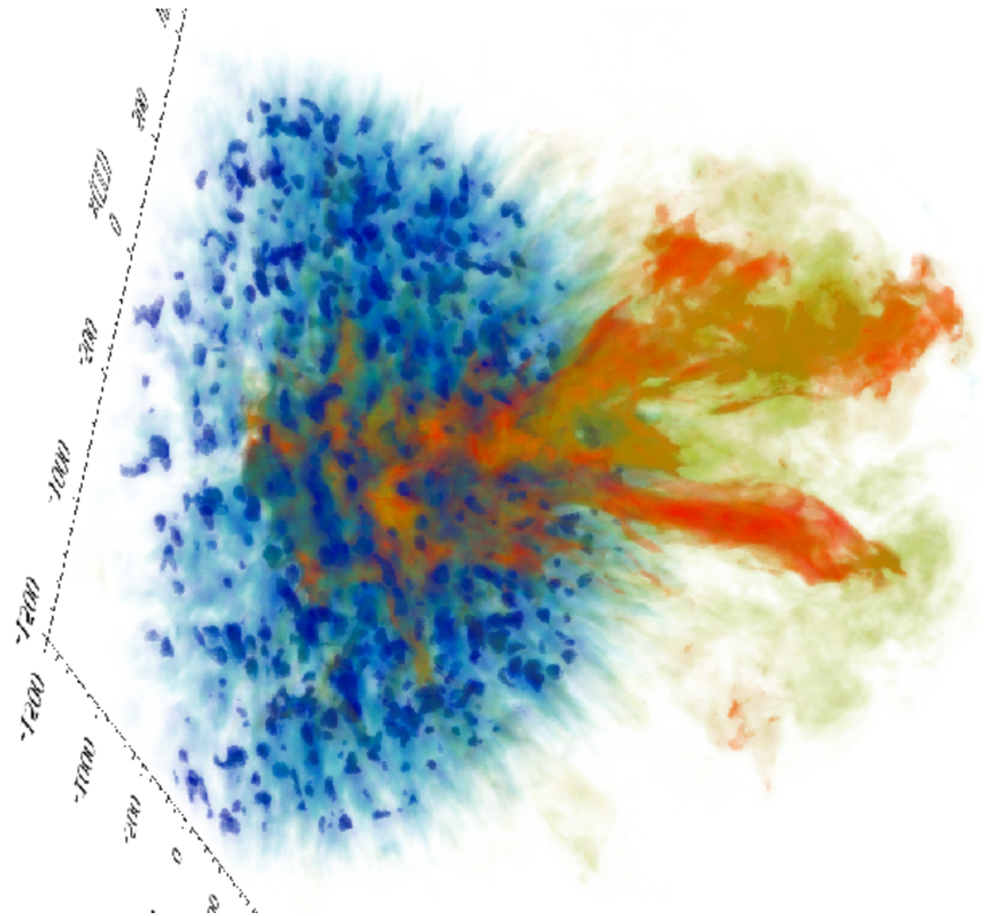
活動銀河核アウトフローによる星間空間フィードバックのMHD計算



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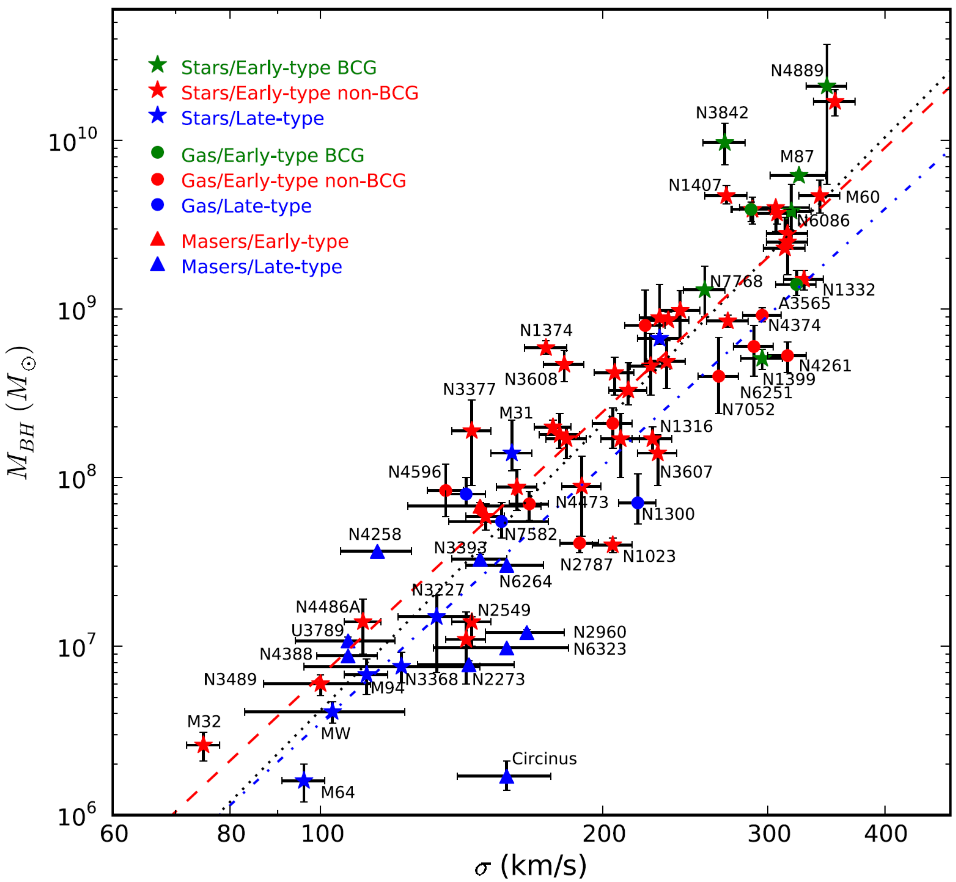
磁気流体プラズマで探る高エネルギー天体現象研究会、2017/8/28-30
海洋研究開発機構 [JAMSTEC] 東京事務所

