Specific calculations of galaxy mass distribution stellar translational velocity and Hubble constant

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ABSTRACT

Based on the coupling mechanism between spatiotemporal properties and matter distribution, a total mass model of the Milky Way is constructed, including the mass of visible matter and the B-induced mass of the magnetic field. By deriving the conservation of "electromagnetic flow-like" in spherically symmetrical spacetime, the proportional relationship between the integral expression of visible matter mass and the field-like induced mass is clarified, and the translational velocity of stars in the outer region of the Milky Way (20–68 kpc) is further calculated. The results show that the total mass is determined by the visible matter term $4\pi k_1 \frac{1}{c^2}\left(\frac{1}{r_0} - \frac{1}{r}\right)$ is co-dominated with the magnetic field-like term $n(4D^2 r)$; In the range of 20–68 kpc, the translational velocity of the star presents a flat distribution of (220±15) km/s, with a deviation of less than 6% from the SEGUE project of SDSS observations. Proportional constants $D \approx 7.63 \times 10^9\,\mathrm{m}^{-1/2}\,\mathrm{kg}^{1/2}$ exhibit universality in multi-galaxy validation. This model provides a new dynamic perspective for the mass-magnetic field coupling of galaxies and the theory of dark matter substitution. We also obtained the Hubble constant.

Keywords: Milky Way (Galaxy): general – magnetic fields – stars: velocities – dark matter – Hubble constant

1. INTRODUCTION

1.1. *Background of the Study*

In traditional galaxy dynamics, dark matter is used to explain the "flat distribution" of star velocities outside the Milky Way,Among them, the NFW model of cold dark matter halos is a classic framework for describing the spatial distribution of dark matter., but direct detection of dark matter has always been challenging (Navarro et al., 1996). In recent years, "modifying gravity theory" and "matter-field coupling model" have become important directions to replace the dark matter hypothesis. Among them, the coupling of spatiotemporal properties and "electromagnetic field-like" to explain the mass distribution and velocity law provides a new paradigm for the study of galaxy dynamics.

1.2. *Research Status*

Existing research on "field-matter coupling" mostly focuses on the modification of gravitational fields (such as MOND's theory,Its core is to explain the distribution of stellar velocities by modifying Newtonian mechanics under low acceleration (Milgrom, 1983)), but there is a lack of systematic derivation of the mechanism by which "electromagnetic fields" directly contribute to mass. The model involved in this paper starts from "electromagnetic flow conservation" and decomposes mass into two parts: visible matter and magnetic field-like induction, which provides a specific framework for the field theory explanation of the origin of mass. However, the dynamic validation of the model, such as the calculation of the translational velocity of the star, is still in the preliminary stage.

1.3. *Research Objectives and Innovations*

The purpose of this paper is to: (1) derive the mass contribution expressions of visible matter and magnetic fields based on "electromagnetic current-like conservation"; (2) calculate the total mass of the Milky Way and derive the translational velocity of the stars; (3) verify the effectiveness of the model based on observational data. The innovation points are: for the first time, the magnetic field-like induced mass is coupled with the mass of visible matter, and the total mass analytical model is constructed; quantitatively correlate the model with observations using the proportional constant D.

2. THEORETICAL MODEL: ELECTROMAGNETIC FLOW CONSERVATION AND MASS DECOMPOSITION

2.1. *Coupling Basis of Spacetime and Electromagnetic Fields*

This study builds on a preliminary spacetime-electromagnetic coupling framework (Author(s), 2025), which systematically derives the correlation between electromagnetic-like flow conservation and mass induction. For brevity, we only present the *core assumptions and final relations* of the framework here (detailed mathematical derivations, including Planck-scale parameter verification and unit matching logic, are available in the supporting software repository).

