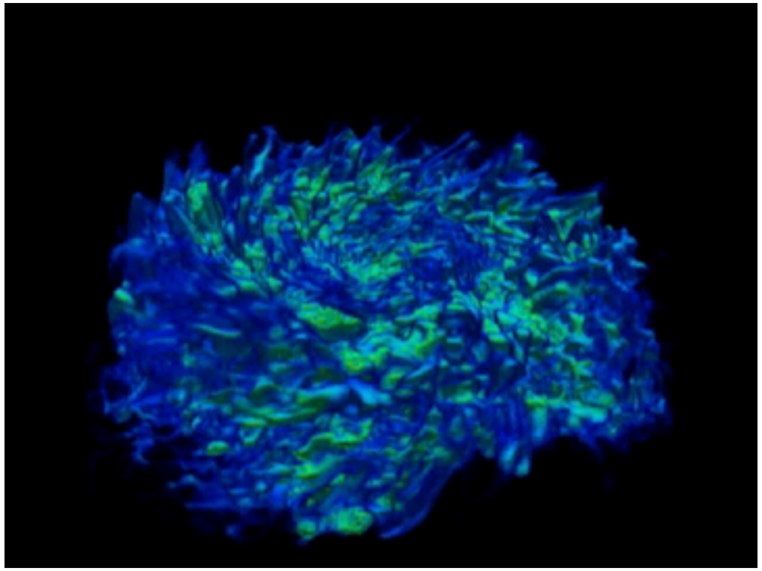
“What drives the growth of black holes?”
Durham, 26-29 July

Multi-phase ISM around AGN:
Effect of X-ray feedback on 10s pc

Some preliminary results of 3D radiative hydro.

Keiichi Wada

Kagoshima University, Japan



KW, Norman 2002

Collaborators:

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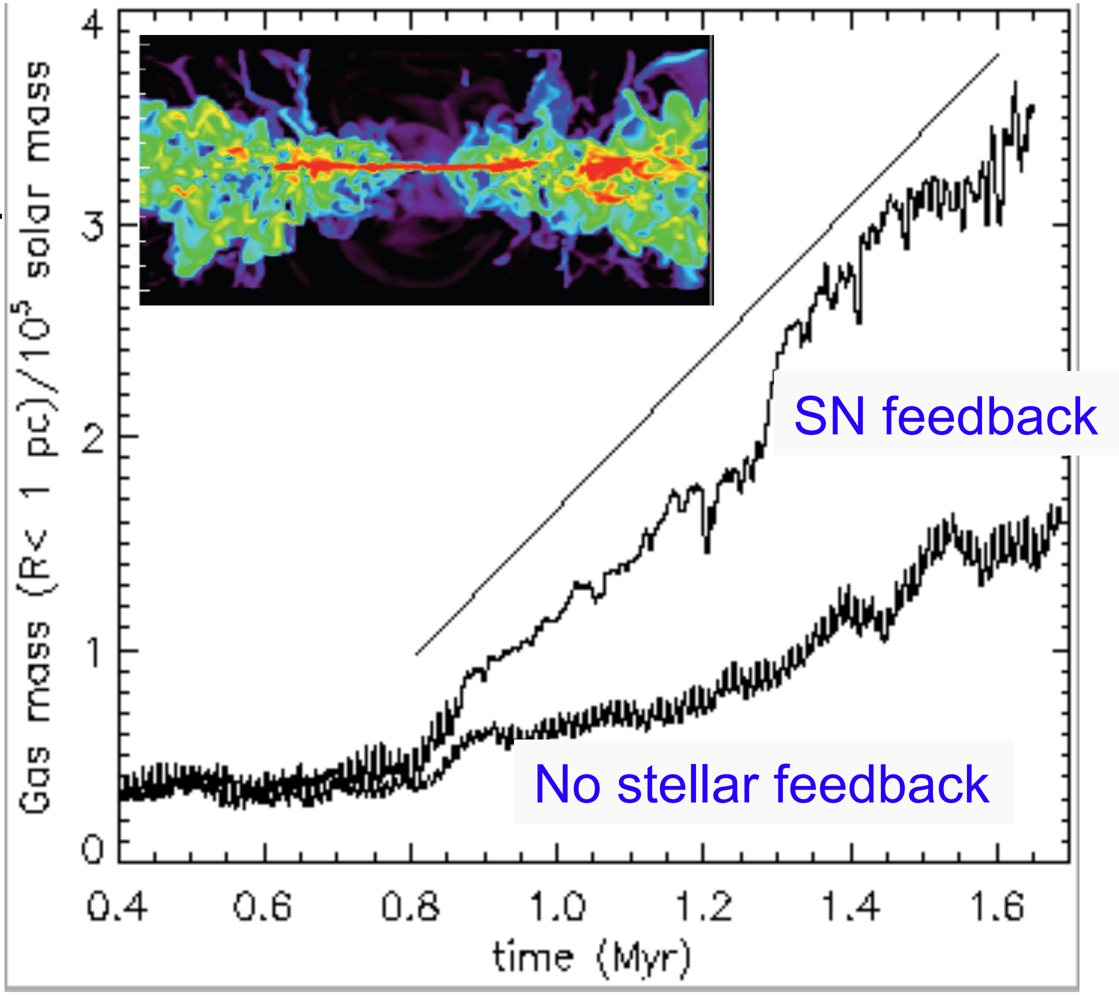
Padeli Papadopoulos (Bonn)
Marco Spaans (Kaptyn, Groningen)
Colin Norman (JHU)
Ken Ohsuga (NAOJ)
Hajime Susa (Konan Univ.)

Gas accretion in a turbulent nuclear disk

Average accretion rate to
central pc ~ 0.3 Msun/yr

Accretion is enhanced by the
starburst.

Turbulent viscosity dominates
the accretion process in the
circum nuclear region
with star formation.