Feedback from Active Galactic Nuclei (AGN) to Galactic Bulge

Black hole mass M



Stellar velocity dispersion σ

McConnell & Ma (2013)

・Active galactic nuclei (AGN) and its galaxy affect each other and coevolute

・The mass of central black hole correlates with the stellar velocity dispertion in the galactic bulge (M-σ relation)

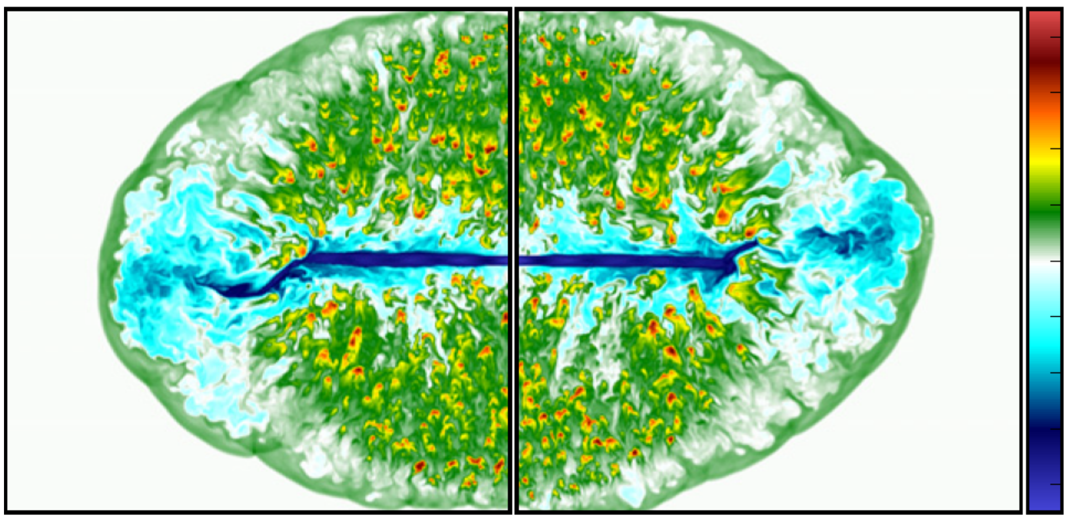
$M \propto \sigma^{4\text{-}5}$

・M-σ relation can be made by AGN feedback

・What mechanism is the origin of M-σ relation?

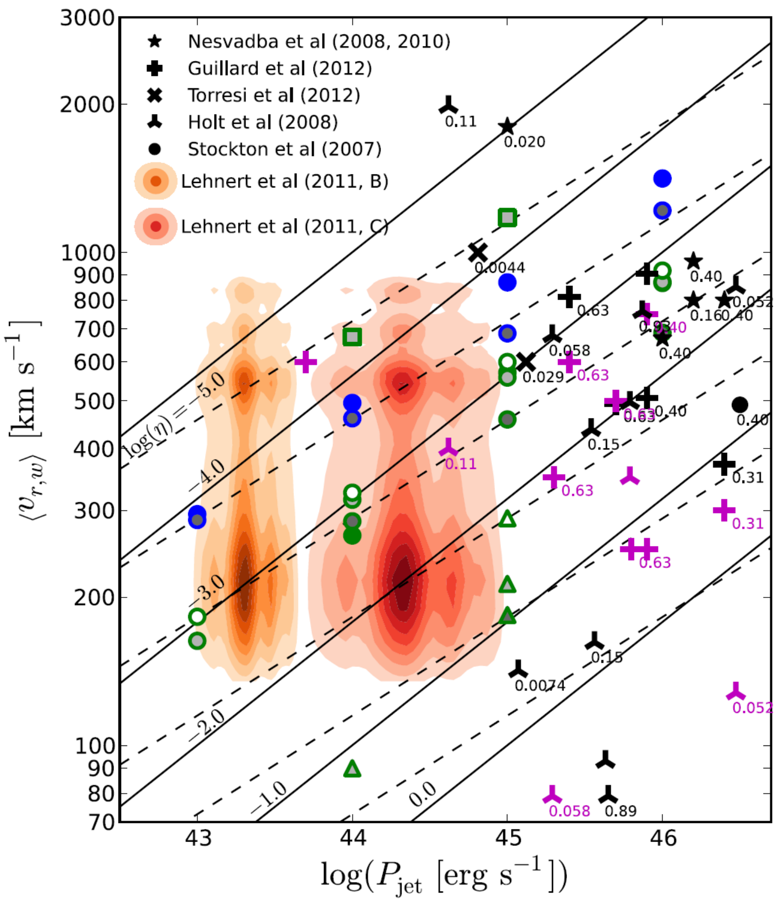
Feedback of an AGN jet to the inhomogeneous ISM

Wagner et al. (2012) revealed that the feedback of an AGN jet to inhomogenious intestellr medium can be origin of M-σ relation



