Cosmological Radiative Transfer Comparison Project Workshop
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Three-dimensional radiation transfer calculation for magnetic jets

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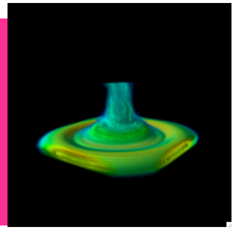
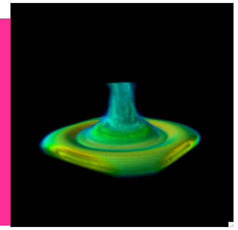
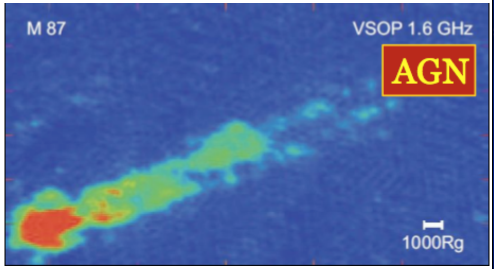
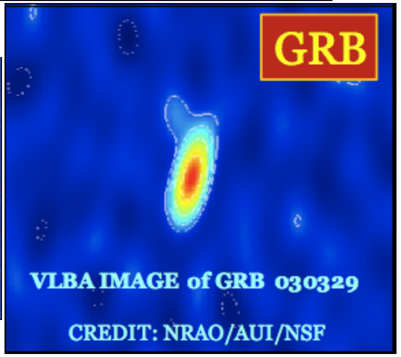


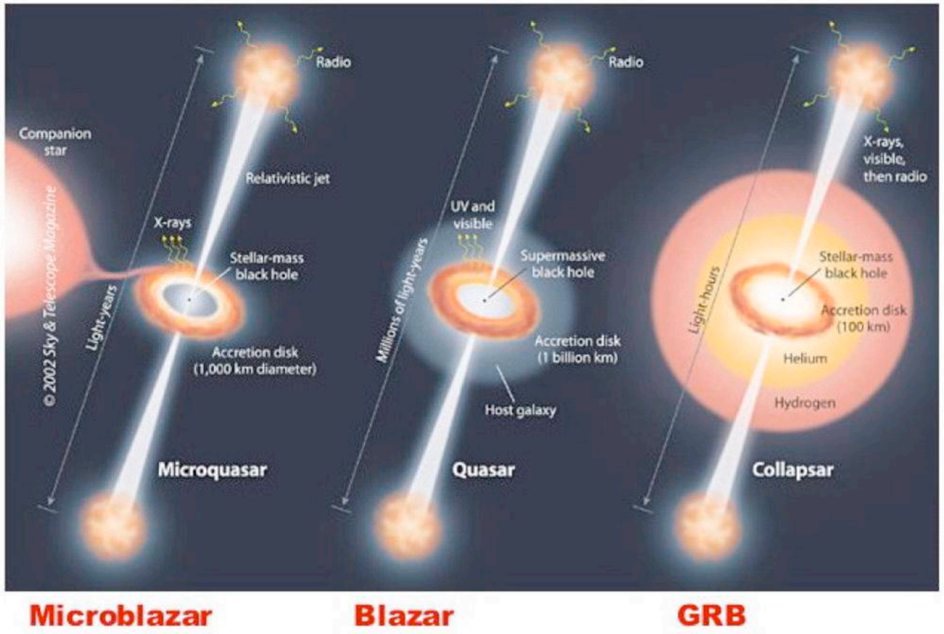
- Introduction to astronomical jets
- ART method (type II: diffuse radiation version)
- Setup
- Effects of radiation force
- Conclusions

Astronomical jet









(Mirabel & Rodriguez; Sky & Telescope, May 2002)

Disk component

Feature1

Super-Eddington luminosity

+

Jet component

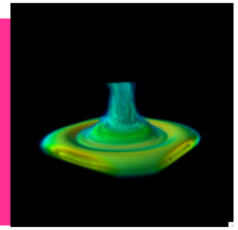
Feature1

Very high velocities (~c)