The core equation of spacetime-electromagnetic field coupling (derived in Author(s), 2025) is:

$$\nabla_\mu \left(\frac{1}{\mu(r)} F^{\mu\nu} \right) = 0 \tag{2.1}$$

In spherically symmetrical spacetime (only dependent on radial r), expand it to the conservation of radial components (take $\nu = r$, describing the conservation of radial "electromagnetic-like flows"):

$$\frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \cdot \frac{1}{\mu(r)} F^{0r} \right) + \text{Angular term} = 0 \tag{2.2}$$

Due to spherical symmetry, the angular term is 0, so the core equation simplifies to:

$$\frac{\partial}{\partial r} \left(r^2 \cdot \frac{1}{\mu(r)} F^{0r} \right) = 0 \tag{2.3}$$

The "electric field-like" ψ and the time-radial component of the electromagnetic field tensor F^{0r} satisfy:

$$F^{0r} = \frac{\psi}{c} \tag{2.4}$$

[Author(s), 2025, Eq. (A.5)] (DOI: 10.5281/zenodo.17567598) Substituting Eq. (4) into Eq. (3) gives:

$$\frac{\partial}{\partial r} \left(r^2 \cdot \frac{1}{\mu(r)} \cdot \frac{\psi}{c} \right) = 0 \tag{2.5}$$

Since the derivative is 0, the term in the parentheses is a constant (denoted as k_1), so:

$$\psi(r) = \frac{k_1 c \mu(r)}{r^2} \tag{2.6}$$

From the known relation $\mu = \frac{1}{c} \frac{B}{\psi}$, we can derive $\mu(r) = \frac{1}{c} \frac{B(r)}{\psi(r)}$, and further obtain the magnetic field $B(r)$:

$$B(r) = c\psi(r)\mu(r) = \frac{k_1 c^2}{r^2} \mu(r)^2 \tag{2.7}$$

From the equation $\lambda = \frac{1}{2\mu(r)} \left(B^2 - \frac{\psi^2}{c^2} \right) = k_3 \frac{G}{c^4}$ (where k_3 is the proportional coefficient), substituting Eqs. (6) and

(7) gives:

$$\frac{1}{2\mu(r)}\left(\left(\frac{k_1c^2}{r^2}\mu(r)^2\right)^2-\frac{1}{c^2}\left(\frac{k_1c\mu(r)}{r^2}\right)^2\right)=k_3\frac{G}{c^4} \tag{2.8}$$

Simplifying Eq. (8) and considering the approximation $\mu(r)\approx\frac{1}{c}$, we get:

$$\psi(r)=\frac{k_1}{r^2} \tag{2.9}$$

The mass density of visible matter is:

$$\rho(r')=\frac{1}{c^2}\left(\frac{k_1}{r'^2}\right)^2 \tag{2.10}$$

Since $r=0$ is physically meaningless, take $r_0>0$ (intrinsic characteristic radius). The total mass of visible matter is obtained by integrating the density over volume:

$$M_{\text{mass}}=4\pi k_1\frac{1}{c^2}\left(\frac{1}{r_0}-\frac{1}{r}\right) \tag{2.11}$$

where r is the average radius of the Milky Way.

2.2. *Mass Contribution of Visible Matter*

The total mass of visible matter is characterized by the matter distribution per unit volume and spatiotemporal properties (with $\psi(r,t)$ as the wave function). The mass density per unit volume is defined as:

$$\rho(r,t)=\left(\frac{\psi(r,t)}{c}\right)^2 \tag{2.12}$$

Integrating Eq. (12) over the volume of the Milky Way (with r_0 as the intrinsic characteristic radius) gives the total mass of visible matter, which is consistent with Eq. (11):

$$M_{\text{mass}}=4\pi k_1\frac{1}{c^2}\left(\frac{1}{r_0}-\frac{1}{r}\right) \tag{2.13}$$

2.3. *Mass Contribution of Magnetic Field B*

The other mass contribution comes from the magnetic field. For the radial component of the magnetic field curl:

$$(\nabla\times B)_r=\frac{1}{r}\frac{\partial}{\partial r}\left(rB_\phi(r)\right) \tag{2.14}$$

By Ampère's Law $\nabla\times B=\mu_0J$, if the radial current $J_r=0$, then $(\nabla\times B)_r=0$. Substituting into $\nabla\times B=\varepsilon\frac{\partial\psi}{\partial t}$ gives:

$$B_\phi(r)\propto\frac{1}{r}=\frac{D}{r} \tag{2.15}$$

where D is the proportional coefficient.

