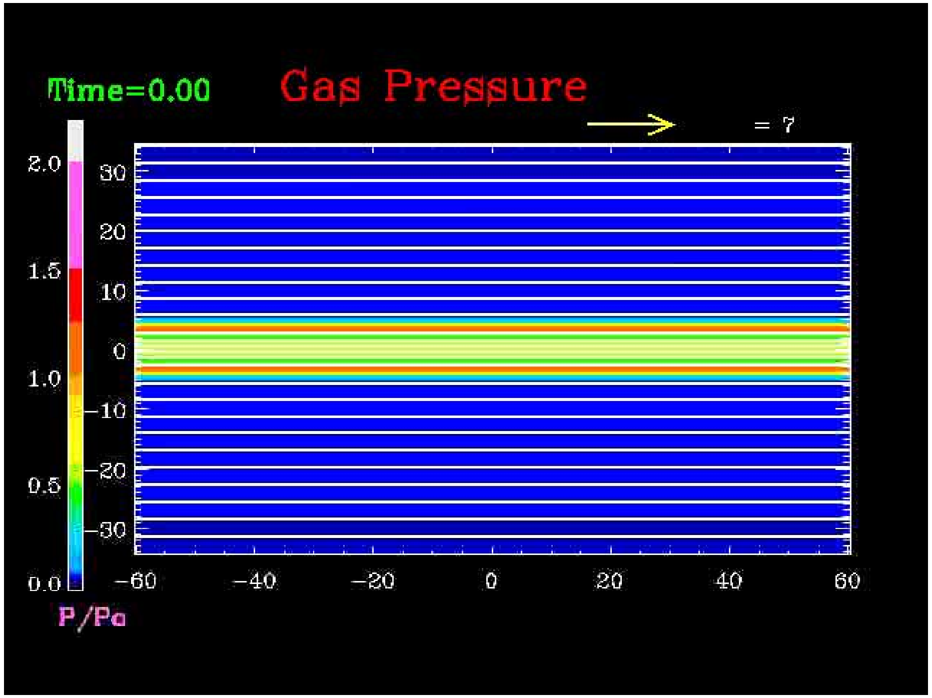
Magnetic Reconnection Triggered by Parker Instability in the Galaxy

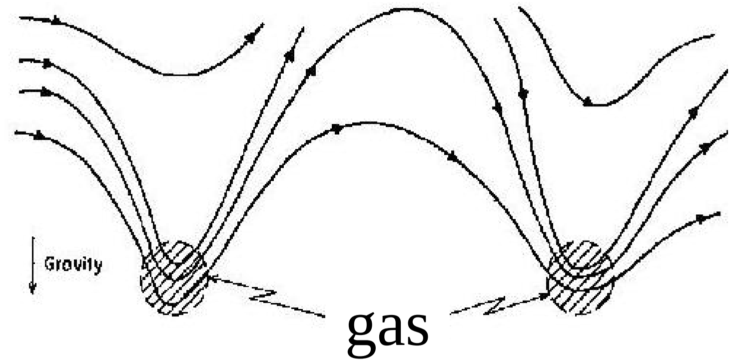
S.Tanuma
(Kwasan Observatory, Kyoto University)



See Tanuma, Yokoyama, Kudoh, Matsumoto, Shibata, & Makishima 2003, ApJ, 582, pp215-229

Parker Instability (Parker 1966)

- The Rayleigh-Taylor instability of magnetized gas supported by the gravity force



- Parker instability influences the locations and motion of gas clouds, OB associations (Sofue & Tosa 1974) and distribution of clouds (Mouschovias, Shu, & Woodward 1974; Blitz & Shu 1980).

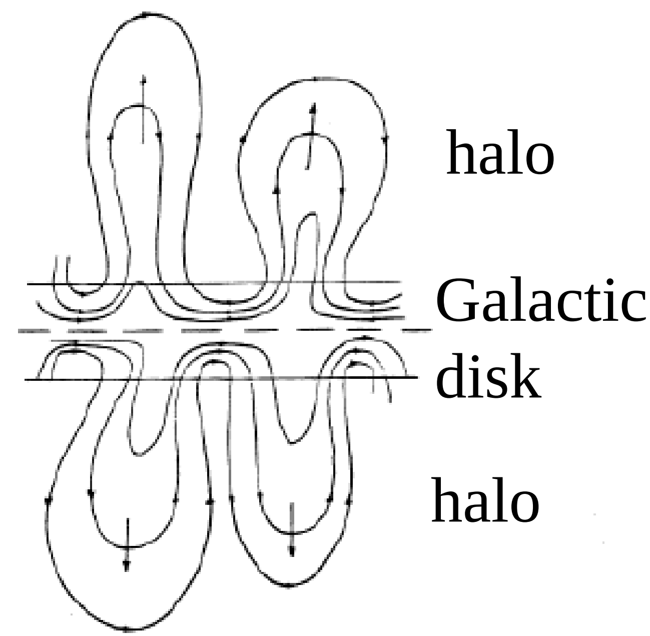
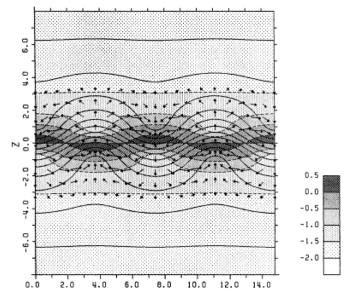


FIG. 2.—Schematic of the extended magnetic lobes inflated outward from both faces of the gaseous disk of the galaxy.

