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Dynamical Effect of Galactic Magnetic Fields on the HI Gas Rotation Curve

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Abstract

Magnetic fields are known to influence the thermal and structural properties of galactic gas, yet their impact on the rotational dynamics of galaxies remains largely underexplored. In this study, we examine how the magnetic arms of the spiral galaxy NGC 6946 affect its HI-traced circular gas rotation, incorporating two dark matter density models: the pseudo-isothermal (ISO) and the Navarro-Frenk-White (NFW) profile. To assess the magnetic contribution, we employ a three-dimensional representation of the galaxy's magnetic field and perform a χ^2 minimization to match the modeled rotation curve with observational data. Our results show that including magnetic effects yields a better fit to the HI rotation curve, particularly in the outer disk where magnetic forces become more significant. The typical amplitude of the regular magnetic field contribution to the rotation curve increases with galactocentric radius, reaching approximately 14 $\mathrm{km\,s^{-1}}$ in the outer gaseous disk of the galaxy NGC 6946, which corresponds to about five percent of the observed rotational velocity. These findings suggest that large-scale magnetic fields play a non-negligible role in the global dynamics of spiral galaxies, especially at large radii.

Keywords: *Galaxy: Kinematics and Dynamics - Galaxies: Magnetic fields - Magneto-Hydrodynamics*

1. Introduction

Magnetic fields are a fundamental component of the interstellar medium (ISM) and contribute significantly to the energy budget and structural evolution of galaxies (e.g., Beck, R., 2007, Tabatabaei et al., 2008). Their interaction with the gaseous component of galaxies influences a wide range of physical processes, including the formation and shaping of spiral arms (Gómez & Cox, 2002, Kim & Ostriker, 2002), the regulation of molecular cloud collapse, the suppression of star formation (Heiles & Crutcher, 2005, Tabatabaei et al., 2018), and the launching of galactic outflows (Tabatabaei et al., 2022). These effects highlight the importance of magnetic fields not only in the microphysics of star-forming regions but also in the large-scale dynamics of galactic disks. Observations of nearby spiral galaxies reveal the presence of coherent, large-scale magnetic fields with dominant azimuthal (toroidal) components, often organized into spiral patterns that align with or lie between optical spiral arms (Beck, 2015b, Beck & Hoernes, 1996). These regular magnetic structures are particularly prominent in face-on galaxies and have been observed to extend into the halo in edge-on systems, forming X-shaped poloidal configurations (Beck, 2015a, Wiegert et al., 2015).

From a dynamical perspective, magnetic fields can exert forces on the ionized gas through magnetic pressure and tension, potentially altering the rotation curves of galaxies. In particular, the contribution of magnetic fields to the circular velocity becomes more relevant in the outer regions of galactic disks, where the gravitational pull from baryonic matter diminishes, and the radial decline of magnetic field strength is slower than that of gravity (Battaner & Florido, 2000, Ruiz-Granados et al., 2012). Several studies have proposed that magnetic forces may reduce the need for dark matter in explaining the observed rotation curves, or at least modify the inferred dark matter distribution (Battaner & Florido, 1995, Jalocha et al., 2012, Sánchez-Salcedo & Santillán, 2013).

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In this paper, we investigate the dynamical influence of the regular magnetic field on the HI rotation curve of the nearby spiral galaxy NGC 6946, which is known for its strong polarized radio emission and well-defined magnetic spiral arms (Beck, R., 2007). Using a three-dimensional model of the magnetic field structure and high-resolution HI rotation data (De Blok et al., 2008), we assess the magnetic contribution to the circular velocity and compare the results under two dark matter halo models: the pseudo-isothermal (ISO) and the Navarro-Frenk-White (NFW) profile.

Our goal is to determine whether the inclusion of magnetic forces improves the fit to the observed HI rotation curve of NGC 6946, and whether these forces represent a dynamically significant component in the outer disk. Section 2 outlines the modeling of the rotation curve, including baryonic, dark matter, and magnetic field contributions. Section 3 describes the structure of the regular magnetic field and its contributions to the circular velocity. Section 4 introduces the fitting methodology and model parameters. Section 5 summarizes the main conclusions.