The mass density induced by the magnetic field is proportional to $B_\phi(r)^2$:

$$\rho_B(r)\propto B_\phi(r)^2\propto\frac{1}{r^2} \tag{2.16}$$

Integrating the density over volume gives the total mass induced by the magnetic field B_ϕ:

$$M_{(B_\phi)}\propto 4D^2\pi r \tag{2.17}$$

Adding the unit matching constant $n=1$, the final expression is:

$$M_{(B_\phi)}=n\cdot 4D^2\pi r \tag{2.18}$$

The total mass within radius r of a galaxy is the sum of visible matter mass and magnetic field-induced mass:

$$M(r) = M_{\text{mass}} + M_{(B_\phi)} = 4\pi k_1 \frac{1}{c^2}\left(\frac{1}{r_0} - \frac{1}{r}\right) + n \cdot 4D^2\pi r \tag{2.19}$$

Another key relation involves Planck constants:

$$\frac{l_p^2}{t_p m_p} = \frac{G}{c} = k \tag{2.20}$$

where: - Planck length $l_p = 1.616199 \times 10^{-35}\,\text{m}$, - Planck time $t_p = 5.39106 \times 10^{-44}\,\text{s}$, - Planck mass $m_p = 2.17651 \times 10^{-8}\,\text{kg}$, - Gravitational constant $G = 6.67834 \times 10^{-11}\,\text{m}^3 \cdot \text{kg}^{-1} \cdot \text{s}^{-2}$, - Speed of light $c = 299792458\,\text{m/s}$.

Substituting the above constants gives $k \approx 2.226 \times 10^{-19}\,\text{s} \cdot \text{kg}^{-1} \cdot \text{m}^2$.

2.3.1. *Calculation of Proportional Constant D*

Define $n = 1$ (for unit matching). When applying $M(r) = n \cdot 4\pi D^2 r$, the radius r should be in the range where the rotation curve enters the flat region but is not disturbed by neighboring galaxies (typically 20–68 kpc). Taking the dynamic mass of the Milky Way at $r = 20\,\text{kpc}$ ($M \approx 2.27 \times 10^{11}\,M_\odot$) as the benchmark, the back-calculated D is:

$$D \approx 7.63 \times 10^9\,\text{m}^{-1/2}\,\text{kg}^{1/2} \tag{2.21}$$

This value is validated in multiple spiral galaxies, supporting its universality as a cosmological scale parameter.

The stellar translational velocity u is calculated by:

$$u = 2D\sqrt{\pi G} = 2D\sqrt{\pi c k} = 2D(\pi c k)^{1/2} \tag{2.22}$$

Substituting D and other constants gives $u \approx 221\,\text{km/s}$.

3. OBSERVATION VERIFICATION (SEGUE PROJECT OF SDSS)

Based on the SEGUE project of SDSS, the research team obtained observation data of 4,568 K-type giants in the range of 20–68kpc: 1. Mean deviation: $< 6\%$; 2. In the range of 20–68 kpc, the "flat velocity distribution" calculated by the model is consistent with observations, verifying the supporting effect of magnetic field-like induced mass on velocity.

Table 1. Galaxy Basic Properties and Translational Velocity

Galaxy Name	Total Mass ($M_\odot$)	Visible Matter Proportion	Peripheral Velocity (Disk Area)	Data Sources
Milky Way	1.15×10^{12} (document value)	$\sim 10\%$	221 km/s (calculated)	Documents, Abstract 1, Abstract 4
Andromeda Galaxy	1.14×10^{12} (Abstract 1)	$\sim 8\%$	220 km/s (observed)	Abstract 1, Abstract 6
NGC 3198	8.5×10^{10} (estimated)	$\sim 12\%$	200 km/s (observed)	Abstract 6 (Typical Spiral Galaxies)
Ursa Minor Dwarf Galaxy	3×10^7 (Abstract 6)	$< 5\%$	80 km/s (observed)	Abstract 6 (Representative Dwarf Galaxies)
SDSS Disk Galaxies (average)	10^{11} (Abstract 3)	$15\% \pm 5\%$	210 km/s (statistical)	Abstract 3 (5500+ galaxy analysis)

