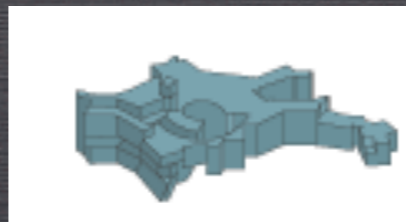


CHAOTIC COLD ACCRETION DRIVING AGN FEEDBACK

Massimo Gaspari

MAX PLANCK FOR ASTROPHYSICS

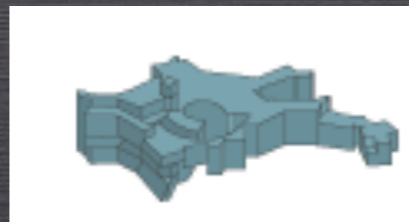


COLLABORATORS - M. RUSZKOWSKI, P. OH , F. BRIGHENTI, P. TEMI, P. SHARMA, S. ETTORI

RAINING ON TO BLACK HOLES

Massimo Gaspari

MAX PLANCK FOR ASTROPHYSICS



COLLABORATORS - M. RUSZKOWSKI, P. OH , F. BRIGHENTI, P. TEMI, P. SHARMA, S. ETTORI

BLACK HOLES

FEEDING ?

- cold versus hot accretion
- mechanisms boosting and stifling accretion
- galactic scale to sub-pc scale link
- the role of varying physics:
cooling, turbulence, heating, rotation

Gaspari, Ruszkowski & Oh 2013
Gaspari et al. 2014

FEEDBACK ?

- amount of energy released
- deposition of energy
- mechanical versus thermal
- duty cycle
- bubbles, shocks, metal uplift,
turbulence, L_x - T_x , ... \Leftrightarrow observations!

Gaspari et al. 2009
Gaspari et al. 2011a, b
Gaspari, Ruszkowski & Sharma 2012
Gaspari, Brighenti & Temi 2012
Gaspari et al. 2014



SELF-REGULATED LOOP

ON SPHERICALLY SYMMETRICAL ACCRETION

H. Bondi

(Received 1951 October 3)

Summary

The special accretion problem is investigated in which the motion is steady and spherically symmetrical, the gas being at rest at infinity. The pressure is taken to be proportional to a power of the density. It is found that the accretion rate is proportional to the square of the mass of the star and to the density of the gas at infinity, and varies inversely with the cube of the velocity of sound in the gas at infinity. The factor of proportionality is not determined by the steady-state equations, though it is confined within certain limits. Arguments are given suggesting that the case physically most likely to occur is that with the maximum rate of accretion.

$$\dot{M}_B = 4\pi\lambda_c \frac{(GM_{BH})^2}{c_{s,\infty}^3} \rho_\infty \propto K_\infty^{-3/2}$$

FEEDING SIMULATIONS

FLASH4 CODE

Gaspari, Ruszkowski & Oh 2013

Gaspari et al. 2014

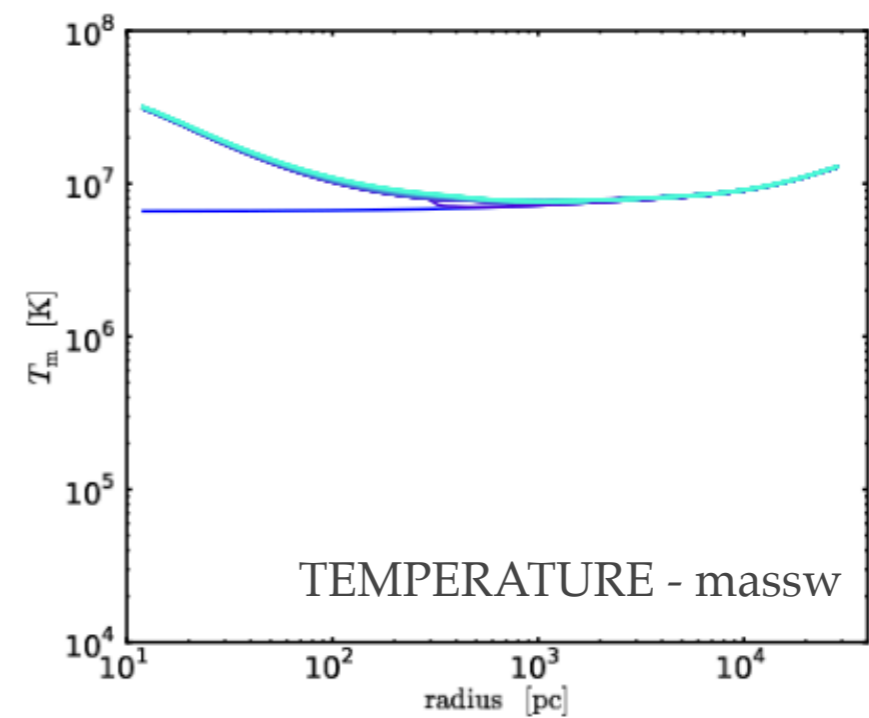
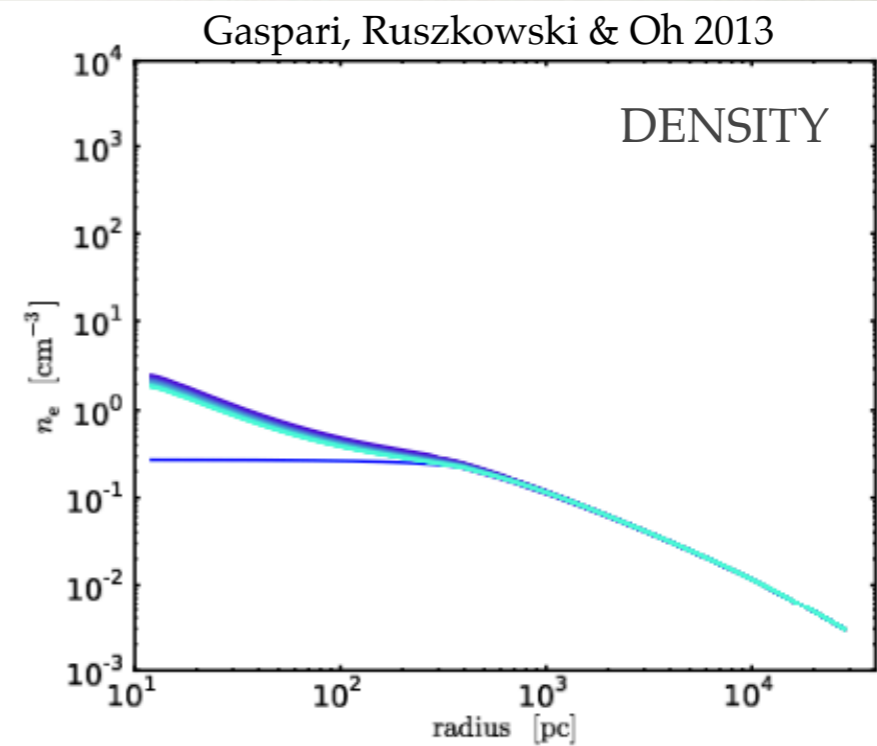
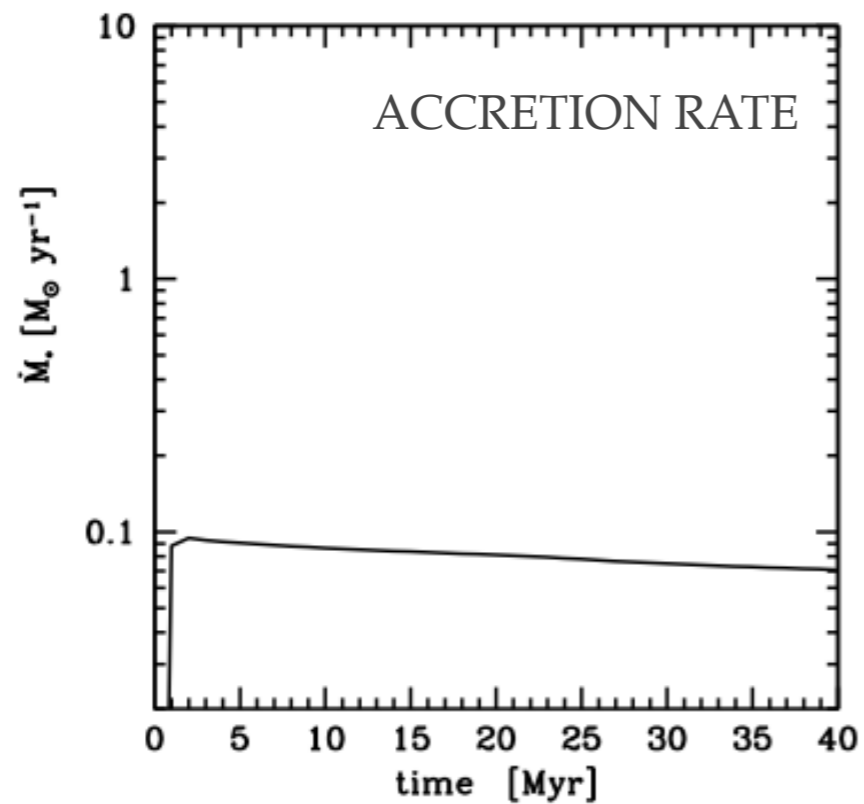
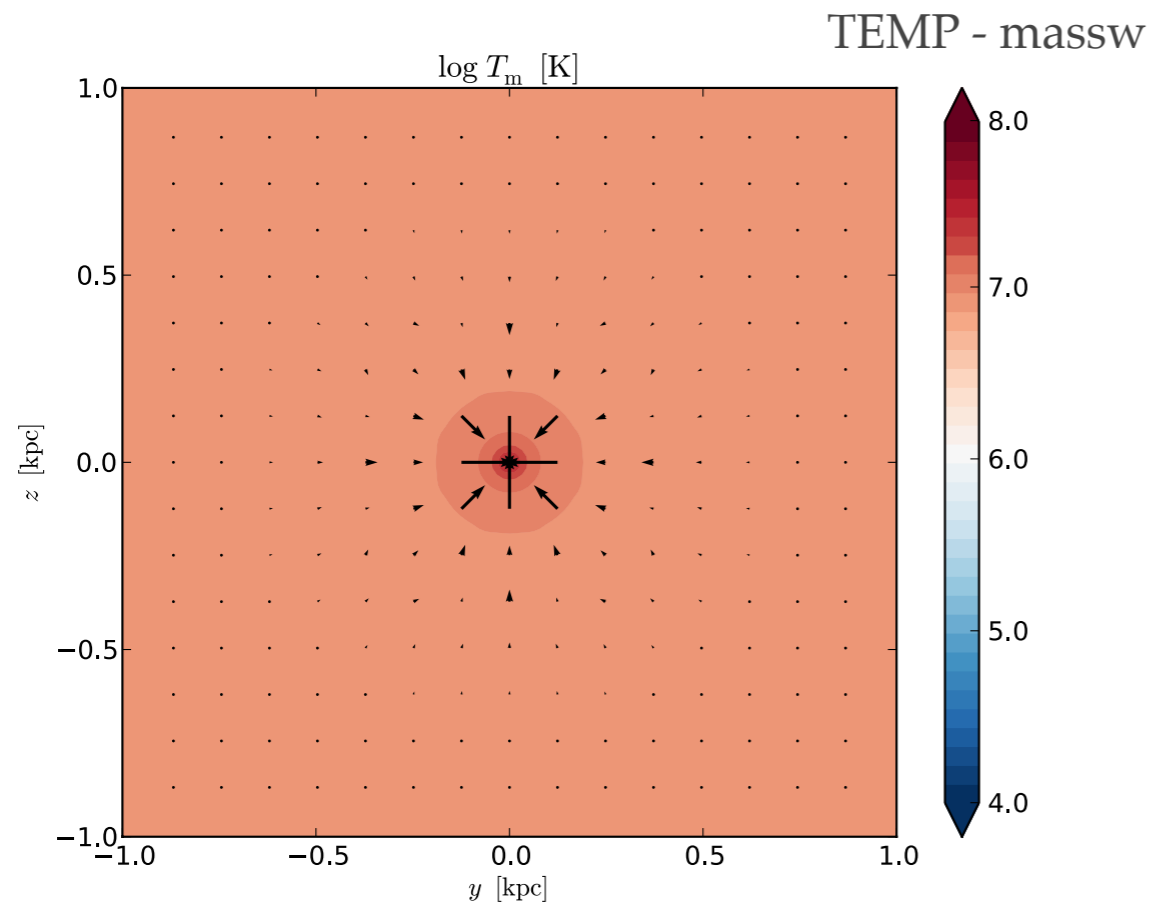
- concentric AMR zooming: **box = 50 kpc** \rightarrow **$dx \sim 20 R_S - 0.1 \text{ pc}$**
 ~ 10 million range $600 r_B$ and $200 t_B$
- 3D eulerian gas dynamics: unsplit PPM (tested different solvers)
- dark matter halo (massive group): $M_{\text{vir}} = 4 \times 10^{13} M_{\odot}$
- massive elliptical galaxy (NGC 5044): $M_{\text{star}} = 3.4 \times 10^{11} M_{\odot}$
- SMBH: $M_{\text{bh}} = 3 \times 10^9 M_{\odot} \rightarrow$ pseudo-relativistic PW: $\phi_{\text{PW}} = -GM_{\text{bh}}/(r - R_S)$
- observed gas $T(r)$ [cool-core group] $\rightarrow n(r)$ via HSE

1.