2. Modeling the Rotation Curve

Galaxies are composed of stars, interstellar gas, dark matter halos, and magnetic fields. These components collectively influence the rotational dynamics of the gas and stars, with magnetic fields exerting additional forces that may alter the observed rotation curves. The rotation curve of disk galaxies serves as a key observable for probing their dynamical structure and mass distribution (Sofue & Rubin, 2001).

In this section, we model the rotation curve of the spiral galaxy NGC 6946 by incorporating the contributions from an exponential stellar disk, an exponential gas disk, a dark matter halo (using both ISO and NFW profiles), and a three-dimensional regular magnetic field. The total circular velocity is computed by summing the squared contributions of each component:

$$v_c^2 = \sum_i^n v_c(i)^2 = v_{\text{stellar disk}}^2 + v_{\text{gas disk}}^2 + v_{\text{dark matter}}^2 + v_{\text{magnetic}}^2, \tag{1}$$

where $v_{\text{stellar disk}}$, $v_{\text{gas disk}}$, and $v_{\text{dark matter}}$ represent the contributions from the stellar disk, gas disk, and dark matter halo, respectively. The term v_{magnetic} accounts for the dynamical effect of the regular magnetic field.

2.1. Baryonic Contribution and the Exponential Disk Model

The surface density of galactic disks, gas disk and stellar disk, is typically modeled with an exponential profile (Binney J, 1987, Dutton, 2009):

$$\mu(r) = \mu_0 \exp\left(-\frac{r}{R_{\text{exp}}}\right), \tag{2}$$

where μ_0 is the central surface density and R_{exp} is the exponential scale length. The gravitational potential generated by such a disk is given by Binney J (1987):

$$\Phi_{\text{Disk}}(r,0) = -4G\mu_0 \int_0^r da \frac{aK_1(a/R_{\text{exp}})}{\sqrt{r^2-a^2}} = -\pi G\mu_0 r\left[I_0(y)K_1(y) - I_1(y)K_0(y)\right], \quad \textit{with} \quad y \equiv \frac{r}{2R_{\text{exp}}}. \tag{3}$$

Differentiating Eq. (3) with respect to r, the circular velocity contribution from the exponential disk is:

$$v_{\text{disk}}^2 = 4\pi G\mu_0 R_{\text{exp}} y^2 \left[I_0(y)K_0(y) - I_1(y)K_1(y)\right], \tag{4}$$

where I_n and K_n are the modified Bessel functions of the first and second kind, respectively.

2.2. Dark Matter Contribution

To model the dark matter halo, we consider two widely used profiles: the pseudo-isothermal (ISO) and the Navarro-Frenk-White (NFW) profiles.

ISO Profile

The pseudo-isothermal profile describes a core-like halo with a flat central density distribution, often used for late-type and dwarf galaxies (Begeman et al., 1991). The density profile is:

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$$\rho(r) = \frac{\rho_0}{1 + \left(\frac{r}{R_c}\right)^2}, \tag{5}$$

where ρ_0 is the central density and R_c is the core radius. The corresponding circular velocity is:

$$v^2_{\text{dark matter}} = 4\pi G\rho_0 R_c^2 \left[1 - \frac{R_c}{r}\arctan\left(\frac{r}{R_c}\right)\right]. \tag{6}$$

NFW Profile

The NFW profile is derived from cosmological N-body simulations and represents a cuspy halo structure typical in cold dark matter models (Navarro et al., 1996, 1997). The density profile is:

$$\rho_{\text{NFW}}(r) = \frac{\rho_c}{\left(\frac{r}{R_s}\right)\left(1 + \frac{r}{R_s}\right)^2}, \tag{7}$$

where ρ_c is a characteristic density and R_s is the scale radius. The gravitational potential is:

$$\Phi_{\text{NFW}}(r) = -\frac{4\pi G\rho_c R_s^3}{r}\ln\left(1 + \frac{r}{R_s}\right), \tag{8}$$

and the circular velocity contribution is:

$$v^2_{\text{dark matter}} = \frac{4\pi G\rho_c R_s^3}{r}\left[\ln\left(1 + \frac{r}{R_s}\right) - \frac{r}{r + R_s}\right]. \tag{9}$$

These models allow us to compare the influence of different halo structures on the rotation curve and assess the relative importance of magnetic fields in the outer disk dynamics of NGC 6946.

