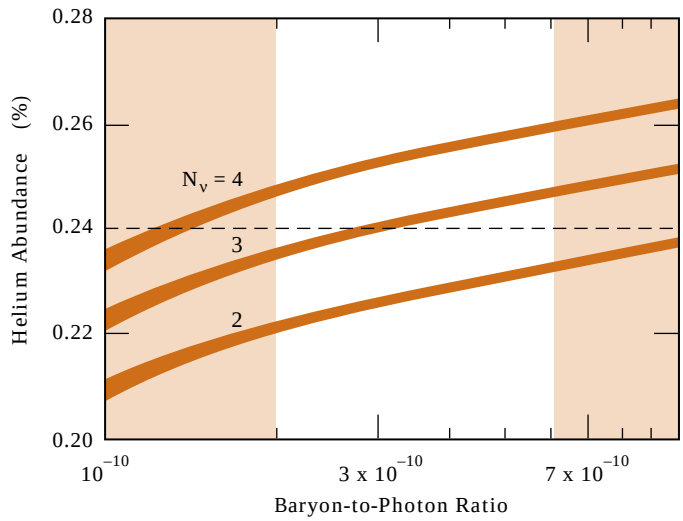

Plot of some of the consequences of nucleosynthesis during the hot dense (big bang) phase. Observed abundances of lithium-7 and deuterium in gas and stars that have experienced very little nuclear processing require that the real universal density of baryonic material (the baryon-to-photon ratio) fall somewhere in the white stripe—corresponding to a baryon density less than 10 percent of the closure density. Then the fact that the abundance of helium is, at very most, a little more than 24 percent says that there can be at most three neutrino flavors in the early universe. (Courtesy C. Copi and D. Schramm, University of Chicago)

made it out of the parent star and through space to us. This is probably rather smaller than the best laboratory limit, and the 1987A data also set limits to neutrino masses, coupling to right-handed and Majorana neutrinos, and such that are comparable to or better than the laboratory numbers.

3. Quite a few of the things you might think of doing with neutrinos would mess up the early universe, including, in particular, adding to the "known" three flavors. A fourth or fifth neutrino family would speed up the early expansion so much that too many neutrons would survive to form more helium than we see. There is, of course, also a limit of roughly three neutrino flavors from the laboratory width of Z^0 decay, but, because we do not know lifetimes or masses a priori, the two considerations rule out somewhat different volumes of parameter space.

4. Any new bosons or weakly interacting massive particles you might want to dream up must not couple to ordinary or degenerate matter tightly enough to transport much energy in either normal stars or white dwarfs and neutron stars. If they do, you will cool off your WDs and NSs too fast (so we wouldn't see the ones we see) and change the internal density and temperature distribution of nuclear-burning stars away from the ones needed to reproduce known correlations of stellar masses, luminosities, radii, and evolutionary phase.

A cross section of 10^{-36}cm^2 at stellar temperatures borders on being "too big" for a number of these contexts. Another false alarm was the attempt to reduce neutrino emission from the sun by cooling its interior with WIMPs whose cross sections fell in the borderline range. At least two problems resulted. The interior distribution of density no longer matched the one derived from analysis of solar pulsation frequencies, and later stages of evolution, like the horizontal branch phase, became so short-lived that you couldn't account for the large numbers of stars seen in them.

There are also a few cases where something new under the sun might still improve agreement between models and observations. One of these is the possible presence of pion condensate or strange quark matter in the interiors of neutron stars (which we should then call pion stars, quark stars, or some such). Either one will hasten cooling after nuclear reactions stop. This could be useful if existing upper limits on thermal emission from the surfaces of neutron stars should ever get pushed lower than the predictions from conventional cooling curves. In addition, each permits a given mass to be somewhat more compact without collapsing. Thus the star can rotate a bit faster without slinging mud in theorists' faces. At the moment (2:37 p.m. Wednesday, September 25, 1996) the two shortest periods of rotation measured for neutron stars are both quite close to 1.55 msec and are comfortably accommodated by most ordinary equations of state for nuclear matter. The false alarm of a 0.5 msec pulsar reported at the site of SN 1987A several