Galactic winds, magnetic fields, and dynamo action in spiral galaxies

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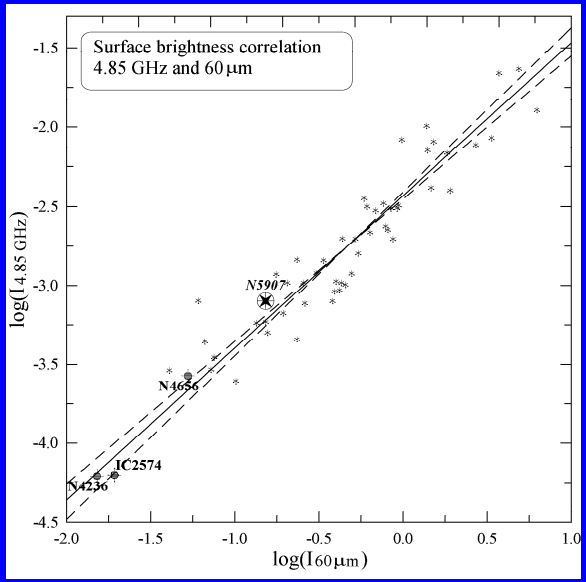
based on total and polarized radio emission of spiral galaxies of different Hubble types and SFRs

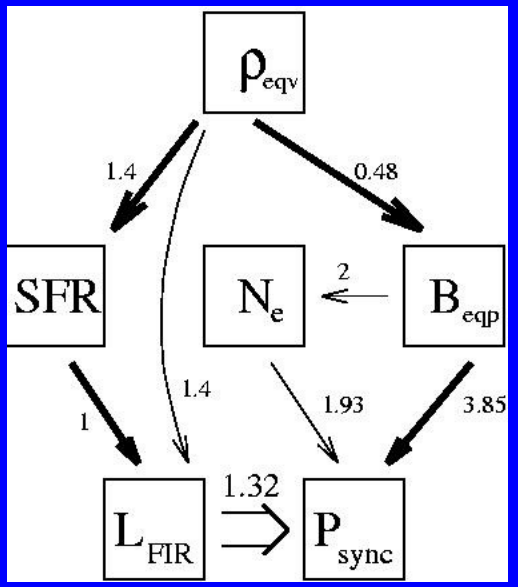
- SFR $\leftrightarrow$ magnetic field strength
- Magnetic field structure
- Vertical scale height

Radio-FIR-correlation



De Jong et al. 1985
Chyzy, Bomans, Krause et al. 2007

Equipartition model



Niklas & Beck 1997

Radio-FIR-correlation holds for galaxies with different SFR, even for late-type galaxies.

Equipartition model of radio-FIR-correlation gives globally:

nonthermal total intensity I_{nth} ~ SFR $^{1.3\pm0.2}$
total magnetic field strength B_t ~ SFR $^{0.34\pm0.14}$

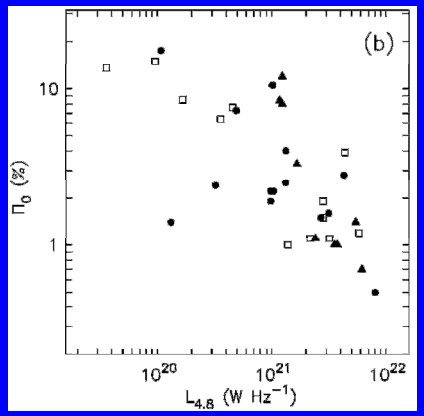
Does the **large-scale field B_{reg}** also depend on SFR?

Polarimetric study of nearby and distant galaxies

Integrated values for 43 nearby spiral galaxies:

→ globally: P decreases with increasing luminosity

B_{reg}/B_t decreases with increasing SFR



fractional polarization

Triangles:

Virgo Cluster galaxies

Circles:

nearby galaxies

4.8 GHz luminosity

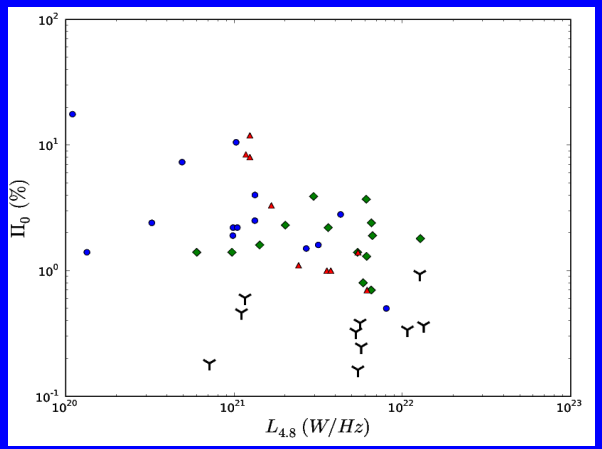
Stil, Krause et al. 2008

Pilot study for 24 distant spiral galaxies with Effelsberg at 6cm , < 2.‘5

-- polarization detected in 14 of them

-- upper limits given for the others

Large polarimetric survey of ~200 distant spiral galaxies started in August 2009 with Effelsberg at 6cm



fractional polarization

Green:

distant galaxies

Black:

upper limits

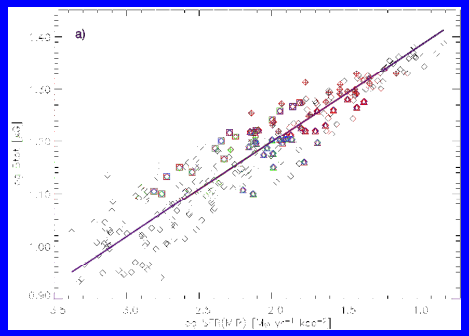
4.8 GHz luminosity

Mitchell, Stil, Krause et al. 2009

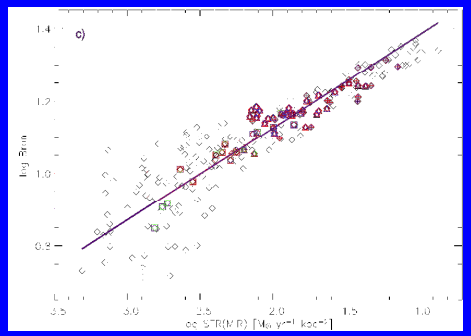
→higher SFR increases only B_r, B_{reg} decreases with SFR (cf. Detlef‘s talk)