3. Models of the Planar Regular Magnetic Field Structures

Models of the planar structure of regular galactic magnetic fields in the disk plane are essential for understanding their morphology and dynamical influence. The spatial distribution of the regular magnetic field strength can be mapped using theoretical configurations that reflect the dominant symmetry modes observed in spiral galaxies. The morphology of regular magnetic fields and the associated radio-polarization patterns in the galactic plane can be characterized by several idealized models: the axisymmetric spiral field (azimuthal mode $m = 0$, ASS), the concentric-ring model, the bisymmetric spiral field ($m = 1$, BSS), and the quadrisymmetric spiral field ($m = 2$, QSS), along with higher-order harmonic modes (Braun, R. et al., 2010, Han & Qiao, 1994, Han et al., 2006, Krause, 1990a, Poezd et al., 1993, Sofue & Fujimoto, 1983, Sofue et al., 1986, Vallée, 1991, Vallee, 1992). Khademi et al. (2023) generated the map of the regular galactic magnetic field strength for these modes and their superpositions.

3.1. Two main magnetic spiral arms

The spiral galaxy NGC 6946 hosts two remarkably symmetric magnetic spiral arms, which exhibit even greater symmetry than the optical arms and are characterized by highly aligned magnetic fields located between the gas and optical spiral arms (Beck, 2015b, Beck & Hoernes, 1996, Beck, R., 2007). Polarized radio observations of NGC 6946 reveal that its regular magnetic field configuration, dominated by a two-armed pattern, cannot be adequately described by simple models such as the axisymmetric spiral field (ASS, $m = 0$), the bisymmetric spiral field (BSS, $m = 1$), or the quadrisymmetric spiral field (QSS, $m = 2$).

A suitable model for representing the two prominent magnetic spiral arms in this gas-rich galaxy must account for the observed field geometry, strength, and orientation. The two bright inner magnetic spiral arms, both with magnetic fields directed toward the galactic center, can be interpreted as a superposition of two even azimuthal dynamo modes, $m = 0$ and $m = 2$ (Arshakian et al., 2007, Beck & Hoernes, 1996, Beck, R., 2007, Beck et al., 1996, Rohde et al., 1999, Vallée, 1991). One of the simplest descriptions of the galactic magnetic field is the axisymmetric model (ASS, $m = 0$) (Poezd et al., 1993, Ruiz-Granados, B. et al., 2010, Ruiz-Granados et al., 2012, Vallée, 1991) as follows:

$$B_\rho = B_0(\rho)\sin(p), \quad B_\phi = B_0(\rho)\cos(p), \quad B_0(\rho) = \frac{B_1}{1 + \frac{\rho}{\rho 1}} \tag{10}$$

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where p is the pitch angle and $B_0(\rho)$ is the regular magnetic field strength as a function of the radial distance ρ. B_1 and ρ_1 are constant. The radial factor ρ_1 represents the characteristic scale at which $B_0(\rho)$ decreases to half its value at the galactic center.
A dominant $m = 2$ dynamo mode, known as a quadri-symmetric spiral (QSS), explains the four magnetic arms and azimuthal reversals seen in some galaxies—twice as many as in the bisymmetric spiral (BSS) mode (Arshakian et al., 2007, Vallee, 1992). The regular magnetic field strength in cylindrical coordinates is:

$$B(\rho, \varphi) = B_0(\rho) \cos \left[2 \left(\varphi \mp \beta \ln(\frac{\rho}{\rho_0}) \right) \right]. \tag{11}$$

