2 D MHD Simulations of Protostellar Flare including Heat Conducton

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Abstract

A disk flare model successfully explains strong X-ray activities of young stellar objects. We simulate the disk flare to study changes of disk structure induced by a magnetic reconnection in the corona surroundings the protostar and disk.

We carried out 2 dimensional magnetohydrodynamic simulations by taking account of heat conduction. Accumulated magnetic energy by the disk rotation was released by a magnetic reconnection and transported along the magnetic field line to the disk and central star.

We show the influence of the disk flare on the disk structure, especially we obtain the time dependence of the emission measure and maximum temperature.

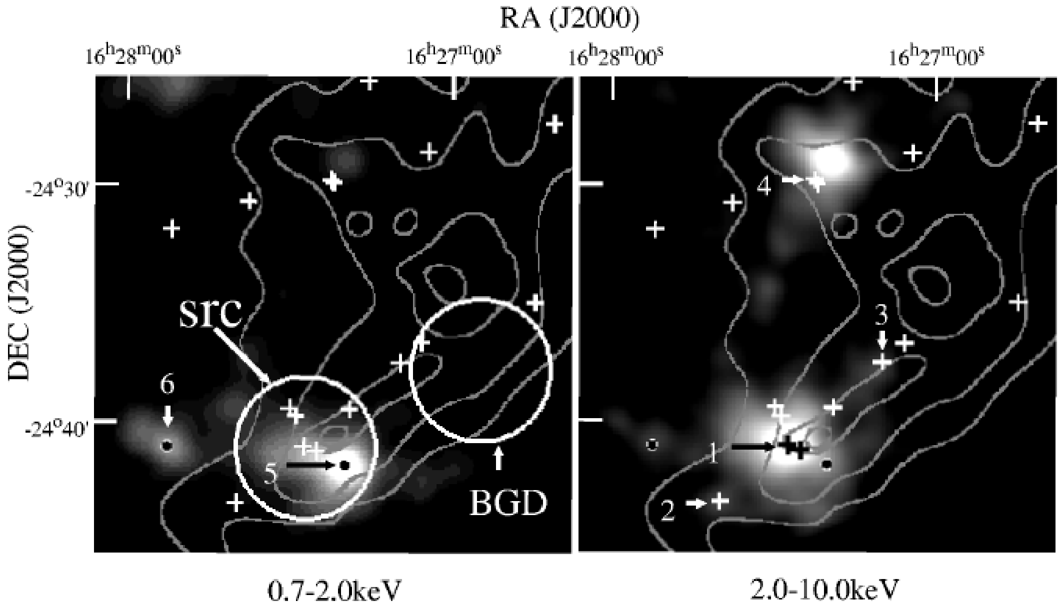
Introduction

- Observation

  Class I Protostar Flare

  Total Energy Release: E ~10^{35-37}ergs

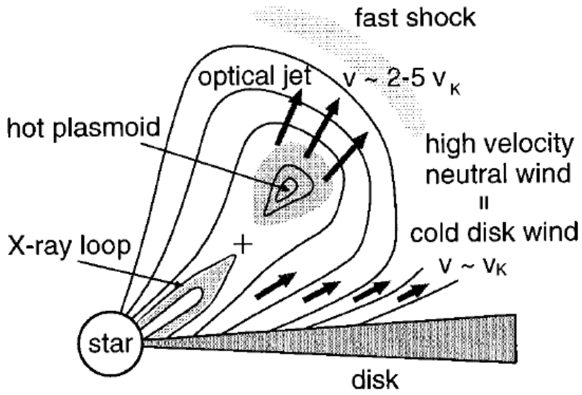
  Temperature: T_{max}~$1.5*10^8$K



ϱOph (Y. Tsuboi et al. 2000)

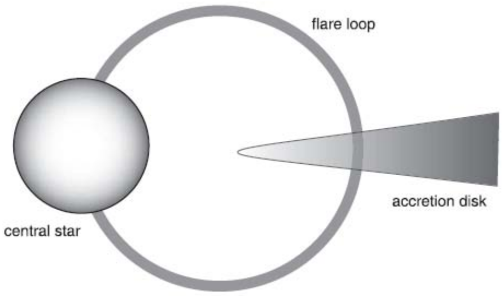
Introduction

- Models



2D Disk Flare Model

(Hayashi et al. 1996)