Feature2

Highly collimated

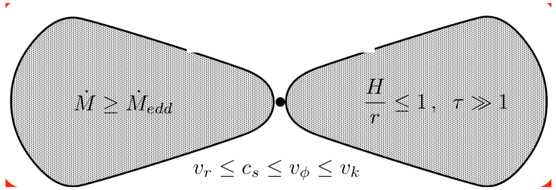
Super Eddington accretion model



Slim disk model

High mass accretion rate $\dot{m} \equiv \dot{M} / \dot{M}_{\rm Edd} > 1$

$\Rightarrow$ **Optically thick & Geometrically thick ADAF (Advection-dominated Accretion Flow)**



$$Q^+_{vis} = Q^-_{rad} + Q^-_{adv}$$

Viscous heating | Radiative cooling | Photon trapping

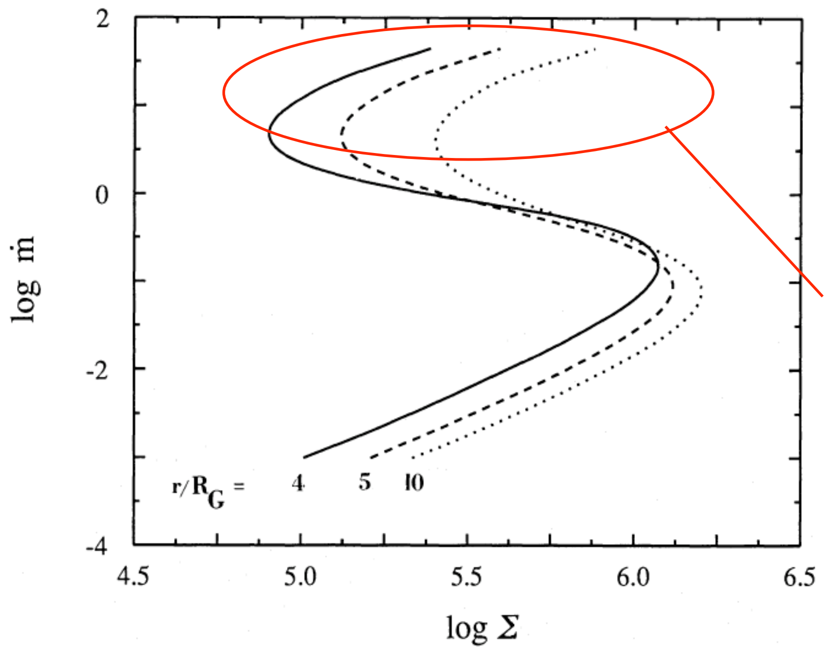
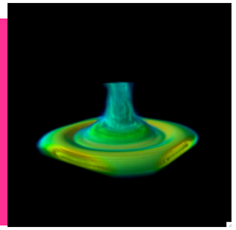


FIG. 2.—The $\dot{m}(\Sigma)$ relation for slim accretion disk models for three fixed radii, $r/R_G = 4$ (*solid line*), 5 (*dashed line*), and 10 (*dotted line*). Σ is a surface density in g cm^{-2}.

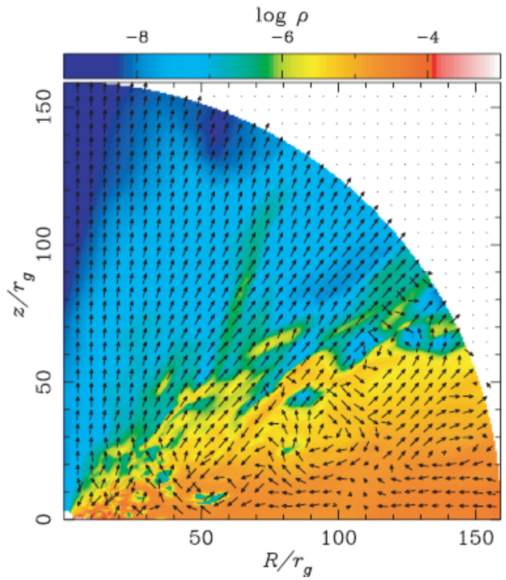
Abramowicz et al. 1988, ApJ, 332, 646

Previous work



Radiation Hydrodynamics simulation

Ohsuga(2006) performed RHD simulation assuming FLD approximation.



