2009年10月15-17日
超広域サーベイによる巨大ブラックホール進化の研究：観測と理論の連携
（松山市）

AGN近傍の星間ガス構造とフィードバック

AGN/SMBH進化の鍵をにぎる”ダークドメイン”

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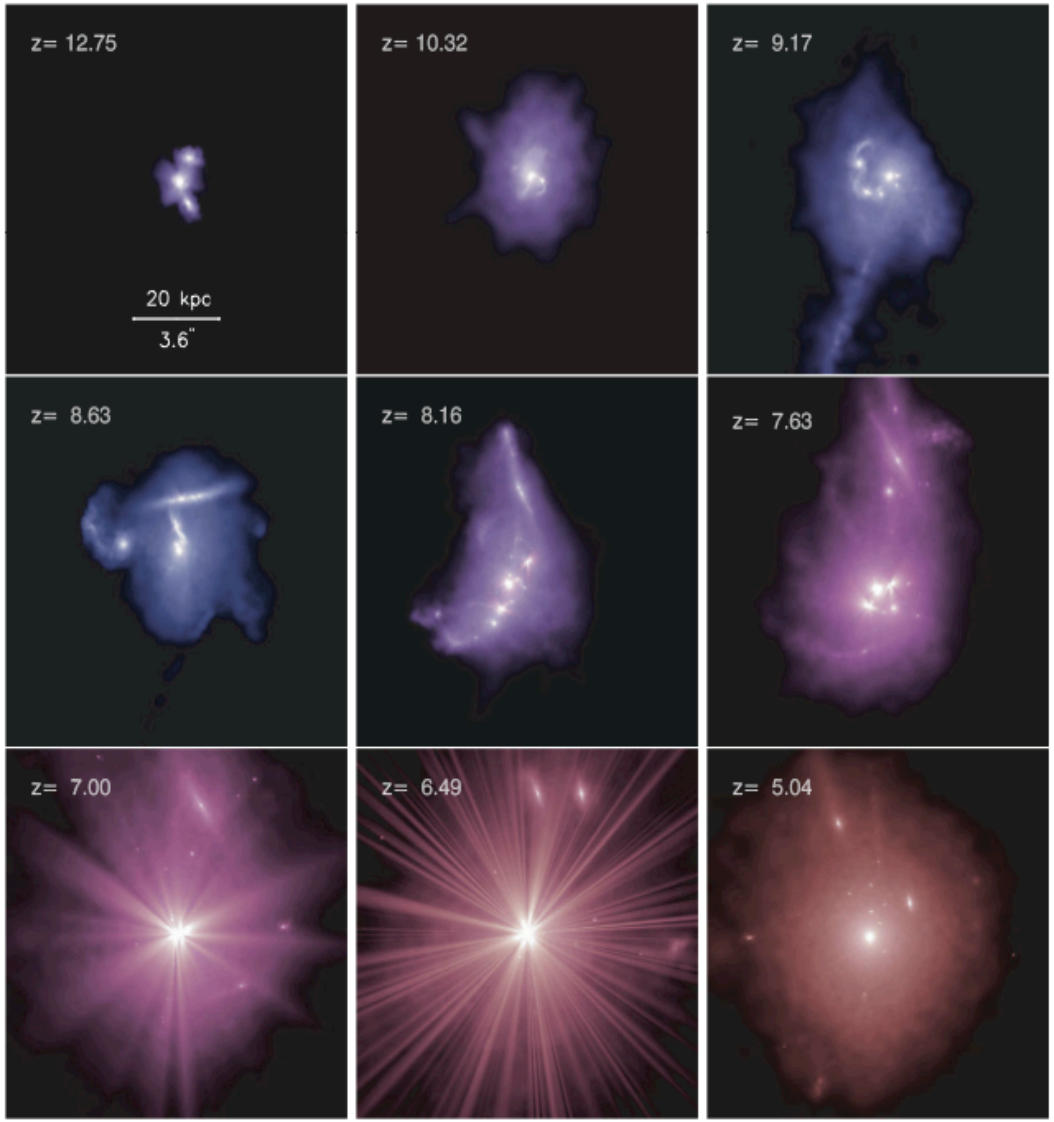
Wada, Papadopoulos, & Spaans, *ApJ* **702**, 63 (2009)

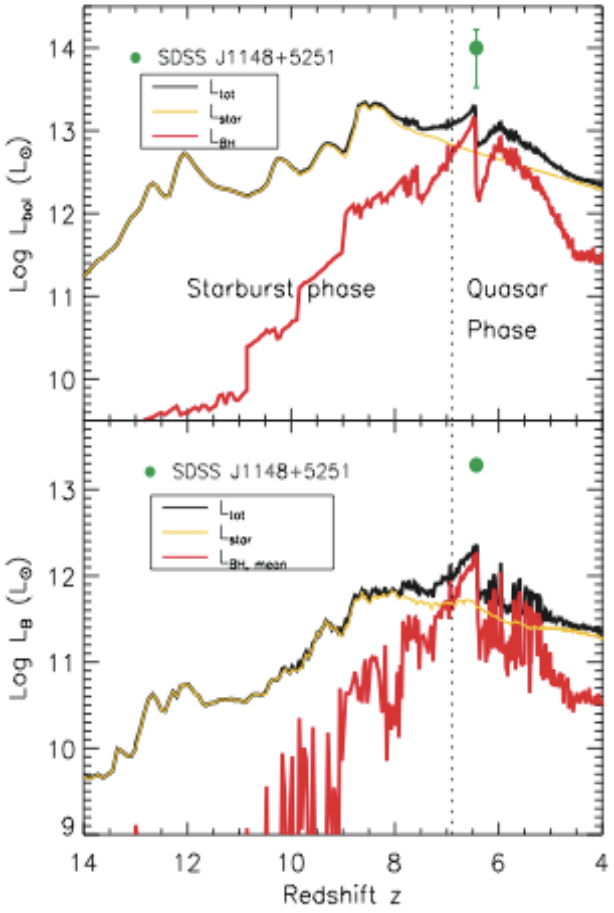
BH formation in a cosmological simulation