1D Disk Flare Model (with Heat Conduction) (Isobe et al. 2003)

Magnetic field loops connecting a central star and its surrounding disk are twisted by the disk rotation. The strongly wound magnetic loops expand and change their initial dipole configuration to an open one. Since a current sheet is formed inside the expanding loop, magnetic reconnection occurs in the presence of resistivity.

Basic Equations (MHD)

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

$$\frac{\partial \rho V}{\partial t} + \nabla \cdot \left(\rho V V + P I - \frac{B B}{4\pi} + \frac{B^2}{8\pi} I \right) = \rho g$$

$$\frac{\partial B}{\partial t} = \nabla \times \left(V \times B - \frac{c}{\sigma} J \right)$$

$$\frac{\partial}{\partial t} \left(\rho U + \frac{1}{2} \rho V^2 + \frac{B^2}{8\pi} \right) + \nabla \cdot \left[\left(\rho U + P + \frac{1}{2} \rho V^2 \right) V + \frac{c}{4\pi} E \times B \right] = \rho g \cdot V$$

$$U = \frac{1}{\gamma - 1} \frac{P}{\rho}$$

$$E = \frac{1}{\sigma} J - \frac{1}{c} V \times B$$

$$J = \frac{c}{4\pi} \nabla \times B$$

Heat Conduction

$$\frac{1}{\gamma - 1}\frac{k}{m}\rho\frac{dT}{dt} = -\nabla \cdot Q_c$$

$$Q_c = -\chi_{||} b(b \cdot \nabla)T$$

$$b = \frac{B}{B}$$ **unit vector**

χ_n **: heat conductivity parallel to *B***

Initial Condition

(1)Disk Torus

angular momentum

$$L = L_0 r^a \quad L_0 = \sqrt{GMr_0} \quad r_0 = 10^{12}\,\mathrm{cm}$$

polytropic relation

$$P = k\rho^{1+\frac{1}{n}}$$

equation of force balance

$$-\frac{1}{\rho}\nabla P = -\nabla \frac{GM}{(r^2+z^2)^{\frac{1}{2}}} - \frac{L^3}{r^3}$$