3.2. Magnetic Field Contribution to the Gas Rotation

The presence of a regular magnetic field can influence the dynamical motion of the HI gas in the galactic disk through its radial force component (Battaner & Florido, 1995, 2000, 2007, Battaner et al., 1992, Chyzy, K. T. et al., 2017, Ruiz-Granados et al., 2012). To quantify this effect, we focus on the regular component of the galactic magnetic field and estimate its contribution to the HI gas rotation.
Under the framework of cosmic magnetohydrodynamics (MHD), the equation of motion for a fluid element subject to magnetic forces is given by:

$$\varrho \frac{\partial \mathbf{v}}{\partial t} + \varrho(\mathbf{v} \cdot \nabla)\mathbf{v} + \nabla P = n\mathbf{F} + \frac{1}{4\pi}(\mathbf{B} \cdot \nabla)\mathbf{B} - \nabla \left(\frac{B^2}{8\pi} \right), \tag{12}$$

where ϱ is the gas density, $\mathbf{v}$ is the fluid velocity, P is the pressure, n is the number density, $\mathbf{F}$ is the gravitational force, and $\mathbf{B}$ is the magnetic field vector. We adopt the ideal MHD approximation, assuming infinite conductivity.
Assuming axisymmetry and pure rotational motion, the velocity field simplifies to:

$$\mathbf{v} = (v_\rho, v_\phi, v_z) = (0, v_c, 0), \tag{13}$$

and the radial component of the equation of motion in cylindrical coordinates becomes:

$$\varrho \left(-\frac{d\Phi(\rho)}{d\rho} + \frac{v_c^2}{\rho} \right) - \frac{dP}{d\rho} - F_\rho^{\rm mag} = 0, \tag{14}$$

where $\Phi(\rho)$ is the gravitational potential, $F_\rho^{\rm mag} = (\mathbf{J} \times \mathbf{B})_\rho$ is the radial component of the magnetic force, and P is the gas pressure. Following the approach of (Ruiz-Granados et al., 2010, 2012), we neglect radial pressure gradients (Battaner & Florido, 2000).
The magnetic contribution to the circular velocity is then expressed as:

$$v_{\rm mag}^2 = \frac{1}{4\pi\varrho} \Big[\left(\partial_\rho(\rho B_\varphi) - \partial_\varphi(B_\rho)\right) B_\varphi - \left(\partial_z(B_\rho) - \partial_\rho(B_z)\right) \rho B_z \Big] \tag{15}$$

where B_φ, B_ρ, and B_z are the azimuthal, radial, and vertical components of the magnetic field, respectively. The regular component of the galactic magnetic field has traditionally been considered predominantly horizontal and aligned with the galactic plane, implying $B_z = 0$ (e.g., Battaner & Florido, 2000, 2007, Ruiz-Granados et al., 2010, 2012). This assumption is motivated by the dominance of the azimuthal component B_φ in the large-scale magnetic fields of spiral galaxies, which is sufficiently strong to warrant inclusion in rotation curve modeling. However, observations of poloidal X-shaped magnetic field structures in edge-on spiral galaxies suggest the presence of significant vertical components B_z in the halo regions (Henriksen & Irwin, 2016, Nixon et al., 2018, Woodfinden et al., 2019). Evidence of magnetic field transport from the disk of NGC 6946 into its halo further supports the existence of a vertical magnetic field component (Heald, 2012). Therefore, to accurately assess the dynamical influence of magnetic fields on the motion of the gaseous disk and its rotation curve, it is essential to consider the full three-dimensional structure of the regular magnetic field (Khademi et al., 2023). In a differentially rotating disk galaxy, mean-field dynamo theory predicts a quadrupolar magnetic field configuration, characterized by an azimuthal magnetic field that maintains the same direction above and below the galactic plane, while the vertical component reverses across the plane (Haverkorn & Heesen, 2012). The magnetic field is divergence-free:

$$\nabla \cdot B = 0. \tag{16}$$

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What we need is a mean radial dependence, so by applying the average $\langle\,\rangle \equiv \frac{1}{4\pi h}\int_0^{2\pi}\int_{-h}^{h} dz d\varphi$ to eq.15, one can be written as follows:

