Magnetic fields and radio halos: as seen in edge-on spiral galaxies

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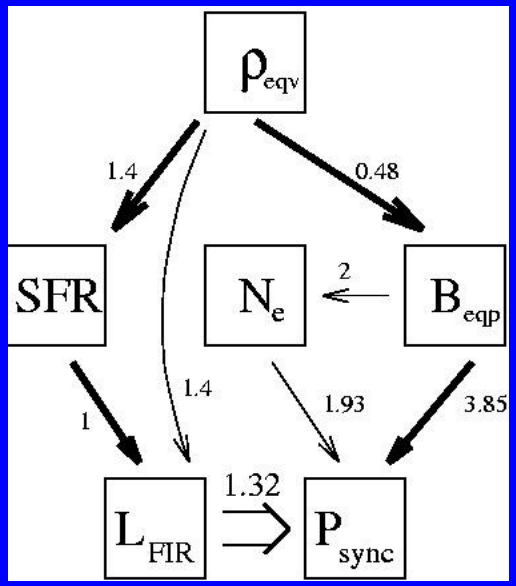
- Magnetic field structure
- Vertical scale heights ↔
  galactic wind, SFR and dynamo action

Magnetic field strength

Equipartition model



Niklas & Beck 1997

Total magnetic field strength $B_t \sim SFR^{\approx 0.34}$

(Niklas & Beck 1997)

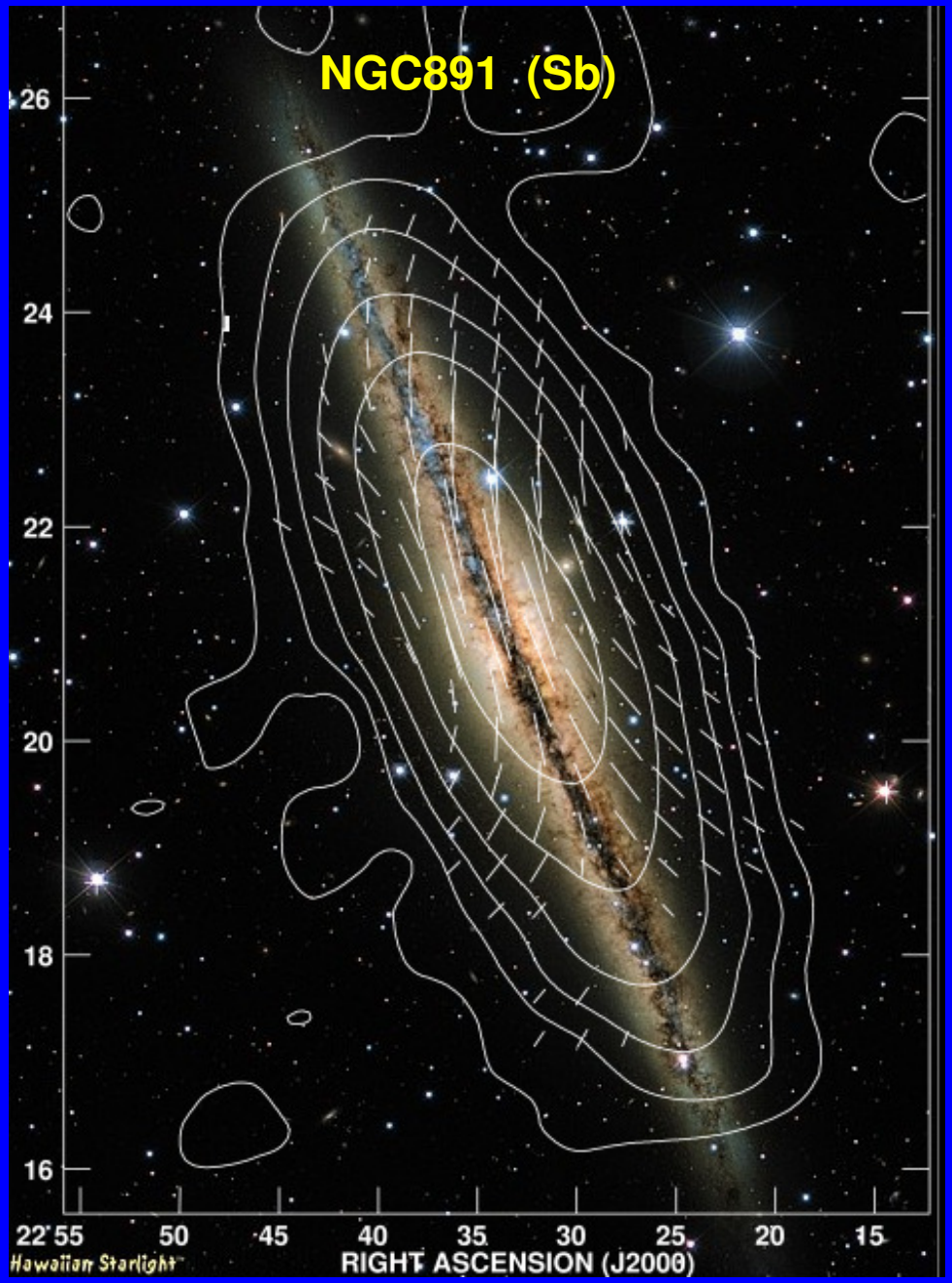
B_{reg} is locally uncorrelated with SFR

(Chyzy 2008)

B_{reg}/B_t decreases with increasing SFR

(Stil, Krause et al. 2009)

