# 銀河系中心領域における磁気活動によって生じる高速度な下降流と観測的影響

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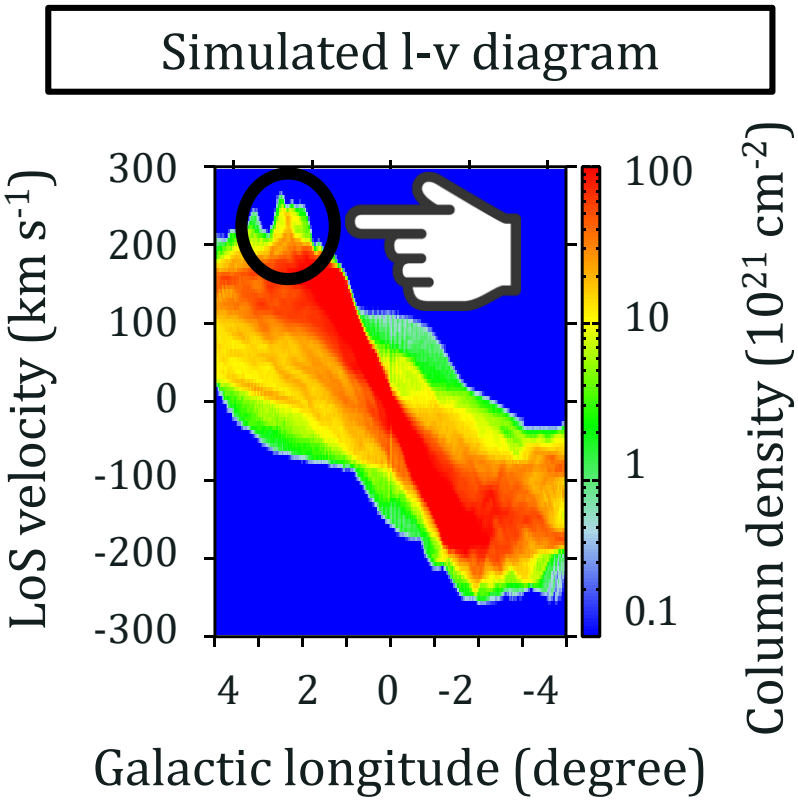
Kakiuchi et al. In prep. (ArXiv:1712.04209)

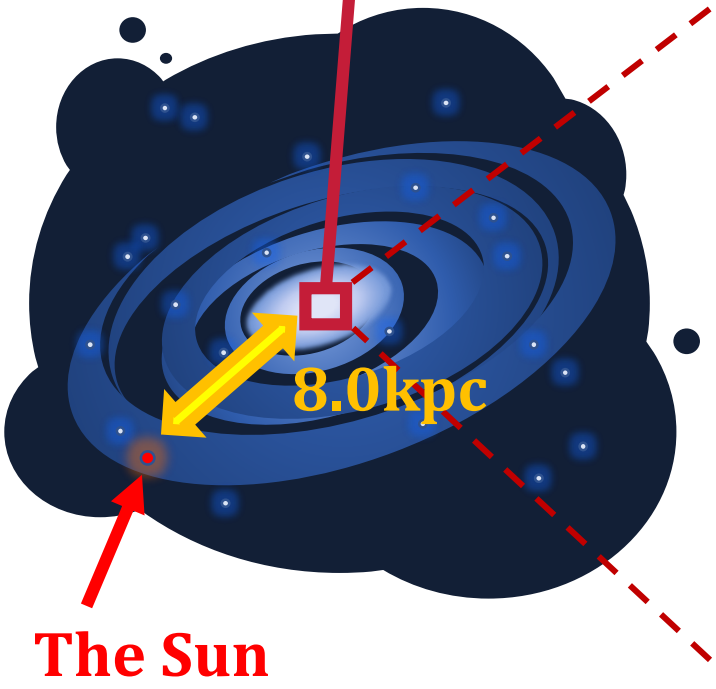
# Outline

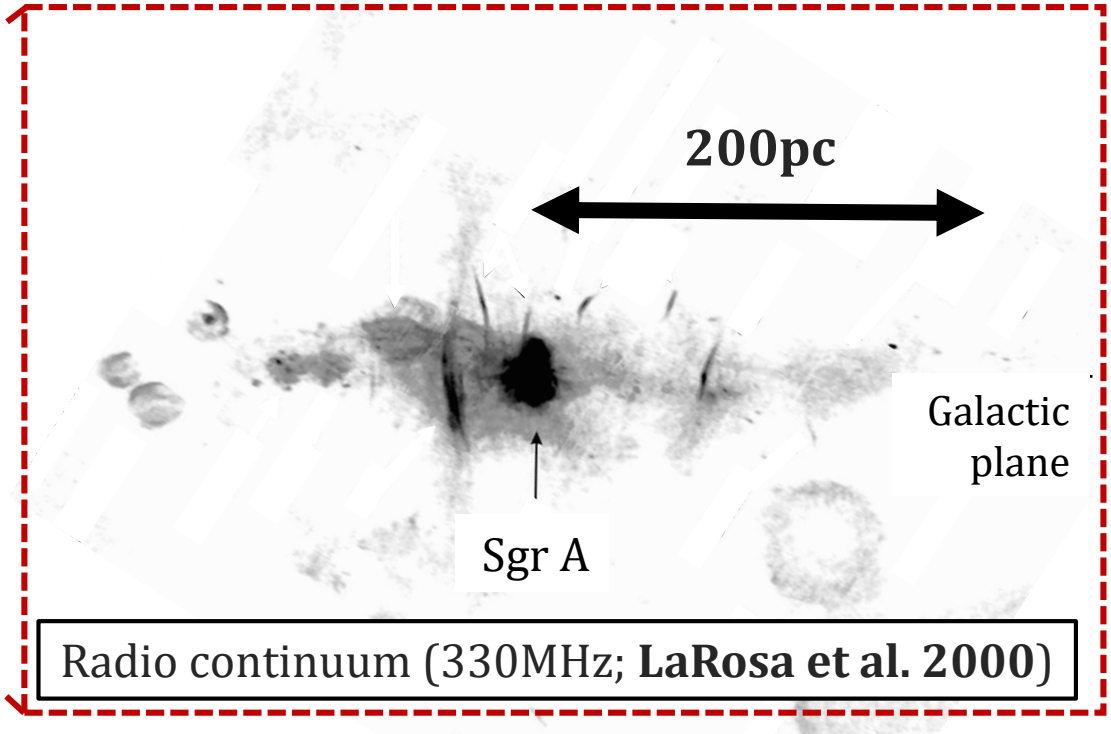
- The Galactic Center (GC) region
- Vertical structure in MHD simulation data
- Rising loops and fast downflows



# The galactic center (GC) region

: Within a few parsec region

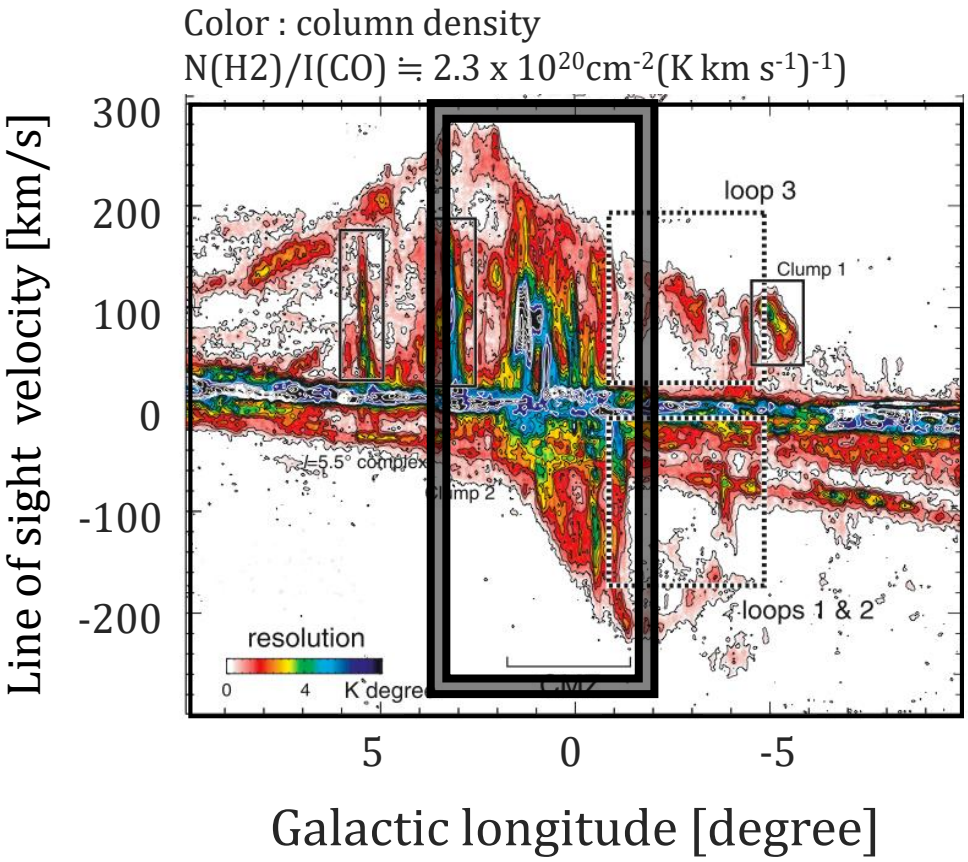


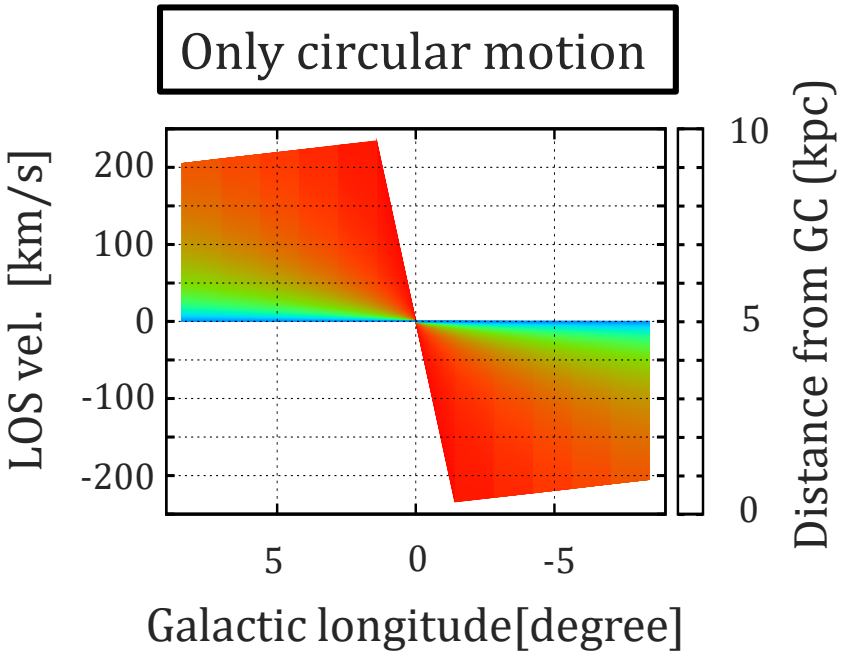




- ✓ Super massive BH Sgr A*, massive star cluster, SNR
- ✓ 5-10 % of total molecular gas in the Milky Way collected.
- ✓ Molecular gas: High density, High temperature