Density distribution of the result of special relativistic HD simulations by Wagner et al. (2012)

Velocity dispersion σ

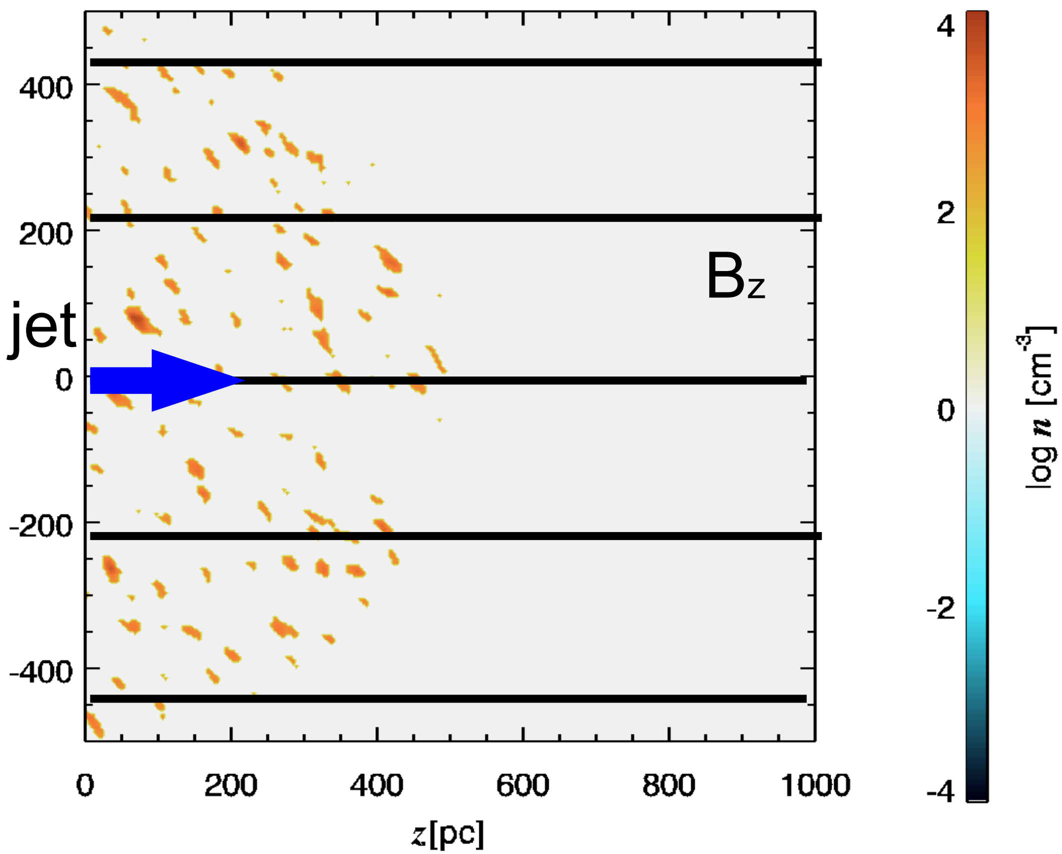


Power of the jet

$\eta = P_{jet}/L_{edd}$

Wagner et al. (2012) do not consider the magnetic fields. However, the existense of the magnetic fields is suggested.
We carried out MHD simulations to reveal the effect of the megnetic fields to the feedback of the AGN jet.

Simulation model



- HLLD scheme (Miyoshi & Kusano 2005)
- 5^{th} order accuracy in space and 3^{rd} order accuracy in time
- Number of grid (Nx, Ny, Nz)=(240,240,240)

Jet gas (blue arrow)
$n=10^{-3}$ cm^{-3}, $T=10^{11}$ K
v_{jet} = 0.2c - 0.3c
P_{jet} = 1.4 - 3.6×10^{43} erg/s