KW & Norman 2002

Growth of a SMBH and circum nuclear disk

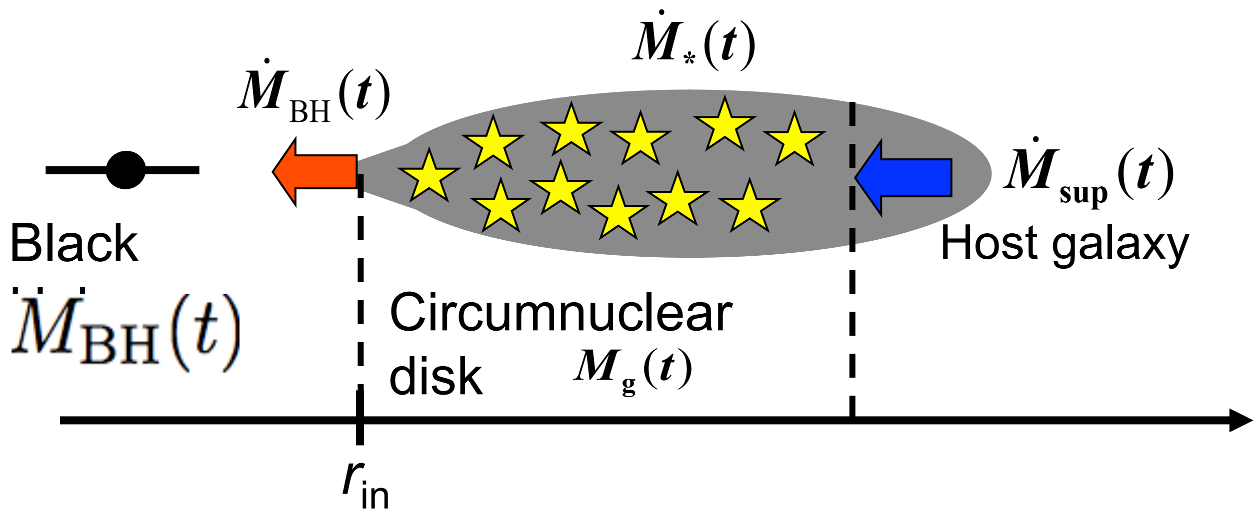
Kawakatu & KW 2009

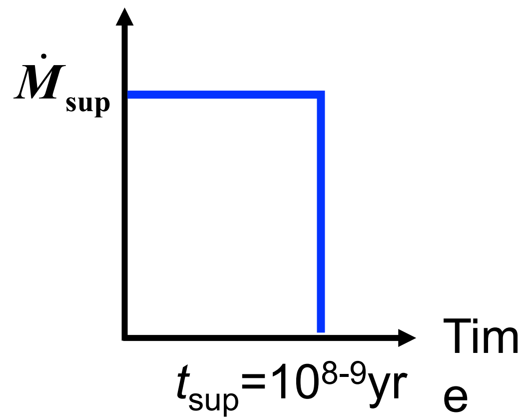
The supplied gas from hosts is eventually consumed to form SMBHs and/or stars. Thus, the time-evolution of gas mass in disk is given by

$$M_{\rm g}(t) = \int_0^t [\dot{M}_{\rm sup}(t') - \dot{M}_*(t') - \dot{M}_{\rm BH}(t')]dt'$$

$$\dot{M}_{\rm BH}(t) \equiv \dot{M}_{\rm BH}(r_{\rm in}, t)$$

$$M_{\rm BH}(t) = M_{\rm BH,seed} + \int_0^t \dot{M}_{\rm BH}(t')dt' \quad ; M_{\rm BH,seed} = 10^3 M_\odot$$





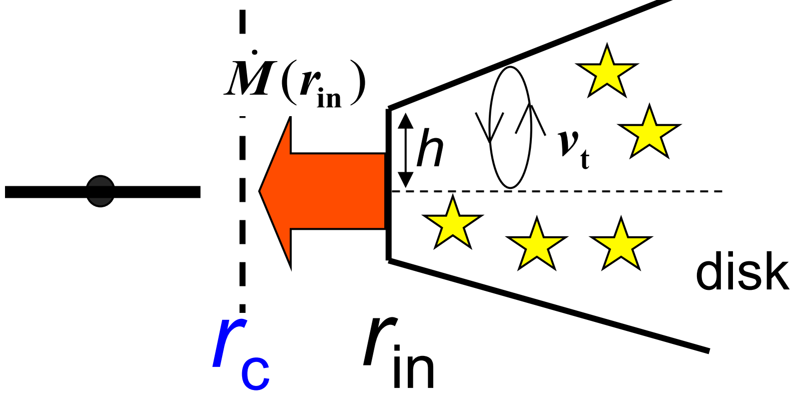
The inner radius is determined by the dust sublimation radius, $r_{\rm in} \sim 3$ pc $M_{\rm BH}^{1/2}$

M_{BH} affects gravitational s… y of the disk

→ SF-driven turb… → Accretion rate → M_{BH}

Gravitational feedback

(i) For small BH

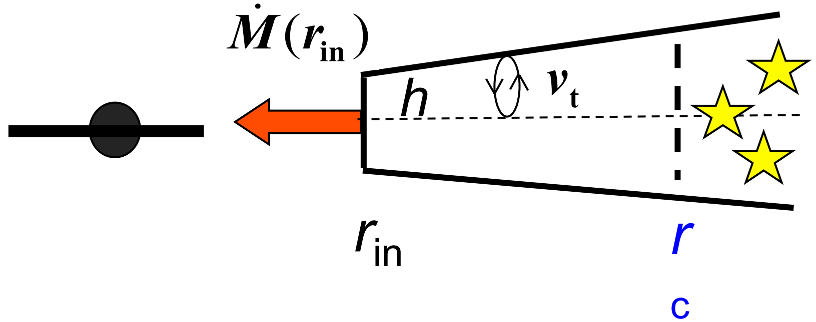


The disk can be unstable and supported by turbulent-pressure

(geometrically thick disk)

