Supermassive BHs in the universe: The Era of the HSC Survery

Dec. 18-20, 2012, Matsuyama, Japan

Theoretical models of feeding and feedback

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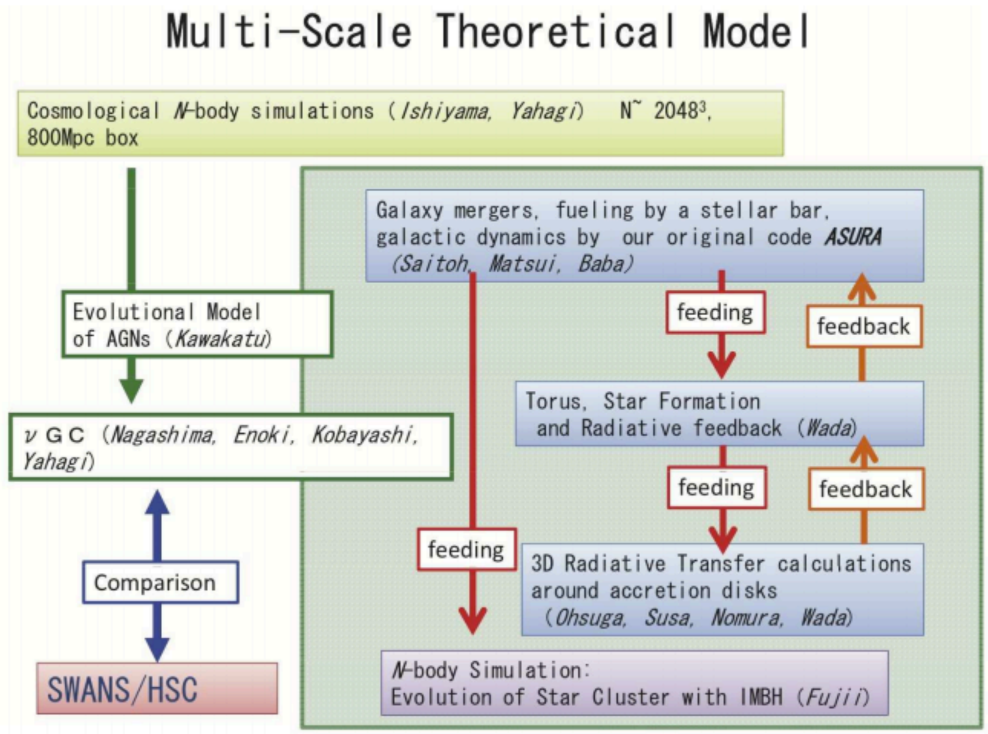


Figure 6.31: Concept of multi-scale theoretical model (see text)

<ins>HSC/SWANS theory "alliance "</ins>

Ishiyama, Yahagi
Kawakatu,N.
Nagashima, M., **Enoki, M.**
Saitoh, Baba, Matsui
Ohsuga, Susa, Nomura, Fujii
Kobayashi,M.
Kawaguchi,T.

AGN feedback: Unsolved issues...

Hopkins 2009

- What effects does that feedback have on the host galaxy? stop forming stars, accreting gas?
- Is feedback necessary and/or sufficient to regulate BH growth?
- How does gas get from a few pc to the AGN?
- What are the actual **microphysical mechanisms** of feedback? ... still not fully understood in 2012
- ...

Q: Do we have reasonable theoretical AGN models to answer these issues based on HSC/SWANS?

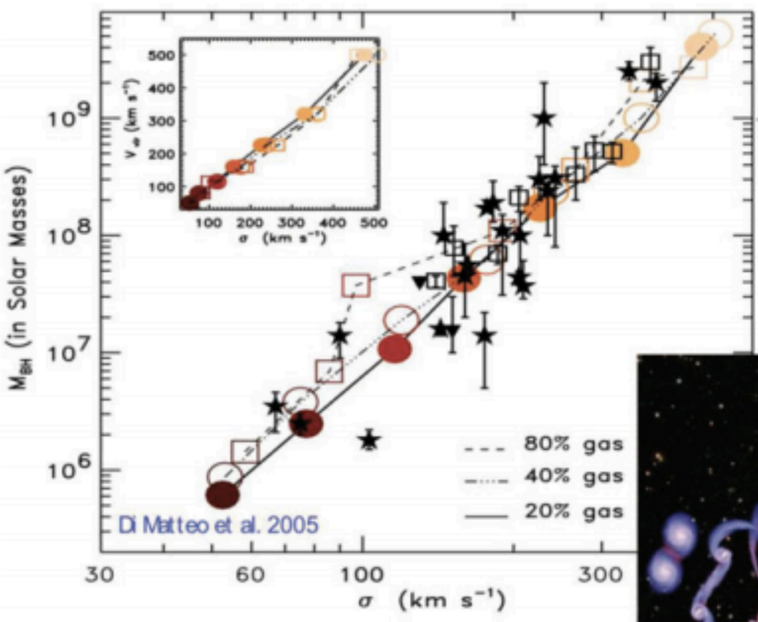
==> A: Currently no, but hopefully yes in several years?

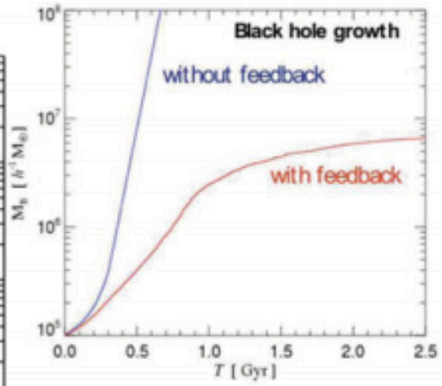
Did AGN feedback explain M-σ ?

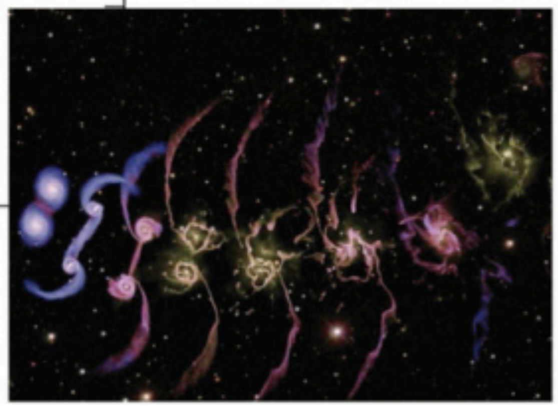
e.g. Di Matteo(2005): **5% of AGN energy** => surrounding material, inside a smoothing kernel (several 100 pc)

spherically symmetric Bondi accretion

$$\dot{M}_{Bondi} = \frac{4\pi G^2 M_{BH}^2 \rho_{gas}}{c_s^3}$$



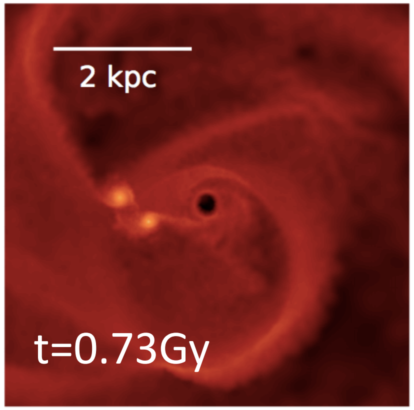


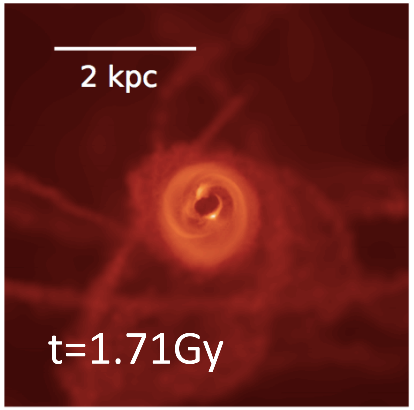


In most models, feedback is depositing thermal energy inside a radius, e.g. ~ 100 pc.