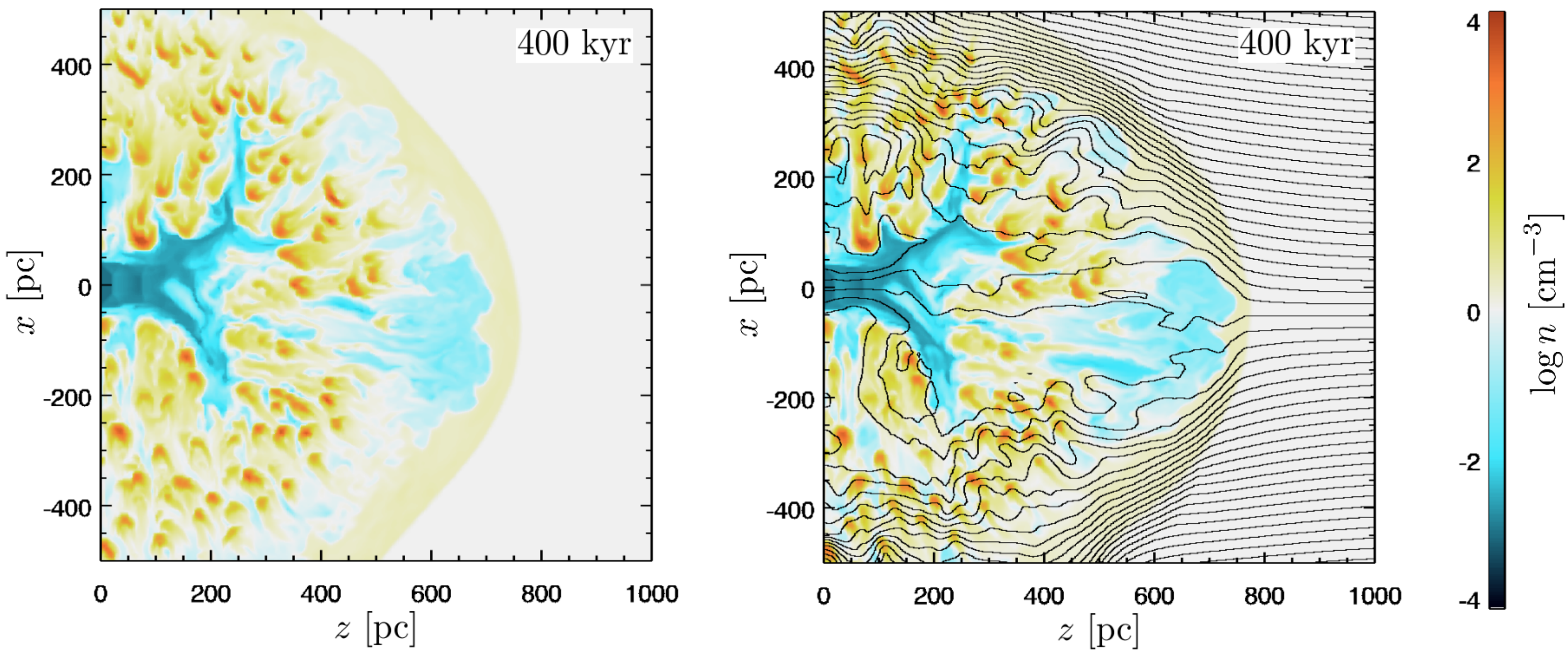
Warm cloud (orange)
$<n>=100$ cm^{-3}
- We use the same method as Wagner et al. (2012)
- Maximum radius of clouds is about 20 pc

Hot gas (white)
$n=1$ cm^{-3}, $T=10^7$ K

We assume uniform magnetic field B_z and plasma $\beta=\infty$, 4, 2, 1

Density Distribution

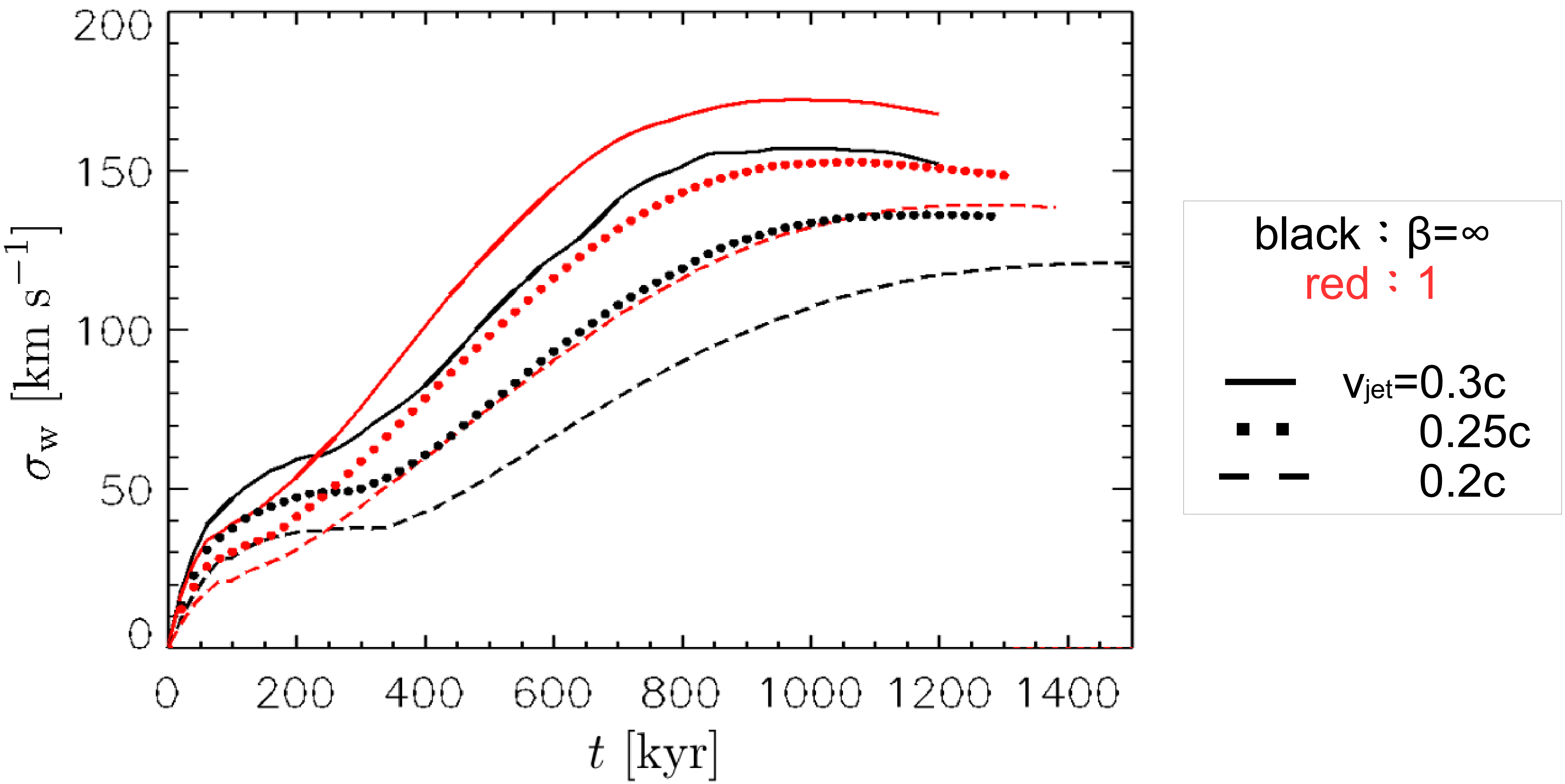
Without magnetic fields	With magnetic fields (β=1)



