DETECTION OF 10^{10} GEV COSMIC NEUTRINOS WITH A SPACE STATION

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ABSTRACT

Studies carried out by the author and a colleague in 1980-83 showed the potential value of SOCRAS (Space Observatory of Cosmic Ray Air Showers) for studying the highest energy cosmic rays, including the neutrinos produced in collisions of cosmic ray protons with photons of the 3° background radiation. This instrument would look down at the atmosphere from a space station orbiting the earth at an altitude of 500-600 km. During the night portion of each orbit, air showers would be imaged in the fluorescent light they produce. Progress toward the eventual realization of this scheme is described, including a suggestion by Torii for improving the vertical resolution, measurements of the terrestrial background light by Halverson, and especially an application of the LPM effect, expected to increase the sensitivity for upward moving neutrinos by several orders of magnitude.

1. Introduction. This is a status report on an idea suggested to me by, I believe, Hugh Hudson, at a meeting of a High Energy Astrophysics Advisory Panel at Caltech in September, 1979. I learned later that independently, at nearly the same time, a similar idea for detecting very large air showers with a "Satellite Fly's Eye", was described by S. Torii at a monthly meeting of the Air Shower Division of the Tokyo University Institute for Cosmic Ray Research.

It is well known, of course, that a proposal for detecting air showers from an aircraft by means of atmospheric Cerenkov light reflected from snow was made much earlier, by Chudakov (1972), and showers have in fact been detected using reflected Cerenkov light from a snow field at Plateau Rosa by Castagnoli *et al.* (1981).

Following the meeting at Caltech, on the basis of some crude calculations, I submitted the following in response to a request by the Panel, for 'Projects and Ideas for the 1980's':

Title. Study of 10^{20} eV Cosmic Rays by Observing Air Showers from a Platform in Space.

Description. Record real-time development of air showers produced in earth's atmosphere by cosmic rays, using mirror of very large size but low optical quality (mylar?) with array of fast photoelectric detectors, to sense air scintillation. Mirror pointed downward from satellite in low orbit. Data obtained during half-orbits when sun is hidden.

Purpose. To determine cosmic-ray energy spectrum and arrival direction distribution in the range 10^{18} to > 10^{20} eV with greatly improved statistical accuracy and notable freedom from systematic errors, compared to alternative methods. It is probable that individual primary particles could be sorted according to approximate mass.

Justification. Goals are the same as those of the Univ. of Utah Fly's Eye project and those of large projects in U.K. and U.S.S.R.--to derive information relevant to astrophysics from a distinct cosmic ray component that appears to be extragalactic in origin.[1]

2. Progress 1980-1983. During the next year I discussed the idea with colleagues, and at length one of them, R. Benson, agreed to help in choosing tentative design parameters and making improved performance estimates. These were reported at an AAS meeting and at the Paris ICRC.[2,3] As indicated above, the plan was to use a single mirror. In order to view what we regarded as a large enough target (100 km diameter circle) with adequate image quality we were constrained to a fairly high orbit (500-600 km). For good enough image quality over such a large field of view the number of sensing elements (photomultipliers) would have to be large, $\sim$ 5000. We estimated that in order to achieve a good enough signal to noise ratio for energies down to 10^{10} GeV we would need a mirror $\sim$ 30 m in diameter.

We concluded that the primary advantage of the method we proposed is that *uniformity of response over a very large sensitive area is achieved using a single compact instrument.* Compared to counter arrays it would have equal angular resolution and possibly better energy resolution. It would observe the entire sky, pole to pole, and the counting rate for highest energy cosmic rays would be 50-100 times greater than the combined rate of all ground based arrays then in existence. Compared to a ground based fluorescence detector the counting rate would again be much greater (100 times as great as the Utah Fly's Eye). Moreover, the sensitive area would be *inherently energy independent*, whereas the sensitive area of a ground based Fly's Eye depends strongly on the primary energy, *in a manner that varies with atmospheric conditions.*