Ndark = 20000
Ngas disk=20000
Nstar disk = 20000

DeBuhr et al.2010,2012





- Resolution(better than Di Matteo)
  - Ndark = $6x10^5$,
  - Ngas disk=$2x10^5$
  - Nstar disk = $2x10^5$
- Momentum injection due to radiation pressure

$$\dot{p} = \tau \frac{L}{c} \quad \text{where } L = min\left(\eta \dot{M}_{visc} c^2, L_{Edd}\right)$$

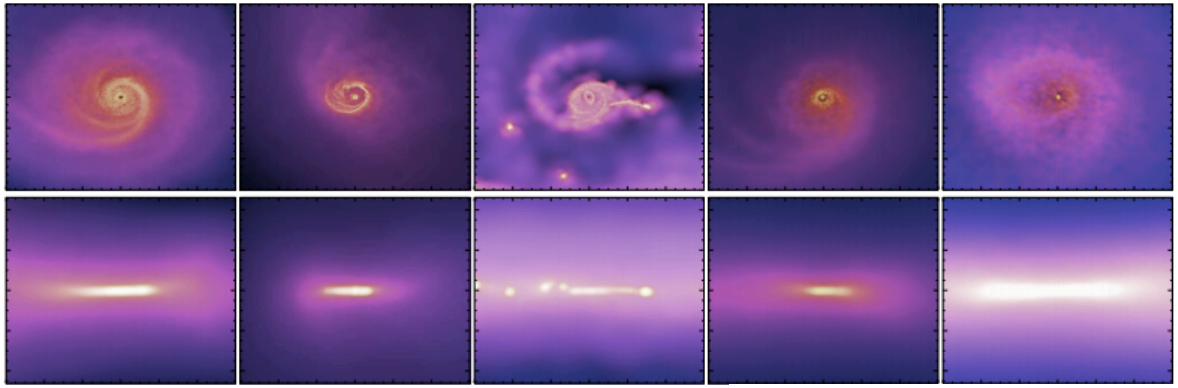
- Accretion rate in a viscous disk is assumed.
- sound velocity and surface density are averaged in **R < 188 pc**

$$\dot{M}_{vis} = 3\pi\alpha\Sigma\frac{c_s^2}{\Omega}$$

- **ISM model: A Polytropic EOS (Hopkins et al.)**

Structures of the ISM depend on the choice of EOS

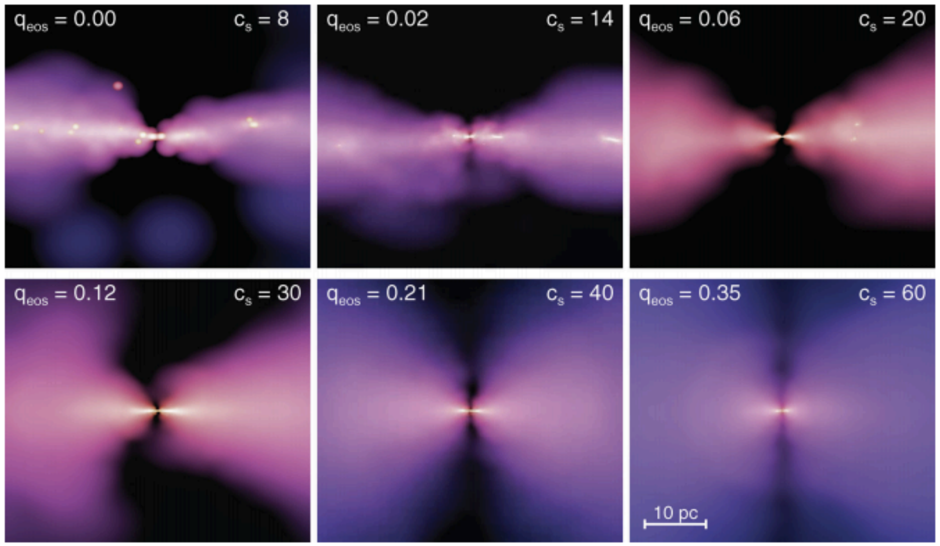
Hopkins 2012

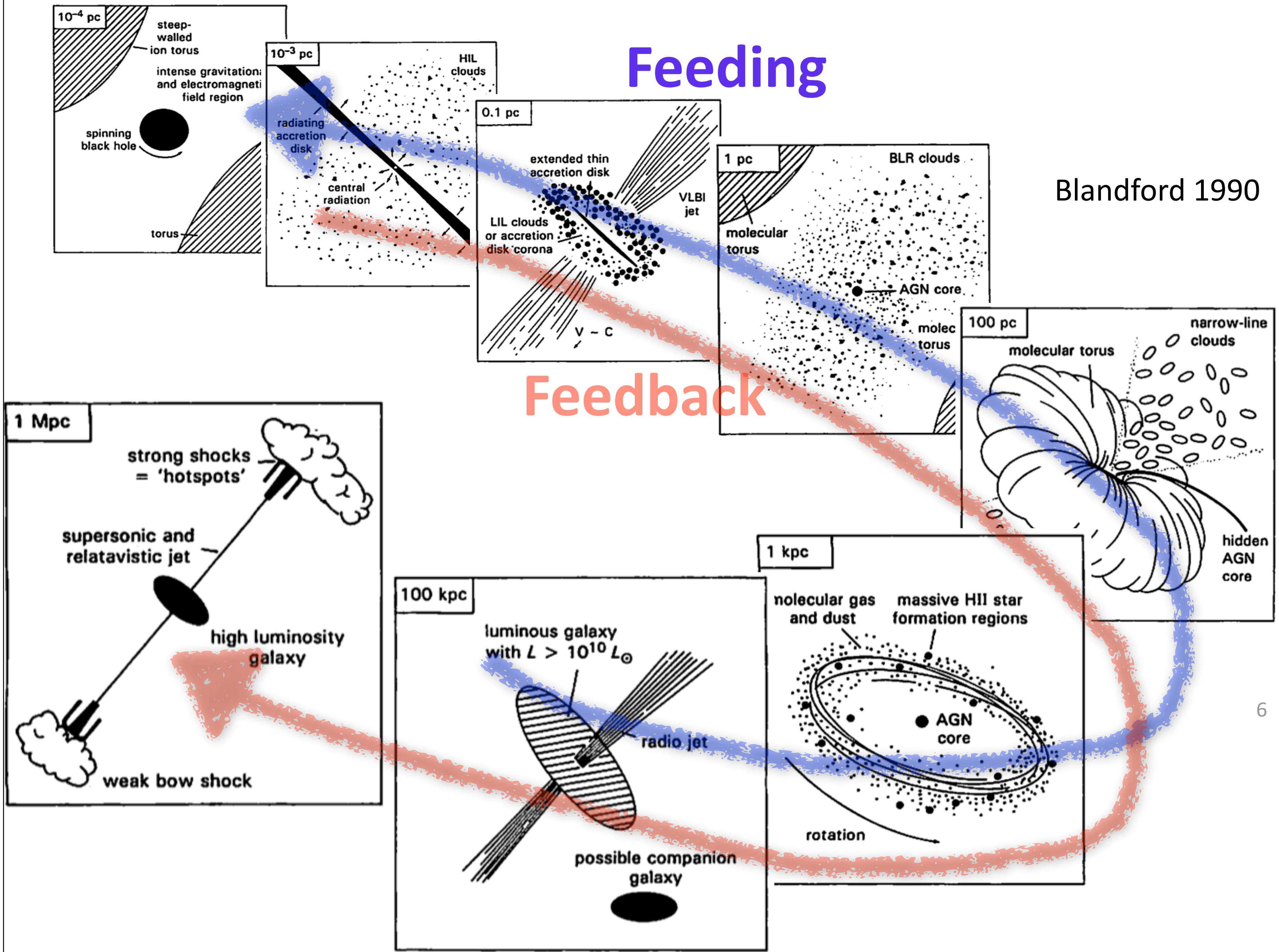


<= different conditions of accretion

Polytropic EOS with a parameter to represent 'hardness' of the gas.