Magnetic field strengths within NGC 4254

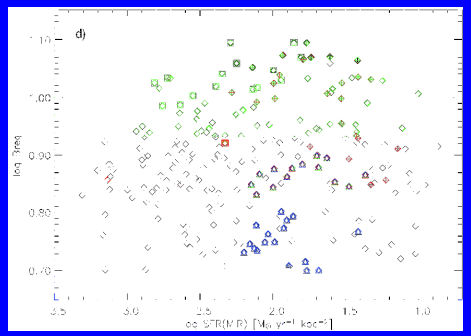
Chyzy 2008



log B_t (log SFR)



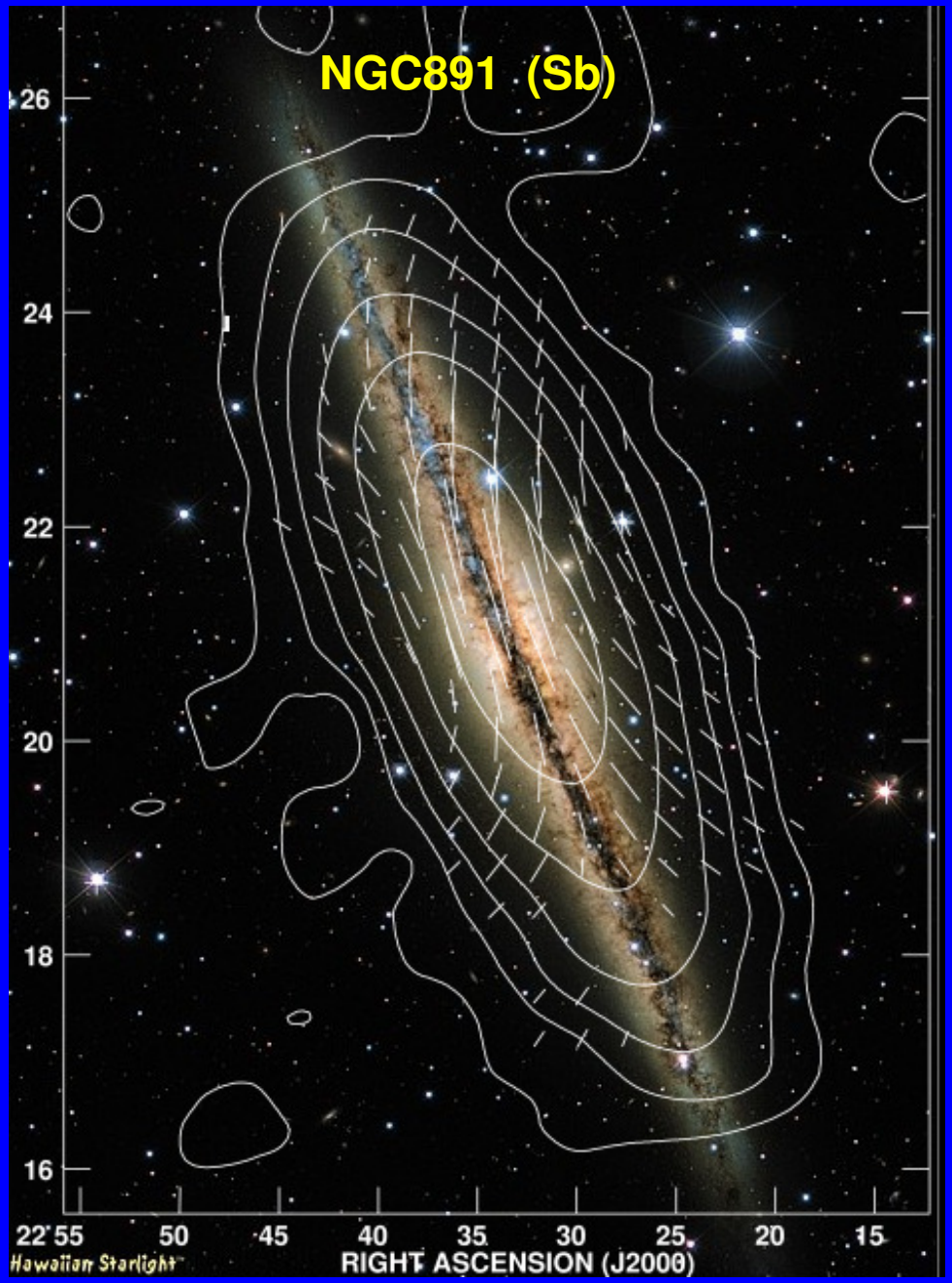
log B_r (log SFR)



log B_{reg} (log SFR)