$$\langle v_{mag}^2\rangle = \frac{1}{4\pi\varrho}\left[\left(\langle B_\varphi^2\rangle - \langle B_\rho^2\rangle\right) + \frac{\rho}{2}\left(\partial_\rho\langle B_\varphi^2\rangle - \partial_\rho\langle B_\rho^2\rangle\right)\right] + \frac{1}{4\pi\varrho}\left[\frac{\rho}{2}\left(\partial_\rho\langle B_z^2\rangle - \frac{1}{\pi h}\int_0^{2\pi} B_\rho(h)B_z(h)\,d\varphi\right)\right]. \tag{17}$$

4. Fitting Methodology and Model Parameters

Our analysis employs the reduced chi-squared statistic, χ_r^2, as a measure of goodness-of-fit, using a χ^2 minimization (least-squares fitting) approach. For the galaxy *NGC* 6946, we fit the observed rotation curve data using two dark matter halo profiles: the pseudo-isothermal (ISO) and the Navarro–Frenk–White (NFW) models. Each profile is evaluated both with and without the contribution of the regular magnetic field to the circular velocity. For each halo model, the dark matter contribution is characterized by two free parameters: ρ_0 and R_c for the ISO profile, and ρ_0 and a for the NFW profile. The parameters for the gas and stellar disks are treated as fixed quantities in our analysis (see Table 1).

The contribution of the three-dimensional regular magnetic field to the rotation curve is modeled as a combination of a planar magnetic field and an out-of-plane quadrupolar poloidal component. The planar field topology is represented by a superposition of two azimuthal dynamo modes: $m = 0$ (Axisymmetric Spiral Model, Eq. 10) and $m = 2$ (Quadri-symmetric Spiral Model, Eq. 11).

The magnetic field contribution is incorporated via an additional free parameter, ρ_1, previously defined in Eq. (10). When the magnetic field is excluded, the model circular velocity depends solely on the two halo parameters. When included, the model velocity becomes a function of three free parameters: ρ_0, R_c (or a), and ρ_1, where ρ_1 quantifies the perturbative effect of the regular magnetic field on the rotation curve.

The best-fit parameters are obtained by minimizing the reduced chi-squared function:

$$\chi_r^2 = \frac{1}{(N-M)}\sum_{i=1}^{N}\left[\frac{v_{c,\mathrm{the}}(r_i) - v_{c,\mathrm{obs}}(r_i)}{\sigma_i}\right]^2, \tag{18}$$

where $v_{c,\mathrm{obs}}(r_i)$ is the observed circular velocity at radius r_i, $v_{c,\mathrm{the}}(r_i)$ is the model velocity (defined in Eq. 1), and σ_i is the observational uncertainty for each data point. The rotation curve data are taken from the high-resolution HI observations of *NGC* 6946 provided by The HI Nearby Galaxy Survey (THINGS) De Blok et al. (2008), which offers some of the most precise HI rotation curves for nearby galaxies.

In Eq. 18, N is the total number of data points, and M is the number of free parameters: $M = 2$ when the magnetic field is excluded, and $M = 3$ when it is included.

Table 1 summarizes the fixed parameters used for the gaseous disk, stellar disk, and regular magnetic field in *NGC* 6946. Column (1) lists the exponential stellar disk scale length, $R_{\exp,\star}$; column (2) gives the gaseous disk scale length, $R_{\exp,\mathrm{gas}}$; column (3) provides the central surface density of the stellar disk, $\mu_{0,\star}$; and column (4) gives the central surface density of the gaseous disk, $\mu_{0,\mathrm{gas}}$, which includes atomic hydrogen (HI), molecular hydrogen (H_2), and helium. Column (5) presents the mean pitch angle of the northern magnetic arm, p_{north}; column (6) gives the pitch angle of the southern inner magnetic arm, p_{south}; and column (7) lists the vertical exponential scale height of the radio halo, representing a thin radio disk typical of spiral galaxies with X-shaped magnetic field structures.