Magnetic field configuration in edge-on galaxies



i = 88°

SFR = 3.3

- **parallel** to the disk along the midplane

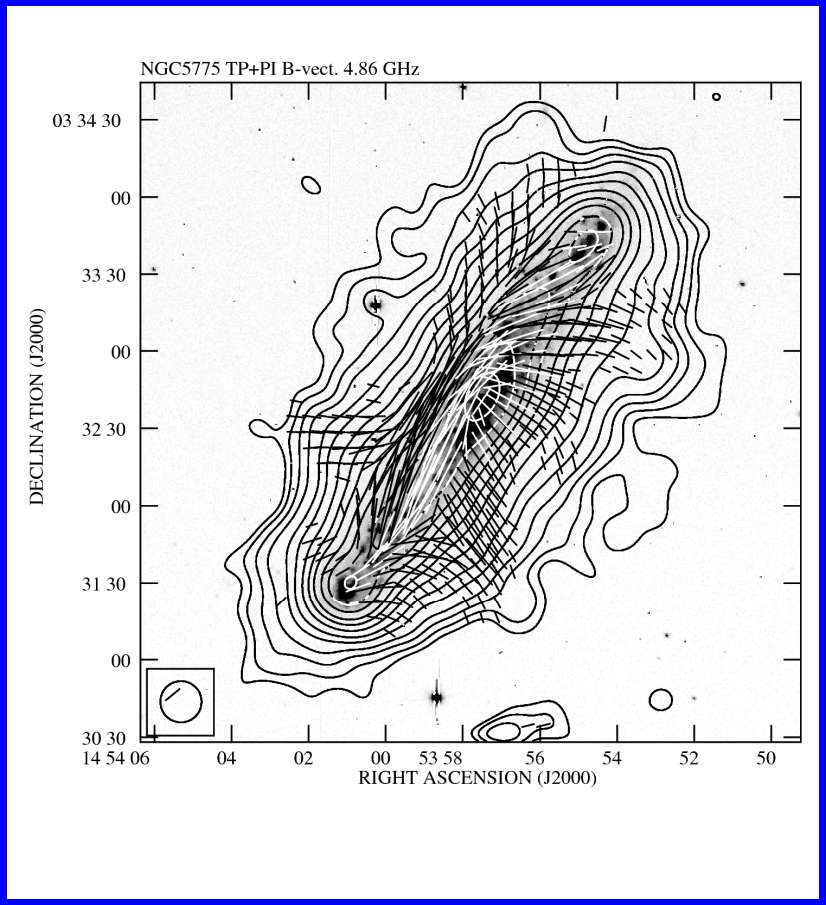
  → projected ASS field as seen in face-on galaxies