RHD simulation
by Ohsuga (2006)

Basic Equations of RHD

Continuity Equation $$\frac{D\rho}{Dt} + \rho\nabla\cdot\mathbf{v} = 0$$

Equation of Motion $$\rho\frac{D\mathbf{v}}{Dt} = -\nabla p - \rho\frac{GM}{(r-r_s)^2} + \frac{\kappa+\sigma}{c}\mathbf{F}_0 + \rho\mathbf{N}$$

Radiation Force ($\frac{\kappa+\sigma}{c}\mathbf{F}_0$); α-viscosity model ($\rho\mathbf{N}$)

Gas Energy Equation $$\frac{\partial e}{\partial t} + \nabla\cdot(e\mathbf{v}) = -p\nabla\cdot\mathbf{v} - 4\pi\kappa B + c\kappa E_0 + \Phi$$

absorption/emission

Radiation Energy Equation $$\frac{\partial E_0}{\partial t} + \nabla\cdot(E_0\mathbf{v}) = -\nabla\cdot\mathbf{F}_0 + 4\pi\kappa B - c\kappa E_0 - \nabla\mathbf{v}:\mathbf{P}_0$$

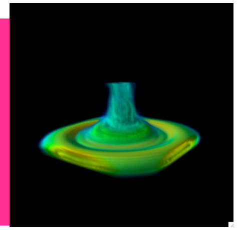
Advection (Photon-trapping); Radiative Flux

Flux Limited Diffusion (FLD) approximation (Levermore & Pomraning 1981)

$$F_0 = -\frac{c\lambda}{\chi}\nabla E_0,$$

FLD approximation is correct at optically thin and thick limit.
But, it is debatable at $\tau \sim 1$ region.
Anyway, it is not clear whether jet is generated by radiation pressure.

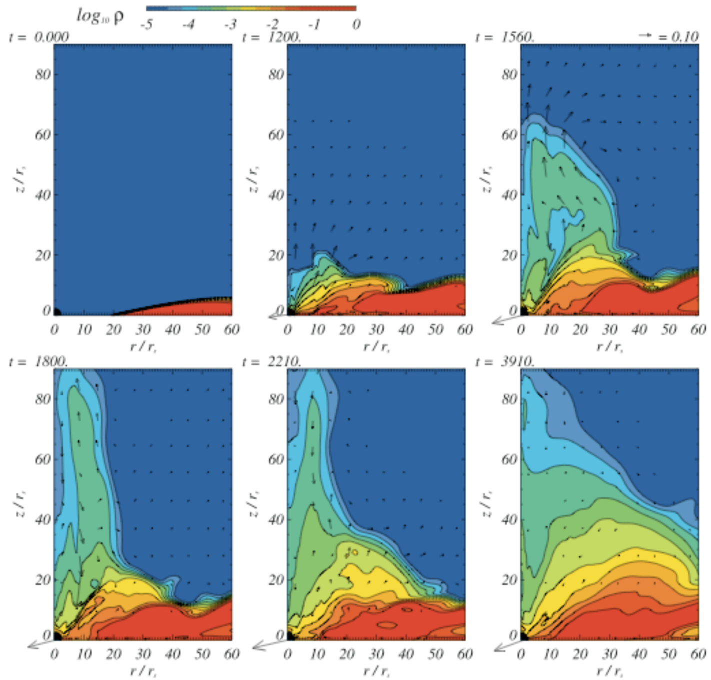
Previous work



Magneto-Hydrodynamics simulation

This is examined the case with initially poloidal field configurations with β~10.
Magnetic jet is driven by magnetic pressure asserted by accumulated toroidal fields which speed is ~0.2c.

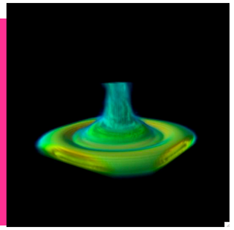
The collimation width of the magnetic jet depends on external pressure.
Nonnegligible external pressure tends to suppress the emergence of the MHD jets.



MHD simulation by Kato et al. (2004)

These calculation do not include radiation pressure.
In the case of slim disk, we should consider the effect of radiation force.