~~CONSTANT BOUNDARIES~~

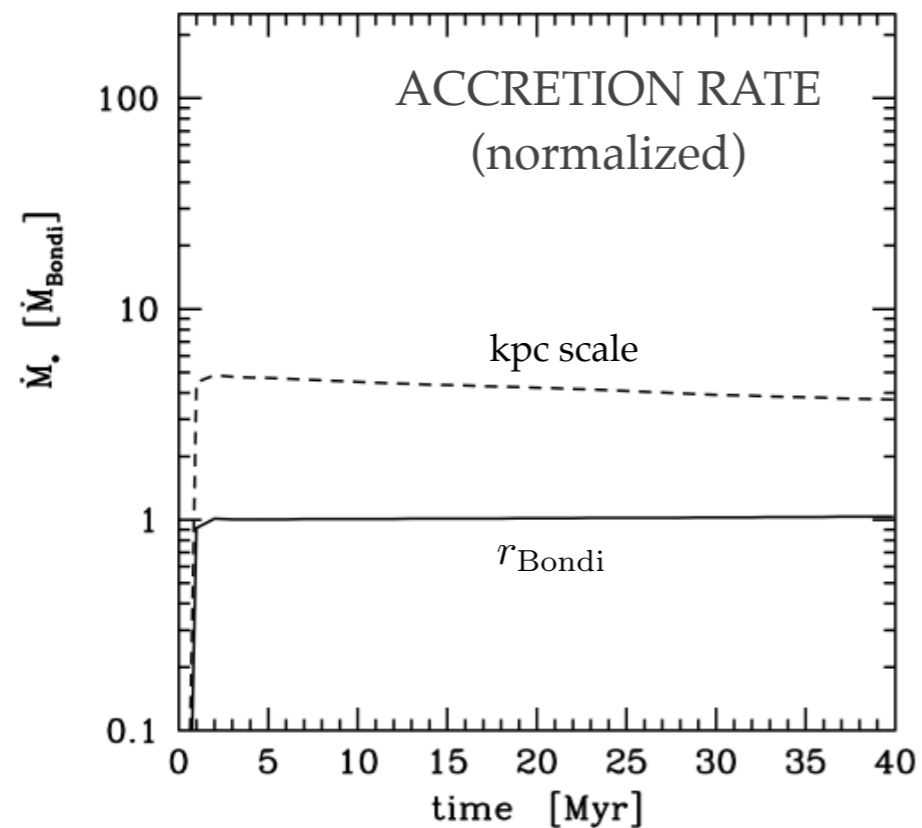
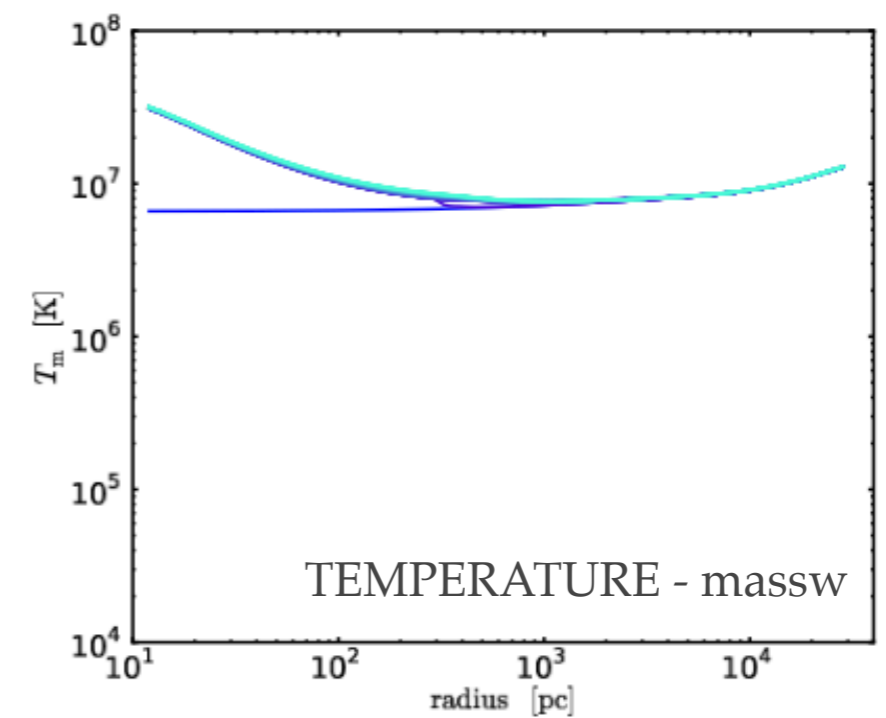
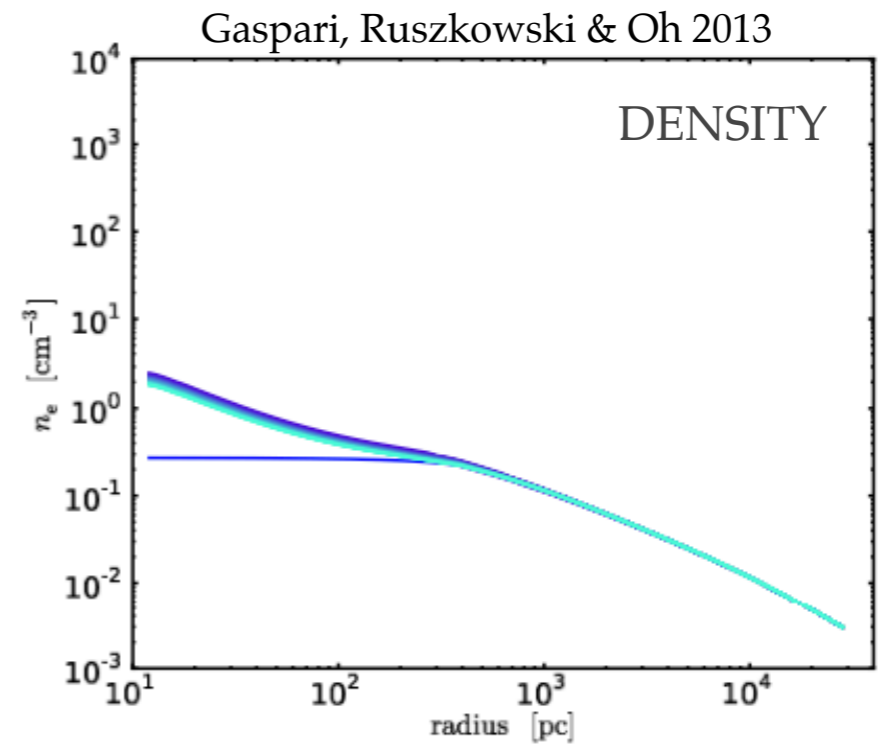
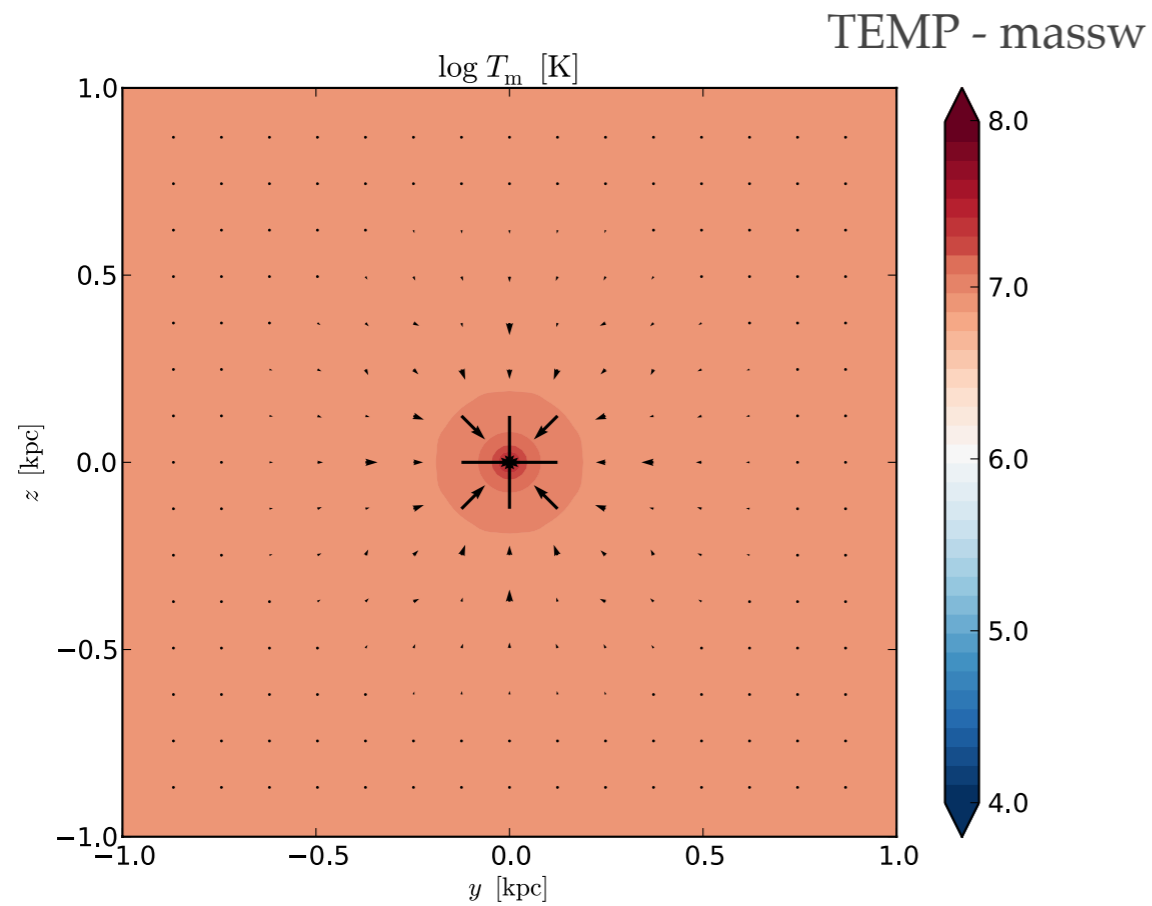
STRATIFICATION

PURE HOT MODE (BONDI)



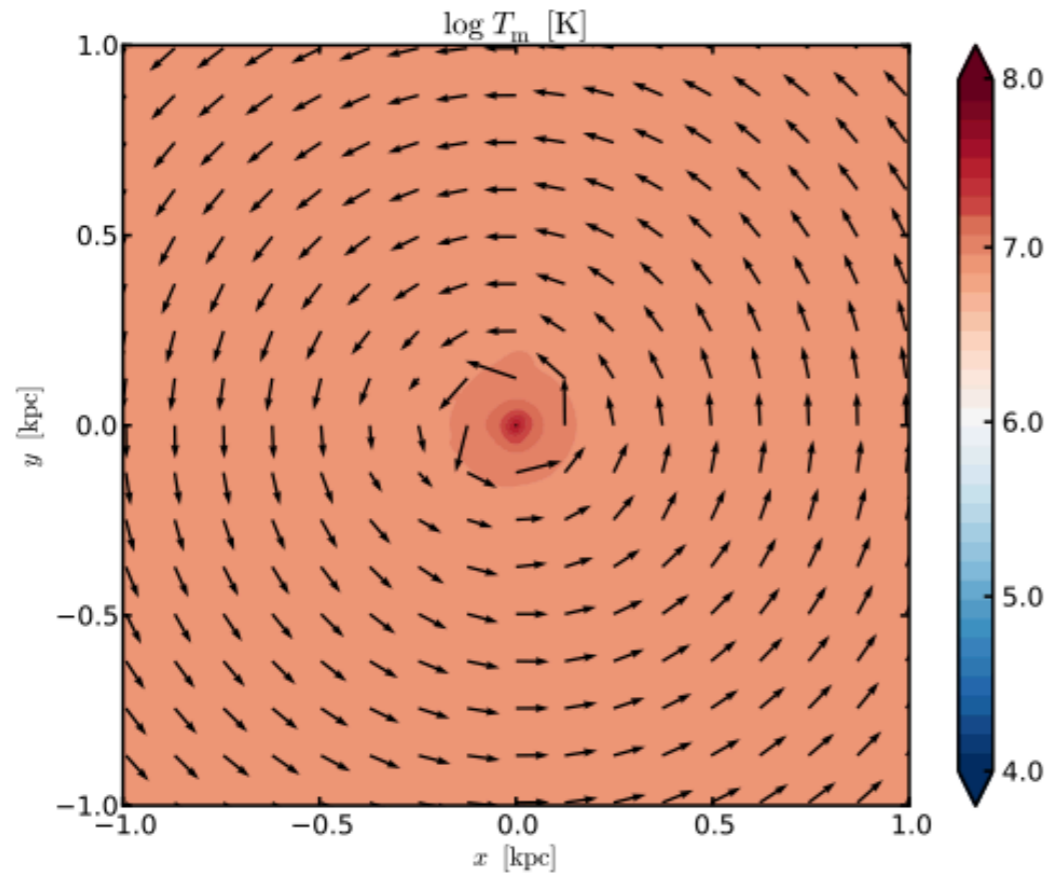
$$\dot{M}_{\text{Bondi}} = 4\pi (GM_{\text{BH}})^2 \rho_\infty / c_{s,\infty}^3$$

PURE HOT MODE (BONDI)



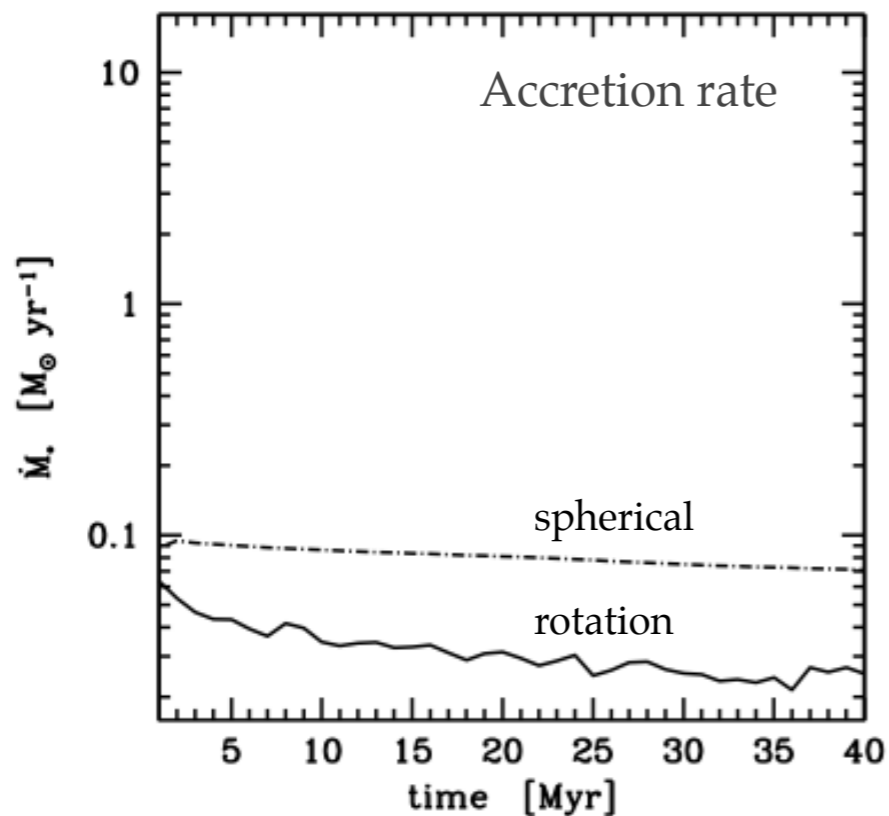
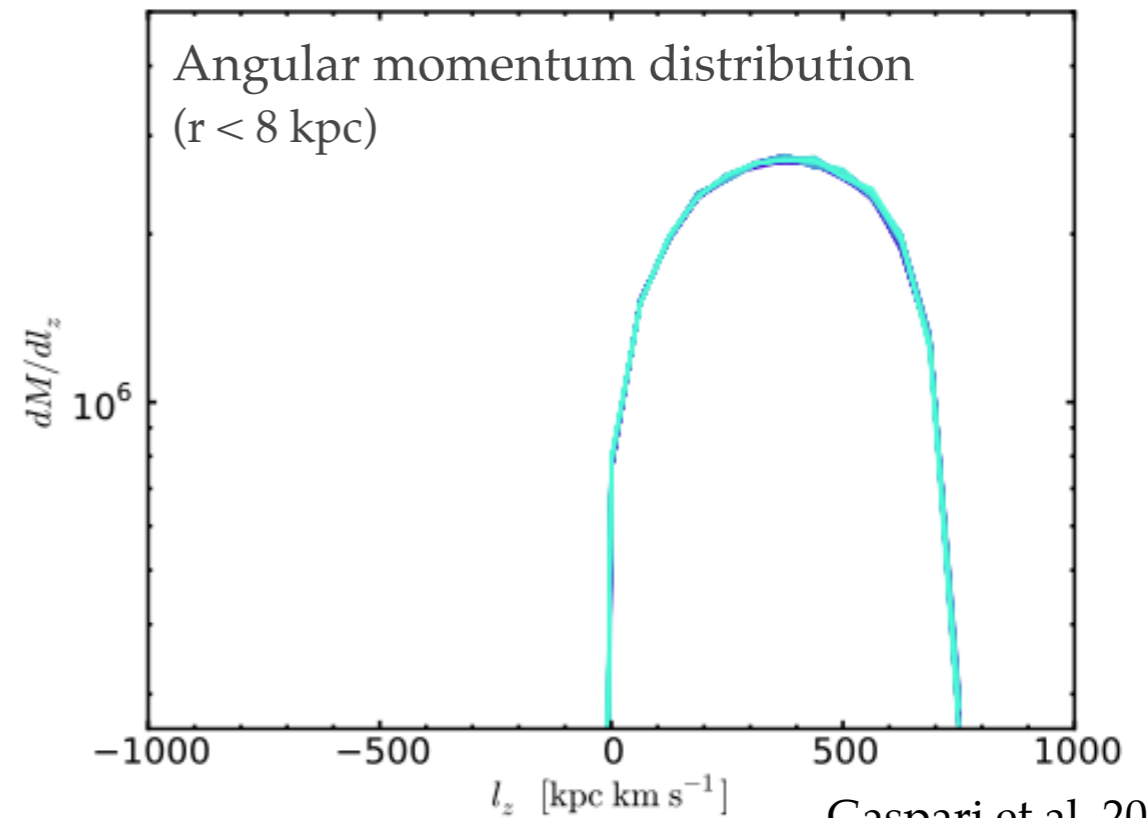
$$\dot{M}_{\text{Bondi}} = 4\pi (GM_{\text{BH}})^2 \rho_{\infty} / c_{s,\infty}^3$$

PURE HOT MODE (ROTATING)



$$v_{\text{rot,gas}} \approx 100 \text{ km s}^{-1}$$

$$\sim 0.3 v_{\text{circ}}$$



1/3 suppression

(geometrically thick toroidal region: \sim invariant with initial rotation)

accretion through a funnel with $\theta \sim \pi/4$

unstable structure: mild variability

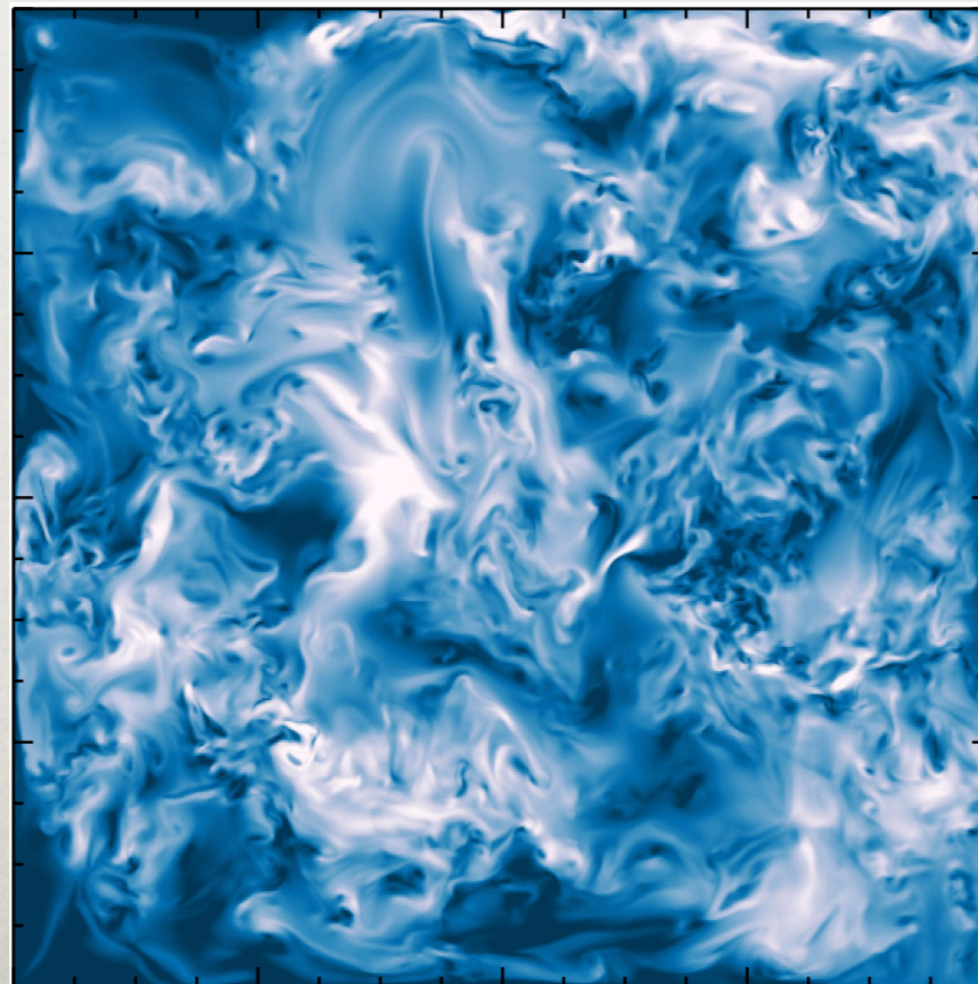
2.