・The jet propagates into channel and interacts with the warm clouds

・Since the kinetic energy density of the jet is much larger than magnetic energy density ($e_{jet}/e_B \sim 40$), the structure of the jet and distribution of the warm clouds look almost same whether there is the magnetic fields.

Evolution of Velocity Dispersion of the Warm Clouds

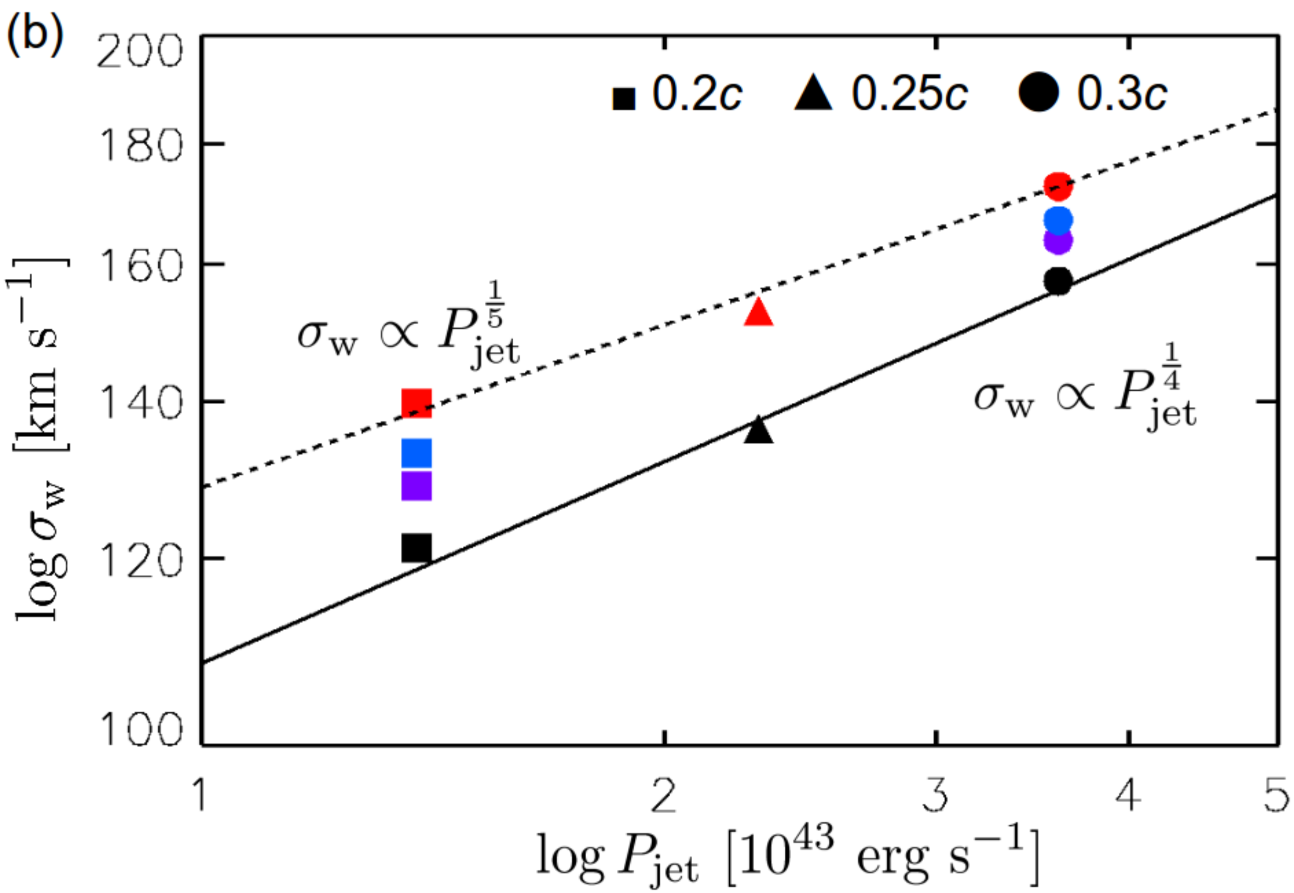


・The warm clouds are accelerated by the jet until the jet goes through the warm cloud region