# Velocity structure in the GC region

- $^{12}$CO(1-0) map NANTEN (Torii+10) -



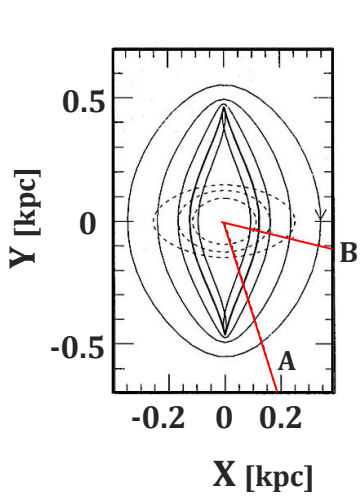



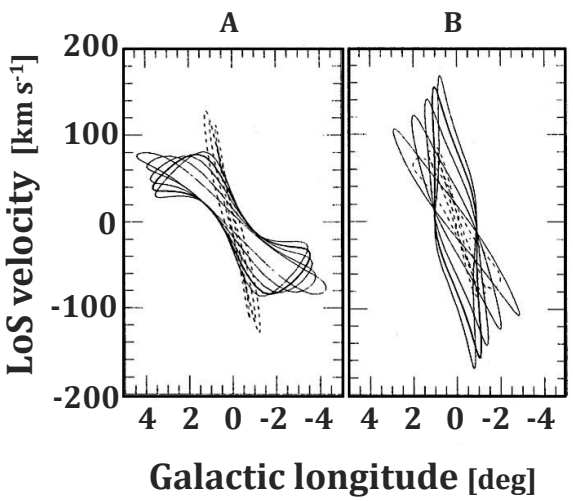

Complex structure ➡ **Non-circular motion**

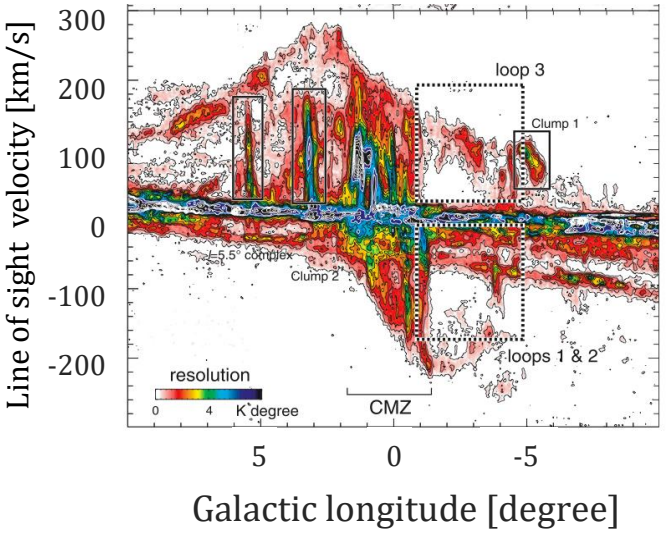
# Bar potential → Non-circular motion ?

❖ Orbital calculation (Binney+1991)

- Bar-like stellar gravitational potential (detected near 3kpc) → gas motion in the GC region ?
- As a result, **the gas is excited radial motion on bar potential**
- However, complex features cannot is reproduced, even if 3D simulation (Rodriguez-Fernandez & Combes 2008).



# Bar potential v.s. Magnetic Field !

- Polarization observation (Chuss+2003, Nishiyama+ 2010)
  - ✓ Detection of vertical field and pallarel field

  (Disccusion: non-thermal filament structure)

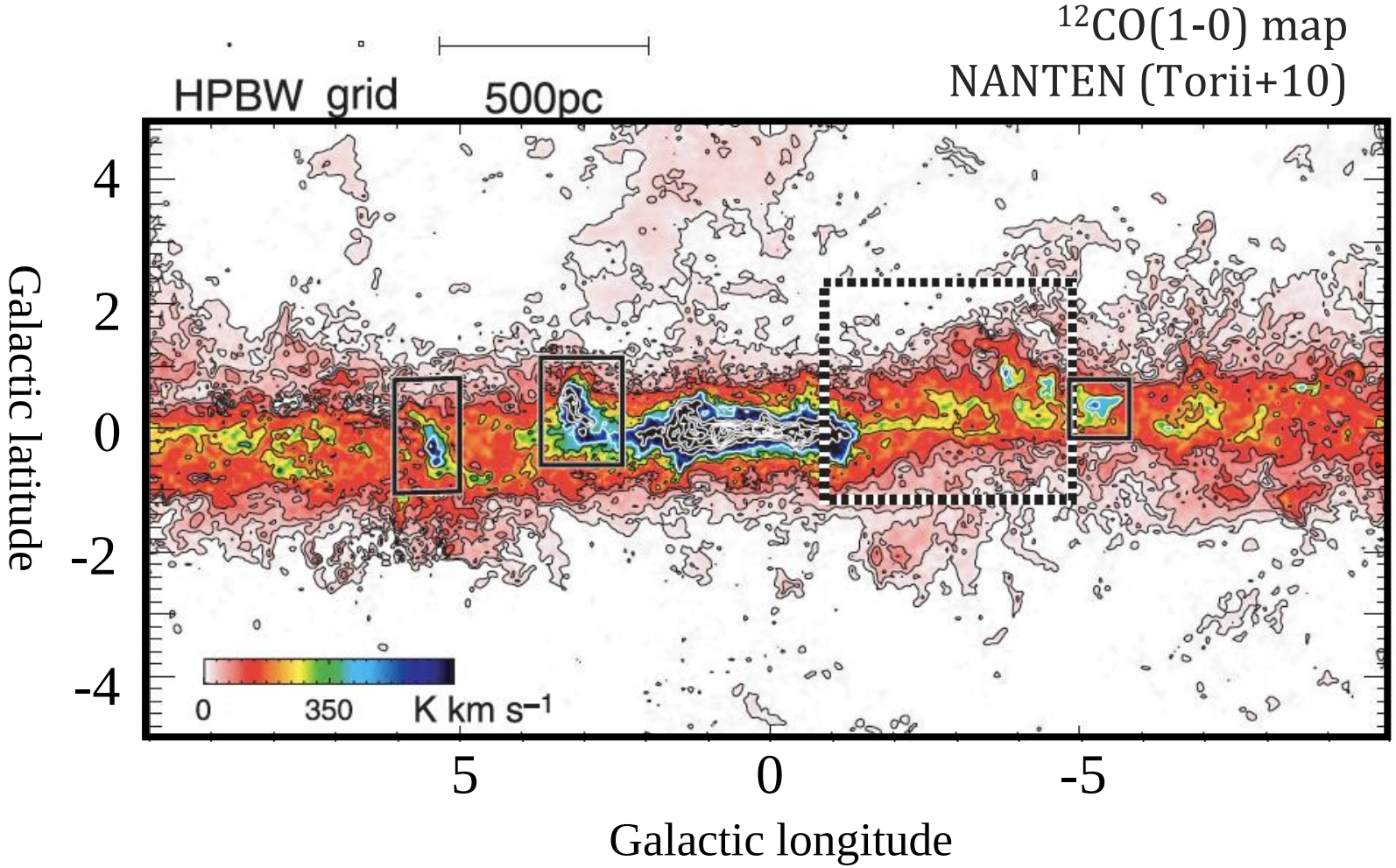
- Large magnetic field strength

  (※typical strength is 1μG @ molecular cloud in disk region)
  - ✓ globally > 50μG (Crocker + 2010)
  - ✓ Locally ~ 0.1-1mG (Yuzef-Zadeh+1984)
  - ✓ Inner the dark cloud 2-5 mG (Pilai et al. 2015)

- The loop structure of molecular cloud

  (Fukui+06, Machida+09, Torii+10a,b)
  - ✓ It has potential that it is sign of Parker Instability.

# Vertical Structure




- Vertical motion can play important roles

  c.f. The Galactic center radio lobe (GCL; Sofue & Handa 1984)

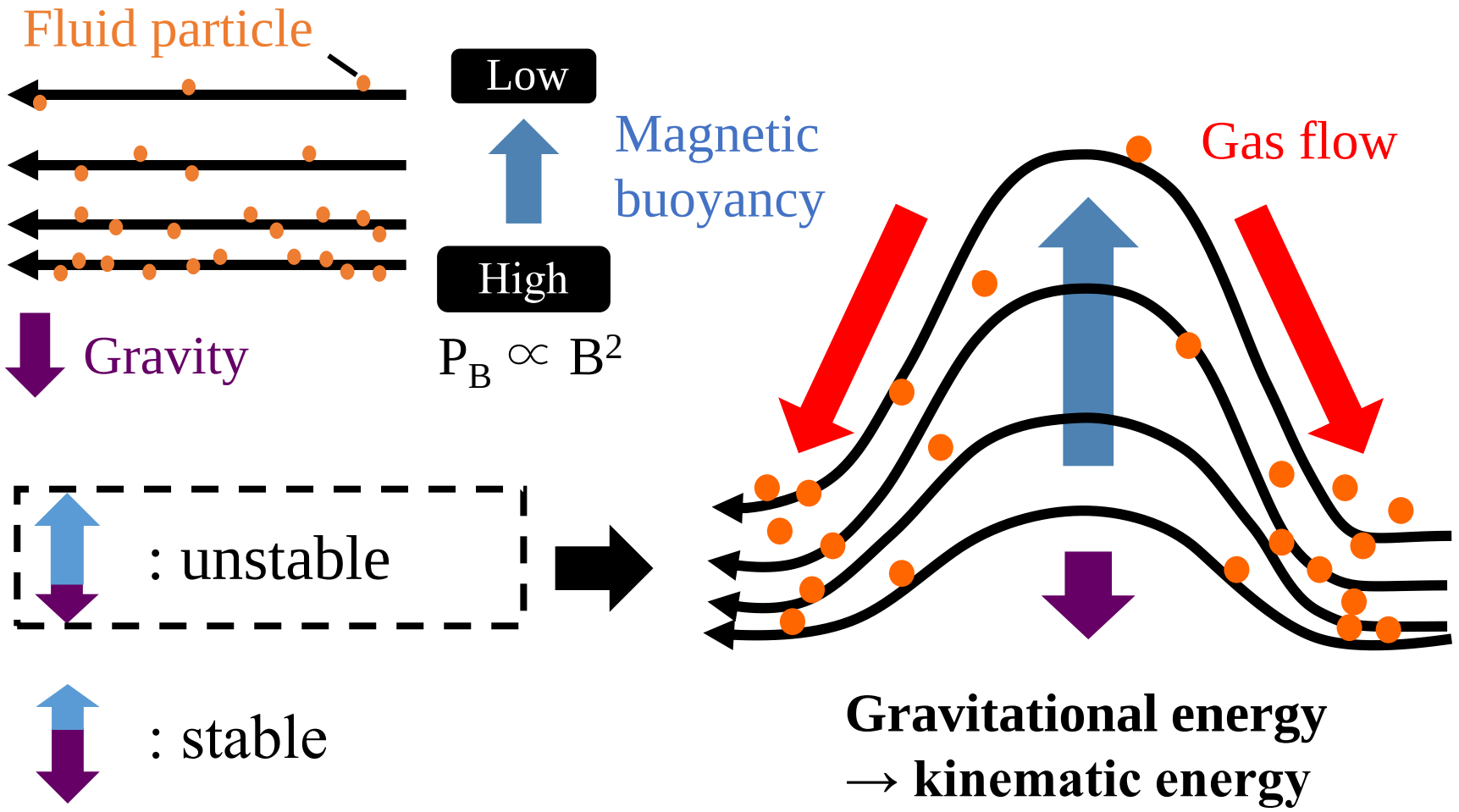
  Double helix structure (Enokiya+2014)

# Parker Instability

Parker (1966,1967),
Matsumoto et al.(1988)

**Magnetic buoyancy > Gravity force**

**Vertical component of magnetic field : ⬆**



# MHD simulation in the GC region

(Suzuki+2015, cf, Machida+2009)

## ❖ SETUP

- ✓ Ideal MHD & locally isothermal gas
- ✓ Axismetry gravitational potential

$$\Phi(R,z) = \sum_{i=1}^{3} \frac{-GM_i}{\sqrt{R^2 + (a_i + \sqrt{(b_i^2 + z^2)})^2}}$$