Purpose



As the first step to explore the significance of radiation pressure, we solve the three-dimensional radiation transfer on the structure obtained by the three-dimensional MHD simulation.

I examine how the radiation force works on the magnetic tower jet.

I use the data from MHD simulation Kato et al. (2004).

The resolution of my simulation is 100×100×50 on Cartesian coordinates.

Then I solve diffusive radiation transfer with ART.

ART (Authentic Radiative Transfer) method

ART method for calculating the transfer of diffuse radiation (Type II)

The technique is slightly complicated, but can reduce computational cost, compared to long characteristic method with high accuracy.

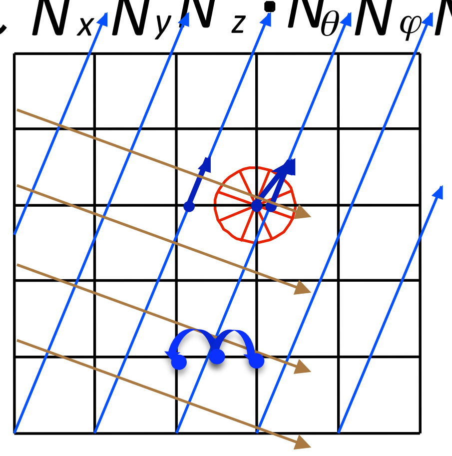
Specific intensities are calculated along the rays.

The specific intensities on the fluid grids are interpolated from the nearest radiation grid.
For different directions, specific intensities on grid points are obtained in the same way.

Finally, they are integrated over all solid angles.

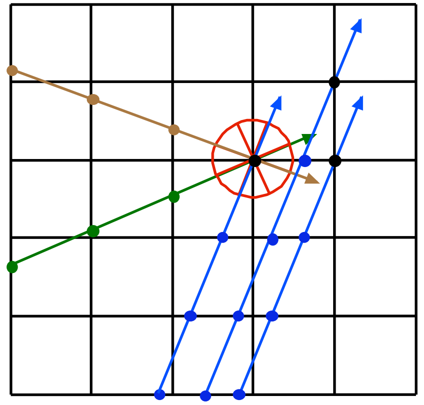
ART

$\sim N_x N_y N_z \cdot N_\theta N_\varphi N_\nu$

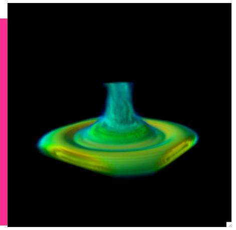


Long Characteristics

$\sim N \cdot N_x N_y N_z \cdot N_\theta N_\varphi N_\nu$

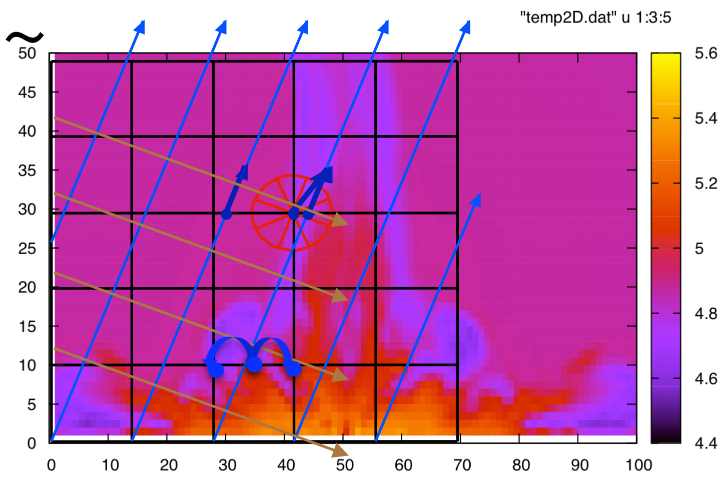


Setup



I use the density and temperature distribution of results of Kato et al (2004).
I assume slim disk model for super massive BH.

