Dissipation of Magnetic Fields in low-metallicity clouds

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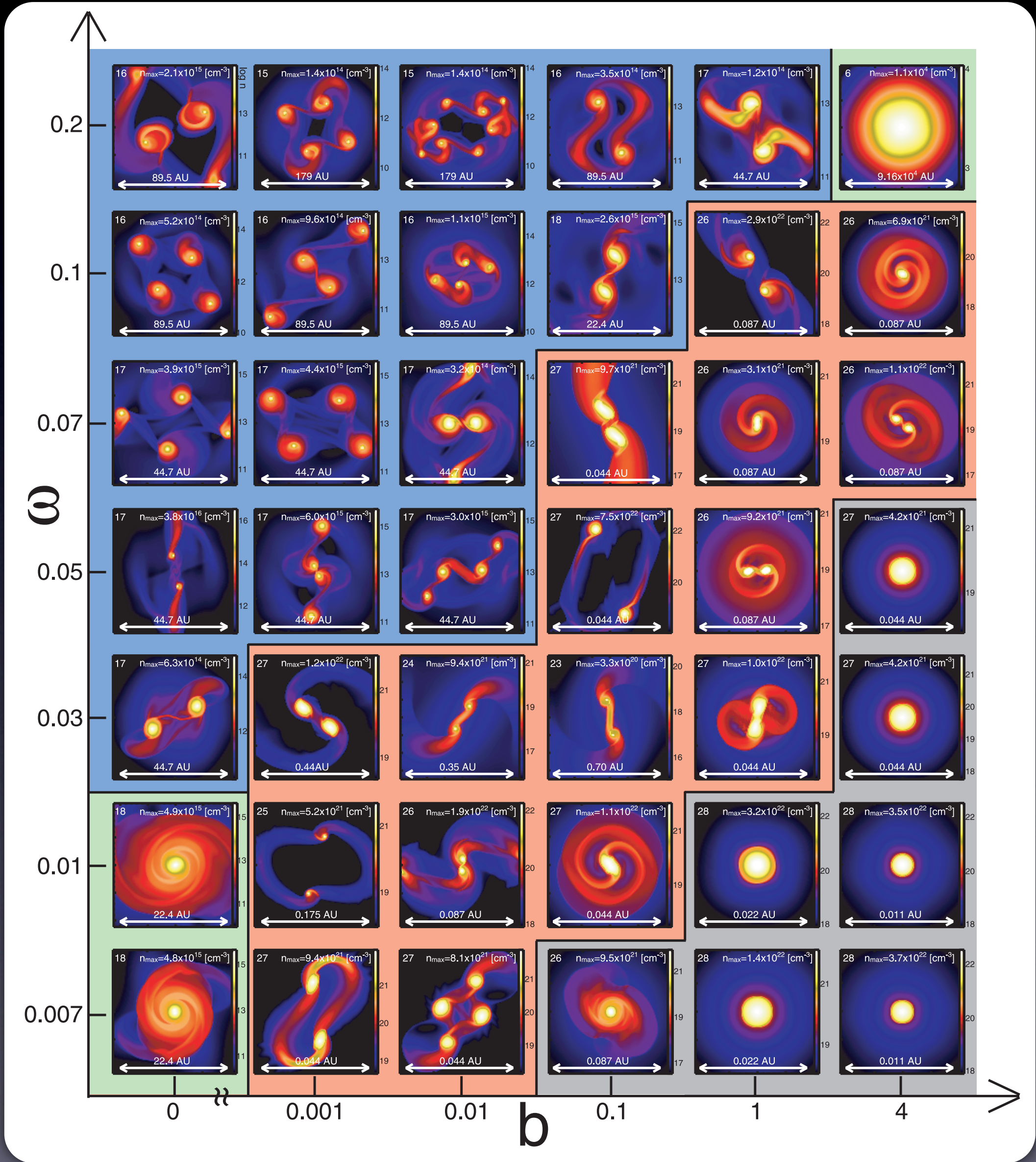
Effects of Magnetic Field on Star Formation