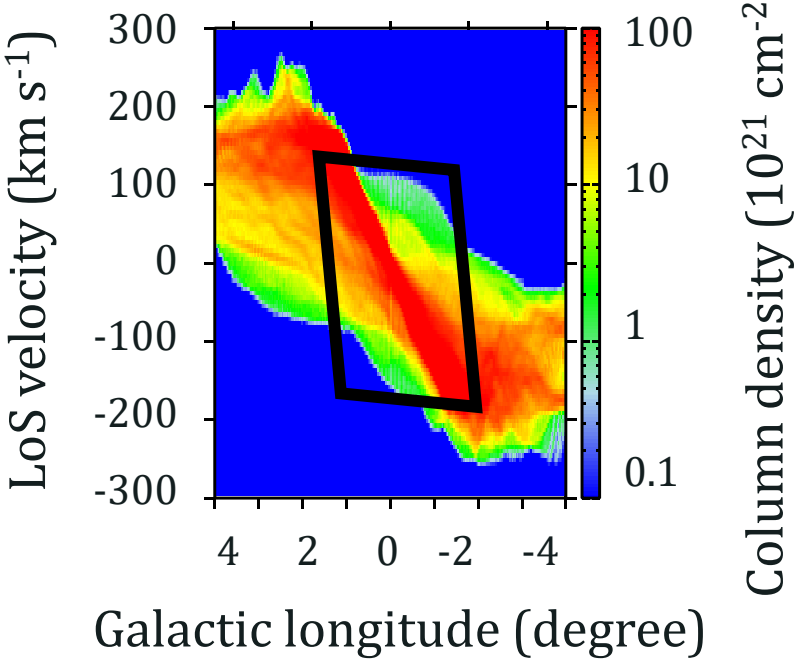
(Miyamoto & Nagai 1975)

Initial magnetic field:

$$B_{z,0} = 0.71\mu\mathrm{G}\left(\frac{R}{1\ \mathrm{kpc}}\right)^{-1} \quad (R > 0.035\ \mathrm{kpc})$$

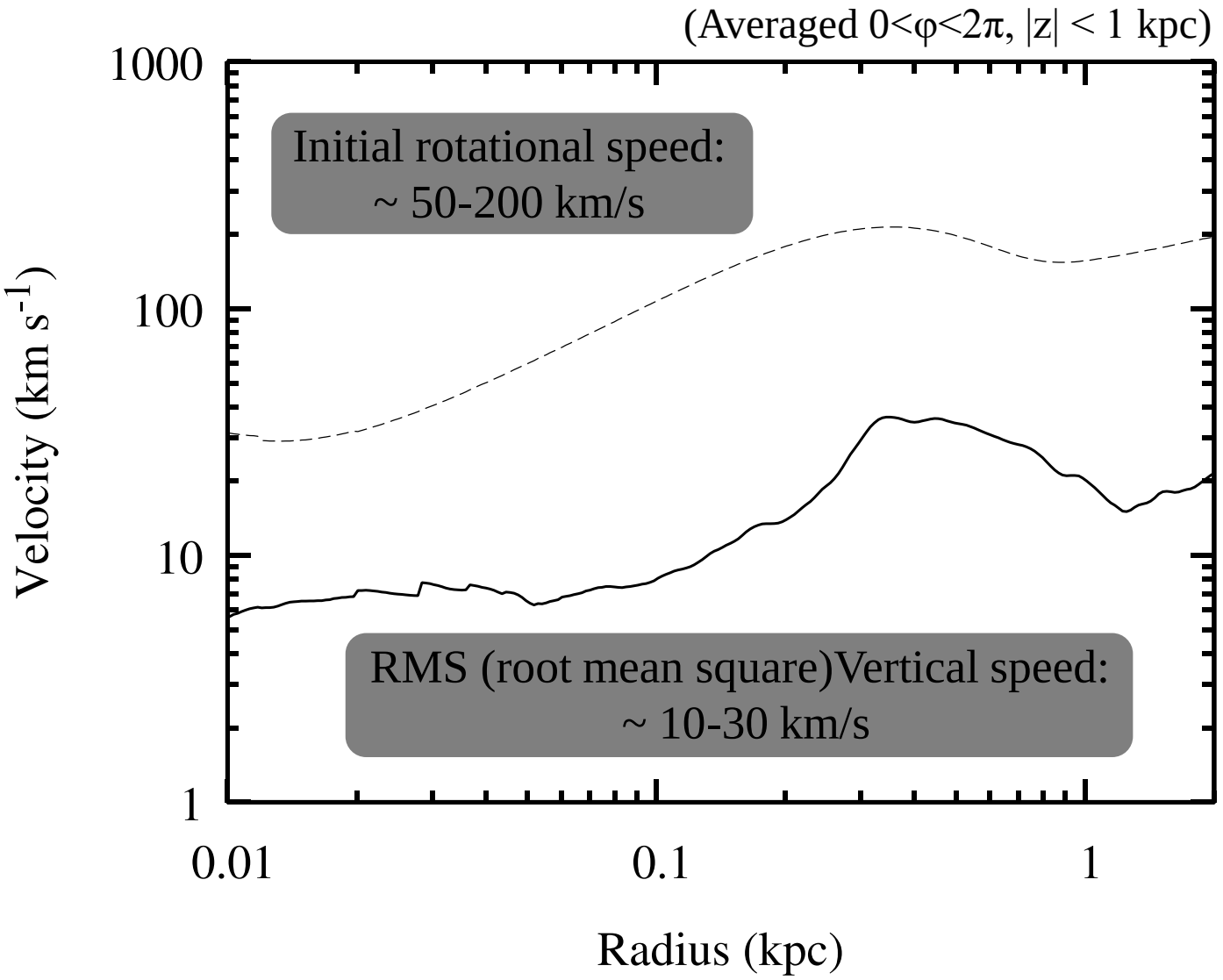
Initial gas profile: hydrostatic equilibrium

Simulated l-v diagram




Non-circular motion : excited by magnetic activity
Observational features(e.g. parallelogram structure) reproduce

# Overview: Radius vs velocity




Vertical motion excited by magnetic activity

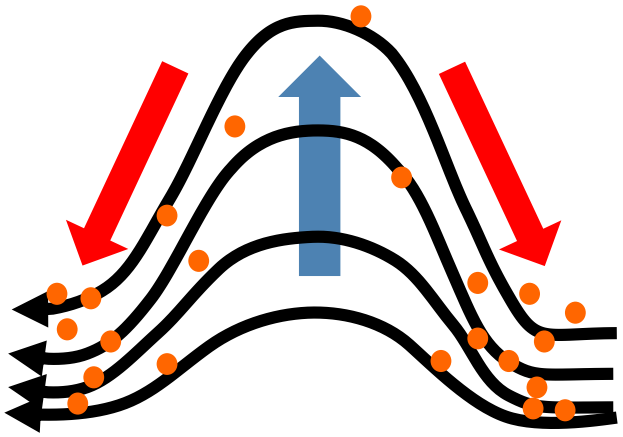
# Overview: Mass flux to vertical direction

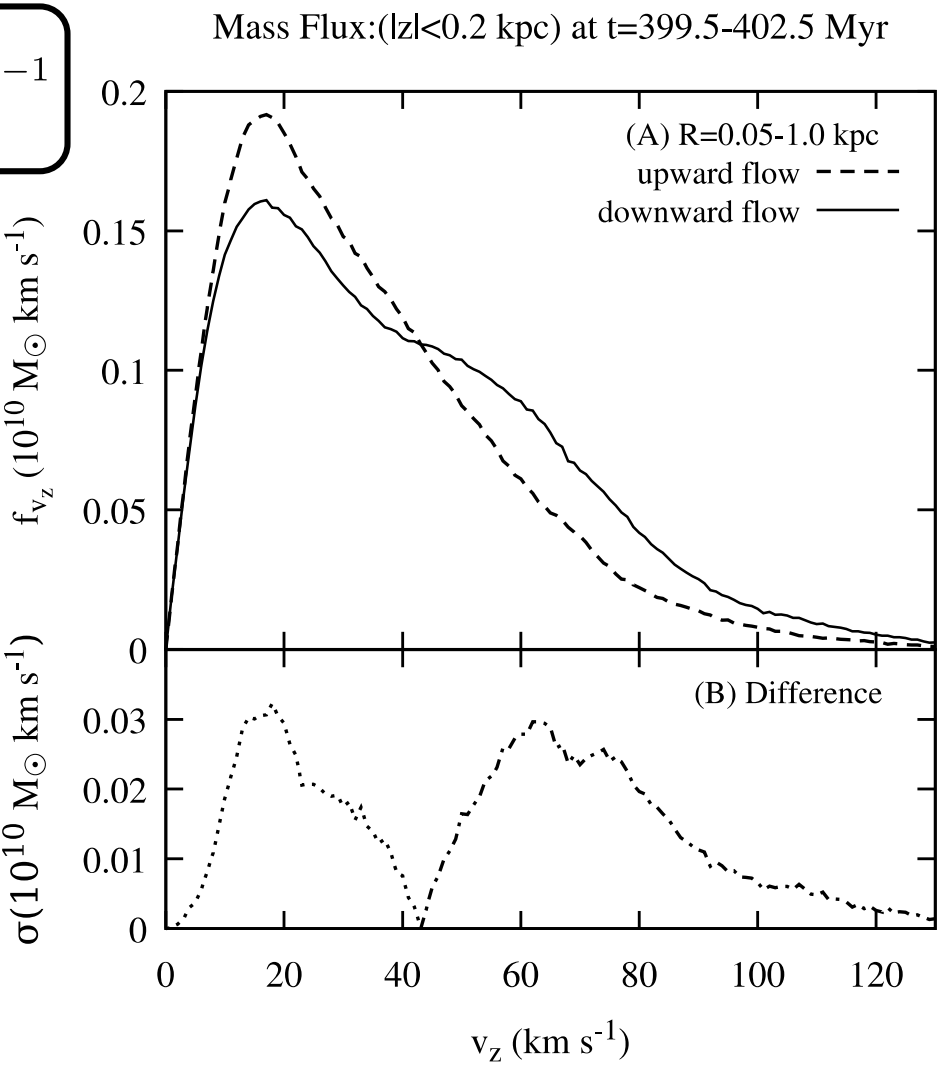
Alfvén velocity ~ upflow speed

$$v_A \sim 45 \left[\frac{B}{500\mu\mathrm{G}}\right] \left[\frac{n}{500\mathrm{cm}^{-3}}\right]^{-1/2} \mathrm{km\ s}^{-1}$$

