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Global Magnetohydrodynamic Simulations of AGN Torus

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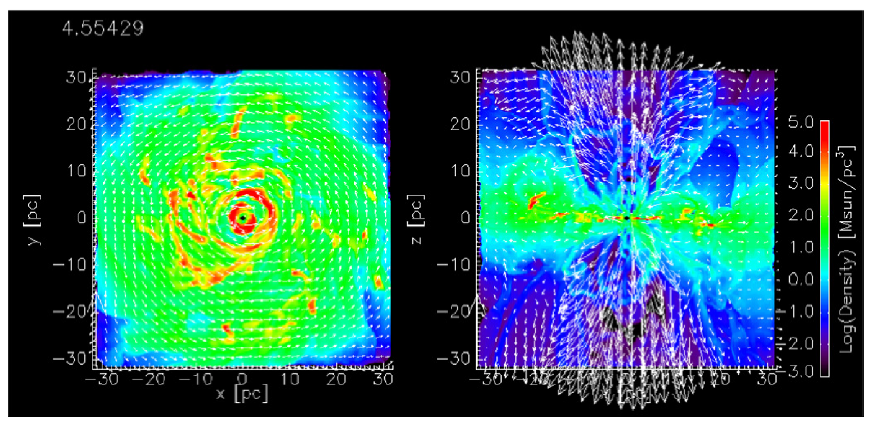
Abstract

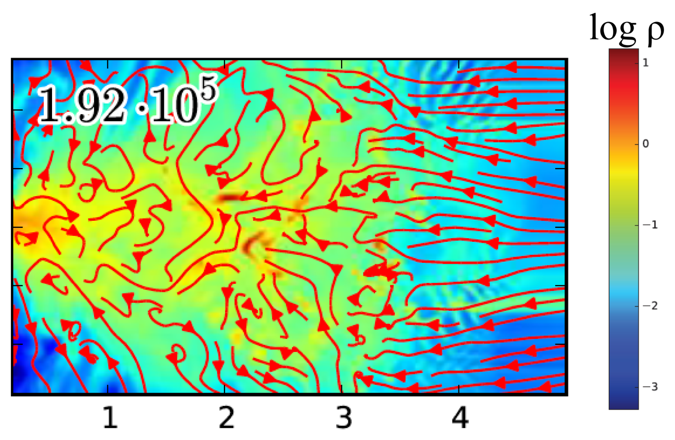
Magnetic fields of the AGN obscuring torus are suppose to play an important role in forming geometrically thick obscured gas and in enhancing the accretion rate due to the magnetohydrodynamic(MHD) turbulence driven by the magneto rotational instability (MRI). We carried out three-dimensional global MHD simulations including X-ray heating and radiative cooling. Numerical scheme is applied to HLLD method which is a standard technique to solve the magnetic field, and achieved by fifth-order accuracy in space and third order accuracy in time. When the radiative heating and cooling are ignored, we confirmed that azimuthal magnetic fields reverse direction quasi-periodically in the time scale of 10 rotation period at each radius.

1. Introduction

- Numerical simulations of AGN Torus



Wada 2012
Hydrodynamic simulation including radiation feedback

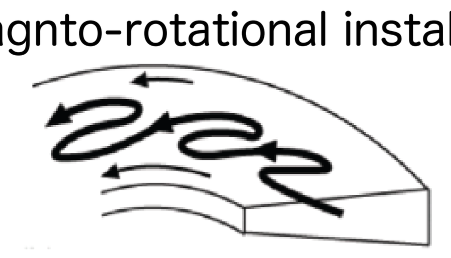


Dorodnitsyn & Kallman 2017
Magnetohydrodynamic simulation including radiation feedback

Chan & Krolik 2017
Radiative magneto-Hydrodynamic simulation

- Activity of magnetized Torus
  MRI-Parker Dynamo is the mechanism of magnetic field amplification and saturation

Radial field is produced from azimuthal field by MRI
Azimuthal field is produced from radial field by differential rotation (Ω-effect)



Buoyant escape of magnetic flux by Parker instability limits the strength of disk magnetic field.

$$\beta = \frac{P_g}{P_B} = \frac{P_g}{B^2/8\pi} > 5$$

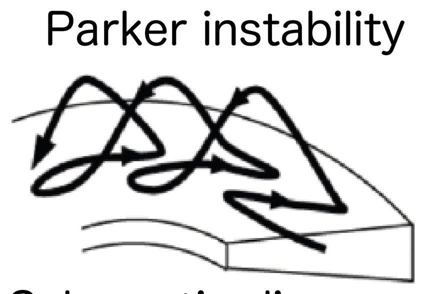


Fig.1 Schematic diagram of MRI-Parker Dynamo

- Global and local 3D simulations show that mean azimuthal magnetic field ($B\varphi$) reverse quasi-periodically.(Machida et al. 2013, Shi et al. 2010)

- Purpose of this study
  (1) Gas supply → Accretion rate
  (2) Dense cloud surrounding the obscuring tori and the outflow → magnetic activity?

