Fermi National Accelerator Laboratory

FERMILAB-Conf-83/22
0001.000

UNDERGROUND NEUTRINO ASTRONOMY*

David N. Schramm

Fermi National Accelerator Laboratory
and
Astronomy and Astrophysics Center
The University of Chicago, Chicago, Illinois 60637

February 1983

*Submitted to the Workshop on Science Underground, Los Alamos National Laboratory, September 27-October 2, 1982

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

UNDERGROUND NEUTRINO ASTRONOMY

David N. Schramm
The University of Chicago and Fermilab

ABSTRACT

A review is made of possible astronomical neutrino sources detectable with underground facilities. Comments are made about solar neutrinos and gravitational collapse neutrinos, and particular emphasis is placed on ultra-high energy astronomical neutrino sources. An appendix mentions the exotic possibility of monopolonium.

INTRODUCTION

Neutrino astronomy divides itself into four areas: 1) Solar neutrinos, 2) Neutrinos from gravitational collapse, 3) High energy background neutrinos, and 4) High energy point source neutrinos, all of which require underground detectors. Since 1 and 2 are covered in other papers in this volume I will concentrate on the High Energy Neutrinos. At the end of the paper I will also briefly mention a possible exotic source of high energy neutrinos and other high energy particles, namely, monopolonium.

SOLAR NEUTRINOS

Before going into the high energy neutrino situation, I feel it is my duty to mention a viewpoint on the theoretical solar neutrino situation which is slightly different from that presented by the others in this volume (Fowler[1], Ulrich[2]). As was pointed out by Filippone and Schramm[3], the difference centers on the formal estimate of the uncertainty in the standard model calculation. Given a set of selected input parameter values we all agree on the best estimate of the number of SNU's predicted. The question comes as to how one should treat the uncertainties on those input parameters and how those uncertainties propagate into an uncertainty in the predicted number of SNU's. On this latter point it should be noted that <u>even if the same estimate of errors</u> is used for the input parameters, a Monte Carlo analysis of the type used by Filippone and Schramm[3] gives a significantly larger (± 2 SNU's vs. ± 1 SNU) estimated uncertainty to the standard model than does the linear least square technique used by Bahcall *et al*.[4]. In addition, the Monte Carlo uncertainty is not symmetric about the standard value. Since solar models are extremely non-linear, it seems reasonable to assume that the Monte Carlo treatment is a more accurate estimate of the uncertainties.

In addition to the Monte-Carlo versus least square analysis, there is also the statistical versus systematic error estimate question. It has been shown that frequently, the input parameters for the calculation as measured by different groups are outside of each others statistical errors. Examples are the $^3He(\alpha,\gamma)^7$ Be experiment, the $^7Be(p\gamma)^8B$ experiments and the opacity and abundance estimates. When several experiments with different techniques converge on a value then one can perhaps ignore the problem value, but when no such convergence occurs it seems to me that one can be mislead as to the confidence one has in the SNU prediction if one ignores data which is outside of the statistical errors of a selected value. To treat that systematic error one can either use input errors which include both statistical and systematic errors as was done by Filippone and Schramm[3] or one can do calculations with all the systematically different inputs and present all results together (see Filippone, 1982)[5]. New $^7Be(p\gamma)^8B$ values[5] are beginning to converge on a value almost 40% less than the "standard". The $^3He(\alpha,\gamma)$ rate is converging near the standard but the low value of Rolfs' group has still not been explained. In addition, the two leading opacity calculations alone yield differences of about 1 SNU. It seems to me that to ignore these possible systematic differences and to just quote an overall error of $\pm$ 1 SNU on the standard model is to give a false sense of confidence. When we include some conservatively estimated systematic errors based on existing differences, with the statistical we increase our Monte Carlo error estimate from ~ 2 to ~ 3 SNU's even without including the disputed Rolfs value.

It is interesting to note that Bahcall's "best estimates" from the past decade scatter with a standard deviation of ~ 3 rather than his stated formal error of $\pm$ 1 SNU. Although I agree with Willy Fowler that some of these systematic errors can in principal eventually be eliminated, they have not yet been so eliminated on all pieces of input and as one gets minimized, new ones seem to crop up. Thus it appears that the solar neutrino "problem" may be less than a "2σ" problem.

The problem as I see it is not the magnitude of the descrepancy but whether or not there is a real descrepancy. As Filippone and Schramm demonstrated, the ^{37}Cl experiment is probably incapable of resolving this problem and the best solution is one upon which all sides agree, namely we need the Gallium experiment.