・The velocity dispersion is larger for MHD models

Pjet (M) – σ Diagram

Peak value of the velocity dispersion



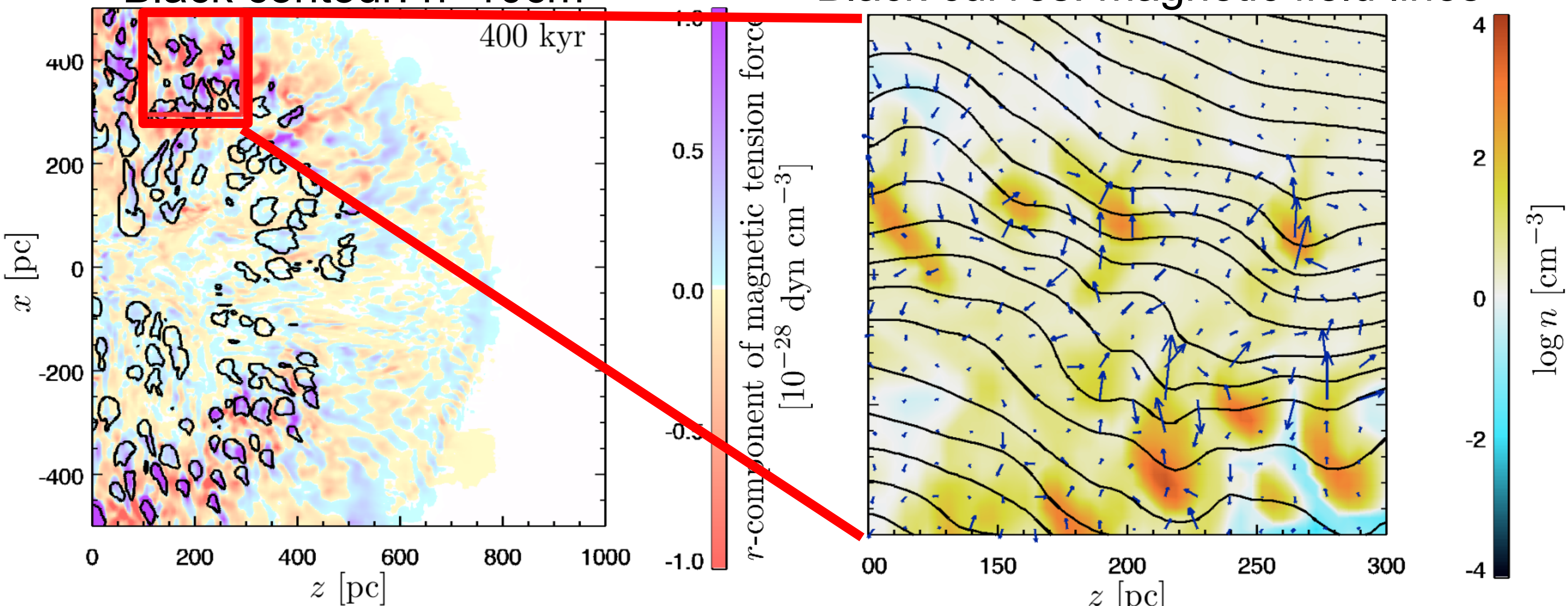
black : β=∞,
violet : 4
blue : 2
red : 1

- For HD simulations σ is proportional to $P^{1/4}$ (solid line)
- The power law index is consistent with that for Wagner's simulations
- For simulations with β=1, σ is proportional to $P^{1/5}$ (dashed line)

Acceleration via Magnetic Tension Force

Magnetic tension force in radial direction
Black contour: $n=10cm^{-3}$

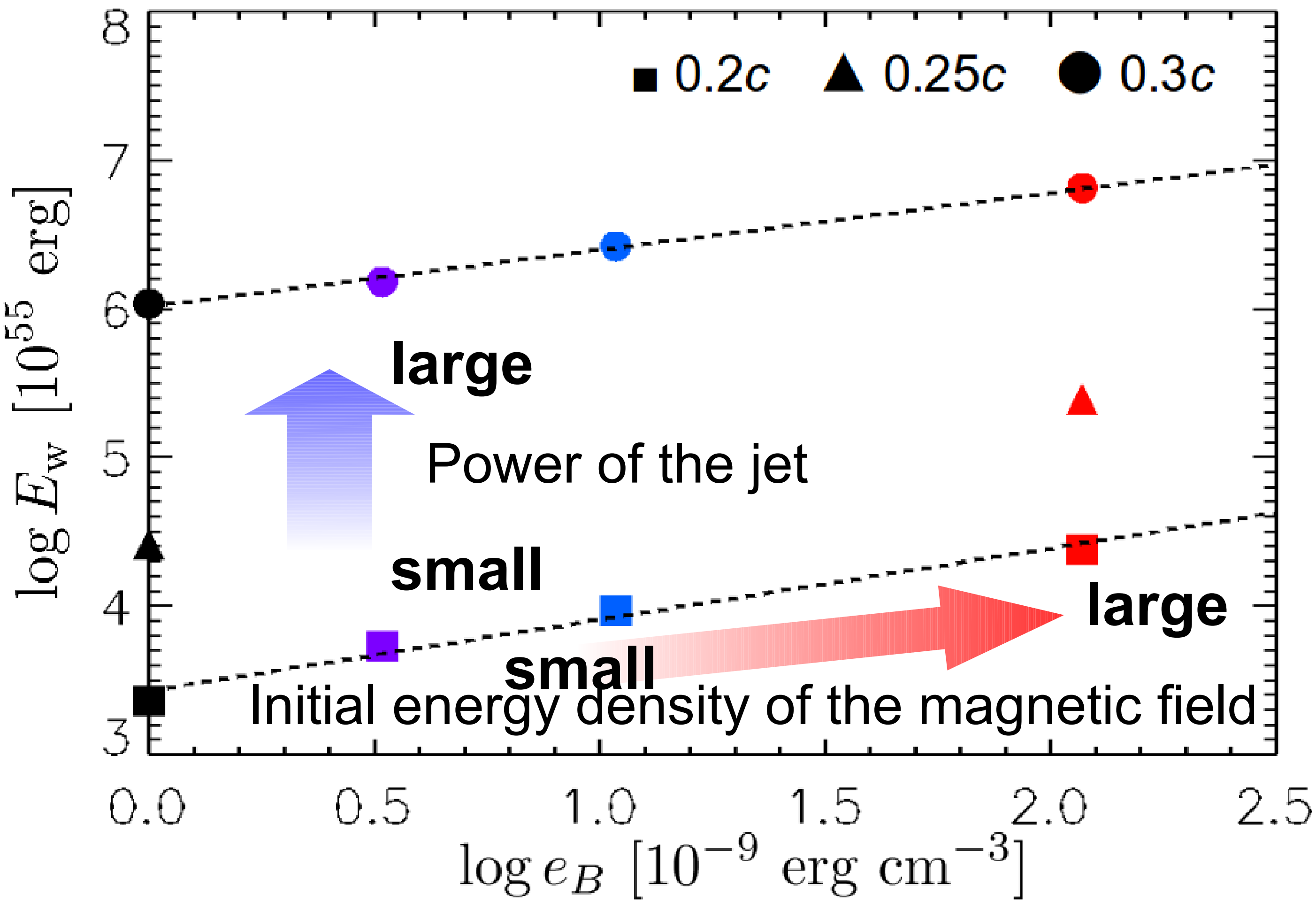
Number density
Vector: magnetic tension force
Black curves: magnetic field lines