Machida+ 08

<u>The magnetic field stabilizes the gas cloud.</u>

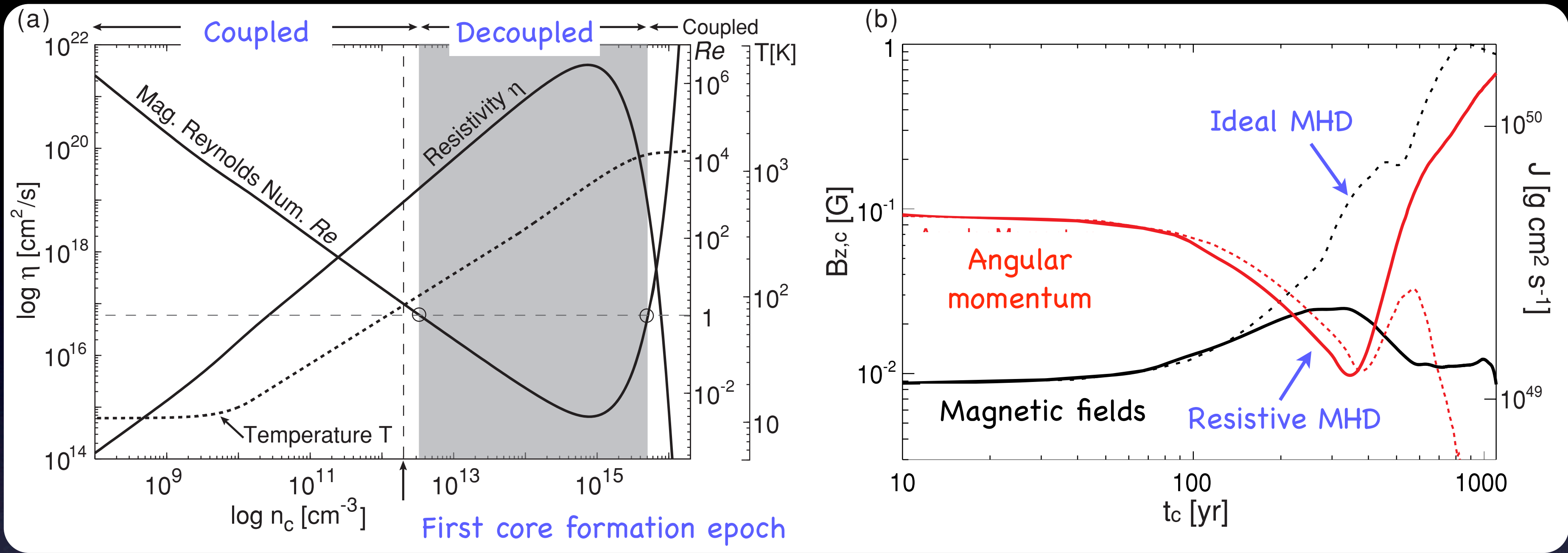
If the magntic field is sufficiently strong

Single star

If the energy of the magnetic field is weaker than the rotational energy

Fragmentation

Importance of Dissipation on Star Formation in ISM



Machida+ 09

- Ideal model
  - The magnetic field continues to increase, while the angular momentum decreases by magnetic breaking.
- Resistive model
  - The magnetic field begins to decrease, since the magnetic field is effectively removed from the adiabatic core.
  - The adiabatic core has a larger angular momentum than that in the ideal model.

Dissipation Velocity

Velocity of field line relative to the neutrals

$$v_{Bx} = \frac{A_1}{A}\frac{1}{c}(\boldsymbol{j} \times \boldsymbol{B})_x$$

Nakano & Umebayashi (1986)

$$A = A_1^2 + A_2^2 \quad A_1 = \sum_\nu \frac{\rho_\nu \tau_\nu \omega_\nu^2}{1+\tau_\nu^2\omega_\nu^2} \quad A_2 = \sum_\nu \frac{\rho_\nu \omega_\nu}{1+\tau_\nu^2\omega_\nu^2}$$

ρ_ν : density of charged particles

τ_ν : viscous damping time

ω_ν : cyclotron frequency

Ambipolar diffusion ($|\tau_i\omega_i| > 1$)

$$v_B \simeq \frac{\tau_i}{\rho_i}\frac{1}{c}(\mathbf{j} \times \mathbf{B})_x \simeq \frac{\tau_\nu}{\rho_\nu}\frac{B^2}{4\pi R}$$

R : radius of the cloud (Jeans scale)

Ohmic dissipation ($|\tau_i\omega_i| < 1$)

$$v_B \simeq \frac{c^2}{B^2\sigma_c}\frac{1}{c}(\mathbf{j} \times \mathbf{B})_x \simeq \frac{c^2}{4\pi\sigma_c R}$$

σ_c : electric conductivity

Dissipation Velocity by the ohmic dissipation

Ohmic dissipation

Velocity of dissipation $v_B \simeq \dfrac{c^2}{4\pi\sigma_c R}$

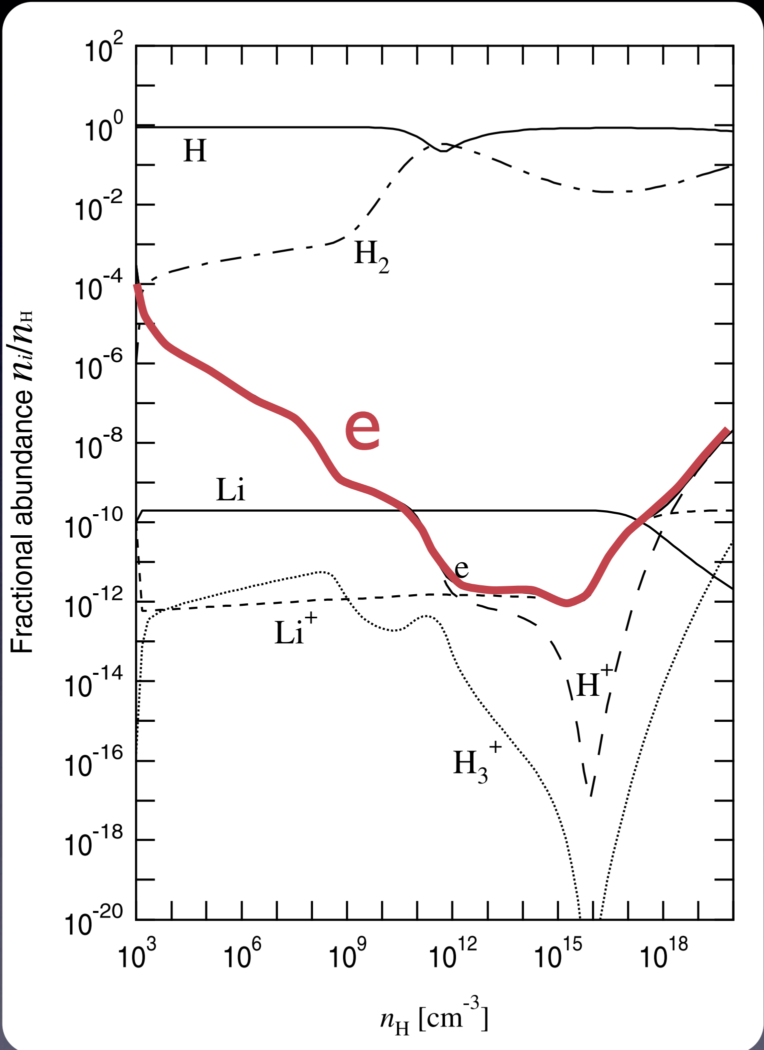
The electric conductivity become larger,
as the mass of main charged particle is large.