Free fall velocity ~ downflow speed

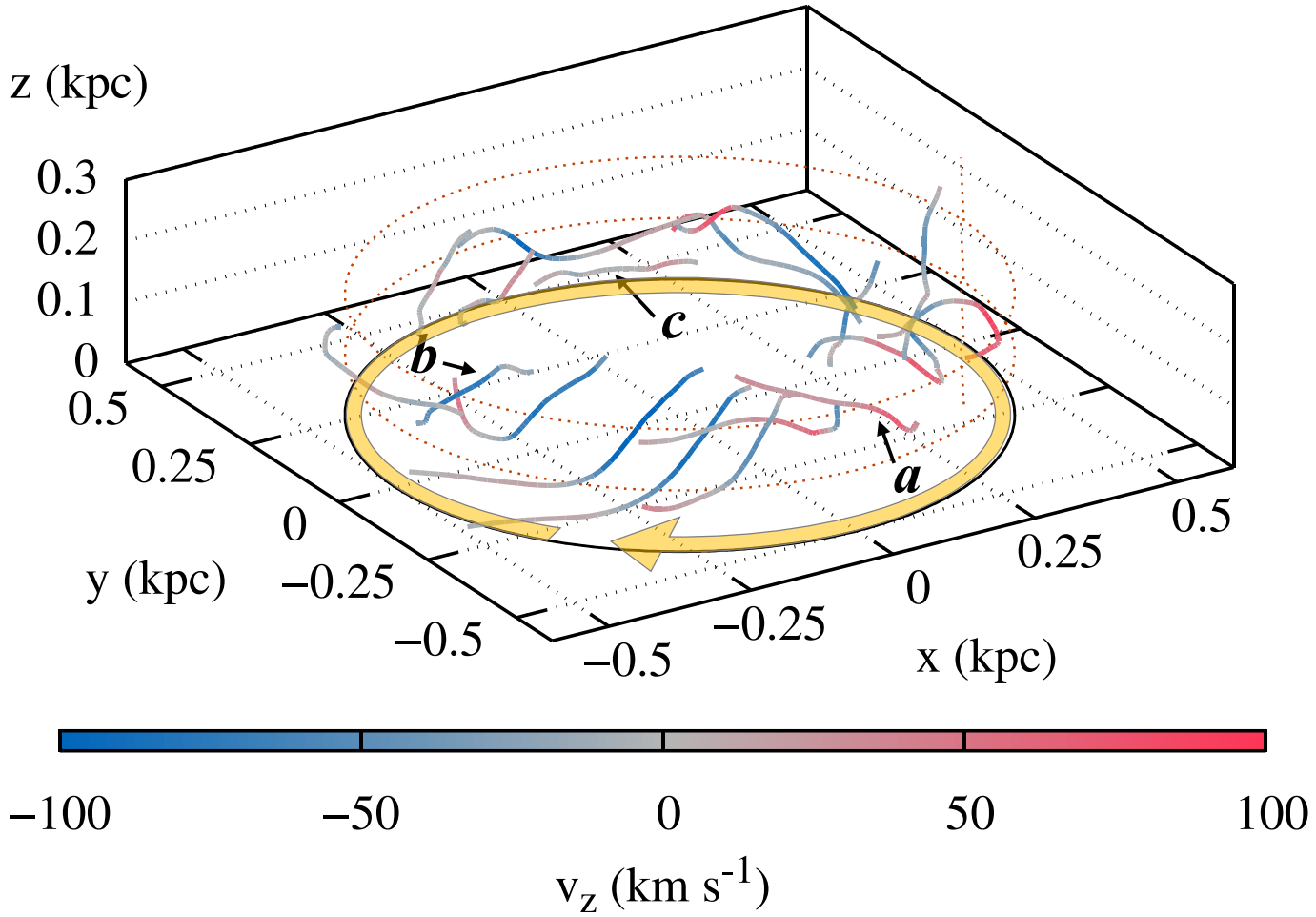
$$v_g = 100\ \mathrm{km\ s}^{-1}$$
$$(z = 0.25 \rightarrow 0.05\mathrm{kpc})$$





# Overview: Gas flows and structure in global

--track the motions of fulid elements with t=399.5-402.5Myr.




✓ Ubiquitously, vertical flows exist

Average life ~ 4-6 Myr

# Overview: Gas flows and structure in global

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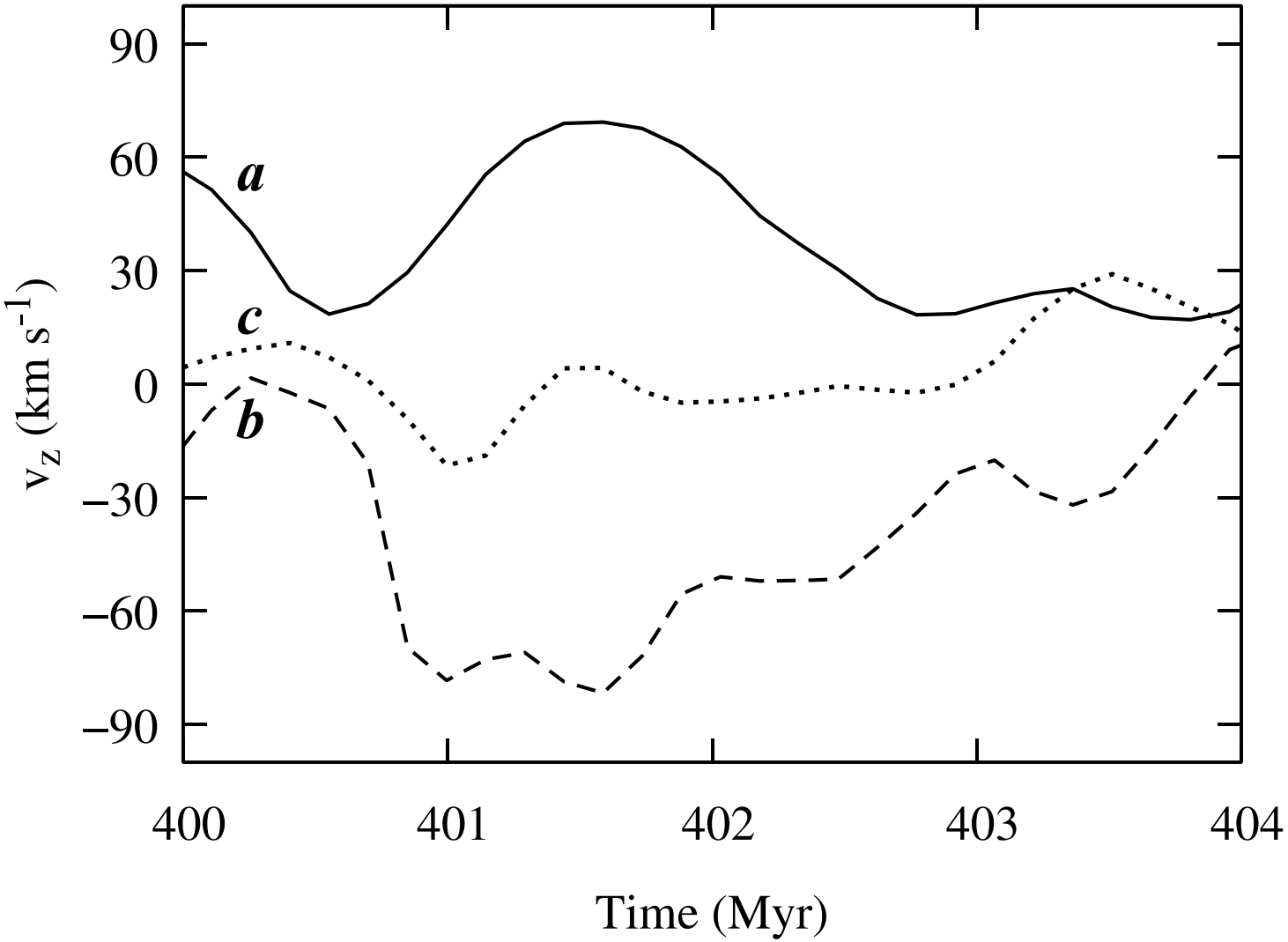

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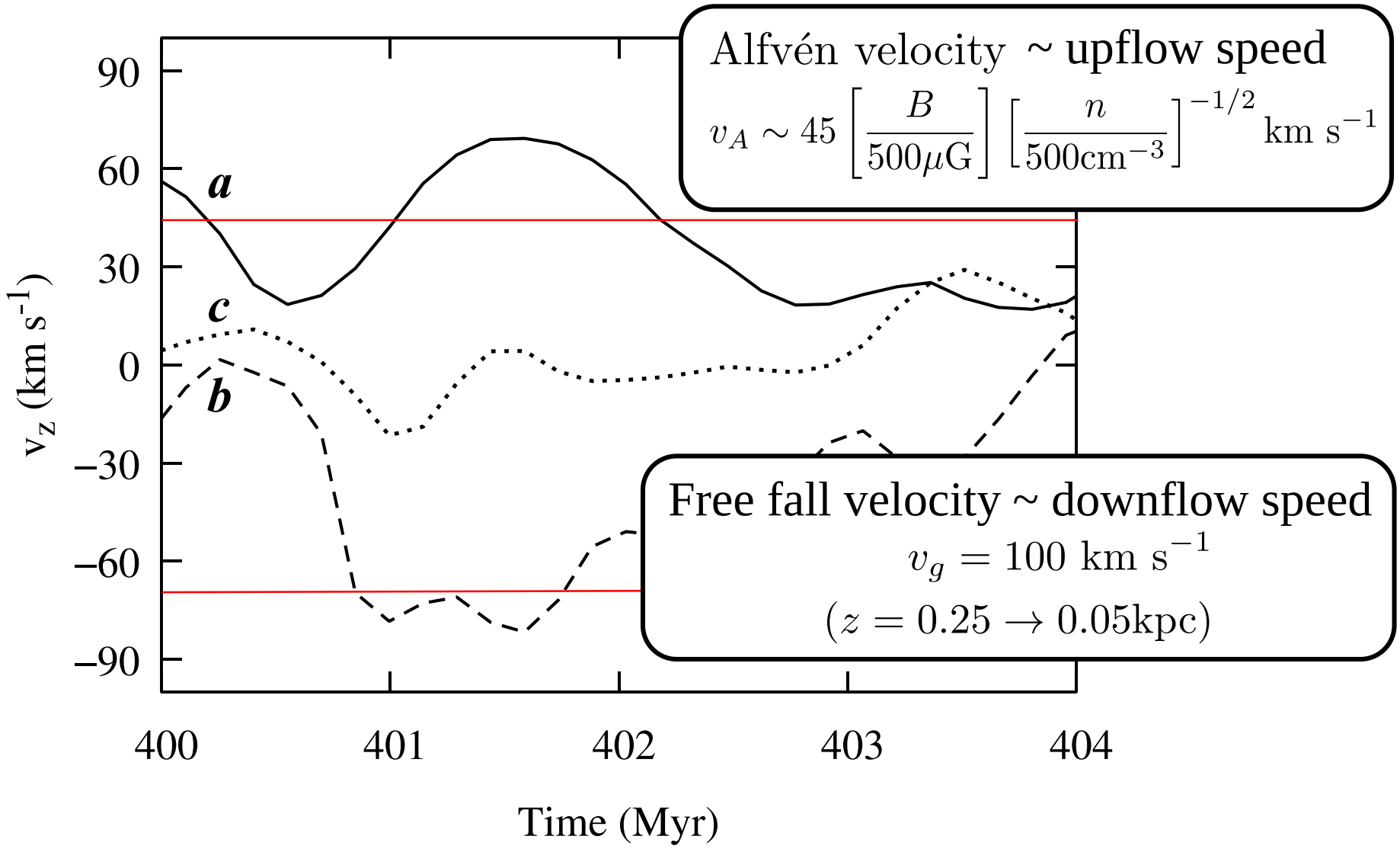

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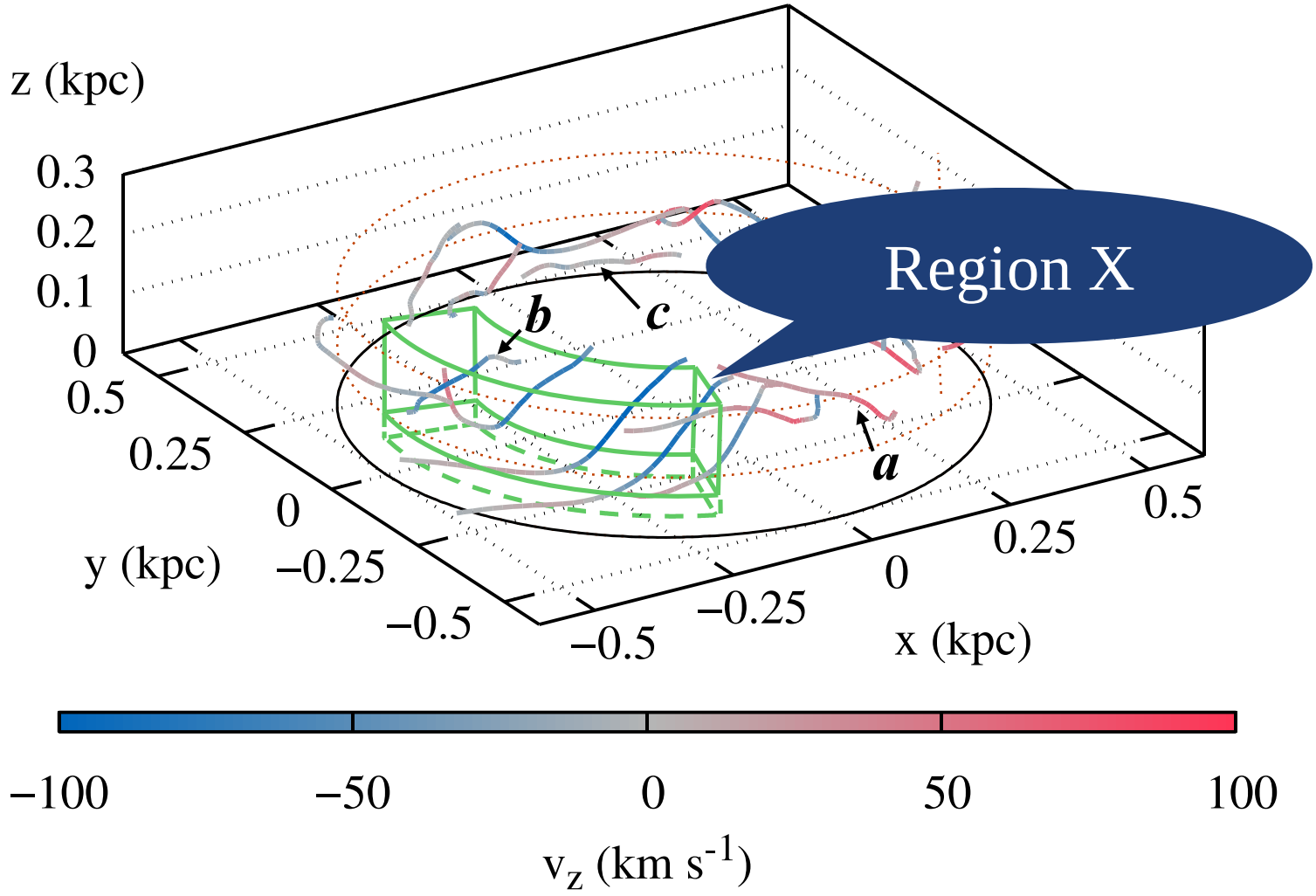

