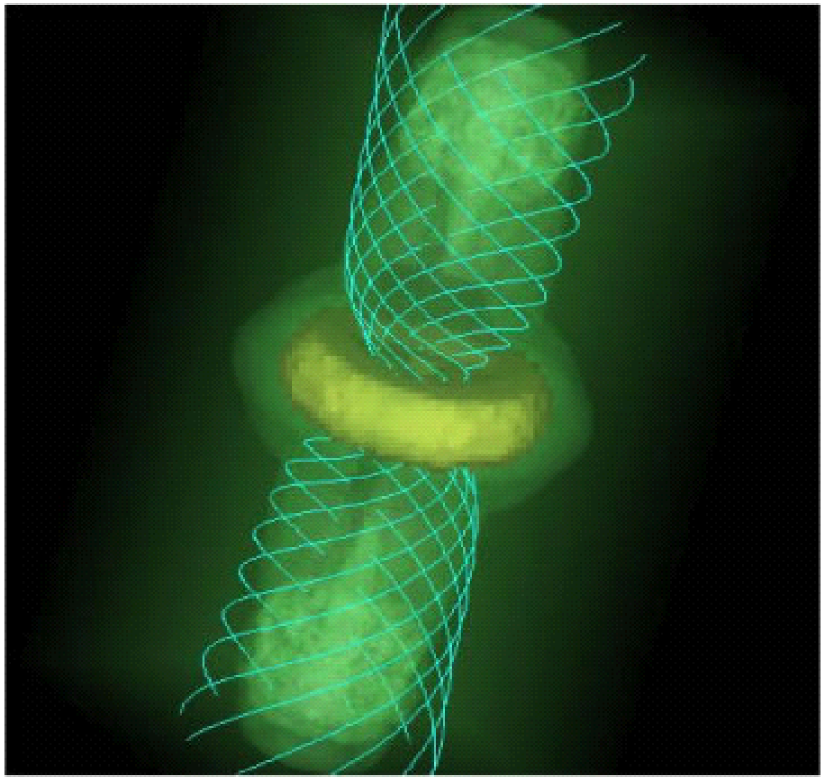
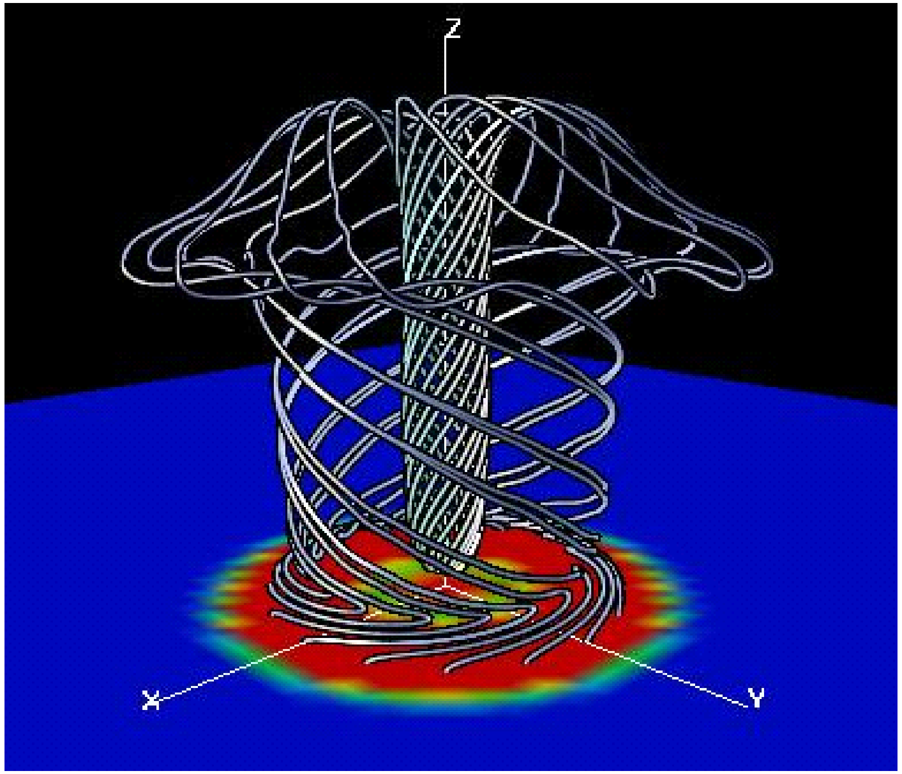
# Similarities of the Launching Mechanism in Protostellar/AGN Jets

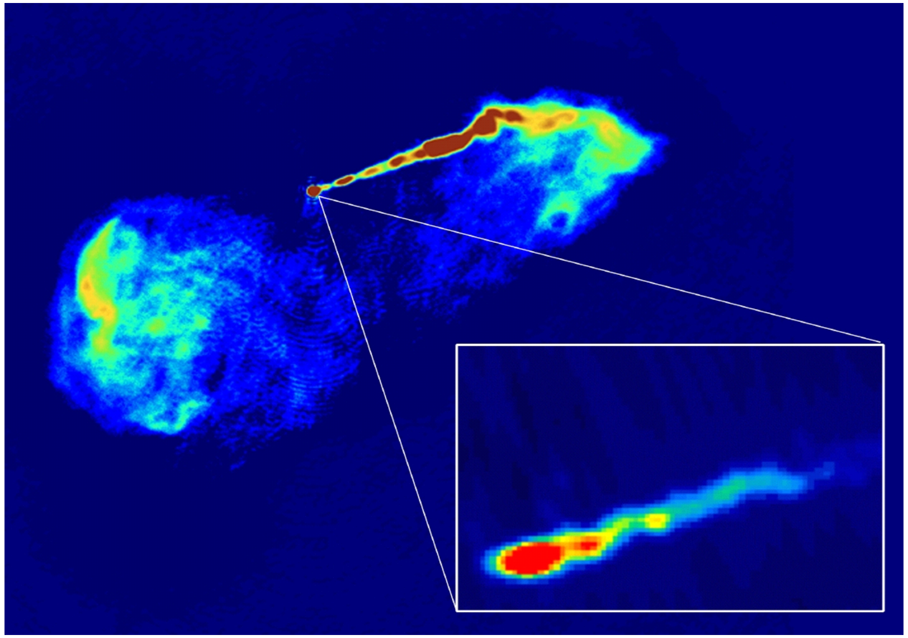





Ryoji Matsumoto (Chiba Univ.)

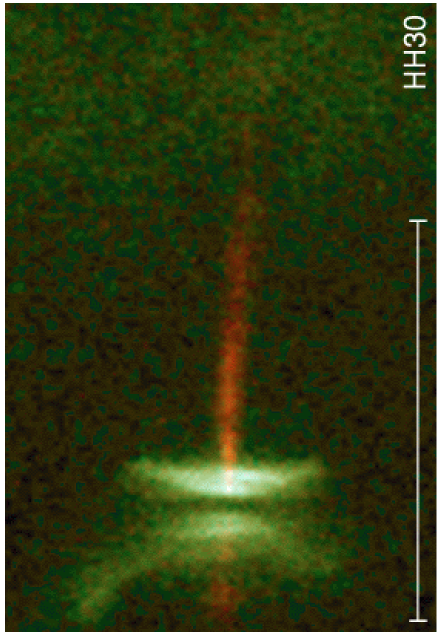
Collaborators: T. Kuwabara, Y. Kato, and Mami Machida

# Jets from AGN and Protostar



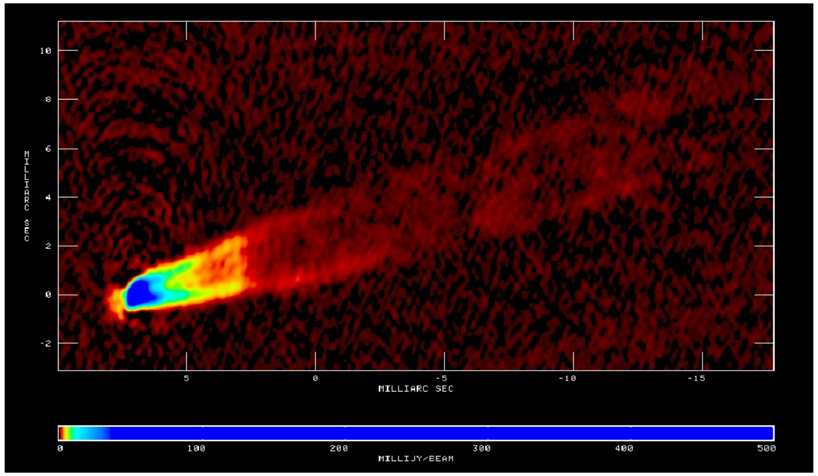
**M87**

**VLA+ HALCA**

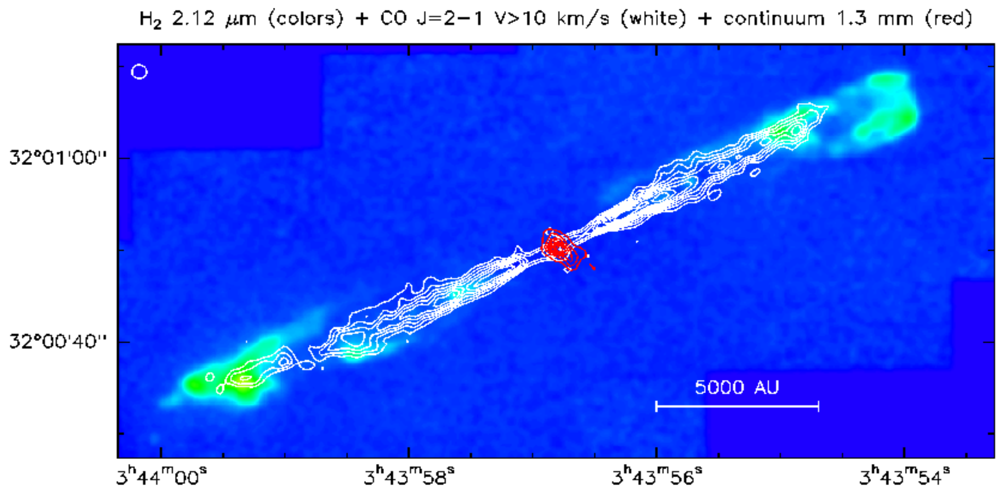



**HH30 Burrows 1995**

1000AU



**M87**

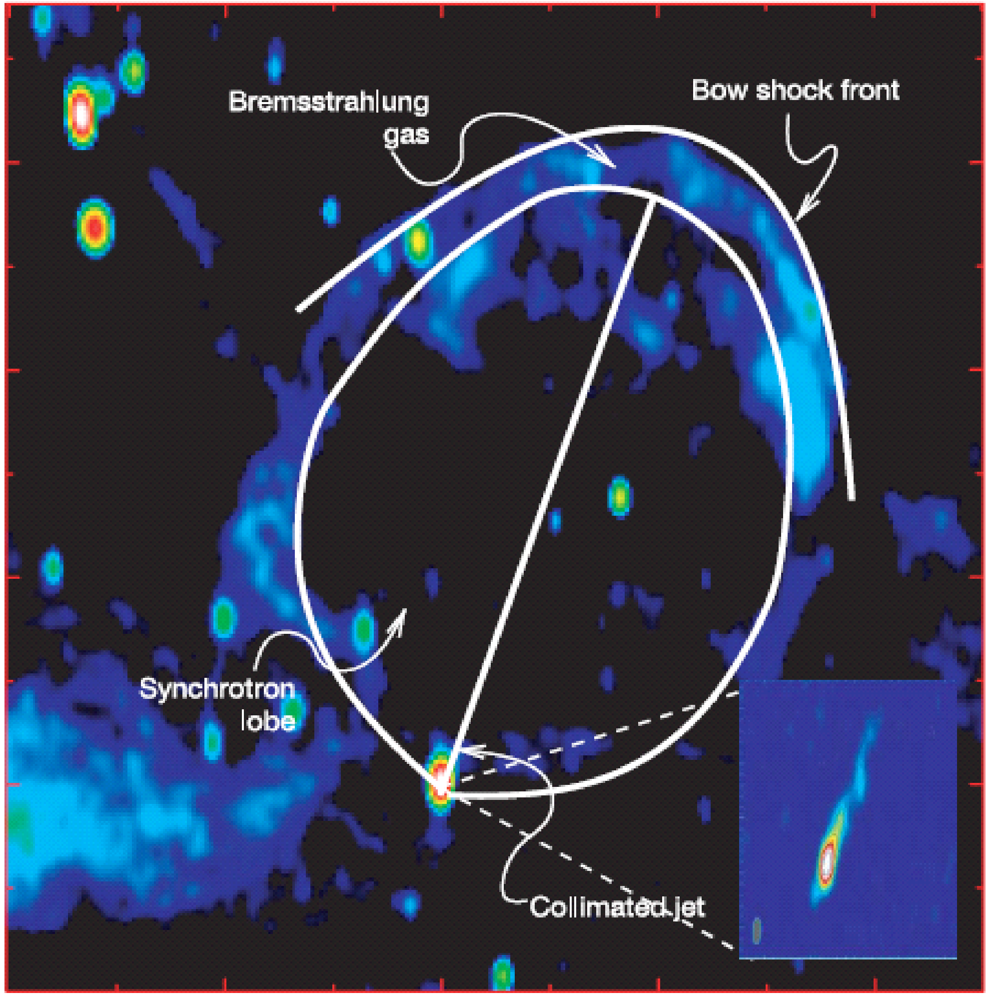



**CO + H2**

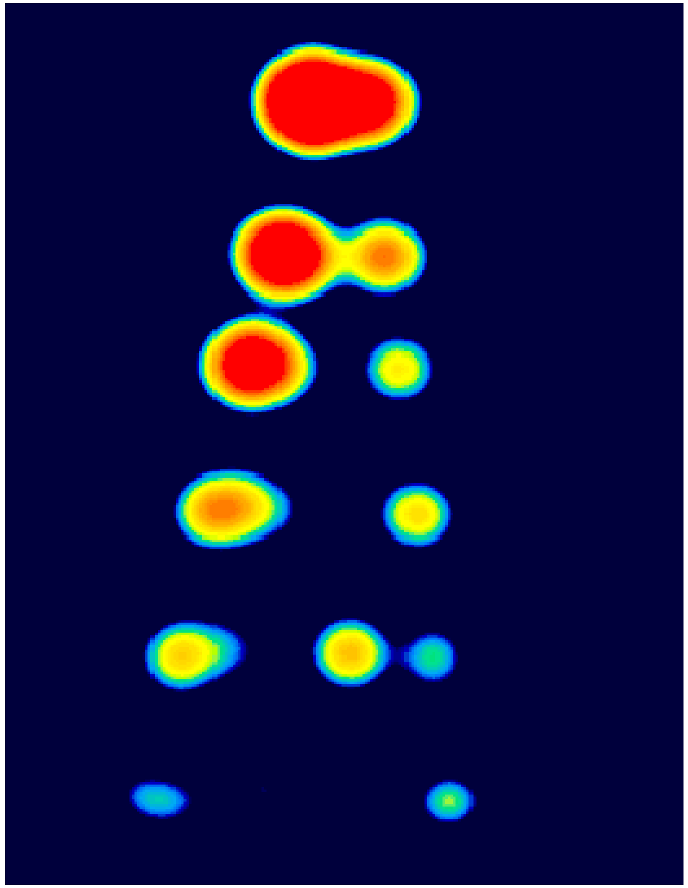
**VLBA 43GHz (Walker et al. 2007)**

**HH211 (Gueth and Guilloteau 1999)**

# Jets in Galactic Black Hole Candidates



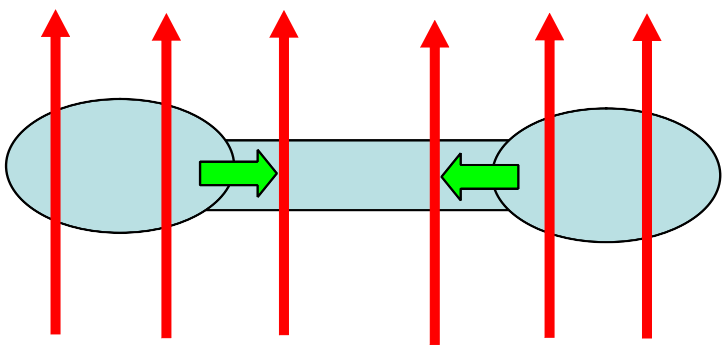

**Core Jet + Outflows in Cyg X-1**
**(Gallo et al. 2005)**



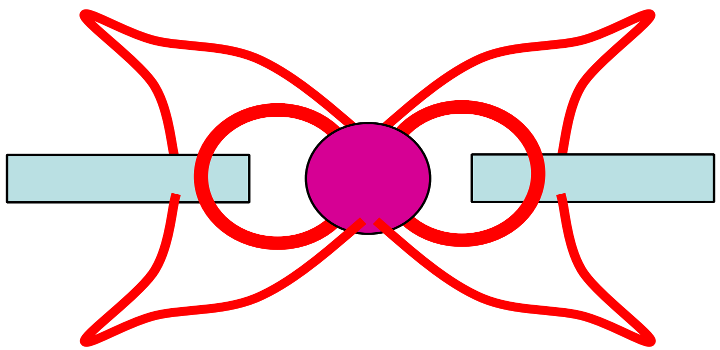
Superluminal Motion in a Microquasar GRS1915+105 (Mirabel et al.1994)