Thicker disk is formed for harder EOS

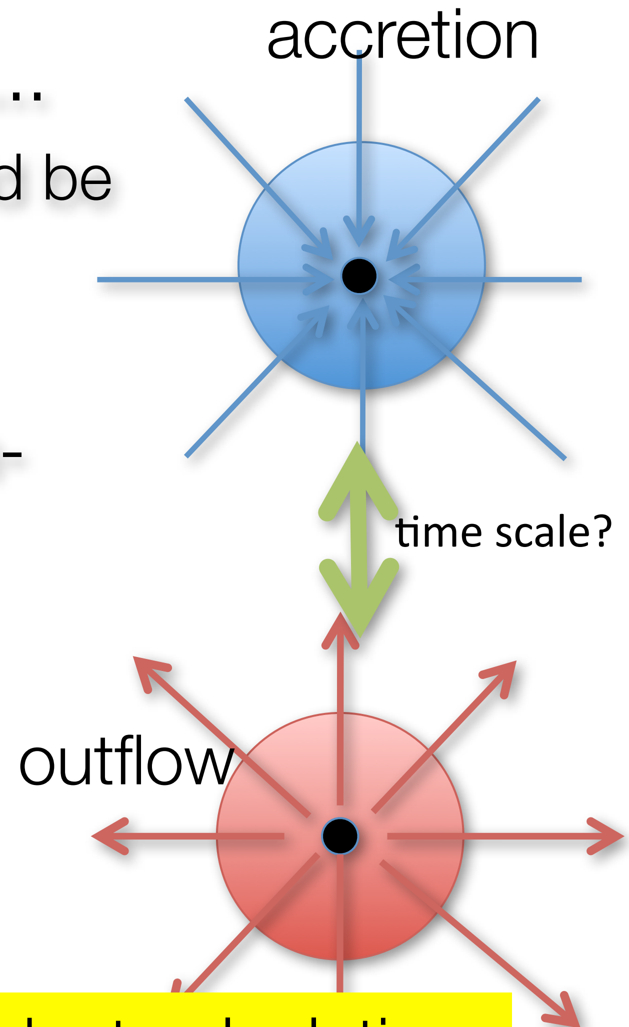


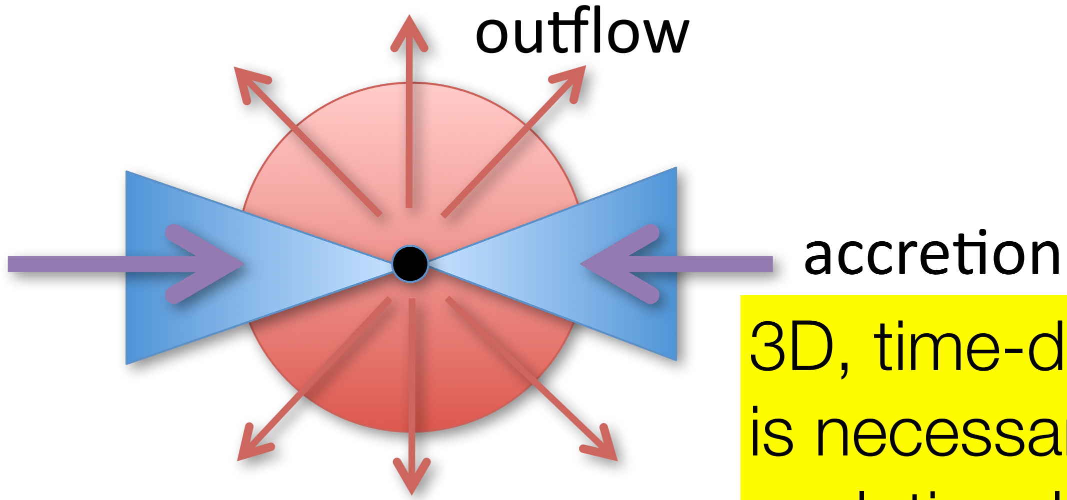


Blandford 1990

How do Feeding/Feedback coexist ?

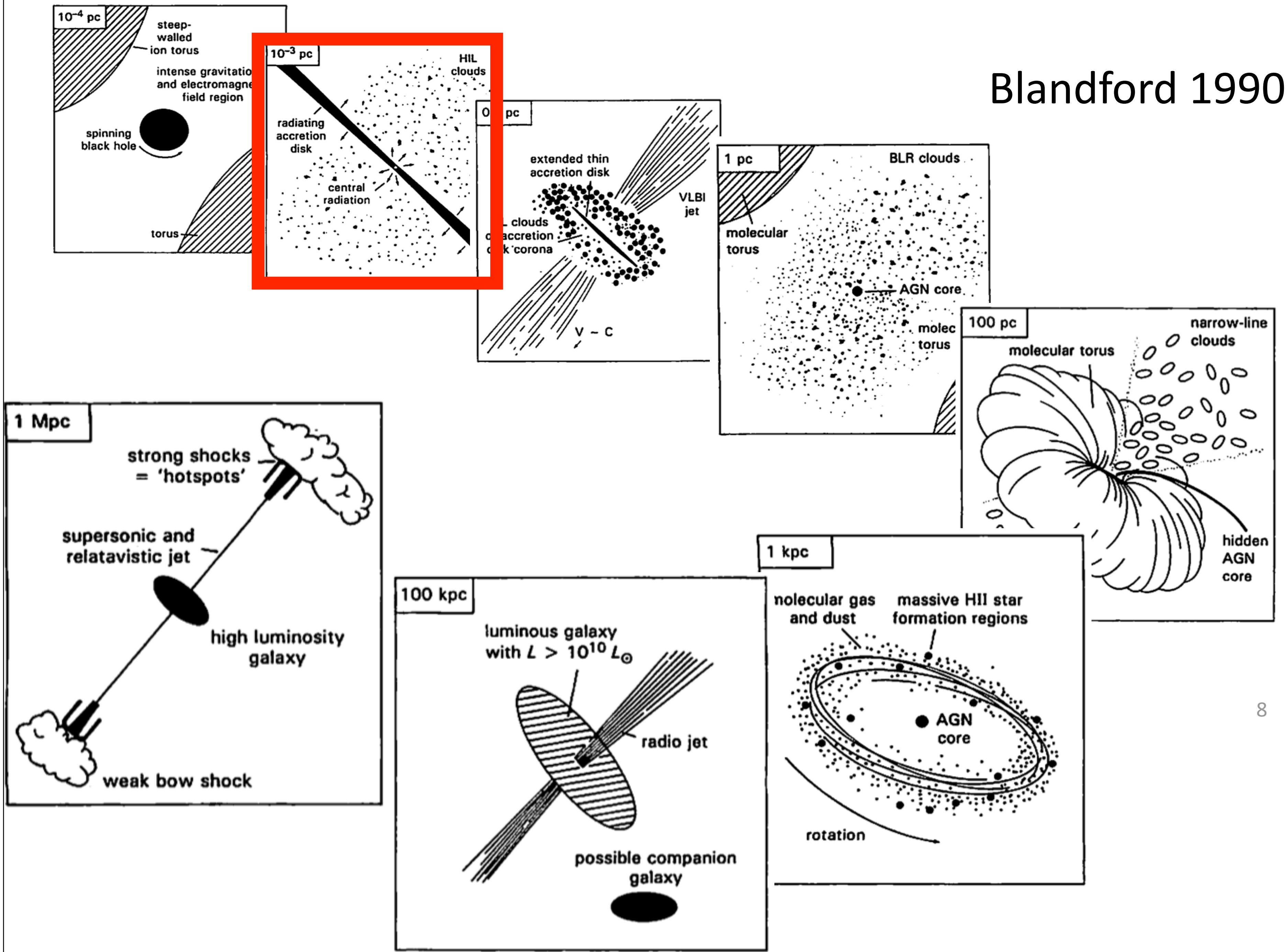
- If system is spherical symmetric ...
  - active phase/inactive phases should be intermittent
  - time scale?
- Outflow/inflow can coexist for non-spherical geometry
  - scale?





3D, time-dependent calculation is necessary for realistic AGN evolutional model

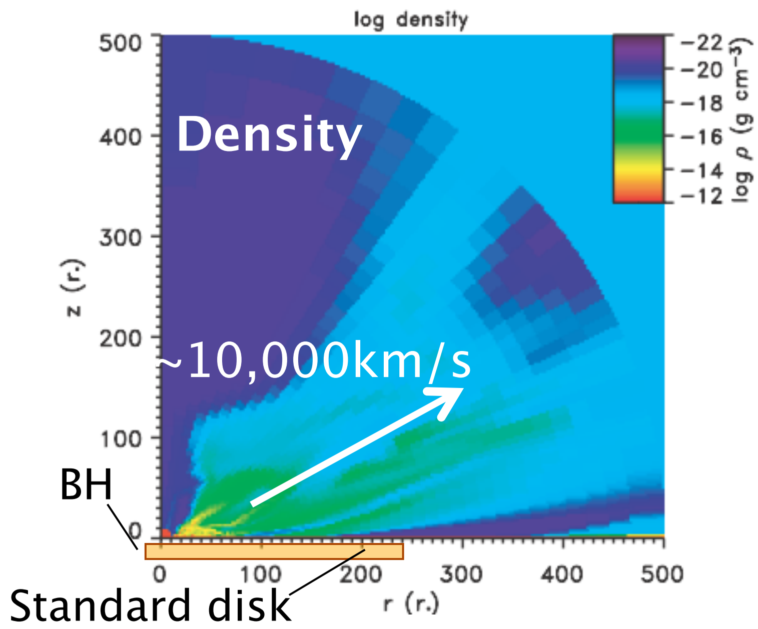
Blandford 1990



Accretion disk scale

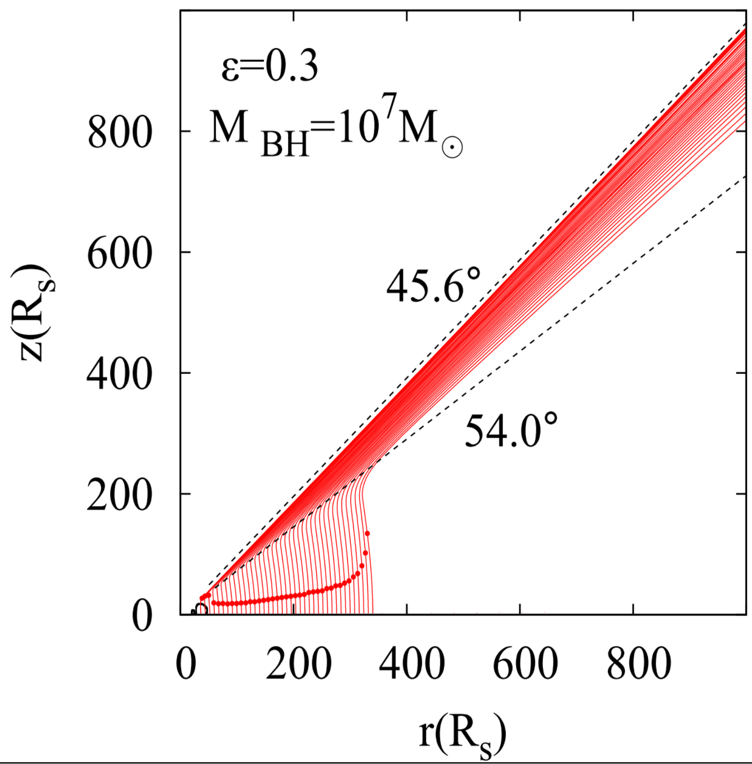
Line-force driven wind

- Proga et al. (2000, 2004)
  - 2-dimensional RHD simulation



Proga & Kallman (2004)