2. Simulation Model

- 3D global magnetohydrodynamic simulation

MHD Code : CANS+ (Matsumoto et al. 2016)
- HLLD scheme
- 3nd order accuracy in time (TVDRK)
- 5th order accuracy in space (MP5 method)

- Computational domain
  $0 < r < 11$ [pc] , $0 < \varphi < 2\pi$
  $-3 < z < 3$ [pc]

- Grid Points
  $(N_r, N_\varphi, N_z) = (256, 64, 512)$
  Spatial resolution in uniform grid
  $\Delta r = 0.01$ [pc], $\Delta z = 0.01$ [pc]

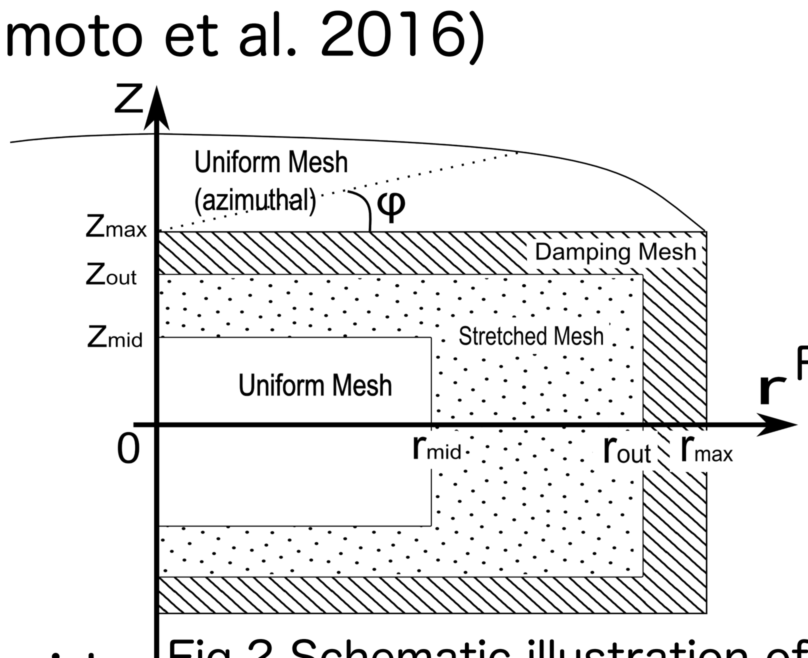


Fig.2 Schematic illustration of computational domain

- Axisymmetric gravitational potential

$$\Phi_{BH}(R, z) = \frac{GM_{BH}}{\sqrt{R^2 + z^2}}$$

- Cooling and Heating
  Cooling function (Meijerink & Spaans 2005)
  X-ray heating
  we assumed spatially uniform.
  (Ionization parameter $\xi = 0.1$)

$$\Gamma_{X,h} = 8.9 \times 10^{-36}\xi(T_X - 4T) \quad T_X = 10^8 \text{ K}$$
$$+ 1.5 \times 10^{-21}\xi^{1/4}T^{-1/2}(1 - T/T_X) \text{ erg s}^{-1}\text{ cm}^3$$

