

## Conclusion

The picture of the junctional channel that emerges from these experiments is of an unusual ionic channel. The fully open channel has a conductance of  $\sim 120$  pS, but states of lower conductance (caused by partial opening or partial obstruction) are frequently encountered. The transitions between the open and closed states are surprisingly slow (several tens of milliseconds). It is conceivable that during these transitions, the channel molecular complex spends some time in several of the states corresponding to the intermediate levels of conductance. The occasional observation of larger conductance jumps suggests that groups of channels operate with a strong internal cooperativity. Finally, the junctional channels discriminate

poorly between cations and anions, cations being slightly more permeable than anions.

The double patch-clamp technique, by enabling control of the composition of the solutions bathing the two faces of a junction, appears to be well suited to the study of mechanisms controlling the permeability of intercellular junctions. For instance, our experimental approach (see also ref. 27) should help to elucidate the intracellular mechanisms involved in the modulation of cell-cell junctions by neurotransmitters<sup>27-31</sup>.

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## LETTERS TO NATURE

### Possible cosmological scenario with an unstable 17-keV neutrino

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Simpson<sup>1</sup> has recently reported evidence for a heavy neutrino of  $\sim 17.1$  keV mass. Cosmological bounds on stable neutrino species imply that this neutrino ( $\nu_H$ ) must be unstable. The most likely decay mode,  $\nu_H \rightarrow \nu_L + f$  where  $\nu_L$  is a light neutrino and  $f$  is a scalar boson, leads to the cosmological scenario presented here, which is quite different from the conventional one. In this scenario, the Universe becomes matter dominated at a redshift of  $z \sim 10^7$  and becomes radiation-dominated (by the decay product  $\nu_L$  of  $\nu_H$ ) at  $z \sim 310$ . The kinematic constraints on the lifetime of  $\nu_H$  do not lead to any contradictions. On the other hand, the growth of baryonic perturbations is severely limited in this model because virtually no growth can take place in the radiation-dominated region  $z < 310$  and decay of  $\nu_H$  is likely to disrupt and smooth-out past growth by a large factor. It is doubtful whether there is a simple way to avoid this difficulty.

A stable  $\nu_H$  with a mass of 17 keV will provide the Universe with  $\sim 300$  times the closure density  $\rho_c$  (for bounds on neutrino masses from cosmology, see refs 2, 3), which is excluded by the observational bounds on the deceleration parameter (see ref. 4). Among the possible decay channels available, the radiative channel ( $\nu_H \rightarrow \nu_L + \text{photons}$ ) is severely constrained by the photon emissivity of the Galaxy<sup>5-8</sup>, whereas the decay mode  $\nu_H \rightarrow \nu_L \bar{\nu}_l + \nu_L$  has a much longer half-life than the age of the Universe<sup>9</sup>. A remaining possibility is the decay of  $\nu_H$  (identified with muon neutrino) into  $\nu_L$  (identified with electron neutrino) and a Goldstone boson  $f$  that couples weakly to a flavour-

changing neutrino current ( $\nu_H \rightarrow \nu_L + f$ ). The lifetime ( $\tau$ ) for such a decay<sup>10</sup> is given by

$$\tau = 6.72 \times 10^{11} \left( \frac{F}{10^{10} \text{ GeV}} \right)^2 \left( \frac{m_H}{17 \text{ keV}} \right)^{-3} \text{ s} \quad (1)$$

where  $F$  is the symmetry-breaking scale for the interaction and  $m_H$  is the mass of  $\nu_H$ . From the  $\mu$ - $e$  decay one can obtain the lower bound

$$F_{10} \equiv \left( \frac{F}{10^{10} \text{ GeV}} \right) \geq 0.14 \quad (2)$$

There are essentially no other constraints on  $F$ . We assume that  $\nu_L$  has a mass in the range  $10 \text{ eV} < m_L < 40 \text{ eV}$ , as suggested in some experiments<sup>11</sup>. Most of our results do not depend crucially on the value of  $m_L$ .