Unit

$\boldsymbol{r_0 = 10^{12}\,cm}$

$\boldsymbol{n_0 = 3\times 10^{10}\,cm^{-3}}$

$\boldsymbol{v_{K0} = 1.2\times 10^{7}\,cm/s}$

Initial Condition

(2)Halo

Hydrostatic balance

$$-\frac{1}{\rho}\nabla P = -\nabla \frac{GM}{(r^2+z^2)^{\frac{1}{2}}}$$

(3)Magnetic Field

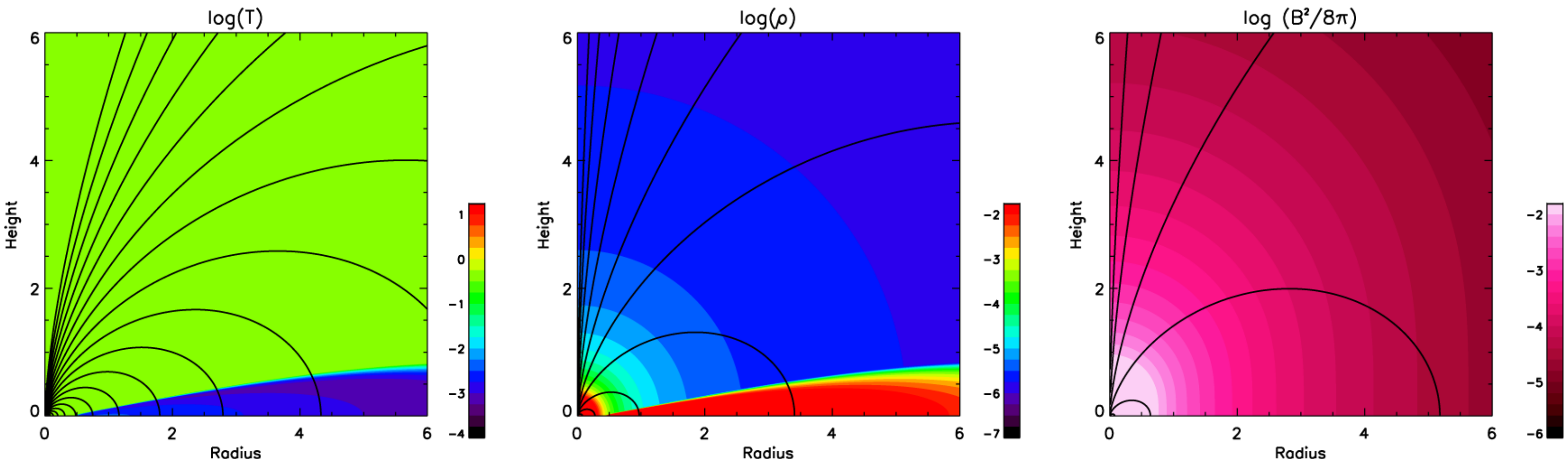
$$B_r = B_0 \frac{3rz}{(r^2+z^2)^{\frac{5}{2}}}$$

$$B_z = B_0 \frac{2z^2-r^2}{(r^2+z^2)^{\frac{5}{2}}}$$

$r, z =$ **nondimensional length**

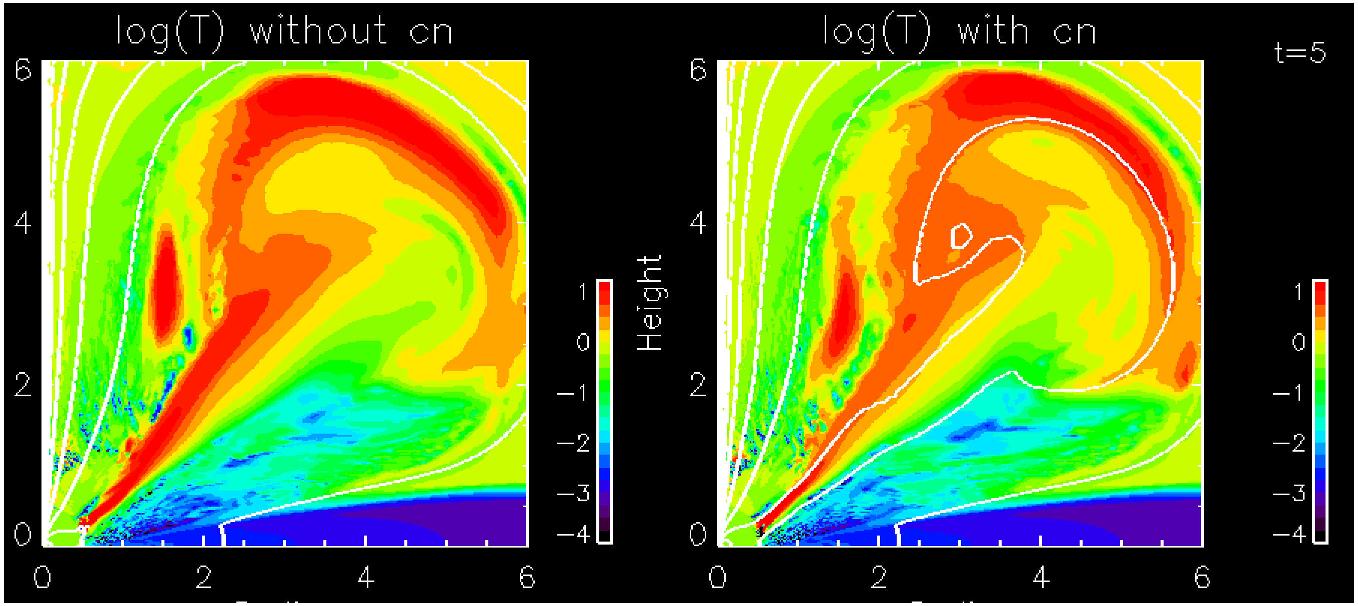
$$B_0 = \left|B(r_0, 0)\right| = 3.9\times10^{-2}$$

Initial Condition



Distributions of temperature, density, magnetic energy density.

