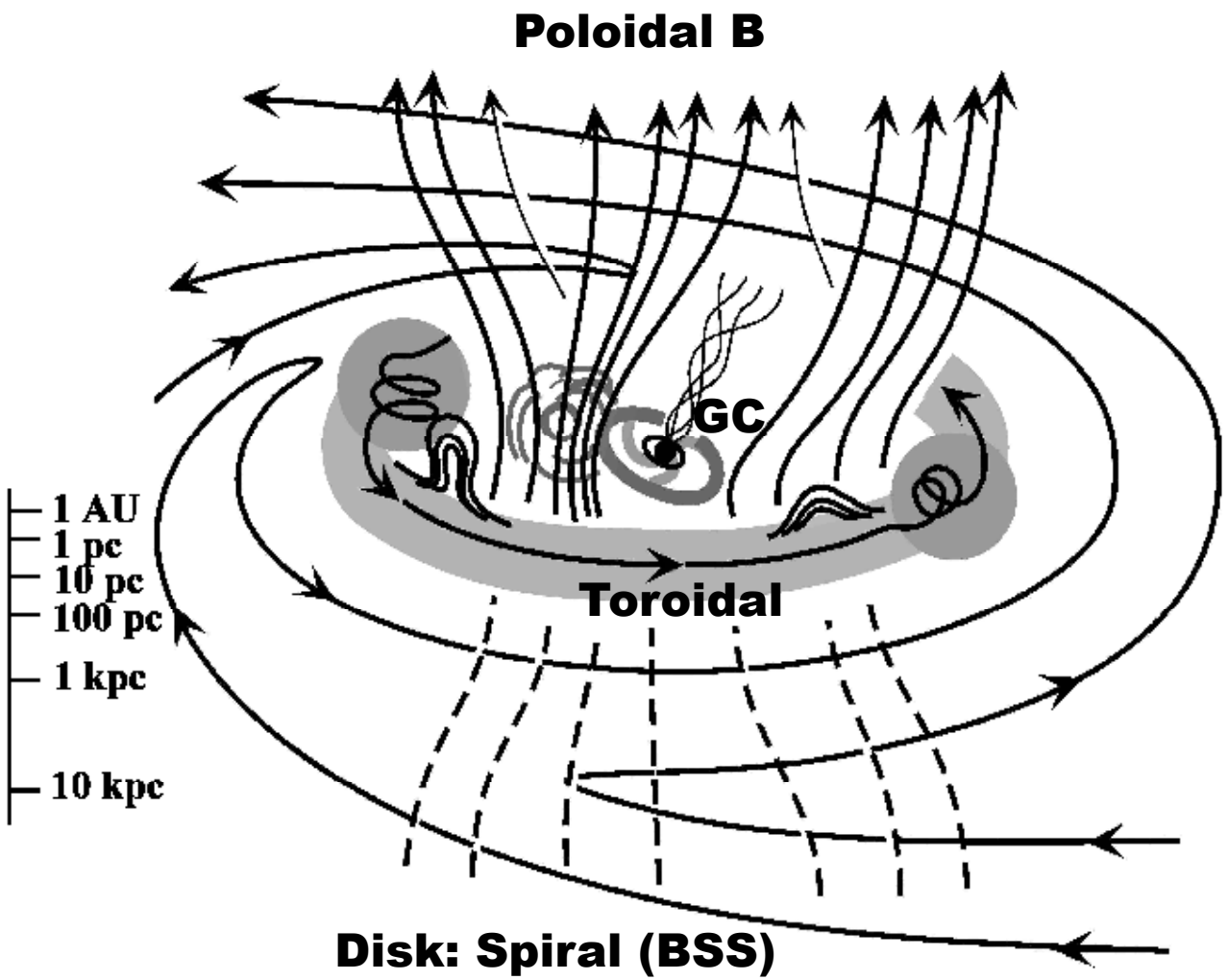
銀河磁場とその起源

祖父江義明

2010.9.27-28

Dynamo Conference @ Nagoya Univ

Magnetic View of the Galaxy



Global B in Disk Galaxy

(1) $B \sim 3\mu G$

(2) $B^2/8\pi \sim 1/2\ \rho v_\sigma^2 \sim 1$ eV/cc

$(10^{-12}$erg/cc) $<<$ $1/2\ \rho V_{rot}^2$

(3) If cosmic origin,

$B \sim 10^{-10}$ G x (1 Mpc/10 kpc)^2

(4) Topology :

BSS + ASS + GP Rev + Ring + Vert.

Global B in Disk Galaxy

Composite Topology :

BSS +

ASS + GP Reversal+

Ring +

Vertical (GC)

銀河磁場の測定

Synchrotron Radio Emission

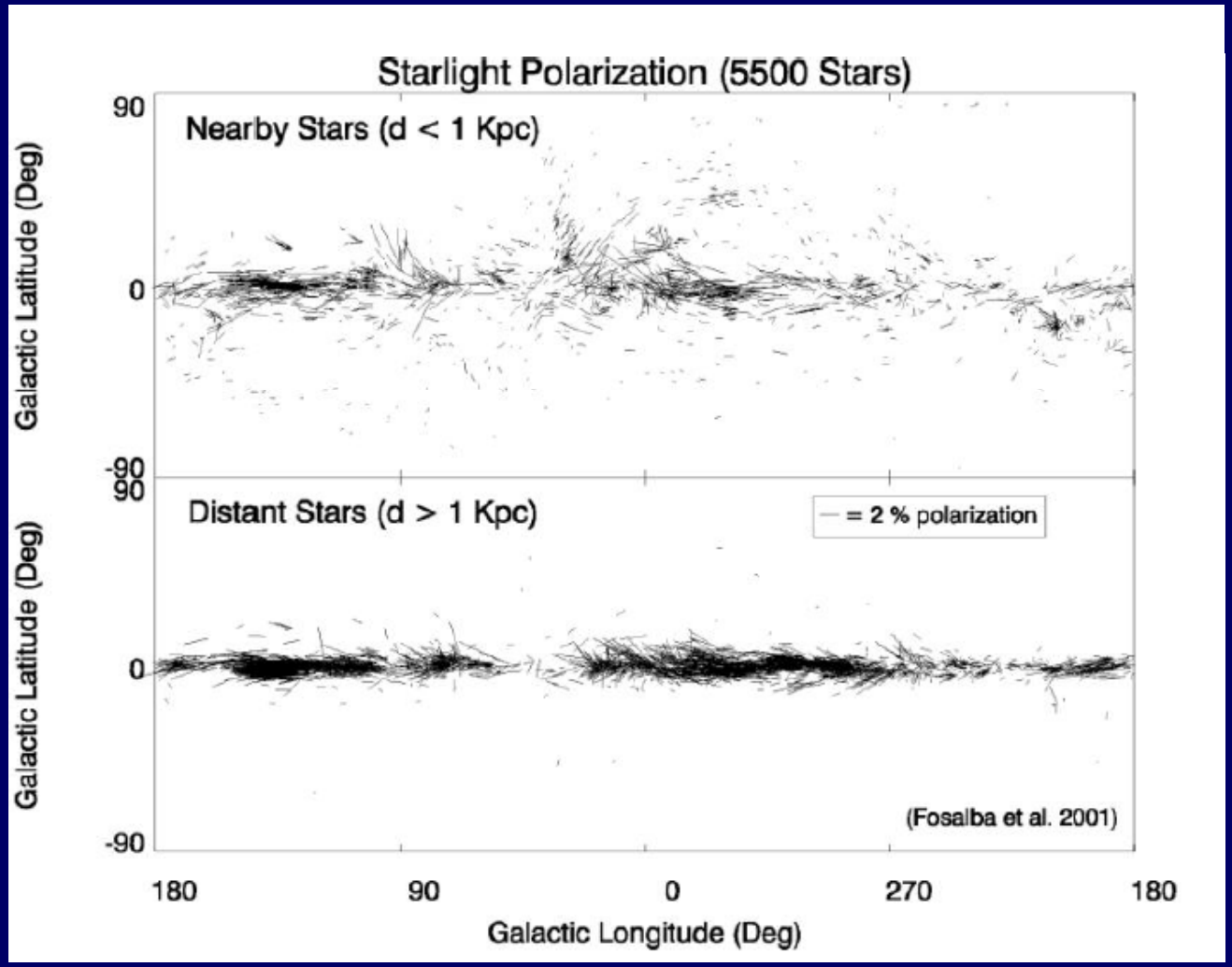
1. Energy Equipartition→ B total
2. Polarized degree → B ordered
3. Faraday RM → B para
4. Faraday De-rotation → B perp

5. Star Light Pol. → B perp
6. Zeeman effect → B (low temp)

→ 3D B Vectors

1. 銀河系

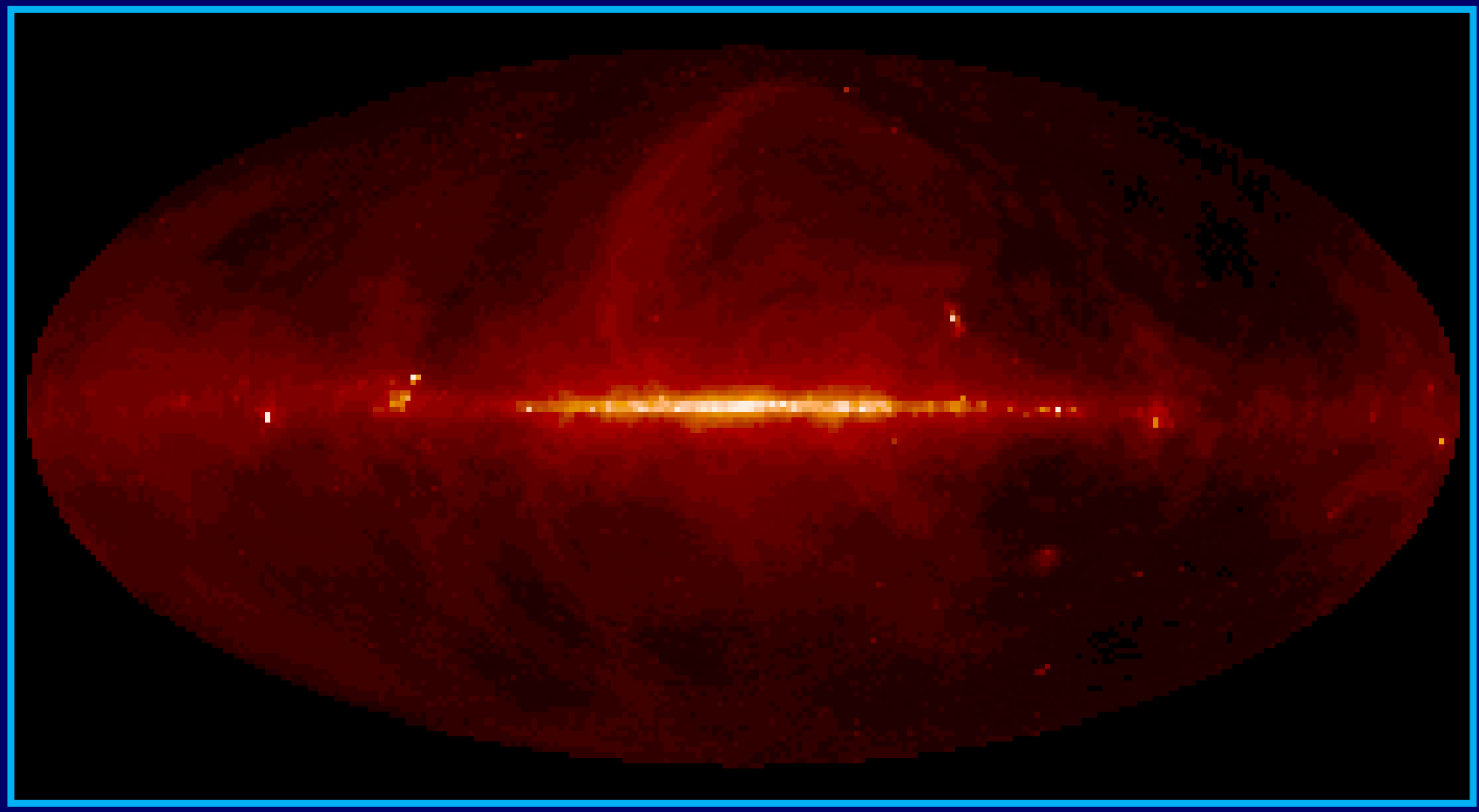
Star Light Polarizatio
D<1 kpc, > 1kpc



Synchrotron Radio Emission

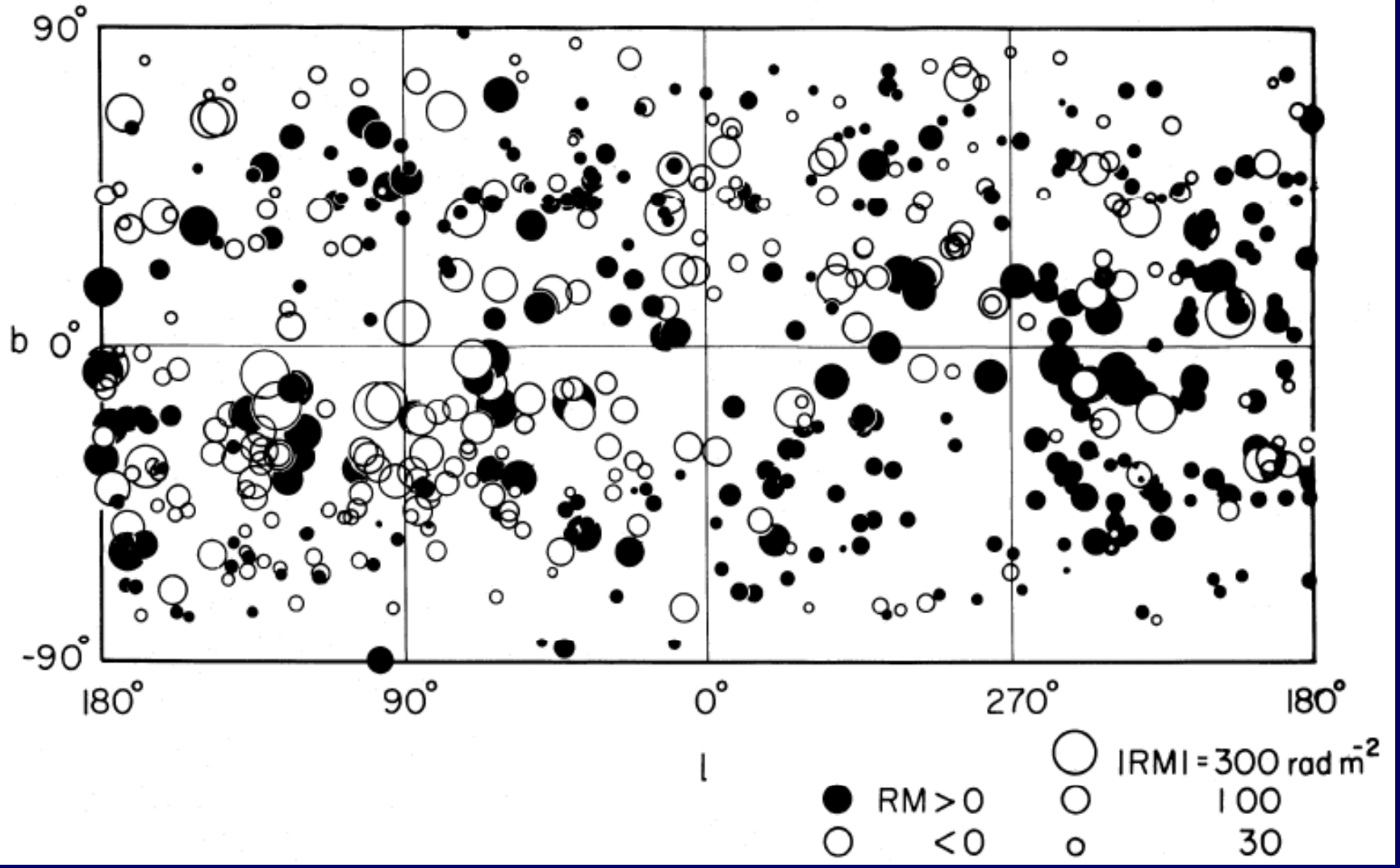
Equipartition : $B^2/8\pi$ =U(ISM therm)=U(ISM turb)

B=a few micro G



RM distribution and BSS field

(Sofue, Fujimoto 1983)

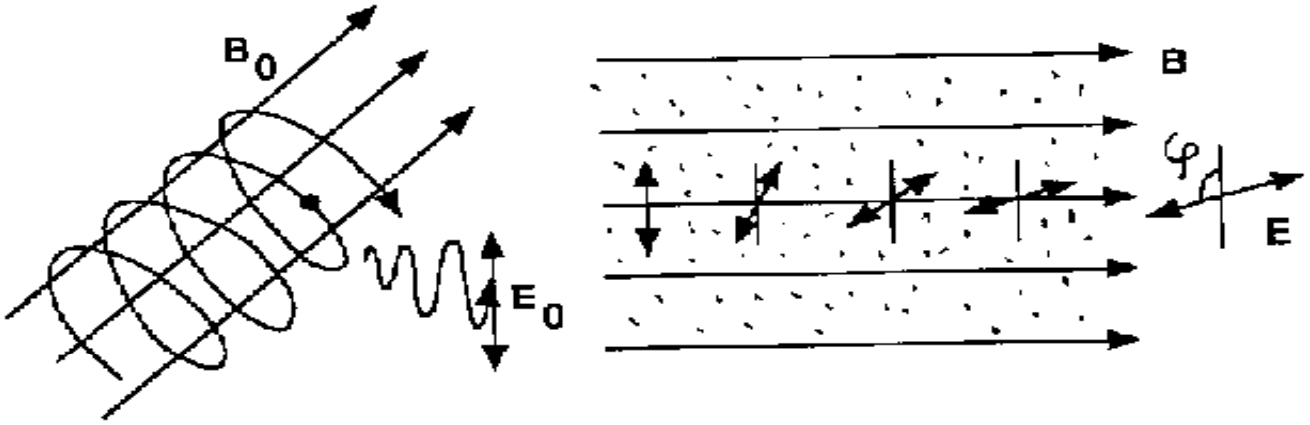


Faraday Rotation
Rotation measure

$$\phi = \phi_0 + \phi_F,$$

$$\phi_F = RM\lambda^2 \text{ [rad]},$$

$$RM = 0.81 \int n_e B_{\parallel} dl,$$



3)

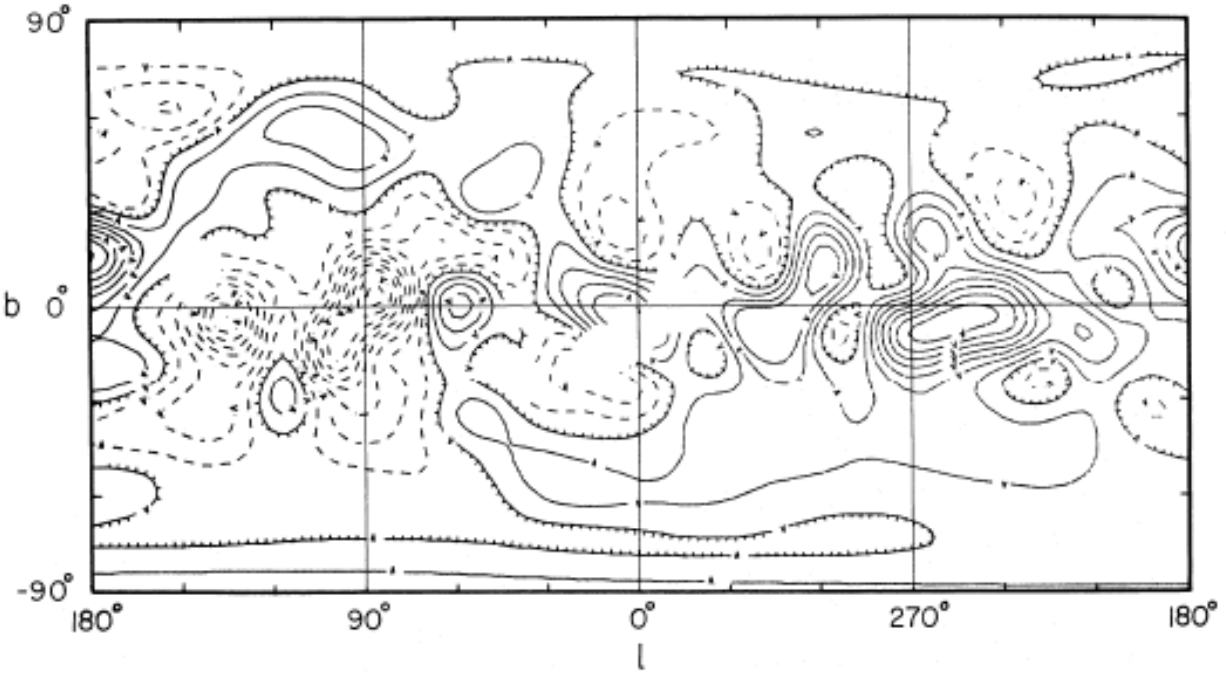
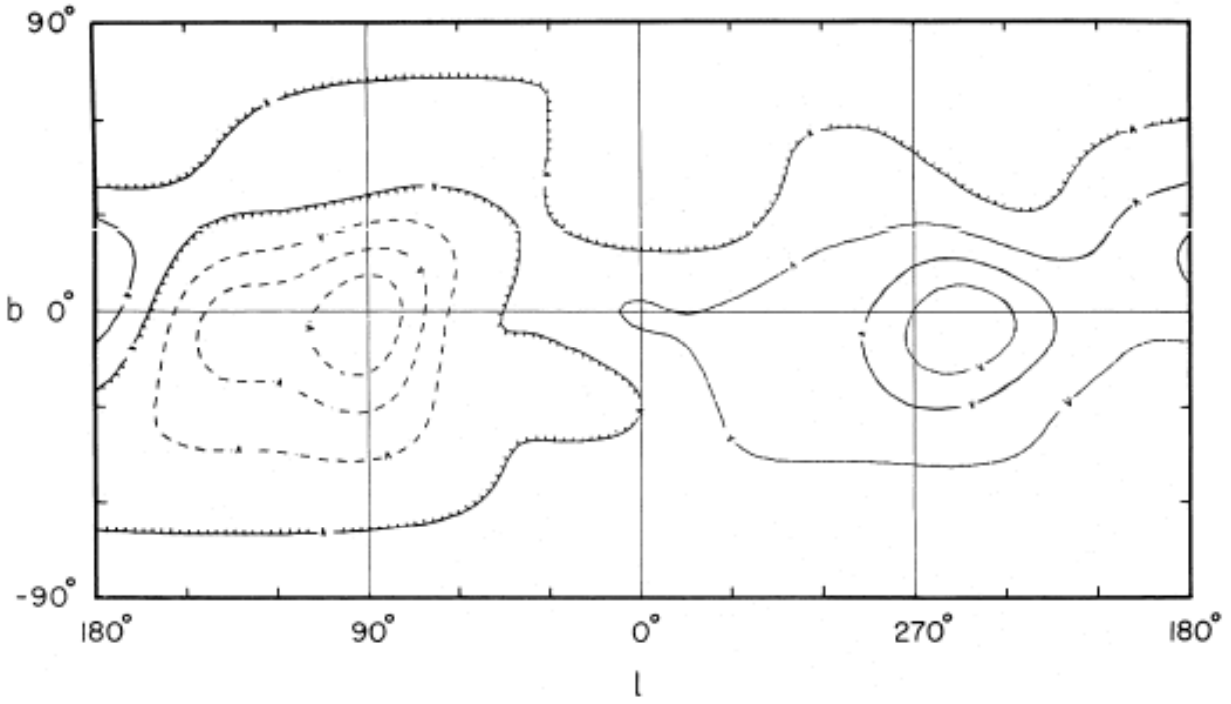
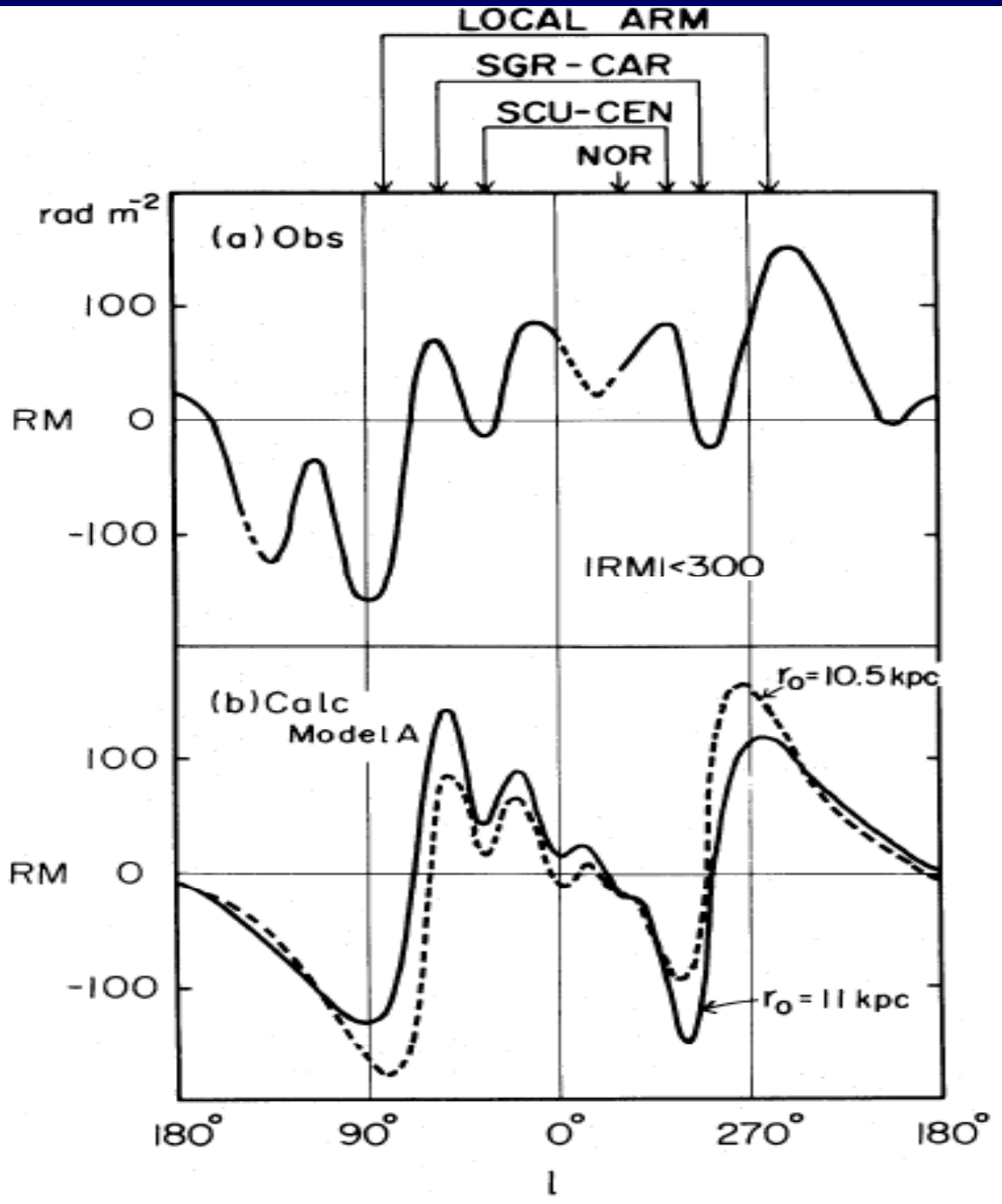


FIG. 2a



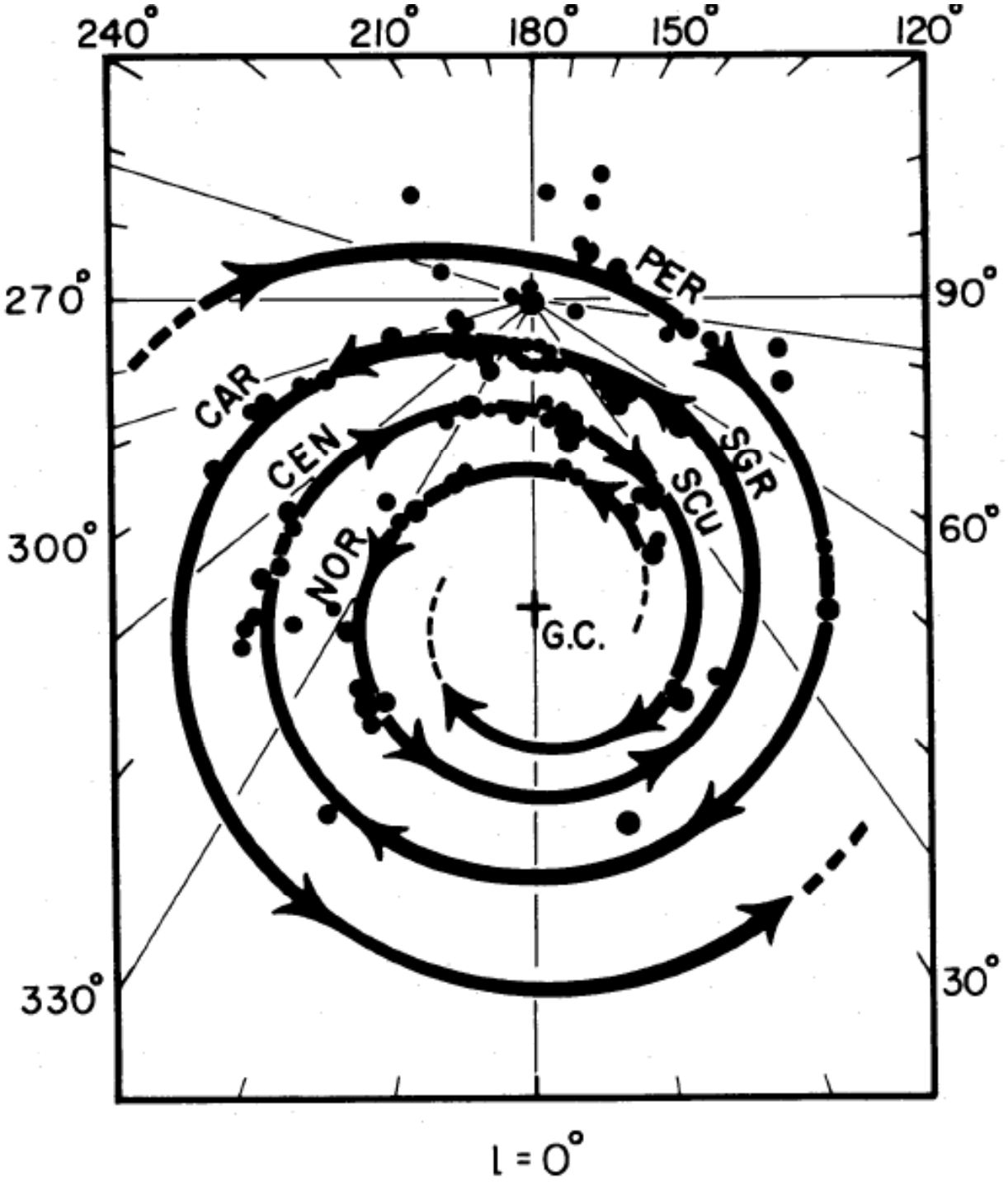
B

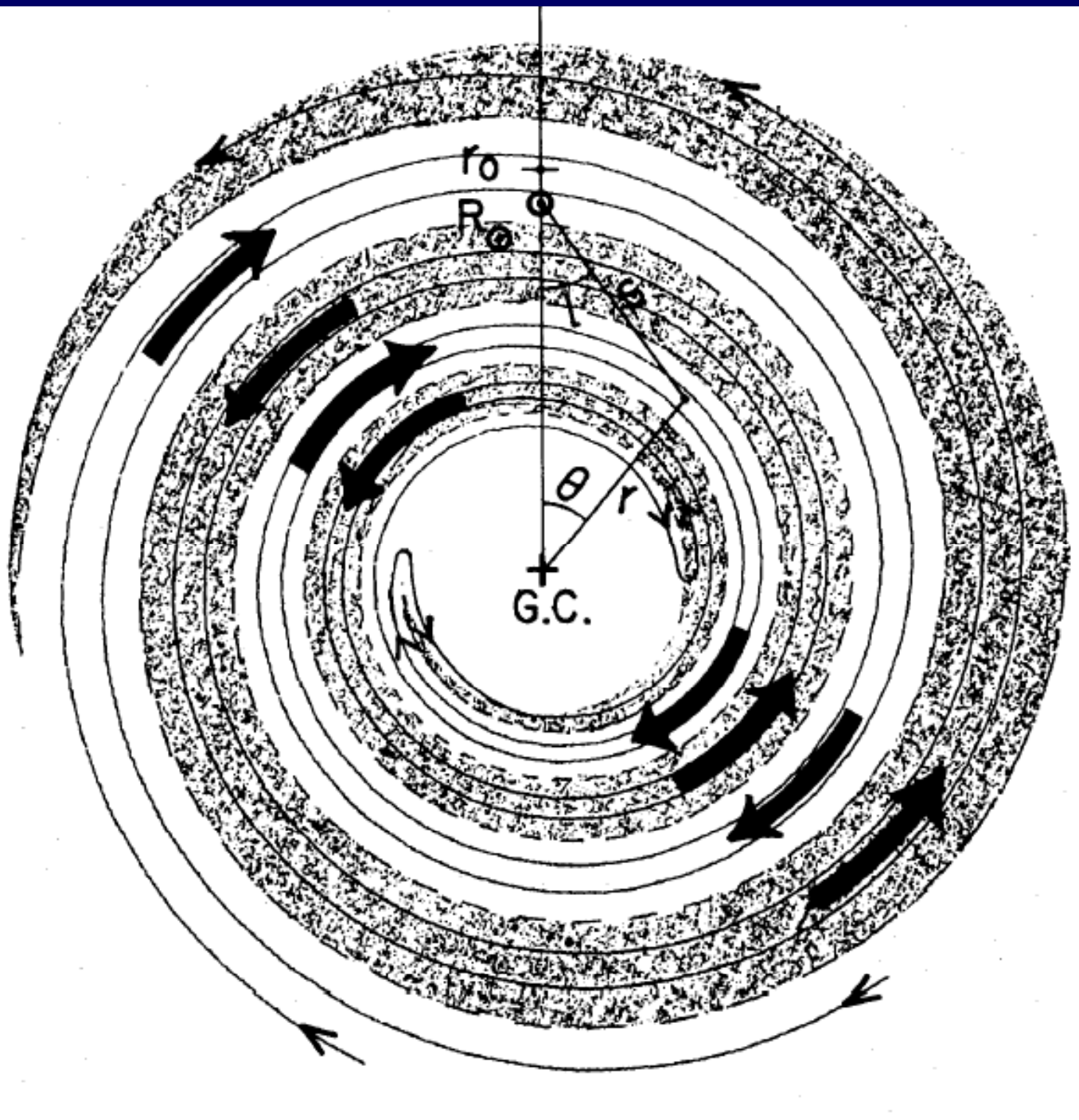
3)


