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Author

Trimble, V

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Astrophysics

Neutrinos and the Sun

from Virginia Trimble

NOTHING can replace real data from a working scientific experiment. This was the most important lesson to be learned by the participants in the Homestake Neutrino Conference*. Among the questions addressed, for which there either are, or should be such data, were the following. (1) What is the flux of neutrinos hitting the Earth? (2) How does it depend on time and neutrino energy? And (3) what is the Sun doing in addition to (or instead of) making neutrinos? In short, the answers are, for (1), still puzzlingly low; for (2), possibly variable with an 11 yr period; and for (3), perhaps stirring its interior, probably driving its magnetic field with a dynamo at the base of the convection zone, and, just maybe, showing a solar activity cycle as far back as 700,000,000 yr.

First the incident flux. There cannot be a physicist, astronomer, or chemist who has not heard of Raymond Davis Jr and his 100,000 gallons of cleaning fluid (C_2Cl_4) in the depths of the Homestake Mine. The experiment was designed to permit recovery of a few atoms of ^{37}Ar , resulting from the decay of ^{37}Cl driven by neutrinos from the Sun. The counting rate from the recovered atoms has persisted for more than a decade in being about one-third of what theorists predict from solar neutrinos alone (observed production rate 0.39 ± 0.05 atoms per day = 2.1 ± 0.26 SNU, after subtracting the current best estimates for assorted backgrounds). There is now no serious doubt about the atoms' identity: they not only have the chemistry and decay energy of ^{37}Ar but also have its half life (J. Rowley, Brookhaven National Laboratory). But the fraction of ^{37}Ar production that should be attributed to backgrounds from cosmic-ray secondaries has become less certain. Two backgrounds are important, muons and neutrinos. E. Fireman (Center for Astrophysics) is currently checking the muon background adjacent to Davis's tank using several thousand gallons of potassium hydroxide. The rationale behind his experiment is that cosmic-ray particles can be expected to make ^{37}Ar from ^{39}K at about the same rate as from ^{37}Cl , whereas neutrinos will make far less. His 1 σ limits on particle production of ^{37}Ar are currently 0.20 ± 0.20 atoms per day, consistent either with the standard best estimate of 0.08 atoms per day or with the entire observed rate of 0.47. Longer runs should tighten the error bars considerably. The flux of cosmic ray-produced neutrinos can easily be checked only by $e-\nu$ scattering at energies ≥ 10 MeV (because of interference from still other kinds of backgrounds at lower energies) using

multi-tone water Čerenkov detectors. At least five of these are now operating and producing consistent results (T. Stanov, Bartol Research Foundation). The detector in Kamioka, Japan, however, has seen a considerable excess of low-energy neutrino-like events. If these result from stopped muons and the same flux hits the perchlorethylene tank, it will produce $0.37^{37}Ar$ per day, essentially the observed level.

An estimate of neutrino flux as a function of energy is vital for deciding whether the low flux at Homestake is due to a minor flaw in the solar model (affecting only the high-energy B^8 neutrinos), neutrino oscillations during propagation (which might reduce the flux at all energies by about a factor of three), or some major defect in modern astrophysical theory (for example, stars do not derive their energy from fusion and so do not produce any neutrinos at all). Apart from the Davis result, there are currently only upper limits, mostly several orders of magnitude above predicted values and pertaining to fluxes made by high-energy cosmic rays (P. Sokolsky, University of Utah) or stellar collapses (A. Burrows, SUNY) rather than by the Sun.

Contributions on the time-dependence of neutrino flux were rather more intriguing. Rowley's simultaneous plot of the ^{37}Ar production rate and sunspot numbers since 1970, particularly the coincidence of the very high run nos 27 and 71 with the giant flare of 4 August 1972 (another indicator of solar activity) strongly suggested a correlation. A. V. Kopylov (Institute for Nuclear Studies, Moscow) pointed out that the present data are not inconsistent with constant ^{37}Ar production rate, and R. Lingenfelter (University of California, San Diego) sketched out calculations eliminating the most obvious sort of connection: energetic particles from a large solar flare produce neutrino secondaries at a rate too low by 10^6 to affect the Homestake experiment. Nonetheless, the possibility of correlated time-dependence is clearly worthy of further study. It is therefore particularly disturbing that the Brookhaven experiment will have to be wound down over the next fiscal year unless a new source of support is found.

Several promising experiments are under construction. The Institute for Nuclear Studies, Moscow (N.V. Gavrin, A.V. Kopylov) has 25 tonnes of gallium metal on hand, and more available, and a chamber ready and lined with iron and concrete shielding at 3,500 m depth at Baksan. The group hopes for construction in 1985 and counting in 1986. $^{71}Ga(\nu, e)^{71}Ge$ has a low enough threshold to see neutrinos from ordinary pp reactions. The

same group is also working on both a scaled-up ^{37}Cl experiment (five times Davis's volume; the equipment is ready, but the chamber still needs to be dug) and $^7Li(\nu, e)^7Be$ (for which they have tested recovery and counting techniques for a 12-litre tank and are ready to try 200 l). The Cl experiment should provide a high enough count rate to see any solar cycle variations unambiguously, and, with patience, annual ones, while the Li experiment is sensitive to CNO cycle and pep neutrinos, thus testing different details of nuclear and solar physics.