- **vertical components** at larger radii away from the plane

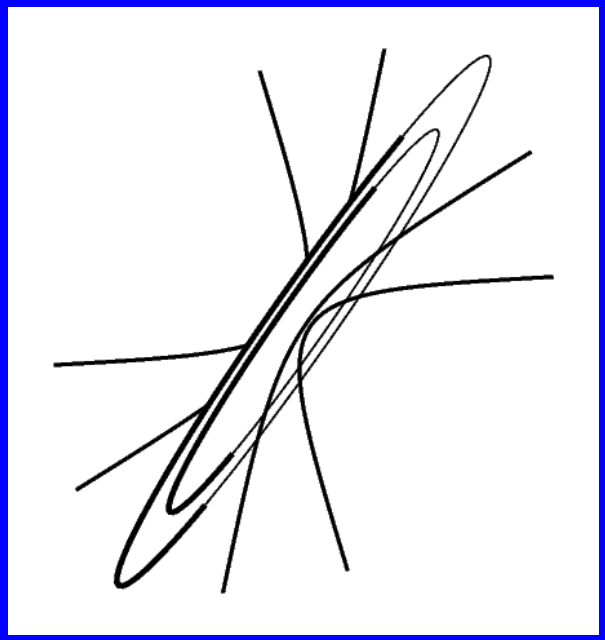
→ **X-shaped magnetic field**

Edge-on galaxies with high SFR

NGC5775 i = 86° SFR = 7.3



Scetch of toroidal disk field and halo field

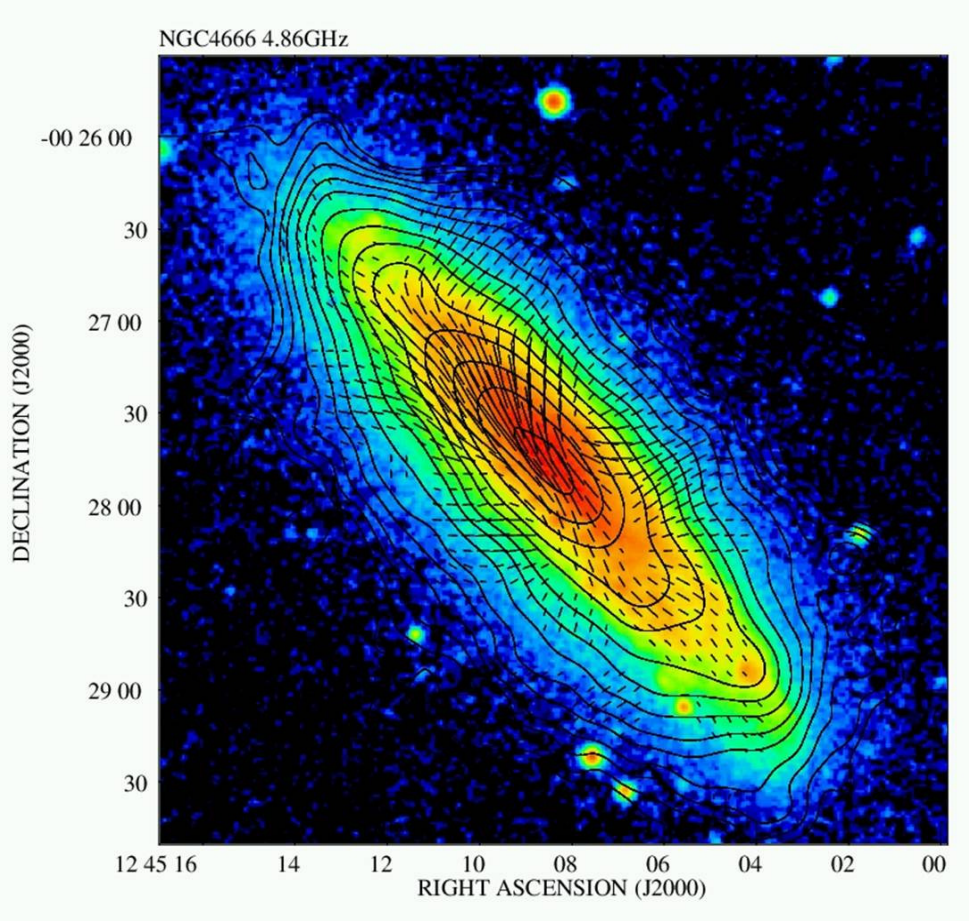


& vertical field below the central disk

Soida, Krause, Dettmar, Urbanik 2011

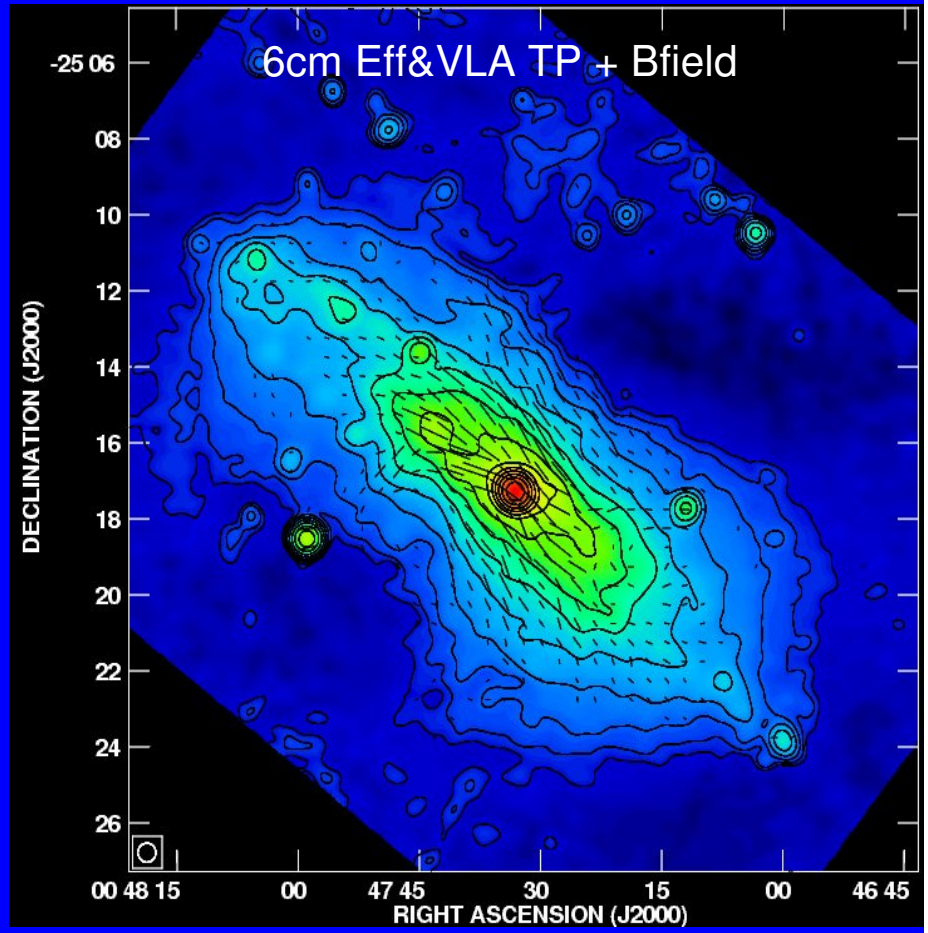
Edge-on galaxies with moderate/high SFR

NGC4666 i = 80° **SFR=1.6**



Soida 2005

NGC253 i =78° **SFR=6.3**

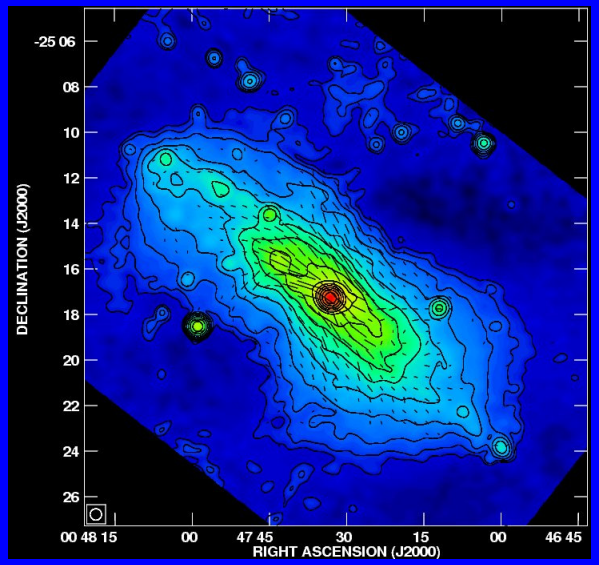


Heesen, Krause, Beck, Dettmar 2009

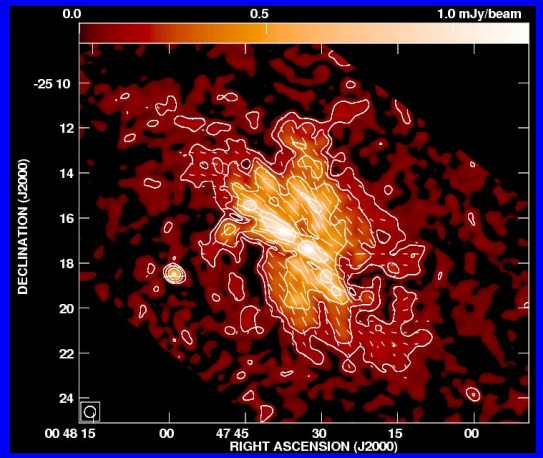
NGC253

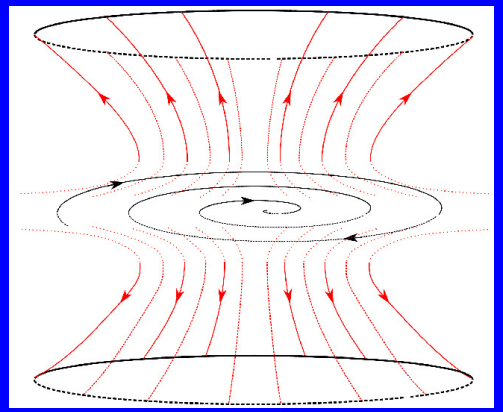
Sc (starburst) i=78° SFR = 6.3

6cm Eff&VLA TP + Bfield