# Formation Process of Jets/Outflows

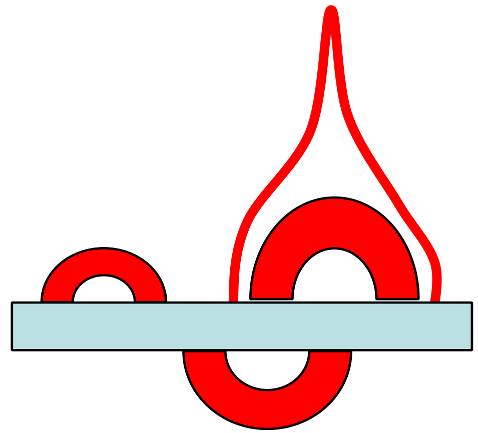
1. Formation of Large Scale Poloidal Magnetic Fields Threading the Disk



accretion



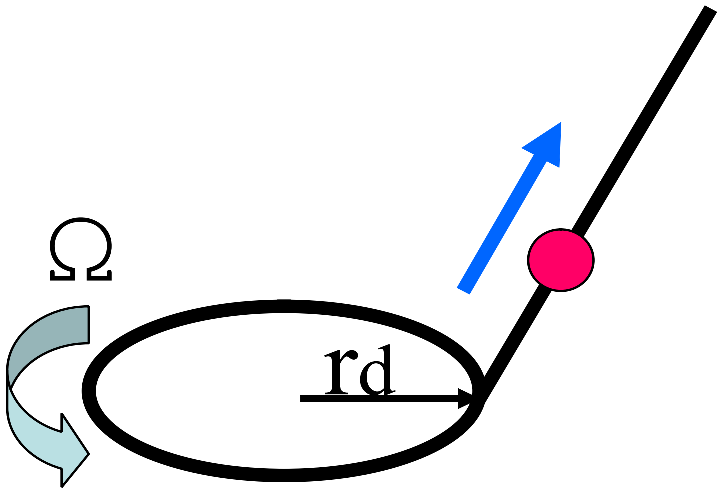
Star-disk connection



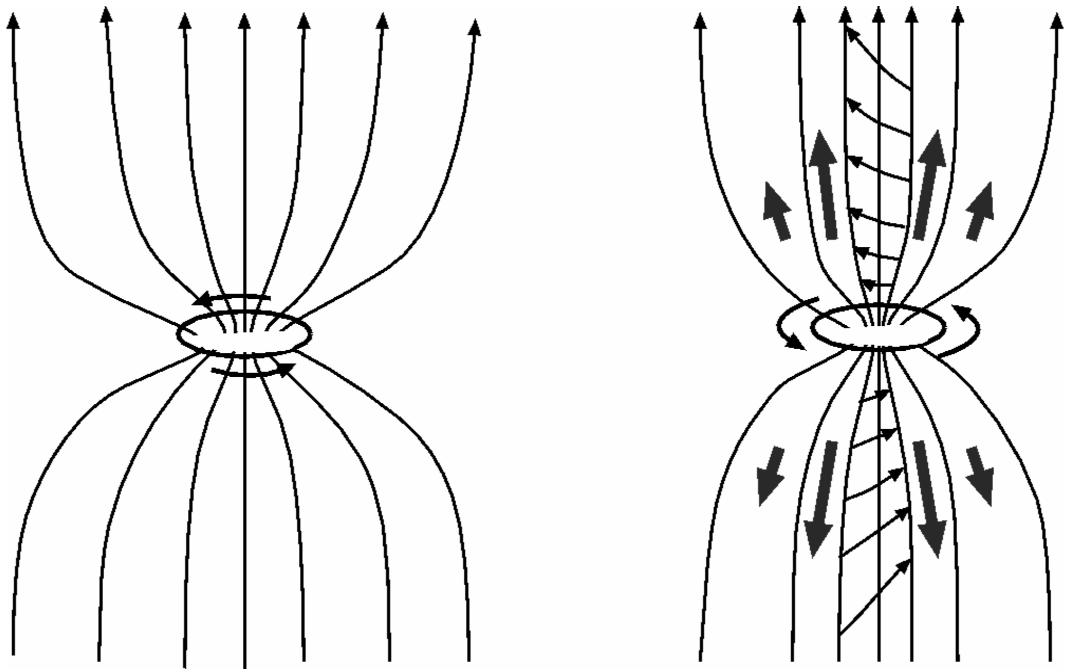
Buoyantly Rising Magnetic Loops

2. Formation of Magnetically Driven Outflows Along the Large Scale Magnetic Field

# Jet Formation from an Accretion Disk Threaded by Large Scale Poloidal Magnetic Field



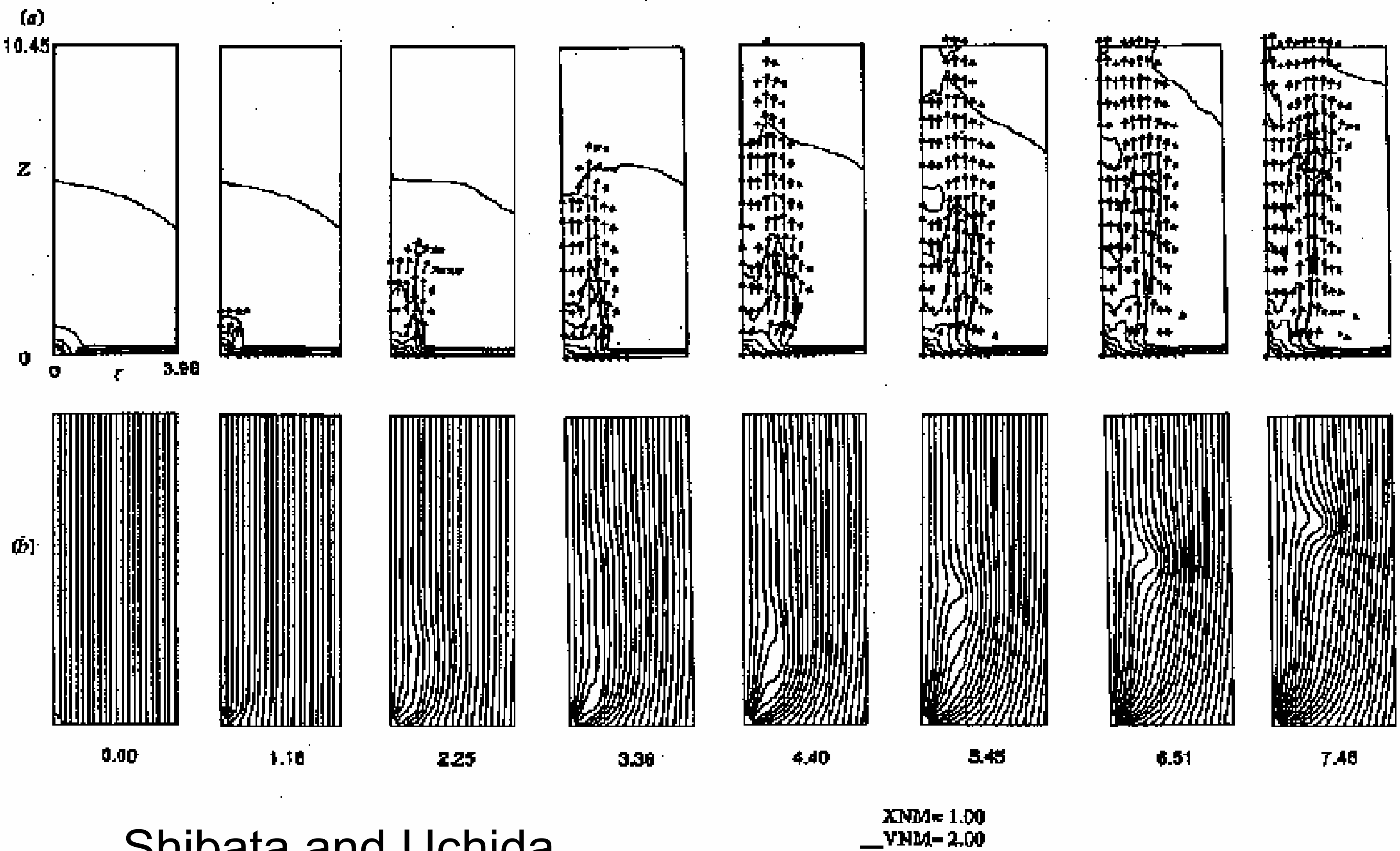

Blandford and Payne (1982)
Theory of Magneto-centrifugally driven jet



Uchida and Shibata (1985)
Shibata and Uchida (1986)

2D MHD Simulations of magnetically driven jet

# Result of 2D MHD Simulation

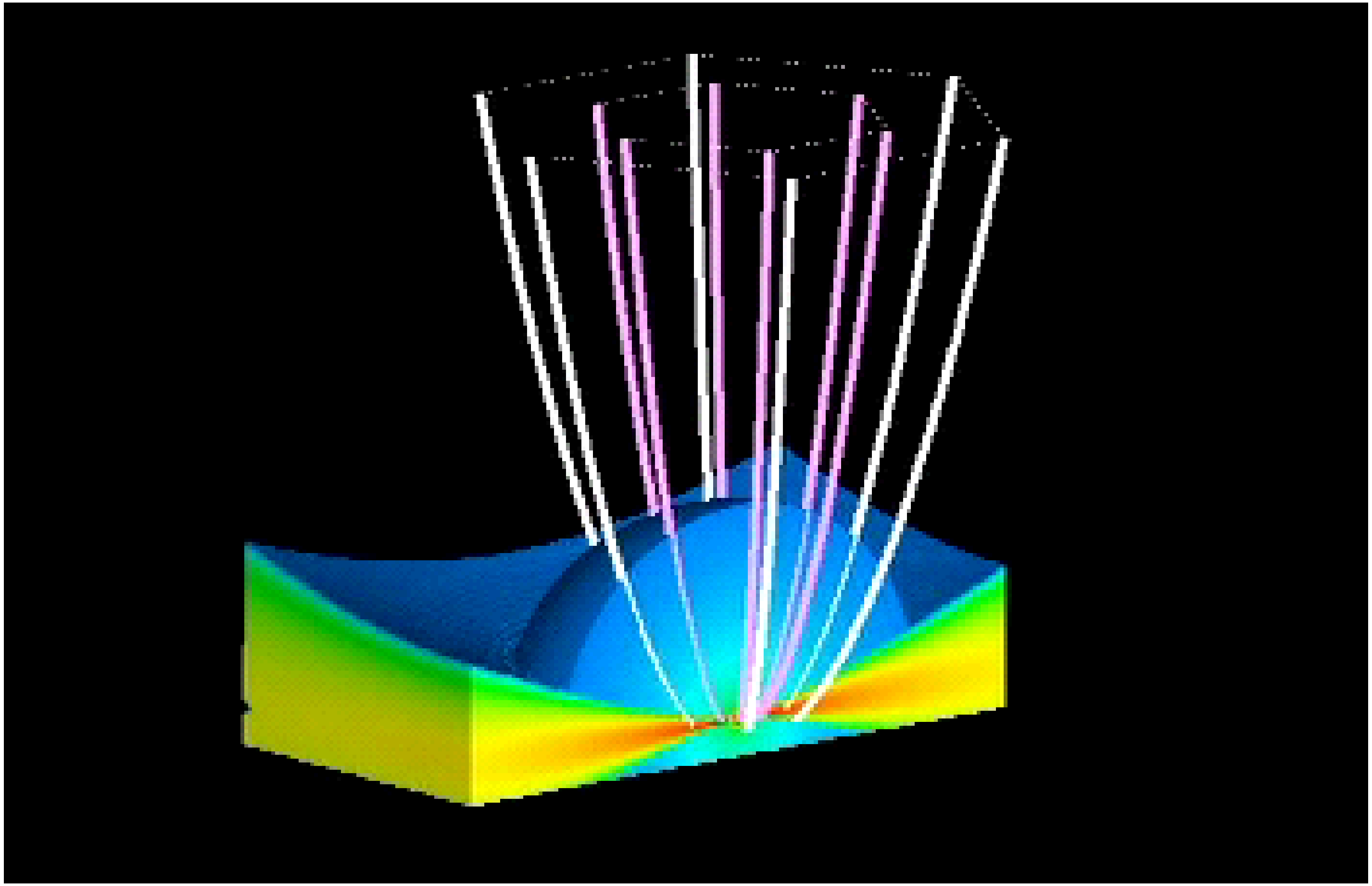



**Density + velocity**

**Magnetic Field LInes**

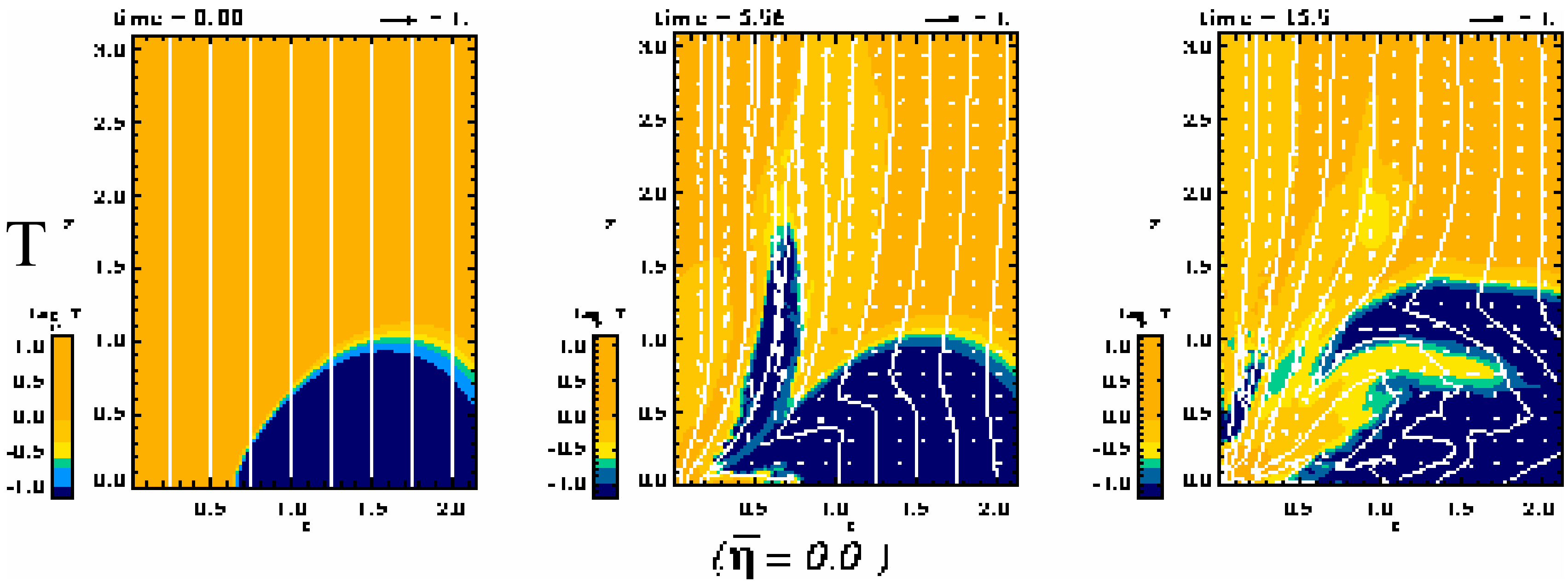
Shibata and Uchida

# MHD Simulation of Uchida-Shibata Model of Jet Formation



Kodoh et al. 2002

# Ideal MHD Simulations often Show Intermittent Ejections




Result of ideal MHD simulation of jet formation by Kuwabara et al. 2000. Jet ejection takes place intermittently due to the growth of MRI in the disk

# Steady Model of Axisymmetric Jets (Kudoh and Shibata 1997)

$$P = K\rho^{\gamma} ,$$

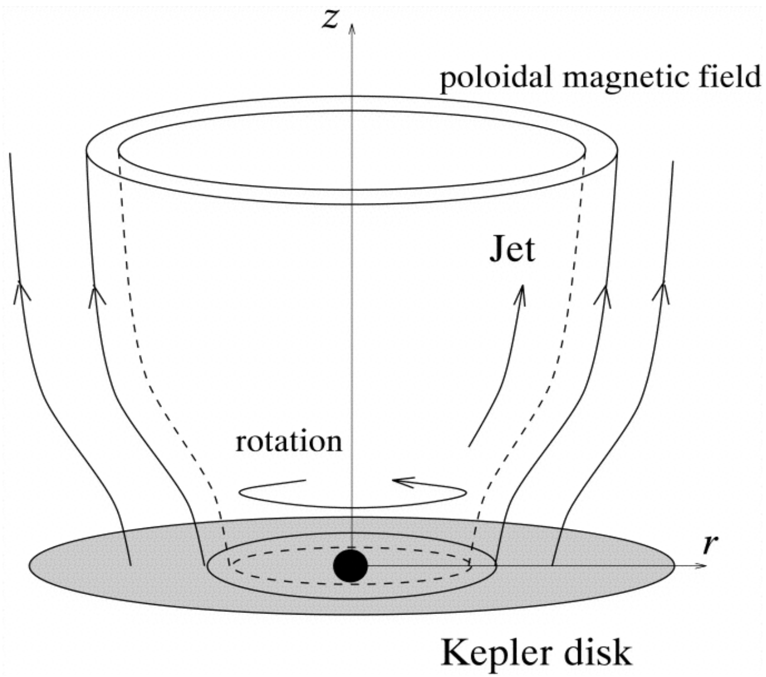
$$\rho v_p = \lambda B_p ,$$

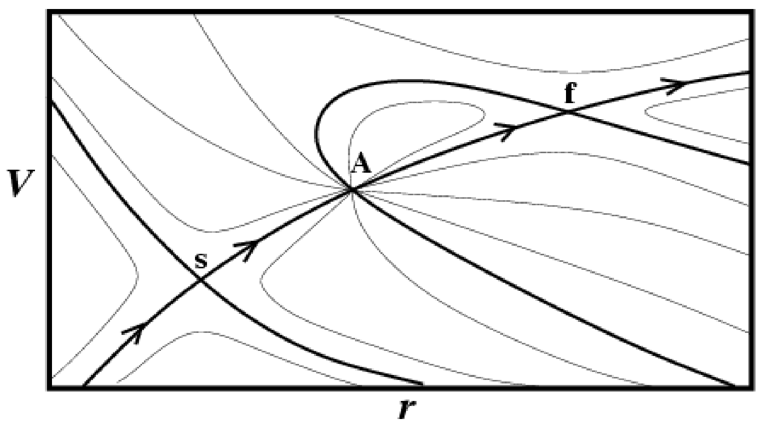
$$(v_\phi - \Omega r)B_p = v_p B_\phi ,$$

$$r\left(v_\phi - \frac{B_\phi}{4\pi\lambda}\right) = L ,$$

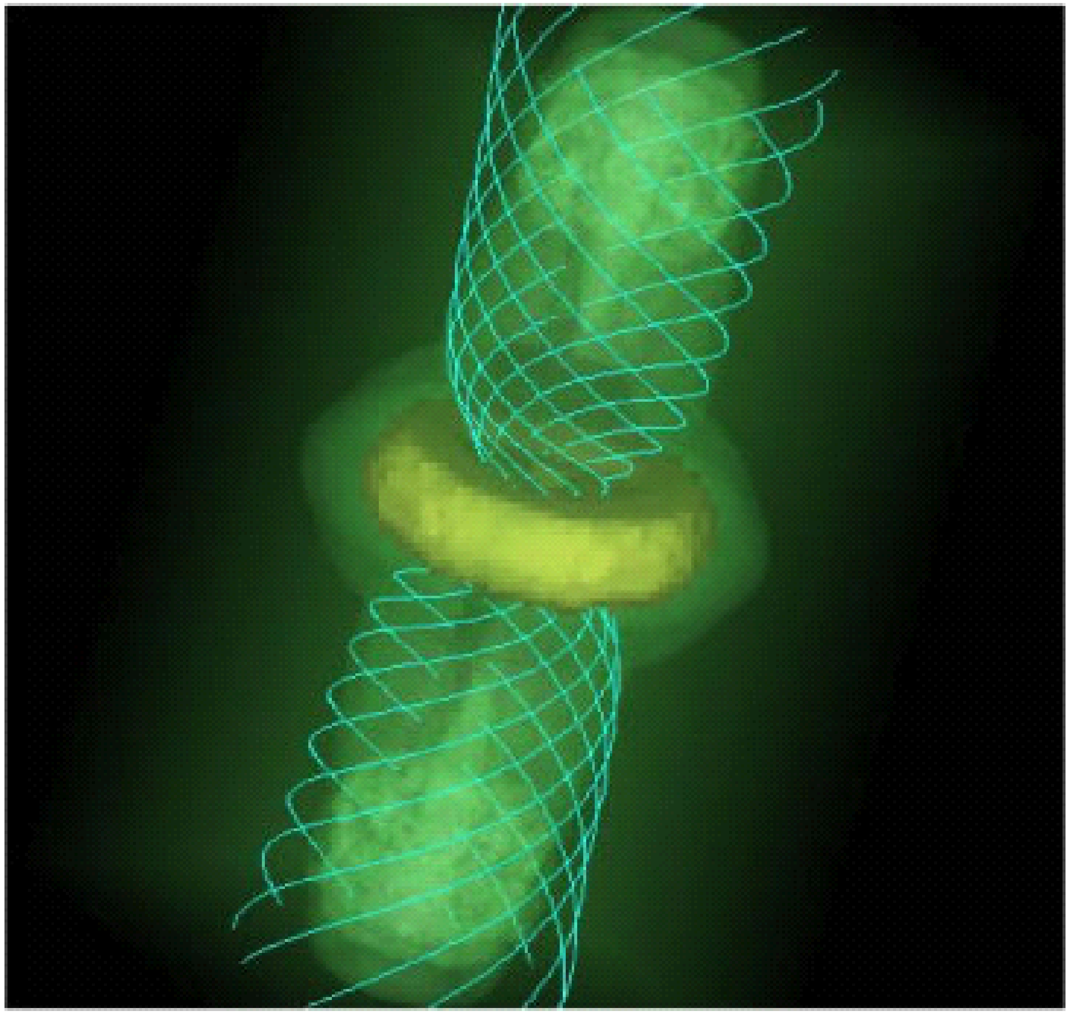
$$\frac{1}{2} v_p^2 + \frac{1}{2} v_\phi^2 + \frac{\gamma}{\gamma - 1} \frac{P}{\rho} + \Psi_g - \frac{r\Omega B_\phi}{4\pi\lambda} = E$$