↓

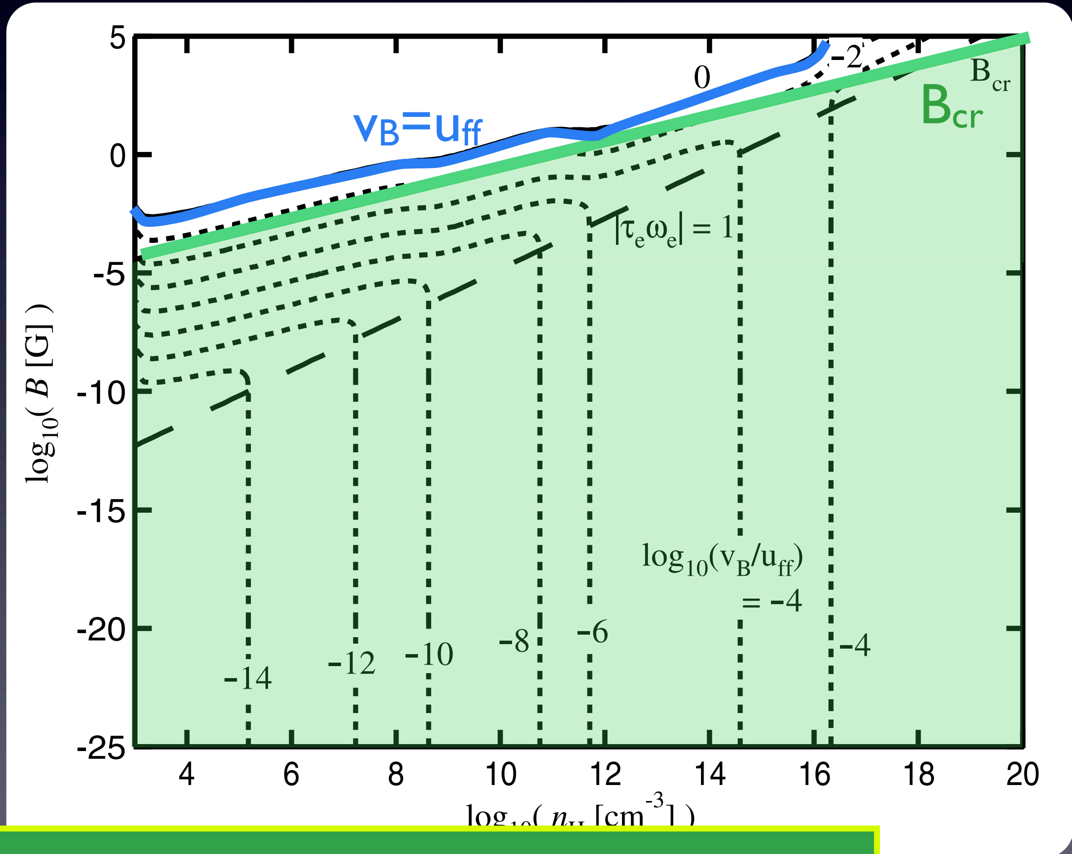
If the main charged particles is the grains,
ohmic dissipation is grater.

→ The mass of main charged particle is crucial for the dissipation velocity.