The cosmological scenario that follows from the above assumptions is easy to analyse<sup>12-15</sup>. At very early epochs,  $z \geq 10^{10}$ ,  $\nu_H$  remains in equilibrium and decouples at  $z = 10^{10}$  (ref. 9). (Helium synthesis takes place around this epoch. The effect of  $\nu_H$  on helium is under investigation.) As the Universe cools,  $\nu_H$  becomes non-relativistic at the redshift of  $z = z_{NR} \approx 10^8$  (when  $kT = m_H c^2$ ) and begins to dominate the energy density ( $\rho(\nu_H) = \rho(\text{others})$ ), slightly later at  $z = z_{eq} = 5.5 \times 10^6 m_{17}$  (we denote ( $m_H/17 \text{ keV}$ ) as  $m_{17}$ ). The time elapsed since the big bang is

$$t_{eq} = 2.97 \times 10^6 m_{17}^{-2} \text{ s} \ll \tau \quad (3)$$

so that the decay of  $\nu_H$  is completely negligible at these epochs. For  $t_{eq} < t \leq \tau$  the Universe is completely dominated by the non-relativistic  $\nu_H$ . The expansion factor  $S(t)$  varies as  $t^{2/3}$  during this epoch. For  $t \geq \tau$  the decay of  $\nu_H$  becomes important. We take the decay to be virtually complete at  $t = t_D$  when  $\rho(\nu_H) \approx \rho(\text{others})$  again. A simple calculation gives

$$t_D \approx 10.4 \tau \quad (4)$$

The photon temperature at the half-life time is  $T_\gamma(\tau) =$

$2.8 \times 10^3 m_{17}^{5/3} F_{10}^{-4/3}$ . We consider the decay to have occurred between  $t = \tau$  and  $t = t_D$ .

In conventional scenarios, the Universe would have been dominated by non-relativistic matter (either baryons or massive light neutrinos) at  $T_\gamma \leq 3,000$  K. The situation here is different. Every  $\nu_H$  produces a  $\nu_L$  with an energy of  $\sim 0.5 m_H = 8.5$  keV on its decay. (The  $f$ -particle which carries  $0.5 m_H$  is virtually massless in most models.) As  $m_L < 40$  eV, the electron neutrinos are extremely relativistic at the time of production. Because their number densities are of the same order as that of photons and primordial  $\nu_L$ , these relativistic decay products dominate the energy density for  $t > t_D$ . Because most of the  $\nu_H$  decays at  $t \geq \tau$ , a reasonable fraction of decay product  $\nu_L$  will become non-relativistic only when the radiation temperature is lower than

$$T \approx T(\tau) \left( \frac{m_L}{8.5 \text{ keV}} \right) \approx 3.2 \text{ K} \left( \frac{m_L}{10 \text{ eV}} \right) \quad (5)$$

Because the complete evolution of the Universe is known we can compute the age of the Universe to be

$$t_U \approx 4.68 \times 10^{10} F_{10}^{-2/3} m_{17}^{1/3} \text{ yr} \quad (6)$$

Taking the age of the globular clusters  $t_{GC} = 1.5 p \times 10^{10}$  yr, where  $p$  is the 'personal prejudice factor'  $\sim 1$ , and demand  $t_U > t_{GC}$ , we obtain the constraint

$$F_{10} \leq 5.51 p^{-3/2} m_{17}^{1/2} \quad (7)$$

A similar constraint can be obtained from the energy density of the decay products of  $\nu_H$ . This energy density is given by

$$\rho = 2.82 \times 10^{-27} \text{ g cm}^{-3} m_{17} \left( \frac{\tau}{t_U} \right)^{1/2} \quad (8)$$

(It is assumed that  $t_0 = \nu_H$ -decoupling epoch  $\ll \tau \ll t_U$ ; see ref. 9.) Demanding  $\rho \leq \Omega_m \rho_c$  (where  $\Omega_m$  is another prejudice factor expected to be  $\sim 1$ ), we obtain ( $H_0 = 100 h_0 \text{ km s}^{-1} \text{ Mpc}^{-1}$ )

$$\left( \frac{\tau}{t_U} \right) \leq 4.98 \times 10^{-5} \Omega_m^2 h_0^4 m_{17}^{-2} \quad (9)$$

which, when coupled with equations (1) and (6), produces the constraint

$$F_{10} \leq 2.45 \Omega_m^{3/4} h_0^{3/2} m_{17}^{1/2} \quad (10)$$

Although these are interesting cosmological bounds on  $F_{10}$ , they do not lead to any contradiction.

