Summer school
Magnetic Fields: From Star-forming Regions to Galaxy Clusters and Beyond

Dynamos in dwarf galaxies

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Content

Observations of dwarf galaxies:

- Why?
- SFR, Rotation curve, Shear
- Magnetic field structure

Modelling and simulations:

- Cosmic-ray driven dynamo
- Local model
- Global model

Collaborators:
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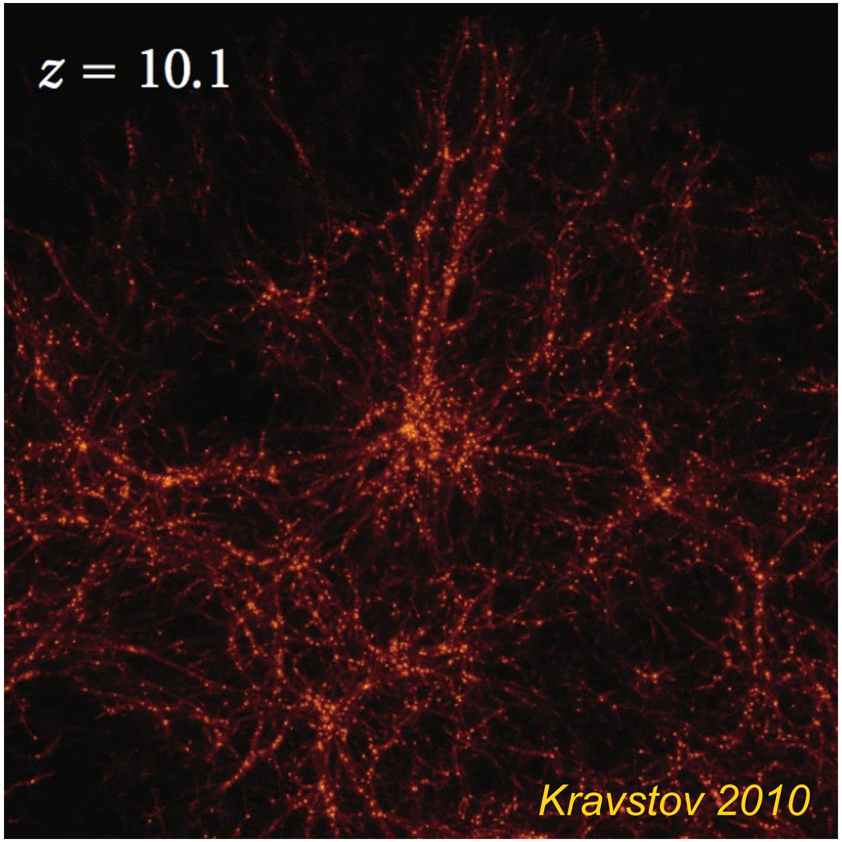
Observations:

Dwarf galaxies

Dwarfs in the Universe

- Most numerous population of galaxies.
- Primary building blocks of more massive galaxies in the past (scenario of hierarchical clustering – bottom-up).
- Today, satellites of big galaxies.
- “Missing satellites”: simulations vs observations
- Tidal interactions: weak and strong.
- Merging.
- Today's (LG) dwarfs are analogs to the high-redshift building blocks.

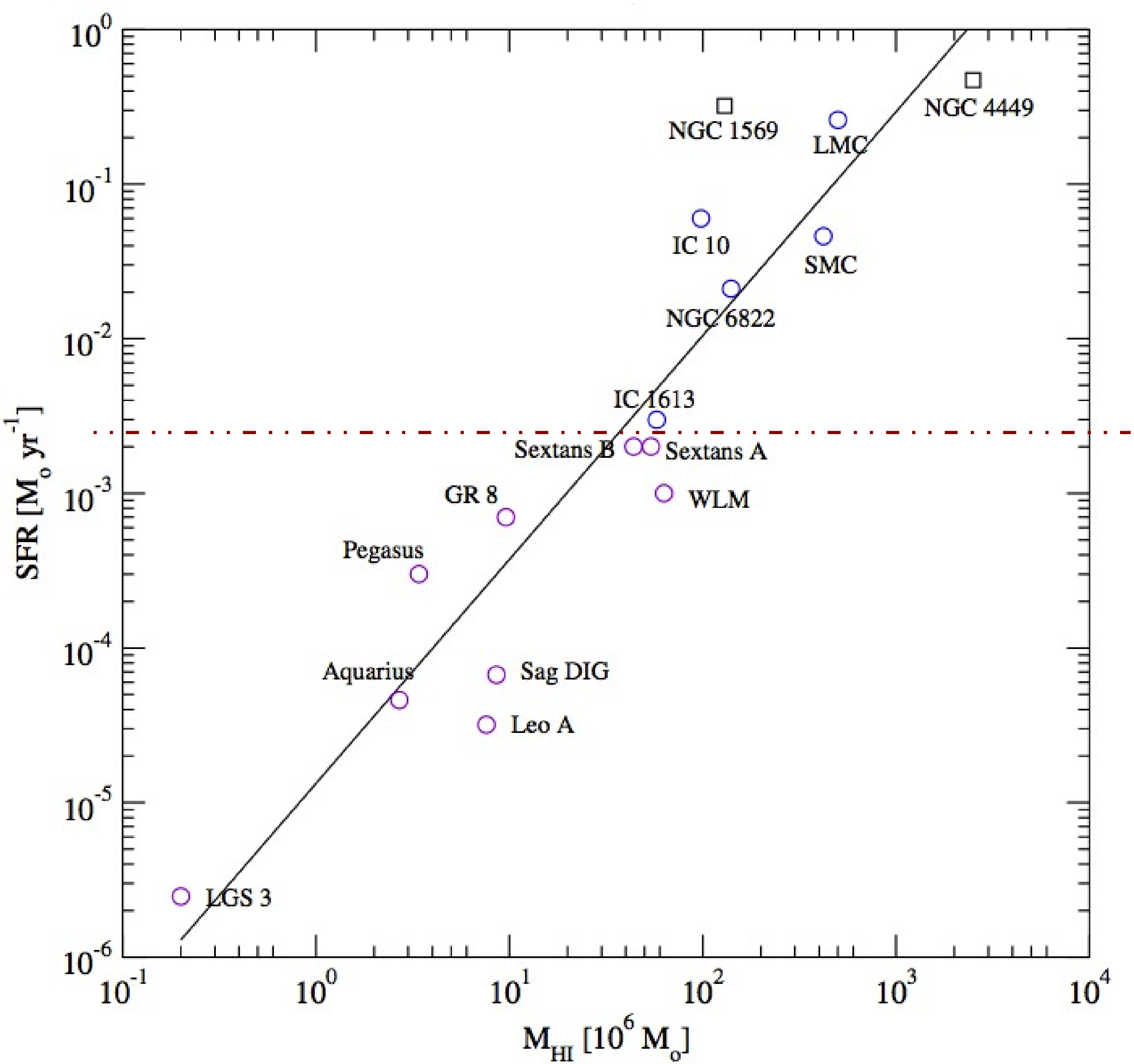


Observations

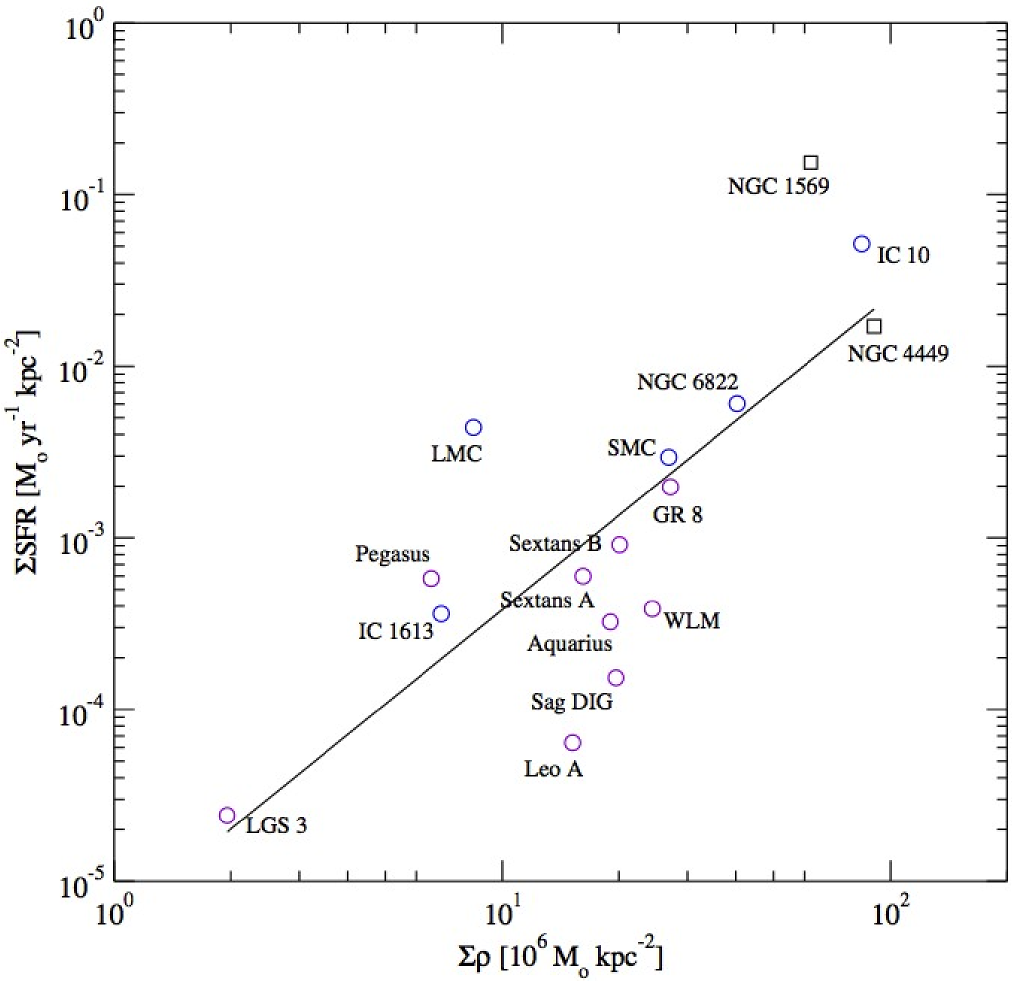
Galaxy name	B_{tot}[a] μG	SFR[b] $M_\odot$ yr^{-1}	H I mass[c] $10^6\ M_\odot$	Total mass[d] $10^6\ M_\odot$	$S_{60\,\mu m}$[e] mJy	v_{rot}[f] km s^{-1}	σ_v[g] km s^{-1}
Aquarius	$<4.5 \pm 1.2$	4.6×10^{-5}	2.7	5.4	139	13	6.6
GR 8	$<3.6 \pm 0.9$	7.0×10^{-4}	9.6	7.6	20	21	11.0
IC 1613	2.8 ± 0.7	3.0×10^{-3}	58	795	1420	37	8.5
NGC 6822	4.0 ± 1.0	2.1×10^{-2}	140	1640	47 600	51	8.0
WLM	$<3.9 \pm 0.9$	1.0×10^{-3}	63	150	320	23	8.0
IC 10	9.7 ± 2.0	6.0×10^{-2}	98	1580	31 200	47	8.0
LGS 3	$<4.0 \pm 1.0$	2.5×10^{-6}	0.2	13	75	18	9.0
SagDIG	$<4.1 \pm 1.1$	6.7×10^{-5}	8.6	9.6	94	14	7.5
Sextans A	$<3.1 \pm 0.8$	2.0×10^{-3}	54	395	503	33	8.0
Sextans B	$<2.8 \pm 0.6$	2.0×10^{-3}	44	885	246	38	18.0
Leo A	$<4.4 \pm 1.2$	3.2×10^{-5}	7.6	11	90	18	9.3
Pegasus	$<3.7 \pm 0.9$	3.0×10^{-4}	3.4	58	55	17	8.6
LMC	4.3 ± 1.0	2.6×10^{-1}	500	20 000	8.29×10^7	72	14.1
SMC	3.2 ± 1.0	4.6×10^{-2}	420	2400	7.45×10^6	60	25.0
NGC 4449	9.3 ± 2.0	4.7×10^{-1}	2500	70 000	36 000	40	20.0
NGC 1569	14 ± 3.0	3.2×10^{-1}	130	297	54 400	42	21.3