$$v_t > c_s$$

(ii) For massive BH



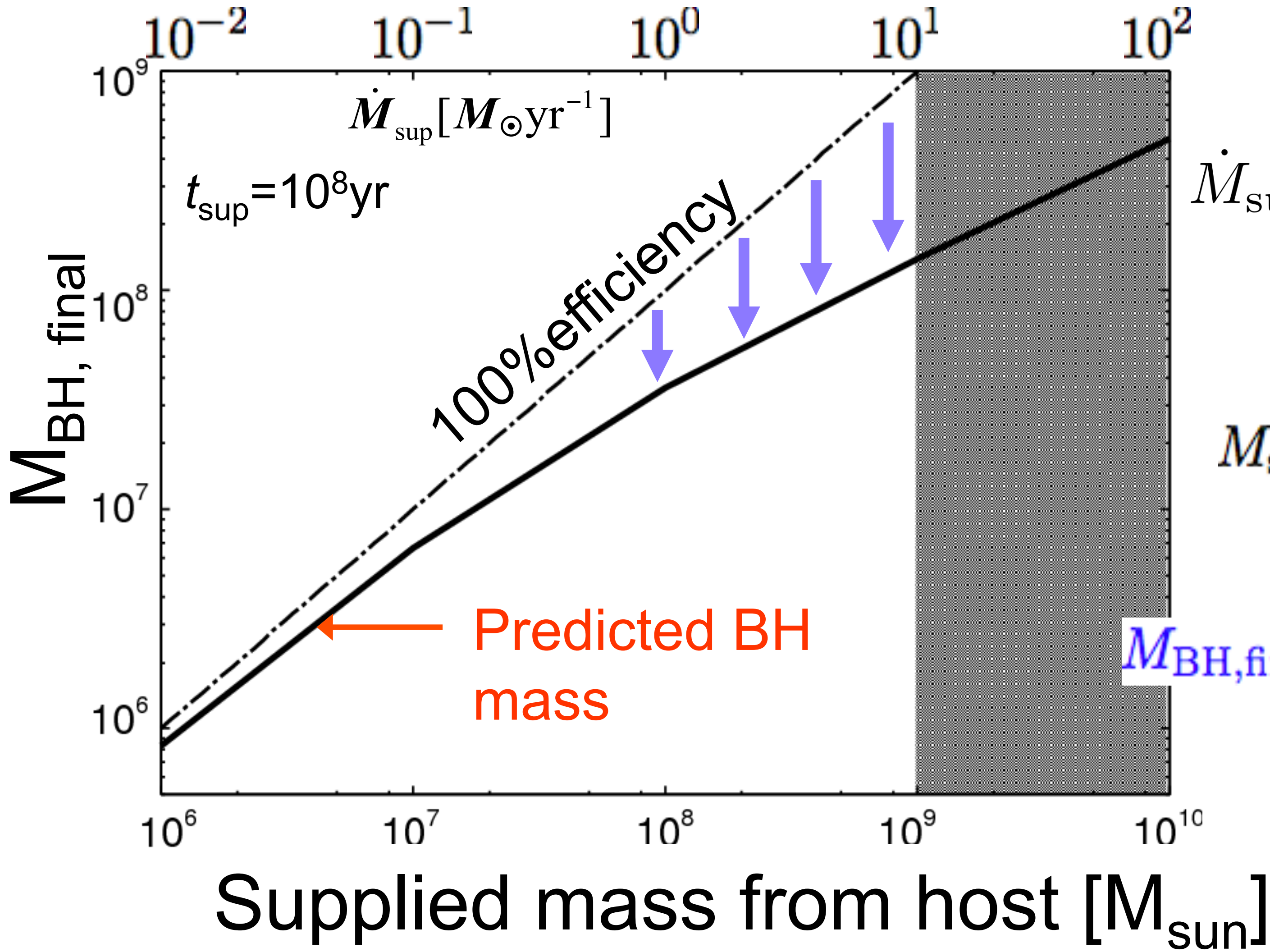
Gas pressure supported disk (geometrically thin disk)

$$v_t = \alpha c_s < c_s$$

$$\dot{M}(r_{in})^{(i)} \gg \dot{M}(r_{in})^{(ii)}$$

Due to 'gravitational feedback', growth is less efficient for larger BH

Kawakatu,KW 08,09



$$\dot{M}_{sup} = 10 M_\odot \ yr^{-1}$$

$$t_{sup} = 10^8 \ yr$$

↓

$$M_{sup,max} \approx 10^9 M_\odot$$

↓

$$M_{BH,final} < a \ few \ 10^8 M_\odot$$

Feedback processes on tens pc are essential for BH growth

- Gravitational
  - Growth of SMBH affects stability of the gas disk & star formation
    - If accretion is controlled by SN-driven turbulence, accretion rate (turbulent viscosity) should be affected by M_{BH}
- Radiative

See also talks on Thursday

  - Dynamical/Thermal

If the radiative feedback too 'effective',
How can SMBHs grow?

op accretion?

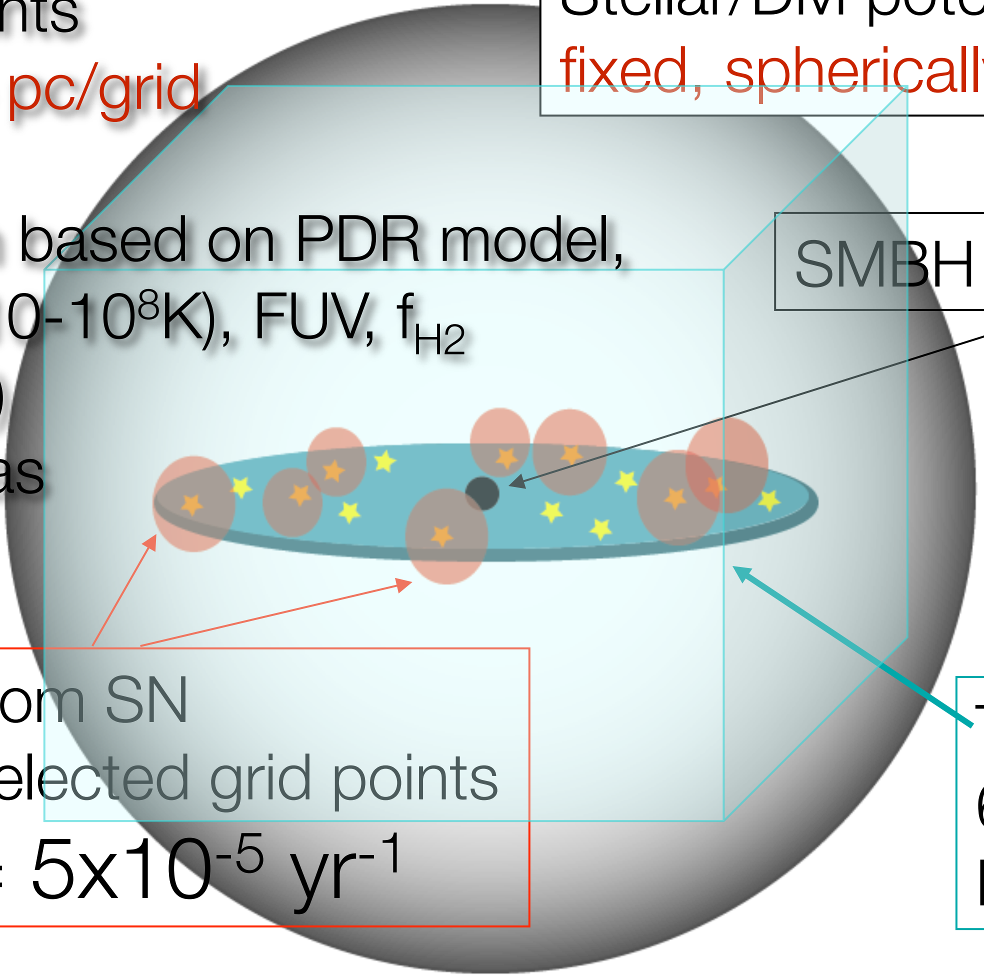
    - Radiation drag → enhance accretion?
  - Chemical
    - PDR, XDR → Molecular gas & SF rate?