GRAVITATIONAL COLLAPSE

Gravitational collapse events produce $\sim 10^{53}$ ergs of ~ 10 MeV neutrinos. The Homestake Gold Mine Detector of Ken Lande, and the Mount Blanc Tunnel Detector of the Torino Group should be able to see a gravitational collapse event any place in our galaxy. From looking at the statistics of supernovae in other galaxies, it seems that the rate of such galactic collapse events should be ~ 1 every thirty years; even though the rate of visual supernovae within our part of the galaxy is only one every two hundred years. This higher number comes from the fact that a large fraction of our Galaxy is obscured visually from us. It would be nice if future proton decay detectors are designed so that as a by product they can detect these gravitational collapse neutrinos. Unfortunately, the $1/r^2$ factor makes it prohibitively expensive with present technology to have a detector large enough to see supernovae in the Virgo cluster of galaxies where a supernovae goes off every few weeks.

HIGH ENERGY BACKGROUND

The High Energy background neutrinos come from proton-proton collisions producing π's and K's which then yield neutrinos. The major source of background (see Margolis, Schramm and Silberberg,[6] and Stecker and Learned,[7] DUMAND) will come from cosmic rays hitting the earth's atmosphere. This neutrino flux has been detected by Reines and his collaborators in a South African goldmine, and by experiments in the Kolar gold fields.

It is also conceivable that there could be high background fluxes due to bright early phases in the formation of galaxies when there may have been significantly higher cosmic ray fluxes, (such models have been proposed by Berezinsky and Zatsepin[8]). However, it is unlikely that a proton decay detector with only 10,000 tons would be able to detect such fluxes, even if they did exist.

There would also be background fluxes from cosmic rays hitting the galactic center. As evidenced by the observed π^o γ-ray background, those fluxes would be even lower still, and tend to require detectors of at least $\sim 10^9$ tons. Very high energy neutrino backgrounds coming from cosmological distances may have their associated γ-rays degraded by γ-γ collisions with the 3^o background[10]. However, energy conservation leads to the scattered γ's coming out at lower energy with higher multiplicity. It would take an exotic special model to get the observed low energy photons to be associated with a high energy ν flux.

However, there is an interesting limit that can be put on a very important cosmological problem; namely, deuterium production. Standard cosmological models have deuterium produced during Big Bang nucleosynthesis[11]. However, it is conceivable that deuterium might be able to be made by high energy spallation reactions in the early universe[12]. As Dave Eichler[13] has emphasized, such spallation reactions, in addition to producing deuterium, will also produce π's and K's and thus neutrinos. Since the amount of deuterium needed to be of cosmological significance is ~ 1 part in 10^5 of the mass of the universe, tremendous amounts of spallation reactions would have to take place, and thus there would be a very high neutrino background from any such process. Reines' experiment already had put severe limits on such models for deuterium production. New, more sensitive proton decay detectors would be able to improve these limits significantly, and should effectively rule out these spallation models for deuterium production.

Another background that may be interesting could be due to the decay of long-lived exotic particles produced in the Big Bang. Appendix I presents an example of one such object, monopolonium which is a monopole-anti-monopole bound state.

POINT SOURCES

Neutrinos from point sources[14] could be exceedingly interesting for large neutrino detectors of $\gtrsim 10^9$ tons. This is true if the angular resolution is sufficiently fine so as to enable ν fluxes from certain precise directions to stand out above the diffuse background. However, we do know that there are severe limits on fluxes of such neutrinos, assuming the neutrinos are accompanied by π^o gamma rays, as would occur if the proton-proton collisions in the sources were occurring without significant shrouding, obscuring the gamma rays. There are high energy γ-ray sources observed in Cygnus X-3, Centaurus A and the crab nebula[15]. From these γ-fluxes, it is clear that the neutrino fluxes would be so low, that they would not be detectable, with a 10^4 ton detector, and even their detectability with 10^9 tons is very model dependent.

The one possibility of getting neutrinos out without having these gamma ray limits imposed would be if there is suitable shrouding in matter (or radiation) to thermalize the γ's, and convert them into infrared radiation. Even then, from the limits on the infrared radiation from sources, it is clear that one would need a detector significantly larger than 10^4 tons before detecting such point sources. Thus, the only way around the limits from electromagnetic backgrounds of various sources would be if there is an object like a gravitational collapse event, which produces more energy in neutrinos than any form of electromagnetic radiation. At present, it seems very difficult to envision such a source, since to produce high energy particles, tends to require relatively low densities from which some form of radiation would get out.

One final point source which may be interesting, would be an extraordinarily energetic solar flare of the type which went off in 1956. Such flares may produce detectable neutrino bursts[13].