Using Python-based modeling, we derive the best-fit solutions for both the pseudo-isothermal sphere (ISO) and Navarro–Frenk–White (NFW) halo profiles. Our main results are illustrated in Fig. 1(a) for the ISO profile and Fig. 1(b) for the NFW profile. In each figure, the red curve represents the best-fit rotation curve including the contribution of the regular magnetic field, while the blue curve shows the fit excluding magnetic effects. These comparisons highlight the dynamical impact of the magnetic component on the rotation curve of *NGC* 6946.

Table 2 summarizes the best-fit results for the pseudo-isothermal (ISO) and Navarro–Frenk–White (NFW) halo profiles, presenting the constrained parameters for two cases: excluding and including the contribution of the regular magnetic field to the dynamics.

Our results indicate that the regular magnetic field strength at $\rho_1 \sim 9$ kpc is approximately half of its value near the galactic center. This estimate is consistent with observational constraints derived from polarized radio synchrotron emission and Faraday rotation measurements (RM) (Beck, R., 2007).

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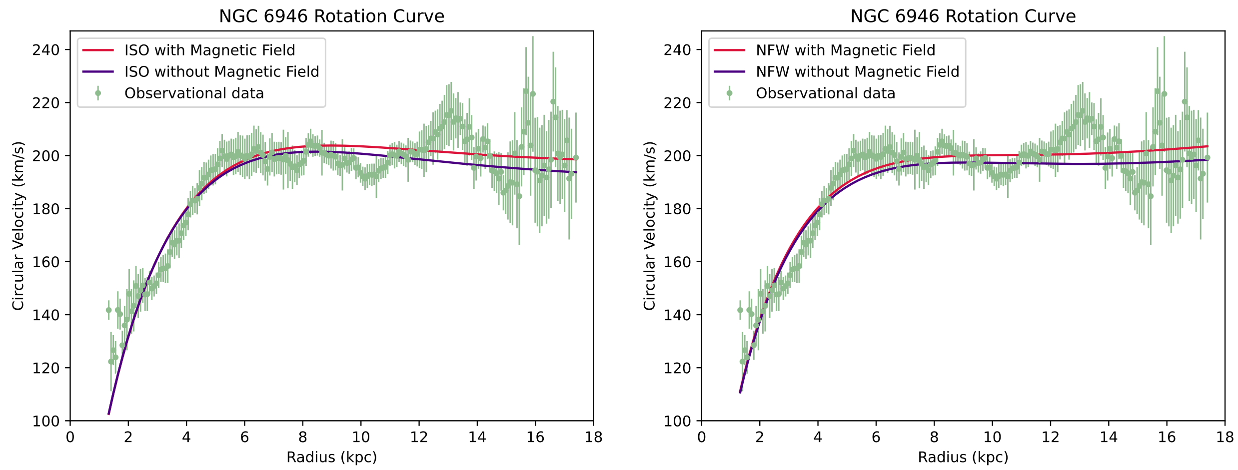
Table 1. Fixed Parameters for the Gaseous Disk, Stellar Disk, and Regular Magnetic Field in *NGC* 6946

(1)	(2)	(3)	(4)	(5)	(6)	(7)
$R_{\mathrm{exp},\star}$ (kpc)	$R_{\mathrm{exp,gas}}$ (kpc)	$\mu_{0,\star}$ ($M_\odot$ pc^{-2})	$\mu_{0,\mathrm{gas}}$ ($M_\odot$ pc^{-2})	p_{north} (degrees)	p_{south} (degrees)	h_{exp} (kpc)
2.57	4.9	900	0.16	$-25° \pm 1°$	$-31° \pm 2°$	0.3

References: Beck, R. (2007), Casasola et al. (2017), Dumke & Krause (1998), Heesen et al. (2008), Krause (2009), Soida et al. (2011)