LOCAL ARM
SGR - CAR
SCU-CEN
NOR
rad m⁻²
(a) Obs
100
RM 0
-100
IRMI<300
(b) Calc
Model A
r₀= 10.5 kpc
r₀ = 11 kpc
100
RM 0
-100
180°
90°
0°
270°
180°
l

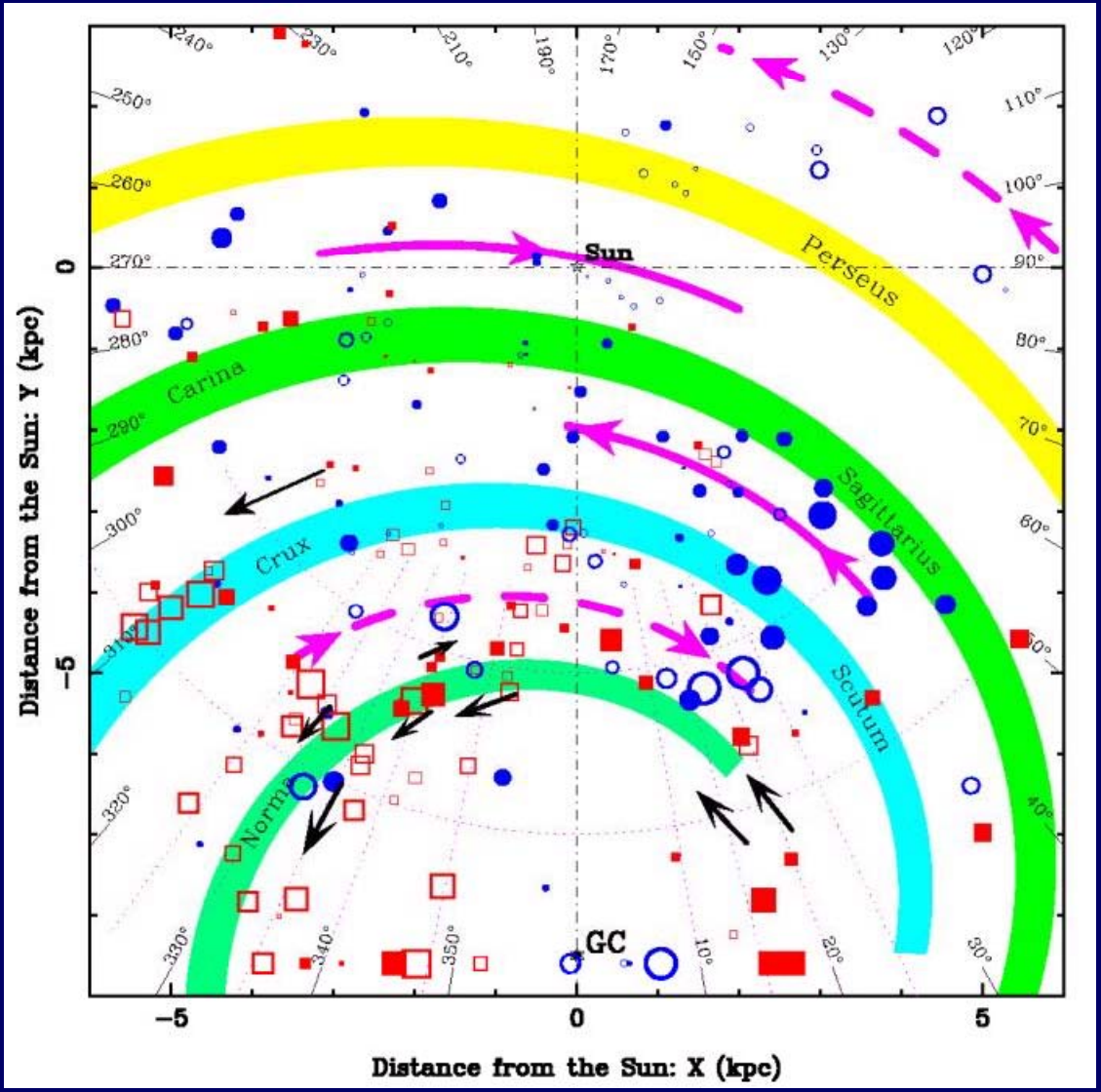
d

83)

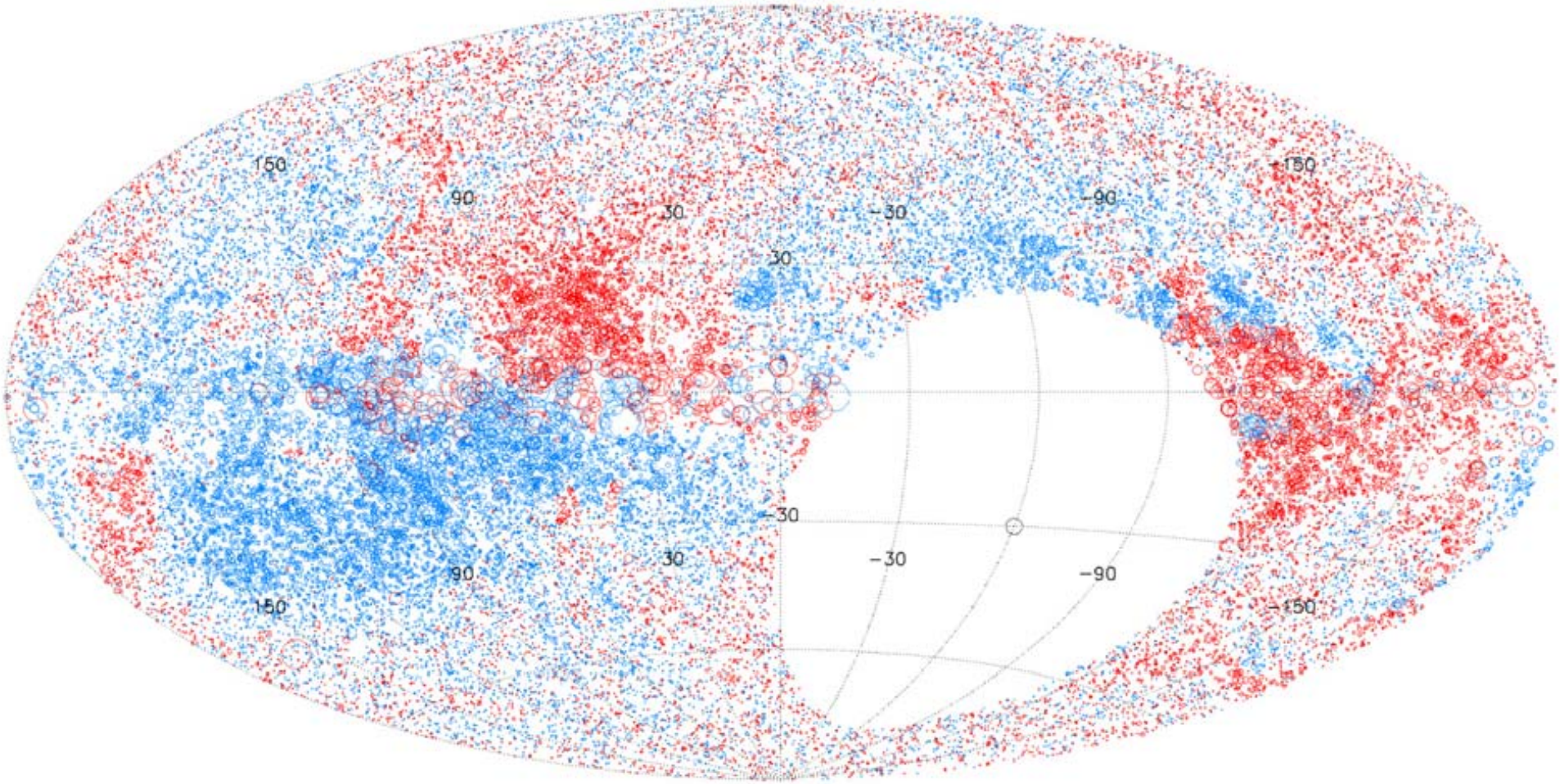

240°
210°
180°
150°
120°
270°
90°
300°
60°
330°
30°
PER
CAR
CEN
NOR
SCU
SGR
G.C.
l = 0°


r0
R0
θ
r
G.C.

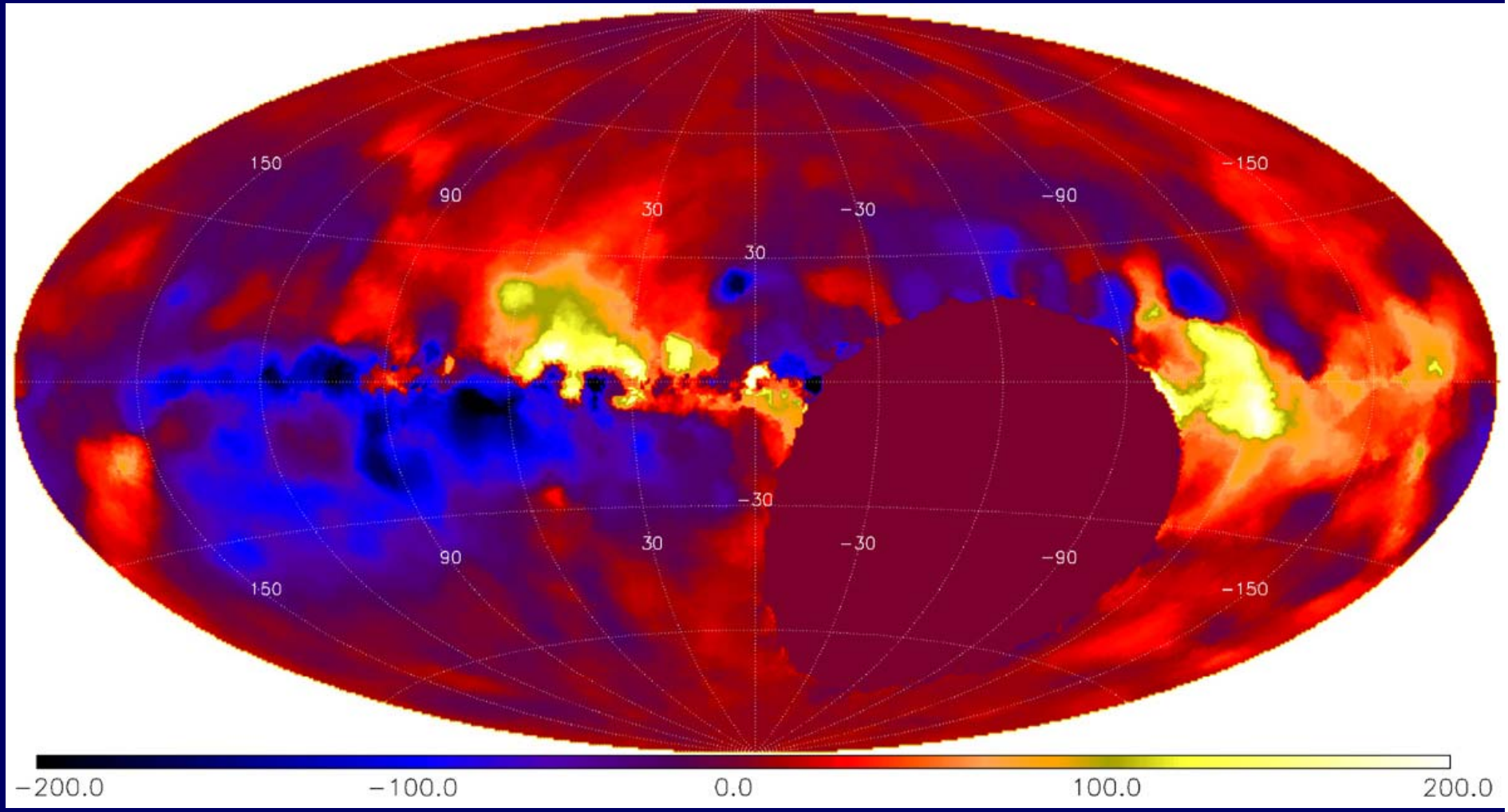
Milky Way : RM+Pulsar distribution
Bisymmetric B field (Han 2000)



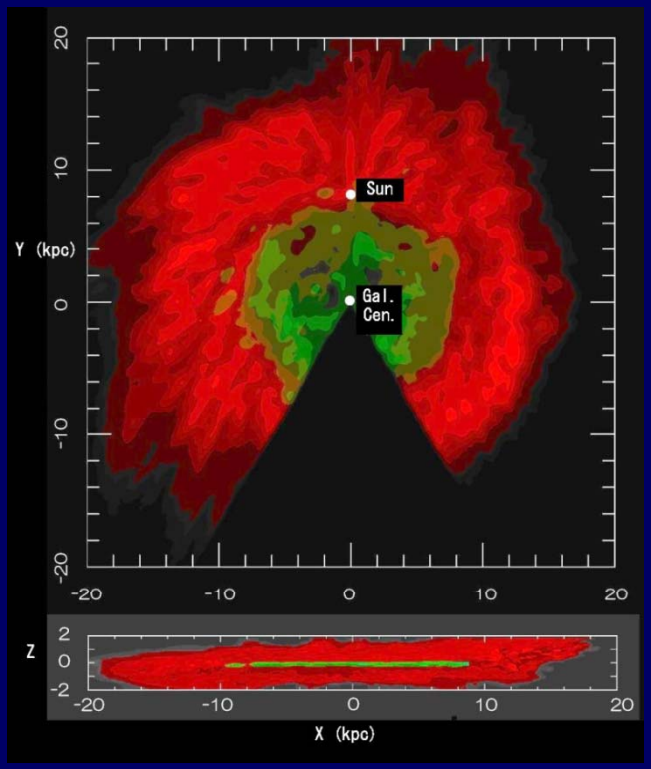
RM (Taylor 2009)

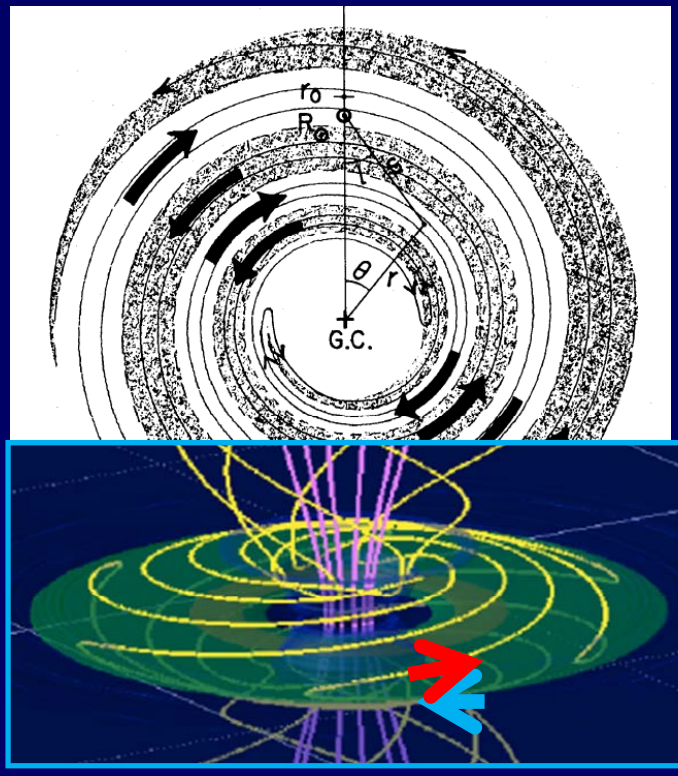


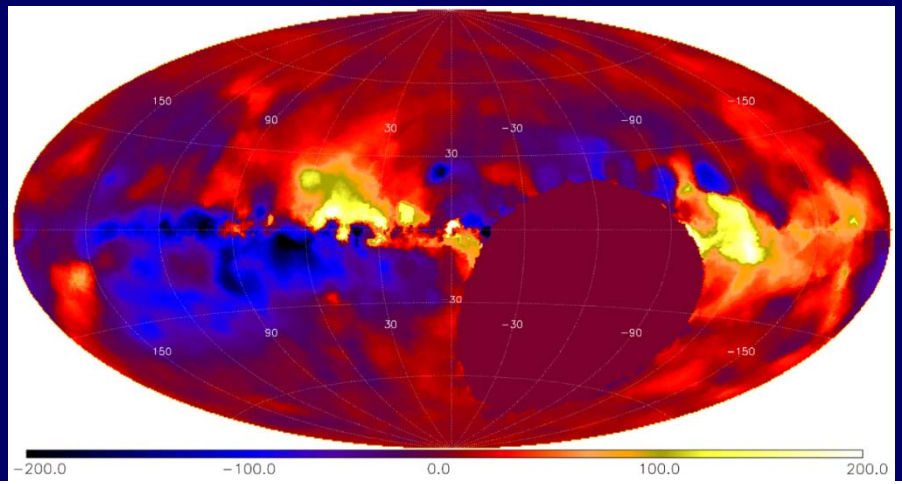
RM Sky (Taylor 2009)



3D Gas (HI+CO) x B Model = RM sky

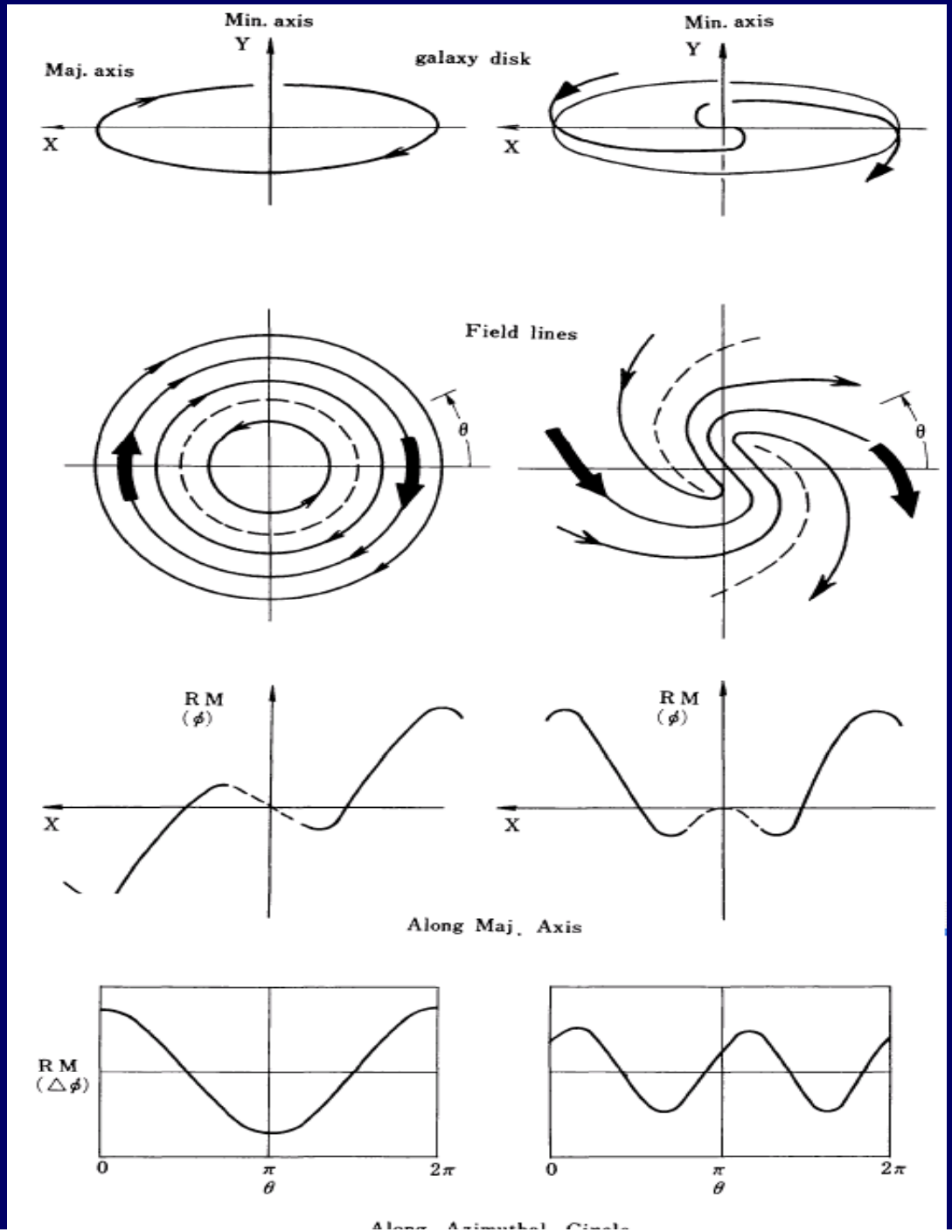




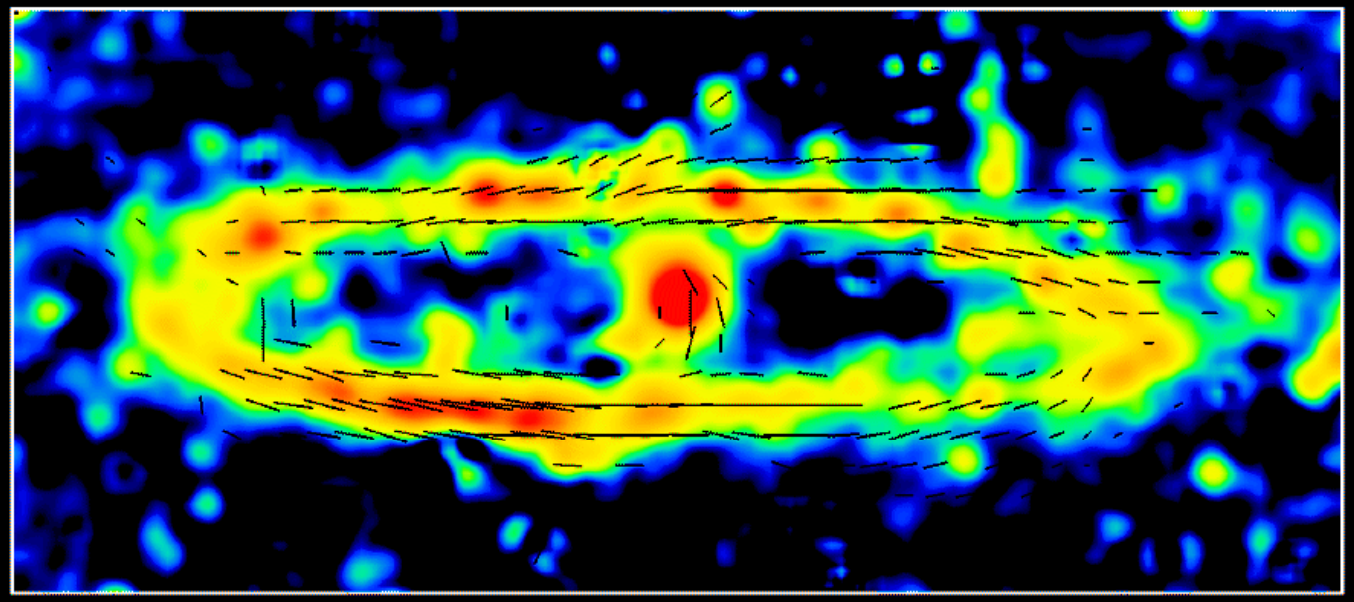


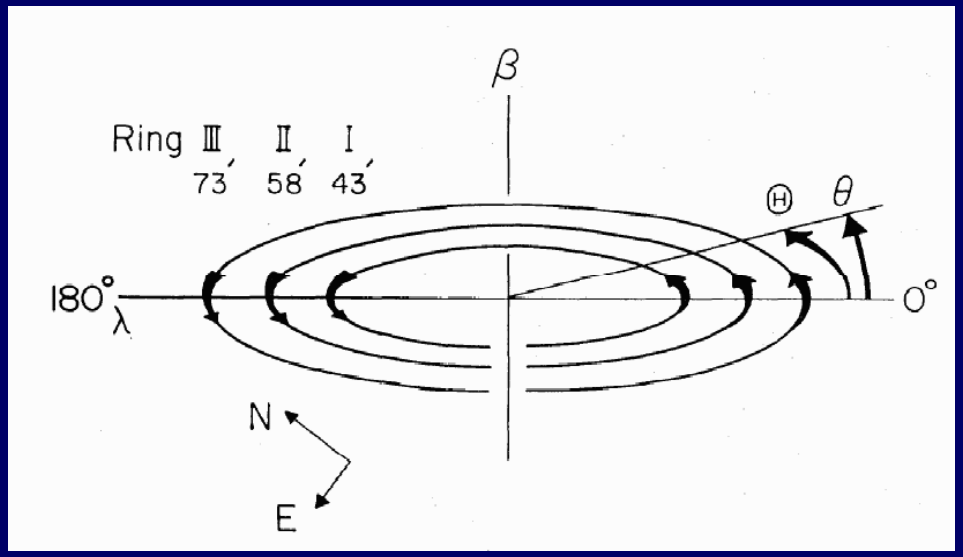
2. 系外銀河

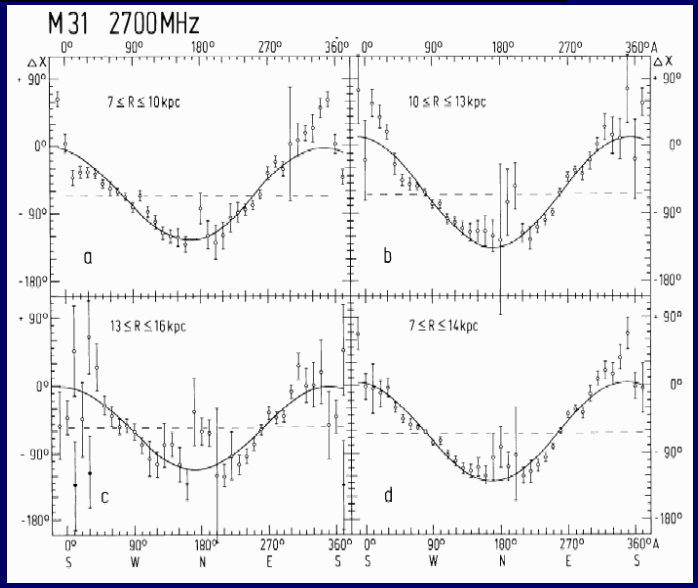
Variaton of RM



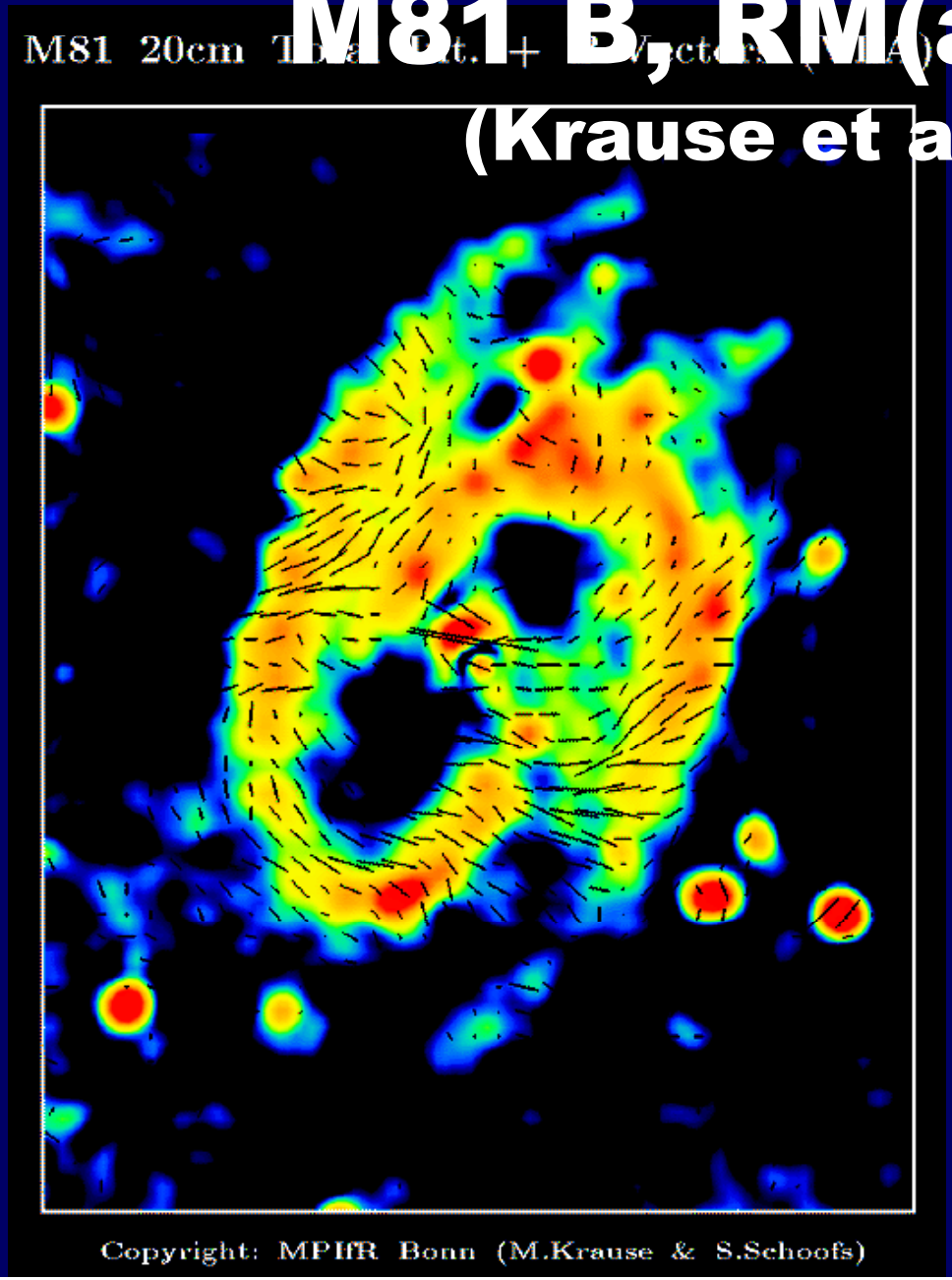
M31 6cm Total Intensity + Magnetic Field (Effelsberg)