Along a Magnetic Field Line



# MHD Simulation including Resistivity



$$E_{th} = \frac{V_{S0}^2}{\gamma V_{K0}^2} = 5 \times 10^{-2}$$

$$E_{mg} = \frac{V_{A0}^2}{V_{K0}^2} = 5 \times 10^{-4}$$

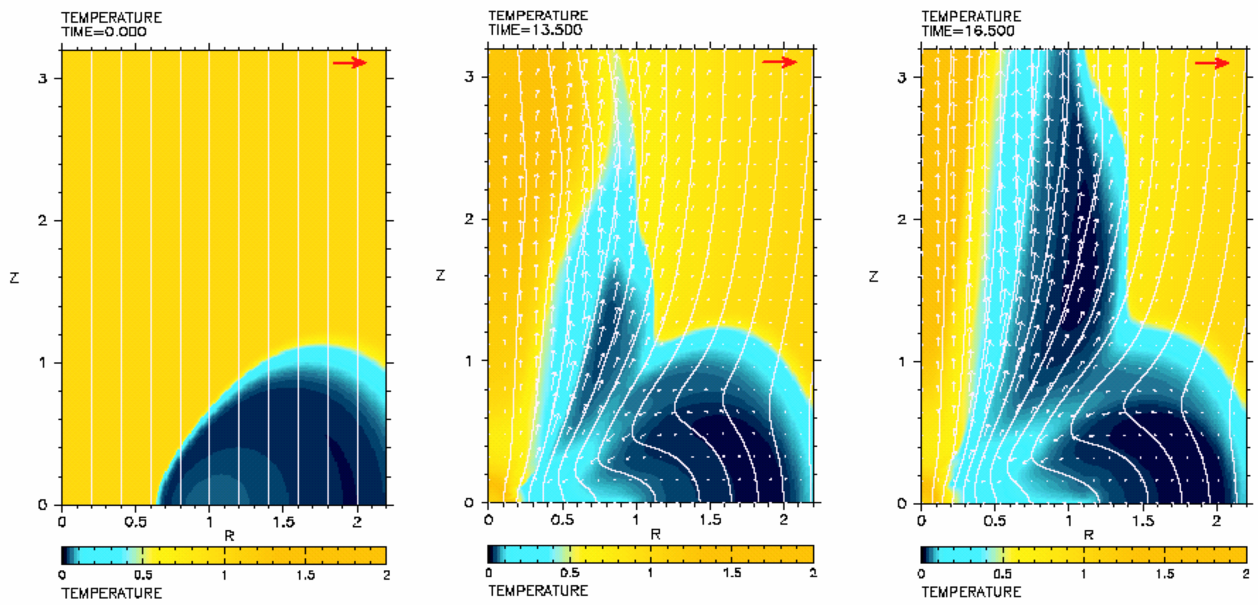
η 0.0125 r_0 V_k0

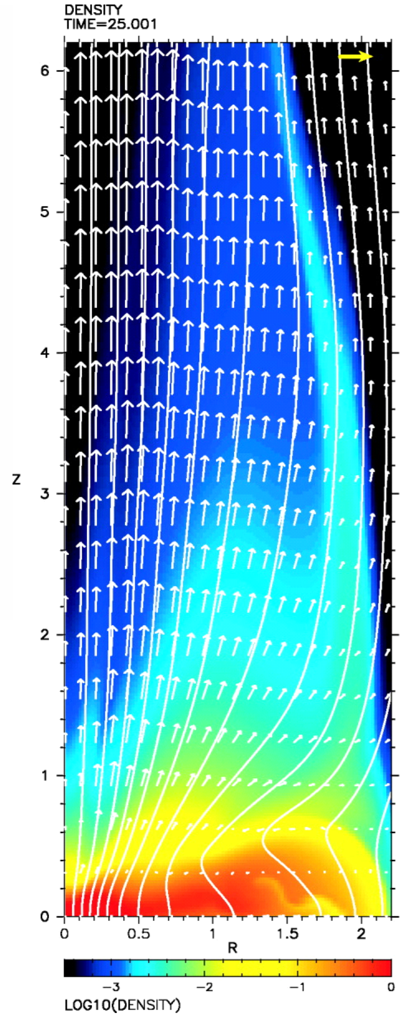
(Rm = 80)

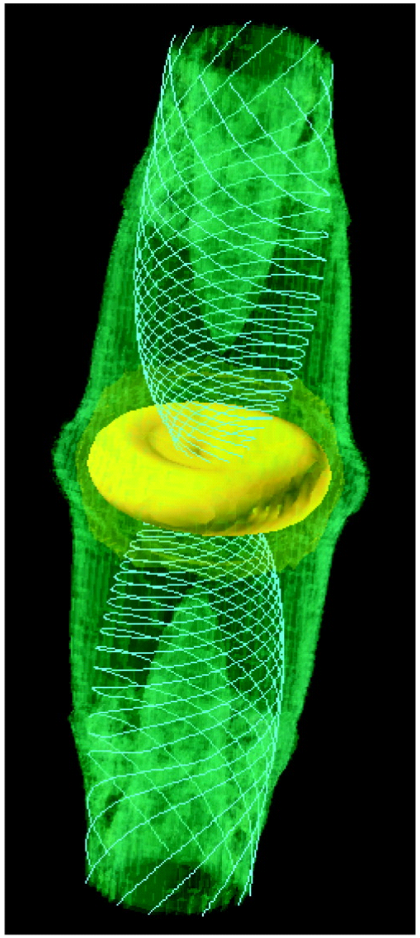
Kuwabara et al. 2000
PASJ 52, 1109

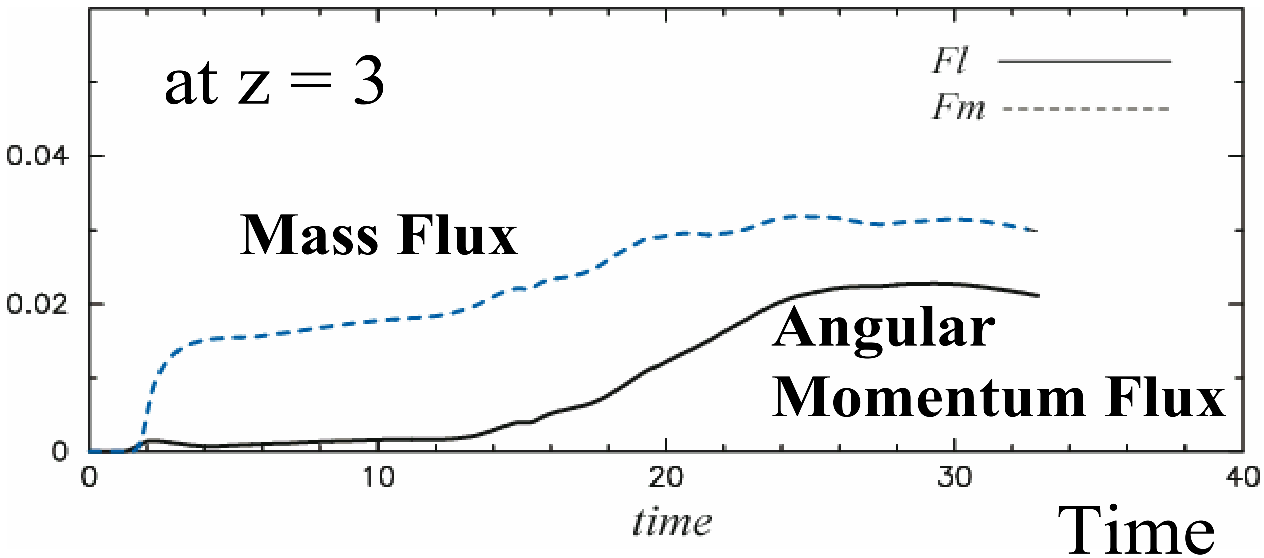
See also Casse and Keppens (2002, 2004)

# Formation of a Quasi-Steady Jet



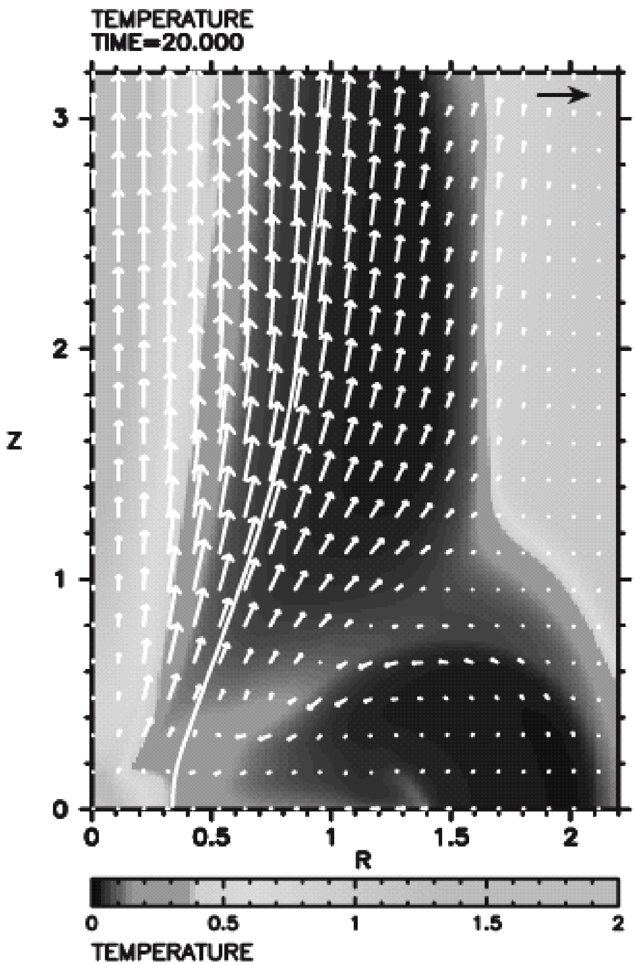



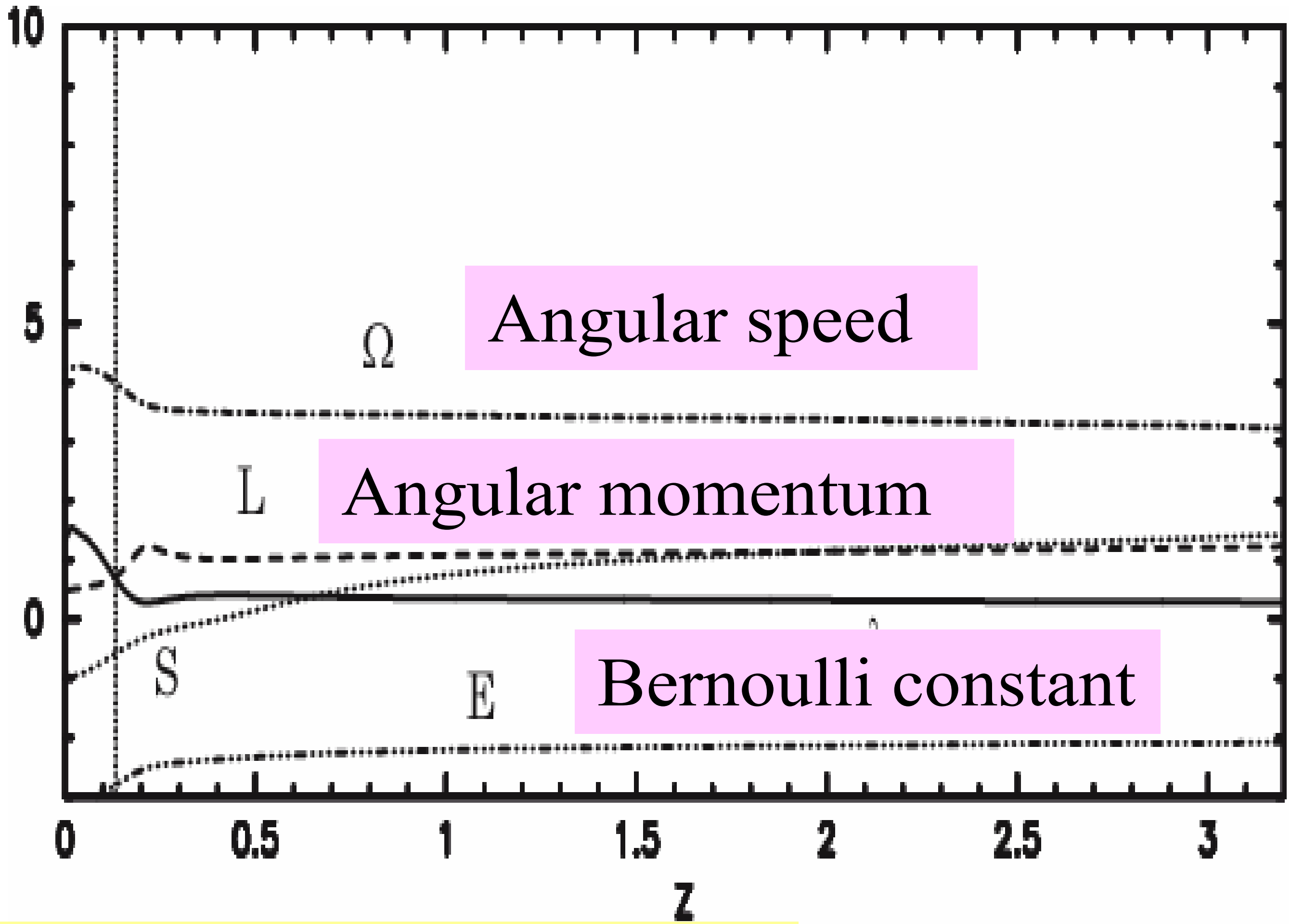



Density distribution at t = 25

Kuwabara et al. (2005)

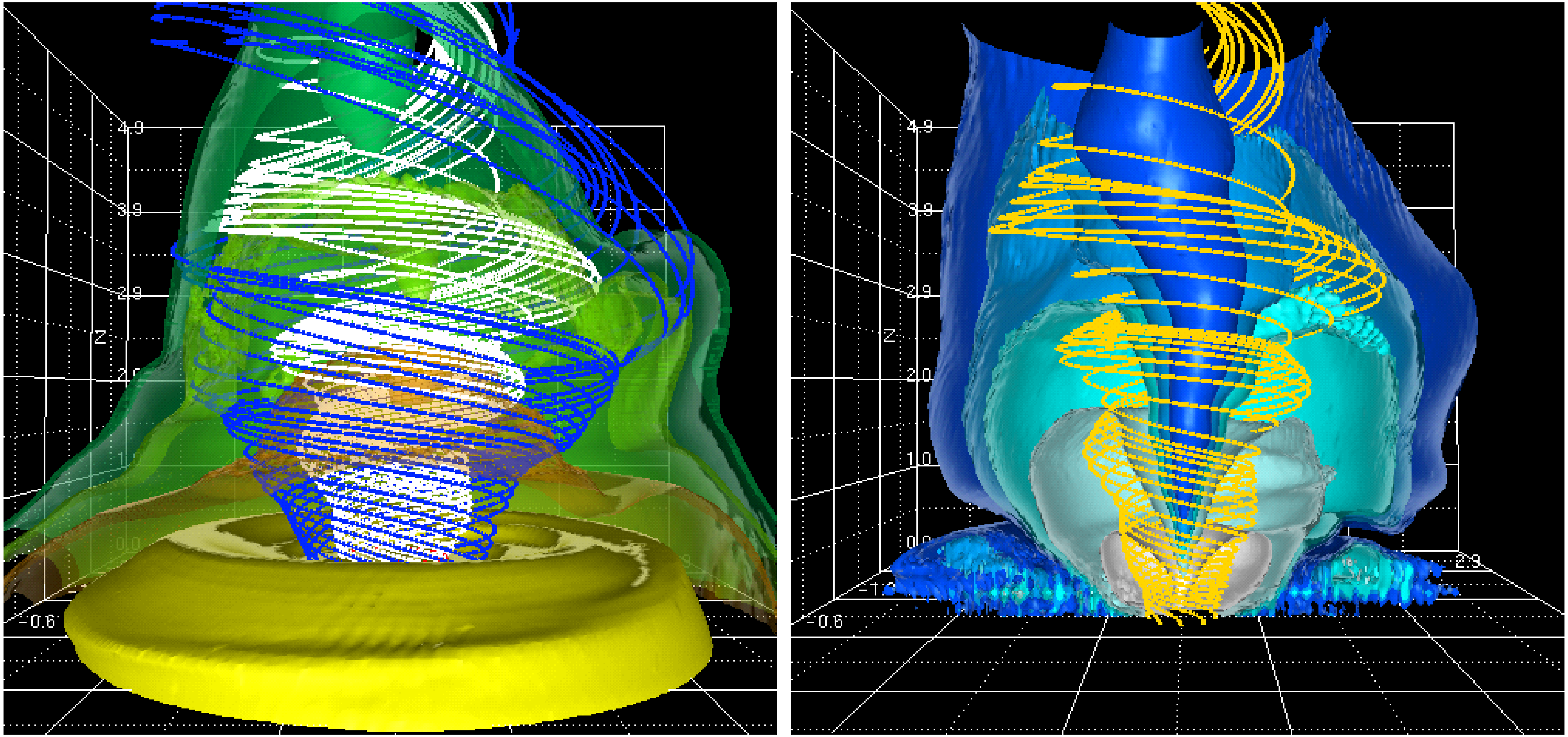
# Constancy of Conserved Quantities along a Magnetic Field Line