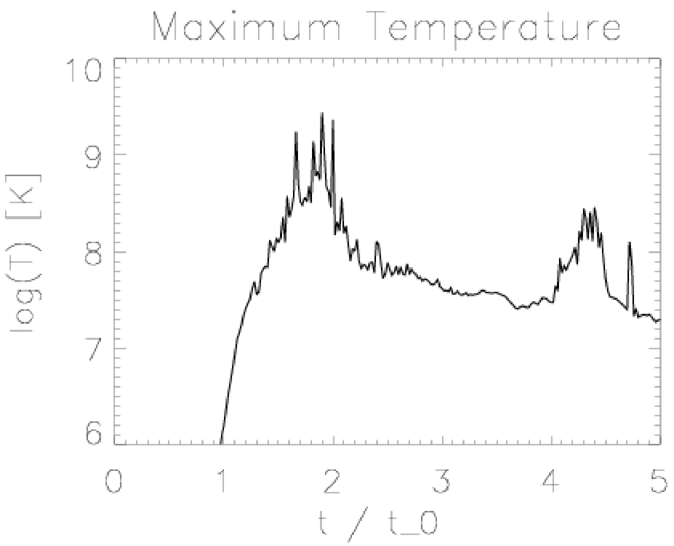
Temperature



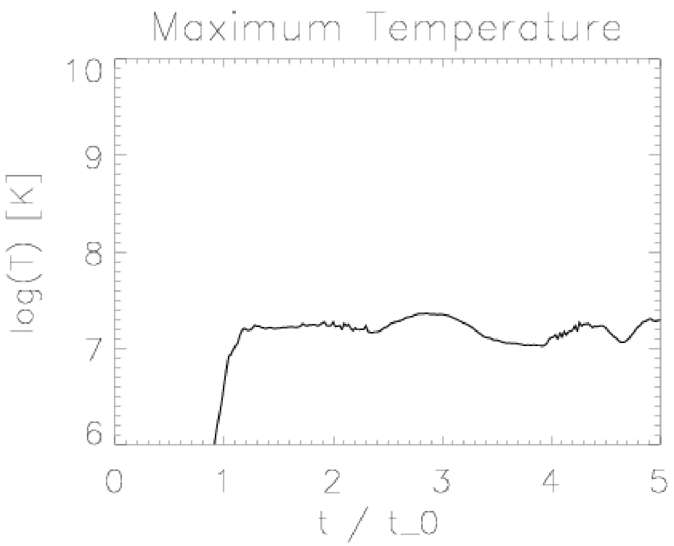
Model1(without heat conduction): High temperature region is localized.

Model2(with heat conduction): Released energy is transported to accretion disk and used to evaporate the gas of accretion disk surface.