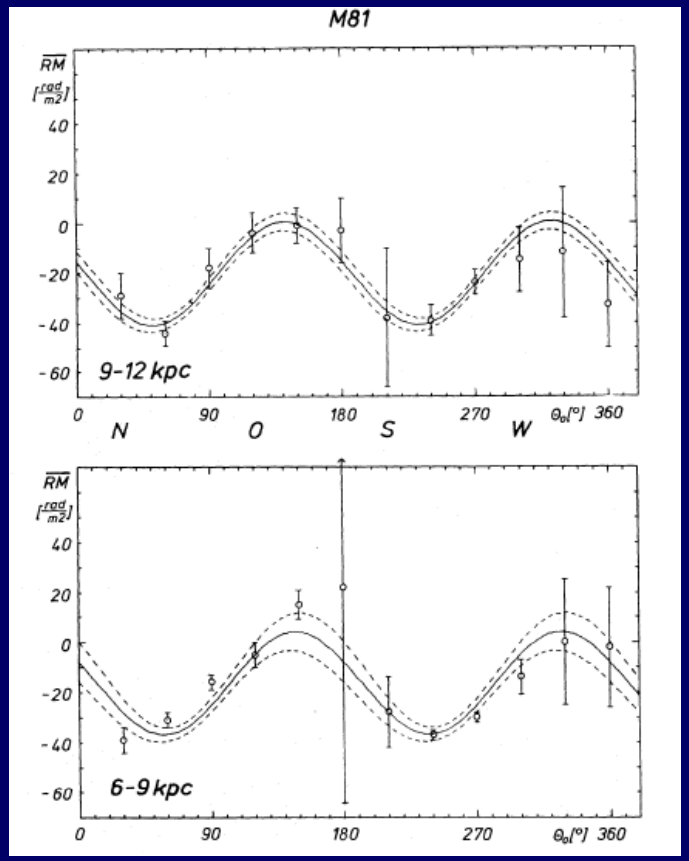




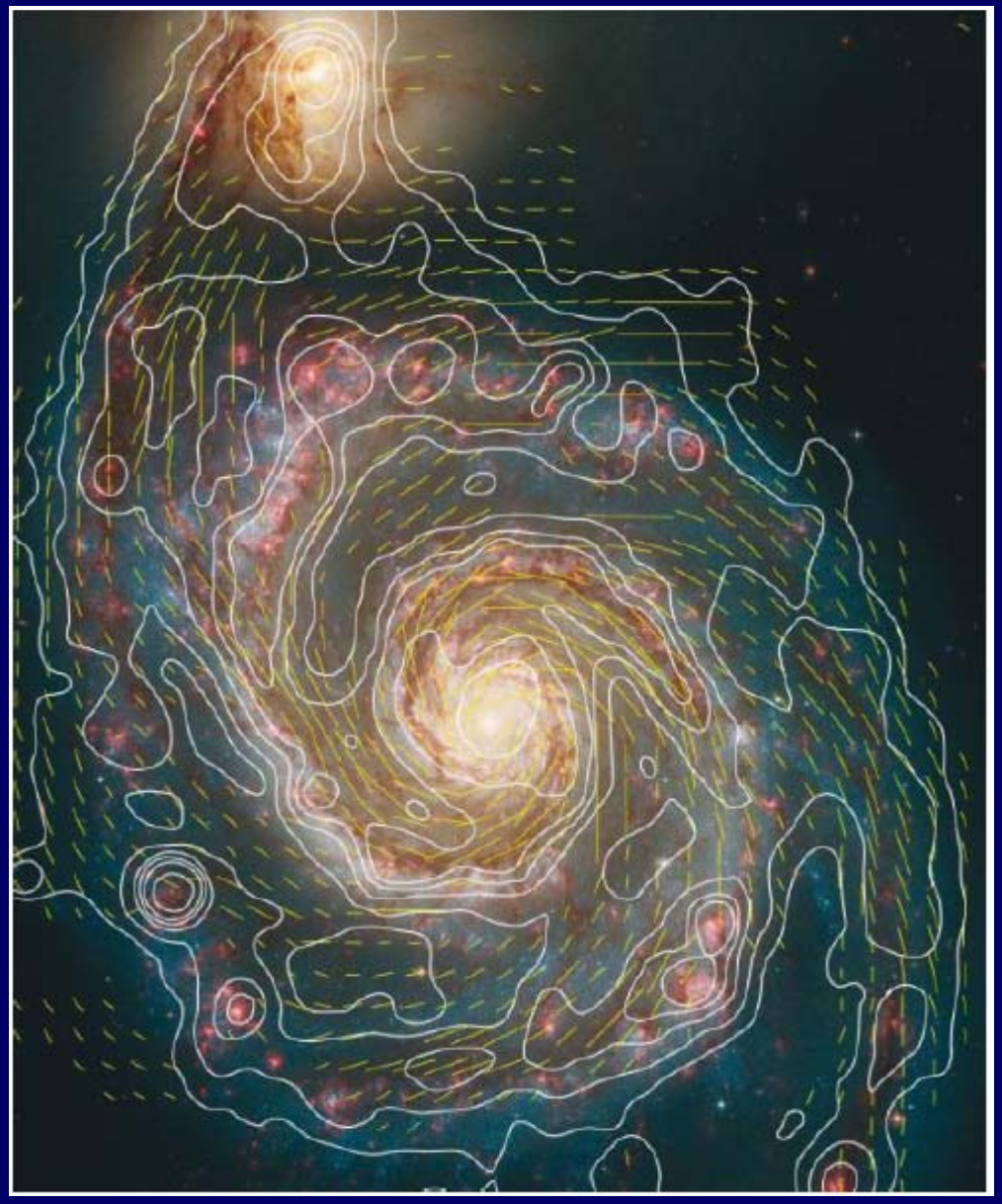


M81 B, RM(azimuth)
(Krause et al. 1989)

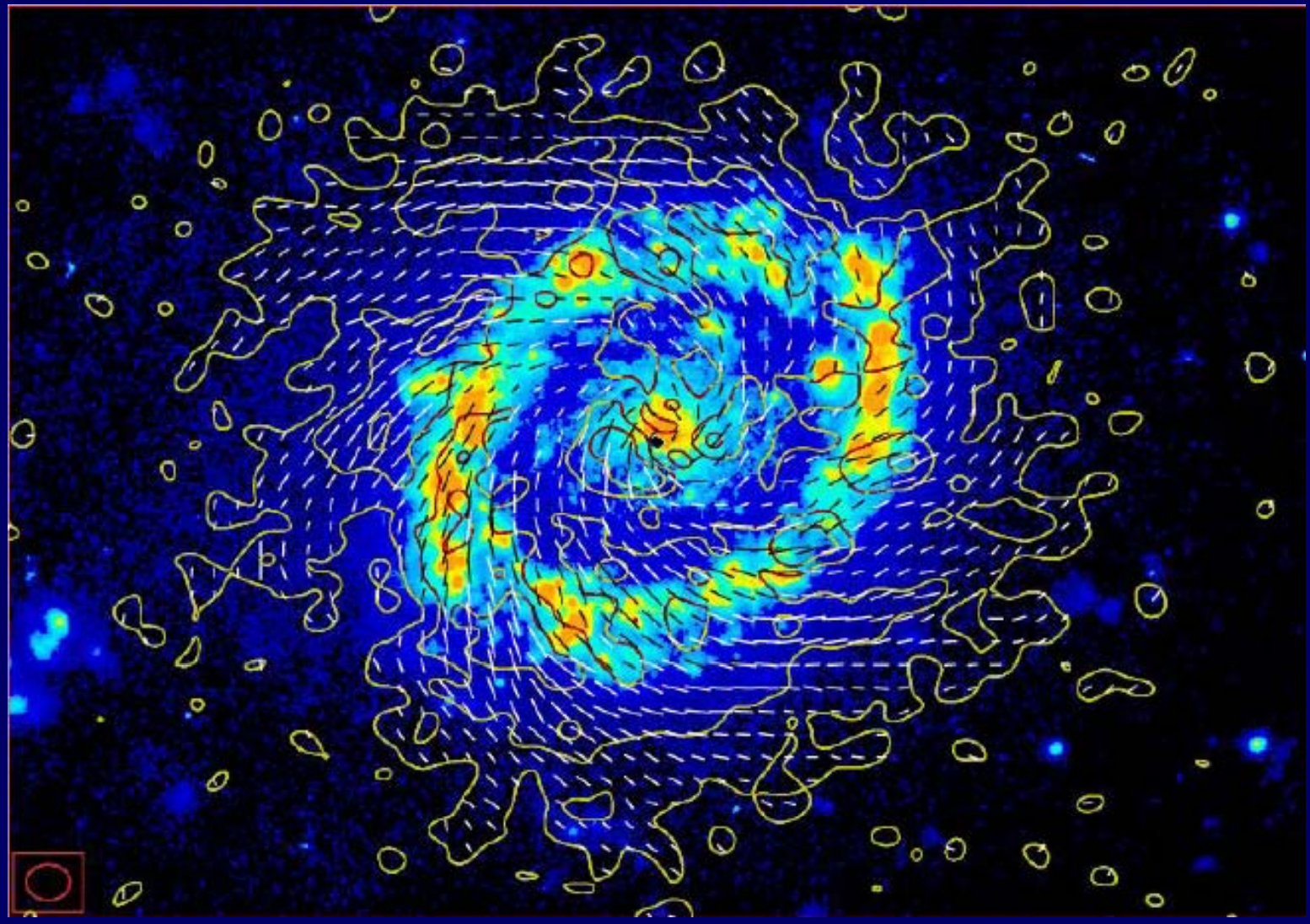


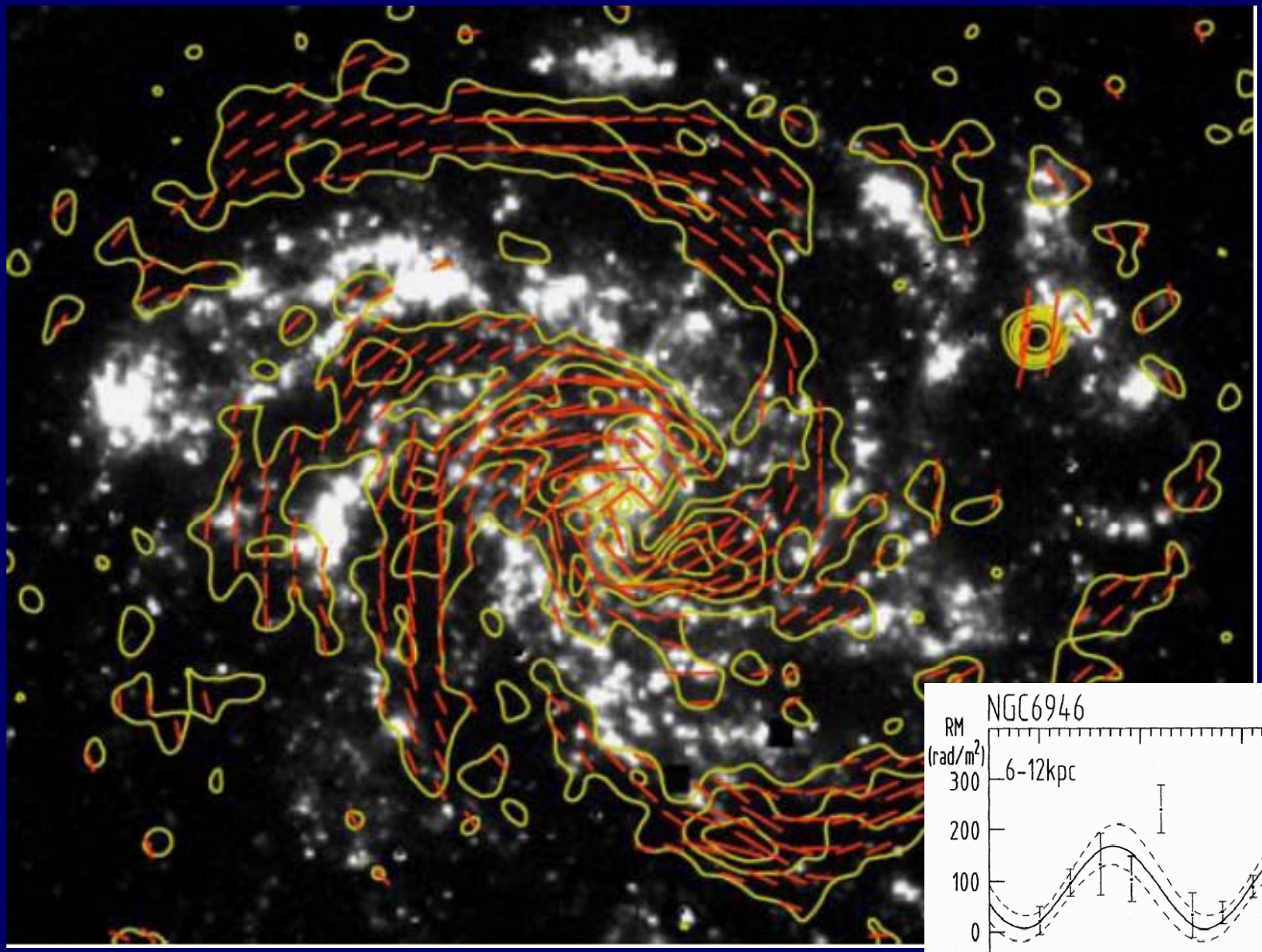


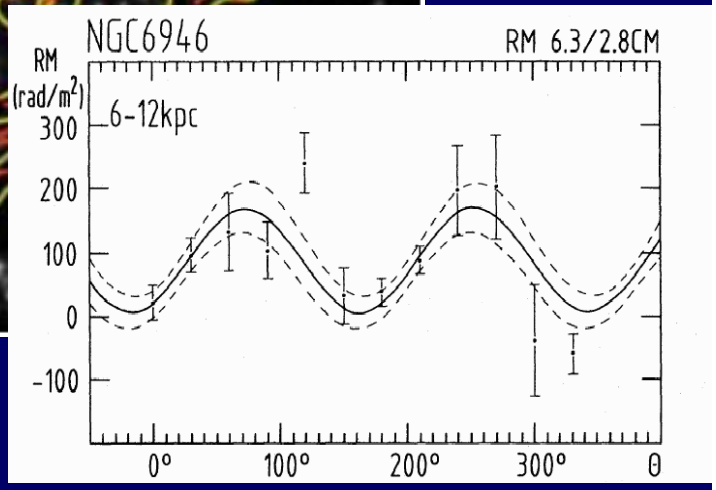
M51 Radio 6cm I+B-Vector (Fletcher et al. 2010)



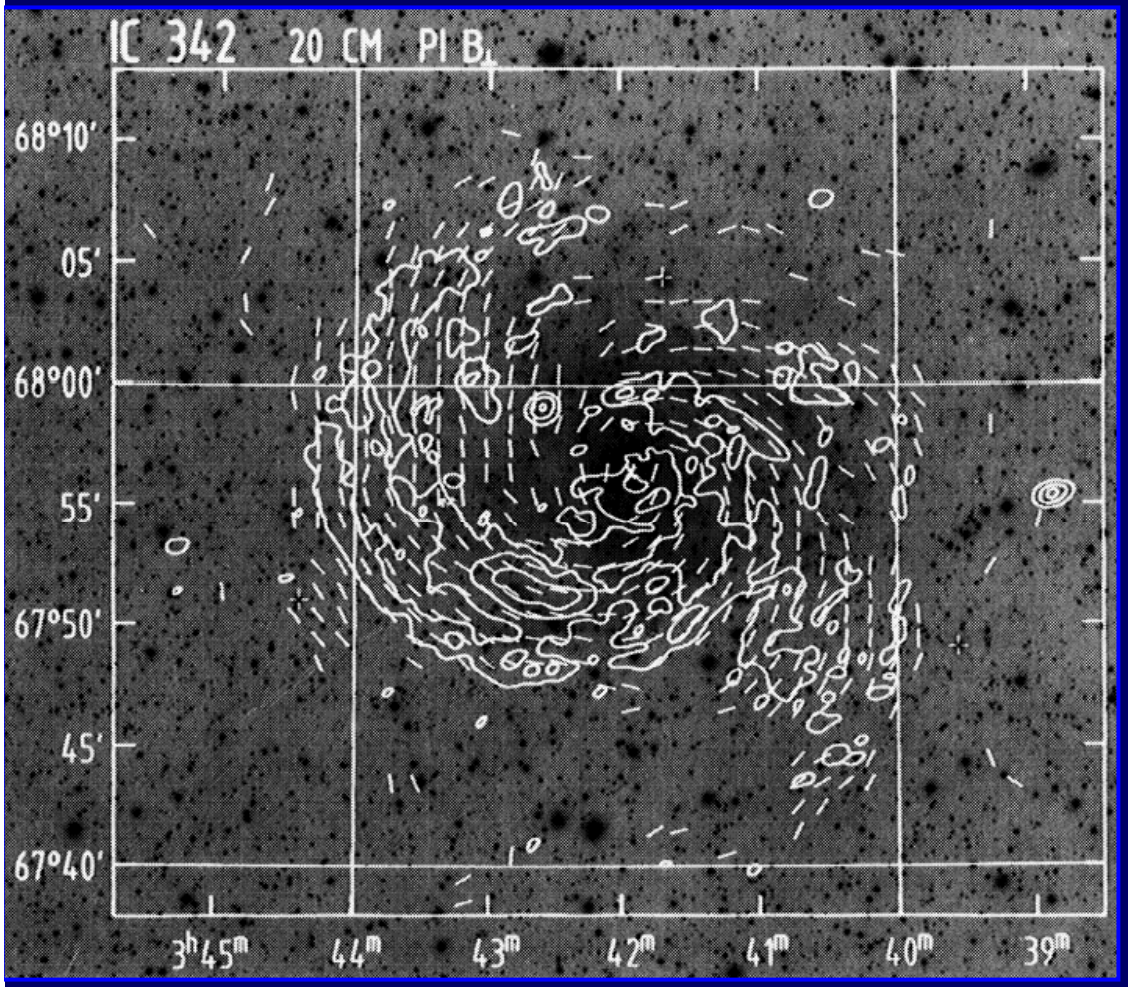
NGC4736 3.6cm B + Halpha (Chyzy and Buta 2008)

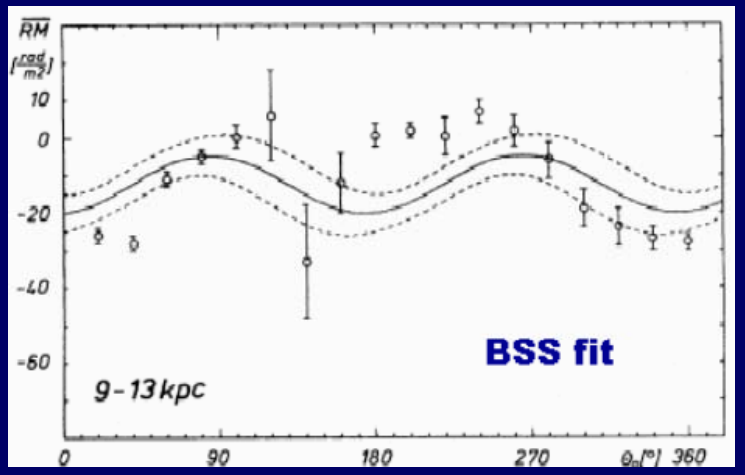


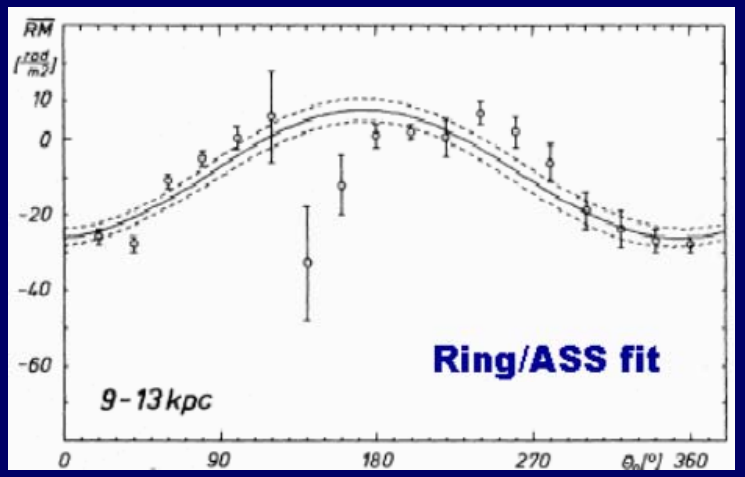



NGC6946
RM 6.3/2.8CM
RM
(rad/m²)
6-12kpc
300
200
100
0
-100
0°
100°
200°
300°
0

IC 342 20cm (Krause et al. 1989)

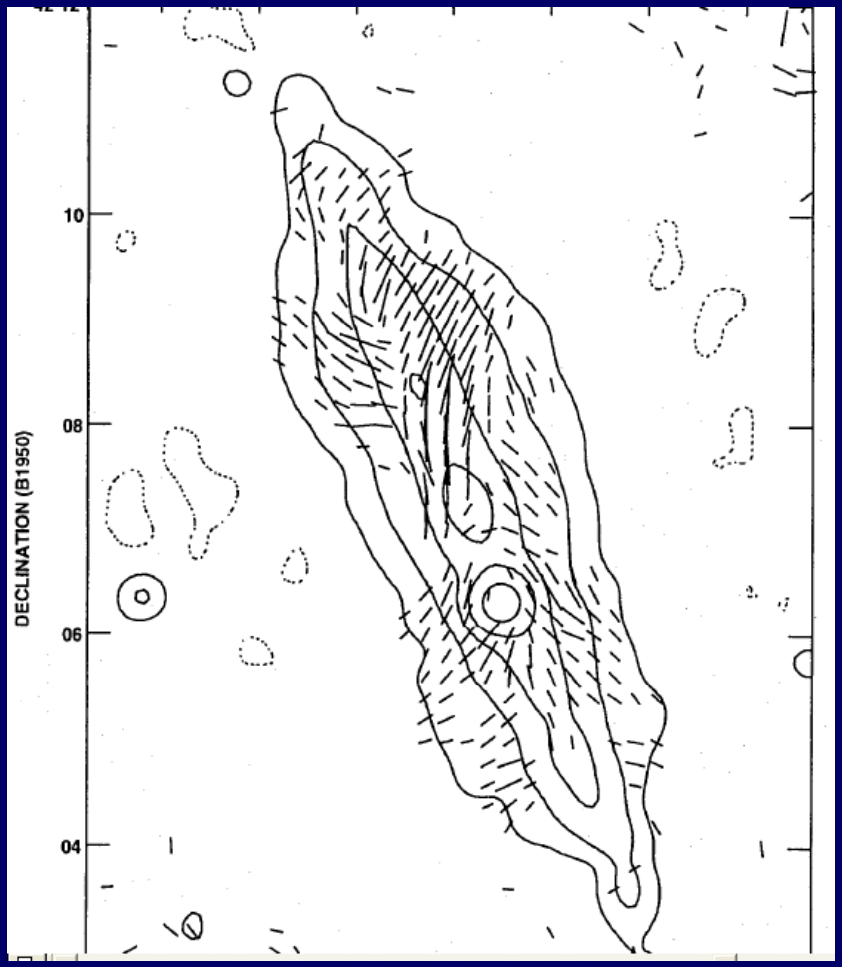


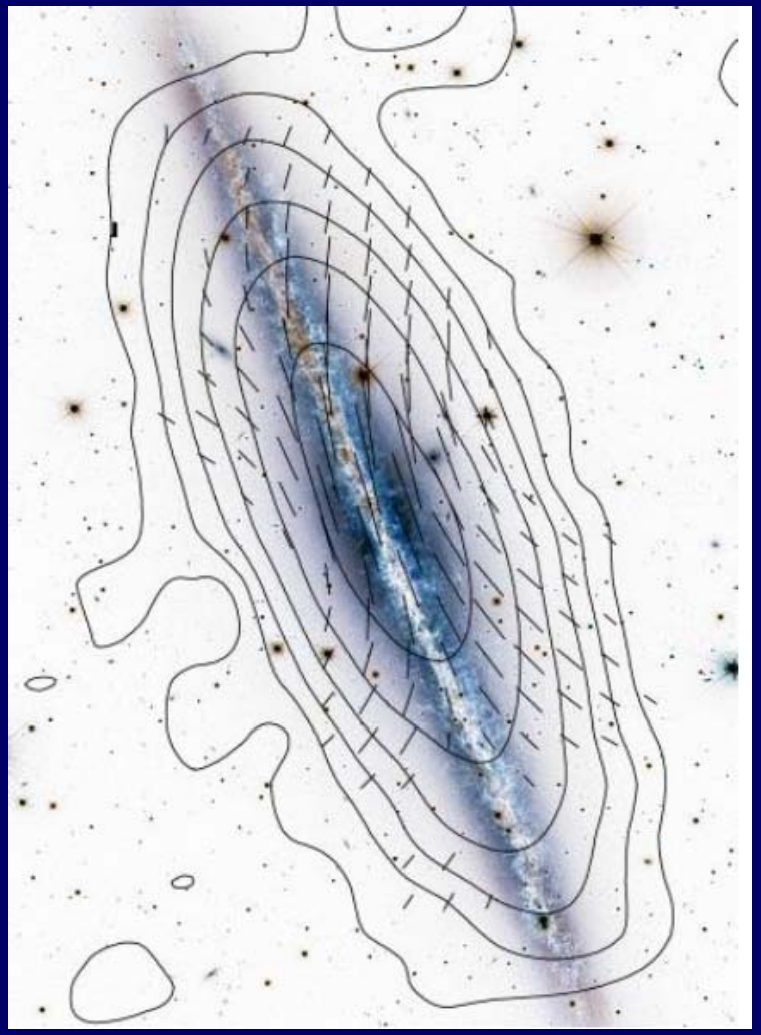




B in Halos of NGC 891

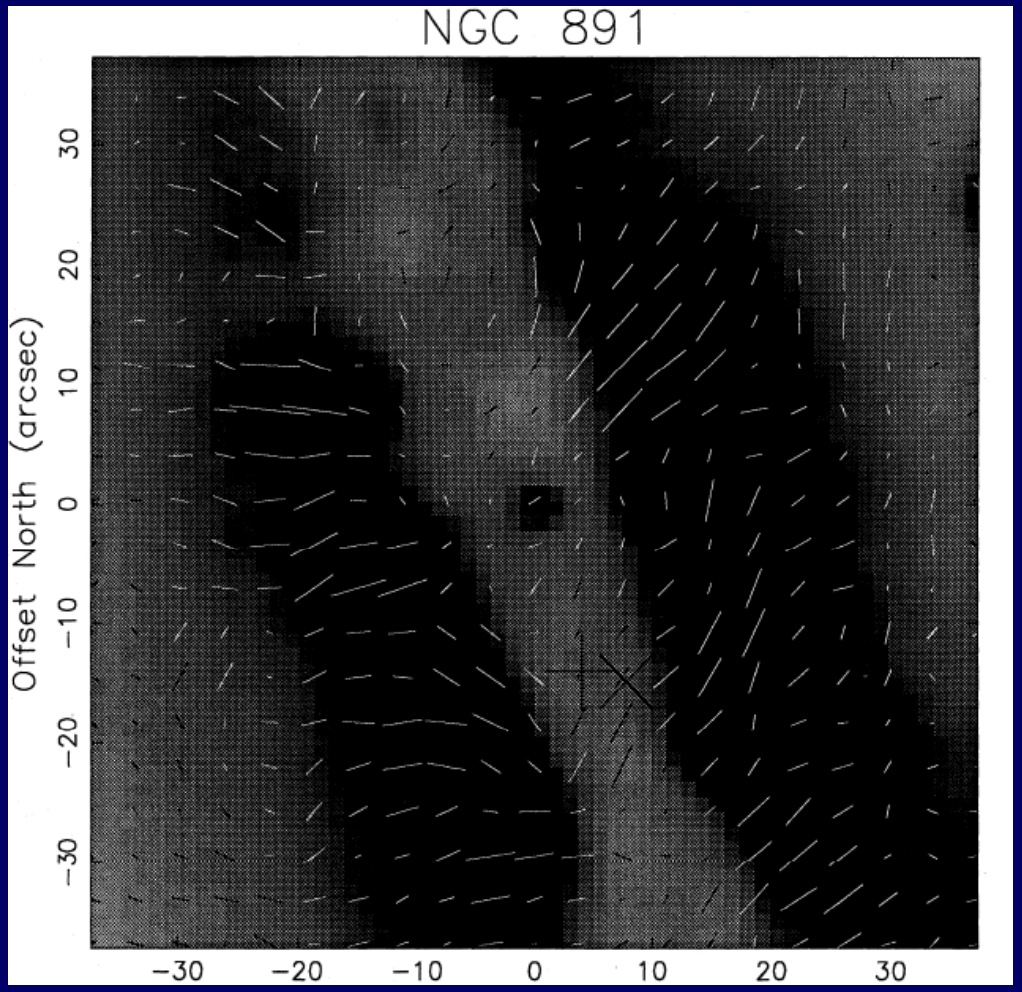
(Radio Sukumar & Allen 1991, Krause 2007)

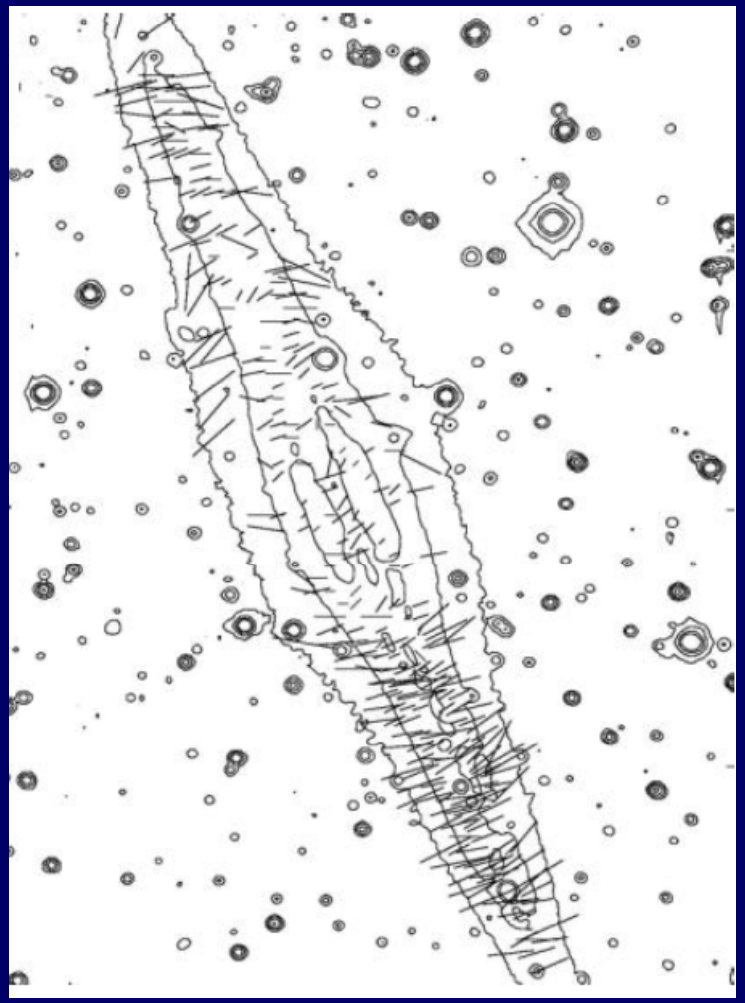




Vertical B (optical) in NGC 891

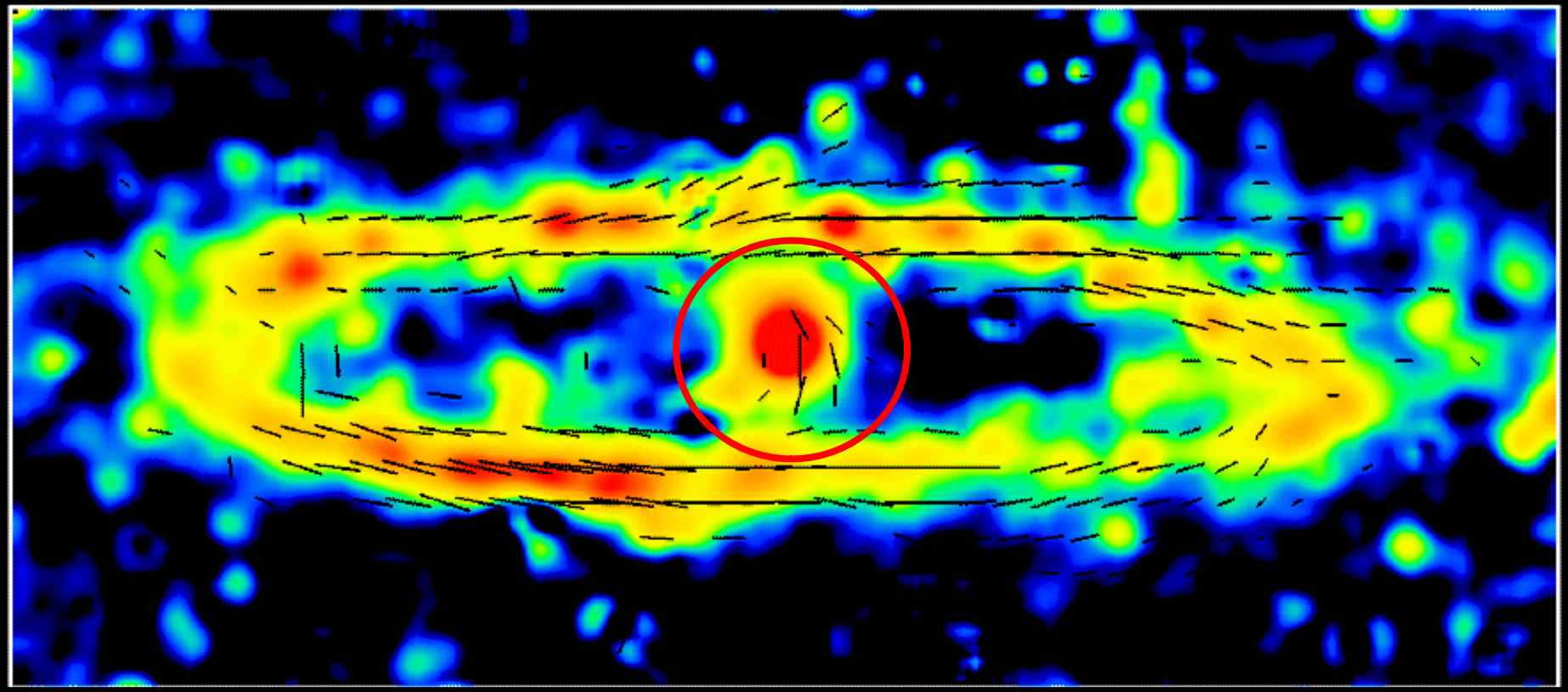
(Scarrot, Draper 1996; Fendt 1996)