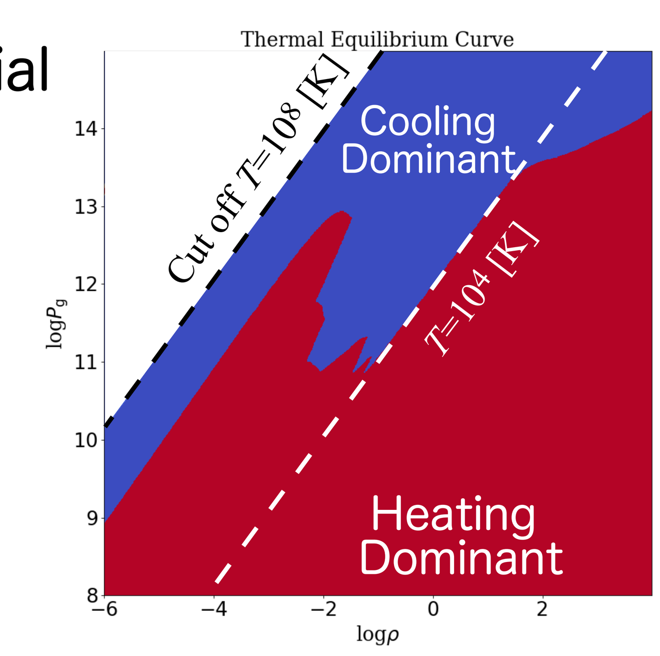
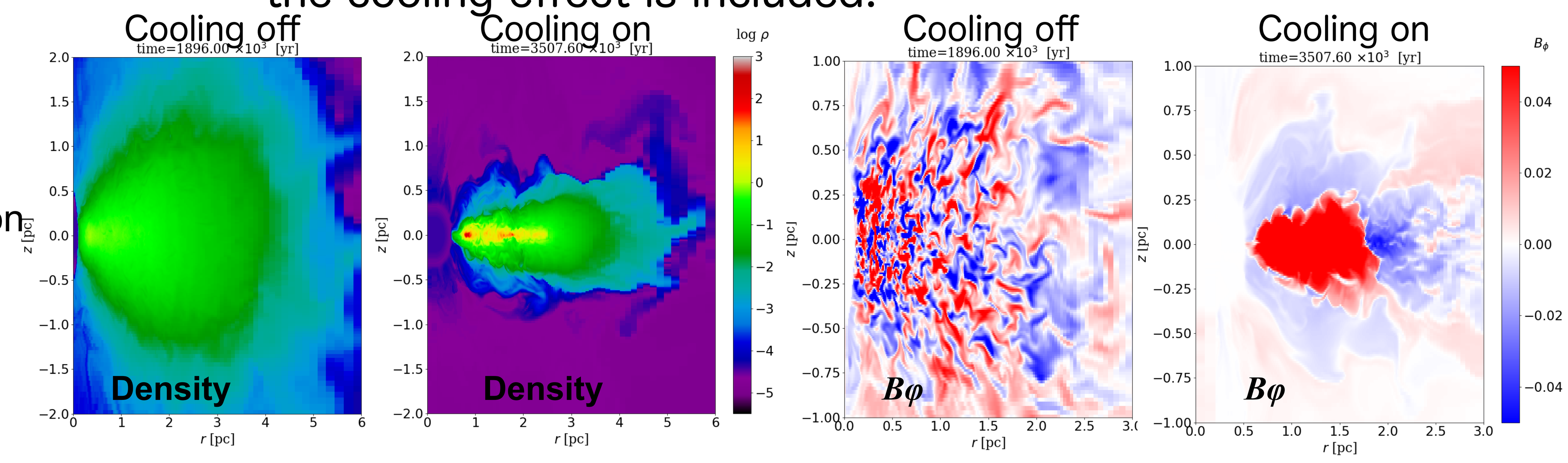


Fig.3 Thermal equilibrium state

3. Results

Model A : We assumed equilibrium torus threaded by weak azimuthal magnetic fields. After the magnetic turbulence is driven, the cooling effect is included.



Model B : We assumed Keplerian disk initially including cooling effect with no magnetic field. After the disk is quasi-hydrostatic equilibrium, weak azimuthal magnetic fields are threaded.