Nomura, et al. (2012) arXiv:1212.3075



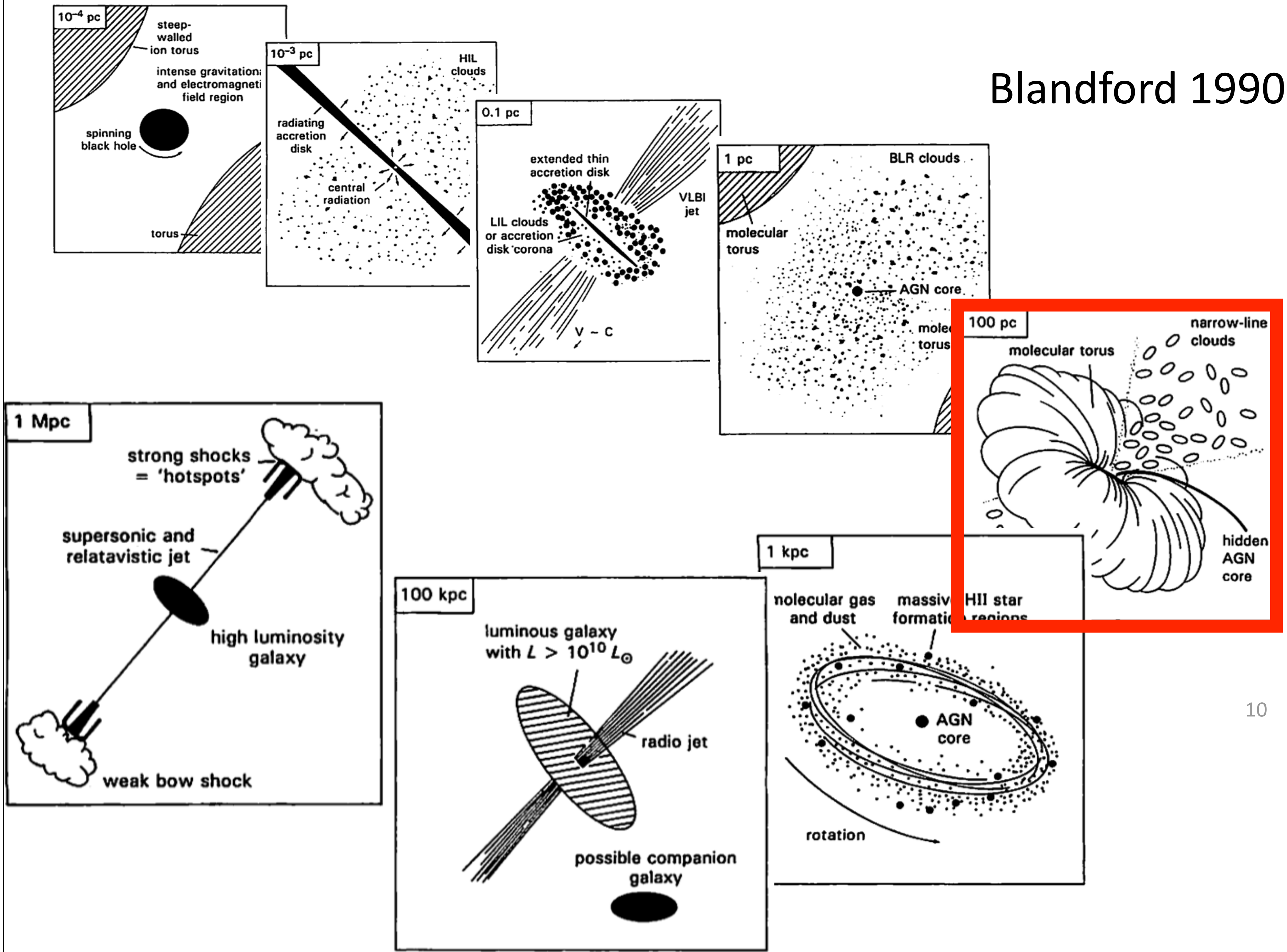
$$\xi = \frac{F_X}{nR^2} < 100$$

velocity > 10,000 km/s

column density > 10^{23}

observed as BAL (Eddington ratio and M_{BH}) ~ 10%

Blandford 1990

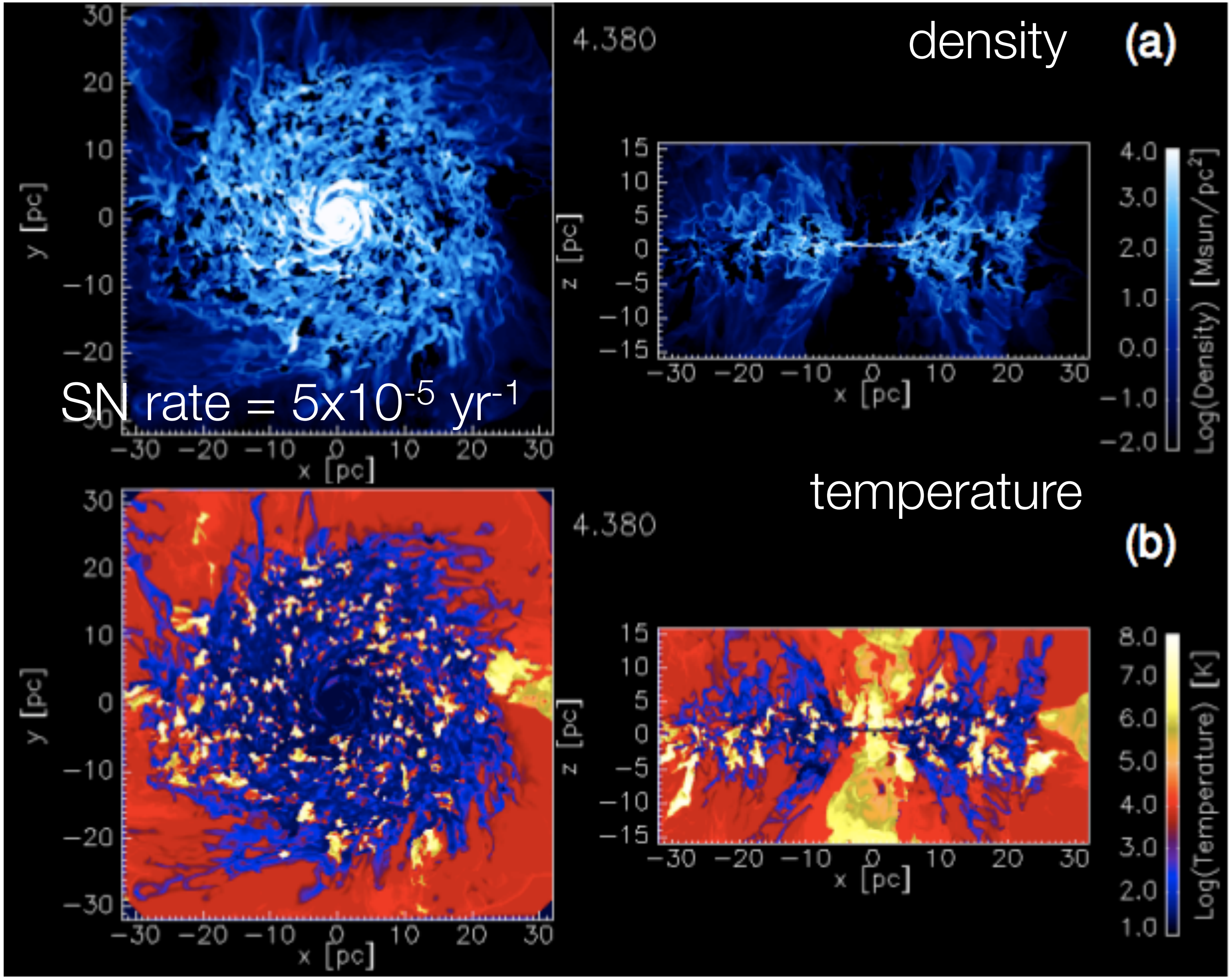


Supernova-driven thick disk

KW, Papadopoulos, Spaans (2009)