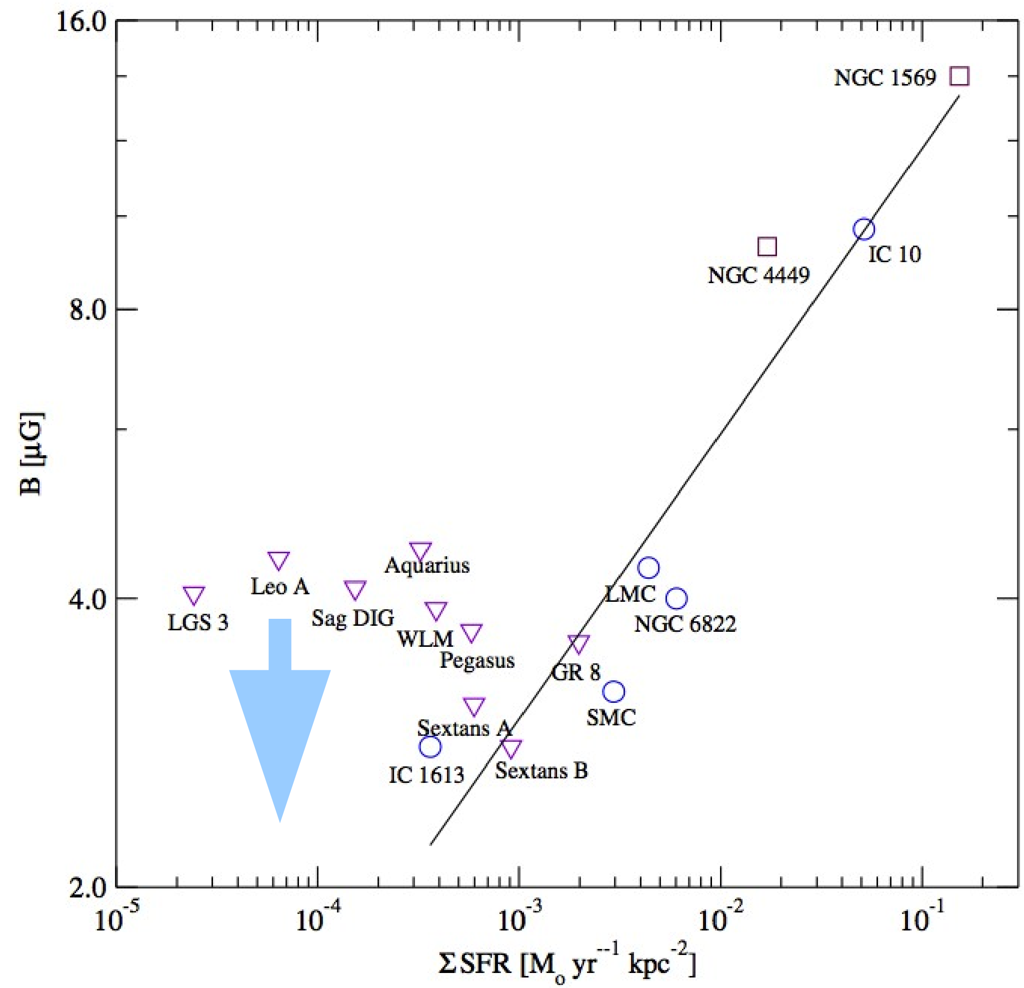
Chyży et al. 2011 and ref. therein

Observations: SFR



Observations: SFR

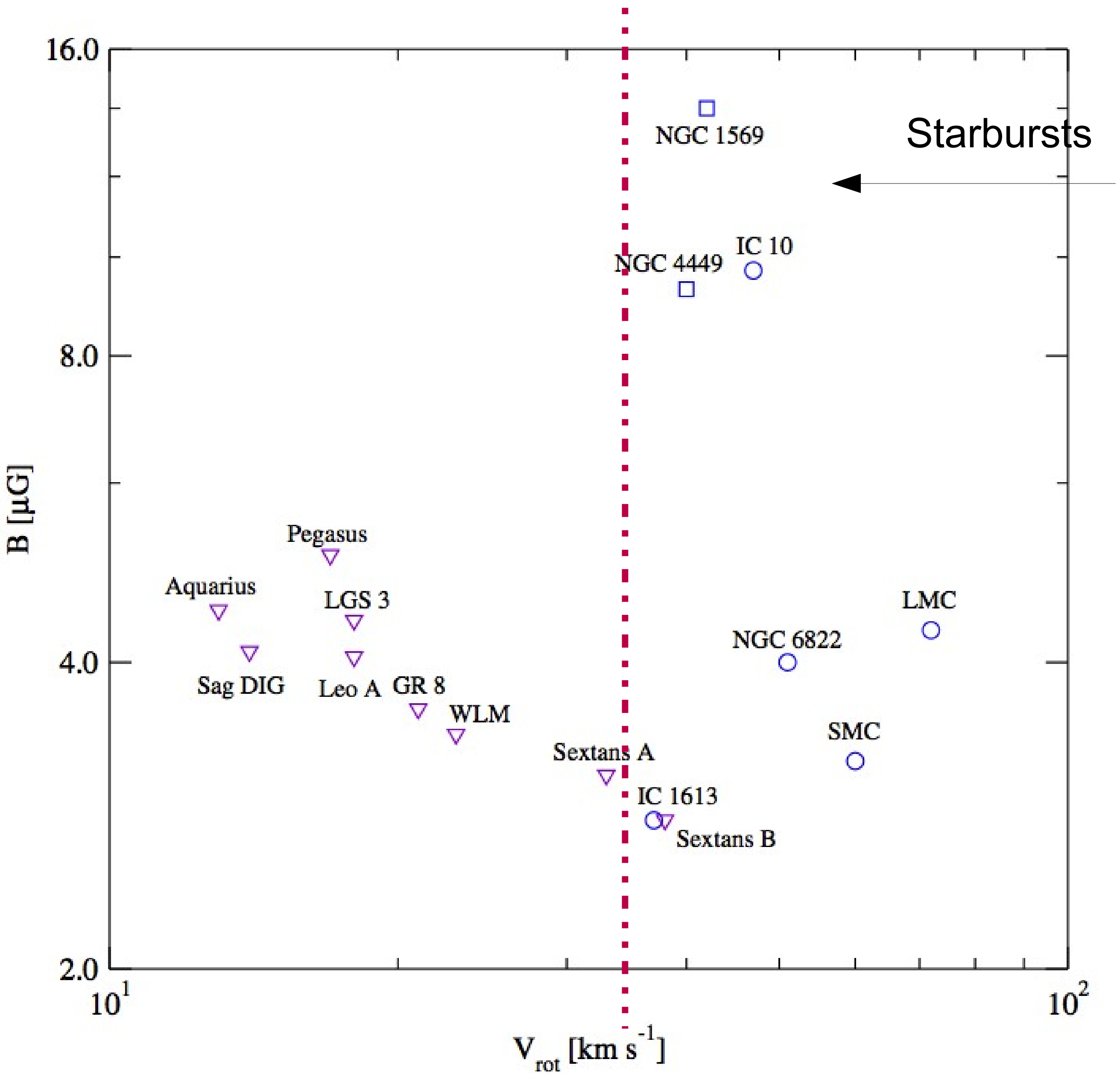




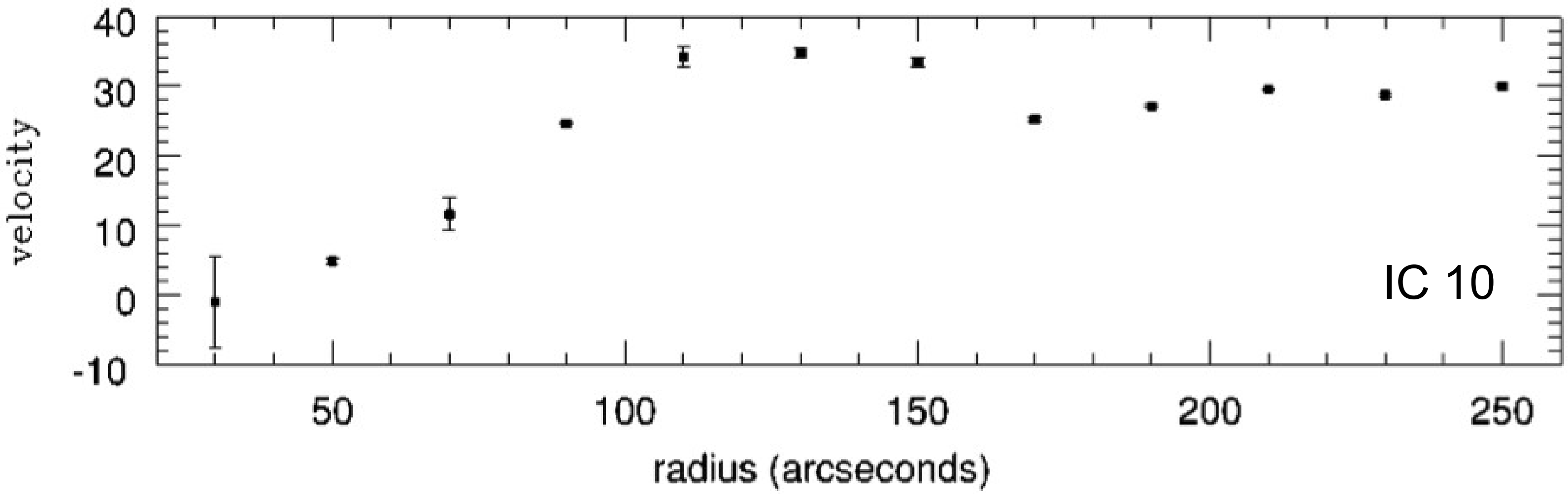
The magnetic field is being controlled by the local gas density $B \propto \Sigma\rho^{0.47}$