3-D Hydrodynamics of a starbursting gas disk around a SMBH (KW, Papadopoulos & Spaans 09)

512^2x256 grid points
Resolution: 0.125 pc/grid

- Cooling function based on PDR model, depending on T (10-10^8K), FUV, f_{H2}
- UV heating(dust)
- Self-gravity of gas

Stellar/DM potential:
fixed, spherically symmetric



SMBH 1.3×10^7 M_{sun}

Thin gas disk
6×10^6 M_{sun}
R=32pc

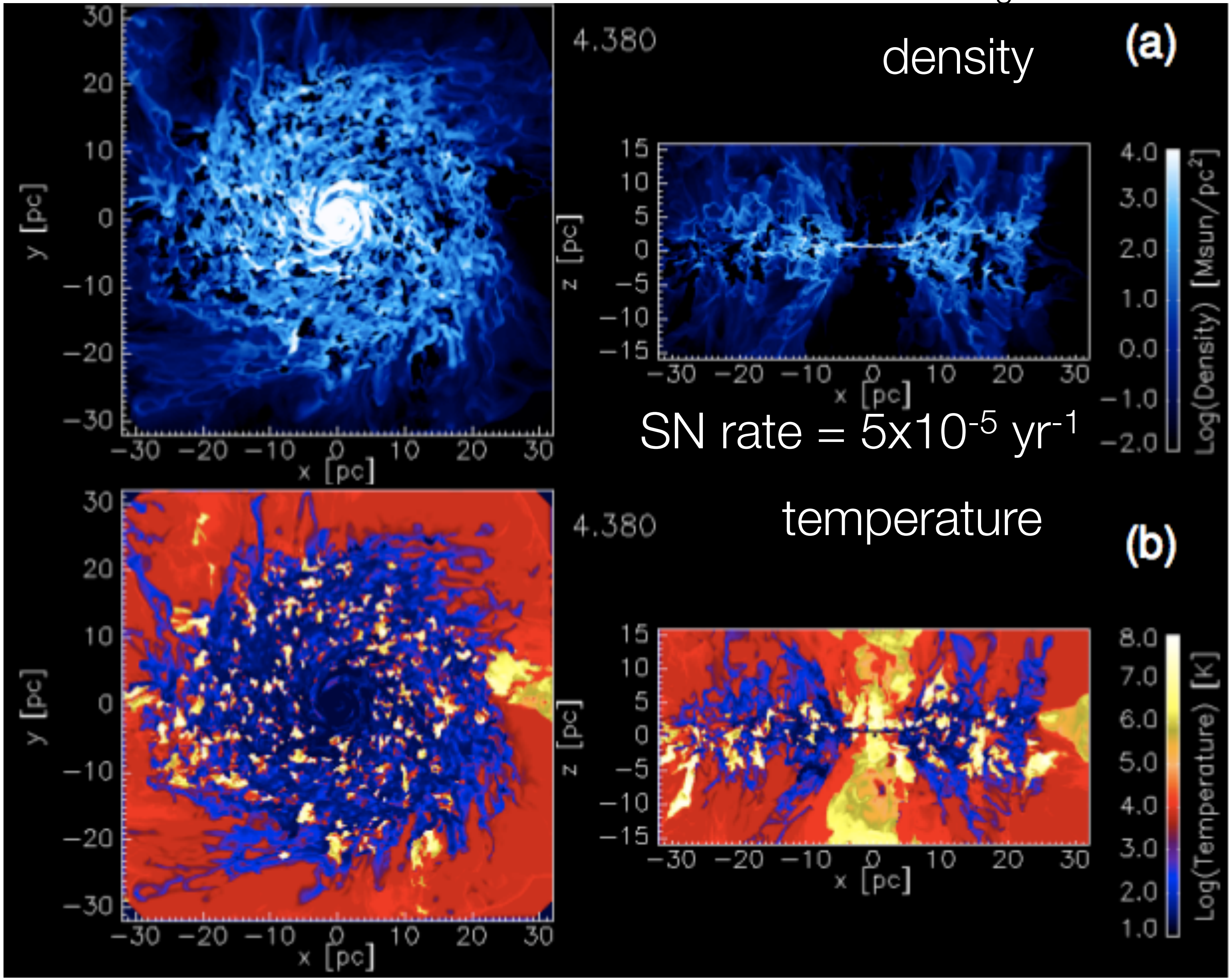
Energy input from SN
at randomly selected grid points
SN rate = 5×10^{-5} yr^{-1}

Gas dynamics irradiated by a central source

- Source: x=y=z=0,
  - non-spherical $L_X(\theta) \propto \cos\theta$
  - $L_x = 0.1\, L_{Edd}$
- Long-characteristic method
  - Optical depth **for 512x512x256 grid points toward the central source are calculated.** No symmetry assumed. fully 3-D
- Heating by X-ray
  - Ionized gas
    - Photoionizing heating
    - Compton heating
  - Neutral/Molecular gas
    - photoionization
    - Coulomb heating
- Radiation forces
  - Thomson scattering for ionized gas
  - Dust

