Fermilab Library
0 1160 0009263 9

UAB - FT - 283

UAB – FT – 283
20 March 1992

ASTROPHYSICAL (SN1987A) CONSTRAINTS ON THE DIRAC NEUTRINO MASS*

J.A. GRIFOLS

Grup de Física Teòrica,
Universitat Autònoma de Barcelona,
08193 Bellaterra (Barcelona), Spain

FERMILAB
JUL 29 1992
LIBRARY

ABSTRACT

Dirac masses of any neutrino species can be bounded by Supernova cooling arguments. The so obtained upper bound lies in the tens of keV. This is obviously relevant for the case of the 17 keV neutrino. We conclude that general luminosity arguments cannot strictly reject the 17 keV neutrino, but detailed analyses using star evolution codes that include the backreaction of neutrino cooling probably do.

ROUTE TO | NAME | LOCATION | RETURN TO

* Invited talk given at the Int. Workshop on Electroweak Physics Beyond the Standard Model, Valencia, Oct. 2-5, 1991 and at the XIIth Moriond Workshop on Massive Neutrinos and tests of Fundamental Symmetries, Les Arcs, Jan. 25 - Feb. 1, 1992.

The energy drain in Supernova collapse proceeds mainly through thermal neutrino emission. This is a surface effect. The neutrinos diffuse through the very dense material (neutrino trapping occurs for core densities in excess of $2 \times 10^{11} g/cm^3$) experiencing very many scatterings until they reach the neutrino-sphere where they are subsequently blackbody radiated. The gravitational binding energy released is about 10^{53} erg. Indeed, at most 4×10^{53} erg are emitted and from observational data[1] (IMB, Kamiokande) on SN1987A we know[2] that the energy carried away by neutrinos was larger than 2×10^{53} erg. This energy was radiated in a diffusion time on the order of 1-10 seconds. As a consequence any additional energy drain (besides the one associated to standard left-handed (LH) neutrino emission) should have a luminosity below 2×10^{53} erg/s.

Should neutrinos be massive Dirac particles, then right-handed (RH) degrees of freedom do exist and they should provide for an extra source of SN cooling[3–6]. In fact, RH-neutrinos should be produced in the hot SN core via helicity flip mechanisms. For small enough neutrino mass, RH-neutrinos stream freely out of the star because RH-neutrinos are (almost) sterile. This is a volume effect. The size of the effect is proportional to the neutrino mass squared and the relevant spin-flip processes are: neutrino nucleon elastic scattering, nucleon nucleon neutrino bremsstrahlung and e^+e^- annihilation. The RH-neutrino luminosity associated to the processes that take place in bulk matter of the SN core ($T \sim 60 MeV$, $R \sim 10 Km$) can be easily calculated.

One reaches the conclusion that[5]

$$m_\nu \lesssim 14\ keV$$

otherwise, the emission power would exceed the limit 2×10^{53} erg/s.

We can check "a posteriori" that neutrinos with $m_\nu < 14\ keV$ do indeed stream out freely. The mean-free-path in the core is calculated to be

$$8 \times 10^2\ km \left(\frac{50\ keV}{m_\nu}\right)^2$$

when the main opacity source $\nu_R N \to \nu_L N$ is taken into account. Now, it is obvious from this that by increasing m_ν sufficiently we shall reach a diffusion regime and, if m_ν is large enough, the corresponding difussion time will be long enough such that

the luminosity is again below 2×10^{53} erg/s. Hence a *lower* neutrino mass bound (as oposed to the previous *upper* limit) follows. It can be obtained in the following way. First, the ν_R-sphere R is calculated by imposing that the optical depth

$$\tau(r) = \int_r^\infty \frac{dr}{\lambda} \qquad (\lambda = \text{mean} - \text{free} - \text{path})$$

be 2/3 at $r = R$. Next, use Stefan-Boltzmann's law to compute the luminosity. One needs to know for this purpose the temperature at the ν_R-sphere (and we use the temperature profile of ref. 7). The luminosity depends inversely on m_ν^2 and the constraint $L < 2 \times 10^{53} erg/s$ implies then

$$m_\nu \gtrsim 34\ MeV$$

Hence, there is a forbidden mass window between about 14 keV and 34 MeV for the Dirac neutrino mass of any species. Only the lower end of this range is of phenomenological interest. Specially in the light of the 17 keV Simpson neutrino[8]. In this respect, the question arises as to the reliability of the bound. Of course, a (most) important source of uncertainty is our ignorance of the equation of state at supernuclear densities. Allowing for the density to change by a factor of two implies that the core temperature spans the range 30 to 100 MeV (i.e. the typical temperature interval entertained in models of stellar collapse) and leads to a factor ~ 3 uncertainty in the bound.

This bound - based on the luminosity argument - could be somewhat improved but not much. We expect that by including previously neglected effects (like charged current processes in nucleon-nucleon bremsstrahlung) one may reach the limit

$$m_\nu \lesssim O(10\ keV) \times (3^{\pm 1})$$

On the other hand, similar conclusions can be obtained using other arguments. Burrows and Gandhi[6] obtain $m_\nu \lesssim 28\ keV$ based on detailed numerical analysis using proto-neutron star evolution codes which include the backreaction of cooling via massive neutrinos. In particular, they study the effect of cooling by emission of wrong helicity neutrinos on the duration of the detected neutrino bursts. Unless $m_\nu \lesssim 28\ keV$, this duration is intolerably short.

Recently, Turner[9] has reexamined the issue and claims that the absolute limit should be well below 10 keV.

Our own conclusion is that the sole luminosity argument is unable to exclude the 17 keV neutrino and that one needs more elaborate considerations as well as detailed analysis (such as the ones used in refs. 6 and 9) to exclude the 17 keV neutrino.

REFERENCES

1. K. Hirata et al., *Phys. Rev. Lett* (1987) 1490;
   R. Bionta et al., *Phys. Rev. Lett* (1987) 1494.
2. D.N. Schramm, in: *1987 Int. Symp. on Lepton and Photon interactions at high energies*, eds. W. Bartel and R. Rückl (North-Holland, Amsterdam, 1988) p. 471.
3. G. Raffelt and D. Seckel, *Phys. Rev. Lett.* **60** (1988) 1793.
4. K.J.F. Gaemers, R. Gandhi and J.M. Lattimer, *Phys. Rev.* **D40** (1989) 309.
5. J.A. Grifols and E. Massó, *Phys. Lett.* **B242** (1990) 77.
6. R. Ghandi and A. Burrows, *Phys. Lett.* **B246** (1990) 149.
7. M.S. Turner, *Phys. Rev. Lett.* **60** (1988) 1797.
8. J.J. Simpson, *Phys. Rev. Lett.* **54** (1985) 1891.
9. M.S. Turner, FERMILAB-Pub-91/136-A, May 1991.