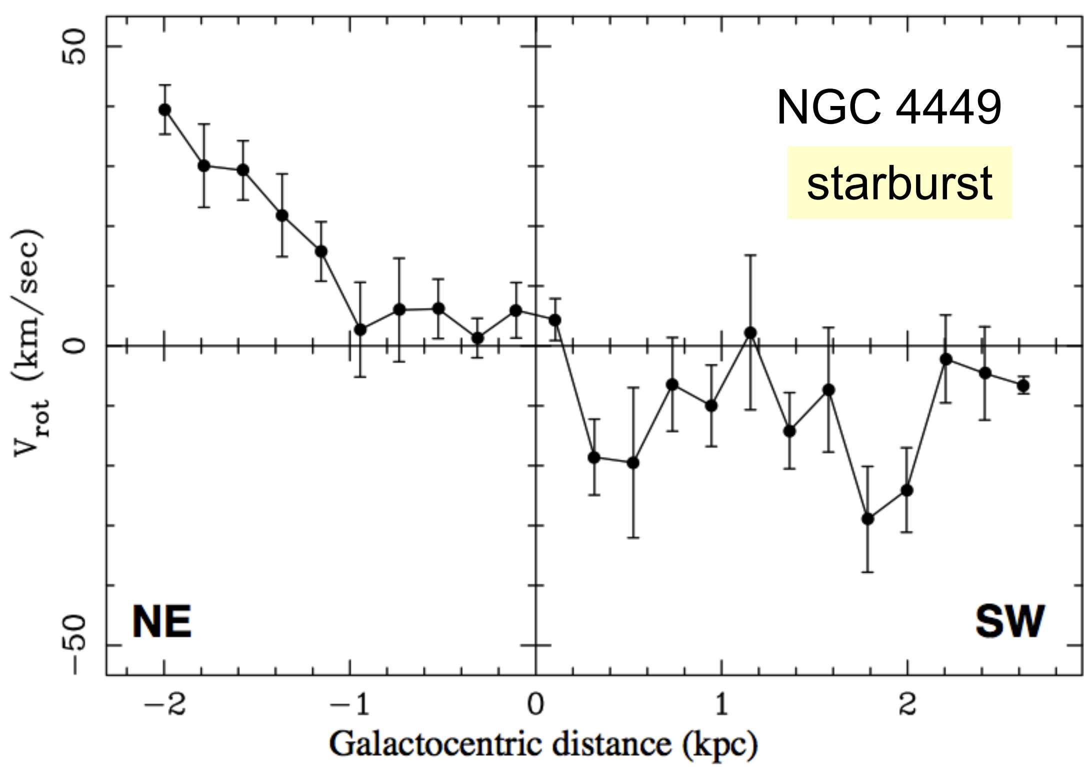
For spirals: 0.48 (Niklas & Beck 1997)

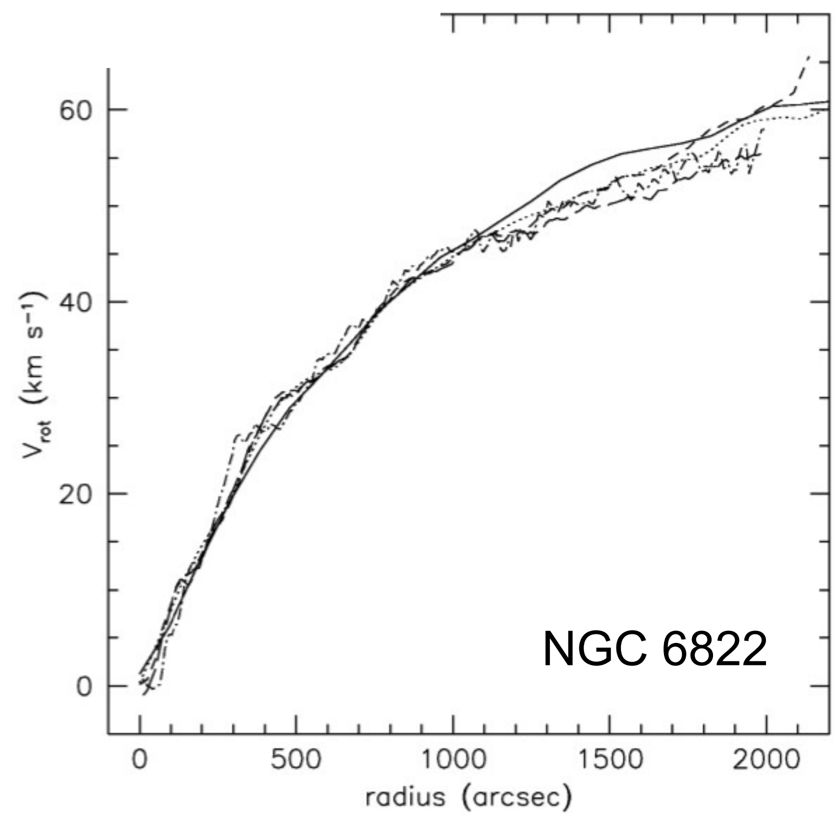
Observations: v_{rot}



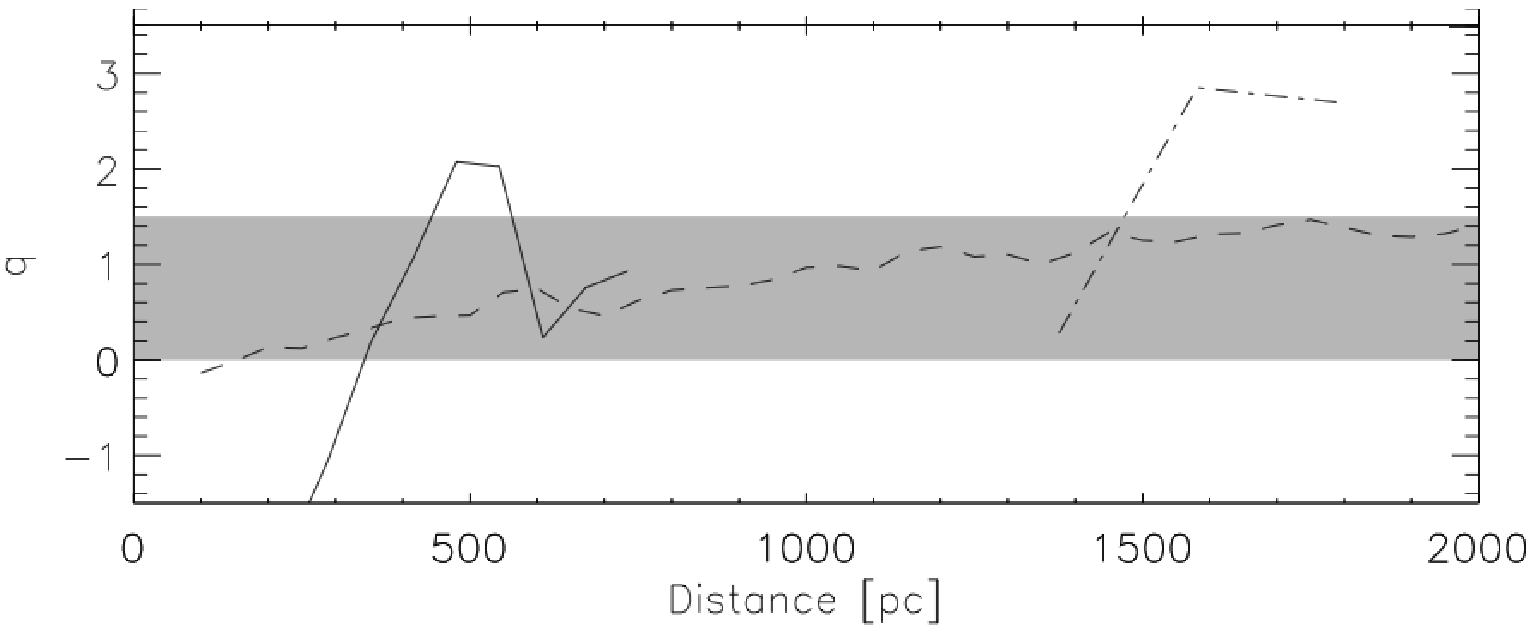
Observations: v_{rot}







Observations: v_{rot} (shear)