→ B_{reg} is locally uncorrelated with SFR

Magnetic field configuration in edge-on galaxies

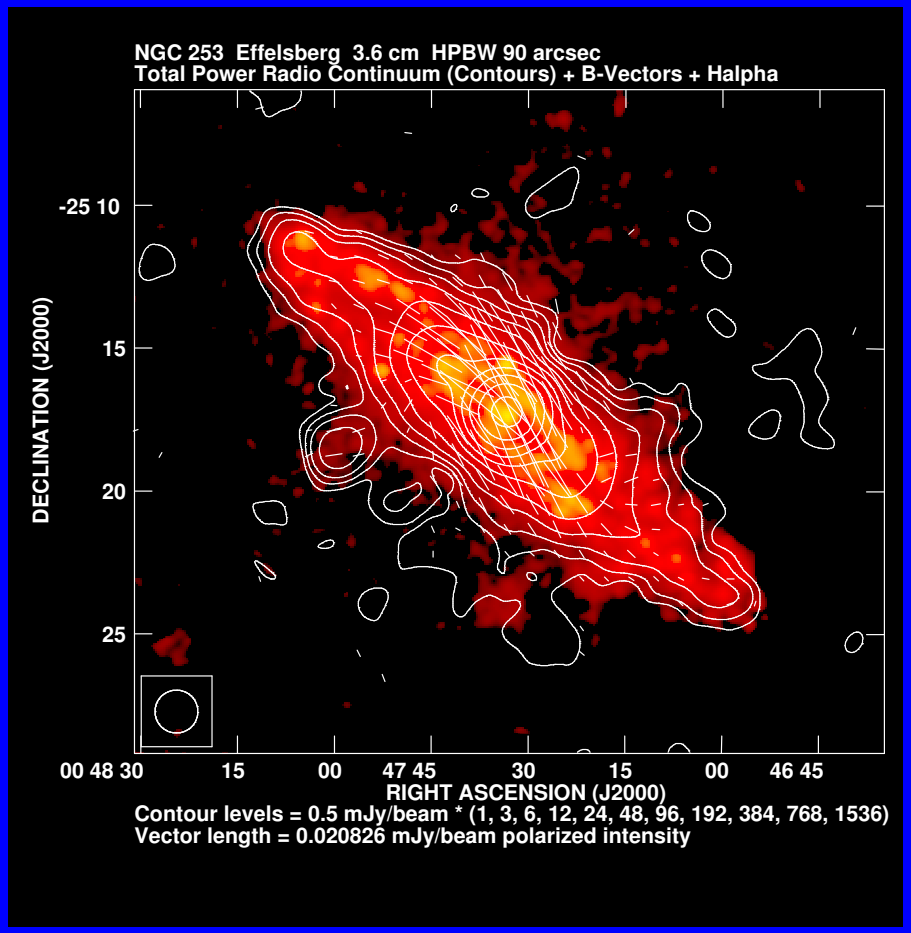


- **parallel** to the disk along the midplane and
- **vertical components** at larger radii away from the plane