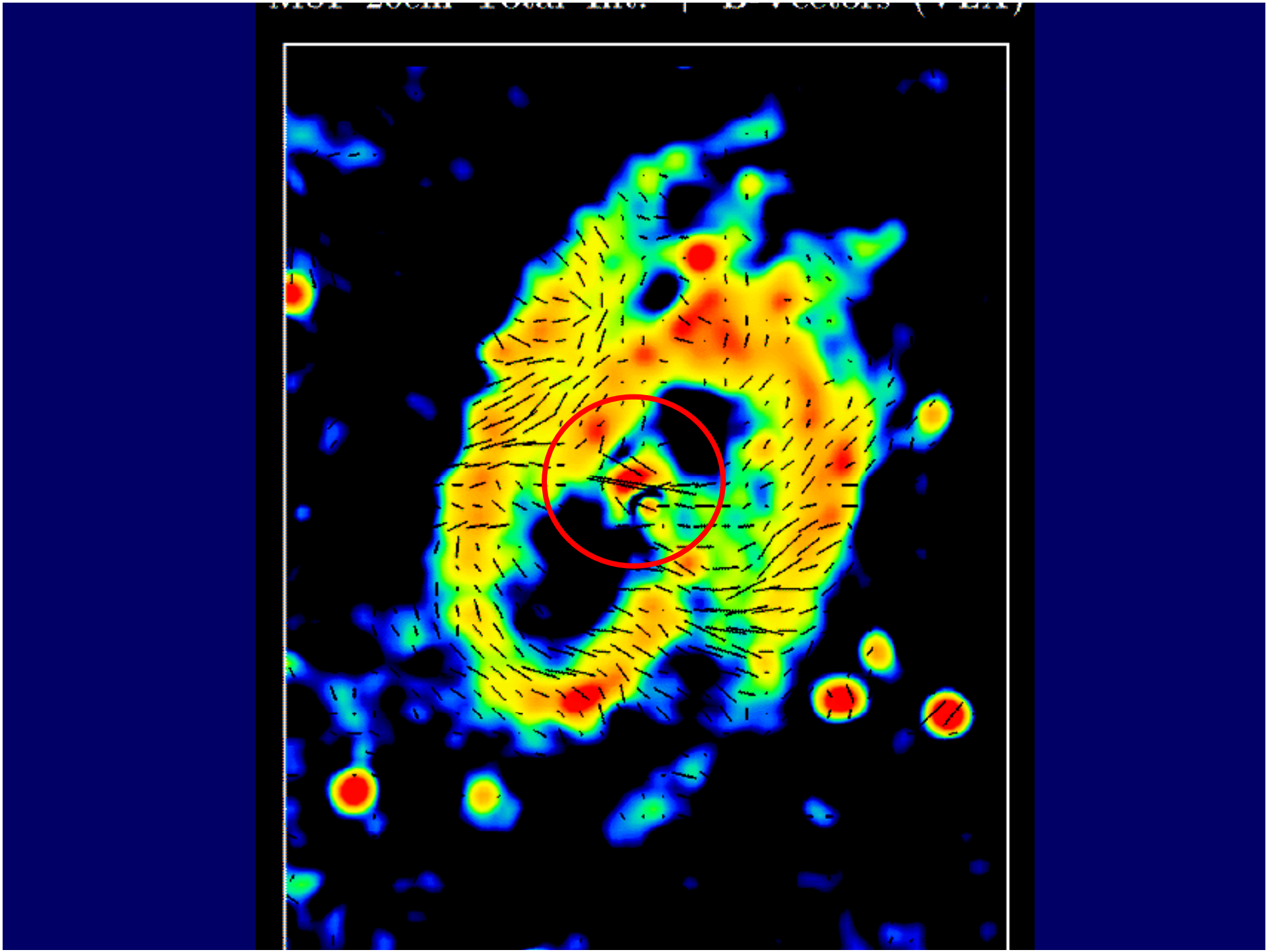




3. 銀河中心垂直磁場

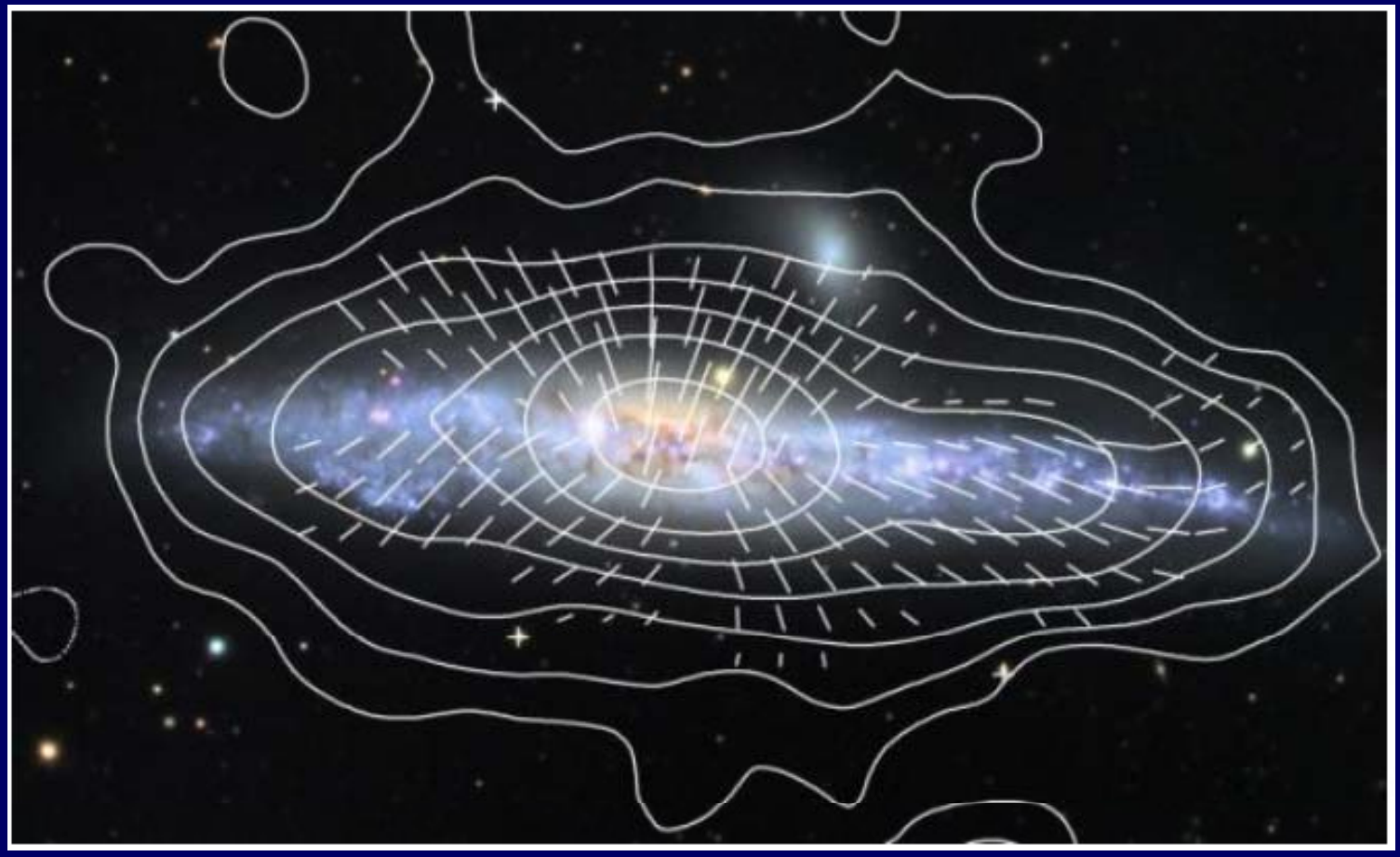
M31 6cm Total Intensity + Magnetic Field (Effelsberg)





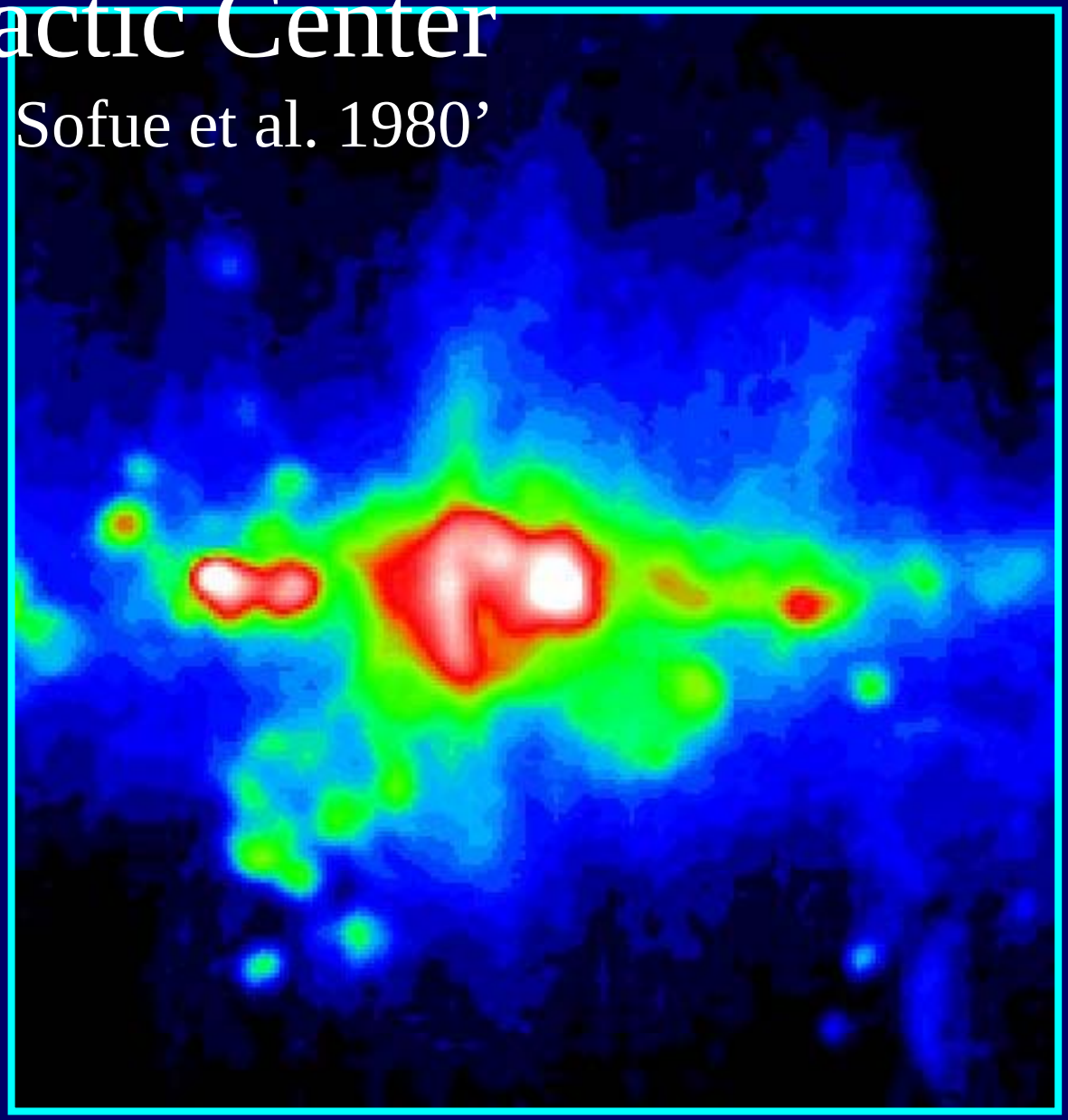
Vertical B in Halo & GC NGC4631

(Krause et al 2009)

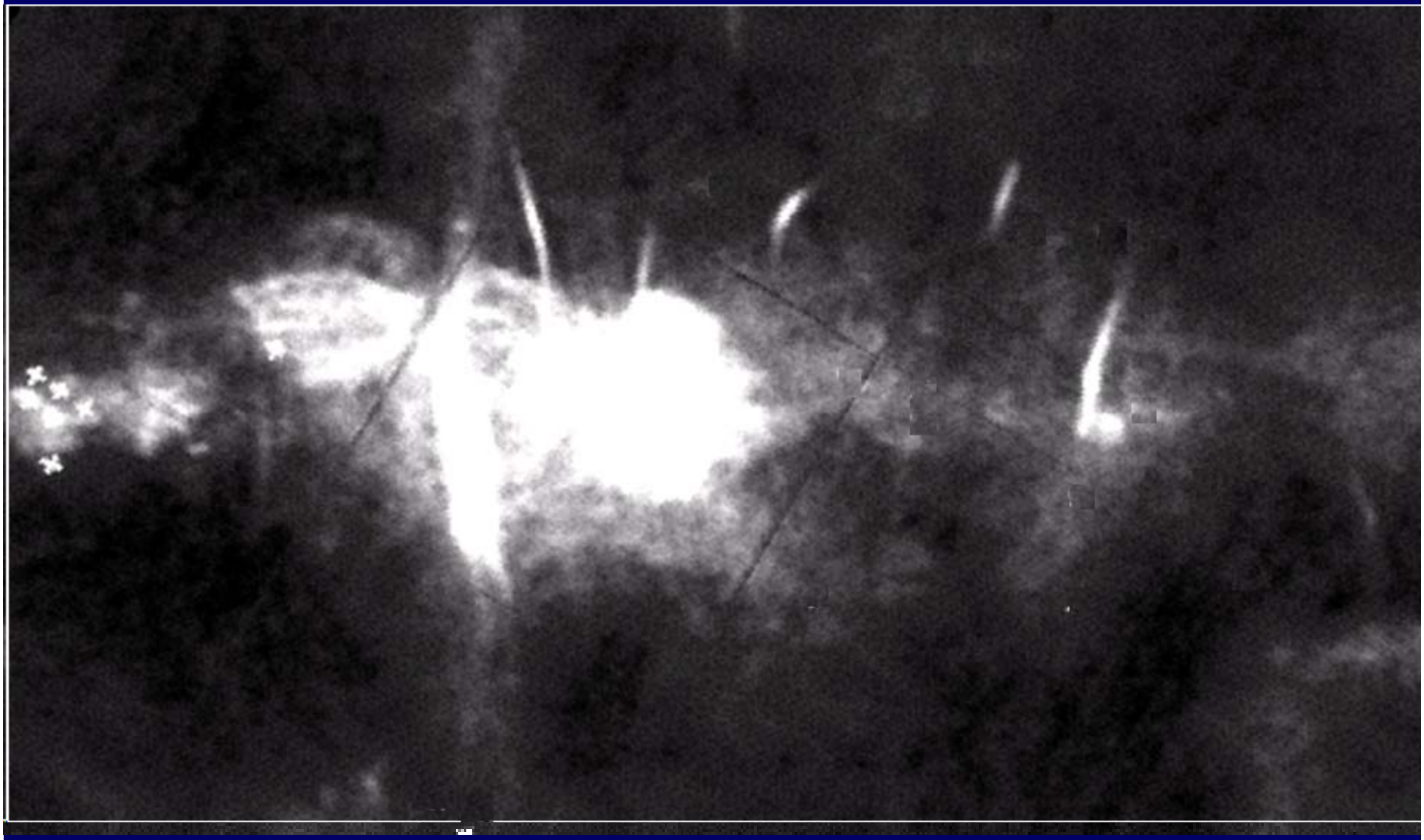


The Galactic Center

NRO 10GHz Sofue et al. 1980’

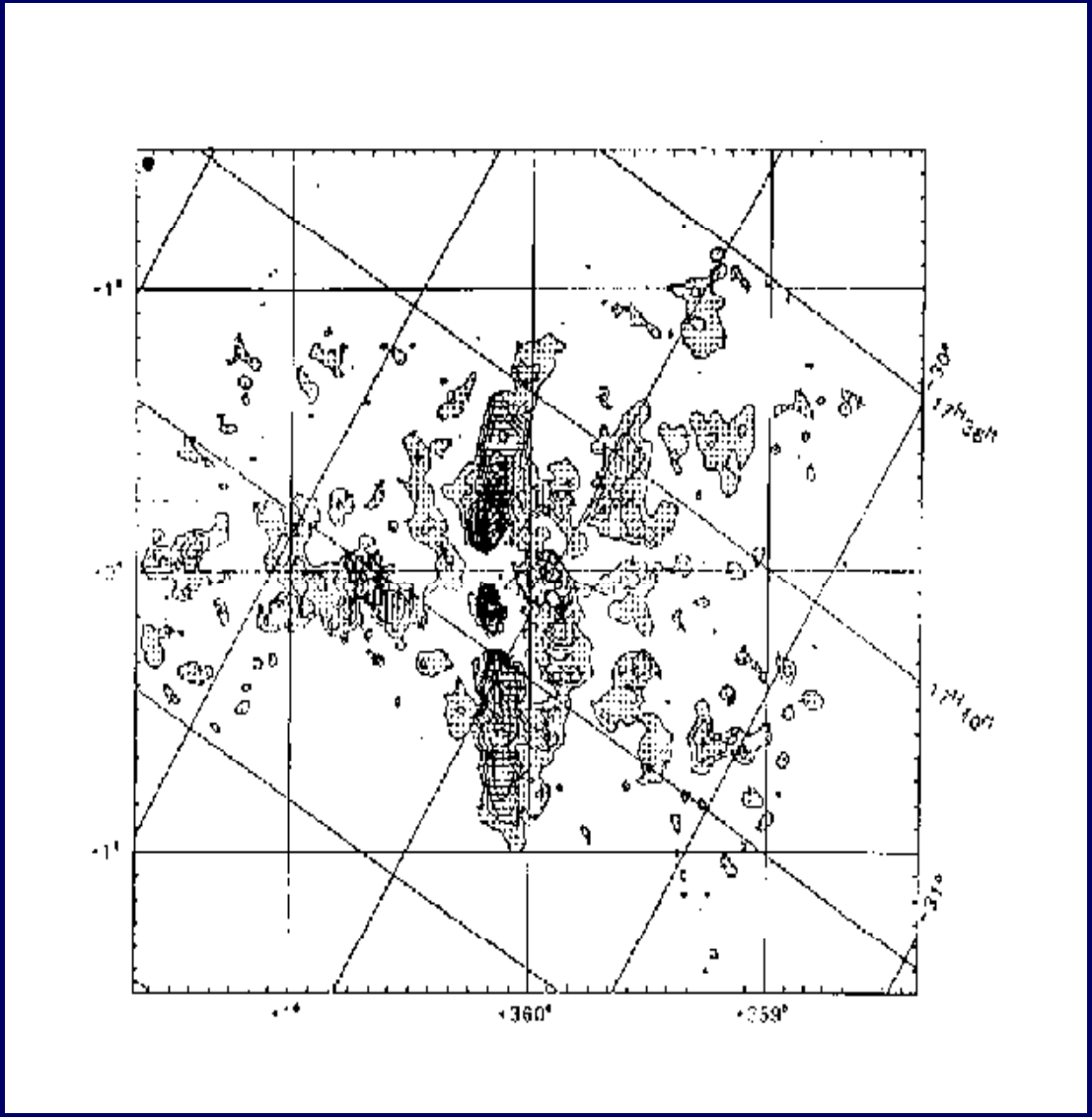


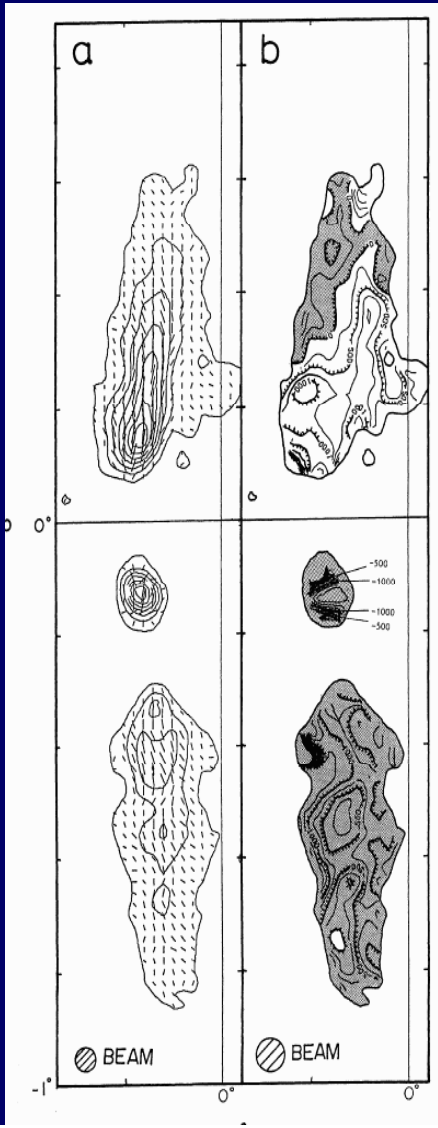
- 90cm laRosa et al. 2000)

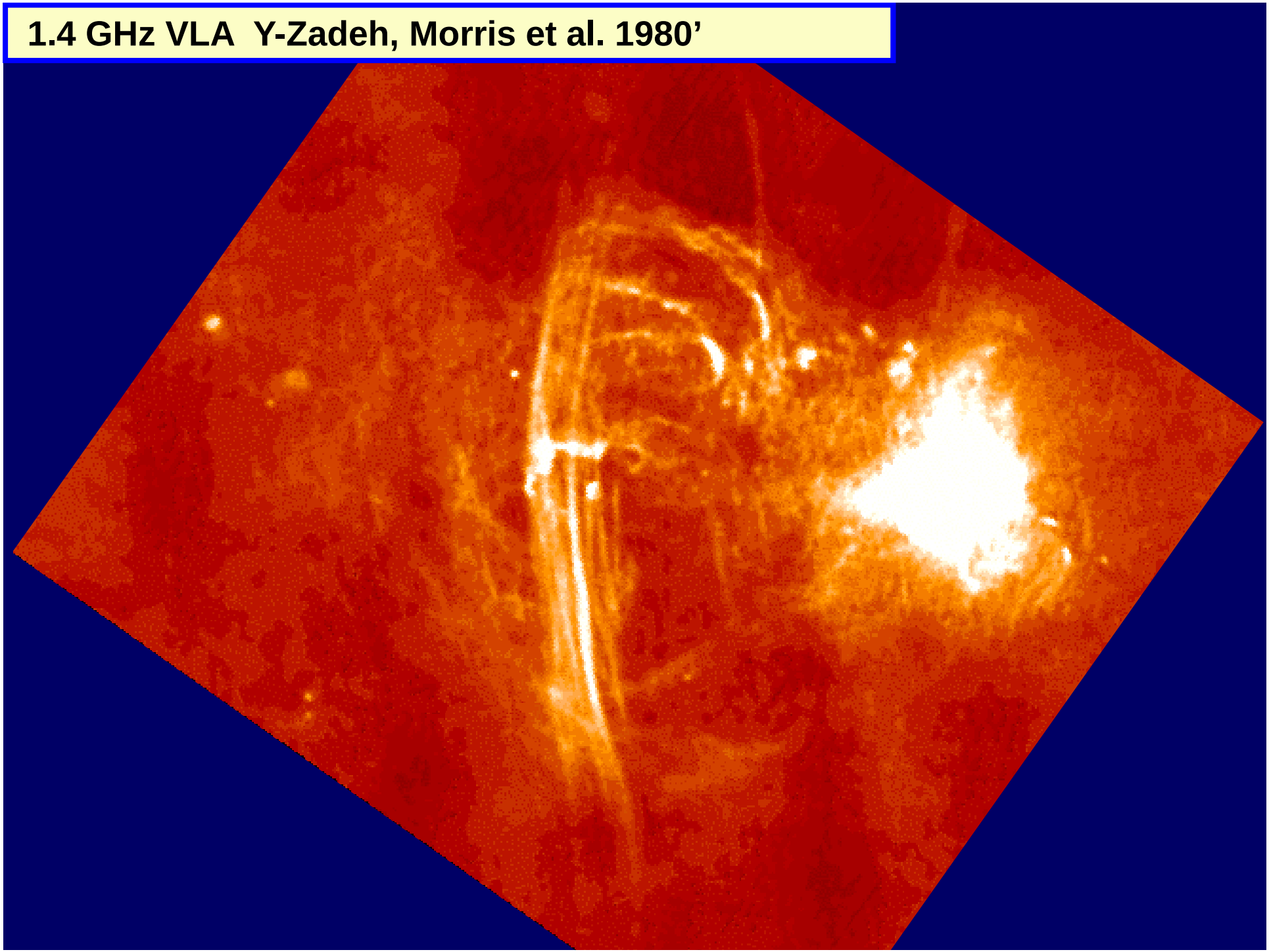


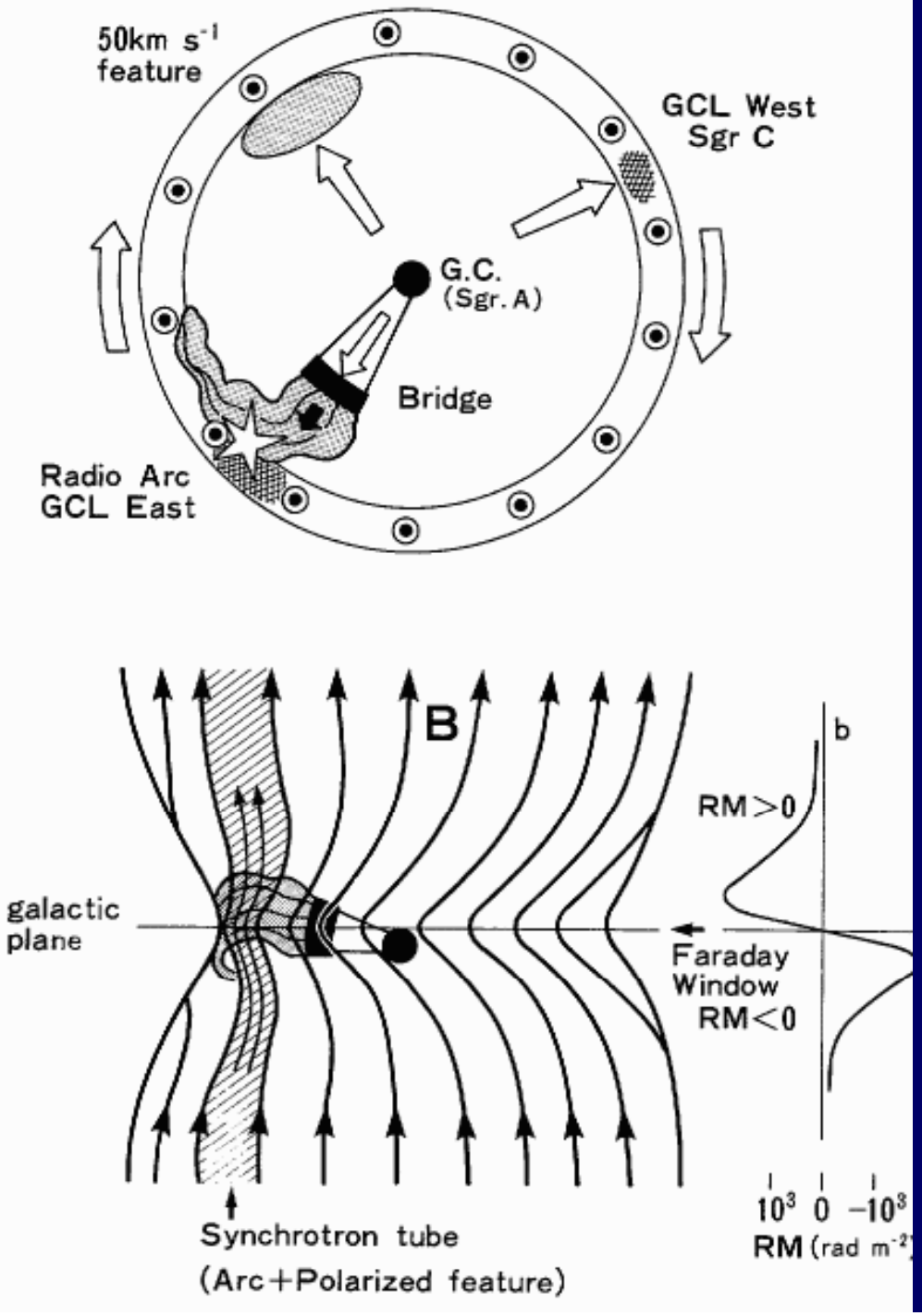
The Galactic Center

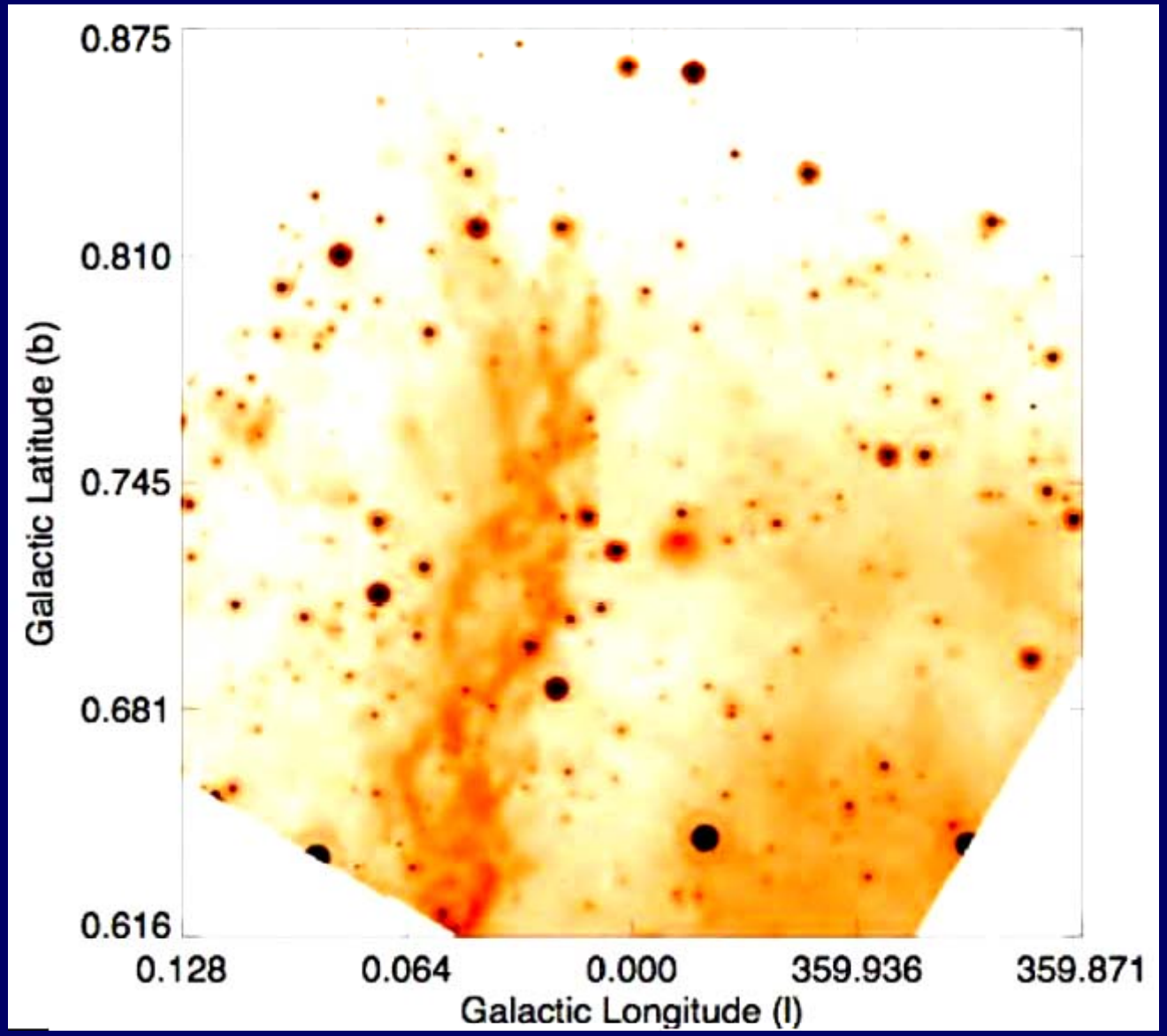
(Tsuboi et al. 1980's Sofue et al. 1980')