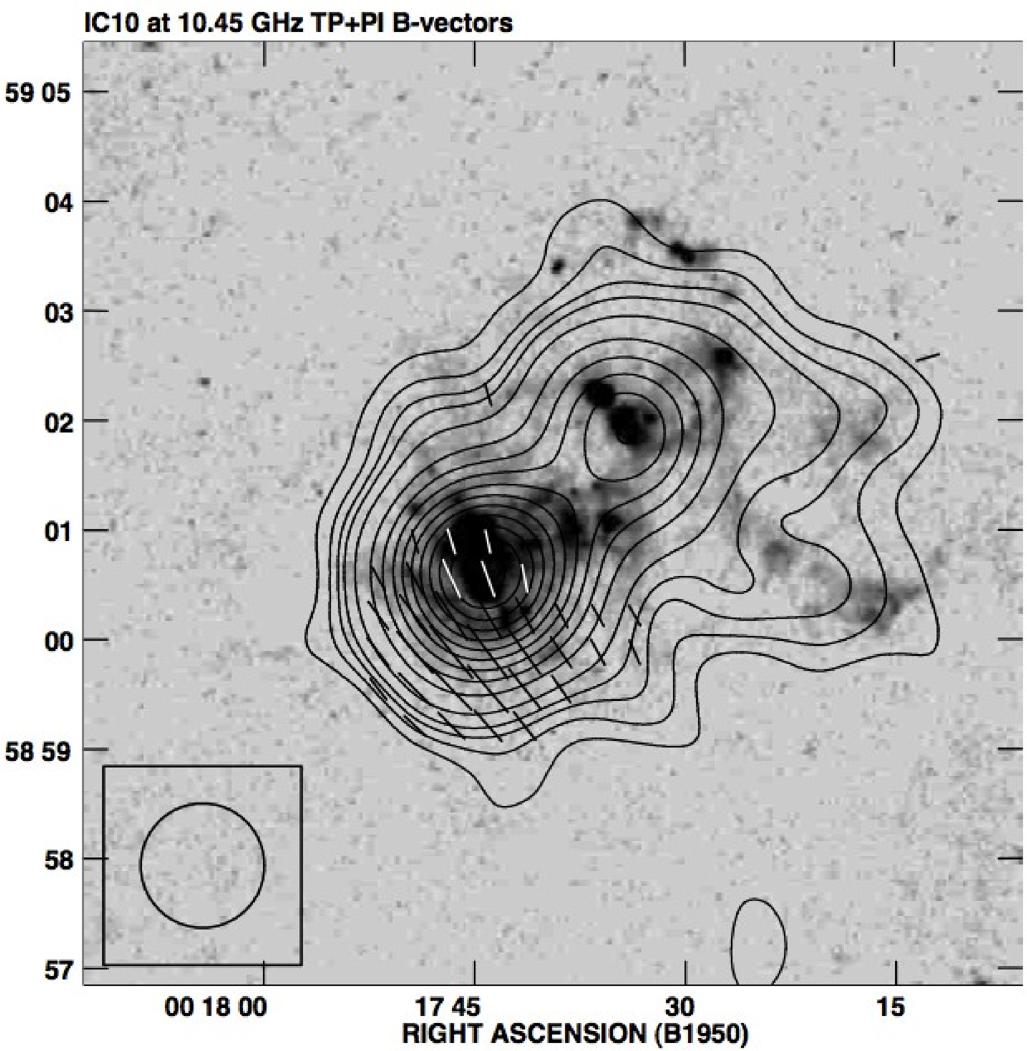


$$q = -\mathrm{d}\ln\Omega/\mathrm{d}\ln R$$

q = 3/2 keplerian
q = 1 flat
q = 0 solid body

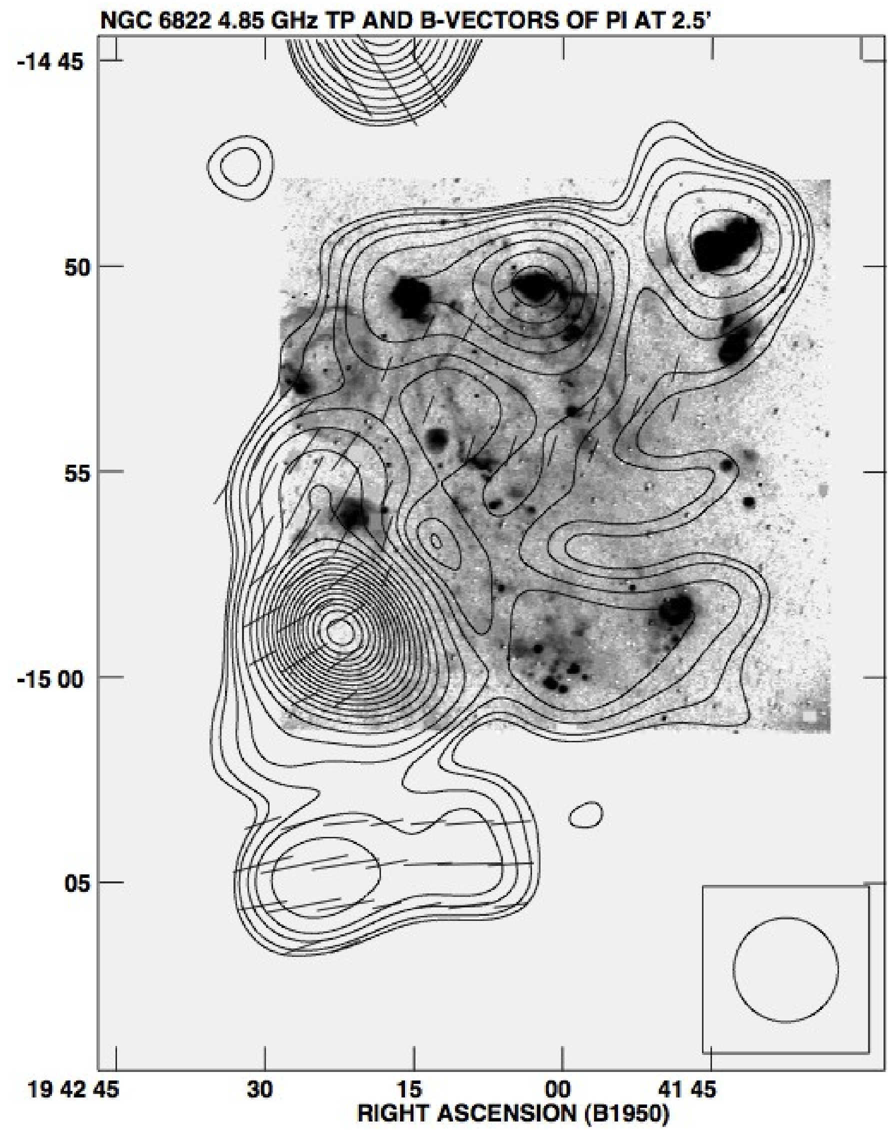
Observations: Magnetic field structure

IC 10



Chyży et al. 2003

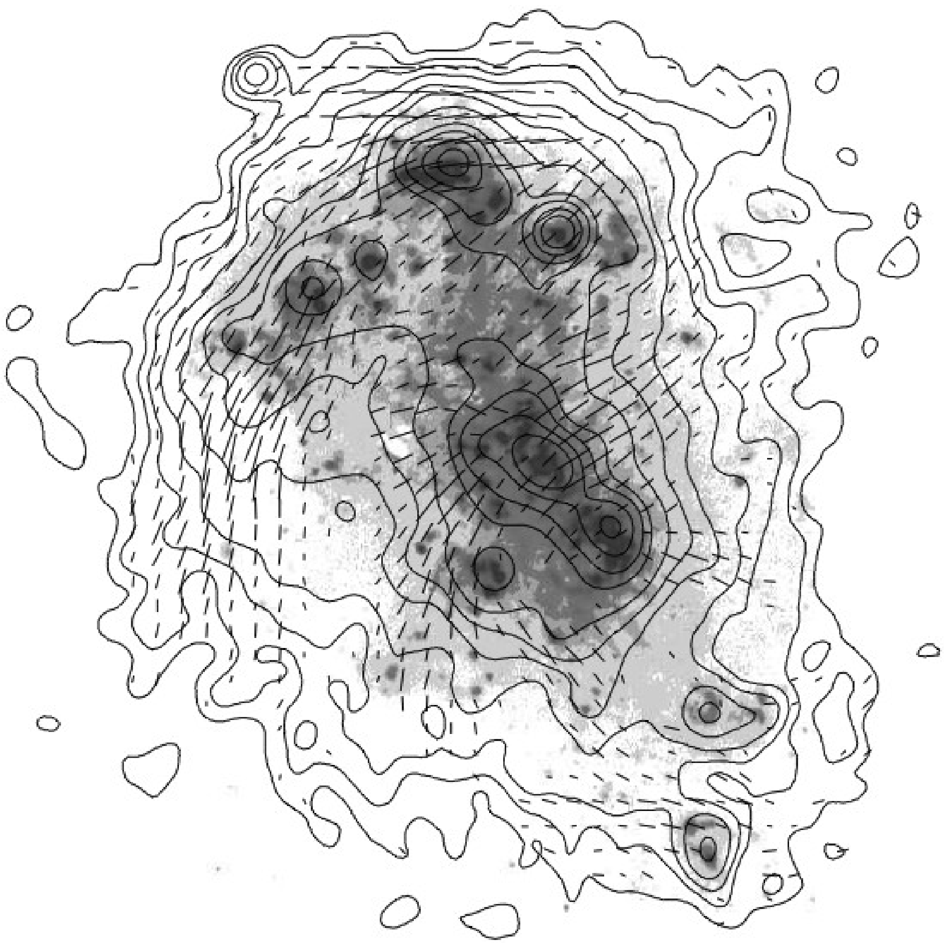
NGC 6822



Chyzy et al. 2003

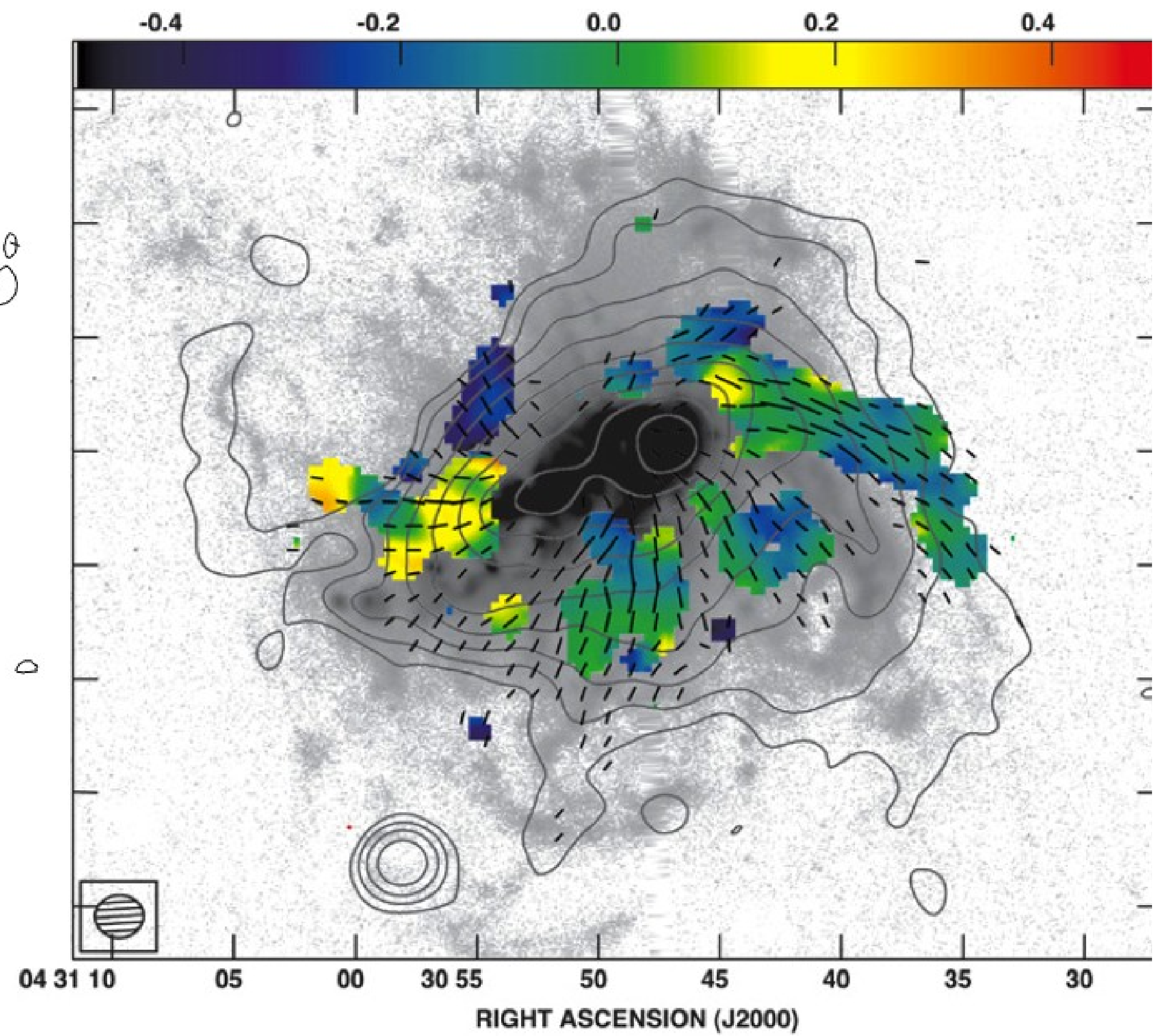
Observations: Magnetic field structure

NGC 4449



Chyży et al. 2000

NGC 1569



Kepley et al. 2010

Observations: Magnetic field

- NGC 1569 B_{tot} = 10-15 uG B_u = 5 uG
  Kepley et al. 2010
- IC 10 B_{tot} = 5-15 uG B_u < 3 uG
  Chyży et al. 2003
- NGC 4449 B_{tot} = 5-15 uG B_u = 8 uG
  Chyży et al. 2000
- LMC B_{tot} = 4.3 uG B_u < 1.1 uG
  Gaensler et al. 2005