Another intriguing possibility concerns the Soudan I multimuon events which seem to have a directionality towards the North Galactic Pole (the Virgo Cluster). Since the energy of these events is $\sim 10^{15}$ eV it is clear that to have such directionality requires a neutral primary. (The cyclotron radius for a 10^{15} eV proton in the galactic magnetic field is ~ 1 light year and yet the disk is at least several hundred light years thick.) Since neutrons (and other massive neutrals) are ruled out by time-of-flight considerations we are left with protons and/or neutrinos. As mentioned above any standard high energy neutrino source would have π^o gamma's associated with it, so one would expect photons to be present. However, photons preferentially produce electrons, not muons so the multiplicity of the events is curious. Also, if the photons were removed by thick blanketing at the source or by scatterings of the 3^o background if the energy were in error, then there should be about as many upward as downward moving events. If we are dealing with a photon source, then the question arises as to why high energy gamma ray detectors have not seen such an intense source. Hopefully new γ-ray searches will help clarify this. At present this Soudan observation is still a mystery and needs further study. The answers may be encouraging to neutrino detectors.

An important point I wish to reiterate is that there is no "sure" high energy neutrino source, either diffuse or point source. Even for a 10^9 ton detector much less a 10^4 ton one, all predictions are model dependent. Even for those few sources where high energy gamma rays are seen, we always have to be aware that purely electromagnetic processes may be responsible for those γ's. (Of course, the discovery that a sensitive neutrino detector did not see ν's from those sources would be interesting since it would confirm the pure electromagnetic option.) However, the fact that there are no "sure" detectable sources should not stop people from looking and from developing new technology to look. (In this regard neutrino astronomy is almost in the identical position as gravitational wave astronomy.) The new technology may be beneficial for a variety of reasons and breakthroughs in sensitivity are certainly possible and of course, the most optimistic neutrino source models may be correct. But, perhaps the most compelling point is the fact that in the past the universe has always shown itself to be more inventive than theorists and probably for neutrino astronomy as with radio, infrared, X-ray and γ-ray astronomy before, the most exciting discoveries will not be model predicted ones.

APPENDIX I

Monopolonium

Chris Hill[16] has shown that monopolonium "molecules" will live the age of the universe if they have radii of $\gtrsim 0.1$ Å. Hill, in collaboration with J. B. Bjorken and I have looked into the astrophysical consequences of such objects. It can be shown that they will be currently radiating in the radio due to spin down radiation. In particular, thermally produced cosmological distribution of monopolonium will lead to a background radiation with a spectral peak at ~ 1 GHz for GUT monopoles of 10^{16} GeV mass.

The final annihilation due to the decay of the monopolonium will produce $\sim 10^{16}$ GeV events which will yield $\sim 10^6$ gluon jets. These jets will have angular spread of ~ 0.1 deg for standard GUT monopoles. Such jets may lead to time correlated high energy cosmic ray events. A detailed paper on the subject is currently being prepared.

ACKNOWLEDGEMENTS

I would like to acknowledge DOE grant DE AC02 80ER10773 and NSF grant AST 81 16750 at the University of Chicago, as well as the Hospitality of Fermilab, where the paper was prepared. I thank Chris Hill and James (BJ) Bjorken for interesting discussions, as well as my former collaborators Brad Filippone, Dave Eichler, Steve Margolis and Rein Silberberg.

REFERENCES

1. W. Fowler, in Proceedings of the Los Alamos Conference of Underground Physics, 1982.
2. R. Ulrich, in Proceedings of the Los Alamos Conference of Underground Physics, 1982.
3. B. Filippone and D. N. Schramm, Ap. J. 253, 1 (1982).
4. J. N. Bahcall, H. F. Huebner, S. H. Lubow, P. D. Parker, and R. K. Ulrich, Rev. Mod. Phy. (1982).
5. B. Filippone, "Nuclear Physics and the Calculation of the Solar Neutrino Flux", Ph.D. Thesis, December, 1982.
6. S. H. Margolis, D. N. Schramm, and R. Silberberg, Ap. J. 221, 990 (1978).
7. J. G. Learned and F. W. Stecker, in Proceedings of Neutrino 79, (Bergen, 1979), p. 461.
8. V. S. Berezinsky, and V. Zatsepin, in Proceedings of DUMAND 76, (Fermilab, Batavia, IL, 1977).
9. C. Fichtel, Phys. Rep. (to be published, 1983).
10. M. M. Shapiro, and R. Silberberg, in Proceedings of DUMAND 80, (Hawaii DUMAND Center, 1980) p. 262.
11. D. N. Schramm, and R. V. Wagoner, Phys. Today, 27, 40 (1974).
12. R. Epstein, J. Lattimer, and D. N. Schramm, Nature 263, 198 (1976).
13. D. Eichler, in Proceedings of DUMAND Ocean 77, (Naval Ocean Systems Center, San Diego, 1978).
14. D. Eichler and D. N. Schramm, Nature 225, 704 (1978).
15. T. Weekes, in Proceedings of DUMAND Ocean 77, (Naval Ocean Systems Center, San Diego, 1978).
16. C. Hill, Nuc. Phys. (in press, 1983).