"Dark matter" neutrinos: A proposed mechanism for the stellar rotational velocity curve of the Milky Way

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Abstract. The inconsistency of the observed rotational velocity curve of the Milky Way with the current theory of gravitational dynamics is well documented. The curve implies the presence of significantly more mass, or “dark matter”, than is observable. Current models estimate the amount of dark matter to be ~85% of total “matter”. This paper explores relativistic neutrinos as a potential source of dark matter and proposes a crude binary star accretion model mechanism at the centre of the Milky Way for their production. The results show this to be consistent with the current theory of gravitation, the observed velocity curve of the Milky Way and current estimates of the proportion of dark matter to baryonic matter ~85%.

Introduction

It is well documented [10] that the observed rotational velocity curve for the Milky Way, as shown in Fig. 1 for example, is not consistent with current gravitational theory applied to observed baryonic mass. For this to be the case, one would expect rotational velocities to reduce according to the inverse square root of their distance from a distance enclosing most of the baryonic mass of the galaxy, at ~ 10 kpc and beyond. However, these velocities appear to remain relatively rather uncorrelated with marginal increasing distance from the edge of the central bulge and beyond the region containing most of the detectable stellar and baryonic mass (Fig. 1). This suggests the potential existence of a relatively dominant component of galactic mass that appears to be largely proportional to the distance from the centre rather than tending to a Keplerian curve. Farther out, beyond 20 kpc, observed velocities appear to drift lower, tending to a ”floor” value in the mid hundreds of kms⁻¹, rather than tailing off.

In order to account for the non-Keplerian observed velocities, various dynamic models have been constructed on the basis of fitting the masses of the three galactic components— bulge, disk and a dark matter “halo”, to observed velocities. This approach has resulted in generating significant implied, yet physically unspecified, dark matter halo masses of ~ 85% of total galactic mass [9]. The aim of this paper is to propose a physical mechanism for the creation of a dark matter halo that is consistent with current understanding of the physical laws of gravitation and neutrinos.

![Figure 1: Observed curve up to 20 kpc](image1.png)  ![Figure 2: Observed curve up to 1000 kpc](image2.png)
The Model

A relatively crude model was employed for the purpose of readily assessing whether the results would be of the order of magnitude required to satisfy the objective of the exercise, thereby warranting further investigation, rather than to consider second order effects and/or a more complex approach that would require resources beyond the scope of the exercise. The relatively unsophisticated approach taken notwithstanding, results appear to be consistent with current physical laws and knowledge.

It was assumed that the disk of the Milky Way contains \( N_B \sim 1.65 \times 10^{10} \) stars and the central bulge of the Milky Way is composed of \( N_B \sim 3.41 \times 10^{10} \) relatively older Population II stars \( \[9\] \) of mass \( M_\odot \) with an average main sequence lifespan of \( 10 \text{Gyr} \) and, given the relatively dense environment and short fall-in times, that such bulge stars would be in binary systems with other stars initially of similar age and mass. It was assumed that an accretion disk structure would form about the primary component of the binary at the time of the secondary leaving the main sequence by way of Roche Lobe overflow due to the level of viscosity/turbulence of the region, with the primary and secondary being potentially interchangeable. The Eddington mass flow rate of consumption of the accretion disk of the primary, \( \dot{M}_p \), is given by:

\[
\dot{M}_p = \frac{4\pi GM_p m_p}{\sigma_p},
\]

where \( \sigma_p = \text{proton cross-section of interaction} \sim 7 \times 10^{-29} \text{m}^2; G \sim 6.7 \times 10^{-11} \text{Nm}^2\text{kg}^{-2}; M_p = \text{mass of primary}; m_p = \text{mass of proton} \sim 2 \times 10^{-27} \text{kg}; c \sim 3 \times 10^8 \text{ms}^{-1}.\]

Given that fall-in times are much less than consumption times, the time taken for a primary to consume the mass of a secondary was taken as \( \dot{M}_p \cdot \frac{M}{\dot{M}_p} = 0.4 \text{Gyr} \) and that after such time it would consume the secondary, doubling its mass after allowing for the mass radiated during the accretion process and subsequently enter the next Phase. This process would then repeat with a frequency once per \( \sim 0.4 \text{Gyr} \) until the current Phase, Phase IX, at \( t = 13.5 \text{Gyr} \), which is estimated to have started at \( t = 13.3 \text{Gyr} \). \( \dot{M}_p \) was initialised to \( 1 M_\odot \) at \( t = 10 \text{Gyr} \). The proportion, \( \eta \), of the accreted mass radiated during each Phase, is given by:

\[
\eta = \frac{GM_p}{c^2 R},
\]

for \( R = 5 R_s \), where \( R_s = \text{Schwarzschild radius} \). The mass of a primary at the start of Phase Z, \( M_p^z \), given the mass of a primary at the start of Phase I of \( M_\odot \), is given by:

\[
M_p^z = M_\odot (2 - \eta)(z-1),
\]

and the temperature of the accreting mass is given by \( \[6\] \):

\[
T_a = 7.3 \times 10^7 (M_p/M_\odot)^{-0.25}
\]