Li et al. (2007) 665, 187



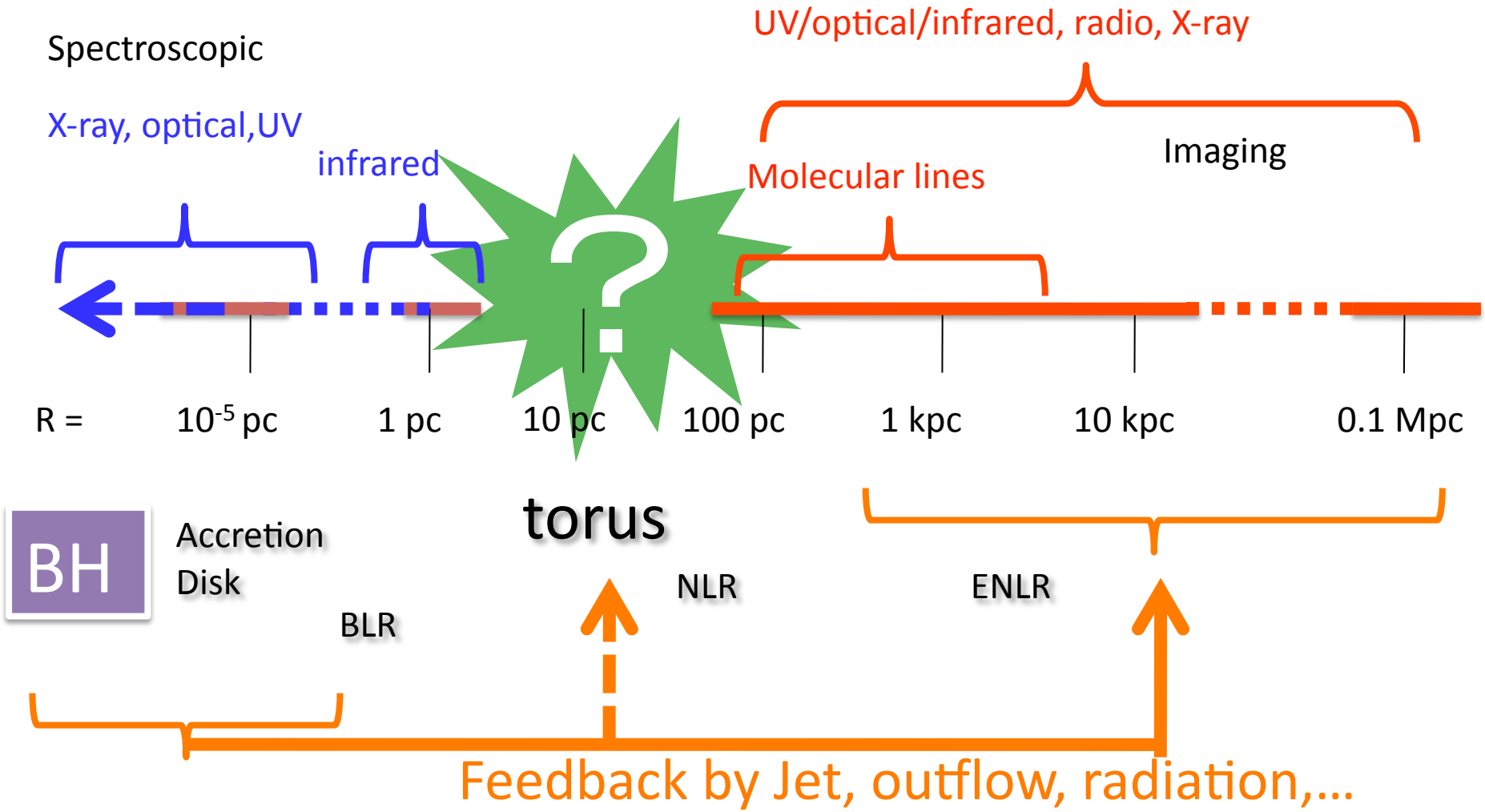
Sink particle

+ Bondi accretion < Eddington



AGN進化　　2つの重要な物理過程：Feeding/Feedback

R = pc-数10 pc領域（ダークドメイン）は未解明



ダークドメインのISM構造＆Feedback は、AGN/SMBH進化&SWANS/HSC理論に 決定的に重要

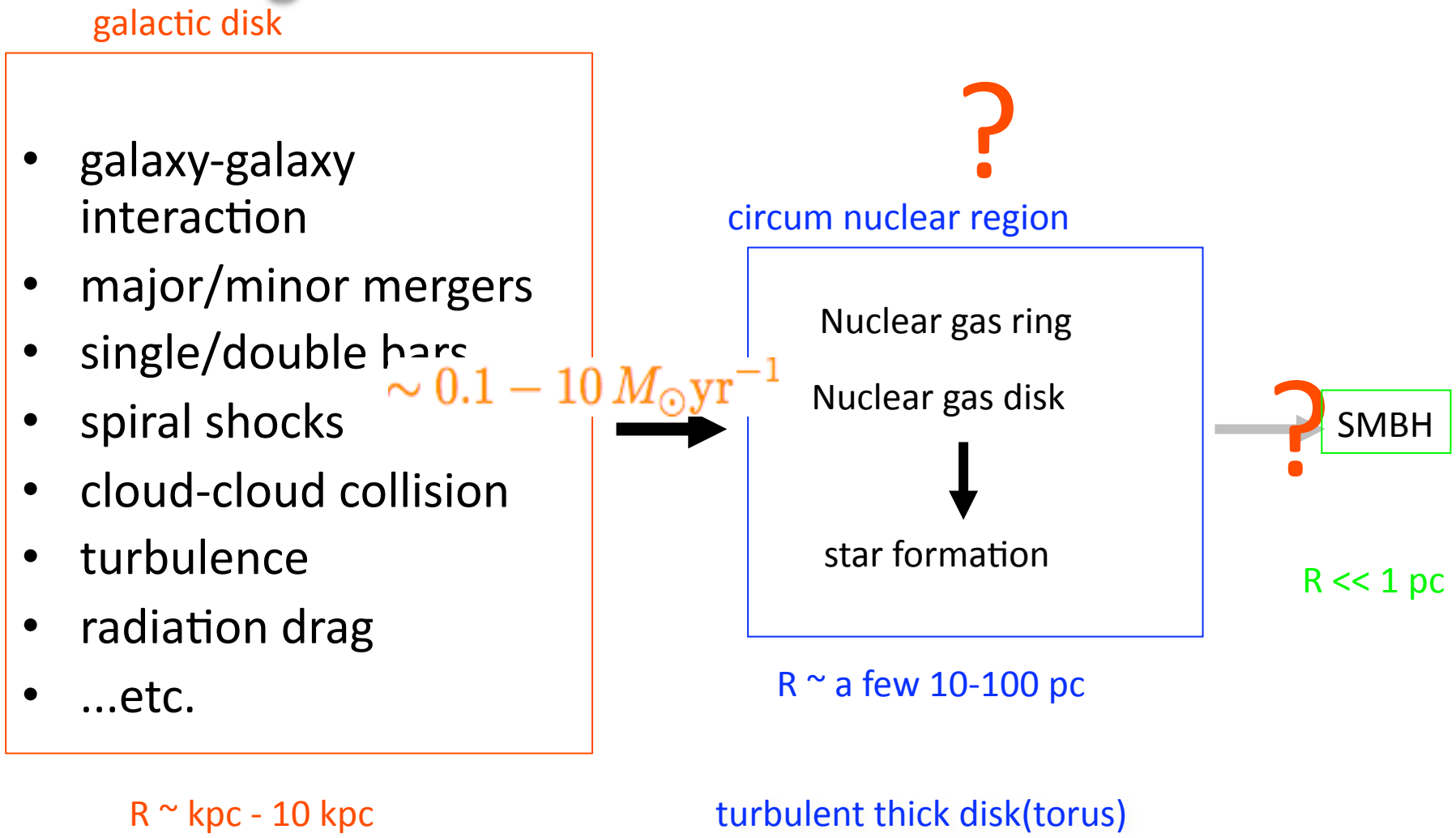
- If it's too NEGATIVE in terms of accretion,
  - no ACCRETION to SMBH ➡ no steady AGN
- If it's too POSITIVE,
  - Too large L_{AGN} ➡ Runaway ➡ ISM is blown away and no steady AGN

But, observed AGNs seem to be steady (at least for a period) …

Feedbackは結局、あまりeffectiveではないのか？

➡ まずは、ISM構造を明らかにする

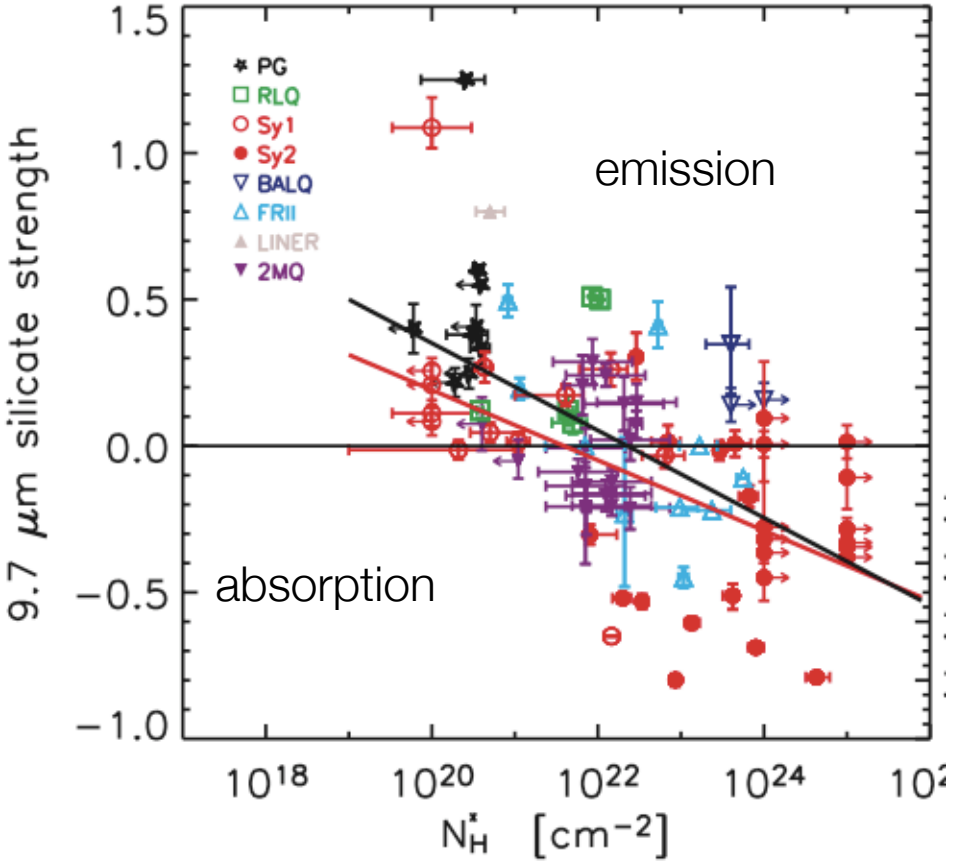
Gas accretion toward SMBH
galactic scale >>>> BH scale



Are tori uniform or clumpy?