Summary of the properties

- Faint (LG and just few more)
- Poor statistics (9 with no m.f. and 7 with m.f.)

- Low mass → shallow well → slow rotation
- Simple structure (in numerics)

- Starburst objects:
  - NGC 1569 SFR $6.4\, M_{\odot}\, yr^{-1}\, kpc^{-2}$
    SNR $7 \times 10^{4}\, \mathrm{Myr}^{-1}\, \mathrm{kpc}^{-2}$

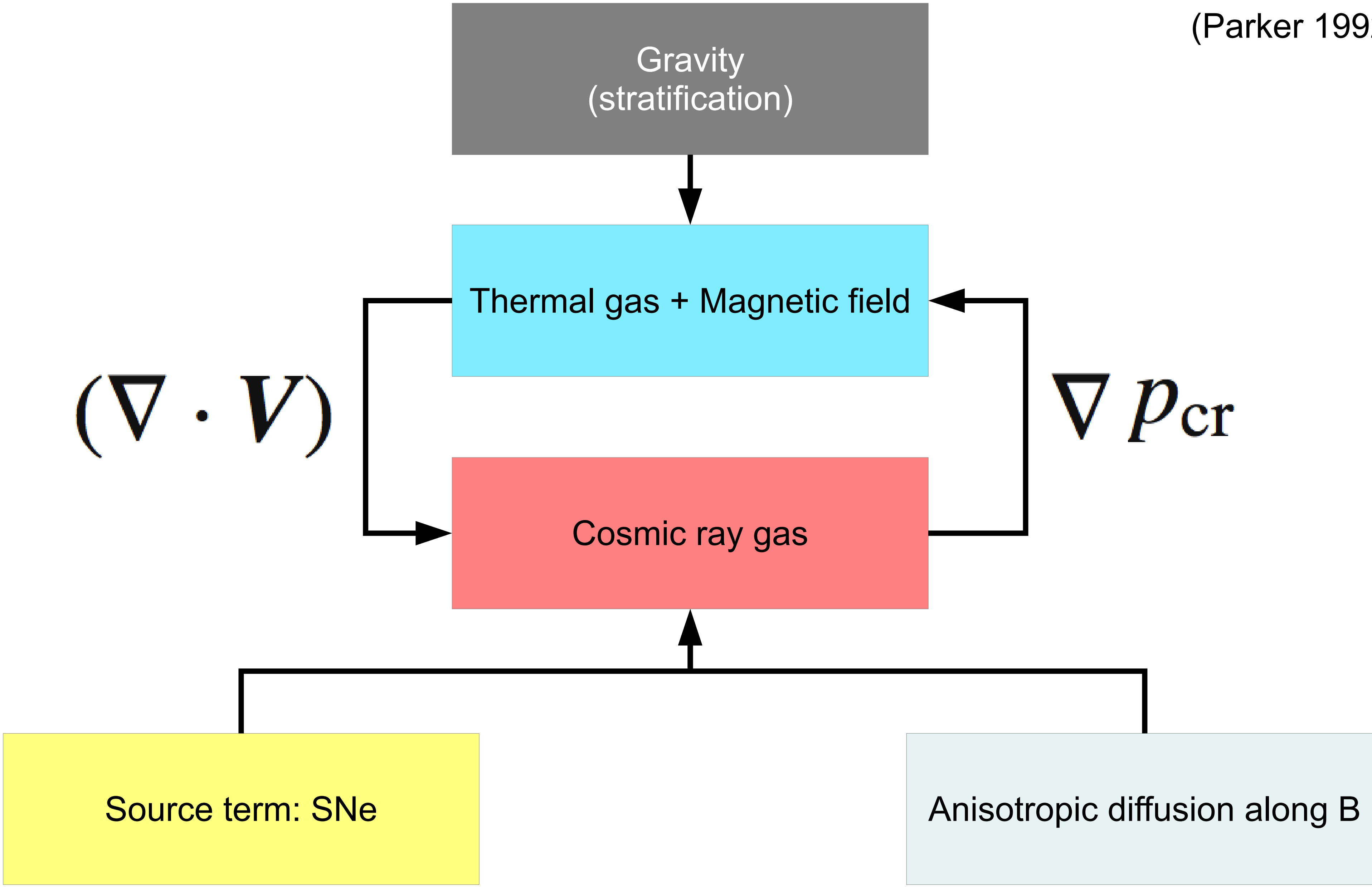
- Strong magnetic fields

Modelling and simulations:

Evolution of the magnetic field.
Dynamo.

Cosmic-ray driven dynamo

(Parker 1992)



Cosmic-ray driven dynamo

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{V}) = 0,$$

$$\frac{\partial \boldsymbol{V}}{\partial t} + (\boldsymbol{V} \cdot \nabla)\boldsymbol{V} = -\frac{1}{\rho}\nabla\left(p + p_{\rm cr} + \frac{B^2}{8\pi}\right) + \frac{\boldsymbol{B} \cdot \nabla \boldsymbol{B}}{4\pi\rho} + g$$

$$\frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times (\boldsymbol{V} \times \boldsymbol{B}) + \eta \Delta \boldsymbol{B},$$

$$\frac{\partial e_{\rm cr}}{\partial t} + \nabla(e_{\rm cr}\boldsymbol{V}) = \nabla(\hat{K}\nabla e_{\rm cr}) - p_{\rm cr}(\nabla \cdot \boldsymbol{V}) + Q_{\rm SN},$$

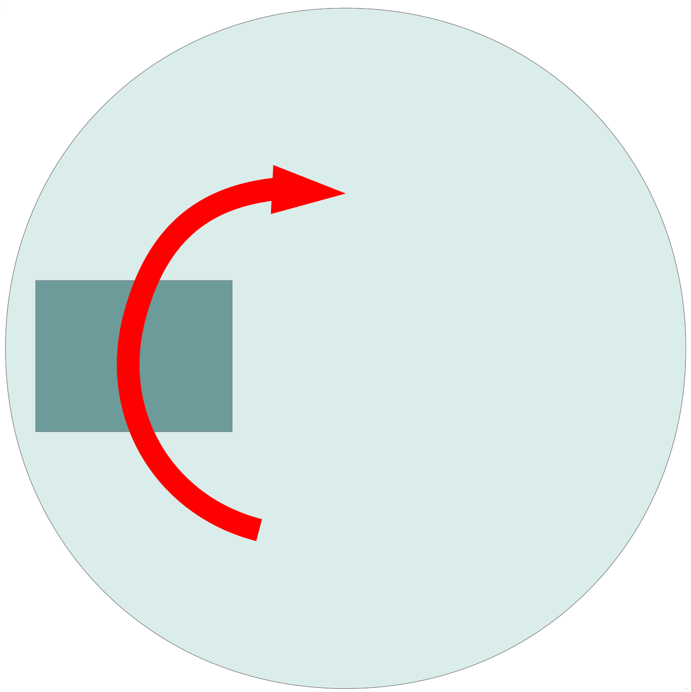
$$p_{\rm cr} = (\gamma_{\rm cr} - 1)e_{\rm cr}, \quad \gamma_{\rm cr} = 14/9.$$

(Hanasz et al. 2004)

Dwarf galaxy setup (local)

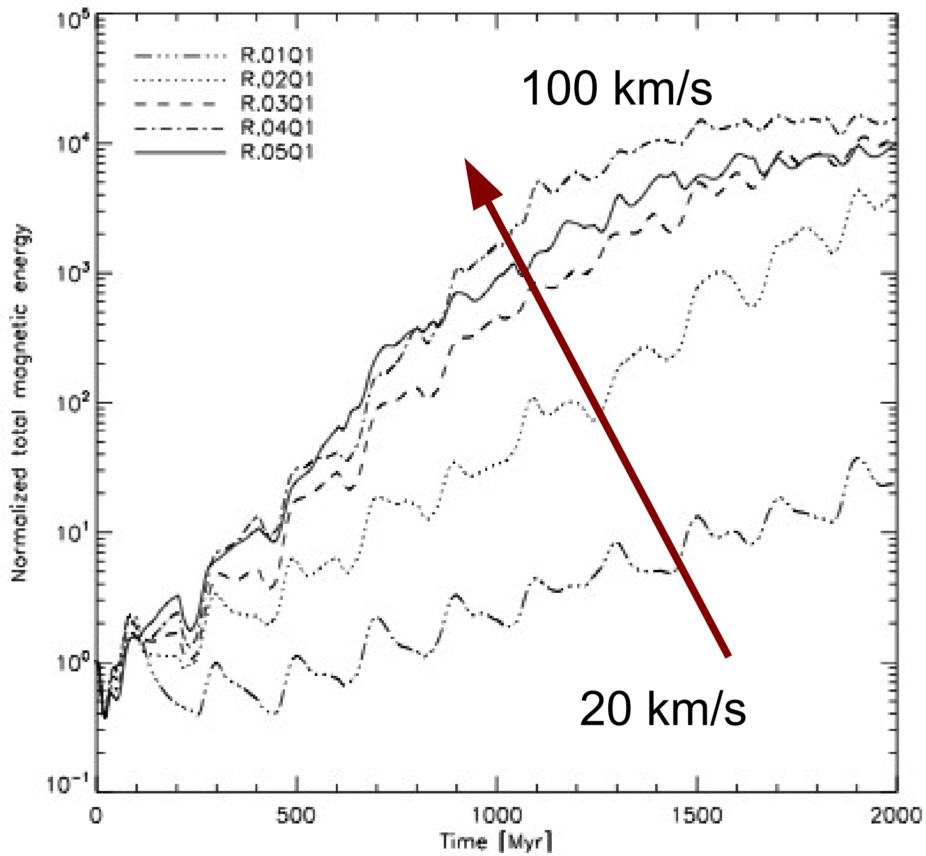
- Slow rotation (20 – 100) km/s
- Different shapes of RC (solid, flat, keplerian)
- SN activity (bursts, constant, only once)
- Weak azimuthal magnetic field $p_{\mathrm{mag}}/p_{\mathrm{gas}} = 10^{-4}$