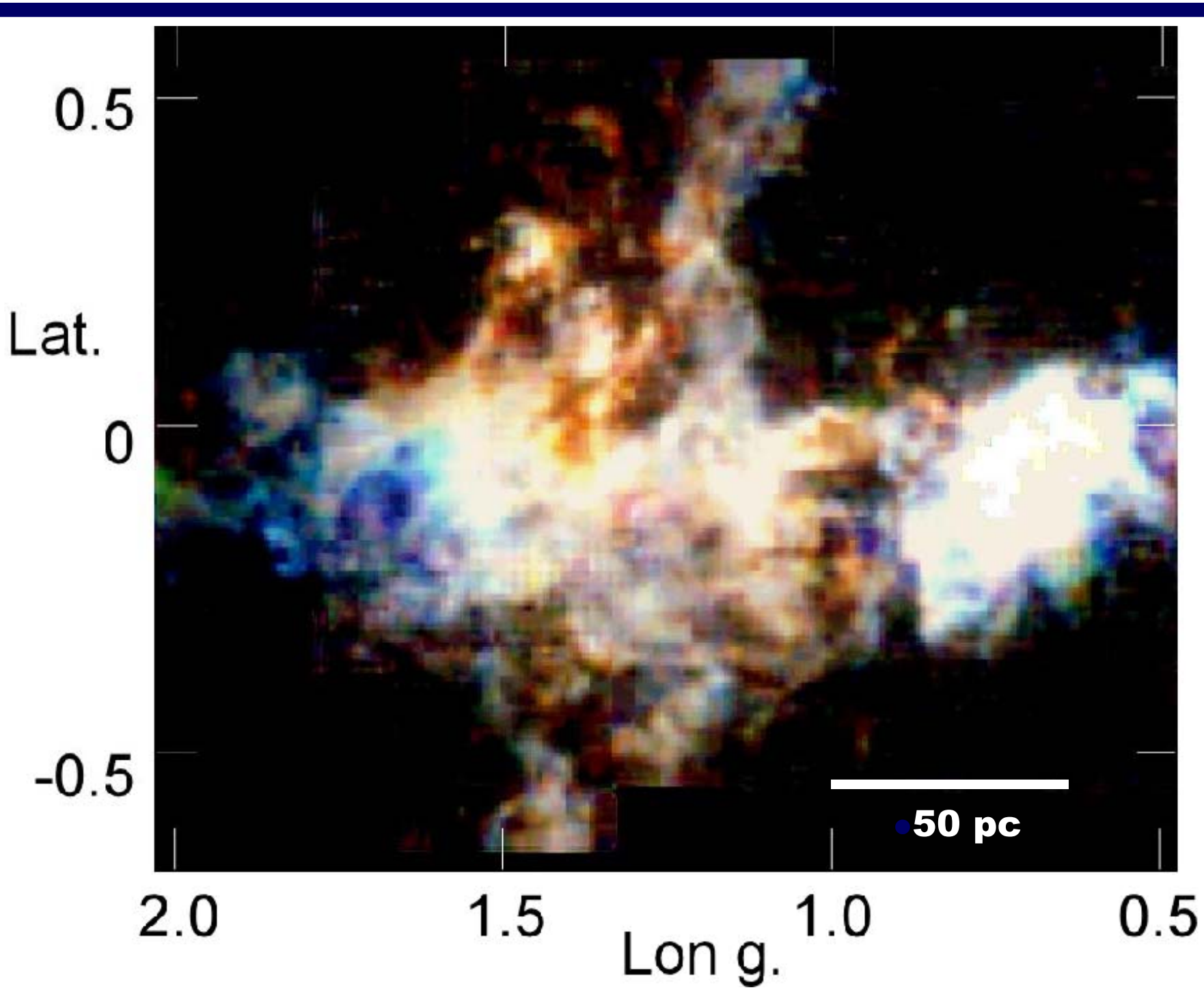



1.4 GHz VLA Y-Zadeh, Morris et al. 1980’


50km s^{-1}
feature
GCL West
Sgr C
G.C.
(Sgr. A)
Bridge
Radio Arc
GCL East
B
b
RM>0
galactic
plane
Faraday
Window
RM<0
10^3 0 -10^3
RM (rad m^{-2})
Synchrotron tube
(Arc+Polarized feature)

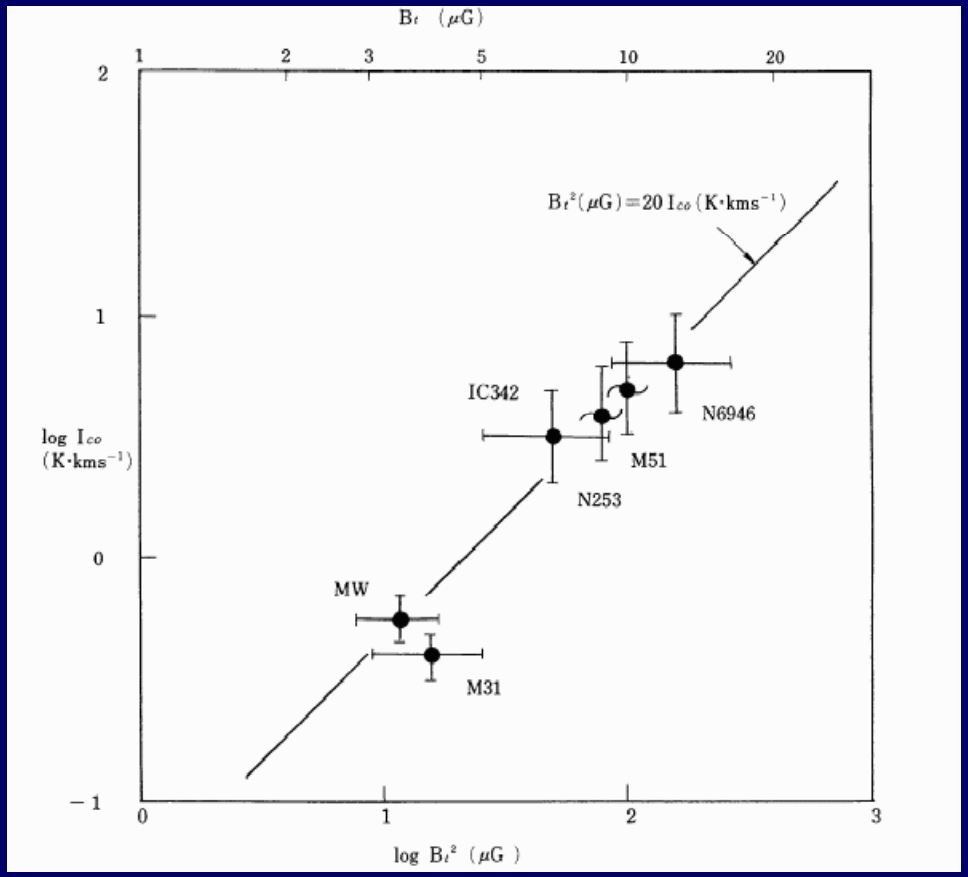


Morris et al. 2005

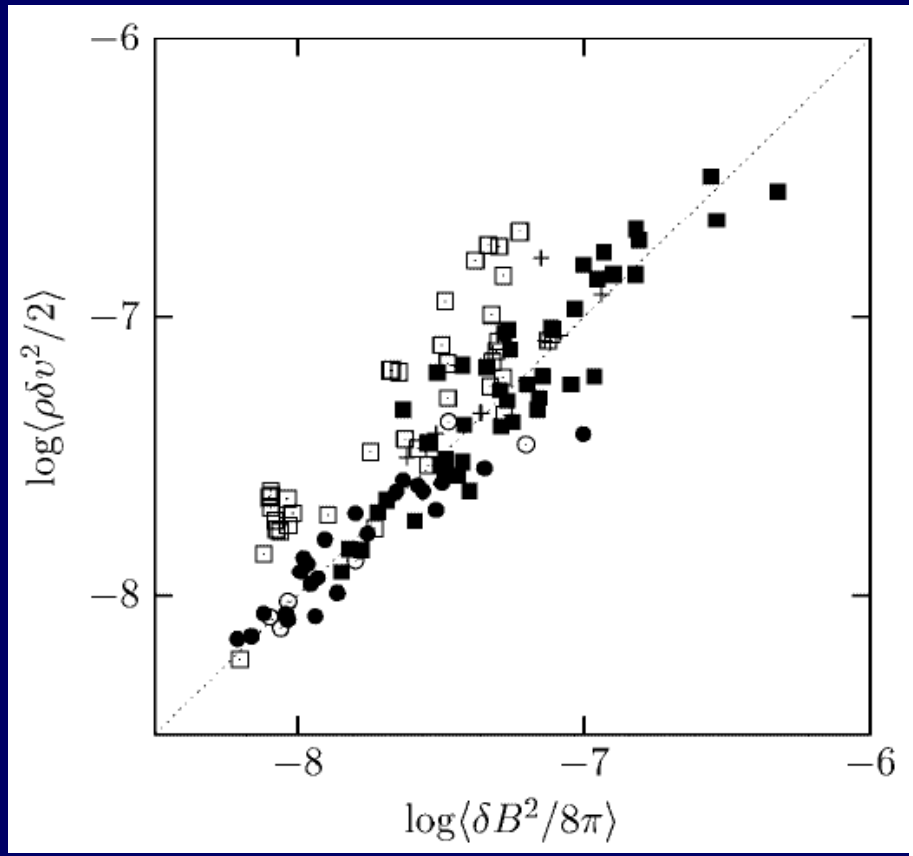

0.5
Lat.
0
-0.5
50 pc
2.0
1.5
1.0
0.5
Lon g.

4. 磁場の起源
ダイナモ or
宇宙磁場起源

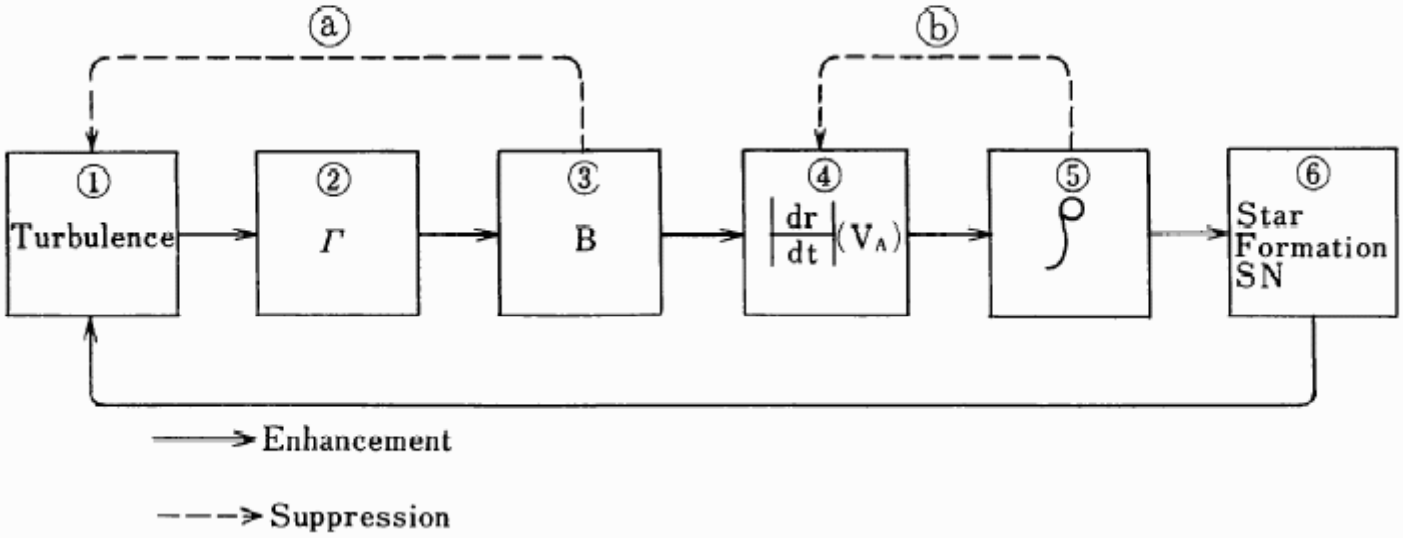
B^2 vs Gas



Sofue+ 1986



Sano, Inutsua+2004



Cyclic process in a disk galaxy controlled by a BSS field. (*a*) Increase in B suppresses turbulence. (*b*) Increase in ρ leads to a decrease in V_A, the local Alfvén velocity.

Bisymmetric B configuration by local theory

(Sawa Fujimoto 1986)

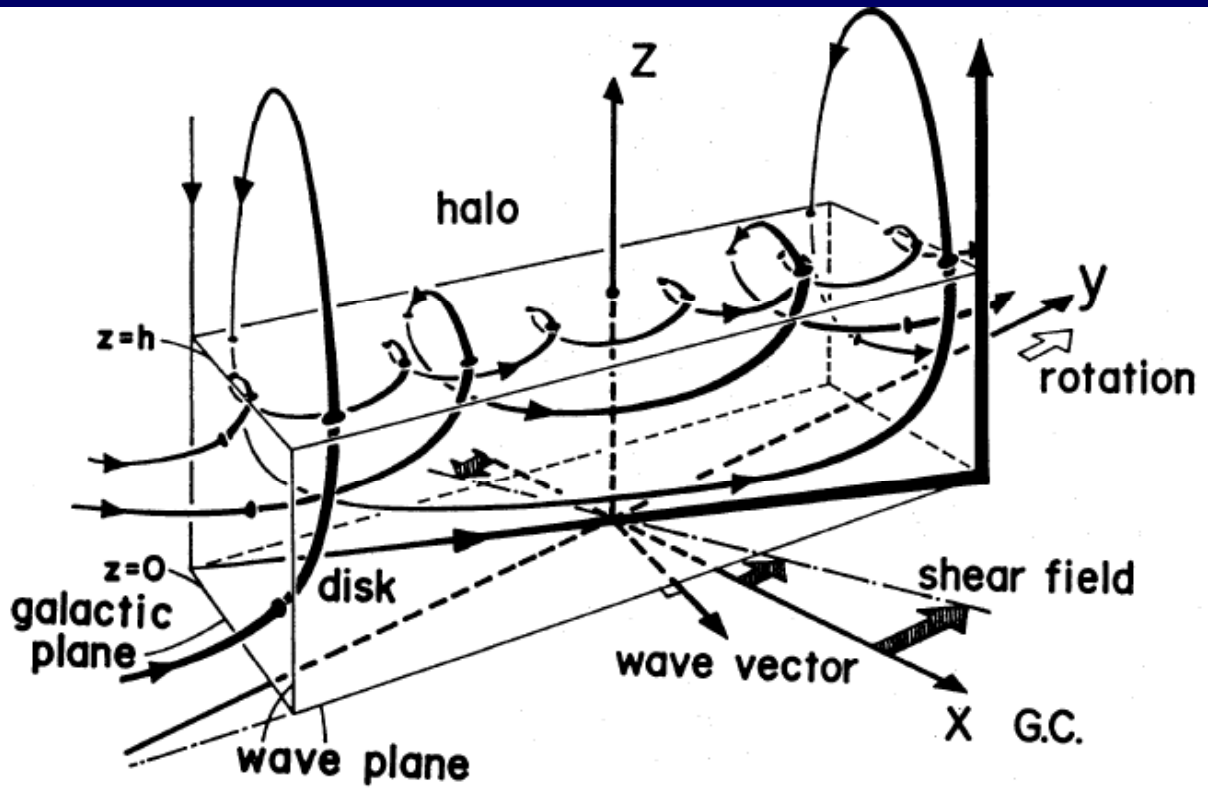
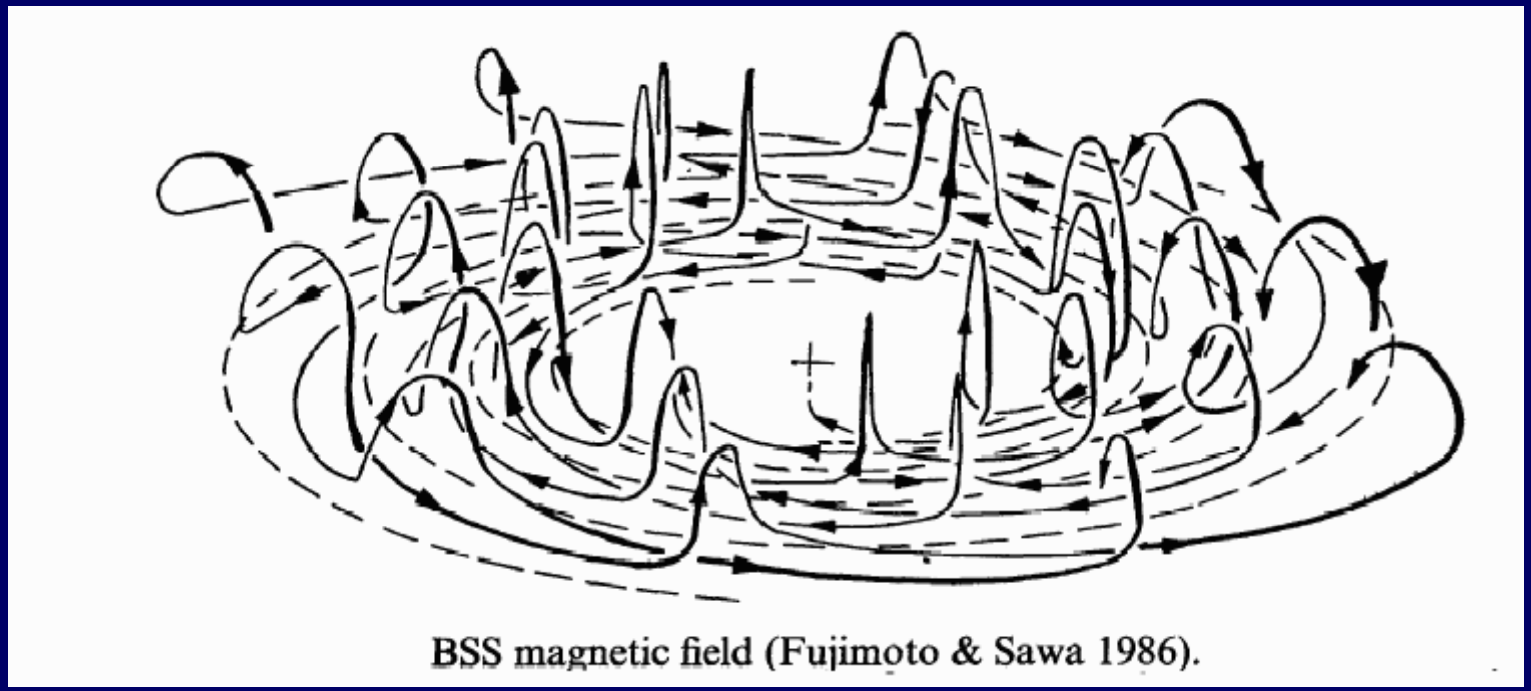
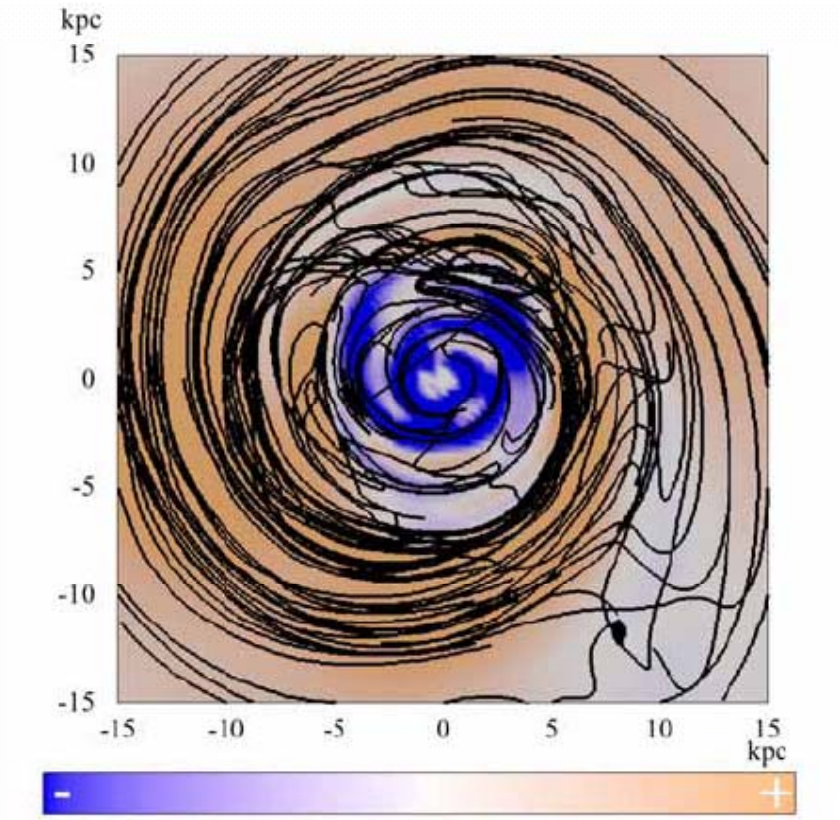


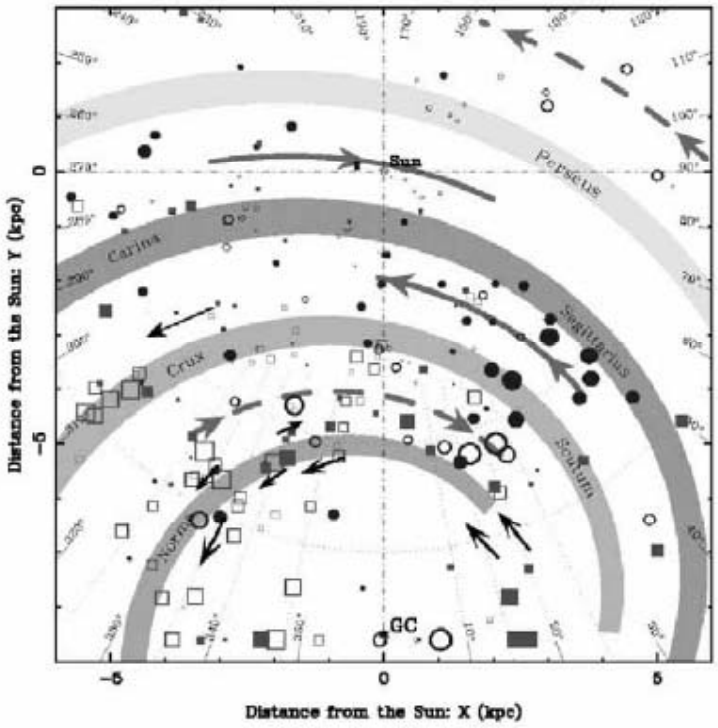
Fig. 4. A bird's-eye view of the magnetic field configuration for the first mode in the trailing sense in panel (a) of figures 2 and 3.



BSS magnetic field (Fujimoto & Sawa 1986).



Azimuthal field at t=3.8Gyr at z=0.25Kpc

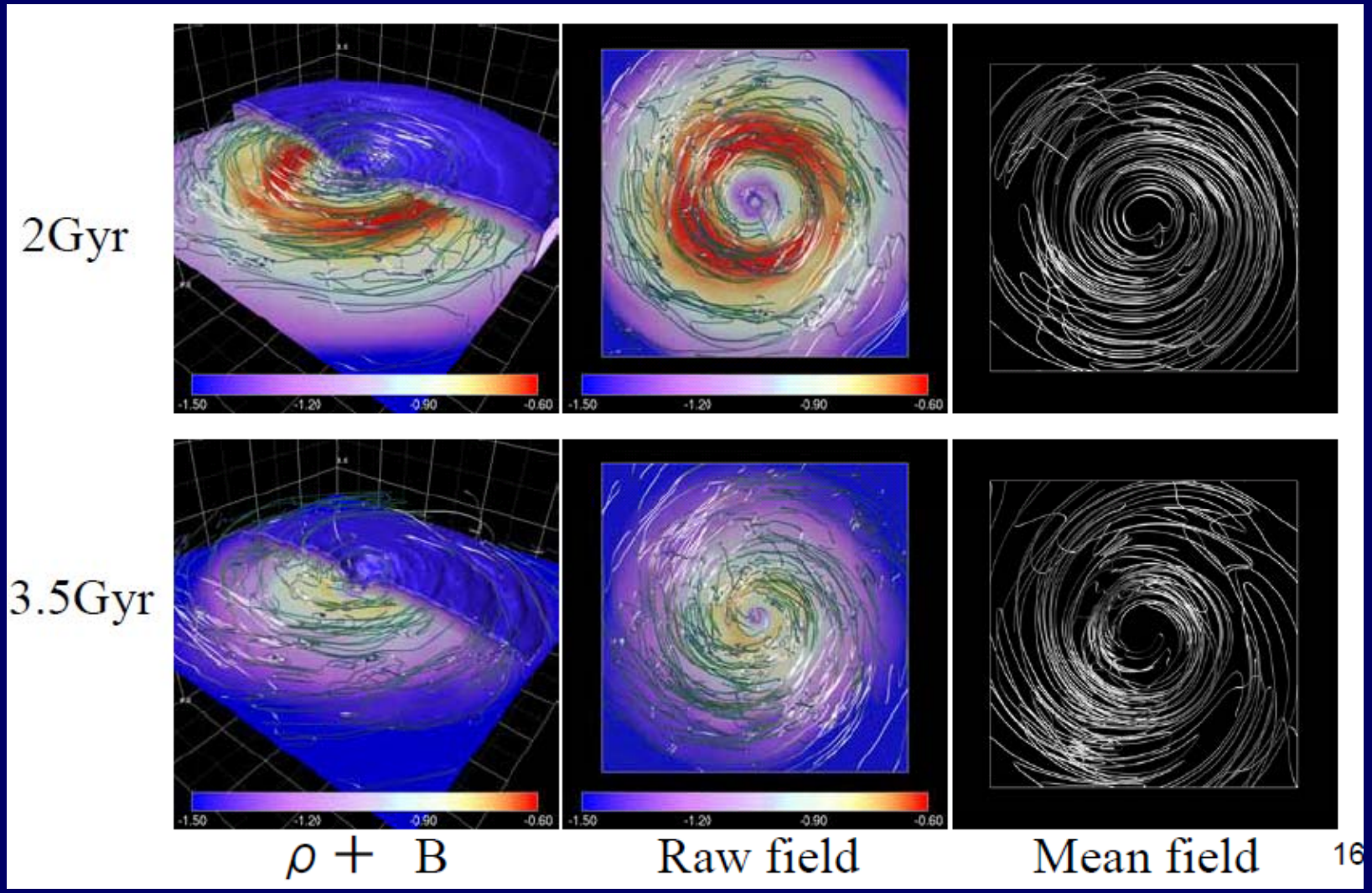


Galactic magnetic field obtained by Rotation Measure

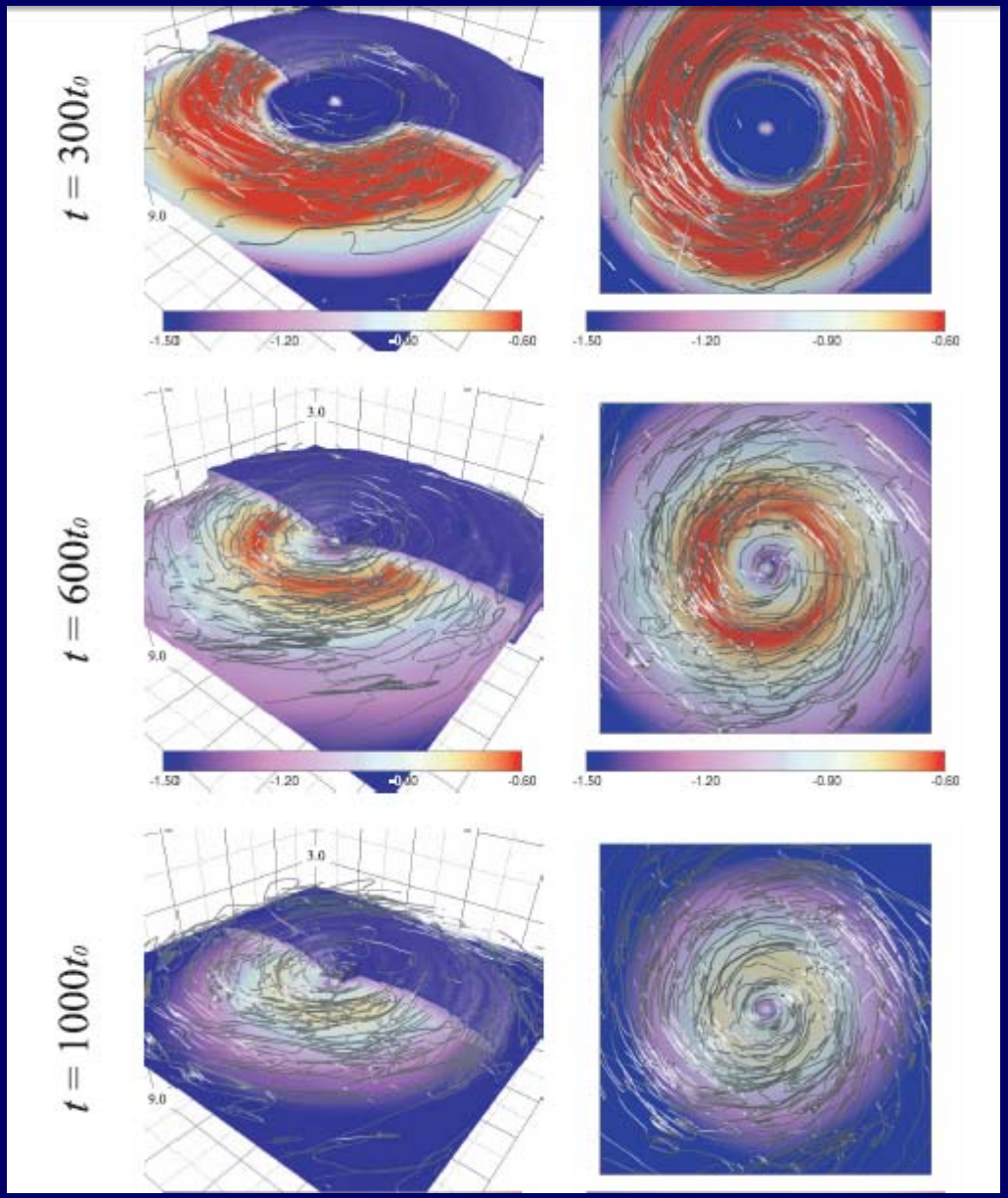
(Han et al. 2001)