- Uniform torus model predicts
  - SiO emissions (10,18micron) in Type1 AGNs
  - SiO absorptions in Type2
- Non-uniform torus?
  - Emission in type 2 (Strum et al. 06;Mason et al.09)
  - Shi et al. 2006: 85 AGNs observed by Spitzer/IRS
    - Weak correlation between N_H and 9.7micron silicate
    - Anomalies: absorption in type 1, emission in type 2
  - SED fitting by clumpy tori: Nenkova et al. 2002; Schartmann et al. 08

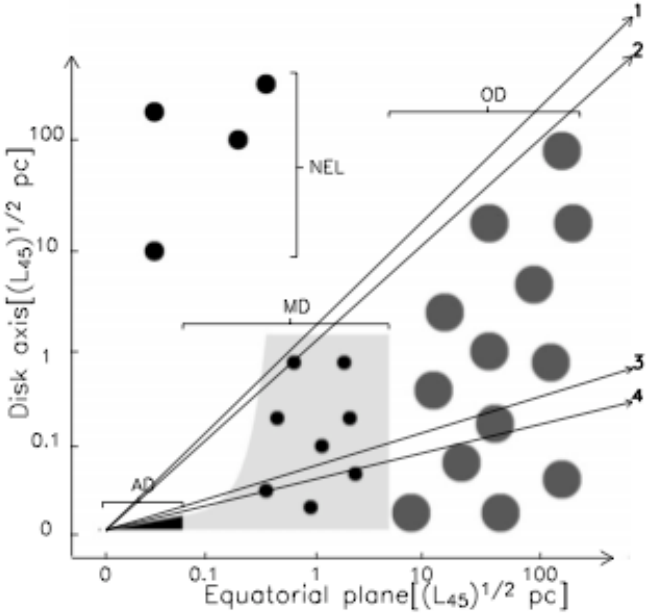
Silicate features roughly correlate with N_H



Shi et al. (2006)

1,2 Silicate emission

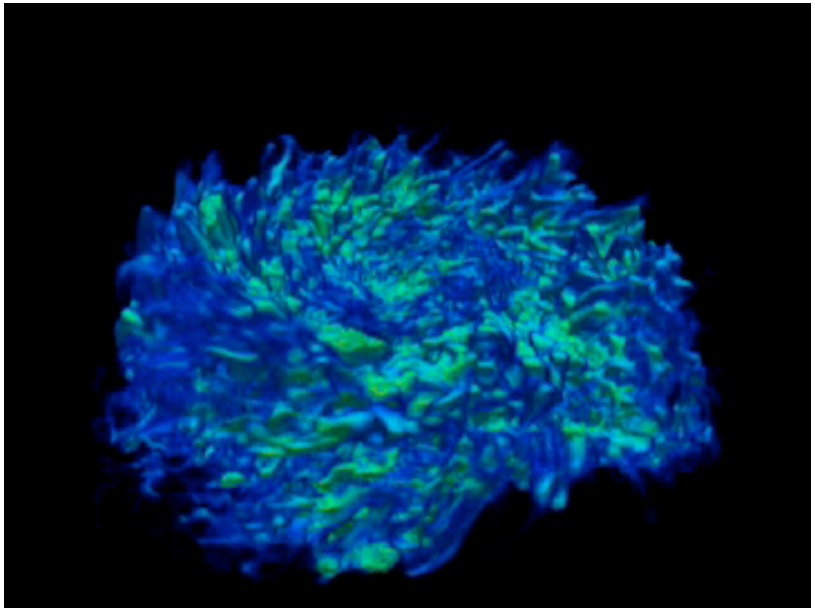
3,4 absorptin

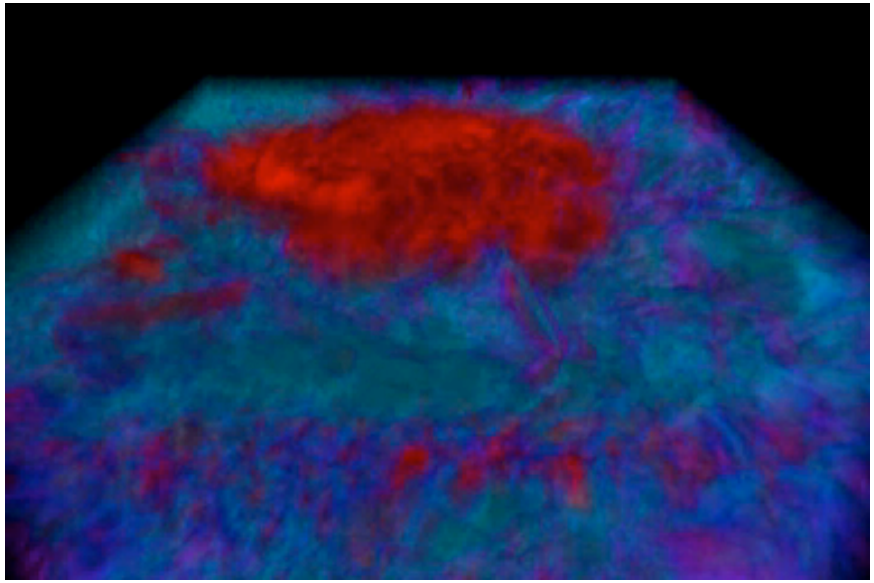


KW & Norman (2002) ApJ 566, L21

256^2 x 128, uniform grid, 0.25pc/grid
Radiative cooling, SN feedback, selfgravity of gas
$M_{BH} = 10^8\ M_{sun}$, $M_{gas} = 10^7\ M_{sun}$,

temperature





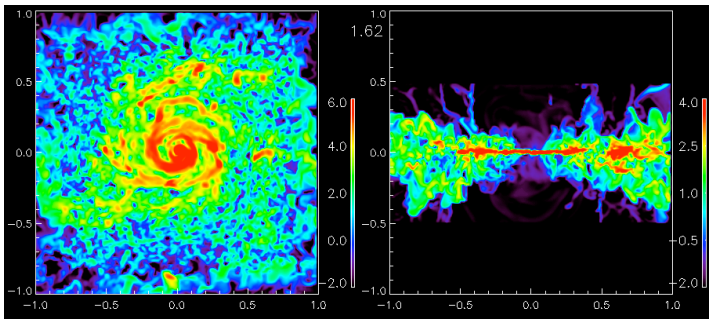
density

KW&Norman02での問題点

1)The SN rate (~0.3 yr^{-1}) is too high

2)Not real multi-phase (no H_2 => no SF)

3)No AGN Radiation ⇒進行中



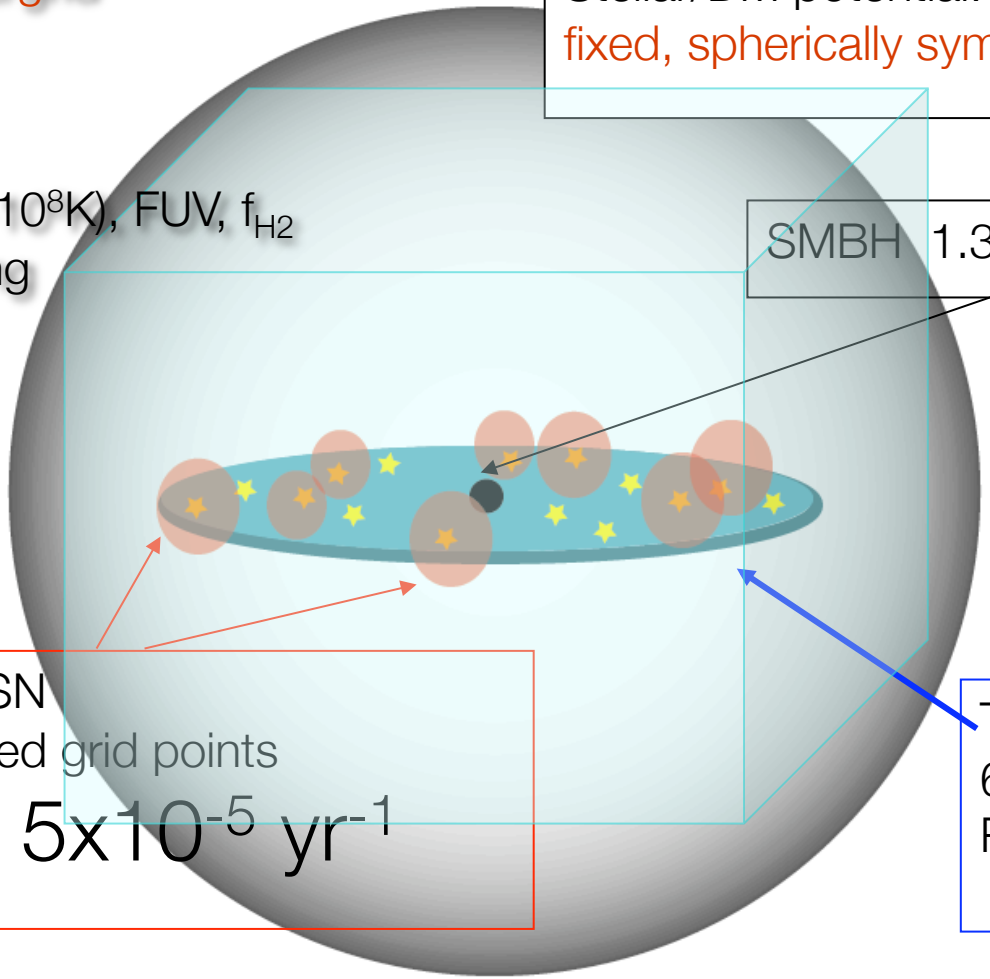
3-D Hydrodynamics of a gas disk around a SMBH (KW, Papadopoulos & Spaans 09)

512^2x256 grid points
Resolution: 0.125 pc/grid
Time step: 80 yr

- Cooling function, depending on T (10-10^8K), FUV, f_{H2}
- Photoelectric heating
- Self-gravity of gas