・Since the hot gas moves faster than the warm clouds, the magnetic fields which are the downward convex form around the warm clouds

・The warm clouds are accelerated not only by the jet but also by the magnetic tnesion force

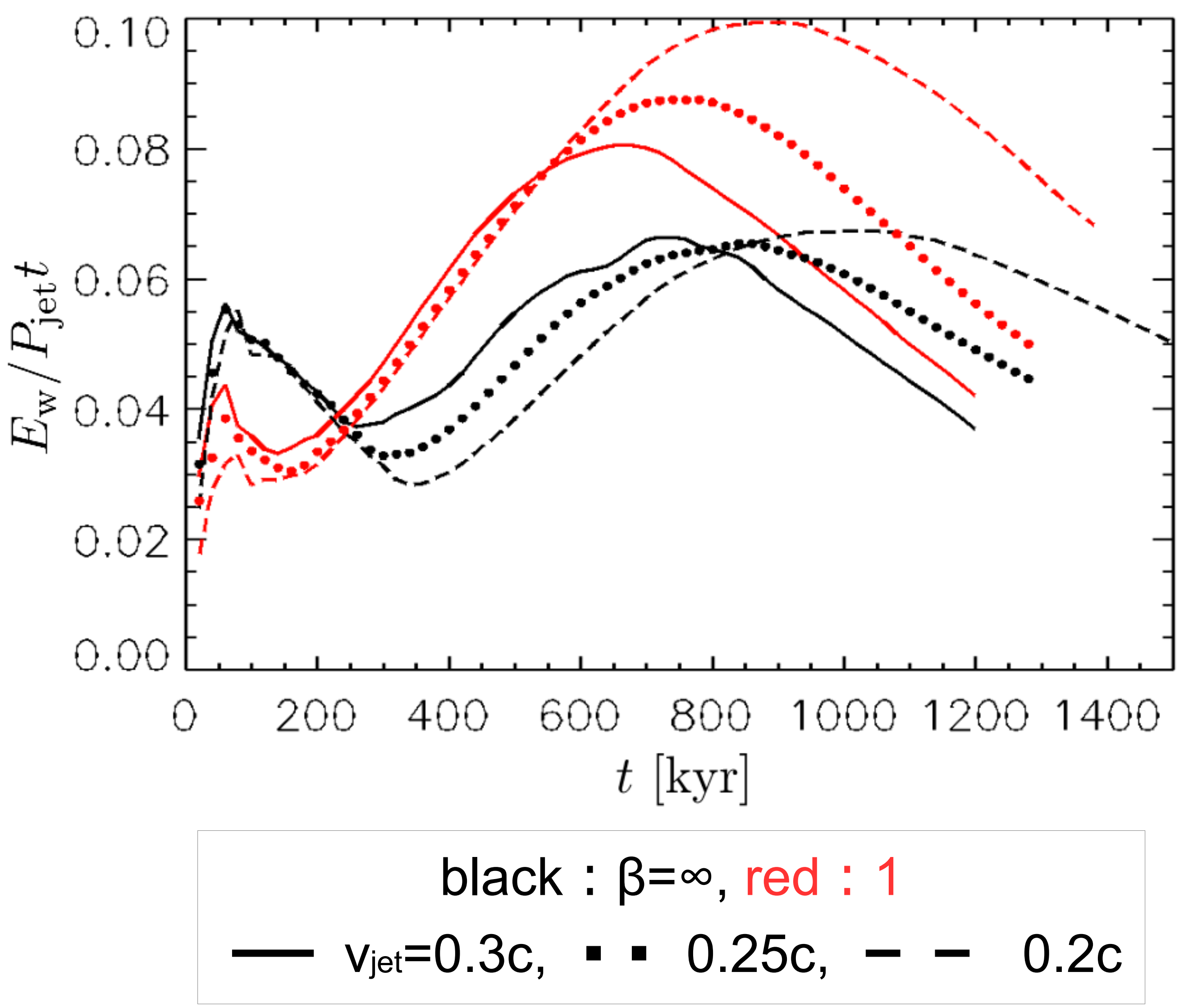
Energy Transport to the Warm Clouds by the Magnetic Field