→ **X-shaped magnetic field**

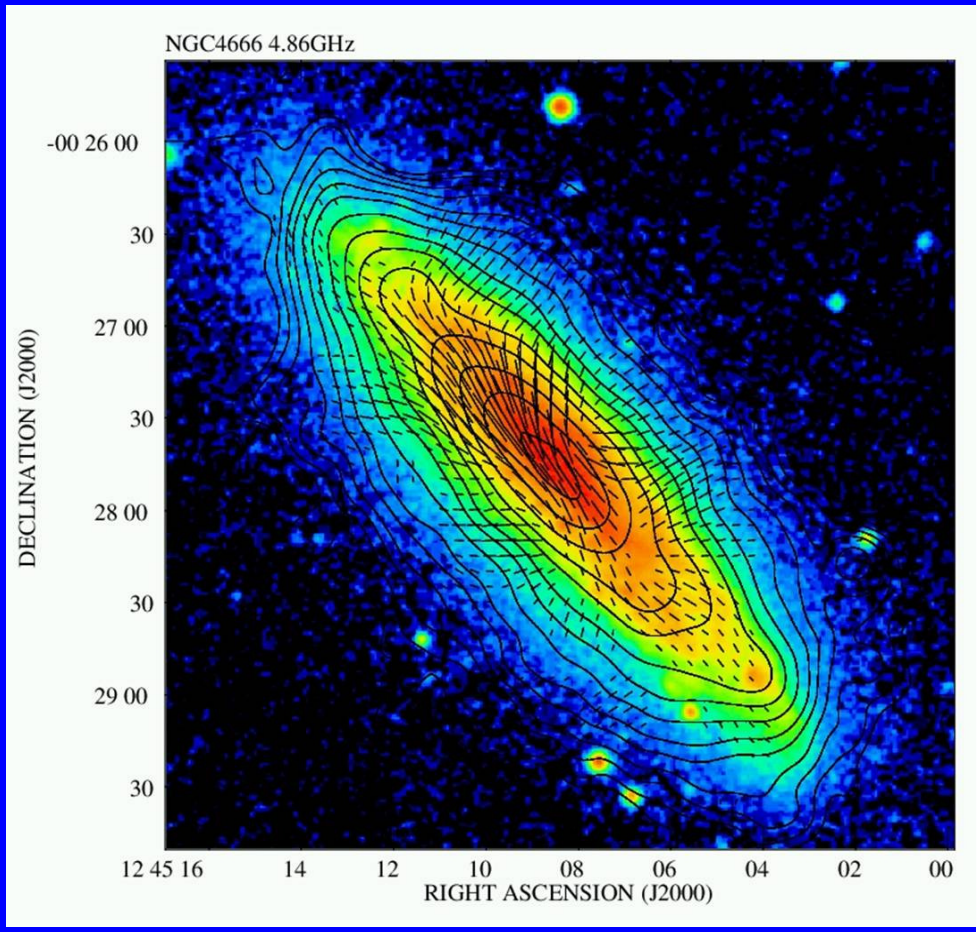
Edge-on galaxies with high SFR

NGC253 i =78°



Heesen, Krause, Beck, Dettmar 2009

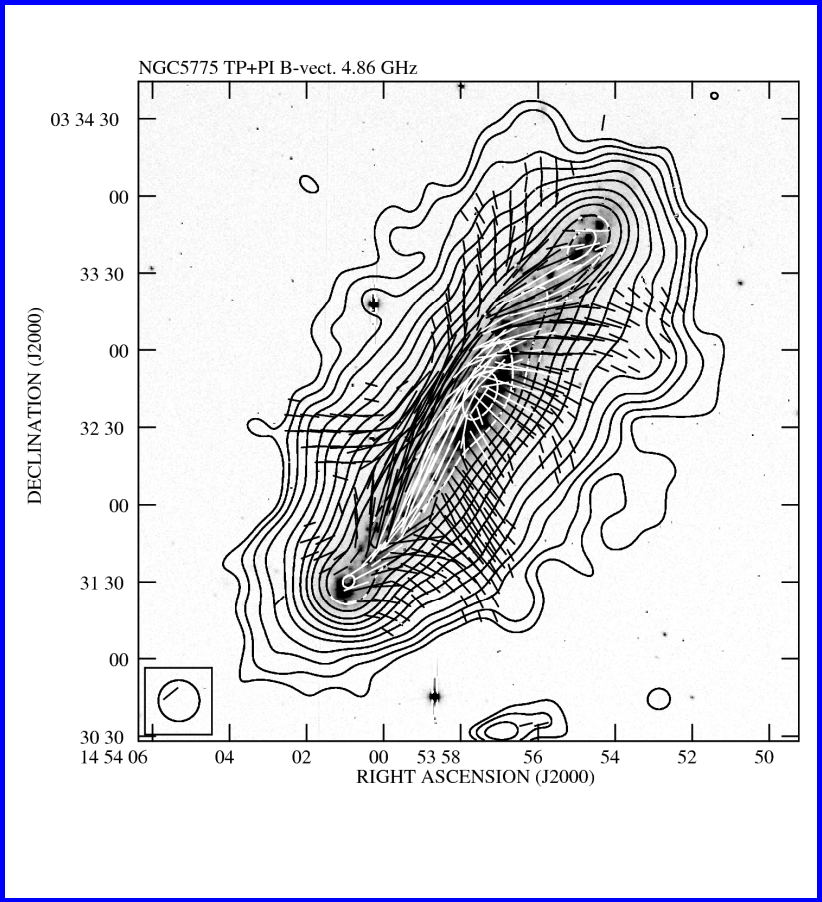
NGC4666 i = 80°



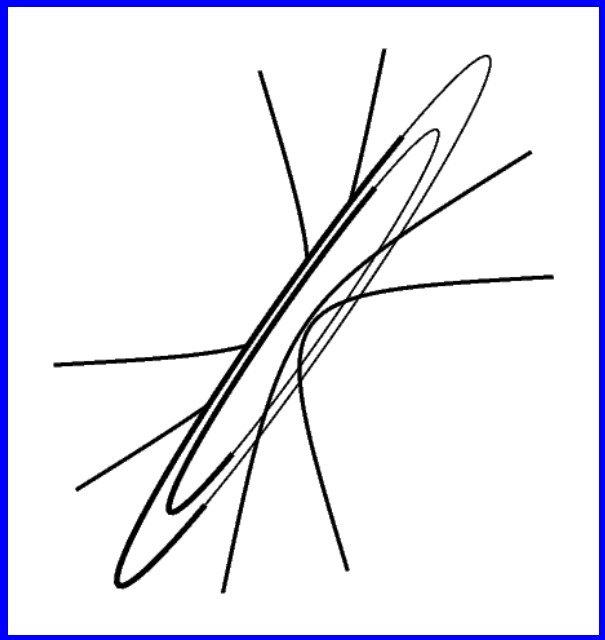
Soida 2005

Edge-on galaxies with high SFR

NGC5775 i = 86°



Scetch of toroidal disk field and halo field



Soida, Krause, Dettmar 2010

11 edge-on galaxies
with

high SFR or **starburst**

	SFR(IR) [$M_\odot$/yr]	i	type
M82	1.8	82°	Irr
N253	6.3	78°	Sc
N891	3.3	88°	Sb
N4217	2 ?	86°	Sb
N4631	2.1	86°	SBd
N4666	1.9	80°	Sc
N5775	7	86°	Sbc

low SFR

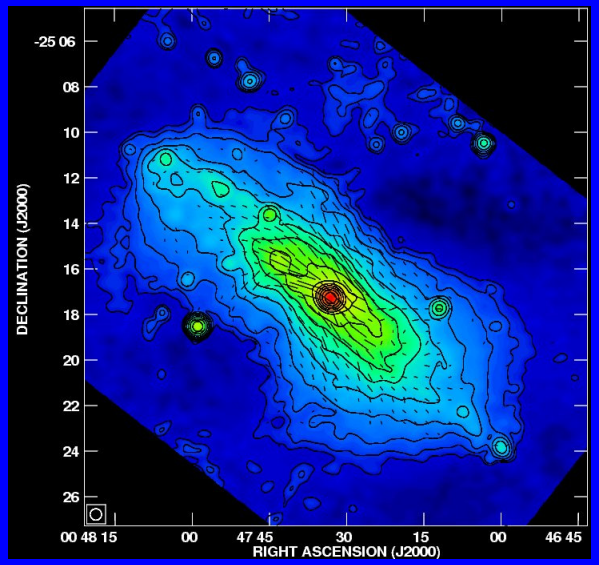
	SFR(IR) [$M_\odot$/yr]	i	type
M104	< 0.6	84°	Sa
N3628	0.61	89°	Sb pec
N4565	0.63	86°	Sb
N5907	0.46	87°	Sc