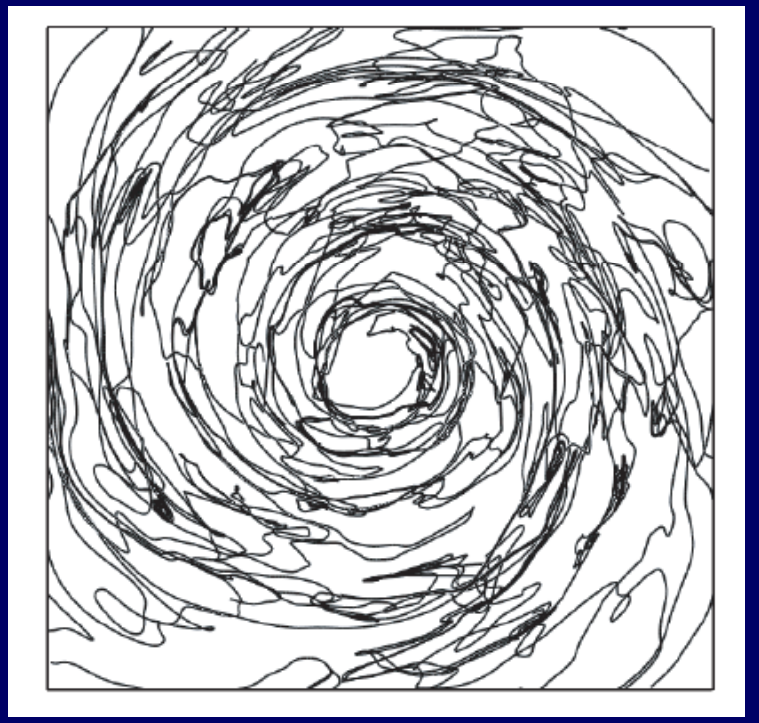
Matsumoto 2005

Matsumoto+2005
Ring B + Disk

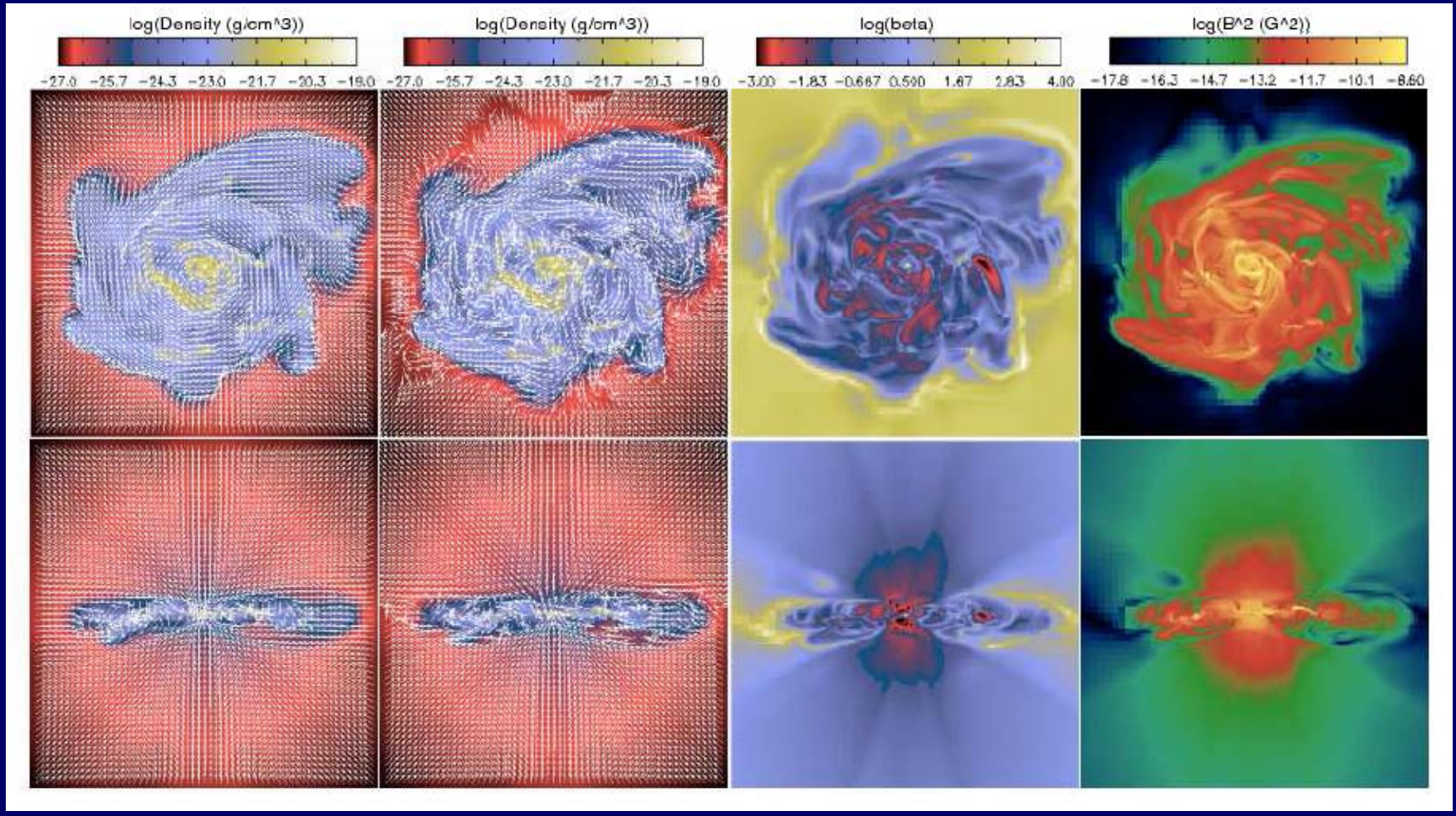


Nishikori, et al. 2006



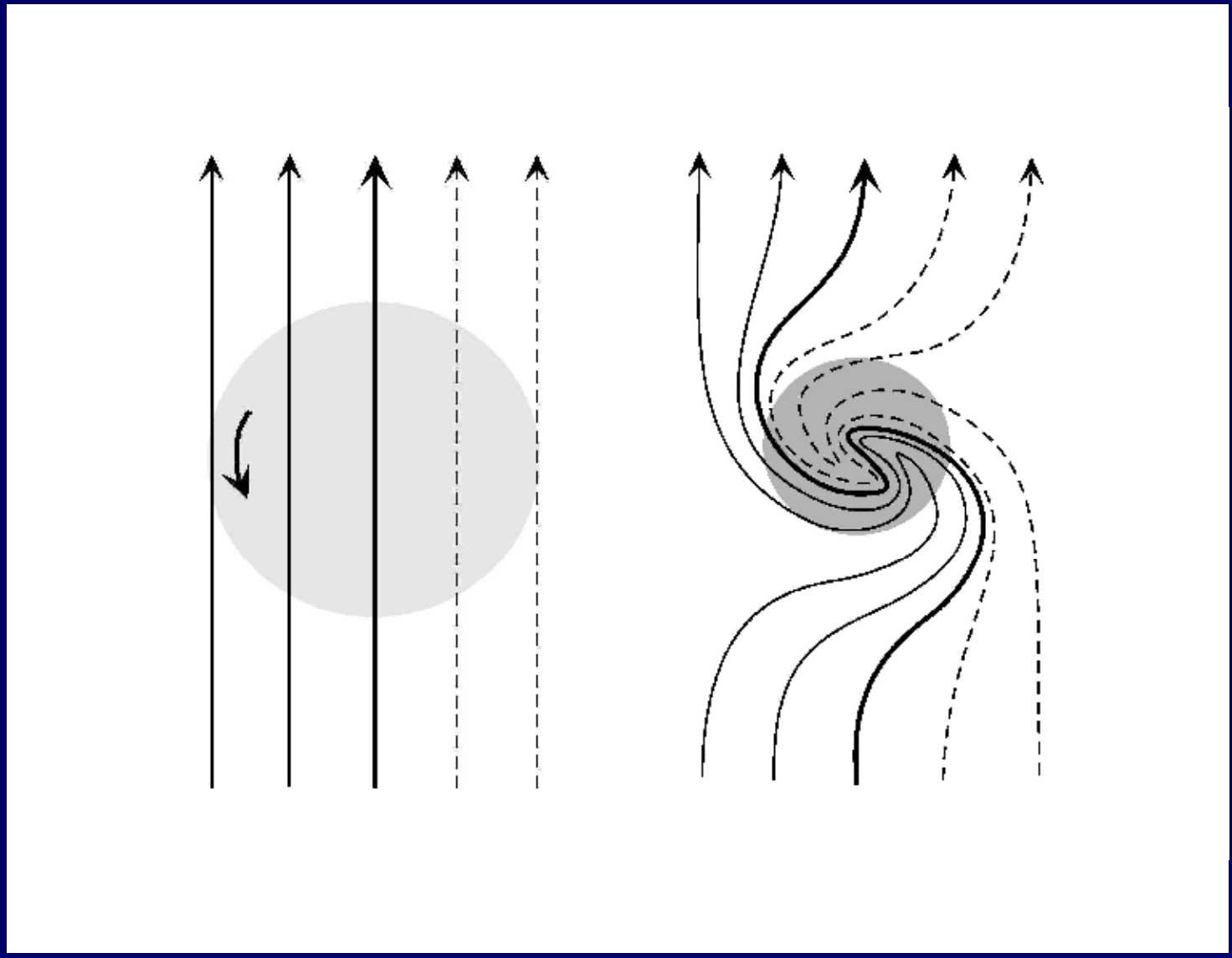


Wang&Abel 2009
1nG Uniform B Galaxy formation

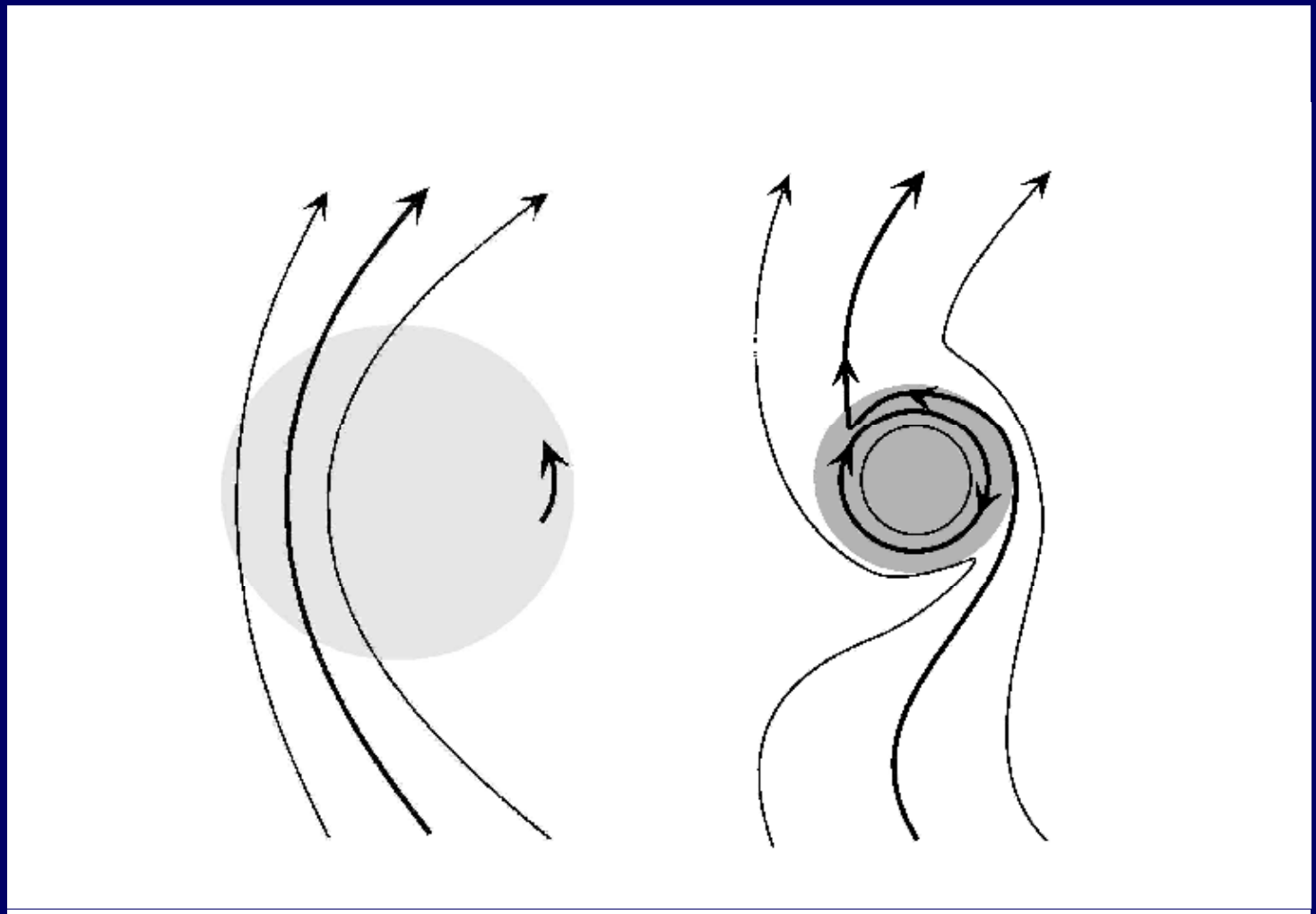


Origin of BSS etc.

Cosmological Origin of BSS

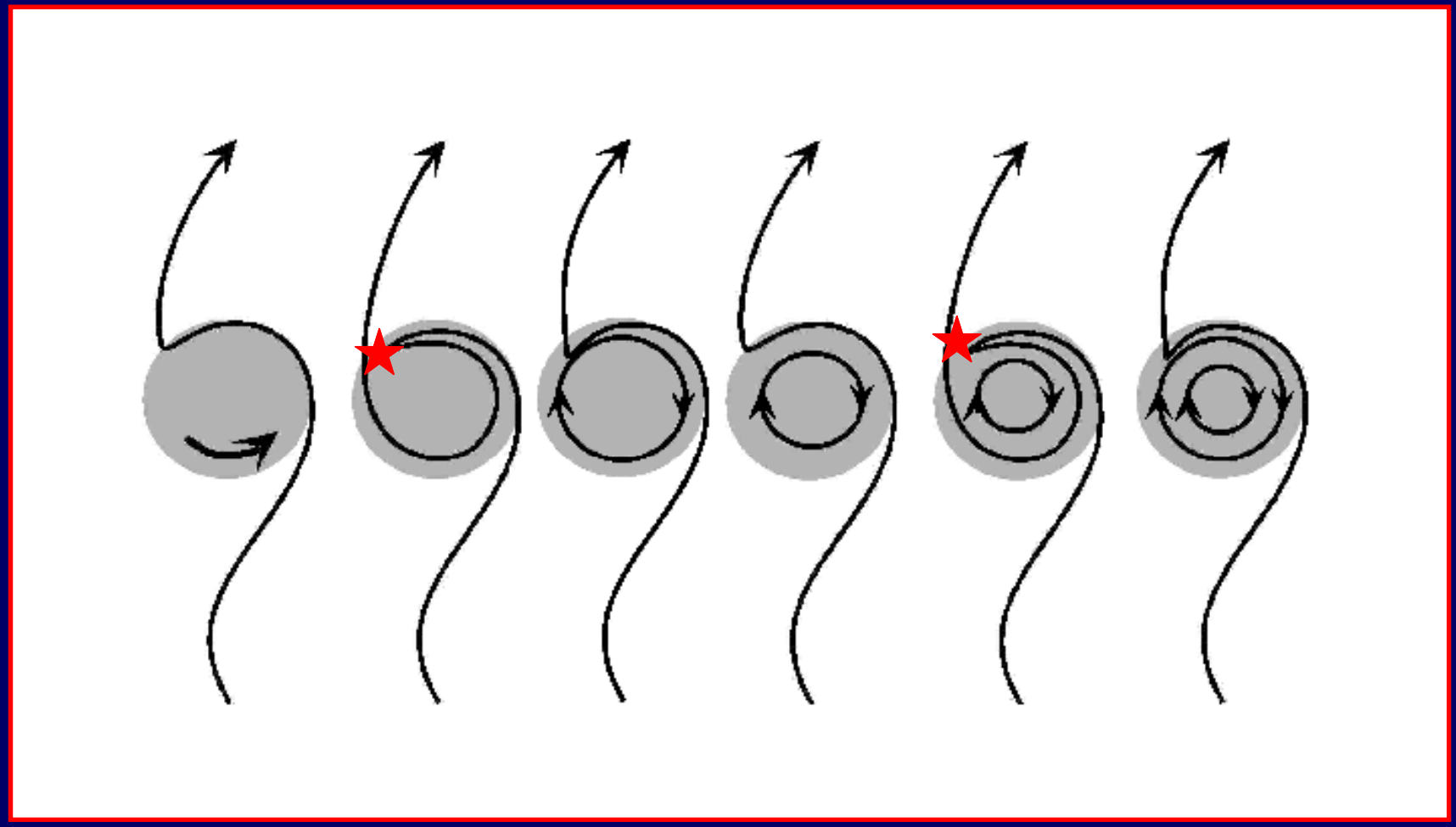


Cosmological Origin of Ring B

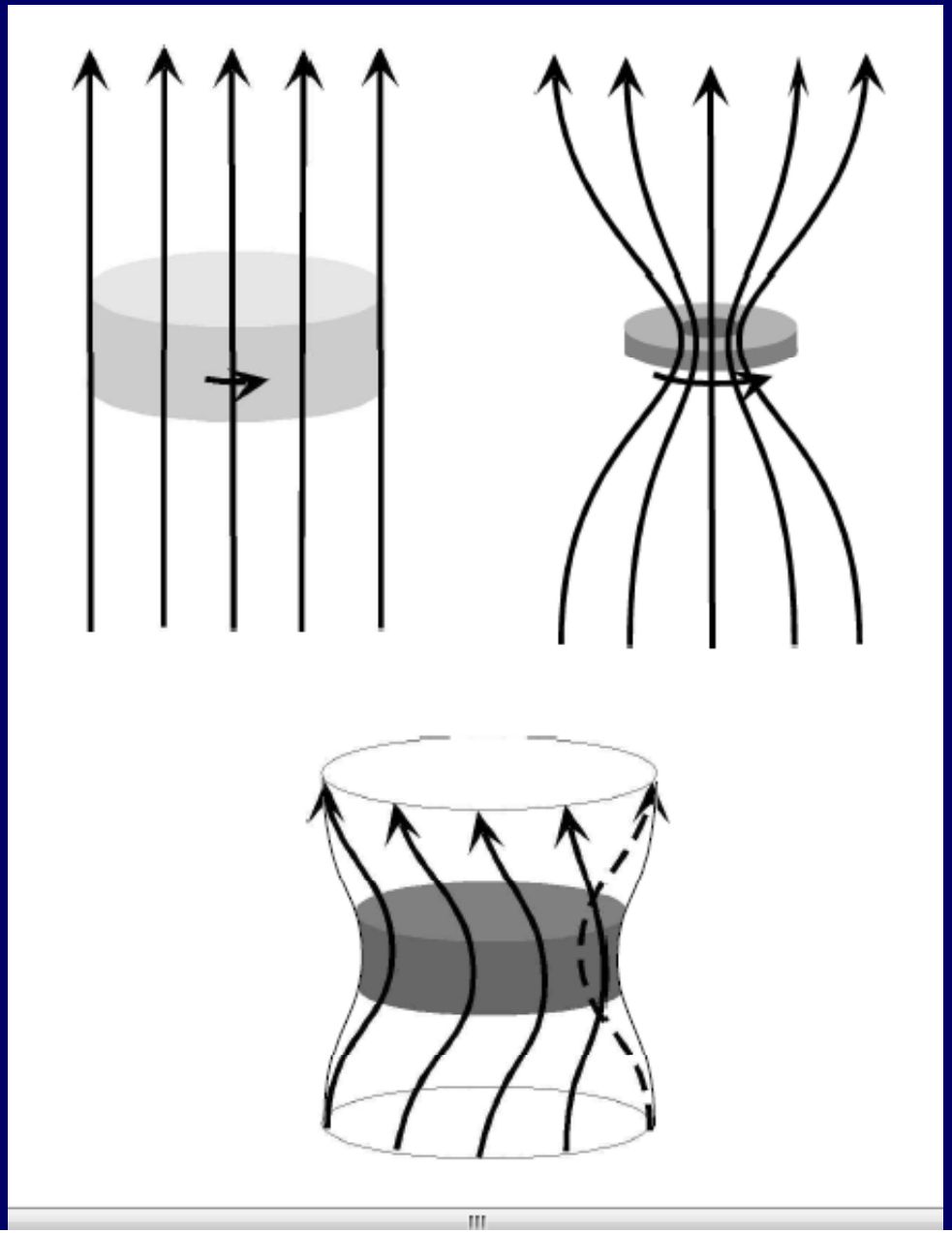


Ring B by "RRA"

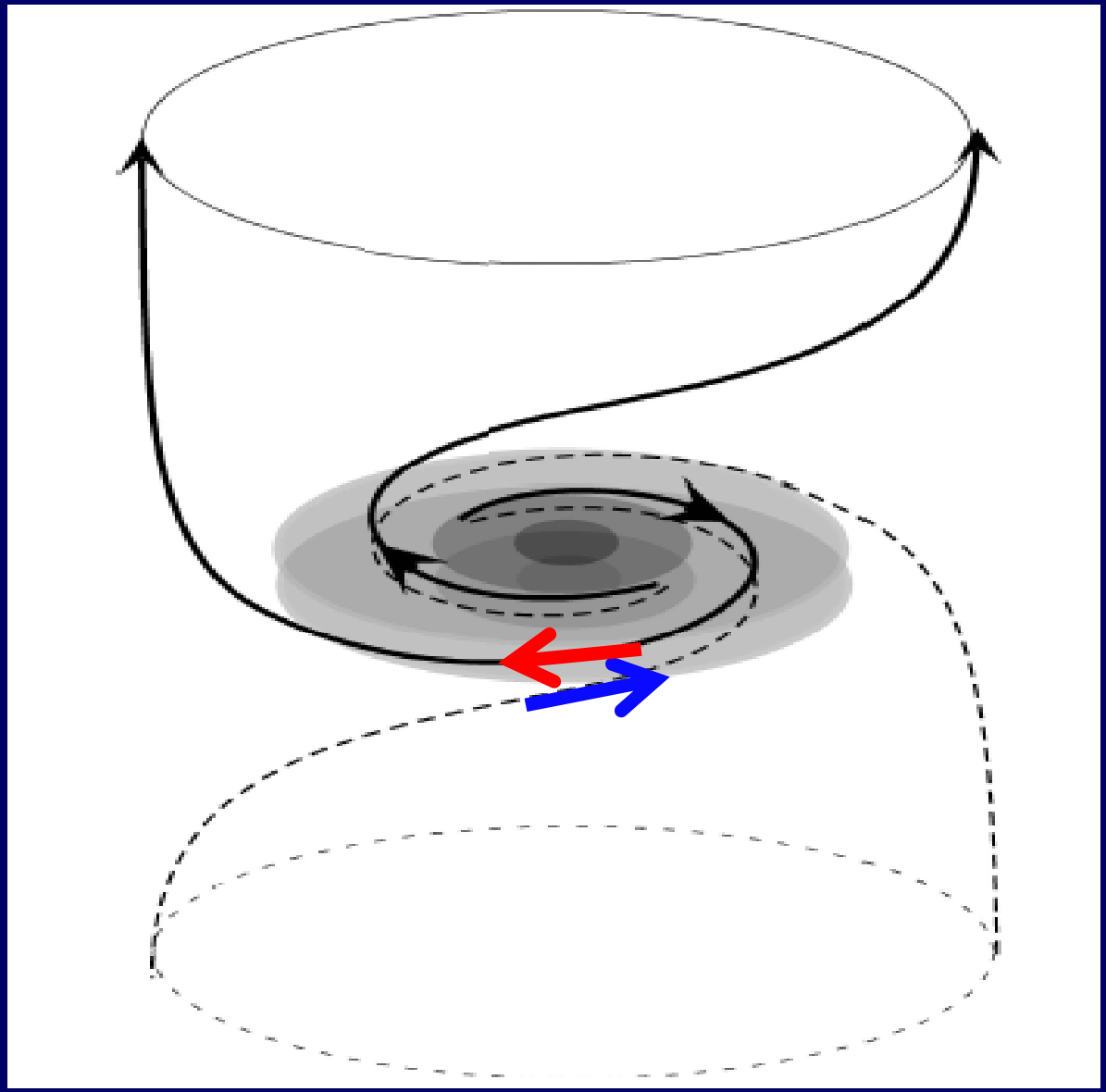
Ring-Reconnection Amplification



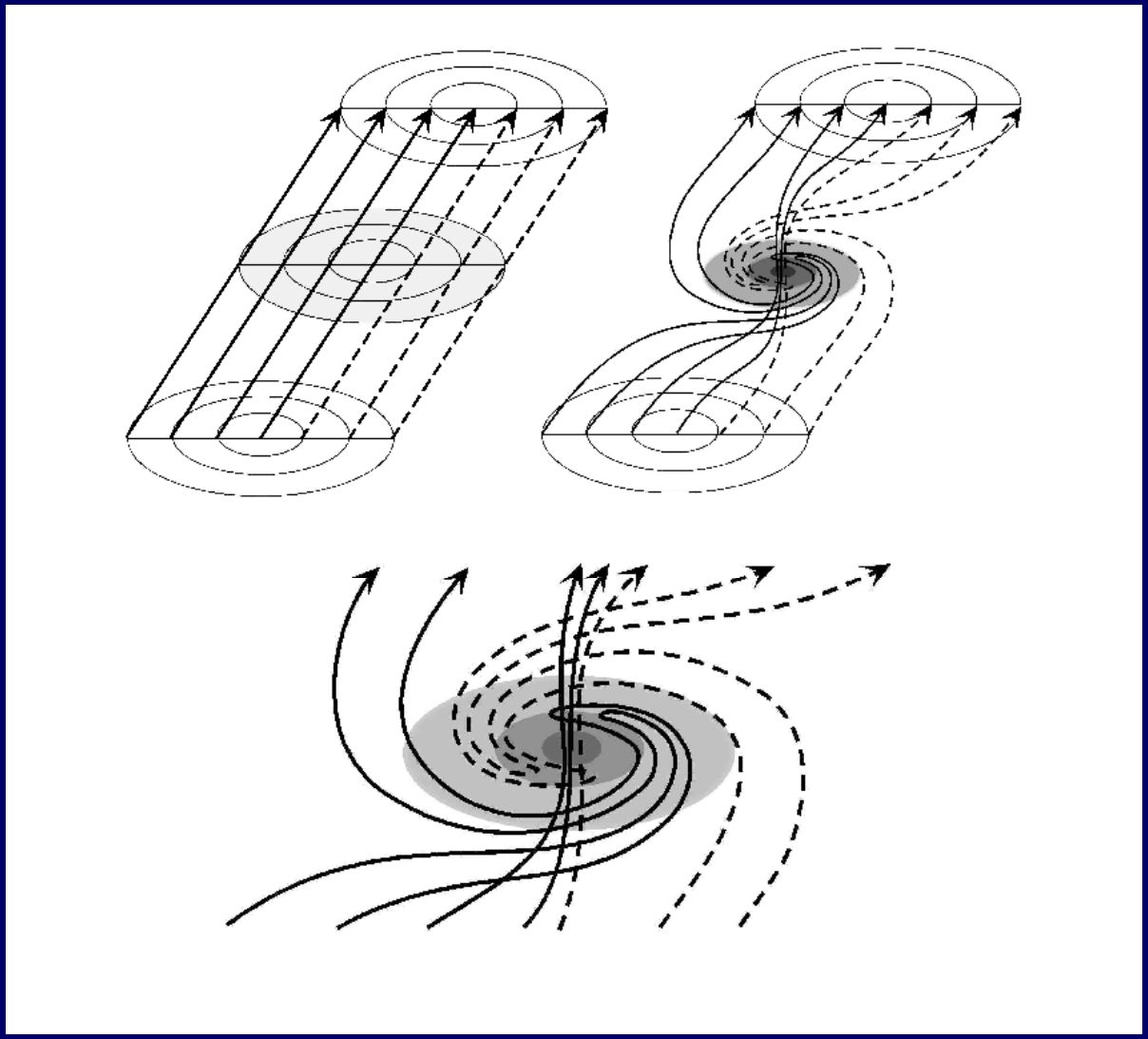
Vertical B



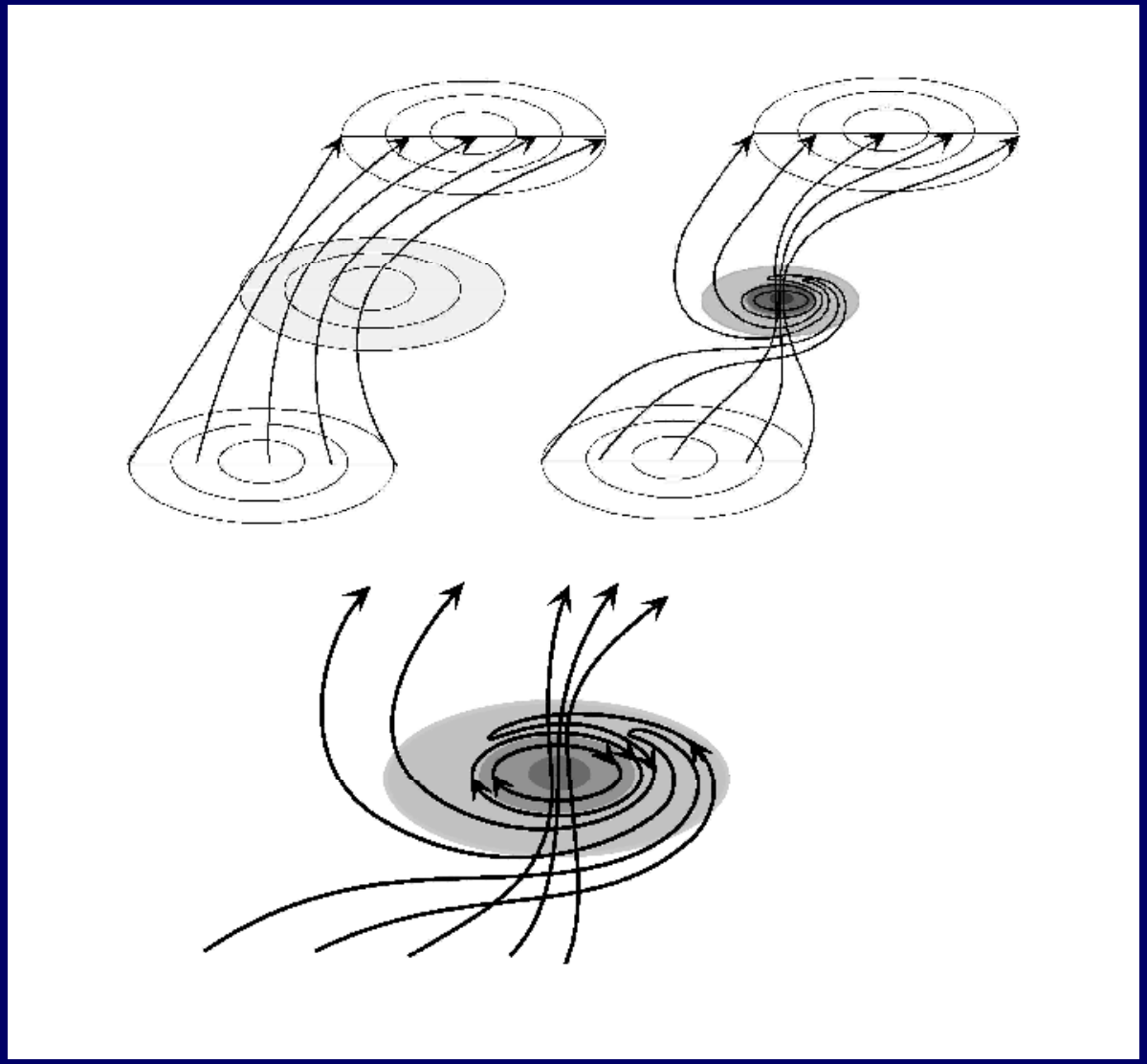
ASS, GPR(reversal) B



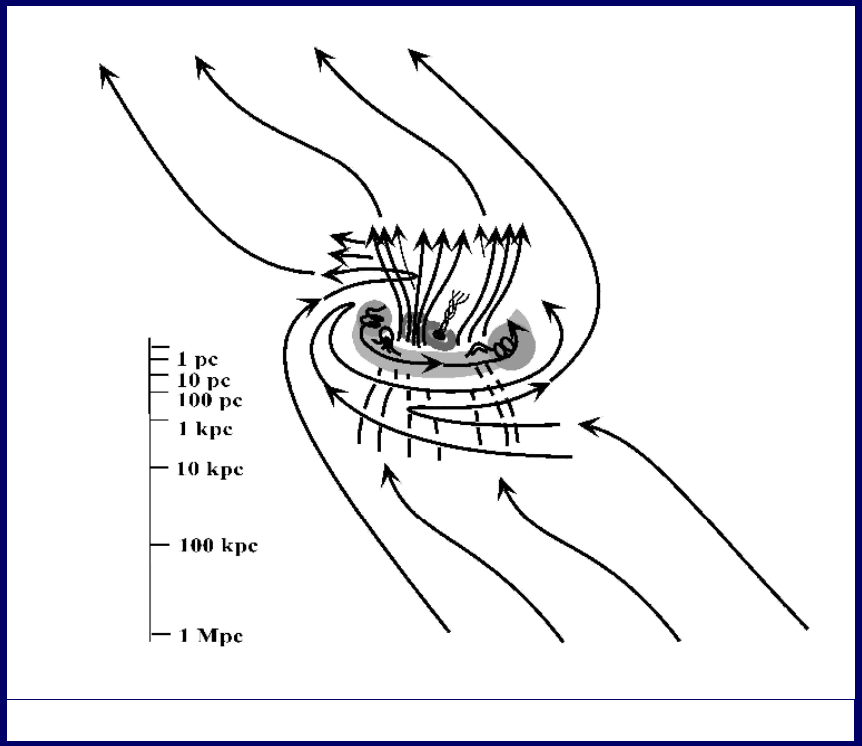
Composite B Cosmological Origin

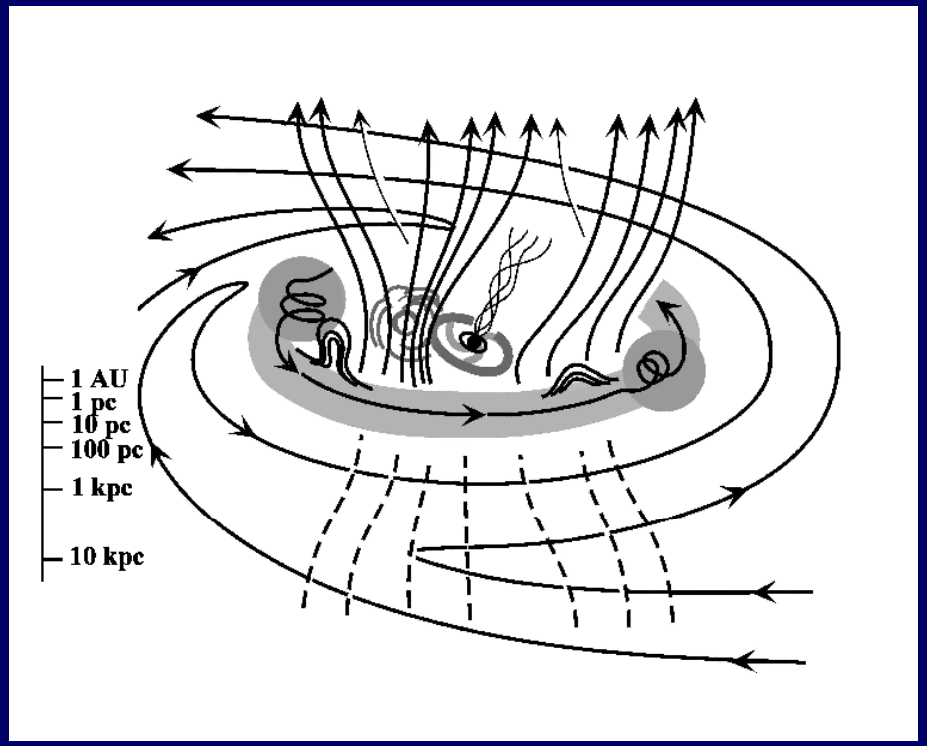


Composite B



Composite Spiral + GC V-field

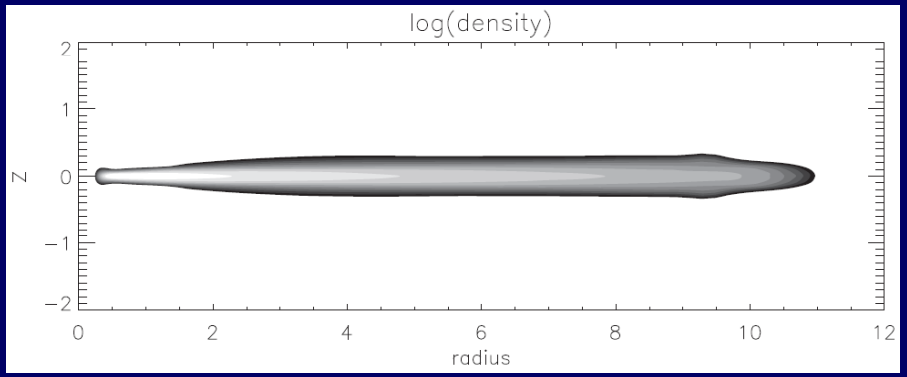


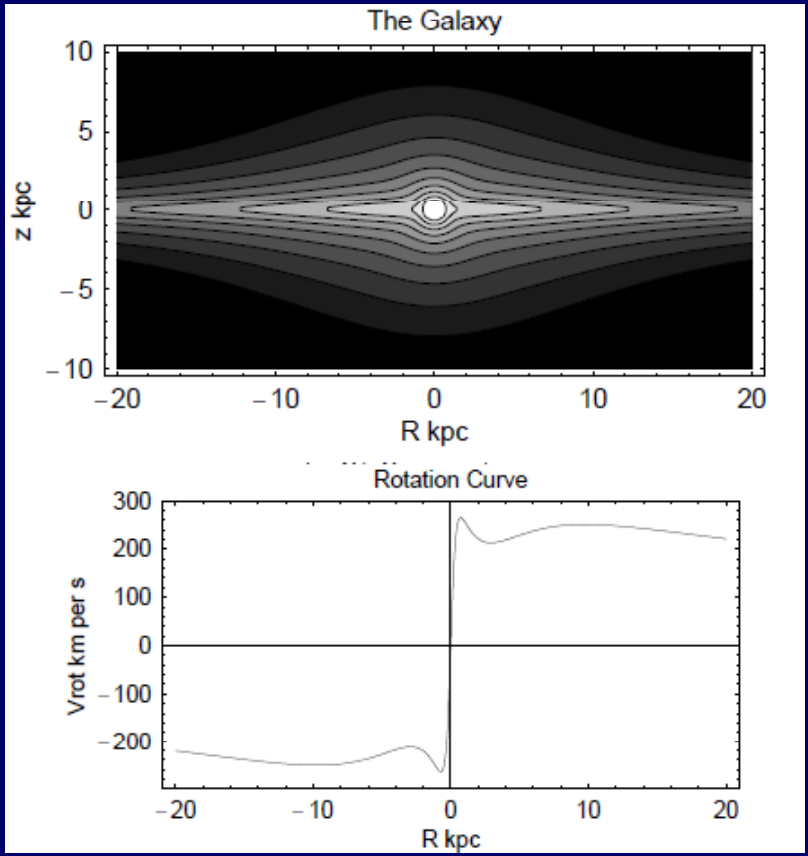


5. 宇宙磁場起源
MHDシミュレーション

Sofue, Machida, & Kudoh
2010 PASJ

MHD Simulation (Sofue, Machida, Kudoh 2010)





$$\phi(r,z) = -\Sigma_{i=1}^{2} \frac{GM_i}{[r^2 + \{a_i + (z^2 + b_i^2)^{1/2}\}^2]^{1/2}},$$