~~STEADY & SPHERICAL~~ TURBULENCE

AGN feedback, SNe, mergers, galaxy motions, ...

subsonic ($\sim 100 \text{ km s}^{-1}$) \rightarrow spectral forcing

Simulations & Observations: e.g.
Sanders & Fabian 2013, Norman &
Bryan 1999, Lau et al. 2009,
Ruszkowski & Oh 2010, 2011, Vazza
et al. 2011, Gaspari et al. 2012b

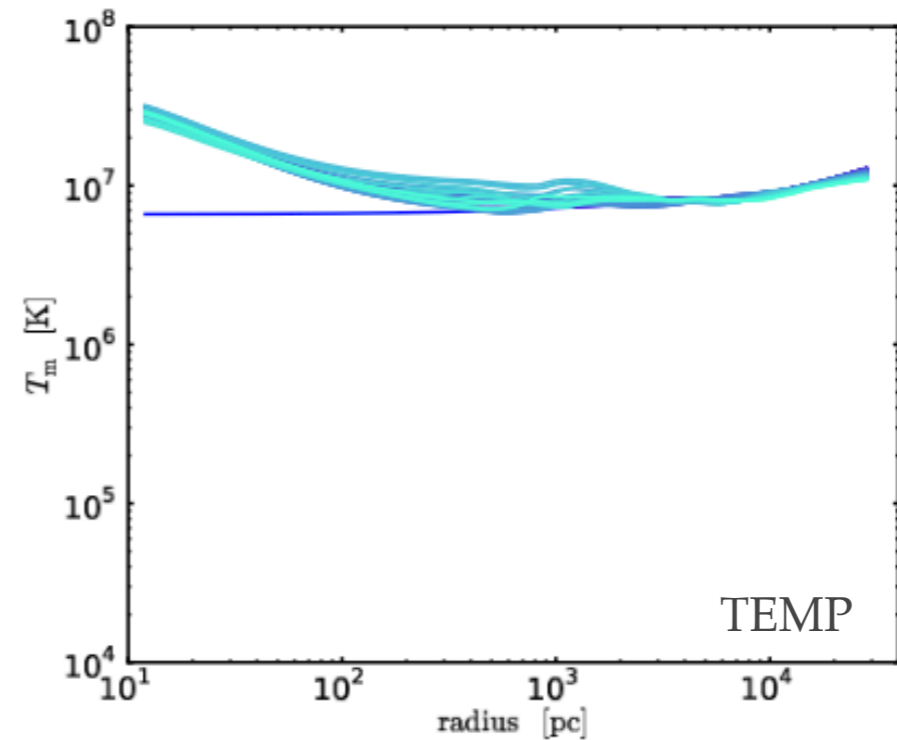
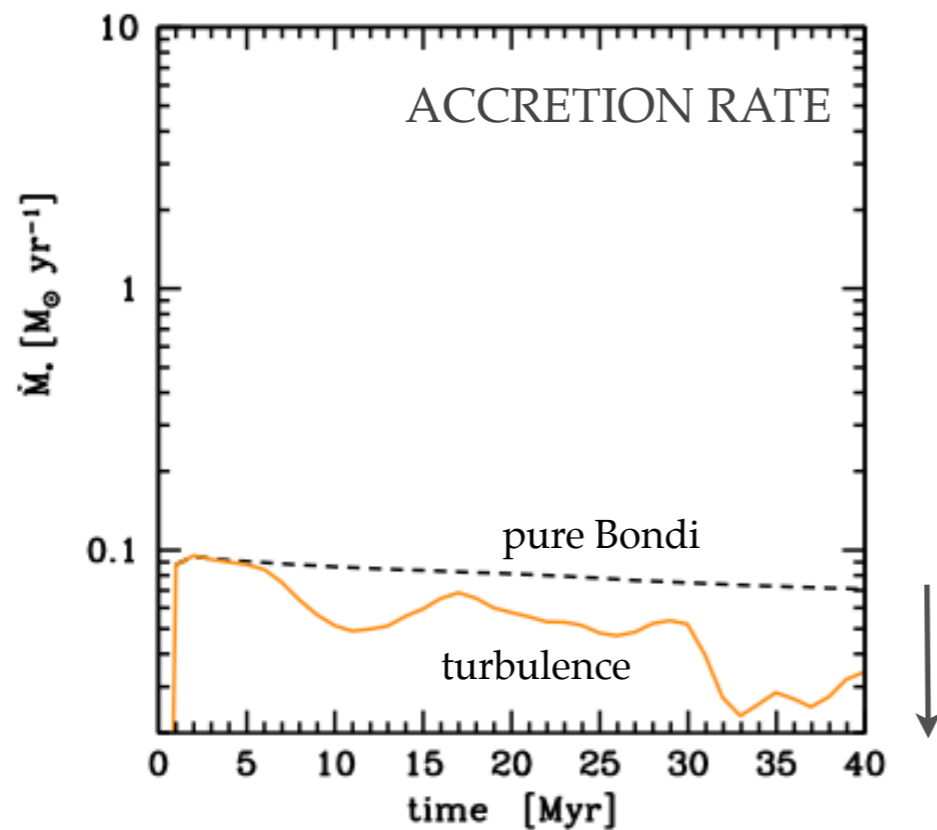
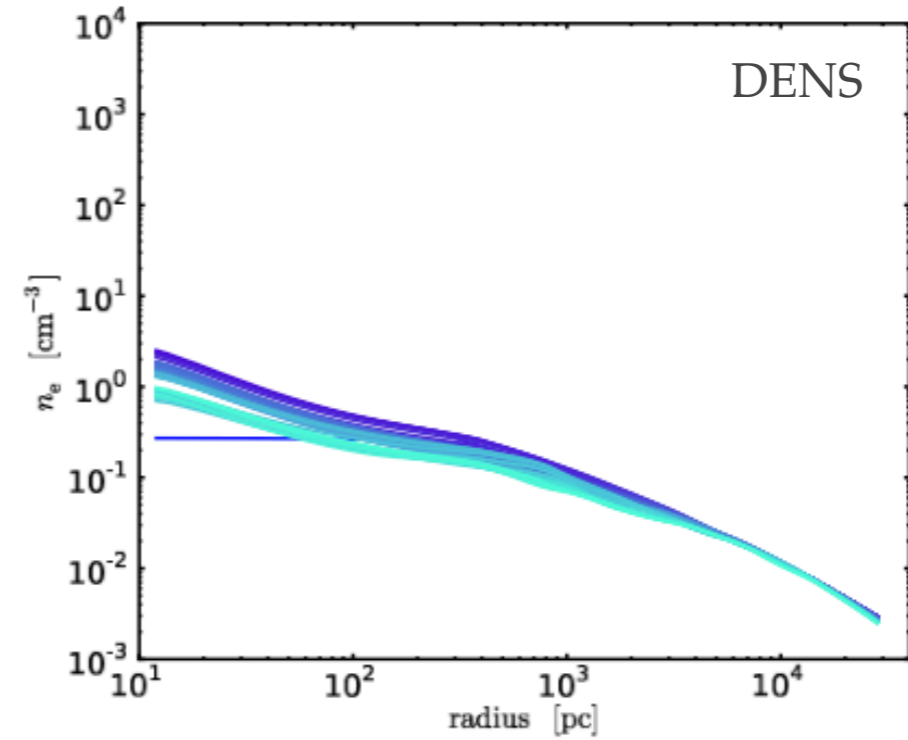
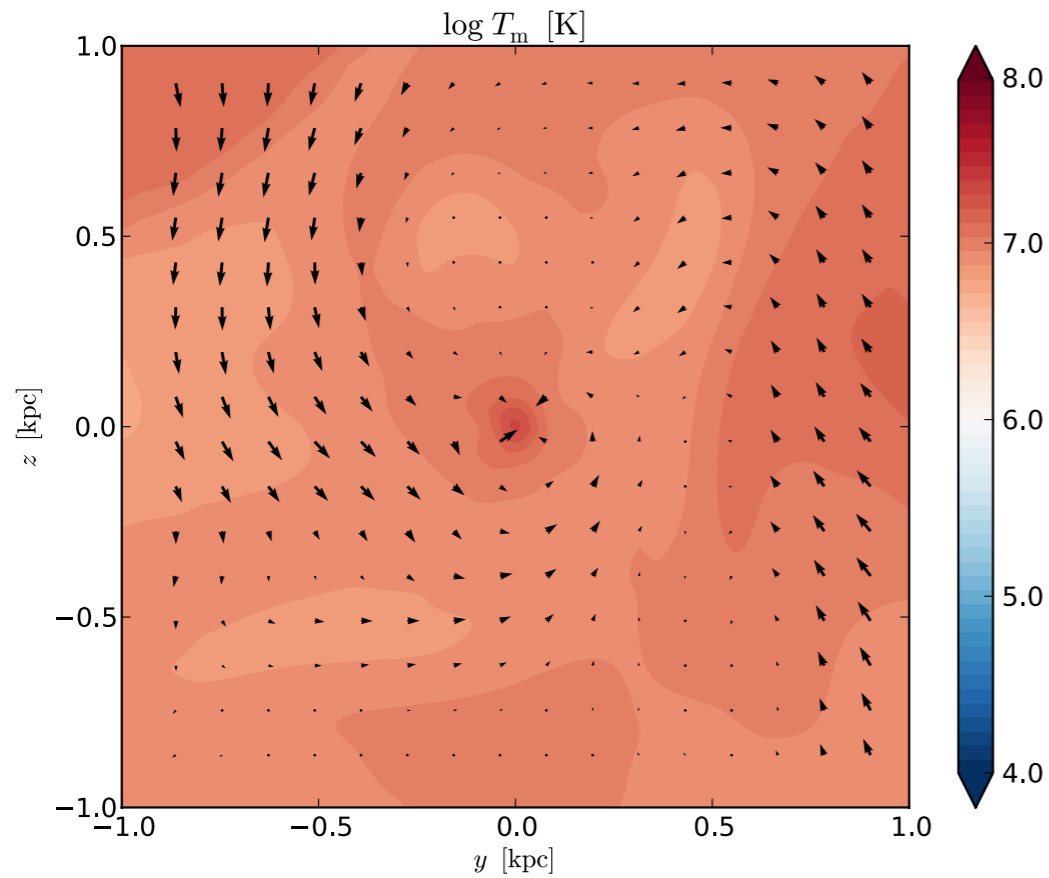


galaxy cluster
turbulence
Gaspari et al. 2014

|v| cut

TURBULENT HOT MODE

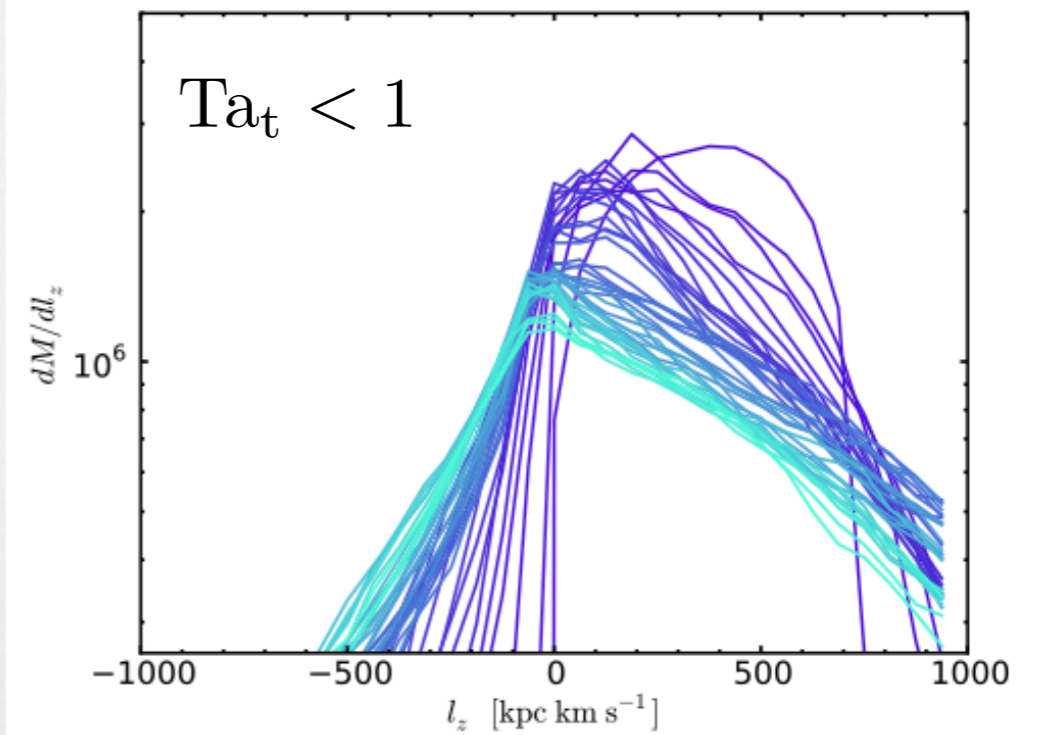
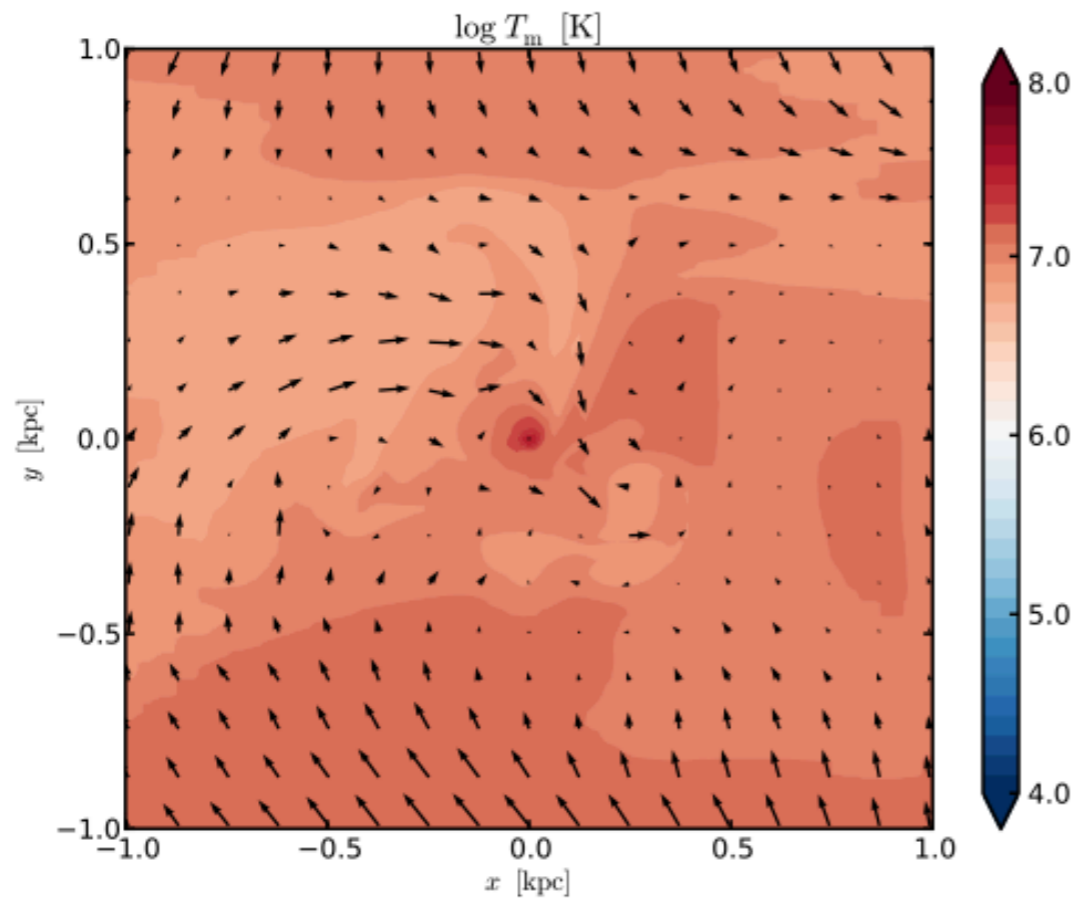
subsonic turbulence $\sigma_v \sim 100 \text{ km s}^{-1}$