All these galaxies have a **similar global magnetic field structure**,

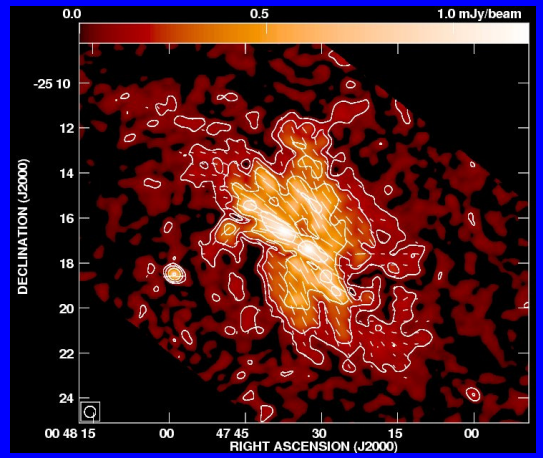
the only exception is NGC4631.

NGC253 Sc (starburst) i=78°

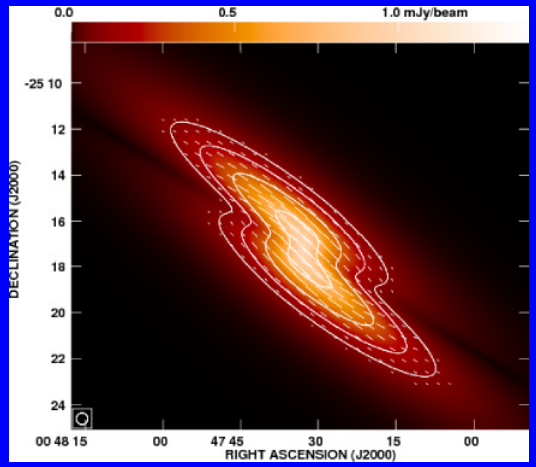
6cm Eff&VLA TP + Bfield



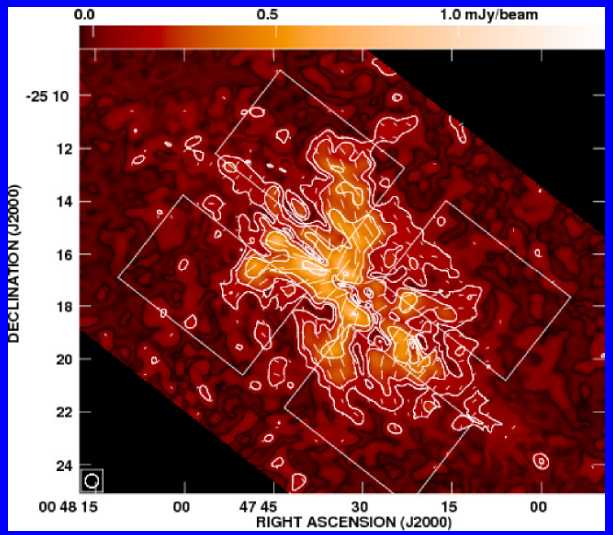
6cm Eff&VLA PI + Bfield



ASS-field (i=78°) PI + B



Bfield – ASSfield = vertical field



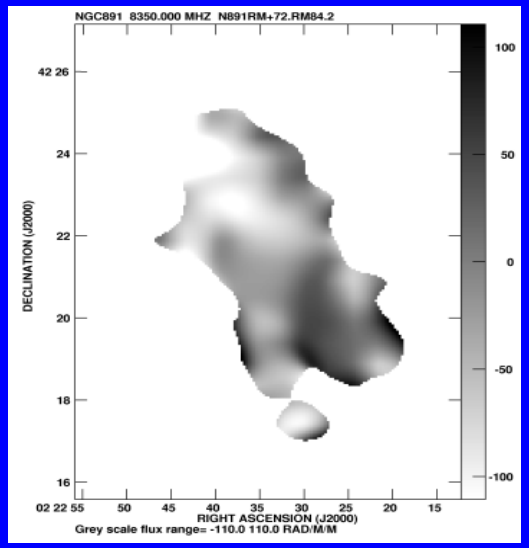
After subtraction of the ASS field:

purly X-shaped field is visible.

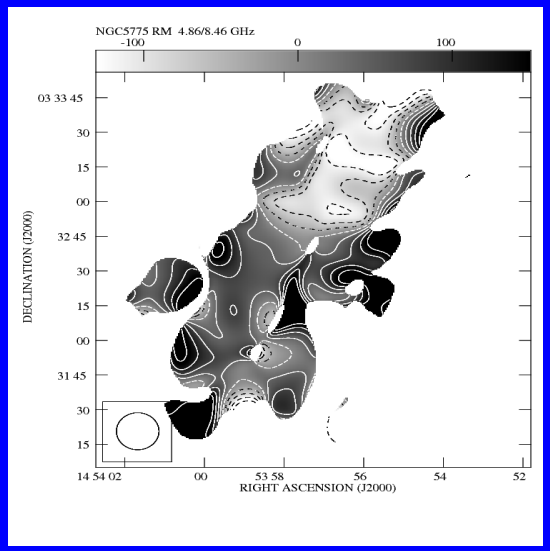
Heesen, Krause, Beck, Dettmar 2009

A dynamo generated large-scale magnetic field in disk and halo?

RM (NGC891)



RM (NGC5775)



Large-scale RM-pattern indicates an **ASS disk-field**. Its poloidal component alone cannot explain the observed vertical fields.