MPI Heidelberg (W. Hampel) intends to continue a gallium experiment, in the form of $GaCl_3$, despite Brookhaven's withdrawal from the collaboration. They have tested germanium recovery and counting in a 1.25 tonne tank and envisage a 30 tonne experiment at an existing European site. L.S. Peak (University of Sydney) reported that his group is about to install its first 10 tonne module of a projected 100 tonne water Čerenkov detector to look for a $\nu-e$ scattering at the Broken Hill mine. In practice, this is sensitive only to B^8 neutrinos, owing to high backgrounds at low energies, but it is otherwise totally different from the Cl experiment and can yield approximate directional information, separating the Sun from other sources.

Models of the solar interior designed to reduce the predicted neutrino flux are numerous and often rather *ad hoc*. G. Michaud (University of Montreal) and E. Schatzman (University of Nice) reviewed the effects of turbulent diffusion. If this provides a diffusion coefficient about 100 times that expected from ordinary molecular diffusion, then fresh hydrogen coming in reduces the necessary central temperature slightly and hence the predicted flux by about the requisite factor of three. Energy to drive the turbulence and mixing can be drawn from the build-up of burnable 3He just outside the solar core (I. Roxburgh, University of London). One price paid is a 30 per cent increase in main-sequence lifetimes for low-mass stars, and thus some difficulty in interpreting the Hertzsprung-Russell diagrams of globular clusters. A partial compensation is a better understanding of lithium abundances on the surface of old stars.

Efforts to probe the central temperature, composition, rotation and magnetic field distribution (all of which can affect neutrino production) of the solar interior using frequencies of g-mode oscillations would seem premature. G. Isaak (University of Birmingham), whose group has collected much of the solar surface velocity data concerned, does not believe that these modes have yet been unambiguously identified. The p-modes have been seen in considerable detail, but are only informative about the solar core after the dominant contributions from the envelope have been understood and subtracted.

Nonetheless, p-modes may already have

*Lead, South Dakota, 23-25 August.

resolved one uncertainty. P. Gilman (High Altitude Observatory) reviewed the discrepancy between solar dynamo models with driving in the convection zone and models for convective driving of the solar differential rotation. The former require angular frequency to increase inwards (to make active zones migrate to lower latitudes through the solar cycle), while the latter require angular frequency to decrease inwards. The observed p -mode-splitting strongly favours ω decreasing inwards (see Duvall, T.L. Jr *et al.* *Nature* **310**, 22; 1984). Gilman suggested an alternative site for dynamo driving at the base of the convection zone, where ω seems to be rising again with depth.

Finally, P. Foukal (Atmospheric and Environmental Research Inc.) showed fragmentary sunspot, auroral and ^{14}C data suggestive of a roughly 11 yr solar activity cycle for several hundred years before the late-seventeenth-century turn-off (the

Maunder minimum). And, in what was perhaps the greatest surprise of the meeting, he showed photographs of a pre-Cambrian varve sequence discovered by George Williams of Broken Hill Proprietary. Varves are layers deposited in periglacial lakes when rapid spring-summer melting and sediment transport alternate with quiet winter settling of silt. The annual layers showed additional banding with periods ranging from 9 to 14 yr and averaging 11.2 yr over a 20,000 yr sequence. This strongly suggests an influence by the solar cycle some 700,000,000 yr ago. There's nothing quite like real data, but you can never be sure where it's going to come from. □

Virginia Trimble is Visiting Professor of Astronomy at the University of Maryland, College Park, Maryland 20742, and Professor of Physics at the University of California, Irvine, California 92717.

Invertebrate neurophysiology

Sodium channels in muscle

from P.R. Stanfield

INFORMATION in the nerve fibres of both vertebrates and invertebrates is signalled by means of action potentials that are generated by an inward movement of sodium ions through channels (Na channels) which are selective and dependent upon membrane potential. Similar channels characterize most of the skeletal muscle fibres of vertebrates, where the all-or-nothing action potentials they produce trigger contraction by releasing calcium ions from an intracellular store in the sarcoplasmic reticulum. In contrast, invertebrate muscles have seemed to lack sodium channels, showing instead an electrical excitability that depends on the presence of calcium channels in the muscle fibre membrane and is either graded or all-or-nothing in nature. This calcium-dependent pattern of electrical excitability has been seen as phylogenetically older than the pattern in vertebrate muscle and Ca channels are themselves believed to be evolutionarily older than Na channels¹.