Stellar/DM potential:
fixed, spherically symmetric

SMBH 1.3×10^7 M_{sun}



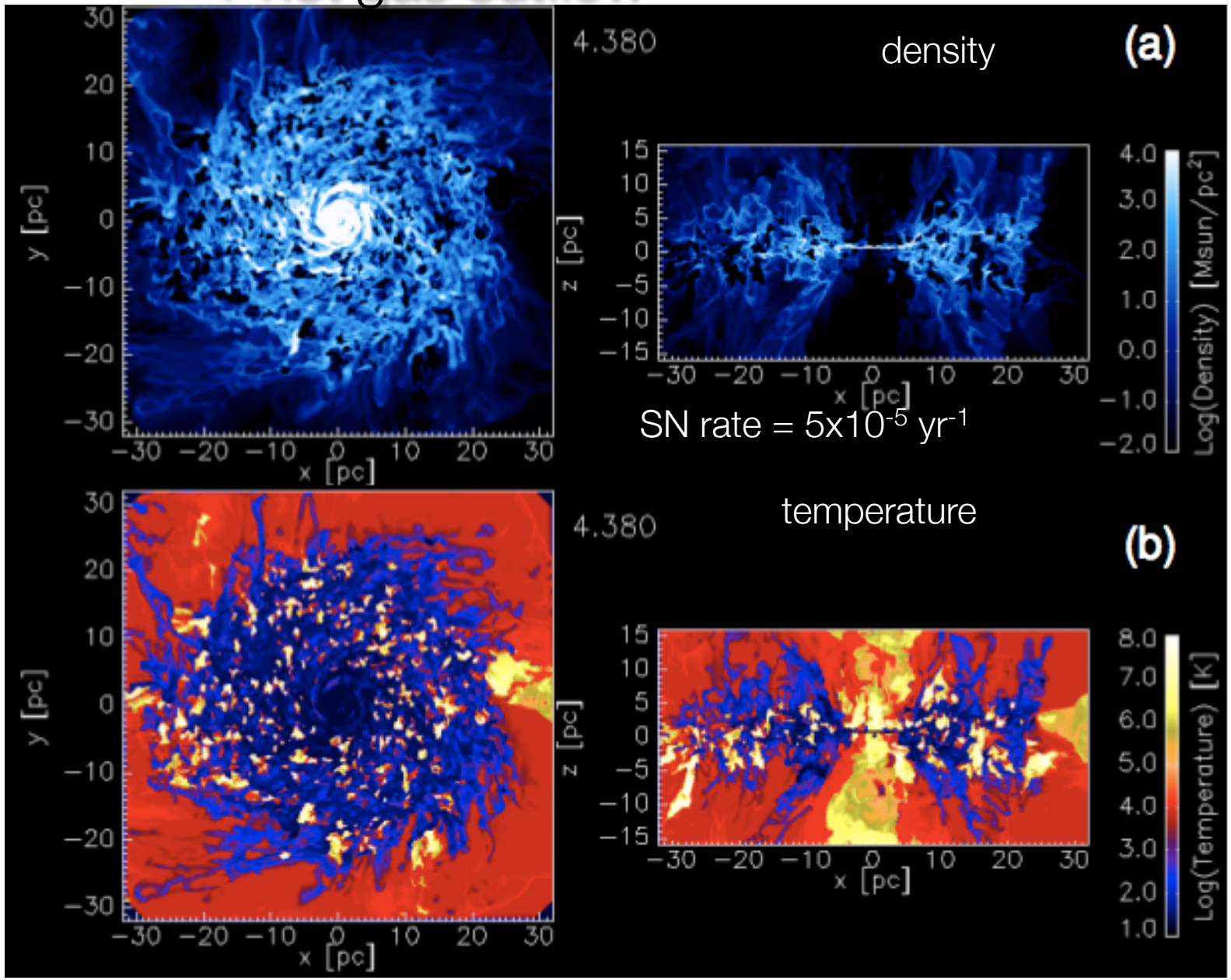
Energy input from SN
at randomly selected grid points

SN rate = 5×10^{-5} yr^{-1}

Thin gas disk
6×10^6 M_{sun}
R=32pc

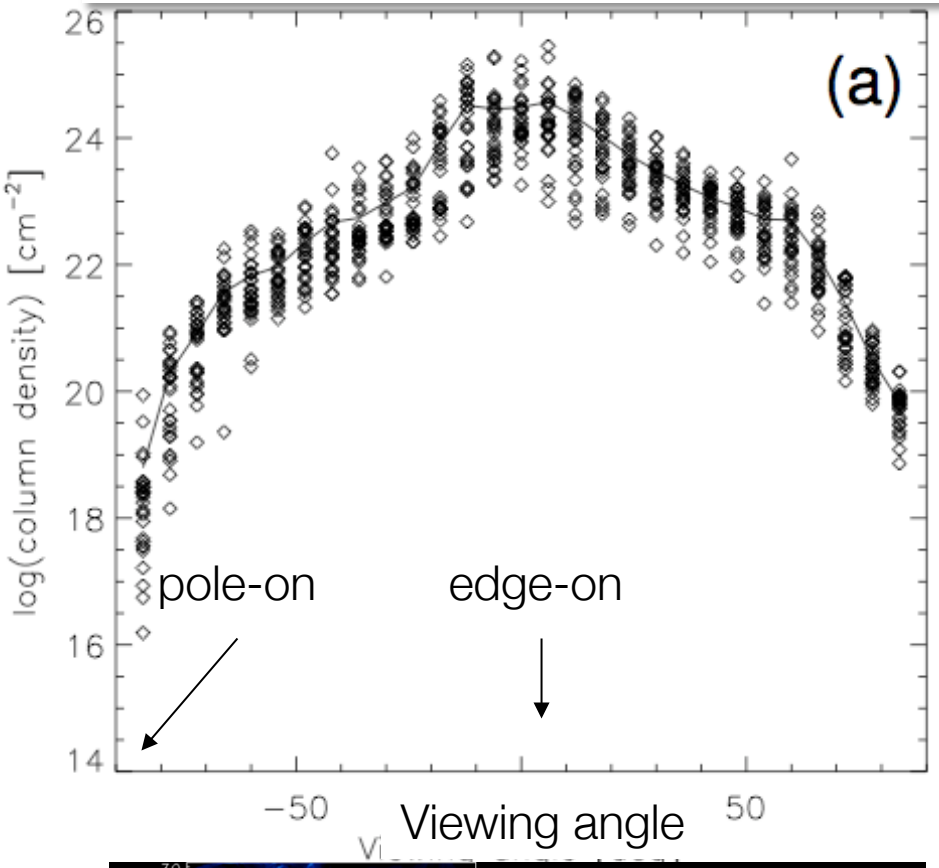
準定常状態： 非一様cold, thick disk + hot gas outflow

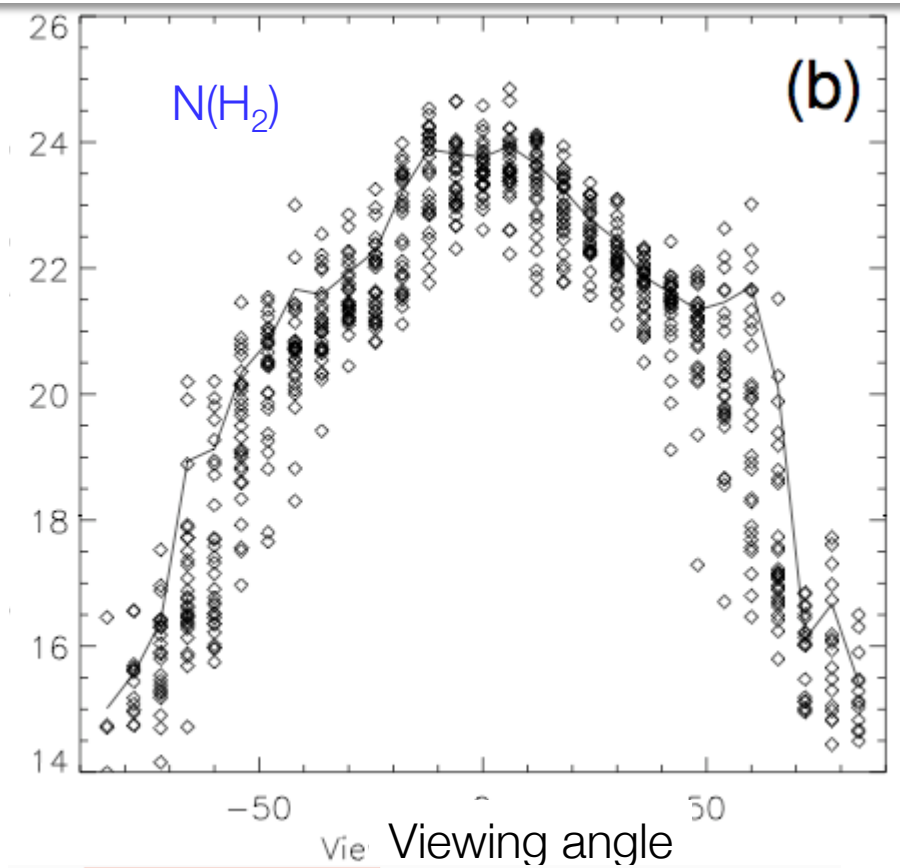
$M_{BH} = 1.3 \times 10^7\ M_{sun}$
$M_{gas} = 6 \times 10^6\ M_{sun}$