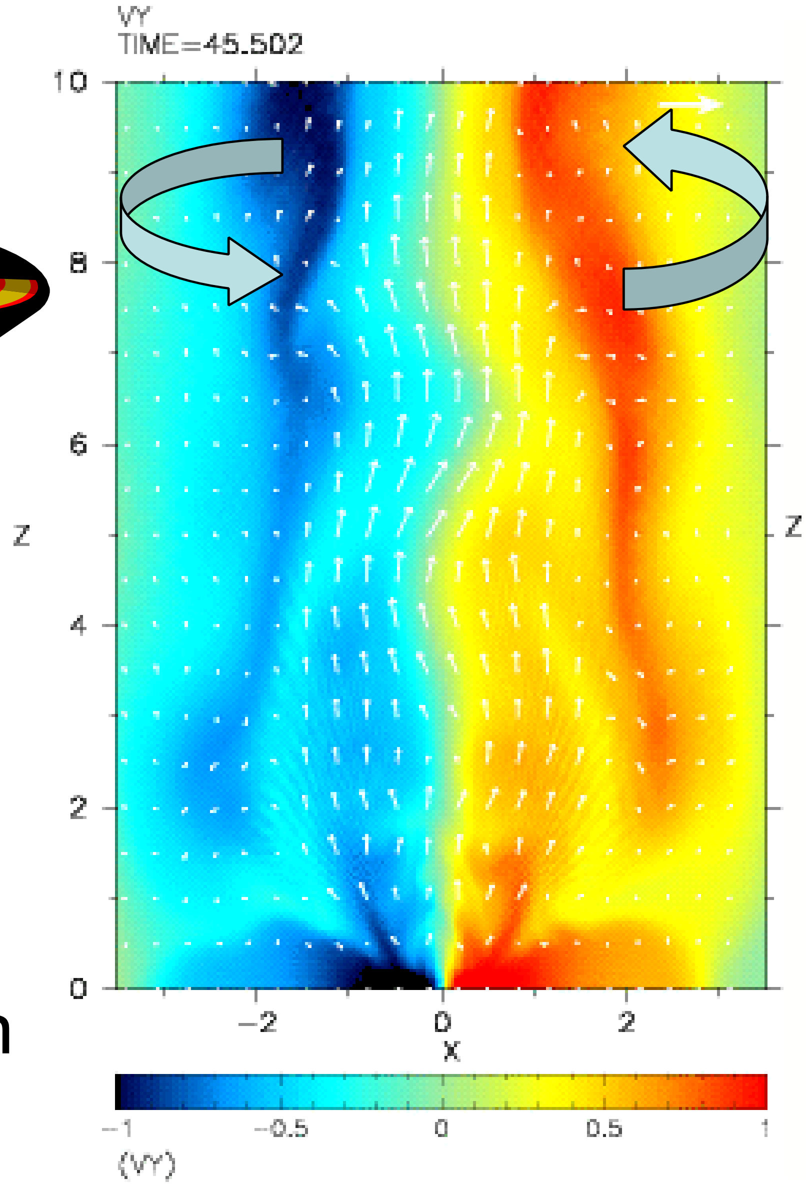

Kuwabara et al. 2005, ApJ 621, 921

# Formation of Wiggle Structure

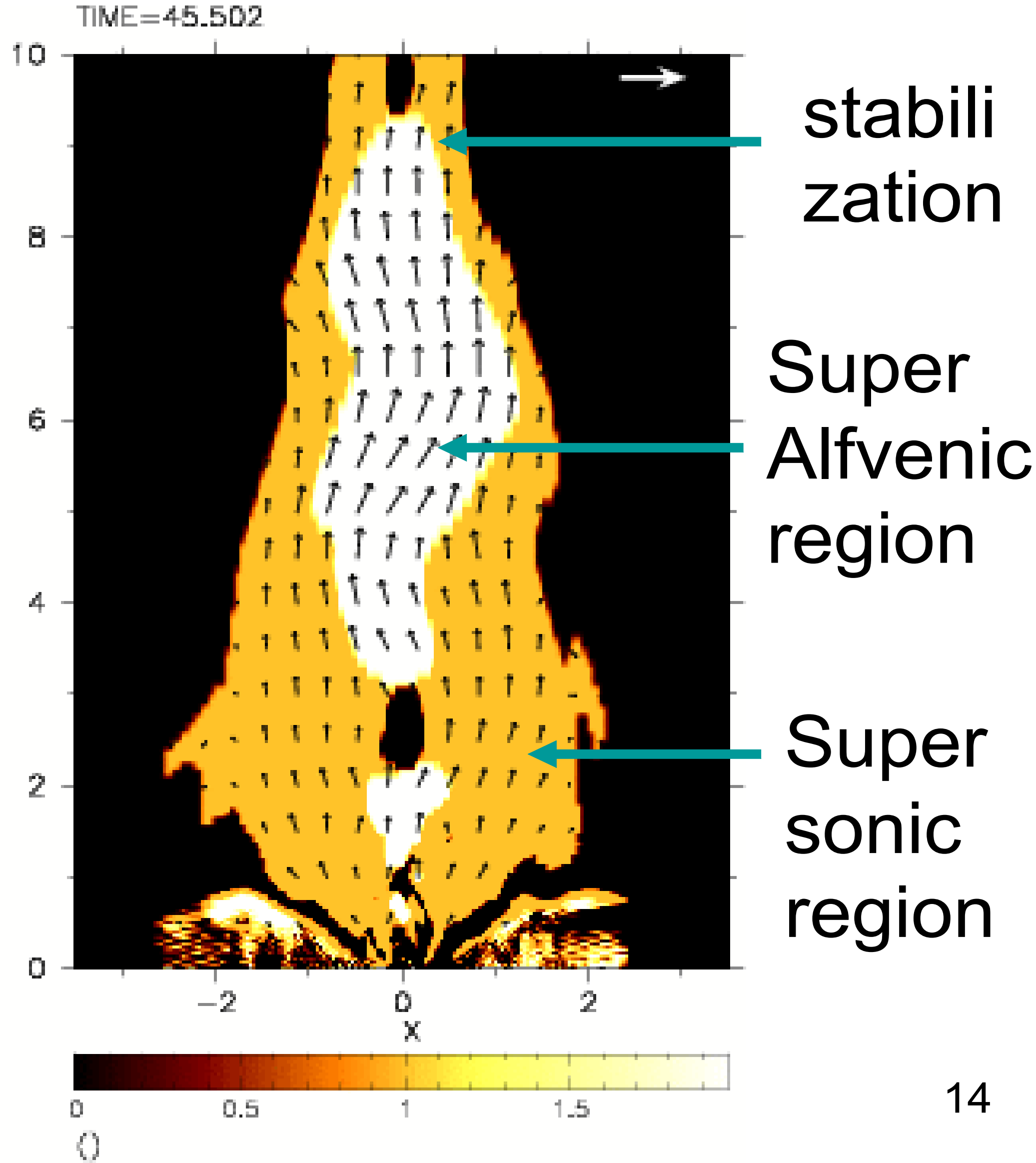



Numerical Result by using Cartesian 3D Code
Kuwabara et al. 2006)

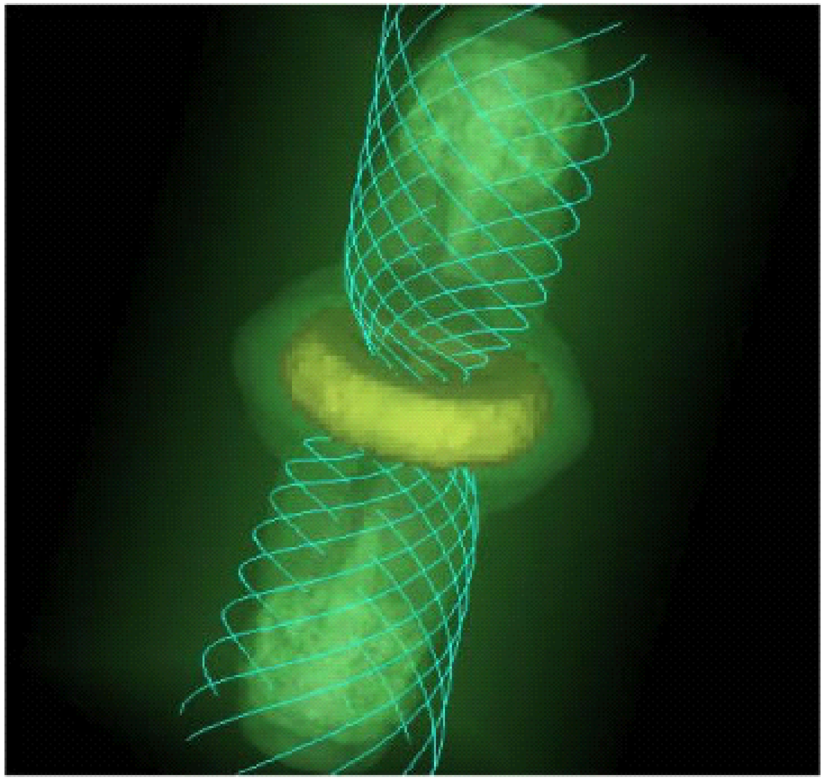
# Stabilization by Rotation




Rotation speed

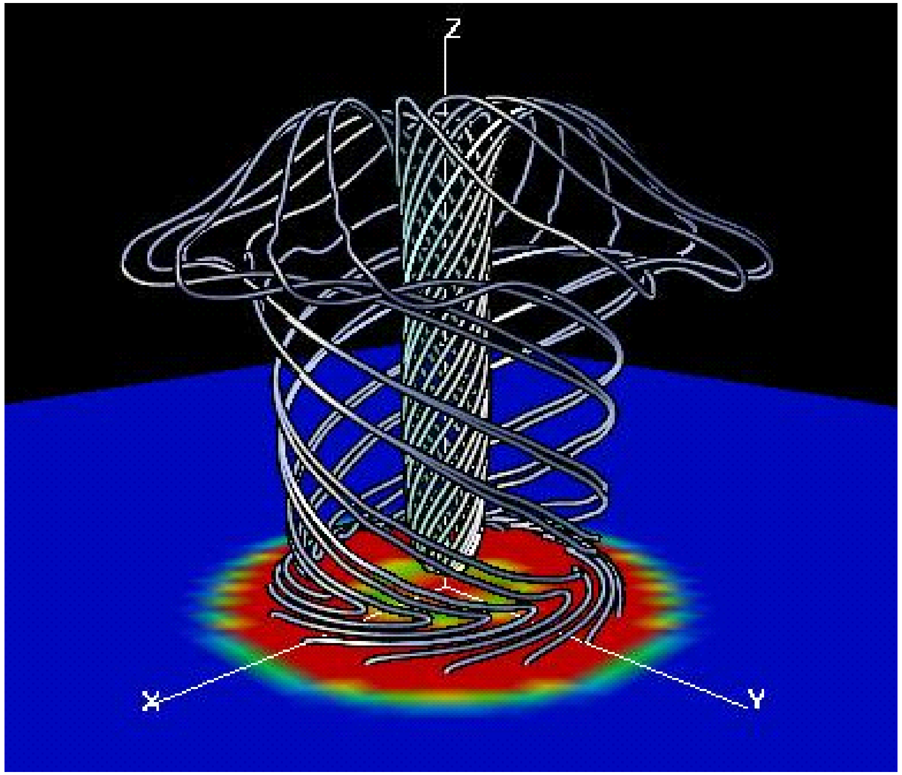


# Magnetic Tower Jet



Magneto-centrifugally launched jet

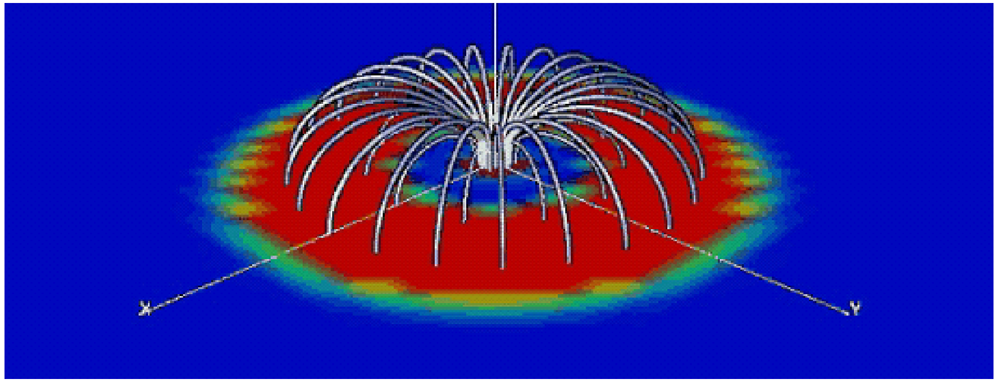
Blandford & Payne (1982)
Uchida and Shibata (1985)

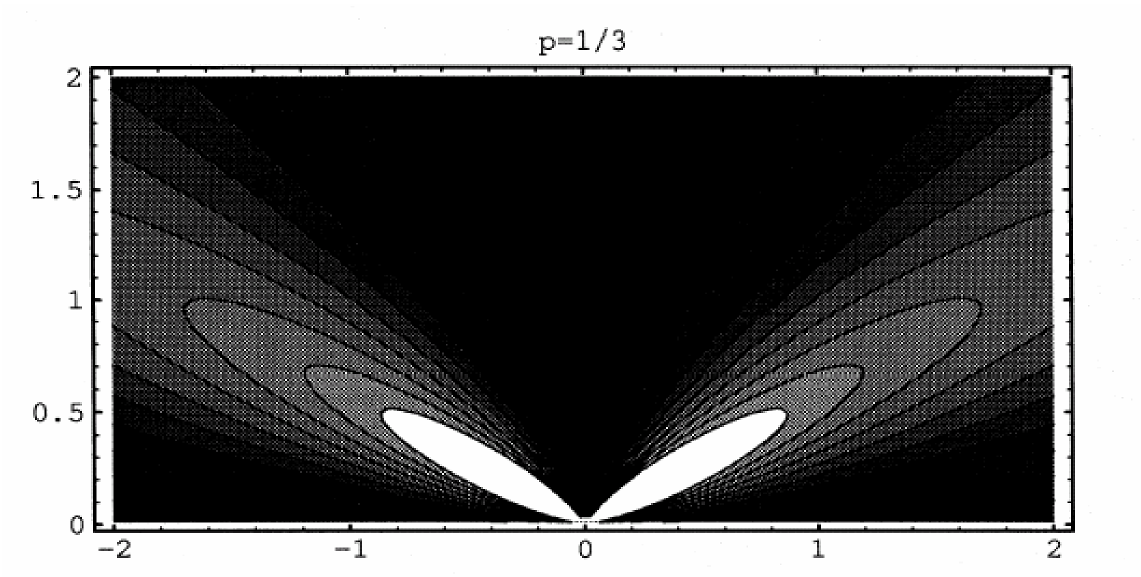


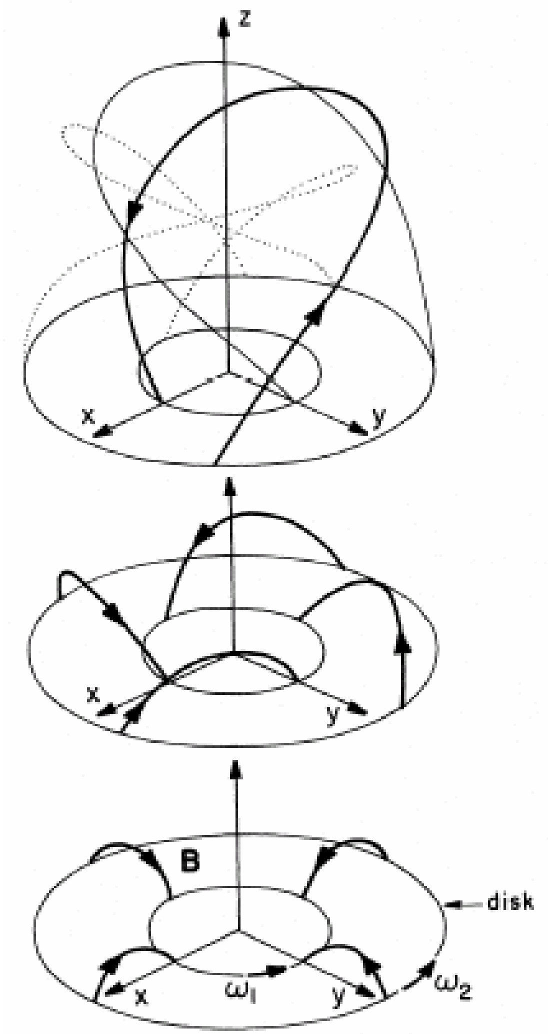

Magnetic tower jet

Lynden-Bell & Boily (1994)
Kato et al. (2004)