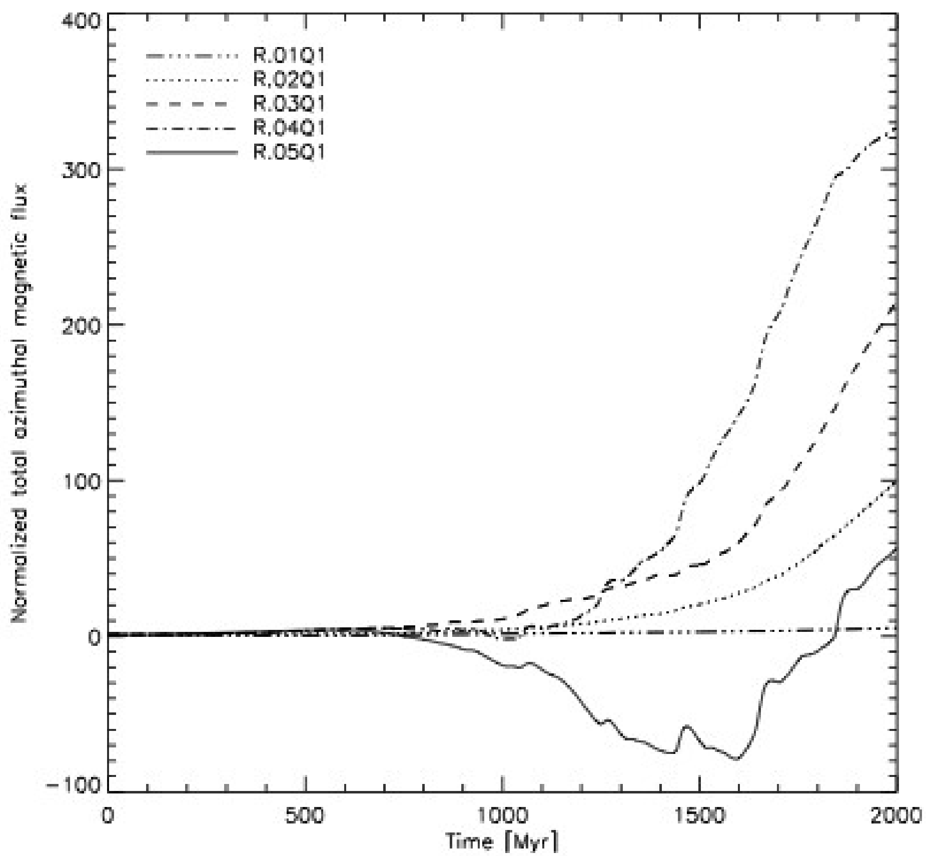
- Shearing box approximation



(Siejkowski et al. 2010)

Simulations: v_{rot}



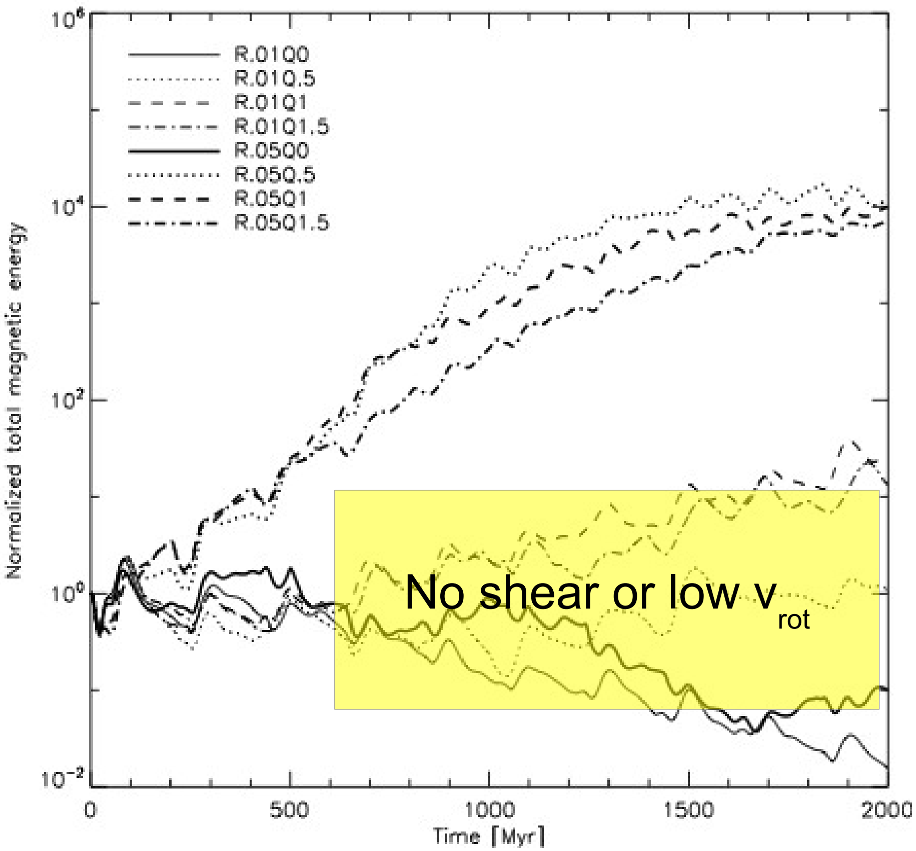


B_{tot}

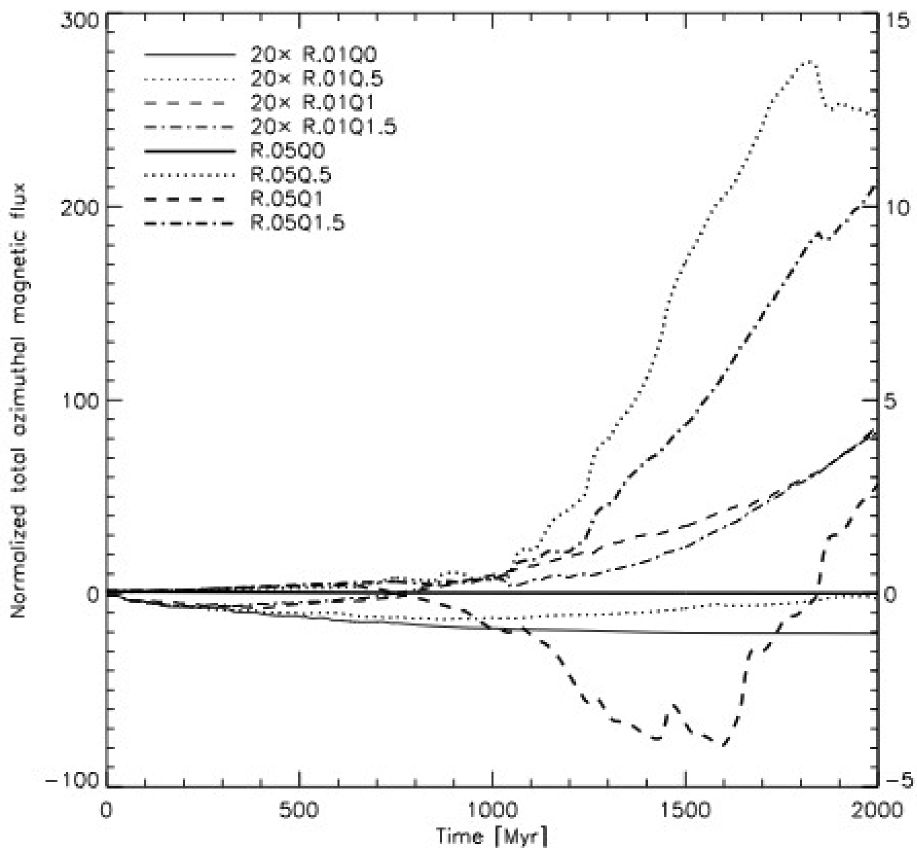
Azimuthal

(Siejkowski et al. 2010)

Simulations: v_{rot} (shear)