It can be seen from above that the effective temperatures associated with the accretion matter range from \( \sim 73 \times 10^6 \text{K} \) for a Phase I primary of mass \( \sim 1 M_\odot \) to \( \sim 20 \times 10^6 \text{K} \) for a Phase IX primary of mass \( 170 M_\odot \) – exceeding the critical temperature required for nucleosynthesis.

Assuming a nucleosynthetic process, whereby a proportion, \( \psi \), of radiated mass \( \sim 0.02 \) takes the form of “solar” neutrinos of energy \( E^\nu = 530 \text{keV} \) \( \[5\] \) produced at a core solar temperature \( T_\odot \sim 15 \times 10^6 \text{K} \), the energy of neutrinos radiated from a Phase IX accretion disk is given by \( E^\nu = T_a/T_\odot \sim 714 \text{keV} \). Assuming a rest mass of \( \sim 0.0132 \text{eV/c}^2 \) \( \[7\] \) for electron neutrinos in their normal hierarchical state, this would result in the production of relativistic neutrinos with a Lorentz gamma of \( \gamma \sim 6.4 \times 10^7 \). The number of primaries in Phase I at time \( t = 10 \text{Gyr} \) is initialised at \( N^1_p \sim 2.48 \times 10^{10} \) to generate a corresponding baryonic bulge mass at \( t = 13.5 \text{Gyr} \) of \( 1.65 \times 10^{10} M_\odot \) \( \[9\] \).

From the above it can be seen that the neutrino mass flux in Phase Z, \( \Phi^z_\nu \), in \( \text{kgyr}^{-1} \), is given by:

\[
\Phi^z_\nu = \frac{4\pi G m_p \psi \gamma N^1_p M_\odot (2 - \eta)(z-1)}{c \sigma_p} 3 \times 10^7
\]

The corresponding neutrino mass enclosed within a sphere of radius \( r \) lyrs from the galactic centre, \( M^z_\nu \), is simply given by:
The raw neutrino mass model above is used to compute the mass function of the neutrino sphere, or halo, for consecutive increasing values of $r$. It can be seen that this function is linear in $r$, which is a key condition for a flat velocity curve.

The mass function of the raw neutrino model was scaled over a bulge distance corresponding to $0 < r < 7kly$ to take into account the baryonic mass function of the bulge, given that neutrino production would be directly proportional to the baryonic mass of the binaries within the bulge. The bulge mass function $M_B(r)$ developed to fit the bulge mass of the above for a radius of $r=7kly$ from the galactic centre is:

$$M_B(r) = \sum_{r=1}^{7000} \rho_0 \frac{V_r M_\odot}{r^2} \frac{1}{4.43508} V_r$$

for $0 < r < 7kly$, where $\rho_0 = 10^7 pc^{-3}$ at $r = 1 pc$ and $V_r$ is the volume of the $r^{th}$ shell of the sphere. The mass function of the disk $M_D(r)$ is assumed to be linear from $r_B=7kly$ to $r_D=30kly$, enclosing the mass given by the above, and is simply given by:

$$M_D(r) = \frac{M_D}{(r_D - r_B)} r,$$

where $r_B$, $r_D$ are the radii of the bulge and disk respectively. It can be seen from the above, and after scaling the bulge neutrinos, the total mass function $M_T(r)$, for Phase IX with $Z=9$, is given by the following four terms:

$$M_T(r) = \sum_{r=1}^{7000} \rho_0 \frac{V_r M_\odot}{r^2} \frac{1}{4.43508} V_r + \frac{M_B}{(r_D - r_B)} r + \frac{4\pi G m_\odot \eta \psi \gamma N_1}{\alpha_p} M_\odot (2 - \eta)^8 3 \times 10^7 r$$

The resulting estimated velocity curve shown in Fig.3 is compared with the observed velocity curve in Fig.1 for $r=0$ to $\sim 70kly$. The two are shown superimposed in Fig.4.
Similarly, Fig.5 and Fig.6 show the corresponding mass-velocity functions over a distance of one galactic radius, assumed to be $\sim 129kly$, and the superimposition of the resulting velocity curve on the observed velocities respectively.

A table of the resulting estimated masses and velocities as a function of radius are shown in Fig.8 and a summary of the model mechanism is shown in Fig.9. A breakdown of the proportion of the total enclosed estimated mass by bulge, disk and neutrino sphere is shown in Fig.7.