NO radiative feedback

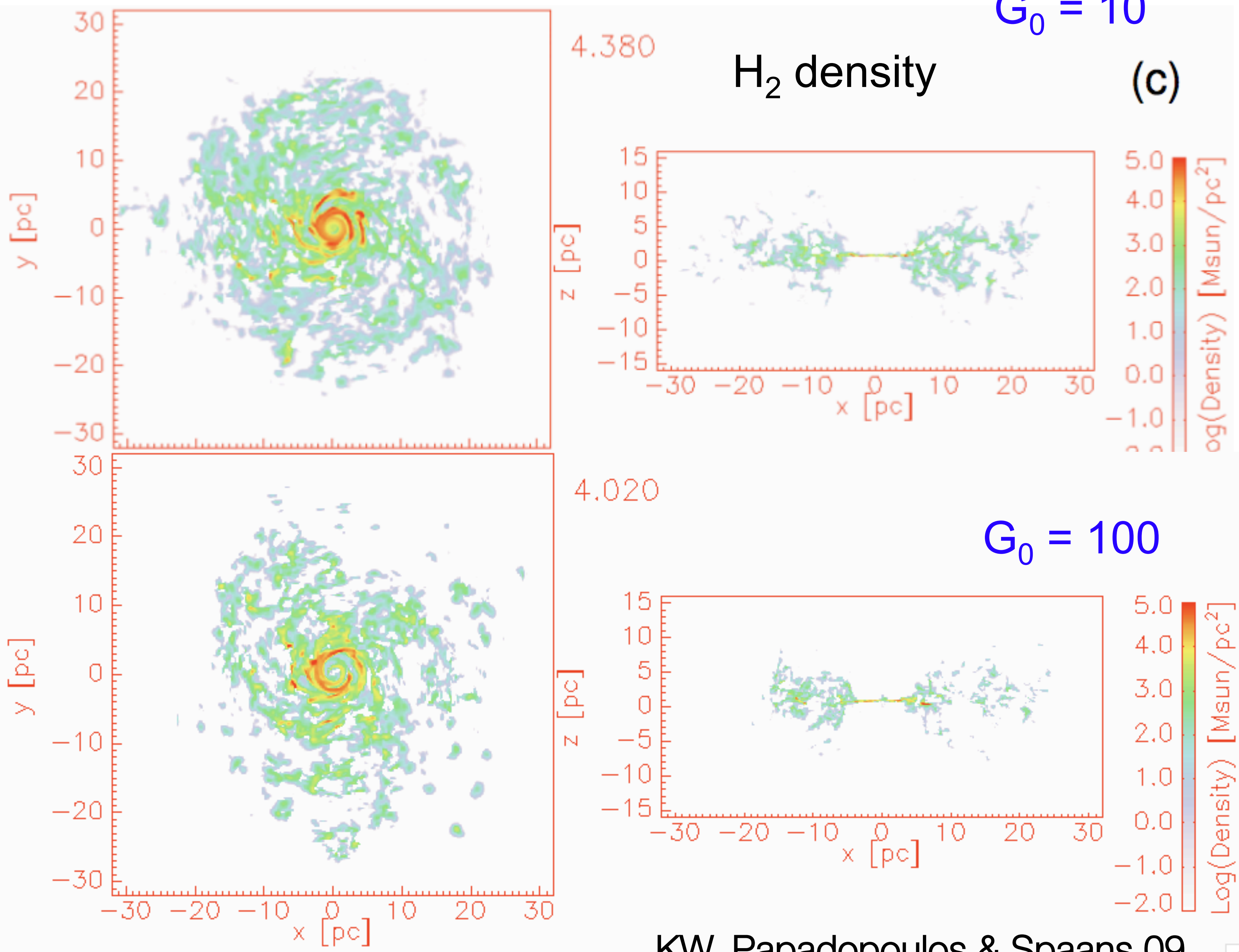
$M_{BH} = 1.3 \times 10^7 \, M_{sun}$
$M_{gas} = 6 \times 10^6 \, M_{sun}$



G_0 = 10

H_2 density

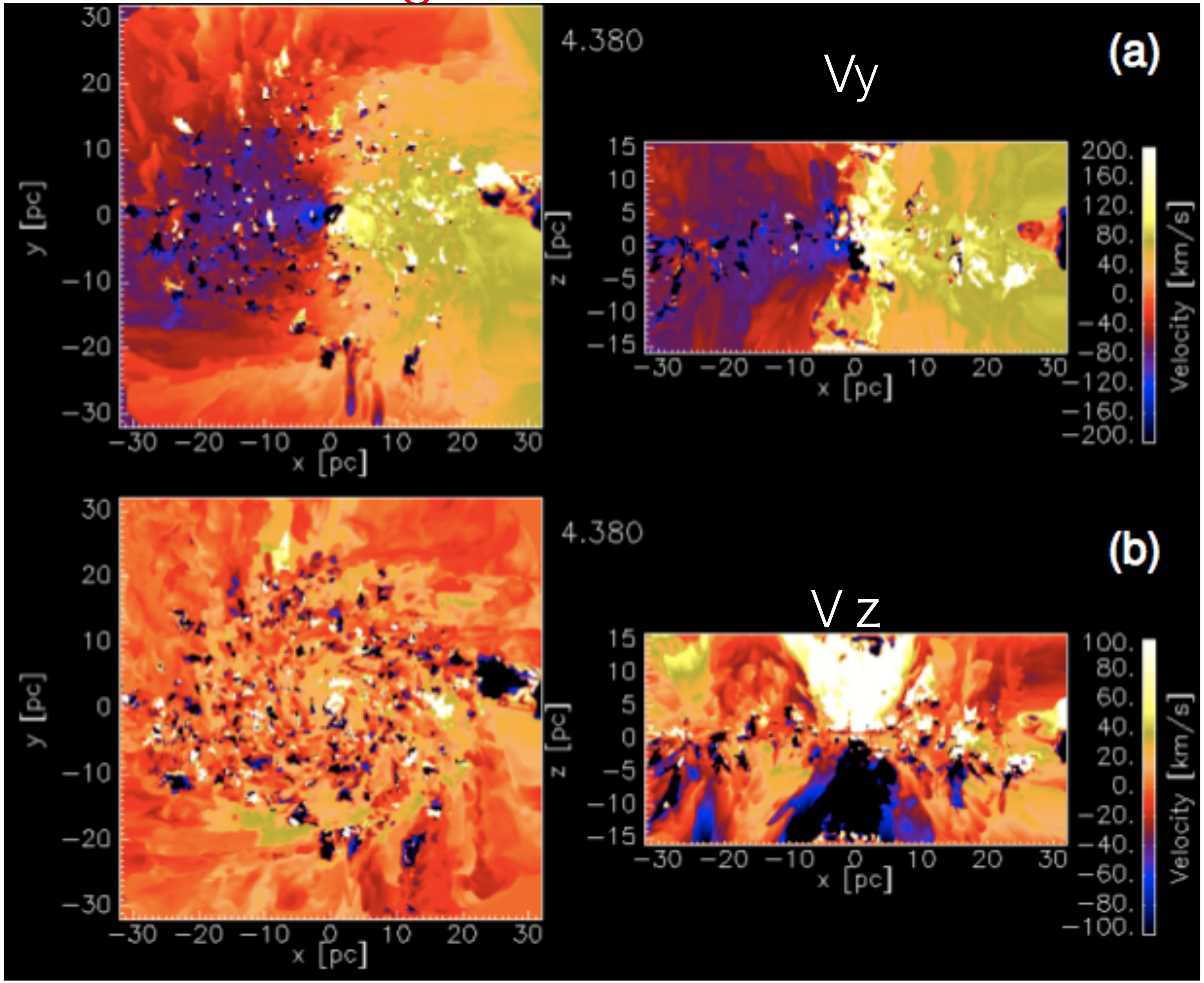
(c)