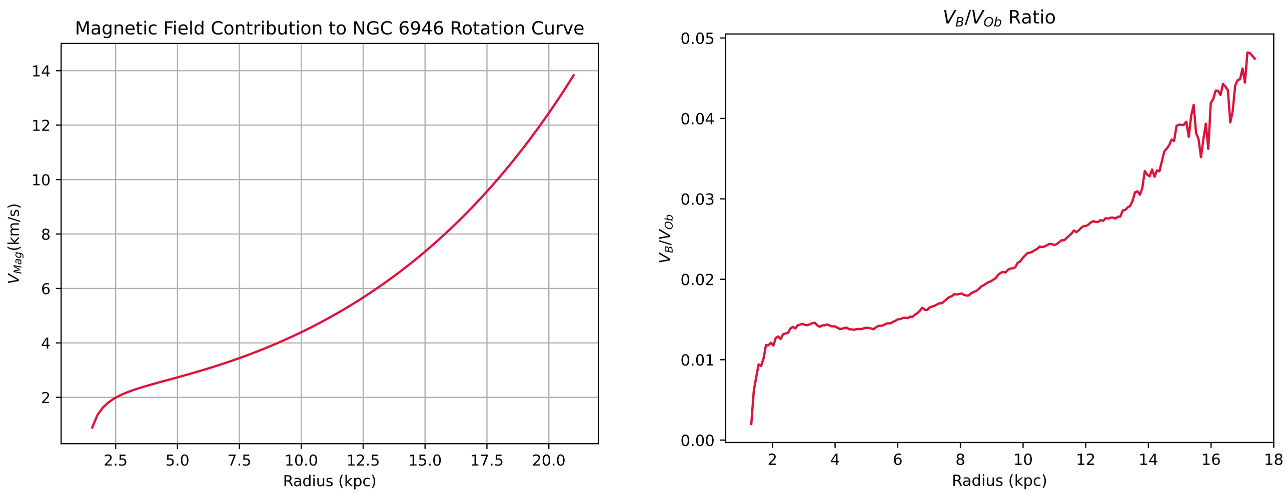


(a) ISO halo profile: best-fit rotation curve of *NGC* 6946 with and without magnetic field contribution.

(b) NFW halo profile: best-fit rotation curve of *NGC* 6946 with and without magnetic field contribution.

Figure 1. Comparison of best-fit rotation curves for *NGC* 6946 under two dark matter halo models: ISO and NFW. Each panel shows fits with and without the contribution of the regular magnetic field.

Figure 2(a) illustrates the radial contribution of the regular magnetic field to the circular velocity of NGC 6946. The curve shows a rising trend, with a typical amplitude ranging from 6 to 14 km s^{-1} in the outer regions of the galaxy's gaseous disk. Figure 2(b) shows that the contribution ratio of the regular magnetic field to the observed circular velocity reaches approximately five percent in the outer disk.



(a)

(b)

Figure 2. (a): Contribution of the modeled regular magnetic field to *NGC* 6946 rotation curve. (b): Contribution ratio of the regular magnetic field to the observed circular velocity.

Using the derived parameter for the regular magnetic field contribution, namely, the characteristic scale radius, we generate a map of the modeled regular magnetic field strength for the spiral galaxy *NGC* 6946, as shown in Fig. 3. The model is constructed as a superposition of two azimuthal dynamo modes: $m = 0$

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Table 2. Best-Fit Parameters for ISO and NFW Profiles With and Without Magnetic Field Contribution

Model	**Derived Parameters**	χ^2_r
ISO	$\rho_0 = 5.77 \times 10^{-2}$ ($M_\odot$ pc^{-2}) $R_c = 3.45$ kpc	1.8
ISO + Magnetic Field	$\rho_0 = 5.58 \times 10^{-2}$ ($M_\odot$ pc^{-2}) $R_c = 3.66$ kpc $\rho_1 = 9$ kpc	1.6
NFW	$\rho_c = 2.35 \times 10^{-3}$ ($M_\odot$ pc^{-2}) $R_s = 41.8$ kpc	1.4
NFW + Magnetic Field	$\rho_c = 2.25 \times 10^{-3}$ ($M_\odot$ pc^{-2}) $R_s = 45.2$ kpc $\rho_1 = 9$ kpc	1.1

(axisymmetric spiral model) and $m = 2$ (quadri-symmetric spiral model). The resulting map reveals two prominent inner spiral contours with the highest magnetic field strength, both directed toward the galactic center. This configuration closely resembles the two bright inner magnetic arms observed in polarized synchrotron intensity maps (Beck, 2001, Beck & Hoernes, 1996, Beck & Wielebinski, 2013, Beck, R., 2007, Beck et al., 1996).