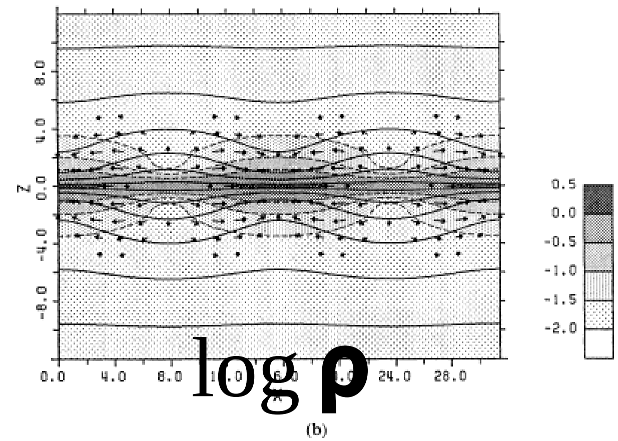
(Fig: Parker 1992; see also Sofue 1983 for Galactic magnetic field)

Parker Instability in the Galaxy

- Linear analysis (Horiuchi, Matsumoto, Hanawa, & Shibata 1988)



log ρ

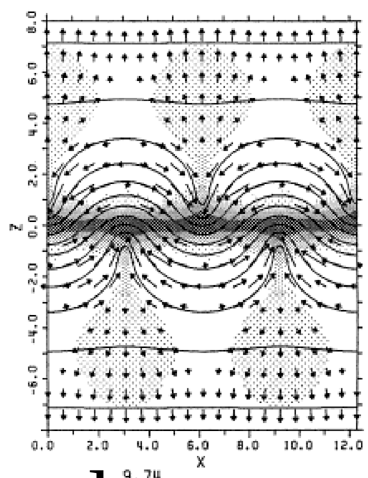


log ρ

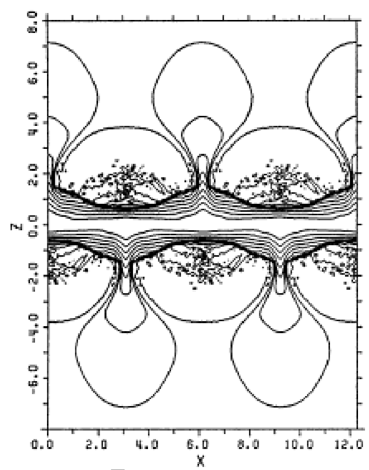
Even mode (glid-reflection mode)

Odd-mode (mirror mode)

- 2D nonlinear MHD simulation (Matsumoto Horiuchi, Shibata, & Hanawa 1988)



log ρ



log ρ

Related Studies on Parker Instability

- Linear Analysis
  - Parker-Jeans instability in the Galactic disk (Hanawa, F.Nakamura, & Nakano 1992; F.Nakamura, Hanawa, & Nakano 1991).
  - Giant molecular cloud formation by Parker instability in a skewed magnetic field (Hanawa, Matsumoto, & Shibata 1992).
  - Parker instability in a realistic gravitational disk (Giz & Shu 1993) and in differentially-rotating disks (Shu 1974), including the effect of cosmic rays.
- 2D MHD Simulation
  - Parker instability including the effect of cosmic rays (Kuwabara, K.Nakamura, & Ko 2004).

Aim of Our Research

- MHD Simulations
  - Parker instability in the solar atmosphere (e.g., Shibata et al. 1989 1992; Nozawa et al. 1992), and magnetic reconnection (e.g., Yokoyama & Shibata 1996)
  - Parker instability in the Galaxy (e.g., Matsumoto et al. 1988, 1998)
- We would like to apply these studies to the reconnection triggered by the Parker instability in the Galaxy; Heating of X-ray gas in the Galactic Halo.

X-ray Gas in the Galactic Halo

The Galactic halo has the X-ray gas:

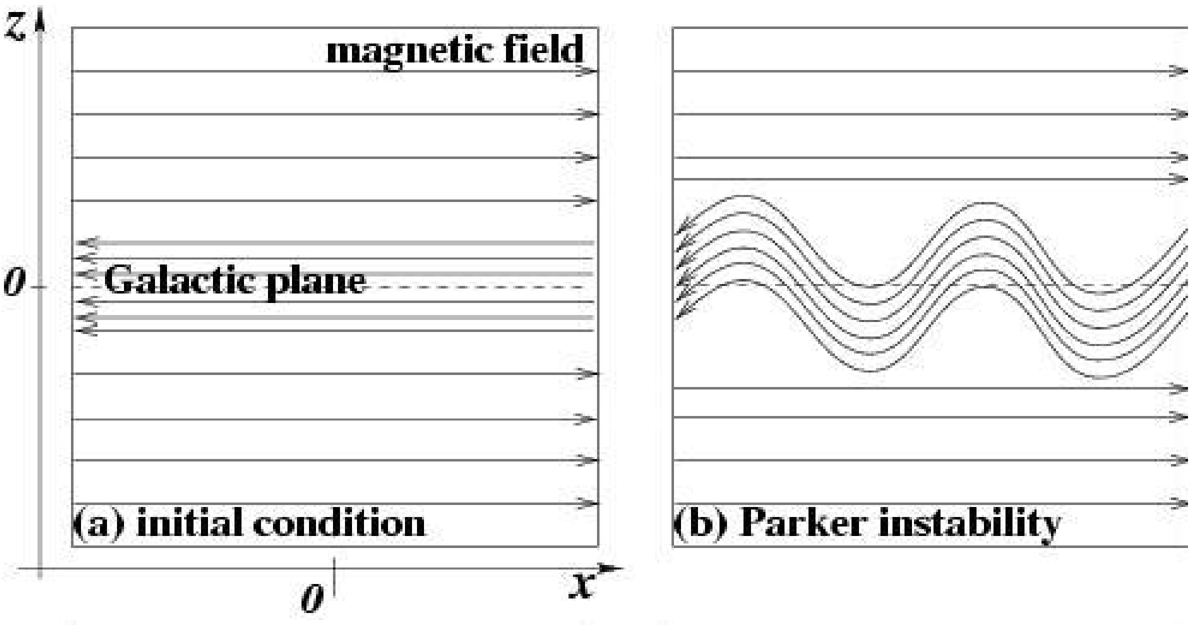
- Temperature $T > 10^6$ K
- Density $n \sim 10^{-3}$ cm^{-3}
- Volume $V \sim (10 \text{ kpc})^3 \sim 10^{66}$ cm^3
- Luminosity $L_X \sim 10^{39-40}$ erg s^{-1} (Pietz et al. 1996)
- Thermal energy $E \sim 10^{57}$ erg

Supernovae ("Galactic fountain"; Norman & Ikeuchi 1989) can not heat the X-ray gas enough (Birk et al. 1998).

We suggest that the reconnection triggered by Parker instability heats X-ray gas in the Galactic halo.

(Tanuma et al. 2003, ApJ, 582, 215)

Numerical Model



Cold, dense disk and hot, rarefied halo

MHD equilibrium, horizontal field, β=0.2 (B=7μG), periodic oundaries at right and left surfaces

Random perturbation in the Galactic disk (<0.05Cso)

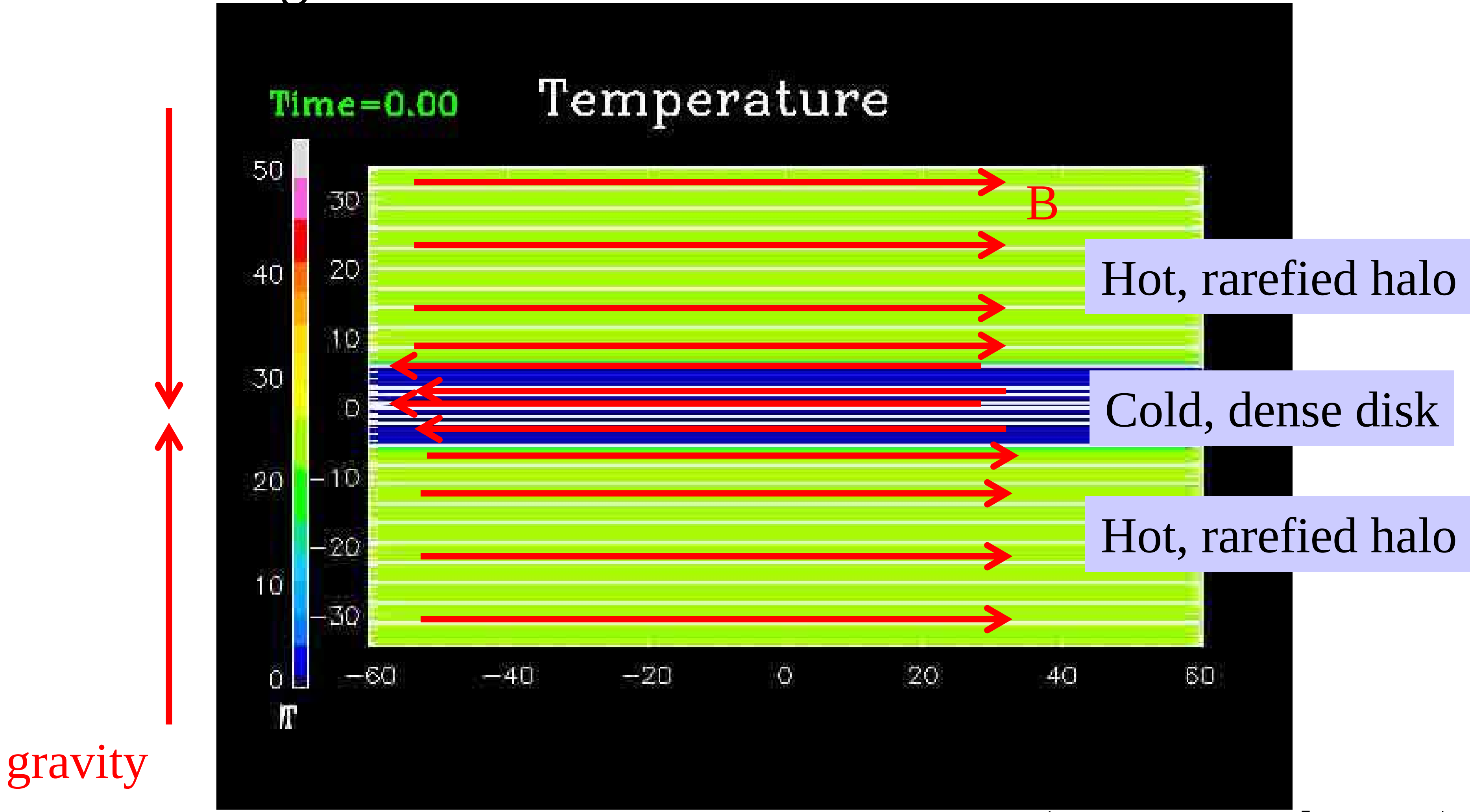
Anomalous resistivity (which sets in J/ρ >400)

