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ON THE POSSIBILITY OF NEUTRINO ATMOSPHERES OF CELESTIAL BODIES

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If the rest mass of a (say, muon) neutrino is not zero there may arise peculiar physical situations with non-trivial consequences in the range of astrophysical phenomena up to the production of neutrino cosmic objects like superstars.

With non-zero rest masses, neutrinos, subject to a purely gravitational attraction of celestial bodies, will produce macroscopic-size bound systems.

Indeed, for a neutrino of mass m_ν in the gravitational field of a celestial body of mass M, the radius of the corresponding "Bohr" orbit is

$$r \approx \frac{\hbar^2}{\kappa\ m_\nu^2\ M} \tag{1}$$

where κ is the gravitation constant.

For the neutrino mass $m_\nu \approx 10^{-4}\ m_e$ the radius of the "Bohr" orbit is of the order of several dozens of meters provided the size of the celestial body is of the same order or larger and the substance density is of the order of unity. For example, the "Bohr" orbit of neutrino of the mass $m_\nu \approx 10^{-12}\ m_e$ must fit within our planet.

Thus, in the case of a non-zero neutrino rest mass there originates a mechanism of accumulation of neutrinos around celestial bodies, or a group of celestial bodies.

In this case we can refer to a neutrino atmosphere of a celestial body.

Two equilibrium state possibilities: electron-nuclear and neutron ones are usually discussed for heavy-mass celestial bodies. True, attention has recently been drawn to the possibility for a hyperon modification of matter in the superdense state/1/.

If the neutrino had a non-zero rest mass it would be possible in principle to discuss also the equilibrium states of a degenerate neutrino gas/2/.

A possible small mass of the neutrino and specific properties of this particle lead to so peculiar characteristics of celestial bodies consisting of vast assemblies of neutrinos bound by gravitation forces that we will not trespass too much against science by devoting a few lines to this discussion, while fully aware of its highly speculative nature.

At present the experimental upper limit for the electron neutrino rest mass lies near/2/ :

$$m_\nu^e \leq 4 \cdot 10^{-4}\ m_e \tag{2}$$

For a muon neutrino this limit is somewhat higher than electron mass (m_e)

$$m_\nu^\mu \leq 6\, m_e \qquad (3)$$

In terms of the general theory of relativity and ideal Fermi gas in thermodynamics and mechanical equilibrium is known to have been considered for the neutron case by Oppenheimer and Volkoff [3].

The corresponding solutions are expressed in units of length

$$a = 2\left(\frac{2\pi}{\kappa\, m_n}\right)^{1/2} \cdot \left(\frac{\hbar}{m_n c}\right)^{3/2} = 1.37\; 10^{6} \text{ cm} \qquad (4)$$

and in mass units

$$b = 1.85 \times 10^{34} \text{ g} = 9.29\ M_\odot \qquad (5)$$

here κ is the gravitation constant and m_n mass of the neutron.

Thus, the parameters of the bodies under study consisting of particles of a degenerate ideal neutrino gas (i.e., the sizes (R_ν) and masses (M_ν)) are connected with the corresponding parameters of neutron stars (R_n , M_n) by simple relations

$$R_\nu = R_n\left(\frac{m_n}{m_\nu}\right)^2 ; \qquad M_\nu = M_n\left(\frac{m_n}{m_\nu}\right)^2 \qquad (6)$$

The most surprising result of Oppenheimer and Volkoff is that the neutron star parameters scarcely at all depend on the assignment of a matter density at the centre of configuration, i.e. the neutron star masses cannot exceed the critical values which all lie below the mass of the Sun but very close to it.

Thus, one of the possible neutron star states fully determined by $\rho(r=0) = 2.2 \times 10^{39}$ neutrons/ cm^3 (in certain units $t(0) = 3$) is characterized by the parameters

$$M_n = 0.7\, M_\odot\ , \qquad R_n = 9.59 \times 10^{5} \text{ cm} \qquad (7)$$

At $\rho(r=0) \to \infty$,

$$M_n = 0.42\, M_\odot\ , \qquad R_n = 6.2 \times 10^{5} \text{ cm} \qquad (7")$$

According to eqs. (4) and (5), the corresponding masses and sizes of neutrino stars increase $\left(\frac{m_n}{m_\nu}\right)^2$ times.

In other words, in the case of muon neutrinos (let $m_\nu \approx m_e$) we have

$$M_\nu^\mu > 10^{6}\, M_\odot\ , \qquad R_\nu^\mu \geq 10^{12} \text{ cm}. \qquad (8)$$

In the case of electron neutrinos (let $m_\nu^e \leq 4 \times 10^{-4}\, m_e$) we have

$$M_\nu^e \geq 10^{13}\, M_\odot \quad \text{and} \quad R_\nu^e \geq 10^{19} \text{ cm}. \qquad (9)$$

It is noteworthy that astrophysicists have recently discovered intensely luminous celestial bodies of such masses ($10^6 - 10^8\ M_\odot$) and sizes ($\approx 10^{16}$ cm). The "superstar 3C 273-B is meant [4]. So far this sensational discovery (huge mass, peculiar luminosity) does not seem to have settled within the framework of the conventional concepts.

