CHANG-ES XXXIV: Magnetic Field Structure in Edge-On Galaxies

Characterising large-scale magnetic fields in galactic halos

M. Stein, et al. (2025)

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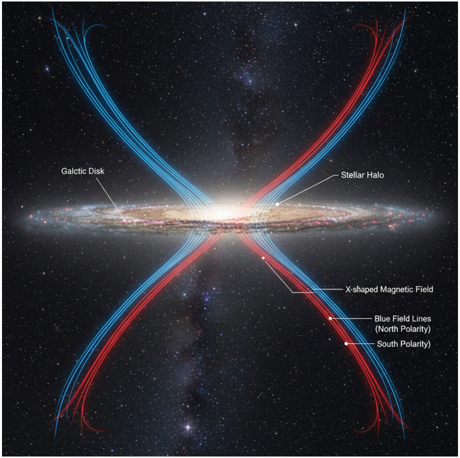
16.1.2025

Scientific Motivation

- **Galactic Feedback:** How do gas and energy leave the disk?
- **Magnetic Fields (B-fields):** Crucial for cosmic ray transport and star formation regulation.
- **Edge-on Perspective:** Allows vertical separation of disk and halo components.
- **Key Question:** What is the geometry of the halo field (X-shape)?

Why Study Halo Magnetic Fields?

- CRs + B-fields crucial for galaxy evolution
- $B^2/8\pi \sim$ turbulent + thermal energy
- Edge-on galaxies: Clean halo/disc separation
- Question: **How is the halo magnetised?**



by E. Schubert with support of Gemini (KI)

Data & Methodology

The Sample

18 late-type edge-on galaxies from the CHANG-ES survey.

- **Instrument:** VLA C-band (6 GHz).
- **Advantage:** High resolution and reduced Faraday depolarization compared to L-band. (Faradayrotation)
- **Analysis:** Polarisation angles transformed into intrinsic B-field vectors (χ). ($\vec{E} \perp \vec{B}$)
- **Masking:** Galactic disks and AGN/Background sources removed to focus on the halo.

CHANG-ES Sample: 18 Edge-On Galaxies

New 3-class system (6 GHz polarimetry):

- **disc dominated** (7/18), Vectors parallel to the mid-plane.
- small-scale (0/18), Patchy, no global order.
- **X-shaped** 11/18 (61%), Clear divergent structure in all four quadrants.

Key observation: X-shapes dominate halo patterns!
Result: 11/18 galaxies show clear X-shaped patterns.

Classification: The 3 Classes

Feature	**disc-dominated (22%)**	**small-scale (17%)**	**X-shaped (61%)**
Polarization	Flat, disk-parallel	Patchy	χ: **sgn(χ)=sgn(z)**
χ-angle	$\chi \approx 0^\circ/180^\circ$	Irregular	$\chi \propto$ —z—
Halo emission	Weak/absent	Patchy	**Strong+structured**
B-field	Disk (Bϕ)	Turbulent	**Poloidal halo**
SF efficiency	**Low** (vs $M^\star$)	-	Normal
Rotation	**Fast** (vs RHI)	-	Normal
Model	No fit	No fit	**const 55±16°**
Feedback	**Weak**	Medium	**Strong**
Numbers	7/18	0/18	**11/18**

Analytical Geometric Models

To quantify the X-shape, three 2D-models were fitted to the data:

- **Constant (const):** Opening angle α is fixed.
- **Wedge:** Angle $\alpha(r)$ increases with radius.
- **Parabolic (par):** Field lines follow $z = c \cdot r^2$.

Model Selection

Selection via **AIC** (Akaike Information Criterion) to avoid over-fitting and find the most likely geometry.

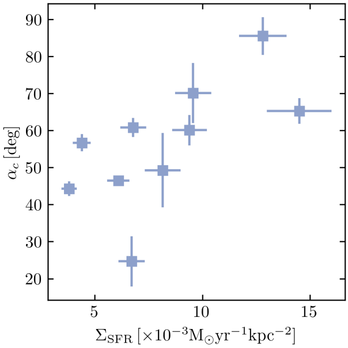
Key Result I: Constant Angle Dominance

- **Preference:** The *Constant Angle Model* is statistically favored for the majority of galaxies.
- **Interpretation:** Suggests a stable, conical outflow or a specific dynamo configuration.
- **Resolution Effect:** Higher resolution data confirms the "const" model more clearly.

Key Result II: Star Formation Connection

- **Correlation:** Opening angle α vs. Star Formation Rate surface density (Σ_{SFR}).
- **Observation:** Higher $\Sigma_{SFR} \rightarrow$ Larger opening angles.
- **Physics:** Increased energy injection from Supernovae "pushes" the magnetic field lines further apart.

Feedback Drives Halo Magnetisation



SFR surface density vs X-opening angle:

$$\mathbf{r = 0.8,\ p = 0.006}$$

disc-dominated galaxies:

- Lower SF efficiency (vs $M_\star$)
- Faster rotation (vs $R_{\rm HI}$)

Model Comparison Results

- **const model dominates** (best χ^2)
- $\bar{\alpha}_c = (55 \pm 16)^\circ$
- **wedge**: Best size scaling ($d_\star < 30\,\mathrm{kpc}$)
- par: Larger scatter $\rightarrow$ SF influence

wedge geometry $\sim$ JF12/coasting X-field!

Discussion: Disk-Parallel vs. X-Shaped

- Disk-dominated galaxies show **lower** specific SFR.
- **Hypothesis:** Parallel fields might act as a "magnetic cage", trapping gas in the disk.
- Once SFR reaches a threshold, the field "breaks out" into an X-shape, facilitating outflows.

Three Dynamical Scenarios

Assuming **B** $\parallel$ wind velocity:

1. *par*: Weak feedback (deceleration)
2. *wedge*: Strong acceleration
3. *const*: **Constant wind speed**

$$\arctan(B_z/B_x) = \arctan(v_z/v_x)$$

Outliers: NGC 4666 & NGC 3735

NGC 4666 (α_c: largest):

- Highest SFR/Σ_{SFR}
- Starburst + superwind
- B-field frozen in ionized outflow

NGC 3735 (α_c: smallest):

- Substructure in quadrants I/III
- Slight face-on bias (85°)

7 Summary Key Results

1. 61% X-shaped halos
2. disc-dominated: Low SF efficiency
3. **const model dominates**
4. $\alpha_c = 55 \pm 16^\circ$
5. wedge scaling $\rightarrow$ JF12-like
6. **SFRΣ vs opening: r $=$ 0.8**
7. Feedback $\rightarrow$ halo magnetisation

Summary & Outlook

- **Prevalence:** X-shaped fields are common in star-forming galaxies.
- **Geometry:** The "Constant Angle" model fits best.
- **Driver:** Star formation activity in the disk directly shapes the halo magnetisation.
- **Future:** Need for higher sensitivity (SKA/ngVLA) to resolve fields in smaller halos.

Next steps

- S-band: Higher resolution
- RM-synthesis: LOS information
- Test competing B-field theories

"**Structured poloidal halo fields are the norm**"

Thank you for your attention!

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Paper Reference: Stein et al. (2025) "Magnetic Field Structure in Edge-On Galaxies, A&A