Normalization Units

- Length: Gravitational scale height without the magnetic field= $H_0 = 100\ \text{pc}$
- Velocity: Sound speed at the midplane= $C_{s0} = 10\ \text{km/s}$
- Time: $\tau = H / C_{s0} = 10^7\ \text{yr}$
- Density at the midplane : $\rho_0 = 1 \times 10^{-25}\ \text{g/cc}$
- Gas presure at the midplane : $P_{go} = 4 \times 10^{-13}\ \text{erg/cc}$
- Magnetic field strength at the midplane: $B_o = 3.2\ \mu\text{G}$
- Grid number: (Nx, Nz)=(403, 604)
- Grid size: dx=0.3, dz>0.075
- Simulation box: |x|<30.0, |z|<34.5

Temperature

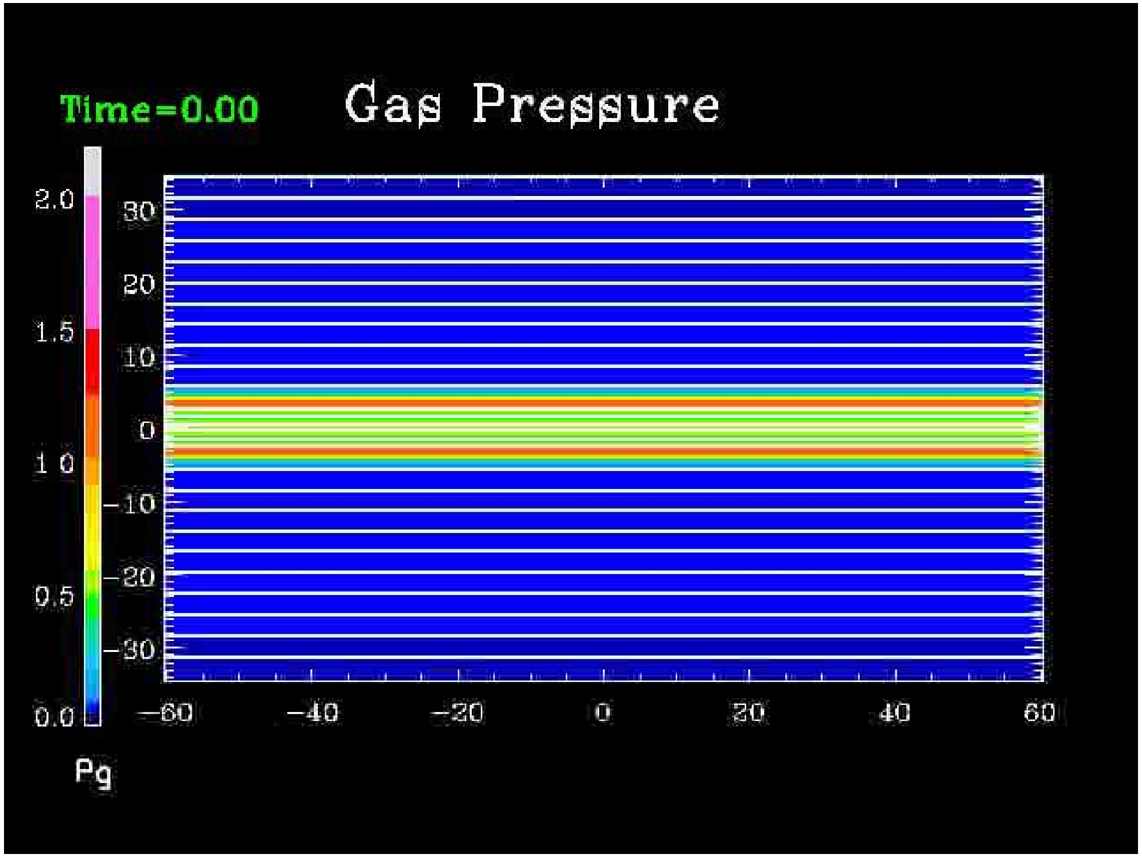
- The reconnection is triggered by Parker instability, and heats the gas in the Galactic halo.