# Inflation of Twisted Poloidal Magnetic Loops



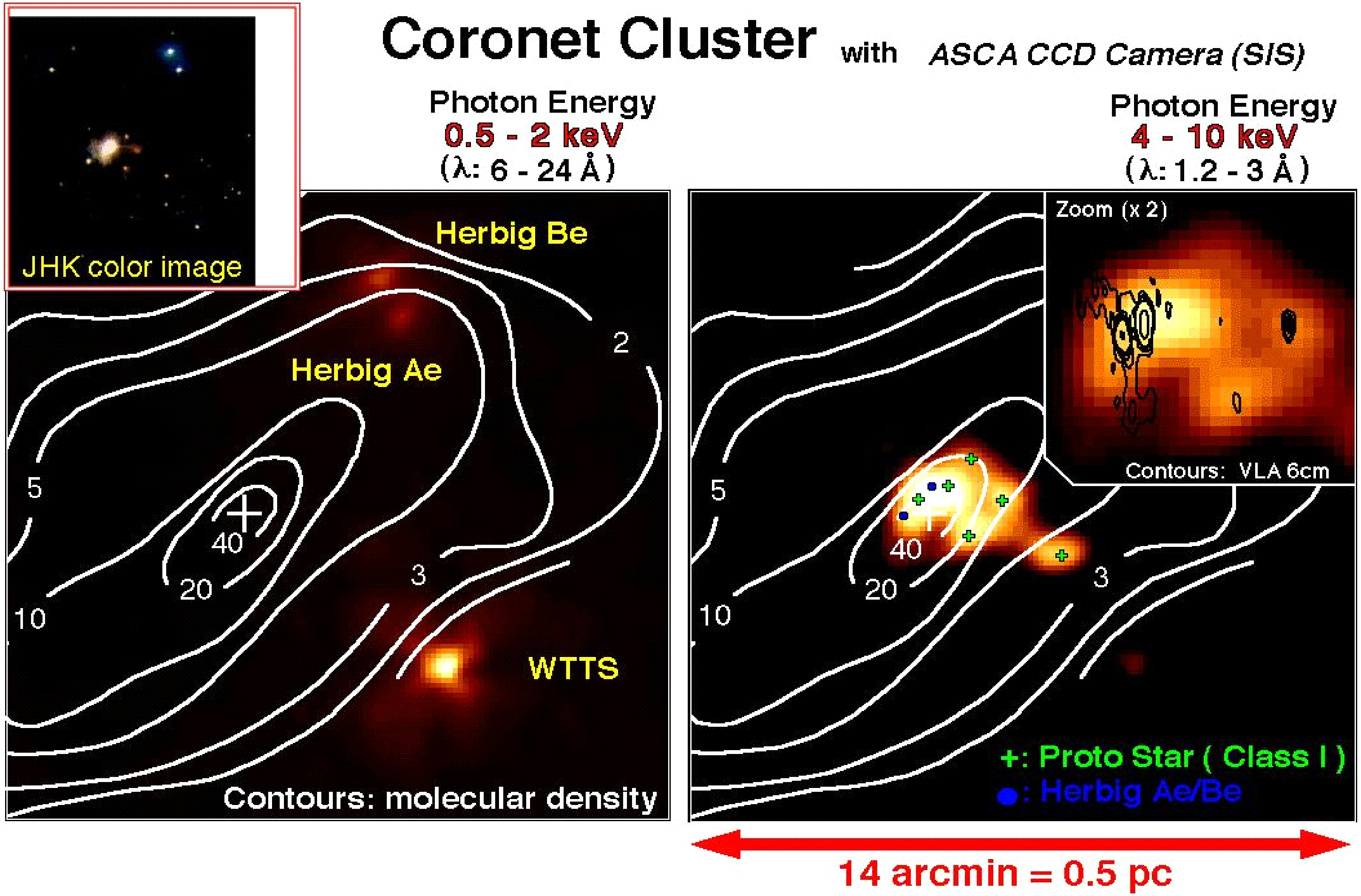



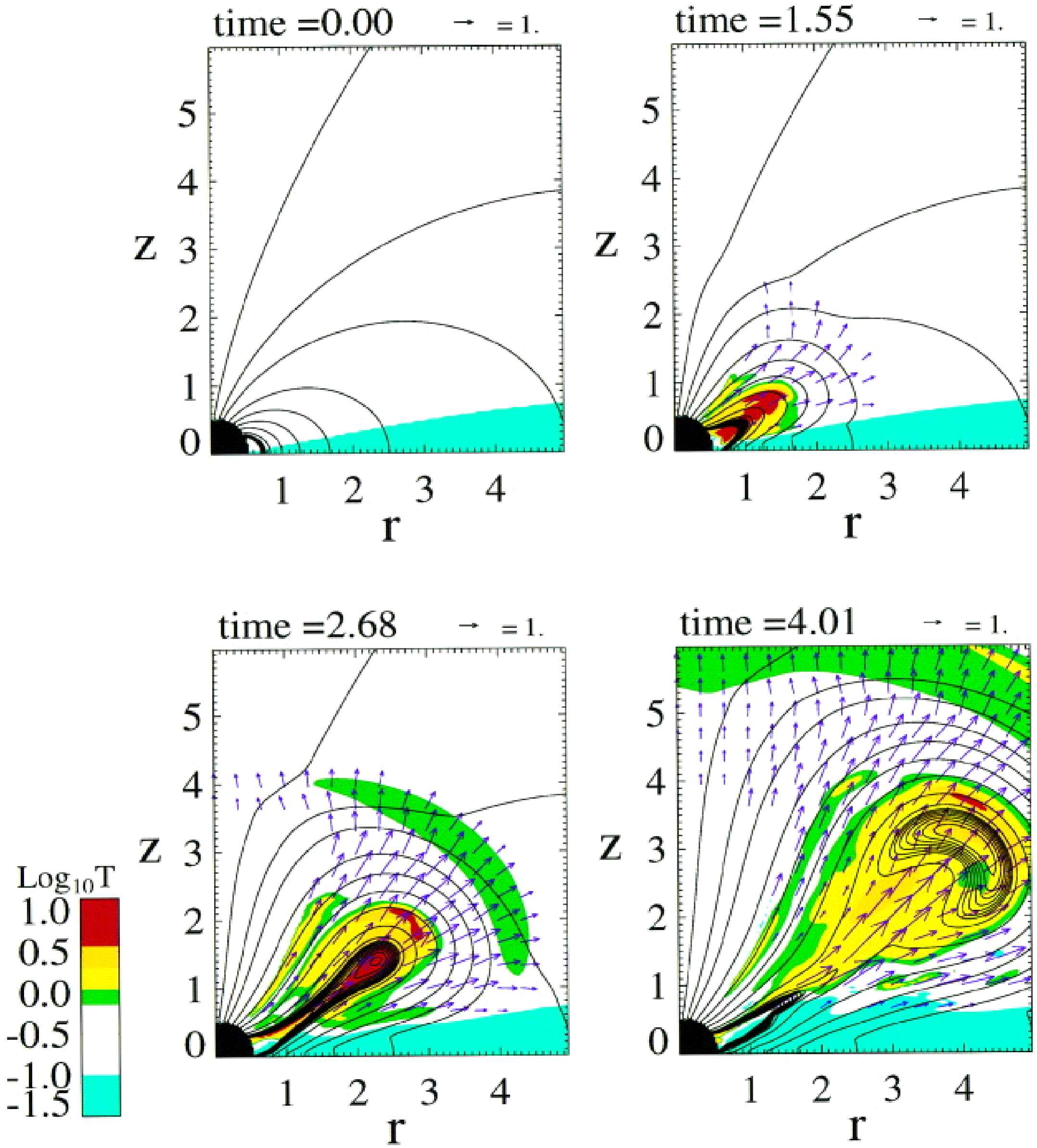

Lynden-Bell and Boily 1994

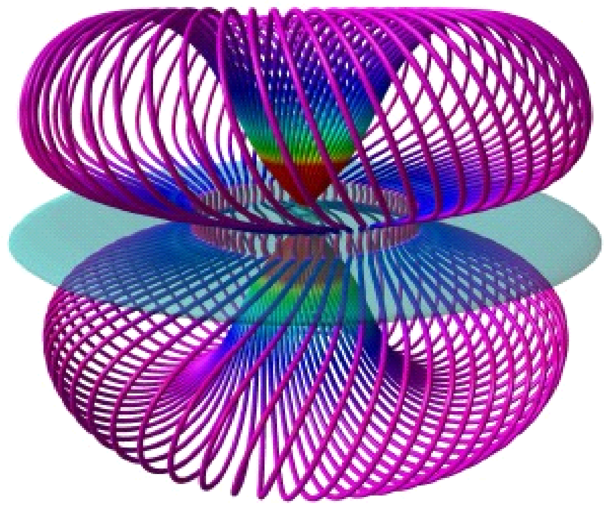
Lovelace et al. 1995

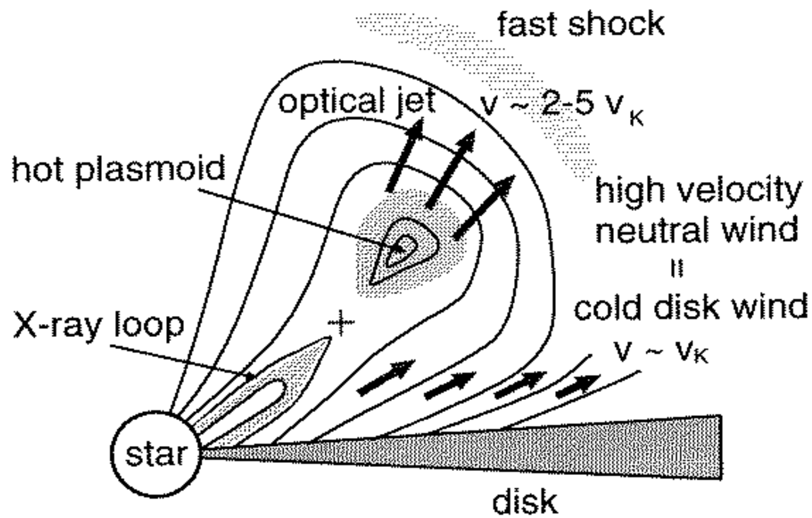
# X-ray Flares in Protostars



# MHD Simulation of Protostellar Flares

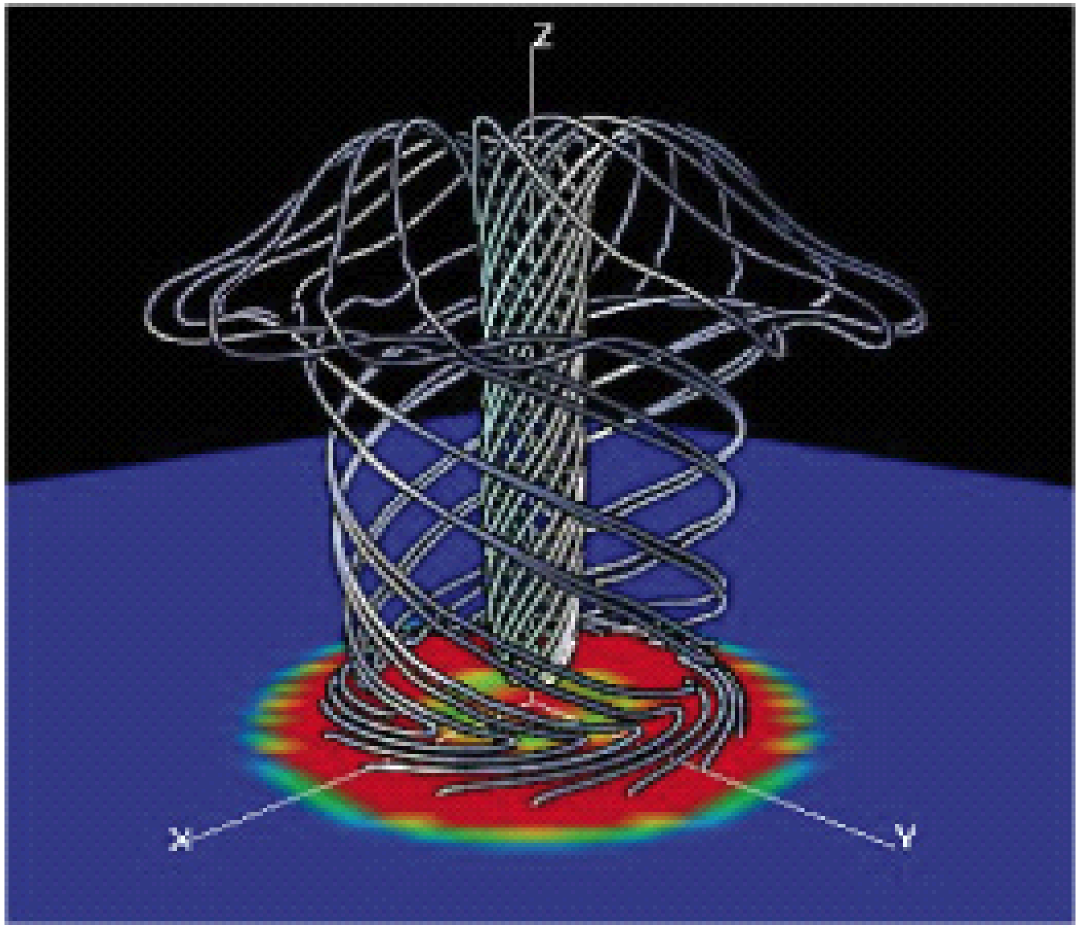


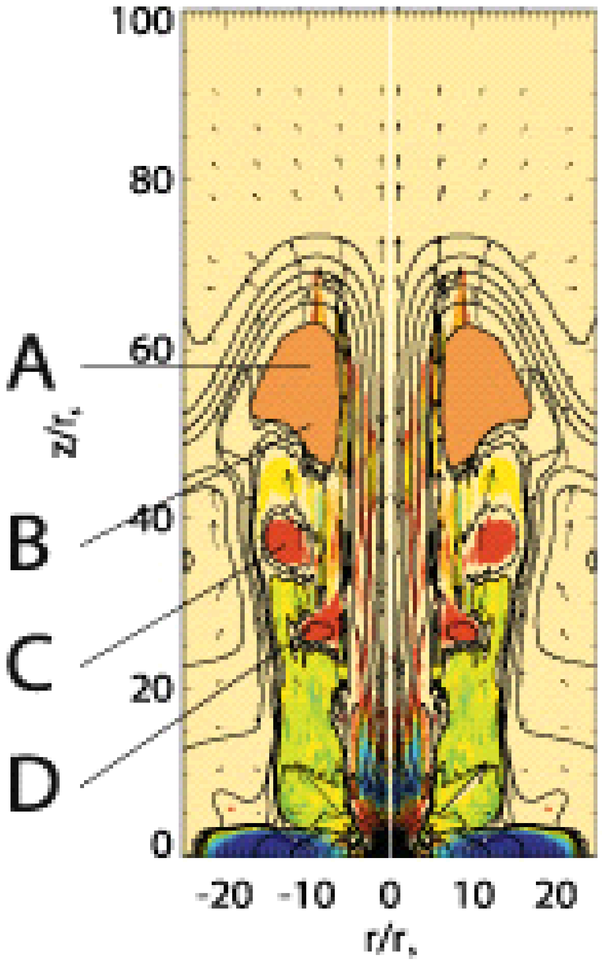





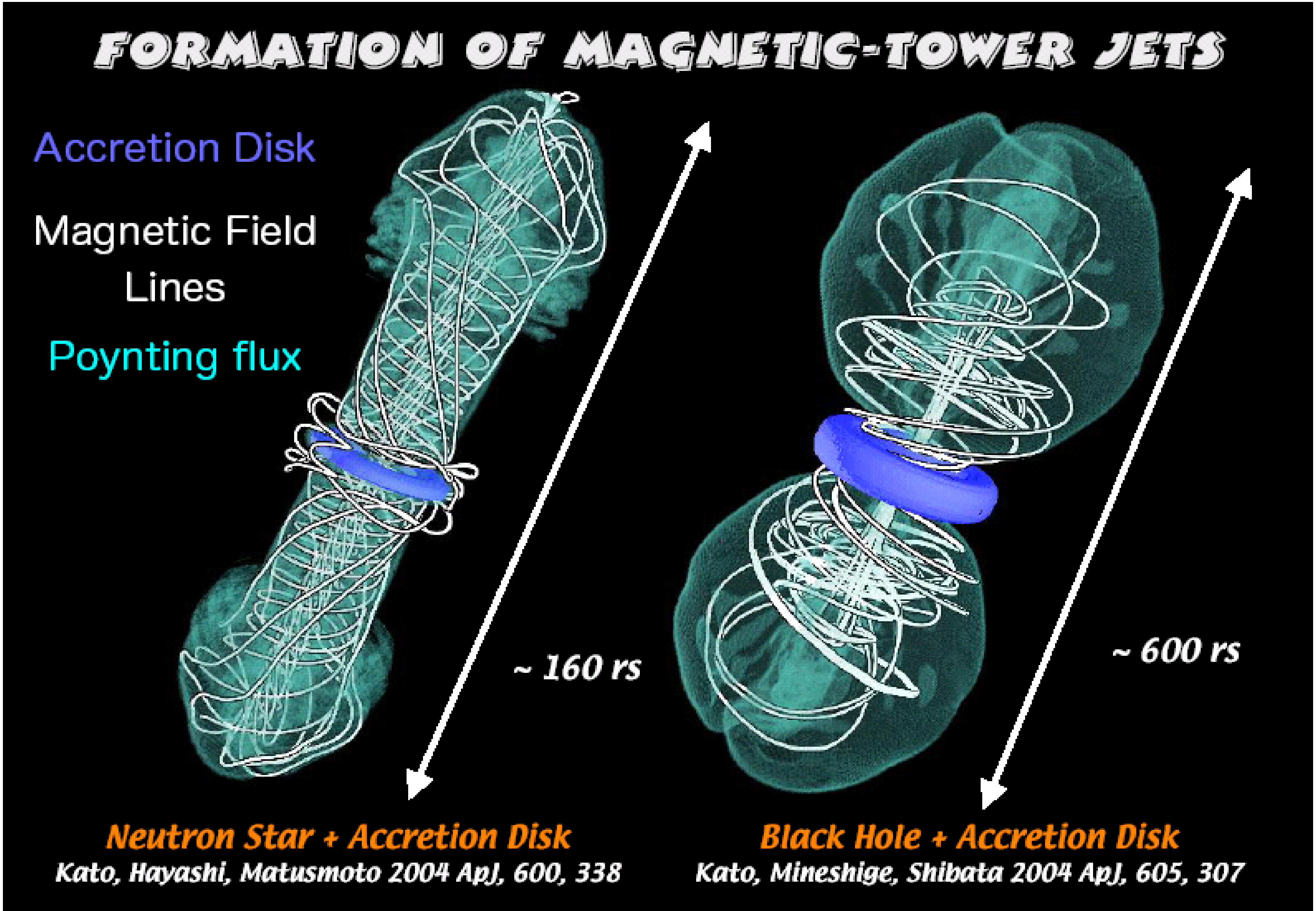

Hayashi, Shibata and Matsumoto 1996 (ApJL)

# Numerical Simulation of the Magnetic Tower Jet




Kato, Hayashi, Matsumoto (2004, ApJ)


FORMATION OF MAGNETIC-TOWER JETS
Accretion Disk
Magnetic Field Lines
Poynting flux
~ 160 rs
~ 600 rs
Neutron Star + Accretion Disk
Kato, Hayashi, Matusmoto 2004 ApJ, 600, 338
Black Hole + Accretion Disk
Kato, Mineshige, Shibata 2004 ApJ, 605, 307

# Global Three-dimensional Resistive MHD Simulations of Black Hole Accretion Flows

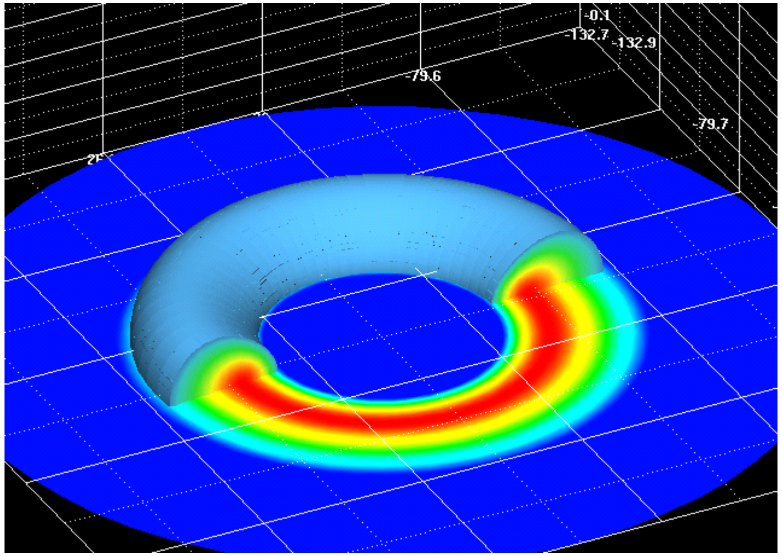
(Machida and Matsumoto 2003 ApJ )