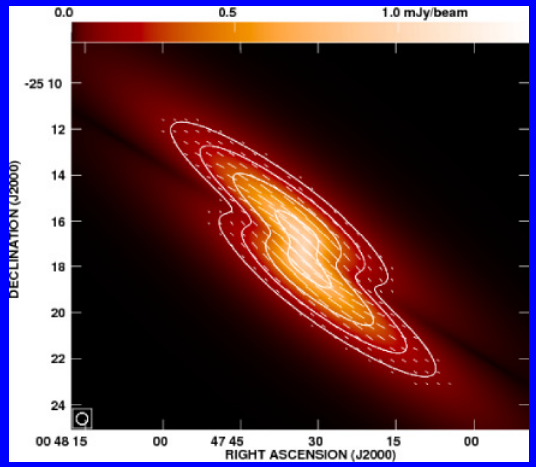


6cm Eff&VLA PI + Bfield

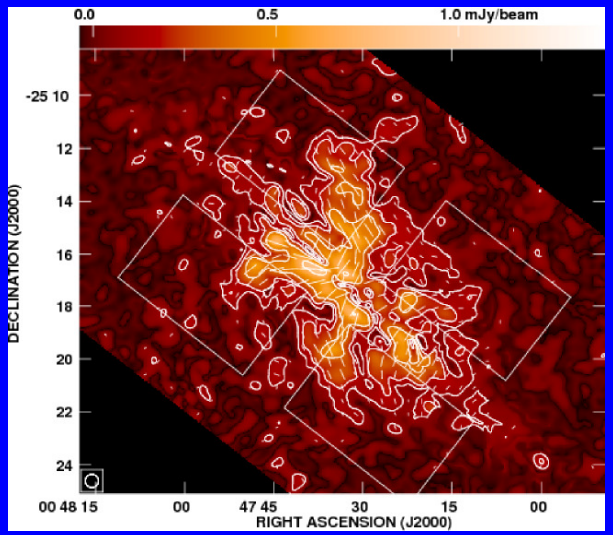




ASS-field (i=78°) PI + B



Bfield – ASSfield = vertical field



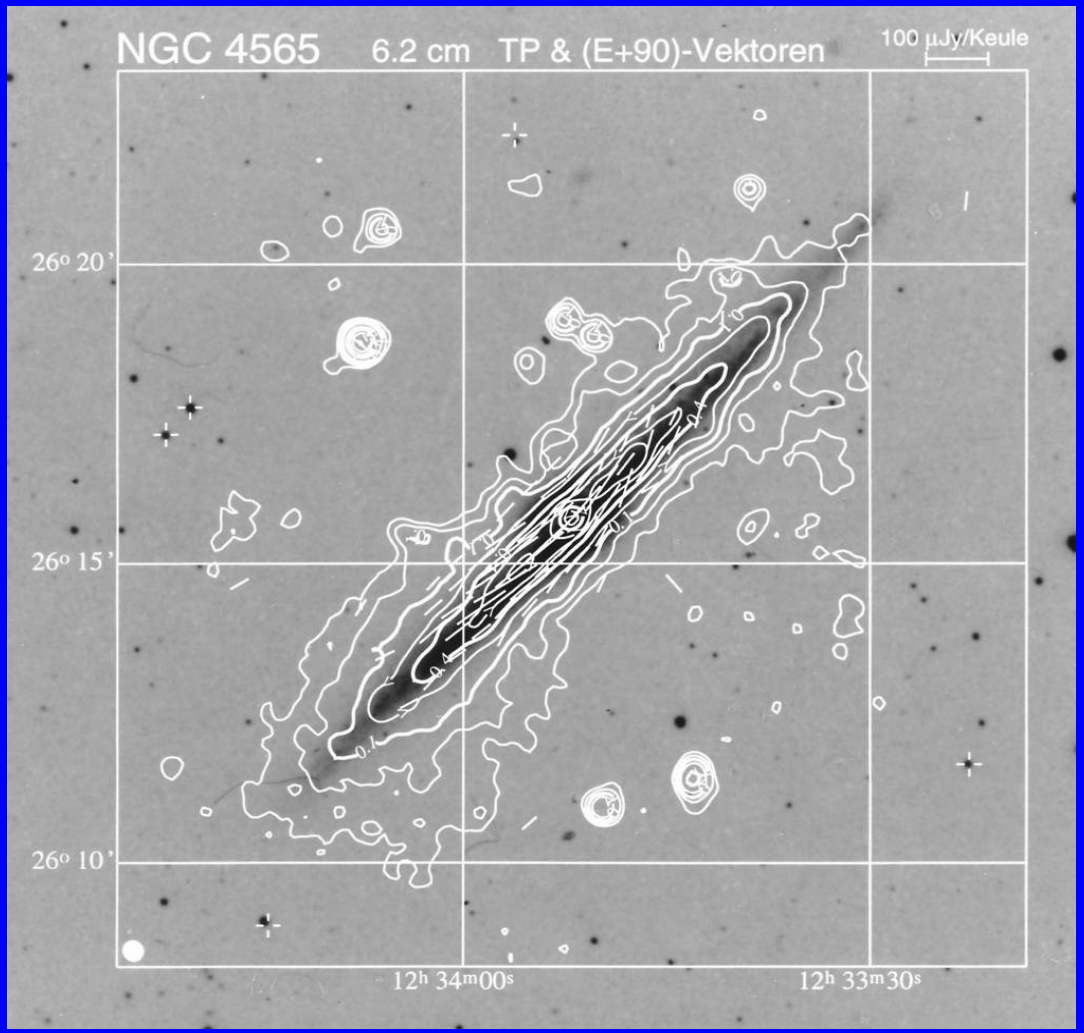
After subtraction of the ASS field:

purly X-shaped field is visible.

Heesen, Krause, Beck, Dettmar 2009

Edge-on galaxy with low SFR

NGC4565 VLA & Eff 6cm



SFR: 1.3

SFE: 3.2

i = 86°

Dumke PhD 1997

11 edge-on galaxies
with

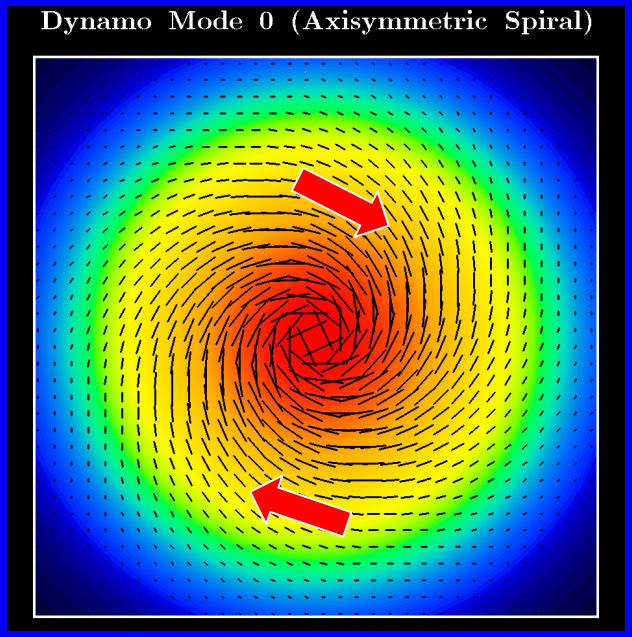
high SFR or starburst

	SFR(IR) [$M_\odot$/yr]	SFE [$L_\odot$/ $M_\odot$]	i	type
M82	**1.8**	**22**	79°	(Irr) SBc
N253	**6.3**	**14**	78°	Sc
N891	3.3	5.0	88°	Sb
N4631	**2.1**	**9.9**	86°	SBcd
N4666	1.9	2.1	80°	Sc
N5775	**7.3**	**6.1**	86°	Sbc

