Galactic Neutrinos and uv Astronomy

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Slowly moving massive neutrinos may be responsible for the invisible mass in galactic halos and the missing mass of the universe. Massive neutrinos are expected to decay into lighter neutrinos and uv photons, with lifetimes long on the Hubble scale. The possible detection of these neutrino-decay photons is discussed.

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Most of the energy of the universe may reside in galactic halos composed of slowly moving massive neutrinos, ν_H. These neutrinos can decay radiatively into lighter neutrinos ν_L and monochromatic uv photons:

$$\nu_H \to \nu_L + \gamma. \tag{1}$$

We discuss the possible detection of this signal. For the decay of a ν_H at rest, the photon in (1) has an energy $E=(m_H^2 - m_L^2)/2m_H$. For purposes of illustration we assume in what follows $m_H^2 \gg m_L^2$, so that $E \simeq m_H/2$.

It has been argued that most of the mass of the universe is "missing", consisting neither of luminous matter, gas, dust, nor electromagnetic or graviton energy. Perhaps the missing mass is in the form of dim or defunct stars or black holes. An appealing possibility,[1] which we adopt in this paper, is that it consists of neutrinos with nonvanishing rest mass. Evidence for missing mass exists at various length scales.

The Hubble plot of red shifts versus apparent distances is roughly linear. This implies that the universe is neither very open nor very closed: It is nearly flat. From Einstein's equations with a null cosmological constant, it is possible to estimate the average mass density required to describe the observed universe. Within large errors, it may be an order of magnitude bigger than the mass density as estimated from known sources. This "cosmological missing-mass problem" recurs more definitively in the study of objects at smaller scales[2]: clusters and groups of galaxies, binary galaxies and, most relevant to us, the halos of individual galaxies. The study of galactic halos yields "rotation curves": gas velocity distributions as functions of distance to the galactic center, obtained from observations of the Doppler shift of the 21-cm hyperfine splitting line of hydrogen. The orbiting hydrogen is shown to have velocities of 200–300 km/sec about its galaxy, quite *independent of distance* R *from the galactic center,* from distances of a few kiloparsecs to ~50 kpc, where the signal becomes too faint to detect.[2] A distribution of mass is required that extends well beyond the visible galaxy:

$$M(R) = \int^R \rho(r) dV = v^2 R G^{-1}. \tag{2}$$

Such a mass distribution corresponds to a mass density

$$\rho(r) = A r^{-2}, \quad A = 1.3 \times 10^{75} \text{ eV/kpc} \tag{3}$$

and induces a total mass perhaps an order of magnitude larger than that of the visible, localized component. All of the above is compatible with the existence of extensive neutrino halos surrounding the galaxies and ultimately providing the missing mass of the universe. Two arguments suggest that the cosmological missing mass may be accounted for by neutrinos, and that neutrinos may have clustered as galactic halos.

The first argument is based on the standard big-bang cosmology, in which photons now outnumber baryons by $\sim 10^8$. These are seen as 2.7°K background radiation. Their contribution to the universal energy density is only 10^{-4} that of baryons. Light ($m < 1$ meV/c^2) neutrinos are as copious as photons, but their contribution to the energy density depends on their rest mass. A neutrino with a Majorana mass of a few electron volts/c^2 will contribute as much as the observed baryon density. *If the heaviest neutrino weighed a few tens of electron volts/*c^2 *it would supply the required missing mass of the universe.* No terrestrial neutrino experiment belies such a possibility.

Can neutrinos, in sufficient numbers, be gravitationally bound to galaxies to form their halos? Clearly, they must be red shifted to velocities below escape velocity. This requires masses in excess of ~1 eV. Furthermore, their number density is limited by Fermi statistics. In order to supply the observed halo mass density, *the neutrinos must weigh at least ~24 eV/c^2*.[3]

From the above arguments, we conclude that the heaviest neutrino should be expected to weigh 10–100 eV/c^2. This hypothesis offers a simultaneous explanation for both the *magnitude* of the missing mass and its *location* as galactic halos.

Let us consider reaction (1) as a possible means of revealing the existence of neutrinos in galactic halos. The emitted uv photon has wavelength λ_0 between ~250 and ~2500 Å. The neutrino velocities are those deduced from the galactic rotation curves. Thus we expect a Doppler width of $v/c \sim 10^{-3}$, or about 1 Å. Three sources of these uv photons can be distinguished: those from our own galaxy, those from a neighboring galaxy, or those arising from all distant galaxies. Only for wavelengths longer than 912 Å (neutrino mass differences smaller than ~27 eV/c^2) is the interstellar medium transparent in the uv; harder photons ionize hydrogen with large cross section.