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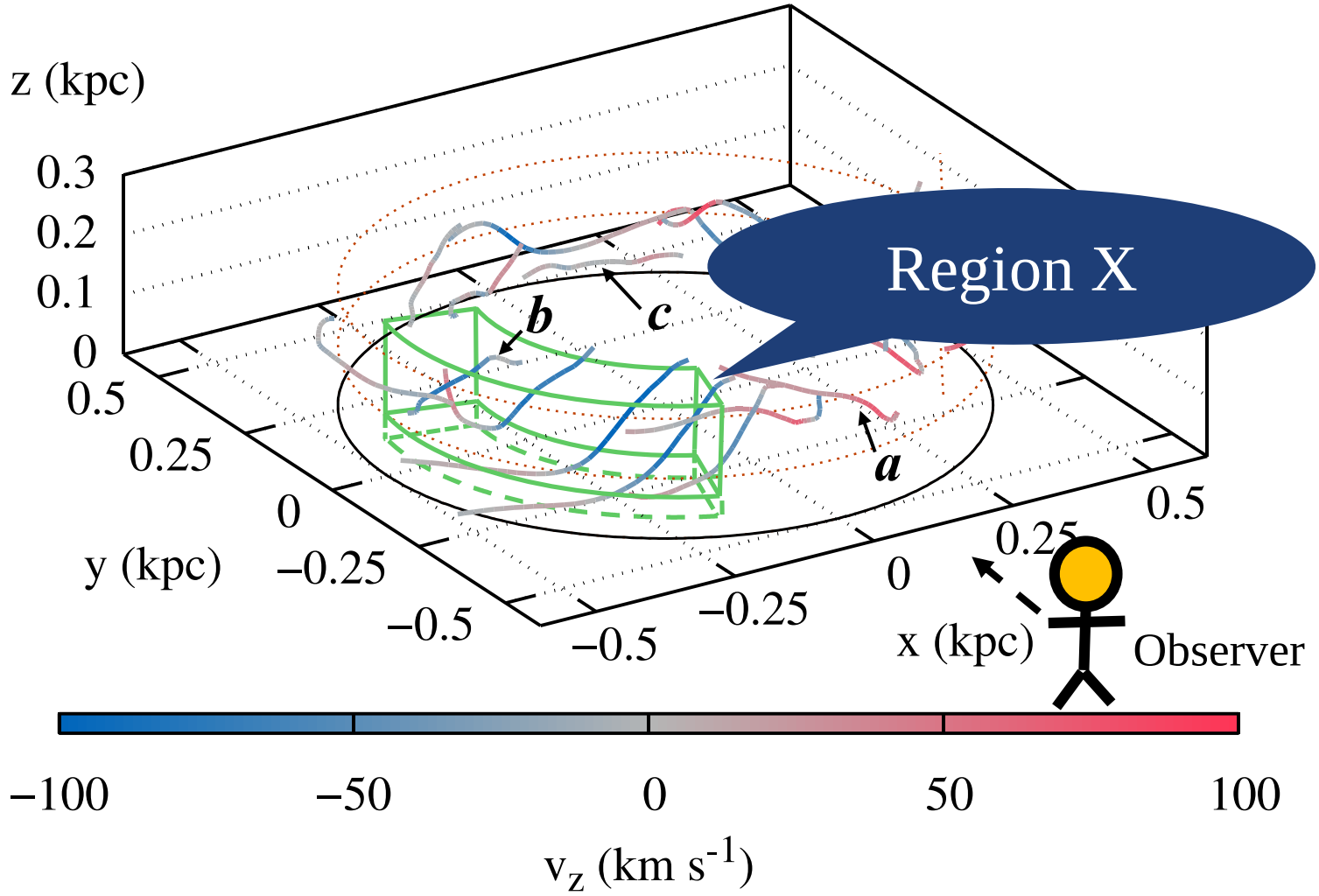
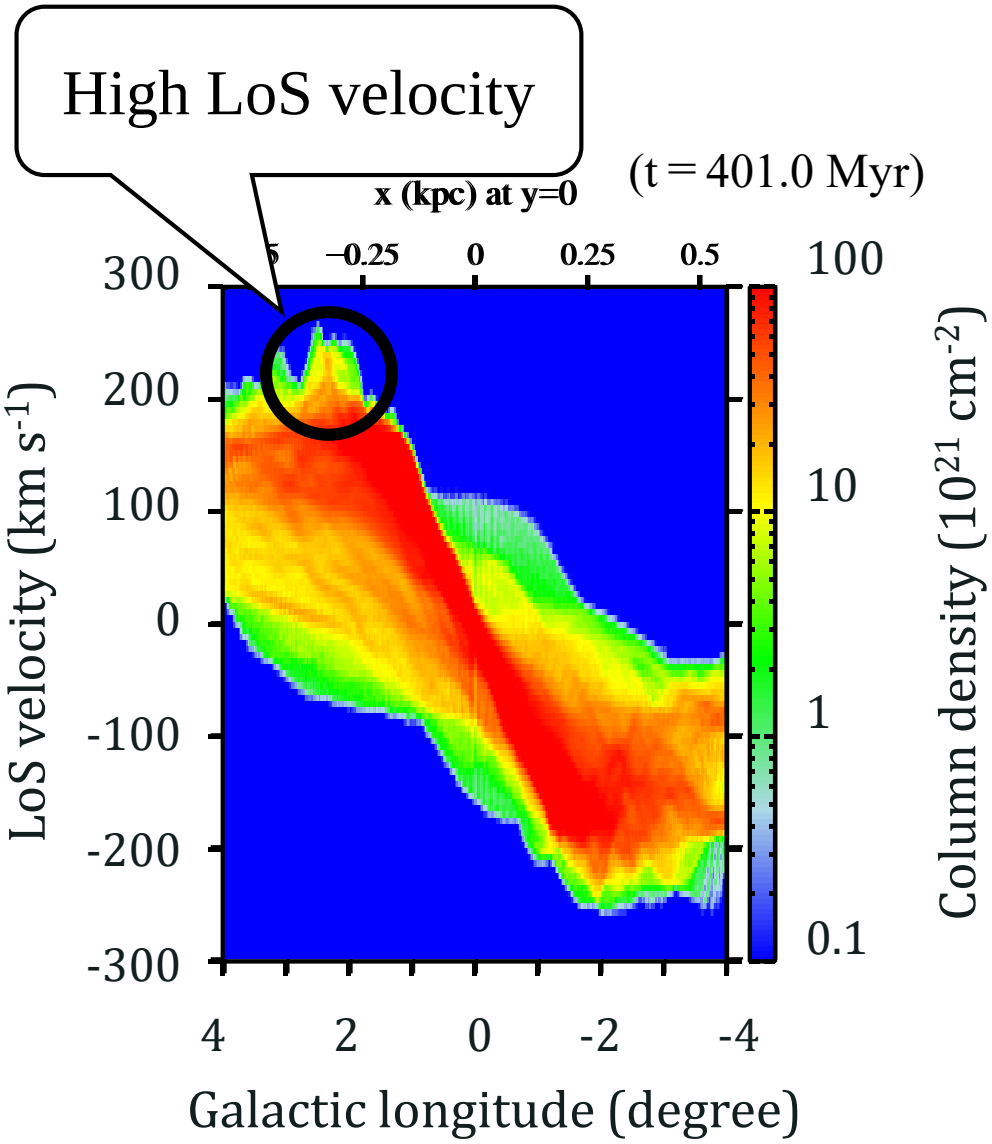
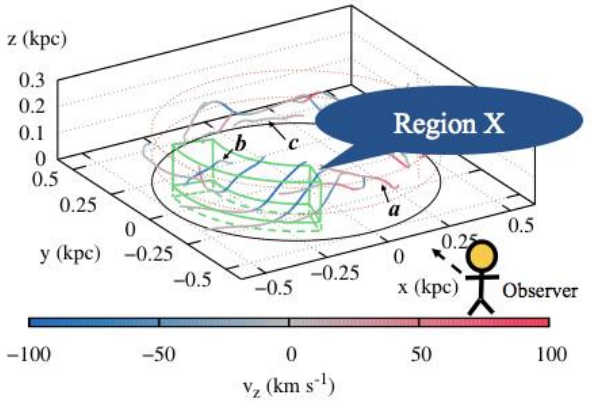
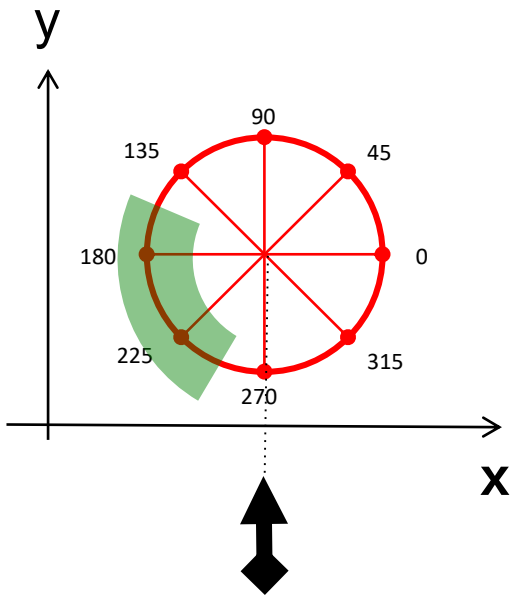