Maximum Temperature



Model 1

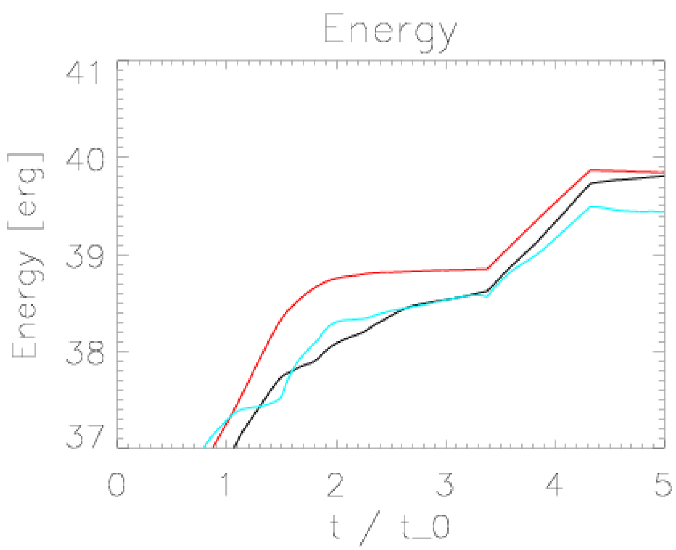


Model 2

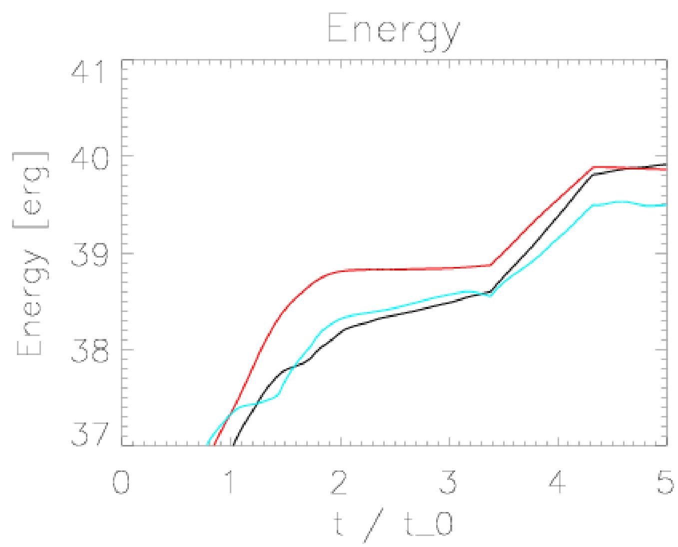
Model 1: Maximum temperature reaches 10^9[K] and decreases.

Model 2: Maximum temperature keeps around 10^7[K]