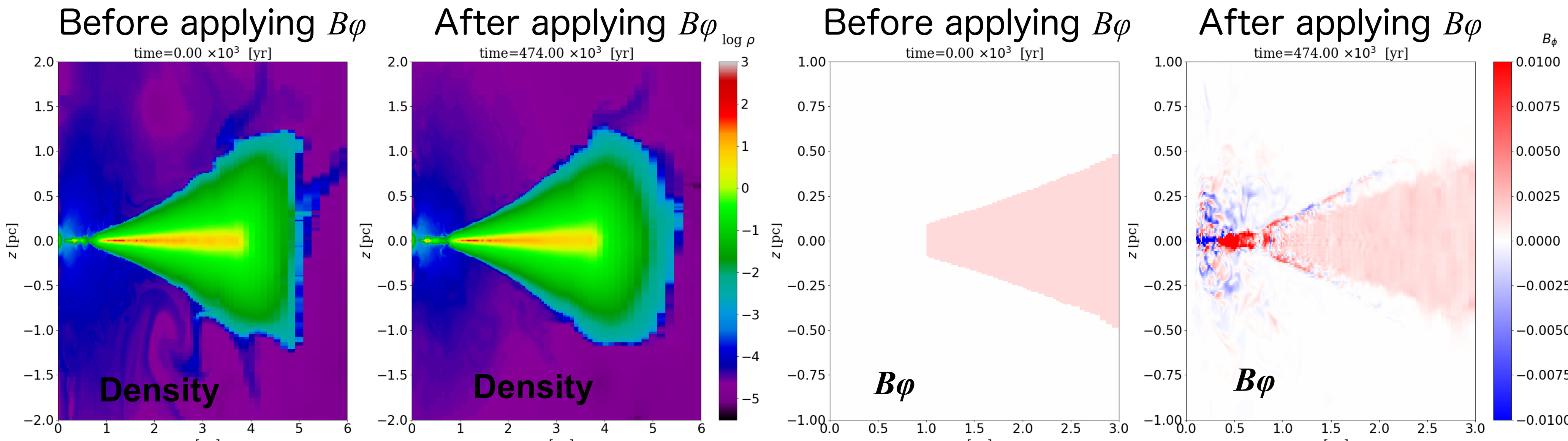


Fig.4 Transition of geometrical structure on r-z plane. Left : Density of logarithmic scale. Right : Toroidal magnetic field $B\varphi$. Direction of $B\varphi$ is different in read and blue.

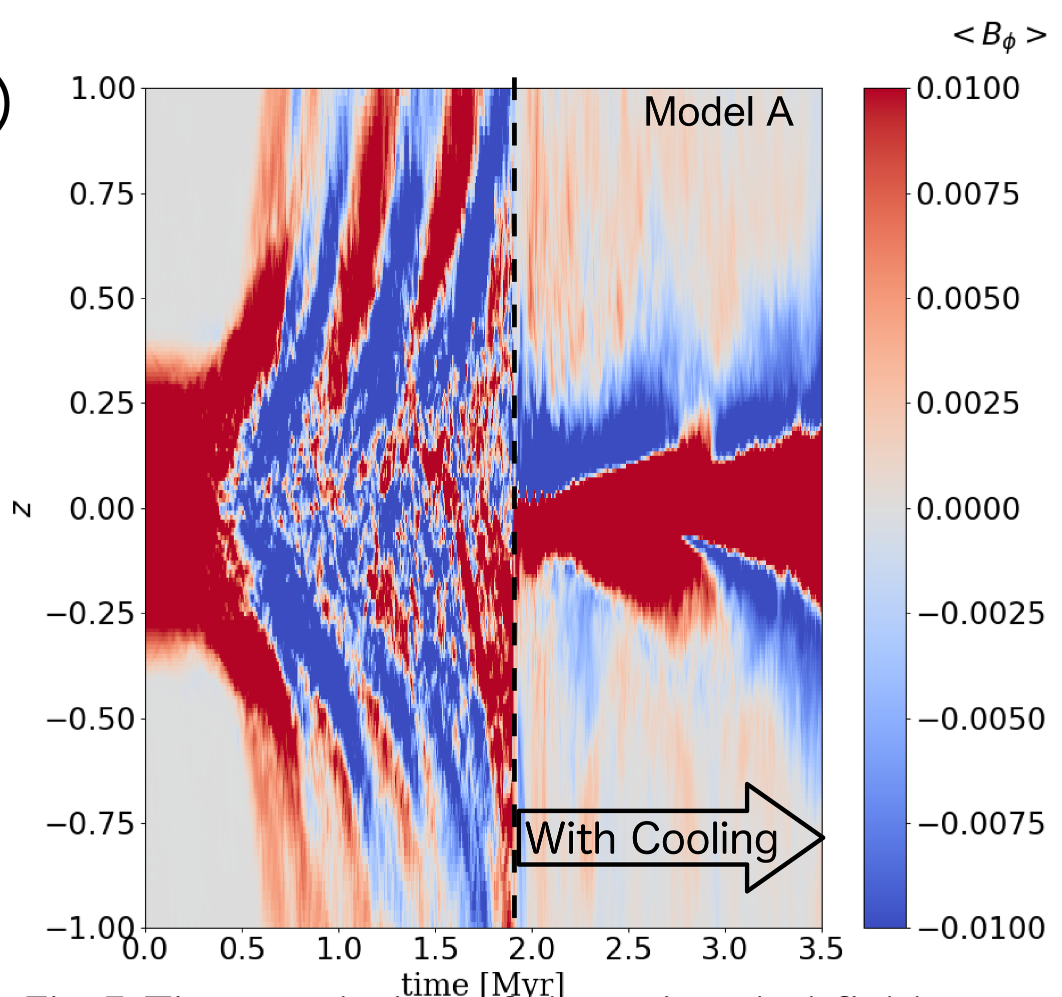


Fig.5 Time evolution of the azimuthal field $B\varphi$ averaged in the azimuthal direction at r=1 [pc]. The rotation period is ~ 4.7 [kyr]