- Mesh:100×100×50
- BH Mass：$10^{8}M_{sun}$
- Density distribution：
  10^{-10}～10^{-12}[g/cm^{3}]（disk）
  10^{-12}～10^{-15}[g/cm^{3}](jet & corona)
- Temperature distribution：
  10^{8}～10^{10}[K]（disk）
  10^{10}～10^{13}[K](jet & corona)
- Frequency：10^{14}～10^{18}[Hz]
- Opacity : Thomson, free-free



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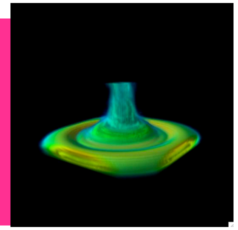
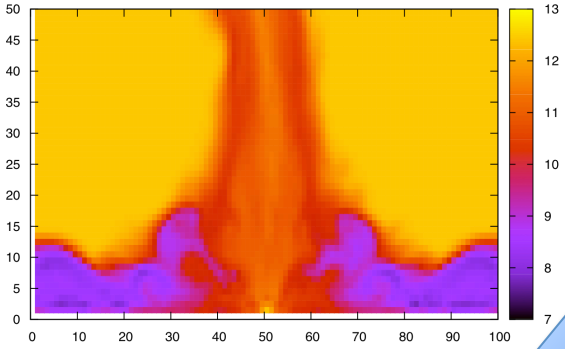
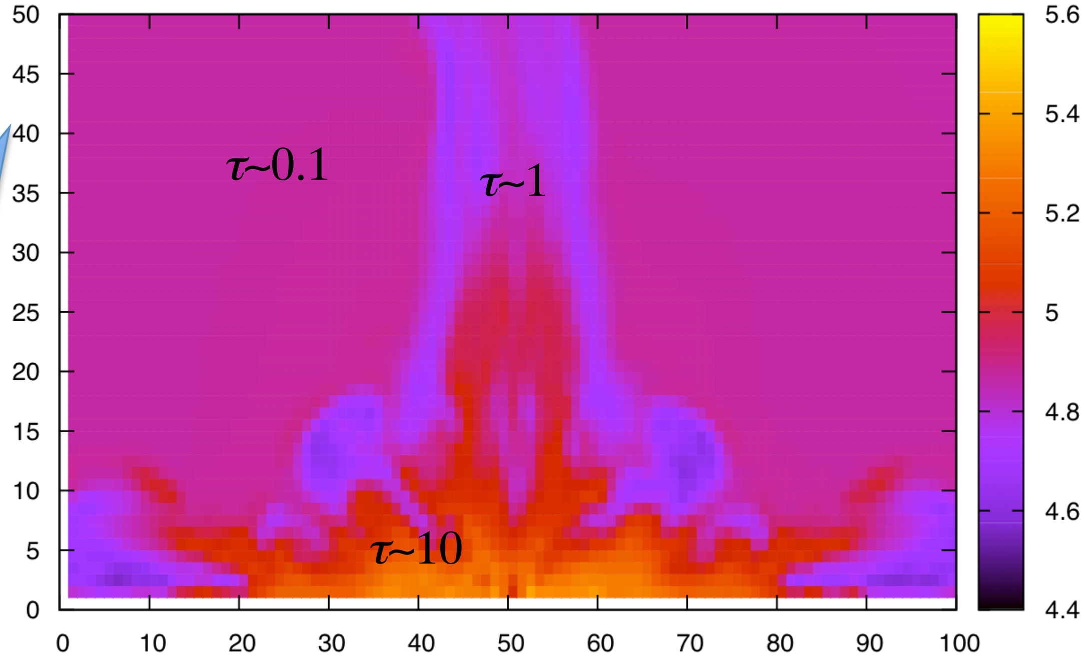


Gas temperature [K]



$$\frac{2}{3} nkT_{gas} = aT_{rad}{}^{4}$$

Radiation Temperature [K]

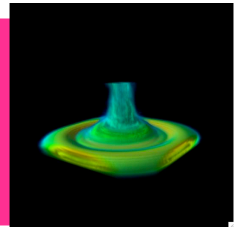


$[R_s]$

I determined radiation temperature using equilibrium of gas internal energy and radiation energy.

