

# Evaluating the Dynamical Importance of Magnetic Fields in NGC 4449

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## Abstract

Using a published magnetic-field estimate and a simplified spherical model, we compare magnetic, turbulent, and gravitational energy scales in NGC 4449. For the adopted radius and masses, the magnetic-to-gravitational energy ratio is approximately 0.12, and the magnetic and turbulent energies differ by a factor of 1.6. The published field uncertainty alone gives ratios of about 0.055–0.22; geometry and mass assumptions introduce additional uncertainty. These estimates suggest that magnetic effects may be relevant to the gas dynamics, but do not establish local support against collapse or regulation of star formation.

**Keywords:** irregular galaxies; magnetic fields; NGC 4449; galactic dynamics; gravitational binding energy X

## 1 Introduction

The interstellar medium is the gas and dust between stars. Its motion is influenced by gravity, rotation, stellar winds, supernova explosions, and magnetic fields. A magnetic field stores energy and can exert pressure and tension on the gas. Comparing this stored energy with other energy scales is an accessible first step toward assessing whether magnetic effects may matter (Beck, 2016).

NGC 4449 is an irregular galaxy: its visible structure does not follow the well-defined spiral pattern of many disk galaxies. Radio observations reveal both disordered and organized magnetic components (Chyży et al., 2000). Its gas and stellar kinematics are complex (Hunter et al., 2002), making a single simple dynamical description difficult.

We ask whether a representative magnetic energy is small compared with the turbulent and gravitational energy scales in an idealized model of NGC 4449. We retain a deliberately simple calculation, explain how the observational quantities are inferred, and test its sensitivity to the assumed field and volume. The result is a conditional energy comparison, not a measurement of magnetic forces throughout the galaxy.

## 2 Literature review

Chyży et al. (2000) used total and polarized radio emission at 4.86 and 8.46 GHz to investigate NGC 4449. Their Table 2 gives an average total field of  $12 \pm 4 \mu\text{G}$ , estimated under an

equipartition assumption. The total field includes the ordered and disordered components; using only the ordered component would miss part of the magnetic energy.

For context, Chyży et al. (2011) found much weaker fields in most of their Local Group dwarf sample, reporting a mean below  $4.2 \pm 1.8 \mu\text{G}$  when upper limits are included. The starburst dwarf IC 10 reaches about  $10 \mu\text{G}$ . Thus, a field near  $12 \mu\text{G}$  is relatively strong for a dwarf galaxy, while remaining comparable to values in actively star-forming systems. This comparison concerns field strengths; it does not imply that different galaxies share the same magnetic-to-gravitational energy ratio.

Hunter et al. (2002) compared stellar, ionized-gas, and neutral-hydrogen kinematics and modeled the unusual gas motions in NGC 4449. Their results emphasize why inclination, rotation, and gas structure matter when adopting a mass model. Our calculation complements such observations by making the dependence of a simple energy estimate on its assumptions explicit.

## 2.1 Observational basis and adopted parameters

We use published information and an explicitly specified reference model; we do not reduce new images or spectra. Table 1 distinguishes the published field estimate from the adopted model inputs. The mass parameters are fiducial choices, meaning reference values used to explore the calculation. They are not presented as precise measurements within a common observational aperture.

Radio synchrotron emission is produced by fast electrons moving in a magnetic field. Its polarization reveals the projected orientation and degree of ordering of the field. Changes of polarization angle with wavelength, called Faraday rotation, also constrain the coherent field along the line of sight. Estimating the total strength from radio brightness requires assumptions about the emitting depth and the energetic particles. Equipartition means assuming comparable energy densities in cosmic rays and magnetic fields (Beck, 2016). It does not assume equality between magnetic and gas-turbulent energies.

Neutral hydrogen emits a spectral line at a wavelength of 21 cm. Its integrated brightness can be converted to an atomic-gas mass when the distance and optical-depth assumptions are specified. A total gas estimate also needs helium and, where relevant, molecular and ionized gas. Doppler shifts measure motion along the line of sight. The spread in velocities, or velocity dispersion, can trace random motions, but thermal broadening, unresolved rotation, and multiple gas components must be considered. Here  $\sigma_v$  is treated as a representative one-dimensional random velocity dispersion. A value near  $20 \text{ km s}^{-1}$  is consistent with the broad H I profiles discussed by Hunter et al. (2002); we do not perform a new separation of their turbulent and thermal contributions.