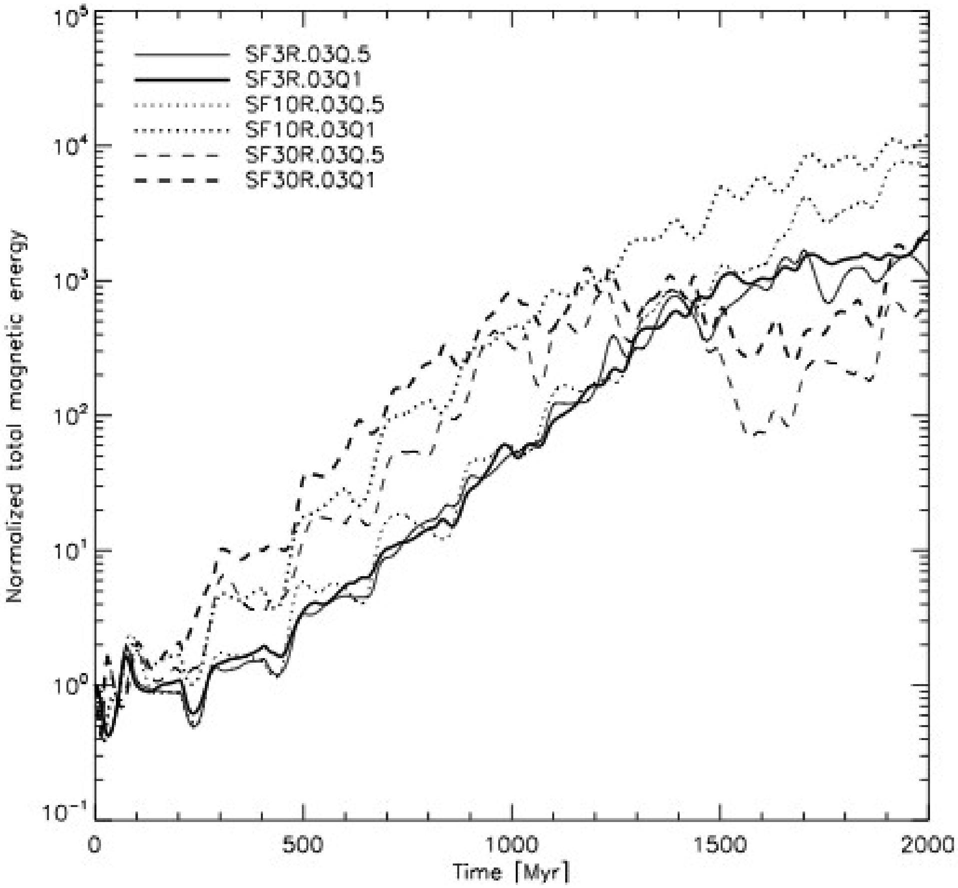
B_{tot}



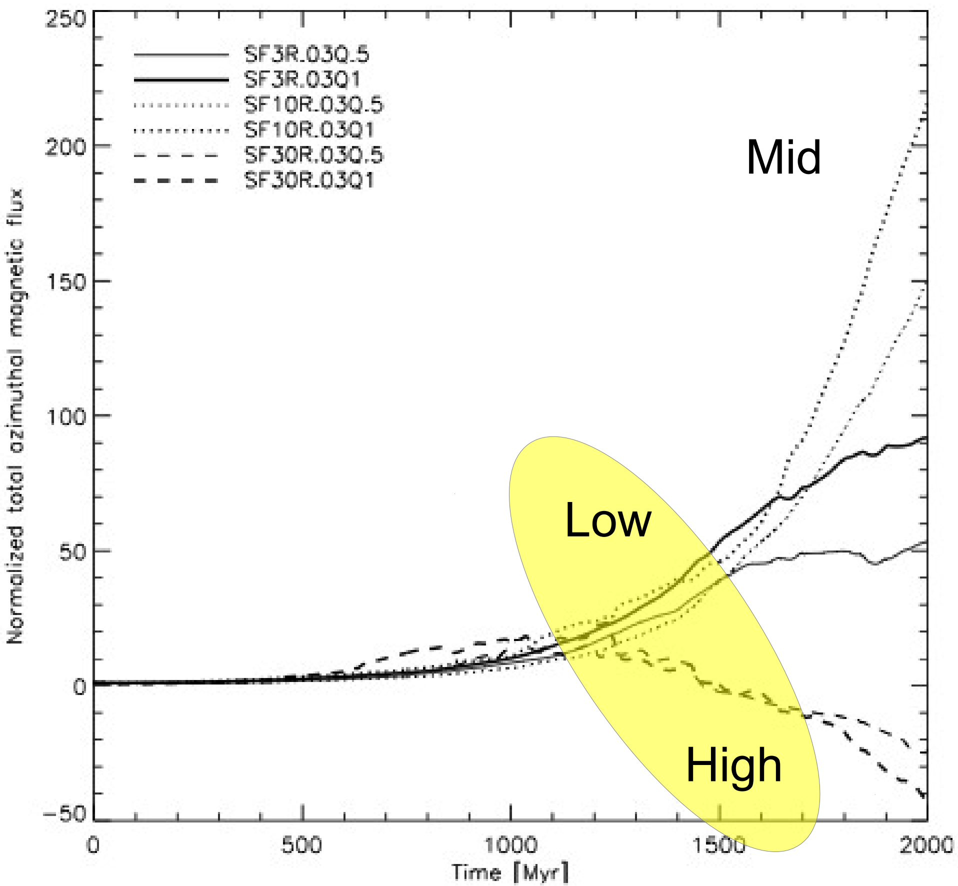
Azimuthal

(Siejkowski et al. 2010)

Simulations: SFR



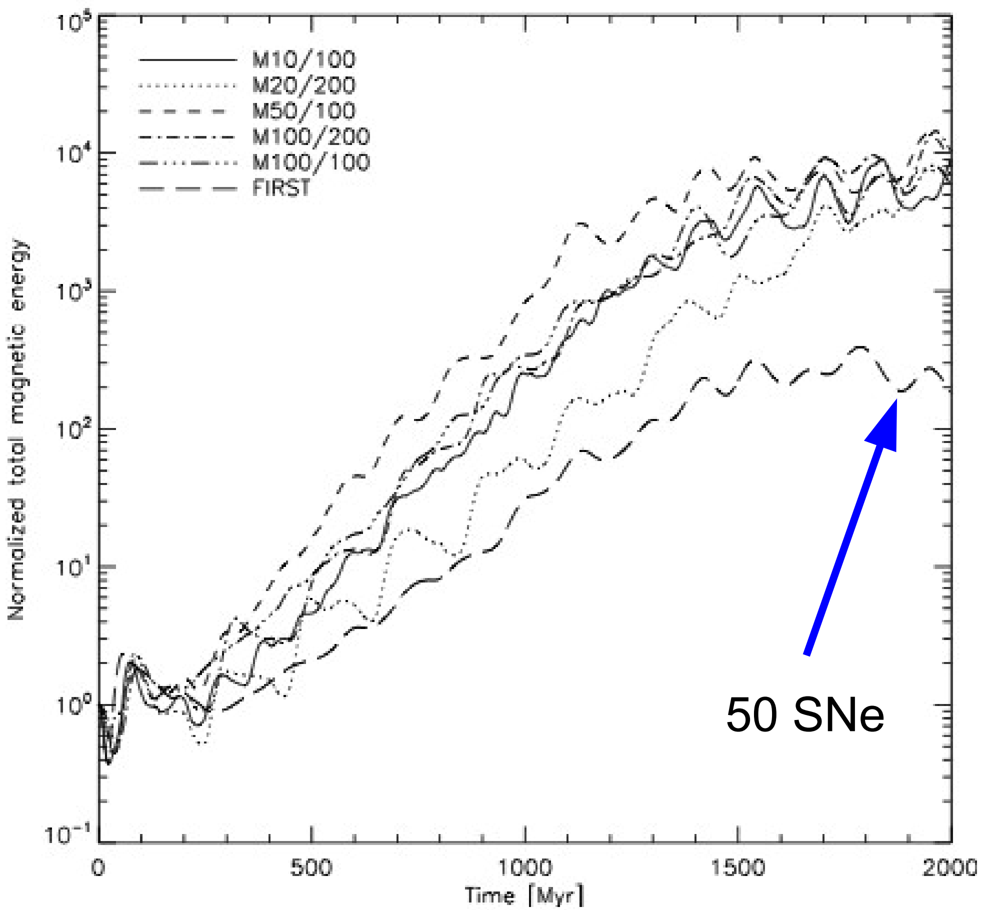
B_{tot}



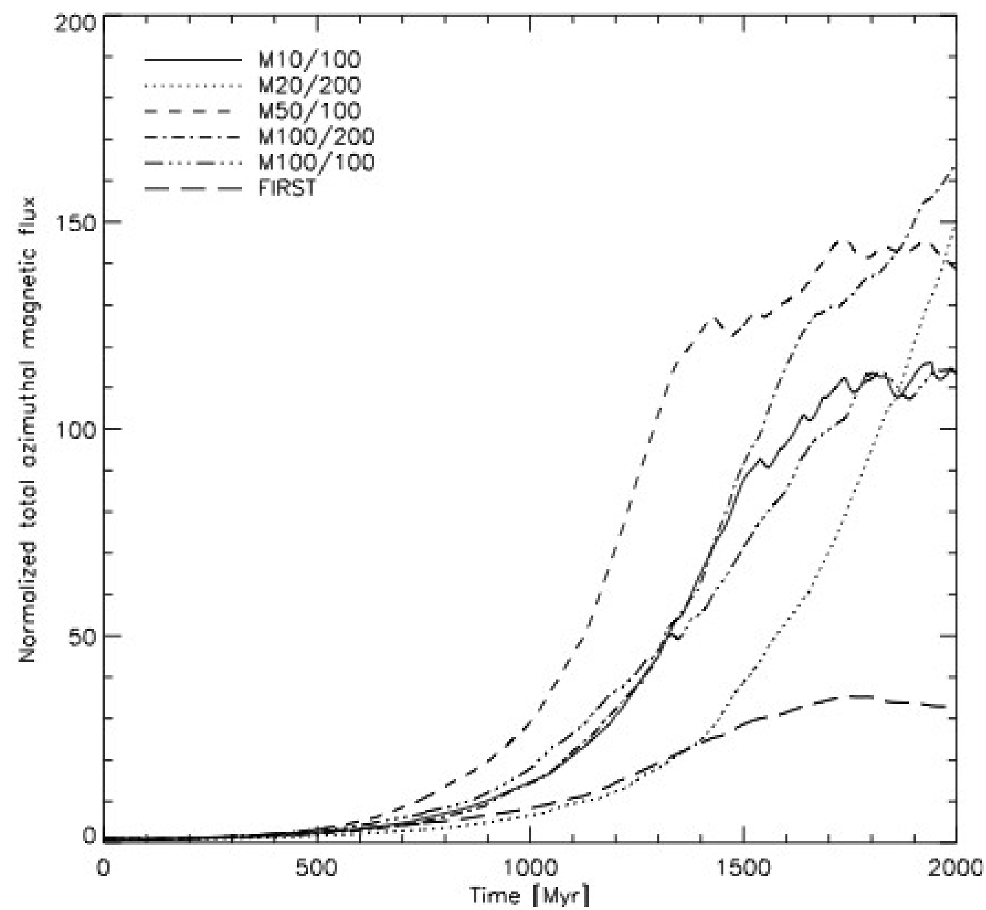
Azimuthal

(Siejkowski et al. 2010)

Simulations: SFR (bursts)



B_{tot}



Azimuthal

(Siejkowski et al. 2010)

Simulations: magnetized wind?

