predicted flash rate as a function of the retina threshold sensitivity for a retinal area with a diameter of 300 μm.

Unfortunately, there are, as far as we know, no light flash data for accelerated protons. Furthermore, there is no certainty that the concept of threshold, which holds for the detection of Cerenkov flashes (*4*), is valid for nonrelativistic particles; experiments with alpha particles indicate that particles with LET values above 10 kev/μm are detected with roughly 40 percent efficiency at exposure rates of 10 per second but with less than 5 percent efficiency at very low exposure rates (*3*). Detection efficiencies probably vary for different regions of the retina. However, in examining the evidence for anomalous flash rates and comparing our results with those of Pinsky *et al.* (*1*), we assume that threshold is a valid concept and that the retina is uniformly sensitive.

The physical model used in our calculations of star production is as follows. Protons that have a typical SAA energy spectrum (*2*) impinge upon the eye, which is considered to be a sphere 2 cm in diameter with two-thirds of its area surrounded by a sensitive layer of the retina 30 μm thick.

Following Pinsky *et al.* (*1*), we ignore the angular anisotropies of the proton flux in the plane of the radiation belt. At the orbital altitude of 400 km the trajectory dispersion is $\leq 5°$. Astronaut Pogue was oriented so that his visual axis was perpendicular to the plane of particle trajectories. Roughly one-fourth of the incident protons have angles of incidence such that they would have to penetrate a minimum of 11 g per square centimeter of shielding to reach the eye. These protons are ignored in our calculations. Because the remaining protons had to traverse a path length of between 3.2 and 3.8 g/cm^2 in the spacecraft shielding to reach the eye, we assumed that all protons with energies below 80 Mev were lost in the shielding.

The medium in the eye is assumed to have a stopping power equivalent to that of water. We used a Monte Carlo program to choose each incident proton based on the SAA energy spectrum and random positions and directions on the eyeball surface. As the particles travel through the eye, they can produce a star in the ocular mediums or directly in the retina. The evaporation prongs from the star then stop in the ocular mediums, pass through the retina, stop in the retina, or escape out of the front of the eye. When the Monte Carlo technique is used to cover all possibilities, a "pulse height" spectrum of energies deposited in the sensitive layer of the retina is generated. The number of protons and alpha particles emitted by each star and their energy distributions were estimated from the data of Powell *et al.* (*5*) and the Fermi evaporation model. In the work reported here, stars produced behind the retina are not included. This effect should increase the predicted flash rates shown in Fig. 1 by approximately a factor of 2.

The cross section for star production is closely approximated by the geometrical cross section, which leads to about 0.025 interaction per centimeter of proton trajectory. The detection efficiency for stars generated in the ocular mediums is quite low. Fewer than 15 percent of these stars emit particles that even reach the retina. The expected light flash frequency is plotted in Fig. 1 as a function of the threshold energy, E_{th}, that must be deposited within an area 300 μm in diameter of the sensitive layer of the retina.

The direct contribution from trapped protons to the light flash rates in the SAA is a sharply decreasing function of the threshold requirement (Fig. 1). A threshold of 1.5 Mev would be in agreement with the flash rate as reported in (*1*).

The thresholds used in (*1*) are lower limits obtained by fitting the non-SAA data while deliberately ignoring Cerenkov radiation in order to be conservative in describing the anomalously high rates. If one includes contributions from Cerenkov radiation to the Apollo and non-SAA Skylab data, it would raise the threshold and thereby lower the SAA flash rates calculated here considerably. Pinsky *et al.* (*1*) showed that spallation products do not contribute sufficiently, and such interactions in the shielding are not included here.

The solid curve in Fig. 1 represents the events in which one or more evaporation prongs from nuclear stars traverse the sensitive layer with the total energy deposited within 300 μm exceeding E_{th}. There are obviously enough stars produced to explain the Skylab flash rates. If the peak flash rates of 20 per minute reported in the second Skylab session are used to obtain a threshold value from Fig. 1, a value of 1.4 Mev results. This value is in agreement with the limited accelerator data. Helium and nitrogen nuclei are detected near the end of their range (*3*). Even particles with a constant LET value as low as 10 kev/μm entering tangent to the retina may deposit as much as 3.0 Mev if they traverse an entire summation unit of 300 μm diameter within the sensitive layer.

Although the available data do not assure that calculations based on threshold concepts are valid, the data presented here show that when the contribution from star production in and near the retina is included calculations of the type introduced by Pinsky *et al.* (*1*) are brought into agreement with the experimental observations without the need to postulate trapped particles with $Z > 1$. Because of the large spatial fluctuations in the SAA flux, we made no attempt to achieve exact fits to the Skylab data. For this reason, the effects of ionization losses in the shielding, spallation, and star production in the sclera were not included in our calculations.

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Nitrogen Fixation in Grasses Inoculated with *Spirillum lipoferum*

Abstract. *Field-grown pearl millet (*Pennisetum americanum*) and guinea grass (*Panicum maximum*), lightly fertilized and inoculated with* Spirillum lipoferum, *produced significantly higher yields of dry matter than did uninoculated controls. Up to 42 and 39 kilograms of nitrogen per hectare were replaced by inoculation for pearl millet and guinea grass, respectively. The data demonstrate that nitrogen fixation by these grass-*Spirillum *systems is efficient and is achieved at a reasonable energy cost to the plant.*

Many important legume crops, such as soybeans and peas, have evolved symbiotic relationships with bacteria, which convert atmospheric nitrogen to a form available to the plants. This biological nitrogen fixation, mediated by the enzyme nitrogenase, requires about 15 molecules of adenosine triphosphate (ATP) for each molecule of N_2 reduced. It is highly wasteful of energy, but possibly only about one-half as wasteful as the commercial Haber-Bosch synthesis (*1*).

Most of the world's staple food crops (maize, wheat, rice, sorghum, and millet) and forages are grasses, which, until recently, were believed to have no potential for biological nitrogen fixation. In 1973, however, rice rhizosphere associations were reported to fix appreciable amounts of nitrogen at the International Rice Research Institute, Los Banos, Philippines (*2*). In Africa, nitrogen fixation rates in flooded rice comparable to those in peanuts were reported (*3*). Researchers in Brazil, using acetylene reduction to measure nitrogenase activity, recently demonstrated nitrogen fixation in maize, wheat, and forage grasses (*4, 5*). They isolated *Spirillum lipoferum* from surface-disinfected grass roots and deter-