low SFR

	SFR(IR) [$M_\odot$/yr]	SFE [$L_\odot$/ $M_\odot$]	i	type
M104	1.2	4.2	84°	Sa
N3628	1.1	4.9	89°	Sb pec
N4217	1.4		86°	Sb
N4565	1.3	3.2	86°	Sb
N5907	1.3	4.0	87°	Sc

A dynamo generated large-scale magnetic field in the disk



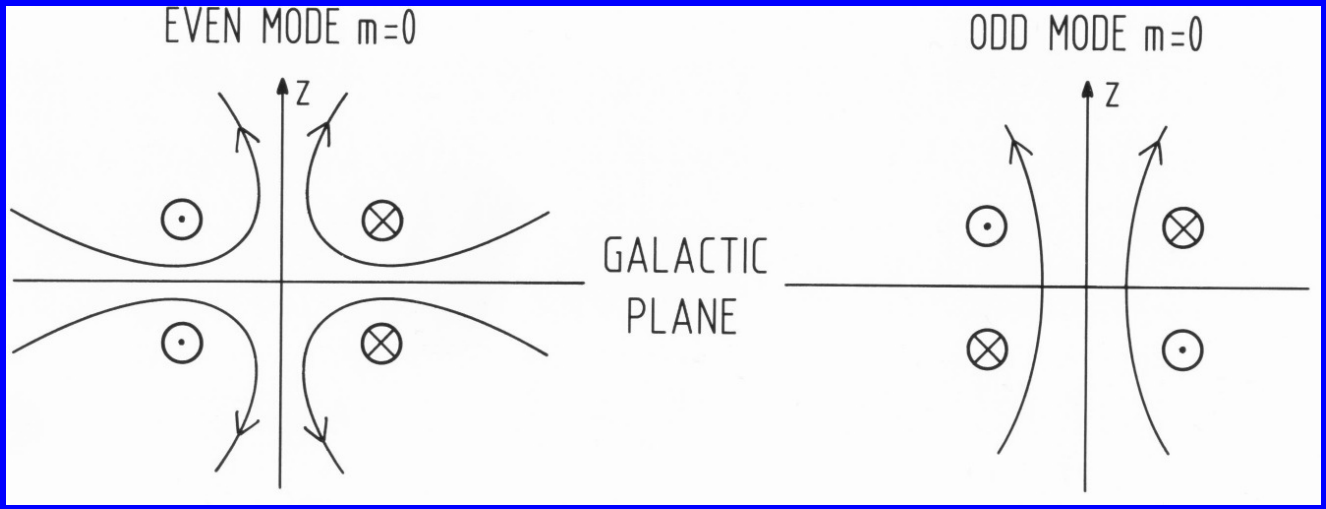
→ASS disk-field

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

→dynamo action in the halo

or

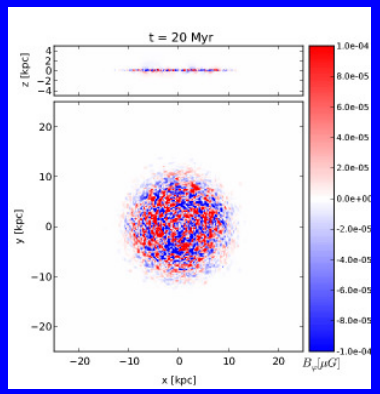
galactic wind needed

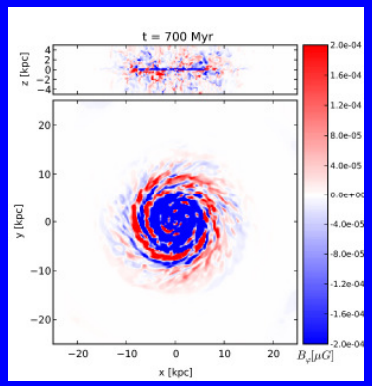


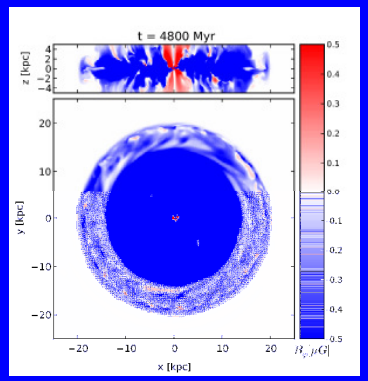
Dynamo theory

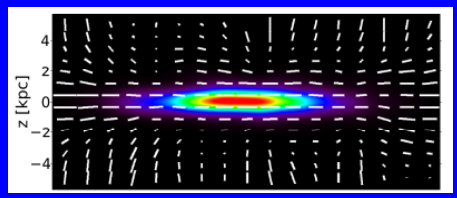
• **Self-consistent local box simulations of a SN-driven turbulent dynamo**
(Gressel, Elstner et al. 2008)

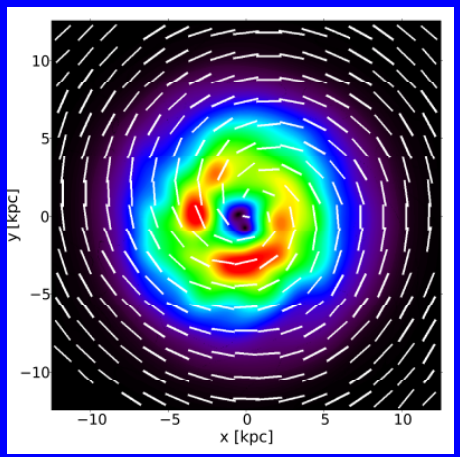
•**Global galactic-scale MHD simulations of the CR-driven dynamo**
(Hanasz et al. 2009):