・Total kinetic energy Ew is proportional to the initial magnetic energy density eB since the magnetic tension force is proportional to B^2

・The increment of the total kinetic energy is not depend of the jet power

Enhancement of the energy transport



・The ratio of the total kinetic energy of the warm clouds to the injected jet power

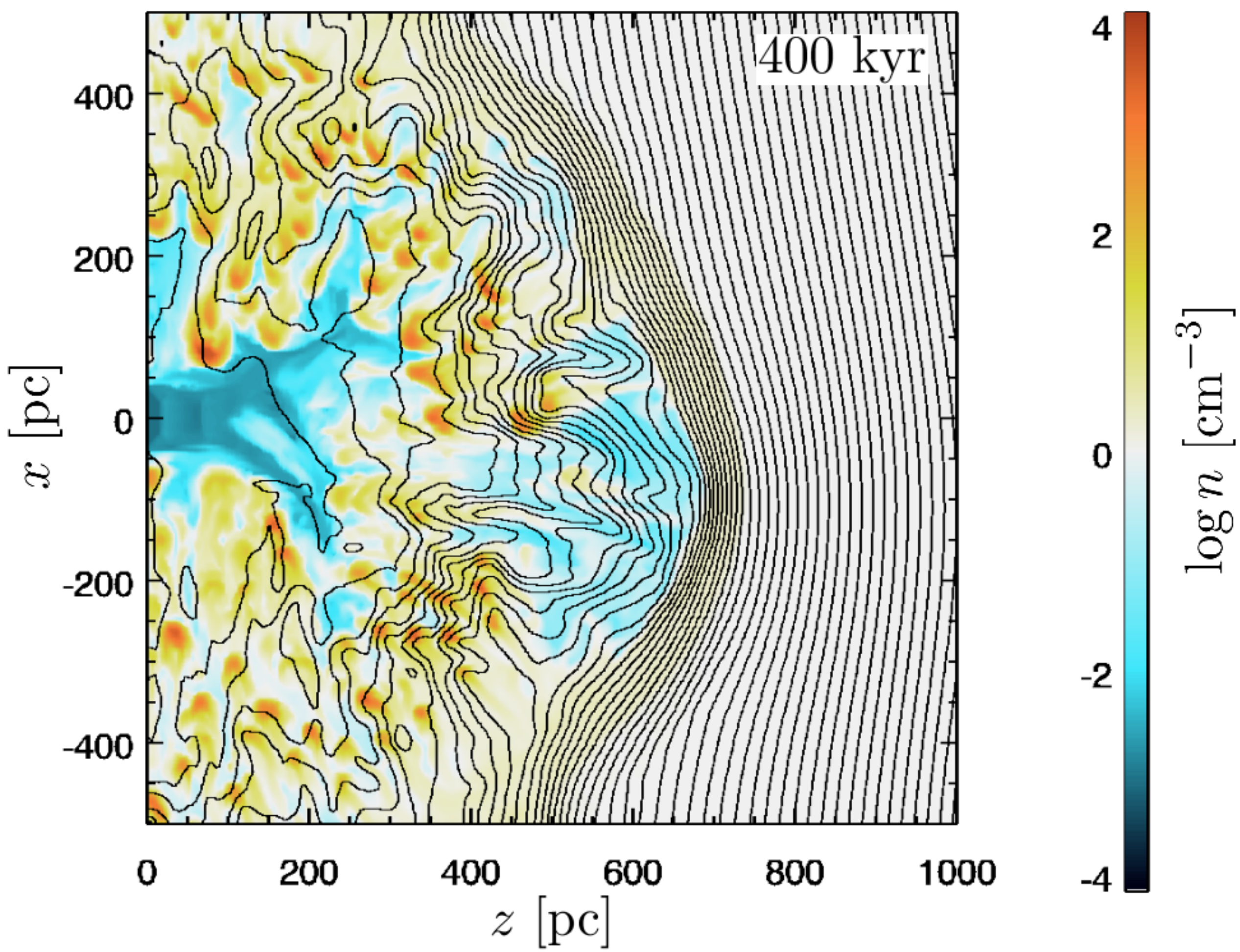
・For all models, the magnetic fields enhances The efficiency of the Energy transport

・The jet power is lower, the increment of the efficiency is lager

・The magnetic field is important relatively when the jet power is small

Dependense of the Topology of the Magnetic Field

We assume the uniform B_x which is perpendicular to the jet axis and plasma β = 1. Jet speed is 0.3c.



- Bx model:
  σ = 184 km/s,
  E_w = 7.9 x 10^{55} erg
- Bz model:
  σ = 172 km/s,
  E_w = 6.8 x 10^{55} erg
- β=∞ model:
  σ = 157 km/s,
  E_w = 6.0 x 10^{55} erg

- Since the jet interacts with the magnetic field more effectively, the velocity dispersion is little larger than that of the simulation with Bz

Summary

- We carried out MHD simulations of the AGN outflow feedback to inhomogenious interstellar clouds
- Interstellar clouds are accelerated not only by the jet but also by the magnetic tension force
- The increment of the kinetic energy of the clouds is propotional to the initial magnetic energy density
- The magnetic field makes the power law index of σ large
- The feedback of the AGN outflow to inhomogenious interstellar clouds can be origin of M-σ relation