G_0 = 100

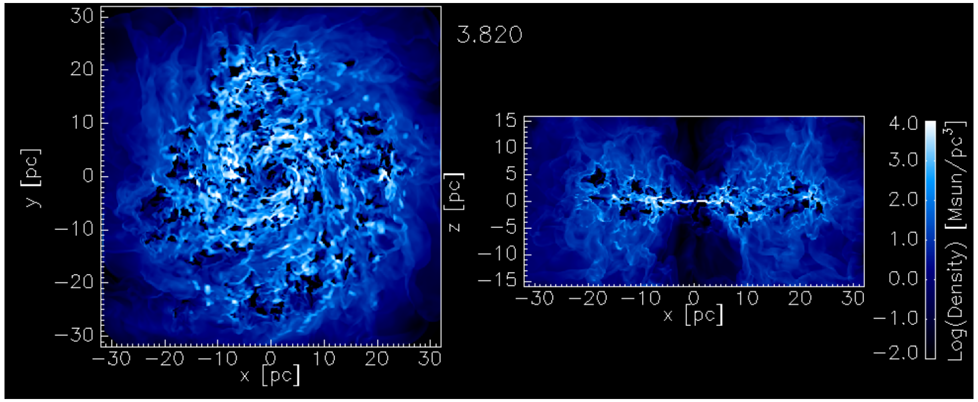
KW, Papadopoulos & Spaans 09

Velocity field: rotation + large dispersion + outflow of hot gas from the central funnel