→ horizontal spiral field &

large lobes of field in vertical direction

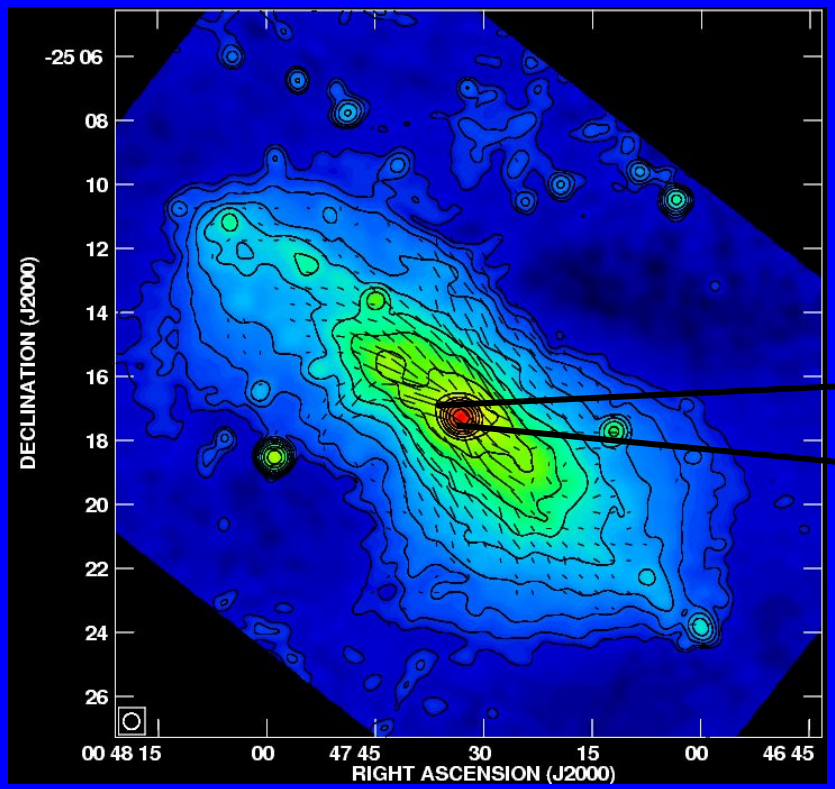
→ **X-shaped field structure and vertical fields**

importance of **galactic wind:**

vertical transport of magnetic flux and helicity

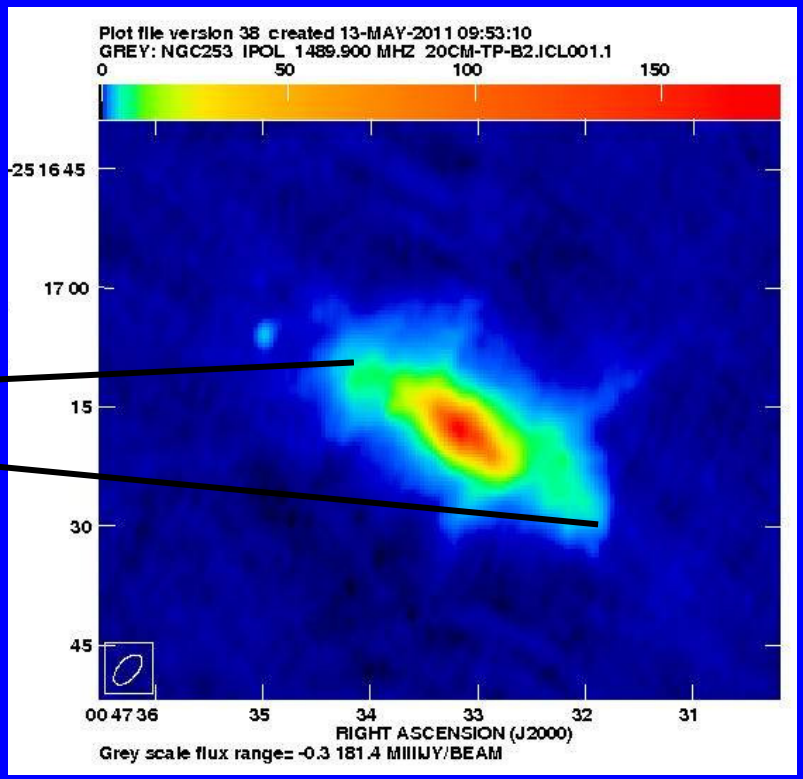
NGC253 Sc (starburst) i=78°

6cm Eff&VLA TP + Bfield



30“ HPBW (600pc)

20cm VLA A-array

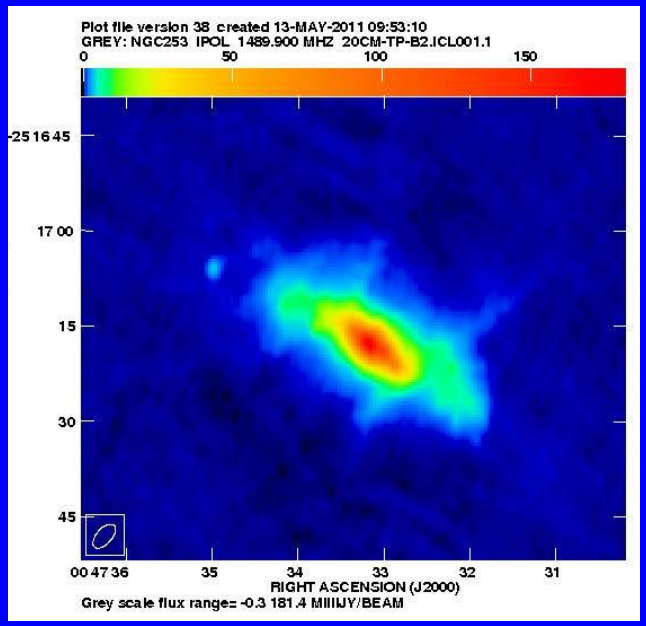


1.3“ x 2.2“ HPBW (25 x 42pc)