Energy



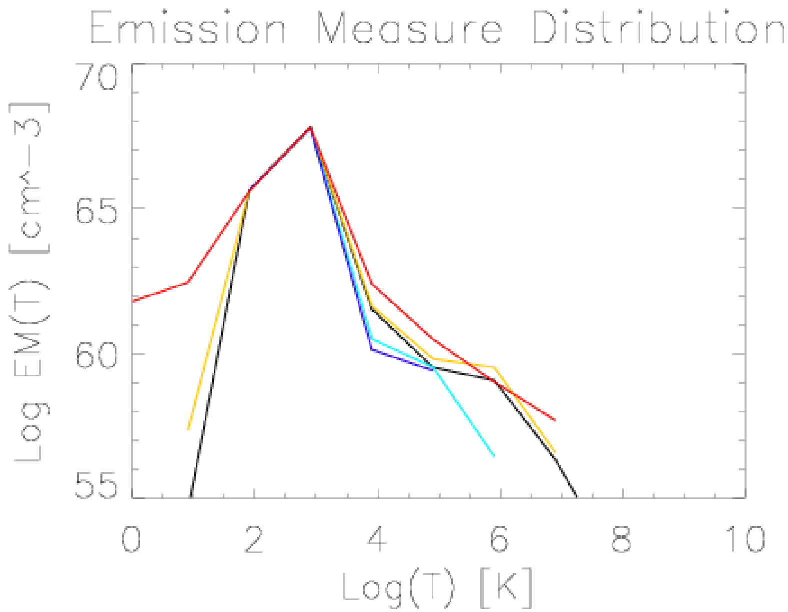
Model 1



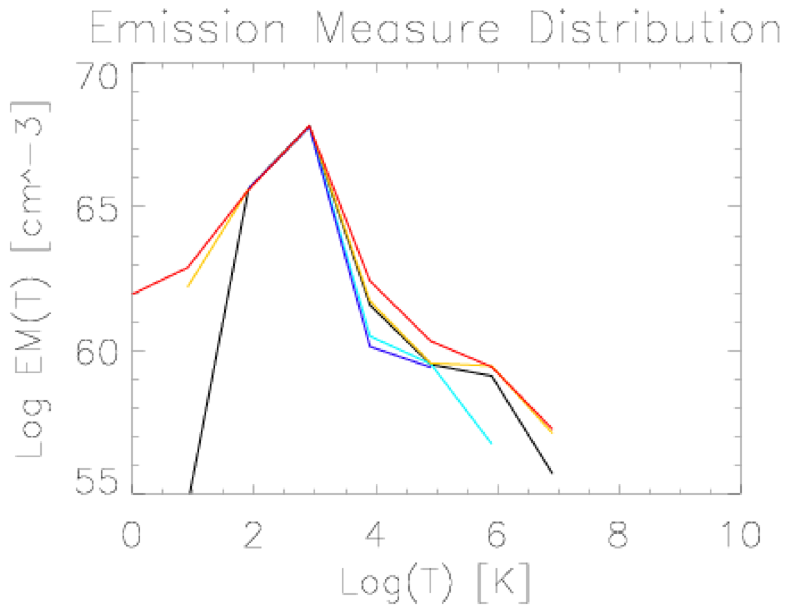
Model 2

Red line:magnetic energy, blue line: thermal energy, white line: kinetic energy. Before and after magnetic reconnection, magnetic energy is dominant.