Gravitational potential $\phi = - GM/(r-r_g)$

Angular momentum initially uniform

Magnetic Field : purely azimuthal

Pgas/Pmag = β = 100 at 50r_g

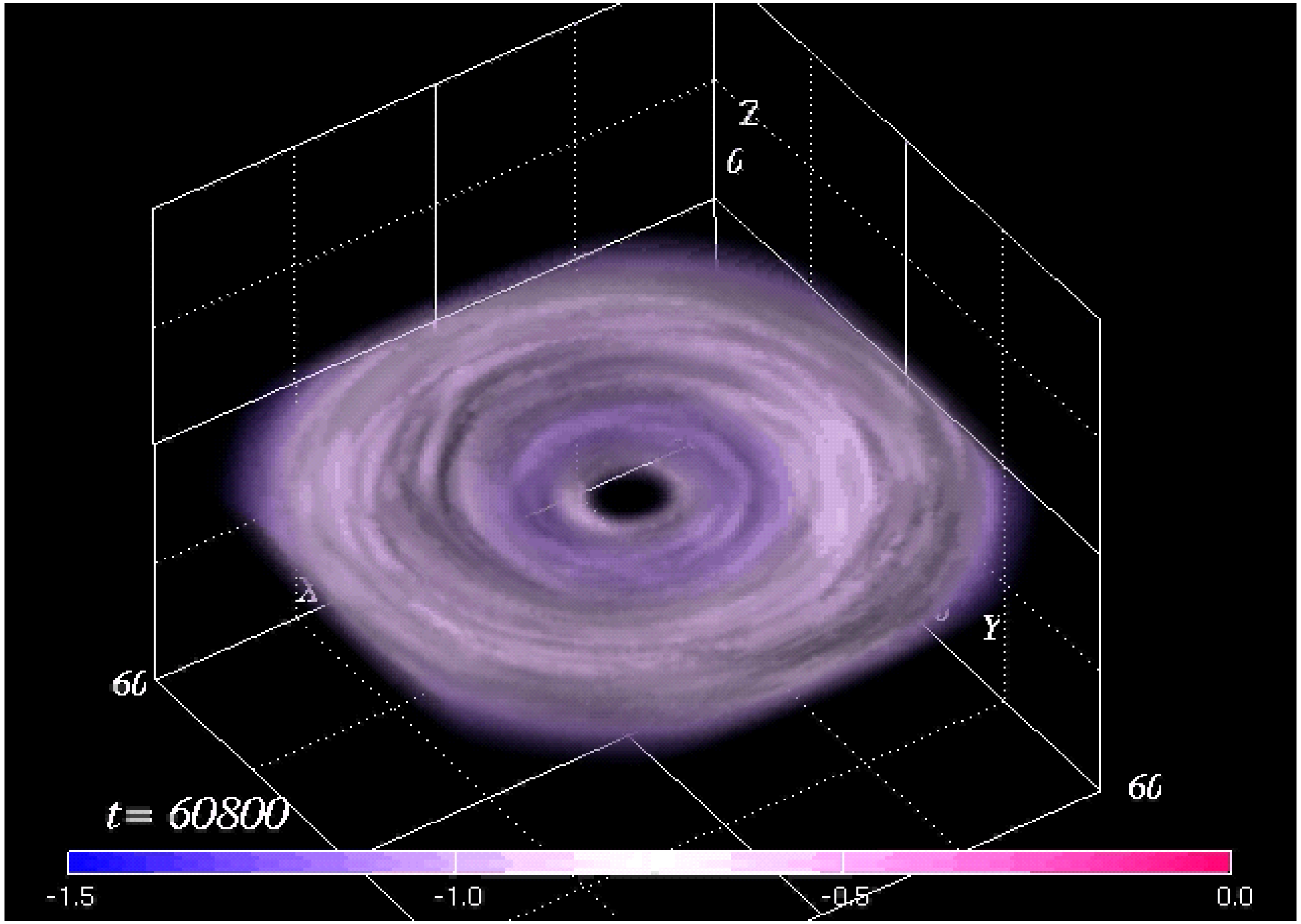


Anomalous Resistivity

$$\eta = (1/Rm) \max [(J/\rho) /v_c - 1, 0.0]^2$$

250*64*192mesh

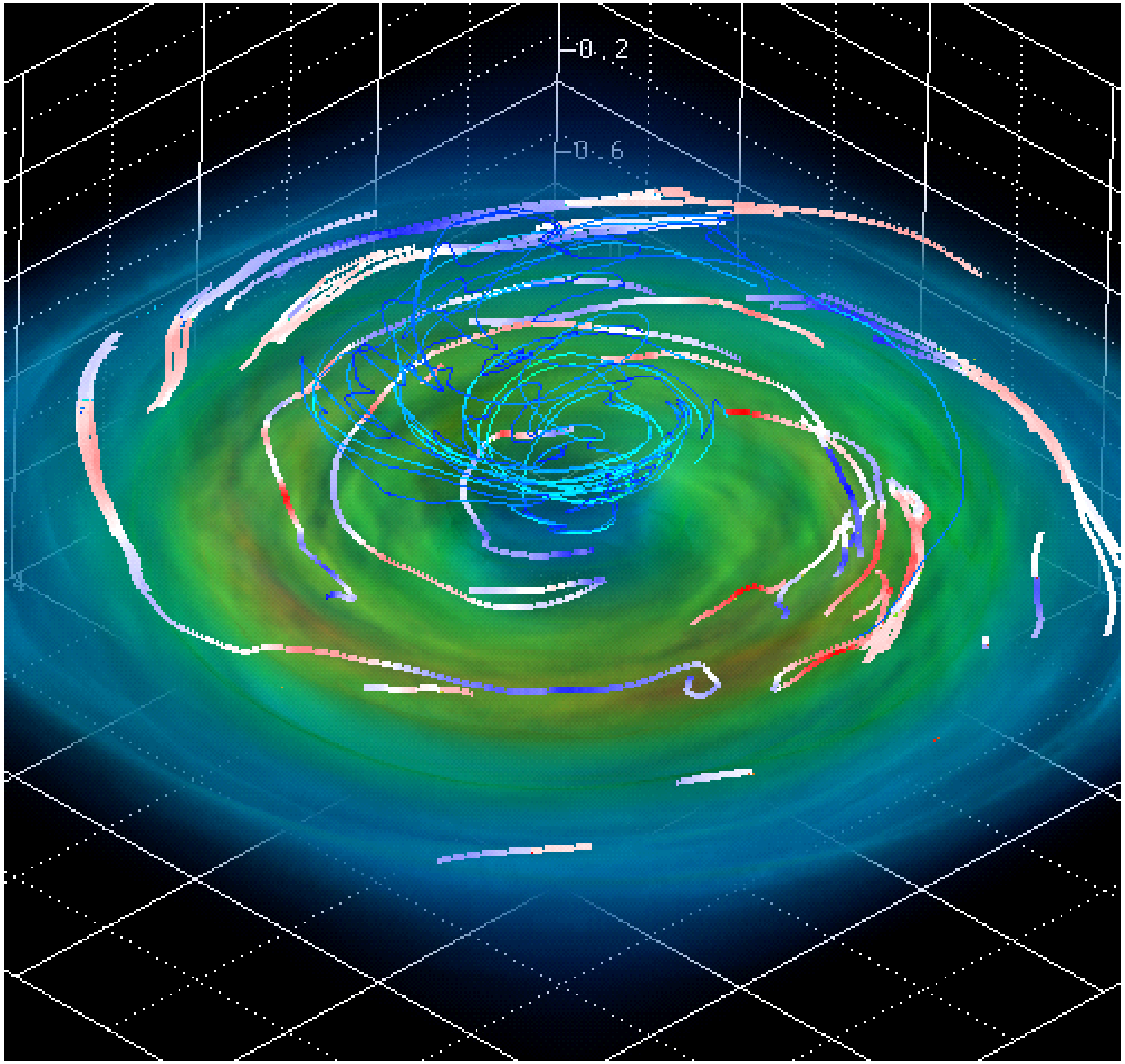
# Formation of an Accretion Disk




Machida (2005)

Volume rendered image of density distribution

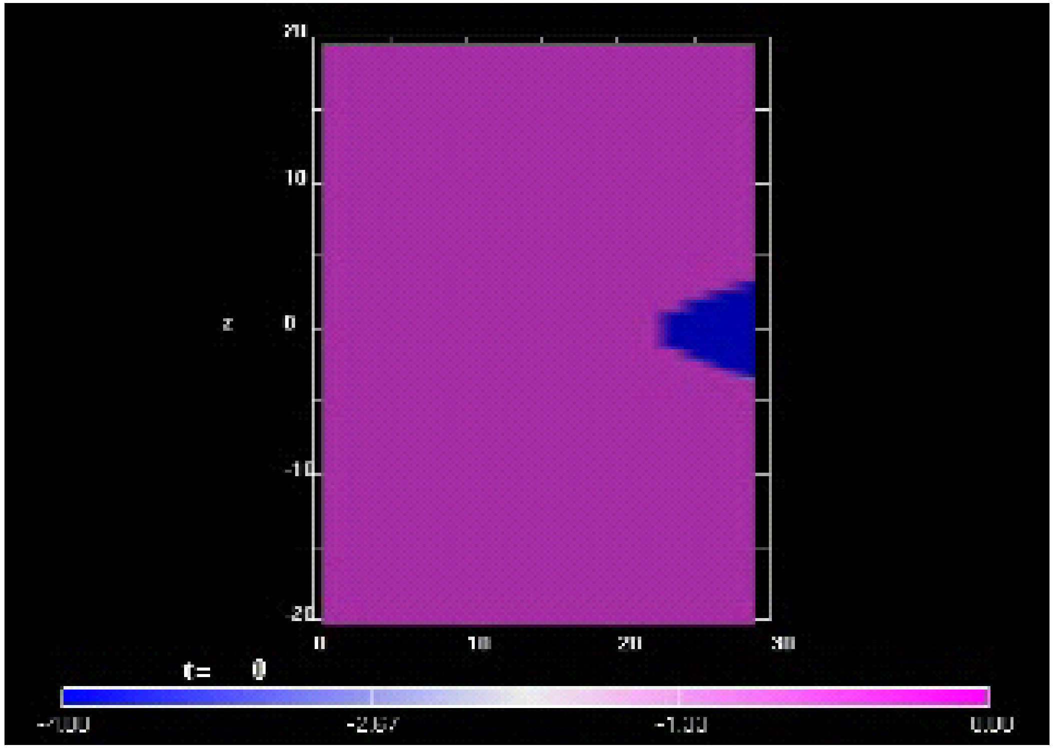
# Magnetic Loops Emerging from the Disk



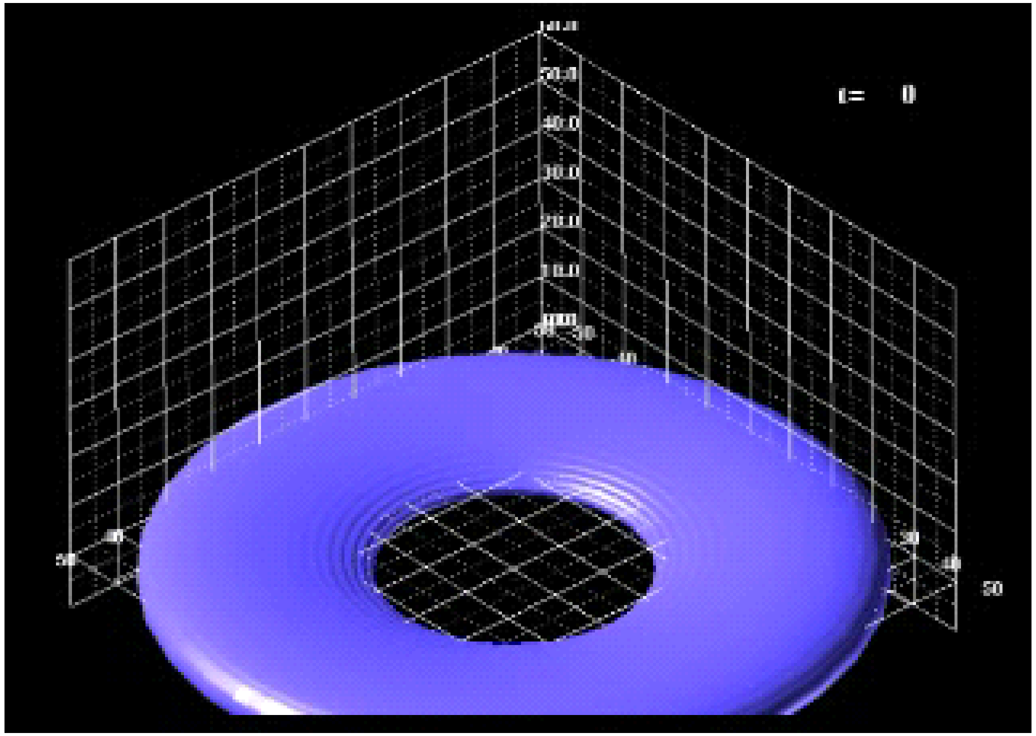
Machida et al. 2008 in preparation

Global 3D MHD Simulations of Galactic Center Gas Disks

# Formation of Outflows from Accretion Disks



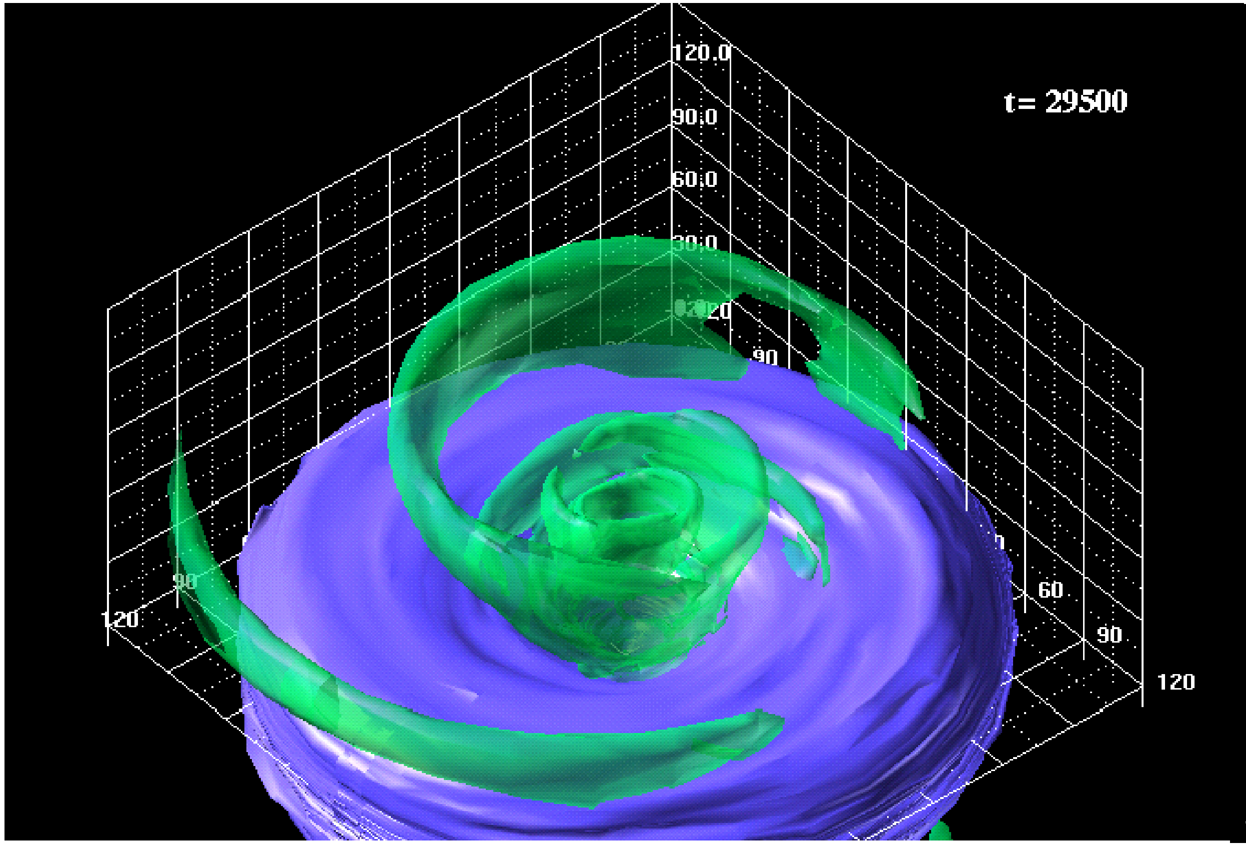

temperature

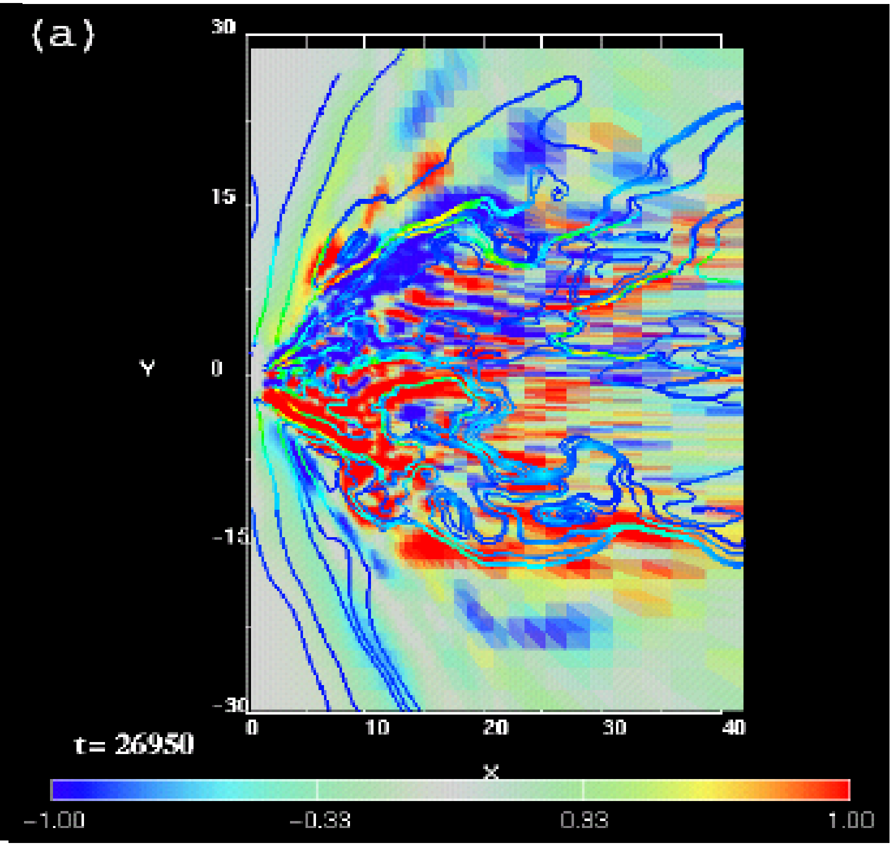



Isosurface of vertical velocity

Machida and Matsumoto 2008 (PASJ)