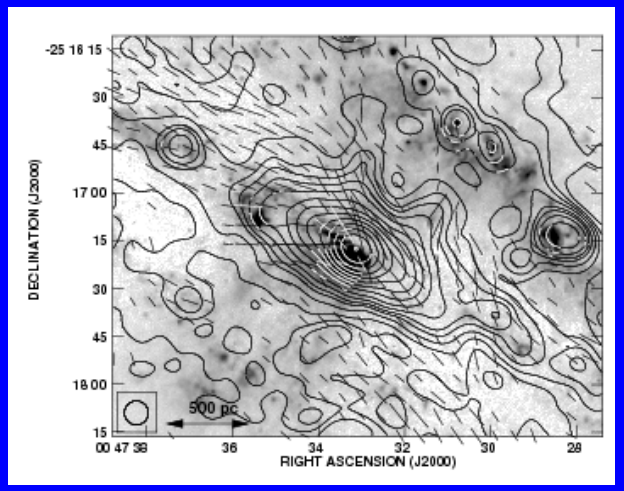
Heesen, Beck, Krause, Dettmar 2011

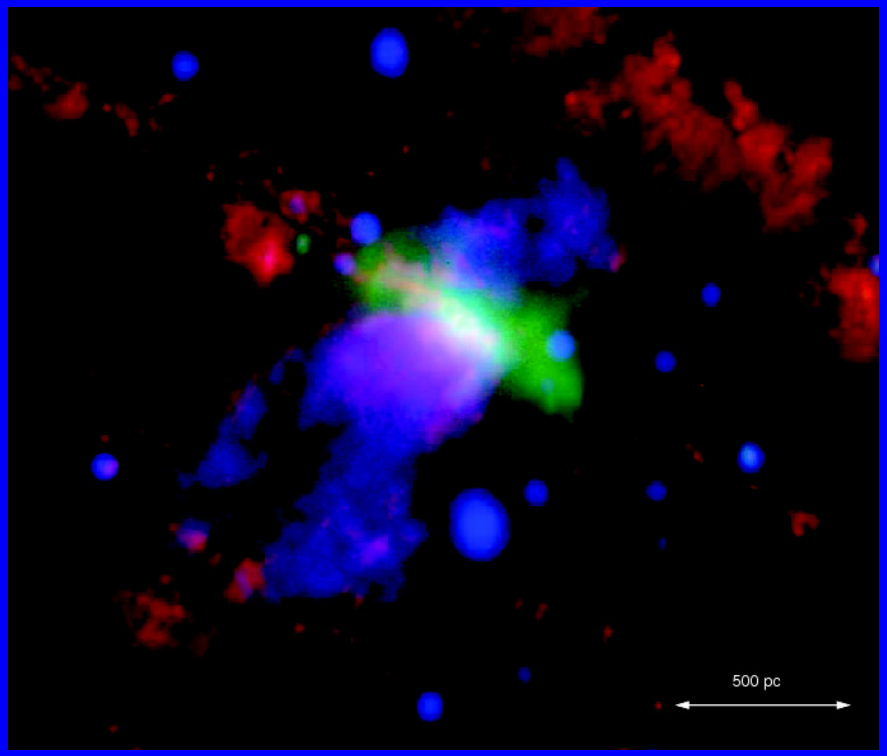
Central region of NGC253: Magnetic Filaments

20cm: 1.3“ x 2.2“ HPBW (25 x 42pc)



3cm (7.5“ HPBW) on Hα



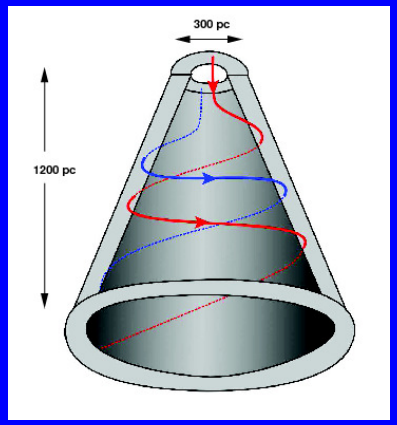


Red: Hα

Blue: Chandra soft X-ray

Green: 20cm

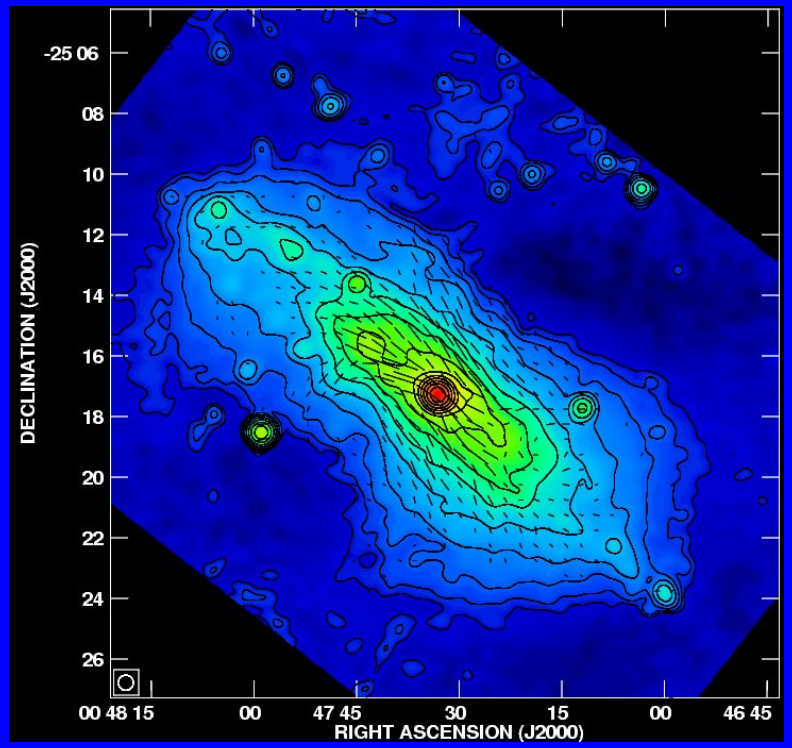
Helical magnetic fields may collimate nuclear outflow



