MATTERS ARISING

Neutrinos of non-zero mass in Friedmann universes

AN interesting comparison of independent methods for calculating the age of the Universe was proposed by Symbalisty *et al.*[1] to obtain a consistent age limit for the Universe in the range

$$13.8 \text{ Gyr} \leq T_U \leq 24 \text{ Gyr} \qquad (1)$$

This has prompted us to make some further applications by using these data to impose stringent limits on the mass of light (≤ 1 MeV) neutrinos in Friedmann universes.

Cosmological arguments have been effectively[2] used to set upper limits on neutrino masses using the values of the Hubble constant, H_0, and the deceleration parameter, q_0, in a universe uniformly populated with neutrinos. We obtain here such limits with the help of the data provided by Symbalisty *et al.* without any recourse to the values of the cosmological parameters H_0, q_0, which are in any case very uncertain.

In Friedmann models the present age T_U of the Universe is given by[3]

$$T_U = H_0^{-1} f(q_0), \qquad (2)$$

where $f(q_0)$ is a monotonically decreasing function of q_0, attaining its maximum value at unity when q_0 approaches zero and tending to zero as q_0 becomes infinitely large. Now, Einstein's equations relate the measurable quantities H_0, q_0 and the present mass density ρ_0 of the Universe by the equation

$$\rho_0 = \frac{3H_0^2 q_0}{4\pi G} \qquad (3)$$

This enables us to write

$$T_U = \left(\frac{3}{4\pi G\rho_0}\right)^{1/2} q_0^{1/2} f(q_0) \qquad (4)$$

Let us now consider a situation at the present epoch where we can specify the mass density of the Universe and treat q_0 as a parameter. It can be easily demonstrated that the function $q_0^{1/2} f(q_0)$ increases monotonically, approaching a maximum of $\pi/2^{3/2}$ as q_0 tends to infinity. Thus, the maximum possible age, T_{max}, for closed Friedmann models ($q_0 > \frac{1}{2}$) is given by

$$T_{max}^{closed} = \pi\left(\frac{3}{32\pi G\rho_0}\right)^{1/2} \qquad (5)$$

and for open models ($0 < q_0 < \frac{1}{2}$), we have

$$T_{max}^{open} = \left(\frac{1}{6\pi G\rho_0}\right)^{1/2} \qquad (6)$$

With the input of ages from Symbalisty *et al.* or from any considerations like nucleocosmochronometry, equations (5) and (6) can be used to obtain upper bounds on neutrino masses. Given the present age, T_U, the requirement $T_U \leq T_{max}$ provides maximum possible mass density ρ_0 for closed and open models. Let us consider neutrinos and antineutrinos of electron, muon and tau type, each having the same mass m. The present number density, $n_{\nu_i}(0)$ of relic neutrinos and antineutrinos of type $i \cong 110 \text{ cm}^{-3}$. Then for a typical age of 14×10^3 Myr the upper bounds on the neutrino mass will be 38.70 eV and 6.92 eV for closed and open models, respectively. For the age of 20×10^3 Myr the same numbers will be 18.91 eV and 3.38 eV.

It is readily seen that the data on the age of the Universe place fairly tight limits on neutrino masses. The recent experimental limits[4] give neutrino masses of the order of a few electron volts, although the Russian experiment[5] reports them to be in the range 14–46 eV. Our results indicate that neutrino masses of the order of several tens of electron volts appear inconsistent with the lower limit on the age implied by nucleocosmochronometry. Again the experimental measurement of neutrino mass ≥ 14 eV is not accommodated in standard open models. Thus, if the neutrinos were to have mass of a few tens of electron volts, the data on the age suggest that neutrinos would dominate the mass of the Universe, leading to its closure[6,7]. Further details and some more applications of these results will be published elsewhere[8].

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Recent $^{13}C/^{12}C$ trends in atmospheric CO_2 and tree rings

FRANCEY'S[1] $^{13}C/^{12}C$ record in tree rings from seven Tasmanian trees shows no systematic decrease. Such a decrease would be expected due to the dilution of the atmospheric CO_2 pool by $^{13}C/^{12}C$ deficient CO_2 released by fossil fuel combustion and forest clearing. Francey therefore questions the interpretation of $^{13}C/^{12}C$ tree ring records in terms of global CO_2 behaviour.

Measurements of more than 30 trees from the Northern Hemisphere published elsewhere[2–10] show, however, a systematic decrease of the $^{13}C/^{12}C$ ratio in tree rings over the second half of the past century (measurements of eight trees over this period) and the first quarter of this century, followed by some increase of the ratio between 1940 and 1960. From about 1960 to 1975 a further decrease of the $^{13}C/^{12}C$ ratio is observed in our more extensive tree-ring record[5,6] from measurements on 22 free-standing trees of different Northern Hemisphere origin (see Fig. 1). This decrease in mean $^{13}C/^{12}C$ tree-ring data compares favourably with the $^{13}C/^{12}C$ decrease in atmospheric CO_2 between 1956 and 1978 determined directly by Keeling *et al.*[11,12]. Such a decrease is also found in measurements on Southern Hemisphere trees, for example one Brazilian tree determined by Rebello and Wagener[13]. Consequently, from a mean record calculation using all published tree-ring data I conclude that the $^{13}C/^{12}C$ ratio in modern wood has decreased significantly[14]. In fact, Pearman *et al.*[15,16] obtained a $^{13}C/^{12}C$ trend on three Tasmanian trees consistent with trends of some other records, which they explained as climatic implications. These three trees are included in the seven trees used by Francey[1] and now demonstrate the absence of any $^{13}C/^{12}C$ trend in tree rings.

Five of the Tasmanian trees were from a rain forest. Forest trees may not reflect the change in the $^{13}C/^{12}C$ ratio of atmospheric CO_2 because of canopy effects and partial uptake of soil respiration CO_2. The $^{13}C/^{12}C$ ratio in the latter would be

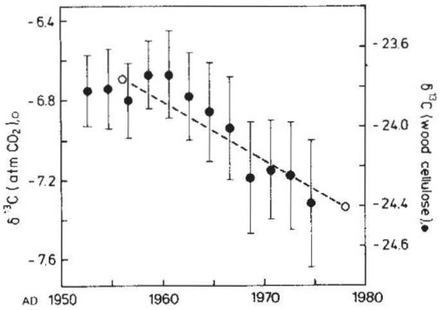

Fig. 1 $\delta^{13}C$ decrease in tree rings derived from about 22 trees of Northern Hemisphere origin for the 1952/53–1974/75 period (●, right scale; adjustment of numerical data from Freyer[6] to $\delta^{13}C = -23.86‰$ for average AD1930–1950 wood cellulose) compared with the $\delta^{13}C$ decrease in atmospheric CO_2 observed by Keeling *et al.*[11,12] (○, left scale). The two scales are offset by −17.07‰ (from centre of gravity coordinates) to account for isotopic fractionation between atmospheric CO_2 and the average of wood cellulose in these trees. The bars of tree-ring data represent 95% confidence limits based on Student's *t* distribution.

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