The flux of uv photons from our galaxy is expected to be strongly peaked towards the galactic center. We obtain

$$N/(\mathrm{cm}^2\ \mathrm{sec\ sr}) \sim 10^{29}(30\ \mathrm{eV}/m_H)\tau^{-1}; \qquad dN/d\theta \propto (\pi-\theta)/\sin\theta, \tag{4}$$

where τ is the neutrino lifetime in seconds and θ is the angle between the directions of observation and the galactic center. The flux of uv photons from Andromeda galaxy is

$$N/(\mathrm{cm}^2\ \mathrm{sec}) \sim 10^{27}[30\ \mathrm{eV}/m_H c^2]\tau^{-1} \tag{5}$$

and that from the universe as a whole is

$$\lambda_0 dn/d\lambda(\mathrm{cm}^2\ \mathrm{sec\ sr}) \sim 10^{25}(75/H_0)(\lambda_0/\lambda)^{5/2} \times[1+(2q_0-1)(1-\lambda_0/\lambda)]^{-1/2}\tau^{-1}, \tag{6}$$

where H_0 is the Hubble parameter (in km/sec kpc), q_0 is the deceleration parameter and λ ($>\lambda_0$) is the red-shifted wavelength of the uv photon. These results depend sensitively upon the neutrino mass (which we know roughly) and its radiative lifetime τ (which we do not know). The remainder of this paper considers estimates of τ.

If there are neutrino halos about galaxies, then we know that the neutrino lifetime must exceed the age of the universe, ~10^{10} yr. However, it is unreasonable for the actual neutrino lifetime to approach this limit. Whatever mechanism is responsible for (1) should produce other couplings of the form $(e/M)\bar{\psi}\sigma_{\mu\nu}\psi F^{\mu\nu}$, where M is a large mass characteristic of the unknown physics. A contribution to the process $\mu\to e\gamma$ could result from such an interaction. We may conclude $\tau > (m_\mu/m_H)^3 B^{-1}\tau_\mu$, where B is the branching ratio for $\mu\to e\gamma$ and τ_μ is the muon lifetime. From the observed limit[4] on B we conclude that $\tau > 10^{16}$ yr, for $m_H = 30$ eV/c^2. Similar, but not stronger, limits are obtained from the absence of anomalous contributions to muon and electron magnetic moments and from the absence of an observed neutron electric dipole moment.

With $\tau = 10^{16}$ yr and $m_H = 30$ eV/c^2, we find

$$N = 3\times10^5/\mathrm{cm}^2\ \mathrm{sec\ sr\ (our\ galaxy)}, \tag{7a}$$

$$N = 3\times10^3/\mathrm{cm}^2\ \mathrm{sec\ (Andromeda\ galaxy)}, \tag{7b}$$

$$dN/d\lambda \sim 3\times10^{-2}(1000\ \text{Å}/\lambda)^{5/2}/\mathrm{cm}^2\ \mathrm{sec\ sr}\ \text{Å} \quad \mathrm{(all\ galaxies)}. \tag{7c}$$

While the local fluxes are easily experimentally detectable, it must be emphasized that they are upper limits to what can be expected. In all models we have at hand, we obtain longer neutrino lifetimes, and photon fluxes smaller by many orders of magnitude. On the other hand, lacking a realistic theory of the origin of neutrino masses, we must take the following estimates as mere educated guesses.

We now discuss three estimates of the neutrino lifetime. We limit ourselves to the conventional Su(2) ⊗ U(1) electroweak model, supplemented by undetermined neutrino masses and mising. The effective interaction responsible for radiative decays comes from the diagrams in Fig. 1.