Model	$\log \bar{E}_B^{\rm end}$	$\log E_B^{\rm out}$	$E_B^{\rm out}/\bar{E}_B^{\rm end}$
R.01Q1[a]	1.37	0.07	0.05
R.02Q1	3.55	2.02	0.03
R.03Q1[b]	4.03	2.89	0.07
R.04Q1	4.17	3.29	0.13
R.05Q1[c]	3.95	3.43	0.30
R.01Q0	–1.73	–0.42	20.48
R.01Q.5	0.06	–0.35	0.39
R.01Q1[a]	1.37	0.07	0.05
R.01Q1.5	1.26	0.15	0.08
R.05Q0	–1.00	0.04	10.78
R.05Q.5	4.03	3.38	0.22
R.05Q1[c]	3.95	3.43	0.30
R.05Q1.5	3.81	3.07	0.18
SF3R.03Q.5	3.14	2.23	0.12
SF3R.03Q1	3.28	2.28	0.10
SF10R.03Q.5[d]	3.87	2.28	0.03
SF10R.03Q1[b]	4.03	2.89	0.07
SF30R.03Q.5	2.79	2.77	0.96
SF30R.03Q1	3.30	3.05	0.57
M10/100	3.78	2.73	0.09
M20/200[d]	3.87	2.28	0.03
M50/100	4.05	2.92	0.07
M100/200	4.11	2.67	0.04
M100/100	3.86	2.72	0.07
FIRST	2.37	1.33	0.09

$$\frac{\text{MF in the disk after 2 Gyr}}{\text{Total MF ejected form the disk}}$$

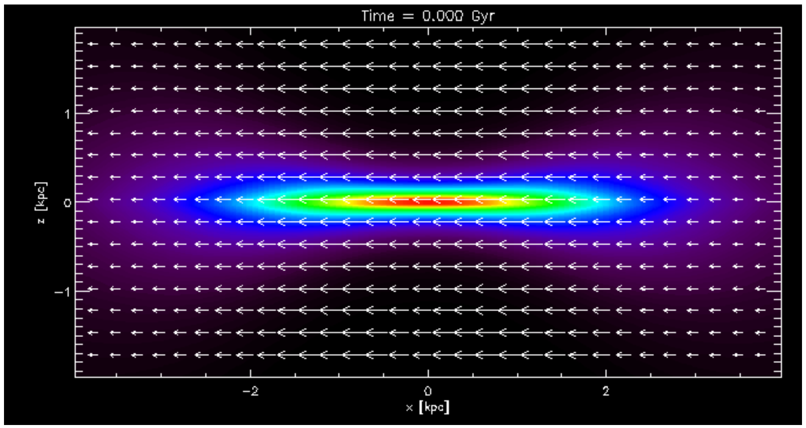
Decay (no dynamo)

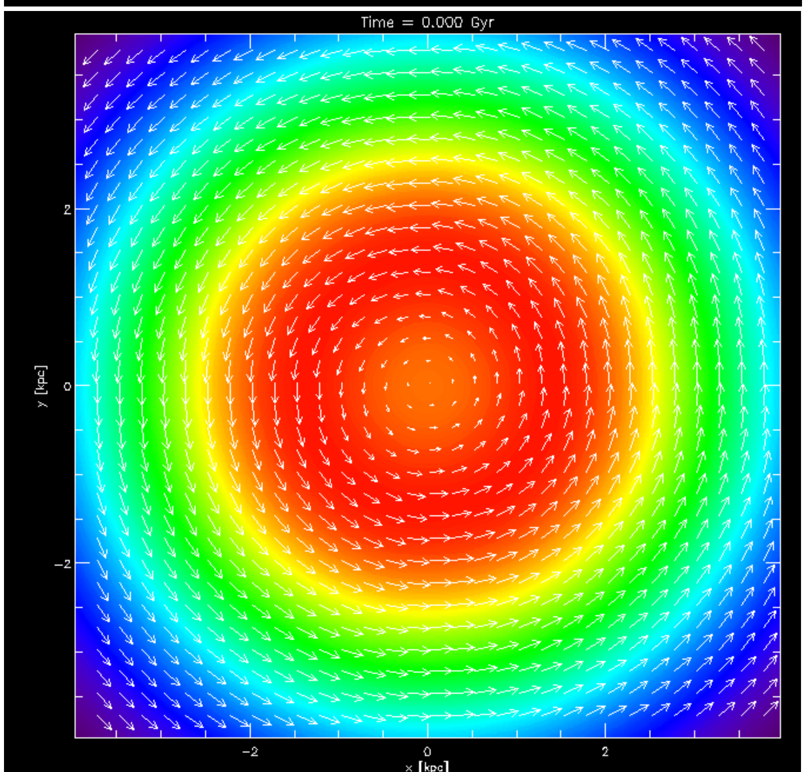
Possible IGM magnetization:
- Kronberg et al. 1999
- Bertone et al. 2006

High SNR

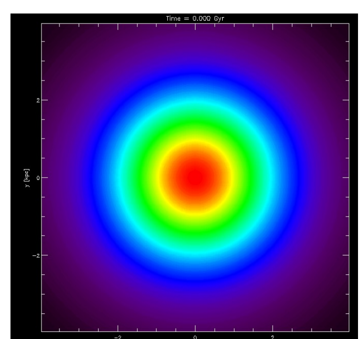
(Siejkowski et al. 2010)

Global model of dwarf galaxy





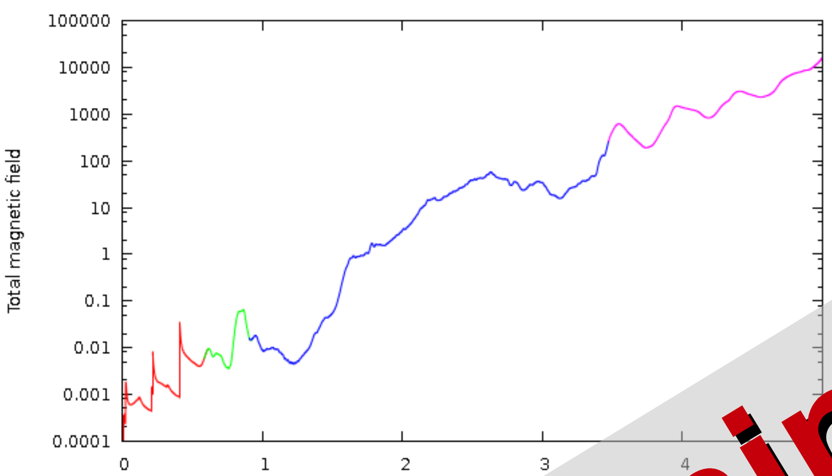
- static gravity (disk + DM halo)
- initital HD + CR hydrostatic
- v_{rot} = 25 km/s
- box 8 x 8 x 4 kpc
- 10/100 Myr SNR
- SNe position weighted according to density

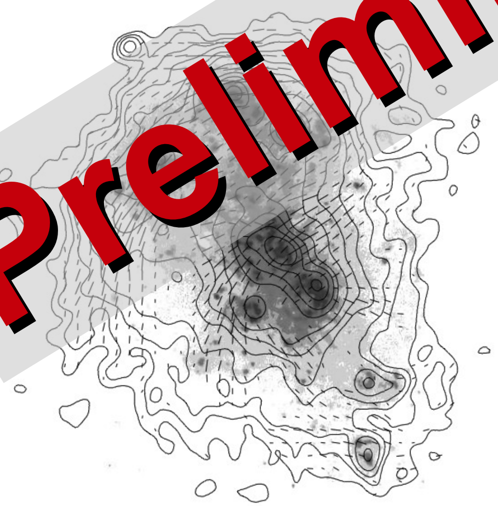


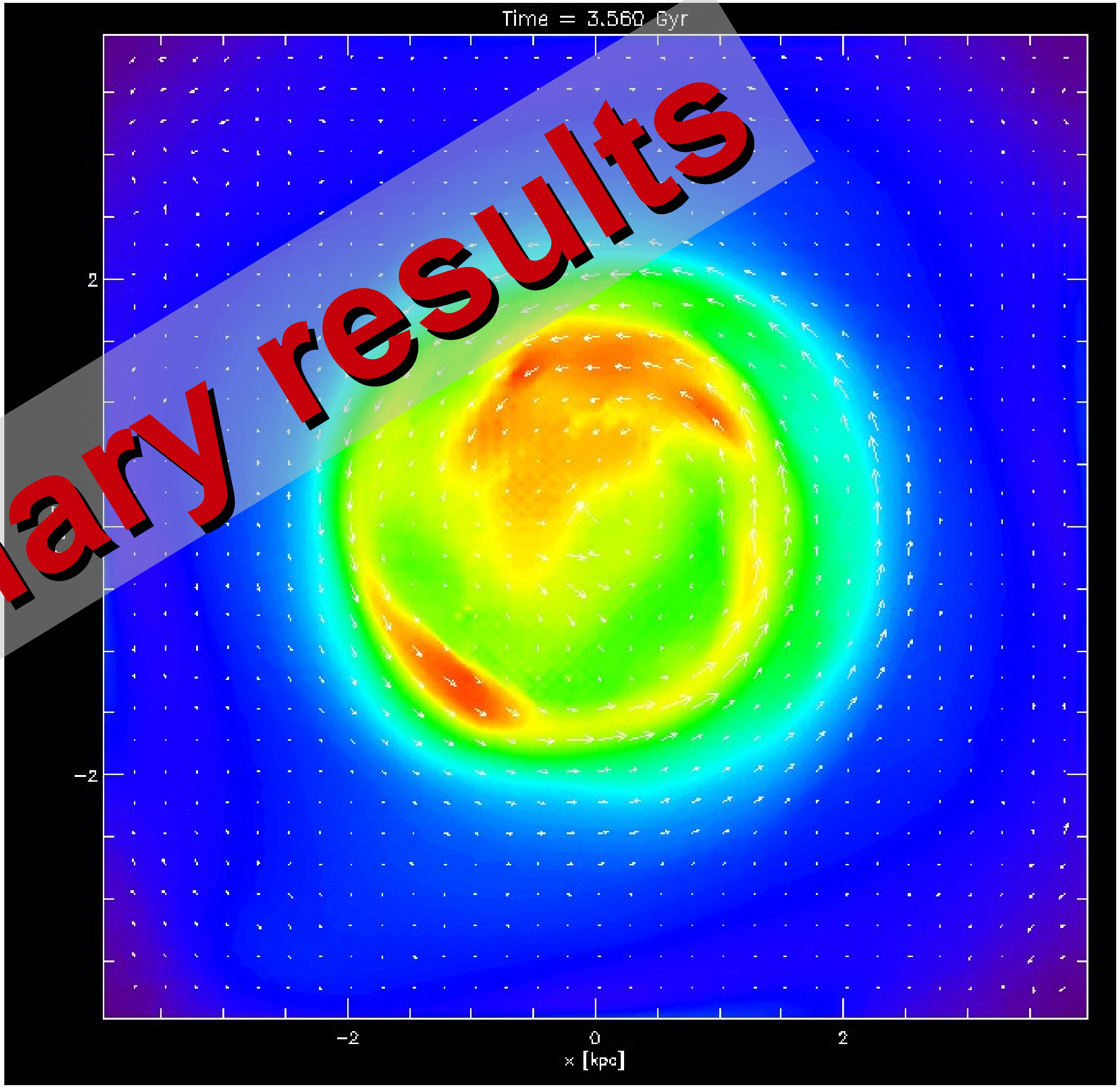
Global model of dwarf galaxy

- Simulation up to 5 Gyr

B_{tot}







Preliminary results

Conclusions

- Dwarf galaxies have strong or weak magnetic fields, in some cases even large scale.
- Despite the adverse conditions (low mass, slow rotation) the dynamo can operate.
- Observations and numerics show some indication for some dynamo thresholds – needs further deep investigation.
- SFR/SNR is the key parameter, but to high destroys the rotation: but we need both to operate the large scale dynamo.
- Possible magnetization of the IGM
- Further development and fine tuning global model, reproduce the observed relations.