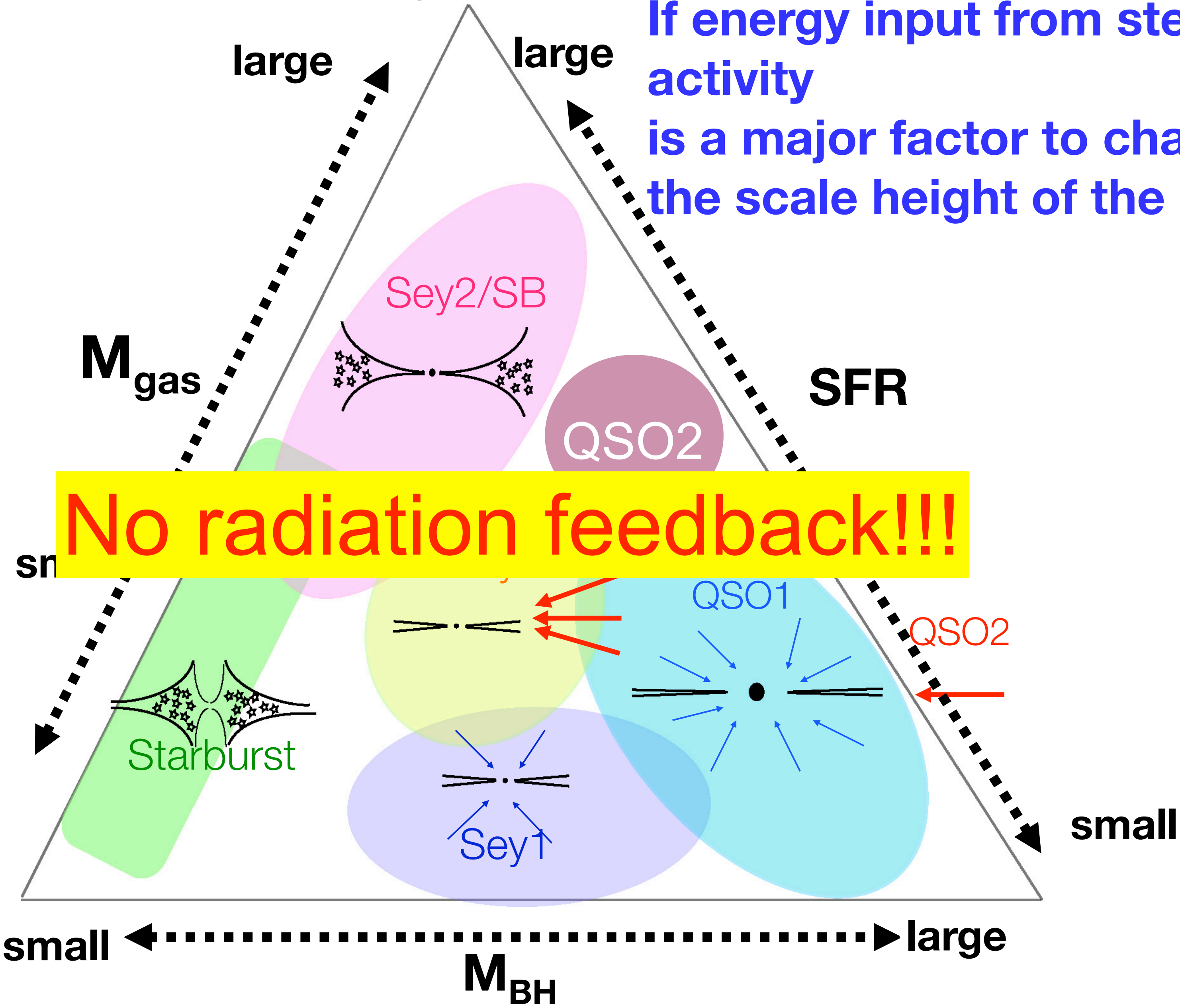
$M_{BH} = 1.3\text{x}10^7\ M_{sun}$

$M_{gas} = 6\text{x}10^6\ M_{sun}$



Wada (2004) Carnegie Observatories Astrophysics Series. Edited by L. Ho

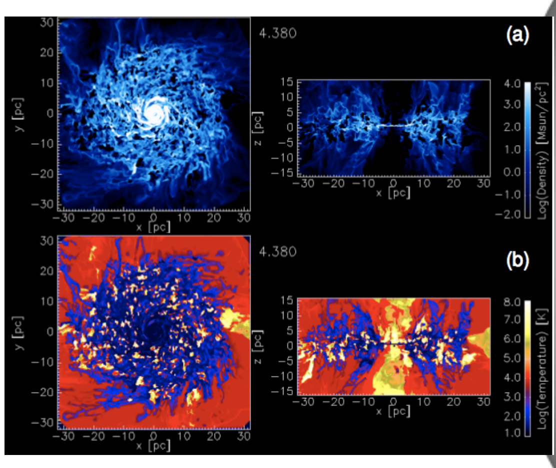
If energy input from stellar activity is a major factor to change the scale height of the disk, ...



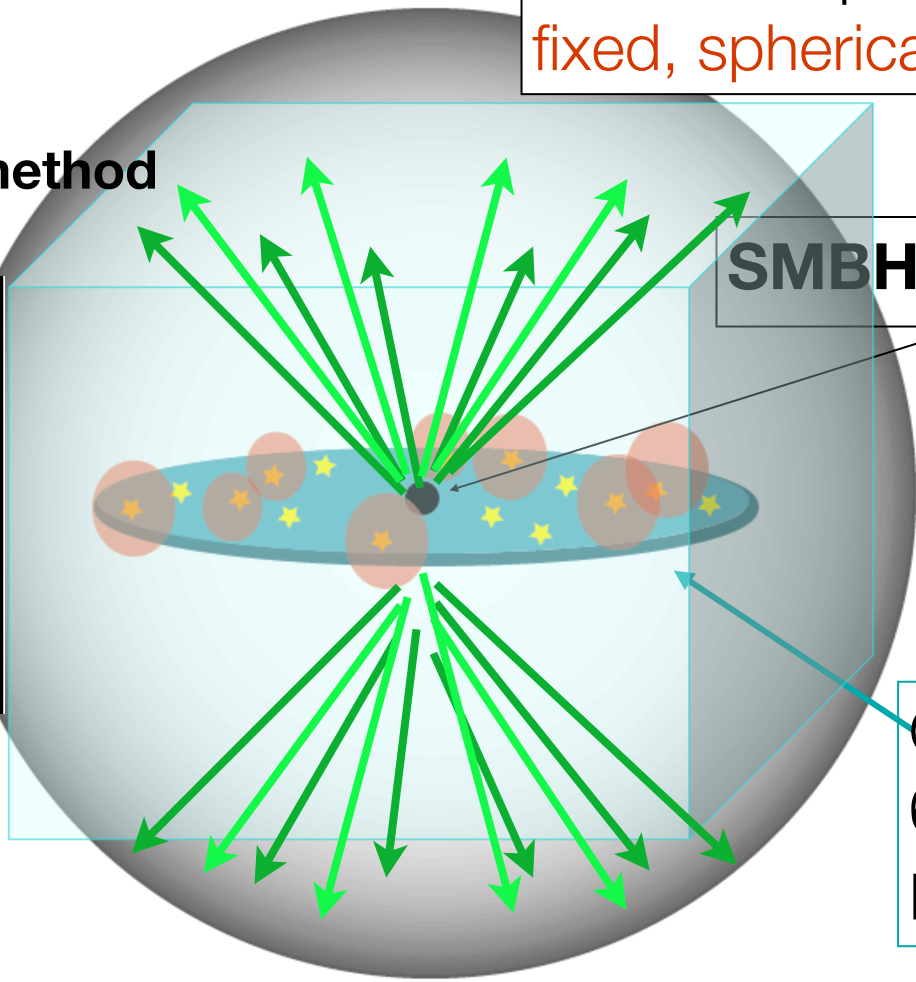
3-D Radiative Hydrodynamics of a gas disk around a SMBH

Code: RHD.* ,
based on HD.* (Wada+09)

***Uniform grid 256^3**
***Long characteristic method**



Stellar/DM potential:
fixed, spherically symmetric



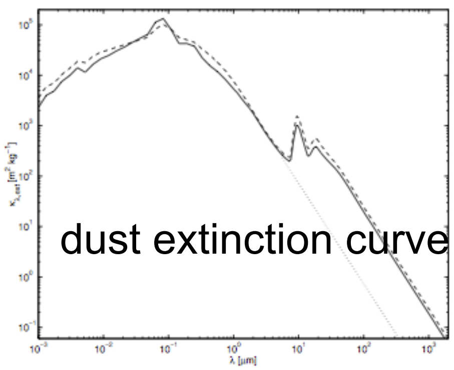
SMBH 1.3×10^7 M_{sun}

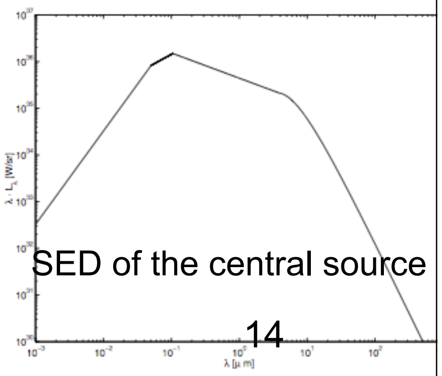
Gas disk
6×10^6 M_{sun}
R=32pc

Gas dynamics irradiated by a central source

Wada (2012)