(Tanuma et al. 2003)

Gas Pressure

Parker instability occurs in the Galaxy, and make many gas clouds in the Galactic disk (see also Matsumoto et al. 1988; Sofue & Tosa 1974)



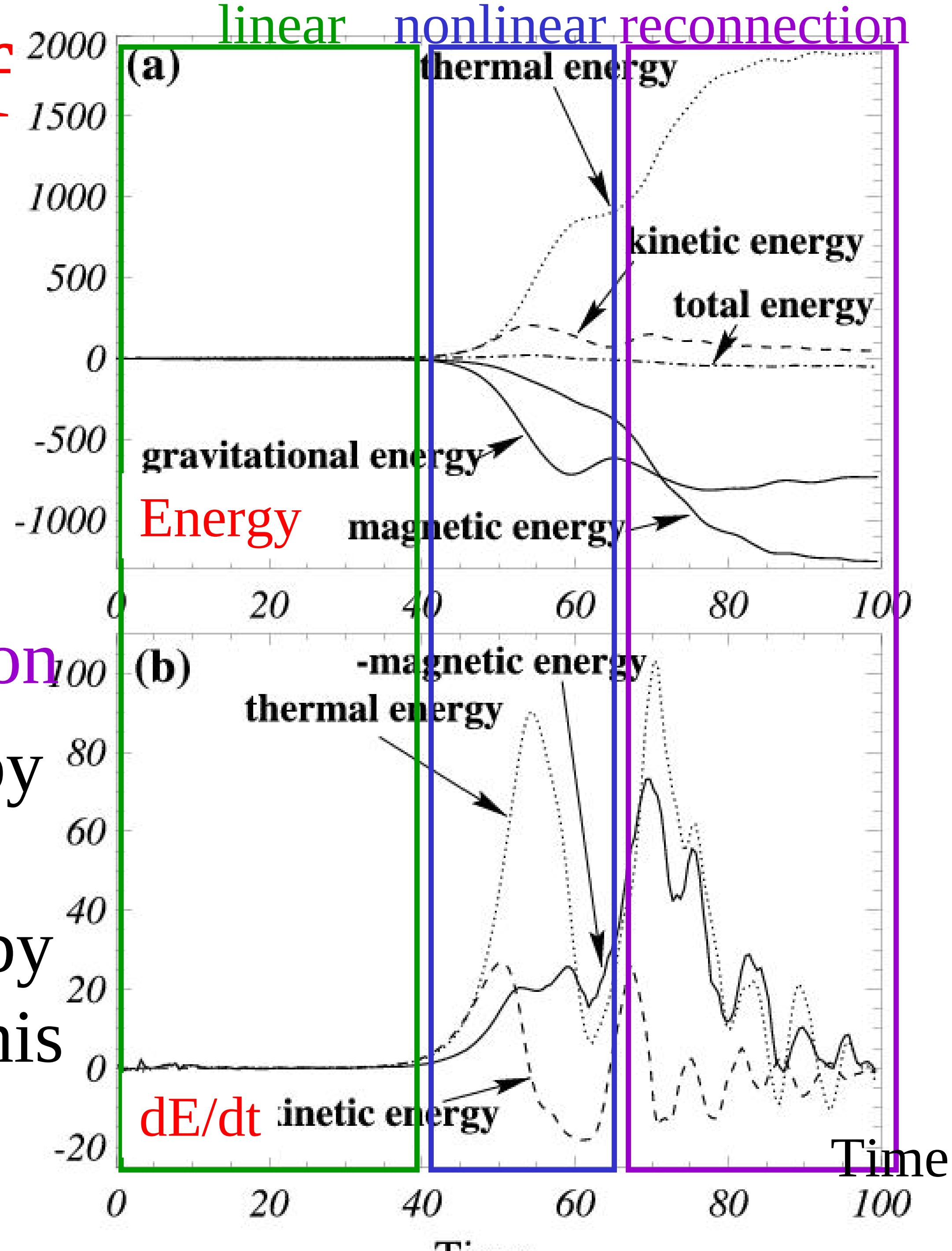
Time variation of various energies

(1)Linear phase,

(2)Nonlinear phase of Parker instability,

(3)Magnetic reconnection

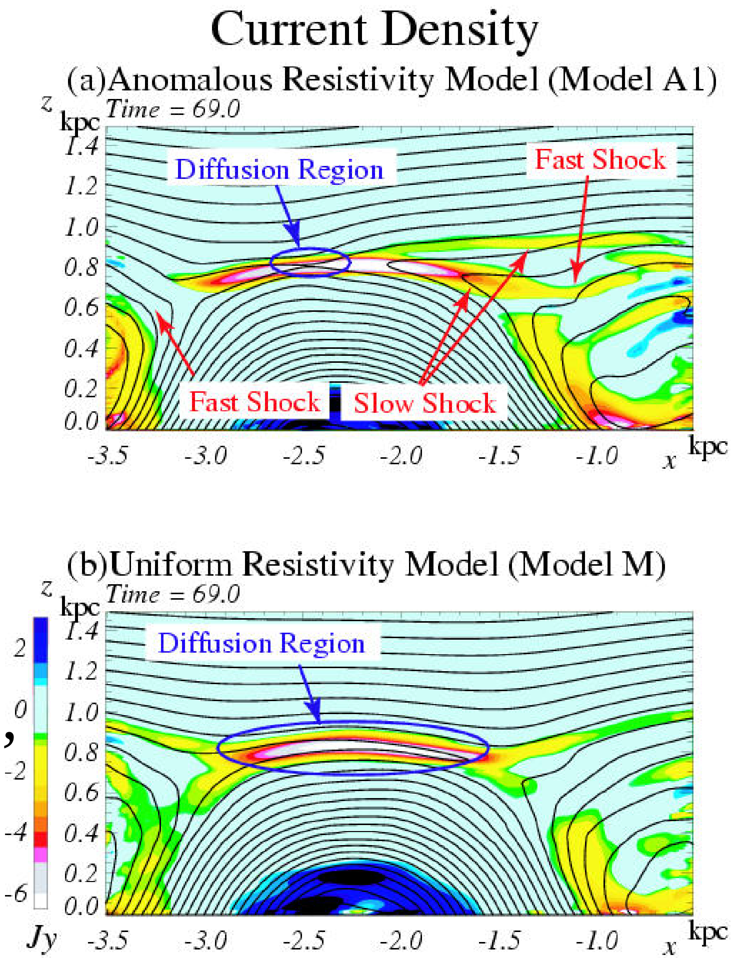
- The released energy by the reconnection is 3 times more than that by Parker instability in this numerical model.



Dependence of Current Density on Resistivity model

