resolve the information problem. He points out that black holes far from extremality (such as the Schwarzschild solution) and the strong-coupling regime still have to be understood with the new techniques, and those cases are precisely the ones of greatest relevance to the information problem.

In an attempt to extend the results to such cases, Horowitz and Polchinski have formulated a "correspondence principle" for black holes and strings.[8] This principle, which generalizes Susskind's 1993 ideas, states that as one reduces the string coupling a typical black hole state becomes a typical state of strings and D-branes with the same charges. The results are not as precise as those described above, but they do include neutral examples such as the Schwarzschild solution. Horowitz says the principle "provides a unified approach to understanding the entropy of all black holes."

Strominger has yet a third view. He feels that the puzzle has been greatly sharpened. On the one hand the string computations predict unitary evolution and radiation with certain amplitudes, so the "lost information" is encoded in subtle correlations in the radiation. On the other hand, he feels that Hawking's arguments, which predict radiation with the same probability distribution but no correlations, are based on very compelling fundamental principles. "The string computation must be correct," he says, "but I haven't found the flaw in Hawking's reasoning, and no one has persuaded me that *they've* found the flaw. I kind of think we're still missing some big point."

Hawking agrees that "it is a major puzzle why the [two computations] should agree so precisely on the rates of emission and yet disagree completely on the question of unitarity." But he adds, "I think it is likely we will know the answer within a year."

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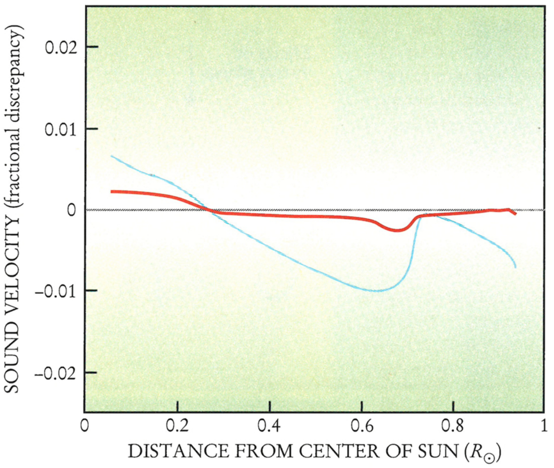
References

1. A. Strominger, C. Vafa, Phys. Lett. B **379**, 99 (1996).
2. For an early review, see G. Horowitz, preprint gr-qc/9604051 on the Los Alamos server, http://xxx.lanl.gov/.
3. C. G. Callan, J. M. Maldacena, Nucl. Phys. B **472**, 591 (1996). S. R. Das, S. D. Mathur, Nucl. Phys. B **478**, 561 (1996). J. M. Maldacena, A. Strominger, Phys. Rev. D **55**, 861 (1997).
4. J. Dai, R. G. Leigh, J. Polchinski, Mod. Phys. Lett. A **4**, 2073 (1989).
5. J. Polchinski, Phys. Rev. Lett. **75**, 4724 (1995). For a review, see the 1996 TASI lectures: J. Polchinski, preprint hep-th/9611050 (Los Alamos server).
6. For a review of string duality, see J. Polchinski, Rev. Mod. Phys. **68**, 1245 (1996).
7. G. T. Horowitz, D. Marolf, preprint hep-th/9610171 (Los Alamos server).
8. G. T. Horowitz, J. Polchinski, preprint hep-th/9612146 (Los Alamos server).

Can Helium Mixing Explain the Solar Neutrino Shortages?

Has the time come to abandon hope of an astrophysical—as distinguished from particle-theoretic—solution of the solar neutrino puzzle? Two recent papers espouse different positions on this important issue. In the 18 November *Physical Review Letters*,[1] Wick Haxton (University of Washington) and Andrew Cumming (a visiting undergraduate from Cambridge University), argued that there might still be an astrophysical explanation for the observed shortfall of ^{8}B decay neutrinos from the Sun *and* for the even greater shortfall of solar neutrinos from electron capture by ^{7}Be: namely the slow mixing of ^{3}He down into the solar core. "This is a very speculative departure from the standard model of how the Sun works," Haxton told us. "But we're all willing to carefully examine some rather exotic particle-physics solutions. So it may be equally important to explore unexpected solar-physics solutions."