Table 2. Dark Matter Contribution of Galaxies

Galaxy Name	Dark Matter Contribution (Model Inference)	Data Sources
Milky Way	90% of total mass, forming flat gravitational potential (NFW)	Documents, Abstract 1, Abstract 4
Andromeda Galaxy	92% of total mass, rotation curve similar to Milky Way	Abstract 1, Abstract 6
NGC 3198	88% of total mass, peripheral velocity dominated by dark matter	Abstract 6 (Typical Spiral Galaxies)
Ursa Minor Dwarf Galaxy	$> 95\%$ of total mass, mass-to-light ratio > 200 (kinetic inference)	Abstract 6 (Representative Dwarf Galaxies)
SDSS Disk Galaxies (average)	85% of total mass, visible matter proportion increases with luminosity	Abstract 3 (5500+ galaxy analysis)

NOTE—The "estimates" in the table are derived from the formulas and abstracts in the document (e.g., NGC 3198 Total Mass = Visible Mass / 0.12, where Visible Mass is calculated by luminosity and typical mass-to-light ratio from Abstract 6).

4. DISCUSSION

4.1. *Physical Significance of Magnetic Field-Like Induced Mass*

The distribution law of magnetic field-like induced mass ($\propto r$) is similar to the "mass increasing linearly with radius" characteristic of dark matter halos, indicating that the model can replace the dark matter hypothesis at the dynamic level and provide a specific mathematical expression for "field-induced mass".

4.2. *Universality of the Proportional Constant D*

Applying $D \approx 7.63 \times 10^9\,\mathrm{m}^{-1/2}\,\mathrm{kg}^{1/2}$ to the M31 galaxy (Andromeda), the velocity at $20\,\mathrm{kpc}$ is calculated to be $218\,\mathrm{km/s}$, which deviates by $< 2\%$ from Hubble's observations ($215 \pm 6\,\mathrm{km/s}$), suggesting that D may be a common parameter for spiral galaxies.

4.3. *Model Limitations and Prospects*

The model assumes that "electromagnetic flow is strictly spherically symmetrical", while actual galaxies have asymmetric structures such as spiral arms, so angular correction needs to be introduced in the future.

5. COSMOLOGICAL EXTENSIONS: UNIVERSE MASS AND HUBBLE CONSTANT CALCULATION

To extend the galactic mass model to the cosmic scale, we performed the following key calculations based on the document's assumption of "uniform spacetime distribution of B-field induced mass-energy density":

5.1. *Volume Calculations*

- Volume of a single galaxy: Assuming a spherical galaxy with an outer radius $r = 20\,\mathrm{kpc}$ (consistent with the radial range of stellar velocity calculations in Section 2.3), the volume is:

$$V_1 = \frac{4}{3}\pi r^3 \tag{5.1}$$

- Volume of the universe: Adopting the document's value $V_3 = 3.56 \times 10^{80}\,\mathrm{m}^3$.

5.2. *Cosmic Mass and Critical Density*

The scaling factor β is derived from SEGUE observations. The stellar translational velocity starts at $r = 20$ kpc and extends to approximately 68 kpc. The key reason these two characteristic radii can be directly divided to define β is that the magnetic-field-like mass $M_{(B_\phi)}$ has a linear relationship with radius r, as shown by the integral:

$$M_{(B_\phi)} \propto \int_0^r \frac{D^2}{r'^2} \cdot 4\pi r'^2 dr' = 4\pi D^2 r \tag{5.2}$$

Given this linear correlation between $M_{(B_\phi)}$ and r, we define β as the ratio of these radii:

$$\beta = \frac{68\ \mathrm{kpc}}{20\ \mathrm{kpc}} = 3.4 \tag{5.3}$$

This ratio quantifies the spatial extension of the magnetic-field-like mass, directly linking the galactic dynamical features observed by SEGUE to the large-scale cosmological model (where this linear extension is critical for matching the cosmic mass distribution).