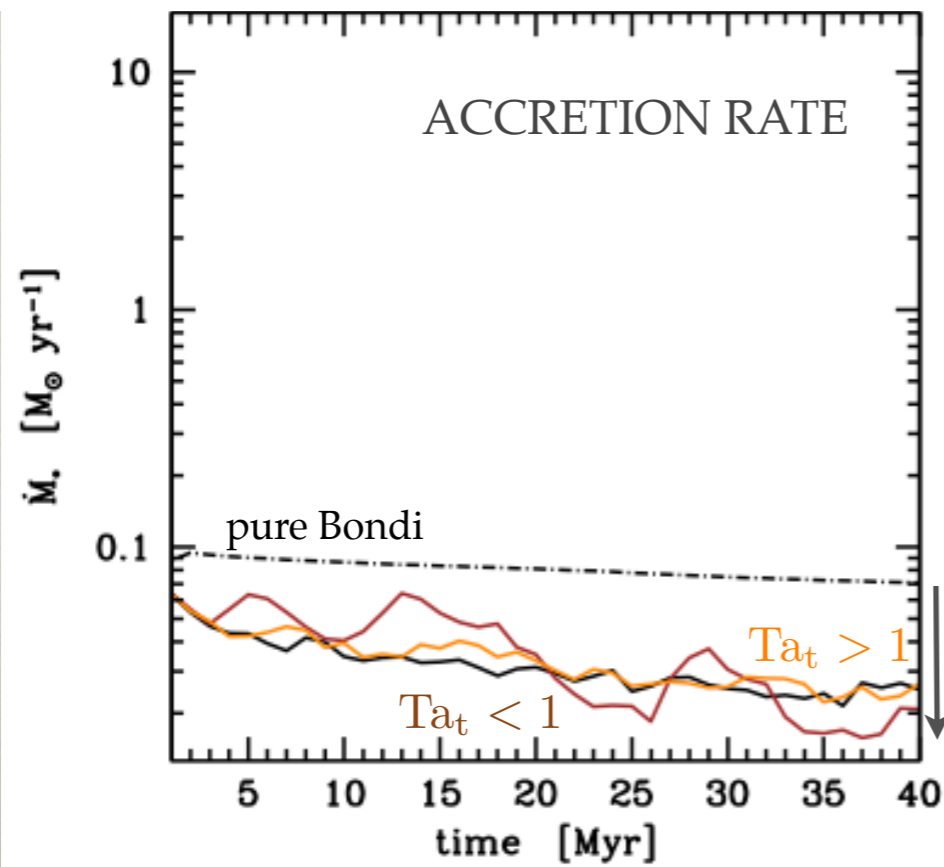
TURBULENT HOT MODE (ROTATION)

$$\text{Ta}_t \equiv v_{\text{rot}} / \sigma_v$$

turbulent Taylor number

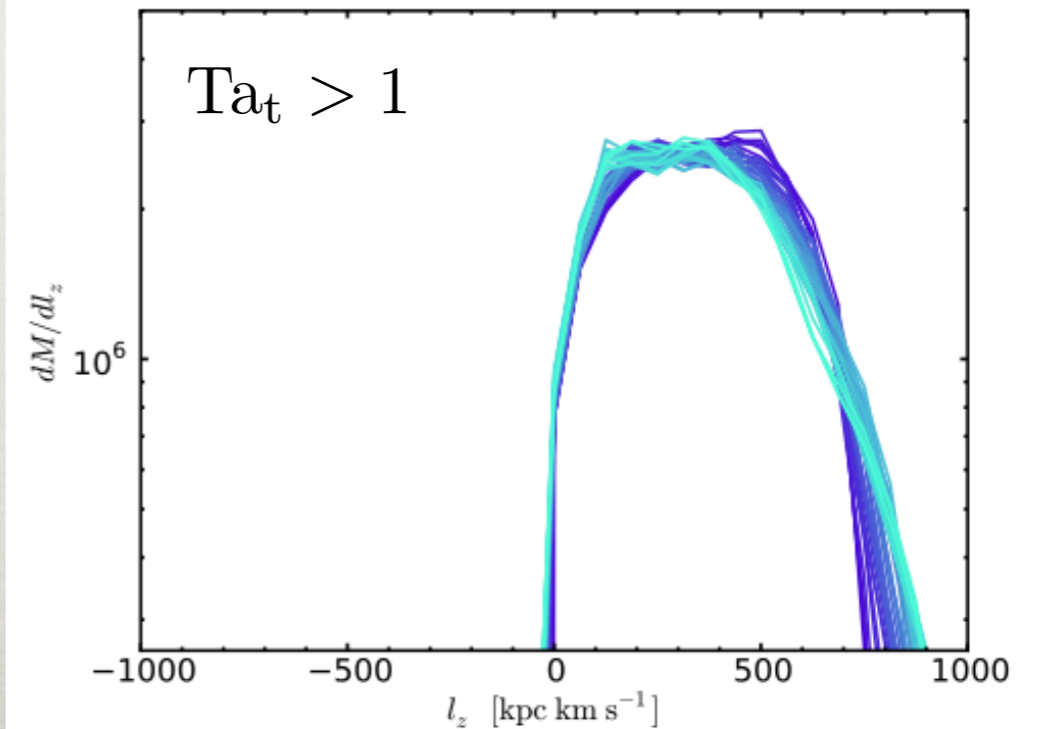


broadening allows retrograde motions



generation of local vorticity: again ~1/3 suppression

similar to purely rotating run (solid black line)

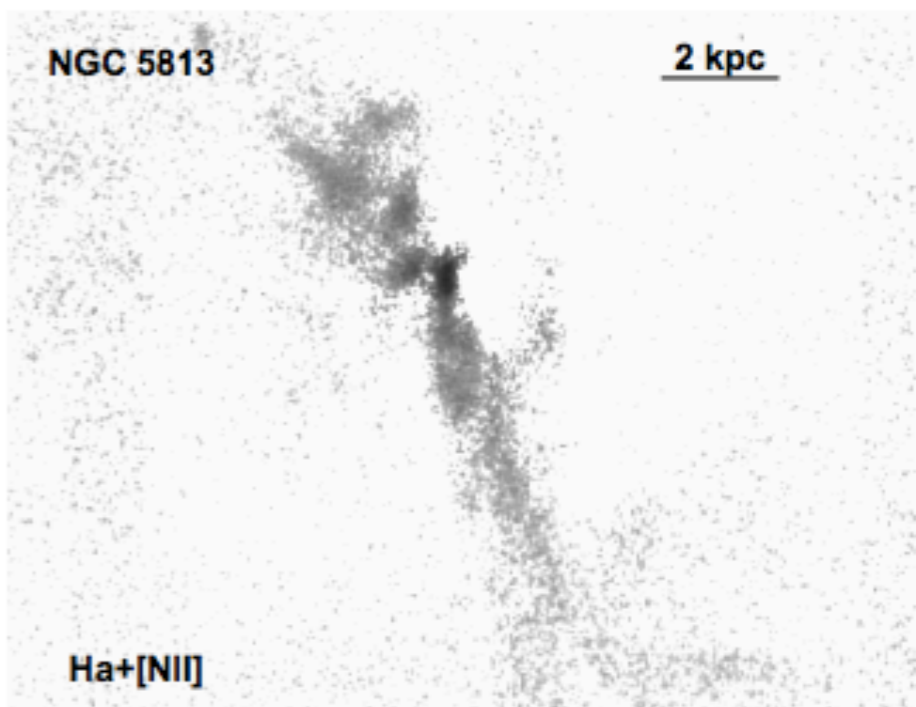
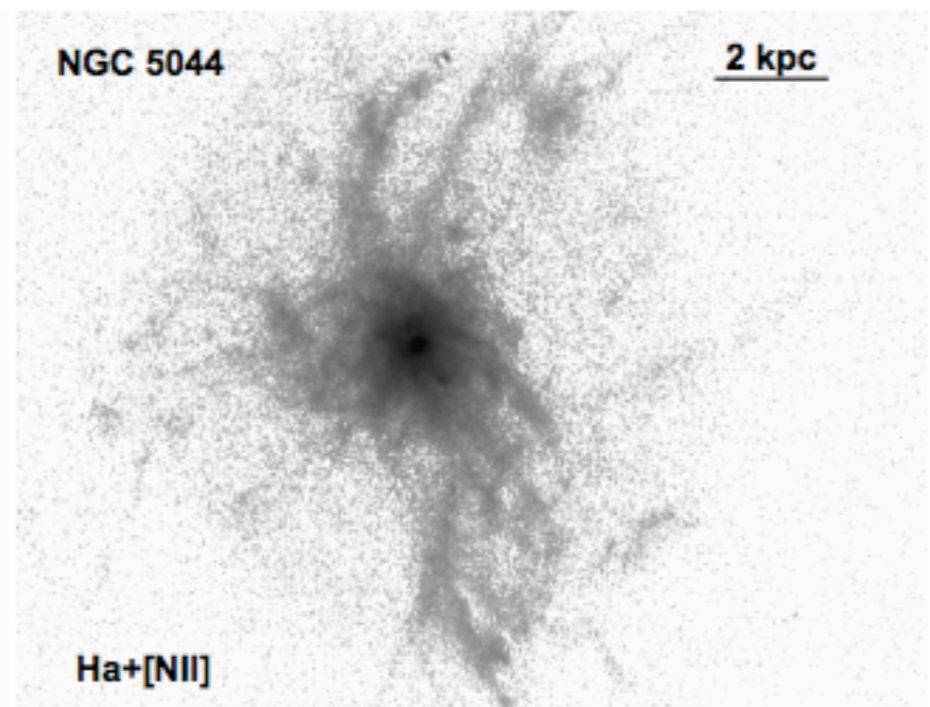
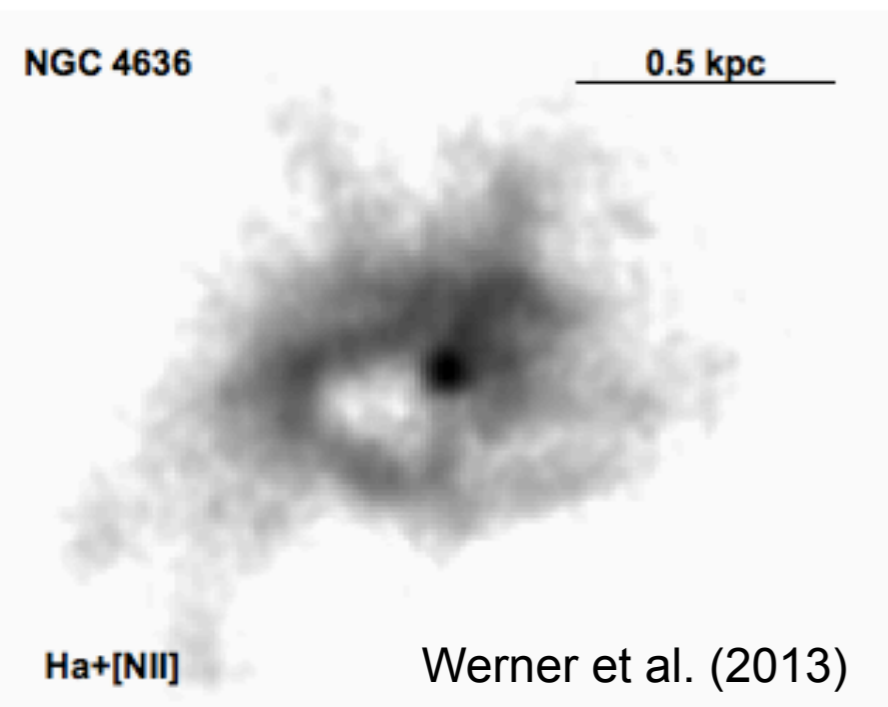


3.

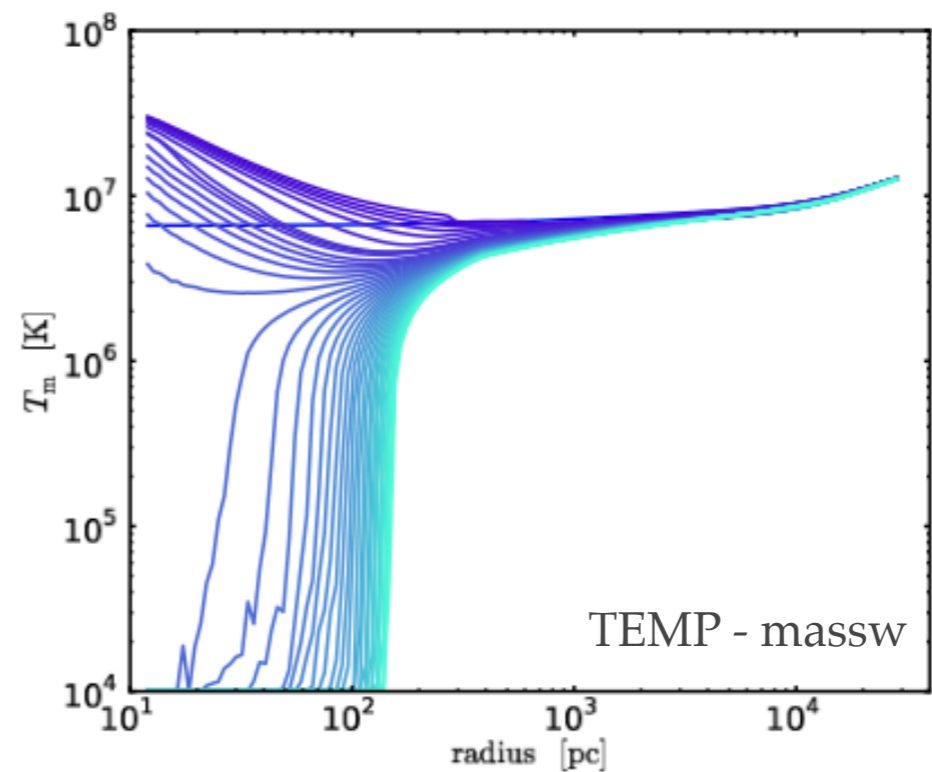
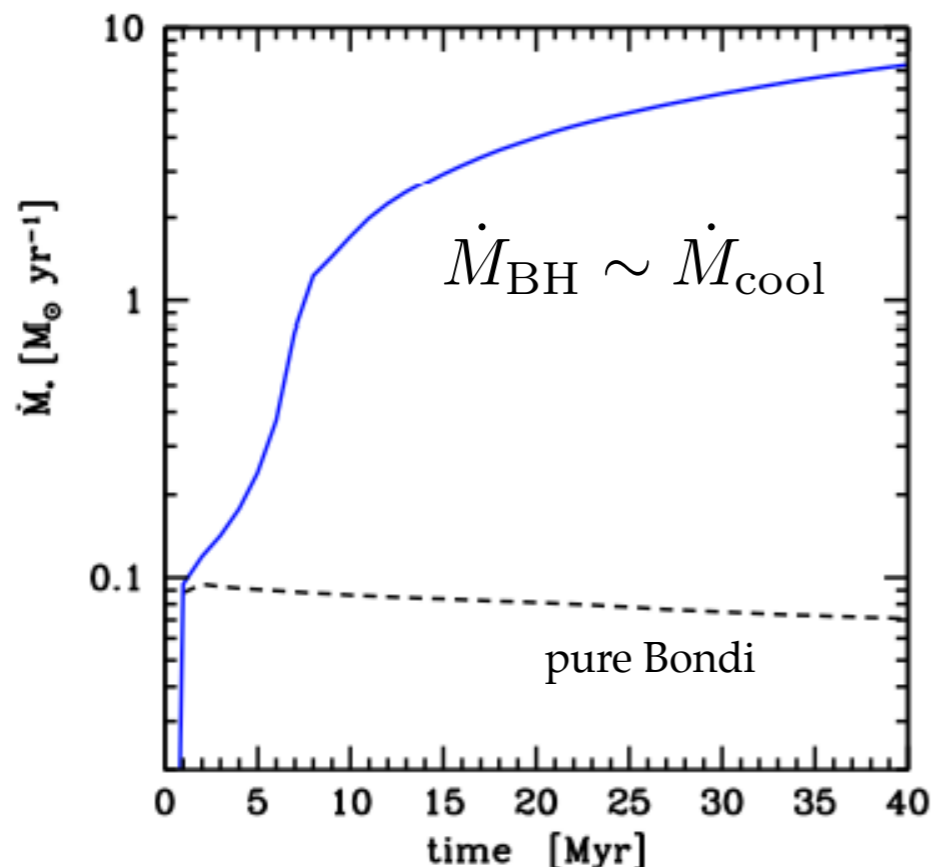
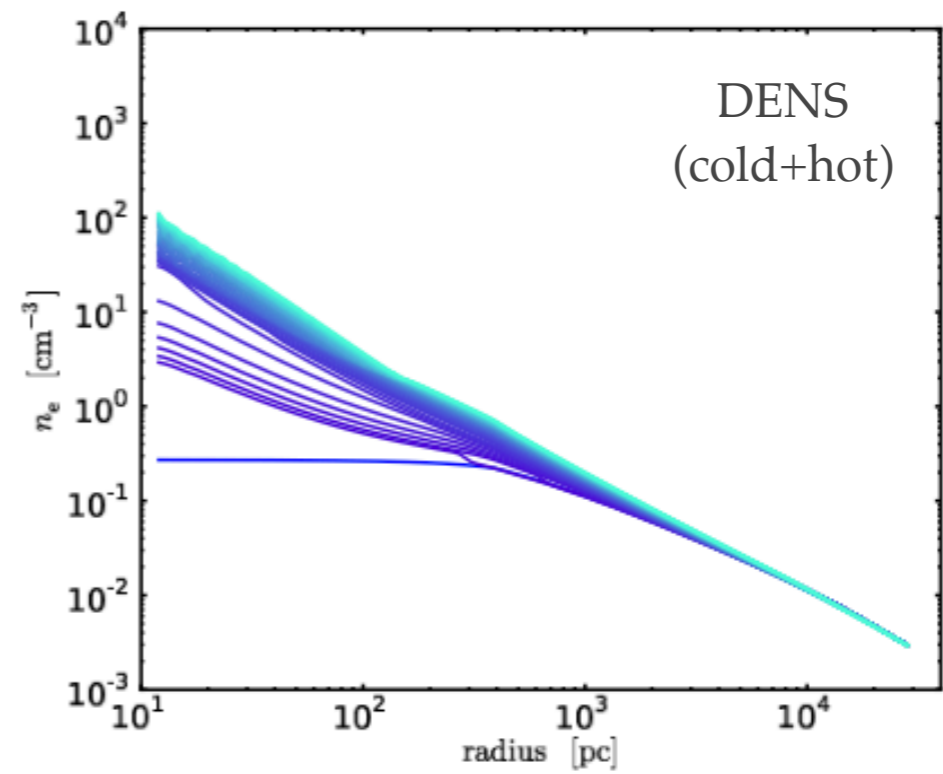
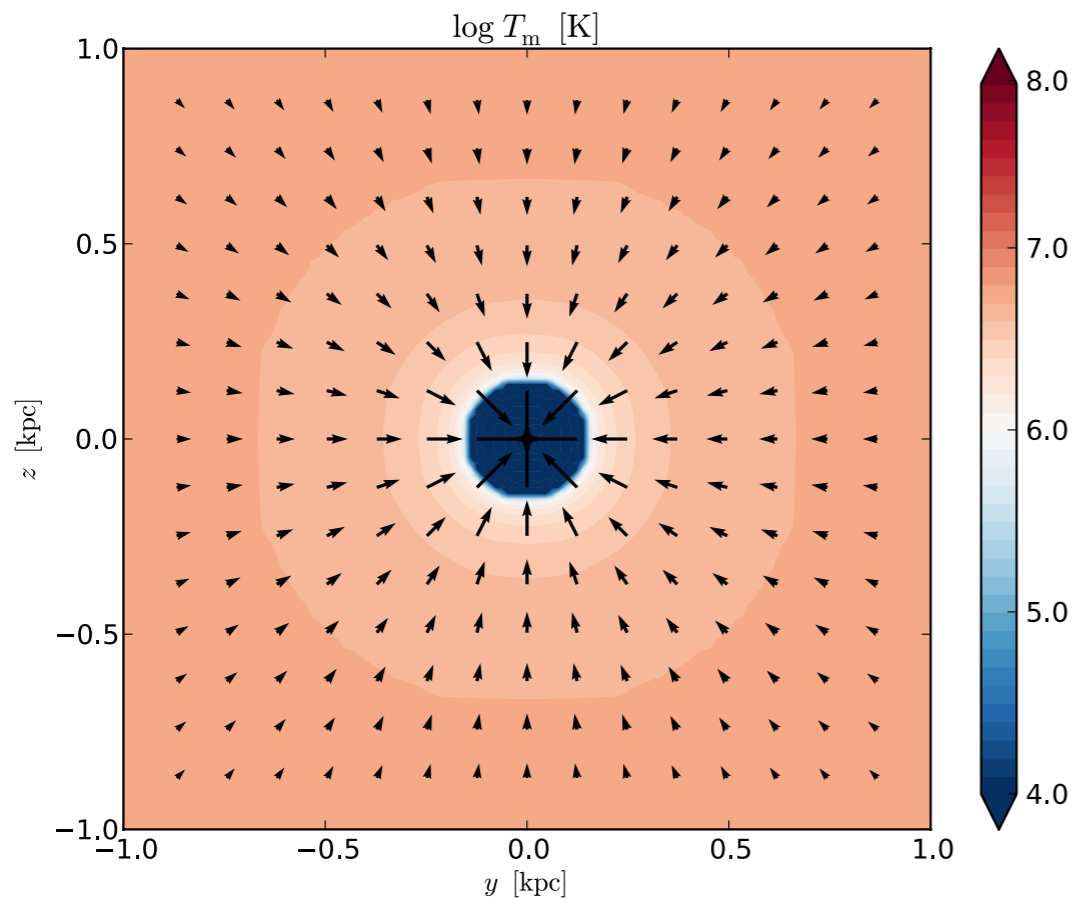
~~**ADIABATIC**~~