(a) Anomalous resistivity model
Petschek-like reconnection occurs.
Small diffusion region, slow shocks, and fast shocks are created.

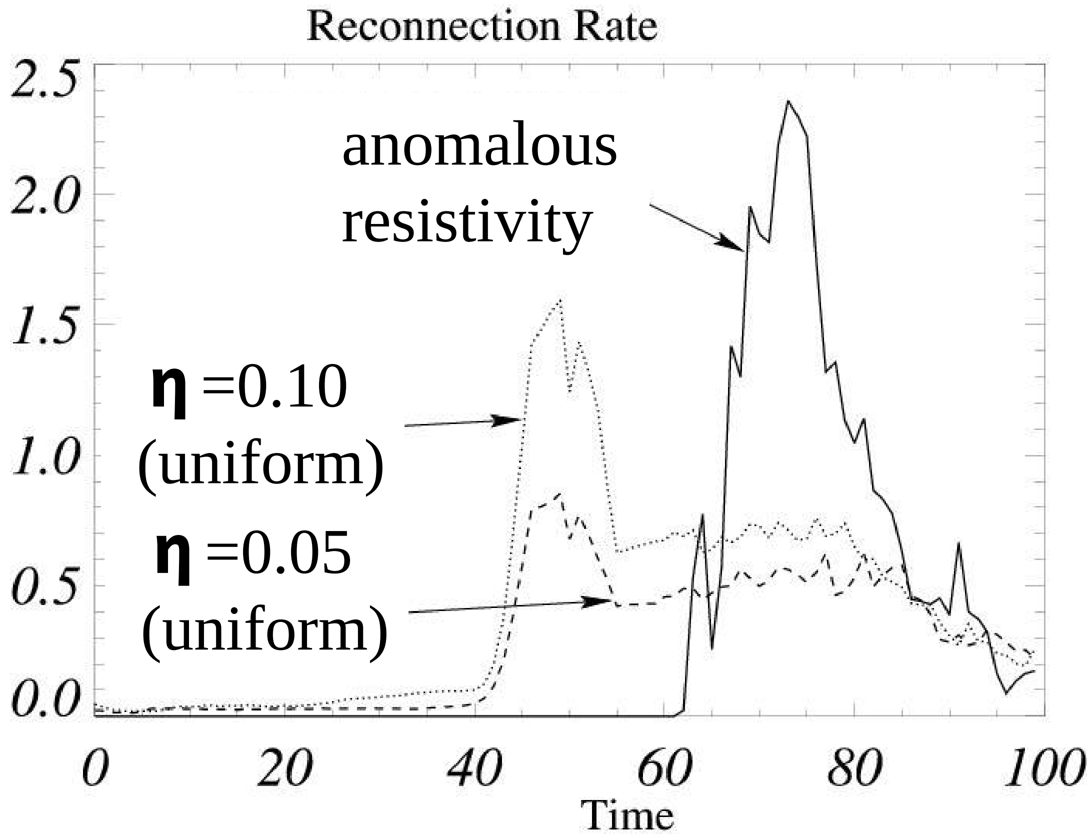
(b) Uniform resistivity model
Sweet-Parker-like reconnection occurs,
Long diffusion region are created.



Time Variation of Reconnection Rate.

- Magnetic reconnection rate (i.e., energy release rate) is higher in anomalous resistivity model than that in the uniform resistivity model.

Reconnection rate is defined by η J.