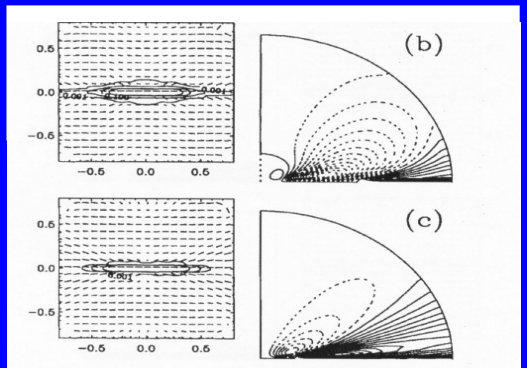


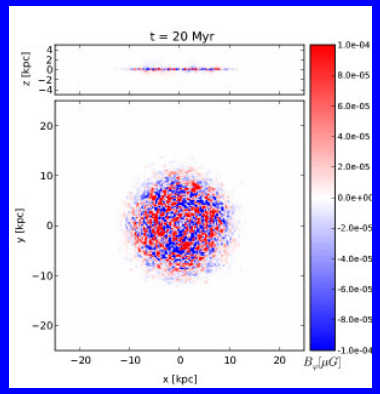
Fig. 9. Polarisation map and poloidal field geometry for a model using the rotation curve parameters of NGC 891 and different wind strengths, for $C_\Omega = 1040$, $w_\Omega = 0.2$, $\xi = 0.02$, $\alpha_z = 0$, $W_z = 0$. (a) $W_r = 0$, (b) $W_r = 50$, (c) $W_r = 200$

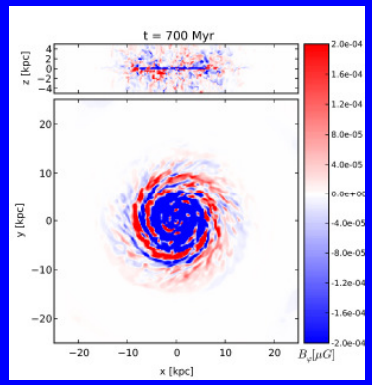
Model calculations of a mean-field αω-dynamo for a disk (ASS) surrounded by a spherical halo **including a galactic wind** (Brandenburg et al.1993).

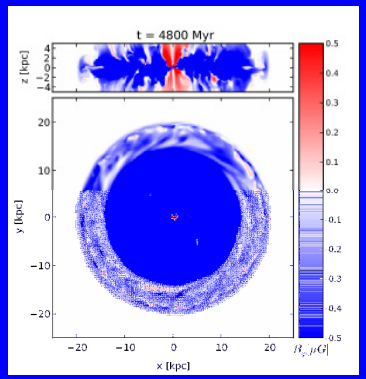
NGC253: observational evidence for a galactic wind

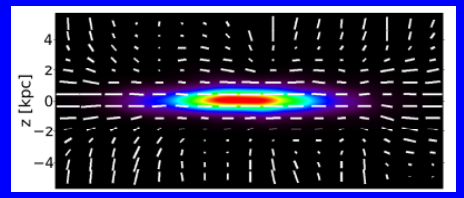
Dynamo theory

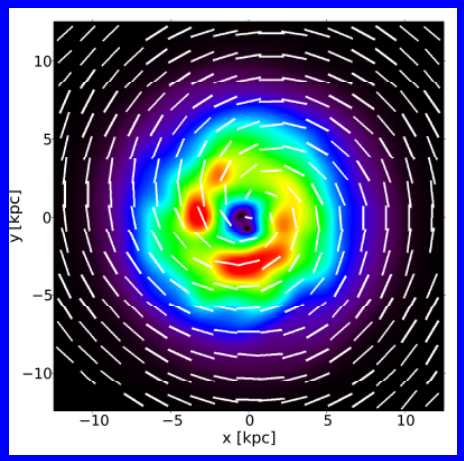
- **Local box simulations of a CR-driven dynamo** (Hanasz et al. 2004, 2006)
- **Self-consistent local box simulations of a SN-driven turbulent dynamo** (Gressel, Elstner et al. 2008)
- **First global galactic-scale MHD simulations of the CR-driven dynamo** (Hanasz et al. 2009):