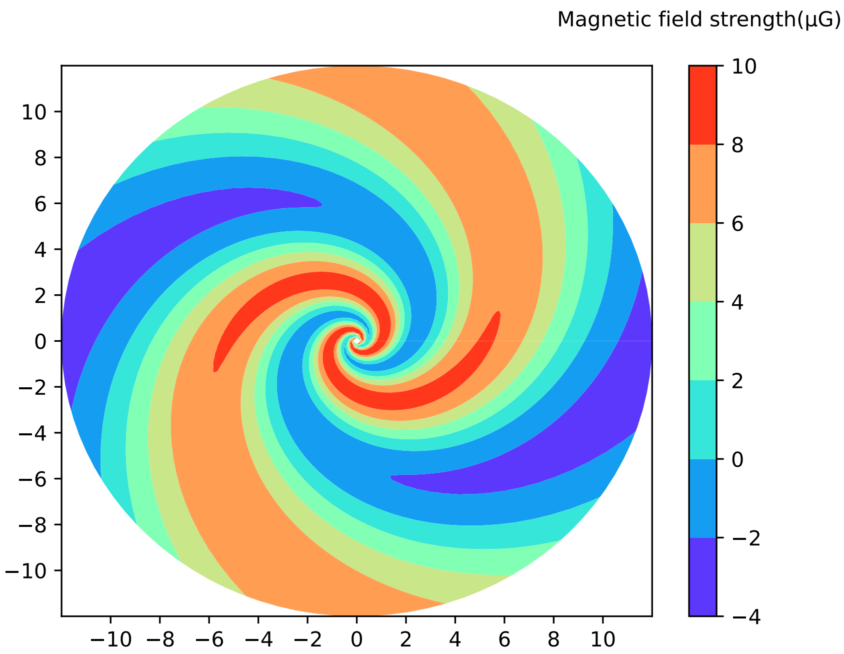

Figure 3. The map of the planar component of the modeled regular magnetic field strength for the spiral galaxy *NGC* 6946 in the galactic disk plane (in the $X - Y$ plane), extracted from a superposition of two azimuthal dynamo modes $m = 0$ (axisymmetric model) and $m = 2$ (quadri-symmetric spiral model) with the same amplitudes, which leads to two dominant magnetic spiral arms with the same direction of the radial field component with respect to the galaxy's center (same field direction).

5. Conclusion

To investigate the dynamical impact of galactic disk magnetic fields on the rotation curve of the spiral galaxy *NGC* 6946, we modeled a three-dimensional regular magnetic field and evaluated its contribution to the circular velocity. The fitting procedure was carried out using a χ^2 minimization method, applied to the observational rotation curve data, for two dark matter halo profiles: the pseudo-isothermal (ISO) and the Navarro–Frenk–White (NFW) models. Each profile was tested under two scenarios, excluding and including the contribution of the regular magnetic field. For both halo models, incorporating the magnetic

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field contribution led to an improved fit in the outer regions of the galaxy, as reflected by a reduction in the value of the reduced χ^2 statistic. The influence of the regular magnetic field to the rotation curve increases with galactocentric radius, reaching up to 14 $\mathrm{km\,s^{-1}}$ in the outer gaseous disk of NGC 6946, corresponding to roughly five percent of the observed rotational velocity (see Fig. 2). While large-scale magnetic fields cannot replace dark matter as the dominant mass component, they play a non-negligible role in the large-scale dynamics of spiral galaxies, particularly in their outer gaseous disks.

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