Dissipation of Magnetic Field in Primordial Gas Clouds



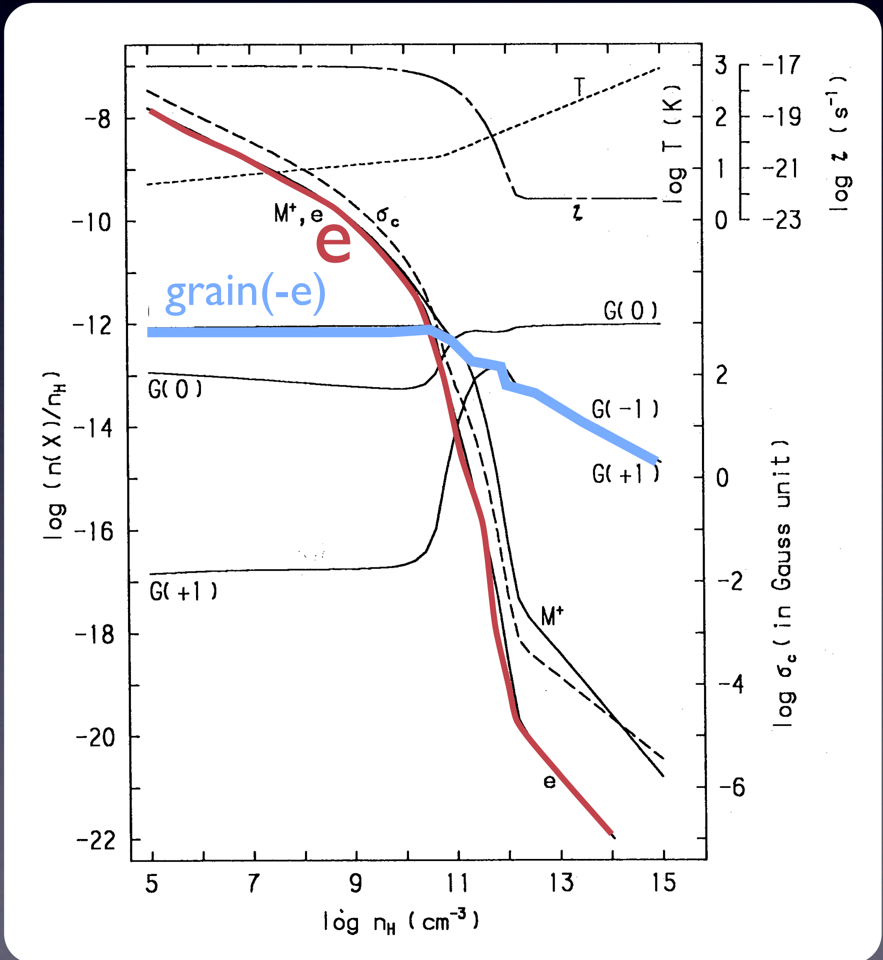
Maki & Susa (2004)

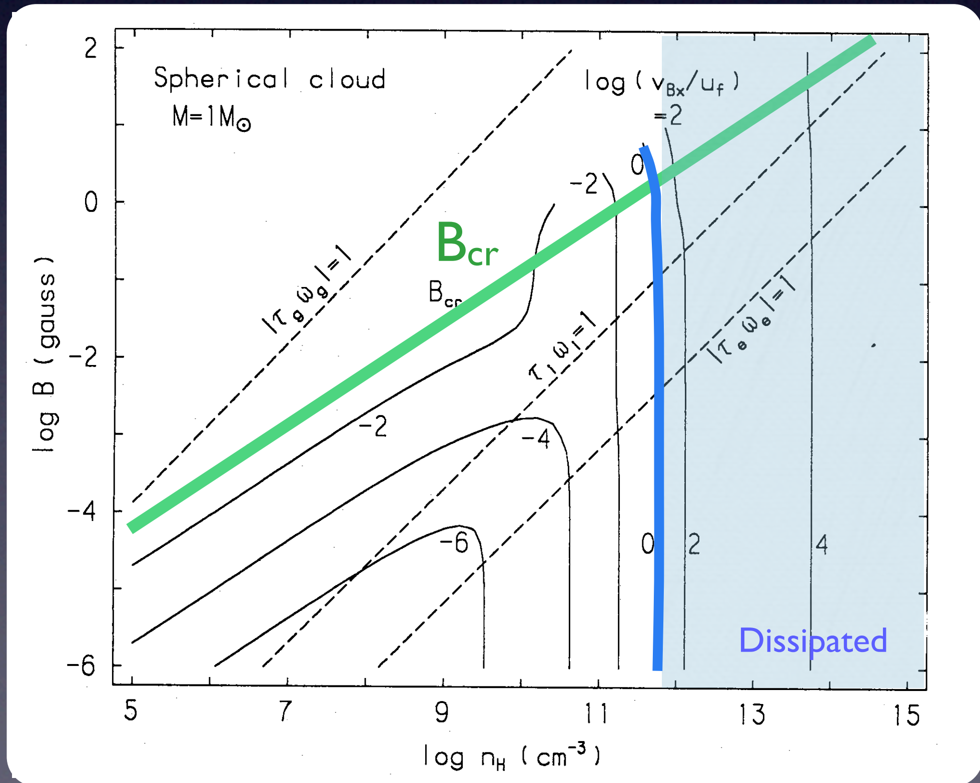


Magnetic field is always frozen to the gas.

Dissipation of Magnetic Field in Interstellar Gas Clouds

Nakano & Umebayashi(1986)





- In primordial gas, the magnetic field is frozen to the gas.
- In interstellar gas, the magnetic field dissipate from the gas for $n_H > 10^{12}$[cm^{-3}].

➡What is critical metallicity above which the magnetic field dissipate from the gas?

We investigate the dissipation of the magnetic field for the collapsing gas clouds with various metallicities.