Emission Measure



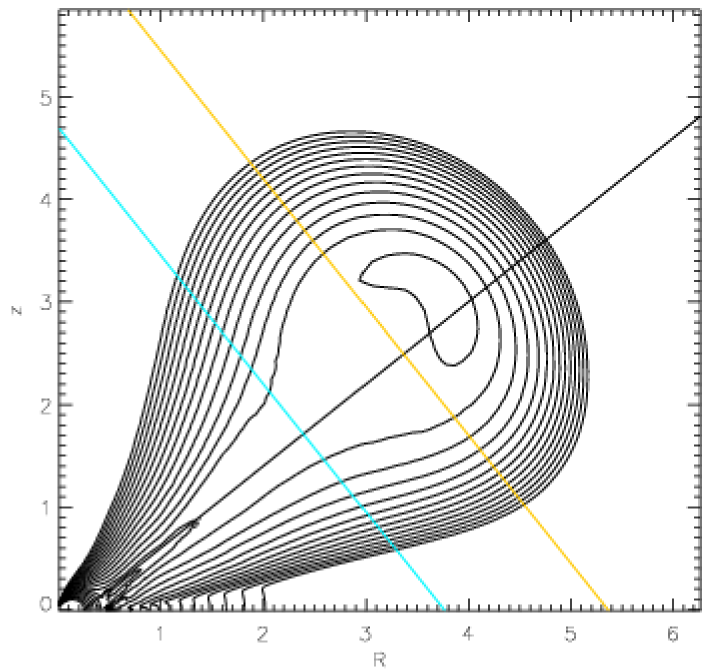
Model 1



Model 2

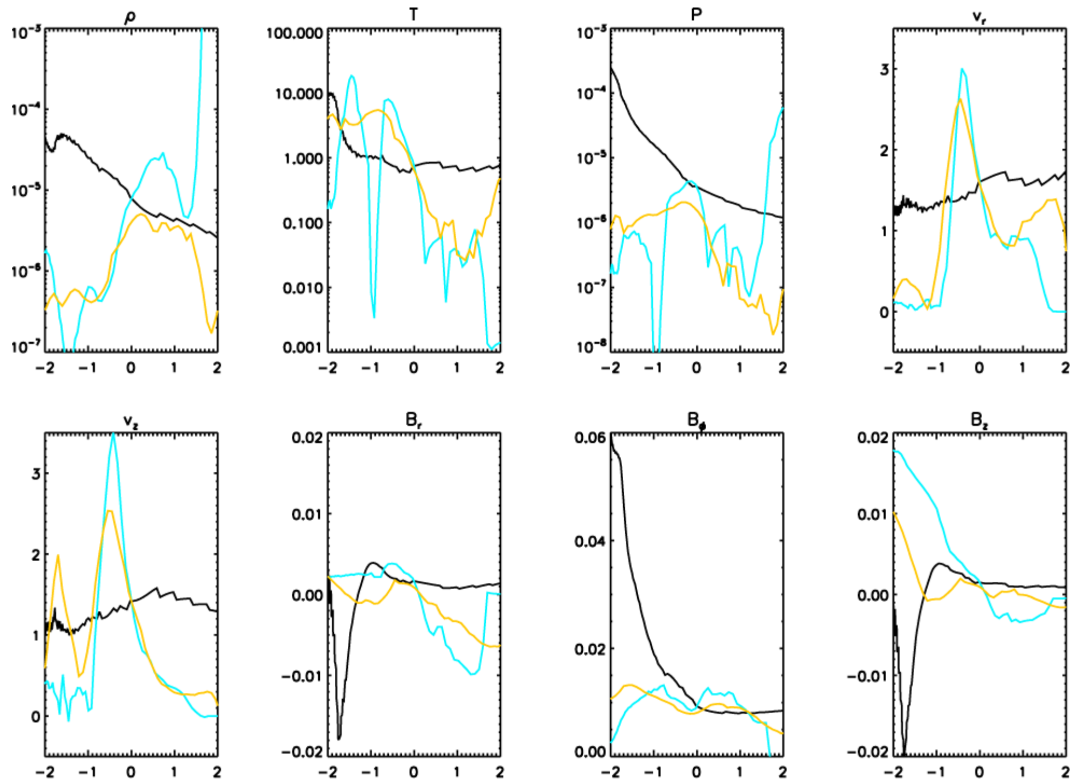
Purple line: initial state (t=0), sky blue line: t=1.0, white line: t=2.0, yellow line: t=3.0, red line: t=5.0

Reference Lines



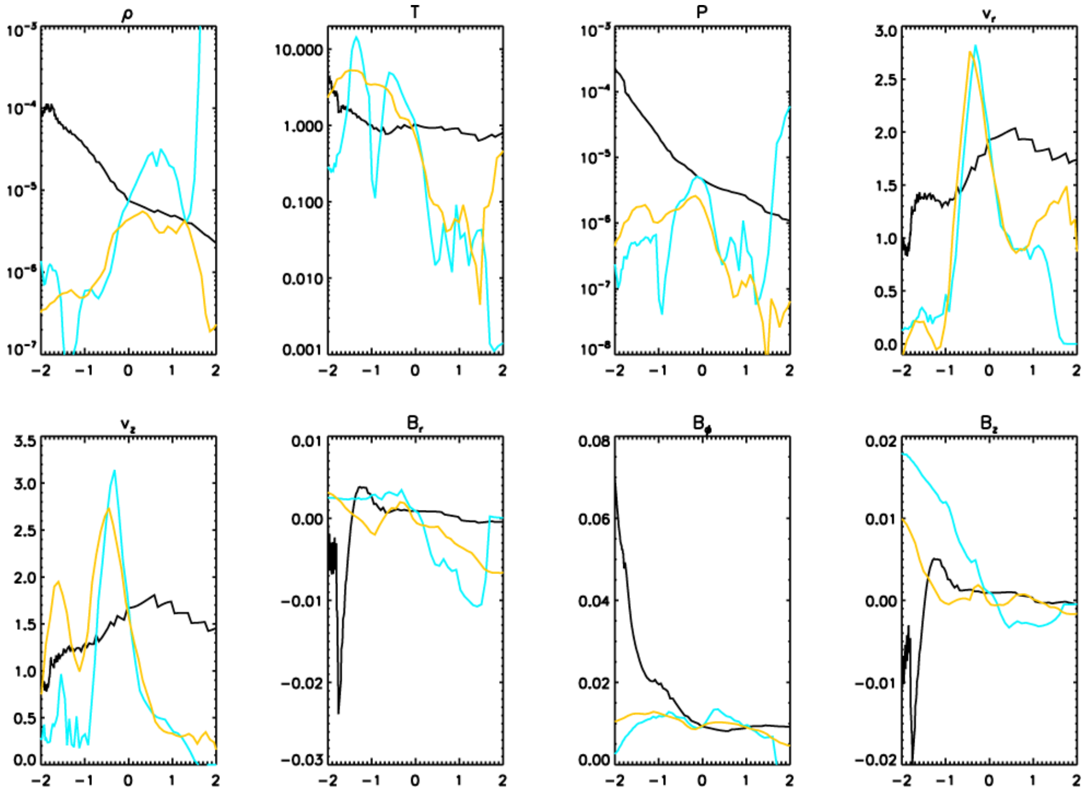
In next four view graphs , Distributions of various values along these reference lines (parallel or perpendicular to current sheet) are shown.