In the first estimate, we assume that there are just three fermion families. The neutrino states coupled to e^-, μ^-, and τ^- (denoted by ν_e, ν_μ, ν_τ) are unitarily orthonormal linear combinations of the mass eigenstates ν_H, ν_L, ν_L', where $m_H \gg m_L$, m_L'. Since the dominant diagram involves an intermediate τ^-, the only relevant neutrino mixing angle is $\langle \nu_H/\nu_\tau\rangle = \cos\beta_1$. The result[5] is

$$\tau^{-1} = G_F{}^2 m_H{}^5(512\pi^4)^{-1}\alpha\sin^2(2\beta_1)I^2, \tag{8}$$

where the factor I^2 results from the analog of Glashow-Iliopoulos-Maiani (GIM) suppression:

$$I = (m_\tau/m_W)^2[\ln(m_W/m_\tau)^2 + O(1)], \tag{9}$$

with the neglect of terms proportional to $m_e{}^2$ and

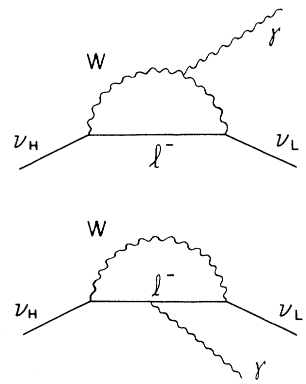

FIG. 1. Feynman diagrams contributing to radiative decay $\nu_H \to \nu_L + \gamma$ where l stands for a charged lepton, and W for the charged intermediate vector boson.

$m_\mu{}^2$. Thus we obtain

$$\tau_1 = 4\times 10^{28} \sin^{-2}(2\beta_1)(30\ \text{eV}/m_H c^2)^5\ \text{yr}, \qquad (10)$$

with the subscript indicating that this is our first estimate.

Another possibility envisages the existence of a fourth family of fermions. The contribution to radiative decay of ν_H can be dominated by a heavier charged lepton $l = \sigma^-$ in Fig. 1. Let the relevant mixing angle be $\langle \nu_H | \nu_\sigma \rangle = \cos\beta_2$. The result will depend on the mass of the σ^-, which will ameliorate the GIM suppression factor I. The maximum enhancement is obtained for $m_\sigma \sim m_W$ whereupon $I \sim 1$. [For larger values of m_σ, I is of order $(m_W/m_\sigma)^2$]. In this second estimate we obtain

$$\tau_2 = [G_F{}^2 m_H{}^5 (512\pi^4)^{-1} \alpha \sin^2(2\beta_2)]^{-1}$$
$$= 5\times 10^{22} \sin^{-2}(2\beta_2)(30\ \text{eV}/m_H c^2)^5\ \text{yr}. \qquad (11)$$

In our third model, we assume that there are three lepton doublets and one additional unpaired neutrino. Thus, we abandon the GIM structure for neutrino states. The relevant angle is $\langle \nu_H | \nu_s \rangle = \cos\beta_3$, where ν_s is the neutrino state that is a weak SU(2) singlet. We obtain

$$\tau_3 = [(25/36) G_F{}^2 m_H{}^5 (514\pi^4)^{-1} \alpha \sin^2(2\beta_3)]^{-1}$$
$$= 6\times 10^{22} \sin^{-2}(2\beta_3)(30\ \text{eV}/m_H c^2)^5\ \text{yr}. \qquad (12)$$

In this model, the heavy neutrino decays even more rapidly into three light neutrinos, but with a lifetime long on the Hubble scale.

In each of our three estimates, we obtain neutrino radiative lifetimes 7–12 orders of magnitude smaller than the model-independent lower limit of 10^{16} yr. With the most optimistic of these estimates, the flux of uv photons from our galaxy is *at most* ~ 1 photon/cm^2 sec, and from Andromeda galaxy, at most ~ 10^{-3} photons/cm^2 sec. We have shown that conservative models of neutrino radiative decay imply uv photon fluxes from the decay of galactic neutrinos that are small and difficult to detect. Yet, our conclusions are tentative. They are based on cosmological considerations with large uncertainties. Our specific estimates of the neutrino lifetime may be wrong, for we may not understand the physical principles underlying neutrino masses and mixing. It is not clear that they are to be preferred to the much more optimistic model-independent estimate. Ultraviolet astronomy may be the only direct way to demonstrate the neutrino dominance of our universe.

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[3] S. Tremaine and J. E. Gunn, Phys. Rev. Lett. 42, 407 (1979). See also G. Steigman and E. Witten, in Proceedings of the First Workshop on Grand Unification, Durham, New Hampshire, April 1980 (to be published). Neutrino-galaxy collisions are not sufficiently dissipative for neutrinos to be captured by preexisting galaxies. For neutrinos to form galactic halos, they must have participated in the primordial density fluctuation that evolved into the galaxy.

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