Method

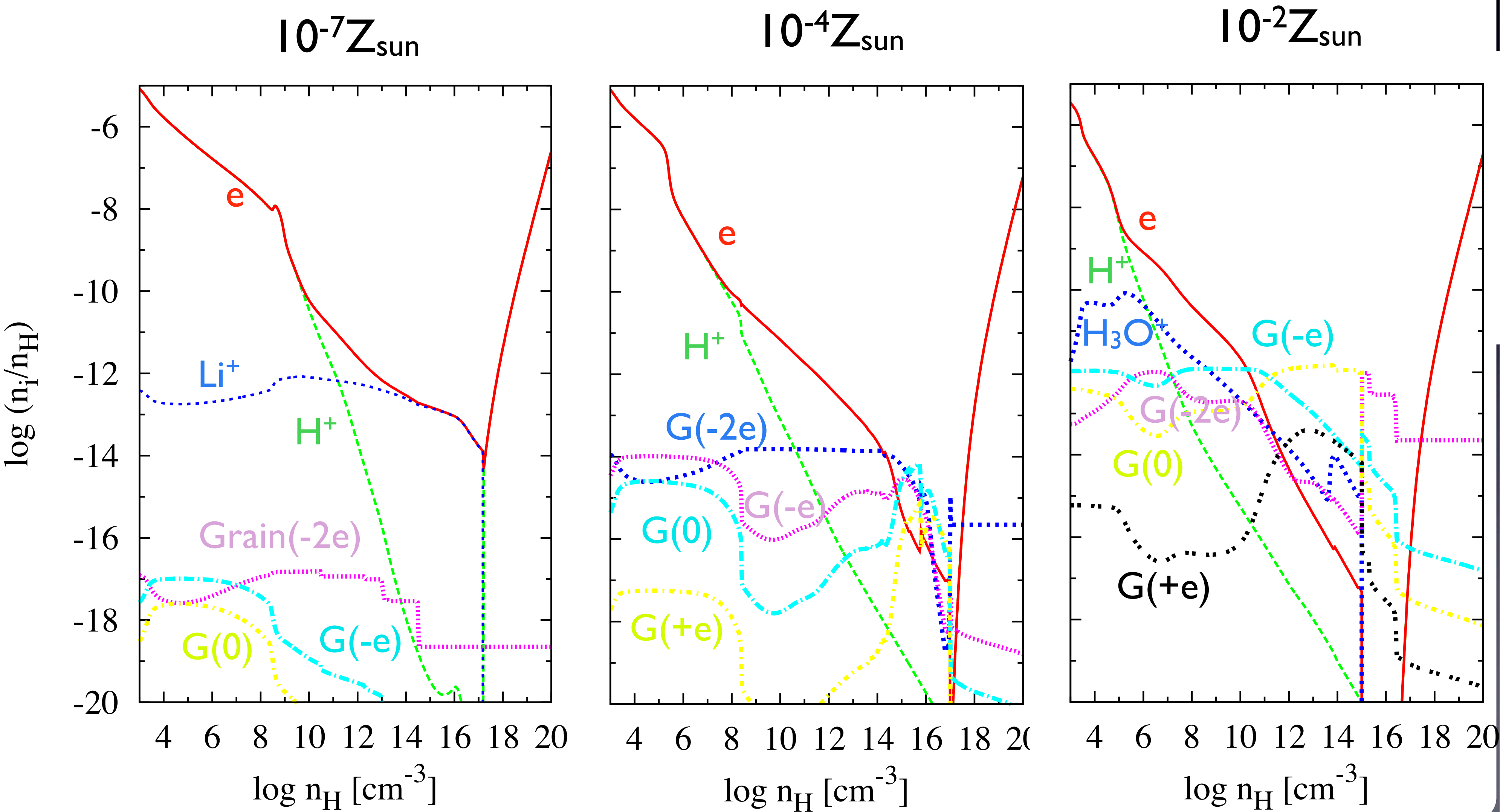
- 1 zone
- Energy eq. + nonequilibrium chemical reaction
- H,He,D,Li,C,O....

  Dust grain : 0, ±e, ±2e(Density:3[g cm^{-3}, standard MRN distribution)

  →63 species
- Mass fraction of grain : 0.939×10^{-2} (Z/Z☉)
- Cosmic Ray : 10^{-2} × ISM (ξ_{CR} = 1.3 × 10^{-19} [s^{-1}]) Stacy & Bromm 07
- Radioactive Elements : Short+Long lived (ξ_{RA}=7.6×10^{-19} [s^{-1}])

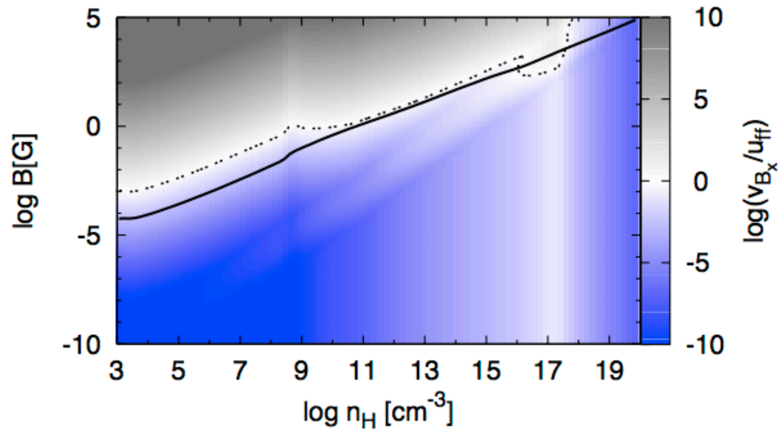
  Umebayashi & Nakano 09

Results
(Chemical evolution)