Heesen, Beck, Krause, Dettmar 2011

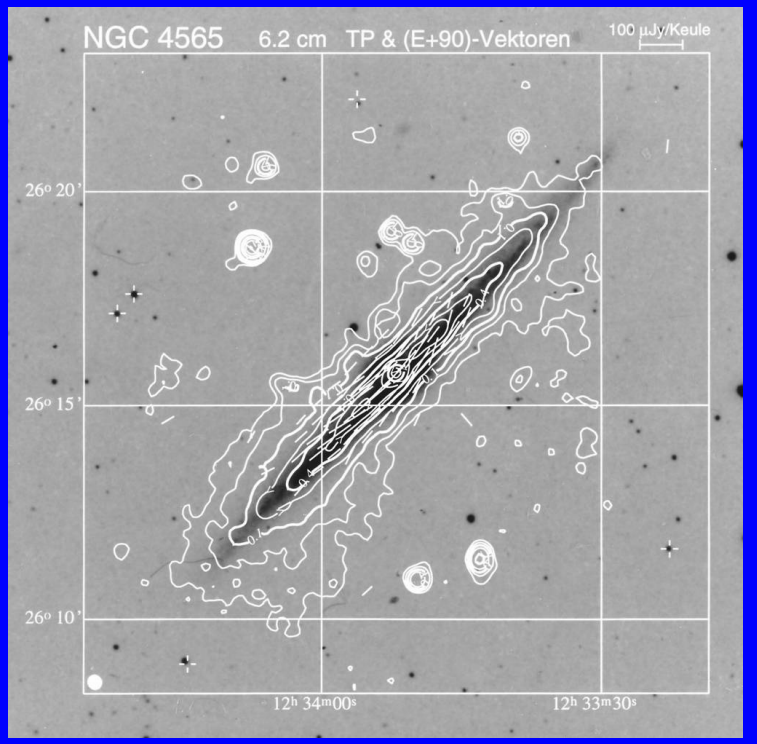
Vertical scale heights in edge-on galaxies

NGC253 VLA & Eff 6cm



Heesen, Beck, Krause, Dettmar 2009

NGC4565 VLA & Eff 6cm



Dumke PhD 1997

- dumbbell shape
- some disks look thicker, others thinner

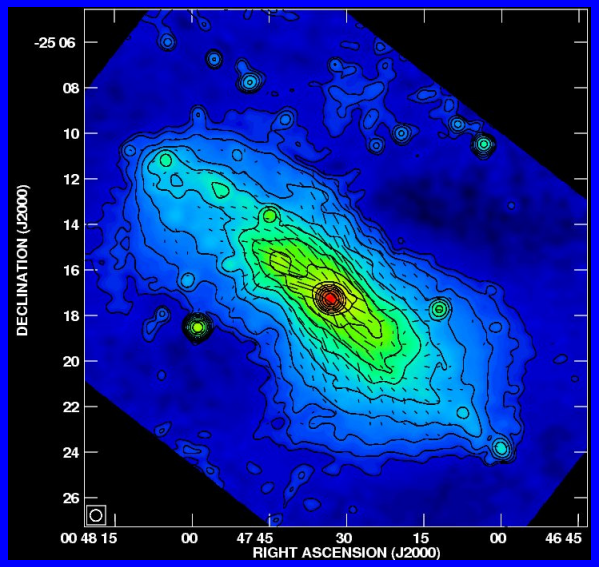
But:

global vertical scale heights are very similar

	Vertical scale heights at 6.2cm		SFR(IR)	SFE	B_t	i	type
	thin disk	thick disk/halo	$M_\odot$/yr]	[$L_\odot$/ $M_\odot$]	[μG]	[°]	
NGC253	380 ± 60 pc	1.7 ± 0.1 kpc	6.3	14	12	78	Sc
NGC891	270	1.8	3.3	5.0	6	88	Sb
NGC3628	300	1.8	1.1	4.9	6	89	Sb pec
NGC4565	280	1.7	1.3	3.2	7	86	Sb
NGC5775	240 ± 30 pc	2.0 ± 0.2 kpc	7.3	6.1	8	86	Sbc
Mean	**300 ± 50 pc**	**1.8 ± 0.2 kpc**					

Vertical scale heights and CR-driven galactic wind

NGC253 VLA & Eff 6cm



Heesen, Beck, Krause, Dettmar 2009

Radial dependence of scaleheight (B) for **NGC253**:

Vertical scale height (halo) is mainly determined by **synchrotron losses of CRE:**

Synchrotron lifetime

at a single frequency is $t_{syn} \sim B_t^{-1.5}$

CR bulk-speed $v_{cr} = h_{CR} / t_{syn} = 2\, h_z / t_{syn}$

v_{cr} = 300 ± 30km/s in north-eastern halo (Heesen, Beck, Krause, Dettmar 2009)

→ existence of a **galactic wind** in NGC253

Similar scale heights h_z → velocity of galactic wind ~ $B_t^{1.5}$ ~ SFR $^{\approx 0.5}$

	Vertical scale heights at 6.2cm		SFR(IR)	SFE	B_t	i	type
	thin disk	thick disk/halo	$M_\odot$/yr]	[$L_\odot$/ $M_\odot$]	[μG]	[°]	
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NGC5775	240 ± 30 pc	2.0 ± 0.2 kpc	7.3	6.1	8	86	Sbc
Mean	**300 ± 50 pc**	**1.8 ± 0.2 kpc**					
NGC4631	390 ± 200 pc	2.7 ± 1.5 kpc	2.1	9.9	6	86	SBd
NGC5907			1.3	4.0	5	87	Sc
M82	small and north-south asymmetry		1.8	22	24/98	79	Irr/SBc
M104	one-comp. gaussian: 1.4 ± 0.2 kpc		1.2	4.2	4	84	Sa

Summary

- **Magnetic field structures** in edge-on galaxies are very similar, independent of SFR: **parallel in the midplane** and **X-shaped** away from the plane, sometimes **vertical fields** above or below the central region.
- **NGC4631** also shows a **plane-parallel** magnetic field along the disk.
- Observations in **NGC253** indicate that **helical magnetic filaments** are able to collimate the nuclear outflow as seen in Hα and X-rays.
- Similar vertical scale heights in galaxies with different SFR imply a **relation** between CR bulk speed (**galactic wind**), total field strength $\mathbf{B_t}$ and **SFR**.
- A **galactic wind** seems to be essential for an **effective dynamo action**, the observed similar vertical scale heights and X-shaped magnetic field structure in edge-on galaxies.
- **Strong tital interaction** may be the reason for deviating and locally different scale heights in **M82** and **NGC4631**.

→ future progress with **EVLA**, **LOFAR**, **SKA**

↓

CHANG-ES

Thank you