COOLING

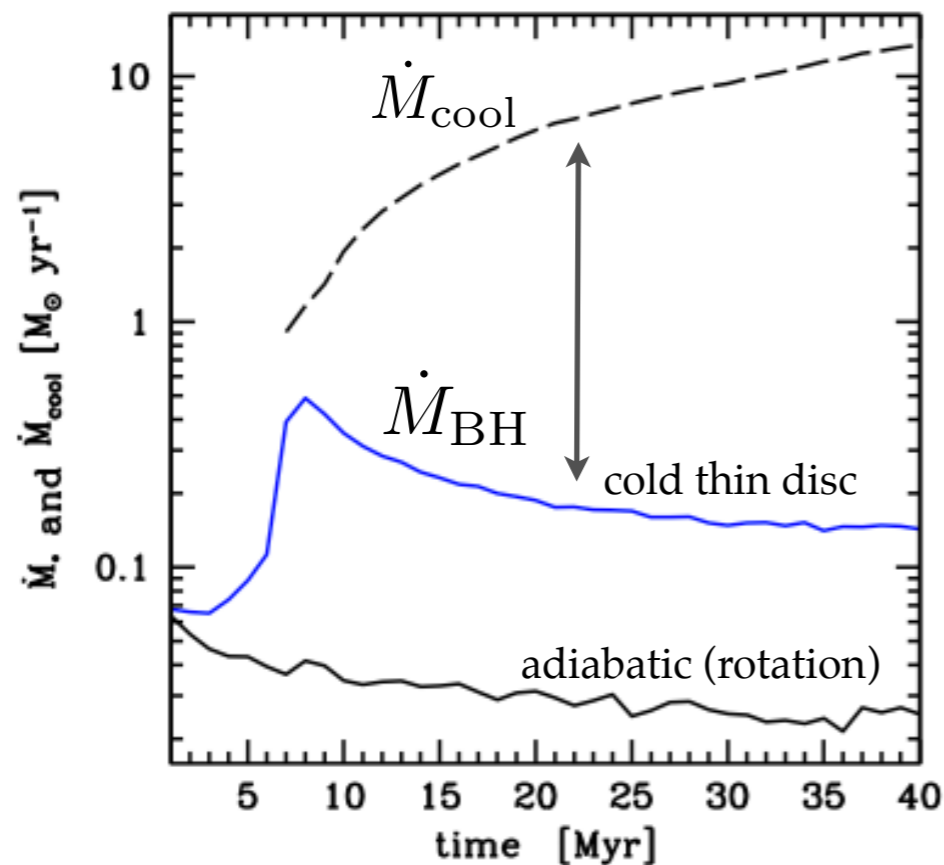
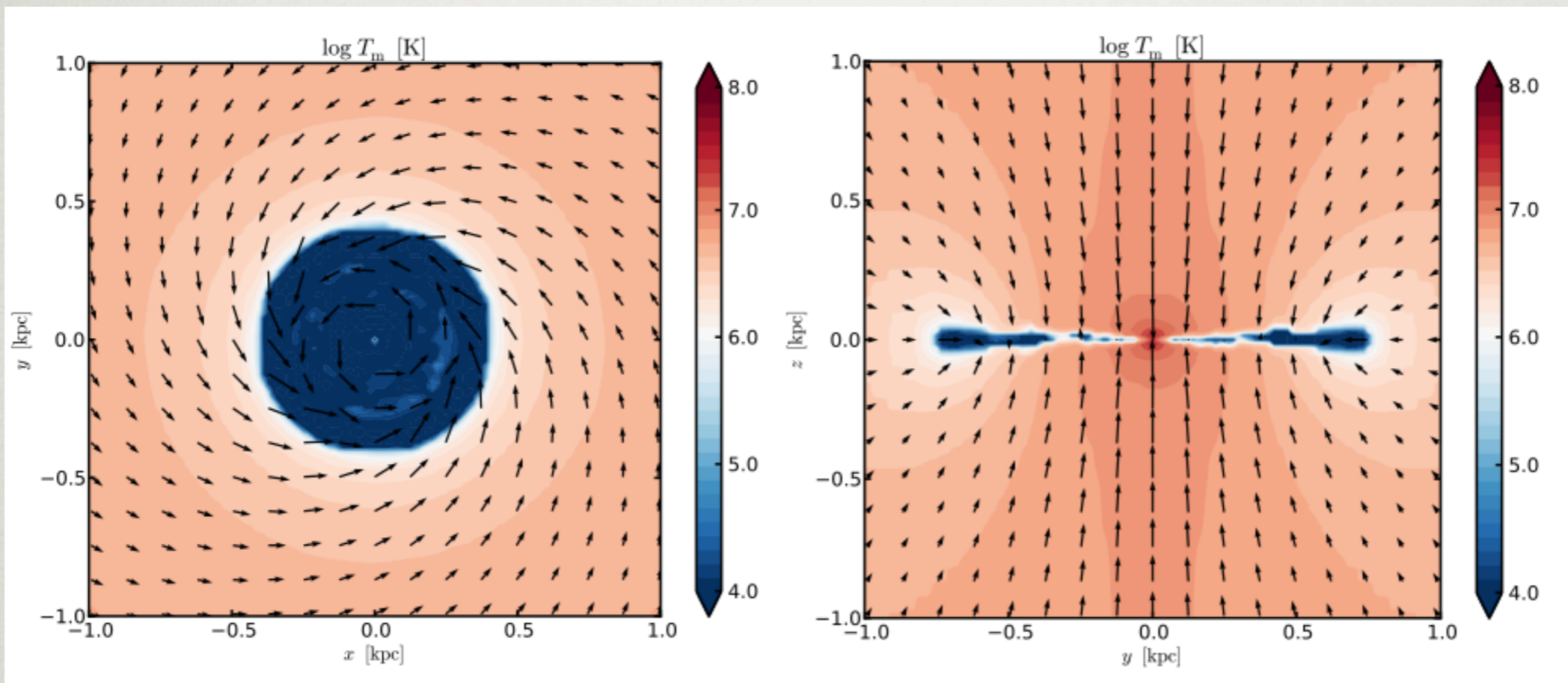
$$\mathcal{L} = -n_e n_i \Lambda(T, Z)$$



PURE COLD MODE



PURE COLD MODE (ROTATION)



COLD THIN DISC

size of the disc: how long the cooling-dominated phase has lasted (low heating and turbulence)

many elliptical galaxies with inner discs: e.g., Mathews & Brighenti 2003; Young et al. 2011; Alatalo et al. 2013; NGC 6868 and NGC 7049 --> Werner et al. 2014).

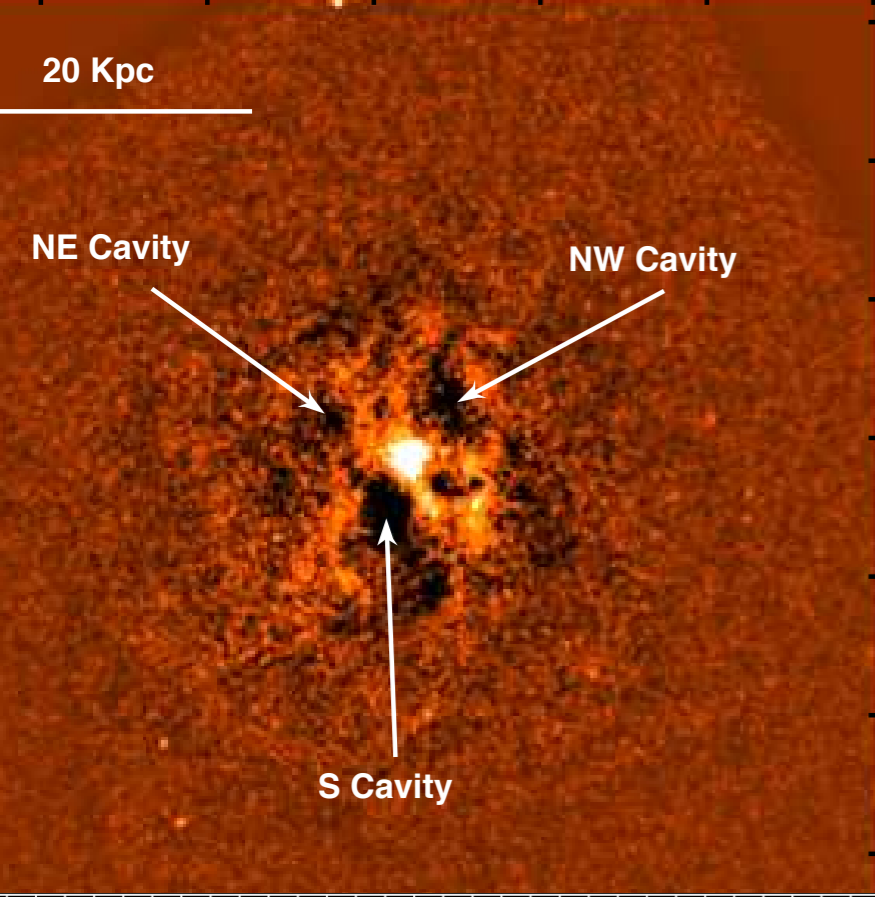
4.