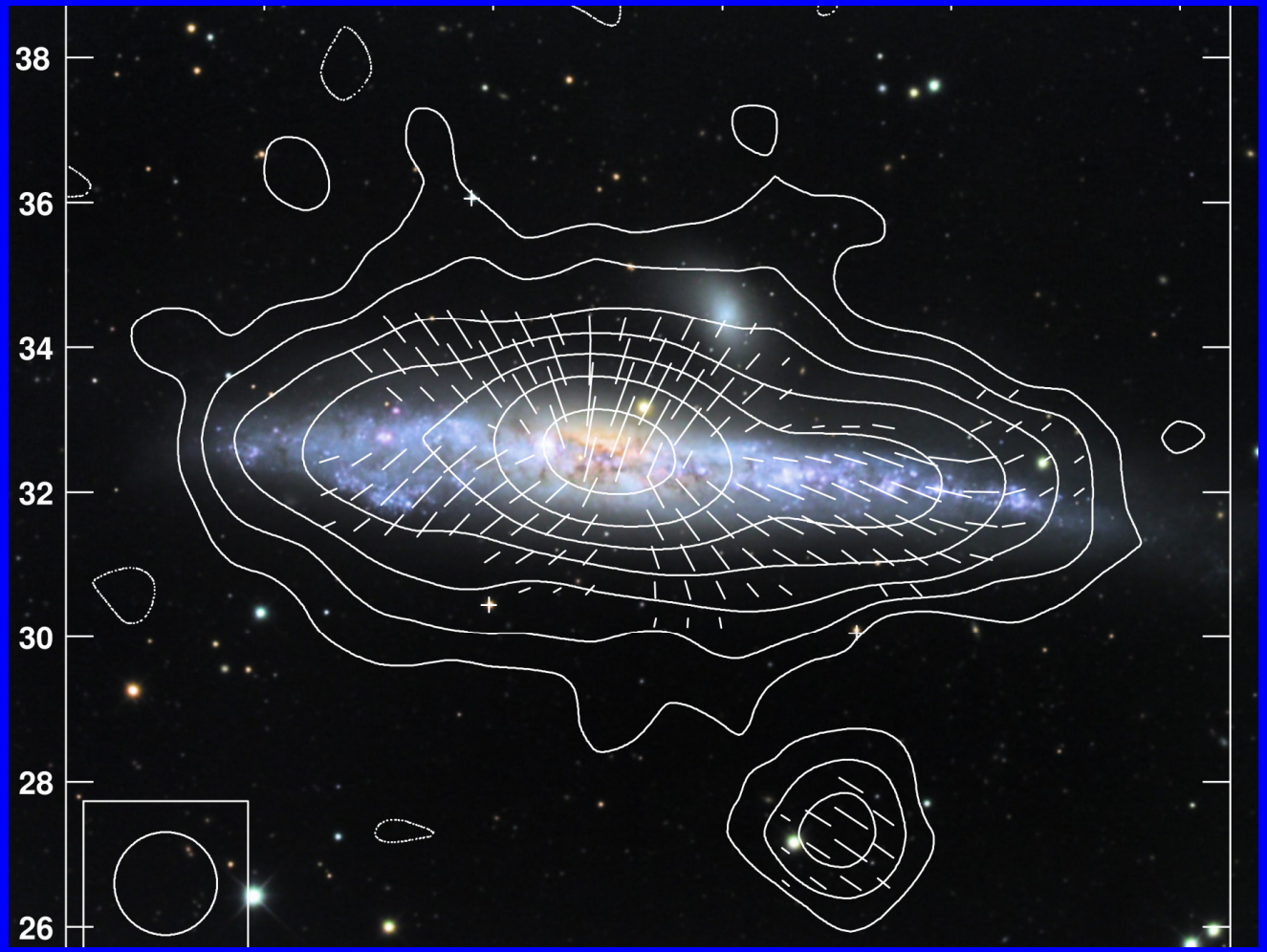


→ horizontal spiral field &

large lobes of unipolar field in vertical direction

→ **X-shaped field structure**

NGC4631 3.6cm TP & **B**field



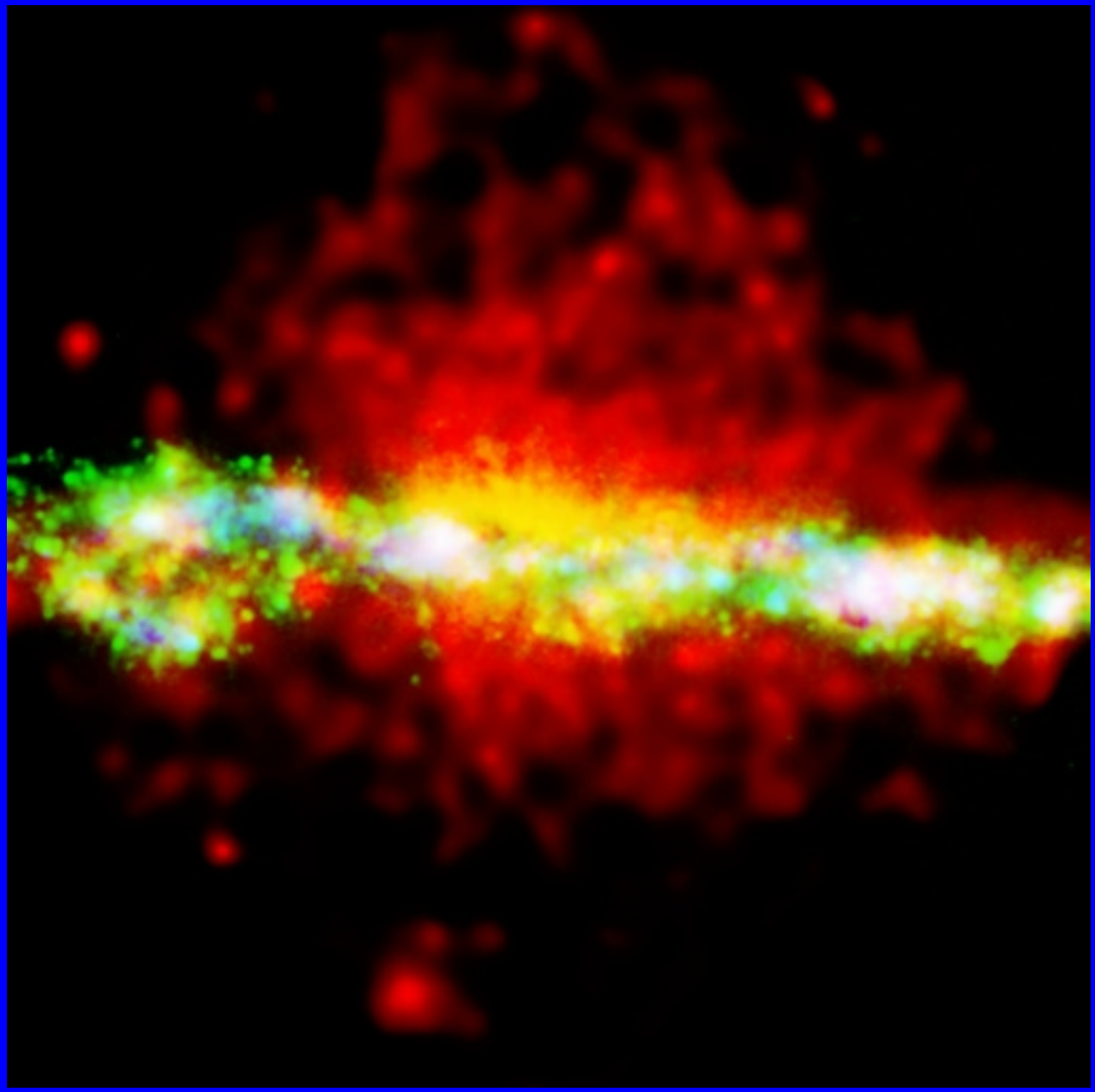
Bfield structure in NGC4631 is different from other galaxies.