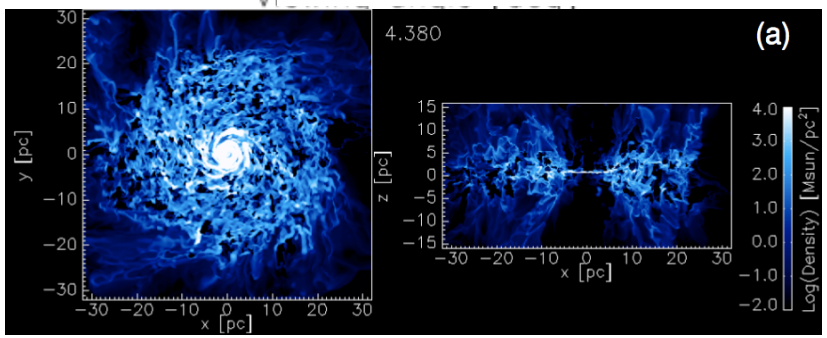


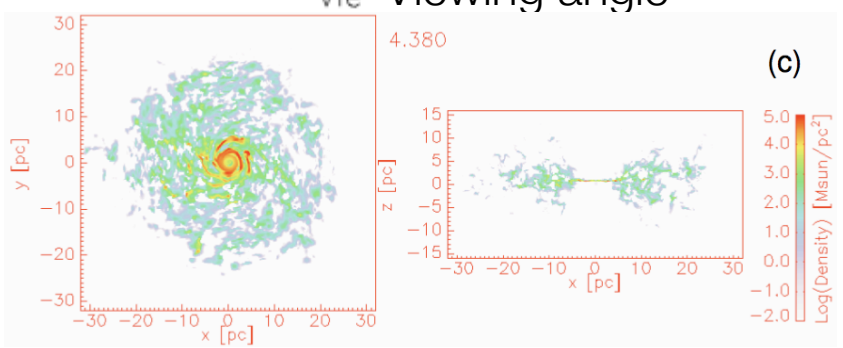
中心核に対する柱密度は、見込み角で一意には決まらない

⇒ Type1/2を決めるのは見込み角だけではない



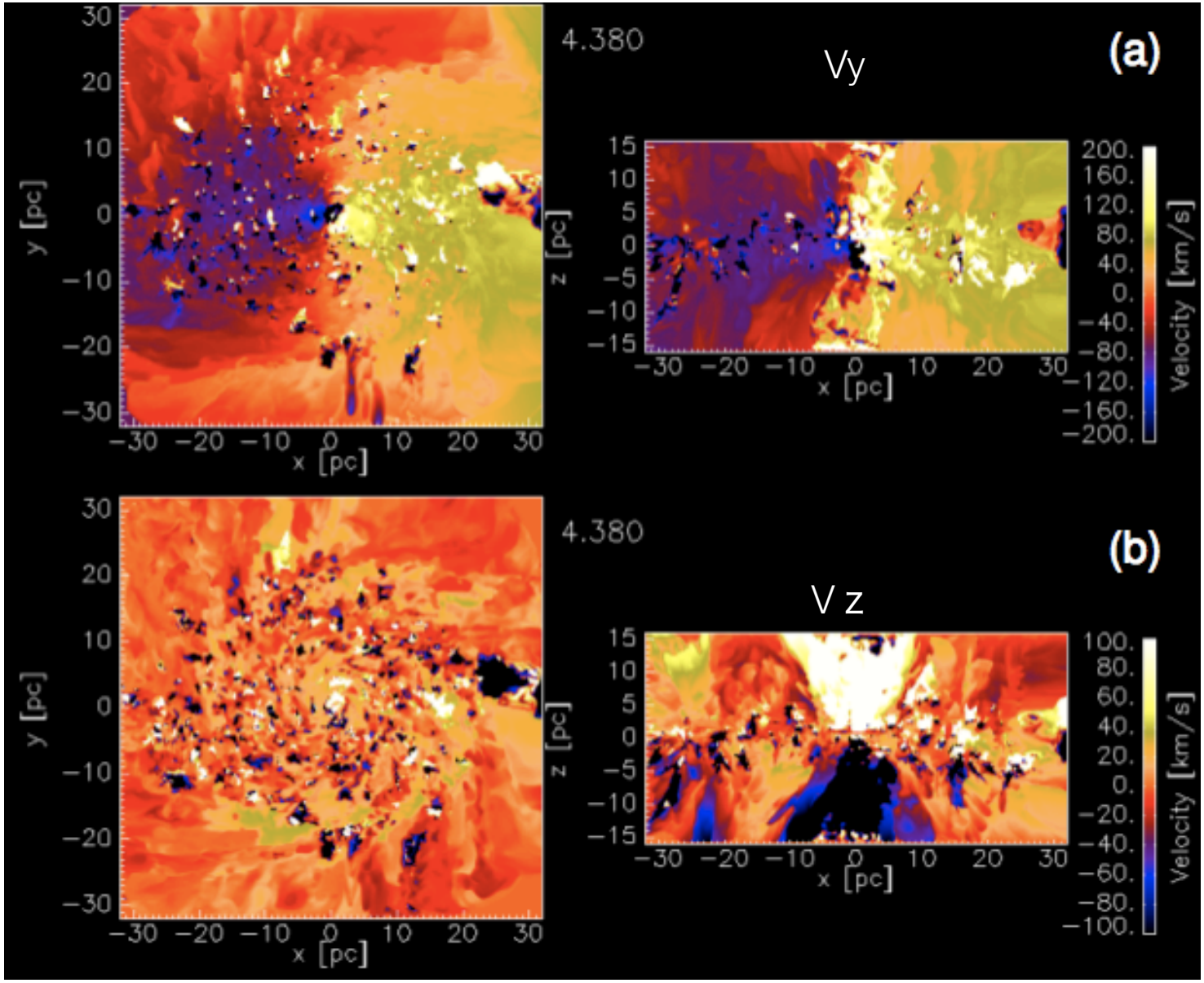






Velocity field: rotation w/ large dispersion

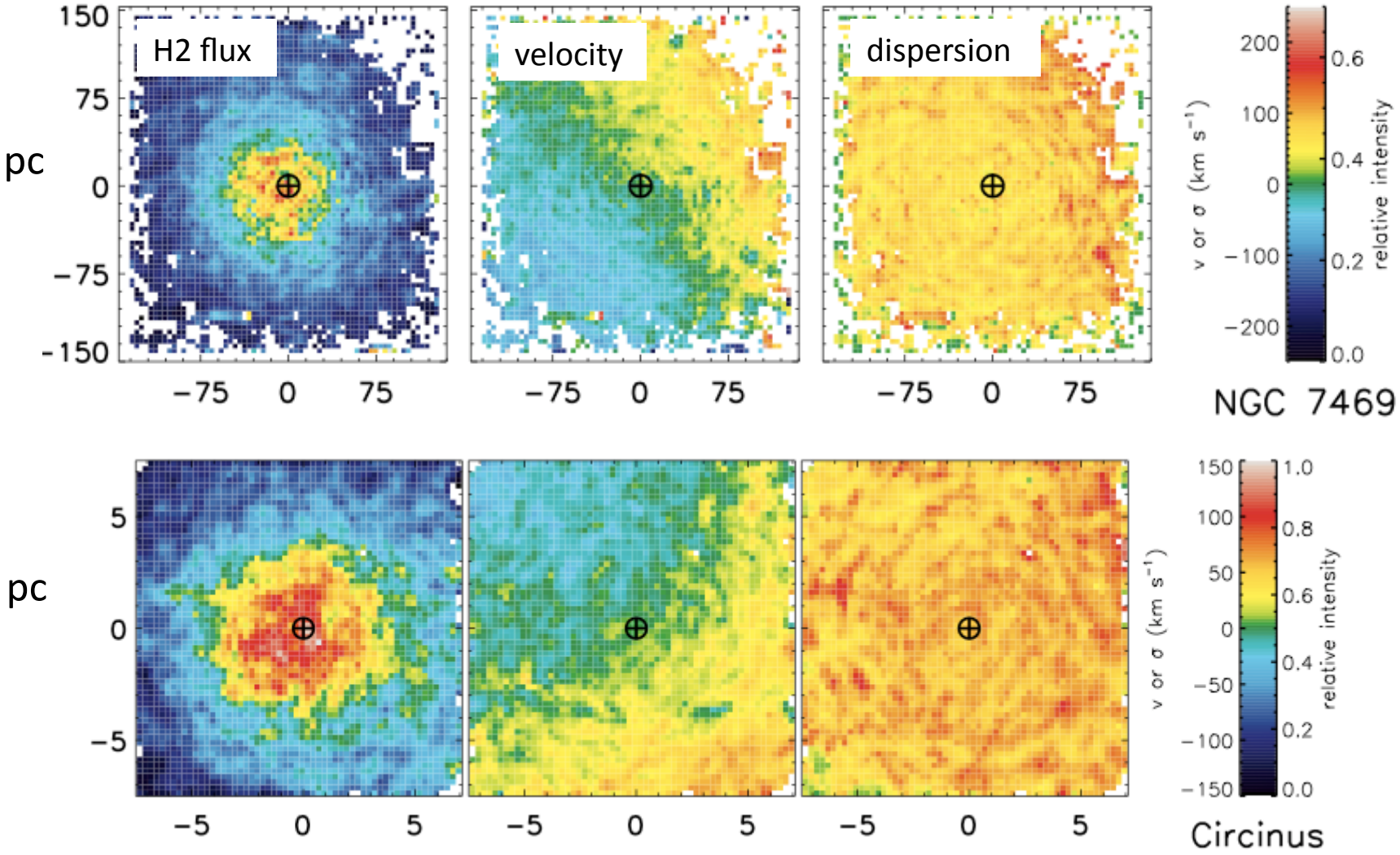
Outflow of hot gas from the central funnel