→ radiation pressure dominant

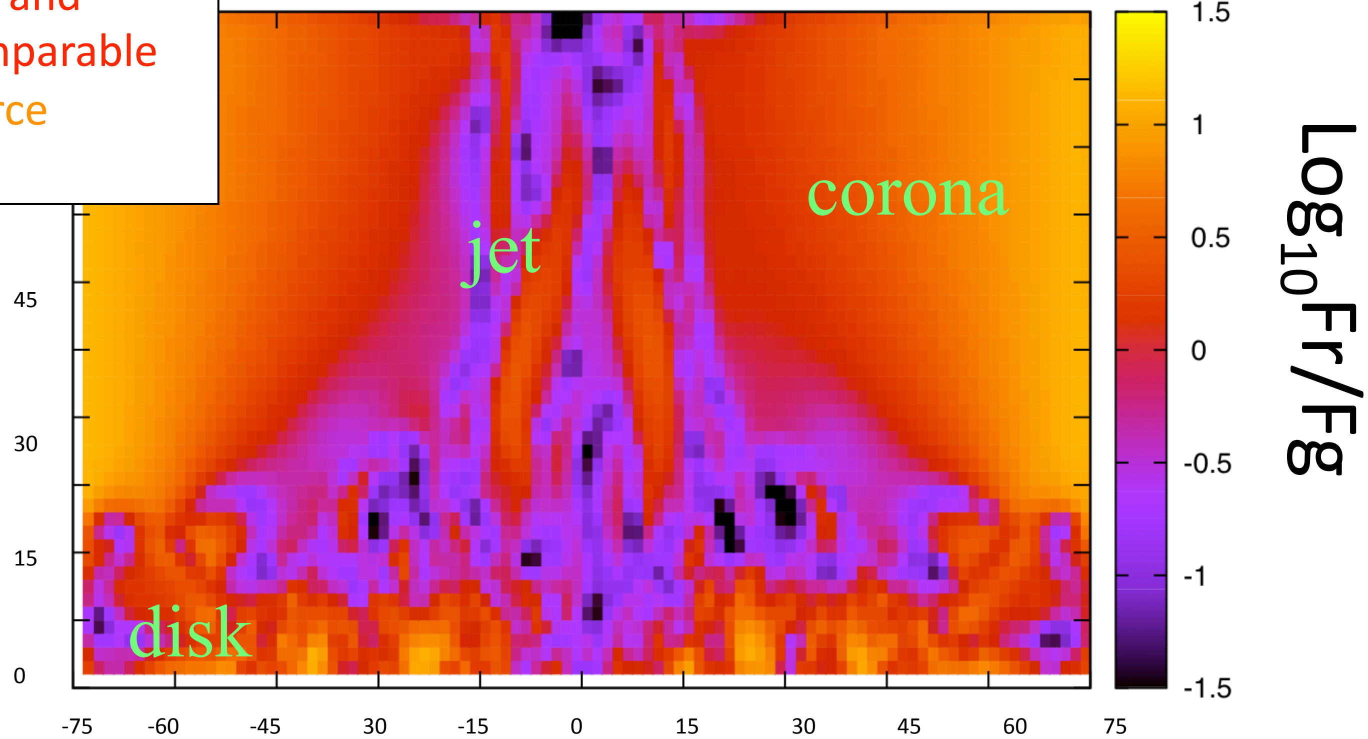
Results



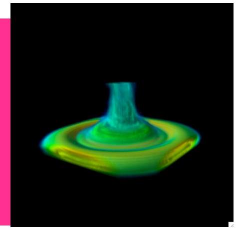
At the inside of the disk and the jet, the radiation force effectively works. But, at the surface of the jet, the gravitational force is stronger than the radiation force. In the region of the corona, the radiation pressure is very strong.

Purple : gravity dominant
Red : radiation force and gravity are comparable
Yellow : radiation force dominant