Ordered velocities, corrected for inclination and other dynamical effects, can constrain the enclosed mass. In a spherical circular-orbit model,  $M(<R) = v_c^2 R / G$ , where  $v_c$  is the circular speed. The adopted  $M_{\text{dyn}}$  represents gas, stars, and dark matter inside the model radius. It is distinct from  $M_{\text{gas}}$ , which enters the gas kinetic energy alone. Because the observations do not supply one uniquely matched set of all five inputs for our model volume, the resulting ratio must be read together with these assumptions.

Table 1  
Parameters of the reference model

| Parameter       | Adopted value    | Source or basis                                       | Uncertainty or limitation                                 |
|-----------------|------------------|-------------------------------------------------------|-----------------------------------------------------------|
| Total field $B$ | $12 \mu\text{G}$ | Chyży et al. (2000), Table 2; equipartition estimate. | Published $\pm 4 \mu\text{G}$ includes model assumptions. |

| Parameter                      | Adopted value             | Source or basis                                                                                          | Uncertainty or limitation                                        |
|--------------------------------|---------------------------|----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| Radius $R$                     | 3 kpc                     | Rounded optical-body scale; the reported optical major diameter is 5.8' at 3.7 Mpc (Chyży et al., 2000). | Model radius; no fitted error. Excludes the extended H I system. |
| Enclosed mass $M_{\text{dyn}}$ | $3 \times 10^9 M_{\odot}$ | Adopted spherical-model mass normalization.                                                              | No observational confidence interval assigned.                   |
| Gas mass $M_{\text{gas}}$      | $10^9 M_{\odot}$          | Adopted gas-mass normalization for the same model region.                                                | No matched-aperture inventory or error assigned.                 |
| Dispersion $\sigma_v$          | 20 km s <sup>-1</sup>     | Representative H I line-width scale discussed by Hunter et al. (2002).                                   | Assumed isotropic; not a new measurement of pure turbulence.     |

Note. The quoted field uncertainty is not a complete error budget for the energy ratio. The masses and radius are explicit model choices, and no unmeasured statistical errors are assigned to them.

## 2.2 Units and energy definitions

We use Gaussian cgs units, based on centimetres, grams, and seconds. A microgauss ( $\mu\text{G}$ ) is one millionth of a gauss, a unit of magnetic field strength. A kiloparsec (kpc) is 1,000 parsecs, approximately 3,260 light-years. A solar mass ( $M_{\odot}$ ) is the mass of the Sun. An erg is a unit of energy equal to  $10^{-7}$  joule. The conversions used are

$$\begin{aligned} 1 \mu\text{G} &= 10^{-6} \text{ G}, & 1 \text{ kpc} &= 3.08568 \times 10^{21} \text{ cm}, \\ 1 M_{\odot} &= 1.98847 \times 10^{33} \text{ g}, & 1 \text{ km s}^{-1} &= 10^5 \text{ cm s}^{-1}. \end{aligned} \quad (1)$$

The gravitational constant is  $G = 6.67430 \times 10^{-8} \text{ cm}^3 \text{ g}^{-1} \text{ s}^{-2}$ .

Energy density is energy per unit volume. For a magnetic field in Gaussian cgs units,

$$u_B = \frac{B^2}{8\pi}, \quad U_B = \int_V \frac{B^2}{8\pi} dV \simeq \frac{B^2 V}{8\pi}. \quad (2)$$

The approximation replaces the spatially varying field by a representative value throughout the chosen volume. Strictly, the relevant average is  $\langle B^2 \rangle$ , not the square of an arbitrary observational average. Treating the radio-derived field as this volume-representative value is an additional assumption.

For isotropic random gas motions, the three spatial directions contribute equally, giving

$$U_{\text{turb}} = \frac{3}{2} M_{\text{gas}} \sigma_v^2. \quad (3)$$

This is a kinetic-energy estimate associated with the adopted dispersion; bulk rotation is not included.

For a uniform sphere,

$$V_{\text{sph}} = \frac{4\pi R^3}{3}, \quad U_{G,\text{sph}} = -\frac{3GM_{\text{dyn}}^2}{5R}. \quad (4)$$

The negative sign describes an attractive, bound gravitational configuration. We compare positive energies with its magnitude  $|U_{G,\text{sph}}|$ . This is the self-gravitational energy of the entire idealized mass distribution. It is not a separately calculated binding energy of the gas in the actual stellar and dark-matter potential, and it does not include the outer halo.