Hicks et al. 2009

VLT/SINFONI, Keck/OSIRIS

H_2 infrared line



H_2 formation & destruction with hydrodynamics

Assumptions (cf. Pelupessy et al. 2006)

- H_2 and HI are fully mixed within a spherical "cloud"
- Size of the "clouds" is scaled (size-line width) ~ 0.5 pc
- FUV field: uniform (G_0 = 10-1000)
- Formation on dust, collisional destruction, photo-dissociation, advection

Cf. Glover & Mac Low '07

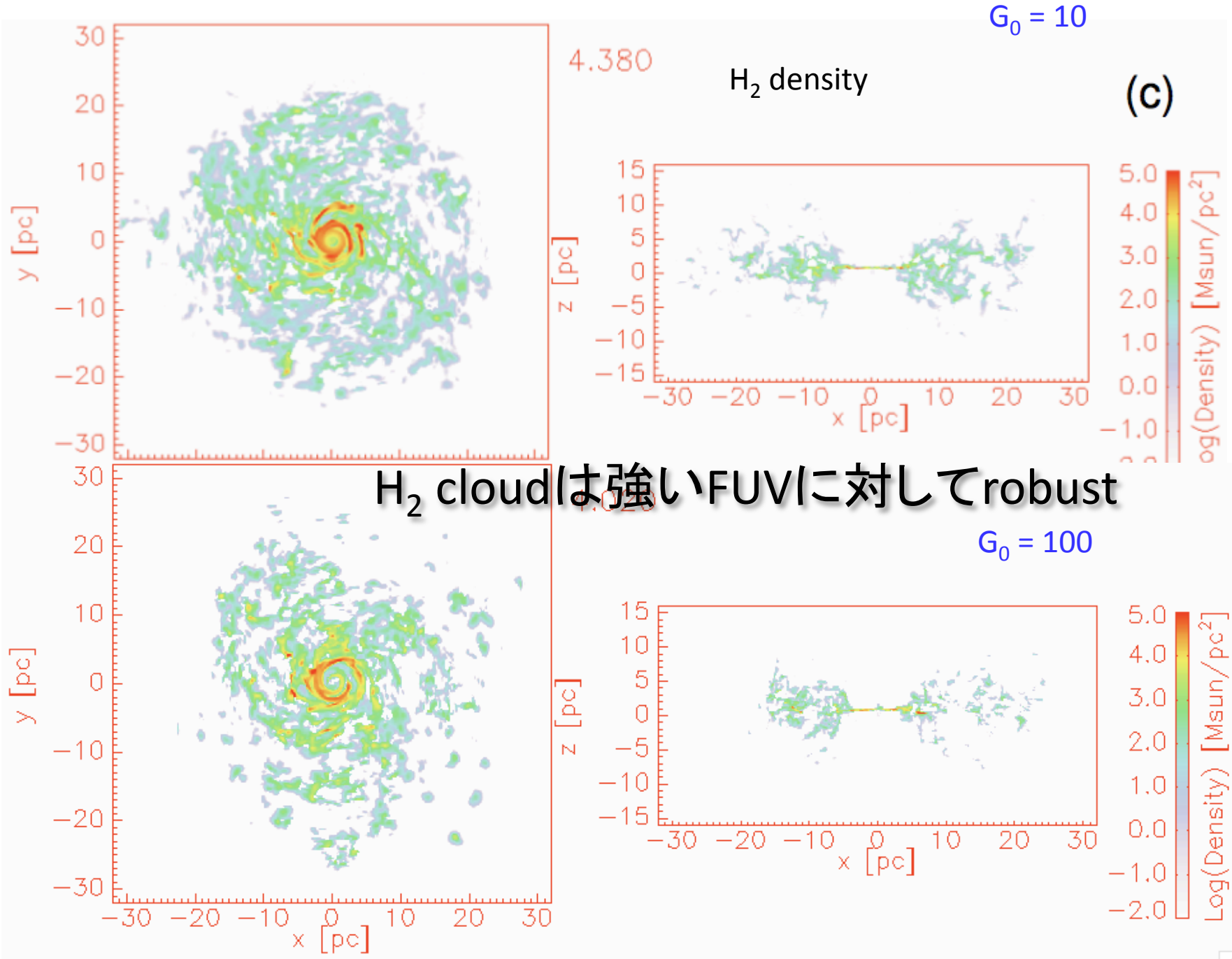
$$\frac{dn_2}{dt} = R_f(T_k) n n_1 \qquad H_2形成$$

$$- \left[\frac{G_0 \chi_d}{4\pi} \int f_s(N_2) e^{-\tau} d\Omega\right] n_2 \qquad H_2光解離$$

$$- \gamma_1(T_k) n_1 n_2 - \gamma_2(T_k) n_2^2 \qquad H_2衝突解離$$

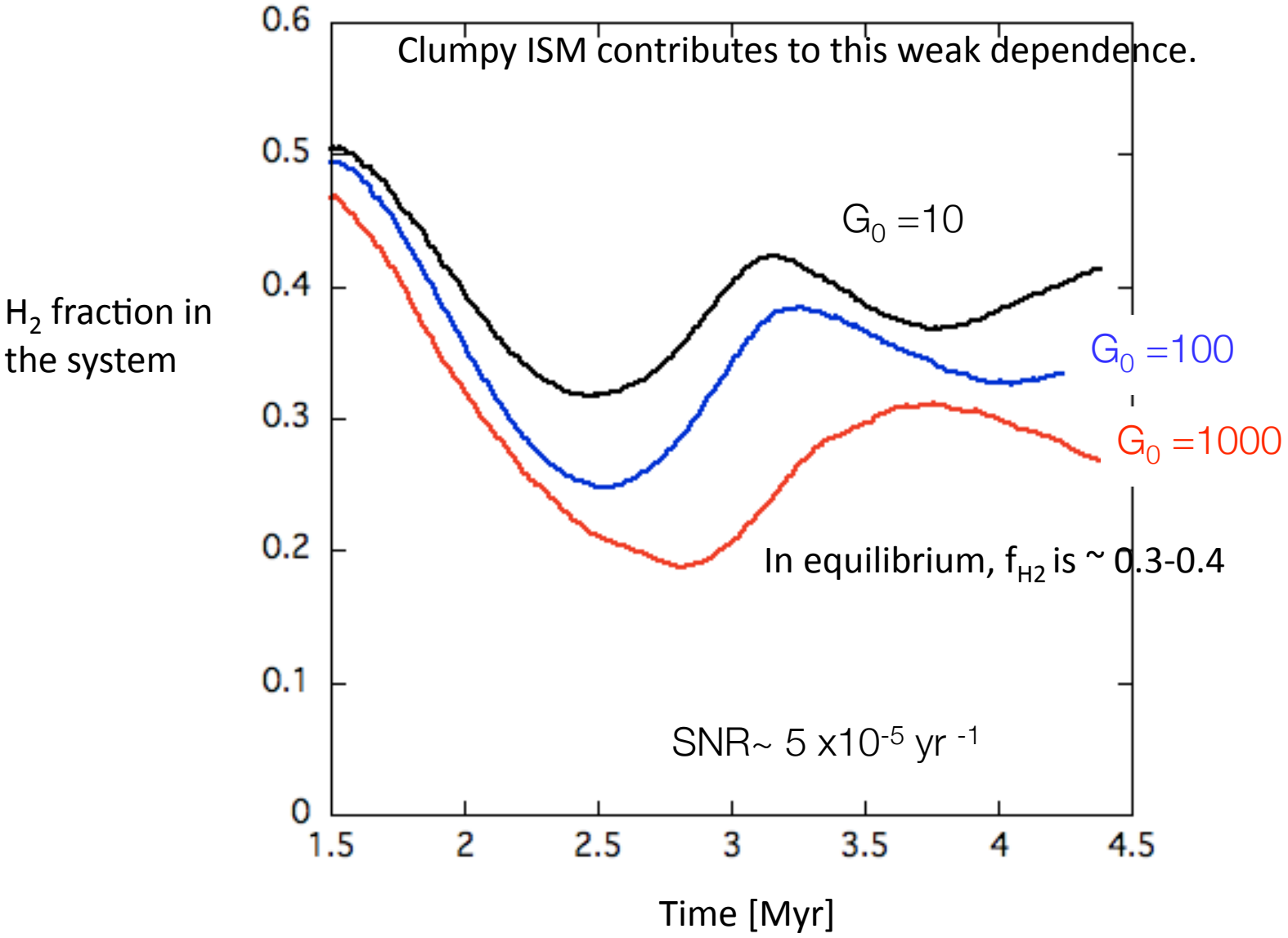
$$f_s = (N_2/N_0)^{-k}, \ if \ N_2 > N_0 = 10^{14} cm^{-2}$$

H_2 self-shielding func.(Draine, Bertoldi 96)