# Structure of the Launching Region of Outflows

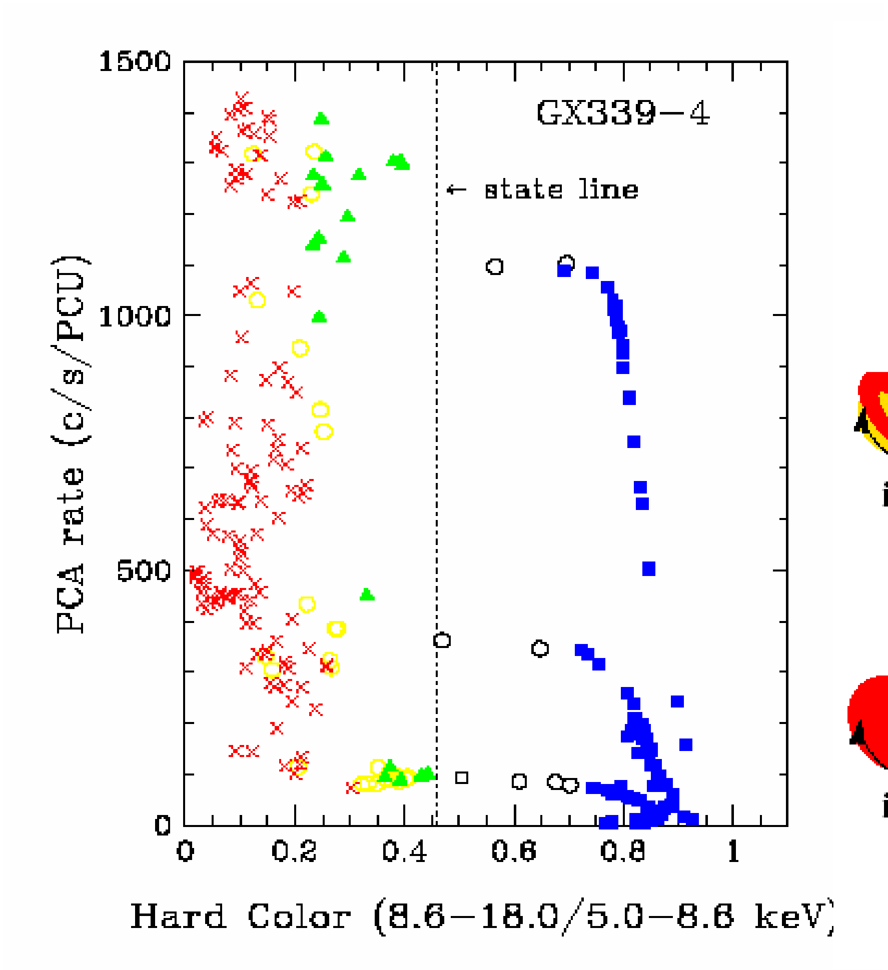


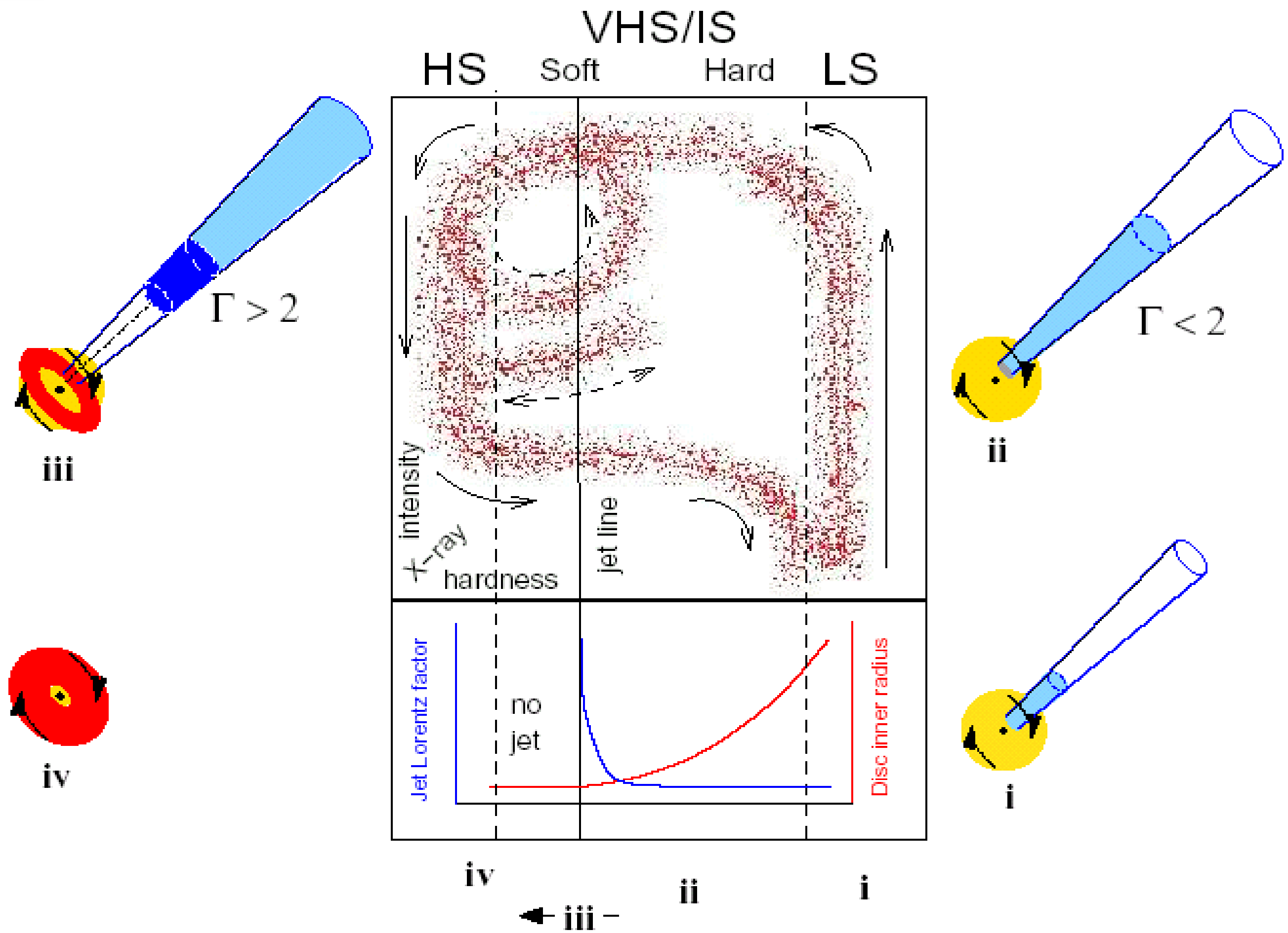

Isosurface of vz=0.05c

Magnetic field lines and azimuthal magnetic field

# Relation between State Transition (cooling) and Jet Formation

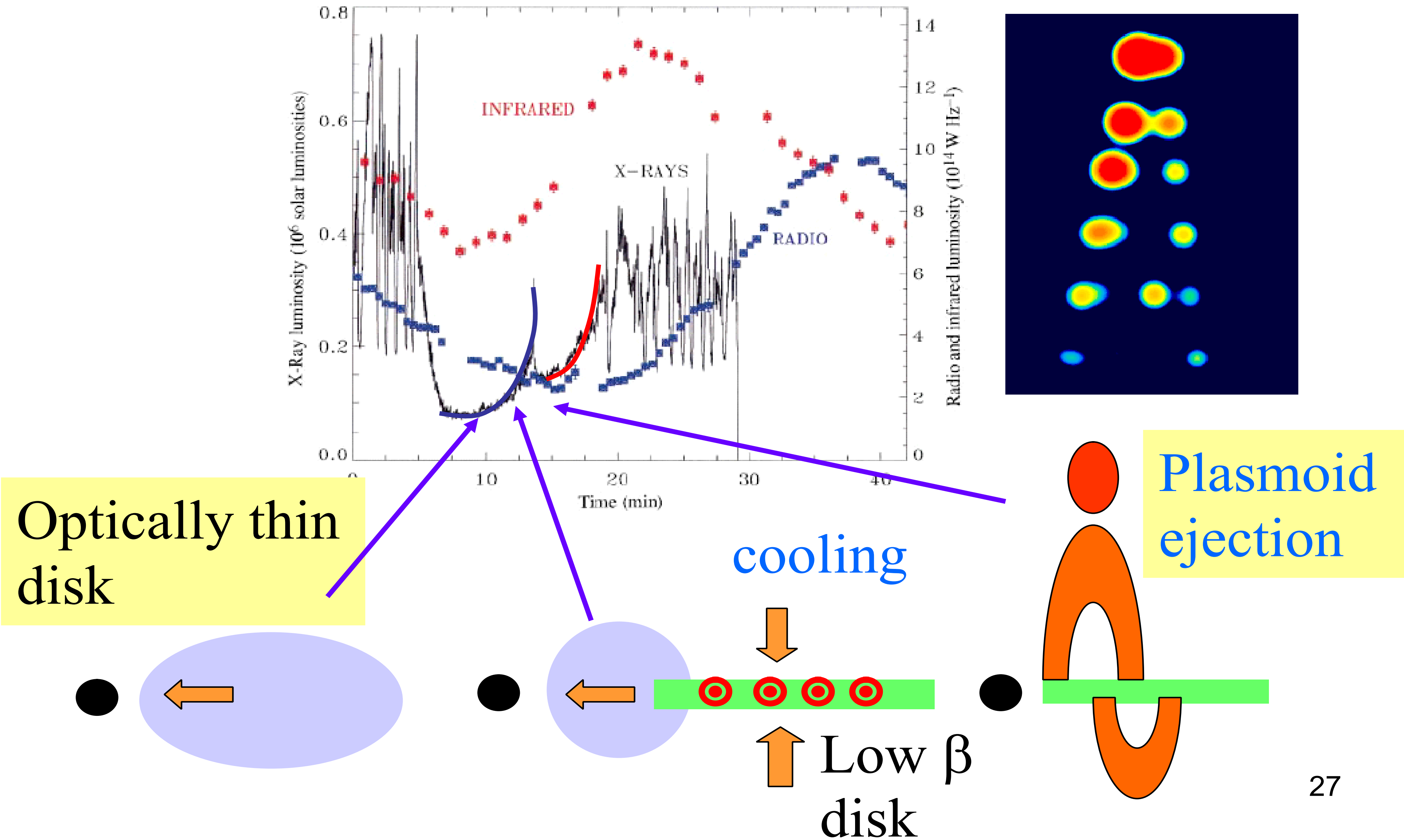



Remillard 2005




Fender, Belloni, Gallo 2004

# A Model of GRS1915+105



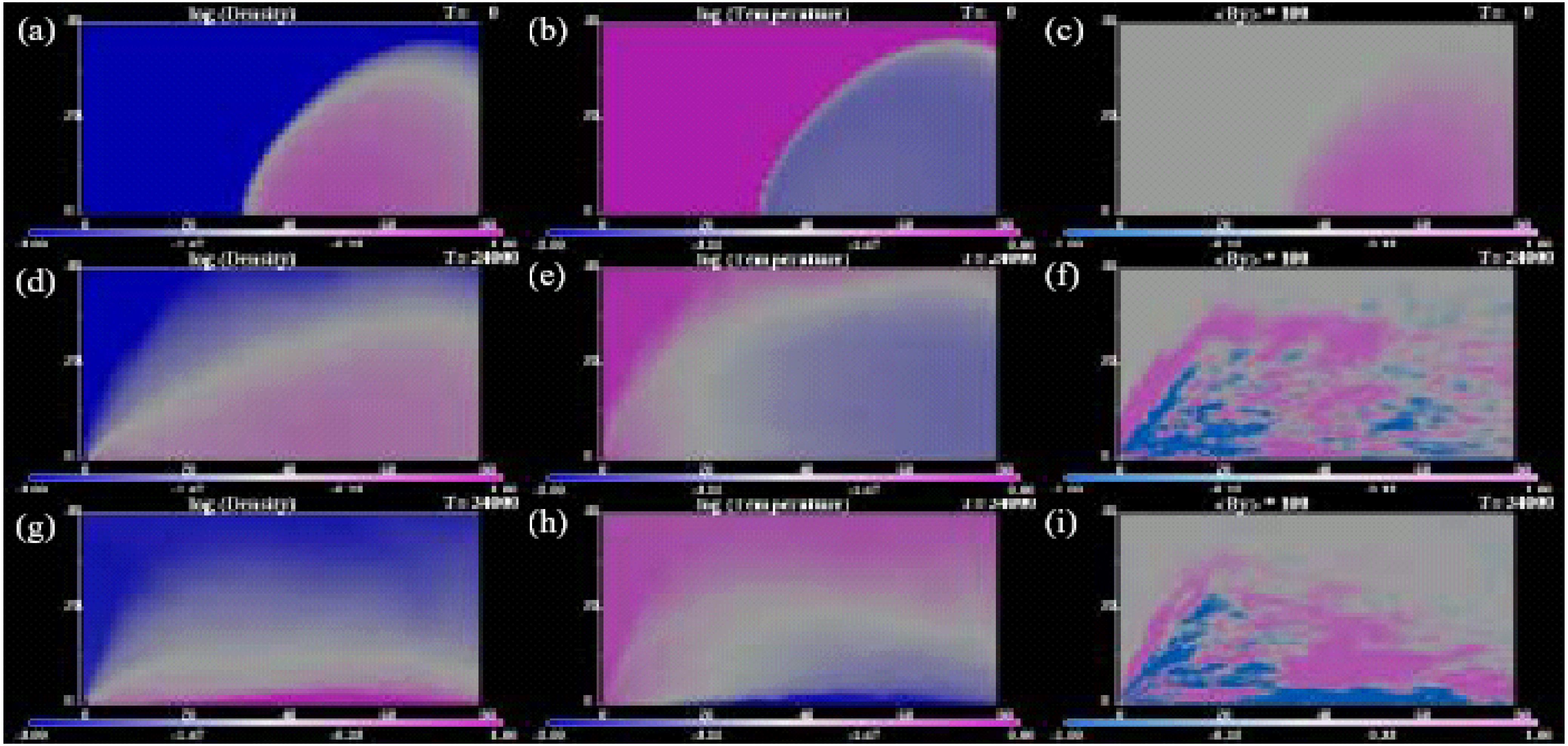
# 3D MHD Simulation Including Optically Thin Radiative Cooling (Machida et al. 2006, PASJ 58, 193)

- Cooling term is switched on after the accretion flow becomes quasi-steady
- We assume bremsstrahlung cooling

  $Q_{rad} = Q_{b} \rho^{2} T^{1/2}$

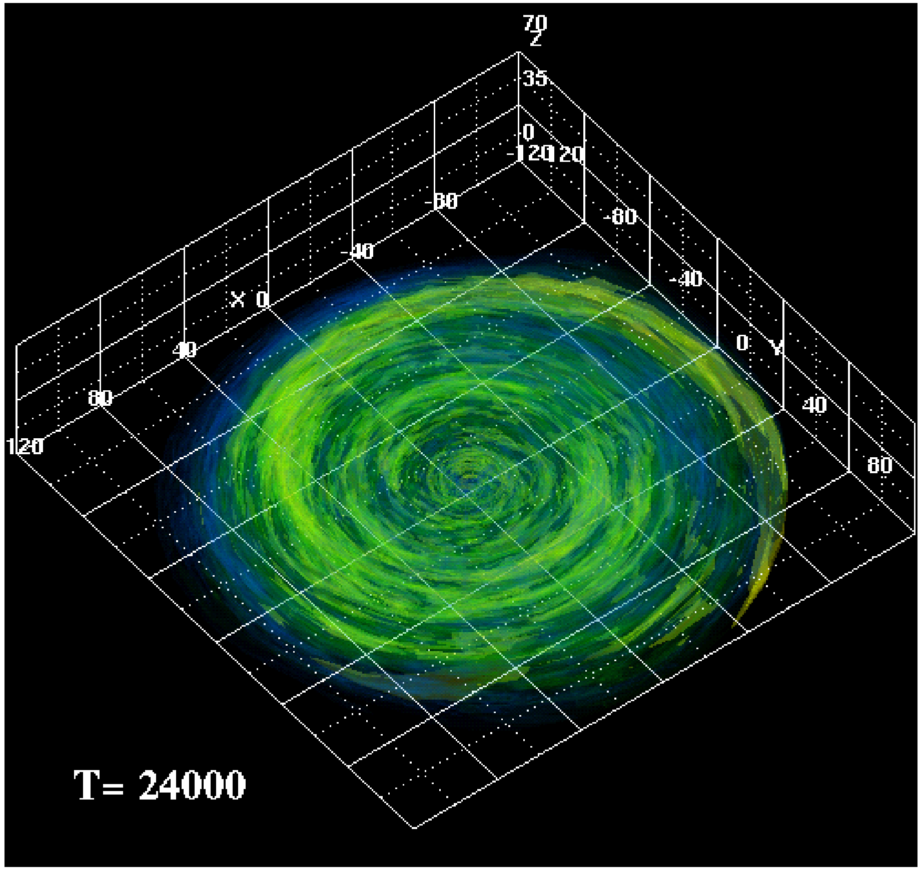
- Cooling is not included in rarefied corona where $\rho < \rho_{crit}$