In Paris we learned about the work of Torii, whose optical design called for wide angle optics (solid angle $\sim \pi$) appropriate to a lower orbit (200-300 km). He called our attention to the importance of reflected Cerenkov light in this application. This light, strongly collimated in the forward direction, will be diffusely reflected by the earth's surface in the vicinity of the core location, yielding an intensity at our receiver comparable to the maximum intensity of the fluorescent light, *but separated in time and space.* In case of a shower whose fluorescent light had effectively died out before the shower reached earth, this additional component would produce an isolated dot (at a time consistent with $v = c$) so that the composite image would resemble an exclamation point. More often the Cerenkov component would simply add to the intensity from the final image pixel. The additional information from the Cerenkov light will be very helpful in fixing the location of shower trajectories along the line of sight to the detector. This is important for estimating the primary mass, and for accuracy in determining the primary energy.[4]

The initial estimates of SOCRAS sensitivity paralleled the initial estimates made for ground based detectors, estimates which had often proven to be overoptimistic. A painstaking study was made of past shortcomings to locate any weakness or possible oversights that would account for this. It was found that the uncertainty in the initial SOCRAS estimate was large enough to be critical, and some possible errors were identified. It was concluded that it is essential to base further planning on the actual performance of ground based complete systems, especially the Utah Fly's Eye, which at that time was just beginning full operation.[7]

3. Neutrino Astronomy. Two circumstances combine to make SOCRAS attractive for neutrino astronomy. One is the very large mass of atmosphere that can be viewed (10^{11} tons); the other is a feature of the energy spectrum of cosmic neutrinos: there is a shoulder due to photopion production in collisions of cosmic ray protons with photons of the 3° background radiation, making energies $\sim 10^{10}$ GeV relatively favorable for detecting such neutrinos. Consequently the capability of SOCRAS as a neutrino detector was made the subject of a special study.

Three detection modes were envisioned. In all cases the neutrino must interact with a nucleus to produce one or more secondaries capable of initiating an air shower. If its energy is very high ($\sim 10^{10}$ GeV) the shower can be detected by means of air fluorescence in the usual way (mode I). For much lower energies ($\sim 10^4$ GeV) the shower could be detected by means of Cerenkov light, provided that the neutrino penetrated the earth, emerging within the target area, and then interacted in the atmosphere (mode II). For intermediate energies ($\sim 10^6$ GeV) the neutrino (in this case ν_μ or $\bar{\nu}_\mu$), travelling upward, would have to interact beneath the surface, producing a very high energy muon (mode III). The muon would be detected by means of atmospheric Cerenkov radiation produced by showers from pairs or bremsstrahlung photons.

It was concluded, however, that for modes II and III there would not be a clear enough signature, so that without great difficulty the signals could not be separated from noise. In addition, because the detection solid angle is very small in these modes, the counting rates would not be as great as for an undersea detector (DUMAND) of comparable complexity. In case of Mode I, the signature of a neutrino is a shower propagating in such a direction, and at such a depth, that the primary particle must have penetrated a very large amount of local material (say more than 1000 g/cm^2 of atmosphere or crust) before interacting. Identification would be no problem. However the predicted rate was disappointingly low.[5,6]

4. Progress since 1983. Regarding sensitivity estimates, the continued improvements in over-all performance of the Utah Fly's Eye are very encouraging. A student of Bowen at the University of Arizona has made tests indicating that the intensity of background light for a downward viewing fluorescence detector is several times less than for upward viewing, and he plans a ground based experiment exploiting this result (Halverson 1984). In tests carried out by the Utah group, optical filters were found to improve the signal to noise ratio of atmospheric fluorescence detectors by a factor of 4 (Cady *et al*. 1983). Similar filters have been tried out in work at Srinagar (Bhat *et al*. 1985). An alternative optical system suggested by Garipov (1982), using crossed cylindrical mirrors, might be easier to construct in space and have other advantages.

