from the mixed clones, genetic markers demonstrated that recombinant sporozoites are produced in excess from mosquitoes that receive mixed clones. Assuming random mating and equal productivity per oocyst, half the sporozoites should be identical to one of the parental types. In fact, more than half those produced were recombinants. Perhaps *P. falciparum* avoids incest? If so, the explanation is unlikely to be the traditional one, avoidance of inbreeding depression. The expression of recessive deleterious alleles inherited in double dose through common descent is thought to be the main cause of inbreeding depression. For most of its life, *P. falciparum* is haploid, so most recessive genes will be expressed every generation, and shielded from selection only during the diploid oocyte stage.

If sex is maintained among most eukaryotes as a parasite-defence mechanism, as is often suggested[8-13], then perhaps it is not surprising that parasites have joined the race by evolving sexuality to keep one step ahead of the defence mechanisms of their host(s). One intriguing question, bound to be the subject of speculation, is why the parasitic protozoa should go through a sexual phase in their insect host whereas many multicellular parasites are sexual in their vertebrate host. One explanation might be historical: parasites normally go through a sexual phase in the host from which they first evolved. (Digenea are an obvious exception to such a theory.) In any event, the patterns and peculiarities of sex among protozoan parasites that are dependent on primary and secondary hosts beg evolutionary interpretation. □

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## Solar physics

# Neutrinos and sunspots

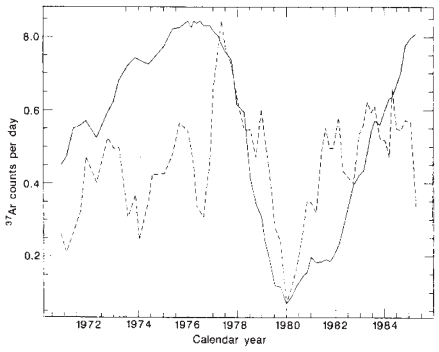
*J.N. Bahcall*

THE surprising discrepancy between the calculated and the observed rate of solar neutrino captures in chlorine (SNUs) is a long-standing puzzle that has spawned many imaginative scientific explanations and several science-fiction novels. The Japanese proton-decay detector Kamiokande, which was converted into a solar-neutrino detector just in time to make the first ever observation of supernova neutrinos, has recently confirmed the solar neutrino discrepancy. R. Davis has pointed out[1] that the neutrino capture rate is apparently inversely correlated with sunspot activity (see figure). But on page 353 of this issue[2], A. de la Zerda Lerner and K. O'Brien present calculations that show one plausible explanation of this modulation is not correct.

What is the significance of the suggested correlation? If it is real, then the observed capture rate does not reflect the rate of neutrino production by nuclear fusion in the solar interior because the characteristics of the solar interior are expected to vary significantly only on the timescale of nuclear burning, which is a billion years or so. Then models based on resonant neutrino oscillations in matter[3-5], by which neutrinos switch back and forth between detectable and undetectable types, would have to be revised, disappointing many physicists who have been delighted by the oscillation explanation, which uses theoretically attractive values of the mass differences and mixing angles of different neutrinos. Nature might have failed to embody a beautiful theory.

Several Soviet theoretical physicists have proposed[6,7] that the correlation between SNUs and sunspots is caused by an unexpectedly large electric or magnetic moment of the neutrino. The correlation reflects, on this hypothesis, the changing structure of the solar magnetic field, which varies with epoch in the sunspot cycle and which could convert detectable (left-handed) neutrinos to sterile (right-handed) neutrinos.

Another, more conventional, idea is that cosmic rays or their secondaries, which produce neutrinos in the atmosphere, cause the correlation of sunspots and neutrino captures: cosmic rays are modulated by the solar wind encountered on the way to the Earth, causing the cosmic-ray intensity at the Earth's orbit to wax and wane in inverse correlation with solar activity. In this issue[2], de la Zerda Lerner and O'Brien describe a careful calculation of the neutrino emission from positrons produced by cosmic rays as they strike the Earth's atmosphere. They calculate the spontaneous decay rate of $\beta$-unstable isotopes produced when secondary particles collide with atmospheric ions. The calculation shows that the positron-neutrino emission falls short of explaining




Average monthly sunspot number (solid curve) and the moving-averaged solar-neutrino capture rate as measured by the conversion of $^{37}$Cl into $^{37}$Ar (dashed curve) as a function of calendar year. The scale of the ordinate is arbitrary for sunspots, which are scaled to the same peak-to-peak range, and inverted (small sunspot number at top). (From refs 1 and 9.)

the correlation by nine orders of magnitude. A previous calculation[8] showed that cosmic-ray secondaries that decay in flight to produce high-energy neutrinos are insufficient to account for the suggested effect by at least three orders of magnitude. The inconstant SNUs are unlikely to be produced by acceleration of energetic particles in the solar magnetic field as this would conflict with accepted ideas about the solar corona and solar flares[9].

My own view is that the suggested correlation is a rare fluke, although many disagree. Our statistical analysis[9] shows that even with the most optimistic interpretation of the experimental errors a correlation as strong as that in the real data is found in 2 per cent of the cases of randomly shuffled time sequences of that data. Almost every event of interest in life, the circumstances in which we first meet our spouses for example, has an *a posteriori* probability of less than 2 per cent. If one correlates the time sequences of enough physically unrelated phenomena, then some will appear to be correlated at the 2 per cent significance level or even higher.

What must be done? Observations made with the chlorine detector during the maximum of the next sunspot cycle (especially in 1990 and 1991) will test whether the correlation does exist. Ray Davis and I have a bottle of champagne wagered on the outcome. □

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