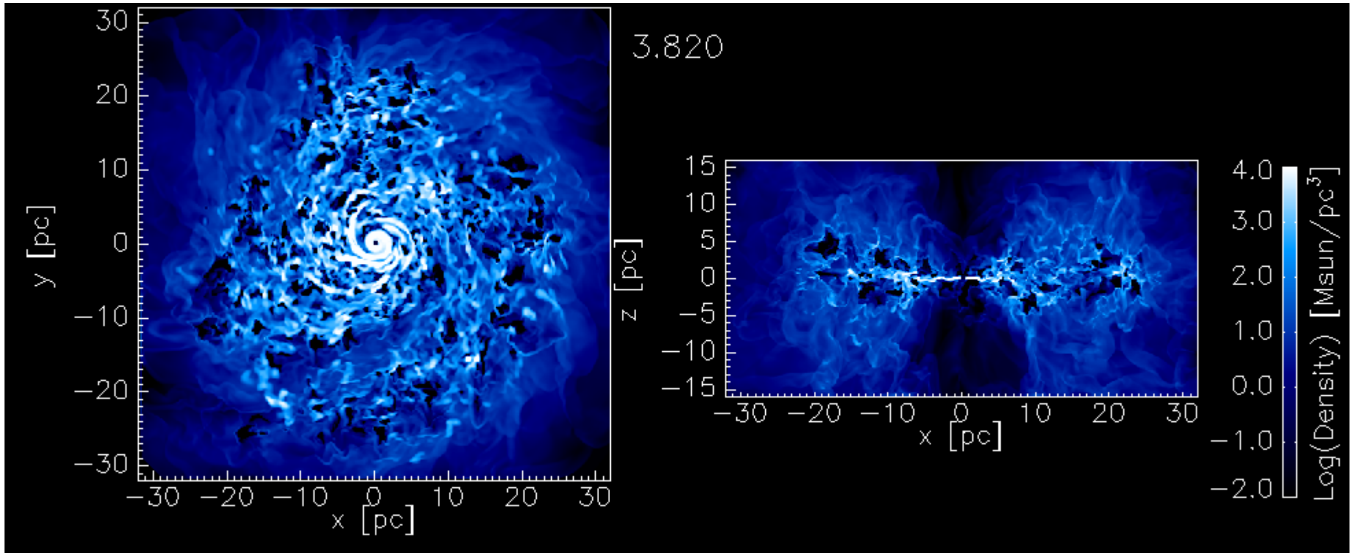


results

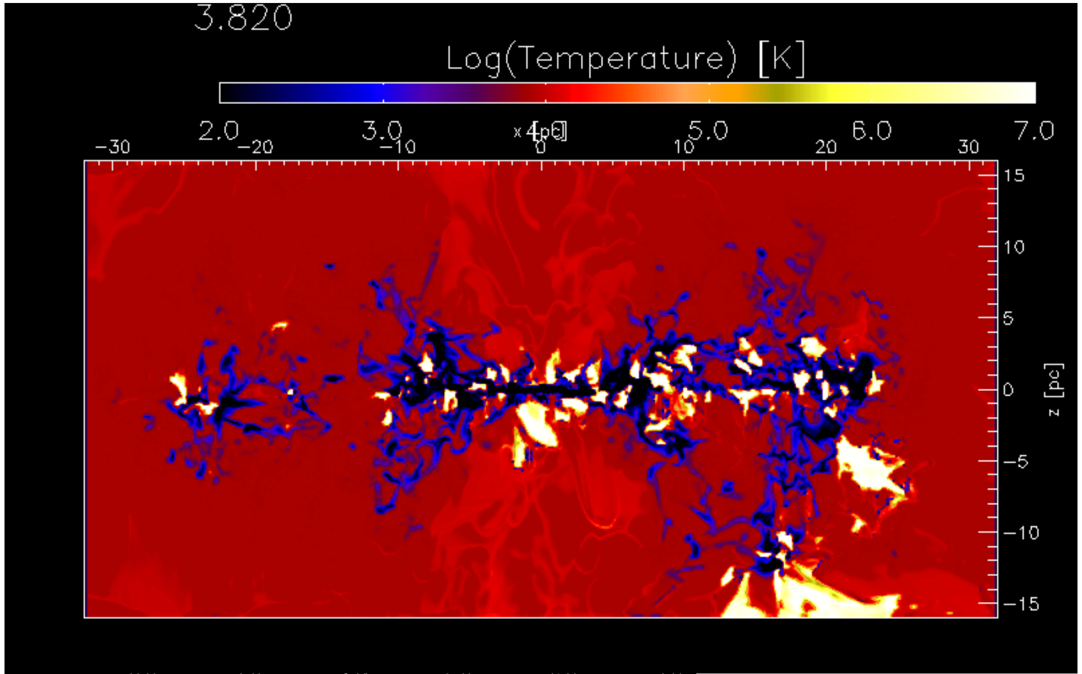
- Initial condition ⇨



- SN feedback: turned off



density

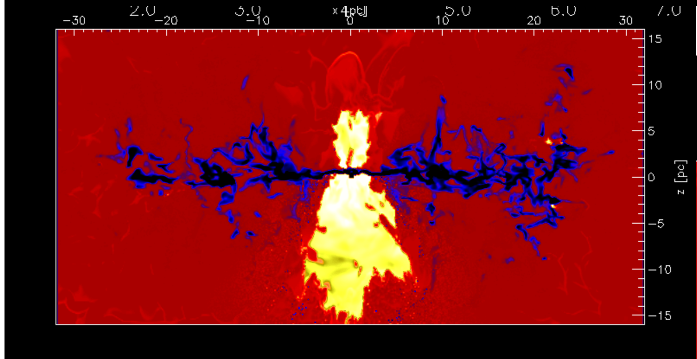


Average outflow rate:

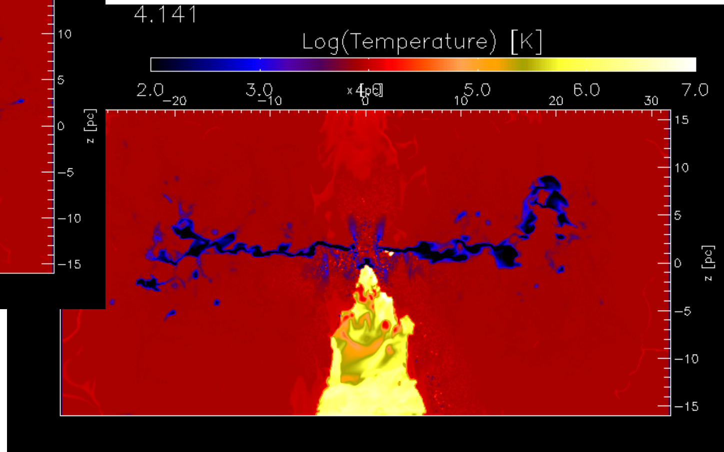
$$\dot{M}_{\rm out} \sim 2 \times 10^{-3}\ M_{\odot}$$

Non-spherical, non-steady outflow is formed.

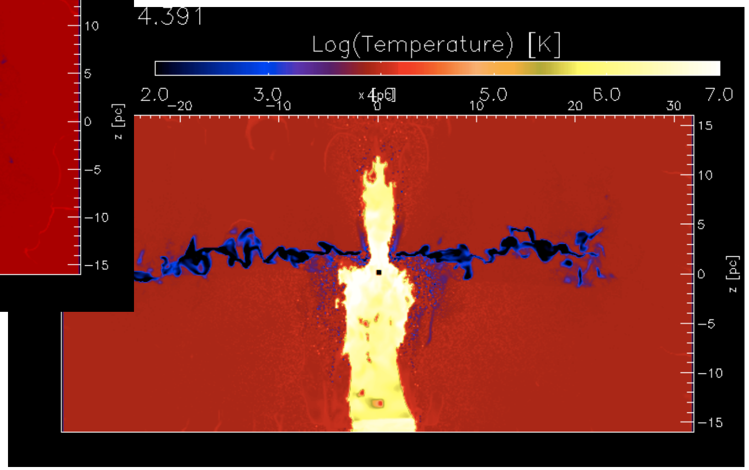
X-ray feedback:
Strong negative feedback.
AGN will be inactive.