The most notable new development, however, relates to neutrino detection. Sokolsky (1983) pointed out that because of the LPM (Landau-Migdal-Pomeranchuk) effect, showers initiated in the earth by upward moving neutrinos will emerge with most of their energy intact, for ν_e-rock collisions within several hundred meters of the surface. The result is an increase of effective target mass by 3 or 4 orders of magnitude (Cady *et al.* 1983b). Even with this much increase, the 10^{10} GeV neutrinos from photopion production may still go undetected by the Utah device. At best the counting rate will be so low that hardly anything can be learned from the neutrino arrival directions (which of course point directly to the site of the initial proton-photon collision) or the zenith angle distribution (from which in principle $\sigma_{\nu h}$ can be learned). The 100-fold greater sensitivity of SOCRAS will result in a counting rate of 2-20 neutrino events per year. For > 10^{10} GeV nuclei the counting rate will be several thousand per year. This is still more than 50 times as great as all existing ground based detectors combined.[8,9]

4. Bibliography

1) LINSLEY, J. 1979, "Study of 10^{20} eV Cosmic Rays by observing Air Showers from a Platform in Space", response to Call for Projects and Ideas in High Energy Astrophysics for the 1980's, Astronomy Survey Committee (Field Committee).

2) BENSON, R. and LINSLEY, J. 1980, "Satellite Observation of Cosmic Ray Air Showers", Bull. Amer. Astron. Soc. 12, 818 (abstract).

3) BENSON, R. and LINSLEY, J. 1981, "Satellite Observation of Cosmic Ray Air Showers", Proc. 17th ICRC (Paris) 8, 145-148.

4) BENSON, R. and LINSLEY, J. 1981, "Astronomical Applications of Large, Aberration-Limited Reflectors on Earth and in Space", Proc. Southwest Regional Conference for Astronomy and Astrophysics, eds. P.S. Riherd and P.F. Gott (Texas Tech Univ.: Lubbock, Texas) 7, 161-168.

5) LINSLEY, J. 1981, "Neutrino Astronomy using SOCRAS, a Satellite Observatory for Cosmic Ray Air Showers", *ibid.*, pp. 169-178.

6) LINSLEY, J. 1981, "Detection of High Energy Cosmic Neutrinos by means of Atmospheric Fluorescence", Bull. Amer. Astron. Soc. 13, 883 (abstract).

7) LINSLEY, J. 1982, "Air Shower Measurements from Space", Proc. Workshop on Very High Energy Interactions in Cosmic Rays, eds. M.L. Cherry *et al.* (Univ. of Pennsylvania: Philadelphia) 476-491.

9) LINSLEY, J. 1983, "Possibilities and Prospects for learning Behavior of Interactions from Extensive Air Shower Data (10^{16}-10^{20} eV Region)", Univ. New Mexico Research Report UNML-9/26/83 (14 pp). See also rapporteur paper, Proc. 18th ICRC (Bangalore) 12, 135.

References. BHAT *et al.* 1985, "Spectral Differentiation of Atmospheric Fluorescent Events from Background Cerenkov Emission", preprint; CASTAGNOLI *et al.* 1981, Proc. 17th ICRC (Paris) 6, 103; CADY *et al.* 1983, Proc. 18th ICRC (Bangalore) 9, 351; 1983b, *ibid.* 11, 485; CHUDAKOV 1972, Proc. Symposium on Cosmic Rays, Yakutsk; GARIPOV 1982, Izv. Akad. Nauk SSSR, Ser. Fiz. 46, 1839; HALVERSON 1984, "Terrestrial Background for Air Fluorescence Detection", Workshop on Cosmic Ray and High Energy Gamma Ray Experiments for the Space Station Era, Louisiana State Univ., talk; SOKOLSKY 1983, Proc. Utah Cosmic Ray Workshop, ed. T.K. Gaisser (Bartol Foundation: Newark NJ) p. 153; TORII 1981, private communication.