# Simulated l-v diagram



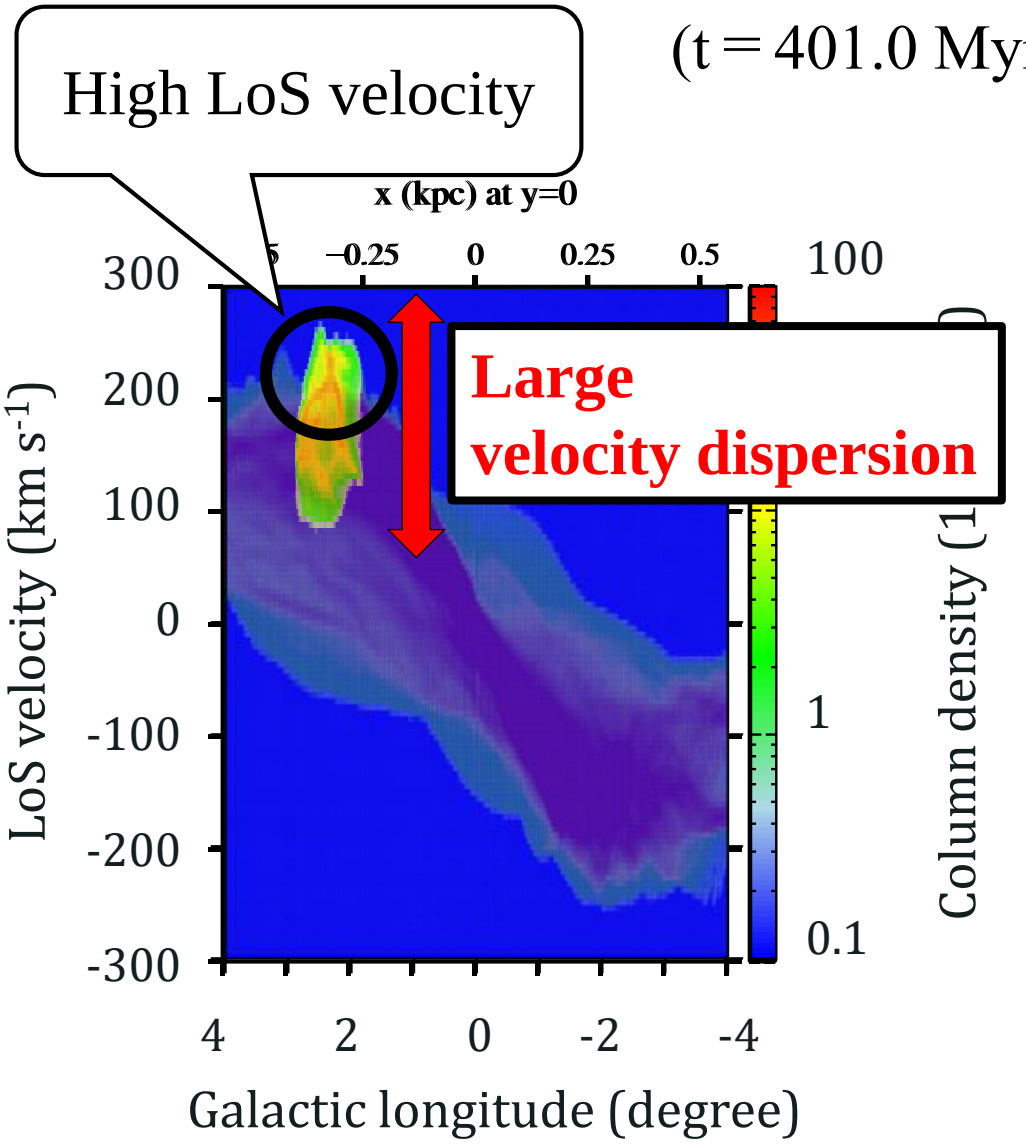



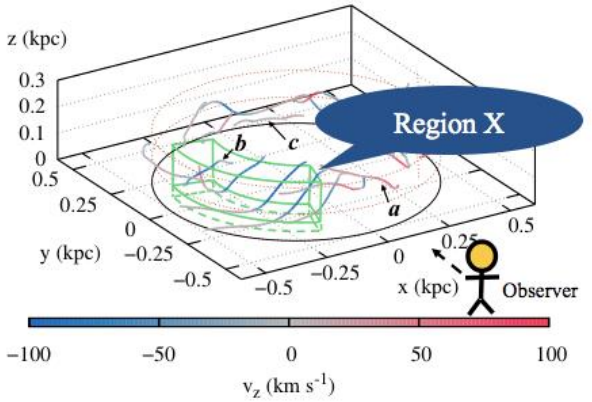



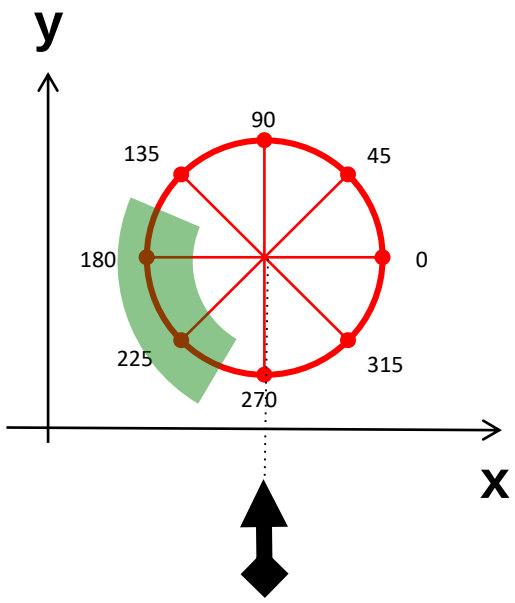

視点(270°)
(r=8.0kpc)

# Simulated l-v diagram

(t = 401.0 Myr)

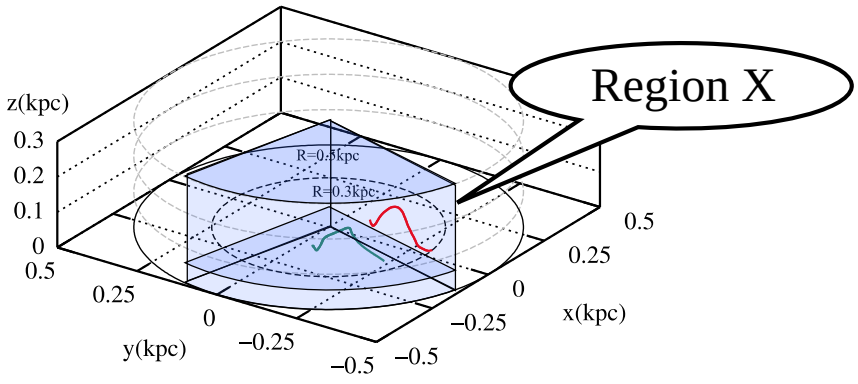


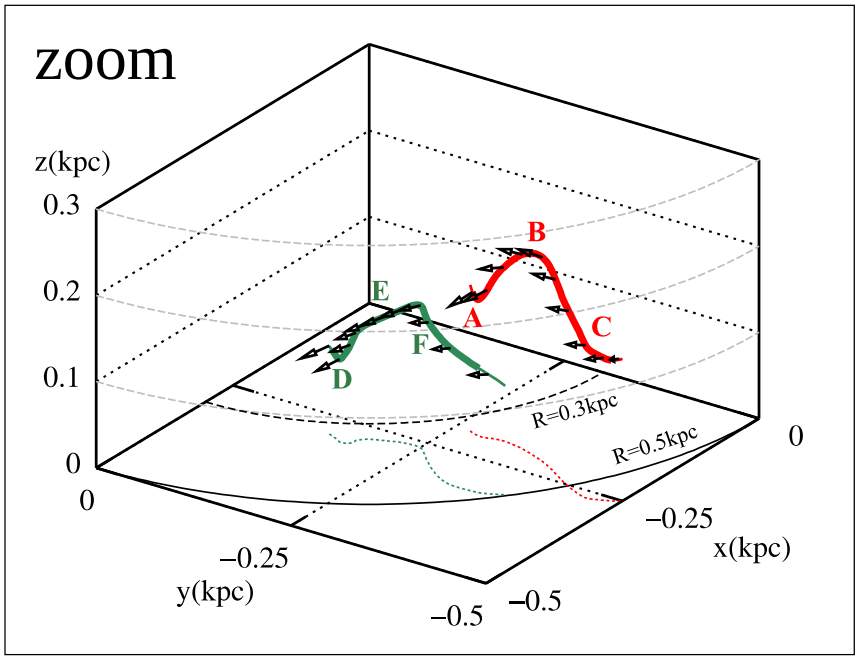



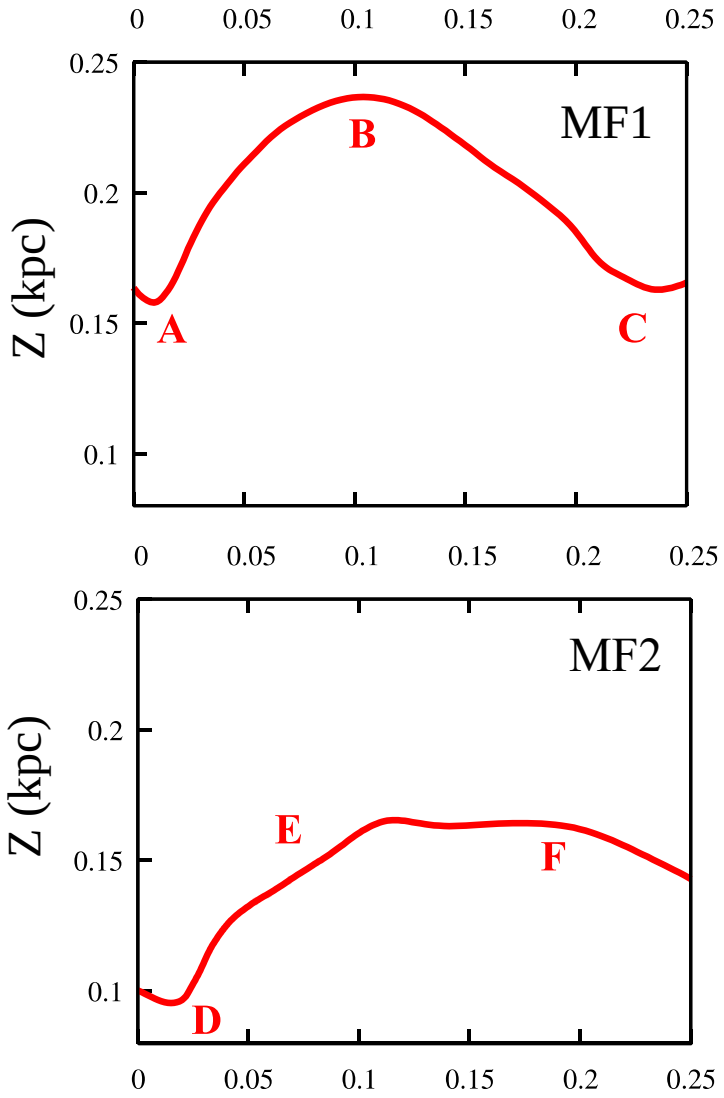




Obs.(270° )
(r=8.0kpc)