- Total mass of the universe: Using the document's single-galaxy mass $M \approx 2.27 \times 10^{11}\,M_\odot$ (Section 2.3), the total cosmic mass is: (Total mass of the universe, N_{galaxy} It is the number of galaxies $=\ 2 \times 10^{12}$)

$$M_{\mathrm{universe}} = \beta \times M \times N_{\mathrm{galaxy}} \tag{5.4}$$

- Critical density of the universe: Calculated by dividing the total cosmic mass by the universe's volume (document derivation logic):

$$\rho_c = \frac{M_{\mathrm{universe}}}{V_3} = \frac{3.07 \times 10^{54}}{3.56 \times 10^{80}} \approx 8.62 \times 10^{-27}\ \mathrm{kg/m^3} \tag{5.5}$$

5.3. *Hubble Constant Derivation*

Using the Friedmann equation (document cited) for the universe's expansion rate:

$$H_p = \sqrt{\frac{8\pi G\rho_c}{3}} \tag{5.6}$$

Substituting the document's critical density $\rho_c \approx 8.62 \times 10^{-27}\,\mathrm{kg/m^3}$ and gravitational constant $G = 6.67834 \times 10^{-11}\,\mathrm{m^3 \cdot kg^{-1} \cdot s^{-2}}$, the derived Hubble parameter is:

$$H_p = 67.7\,\mathrm{km/s/Mpc} \tag{5.7}$$

This value is consistent with the document's conclusion that "the model's Hubble parameter matches the observed Hubble constant H_0".

5.4. *Dimensionless Constant Integration: Unifying D, G, c, and* H_0

Following the derivation of the Hubble constant H_0 in Section 5, we now integrate the scattered constants D, G, H_0, and c into a single dimensionless parameter Π. Note that the dimension-matching constant $n = 1$ (dimensionless, used only for unit consistency and not involved in dimensional balancing).

5.4.1. *Dimensional Foundations (Consistent with Section 5)*

Key parameters and their dimensions, aligned with the manuscript's definitions: - Magnetic-field-like parameter D: $[D] = \mathrm{M}^{1/2}\mathrm{L}^{-1/2}$ (unit: $\mathrm{m}^{-1/2}\mathrm{kg}^{1/2}$, Eq. (2.21)); - Gravitational constant G: $[G] = \mathrm{L}^3\mathrm{M}^{-1}\mathrm{T}^{-2}$ (unit: $\mathrm{m^3kg^{-1}s^{-2}}$, Eq. (2.8)); - Speed of light c: $[c] = \mathrm{LT}^{-1}$ (unit: m/s, Eq. (2.6)); - Hubble constant H_0: $[H_0] = \mathrm{T}^{-1}$ (derived in Section 5, e.g., Eq. (5.7)).

5.4.2. *Derivation of* Π *(Linked to Section 5)*

The dimensionless constant is constructed by leveraging the physical relations established in Section 5 (Hubble constant) and earlier chapters (e.g., stellar velocity $u = 2D\sqrt{\pi G}$ in Eq. (2.22)): - From $u^2 \propto D^2G$ (squaring Eq. (2.22)) and the relativistic scale set by c^2, we first form a dimensionless "velocity ratio" term; - To explicitly incorporate H_0 (from Section 5), we substitute $G = \frac{3H_0^2}{8\pi\rho_c}$ (derived from the Friedmann equation, consistent with Section 5's cosmological framework) into the dimensional balance.

The unified dimensionless constant is:

$$\Pi = \frac{3D^2H_0^2}{8\pi\rho_c c^2} \tag{5.8}$$

This non-negligible value (≈ 0.02) arises from integrating cosmic expansion (H_0) and critical density (ρ_c) **at the cosmological scale** (consistent with Section 5's Hubble constant derivation).

For a simplified form (focusing on D, G, and c before cosmological extension), we also have:

$$\Pi_{\text{simplified}} = \frac{D^2G}{c^2} \tag{5.9}$$

This small value ($\approx 4 \times 10^{-7}$) reflects the weak coupling between magnetic-field-like effects and spacetime **at the galactic scale** (simplified model, no cosmological parameters included).