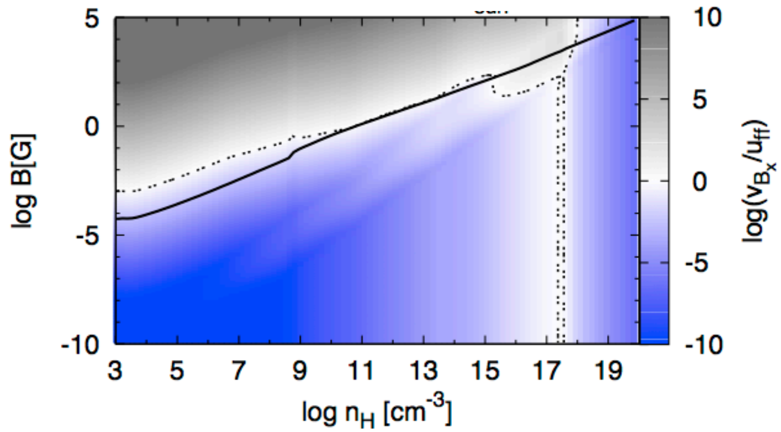


Dissipation of Magnetic Field

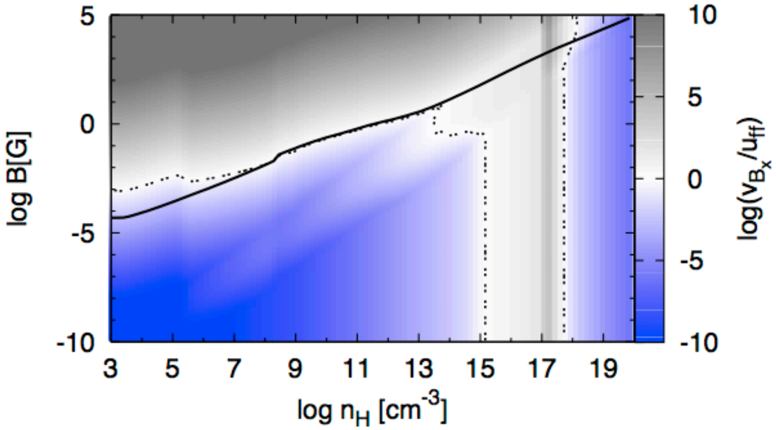
$10^{-7}Z_{sun}$



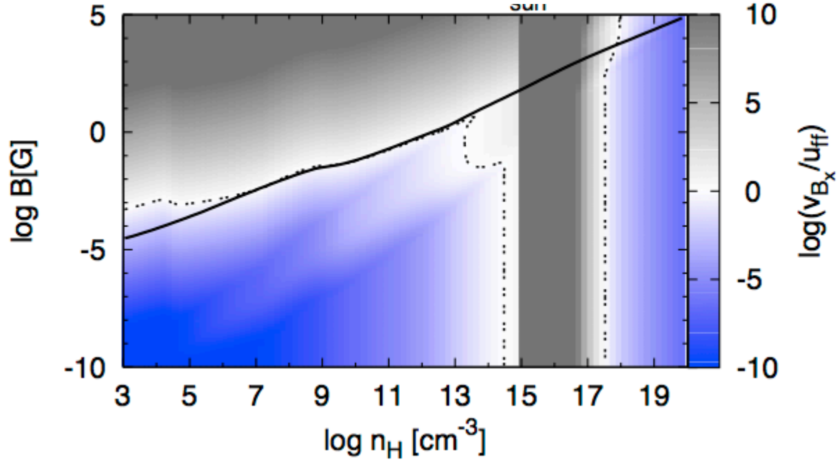
$10^{-6}Z_{sun}$



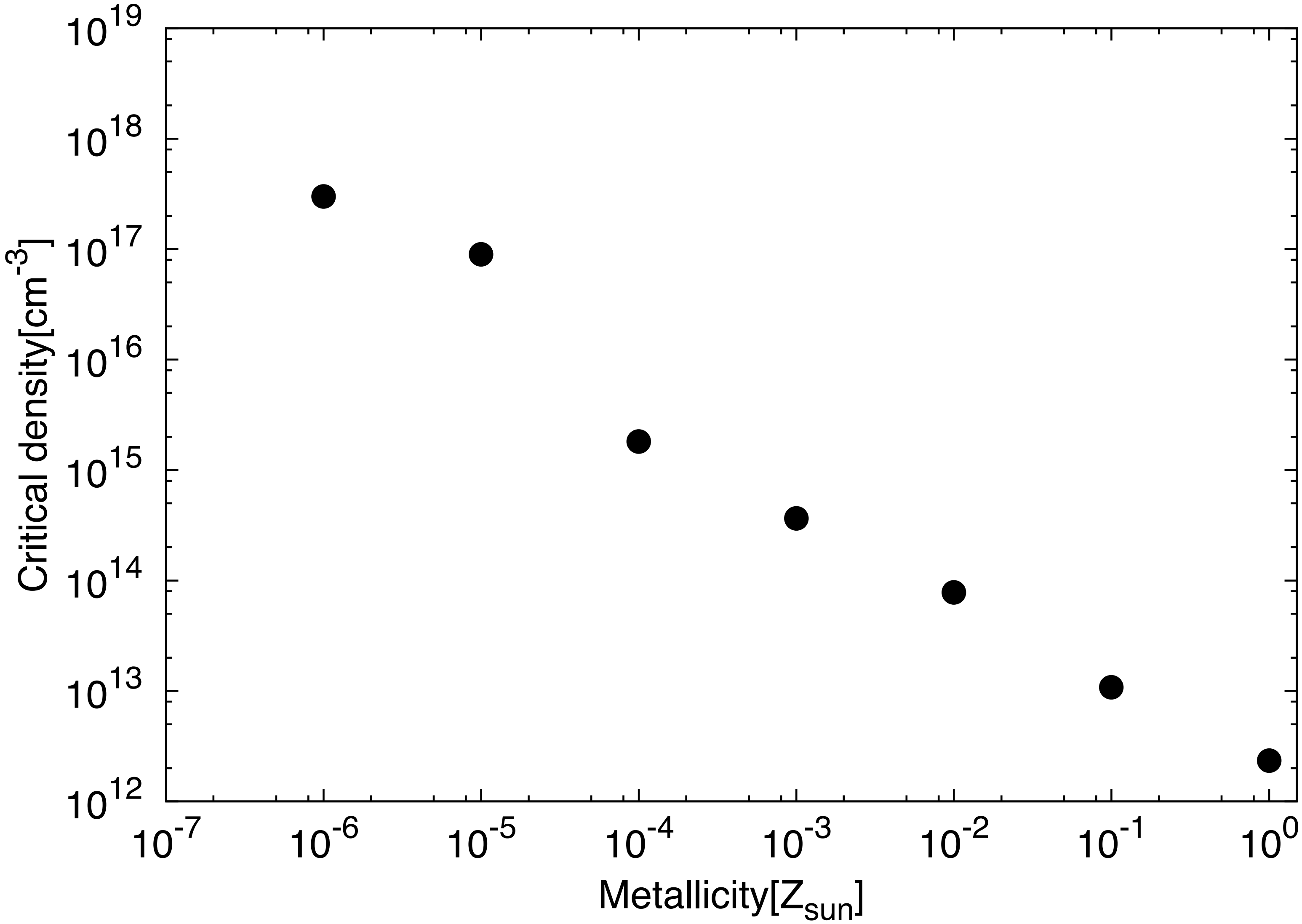
$10^{-4}Z_{sun}$



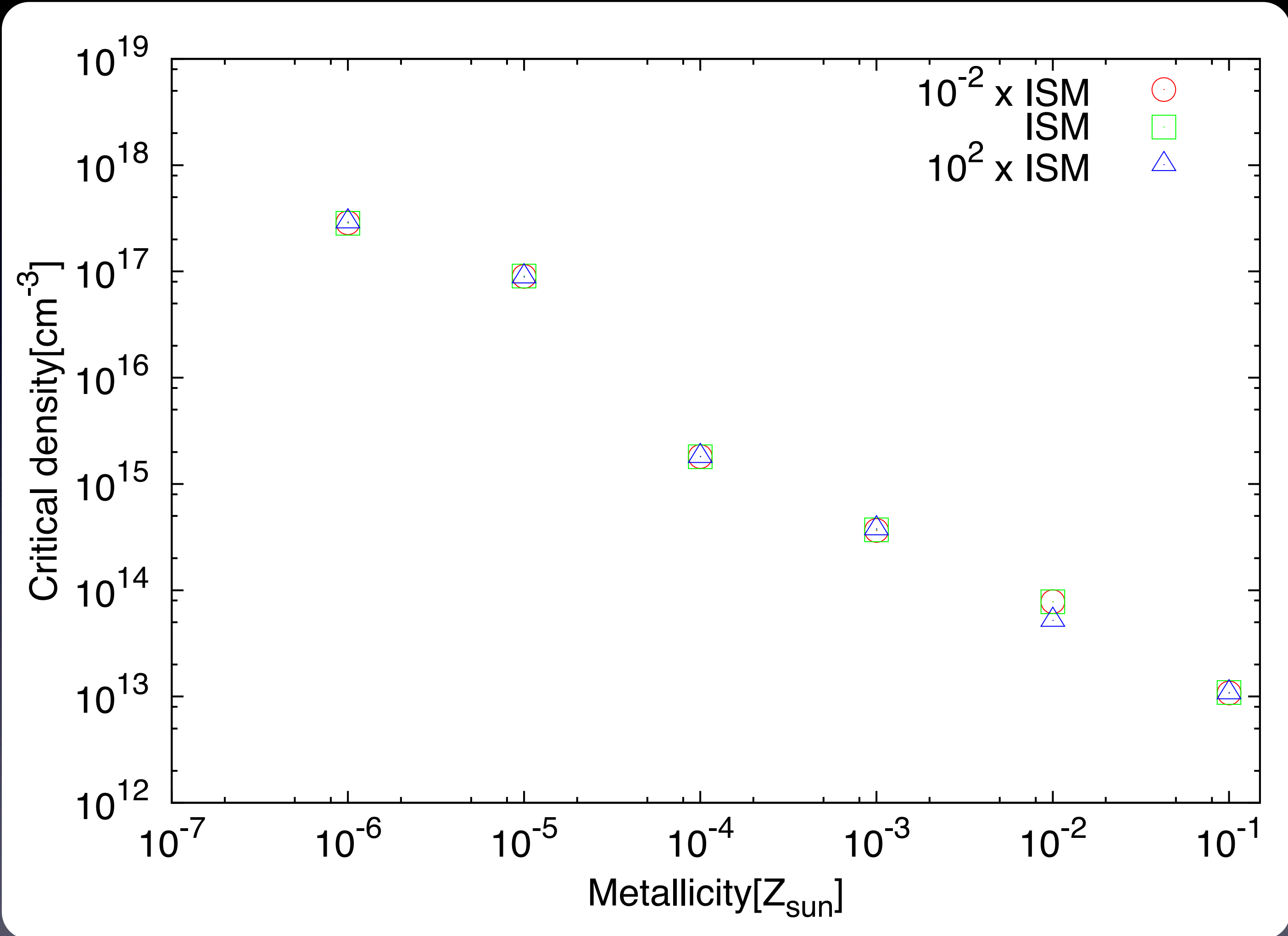