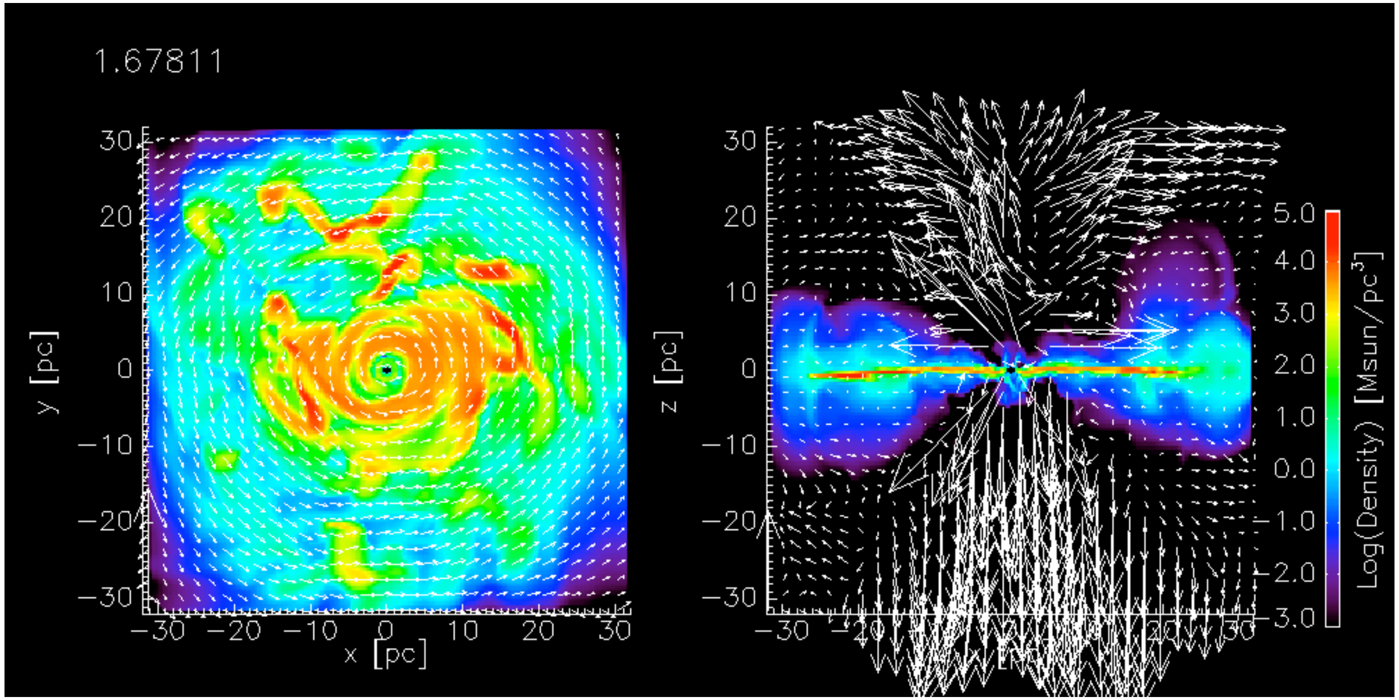
- **Non-spherical Central source**: x=y=z=0,
  - $L_{AGN}(\theta) \propto \cos(\theta)$
  - L_{AGN} = **{0.1, 0.01}** ***L_{Edd}*** = ***1.6x10$^{43\text{-}44}$ erg/s***
- **Ray tracing with 256^3 rays**
  - Optical depth for all 256^3 grid points are calculated along rays toward the central source.
  - **No symmetry is assumed.** **3-D, time-dependent**
- **Radiation pressure** for dust *(Schartmann+05)* and ionized gas
  - Frequency dependent dust absorption and AGN SED (for 10^{-3} ~ 10^{2} μm)
- **X-ray heating** (Maloney+06, Meijerink & Spaans96, Blondin94)
  - Coulomb heating
  - photo-ionization for H and H2
  - Compton heating





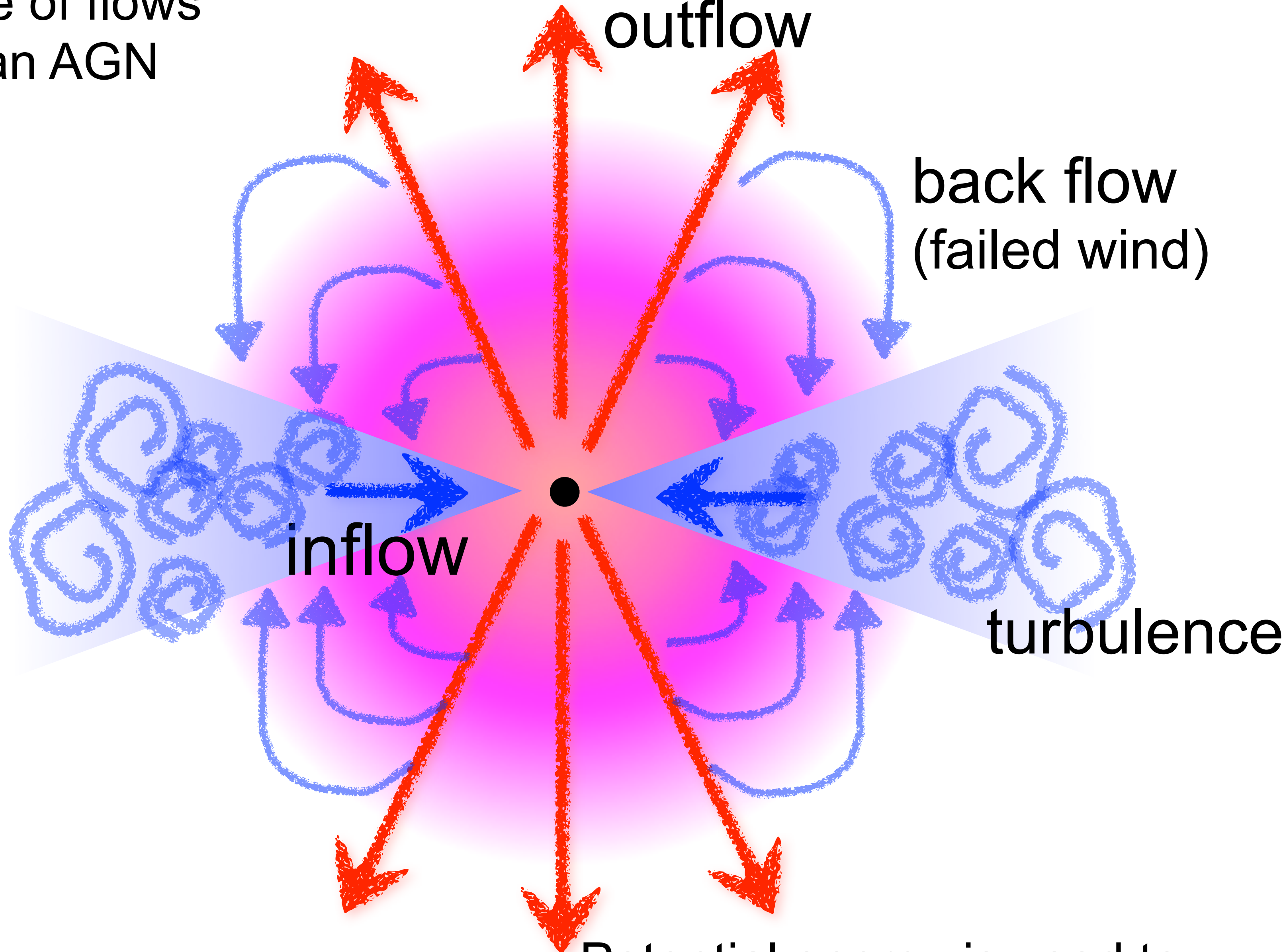
Result: Radiation (X-ray heating+Radiation pressure)-driven non-steady outflows and thick torus are formed.

density $L/L_E = 0.1$



Wada (2012)