# Magnetic field line in region X



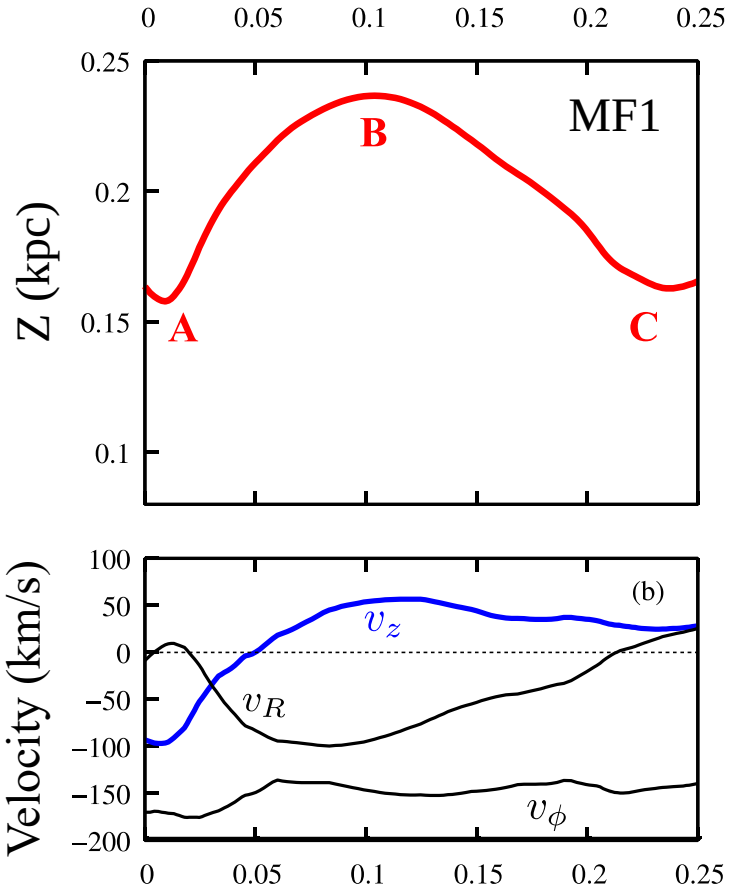



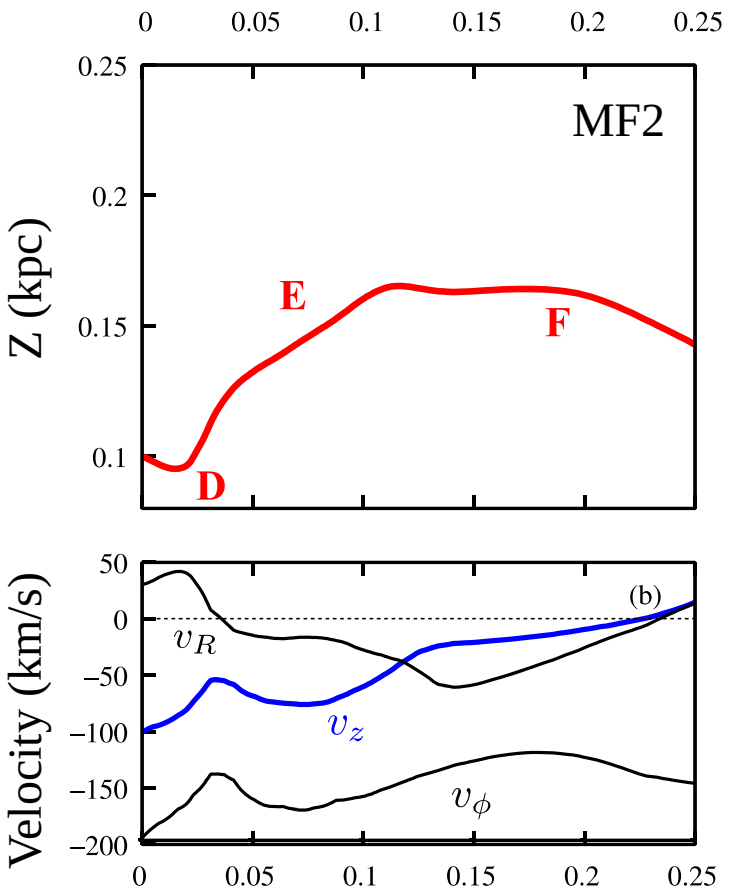




Distance along Magnetic Fieldline (kpc)