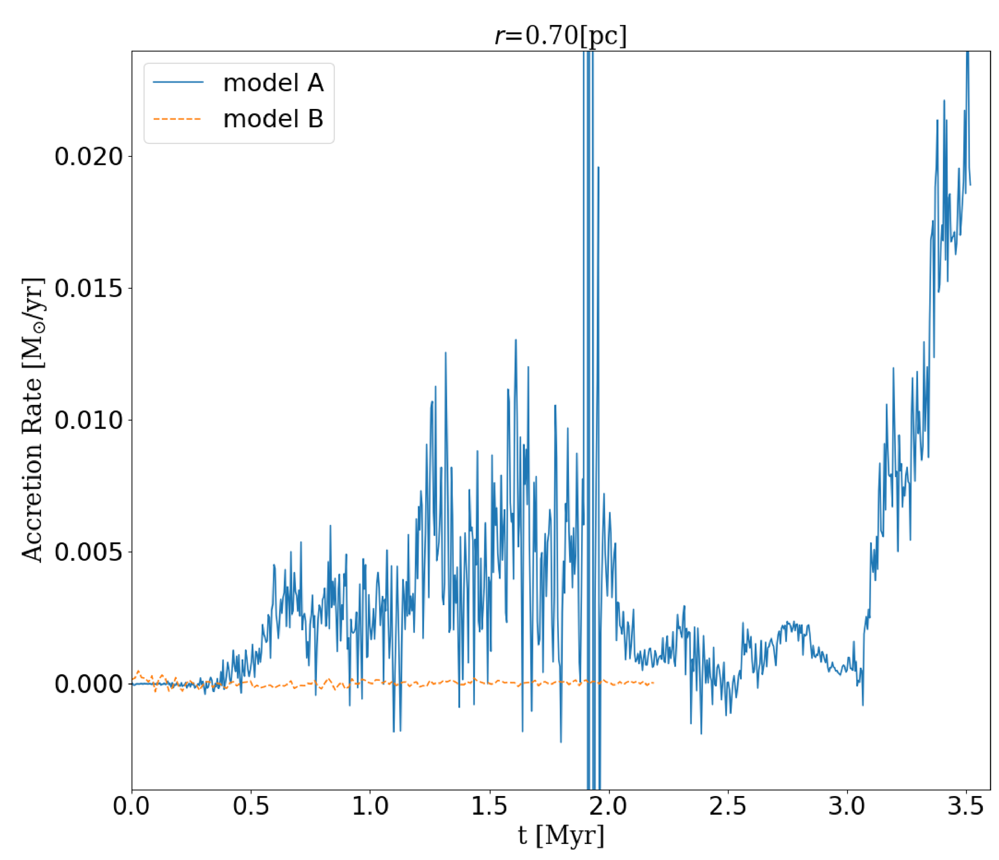


Fig.6 Accretion rate estimated by mass flux (ρv_r) averaged in the azimuthal direction at r=0.7 [pc].

4. Summary

- We carried out global MHD simulations including cooling effects.
  Formation of geometrically thin disk due to cooling effect.
  Without cooling, mean azimuthal field ($B\varphi$) reverse quasi-periodically.
  With cooling, azimuthal field ($B\varphi$) reverse around the disk surface only.
- Spatial resolution in these simulations can not drive MRI.

Maximum grow wave length $\lambda_{MRI} = 2\pi r \frac{v_A}{v_{rot}} \sim 1.2 \times 10^{-2}$ [pc] $\left[\frac{r}{1\text{pc}}\right]\left[\frac{v_{rot}}{200\text{km/s}}\right]^{-1}\left[\frac{\beta}{1}\right]^{-\frac{1}{2}}\left[\frac{T}{100\text{K}}\right]^{\frac{1}{2}}$

this work $\lambda = \frac{2\pi r}{N_\varphi} = 9.8 \times 10^{-2}$ [pc] $\left[\frac{r}{1\text{ [pc]}}\right]$

- Accretion rate 1×10^{-3} - 10^{-2} [M☉/yr]
  This results is smaller than 0.1[M☉/yr] shown by Wada & Norman 2012 and 0.1-10 [M☉/yr] shown by Dorodnitsyn & Kallman 2017.
- Future Work
  Irradiation of X-ray emitted from Schwarzschild radius scale.
  Heating sources of the SNe (Wada & Norman 2002)

5. Reference

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