Component	i	a_i (kpc)	b_i (kpc)	$M(M_\odot)$
Bulge	1	0.0	0.495	2.05×10^{10}
Disk	2	7.258	0.520	2.547×10^{11}

$$\frac{\partial \rho}{\partial t} + \bigtriangledown \cdot (\rho \mathbf{v}) = 0, \tag{1}$$

$$\rho \left[\frac{\partial \mathbf{v}}{\partial t} + v \cdot \bigtriangledown \right] = - \bigtriangledown P - \rho \bigtriangledown \phi + \frac{\mathbf{j} \times \mathbf{B}}{c}, \tag{2}$$

$$\frac{\partial \mathbf{B}}{\partial t} = \bigtriangledown \times (\mathbf{v} \times \mathbf{B}) - \frac{4\pi}{c} \eta_0 \mathbf{j}, \tag{3}$$

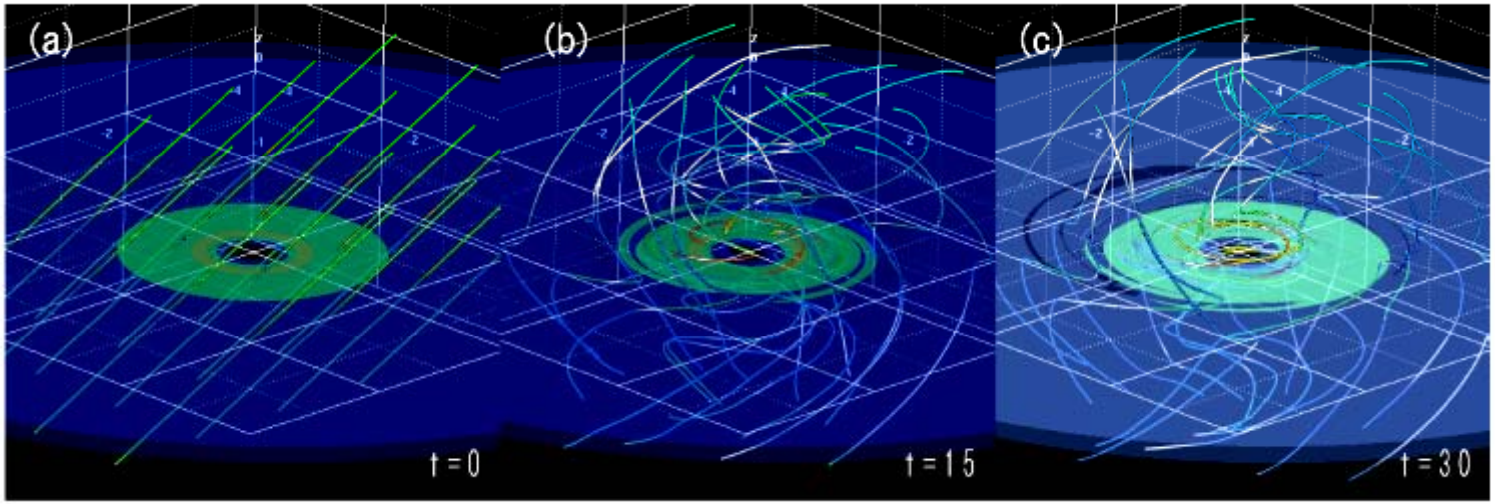
$$\rho T \frac{dS}{dt} = 0, \tag{4}$$

Table 2. Units adopted in this paper.

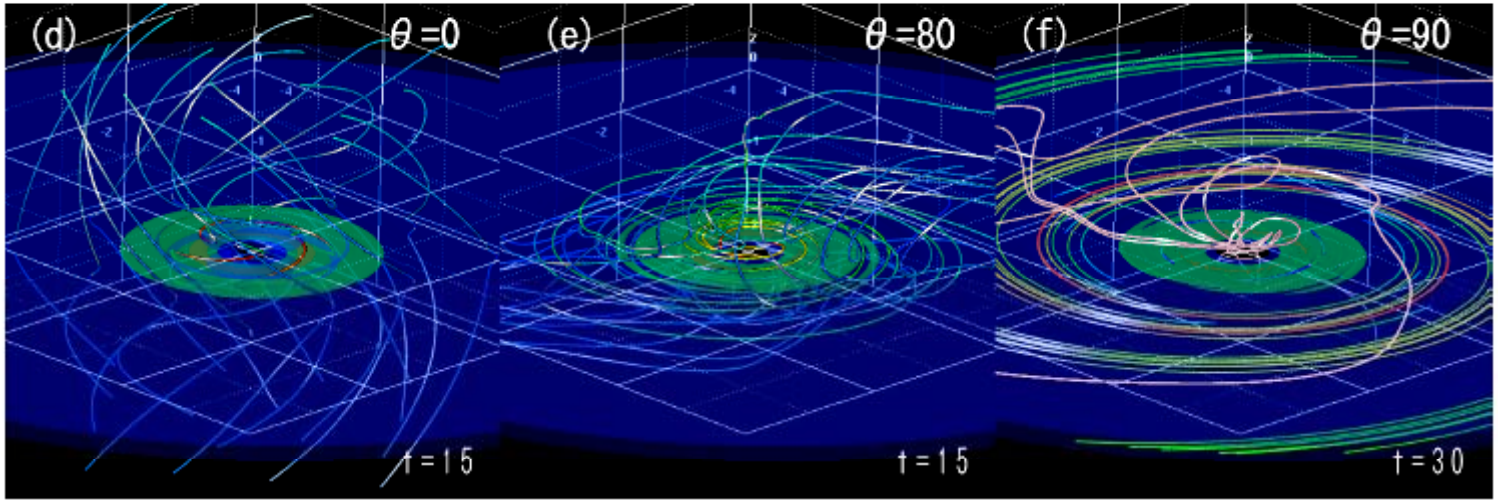
Physical quantity	Symbol	Numerical unit
Length	r_0	1 kpc
Velocity	v_0	207 km s^{-1}
Time	t_0	4.7×10^6 yr
Density	ρ_0	1.6×10^{-24} g cm^{-3}
Magnetic field	$B_0 = \sqrt{\rho_0 v_0^2}$	26 μG

MHD Simulation （Sofue, Machida, Kudoh 2010)

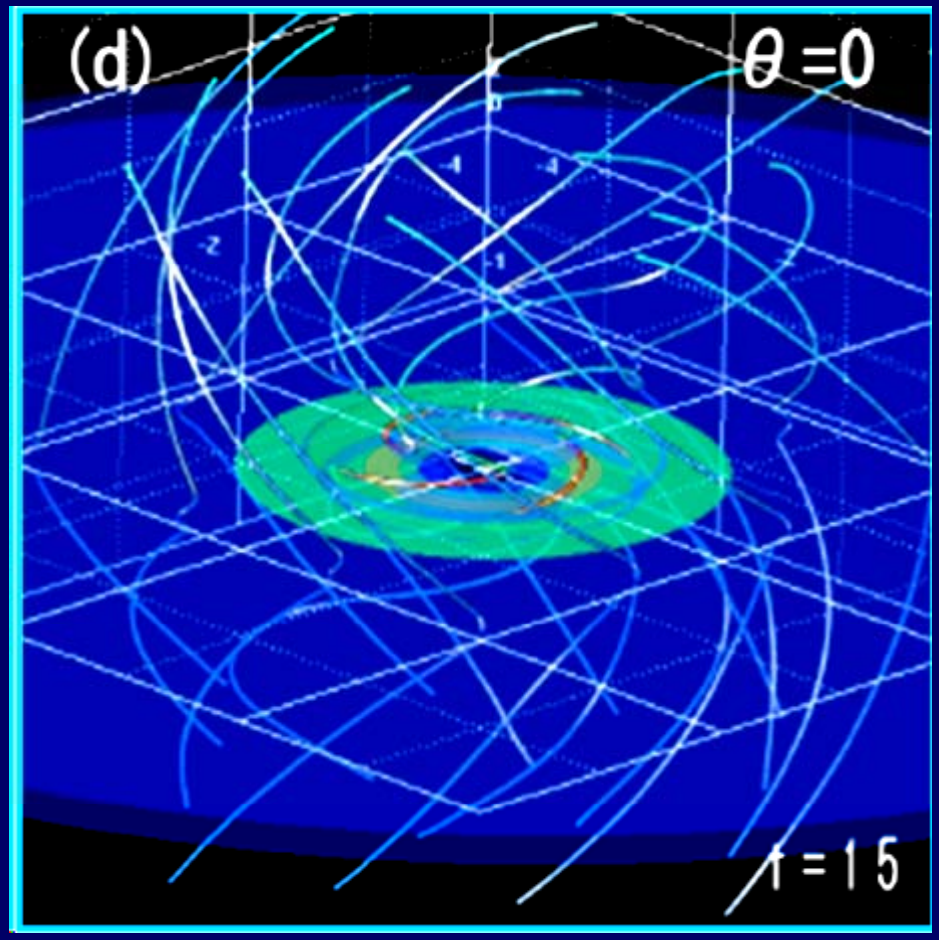
Time evolution : θ =45



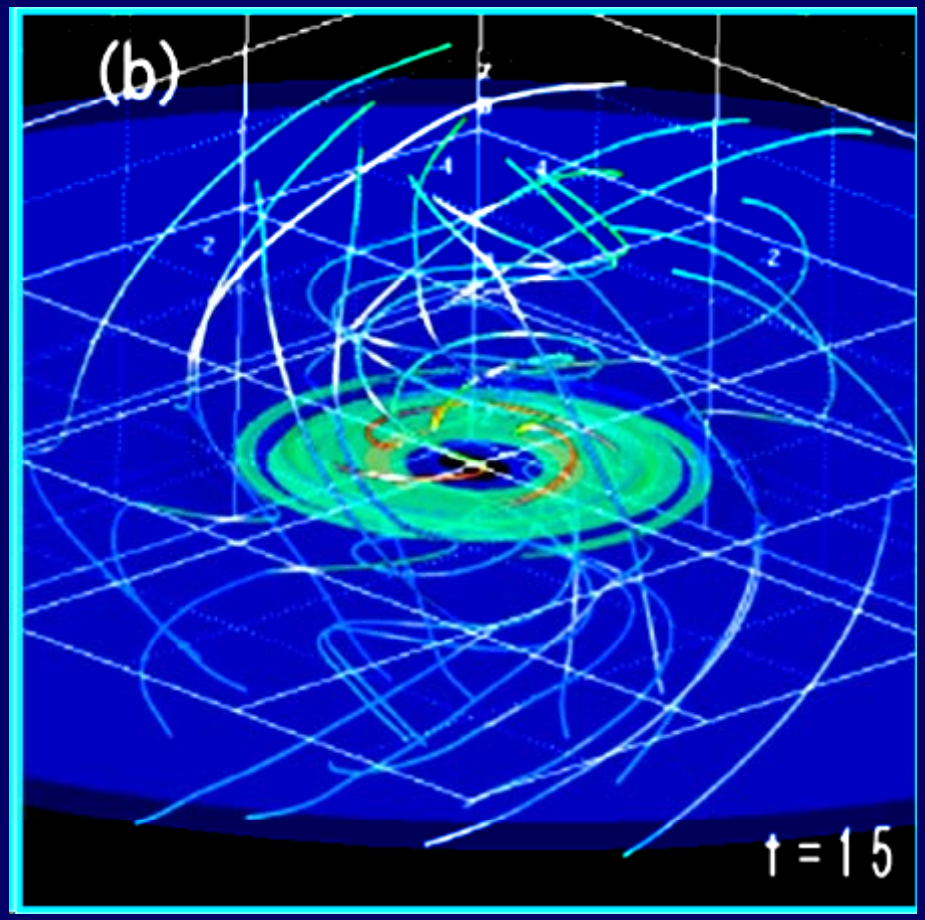
Snapshots of the other models



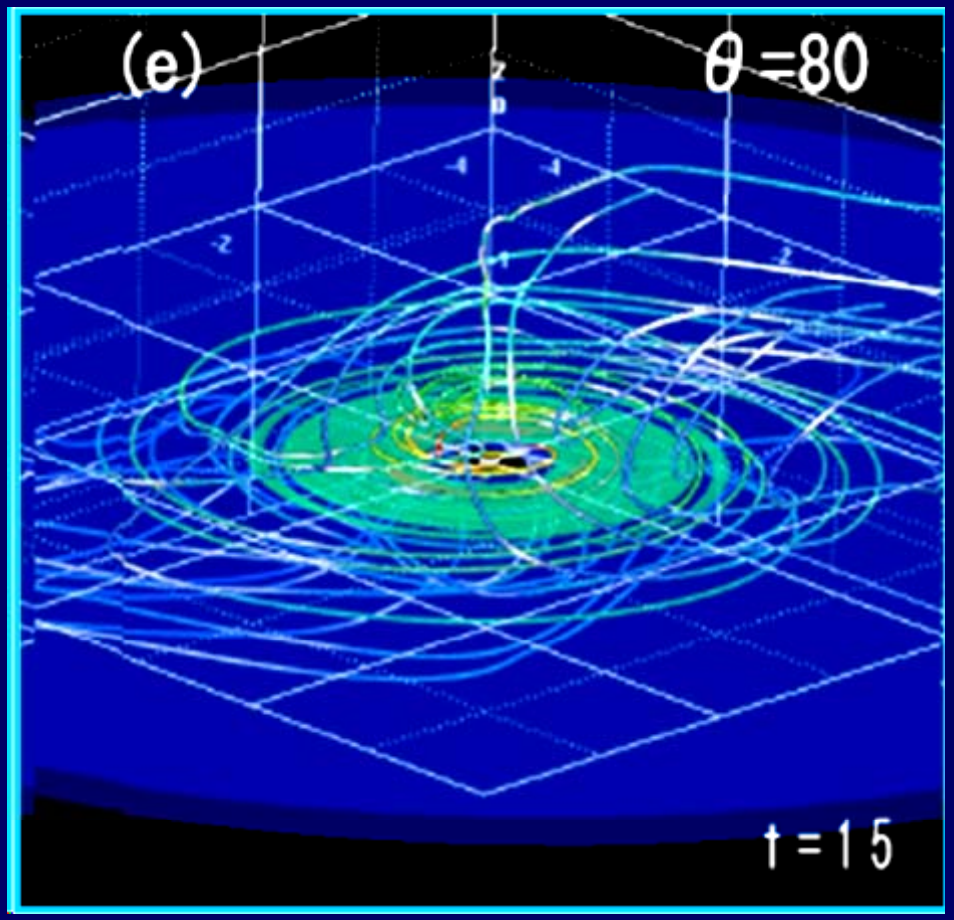
MHD Simulation （Sofue, Machida, Kudoh 2010)