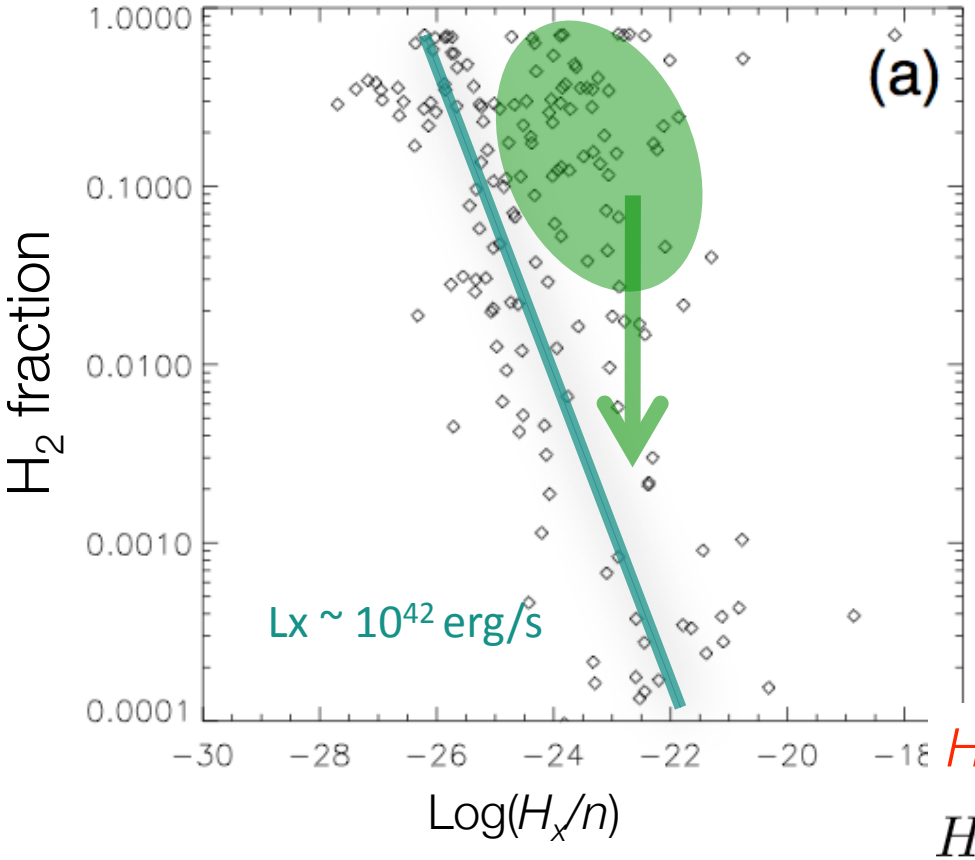

G_0 = 10
4.380
H_2 density
(c)
y [pc]
z [pc]
x [pc]
Log(Density) [Msun/pc^2]
H_2 cloudは強いFUVに対してrobust
G_0 = 100
y [pc]
z [pc]
x [pc]
Log(Density) [Msun/pc^2]

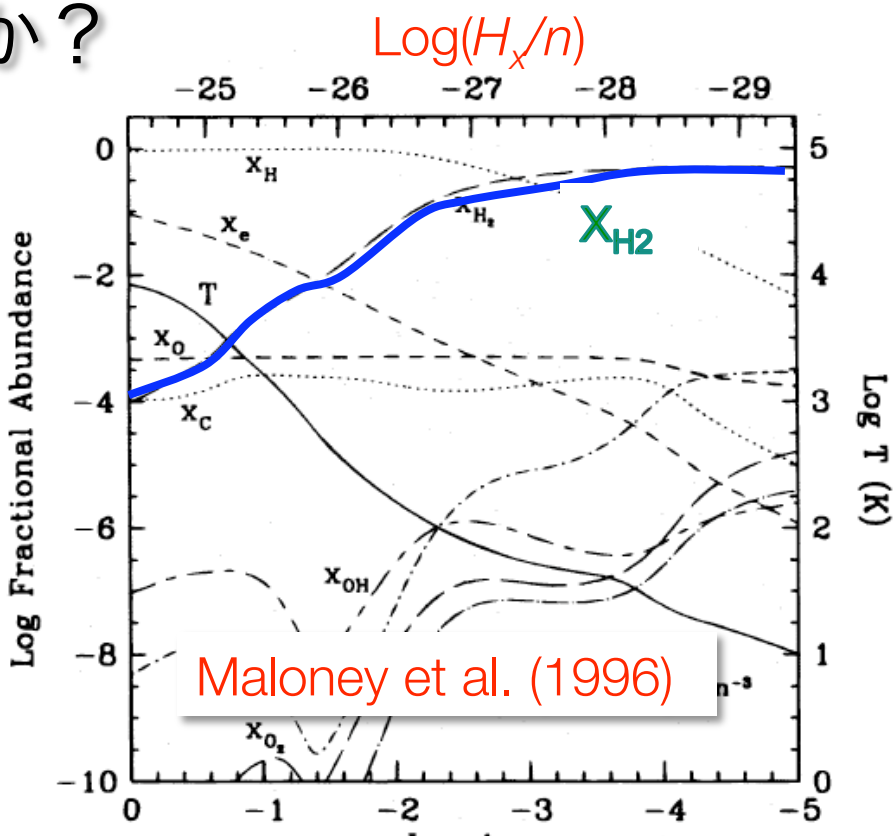
FUV => M_{H2} に対して弱い負のフィードバック

M_{H2} <=> SFR <=> FUV



X-ray Feedback は効くか？





H_x: X-ray heating energy deposition rate

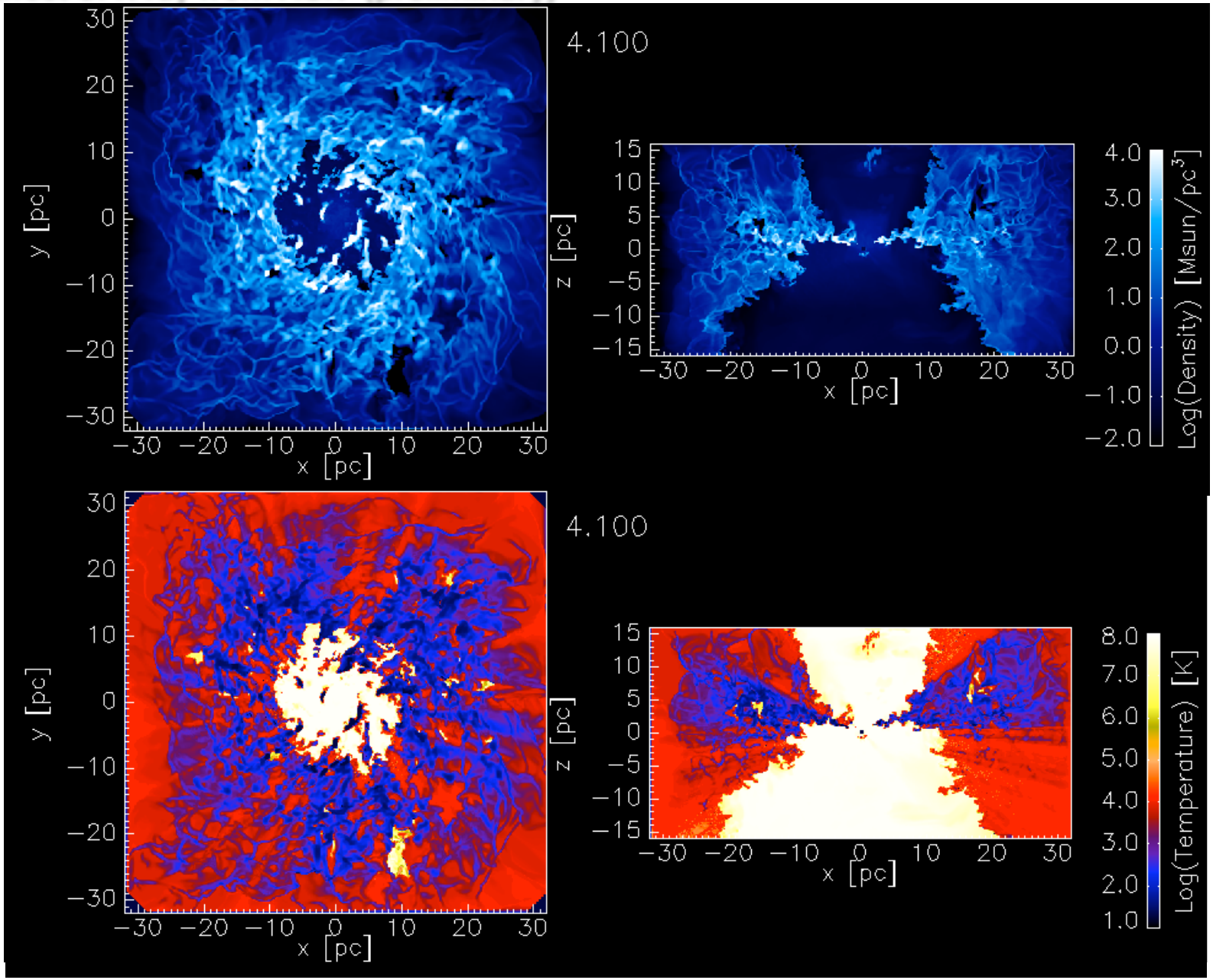
$$H_X \simeq 7 \times 10^{-22} L_{44} r_{100} N_{22}^{-1} \ \text{ergs s}^{-1}$$