### 2.3 Why use a sphere, and how is the approximation tested?

A sphere allows an order-of-magnitude calculation with one length scale; it is not a claim that an irregular galaxy has a spherical shape or uniform density. The optical extent tabulated by Chyży et al. (2000) is  $5.8' \times 4.5'$ , giving a projected minor-to-major axis ratio of about 0.78. This projected shape does not determine the unseen depth of the magnetized region.

We therefore test two alternative volumes. An ellipsoid with semi-axes  $(a,b,c)$  and a cylindrical disk with radius  $R$  and full thickness  $H$  have volumes

$$V_{\text{ell}} = \frac{4\pi abc}{3}, \quad V_{\text{disk}} = \pi R^2 H. \quad (5)$$

Relative to the reference sphere, and holding  $B$  fixed,

$$\frac{U_{B,\text{ell}}}{U_{B,\text{sph}}} = \frac{abc}{R^3}, \quad \frac{U_{B,\text{disk}}}{U_{B,\text{sph}}} = \frac{3H}{4R}. \quad (6)$$

These are controlled volume tests. A new fit to the radio data would also need to reconsider the emitting path length used to infer  $B$ .

## 3 Results and Discussion

### 3.1 Reference energy comparison

The adopted field and radius give  $u_B = 5.73 \times 10^{-12} \text{ erg cm}^{-3}$  and  $V_{\text{sph}} = 3.32 \times 10^{66} \text{ cm}^3$ . The resulting energies are listed in Table 2; direct substitution in Equations (2)–(4) gives

$$\frac{U_B}{|U_{G,\text{sph}}|} = 0.124, \quad \frac{U_{\text{turb}}}{|U_{G,\text{sph}}|} = 0.0775, \quad \frac{U_B}{U_{\text{turb}}} = 1.60. \quad (7)$$

Thus, the magnetic energy is about 12% of the reference gravitational energy magnitude, close to the approximately 13% obtained when the individual energies are rounded more coarsely. Magnetic and turbulent energies are comparable in order of magnitude. These percentages are ratios to a gravitational reference, not shares of a complete galactic energy budget.

**Table 2**  
Energy scales for the spherical reference model

| Component                             | Energy (erg)          | Ratio to $ U_{G,\text{sph}} $ |
|---------------------------------------|-----------------------|-------------------------------|
| Magnetic, $U_B$                       | $1.90 \times 10^{55}$ | 0.124 (12.4%)                 |
| Gas random motions, $U_{\text{turb}}$ | $1.19 \times 10^{55}$ | 0.0775 (7.75%)                |
| Gravity, $ U_{G,\text{sph}} $         | $1.54 \times 10^{56}$ | 1                             |

*Note.* Ratios are calculated before rounding the energies. These are derived model values, with uncertainties inherited from Table 1.

### 3.2 Field uncertainty and dependence on other inputs

Because  $U_B \propto B^2$ , the published field estimate  $12 \pm 4 \mu\text{G}$  (Chyży et al., 2000) corresponds to a sensitivity interval  $B = 8\text{--}16 \mu\text{G}$ . With all other inputs fixed, this gives

$$U_B = (0.85\text{--}3.38) \times 10^{55} \text{ erg}, \quad \frac{U_B}{|U_{G,\text{sph}}|} = 0.055\text{--}0.220. \quad (8)$$

This interval propagates the quoted field range only. It is not a formal confidence interval for the full model, because uncertainties and covariances in the other inputs are not established.

The sensitivity of the gravitational comparison can be written explicitly as

$$\frac{U_B}{|U_{G,\text{sph}}|} = 0.124 \left( \frac{B}{12 \mu\text{G}} \right)^2 \left( \frac{R}{3 \text{ kpc}} \right)^4 \left( \frac{M_{\text{dyn}}}{3 \times 10^9 M_\odot} \right)^{-2}. \quad (9)$$

At fixed  $B$  and mass, increasing  $R$  by 20% increases this ratio by a factor of about 2.1. At fixed  $B$  and  $R$ , doubling  $M_{\text{dyn}}$  reduces it by a factor of four. These examples illustrate sensitivity, not measured error bounds. Radius, mass, distance, and emitting depth can be correlated in an observational analysis.