~~**PURE COOLING**~~

HEATING

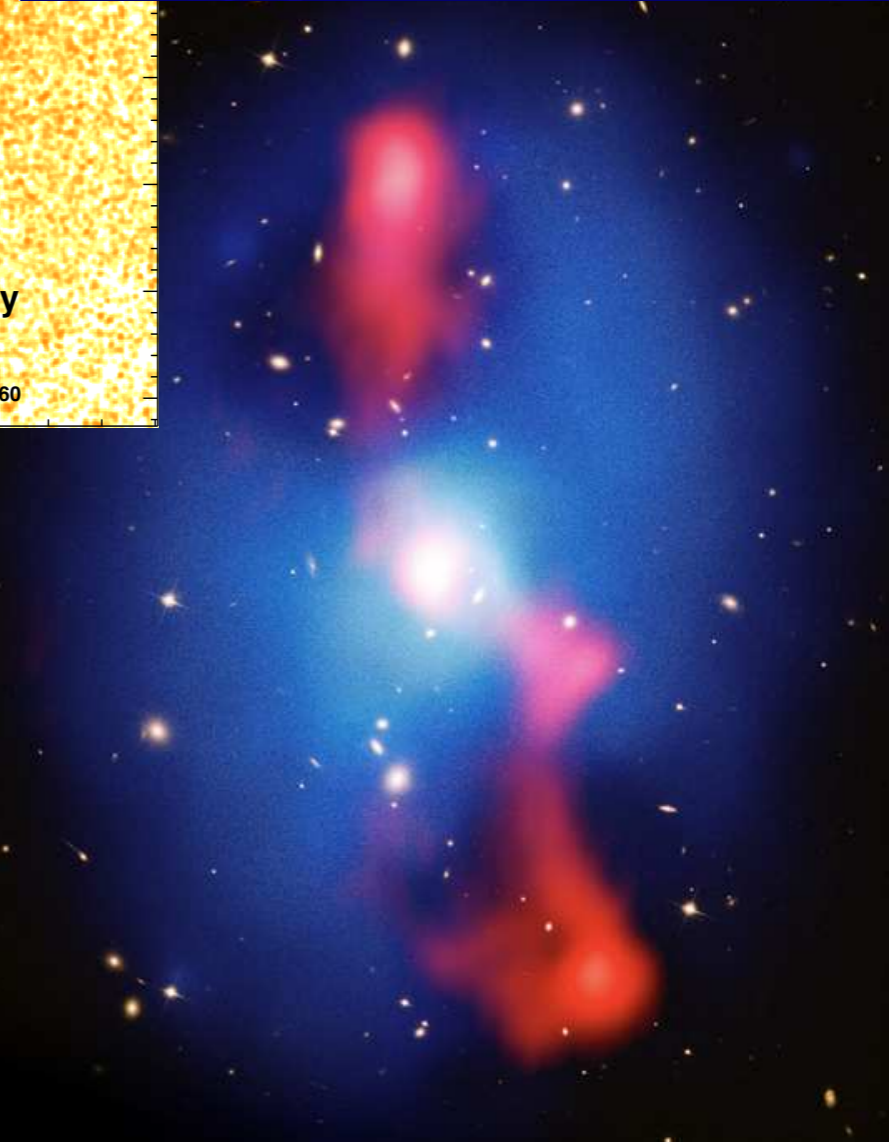
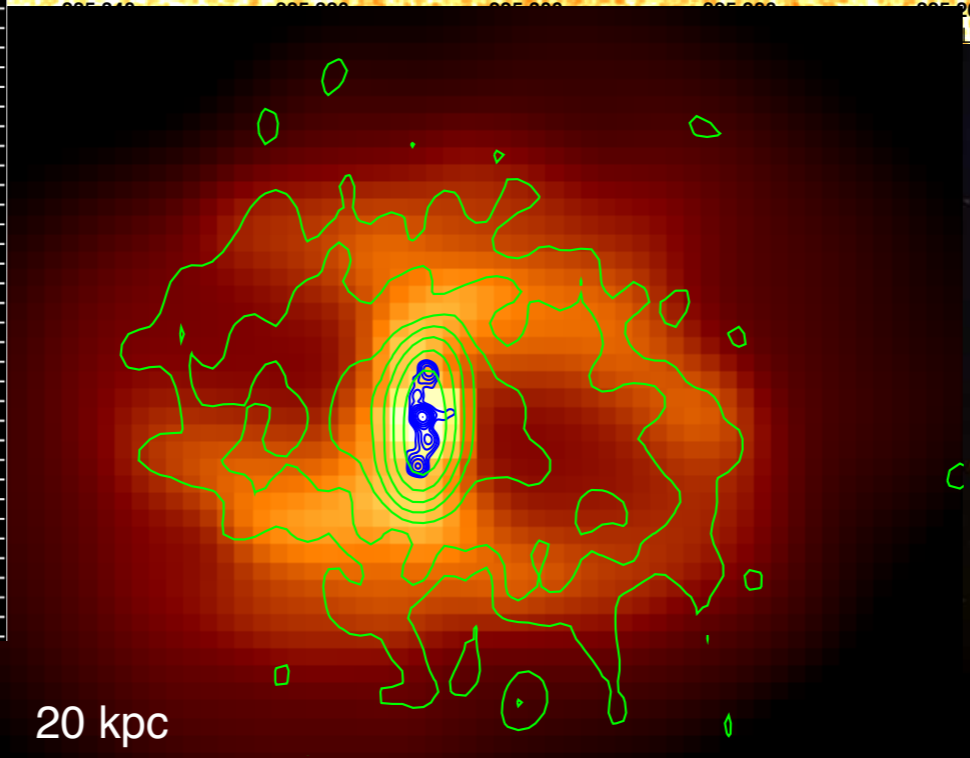
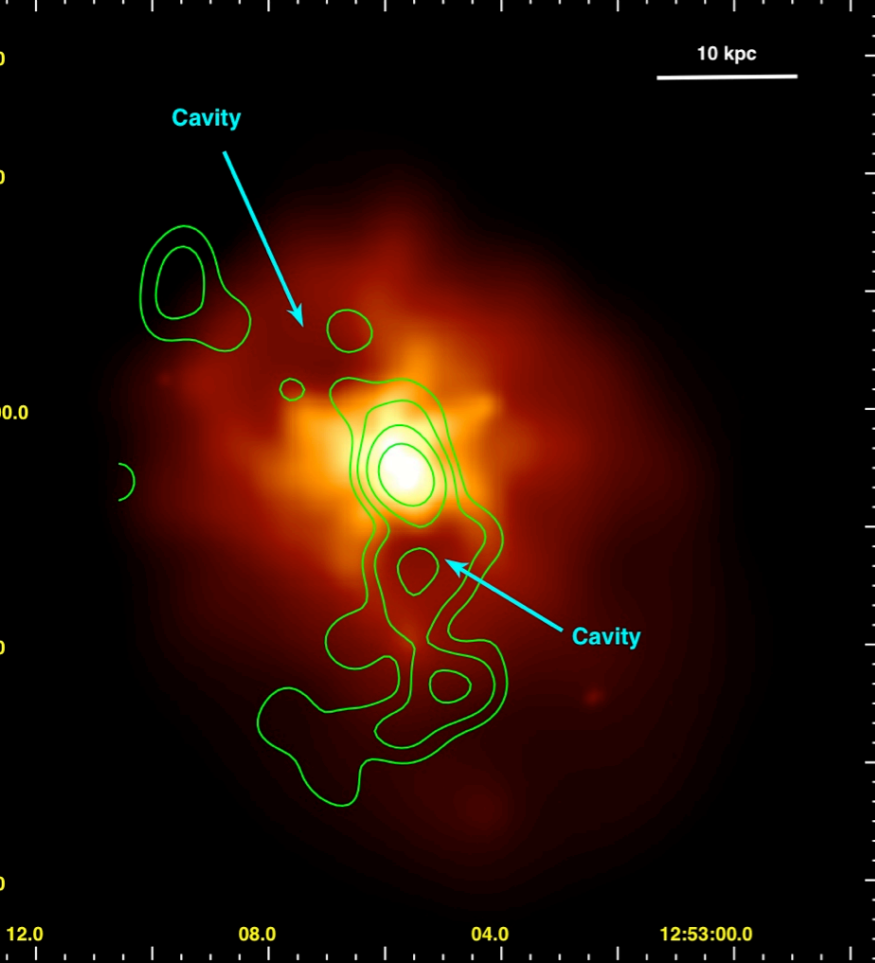
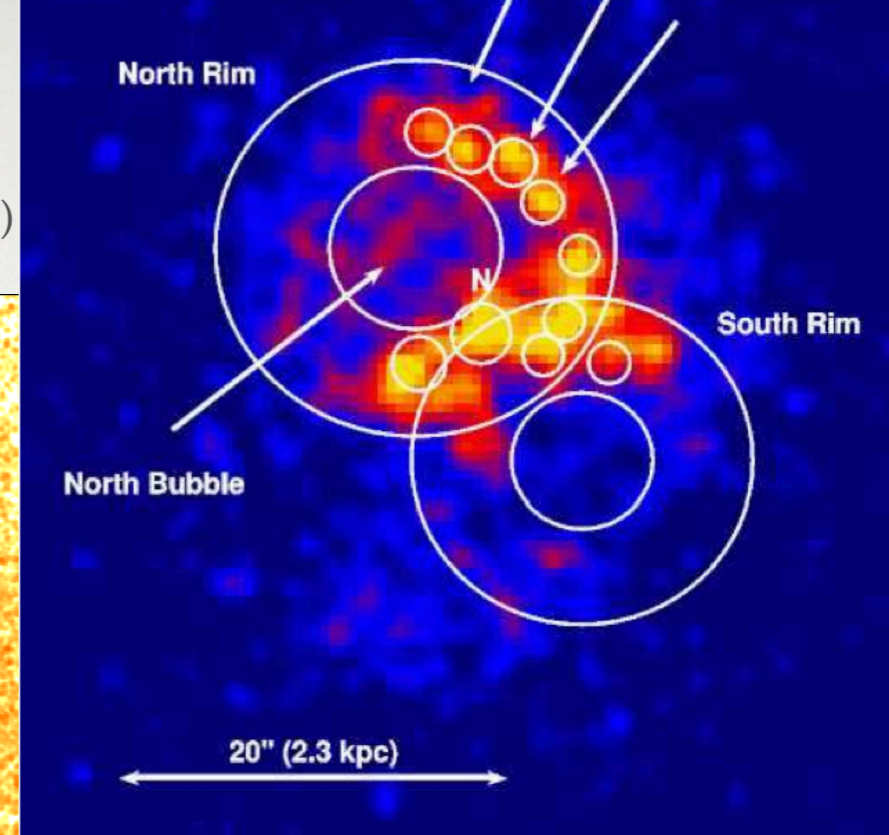
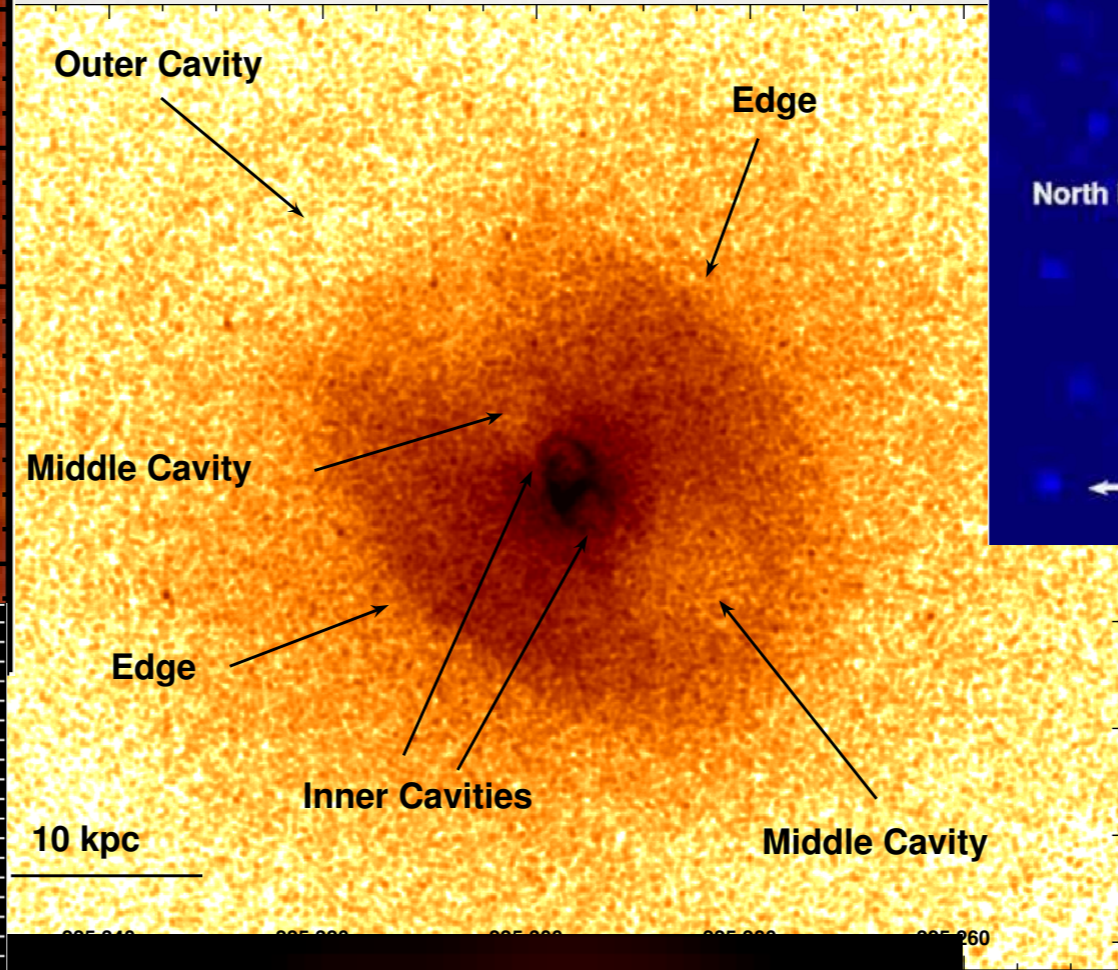
AGN feedback: outflows, shocks, turbulence

SNe, mergers, conduction, cosmic rays can contribute



AGN FEEDBACK

NGC 5044 (David+2009) NGC 5846 (Machacek+11)
 NGC 5813 (Randall+11)



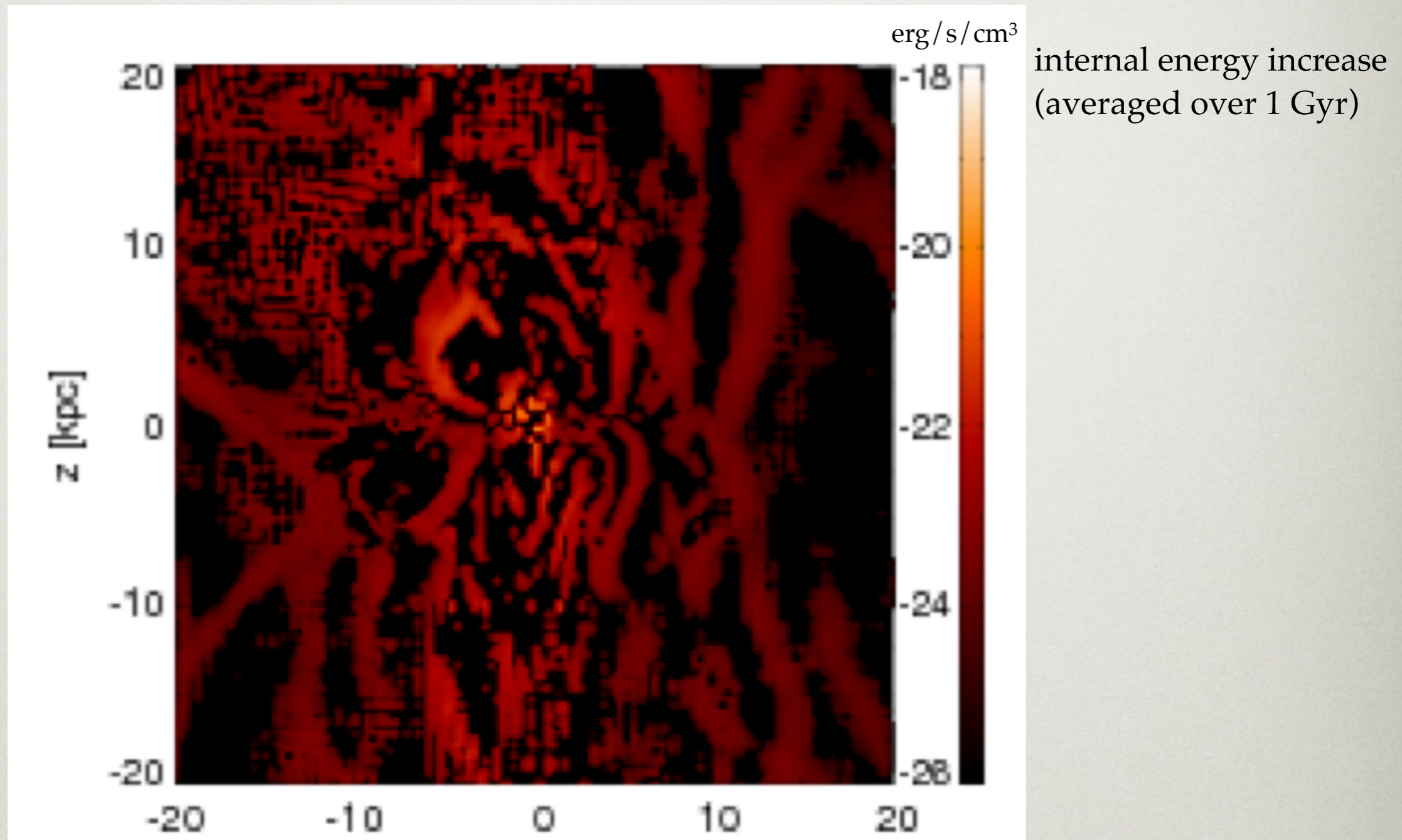
HCG 62 (Gitti+10)

RBS 797
(Gitti+11)

MS0735.6 cluster (McNamara+05)