Structure of flows around an AGN

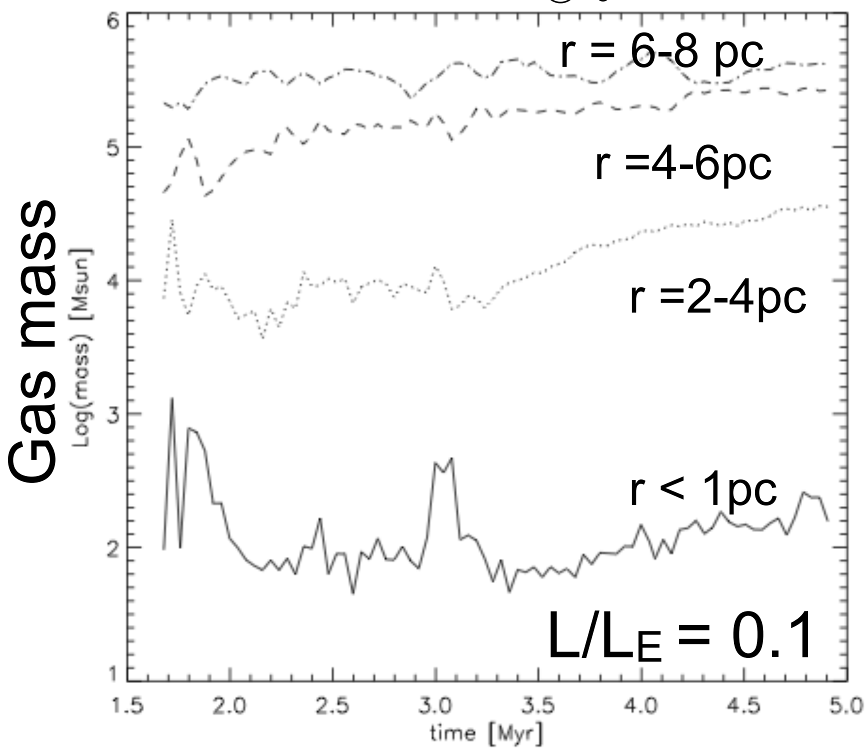


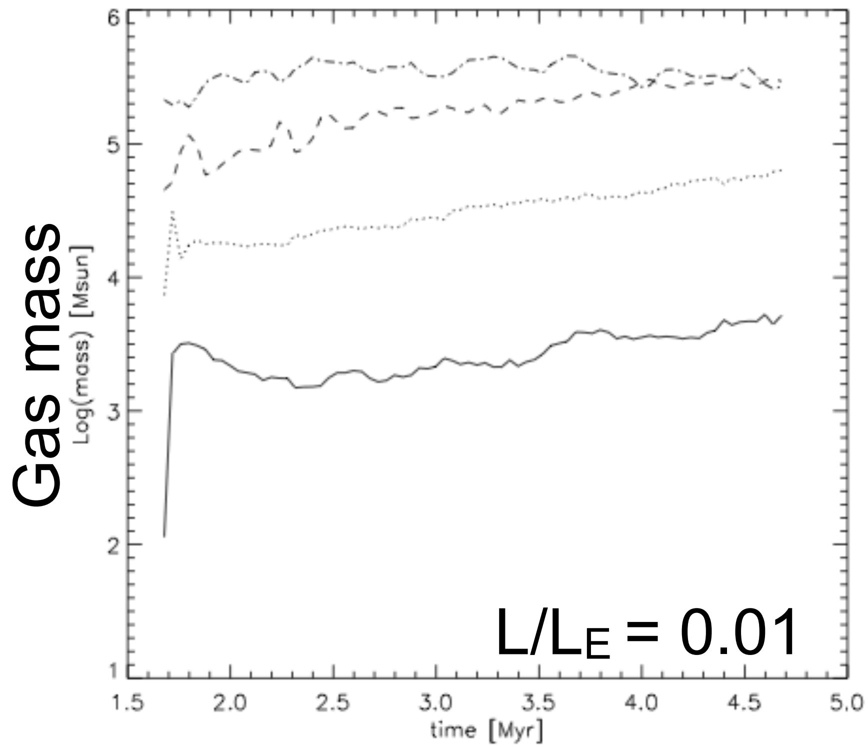
Potential energy is used to maintain thick disk

Accretion rate to central parsecs

$$< L_{AGN}/\eta c^2 \sim 2 \times 10^{-3} (L_{44}/\eta) M_\odot \, \mathrm{yr}^{-1}$$

$\dot{M} = 1.3 \times 10^{-4} \ M_\odot \, \mathrm{yr}^{-1}$ $\dot{M} = 1.7 \times 10^{-3} \ M_\odot \, \mathrm{yr}^{-1}$





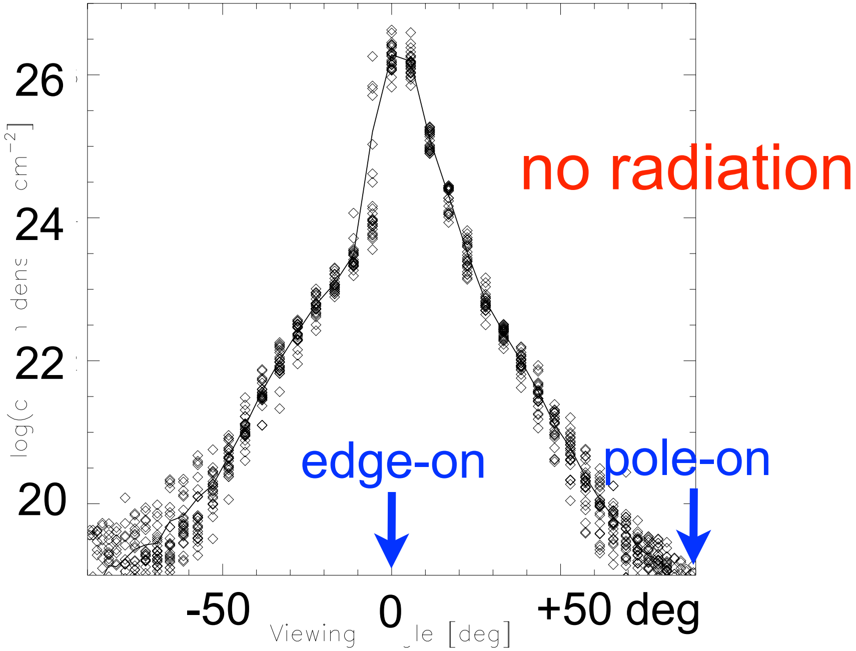
Radiation feedback CANNOT stop mass accretion.

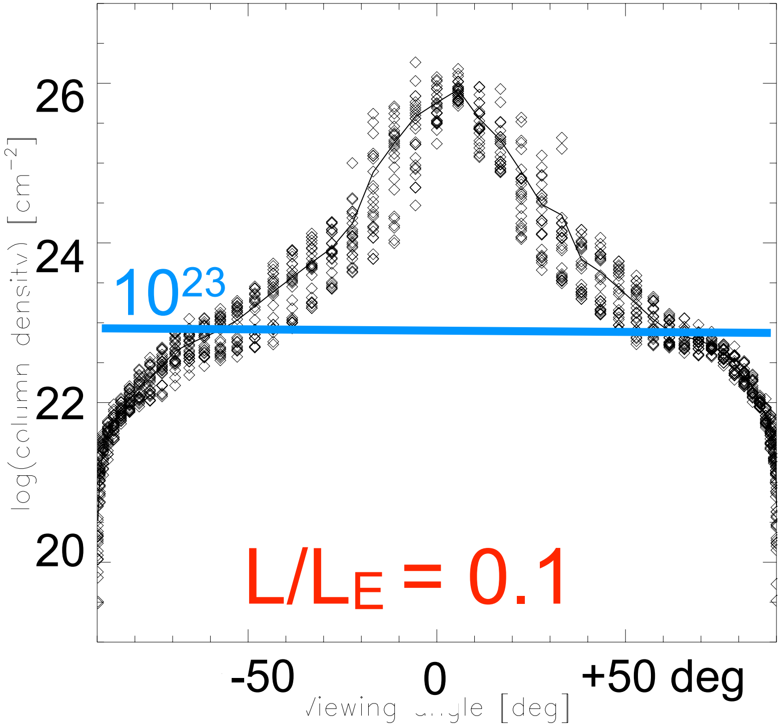
The accretion rate is too small to keep L_{AGN} =0.1 L_E

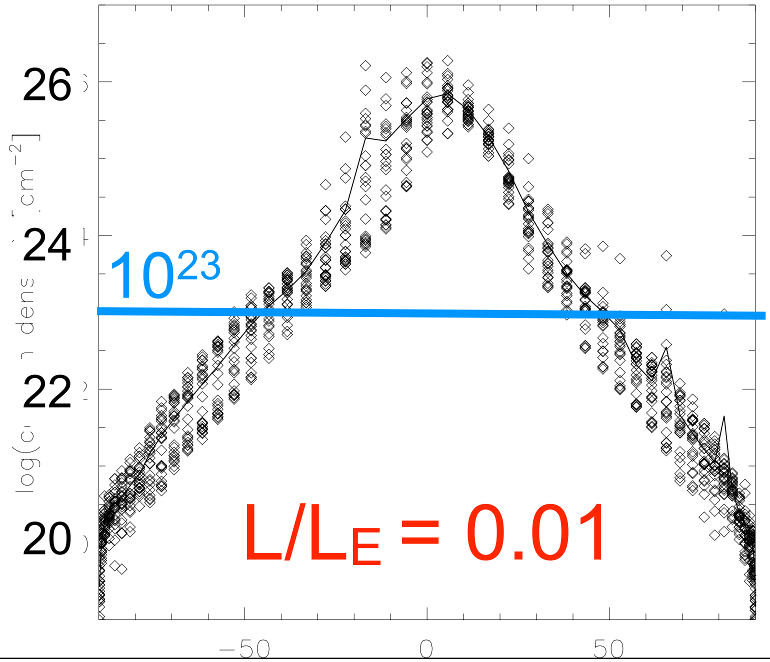
⇒ episodic accretion? other fueling mechanism?