The turbulent estimate has its own dependence,  $U_{\text{turb}} \propto M_{\text{gas}} \sigma_v^2$ . In particular, the gas mass must refer to the same physical region as the magnetic energy. A gas mass integrated over an extended H I envelope cannot simply be combined with the field of the optical body. Our assumed common region makes the calculation reproducible, but does not establish this observational matching.

### 3.3 Effect of a different geometry

For an illustrative ellipsoid, we adopt  $(a,b,c)=(R,0.78R,0.5R)$ . The factor 0.78 is motivated by the observed projected axis ratio, while the third axis is chosen solely for this sensitivity test. The volume and magnetic energy become 0.39 times the spherical values. For a disk with  $R=3 \text{ kpc}$  and  $H=2 \text{ kpc}$ , they become 0.50 times the spherical values. The chosen disk thickness also matches the face-on nonthermal thickness assumed in the radio analysis of Chyży et al. (2000); it is not an independently measured thickness.

Table 3  
Magnetic-energy sensitivity to the adopted volume

| Geometry                                    | $V/V_{\text{sph}}$ | $U_B \text{ (erg)}$   | $U_B/ U_{G,\text{sph}} $ |
|---------------------------------------------|--------------------|-----------------------|--------------------------|
| Sphere, radius $R$                          | 1.00               | $1.90 \times 10^{55}$ | 0.124                    |
| Ellipsoid, $(R, 0.78R, 0.5R)$               | 0.39               | $7.42 \times 10^{54}$ | 0.0482                   |
| Disk, $R=3 \text{ kpc}$ , $H=2 \text{ kpc}$ | 0.50               | $9.52 \times 10^{54}$ | 0.0618                   |

Note. The field is fixed at  $12 \mu\text{G}$ . Every row is normalized to the same *spherical* gravitational energy. The alternative geometries require their own mass distributions to calculate their actual binding energies.

Geometry can therefore alter the magnetic-energy estimate by factors of a few even before the mass model is changed. The spherical result should be treated as one reference configuration, rather than a geometry-independent property of NGC 4449.

### 3.4 Physical interpretation and limitations

The field-strength comparison in the literature review places NGC 4449 among relatively strongly magnetized star-forming dwarfs. It does not establish whether a 12–13% gravitational energy ratio is typical of that population: such a comparison would require compatible volumes, mass profiles, and definitions of gravitational energy. Our result therefore indicates a potentially relevant contribution under the adopted assumptions, without assigning NGC 4449 a measured ranking in dynamical importance.

The similarity of  $U_B$  and  $U_{\text{turb}}$  provides motivation to include magnetic effects when modeling the gas. However, an integrated energy contains no information about where a force acts. Magnetic pressure depends on variations of field strength, and magnetic tension depends on field curvature (Beck, 2016). A substantial magnetic energy can coexist with small net forces in a particular region; locally important magnetic forces can also occur when the galaxy-wide energy ratio is small.

Consequently, these calculations do not demonstrate that the field prevents collapse, sets the star-formation rate, or directly controls stellar motions. Gravity, gas density, rotation, turbulence, stellar feedback, dark matter, and the spatial structure of the field must be considered together. A full dynamical or virial analysis would also require bulk kinetic energy, appropriate boundary stresses, and other relevant pressure terms.

Additional limitations include the use of a uniform mass distribution, the replacement of a spatially varying field by one value, and the incomplete separation of turbulent from other gas motions. Spatially resolved radio and gas observations, measured over matching regions and combined with a mass model, are needed to determine where magnetic forces affect the interstellar medium.

## 4 Conclusion

For an idealized spherical model of NGC 4449 with the parameters in Table 1, we obtain  $U_B=1.90\times10^{55}$  erg,  $U_{\text{turb}}=1.19\times10^{55}$  erg, and  $|U_{G,\text{sph}}|=1.54\times10^{56}$  erg. The magnetic-to-gravitational energy ratio is approximately 0.12, while the magnetic and turbulent energies are of the same order.

The published field range alone gives ratios of about 5.5–22%; changing the emitting geometry can further change the magnetic energy by factors of a few. The mass and aperture assumptions remain important limitations. The energy comparison suggests that magnetic effects should be considered in models of the gas and may play a dynamically relevant role. Establishing their local influence on gas flows or star formation requires resolved observations and a more complete force balance.

### 4.1 AI assistance

ChatGPT (OpenAI) assisted with language revision, literature checking, calculation checks, and LaTeX formatting. Responsibility for the accuracy, originality, and interpretation of the manuscript remains with the authors.

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