Radiation Force / gravity

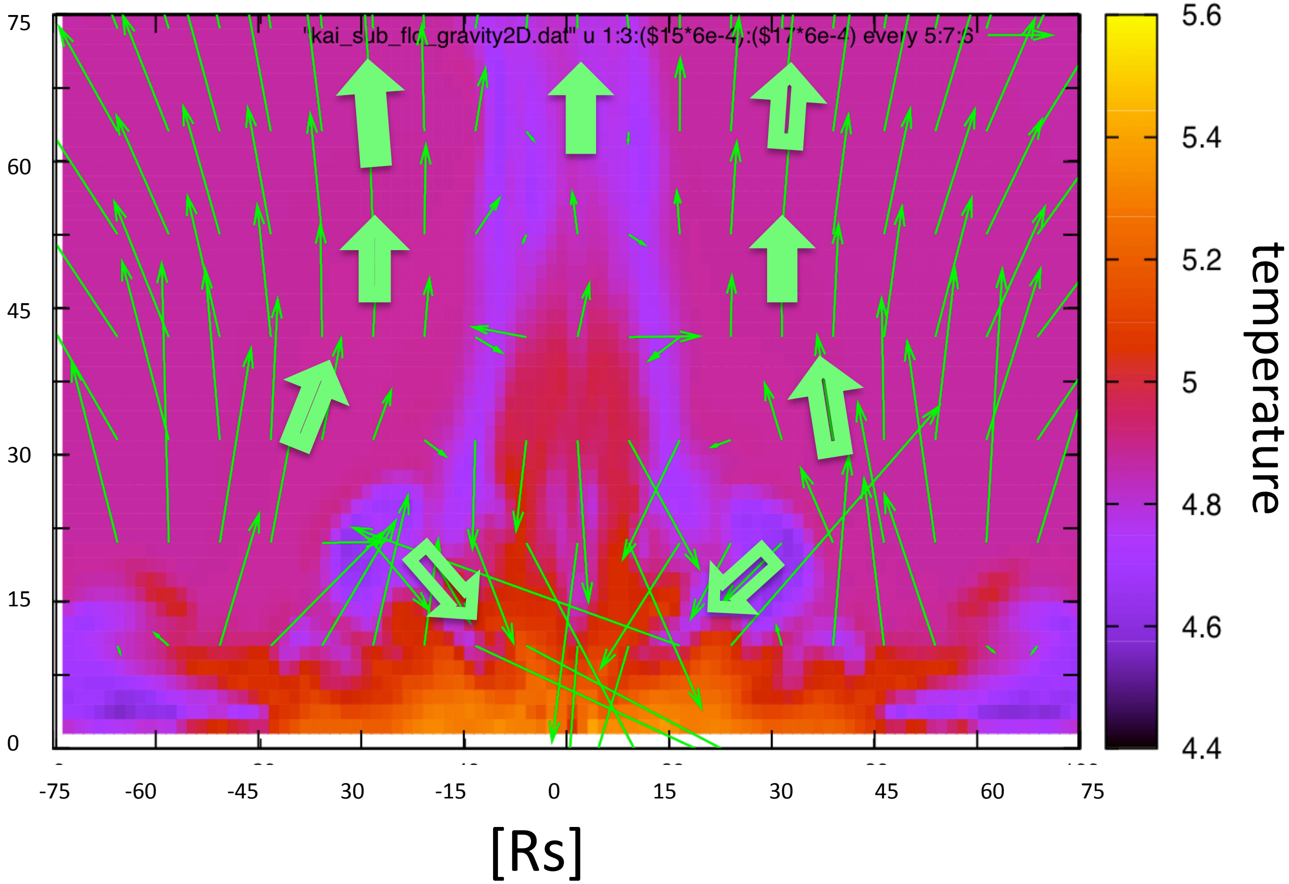


Effects of radiation force

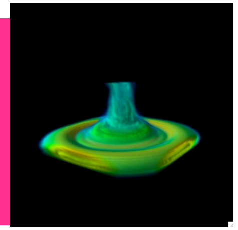


The radiation force cannot contribute to the collimation of the jet.
In the inside of the jet, radiation force works to accelerate the jet.

The green vector is the net force (**F_r-F_g**).



Conclusions

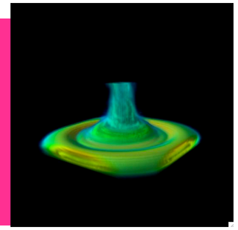


We investigated the significance of radiation pressure in astronomical jets by ART calculation.
Three-dimensional radiation transfer was calculated by using density and temperature structure for the jet and disk of Kato et al.(2004).

We have found

1) The radiation force can contribute to the acceleration of the jet.

2) The radiation force does not seem to work significantly to collimate the jet.



Thank you!!