A disturbing contradiction arises, however, when we look at the growth of perturbations in this scenario (see ref. 16). Perturbations in the non-relativistic component cannot grow much in a universe dominated by relativistic particles<sup>17</sup>. Thus, the growth of baryonic perturbations is effectively confined to epochs at which  $T_\gamma > T_\gamma(t_D)$ , that is,  $T_\gamma > 590$  K. On the other hand, baryonic perturbations can grow only after they decouple from radiation, that is, only during  $T_\gamma < T_{\text{recombination}} \approx 3 \times 10^3$ . If one follows adiabatic growth, which evolves as  $\propto S(t)$  in the matter-dominated epoch, we obtain a growth factor of only  $\sim 5$ , which is totally insufficient. This argument, however, is not complete. Perturbations in  $\nu_H$  can grow right from  $z \sim 10^7$ . There is a possibility that the baryons, as soon as they decouple (at  $T \approx 3 \times 10^3$  K) 'fall' into the already existing  $\nu_H$  potential well and quickly attain a density contrast value of  $(\delta\rho/\rho)_B \approx (\delta\rho/\rho)_\nu$  (see ref. 18). It turns out that the values are still insufficient.

From the study of galaxy-galaxy correlation function, it is known that the scales which are entering the nonlinear regime today  $(\delta\rho/\rho) \sim 1$  have a size  $L \approx 5 h_0^{-1} \text{ Mpc}$ . This length scale  $L$  entered the horizon in the past (in the  $\nu_H$ -dominated era) when the radiation temperature was

$$T_L = T(\tau) \left( \frac{3c\tau}{L} \right)^2 \left( \frac{T_\tau}{T_{\gamma 0}} \right)^2 \approx 9.8 \times 10^4 \text{ K} \quad (11)$$

In the best possible situation, the growth factor obtainable ( $\varepsilon$ ) is

$$\varepsilon \equiv \frac{T_L}{T(10.4\tau)} \approx 170 \quad (12)$$

(In equation (12), it is assumed, unrealistically, that the density contrast of baryons instantaneously increases to the pre-existing  $\nu_H$ -density contrast, just after decoupling.) Thus, the perturbations when they enter the horizon must have an amplitude

$$\left( \frac{\delta\rho}{\rho} \right)_H = \varepsilon^{-1} = 6 \times 10^{-3} \quad (13)$$

which is  $\sim 600$  times higher than the usually accepted value of  $10^{-5}$ . Currently popular models interpret  $(\delta\rho/\rho)_H$  to be the signature of quantum fluctuations that 'went out' of horizon at a primordial epoch<sup>19</sup>. It is difficult to imagine a scenario that will allow widely different  $(\delta\rho/\rho)$  for neutrinos and baryons at the primordial epoch. (The baryonic part of  $(\delta\rho/\rho)$  is severely constrained by observations on temperature anisotropies of microwave background to be  $\leq 10^{-5}$ .) The existence of 17-keV  $\nu_H$  may thus undo the original benefits of a neutrino-dominated Universe.

There is another problem with the dynamics. When the  $\nu_H$  decays, all scales at which

$$t_{\text{dyn}} > \tau \quad (14)$$

(where  $t_{\text{dyn}}$  is the dynamic, free-fall timescale of the particular condensate) will be disrupted. For galactic sizes,  $t_{\text{dyn}} \approx 3.15 \times 10^{15} \text{ s}$  and  $\tau \approx 10^{12} F_{10}^2 m_{17}^{-3} \text{ s}$ . We cannot violate equation (14) while maintaining the bound equation (10) on  $F_{10}$ . It is necessary to assume that only scales much smaller than galactic sizes survive the disruption. Stable scales (with  $t_{\text{dyn}} < \tau$ ) will respond adiabatically and increase in size by a factor of  $f \sim (\rho_{\nu_H}/\rho_B) \sim 10^3$ . Still, one would expect larger clustering at small scales than predicted in the standard scenarios.

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## HCN emission from OH infrared sources

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Radio line emission of the HCN molecule has been considered to be a tracer of carbon-rich circumstellar environments<sup>1</sup>. We report here, however, the detection of HCN radio emission from oxygen-rich late type stars. These results relate to the issue of the progenitors for planetary nebulae<sup>2</sup>. The presence of the HCN molecule in oxygen-rich stars suggests that complex photochemical reactions are proceeding in the outer circumstellar envelope of late type stars.