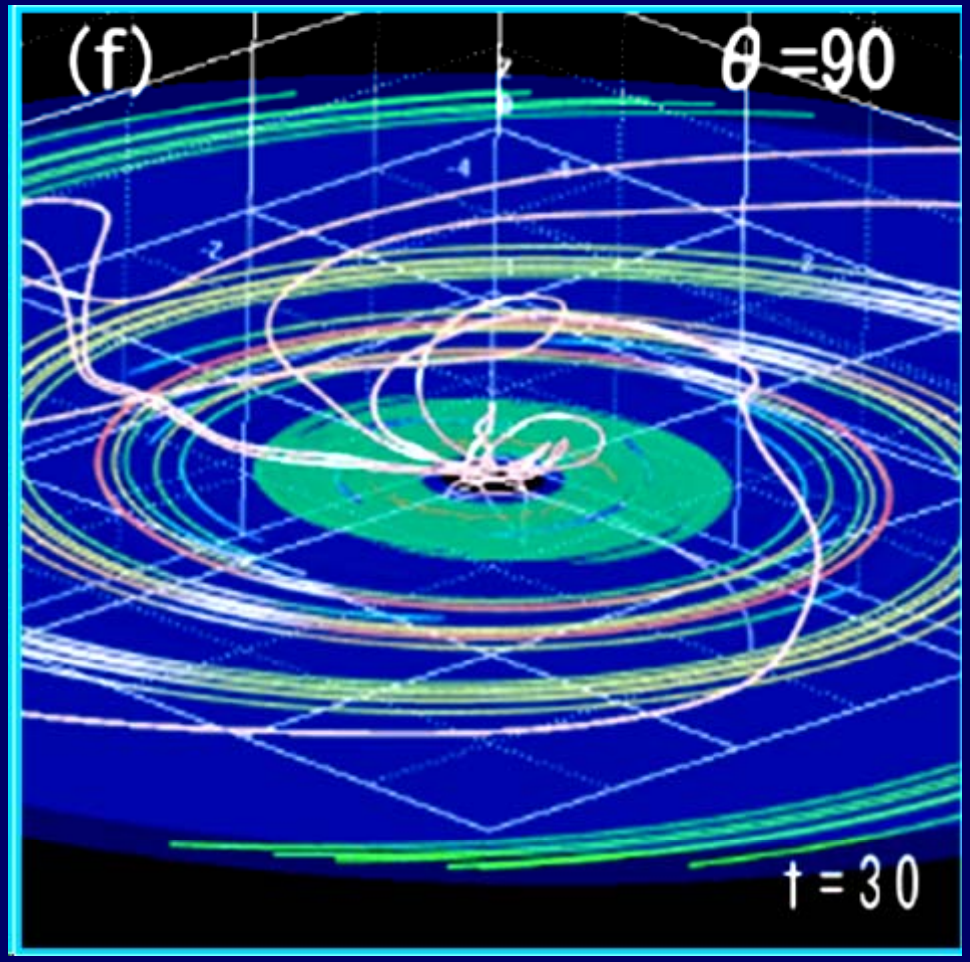
MHD Simulation



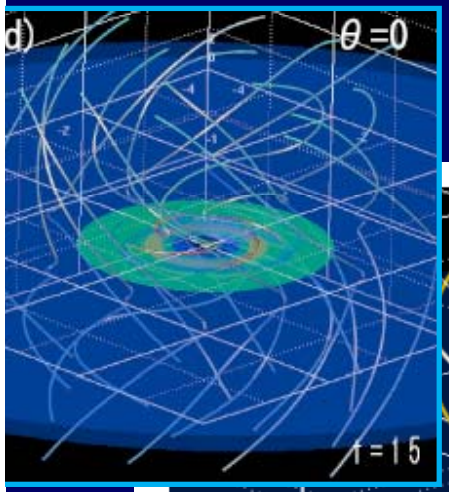
MHD Simulation

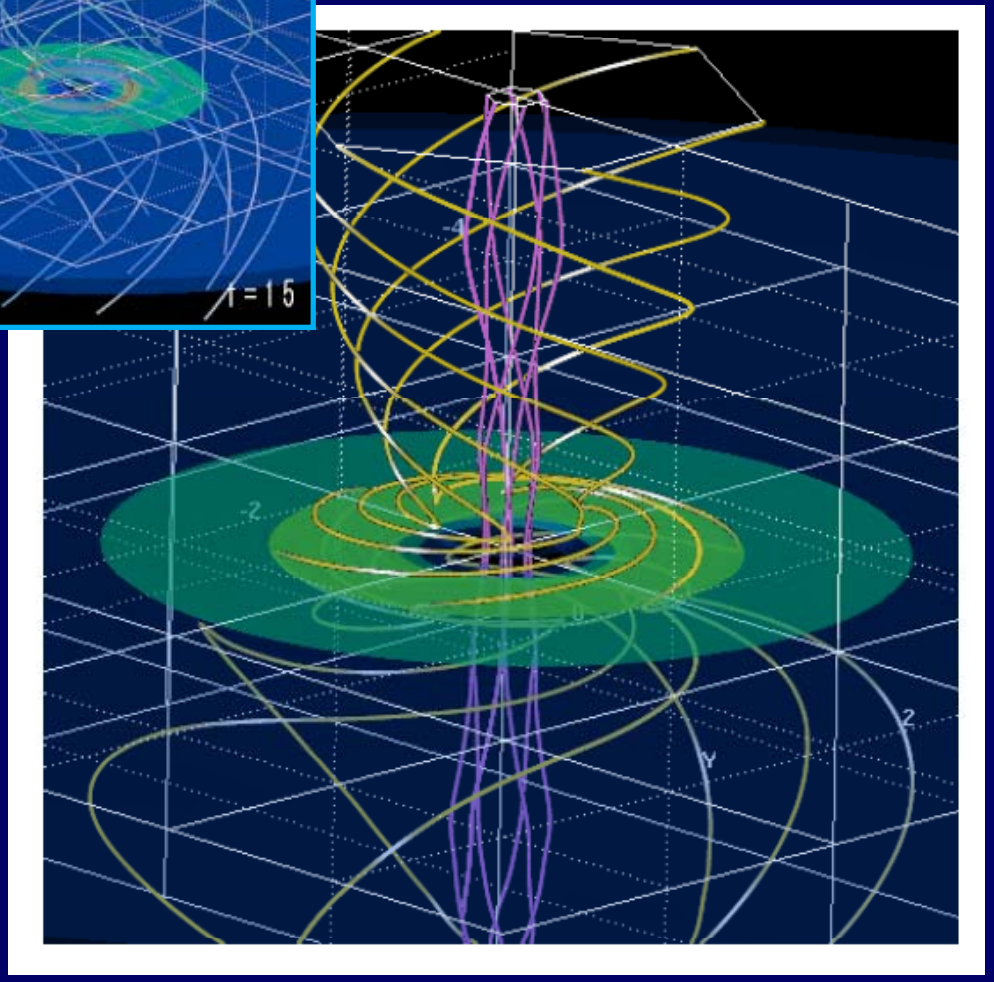


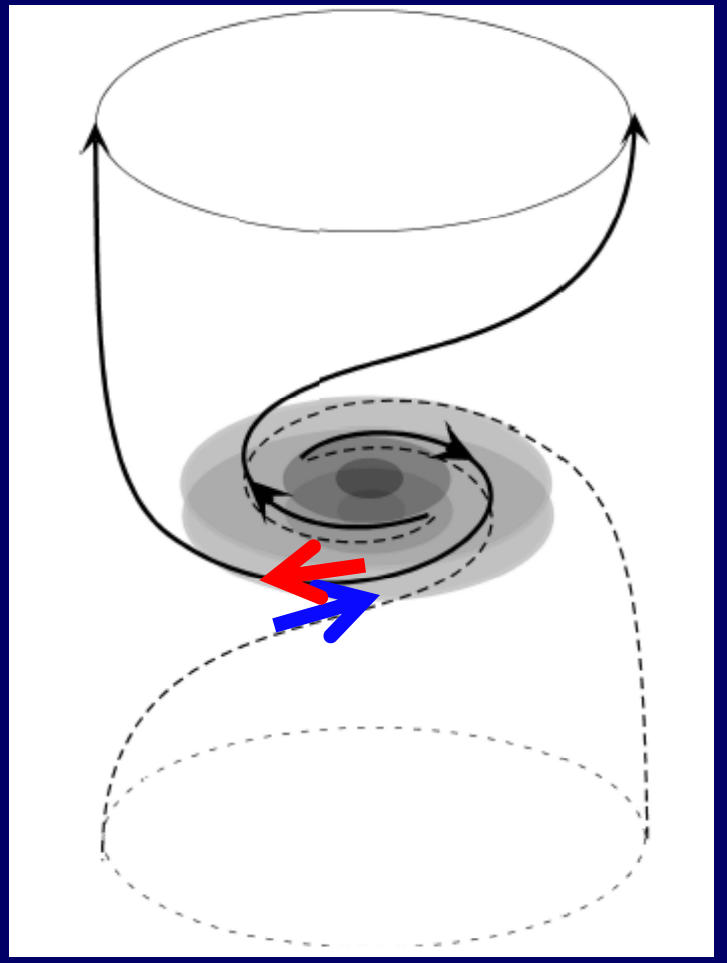
MHD Simulation



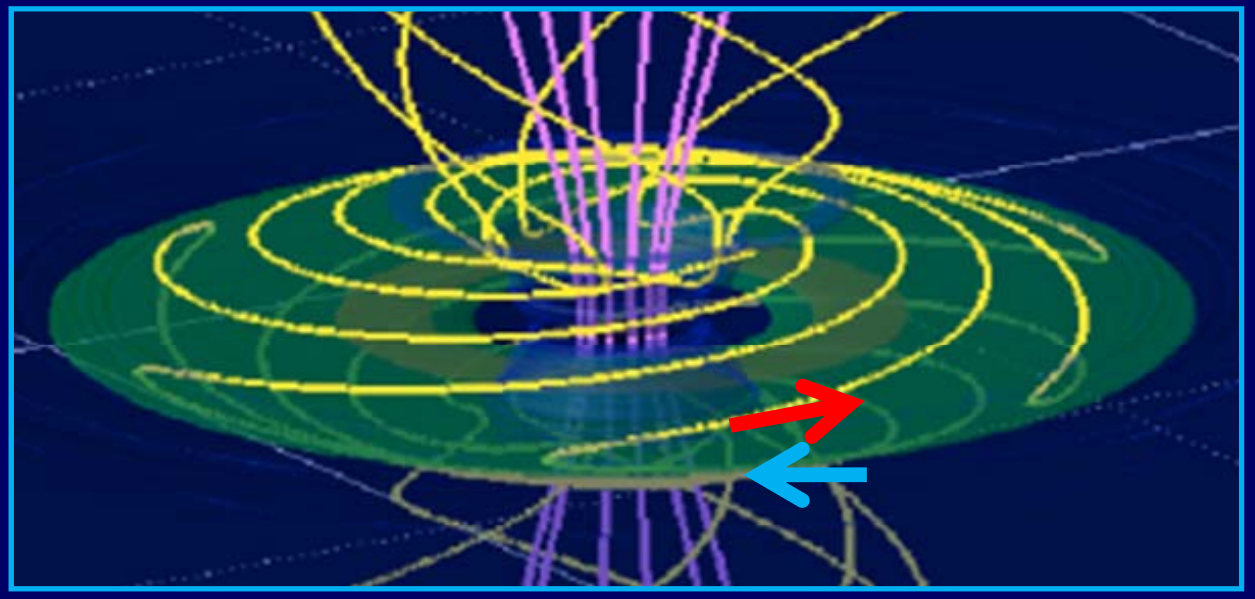
ASS creation from V

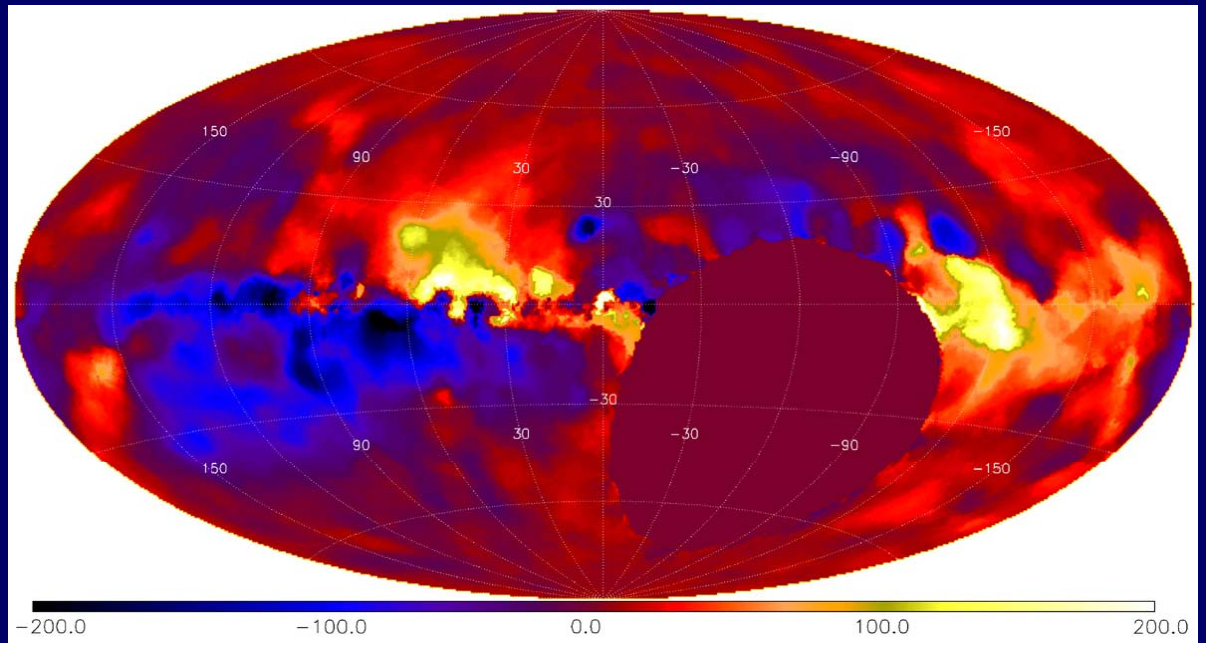






ASS +G-Plane Reversal





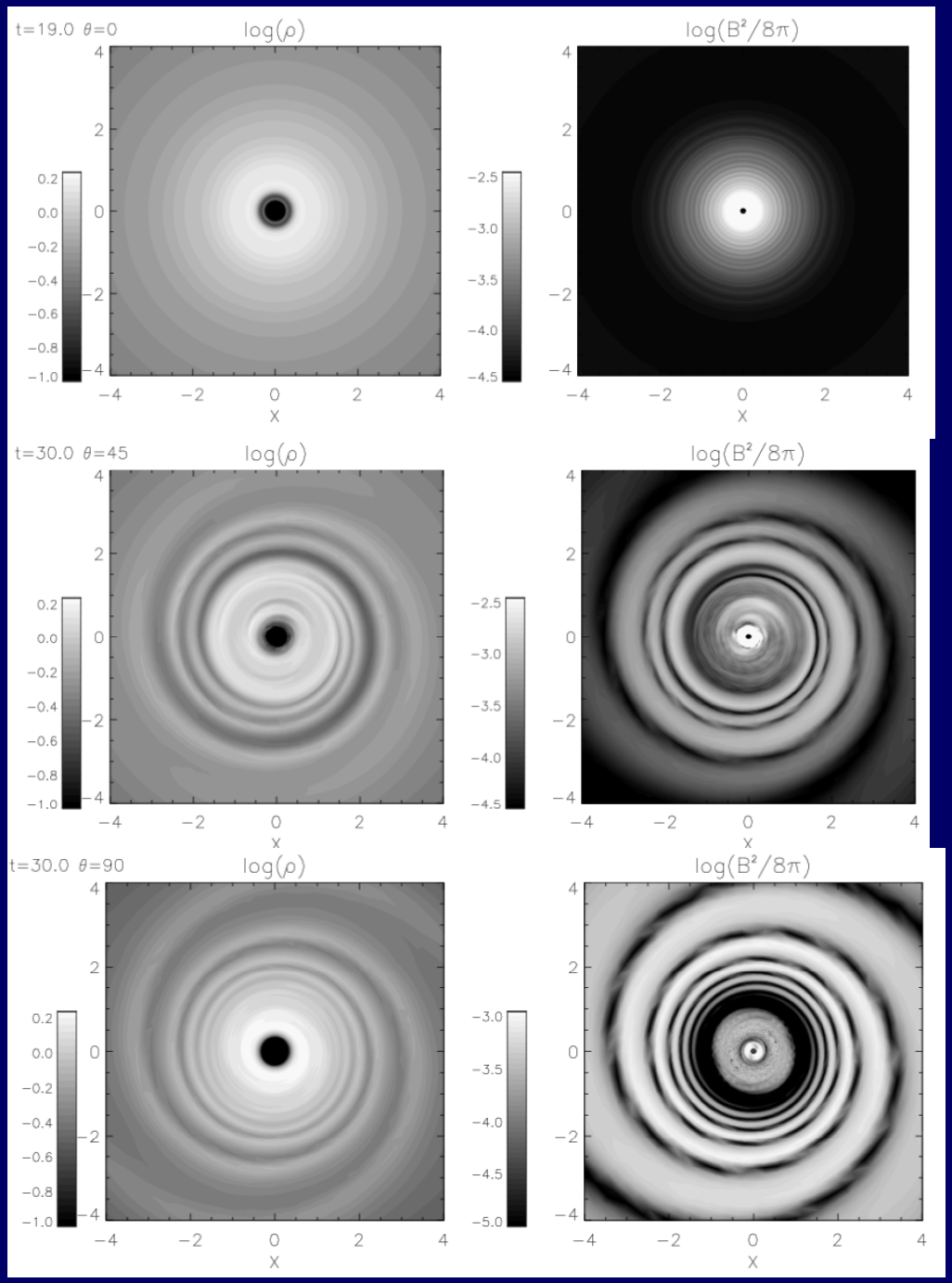
Gas

B^2

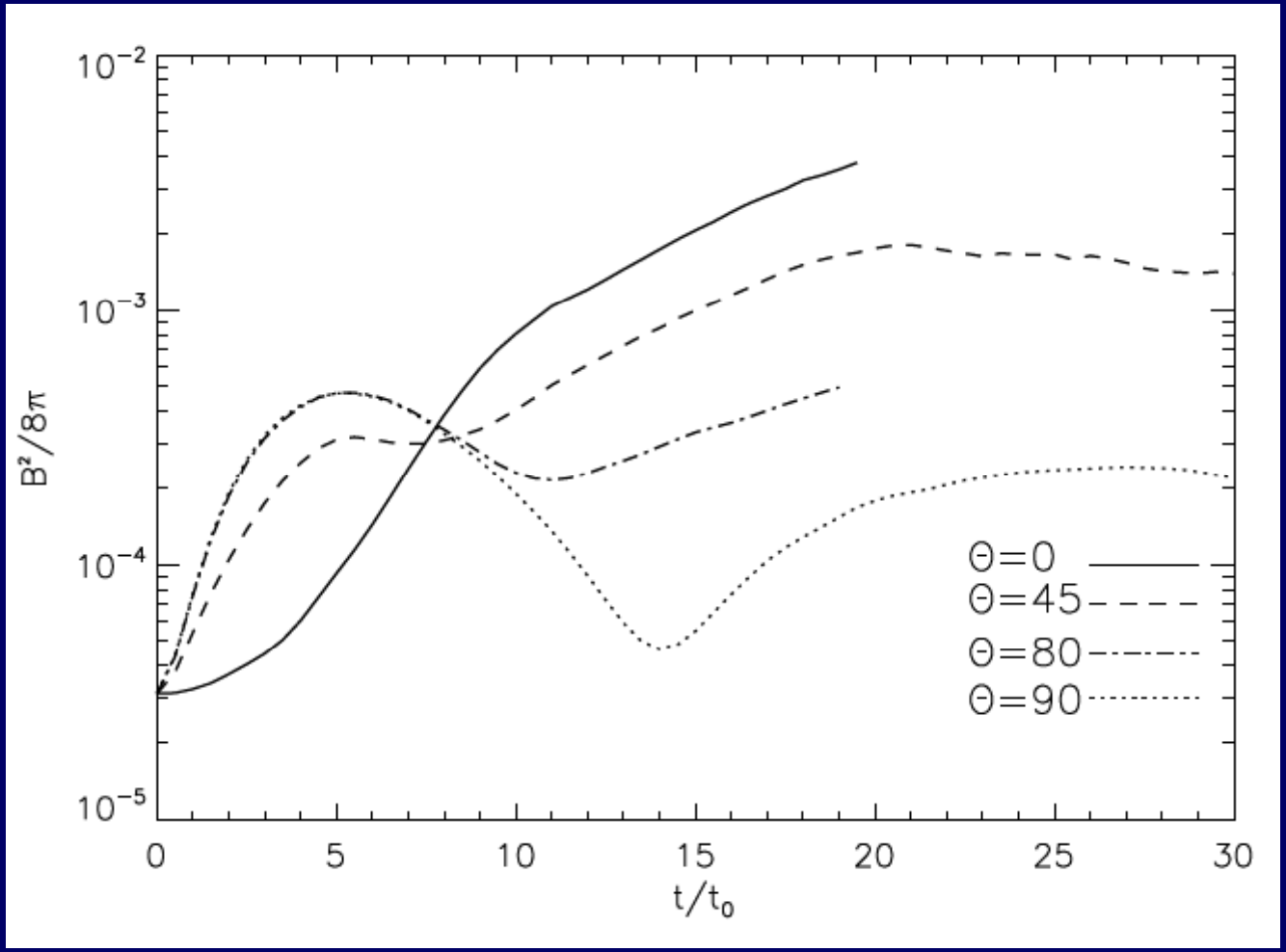
Θ=0 deg

Θ=45 deg

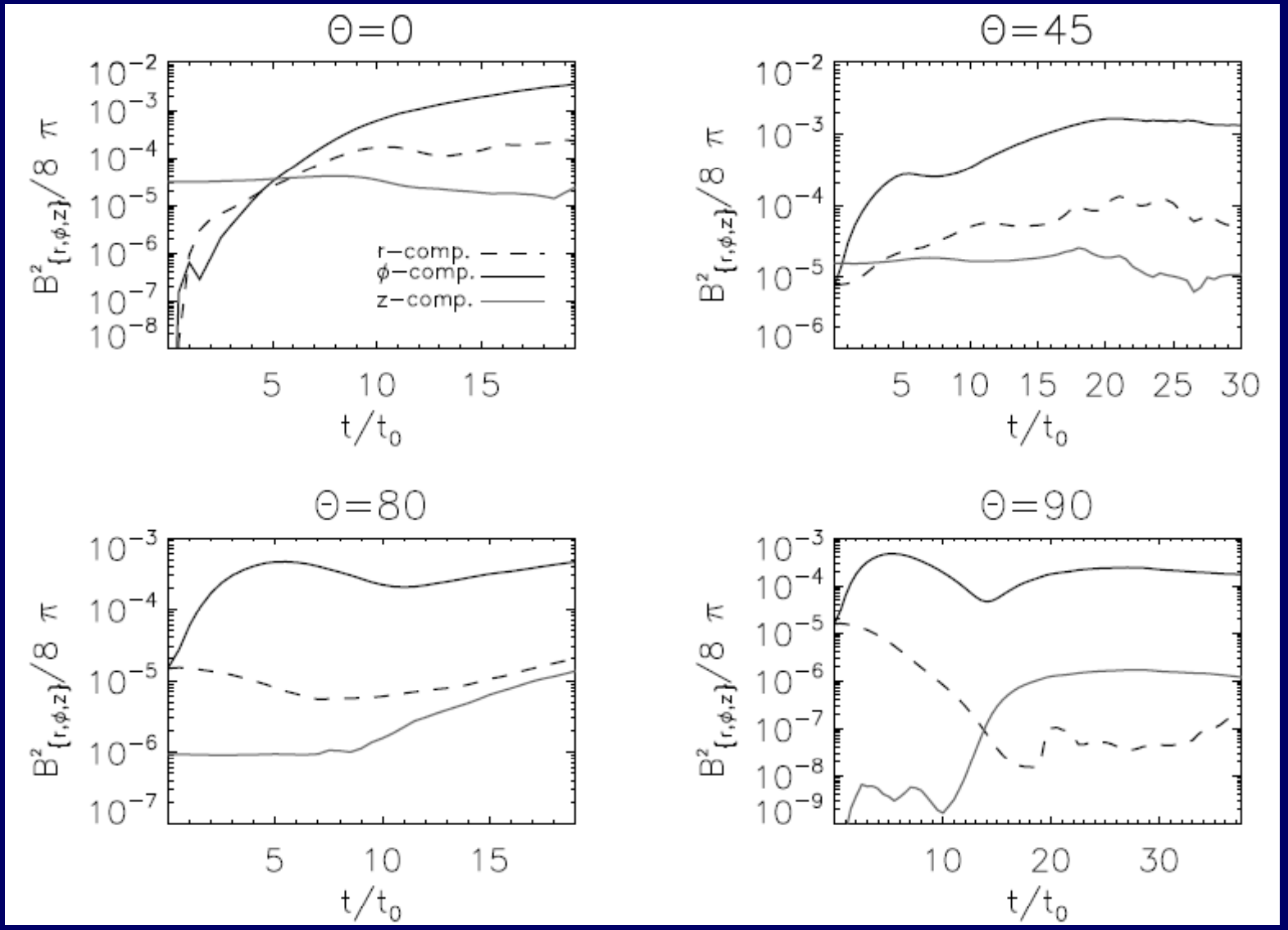
Θ=90 deg



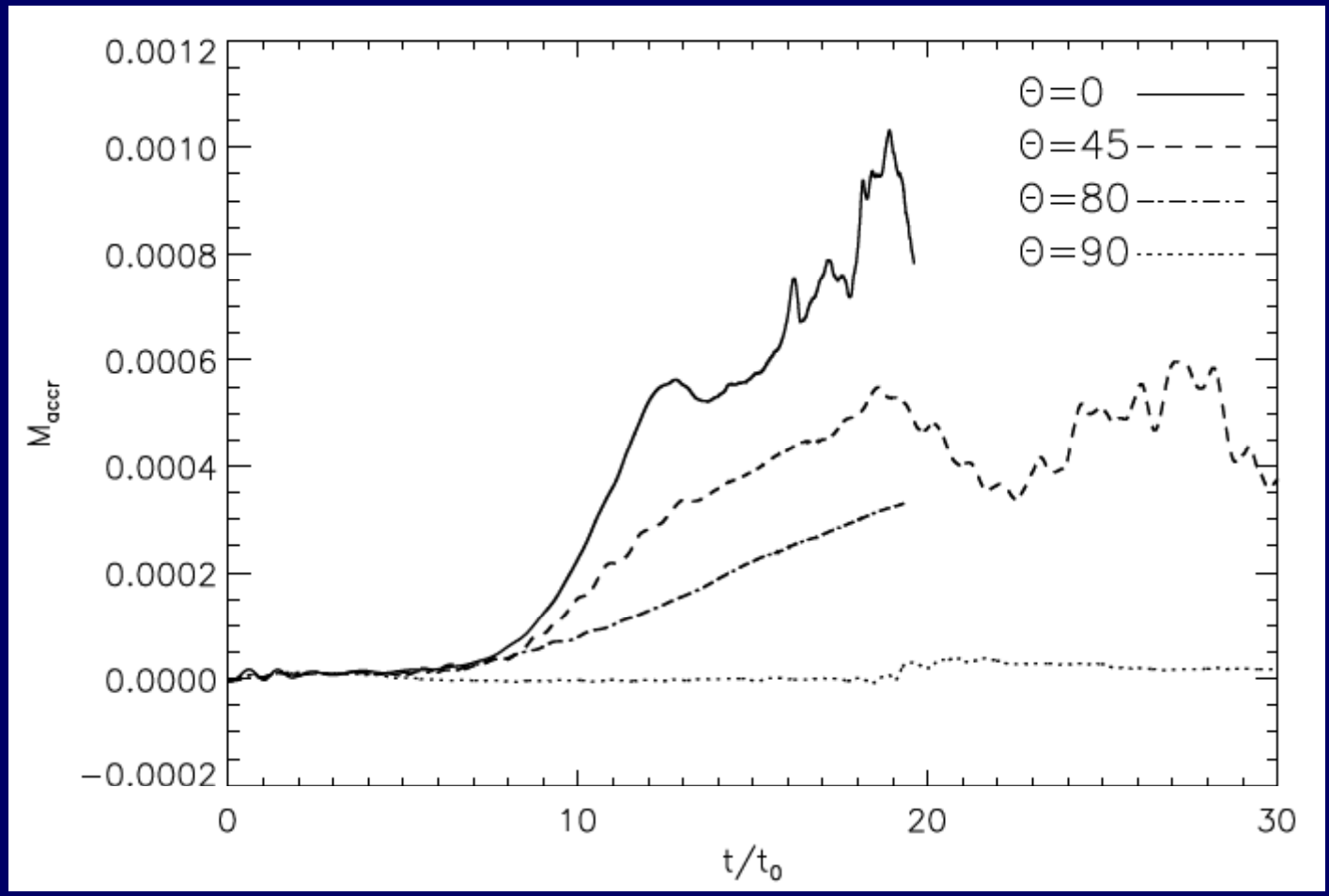
Magnetic Energy Density



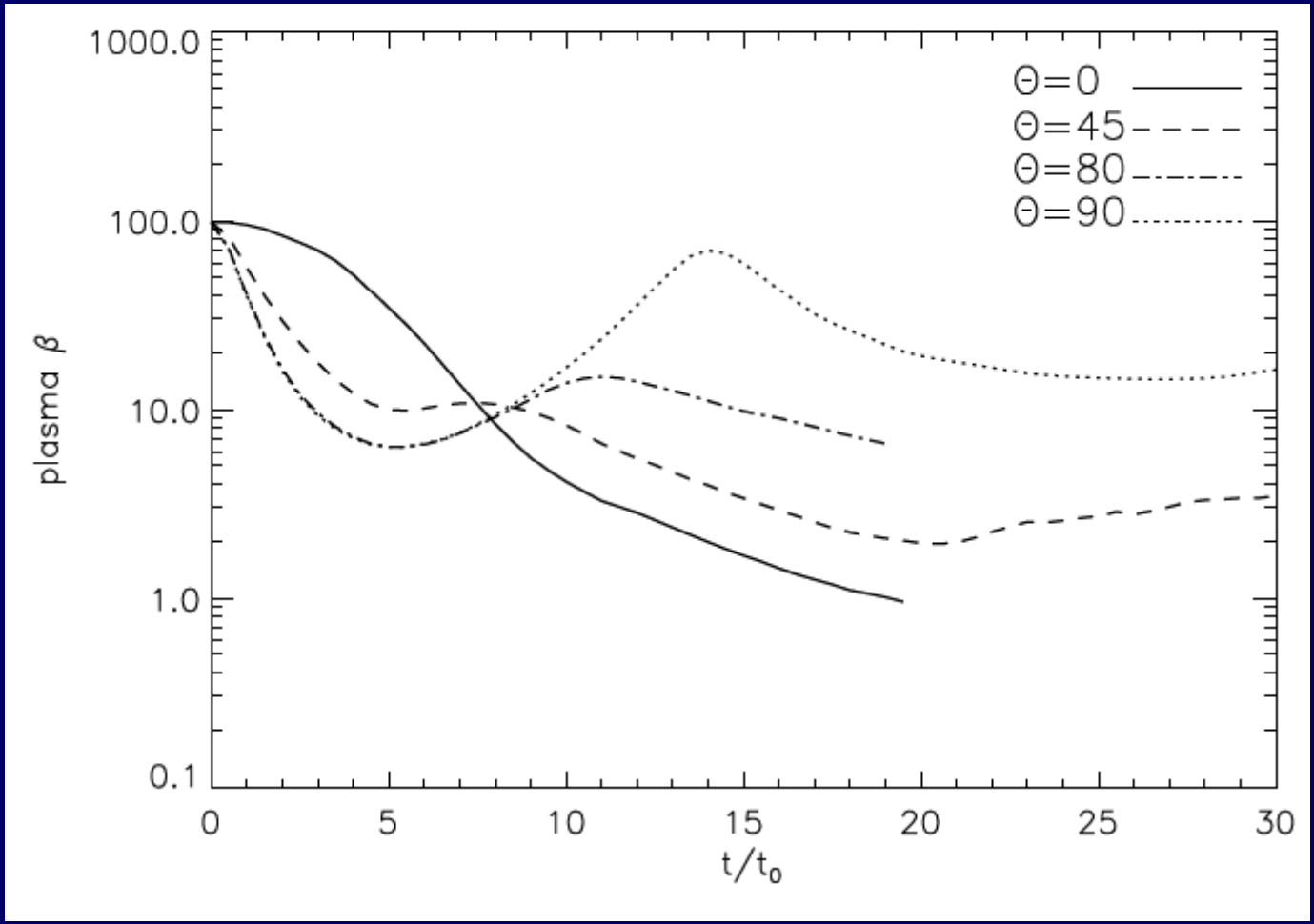
Magnetic Energy Density



Accretion Rate

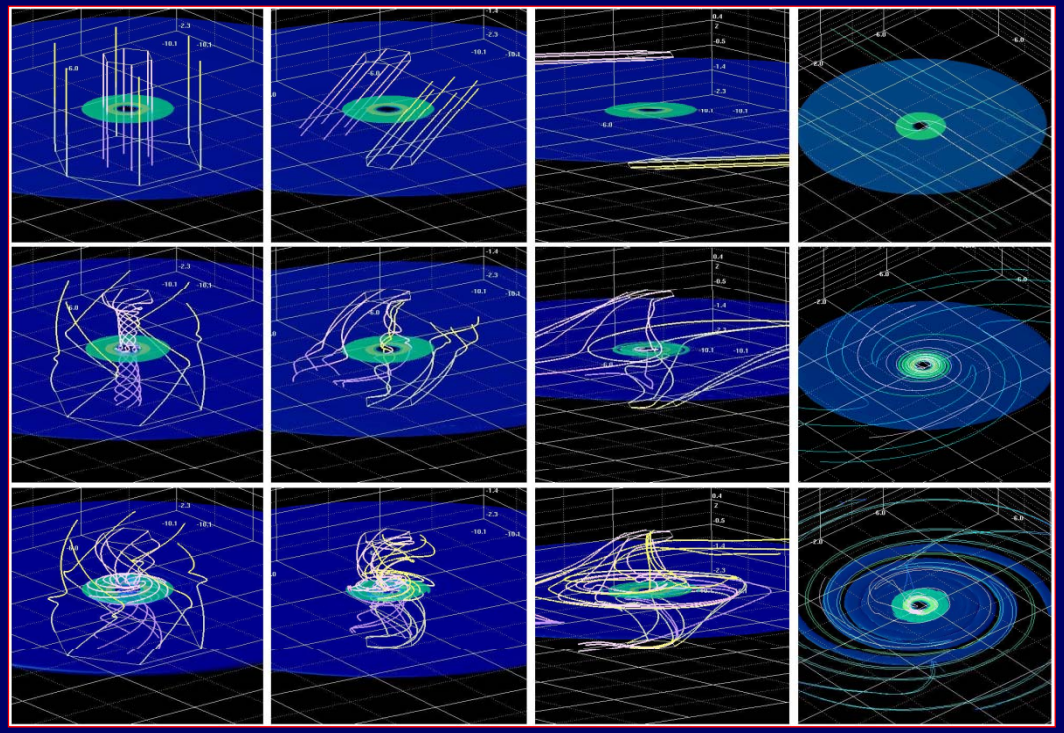


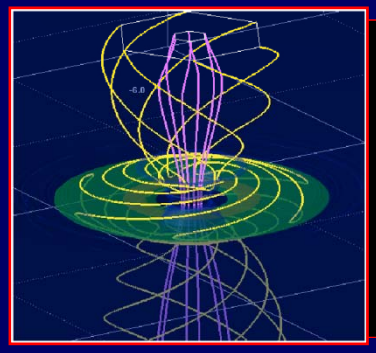
Plasma Beta

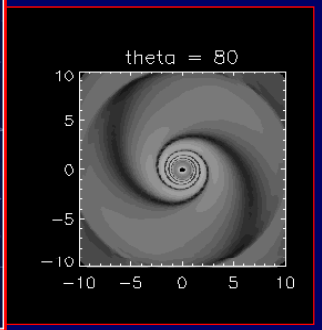


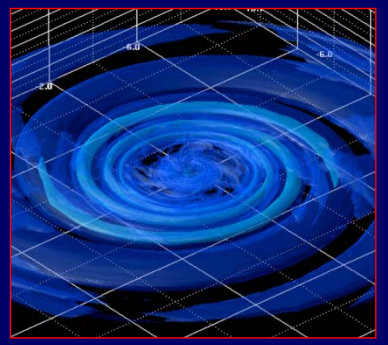
MHD can simulate

B



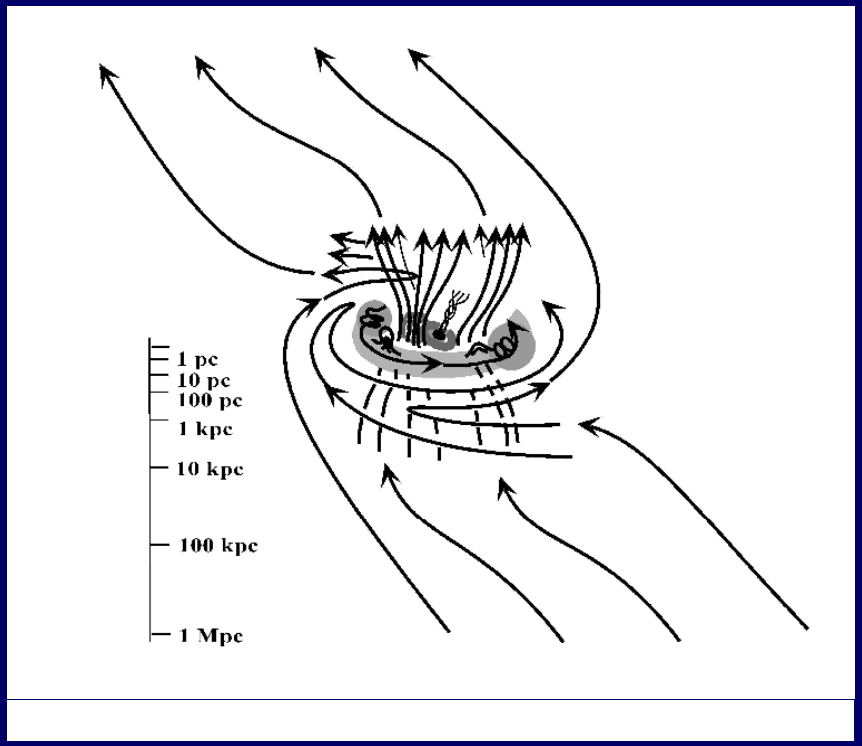


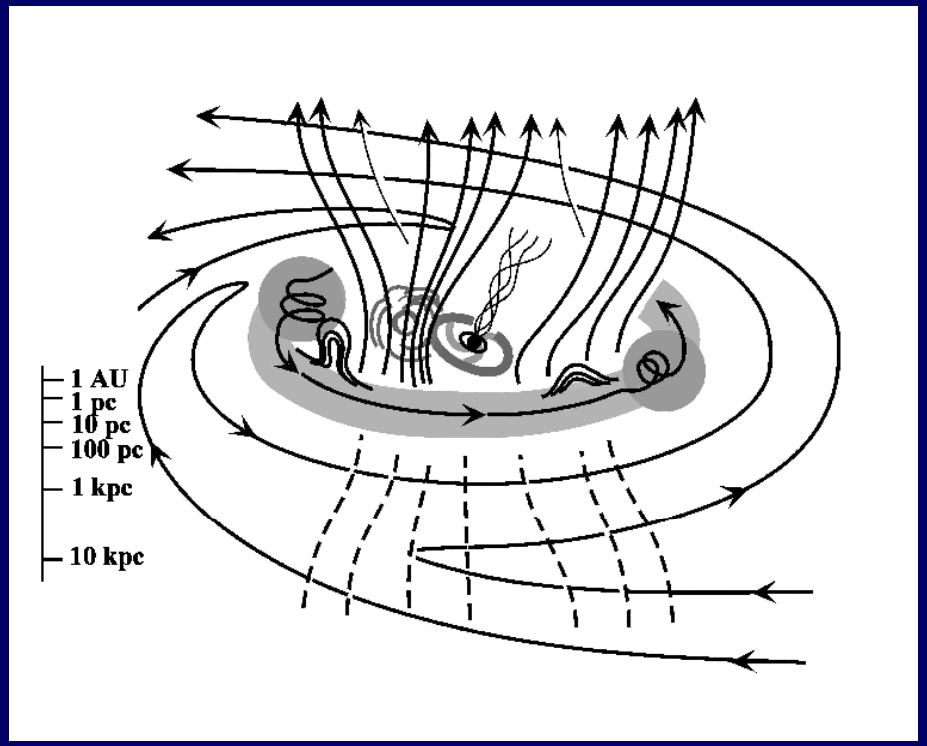




B^2

Cosmological origin model of Galactic B

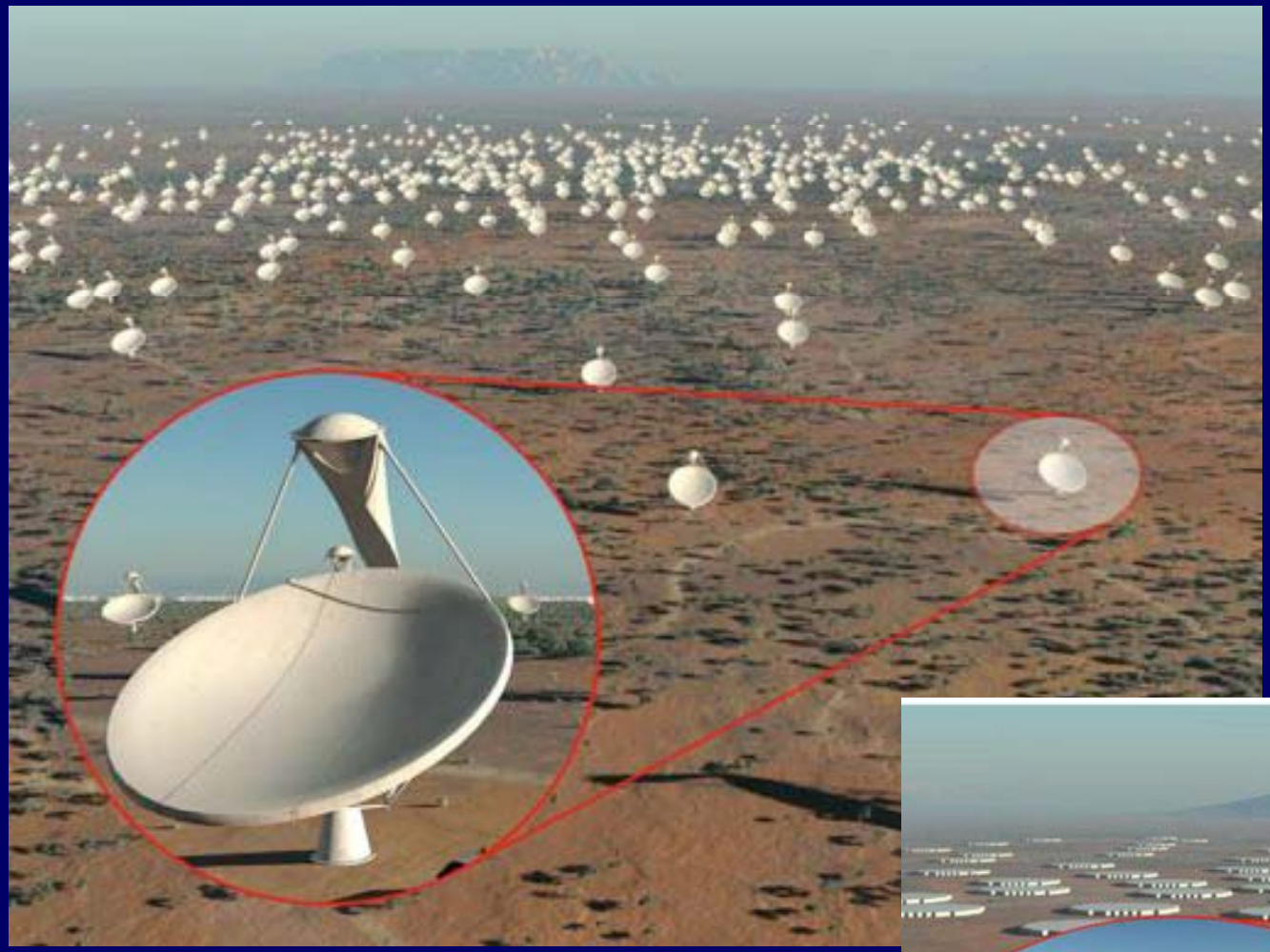


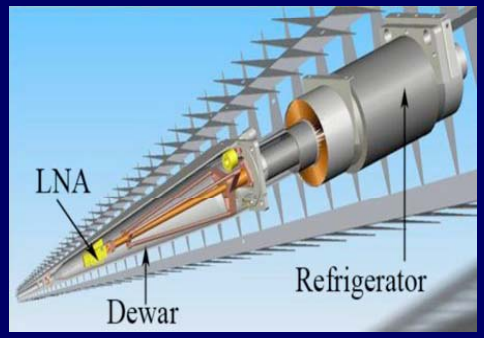


6. SKA

― 銀河磁場作戦 ―

SKA





SKA（Square km Array）とは:

開口面積＝1 km^2

~ 100m 電波望遠鏡 x100台

~ 10m 電波望遠鏡　x 1万台

D ~ 3000km~ 大陸VLBI

Θ ~ 21cm/3000 km ~ 0.02”

1. 宇宙生命
2. 宇宙暗黒時代
3. 宇宙磁場の進化
4. 重力理論の検証
5. 銀河進化

所要経費（全体額）

建設費**2000**億円（初期投資：**2000**億円、運営費等：年間**200**億円）

欧・米・その他で**3**分の**1**ずつ拠出されることが想定される

建設計画

2007－12 望遠鏡のデザイン、コスト見積もり

2012－13 サイト決定。**10%SKA**の建設費採択

2012－13 SKA組織の設立

2013－18 詳細なデザイン研究。**SKA-mid, low**の**10%**建設。

2013－22 SKA-highの技術開発

2017－ 初期運用

100%SKA建設費の採択。

2017－22 SKA-low, midの完成

2023－ SKA-low, midの本格運用。

SKAに