GLOBAL THERMAL EQUILIBRIUM

AGN jet feedback: net heating deposition

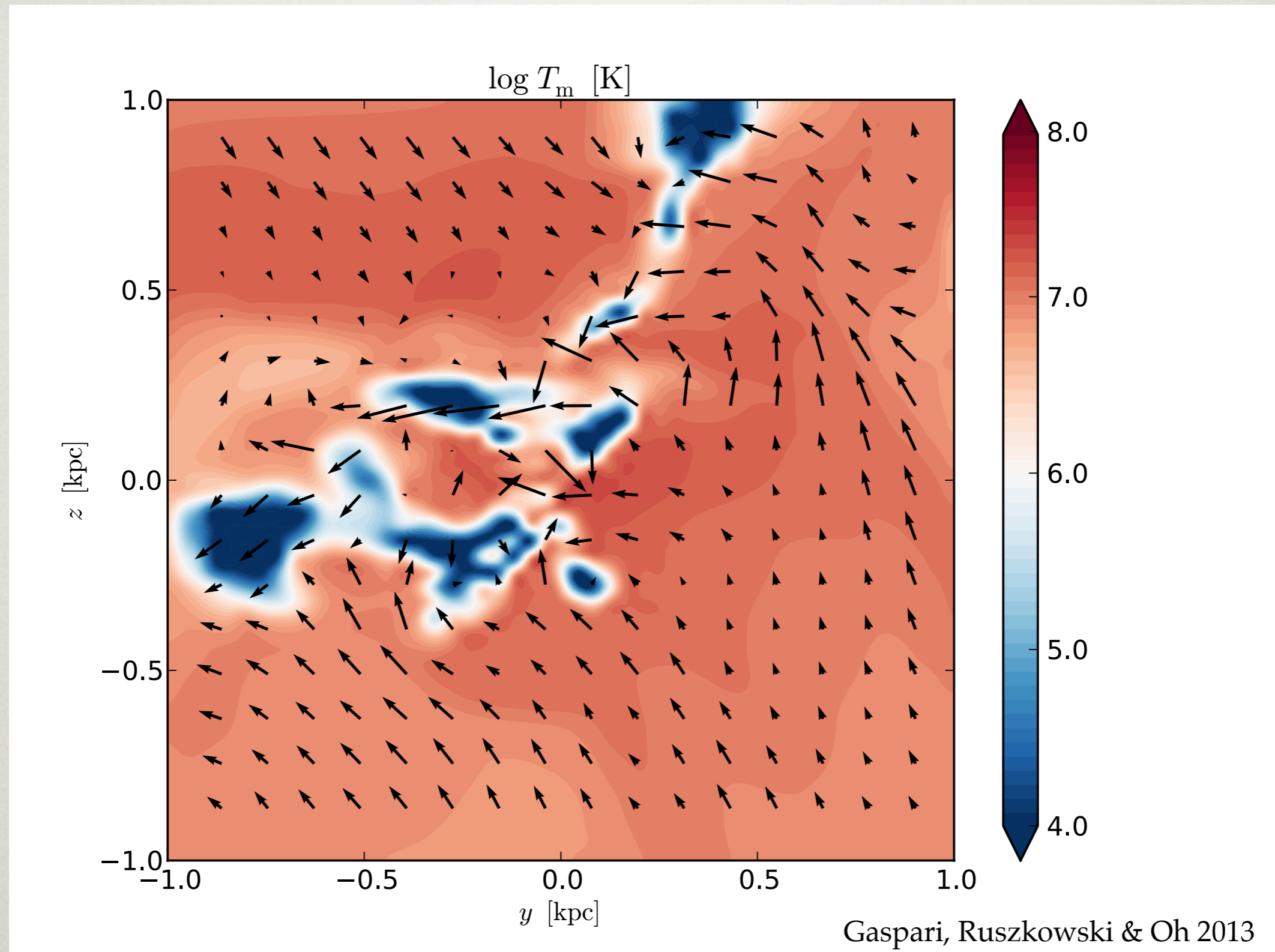


Gaspari, Ruszkowski & Sharma 2012

$$\mathcal{H} \sim \langle \mathcal{L} \rangle$$

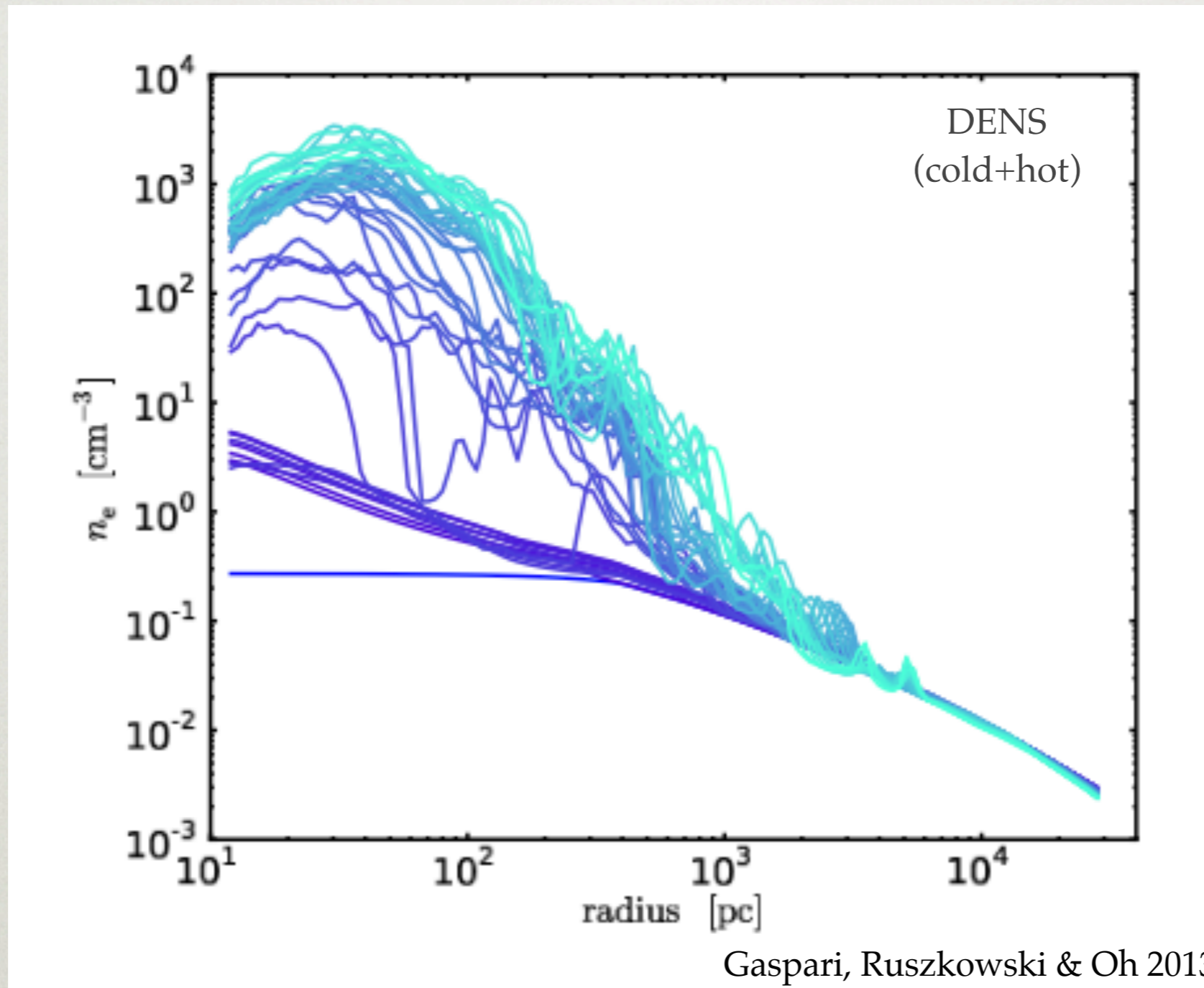
see also McCourt et al. 2012, Sharma et al. 2012, Banerjee & Sharma 2014

CHAOTIC COLD ACCRETION (“CCA”)



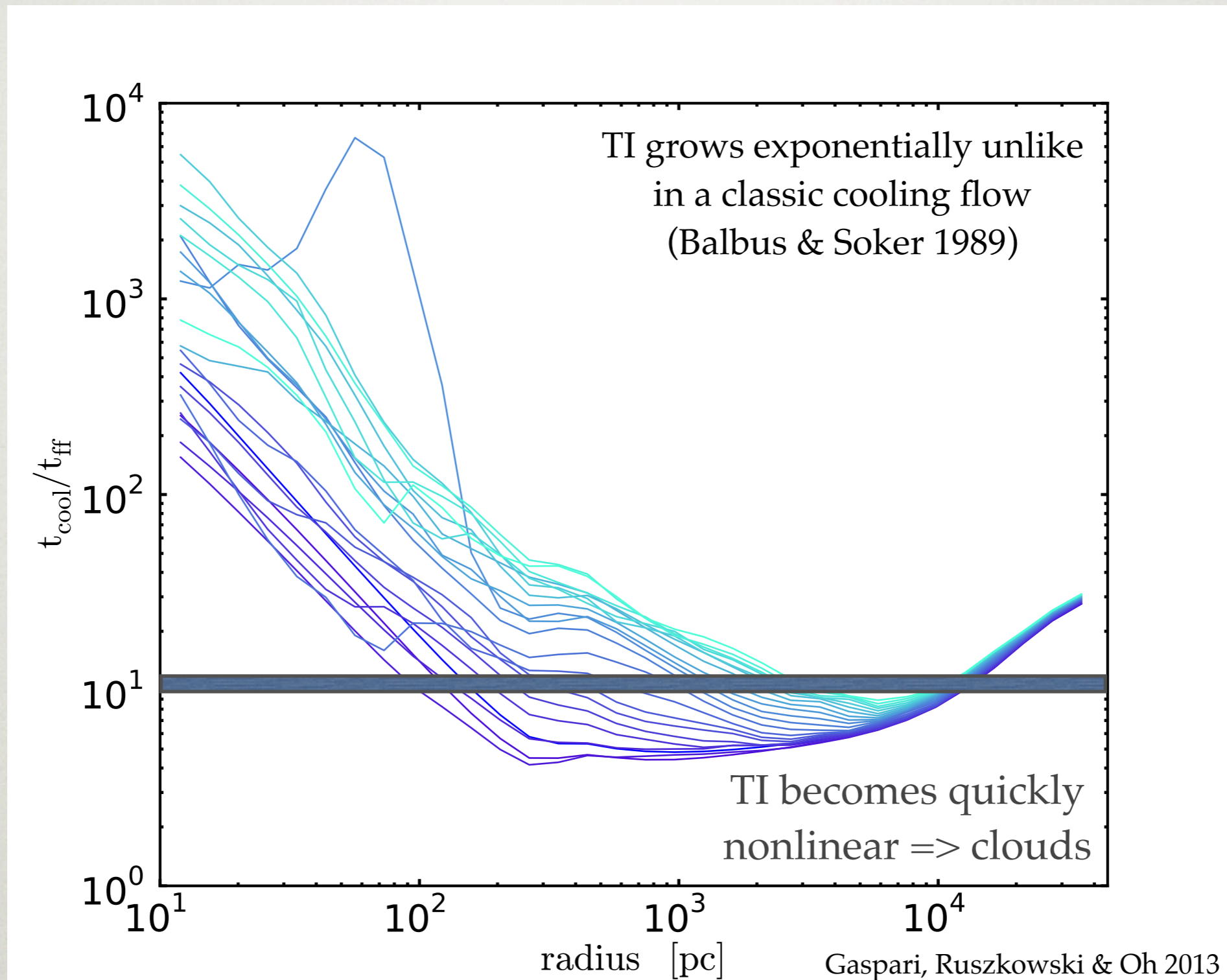
COOLING + HEATING + TURBULENCE

CHAOTIC COLD ACCRETION



condensation up to several kpc

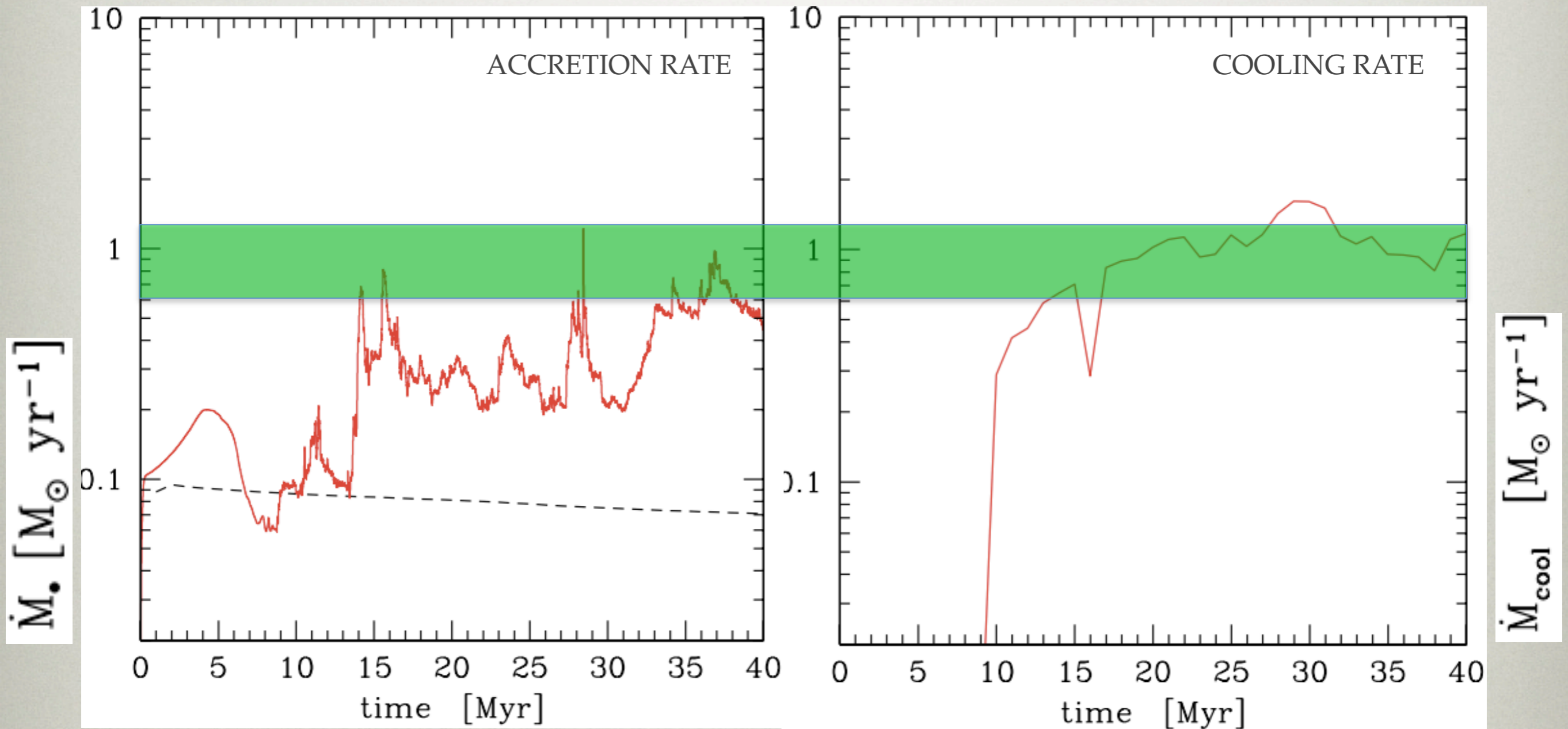
CHAOTIC COLD ACCRETION



Thermal Instability (TI): $t_{\text{cool}}/t_{\text{ff}} < 10$

CHAOTIC COLD ACCRETION

Gaspari, Ruszkowski & Oh 2013



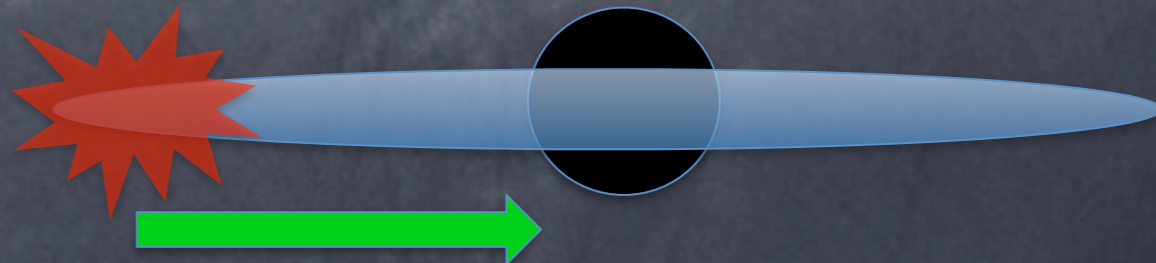
$$\dot{M}_{\text{BH}} \sim \dot{M}_{\text{cool}}$$