Distributions of physical values Model 1



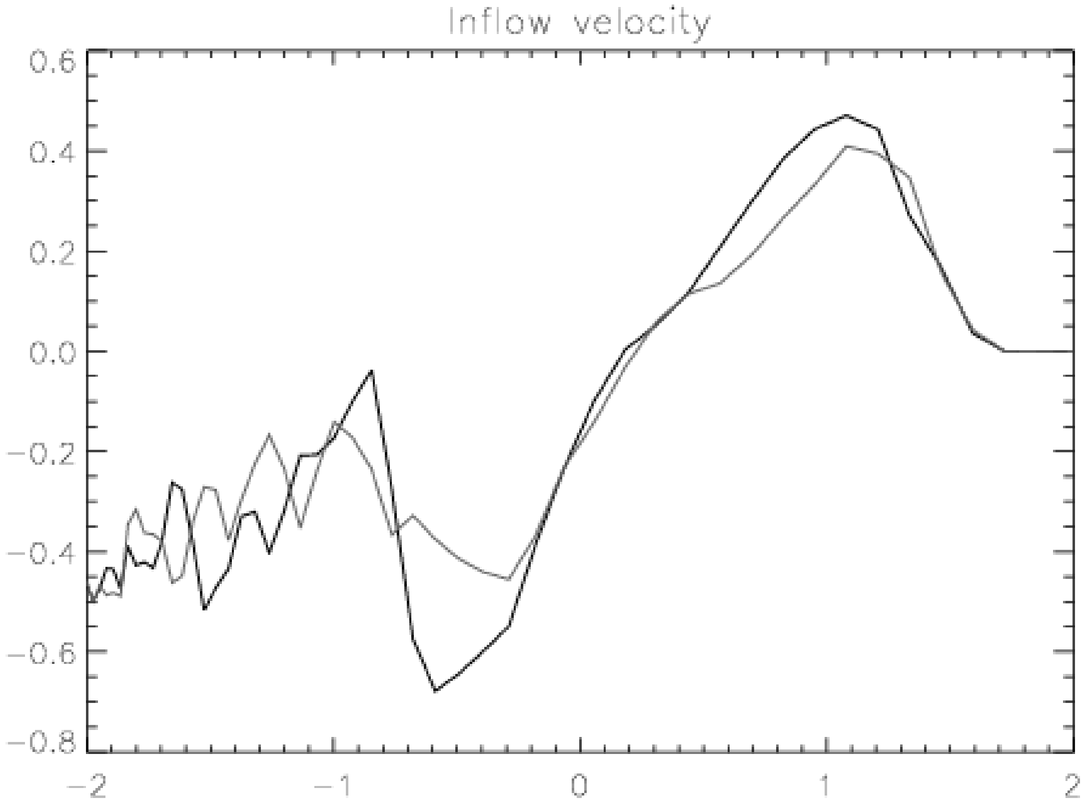
Black line: along the base line, blue and yellow lines: perpendicular to the base line

Distributions of physical values Model 2



Black line: along the base line, blue and yellow lines: perpendicular to the base line

Inflow velocity around the reconnection point



Black line: Model 1, gray line: Model 2

Magnetic reconnection is restrained in Model 2 slightly.

Summary

- We performed 2D MHD simulation of protostellar flare by taking account of heat conduction process.
- According to heat conduction
  - Temperature maximum decreases
  - Accretion rate increases
  - Magnetic reconnection is restrained
  - Accretion disk gas evaporates into the halo and emission measure increases.