STANDARD SOLAR MODEL calculation minus measurement of sound velocity as a function of distance from Sun's center, expressed as a fractional discrepancy.[2] The calculation (red) that includes gravitational diffusion never departs from the measurements by more than 0.2%. Even without diffusion (blue) the standard model stays within 1% of the measurements.

John Bahcall (Institute for Advanced Study) thinks otherwise. "The astonishing agreement between the standard solar model and the most recent helioseismological measurements of sound velocities inside the Sun," he told us, "have convinced me that the explanation of the solar neutrino data can now come only from new neutrino physics." In the 13 January *Physical Review Letters,* Bahcall and coauthors[2] compare sound velocities predicted by the standard solar model with the velocities determined from measurements of the seismic oscillation of the Sun's surface. From $0.95R_\odot$ all the way in to $0.05R_\odot$, they point out, the measured and predicted velocities never differ from each other by more than 0.2%. ($R_\odot$ is the solar radius. See the red curve in the figure above.) Measuring the sound velocity so close to the center of the Sun has only recently been made possible, by helioseismological instrumentation developed by Steven Tomczyk at the NCAR High Altitude Observatory in Boulder, Colorado.

In the highly ionized interior of the Sun, the sound velocity has the same dependence on temperature and μ, the local mean atomic mass, as in an ideal gas; it is proportional to $\sqrt{T/\mu}$. According to the standard model, T decreases by two orders of magnitude and μ decreases by about 50% as one moves out from $0.05\ R_\odot$ to $0.95R_\odot$. So the remarkable agreement between the measured and predicted sound velocities implies that the standard model gets both the T and μ profiles very nearly right over almost the entire interior of the Sun—unless, by some perverse coincidence, both profiles depart from the standard model in just such a way that their ratio remains unchanged.

Most of the μ falloff in the standard solar model occurs in the deep interior, at depths below $0.25R_\odot$, where the neutrinos are being made by the fusion reactions that power the Sun. Cumming and Haxton's ^{3}He mixing scenario, on the other hand, would produce a much more uniform atomic mass distribution in that region.

^{3}He is made in the solar core by proton–deuteron fusion. Then the ^{3}He is consumed, mostly by ^{3}He + ^{3}He fusion to $^4He + 2p$, and less often by $^3He + ^4He$ fusion to form ^7Be. A small fraction of this ^7Be later fuses with a proton to become ^8B. The net result of all of these highly temperature-sensitive processes is that most of the surviving ^3He, in the standard solar model, is concentrated in the relatively cool precincts near $0.3R_\odot$. In the Haxton–Cumming scenario, which imagines plumes of that accumulated ^3He carried down to the hotter regions, $^3He + ^3He$ burning becomes even more dominant over $^3He + ^4He$ burning. So one gets much less ^7Be than the standard model predicts, but that little bit is much more likely to form ^8B.

The result is a better but still very imperfect fit to the solar neutrino data, without recourse to new particle physics. But it does require three adjustable paramenters, whereas the Mikheyev–Smirnov–Wolfenstein model, the most popular of the scenarios that wed the standard solar model to new neutrino physics, achieves a much better fit with only two free parameters. (See PHYSICS TODAY, April 1995, page 19.) "Even I would bet on the MSW model, if I had to wager," Haxton told us. "But those two MSW parameters have extraordinary implications for particle physics. So it might be prudent not to close the books on astrophysical solutions just yet. The standard one-dimensional helioseismology calculations don't really constrain the kind of mixing-plume picture we've sketched."

Nonetheless, Bahcall and coauthors undertook to calculate the sound velocities implied by the ^3He mixing scenario, and they claim that those velocities differ from the helioseismological measurements by as much as 8% in the core region. The standard-solar-model calculation without mixing, which nowhere differs from the measurements by more than 0.2%, does include a much slower kind of transport: the steady gravitational diffusion of heavier elements down toward the center. Even before this subtle but indisputably real effect is included, the standard-model calculation (blue curve) already agrees with the measurements to within 1%. "That kind of improvement of an already good match would be very unlikely if the agreement with the standard model were fortuitous," says Harvard astrophysicist William Press.

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References

1. A. Cumming, W. Haxton. Phys. Rev. Lett. **77**, 4286 (1996).
2. J. Bahcall, M. Pinsonneault, S. Basu, J. Christensen-Dalsgaard, Phys. Rev. Lett. **78**, 171 (1997). ■