As for the evolution of possible neutrino cosmic objects (in particular, their luminosity and energy release) its character may depend on many different causes and in particular on the model of a star, i.e. on the mass density at $r = 0$.

The density ρ of a neutron star is known [3] to be connected with the specific units t by the relations $\rho = K_n\ (\text{sh}t - t)$ where $K_n = m_n^4 c^5 / 32\pi^2 \hbar^3$; $t = \text{arsh}\left(\frac{p_n}{m_n c}\right)$; and p_n is the upper value of the neutron gas momentum (or Fermi energy $E_F = c p_n$) .

Thus for the same value $t(0)$ the density of the neutrino star (in $r = 0$) is smaller by a factor of $\left(\frac{m_\nu}{m_n}\right)^4$ than that of the neutron star.

When the upper limit of degenerate gas energy reaches a value $E_F \geq 10^2\, m_e c^2$ in regions close to the centre of a star, i.e. when the processes $\nu_\mu + N \to N' + \mu$ become possible for the muon neutrino, the neutrino density becomes of the order of

$$N_{E<E_F} = \frac{1}{(2\pi)^2}\left(\frac{E_F}{\hbar c}\right)^3 \frac{1}{3} \approx 10^{35} \text{ particles/ cm}^3.$$

Neutrino fluxes reach values $\approx 10^{45}$ neutrinos/ cm^2sec. Relatively small densities of the usual matter will already lead to explosive-rate reactions for such neutrino fluxes.

For electron neutrinos the processes $\nu_e + N \to N' + e$ will begin at lower energies $\approx$ 1 MeV.

Finally, the evolution of the neutrino star will occur differently if there exists an ($e\nu$) ($e\nu$) interaction.

The quantitative relations between the neutrino and antineutrino components of such a celestial body may also be of importance in the evolution of the star.

The existence of such an accumulation of degenerate neutrino gas localized in sections of the universe remote from the Earth can in principle be observed by terrestrial instruments.

The fact is that at a Fermi energy of 17 keV it is Tritium that will prove stable in the region occupied by such a neutrino accumulation. A discovery of the tritium spectrum (isotopic shift of hydrogen spectrum levels) would be a unique indication of the existence of such degenerate neutrino atmospheres.

It is probable that an atom spectrum more suitable for research can be found as well if the Fermi energy may be higher.

At a Fermi energy 40 MeV π and μ mesons become stable.

Under such conditions there will arise stable atoms of "hydrogen" in which an electron is replaced by a muon.

Hard hydrogen-like spectra would testify in favour of the existence of the celestial objects under consideration. The latter should be differentiated from objects known as Geons.

With zero neutrino masses, the neutrino celestial bodies in question are not produced, or rather at $m_\nu = 0$ the critical masses and sizes of the equilibrium cold gas accumulation tend to infinity.

The thing is that Geons are treated by definition relativistically: these are in a sense dynamic formations.

The formations under consideration here permit a purely non-relativistic consideration as well, just as in the case of a degenerate neutron gas.

In the latter case the mass and size of the system are known to be given by the expression/5/

$$M R^3 = 91,9 \frac{\hbar^6}{\kappa^3 m_n^8}$$

In the case of the relativistic treatment of such objects the assigning of the boundary condition is also characteristic: at the limit of the object the neutrino velocities are zero - the boundary conditions are non-relativistic by definition.

At $m_\nu \neq 0$ there is a mechanism leading to the accumulation of neutrinos near cosmic bodies which may under corresponding conditions lead to the production of degenerate neutrino atmospheres. At $m_\nu = 0$ there is no such mechanism of accumulation leading to the origin of neutrino Geons.

As the critical mass is exceeded the objects under consideration become unstable and tend to an unlimited compression under the action of gravitation forces.

If these and similar neutron and macroscopic objects actually reach sizes of gravitation radii as these objects are compressed, they could more properly be called elementary particles than those particles which are turned thus now. The gravitation radius is for the time being the only length in modern theory which in a sense naturally restricts the size of a particle without contradicting relativism. It is not impossible that it is precisely to the gravitation radius that the future in the rational theory of elementary particles belongs/6/.

In conclusion it can be recalled that there are cosmological considerations requiring a further experimental specification of the masses of the electron and especially muon neutrino. The world would be much simpler if the neutrino had no rest mass.

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