t= 3.91Myr



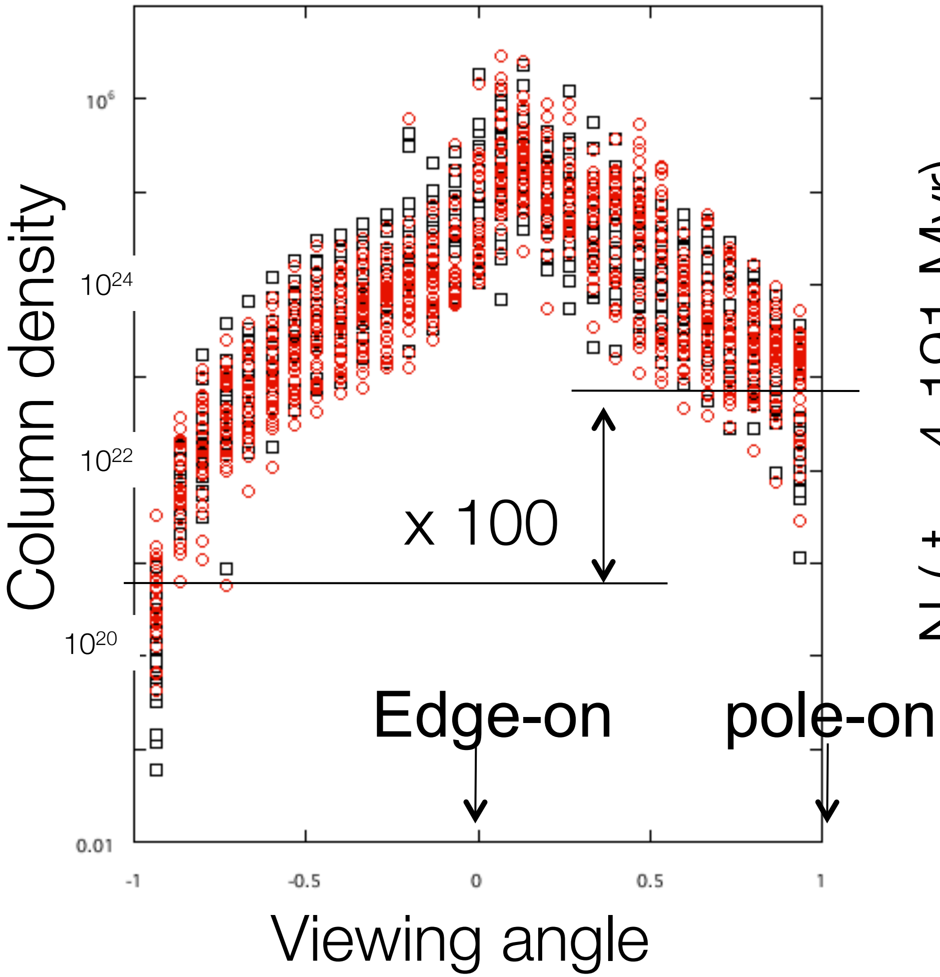
t= 4.14Myr



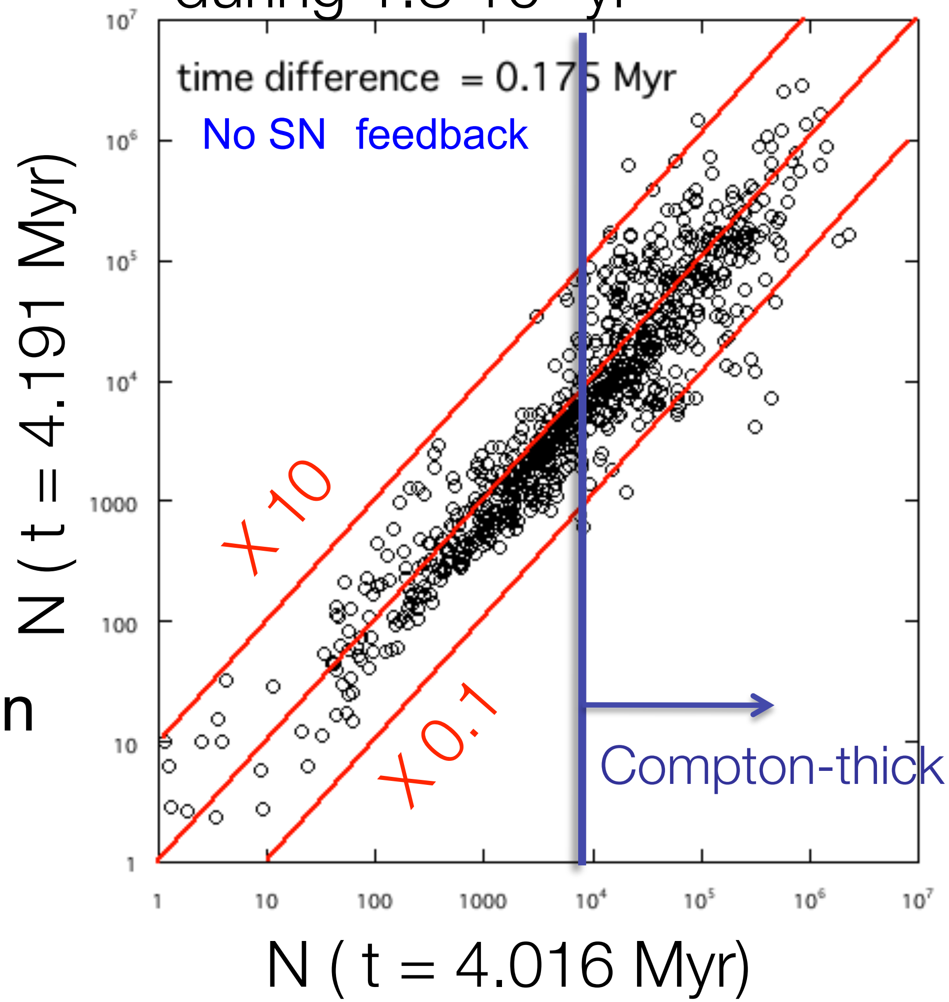
t= 4.29Myr

Time-scale of the change: ~0.1 Myr

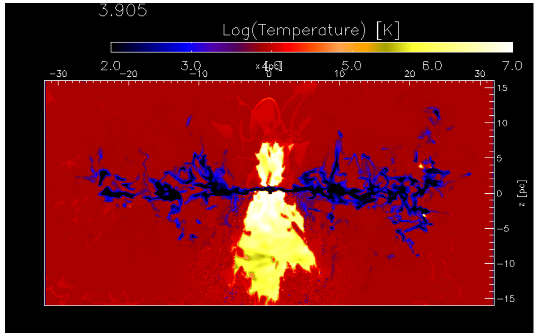
Radiative feedback enhances asymmetry of the ISM, and inner 10 pc is non-steady?



Change in column density during 1.8 10^5 yr



Summary: feedback on the central 10s pc



* Star formation and its energy feedback are a key to understand BH growth
  - SN feedback is important to generate turbulence and viscous accretion.
  - BH growth depends on SF activity and stability of the disk → It becomes inefficient when BH grows.
  - H_2 is robust for UV feedback → SF cannot be stopped.

** X-ray feedback gives strong impact on the ISM, and we expect
  - Asymmetric structures (outflow, torus/disk)
  - Non-steady structures (time scale ~ 10^4 yr – 10^5 yr)
  - Small or negative accretion rate, if the AGN is luminous

➔ BH growth should be intermittent?

What's next?

- Long-term behavior (currently only ~ 1Myr)
  - How about L_x is linked to the mass accretion rate?
  - Can the BH grow? Is it episodic?
  - SN feedback can help accretion?

- Radiation pressure → Can we have large enough accretion rate?
- chemistry → H_2 fraction → SFR→ accretion rate
- UV radiation from AGN and massive stars (multi-source)