$10^{-3}Z_{sun}$



Dissipation of Magnetic Field

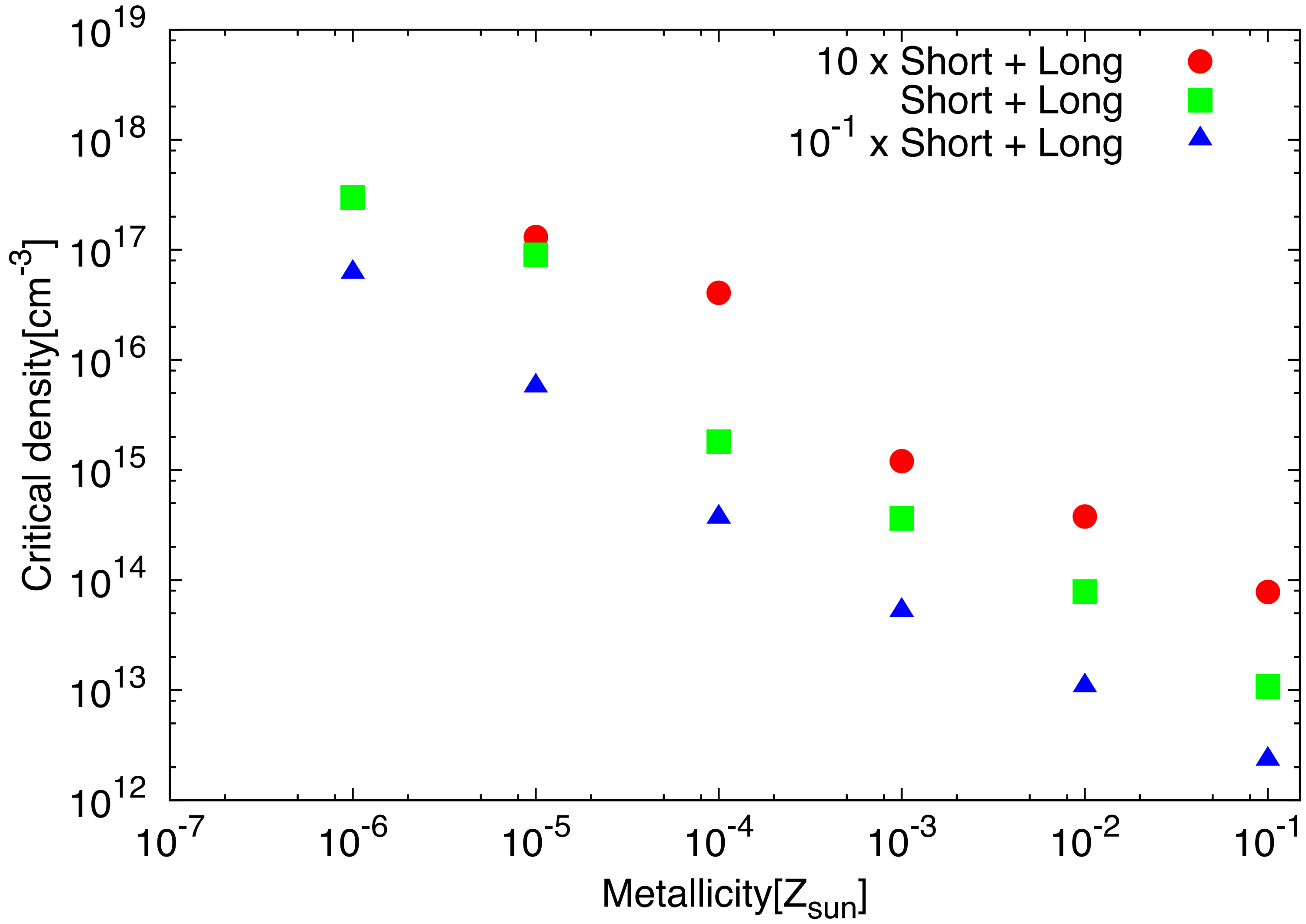


Effects of the cosmic ray



The cosmic ray not affect the critical density, since the cosmic ray is shielded at high density .

Effects of the radioactive elements



Summary

- We calculate the dissipation of magnetic fields in low-metallicity clouds.
- The critical metallicity above which the magnetic field dissipate from the gas is 10^{-7} - 10^{-6} $Z_{\odot}$.
- The radioactive elements affect to the dissipation of the magnetic fields.