# Transition to Cool Disk

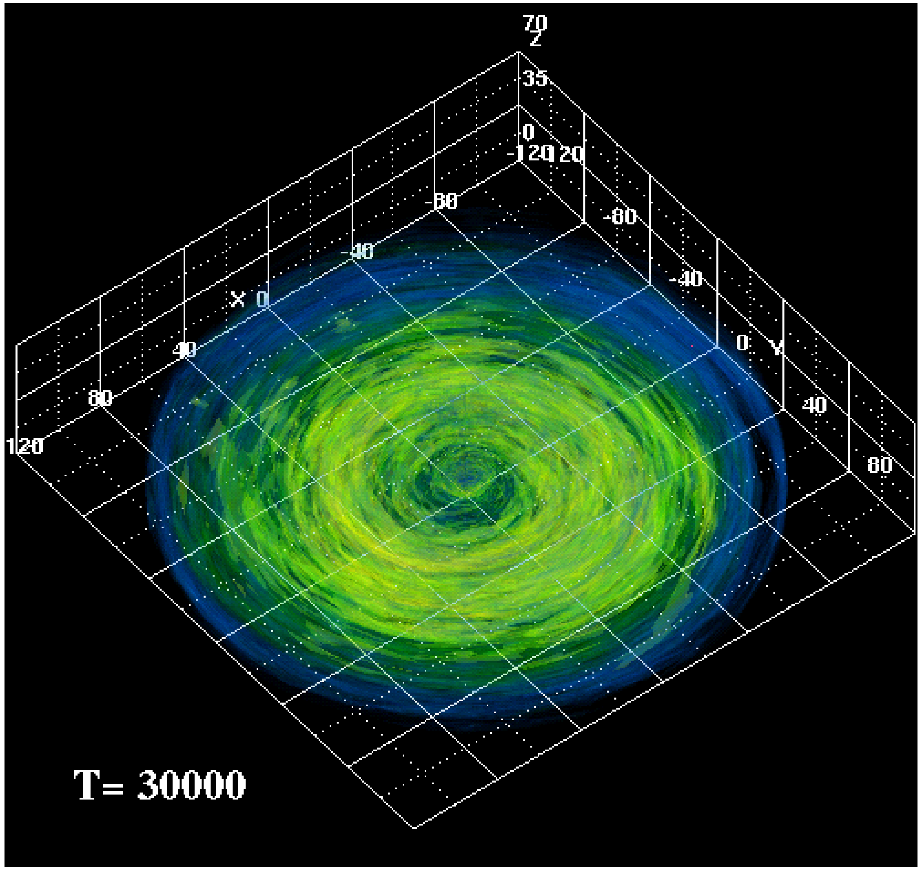



density temperature Toroidal field

# Formation of Low-beta Disk

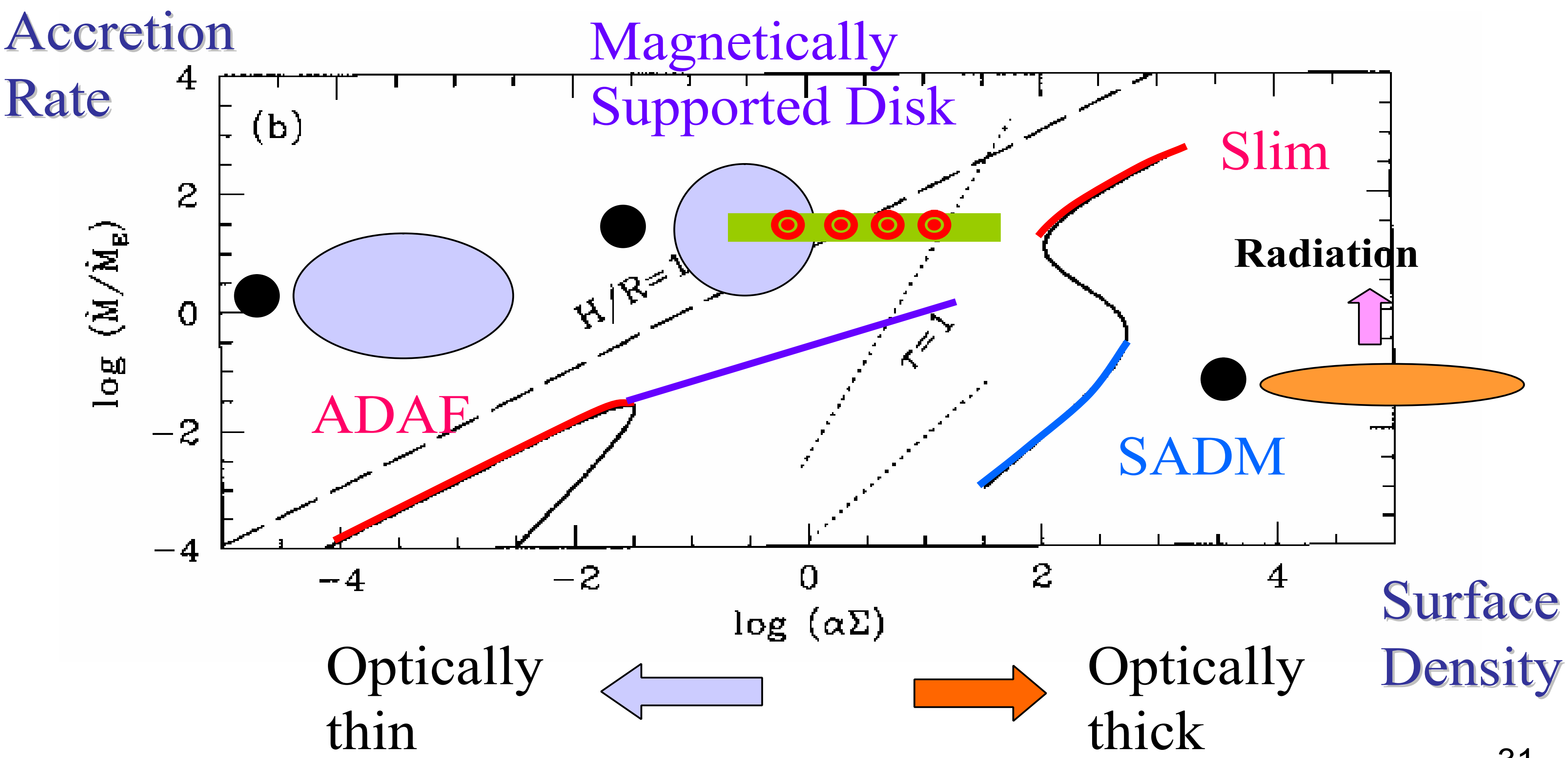



Before the transition

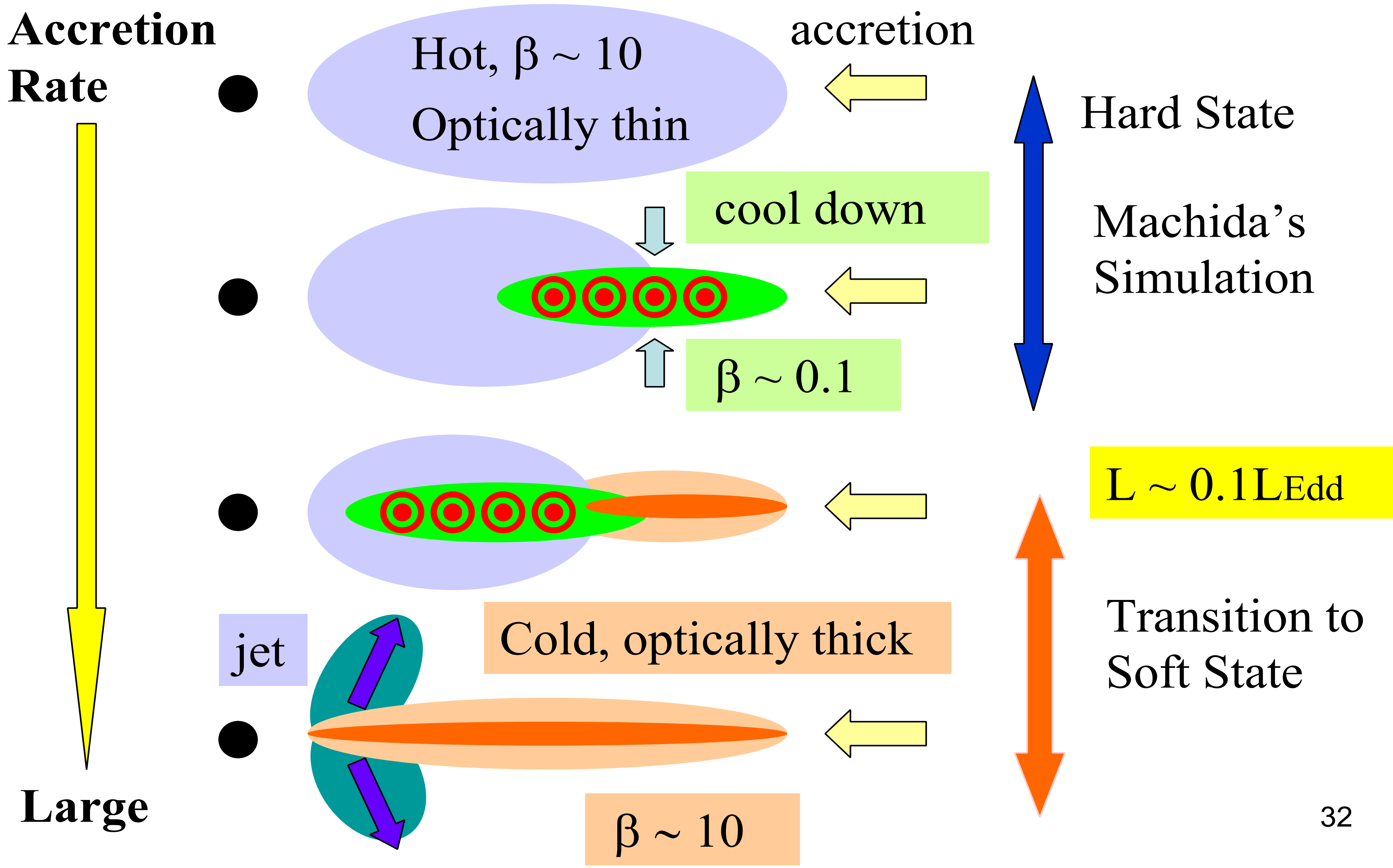



After the transition

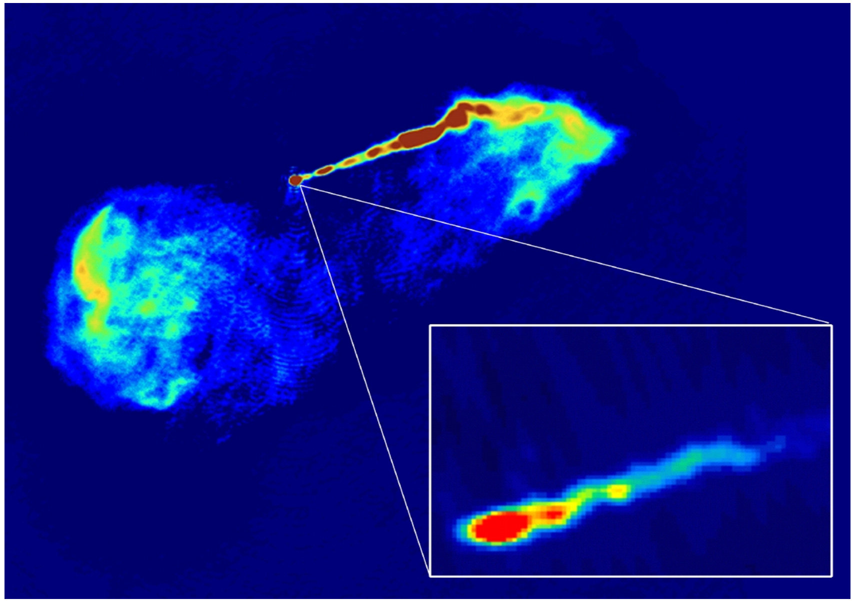
# Thermal Equilibrium Curves of Accretion Disks Supported by Toroidal Magnetic Fields (Oda et al. 2007)



# Evolution of an Accretion Disk During Outburst

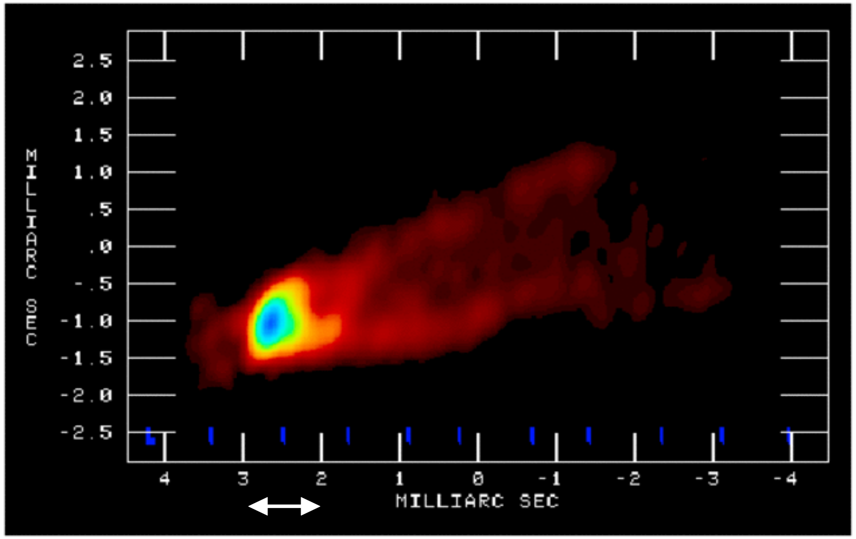


# Relativistic Jets from Active Galactic Nuclei



**M87**

**VLA+ HALCA**

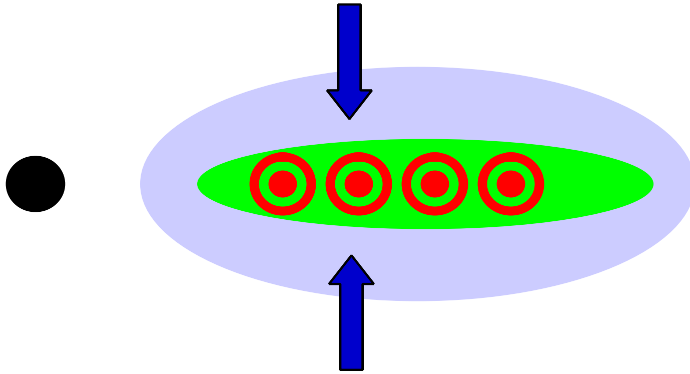



**VLBA 43GHz**

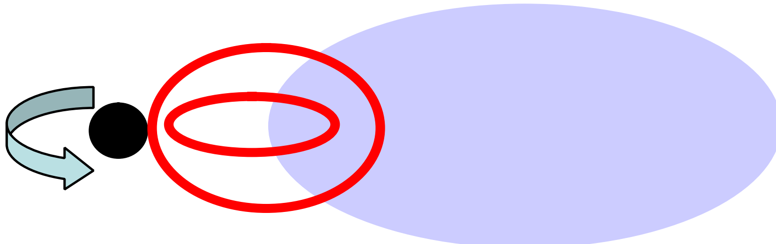
**Walker et al. 2007**

**$300r_s$=0.078pc**

**Resolution 0.21mas**

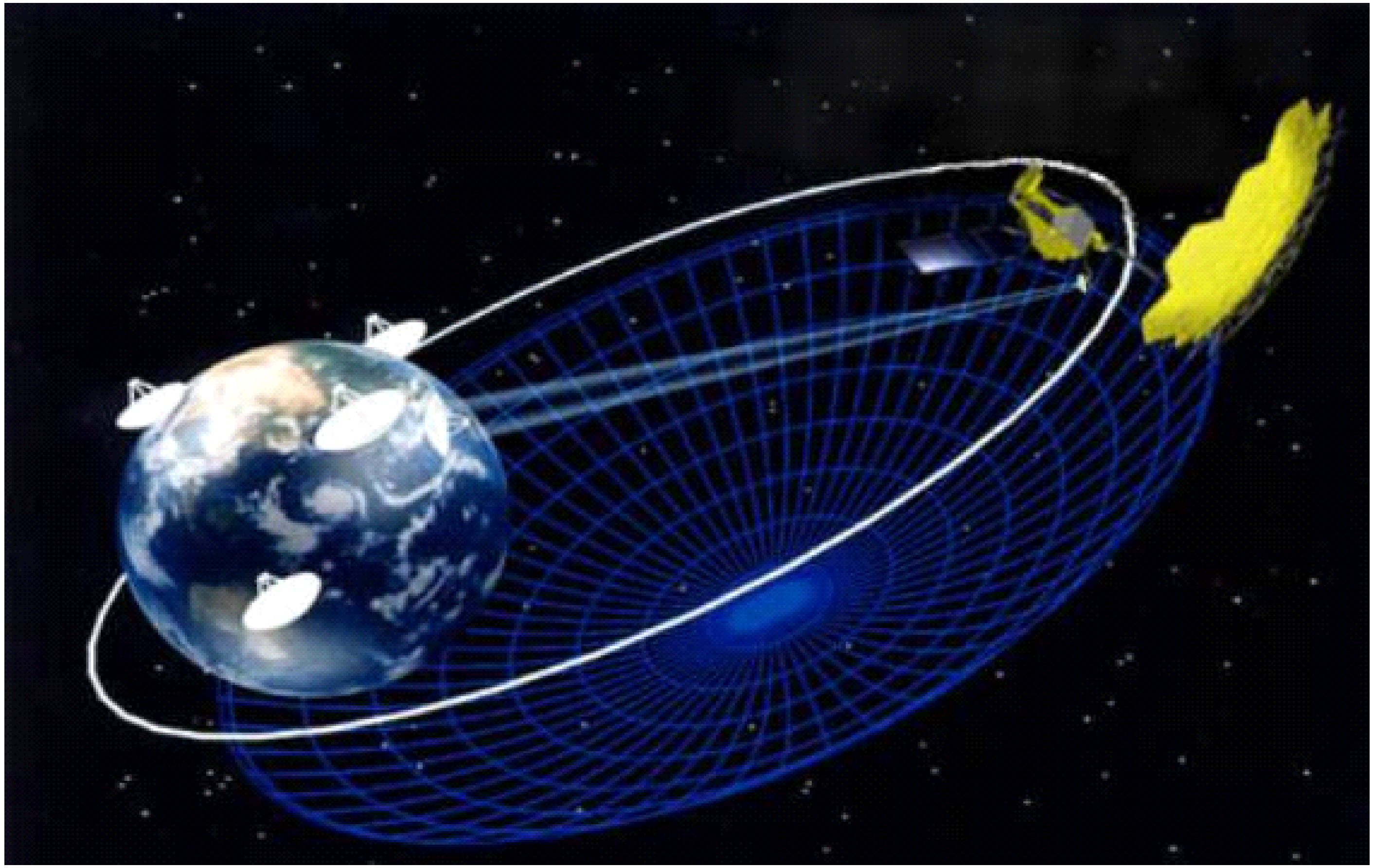


Lower Threshold for Cooling Instability ?



Kerr Black Hole – Disk Connection ?

# Observations of Jet Launching Region by VSOP2 (VLBI Space Observatory Program)



Astro-G (VSOP2)
JAXA mission

will be launched in 2012

Antenna diameter 9m

Data link 1Gbps

Spatial Resolution : 0.037mas @ 43GHz

# Summary

- Global poloidal magnetic fields threading the disk can be formed by twisting of 1) magnetic loops connecting the central object and accretion disk, or 2) magnetic loops buoyantly rising from the accretion disk
- The expanding magnetic loops are collimated toward the rotation axis, and form a magnetic tower. Magnetic reconnection taking place in the expanding magnetic loops inject hot plasmoids into the magnetic tower.
- Magnetically driven outflows are launched and accelerated along the global poloidal magnetic fields threading the accretion disk
- Core-jet and outer wind structure is formed
- When the innermost disk shrinks by cooling, magnetically dominated disk is formed. Such disks may produce relativistic jets.

# End