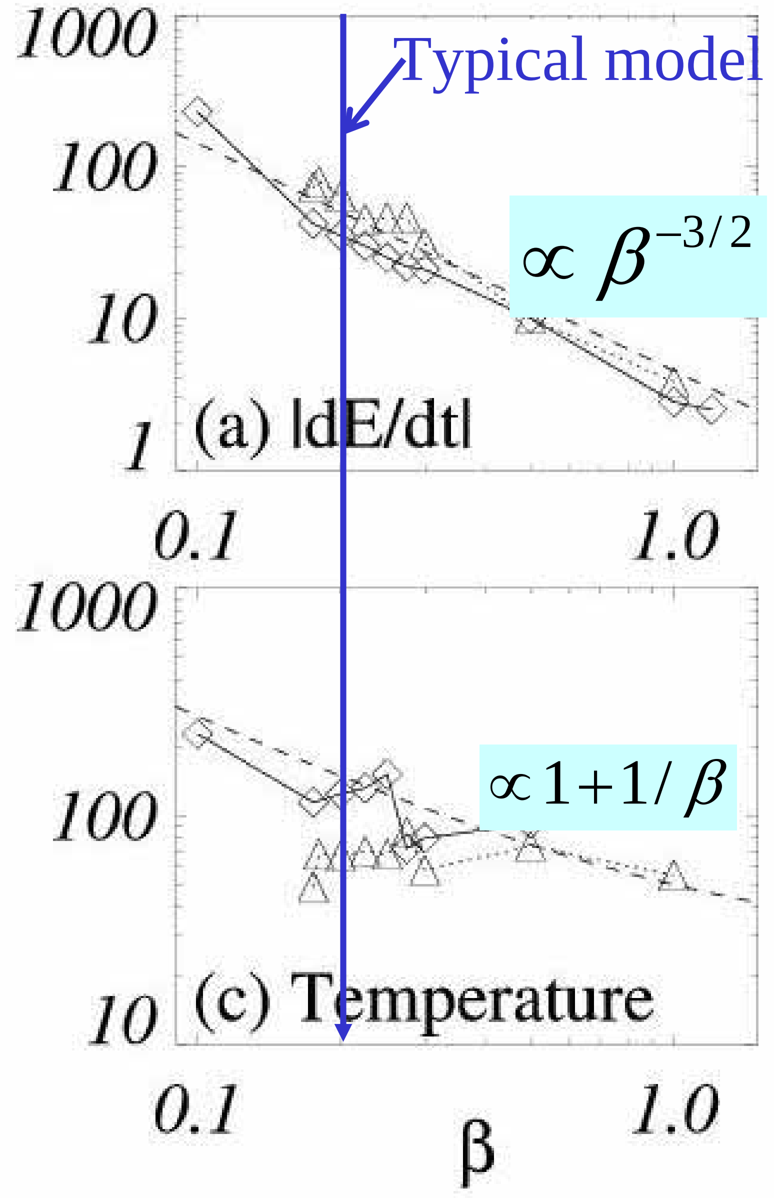
Dependence of the Resuls on Plasma β

Magnetic energy release rate is determined by Poynting flux toward diffusion region:

$$|\partial E/\partial t| \propto \beta^{-3/2}$$

Temperature is determined by energy conservation:

$$T = (1 + 1/\beta) T_0$$



The Actual Galactic Halo

If magnetic field with the strength of 3 μG releases the energy by the reconnection, it heats gas to

$$T \sim 10^{6} \left(\frac{n}{10^{-3}\ \mathrm{cm}^{-3}} \right)^{-1} \left(\frac{B}{3\ \mu\mathrm{G}} \right)^{2}\ \mathrm{K}$$

the magnetic energy release rate is

$$\frac{E}{t} \sim 10^{40} \left(\frac{B}{3\ \mu\mathrm{G}} \right)^{3} \left(\frac{\lambda}{1\ \mathrm{kpc}} \right)^{2} \left(\frac{n}{10^{-3}\ \mathrm{cm}^{-3}} \right)^{-1/2}\ \mathrm{erg\ s}^{-1}$$

(1

The heated gas is confined in the time

$$\tau_{\mathrm{cond}} \sim 10^{9} \left(\frac{n}{10^{-3}\ \mathrm{cm}^{-3}} \right) \left(\frac{\lambda_{\mathrm{eff}}}{3\ \mathrm{kpc}} \right)^{2} \left(\frac{T}{10^{6}\ \mathrm{K}} \right)^{-5/2}\ \mathrm{yr}$$

by the magnetic field (helical or random field).

So, the reconnection can explain the origin of X-ray gas in the Galactic halo.

Summary

- We perform 2D MHD Simulations of the magnetic reconnection triggered by the Parker instability in the Galaxy.
- As the results, in the Galactic halo X-ray gas is created by the reconnection triggered by the Parker instability.
- We suggest that the actual X-ray gas can be heated by the reconnection in the Galactic halo.
- We also suggest that the heating and particle acceleration by the reconnection can occur in the Galactic center and Galactic disk as well as solar corona.