The generalization that invertebrate muscles lack Na channels has recently been challenged by Lawrence Schwartz and Walter Stühmer², who have used electrophysiological techniques to show that the striated muscle fibres of the planktonic arrow worm, *Sagitta elegans*, possess Na channels and certain other properties that make them very like skeletal muscle fibres of vertebrates. *Sagitta* was chosen because it belongs to the phylum Chaetognatha and in turn to the deuterostome branch of coelomate animals, the branch to which the vertebrates also belong.

In discussing their data, Schwartz and Stühmer argue that, since Na action potentials are always more rapid events

than those depending on Ca^{2+} , they permit a more rapid switching on and off of muscle activation. The advantages of a rapid switch may have provided part of the selection pressure that led to the expression of Na-channels in muscle as well as in nerve. The rapid muscular responses required of a successful predator like *Sagitta* may account for its adoption of Na channels. The alternative, however, is that they are the bequest of an evolutionary ancestry shared with the chordates, and that the Na action potential in muscle is a deuterostome trait.

If this is a deuterostome trait, it is not a universal property among the group, nor is it limited to them. Indeed, since Na channels of very consistent properties are almost universal in nerve, it is possible that their expression in muscle has arisen independently in a number of groups. Thus, the tunicates (urochordates) lack muscle Na channels, while *Amphioxus* (among the cephalochordates) possesses them; these protochordates have therefore been seen as transitional between non-chordates that lack muscle Na channels and the vertebrates¹. Furthermore, among the vertebrates, lack of Na channels lives on in smooth muscle and also in the slowly-contracting tonic skeletal muscle fibres, found in frog and, for example, in the extraocular muscles of certain mammals. Moreover, protostomes (the other branch of the coelomates) can also have muscle Na channels, for these have now been demonstrated in an evolutionary ancient group of arthropods, the scorpions³.

While muscle fibres of the scorpion and of *Sagitta* both give brisk twitch-like contractions in response to Na-dependent

action potentials, they are very different in other ways. First, in scorpion, the Na action potential is followed by a brief train of Ca-dependent ones³, an electrical behaviour that has not been described in other muscles. Second, blockage of Ca channels or removal of external Ca^{2+} blocks contraction in the scorpion, in spite of the presence of a well-developed cellular store of Ca^{2+} . This dependence on external Ca^{2+} is commonly found in invertebrate muscles that lack Na channels. In *Sagitta*, as in vertebrate muscle, removal of external Ca^{2+} seems not to block contraction².

The presence of Na-channels in scorpion muscle may raise the question of whether Ca-dependent excitability really is the older form. There remains little doubt that it is, and arguments from ontogeny support the position. During development, vertebrate muscles go through a stage where they possess only Ca action potentials. And even in adult muscle, Ca channels are retained at a high density. In addition, in the tunicates, whose muscles lack Na channels, these channels are lacking in all cells in the initial stages of development (though they are present in the unfertilized egg) and are never expressed in presumptive muscle cells. Indeed, these cells acquire their mature pattern of ionic permeability very early in embryonic life, and at much the same stage at which Na channels first appear in presumptive nerve cells⁴.

To confuse the picture, certain muscle fibres seem to have the potential but not usually the stimulus to express Na channels. Thus denervation of tonic muscle fibres of the frog leads to the development of Na action potentials; since reinnervation suppresses them again, some trophic effect of nerve seems to be involved⁵. Denervation of crayfish muscle has similar results⁶.

At the end of their article, Schwartz and Stühmer challenge comparative physiologists to use new methods to investigate muscle cells hitherto inaccessible to electrophysiological attack. Since it was in a crustacean muscle that the first evidence for the Ca channel was obtained⁷, since the pattern of evolution of muscle excitability turns out to be complex, and since a comparative approach will help sort out the poorly understood problem of excitation-contraction coupling³, there is a strong case for a wide survey. □

1. Hagiwara, S. *Membrane Potential-dependent Ion Channels in Cell Membranes, Phylogenetic and Developmental Approaches* (Raven, New York, 1983).
2. Schwartz, L. & Stühmer, W. *Science* **225**, 523 (1984).
3. Gilly, W.F. & Scheuer, T. *J. gen. Physiol.* **84**, (in the press).
4. Hirano, T., Takahashi, K. & Yamashita, N. *J. Physiol. Lond.* **347**, 301 (1984).
5. Miledi, R., Stefani, E. & Steinbach, A.B. *J. Physiol. Lond.* **217**, 737 (1971).
6. Lehoucq, J., Cuadras, J. & Bruner, J. *Neuroscience Lett.* **37**, 227 (1983).
7. Fatt, P. & Katz, B. *J. Physiol., Lond.* **120**, 171 (1953).

P.R. Stanfield of the Department of Physiology at Leicester University is currently in the Department of Biological Sciences, Purdue University, West Lafayette, Indiana 47907.