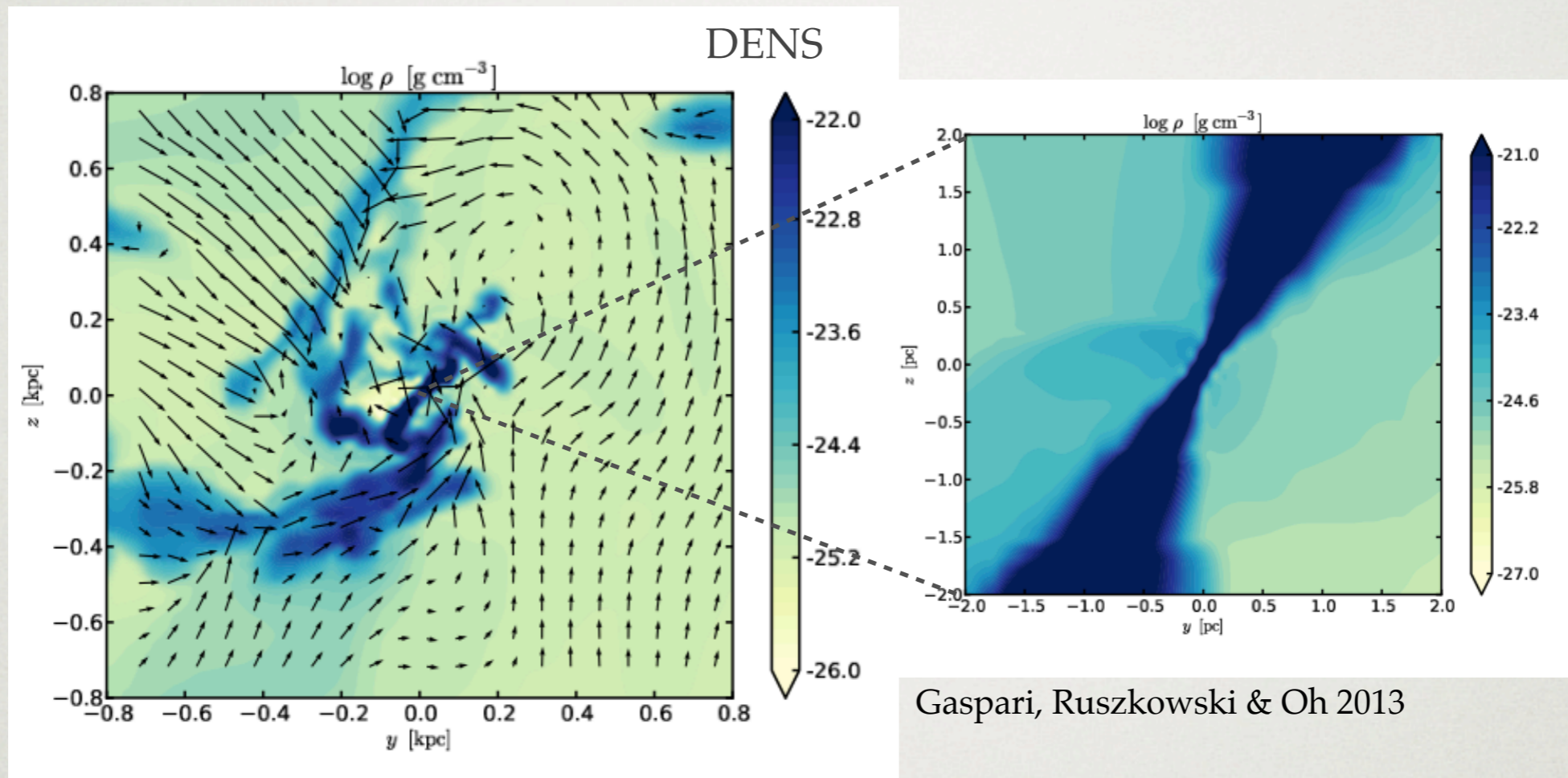
Angular momentum
cancellation



Capture
by clumpy
torus



CHAOTIC COLD ACCRETION

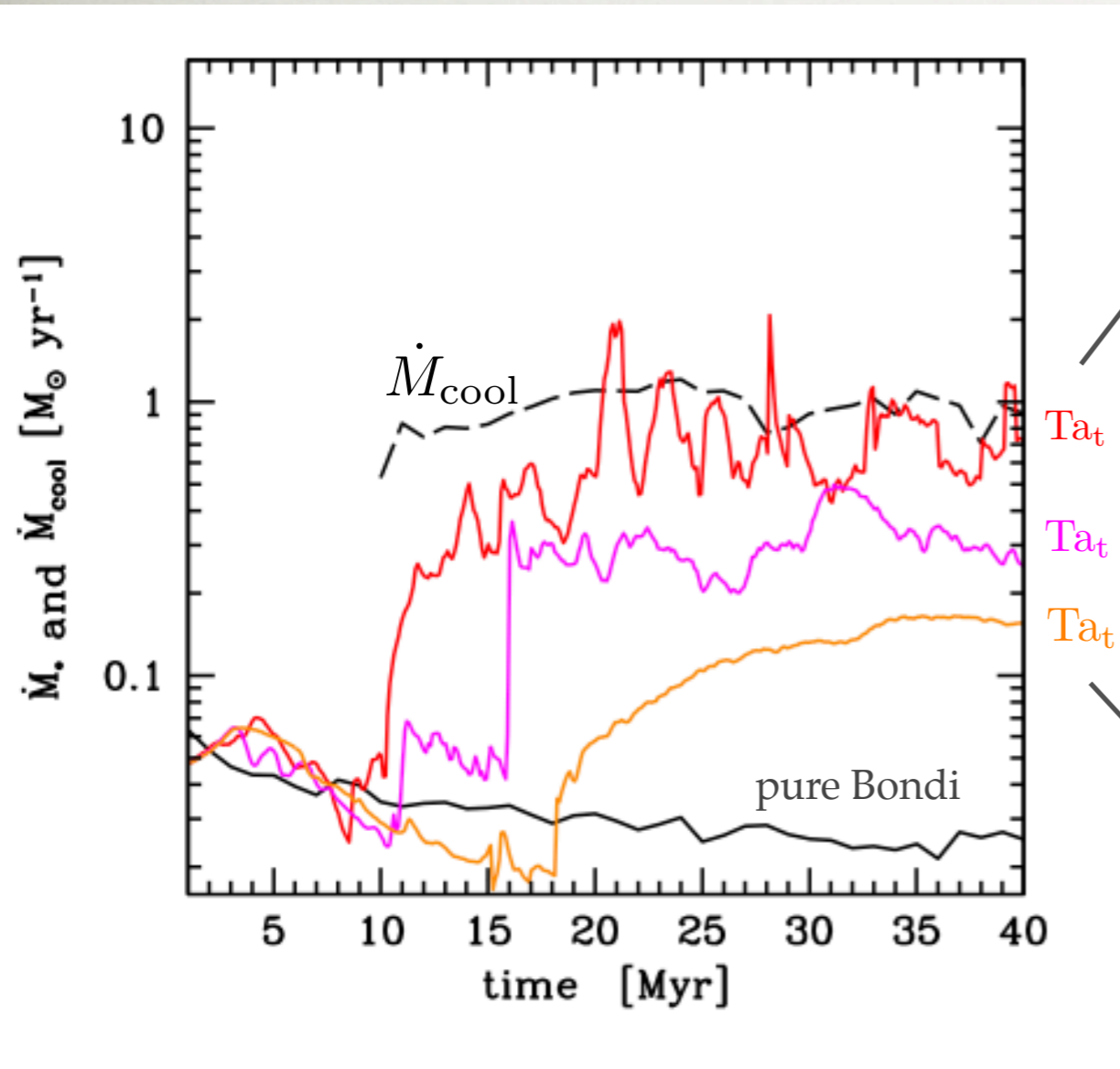


- Accretion driven by **inelastic collisions**: cloud-cloud and cloud-torus
- Very clumpy & turbulent torus (crucial for the AGN unification theory)
- Cold clouds may form the BLR/NLR or HVC
- Deflection of jets/outflows & BH spin changes

CHAOTIC COLD ACCRETION (ROTATION)

Gaspari et al. 2014

$$\dot{M}_{\text{BH}} \sim 100 \dot{M}_{\text{Bondi}} \sim \dot{M}_{\text{cool}} \quad \text{efficient collisions}$$



CCA dominates:

$$\text{Ta}_t < 1$$

$$\text{Ta}_t \sim 0.75$$

$$\text{Ta}_t \sim 1.5$$

$$\text{Ta}_t \sim 3$$

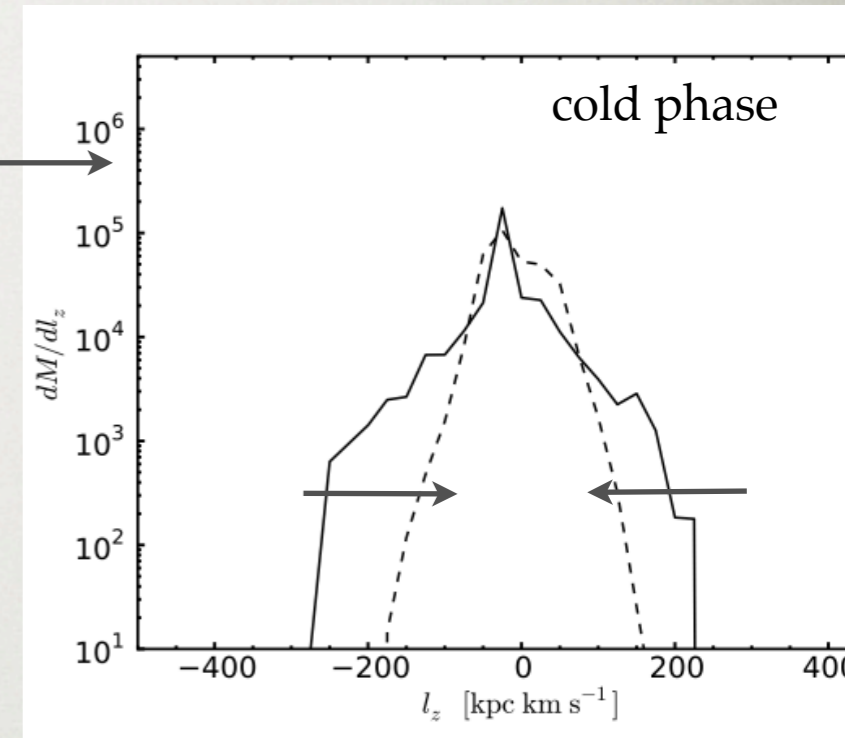
$$\dot{M}_\bullet \propto \text{Ta}_t^{-1}$$

$$\text{Ta}_t > 1$$

rotating structure dominates:

1. weaker turbulent broadening
2. less efficient collisions

3. TI are weaker as rotation dominates: vertical infall => radial compression is marginal => lower TI threshold $t_{\text{cool}}/t_{\text{ff}} < 1$ (non-spherical case; McCourt et al. 2012)



shrinking of angular momentum PDF
(20-27 Myr: 3 major accretion peaks)

COLD

VS

HOT

ACCRETION

- $t_{\text{cool}}/t_{\text{ff}} < 10 \Rightarrow$ condensation & TI

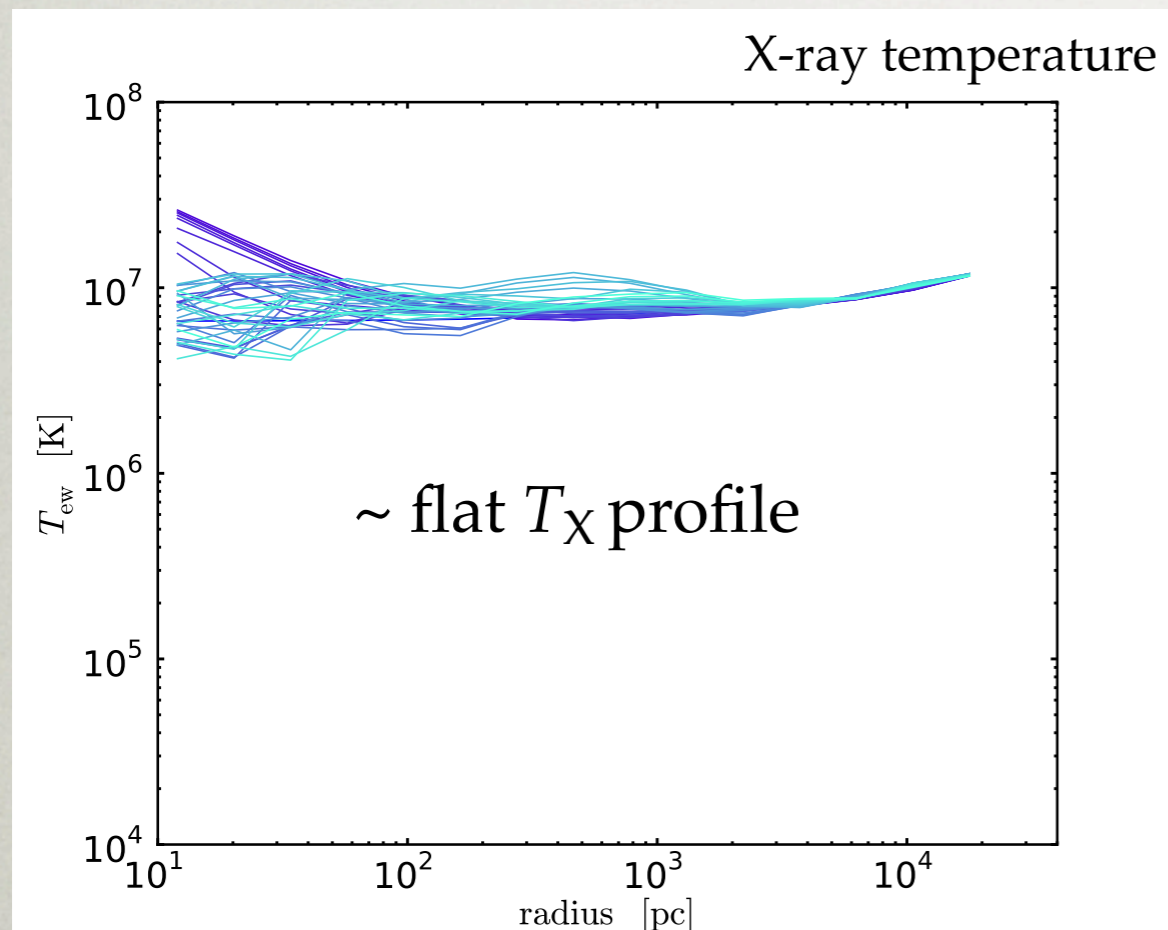
chaotic cold accretion

$$\dot{M}_{\text{BH}} \sim 100 \dot{M}_{\text{Bondi}}$$

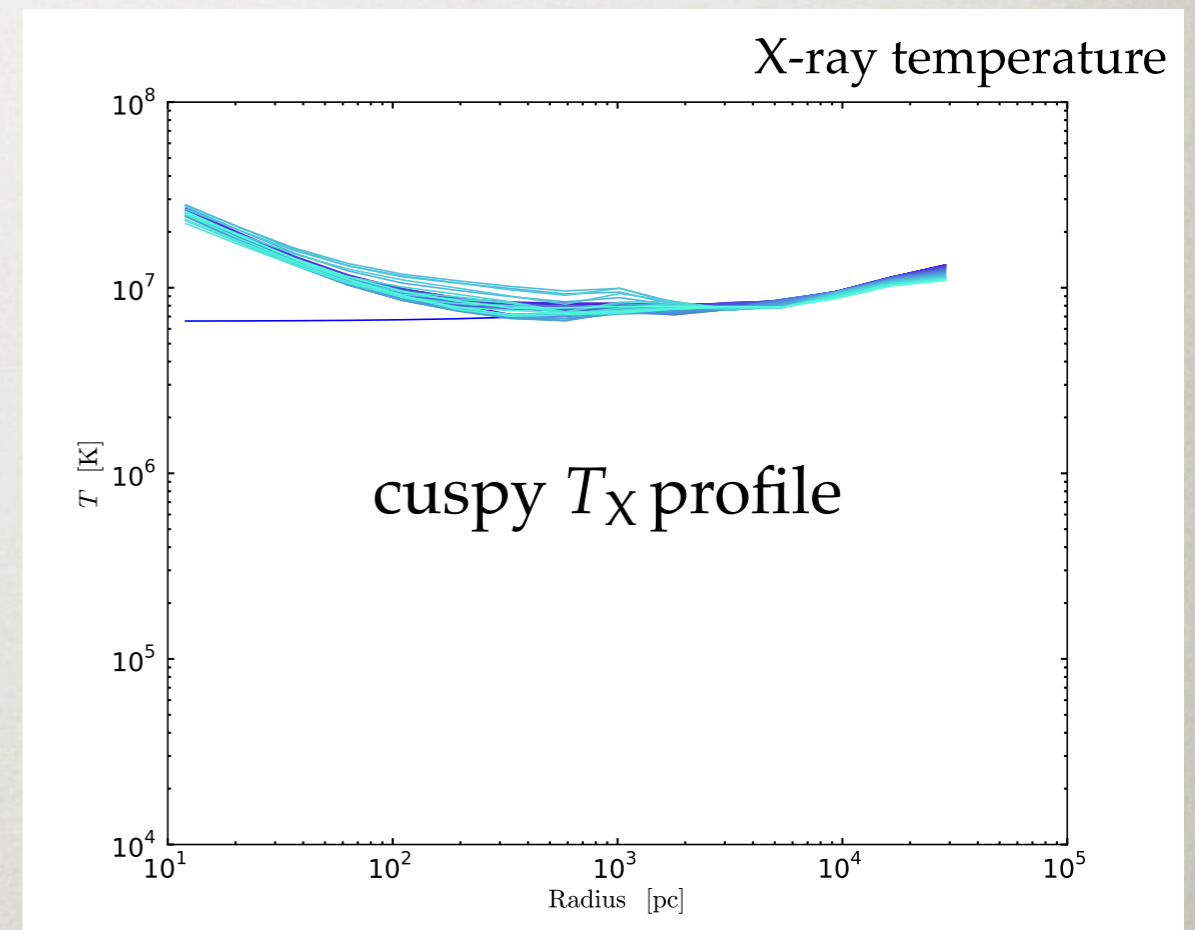
- $t_{\text{cool}}/t_{\text{ff}} \gg 10 \Rightarrow$ overheated phase

stifled Bondi/hot accretion

$$\dot{M}_{\text{BH}} \lesssim 1/3 \dot{M}_{\text{Bondi}}$$



e.g. NGC 3115 (Wong et al. 2014)
NGC 4261, 4472 (Humphrey et al. 2009)



e.g. NGC 4649 (Humphrey et al. 2008)
NGC 1332 (Humphrey et al. 2009)

SELF-REGULATED COLD FEEDBACK

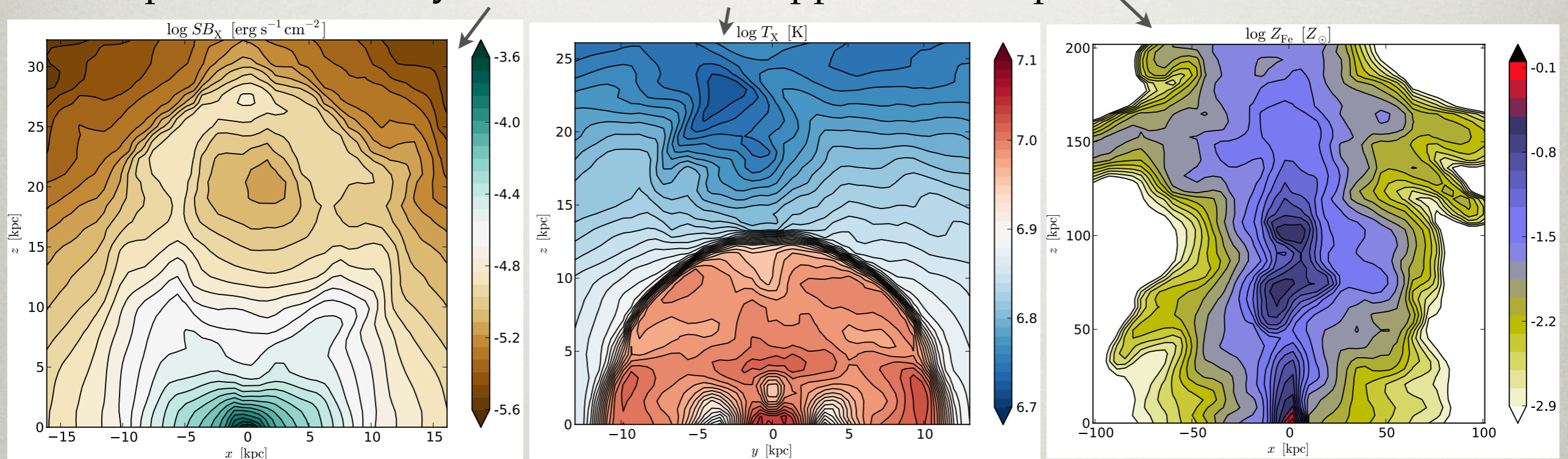
$$\dot{M}_{\text{BH}} \sim \dot{M}_{\text{cool}}$$

self-regulated AGN feedback:
Gaspari et al. 2009, 2011a,b, 2012a,b

- Simple yet powerful subgrid model, **no need to boost the Bondi rate:**

$$\alpha_{\text{boost}} \sim 50 - 100$$

- **Fast communication time** between the gas and the BH
- **Rapid intermittency:** bubbles, shocks, ripples, metal uplift



Gaspari et al. 2009-2014

- **Symbiosis** between the BH and the whole galaxy => Magorrian (linear) relation

$$M_{\text{BH}} \propto M_{\text{cold}} \propto M_{*}$$

SELF-REGULATED AGN FEEDBACK