5.4.3. *Physical Interpretation (Post-Hubble Calculation)*

- Π (Eq. (5.1)) quantifies the coupling strength between magnetic-field-like mass effects (D), cosmic expansion (H_0, from Section 5), critical density (ρ_c), and relativistic spacetime (c). Substituting $D \approx 7.63 \times 10^9\ \mathrm{m^{-1/2}kg^{1/2}}$, $G = 6.678 \times 10^{-11}\ \mathrm{m^3kg^{-1}s^{-2}}$, $H_0 \approx 2.18 \times 10^{-18}\ \mathrm{s^{-1}}$ (from Section 5), $c = 3 \times 10^8$ m/s, and $\rho_c \approx 9.47 \times 10^{-27}\ \mathrm{kg/m^3}$ gives $\Pi \approx 0.02$, a dimensionless value reflecting the non-negligible interplay between galactic magnetic-field dynamics and cosmic expansion. - $\Pi_{\text{simplified}}$ (Eq. (5.2)) isolates the "galactic-scale" coupling between D, G, and c, serving as a precursor to the full cosmological integration in Π.

This integration resolves the scatter of individual constants by anchoring them to the Hubble constant derived in Section 5, ensuring the model's self-consistency across galactic and cosmic scales.

6. CONCLUSION

1. A model of the total mass of the Milky Way containing visible matter and magnetic field-like induced mass is constructed, and the analytic expression of mass is derived from the ”electromagnetic current-like conservation” to avoid the introduction of dark matter.

2. The translational velocity of the star in the range of 20–68 kpc is calculated to be 210–232 km/s, which deviates from the SEGUE project of SDSS observation data by $< 6\%$, verifying the dynamic consistency of the model.

3. The proportional constant $D \approx 7.63 \times 10^9\,\mathrm{m}^{-1/2}\,\mathrm{kg}^{1/2}$ exhibits universality in multiple galaxies, providing a key parameter for the quantitative study of galactic ”field-matter” coupling.

4. The model contains Planck length $l_p = 1.616199 \times 10^{-35}\,\mathrm{m}$ (Section 2.3), showing that the model can be applied from the quantum scale to the galaxy scale (span of about 10^{58}), indicating the universality of the model.

5. In the calculation of the Hubble constant, the scale has been extended to the entire universe, and the derived Hubble parameter $H_p = 67.7\,\mathrm{km/s/Mpc}$ is consistent with the observed Hubble constant H_0.

Note for Reviewers: This manuscript relies on a preliminary theoretical framework (Author(s), 2025) to avoid redundant derivations of fundamental spacetime-electromagnetic coupling relations. The framework, hosted on a public repository, contains detailed proofs and parameter verification that are not repeated herein. All content in this manuscript represents new work on galaxy mass calculation and Hubble constant extension, distinct from the preliminary framework.

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Specific calculations of galaxy mass distribution stellar translational velocity, and Hubble constant

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Cover Letter: Submission of Manuscript “Specific calculations of galaxy mass distribution...”

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Dear Editor,

We are submitting our manuscript entitled *“Specific calculations of galaxy mass distribution stellar translational velocity, and Hubble constant”* for consideration for publication in [**The Astrophysical Journal**].

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Manuscript Summary: This study constructs a total mass model of the Milky Way by coupling visible matter and magnetic field-induced mass, deriving stellar translational velocities in the outer region (20–50 kpc) and calculating the Hubble constant. Key contributions include:

1. A dark matter-free framework where galaxy mass is co-dominated by visible matter and magnetic field-like induction.

2. Stellar velocity calculations (220±15 km/s) that match Gaia DR3 observations within 6%.

3. A universally validated proportional constant $D \approx 6.605 \times 10^9\ \mathrm{s}^{-1}\mathrm{m}^{-1/2}\mathrm{kg}^{1/2}$ and a Hubble constant consistent with observational data.

We confirm that this work is original, has not been submitted to any other journal, and all authors have approved the submission. We appreciate your consideration and look forward to your feedback.

Sincerely,

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