✓ **Magnetic arch-like structure !**

# Rising loop & Fast downflows



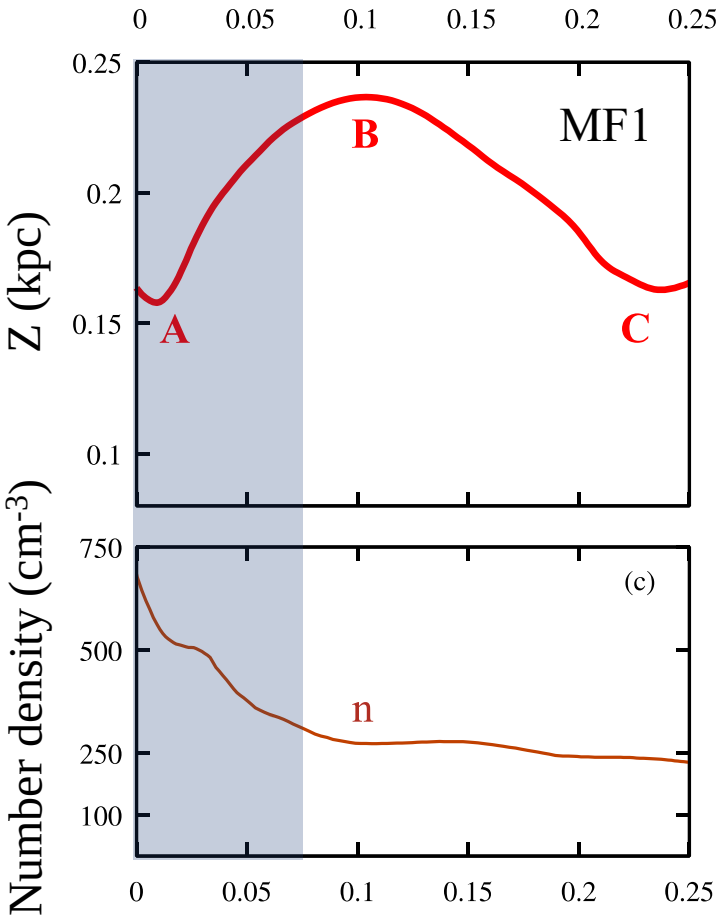



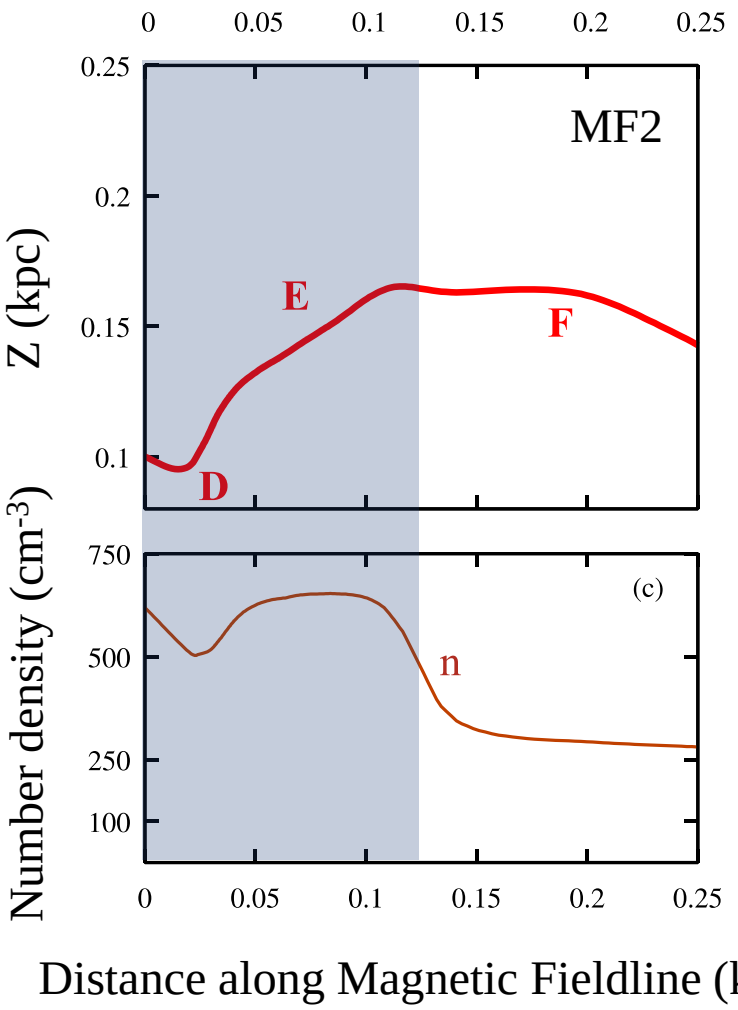

- ✓ Loop-foot (A): downflows ~100 km/s
- ✓ Loop-top (B): Rising ~ 50 km/s

The gases fall down to one side

Vertical velocity ↑

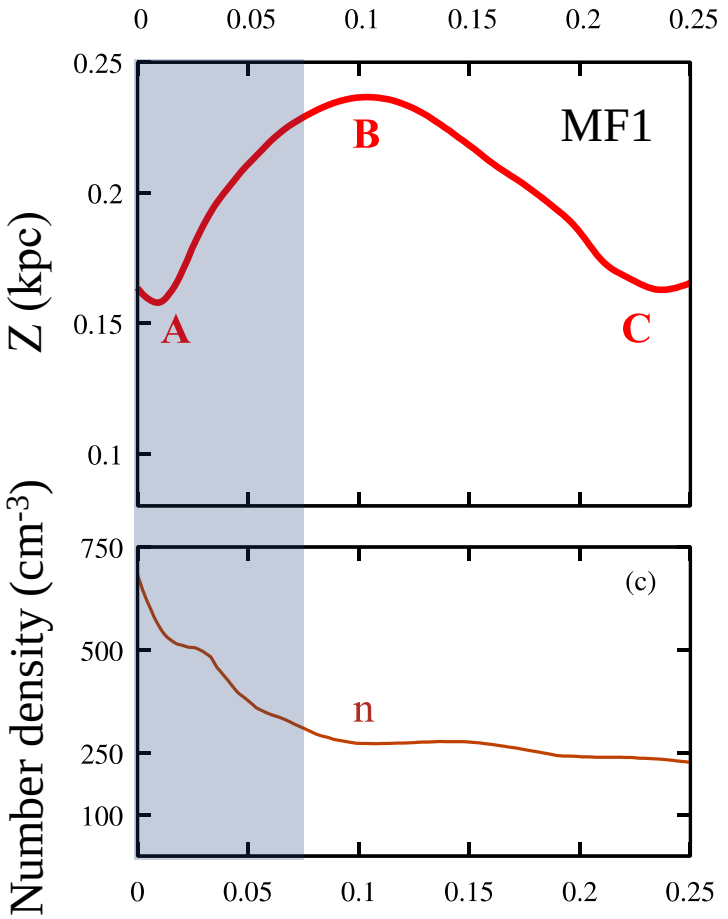
# Rising loop & Fast downflows

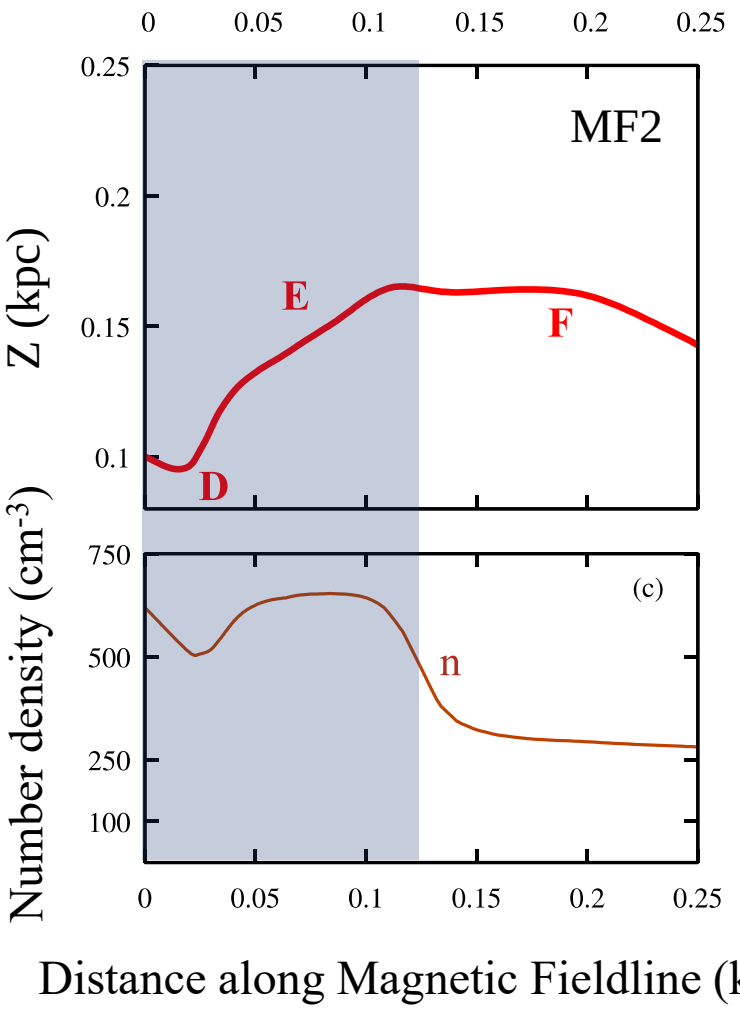



- ✓ Downflows with high density
- ✓ The gases collect and compress

# Rising loop & Fast downflows

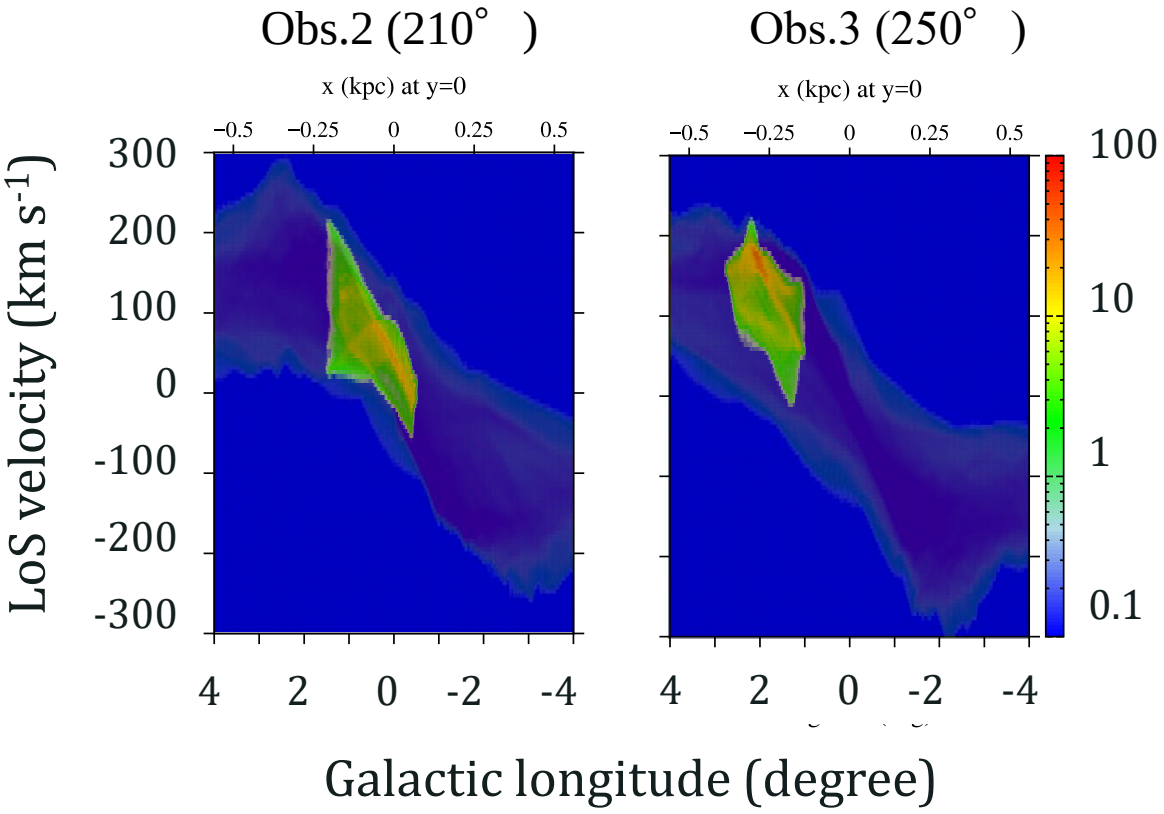


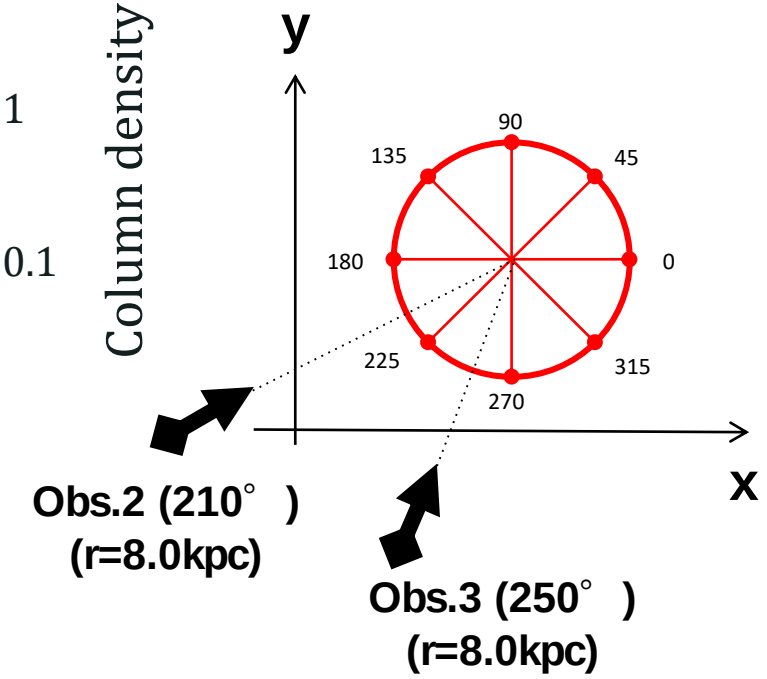




- ✓ Downflows with high density
- ✓ The gases collect and compress

# Discussion – Region X in l-v diagram

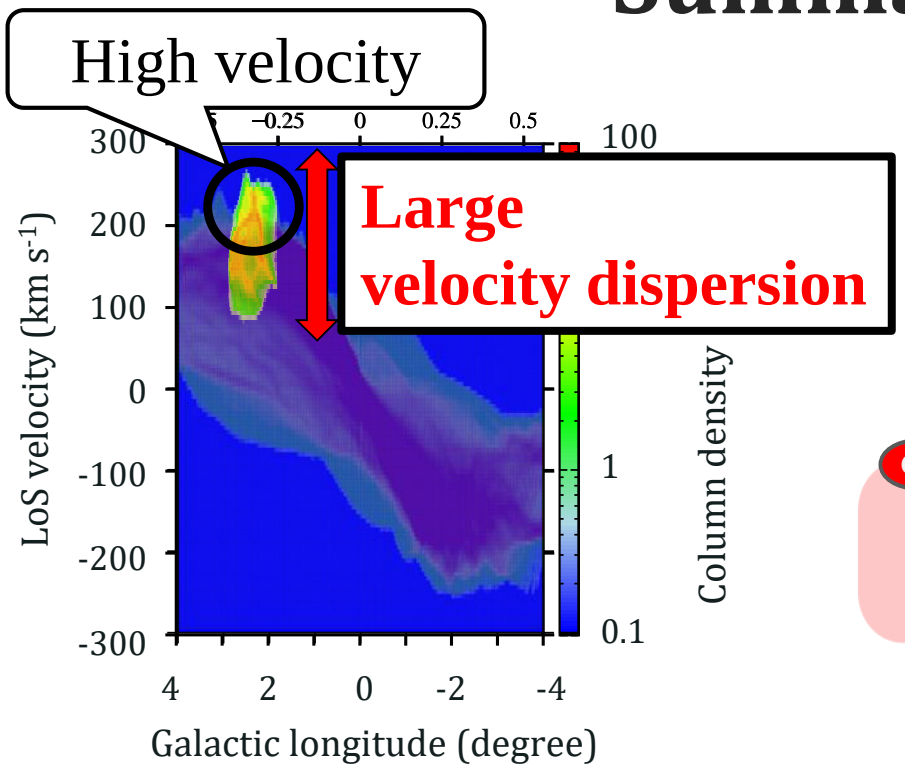
✓ Different features depending on the viewing angle.

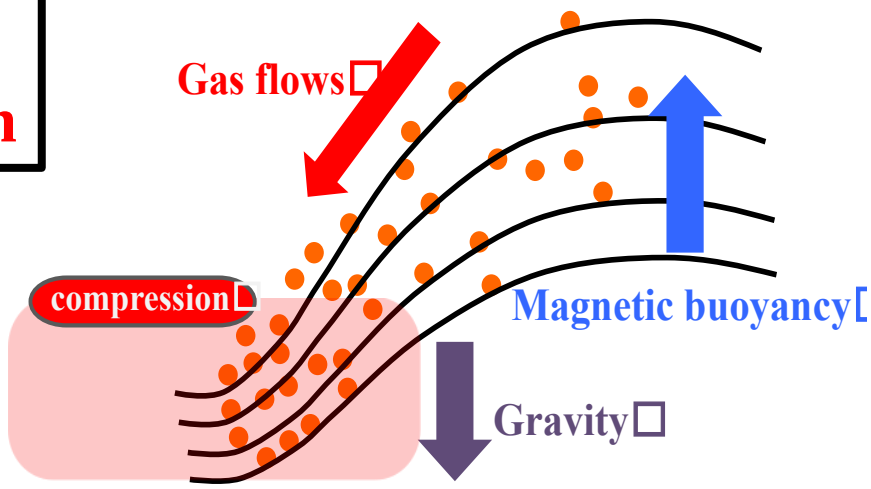



- Shape
- Velocity dispersion

# Summary




(Magnetic Activity; Parker Instability)

High velocity ➡ Downflows along the line of sight

➡ Large velocity dispersion

Fall down align the magnetic slope **Acceleration : ~100 km/s**

Footpoint of slope: collect and compress gases

# Appendix: Basic Equation

Eq. of continuity

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

Eq. of motion

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

Eq. of Induction

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\boldsymbol{v} \times \boldsymbol{B})$$

$$\Phi(R, z) = \sum_{i=1}^{3} \frac{-GM_i}{\sqrt{R^2 + (a_i + \sqrt{(b_i^2 + z^2)})^2}}$$

Axisymmetry gravitational potential
(Miyamoto & Nagai 1975)

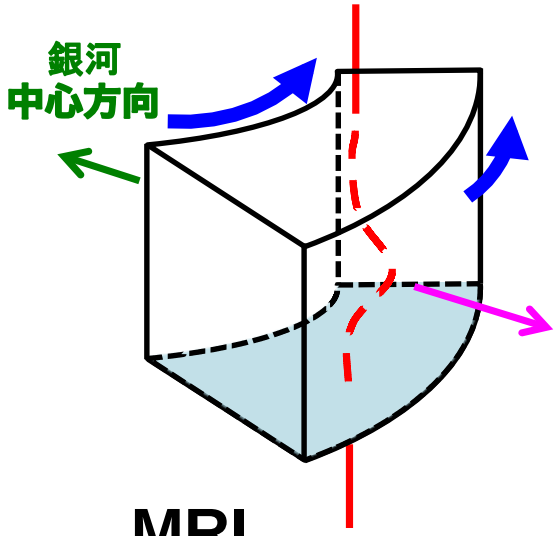
# Magnetic Field in The Galactic Centre Region

❖ **Strong magnetic fields**

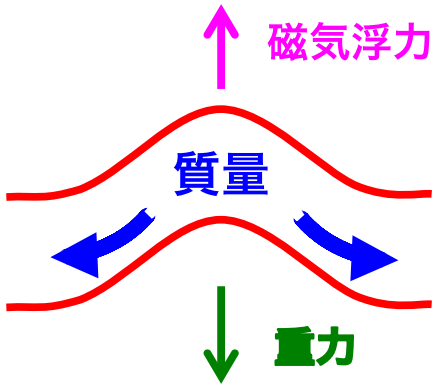
- ✓ **globally** > 50μG (Crocker+ 2010)
- ✓ **Locally** ~ **100-1000μG** (Yuzef-Zadeh+ 1984; Morris 1990; Pillai+15)

(※ a few μG in a typical molecular cloud at the disk)

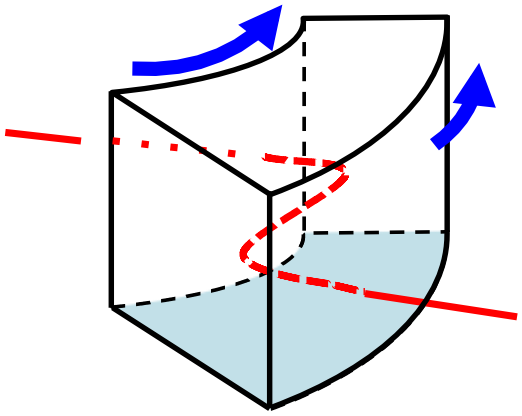
❖ **Amplification of Magnetic fields**




MRI




Parker Instability



Differential rotation