・XDRモデルの予想どおり, H_x/n が小さいところで、 f_{H2}が急激に大きくなる（分散大）

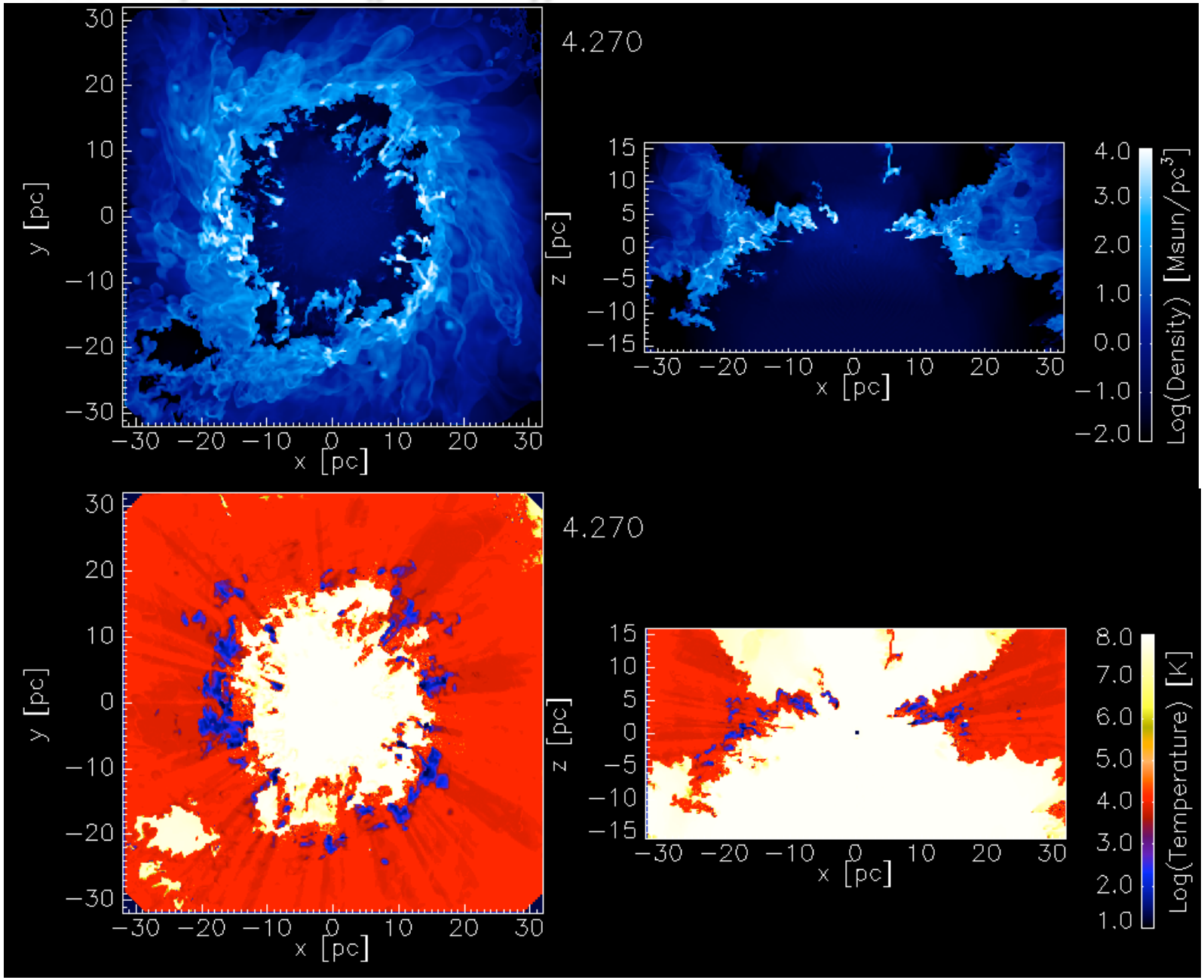
・中心核からのX線の効果を直接計算にいれると、H_2 の量は大きく減少？

Negative feedback

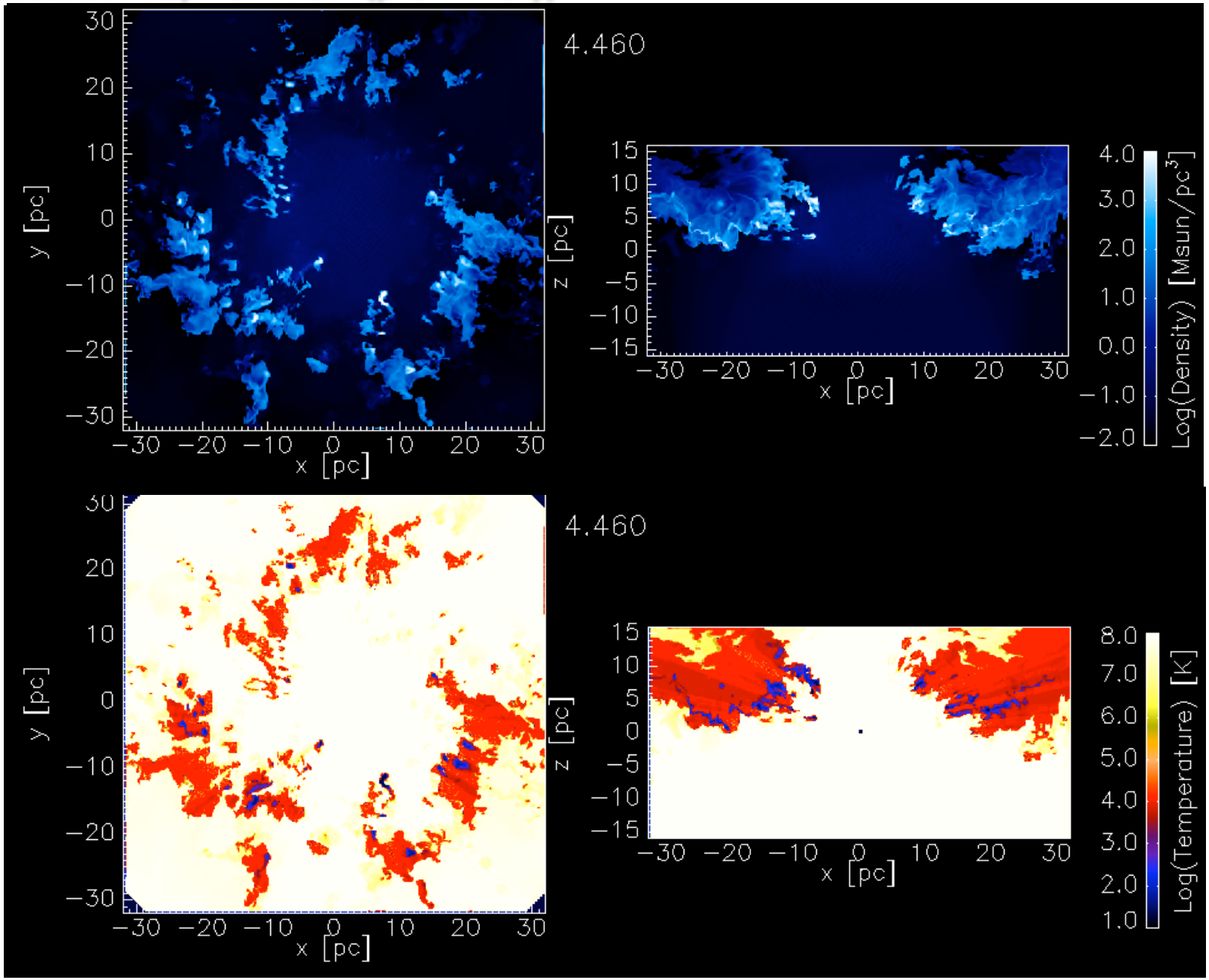
Effect of X-ray from AGN (preliminary)



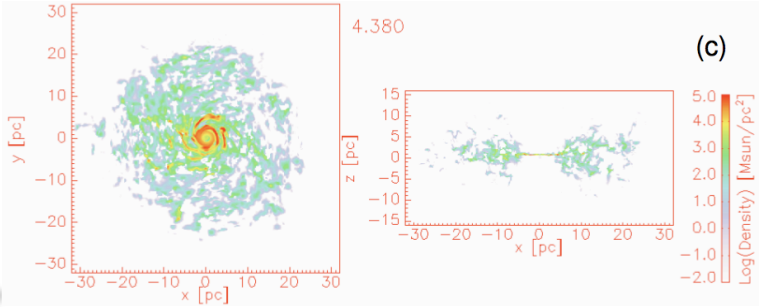
Effect of X-ray from AGN (preliminary)



Effect of X-ray from AGN (preliminary)



“ダークドメイン”の構造とfeedback



☆ 理論的予想

- 非一様，乱流的な多相“トーラス”
  - ポテンシャル自己重力、cooling/ heating
  - SN rate 10^{-5} yr^{-1} あれば、エネルギー源としては十分
- N(H)は非常にばらつく
- High-z QSO(形成中）がどのように観測されるか？

☆さまざまなPositive or Negativeフィードバック過程

- Star formation (FUV, SNe) ⇒ M_{H2} にnegative, but 影響小
  ⇒ 速度分散にはpositive
- X-ray ⇒ negative on M_{H2}, 影響大？ Negative on accretion
- BHの成長⇒ negative （川勝）

★ Radiative feedback/電離ガス構造 ⇒ 須佐、大須賀、和田