Cooling Time in the Galactic Halo

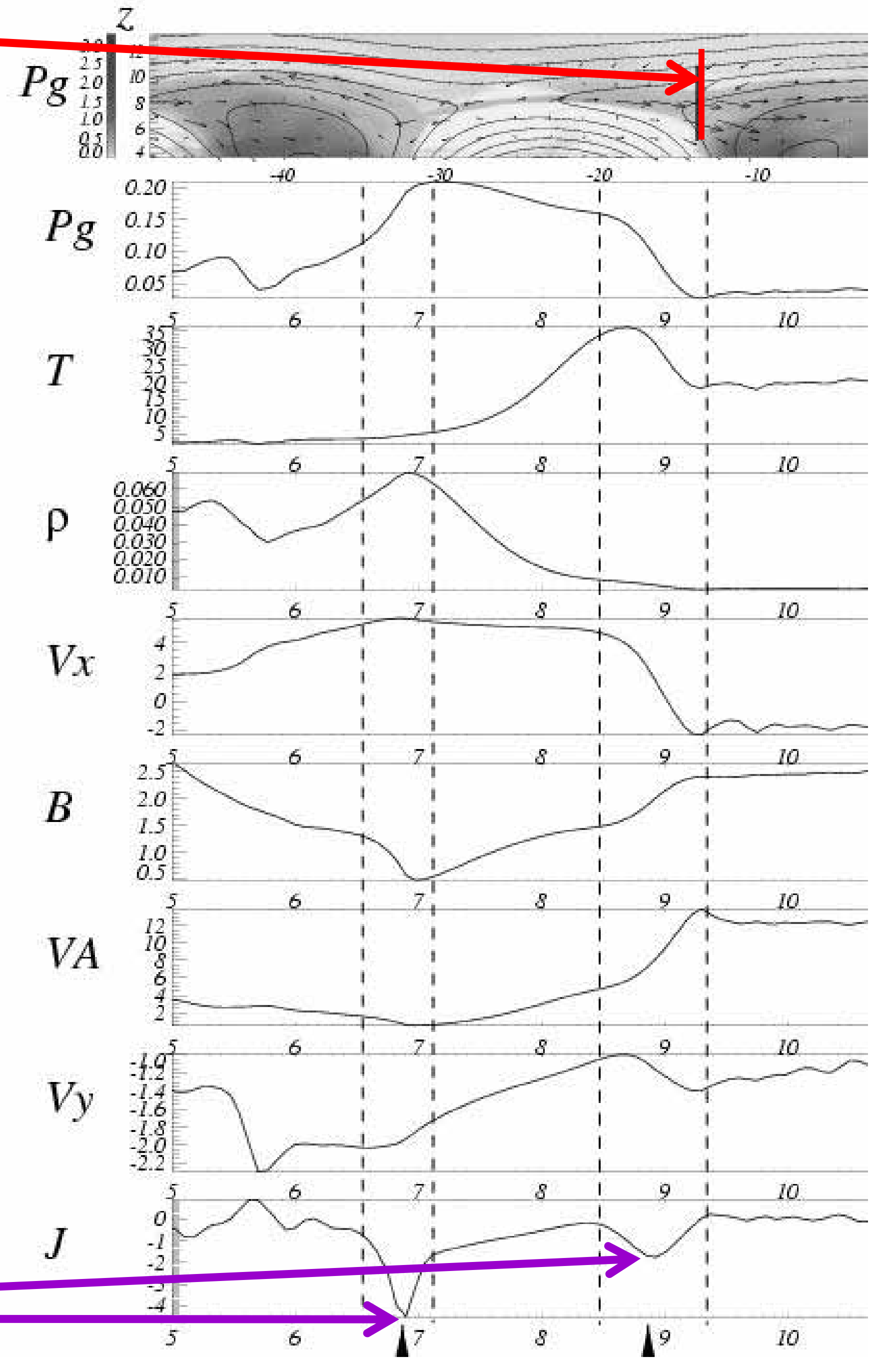
$$\tau_{cond} = 10^9 \left(\frac{n}{10^{-3}\ \mathrm{cc}} \right) \left(\frac{\lambda_{eff}}{3\,\mathrm{kpc}} \right)^2 \left(\frac{T}{10^6\ \mathrm{K}} \right)^{-5/2} \ \mathrm{yr}$$

$$\tau_{\mathrm{rad}} = 10^9 \left(\frac{T}{10^6\ \mathrm{K}} \right) \left(\frac{n}{10^{-3}\ \mathrm{cc}} \right)^{-1} \left(\frac{\Lambda(10^6\ \mathrm{K})}{10^{-23}\ \mathrm{erg\,cc\,s^{-1}}} \right)^{-1} \ \mathrm{yr}$$

- They are longerer than typical time scale of Parker instability (10^8 yr)

Slow shocks

- The pairs of facing low shocks between the reconnection jet are created by Petschek-like fast reconnection in the Galactic halo



Two peaks in current density profile shows that the slow shocks are created.

Numerical Grid and Simulation Region Size

- $(N_x, N_z)=(403, 604)$
- $dx=0.3$, $dz>0.075$
- $|x|<30.0$, $|z|<34.5$

Current Density

Strong current sheets are created by the Parker instability.