Why?

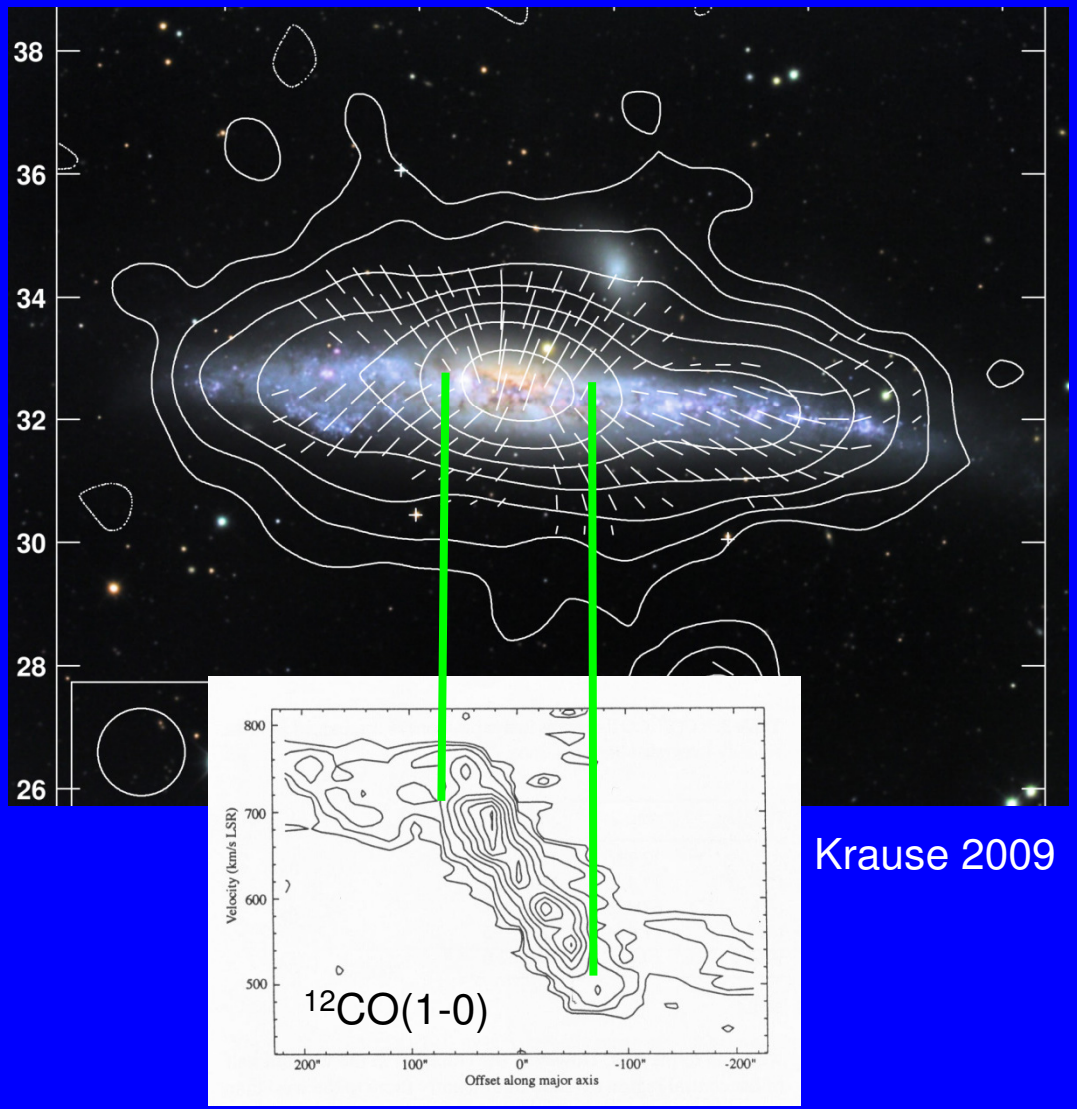
NGC4631
(CHANDRA+RGB)

SBd galaxy

- ~~high SFR~~
- no differential rotation in the central ~5 kpc



NGC4631 3.6cm TP & **B**field



Golla & Wielebinski 1994

Krause 2009

rigid rotation up to
r < 70“ (2.5 kpc)

→no αω-dynamo action in the central ~5 kpc.

→**dominant vertical fields** in this central area as indicated by simulations of Michal Hanasz.

Summary

- **Total magnetic field strength B_t** and nonthermal emission **increase nonlinearly** with **SFR**
- The **similar vertical scale heights** in galaxies with different SFR imply a **relation** between CR bulk speed (**galactic wind**), total field strength **B_t** and **SFR**.
- Strength of **regular magnetic field B_{reg}** seems to decrease with SFR.
- **Magnetic field structures** in edge-on galaxies are very similar, independent of SFR: **parallel to the midplane** and **X-shaped** away from the plane → Similar field configuration could be attained by the first global, galactic-scale MHD-simulation of a CR-driven dynamo (Hanasz et al. 2009)

→ Hence, a **galactic wind may be essential** for an **effective dynamo action**, the **observed similar vertical scale heights** and **X-shaped magnetic field structure** in edge-on galaxies.