gene cloning and DNA sequencing. But the data that have since flowed from this technology, patchy though it is, is consistent with those initial predictions, he says. "Molecular maps covering 100 kb of DNA are characterized by islands of transcribed sequences in a sea of silent DNA," write Loomis and Gilpin. "But how do you summarize the empirical data?" asks Loomis. "You can take the globin region, you can take the chorion region and so on and so on. Each case is just a single case, and you need the sum of a hundred or so. No one has compiled that." Hence the importance of the computer-generated genomes.

It is of course very difficult to prove that a structure or a sequence of DNA has no function. "People will always say, ah, but you haven't looked under the right conditions," says Loomis. In the case of multigene families, the best data come from mutation experiments. Nematodes, for instance, have two acetylcholinesterase genes, both of which have to be inactivated before the animal is paralyzed. "Knock either one out, and the worm is fine, which tells you that the fact that there are two genes in this family is of no particular functional significance, probably," says Loomis. But this kind of work is exceedingly hard to do, and so the data coming from it will be limited.

Loomis and Gilpin have by now generated many complex genomes using their simulation program. "I considered at one point following in detail the history of different sections," says Loomis. "I would have been able to say, here's where the duplication occurred, here's where the deletion occurred and so on. It would have been a clear evolutionary tree." He didn't do it, because he realized there would be no real information to be gained. "Every simulation is different and therefore any given simulation is rather meaningless: each is like a different planet."

Although the simulation data encourage Loomis to believe that his earlier predictions are correct, this recent work should not be seen as answering every question about eukaryotic genomes, he stresses. "We are simply explaining one aspect of genomes: the outcome of random duplications and deletions. For instance, multigene families can appear as a consequence of random duplications and deletions, and have no necessary selectively advantageous function. Large quantities of dispensable sequences will accumulate in the genome before its size stabilizes. We are not trying to explain anything else." ■ **ROGER LEWIN**

ADDITIONAL READING

W. F. Loomis and M. E. Giplin, "Multigene families and vestigial sequences," *Proc. Natl. Acad. Sci. U.S.A* **83**, 2143 (1986).

Briefing:

A Solution to the Solar Neutrino Puzzle?

Two Soviet physicsts have offered what seems to be the most natural and plausible explanation yet for the mystery of the missing solar neutrinos. Their mechanism requires no exotic new particles, no unobserved new forces, and no modifications to the standard model of the solar interior.

Instead, S. P. Mikheyev and A. Yu. Smirnov of the Institute for Nuclear Research, Academy of Sciences, Moscow, have pointed out a previously unrecognized effect caused by the conventional weak interactions. Simply put, electron-type neutrinos emitted in the core of the sun are changed into muon-type neutrinos on their way out. These transformed particles then escape detection on Earth.

Although Mikheyev and Smirnov actually announced their result at a meeting last year in Finland, it was not widely appreciated until this spring, when Cornell University physicist Hans A. Bethe called attention to it in a paper published in *Physical Review Letters*. "I think this is the first explanation [of the solar neutrino problem] that could be right," Bethe says, echoing a perception now common among his colleagues. As University of Washington physicist Wick Haxton puts it, "Looking back, it's almost unbelievable that this mechanism was overlooked for so long."

Indeed, the solar neutrino problem is now nearly two decades old. According to the standard argument, nuclear reactions in the core of the sun will produce neutrinos at a certain, calculable rate. These neutrinos will then stream freely through the sun's outer layers and will be detectable on Earth. However, the standard argument is clearly going wrong somewhere: a solar neutrino detector developed by Brookhaven National Laboratory's Raymond Davis has operated since 1968 in South Dakota's Homestake gold mine, and has consistently measured a neutrino flux of only one-third the predicted value.

The theorists are thus left with two alternatives. Either the neutrinos are not being produced at the predicted rate—and it is hard to think of a plausible reason why not, since the standard model of the sun is based on well-understood nuclear physics and has been very successful in relating the mass and composition of the sun to its luminosity and lifetime—or else the particles are somehow getting lost on their way to South Dakota. More precisely, since the Homestake detector is sensitive only to electron neutrinos produced by certain high-energy reactions, it is the high-energy electron neutrinos that are getting lost. The question is, Where?

The answer given by Mikheyev and Smirnov starts from the fact that any neutrino traveling through ordinary matter has a slight chance of being scattered by the weak interactions. In the case of the muon- and tau-type neutrinos this effect is negligible. However, as Lincoln Wolfenstein of Carnegie-Mellon University first pointed out in 1978, the implications for an electron neutrino are quite different: the particle behaves as if its mass had been increased by a tiny fraction proportional to the density of the surrounding matter.

What Mikheyev and Smirnov realized is that this tiny effect can have large consequences at the center of the sun, where the density is more than 130 grams per cubic centimeter. In those regions an electron neutrino might actually be more massive than its cousin, the muon neutrino; moreover, as the electron neutrino propagated outward to regions of lower density and lower mass it would actually *become* a muon neutrino—and thus be rendered unobservable in the Homestake detector.

This mechanism obviously depends upon neutrinos having a small mass to begin with. It also requires a certain amount of mixing between the electron and muon neutrinos—that is, a certain probability that one type of neutrino can transform itself into the other as it moves along. While neither of these phenomena have been observed in the laboratory, both are predicted by the grand unified theories of particle interaction. Indeed, by requiring that the Mikheyev and Smirnov theory agree with the data from the Homestake detector, Bethe and others have estimated that the mass of the muon neutrino is less that 0.008 electron volts, and that the probability of mixing is less than 1 percent. Both figures are right in line with the results of the grand unified theories.

Unfortunately, it will be very difficult to detect such small effects in laboratory experiments. However, some predictions of the Mikheyev-Smirnov theory could be tested by a solar neutrino detector made of gallium—a project often proposed, and never yet funded. "It's deserved support for many years," says Paul Langaker of the University of Pennsylvania. "And now it's even more important." ■ **M. MITCHELL WALDROP**

ADDITIONAL READING

S. P. Mikheyev and A. Yu. Smirnov, in *Proceedings of the Tenth International Workshop on Weak Interactions*, Savonlinna, Finland, 16–25 June 1985 (unpublished).
H. A. Bethe, "Possible explanation of the solar neutrino puzzle," *Phys. Rev. Lett.* **56**, 1305 (1986).