# Stellar stuff

*Michael L. Cherry*

**Neutrino Astrophysics.** By John N. Bahcall. *Cambridge University Press: 1989. Pp. 567. Hbk £40, $75; pbk £14.95, $24.95.*

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Air bubbles — female workers at the Douglas Aircraft Company's plant in Long Beach, California assembling plexiglass canopies for warplanes around 1943. The canopies show a reflection of the factory's overhead lights. The picture is taken from *Beyond the Limits: Flight Enters the Computer Age*, published by MIT Press.

THE textbooks tell us that the Sun is powered by the fusion, deep within the solar core, of hydrogen into helium. Our Sun is a modest and unexceptional example, we are told, of the large numbers of main sequence stars in the Galaxy whose structure and evolution are well understood. Astronomers routinely and successfully use the predictions of stellar structure and evolution theory to explain many of the observed features of stars. But for the one star close enough for us to study in detail, direct observations of the fusion reactions give lower results than are predicted by standard models.

Typically, it takes some $10^4$ years for photons to diffuse out from the Sun's interior. But neutrinos, since they interact only weakly with matter, get out directly and thus (presumably) provide the desired probe of the nuclear fusion processes in which they are created. Because the neutrinos interact so rarely, however, they are difficult to detect. Experiments must be massive (in order to provide enough sensitivity) and exceedingly free of background. Raymond Davis and his colleagues built the first (and for nearly 20 years the only) detector capable of measuring neutrinos from the Sun. It consists of 615 tons of $C_2Cl_4$ buried nearly a mile underground in the Homestake Gold Mine in South Dakota. Roughly once every two days, a neutrino is absorbed by a nucleus of $^{37}$Cl, which is then transformed into $^{37}$Ar. About every two months, in an elegant and now routine radiochemical procedure, the resulting handful of argon atoms is extracted and counted. The observed rate of $^{37}$Ar production, averaged over two decades, is only 25–30 per cent of the predicted rate.

A second experiment, involving the Kamiokande II water Cerenkov detector, has recently confirmed the low rate observed by Davis with a totally independent and equally impressive technique. Although the measurements are difficult to carry out, there appears to be nothing wrong with the experimental results. Instead, it seems that there is something wrong either with our understanding of the Sun or with our knowledge of neutrino physics. If the fault lies in the solar models, then there may be important ramifications for stellar evolution and for astronomy in general. And if the problem lies with the neutrinos, then these studies of low-energy solar neutrinos may in fact be trying to tell us something fundamental about electroweak physics at very high (grand unification) mass scales.

Like the experiments, the calculations aren't easy. They involve a blend of astronomy, nuclear physics, atomic physics, particle physics and hydrodynamics, and must be carried out with high numerical precision. Indeed, when one realizes how sensitively the calculated neutrino flux depends on the temperature of the solar core (for the observed neutrinos from $^8$B decay in the Sun, the flux is proportional to $T^{18}$!), it appears quite remarkable that such difficult and involved calculations agree with the experimental result as well as they do.

John Bahcall has been a leading and influential contributor to solar-neutrino calculations and theory since the field was young. In fact, nobody seriously interested in the subject should need to be told that his new book is worth reading. Bahcall spends the first half of the text authoritatively reviewing the theory and the models. His treatment reflects both his biases and much of the current interest and emphasis in the field. But even where the discussion is brief, he covers the main points, presents the conclusions and gives extensive references to the original papers. He reviews the possibilities for non-standard models thoroughly (making no attempt to hide his own strongly held opinions), but again the references more than make up for any unevenness in the treatment. A crucial question concerns the various uncertainties in the calculations: is the factor of 3 – 4 difference between the chlorine measurement and the prediction a real problem? Bahcall's answer is a resounding yes. He also covers the hot topics of new neutrino physics (neutrino oscillations, for example) and supernova neutrinos in some detail.

Some of the excitement about solar neutrinos comes from the anticipation of imminent new experimental results. Two gallium experiments are now being prepared to look for the neutrinos from the fundamental proton–proton fusion reaction itself. These are by far the most abundant of all solar neutrinos, but are too low in energy to be seen by the existing detectors. The gallium measurement is expected to be crucial. Also, the Sudbury heavy water detector, to be built in Canada, promises to measure the neutrino energy spectrum and the neutral current contribution to the flux, both important pieces of information required to disentangle the effects of solar models and neutrino physics. Bahcall describes the existing and most of the proposed experiments, and finally includes a delightful history of solar-neutrino research, written with Ray Davis. *Neutrino Astrophysics* might more properly have been entitled *Solar Neutrinos*; but whatever the title, the book provides a thorough and expert summary of a field of intense current interest. □

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