Column density vs. viewing angle

Wada (2012)





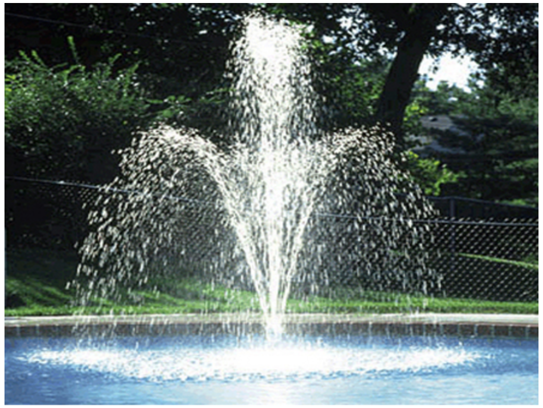


Opening angles of “torus” with $N < 10^{23}$ cm^{-2} are 60-100°

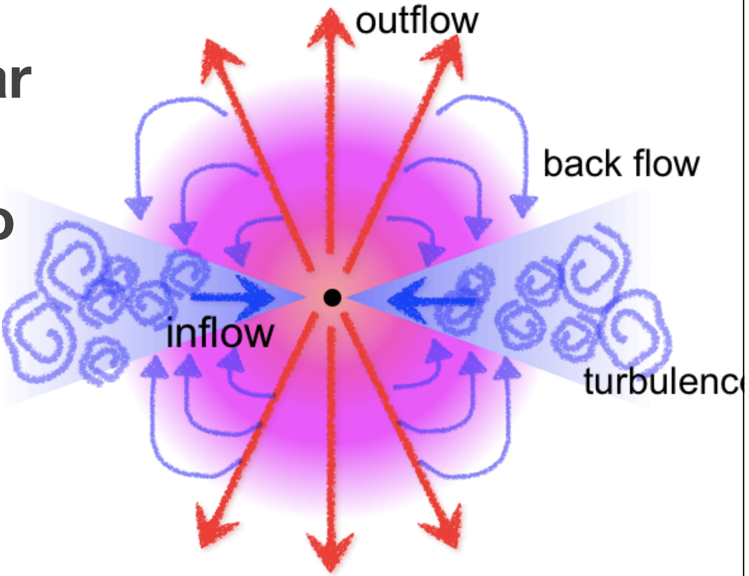
Obscuring fraction is larger for larger L/L_E

Conclusions from **Wada (2012), ApJ 758, 66**

- **ISM is highly affected by the radiation from the central source**
  - **Structures/Dynamics is non-spherical.**
  - **Turbulent thick disk could be formed by "radiation-driven fountain"**
  - **Non-uniform, non-steady bi-polar outflows (~100-200 km/s) .**
  - **AGNs with larger Eddington ratio are more obscured.**
  - **Accretion coexist with the outflows.**



Motor-driven fountain



Radiation-driven fountain

Obscured fraction in nearby AGNs (Noguchi+2010)

THE ASTROPHYSICAL JOURNAL, 711:144–156, 2010 March 1 doi:10.1088/0004-637X/711/1/144

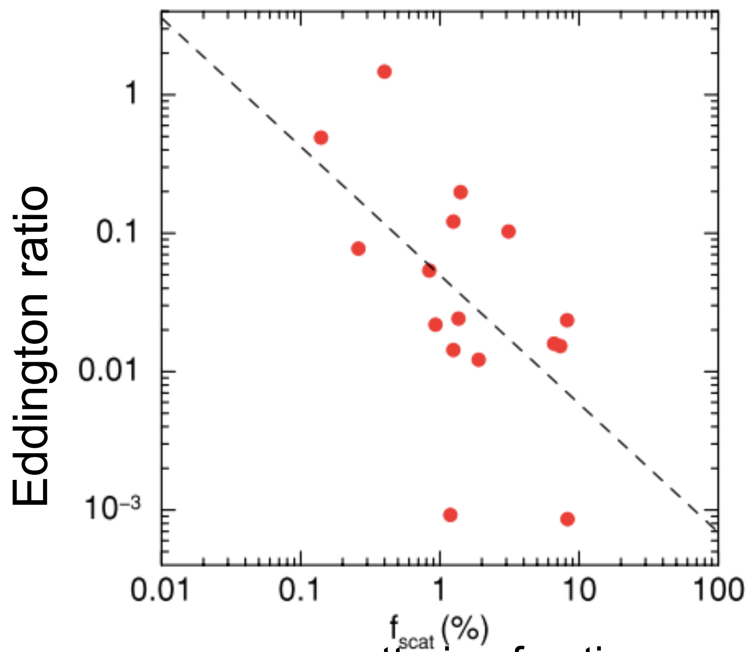
SCATTERED X-RAYS IN OBSCURED ACTIVE GALACTIC NUCLEI AND THEIR IMPLICATIONS FOR GEOMETRICAL STRUCTURE AND EVOLUTION

KAZUHISA NOGUCHI[1], YUICHI TERASHIMA[1], YUKIKO ISHINO[2], YASUHIRO HASHIMOTO[3], MICHAEL KOSS[4,5], YOSHIHIRO UEDA[2], AND HISAMITSU AWAKI[1]

- XMM-Newton
- 8/32 type2 AGNs = low scattering fraction(Xsoft/Xdirect) = buried in thick torus?

Larger Eddington ratio, more barried

→ consistent with the radiation-driven fountain (Wada 2012)



scattering fraction

Obscured fraction => Strong redshift evolution

Subaru/XMM-NEWTON survey (**Hiroi** et al. 2012)

Type-2 AGNs ($N_H = 10^{22-24}$, $Lx = 10^{44-45}$):

f_{type2} ~ 0.22 at z = 0 ==> ~ 0.54 at z = 3-5

cf. Iwasawa san's talk

high-z AGNs are obscured by

1) radiation-driven fountain with higher Eddington ratio?

and/or

2) starburst-driven torus with higher SFR, due to higher merger rate + higher gas fraction

=> It should be explored by SWANS/theory

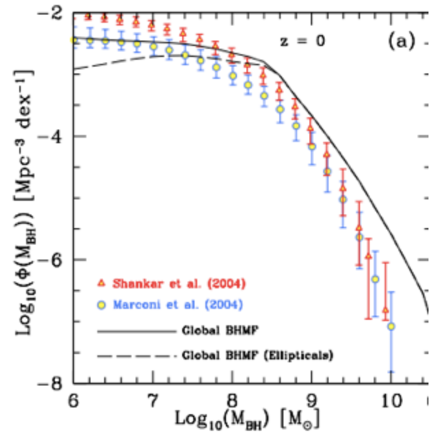
Summary: modeling AGN feeding/feedback:

Before HSC/SWANS

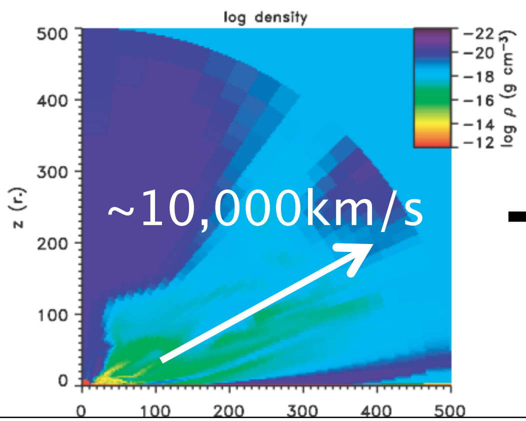
$$\dot{M}_{Bondi} = \frac{4\pi G^2 M_{BH}^2 \rho_{gas}}{c_s^3}$$

$$\dot{M}_{vis} = 3\pi\alpha\Sigma\frac{c_s^2}{\Omega}$$

$$\dot{p} = \tau\frac{L}{c} \quad \text{where } L = min\left(\eta \dot{M}_{visc} c^2, L_{Edd}\right)$$



After HSC/SWAnS



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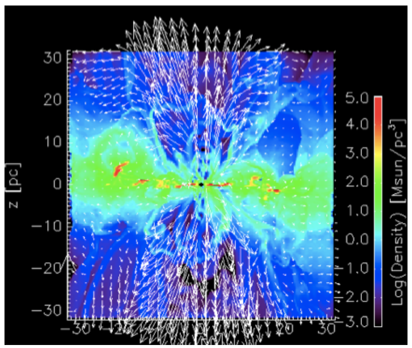

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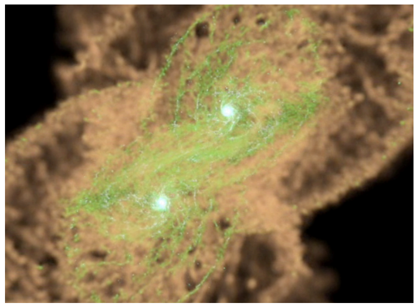

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