**Discussion**

The estimated rotational velocity curve (Fig.3) appears to be consistent with the observed velocity curve (Fig.1) over a distance of $\sim 70kly$. For distances beyond this, the dispersion of observed velocities for a given distance appears to increase significantly (Fig.2), thereby affecting the significance of the observations - after initially appearing to decline, velocities subsequently increase to a level of $\sim 150kms^{-1}$ at a distance of 385kpc compared to $\sim 175kms^{-1}$ for the model. One of the possible causes of this may be that the model does not consider other gravitational potentials not related to the Milky Way. Given that this distance corresponds to approximately the mid-point between the Milky Way and the similarly sized M31, it may be close to a Lagrange point in the overall gravitational field, which may have an impact on the rotation curve when viewed relative to the Milky Way.

The reasonable fit of the estimated velocity curve with the observed velocities (Fig.4) is also consistent with electron neutrinos in their normal hierarchical state of having a rest mass of of $\sim 13meV/c^2$, which does not appear inconsistent with [7], who suggest the rest masses of the three neutrino species can follow a normal hierarchy with two light states and a heavier one, in which case the minimum total rest mass would be $\sim \sum m_{\nu} = 0.06eV$. Their suggested masses of the three species by hierarchy for $\sum m_{\nu} = 0.10eV$ are shown in Fig.10, for which $\sum m_{\nu} = 0.06eV$ would suggest that an electron neutrino in the normal hierarchy may have a rest mass of $\sim 0.022\times0.06/0.10eV$ or $\sim 13meV/c^2$. This value was utilised in the model and generated a "dark matter" neutrino sphere mass corresponding to $\sim 84\%$ of total mass for the Milky Way.
Way (at $R = 129\text{kly}$), which appears to be consistent with the observed rotational velocity curve [9].

**Conclusion**

The gravitational effect of stellar neutrinos produced during a typical stellar main sequence nucleosynthetic process appears to be insignificant compared to stellar baryonic mass due to a combination of relatively low $\dot{M}$ and $\eta$ associated with this process. Conversely, however, the model herein suggests a mechanism whereby concentration of matter associated with mass-radiating accretion disks, such as potentially at the centre of the Milky Way, could provide the relatively higher $\dot{M}$ and $\eta$ required to generate relativistic neutrinos with sufficient flux and energies to have a gravitational effect significantly higher than that due to baryonic mass and that such mass could be sufficient to give a reasonable account of the observed observed rotational velocity curves (Fig.4) and the estimated proportion of dark matter to baryonic matter $\sim 84\%$, consistent with current physical laws of gravitation. The model additionally implies that the observed rotational dynamics of the Milky Way is consistent with a rest mass of the electron neutrino in the normal hierarchy of $\sim 13\text{meV/c}^2$, consistent with current understanding [7].

As, “the rotational velocity curve of the Milky Way is not atypical of other spiral galaxies” [9], this may suggest that such a mechanism may also be a systematic galactic phenomenon. However, the model implies that until such galaxies reach an apparent age of $\sim 10\text{Gyr}$ required for Phase I of the accretion-burning neutrino sphere to commence, galaxies should, everything else being equal,
exhibit a relatively insignificant proportion of neutrino sphere mass relative to baryonic mass, when compared to their apparently “older” counterparts. This is consistent with the observation that the proportion of “dark matter” mass to baryonic mass is insignificant for galaxies of relatively high red shifts $z \sim 0.6 - 2.5$ [4], corresponding to an apparent distance of at least $\sim 5Glyr$ away, assuming a Hubble ”constant” of $76kms^{-1}$, compared to an apparent distance of $\sim 4Glyr$ away implied my the model.

An additional implication of the model is that the radiative neutrino spheres of galaxies less than $\sim 3.5Glyr$ away would act as mass-radiating beacons that would be expected to create mass-interference patterns with spheres radiated by other galaxies to potentially create an overall stationary superposition of radiated ”mass” to which baryonic matter, such as gas and dust in the intergalactic medium, may clump to, not dissimilar to observed dark matter filaments [8].

Finally, the model implies two relatively different apparent mass distribution functions for the observable universe corresponding to $t < 10Gyr$ and $t > 10Gyr$ respectively. The denser mass function of the latter relating to observable galaxies that are apparently relatively closer by, suggests a relatively greater enclosed mass density of nearby observable galaxies compared to those more ”baryonic” galaxies observed to be relatively farther afield, thereby potentially creating an apparent observed acceleration effect on galaxies with distance that may be associated with ”dark energy”.

Further research would need to be undertaken to confirm and refine the mechanism herein, to evaluate its consistency with other observable astrophysical galactic and extragalactic phenomena and to explore the suggested potential implication on ”dark energy”.

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